

Geophysics and Hydrographic Data Processing and Interpretation Report

Arklow Bank Wind Park (ABWP)



Client	SSE Offshore Wind Limited
Contractor	Green Rebel Group Ltd
Prepared by	EOM, LOR, JM, SB, LOH, CG, PW
Reviewed by	JP
Approved by	JP
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Executive Summary

Green Rebel Ltd was contracted by SSE (referred to herein as ‘the client’) to complete a reconnaissance grade geophysical and hydrographic investigation of a new Irish offshore windfarm, Arklow Bank Wind Park (ABWP) situated approximately 10 km East of Arklow Town, Co. Wicklow. The investigation consisted of the acquisition, processing and interpretation of Sub-bottom profiler, multibeam bathymetry and backscatter, side-scan sonar and magnetometer data. The purpose of the investigation is to underpin and support the development of the windfarm through:

- The identification and mapping of potential geohazards;
- The facilitation of the development of a ground model;
- The provision of data and information in support of EIAR’s;
- The provision of data in support of provisional turbine placement planning and;
- The provision of data and information to inform Cable Burial Risk Assessment (CBRA).

To this end, Green Rebel commenced geophysical and hydrographic survey operations on the 27th August 2022 for the Lady Kathleen (28th August 2022 for the Roman Rebel). The initial survey operations were completed before demobilisation of the Roman Rebel (26th September 2022) and the Lady Kathleen (4th November 2022). Data were processed, analysed, and interpreted; the results are presented herein.

This report presents background information that includes a summary of the ABWP project objectives and variations from the scope of work. Following this, the acquisition and subsequent processing steps for each type of geophysical data (multibeam, side-scan sonar, magnetometer and sub-bottom profiler) are described. The classifications used for analyses are described. Finally, the results of the data analyses are documented; these are organised by the type of data.

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List of Acronyms

AOI	Area Of Interest
ARA	Angular Range Analysis
BIIS	British-Irish Ice Sheet
CTI	Chesapeake Technology International
DEM	Digital Elevation Model
DOP	Dilution Of Precision
EGN	Empirical Gain Normalisation
EIAR	Environmental Impact Assessment Report
ETRS89	European Terrestrial Reference System 1989
FOM	Figure of Merit
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Geographic Positioning System
GSI	Geological Survey of Ireland
HDOP	Horizontal Dilution Of Position
IHO	International Hydrographic Organization
ISIS	Irish Sea Ice Stream
ka BP	thousand (calendar) years Before Present
LAT	Lowest Astronomical Tide
MAG	Magnetometer
MBES	Multibeam Echosounder
NaN	Not a Number
ABWP	Arklow Bank Wind Park
NMO	Normal Move Out
pUXO	Potential Unexploded Ordinance
QC	Quality Control
QINSy	Quality Integrated Navigation System
SBP	Sub-bottom Profiler
SSS	Side-scan sonar
THU	Total Horizontal Uncertainty
TVU	Total Vertical Uncertainty

USBL	Ultra-short Baseline
VDOP	Vertical Dilution Of Position
VORF	Vertical Offshore Reference System

1 Introduction

Green Rebel acquired data for the Arklow Bank Wind Park project (Figure 1) between August and November 2022. These data consisted of a Geophysical survey and a Hydrographic survey. The Geophysical survey (Figure 1) consisted of Sub-bottom Profiler, UHRS, Side-scan Sonar and Magnetometer. The Hydrographic survey consisted of multibeam bathymetry and backscatter. These survey legs were carried out between the 27th of August and 4th of November 2022. Data were acquired on the MV Roman Rebel, a 27.5 m, semi-SWATH (Small Waterplane Area Twin Hull), DP1 vessel, and the MV Lady Kathleen, a 14 m Catamaran, both purpose built for hydrographic and geophysical data acquisition. The survey mobilised and departed from Crosshaven Harbour (Co. Cork) on the 27th of August. Survey demobilisation took place between the 5th and the 11th of November 2022 at Crosshaven harbour.

During the Geophysical survey, a total length of c.1148 km was surveyed during the Hydrographic survey. The survey area is c.90 km² (Figure 1). Approximately 5.63 TB of raw data were acquired during the full survey.

Existing reports provided by the client to Green Rebel were carried out by Ultrabeam Ltd. in 2019. The survey comprised of Arklow Bank and the surrounding waters, as well as three potential cable routes to shore. Figure 1 shows overlap between carried out by Ultrabeam Ltd. and Green Rebel (roughly 8%). Where possible, comparisons will be made between both data sets.

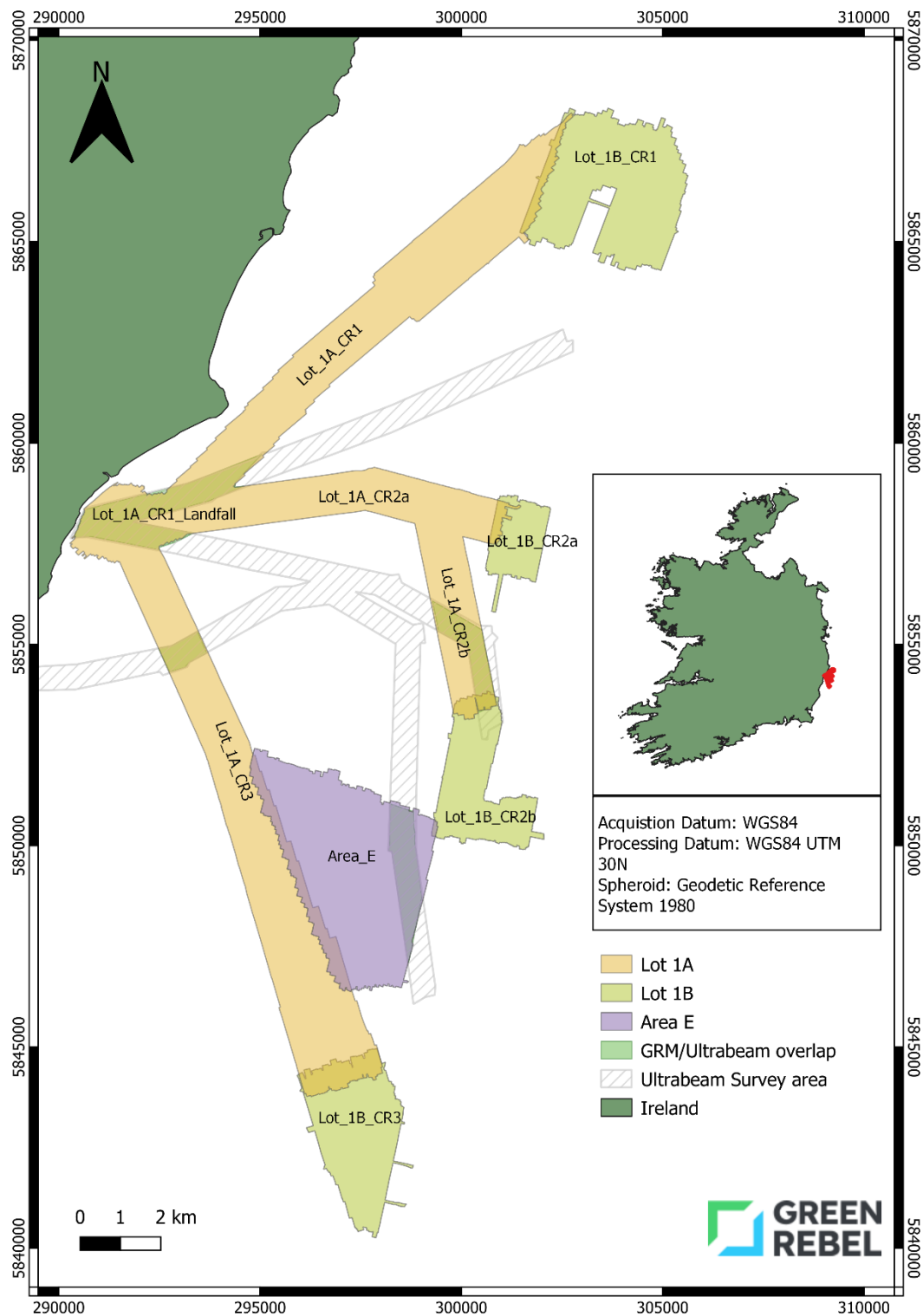


Figure 1: The Arklow Bank Wind Park geophysical survey area (MBES, MBES BS, SSS, Magnetometer, SBP). Grey hashed area displays coverage from the previous Ultrabeam geophysical survey in 2019 with the overlap to the Green ABWP 2022 survey highlighted. Each Lot from the survey is annotated for reference to data examined in this report.

1.1 Survey Objectives and Scope of Work

The objectives of the survey are described in the “Purpose of Investigation” in the Scope of Work (SoW). The desired outcomes of the project as stated in the SoW include:

- Identify and map potential geohazards.
- Facilitate the development of a ground model.
- Provide data and information in support of Environmental Impact Assessment reporting.
- To allow preliminary turbine placement.
- To provide relevant seismic information to inform Cable Burial Risk Assessment (CBRA).

To achieve these outcomes, the data deliverables outlined in Table 1 were stipulated by the technical specifications.

Table 1: List of main data deliverables (Additional deliverables specified in the data matrix)

Type	Description	Resolution (m)	File
Position	Tracklines for each sensor	NA	*.shp
Multibeam Bathymetry	LAT-corrected, post-processed, IHO 1a bathymetric grid	0.3	*.tif, *.xyz
Multibeam backscatter	Multibeam backscatter grid	0.3	*.tif, *.xyz
Side-scan sonar data	Single line data corrected for navigation (including heading) with no additional processing applied	NA	*.xtf
Side-scan sonar mosaic	Processed side-scan sonar grid	0.2	*.tif
Magnetometer	Processed magnetometer grid (total field)	0.5	*.tif, *.grd
Magnetometer	Processed magnetometer grid (residual field)	0.5	*.grd
Magnetometer	Processed magnetometer grid (depth)	1.0	*.grd
Magnetometer	Processed magnetometer grid (altitude)	1.0	*.grd
Sub-bottom profiler data	Raw sub-bottom profiler data	NA	*.raw, *.ses3
Sub-bottom profiler data	Processed sub-bottom profiler data in time	NA	*.sgy
Side-scan sonar target list	Target list of selected contacts from side-scan sonar data to include Target ID, X, Y, Contact Type	NA	*.xlsx
Mobilisation Report	Presented to CSR within 48 hrs of mob completion.	NA	*.doc, *.pdf
Survey Operations Report	Completed within 1 week of survey completion.	NA	*.doc, *.pdf
Data Acquisition, Processing and Interpretation Report	To include full details of processing and interpretation results.	NA	*.doc, *.pdf
Chart	Bathymetry with contours	NA	*.pdf
Chart	Seabed features and contacts	NA	*.pdf
Chart	Isopach map	NA	*.pdf
Chart	Cross profile through the data with horizons and bathymetry	NA	*.pdf
Chart	Multibeam backscatter	NA	*.pdf

1.2 Variations from the SoW

Table 2: Summary of variations from the SoW

Reference Number	Description	Cause
ABWP-Var-002	Operations with SSS, SBP and, Magnetometer instruments to align only with the initial UHRS survey (500m line spacing). This variation reduced the data acquired.	ABWP request.
ABWP-Var-004	ALARP – Additional data processing and interpretation of potential geohazards including: producing high resolution bathymetric grids, side-scan sonar grids and magnetometry at a higher resolution than previously outlined in initial scope of works.	ABWP request for derisking upcoming geotechnical operations.
ABWP-Var-006	SBP horizon interpretation – Additional processing and interpretation including: picking horizons, creating isopach maps and elevation grids previously not outlined in initial scope of works.	ABWP request.

1.3 Reference documents

Table 3: Summary of referenced documents

File name	Title	Author
Part 2.1 Geophysical Survey - Scope of Work - ABWP rev02	Scope of works	ABWP
Part 2.2 Geophysical Investigation – Technical Specification rev02	Technical specifications	ABWP
220315_Project_Execution_Plan_SSE_ABWP_Rev0.1	Project execution plan	GR
Mobilisation_and_Calibration_Plan_001	Mobilisation and Calibration Plan	GR
GRM_22G03_RR_ABWP_MOB-Report_003	Mobilisation Report	GR
220626 EN_Operations Report	Operations Report	GR

1.4 Summary of Findings

Table 4: Summary of findings, including metadata, quality, results, interpretations, and potential hazards.

Acquisition	
Survey Dates	28 th of August to 4 th of November 2022
Geophysical systems used	Multibeam echo sounder (MBES), multibeam backscatter (MBES BS), side-scan sonar (SSS), magnetometer (MAG), sub-bottom profiler (SBP)
Bathymetry	
Water depths range from -1.99 m to -48.13 m. The site is characterised by a relatively flat bathymetric surface with isolated glacial and anthropogenic features such as eskers and shipwrecks. Localised gradients exceeding 86° were observed in areas of seafloor bedforms and sites where debris is potentially present. Backscatter values were simultaneously recorded during bathymetric acquisition and gridded to a resolution of 0.3 m allowing for a non-invasive sediment classification.	
Seafloor Morphology	
Several morphological features were observed in the site, including: a large presence of sand sandwaves, occasional megaripples and isolated incidents of glacial scars.	
Substrate Type	
The seabed surface substrate is interpreted to consist of marine sands, muds and gravels. Sheets of mobile sandy drifts are also present across the proposed site. Noteworthy estimates about geological substrates present in the area, cannot be deemed reliable without a geotechnical investigation and dedicated sediment sampling campaign.	
Seafloor Sediments	
The ABWP survey area shows predominant facies of medium to coarse – gravelly sands, where it can be assumed higher current velocities are present. In the south-central ABWP survey area, there is a low incidence of sandwaves or megaripples, suggesting a lower current velocity supported the presence of finer-grained facies-type clays to sandy clay. Noteworthy estimates about seafloor sediments present in the area cannot be deemed reliable without a geotechnical investigation and dedicated sediment sampling campaign.	
Seabed Targets and Potential Site-Specific Hazards	
Wrecks	10
Debris	56
Boulders and coarse material	6465 boulders
Other targets	122 sonar contacts (unidentifiable), 2 pipeline, 3 linear contacts
Mobile Seafloor sediments	Sandwaves with heights ≤ 1 m and wavelengths ≤ 10 m cover 7.44% of the site, whereas megaripples with heights ≤ 10 m and wavelengths ≤ 200 m 0.4% of the site, respectively. Of the sandwaves and megaripples recorded, most trend NW-SE. The

	sandwaves are often superimposed on the megaripples. Obstacle-induced, local seabed scour is observed around shipwrecks and boulders.
Geological Features	
Boulders, cobbles and gravel	Glaciomarine sediments were prominent throughout the site. A high concentration of boulders and boulder fields were present throughout.
Potential Hazards	
Steep gradients	Areas of localised steep slopes are present. Slopes up to 35° were identified on bedforms (megaripples), and steeper gradients were found to be associated with anthropogenic targets (i.e. shipwrecks).
Mobile sediments	Sandwaves and mega-ripples are common in the site and suggest an active hydrodynamic regime.
Shipwrecks	10 shipwrecks were identified in the datasets
Magnetic anomalies	975 Monopoles, 34 Dipoles and 135 Complex

2 Data Acquisition and Processing

The site was surveyed using the *MV Roman Rebel* and *Lady Kathleen* (Appendix 3). Mobilisation, calibrations, trials and verifications of both vessels took place in Cork Harbour (Co. Cork) and were completed at the survey site (Arklow Bank, Co. Wicklow). Surveying commenced on 28/08/2022 and lasted a period of 69 days, concluding on the 04/11/2022. The mobilisation is documented in the Mobilisation Report and survey activities are documented in the Operations Report (Table 3).

2.1 Surface and sub-surface positioning

2.1.1 Surface Positioning

2.1.1.1 *Roman Rebel*

All survey positioning and navigation data were recorded via a primary and independent secondary GNSS antenna for redundancy and QC. The primary antenna used was an Oceaneering C-Nav 3050 receiver which used Precise Point Positioning (PPP) via C-NavC² corrections to achieve 5 cm horizontal and 20 cm vertical accuracy. PPP is a global precise positioning service using the available GNSS system. A PPP solution depends on GNSS satellite clock and orbit corrections, generated from a network of global reference stations. Once the corrections are calculated, they are delivered to the end user via satellite or over the Internet. These corrections are used by the receiver, resulting in decimetre-level or better positioning with no base station required. C-Nav data are logged and monitored continuously in QINSy as well as the C-Nav RINEX which provides a live display of height error. C-Nav logs files in a *.cnav 3050 format which can be subsequently interrogated by C-Proc, a software made to extract C-Nav QC statistics.

2.1.1.2 *Lady Kathleen*

All survey positioning and navigation data were recorded via a primary GNSS antenna. Two antennas used were a Trimble AT1675-540TS receiver which used VRS Now via Trimble corrections to achieve 2 cm accuracy. VRS is a provides real-time differential corrections to a GNSS system. A VRS solution depends on data from several permanent reference stations to compute corrections that are generally more accurate than corrections from a single reference station. Once the corrections are calculated, they are delivered to the end user via satellite or over the Internet. VRS data are logged and monitored continuously in QINSy.

2.1.2 Sub-surface positioning

2.1.2.1 *Roman Rebel*

Towed sensors were positioned via Kongsberg uPAP USBL with an accuracy of $\pm 0.44\%$ of the slant range. Overall, the USBL tracked the positions of towed bodies well. However, isolated, localised deviations were observed. Minor navigation wobbles and inconsistencies (causing up to 20 m offsets) are common with USBL systems and easily influenced by environmental factors (cf. Li et al., 2018). This is typical and can be rectified in post-processing to ensure that geographic accuracy of 2 m can be attained in accordance with project specifications.

Sub-surface position navigation data were parsed online with the associated survey files (*.jsf and *.txt). These navigation data were processed as initial processing steps for each specific workflow separately (details in sections 2.6.2).

2.1.2.2 *Lady Kathleen*

Towed sensors were positioned via a iXblue GAPS M5 GAPS MMI with an accuracy of $\pm 0.2 - 0.5\%$ of the slant range. Overall, the USBL tracked the positions of towed bodies well. Like the Roman Rebel, deviations occurred which is common especially in shallower banked or shoreline areas where the Lady Kathleen would have surveyed. Again, this is typical and can be rectified in post-processing to ensure that geographic accuracy of 2 m can be attained in accordance with project specifications.

2.1.3 *Tidal Reduction Methodology*

Vertical correction were applied to the data in real-time via Quality Integrated Navigation System (QINSy) using the PPP system on the Roman Rebel and the VRS system on the Lady Kathleen. All data were then reduced specifically to Lowest Astronomical Tide (LAT). To do this, the UCL and UKHO product, Vertical Offshore Reference Frames system (VORF) was used. The VORF project allows to seamlessly transform vertical height information to other common coastal and offshore levels within the Irish and UK 12 nautical mile zones.

2.2 Multibeam bathymetry data (including tidal reduction methodology)

2.2.1 Data acquisition

2.2.1.1 Roman Rebel

Bathymetric and acoustic backscatter data were acquired using two hull-mounted Reason SeaBat T50-R multibeam echosounders (MBES). Each MBES transceiver produces 1,024 beams per ping and can operate from 190 to 420 kHz. During the SSE ABWP survey operations the MBES was operated typically at a frequency of 400 kHz. Opening beam angles were set to 60–65 degrees. The sonar heads were integrated with a real-time sound velocity sensor, an iXBlue HYDRINS inertial navigation system and two independent GNSS antennas (C-Nav and Hemisphere).

Data were acquired in a boustrophedonic, gridded survey design, roughly parallel to depth contours. Survey speed was approximately 4.5 knots. Sound Velocity Profiles were acquired at a minimum of every 12 hours but always whenever clear changes were observed in sound speed recordings (QINSy alarm set to sound velocity changes greater than 2 m/s). A Valeport Swift sound velocity profiler was used for SVP casts and a total of 74 profiles were recorded during acquisition. Data acquisition was managed in QINSy which was also used visualise raw data and construction of *.db files with raw multibeam data. All data were stored on a dedicated offshore data server.

2.2.1.2 Lady Kathleen

Bathymetric and acoustic backscatter data were acquired using a single hull-mounted Reason SeaBat T50-R multibeam echosounder (MBES). The MBES transceiver produces 1,024 beams per ping and can operate from 190 to 420 kHz. During the SSE ABWP survey operations the MBES was operated typically at a frequency of 400 kHz. Opening beam angles were set to 60–65 degrees (or adapted for shallow depths). The sonar head was integrated with a real-time sound velocity sensor, a Teledyne Type-30 IMU and integrated Applanix INS (inertial navigation system) and two independent GNSS antennas (Trimble AT1675-540TS).

Data were acquired in a boustrophedonic, gridded survey design, roughly parallel to depth contours. Survey speed was approximately 4.5 knots. Sound Velocity Profiles were acquired at a minimum of every 12 hours but always whenever clear changes were observed in sound speed recordings (QINSy alarm set to sound velocity changes greater than 2 m/s). A Valeport Swift sound velocity profiler was used for SVP casts and a total of 101 profiles were recorded during acquisition. Data acquisition was managed in QINSy which was also used visualise raw data and construction of *.db files with raw multibeam data. All data were stored on a dedicated offshore data server.

2.2.2 Processing workflow

Multibeam bathymetric data show water depth and seabed morphology. These data are interpreted to accurately measure water depth, seafloor features and seabed structure. Raw multibeam echosounder data were acquired and stored in a series of QPS *.db files. These files contain the raw sounding, GNSS, attitude and applied sound velocity data. As such, data processing were required to merge these data, remove or correct anomalous data, create a bathymetric surface corrected to a

defined vertical reference system, confirm that the data conforms with IHO standards and export the data in a transparent and GIS-friendly format. The general processing workflow is outlined in the Project Execution Plan (Table 3).

The *.db files were imported to QPS Qimera which converts the data to a proprietary (*.qpd) file format. From the *.db files, sound velocity, vessel and offset values are automatically read into the project. The processing parameters were defined to ensure that the sound velocity strategy is in accordance with the surveyed strategy, that the attitude values are applied from the correct source from the *.db file as well as GPS tide and the correct separation model. A raw surface was then created using these processing parameters. Vessel configuration was checked for any clear deviations from those set during acquisition. Nearest in time sound velocity profile casts are selected in Qimera to reduce the possibility of interference or data spikes. Surface and profile sound velocity data were then inspected for anomalous data values and spikes which are subsequently removed. Although vertical errors within the GPS heights were low (± 15 cm), navigation data were smoothed in QPS Qimera where appropriate. The raw bathymetric surface was then colour coded based on uncertainty (95% confidence interval) with a standard range of 0 to 0.4%, to view areas of high-sounding standard deviation.

Large data spikes from sonar interference (sound sources with similar frequency values), poor weather or other, were manually removed using the 3D editor mode. Small areas of excessive weather noise were also observed, and a medium spline filter was applied to reduce the noise, before further manual cleaning. The results of filtering were carefully examined by qualified data processors. This strategy allows for a reconnaissance of the data while offering the ability to remove the majority of the erroneous data. Subsequently, the data were cleaned using the more precise swath and slice editor modes. This allowed for thorough and differential cleaning options depending on the morphology of the seabed and intensity of noise. In areas with upstanding, anthropogenic seabed features (wrecks, pipelines, infrastructure), data were examined and cleaned with utmost caution.

If high standard deviation values remained in the outer beams or line overlap, then the data were interrogated further. If this error was related to sound velocity, a series of checks were performed: i) re-inspection the surface and profile sound speed data and smoothing/despiking if required; ii) application of a refraction edit ($\pm 1 \text{ ms}^{-1}$ at 1 m water depth) and/or; iii) application of QPS's TU Sound Speed Inversion algorithm which utilises neighbouring soundings to determine the 'best-fit' sound speed refraction solution that minimises sounding mismatch in areas where there is sufficient overlap.

All data were corrected to LAT using the VORF separation model. Total Horizontal Uncertainty (THU) and Total Vertical Uncertainty (TVU) were computed for each sounding within the dataset. These were used for quality control purposes to ensure that the data is within client-specified limits. A further surface was created to ensure adequate sounding density. Finally, cross lines, which are independent of the surface grid were cross checked with the grid. This check, carried out in Qimera's cross check tool, generated a table of statistics that provide the results of the analysis of beam footprint values within the processed surface.

On inspection of the data and ensuring that the data meet the required IHO survey specifications, the data were exported. Initially, *.gsf as well as *.asc, *.tif and *.xyz files were exported comprising the

backscatter and bathymetric surface data, respectively. The LAT-reduced, cleaned bathymetric data was then inspected in ArcMap v.10.8.1. A simple, focal neighbourhood average interpolation was applied to the 0.3 m gridded tiffs, interpolating data only in the places where minor pixel-sized data gaps were observed. Areas where larger gaps were present due to fishing gear obstacles were not interpolated.

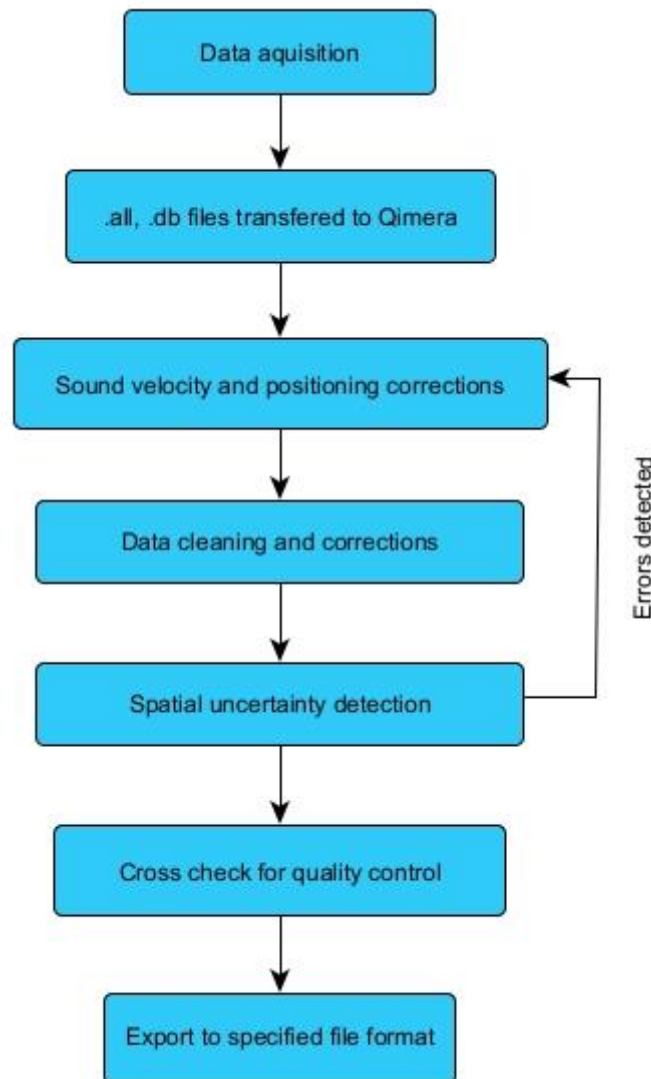


Figure 2: General multibeam echo sounder data processing workflow for corrected bathymetric grids

2.2.3 Coverage

Multibeam echosounder swath coverage was optimised for sounding density to ensure that depth-induced swath width changes do not cause unnecessary fluctuations to sounding density. This ensures that all pixels on the final bathymetric surface were binned based on a similar number of soundings. Furthermore, it facilitates consistent data quality when sea state is less favourable.

To do this, an alarm was set in QPS QINSy to note considerable sounding density changes and the swath was subsequently adjusted based on the discretion of the senior surveyor. Given that water

depth throughout the ABWP survey only ranges from -1.99 m to -56.52 m, swath width remained relatively constant. Recorded swath width ranged significantly due to depths and was approximately 18 m on the bank and up to 70 m in deeper areas. Figure 3 demonstrates swath width and water depth in cross track data.

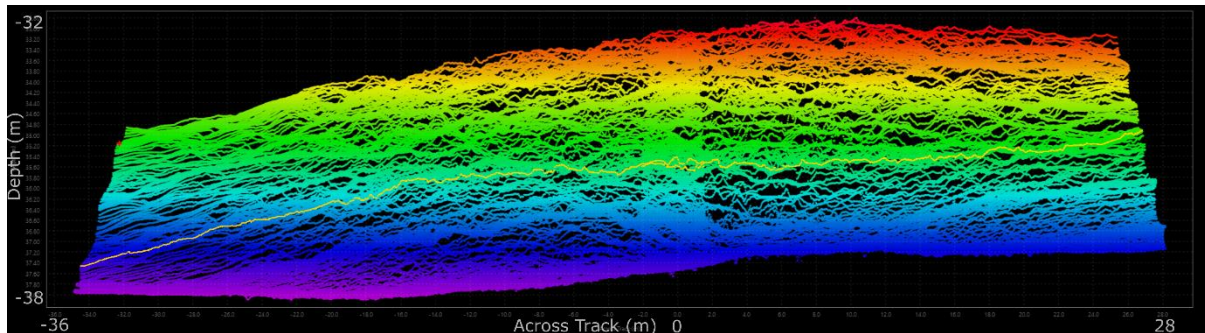


Figure 3: PLOT showing typical raw cross track sounding profile from the Roman Rebel on several both port and starboard side multibeam echosounder pings merged (Note: overlap of swaths in centre) during the ABWP survey. Note: water depth (-38 m) and swath width (64 m). Data are colour coded by water depth.

Using the swath coverage strategy outlined above, an area of approximately 91 km² was surveyed by multibeam in the ABWP survey area (Figure 4). The coverage consisted of a series of parallel, broadly east-west oriented lines and 17 cross lines perpendicular to these survey lines. These cross lines were used in the final assessment of the post-processed data to confirm product quality in terms of accuracy.

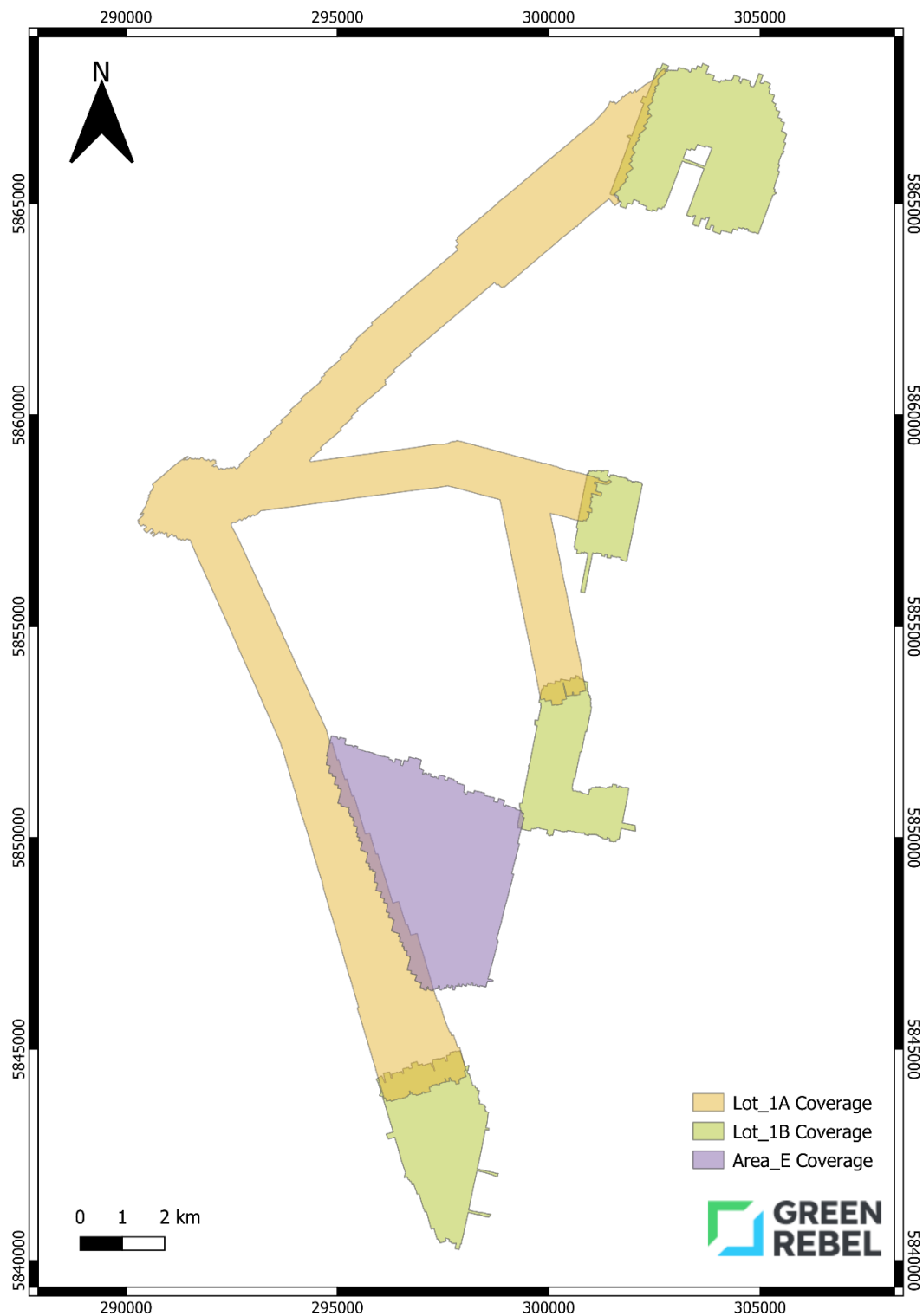


Figure 4: Map showing the total survey coverage during the initial ABWP survey.

2.2.4 Positioning accuracy

The surface positioning quality during field operations met the required project's specifications, as documented in the Mobilisation Report (Table 3) and these data provided positioning for the

multibeam. The accuracy of this system is apparent with visual inspections of neighbouring lines in the raw data. This assessment shows consistent vertical alignment of sounding overlap (Figure 5).

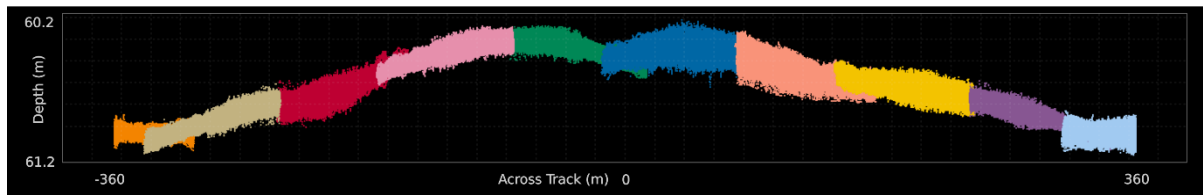


Figure 5: PLOT showing a typical across track bathymetric data to highlight the vertical 'matching'/positioning of the raw data acquired with the primary GNSS antenna (Vertical Exaggeration: x50.2)

2.2.5 Sound velocity control

Sound velocity was measured both at the multibeam transducer as well as through the water column via sound velocity profiles. Sound velocity profile values are required to calibrate the multibeam-derived sounding values for speed of sound in water. These data enabled accurate calculation of bathymetric values.

Sound velocity profiles were recorded at a minimum of every 12 hours or by the discretion of the senior surveyor. A total of 86 sound velocity profile casts were acquired during survey operations, (37 Roman Rebel and 49 Lady Kathleen). Surface sound velocity values measured at the multibeam transducer head were continuously measured and monitored by the acquisition software (i.e. QPS QINSy). When QINSy measures a difference between the sound velocity at the transducer (Figure 6) and in the profile, an alarm is set off. When this happens, a new sound velocity profile is recorded. This cautionary procedure ensured that the sound velocity value was updated whenever there was any considerable change in the physio-chemical properties of the underlying water mass. Particular care was taken in environments/situations that were likely to influence sound velocity changes (e.g. heavy rain fall, nearby estuaries, harbours, surface water influx).

Figure 6 shows a sample of typical sound velocity values recorded during the ABWP survey. Sound velocity profiles measured during the survey period reveal minor fluctuations in these profiles with depth, indicating that local variation is abundant in the upper layers.

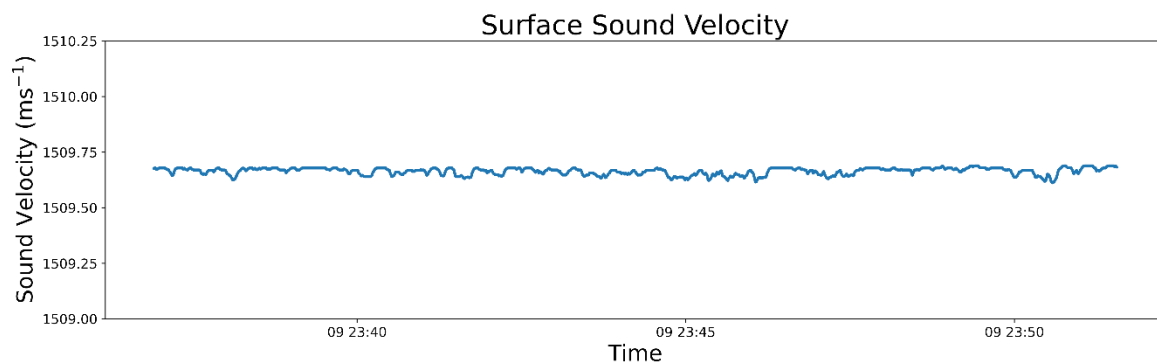


Figure 6: Representative example of surface sound velocity measurements recorded during survey operations ($\pm 0.4 \text{ ms}^{-1}$ variation over a 30-minute period)

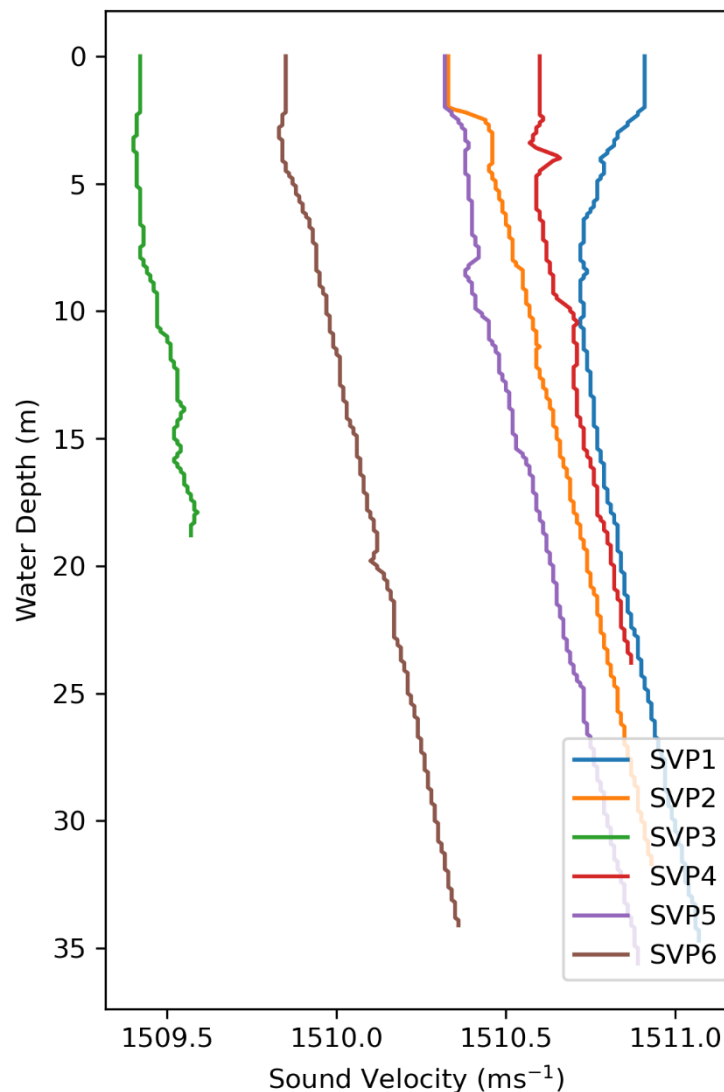


Figure 7: Representative sound velocity profiles acquired during the Area_E survey period during the ABWP survey

2.2.6 Sounding quality

Multibeam echosounders record acoustic energy using a transducer. As such, they are sensitive to noise that can be expressed in the resulting raw data. This is a common phenomenon and can be the result of either direct impact between air bubbles and the transducer when sea states are less favourable, biofouling, or interference by acoustic energy that is similar in frequency to that of the multibeam (400 kHz). Green Rebel has completed testing to optimise survey parameters for minimal across-sounder interference. However, it is impossible to eliminate these artefacts completely. Noise and artefacts expressed in the raw multibeam bathymetric data during the ABWP survey operations are uncommon and when they do occur, they are minor (Figure 8). These anomalous soundings are clear and obvious in the raw datasets and can be removed when the data are processed.

One possible measure of multibeam data quality is sounding density. To assess this, the density of soundings per 1 m cell were measured and values range from 1 to 1,636 soundings per 1 m cell. The mean number of soundings in the raw bathymetric data are 47 per 1 m cell. Traditionally, a minimum of 9 soundings per 1 m cell are required for IHO standard Order 1a. As such, sounding density is well within the range to achieve the final product specification after post-processing.

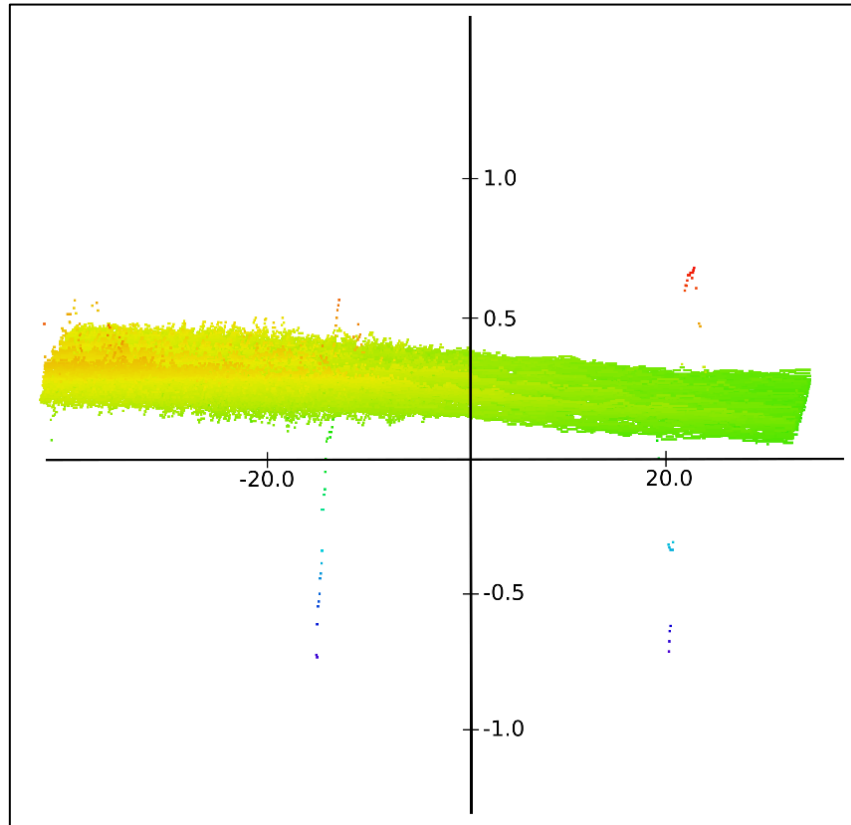


Figure 8: Sample of typical noise artefacts recorded by the multibeam echosounder and expressed in the sounding data. Note: units in meters and vertical exaggeration of x22.78.

2.2.7 Data quality

2.2.7.1 Roman Rebel

The processed multibeam echosounder-derived bathymetric data achieves the required specifications IHO Order 1a. Criteria for Order 1a standard include feature search (100%), bathymetric coverage (100%) and maximum allowable total vertical uncertainty (TVU). To calculate TVU, (Equation 1 is utilised:

(Equation 1)
$$TVU_{max}(d) = \sqrt{a^2 + (bd)^2}$$

Where a is the proportion of the uncertainty that does not vary with depth (0.5 m), b is a coefficient which represents that portion of the uncertainty that varies with depth (0.013) and d is the measured

water depth (m). Table 5 shows the test results used to determine if the data acquired during the ABWP survey achieved the level of accuracy required for IHO Special Order.

Table 5: Multibeam bathymetric data cross check results

Attribute	Value		
	Lot 1A	Lot 1B	Area E
Special Order Error Limit	0.270377	0.31902	0.35033
Special Order # Rejected	59247	785535	3123
Special Order P-Statistic	0.00316651	0.00534795	1.92779e-05
Special Order Test	ACCEPTED	ACCEPTED	ACCEPTED
Number of Points	18710509	146885261	161999165
Grid Cell Size	0.300	0.300	0.300
Difference Mean	0.030	-0.000	-0.009
Difference Median	0.023	-0.004	-0.010
Difference Std. Dev	0.066	0.074	0.039
Difference Range	[-5.954, 2.820]	[-29.190, 5.862]	[-2.466, 1.441]
Mean + 2*Std. Dev	0.161	0.149	0.087
Median + 2*Std. Dev	0.155	0.153	0.088
Data Mean	-13.700	-26.424	-32.732
Reference Mean	-13.730	-26.424	-32.723
Data Z-Range	[-21.226, -9.060]	[-54.557, -3.251]	[-39.797, -23.437]
Reference Z-Range	[-16.463, -9.153]	[-44.534, -3.312]	[-39.456, -23.576]

Online quality control inspections were performed during acquisition by the lead surveyor to ensure a high-density (40) of soundings per 1 m cell. This was confirmed in post-processing where the final sounding grid had a minimum of 1 sounding per 1 m bin (near empty cell due to noise), a maximum of 2303 soundings per 1 m bin and a mean of 227 soundings per cell. For transparency, this is visualised below (Figure 9) and highlights the quality of the final bathymetric data.

Navigation data were logged in standard C-Nav format which were integrated within the raw QINSy database files. Real-time positioning data quality from C-Nav was of sufficient quality to achieve IHO Special Order standard requirements. Vertical errors within GPS heights were low (± 7 cm) and provide a robust solution for computation of GPS tide. GPS tide was computed using the separation model between World Geodetic System 1984 (WGS84) datum and VORF LAT.

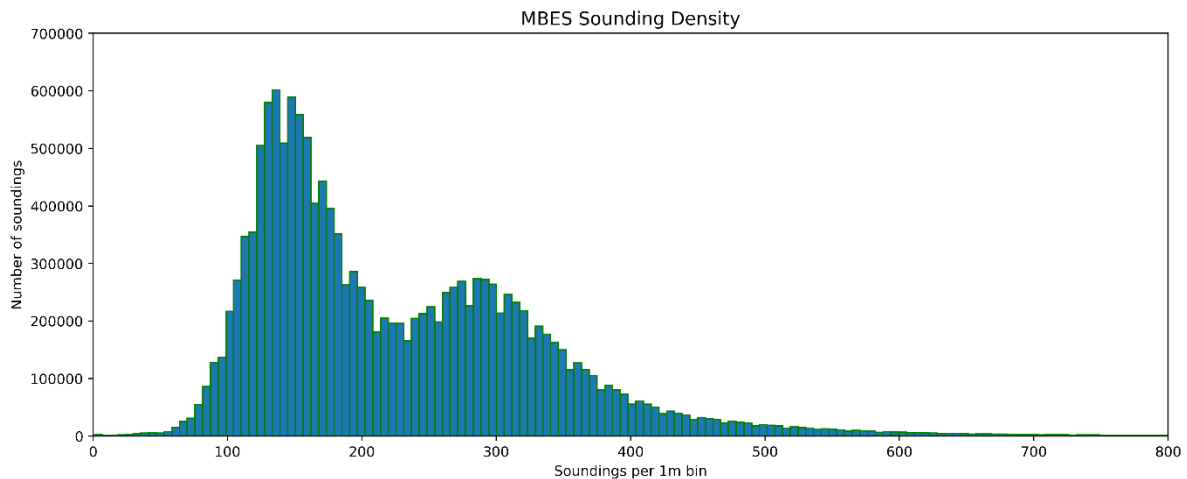


Figure 9: Histogram showing the number of soundings per 1 m bin within a representative bathymetric surface

Overall quality control of the data was completed by generating a QPS Qimera Dynamic surfaces from all MBES sonar data within the ABWP survey area. The dynamic surface was created with a range of parameters used to assess the data and ensure it falls within specification. The uncertainty at 95% confidence interval was assessed in order to highlight areas where the vertical spread of soundings within a DEM grid are high and checks can be made to determine the cause. Areas within this layer that coincide with high standard deviations can occur where there are sound velocity errors, errors in the navigation, or when acquiring data in heavy weather and where there is a change in seabed relief such as boulder fields. The varying vertical shift tool was utilised to reduce standard deviation in depth values of adjacent lines ensuring an accurate representation of seabed morphology.

Figure 10 shows the uncertainty of the final bathymetric sounding grid at the 95% confidence interval. These data show that the uncertainty is typically < 0.03 m and typically do not exceed 0.1 m although in rare circumstances there are higher standard deviations (up to 7.1 m) around small seabed features that occur in the outer beams where higher beam scattering occurs. Nevertheless, the mean and modal uncertainty are 0.049 and 0.03 m respectively, which demonstrates the quality and consistency of the overall 1 m grid. This is plotted spatially in Figure 10, which shows the spread of uncertainty data between 0 and 0.4 m. In addition, a longitudinal cross section through the surface shows that the data are vertically well-aligned (Figure 11). No clear and obvious vertical offsets were observed.



Figure 10: Multibeam bathymetric surface uncertainty (95% c.i.) and a cross profile showing the vertical alignment of adjacent survey lines (A-A'-B)

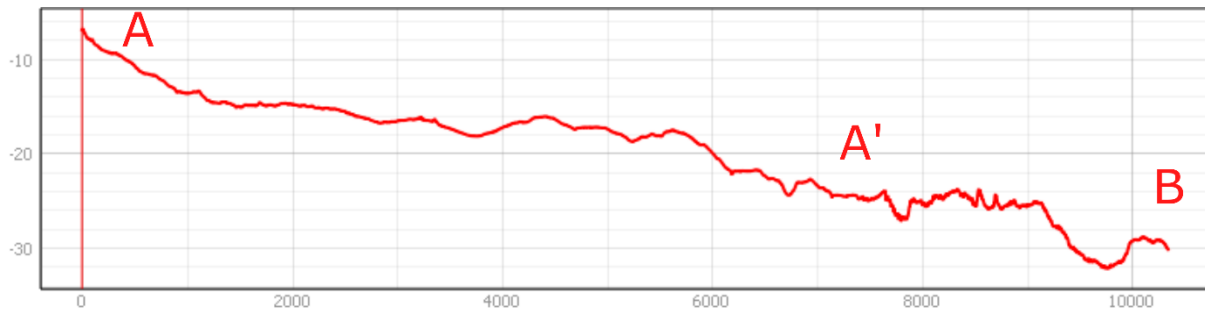


Figure 11: Cross section A – A' – B as seen in Gr. Note: the vertical distribution of lines matches well.

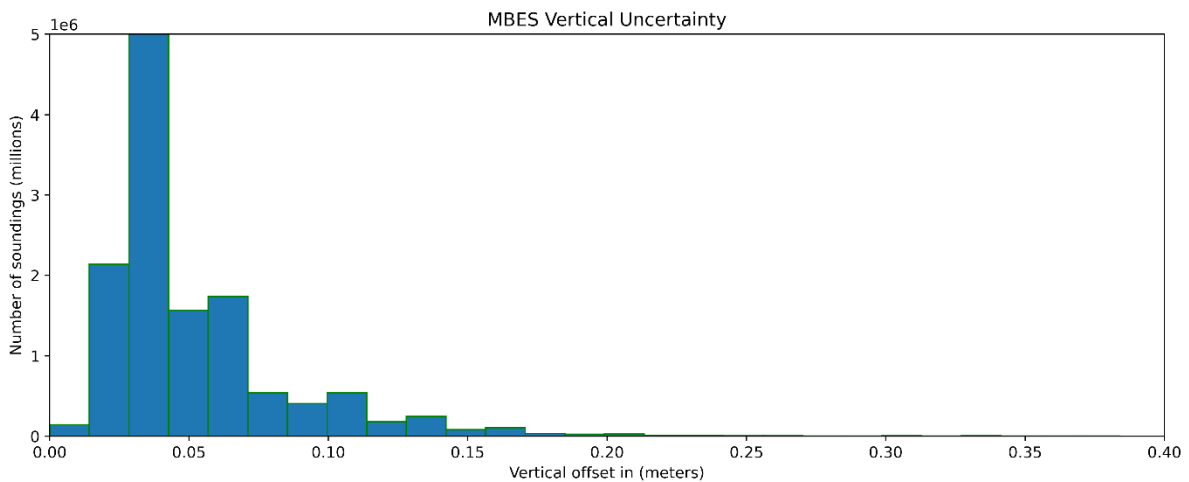


Figure 12: Histogram showing the vertical offset for each 1m cell in a representative area (Note: values do not exceed 0.35 m).

