Bellrock OFFSHORE WIND

Bellrock Offshore Wind Farm

Wind Farm Development Area

Environmental Impact Assessment Report - Volume IV

Appendix 15.1: Archaeological Assessment of Geophysical and Hydrographic Data

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Bellrock Wind Farm Development Area

Archaeological Assessment of Geophysical and Hydrographic Data

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MSDS Marine

MSDS Marine MSDS Heritage

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Bellrock Wind Farm Development Area

Archaeological Assessment of Geophysical and Hydrographic Data

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1.0 Introduction

1.0.1 MSDS Marine Limited (MSDS Marine) have been contracted by the BlueFloat Energy | Nadara Partnership ("the Partnership") to undertake an archaeological assessment of geophysical and hydrographic survey data collected for the Bellrock Offshore Wind Farm (Bellrock Project) Wind Farm Development Area (WFDA), hereafter referred to as the "Bellrock WFDA", in the North Sea, approximately 125 km east of Stonehaven, Scotland.

1.0.2 The survey was conducted by TerraSond Limited (part of the Acteon Group) between 24th June 2023 and 12th August 2023, and consisted of Sidescan Sonar (SSS), Multibeam Bathymetry (MBES), Magnetometer, Parametric Sub-bottom Profiler (SBP), and Sparker.

1.0.3 The assessment is being undertaken to inform the Environmental Impact Assessment (EIA) process. This document forms the archaeological assessment of the geophysical and hydrographic survey data, and outlines the specification of the data, the method of archaeological assessment, the presentation of the results, and recommendations for mitigation strategies.

2.0 Project location and status

2.0.1 In January 2022, as part of the ScotWind leasing round managed by Crown Estate Scotland (CES), Bellrock Offshore Wind Farm Limited (the Applicant) was successfully awarded exclusivity of the area of seabed shown in Figure 1 to develop the 1.8 gigawatts (GW) Bellrock Project.

2.0.2 For consenting purposes, the Bellrock Project comprises two development areas for which separate consents will be sought by the Applicant:

- The WFDA, for the installation and operation of the offshore generating station; and
- The Offshore Transmission Development Area (OfTDA), for the installation and operation of the offshore grid infrastructure required to export the electricity from the Bellrock WFDA to a Scottish and Southern Electricity Networks (SSEN) Transmission offshore substation.

2.0.3 SSEN Transmission are responsible for consenting and developing the electrical infrastructure from the SSEN Transmission offshore substation to shore, as this forms part of the National Electricity Transmission System.

2.0.4 The location of the WFDA is shown in Figure 1.

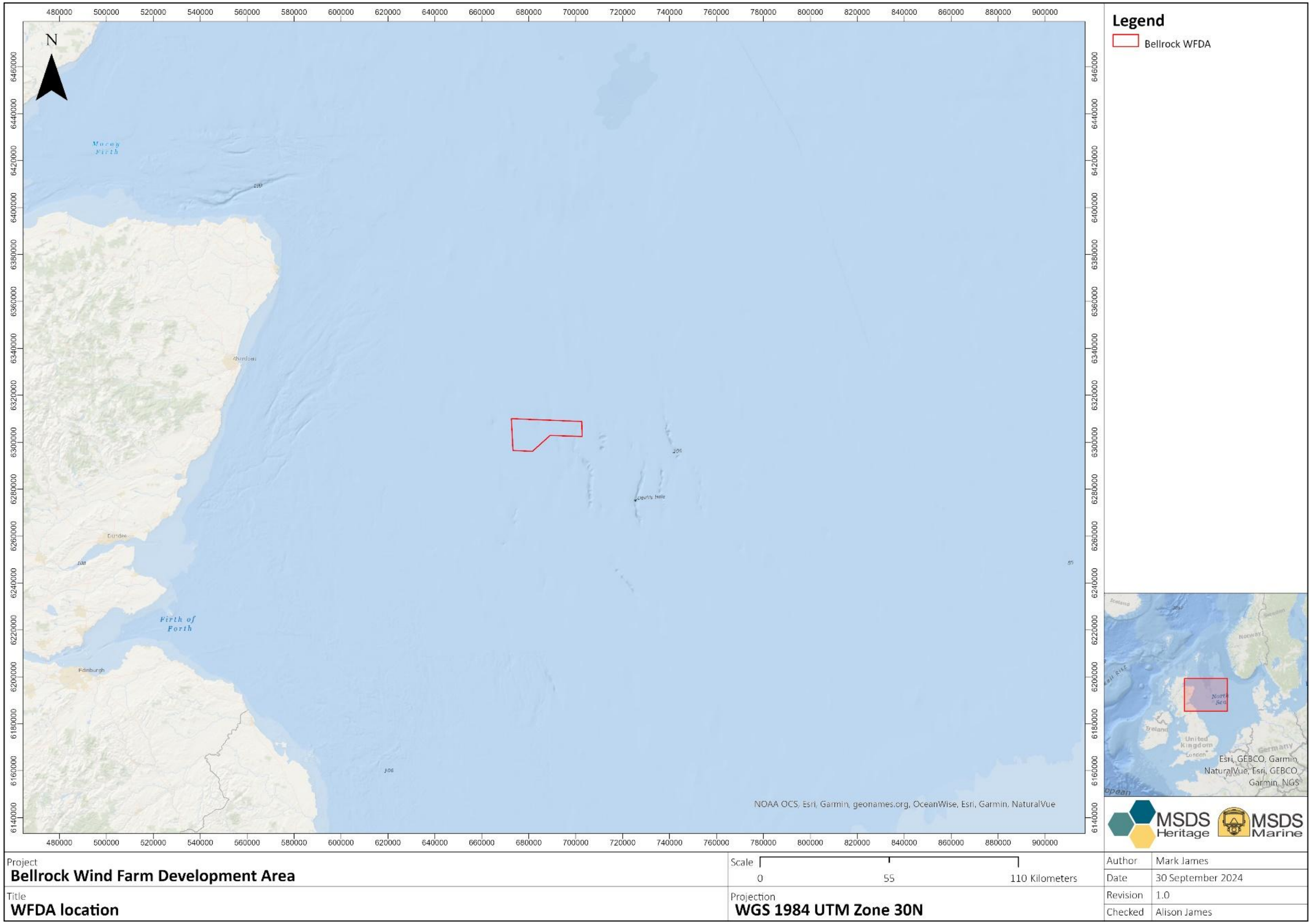

Figure 1: Location of Bellrock WFDA

3.0 Aims and objectives

3.1 Archaeological review of geophysical and hydrographic data

3.1.1 The principle aim of the archaeological review of geophysical and hydrographic data is to establish the presence of material of potential archaeological significance on the seabed, and 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 presence of anthropogenic material of archaeological potential;
- To interpret the identified anomalies as to their potential to be of archaeological significance;
- To recommend mitigation strategies for the anomalies appropriate to their archaeological potential;
- To establish the palaeolandscape potential;
- To recommend mitigation strategies in relation to the palaeolandscape and palaeoenvironment; and
- To recommend further works that may be required and their specifications.

4.0 Existing infrastructure

4.0.1 Existing third-party infrastructure within the Bellrock WFDA was identified through interrogation of data sets from Kingfisher Information Service – Offshore Renewable & Cable Awareness (KIS-ORCA)[1] and Oil and Gas data from the United Kingdom Continental Shelf (UKCS) supplied by the North Sea Transition Authority (NSTA)[2]. In addition, magnetometer data were correlated with the expected positions of infrastructure and used to identify linear features that may represent cables and pipes.

4.0.2 No existing, recorded, cables were identified within the WFDA or the extents of the geophysical and hydrographic data. No recorded pipelines, wells, bottom holes, or wells paths were identified within the WFDA in the extents of the geophysical and hydrographic data.

4.0.3 No evidence of cables, pipelines, or infrastructure was identified with the geophysical and hydrographic data.

4.0.4 The locations of infrastructure within the wider area are presented in Figure 2.

[1] www.kis-orca.org
[2] https://www.nstauthority.co.uk/data-centre/

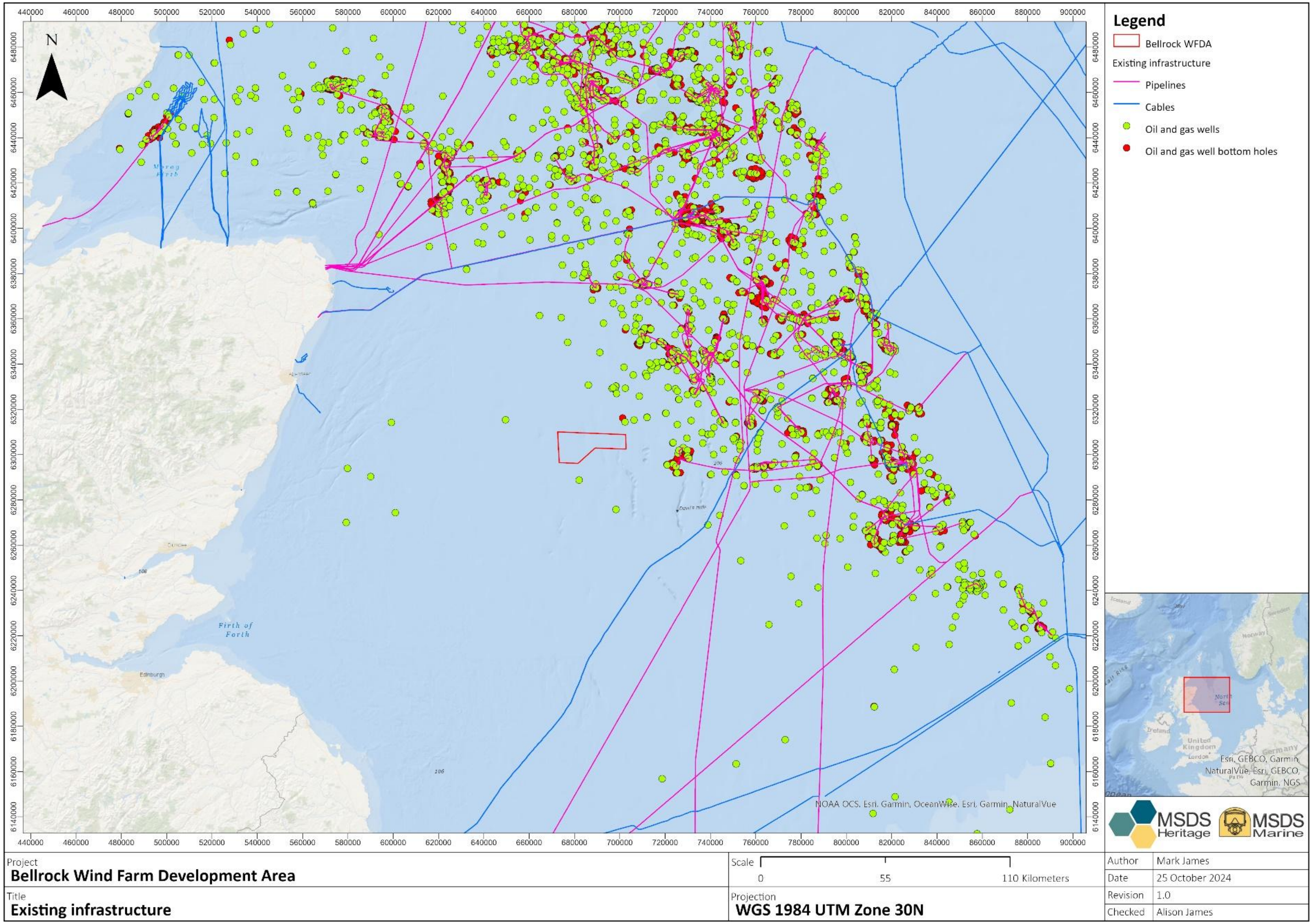

Figure 2: Existing infrastructure

5.0 Methodology

5.1 Data collection

5.1.1 The geophysical and hydrographic survey was conducted by TerraSond Limited (TerraSond) between 24th June 2023 and 12th August 2023, and consisted of SSS, MBES, Magnetometer, Parametric SBP, and Sparker. In addition, the survey campaign included the collection of environmental data. All survey operations were undertaken from MV *Ocean Fortune*, a dedicated survey vessel of 69.8 m.

5.1.2 The SSS, Magnetometer, and Sparker were towed behind the vessel, the MBES and SBP were mounted to the vessels.

5.1.3 Survey operations were undertaken within a pre-defined boundary of the WFDA of c. 280 km^2, plus a 1.0 km buffer.

5.1.4 The survey was planned with a line spacing of 140 m for the main lines, and 1,000 m for the cross lines. The line spacing ensured 100% coverage of MBES data (with a minimum of 10% overlap) and 200% coverage of SSS.

5.1.5 In addition, SBP, Sparker, and Magnetometer data were collected along each of the survey lines. The survey navigation tracklines are presented in Figure 3, the SSS coverage in Figure 4, and the MBES coverage in Figure 5. The equipment specification for the surveys is shown in Table 1.

Sensor	Manufacturer	Model	Frequency
Sidescan Sonar	Klein Edgetech	5000 v2 4205	455 kHz 540 kHz
Multibeam	Norbit	Winghead i80s	350 to 450 kHz
Magnetometer	Geometrics	G-882	4 to 6 m altitude
Parametric SBP	Innomar	SES-2000 Medium	2 to 22 kHz
Sparker	Applied Acoustics	Dura-Spark 400	0.3 to 1.2 kHz

Table 1: Geophysical and hydrographic sensor specifications

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

- Sidescan Sonar: ensonification of anomalies > 0.5 m
- Multibeam Bathymetry: ensonification of anomalies > 1.0 m
- Magnetometer (TVG): 5 nT threshold for anomaly picking
- Parametric Sub-bottom Profiler (SBP): penetration >5 m was achieved
- Sparker: penetration >20 m was achieved

5.2 Positioning

5.2.1 All data were collected with reference to the World Geodetic System 1984 (WGS84) datum and Universal Transverse Mercator (UTM) Zone 30 North projection (WGS84 Z30N). All vertical depths are relative to LAT and were reduced to LAT using Vertical Offshore Reference Frames (VORF).

5.2.2 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).

5.2.3 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.

5.2.4 Surface and sub-sea position sensors specifications are detailed below in Table 2.

Sensor	Manufacturer	Model	Accuracy
Surface positioning	Applanix	POS MV	Roll / pitch 0.008° Heading 0.02° Position 0.01 m
Sub-sea positioning	Sonardyne	Ranger 2	0.06% slant range

Table 2: Position sensor specifications

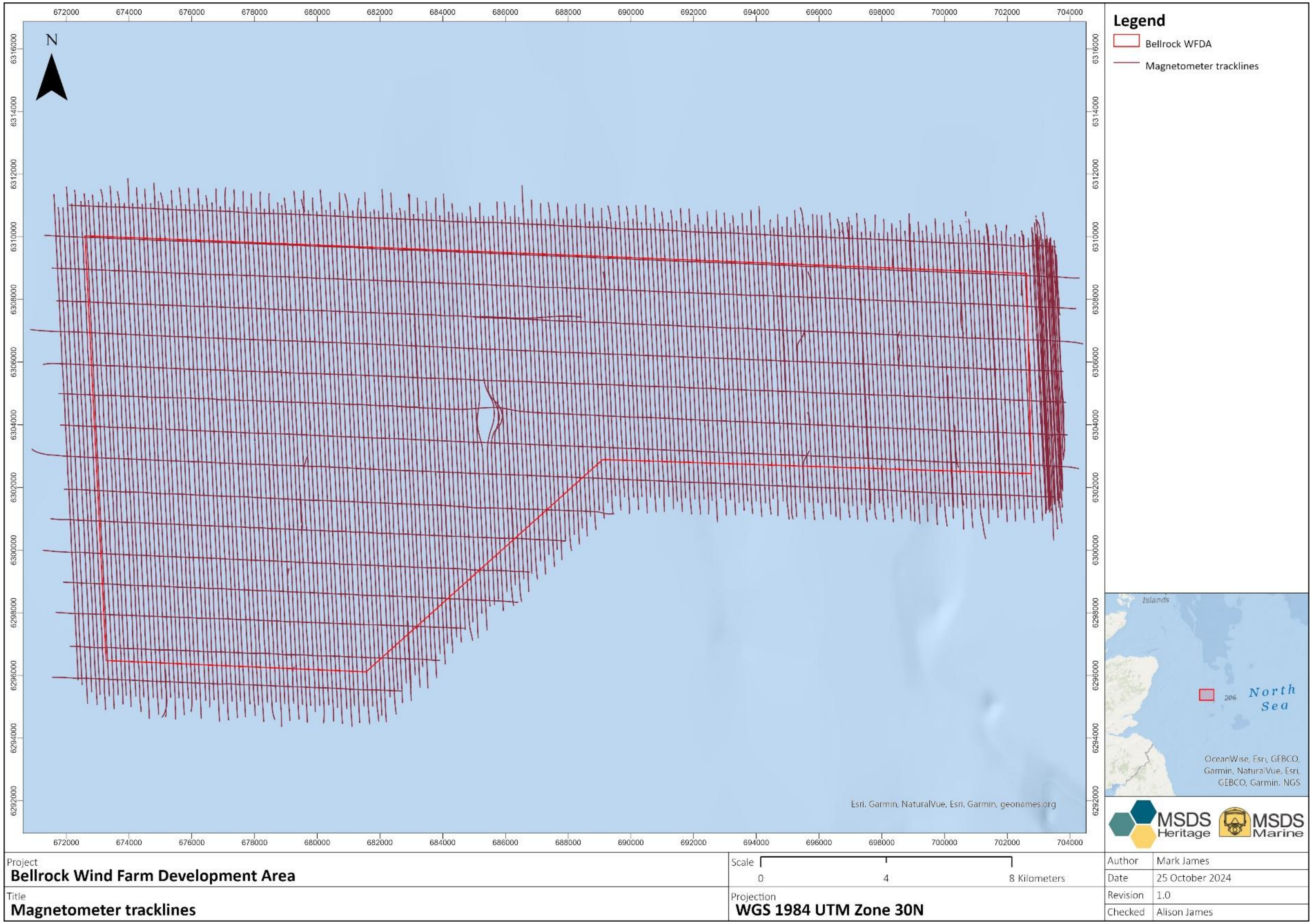

Figure 3: Geophysical survey tracklines

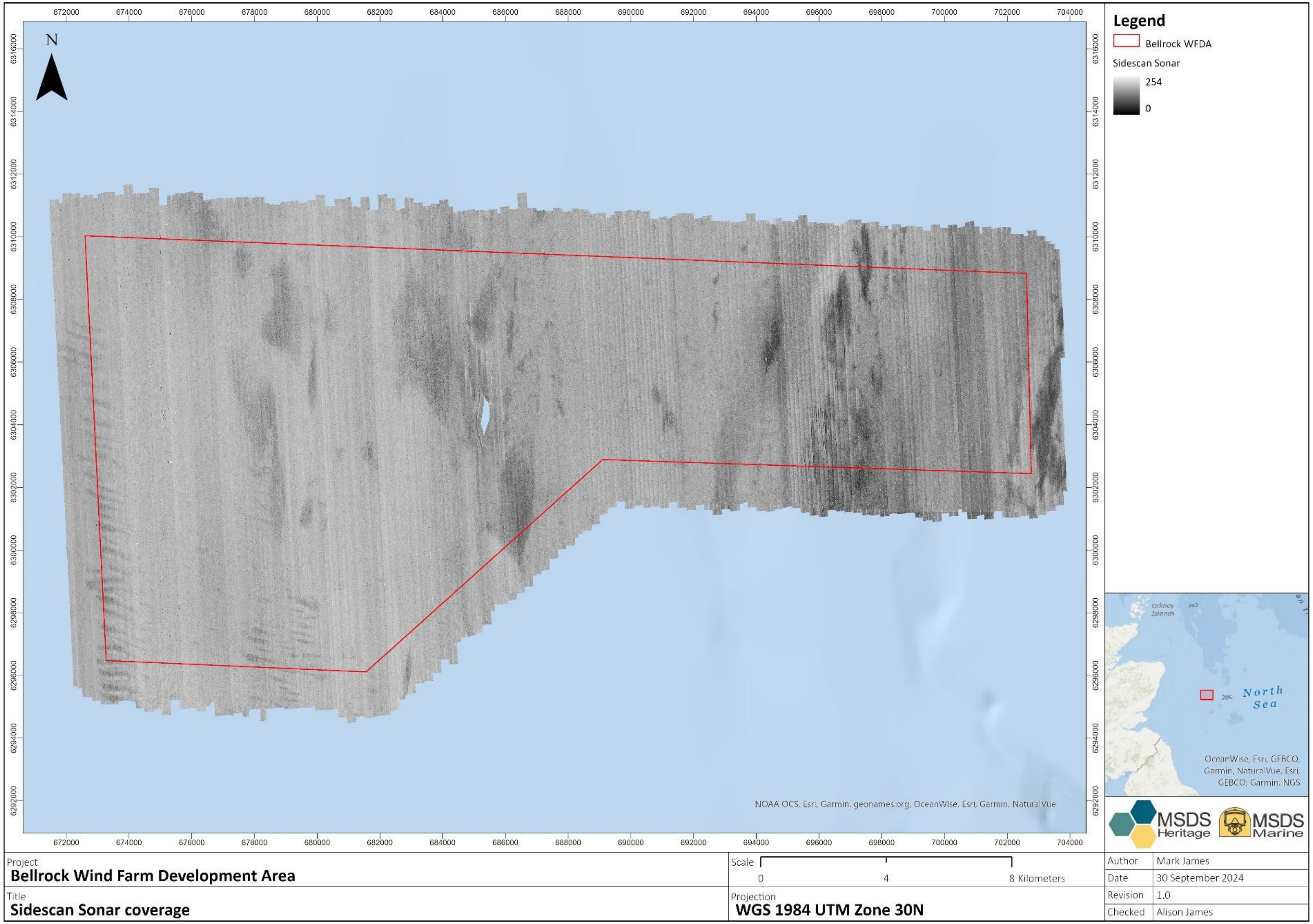

Figure 4: Sidescan Sonar coverage

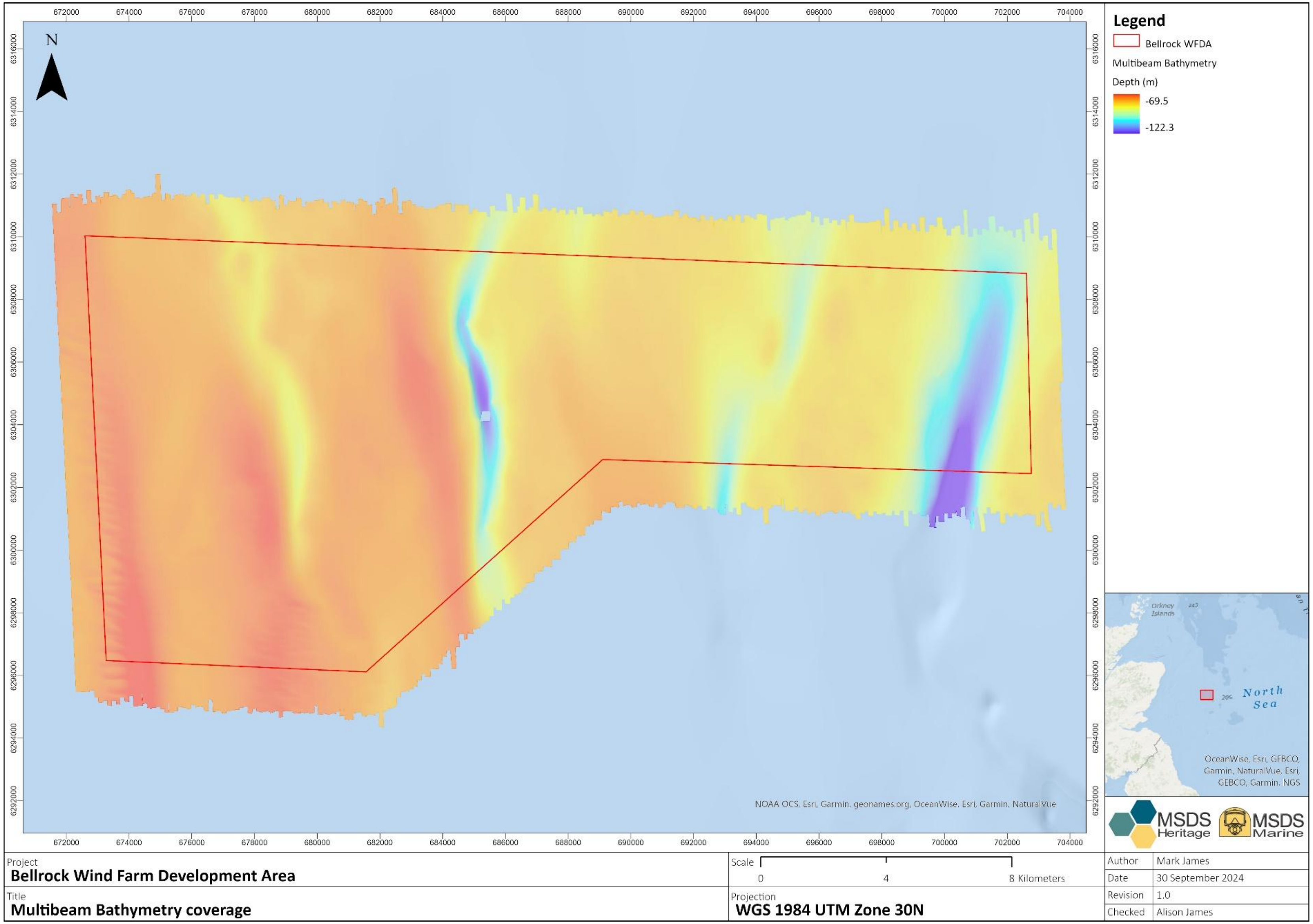

Figure 5: Multibeam Bathymetry coverage

5.3 Data deliverables to MSDS Marine

5.3.1 MSDS Marine were provided with the survey deliverables by the Partnership, including both raw and processed data, alongside interpretations and operations reports. The primary deliverables are detailed in Table 3 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
Sub-bottom Profiler (both)	Raw lines	.sgy
	Processed lines	.sgy
	Isopach	.shp
	Horizons	.tif
Magnetometer (TVG)	Raw lines	.csv
	Grids	.tif
	Contacts	.csv
Multibeam Bathymetry	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 3: Data deliverables to MSDS Marine

5.4 Data quality and limitations

Sidescan Sonar (SSS)

5.4.1 The SSS data covered the extents of the pre-defined survey boundary, providing coverage of approximately 200% (excluding the nadir). The data were generally of good quality, with minimal interference or data degradation caused by environmental factors, or the simultaneous use of different sensors. In areas, the presence of fish and floating debris (potentially) obscured some areas of the seabed, however the coverage of 200% SSS data, and 100% MBES data largely mitigated this. An area towards the centre of the WFDA was not able to be surveyed due to the presence of the Bellrock Project Light Detection and Ranging (LiDAR) buoy. The area measures c. 1.2 km x 0.2 km, and has not been subject to archaeological assessment.

5.4.2 Some small horizontal offsets were noted in places between the SSS and MBES data, although these were not significant and were within what would be considered normal tolerances. However, the positions of medium and high potential (and a large number of low potential) anomalies were taken from the MBES data to ensure positional accuracy.

5.4.3 An assessment of seabed composition and morphological features was made based on the interpretations contained within the 2023 survey geodatabase provided by the Project. Seabed composition and features can affect the appearance, and interpretation, of anomalies as well as the likelihood of anomalies being obscured or buried. Seabed composition varies across the WFDA predominantly comprising sands and slightly gravelly sand, with muddy sand, slightly gravelly muddy sand, and gravelly muddy sand to the east (Figure 6). Seabed features are characterised by large channels and dunes running north-south, with an area of sand waves to the south and east (Figure 6)[3].

5.4.4 Prominent features, such ripples and sand waves, can cause obstructions to the line of sight of sonar data, in particular the SSS, the data from which is collected closer to the seabed. Typically, this is mitigated through the collection of 200% coverage SSS data, ensuring that the seabed is ensonified from two directions.

Multibeam Bathymetry (MBES)

5.4.5 The MBES data covered the extents of the pre-defined survey boundary, providing coverage of 100%. A review of the un-gridded point cloud data shows that the quality is good with no significant height or positioning errors that effect the overall dataset. The data density is good, and the data is able to be gridded to 0.5 m, increasing the ability to identify smaller features. Features identified within the MBES data generally correlate well with those identified in the SSS data. An area towards the centre of the WFDA, measuring c. 0.3 km x 0.3 km, was not able to be surveyed and this area has not been subject to archaeological assessment.

5.4.6 MBES data is considered to provide the most accurate positioning due to the direct, and fixed, correlation between the sensor, the DGPS antennas, and the Motion Reference Unit (MRU) and is the primary source of anomaly positioning.

Magnetometer

5.4.7 The Magnetometer data covered the extents of the pre-defined survey boundary and was

[3] Acteon. 2023. *Bellrock Integrated Geophysical and Habitat Assessment Report*. 2023-002 Rev.1 including GIS deliverables.

collected along the pre-defined survey line plan of 140 m in most areas. The data were sampled at 10 Hz and the data were suitable to identify anomalies with a peak-to-peak amplitude of 5 nT. It should be noted that the 140 m line spacing achieved within the WFDA is too great for the accurate positioning of magnetic anomalies at distances away from the tracklines but can indicate areas of archaeological potential or can be correlated with visible feature on the seabed that lie on the same plane. Due to the line spacing it is likely that buried ferrous material, particularly smaller objects, between the run lines will not have been identified within the data.

5.4.8 However, the magnetometer data is considered be of a sufficient specification to enable a robust assessment to be undertaken for the purposes of Environmental Impact Assessment (EIA), noting also Section 5.8.5 and 7.0.3.

Sub-bottom profiler

5.4.9 The SBP and Sparker data covered the extents of the pre-defined survey boundary. The SBP data were collected at a central frequency of 6 kHz, achieving a maximum depth of 5 m at a vertical resolution of 0.1 m. The Sparker data were collected at a lower frequency (varied throughout the survey), achieving depths greater than 20 m at a vertical resolution of c. 0.4 m.

5.4.10 The data were of good quality, and the combination of the high resolution, shallow penetration and the lower resolution, deeper penetration systems allowed for an effective assessment of the palaeolandscape, and the archaeological potential.

5.4.11 SBP and Sparker data is collected directly beneath the sensor, in general terms, and outside the identification of the palaeolandscape, SBP is not suited to the prospection for buried material of potential anthropogenic origin due to the wide line spacing. It can however be useful for the corroboration of other datasets where a trackline passes directly over a magnetic anomaly, or a potentially buried feature, visible in the SSS or MBES data.

Summary

5.4.12 The data collected across the extents of the pre-defined survey boundary are of good quality overall, with the MBES provided 100% coverage and the SSS providing 200% coverage (with the exception of a small area towards the centre of the WFDA that was not surveyed). SBP and Sparker data were collected to a pre-determined line plan, largely providing suitable coverage and penetration for the interpretation of the palaeoenvironment. The Magnetometer data were collected to a pre-determined line plan suitable for the identification of ferrous material with a peak-to-peak amplitude of 5 nT, with the minimum detection size increasing with distance from the tracklines.

5.4.13 The data is considered of an appropriate specification, coverage, and quality, to undertake a robust archaeological assessment to inform the EIA process, noting that additional data collection, and interpretation, will be required prior to construction.

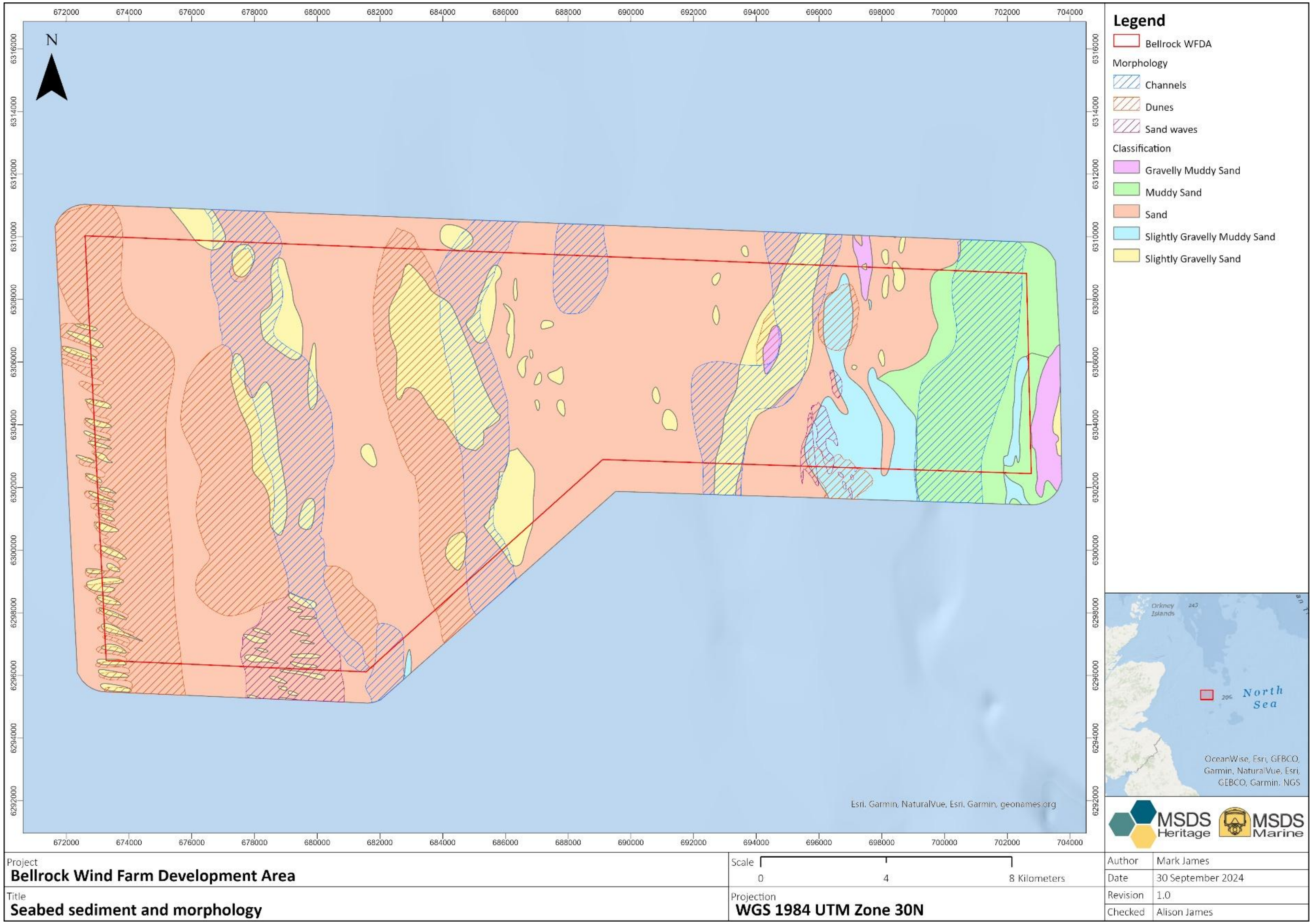

Figure 6: Distribution of Seabed Sediments

5.5 Archaeological assessment of data

5.5.1 The archaeological assessment of data was undertaken by a qualified and experienced maritime archaeologist with a background in geophysical and hydrographic data acquisition, processing, and interpretation.

5.5.2 Following delivery of the required datasets, an initial review was undertaken to gain an understanding of the geological and topographic make-up of the survey area. Within the extent of the survey area the potential for variations in the seabed are high and can affect the interpretation of anomalies. The assessment considers the full extents of the survey data, which was collected within a pre-defined survey boundary, including the WFDA and a 1 km buffer. The assessment of United Kingdom Hydrographic Office (UKHO)[4] and Canmore data[5] was undertaken within the extents of the survey data, relating to seabed wrecks and obstructions (UKHO) and historic environment assets, wrecks and documented sightings/experiences of historic wrecks (Canmore). These data are used to inform of known wrecks or the likelihood of encountering physical remains relating to such.

5.5.3 Whilst some of the data extends beyond the WFDA, the purpose of the assessment is to characterise the historic environment and therefore data from the wider area were considered. The focus of the mitigation measures is, however, on anomalies within the WFDA, or where mitigation measures would impact within the WFDA. The WFDA is presented in Figure 1.

Sidescan Sonar

5.5.4 SSS is considered the best tool for the identification of anthropogenic anomalies on the seabed due to the ability to ensonify small features and as such forms the basis of any archaeological assessment of data. SSS data in .xtf format were imported into Moga Seaview 6.2 software, navigation and positioning were checked and corrected where required, and optimal gains were applied to ensure the consistent presentation of data.

5.5.5 Data were reviewed on a line-by-line basis, and all anomalies of potential anthropogenic origin identified and recorded. Records include at a minimum an image of the anomaly, dimensions, and a description. Whilst typically only images of medium and high potential anomalies are presented with the assessment report, images of all anomalies are recorded as interpretations can change as the data assessment progresses. A rating of archaeological potential was assigned to the anomaly following the criteria outlined in Table 4 below.

5.5.6 Following assessment of the individual lines, a mosaic was created and a Geotiff exported to allow for the checking of positional accuracy against the MBES data and to identify the extents of any anomalies that may have extended past the limits of individual lines.

