MachairWind Offshore Windfarm

Appendix 14.2 Palaeolandscape Assessment

MachairWind Offshore Windfarm

Archaeological Assessment of Geophysical and Hydrographic Data Palaeolandscape Assessment

Produced for Haskoning
MSDS Marine

2025/MSDS25344/2

MachairWind Offshore Windfarm

Archaeological Assessment of Geophysical and Hydrographic Data
Palaeolandscape Assessment

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Contents

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Abbreviations

Abbreviation	Description
<	Less than
>	Greater than
AD	*Anno Domini*
BGS	British Geological Society
BP	Before Present
.csv	Comma Separated Values
c.	Circa
CES	Crown Estate Scotland
CIfA	Chartered Institute for Archaeologists
DGNSS	Differential Global Navigation Satellite System
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
ETRS89	European Terrestrial Reference System 1989
FEED	Front End Engineering Design
.gdb	Geodatabase
GIA	Glacial Isostatic Adjustment
GIS	Geographical Information System
GW	Gigawatt (unit of measurement)
HES	Historic Environment Scotland
HF	High Frequency
HiPAP	High Precision Acoustic Positioning
Hz	Hertz (unit of measurement)
kHz	Kilohertz (unit of measurement)
km	Kilometre (unit of measurement)

Abbreviation	Description
LAT	Lowest Astronomical Tide (lowest predicted tide level)
LGM	Last Glacial Maximum
LF	Low Frequency
m	Metre (unit of measurement)
MBES	Multibeam Echo Sounder (sonar used for bathymetric modelling of the seabed)
MIS	Marine Isotope Stage
MOD	Minimum Object Detection
MRU	Motion Reference Unit
m/s	Meters Per Second
MV	Motor Vessel
nT	Nanotesla (unit of measurement)
OAA	Option Agreement Area
OnTDA	Onshore Transmission Development Area
POA	Plan Option Area
PAD	Protocol for Archaeological Discoveries
POSMV	Positioning and Orientation System for Marine Vessels
RSL	Relative Sea Level
.sgy	SEG file - type Y
.shp	Shapefile
SMP	Sectoral Management Plan
SBP	Sub-bottom Profiler (sonar used for modelling below the seabed)
SLIP	Sea Level Index Point
SSS	Sidescan Sonar (sonar used for imaging the seabed)
.tif	Tagged Image File
TWTT	Two Way Time Travel

Abbreviation	Description
UHRS	Ultra-High Resolution Seismic
UK	United Kingdom
UKHO	United Kingdom Hydrographic Office
USBL	Ultra Short Baseline (acoustic positioning system)
UTM	Universal Transverse Mercator
VORF	Vertical Offshore Reference Frames
WDA	Windfarm Development Area
WSI	Written Scheme of Investigation
WTG	Wind Turbine Generator
.xtf	eXtended Triton Format

1.0 Introduction

1.0.1 MSDS Marine Limited (MSDS Marine) have been contracted by Haskoning to undertake an archaeological assessment of geophysical and hydrographic survey data collected for the MachairWind Offshore Windfarm Development Area (WDA), approximately 15 km northwest of Islay, and 12.4 km west of Colonsay, Scotland.

1.0.2 The geophysical and hydrographic surveys were undertaken over two campaigns. A preliminary geophysical and environmental site investigation survey campaign was completed in 2023 by Fugro GB (North) Marine Limited (Fugro). The survey was undertaken within the Option Agreement Area (OAA) to inform the identification of a refined and optimised Windfarm Development Area (WDA). The WDA survey campaign was completed in 2025 by Sulmara Subsea International Limited (Sulmara). Both surveys undertook the collection of Sidescan Sonar (SSS), Multibeam Bathymetry (MBES), Magnetometer, Parametric Sub-bottom Profiler (SBP), and Ultra High-Resolution Seismic (UHRS) data (utilising a Sparker as the source system).

1.0.3 The archaeological assessment of the data is being undertaken to inform the Environmental Impact Assessment (EIA) process and has been completed in two phases. Phase 1[1] forms the assessment of the surface, and near surface datasets to identify anomalies of potential archaeological interest within the WDA.

1.0.4 Phase 2 (this report) forms the assessment of the subsurface datasets to inform the palaeolandscape and palaeoenvironmental potential of the WDA. The report outlines the specification of the data, the method of archaeological assessment, the presentation of the results, and recommendations for mitigation.

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[1] MSDS Marine (2025). MachairWind Offshore Windfarm. Archaeological Assessment of Geophysical and Hydrographic Data. Ref: MCW-DWF-ENV-REP-RHS-000152

2.0 Project Location and Status

2.0.1 In April 2022, as part of the ScotWind leasing round, Machairwind Limited ('the Applicant') entered into an Option to Lease Agreement with Crown Estate Scotland (CES) for the entire W1 Plan Option Area (POA). W1 is one of 15 POAs that the Scottish Government identified in its Sectoral Marine Plan (SMP) for Offshore Wind Energy (Scottish Government, 2020) following comprehensive review and consultation.

2.0.2 W1, hereinafter referred to as the OAA, is located off the west coast of Scotland, northwest of Islay and west of Colonsay. To identify the developable area within the OAA, the Applicant undertook a preliminary geophysical and environmental site investigation survey campaign in 2023. Subsequent analysis of this and other datasets enabled the identification of a refined and optimised development area, referred to in the Scoping Report, and this report, as the WDA. Within the WDA a Restricted Build Area has been identified. The WDA Restricted Build Area is not suitable for construction and the installation of Wind Turbine Generators (WTGs. The area outside of the WDA Restricted Build Area is deemed feasible from a technoeconomic perspective taking into account key technical, regulatory, social and environmental constraints.

2.0.3 The grid connection location for the Project was confirmed in August 2025 to be in the vicinity of Girvan, South Ayrshire. Consequently, separate consent / marine licence applications will be sought for the Offshore Export Cable Corridor (ECC) and the Onshore Transmission Development Area (OnTDA). When operational, the WDA is anticipated to have a capacity of around 2 Gigawatts (GW) generated by up to 144 WTGs. This will have the potential to generate renewable electricity for up to two million UK homes, contributing to Scotland and the UK's transition to Net Zero and the UK's energy security in line with Government policy.

2.0.4 The location of the OAA, WDA, and the WDA Restricted Buildable Area is shown in **Figure 1.**

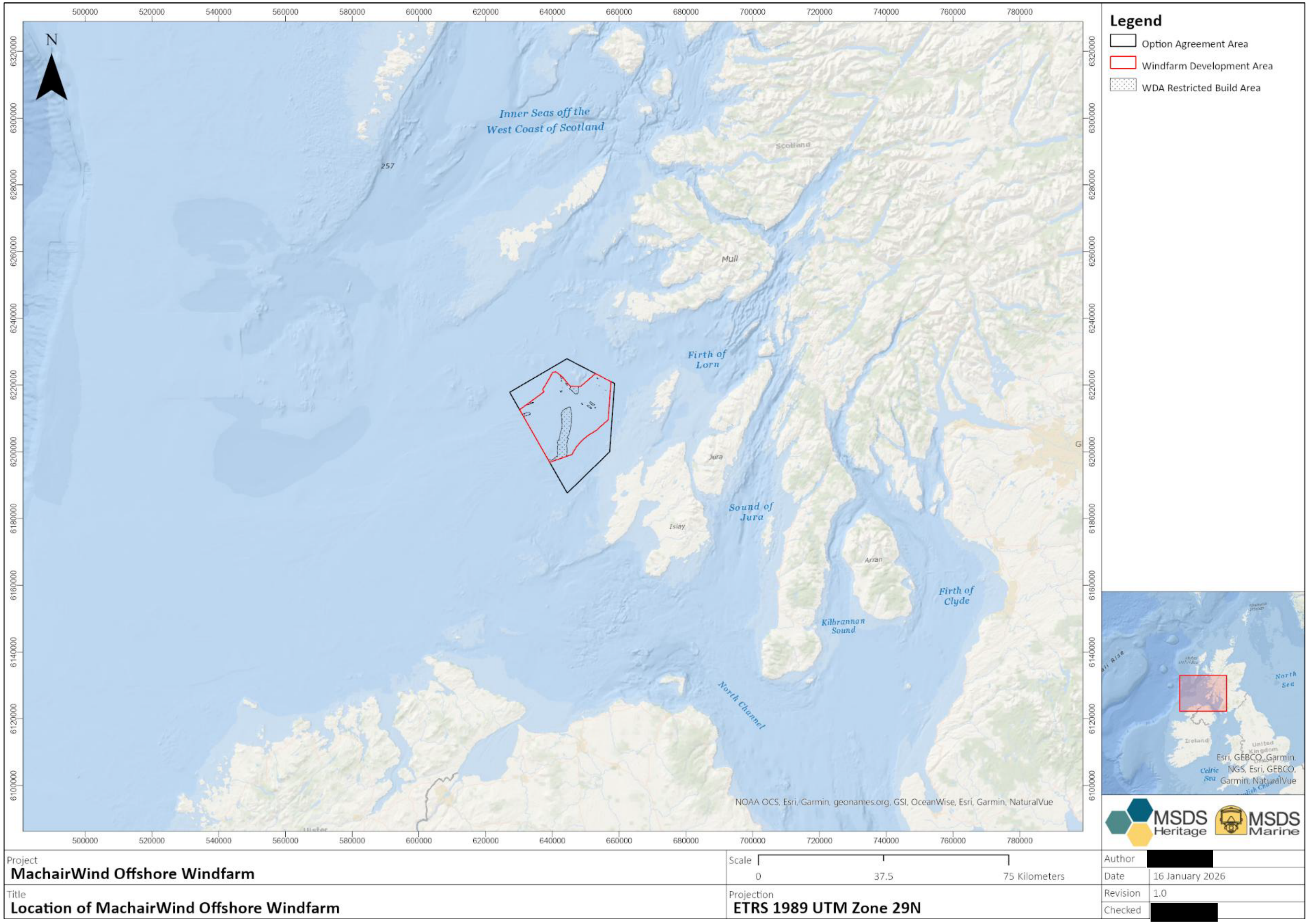


Figure 1 Location of MachairWind Offshore Windfarm

3.0 Aims and Objectives

3.1 Palaeolandscape assessment of geophysical and hydrographic data

3.1.1 The principal aim of the palaeolandscape assessment of geophysical and hydrographic data is to investigate the potential for submerged prehistoric remains laid down during different climatic and environmental conditions in the past. The identification of material and geological horizons allows for strategies to be recommended to mitigate against any negative effects that may be caused by the development process.

3.1.2 The objectives of the archaeological interpretation can be summarised as follows.

- To establish the palaeolandscape potential;
- To recommend mitigation in relation to the palaeolandscape and palaeoenvironment; and
- To recommend any further work that may be required and their specifications.

4.0 Methodology

4.1 Data Collection

4.1.1 The geophysical and hydrographic survey was undertaken over two campaigns. A preliminary geophysical and environmental site investigation survey campaign was completed in 2023 by Fugro GB (North) Marine Limited (Fugro). The survey was undertaken within the Option Agreement Area (OAA) to inform the identification of a refined and optimised development area (WDA). The WDA survey campaign was completed in 2025 by Sulmara Subsea International Limited (Sulmara). The survey coverage of each campaign is presented in **Figure 2**.

2023 Fugro survey

4.1.2 The Fugro survey was undertaken between 22nd August and 8th November 2023, and consisted of SSS, MBES, Magnetometer, Parametric SBP, and UHRS. In addition, the survey campaign included the collection of environmental data. All survey operations were undertaken from MV *Fugro Galaxy*, a dedicated survey vessel of 55.6 m.

4.1.3 The SSS, Magnetometer, and UHRS systems were towed behind the vessel, the MBES and SBP were mounted to the vessels.

4.1.4 Survey operations were undertaken within a pre-defined boundary of the OAA of c. 754 km^2, plus a 1.0 km buffer.

4.1.5 The survey was planned with a line spacing of 500 m for the main lines, and 2,000 m for the cross lines. The line spacing meant that 100% coverage of SSS and MBES data across the OAA was not achieved (nor planned), however the coverage was suitable for the identification of a refined and optimised WDA. In addition, SBP, UHRS, and Magnetometer data were collected along each of the survey lines.

2025 Sulmara survey

4.1.6 The Sulmara survey was undertaken between 14 April and 16 July 2025, and consisted of SSS, MBES, Magnetometer, Parametric SBP, and UHRS. All survey operations were undertaken from *Mainport Edge*, a dedicated survey vessel of 59.6 m.

4.1.7 The SSS, Magnetometer, and UHRS systems were towed behind the vessel, the MBES and SBP were mounted to the vessels.

4.1.8 Survey operations were undertaken within a pre-defined boundary of the WDA of c. 449 km^2.

4.1.9 The survey was planned with a line spacing of 100 m for the main lines, and 500 m for the cross lines. The line spacing largely ensured ≤100% coverage of MBES data (with a minimum of 10% overlap) and 200% coverage of SSS (100% at the nadir) across the survey areas.

4.1.10 In addition, SBP, UHRS, and Magnetometer data were collected along each of the survey lines.

2023 and 2025 combined survey data

4.1.11 The results of the 2023 and 2025 survey campaigns were combined by Sulmara in 2025, with the resulting datasets being subject to archaeological assessment.

Combined specifications

4.1.12 The equipment specification for the surveys is shown in **Table 1** and **Table 2**. The survey navigation track lines are presented in **Figure 3**, and the MBES coverage in **Figure 4**.

Sensor	Manufacturer	Model	Frequency
SSS	Edgetech	4205	230/540 kHz
MBES	Kongsberg	EM2040	400 kHz
Magnetometer	Geometrics	G-882	10 Hz update rate
Parametric SBP	Innomar	Medium-100	6 kHz
UHRS	Applied Acoustics & Geometrics	Dura-Spark UHD-240 & GeoEel LH-16	500 Joules

Table 1 Geophysical and hydrographic sensor specifications (Fugro 2023)

Sensor	Manufacturer	Model	Frequency
SSS	Edgetech	4205	230/540 kHz
MBES	Norbit	Winghead i80s	350 to 450 kHz
Magnetometer	Geometrics	G-882	10 Hz update rate
Parametric SBP	Innomar	Medium-100	6 kHz
UHRS	Applied Acoustics & Geometrics	Dura-Spark UHD-400 & GeoEel LH-16	500 Joules

Table 2 Geophysical and hydrographic sensor specifications (Sulmara 2025)

4.1.13 The data were collected to a specification appropriate to achieve the following interpretation requirements:

- SSS: ensonification of anomalies > 0.6 m;
- MBES: ensonification of anomalies > 1.0 m;
- Magnetometer: 5 nT threshold for anomaly picking;
- Parametric SBP: expected penetration of 10 m below seabed was achieved; and
- UHRS: expected penetration of 90 m below seabed was achieved.

4.2 Positioning

4.2.1 All data were collected with reference to the European Terrestrial Reference System 1989 (ETRS89) datum and Universal Transverse Mercator (UTM) Zone 29 North projection (ETRS89

Z29N). All vertical depths are relative to LAT and were reduced to LAT using Vertical Offshore Reference Frames (VORF).

4.2.2 Towed sensors were positioned using an Ultra Short Baseline (USBL) positioning system to ensure positional accuracy throughout the survey. USBL ensures the actual position of the sensor is recorded, as opposed to when the position is estimated based upon the direction of the vessel and the amount of cable out (layback).

4.2.3 Although the accuracy of the USBL system is dependent on the angle, and the distance of the beacon from the transceiver, tolerances of between 0.5 m and 2.0 m can be achieved. Positional accuracy is further increased through the correlation of the SSS dataset with the MBES dataset.

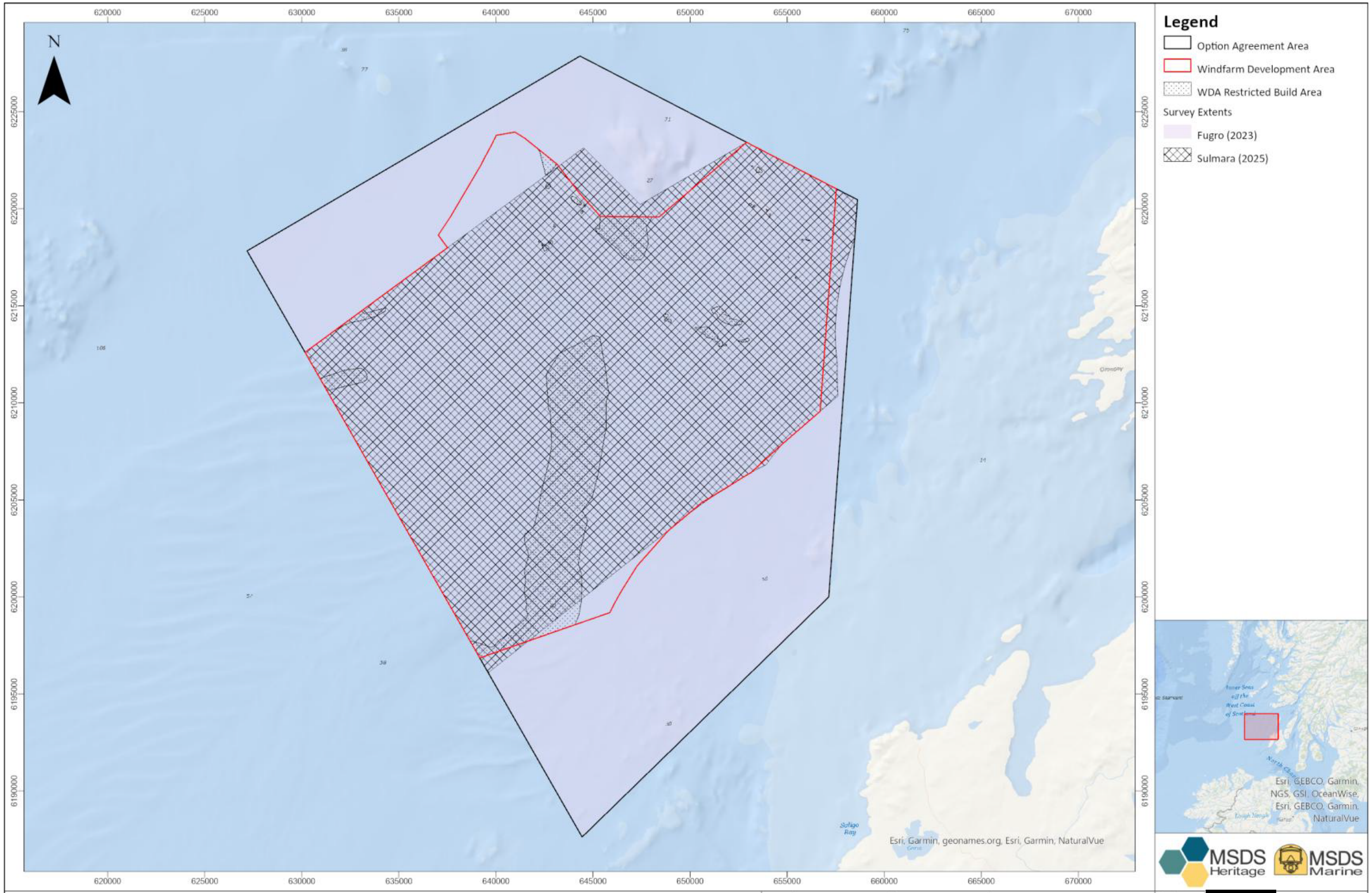
4.2.4 Surface and sub-sea position sensors specifications are detailed below in **Table 3** and **Table 4**.