2.2.8 Final product

The final bathymetric grid was exported at 0.3 m per pixel as specified in the scope of works. The final bathymetric product was clean, exceeding all industry standard tests as previously outlined. No artefacts or issues are observed with the final bathymetry product (Figure 13).

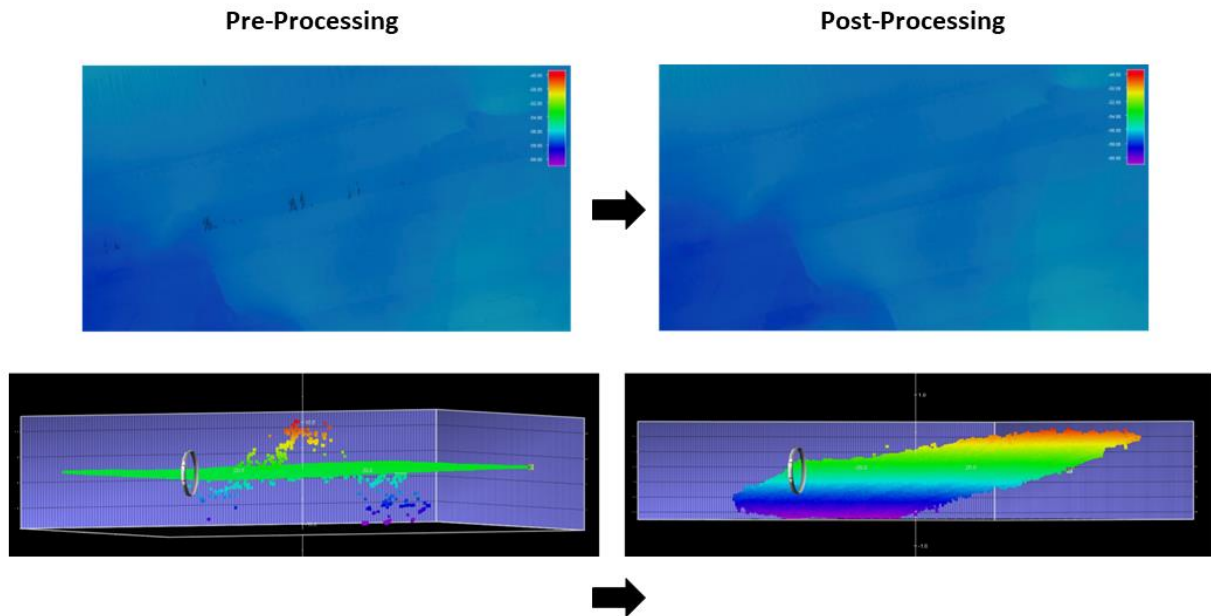


Figure 13: Comparison of pre- and post-processed bathymetric grids and respective point clouds.

2.3 Multibeam backscatter

2.3.1 Data acquisition – RR and LK

Multibeam backscatter strength data depend on seabed hardness and roughness. Interpretations of these data are typically carried out to describe seabed composition and texture. The aim of multibeam backscatter data processing is to combine all sonar data into a backscatter mosaic depicting intensity (decibels) in a GIS-friendly format. To do this, the multibeam *.db files were exported as a series of generic sensor formatted files (*.gsf) from Qimera. These files were then imported into QPS's GeoCoder Toolbox (FMGT). The Geocoder algorithm removes all the gains used during acquisition and applies a series of radiometric and geometrical corrections to the original acoustic observations to obtain a correct value of backscatter strength (Fonseca et al., 2009). To do this, all sonar parameters were defined (number of beams, frequency, etc.). Any cross lines were removed to reduce the presence of artefacts in areas that already have pre-existing coverage within the project.

2.3.2 Processing workflow

The intensity of each ping was read by the algorithm which subsequently normalised them to account for variability (beam angles, vessel motion/weather, along track variability, etc.). The resulting data were coloured and plotted. This shows seabed spatial variation recorded during the survey leg. The gridded backscatter mosaic was then exported as a raster (*.asc ArcView Grid and *.tif GeoTiff) which corresponds to XYZ where X and Y are co-ordinate notation and Z is backscatter intensity in decibels. Throughout this report, references to backscatter refer to relative backscatter strength.

The processed bathymetric dataset was exported in a generic sensor format (*.gsf) and processed to create a single, backscatter-standardised gridded dataset. The specific aim of this processing was to

create a map of comparable acoustic seafloor backscatter values that clearly delineates seabed features and sediment boundary types. To quality control the data in the context of this aim, the mosaic was inspected to ensure that the sediment boundaries between different survey lines were well characterised with matching backscatter values between different lines and survey legs. The main problem with these data were along-line backscatter shifts which were either time-varying or constant. These issues were easily resolved through the application of a full line backscatter adjustment, which applies a backscatter value offset to standardise backscatter values between adjacent lines. The resultant backscatter mosaic was inspected and determined suitable for the delineation of seabed features and sediment boundaries. The mosaic was tiled, exported (binned at 0.5 m) and coloured by backscatter value (Figure 14).

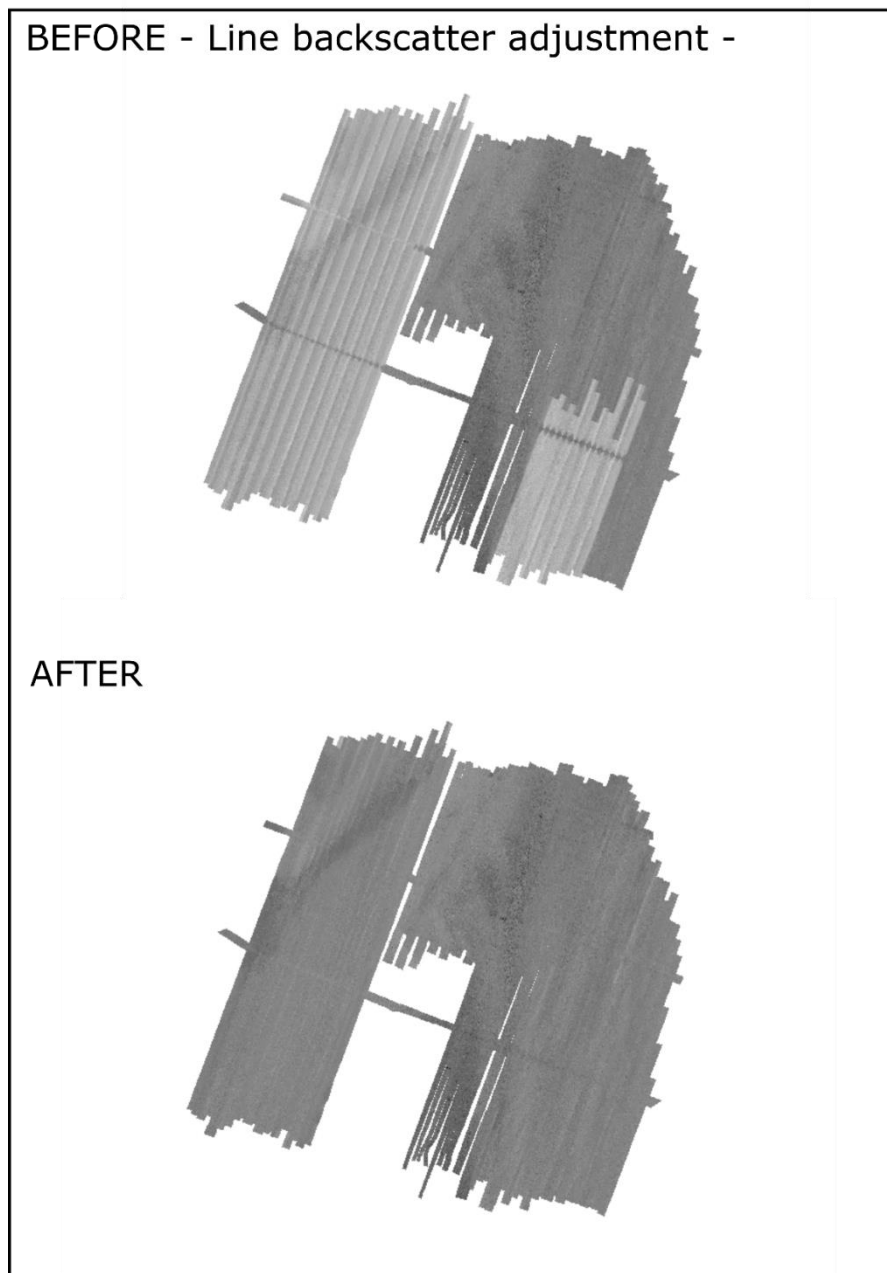


Figure 14: Before and after line backscatter adjustment to MBES BS files from ABWP CR1 Lot 1B

2.3.3 Angular Range Analysis (ARA) and Seabed Sediment Interpretation

Angular Range Analysis (ARA) was derived from MBES acoustic backscatter data using FMGT v. 7.10.1. This process allows for a multifaceted characterisation of the seafloor substrate type while maintaining a non-invasive survey status. These data can provide important information and context to planning for subsequent geotechnical survey operations beyond the insights possible from bathymetric data alone; it can be used to highlight areas where seabed substrate may be consolidated and could damage sampling equipment.

A beam-by-beam time-series of acoustic backscatter provided by the multibeam sonar was analysed. These backscatter values were then corrected for seafloor slope, beam pattern, time varying and angle varying gains including area of insonification, i.e. area flooded with controlled sound waves. From this, a series of parameters were calculated from stacking of consecutive time series over a spatial scale. Consequently, the acoustic impedance and the roughness of the insonified area on the seafloor could then be estimated (Fonseca and Mayer, 2009).

Following ARA, seabed sediments were manually delineated further by utilising MBES Bathymetry, MBES Backscatter and the subsequent backscatter derived ARA grid. Under this approach sediments were grouped into the most commonly occurring grain size categories based on values derived from ARA and backscatter intensity. These were; Medium Sand, Coarse Silt, Sandy Mud and Clay. Individual shapefiles of these sediment types were created.

2.4 Side-scan Sonar

2.4.1 Data acquisition – Roman Rebel and Lady Kathleen

Side-scan sonar (SSS) data were acquired with a deep-towed Edgetech 4205 side-scan. The fish was towed at approximately 7–8 m above the seabed, approximately 100 m behind the vessel. During acquisition, the fish was operated at two frequencies (230 and 850 kHz). Positioning for the SSS data on the Roman Rebel was acquired with a Kongsberg uPAP USBL (Ultra Short Base Line). On the contrary, positioning for the SSS data on the Lady Kathleen was acquired with the ixBlue GAPS USBL positioning system. Data acquisition was managed in Edgetech Discovery where range, frequency and file type were controlled. Logging of raw data were managed in QINSy which created a series of Logfiles as well as saved the *.jsf files storing the raw backscatter data including the USBL positioning, vessel position, time, date, cable out and heading.

2.4.2 Processing workflow

SSS systems measure the intensity of their returning signal. The aim of SSS data processing is to merge all sonar data, apply offsets and navigation correction (as required), and correct the sonar signal (gains and bottom tracking) to create a streamlined sonographic mosaic in a GIS-friendly format. To this end, all SSS data processing was carried out in SonarWiz v7.07. The general processing workflow is outlined in Figure 15. All raw SSS data are stored in *.jsf files (Edgetech proprietary file format) which include sonar data, vessel and fish XY position, cable out, fish height and frequency. As a backup, logfiles containing vessel and fish positions were exported in a *.txt file format from QINSy independently.

Navigation 300 ping smoothing was applied when files were imported into the SonarWiz project, limiting nav drops and swirls.

SSS *.jsf files were imported to SonarWiz which was set up to correctly read the correct fields from the file (USBL position and heading rather than vessel position). Once the data were imported, they were converted to a CTI proprietary processing file type (*.csf). When preliminary investigation showed that they plot correctly, each line was inspected for navigation. To do this, the navigation for each line was inspected and anomalous spikes were corrected using the interpolating tool in “Z editor”. The lines were inspected to determine the bottom tracking parameters for each line. Manual bottom tracking edits were applied if deemed essential. To enhance the sonographic imagery for subsequent analyses, at this stage, gains could be applied. Typically, Empirical Gain Normalisation (EGN) is applied which creates a dictionary of all amplitude data from all files and assesses them by distance from the sonar. This then creates a signature of the mean sonar signal. When applied to a full suite of survey lines, this is particularly useful for surficial geological features. During the processing workflow, it was determined that contacts were best captured using a black to bronze colour palette, where shadows are illustrated in black.

Geographic accuracy was measured by isolating each line and measuring the linear distance between multiple seafloor features that are seen in both the SSS line and the bathymetric data (collected by MBES, passing IHO Order 1a). Seafloor features of interest were typically boulders or rocky outcrops with visual characteristics that are easily identified. Attempts were made to ensure that the measurements are equally distributed near both ends of the SSS survey and at several points along the middle when possible. A minimum of 5 points was sought after from each line. However, if an area had little in the way of distinctive seafloor features, fewer points were used. If the average (mean) difference was 2 m or less, the line was considered geographically accurate and no geographic corrections were required. If the average error was greater than 2 m, map corrections were applied to georeference the SSS data to the bathymetry. After map corrections were made, the accuracy assessment process was repeated, whilst taking care not to measure the same seafloor features that the map corrections were based on. However, in some areas where distinctive seafloor features were rare, this might not be possible. With these amendments, the average difference is now less than 2 m, and the line with map corrections was accepted. If not, further map corrections and subsequent accuracy assessments were made. In the case of this project, the side-scan sonar data was categorized based on its level of quality after applying navigation corrections (see Figure 15). These are: **Category 1:** No map corrections were needed following an offset assessment. On these lines, an average assessment of at least 5 seafloor features (boulders, debris or unique bedforms) were made in the side-scan data and compared to the bathymetry data. The average offset of these points was now <2m; **Category 2:** Map corrections were needed following an offset assessment. On these lines, an average assessment of at least 5 seafloor features (boulders, debris or unique bedforms) were made in the side-scan data and compared to the bathymetry data. The average offset of these points was >2m. Map corrections were then applied, and the spatial offset of seafloor features were reassessed. Category 2 lines represent side-scan data which has an average offset of <2m following map corrections; **Category 3:** Map corrections could not rectify offsets between the side-scan sonar data and the bathymetry. Following map corrections, the average offset of these points was well above

>2m; and **Category 4:** These lines were unusable due to bad quality navigation data]. Sonar contacts were picked from Category 1 and Category 2 SS files, as they provide trustworthy navigation.

The processed sonar files from Category 1 and Category 2 data were then converted into a grid using the Inverse Distance Weighted algorithm. The final surface was then exported as a geoTiff (*.tif) at a resolution of 0.2m.

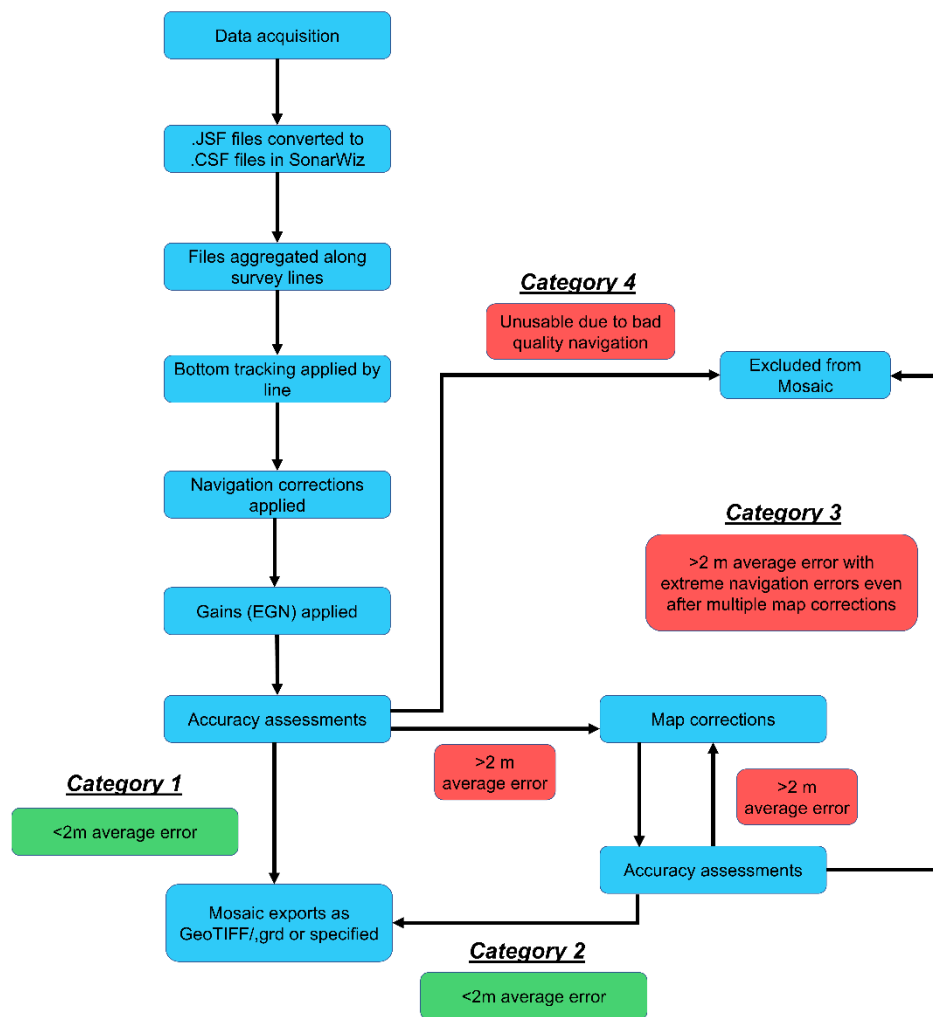


Figure 15: Green Rebel's side-scan sonar data processing and assessment strategy

2.4.3 Accuracy assessment and corrections

The SSS data were positioned with an accuracy of $\pm 0.44\%$ of the slant range. Overall, the USBL tracked the position of the SSS well, meeting the required specifications. However, isolated, localised deviations were observed (~ 30 m), particularly in Lot 1A. Minor navigation wobbles and inconsistencies are common with USBL systems and easily influenced by environmental factors (cf. Li et al., 2018; Figure 16). This is typical and can be rectified in post-processing to ensure that geographic accuracy of 2 m can be attained per project specifications. Minor navigation errors also correlate with rapid change in sensor depth when the cable is retrieved to avoid the fish crashing into a topographic high (anthropogenic and natural), as seen in Figure 17.

Momentary drops in USBL navigation (likely induced by drops in communication between transponder beacons) lead to incorrect interpolation of the data in SonarWiz. This forces the stretching of pixels to bridge the data drops (Figure 18), resulting in mosaic geographic errors over 100 m, in extreme examples. This was rectified in processing steps through the linear interpolation of data within USBL drops resulting in accurate mosaics. Without any navigation corrections, in areas where no navigation abnormalities were observed, the accuracy of the mosaicked raw data were generally within specification.

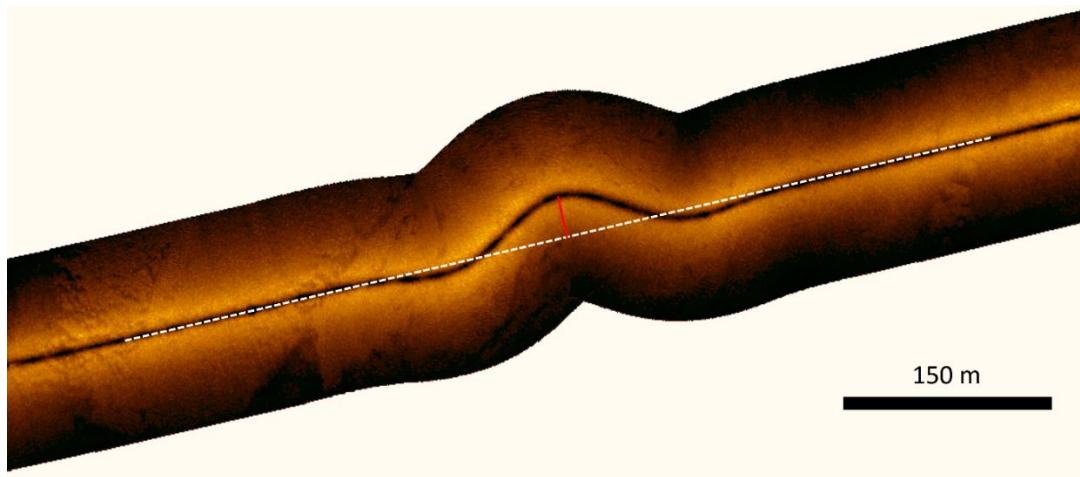


Figure 16: A singular mosaiced line showing poor navigation. The red line indicates a 30 m localised offset which was infrequent.

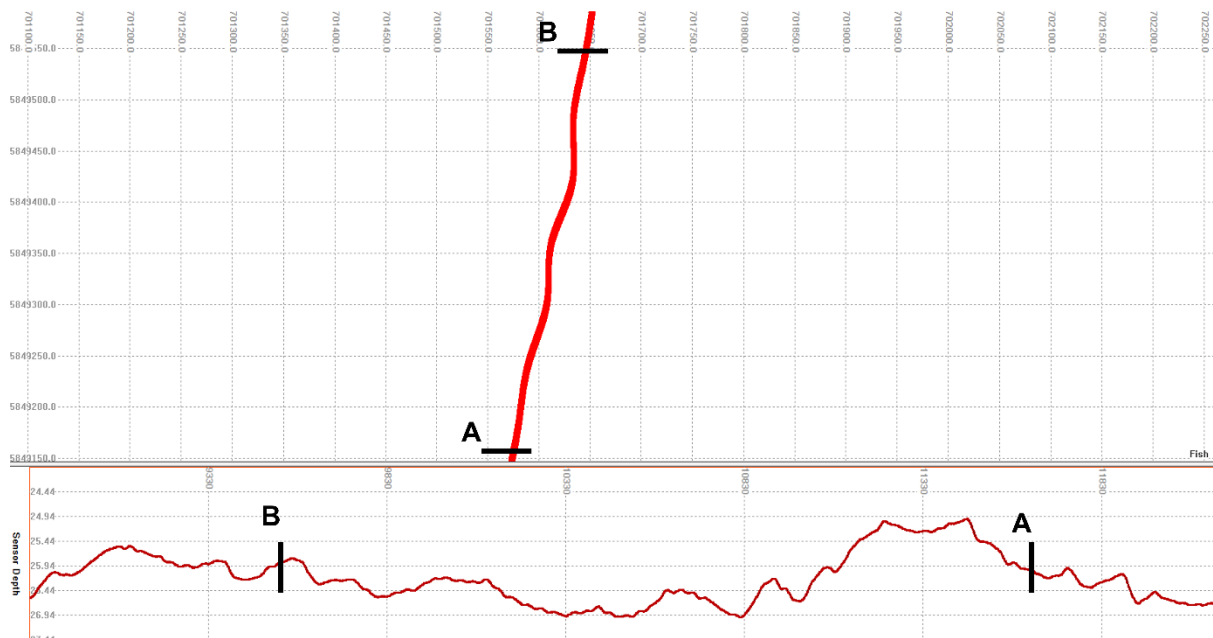


Figure 17: Navigation errors seen in the x y plot (top panel) broadly correlate with changes in fish depth due to local topography or contacts protruding into the water column which presented a potential collision hazard (bottom panel)

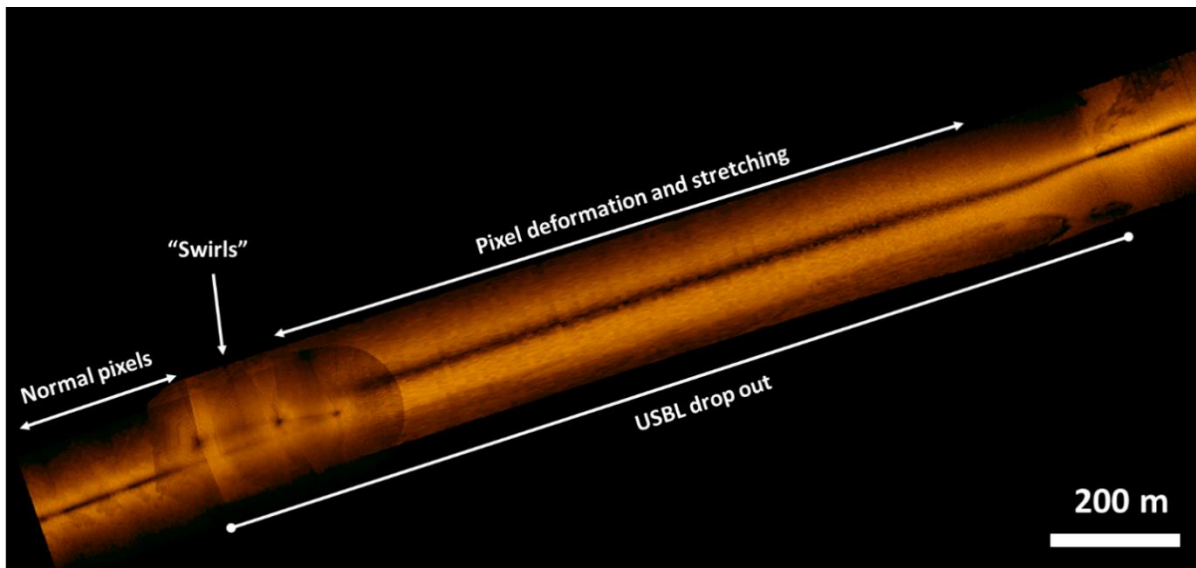


Figure 18: USBL navigation drops result in “swirl” patterns and pixels that are stretched

2.4.4 Image quality

The objective of SSS surveying and analyses is to reveal surficial seabed characteristics. Typically, this means delineating/identifying geological features, sedimentary structures, changes in sediment types, boulders, wrecks and geohazards. Features such as boulders and changes in geology are identifiable and well defined (e.g. Figure 19, Figure 20, Figure 21); thus, the data were deemed fit for purpose and processing. Noise and interference are typically absent from the data.

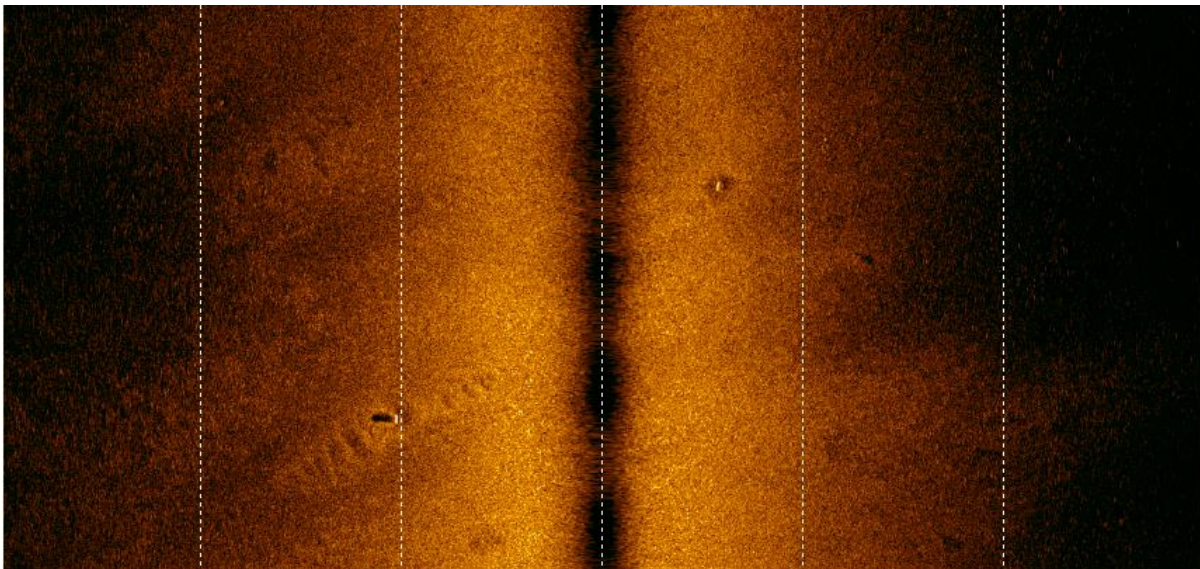


Figure 19: Unprocessed side-scan mosaic close-up showing two boulders from the site

Bottom tracking was successfully applied (3, 3, 6 for the parameters “Blanking”, “Duration” and “Threshold” for seafloor threshold detection), with minimal manual modifications required. The EGN gains improved the peripheral image clarity, resulting in a clear image across the whole swath (Figure 20). The SSS data was of consistently high quality, corroborated by the obvious identification of

seafloor objects such as boulders and sediment boundaries (Figure 21). The data had only isolated minor artefacts over the entire area.

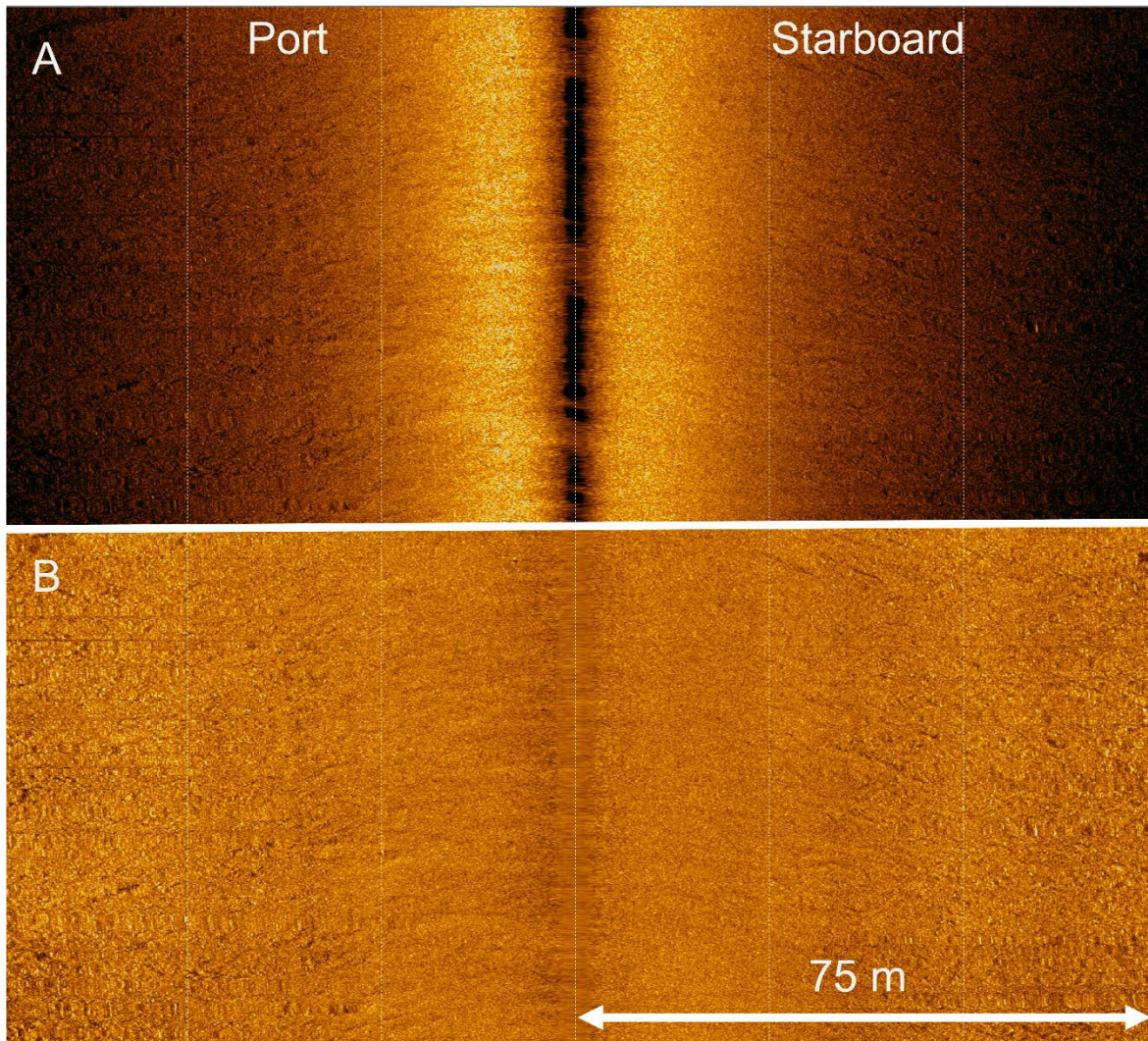


Figure 20: Example of the raw and processed data (Line GRM_22G03_RR_E_051_ABWP_20220922-1722). The top image shows the raw side-scan, the nadir is visible down the centre of the image and dark edges at the periphery of the swath where sound attenuation influences the visual quality. The bottom image shows the same area with processing parameters implemented (Bottom tracking and EGN gains applied) to improve the visual quality.

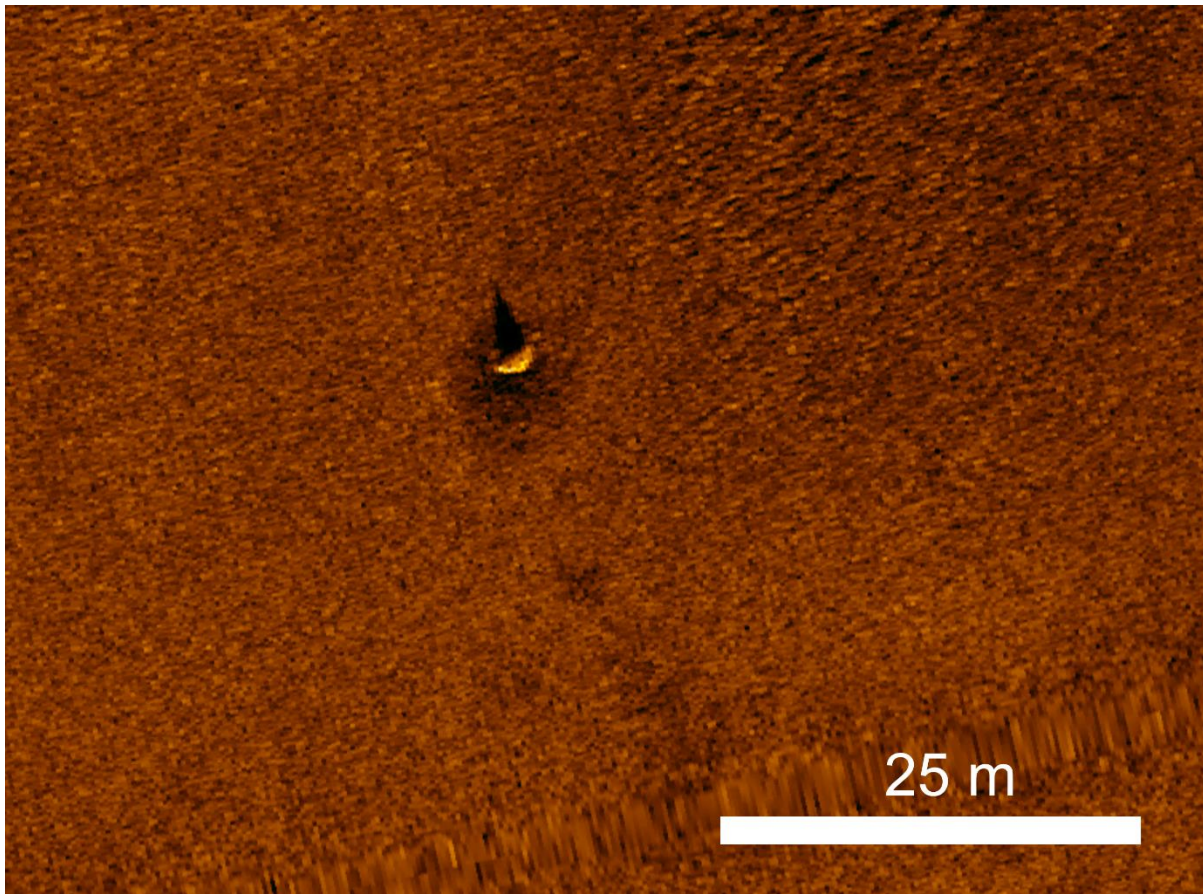


Figure 21: Image quality from the low-frequency channel with a boulder clearly in view

2.5 Magnetometer

2.5.1 Data acquisition

2.5.1.1 Roman Rebel

Magnetometer data were acquired using a single Geometrics G882 Magnetometer which was deep towed at a range of 0.34 m to 16 m off the seafloor, depending on local bathymetry and/or presence of in-situ fishing equipment. The fish was towed approx. 100 m behind the vessel. During acquisition, the fish measures the total magnetic field in nT, with a typical sensitivity of 0.02 nT at a 0.1 sec sample interval. On the Roman Rebel, positioning for the magnetometer data was acquired with a Kongsberg uPAP USBL with an accuracy of $\pm 1.3\%$ of the slant range. On the contrary, positioning for magnetometer data collected on the Lady Kathleen was acquired with the ixBlue GAPS USBL positioning system. Data acquisition was managed in QINSy which created a series of log files with details including USBL positioning, line name, magnetic amplitude, signal strength, altitude, depth, vessel speed. Coverage was varied throughout the site, with line spacing averaging approx. 25 m (Figure 62).

Diurnal variations in magnetometer readings can vary as much as 80 nT daily. These variations are caused by the rotation of the earth and solar winds. Variations are on hours to days scale and significant deviations may be indicative of geomagnetic storms. These variations can be influential on

marine magnetometer readings. It is unlikely that diurnal magnetic variation would influence the detection of anomalies, as anomalies caused by shipwrecks, unexploded ordnance etc. are significantly greater than normal diurnal variations. In addition, an anomaly is detected as a significant and rapid change in magnetic amplitude due to the movement of the magnetometer at 4 knots, providing little time in the vicinity of a true magnetic anomaly on the seafloor. Land-based magnetometers were used to provide background offset values to correct diurnal variations. These are not considered the most robust normalising dataset for marine-based data (Sergipe et al., 2021), but this was requested by the client. The nearest land-based magnetometer was located at the DIAS Dunsink Observatory. This Dublin based observatory uses a Long-Period Magnetotelluric Instrument (LEMI-417M) to record geomagnetic readings every minute. These data are readily available in the (The Magnetometer Network of Ireland, 2022)

2.5.2 Processing workflow

Magnetometer data show the total magnetic field values across the survey area binned per unit area. From this, magnetic anomaly values can be derived. These datasets are useful for the interpretation of seabed feature composition, ferrous object detection (such as wrecks, pUXO and sub-sea infrastructure) and seabed geology characterisation.

The general processing workflow is outlined in Figure 22. The magnetometer data was logged as a QINSy logfile (*.txt) which includes vessel and fish XY, cable out, fish depth, fish altitude, magnetic amplitude and signal strength. Magnetometer data processing aims to format the data, QC the validity of the traces, correct for erroneous spiking, and calculate and remove the background magnetic amplitude to derive the residual for target isolation. To do this, two main tools were used. The first is an in-house created Python script. This script, written in Jupyter Notebook (v6.4.5), utilises the Pandas library to manipulate the data such that all NaN data values are removed, with these files then aggregated together. This significantly increases the rate of processing. The result is a *.CSV file that can be imported into SonarWiz using a customised file template.

Before importing into SonarWiz for processing, diurnal corrections were applied. To match the marine magnetic dataset collected by Green Rebel, the Dunsink dataset needs upscaling to second interval data. This was achieved by linear interpolation (Blake et al., 2016) using a bespoke python code. Gaps in the dataset did not exceed 20 minutes. The Valentia observatory collects derivative magnetic field strength across the x, y and z directions; Bx, By and Bz which were then converted to Bt (magnetic strength) using (Equation) below.

(Equation 2)

$$Bt = \sqrt{Bx^2 + By^2 + Bz^2}$$

To offset the marine magnetometer, the residuals around the mean value of the land magnetometer was taken as offset values. Firstly, the mean was calculated using formula B where X1 was the first recording and Xn was the last recording between date 1 and date 2 at x intervals (Equation 3).

(Equation 3)

$$\overline{x_n} = \frac{X_1 + \dots + X_n}{n}$$

The mean was subtracted from the Bt values to achieve a residual, normalised value for use as an offset of the marine magnetometer. (Equation 4).

(Equation 4)

$$Br = Bt - \overline{x_n}$$

The offset was applied by subtracting the residual around the mean values from the record marine data where Bm represents the marine magnetometer data (Equation 5).

(Equation 5)

$$Bc = Bm + Br$$

The treated magnetometer files were then imported to SonarWiz v7.09 where they were displayed over bathymetric data to ensure that they plot correctly. Each file was inspected for navigation-related data errors. Data spikes were removed from the navigation lines using a non-linear smoothing tool. Similarly, anomalous altitude and depth values were removed from the data. The raw magnetic values were inspected and erroneous spikes were removed through the implementation of an upper and lower threshold limiter filter with a range of approximately 47,000 nT and 52,000 nT. Similarly, the altitude and corresponding depth of the Geometrics are validated to ensure data exceeds agreed standards. To determine regional background values, a stationary filter (smoothing constant) was applied to the raw magnetic trace (M1). A moving average, low-pass filter was then applied to the data to remove minor background data spikes (M2). The residual magnetic trace was subsequently calculated by (Equation 6):

(Equation 6)

$$M1 - M2 = K$$

where K is the residual trace. The total and residual magnetic field grids were subsequently generated using Surfer 23 software. Kriging was used to grid both the residual and total field grids at 0.5 m resolution, with 5 m of blanking distance applied. A standard of 10 nT (peak to peak SD) was used to automatically identify and pick magnetic targets. Targets with residual values approximate to the threshold were also picked, where appropriate. A target shapefile was then exported and brought into

the SSS/UHRS/MBES projects when appropriate, where they were inspected manually over these datasets to determine both their source and the validity of the anomalous reading. When no obvious feature can be observed, other data strings were assessed (e.g. vessel log for nearby vessels, buoys, sudden depth changes) that may have induced spurious data values. Induced anomalies (vessels, buoys, depth changes etc) are removed from the list of anomalies. The total and residual magnetic grids were exported in multiple formats for convenience (*.tif, *.grd, *.flt, *.csv/*.xyz). This gridding procedure was repeated for altitude and depth at 1 m resolution.

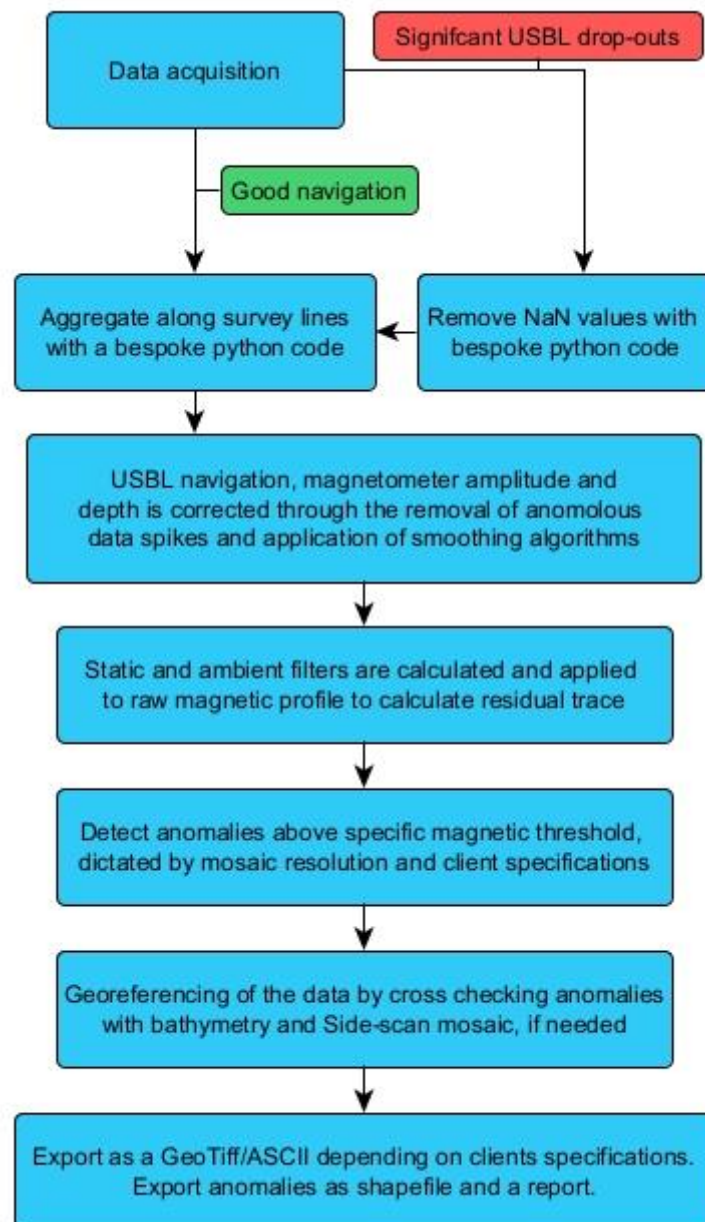


Figure 22: Green Rebel's magnetometer processing and assessment workflow

2.5.3 Positioning and navigation

The magnetometer data were positioned via Kongsberg UPAP USBL with an accuracy of $\pm 1.3\%$ of the slant range. Overall, the USBL regionally tracked the position of the magnetometer well. However, local scale variations were observed (1–60 m). Navigation wobbles and inconsistencies are common with USBL systems (cf. Li et al., 2018) and are easily influenced by environmental factors. The raw magnetometer navigation track contrasted with the processed from the site (Figure 63) shows these local scale variations. These variations are normal and were rectified in post-processing through the application of smoothing filters. Occasional dropouts from the USBL, induced by the magnetometer losing connection with the USBL beacon onboard were noted. This was more apparent in the shallow bank & landfall sites, where readings from the Geometrics were more inconsistent and noise-induced. This was also corrected in post-processing by interpolating the navigation between the observed error windows. Within the survey the area, approximately 827.9 km of magnetometer survey line length was required. However, it is worth noting that these values are skewed due to local scale variations adding extra line length to each line.

The total field and residual data were gridded at 0.5 m resolution using a Kriging algorithm in the Surfer software (Figure 66 and Figure 67). To adjust for blanking, a 5m radius search limit was applied in both the X & Y derivatives. Finally, the grids were manually projected to the correct CRS, before being exported in *.GRD, *.FLT, *.TIFF & *.CSV formats. This gridding process was repeated for altitude and depth at 1m resolution.

2.6 Sub-bottom profiler

2.6.1 Data acquisition

2.6.1.1 Roman Rebel

Sub-bottom profiler data were acquired with a hull-mounted Innomar Medium 100 parametric sub-bottom profiler. The primary frequency of 100 kHz was used to determine the bathymetry and the secondary frequency of 8kHz was used to determine the sub-seafloor strata. All acquisition was managed via Innomar SESWIN software, which visualised raw sub-bottom profiles in real-time. Online data was quality controlled in SESWIN to ensure acquisition parameters were optimised during the survey operations. Raw data were recorded as *.ses3 files and subsequently converted to SEG-Y file format. Format handling procedure and the relevant trace header byte information are included in Appendix 1. The geophysical lines were surveyed with a line spacing of 50 m for mainlines and 1000m for crosslines (Figure 23)

2.6.1.2 Lady Kathleen

The Lady Kathleen is out fitted a pole mounted Innomar standard 100 parametric sub-bottom profiler. Similar to the Roman Rebel, the primary frequency of 100 kHz was used to determine the bathymetry and the secondary frequency of 8kHz was used to determine the sub-seafloor strata. Acquisition was managed using Innomar SESWIN software, which visualised raw sub-bottom profiles in real-time. Online data was quality controlled in SESWIN to ensure acquisition parameters were optimised during the survey operations. Raw data were recorded as *.ses3 files as a 32bit floating integer and

subsequently converted to SEG-Y file format. Format handling procedure and the relevant trace header byte information are included in Appendix 1. The geophysical lines were surveyed with a line spacing of 25 m for mainlines and 1000m for crosslines (Figure 23).



Figure 23: SBP track lines for processed from the Roman Rebel and the Lady Kathleen. Colours denote the individual survey areas.

2.6.2 *Processing workflow*

Sub-bottom Profilers (SBP) are used to image and characterise the physical properties of the sub-seabed and its internal structure. Sub-bottom profiler processing aims to generate high-resolution images that can aid geological interpretation and characterisation of the study area. The general workflow is outlined (Figure 25).

2.6.2.1 *Post processing - navigation injection*

During acquisition, a timing issue between the Innomar unit and Qinsy unit caused a temporary unsynchronisation. Following acquisition, the data were assessed for navigation quality at the office by checking the trackPlot navigation for each line. Qinsy navigation was replayed on the vessel and exported out as logfiles. A total of 55 sub-bottom lines were identified as having no navigation (Figure 24) and a timing offset was noted between the timestamps of the SBP data and the Qinsy track pLot data. The Qinsy trackpLot logfiles were adjusted to accommodate the timing offset manually by adjusting the start times of the logfiles to match the SBP timestamps and following this step were injected into the RAW files using the SIS Replace function in the ISE2 software. In some cases a timing issue still existed and a 200 - 400 metre offset could be observed in the newly injected data. As a secondary fix, all data were cross referenced with the MBES and each line manually georeferenced to the bathymetry grid by using contacts and seabed features prominent in both data sets.

2.6.2.2 *Signal processing*

Before signal processing, SBP data files were converted from *.ses3 format into *.sgy format using SES Convert v. 2.3. The *.sgy files were then imported into SonarWiz v7.09.04 post-processing software, where quality, range and navigation were checked. QC was performed to identify any problems, gaps or excessive noise in the data. All data were cross-checked using ISE v.2 to ensure data quality by identifying reflectors and features within the 2D profile data.

Using SonarWiz, the data were bottom-tracked using the threshold detection bottom-tracking algorithm and the results were manually adjusted where needed. Subsequently, the dataset was vertically referenced to LAT (Figure 31). A corrected bathymetric grid for the area was imported and provided a reliable tidal, heave and sound velocity-corrected surface for cross-reference. Following LAT datum correction, the data were filtered, and the water column blanked (Figure 32). Filters were applied to remove excessive noise and improve the visibility of sub-seabed reflectors. Firstly, data were corrected for heave and swell. After corrections, a hamming bandpass filter was applied (3000–9000 Hz). Water column noise was removed from the data by applying water column blanking. After a preliminary inspection of the data, reflectors were digitised systematically, starting with those closest to the seabed.



Figure 24: Post processed navigation for SBP - area Lot1A

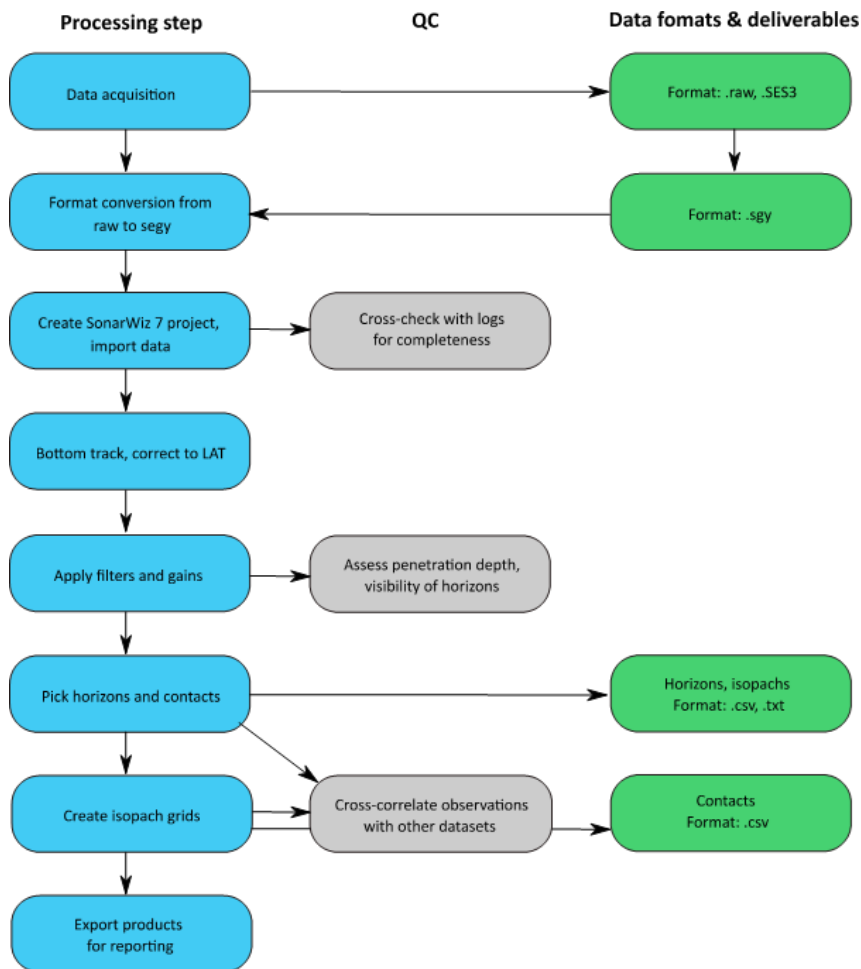


Figure 25: Green Rebel's sub-bottom profiler data processing and assessment workflow

2.6.3 Tidal and datum control

The sub-bottom profiler was hull mounted and received its ellipsoidal absolute position from the iXBlue HYDRINS (a Global Navigation Satellite System inertially aided), with centimetric accuracy vertical positioning corrections. Subsequently, the SBP transducer data needed to be reduced to the survey datum: LAT. This was achieved by correcting the bottom-tracked SBP data to datum-corrected bathymetry during post-processing using the SBP vertical offset tool available in SonarWiz.