Magnetometer

5.5.7 Magnetometer data indicates the presence of ferrous, and thus usually anthropogenic, material both on, and under the seabed. Where line spacing allows, typically to a specification for the detection of potential UXO, magnetometer data can provide accurate positions of buried ferrous anomalies. The survey line spacing is c.140 m which is too great for the accurate positioning of magnetic anomalies at distances away from the tracklines but can indicate areas

[4] https://datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal/datasets/4dbf2ace22bf4f9785fb445d0593bc2c/about Accessed 07/08/2024.
[5] https://portal.historicenvironment.scot/apex/f?p=PORTAL:downloads:::::DATASET:NHRE Accessed 07/08/2024.

of archaeological potential. Where possible, magnetic anomalies were correlated with anomalies visible on the seabed.

5.5.8 Magnetometry data were provided as .csv files and as a gazetteer detailing all anomalies greater than 5 nT. An assessment was made by MSDS Marine as to the suitability of the gazetteer for archaeological interpretation. Where required the .csv magnetometer data were imported into Moga Seaview 6.2 software where the data were smoothed, and a 'baseline' identified and removed from the data to highlight ferrous anomalies whilst taking into account geological variations in the data.

5.5.9 Magnetic anomalies identified within the data had the position, amplitude, and dimensions recorded. A rating of archaeological potential was assigned to the anomaly following the criteria outlined in Table 4 below. The data were gridded to visually identify areas where the distribution of anomalies may represent a wider feature such a buried but dispersed wreck, or modern features such as buried cable or chain.

Multibeam Bathymetry

5.5.10 Due to the minimum anomaly detection size of MBES data being larger than that of SSS data, the primary use during archaeological assessment, outside of seabed characterisation, is the corroboration of anomalies identified within other datasets and the visualisation of anomalies that may otherwise be obscured by shadow.

5.5.11 Navigation corrected, but unprocessed, MBES data were provide to MSDS Marine as .xyz files, the data were imported into QPS Fledermaus where it was gridded and exported as a depth embedded raster, the raster was imported into ArcGIS Pro 3.3.2 and a hill-shaded surface applied, shading was adjusted to ensure the optimal presentation of data. The resulting 3-Dimensional image was viewed on a block-by-block basis, and all anomalies of potential anthropogenic origin identified and recorded.

5.5.12 Records include, at a minimum, an image of the anomaly, dimensions, and a description. A rating of archaeological potential was assigned to the anomaly following the criteria outlined in Table 4 below. Where the interpretation of an anomaly was unclear, the data were imported into point cloud visualisation software such as Cloud Compare, in order to view the un-gridded data. The gridded surface image was exported as a Geotiff to allow further assessment alongside other datasets.

Potential	Criteria
Low	An anomaly potentially of anthropogenic origin but that is unlikely to be of archaeological significance – Examples may include discarded modern debris such as rope, cable, chain, or fishing gear; small, isolated anomalies with no wider context; or small boulder-like features with associated magnetometer readings.
Medium	An anomaly believed to be of anthropogenic origin but that would require further investigation to establish its archaeological significance – Examples may include larger unidentifiable debris or clusters of debris, unidentifiable structures, or significant magnetic anomalies.

High	An anomaly almost certainly of anthropogenic origin and with a high potential of being of archaeological significance – high potential anomalies tend to be the remains of wrecks, the suspected remains of wrecks, or known structures of archaeological significance.

Table 4: Criteria for the assessment of archaeological potential

Combined assessment

5.5.13 Following the assessment of all datasets the results were loaded into ESRI ArcGIS Pro 3.3.2, a Geographical Information System (GIS), and reviewed alongside each other, along with Geotiffs of the SSS, MBES, and Magnetometer data. The concurrent review allows the amalgamation of duplicate anomalies, the assessment of the wider context, and an understanding of the extents of a feature that may be partially buried or span across two or more lines of data.

5.5.14 Data from the UKHO, including the positions of wrecks and obstructions, and Canmore, as well as all other relevant data such as third-party assets (see section 4.0) were assessed to ensure that any additional information is drawn upon, but also that anomalies are not unnecessarily identified as having archaeological potential when the origination can be identified. The resultant remaining anomalies assessed as having archaeological potential were compiled into a gazetteer and a shapefile.

5.5.15 The interpretation of geophysical and hydrographic data is, by its very nature, subjective. However, with experience and by analysing the form, size, and characteristics of an anomaly, a reasonable degree of certainty as to the origin of an anomaly can be achieved.

5.5.16 Measurements can be taken in most data processing software, and whilst largely accurate, discrepancies can be noted due to a number of factors. Where there is uncertainty as to the potential of an anomaly, or its origin, a precautionary approach is always taken to ensure the most appropriate mitigation for the historic environment.

5.5.17 It should be noted that there may be instances where an anomaly may exist on the seabed but not be visible in the geophysical data. This may be due to being covered by sediment or being obscured from the line of sight of the sonar. The use of both SSS and MBES data mitigates this by visualising anomalies from multiples angles, including from above. Anomalies were named following the standard MSDS Marine convention, [PROJECTYEAR_ID], e.g., BR24_XXX.

5.6 Palaeolandscape and Sub-bottom Profiler sources

5.6.1 A number of data sources were used for the assessment. The principal sources which were reviewed and assessed are set out below, while other published sources are referred to in-text.

5.6.2 The data available for the WFDA includes:

- MBES data collected by TerraSond achieving 100% coverage at a minimum cell size of 0.5 m;
- Parametric SBP data collected by TerraSond, achieving penetration of c. 5 m at a vertical resolution of 0.1 m and at a line spacing detailed in section 5.1;
- Sparker data collected by TerraSond, achieving penetration of c. 20 m at a vertical resolution of 0.4 m and at a line spacing detailed in section 5.1;

- Interpretation reports, including:
  - Acteon. 2023. *Bellrock Integrated Geophysical and Habitat Assessment Report*. 2023-002 Rev.1;
  - OWC. 2024. *Bellrock Offshore Wind Farm Phase 1 Ground Model Revision 2*;
- Boreholes, cores, and seismic data collected by the British Geological Survey (BGS) containing evidence which has fed into publications, online databases, and maps, including:
  - BGS. 1986. *"Devil's Hole" Map Sheet 56°N-00°E*. Solid Geology 1:250,000 Series;
  - BGS. 1985. *"Devil's Hole" Map Sheet 56°N-00°E*. Quaternary Geology 1:250,000 Series;
  - BGS. 1985. *"Devil's Hole" Map Sheet 56°N-00°E*. Seabed Sediment 1:250,000 Series;
  - Gatliff, et al. 1994. T*he geology of the central North Sea – United Kingdom offshore regional report*. London: HMSO (abbreviated in this assessment as the "ORR" (Offshore Regional Report));
- Other studies and research reports, including:
  - Brooks *et al*. 2011. *The Palaeogeography of Northwest Europe during the last 20,000 years*. Journal of Maps 7:1, pp. 573-587; and
  - Shennan *et al*. 2018. *Relative sea-level changes and crustal movements in Britain and Ireland since the Last Glacial Maximum*. Quaternary Science Reviews 188, pp. 143-159.

5.7 Palaeolandscape and Sub-bottom Profiler interpretation

5.7.1 Whilst the interpretation of the palaeolandscape is based upon the archaeological review of geophysical and hydrographic data, the method of assessment, the assessment criteria and the best practise mitigation strategies differ from those presented in the preceding sections and thus it is detailed separately for clarity.

5.7.2 Sub-surface data acquired from seismic and geotechnical surveys is key to understanding the palaeolandscape potential of the WFDA. These data have been assessed to identify ground conditions and the interpretations fed into the ground model[6]. Seismic data were gathered using SBP and Sparker sensors. The SBP used high frequency (*c*. 6 kHz) to produce high resolution data with shallow penetration, whilst the Sparker used low frequency (*c*. 0.3 to 1.2 kHz) to produce low resolution data with deeper penetration.

5.7.3 Sedimentary units have been identified within the seismic data based on their seismic character and likely depositional environment and tentatively correlated with known geological formations in the area, where possible. The basal horizon of each sedimentary unit has been mapped to feed into the ground model and grids have been exported from the ground model for this assessment. From an archaeological perspective, the ground model provides insight into the potential geological formations within the WFDA and their likely depositional

[6] OWC. 2024. *Bellrock Offshore Wind Farm. Phase 1 Ground Model Revision 2*. Ref: O-LO-R25-0145-GEO-003R

environment, informing the assessment of the palaeolandscape through time and corresponding archaeological potential.

5.7.4 Sedimentary unit grids and geological maps derived from the interpretation of surface and sub-surface data, produced by the survey contractor, were assessed alongside existing studies. The initial assessment contributes to the understanding of the palaeolandscape and prehistoric archaeological potential within the region and provides the baseline from which archaeological interpretation is undertaken. This approach allows for the targeted archaeological assessment of seismic data where the palaeolandscape and prehistoric archaeological potential is highest, or where broad geological interpretations require further investigation.

5.7.5 Based on the assessment of the ground model, twenty lines of seismic survey data were selected for further archaeological assessment, the data were reviewed line-by-line, alongside the original interpretations, by archaeologists at MSDS Marine, with contributions from Professor Richard Bates of the University of St Andrews. This included a review of geophysical survey data reports, the raw seismic profiles, and the ground model outputs, including mapped horizons and grids.

5.7.6 These sources were reviewed to establish an understanding of the geological make-up of the WFDA, formations present and their palaeoenvironmental and archaeological potential. Information about the wider area has also been used to better contextualise the various environments experienced in the area during the Pleistocene and Holocene.

5.8 Mitigation (methodology)

5.8.1 The following section discusses the archaeological mitigation strategies which are considered for the Bellrock WFDA, the proposed mitigation is presented in Section 0.

Surface anomalies

5.8.2 To ensure the most appropriate and robust mitigation for the historic environment, whilst being proportional to the requirements of the development, mitigation recommendations are determined on an anomaly-by-anomaly basis, and consider all available data including;

- Potential significance;
- Size;
- Seabed type;
- Seabed dynamics;
- Development type; and
- Potential negative impacts.

5.8.3 Mitigation strategies have been based on the criteria in Table 5 below.

Potential	Criteria

Low	No archaeological significance interpreted, and a low potential to be of archaeological significance. Maintain an operational awareness of the anomaly's location and reporting through the agreed protocol should material of potential archaeological significance be encountered.
Medium	Avoidance of the anomaly's position and where appropriate an archaeological exclusion zone may be recommended. Ground truthing of the anomaly through the use of divers or an ROV would establish the archaeological potential.
High	Archaeological exclusion zones will be recommended based on the size of the anomaly, any outlying debris and the seabed dynamics as interpreted from the SSS and MBES data.

Table 5: Mitigation criteria for archaeological anomalies

5.8.4 Where an anomaly is visible in the MBES data, that position will generally be used for the implementation of mitigation recommendations. The position obtained from the MBES data is generally more accurate due to the sensor and the GPS receiver being fixed to the vessel in known planes. SSS and magnetometer sensors are towed, and thus the margin for error is greater even with USBL, as the positional tolerance can be between 0.5 m and 2.0 m.

5.8.5 A phased approach to mitigation is proposed for Bellrock WFDA, corresponding with the planned future survey strategy. The survey specification was designed for the purposes of consenting and project planning to determine the most appropriate area for development. Future surveys will likely combine an increase in resolution, and the addition of magnetometer data with tighter line spacing (as determined by the pUXO risk), within the development area. With the data resolution and coverage set to increase, the confidence in interpretation and appropriateness of mitigation strategies will also increase. Following the archaeological assessment, recommendations have been made as to the coverage and specification of future surveys to ensure a robust archaeological assessment of the development area at all stages of the development process.

5.8.6 At this phase, differentiation has made between anomalies that are visible and identifiable in the survey data (e.g., SSS and MBES anomalies), and potential anomalies that have not been identified in the survey data but are likely to exist on the seabed (e.g., Live UKHO records).

5.8.7 The mitigation strategies detailed in Table 6 have been used.

Potential	Criteria
Archaeological Exclusion Zones (AEZs)	For archaeologically significant anomalies that are clearly identifiable in the survey data and where the extents are largely known, Archaeological Exclusion Zones (AEZs) will be recommended. AEZs will remain for the life of The Project or until ground truthing or higher resolution data determines a reduction in potential, significance, or extents.
Temporary Archaeological	Where an anomaly is not visible in the survey data but likely to exist on the seabed at a known position or where the extents of an anomaly are not fully identifiable, Temporary Archaeological Exclusion Zones (TAEZs)

Exclusion Zones (TAEZs)	will be recommended. TAEZs have been identified as highly likely to be altered following higher resolution or full coverage data assessment, however, they will remain in place until alterations have been formally agreed.
Areas of Archaeological Potential (AAP)	Areas of Archaeological Potential (AAP) are primarily reserved for magnetic anomalies where, due to line spacing, positions are not accurately known. AAPs demonstrate that there is potentially an anomaly of archaeological significance around the given position. The anomaly is likely to be identified following higher resolution or full coverage data assessment but as the nature and position is not precisely known, no formal exclusion zone is recommended but instead a general awareness of the position is considered appropriate at this phase.

Table 6: Archaeological mitigation strategies

Palaeolandscape

5.8.8 Dependent on the assessed potential, the process of mitigation in relation to the palaeolandscape and palaeoenvironmental remains typically follows a staged approach of continued assessment aligning with the engineering requirement to undertake geotechnical works. The staged process is broadly outlined within The Crown Estate (2021) guidance on *Archaeological Written Schemes of Investigation for Offshore Wind Farm Projects* and COWRIE (Gribble and Leather 2011) guidance on *Offshore Geotechnical Investigations and Historic Environment Analysis*.

5.8.9 Archaeological input into geotechnical core locations can allow for the greatest insights into the palaeolandscape, such as through the sampling of stratified channel deposits, deposits likely to contain organic remains or un-eroded surfaces. Typically, this process involves close collaboration with the Site Investigation team. Round-table discussions and the review of seismic profiles tends to be a conducive method of allowing engineering and archaeological requirements to be taken into consideration when micro-siting geotechnical cores.

5.8.10 Archaeological input into the planning of core locations is not essential, however, and sufficient information can be gained from the sharing of derived data, such as core logs, photographs and soil descriptions. This data has been gathered for the Bellrock WFDA and will be archaeologically assessed as part of the forthcoming impact assessment.

5.8.11 Following the collection of geotechnical cores, they will typically undergo a staged program of geoarchaeological assessment and analysis. In brief the process is as follows;

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

6.0 Results of surface geophysical anomalies

6.0.1 For the avoidance of confusion, the results of magnetic anomalies with no surface expression are presented in Section 7.0, UKHO records in Section 8.0, Canmore records in Section 9.0, and the palaeolandscape assessment in Section 10.0.

6.0.2 A total of 184 surface anomalies of potential archaeological interest were identified within the geophysical survey data extents, of which 119 are within the WFDA. The anomalies are categorised by potential in Table 7.

Potential	WFDA	Survey extents	Total
Low	108	62	170
Medium	8	2	10
High	3	1	4
Total	119	65	184

Table 7: Distribution of archaeological anomalies by potential

6.0.3 The distribution of anomalies is shown in Figure 7, as can be noted the distribution is fairly uniform across the surveyed area. The ratios, and distribution, of high, medium, and low potential anomalies are relatively consistent with a typical archaeological assessment of data.

6.0.4 The distribution of anomalies within the geophysical data shows a consistent approach to the assessment. The high, medium, and low potential anomalies are discussed below according to their assessed potential.

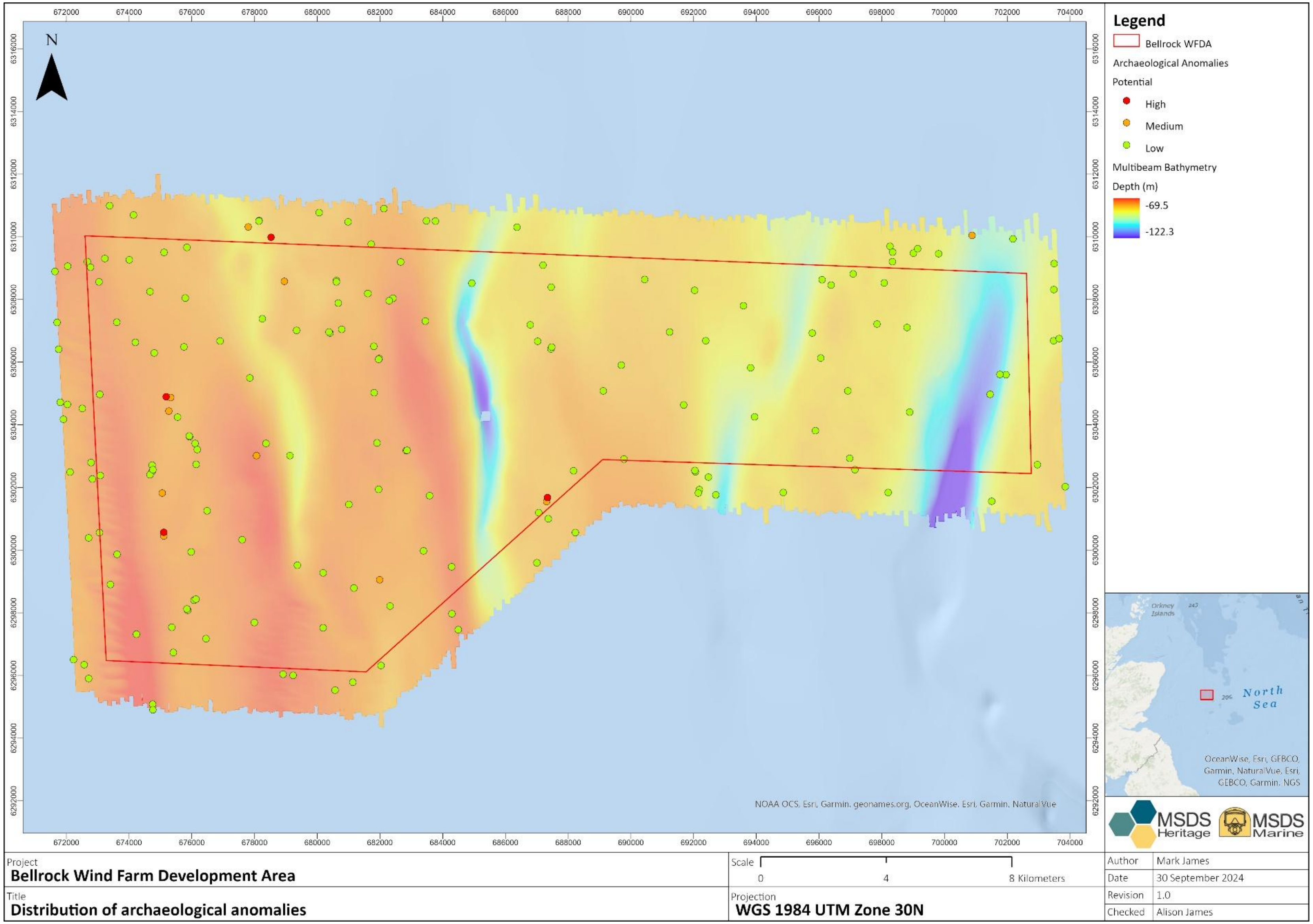

Figure 7: Distribution of Archaeological Anomalies

6.1 Low potential anomalies

6.1.1 170 anomalies interpreted as of low archaeological potential were identified within the geophysical survey data extents, of which 108 are within the WFDA. The anomalies can be categorised as follows in Table 8.

Anomaly category	WFDA	Survey extents	Total
Chain, cable, or rope	50	34	84
Likely geological	8	5	13
Potential debris	19	9	28
Linear Feature	10	3	13
Fishing gear	14	9	23
Seabed disturbance	0	1	1
Anchor - modern	7	1	8
Total	108	62	170

Table 8: Low potential anomaly categories

6.1.2 The anomalies interpreted as of low archaeological potential (see Table 4) are a mixture of small features, often boulder-like, or likely to represent modern debris such as chain, cable, or rope, or small items of debris with no features indicating archaeological potential. Each anomaly was reviewed and interpreted to be of low archaeological potential. A further review was undertaken following the assessment of the survey area extents.

6.1.3 Table 9 below provides a brief justification for the interpretation of each category of low potential anomalies. To note, the descriptions below are generalised, and each anomaly is interpreted based on individual characteristics, other anomalies within the wider area, seabed characterisation, etc.

Anomaly category	Description
Chain, cable, or rope	Features identified as chain, cable, or rope are generally identified as long, linear, or curvilinear features with little or no measurable height. The length and form will generally preclude their assessment as of a higher archaeological potential.
Likely geological	Features identified as likely geological, are generally precautionary identifications where the form is indictive of a geological feature but may be of a size, or form, which is unusual in the surrounding area.
Potential debris	Features identified as potential debris will generally display characteristics indicating anthropogenic origin, such as straight or angular edges. Boulder like features, with associated magnetic anomalies can also be categorised as potential debris.
Seabed disturbance	Features identified as seabed disturbances are where the main characteristic is a change in the seabed surface that may indicate either low lying material, or partially buried material. The potential will be determined based on the size, associated magnetic anomalies, and the surrounding environment.
Linear Feature	Linear features are anomalies which primarily consist of a single linear element, but that don't appear to be chain, cable or rope. A single isolated linear feature, whilst potentially indicative of anthropogenic debris, may not warrant an interpretation of higher archaeological interest.
Fishing gear	Features identified as fishing gear may include pot strings where small features are linked by rope like features, features with a mid-water component indicating snagged nets, or features associated with trawl scars.
Modern anchor	Features identified as low potential anchors (potentially with chains) have been assessed to be of modern origin. However, they are recorded due to their anthropogenic origin.

Table 9: Low potential anomaly descriptions

6.1.4 Low potential anomalies have been assessed against all available evidence and are deemed unlikely to be of archaeological significance and as such are not discussed further within the results section of this report. The identification of an anomaly as of low archaeological potential is commensurate with the mitigation for this category - *Maintain an operational awareness of the anomaly's location and reporting through the agreed protocol should material of potential archaeological significance be encountered*.

6.1.5 The distribution of low potential anomalies is shown in Figure 8. Further information regarding mitigation can be found in Section 11.1, and a gazetteer of low potential anomalies, including positions and dimensions, can be found in Annex A – *Anomalies of archaeological potential*.

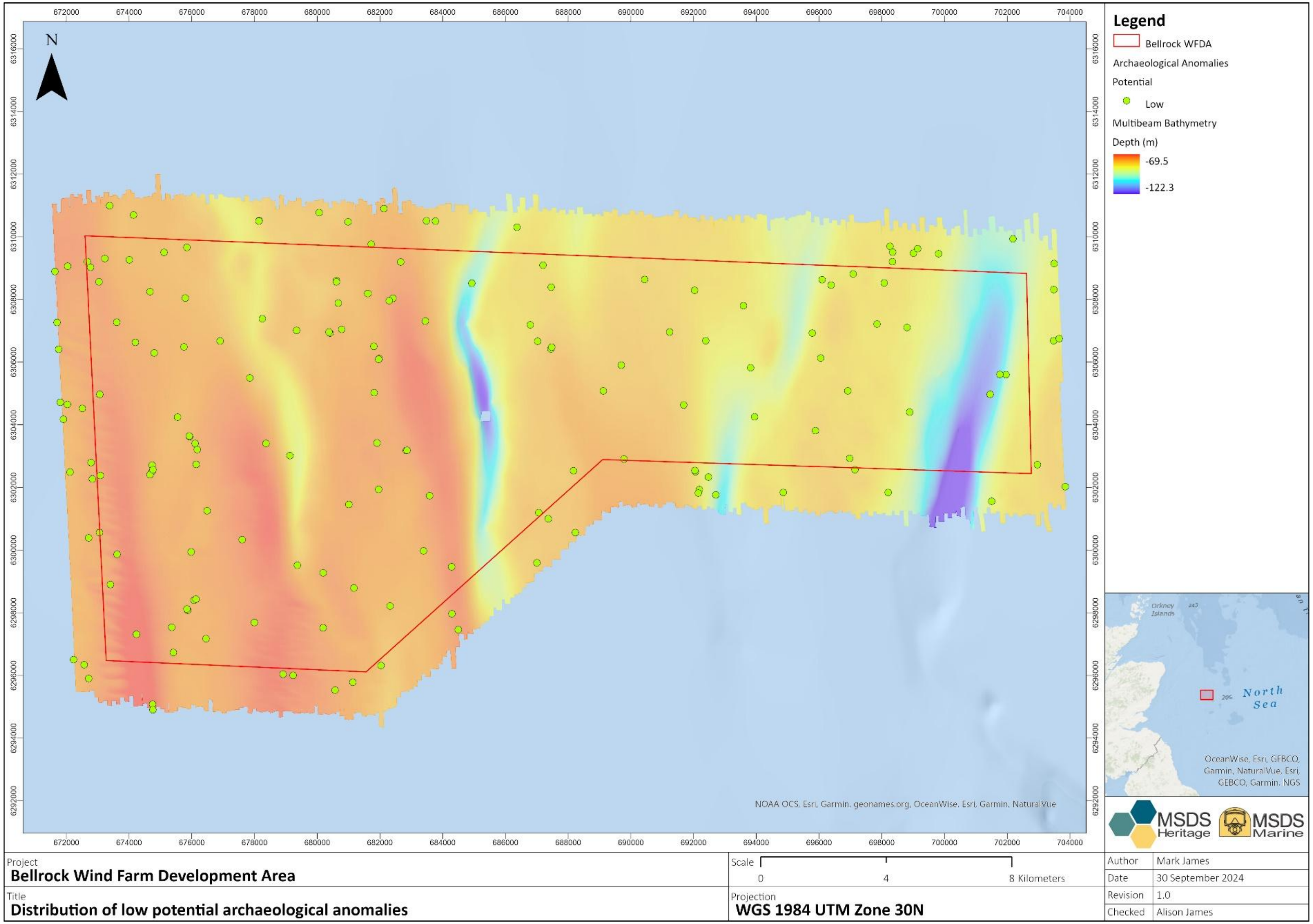

Figure 8: Distribution of Low Potential Archaeological Anomalies

6.2 Medium potential anomalies

6.2.1 Ten anomalies interpreted as of medium archaeological potential were identified within the geophysical survey data extents, of which eight lie within the WFDA. The anomalies can be categorised as follows in Table 10, the distribution is presented in Figure 9.

Anomaly category	WFDA	Survey extents	Total
Potential debris	2	0	2
Anchor - wreck	2	0	2
Wreck debris	1	0	1
Mound	1	2	3
Seabed disturbance	2	0	2
Total	8	2	10

Table 10: Medium potential anomaly categories

6.2.2 The anomalies interpreted as of medium archaeological potential have characteristics that indicate a likelihood of representing anthropogenic material that has the potential to be of archaeological interest, or where a precautionary approach has been taken for anomalies where the identification isn't clear.

6.2.3 The identification of an anomaly as of medium archaeological potential is commensurate with the mitigation for this category - *Avoidance of the anomaly's position and where appropriate an archaeological exclusion zone may be recommended. Ground truthing of the anomaly through the use of divers or an ROV would establish the archaeological potential*.

6.2.4 Each medium potential anomaly is discussed, along with an image, within this section of this report. Further information regarding mitigation can be found in Section 11.0, and a gazetteer of medium potential anomalies, including positions and dimensions can be found in Annex A – *Anomalies of archaeological potential*.

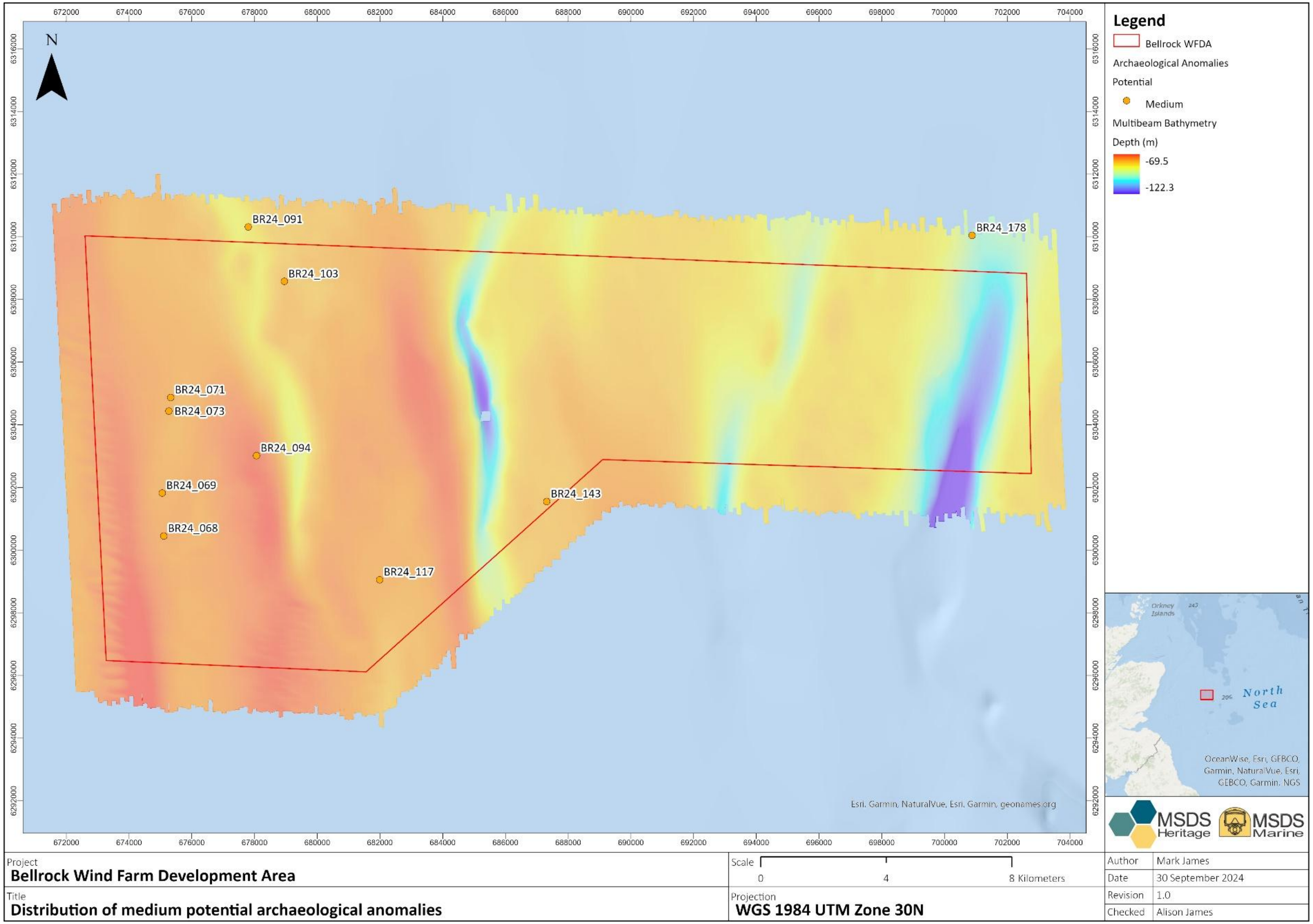

Figure 9: Distribution of Medium Potential Archaeological Anomalies

Medium potential BR24_068

6.2.5 Medium potential BR24_068 is potentially an anchor related to high potential BR24_067 and is discussed within the following high potential section.

Medium potential BR24_069

6.2.6 BR24_069 (Figure 10) lies within the WFDA approximately 5.6 km north-northeast of the southwestern corner. The anomaly is visible in both the SSS and MBES data, although predominantly in the SSS data, and has no corresponding magnetic anomaly although it lies c. 19.0 m from an adjacent trackline. The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 8.5 km to the east-southeast.

6.2.7 The anomaly is an incoherent ovular feature consisting of two parallel ridges measuring 11.7 m x 6.2 m with a measurable height of 0.2 m. Extending from the northern end is a linear feature running to the southwest which is 16.5 m in length. The form indicates anthropogenic material, however the origin is unclear. Whilst it could relate to modern debris such as fishing gear, a medium potential rating is considered appropriate. Further assessment of Remotely Operated Vehicle (ROV) data would be required to better understand the origin, and therefore the archaeological potential.

Medium potential BR24_071

6.2.8 Medium potential BR24_071 is potentially debris relating to high potential BR24_071 and is discussed within the following high potential section.

Medium potential BR24_073

6.2.9 BR24_073 (Figure 11) lies within the WFDA approximately 2.4 km east of the western boundary. The anomaly is visible in both the SSS and MBES data and has a corresponding magnetic anomaly of 81.4 nT with a calculated mass of 698.1 kg. The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 9.5 km to the southeast.

6.2.10 The anomaly consists of three depressions orientated northeast, southwest and covering an area of 24.3 m x 6.1 m. There are potentially small features visible within the central depression. Whilst the origin of the anomaly is unclear, the associated magnetic anomaly indicates anthropogenic origin, and the size means a medium potential rating is appropriate. Further assessment of ROV data would be required to better understand the origin, and therefore the archaeological potential.

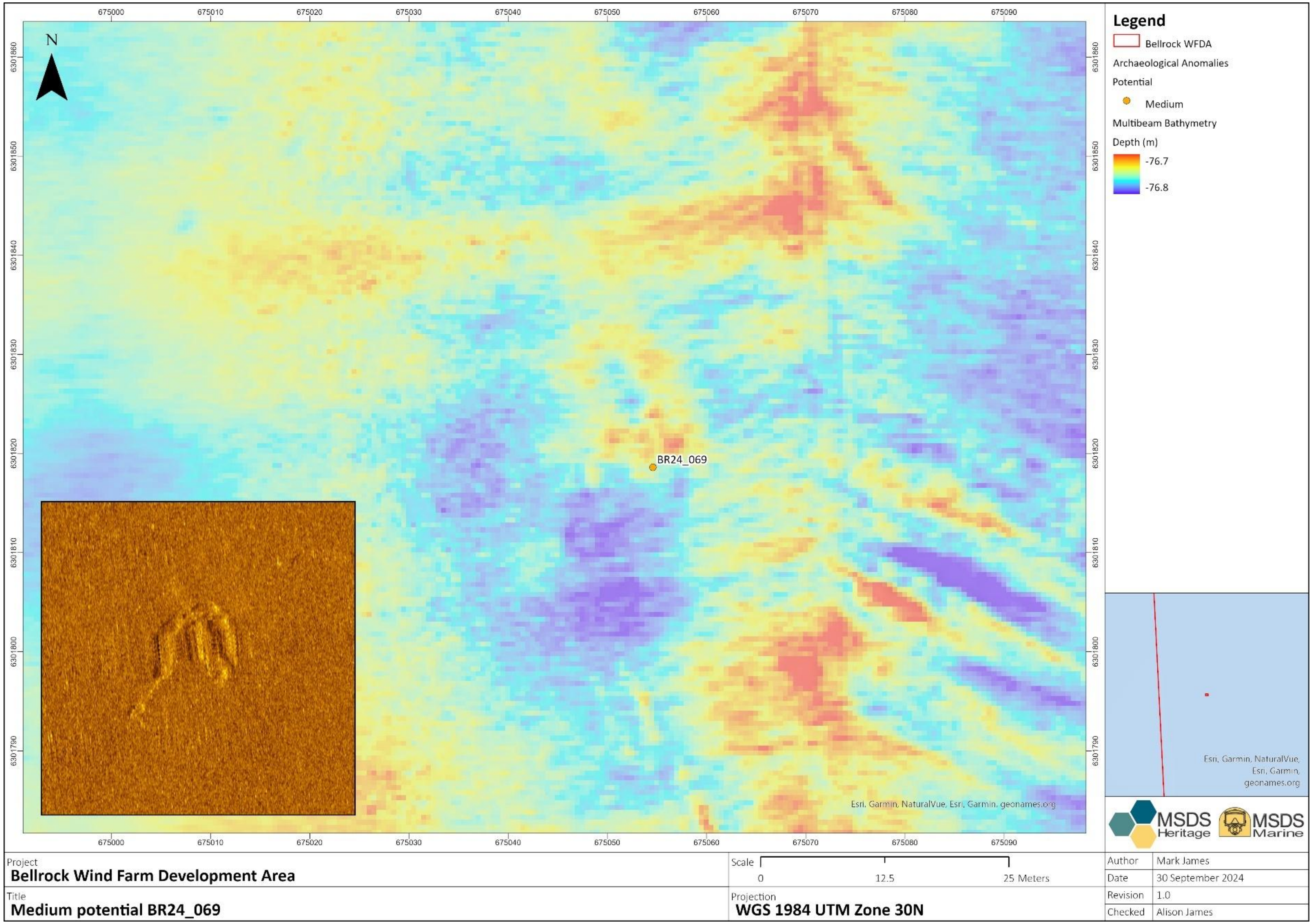

Figure 10: Medium potential BR24_069

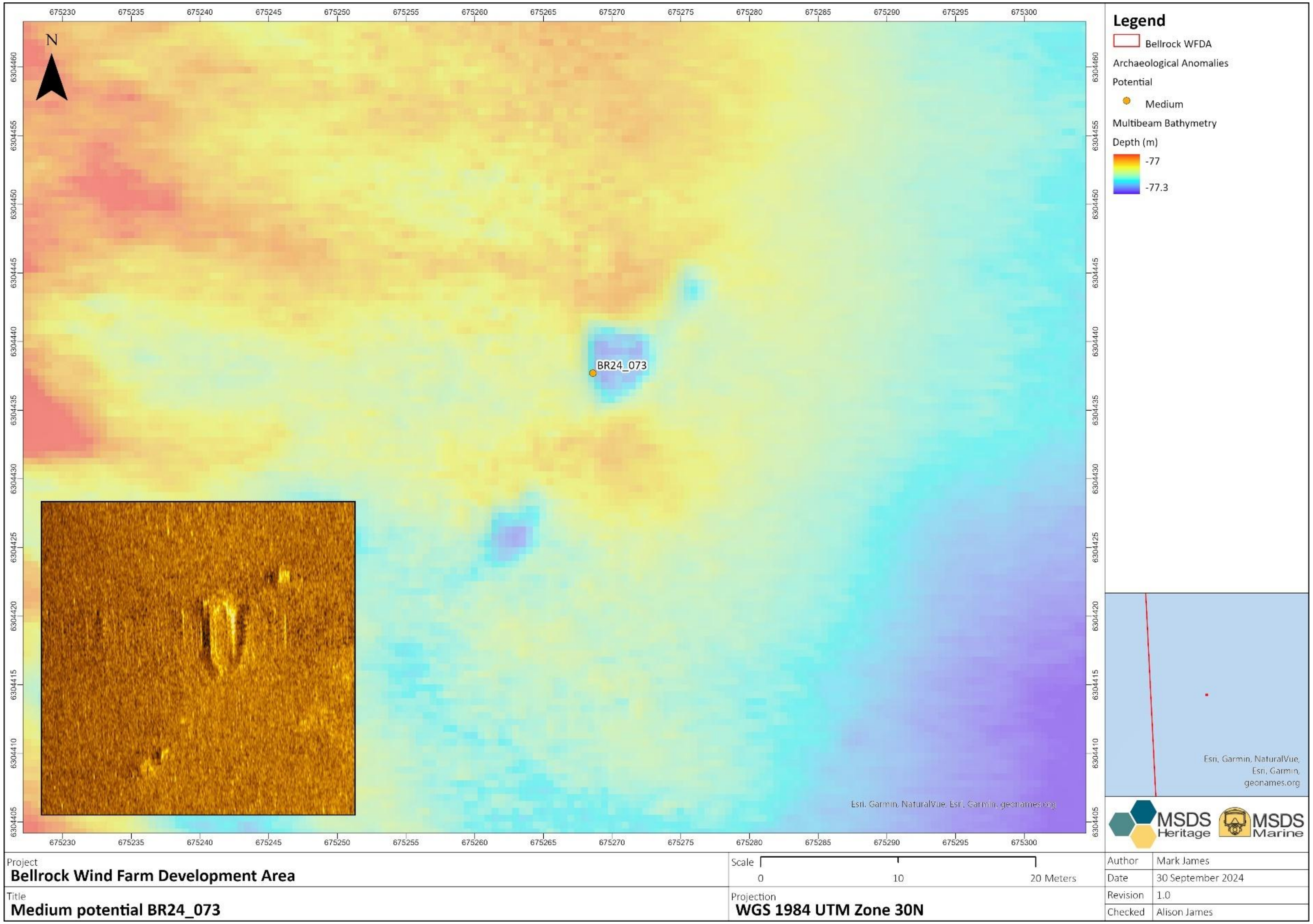

Figure 11: Medium potential BR24_073

Medium potential BR24_091

6.2.11 BR24_091 (Figure 12) lies outside the WFDA approximately 0.5 km north of the northern boundary. The anomaly is visible in both the SSS and MBES data and has no corresponding magnetic anomaly although it lies c. 20.0 m from an adjacent trackline. The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 12.4 km to the east-southeast.