Sensor	Manufacturer	Model	Accuracy
Surface positioning	Kongsberg	Seapath 380 MGC R3 and Seatex MRU5+	Roll / pitch 0.008° Heading 0.01° Position 0.01 m
Sub-sea positioning	Kongsberg	HiPAP 501	0.12° Angular 0.1 m Range

Table 3: Position sensor specifications (Fugro 2023)

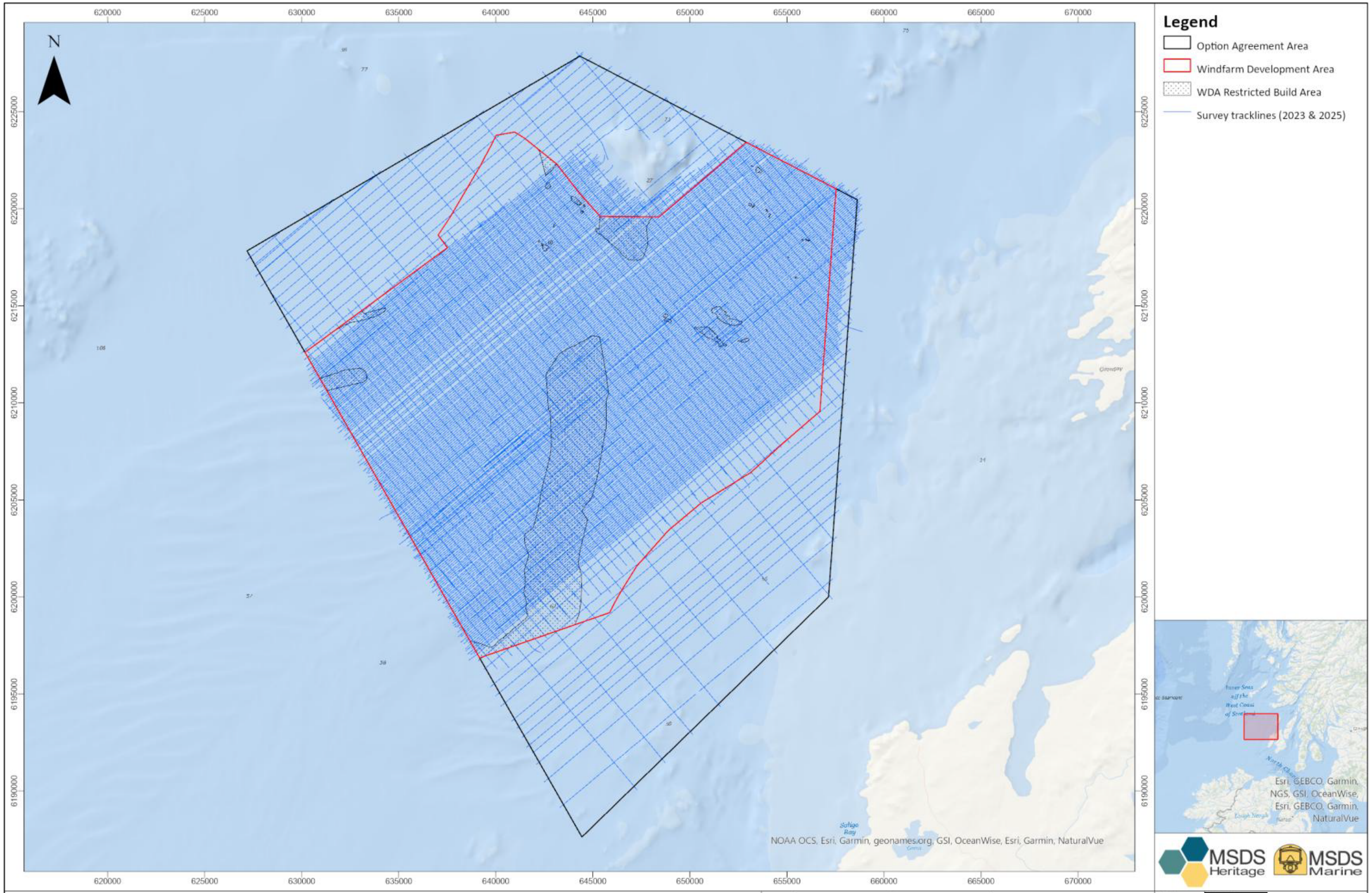
Sensor	Manufacturer	Model	Accuracy
Surface positioning	Applanix	POS MV	Roll / pitch 0.008° Heading 0.02° Position 0.01 m
Sub-sea positioning	Kongsberg	HiPAP 501	0.12° Angular 0.1 m Range

Table 4: Position sensor specifications (Sulmara 2025)



Project **MachairWind Offshore Windfarm**	Scale 0 5 10 Kilometers	Author: [redacted] Date: 12 February 2026
Title **Survey extents by year**	Projection **ETRS 1989 UTM Zone 29N**	Revision: 1.0 Checked: [redacted]

Figure 2 Survey extents by year



Project
MachairWind Offshore Windfarm

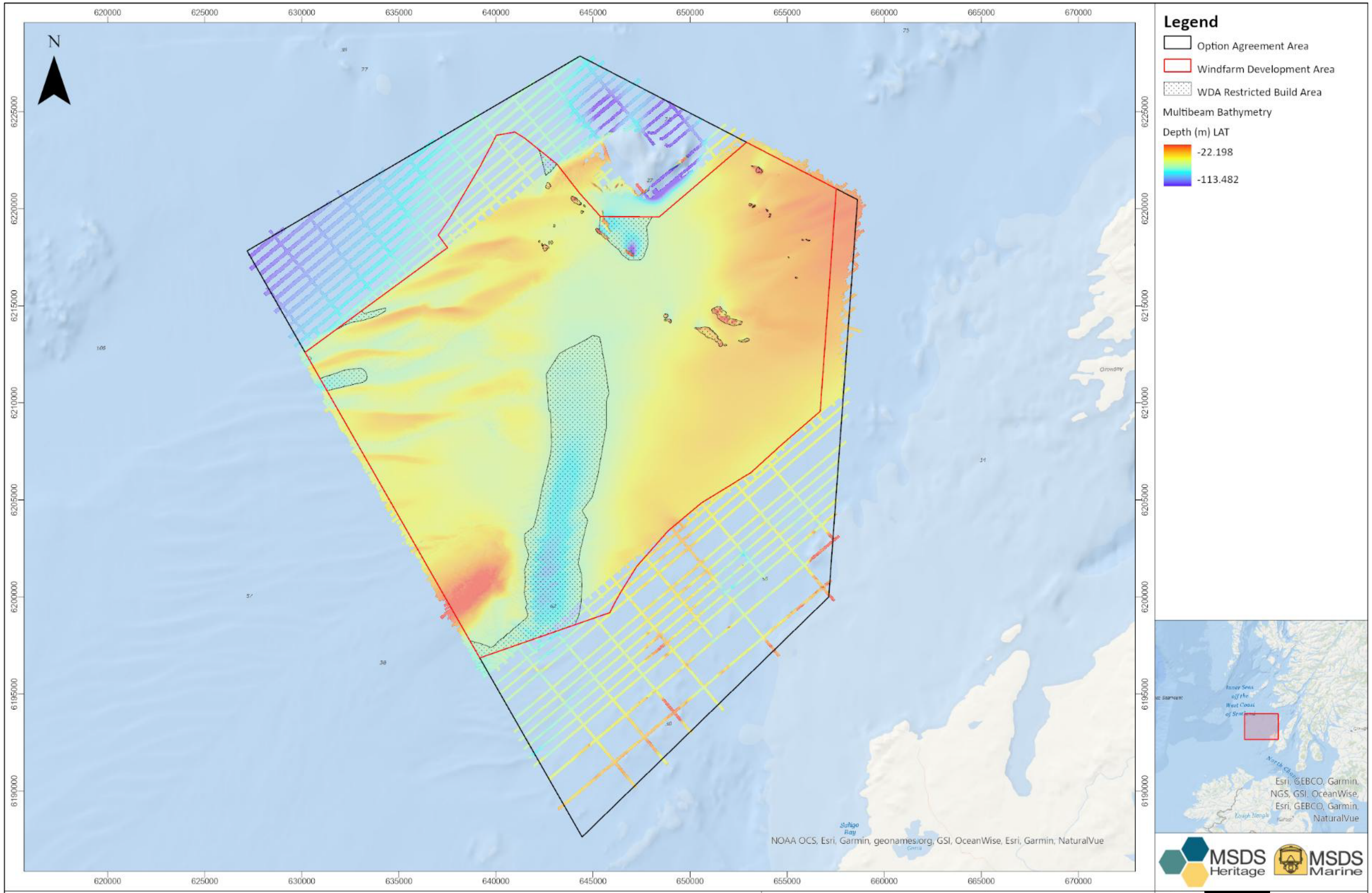
Title
2023 and 2025 combined geophysical survey tracklines

Scale
0 5 10 Kilometers

Projection
ETRS 1989 UTM Zone 29N

Author [redacted]
Date 12 February 2026
Revision 1.0
Checked [redacted]

Figure 3 Geophysical survey tracklines



Project **MachairWind Offshore Windfarm**	Scale 0 5 10 Kilometers	Author	[redacted]
		Date	12 February 2026
Title **2023 and 2025 combined Multibeam Bathymetry coverage**	Projection **ETRS 1989 UTM Zone 29N**	Revision	1.0
		Checked	[redacted]

Figure 4 2023 and 2025 combined Multibeam Bathymetry coverage

4.3 Data deliverables to MSDS Marine

4.3.1 MSDS Marine were provided with the survey deliverables for the Fugro (2023) and Sulmara (2025) surveys by Haskoning. The data included both raw and processed data, alongside interpretations and operations reports. The primary deliverables are detailed in **Table 5** below.

Sensor	Data type	Format
Sidescan Sonar	Raw lines (LF and HF)	.xtf
	Processed lines (HF)	.xtf
	Mosaic (HF) 0.25 ppm	.tif
	Contacts	.shp
SBP	Raw lines	.sgy
	Processed lines	.sgy
	Isopach	.shp
	Horizons (at 5.0 m x 5.0 m)	.flt, .xyz
UHRS	Raw lines	.sgy
	Processed lines	.sgy
	Isopach	.shp
	Horizons (at 5.0 m x 5.0 m)	.flt, .xyz
Magnetometer	Raw lines	.csv
	Grids	.tif
	Contacts	.csv
MBES	Raw lines	.xyz
	Grids (at 0.5 m)	.xyz
	Mosaic (at 0.5 m)	.tiff
GIS	Geodatabase	.gdb
Reports	Interpretation report	.pdf
	Operations report	.pdf
	Mobilisation report	.pdf

Table 5 Data deliverables to MSDS Marine

4.4 Archaeological assessment of data

4.4.1 The palaeolandscape archaeological assessment of geophysical and hydrographic data was undertaken by a qualified and experienced geoarchaeologist with a background in geophysical data acquisition, processing, and interpretation.

4.5 Palaeolandscape and Sub-bottom Profiler sources

4.5.1 The principal sources reviewed and assessed comprised:

- Project specific SBP and UHRS data as described in **Section 4.0**.
- Interpretation reports, including:
    - Fugro, 2024. MachairWind Phase 1 Geophysical and Environmental Site Investigation, OWF Geophysical Results Report (included as **Appendix 7.3** of the EIAR).
    - Sulmara, 2025. Results Report, Machair Offshore Windfarm, Geophysical Characterisation SI Phase 2 (included as **Appendix 8.1** of the EIAR).
- Boreholes, cores, and seismic data collected by the British Geological Survey (BGS) containing evidence which has fed into publications, online databases, and maps, including:
    - Fyfe, J A, Long, D, and Evans, D . 1993. *United Kingdom offshore regional report: the geology of the Malin–Hebrides sea area*. (London: HMSO for the British Geological Survey.)
    - BGS. 1983. “Malin” Map Sheet 55°N-08°W Solid Geology 1:250,000 Series
    - BGS. 1986. “Tiree” Map Sheet 56°N-08°W. Solid Geology 1:250,000 Series;
    - BGS. 1986. “Malin” Map Sheet 55°N-08°W Seabed Sediments and Quaternary Geology 1:250,000 Series;
    - BGS. 1986. “Tiree” Map Sheet 56°N-08°W. Quaternary Geology 1:250,000 Series;
- Other published resources are referred to in-text.

4.5.2 While the BGS regional datasets are highly valuable, much of this mapping is based on relatively sparse data acquired during the 1970s and 1980s. As such, regional BGS interpretations are necessarily superseded by the site-specific geological ground model derived from geophysical and any future geotechnical investigations undertaken for the development. This reinforces the importance of archaeological input at the geotechnical stage and throughout the development process.

4.6 Palaeolandscape and Sub-bottom Profiler interpretation

4.6.1 Subsurface data from seismic surveys are central to understanding the palaeolandscape potential of the WDA. These datasets have been reviewed and incorporated into a geological ground model by the geophysical contractor, which informs both engineering design and geological interpretation. Sedimentary units within the model have been identified and tentatively correlated with known geological formations based on the available data.

4.6.2 From an archaeological perspective, the ground model provides insight into the depositional environments present within the WDA and their associated palaeolandscape and archaeological potential. Interpretation of subsurface data, geological mapping, and present-day seabed morphology derived from MBES data have been assessed alongside relevant published studies to inform understanding of prehistoric landscape development within the WDA.

4.6.3 An archaeological review of the ground model was undertaken by MSDS Marine, drawing on geophysical survey reports, seismic profiles, and ground model outputs. The review focused on assessing the suitability of the data for archaeological interpretation and understanding the geological framework, palaeoenvironmental conditions, and archaeological potential of the WDA, informed by wider regional context.

4.6.4 The assessment of submerged prehistoric remains considers periods when the WDA was potentially habitable, as well as phases of glaciation or marine inundation. It examines the Quaternary sequence to reconstruct past environments and assess archaeological potential and preservation, taking account of geological processes such as erosion, glaciation, and marine transgression.

4.6.5 The Quaternary chronology of the UK, used for the assessment of submerged prehistory is set out in **Table 6**. Marine Isotope Stages (MIS) are alternating warm and cold periods originally defined from oxygen isotope ratios measured in foraminifera from deep-sea sediment cores. These marine records are now correlated with ice cores, terrestrial sequences and other palaeoclimate archives to form a global Quaternary climate framework.

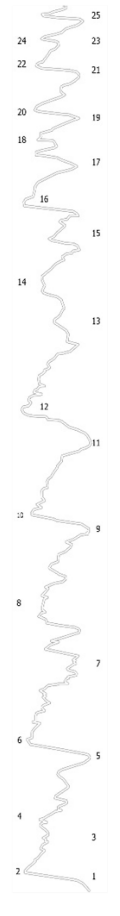
Stage			Age		Climate	Marine Isotope Stage		Epochs and Periods		
Main	Sub.		Start	End		Stages	Record			
Beestonian			970,000	936,000	Interglacial	25		Pleistocene	Early Pleisto.	Lower Palaeolithic
			936,000	917,000		24				
			917,000	900,000	Interglacial	23				
			900,000	866,000	Stadial	22				
			866,000	814,000	Sequence poorly understood but evidence for a series of small expansions of the British Ice Sheet marking at least 4 interstadials and 5 warm episodes.	21				
			814,000	790,000		20				
Bruhnes-Matuyama reversal (c. 780kBP) Cromerian Complex			790,000	761,000		19			Middle Pleistocene	
			761,000	712,000		18				
			712,000	676,000		17				
			676,000	621,000		16				
			621,000	563,000		15				
			563,000	524,000		14				
			524,000	478,000		13				
Anglian			478,000	424,000	Stadial	12				
Hoxnian			424,000	374,000	Interglacial	11				
Wolstonian/ Saalian complex	Unnamed		374,000	337,000	Stadial?	10				
	Purfleet		337,000	300,000	Interglacial	9				Middle Palaeolithic
	Early		300,000	243,000	Stadial?	8				
	Aveley		243,000	191,000	Interglacial	7				
	Late		191,000	123,000	Stadial	6				
Ipswichian			123,000	109,000	Interglacial	5e			Late Pleistocene	
Devensian	Early		109,000	96,000	Stadial	5d				
		Chelford	96,000	87,000	Interstadial	5c				
			87,000	82,000	Stadial	5b				
		Brimpton	82,000	71,000	Interstadial	5a				
			71,000	57,000	Stadial	4				
	Mid	Upton Warren	57,000	29,000	Interstadial	3				Upper Pal
	Late	Dimlington	29,000	14,700	Stadial	2				
		Windemere	14,700	12,900	Interstadial					
		Loch Lomond	12,900	11,700	Stadial					
Holocene			11,700	Present	Interglacial	1		Holocene		Meso.

Table 6 Quaternary chronology (based on Marshall et al. 2020[2], with dates from Lisiecki and Raymo[3])

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[2] Marshall, P., Bayliss, A., Grant, M., Bridgland, D.R., Duller, G., Housley, R., Matthews, I., Outram, Z., Penkman, K.E.H., Pike, A., Schreve, D. & Xuan, C. (2020). *6390 Scientific dating of Pleistocene sites: guidelines for best practice*. Consultation Draft. Swindon: Historic England.

[3] Lisiecki, L. E. & Raymo, M. E. '*A Pliocene-Pleistocene stack of 57 globally distributed benthic 18O records. Paleoceanography*. 20.

4.7 Data quality and limitations

General notes on data quality and limitations

4.7.1 The data has been collected in two phases, by Fugro in 2023 covering the OAA at a wide survey line spacing, and by Sulmara in 2025 covering the WDA at a narrower survey line spacing. The below discussion focuses on the data within the WDA as this is the area being taken forward for consent.

4.7.2 Due to changes in the WDA boundary, first following scoping and then following the 2025 survey, there are areas within the current WDA that are only covered by the 2023 survey. These gaps are to the southeast and the north of the WDA and total c. 20 km^2, of which c. 2 km^2 is the WDA Restricted Build Area (**Figure 5**). Within these areas only the 2023 data have been subject to archaeological assessment, thus 100% of the seabed has not been assessed. As a percentage of the total WDA this area is relatively small (c.4.5%), and thus the overall coverage of the WDA is considered of appropriate coverage to undertake a robust archaeological assessment to inform the EIA process, noting that additional data collection, and interpretation, may be required prior to construction

Subsurface Data

4.7.3 SBP and UHRS data covered the full extent of the pre-defined survey boundary. Data quality was assessed by Fugro[4] and Sulmara[5] in relation to their respective datasets. The seismic interpretation deliverables were also subject to quality control by external consultants AtkinsRéalis. In addition, MSDS Marine undertook an independent assessment of data quality for the purposes of palaeolandscape assessment.

4.7.4 The assessment of data quality and limitations in this section focuses on SBP/UHRS data quality and broader interpretative issues. Interpretation issues relating to specific horizons and formations are discussed separately in **Section 5.2**. Gridded surfaces derived from Sulmara's interpretation of the 2023 and 2025 UHRS survey data were made available for this evaluation.

4.7.5 A subset of 22 survey lines from the Fugro 2023 UHRS/SBP survey were selected and compared with the 22 nearest corresponding lines from the Sulmara 2025 UHRS/SBP survey for the purpose of evaluating data quality. These lines were also taken forward for the assessment of the interpretation.

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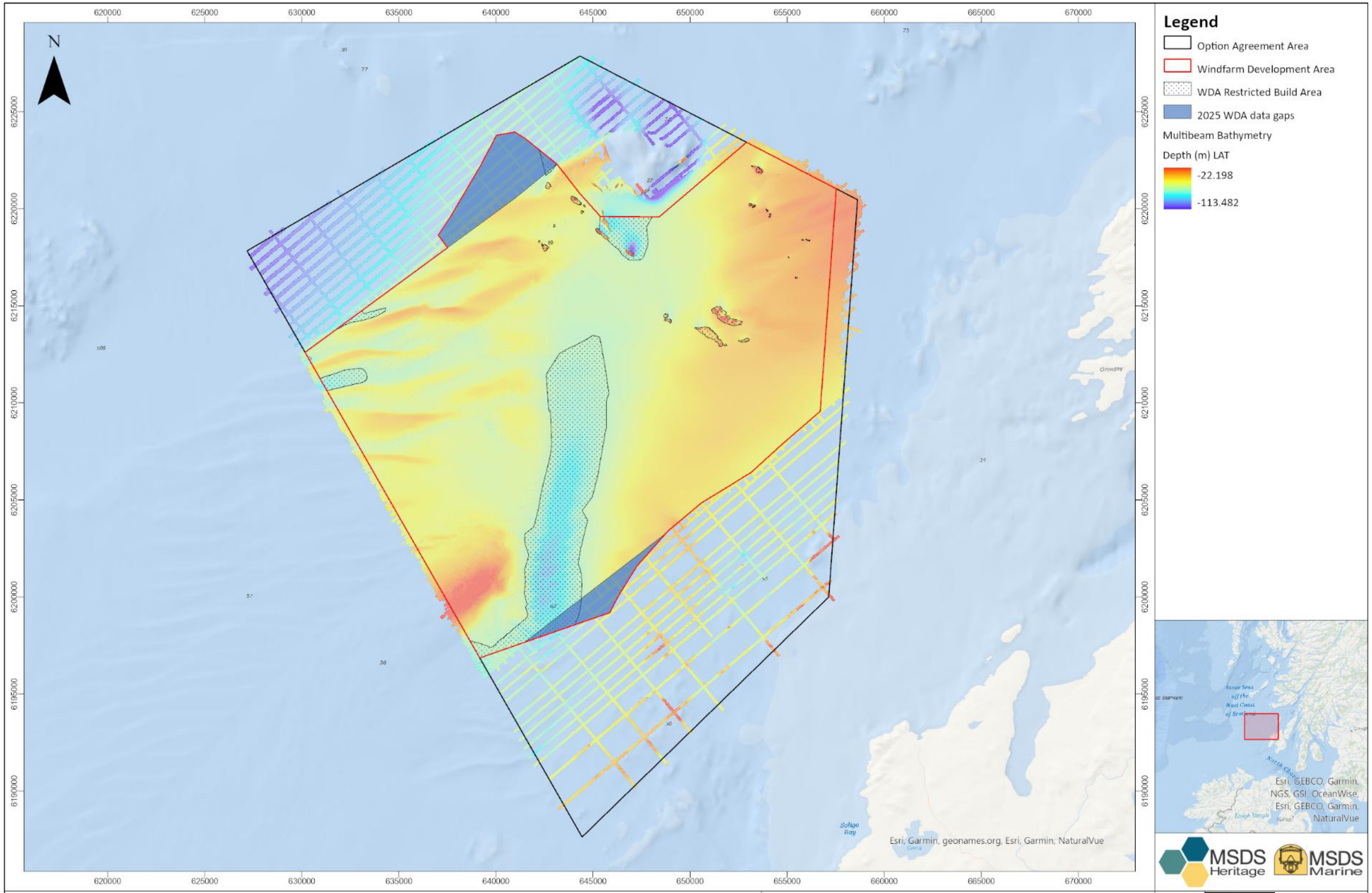
[4] Fugro (2024). *MachairWind Phase 1 Geophysical and Environmental Site Investigation, OWF Geophysical Results Report*

[5] Sulmara (2025). *Results Report, Machair Offshore Windfarm, Geophysical Characterisation SI Phase 2*



Project
MachairWind Offshore Windfarm

Title
2025 data gaps within the Windfarm Development Area

Scale
0 5 10 Kilometers

Projection
ETRS 1989 UTM Zone 29N

Author [redacted]
Date 12 February 2026
Revision 1.0
Checked [redacted]

Figure 5 2025 data gaps within the Windfarm Development Area

Fugro 2023

4.7.6 The 2023 Fugro survey was planned with a line spacing of 500 m for the main lines and 2,000 m for the cross lines. Although survey coverage is relatively sparse, the SBP and UHRS datasets image the shallow subsurface at a level of detail not previously achieved in the Inner Hebrides[3]. The SBP employed higher-frequency sources to produce high-resolution data with shallow penetration, whereas the UHRS utilised lower frequencies to produce lower-resolution data with greater penetration.

4.7.7 Within the Fugro SBP dataset, seismic reflectors are visible down to approximately 35 ms two-way travel time (TWTT) (c. 28 m) below the seafloor[4]; however, within the subset of seismic lines evaluated for this assessment, good-quality imaging typically ceased at around 20 m below the seabed. In some areas, usable imaging was limited to as little as approximately 5 m below the seabed (see **Figure 6**). Vertical resolution is estimated to be up to approximately 0.1 m where relatively less dense and lower-strength sediments are present[4].

4.7.8 Data quality within the Fugro UHRS dataset is reduced in areas affected by shallow gas, which occurs across large parts of the site (**Figure 7** and **Figure 8**). Where not affected by gas, stratigraphic interpretation is possible to approximately 310 ms TWTT (c. 271 m, assuming an internal sound velocity of 1,750 m/s), according to Fugro[4]. Vertical resolution varies across the dataset but is estimated to be up to approximately 0.3 m, with a horizontal resolution of approximately 0.7 m.

Shallow gas

4.7.9 Shallow gas accumulations observed in the UHRS data may derive from mixed sources, but likely largely from deeper thermogenic hydrocarbons that have migrated into shallow sediments[6].

4.7.10 Evaluation of the Fugro UHRS lines indicates that reflections can generally be imaged to depths of up to approximately 200 m below the seabed. However, in areas affected by shallow gas, effective imaging is significantly reduced and typically limited to the upper ~20 m of the subsurface.