2.6.4 Resolution and penetration

The theoretical vertical resolution depends on the physical parameters of the used frequency and pulse length. It can be calculated as:

$$\lambda = \frac{vT}{4},$$

Where the pulse length, $T = \frac{1}{f}$, f is the centre transmitted frequency, and v is the sound speed in a medium. The Innomar sub-bottom profiler was operated using a transmitted frequency of 8 kHz, thus providing a vertical resolution of up to 0.05 m.

The Innomar medium 100 SBP has a transmit beam width of $\pm 1^\circ$ (at the reference level of -3dB), which corresponds to the footprint of c. 3.5% water depth. This means that at 1 m water depth, the horizontal resolution is 0.035 m. The average depth at the survey site, calculated from the MBES bathymetry, equals 25.5 m. Hence, the mean SBP beam footprint during the survey operations was 0.89m. The typical sample frequency was 96,000 samples, with a mean of 6400 samples per echo recorded. The signal pulse length was 120 μ s.

The range length for the recorded Innomar SBP data was adjusted when needed during the survey operations according to the observed water depth and sub-seabed penetration and spans between 30 and 50m. The parameters above optimise the Innomar sub-bottom profiler to capture a range of up to 15 m below the seabed. However, the penetration depth largely depends on the acoustic properties of encountered substrates.

2.6.5 *Data quality and signal processing*

Sub-bottom profilers define and characterise sediment structures in the shallow subsurface (i.e. unlithified sediments) but can also detect the surface of the underlying bedrock under the right conditions. Given that the sub-surface features can be well-delineated in the raw data, the Innomar SBP data meet specifications and fit for purpose. Sub-seabed reflectors are evident and display a strong signal where present everywhere across the survey area.

Some data were affected by weather-induced noise, given the sensitivity of the Innomar transducer to collision with air bubbles during less favourable sea states. This phenomenon typically occurs as vertical stripes in the data and is known as 'bubble rush' and is often accompanied by minor gaps (Figure 32). Despite these artefacts, seabed reflectors are visible, continuous and can be objectively resolved. The noise unaffected the penetration depth and, as mentioned in the previous subsection, depends on subsurface geology. Throughout the dataset static seabed offsets are apparent. This is likely due to the altering of the recording range setting during acquisition as the transducer moved from shallow to deep water (Figure 30). Offsets in the data were corrected by manually bottom tracking the seabed and correcting the surface to the MBES surface (Figure 30).

The raw data from the Innomar Medium show a notable low-frequency noise (Figure 26) recorded (up to -27 dB at < 3000 Hz) and some additional interference at the higher frequency (> 8000 Hz). Similarly, the raw data from the Innomar Standard show low frequency noise (Figure 27) recorded up to (-29 dB at < 3000 Hz) with notable notches at 6000 Hz and 8000Hz. It is expected that the noise experienced at lower frequencies is ambient noise within the water column and from the vessel (Figure 32), while noise associated with higher frequency is likely introduced from other survey equipment e.g., multibeam echosounder or SSS. This interference can be cleaned and filtered out post-processing by applying a bandpass filter to remove the excess low and high-frequency signal components. The step-by-step filtering process is described in sub-section 2.6.2.2

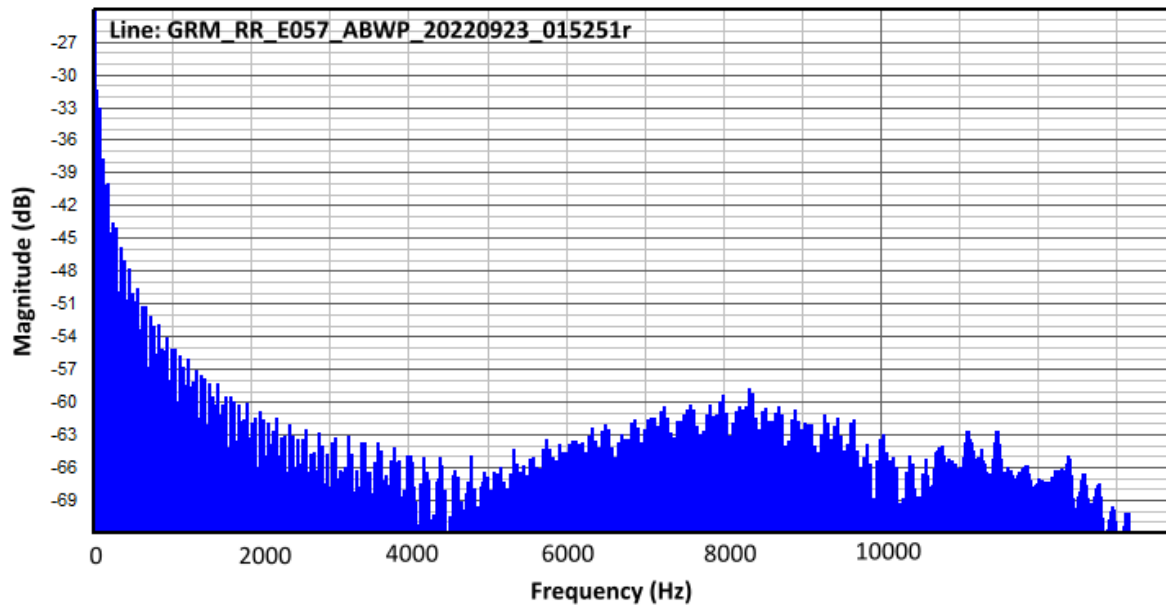


Figure 26: An example spectrograph representing one trace of the Innomar Medium SBP data from Area E on the Roman Rebel

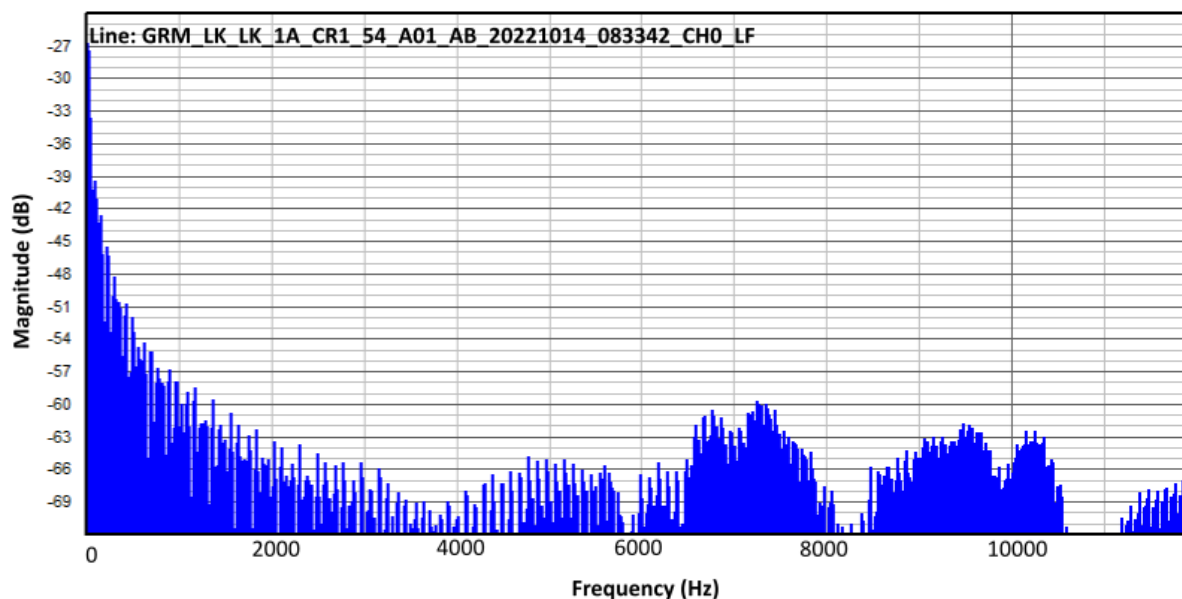


Figure 27: An example spectrograph representing one trace of the Innomar Standard SBP from area Lot1A on the Lady Kathleen vessel.

2.6.6 Final product (Quality)

Noise artefacts can be corrected and improved during data processing through signal processing, gains and filters. Therefore, after bottom tracking filters were chosen and applied to the acquired SBP data based on frequency distribution of the noise visible in the spectrographs (Figure 28 and Figure 29). A “Hamming” type bandpass was utilised, filtering noise from a frequency range of (3,000 Hz to 9,000

Hz) was used. This improved the data quality and helped distinguish reflectors within the sub-bottom data.

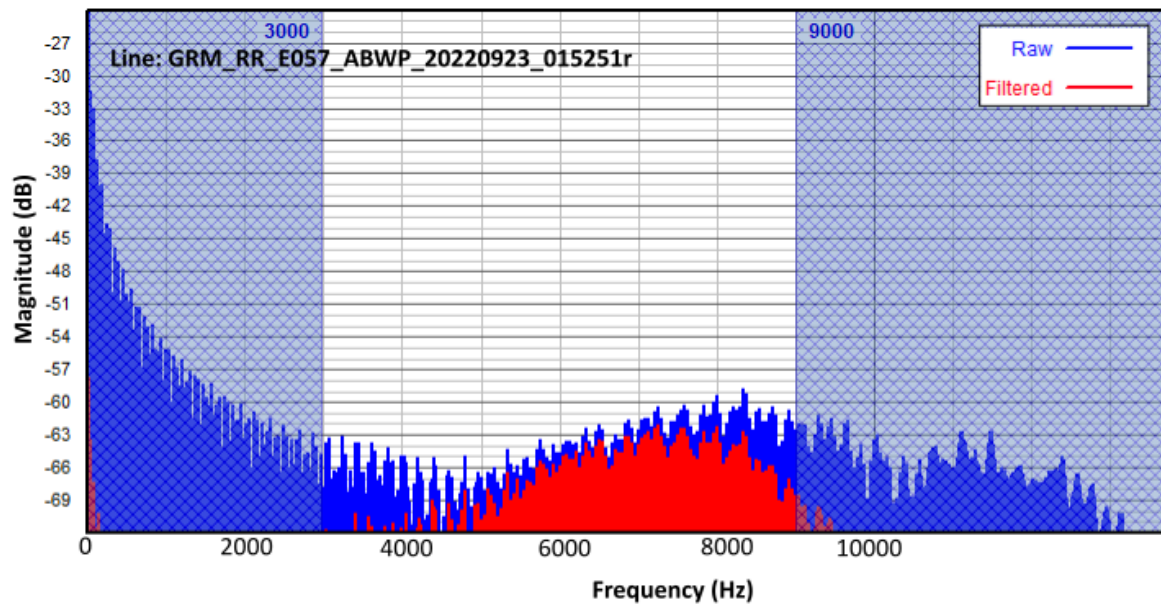


Figure 28: Spectrograph histogram of bandpass filtering applied to the Innomar standard data on the Roman Rebel

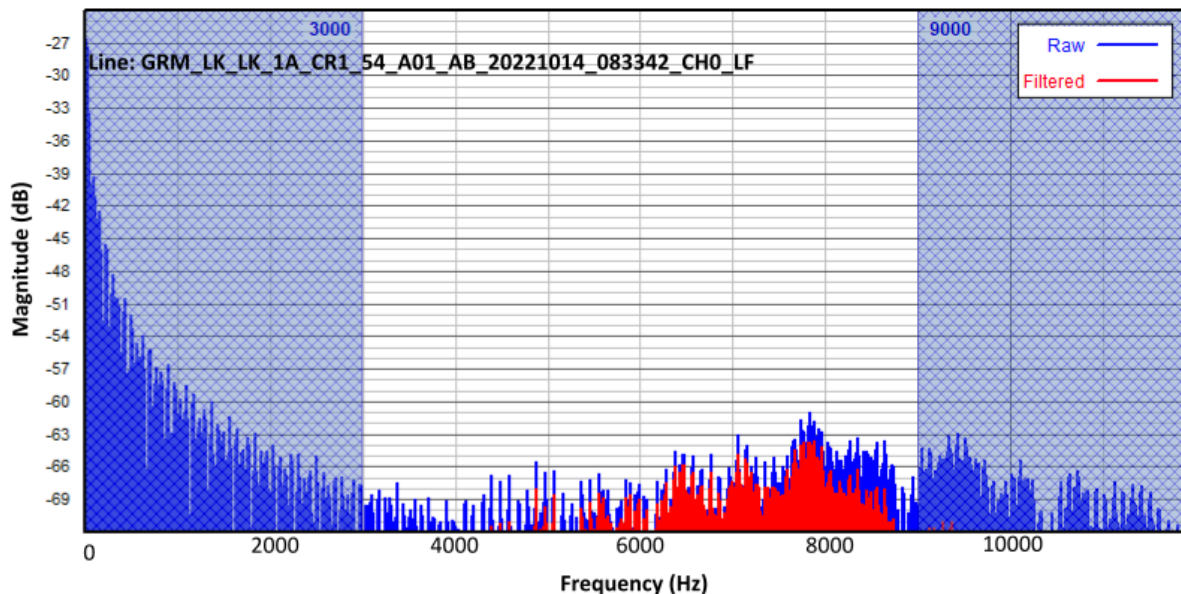


Figure 29: Spectrograph histogram of bandpass applied to the Innomar Standard SBP data on the Lady Kathleen

These filters, together with the applied “water column blanking” tool, which eliminates the signal component corresponding to the water column above the seabed, significantly increase the visibility of weaker signals and enhance reflectors (Figure 31).

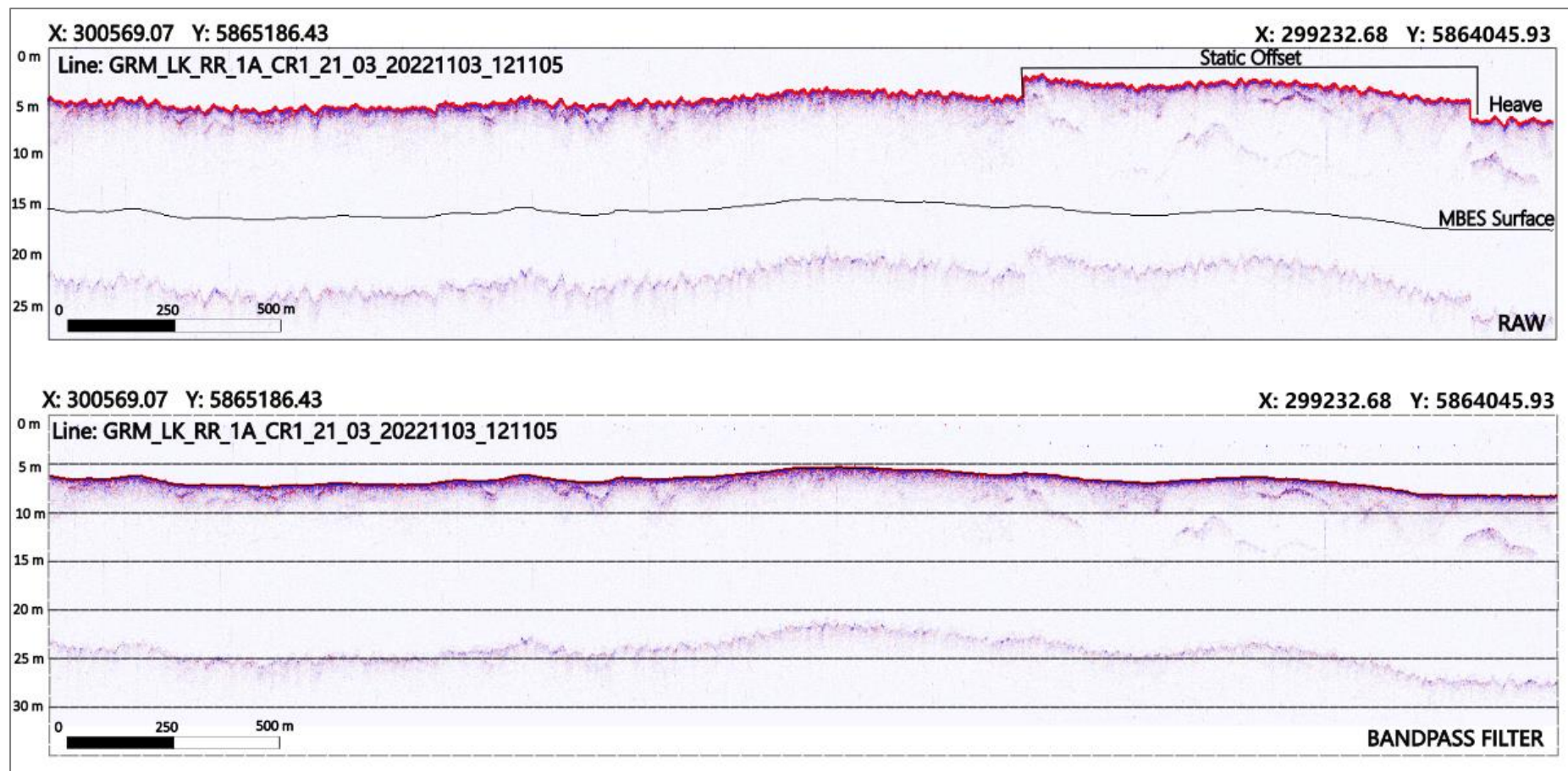


Figure 30: Top image: Raw sub-bottom profiler data before processing displaying heave at the seabed and a static offset. The black line represents the MBES grid surface before LAT correction. Bottom image; Processed data shows the bandpass filter has cleaned the signal and enhanced reflectors. Heave and swell have been removed from the data.

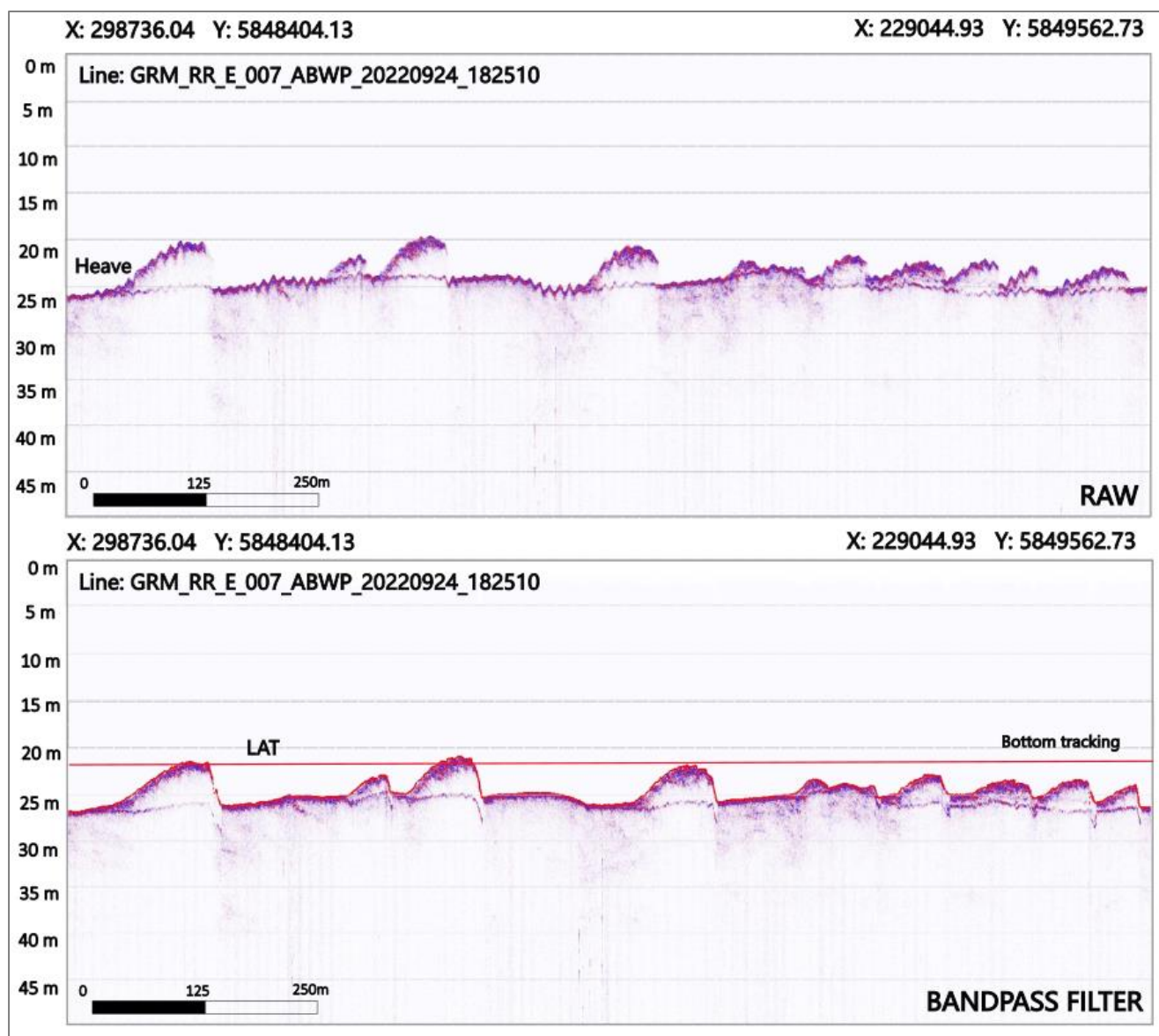


Figure 31: Top image; Raw data from Area E uncorrected for heave and with no vertical offsets applied. Bottom image; Processed data displays bottom tracked SBP data that is heave corrected and reduced to the LAT datum. A bandpass filter improves the signal to noise ratio.

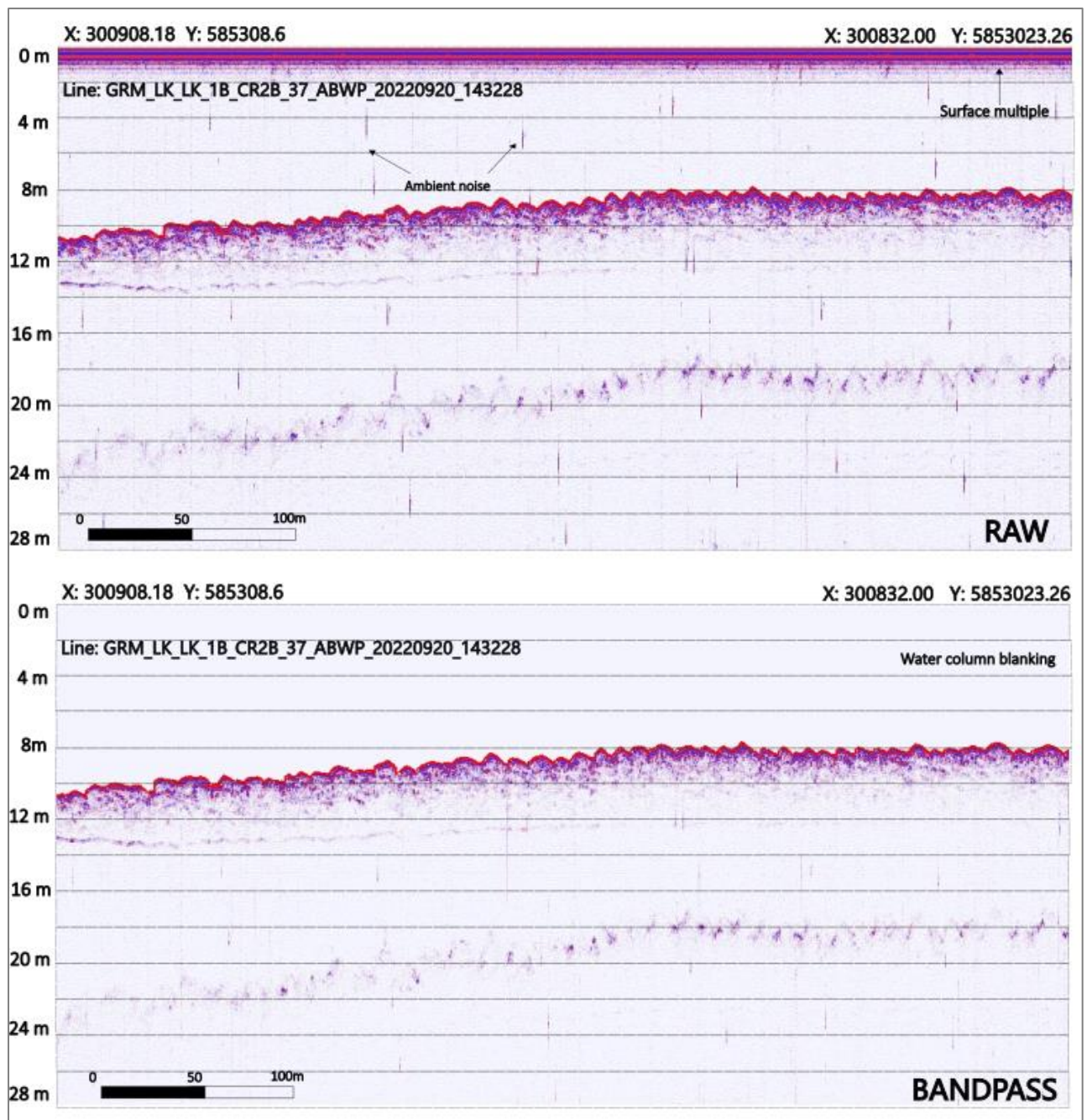


Figure 32: Top image; Example of signal processing of SBP data from the Lady Kathleen vessel. The raw data image displays vertical striping and a water surface multiple. Bottom image; Processed data has applied water column blanking to remove noise from the water column and to a bandpass filter has been utilised to improve the signal to noise ratio

3 Classifications

3.1 Seabed Targets

Seven types of seabed contacts were identified in the ABWP site (Table 6).

Table 6: Types of seabed contacts

Contact type	Description
Boulder	Rock >0.3 m
Debris	Small contacts, likely anthropogenic
Outcrop	Bedrock protruding from seafloor
Pipeline	Linear contact cross referenced versus known pipeline
Linear Contact	Unknown contact, linear morphology
Sonar Contact	Unknown contact, alternative morphologies
Wreck	Shipwreck

3.2 Inferred Seabed Sediments

8 seabed sediment types of 20 classes outlined by Fonseca et al., (2009). were used to categorise the ARA results (subsection 2.3.3). These are summarised in Table 7.

Table 7: Seabed sediment categories used to classify ARA results

Texture	Sediment type	Description *
Coarse ↑ Fine ↓	Coarse to gravelly sand	4
	Medium to gravelly muddy sand	5
	Medium sand	6
	Fine sand	7
	Silty sand	8
	Muddy sand	9
	Very fine sand	10
	Coarse silt	12
	Sandy silt	13
	Medium silt	14
	Sandy mud	15
	Fine silt	16
	Sandy clay	17
	Very fine silt	18
	Clay	20

*Values listed are an empirical representation of classes described in QPS FMGT (www1)

3.3 Sedimentological bedforms

Two types of sedimentological seabed forms were used to categorise MBES bathymetry, MBES backscatter and SSS results. These are summarised in Table 8.

Table 8: Sedimentological bedform categories

Feature Name	Feature Morphology
Sandwaves	Wavelength ≤ 10 m Height ≤ 1 m
Megaripples	Wavelength ≤ 200 m Height ≤ 10 m

3.4 Magnetometric Targets

Magnetic targets were identified as having a residual range of $> \pm 10\text{nT}$, as outlined in the scope of works. Within this range, four target types were classified based on the characteristic of the residual signal (Table 9).

Table 9: Magnetometric target classifications.

Target classification	Description
Monopole	Target with a singular positive or negative signature
Dipole	Target with both positive and negative signatures
Complex	Target with multiple positive and/or negative signatures

4 Results

4.1 Regional Geology Review

The present day seabed bathymetry and structure is a result of pre-quaternary processes, quaternary glacial processes and the modern hydrodynamic regime. The area's hydrodynamic regime is dominated by tidal currents and is characterised by coarse sediments, sand wave fields and gravel banks. Waves are generally characterised by a short-period with a limited access of swell waves to the basin, as it is partially enclosed.

4.1.1 Pre-Quaternary Geology

The pre-quaternary geology across the Arklow Bank is characterised by three different formation types ; Cambrian sandstone, Cambrian metamorphic and Ordovician slate. This is based on the (EMODnet Map Viewer (europa.eu) offshore bedrock map where chronological and compositional information indicates the presence of predominantly Cambrian and Ordovician metasediments and volcanics. The onshore formations most likely present offshore are listed in Table 10.

Table 10 : Rock formation found in Arklow onshore region

Geological Period	Formation	Description
Ordovician	Oaklands Formation	Green-red purple slate
	Dolerite	Basalt and Gabbro's
	Arklow Head Formation	Black slates overlain by rhyolitic tuffs
	Ballymoyle Formation	Rhyolitic volcanics, grey and black slate.
	Kilmacrea Formation	Dark grey slate, minor pale sandstone
	Maulin Formation	Dark blue-grey slate, phyllite and schist

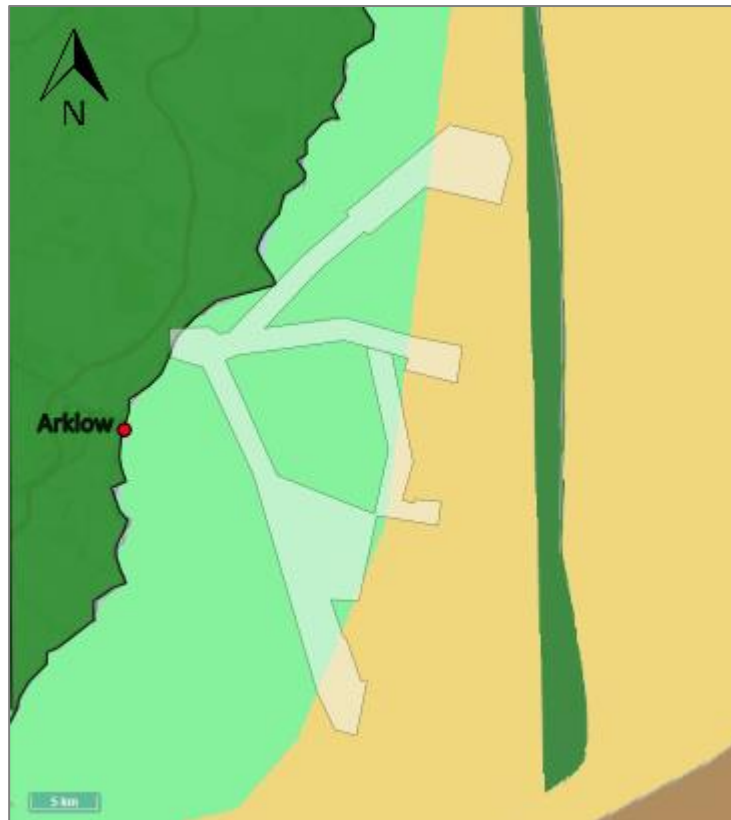


Figure 33: Bedrock geology map displaying Ordovician slate (pale green), Cambrian sandstone (yellow) and Cambrian metamorphic rock (dark green) bedrock extents in the survey site. (Source: EMODnet Map Viewer (europa.eu))

4.1.2 Quaternary Geology

The Irish Sea was glaciated during the Last Glacial Maximum (27 ka–18 ka BP; Scourse et al., 2019; Van Landeghem & Chiverrell, 2020) when the Irish Sea Ice Stream advanced through the Irish Sea, eroding and reworking sediment, and depositing variable thicknesses of glacial diamict. This diamict was often deposited directly on the bedrock and is referred to as the upper till member (Jackson et al., 1995). The upper till member comprises sand to boulder-grade material and is often overconsolidated (Coughlan et al., 2019; Mellet et al., 2015). During the retreat phase of the Irish Sea Ice Stream during deglaciation, large amounts of meltwater were discharged along with outwash material in the form of a heterogeneous mix of sediments, predominately gravels, with mud, sand, and cobbles, referred to as the chaotic facies (Coughlan et al., 2019; Jackson et al., 1995).

The subsequent marine transgression and present-day hydro-dynamics reworked much of the glacial and postglacial sediment in the south Irish Sea into a mosaic of substrates (S. L. Ward et al., 2015). These processes created a series of dynamic bedforms, including migrating sediment waves, in an area dominated by coarse lag deposits. The sediment waves vary in size and morphology, with the magnitude of migration highest in the central Irish Sea, with average rates of up to 35 m/year, decreasing northward (Van Landeghem, Uehara et al., 2009; Van Landeghem et al., 2012; Coughlan et al., 2020).

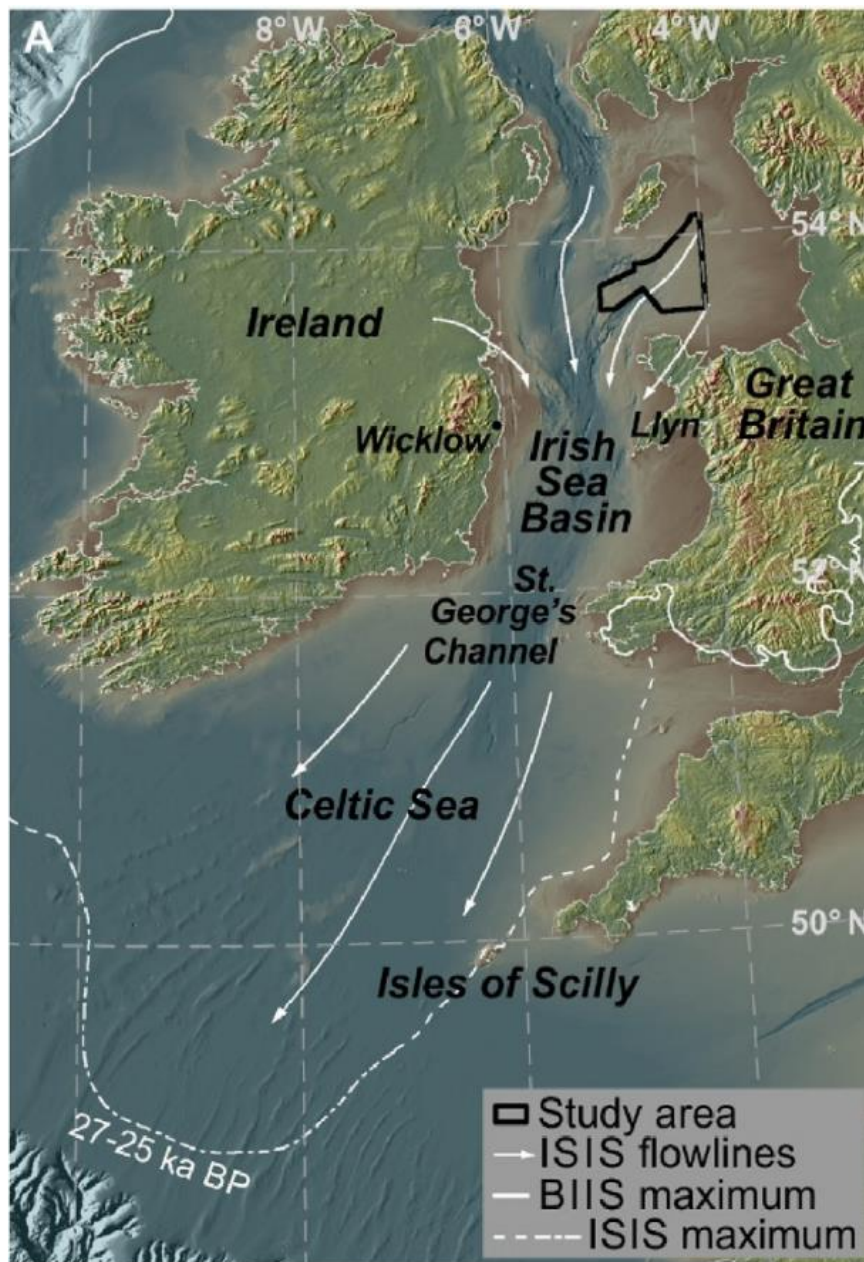


Figure 34: Map displaying the extent Irish Sea Basin and the extent of the Irish Sea Stream (ISIS) flow (Van Landeghem et al., 2021)

The near-shore marine environment off the east coast of Ireland is characterised by a series of coast-parallel, north-south trending linear sandbanks (Warren & Keary, 1989; Kearns-Mills, 1996; Molloy & Kennedy, 2001). The Arklow Bank is a dominant geomorphological feature around 12 km offshore Arklow town and it is situated in an area known as the Irish Platform, which occupies a corridor some 20 to 30 km wide off the east coast of Ireland. The Arklow Bank is a ridge approximately 25 km long, oriented roughly north-south, around 1.5 km wide and reaches heights of 2-3 m above the surrounding seafloor; sandwaves and megaripples are common in and near the site. Net average annual rate of sediment wave migration in the investigated Arklow Bank area was previously reported as 27 m/y (Van Landeghem et al., 2012). The seafloor in the area is dominated by sand and gravel deposited by an ice front during the last glaciation. Through analysis of seismic profiles, Hanna (2002)

interpreted the bank as a moraine formed during the last glaciation across the area. Furthermore, the bank is located south-east of the inferred limit of the Delgany Moraine, which might suggest that the two ridges were part of a morainic system. However, no evidence has been reported to date to fully test this hypothesis.

Around 10 ka BP, sea level rise caused reworking of sediments at the surface formed predominantly by sandy sediments. Areas around the bank are also characterised by mobile sand overlaying glacial clays. To the west of the bank, gravels are exposed on the seafloor. Near-shore hydrodynamics (e.g. waves, tides) are considered as a major control on the sandbank morphology and coastal configuration (Hanna, 2002).

4.2 General narrative on the survey results

Water depths range from -2.07 m to -56.52 m. The site is characterised by a relatively low relief bathymetric surface within the cable corridors. High bathymetric relief is seen in approach and on the Arklow bank. Anthropogenic features such as shipwrecks produce high relief. Localised gradients exceeding 90° were observed in areas of seafloor sediment waves and sites where debris is potentially present. Backscatter values were simultaneously recorded during bathymetric acquisition and gridded to a resolution of 0.3 m allowing for a non-invasive sediment classification. Several morphological features were observed in the site, including: a large presence of sandwaves, megaripples and sediment waves. The seabed surface substrate is interpreted to consist of marine sands, muds and gravels. Sheets of mobile sandy drifts are also present across the proposed site.

The ABWP survey area shows predominant facies of medium to coarse sediments, where it can be assumed higher current velocities are present. Where in the landfall area and Area E in the ABWP survey there is a low incidence of sandwaves or megaripples, suggesting a lower current velocity supported a presence of finer grained facies type clays to sandy clay. Five sub-surface units were identified in the SBP and datasets. Identified geohazards such as shallow gas and palaeo-channel infills showed, in places, correlation with magnetometer data.

Noteworthy estimates about seafloor sediments, substrates and sub-surface substrates present in the area, cannot be deemed reliable without a geotechnical investigation and dedicated sediment sampling campaign. Such an investigation would further rectify uncertainties associated within the subsurface datasets, thus reducing uncertainties associated with interpretation.

4.3 Multibeam bathymetry

4.3.1 Lot 1A

4.3.1.1 IHO Order 1a Cross Check

Each Area passed the IHO Special Order cross check examination (Table 5; see also Figure 35).

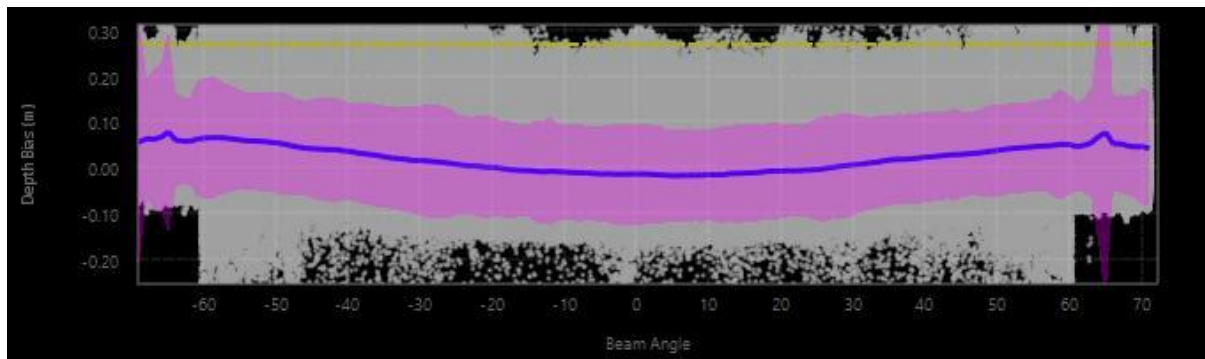


Figure 35: Cross sectional view of multibeam soundings accepted to IHO Special Order standards from Lot 1A. Yellow dashed line represents: IHO Special order vertical maximum soundings. Pink area represents: 95% Confidence Interval. Blue area represents: mean offset values.

4.3.1.2 Final bathymetric product

The final Lot 1A bathymetric surface was gridded at 0.3 m x 0.3 m pixel resolution. Water depths range from -1.99 m to -40.13 m (Figure 37). The site is characterised by a relatively flat bathymetric surface with sandwaves and megaripples with superimposed sandwaves.

Lot 1A of the ABWP survey area can be described as displaying a relatively flat topography with a few exceptions (Figure 36). These exceptions are areas with local presence of megaripples in cable route CR2 and on approach to Lot 1B areas which exhibit gradients from 10° to 83°. Anthropogenic seabed features such as shipwrecks are also observed scattered across the survey site which displays gradients up to 83.31°. High slope gradients highlight the areas of potential geohazard occurrence i.e., shipwrecks, sedimentological bedforms of various scales and individual objects and debris.

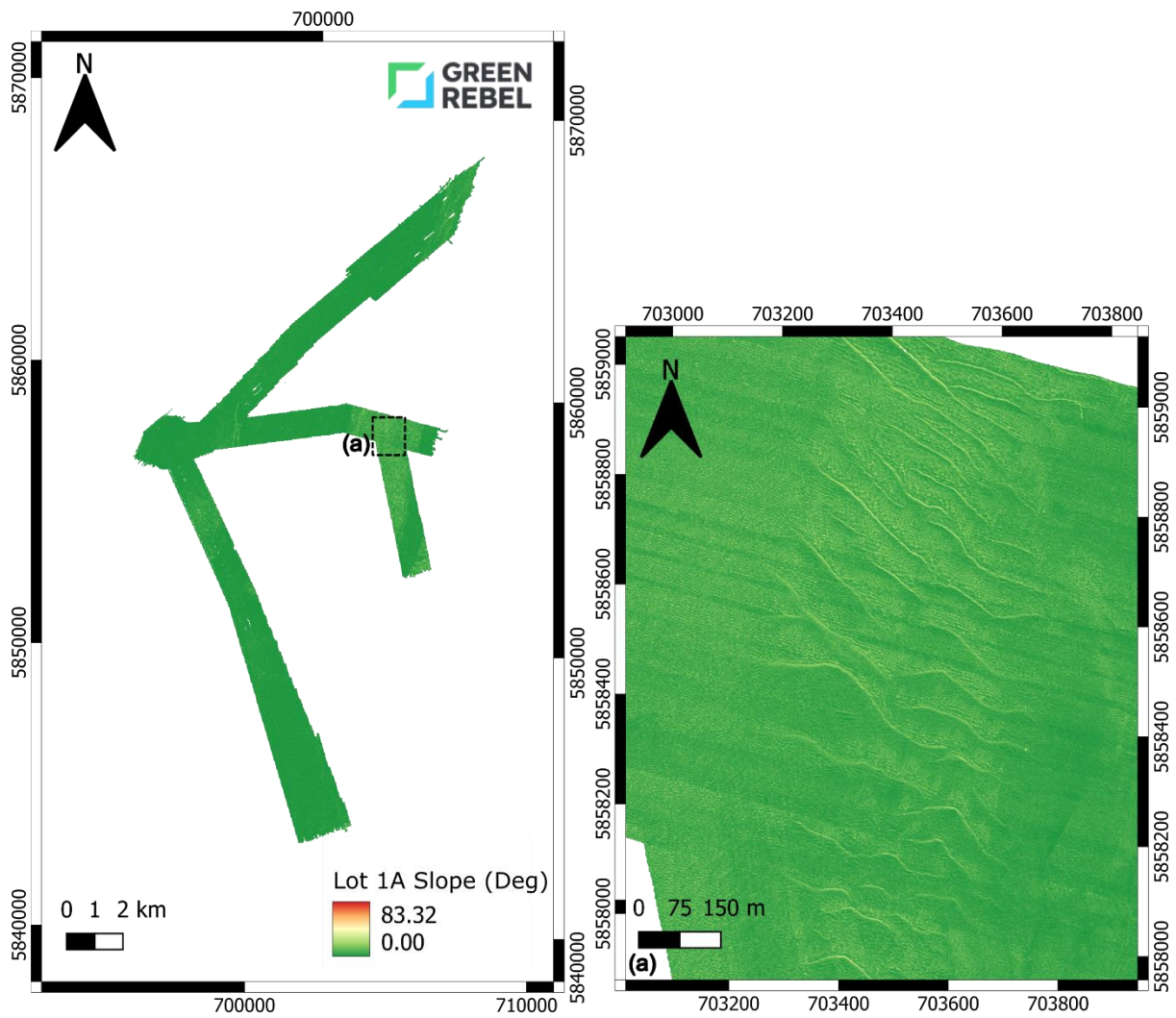


Figure 36: Lot 1A bathymetric slope measured in degrees. (a) inset showing high slope values associated with the presence of megaripples. The location of the inset is highlighted with a box on the main map presented on the left side.



Figure 37: ABWP Lot1A bathymetric data coloured by depth (m)

4.3.2 Lot 1B

4.3.2.1 IHO Order 1a Cross Check

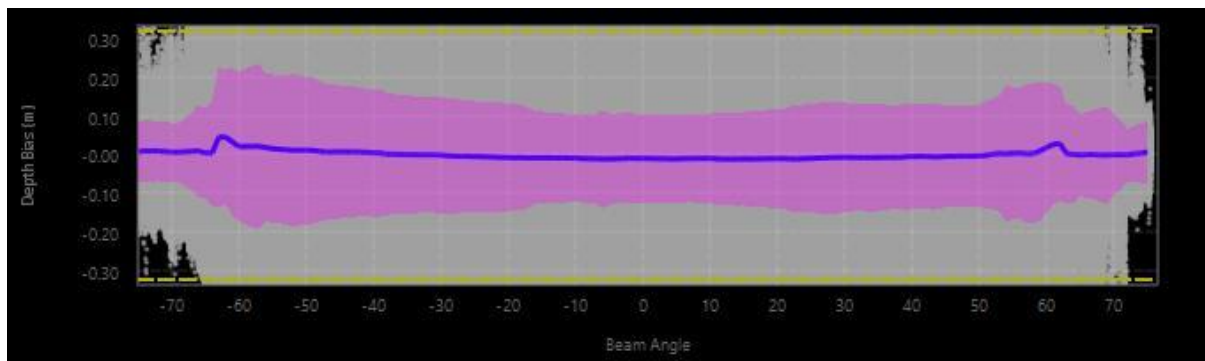


Figure 38: Cross sectional view of multibeam soundings accepted to IHO Special Order standards from Lot 1B. Yellow dashed line represents: IHO Special order vertical maximum soundings. Pink area represents: 95% Confidence Interval. Blue area represents: mean offset values.

4.3.2.2 Final bathymetric product

The Lot 1B bathymetric surface was gridded at 0.3 m x 0.3 m pixel resolution. Water depths range from -2.16 m to -56.52 m (Figure 39). The site is characterised by a complex bathymetry with sandwaves, and megaripples with superimposed sandwaves.

Lot 1B in the ABWP survey area is characterized by a high relief bathymetric structure (Figure 40). Sedimentological bedforms present in areas such as CR2b and CR3 in the south exhibit gradients from 0° to 86° and anthropogenic seabed features such as shipwrecks, seen in CR2b seen scattered across the survey site which display gradients up to 86.04°. From this dataset, it can be derived that slope gradient can highlight the areas of potential geohazard concern i.e. shipwrecks, megaripples and sandwaves.

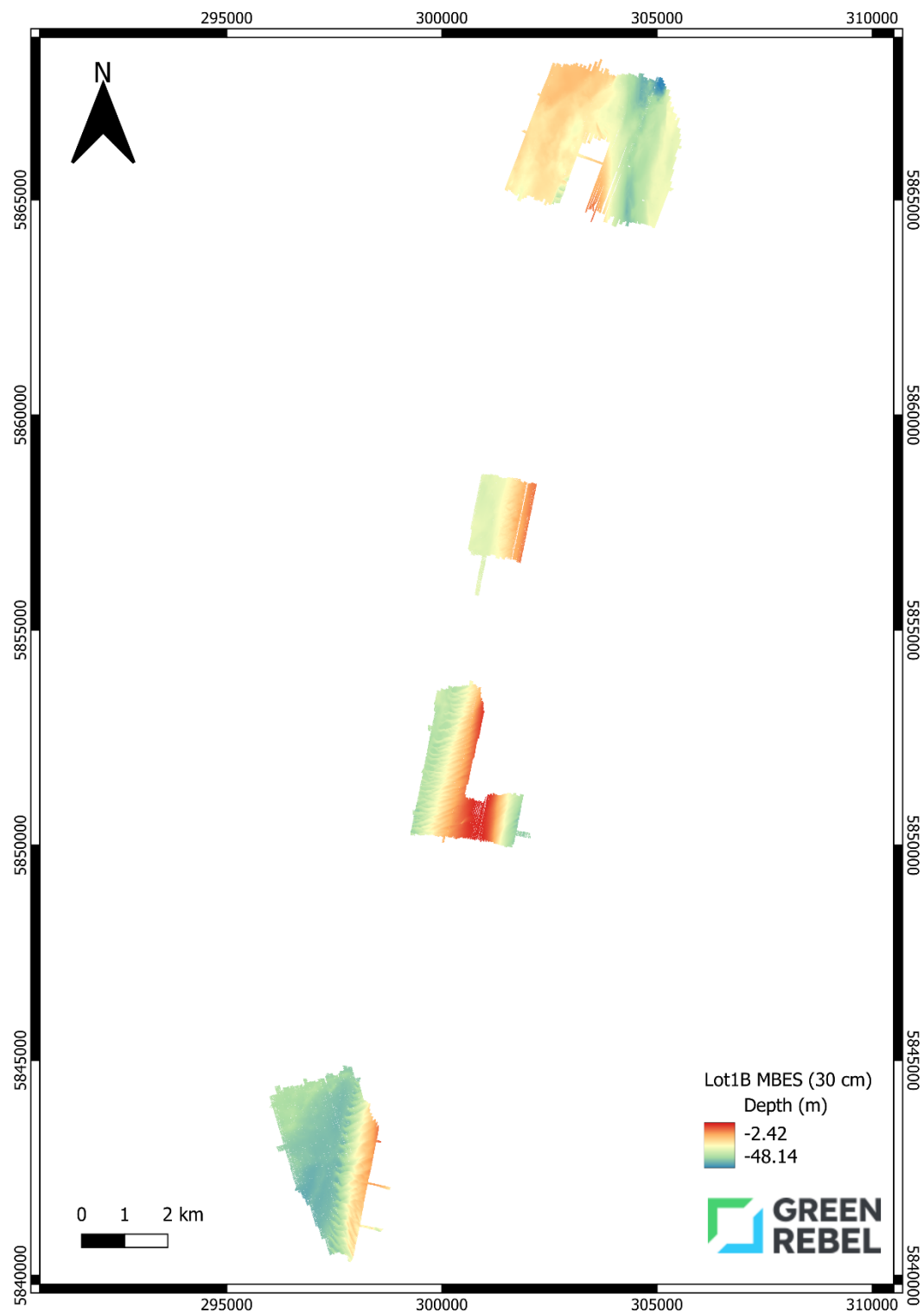


Figure 39: ABWP Lot1B bathymetric data coloured by depth (m)

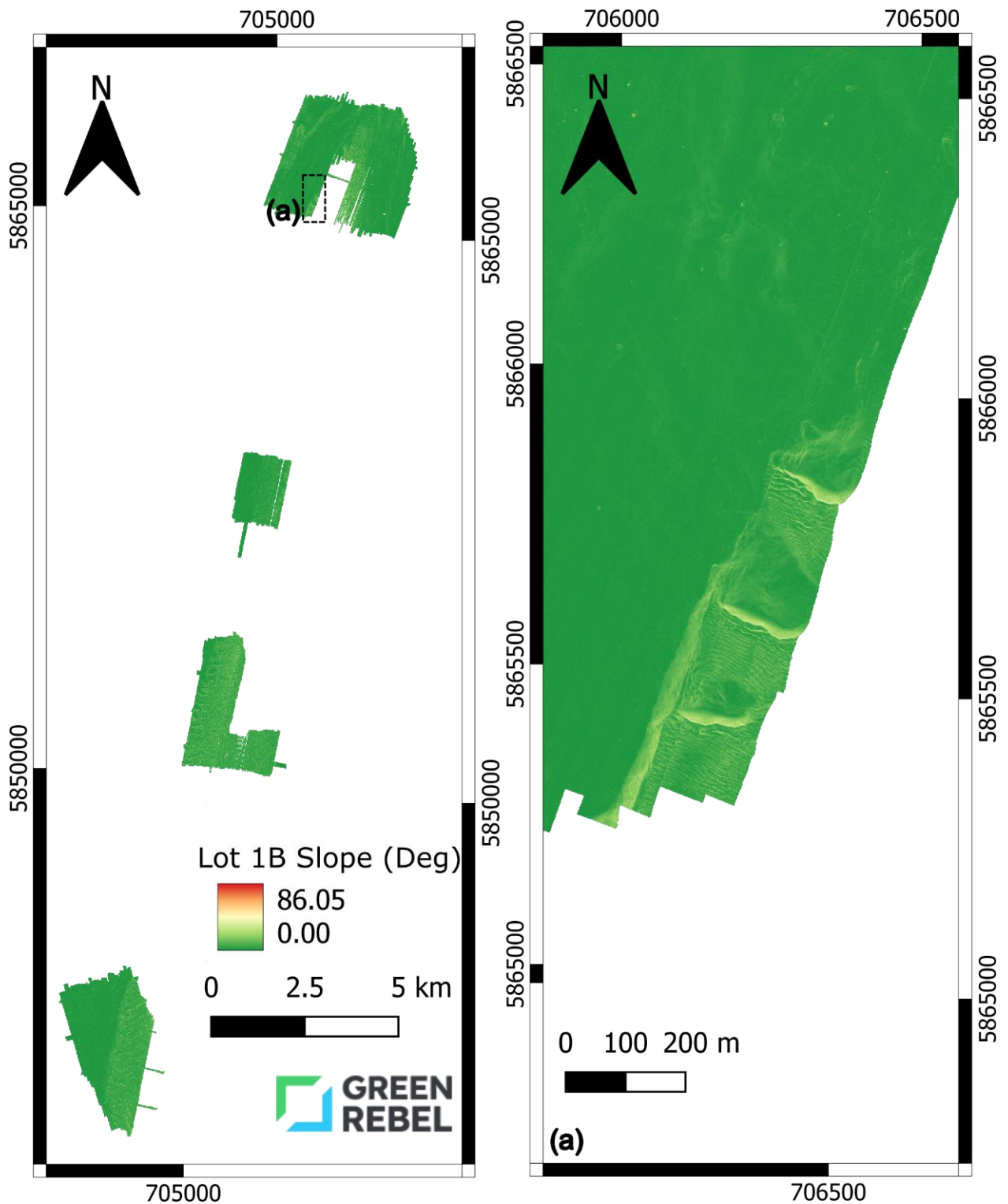


Figure 40: Lot 1B bathymetric slope measured in degrees. (a) inset showing high slope values associated with the presence of megaripples. The location of the inset is highlighted with a box on the main map presented on the left side.

