Geophysical Site Survey Report

Danish Offshore Wind 2030

LOT 4, Work Package C, Area 1

Geophysical Survey – SN2023_010
North Sea, Danish Sector

CLIENT
Energinet

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EXECUTIVE SUMMARY

PROJECT AREA NORTH SEA 1 – GEOPHYSICAL SITE SURVEY AREA 1 (NSA1)	
INTRODUCTION	
Survey Dates	M/V Northern Maria: 03 April to 17 September 2023 M/V Northern Franklin: 06 May to 12 September 2023 M/V Geo Ranger: 13 June to 11 September 2023
Equipment	Multibeam Echo Sounder (MBES), Side Scan Sonar (SSS), Magnetometer (MAG), Innomar Sub-bottom Profiler (SBP), Sediment Grab Samples (GS).
Coordinate System	Datum: European Terrestrial Reference System 1989 (ETRS89) Projection: Universal Transverse Mercator (UTM) Zone 32N, Central Meridian (CM) 9°E

BATHYMETRY AND SEAFLOOR MORPHOLOGY

The bathymetric survey recorded water depths across the NSA1 survey area ranged between 15.56 m and 33.51 m (DTU21 MSL) with depth generally increasing from the south to the north across the site.

The seabed has a range of natural topographic variability occurring throughout the site but is dominated by the northern extent of the Horns Rev sandbank. Extensive areas of mobile sediments are widespread, with areas of ripples, large ripples and megaripples present across a large part of the survey area.

SURFICIAL GEOLOGY

The surficial geology in the NSA1 survey area is dominated by SAND and GRAVEL and coarse SAND with some areas of TILL/DIAMICTON and QUATERNARY CLAY.

The SAND is more prominent in the eastern and central parts of the area with some patches of Gravel and coarse SAND to the northeast. SAND and GRAVEL and Coarse SAND are present in the western parts of the NSA1 area. Small areas of TILL/DIAMICTON are present in the western part of the area while isolated patches of QUATERNARY CLAY and SILT are found in the northern, central part of the area.

Areas of ripples, large ripples and megaripples, indicative of mobile sediments, are present across a large part of the NSA1 survey area. Areas of ripples occur mainly within the areas of GRAVEL and coarse SAND. In addition to these, sand wave areas, predominantly composed of SAND or coarse SAND and GRAVEL, are visible in the northeast and west of the survey area.

SEAFLOOR FEATURES AND CONTACTS

A total of 5021 individual seabed contacts were detected within the NSA1 survey area. They were classified as: Anchor (5), Boulders (1394), Fish Net (2588), Soft Ropes (28), Wire (6), Wrecks (10, these include known, unknown or possible wrecks)), Scour Marks (70) and Other (914). This last class mainly consists of possible Man-Made Objects that could not be placed in one of the specific debris classifications. Intermediate boulder fields are observed in the far west of NSA1. In addition, very occasional high-density boulder fields are present within the areas of intermediate density areas. Scattered boulders are almost exclusively located within the western half of the site. Within the boulder field areas, boulders >2 m have been identified. For individual boulders, boulders >1 m outside boulder fields were picked.

A total of 5540 magnetic anomalies were detected within the NSA1 survey area. 2067 are possibly related to geology, 469 of these are individual discrete anomalies, 2798 relate to existing infrastructure which correlate to 10 known cables, 181 have a linear sequence which form eight unknown linear features and 25 related to wrecks or debris from possible wrecks.

Areas of ripples, large ripples and megaripples, indicative of mobile sediments, are present across a large part of the NSA1 survey area. Larger sandwave features are almost exclusively observed on the western edge of the survey boundary and in the northeast corner of the site.

PROJECT AREA NORTH SEA 1 – GEOPHYSICAL SITE SURVEY AREA 1 (NSA1)

Evidence of trawling is found across much of the survey area.

Occasional areas of interest have been identified as possible biogenic features. These areas were assessed by a senior biologist who determined they are unlikely to be biogenic in nature. These areas maintain their biogenic classification however, in case further investigation is deemed necessary.

GEOLOGY

The NSA1 survey area is located within a complex geologic setting. The interpreted Ground Model is based on six horizons that correspond to erosive surfaces and make up the base of the seismostratigraphic units, and two reflectors interpreted to be internal reflections within units.

Reflector name	Expected Composition
H10	SAND with local variations in grain size from silty to gravelly
H20_internal	SAND with local variations in grain size from silty to gravelly
H20	SAND with local variations in grain size from silty to gravelly
H30_internal	SAND with local variations in grain size from silty to gravelly
H30	SAND with local variations in grain size from silty to gravelly
H35	Channel infill. CLAY, SILT and SAND. Organic material
H37	Channel infill. CLAY, SILT and SAND. Organic material
H40	Glacial deposit, in some area lagoonal and shallow marine depositional environment of SAND, SILT and organic matter. Only partially mapped due to the limited penetration at this depth.

SEABED AND SUB-SEABED HAZARDS

Seabed gradients	Slope angles across the site are typically very gentle (<1°), with gentle (1° to 5°) gradients found on the sides of the mobile seabed sediment and erosional features. The largest reported slope values (> 20°) coincide with features either from a wreck or from the sides of a single prominent outcrop.
Mobile seabed sediments	Mobile sediments are present frequently throughout the surveyed area. The mobile sediments comprise of ripples, megaripples, large ripples and sand waves.
Wreck	Two known wrecks were detected during the survey, correlating with the background information; Wreck 007 (S_NM_BM13_0255) was found at 388404.3 m E, 6221212.4 m N and Wreck 013, thought to be SIERRA CORDOBA (S_FR_BM08_0059) was found at 409091.6 m E, 6189131.5 m N. Four uncharted wrecks and four possible wrecks were also detected during the survey, outlined in Table 36.

PROJECT AREA NORTH SEA 1 – GEOPHYSICAL SITE SURVEY AREA 1 (NSA1)	
	Two additional contacts were detected but with low confidence. These targets are most likely debris.
Cable	Ten linear magnetometer anomalies associated with existing infrastructure were interpreted within NSA1. Three CANTAT telecom cables were not identified in the magnetometer data. Periodically, cables could be identified on the SSS and backscatter data.
Pipeline	According to available background data, there are no known pipelines in the area. No pipelines were observed in the survey area.
Buried channels and tunnel valleys	Buried channels carved out by glacial meltwater and later infilled occur throughout the site.
Possible peat	High-amplitude features occur within seismic units U30 and U35. These features are interpreted to possibly be peat accumulation.
Coarse sediments/gravel beds/boulders/tills	Coarser material, such as boulder accumulations, cobbles, and gravel lags are present in glacial deposits in the site. These are potential hazards and may constitute a constraint on drilling and other operations.
Gas features	Acoustic blanking features are observed periodically in the SBP data, most likely caused by gas accumulation from organic rich material.

Revision History

REVISION	DATE	STATUS	CHECK	APPROVAL
04	2024-03-11	For Use	DJO / DKP	KG
03	2024-02-20	For Use	DJO / DKP	KG
02	2024-01-02	Issue for Client Review	DJO / DKP	KG
01	2024-01-01	Issue for Internal Review	DJO / DKP	KG

Revision Log

DATE	SECTION	CHANGE
2024-03-11	Various	As per client comments: Deliverable_Register_DOW2030_WPC_NS1_Area1 (Rev03)
2024-02-20	Various	As per client comments: Deliverable_Register_DOW2030_WPC_NS1_Area1

Document Control

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Approval	Project Manager	Karin Gunnesson

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Abbreviations and Definitions

ASCII	American Standard Code for Information Interchange
BSB	Below Seabed
BM10	Survey Block with corresponding block number (1 to 18)
CM	Central Meridian
DDM	Denmark's Depth Model
DOW2030	Project Name: Danish Offshore Wind 2030
DTU21	Denmark Technical University 2021
DPR	Daily Progress Report
DTM	Digital Terrain Model
ENE	East-northeast
ENN	Energinet
EPSG	European Petroleum Survey Group
ESRI	Environmental Systems Research Institute, Inc.
ETRS	European Terrestrial Reference System
FME	Feature Manipulation Engine
FMGT	Fledermaus GeoCoder Toolbox
GEUS	Geological Survey of Denmark and Greenland
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRS80	Geodetic Reference System 1980
GS	Grab Sample
HiPAP	High Precision Acoustic Positioning
IHO	International Hydrographic Organisation
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LGM	Late Glacial Maximum
MAC	Mobilisation and Calibration
MAG	Magnetometer
MBBS	Multibeam Backscatter
MBES	Multibeam Echo Sounder
MMO	Man Made Object \ Marine Mammal Observer
MMS	Mobile Mapping Suite

MSL	Mean Sea Level
M/V	Motor Vessel
NNW	North-northwest
NS1	Project Area: North Sea 1
NSA1	Project Subarea: North Sea Area 1
NSA2	Project Subarea: North Sea Area 2
OI	Ocean Infinity
OWF	Offshore Wind Farm
POS MV	Position and Orientation System for Marine Vessels
POSPac	Position and Orientation System Package
PPS	Pulse Per Second
PtoP	Point to Point
QC	Quality Control
QPS	Quality Positioning Services
RMS	Root Mean Square
ROTV	Remotely Operated Towed Vehicle
RSD	Rippled Scour Depressions
SBET	Smoothed Best Estimated Trajectory
SBP	Sub-Bottom Profiler
SOW	Scope of Work
SSE	South-southeast
SSS	Side Scan Sonar
SV	Soud Velocity
SVP	Sound Velocity Profile
SVS	Sound Velocity Sensor
TFD	Time Frequency Distribution/Domain
THU	Total Horizonatal Uncertainty
TPU	Total Progagated Uncertainty
TQ	Technical Query
TSG	Template Survey Geodatabase
TVU	Total Vertical Uncertainty
TWT	Two-Way Time
USBL	Ultra Short Baseline
UTC	Coordinated Universal Time

UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
WD	Water Depth
WSW	West-southwest
WGS84	World Geodetic System 1984

1. Introduction

1.1 Project Information

Energinet have awarded Ocean Infinity (OI) the LOT 3 (WPB) and LOT 4 (WPC) geophysical site survey activities for the North Sea 1 project area (NS1) which are to be performed in 2023. The survey will be conducted in the North Sea 1 and 2 development subareas (NSA1 / NSA2), see Figure 1.

The LOT 4 (WPC) consists of a geophysical site survey which shall cover NSA1 and using the vessels M/V Northern Franklin, M/V Northern Maria and M/V Geo Ranger.

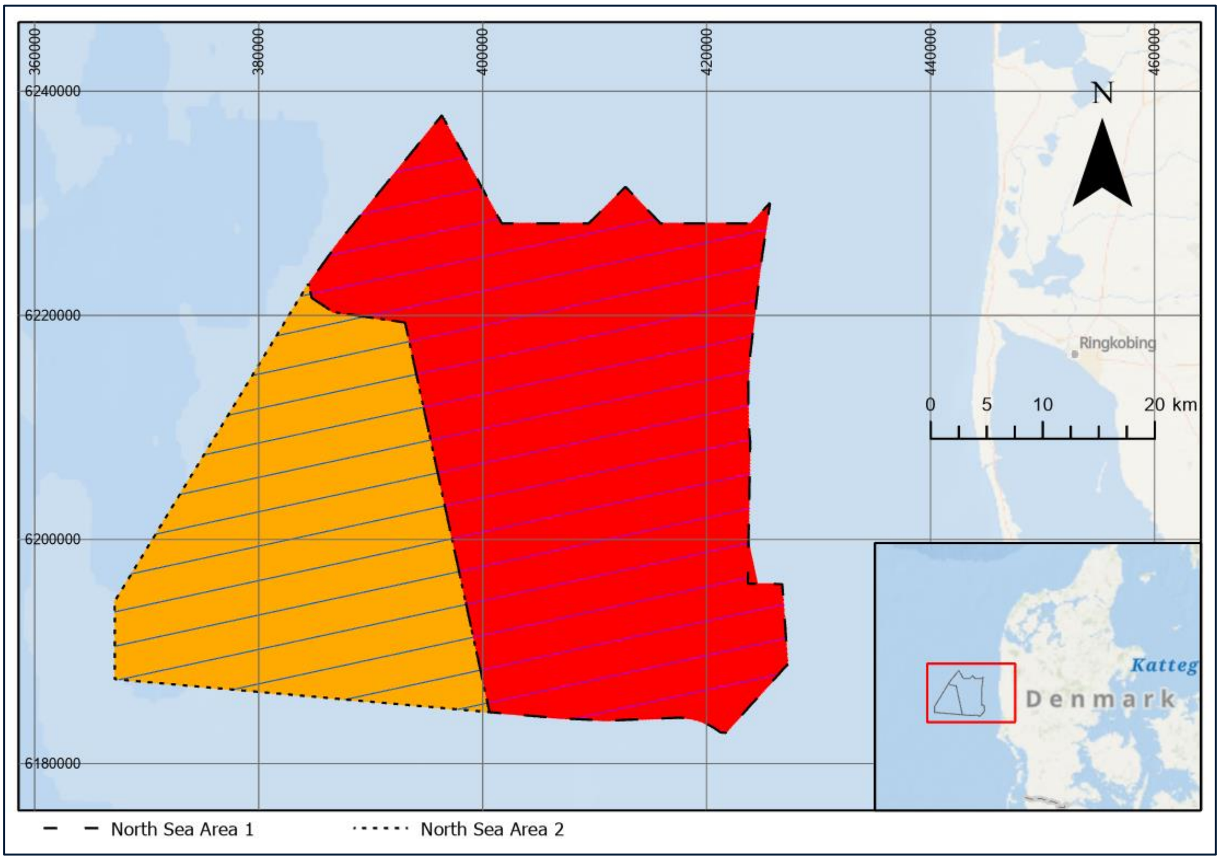


Figure 1 Overview of Project Area.

Table 1 Project details.

Client:	Energinet
Project:	Danish Offshore Wind 2030 (DOW2030)
Ocean Infinity (OI) Project Number:	104287
Survey Type:	Geophysical Site Survey
Area:	North Sea 1, Area 1, Danish Sector
Survey Period:	03 April to 17 September 2023
Survey Vessels:	Northern Franklin, Northern Maria, Geo Ranger
OI Sweden Project Manager:	Karin Gunnesson
Client Project Manager:	Jens Colberg Larsen

1.2 General Scope of Work

The project scope of work concentrates on Lot 4 (WPC) Geophysical Site Survey.

This report details the results of the Lot 4 WPC scope for Area 1.

LOT 4 Work Package C (WPC)

The survey shall ensure to have full coverage in the area of investigation. The survey must map the bathymetry, the static and dynamic elements of the seabed surface and the sub-surface geological soil layers to at least 10 m below seabed. All data acquired from the offshore investigations shall be processed, interpreted, and supplied as a number of reports, charts and a set of digital deliverables.

The purpose of the survey is that the results should be suitable for use as basis for:

- Initial marine archaeological site assessment.
- Planning of environmental investigations.
- Planning of developer's geotechnical investigations.
- Decision of foundation concept and preliminary foundation design.
- Assessment of installation conditions for foundations and inter-array cables.
- Site information enclosed in the tender for the offshore wind farm concession.

1.2.1 Deviations to Scope of Work

Deviations to the SOW are presented below, split by vessel. Concession forms for SOW deviations were implemented in July and are provided in Appendix C.

M/V Northern Franklin

During the geophysical survey there were two deviations from the original SOW (Table 2).

Table 2 Deviations from the Work Package C SOW during survey (M/V Northern Franklin).

Date	Document	Decision/Result/Conclusion
2023-06-24	104287-ENN-OI-SUR-MEM-010-FR_SSS_100_Percent_Coverage_BM07	MEMO for 100% SSS coverage in areas of pycnocline in BM07.
2023-06-24	104287-ENN-OI-SUR-MEM-011-FR_Out_of_Spec_Data_Over_Charted_Wreck_BM08	MEMO for increased MAG altitude over wreck in BM08

M/V Northern Maria

During the geophysical survey there were seven deviations from the original SOW (Table 3).

Table 3 Deviations from the Work Package C SOW during survey (M/V Northern Maria).

Date	Document	Decision/Result/Conclusion
2023-05-22	TQ-012	Sensor gap specification – Detailing allowance for gaps in the data.
2023-07-05	104287-ENN-OI-SUR-CCO-001-NM_BM11_data_gaps	Client concession form detailing approved data gaps in BM11
2023-07-07	104287-ENN-OI-SUR-CCO-002-NM_BM04_MMO_buoy	Client concession form detailing approved data gaps in BM04

Date	Document	Decision/Result/Conclusion
2023-08-06	104287-ENN-OI-SUR-CCO-003-NM_BM12_buoy	Client concession form detailing approved data gaps in BM12
2023-08-16	104287-ENN-OI-SUR-CCO-004-NM_SBP_Gaps_over_5m	Client concession form detailing SBP data gaps over 5m
2023-08-25	104287-ENN-OI-SUR-CCO-005-NM_BM13_Buoy_NordLink_Cable	Client concession form detailing approved data gaps in BM13
2023-09-01	104287-ENN-OI-SUR-CCO-006-NM_BM10_Buoy	Client concession for data gaps due to avoiding MMO buoy NS17_S in BM10.

M/V Geo Ranger

During the geophysical survey there was one deviation from the original SOW (Table 4).

Table 4 Deviations from the Work Package C SOW during survey (M/V Geo Ranger).

Date	Description	Decision/Result/Conclusion
2023-07-24	104287-ENN-OI-SUR-CCO-001-GR_BM09_MMO_Buoy_NS19_S_Data_Gap_RevA_signed	Client concession for data gaps due to avoiding MMO buoy NS19_S in BM09.

1.3 Survey Information – Geophysical Site Survey

The North Sea 1 project area (NS1) geophysical site survey work scope comprises several tasks including:

- Project Management and Administration
- Geophysical surveys (MBES, SSS, SBP, MAG)
- Grab Sampling

The site investigation covers an approximately 2200 km^2 area and was divided into two development subareas (Figure 1). Area 1 (NSA1) is approximately 1395 km^2, and Area 2 (NSA2) is approximately 805 km^2.

This report covers the geophysical survey of NSA1 with integrated grab sample data results (Appendix B).

1.4 Survey Objectives

The survey objectives for this work package were to carry out detailed mapping of the seabed surface to provide:

- Accurate bathymetric data and charts in the surveyed area.
- The morphology and natural features of the seabed surface such as mega-ripples, sand-waves, boulders, outcropping geology, seaweed and reefs.
- Possible man-made features such as wrecks, debris, fishing gear, trawl marks, anchor scars and objects of potential archaeological interests.
- Identification of features of potential conservation interest including but not limited to: sandbanks, gravel reef, cobble reef, rocky reef and biogenic reef structures.

The survey objectives for this project also included a requirement for mapping of the upper part of the subsurface in a sufficient level of detail to:

Locate structural complexities or geohazards within the shallow geological succession such as faulting, accumulations of shallow gas, buried channels, soft sediments, hard sediments, mobile sediments etc.

1.5 Purpose of Document

This report details the interpretation of the geophysical survey and grab sample results from the NSA1 survey area.

The report summarises the conditions within the survey area with regards to: bathymetry, surficial geology and seabed features, contacts and anomalies, existing infrastructure, and subsurface geology. Geo-hazard identification and interpretation has also been considered.

All data obtained from the geophysical survey and grab sample results have been correlated with each other and compared against the existing background information, in order to ground-truth the survey results.

A full list of reports is given in Table 5 (Reference Documents).

1.6 Report Structure

The results from the geophysical site survey campaign are presented in this report and includes a chart series of results. The chart series is described below in Section 1.6.1.

Attached to the report are the following appendices:

Appendix A List of Produced Charts

Appendix B Grab Sample Lab Report

Appendix C Client Concession Forms

1.6.1 Charts

The charts describe and illustrate the results from the survey. The charts include an overview chart with a scale of 1:100 000, north up charts at a scale of 1:50 000 and longitudinal profile charts with a horizontal scale of 1:20 000 and a vertical scale of 1:100.

The overview and north up charts contain background data (existing infrastructure, Exclusive Economic Zones (EEZ), 12 nautical mile zone, safety zones and wreck database) alongside survey results.

A list of all produced charts is presented in Appendix A.

Overview Chart

Shows coastlines, EEZ, large scale bathymetric features and area of investigations.

Trackline and Seabed Sampling Charts

The actual performed survey lines are presented along with seabed grab sampling positions.

Bathymetry Charts

The bathymetry is presented as a shaded relief colour image with 1 m colour interval, overlain with contour lines (1 m (minor) and 10 m (major)) with depth labels.

Backscatter Mosaic Charts

The backscatter mosaic imagery is presented.

Seabed Surface Geology Classification Charts

The surface geology is divided into 4 different classes; Sand, Gravel and Coarse Sand, Till/Diamicton, and Quaternary Clay and Silt, and are presented as solid hatches.

Seabed Surface Morphology Charts

The surface morphology is divided into 8 different classes; Ripples, Large Ripples, Megaripples, Rock Dump, Sand Waves, Erosional Depression, Disturbed Sediments, and Trawl Mark Lines. Major and minor sediment direction arrows are also shown.

Seabed Objects Charts

The SSS, MBES and magnetic contacts and linear features are presented.

Seabed Features Charts

The seabed features are divided into 13 different classes; Ripples, Large Ripples, Megaripples, Rock Dump, Sand Waves, Erosional Depression, Disturbed Sediments, Intermediate Boulder Field, High Density Boulder Field, Trawl Mark Lines, Soft Rope, Cable/Pipeline, and MAG Linear Sequence. Major and minor sediment direction arrows are also shown.

The SSS, MBES and magnetic contacts are also presented.

Sub-Seabed Geology Charts

Depth below seabed (BSB) and depth as MSL elevation for each interpreted horizon is presented as a gridded surface with contour lines and depth labels at 1 m major and 0.5 m minor intervals. Some grids with steep flanks used 2 m major and 1 m minor intervals.

Sub-Seabed Geology Profile Charts

A total of 23 profile charts shows the interpretation of the horizons and structures across 12 mainline profiles and 9 crossline profiles.

1.7 Reference Documents

The documents used as references to this report are presented in Table 5.

Table 5 Reference documents.

Document number	Title	Author
104287-ENN-OI-HSE-PRO-HAZOP	Hazard and Operability Study	OI
104287-ENN-OI-HSE-PRO-HSEPLAN	HSE Plan	OI
104287-ENN-OI-QAC-PRO-PROJMANU	Project Manual	OI
104287-ENN-OI-SCH-PRO-SCHEDULE	Time Schedule	OI
104287-ENN-OI-HSE-PRO-ERPFRANK	Emergency Response Plan - Northern Franklin	OI
104287-ENN-OI-HSE-PRO-ENFFRANK	Emergency Notification Flowchart - Northern Franklin	OI
104287-ENN-OI-MAC-PRO-FR	Mobilisation and Calibration Procedures Northern Franklin	OI
104287-ENN-OI-MAC-REP-NFRANKLIN	Mobilisation and Calibration Report Northern Franklin	OI
104287-ENN-OI-HSE-PRO-ERPMARIA	Emergency Response Plan Northern Maria	OI
104287-ENN-OI-HSE-PRO-ENFMARIA	Emergency Notification Flowchart Northern Maria	OI
104287-ENN-OI-MAC-PRO-NM	Mobilisation and Calibration Procedures Northern Maria	OI
104287-ENN-OI-MAC-REP-MARIA	Mobilisation and Calibration Report Northern Maria	OI
104287-ENN-OI-HSE-PRO-ERPGEORA	Emergency Response Plan Geo Ranger	OI

Document number	Title	Author
104287-ENN-OI-HSE-PRO-ENFRANG	Emergency Notification Flowchart Geo Ranger	OI
104287-ENN-OI-MAC-PRO-GR	Mobilisation and Calibration Procedures Geo Ranger	OI
104287-ENN-OI-MAC-REP-GEORANGER	Mobilisation and Calibration Report Geo Ranger	OI
104287-ENN-OI-SUR-REP-LOT3WPB	Survey Report – LOT 3 – Work Package B	OI
104287-ENN-OI-OPE-REP-LOT4WPC	Operations Report – LOT 4 – Work Package C	OI
Appendix 1 - Scope of Services (Version 3)	Scope of Work for Lot 4 Geophysical Survey	ENN

1.8 Area Line Plan and Cumulative Quantities

The survey line spacing and minimum parameters are detailed in Table 6.

A summary of the survey quantities is provided in Table 7.

An overview of the geophysical survey lines is shown in Figure 2.

Table 6 Survey line parameters.

Geophysical Survey Area	Number of lines	Total km	Line spacing
North Sea Area 1 (NSA1)	Main Lines: 627 Cross Lines: 18	19 952 km 458 km	70 m 3 000 m
North Sea Area 2 (NSA2)	Main Lines: 458 Cross Lines: 14	11 499 km 269 km	70 m 3 000 m

Table 7 Survey quantities summary.

Survey Quantities Summary (M/V Northern Franklin)	Accumulated Hours	Accumulated km, pcs	Total Scope (NSA1 & NSA2)
Geophysical Survey	1778:19	12,698.8 km	32,178 km
Geophysical Survey (Infill, Weather)	62:54	-	-
Geophysical Survey (Infill, Technical)	45:52	-	-
Geophysical Survey (Infill, Fisheries)	16:30	-	-
Geophysical Survey (Infill, Pycnocline)	155:17	-	-
Transit within Survey Operations	08:21	-	-
Transit Crew Change	47:35	-	-
Additional transit due to pycnoclines	05:06	-	-
Additional transit / standby due to fisheries	04:25	-	-
Waiting on Weather (Geophysical Survey)	776:36	-	-
MMO Shutdown	04:19	-	-
Breakdown Equipment	42:42	-	-

Survey Quantities Summary (M/V Northern Maria)	Accumulated Hours	Accumulated km, pcs	Total Scope (NSA1 & NSA2)
Geophysical Survey	2295:50	16,953.7 km	32,178 km
Geophysical Survey (Infill, Weather)	08:55	-	-
Geophysical Survey (Infill, Technical)	77:53	-	-
Geophysical Survey (Infill, Fisheries)	106:12	-	-
Geophysical Survey (Infill, Pycnocline)	35:17	-	-
Grab Sampling	30:18	-	-
Transit within Survey Operations	147:53	-	-
Transit Crew Change	70:07	-	-

Survey Quantities Summary (M/V Northern Maria)	Accumulated Hours	Accumulated km, pcs	Total Scope (NSA1 & NSA2)
Additional transit due to pycnoclines	06:28	-	-
Additional transit / standby due to fisheries	41:30	-	-
Waiting on Weather - Grab Sampling	27:15	-	-
Waiting on Weather (Geophysical Survey)	904:27	-	-
MMO Shutdown	09:42	-	-
Breakdown Equipment	47:31	-	-

Survey Quantities Summary (M/V Geo Ranger)	Accumulated Hours	Accumulated km, pcs	Total Scope (NSA1 & NSA2)
Geophysical Survey	353:34	2,584.2 km	32,178 km
Geophysical Survey (Infill, Technical)	09:19	-	-
Geophysical Survey (Infill, Fisheries)	21:53	-	-
Geophysical Survey (Infill, Pycnocline)	12:06	-	-
Grab Sampling	109:57	-	-
Transit within Survey Operations	177:38	-	-
Transit Crew Change	33:00	-	-
Additional transit / standby due to fisheries	01:21	-	-
Waiting on Weather - Grab Sampling	73:43	-	-
Waiting on Weather (Geophysical Survey)	338:46	-	-
Breakdown Equipment	104:45	-	-

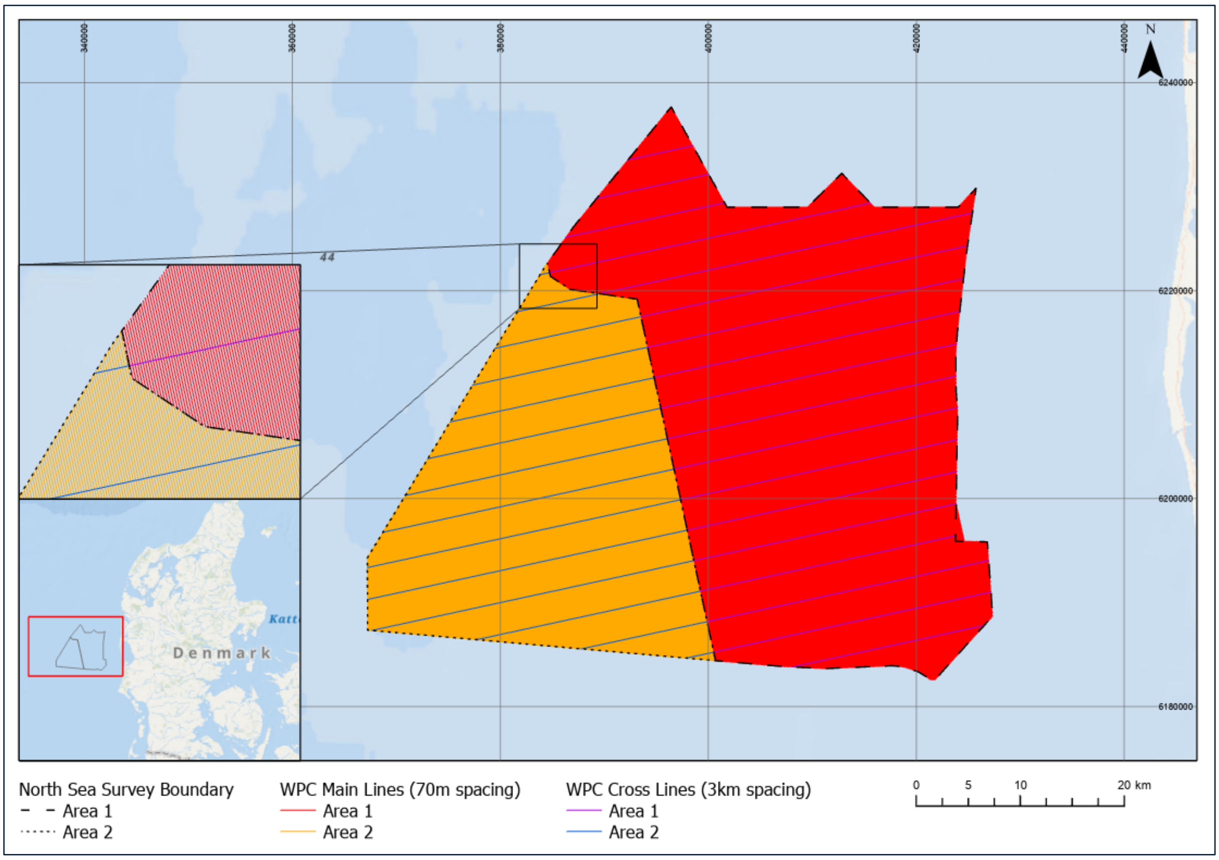


Figure 2 Survey line plan overview.

1.8.1 Survey Blocks

To facilitate survey data management and survey planning, and to allow the fishing community to plan around the survey work, NS1 survey area was divided into 18 blocks (Figure 3).

The survey blocks were also used as reporting tiles to aid in the description of specific areas.

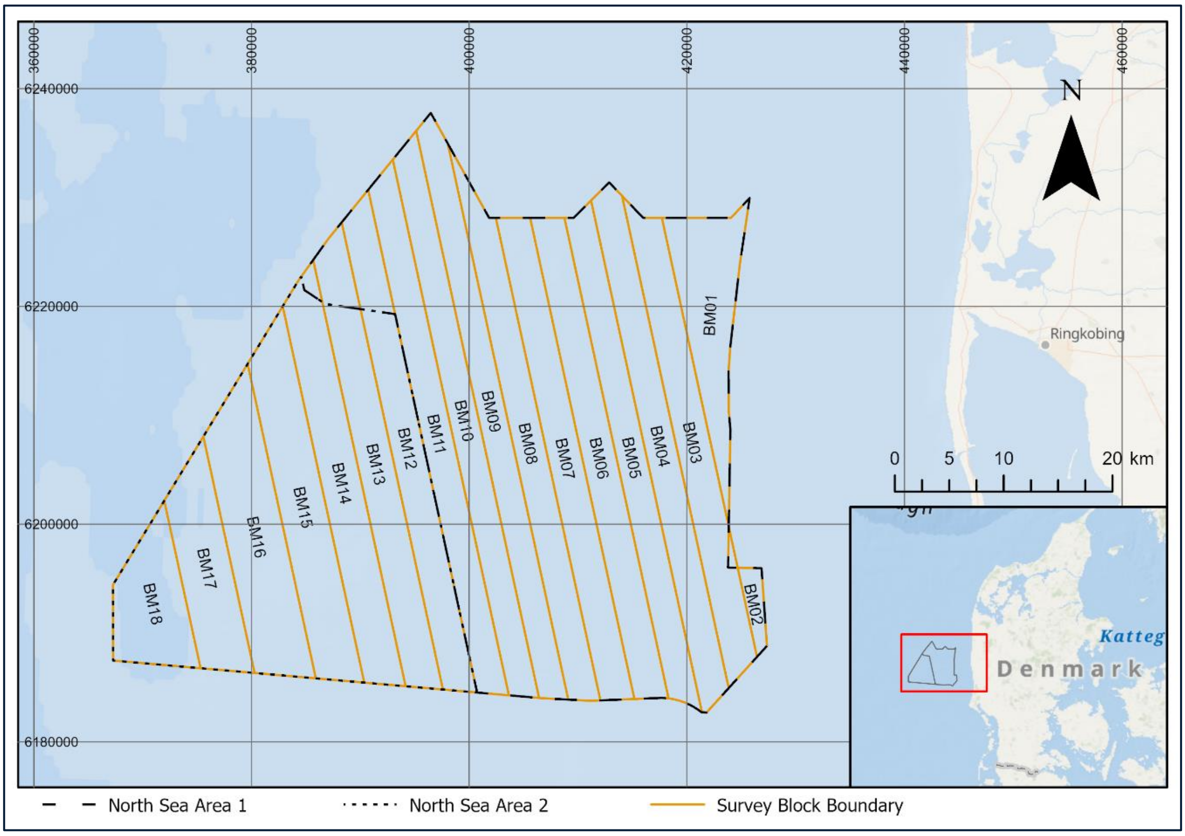


Figure 3 Overview of survey block divisions. These were also used as reporting tiles.

2. Survey Parameters

2.1 Geodetic Datum and Grid Coordinate System

2.1.1 Acquisition

The geodetic datum used for MBES, SSS and SBP during acquisition are presented in Table 8. The geodetic datum used for magnetometer during acquisition are presented in Table 9.

Table 8 Geodetic parameters used during acquisition for MBES, SSS, SBP.

Horizontal datum: WGS84	
Datum	World Geodetic System 1984 (6326)
Ellipsoid	World Geodetic System 1984 (7030)
Prime Meridian	Greenwich (8901)
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.3142 m
Inverse Flattening (1/f)	298.257223563
Unit	International metre

Table 9 Geodetic parameters used during acquisition for magnetometer.

Horizontal datum: ETRS89	
Datum	ETRS89
Ellipsoid	GRS80
Prime Meridian	Greenwich
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.3142 m
Inverse Flattening (1/f)	298.257222101
Unit	International metre

2.1.2 Processing

The geodetic datum used during processing and reporting are presented in Table 10.

Table 10 Geodetic parameters used during processing.

Horizontal datum: ETRS89	
Datum	ETRS89 (EPSG 25832)
Ellipsoid	GRS80
Prime Meridian	Greenwich
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.3142 m
Inverse Flattening (1/f)	298.257222101
Unit	International metre

2.1.3 Transformation Parameters

The transformation parameters used to covert from acquisition datum (WGS84) to processing/reporting datum (ETRS89) are presented in Table 11.

Table 11 Transformation parameters.

Datum Shift From WGS84 to ETRS89 (right-handed convention for rotation - coordinate frame rotation)	
Parameters	**Epoch 2022.5**
Shift dX (m)	0.110250
Shift dY (m)	0.067110
Shift dZ (m)	-0.132890
Rotation rX (“)	-0.003543
Rotation rY (“)	-0.014426
Rotation rZ (“)	0.025962
Scale Factor (ppm)	0.003300

Table 12 Test coordinate for datum shift.

UTM Zone	Datum	Easting (m)	Northing (m)	Latitude	Longitude
32	WGS84	-	-	54° 59' 59.998" N	13° 29 ' 59.989 " E
	ETRS89	787756.3706	61040522.2342	54° 59' 59.979" N	13° 29' 59.956" E

2.1.4 Projection Parameters

The projection parameters used for processing and reporting are presented in Table 13.

Table 13 Projection parameters.

Projection Parameters	
Projection	UTM
Zone	32 N
Central Meridian	09° 00’ 00’’ E
Latitude origin	0°
False Northing	0 m
False Easting	500 000 m
Central Scale Factor	0.9996
Units	metres

2.1.5 Vertical Reference

The vertical reference parameters used for processing and reporting are presented in Table 14.

Table 14 Vertical reference parameters.

Vertical Reference Parameters	
Vertical reference	MSL
Height model	DTU21

2.2 Vertical Datum

Global Navigation Satellite System (GNSS) tide was used to reduce the bathymetry data to Mean Sea Level (MSL) the defined vertical reference level (Figure 4). The vertical datum for all depth measurements was MSL via DTU21 MSL reduction from WGS84-based ellipsoid heights.

This tidal reduction methodology encompasses all vertical movement of the vessel, including tidal effect and vessel movement due to waves and currents. The short variations in height are identified as heave and the long variations as tide.

This methodology is very robust since it is not limited by the filter settings defined online and provides very good results in complicated mixed wave and swell patterns. Improved accuracy is also achieved, as this approach accounts for any changes in height caused by changes in atmospheric pressure, storm surge, squat, loading or any other effect not accounted for in a tidal prediction.

For the vessels M/V Franklin and M/V Northern Maria the presence of an Applanix POS MV system enabled post-processing of the vessel navigation data, which could be exported in the Smoothed Best Estimated Trajectory (SBET) format that is then applied onto the multibeam echo sounder (MBES) data. For M/V Geo Ranger the real-time solution was utilised.

All positions lie below the sea surface so are referred to in the results section of this report as ***depths***.

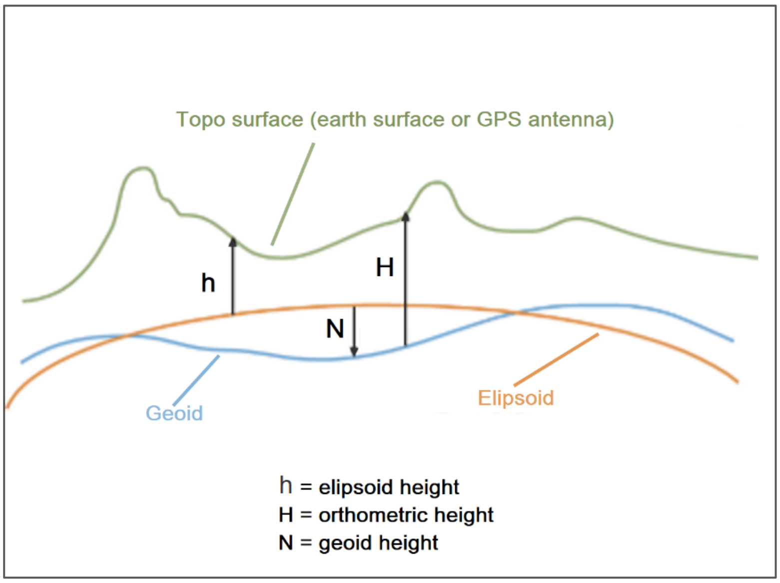


Figure 4 Overview of the relation between different vertical references.

2.3 Time Datum

Coordinated universal time (UTC) is used on all survey systems on board the vessel. The synchronisation of the vessels on board system is governed by the pulse per second (PPS) issued by the primary positioning system. All displays, overlays and logbooks are annotated in UTC as well as the Daily Progress Report (DPR) that is referred to UTC.

3. Survey Vessels

3.1 M/V Northern Franklin

Part of the geophysical site survey operation was conducted by the survey vessel M/V Northern Franklin (Figure 5). The M/V Northern Franklin is fully equipped for survey activities in water depths between 10 - 250 m.

The vessel equipment is shown in Table 15. The ROTV equipment is shown in Table 16.

A summary of the spatial accuracies is presented in Table 17.

For full details of the specification and operational performance see the WPC Operations Report referenced in Table 5.

Figure 5 M/V Northern Franklin.

Table 15 M/V Northern Franklin equipment.

INSTRUMENT	NAME
Primary Positioning System	Applanix POS MV 320 with C-Nav 3050 with C-NavC^2 corrections on the SF2 service
Secondary Positioning System	C-Nav 3050 using C-NavC^2 corrections on the SF1 service
Primary Gyro and INS System	Applanix POS MV 320
Secondary Gyro and INS System	iXblue GAPS
Underwater Positioning System	iXblue GAPS
Survey Navigation System	QPS QINSy v9.4
Surface Pressure Sensor	Vaisala Pressure Sensor
Pressure Sensor	Combined Valeport MiniSVS-P hull-mounted at the MBES transducers
Sound Velocity Sensor	Valeport SVX2 Real-time SVS Valeport MiniSVS-P, hull-mounted at the MBES transducers
Multibeam Echo sounder	Kongsberg EM2040D (200-400 kHz)
Sub-bottom profiler	Innomar Medium 100
Grab sampler	Day grab
PAM	Seiche towed PAM (SIEM111T)

Table 16 ROTV equipment, M/V Northern Franklin.

INSTRUMENT	NAME
ROTV	MacArtney FOCUS 2
USBL Transponders	IXblue MT8
Primary Gyro and INS System	IXBLUE ROVINS
Sound Velocity and Pressure Sensor	Valeport MiniSVS&P
Altimeter	Kongsberg 1007
Side Scan Sonar	Edgetech 2200 MP (300/600KHz)
Magnetometer	Geometrics G882

Table 17 Summary of accuracy of positioning systems, M/V Northern Franklin.

SSS (m)	SBP (m)	MAG (m)	MBES Patch Test			GPS		SVP (ms^{-1})
			Pitch (Degree)	Roll (Degree)	Yaw (Degree)	Static (m)	Dynamic (m)	
0.64	0.25	1.20	PRT: -0.22 STBD: -0.22	PRT: -33.87 STBD: -34.52	PRT: 180.43 STBD: 180.43	0.03 (E) -0.02 (N)	-0.02 (E) 0.02 (N)	0.04

3.2 M/V Northern Maria

Part of the geophysical site survey operation was conducted by the survey vessel M/V Northern Maria (Figure 6). The M/V Northern Maria is fully equipped for survey activities in water depths between 10 - 250 m.

The vessel equipment is shown in Table 18. The ROTV equipment is shown in Table 19.

A summary of the spatial accuracies is presented in Table 20.

For full details of the specification and operational performance see the WPC Operations Report referenced in Table 5.

Figure 6 M/V Northern Maria.

Table 18 M/V Northern Maria equipment.

INSTRUMENT	NAME
Primary Positioning System	Applanix POS MV 320 with Fugro Starpack G2 Corrections
Secondary Positioning System	Fugro Starpack
Primary Gyro and INS System	Applanix POS MV 320
Underwater Positioning System	Kongsberg HiPAP 502
Survey Navigation System	QPS QINSy
Multibeam Echo sounder	Kongsberg EM2040D (200-400 kHz)
Sub-bottom profiler	Innomar Medium
Sound Velocity Sensor	Valeport SVX2
Grab sampler	Day grab
PAM	Seiche towed PAM (SIEM111T)

Table 19 ROTV equipment, M/V Northern Maria.

INSTRUMENT	NAME
ROTV	MacArtney FOCUS 2
USBL Transponder	Kongsberg cNODE
Primary Gyro and INS System	IXBLUE ROVINS
Pressure Guage	Valeport MiniSVS&P
Altimeter	Kongsberg 1007

INSTRUMENT	NAME
Side Scan Sonar	Edgetech 2200
Magnetometer	Geometrics G882

Table 20 Summary of accuracy of positioning systems, M/V Northern Maria.

SSS (m)	SBP (m)	MAG (m)	MBES Patch Test			GPS		USBL St.Dev (m)	SVP (ms-^{1})
			Pitch (Degree)	Roll (Degree)	Yaw (Degree)	Static (m)	Dynamic (m)		
0.56	1.10	0.85	PRT: 0.24 STBD: -0.27	PRT: -33.71 STBD: 34.22	PRT: 179.52 STBD: 180.37	-0.09 (E) 0.00 (N)	0.06 (E) 0.06 (N)	0.43 (E) 0.50 (N)	0.06

3.3 M/V Geo Ranger

Part of the geophysical site survey operation was conducted by the survey vessel M/V Geo Ranger (Figure 7). The M/V Geo Ranger is fully equipped for survey activities in water depths between 10 - 250 m.

The vessel equipment is shown in Table 21. The ROTV equipment is shown in Table 22.

A summary of the spatial accuracies is presented in Table 23.