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[6] Szpak, M. T., X. Monteys, S. O'Reilly, A. J. Simpson, X. Garcia, R. L. Evans, C. C. R. Allen, D. J. McNally, D. Courtier- Murias, and B. P. Kelleher (2012), *Geophysical and geochemical survey of a large marine pockmark on the Malin Shelf, Ireland, Geochem*. Geophys. Geosyst., 13.

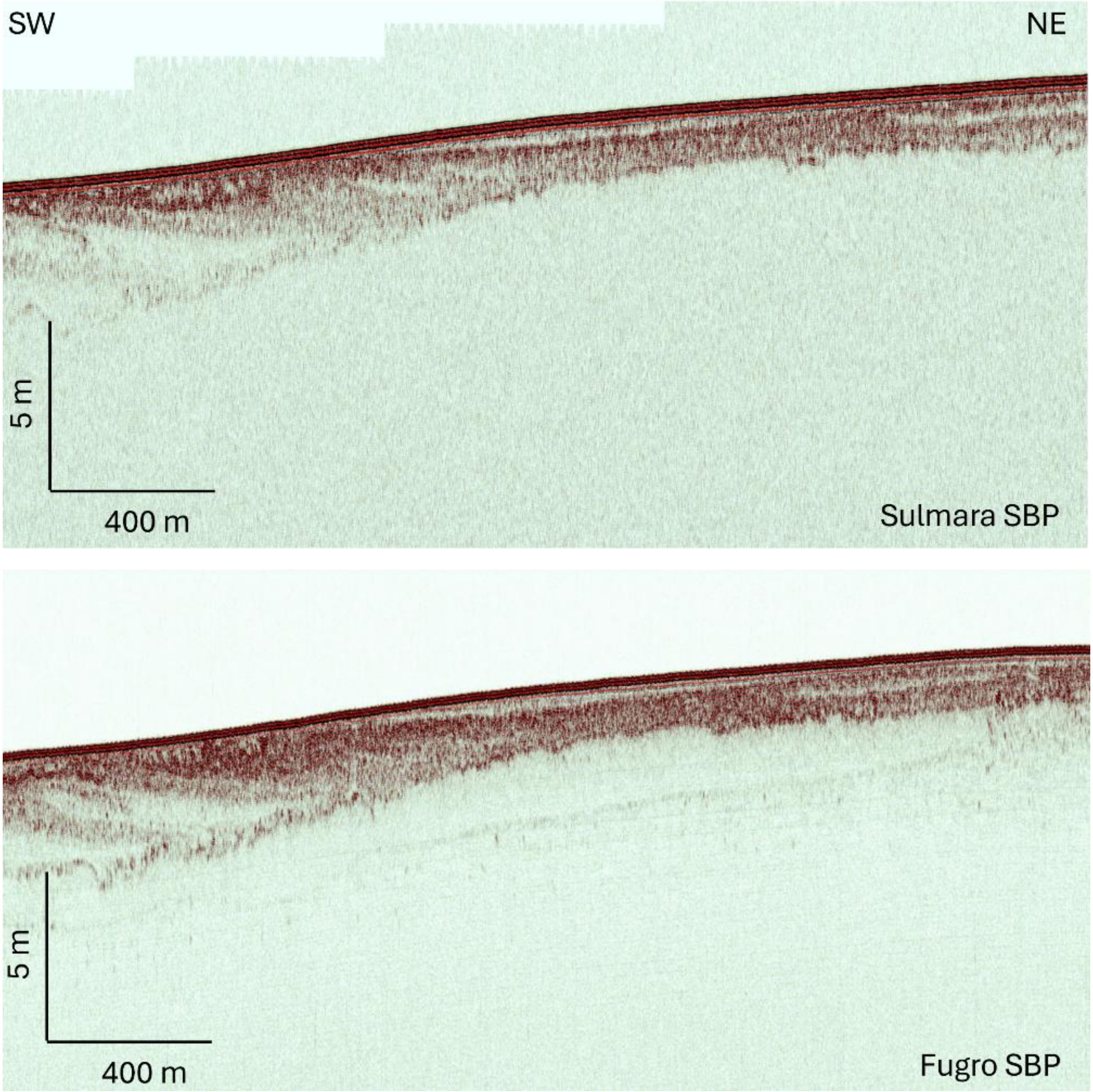


Figure 6 Sub-bottom profiler comparison. Sulmara seismic line SPB_ML_S02100 and Fugro seismic line SPB C040

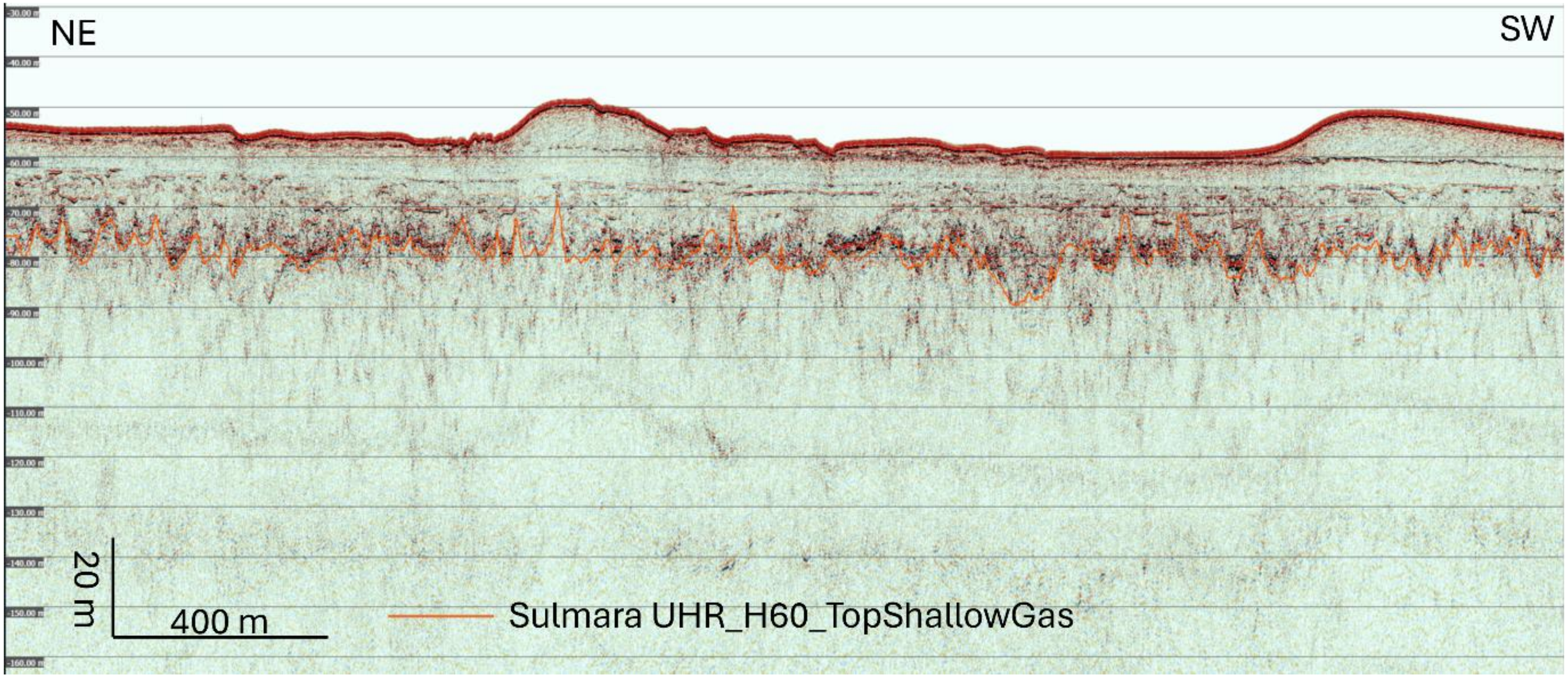
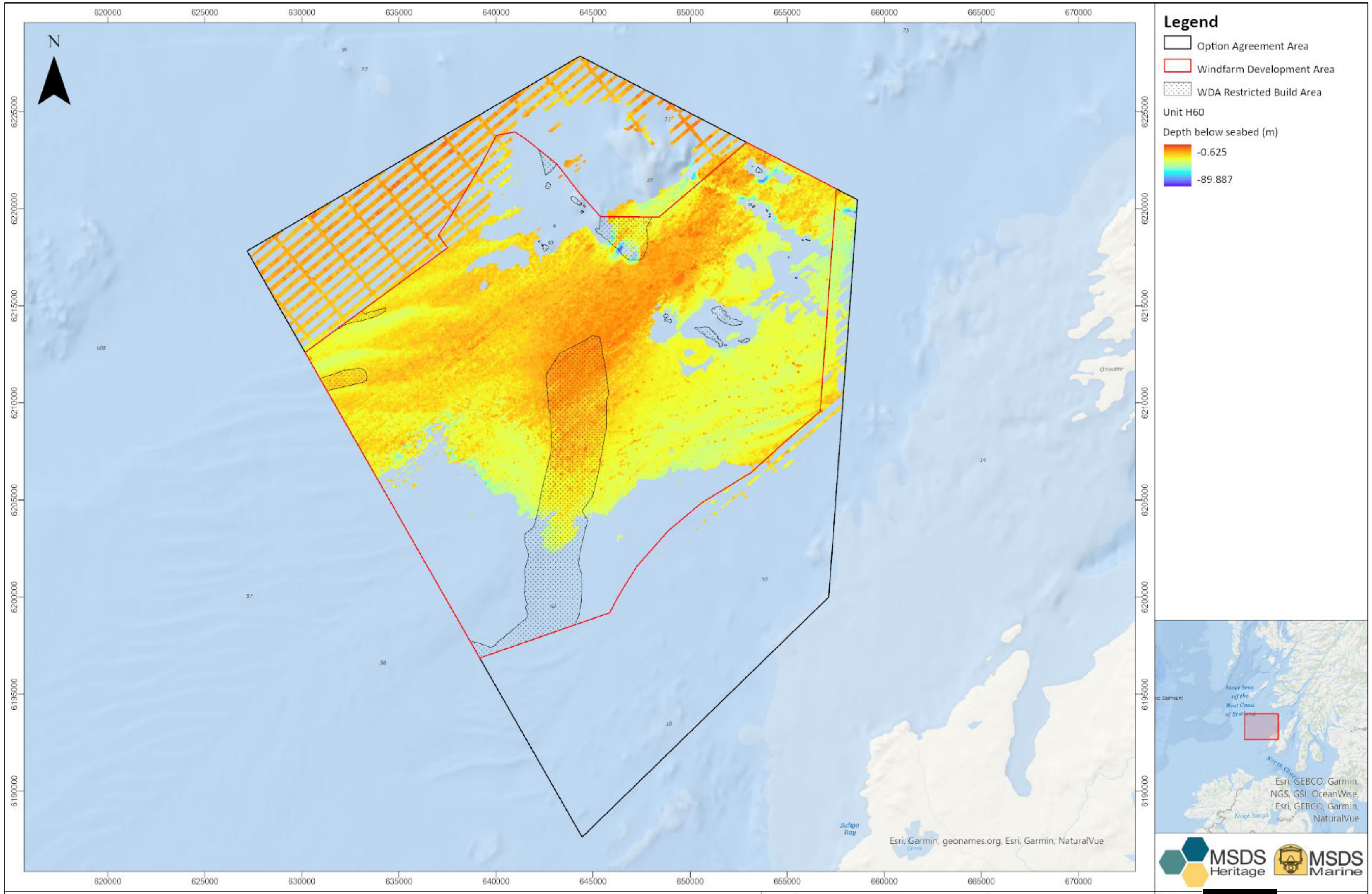


Figure 7 Fugro UHRS data example of Shallow Gas limiting imaging below 20-30 m below seabed (line MCWA018B)



Project
MachairWind Offshore Windfarm

Title
Distribution of shallow gas across the WDA (Sulmara H60 - Top Shallow Gas Front)

Projection
ETRS 1989 UTM Zone 29N

Author	[redacted]
Date	23 March 2026
Revision	1.0
Checked	[redacted]

Figure 8 Distribution of shallow gas across the WDA (Sulmara H60 Top Shallow Gas Front)

Sulmara 2025

4.7.11 The 2025 Sulmara survey was planned with a line spacing of 100 m for the main lines, and 500 m for the cross lines. For the SBP data, a vertical resolution of approximately 0.2 m was anticipated, with an expected penetration of up to 10 m below the seabed[5].Evaluation of the SBP data indicates that penetration was generally less than anticipated, with traceable reflections typically limited to around 5 m below the seabed (**Figure 6**).

4.7.12 Sulmara SBP penetration was reduced in some areas compared to the 2023 Fugro survey (**Figure 6**), and occasional navigation and streamer control issues affected a small subset of UHRS lines. Additional limitations identified within the SBP and UHRS datasets include the following[5]:

- Acoustic blanking associated with shallow gas horizon across approximately 67% of the survey area, obscuring deeper stratigraphic features. As mentioned, this issue is also present within the Fugro UHRS dataset.
- Data acquisition constraints in the vicinity of the Dubh Artach Lighthouse, located on a bedrock outcrop in the north-east of the site. Survey lines were curtailed for vessel safety reasons, resulting in locally incomplete coverage.
- The Sulmara 2025 SBP data exhibit a higher level of general background noise compared to the Fugro 2023 SBP dataset.
- Issues relating to seabed bottom tracking on the Innomar SBP system, as well as navigation inconsistencies, were also noted.

4.7.13 For the Sulmara UHRS data, vertical resolution was expected to be approximately 0.3 m to depths of around 40 m below the seabed, decreasing to approximately 1 m below this depth, with an anticipated penetration of up to 90 m below the seabed[5]. Evaluation of the seismic lines indicates that reflections can be imaged to depths of up to approximately 200 m below the seabed. However, in areas affected by shallow gas, effective imaging is significantly reduced, similar to observations from the Fugro dataset.

4.7.14 Data quality issues noted with the UHRS include:

- Feather angles were higher than specified due to currents and exposed nature of the site.
- Issues with application of navigation, most issues were corrected via post-processing of navigation files, however, not for all lines.
- Weather conditions increased noise in the dataset towards the end of the survey.

4.7.15 Despite these issues, interpretation of key seismic reflections within the upper 200 m is possible in the UHRS data where shallow gas is absent. Although overall data quality is slightly lower than that of the Fugro 2023 dataset (**Figure 9**), both datasets allow consistent interpretation within these intervals away from the shallow gas.

Summary

4.7.16 The Fugro UHRS and SBP datasets, while relatively sparse across the site, are sufficient for the purposes of this assessment when considered alongside the additional Sulmara UHRS dataset. Although parts of the UHRS data are affected by the presence of shallow gas, limiting imaging of the lower formations, the unaffected areas combined with regional geological evaluation provide sufficient information to evaluate archaeological potential. The 2025 Sulmara SBP survey, despite lower overall data quality, offers supplementary context when used in conjunction with the Fugro datasets. Collectively, the 2023 and 2025 seismic datasets are considered adequate to support a robust archaeological assessment to inform the EIA process.

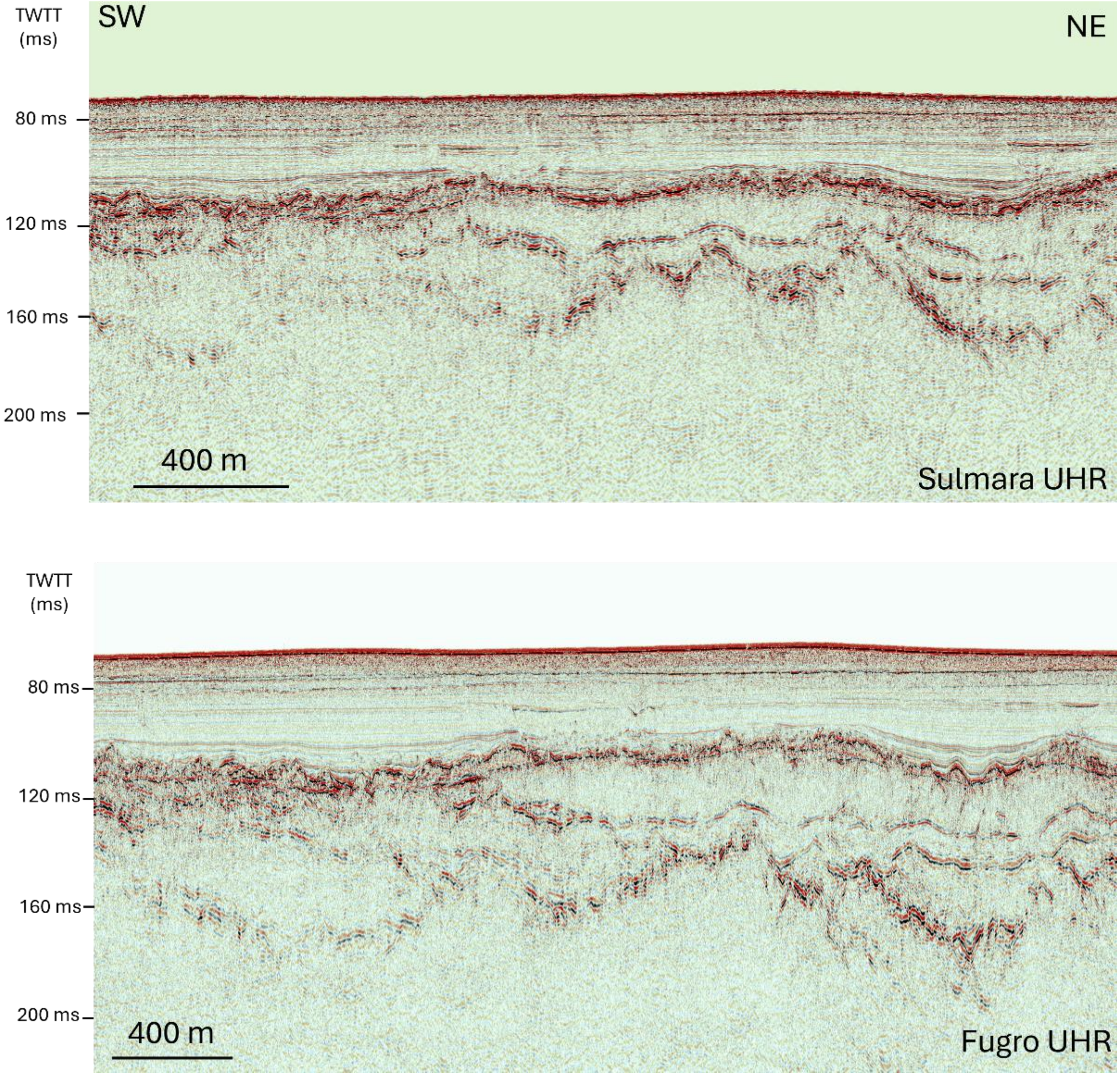


Figure 9 Comparison of Sulmara 2025 and Fugro UHRS survey data (ML_S06400 and MCWC049 respectively)

5.0 Palaeolandscape Assessment

5.0.1 This Section examines the source material, including the assessment of SBP and UHRS data, the ground model, and desk-based sources (detailed in Section 4.5.1 and Appendix A), to determine the likely chronostratigraphy and sea level history within the WDA. Initial interpretations of the data were used to inform a broad archaeological potential.

5.0.2 The prehistoric archaeological record of the UK covers the period from the earliest hominin occupation, potentially as far back as 970,000 BP, to the "end" of the Iron Age and the Roman invasion of Britain in AD 43. In Scotland, particularly the Highland zone where the Roman sphere of influence had a lesser socio-cultural impact, the Iron Age is considered to last up to 400 AD, encapsulating a shorter and predominantly military-focussed Roman period (AD 77 to 211)[7]. The coastline of the UK changed drastically during prehistory and large tracts of what is now the seabed were once sub-aerially exposed.

5.0.3 Prehistoric archaeological potential is gauged with reference to evidence for human activity in Britain during each period and the contemporary environment within the WDA, also considering depositional and post-depositional factors through interpretation of geological deposits present. Deposits with potential are generally those laid during periods of sub-aerial exposure or by fluvial process, rather than sub-glacial or marine deposits. However, there is also potential for archaeological material to be redeposited or reworked within secondary contexts resulting from fluvial erosion or glacial processes[8].

5.0.4 The Upper Palaeolithic (57,000 to 11,700 BP; MIS 3 to 2) spans the Mid to Late Devensian, including the Dimlington and Loch Lomond stadials. The earliest reliably dated human artefacts within a secure Scottish context (a large assemblage of flint tools) have been correlated with other northern European typologies to suggest a late Upper Palaeolithic date. In the absence of organic preservation at the site, a broad date range of 12,000 to 11,500 BP is currently accepted[9].

5.0.5 The Mesolithic period (11,700–6,000 BP; MIS 1) marks the onset of the Holocene following the last glacial period. Climatic amelioration led to the development of carr woodland in stable terrestrial areas and increased ecological diversity. Meltwater from retreating Devensian glaciers formed river valleys and lakes, creating fluvial and marginal environments rich in resources and well suited to human exploitation.

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[7] Hunter, F. and Carruthers, M. (eds.) (2012). *Scotland: The Roman Presence*. Scottish Archaeological Research Framework Summary Roman Panel Document.

[8] Hosfield, R. & Chambers, J. (2004). *The Archaeological Potential of Secondary Contexts*. ALSF Project 3361.

[9] Saville, A. and Ballin, T.B. (2009). 'Upper Palaeolithic evidence from Kilmelfort Cave, Argyll: a re-evaluation of the lithic assemblage'. *Proceedings of the Society of Antiquities for Scotland.* **139**, pp. 9-45.

5.1 Geological Ground Model

5.1.1 Quaternary sediments within the WDA represent a succession of Pleistocene and Holocene environments, predominantly associated with cold-climate and/or marine conditions. Pre–Last Glacial Maximum (LGM) sediments are present within the dataset; however, no terrestrial formations have been identified to date.

5.1.2 Given that the SBP and UHRS datasets acquired across the WDA significantly exceed the resolution and coverage of previously available data, there remains some potential for terrestrial sediments deposited during interglacial or interstadial periods to be identified at greater depths.

Pre-Quaternary bedrock

5.1.3 The pre-Quaternary bedrock within the WDA has been identified within the UHRS data (**Figure 10**). The WDA is crosscut by the Dubh Artach and the Colonsay fault, splays in the Great Glen Fault complex, active from the at least the Carboniferous into the Mesozoic[5,10].