4.3.3 Area E

4.3.3.1 IHO Order 1a Cross Check

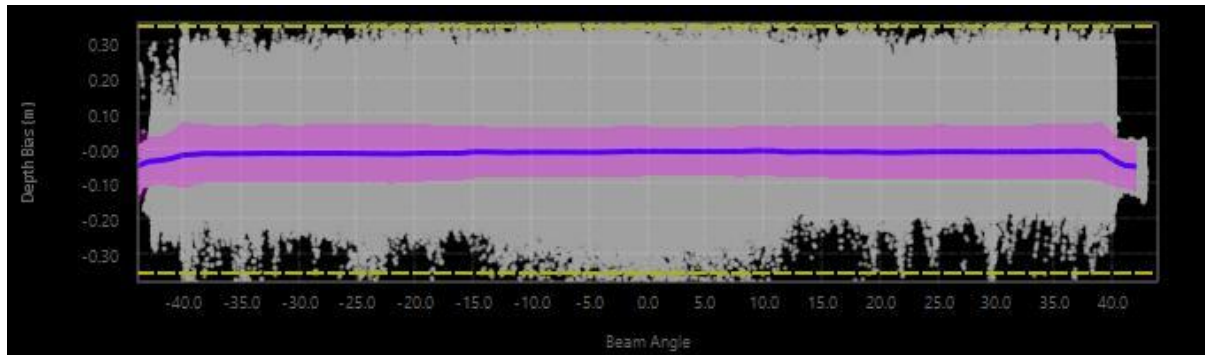


Figure 41: Cross sectional view of multibeam soundings accepted to IHO Special Order standards from Area E. Yellow dashed line represents: IHO Special order vertical maximum soundings. Pink area represents: 95% Confidence Interval. Blue area represents: mean offset values.

4.3.3.2 Final bathymetric product

The Area E bathymetric surface was gridded at 0.3 m x 0.3 m pixel resolution. Water depths range from -23.57 m to -40.35 m (Figure 42). The site is characterised by diverse morphology with flat areas, ridges but also sandwave fields and megaripples in its eastern side. A pronounced, positive ridge-like relief covered with sandwaves is also present in the center-north part of this area.

Area E in the ABWP survey area generally has a downwards slope trend towards the eastern direction with areas of local high-slope gradients (Figure 43). The high-slope gradients are concentrated along the megaripples in the east, which exhibit gradients from 0° to 75.36°. These features can be seen to be an extension of the same megaripple chain seen in Lot 1B (Figure 40; see also Figure 45). High slope gradients in this area can be associated with potential geohazards i.e. shipwrecks, mobile sandwaves and megaripples.

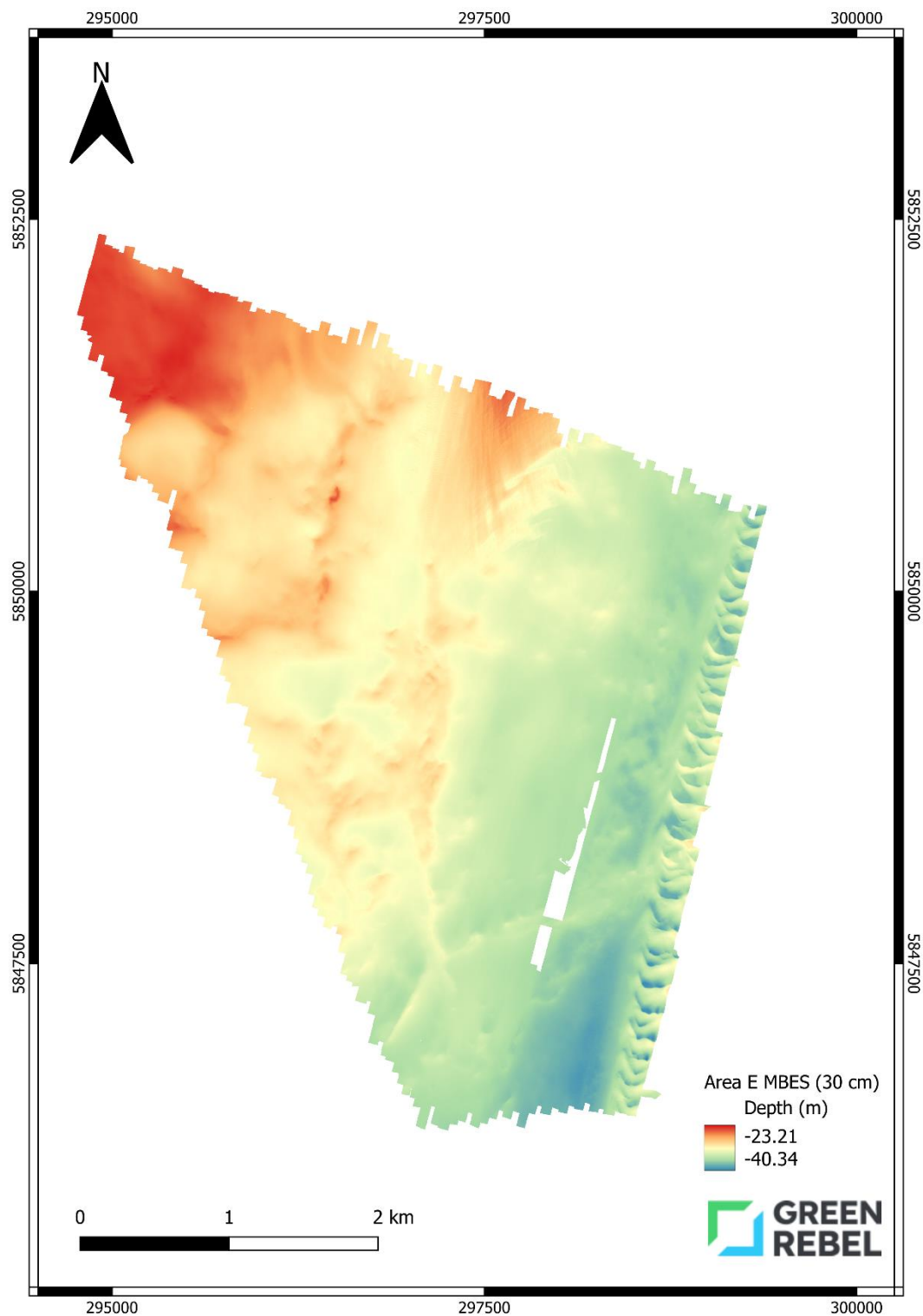


Figure 42: ABWP Area E bathymetric data coloured by depth (m)

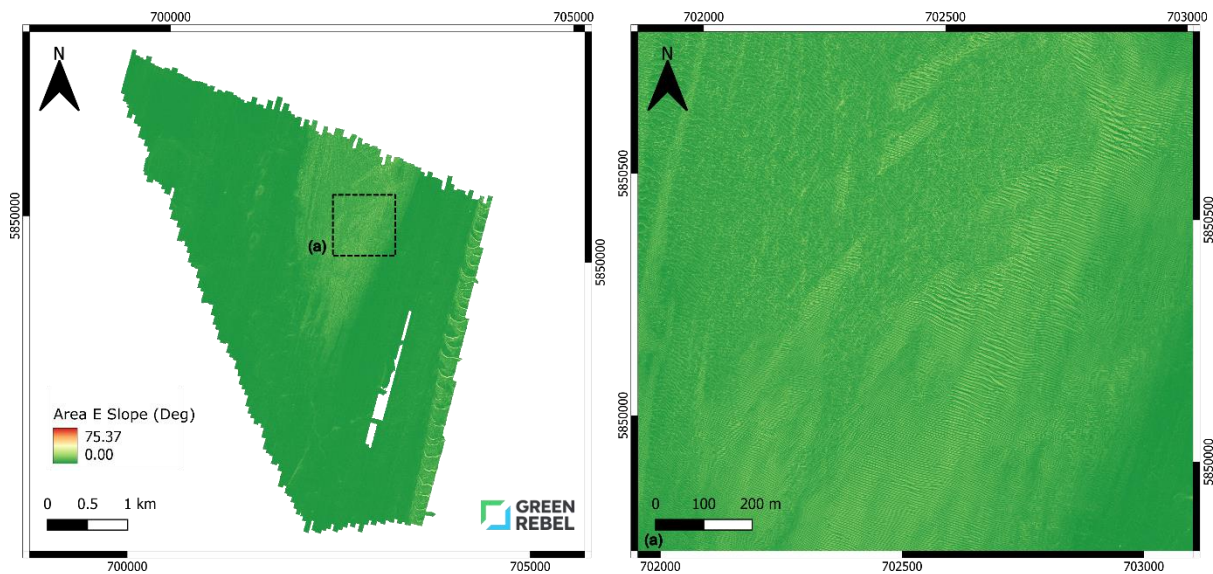


Figure 43: Area E bathymetric slope measured in degrees. (a) inset showing high slope values associated with the presence of sandwaves. The location of the inset is highlighted with a box on the main map presented on the left side.

4.3.4 Sandwaves and megaripples

Sandwaves and megaripples were widespread throughout the site and were analysed using the MBES bathymetry. Sandwave and megaripple shapefiles were delineated in ArcMap 10.8.1. As manual delineation through vectorization can be highly subjective, the semi-automated residual relief modelling approach was used to separate the sediment waves from the surrounding geomorphology. The workflow relies on a high-pass filtered digital elevation model (Majcher et al., 2020; Wessel, 1998), combined with a breakpoint classifier. Two separate circular high-pass filter moving mean kernels, with 5 and 15 m radii were chosen to delineate sandwaves and megaripples, respectively.

This classification system separates the geomorphological features based on relative differences to focal means, rather than observed heights or wavelengths. It was chosen as the sediment wave morphology is highly variable in the area. Nevertheless, it was observed that the delineated sandwaves are typically characterized by wavelengths ranging from 5 to 10 m and heights from 0.1 to 1 m (Figure 44a;

Table 11)., while the much larger megaripples have wavelengths of 50 to 200 m and heights of 2 to 10 m (Figure 44b;

Table 11).

The sandwaves are present across the investigated areas both as extensive wave fields and individual, linearly distributed sand wave trains (Figure 45). Occasionally, smaller, isolated groups containing only several waveforms are visible in the data. The megaripples form fields and are always covered with pervasive sandwaves, migrating over them. Across the whole survey site 7.4% coverage was comprised of sandwaves, and 0.4% was made up of megaripples, respectively.

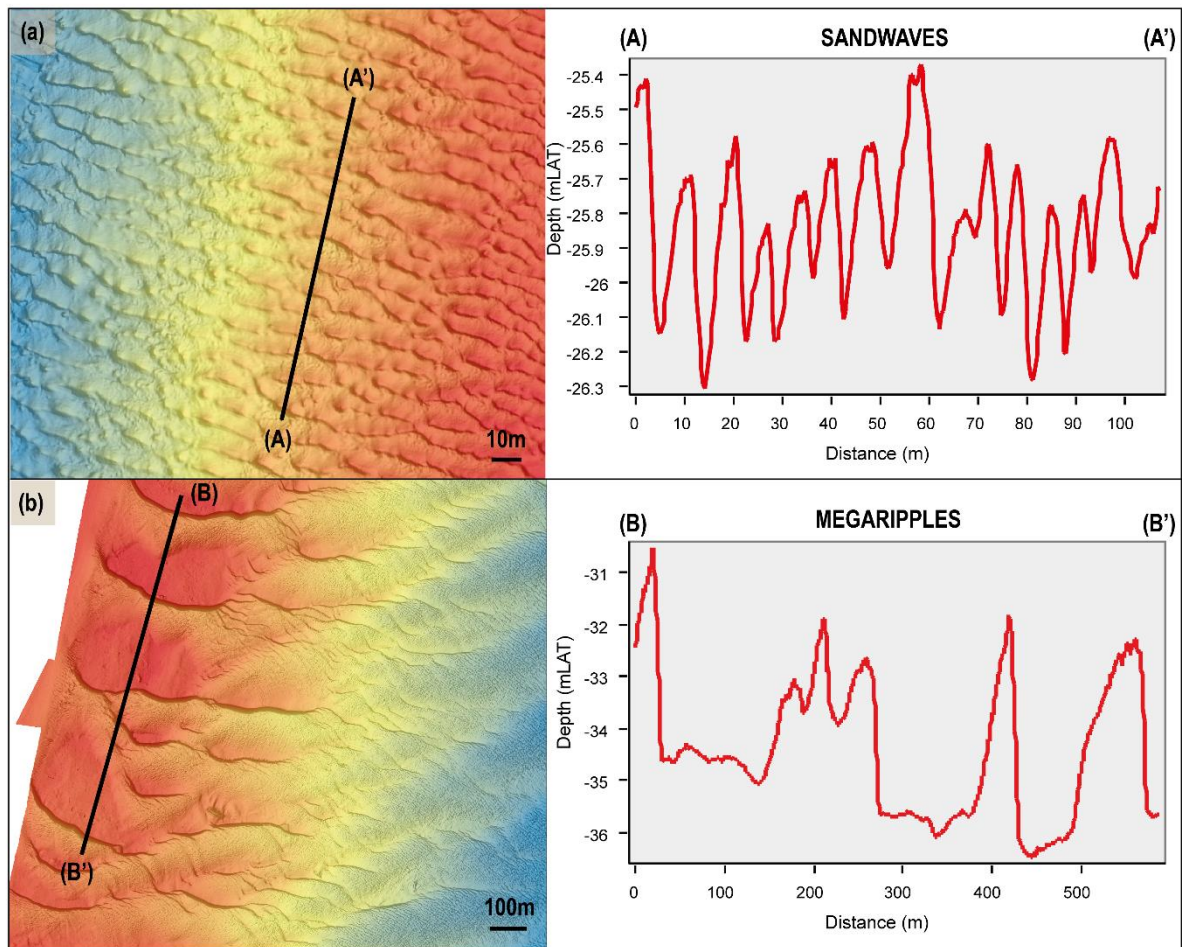


Figure 44: Examples of periodical bedform morphologies typically observed in the investigated area: (a) sandwaves with wavelengths $\leq 10\text{m}$ and heights $\leq 1\text{m}$ and (b) megaripples with wavelengths $\leq 200\text{m}$ and heights $\leq 10\text{m}$.

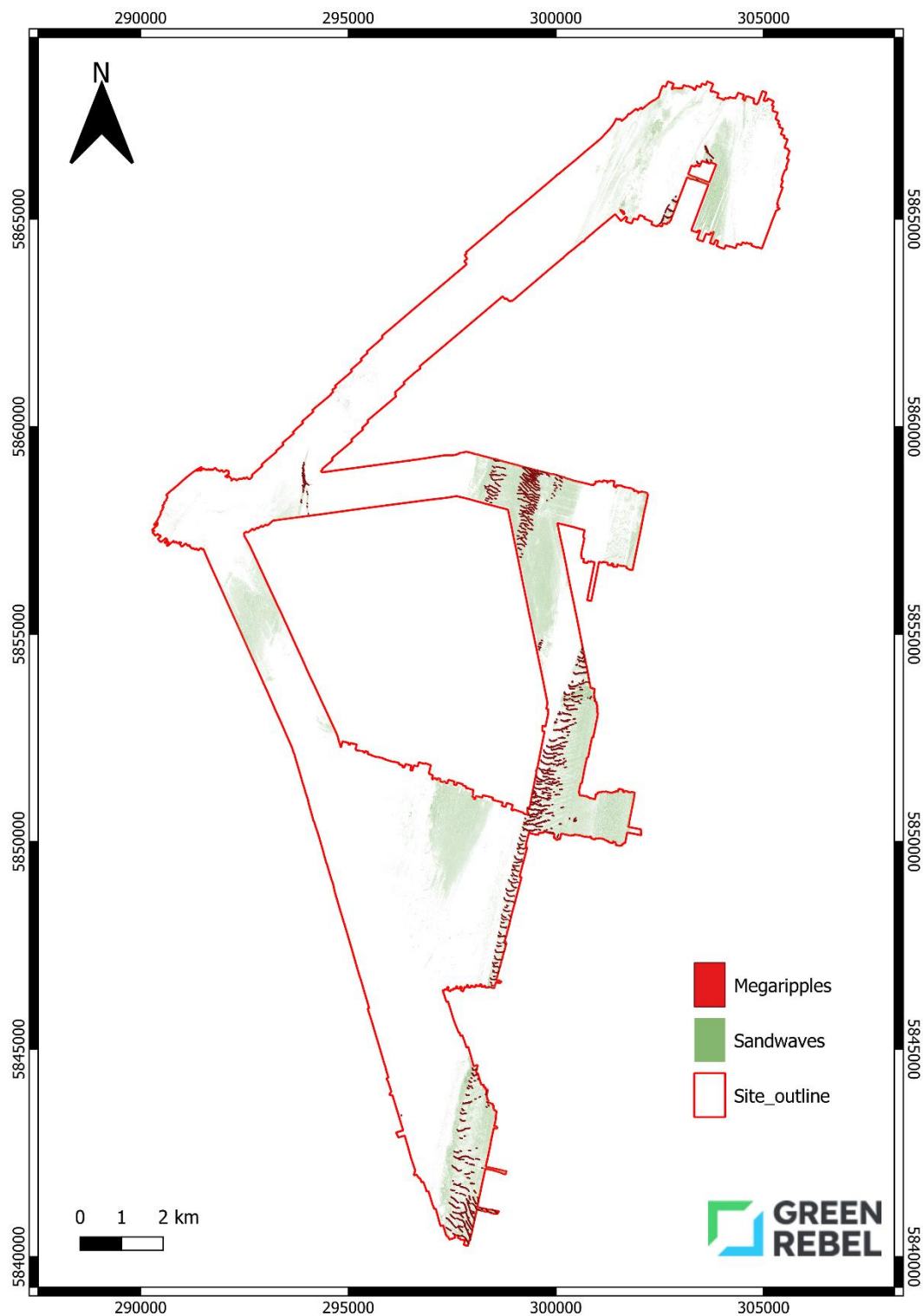
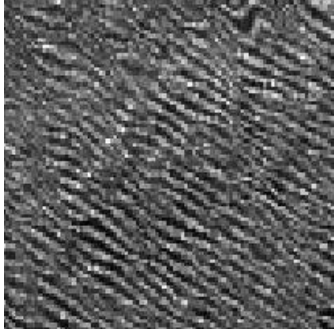
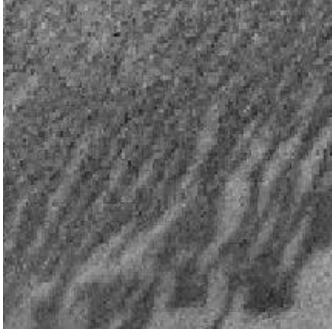
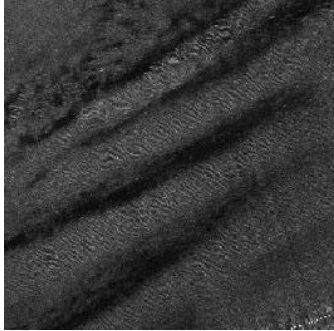
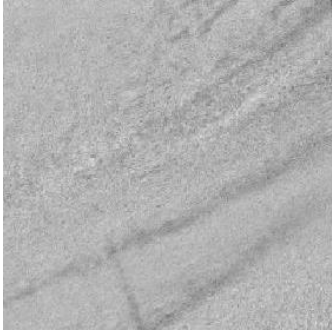


Figure 45: Sandwave and Megaripple distribution throughout the survey site

Table 11: Comparison between SSS and Backscatter images that denote sandwaves and megaripples

Feature Name	SSS Image	Backscatter Image	Feature Morphology
Sandwaves			Wavelength $\leq 10\text{m}$ Height $\leq 1\text{m}$
Megaripples			Wavelength $\leq 200\text{m}$ Height $\leq 10\text{m}$

4.4 Multibeam backscatter

4.4.1 Lot 1A

4.4.1.1 Final backscatter product

The final backscatter data were tiled 2 x 2 km and exported at 0.3 m resolution as per the scope of works. See Figure 46 for a combined mosaic of the Lot 1A area of the ABWP survey area which displays the extent of the backscatter coverage.

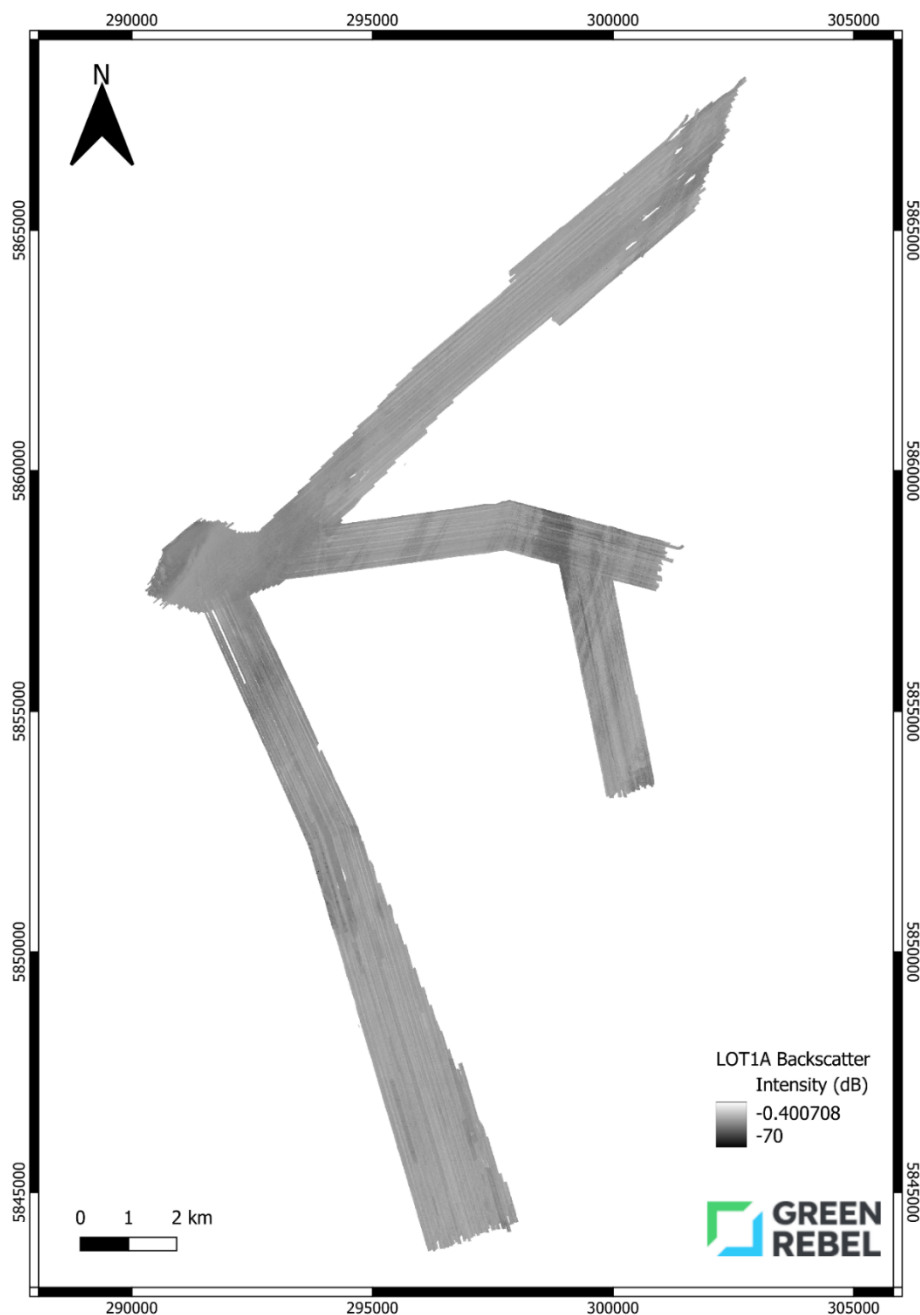


Figure 46: ABWP Lot 1A backscatter Map displaying intensity in dB

4.4.2 Lot 1B

4.4.2.1 Final backscatter product

The final backscatter data were tiled 2 x 2 km and exported at 0.3 m resolution as per the scope of works. See Figure 47 for a combined mosaic of the Lot 1B area of the ABWP survey area which displays the extent of the backscatter coverage.

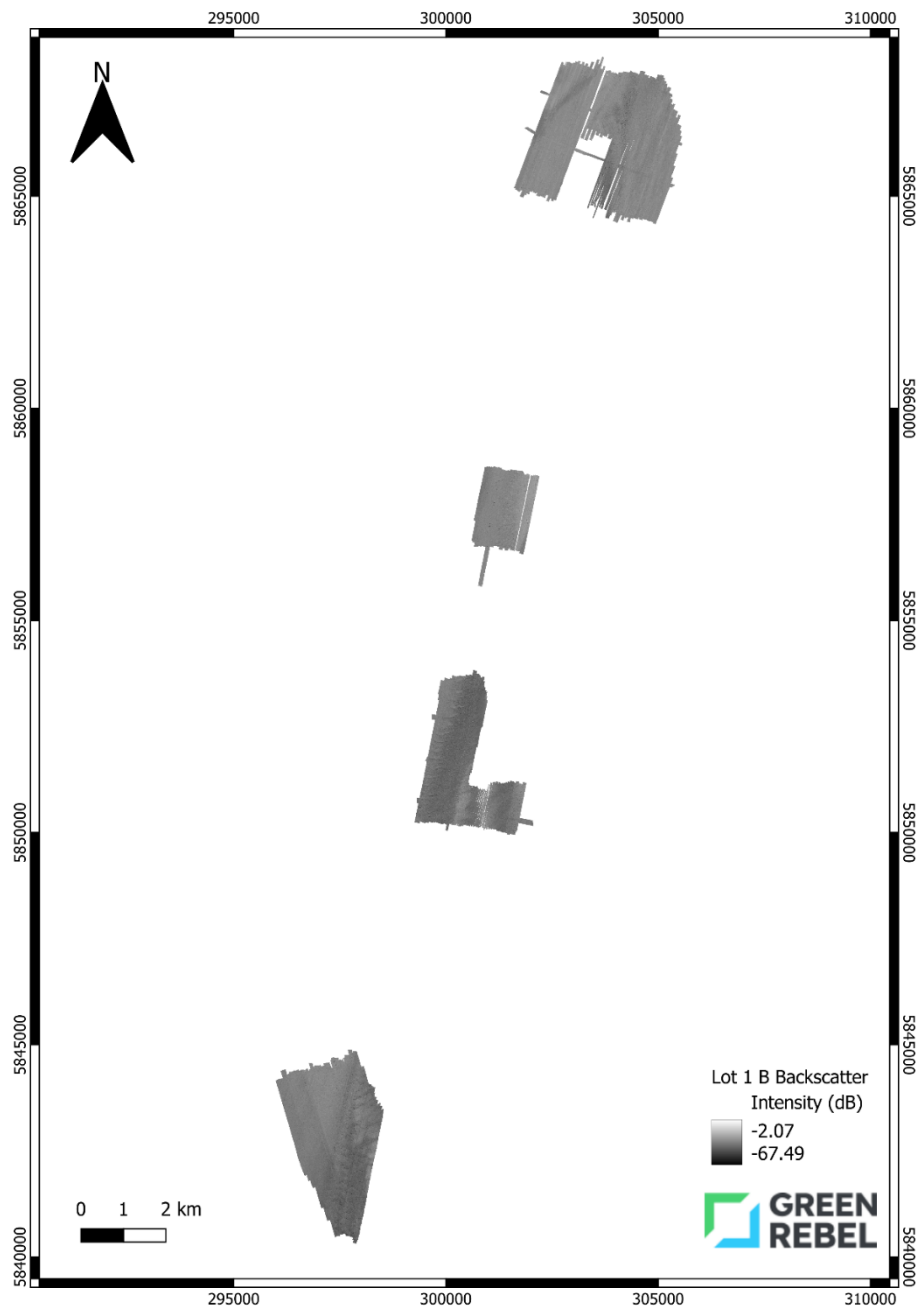


Figure 47: ABWP Lot 1B backscatter Map displaying intensity in dB

4.4.3 Area E

4.4.3.1 Final backscatter product

The final backscatter data were tiled 2 x 2 km and exported at 0.3 m resolution as per the scope of works. See Figure 48 for a combined mosaic of the Area E area of the ABWP survey area which displays the extent of the backscatter coverage.

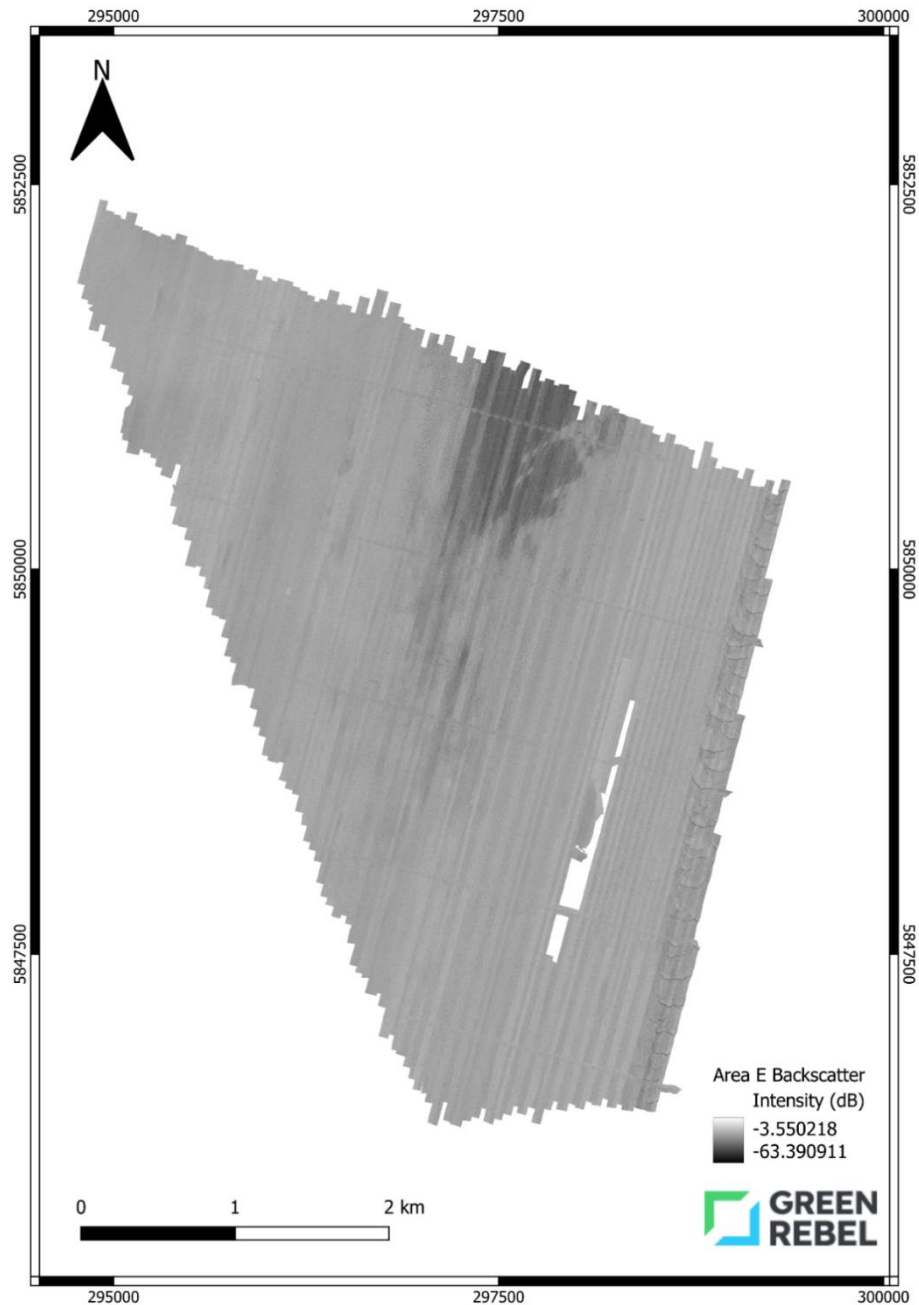


Figure 48: ABWP Area E backscatter Map displaying intensity in dB

4.4.4 Seabed sediments

Delineation of backscatter sediments supported using ARA analysis suggests that the distribution of sediment across the ABWP survey area shows predominant facies of medium to coarse sands (see Figure 49; red). This facies dominance coincides with the large presence of sandwaves, megaripples and sediment waves in the eastern regions of the ABWP survey area on approach to the shallower Arklow sand bank (Lot 1B). Conversely, the presence of finer-grained facies types, such as sandy mud – to clay are visible in the trough areas between sand wave crests in the Lot 1B ABWP survey area (see Figure 49; red and orange). The thin interbedded fine grained sediment distribution is most notably present in Lot 1B CR2a and CR2b survey areas. This inference is supported when corroborating these observations with the seabed morphological classification, where the trough areas between sediment waves have a low incidence of sandwaves or megaripples (Figure 45). ARA seabed sediment analysis is furthermore delineated with side-scan sonar mosaic analysis to support accuracy in tracing seabed sediment distributions.

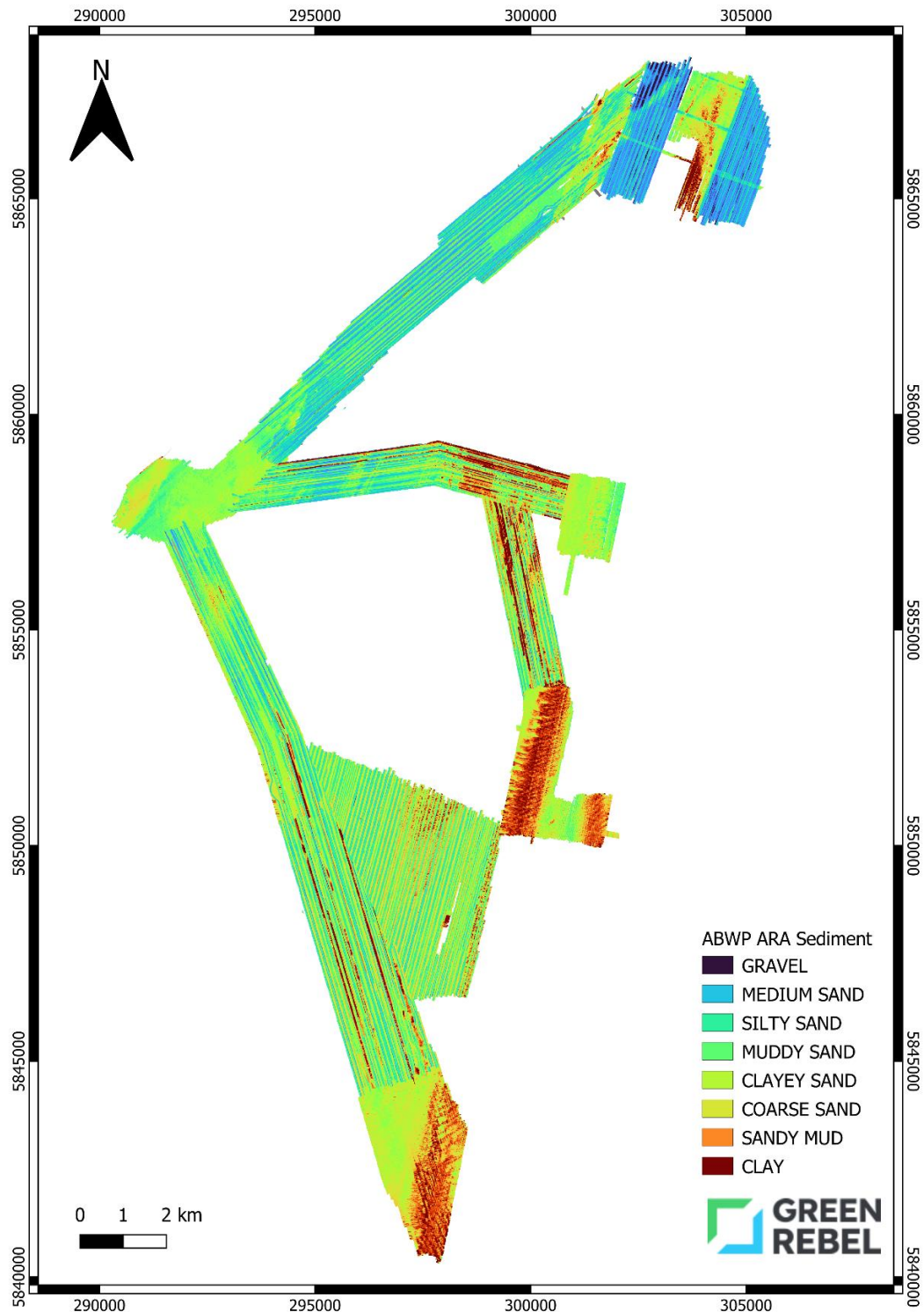


Figure 49: ARA analysis derived from MBES BS. Blue and Green NE-SW trending stripes appear due to differing backscatter values along swath profiles.

The manual classification of SSS and MBES backscatter data has revealed the sediment distribution in the ABWP area. The characterization of coarse, medium, and fine sediment is crucial in comprehending the hydrodynamic processes of water bodies and can aid in optimizing wind turbine design to reduce potential environmental impacts. The landfall area (CR1 landfall) is primarily composed of fine-grained sediment, with a coarse-grained enclave and minor occurrences of medium-

grained bedforms. The northernmost cable route, Lot 1A CR1, is mostly composed of coarse-grained sediments, while the western approaches and Lot 1B CR1 are primarily medium to fine-grained. The middle cable route, Lot 1A CR2a, is primarily composed of coarse and medium-grained sediments with minor NNE-SSW trending fine-grained bands. At the intersection of Lot 1A CR2a and Lot 1A CR2b, the primary sediment type is fine-grained, with areas of medium and coarse-grained sediments marking the presence of megaripples (Figure 45). At the boundary between Lot 1A CR2a and Lot 1B CR2a, NNE-SSW interbedded fine-grained sediments reappear. In Lot 1B CR2a, the sediment types further define the local bedforms, with fine-grained sediment accumulation along the crests of east-west trending megaripples and medium to coarse-grained sediments composing the troughs and lower planes. The northern parts of Lot 1A CR2b are heterogeneous, while the southern part is mostly coarse-grained. Lot 1B CR2b is primarily fine-grained, with coarse-grained sediments defining the crests of NNE-SWW extending megaripples and two north-south trending bands of medium-grained sediments visible in the centre. The south westernmost cable route, Lot 1A CR3, is characterized by well-defined packages of sediment with the northernmost part composed of roughly 3 km of fine-grained sediment extending from CR1 landfall and transitioning to a medium-grained sediment type with a serrated boundary. The southern border of this medium-grained sediment extends southwards for roughly 4.5 km with occasional occurrences of finer and coarser sediments. Adjacent to Area E, the sediment becomes notably coarser, alternating between coarse and medium-grained sediment types with minor NNE-SWW trending fine bands also visible. In Area E, the majority of sediment is coarse-grained, with a 3.5 km long, 1.5 km wide interbedded fine-medium-grained feature visible in the centre. The fine-grained NNE-SWW trending bands crosscut into both medium-grained facies and the surrounding coarser sediment, and the coarse-grained sandwaves surrounded by fine-grained sediment previously described in Lot 1B CR2b are further observed in the eastern part of Area E. Finally, in Lot 1B CR3, bedform-defined sediment types are visible again, with medium-grained megaripples surrounded by finer-grained material and a coarse-grained sediment package visible to the west. The NNE-SWW linear features are also present in this area.

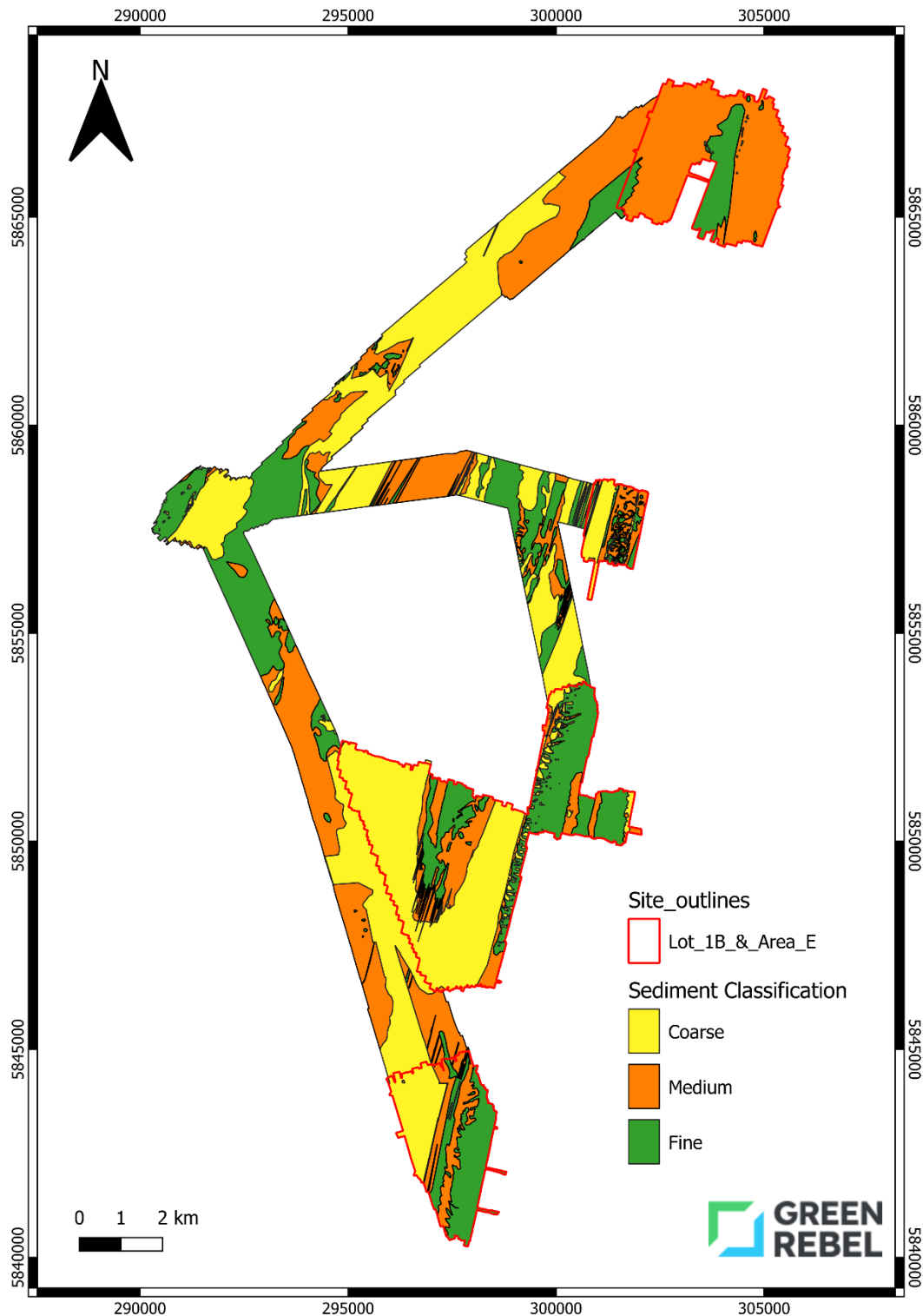


Figure 50: Sediment classification manually delineated from side-scan sonar mosaic. Results were cross correlated versus bathymetry and backscatter to ensure continuity across site. Outline of Lot 1B and Area E is also delineated.

4.5 Side-scan Sonar

4.5.1 Coverage

A SSS swath of 75 m wide on either side of the nadir was collected (Figure 51). The raw SSS data exhibits progressive darkening along the outer swath. This is typical of all side-scan systems and represents the attenuation of sound in water. This is typically rectified through the assessment of the side-scan amplitude data by applying gains that homogenise the swath data. To survey the area, approximately 2,088.5 km of SSS survey line length was collected, including infill lines. Given the specifications of the survey, 300% overlap between the lines was achieved. However, some lines were excluded from the final mosaic as they were deemed as bad quality (i.e. Category 3 and Category 4; see section 2.4.3; Figure 52). Despite this, areas which had bad quality data still maintained 100% coverage due to the high density nature of the lineplan. This achieved a grid with low-frequency side-scan data covering 96.07 km² (Lot 1A - 53.4 km², Lot 1B – 26.5 km², Area E – 16.1 km²).

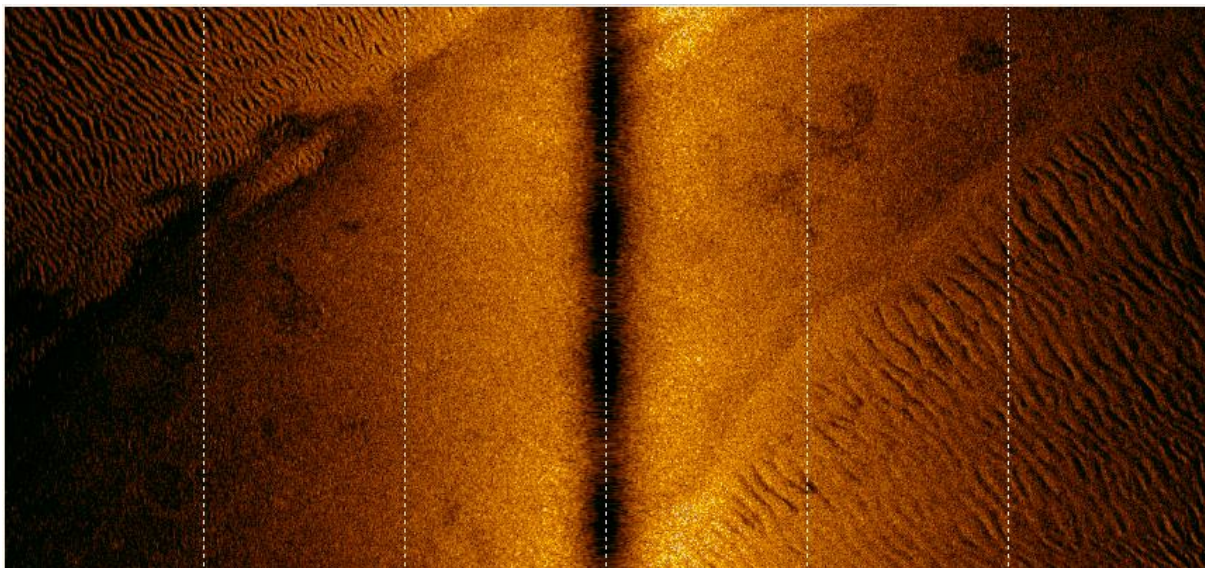


Figure 51: Typical example of low-frequency side-scan mosaic coverage from line 11 before any processing. The white dashed vertical lines are 25 metres apart.

4.5.2 Processed Accuracy

SSS navigation and positional accuracy were good throughout Lot 1B and Area E bar for a few isolated instances where possible vessel turns or poor weather where accuracy was out of spec (Figure 53). Positional accuracy declined in Lot 1A due to USBL drop out. Post-processing navigation and map corrections were then utilised to bring the whole dataset into the specification outlined in the scope of works. Figure 54 display the trackline and position of the SSS data when post-processed. These processes highlight where isolated areas where navigation is considered “out of spec” are improved significantly.