For full details of the specification and operational performance see the WPC Operations Report referenced in Table 5.

Figure 7 M/V Geo Ranger.

Table 21 M/V Geo Ranger equipment.

Equipment	Model
Primary Positioning System	C-Nav 3050 with C-Nav C2 corrections on the SF2 service
Secondary Positioning System	Trimble SPS855 with Fugro Seastar G4+ corrections

Equipment	Model
Heading/Motion Sensor	iXblue HYDRINS III
USBL	Kongsberg HiPAP 502
Hull Sound Velocity Probe	Valeport miniSVS
Transponders	Kongsberg cNODE MiniS transponder
Sound Velocity Profiler	Valeport SVX2
Multibeam Echosounder	Kongsberg EM2040 Dual Head (EM2040D) (200-400 kHz)
Parametric Sub-bottom Profiler	Innomar Medium 100

Table 22 ROTV equipment, M/V Geo Ranger.

Equipment	Model
Primary Positioning and INS System	iXblue ROVINS
Altimeter	Kongsberg 1007
USBL Transponder	Kongsberg CNODE minis omnidirectional
Sound Velocity Sensor	Valeport miniSVP
Side Scan Sonar	EdgeTech 2200 300/600 kHz
Magnetometer (towed)	Geometrics G882

Table 23 Summary of accuracy of positioning systems, M/V Geo Ranger.

SSS (m)	SBP (m)	MAG (m)	MBES Patch Test			GPS		USBL St.Dev (m)	SVP (ms-¹)
			Pitch (Degree)	Roll (Degree)	Heading (Degree)	Static (m)	Dynamic (m)		
0.28	0.25	1.09	PORT: -- 0.39° STBD: -0.39°	PORT: - 40.18° STBD: 39.71°	PORT: 178.135° STBD: 179.145°	0.01 (E) -0.01 (N)	0.01 (E) 0.02 (N)	0.08 (E) 0.10 (N)	0.12

3.4 Operational Summary

This section provides a summary of the operations during the geophysical site survey of NS1.

For complete operational, QHSE and positioning accuracies details see the Operations Report WPC referenced in Table 5.

A summary of the survey tasks performed are presented in Table 24, Table 25 and Table 26.

Table 24 Survey tasks – M/V Northern Franklin.

TASK	DATE	DESCRIPTION
Mobilisation	2023-05-06 – 2023-05-07	Mobilisation alongside Esbjerg, Denmark.
Calibrations and verifications	2023-05-06 – 2023-05-08	Alongside Esbjerg, Denmark. In block BM05 over a shipwreck and exposed cable.
Geophysical Survey	2023-05-08 – 2023-09-12	Geophysical survey operations.

TASK	DATE	DESCRIPTION
Demobilisation	2023-09-12	Demobilisation alongside Esbjerg, Denmark.

Table 25 Survey tasks – M/V Northern Maria.

TASK	DATE	DESCRIPTION
Mobilisation	2023-04-03 – 2023-04-03	Mobilisation alongside Eemshaven, Netherlands.
Calibrations and verifications	2023-04-03 – 2023-04-06	Alongside Eemshaven and 2 offshore locations in survey area.
Geophysical Survey	2023-04-06 – 2021-09-11	Geophysical survey operations.
Grab Samples	2023-09-11 – 2023-09-16	Grab sample operations.
Demobilisation	2023-09-16 – 2023-09-17	Demobilisation alongside Esbjerg, Denmark.

Table 26 Survey tasks – M/V Geo Ranger.

TASK	DATE	DESCRIPTION
Mobilisation	2023-06-13 – 2021-06-15	Mobilisation alongside Esbjerg, Denmark.
Calibrations and verifications	2023-06-15 – 2023-06-17	Alongside Esbjerg, offshore wreck location and third-party cable.
Geophysical Survey	2023-06-17 – 2023-07-24	Geophysical survey operations.
Demobilisation	2023-07-24	Demobilisation alongside Esbjerg, Denmark.
Grab Samples	2023-08-24 – 2023-09-11	Grab sample operations.
Demobilisation	2023-09-11	Demobilisation alongside Great Yarmouth, UK.

4. Data Processing and Interpretation Methods

4.1 Bathymetry

The objective of the processing workflow is to create a Digital Terrain Model (DTM) that provides the most realistic representation of the seabed with the highest possible detail. The processing scheme for MBES data comprised two main scopes: horizontal and vertical levelling in order to homogenise the dataset, and data cleaning to remove outliers.

The processing of the MBES data was performed in Caris HIPS (M/V Franklin and M/V Northern Maria) and in Qimera (M/V Geo Ranger).

For M/V Franklin and M/V Northern Maria a post-processed navigation solution was applied in the form of a Smoothed Best Estimate of Trajectory (SBET). The SBET was created by using post-processed navigation and altitude derived primarily from the POS MV Inertial Measurement Unit (IMU) data records. This data is processed in POSPac MMS and then applied to the project in Caris HIPS.

For M/V Geo Ranger the real-time positioning (C-Nav with C2 corrections) was utilised, since a post-processing solution was not possible with the equipment installed.

After the post-processed position and error data is applied, GPS vertical adjustment is computed using DTU21 data model to reduce the depths to MSL.

Several stages have been performed in the processing of the bathymetry data. These can be summarised as;

- Importation of Raw MBES data; Kongsberg.all into Caris HIPS and Qinsy.db into Qimera.
- MBES data was then corrected and compensated for the variations in sound velocity, ray bending, and other environmental/atmospheric effects.
- Post-processed navigation was applied to the data.
- Depths reduced to the project specified vertical datum.
- A DTM was created in Caris HIPS/Qimera at the project specified resolution to undertake the next stage of processing.
- The MBES data underwent iterative analysis and corrective measures to ensure that all per definition outliers are flagged as rejected.
- This used both manual editing and the use of analytical algorithms such as customisable spline filters and automatic de-spiking, followed by manual verification of the affected area to ensure the survey objective has been met.
- The MBES data was then reviewed against the survey specifications to ensure that it has met the project criteria.
- Required products were then exported from Caris HIPS/Qimera for further use in other software such as NaviModel, Feature Manipulation Engine (FME) or ArcGIS.

The workflow diagram for MBES processing is shown in Figure 8.

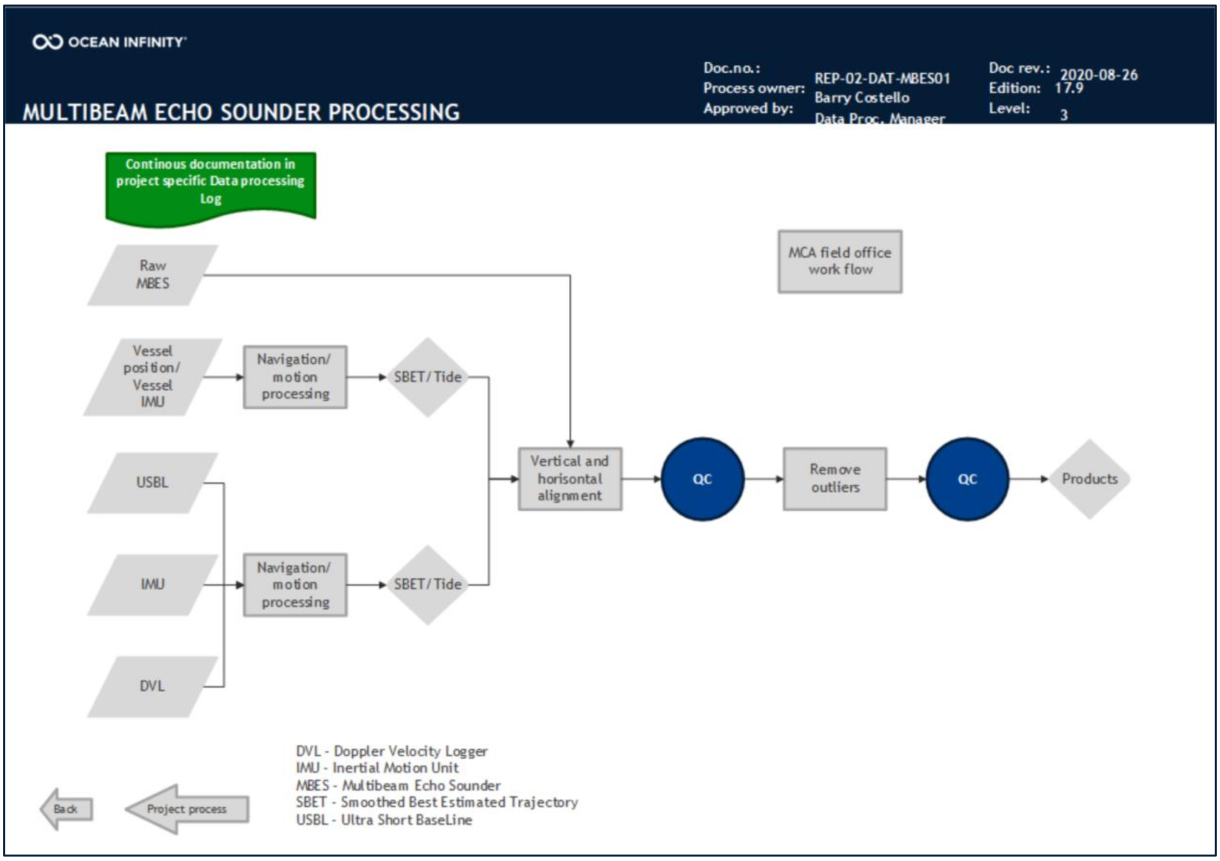


Figure 8 Workflow MBES processing.

Files exported after processing:

- Un-gridded soundings of all blocks and sub blocks (all accepted x,y,z values in ASCII format).
- Gridded average depth soundings of all blocks and sub blocks (x,y,z values) in 25 cm, 1 m and 5 m sizes.
- Vessel Tracks of all utilised survey lines in the data. (For use in ArcGIS).
- Gridded Total Horizonal Uncertainty (THU) soundings (x,y,THU values) at 1 m resolution from all survey blocks.
- Gridded Total Vertical Uncertainty (TVU) soundings (x,y,TVU values) at 1 m resolution from all survey blocks.

In the final steps FME was used to generate products for delivery. All gridded ASCII data were tiled and renamed following a 10 km squared UTM grid. The lower left corner of each grid cell was used to name the gridded tiles with the first three numbers of the easting coordinate and the first four numbers of the northing coordinate. E.g. 360_6180_MBES_AVE_1m (EEE_NNNN_MBES_AVE_1m).

Once all gridded files have been tiled in FME all gridded ASCII tiles are also converted to into 32-bit floating GeoTIFFs for import use in ArcGIS.

Multibeam files converted and exported through FME:

- All gridded ASCII files as named according to UTM grid.
- All exported ASCII UTM tiles as 32 -bit floating point tiffs.

4.2 Backscatter

Backscatter is a term used to describe the reflection of a sound wave off the seafloor or other underwater structures. In the context of multibeam sonar, backscatter refers to the strength of the returned echoes that are captured by the sonar system. These echoes can provide information about the composition and texture of the seafloor.

Post processing of backscatter data is performed in QPS software FMGT (Fledermaus Geo Coder Toolbox). The process involves normalizing the recorded multibeam backscatter (MBBS) data to minimize variations in intensity due to factors like vessel movement or the angle of the sound waves. The normalized values for each ping are then combined into a raster with a specific resolution chosen by the user, typically matching the resolution used for the bathymetric data. Survey lines that run perpendicular to the main survey line direction are excluded to reduce the presence of artefacts. Processing backscatter is a very CPU intensive task, so each survey block was processed individually. If multiple vessels have performed survey within the same block boundary, they have been processed within the same FMGT project.

FMGT is utilizing a scale ranging from minimum -70 to maximum 10 to capture the full spectrum of backscatter intensity values. While this comprehensive scale provides detailed information, it is typical to adjust the presentation scale to a narrower range of approximately -40 to 5 for enhanced visual clarity and interpretability. However, the delivered files always contain the full range of the collected data. With the data tiled for delivery it means that the full range of each tile can vary since they are only snippets of the complete data set.

All backscatter data was built as a 25 cm mosaic and exported as 32-bit floating GeoTiffs. Final tiffs will be imported and stored in an ESRI file geodatabase as a deliverable.

During the delivery phase of the project, QPS released a new version of FMGT which greatly improved the handling of .KMALL files. Older versions tended to speckle the finished product and this new version deals with these issues and improves the visual data quality.

Several stages have been performed in the processing of the backscatter data. These can be summarised as:

- Raw data from the Multibeam (Kongsberg .all) is imported directly into the FMGT 7.10 software.
- Raw data from the Multibeam (Kongsberg .kmall) is imported directly into the FMGT 7.11 software.
- Each block was processed individually and generated into 25 cm resolution mosaics.
- Mosaics are exported as XYi ASCII data files with intensity values ranging from -70 to 10.
- FME is used to reproject XYi files to the project coordinate system.
- FME is used to convert reprojected files to 32-bit floating-point tiff files and make them into tiles.
- Tiff tiles are imported to ArcGIS for delivery.

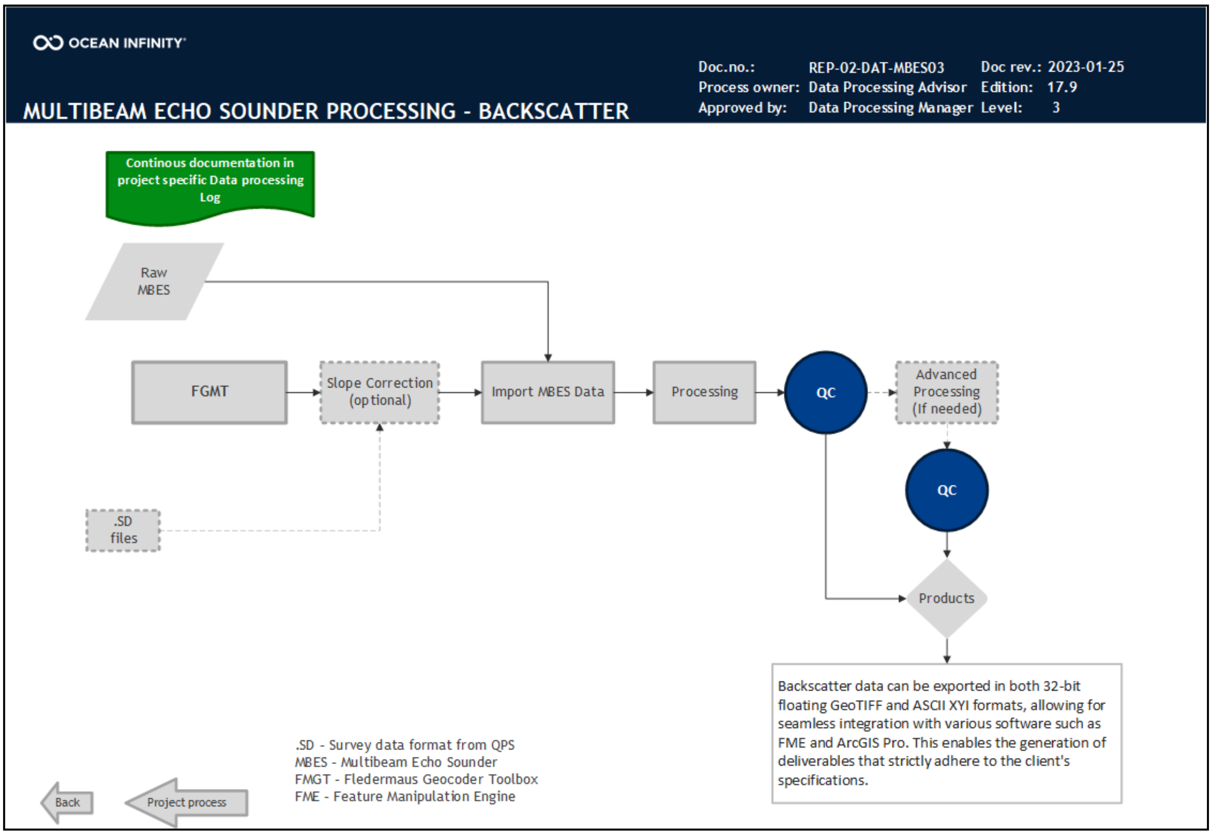


Figure 9 Workflow MBBS processing.

4.3 Side Scan Sonar

SSS processing and interpretation was conducted within SonarWiz (V7.10.02). Prior to importing raw SSS JSF files the water sound velocity at towing depth was confirm and updated within the SonarWiz. The raw SSS data was then imported into SonarWiz without the application of any gains, and the following QC/processes were conducted:

Navigation data QC'd and any occasional spikes removed.

Seabed auto tracked, QC'd and manually adjusted if necessary.

EGN (Empirical Gain Normalization) gain was applied to the data to show data throughout the entire range with good resolution on contacts and to enhance seabed sediment contrasts and seabed features.

SSS data QC'd against MBES data by locating features/contacts clearly distinguishable in both data sets and comparing appearance and position.

Coverage QC'd and any gaps flagged and infilled to meet client coverage requirements.

The SSS processing workflow is outlined in Figure 10, Figure 11 and Figure 12.

The processing was conducted with the following objectives:

- To classify seabed surface sediments
- To classify mobile bedforms and other potential hazards
- To identify natural and anthropogenic seabed features
- To detect contacts
- To detect cables and pipelines

The processing was conducted to identify and locate any man-made or natural objects on the seabed larger than 0.5 m and so, the SSS lines were reviewed in digitizing mode and any contacts > 0.5 m were picked. These were then correlated with MBES data and MAG anomalies to assign a confidence level following the classification in Table 27. Wrecks/cables were correlated to existing databases. Correlation with MAG anomalies were done using a 5 m radius through an FME routine.

Table 27 SSS Contact interpretation confidence level.

CONFIDENCE	CLASSIFICATION
HIGH	SSS contact observed on two or more SSS lines and detected in multiple sensors. It is well resolved and there is high confidence in the measurements made.
MEDIUM	SSS contact observed on multiple lines. Target can be resolved to satisfactory resolution and there is medium confidence in the measurements made.
LOW	Target is not well resolved or visible only on one SSS line. Low confidence in the measurements made.

Finally, SSS files were arranged so the best available data was uppermost, nadir transparency was applied, and mosaics exported.

The interpretation of SSS geo-boundaries was conducted within AutoCAD software. For digitisation of geo-boundaries, Backscatter images and SSS mosaics were loaded into AutoCAD and line and polygon features mapped. Seabed sediment classifications were also reconciled against the geotechnical grab sample (GS). Interpretations were QC'd and finalised by a Senior Geologist.

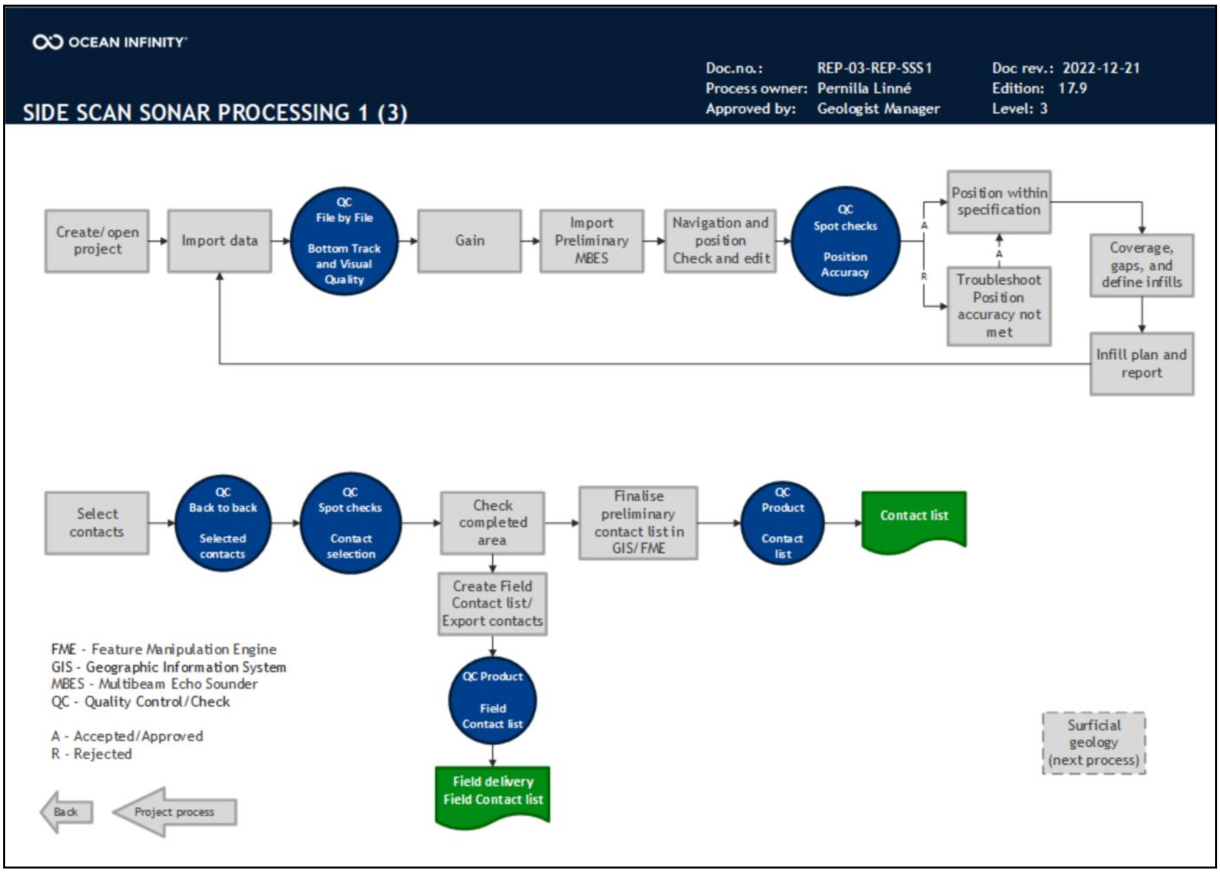


Figure 10 Workflow side scan sonar processing (1/3).

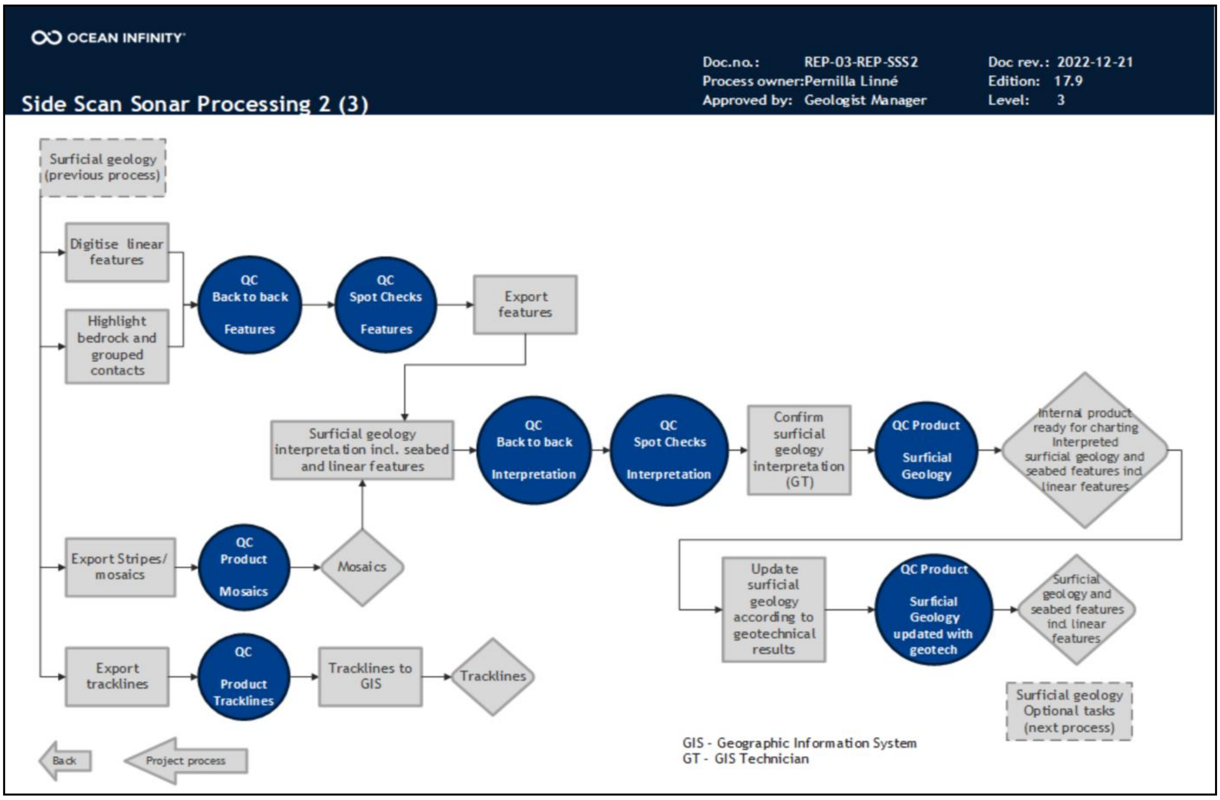


Figure 11 Workflow side scan sonar processing (2/3).

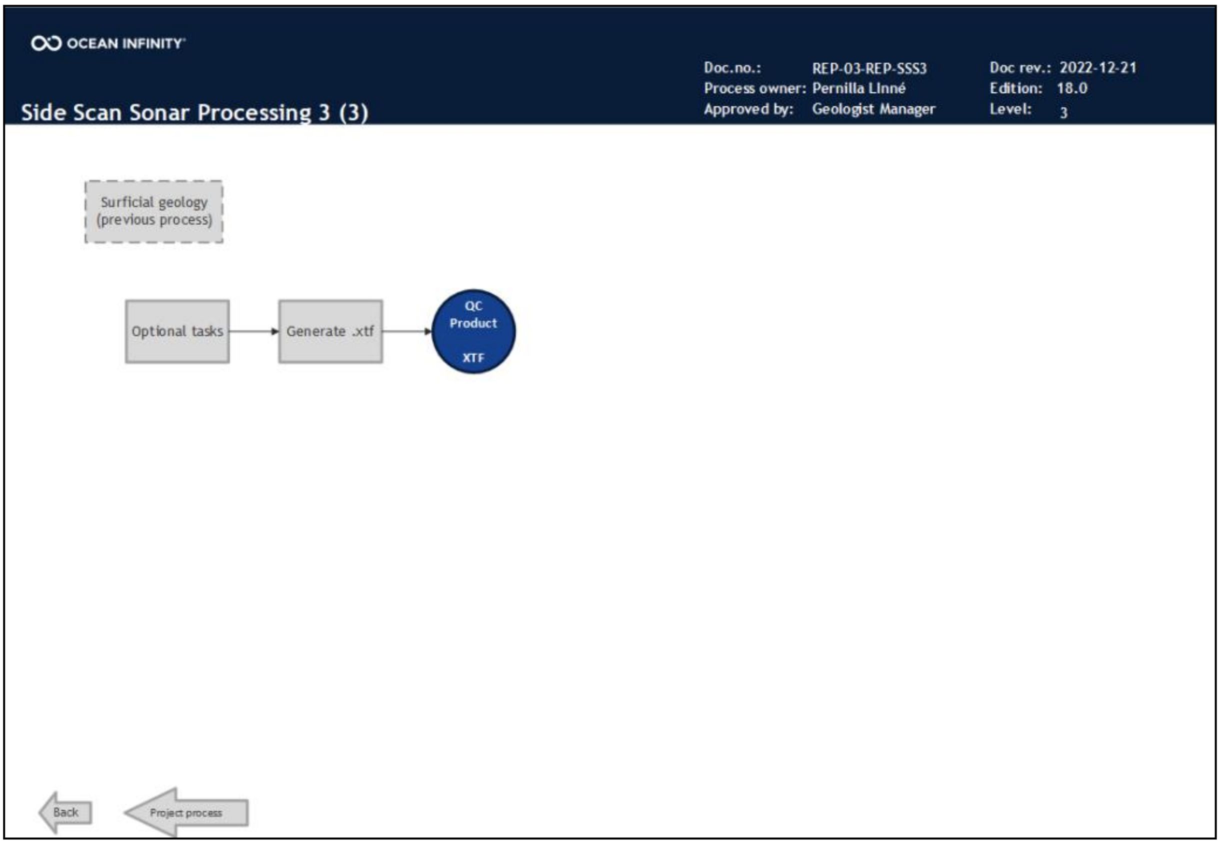


Figure 12 Workflow side scan sonar processing (3/3).

4.4 Sub-Bottom Profiler

Prior to import, the SBP data files were converted from SES3 format to SGY format using an in-house software; OI GeoTools. The conversion software corrects the navigation and applies vertical corrections to the data with the application of an SBET (Smoothed Best Estimate Trajectory) exported from PosPAC. The SGY files were then imported into RadExPro for signal processing. The seabed was auto tracked and then quality checked and manually adjusted, if required. Positional accuracy was verified during the MAC by using MBES data to locate features clearly distinguishable in both data sets and comparing the positions. Within RadExPro the processing flows were designed to improve the quality and resolution of the data by removing noise and enhancing the primary signal. In general, the signal processing flow applied to the data was:

- Burst noise removal
- TFD noise attenuation
- Source signature deconvolution
- Butterworth filtering
- Amplitude correction
- Amplitude recovery
- 2D spatial filter
- Export in standard SGY

Visual QC was performed before and after each processing step to check:

- The natural continuity of geological units was preserved
- Creations of artefacts which could mislead the interpretation process
- Suppression and/or removal of all kinds of noise without compromising the true signal

Another in-house software, OI PostProc GeoTools, was then used to write the final processed ASCII textual header to all SGYs. This program was also used to export corrected instrument tracklines, high resolution images of each SGY and conduct the depth conversion. The depth conversion is executed using water sound velocities acquired on the vessel. SVP data is loaded into the software to calculate the mean harmonic sound speed in the water, and then a layer-cake velocity is used for the sediment. The velocity value for the sediment was 1600 m/s.

OI PostProc GeoTools exports three final SGYs; time domain with corrected ASCII header, depth domain and an interval velocity SGY. All three of these SGYs are loaded into Kingdom Suite using Seismic Direct. Geological interpretation is then carried out on the data in the time domain, and later converted to the depth domain using the interval velocity SGY.

The general workflow of the SBP processing is outlined in Figure 13 and Figure 14.

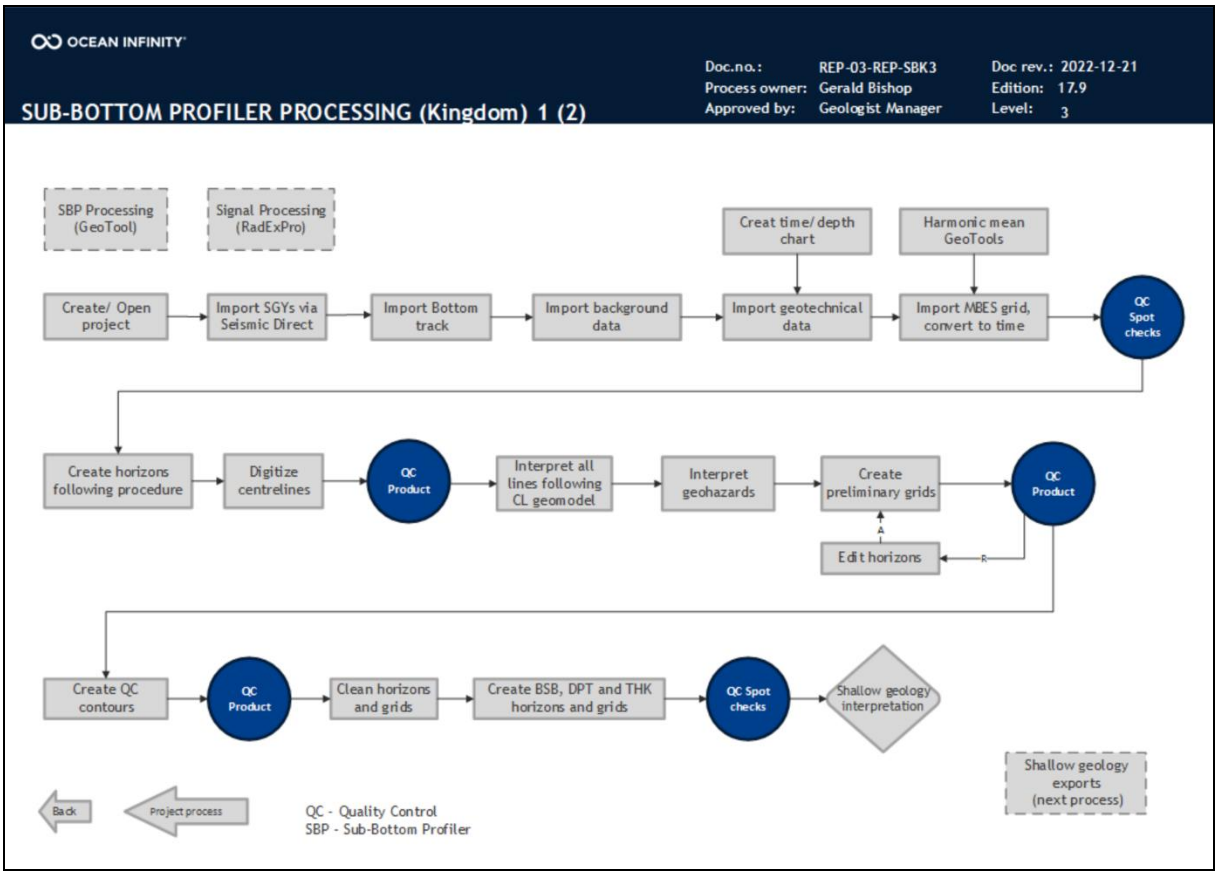


Figure 13 Workflow SBP processing (1/2).

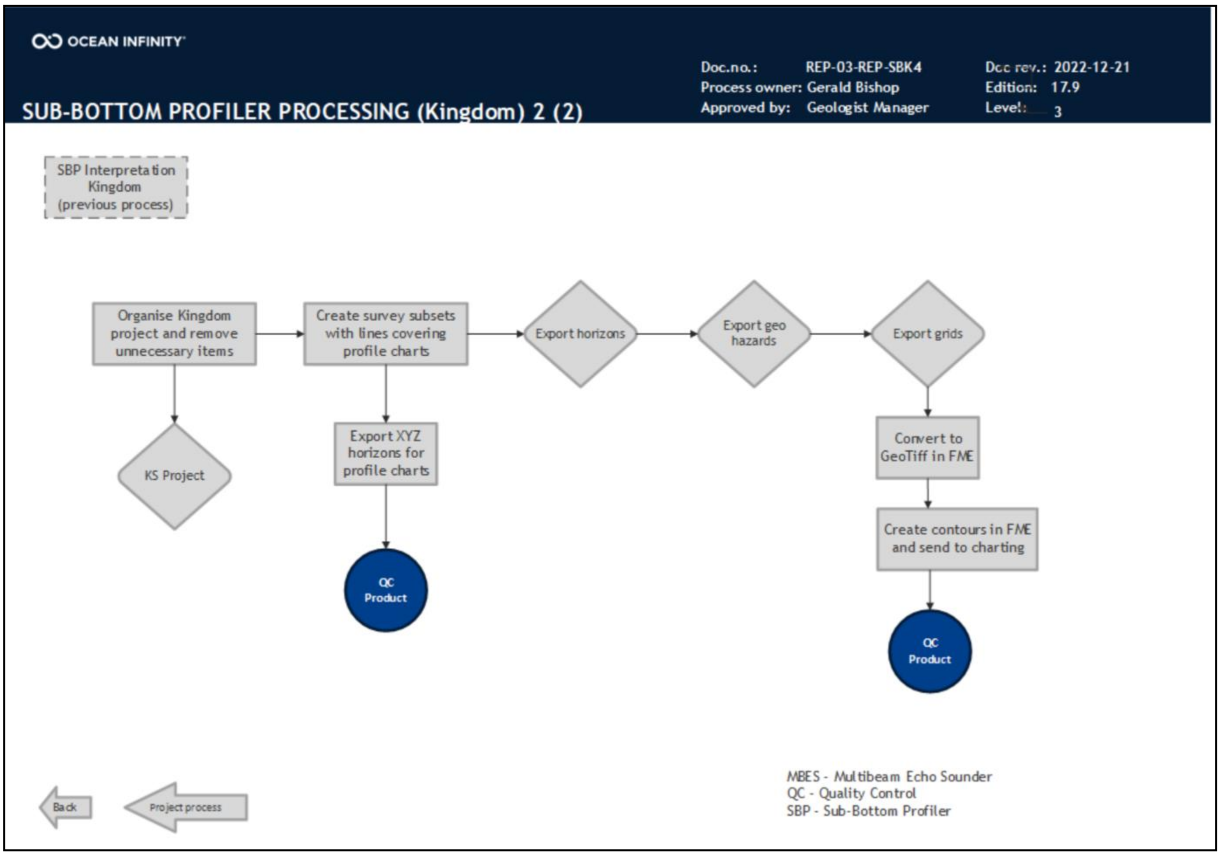


Figure 14 Workflow SBP processing (2/2).

4.5 Magnetometer

MAG data was processed and interpreted within Oasis Montaj software.

Navigation is despiked by removing outliers through a set distance from the navigational trend. Following this, a manual quality check is performed, and additional spikes are removed as needed. Small gaps are interpolated, and bigger navigational gaps are flagged for infill. 100 samples are interpolated: at 4 knots survey speed with a sample rate of 10 Hz, approximately 20m is the maximum interpolation distance. Once the navigation has been despiked a small rolling statistic smoothing filter is applied.

Altitude, depth, and motion is despiked to remove outliers that vastly contradict the mean data value. Following this, a manual check is performed, and additional spikes removed as needed. Once despiked a small rolling statistic smoothing filter is applied for each sensor.

The raw MAG data was de-spiked using a pre-set cut off value of 43,000 nT and 55,000 nT to remove occasional spikes. To generate the regional background field, a series of four filters were used. The regional background field was then subtracted from the total field to generate the residual field.

Applied filters to generate background:

Non-linear filter 1; Width = 110, Tolerance = 1.8

Non-linear filter 2; Width = 42, Tolerance = 1.0

Non-linear filter 3; Width = 12, Tolerance = 0.25

Non-linear filter 4; Width = 7, Tolerance = 0.17

Example of the filter result can be seen in Figure 15 for Northern Franklin, Figure 16 for Northern Maria and Figure 17 for Geo Ranger.

The same set of filters were used over the whole dataset to remove the regional background field.

The final magnetic data is based on the final navigation. Parts where altitude or noise level are above threshold the data is masked in final navigation (Easting2, Norting2 in MAG measurement 'raw' CSV). The final easting and northing are used for all grids and the picking of anomalies.

No altitude correction has been performed on the magnetic data set.

Each file was individually studied for anomalies. The criteria for magnetic anomalies are 10 nT (peak to peak, PtoP). However, clear anomalies related to existing infrastructure below the threshold have also been picked.

Once an anomaly was identified, additional sensor information (anomaly statistics, altitude, depth, motion and quality) was analysed to determine the confidence of the anomaly and ensure no false anomalies were picked. Once an anomaly was confirmed to be real the location was added to a database and the anomaly's amplitude and wavelength was manually measured. Once completed, each picked anomaly was individually Quality Checked to confirm stored values.

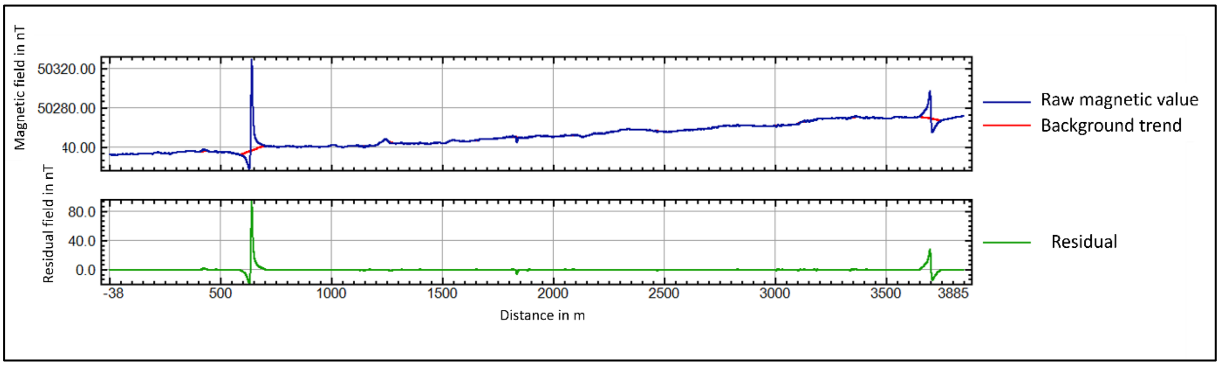


Figure 15 Data example for Northern Franklin from BM07.

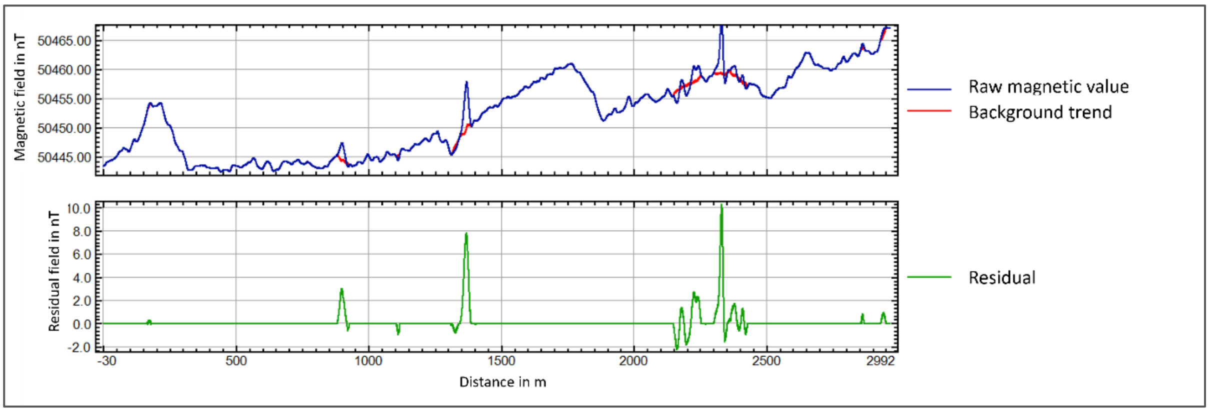


Figure 16 Data example for Northen Maria from BM04.

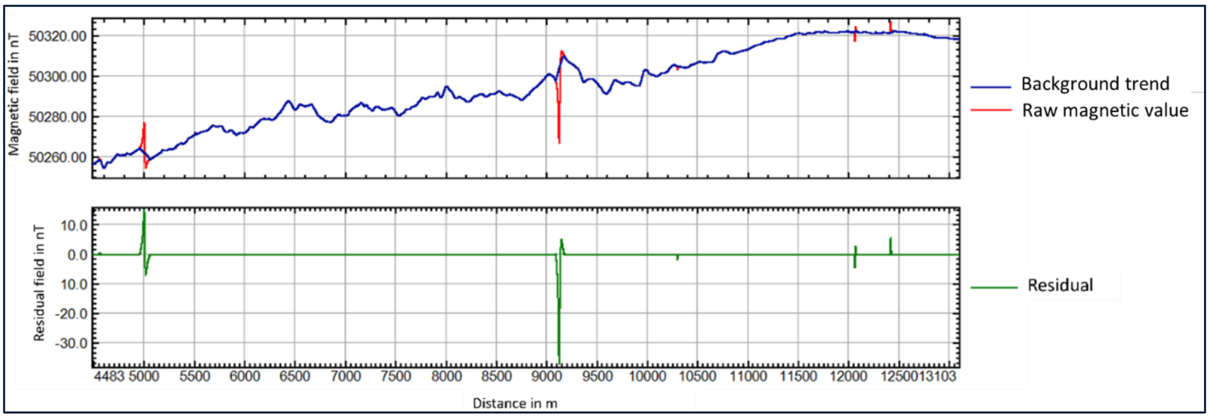


Figure 17 Data example for Geo Ranger from BM09.

The general workflow of the MAG processing is outlined in Figure 18.