5.1.4 The bedrock within the WDA area is expected to include rocks of sedimentary, metamorphic and igneous origin, comprising strong to very strong sandstone, mudstone, phyllite, and strong to very strong basaltic intrusions[4]. Regional geological mapping and geophysical interpretation indicate metamorphic (metasedimentary) basement rocks, with undifferentiated mudstone, sandstone, limestone and other siliciclastic units also present, particularly within the central part of the WDA. Igneous rocks, interpreted as intrusive dykes and sills, are locally present and contribute to strong to very strong bedrock conditions.

5.1.5 Elevated magnetic field values in the northern part of the site suggest that igneous rocks extend further north than indicated on the BGS 1:250,000 Tiree solid geology sheet and are consistent with the regional orientation of Paleogene and Late Carboniferous dykes along the west coast of Scotland[4].

5.1.6 Across some of the site, bedrock forms the lower boundary of the Till Unit identified by Sulmara, representing the geological basement beneath the glacial and post-glacial sedimentary succession and corresponding to the H40 surface (**Figure 11**).

5.1.7 In localised areas in the north, bedrock is interpreted to outcrop at the seabed, particularly at seabed highs such as in the vicinity of the Dubh Artach Lighthouse (**Figure 12**). Acoustically, the bedrock is typically defined by a well-developed basal reflector and is largely internally structureless (Acoustic Facies J in **Figure 10**). Locally, stronger internal reflectors forming angular unconformities with overlying Quaternary sediments are observed (Acoustic Facies K in **Figure 10**) and are tentatively interpreted as possible interbedded Tertiary sediments within or overlying the basement, although this remains uncertain in the absence of ground truthing[4].

Thickness of Quaternary deposits

5.1.8 Resistant bedrock highs separating sedimentary basins result in Quaternary sediments being preserved within discrete basin infills that are laterally limited and commonly isolated from one another. The earliest preserved sediments within the Study Area are likely to pre-date the Devensian glaciation, although the majority of the Quaternary sequence is interpreted to have

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[10] Fyfe, J A, Long, D, and Evans, D. (1993). *United Kingdom offshore regional report: the geology of the Malin–Hebrides sea area*. (London: HMSO for the British Geological Survey.)

been deposited during the late Devensian[10].

5.1.9 The BGS Quaternary Thickness map indicates that Quaternary sediment thickness exceeds 50 m across the majority of the WDA (**Figure 13**), thinning towards the south-east. The thickness is zero where bedrock is present at the seabed (**Figure 12**).

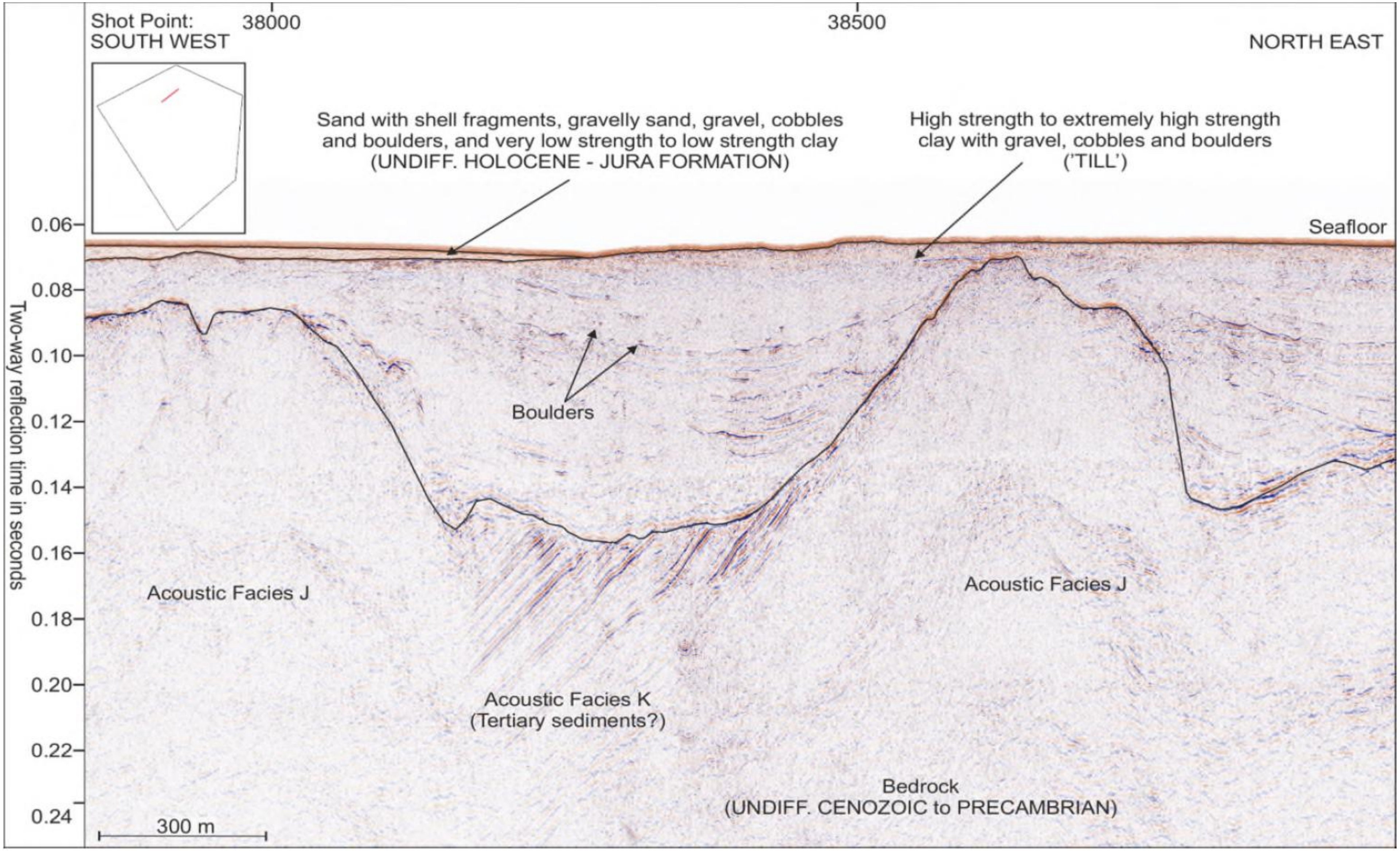
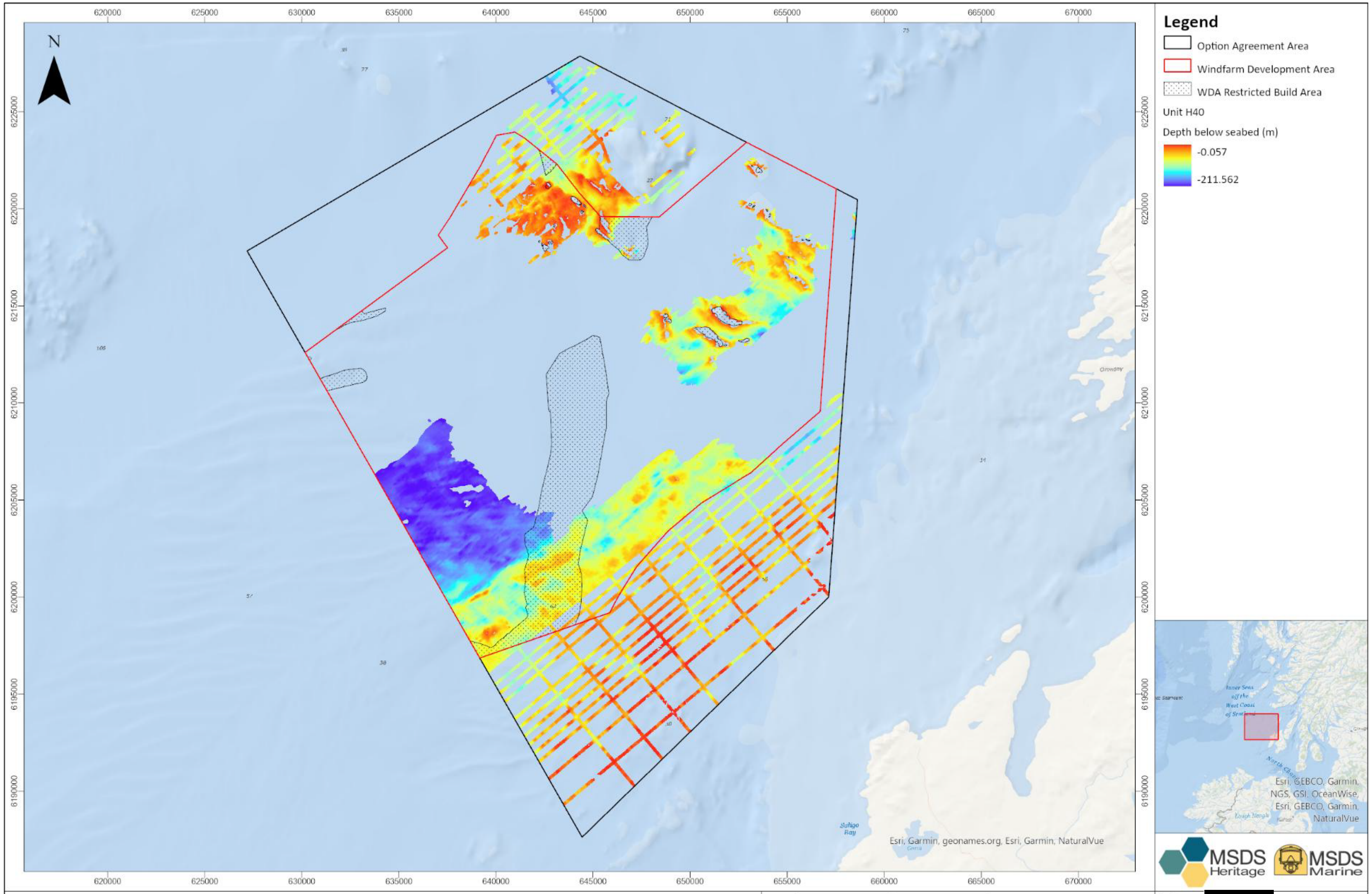
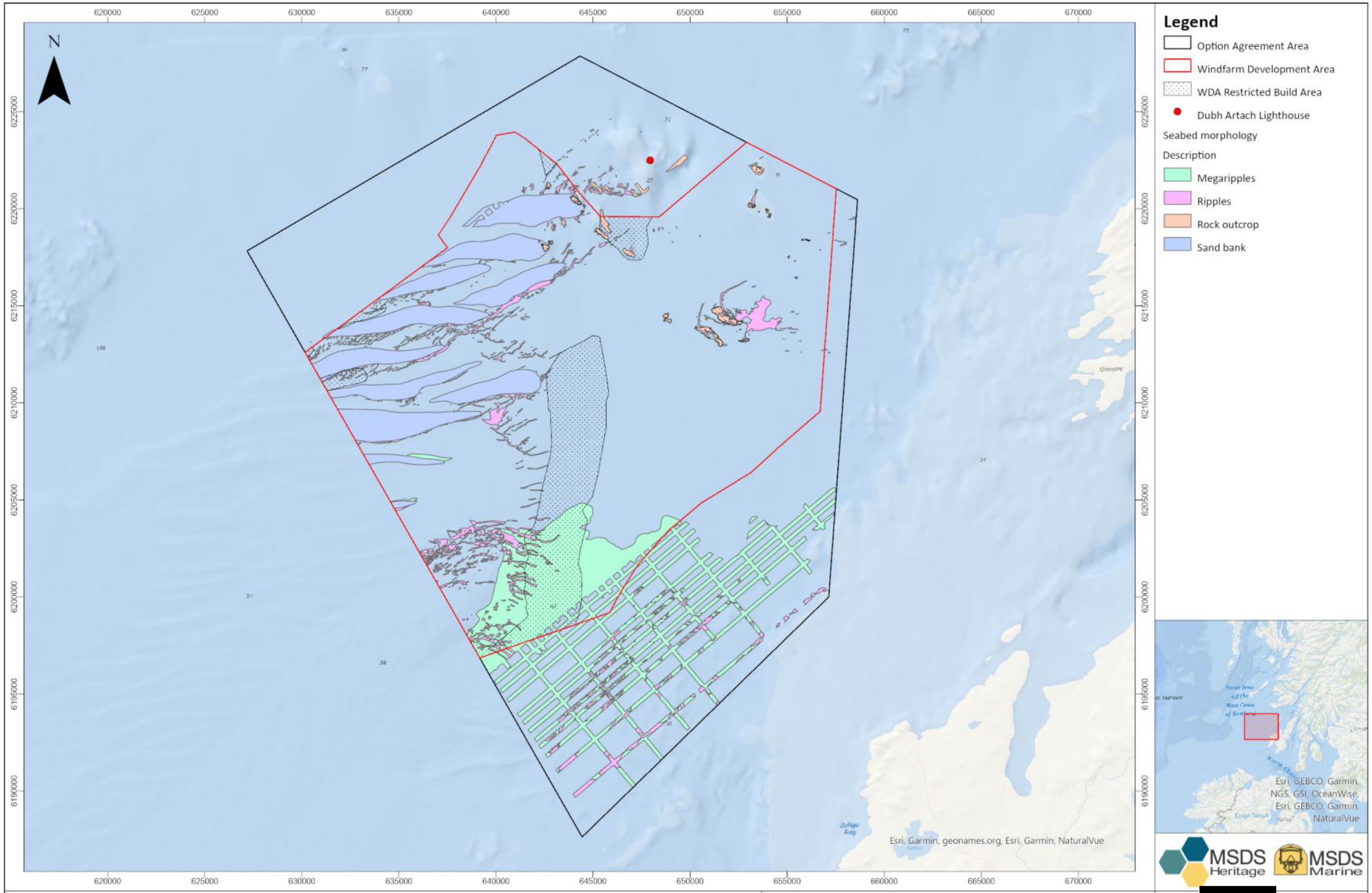


Figure 10 Example of bedrock character in the north of the WDA, Acoustic Facies J and K. Fugro UHRS data (line MCWA01A)



Project **MachairWind Offshore Windfarm**	Scale 0 5 10 Kilometers	Author	[redacted]
		Date	23 March 2026
Title **Bedrock across the WDA (Sulmara H40 - Base of ‘Till Unit’ de facto ‘Basement’)**	Projection **ETRS 1989 UTM Zone 29N**	Revision	1.0
		Checked	[redacted]

Figure 11 Bedrock across the WDA (Sulmara H40- Base of ‘Till Unit’ de facto ‘Basement’)



Project
MachairWind Offshore Windfarm

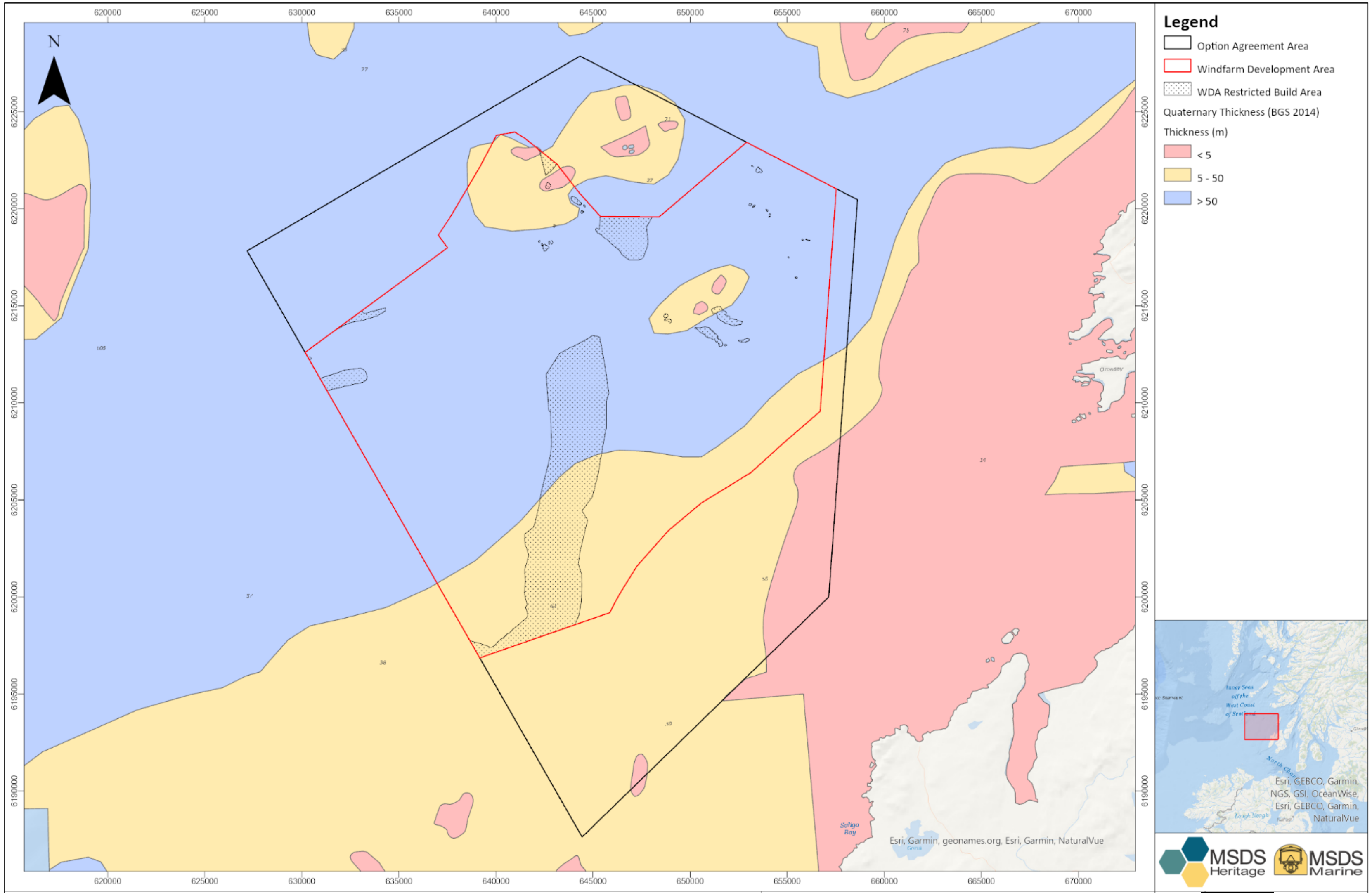
Title
Seabed morphology (highlighting exposed bedrock as rock outcrop)

Scale 0 5 10 Kilometers

Projection
ETRS 1989 UTM Zone 29N

Author	[redacted]
Date	23 March 2026
Revision	1.0
Checked	[redacted]

Figure 12 Seabed morphology (highlighting exposed bedrock as rock outcrop)



Project **MachairWind Offshore Windfarm**	Scale 0 5 10 Kilometers	Author [redacted] Date 23 March 2026
Title **Quaternary thickness across the WDA**	Projection **ETRS 1989 UTM Zone 29N**	Revision 1.0 Checked [redacted]

Figure 13 Quaternary thickness across the WDA

5.2 Quaternary deposits: Interpretation

5.2.1 Three geological horizons have been identified within the UHRS dataset by Sulmara, in addition to the seabed (H00) and the top of the shallow gas front (H60). MSDS Marine have assigned unit numbers to the strata between the interpreted horizons (**Table 7**) and tentatively attributed geological formations to them.

5.2.2 In addition, Fugro interpreted a Cobble Layer[4] (H10) which is a distinctive reflection between the Seabed and H20, this was not extended by Sulmara into the 2025 data[5].

5.2.3 The horizons were compared against the available geophysical datasets described in **Section 4.3**. Interpretation was specifically evaluated along the 44 seismic lines, alongside relevant published literature for the area. The interpretations are considered provisional, as a geotechnical investigation has not yet been undertaken, and are primarily based on seismic amplitude characteristics in combination with previous geological studies referred to in the following text and 7.0 Appendix A. The results of any future geotechnical investigations should be reviewed to further assess the Quaternary sequence within the WDA and to ground-truth the current interpretations.

5.2.4 The consistency and quality of horizon picking have been evaluated and are deemed sufficient for the palaeolandscape assessment, in conjunction with the review of BGS data for the area and relative sea level data. The attribution of geological formations to the interpreted units, are considered in the sections below.

	Horizon		Depth to base (m below seafloor)	Seismic character	Expected lithology	Depositional environment	Correlated formation/ member	MIS	Age	Archaeological Potential
	Top	Base								
Units identified in UHRS data										
U01	H00	H20	0.1–48.4	Unit: Predominantly acoustically chaotic with diffraction hyperbolae, to continuous reflections towards the base of the unit. Locally with discontinuous inclined reflections of moderate amplitude. Chaotic reflections at the top associated with mobile bedforms of the Lorne Fm. H10 cobble layer sits within this unit currently, chaotic reflectors with numerous high amplitude diffraction hyperbolae. Onlaps onto basal horizon. Basal horizon: Continuous strong amplitude reflection where shallow gas is not	Structureless low to medium strength dark grey silty clay with sand and frequent shell fragments, occasional cobbles and boulders. The H10 ‘Cobble Layer’ contains gravel, cobbles and boulders.	Glacio-marine (ice-distal)	Jura Formation, potentially Rhum and Arisaig members (Davies et al., 1984[11], Boulton et al 1981[12]) corresponds to Unit IVB in Arosio et al. (2018)[13]	1	Late Pleistocene to Holocene (Windermere Interstadial to Holocene)	Very low

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[11] Davies, H.C., Dobson, M.R. and Whittington, R.J., 1984. A revised seismic stratigraphy for Quaternary deposits on the inner continental shelf west of Scotland between 55°30′N and 57°30′N. *Boreas*, 13, pp.49–66.

[12] Boulton, G.S., Chroston, N.P. and Jarvis, J., 1981. A marine seismic study of late Quaternary sedimentation and inferred glacier fluctuations along western Inverness-shire, Scotland. *Boreas*, 10, pp.39–51.

[13] Arosio, R. and Howe, J.A., 2018. Lateglacial to Holocene palaeoenvironmental change in the Muck Deep, offshore western Scotland. *Scottish Journal of Geology*, 54(2), pp.1–31.

	Horizon		Depth to base (m below seafloor)	Seismic character	Expected lithology	Depositional environment	Correlated formation/ member	MIS	Age	Archaeological Potential
	Top	Base								
🟨				present. Erosional in nature, truncates underlying reflections. V-U shaped incisions into surface locally.						