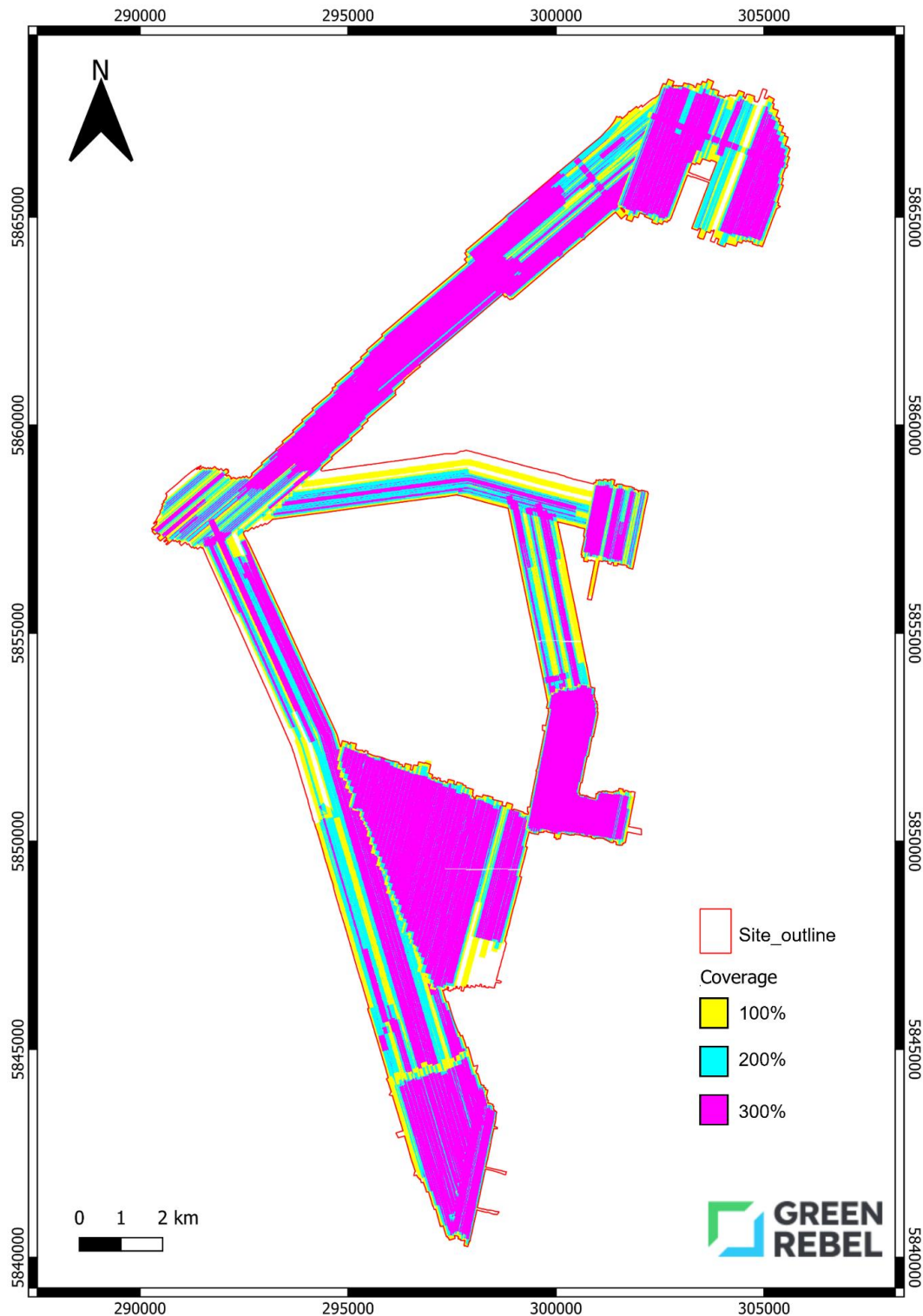


Figure 52: Side-scan mosaic coverage (%) taken from low-frequency SSS. Note the reduction of coverage in the eastern part of Area E. This resulted in a sonar contact artifact, where it appears that a hard border of contacts occurs here (see section 4.5.4.2)



Figure 53: Map showing raw track lines for SSS data acquisition

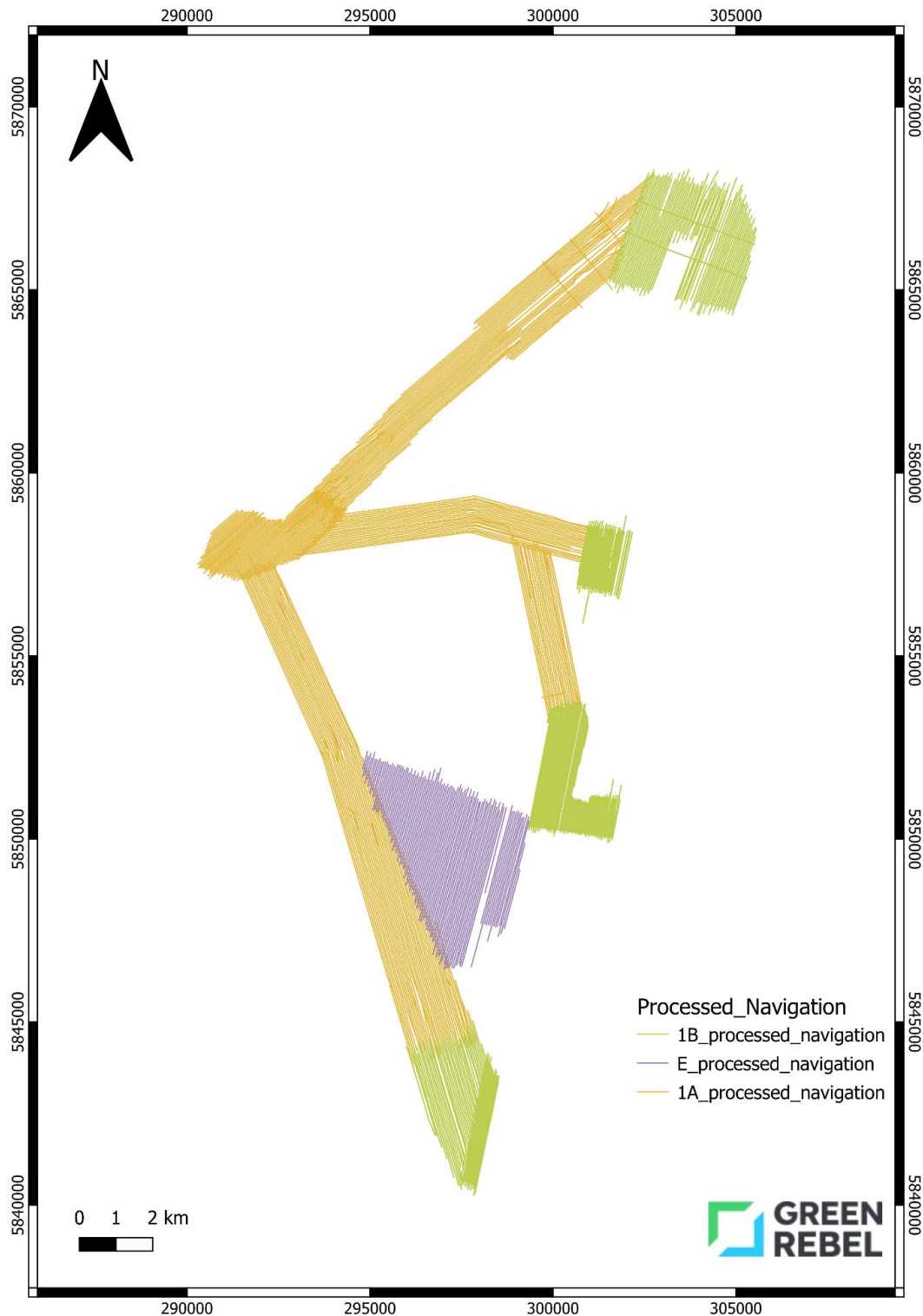


Figure 54: Map of SSS tracklines post navigation corrections and processing.

The navigation required modification to remove data gaps caused by USBL dropouts and spatial jumps caused by USBL position. Corrections were made by interpolating manually with the map corrections tool, applying a linear interpolation within USBL drops. 3,311 (1735 - Lot 1A, 1105 – Lot 1B and 471 Area E) map corrections applied across the whole area (Figure 55). The accuracy score is calculated from the difference between seafloor features (such as boulders) observed in the multibeam

bathymetry (considered the gold standard for geographical positioning) and the side-scan mosaic. The initial average accuracy of Category 2 files (see section 2.4.2 for further details) was greater than the originally specified 2 m accuracy, with a final average accuracy of 1.8 m (range: 0–7.2 m) calculated from a total of 3896 error measurements. Larger errors (> 5 m) were in isolated areas and often associated with poor weather or changes in vessel direction of fish altitude (for object avoidances for example).

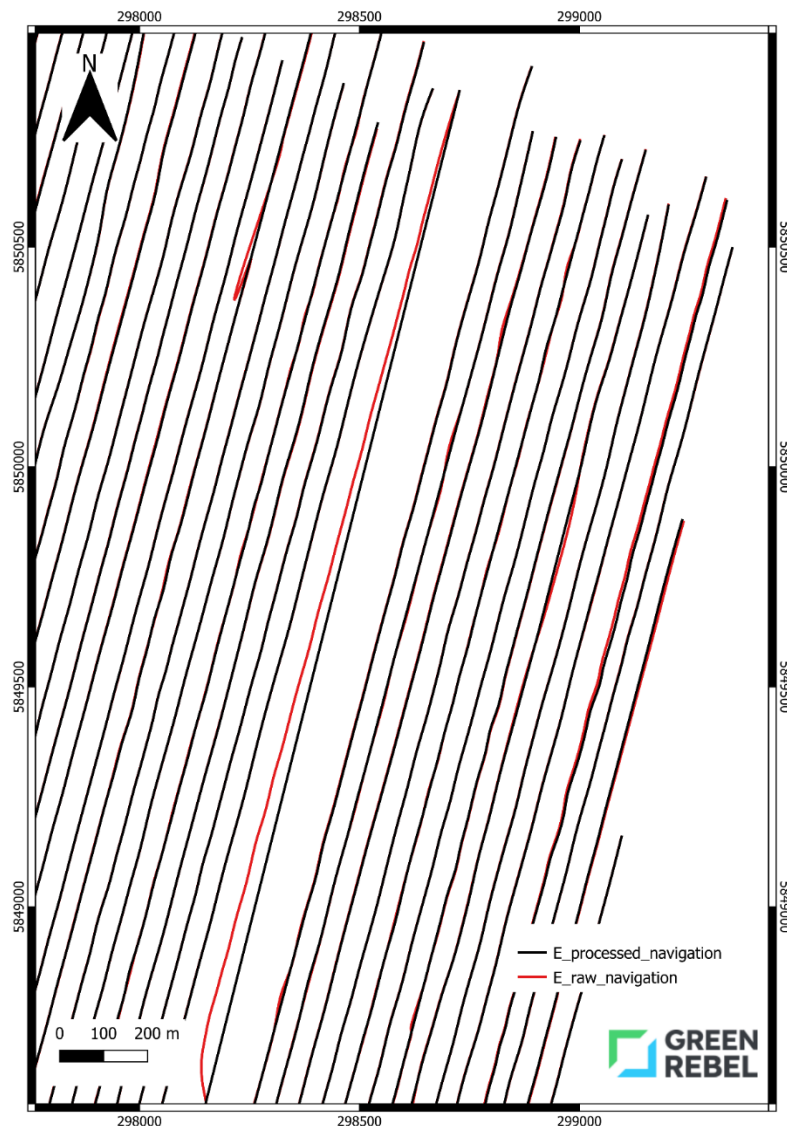


Figure 55: Raw and corrected navigation from the ABWP survey. Both datasets have had a 300-ping smoother applied (course made good).

4.5.3 Final product

The final mosaic was exported with a 0.2 m pixel resolution as specified in the scope of work. Whilst the survey line distinctions and nadir lead to natural lines across the survey, the mosaic was of very high quality and sediment patterns, seafloor features and shipwrecks are clearly discernible, this is demonstrated by the distinct patches of low and high backscatter. The .csf files were converted to .xtf file type using floating point conversion, to avoid over-compression and maintain 8-bit scaling.

4.5.3.1 Lot 1A



Figure 56: Low-frequency SSS mosaic from Lot 1A, presented with a pixel resolution of 0.2 m

4.5.3.2 Lot 1B

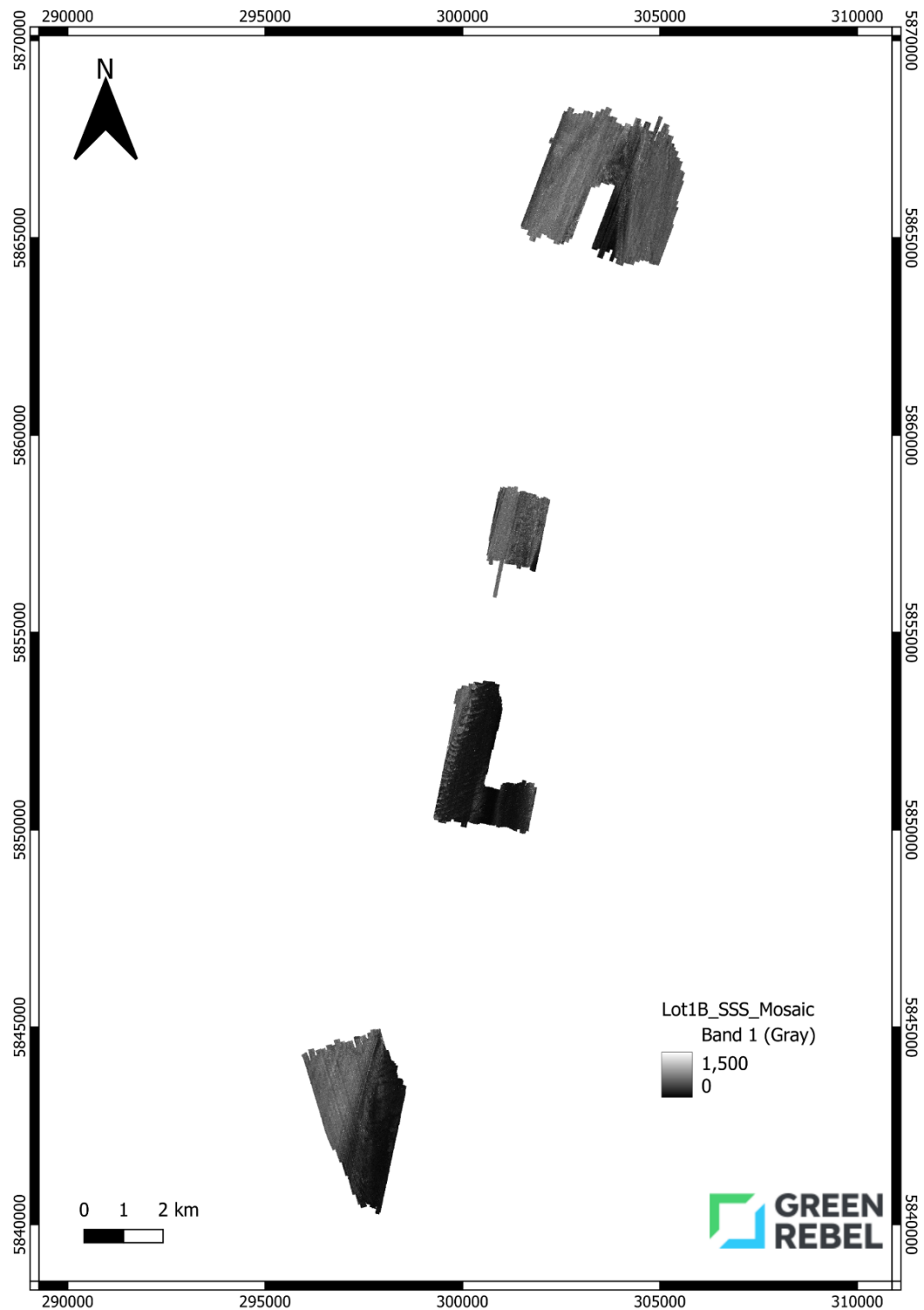


Figure 57: Low-frequency SSS mosaic from Area 1B, presented with a pixel resolution of 0.2 m

4.5.3.3 Area E

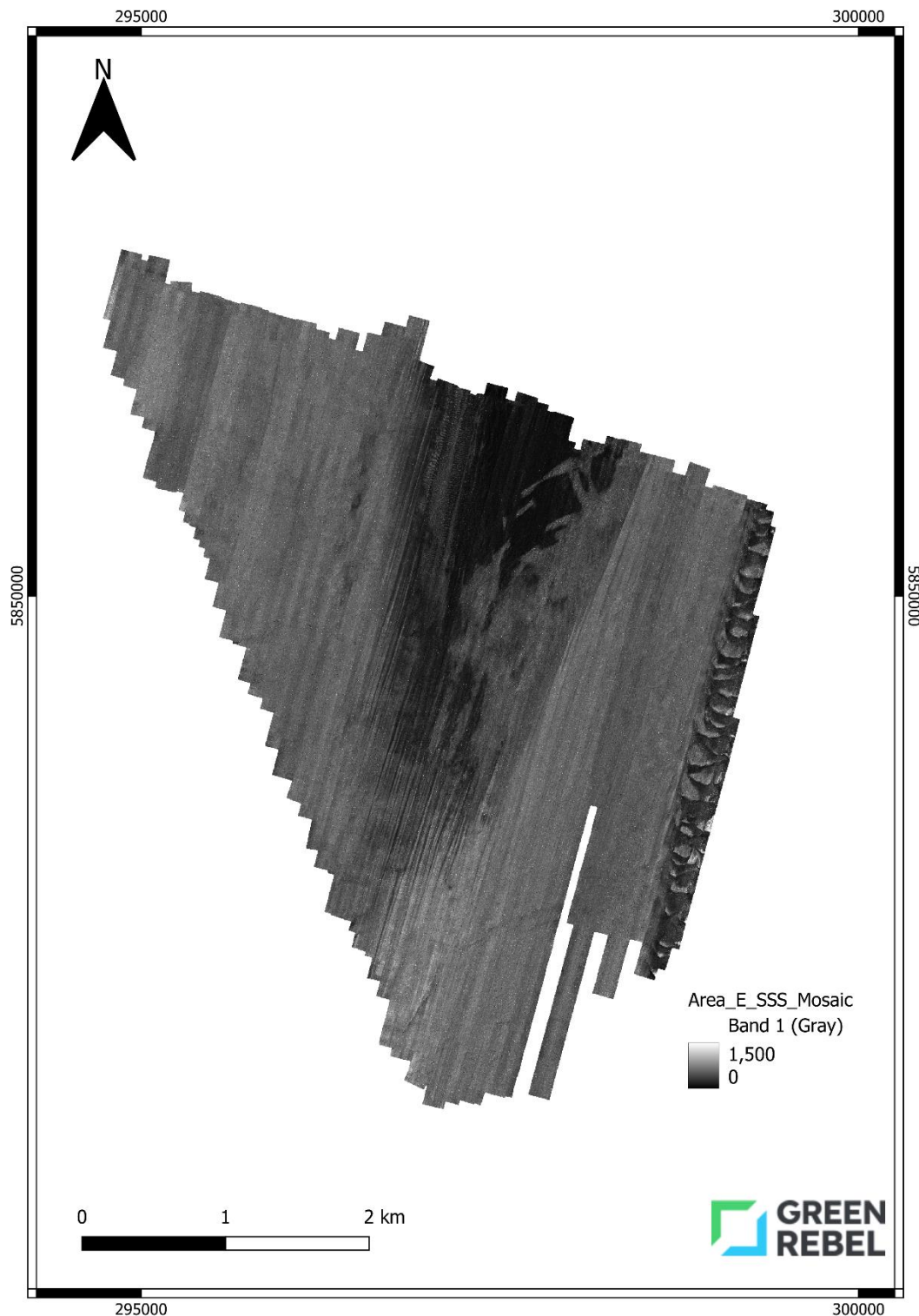


Figure 58: Low-frequency SSS mosaic from Area E, presented with a pixel resolution of 0.2 m

4.5.4 Sonar Contacts

A variety of contact types were determined during the data analysis phase (Table 12). The contacts are described on a site-to-site basis below. A summary of contacts is also provided in Appendix 2.

Table 12: SSS contacts from the AWBP site.

Contact Type	Lot 1A	Lot 1B	Area E
Boulders	3734	1776	955
Sonar Contact	100	22	-
Debris	33	12	11
Outcrop	11	-	-
Linear Contact	2	3	-
Wrecks	4	6	-

4.5.4.1 Lot 1A

In total, 3884 contacts were visible in Lot 1A (Table 12). These were classified as boulders (n – 3734), sonar contacts (unidentifiable; n – 100) debris (n – 33), outcrop (n – 11), wrecks (n – 4) and linear contacts (n – 2). The average height of the boulders identified in Lot 1A was 0.31 m, and the tallest contact, Contact3258, was 2.08 m in size. Most boulders are seen within Lot 1A CR1 (Figure 1) and the southern half of Lot 1A CR3 (Figure 59). CR1 landfall has a moderate degree of boulders, whereas Lot 1A CR2a, Lot 1A CR2b and the northern half of Lot 1A CR3 has a minor amount of boulders. A similar distribution is seen with boulder fields, which are interspersed throughout areas where abundant boulders occur. In addition, 12% of Lot 1A is comprised of boulderfields. Debris is interspersed throughout the site, but the majority were identified in the CR1 landfall district of Lot 1A. Two Contacts (Contact1302 and Contact1310) capture a linear contact over 400m in length and is a cable (Figure 91). Outcropping rock was also identified in the site, the majority of which were confined to CR1 landfall. Wrecks are clustered in Lot 1A CR2b.

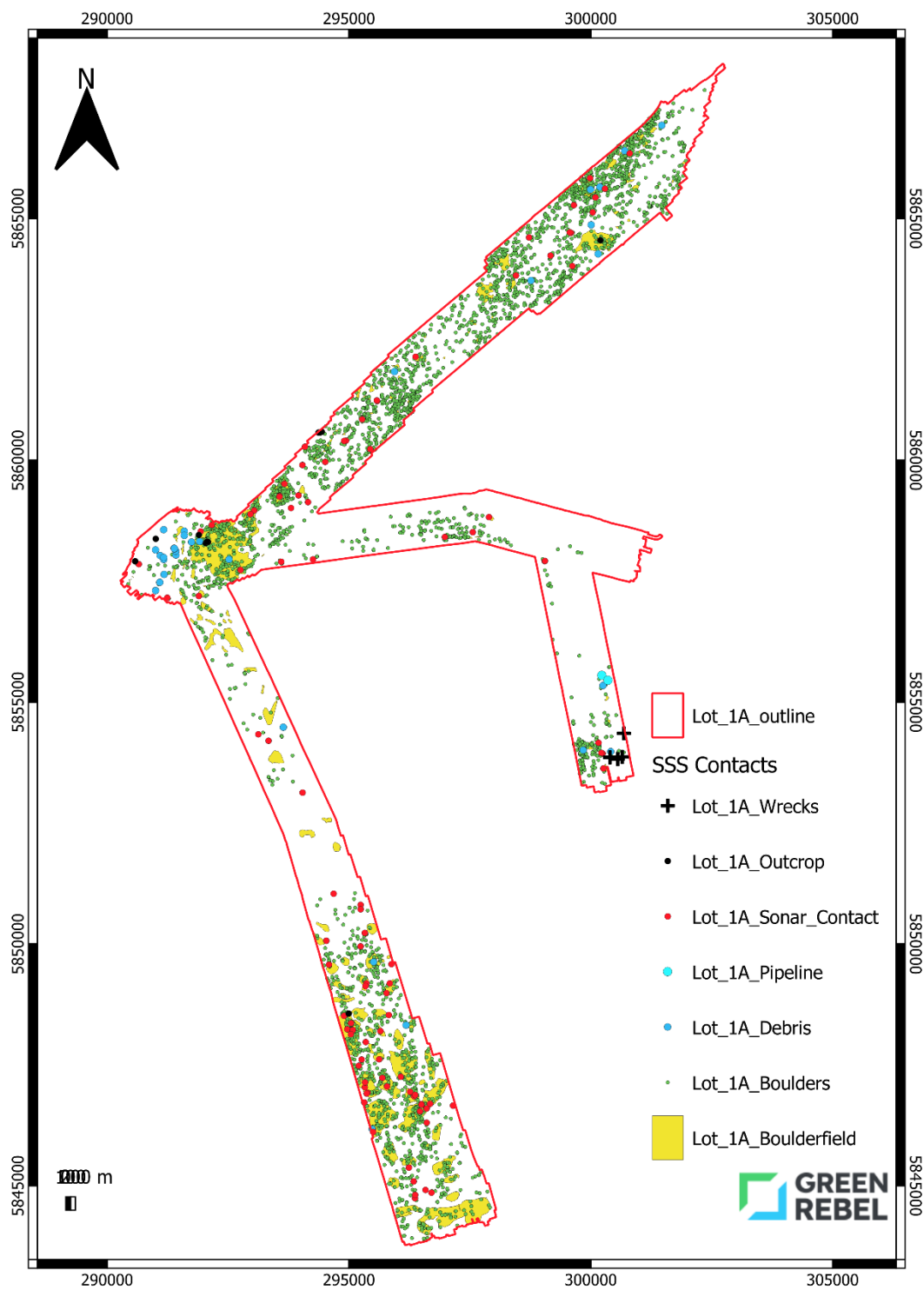


Figure 59: Sonar contacts and boulderfields in Lot 1A

4.5.4.2 Area 1B

In total, 1819 contacts were visible in Area 1B (Table 12). These were classified as boulders (n – 1776), sonar contacts (unidentifiable; n – 22) debris (n – 12), linear contact (n – 3) and wrecks (n-6). The average height of the boulders identified in Area 1B was 0.38 m, and the tallest contact, Contact0789, was 1.9 m in size. Most boulders are seen within Lot 1B CR1 (Figure 60). A moderate amount of boulders were identified in Lot 1B CR3. A minor amount of boulders were identified in Lot 1B CR2b and a trace amount were noted in Lot 1B CR2A. Wrecks are confined to Lot 1B CR2b. Debris was identified in Lot 1B CR2b and Lot 1B CR1. The largest of these contacts is 75 m in length (Contact1811), and is likely fishing gear. Wrecks are confined to Lot 1B CR2b. The largest, Contact0138, is 65.1m in length, 28.6 m in width and 6.4 m in height. Boulderfields occur alongside high density of boulders, as such, most are found in Lot 1B CR3 and Lot 1B CR1. (Figure 60). In addition, 7% of Lot 1A is comprised of boulderfields.

4.5.4.3 Area E

In total, 966 contacts were visible in Area E (Table 12). These were classified as boulders (n – 955) and debris (n – 11). The average height of the boulders identified in Area E was 0.29 m, and the tallest contact, Contact0358, was 1.3 m in size. Most boulders are found on the western part of the site, whereas moderate amounts are visible on the eastern sectors (Figure 61). A trace amount of boulders are found in the central north and extreme south eastern and north western parts of the site. Boulderfields occur where higher density of boulders are found and as such were identified on the western parts of the site (Figure 61). Debris is interspersed throughout the site, with the largest identifiable contact (Contact0605), expressed as 74.2 m long fishing gear. Boulderfields account for 9% of coverage in Area E.

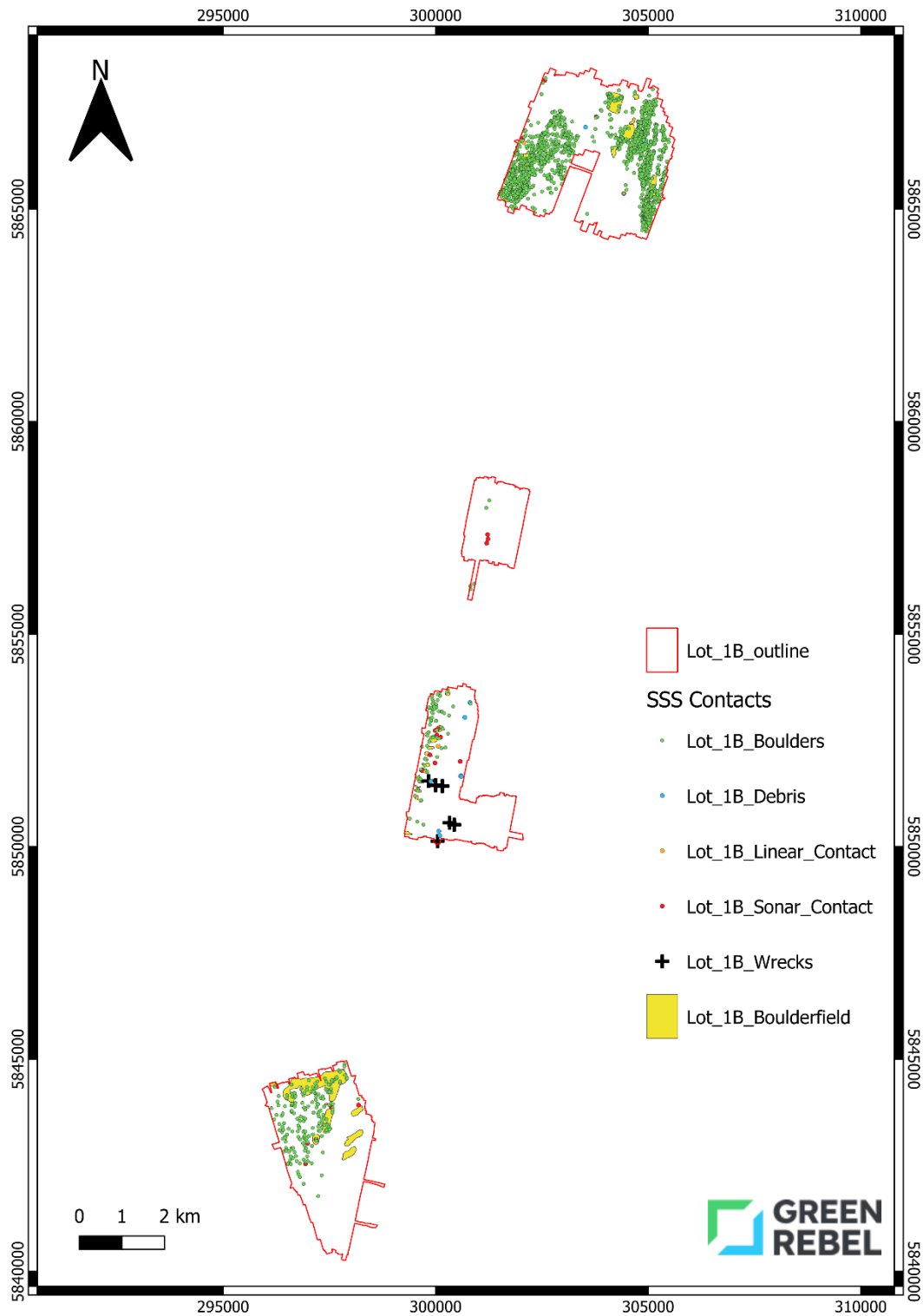


Figure 60: Sonar contacts and boulderfields in Lot 1B

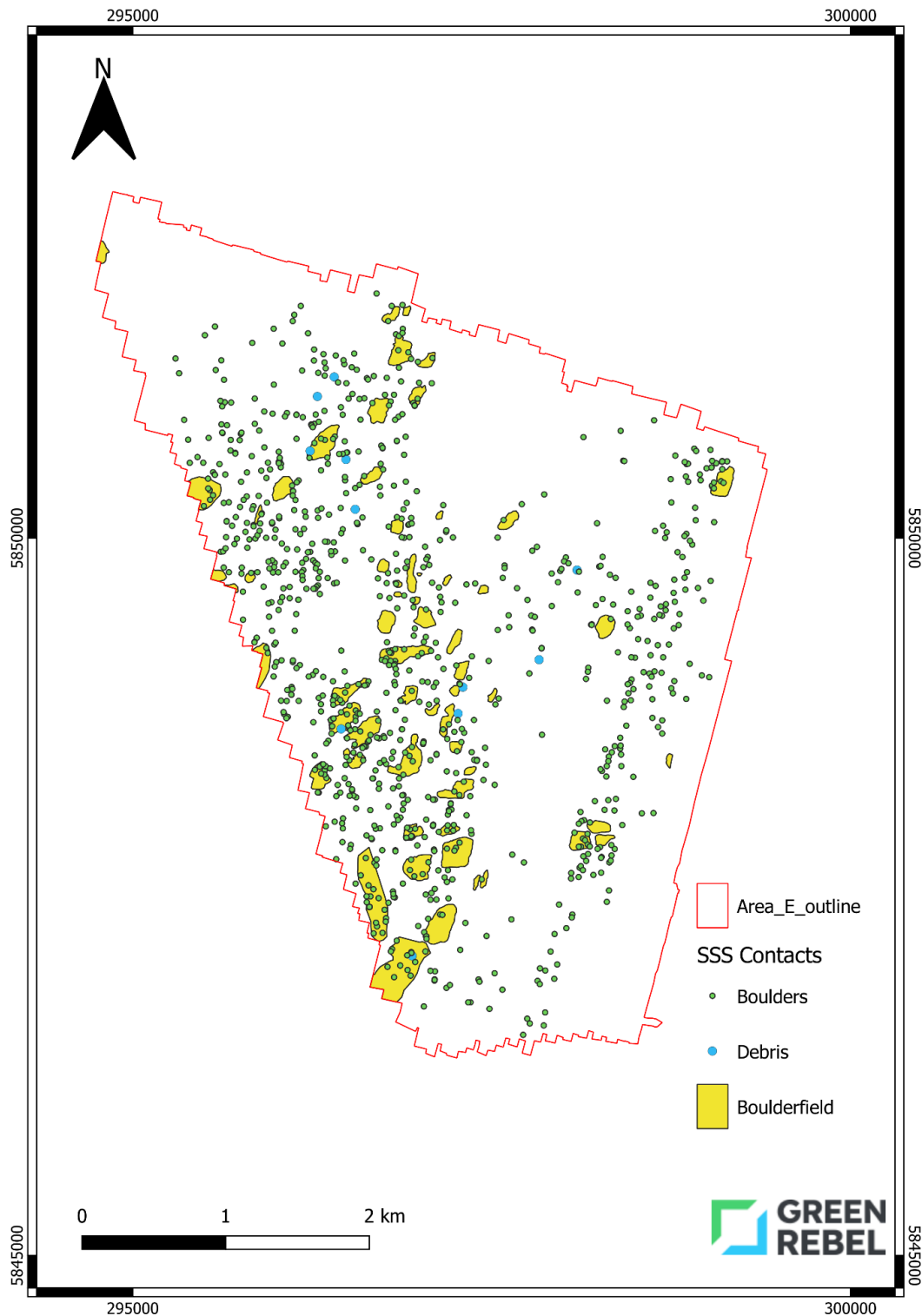


Figure 61: Sonar contacts and boulderfields in Area E. Note that the linear pattern of boulders occurring in the eastern part of the site is an artifact of data acquisition. No data was collected for the area to the immediate west, and as such, a harsh boundary of boulder picking is observed in the data (see Figure 52)

4.6 Magnetometer

Overall, the coverage of the dataset was deemed of high quality despite the navigation spikes. Navigational gaps were present when the USBL lost signal to the beacon which was likely weather induced. As a result, given that the raw magnetic signal could not then be parsed with x and y coordinates, these data were rejected based on precautionary principles. This is rectified in post-processing by simply interpolating within the error window. The processed magnetometer data were gridded and covered a line length of approximately 1,200 km (Figure 62). A summary of contacts is provided in Appendix 2.

4.6.1 Lot 1A

The mean survey depth observed was 20.12 m (Table 1), with a standard deviation of 7.30 m. The mean survey altitude of the fish above the seafloor was 3.55 m, with a minimum and maximum of 0.34 m and 15.0 m respectively. However, it is worth noting that the maximum value and other high values were recorded during the ascent and descent of the fish to and from the survey vessel during deployment and recovery of the fish. The standard deviation of 1.10 m shows that the fish remained consistent across the survey area. The altitude across 1A was distributed normally, with a slight right-skew spread observed in the depth. This can be attributed to the variation of water depth across the site (Figure 64). Despite this, the quality of the altitude and depth Lot 1A data meet the required specifications outlined in the scope of works.

Variation in Total Field across 1A was minimal at 378.74 nT, distributed normally around a mean of 49110.87 nT. Residual activity was much more pronounced, with the minimum and maximum far exceeding the 10 nT target threshold. This complements the data well, as 900 mag targets were identified in Lot 1A alone. The mean residual value is – 0.06 nT, reflecting areas in which no significant ferrous activity was noted.

Table 13: Magnetometer Statistics across Lot 1A

Data	Depth of Magnetometer (m)	Altitude of Magnetometer (m)	Total Field (nT)	Residual Amplitude (nT)	Signal Strength (nT)
Minimum	2.68	0.34	48928.07	- 208.95	15
Maximum	38.46	15.0	49306.81	167.57	1296
Mean	20.12	3.55	49110.87	-0.06	784.95
Median	16.59	3.46	49106.34	3.19	872
Mode	14.58	3.3	49102.82	-0.04	1218
St. Deviation	7.30	1.10	29.03	14.91	416.44



Figure 62: Processed magnetometer tracklines

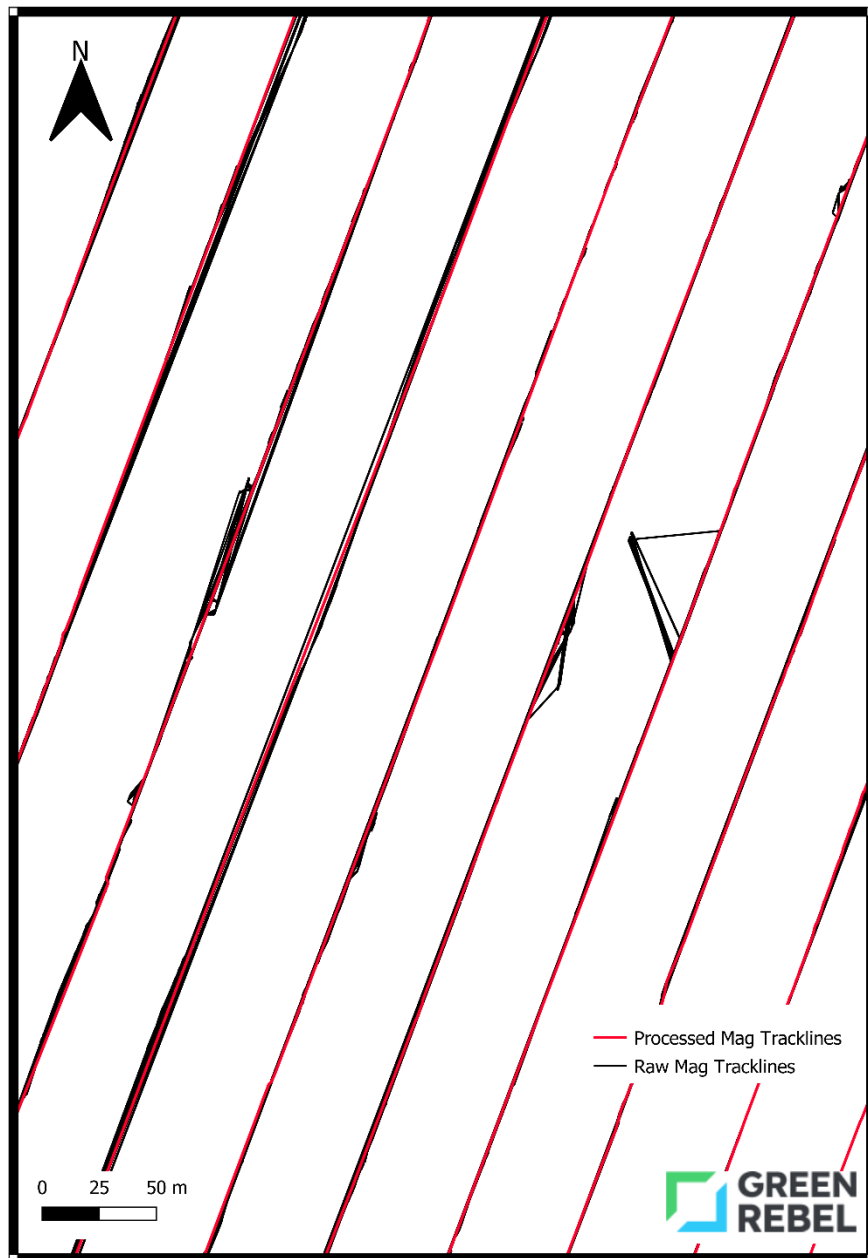


Figure 63: Map showing raw mag track lines sv processed variant

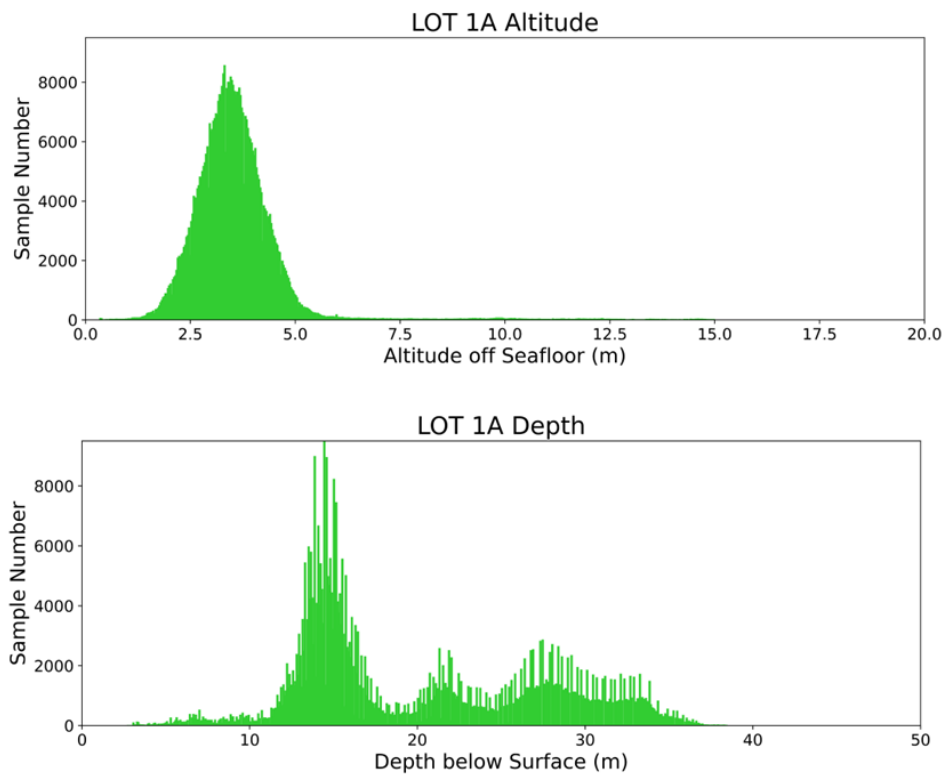


Figure 64: Altitude and Depth of magnetometer across Lot 1A.

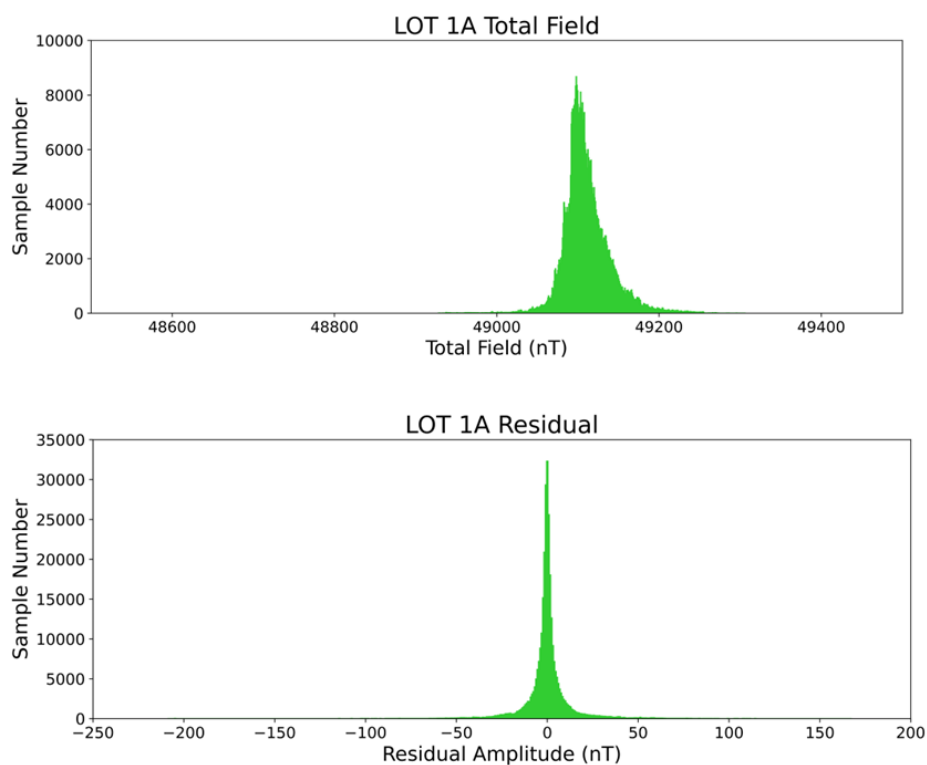


Figure 65: Total and residual field across Lot 1A. Note – Normal Distribution

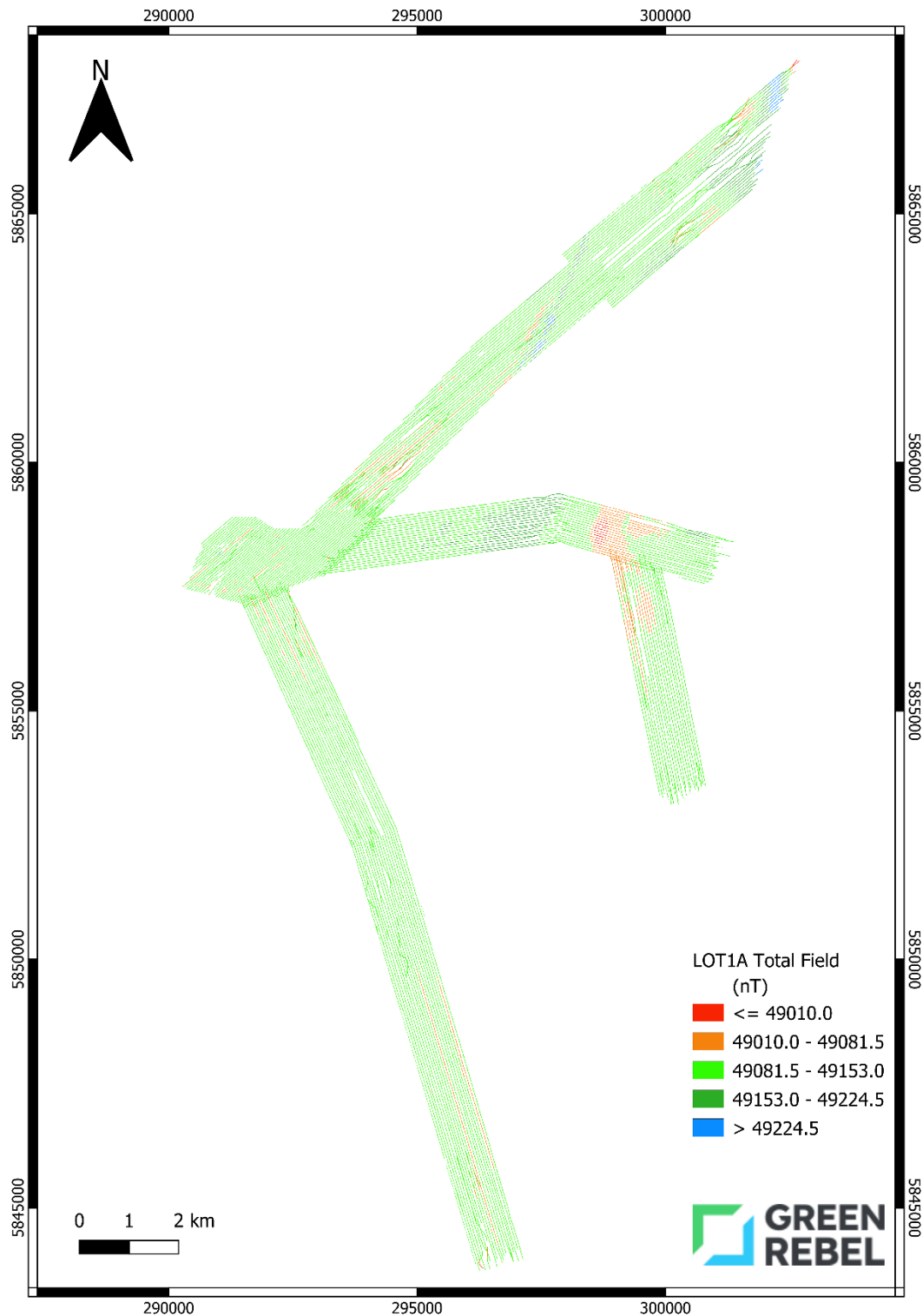


Figure 66: Total magnetic amplitude grid (pixel resolution 0.5 m)



Figure 67: Residual amplitude grid across Lot 1A (pixel resolution 0.5 m)



Figure 68: Altitude of magnetometer across Lot 1A gridded at 1 m pixel resolution.



Figure 69: Depth of magnetometer gridded at 1 m pixel resolution

4.6.2 Lot 1B

Lot 1B statistics continue to remain consistent (Table 14). Average survey depth here was 24.27 m, with a standard deviation of 8.89 m. The altitude reached its lowest point in 1B, at 0.34 m off the seafloor. This is indicative of the acquisition environment of the shallow banks. Residual also reached its minimum, at -4449.66 nT. This is due to the presence of a large shipwreck found in the CR2B sub-site. This has also resulted in the slightly skewed deviation at 38.63 nT, more than double the value of 1A. The trend in altitude remains normally distributed, with the right-skew in depth again reflective of the varying depth conditions across 1B (Figure 70).