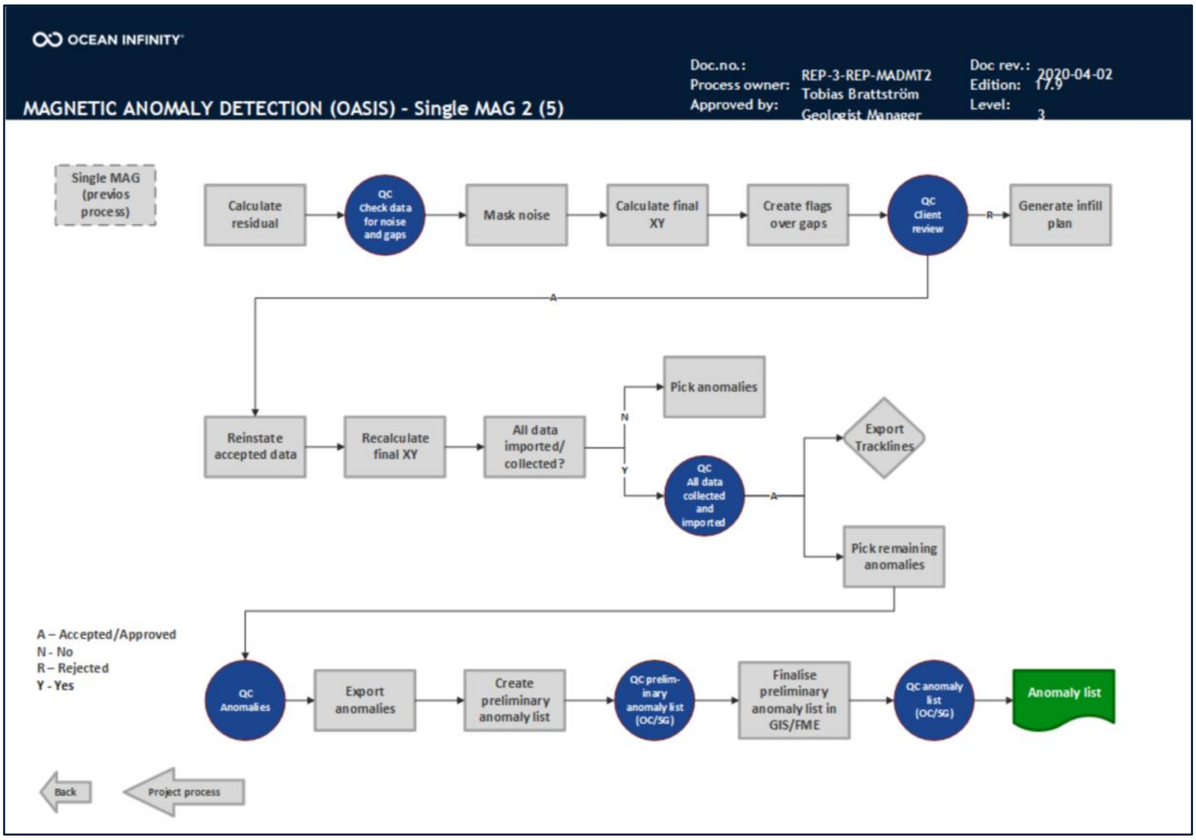


Figure 18 Workflow MAG processing.

5. Processed Data Quality

5.1 Bathymetry Data

Overall, the processed MBES bathymetry data meets the required specifications. The total horizontal (Figure 19) and vertical (Figure 20) uncertainties of the soundings data were, for the vast majority of the NSA1 survey area, within acceptable tolerance. The 'Uncertainty' estimate characterises the range of values within which the true value of a measurement is expected to lie as defined within a particular confidence level. The project specification required that the horizontal and vertical uncertainty of the vessel position should be less than 0.5 m (95%). Although no Total Propagated Uncertainty (TPU) values were specified (where all contributing measurement uncertainties are calculated for each sounding), the IHO Special Order calculation was used as a reference. This suggests a Total Horizontal Uncertainty (THU) of 2 m, and a Total Vertical Uncertainty (TVU) range of between 0.26 (at 10 m WD) to 0.39 (at 40 m WD). The uncertainty values for each sounding are calculated within the processing software based on equipment specifications and RMS values derived from post-processing the navigation (within POSPac MMS). It should be noted that for the M/V Geo Ranger data, real-time 'a priori' values are utilised within Qimera, as no navigation post-processing was applied. A higher derived value merely indicates the degree of uncertainty associated with the data, rather than the data (i.e. the sounding position and depth) being incorrect. Examples of the M/V Geo Ranger THU and TVU ranges are presented in Figure 21 and Figure 22 respectively.

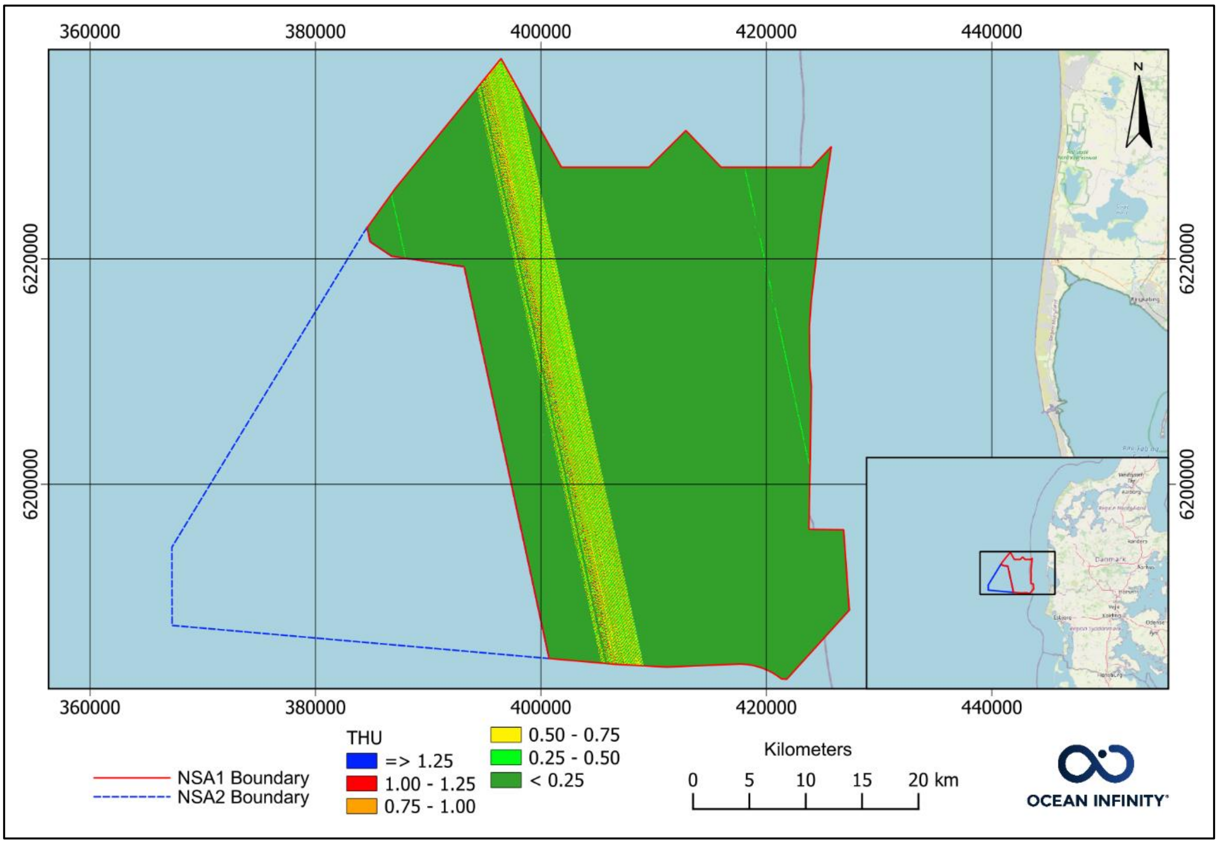


Figure 19 Total Horizontal Uncertainty - NSA1.

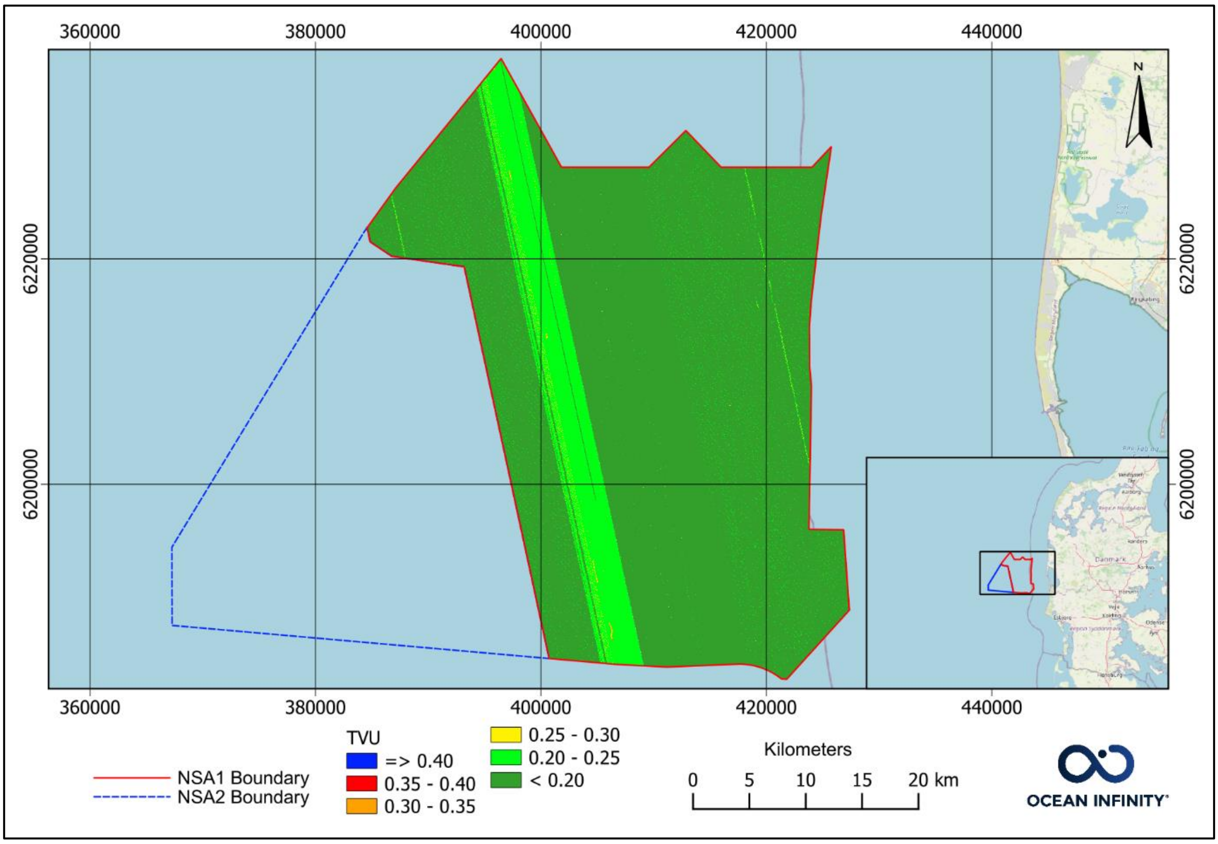


Figure 20 Total Vertical Uncertainty - NSA1.

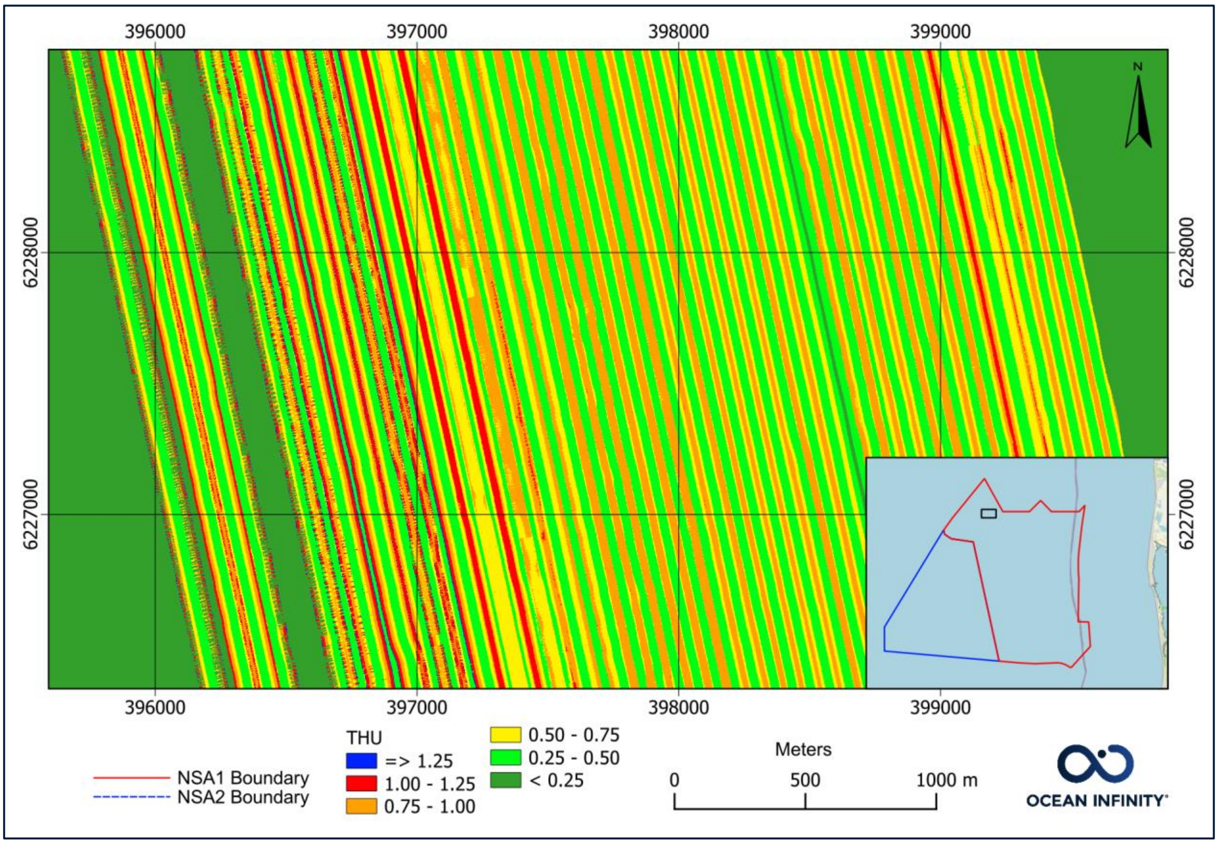


Figure 21 Total Horizontal Uncertainty - M/V Geo Ranger data.

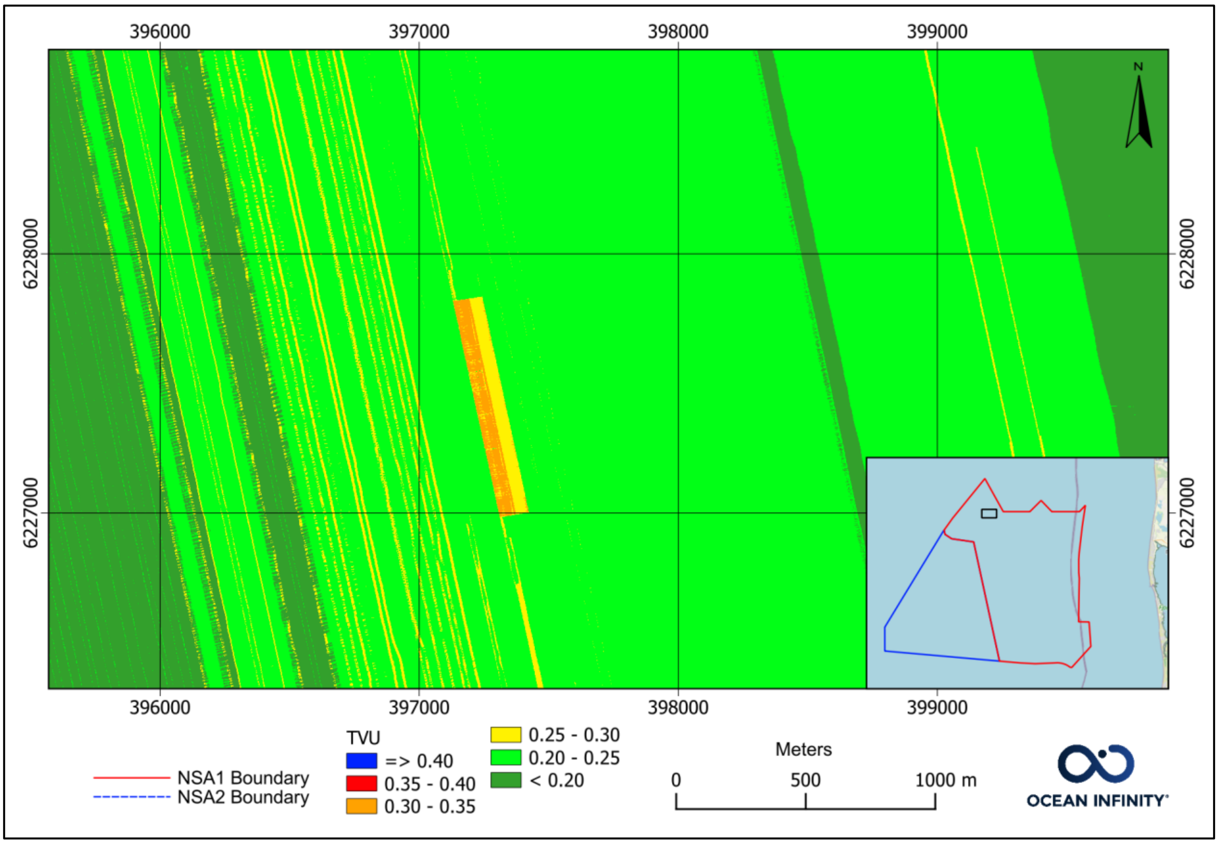


Figure 22 Total Vertical Uncertainty - M/V Geo Ranger data.

Checks were made during acquisition to ensure that the sounding density conformed to the 16 soundings per 1 m cell requirement. When data gaps were identified during the survey an infill plan was presented and discussed with the Client Representative, leading to some client concessions where the obtained data was deemed acceptable. For example, as shown in Figure 23, safe access was not possible in the vicinity of a MMO buoy, leading to a large data gap. Shadowing around wrecks and other steep sided features also led to low-density cells, however, this did not impact feature definition (see Figure 24). In other instances, low-density cells correspond to areas that were flagged as rejected during office data cleaning after the vessels had left the survey area. Whilst the initial coverage and density may have exceeded requirements, post-processing and further analysis occasionally revealed poorer quality data that was subsequently rejected. An example of this is shown in Figure 25, where the rejection of several erratic MBES pings reduces the number of accepted soundings. A summary of the number of low-density cells experienced across the survey area is presented in Table 28.

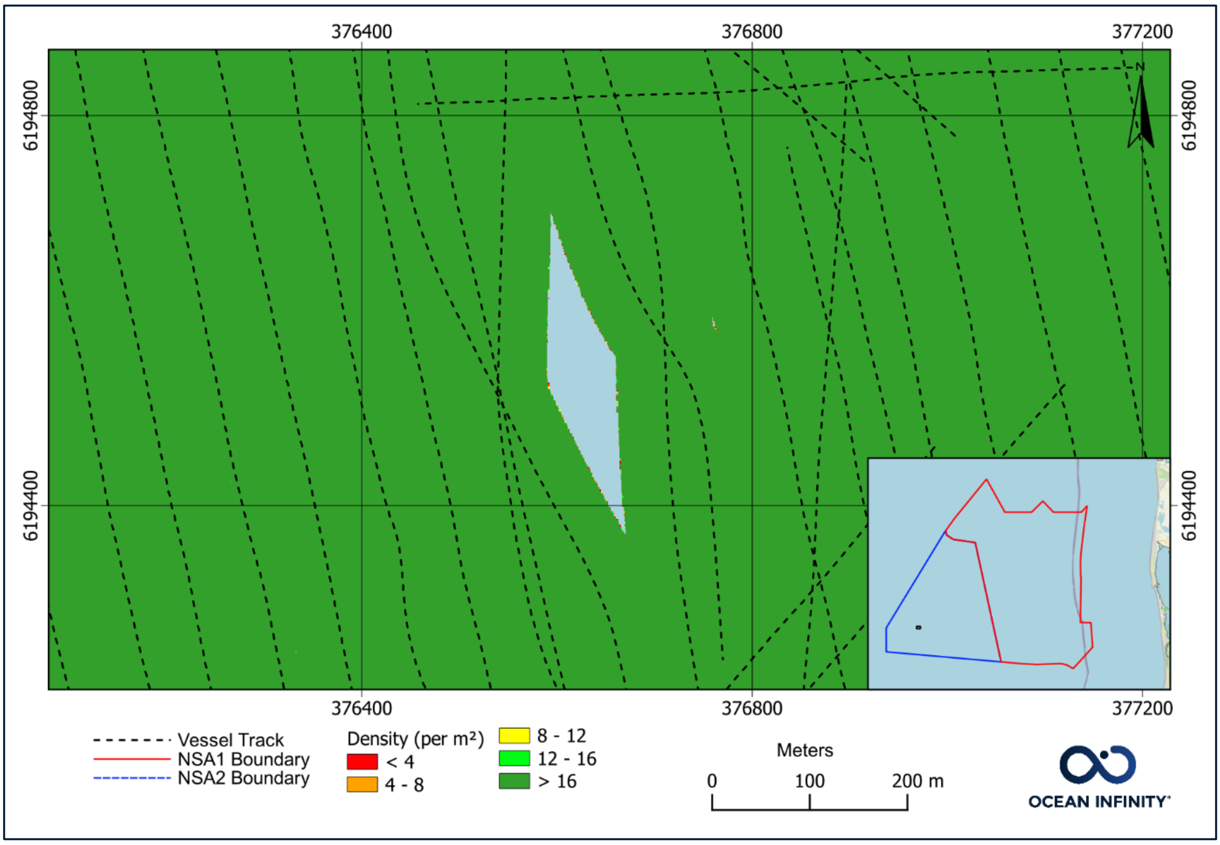


Figure 23 MBES Data Gap in vicinity of MMO Buoy.

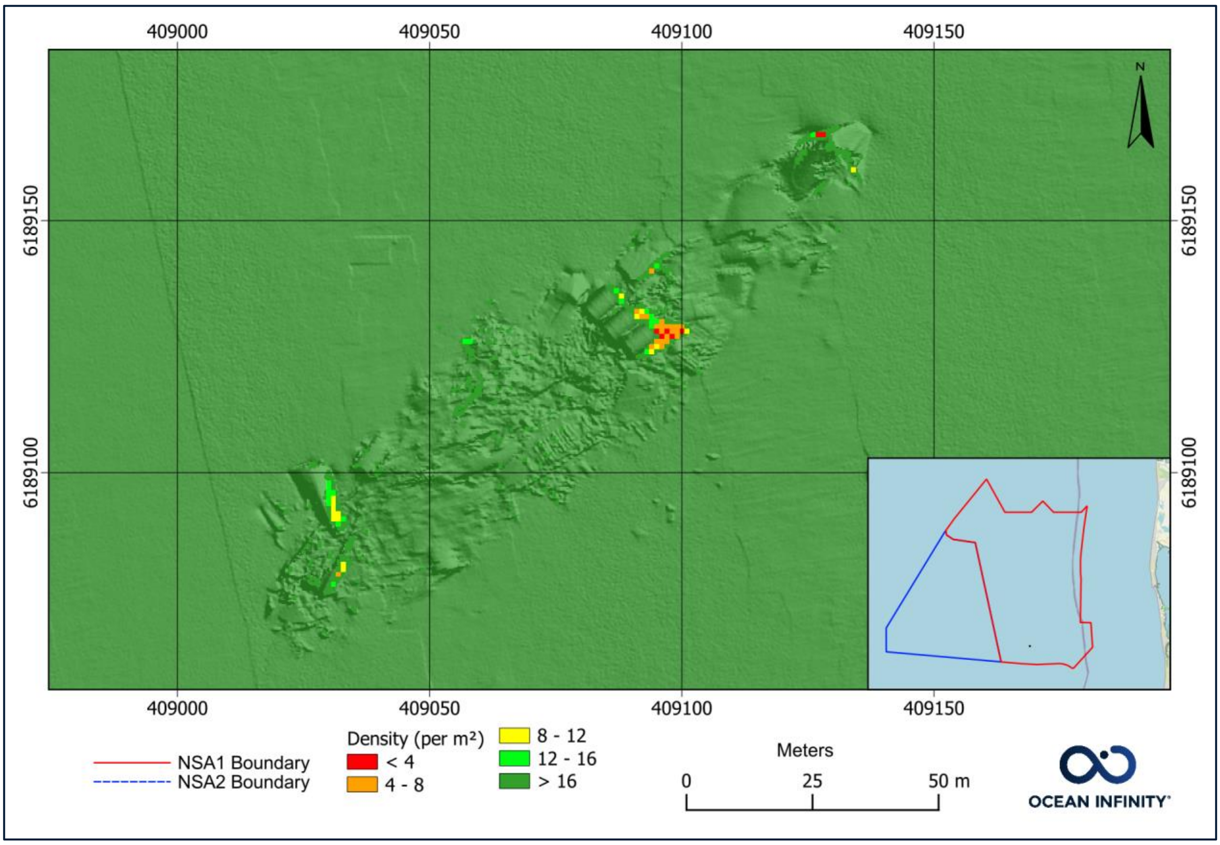


Figure 24 Low-density cells caused by feature shadowing.

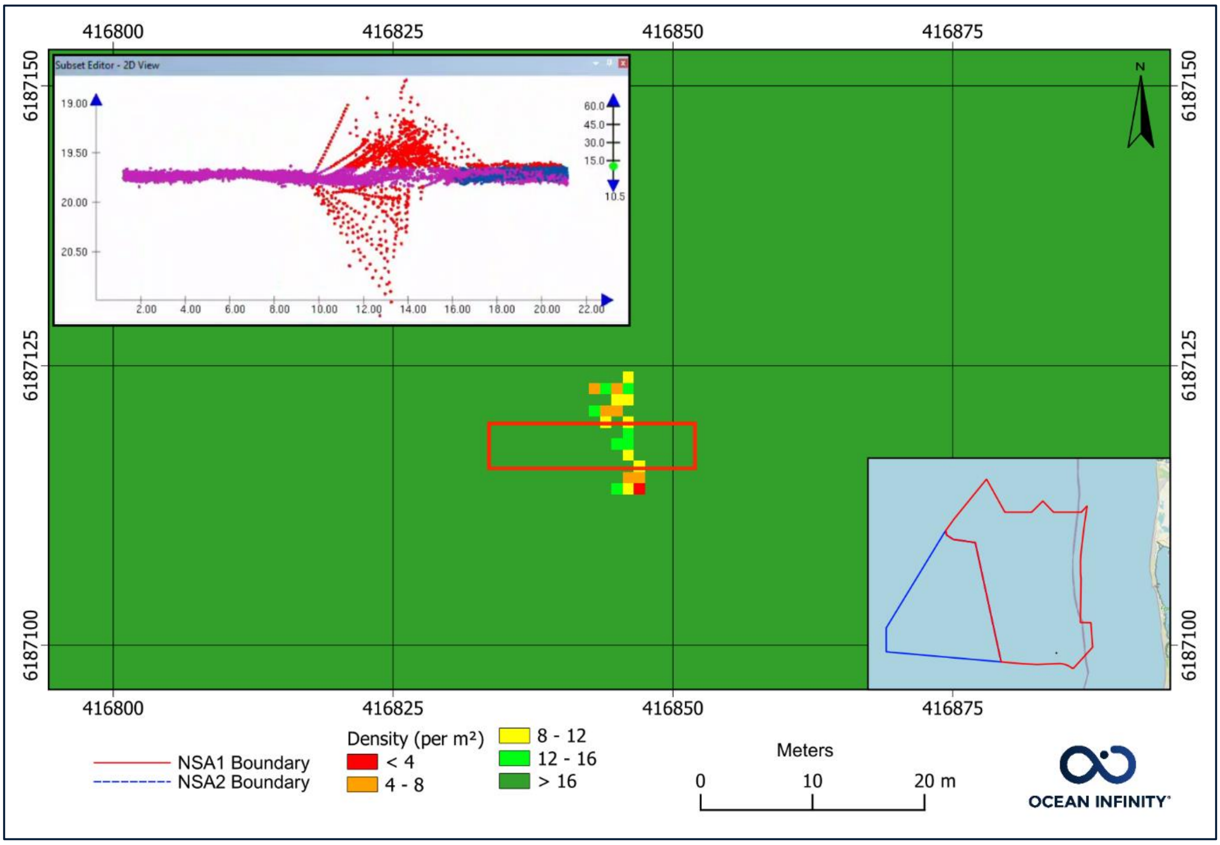


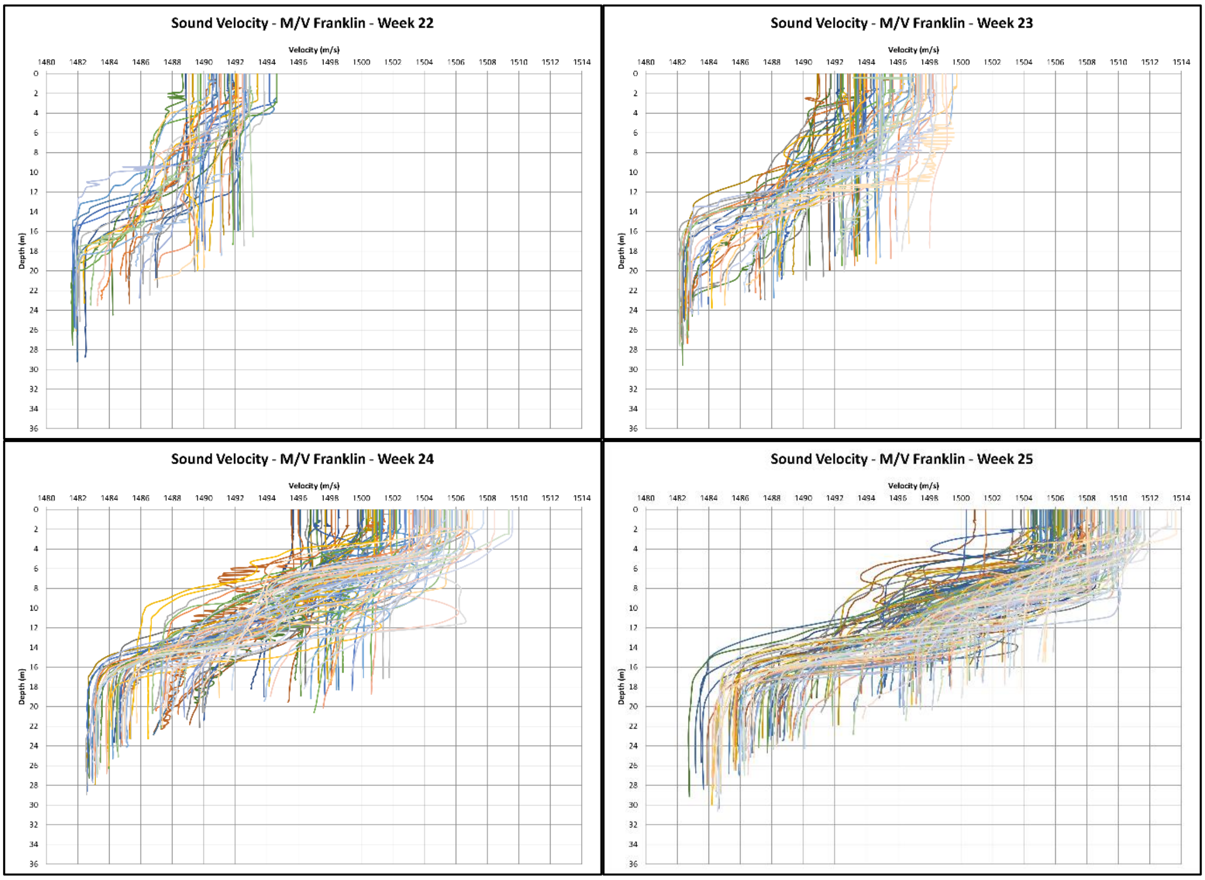
Figure 25 Low-density cells caused by data rejection during post-processing.

Table 28 Number of low-density cells.

SURVEY BLOCK	SURVEY AREA (m²)	# LOW-DENSITY 1m² CELLS	% SURVEY AREA
BM01	99,325,577	45	0.0000
BM02	12,434,868	3	0.0000
BM03	134,417,008	2,785	0.0021
BM04	137,905,709	1,390	0.0010
BM05	126,161,078	1,902	0.0015
BM06	139,079,533	3,169	0.0023
BM07	139,461,459	2,299	0.0016
BM08	138,023,288	145	0.0001
BM09	139,880,011	0	0.0000
BM10	137,860,907	37	0.0000
BM11	136,637,246	5,227	0.0038
BM12	137,185,254	1,178	0.0009
BM13	138,281,580	81	0.0001
BM14	137,539,576	5	0.0000
BM15	138,617,915	0	0.0000
BM16	139,552,527	23	0.0000

SURVEY BLOCK	SURVEY AREA (m²)	# LOW-DENSITY 1m² CELLS	% SURVEY AREA
BM17	90,370,643	12,602	0.0139
BM18	77,120,200	195	0.0003
Total	**2,199,854,379**	**31,086**	**0.0014**

During the project, the single largest influencer on data quality has been the sound velocity related errors due to the pycnocline effect. A very settled weather period from late-May to mid-July saw little mixing and an increasing stratification of the water column, as shown in the series of Sound Velocity Profiles (SVP) in Figure 26. New casts were routinely taken whenever the Sound Velocity (SV) at the MBES head was found to differ at the transducer depth within the current profile by > 2.5 m/s, or if an issue was seen in the real-time MBES data. However, it is not possible to monitor the entire water column, so inevitably changes at depth were also likely to be occurring undetected. Significant geographical and temporal variations were observed, leading to new casts being taken every hour within some of the survey blocks. An illustration of these variations can be seen in Figure 27, which shows the cast locations coloured by the Standard Deviation of the sound velocity values within the profiles.



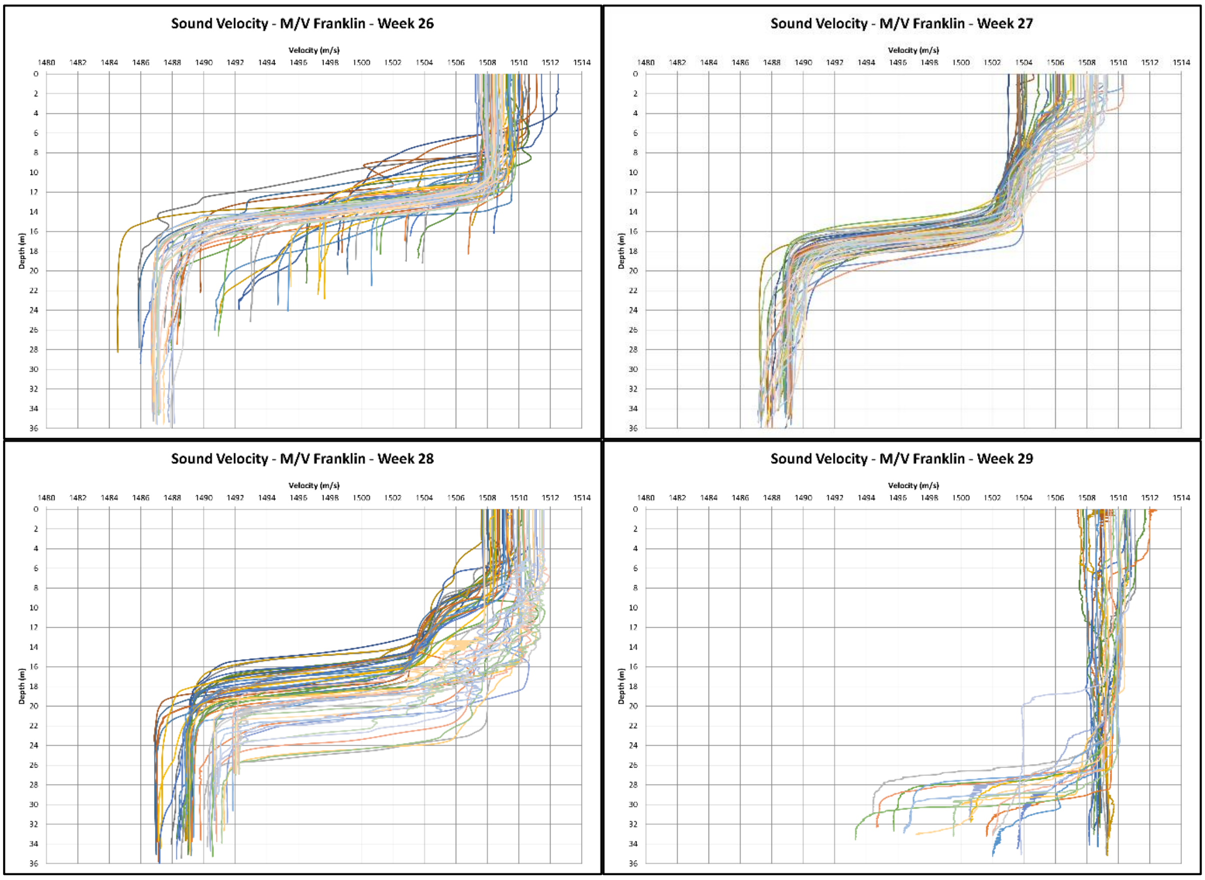


Figure 26 M/V Franklin Sound Velocity Profiles – Weeks 22 to 29.

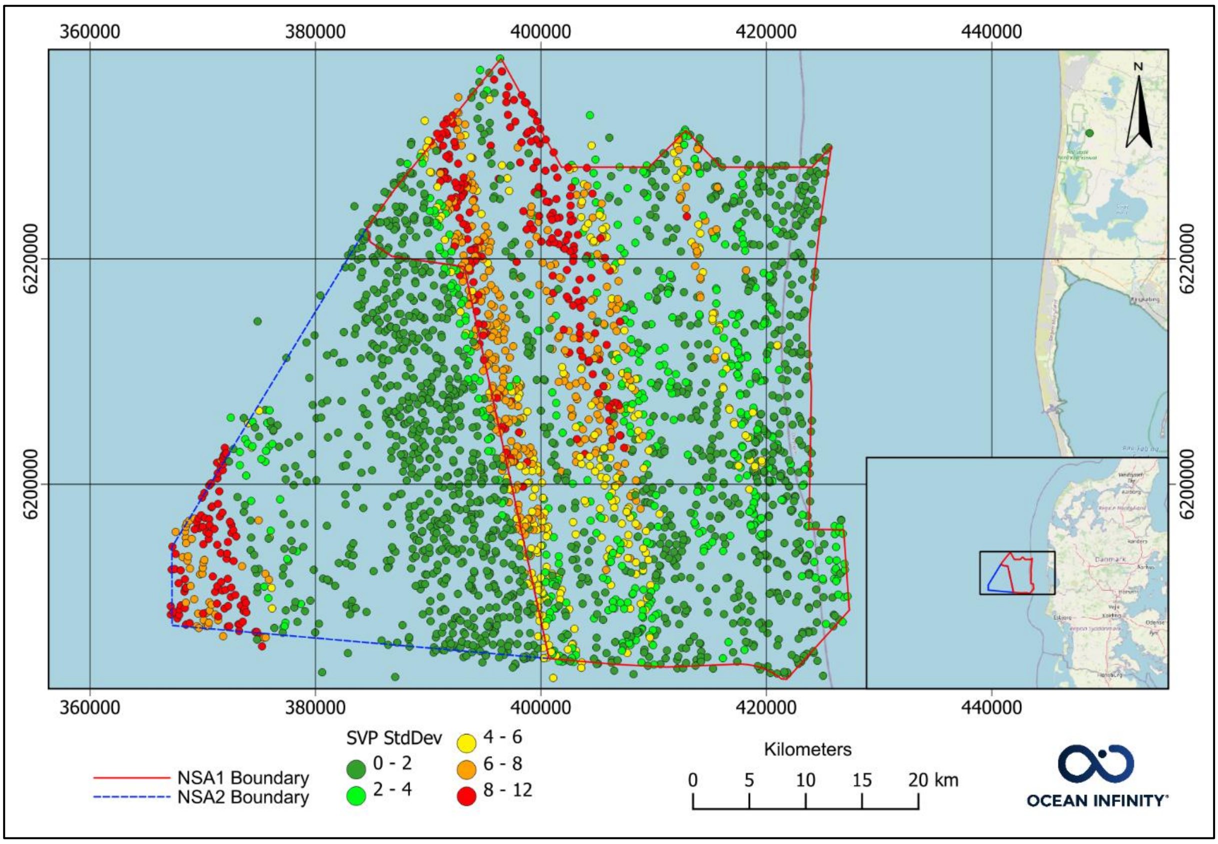


Figure 27 Sound Velocity Profile locations and Standard Deviation.

The presence of pycnoclines and rapidly changing sound velocities can create unwanted fluctuations in the outer beams and slight ‘bending’ of the seafloor in the MBES data. As the sound pulse travels through the water column it encounters water masses of varying densities. At each density boundary the path of the sound pulse is altered due to refraction and the degree of deviation is dictated by the difference in density and the angle of incidence, with increasing angles of incidence creating greater degrees of refraction. Furthermore, with increasing water depth, the ray has more time to travel along its refracted path. Ultimately, the difference in position between the detected seabed from the natural seabed is controlled by depth, beam angle and the density profile of the water column. During post-processing alternative profiles may be utilised to minimise the impact on the data, however, it is not always possible to completely remedy the situation, with slight misalignments in problem areas likely to remain. Example cross-sections from pre- and post-processed data are presented in Figure 28. Whilst the solution is not perfect, the data is still within expected tolerances.

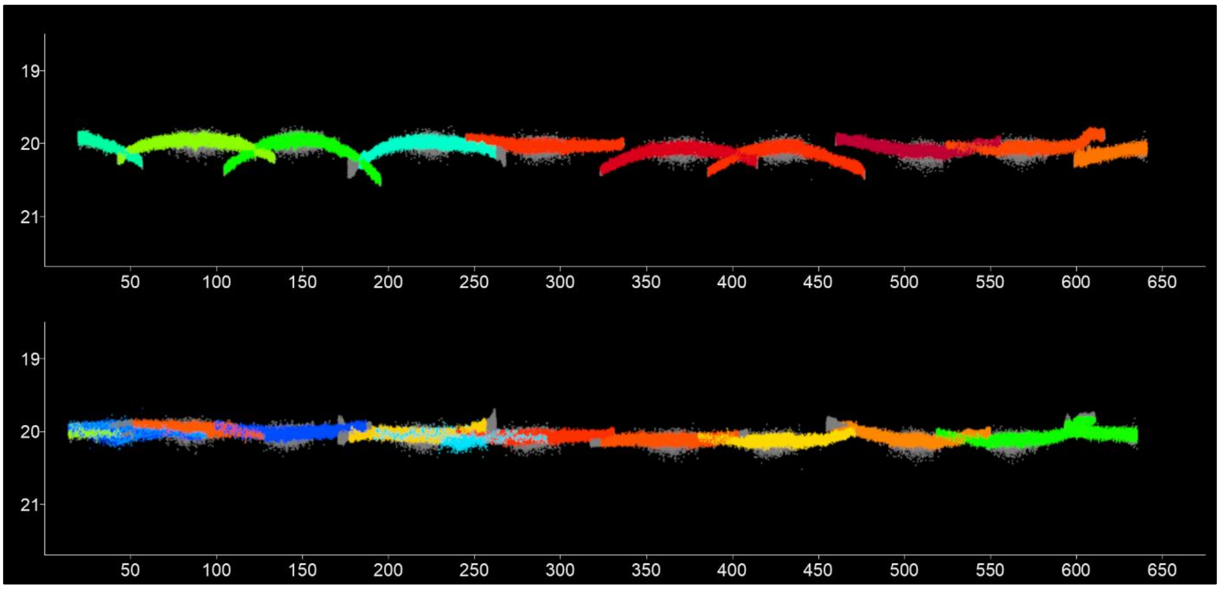


Figure 28 Cross-section of MBES data with sound velocity issues pre- and post-processing.

The MBES data from M/V Franklin, M/V Northern Maria and M/V Geo Ranger was combined in the office after survey operations were completed. The principal QC check that was required was to ensure that all the survey line data was vertically aligned. This is done by generating Caris HIPS QC surfaces with a range of properties computed for each surface, which are subsequently checked systematically to ensure that the data falls within specification. The Standard Deviation (at 95% confidence interval) is primarily used to highlight areas where the vertical spread of individual soundings within a DTM grid cell is high in relation to the cell’s mean depth, with checks made to determine the cause. If necessary, action can be taken to bring the soundings into closer alignment. Regions that have high standard deviations can occur where there are sound velocity issues or errors in the post-processed navigation (I.e. between survey lines), where data is acquired in heavy weather, or where there are steep slopes (including boulder fields). Due to the scale of the survey, where data is within the required tolerance then no further steps are taken to improve the alignment. An example of a Standard Deviation plot is presented in Figure 29. Whilst most of the area is within specification, the higher reported values can be attributed to seabed features, as shown by the bathymetry in Figure 30.