	Horizon		Depth to base (m below seafloor)	Seismic character	Expected lithology	Depositional environment	Correlated formation/ member	MIS	Age	Archaeological Potential
	Top	Base								
Units identified in UHRS data										
U02	H20	H30	0.1–88.5	Unit: Acoustically well layered with low to moderate amplitude continuous parallel to inclined reflections. V and U-shaped incisions (some infilled with very strong amplitude parallel reflections, some have a transparent infill). Lower ~10 m of unit infills topography whilst the rest drapes or onlaps onto this initial infill. Basal horizon: Very strong amplitude thick reflection, laterally continuous where imaged. Minor erosional surface, both positive and negative geomorphological features associated with the surface.	Predominantly silts and clays with occasional dropstones. Potential coarse-grained material delivered as ice rafted debris (from Callard et al., 2018) alternating massive pebbly rich mud with laminated silts and clays)	Glacio-marine (ice-distal)	Jura Formation, potentially Muck Formation (Arosio et al., 2018[13]). Basal surface itself and just above it could represent till, glacial retreat.	1/2	Late Pleistocene to Holocene (LGM to Holocene)	Very low

	Horizon		Depth to base (m below seafloor)	Seismic character	Expected lithology	Depositional environment	Correlated formation/ member	MIS	Age	Archaeological Potential
	Top	Base								
Units identified in UHRS data										
U03	H30	H40	0–207	Unit: This unit can likely be subdivided into two sub-units. The lower sub-unit comprises strong-amplitude, laterally continuous, horizontal to sub-horizontal parallel reflections that infill the underlying H40 palaeotopography. This is overlain by an upper sub-unit characterised by chaotic, weak-amplitude reflections with strong amplitude points. Basal horizon: Marked by a very strong-amplitude, thick, laterally continuous reflection. The surface is undulating and is interpreted as erosional in nature. H40 represents the base of Till, and within areas where the bedrock is recognisable, it represents Top bedrock	Predominately silty clays with drop stones	Glacio marine to fully glacial	Malin A & B	>2	Late Pleistocene, pre Devensian to late Devensian	Very low

Table 7 Summary of identified units and horizons

5.3 Quaternary Formations

5.3.1 This section discusses the Quaternary formations expected within the WDA and the wider region in relation to the interpretation of the available geophysical data. The expected stratigraphy of the offshore Hebridean region is shown in **Figure 14**. Formation descriptions are based primarily on Fyfe et al. (1993)[10], with additional sources referenced where relevant throughout the text.

5.3.2 Although several formations have been identified in the region through legacy BGS mapping and contractor interpretations (Fugro4and Sulmara[5], review of the data indicates that only two formations can be confidently interpreted. Within the WDA: the glaciomarine Jura Formation and the Malin Formation (A and B), which is interpreted as a composite till and glaciofluvial unit are interpreted.

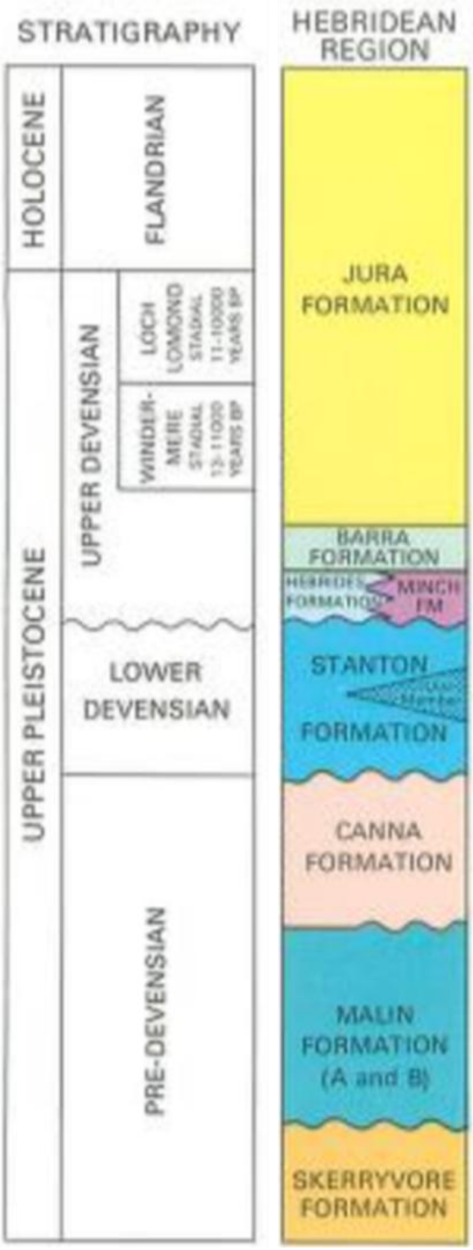

Figure 14 Expected Stratigraphy of the Offshore Hebridean Region from Fyfe et al., 1993[10]

5.3.3 The Malin Formation comprises two seismic facies. Malin A is characterised by discontinuous reflectors, point-source diffraction patterns and a hummocky upper surface, whereas Malin B, which largely overlies Malin A, displays parallel to subhorizontal, medium-spaced reflectors with a general absence of diffraction hyperbolae A major erosional surface occurs above the unit. Lithologically, the formation consists of subglacial diamicton (Malin A) overlain by glacifluvial stratified sediments (Malin B)[14]. The formation is pre-Devensian in age and broadly assigned to MIS 4–12[14].

5.3.4 Within the WDA, this formation corresponds most closely to MSDS Marine U03 between Horizons H30 and H40. The upper ~20 m of MSDS Marine Unit U03 contains inclined accretion surfaces consistent with migrating glaciofluvial channels, supporting correlation with Malin B, although well-bedded intervals within the unit suggest that multiple formations may be present (see Appendix A - Figure 18).

5.3.5 The glaciogenic and glaciofluvial depositional environments indicate very low potential for archaeological remains or palaeoenvironmental material.

Jura Formation

5.3.6 The lower part of the Jura Formation is characterised by predominantly weak-amplitude, stratified seismic reflections that initially infill the topography before transitioning to a draping geometry (see Appendix A Figure 20). The upper part of the formation is also stratified but exhibits locally more chaotic seismic character, inclined reflections with increased reflection amplitudes and the occurrence of point-source diffractions. These two sub-units are separated locally by an erosional surface in the south of the Fugro UHRS dataset, and a change in seismic character throughout (see Appendix A Figure 20).

5.3.7 Lithologically, the Jura Formation is typically described as structureless dark grey silty clays with a high sand content, containing rare oversized clasts and shell fragments. The upper part of the formation (Jura B) includes larger clast sizes, locally including cobbles and boulders. This interval corresponds to the “Cobble Layer” described by Fyfe et al. (1993)[10] and was interpreted by Fugro[4] as a discrete horizon (H10). The presence of these coarse clasts provides a plausible explanation for the point-source diffractions observed within the upper unit.

5.3.8 The Jura Formation correlates to MSDS Marine U02 and U01. The formation is interpreted to represent deposition within a dynamic glacimarine environment under fluctuating climatic conditions following the Last Glacial Maximum, including the Loch Lomond Stadial (MIS 2-1). and thus has very low archaeological potential.

Formations Summary

5.3.9 In summary, there are differences between the MSDS Marine interpretation and that presented by Sulmara. The principal difference is that the sediments between horizons H00 and H30 are interpreted here as belonging entirely to the Jura Formation, rather than being subdivided into the Jura and Stanton formations. The rationale for this interpretation is outlined in the formation descriptions below and in Appendix A.

5.3.10 The difference in interpretation has no impact on the evaluation of the archaeological potential

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[14] Craven, K.F., McCarron, S., Monteys, X. and Dove, D. (2021) ‘Interaction of multiple ice streams on the Malin Shelf during deglaciation of the last British–Irish Ice Sheet’, *Journal of Quaternary Science*, 36(2), pp. 153–168. https://doi.org/10.1002/jqs.3266

as all potential formations are either glacial or glaciomarine.

5.4 Ice sheet history and sea level

5.4.1 Data on past sea levels, when integrated with geological and glaciogenic evidence, provide important context for palaeolandscape development during the Late Quaternary and early Holocene. A detailed discussion of ice-sheet extent and sea-level history is provided in the Appendix, with the key points summarised below. Reconstruction of palaeolandscapes informs subsequent assessment of human occupation and archaeological potential. The WDA currently lies at between -21 m to -119 m[5].

5.4.2 The British Irish ice sheet developed outward from the Scottish Highlands during the Dimlington stadial (29,000 to 14,700 BP) extending as far as west as the continental shelf edge of the west coast of Scotland at ~26, 000 BP [15] (see Appendix A Figure 26 to Figure 31) and as far south as the Norfolk coast. Northern parts of Britain were therefore subject to greater depression and rebound, with localised variations in ice thickness potentially causing further local variations in relative sea level[16].

5.4.3 Relative sea-level (RSL) change in western Scotland following the Last Glacial Maximum (LGM) reflects the strong influence of glacio-isostatic rebound (uplift) following ice unloading, superimposed on eustatic sea-level rise.

5.4.4 Importantly for the WDA, the two closest SLIPs (Sea Level Index Points), Islay and Coll[17], indicate that relative sea level remained above present until approximately 10–8 ka BP, after which it fell only slightly to around ~1 m below present sea level (**Figure 15**). These data are supported by topographic and palaeocoastline outputs from recent Glacial Isostatic Adjustment (GIA) modelling from Bradley et al, 2023[18] which also demonstrate that since local deglaciation there has been no period of substantially lowered RSL that would have resulted in meaningful exposure of the WDA (**Figure 16**).

5.4.5 Geomorphological evidence further indicates that marine conditions were already established in the region during ice retreat, rather than developing later as a result of Holocene transgression. Dove et al. (2015)[19] describe assemblages of minor transverse ridges occurring between larger recessional moraines in areas including the Sound of Mull and Sound of Jura. These ridges are interpreted as De Geer moraines, which are diagnostic of grounding-line retreat in a sub-aqueous setting.

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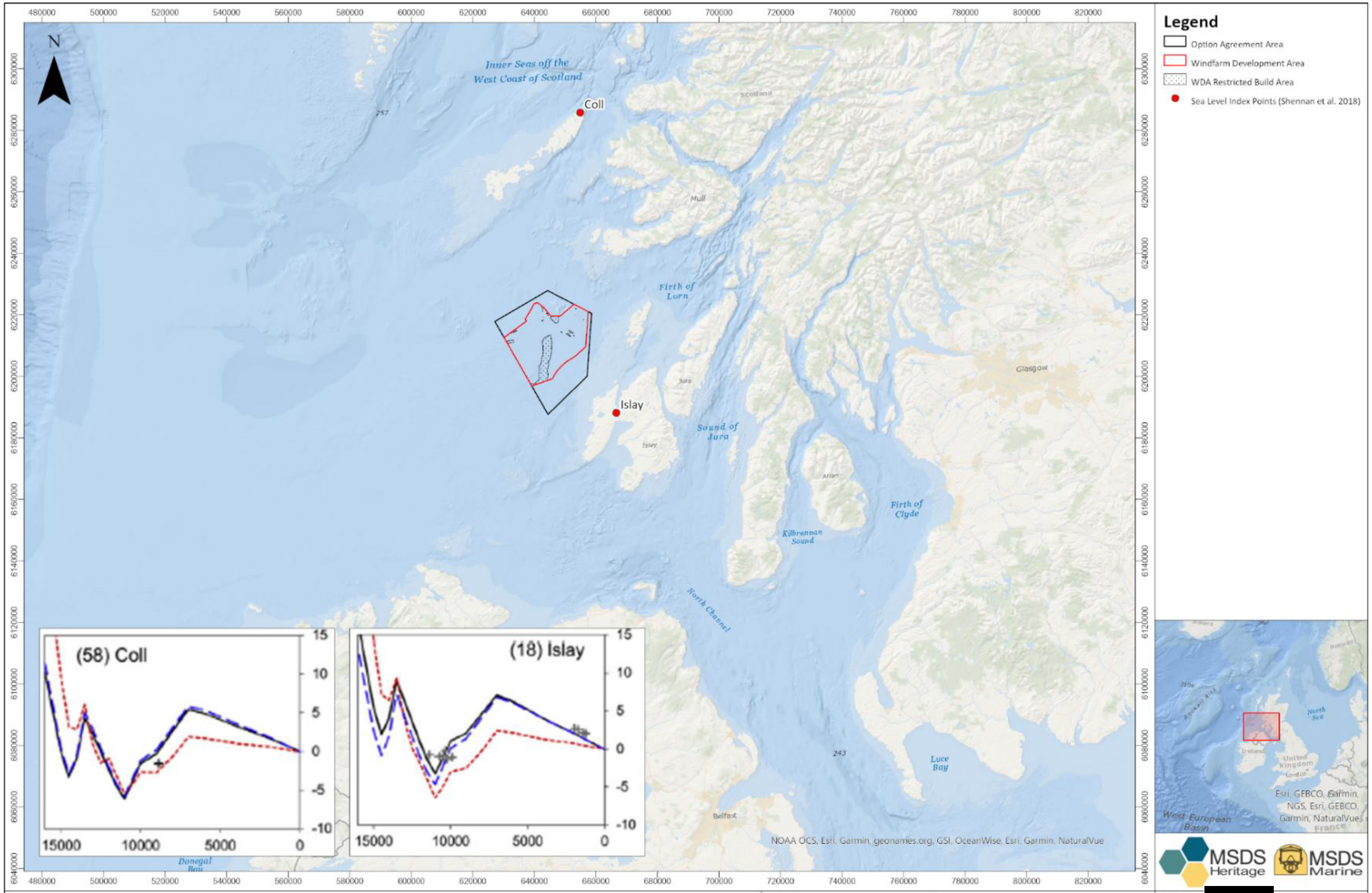
[15] Clark, C.D., Ely, J.C., Fabel, D. and Bradley, S.L. (2022) BRITICE-CHRONO maps and GIS data of the last British-Irish Ice Sheet 31 to 15 ka, including model reconstruction, geochronometric age spreadsheet, palaeotopographies and coastline positions [dataset]. PANGAEA. https://doi.org/10.1594/PANGAEA.945729

[16] Jordan, J. T., Smith, D. E., Dawson, S. and Dawson, A. G. 2010. Holocene relative sea-level changes in Harris, Outer Hebrides, Scotland, UK. *J. Quaternary Sci.*, Vol. 25 pp. 115–134. ISSN 0267-8179.

[17] Shennan, I., Bradley, S.L. and Edwards, R. (2018) 'Relative sea-level changes and crustal movements in Britain and Ireland since the Last Glacial Maximum', *Quaternary Science Reviews*, 188, pp. 143–159.

[18] Bradley, S.L., Ely, J.C., Clark, C.D., Edwards, R.J. and Shennan, I. (2023), Reconstruction of the palaeo-sea level of Britain and Ireland arising from empirical constraints of ice extent: implications for regional sea level forecasts and North American ice sheet volume. J. Quaternary Sci, 38: 791-805.

[19] Dove, D., Ó Cofaigh, C., Geirsdóttir, Á. and Smith, J.A. (2015) 'Submarine glacial landforms record Late Pleistocene ice-sheet dynamics, Inner Hebrides, Scotland', *Boreas*, 44(1), pp. 1–17.



Project
MachairWind Offshore Windfarm

Scale
0 45 90 Kilometers

Author [redacted]

Title
Sea Level Index Points (SLIPs) from Shennan et al., 2018

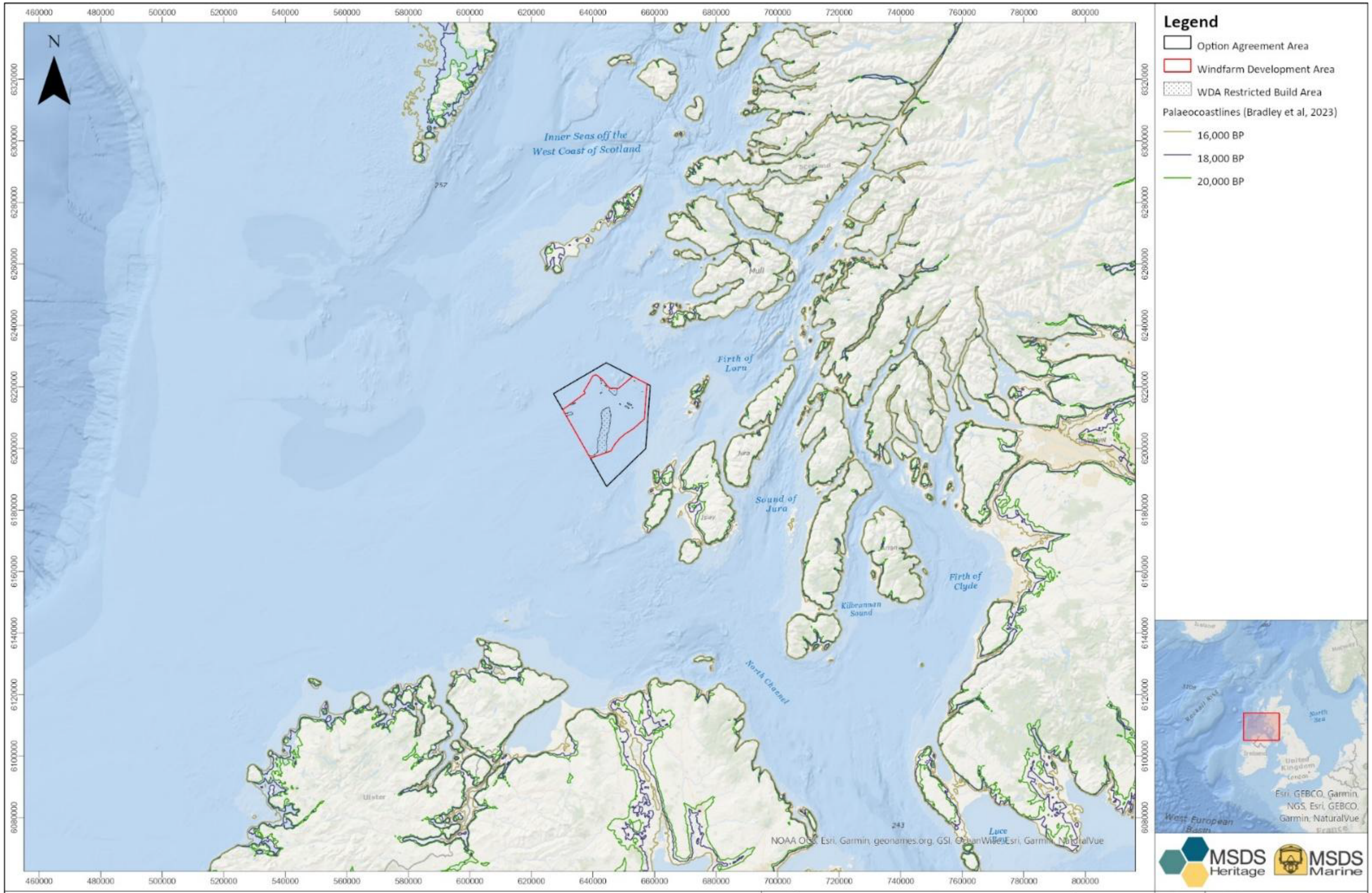
Projection
ETRS 1989 UTM Zone 29N

Date 09 February 2026

Revision 1.0

Checked [redacted]

Figure 15 Sea Level Index Points (SLIPs) from Shennan et al., 2018



Project **MachairWind Offshore Windfarm**	Scale 0 45 90 Kilometers	Author [redacted] Date 09 February 2026
Title **Palaeocoastlines (post Last Glacial Maximum)**	Projection **ETRS 1989 UTM Zone 29N**	Revision 1.0 Checked [redacted]

Figure 16 Palaeocoastlines (post Last Glacial Maximum)

5.5 Palaeolandscape assessment summary and archaeological implications

5.5.1 The combined evidence from SLIPs, geomorphology, raised shoreline records and GIA modelling demonstrates that there has been no sustained period since deglaciation when relative sea level was sufficiently low to expose the WDA.

5.5.2 Although GIA models suggest earlier exposure prior to ~29 ka BP, this occurred under glacial or periglacial conditions close to the ice margin and is unlikely to have been habitable. During and after ice retreat (~20–15 ka BP), marine conditions were already prevalent, as demonstrated by De Geer moraines and relative sea level remained close to or above present during periods of climatic amelioration.

5.5.3 Consequently, the likelihood of preserved prehistoric archaeology within the WDA is considered very low, as the area was not subaerially exposed during climatically favourable post-glacial periods. There is also a negligible likelihood of material being preserved that would be suitable for palaeoenvironmental analysis (**Table 8**).

5.5.4 There is likely to be low potential also for reworking of pre-LGM terrestrial deposits that may contain prehistoric archaeology as current evidence has not found evidence of humans in Scotland prior to 12,000 to 11,500 BP

Unit	MIS	Potential	
		Prehistoric archaeology	Palaeoenvironmental
U01	1	Very low	Negligible
U02	1–2	Very low	Negligible
U03	>2	Very low	Negligible

Table 8 Summary of archaeological potential

6.0 Mitigation

6.0.1 This assessment has examined the archaeological and palaeoenvironmental potential of identified geological units within the WDA. The assessment has attributed a very low archaeological potential for all identified units.

6.0.2 Given the very low potential for palaeoarchaeological remains, no specific recommendations are made with regards to the targeted geoarchaeological assessment of geotechnical samples. However, some uncertainty remains regarding the age and depositional environment of pre–Last Glacial Maximum sediments, compounded by localised masking from shallow gas.

6.0.3 It is therefore recommended that as geotechnical investigations progress, the samples are subject to Stage 1: Geoarchaeological review of core logs to ground truth the interpretations made during this assessment.

6.0.4 Should material of palaeoenvironmental potential be identified (which is deemed unlikely), the samples should progress through the staged process outlined below.

- Stage 1: Geoarchaeological review of core logs;
- Stage 2: Geoarchaeological recording;
- Stage 3: Geoarchaeological assessment;
- Stage 4: Geoarchaeological analysis, and;
- Stage 5: final reporting.

6.0.5 This work should be undertaken by a geoarchaeologist. Each stage should inform the scope of the next, and work may cease at any point where no recommendations for further work are made.

6.0.6 This geoarchaeological assessment and analysis should aim to deliver conclusions on the prehistoric archaeological and palaeoenvironmental remains within the area. Further mitigation may be required based on the results of this assessment. The geoarchaeological work should follow guidance set out within COWRIE's *Offshore Geotechnical Investigations and Historic Environment Analysis: Guidance for the Renewable Energy Sector* (Gribble and Leather 2010).

6.0.7 The use of an appropriate protocol for archaeological discoveries such as the *Crown Estates Protocol for Archaeological Discoveries: Offshore Renewables Projects*[20] also provides mitigation for prehistoric and palaeoenvironmental remains.

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[20] The Crown Estate (2014). *Protocol for Archaeological Discoveries: Offshore Renewables Projects*. Wessex Archaeology on behalf of the Crown Estate.