6.2.12 The anomaly appears as a mound in both the SSS and MBES data, and measures 34.1 m x 15.1 m with a measurable height of 1.5 m. The form of the mound is regular, with irregular edges suggesting outlying material, smaller features are visible in the SSS data extending up to 10.0 m from the main mound. The mound is unusual in the surrounding area. The assessment of mounds as of medium archaeological potential is precautionary, mounds can represent evidence of buried anthropogenic material and remains such as ballast, but equally geological or natural features. Further assessment of ROV data would be required to better understand the origin, and therefore the archaeological potential.

Medium potential BR24_094

6.2.13 BR24_094 (Figure 13) lies within the WFDA approximately 5.1 km east of the western boundary. The anomaly is visible in the MBES data and has no corresponding magnetic anomaly although it lies c. 38.0 m from an adjacent trackline. The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 6.4 km to the southeast.

6.2.14 The anomaly is an incoherent area of seabed measuring 36.4 m x 14.9 m with a measurable height of 0.4 m. The anomaly is broadly an ovular shaped feature consisting of irregular ridges around the edges, most prominent to the east. Within the bounds of the ridges is a what appears to be an area of scour lower than the surrounding seabed. Further scour is visible to the northeast and south east. The form is unusual in the surrounding area, and the shape and nature of the overall anomaly, could potentially indicate anthropogenic material such as the remains of a wooden wreck. However, the lack of evidence within the SSS data may indicate a natural 'soft' feature or potentially fishing gear. Therefore, a medium potential rating is considered appropriate. Further assessment of ROV data would be required to better understand the origin, and therefore the archaeological potential.

Medium potential BR24_103

6.2.15 BR24_103 (Figure 14) lies within the WFDA approximately 1.2 km south of the northern boundary. The anomaly is visible in the MBES data and has no corresponding magnetic anomaly although it lies c. 43.0 m from an adjacent trackline. The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 10.4 km to the south-southeast.

6.2.16 The anomaly is an incoherent cluster of at least five irregular features covering an area 12.5 m x 11.5 m with a measurable height of 0.6 m. Scour, lower than the surrounding seabed, is visible between the features with further scour to the north. The form of the anomaly, and its uniqueness within the surrounding area, potentially indicates anthropogenic material of unknown origin. Due to the size of the anomaly a medium potential rating is considered appropriate. Further assessment of ROV data would be required to better understand the origin, and therefore the archaeological potential.

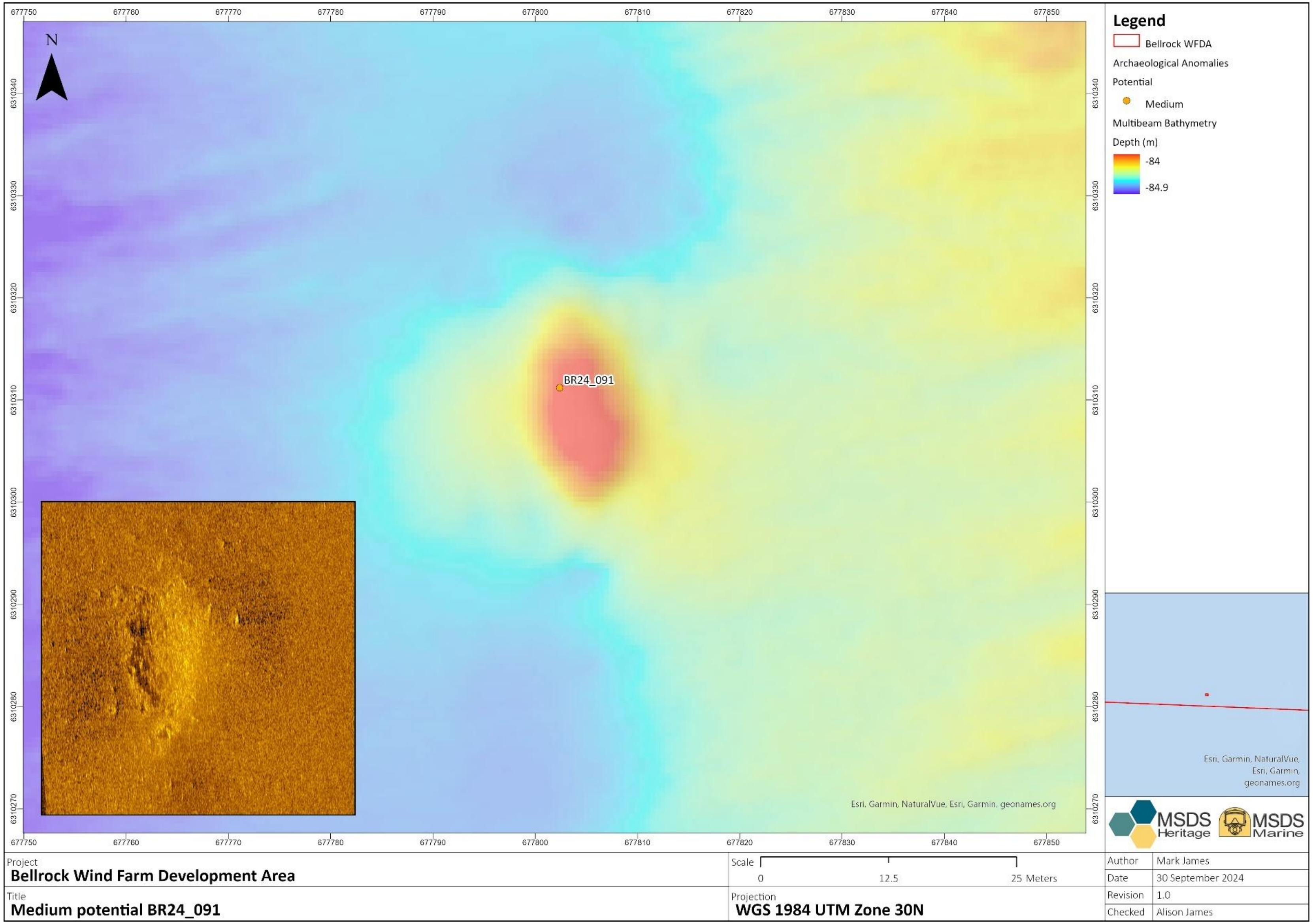

Figure 12: Medium potential BR24_091

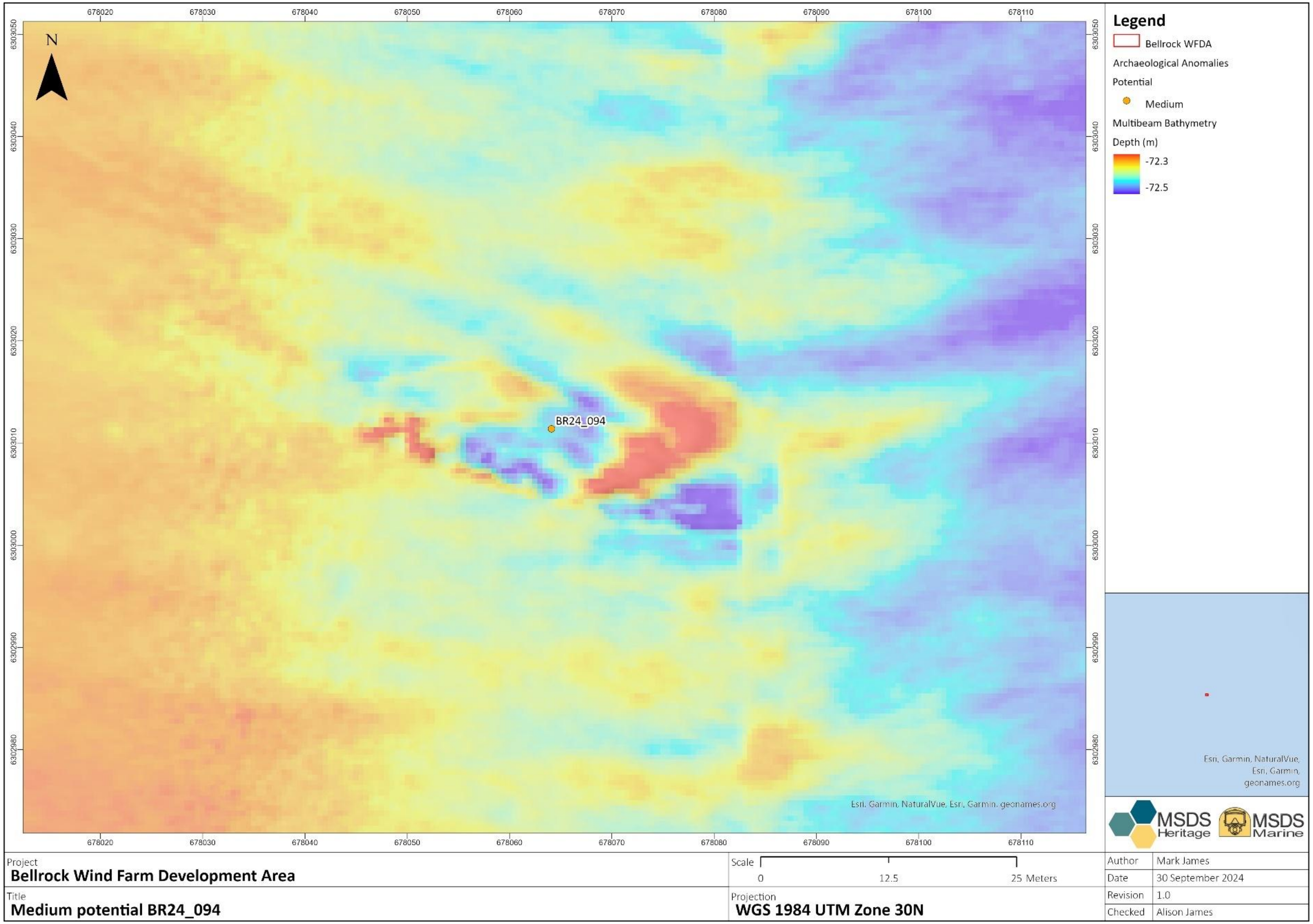

Figure 13: Medium potential BR24_094

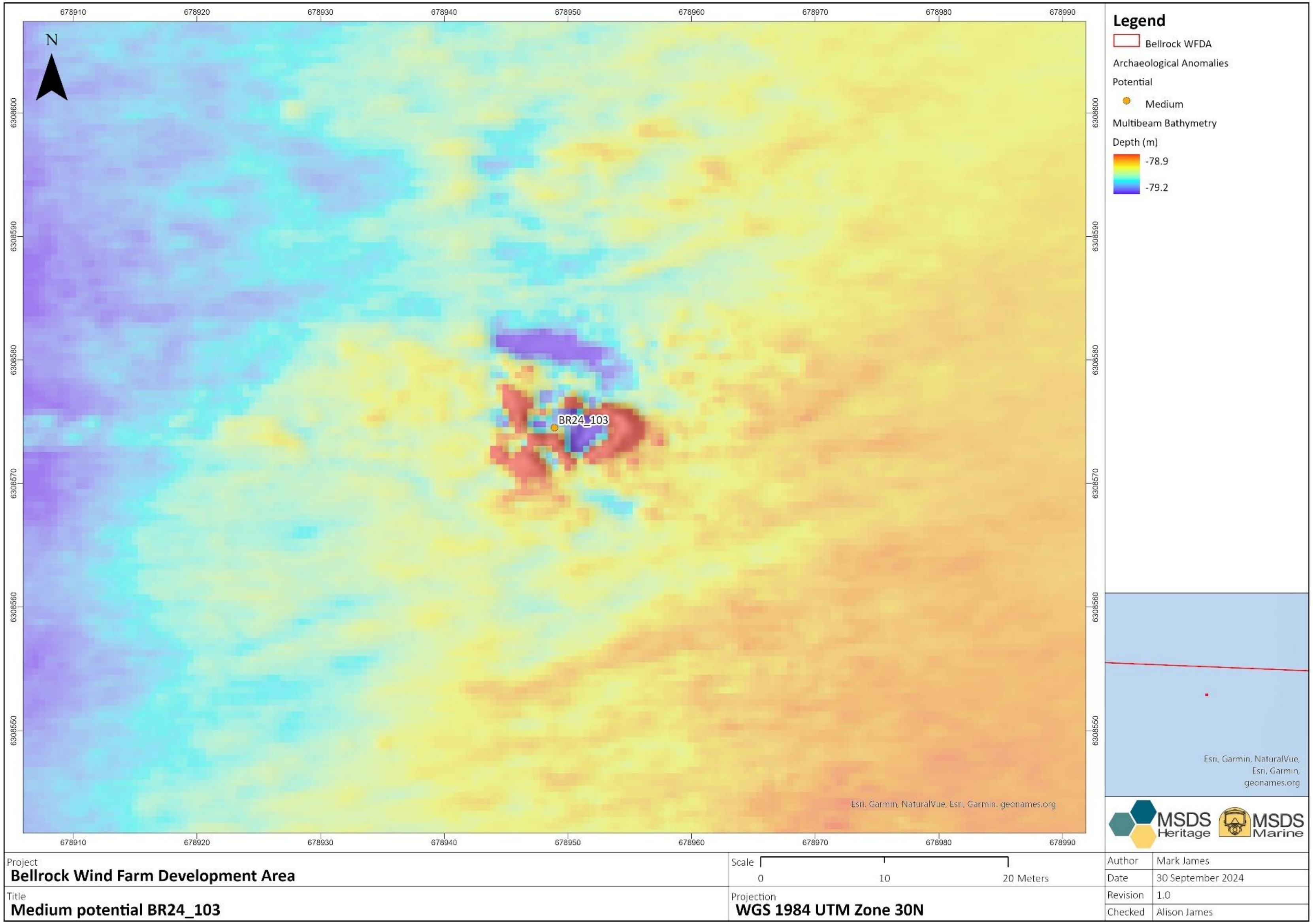

Figure 14: Medium potential BR24_103

Medium potential BR24_117

6.2.17 BR24_117 (Figure 15) lies within the WFDA approximately 2.9 km north of the southeastern corner. The anomaly is visible in both the SSS and MBES data and has no corresponding magnetic anomaly although it lies c. 18.0 m from an adjacent trackline. The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 1.1 km to the east.

6.2.18 The anomaly appears as a mound in both the SSS and MBES data, and measures 22.1 m x 16.7 m with a measurable height of 0.5 m. The form of the mound is irregular with scour visible to the north and the south and is unusual in the surrounding area. The assessment of mounds as of medium archaeological potential is precautionary, mounds can represent evidence of buried anthropogenic material and remains such as ballast, but equally geological or natural features. Further assessment of ROV data would be required to better understand the origin, and therefore the archaeological potential.

Medium potential BR24_143

6.2.19 Medium potential BR24_143 is potentially an anchor related to high potential BR24_142 and is discussed within the following high potential section.

Medium potential BR24_178

6.2.20 BR24_178 (Figure 16) lies outside the WFDA approximately 1.1 km north of the northern boundary. The anomaly is visible in the SSS data and has no corresponding magnetic anomaly although it lies c. 62.0 m from an adjacent trackline. The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 102135 11.2 km to the southwest.

6.2.21 The anomaly appears as a mound in the SSS data, and measures 18.5 m x 9.6 m with a measurable height of 2.0 m. The form of the mound is regular, with irregular edges suggesting outlying material, smaller features are visible in the SSS data extending up to 5.0 m from the main mound. The mound is unusual in the surrounding area. The assessment of mounds as of medium archaeological potential is precautionary, mounds can represent evidence of buried anthropogenic material and remains such as ballast, but equally geological or natural features. Further assessment of ROV data would be required to better understand the origin, and therefore the archaeological potential.

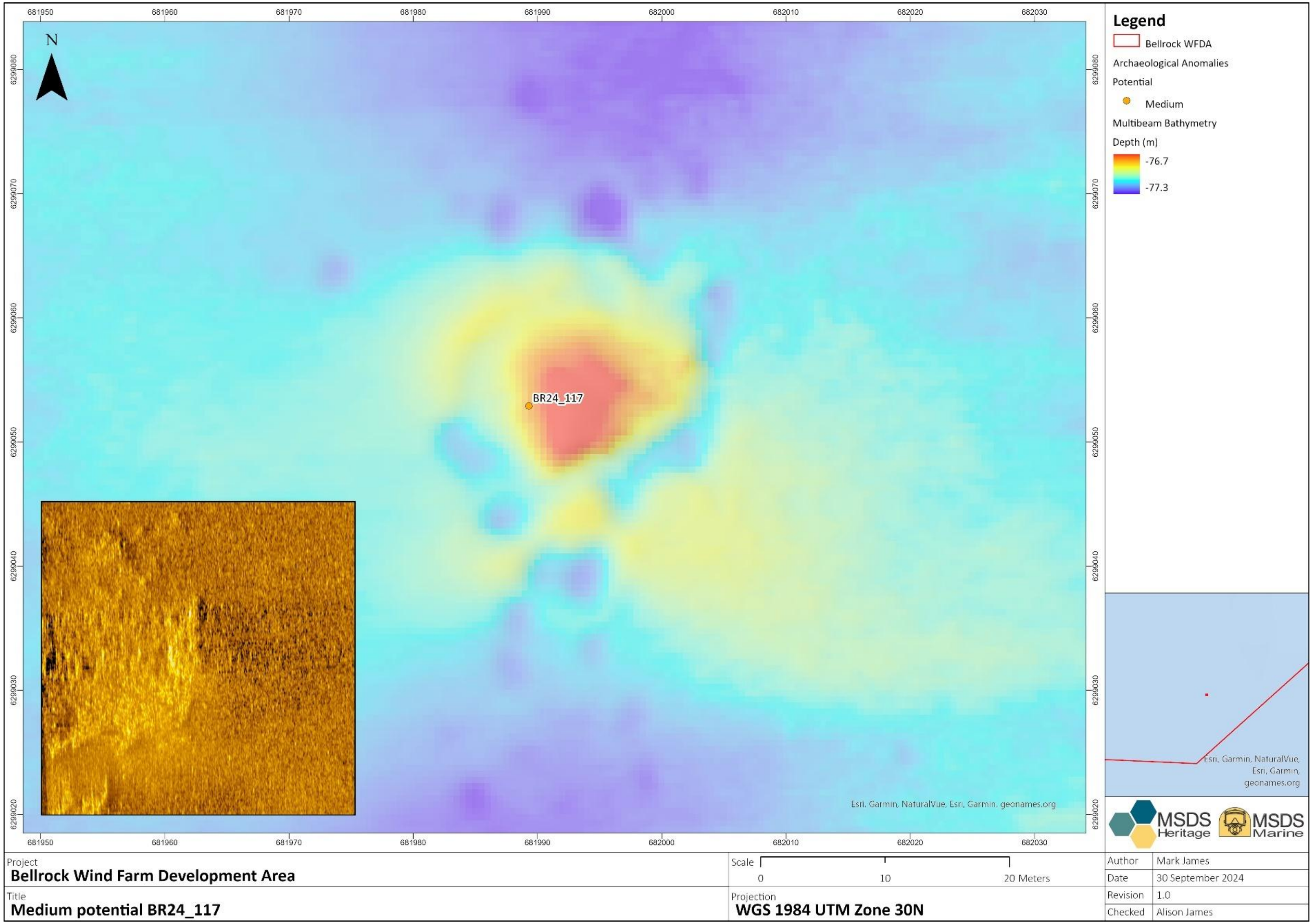

Figure 15: Medium potential BR24_117

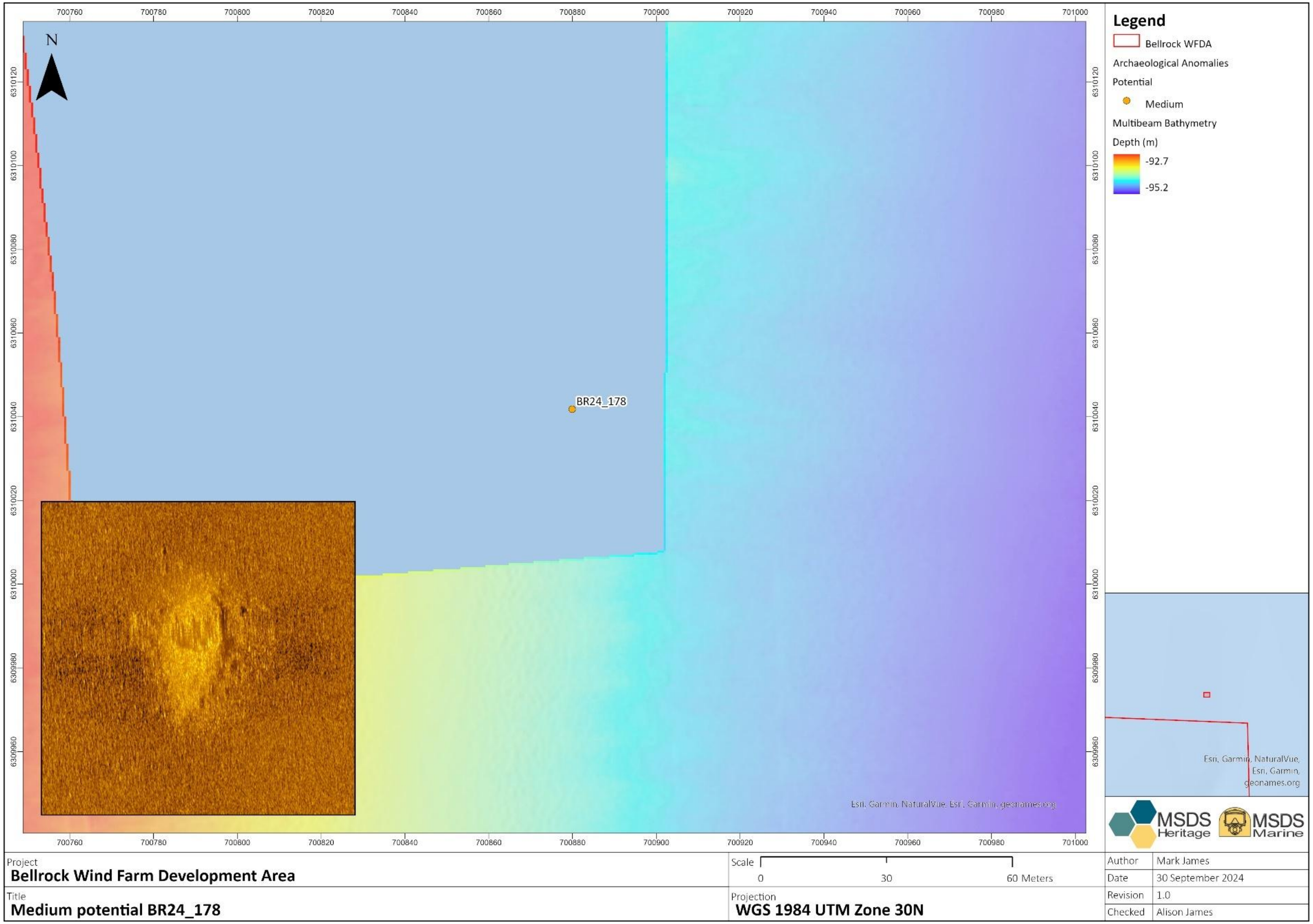

Figure 16: Medium potential BR24_178

6.3 High potential anomalies

6.3.1 Four anomalies interpreted as of high archaeological potential were identified within the geophysical survey data extents, of which three lie within the WFDA. The anomalies can be categorised as follows in Table 11, the distribution is presented in Figure 17.

Anomaly category	WFDA	Survey extents	Total
Wreck	3	0	3
Potential wreck	0	1	1
Total	3	1	4

Table 11: High potential anomaly categories

6.3.2 The anomalies interpreted as of high archaeological potential have characteristics that indicate a high likelihood of representing anthropogenic material that has a high potential to be of archaeological interest, or where a precautionary approach has been taken for anomalies where the identification isn't clear.

6.3.3 The identification of an anomaly as of high archaeological potential is commensurate with the mitigation for this category - *Archaeological exclusion zones will be recommended based on the size of the anomaly, any outlying debris and the seabed dynamics as interpreted from the SSS and MBES data*.

6.3.4 Each high potential anomaly is discussed, along with an image, within this section of this report. Further information regarding mitigation can be found in Section 11.0, and a gazetteer of high potential anomalies, including positions and dimensions can be found in Annex A – *Anomalies of archaeological potential*.

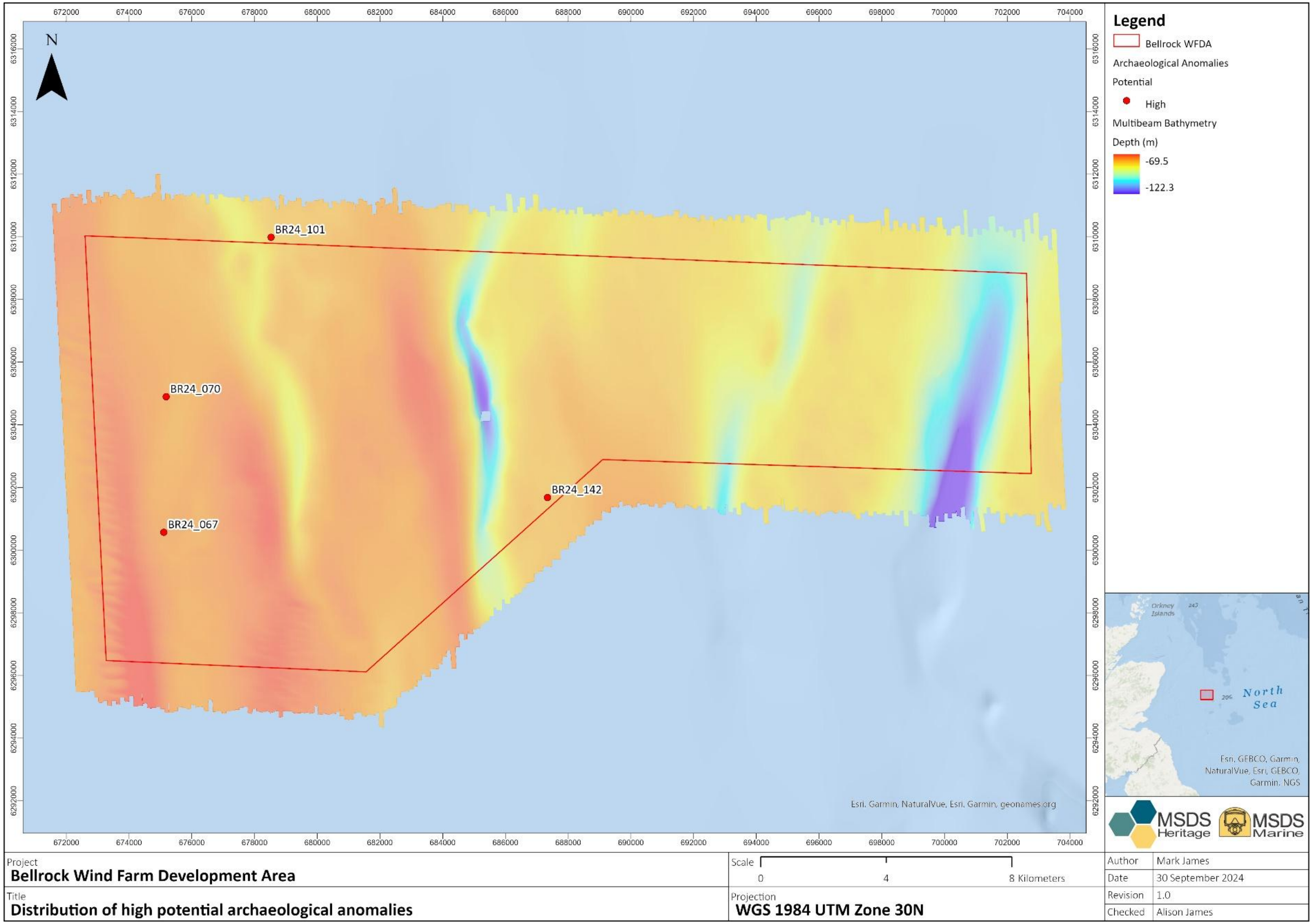

Figure 17: Distribution of High Potential Archaeological Anomalies

High potential BR24_067

6.3.5 BR24_067 (Figure 18) lies within the WFDA approximately 4.5 km north-northeast of the southwestern corner. The anomaly is visible in both the SSS and MBES data and has a corresponding magnetic anomaly of 127.3 nT with a calculated mass of 1,790.5 kg (likely to be higher due to the distance from the sensor). The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 8.1 km to the east-southeast.

6.3.6 The anomaly is the remains of a wrecked vessel measuring 33.9 m x 7.5 m with a measurable height of 3.6 m. the wreck is upright and orientated north-south with what appears to be the bow towards the south. Scour is visible all around the wreck, most prominent along the sides where there is also an accumulation of seabed past the extents of the scour.

6.3.7 Whilst the overall form of the wreck is coherent, the form would suggest a degree of collapse although there are still upstanding features. Debris related to the wreck appears largely contained within the scour although small features can be noted within the immediate vicinity. Extending 98.7 m south from the bow is a linear feature terminating in what is believed to be the anchor (medium potential BR24_068). Whilst the feature could represent snagged fishing gear, the origination from the bow of the wreck likely indicates the anchor and associated chain. The form of the wreck, and associated magnetic anomaly, suggests steel construction, however the identity is not known

High potential BR24_070

6.3.8 BR24_070 (Figure 19) lies within the WFDA approximately 5.8 km south-southeast of the northwestern corner. The anomaly is visible in both the SSS and MBES data and has a corresponding magnetic anomaly of 148.7 nT with a calculated mass of 2,177.0 kg (likely to be higher due to the distance from the sensor). The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 9.8 km to the southeast.

6.3.9 The anomaly is the remains of wrecked vessel measuring 31.8 m x 6.9 m with a measurable height of 3.4 m. The wreck is upright and orientated east-west with what appears to be the bow towards the west. Scour is visible predominantly to the east and the west, where there is also an accumulation of seabed to the southeast and southwest of the wreck.

6.3.10 Whilst the overall form of the wreck is coherent, the form would suggest a degree of deterioration. The SSS data appears to show deck beams running port to starboard. Amidships there is upstanding feature with debris extending outside of the line of the hull to the south by 2.4 m. One significant item of debris, medium potential BR24_071, lies 135 m to the east. BR24_071 is a broadly linear feature measuring 9.8 m x 1.6 m with an associated magnetic anomaly of 81.9 nT and a calculated mass of 1,099.0 kg. Whilst not conclusively related to the wreck, the distance increases the likelihood, no further debris is noted between the wreck and the anomaly. The form of the wreck, and the associated magnetic anomaly, suggests steel construction, however the identity is not known

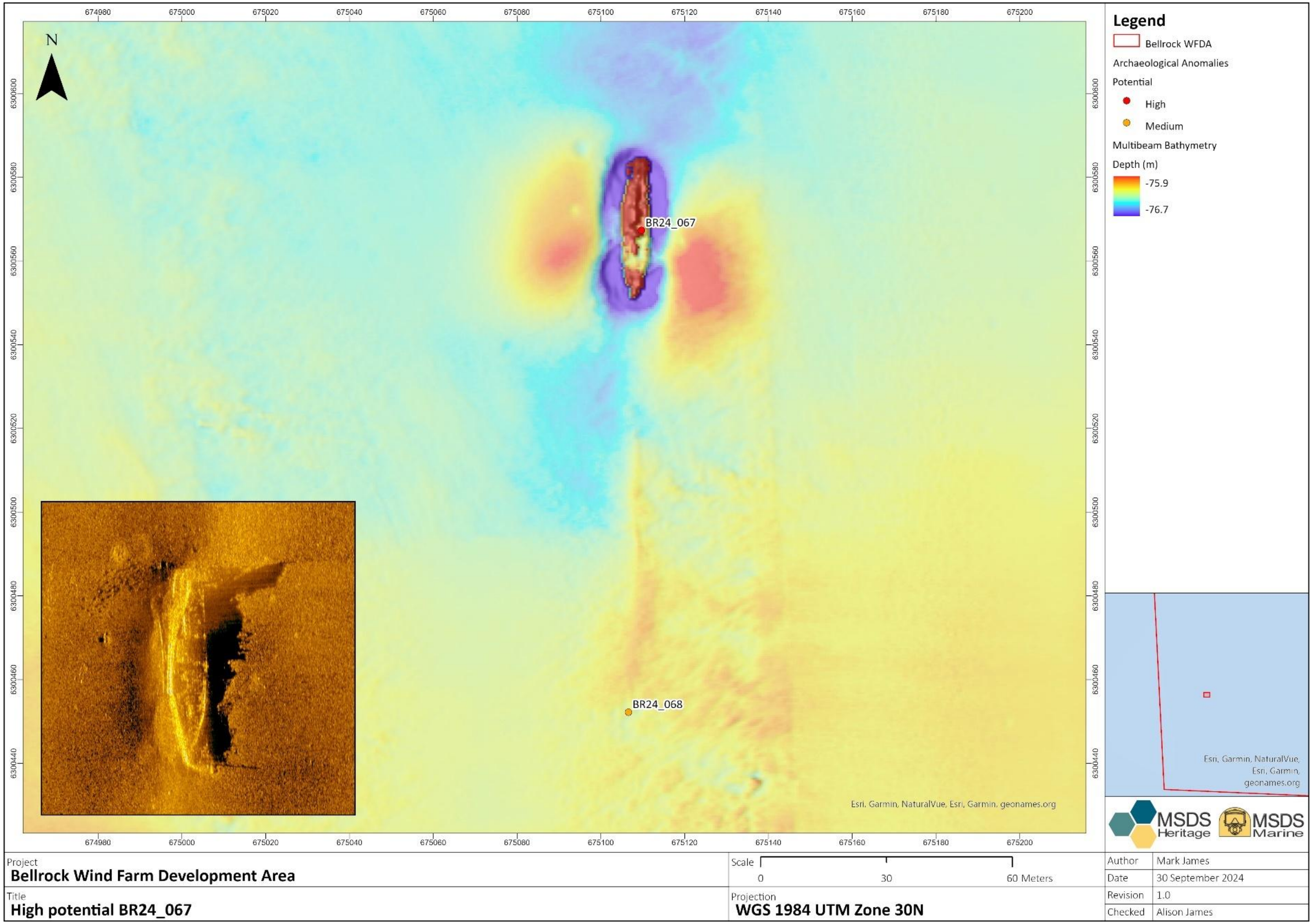

Figure 18: High potential BR24_067

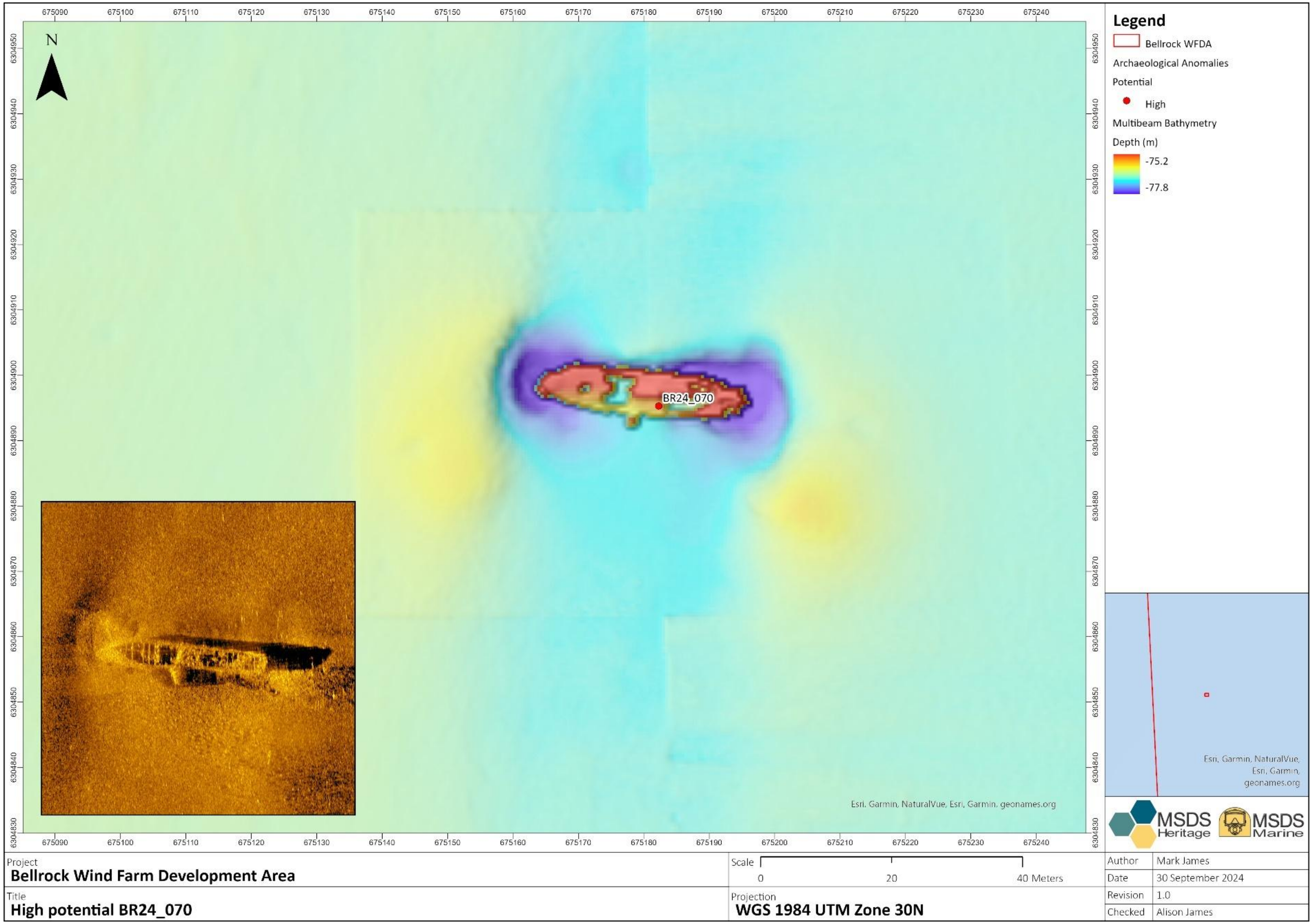

Figure 19: High potential BR24_070

High potential BR24_101

6.3.11 BR24_101 (Figure 20) lies outside the WFDA approximately 187 m north of the northern boundary. The anomaly is visible in both the SSS and MBES data and has no corresponding magnetic anomaly although it lies c. 18.0 m from an adjacent trackline. The anomaly does not correspond with any UKHO or Canmore records, the closest being UKHO 3209 11.8 km to the south-southeast.