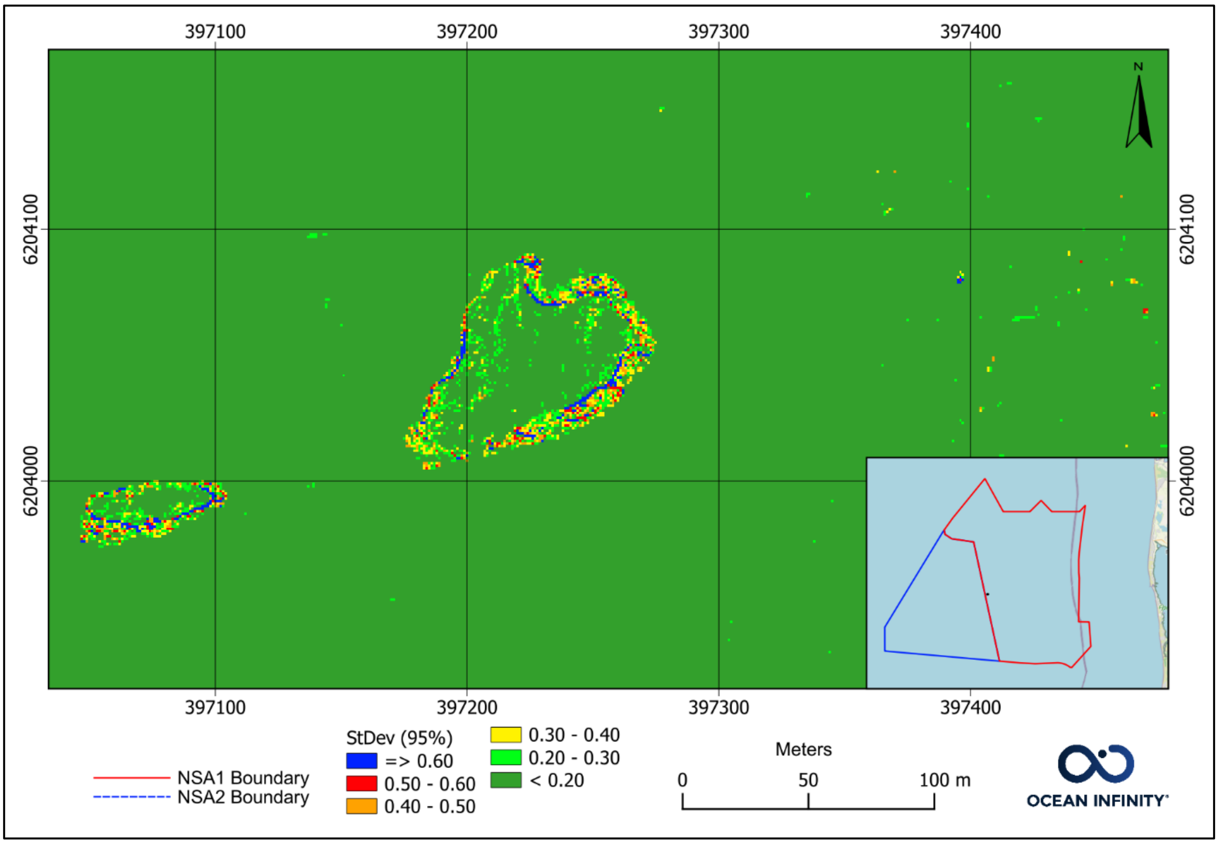


Figure 29 Example QC Standard Deviation plot.

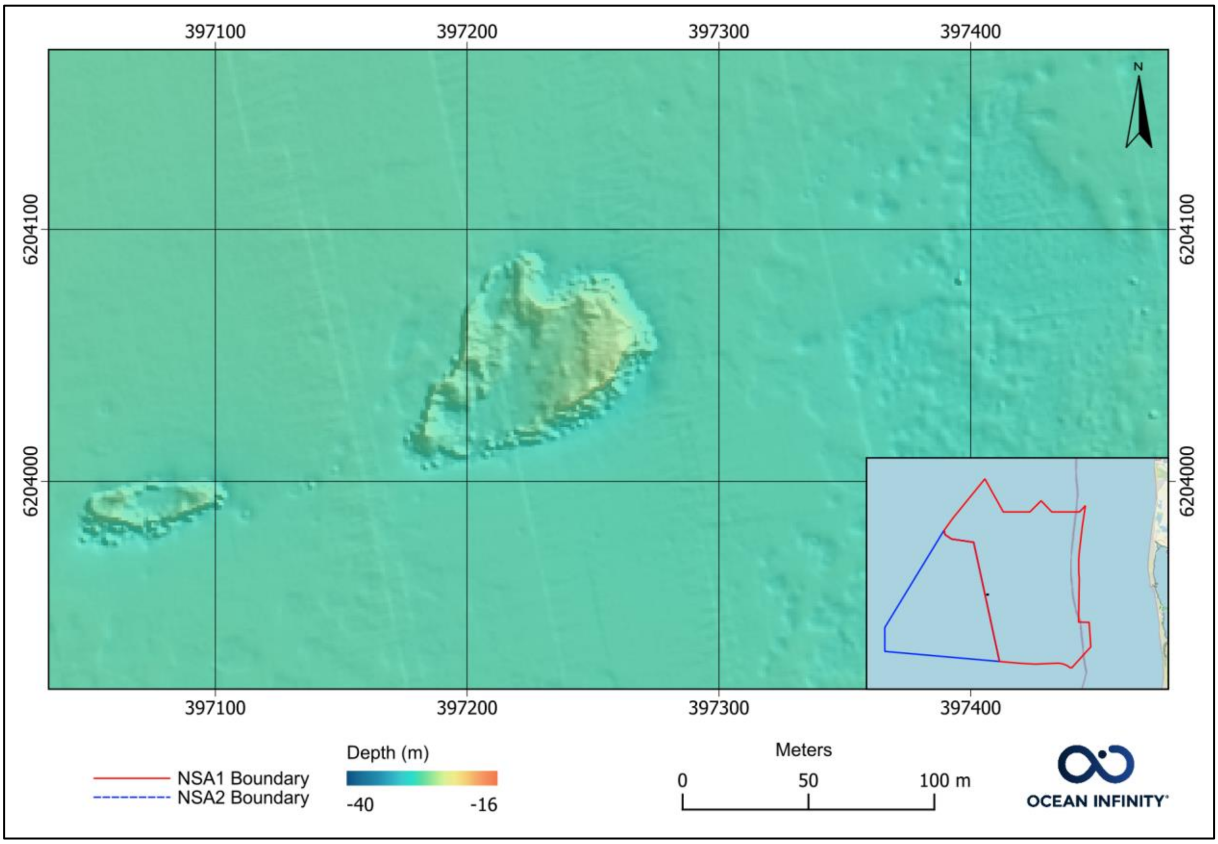


Figure 30 Corresponding sun-illuminated bathymetry.

By way of comparison, and to illustrate the problems experienced with the pycnocline, Figure 31 shows an area processed using the real-time sound velocity profile observations. The outer beams are severely affected, leading to higher standard deviation values in the areas of overlap. By reviewing the applied sound velocity profile strategy, it is possible to improve the data significantly, as shown in Figure 32.

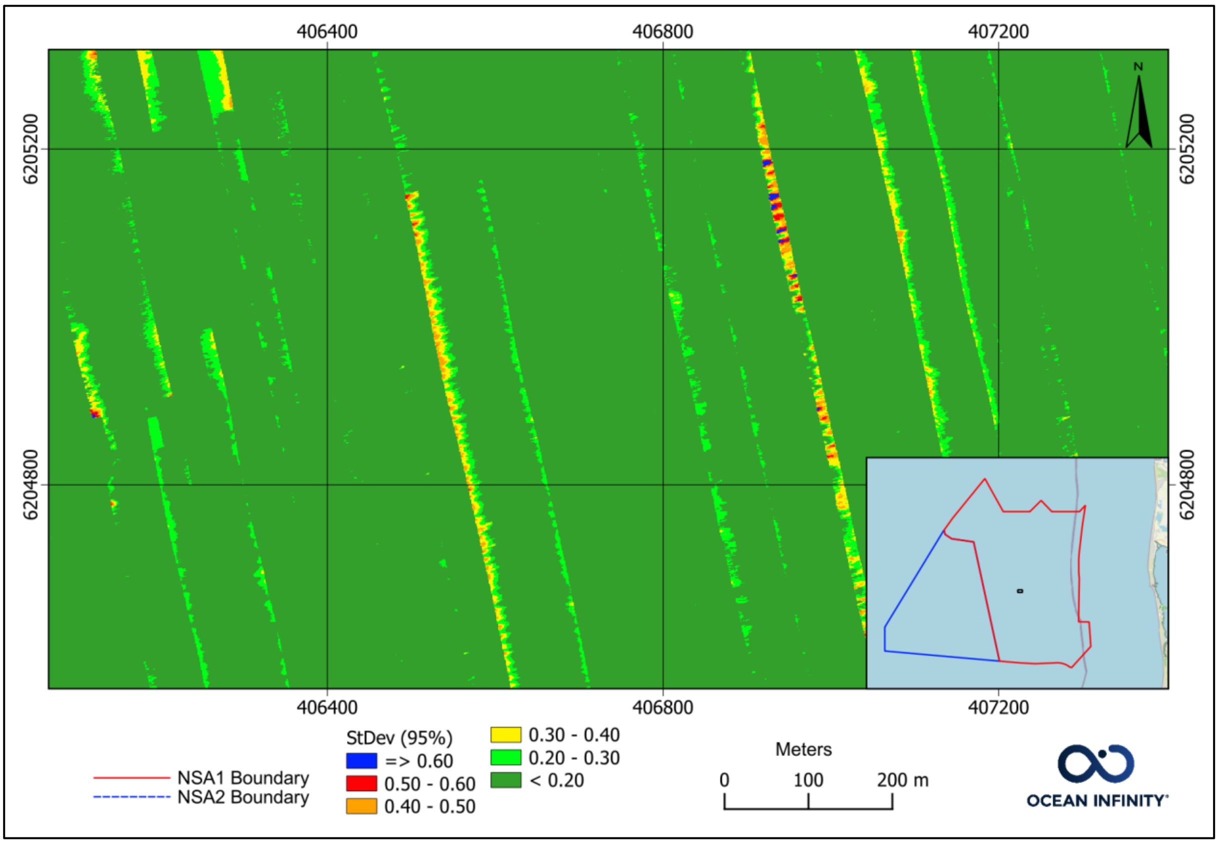


Figure 31 Example Standard Deviation plot of pycnocline affected area after initial processing.

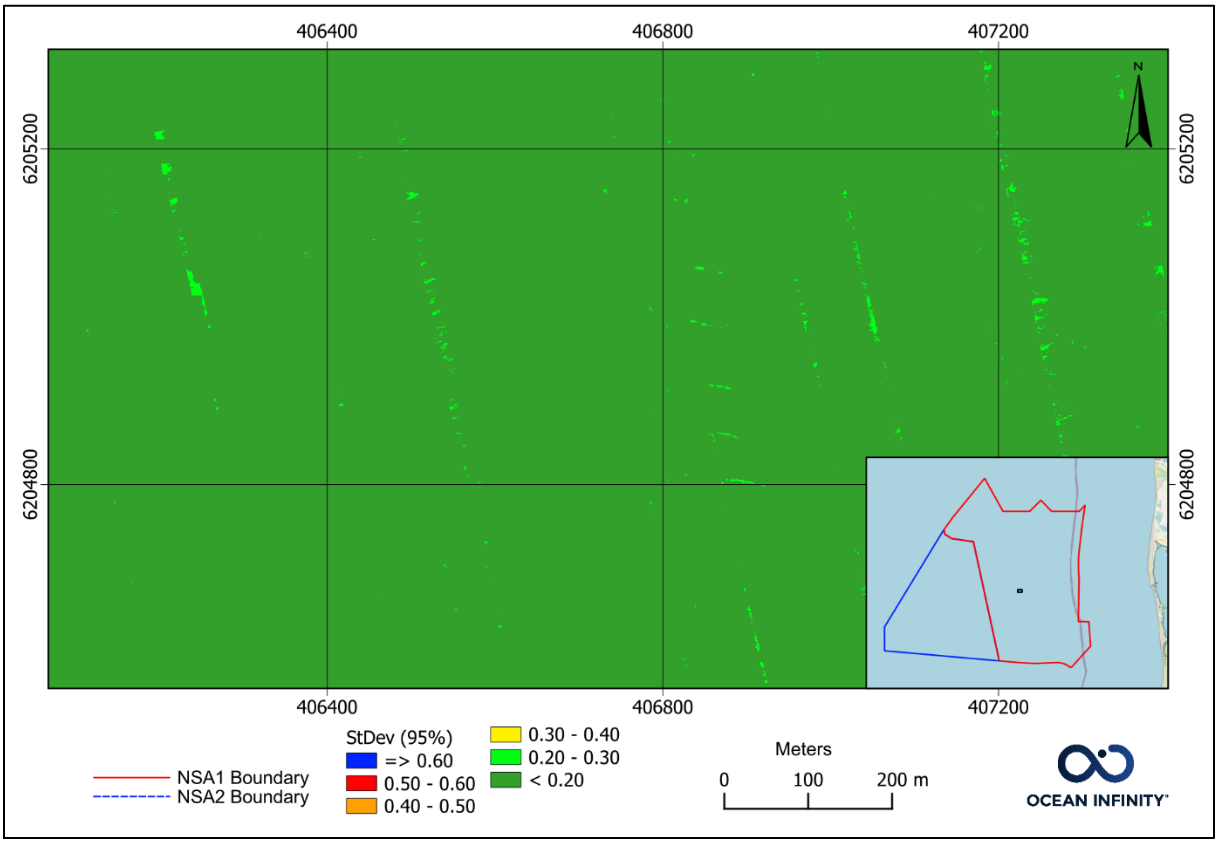


Figure 32 Example Standard Deviation plot of pycnocline affected area after further post-processing.

5.2 Backscatter Data

The overall quality for the backscatter data delivery is good. Assessment of the combined mosaic indicates that the boundaries between different sediment types were well delineated with good agreement between the relative intensities of the data acquired by M/V Northern Maria, M/V Franklin and M/V Geo Ranger.

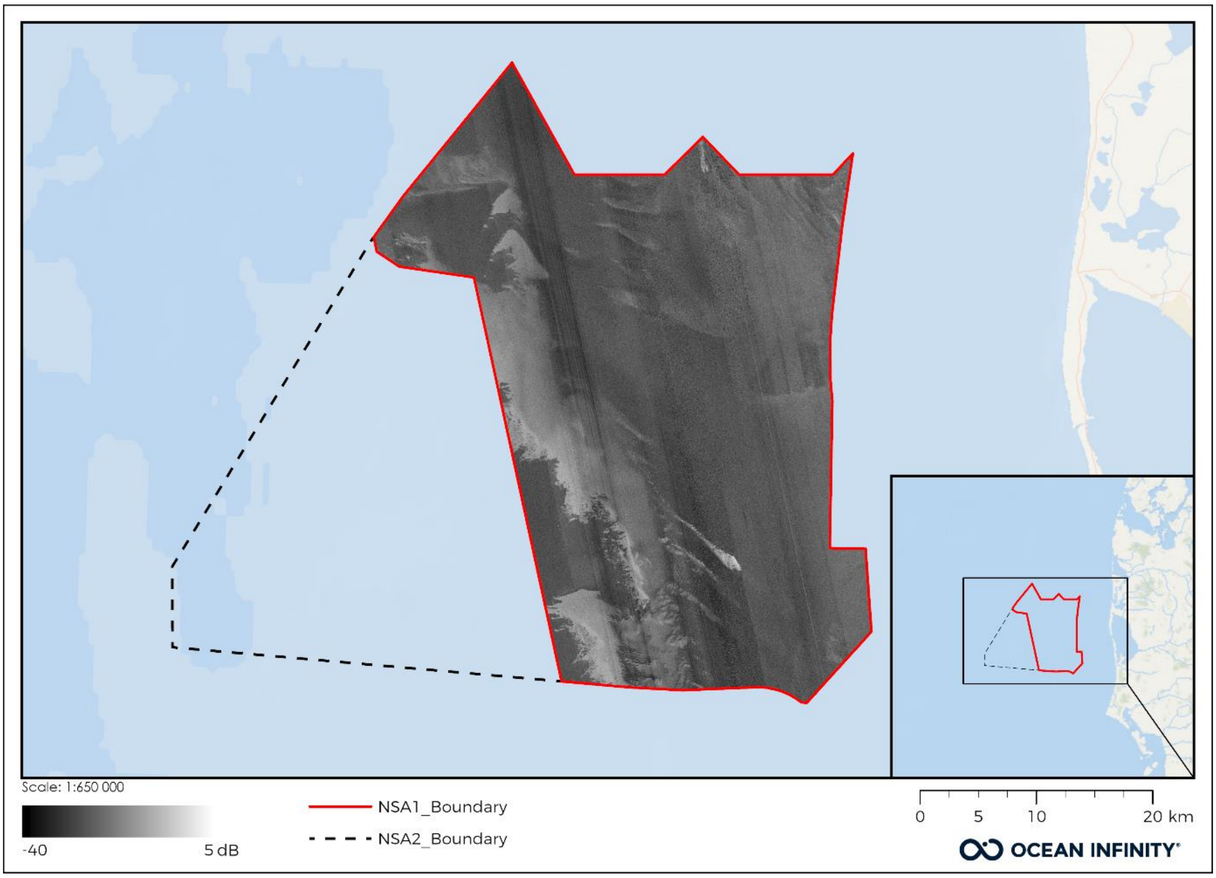


Figure 33 showing an overview of backscatter data in NSA1.

Despite all vessels being equipped with the same multibeam echosounders, smaller variations in backscatter intensity were observed between the vessels. Differences could be indicative of various factors such as equipment calibration, vessel configuration, or environmental conditions.

One significant environmental factor during the survey was the large variations in sound velocity. Sound velocity is essential for accurately calculating the depth of the seafloor, and fluctuations can impact the precision and quality of the collected data. In some cases, the vessels have left the survey area due to hindrance or bad weather and then returned at later date to continue has also caused some differences in intensity between survey lines due to big variations in sound velocity.

Furthermore, the backscatter dataset contains some artefacts that FMGT is not able to remove from the mosaics during processing. These are quite typical in MBES backscatter mosaics and are mainly derived from the motion of the vessel or the occurrence of bubble-wash over the MBES transducers. Since the data is processed from raw files directly, no cleaning of data outliers or adjustment for other possible sources of error is possible. Bubble-wash occurs when air bubbles are dragged across the sonar transducers as the vessel encounters white-water or pitches heavily. These bubble-wash effects manifest as black lines that run across the MBES swath (perpendicular to the survey line direction). Example shown in Figure 34.

Other artefacts can arise from the survey line in relation to the sediment area boundaries. When the vessel is passing the sediment boundary a "smearing" artefact can sometimes arise. This occurs as FMGT attempts to normalise along track variations to produce mosaics that have reduced noise. This is achieved by normalising the backscatter intensity for a moving window of pings. When this window crosses a sharp sediment boundary the apparent clarity gets reduced due to differences in intensity being averaged out. Example shown in Figure 35.

The presence of artefacts can be visually distracting but does not affect the results of the seabed interpretation. Experienced marine geologists can see beyond the artefacts and use all available datasets to determine whether these variations arise from real features or artefacts.

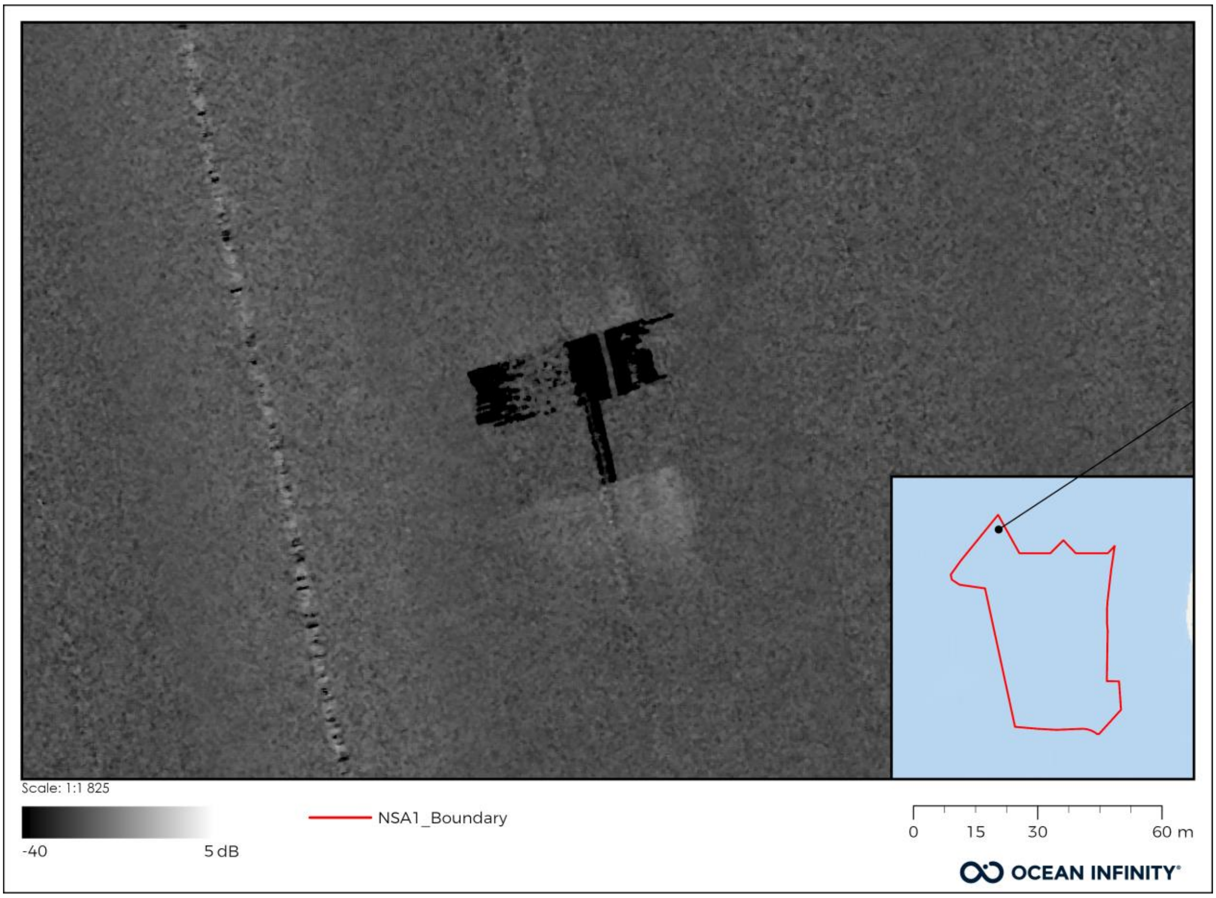


Figure 34 showing example of artefact (black) due to bubble-wash.

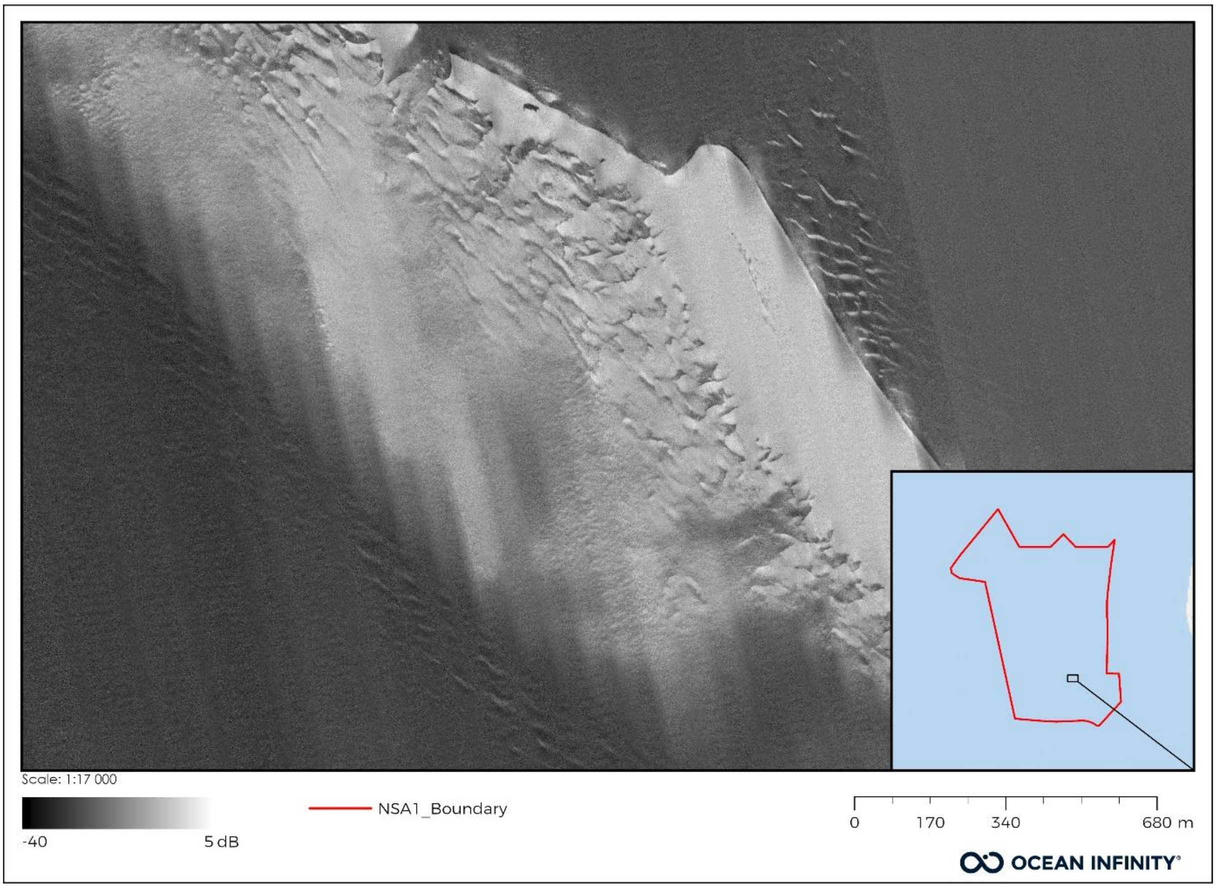


Figure 35 showing smearing artefacts showing smearing caused when passing sediment boundaries.

Additionally, our analysis has revealed that data collected by M/V Geo Ranger tends to exhibit more speckling compared to data from other vessels. The one notable distinction being the software utilized for data collection. Geo Ranger employs a newer version of Kongsberg SIS (SIS 5), resulting in data being stored in a newer file format (.KMALL). Given that the file format is quite recent, we suspected that FMGT 7.10 did not handle the files correctly.

During the delivery phase of the project QPS released a new version of FMGT (7.11) and to improve the Geo Ranger data we reprocessed it in this newer version. This adjustment notably reduced speckling and enhanced backscatter details.

The area collected by M/V Geo Ranger is highlighted in Figure 36. The .KMALL data processed in FMGT 7.10 can be seen in Figure 37 and the improved result from FMGT 7.11 can be seen in Figure 38.

FMGT is utilizing a scale ranging from minimum -70 to maximum 10 to capture the full spectrum of backscatter intensity values. While this comprehensive scale provides detailed information, it is typical to adjust the presentation scale to a narrower range of approximately -40 to 5 for enhanced visual clarity and interpretability. However, the delivered files always contain the full range of the collected data. With the data tiled for delivery it means that the full range of each tile can vary since they are only snippets of the complete data set.

Figure 36 showing the affected area surveyed by Geo Ranger.

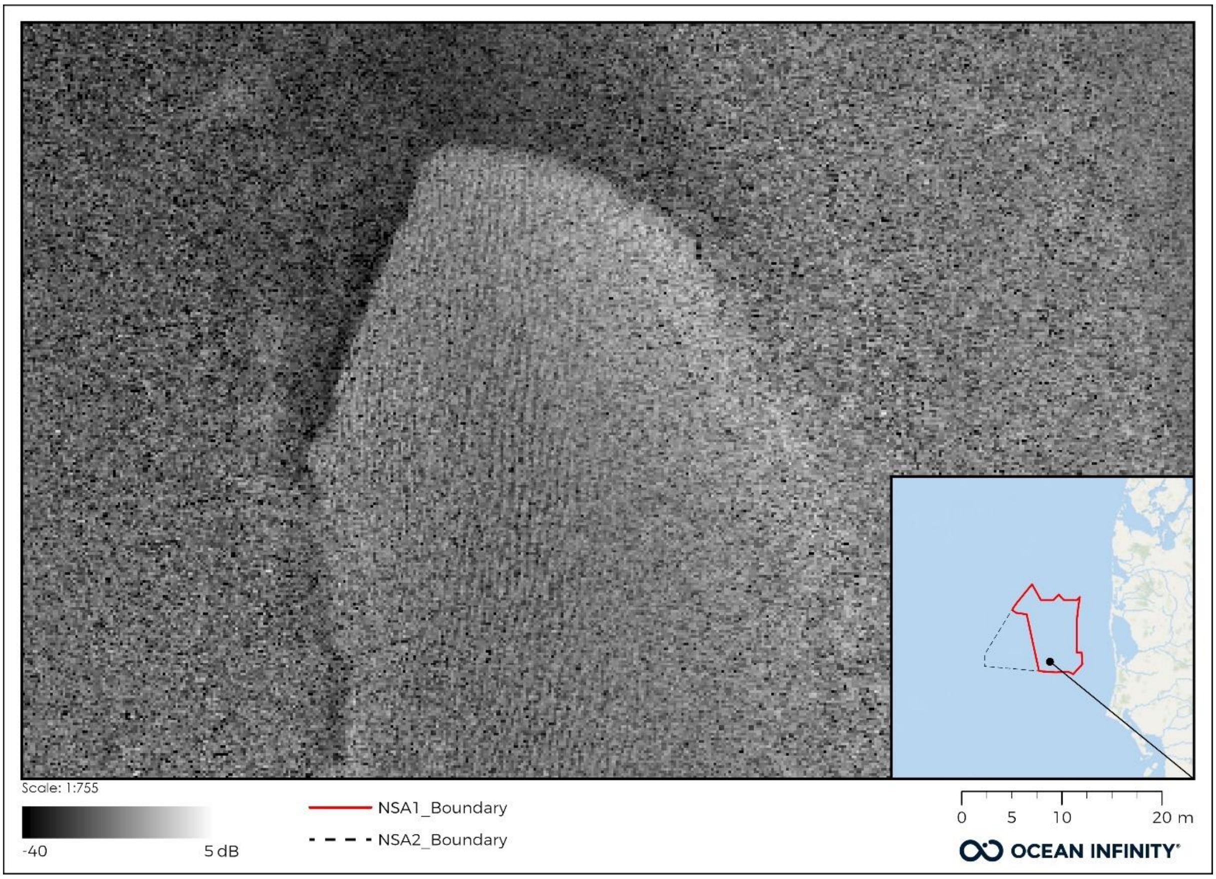


Figure 37 showing the speckled data processed in version 7.10 of FMGT.

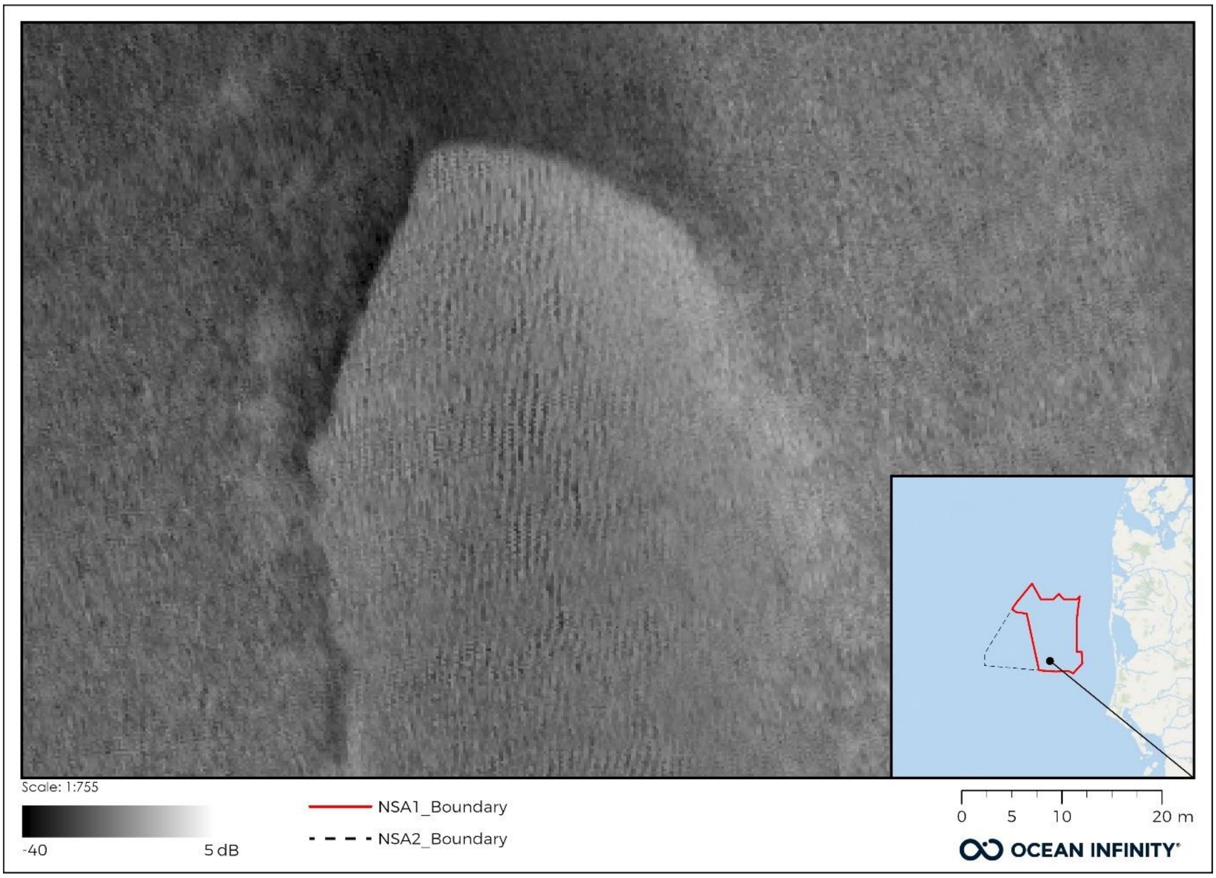


Figure 38 is showing the improved result when using the 7.11 version of FMGT. Details like ripples become more prominent.

5.3 Side Scan Sonar Data

SSS data was acquired to provide 80 m range with a 300/600kHz frequency. The altitude of the SSS was to be kept at 10-15% of the range. 200% coverage was to be achieved to ensure overlap with the nadir of adjacent lines. Debris object detection was specified as >0.5 m for individual targets while boulder detection was specified as >1.0 m.

The SSS data quality was overall good (Figure 39 and Figure 40) but affected by pycnocline localized in short intervals, affecting the data in the outer ranges; in some sections up to 70% of the data was affected (Figure 41).

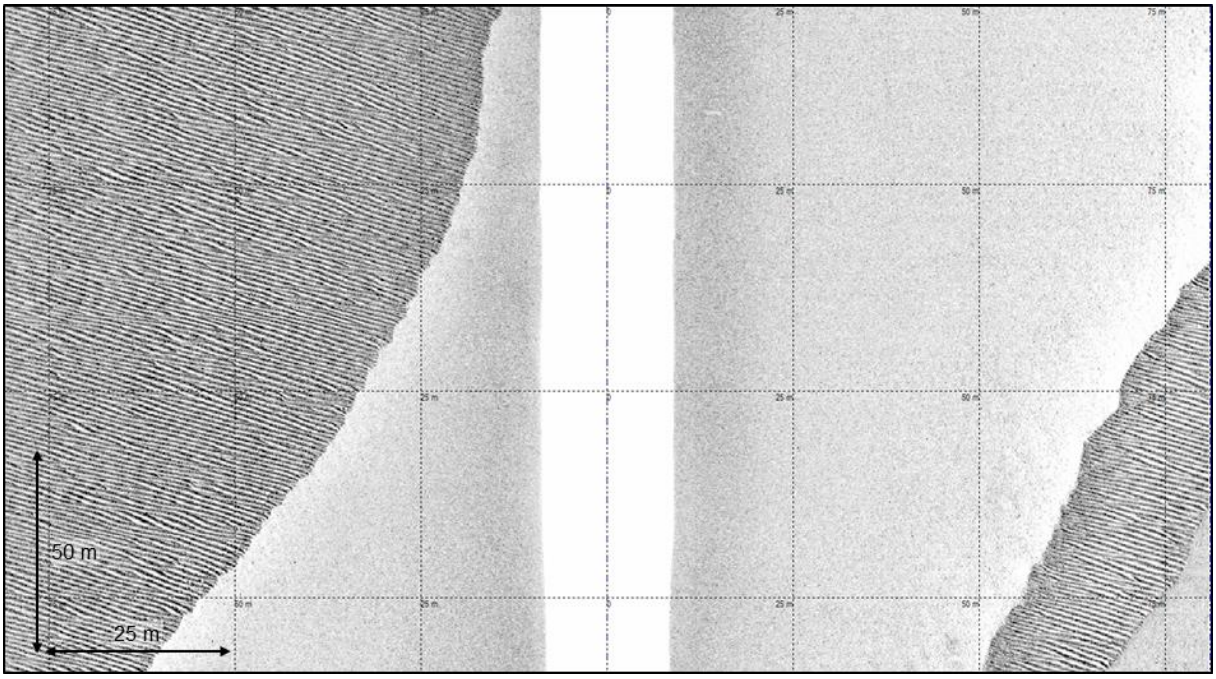


Figure 39 Example of good SSS data along line BM14_43540_0659.009, waterfall view.

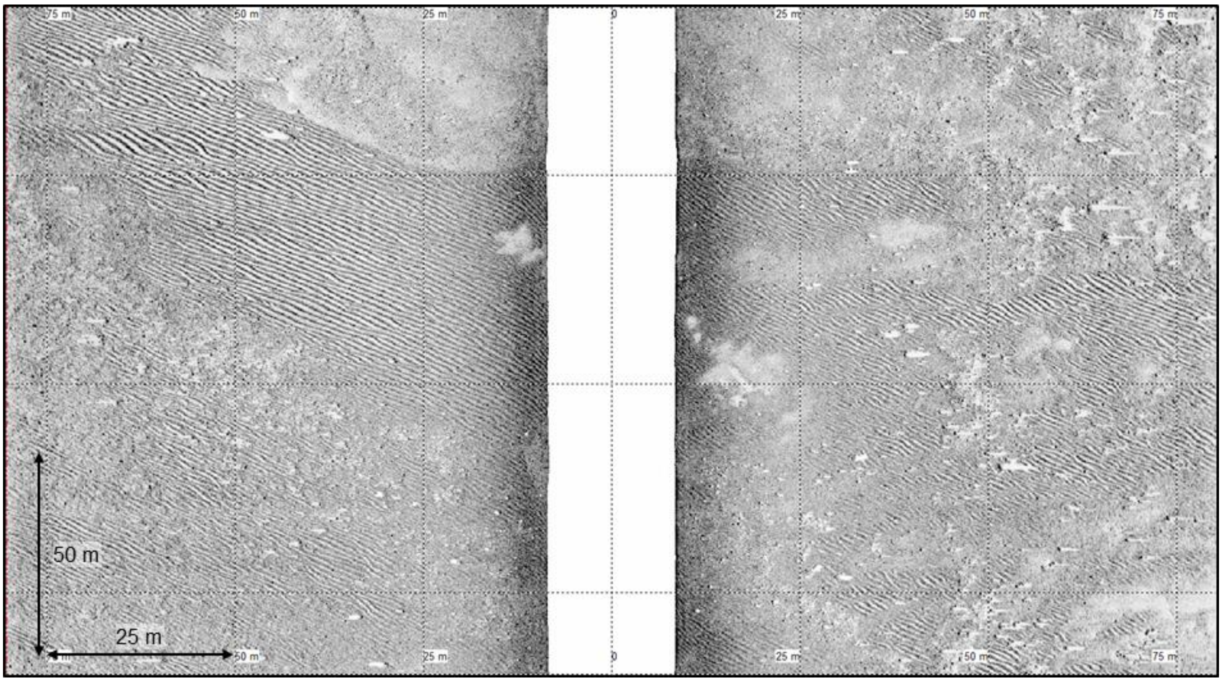


Figure 40 Example of good SSS data along line BM10_30240_INF001_0707, showing boulders and ripples.

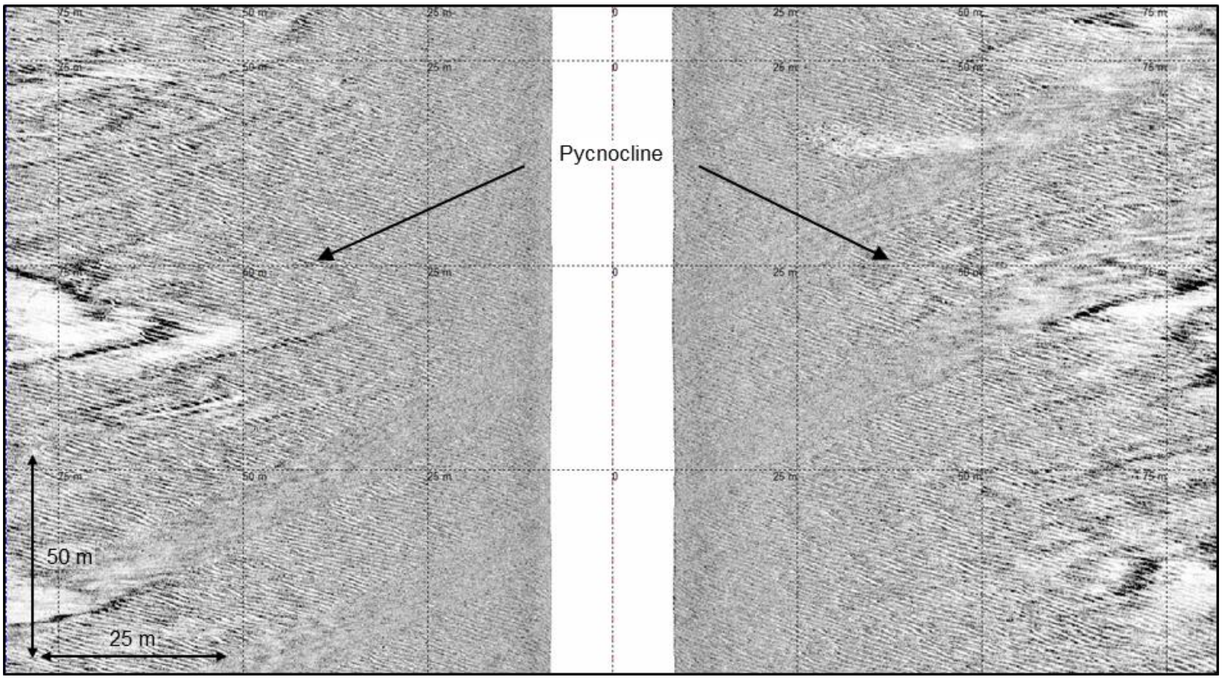


Figure 41 Pycnocline as observed on line BM14_43540_0659.009.

Artefacts due to marginal weather were observed on some SSS records. These are due to roll and pitch motion on the towfish causing a 'striping' effect on the data, shown in Figure 42. The data had various amounts of gain applied to improve the overall appearance of the data and reduce the appearance of weather-related artefacts.

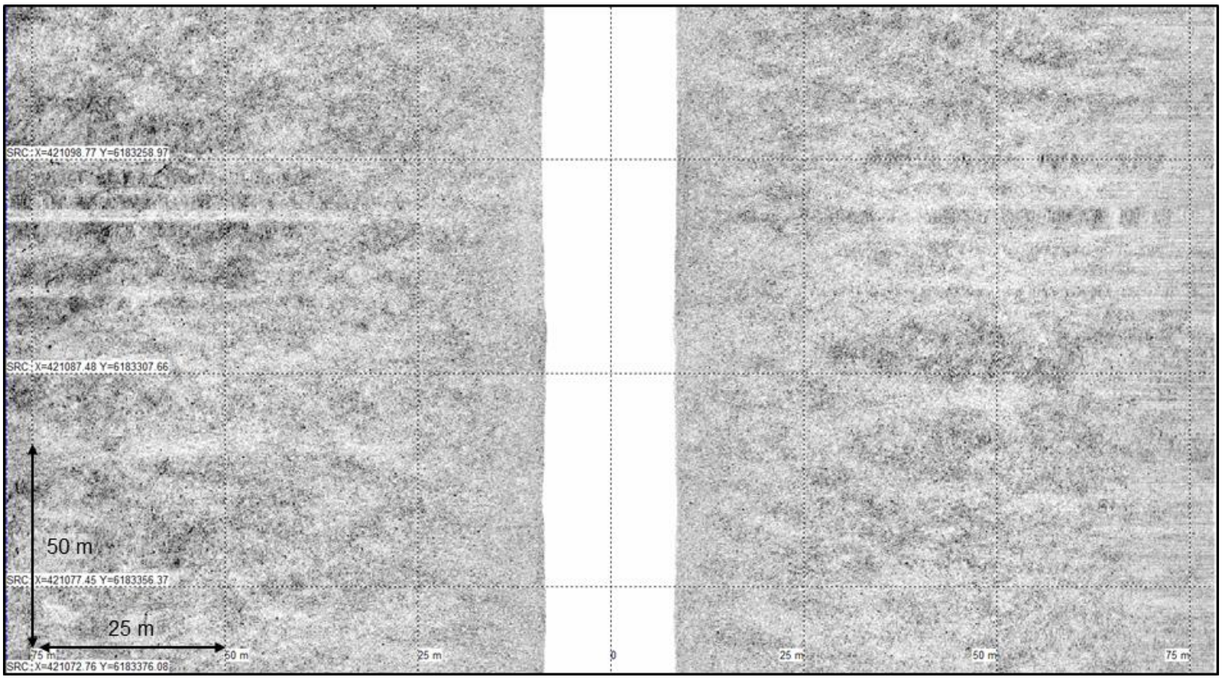


Figure 42 Example of striping in SSS data from strong pitch and roll effects in line BM05_14420_0005.