7.0 Appendix A

7.1 Quaternary Formations/MSDS Interpretation

Skerryvore Formation

7.1.1 The Skerryvore Formation is characterised by a structureless lower seismic unit overlain conformably by faint, horizontally bedded reflections containing diffraction hyperbolae consistent with dropstones. It comprises stiff silty clays up to approximately 45 m thick overlain by around 25 m of bedded fine-grained sediments. The formation is pre-Devensian in age and interpreted as representing a temperate shallow marine to glaciomarine depositional environment in its upper section[10].

7.1.2 The Skerryvore Formation has not been confidently identified within the WDA; if present, it would most likely occur between Horizons H40 and H30 (**Figure 11** and **Figure 17**, respectively). Given its shallow marine to glaciomarine origin, the formation is considered to have very low archaeological potential for the preservation or recovery of archaeological material.

Malin Formation

7.1.3 The Malin Formation comprises two seismic facies. Malin A is characterised by discontinuous reflectors, point-source diffraction patterns and a hummocky upper surface, whereas Malin B, which largely overlies Malin A, displays parallel to subhorizontal, medium-spaced reflectors with a general absence of diffraction hyperbolae A major erosional surface occurs above the unit. Lithologically, the formation consists of subglacial diamicton (Malin A) overlain by glacifluvial stratified sediments (Malin B)[21]. The formation is pre-Devensian in age and broadly assigned to MIS 4–12[21].

7.1.4 Within the WDA, this formation corresponds most closely to MSDS Marine U03 between Horizons H30 and H40, which agrees with the Sulmara intepretation[5] The upper ~20 m of MSDS Marine Unit U03 contains inclined accretion surfaces consistent with migrating glaciofluvial channels, supporting correlation with Malin B, although well-bedded intervals within the unit suggest that multiple formations may be present (see **Figure 18**). The glaciogenic and glaciofluvial depositional environments indicate very low potential for archaeological remains or palaeoenvironmental material.

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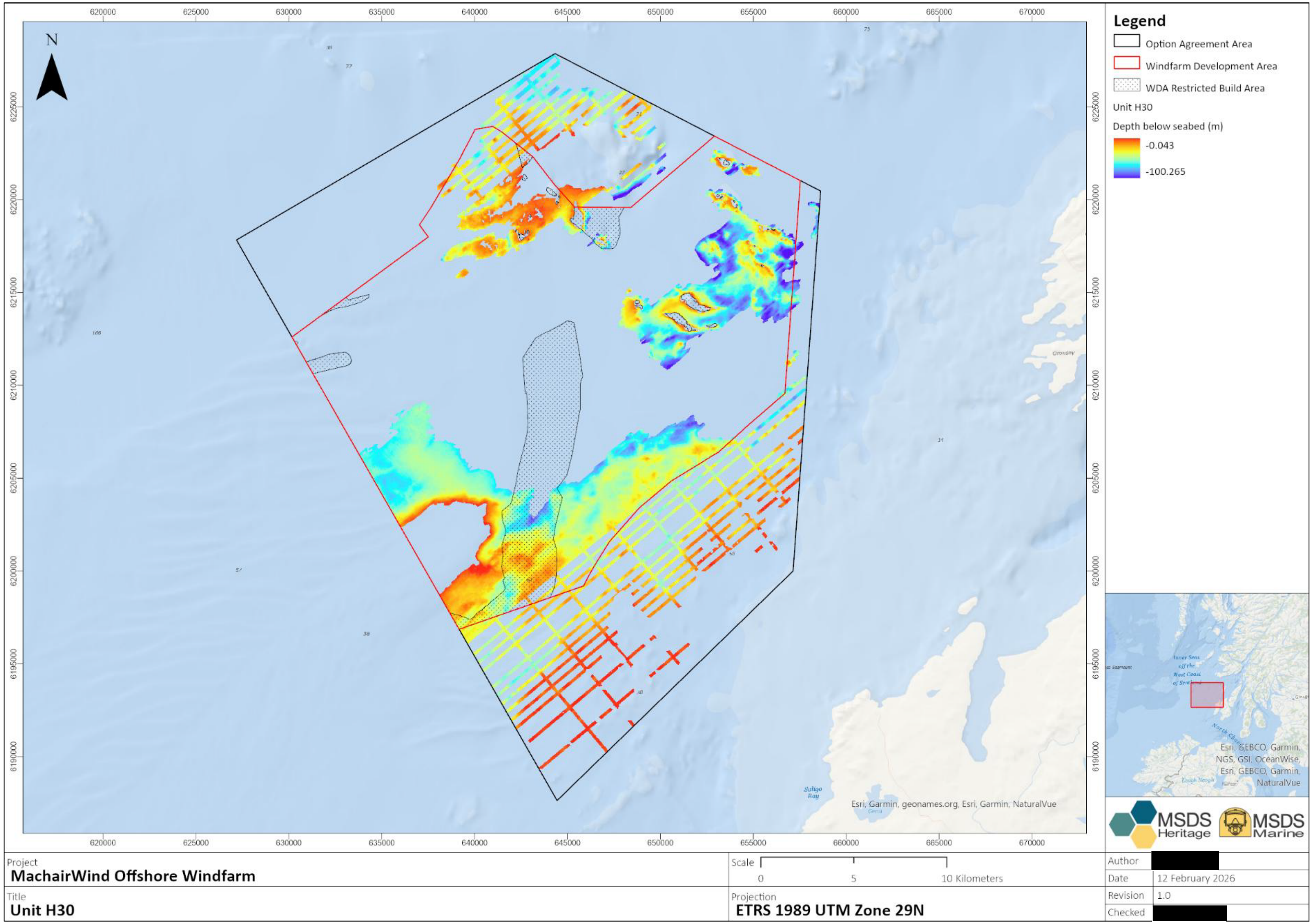
[21] Craven, K.F., McCarron, S., Monteys, X. and Dove, D. (2021) 'Interaction of multiple ice streams on the Malin Shelf during deglaciation of the last British–Irish Ice Sheet', *Journal of Quaternary Science*, 36(2), pp. 153–168. https://doi.org/10.1002/jqs.3266



Project
MachairWind Offshore Windfarm

Title
Unit H30

Projection
ETRS 1989 UTM Zone 29N

Author [redacted]
Date 12 February 2026
Revision 1.0
Checked [redacted]

Figure 17 Sulmara H30 Surface

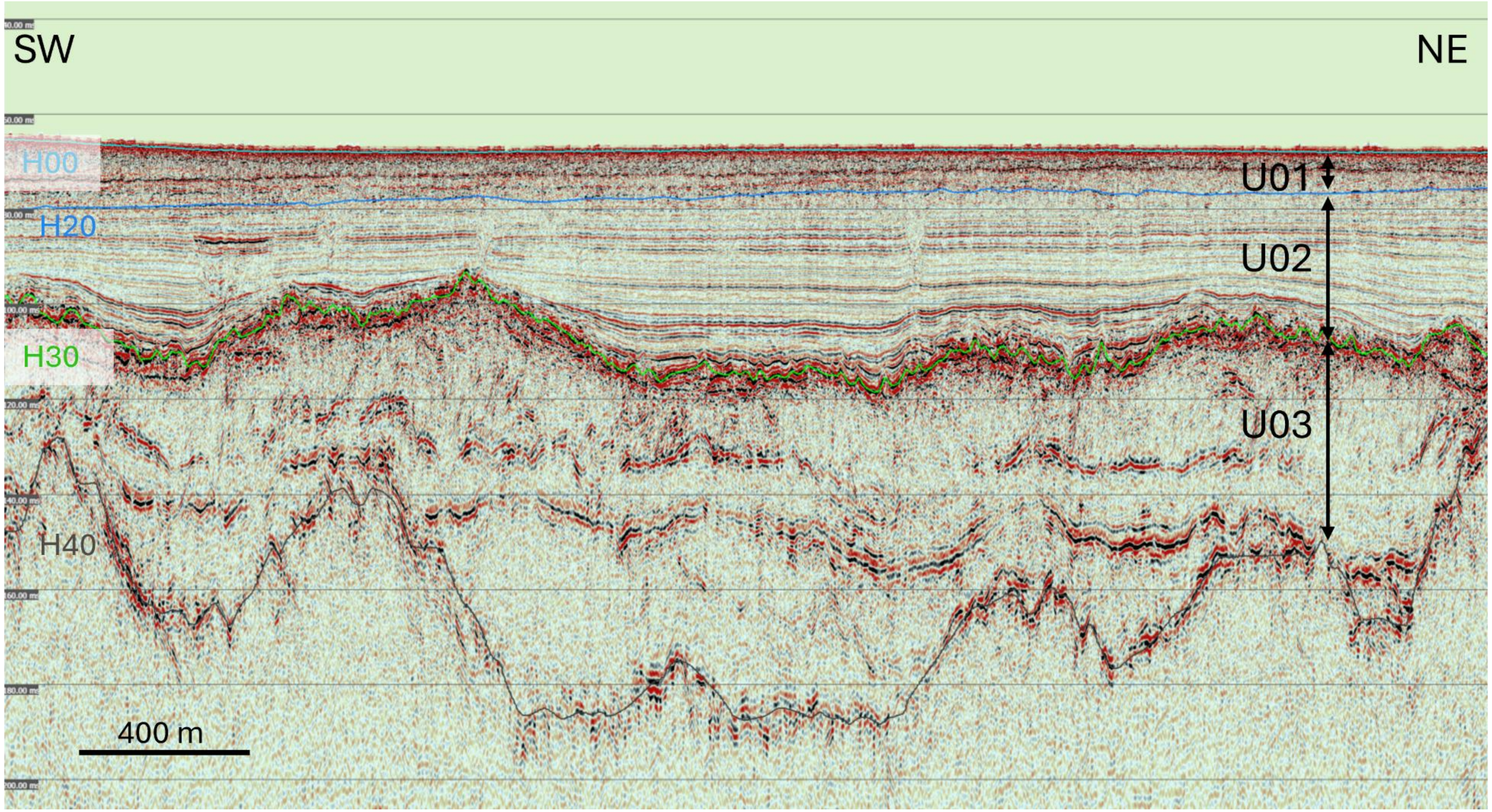


Figure 18 Variable seismic character of U03. Sulmara UHRS seismic line ML_S06400. Potentially representing multiple geological formations. Green H30, Grey H40

Canna Formation

7.1.5 The Canna Formation is expressed seismically as short, discontinuous, randomly spaced reflectors or as an acoustically transparent sequence separated from younger units by a widespread erosional surface. It comprises very stiff dark grey to brown silty sandy clays with numerous pebbles and cobbles. The formation is certainly pre-late Devensian and possibly pre-Devensian in age and is interpreted as rapidly deposited glaciomarine sediment comparable in character to the Barra Formation[10].

7.1.6 Although it has not been confidently identified within the WDA, it may form part of MSDS Marine Unit U03 between Horizons H30 and H40. Its glaciomarine depositional environment suggests very low archaeological potential.

Stanton Formation

7.1.7 The Stanton Formation is characterised by extremely well stratified seismic reflections commonly draped over irregularities in the rockhead, with locally reported point-source diffraction patterns (**Figure 19**). It comprises dark grey, stiff, laminated silty clay containing lignite debris, shell fragments and dropstones. The formation is early to mid-Devensian in age and represents stratified glaciomarine sediments deposited prior to full glacial overriding of the area[10].

7.1.8 Sulmara interpret Horizon H30 as the base of the Stanton Formation. MSDS interpret Horizon H30 as the base of the Jura Formation. Though there is this difference in interpretation, this does not impact archaeological or palaeoenvironmental potential as the Stanton and Jura Formations are both glaciomarine in depositional environment and have similar lithology. Regionally, the formation is expected to be capped by a major unconformity and would therefore lie below Horizon H30 if present within the WDA. The regional limit of the Stanton Formation is uncertain, although it is reported not to extend east of approximately 6°40′W, placing the WDA near or beyond its eastern margin. Possible Stanton-like seismic facies occur south of the WDA and within the Fugro UHRS lines (**Figure 19**) but its presence within the WDA remains uncertain. The rational for a different interpretation is discussed further in the Jura Formation. The glaciomarine depositional environment indicates very low archaeological potential.

Minch/Hebrides Formation

7.1.9 The Minch and Hebrides formations are expressed seismically as thin, discontinuous glacigenic units. The lithology is coarse-grained diamicton of variable colour, and up to 10 m thick[10]. The formations comprise subglacial till deposited during the Late Devensian glacial advance across the WDA.

7.1.10 These formations are not clearly differentiated within the WDA; however, localised pockets of stratified sediments within MSDS Marine Unit U03 above and below Horizon H30, associated with positive geomorphological features, may represent equivalents of this formation along the surface of Horizon H30. These features correspond to Acoustic Facies G in the Fugro geophysical results report[4] and are consistent with till deposits forming mounds and ridges interpreted as moraines or drumlins. The glaciogenic depositional environment indicates very low potential for archaeological remains.

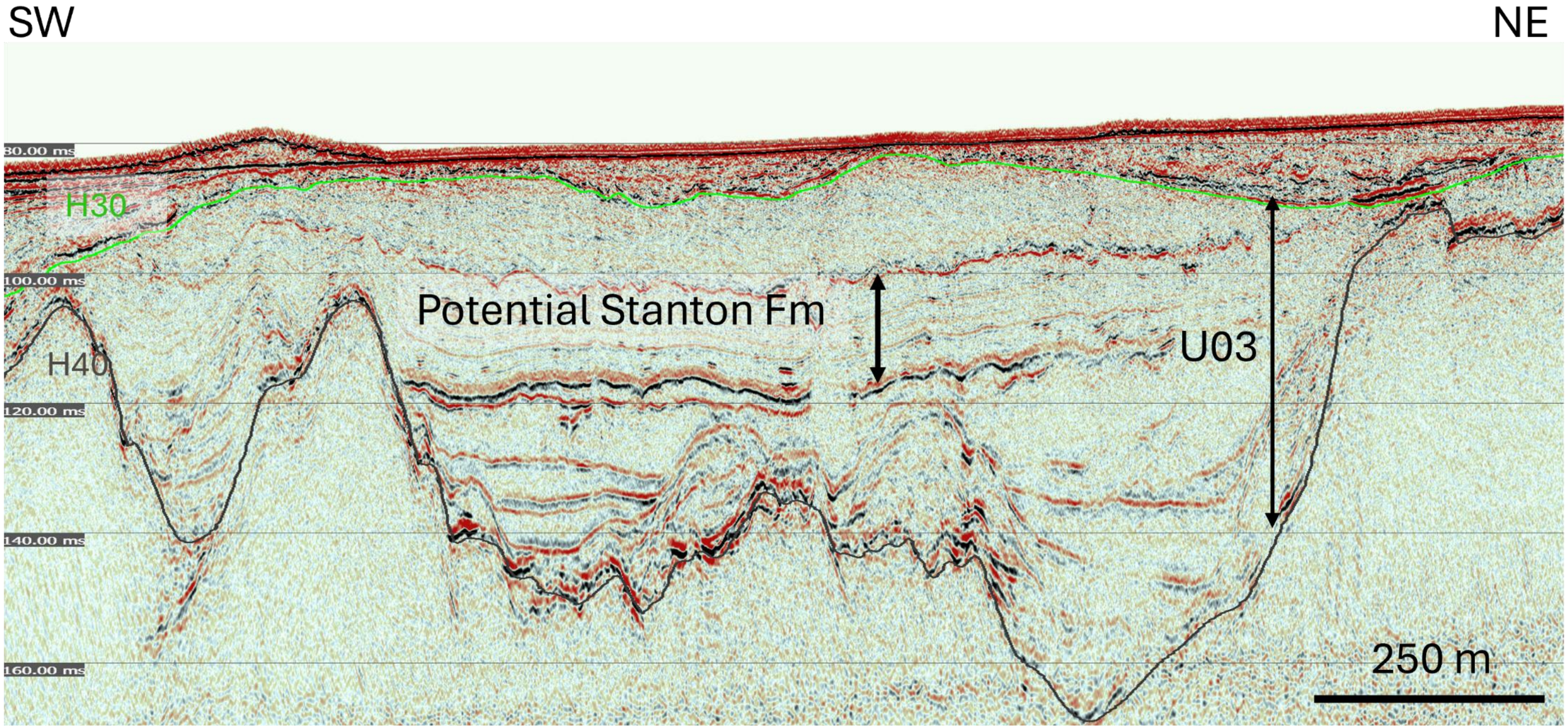


Figure 19 Example of possible Stanton Formation. Below H30 in Fugro UHRS line MCWD059 south of the WDA. Green H30, Grey H40

Barra Formation

7.1.11 The Barra Formation displays an acoustically transparent to chaotic seismic response and comprises silty clays containing dropstones deposited in an ice-proximal glaciomarine environment immediately following the Late Devensian glacial maximum in the region (~26,000 BP)[10].

7.1.12 The formation has not been confidently identified within the WDA and this agrees with the interpretation of Sulmara[5]. Regional mapping places the Study Area near the eastern limit of the Barra Formation extent, and its absence within the dataset is plausible. The ice-proximal glaciomarine depositional environment indicates very low archaeological potential.

Jura Formation

7.1.13 The lower part of the Jura Formation is characterised by predominantly weak-amplitude, stratified seismic reflections that initially infill the topography before transitioning to a draping geometry (**Figure 20**). The upper part of the formation is also stratified but exhibits locally more chaotic seismic character, inclined reflections with increased reflection amplitudes and the occurrence of point-source diffractions. These two sub-units are separated locally by an erosional surface in the south of the Fugro UHRS dataset, and a change in seismic character throughout (**Figure 20**). The erosional surface is correlates with H20.

7.1.14 Immediately below this erosional surface, within the MSDS Unit U02, particularly in the north-east of the dataset, a series of V to U-shaped depressions are observed. These features are capped by very strong-amplitude reflections and contain variable internal seismic character, with some examples showing strong, stratified infill and others weak, chaotic reflections (**Figure 21**). The origin of these features is currently uncertain; however, given the known age and depositional environment of the Jura Formation, they may represent iceberg keel scours, based on their morphological similarity to published examples from the Barents Sea[22].

7.1.15 Lithologically, the Jura Formation is typically described as structureless dark grey silty clays with a high sand content, containing rare oversized clasts and shell fragments. The upper part of the formation (Jura B) includes larger clast sizes, locally including cobbles and boulders. This interval corresponds to the “Cobble Layer” described by Fyfe et al. (1993)[10] and was interpreted by Fugro[4] as a discrete horizon (H10). The presence of these coarse clasts provides a plausible explanation for the point-source diffractions observed within the upper unit. The Jura Formation is interpreted to represent deposition within a dynamic glacimarine environment under fluctuating climatic conditions following the Last Glacial Maximum, including the Loch Lomond Stadial.

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[22] Zecchin, M., Rebesco, M., Lucchi, R.G., Caffau, M., Lantzsch, H. and Hanebuth, T.J.J. (2016). *Buried iceberg-keel scouring on the southern Spitsbergenbanken, NW Barents Sea*. Marine Geology, 382, pp.68–79.

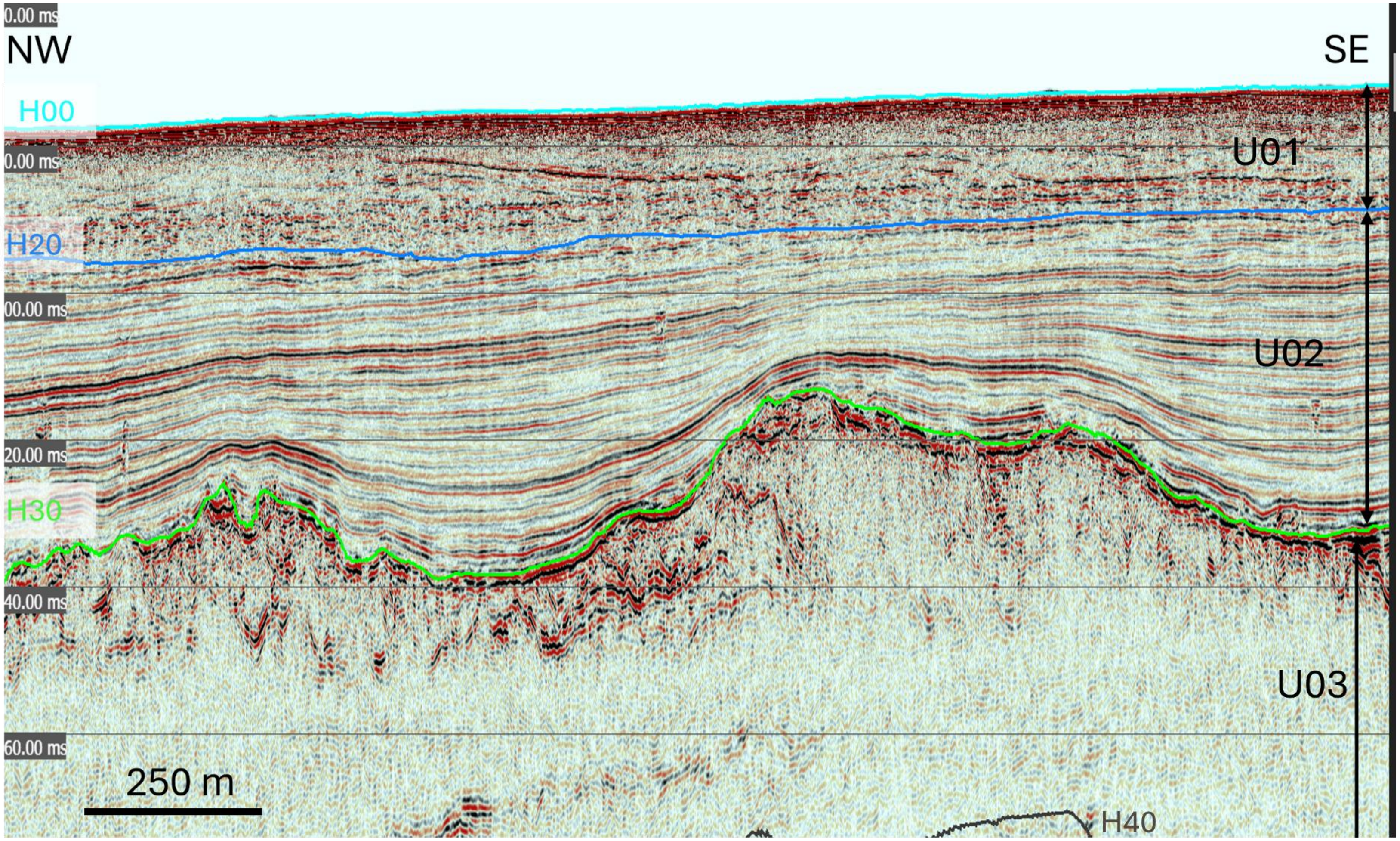

Figure 20 Jura Formation seismic character between H00 and H20. Cyan H00, Blue H20, Green H30, Grey H40 (Sulmara UHR XL_S00500)