Table 14: Magnetometer Statistics across Lot 1B

Data	Depth of Magnetometer (m)	Altitude of Magnetometer (m)	Total Field (nT)	Residual Amplitude (nT)	Signal Strength (nT)
Minimum	2.48	0.34	44492.73	- 4449.66	12
Maximum	44.67	16	51895.94	2586.4	1533
Mean	24.27	3.52	49126.69	-0.007	949.33
Median	24.45	3.51	49112.78	-0.01	962
Mode	21.3	4.05	49097.96	-0.07	781
St. Deviation	8.89	1.01	58.66	38.63	177.14

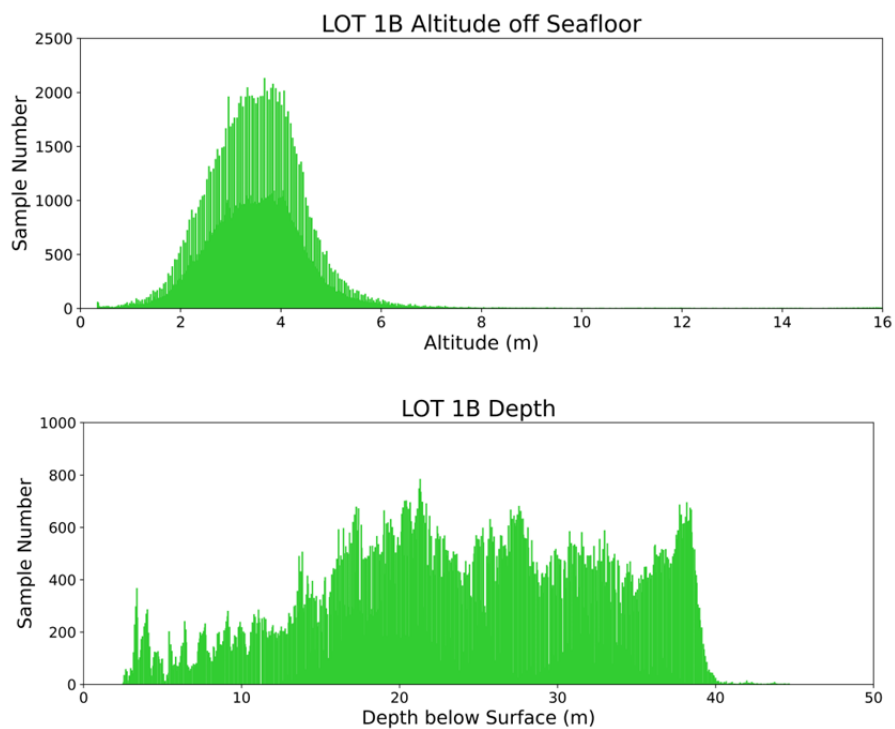


Figure 70: Altitude & Depth across Lot 1B

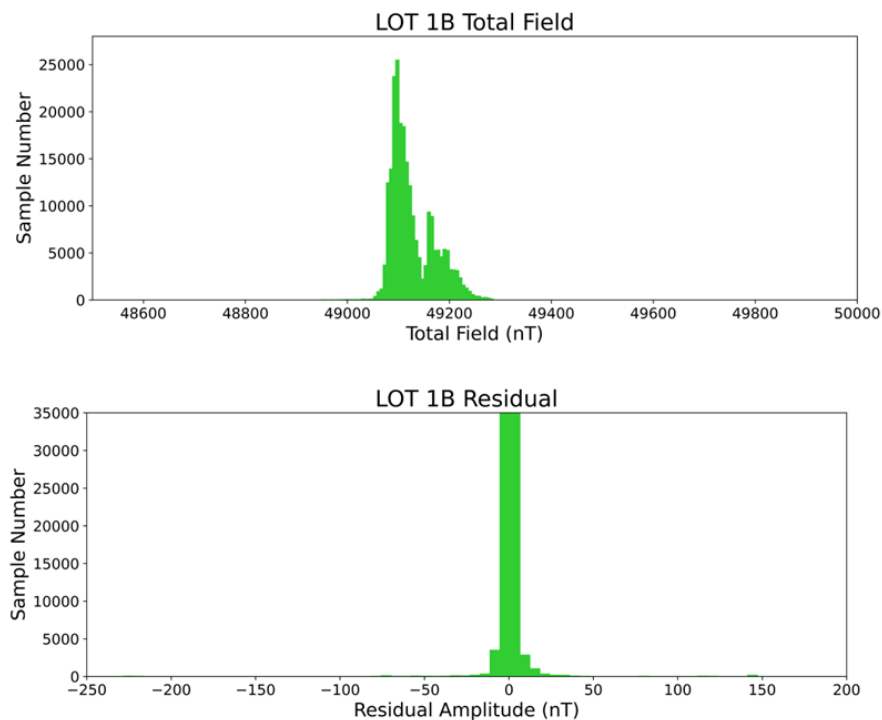


Figure 71: Residual & Total Field across Lot 1B

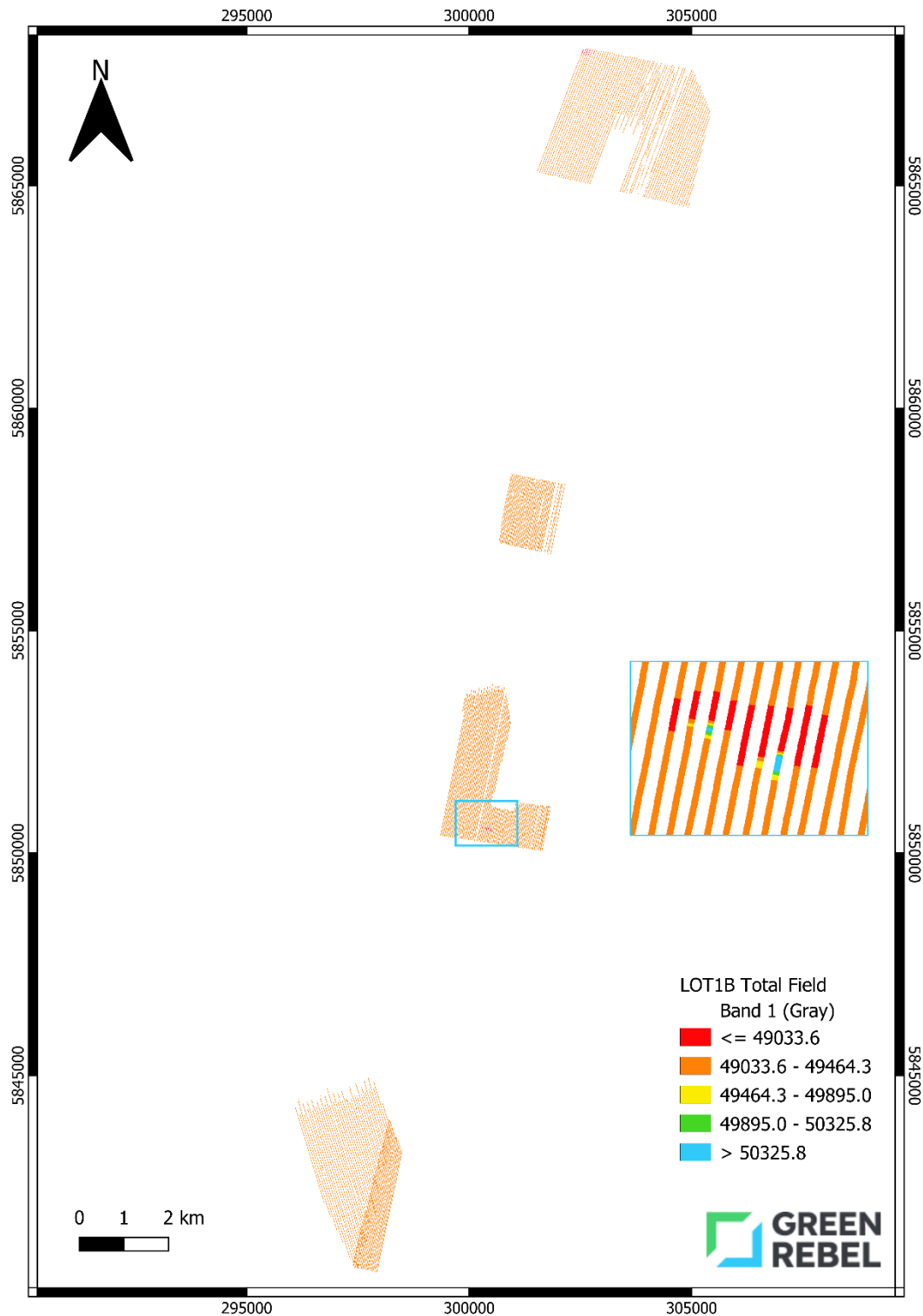
*Figure 72: Mag Total Field across Lot 1B*



Figure 73: Mag Residual across Lot 1B

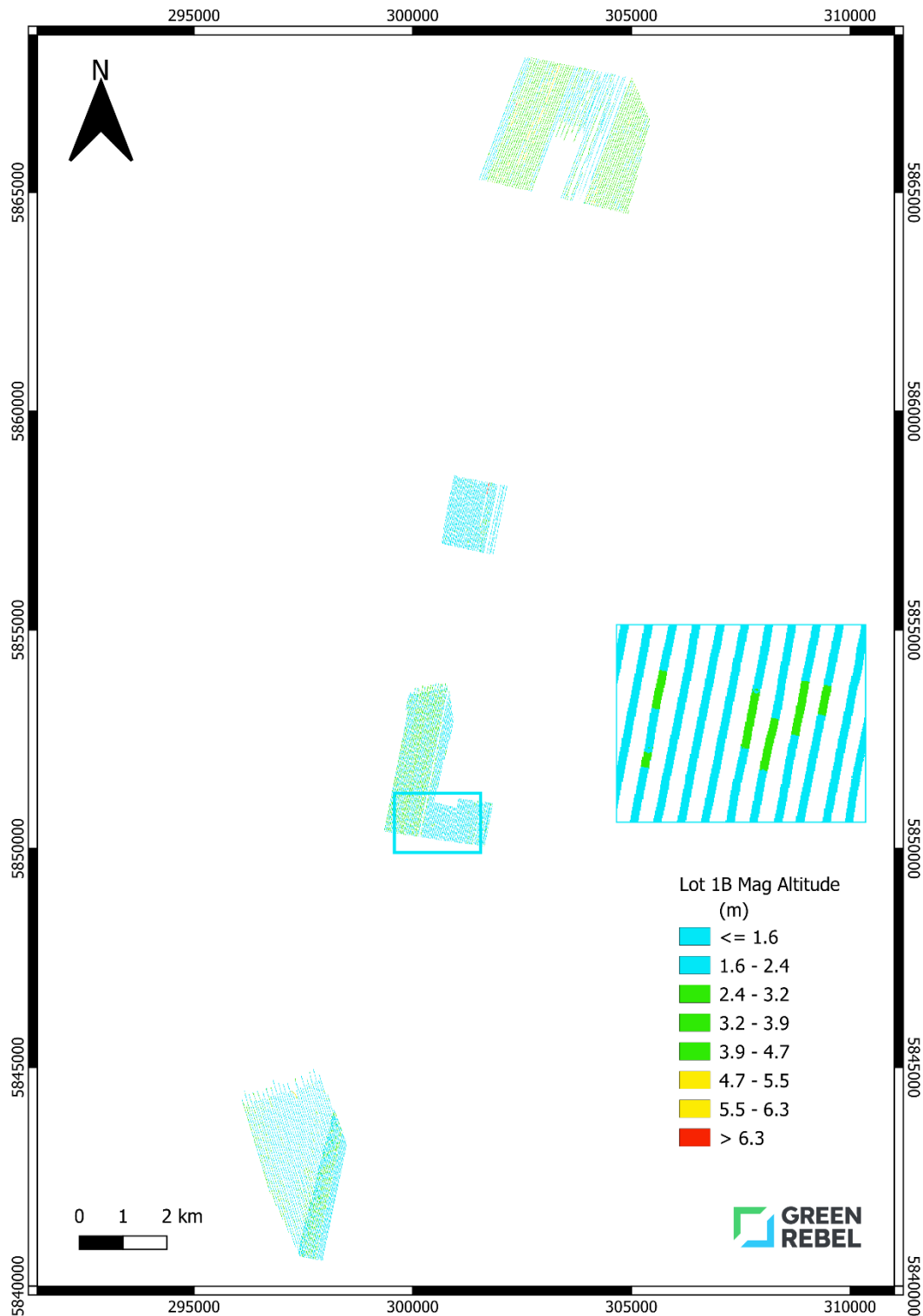
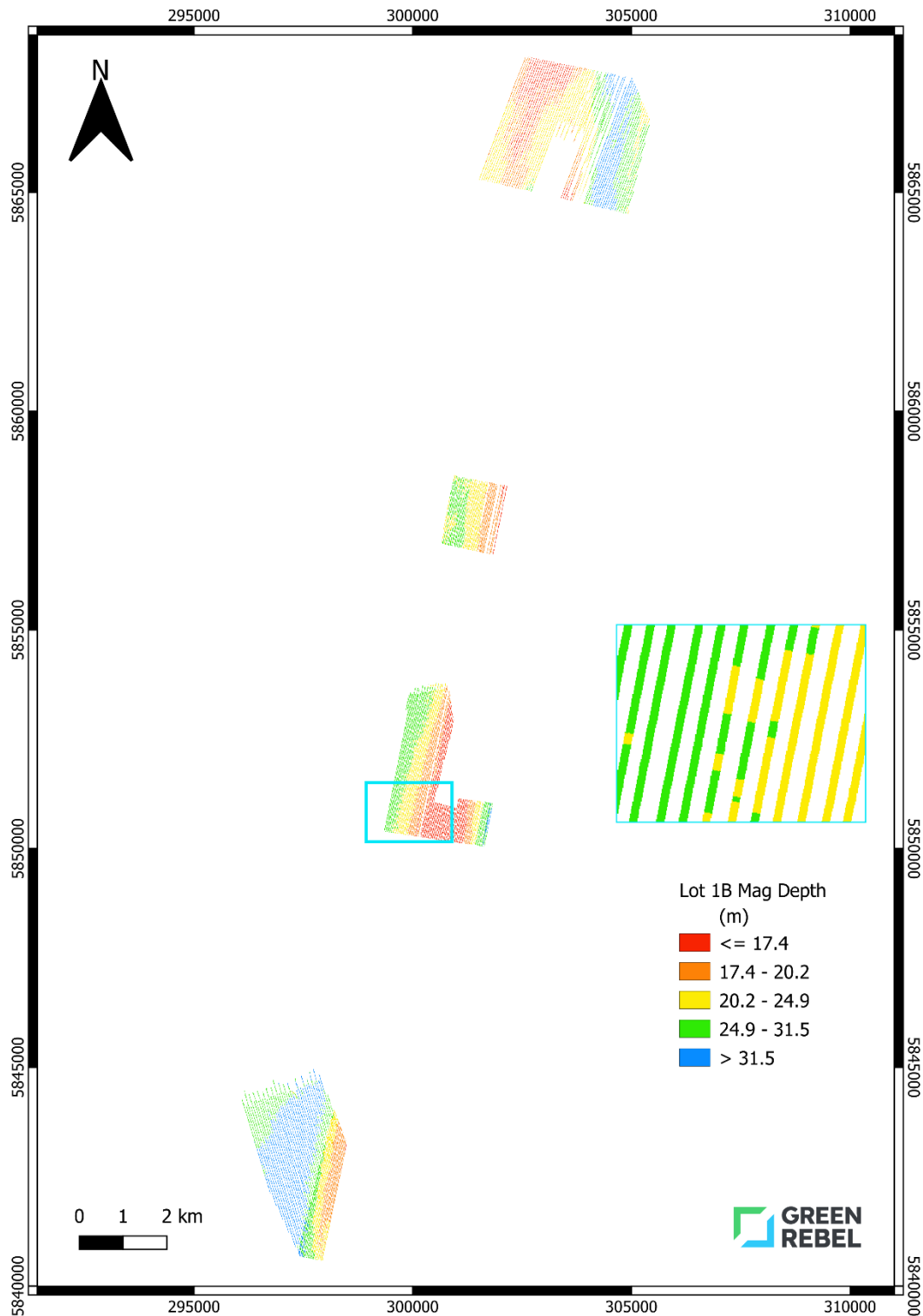


Figure 74: Mag Altitude across 1B

*Figure 75: Mag Depth across 1B*

4.6.3 Area E

Area E continues to display expected statistical readings (Table 15). Median depth and altitude values were 29.21 m and 3.61 m respectively. The deviation of the altitude was quite low at 0.69 m , implying a consistent height off the seafloor during acquisition. Residual activity was again noted here, predominantly in the north-west due to the presence of a potential sub-surface sedimentary unit. However the mean reading of 0.01 nT reflects the lack of magnetic significance in most of this site.

Table 15: Magnetometer Statistics across Area E

Data	Depth of Magnetometer (m)	Altitude of Magnetometer (m)	Total Field (nT)	Residual Amplitude (nT)	Signal Strength (nT)
Minimum	1.43	0.42	49053.84	-48.35	49
Maximum	37.07	9.87	49237.38	110.33	1294
Mean	29.12	3.56	49103.69	0.01	812.84
Median	29.21	3.61	49104.00	0.02	703
Mode	28.49	3.91	49103.27	0.12	640
St. Deviation	3.81	0.69	10.79	2.83	210.71

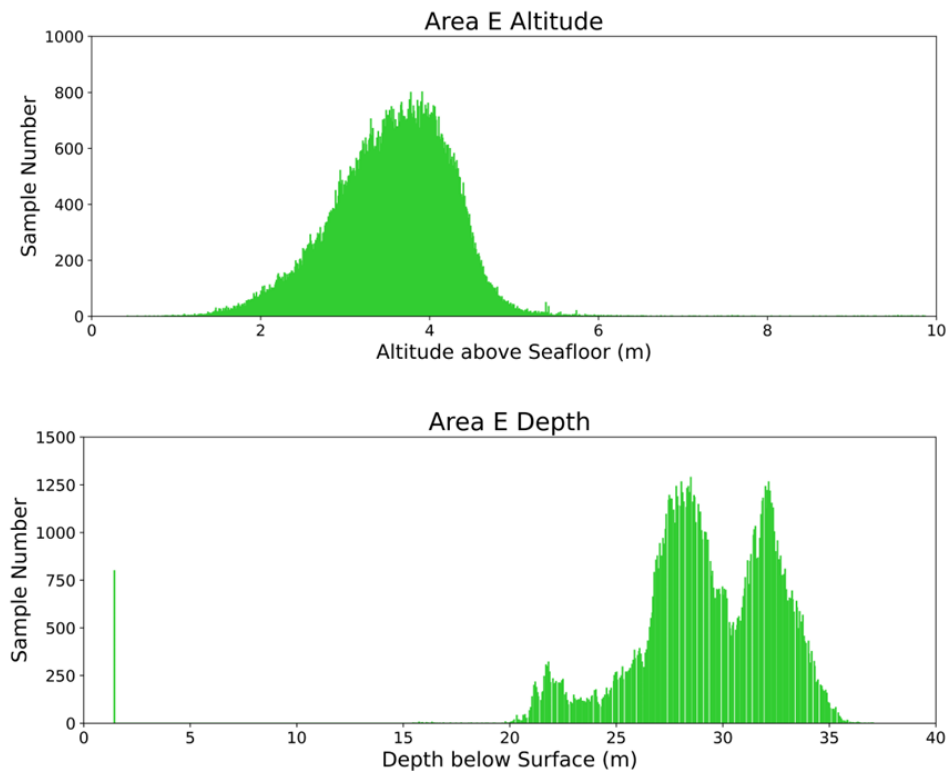


Figure 76: Depth & Altitude across Area E

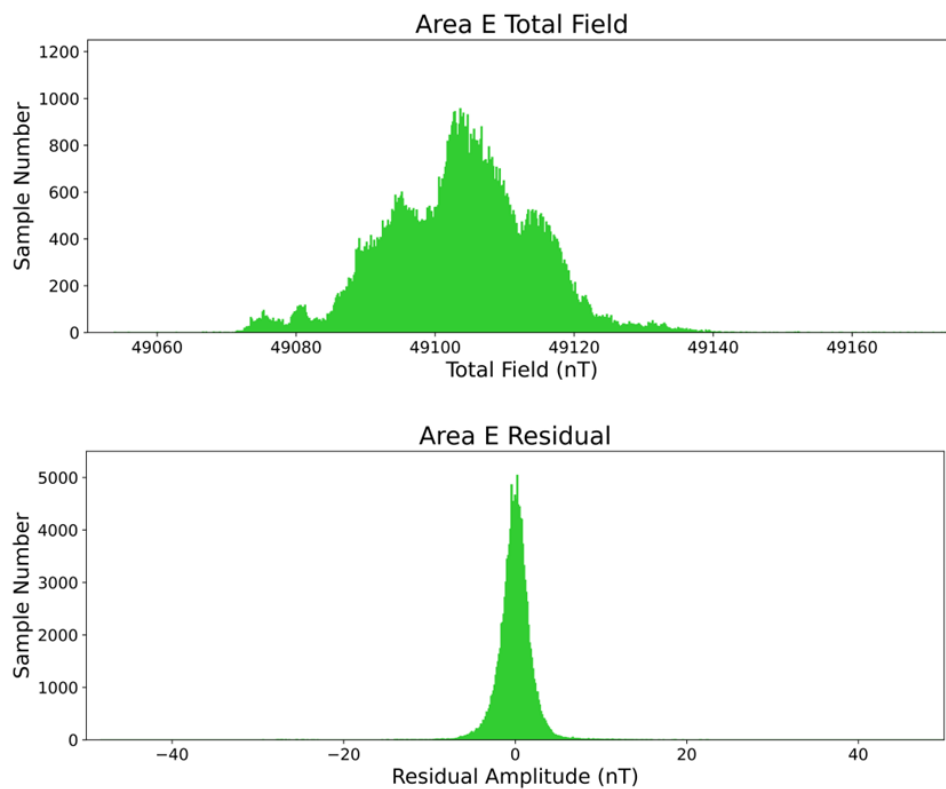


Figure 77: Total Field & Residual across Area E

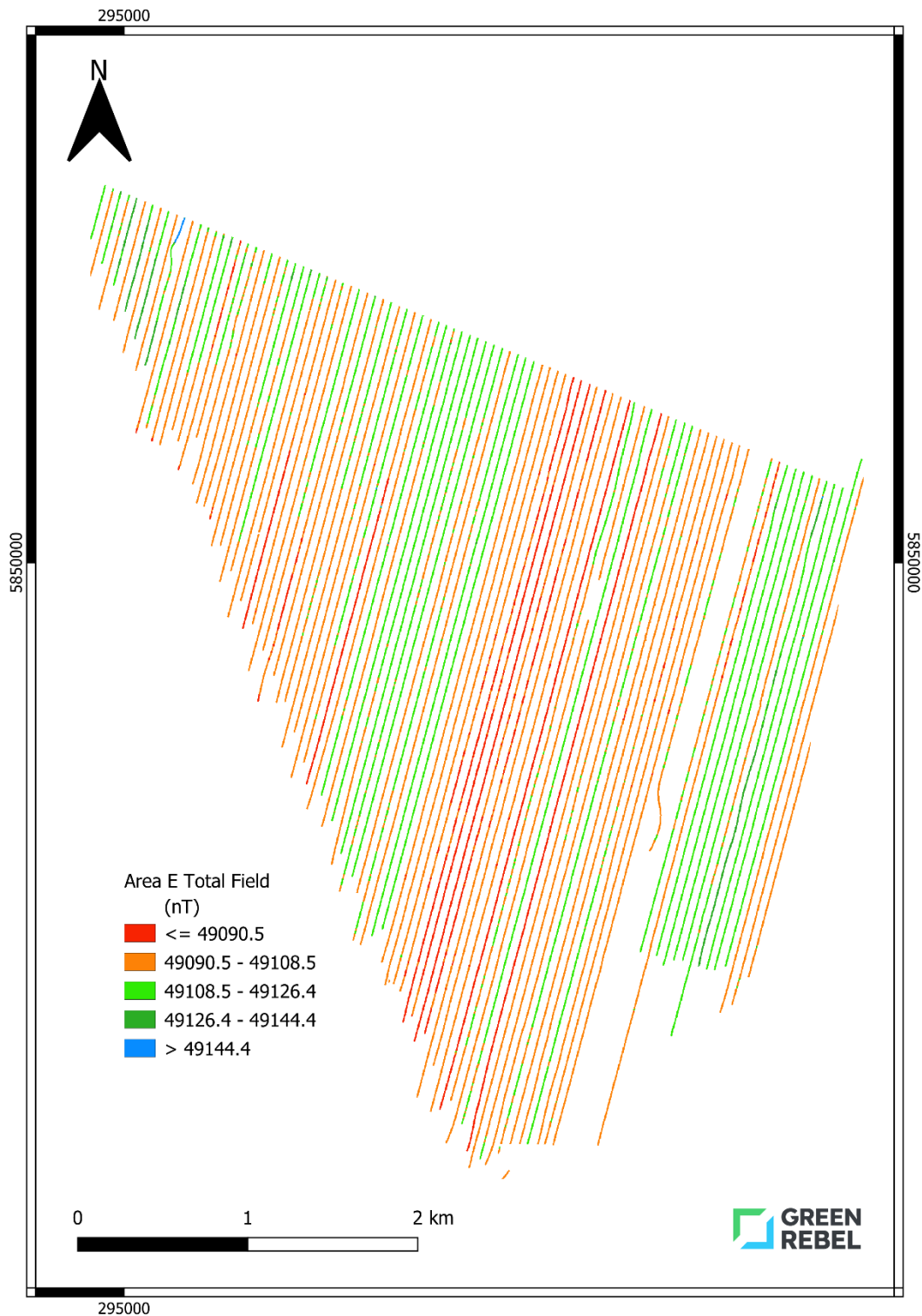


Figure 78: Total Magnetic Field across Area E

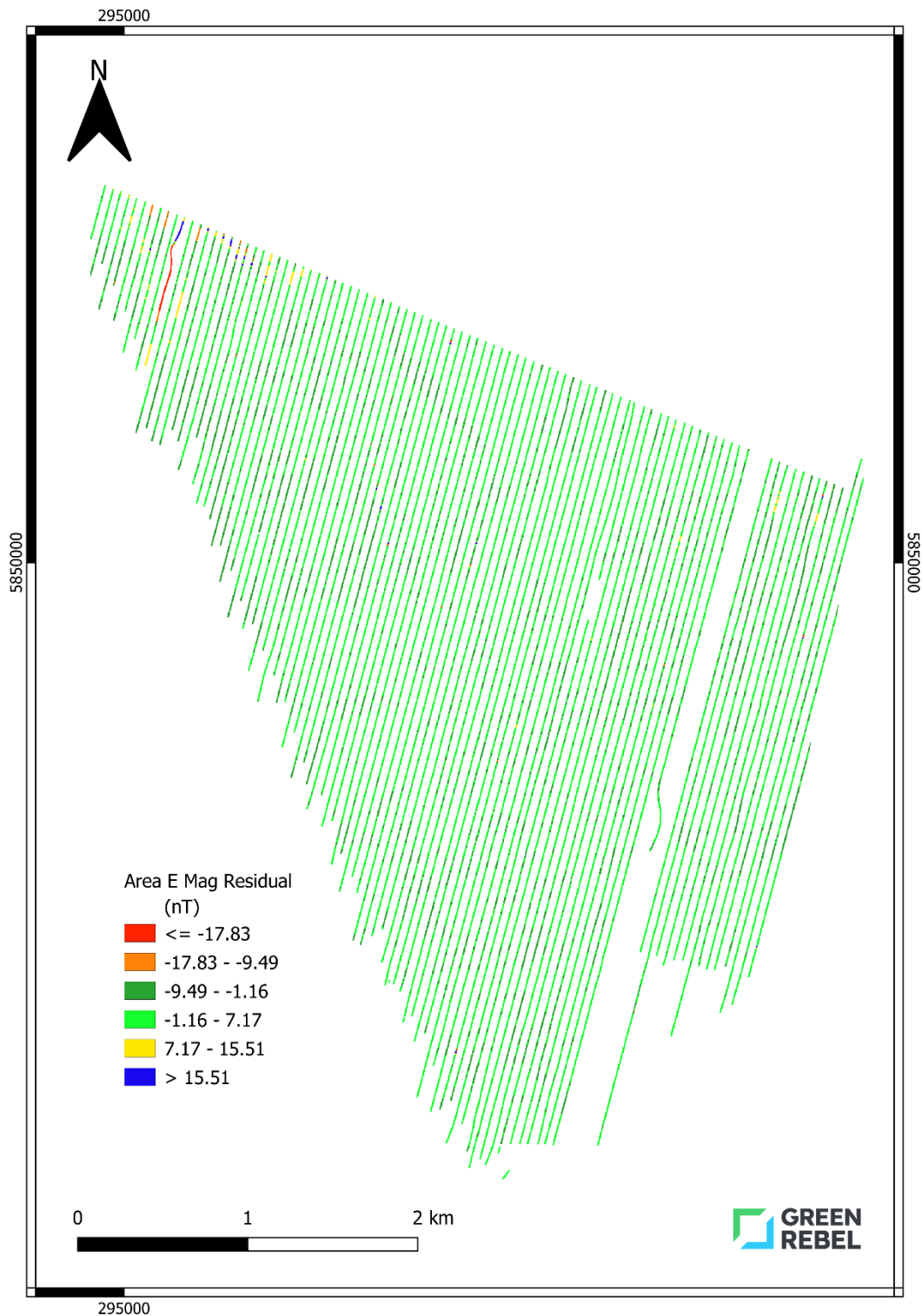


Figure 79: Mag Residual across Area E

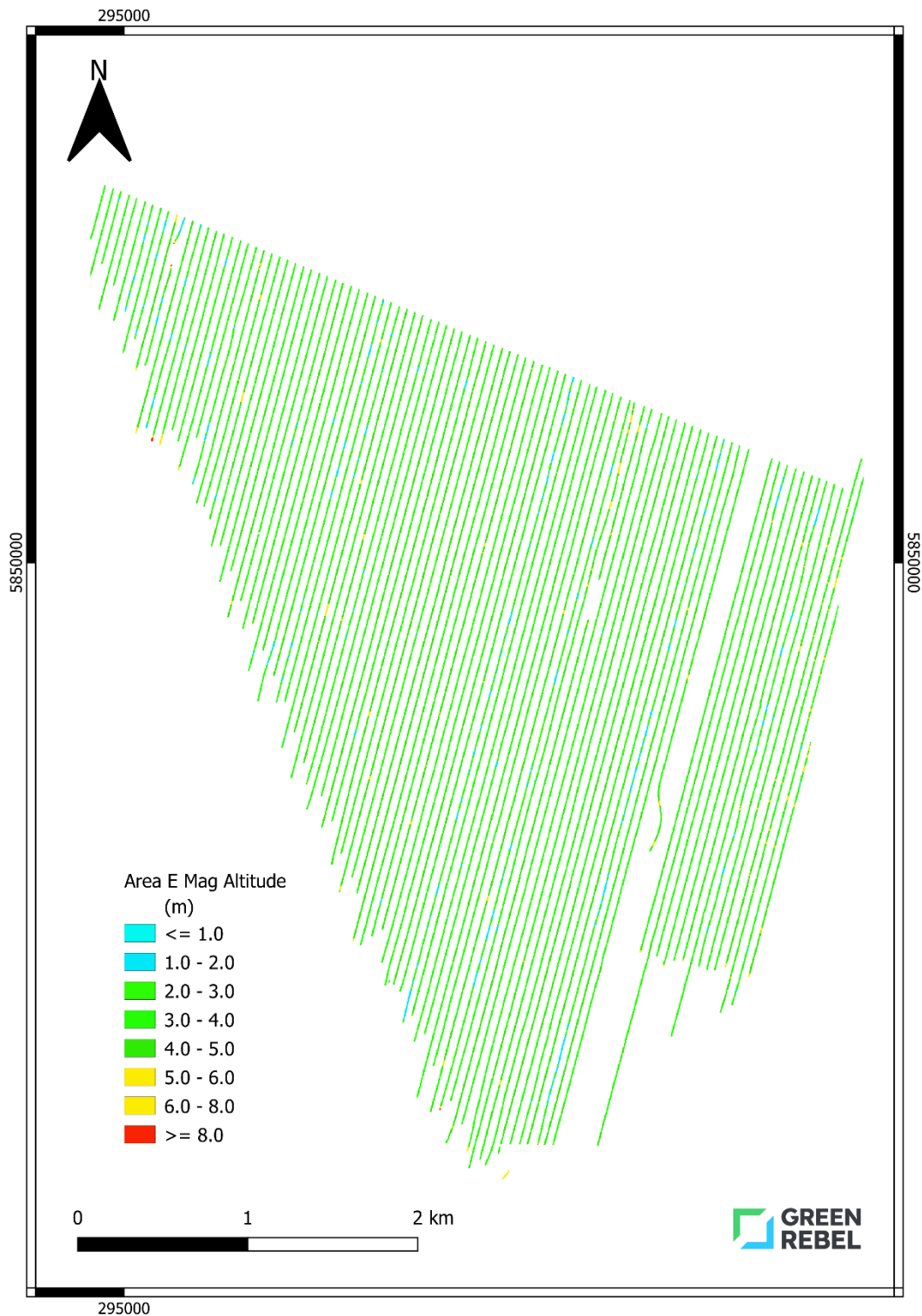


Figure 80: Mag Altitude across Area E

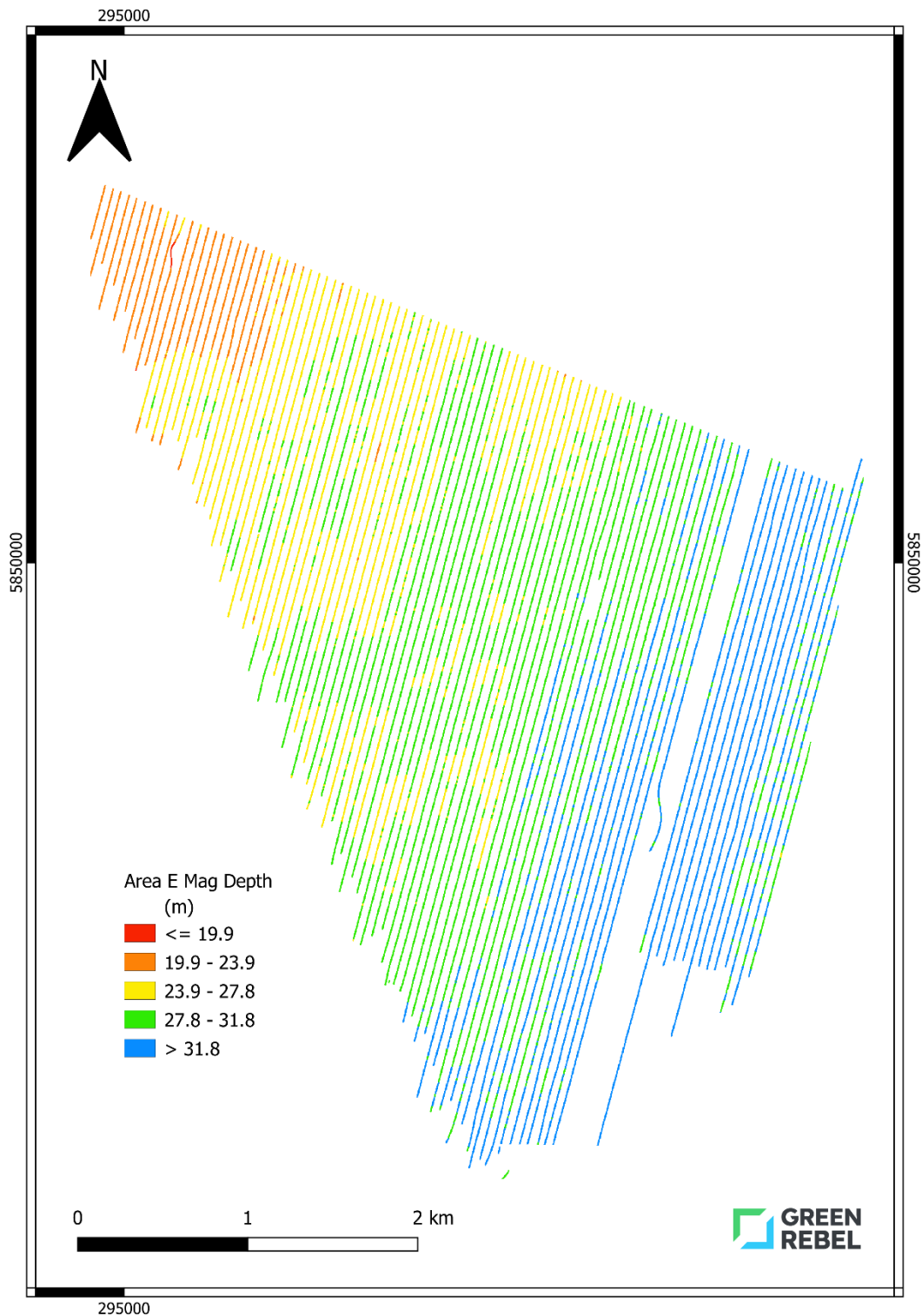


Figure 81: Mag Depth across Site E

4.6.4 Data quality

All magnetometer data acquisition was managed by QPS QINSy where the raw information was read into a series of *.txt files. To assess the data quality for the magnetometer, an examination of the magnetometer's signal strength across the area was conducted. This parameter is measured in nT and has a typical measurement range of 0 – 1500 nT. The parameter measures the intensity of interference on the magnetometers caesium sensor. Sources of interference include light penetration, usually an influence during shallow acquisition. A second interference concerns piggyback configuration, in which the tow cable is taut/slack by sudden changes in vessel speed. Data of good standard will have signal strength exceeding 300 nT, with exceptional data passing 750 nT. Data collected in shallower environments tends to have lower signal quality, as a result of surface light and/or interference with sensors on the vessel due to the reduction in cable out length. To assess the quality of the Arklow site, an investigation into the signal strength in Lot 1A, 1B and site E was conducted independently, with results below.

4.6.4.1 Lot 1A

Signal quality across 1A was divided clearly by two clusters (Figure 82). The deeper waters of the corridors exhibited consistently high readings exceeding 1000 nT. Difficulties associated with acquisition of the shallow CR1 landfall site onboard the Lady Kathleen vessel resulted in lower signal quality readings with greater range here. Despite this, the statistical analysis of this site as referenced in Figure 82 indicative that the quality of the magnetometer data across 1A is of a high grade.

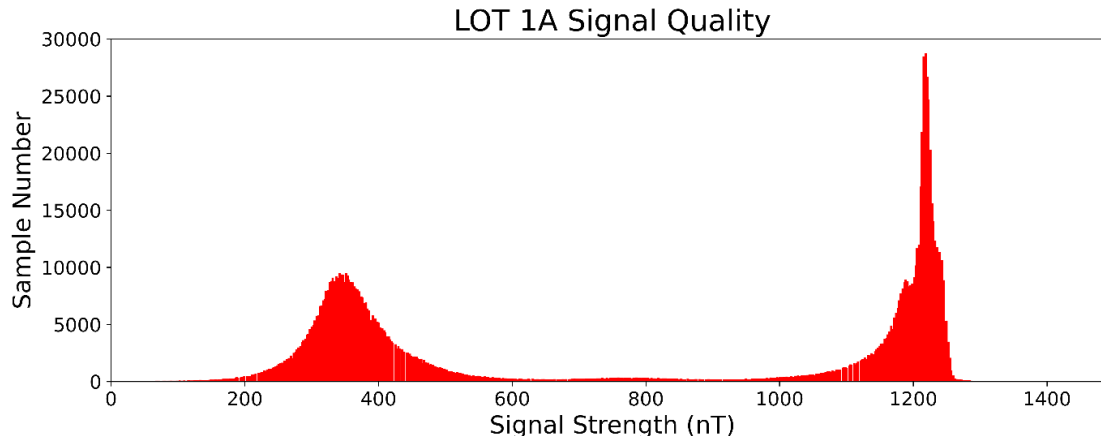


Figure 82: Magnetometer signal quality across Lot 1A.

4.6.4.2 Lot 1B

Signal quality across 1B was found to be more consistent than 1A, with two data peaks across the full data located in close proximity (Figure 83). Referencing Table 14, the mean signal quality was 949.33 nT, with a standard deviation of 177.14 nT. For quality control purposes, this variable remains unprocessed during post-processing work. As a result, the minimum and maximum values of 12 nT & 1533 nT respectively are erroneous, as they lie outside of the operating range of the signal quality channel.

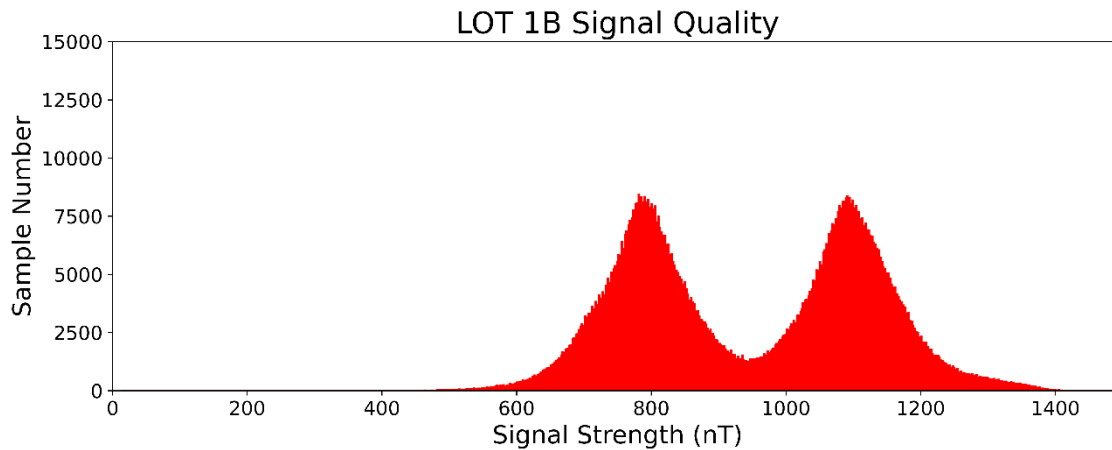


Figure 83: Magnetometer signal quality across Lot 1B

4.6.4.3 Area E

Area E signal quality was found to exhibit similar trends to 1B, with two identified peaks visible (Figure). Variation here was more apparent, reflected by the increased standard deviation of 210.71 nT as per Table 15. The median was 703 nT, with the mode calculated at 640 nT. No visible outliers appear present here, implying that the quality of the magnetometer data here also remains consistent and complying with the outlined scope of works.

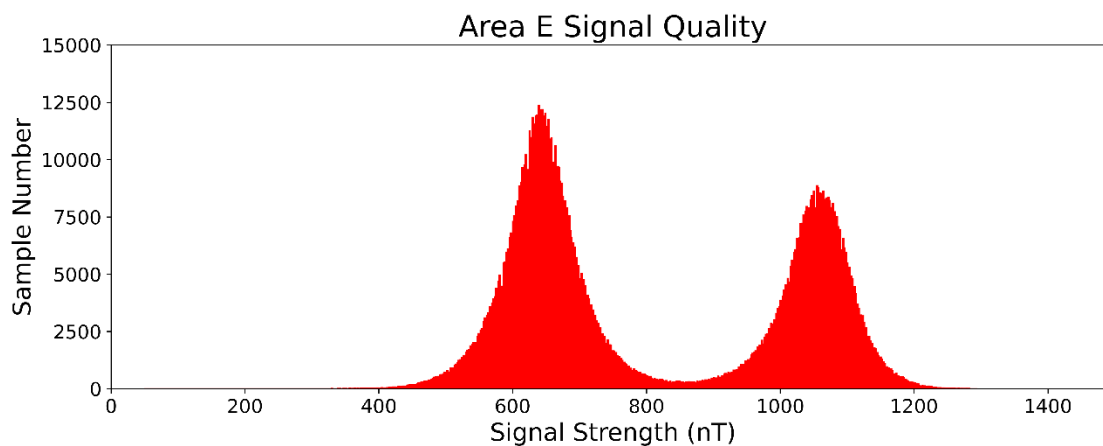


Figure 84 - Magnetometer signal quality across Area E

4.6.5 Magnetometer Targets

In total, 1144 magnetometer targets were identified across the full site. These were classified based on the nature of the residual signal response. Targets with one identifiable positive/negative charge were classified as monopole. Targets found to have opposing charges due to polarity (both positive and negative) were identified as dipole structures. Finally, signals found to elongate over a large sample distance, and/or were found to have multiple distinguishable positive/negative residual spiking were classified as complex. Figure 85 shows the distribution of monopole targets across the full site, with Figure 86 displaying complex and dipole structures.

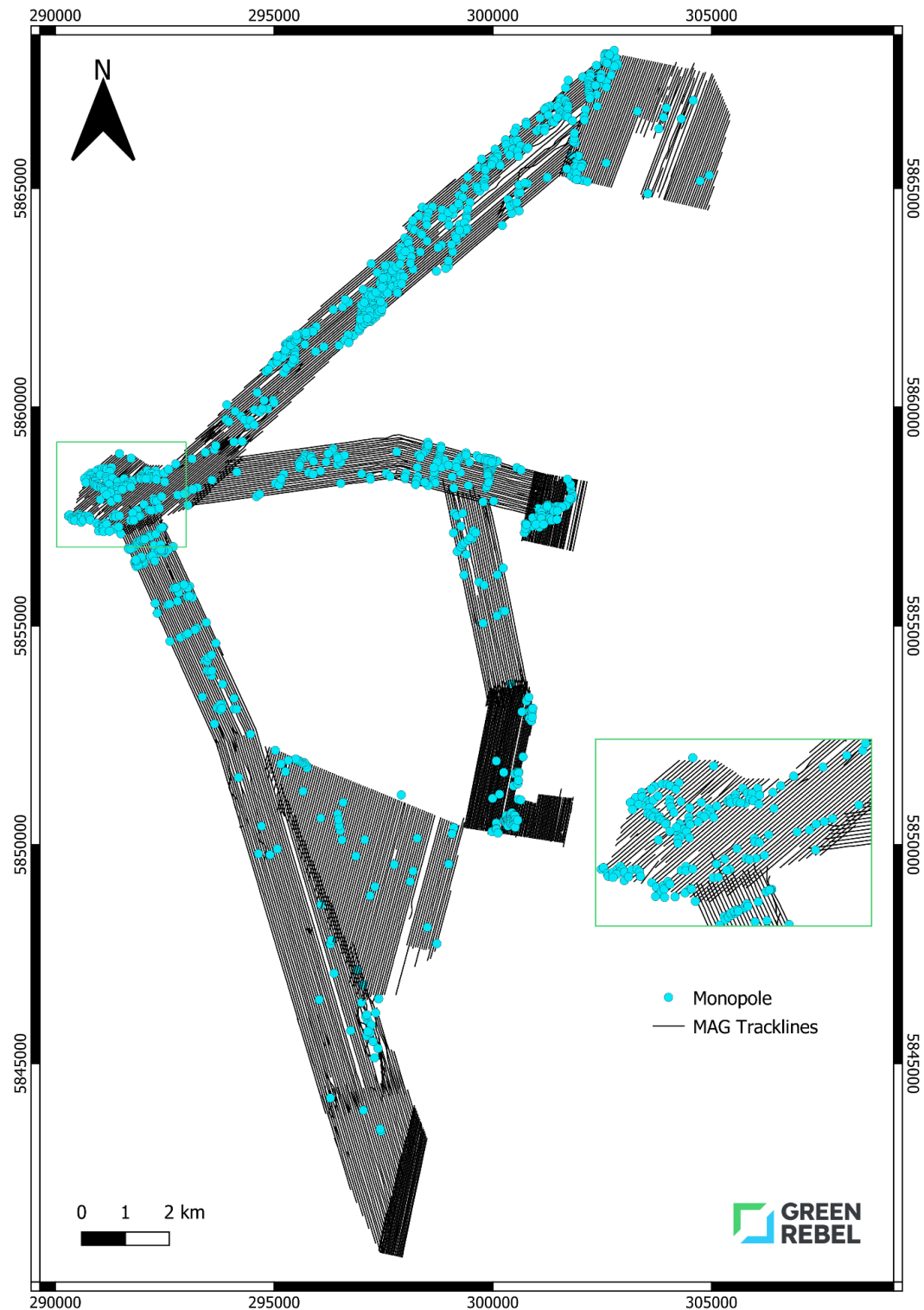


Figure 85 - Magnetometer all Monopoles across AOI

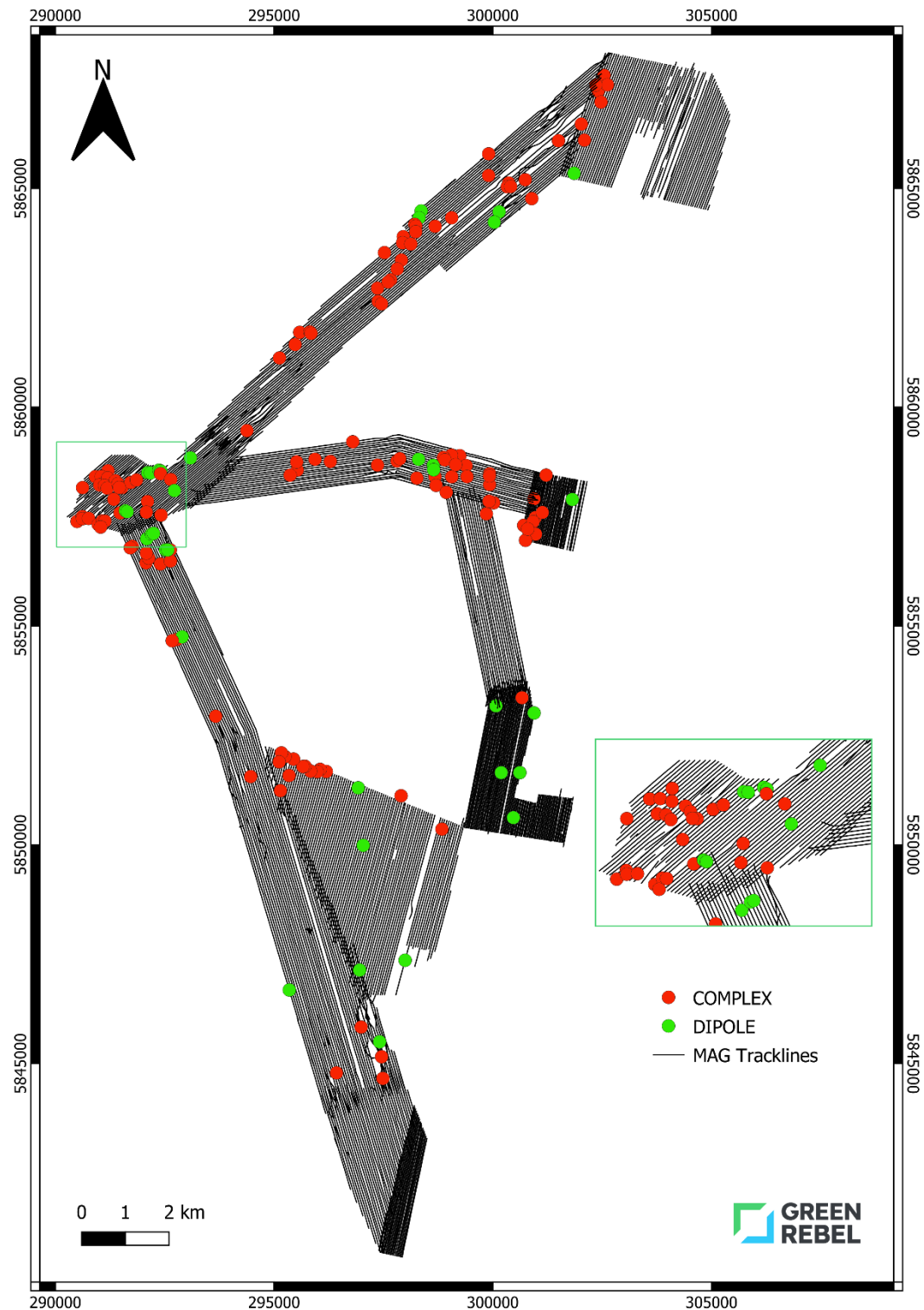


Figure 86 - Magnetometer all Complex/Dipole targets across AOI

4.6.5.1 Lot 1A

In total, 900 magnetic targets were identified across Lot 1A (Figure 87). A residual range of $\geq \pm 10$ nT was used as outlined in the scope of works. Targets appear to cluster across the entirety of the area, with particularly high density visible across corridors 1A & 2A, as well as the landfall site. Corridors 2B & 3 also contained high volume of targets, however the density of these appears lower than the other corridors. Targets were classified using peak-to-peak amplitude values for the monopoles and dipoles/complex structures respectively, as well as the characteristic of the residual signal. Out of the identified targets, 771 were found to be positive/negative monopoles. There were 23 dipoles found, with the remaining 106 targets classified as complex.

A significant variation in peak-to-peak amplitude across the targets was observed. 22 targets exhibited > 100 nT in amplitude. 146 targets were between a range of 50nT–100nT. The remaining 702 targets had an amplitude strength of < 50 nT.

4.6.5.2 Lot 1B

In total, 188 magnetic targets were identified across Lot 1B (Figure 88Figure 87). A residual range of $\geq \pm 10$ nT was used as outlined in the scope of works. A high-percentage of targets appear in clusters in the northern areas of Lot 1B, with a smaller pocket in the southern area. Targets were classified using peak-to-peak amplitude values for the monopoles and dipoles/complex structures respectively, as well as the characteristic of the residual signal. Out of the identified targets, 166 showed monopole peaking. There were 7 dipoles found, with 15 complex structures noted.

A considerable variation in peak-to-peak amplitude across the targets was observed. 28 targets exhibited > 100 nT in amplitude. 15 targets were between a range of 50nT–100nT. The remaining 145 targets had an amplitude strength of < 50 nT.

4.6.5.3 Area E

Across Area E, a total of 56 magnetometer targets were identified. These appear to cluster dominantly in the north-west section of this area (Figure 89) This is caused by the presence of a sub-surface sedimentary unit. The potential presence of ferrous material from this unit were likely identified by the magnetometer. This however cannot be interpreted in confidence until an investigation of the SBP is concluded. 38 of the targets were classified as positive/monopole, with the remaining 4/14 identified as dipole/complex respectively.

Minimal variation in peak-to-peak amplitude across the targets was observed. 2 targets exhibited > 100 nT in amplitude. 8 targets were between a range of 50nT–100nT. The remaining 46 targets had an amplitude strength of < 50 nT.