Areas where pycnocline were present, far field tool in SonarWiz was used to track the extent of good data, later adjusting the displayed range of these lines to obtain the actual coverage of the acceptable data, infill lines were appropriately acquired in areas where the coverage did not comply with the project specifications.

Following the tracking of the pycnocline and multiple infill lines, some areas had 100% coverage in the nadir gap and between adjacent lines. This data with 100% coverage was accepted by the client *(reference to TQ-012-Sensor Gap Specification)*. SSS data quality is described per block in Table 29 and coverage maps are presented in Figure 43, Figure 44, Figure 45, Figure 46, Figure 47 and Figure 48.

Table 29 SSS data quality description by block

Block	SSS High Frequency Data Quality
BM01	Northern Maria acquired data. SSS data overall good. Light to moderate pycnoclines throughout the block overlapped with good quality data. Some minor weather/motion related noise affecting some outer ranges. SSS range was 80 m. Line spacing was 70m.
BM02	Northern Maria acquired data. SSS data overall good. Light to moderate pycnoclines throughout the block overlapped with good quality data. SSS range was 80 m. Line spacing was 70m.
BM03	Northern Maria acquired data. SSS data overall good. Light to moderate pycnoclines throughout the block overlapped with good quality data. Light to moderate stripes and environmental noise in some lines. SSS range was 80 m throughout survey area and line spacing 70 m.
BM04	Northern Maria acquired data. SSS data overall good. Moderate to strong pycnoclines and stripes throughout the block overlapped with good quality data. SSS range 80 m throughout with mainline line spacing at 70 m.
BM05	Northern Maria acquired data. SSS data overall good. Light to moderate pycnoclines and striping throughout the block overlapped with good quality data. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM06	Northern Maria and Northern Franklin acquired data. Light to moderate pycnoclines and stripes throughout the block overlapped with good quality data. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM07	Northern Franklin acquired data. Light to moderate pycnoclines and stripes throughout the block overlapped with good quality data. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM08	Northern Franklin acquired data. Light to moderate pycnoclines and stripes throughout the block overlapped with good quality data. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM09	Geo Ranger acquired data. Light to moderate pycnoclines throughout the block. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM10	Geo Ranger and Norther Maria acquired data. Light to moderate pycnoclines and stripes throughout the block overlapped with good quality data. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM11	Northern Maria acquired data. Moderate to strong pycnoclines throughout the block. Light to moderate striping. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM12	Northern Maria acquired data. Light to moderate pycnoclines and striping throughout the block. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM13	Northern Maria acquired data. Moderate pycnoclines, snatch and stripes throughout the block. SSS range was 80 m throughout with mainline line spacing at 70 m.
BM14	Northern Maria acquired data. Light to moderate pycnoclines and stripes throughout the block. SSS range was 80 m throughout with mainline line spacing at 70 m.

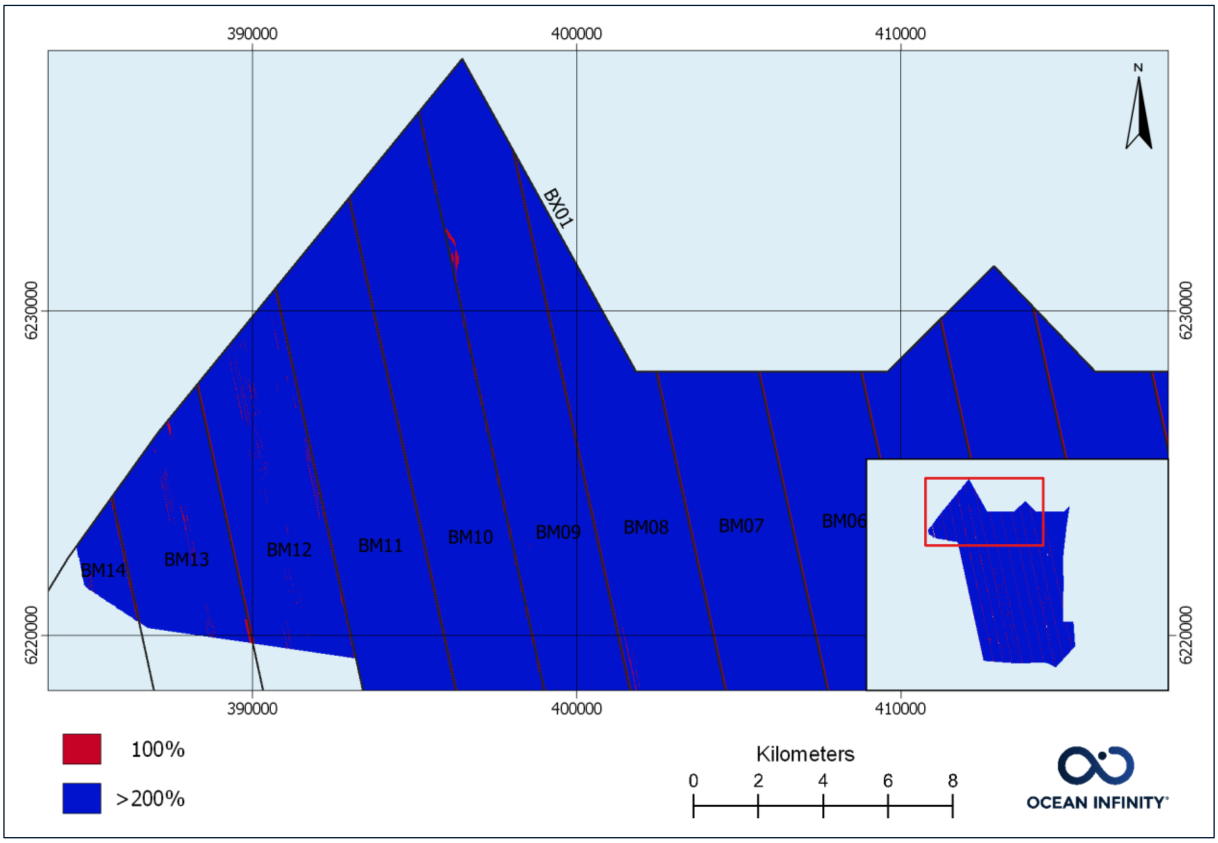


Figure 43 Coverage map of NSA1 survey area (1/6).

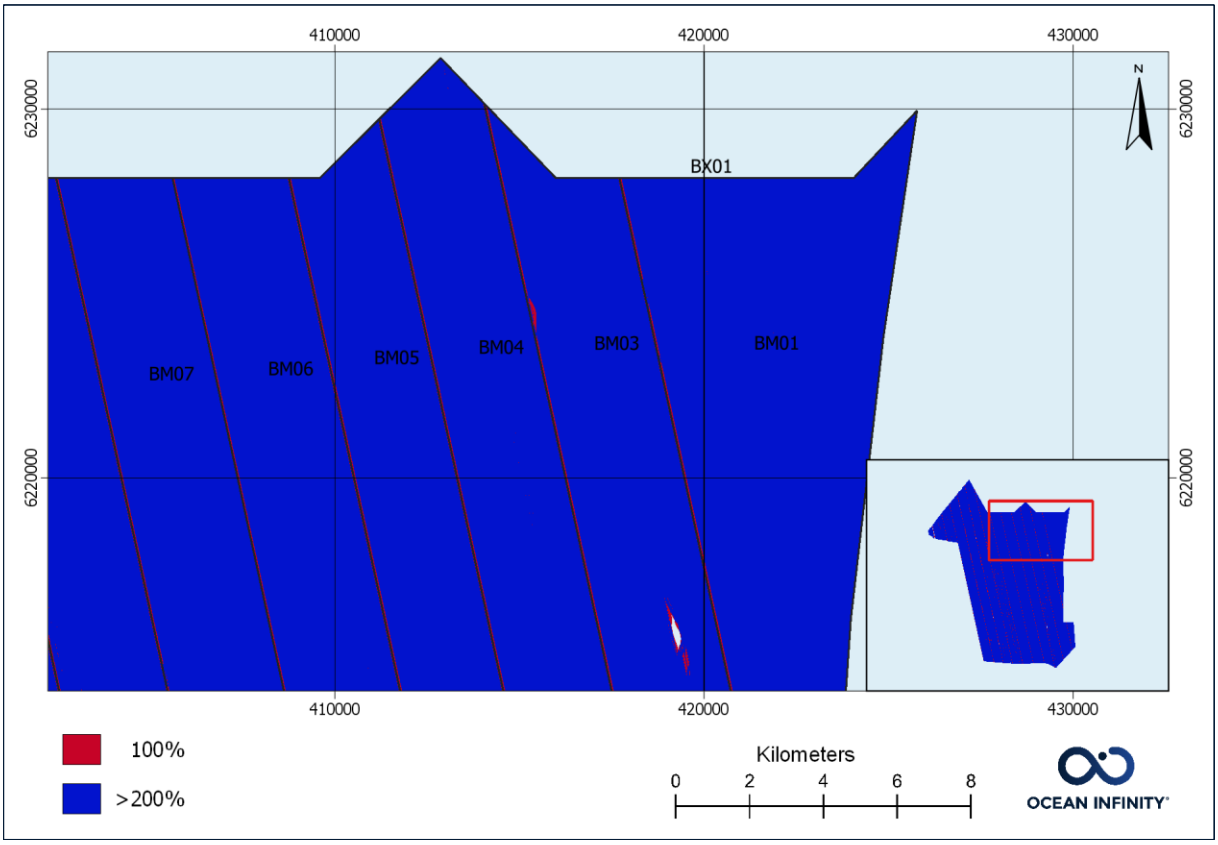


Figure 44 Coverage map of NSA1 survey area (2/6).

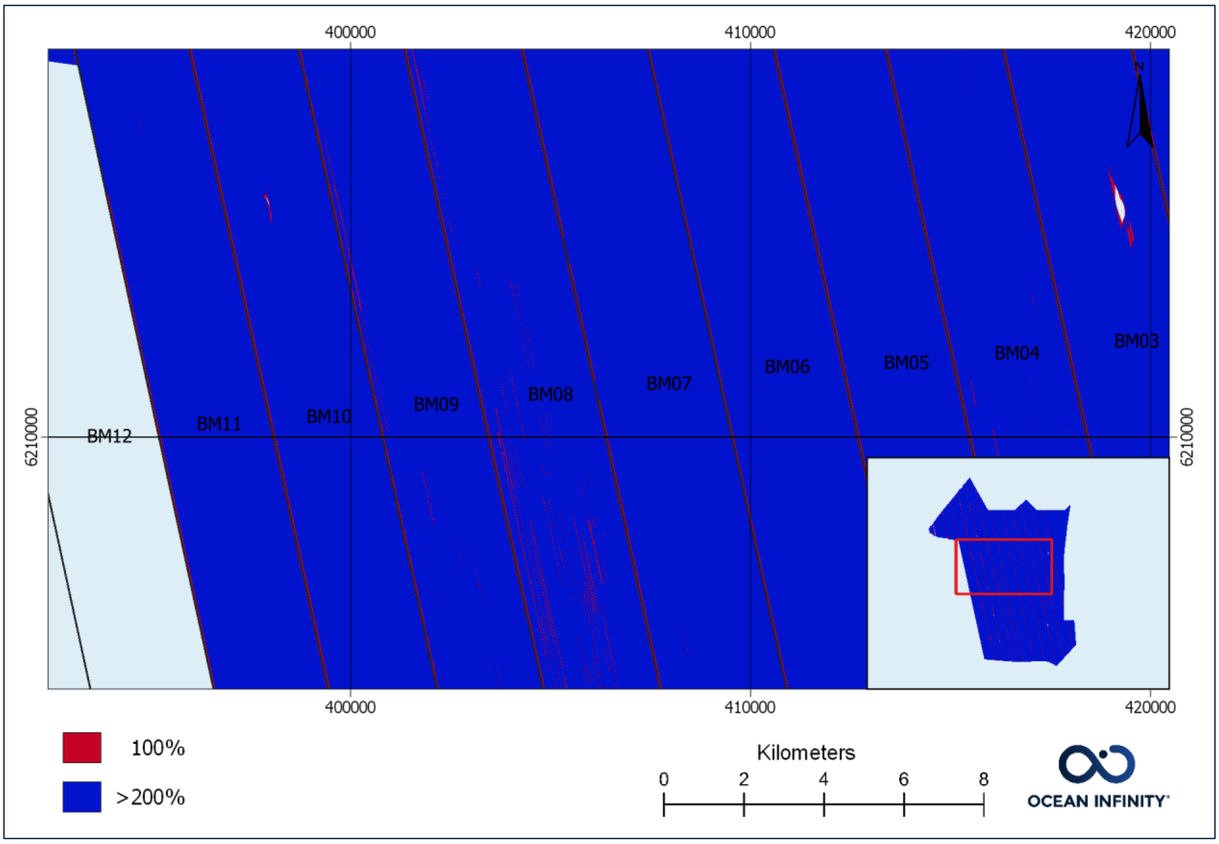


Figure 45 Coverage map of NSA1 survey area (3/6).

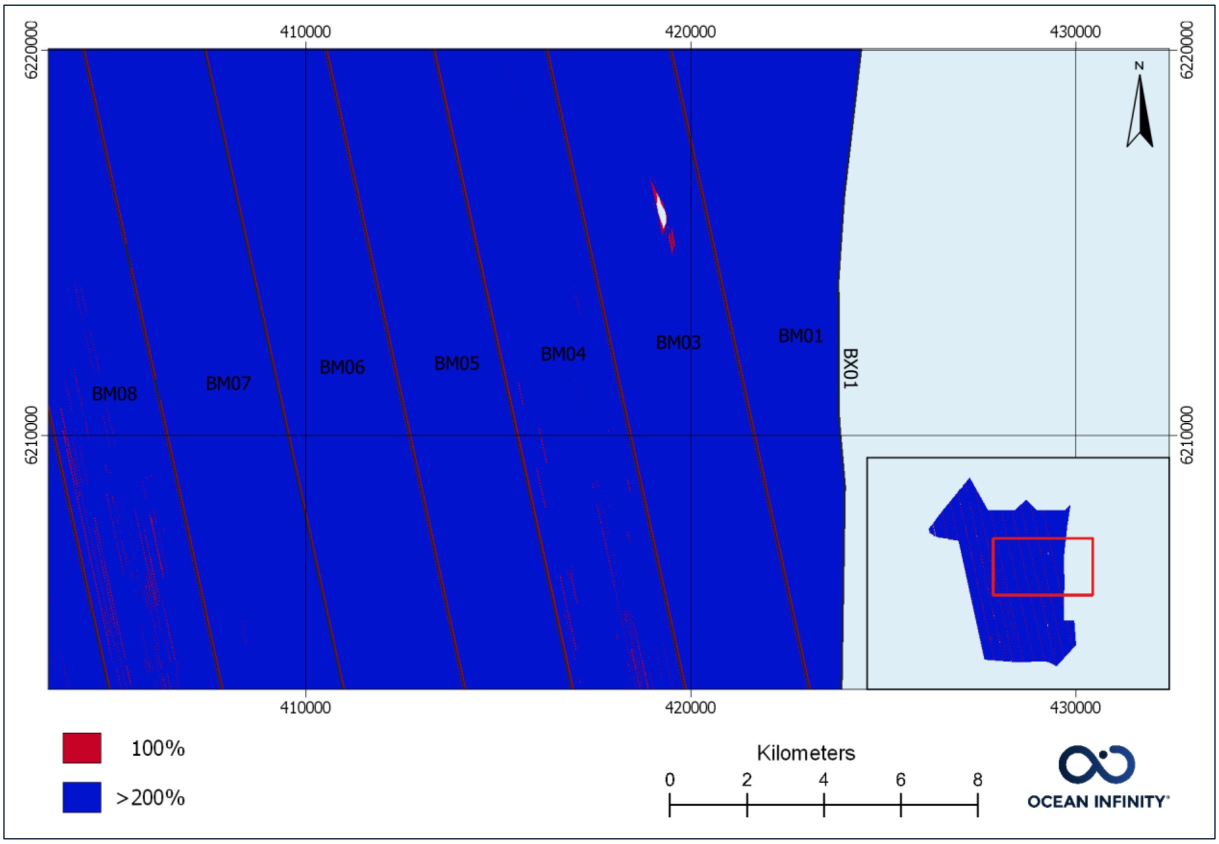


Figure 46 Coverage map of NSA1 survey area (4/6).

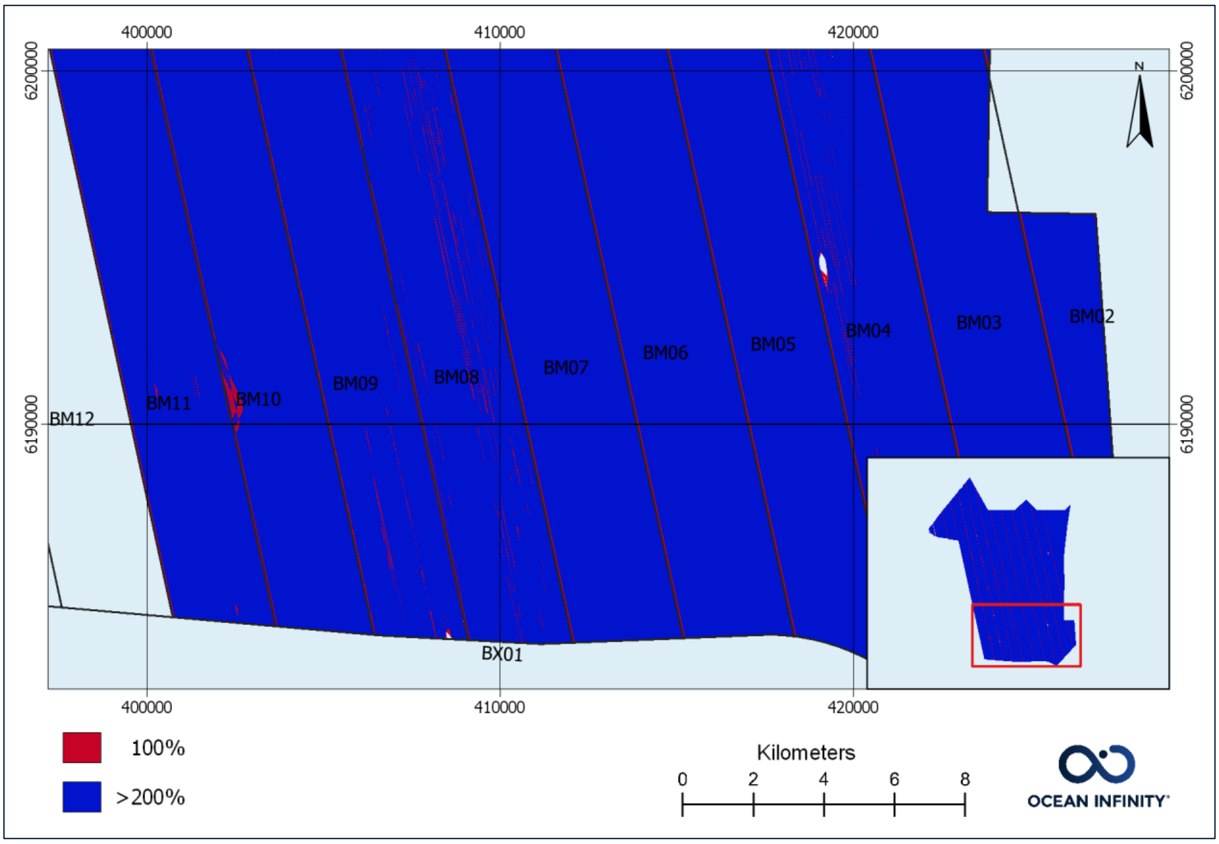


Figure 47 Coverage map of NSA1 survey area (5/6).

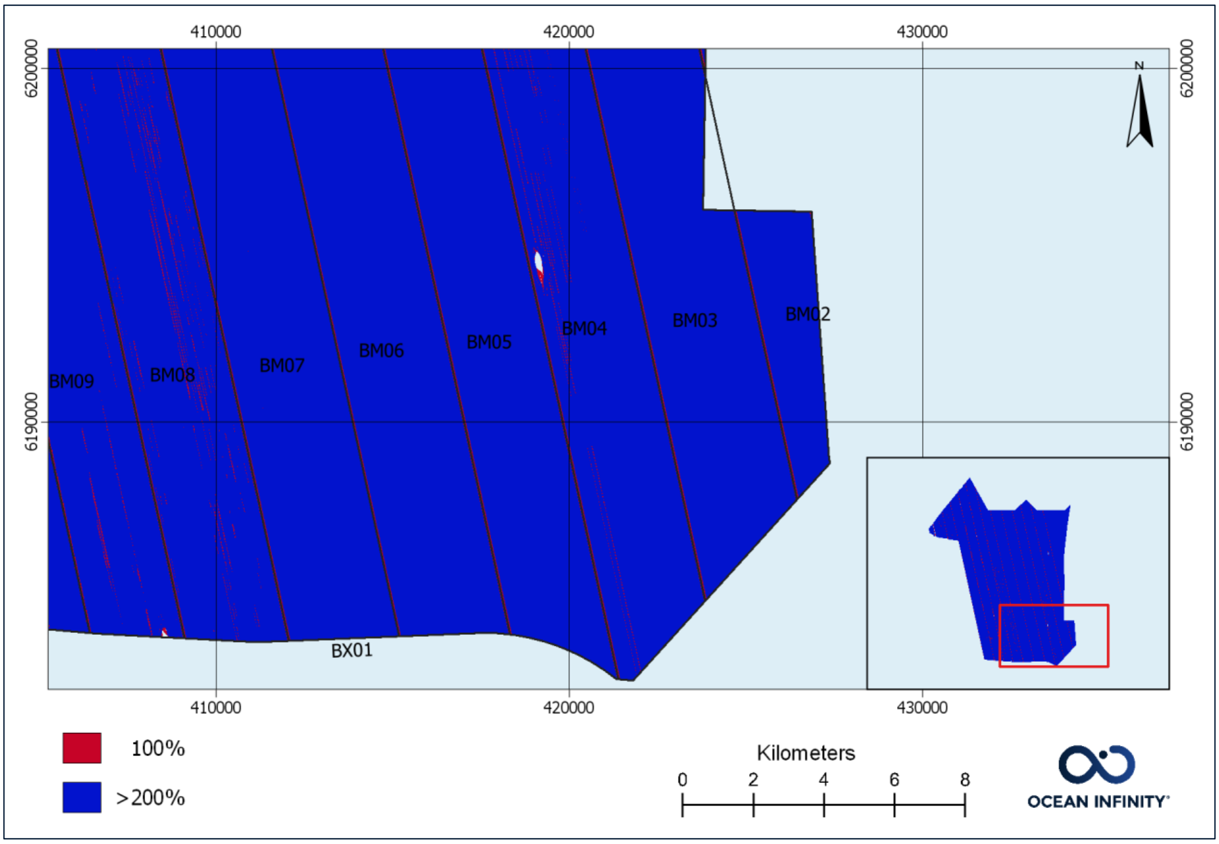


Figure 48 Coverage map of NSA1 survey area (6/6).

5.4 Sub-Bottom Profiler Data

The Innomar data was collected in order to acquire good resolution data in the upper 10 m of the seabed. The settings of the Innomar were adjusted to achieve this. Three different vessels (M/V Geo Ranger, M/V Northen Maria and M/V Northen Franklin) were used to collect the SBP data.

SBP data quality was generally good for all three vessels. (Figure 49, Figure 50 and Figure 51). Penetration achieved up to 10 m (target depth), this was variable across the site due to changing ground conditions; achieved penetration was dependent on the distribution of channelling beneath an initial coarse unit and dependent on the presence of observable units below H10. Occasionally Innomar data was impacted by bad weather.

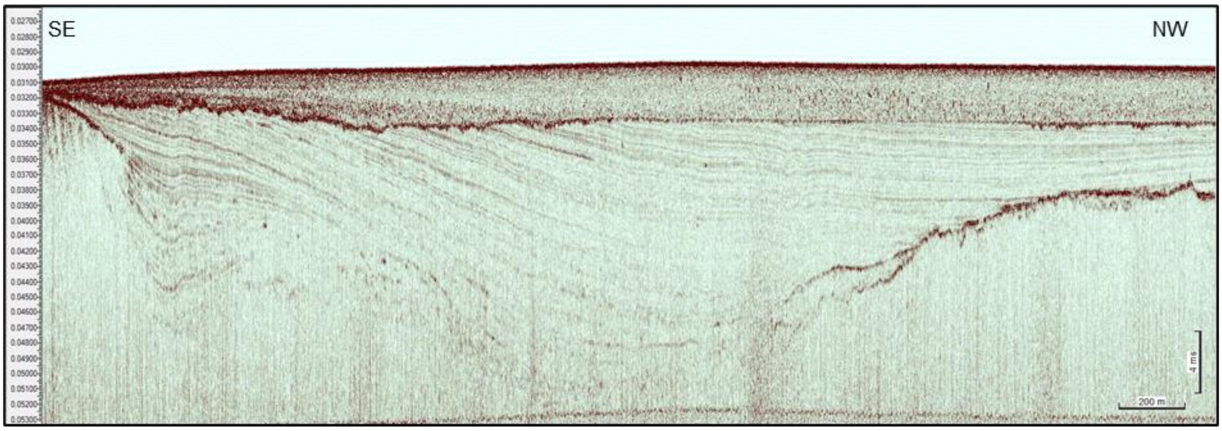


Figure 49 Innomar data (M/V Northen Maria) showing achieved penetration of 10 m.

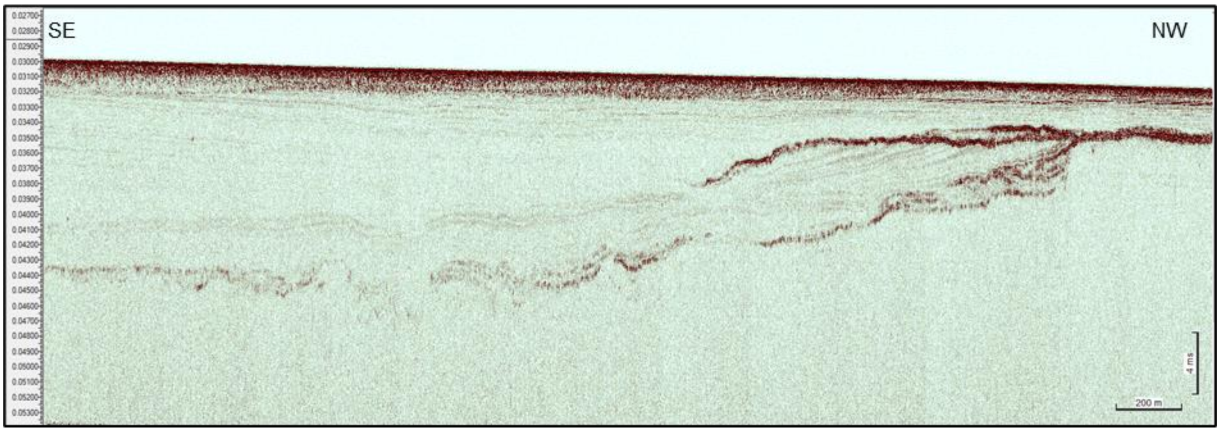


Figure 50 Innomar data (M/V Northen Franklin) showing achieved penetration of 10 m.

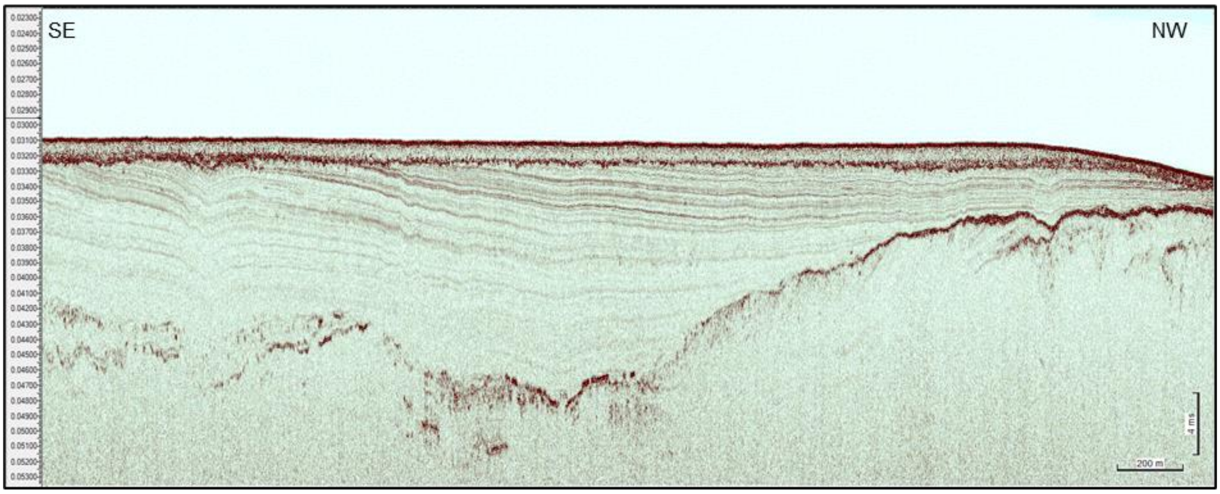


Figure 51 Innomar data (M/V Geo Ranger) showing achieved penetration of 10 m.

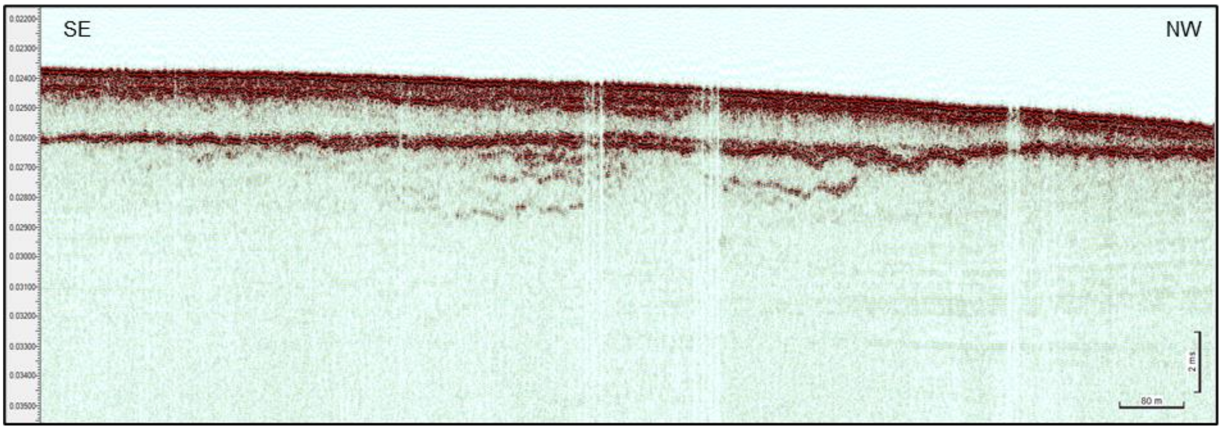


Figure 52 Processed Innomar data showing vertical striping due to weather conditions.

Due to a wide range of measured water velocities, apparent offsets at the seabed can be observed in the time domain. However, the appropriate velocities are applied to the SGYs during depth conversion and cross-checked against the MBES DTM. At the client request, velocity SGYs were also provided enabling the depth conversion to be re-produced, if required.

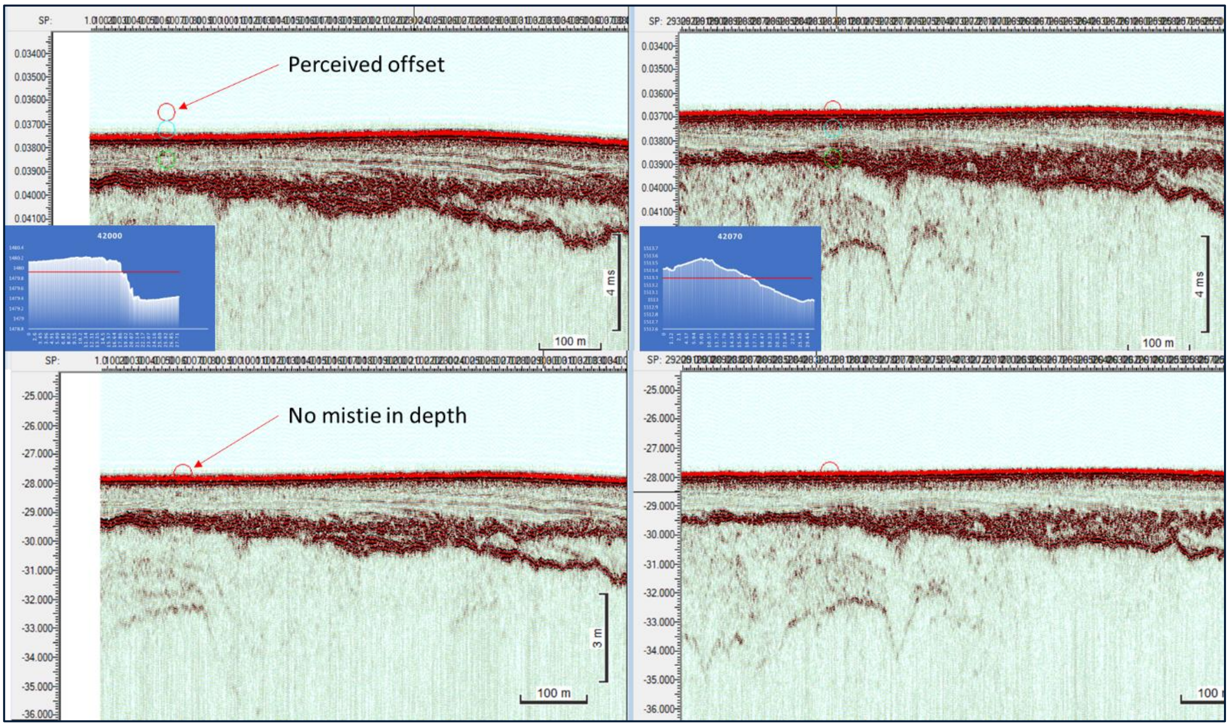


Figure 53 Demonstration of offsets in the time domain, corrected in the depth domain.

5.5 Magnetometer Data

The aim of the magnetometer survey was to identify large anomalies as well as linear features such as existing infrastructure (cables and pipelines) and unknown linear debris.

MAG data quality was generally good. System noise levels were below +/- 0.5 nT and no data was rerun due to noise masking. Noise profiles of all three vessels that acquired magnetometer data during the project are displayed below in Figure 54. The system noise QC is displayed in the profile by presenting the difference between incremental raw nT values in the Y axis and the distance along the line in the X axis.

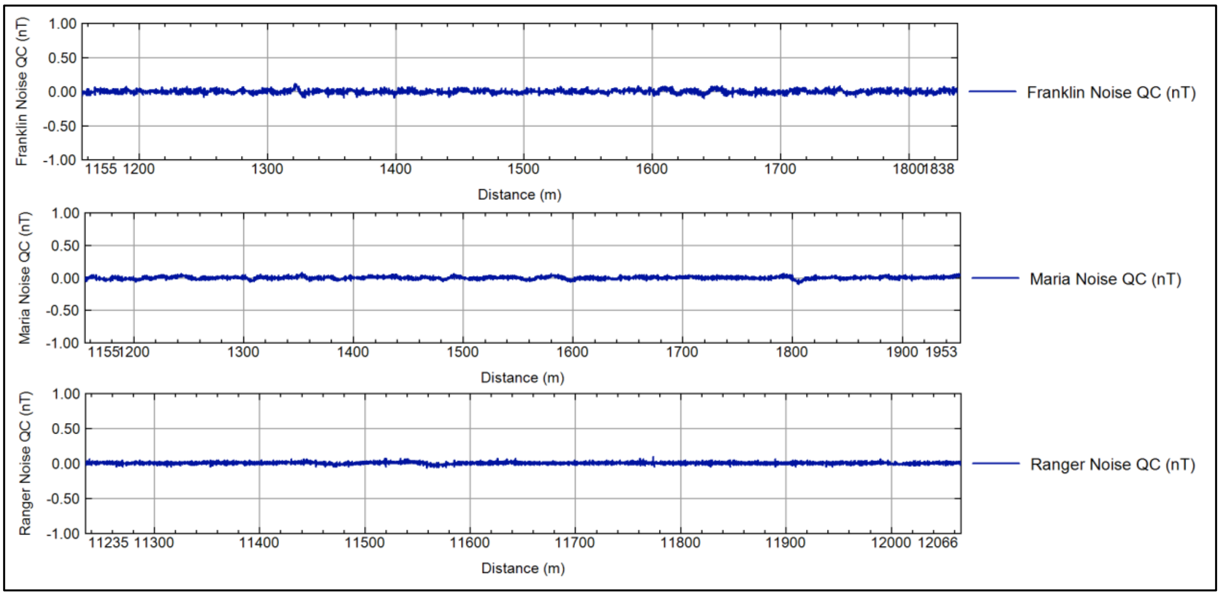


Figure 54 Noise QC of the raw nT data from the three vessels that acquired magnetometer data.

In general, the sensor positioning throughout the survey was very good and minimal dropouts were witnessed from the USBL systems onboard all vessels. Where navigation was lost the total time of dropout had negligible impact on the overall positioning of the magnetometer.

The magnetometer was piggy backed behind the SSS tow fish, therefore its altitude was dictated by the flying altitude of the SSS. It was envisaged that the magnetometer would be flown at an altitude < 7 m during the survey, however due to various factors such as bathymetry and obstacles on the seabed, there were instances when the altitude increased ≥7 m. Reruns were required when the altitude was out of specification (≥7 m for >100 m along track).

A statistical analysis for magnetometer altitude was conducted over the whole NSA1 survey area and the results displayed in Table 30 . A total of 20569.023 km of MAG survey was ran within this area with a mean altitude of 5.48 m. 38.672 km was acquired with the MAG altitude ≥7 m which equated to 0.2 % of the survey as detailed below in Table 30. Note that some instances where the altitude is ≥7 m is during the run-in and run-out of infill lines which will also have overlapping data where the altitude is within specification.

Table 30 Summary of Altitudes statistics above and below 7m during the survey with NSA1 boundary.

Magnetometer Altitude (m)	Distance (km)	Percentage of survey
<7	20530.4	99.8%
≥7	38.7	0.2%

The data was deemed fit to identify large anomalies and existing infrastructure as per the requirements of the work scope. Multiple cables were witnessed within the magnetic data throughout the survey area. Cables that are orientated perpendicular to the direction of survey give the clearest signature and provide the most accurate position. Linear anomalies with a parallel orientation to the direction of survey can result in continuous complex anomalies which mask the surrounding area.

The Nordlink cable ran across the site in a NNW to SSE orientation, similar to the survey line orientation and created a masking of the magnetic data in its vicinity. Figure 55 below shows the profile data of a line run adjacent to the cable. The top profile shows the raw magnetic value with a large background range created by the cable interference. The two lower profiles display the residual value of the same line with the bottom profile showing a reduced Y-axis scale to highlight the complete masking above the anomaly picking threshold.

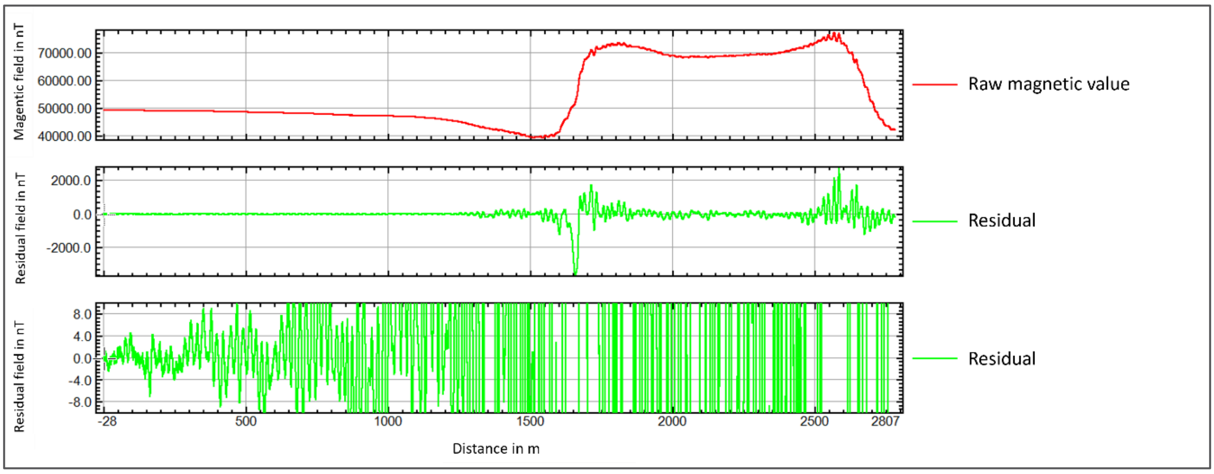


Figure 55 Magnetometer profiles showing magnetic response of cable Nordlink.

Geology within the magnetic data was witnessed in isolated areas throughout survey. It was more prominent within certain areas and its amplitude often exceeded the target picking threshold. All anomalies above the picking threshold have been picked with the survey area. Anomalies believed to be related to geology have been given the comment 'Possible geology' due to their unique characteristic including the anomaly shape, wavelength and correlation with the interpreted SBP data.

Areas of geologic related interference often produced large complex anomalies and correlated at times with the SBP horizon data. Figure 56 below shows the correlation of the raw magnetic residual value with gridded Horizon H35 picked from the SBP data within the northeast corner of NSA1. The black lines in the image represent the residual nT profile displayed spatially on a map which overlays the interpreted Horizon H35 grid. You can see from the image that many magnetic anomalies in this area correlated very well with the sub-sea geological interpretation.

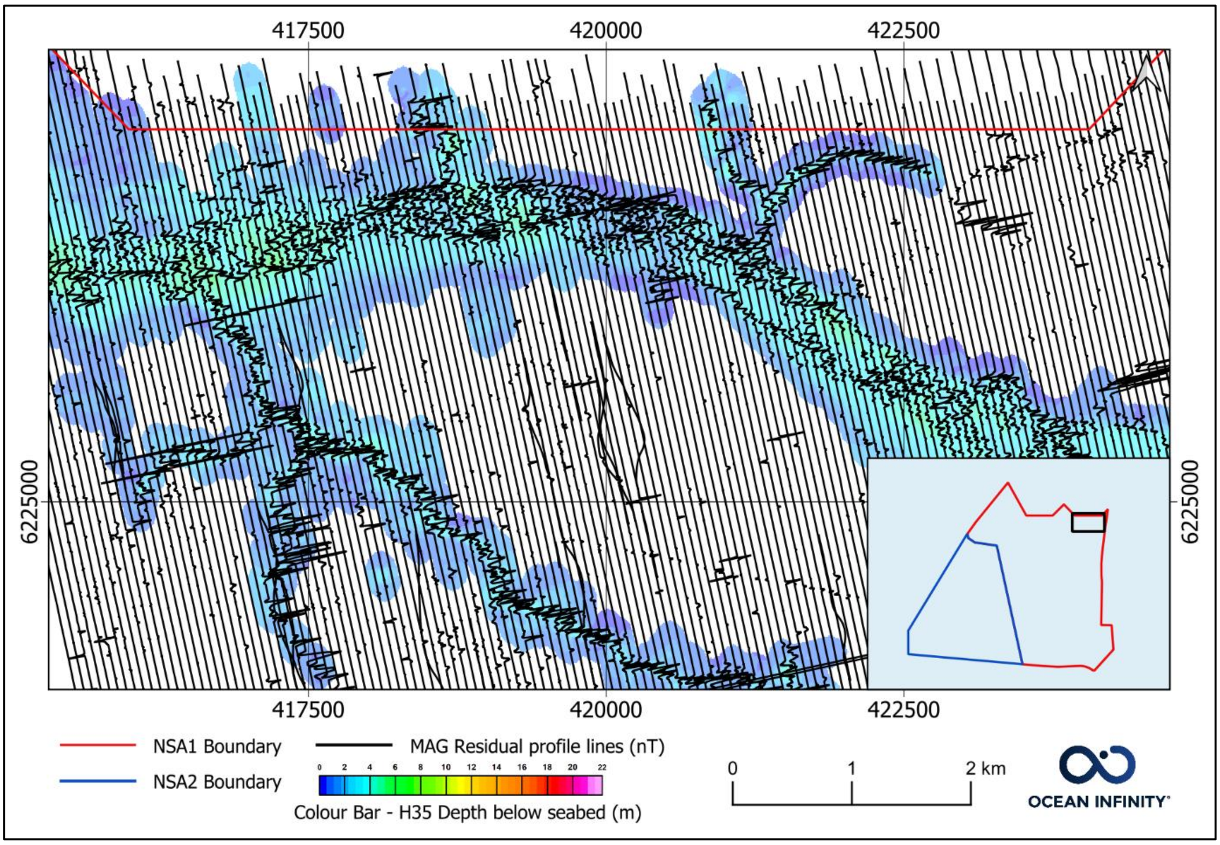


Figure 56 Close correlation between magnetic anomalies and SBP horizon H35 within NSA1 survey area.