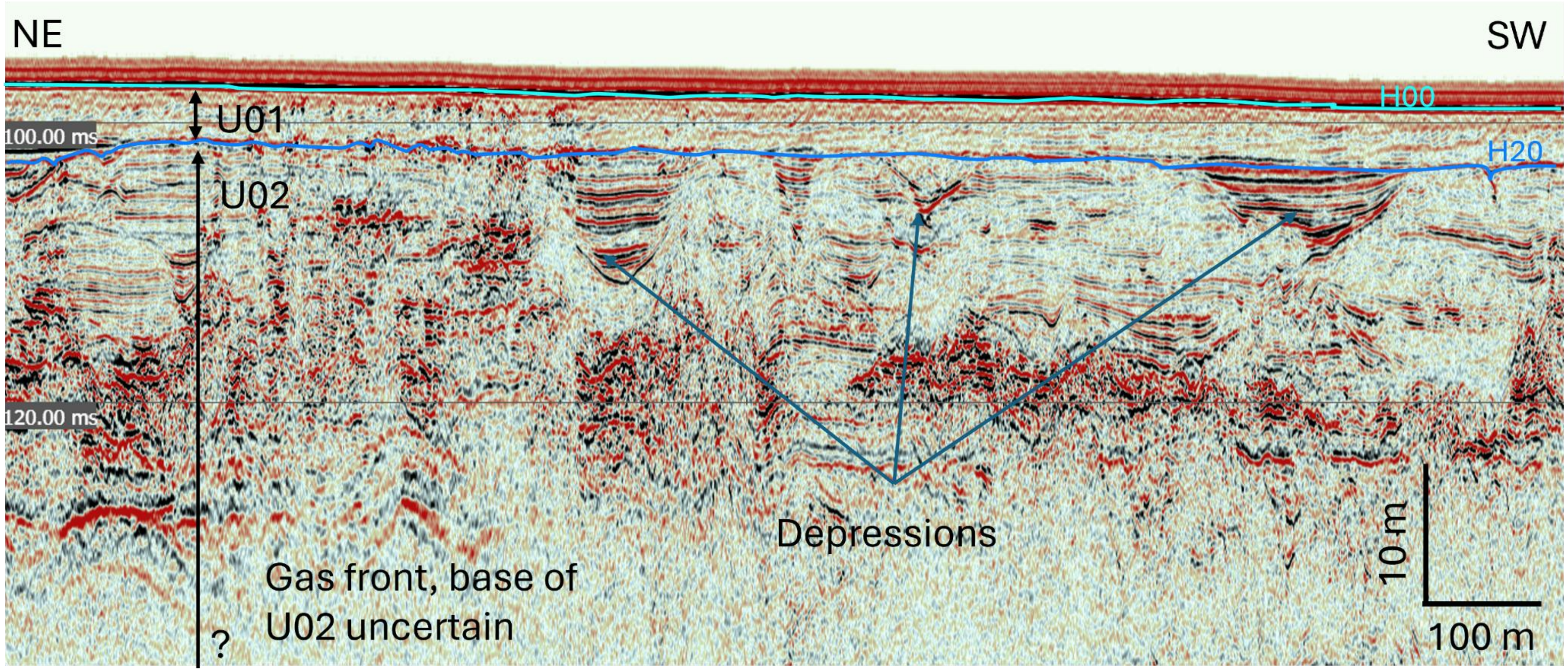

Figure 21 Example of potential iceberg keel scour marks at the top of U02 (Fugro SBP line MCWA002A)

7.1.16 Within the WDA, Sulmara interpret the Jura Formation as being limited to MSDS Marine Unit U01 only, corresponding to the interval between horizons H00 and H20, with the underlying H20–H30 interval (MSDS Marine Unit U02) attributed to the Stanton Formation. The H20 surface is shown in **Figure 22** and the H00 surface is shown in **Figure 23**. In contrast, the MSDS Marine interpretation assigns the entire interval between H00 and H30 to the Jura Formation (**Figure 20**). The rationale for this interpretation is outlined below:

- Recent work by Arosio (2017)[23] and Arosio et al. (2018)[24] utilised legacy single-channel 3.5 kHz pinger data collected by BGS in 1972 and 1985, integrated with legacy BGS cores as well as vibrocores collected in 2014 and 2015 by BGS and the BRITICE-CHRONO project. The interpreted Pinger line shown in **Figure 24** identifies Unit IVA as equivalent to MSDS Marine Unit U02 in this report and Unit IVB as equivalent to MSDS Marine Unit U01. Both units are interpreted as post-glacial retreat deposits and assigned to the Jura Formation.

- As part of the BRITICE-CHRONO project, Callard et al. (2018)[25] dated the similar seismic facies as MSDS Marine Units U01 and U02 in this report from vibrocores 151VC and 147VC. These yielded limiting radiocarbon ages between 19,690 ± 90 and 14,320 ± 41 ^{14}C yrs BP, indicating that the majority of the infill post-dates grounding-zone wedges dated to ~20 ka in several cores. This places deposition firmly after final glacial retreat and is inconsistent with the Stanton Formation, which Fyfe et al. (1993)[10] describe as Early Devensian and possibly older.

- MSDS Marine Unit U02 lacks the point-source hyperbolae characteristic of the Stanton Formation (**Figure 19**), further supporting its interpretation as part of the Jura Formation.

- Horizon H30 is interpreted as a major unconformity associated with glacial retreat, with numerous geomorphological features developed on and immediately below the surface[23, 24, 25]. It therefore follows that sediments overlying this surface are post-LGM and are more consistent with Late Devensian dynamic glacimarine deposition of the Jura Formation than with the older Stanton Formation.

- The local unconformity and change in seismic character represented by Horizon H20 is not interpreted here as the upper surface of the Stanton Formation, but rather as reflecting a change in depositional dynamics associated with the Loch Lomond Stadial and/or accommodation changes linked to glacio-isostatic rebound following ice retreat.

7.1.17 The Jura Formation is glacio-marine to marine in depositional environment and thus has very low archaeological potential.

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[23] Arosio, R. (2017) Late Devensian ice sheet dynamics and the deglaciation of the Hebridean shelf, western Scotland, UK. PhD thesis. University of the Highlands and Islands (SAMS UHI).

[24] Arosio, R., Dove, D., Ó Cofaigh, C. and Howe, J.A. (2018) 'Submarine deglacial sediment and geomorphological record of southwestern Scotland after the Last Glacial Maximum', Marine Geology, 403, pp. 62–79. doi:10.1016/j.margeo.2018.04.012.

[25] Callard, S.L., Ó Cofaigh, C., Benetti, S., Chiverrell, R.C., Van Landeghem, K.J.J., Saher, M.H., Gales, J.A., Small, D., Clark, C.D., Livingstone, S.J., Fabel, D. and Moreton, S.G. (2018) 'Extent and retreat history of the Barra Fan Ice Stream offshore western Scotland and northern Ireland during the last glaciation', Quaternary Science Reviews, 201, pp. 280–302. doi:10.1016/j.quascirev.2018.10.002.

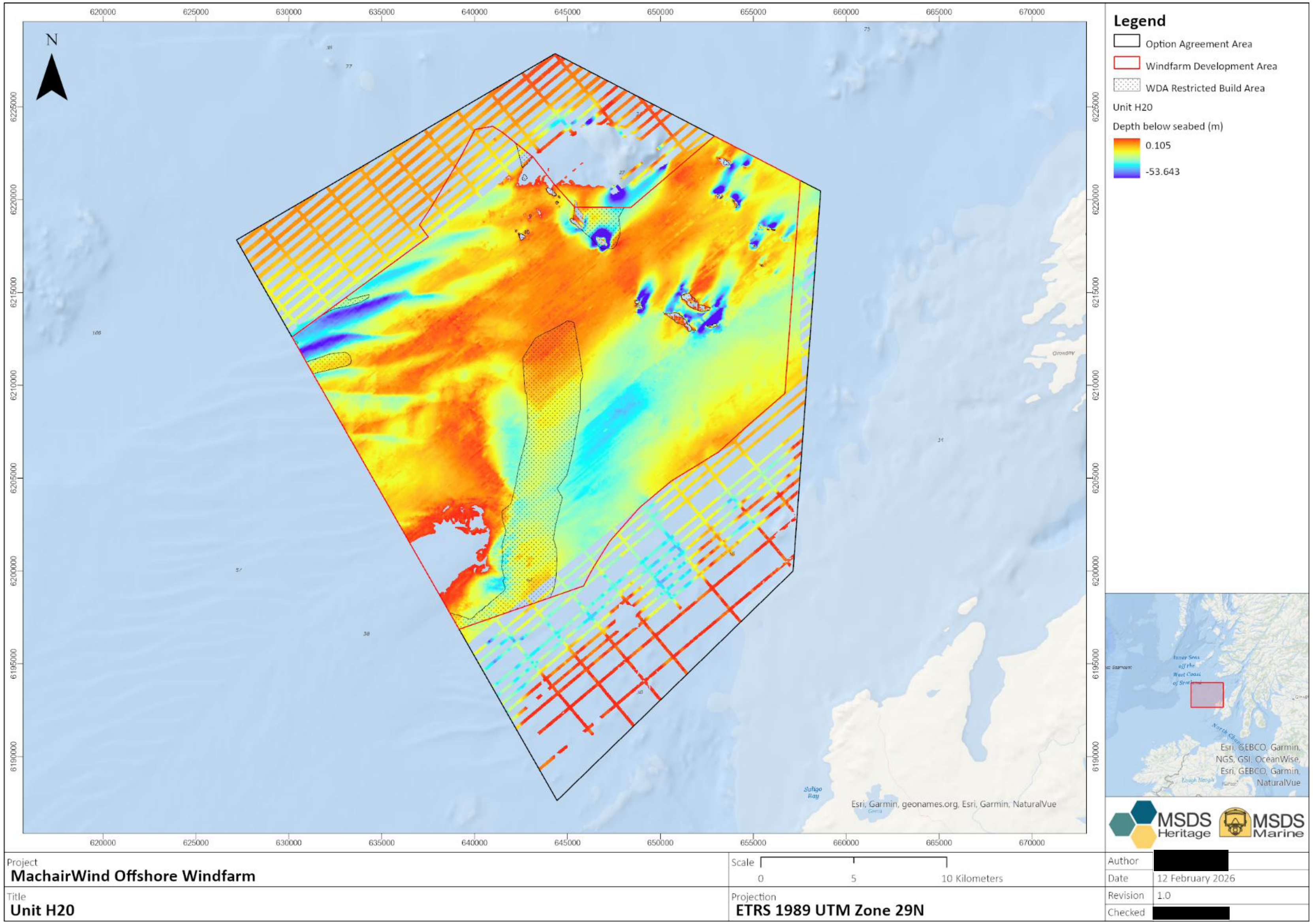
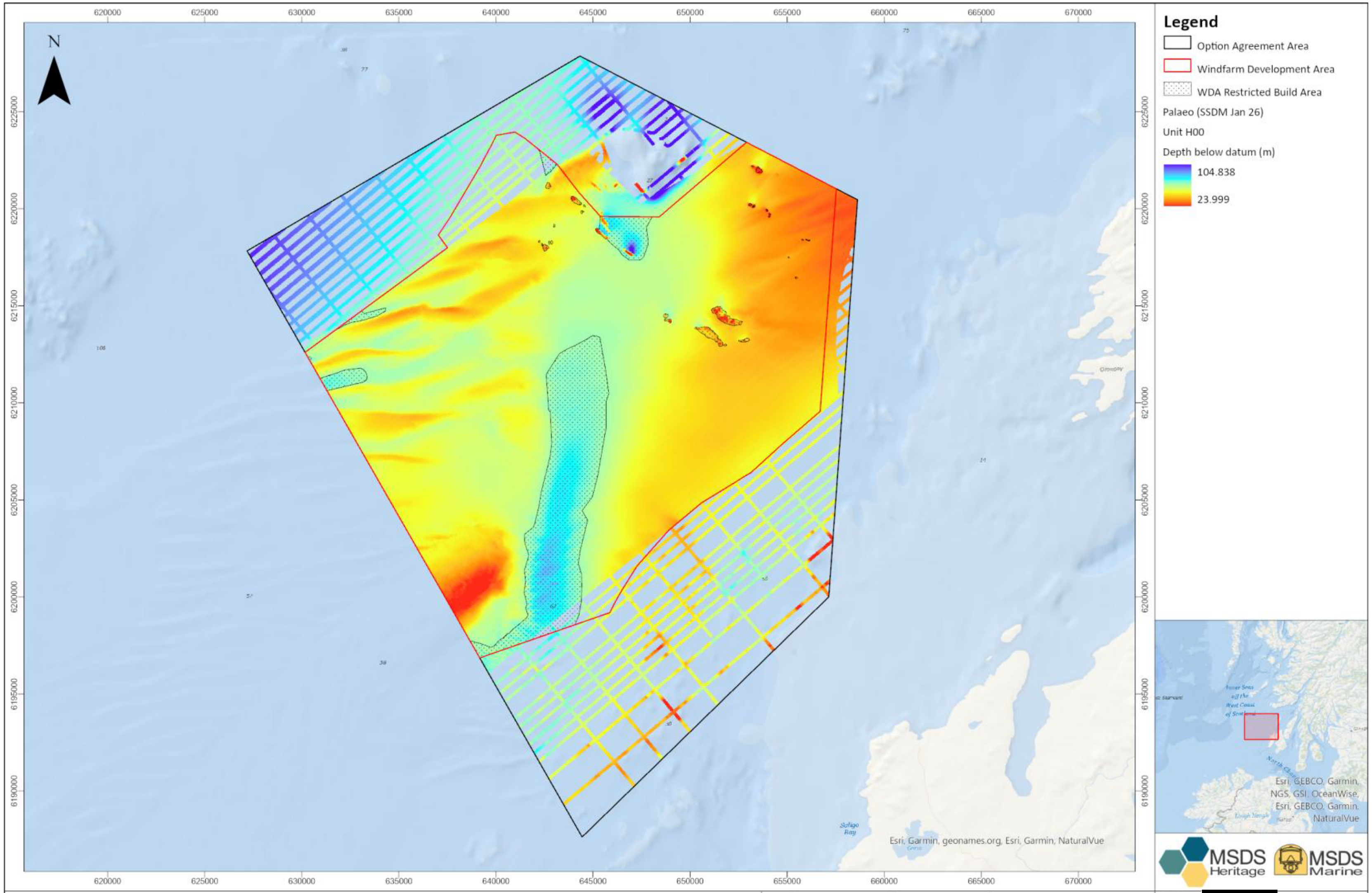


Figure 22 Sulmara H20 surface



Project
MachairWind Offshore Windfarm

Title
Unit H00 (seabed)

Scale 0 5 10 Kilometers

Projection
ETRS 1989 UTM Zone 29N

Author	[redacted]
Date	12 February 2026
Revision	1.0
Checked	[redacted]

Figure 23 Sulmara H00 surface (seabed)

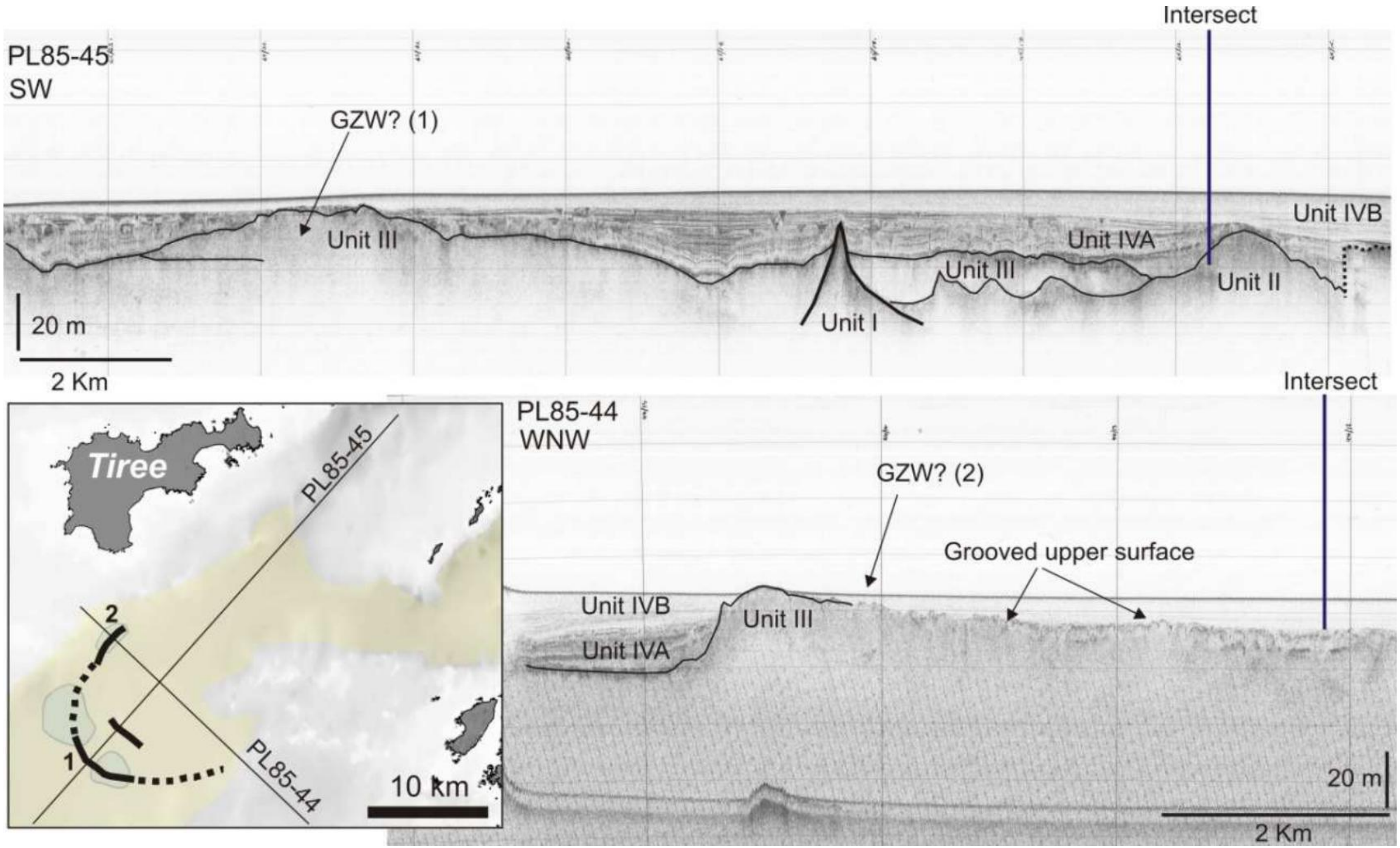


Figure 24 Interpreted Pinger Lines near the WDA from Arosio, 2017. Unit IVA equivalent to Unit U02 and Unit IVB equivalent to Unit U01 in this report. Both are interpreted as Jura Formation in the cited study. The Pinger lines shown are ~20 km north-east of the WDA

Lorne Formation

7.1.18 The Lorne Formation is expressed seismically as a thin, acoustically transparent to weakly stratified unit associated with the modern seabed. It comprises unconsolidated sands, gravels and muddy sands representing mobile marine shelf sediments (**Figure 25**). In areas where mobile bedforms are developed, the formation cannot be considered a simple sediment veneer but instead forms an actively reworked sediment body. The seabed exhibits a variety of mobile depositional bedforms, including ripples, megaripples and sandwaves (**Figure 12**), with heights ranging from <1 m to over 12 m and orientations reflecting multiple flow regimes[5]. The formation is Holocene in age and reflects post-glacial marine reworking of the Hebridean shelf following the Late Devensian glacial retreat.

7.1.19 Within the WDA, the Lorne Formation corresponds to the modern seabed sediment cover and is interpreted as a discontinuous, geomorphically active unit rather than a major stratigraphic package. It has not been mapped as a separate unit by Sulmara and would overlie MSDS Marine Unit U01. The high-energy marine depositional environment, and the active reworking of the underlying glacial and marine formations, indicate very low potential for the preservation of archaeological remains; consequently, it has not been interpreted as a separate stratigraphic unit within this assessment.