6.3.12 The anomaly is a concentration of small features, including linear features, distributed over an area 43.5 m x 13.4 m with a measurable height of 1.3 m. Within the MBES data scour is visible around the extents of the features, with an accumulation of seabed to the southeast. The assessment as of high potential is precautionary, there is the potential for the features to represent geological material such as boulders, however this is unusual in the surrounding area. The overall shape, dimensions, and the presence of linear features may indicate anthropogenic debris, and potentially the remains of a wrecked vessel.

High potential BR24_142

6.3.13 BR24_142 (Figure 21) lies within the WFDA approximately 274 m northwest of the southeastern boundary. The anomaly is visible in both the SSS and MBES data and has a corresponding magnetic anomaly of 140.8 nT with a calculated mass of 1,257.7 kg (likely to be higher due to the distance from the sensor). The anomaly corresponds with UKHO record 102075, although noting that the record originated from the survey to which this report pertains.

6.3.14 The anomaly is the remains of wrecked vessel measuring 49.4 m x 8.9 m with a measurable height of 6.1 m. The wreck is upright and orientated north-south with what appears (tentatively) to be the bow towards the south. Scour is visible predominantly to the north and the south.

6.3.15 Whilst the overall form of the wreck is coherent, the form would suggest a large degree of collapse in particular towards amidships, it not clear whether this is from natural degradation or a break in the hull from the wrecking event. A number of small depressions, potentially indicating debris with scour, are noted around the wreck, and extending up to 100 m to the southeast, and potentially further to the west (although the features are not dissimilar to many others in the wider area). Extending 108.3 m south-southwest from the bow is a linear feature terminating in what is believed to be the anchor (medium potential BR24_143). Whilst the feature could represent snagged fishing gear, the origination from the bow of the wreck likely indicates the anchor and associated chain. The form of the wreck, and associated magnetic anomaly, suggests steel construction, however the identity is not known. The UKHO record provides no further detail than that which be ascertained from the survey data.

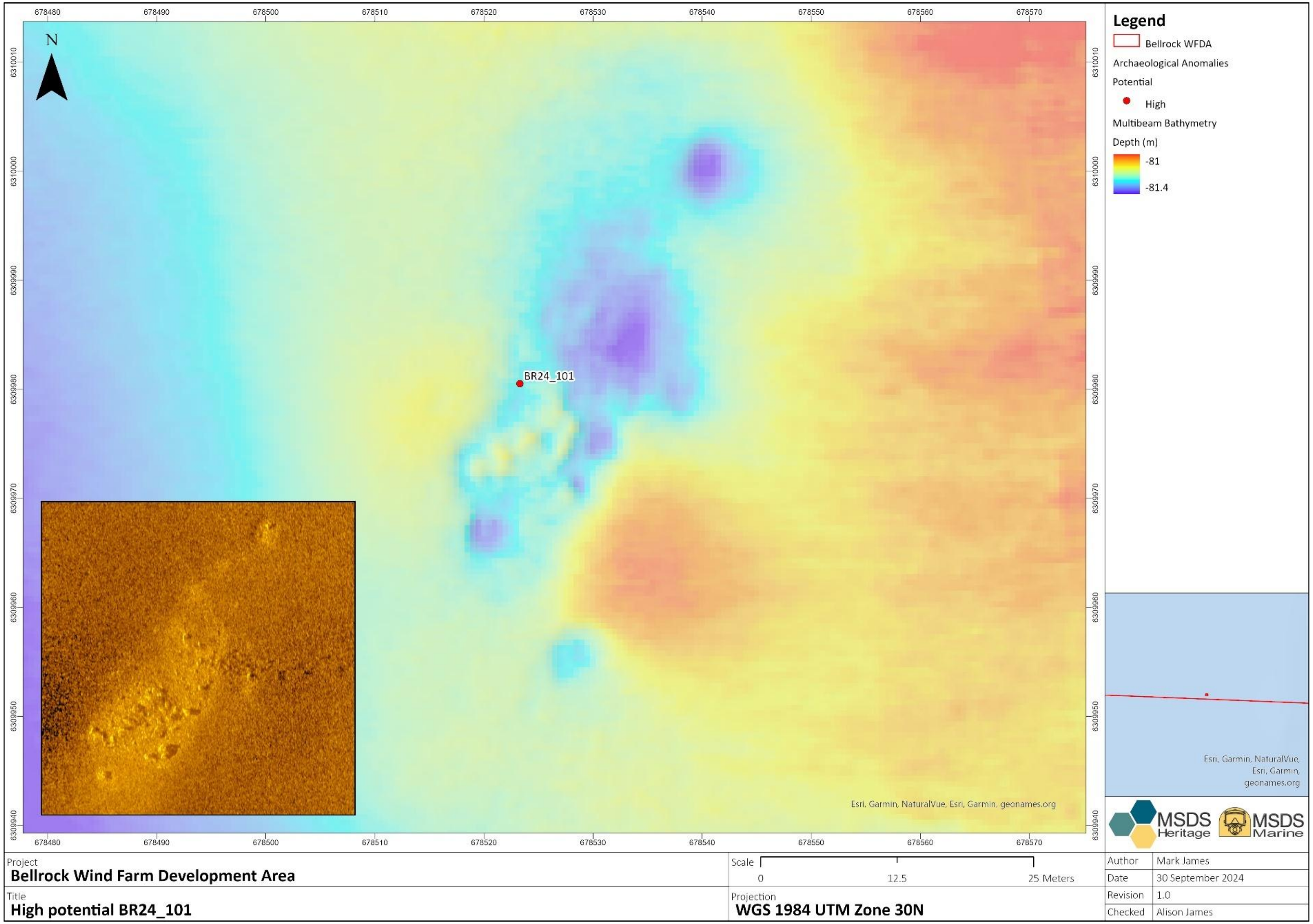

Figure 20: High potential BR24_101

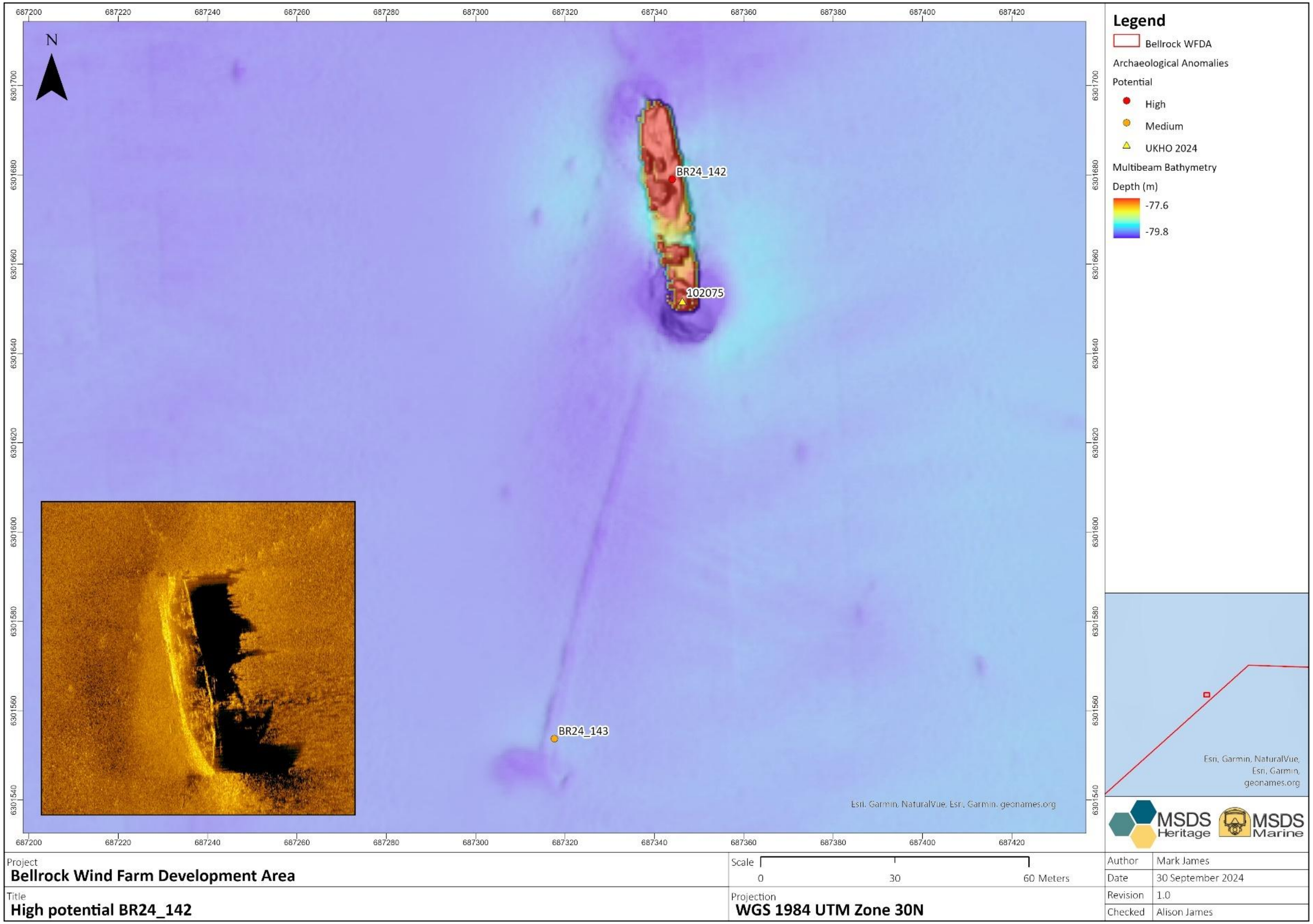

Figure 21: High potential BR24_142

7.0 Magnetic anomalies

7.0.1 222 magnetic anomalies, ranging between 5.0 nT and 309.9 nT, were identified within the magnetometer data and within the geophysical survey data extents. Of these 202 do not correlate with known, or visible, features or infrastructure and have therefore been taken forward for assessment within this section. The remaining twenty anomalies have been discussed previously in relation to their corresponding features. The distribution of anomalies by amplitude is shown below in Table 12 with their spatial distribution presented in Figure 22.

Amplitude (nT)	WFDA	Survey extents	Total
5 to 50	120	77	197
50 to 100	4	0	4
100 to 200	0	0	0
200 +	0	1	1
Total	124	78	202

Table 12: Magnetic anomalies by Amplitude (nT)

7.0.2 Anomalies identified from the magnetometer data are ferrous and thus generally anthropogenic in origin although they can be associated with geological features, however, there is no visual interpretation as with other geophysical data.

7.0.3 The magnetometer data collection methodology across the geophysical survey data extents was to run lines concurrently with the SSS and MBES, thus the line spacing is not sufficient for the detailed assessment of small, ferrous features on or below the seabed. The position for a magnetic anomaly can only be determined from directly below a single sensor, or where lines are run close enough together to be able to confidently position an anomaly seen on two, or more, lines. However, in combination with SSS and MBES data the magnetometer specification is considered sufficient to develop a broad understanding of the potential of the survey area, and to identify larger features of potential archaeological significance.

7.0.4 The positions of magnetic anomalies were viewed in the available datasets and where there was a strong correlation with a seabed anomaly, they were assessed for archaeological potential. All remaining anomalies have been included within this section.

7.0.5 All isolated magnetic anomalies of 50 nT or less are considered to be of limited potential to be of archaeological significance. This is however dependant on the distance from the sensor.

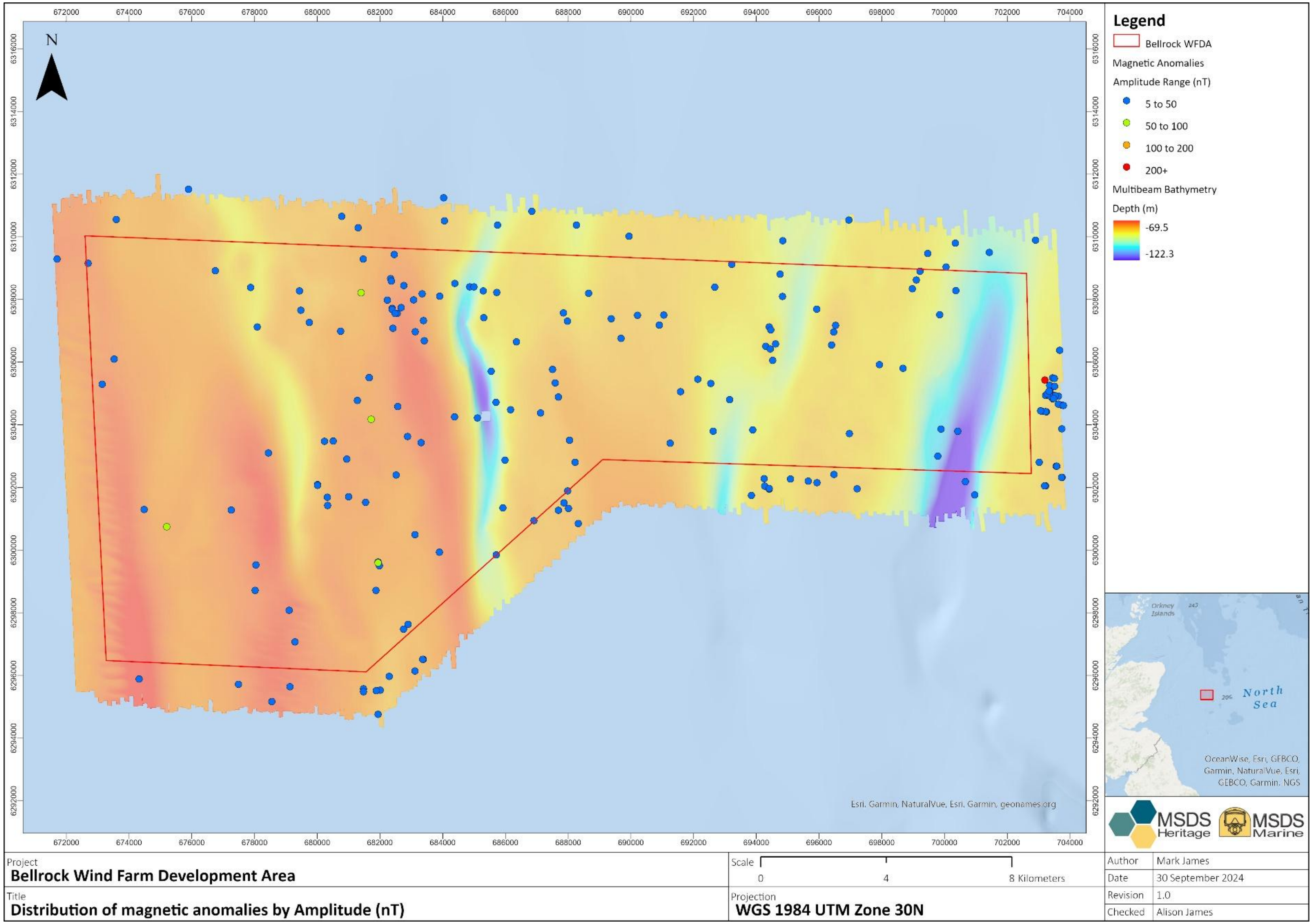

Figure 22: Distribution of Magnetic Anomalies by Amplitude (nT)

7.1 Calculation of mass

7.1.1 The presentation, and categorisation, of magnetic anomalies by amplitude (nT) provides an effective way to gain a broad understanding of the distribution of ferrous material on, or just below, the seabed. However, to understand the data more comprehensively the ferrous mass needs to be calculated which is based on the amplitude and the distance from the magnetometer. However, with a line spacing of 140 m this is not possible to undertake accurately for anomalies that are not visible on the surface or visible on two lines of data, due to the potential distance of an anomaly from the magnetometer ranging from the altitude to the slant range of 50% of the line spacing (70.0 m range is equal to 70.5 m slant range at 7.5 m altitude).

7.1.2 Therefore, all calculations of mass are made using the assumption the anomaly lies directly below the magnetometer, with the distance used for the calculation being equal to the recorded altitude of the magnetometer. Furthermore, calculations are made assuming an anomaly ratio of 1:1. The distribution of anomalies by estimated mass is shown below in Table 13 with their spatial distribution presented in Figure 23.

Estimated mass (kg)	WFDA	Survey extents	Total
1 to 100	85	58	143
100 to 500	37	19	56
500 to 1,000	1	0	1
1,000 +	1	1	2
Total	124	78	202

Table 13: Magnetic anomalies by ferrous mass (kg)

7.1.3 As can be noted, the distribution of the anomalies by estimated mass is broadly similar to the distribution by amplitude, however, there is a notable difference between the distribution of anomalies between 5 and 100 nT, and between 1 to 500 kg.

7.1.4 Typically, and dependant on the survey specification and the distance from the target, isolated anomalies under 50 to 100 nT or 500 kg are considered to be of limited, or low, potential to be of archaeological significance.

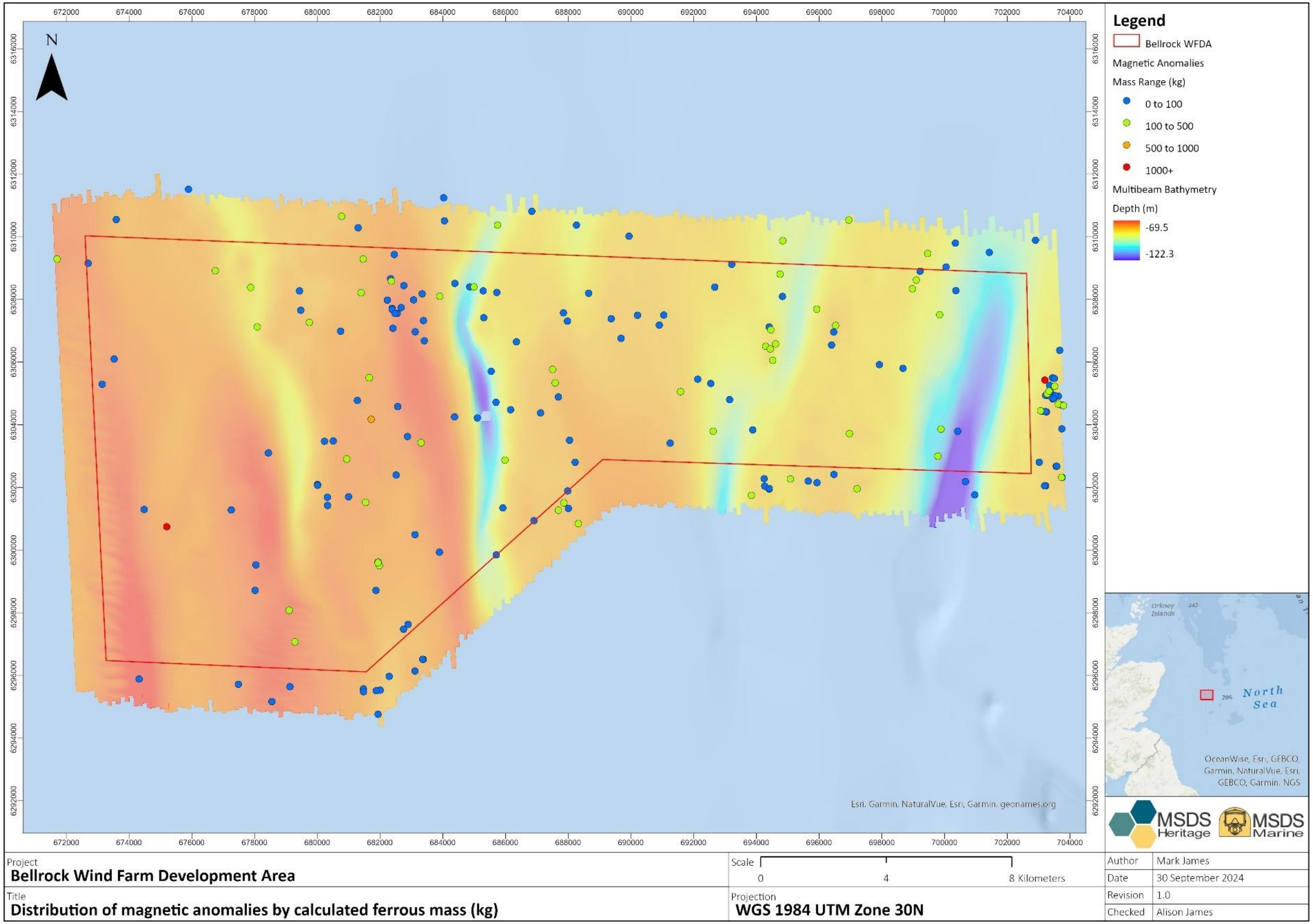

Figure 23: Distribution of magnetic anomalies by mass (kg)

7.2 Overview of magnetic anomaly distribution

7.2.1 The distribution of magnetic anomalies is fairly uniform within the extents of the magnetometer data, primarily consisting of anomalies <50 nT and <500 kg. Due to the 140 m line spacing used during data collection this is a fairly typical distribution, both geographically and in terms of recorded amplitude and mass.

7.2.2 The size (in nT) of a magnetic anomaly is dependent on both the mass of ferrous material, and the distance from the sensor. Therefore, unless there is a strong correlation between a magnetic anomaly and a seabed feature perpendicular to the track, it is not possible to accurately position or determine the mass of an anomaly. For example, an anomaly of <50 nT relating to a feature direct below the track could, and often does, represent small pieces of debris, steel cable, fishing gear, etc. whilst an anomaly of <50 nT 100.0 m from the track could indicate a much larger feature. If that feature is not visible in the other geophysical datasets (potentially due to being buried) then the position is unable to be reconciled. As such, a bias towards anomalies <50 nT is expected as the range to the sensor is greater than 35 m for 50% of the seabed at a 140 m line spacing.

7.3 Discussion of potential

7.3.1 Magnetic anomalies >100 nT are typically described as large and have the potential to be of archaeological significance. It should be noted that these anomalies, and any interpretations, are based on a magnetic signature rather than a visible image of the anomaly on the seabed. It is often the case that during intrusive investigations these anomalies are identified as modern marine debris, including cable, chain, modern anchors, fishing gear, and parts of modern vessels such as outboard engines, and other detritus either deliberately or accidentally, put overboard. Where anomalies are largely isolated, or relating to a single feature, the most commonly identified material of archaeological interest are isolated anchors, often of indeterminate age. The difficulties in determining the age of concreted anchors, and the lack of a wider context means these are often classed as of low or medium potential to be of archaeological significance. However, whilst the chances of isolated magnetic anomalies being of archaeological interest is potentially low, this does not reduce the potential of anomalies to be of archaeological significance, and both must be considered during the recommendation of mitigation (section 0).

7.3.2 As discussed, given the vagaries with positioning, size, etc. it would not be proportional to assign potential, and therefore mitigation of avoidance, to anomalies where there is no correlating seabed feature - the anomalies to which this section pertains. Therefore, a broad statement of potential is provided below, and mitigation discussed further in section 0.

7.3.3 124 magnetic anomalies of between 5.0 nT and 79.9 nT, and 1.1 kg and 1,217.3 kg, with no definitive correlation with archaeological anomalies, seabed features, or infrastructure, have been identified within the WFDA. Magnetic anomalies are ferrous and thus generally anthropogenic in origin, anthropogenic material has the potential to be of archaeological significance. Therefore, there is broad potential to identify additional material of potential archaeological interest within the extents of the geophysical survey data.

7.3.4 At the line spacing of the survey (c.140 m) the potential for anomalies of a significant mass to lie, either undetected, or underestimated is high. For example (using Hall's Equation and a minimum reliable detection limit of 5.0 nT) the minimum mass that can be identified at 5.0 nT at a range of 27.0 m is calculated as 10.0 tons, Holt (2019)[7]. Holt also notes that the results of field-testing using divers has demonstrated that Hall's Equation can have errors in the calculation of mass in some instances by a factor of three, potentially due to the magnetism of the anomaly, known as permanent or residual magnetism. Therefore, calculations should be considered as estimations of mass, not precise measurements of mass. However, they remain a more robust indication of archaeological potential than the presentation of amplitude with no supporting distance from the anomaly data.

7.3.5 Based on the experience of MSDS Marine within the North Sea, and the visual inspection of a significant number of magnetic anomalies, it is our opinion that a mass range of 500 - 1,000 kg (and above) presents a robust but proportional mass from which mitigation recommendations can be based.

7.3.6 The above discussion highlights the importance of the archaeological assessment of high specification (low altitude, tighter line spacing) magnetometer data, to identify the presence of anomalies of potential archaeological interest in areas that will be directly impacted by development. This is discussed further in section 0.

[7] Holt, P. 2019. *Marine Magnetometer Processing*. 3H Consulting Ltd.

8.0 United Kingdom Hydrographic Office (UKHO) Data

8.0.1 UKHO data from 2024 were obtained for the extents of the geophysical survey data, for correlation with anomalies identified within the geophysical data, and the establishment of TAEZs.

8.0.2 Four UKHO records (none of which are classed as dead) were identified within the extents of the geophysical survey data.

8.0.3 The categories of records, along with record counts (dead record counts in brackets), are detailed in Table 14, and the distribution presented in Figure 24.

Record type	WFDA	Survey extents	Total
Wreck	3 (0)	1 (0)	4 (0)
Total	3 (0)	1 (0)	4 (0)

Table 14: UKHO records by type within the geophysical survey data extents

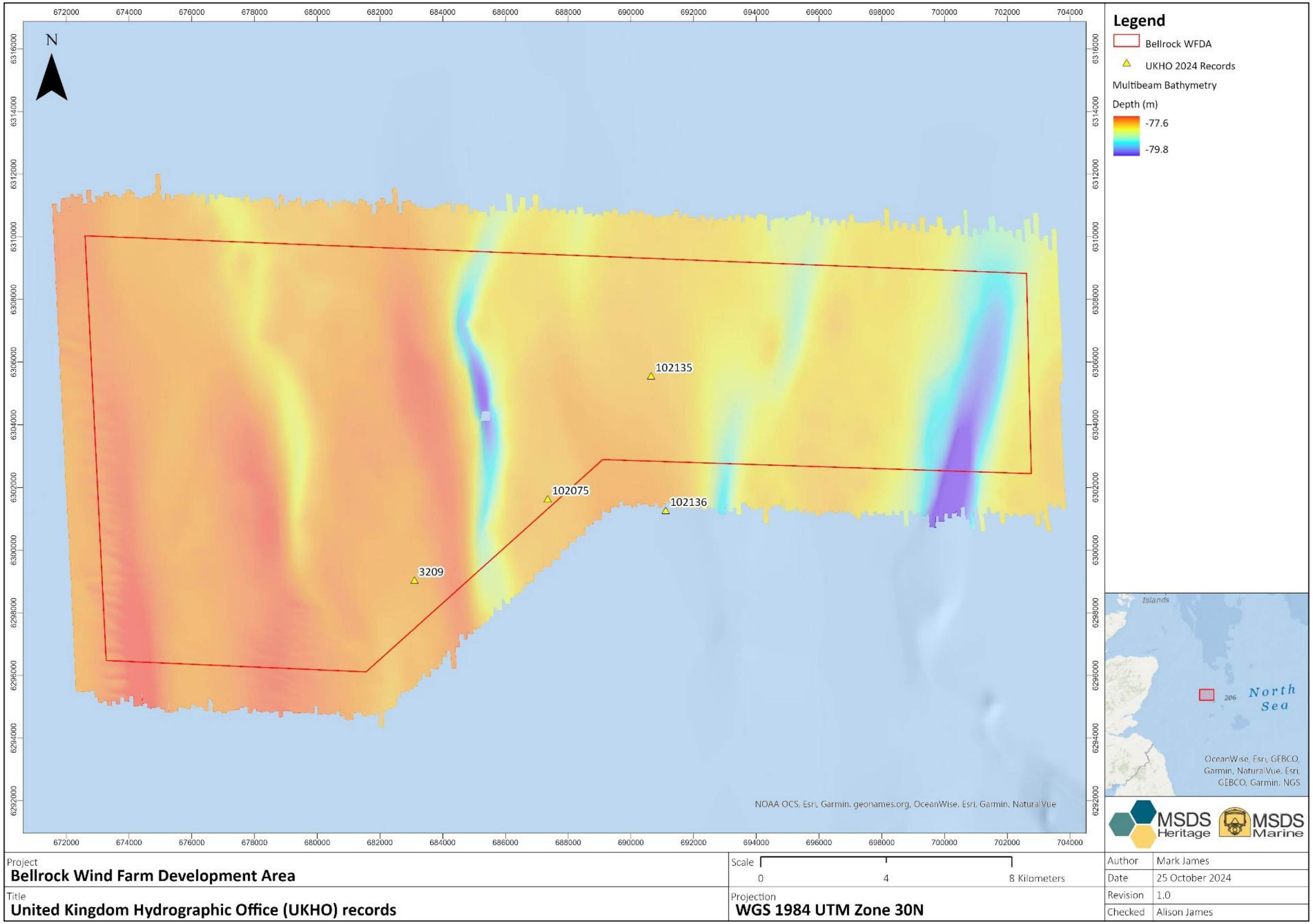

Figure 24: Distribution of United Kingdom Hydrographic Office (UKHO) Records

8.1 UKHO Records of Wreck

8.1.1 Of the four UKHO records identified, all are records of wrecks. UKHO data typically, where known, lists information about the wreck, the circumstances of its loss, surveying details, and whether the record is considered live or dead. A dead record is one which has *not been detected by repeated surveys, therefore considered not to exist*[8]. Whilst the decision to amend a wreck to dead is based on data available from repeat surveys, records can be amended for a number of reasons including:

- Deterioration of the wreck to such a degree that it no longer exists on the seabed;
- Continual burial of the wreck so that the presence is not detected over repeat surveys;
- The identification of the wreck as a natural feature; or perhaps most commonly,
- The wreck not existing at the listed location due to inaccurate reporting or positioning at the period of identification.

8.1.2 The position of the UKHO records were reviewed in the data, where there was coverage, and an assessment made as to whether they were visible, or likely to exist on the seabed. The UKHO records relating to wreck are summarised in Table 15 and a description of each wreck provided below.

Record	Status	Name	Date sank	Date recorded	Last detected	Visible in data
3209	Live	*Karen*	1978	1978	-	No
102136	Live	Unknown	Unknown	2023	-	No
102135	Live	Unknown	Unknown	2023	-	No
102075	Live	Unknown	Unknown	2023	-	Yes

Table 15: UKHO records of wreck within the geophysical survey data extents

[8] https://www.wrecksite.eu/ukhoAbbrev.aspx

UKHO record 3209

8.1.3 UKHO record 3209 lies with the WFDA approximately 1.2 km northwest of the southeastern boundary. The record relates to the wreck of the *Karen* a fishing vessel sunk in 1978. The record was created following a reported sinking, and no evidence of a potential wreck were identified within the geophysical and hydrographic data. Given the likely inaccurate position from which the record originated, and the lack of evidence within the geophysical and hydrographic data, it is highly unlikely that the remains of the vessel lie at the stated position.

8.1.4 There is the potential for one of the wrecks identified within the data to represent the *Karen*, however no record of the dimensions, construction type, etc. were available to support a potential correlation.

UKHO record 102136

8.1.5 UKHO record 102136 lies outside the WFDA (1.5 km south of the eastern southern boundary) and outside the extents of the geophysical and hydrographic data, however it has been included within this chapter due to it originating from the 2023 survey to which this report pertains.

8.1.6 The record is that of a wreck measuring 33.2 m x 6.7 m, however as the wreck lies outside the extents of the survey data it is highly likely that there is an error in the position of the UKHO record. Based on the dimensions it is likely that the wreck is that identified as high potential BR24_070 which was recorded as measuring 31.8 m x 6.9 m or high potential BR24_067 which was recorded as measuring 33.9 m x 7.5 m.

UKHO record 102135

8.1.7 UKHO record 102135 lies within the WFDA (2.7 km north of the eastern southern boundary) and within the extents of the geophysical and hydrographic data. The record originated from the 2023 survey to which this report pertains.

8.1.8 The record is that of a wreck measuring 31.5 m x 8.7 m, no evidence of the wreck was identified at the record location in the data from which the record originated, therefore it is highly likely that there is an error in the position of the UKHO record. Based on the dimensions it is likely that the wreck is that identified as high potential BR24_070 which was recorded as measuring 31.8 m x 6.9 m or high potential BR24_067 which was recorded as measuring 33.9 m x 7.5 m.

UKHO record 102075

8.1.9 UKHO record 102075 was identified during this assessment as high potential BR24_142 and is discussed as such in section 6.0.

9.0 Canmore

9.0.1 Canmore maritime data from 2024 were obtained for the extents of the geophysical survey data, for correlation with anomalies identified within the geophysical data, and the establishment of TAEZs.

9.0.2 One Canmore record was identified within the extents of the geophysical survey data.

Canmore record 322404

9.0.3 Canmore record 322404 originates from UKHO record 3209 and contains no additional information from that presented in section 8.1.

10.0 Palaeolandscape assessment

10.0.1 This Section examines the source material, including the archaeological assessment of seismic data (undertaken by MSDS Marine and Professor Richard Bates), the archaeological assessment of the ground model[9], and desk-based sources (detailed in Section 5.6), to determine the likely chronostratigraphy within the WFDA. The assessment was undertaken inline with the methodology presented in Section 5.7.

10.0.2 Initial interpretations of the seismic data (produced by Acteon[10]) were used to inform a broad archaeological potential. Based on the broad assessment of archaeological potential twenty lines of seismic data were selected for further assessment by MSDS Marine archaeologists, assisted by Professor Richard Bates of the University of St Andrews, alongside the original interpretations.