6. Background Data and Classifications

Client provided desktop study report together with OI GIS database were the main resources used during data interpretation. Additionally, academic literature resources were used to support interpretations and are listed within the references in Section 11.

6.1 Seabed Gradient Classification

The seabed gradient is classified according to Table 31.

Table 31 Seabed gradient classification.

CLASSIFICATION	GRADIENT
Very Gentle	< 1°
Gentle	1° - 4.9 °
Moderate	5° - 9.9°
Steep	10° - 14.9°
Very Steep	> 15°

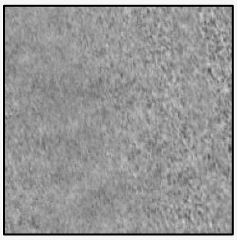
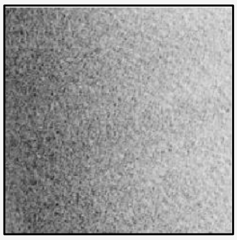
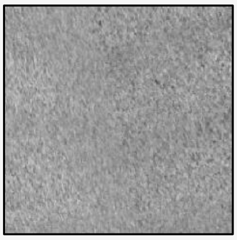
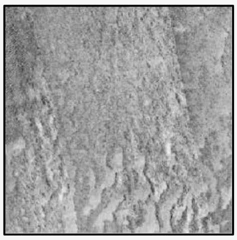
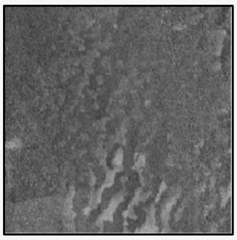
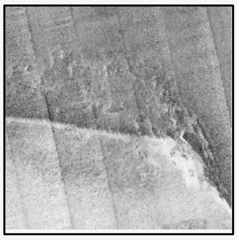
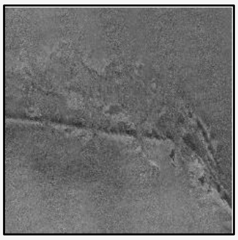
6.2 Seabed Sediment Classification

The seabed sediment classification was derived from the interpretation of the acoustic character of high frequency SSS data, MBES data and multibeam backscatter (MBBS) along with the results from the grab sampling collected in the survey area.

During the review of the SSS survey data, higher acoustic response (darker greys) was interpreted as relatively coarser grained sediments, and lower acoustic response (lighter greys) were interpreted as relatively finer grained sediments. Bathymetric and Backscatter data was mainly used to adjust sediment and seabed features boundaries.

The seabed sediment classification used for WPC NSA1 is described in Table 32. The ID column defines the colour in the charts for the specific sediment type mapped along the area. Primarily the seabed surface geology classes used for charts and Template Survey Geodatabase (TSG) have been made in accordance with that of the Geological Survey of Denmark and Greenland (GEUS) seabed sediment classes.

Table 32 Sediment classification.

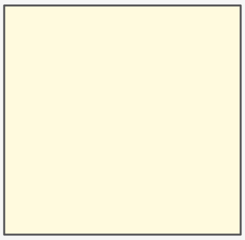
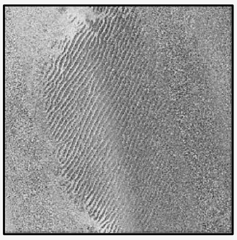
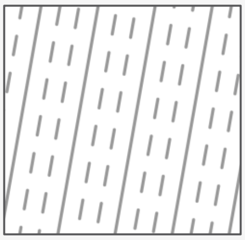
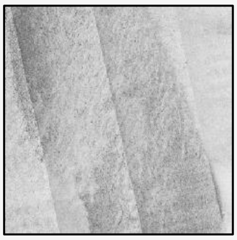
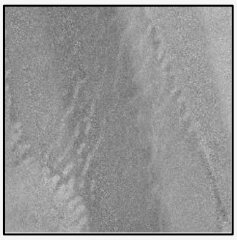
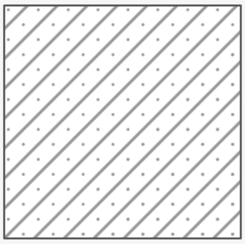
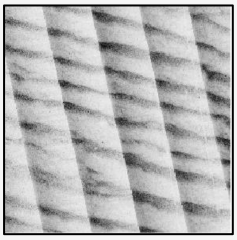
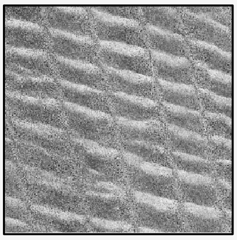
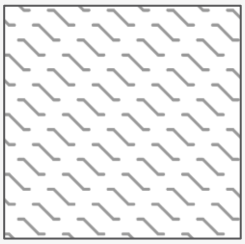
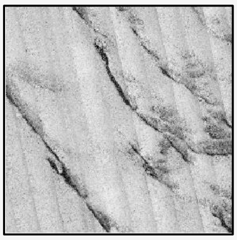
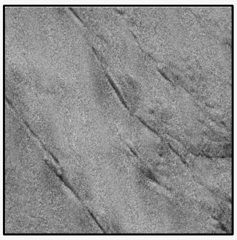
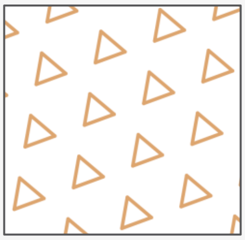
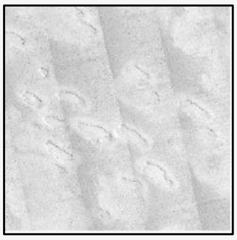
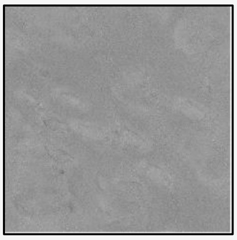
ID	SSS IMAGE	MBBS IMAGE	ACOUSTIC DESCRIPTION	SEABED SURFACE GEOLOGY
			Medium acoustic reflectivity. Slightly grainy to grainy texture, coarse texture in places.	**SAND** Predominantly sand, may have minor fractions of clay, silt and/or gravel.
			Medium to high acoustic reflectivity. Grainy, coarse texture with boulders.	**GRAVEL and coarse SAND** Predominantly gravelly sand; may contain silt. The ratio between sand and gravel can vary within this sediment type.
			Medium to high acoustic reflectivity. Bands of high reflectivity interspersed with pockets of low reflectivity. Slightly grainy to coarse texture with boulders.	**TILL/DIAMICTON** Mixed sediment type of glacial origin. Often covered by a thin layer of sand, gravel, boulder and/or sandy mud washed out of the till.
			Medium to high acoustic reflectivity	**QUATERNARY CLAY AND SILT** Marine, meltwater or lake deposits of clay. Often laminated with sand/silt and/or peat layers.

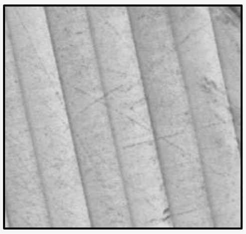
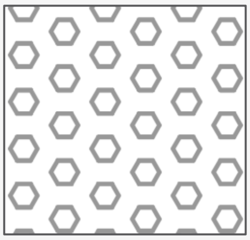
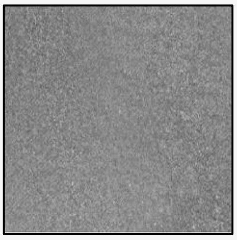
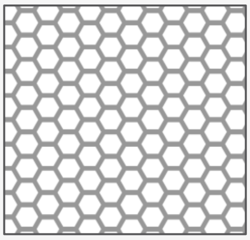
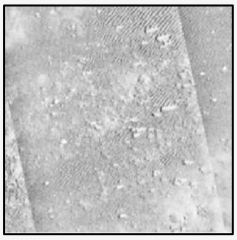
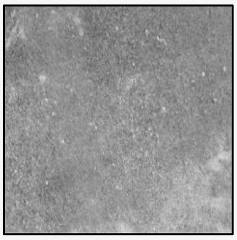
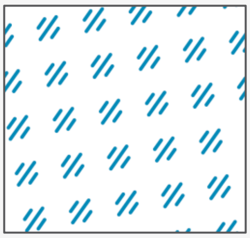
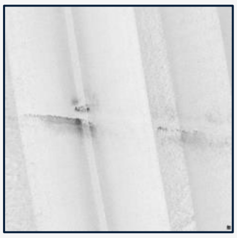
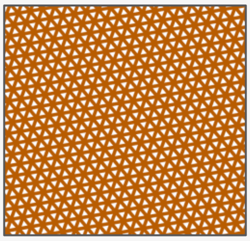
6.3 Seabed Feature / Bedform Classification

The ID column in Table 33 defines the pattern in the charts for the specific feature type.

SSS, MBES and MBBS data have been used for interpretation of the seabed feature boundaries, features are predominantly digitized manually based on acoustic response, texture, geotechnical and background information.

Table 33 Seabed features classification.

ID	SSS IMAGE	MBBS IMAGE	SEABED FEATURE	CRITERIA
			Ripples	Wavelength <5 m Height <0.1 m
			Ripples Large	Wavelength 5 – 15 m Height 0.1- 1 m. Wavelength is the primary classifier.
			Ripples Mega	Wavelength 15 - 50 m Height 1 - 3 m. Wavelength is the primary classifier.
			Sand Waves	Wavelength 50 - 200 m Height 3 - 5 m. Wavelength is the primary classifier.
			Erosional Depression	Areas of seabed erosion.

ID	SSS IMAGE	MBBS IMAGE	SEABED FEATURE	CRITERIA
			Trawl Marks	Linear seabed scaring due to fishing activity.
			Boulder zone type 1: Intermediate boulder density	10- 20 boulders per 50x50 m.
			Boulder zone type 2: High boulder density All >1.0 m	>20 boulders per 50x50 m.
			Disturbed Sediment	Area with marks in seabed due to intervention activity.
			Rock Dump	Extents of rock dumping due to intervention activity.

6.4 Contacts and Anomalies Classification

The SSS contacts were classified according to criteria provided by Energinet, which includes:

- Anchor
- Anchor scar
- Archaeology
- Boulder
- Cable
- Fish Net
- Other

- Pipeline
- Pock mark
- Scour mark
- Soft Rope
- Wire
- Wreck

Contacts classified as "Other" were mainly possible Man-Made Objects that could not be placed in one of the specific debris classifications.

For boulder classification, individual boulders ≥ 1.0 m were picked outside boulder fields. Boulder fields were grouped based on their spatial density as follow:

< 10 boulders per 50x50 m – not a boulder zone

10 - 20 boulders per 50x50 m – boulder zone type 1: Intermediate boulder density zone

> 20 boulders per 50x50 m – boulder zone type 2: High boulder density zone

Only boulders ≥ 2.0 m were interpreted inside of boulder fields using the SSS data. However, for defining boulder fields, all boulders ≥ 0.5 m were used.

6.5 Sub-Seabed Geology Classification

The subsurface geological interpretation and description is based on the assessment of the Innomar SBP data acquired within the survey area.

The descriptions of the seismic units are provided according to the seismic facies, stratigraphic boundaries, and internal reflector terminations. The interpreted reflectors represent the base of the overlying unit. The units used are presented in Table 34.

For further information on the processing steps and classification methods, see Section 4.4.

Table 34 Summary of seismic reflectors.

Unit name (corresponding reflector)	Acoustic Facies and Internal Configuration	Expected Composition	Probable Geological Age	Kingdom Reflector Colour
GHz_Gas	High amplitude causing acoustic blanking			**Dark Red**
GHz_Peat	Medium to high amplitude	Organic material	Holocene	**Sienna**
Unit 10 (H10)	Low to medium amplitude and chaotic	SAND with local variations in grain size from silty to gravelly	Holocene	**Cyan**
H20_internal	Medium to high amplitude	SAND with local variations in grain size from silty to gravelly	Holocene	**Spring Green**
Unit 20 (H20)	Low to medium amplitude, semi-transparent, with strong chaotic or	SAND with local variations in grain	Holocene	**Green**

Unit name (corresponding reflector)	Acoustic Facies and Internal Configuration	Expected Composition	Probable Geological Age	Kingdom Reflector Colour
	continuous to semi-continuous internal reflectors	size from silty to gravelly		
H30_internal	Medium to high amplitude	SAND with local variations in grain size from silty to gravelly	Holocene	**Light Gold**
Unit 30 (H30)	Well layered unit with low to medium amplitude concordant internal reflectors	SAND with local variations in grain size from silty to gravelly	Holocene	**Yellow**
Unit 35 (H35)	Medium to high amplitude and well laminated	Channel infill. CLAY, SILT and SAND. Organic material	Holocene	**Dodger Blue**
Unit 37 (H37)	Low to medium amplitude and well laminated	Channel infill. CLAY, SILT and SAND. Organic material	Holocene / Weichselian	**Blue**
Unit 40 (H40)	Medium to high amplitude and chaotic with a mix of small channels, acoustically transparent and sub parallel reflectors	SAND/ SILT/ CLAY/ organic material	Weichselian	**Gold**

6.6 Grab Sample Classification

For details of the grab sample classification, see section 8.9 and Appendix B.

7. Geological Framework

The Danish Basin the North Sea basin is separated from the Scandinavian Shield to the east by the WNW-ESE striking Sorgenfrei-Tornquist fault zone. The Ringkøbing-Fyn High, located further south, emerged during the Late Permian (Pre-Zechstein) as a result of tectonic subsidence (Vejbæk, 1997; Vejbæk et al., 2007). The survey area is located on the most northern section of the Ringkøbing-Fyn High (Figure 57). This structural feature divides the Danish sector of the North Sea basin into the North German Basin, located south of the Ringkøbing-Fyn High, and the Danish-Norwegian Basin, north of Ringkøbing-Fyn High. The western fraction of the high is bounded by the Central Graben in the West and the Horn Graben in the east, which is characterized by extensional faults, displaying half-graben structural settings. Mainly normal faults belong to an early Permian rifting event based on the stratigraphic dating method. However, extensional faults related to a rifting phase older than Permian extension is limited to the southwestern part of the Ringkøbing-Fyn High (Javed, 2012). The Ringkøbing-Fyn Highs characterised as an area where the crystalline basement is shallow compared to the adjacent basins (Clausen et. al., 1999). During the Zechstein (Late Permian), four to five cycles of evaporites were deposited, infilling the structural lows (Sorgenfrei and Buch, 1964; Vejbæk et al., 2007). Further deepening of the North Sea basin resulted in thousands of metres of Mesozoic sediment deposition over the evaporites. In the survey area only thin deposits of salt, if present at all, are expected. The oldest deposits in the screening area are probably sandstones and claystones of Lower Permian age to the north and sandstones, claystones and shales of Triassic age to the south (Nørgaard-Pedersen et al., 2023).

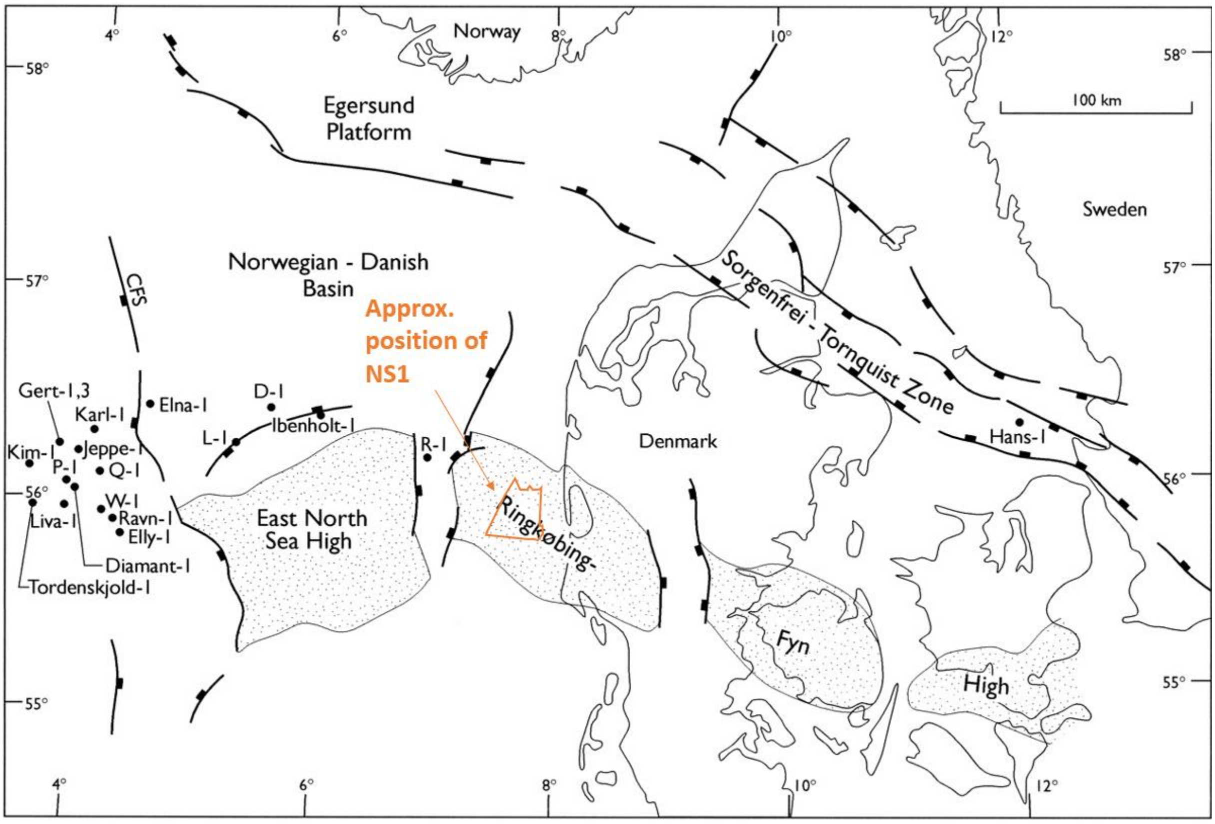


Figure 57 Major Danish structural elements (After Stemmerik et al., 2000).

During the Late Cretaceous, a major tectonic inversion episode affected the North Sea region, associated with initiation of the Alpine Orogeny, (Clausen and Huuse, 1999; Japsen, 2000). Cretaceous tectonism was followed by sequential episodes of uplift and major sea level fluctuations during the Paleogene to Neogene (Japsen et al. 2008). These events resulted in variable rates and types of sediment deposition. A major regional unconformity occurs between the Upper Eocene and lower Upper Oligocene, Brejning Fm. (Mica Clay) (Rasmussen et al., 2010). The Neogene deltaic deposits show a general shift moving from east to west. The Miocene succession is hundreds of metres thick in the Danish sector of the North Sea. From the rim of the North Sea basin at the Sorgenfrei-Tornquist Zone towards the central basin, the Pre-Quaternary deposits are successively younger below the base of the Quaternary. The Quaternary base represents an unconformity east of the so-called transition zone in the North Sea (Nielsen et al. 2008, Japsen 2003) (Figure 58). West of the transition, the Quaternary sequences rest conformably on Pliocene deltaic sediments (Nielsen et al. 2008). Often, the unconformity shows a significant relief due to Quaternary glacial processes and occurs at depths of a few hundred metres within valley structures to just below the seabed along the Danish west coast (Andersen, 2004; Huuse and Lykke-Andersen, 2000b; Leth et al., 2004, Novak and Duarte 2018).

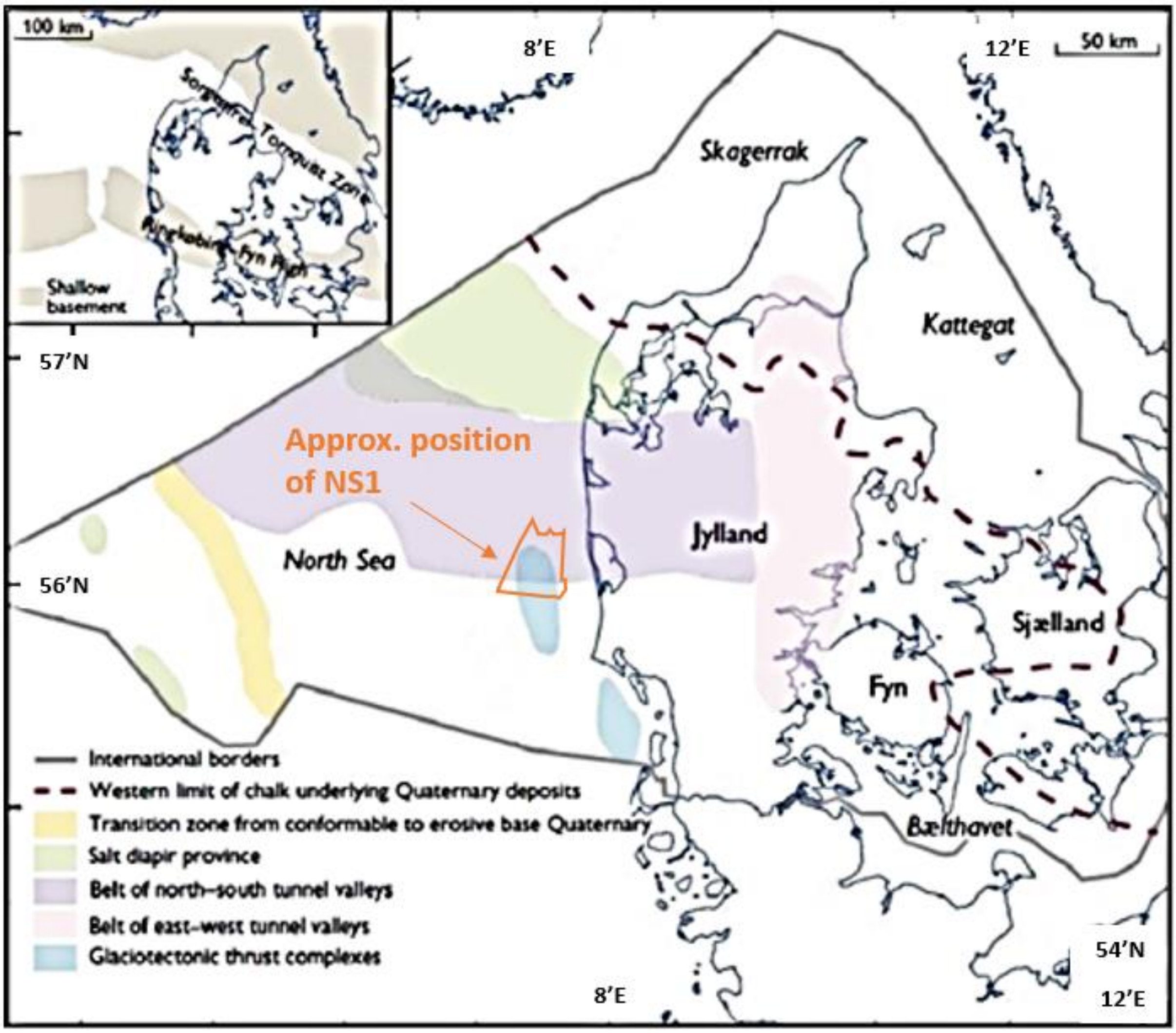


Figure 58 Regional geological map (After Nielsen et al., 2008).

Only a few studies have been performed on the Quaternary deposits in the Danish North Sea. However, onshore studies provide a decent foundation for outlining the regional geology in the eastern North Sea (e.g. Sjørring and Frederiksen, 1980; Ehlers, 1990; Sandersen and Jørgensen, 2003; Pedersen, 2005; Jørgensen and Sandersen, 2006; Jacobsen, 2003; Høyer A-S et al., 2013; Houmark-Nielsen, 2007).

In general, the Quaternary sequence thins from the central North Sea towards the Danish mainland. The Elster and Saale ice sheets extended across the entire North Sea (Figure 59). Glaciation came from the northwest over northeast and from the Baltic region (Sjørring and Frederiksen, 1980; Ehlers, 1990). The Weichselian ice sheet extended north and east of the main stationary line at the Late Glacial Maximum (LGM), which was located from inland Jutland towards the northwest into the North Sea (Figure 59). Morphological elements such as moraine ridges and elongated boulder reefs, occurring perpendicular to the main stationary line, indicate the location of the ice boundary on the seabed west of the Thyborøn at the Danish west coast (Nicolaisen, 2010). Onshore, southwest of the LGM, the so called "hill islands" (Dalgas, 1867), which outline the Saalian landscape, are found to extend into the North Sea (Larsen, 2003; Larsen & Andersen, 2006, Leth et al., 2001; Anthony, 2001; Leth, 2003). Morphological remnants are absent on the seabed due to marine erosion. However, seismic profiles reveal horizons that have been interpreted to represent this same landscape.

Large-scale glaciotectonic thrust complexes have been identified in the Danish North Sea, as well as onshore the Danish mainland (e.g. Huuse and Andersen 2000a, 2000b, Larsen and Andersen 2005, Vaughan-Hirsch and Phillips 2017, Novak and Duarte 2018, Høyer et al. 2013, Shack Pedersen 2005, Jacobsen 2003). In the eastern North Sea, the décollement surfaces are located in the Miocene or in the Quaternary level, and the thrust blocks comprise these sediments. The formation of glacial tectonic complexes found to the west and south of the Weichselian LGM boundary are attributable to the Saalian or older ice cover (Andersen, 2004; Huuse and Lykke-Andersen, 2000b; Vaughan-Hirsch and Phillips, 2017).

Systems of buried shelf valleys, 100-300 m deep and several tens of kilometres long, are present (Figure 59) (Andersen, 2004; Huuse and Lykke-Andersen, 2000b; Novak and Duarte 2018). The submarine valleys can be correlated to onshore valleys and are considered to be of the Elster and Saale ages. Younger, reactivated Saale valleys have been found north and east of the Weichselian main stationary line (Smed 1979, 1981a; Jørgensen et al., 2005).

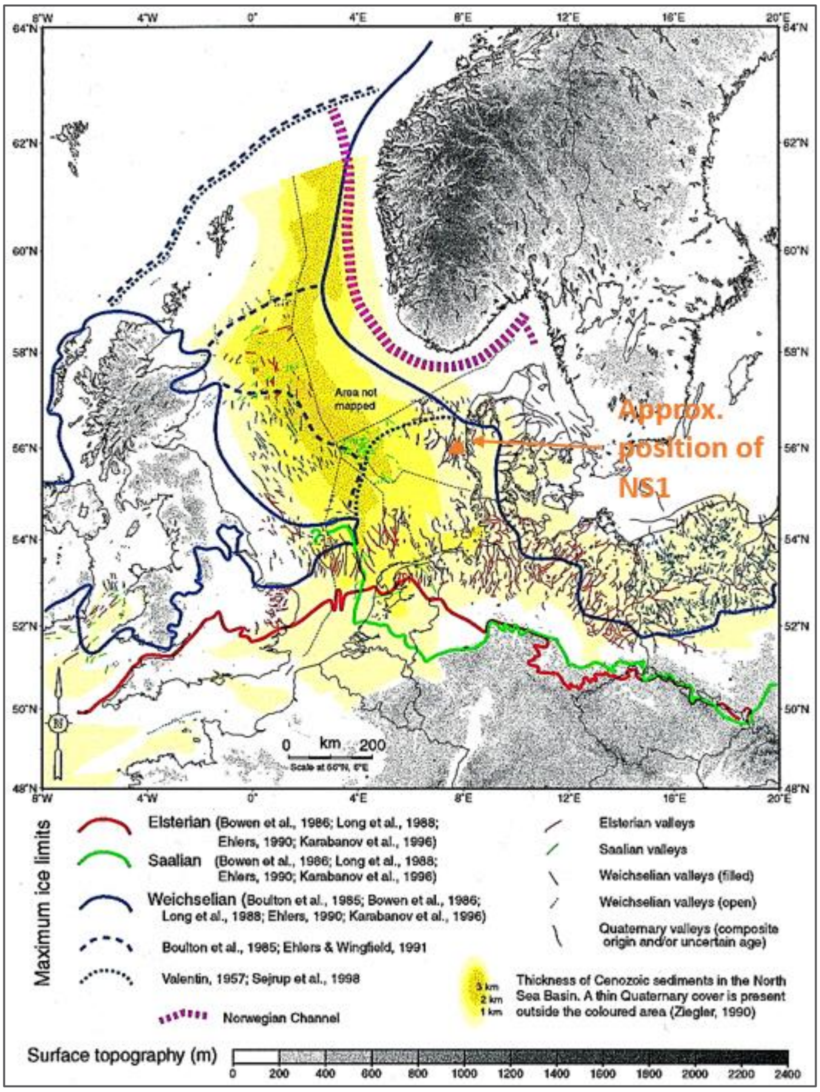


Figure 59 The Quaternary glaciations and an overview of Quaternary valleys in northwest Europe. (Huuse, M., and Lykke-Andersen, H. 2000).

The Paleo-North Sea extended across the region during the Eemian period. Eemian deposits are described both on and offshore in the south-westerly North Sea (Konradi et al., 2005), and Eem deposits representing valley infill were found in a borehole in the Vesterhav area (Fugro 2014).

Deposits from the Weichselian glaciations comprise tills alternating with glaciofluvial sand and gravel, glaciolacustrine clay, silt, and sand, toward the north and east of the main stationary line. Towards the west and south of the LGM, glaciofluvial sand and gravel were deposited in morphological lows above the older Saale landscape (Houmark-Nielsen, 2007). The LGM occurred in the region around 22ka BP. The glaciers´ subsequent retreat generated accommodation space close to the ice front, where deposition of glaciolacustrine clay filled in, e.g Younger Yoldia Clay around 16-15ka BP. As Weichselian ice melted back, the subglacial-generated valleys emerged and laminated clay, silt, and fine sand deposited in the valleys.

The removal of the glacial load triggered isostatic rebound and a regression that took place until 11ka BP. During this timeframe, relative sea level was, at a minimum, 55 to 45 metres lower than present, thus maintaining the eastern Danish shelf above sea level. Terrestrial conditions and rising temperatures increased organic material production, resulting in peat accumulations. This marker horizon has been found in many survey areas across Danish waters (Leth, 1996; Bennike et al., 1998, 2000; Novak and Björck, 2002; Novak and Pedersen, 2000). In the eastern Danish North Sea, fine-grained material was deposited in sheltered areas between till "islands", e.g, the Agger Clay unit (Leth, 1996). During the Holocene transgression, from 11ka BP to 6 ka BP, the Agger Clay depocenter shifted coastward and offshore low-lying islands were submerged. At the same time, coastal processes overtook the glaciogenic landscape where it was exposed to waves and currents. The result was the formation of spit/platform/lagoon deposits throughout the region (Nielsen and Johannesen, 2004; Johannesen et al., 2008; Novak and Pedersen, 2000).

In the eastern North Sea, metre-thick fossil sand waves were present at Jyske Rev (Leth 1996). These current- and wave-generated structures have often been formed around sandy-gravelly fossil beach ridges. Seismic data depict multiple generations of these events. After 6 ka BP, sea level was at its highest and the North Sea tidal system and coast-parallel Jylland current developed.

A recent mobile sediment unit is the latest deposit and is found to cover major areas of the eastern North Sea seabed. Coast-parallel strong currents and waves generate the active bedforms, i.e., mobile sandwaves and dunes. The Danish Coast Agency has documented bedform migrations of up to 20-50 m per year; the dunes and waves are organized in kilometre-wide areas migrating across an apron of relict gravelly sand (Anthony and Møller, 2003; Anthony and Leth, 2001; Leth et al., 2004).

8. Results

8.1 General

The results from the NSA1 geophysical survey area are presented in this report together with associated north-up and profile charts. The charts are presented in Appendix A. The results of the grab sample campaign are presented in Appendix B

To facilitate survey data management and survey planning, and to allow the fishing community to plan around the survey work, the NS1 survey area was divided into 18 smaller areas, designated BM01 to BM18. An overview image of the survey blocks is found in Figure 3.

To assist with organisation in reporting, the blocks used during the survey operations were also used as a reporting reference when describing the features present.

8.2 Bathymetry

Overall, the bathymetric depth changes moderately over the NSA1 site (Figure 60). The minimum surveyed depth is 15.56 m at 410177.00 E, 6184192.00 N on the sandbank at the southern end of BM08. The maximum surveyed depth is 33.51 m at 387482.00 E, 6226238.00 N within a channel at the northern end of BM13. The depth range across the NSA1 site is therefore 17.95 m.

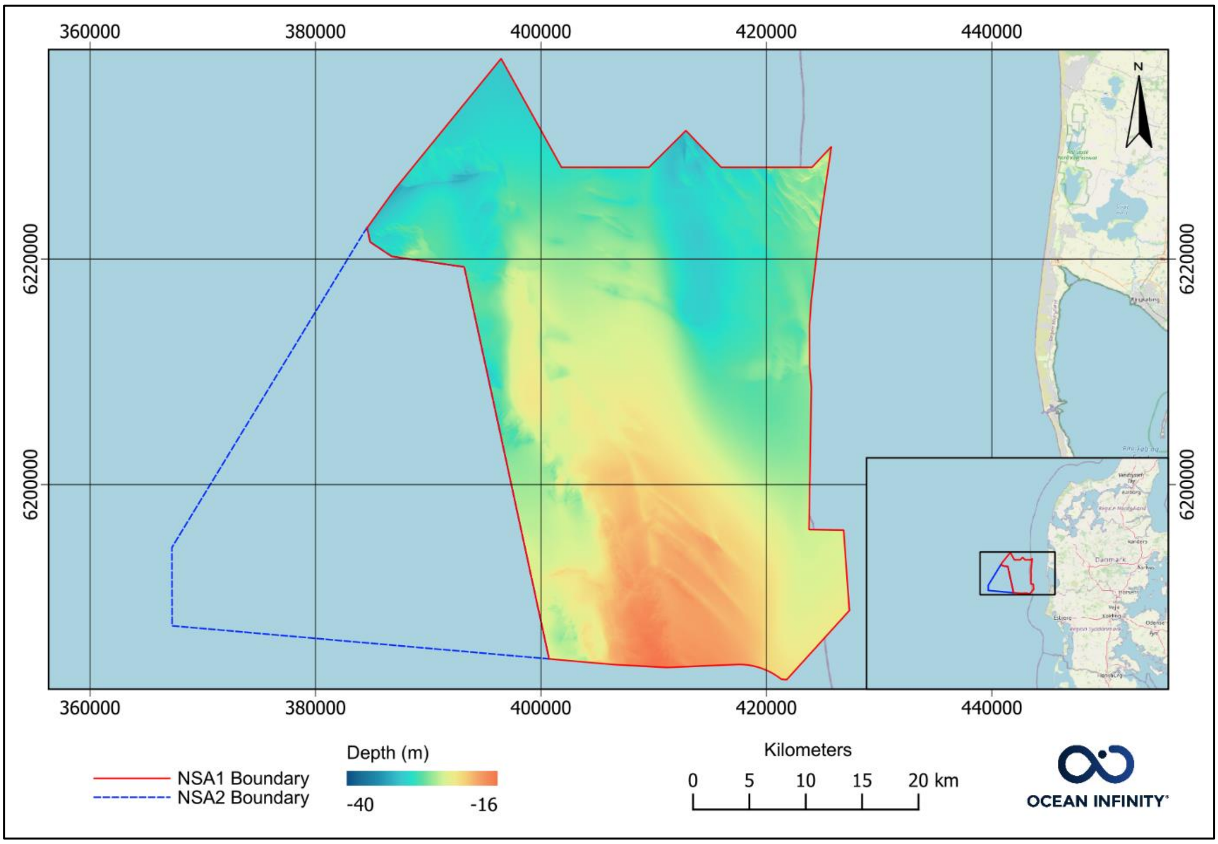


Figure 60 Site bathymetry – NSA1.

When compared against the latest Admiralty Chart (1422) there is a broad correlation of the 20 m contour that delineates the northern extent of the Horns Rev sandbank. However, there is significant variation between the surveyed and charted 30 m contours (Figure 61). This difference is also reflected when comparisons are made against Denmark's Depth Model (DDM) shown in Figure 62. It should be noted that DDM is based on a collection of modern and historical sources, so the accuracy of the data must be considered. However, a surface difference plot (Figure 63Figure 63) generally suggests that the depths to the north-west of the NSA1 site are shallower than perhaps anticipated.

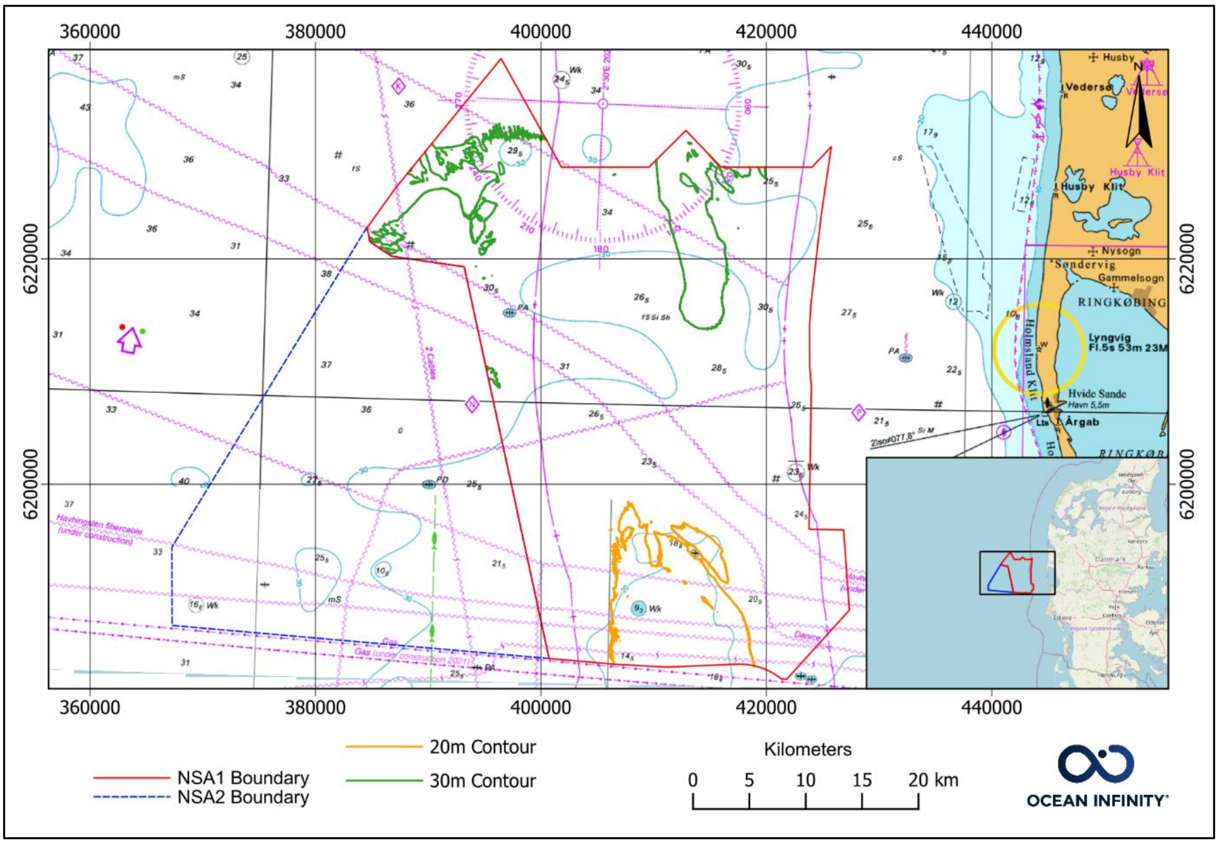


Figure 61 Surveyed contours for NSA1 overlaid on Admiralty Chart.

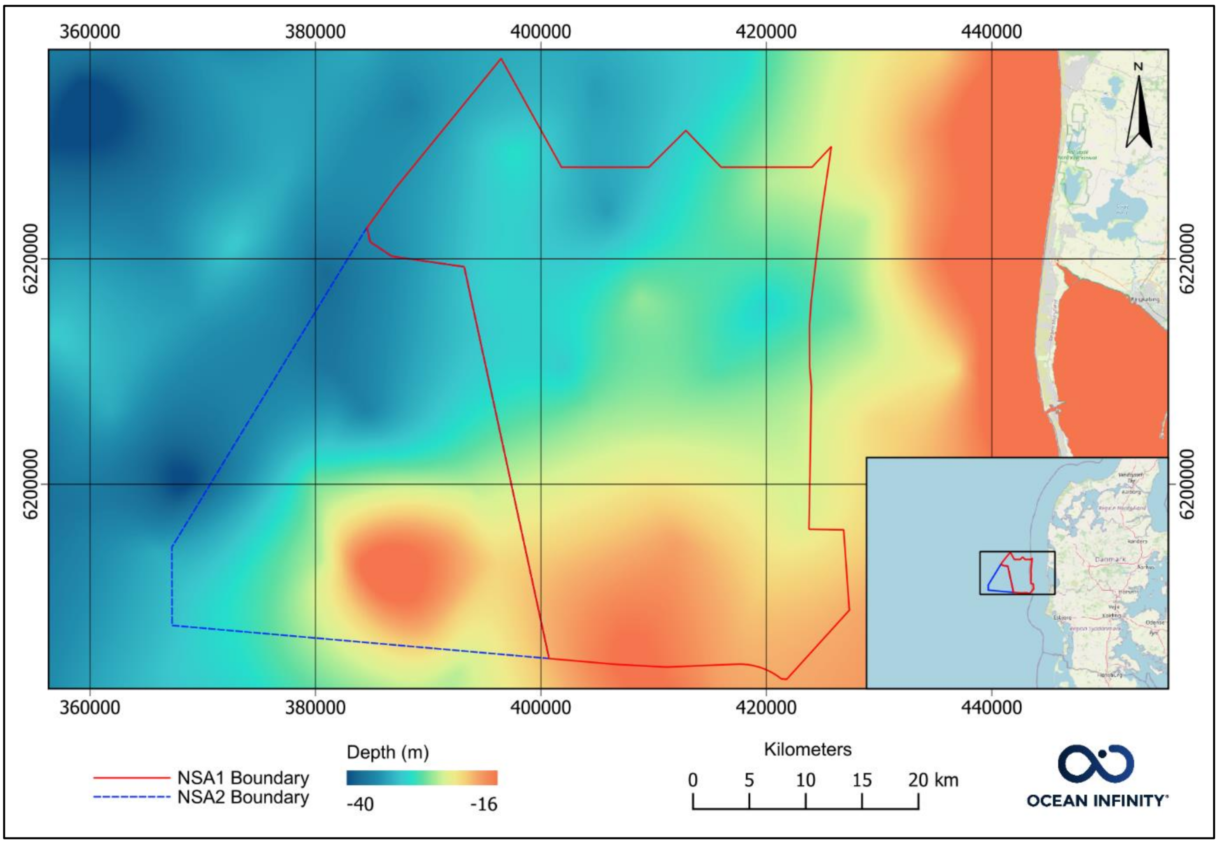


Figure 62 Denmark's Depth Model.