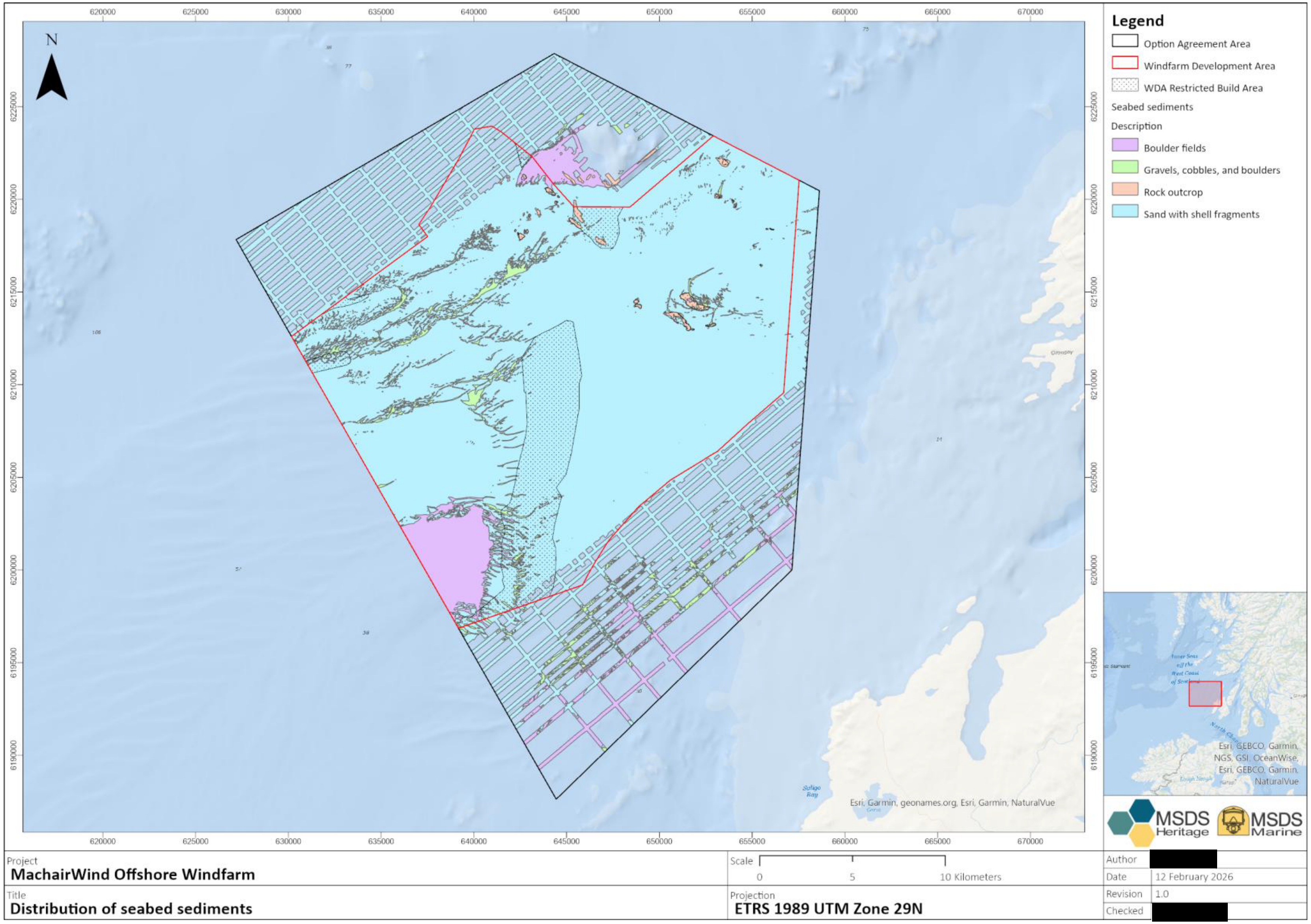


Figure 25 Distribution of seabed sediments

7.2 Sea level data

7.2.1 Data relating to past sea levels can be correlated with geological and glaciogenic data to inform our understanding of palaeolandscape development during the late Quaternary and early Holocene. Analysis of reconstructed palaeolandscapes can inform subsequent discussions relating to human occupation and archaeological potential. The WDA currently lies at between -21 m to -119 m[5].

7.2.2 Studies of sea level in the past are complex and subject to a wide range of variables. One of the key factors is that of glacial isostatic adjustment (GIA), relating to the viscoelastic response (deformation) of Earth structures arising from glacial ice-load[26]. The British Irish ice sheet developed outward from the Scottish Highlands during the Dimlington stadial (29,000 to 14,700 BP) extending as far as west as the continental shelf edge of the west coast of Scotland at ~26, 000 BP [27] (**Figure 26** to **Figure 31**) and as far south as the Norfolk coast. Northern parts of Britain were therefore subject to greater depression and rebound, with localised variations in ice thickness potentially causing further local variations in RSL[28].

Sea Level Index Points (SLIPS)

7.2.3 A variety of sources of evidence exist on former sea levels. These include Sea Level Index Points (SLIPs), GIA models, physical evidence observed in geophysical survey data (e.g. deposit and environment types) and key features such as submerged rock cut platforms indicating former stabilised shorelines as well as raised beaches for periods where sea level was higher. Key studies include models by Bradley et al. (2023)[29] and the SLIP index compiled by Shennan et al. (2018)[30].

7.2.4 Relative sea-level (RSL) change in western Scotland following the Last Glacial Maximum (LGM) reflects the strong influence of glacio-isostatic rebound (uplift) following ice unloading, superimposed on eustatic sea-level rise. As synthesised in Arosio et al, 2017[23], isostatic uplift during early deglaciation generally outpaced eustatic rise, producing a net fall in RSL from high marine limits immediately after ice retreat. This regime persisted until the Holocene transgression, when accelerating eustatic sea-level rise exceeded the slowing rate of uplift. Crucially, this framework indicates that post-LGM sea-level fall occurred from a highstand, rather than from a lowstand capable of exposing large areas of the inner shelf during periods of climatic amelioration.

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[26] Bagge, M., Klemann, B., Steinburger, M. Latinovíc, M. and Thomas, M. 2021. 'Glacial-Isostatic Adjustment Models Using Geodynamically Constrained 3D Earth Structures'. *Geochemistry, Geophysics, Geosystems*. **22**(11).

[27] Clark, C.D., Ely, J.C., Fabel, D. and Bradley, S.L. (2022) BRITICE-CHRONO maps and GIS data of the last British-Irish Ice Sheet 31 to 15 ka, including model reconstruction, geochronometric age spreadsheet, palaeotopographies and coastline positions [dataset]. PANGAEA. https://doi.org/10.1594/PANGAEA.945729

[28] E.g as postulated by Jordan, J. T., Smith, D. E., Dawson, S. and Dawson, A. G. 2010. Holocene relative sea-level changes in Harris, Outer Hebrides, Scotland, UK. *J. Quaternary Sci.*, Vol. 25 pp. 115–134. ISSN 0267-8179. Though no evidence of local variations in RSL was found by this study.

[29] Bradley, S.L., Ely, J.C., Clark, C.D., Edwards, R.J. and Shennan, I. (2023), Reconstruction of the palaeo-sea level of Britain and Ireland arising from empirical constraints of ice extent: implications for regional sea level forecasts and North American ice sheet volume. J. Quaternary Sci, 38: 791-805.

[30] Shennan, I., Bradley, S.L. and Edwards, R. (2018) 'Relative sea-level changes and crustal movements in Britain and Ireland since the Last Glacial Maximum', *Quaternary Science Reviews*, 188, pp. 143–159.

NOAA OCS, Esri, Garmin, GSI, OceanWise, Esri, Garmin, NaturalVue

Esri, GEBCO, Garmin, NGS, Esri, GEBCO, Garmin, NaturalVue

Project **MachairWind Offshore Windfarm**	Scale 0 75 150 Kilometers	Author	[redacted]
		Date	23 March 2026
Title **Ice sheet extent at 15,000 BP**	Projection **ETRS 1989 UTM Zone 29N**	Revision	1.0
		Checked	[redacted]

Figure 26 Ice Sheet Extent at 15,000 BP

Project
MachairWind Offshore Windfarm

Title
Ice sheet extent at 17,000 BP

Scale
0 75 150 Kilometers

Projection
ETRS 1989 UTM Zone 29N

Author	[redacted]
Date	23 March 2026
Revision	1.0
Checked	[redacted]

Figure 27 Ice Sheet Extent at 17,000 BP

Project
MachairWind Offshore Windfarm

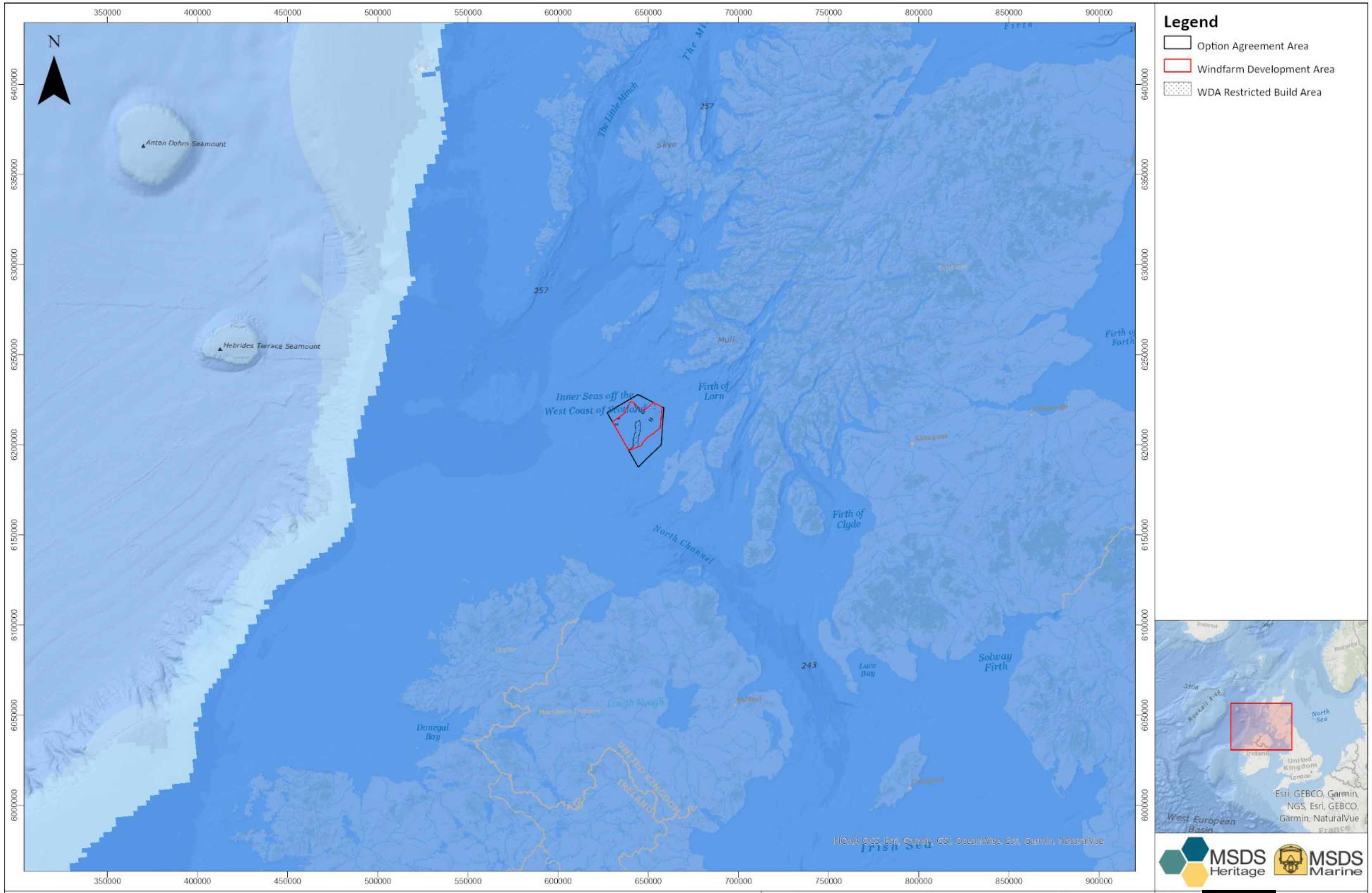
Scale
0 75 150 Kilometers

Title
Ice sheet extent at 20,000 BP

Projection
ETRS 1989 UTM Zone 29N

Author	[redacted]
Date	23 March 2026
Revision	1.0
Checked	[redacted]

Figure 28 Ice Sheet Extent at 20,000 BP



Project
MachairWind Offshore Windfarm

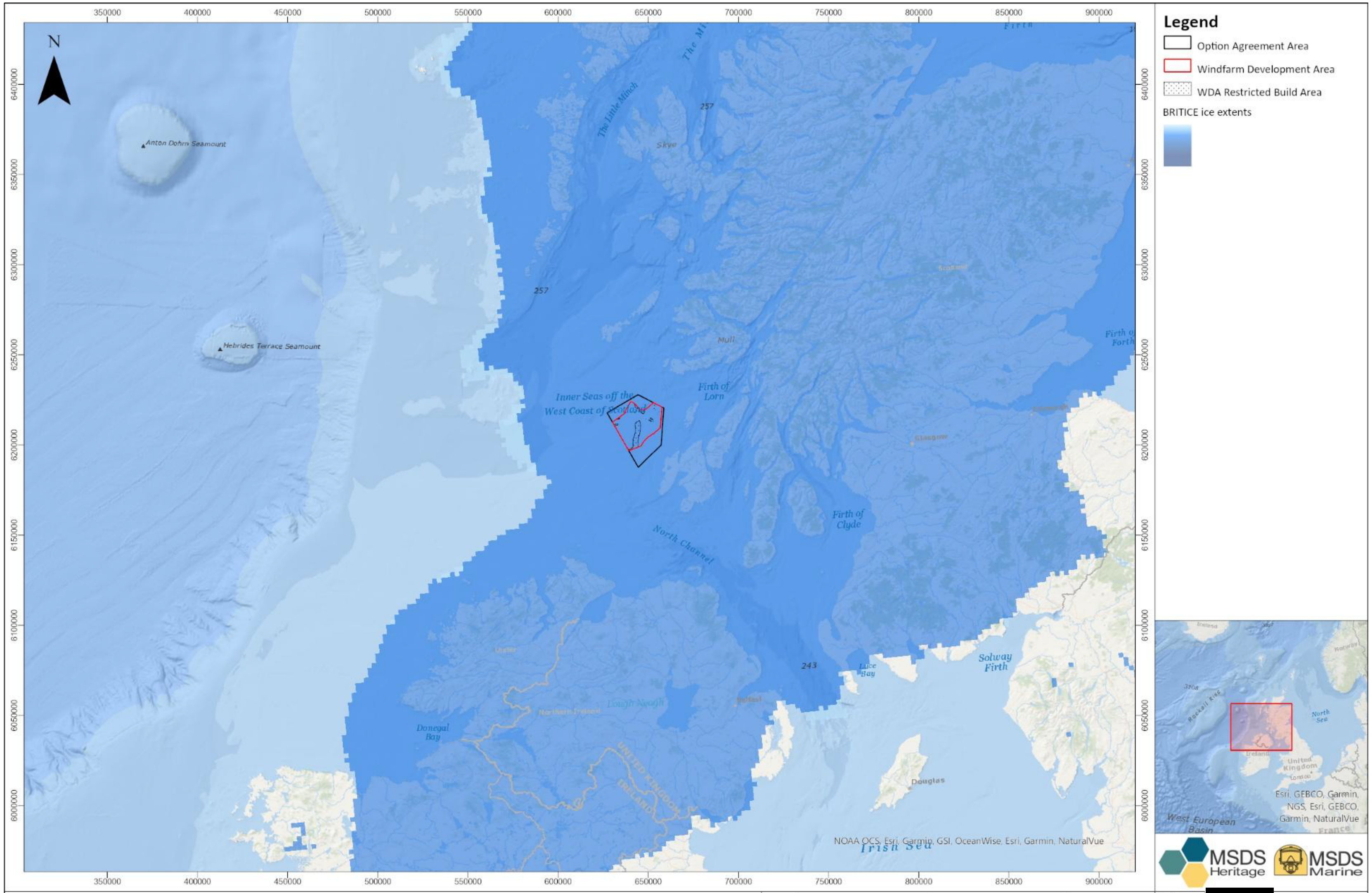
Title
Ice sheet extent at 26,000 BP

Scale
0 75 150 Kilometers

Projection
ETRS 1989 UTM Zone 29N

Author [redacted]
Date 23 March 2026
Revision 1.0
Checked [redacted]

Figure 29 Ice Sheet Extent at 26,000 BP



Project
MachairWind Offshore Windfarm

Scale
0 75 150 Kilometers

Author [redacted]

Date 23 March 2026

Revision 1.0

Checked [redacted]

Title
Ice sheet extent at 30,000 BP

Projection
ETRS 1989 UTM Zone 29N

Figure 30 Ice Sheet Extent at 30,000 BP

Project
MachairWind Offshore Windfarm

Title
Ice sheet extent at 31,000 BP

Scale
0 75 150 Kilometers

Projection
ETRS 1989 UTM Zone 29N

Author [redacted]
Date 23 March 2026
Revision 1.0
Checked [redacted]

Figure 31 Ice Sheet Extent at 31,000 BP

7.2.5 Empirical sea-level index point (SLIP) data from western Scotland (**Figure 15**) reinforce this interpretation. Lateglacial SLIPs from the Kentra–Arisaig area[31] show regression from a marine limit between c. 36.5 and 40 m OD at ~16 ka cal BP to a Younger Dryas minimum of approximately −10 m OD. Further south, SLIPs from Knapdale and Kintyre[32] document a fall from ~30.5 m OD at ~17 ka BP to <9–10 m OD by ~10 ka BP. Importantly for the WDA, the two closest SLIPs, Islay and Col[30], indicate that relative sea level remained above present until approximately 10–8 ka BP, after which it fell only slightly to around ~1 m below present sea level. These data demonstrate that since local deglaciation there has been no period of substantially lowered RSL that would have resulted in meaningful exposure of the WDA.

7.2.6 Geomorphological evidence further indicates that marine conditions were already established in the region during ice retreat, rather than developing later as a result of Holocene transgression. Dove et al. (2015)[33] describe assemblages of minor transverse ridges occurring between larger recessional moraines in areas including the Sound of Mull and Sound of Jura. These ridges are interpreted as De Geer moraines, which are diagnostic of grounding-line retreat in a sub-aqueous setting. Their presence indicates that ice retreat occurred into marine or shallow-water conditions, consistent with the SLIP evidence for high relative sea level during deglaciation and incompatible with widespread subaerial exposure of the seabed at this time.

7.2.7 Regional glacial isostatic adjustment modelling provides additional constraint on earlier periods. Topographic and palaeocoastline outputs from recent GIA modelling from Bradley et al, 2023[29] show that between ~34 and 29 ka BP relative sea level was lower than present, and parts of the WDA may have been exposed (**Figure 32**). However, during this interval the area lay within ~50 km of the ice margin and experienced cold glacial or periglacial conditions, making human occupation highly unlikely. Following ice-sheet retreat from the region between ~20 and 15 ka BP, the same GIA outputs indicate that relative sea level was largely at, or above, present levels (**Figure 16**). This is also consistent with extensive onshore evidence for raised shorelines and emerged beach ridges in western Scotland, including from the nearby islands of Jura and Islay[34].

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[31] Shennan, I., Lambeck, K., Flather, R., Horton, B., McArthur, J., Innes, J., Lloyd, J., Rutherford, M. and Wingfield, R. (2000) 'Late Devensian and Holocene records of relative sea-level changes in northwest Scotland and their implications for glacio-hydro-isostatic modelling', *Quaternary Science Reviews*, 19, pp. 1103–1135.

[32] Shennan, I., Bradley, S., Milne, G., Brooks, A., Bassett, S. and Hamilton, S. (2006) 'Relative sea-level changes, glacial isostatic modelling and ice-sheet reconstructions from the British Isles since the Last Glacial Maximum', Journal of Quaternary Science, 21, pp. 585–599.

[33] Dove, D., Ó Cofaigh, C., Geirsdóttir, Á. and Smith, J.A. (2015) 'Submarine glacial landforms record Late Pleistocene ice-sheet dynamics, Inner Hebrides, Scotland', *Boreas*, 44(1), pp. 1–17.

[34] Dawson, A.G., Bishop, P., Hansom, J. and Fabel, D. (2022) '10Be exposure age dating of Late Quaternary relative sea-level changes and deglaciation of western Jura and northeast Islay, Scottish Inner Hebrides', *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 113(1), pp. 1–20.

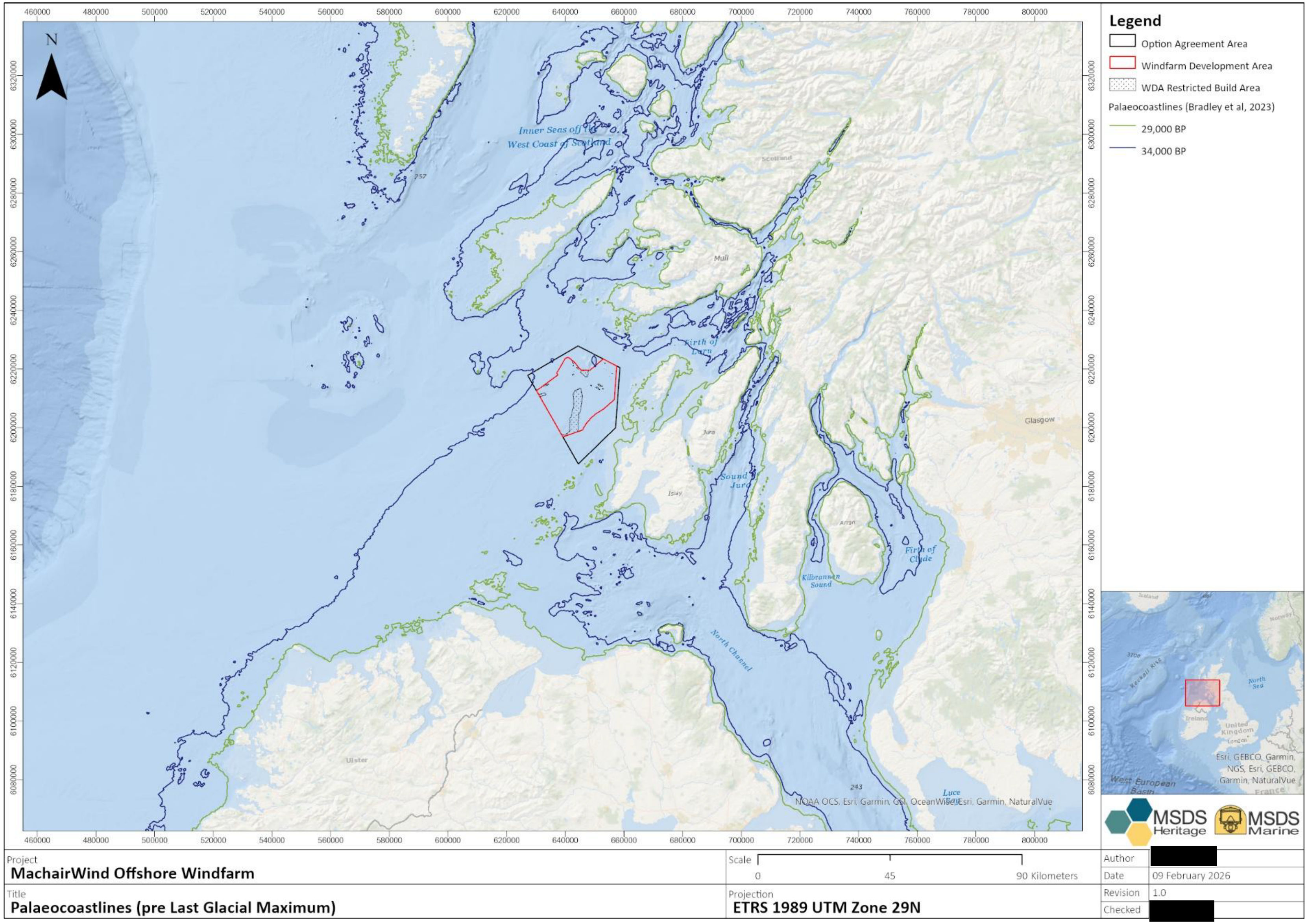

Figure 32 *Palaeocoastlines (pre Last Glacial Maximum)*