10.0.3 The Phase 1 Ground Model reviewed and revised the results and initial seismic interpretations, alongside project-specific geotechnical data and independent of the archaeological assessment, necessitating revision of the latter. The identified and anticipated geologic units, as presented by the Phase 1 Ground Model[11], are discussed here alongside key geomorphic processes, to determine the likely condition, form and extent of the units. The results of the discussion feed into the archaeological assessment by MSDS Marine.

10.0.4 Quaternary sediments present within the central North Sea region represent a series of Pleistocene and Holocene environments, mostly representing cold climate and/or marine conditions. Evidence of interglacial phases are also locally present and Holocene sediments are well represented throughout. Palaeolandscape features and Quaternary sediments are discussed below in relation to the WFDA and the ground model, with nomenclature retained from the ground model to ensure consistency in descriptions, etc. throughout the resulting EIA which this assessment informs. For concision, additional detail relating to geologic units, glaciations, geomorphology and sea level studies have been included as Annex C (Section 15.0).

10.1 Pre-Quaternary Bedrock

10.1.1 The pre-quaternary bedrock within the WFDA is mapped by the BGS as siliciclastic, argillaceous rock and sandstone (undifferentiated) of the Palaeogene to Neogene periods[12]. The deep-water muds and deltaic sands of the Palaeogene were heavily eroded during Pleistocene glaciations, resulting in transportation and redeposition of sediments as new units[13]. No geotechnical data were available for the pre-Quaternary deposits within the WFDA and the seismic data did not penetrate sufficiently to reach underlying bedrock.

10.2 Quaternary deposits and formations

10.2.1 Eight horizons were picked from the combined SBP and SCS data, relating to eight geologic units. These are presented by Table 16, below. The geometry and distribution of the units is

[9] OWC. 2024.
[10] Acteon. 2023.
[11] OWC. 2024.
[12] Gatliff, R.W., Richards, P.C., Smith, K., Graham, C.C., McCormac, M., Smith, N.J.P., Long, D., Cameron, T.D.J., Evans, D., Stevenson, A.G., Bulat, J. and Ritchie, J.D. 1994. *The geology of the central North Sea.* United Kingdom offshore regional report. London: HMSO.
[13] OWC. 2024.

closely linked with a series of buried channels. Four principal channels were identified and named by the initial interpretation report as (from west to east) A, B, C and D. A fifth channel, Channel E, was interpreted as more widespread by the ground model and named by this assessment for ease of understanding. Channel locations are labelled by Figure 28 to Figure 34.

10.2.2 Further analysis of a representative sample of twenty seismic lines by MSDS Marine and Prof. Bates (including both SBP and Sparker data and chosen to represent all units) was based on the initial interpretations and partly concurred with these. Subsequent correlation of the further analysis with the Phase 1 Ground Model also largely concurred, though the ground model did not pick all of the horizons of the initial interpretation and extended or combined others. The disparity in picking of horizons is noted (MSDS picked horizons in bold within Table 16 – see note below table). The ground model and MSDS Marine review examined both datasets (SBP and SCS) concurrently, to maximise interpolation of identified units.

10.2.3 Discrepancies between the two reviews of the SBP data generally focus on the picking of horizons within these channels, with the MSDS Marine review opting for a higher count of horizons within the channel fills, partly informed by concurrent examination of the Sparker data. The MSDS Marine review also extended slightly further beyond the limit of interest of the initial interpretation and ground model. An example of the MSDS Marine picking is illustrated by Figure 25.

10.2.4 Preliminary geotechnical investigation was used by the Phase 1 Ground Model to correlate the seismic data and provide lithological descriptions through sampling. It is noted where sampling of units was not undertaken at this stage, namely of units C, D2 and E. Therefore, the interpretations for these unsampled units are provisional at present and are primarily determined by analysis of the seismic amplitude response alongside previous regional geological studies and published literature. Further detail was afforded by the interpretation and mapping of geological features within the identified units.

10.2.5 Project-specific geotechnical data relating to all units was not essential for the preliminary archaeological assessment of the Quaternary sequence and the reviewed geophysical and wider published data, in conjunction with the ground model, was suitable for the purposes of the palaeolandscape assessment. The results of the preliminary geotechnical investigation and any further campaigns will be reviewed and assessed from a geoarchaeological perspective to further examine the Quaternary sequence within the WFDA and ground truth the current interpretations, as part of the forthcoming EIA.

Thickness of Quaternary deposits

10.2.6 The thickness of Quaternary deposits within the region follows a general trend of increasing seaward (east). A thickness of 0 to 200 m is expressed from the coastlines of eastern Scotland and northeast England to approximately 56°N 1°E and 57°N 0°, thickening more significantly further east[14]. Deposits are locally thicker, where occurring as infills of glacial tunnel valleys.

10.2.7 Within the WFDA, the identified Quaternary units measure >65 m thick. This measurement marks the limit of assessment, as the Quaternary sequence was not fully penetrated by the geophysical survey. Deeper stratigraphy was however identified within a series of channels.

10.2.8 The depth of interest for the seismic interpretation was defined at 20 m below seabed. All units

[14] Gatliff *et al*. 1994.

above Unit E were fully resolved across the WFDA. The basal horizon of Unit E lay beyond the penetration of the seismic sensors.

Unit	Horizon		Depth to base (m below seafloor)	Seismic character	Expected / demonstrated lithology	Depositional environment	Correlated formation/ member	MIS	Age
	Top	Base							
A1	H000 (Seabed)	H010/**C4 (partly)**	<10.2	Unit: low amplitude unit, generally structureless. Sometimes more layered reflectors observed in lenses. Best observed in SBP data. At channel bases discontinuous reflections become stronger, with low to moderate amplitudes and some onlap to channel margins. Upper horizon (seabed): positive, high-amplitude acoustic reflector with sharp underlying trough. Basal horizon: positive, low amplitude acoustic reflector. Often forms an undulating, smooth surface. Downward dip in channel areas following channel profiles. Irregular, undulating surface beneath seafloor topographic highs.	Loose, silty fine sand, slightly gravelly with frequent shell fragments.	Marine	Seabed sediments	1	Holocene
A2	H010	H020/**C1**	<56.5	Unit: low amplitude unit, structureless and layered in appearance. Layering typically observed in channels and has continuous reflectors. Variable transparent to weak reflectors, transitioning to strong parallel	Medium to very dense, fine- to medium grained silty sand, with rare shell fragments.	Shallow marine	Whitehorn Member, Forth Formation	1	Holocene

Unit	Horizon		Depth to base (m below seafloor)	Seismic character	Expected / demonstrated lithology	Depositional environment	Correlated formation/ member	MIS	Age
	Top	Base							
				(sometimes horizontal) to discontinuous and hummocky/contorted reflectors. General lack of organization. Chaotic to complex fill, onlap and divergent. Basal horizon: Positive, moderate amplitude acoustic reflector with sharp overlying and underlying trough. Often forms an erosive surface that can be irregular. Major unconformity marks channel base. Cuts through most horizons mapped beneath. Topography potentially outcrops this horizon at, or very close to, the present seafloor.					
B	H020	H030/**P2**	<54.3	Unit: moderate-high amplitude unit, often with well-layered appearance and continuous reflectors. Can also appear more structureless. Basal horizon: positive, low-moderate amplitude acoustic reflection, often unclear and marked by change from layered to	Extremely low to medium strength clay and silty clay, possibly interlaminated with slightly clayey, fine-grained sand.	Low energy marine; lagoonal or marginal marine.	Fitzroy Member, Forth Formation	2 to 1	Pleistocene - Holocene

Unit	Horizon		Depth to base (m below seafloor)	Seismic character	Expected / demonstrated lithology	Depositional environment	Correlated formation/ member	MIS	Age
	Top	Base							
				chaotic texture. Forms an erosive surface.					
C	H030/**P2**	H040	<26.1	Unit: moderate-low amplitude unit, typically structureless with discontinuous reflectors. Subtle layering can be observed in association with moderate amplitudes. Internal reflections weaker near incisions. Basal horizon: positive, moderate-high amplitude acoustic reflector, sometimes overlying and underlying sharp troughs. Mostly planar surface. Characterised by major unconformity, marked by discontinuous strong events with wavy appearance of doublet. Generally, dips to west.	Dense to very dense, silty, fine-grained sand, possibly with occasional cobbles.	Shallow glaciomarine inner shelf to estuarine.	Marr Bank Formation	2	Pleistocene
D1	H040	H050	<81.4	Unit: low-moderate amplitude unit, chaotic or structureless in appearance. Reflectors discontinuous where present, stronger at base of channels. Some stronger and conformable reflectors suggest internal	Medium density, very high strength interlaminated clay and silty, fine-grained sand, with occasional black, organic staining.	Intertidal	Coal Pit Formation (channels)	5d to 3	Pleistocene

Unit	Horizon		Depth to base (m below seafloor)	Seismic character	Expected / demonstrated lithology	Depositional environment	Correlated formation/ member	MIS	Age
	Top	Base							
				stratification. Basal horizon: often lacks sharp boundary, instead marked by a cluster of moderate negative and positive amplitudes. Forms an irregular and erosive surface.					
D2	H050	H060	<37.6	Unit: low-moderate amplitude unit, can exhibit bands of subtle layering and chaotic texture. Layered reflectors are semi-continuous. Reflections are conformable to base, suggesting stratification. Dipping to northwest. Basal horizon: positive, low amplitude acoustic reflectors, sometimes with diffuse overlying trough. Often appearing as a faint reflection, difficult to discern.	Very dense clayey silt to silty clay and clean to silty sand.	Glaciomarine; possibly intertidal or glaciolacustrine	Coal Pit Formation (upper facies)	6 to 3	Pleistocene
D3	H060	H070/**P1**	<57.8	Unit: low-moderate amplitude unit, structureless and mostly chaotic texture. Defined more in west by parallel, continuous reflections, indicating bedding. In east, transitions to less continuous	Dense to very dense, high to very high strength sandy/silty clay and interlaminated clay and fine-grained silty	Glaciomarine; possibly intertidal or glaciolacustrine	Coal Pit Formation (lower facies)	6 to 3	Pleistocene

Unit	Horizon		Depth to base (m below seafloor)	Seismic character	Expected / demonstrated lithology	Depositional environment	Correlated formation/ member	MIS	Age
	Top	Base							
				reflections. Basal horizon: positive, low amplitude acoustic reflection, often with diffuse overlying and underlying troughs. In part forms an erosive and irregular surface. Base defined by a weak truncation event, minor topography of wavy character, generally dipping to west.	sand.				
E	H070/**P1**	Not identified		Unit: typically low amplitude, with some areas of moderate amplitude reflections. Exhibits both chaotic and layered appearance.	Very high to extremely high strength clay, with beds of sandy clay. Shell fragments and plant remains may be present and lenses and laminae of silt and fine-grained sand likely to be observed.	Subglacial to glaciomarine.	Aberdeen Ground Formation	100 to 13	Tiglian to Cromerian

Table 16: Summary of identified units and horizons

Note: MSDS Marine horizon picks in **bold**

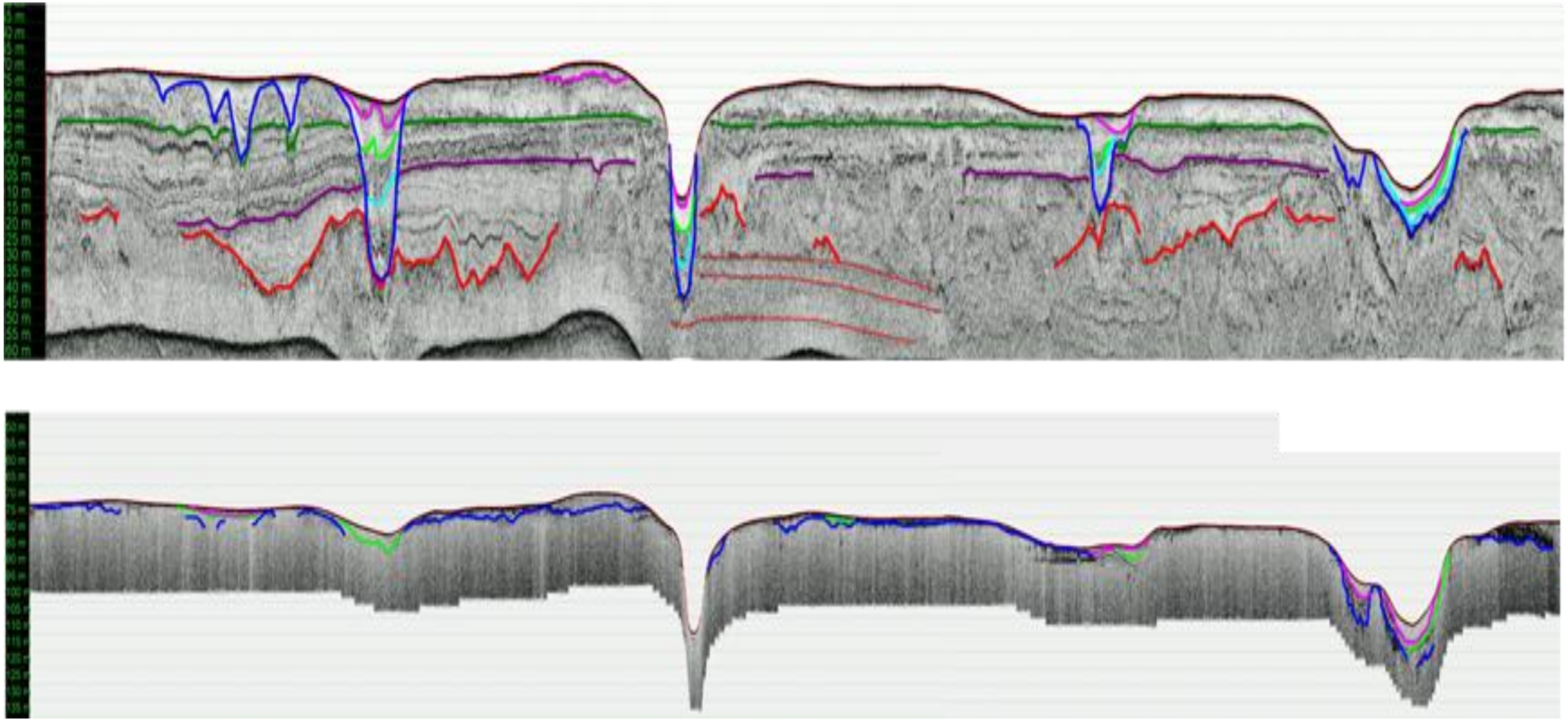

Figure 25: MSDS Marine interpretation of Line 1488, showing the Sparker (top) and SBP (bottom) data. MSDS picked horizons: C4 (pink); C3 (light green); C2 (cyan); C1 (blue); P2 (dark green); P1 (purple); and P0 (red)

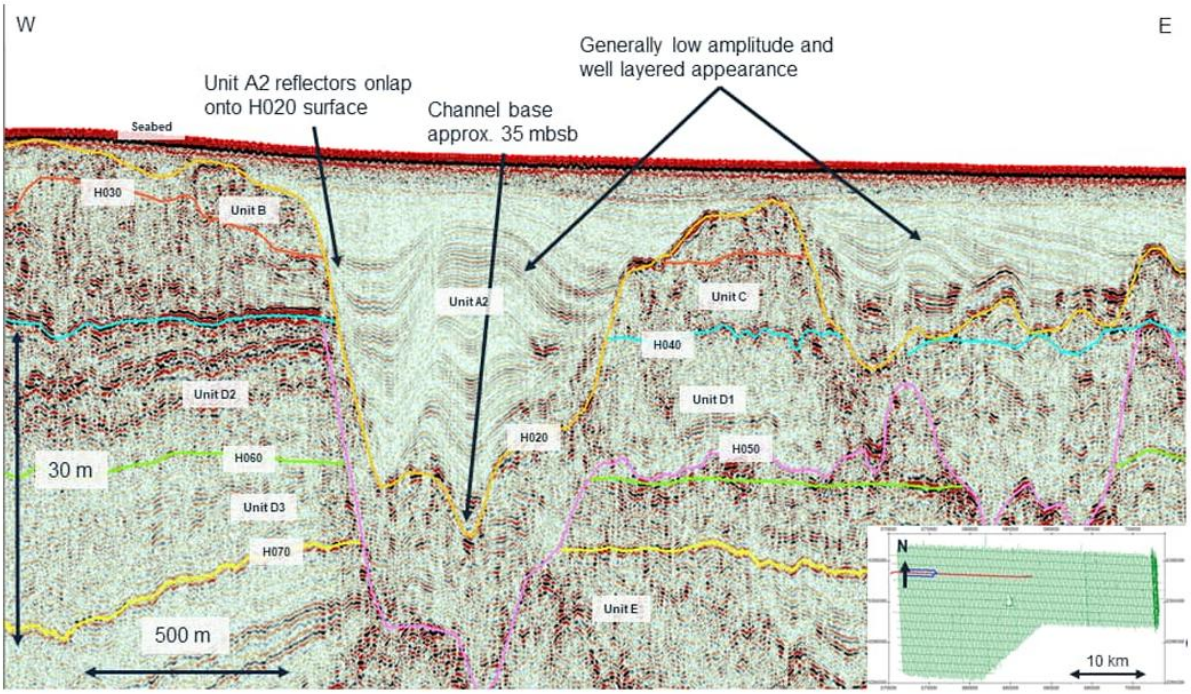

Figure 26: East-west section in northwest of the WFDA (OWC, 2024)

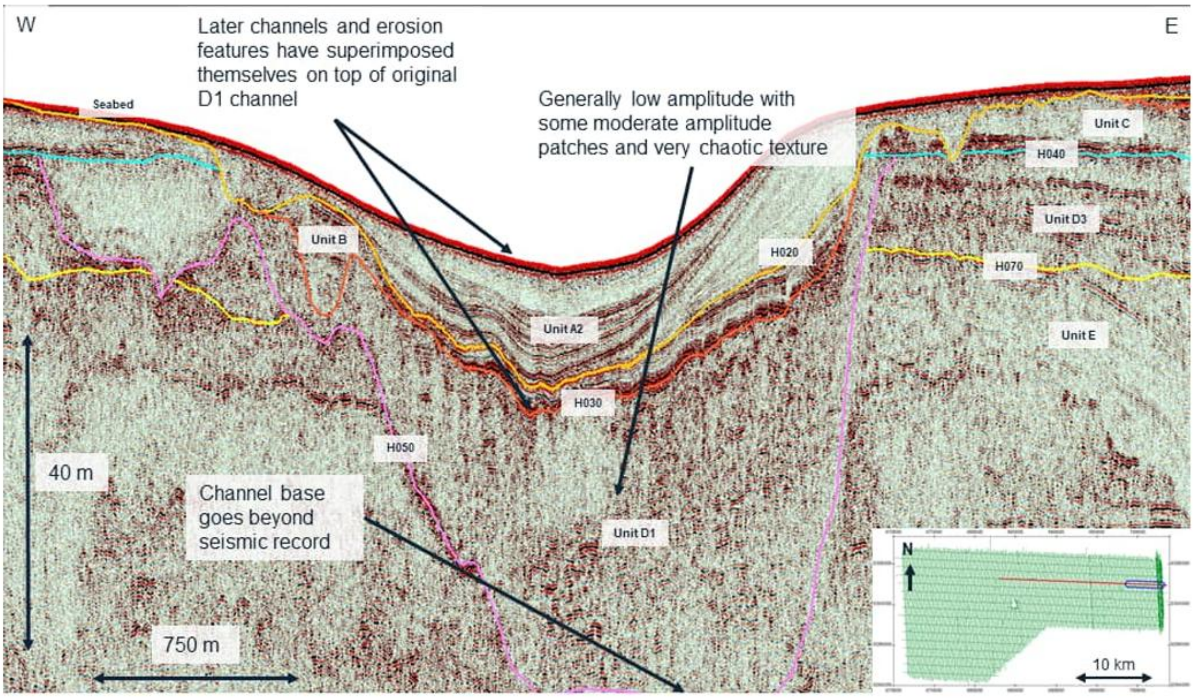

Figure 27: East-west section in east of WFDA (OWC, 2024)

Unit A1

10.2.9 Seismic **Unit A1** (Figure 28) represents the uppermost seabed sediments and is defined by basal **Horizon H010**. Unit A1 is confined to channels C, D and E, measuring up to *c*. 10 m thick. Greater thickness of the unit is achieved at the centre of the channels, pinching out further up the walls and at the upper breaks of slope where Horizon H010 meets the seabed (Figure 25). Horizon H010 partly correlates with MSDS Marine picked horizon **C4**, though this horizon was also picked infrequently as an outcropping deposit between channels (see Figure 25). Unit A1 is interpreted as a Holocene (MIS 1) marine deposit, shown in samples to comprise silty, fine-grained sands.

Unit A2

10.2.10 Seismic **Unit A2** (Figure 29) is present across the whole WFDA and within all channel systems, with some areas of outcropping at the seabed. Although measuring <56.5 m thick within channels (thickest in channels A and B), the general thickness of the unit is *c*. 1 to 10 m. Thickness of Unit A2 varies significantly, in correlation with the size of parent channels. Within deeper channels in the western part of the WFDA, the unit measures up to 56.5 m thick, whereas smaller, tributary channels exhibit a thickness of *c*. 10 to 30 m.

10.2.11 The basal **Horizon H020** correlates with MSDS picked horizon **C1**.

10.2.12 Unit A2 comprises silty, fine- to medium-grained sands, interpreted as shallow marine deposits of the Whitehorn Member, Forth Formation, laid down after the LGM during the early Holocene (MIS 1). The spread of this unit within Channel D correlates with a lobe of muddy sands mapped by the BGS[15].

10.2.13 Both Unit A2 and Horizon H020 are expected to have been reworked by the subsequent marine environment and associated processes.

Unit B

10.2.14 Seismic **Unit B** (Figure 30) is present within the west of the WFDA (except for Channel A) and channels B to E. The Unit generally measures <5 m thick, though as a channel infill this can reach <56 m and where locally eroding into the underlying Marr Bank Formation (Unit C) this can increase to *c*. 15 m.

10.2.15 The basal Horizon **H030** correlates with the MSDS picked horizon **P2**.

10.2.16 Unit B comprises clay and silty clay (possibly interlaminated with slightly clayey, fine-grained sand), interpreted as low energy marine deposits of the Fitzroy Member, Forth Formation.

Unit C

10.2.17 Seismic **Unit C** (Figure 31) is present across much of the WFDA, except where incised by major and tributary channels, exhibiting a general blanket-like geometry. Basal **Horizon H040** occurs deeper below seafloor at channel margins in the west of the WFDA and shallower at the margins in the east and outcropping frequently alongside channels B to E. In general, the unit thickness ranges from 0.2 to 8 m near the channels and 8 to 18 m elsewhere, with thicker concentrations in the southwest corner and alongside Channel B.

10.2.18 It is noted that Unit C exhibits characteristics of a basal accumulation, with the potential for subdivision on review of further data.

10.2.19 Unit C was not sampled during the preliminary geotechnical campaign but has been interpreted through its acoustic signature and regional geological studies as the Marr Bank Formation, comprising silty, fine-grained sands, with occasional cobbles. Unit C was likely laid down in shallow glaciomarine inner shelf to estuarine conditions of the Late Devensian (MIS 2),

[15] BGS. 1985a. "Devil's Hole" Map Sheet 56°N-00°E. Seabed Sediment 1:250,000 Series.

exhibiting boreal/arctic sea temperatures[16 17 18 19].

10.2.20 The ORR notes that the basal reflector of the Marr Bank Formation becomes discontinuous further east in its distribution, locally grading into the upper part of the Coal Pit Formation within the easternmost part of the WFDA, complicating seismic resolution of the two[20].

Unit D1

10.2.21 Seismic **Unit D1** (Figure 32) has been identified within a series of channels across the WFDA, including channels C and D, but notably not channels A, B and E. Basal **Horizon H050** marks the base of the eastern channels (aligned north-northeast-south-southwest) and a series of lesser channels within the west and, to a lesser extent, east of the WFDA (aligned northwest-southeast). The latter alignment represents older features, occasionally intersected by the former. Channel D principally comprises infill of Unit D1 deposits, ranging from 2 to 65 m in thickness (Figure 27).

10.2.22 Unit D1 comprises interlaminated clay and silty, fine-grained sand, interpreted as Coal Pit Formation deposits. Black staining is suggestive of inclusions of organic matter.

Unit D2

10.2.23 Seismic **Unit D2** (Figure 33) has been identified only within the west of the WFDA, incised by a series of northwest-southeast aligned channels. The basal **Horizon H060** declines to the northwest, appearing up to *c*. 37.5 m below seabed. The expected stratified deposits of Unit D2 thicken to the northwest, from c. 10 m up to 1 m within the WFDA.

10.2.24 Unit D2 was not sampled by the preliminary geotechnical campaign but has been interpreted through its acoustic signature as the Coal Pit Formation. The BGS describe the Formation as comprising upper and lower facies, of which Unit D2 represents the former. Provisionally interpreted as comprising clayey silt to silty clay and clean to silty sand, the upper part of the Coal Pit Formation is understood to have been laid down in cold-climate, intertidal conditions[21].

Unit D3

10.2.25 Seismic **Unit D3** (Figure 34) has been identified across much of the WFDA, except where incised by channels A to E and a series of lesser channels (Figure 26 and Figure 27). The basal **Horizon H070** correlates with the MSDS Marine picked horizon **P1**.

10.2.26 Unit D3 comprises sandy/silty clay and interlaminated clay and fine-grained, silty sand, interpreted as representing the lower facies of the Coal Pit Formation.

Unit E

10.2.27 Seismic **Unit E** (Figure 26 and Figure 27) was not defined by a basal horizon, as this lay beyond the penetration of the seismic sensors and the depth of interest for the surveys. Although the Unit was not sampled by the preliminary geotechnical campaign, it has been interpreted as clay, with beds of sandy clay, of the Aberdeen Ground Formation. The Formation was laid down over a long period of the Pleistocene and exhibits a range of facies and depositional

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[16] Gatliff *et al*. 1994.
[17] Stoker, M.S., Long, D. and Fyfe, J.A. 1985. 'The Quaternary succession in the central North Sea'. *Newsletters on Stratigraphy*. **14**(3), pp. 119-128.
[18] Davies, B.J., Roberts, D.H., Bridgland, D.H., Ó Cofaigh, C. and Riding, J.B. 2011. 'Provenance and depositional environments of Quaternary sediments from the western North Sea Basin'. *Journal of Quaternary Science*. **26**(1), pp. 20.
[19] Thomson, M.E. 1978. *IGS studies of the geology of the Firth of Forth and its Approaches*. Natural Environment Research Council Report 77/17, pp. 9. London: HMSO.
[20] Gatliff *et al*. 1994.
[21] Gatliff *et al*. 1994.

environments (see Annex C – Section 15.4). Aberdeen Ground Formation deposits within the WFDA are interpreted as the product of subglacial to glaciomarine conditions.

10.3 Buried channels

10.3.1 The numerous channels identified within the WFDA have been classed as Type 1 or Type 2 channels. Hybrid channels also likely occur.

Type 1 channels

10.3.2 The youngest observed channels are interpreted as having been formed in Late Devensian and Early Holocene terrestrial and/or coastal environments. Type 1 channels incise the underlying Marr Bank, Coal Pit and even Aberdeen Ground formations, often exploiting pre-existing depressions and incisions. The infill of these channels comprises units A1, B and, primarily, A2, forming during the Holocene (Figure 26 and Figure 27).

10.3.3 The basal horizons of Type 1 channels (characterised by horizons H020 and H030) can be highly irregular, suggesting a possible glacio-fluvial origin or influence from earlier subglacial features.

Type 2 channels

10.3.4 Type 2 channels are interpreted as Pleistocene tunnel valley systems, having formed during glacial conditions. These are only partly filled, by Unit D1, which may represent deposits laid down in a high energy, glacial meltwater environment. The deeper channels are incised by Type 1 channels and include notable Forth Formation infill. Channels A and B exhibit extensive incision of Unit D1 by Type 1 channels, either reusing the underlying valleys or incising them (Figure 26, Figure 27 and Figure 32). Channel C exhibits extensive survival of D1 deposits and Channel D infill is principally comprised of these (Figure 27).

10.3.5 Type 2 channels incise older units D2, D3 and E, marked by basal Horizon H050. They appear to have formed between the deposition of units D2 and C, suggesting a Late Pleistocene age, correlating with the Late Wolstonian and Devensian stadials (MIS 6 to 3).

10.3.6 The orientation of Type 2 channels appears random, however, dominant northwest-southeast and northeast-southwest alignments have been identified, exhibiting multiple intersections. The thickness of the Pleistocene infill ranges from 2 to >65 m.

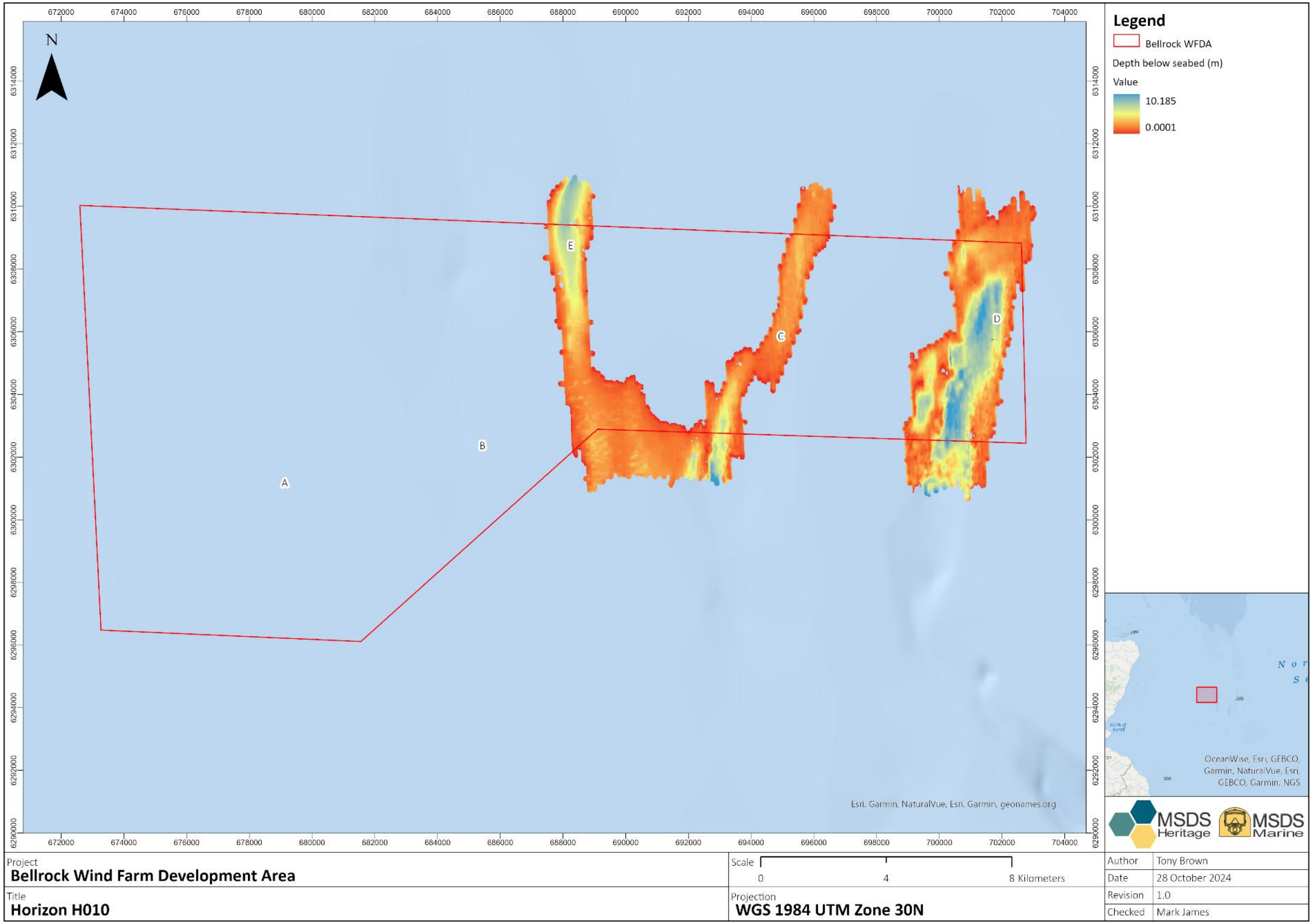

Figure 28: Horizon H010 (OWC, 2024)

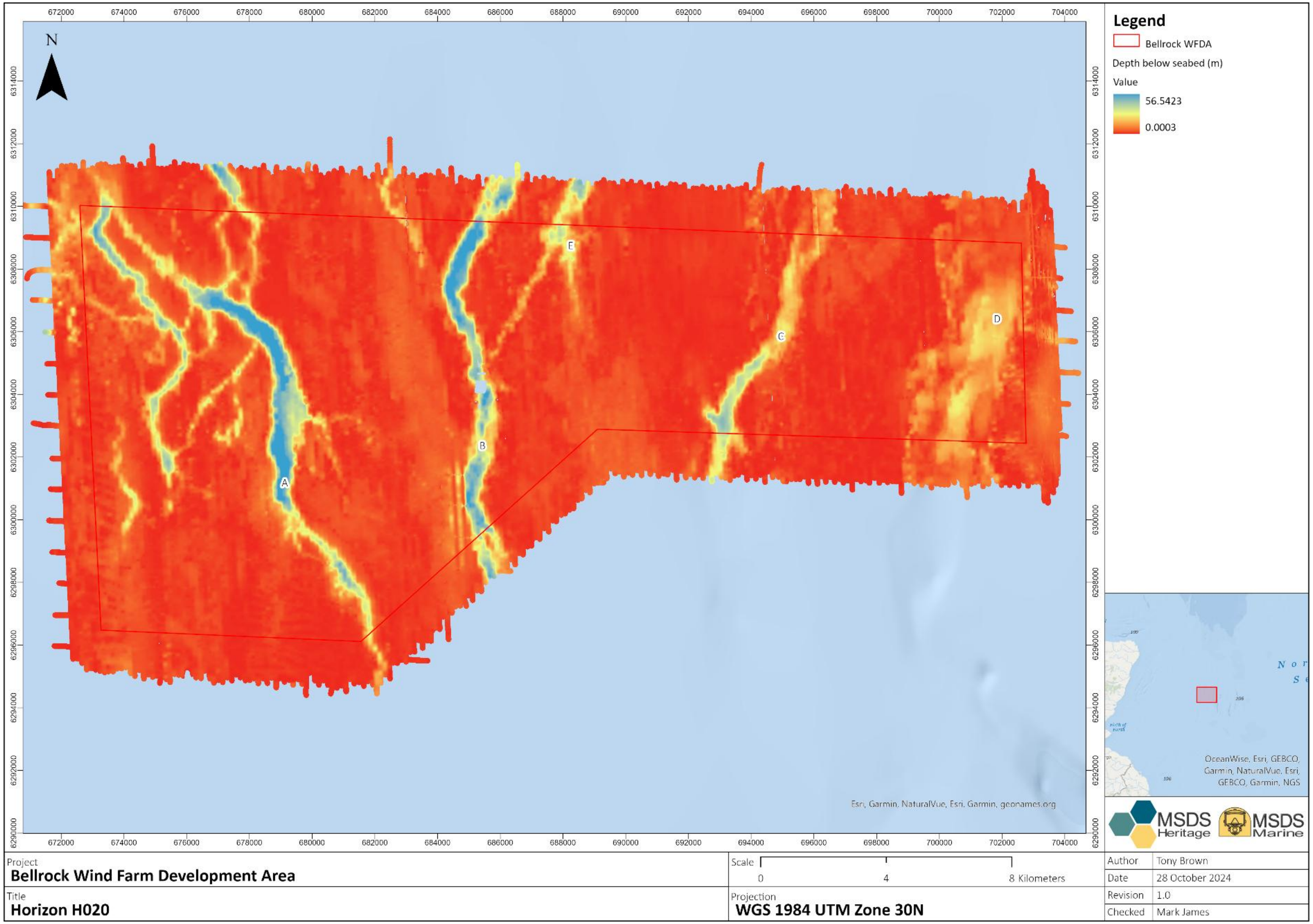

Figure 29: Horizon H020 (OWC, 2024)