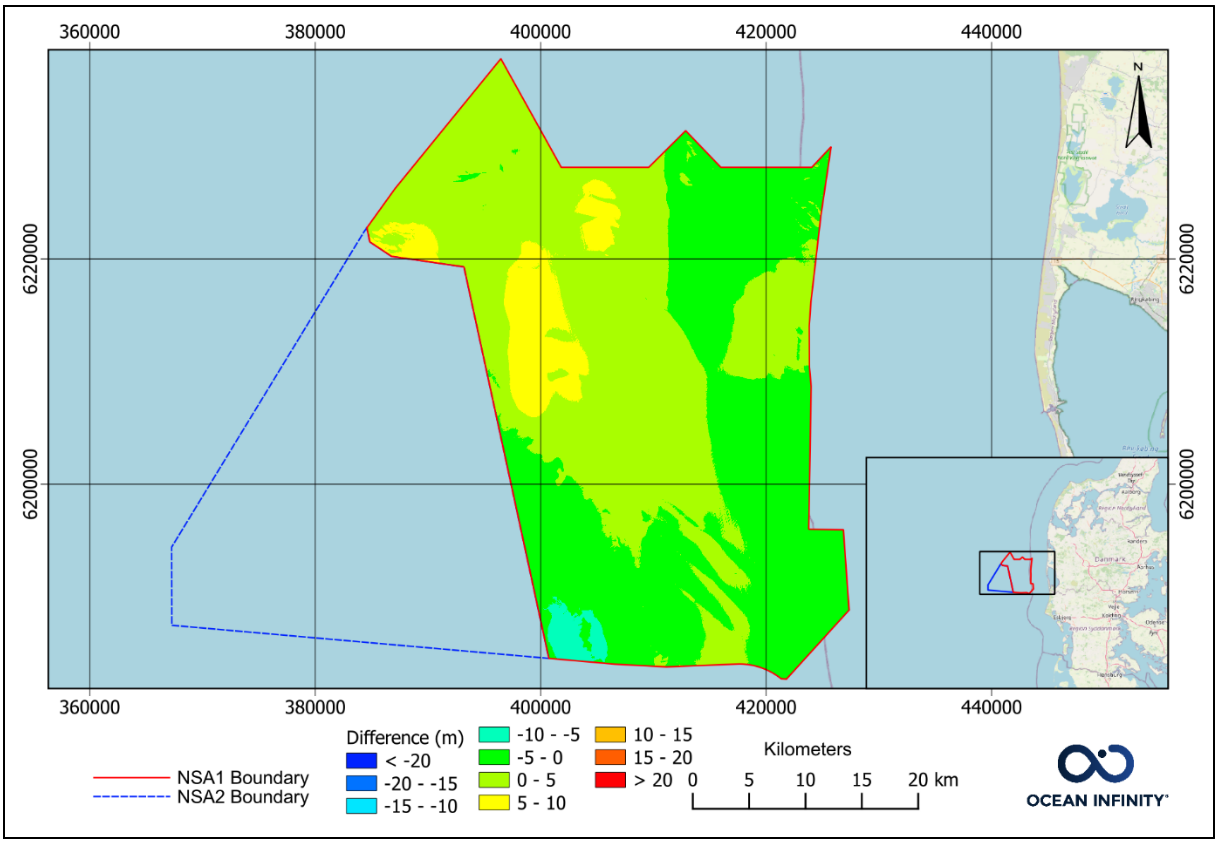


Figure 63 Depth difference NSA1 (DDM minus surveyed depth).

8.2.1 Longitudinal Profiles

Several longitudinal profile lines have been chosen for charting, with a selection of these presented below to aid description of the NSA1 site. Figure 64 displays the five profile lines discussed in the following sections.

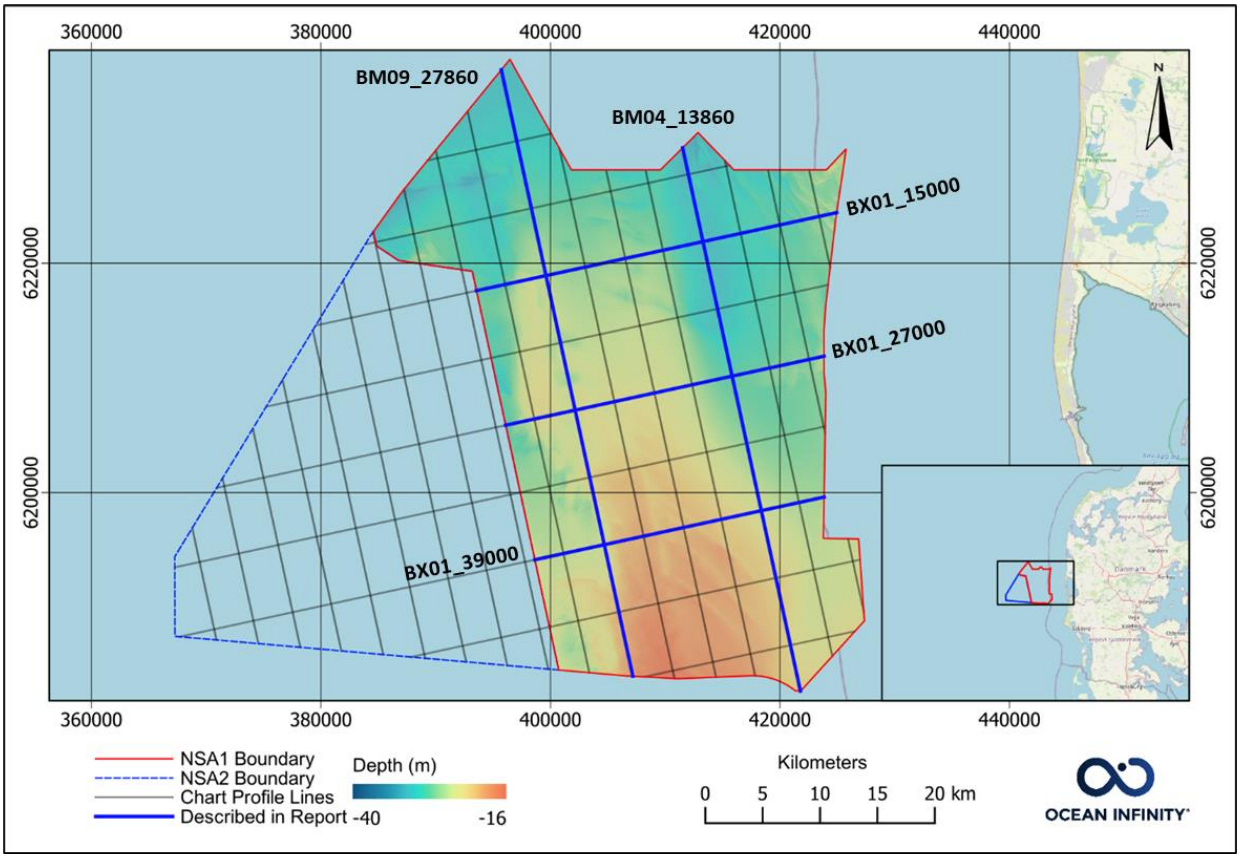


Figure 64 Overview of profile lines presented in charts and report.

8.2.2 BX01_15000 (WSW to ENE)

Examination of the BX01_15000 longitudinal profile (from WSW to ENE) shows the northern extremity of the Horn Rev sandbank commencing around KP 17.500. The profile across the sandbank is quite uniform until its' eastern extent, characterised by a deeper channel around KP 35.000. From this point onwards the profile is unremarkable until a number of sandwaves from KP 42.500 to the extent of the section at KP 46.500. Slope values across the profile are very low, with the largest values occurring on the lee side of the sandwaves (Figure 65).

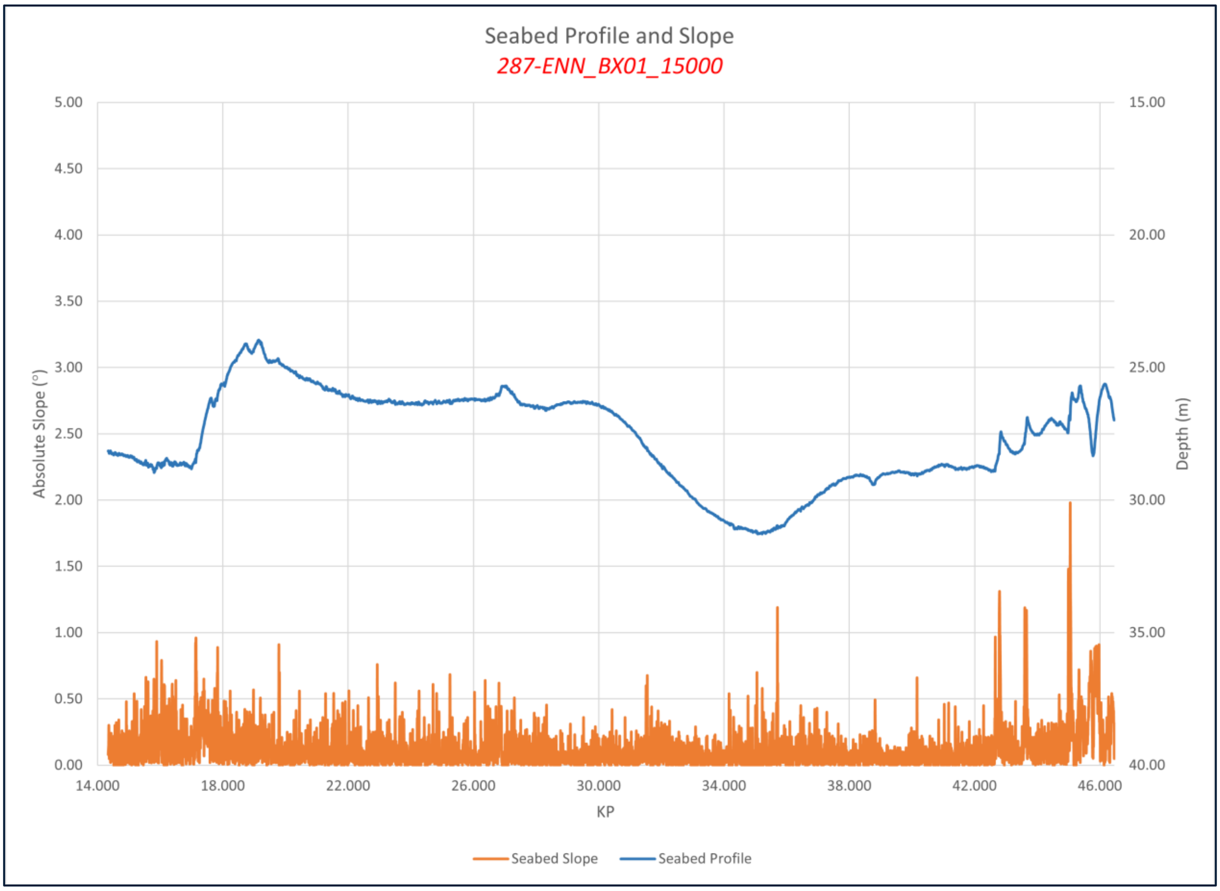


Figure 65 BX01_15000 bathymetry longitudinal profile and slope.

8.2.3 BX01_27000 (WSW to ENE)

The BX01_27000 longitudinal profile (from WSW to ENE) crosses the middle of the NSA1 site. The profile is relatively unremarkable, other than dissecting the Horn Rev sandbank which rises up from the surrounding seabed abruptly near the start of the section at KP 26.000, and then falls away more gradually around KP 45.000. Slope values across the profile are very low, with the largest values occurring on the western side of the sandbank (Figure 66).

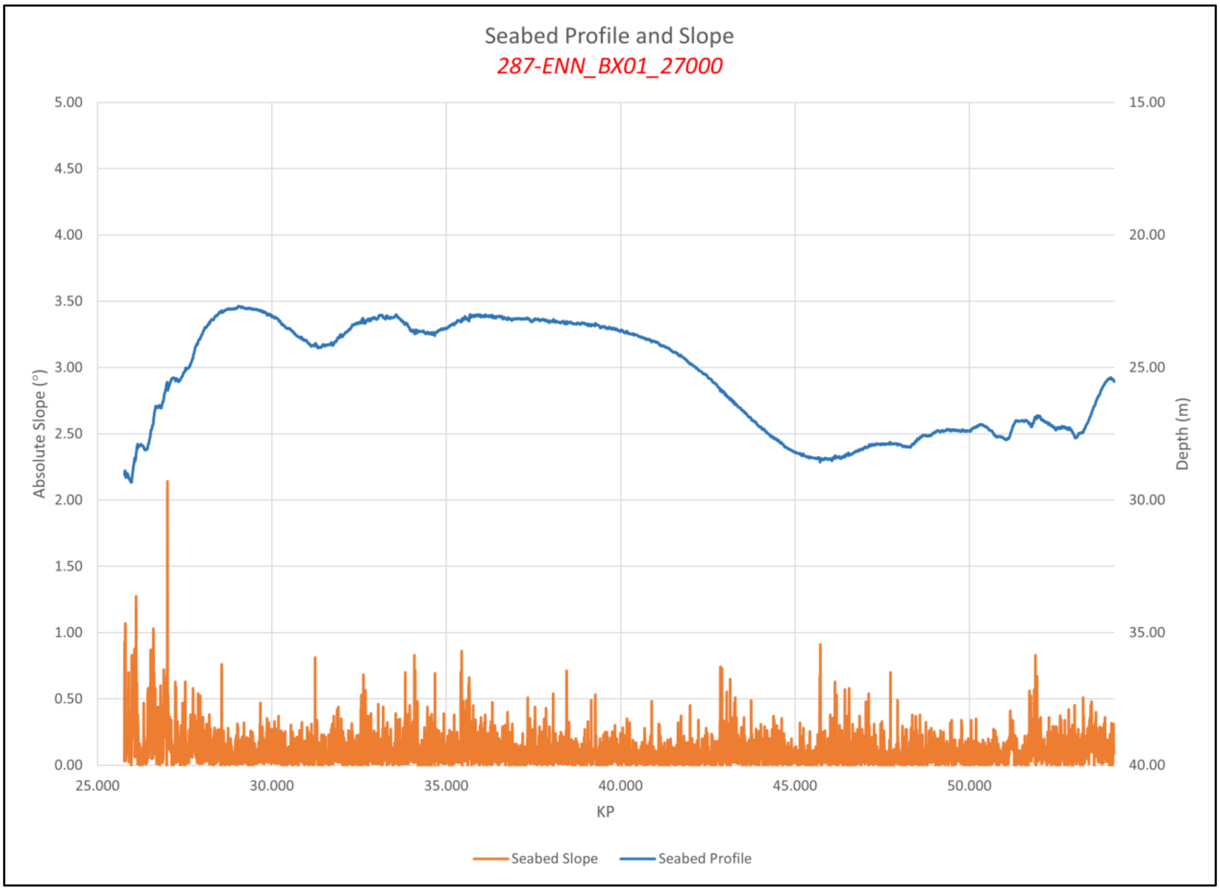


Figure 66 BX01_27000 bathymetry longitudinal profile and slope.

8.2.4 BX01_39000 (WSW to ENE)

The BX01_39000 longitudinal profile (from WSW to ENE) is very similar to BX01_27000, with the Horn Rev sandbank shown in profile. In this instance however, there is evidence of megaripples forming on top of the bank itself, particularly between KP 43.000 and KP 46.500. Slope values across the profile are very low, with the largest values occurring at the bank megaripples and on the western side as the sandbank falls away (Figure 67).

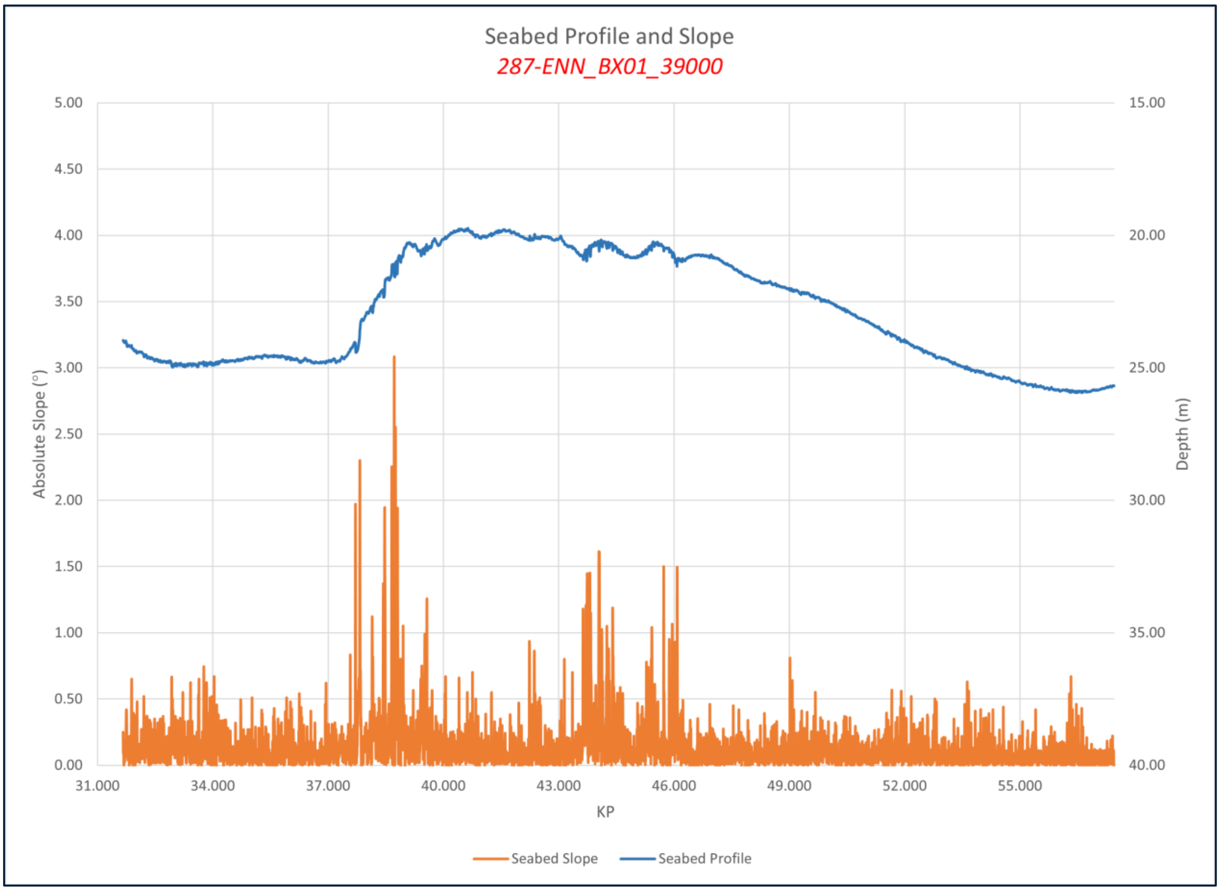


Figure 67 BX01_39000 bathymetry longitudinal profile and slope.

8.2.5 BM04_13860 (NNW to SSE)

The BM04_13860 longitudinal profile (from NNW to SSE) shows a gradual shallowing of the seabed along the side of the Horn Rev sandbank. The profile is predominantly smooth, with exceptions noted around KP 4.000 and KP 44.000 where some small ripples exist. Slope values across the profile are very low, <1.5° (Figure 68).

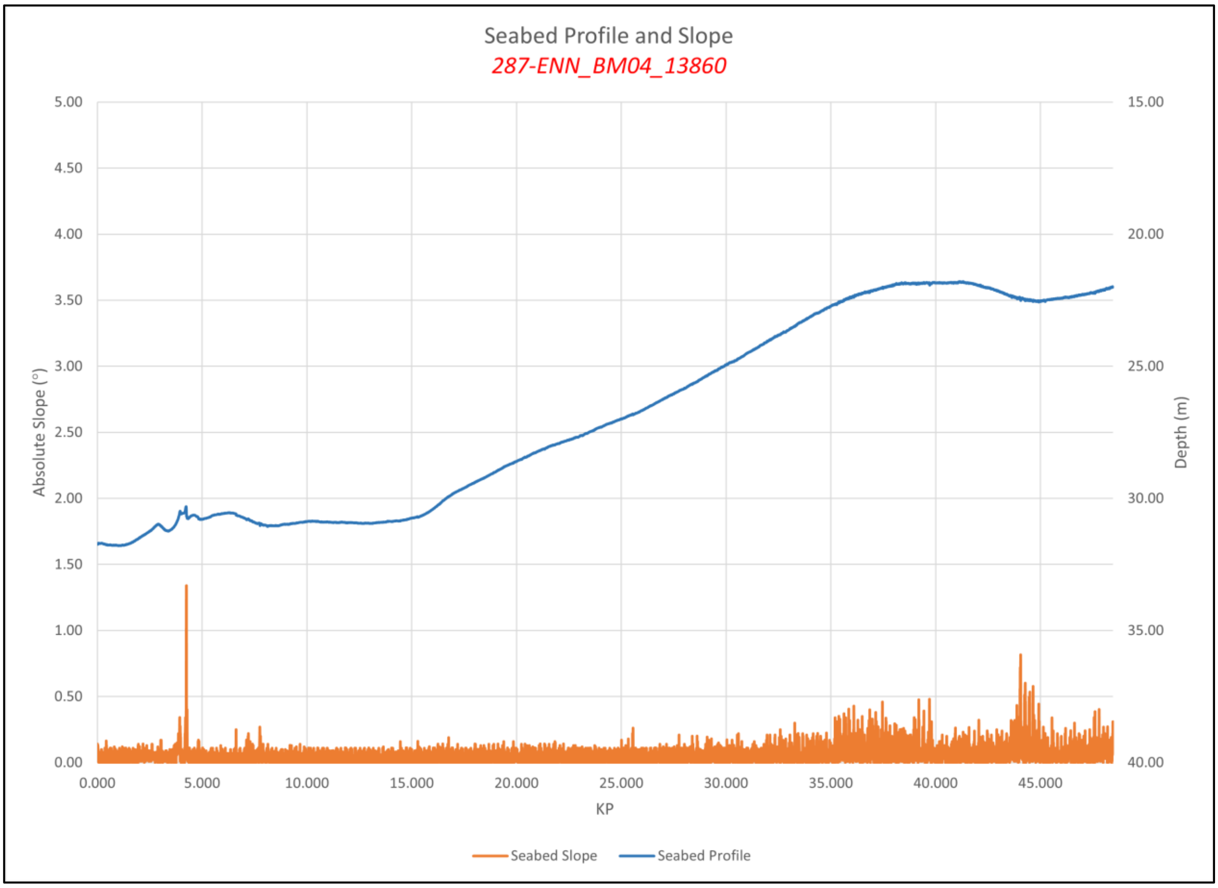


Figure 68 BM04_13860 bathymetry longitudinal profile and slope.

8.2.6 BM09_27860 (NNW to SSE)

The BM09_27860 longitudinal profile (from NNW to SSE) also shows the reducing water depth as the section rises up onto the Horn Rev sandbank. In contrast however, the profile reveals several relatively sharp features along the profile. From KP 0.000 the profile is relatively smooth, until three smaller channels/depressions are bisected around KP 18.000, KP 24.000 and KP 28.000. Erosional features also lead to small scale depth changes from KP 37.000 to KP 43.000, and from KP 50.000 to KP 54.000, in an otherwise smooth profile. Slope values across the profile are still predominantly very low, with the largest values occurring where the depth steps down across the erosional features (Figure 69).

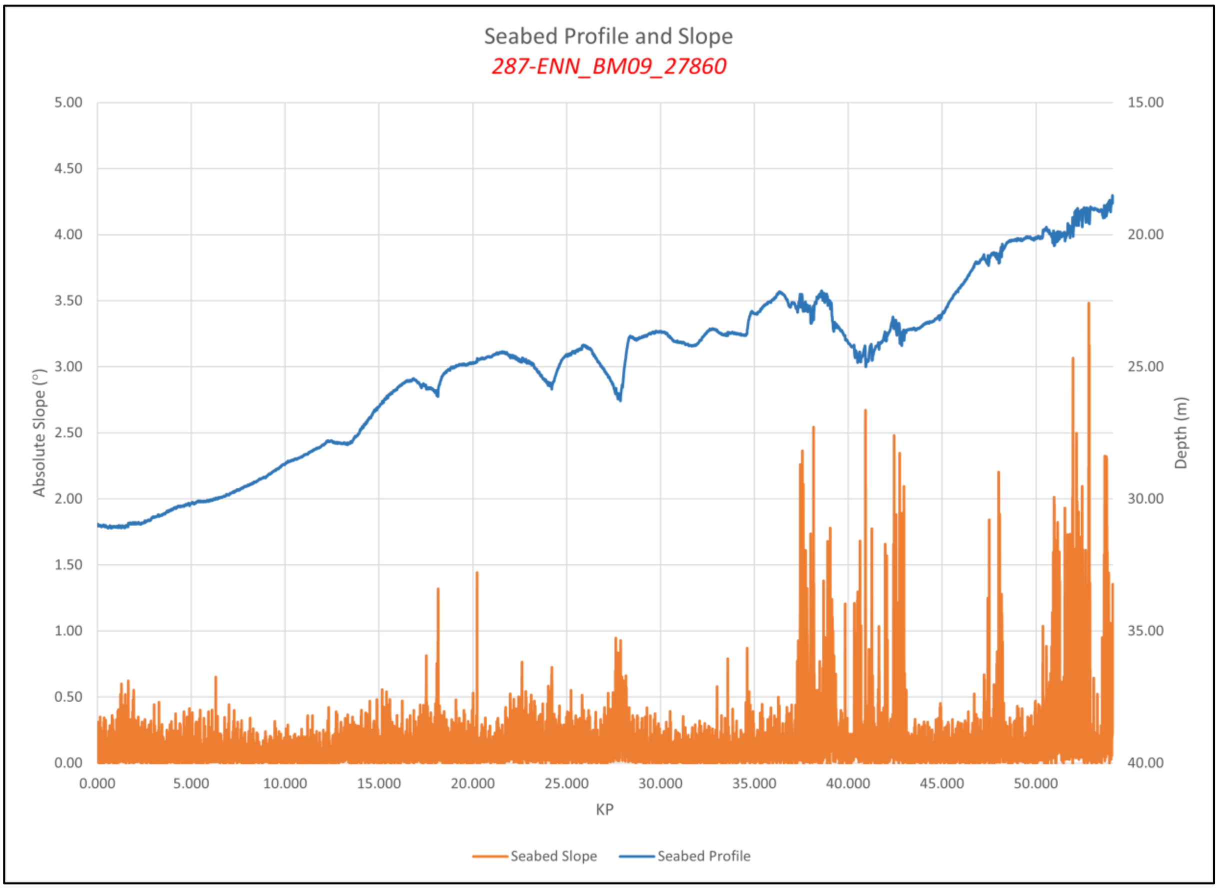


Figure 69 BM09_27860 bathymetry longitudinal profile and slope.

8.2.7 Slope Analysis

Seabed slope values of less than 1° are observed across the majority of the NSA1 site (Figure 70), with larger values (1° to 5°) corresponding to the sides of megaripples and erosional features. The largest reported slope values (> 20°) coincide with features from the wreck of the SS Sierra Cordoba (Figure 109 and Figure 108) and the sides of the outcrop shown in Figure 71.

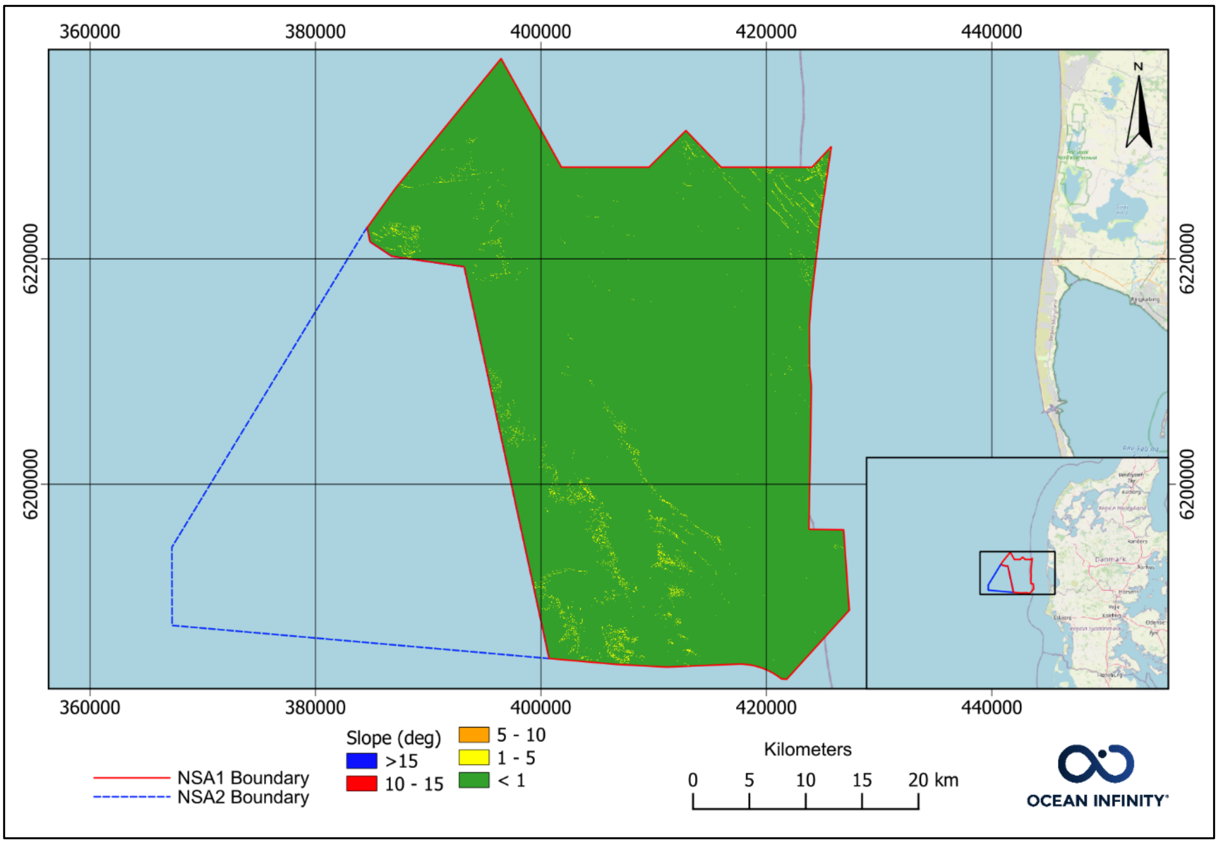


Figure 70 NSA1 bathymetry slope angle plot.

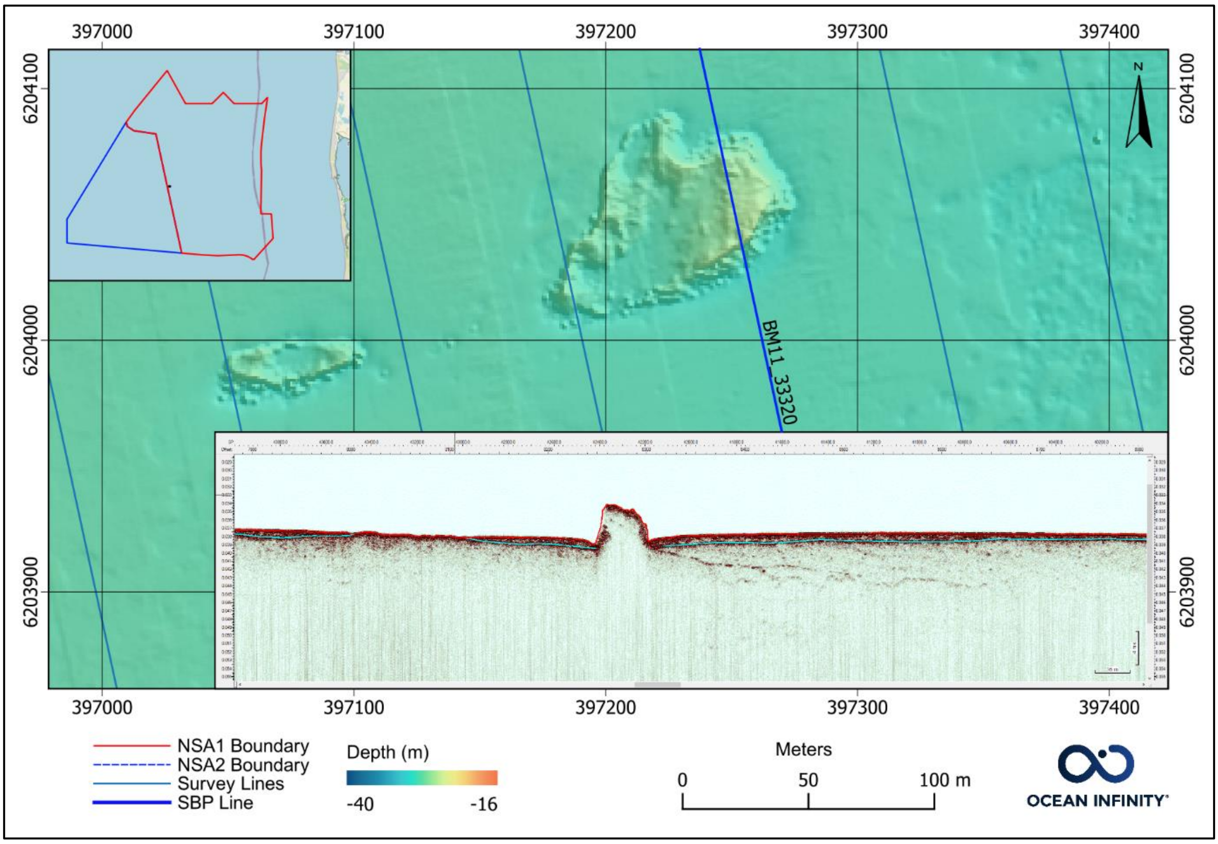


Figure 71 Till outcrop in block BM11 (MBES image above with SBP insert).

8.2.8 Seabed Features

A variety of seabed features such as sandwaves, megaripples, depressions and boulder fields were observed across the NSA1 site. The extent and distribution of these are discussed in detail within Sections 8.4 and 8.5 with examples from the bathymetry dataset provided below in Figure 72 to Figure 77.

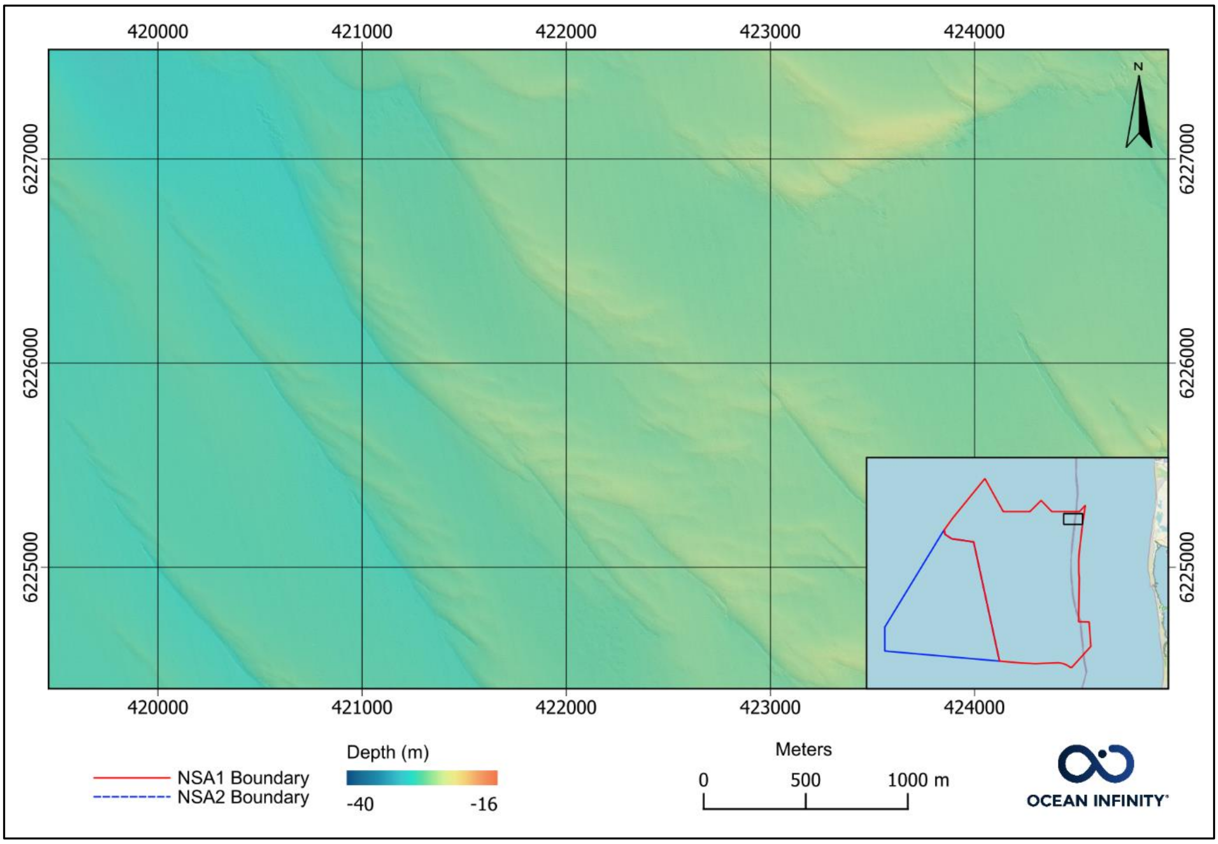


Figure 72 Sun-illuminated bathymetry – sandwaves.

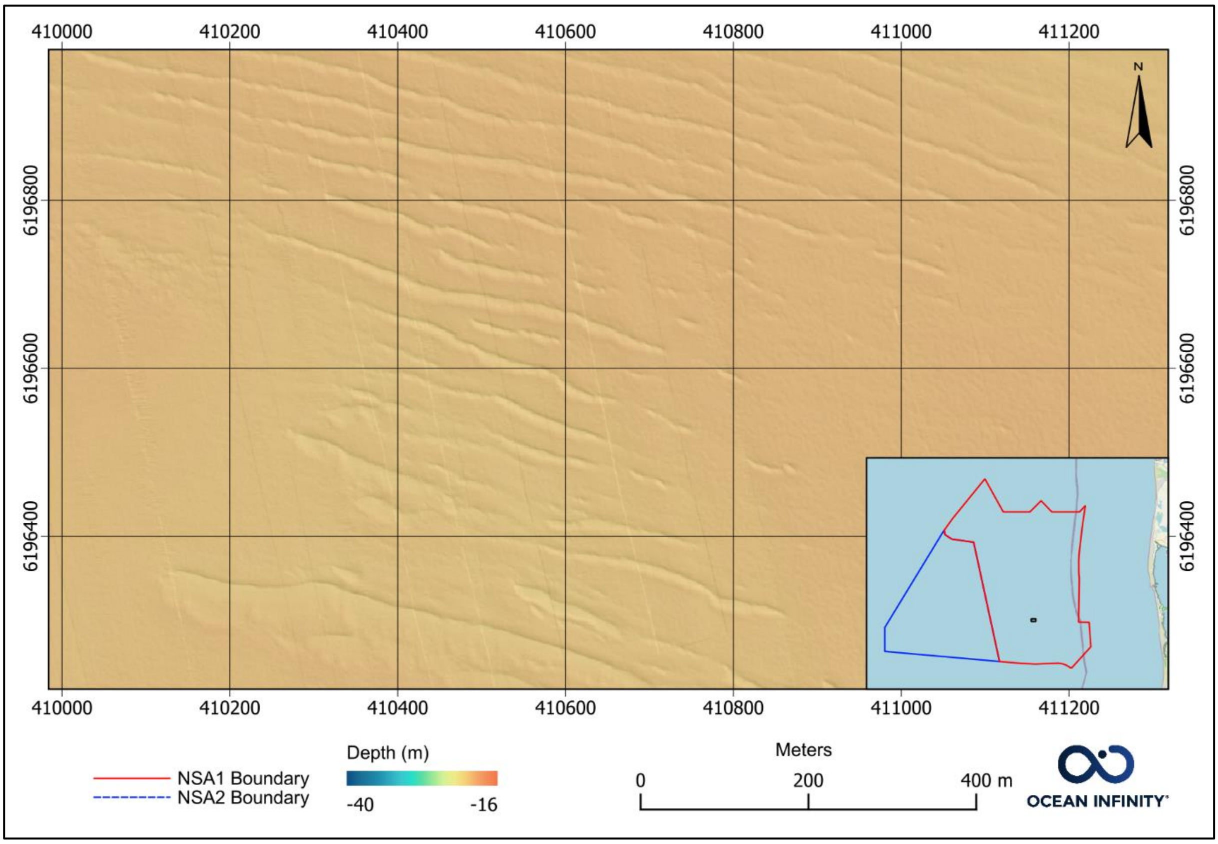


Figure 73 Sun-illuminated bathymetry – megaripples.

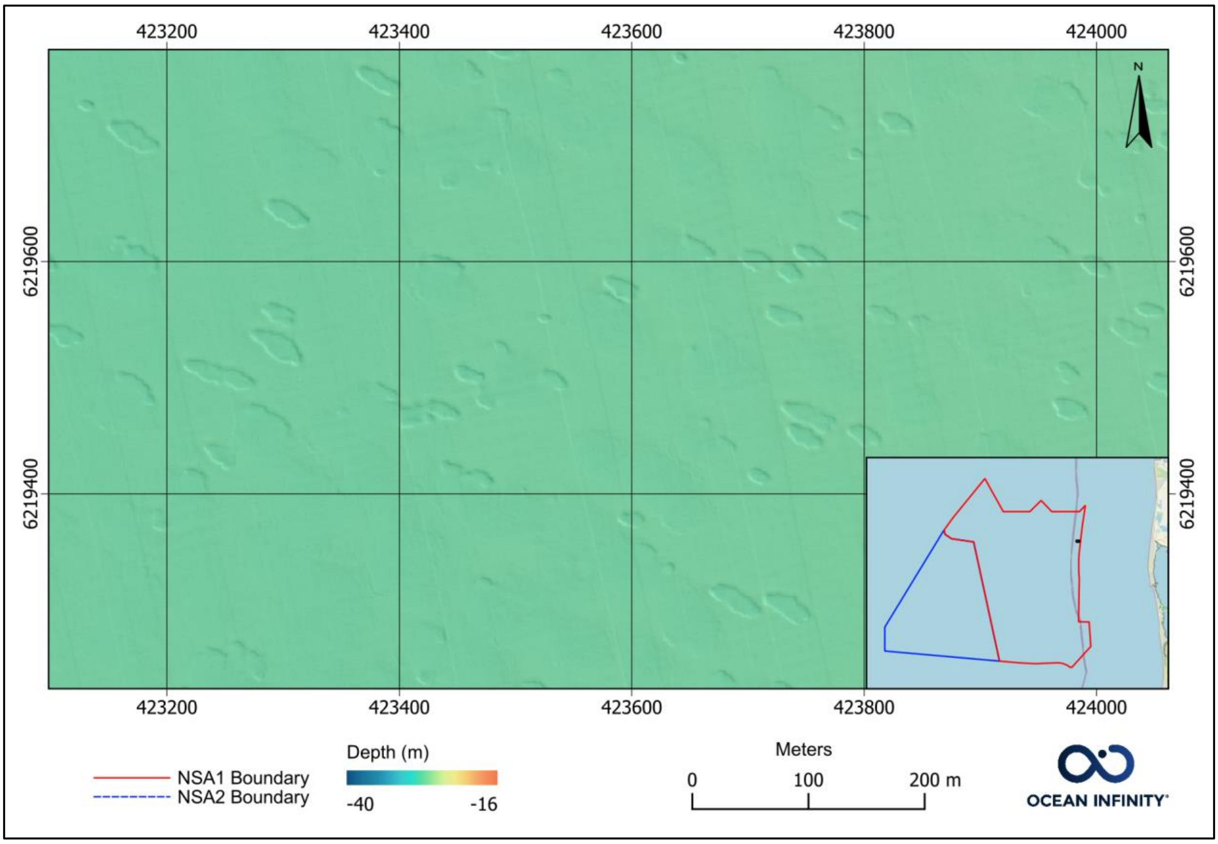


Figure 74 Sun-illuminated bathymetry - erosional depressions.