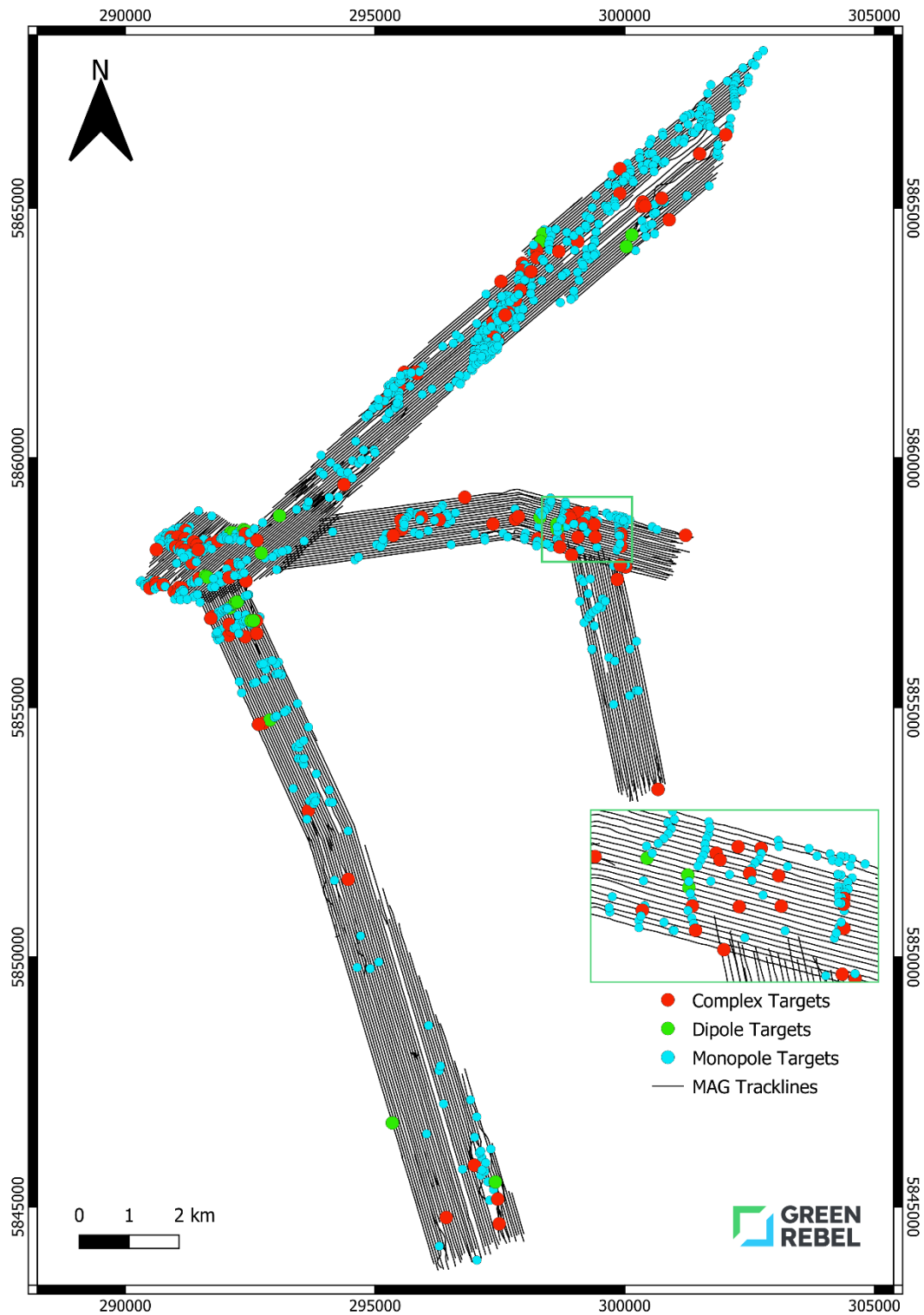


Figure 87: All identified magnetometer targets across Lot 1A [residual reading $\geq \pm 10$ nT]

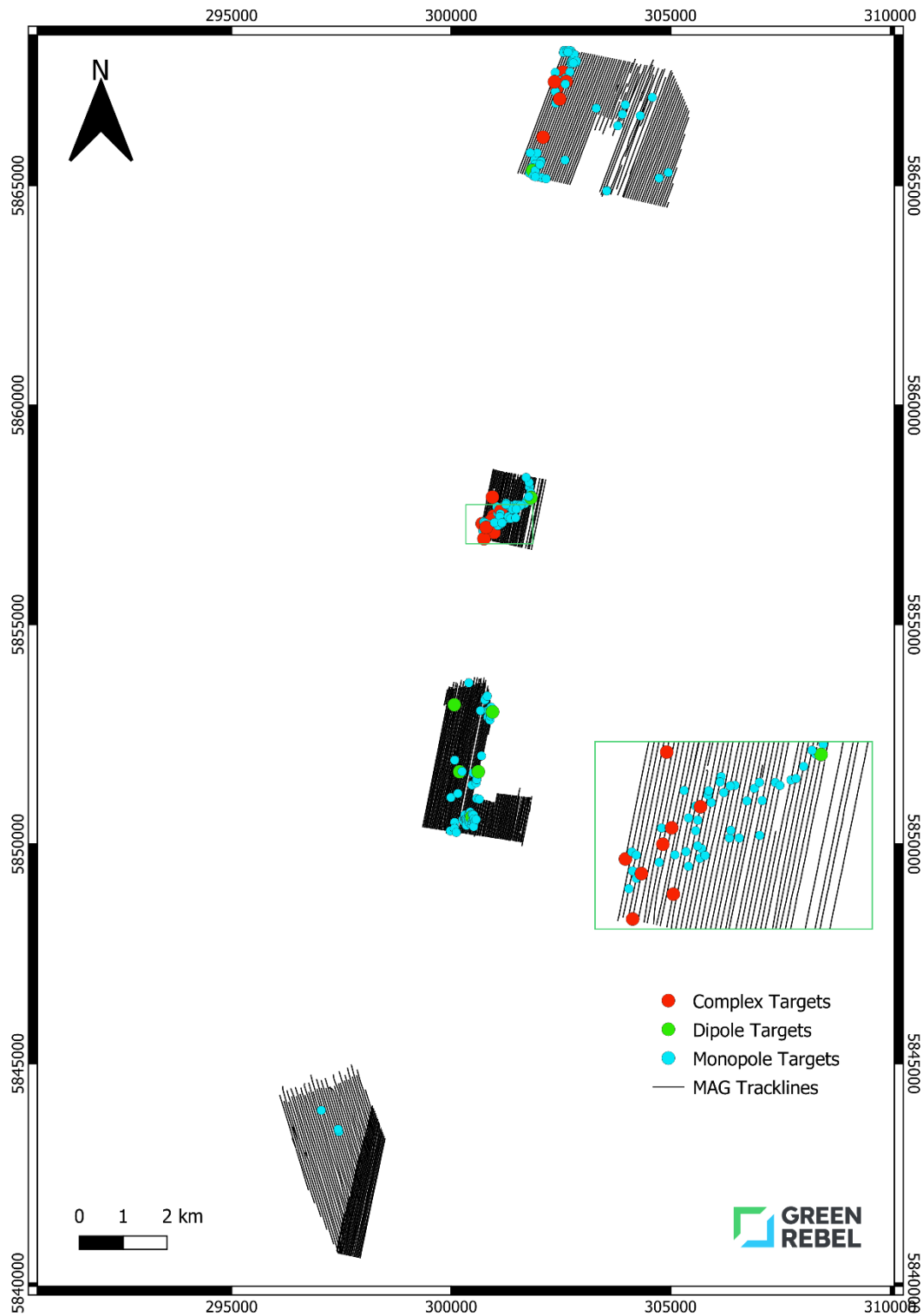


Figure 88: All identified magnetometer targets across Lot 1B

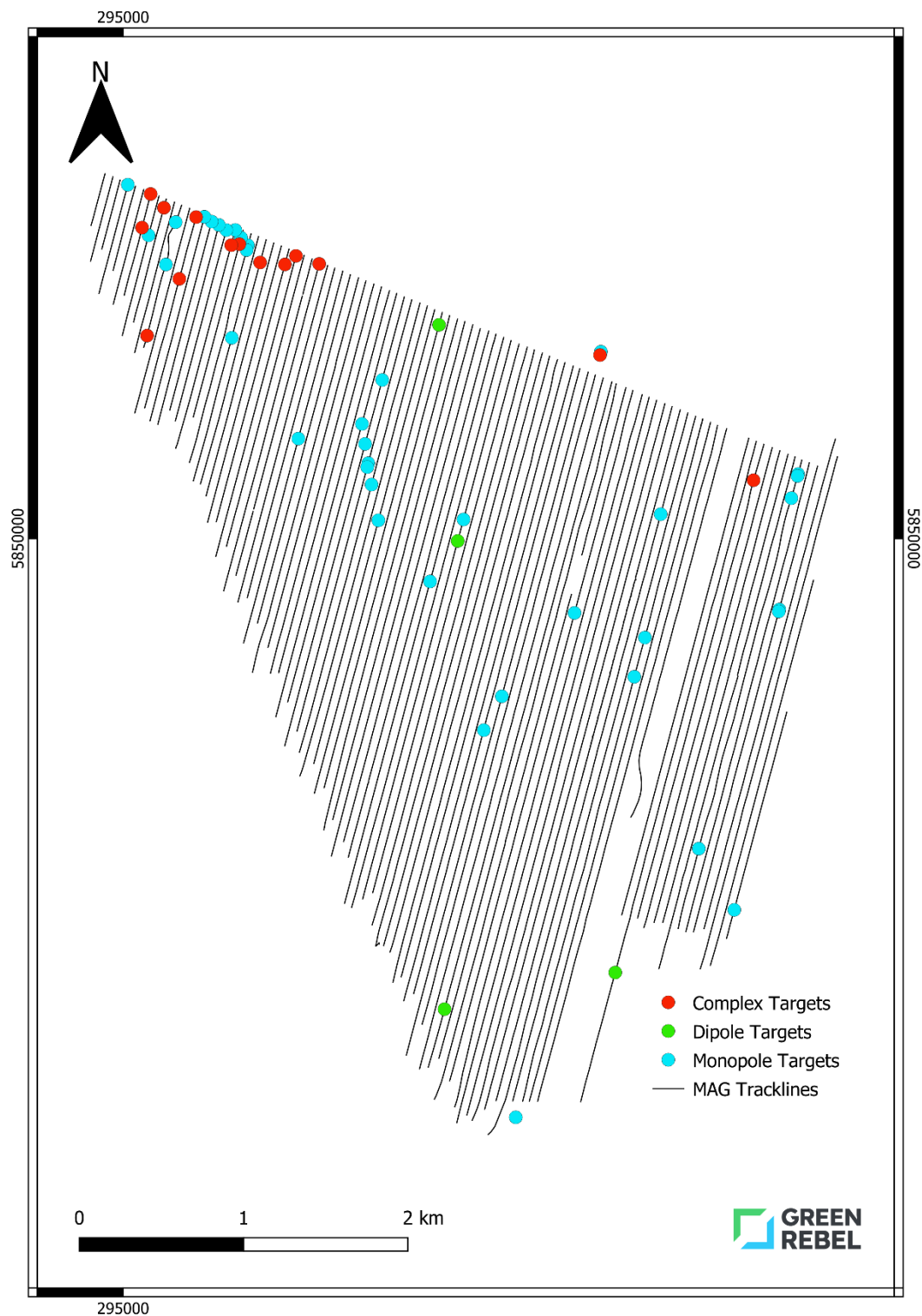


Figure 89: Magnetometer Targets across Area E

4.7 Potential Engineering Geohazards

4.7.1 Surface Geohazards

MBES, magnetometer and SSS datasets were used to identify geohazards on the seabed which should be considered during site planning. These are summarised below.

4.7.1.1 Gradients

Steep gradients should be investigated as a surface geohazard. Slope failure on these settings is common and represents a major threat to wind turbine infrastructure. Steep slopes can lead to substrata instability and can produce destructive losses in geotechnical drilling and foundation construction. In the case of the target site, gradient geohazards were mostly identified along the megaripples, characterized by relatively steep sloping angles (up to 35°).

In terms of bathymetry gradients, the results of the investigation here broadly agree with the earlier surveys conducted by Ultrabeam Ltd., what is expressed for example in the outline of the bathymetric profile derived along the Lot 1A CR2 (Figure 12), which matches with the Ultrabeam report's profile (Ultrabeam Limited, 2019 – Figure 14)

4.7.1.2 Mobile Sediments and Bedforms

The distribution of sediments on the seafloor is a critical aspect from the perspective of offshore wind farm geohazards. Different sediment types, characterized by grain size, composition, and stiffness, can affect the stability of wind turbine foundations. For instance, soft sediments may be more prone to liquefaction or settling, whereas dense or stiff sediments may provide a more stable base. Each sediment type reacts differently to water flow-induced frictional drag, known as scour. This information is vital for cable burial and can inform the design of cable protection. This knowledge is based on sediment classification maps produced using SSS technology.

The heterogeneity of sediment types seen in the AWBP area, as illustrated in (Figure 47), represents a complex energy system. A dominant, roughly north-south trending sediment bank crosses the site, composed mostly of fine-grained sediments. On a smaller scale, medium and coarser-grained sediments, coeval with large bedforms such as sandwaves and megaripples (Figure 50), are present. This represents the classification of sediments by wave and current action. Coarser, uniform sediment bodies surrounding these banks are likely the result of high-energy current action.

Sediments in the shallow landfall area (CR1_landfall) are variable, indicating the presence of different deposition mechanisms. This is supported by previous work conducted by Ultrabeam Ltd., which found that the landfall area comprised of "sand with mobile sediments". The Redcross River, flowing into the Irish Sea, creates an intertidal setting, causing increased turbulence at the boundary between fresh and saltwater masses, leading to intertidal mixing. These mechanisms may have contributed to the sediment heterogeneity in this part of the site. Further clarification can be obtained through sediment grab analysis.

In addition to sediment distribution, the presence of seafloor bedforms should also be taken into account from a geohazard perspective. Megaripples can present a significant geohazard when

constructing offshore wind turbines and installing related cables. Installing turbines and cables in areas with megaripples can become more difficult and time-consuming, as specialized equipment may be required to excavate and level the seabed and lay the cables securely. Furthermore, these areas have enhanced hydrodynamism and can create turbulence through the interaction of water flow with bedform geometry (Bellec et al., 2019). This can cause currents and waves to move and shift the cables, leading to freespan, abrasion and damage to the cable insulation and affecting their electrical performance.

Across the bathymetry, 7.4% coverage was comprised of sandwaves, and 0.4% was made up of megaripples, respectively (Figure 45). The occurrence of sandwaves is broadly concurrent with finer-grained sediment facies (Figure 50), reflecting the control of sediment distribution by the regional hydrodynamic regime. Of the sandwaves and megaripples delineated, the majority trend NE-SW (Figure 90). The impact of these waveforms on infrastructure can vary greatly, depending on specific site conditions and the methods used for installation (e.g., Couldrey 2020). Thus, further investigation and analysis may be required to assess their potential impact.

The transition zone between megaripples and sandwaves appear concurrent with magnetic anomalies (Figure 90). In areas of enhanced hydrodynamism, such as along the troughs of megaripple wavefields, winnowing of less dense material can occur. This leads to the preferential accumulation of denser (potentially ferrous) material. This may account for the linear assemblage of magnetic targets observed in Figure 90. However, this sediment would need to be sampled to substantiate this interpretation.

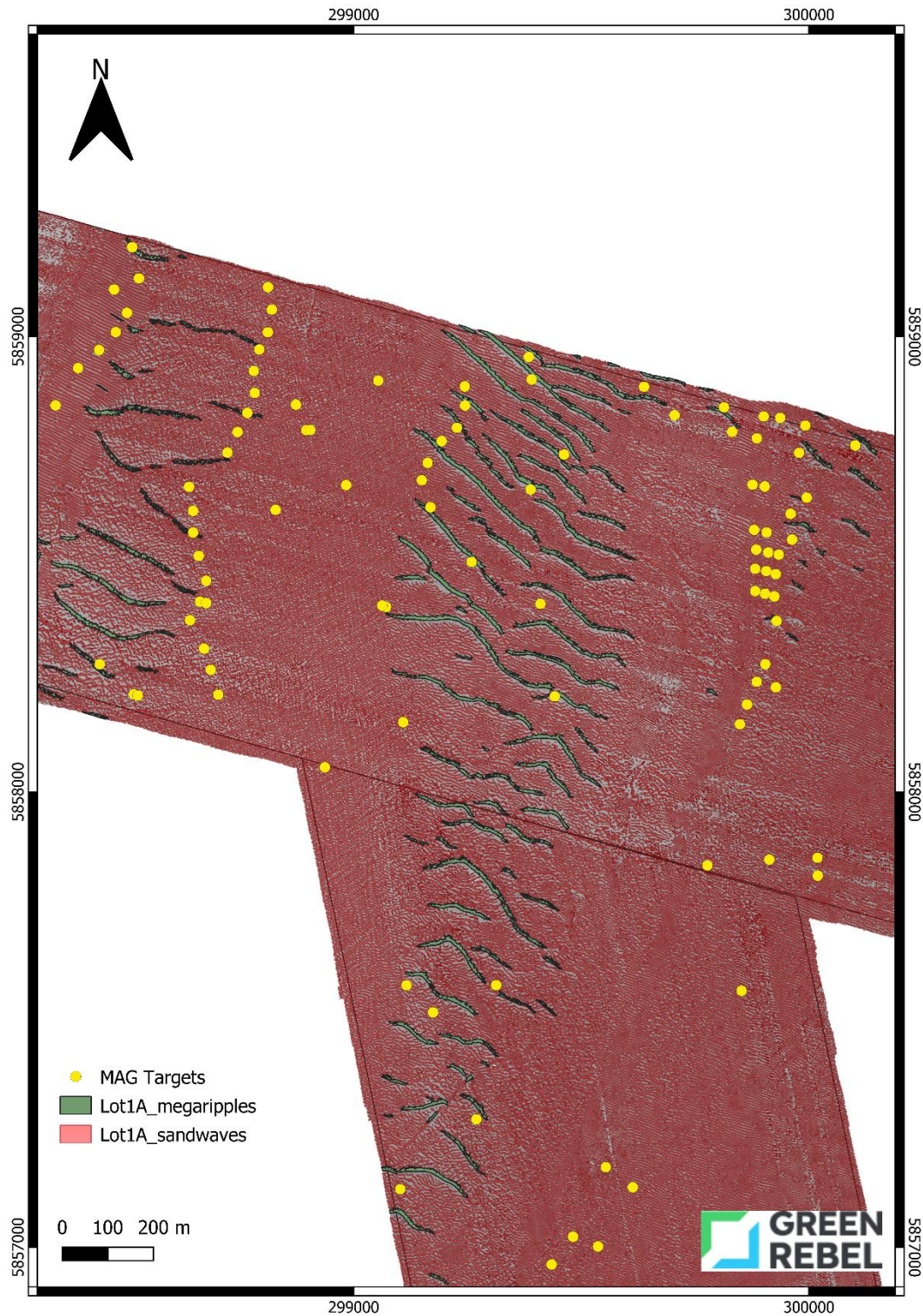


Figure 90: Correlation of magnetometer targets with boundary of Sediment Waves

4.7.1.3 *Boulders*

Coarse sediments/gravels/boulders/boulder fields are interpreted as having been deposited in glacial or peri/para-glacial environments. The deposits are a potential geohazard as they may constrain drilling operations by damaging equipment or otherwise affect infrastructure installation and foundation piling. Therefore, careful site selection and thorough geotechnical assessments are crucial to minimize these risks and ensure the safe and stable construction of wind turbines in the ocean. Acoustic signalling inferred from SSS and seismo-stratigraphic methods can be used to interpret these areas. A detailed description of boulders and boulder fields is given in section 4.4.4, which show that the site was mostly exposed to glacial deposition. These results are broadly concurrent with observations summarized from prior survey work (Ultrabeam Limited, 2019). It was shown that the boulderfields covered 10.2% of the total site. It is recommended that these areas should be considered during the construction phase. Furthermore, potential bedrock outcrop can be seen in the CR1_landfall area of Lot_1A. These are delineated through examining bathymetric data and the relative slope gradient derived from these data.

There were 36 incidences of boulders with occurring within the vicinity of magnetic anomaly (see Appendix 4 and Figure 94), the majority ($n = 31$) occurring as monopole anomalies, 3 as complex anomalies and the remaining 2 occurring as dipole anomalies. Each of these contacts may have initially misclassified as boulders, given their spherical shape. However, given their proximity to magnetic spikes, they fall within the remit of being potential unexploded ordnates (pUXOs), mostly likely as moored mines. Under this interpretation, 8 pUXOs may be present in the landfall, 15 in CR1, 3 in CR2, 5 in CR3, 5 in Area E (Figure 94). These results contrast versus previous findings, where 2 pUXOs were identified in CR1, 1 pUXO was identified in CR2 and no pUXOs were identified in CR3 (Ultrabeam, 2019). Although these targets were not verified for ferrous content, they were interpreted as German WW1 mines based on morphology.

In summary, our findings expand greatly on this data set, resulting from densely collected magnetometer data and detailed sonar contact picking. Further investigation with a dedicated high-resolution UXO survey is needed to ground truth these anomalous contacts, to ascertain if the aforementioned are to be considered pUXOs.

4.7.1.4 *Existing infrastructure and wrecks*

Cables are geohazards which need to be taken into consideration when identifying geohazards. During the construction phase, pipelines and cables on the sea floor can get damaged or disrupted, which can cause leaks or breakages, resulting in environmental hazards and potential harm to marine life. Moreover, the presence of pipelines and cables can affect the placement of the wind turbine foundation and its anchors, potentially increasing the risk of stability issues and foundation failure. Additionally, electromagnetic interference from pipelines and cables can affect the performance of the wind turbine's electrical systems, including the control and monitoring systems, potentially leading to power outages or other malfunctions. Therefore, it's important for engineers to conduct thorough surveys of the sea floor and identify the presence of pipelines and cables before building wind turbines in the ocean, and to design the wind turbine and its foundation accordingly to minimize these risks. According to the SSS data, two linear contacts were identified in Lot_1A, specifically in CR2b (Figure 59 and Figure 91), which occur parallel to a known cable annotated on Admiralty Nautical Charts.

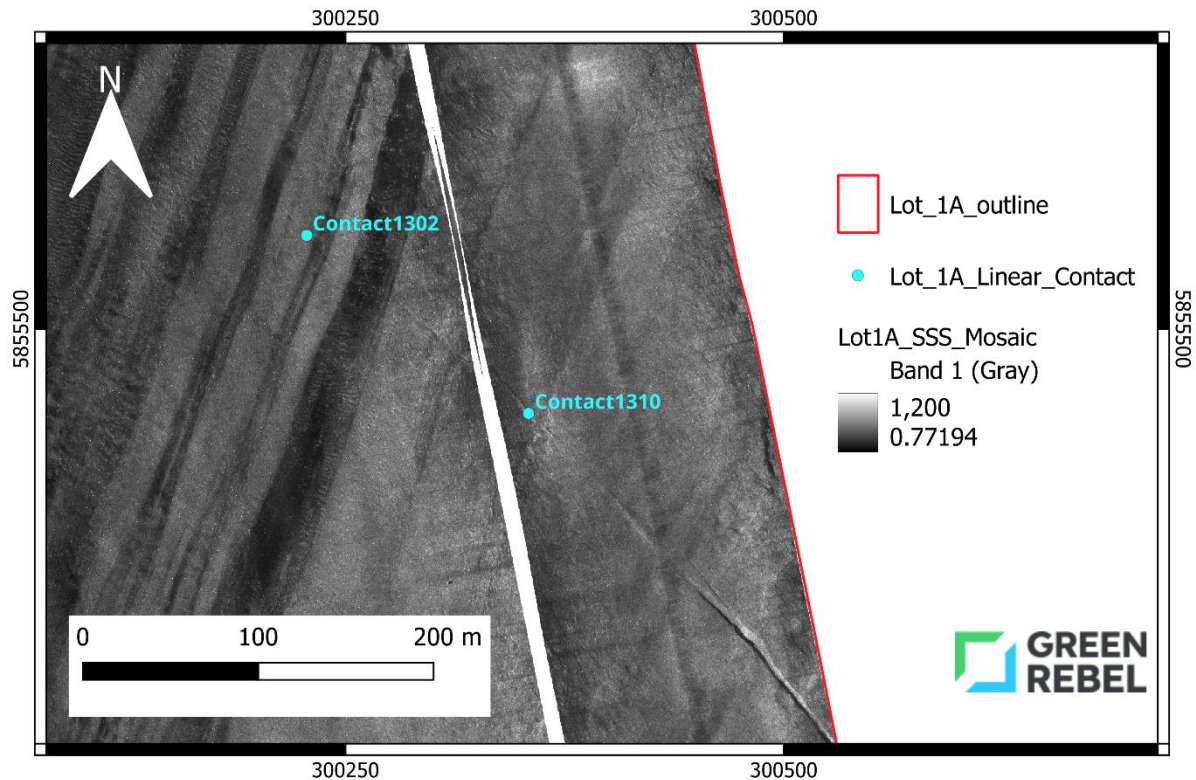


Figure 91: Sonar contacts Contact1302 and Contact1310 were picked from NW-SE trending linear contact (most likely cable) in Lot_1A_CR2B.

53 occurrences of debris were noted in the SSS analysis (Table 12). Of these contacts, 9 occurred within close proximity to magnetic anomalies (

Appendix 4). When considering the imagery provided by the SSS, it appears the magnetic debris could be abandoned fishing equipment or anchors, comparable to previous findings (Ultrabeam Ltd., 2019).

Shipwrecks are considered in the site selection, as they are of archaeological and cultural importance. In the Republic of Ireland, there is blanket protection for all shipwrecks over 100 years old, as implemented under the National Monuments Acts 1986 and 1994. Additionally, observations of shipwreck-induced seabed erosion may provide initial information about basic geotechnical properties of the seabed, including its scour potential.

A total of 10 wreck sites were detected within the survey site, two of which (*SS Hellenis*, SSS contact no. 0138 and *MV Cameo*, SSS contact no. 1211) have been previously identified as per public archives (National Monuments Service, 2022). While *MV Cameo* and *SS Hellenis* rest fully exposed on the seabed, the other four shipwrecks are semi-buried or barely recognizable in SSS and MBES datasets. While the SSS contact no. 1462 can be clearly identified as a semi-buried/substantially deteriorated wreck, the other sites have outlines which suggest the presence of wrecks, but could not be confirmed.

The detected wreck positions were compared to the results of the previous investigations in the area conducted by Ultrabeam Ltd (Ultrabeam 2019; 2019a). Out of eight positions, where Ultrabeam Ltd. observed shipwrecks, three (SSS contacts 1462, 1211, 0138) in Lot 1B and two in Lot 1A (SSS contacts 4454, 4456) match the investigation presented herein. One position (denoted by Ultrabeam as UHL19004_SSS_LA_0761) was not confirmed i.e., no evidence of shipwreck is visible in the SSS, mag and MBES datasets, and two positions (SSS contacts 0000 and 0139) were marked as debris rather than wrecks. Noteworthy, wrecks denoted here as SSS contacts 0121, 0133, 0137 (

Figure 92a) and 4455, 4457 (Figure 93a) were not reported in the Ultrabeam reports. The wreck positions were also cross-referenced with magnetometer contacts and three of them located in the southern part of Lot 1B (SSS contacts 1462, 1211, 0138) correspond to multiple magnetic anomalies. The lack of magnetic anomalies at the other seven sites may suggest that these wrecks are either wooden or may not be wrecks, but their outlines resemble wreck mounds/ship structures with scour visible around them. Noteworthy, all of these seven wrecks look buried/semi-buried with no clearly protruding, individual structural elements.

Shipwrecks and other objects emplaced on the seabed act as obstacles to water flow and modify shear stress exerted on the adjacent seabed. Depending on the properties of the surficial sediments, this can lead to the development of seabed scour. The process is usually manifested as bathymetric depressions developed around its nucleus (i.e., the structure), occasionally accompanied by mounds of re-deposited sediment. Scour is considered detrimental to the stability of engineering structures. Shipwrecks, boulders and other substantial objects act as good proxies of seabed scour potential (e.g., Caston, 1979; Majcher et al., 2022).

The most significant scour pit has developed around the *MV Cameo* shipwreck, reaching up to 5 m in depth in relation to the surrounding seabed. The scour is asymmetric; deeper (≤ 5 m) and more extensive (≤ 160 m from the wreck) towards the NE direction than towards the SW direction (≤ 3 m deep, ≤ 60 m long). This may suggest that tidal currents in the area are slightly asymmetric, with stronger magnitudes towards the NE direction. The occurrence of deep and extensive scour around

objects and pervasive sandwaves seen on the seabed in the area suggest high seabed dynamism and should be taken into account when planning developments.

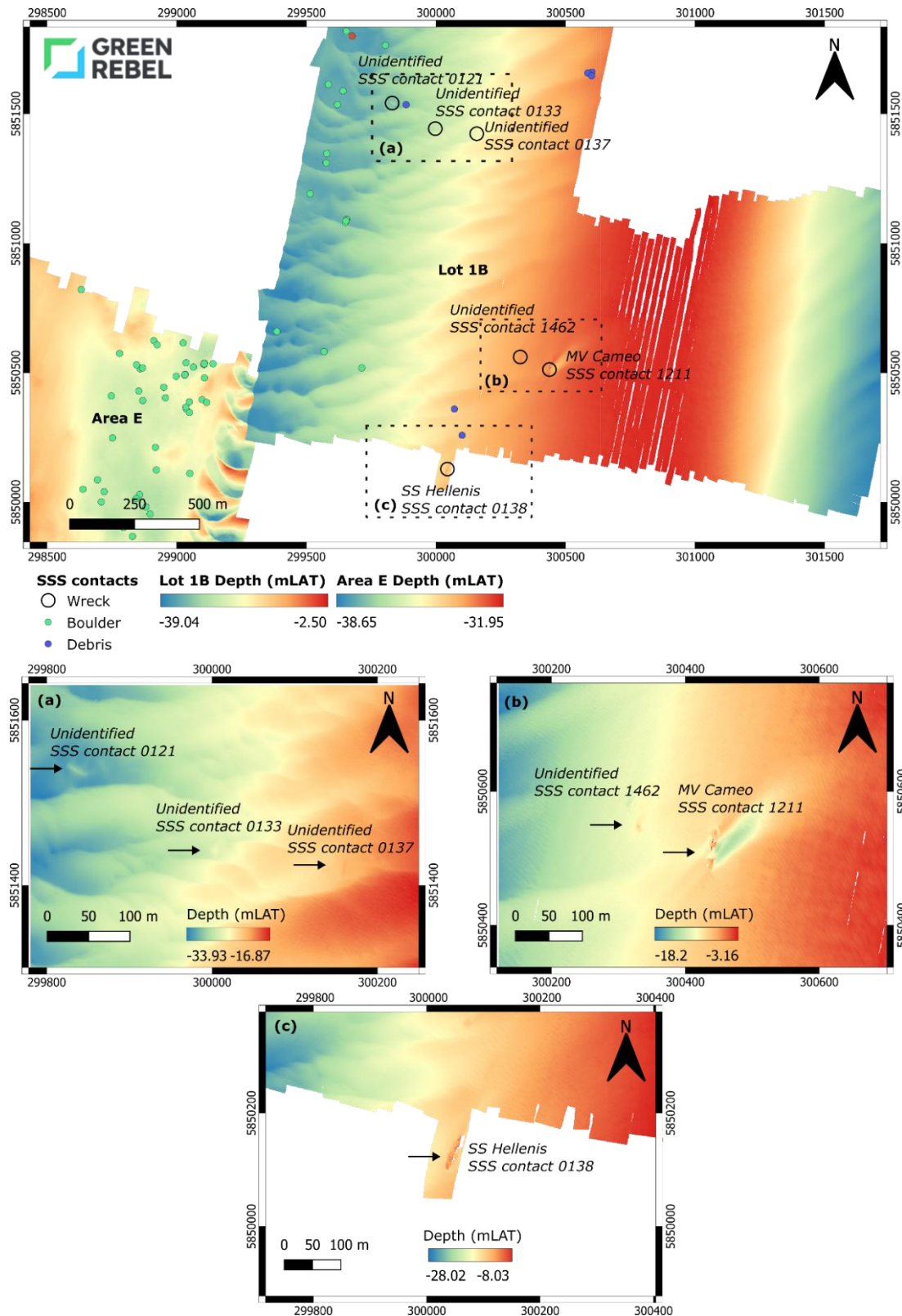


Figure 92: Detected wreck sites in the southern part of Lot1B CR2b: insets a), b) and (c) correspond to the areas marked in the main map shown on top.

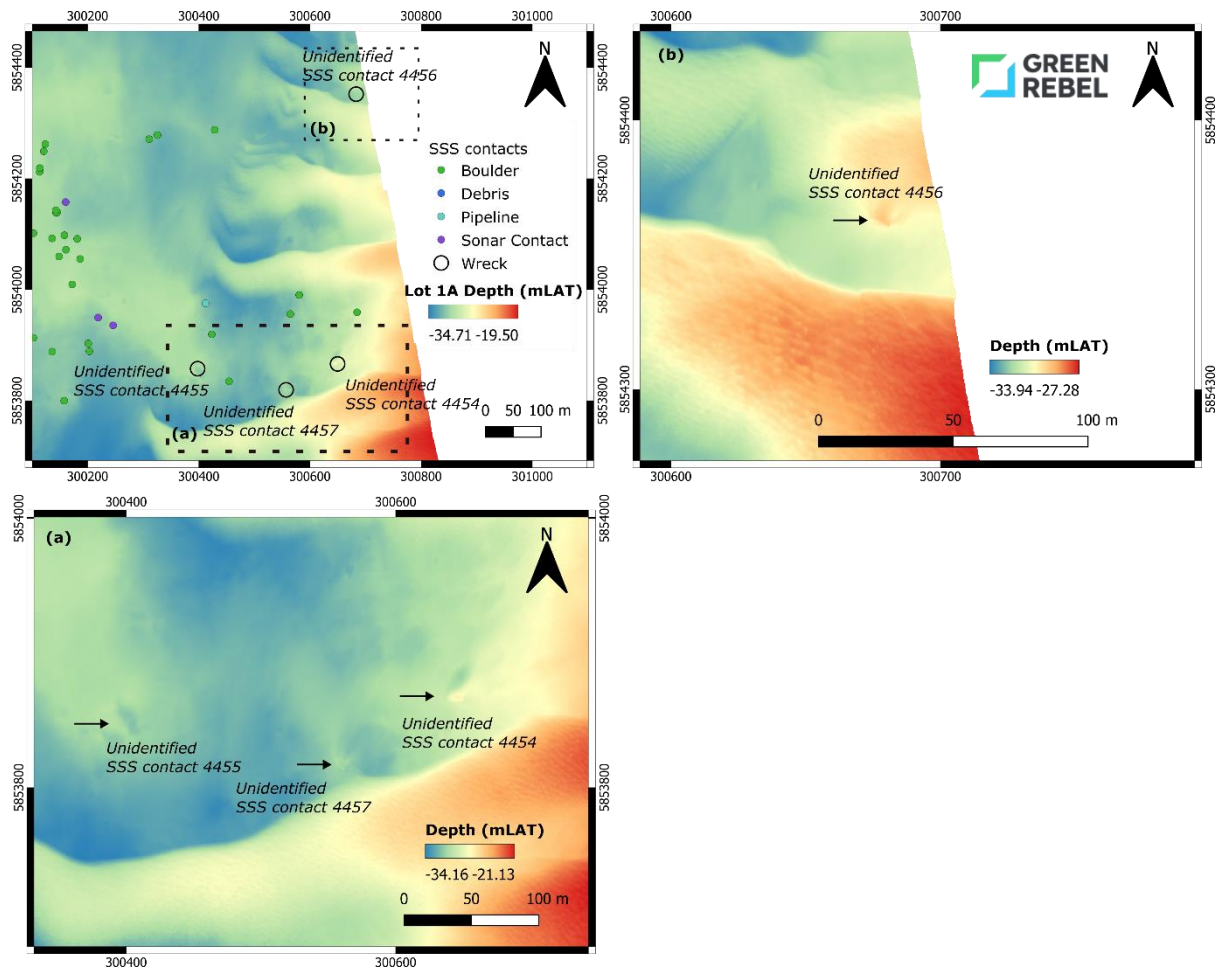


Figure 93: Detected wreck sites in the southern part of Lot1A CR2b: insets a) and b) correspond to the areas marked in the main map in the upper left corner.



Figure 94: Identified SSS/magnetometer contacts which occurred within close proximity of each other (see Appendix 4).

5 Conclusions and Recommendations

In conclusion, this report uses MBES, magnetometer, and SSS datasets to identify geohazards on the seabed that should be considered during site planning. The distribution of sediments on the seafloor and the presence of seafloor bedforms also play a critical role in offshore wind farm geohazards. The study found that the site was characterized by a complex energy system with a dominant north-south trending sediment bank composed mostly of fine-grained sediments and smaller-scale medium to coarse-grained sediments coeval with large bedforms such as sandwaves and megaripples. The shallow landfall area was found to be variable, indicating different deposition mechanisms, with potential intertidal mixing from the Redcross River. The study also found that 7.4% of the site was comprised of sandwaves and 0.4% was made up of megaripples. These waveforms can impact infrastructure depending on specific site conditions and the methods used for installation. The megaripple fields, where slope angles reach up to 35°, may be associated with potential gradient geohazards.

Coarse sediments, gravels, boulders, and boulder fields were found to have been deposited in glacial or peri/para-glacial environments and represent a potential geohazard that can constrain drilling operations and affect infrastructure installation and foundation piling. The study showed that the site was mostly exposed to glacial deposition and the boulderfields covered 10.2% of the total site. Moreover, the survey identified a considerable amount of debris and boulders in the study area, which show evidence as pUXOs.

In light of these findings, it is recommended that steep gradients, sediment heterogeneity, bedforms, shipwrecks and boulder fields should be carefully considered during the site planning and construction phases. Thorough geotechnical assessments (including a pUXO dedicated survey) and site selection processes should be carried out to minimize potential risks and ensure the safe and stable construction of wind turbines in the ocean. Additionally, further investigation and analysis (i.e. sediment grabs) may be required to assess the potential impact of bedforms on infrastructure.

6 Charts

The charts are supplied in a separate folder, which includes the following information:

Chart	Data Type	Name (PDF)
Bathymetry and	Bathymetry with contours	Bathymetry Chart
Shaded relief	Slope gradient	Slope Gradient Chart
Seabed features	Magnetometer targets	Magnetometer Targets Chart
	Seabed sediment distribution	Seabed Sediment Distribution Chart
	Seabed features - contacts	Seabed Contacts Chart
	Seabed features - bedforms	Seabed Bedforms Chart
	Limits of survey	Limits of Survey Chart

Appendices

Appendix 1

Seismic data handling

Raw Innomar sub-bottom *.ses3 converted to SEGY using SESconvert64. SEGY is a universal sonar format that can be edited and viewed in various software and programs. By importing the SEGY format, the trace headers were adjusted and edited within the software with additional gains, offsets and filters applied to the original file. Information pertaining to the handling of seismic data is provided below.

Relevant bytes for the processed Innomar SBP.sgy data

SEG-Y bytes	Property
<i>All co-ordinates, depths and times multiplied by a scalar equal to 100 Big Endian byte order, IEEE Float 32 Bit</i>	
1-4	Trace sequence number
9-12	Original Field Record Number
73-76	Source X co-ordinate, scalar=100
77-80	Source Y co-ordinate, scalar=100
109-110	Delay recording time (storing vertical corrections for the time domain data), scalar=100
49-52	Source depth (storing vertical corrections for the depth domain data), scalar=100 Velocities used for TWT/Depth conversion: 1500 m/s water, 1600 m/s sediments

Relevant SIS strings for the Innomar SBP.raw/.ses3 data

SIS string	Property
SIS 1	Time
SIS 7	Easting
SIS 8	Northing

Opening the data in SonarWiz

The project data can be viewed in SonarWiz should access have been granted via a project *.mml file within CTI SonarWiz. The project file is all encompassing and self-contained so by ensuring that the project files are kept together in the same folder and unedited or moved, it will open with all project features and files.

When importing the data into a new SonarWiz project the features and sonar files must be imported with the correct coordinate system. SonarWiz digitiser can only read water column data within the profile viewer. As such, to plot the digitised reflectors correctly, the sound and sediment velocity values must be the same. For example, this can be done by changing the water velocity figure (1500 ms^{-1}) to match the sediment velocity (1600 ms^{-1}) of the file. This process requires that you make the edits in the properties window for the file which is located under the Project Explorer tree.

Opening the data in Kingdom

The data can be loaded into Kingdom by importing SEGY files with coordinates using the numeric byte order "Big Endian". Choose the domain of the data (Time or Depth). All coordinates, depths and times multiplied by a scalar of 100 (Table 16).

Table 16: Kingdom data loading parameters and trace byte locations

Byte Description	Byte number	Scale Factor	Format
Shotpoint	9	1	32 bit
X coordinate	73	0.01	32 Bit
Y coordinate	77	0.01	32 bit

Appendix 2

Summary of seafloor targets across the ABWP site

Device Type	Target Type	Count
SSS/MBES	Boulders	6465
	Sonar Contacts	122
	Linear Contacts	5
	Wrecks	10
	Debris	56
MAG	Monopoles	975
	Dipoles	34
	Complex	135

Appendix 3

Vessel Information.



A 27.5 m, semi-SWATH (Small Waterplane Area Twin Hull), DP1 vessel, purpose built for hydrographic and geophysical data acquisition.



Q4 2021

Roman Rebel

Vessel Data (v2)

**General**

Builder:	Socarenam Boulogne, France
Designer:	Bureau Mauric, Marseilles
Launched:	2014
Length:	27.5 m
Beam:	10.0 m
Draught:	3.5 m
Tonnage:	134 GT
Ops Code:	UK MCA SCV Category 1 (150 miles)
Class:	Lloyd's Register 100A1SSC Catamaran, G6, DP1
Flag:	UK
Previous name:	Bibby Athena

Propulsion

Main:	2 x Cummins KTA19 M3 447 kW each (600 hp) marine diesels
Main Propellers:	5 blade fixed pitch
Main Gearbox:	MG516C twin disk hydraulic gearboxes
Survey:	2 x Schottel SPJ57 azimuth pump jets 175 kW (235 hp)
Bow Thrusters:	2 x Schottel SPJ15 azimuth pump jets 60 kW (80 hp)
Max speed:	12 knots
Cruising speed:	10 knots
Survey speed:	3.5 – 6.0 knots

Generators

Main:	2 x Scania DI13-074M (340 kVA each)
Harbour:	1 x Cummins Onan 35 kVA
Deck Connection:	1 x 175 kVA and 1 x 50 kVA

Manning and Endurance

Berths:	16
Safe manning:	5
Endurance:	10 days (with 16 crew)

Capacities

Gas oil:	24 m ³
Fresh water:	8 m ³
Water maker:	2 m ³

Fuel Consumption

Transit:	2.5 m ³ · day ⁻¹
Survey:	1.2 m ³ · day ⁻¹
DP:	1.8 m ³ · day ⁻¹

Nav aids

Radar:	2 x 94m Furuno FAR 2117 Black Box
Autopilot:	Navico AP50 with remote control
ECDIS:	Navmaster
AIS:	Furuno FA150
dGPS:	C&C Tech C-Nav 3050 and Furuno GP150
Echosounder:	Furuno FE700
Heading INS Gyro:	iXBlue Quadrans
Secondary Heading:	2x iXBlue Hydrans
Speed log:	Skipper Electromagnetic
Navtex:	Furuno700B
Weather:	2 x Furuno WS200
VHF:	2x Icom 603 DSC
MF:	Furuno FS1570
Sat Comms:	Furuno 250 Fleet Broadband; Furuno Felcom 15 Sat C
GNSS:	C-NAV and Hemisphere

Dynamic Positioning (DP1)

System:	Sirehna EasyDP BV - AM/AT
Modes:	Station keeping, ROV follow, slow speed line keeping, high speed line keeping, Auto heading
Ref Sensors:	2 x dGPS, 2 x MRU (Hydrins and Quadrans), dual axis log, 2 x wind sensors, Sonardyne Mini-Ranger 2 USBL acoustic navigation system

Roman Rebel
 Vessel Data (v3)

Deck Equipment

Crane:	Palfinger PK23500-M, 5,450 kg at 4.2 m, 8 m reach
Crane remote:	Full function radio control
A-Frame:	Hydraulic 8,000 kg SWL with 6.5m deck clearance
A-Frame outriggers:	Full beam width for towing geophysical sensors
Lifting winch:	Hydraulic 8,000 kg line pull
Moonpool:	2.05 m x 2.30 m central moonpool
Main Survey Winch:	MacArtney "Cormac" 4 1,500 m of 8.2 mm coax cable
Secondary survey winch:	2x STR ESW-1500 600 m of 11.4 mm coax cable
Sonar well:	2x 600 mm x 540 mm
USBL well:	310 mm diameter
Capstan:	2 x deck mounted 2000 kg line pull

Survey Positioning

GNSS 1:	C&C Tech C-Nav 3050
GNSS 2:	Hemisphere R330
INS:	2x iXBlue Hydrans

Underwater Positioning

USBL:	Sonardyne HPT 3000
transceiver:	("Mini Ranger 2")
Surface unit:	Sonardyne Hub
Transponder:	Sonardyne WSM 6+

Safety

Liferaft capacity:	2x 16 man
Lifejackets:	16x emergency; 8x deck work
Survival suits:	16x neoprene immersion suits
Emergency positioning:	EPIRB 406 kHz
Other:	2x SAR transponders

Multibeam Echosounder

Sonar heads:	2x Teledyne SeaBat T50-R (total 2,048 beams per ping)
Processor:	2x Teledyne Reson T50 IDH processor
SV sensor:	2x Reson SVP-70

Sub-Bottom Profilers

Pinger	4x Neptune T335
Transducer:	
Parametric Transducer:	Innomar Medium-100; 2-22 kHz secondary frequencies; vertical resolution better than 5 cm
Surface unit 1:	Kongsberg Geoacoustics Geopulse 5430A
Surface unit 2:	2x Coda DA4G Acquisition Unit - Simultaneous A/D System
Surface unit 3:	Innomar Medium topside

Side-Scan Sonar

Towfish:	EdgeTech 4205
Processor:	EdgeTech 701-DL

Magnetometers

Magnetometer:	Geomatrix G-882
TVG frames:	Geomatrix carbon fibre with telemetry
Gradiometer setups:	up to 3x 2-sensor TVG frames (6 sensors); up to 3x EIVA 4-sensor scanfish (12 sensors)

Deck space

Available:	7 m x 5 m (35 m ²)
Surface:	wooden planks
Typical uses:	ROV LARS systems; shallow coring and grabs; 20' storage container

Roman Rebel

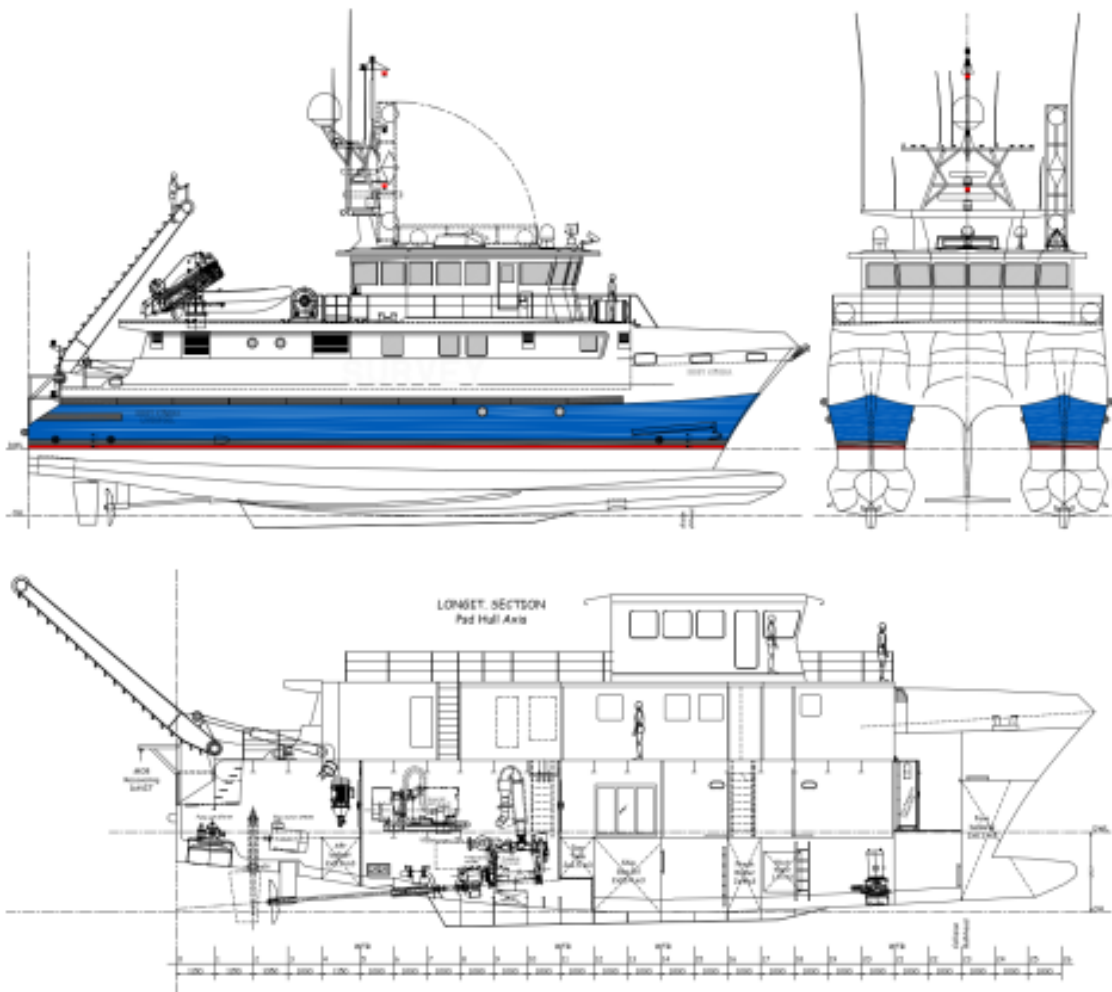
Vessel Data (v3)

**Specifications**

Name:	Roman Rebel
Call Sign:	2ICA5
Lloyd's Register Class:	Oceanographic Survey Vessel, DP(AM)
IMO Number:	9714824

Inquiries

Contact:	Jared Peters
Email:	info@greenrebel.ie



Green Rebel Marine Limited

Crosshaven Boatyard, Point Road,
Crosshaven, Co Cork, P43 EV21, IrelandEmail: info@greenrebel.iewww.greenrebel.ie



The Lady Kathleen is a state-of-the-art 14 m survey vessel that provides a stable platform for reliable, cutting-edge sensor deployment. The vessel is purpose built for hydrographic and geophysical data acquisition. It is a cutting-edge survey platform with exceptional manoeuvrability both at low and high speed and can conduct nearshore work in a wide range of water depths from <3 m to >100 m.