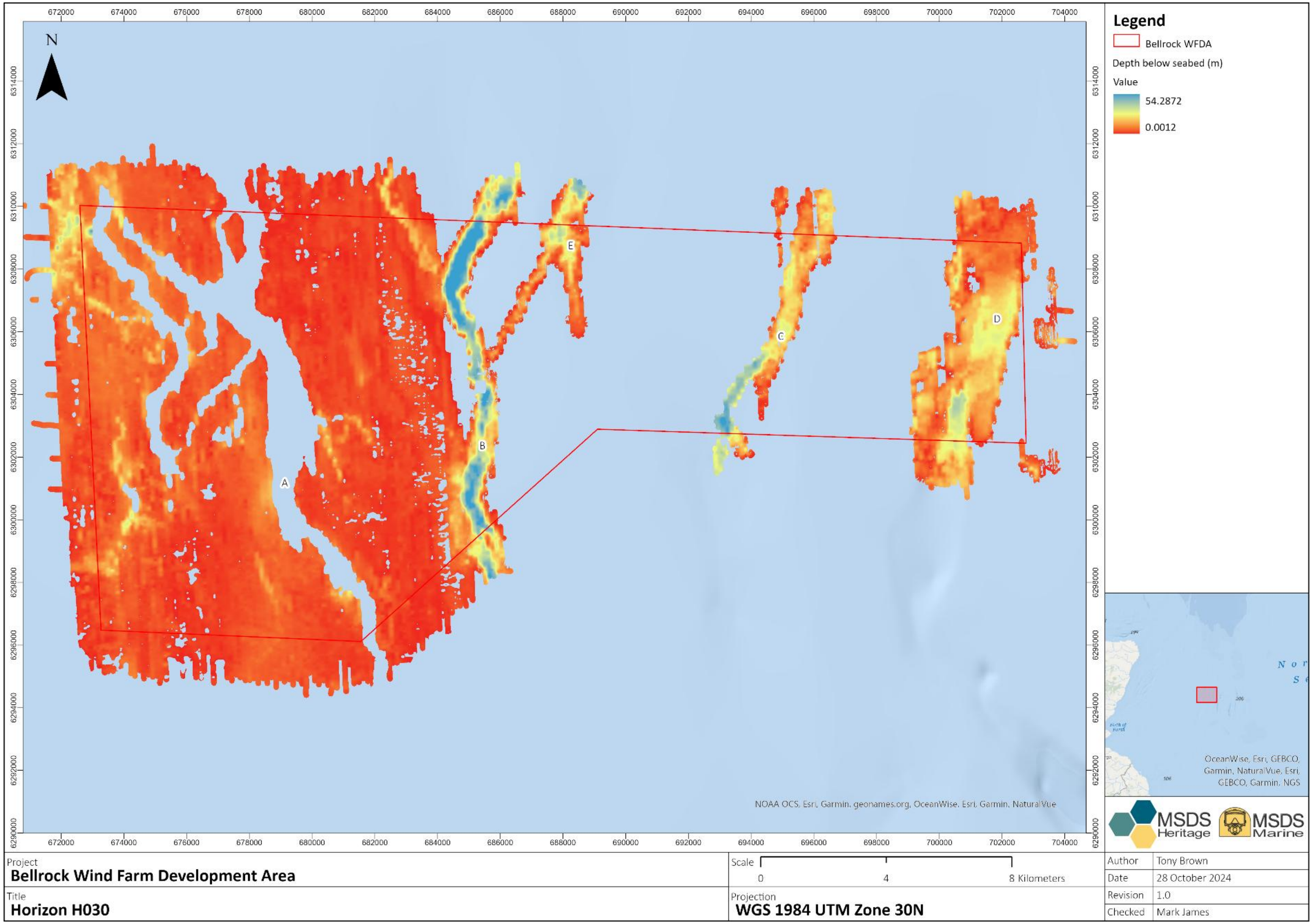

Figure 30: Horizon H030 (OWC, 2024)

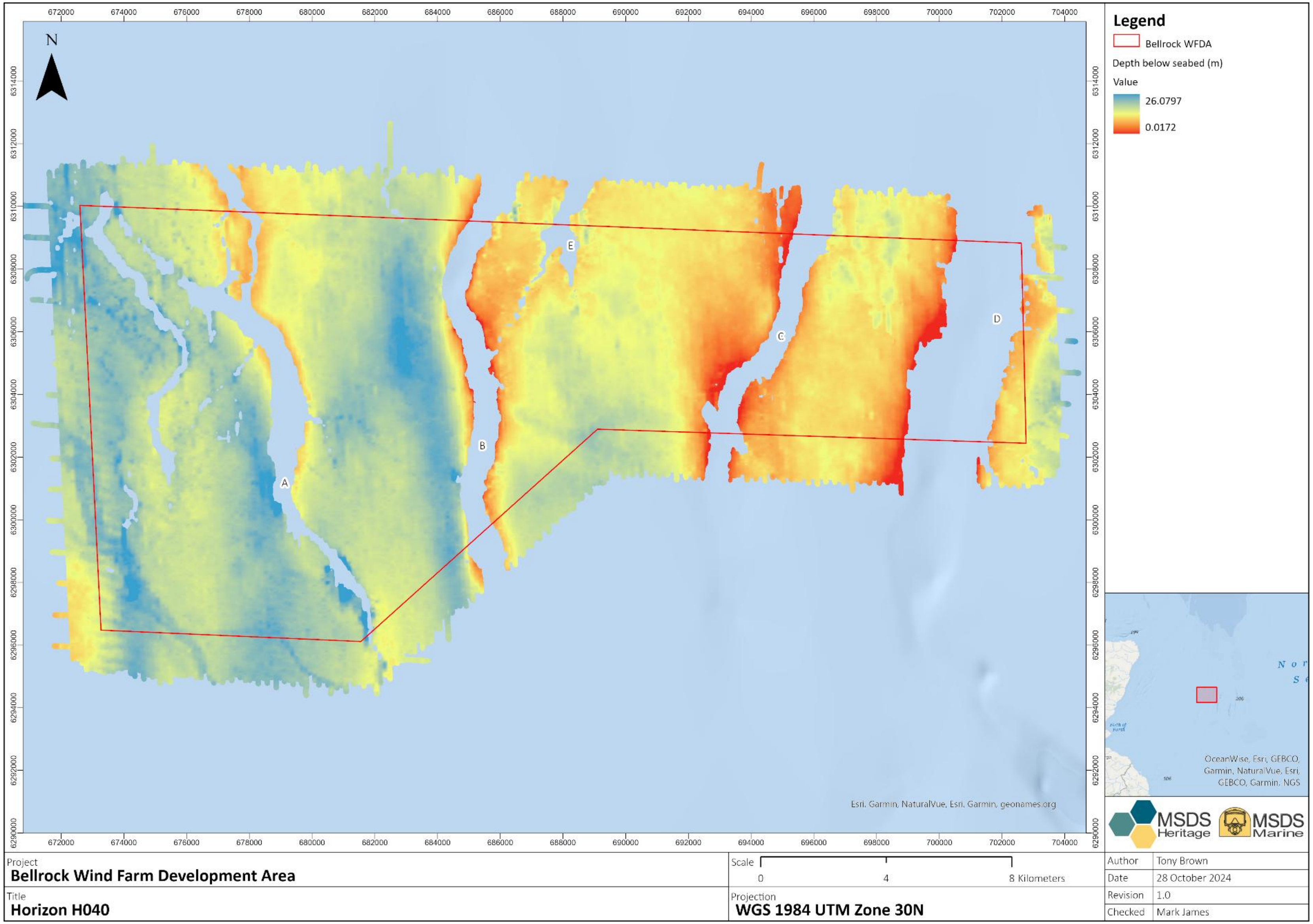

Figure 31: Horizon H040 (OWC, 2024)

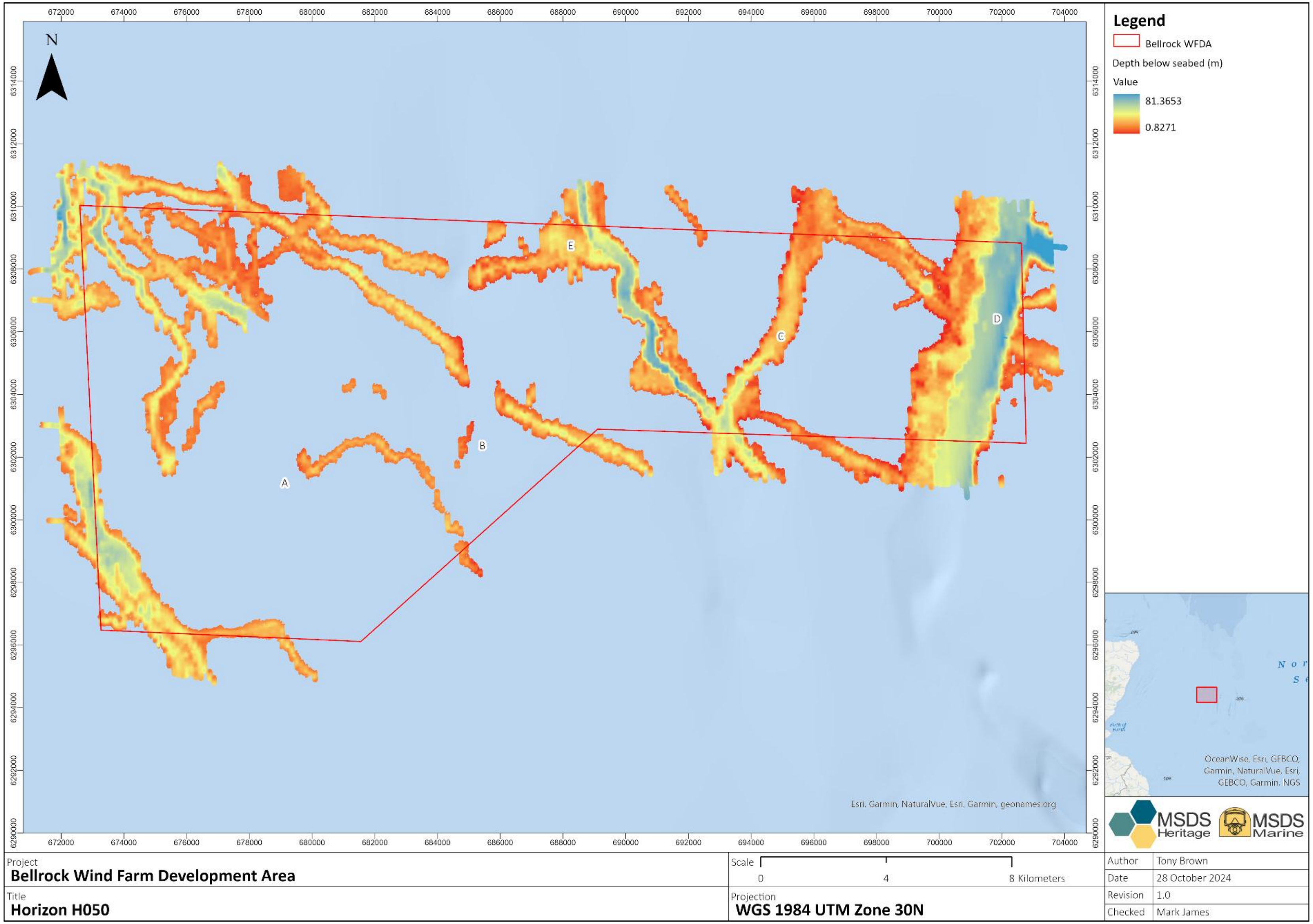

Figure 32: Horizon H050 (OWC, 2024)

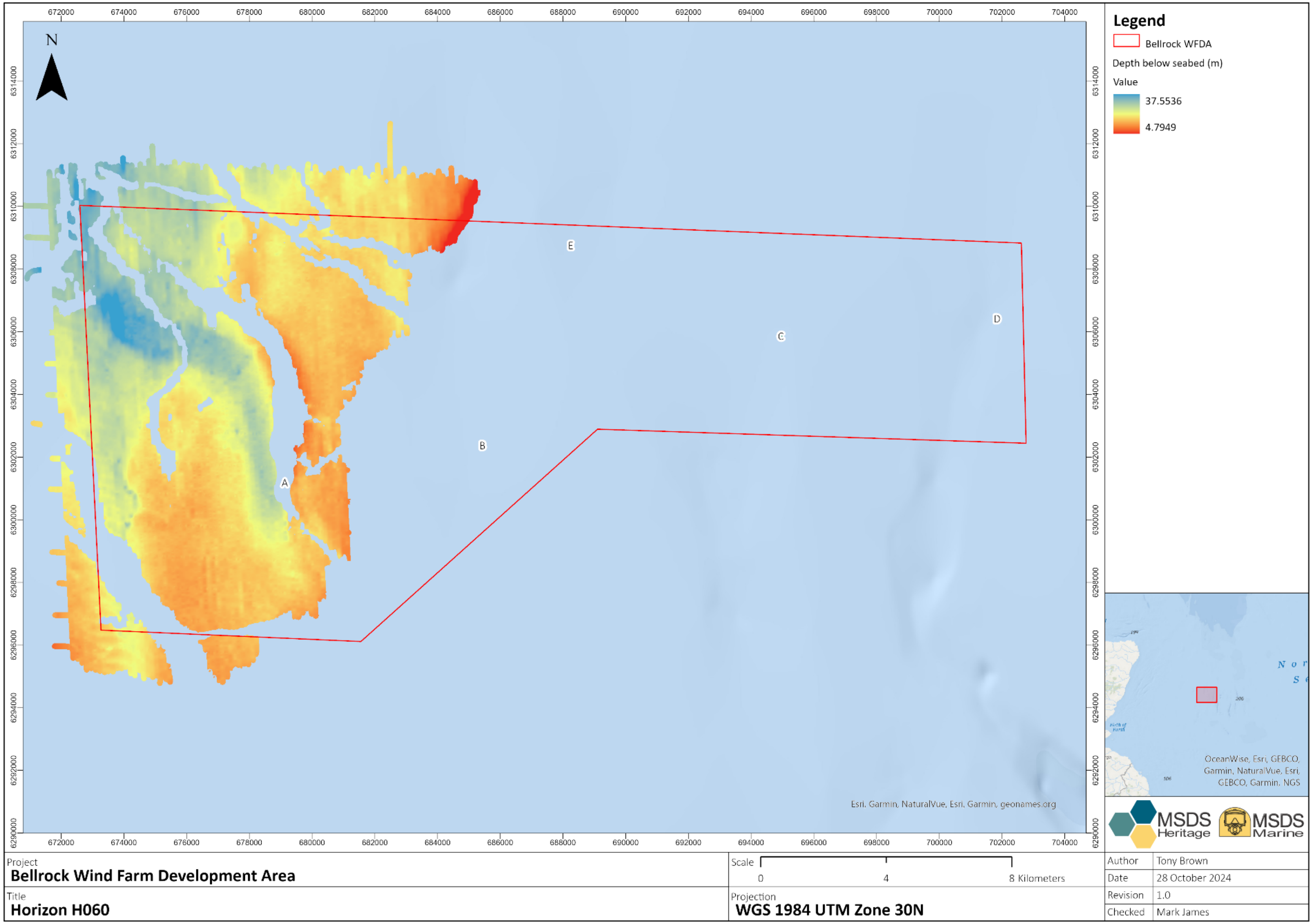

Figure 33: Horizon H060 (OWC, 2024)

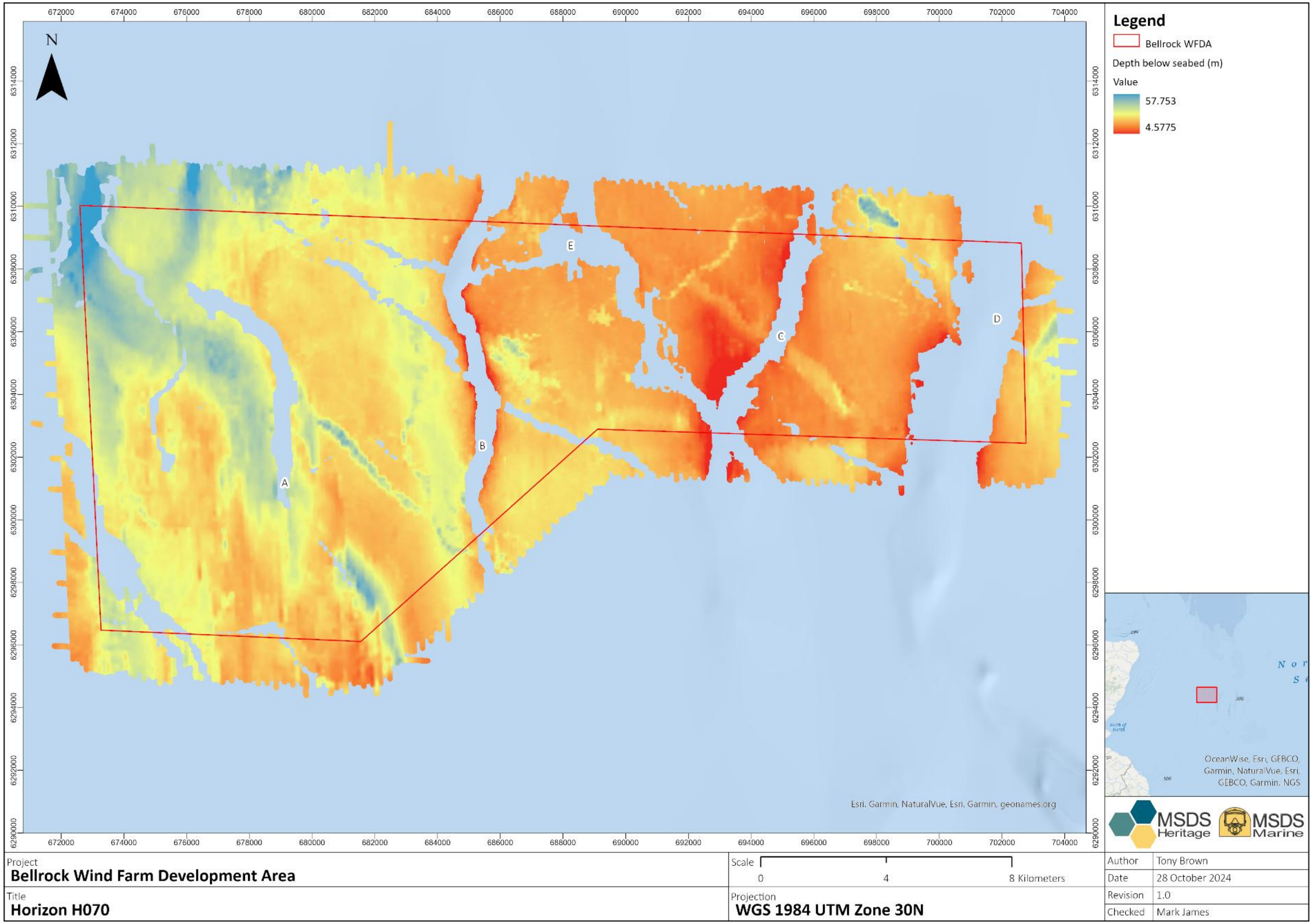

Figure 34: Horizon H070 (OWC, 2024)

10.4 Geomorphology

Glaciations

10.4.1 The known history of hominin occupation of Britain is marked by three main stages of glaciation: the Anglian (478,000 to 424,000 BP; MIS 12), the Wolstonian complex (374,000 to 123,000 BP; MIS 10 to 6) and the Devensian (109,000 to 11,700 BP; MIS 5d to 2). The latter two each include several interstadials, of which less information is available for the Wolstonian. The pre-Anglian Cromerian complex and Beestonian stage also express evidence of a series of stadials and interstadials, however, these sequences are poorly understood at present[22] [23] and the latter generally precedes known hominin occupation of Britain.

10.4.2 Glaciation models (see Annex C – Section 15.4) suggest that the WFDA was likely covered by ice during much of MIS 12, 10, 8 and 6 and ice-free during MIS 5d to 5a. The maximum glacial extent for the LGM, informed by several studies, is presented by Figure 35.

Glacial landforms

10.4.3 Glaciation introduces a range of processes which result in changes to the bedrock, sedimentary deposits and geometry of the landscape. Some of the resultant landforms are determined by the movement and weight of the ice overburden, whereas others are caused by hydrodynamic processes.

10.4.4 The EMODnet geological database[24] maps a series of glacial moraines and tunnel valleys both within the WFDA and nearby, expressing the impact of glacial ice on the subsea landscape (Figure 36). The moraines likely date to the LGM, as Anglian or Wolstonian moraine formations would likely have been reworked during subsequent glaciations. Part of a north-south aligned moraine is illustrated along the southwest boundary of the WFDA and a potential for such features is identified by the ground model report[25].

10.4.5 The BRITICE project[26] mapped glacial landforms across England, Scotland and Wales dating to the LGM. Although largely focussed on terrestrial landforms, mapping of offshore glacial tunnel valleys was also undertaken. A series of these is shown traversing the WFDA and surrounding subsea landscape, largely correlating with those mapped by EMODnet. This data also correlates well with the identified channels B, C and D and, to a lesser extent, Channel A.

10.4.6 The age of the tunnel valleys can be inferred from the associated geological formation. Older channels (Type 2) relate to Horizon H050 and define a sub-unit of the Coal Pit Formation. Although this Formation may have basal elements dating to MIS 6, Unit D1 represents the youngest identified sub-unit of the Formation within the WFDA, likely dating to the Early Devensian (MIS 5d to 3). Younger channels (Type 1) exhibit reuse of these Pleistocene tunnel valleys and incision of their infills. Type 1 channels relate to horizons H020 and H030, defining the basal horizon of Late Devensian and Early Holocene Forth Formation deposits (Figure 29 and Figure 30).

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[22] Lamb, R.M., Harding, R., Huuse, M., Stewart, M. and Brocklehurst, S.H. 2017. 'The early Quaternary North Sea Basin.' *Journal of the Geological Society*. **175**, pp. 275-290.

[23] Lauer, T. and Weiss, M. 2018. 'Timing of the Saalian- and Elsterian glacial cycles and the implications of Middle-Pleistocene hominin presence in central Europe.' *Scientific Reports.* **8**, pp. 1-12.

[24] EMODnet. https://www.emodnet-geology.eu/map-viewer/?p=submerged_landscapes Accessed 27/08/2024.

[25] OWC. 2024, pp. 78.

[26] Clark, C.D., Evans, D.J.A., Khatwa, A., Bradwell, T., Jordan, C.J., Marsh, S.H., Mitchell, W.A. and Bateman, M.D. 2004. 'Map and GIS database of glacial landforms and features related to the last British Ice Sheet'. *Boreas.* **33**, pp. 359-375.

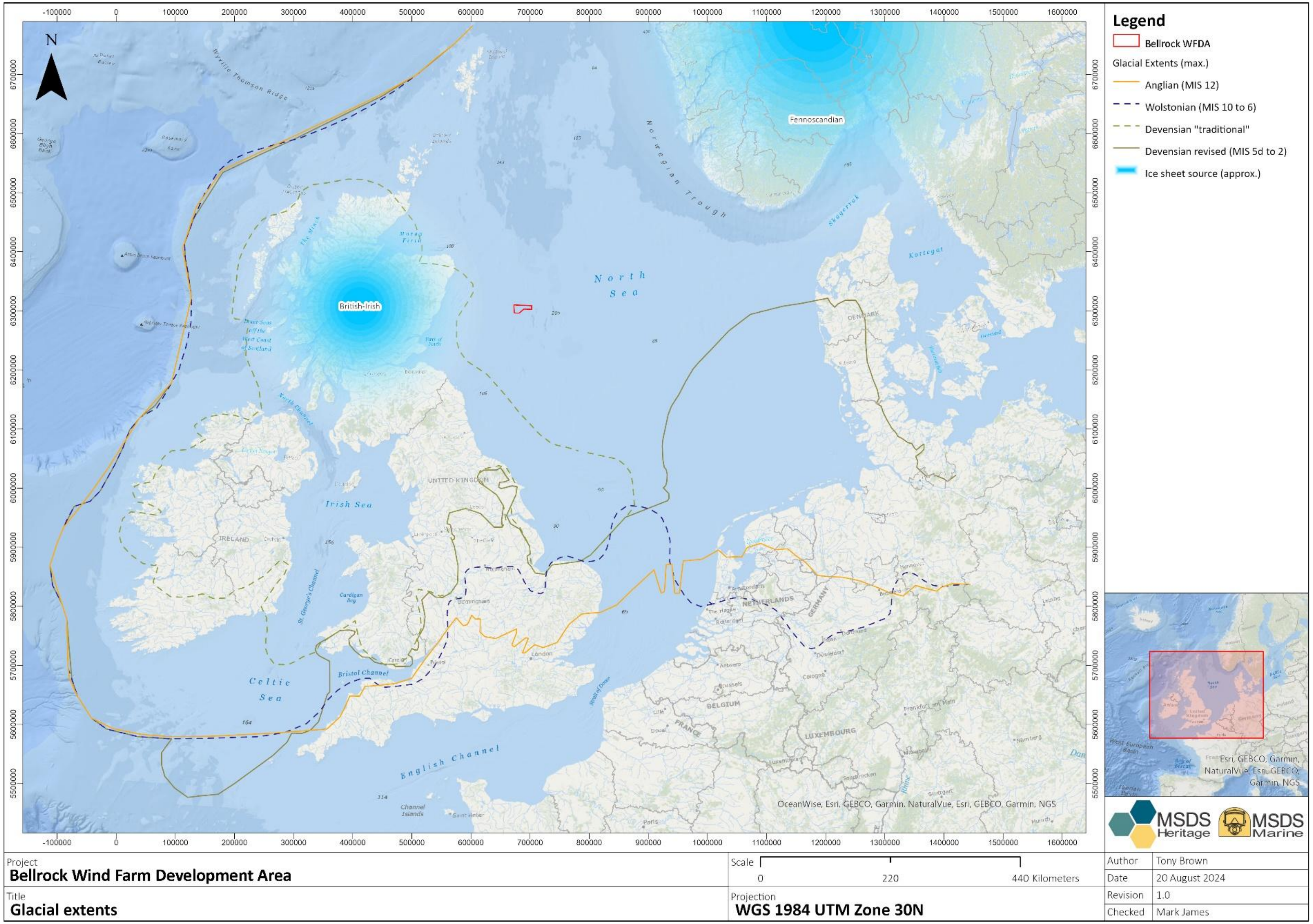

Figure 35: Glacial extents

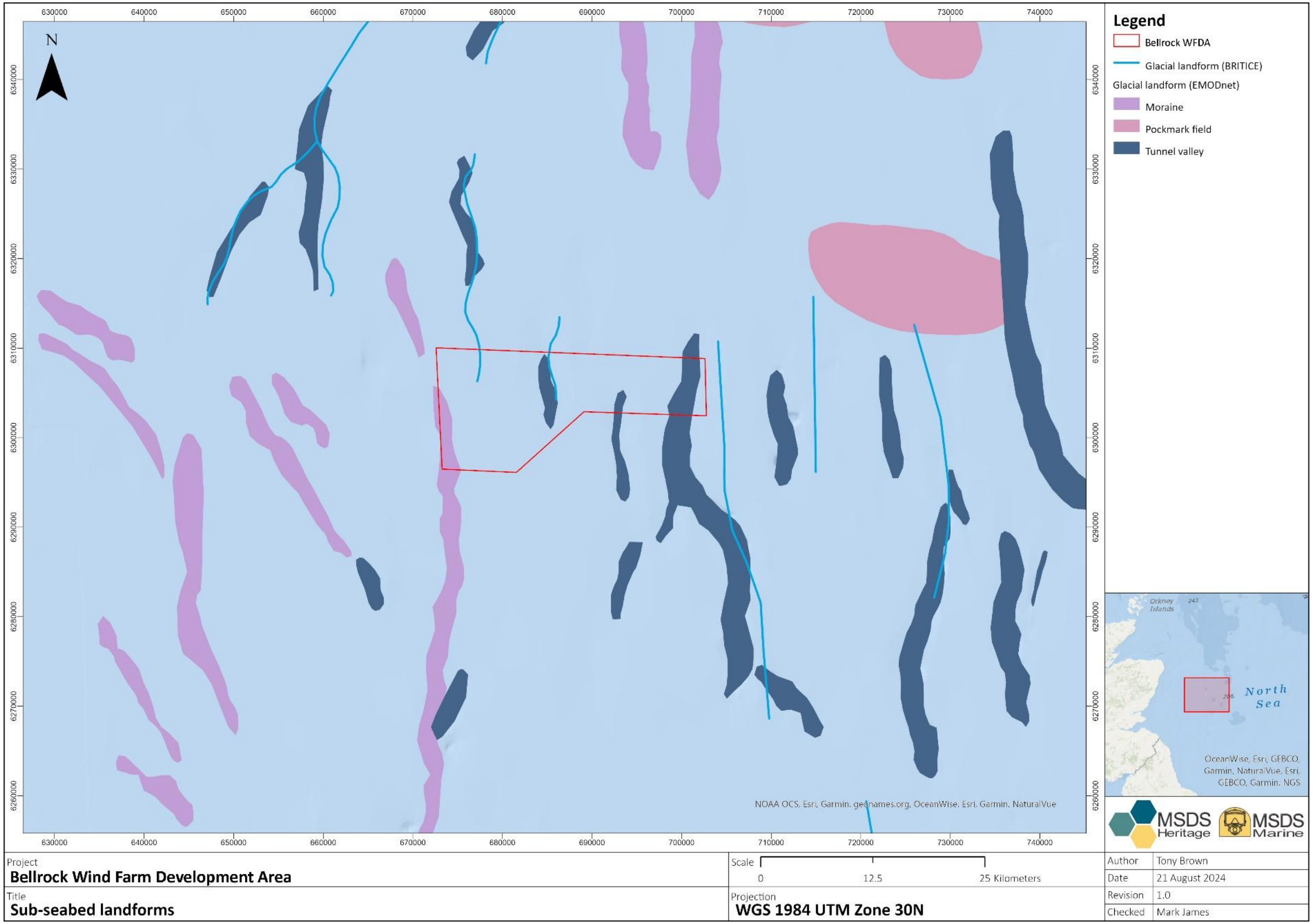

Figure 36: Sub-seabed landforms

Sea level data

10.4.7 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.

10.4.8 Data presented by Shennan *et al*.[27] indicates that the local RSL was between -9.66 and -9.81 m OD (Sample IDs: SRR4707 & SRR5099, respectively) around 10,000 BP and between 1.75 and -0.55 m OD around 8,000 BP (Sample IDs: SRR869 & SRR4717, respectively). However, Stoker *et al.*[28] indicate a highstand of *c*. +5 m OD from *c*. 8,000 to 2,000 BP. All sources indicate that the WFDA was fully submerged prior to 18,000 BP and remained marine thereafter.

10.4.9 The exact date of final marine inundation of the WFDA is debated and different models exist. The most widely recognised models, created by Brooks *et al*.[29] and Shennan *et al*.[30], largely concur that the WFDA had been inundated prior to 18,000 BP. An area of higher ground is suggested to the immediate south of the WFDA from *c*. 16,000 BP, disappearing shortly after 13,000 BP (Figure 37).

10.4.10 The data subset used to inform this assessment is presented within Annex B (Section 14.0) and further detail regarding the analysis and interpretation is presented within Annex C (Section 15.6).

[27] Shennan, I., Bradley, S.L. & 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..

[28] Stoker, M.S., Golledge, N.R., Phillips, E.R., Wilkinson, I.P. and Akehurst, M.C. 2008. 'Lateglacial-Holocene shoreface progradation offshore eastern Scotland: a response to climatic and coastal hydrographic change'. *Boreas*. **38**, pp. 292-314.

[29] Brooks, A.J., Bradely, S.L., Edwards, R.J. and Goodwyn, N. 2011. 'The palaeogeography of Northwest Europe during the last 20,000 years.' *Journal of Maps*. **7**(1), pp. 573-587.

[30] Shennan *et al*. 2018.

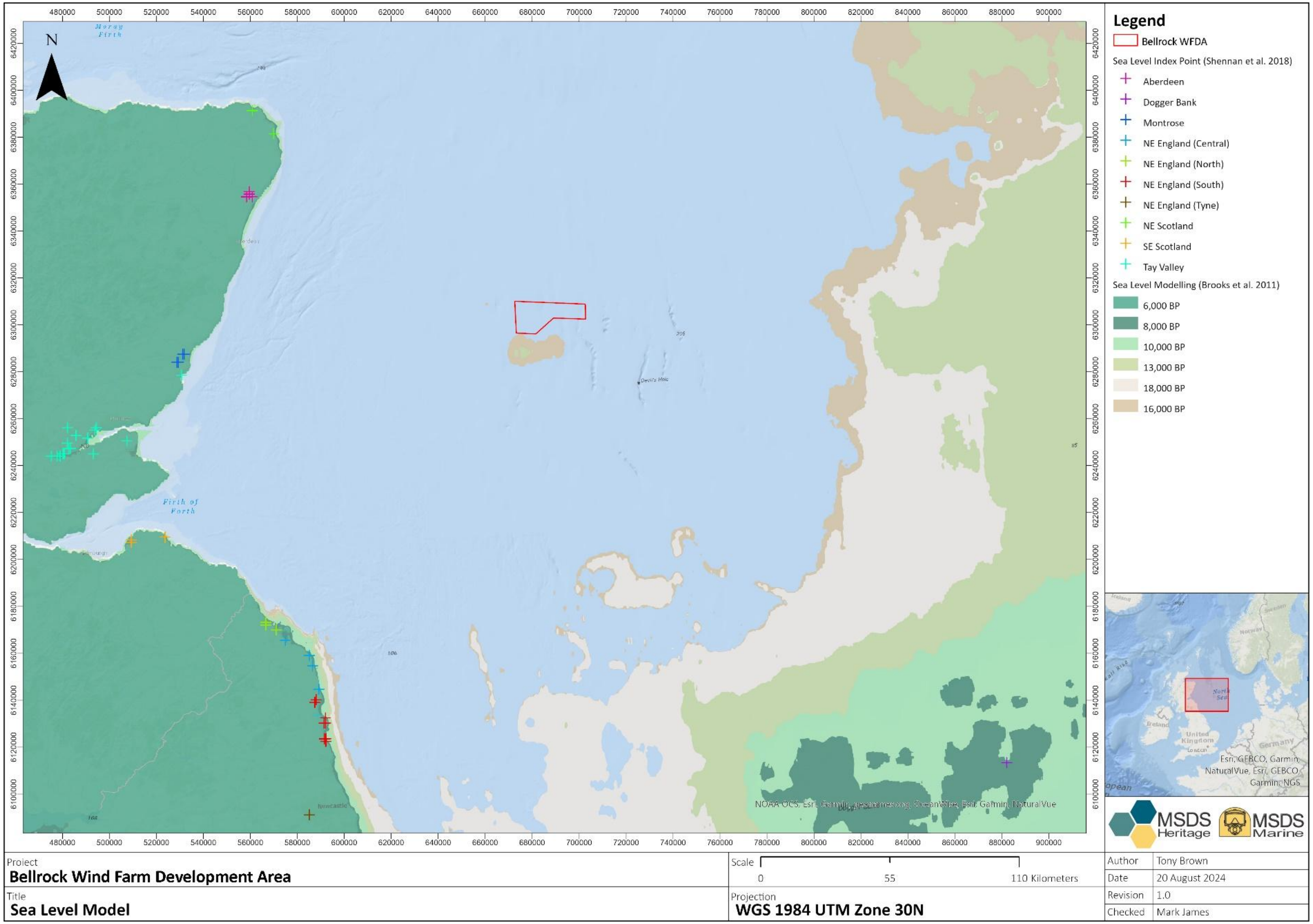

Figure 37: Sea Level Model

10.5 Palaeolandscape Assessment and Prehistoric Archaeological Potential

10.5.1 This Section considers the potential for submerged prehistoric remains, including archaeological sites, palaeolandscape elements and palaeoenvironmental evidence, to be present within the WFDA.

10.5.2 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)[31]. The coastline of the UK changed drastically during prehistory and large tracts of what is now the seabed were once sub-aerially exposed.

10.5.3 Prehistoric archaeological potential is gauged with reference to evidence for human activity in Britain during each period and the contemporary environment within the WFDA, 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[32].

Lower and Middle Palaeolithic

10.5.4 The Lower and Middle Palaeolithic span most of the known human history of the British Isles (*c*. 970,000 to 57,000 BP; MIS 25 to 4). Pre-dating the earliest recorded modern human remains, these periods witnessed the occupation of the British Isles and associated palaeolandscape by human ancestors, such as *h. heidelbergensis* and *h. neanderthalensis*. No well-provenanced finds of Lower or Middle Palaeolithic date are recorded in Scotland and a general absence of recorded hominin remains in Britain is noted between 180,000 to 60,000 BP[33].

10.5.5 The oldest identified geological unit within the WFDA is provisionally attributed to the Aberdeen Ground Formation (Unit E). This Formation was laid down through a range of Pleistocene environmental conditions (MIS 100 to 13). The earliest hominin evidence in Britain was derived from the Cromer Forest Beds Formation, the onshore equivalent of the Yarmouth Roads Formation, which is coeval, in part with the Aberdeen Ground Formation. The Cromerian Complex (MIS 21 to 13) is relatively poorly understood in terms of climatic cycles and it is therefore unclear if periods of sub-aerial exposure of the Aberdeen Ground Formation coincided with both suitable conditions and hominin presence in Britain.

10.5.6 Unit E is provisionally interpreted as representing subglacial and glaciomarine facies of the Aberdeen Ground Formation, suggesting depositional conditions unsuitable for hominin occupation. A slight potential for palaeoenvironmental remains may exist.

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

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

[33] https://scarf.scot/national/palaeolithic-mesolithic-panel-report/1-introduction-to-the-palaeolithic-and-mesolithic-periods/ Accessed 29/08/2024.

10.5.7 The Coal Pit Formation is represented within the WFDA by **units D1**, **D2** and **D3**. Elements of this Formation, beyond the WFDA, have been attributed a Late Wolstonian (MIS 6) date and deposition is understood to have continued throughout the Early and Mid-Devensian (MIS5d to 3). The literature and geophysical data suggest that the Coal Pit Formation is almost exclusively comprised of glaciomarine sediments, though the upper facies (**Unit D2**) may have been laid down in intertidal conditions. The BGS borehole (BH81/27) suggesting this interpretation lies *c*. 37 km to the southwest of the WFDA, therefore **Unit D2** may have been laid down in marine or glaciomarine conditions. The WFDA lay beneath glacial ice during much of the Wolstonian and Devensian glaciations (Figure 35) and was therefore unlikely to have been inhabited by hominins or Pleistocene fauna.

10.5.8 Black staining was observed in samples attributed to **Unit D1**, highlighting a potential for organic remains of palaeoenvironmental interest. BGS borehole BH81/37, *c*. 73.5 km to the east of the WFDA, noted wood fragments within lower elements of the Coal Pit Formation, raising a slight potential for palaeoenvironmental remains within **Unit D3**.

10.5.9 As a unit laid down over a long period, the Coal Pit Formation may feasibly contain evidence relating to the glacial cycles of MIS 6 to 3, such as foraminifera and dinoflagellates. Analysis of Coal Pit Formation samples from borehole SLN33, *c*. 134 km north from the WFDA, used proportions of *Elphidium? ustulatum* to identify a sub-unit dating to the Ipswichian interglacial (MIS 5e)[34].

Upper Palaeolithic

10.5.10 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. There is evidence of hominin activity in Britain in the Mid to Late Devensian, following a period yet to be associated with occupation (180,000 to 60,000 BP). Flint artefacts and skeletal remains indicating the presence of Neanderthals or *h. sapiens* (modern humans) have been identified in Kent's Cavern (Devon)[35], Dartford (Kent)[36], Gower (Wales)[37] and Creswell (Derbyshire)[38].

10.5.11 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[39].

10.5.12 **Unit C** was laid down in shallow glaciomarine inner shelf and/or estuarine environments of the Late Devensian. The WFDA likely lay beneath glacial ice for much of the Dimlington stadial, therefore preventing hominin occupation. Furthermore, the Dimlington stadial is associated with another period currently lacking evidence of human occupation in Britain (25,000 to

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[34] Gregory, D. and Bridge, V.A. 1979. 'On the Quaternary Foraminiferal Species *Elphidium ? Ustulatum* Todd 1957: Its Stratigraphic and Palaeoecological Implications'. *Journal of Foraminiferal Research*. **9**, pp. 70-75.
[35] Higham, T., Compton, T., Stringer, *c.*, Jacobi, R., Shapiro, B., Trinkaus, E., Chandler, B., Groning, F., Collins, *c.*, Hillson, S., O'Higgins, P., Fitzgerald, *c.* and Fagan, M. 2011. 'The Earliest Evidence for Anatomically Modern Humans in Northwestern Europe'. *Nature*. **479**, pp. 521-524.
[36] Wenban-Smith, F., Bates, M. and Schwenninger, J. 2010. 'Early Devensian (MIS 5d–5b) occupation at Dartford, southeast England'. *Journal of Quaternary Science*. **25**(8), pp. 1193-1199.
[37] Dinnis, R. 2012. 'Identification of Longhole (Gower) as an Aurignacian site'. *Lithics: The Journal of the Lithic Studies Society*. **33**, pp. 17–29.
[38] Pike, A.W.G., Gilmour, M., Pettitt, P., Jacobi, R., Ripoll, S., Bahn, P. and Munoz, F. 2005. 'Verification of the age of the Palaeolithic cave art at Creswell Crags, UK'. *Journal of Archaeological Science*. **32**(11), pp. 1649–1655.
[39] 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.

18,000 BP). **Unit C** may have continued to be laid down, however, sea level modelling demonstrates that the WFDA was fully inundated by *c*. 18,000 BP, remaining so thereafter. This Unit therefore holds a very low archaeological potential. **Unit C** may contain foraminifera which can improve our understanding of developing marine conditions during the Late Devensian and refine sea level models prior to 18,000 BP, however, it may be considered unlikely that samples might be able to provide precise dating evidence.

10.5.13 **Unit B** was laid down over MIS 2 to 1, spanning part of the Upper Palaeolithic. The Fitzroy Member of the Forth Formation, represented within the WFDA by **Unit B**, is interpreted as a low energy marine deposit, suggesting a possible lagoonal, protected bay or marginal marine environment. In consideration of the span of known human occupation during this period and marine inundation of the WFDA, **Unit B** holds a very low archaeological potential.

10.5.14 Low energy marine deposits have a greater potential for containing organic material and other evidence of palaeoenvironmental interest. Therefore, **Unit B** holds a slight, albeit low, potential to contain such.

Mesolithic

10.5.15 The Mesolithic period (11,700 to 6,000 BP; MIS 1) correlates with the start of the Holocene and the culmination of the last glacial period. As climatic conditions ameliorated during the onset of the Holocene, carr woodland would have developed in stable terrestrial areas which could support a much greater variety and density of fauna. Meltwater from the recently retreated Devensian glaciers shaped the landscape with river valleys and lakes, which, in turn, supported new and extensive flora and fauna. These fluvial and adjacent environments provided ideal conditions for human exploitation. Available resources would have increased as the local flora and fauna became more diverse, and the range of environmental conditions would have presented more varied opportunities for exploitation.

10.5.16 The WFDA is understood to have transitioned to a fully marine environment prior to the onset of the Holocene, therefore precluding evidence of human occupation. Units identified within the WFDA and provisionally attributed an MIS 1 deposition date (**A1** and **A2**) do not have potential for evidence of human occupation, however, they may feasibly contain remains eroded from onshore deposits. Palaeoenvironmental remains are typically supported in their utility by primary context data, therefore, redeposited evidence would unlikely hold significant interest.

10.6 Summary of Submerged Prehistoric Potential

10.6.1 This Section has examined the initial interpretations of the geophysical survey and ground model review of these, alongside wider evidence, describing eight geological units within the WFDA. The geological assessment has informed the assessment of archaeological and palaeoenvironmental potential.

10.6.2 Most identified units have been provisionally interpreted as marine or glaciomarine in origin, thus precluding the potential for *in situ* archaeological remains relating to prehistory prior to or during the Flandrian marine transgression.

10.6.3 Units D1 and D3 have been attributed a moderate and low to moderate potential, respectively, for palaeoenvironmental remains, with the potential to further our understanding of LGM environments and the timing of the post-LGM marine inundation of central North Sea palaeolandscapes.

10.6.4 A summary of provisionally identified units and their attributed archaeological and palaeoenvironmental potential is presented by Table 17.

Unit	MIS	Potential	
		Prehistoric archaeology	Palaeoenvironmental
A1	1	Very low	Negligible
A2	1	Very low	Negligible
B	2 to 1	Very low	Low
C	2	Very low	Very low
D1	5d to 3	Very low	Moderate
D2	6 to 3	Very low	Low
D3	6 to 3	Very low	Low to moderate
E	100 to 13	Very low	Low

Table 17: Summary of archaeological potential

11.0 Mitigation

11.0.1 This section provides recommendations for the robust, but proportional, mitigation of impacts to the historic environment for low, medium, and high potential anomalies, and magnetic anomalies, identified within the geophysical dataset. As outlined in Section 5.8 recommended mitigation for these anomalies will be through the implementation of AEZs, TAEZs and AAPs. Mitigation relevant to the palaeolandscape is discussed in Section 11.7.

11.0.2 The mitigation strategies recommended within this report are based on the available data, which includes full coverage (100%) MBES and (200%) SSS. Magnetometer data were collected at the same line spacing as the SSS and MBES which means there is potential for items of buried material of archaeological interest to be present within the assessment area that is not visible within the current dataset, or for magnetic anomalies to not be represented in their true position.

11.0.3 However, the data serve to characterise the potential of the area with respect to the requirement for exclusion zones. Mitigation will be developed through each phase of survey works as detailed within Section 12.0.

11.1 Low Potential Anomalies

11.1.1 Low potential anomalies, and small magnetic anomalies, have been identified as potentially anthropogenic in origin but unlikely to be of archaeological significance and no exclusion zones are recommended for these anomalies. Should material of potential archaeological significance be identified during the course of pre-construction and construction works they should be reported under an appropriate protocol for archaeological discoveries such as the *Crown Estates Protocol for Archaeological Discoveries: Offshore Renewables Projects*[40] or a project specific protocol that considers the individual requirements of the Transmission Assets.

11.2 Archaeological Exclusion Zones (AEZ)

11.2.1 Four high potential surface anomalies, and ten medium potential anomalies, have been identified within the geophysical survey data extents, of which three high potential and eight medium potential anomalies lie within the WFDA. The anomalies have been identified as likely to be of anthropogenic origin and potentially of archaeological significance. The anomalies have been recommended AEZs based on the size of the anomaly, the extents of any debris, the potential significance of the anomaly, the potential impact of the development and the seabed dynamics within the area.

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

11.2.3 Dependant on the form of anomalies, AEZs will either be recommended as a radius from the centre point of the anomaly or as a distance from the extents. Particularly in the case of shipwrecks, which tend to be longer in length than width, the use of a circle provides unequal protection around the extents. This not only impacts the protection afforded but does not represent proportional mitigation.

11.2.4 In total nine AEZs relating to high and medium potential anomalies have been recommended within the geophysical survey data extents, all of which are within the WFDA. Medium potential anomalies BR24_068 and BR24_143 are encompassed in the AEZs for high potential BR24_067 and BR24_142, respectively, and as such have not been recommended individual AEZs.

11.2.5 Anomalies and their recommended exclusion zones are detailed in Table 18 and the distribution presented in Figure 38. Note, where discrepancies exist between the position within different datasets, the position deemed to be most accurate has been used, typically that derived from the MBES data.

Anomaly ID	Description	Potential	WGS84 Z30N		AEZ (m)
			X	Y	
BR24_067	Wreck	High	675109.7	6300567.3	50 (extents)
BR24_070	Wreck	High	675182.3	6304895.3	50 (extents)
BR24_142	Wreck	High	687344.0	6301679.0	100 (extents)
BR24_069	Potential debris	Medium	675054.6	6301818.6	25 (extents)
BR24_071	Wreck debris	Medium	675330.2	6304868.2	25 (radius)
BR24_073	Potential debris	Medium	675268.6	6304437.7	25 (extents)
BR24_094	Seabed disturbance	Medium	678064.1	6303011.4	25 (extents)
BR24_103	Seabed disturbance	Medium	678948.9	6308574.5	25 (extents)
BR24_117	Mound	Medium	681989.3	6299052.9	25 (extents)
BR24_069	Potential debris	Medium	675054.6	6301818.6	25 (extents)

Table 18: Archaeological Exclusion Zones within the geophysical survey data extents

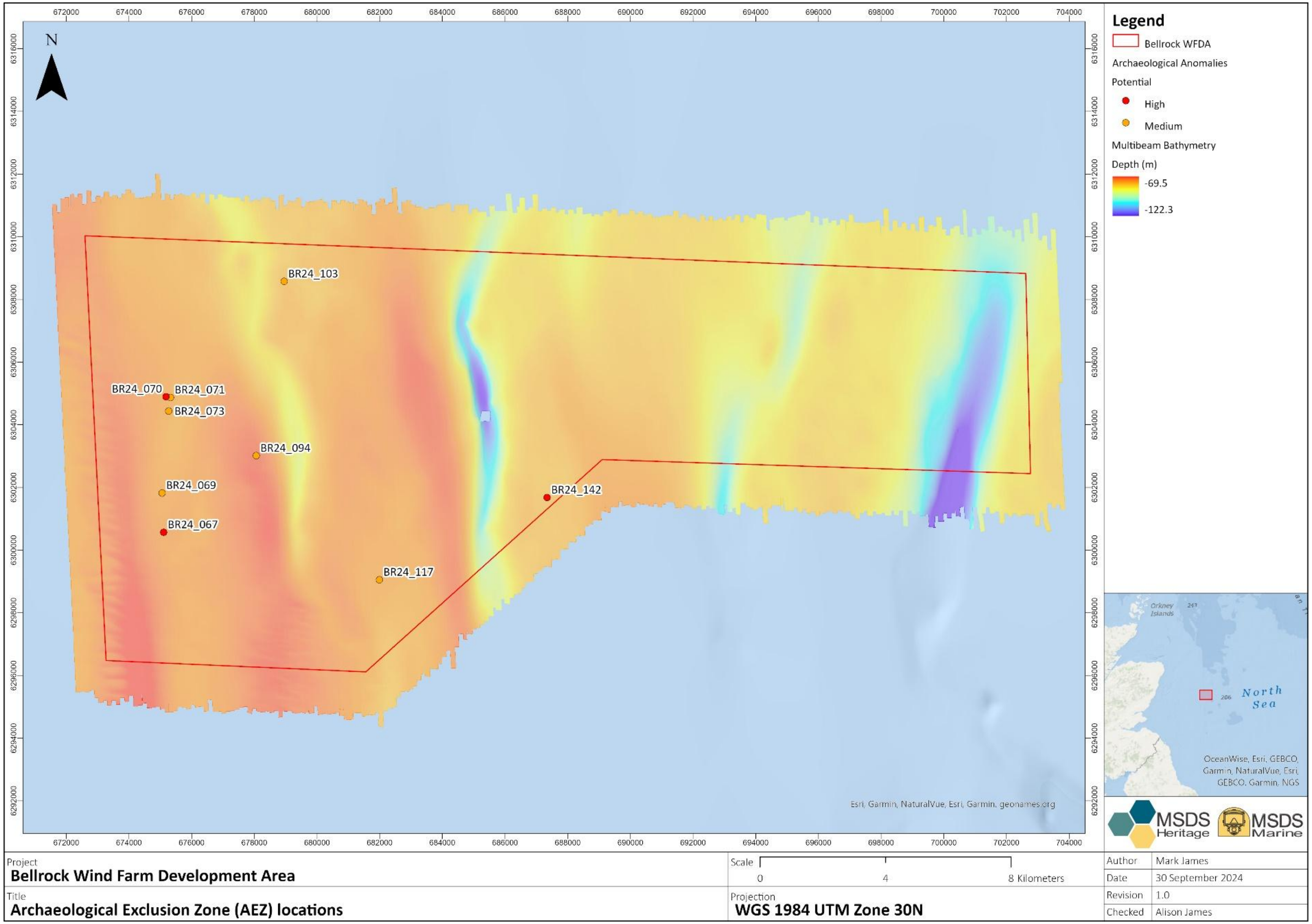

Figure 38: Location of Archaeological Exclusion Zones

11.3 Temporary Archaeological Exclusion Zones (TAEZ)

11.3.1 TAEZs are recommended where an anomaly is not visible in the dataset but is known to exist, where the position cannot be determined with enough accuracy for refined exclusion zones, or where the extents are not fully known. They are often larger than AEZs but are identified as temporary as they are highly likely to be altered following higher resolution or full coverage data assessment, they will remain in place until alterations have been formally agreed.

11.3.2 No TAEZs are recommended for records originating from the UKHO or Canmore. All record locations have been viewed within the geophysical data, where a feature was visible on the seabed this was assessed for archaeological potential with mitigation recommended as appropriate. Where no feature was visible on the seabed the records were assessed, and in all instances, it was determined unlikely that remains were present, but not visible, on the seabed.

11.3.3 No TAEZs are recommended for magnetic anomalies that do not have a strong correlation with a seabed feature due to the 140 m line spacing. However, it should be noted that this is not due to the likely absence of magnetic anomalies that may be of potential archaeological interest, but the vagaries in even approximate positioning, and size of the anomalies due to the wide line spacing. Mitigation should take the form of a commitment to the recommendations for further work in section 12.1, in particular those relating to the collection, and assessment, of magnetometer data.

11.4 Areas of Archaeological Potential (AAP)

11.4.1 No formal mitigation in the form of exclusion zones is recommended for AAPs, however they serve to highlight the potential for material of archaeological interest to identified following the collection of higher resolution, or denser, geophysical survey data. These could originate, for example, from the identification of a high concentration of magnetic anomalies where the positions cannot be determined and with no correlating seabed feature.

11.4.2 No AAPs are recommended within the geophysical survey data extents. However, due to the wide spacing of the magnetometer data, there should be a general awareness that following the collection of denser data it is highly likely that additional anomalies of potential archaeological interest will be identified.

11.5 Notes on Exclusion Zones

11.5.1 Exclusion zones have been recommended based on the available evidence as interpreted by an experienced and qualified maritime archaeologist, they are to be agreed between the developer, the archaeological curator, and the regulator. Exclusion zones are implemented to protect, in-situ, potentially archaeologically significant material.

11.5.2 Where an exclusion zone has been implemented, no development work impacting the seabed is to take place within the prescribed area. Should an exclusion zone impact the development program it is recommended that a program of ground truthing be undertaken to establish the identity of an anomaly in order that the potential archaeological significance can be assessed by a qualified and experienced archaeologist. Following identification and assessment, the exclusion zone can be re-assessed to ensure mitigation is appropriate to the archaeological significance of the anomaly.

11.6 Protocol for Archaeological Discoveries

11.6.1 An appropriate protocol for archaeological discoveries such as the *Crown Estates Protocol for Archaeological Discoveries: Offshore Renewables Projects*[41] should also be applied across the scheme. Such protocols provide a means of identifying previously unidentified archaeological remains and are an important part of the mitigation process.

11.7 Prehistoric Archaeology and Palaeoenvironmental Remains

11.7.1 This assessment has attributed a very low archaeological potential for all identified units (Table 17).

11.7.2 Most identified units have been attributed a low, very low or negligible potential for palaeoenvironmental remains. A slightly higher (low to moderate) potential has been attributed to Unit D3 and a moderate potential for Unit D1, accounting for organic inclusions within the correlated Coal Pit Formation elsewhere in the central North Sea and black staining within cores from the WFDA, respectively (Table 17). These units have the potential to contain evidence relating to Late Pleistocene environments and further investigation is therefore recommended. Unit D1 appears thickest within channels D and E and Unit D3 appears thickest within the channel A system. Further investigation, potentially including geoarchaeological assessment, should target these areas, as a minimum.

11.7.3 The key mitigation in relation to the palaeolandscape and palaeoenvironmental remains follows a staged approach of geoarchaeological assessment aligned with the engineering requirement to undertake geotechnical works. Typically, this process involves close collaboration with the Site Investigation team. Archaeological input into geotechnical core locations can allow for the greatest insights into the palaeolandscape, such as through the sampling of stratified channel deposits, deposits likely to contain organic remains or un-eroded surfaces. Round-table discussions and the review of seismic profiles tends to be a conducive method of allowing engineering and archaeological requirements to be taken into consideration when micro-siting geotechnical cores.

11.7.4 Following the collection of geotechnical cores, it is recommended that they undergo a staged program of geoarchaeological assessment and analysis as the primary means of ground-truthing the potential identified in this report, and of mitigating impacts to remains. In brief the process is as follows;

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

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

11.7.5 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. This would be the case if, for example, cores were determined to hold no geoarchaeological potential at the end of Stage 2.

11.7.6 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).

11.7.7 The use of an appropriate protocol for archaeological discoveries such as the *Crown Estates Protocol for Archaeological Discoveries: Offshore Renewables Projects*[42] also provides mitigation for prehistoric and palaeoenvironmental remains.

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

12.0 Recommendations for Future Work

12.1 Archaeological Assessment of Geophysical Data

12.1.1 The archaeological interpretation of the geophysical data collected at the pre-application stage, to which this assessment pertains, fits within a wider framework of planned geophysical survey for the Bellrock WFDA. The survey specification was designed for the purposes of consenting and project planning to determine the most appropriate area for development. Future surveys will likely combine an increase in resolution, and the addition of magnetometer data with tighter line spacing (as determined by the pUXO risk). With the data resolution and coverage set to increase, the confidence in interpretation and appropriateness of mitigation strategies will also increase.

12.1.2 It is recommended that higher resolution data, acquired post-consent as part of the planned pre-construction and potential Unexploded Ordnance (pUXO) surveys, be subject to archaeological assessment. The assessment should be undertaken by a qualified and experienced maritime archaeologist that has a demonstrable background in both the collection and processing of geophysical data as well as the archaeological review of data.

12.1.3 The archaeological review of data at these stages is considered necessary, not only for the robust assessment of the historic environment and archaeological potential but also for development planning. As the planned surveys increase in coverage (i.e. narrower line spacing) and resolution but decrease in area, it is beneficial to be aware of any potential archaeological mitigation that may be required to ensure minimal re-planning.

Survey Specification

12.1.4 Post-consent survey specifications will vary dependent on a number of factors including, water depth, vessel, and equipment as well as the purpose of the survey. However, some general specifications for data acquisition are provided below.

- Sidescan Sonar: data should be high frequency (at least 400-600 kHz), collected with a minimum of 200% coverage and the towfish should be flown at an optimal altitude (typically c. 10% of range). The towfish should be positioned with a correctly calibrated USBL system and layback recorded as a backup. The data should be of a quality and resolution to identify seabed anomalies >0.3 m;

- Sub-bottom Profiler: data should be collected at a frequency and power appropriate to the seabed type and the required penetration, vertical resolution should be <0.3 m where possible and the data should be heave corrected. Sub-bottom data are only collected below the sensor; therefore, data should be collected on all magnetometer lines as these are generally the tightest spacing;

- Multibeam Echo Sounder: for archaeological interpretation multibeam data are used for general seabed characterisation and quality control for the positioning of anomalies identified in the sidescan data. Data should be high resolution (typically 300-450 kHz) and acquired within IHO Special Order specifications, this includes full coverage data and a requirement to detect features >1.0 m on the seabed; and

- Magnetometer: the method for magnetometer surveys will vary between multiple close survey lines or multiple magnetometers in an array and wider survey lines. Magnetometer surveys for UXO identification should aim for full coverage with a sensor spacing not exceeding 10 m. The towfish should be flown between 2.0 m and 4.0 m above seabed and positioned with a correctly calibrated USBL system and layback recorded as a backup.

12.2 Palaeolandscape

12.2.1 This assessment has examined the archaeological and palaeoenvironmental potential of identified geological units within the WFDA. Following the detailed assessment, it is concluded that no identified units hold a high potential for archaeological or palaeoenvironmental remains. Unit D1 has been identified as having a moderate potential for palaeoenvironmental evidence and Unit D3 as having a low to moderate potential. As such, these units may benefit from further investigation.

12.2.2 Recommendations are as follows:

- More detailed investigation of units D1 and D3. These units have the potential to contain palaeoenvironmental evidence relating to the Late Pleistocene and although the depositional environment was not likely conducive for human occupation, further analysis of these sediments may improve understanding of the timing of Late Devensian/Early Holocene marine transgression in the central North Sea. Archaeological input into future geotechnical programmes will enable this resource to be investigated further. The resulting report should make recommendations for further investigation of key areas of potential, if identified. Recommendations may include a staged process of geoarchaeological assessment.

12.3 Protocol for Archaeological Discoveries (PAD)

12.3.1 A suitable protocol for archaeological discoveries is a key element of the mitigation procedures, particularly for anomalies identified as low archaeological potential, including small magnetic anomalies. A suitable protocol should also be implemented during any works that may visually inspect the seabed or recover material to deck.

12.3.2 The protocol could take the form of the Crown Estates *Protocol for Archaeological Discoveries: Offshore Renewables Projects*[43] or a project specific protocol that considers the individual requirements of the Project. The protocol should be agreed with the curator and the regulator prior to any impact on the seabed.

12.4 Ground Truthing

12.4.1 Should archaeological exclusion zones impact on the proposed development works it is recommended that a program of ground truthing is undertaken to establish the identity of the anomalies so that further archaeological assessment can be undertaken, and interpretations revised as appropriate.

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

13.0 Annex A – Anomalies of Archaeological Potential

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_001	Low	Likely geological	<Null>	1.9	1.2	0.3	<Null>	<Null>	703656.8	6306749.4
BR24_002	Low	Linear feature	<Null>	8.9	0.5	0	<Null>	<Null>	703491.0	6308313.6
BR24_003	Low	Chain, cable, or rope	<Null>	14.4	10.0	0	<Null>	<Null>	699004.5	6309476.4
BR24_004	Low	Chain, cable, or rope	<Null>	10	2.5	0	<Null>	<Null>	699141.1	6309621.0
BR24_005	Low	Likely geological	<Null>	25.6	16.6	0.1	<Null>	<Null>	697846.7	6307216.2
BR24_006	Low	Potential debris	<Null>	5.2	1.6	0.7	<Null>	<Null>	698206.4	6301839.1
BR24_007	Low	Chain, cable, or rope	<Null>	18.1	0.3	0	<Null>	<Null>	697083.4	6308817.1
BR24_008	Low	Chain, cable, or rope	<Null>	11.5	4.1	0	<Null>	<Null>	697142.0	6302563.5
BR24_009	Low	Potential debris	<Null>	4.7	0.7	0	<Null>	<Null>	696385.8	6308456.5
BR24_010	Low	Fishing gear	<Null>	11.4	1.6	0	<Null>	<Null>	693942.2	6304253.3
BR24_011	Low	Chain, cable, or rope	<Null>	79.5	0.2	0	<Null>	<Null>	692053.8	6302495.5
BR24_012	Low	Chain, cable, or rope	<Null>	8.6	6.0	0.1	<Null>	<Null>	692037.8	6302538.9
BR24_013	Low	Chain, cable, or rope	<Null>	7.8	4.1	0	<Null>	<Null>	692151.2	6301817.2
BR24_014	Low	Potential debris	<Null>	2.0	0.8	0.1	<Null>	<Null>	691688.0	6304635.1
BR24_015	Low	Potential debris	<Null>	4.5	1.4	0.3	<Null>	<Null>	684285.9	6299463.8
BR24_016	Low	Chain, cable, or rope	<Null>	72.4	0.2	0	<Null>	<Null>	681902.2	6303425.0

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_017	Low	Potential debris	<Null>	5.8	0.7	0	<Null>	<Null>	681808.6	6305021.3
BR24_018	Low	Anchor - Modern	<Null>	2.1	0.8	0.2	<Null>	<Null>	681969.2	6306117.2
BR24_019	Low	Chain, cable, or rope	<Null>	76.5	0.1	0	<Null>	<Null>	681959.5	6306086.1
BR24_020	Low	Linear feature	<Null>	10.1	0.1	0.2	<Null>	<Null>	681806.5	6306504.4
BR24_021	Low	Chain, cable, or rope	6.8	12.2	7.3	0.1	<Null>	<Null>	681006.7	6301455.9
BR24_022	Low	Chain, cable, or rope	<Null>	58.9	10.4	0	<Null>	<Null>	681171.9	6298792.6
BR24_023	Low	Potential debris	<Null>	6.8	0.8	0.1	<Null>	<Null>	681133.3	6295783.5
BR24_024	Low	Potential debris	65.0	1.8	0.4	0.1	<Null>	<Null>	677608.0	6300332.1
BR24_025	Low	Fishing gear	<Null>	71.4	3.0	0.1	<Null>	<Null>	675793.1	6308047.8
BR24_026	Low	Chain, cable, or rope	<Null>	45.7	0.3	0	<Null>	<Null>	676075.4	6298399.6
BR24_027	Low	Chain, cable, or rope	<Null>	9.8	5.5	0	<Null>	<Null>	676135.1	6298435.5
BR24_028	Low	Potential debris	<Null>	5.5	0.6	0.1	<Null>	<Null>	674203.6	6306627.4
BR24_030	Low	Chain, cable, or rope	<Null>	100.4	0.2	0	<Null>	<Null>	671634.6	6308890.7
BR24_031	Low	Fishing gear	<Null>	54.8	6.6	0.3	<Null>	<Null>	671703.2	6307266.4
BR24_032	Low	Fishing gear	<Null>	58.7	8.0	0.3	<Null>	<Null>	671752.9	6306413.7
BR24_033	Low	Fishing gear	<Null>	60.5	9.5	0.2	<Null>	<Null>	672033.2	6304647.2
BR24_034	Low	Fishing gear	<Null>	80.2	8.8	0.2	<Null>	<Null>	671808.3	6304717.2
BR24_035	Low	Fishing gear	<Null>	35.8	7.8	0.1	<Null>	<Null>	671903.4	6304177.5

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_036	Low	Chain, cable, or rope	<Null>	37.3	0.2	0	<Null>	<Null>	672116.8	6302486.0
BR24_037	Low	Potential debris	<Null>	11.9	4.1	0	<Null>	<Null>	672229.9	6296501.3
BR24_038	Low	Fishing gear	<Null>	13.0	1.0	0.1	<Null>	<Null>	672563.3	6296341.8
BR24_039	Low	Chain, cable, or rope	<Null>	33.0	8.6	0.1	<Null>	<Null>	672041.0	6309056.9
BR24_040	Low	Fishing gear	<Null>	14.4	4.9	0.1	<Null>	<Null>	673054.7	6300559.6
BR24_041	Low	Chain, cable, or rope	<Null>	59.0	0.3	0.1	<Null>	<Null>	672787.9	6302797.2
BR24_042	Low	Potential debris	<Null>	5.4	1.0	0	<Null>	<Null>	672667.8	6309205.2
BR24_043	Low	Linear feature	<Null>	30.5	0.5	0.1	<Null>	<Null>	672507.4	6304521.3
BR24_044	Low	Fishing gear	<Null>	48.0	13.9	0.3	<Null>	<Null>	672829.2	6302266.0
BR24_045	Low	Chain, cable, or rope	<Null>	91.5	0.4	0	<Null>	<Null>	672708.3	6300390.2
BR24_046	Low	Fishing gear	<Null>	13.4	2.6	0.6	<Null>	<Null>	673401.6	6298899.9
BR24_047	Low	Fishing gear	<Null>	29.5	11.3	0.2	<Null>	<Null>	673079.1	6302381.5
BR24_048	Low	Chain, cable, or rope	<Null>	76.9	0.4	0.1	<Null>	<Null>	672773.9	6309029.5
BR24_049	Low	Chain, cable, or rope	<Null>	39.0	0.7	0	<Null>	<Null>	673038.0	6308563.3
BR24_050	Low	Anchor - Modern	<Null>	3.9	2.4	1.0	<Null>	<Null>	673228.0	6309302.0
BR24_051	Low	Fishing gear	<Null>	20.1	8.4	0.1	<Null>	<Null>	673062.9	6304972.3
BR24_052	Low	Chain, cable, or rope	<Null>	69.6	34.1	0	<Null>	<Null>	673380.4	6310990.7
BR24_053	Low	Chain, cable, or rope	8.3	18.8	0.3	0	<Null>	<Null>	673613.2	6299861.1

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_054	Low	Anchor and chain	<Null>	118.1	0.6	1.0	<Null>	<Null>	673605.5	6307273.9
BR24_055	Low	Likely geological	<Null>	6.0	1.1	0.3	<Null>	<Null>	674748.6	6295078.6
BR24_056	Low	Potential debris	<Null>	6.0	5.0	0.2	<Null>	<Null>	674758.3	6294901.6
BR24_057	Low	Potential debris	11.8	4.2	0.6	0.1	<Null>	<Null>	674237.9	6297319.1
BR24_058	Low	Chain, cable, or rope	<Null>	137.3	0.2	0	<Null>	<Null>	674667.2	6302406.1
BR24_059	Low	Chain, cable, or rope	<Null>	67.2	0.5	0.1	<Null>	<Null>	674008.8	6309266.1
BR24_060	Low	Fishing gear	<Null>	38.6	16.4	0.5	<Null>	<Null>	674731.5	6302506.1
BR24_061	Low	Chain, cable, or rope	<Null>	20.8	6.8	0.1	<Null>	<Null>	674736.5	6302710.0
BR24_062	Low	Likely geological	<Null>	4.5	1.2	0.1	<Null>	<Null>	674669.1	6308245.4
BR24_063	Low	Chain, cable, or rope	<Null>	26.6	18.3	0.1	<Null>	<Null>	674759.9	6302567.3
BR24_064	Low	Seabed disturbance	<Null>	20.2	14.6	0.5	<Null>	<Null>	674138.6	6310697.5
BR24_065	Low	Potential debris	<Null>	1.4	5.4	0.4	<Null>	<Null>	674802.9	6306293.6
BR24_066	Low	Chain, cable, or rope	<Null>	250	0.5	0	<Null>	<Null>	675408.1	6296735.7
BR24_067	High	Wreck	127.3	33.9	7.5	3.6	50	Extents	675109.7	6300567.3
BR24_068	Medium	Anchor - wreck	<Null>	1.4	1.1	0.1	<Null>	<Null>	675106.6	6300452.2
BR24_069	Medium	Potential debris	<Null>	18.9	11.5	0.2	25	Extents	675054.6	6301818.6
BR24_070	High	Wreck	148.7	31.8	6.9	3.4	50	Extents	675182.3	6304895.3
BR24_071	Medium	Wreck debris	81.9	9.8	1.6	0	25	Radius	675330.2	6304868.2

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_072	Low	Linear feature	<Null>	5.4	0.3	0	<Null>	<Null>	675110.9	6309498.3
BR24_073	Medium	Potential debris	81.4	24.3	6.1	0	25	Extents	675268.6	6304437.7
BR24_074	Low	Chain, cable, or rope	<Null>	40.5	14.8	0.1	<Null>	<Null>	675360.2	6297539.7
BR24_075	Low	Anchor - Modern	7.0	1.5	3.6	0	<Null>	<Null>	675868.8	6298074.9
BR24_076	Low	Chain, cable, or rope	<Null>	107.9	0.2	0.1	<Null>	<Null>	675840.6	6298120.3
BR24_077	Low	Linear feature	<Null>	60.5	1.1	0.1	<Null>	<Null>	675548.4	6304241.7
BR24_078	Low	Likely geological	<Null>	2.8	1.1	0.4	<Null>	<Null>	675981.8	6299943.0
BR24_079	Low	Linear feature	<Null>	7.1	0.3	0.1	<Null>	<Null>	676141.1	6302739.2
BR24_080	Low	Potential debris	<Null>	1.4	0.8	0.1	<Null>	<Null>	672711.0	6295902.9
BR24_081	Low	Fishing gear	<Null>	10.0	3.7	1.2	<Null>	<Null>	675842.7	6309658.2
BR24_082	Low	Linear feature	<Null>	10.0	0.6	0	<Null>	<Null>	675746.6	6306482.6
BR24_083	Low	Linear feature	<Null>	9.8	0.3	0	<Null>	<Null>	675931.8	6303616.6
BR24_084	Low	Linear feature	<Null>	5.2	0.4	0	<Null>	<Null>	675918.1	6303640.4
BR24_085	Low	Chain, cable, or rope	<Null>	80.7	0.1	0	<Null>	<Null>	676109.4	6303408.1
BR24_086	Low	Linear feature	6.9	10.6	0.5	0	<Null>	<Null>	676177.3	6303207.9
BR24_087	Low	Fishing gear	<Null>	35.7	5.2	0.3	<Null>	<Null>	676452.6	6297172.1
BR24_088	Low	Fishing gear	<Null>	8.8	7.3	1.0	<Null>	<Null>	676489.0	6301251.6
BR24_089	Low	Chain, cable, or rope	<Null>	91.1	0.2	0.1	<Null>	<Null>	676900.8	6306673.0

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_090	Low	Potential debris	9.9	4.5	2.1	0.3	<Null>	<Null>	677992.1	6297687.7
BR24_091	Medium	Mound	<Null>	34.1	15.1	1.5	<Null>	<Null>	677802.4	6310311.2
BR24_092	Low	Chain, cable, or rope	<Null>	20.6	19.7	0.1	<Null>	<Null>	677850.5	6305493.1
BR24_093	Low	Chain, cable, or rope	<Null>	112.1	0.3	0.1	<Null>	<Null>	678906.9	6296042.1
BR24_094	Medium	Seabed disturbance	<Null>	36.4	14.9	0	25	Extents	678064.1	6303011.4
BR24_095	Low	Likely geological	<Null>	24.0	1.9	0.2	<Null>	<Null>	678244.7	6307382.5
BR24_096	Low	Likely geological	<Null>	4.1	3.0	0.2	<Null>	<Null>	678366.9	6303406.9
BR24_097	Low	Anchor - Modern	<Null>	3.9	1.1	0.1	<Null>	<Null>	678144.6	6310512.6
BR24_098	Low	Chain, cable, or rope	<Null>	46.2	0.2	0.1	<Null>	<Null>	678138.3	6310497.2
BR24_099	Low	Chain, cable, or rope	<Null>	95.5	0.1	0	<Null>	<Null>	679231.9	6296008.0
BR24_100	Low	Potential debris	<Null>	6.2	1.4	0.3	<Null>	<Null>	679124.8	6303012.4
BR24_101	High	Potential wreck	<Null>	43.5	13.4	1.3	<Null>	<Null>	678523.3	6309980.5
BR24_102	Low	Chain, cable, or rope	<Null>	125.8	0.2	0	<Null>	<Null>	679368.6	6299516.4
BR24_103	Medium	Seabed disturbance	<Null>	12.5	11.5	0	25	Extents	678948.9	6308574.5
BR24_104	Low	Chain, cable, or rope	<Null>	52.8	0.2	0	<Null>	<Null>	680186.3	6297518.2
BR24_105	Low	Chain, cable, or rope	23.4	79.9	0.5	0	<Null>	<Null>	679338.9	6307013.8
BR24_106	Low	Chain, cable, or rope	<Null>	8.6	8.3	0.1	<Null>	<Null>	680567.3	6295533.9
BR24_107	Low	Linear feature	<Null>	23.8	0.4	0.1	<Null>	<Null>	680183.6	6299272.6