Lady Kathleen

Vessel Data (v2)

**General**

Builder:	Blyth Catamarans, United Kingdom
Designer:	Blyth Catamarans
Launched:	2021
Length:	14 m
Beam:	5 m
Draught:	1.4 m
Flag:	Irish

Propulsion

Main:	2 x Cummins QSC8.3 (447 kW each) marine diesels
Main Propellers:	5 blade
Max speed:	17 knots
Cruising speed:	15 knots
Survey speed:	3.5 – 6.0 knots

Generators

Main:	240 kVA
Secondary:	8 KW

Manning

Berths:	2
Safe manning:	2
Crew capacity:	12 hours with up to 10 crew/passengers

Capacities

Gas oil:	2 x 300 gal
Fresh water:	180 ltr

Safety

Liferaft capacity:	16 man
Lifejackets:	16x emergency; 8x deck work
Survival suits:	16x neoprene immersion suits
Emergency positioning:	EPIRB 406 kHz
Other:	2x SAR transponders

Nav aids

Radar:	Raymarine Quantum Q24C
Autopilot:	Raymarine Evolution ACU 200 autopilot
ECDIS:	2x Raymarine Axiom Multi 16" Pro-RVX display
AIS:	Class A
dGPS:	KGP-922 GPS
Echosounder:	Raymarine Axiom 16 ProRVX
Heading INS Gyro:	Applanix OceanMaster
Navtex:	Furuno700B
GNSS:	Applanix

Deck Equipment

A-Frame:	1 ton
Lifting winch:	Hydraulic 1 ton
Survey Winch:	2x STR ESW-500 500 m of coax cable
Capstan:	1x Electric

Multibeam Echosounder

Sonar head:	Teledyne SeaBat T50-R
Processor:	Teledyne Reson T50 IDH processor
SV sensor:	Reson SVP-70

Geophysical

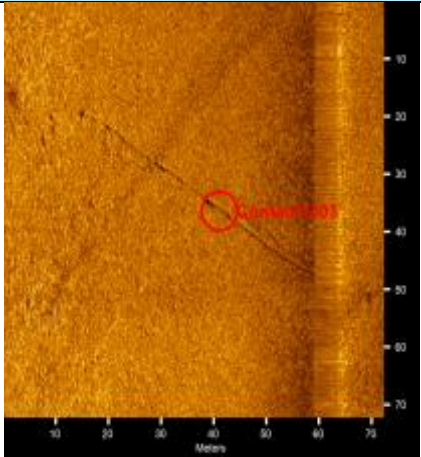
Parametric SBP:	Innomar SES-2000 Standard
SSS	EdgeTech 4205
Magnetometer	Geomatrix G-882
Gradiometers	2-sensor TVG frame

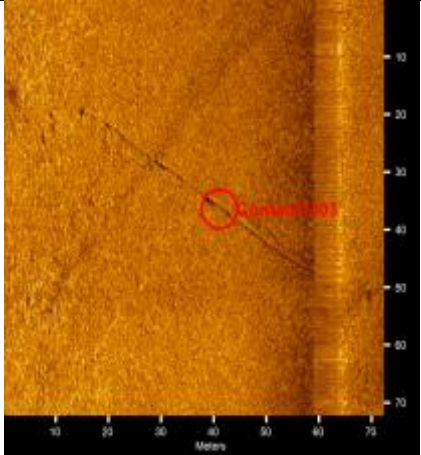
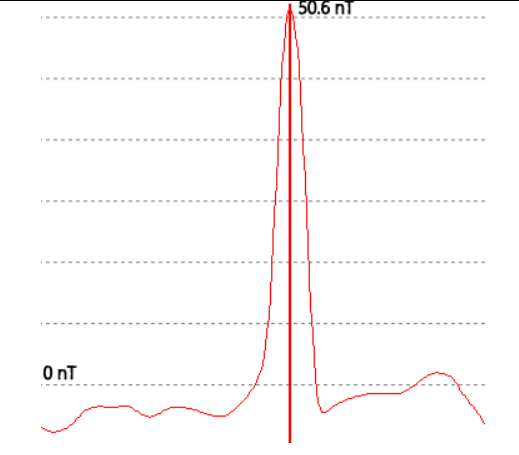
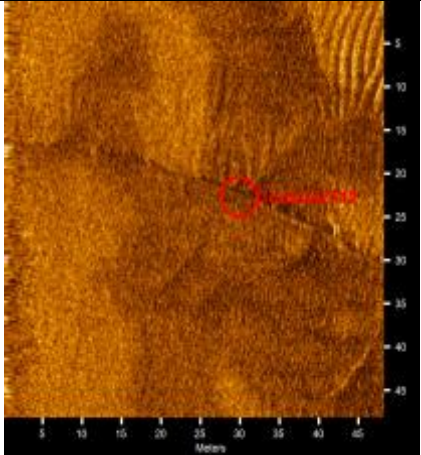
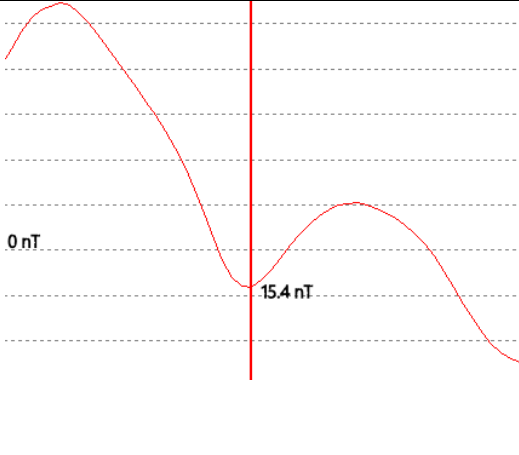
Inquiries

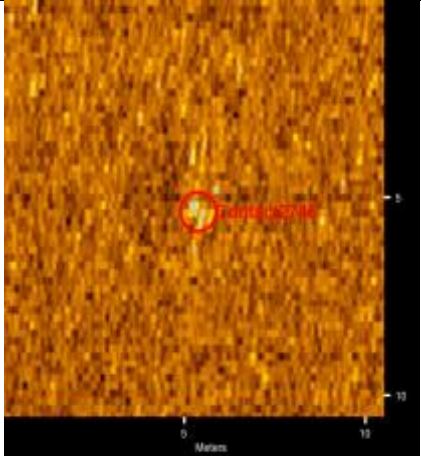
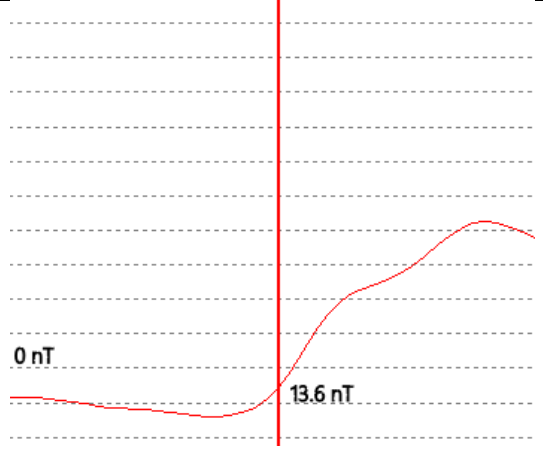
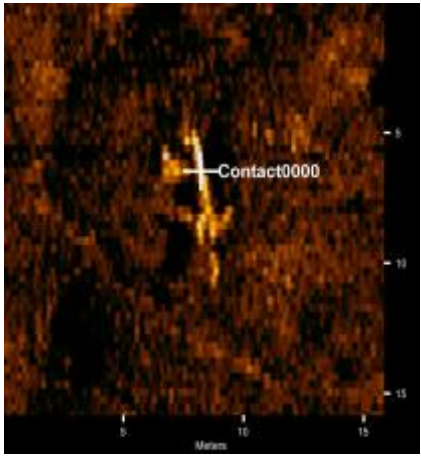
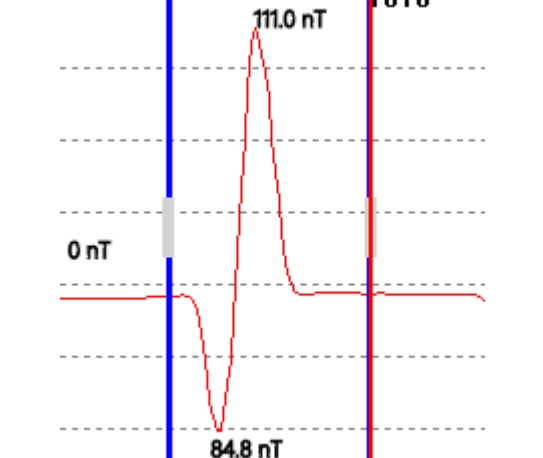
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Email:	info@greenrebel.ie

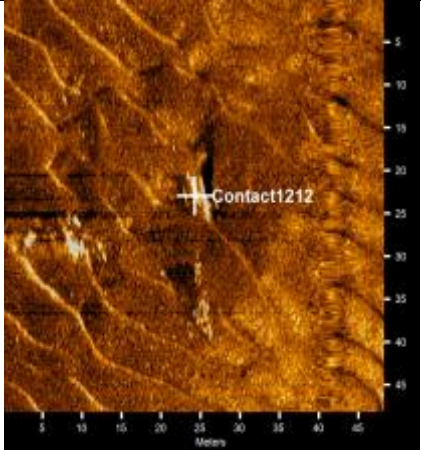
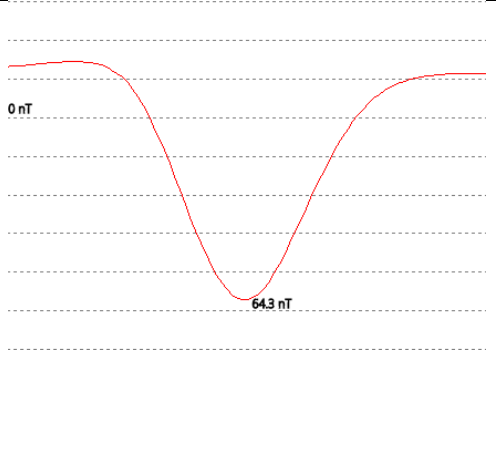
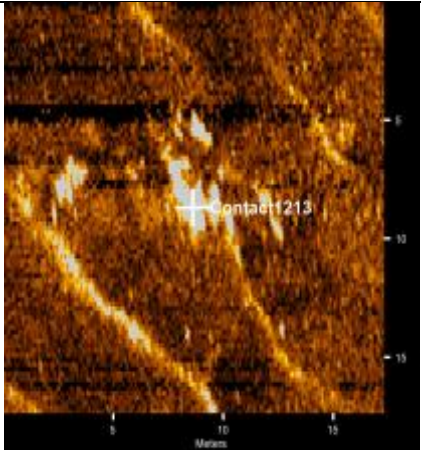
Appendix 4

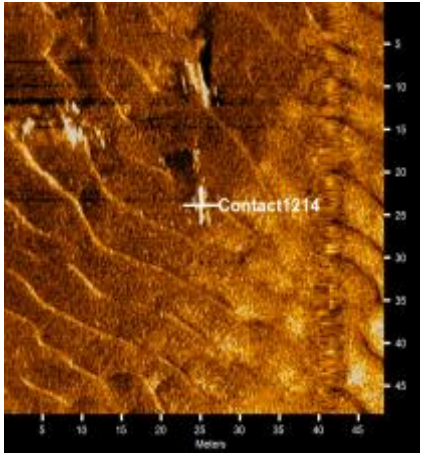
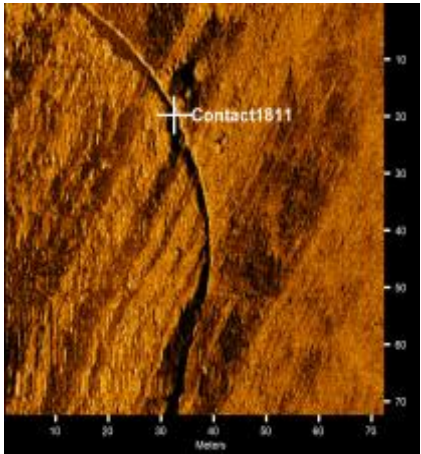
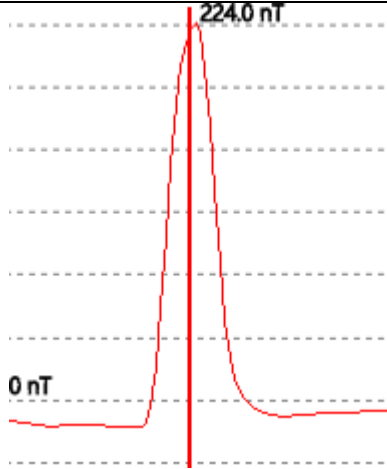
SSS and Magnetometer correlation points. Shown (where possible) are SSS Contacts and respective magnetic signal captured nearby.

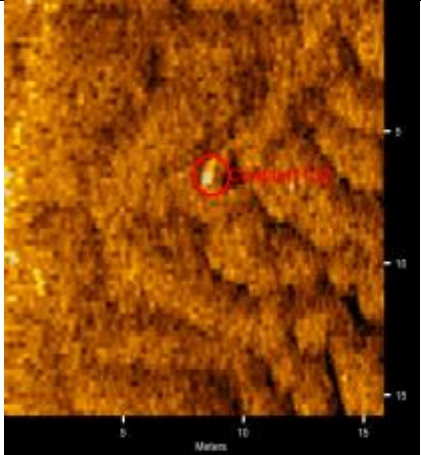
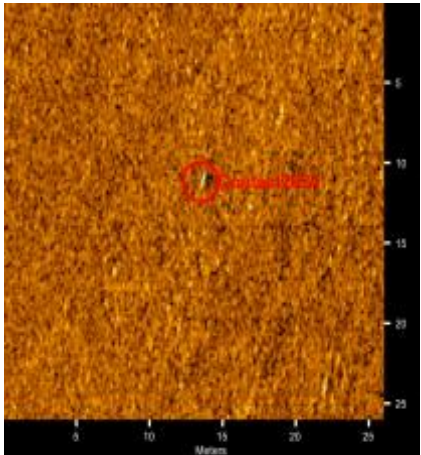
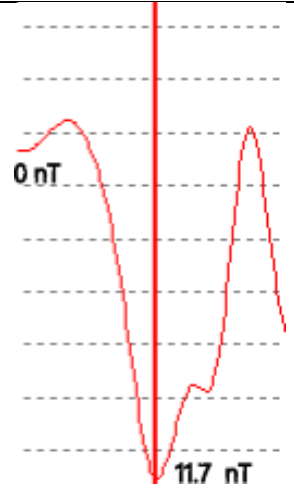
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Lot_1A	Target 173	Contact1303	Debris Monopole	 A side-scan sonar image showing a seabed with a red circle highlighting a contact point. The image has a vertical scale on the right from 10 to 70 and a horizontal scale at the bottom from 10 to 70 meters.	 A magnetic signal graph showing a sharp negative peak. The y-axis is labeled "0 nT" at the top and "24.2 nT" at the bottom of the peak. The signal is plotted on a grid of horizontal dashed lines.

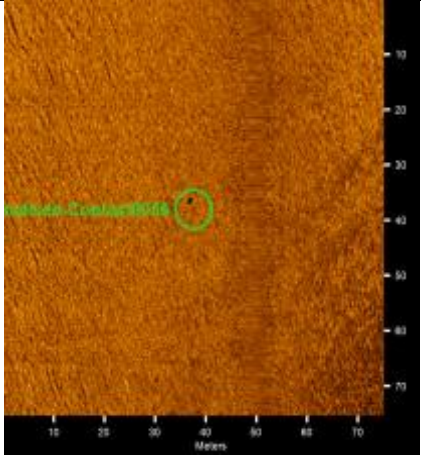
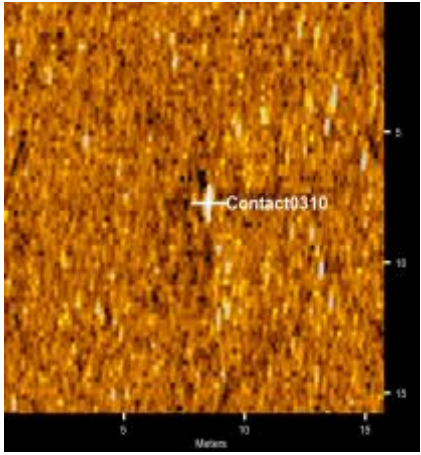
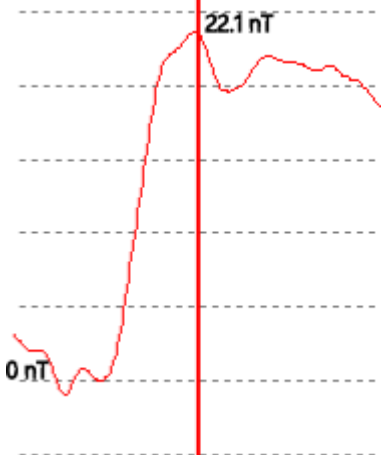
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Lot_1A	Target 356	Contact2742	Debris Monopole		

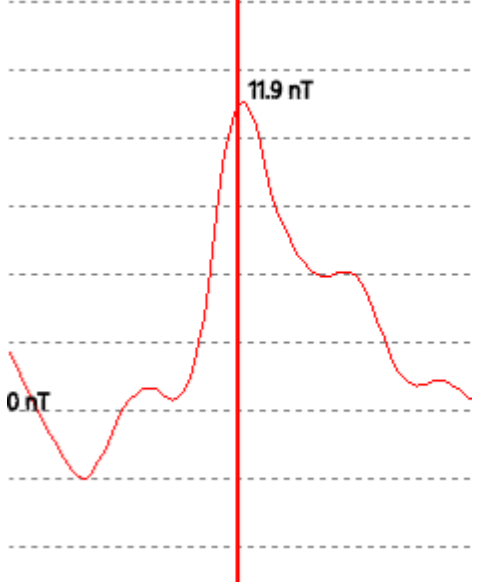
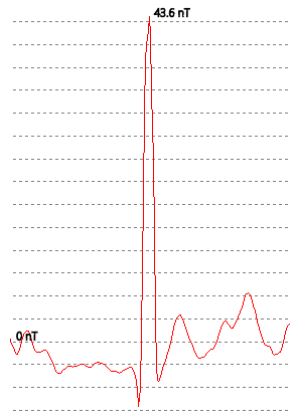
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Lot_1B	Target 1019	Contact0000	Debris Monopole		

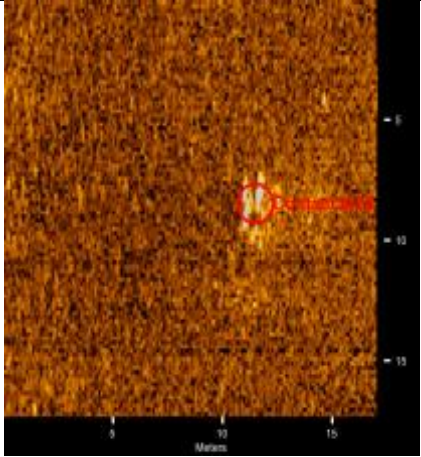
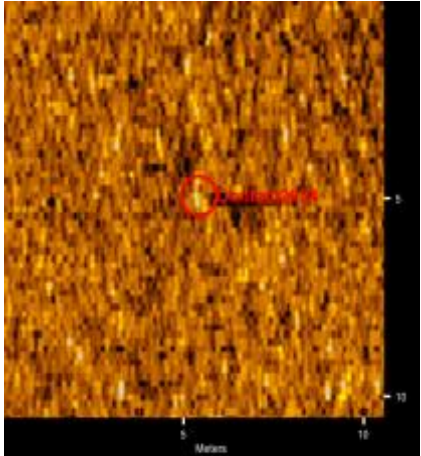
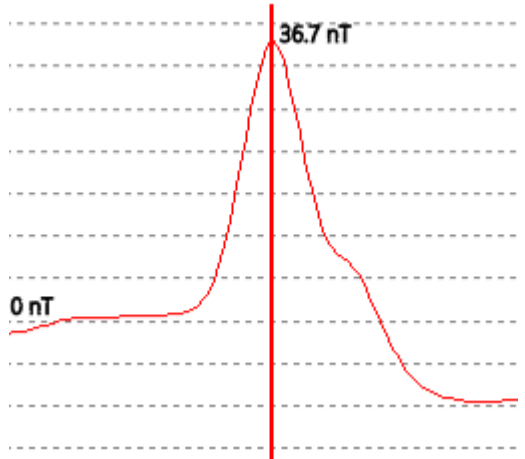
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Lot_1B	Target 1037	Contact1213	Debris Monopole		

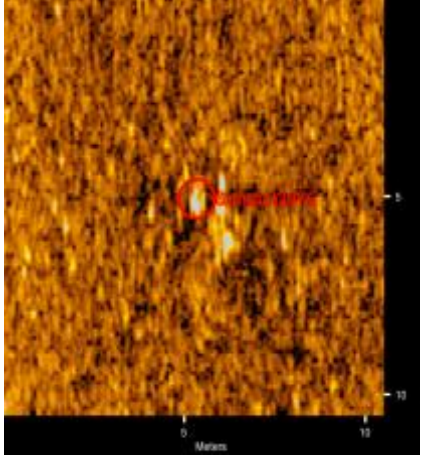
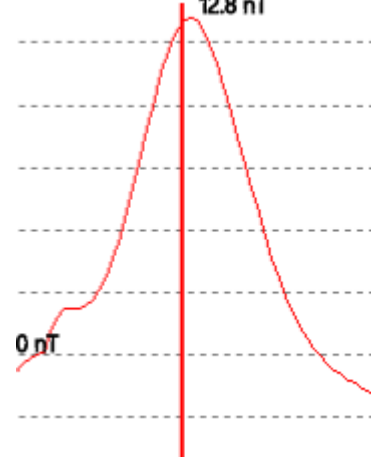
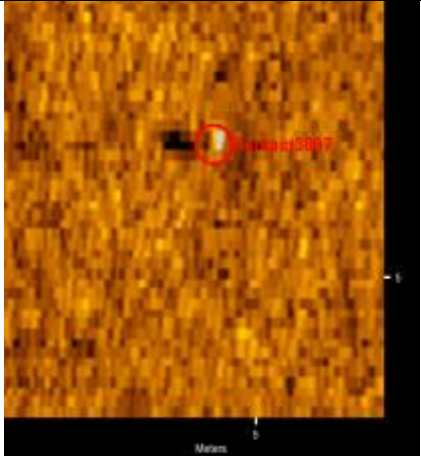
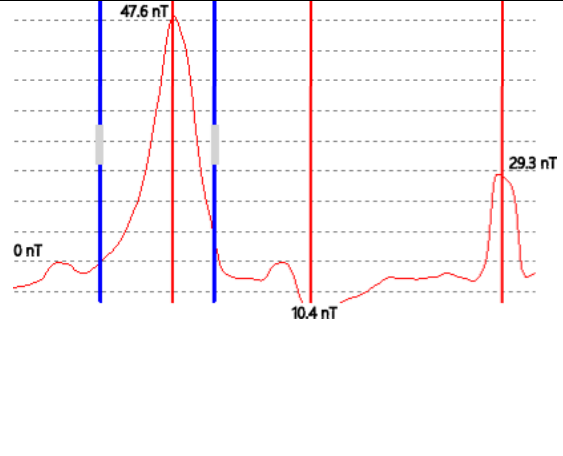
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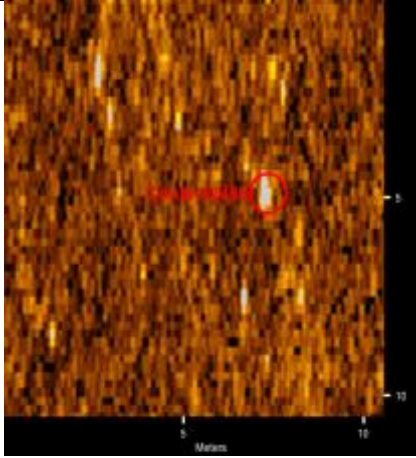
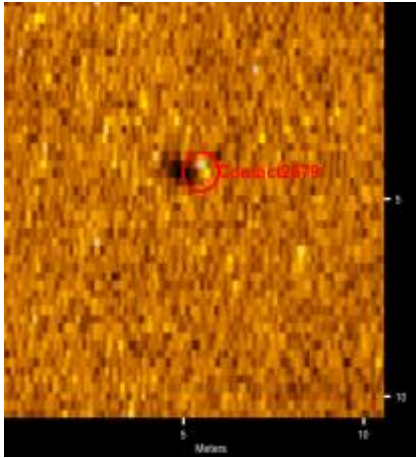
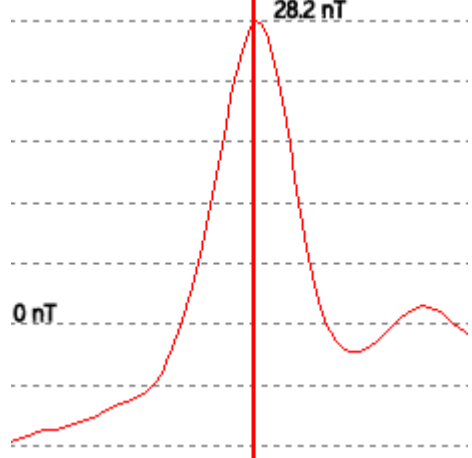
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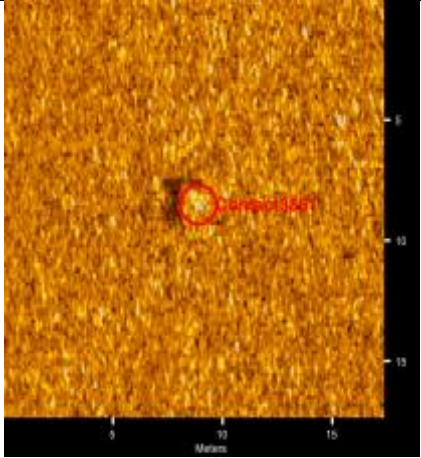
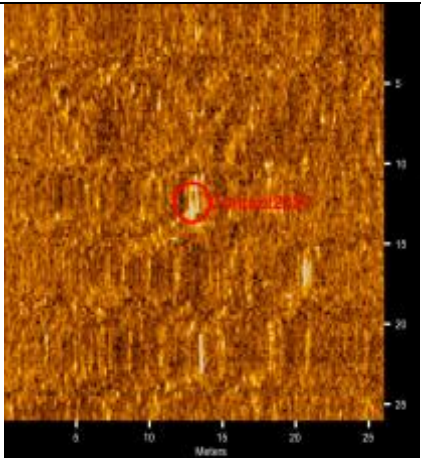
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Lot_1A	Target 231	Contact0310	Boulder Monopole		

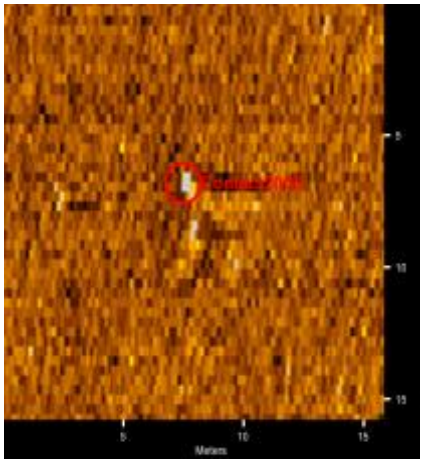
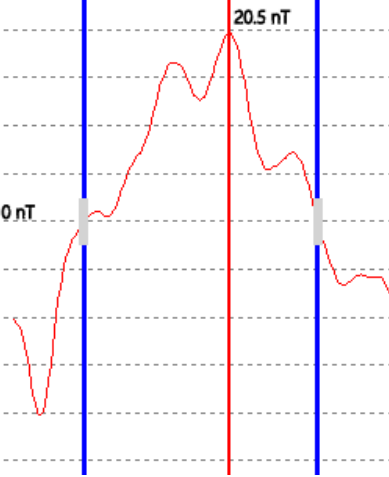
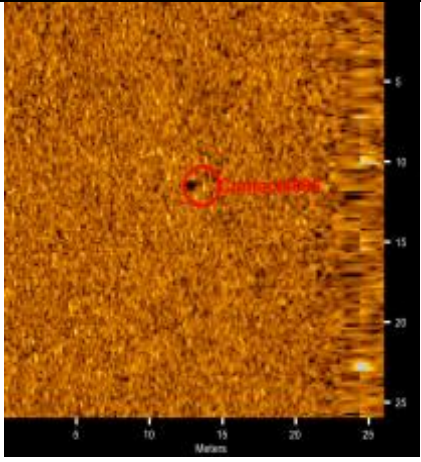
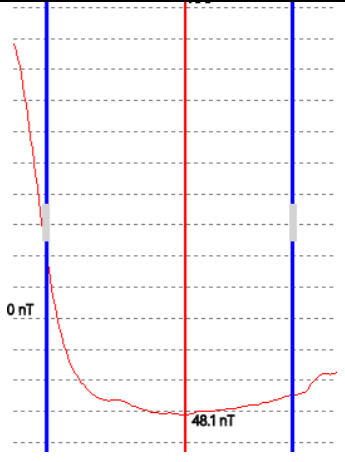
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Lot_1A	Target 272	MBES (no SSS contact)	Boulder Monopole		

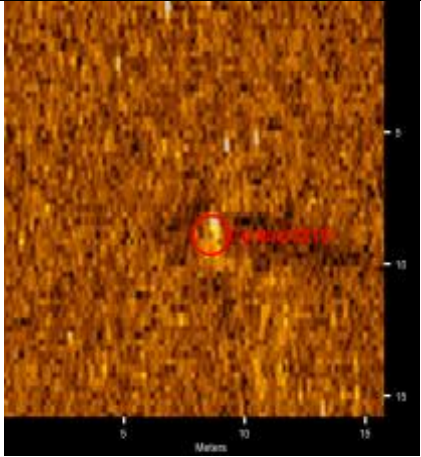
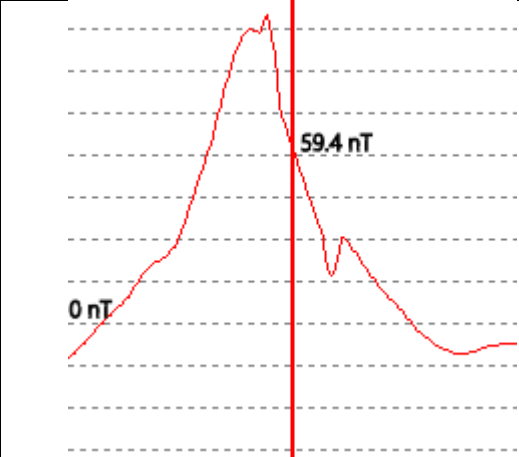
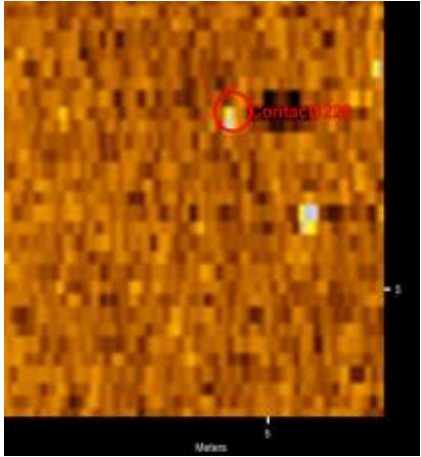
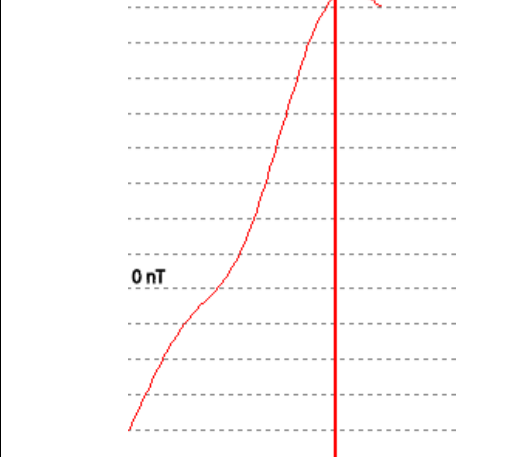
Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1A	Target 300	Contact3028	Boulder Monopole		
Lot_1A	Target 398	Contact2934	Boulder Monopole		

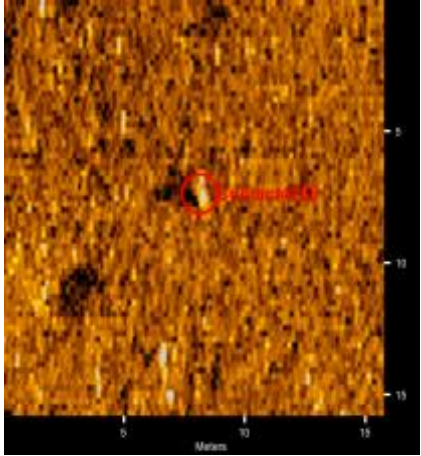
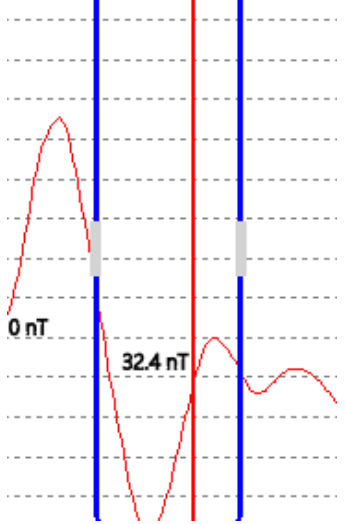
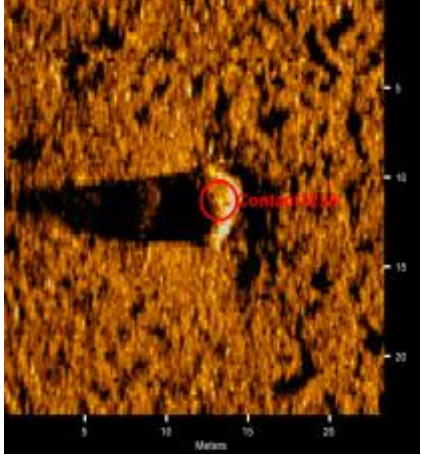
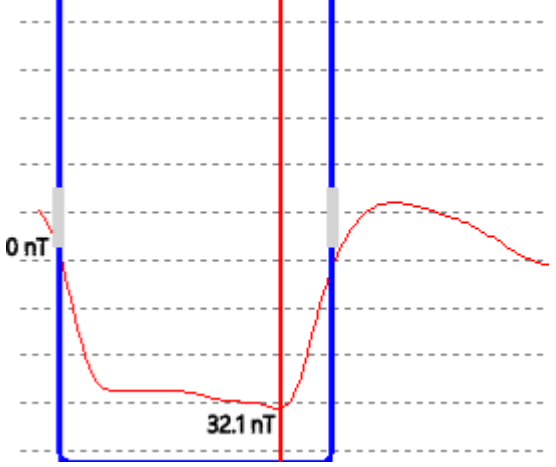
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Lot_1A	Target 403	Contact2975	Boulder Monopole		
Lot_1A	Target 421	Contact3897	Boulder Monopole		

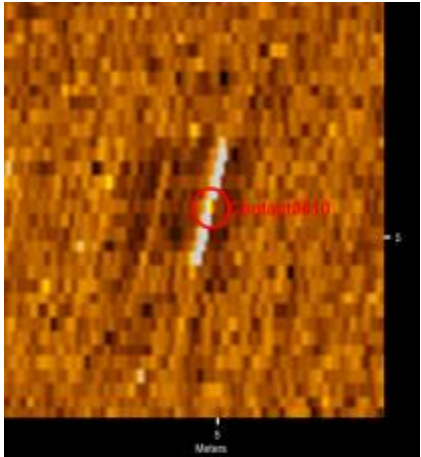
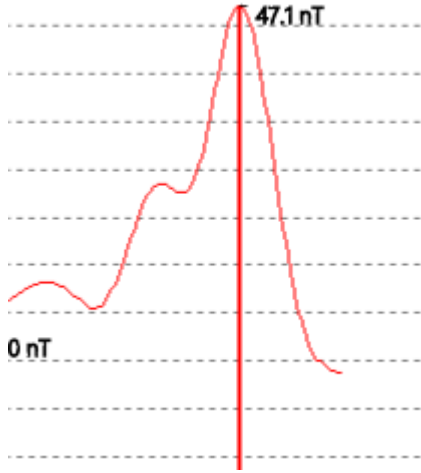
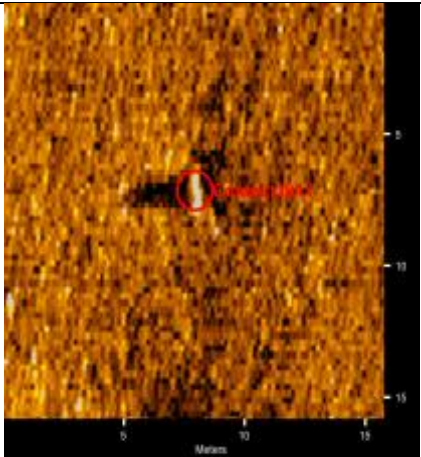
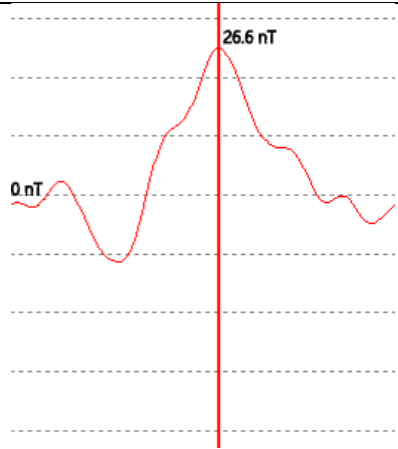
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Lot_1A	Target 424	Contact2460	Boulder Monopole		
Lot_1A	Target 432	Contact2679	Boulder Monopole		

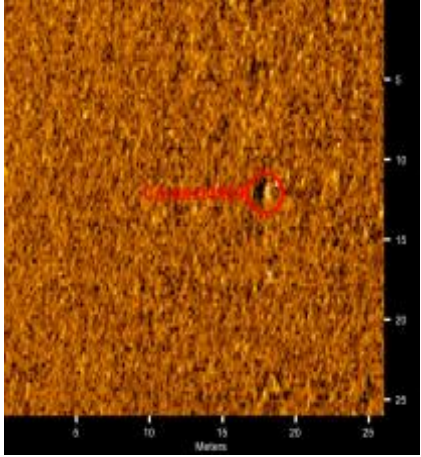
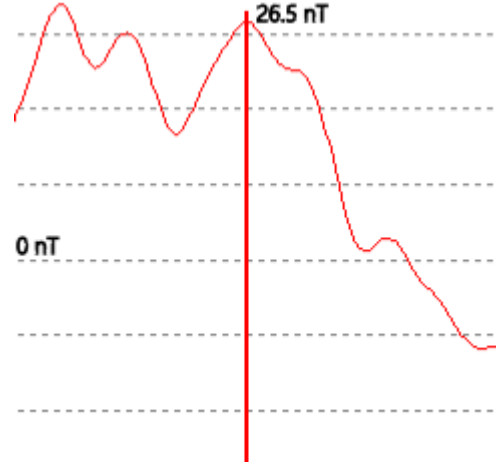
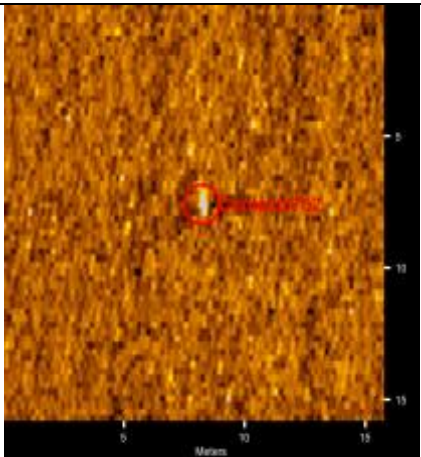
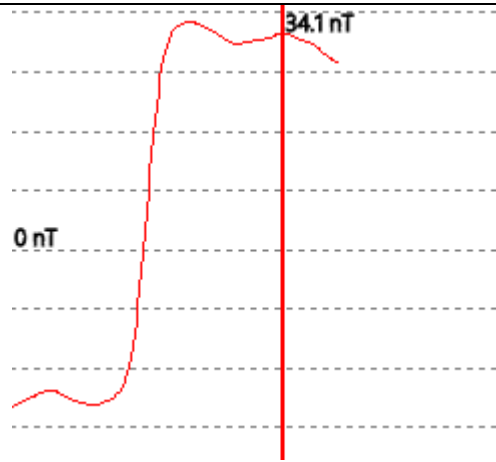
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Lot_1A	Target 437	Contact3851	Sonar Contact Monopole		
Lot_1A	Target 449	Contact 2227	Boulder Monopole		

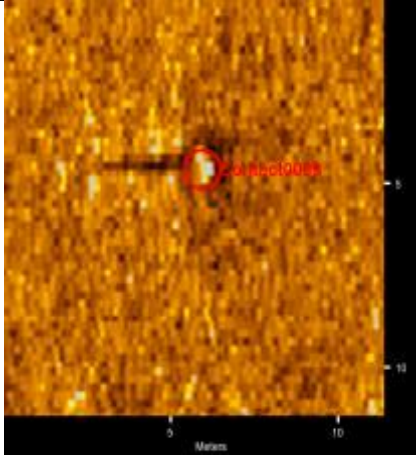
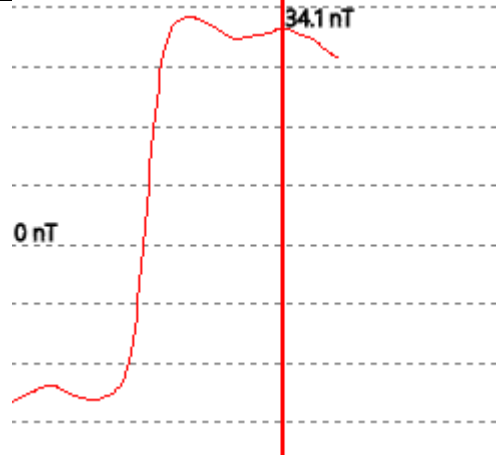
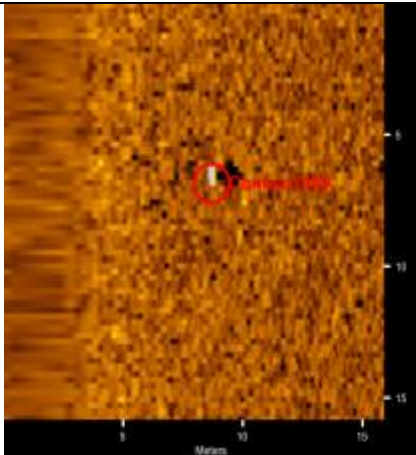
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Lot_1A	Target 466	Contact2000	Boulder Complex		
Lot_1A	Target 487	Contact4085	Boulder Monopole		

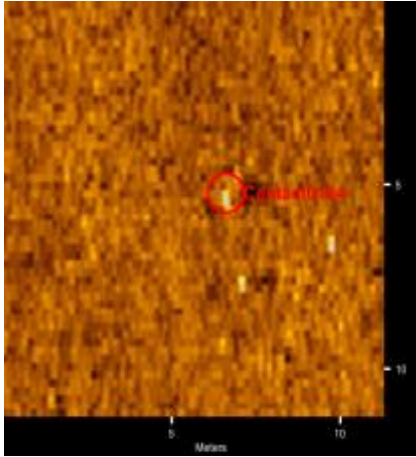
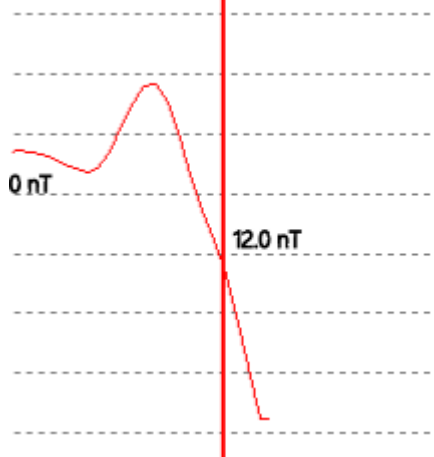
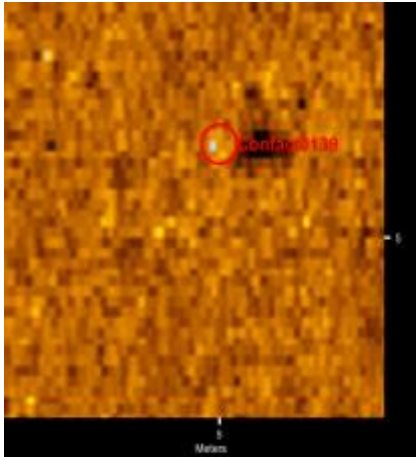
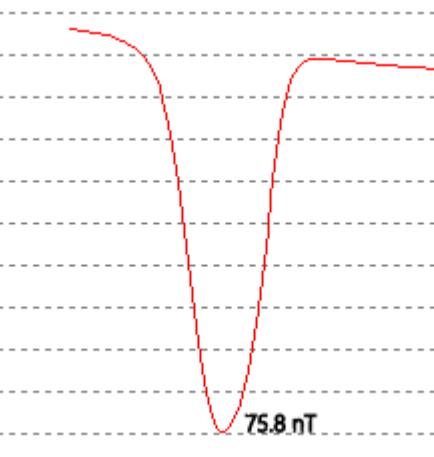
Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1A	Target 514	Contact3216	Boulder Monopole		
Lot_1A	Target 529	Contact3220	Boulder Monopole		

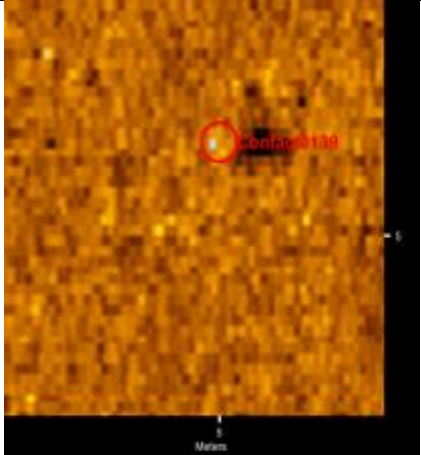
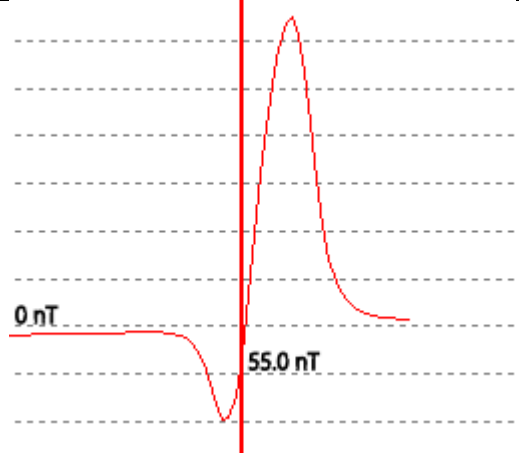
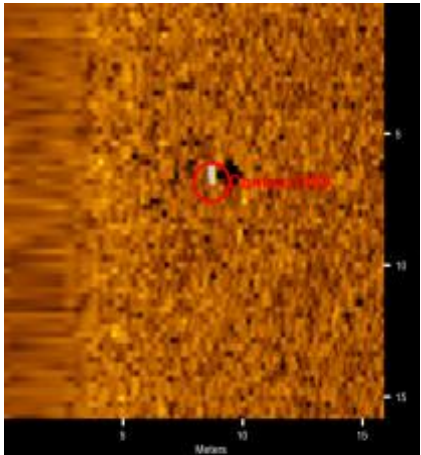
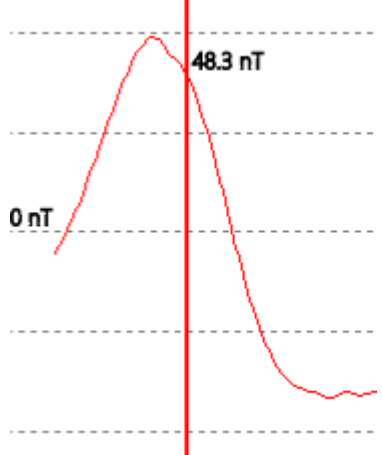
Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1A	Target 550	Contact4268	Boulder Monopole		
Lot_1A	Target 560	Contact3226	Boulder Monopole		

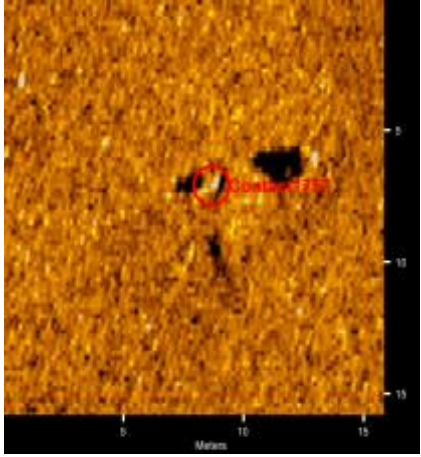
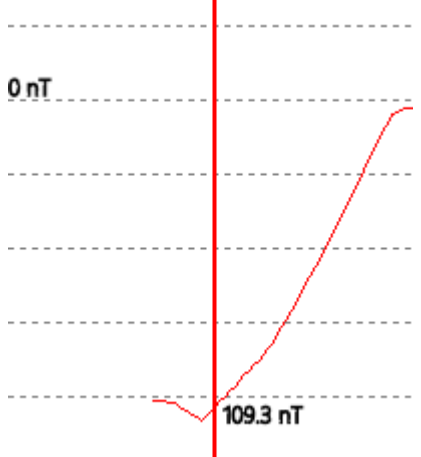
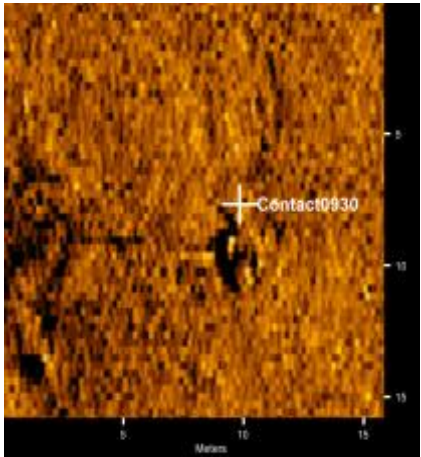
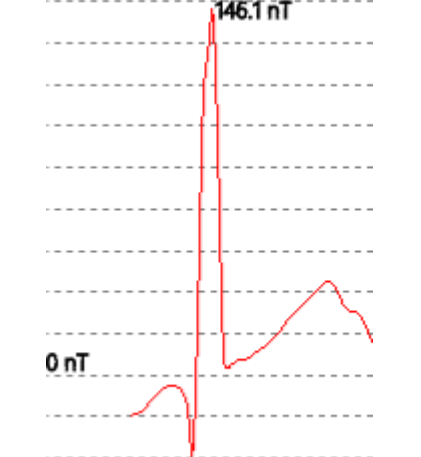
Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1A	Target 592	Contact0610	Boulder Monopole	 A false-color SSS image showing a boulder monopole. A red circle highlights the contact point, labeled "Contact0610". A scale bar at the bottom indicates 5 meters.	 A magnetic signal plot showing a sharp peak. The peak is labeled "47.1 nT". The baseline is labeled "0 nT".
Lot_1A	Target 623	Contact3941	Boulder Monopole	 A false-color SSS image showing a boulder monopole. A red circle highlights the contact point, labeled "Contact3941". A scale bar at the bottom indicates 5, 10, and 15 meters.	 A magnetic signal plot showing a peak. The peak is labeled "26.6 nT". The baseline is labeled "0 nT".

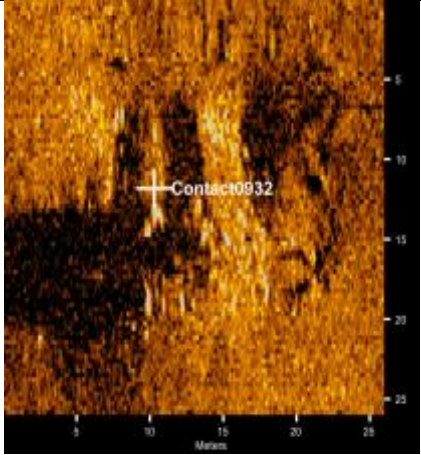
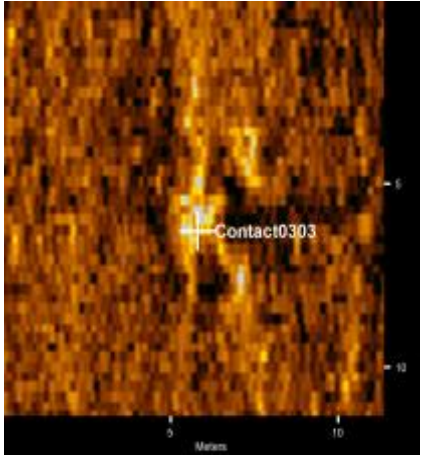
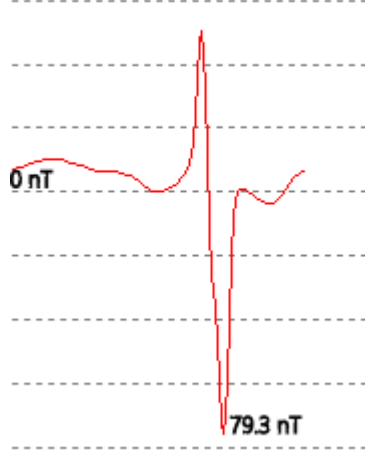
Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1A	Target 670	Contact3959	Boulder Complex		
Lot_1A	Target 721	Contact3752	Boulder Monopole		

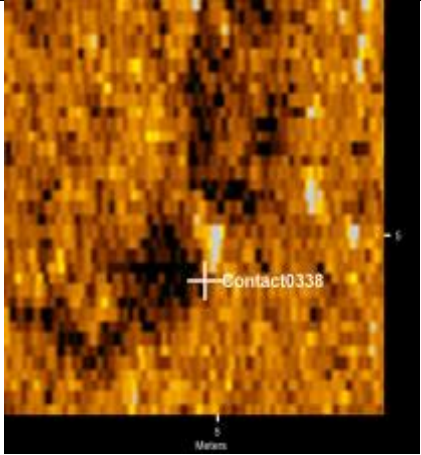
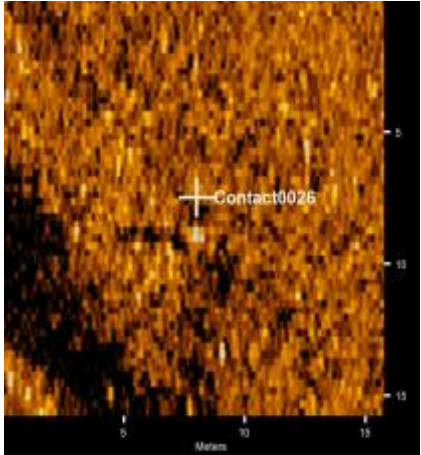
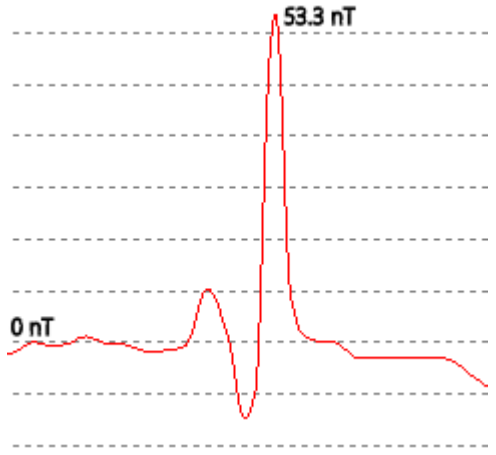
Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1B	Target 747	Contact0089	Boulder Monopole		
Lot_1B	Target 870	Contact1469	Boulder Complex		

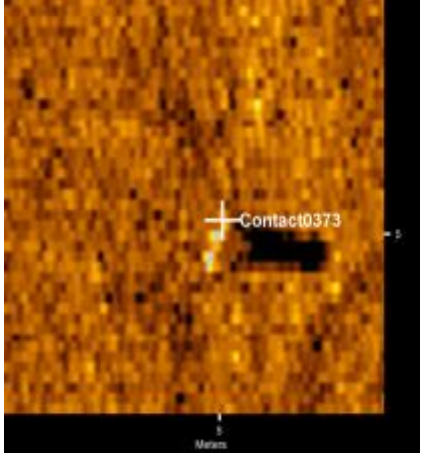
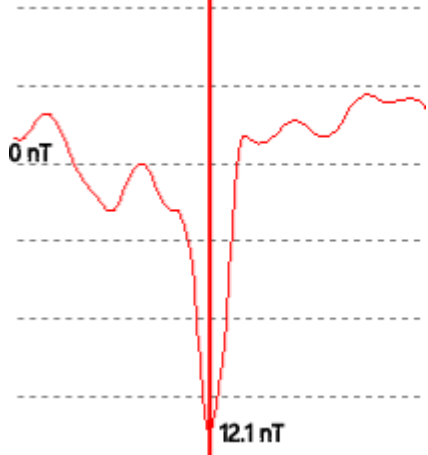
Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1B	Target 1004	Contact0104	Boulder Dipole		
Lot_1B	Target 1013	Contact0139	Boulder Monopole		

Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1B	Target 1014	Contact0139	Boulder Monopole		
Lot_1B	Target 1131	Contact1469	Boulder Monopole		

Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Lot_1B	Target 1143	Contact1757	Boulder Monopole		
Area_E	Target 904	Contact0930	Boulder Monopole		

Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Area_E	Target 905	Contact0932	Boulder Monopole		
Area_E	Target 923	Contact0303	Boulder Dipole		

Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Area_E	Target 924	Contact0338	Boulder Monopole		
Area_E	Target 926	Contact0026	Boulder Monopole		

Area	Mag Contact ID	SSS Contact ID	Contact Type	SSS Contact Image	Magnetic Signal
Area_E	Target 927	Contact0373	Boulder Monopole	 A false-color SSS (Scanning Sidelobe Suppression) image showing a textured, orange-brown surface. A white crosshair marks a specific point labeled "Contact0373". A scale bar at the bottom indicates "5 Meters".	 A line graph showing the magnetic signal for Contact0373. The signal is plotted as a red line on a grid with horizontal dashed lines. The signal starts near 0 nT, dips to a minimum of 12.1 nT, and then rises back towards 0 nT. A vertical red line marks the minimum point.

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