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_108	Low	Anchor - Modern	<Null>	4.4	3.5	1.1	<Null>	<Null>	680403.1	6306929.4
BR24_109	Low	Chain, cable, or rope	<Null>	78.7	0.4	0.1	<Null>	<Null>	680373.6	6306956.2
BR24_110	Low	Chain, cable, or rope	<Null>	29.9	0.2	0	<Null>	<Null>	680060.1	6310770.6
BR24_111	Low	Chain, cable, or rope	<Null>	27.5	0.2	0	<Null>	<Null>	680670.9	6307881.9
BR24_112	Low	Anchor - Modern	<Null>	6.7	3.8	1.1	<Null>	<Null>	680607.7	6308606.5
BR24_113	Low	Chain, cable, or rope	<Null>	81.3	0.1	0	<Null>	<Null>	680607.5	6308558.8
BR24_114	Low	Chain, cable, or rope	<Null>	10.0	7.9	0.1	<Null>	<Null>	680983.1	6310476.2
BR24_115	Low	Chain, cable, or rope	<Null>	32.3	0.5	0	<Null>	<Null>	680779.8	6307047.4
BR24_116	Low	Chain, cable, or rope	<Null>	170.8	112.6	0.1	<Null>	<Null>	682034.8	6296320.2
BR24_117	Medium	Mound	<Null>	16.7	22.1	0.5	25	Extents	681989.3	6299052.9
BR24_118	Low	Chain, cable, or rope	<Null>	130.0	0.2	0	<Null>	<Null>	681955.3	6301939.2
BR24_119	Low	Potential debris	<Null>	2.5	1.6	0.3	<Null>	<Null>	681721.6	6309764.5
BR24_120	Low	Chain, cable, or rope	<Null>	5.3	4.5	0	<Null>	<Null>	681612.3	6308191.7
BR24_121	Low	Potential debris	34.8	7.1	3.1	0.8	<Null>	<Null>	682319.6	6298218.2
BR24_122	Low	Chain, cable, or rope	<Null>	21.9	3.3	0.1	<Null>	<Null>	682125.8	6310893.3
BR24_123	Low	Fishing gear	<Null>	120.2	0.5	0.1	<Null>	<Null>	682292.0	6307955.3
BR24_124	Low	Likely geological	<Null>	12.7	5.1	1	<Null>	<Null>	682655.5	6309195.0
BR24_125	Low	Anchor - Modern	<Null>	4.7	1.6	0.3	<Null>	<Null>	682417.5	6308039.2

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_126	Low	Potential debris	<Null>	24.3	6.4	0.4	<Null>	<Null>	682858.9	6303183.9
BR24_127	Low	Chain, cable, or rope	<Null>	26.4	0.2	0	<Null>	<Null>	682834.7	6303177.1
BR24_128	Low	Chain, cable, or rope	<Null>	14.8	10.5	0.1	<Null>	<Null>	683391.0	6299973.6
BR24_129	Low	Chain, cable, or rope	<Null>	217.9	0.2	0	<Null>	<Null>	683477.8	6310510.0
BR24_130	Low	Chain, cable, or rope	<Null>	211.4	0.3	0.2	<Null>	<Null>	683446.3	6307304.6
BR24_131	Low	Potential debris	<Null>	5.1	0.7	0.3	<Null>	<Null>	683583.9	6301733.1
BR24_132	Low	Potential debris	<Null>	3.0	1.5	0.3	<Null>	<Null>	683764.3	6310497.3
BR24_133	Low	Chain, cable, or rope	<Null>	12.8	9.4	0	<Null>	<Null>	684291.9	6297969.0
BR24_134	Low	Chain, cable, or rope	<Null>	49.2	8.9	0.1	<Null>	<Null>	684493.0	6297459.3
BR24_135	Low	Potential debris	<Null>	4.4	2.8	0.4	<Null>	<Null>	684924.4	6308516.7
BR24_136	Low	Chain, cable, or rope	<Null>	7.7	3.2	0.1	<Null>	<Null>	686365.5	6310305.4
BR24_137	Low	Chain, cable, or rope	<Null>	114.8	0.2	0	<Null>	<Null>	687060.7	6301196.1
BR24_138	Low	Chain, cable, or rope	<Null>	58.6	15.7	0	<Null>	<Null>	687027.5	6306660.1
BR24_139	Low	Chain, cable, or rope	<Null>	18.5	10.7	0	<Null>	<Null>	686792.2	6307192.6
BR24_140	Low	Chain, cable, or rope	<Null>	50.1	11.7	0.1	<Null>	<Null>	687004.7	6299598.2
BR24_141	Low	Chain, cable, or rope	<Null>	23.8	2.8	0	<Null>	<Null>	687365.7	6300998.4
BR24_142	High	Wreck	140.8	49.4	8.9	6.1	100	Extents	687344.0	6301679.0
BR24_143	Medium	Anchor - wreck	16.8	5.0	3.2	0.3	<Null>	<Null>	687317.6	6301553.7

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_144	Low	Fishing gear	<Null>	24.7	0.6	0.1	<Null>	<Null>	687195.5	6309096.3
BR24_145	Low	Chain, cable, or rope	<Null>	234.7	0.3	0	<Null>	<Null>	687463.7	6308388.9
BR24_146	Low	Chain, cable, or rope	<Null>	82.3	0.2	0	<Null>	<Null>	687452.8	6306418.9
BR24_147	Low	Fishing gear	<Null>	73.4	0.2	0.2	<Null>	<Null>	687480.4	6306481.6
BR24_148	Low	Chain, cable, or rope	<Null>	179.7	0	0	<Null>	<Null>	688226.3	6300555.6
BR24_149	Low	Chain, cable, or rope	<Null>	29.0	7.6	0	<Null>	<Null>	688167.1	6302533.8
BR24_150	Low	Linear feature	<Null>	50.5	0.5	0.1	<Null>	<Null>	689117.9	6305078.2
BR24_151	Low	Potential debris	<Null>	9.4	1.2	0.1	<Null>	<Null>	689781.8	6302906.6
BR24_152	Low	Likely geological	<Null>	6.6	2.7	0.3	<Null>	<Null>	689697.6	6305900.6
BR24_153	Low	Potential debris	<Null>	2.7	0.8	1	<Null>	<Null>	690438.0	6308633.5
BR24_154	Low	Chain, cable, or rope	<Null>	73.6	40.4	0	<Null>	<Null>	691236.9	6306956.3
BR24_155	Low	Chain, cable, or rope	<Null>	27.9	0.2	0	<Null>	<Null>	692471.2	6302327.3
BR24_156	Low	Chain, cable, or rope	<Null>	132.9	13.1	0	<Null>	<Null>	692032.5	6308287.1
BR24_157	Low	Chain, cable, or rope	<Null>	23.6	3.4	0	<Null>	<Null>	692183.4	6301928.3
BR24_158	Low	Potential debris	<Null>	4.4	2.1	0	<Null>	<Null>	692389.0	6306683.2
BR24_159	Low	Potential debris	<Null>	6.1	0.8	0.1	<Null>	<Null>	692705.7	6301758.4
BR24_160	Low	Chain, cable, or rope	<Null>	7.4	4.6	0	<Null>	<Null>	693814.8	6305813.9
BR24_161	Low	Chain, cable, or rope	<Null>	54.6	0.3	0	<Null>	<Null>	693587.5	6307795.2

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_162	Low	Likely geological	<Null>	2.2	2.1	0.3	<Null>	<Null>	701455.3	6304967.0
BR24_163	Low	Fishing gear	<Null>	52.8	14.9	0	<Null>	<Null>	694862.7	6301836.5
BR24_164	Low	Chain, cable, or rope	<Null>	38.2	0.2	0	<Null>	<Null>	695887.1	6303813.8
BR24_165	Low	Chain, cable, or rope	<Null>	13.3	7.1	0	<Null>	<Null>	695779.0	6306923.6
BR24_166	Low	Chain, cable, or rope	<Null>	84.7	0.2	0	<Null>	<Null>	696049.6	6306128.0
BR24_167	Low	Chain, cable, or rope	<Null>	49.4	0.1	0	<Null>	<Null>	696092.7	6308627.0
BR24_168	Low	Chain, cable, or rope	<Null>	52.5	12.7	0	<Null>	<Null>	696979.6	6302927.0
BR24_169	Low	Chain, cable, or rope	<Null>	15.0	5.7	0.1	<Null>	<Null>	696912.7	6305084.3
BR24_170	Low	Chain, cable, or rope	<Null>	11.1	7.0	0	<Null>	<Null>	698075.3	6308527.6
BR24_171	Low	Chain, cable, or rope	8.2	23.4	0.3	0.1	<Null>	<Null>	698338.3	6309203.4
BR24_172	Low	Potential debris	33.7	2.6	1.2	0.6	<Null>	<Null>	698346.8	6309504.6
BR24_173	Low	Potential debris	6.1	2.9	1.3	0.2	<Null>	<Null>	698887.7	6304405.2
BR24_174	Low	Chain, cable, or rope	<Null>	25.1	20.4	0.1	<Null>	<Null>	698260.2	6309691.4
BR24_175	Low	Fishing gear	<Null>	7.9	1.5	0.3	<Null>	<Null>	698805.3	6307107.4
BR24_176	Low	Chain, cable, or rope	<Null>	8.1	5.1	0	<Null>	<Null>	699812.2	6309454.2
BR24_177	Low	Likely geological	<Null>	4.6	1.3	0	<Null>	<Null>	701506.0	6301558.7
BR24_178	Medium	Mound	<Null>	18.5	9.6	2.0	<Null>	<Null>	700879.9	6310041.8
BR24_179	Low	Fishing gear	<Null>	43.0	1.7	0.1	<Null>	<Null>	701769.0	6305606.7

Name	Potential	Description	Mag (nT)	Length (m)	Width (m)	Height (m)	AEZ (m)	AEZ Type	X	Y
BR24_180	Low	Chain, cable, or rope	<Null>	8.3	4.1	0.1	<Null>	<Null>	701962.7	6305598.8
BR24_181	Low	Chain, cable, or rope	<Null>	196.4	0.1	0	<Null>	<Null>	702181.9	6309928.3
BR24_182	Low	Chain, cable, or rope	8.0	39.9	13.9	0	<Null>	<Null>	702963.8	6302726.4
BR24_183	Low	Likely geological	<Null>	49.0	21.2	1.1	<Null>	<Null>	703491.8	6309142.4
BR24_184	Low	Linear feature	<Null>	11.4	0.2	0	<Null>	<Null>	703851.1	6302026.7

14.0 Annex B – Sea Level Index Points

Sub-region	Sample ID	Age (cal. BP)	RSL (m)	Secondary indicator type
Aberdeen	SRR4716	8332	-1.86	High marsh environment
Aberdeen	SRR4712	8548	-5.04	High marsh environment
Aberdeen	SRR4715	8266	-1.57	High marsh environment
Aberdeen	SRR4717	7970	-0.55	High marsh environment
Aberdeen	SRR4718	8245	-0.66	Uniquely defined
Aberdeen	SRR4714	8254	-1.24	High marsh environment
Aberdeen	SRR4719	6755	1.76	High marsh environment
Aberdeen	SRR4713	9030	-5.5	High marsh environment
Aberdeen	SRR1565	7707	0.16	Extreme water level
Aberdeen	SRR1193	7083	1.1	High marsh environment
Aberdeen	SRR1192	4217	1.57	High marsh environment
Aberdeen	SRR1769	4481	1.57	High marsh environment
Aberdeen	SRR4706	9303	-9.48	High marsh environment
Aberdeen	SRR4711	8558	-4.75	High marsh environment
Aberdeen	SRR4710	9081	-7.5	High marsh environment
Aberdeen	SRR4709	8593	-5.4	High marsh environment
Aberdeen	SRR4708	8674	-5.07	High marsh environment
Aberdeen	SRR5099	9519	-9.81	Freshwater to high marsh transition
Aberdeen	SRR4707	11882	-9.66	Freshwater/Terrestrial limiting
Montrose	AA68681	13983	9.82	Marine limiting
Montrose	BIRM823	7964	2.62	Freshwater/Terrestrial limiting
Montrose	SRR2119	7691	2.63	High marsh environment
Montrose	SRR2120	7945	2.03	Uniquely defined
Montrose	BIRM867	7730	2.8	High marsh environment
Montrose	SRR1148	7574	4.09	High marsh environment
Montrose	SRR1149	7911	3.62	High marsh environment
Montrose	SRR869	8153	1.75	High marsh environment

Sub-region	Sample ID	Age (cal. BP)	RSL (m)	Secondary indicator type
NE England (Central)	OxA11858	8107	-3.23	Marine limiting
NE England (Central)	AA27226	8126	-2.78	High marsh environment
NE England (Central)	AA27228	8173	-2.27	High marsh environment
NE England (Central)	AA27229	7969	-2.44	High marsh environment
NE England (Central)	OxA11859	7988	-4.49	High marsh environment
NE England (Central)	SRR3842	7764	-1.13	High marsh environment
NE England (Central)	OxA11860	7980	-4.52	High marsh environment
NE England (Central)	OxA12944	3156	-0.63	Freshwater to high marsh transition
NE England (Central)	OxA12954	7900	-4.05	High marsh environment
NE England (Central)	OxA12953	7949	-4.02	High marsh environment
NE England (Central)	OxA12952	7825	-4.02	High marsh environment
NE England (Central)	OxA13029	7484	-3.55	Freshwater to high marsh transition
NE England (Central)	OxA12951	7211	-3.14	Freshwater to high marsh transition
NE England (Central)	OxA12950	7219	-3.07	Freshwater to high marsh transition
NE England (Central)	OxA12949	6824	-2.76	Freshwater to high marsh transition
NE England (Central)	OxA12947	6665	-2.23	Freshwater to high marsh transition
NE England (Central)	OxA12946	4213	-1.39	Freshwater to high marsh transition
NE England (Central)	OxA12967	3533	-1.26	Freshwater to high marsh transition
NE England (Central)	OxA11833	8093	-3.25	Marine limiting
NE England (Central)	SRR3844	7709	-1.47	High marsh environment
NE England (Central)	SRR3845	8046	-1.9	High marsh environment
NE England (Central)	SRR3843	7993	-1.65	High marsh environment
NE England (Central)	AA23498	4030	0.44	Freshwater to high marsh transition
NE England (Central)	OxA11936	11535	-5.34	Freshwater/Terrestrial limiting
NE England (Central)	OxA13370	11511	-5.39	Freshwater/Terrestrial limiting
NE England (Central)	OxA12825	12026	-5.53	Freshwater/Terrestrial limiting
NE England (Central)	AA27616	8255	-2.18	Uniquely defined
NE England (Central)	AA27227	11456	-2.06	Uniquely defined

Sub-region	Sample ID	Age (cal. BP)	RSL (m)	Secondary indicator type
NE England (Central)	OxA12824	12289	-5.61	Freshwater/Terrestrial limiting
NE England (North)	AA25595	4790	1.7	High marsh environment
NE England (North)	AA24226	7211	1.49	Freshwater to high marsh transition
NE England (North)	AA23824	7726	-0.11	High marsh environment
NE England (North)	AA24225	6078	2.05	High marsh environment
NE England (North)	AA23825	8249	-0.45	Freshwater to high marsh transition
NE England (North)	AA23894	5947	1.34	High marsh environment
NE England (North)	AA23896	7409	0.45	High marsh environment
NE England (North)	AA25596	7570	0.35	High marsh environment
NE England (North)	AA24223	3601	2.57	High marsh environment
NE England (North)	AA23823	7790	-0.03	Freshwater to high marsh transition
NE England (North)	AA24224	4635	2.1	High marsh environment
NE England (North)	AA23893	5867	1.19	High marsh environment
NE England (North)	AA25597	12788	0.8	Uniquely defined
NE England (North)	AA34199	15744	1.81	Uniquely defined
NE England (North)	AA25598	13900	0.39	Uniquely defined
NE England (North)	AA25601	7986	1.16	Uniquely defined
NE England (North)	AA27618	8427	1.07	Uniquely defined
NE England (South)	AA27617	8719	-3.62	High marsh environment
NE England (South)	SRR3847	6073	-1.1	High marsh environment
NE England (South)	SRR3846	3856	0.13	High marsh environment
NE England (South)	AA24221	8745	-4.69	High marsh environment
NE England (South)	AA22663	3510	-0.91	Freshwater to high marsh transition
NE England (South)	SRR3848	7080	-1.72	High marsh environment
NE England (South)	AA24220	8449	-3.96	High marsh environment
NE England (South)	AA24219	7939	-2.01	Freshwater to high marsh transition
NE England (South)	SRR3703	7871	-1.99	Freshwater to high marsh transition
NE England (South)	SRR3700	4984	-0.26	Freshwater to high marsh transition

Sub-region	Sample ID	Age (cal. BP)	RSL (m)	Secondary indicator type
NE England (South)	AA24227	6518	-1.09	High marsh environment
NE England (South)	AA24218	7520	-1.17	High marsh environment
NE England (South)	SRR3701	5748	-0.62	High marsh environment
NE England (South)	SRR3702	7465	-1.77	High marsh environment
NE England (South)	UB3904	3601	-0.26	High marsh environment
NE England (South)	SRR3699	2914	0.5	Freshwater to high marsh transition
NE England (South)	AA24230	7960	-3.57	High marsh environment
NE England (South)	AA23892	7708	-1.91	Freshwater to high marsh transition
NE England (South)	AA24217	7442	-2.14	High marsh environment
NE England (South)	AA24222	8711	-5.1	High marsh environment
NE England (South)	AA24229	8420	-3.2	High marsh environment
NE England (South)	SRR3850	7774	-1.93	Freshwater to high marsh transition
NE England (South)	UB3905	2779	-0.69	Freshwater to high marsh transition
NE England (South)	SRR4584	7764	-2.34	High marsh environment
NE England (South)	AA24228	3330	-0.12	High marsh environment
NE England (South)	UB3906	3655	-0.79	High marsh environment
NE England (South)	SUERC30014	2588	2.37	Freshwater/Terrestrial limiting
NE England (South)	OxA22733	5398	1.66	Freshwater/Terrestrial limiting
NE England (South)	SUERC30008	5517	1.66	Freshwater/Terrestrial limiting
NE England (South)	SRR1420	2913	2.7	Freshwater/Terrestrial limiting
NE England (South)	SUERC54086	6845	-1.46	Freshwater/Terrestrial limiting
NE England (South)	SUERC49900	5516	1.61	Freshwater/Terrestrial limiting
NE England (South)	SUERC49871	7359	-1.15	Freshwater/Terrestrial limiting
NE England (South)	SUERC30010	6765	1.61	Freshwater/Terrestrial limiting
NE England (South)	SRR1422	5629	1.61	Freshwater/Terrestrial limiting
NE England (South)	SUERC52427	5517	1.61	Freshwater/Terrestrial limiting
NE England (South)	UB3907	3780	1.68	Uniquely defined
NE England (South)	SUERC54087	6759	-1.54	Freshwater/Terrestrial limiting

Sub-region	Sample ID	Age (cal. BP)	RSL (m)	Secondary indicator type
NE England (South)	SUERC49869	7097	-1.03	Freshwater/Terrestrial limiting
NE England (South)	SUERC49870	7236	-1.08	Freshwater/Terrestrial limiting
NE England (South)	OxA22732	6733	1.61	Freshwater/Terrestrial limiting
NE England (South)	HAR8973	2355	2.75	Freshwater/Terrestrial limiting
NE England (South)	HAR8975	3602	2.26	Freshwater/Terrestrial limiting
NE England (South)	HAR8974	3511	2.37	Freshwater/Terrestrial limiting
NE England (South)	SUERC30009	5400	1.66	Freshwater/Terrestrial limiting
NE England (South)	HAR8977	4850	2.08	Freshwater/Terrestrial limiting
NE England (South)	SRR1421	5461	1.65	Freshwater/Terrestrial limiting
NE England (Tyne)	AA23822	8586	-5.68	High marsh environment
NE Scotland	Beta101953	17483	12.97	Marine limiting
NE Scotland	LU3028	18143	12.97	Marine limiting
NE Scotland	SRR1661	7227	-1.46	Extreme water level
NE Scotland	SRR1655	5499	1.09	High marsh environment
NE Scotland	SRR1660	6498	-0.35	Freshwater to high marsh transition
NE Scotland	SRR1686	5888	0.11	Freshwater to high marsh transition
NE Scotland	SRR1687	6973	-1.09	Extreme water level
NE Scotland	SRR1659	9463	0.2	Freshwater/Terrestrial limiting
NE Scotland	SRR1658	8312	0.26	Freshwater/Terrestrial limiting
NE Scotland	SRR1657	7731	0.33	Freshwater/Terrestrial limiting
NE Scotland	SRR1656	7016	0.37	Freshwater/Terrestrial limiting
Dogger Bank	AA22662	9088	-33.26	High marsh environment
SE Scotland	IGS5A	5925	1.44	Marine limiting
SE Scotland	IGS5B	5402	1.44	Marine limiting
SE Scotland	IGS6	2571	2.95	High marsh environment
SE Scotland	SRR1431	8302	-0.01	High marsh environment
SE Scotland	SRR1430	8272	0.14	High marsh environment
Tay Valley	Beta111509	15458	17.37	Marine limiting

Sub-region	Sample ID	Age (cal. BP)	RSL (m)	Secondary indicator type
Tay Valley	CAMS111599	16480	10.37	Marine limiting
Tay Valley	CAMS111598	16451	10.37	Marine limiting
Tay Valley	CAMS111597	20577	14.82	Marine limiting
Tay Valley	AA37788	15996	16.17	Marine limiting
Tay Valley	AA37787	16694	16.17	Marine limiting
Tay Valley	Beta111507	15923	3.12	Marine limiting
Tay Valley	AA37791	15204	-18.73	Uniquely defined
Tay Valley	AA37790	15141	2.57	Uniquely defined
Tay Valley	Beta111508	16001	2.52	Marine limiting
Tay Valley	CAMS77912	16777	16.17	Marine limiting
Tay Valley	AA37789	14896	2.14	Uniquely defined
Tay Valley	CAMS111596	21447	14.82	Marine limiting
Tay Valley	I2796	10961	0.29	High marsh environment
Tay Valley	SRR71	8554	1.1	High marsh environment
Tay Valley	SRR72	10863	0.29	High marsh environment
Tay Valley	SRR1652	7149	7.43	High marsh environment
Tay Valley	SRR1147	9401	-0.1	High marsh environment
Tay Valley	SRR70	9582	-4.32	High marsh environment
Tay Valley	NPL127	8418	1.18	High marsh environment
Tay Valley	IGS2	8411	3.85	High marsh environment
Tay Valley	SRR69	9128	-3.41	High marsh environment
Tay Valley	SRR66	9094	-1.55	High marsh environment
Tay Valley	IGS1	6639	4.73	High marsh environment
Tay Valley	SRR1684	6535	7.03	High marsh environment
Tay Valley	SRR67	9338	-1.95	High marsh environment
Tay Valley	IGS3	11488	2.07	High marsh environment
Tay Valley	SRR1151	6947	6.92	High marsh environment
Tay Valley	SRR1397	8352	1.04	High marsh environment

Sub-region	Sample ID	Age (cal. BP)	RSL (m)	Secondary indicator type
Tay Valley	SRR1396	8556	2.9	Uniquely defined
Tay Valley	SRR1649	6855	7.24	High marsh environment
Tay Valley	SRR1394	8348	0.56	High marsh environment
Tay Valley	SRR1334	8359	3.05	Extreme water level
Tay Valley	SRR1333	7872	3.24	Extreme water level
Tay Valley	SRR1399	9530	-0.14	Freshwater to high marsh transition
Tay Valley	SRR1400	7997	4.08	High marsh environment
Tay Valley	SRR1332	8127	4.41	High marsh environment
Tay Valley	SRR1398	9506	-0.06	High marsh environment
Tay Valley	SRR1331	6713	4.59	High marsh environment
Tay Valley	SRR1510	7066	7.14	High marsh environment
Tay Valley	SRR1511	8306	7.02	High marsh environment
Tay Valley	SRR1150	7545	6.92	High marsh environment
Tay Valley	SRR1395	8372	2.19	High marsh environment
Tay Valley	SRR1685	8301	5.97	High marsh environment
Tay Valley	SRR1650	8417	6.23	High marsh environment
Tay Valley	SRR1651	6812	7.43	High marsh environment
Tay Valley	SRR1654	8463	7.25	High marsh environment
Tay Valley	SRR1653	6883	7.22	High marsh environment
Tay Valley	SRR1401	8284	3.7	High marsh environment

15.0 Annex C – Further details relating to the palaeolandscape discussion

15.1 Forth Formation

15.1.1 The Forth Formation is the youngest of the three identified Quaternary units within the WFDA in the Sparker data. Within the WFDA, the formation has been divided into two sub-units, provisionally correlated with the Whitehorn (FHW) and Fitzroy (FHF) members, based on their chronostratigraphy and seismic characteristics. Two other members of the Formation, the Largo Bay and St Andrews Bay members[44], were not identified within the WFDA.

15.1.2 The BGS describes the Forth Formation as widespread north of 55°N and east of 0°, exhibiting a blanket-like geometry generally less than 20 m thick, although it can occur up to 150 m thick as a channel fill[45].

15.2 Marr Bank Formation

15.2.1 The Marr Bank Formation comprises a contiguous spread of glacigenic deposits within the western central part of the central North Sea, frequently outcropping.

15.2.2 The BGS[46] and Stoker *et al*.[47] concur that the Marr Bank Formation comprises Late Devensian glaciogenic sediments, generally composed of sands of varying grain size but also exhibiting gravels, wood fragments and clay balls, where encountered in boreholes. Foraminifera from these samples indicate a high energy, shallow marine depositional environment, of high-boreal to arctic temperatures[48] [49].

15.3 Coal Pit Formation

15.3.1 Stoker *et al*.[50] attribute the Coal Pit Formation a Wolstonian to Devensian age, widespread across the region and measuring up to 120 m thick, where occurring as the infill of Wolstonian-age channels. Upper parts of the formation are noted by Stoker *et al*. and the ORR[51] as indistinguishable from the overlying Marr Bank and Swatchway formations, i.e. generally comprising sand of variable grain size, however, the ORR also notes that the upper element of the formation is characterised by stiff, glaciomarine clay in BGS borehole BH81/37, *c*. 73.5 km to the east of the WFDA. Lower elements of the Coal Pit Formation within the same borehole are characterised by interbedded sand and stiff clay, the latter containing shells, pebbles and wood fragments.

15.3.2 The same two sources conclude that much of the Coal Pit Formation is likely glaciomarine in origin, however, the upper part from borehole BH81/27, *c*. 30 km to the southwest of the WFDA, was interpreted as an intertidal deposit. As the infill of tunnel valleys, the depositional process may be complex, however, a general interpretation describes the basal deposits as

[44] Stoker *et al*. 1985.
[45] Gatliff *et al*. 1994.
[46] Gatliff *et al*. 1994.
[47] Stoker *et al*. 1985.
[48] Davies *et al*. 2011.
[49] Thomson. 1978.
[50] Stoker *et al*. 1985.
[51] Gatliff *et al*. 1994.

glaciogenic in origin, often containing diamictons, whereas later fills are more varied, also exhibiting laminated clays and silts of distal glaciomarine and glaciolacustrine environments[52].

15.4 Aberdeen Ground Formation

15.4.1 The Aberdeen Ground Formation is mapped widely throughout the central North Sea by the BGS, equivalent, in part, to the Yarmouth Roads Formation south of 56° N. The Formation was laid down over a long period during the Early to Middle Pleistocene (MIS 100 to 13) and, although dating of the Formation is not fully resolved, the upper parts of the deposit in this region are thought to date to the Middle Pleistocene. The Brunhes-Matuyama (B-M) magnetic boundary, dated to *c*. 780,000 ±5,000 BP, has been identified within the deposit in the central North Sea area[53][54], indicating that parts of the Formation post-date this event.

15.4.2 The base of the Aberdeen Ground Formation is associated with a distinctive acoustic reflector considered to correlate with the base of the Quaternary deposits in the central North Sea[55] and, like the partly equivalent Yarmouth Roads Formation, covers a period of fluctuating climatic cycles, including warmer and cooler periods. Analysis has demonstrated the presence of clay units with dipping clinoforms, interpreted as evidence of deltaic environments[56]. Analysis has also shown that sub-aerial conditions may have been present during the later Early Pleistocene, though the Middle Pleistocene was dominated by increasingly glacial conditions.

15.4.3 The muds, pebbles and sandy sediments of the upper Aberdeen Ground Formation are thought to have been deposited in glacial environments of the Cromerian complex[57]. Cold water foraminifera identified within this part of the Formation are the product of sub-glacial or pro-glacial environments associated with a tide-water ice sheet. This is the earliest evidence of full glacial conditions in the central North Sea area[58][59]. Four lithofacies have been identified in the upper part of the Aberdeen Ground Formation: sub-glacial facies, proximal glaciomarine facies, distal glaciomarine facies and marine facies - representing a series of different depositional environments during the Early to Middle Pleistocene[60].

15.5 Glacial extents

15.5.1 With the source of the British-Irish ice sheet situated in the Western Highlands, the WFDA lay beneath glacial ice for much of the Anglian and Wolstonian stadials (Figure 35). The longevity of the deposition of the Aberdeen Ground Formation (MIS 100 to 13), underlying large parts of the central North Sea, suggests that glacial activity likely influenced this unit during stadials of

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[52] Kirkham, J.D., Hogan, K.A., Larter, R.D., Self, E., Games, K., Huuse, M., Stewart, M.A., Ottesen, D., Le Heron, D.P., Lawrence, A., Kane, I., Arnold, N.S. and Dowdeswell, J.A. 2024. 'The infill of tunnel valleys in the central North Sea: Implications for sedimentary processes, geohazards, and ice-sheet dynamics'. *Marine Geology*. **467**.
[53] Stewart, M., Lonergan, L., and Hampson, G. 2012. '3D seismic analysis of buried tunnel valleys in the Central North Sea: tunnel valley fill sedimentary architecture', in Huuse, M., Redfern, J., Le Heron, D.P., Dixon, R.J., Moscariello, A. and Craig, J. (eds). *Glaciogenic reservoirs and Hydrocarbon Systems*. London: Geological Society Special Publications **368**.
[54] Stoker, M. S., Skinner, A. C., Fyfe, J. A. and Long, D. 1983. 'Palaeomagnetic evidence for early Pleistocene in the central and northern North Sea'. *Nature*. **304**, pp. 332–334.
[55] Stoker *et al*. 2011.
[56] Buckley, F. 2014. 'Seismic Character, Lithology and Age Correlation of the Aberdeen Ground Fm. in the Central North Sea'. Near Surface Geoscience 2014 – 20th European Meeting of Environmental and Engineering Geophysics. **2014**, pp. 1-5.
[57] Vaughan-Hirsch, D.P. and Phillips, E.R. 2017. 'Mid-Pleistocene thin-skinned glaciotectonic thrusting of the Aberdeen Ground Formation, Central Graben region, central North Sea'. *Journal of Quaternary Science*. **32**, pp. 196-212.
[58] Vaughan-Hirsch and Philips. 2017.
[59] Gatliff *et al*. 1994.
[60] Vaughan-Hirsch and Phillips. 2017.

the preceding Cromerian complex and Beestonian stage, however, as previously mentioned, these sequences are currently poorly understood.

15.5.2 Basal deposits of the Coal Pit Formation have been attributed a Late Wolstonian date (MIS 6)[61], however, deposits of such provenance most likely occur as basal channel fills. Although three sub-units of the Coal Pit Formation have been provisionally identified within the WFDA, none were defined as a basal unit of the Formation.

15.5.3 The Devensian glaciation was the last glaciation to affect Britain. The maximum extents of the glaciation (the "Last Glacial Maximum"; LGM) were achieved at various points between 27,000 to 17,000 BP, although there is some disparity in the scholarship. The 'traditional' view places northern England, parts of the Midlands, most of Wales, northern and central Ireland, most of mainland Scotland and the Western Isles under glacial conditions (Figure 35). This viewpoint suggests that southern Ireland and parts of northeast Scotland, including the Orkney and Shetland archipelagos, the northeast coast (approximately between Banff and Peterhead) and much of the North Sea, were not covered by glacial ice during the Devensian stage[62]. Under this interpretation, the WFDA would not have lain under glacial ice during the LGM.

15.0.2 More recent review of the evidence and incorporation of new data, however, has significantly extended the perceived extent of glaciation to the southwest and northeast, concluding in the latter at a confluence of the British-Irish and the Fennoscandian ice sheets within the present North Sea[63] [64] [65] (Figure 35). This revised interpretation would place the WFDA beneath glacial ice at the height of the LGM.

15.0.3 Batchelor *et al.*[66] examined empirical data and numerical modelling from over 180 studies to reconstruct ice-sheet extents in the Northern Hemisphere at intervals throughout the Pleistocene. Glaciers readvanced over much of the North Sea during MIS 4, retreating again during the Upton Warren interstadial (MIS 3). By the end of MIS 3, temperatures had fallen enough to allow expansion of the Fennoscandian ice-sheet over the Baltic Sea, leading up the LGM and confluence of the Fennoscandian and British-Irish ice-sheets in MIS 2.

15.6 Sea level data

15.6.1 There are few Sea Level Index Points (SLIPs) offshore in the North Sea and none within the central or northern regions. Many nearby SLIPs are largely located along the current coastline and within waterways and lowlands, such as the Tay Valley, the Forth Valley and the River South Esk estuary.

15.6.2 Sea level studies for this period 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[67]. The British-Irish ice-sheet

[61] Gatliff *et al*. 1994.
[62] Hall, A.M. and Bent, A.J.A. 1990. 'The limits of the last british ice sheet in northern Scotland and the adjacent shelf'. *Quaternary Newsletter*. **61**, pp. 2-12.
[63] Gibbard, P.L. and Clark, C.D. 2004. 'Pleistocene Glaciation Limits in Great Britain'. *Developments in Quaternary Science.* **2**, pp. 47-82.
[64] Batchelor, C.L., Margold, M., Krapp, M., Murton, D.K., Dalton, A.S., Gibbard, P.L., Stokes, C.R., Murton, J.B. and Manica, A. 2019. 'The configuration of Northern Hemisphere ice sheets through the Quaternary'. *Nature Communications.* **10**.
[65] Kirkham *et al*. 2024.
[66] Batchelor *et al*. 2019.
[67] 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).

developed outward from the Scottish Highlands during the Dimlington stadial (MIS 2; 29,000 to 14,700 BP), extending as far south as the Norfolk coast and the Western Approaches (Figure 35). Northern parts of Britain were therefore subject to greater depression and rebound, which are to be expected within the RSL record. Similar glacial origins are to be expected for the earlier Wolstonian (MIS 10 to 6) and Anglian (MIS 12) glaciations, however, little RSL data is available to inform GIA modelling for these periods.

15.6.3 Shennan *et al*.[68] have produced a recent and extensive study of RSL in Britain and Ireland since the LGM. Their study, incorporating over 2,100 data points including SLIPs and marine and terrestrial limiting data, provides regional insights into RSLs across the British Isles. A sub-sample of 187 SLIPs and limiting points was consulted to inform the discussion of this sub-section (Figure 37), ranging in date from 21,447 to 2,355 BP. A gazetteer of the sub-sample is included as Annex B – *Sea Level Index Points*.

15.6.4 Modelling of palaeo-coastlines have applied RSL data to illustrate the development of marine boundaries, such as the model produced by Brooks *et al*.[69]. This model, reproduced in part by Figure 37, demonstrates the Flandrian marine transgression of the Late Devensian and Early Holocene, concurring largely with the results of Shennan *et al*.[70], although based partly on the results of the same team's earlier studies[71].

15.6.5 The earliest marine limiting points date to *c*. 21,447 and 20,577 BP (Sample IDs: CAMS111596 and CAMS111597, respectively) and demonstrate higher RSL (14.82 m), coinciding with the mid-point of the Dimlington stadial. A series of limiting points and SLIPs from the Tay Valley and northeast Scotland demonstrate a broad trend of rising sea level during the latter part of the Dimlington stadial (18,143 to 14,896 BP), although the progression is somewhat erratic.

15.6.6 Evidence of raised marine deposits has also been attributed to the subsequent Windermere interstadial (*c*. 14,700 to 12,900 BP; MIS 2) by numerous authors, including Peacock and Holloway *et al*, as indicative of higher RSL.

15.6.7 The Loch Lomond stadial (*c*. 12,900 to 11,700 BP; MIS 2) witnessed localised glaciation in the Scottish Highlands and Western Isles, although the associated GIA would have been significantly less than during the Dimlington[72] [73]. Lower RSL during the Loch Lomond stadial is reflective of isostatic rebound, counteracting the RSL increase from the freeing up of a large volume of water from glacial ice witnessed further south in the British Isles. Lower RSL is expressed by local SLIPs, indicating -9.7 m at *c*. 11,900 BP (Sample ID: SRR4707). Stoker *et al*.[74] found evidence of a late glacial shoreline in eastern Scotland, also demonstrating lower RSL during this period, but placed this at -20 to -30m OD.

15.6.8 A relatively swift period of sea level rise after *c*. 10,000 BP is expressed in the SLIP data,

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[68] Shennan *et al*. 2018.
[69] Brooks *et al*. 2011.
[70] Shennan *et al*. 2018.
[71] 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.
[72] Ballantyne, C.K., McCarroll, D., Nesje, A., Dahl, S.O. and Stone, J.O. 1998. 'The Last Ice Sheet in North-West Scotland: Reconstruction and Implications'. *Quaternary Science Reviews*. **17**, pp. 1149-1184.
[73] Ballantyne, C.K. 2007. 'Loch Lomond Stadial glaciers in North Harris, Outer Hebrides, North-West Scotland: glacier reconstruction and palaeoclimatic implications'. *Quaternary Science Reviews*. **26**, pp. 3134-3149.
[74] Stoker *et al*. 2008.

attributed to the Holocene transgression and regional by the Storegga tsunami (*c*. 8,200 BP)[75]. This largely concurs with the sea level curve for eastern Scotland presented by Stoker *et al.*[76].

[75] Nyland, A.J., Walker, J. and Warren, G. 2021. 'Evidence of the Storegga Tsunami 8200 BP? An Archaeological Review of Impact After a Large-Scale Marine Event in Mesolithic Northern Europe'. Frontiers in *Earth Science.* 9.
[76] Stoker *et al*. 2008.