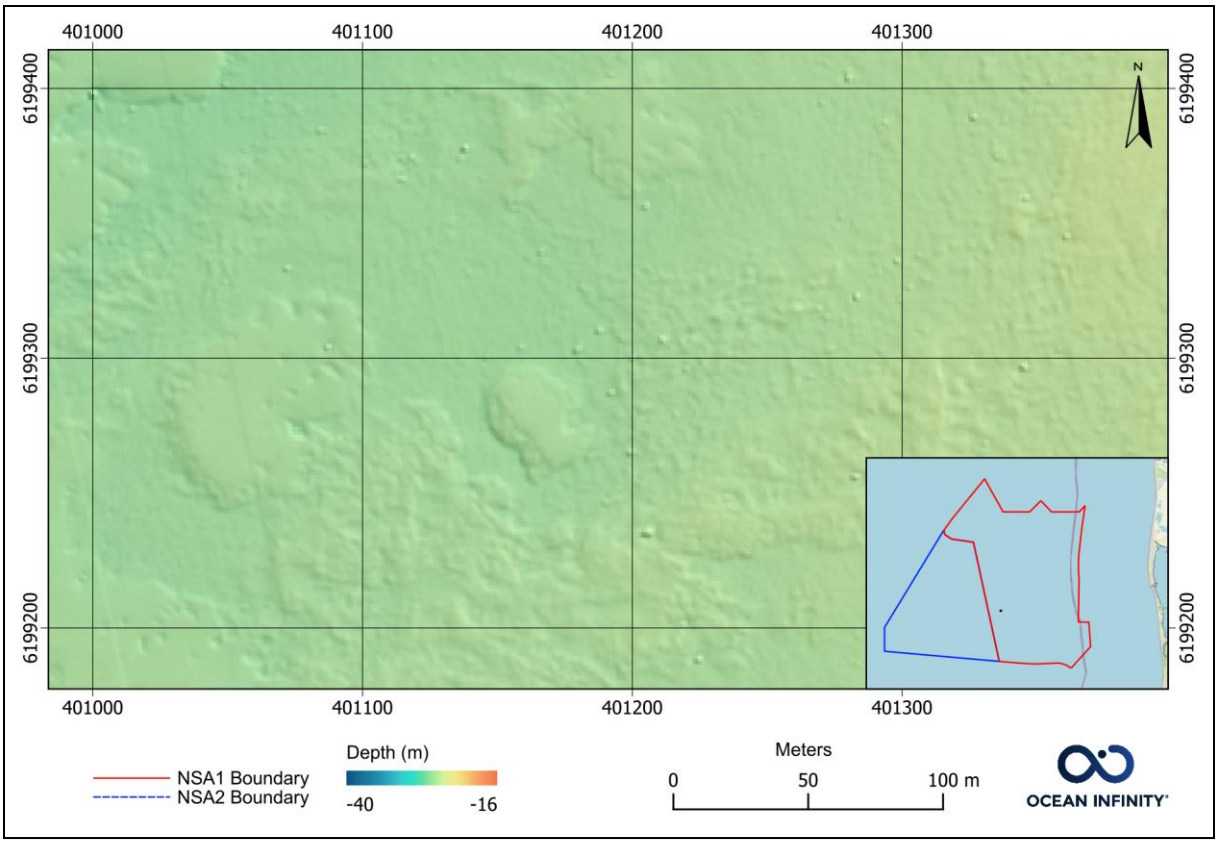


Figure 75 Sun-illuminated bathymetry - boulder field.

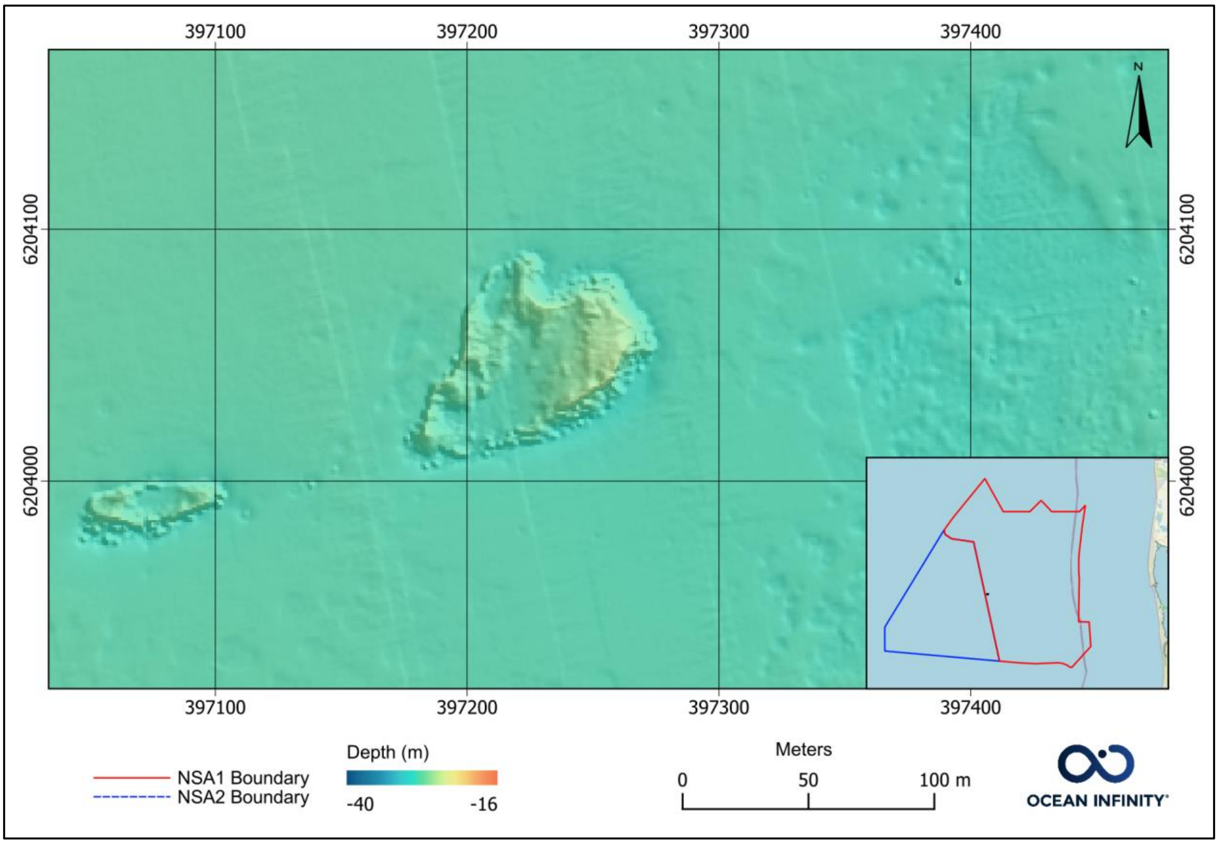


Figure 76 Sun-illuminated bathymetry – outcrop.

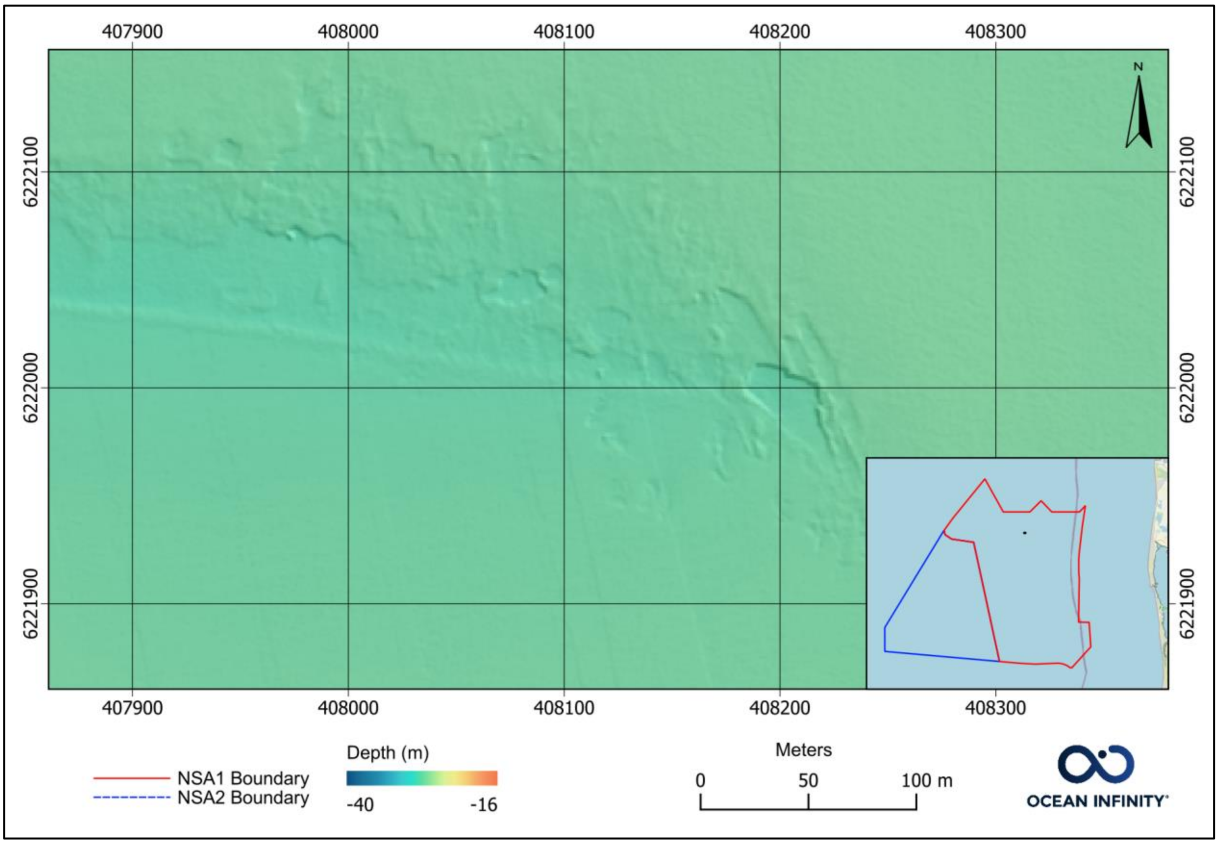


Figure 77 Sun-illuminated bathymetry - outcropping clay.

8.3 Backscatter

Our dataset, while not without challenges—specifically with the Geo Ranger data and the very large variations in sound velocity—yields satisfactory results overall. The nuanced acoustic reflectivity captured by multibeam allows for effective seafloor characterization, enabling the identification of various materials and the mapping of geomorphic features. Despite encountered challenges, the backscatter proves to be a versatile tool, contributing to the analysis of dynamic geological processes.

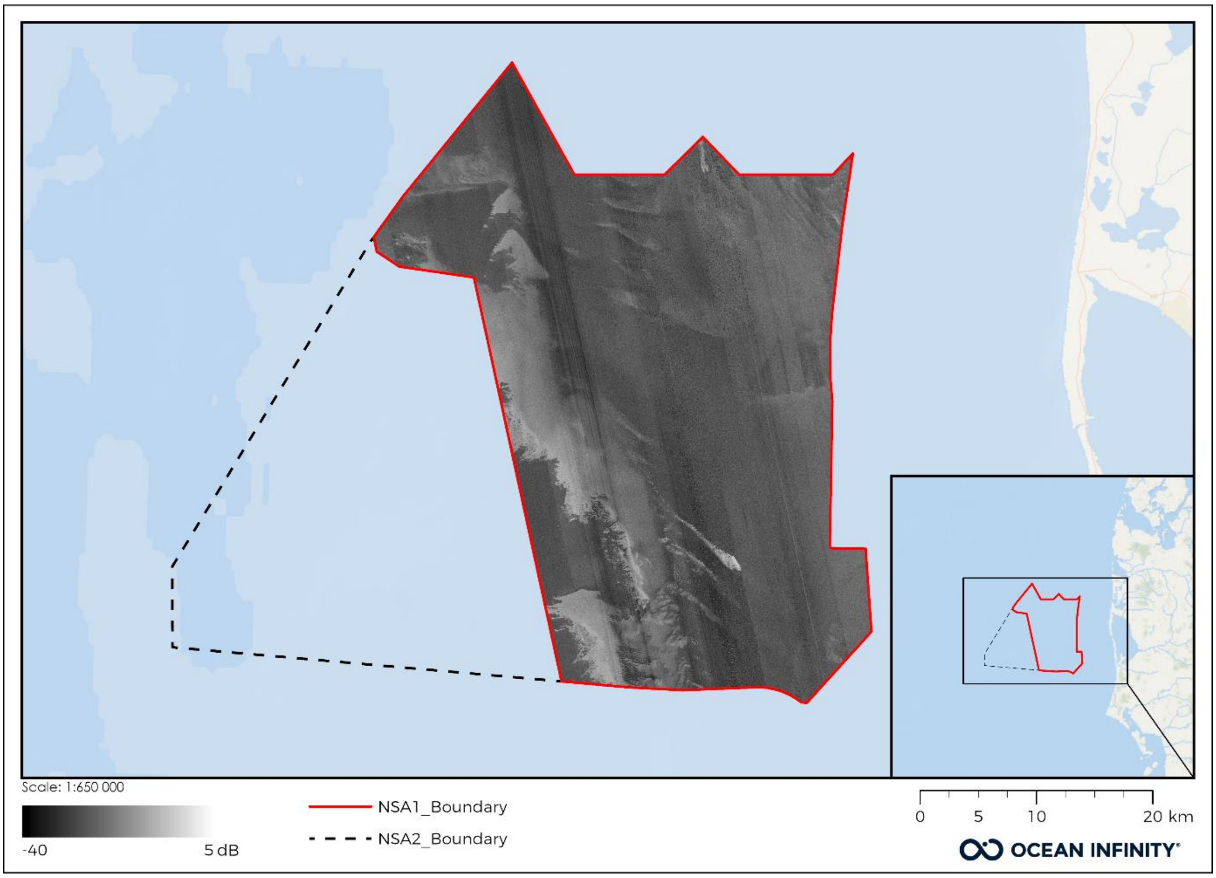


Figure 78 showing an overview of the collected backscatter for NSA1.

Following are a few examples of what can be seen in the backscatter data and what type of detail that is to be expected when conducting surveys with hull mounted multibeam echosounders at the depths 16 to 40 m meters. For a more comprehensive exploration of the surficial geology and a detailed analysis of seabed features, readers are encouraged to refer to the dedicated 8.4 Surficial Geology and Seabed Features chapter.

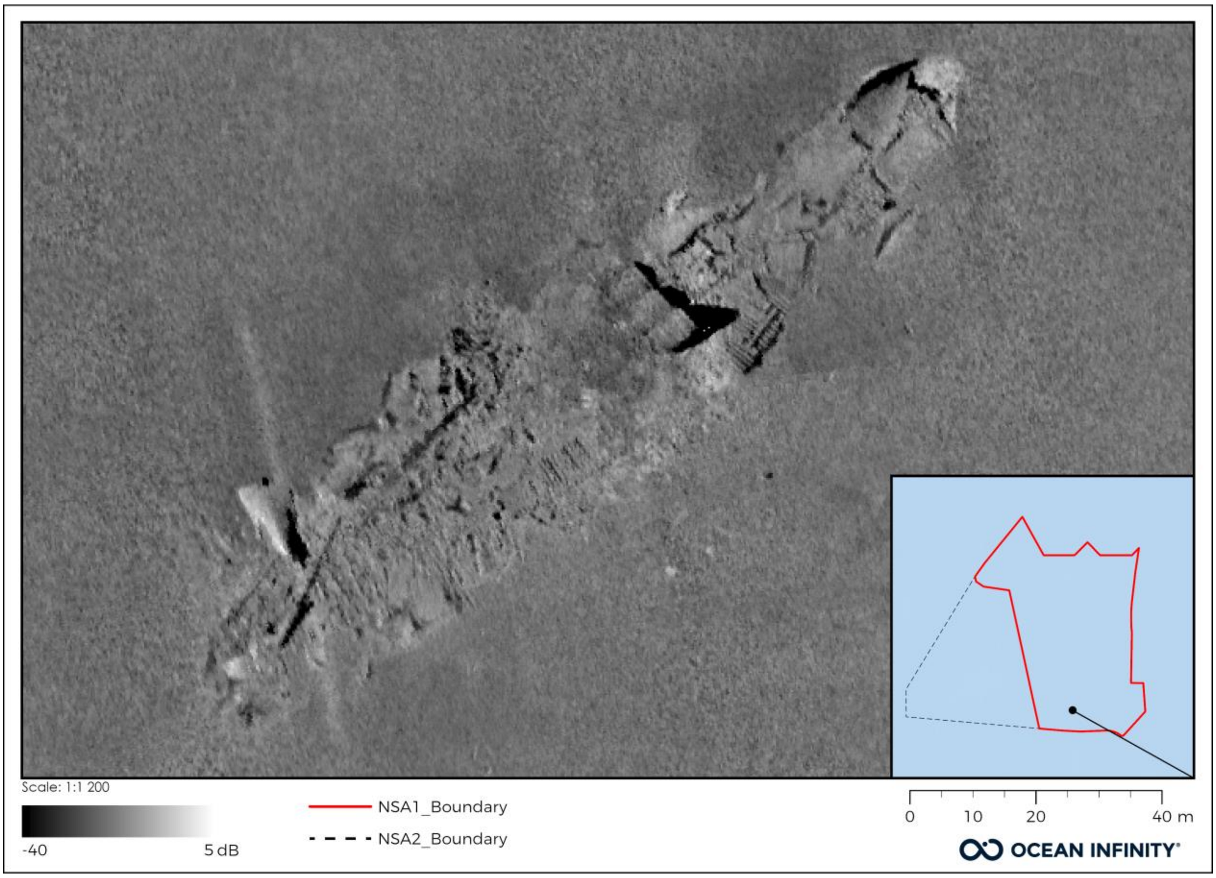


Figure 79 image of charted wreck SS Sierra Cordoba.

Figure 80 Outcropping till. Can also be seen in the bathy data in Figure 76 and in the SBP in Figure 143.

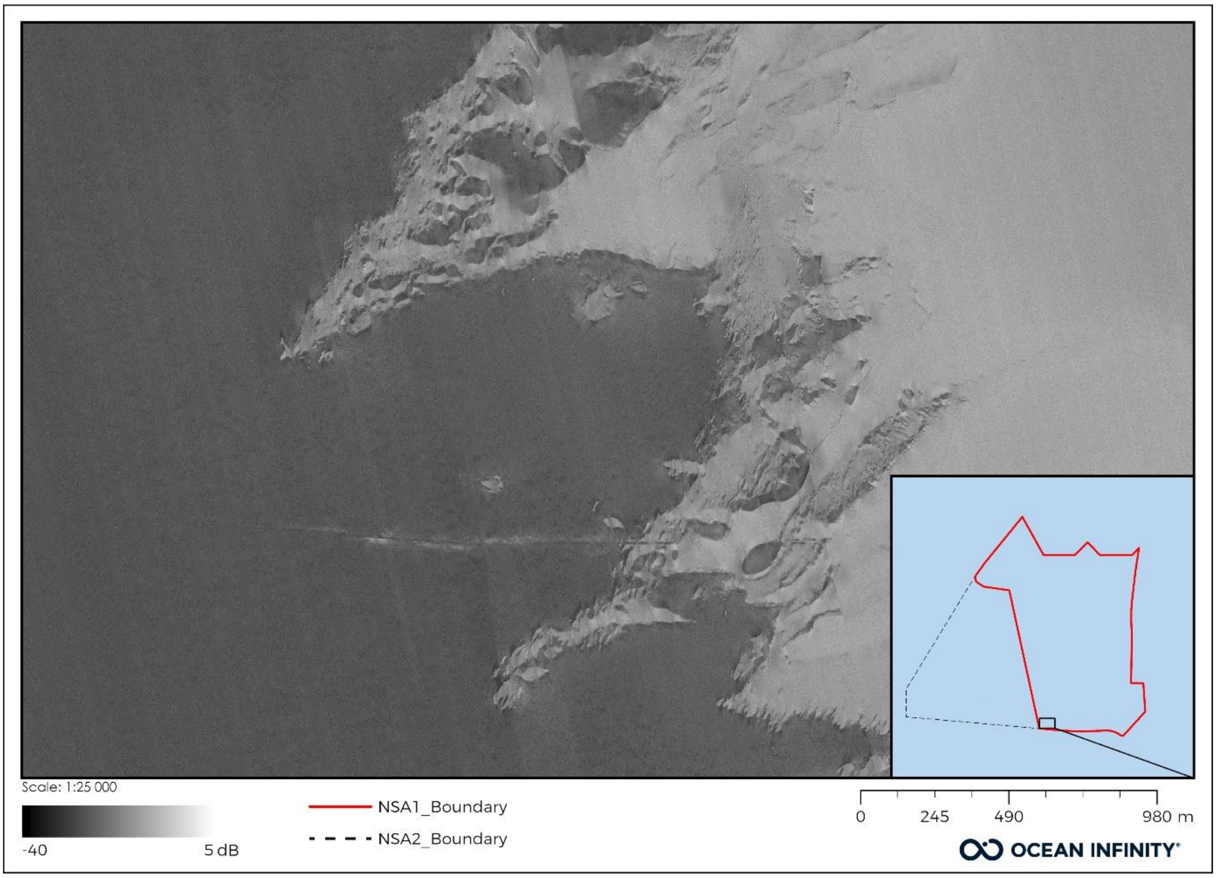


Figure 81 Sediment boundaries from the backscatter. Dark grey area is sand and lighter area is gravel and coarse sand.

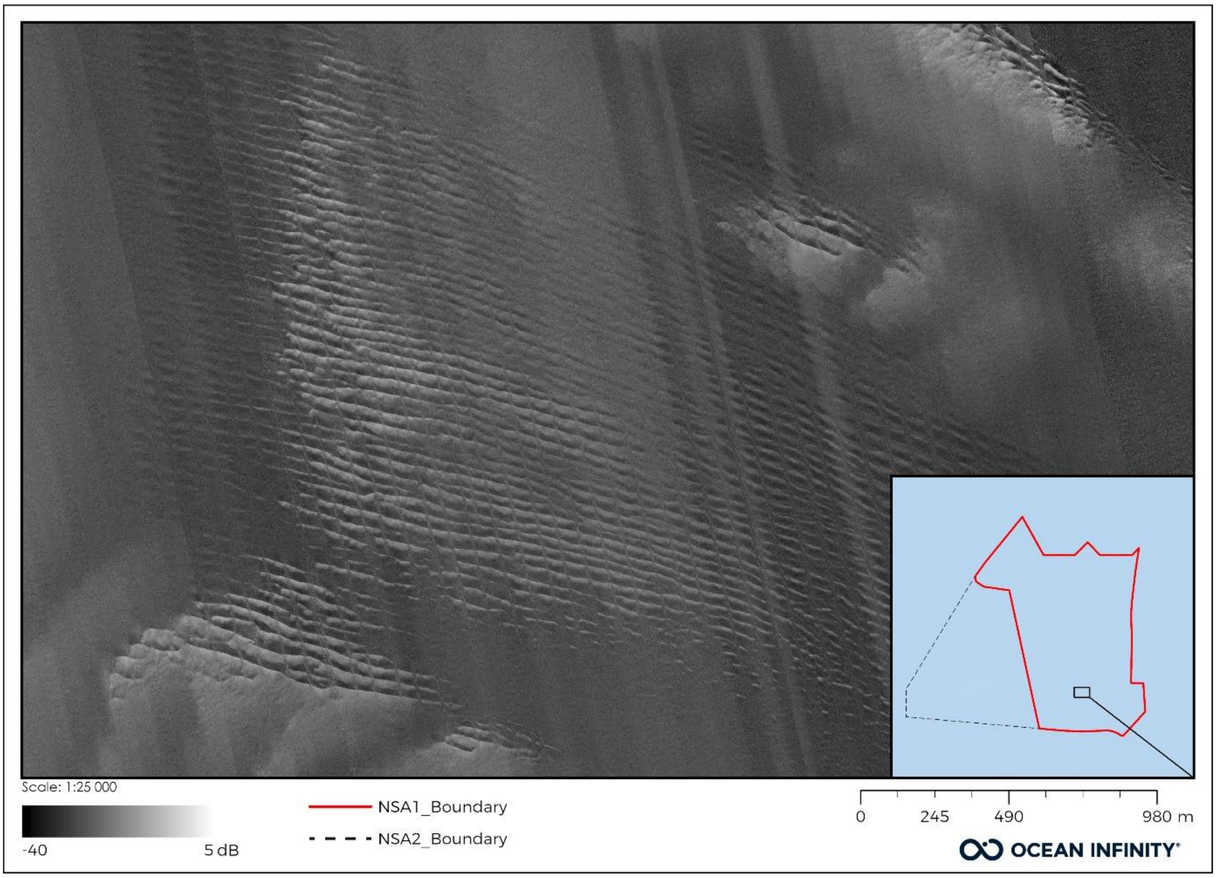


Figure 82 backscatter showing ripples in sand.

8.4 Surficial Geology and Seabed Features

8.4.1 Seabed Sediments

The surficial geology is interpreted from the SSS imagery based on the relative SSS reflectivity, where lighter reflectivity is interpreted as relatively finer grained sediments and darker reflectivity is interpreted as relatively coarser grained sediments. The SSS imagery has low to medium acoustic reflectivity overall. Backscatter data was used to confirm the interpretation of SSS data and delimit sediment boundaries. Grab Samples collected in the survey area were used to aid the seabed sediment interpretation.

The seabed sediments in the NSA1 area are dominated by SAND (medium acoustic reflectivity), and GRAVEL and coarse SAND (medium to high acoustic reflectivity) with some small areas of TILL/DIAMICTON (medium to high acoustic reflectivity) and QUATERNARY CLAY (medium to high acoustic reflectivity). It must be noted that CLAY was not observed in any of the grab samples (only clayey SAND), the acoustic character suggests CLAY sediments are present in patches across the site and are likely observed where the sediments above are removed.

SAND is predominantly visible in the eastern and central parts of the area with some patches of Gravel and coarse SAND to the northeast (Blocks BM02, BM03, BM04, BM05, BM06 and BM07) while SAND and GRAVEL and coarse SAND are present in the western parts of the area (Blocks BM08, BM09, BM10, BM11, and North of BM12, BM13 and BM14). Small areas of TILL/DIAMICTON are found in the western part of the area (central and southern part of blocks BM10 a BM11). Small, isolated patches of Quaternary Clay and Silt are present outcropping North of BM06. Figure 83 shows an overview of the seabed sediments observed in NSA1.

SSS data examples showing different sediment types, are presented in Figure 84, Figure 85 and Figure 86.

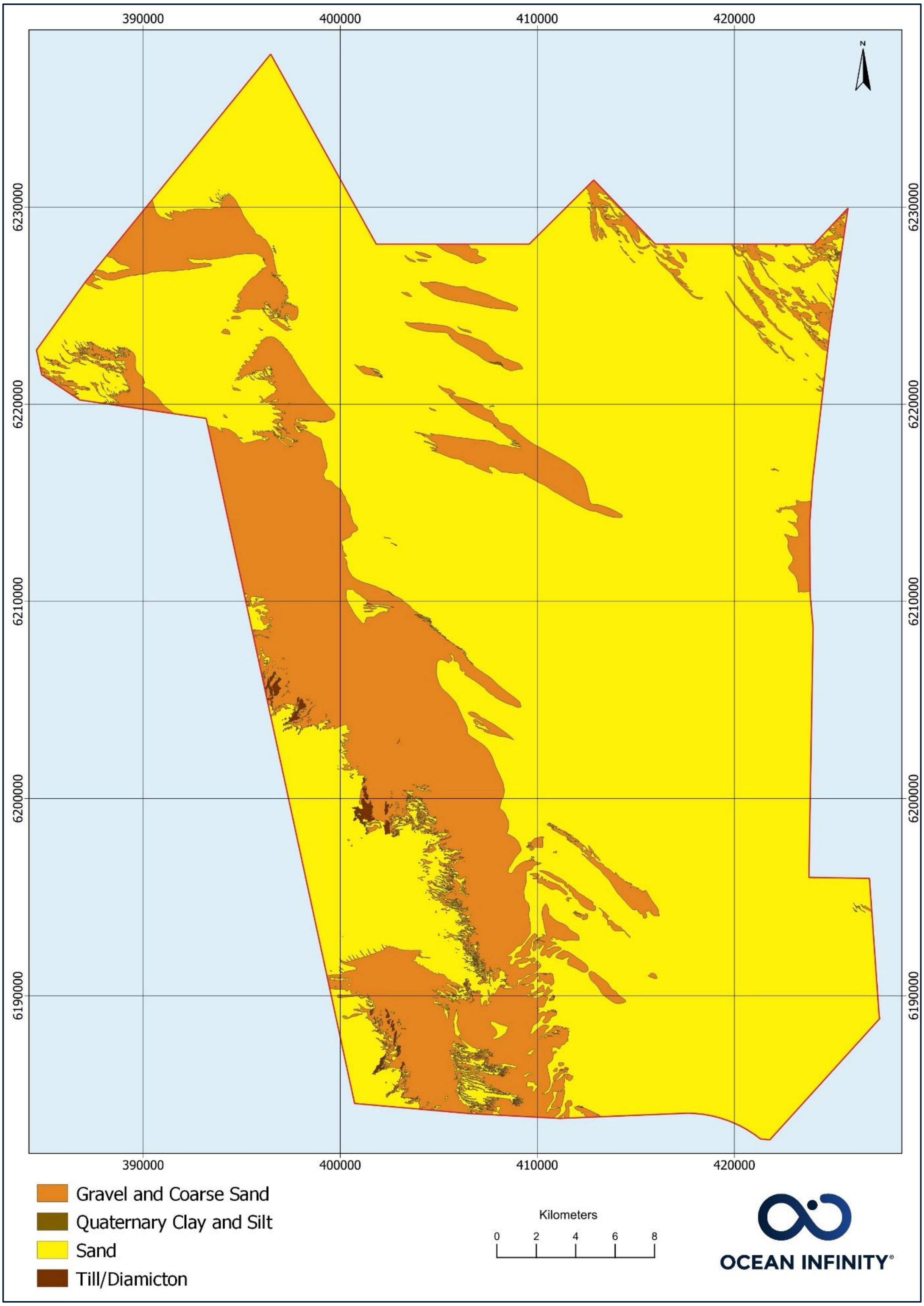


Figure 83 Overview of seabed sediments in the NSA1 survey area.

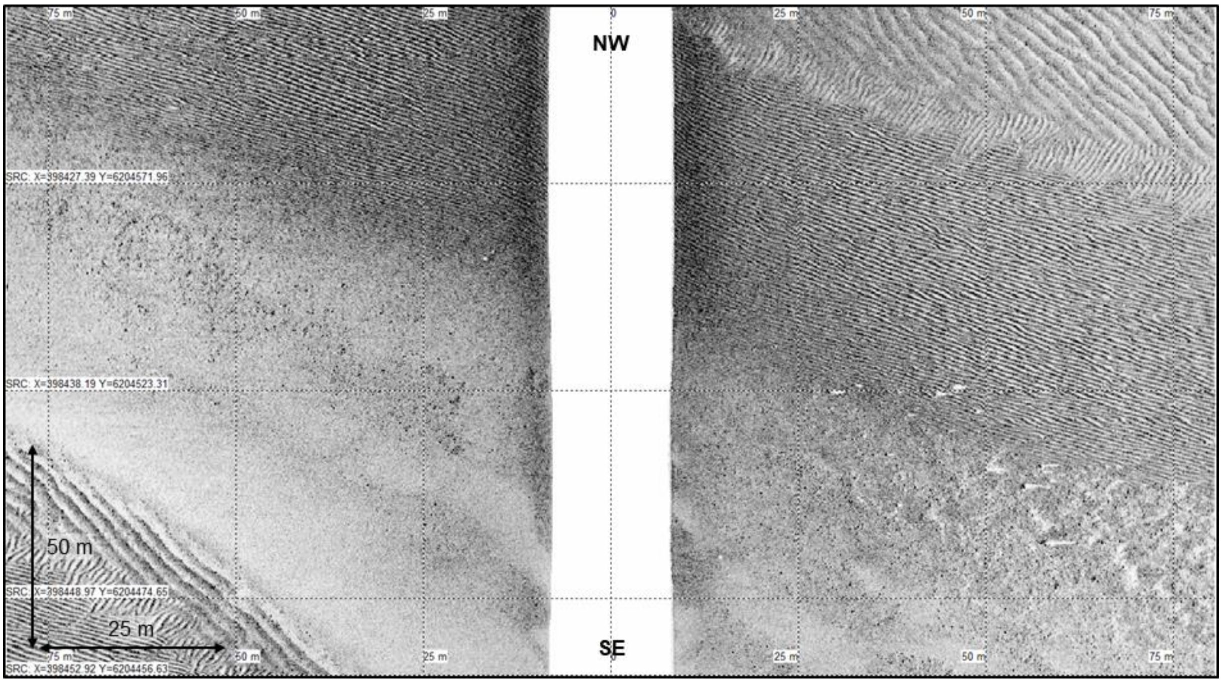


Figure 84 High frequency SSS example of SAND (medium acoustic return) and GRAVEL and coarse SAND (medium to high acoustic return) sediments.

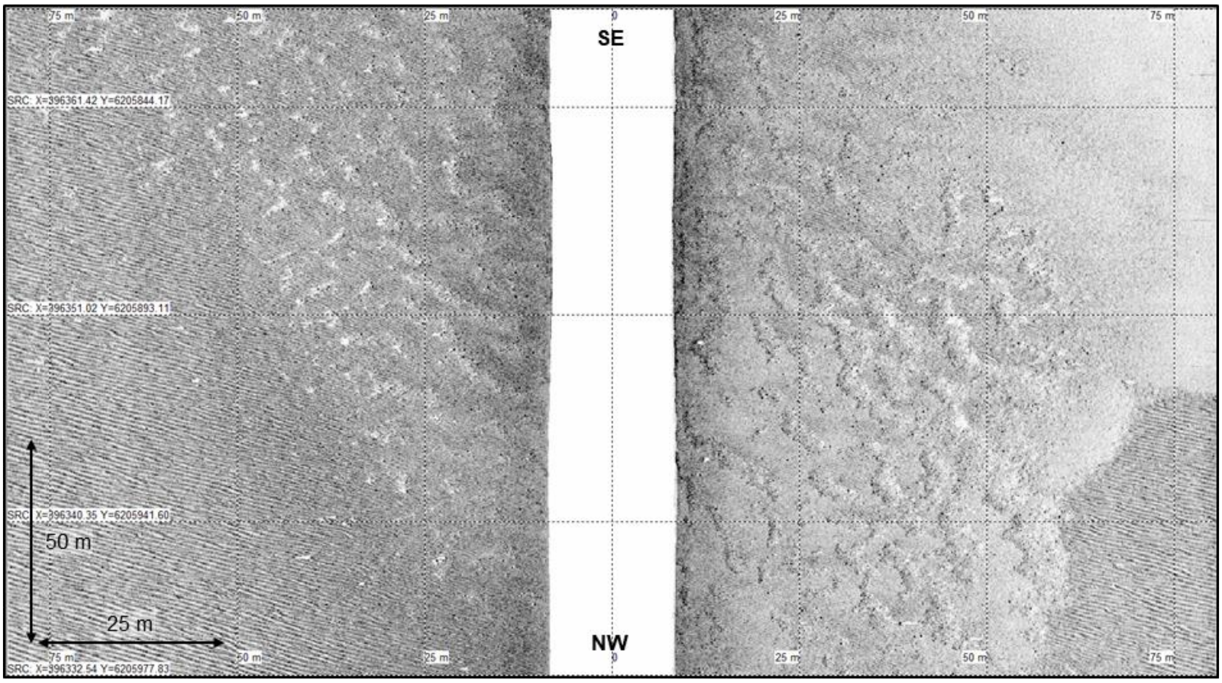


Figure 85 High frequency SSS example of TILL/DIAMICTON sediments (medium to high acoustic return).

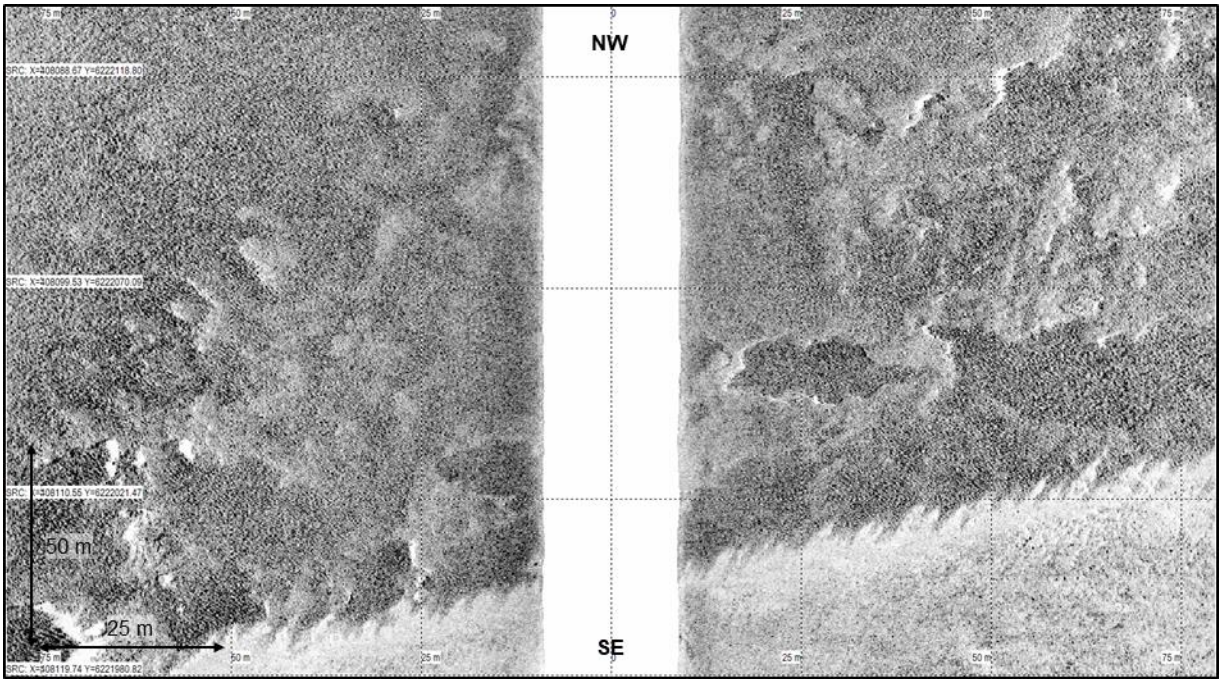


Figure 86 High frequency SSS example of Quaternary Clay and Silt sediments outcropping in block BM06.

8.4.2 Mobile Sediments

Areas of ripples, large ripples and megaripples, indicative of mobile sediments, are present across a large part of the NSA1 survey area. Areas of ripples occur mainly within the areas of GRAVEL and coarse SAND. The direction of these mobile sediments varies within the survey area (Figure 87). Arrows indicating sediment direction are presented within the TSG and charts. Where a double headed arrow is used, this indicates a dominant direction of sediment travel could not be ascertained.

The areas of ripples are scattered along the extent of NSA1 (Blocks BM01-BM14), ripples typically exhibit wavelengths between 2 and 3 m. Areas of large ripples are seen in the northern part of the survey area (Blocks BM04 and BM10) and typically exhibit wave lengths of 5 to 7 m. Areas of megaripples are mainly visible in the south of NSA1 with smaller, scattered areas present in the northwest of NSA1 (Blocks BM05, BM06, BM07, BM08 and BM09), with wavelength between 15 and 35 m.

Sand wave areas are visible particularly in the northeast and west of the survey area (Blocks BM01, BM03, BM04, BM08, BM09, BM10, BM11 BM12, BM13 and BM14), with wavelengths ranging between 50 m and 200 m and exhibit a northwest-southeast orientation, with a dominating current regime SW-NE (major mobile sediment direction arrows present with the TSG). The sand waves are typically comprised of SAND or GRAVEL and coarse SAND (Figure 88).

Figure 89 shows an overview of mobile sediments observed in the NSA1.

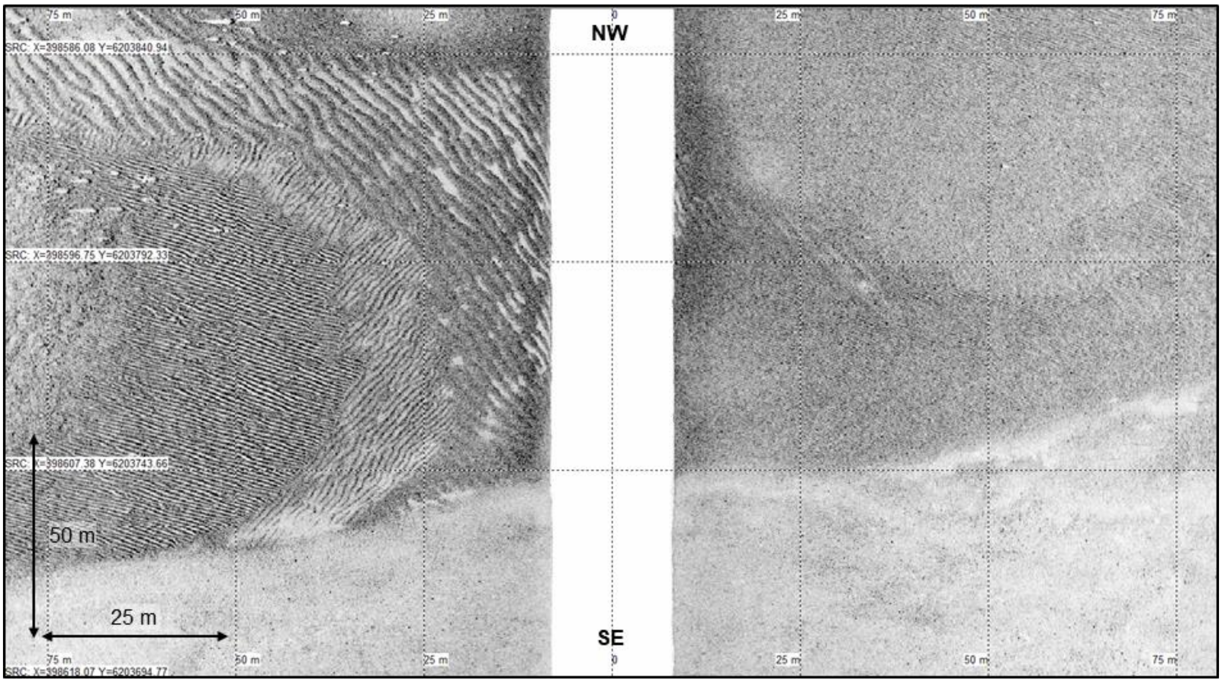


Figure 87 Example of different bedform direction in line BM11_32060_0372_010.

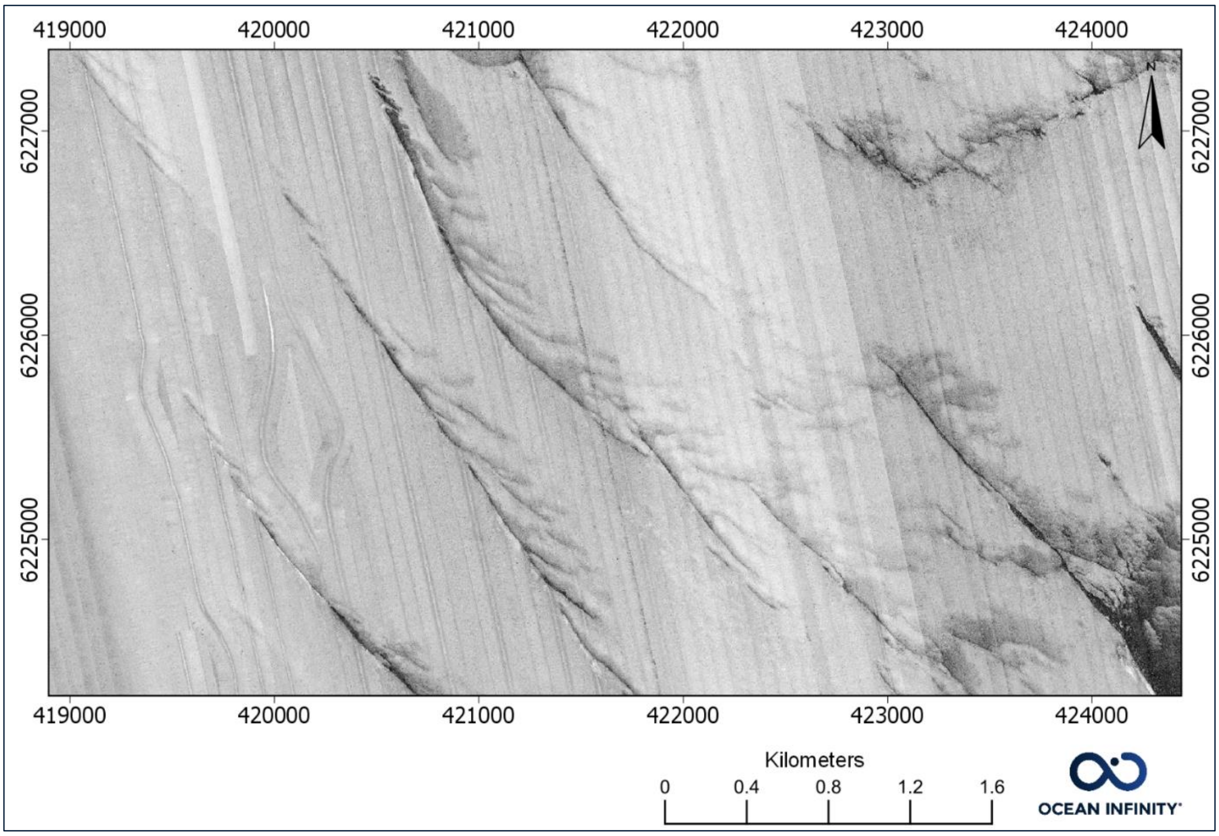


Figure 88 Example of sand waves on block BM01, orientated NW-SE.

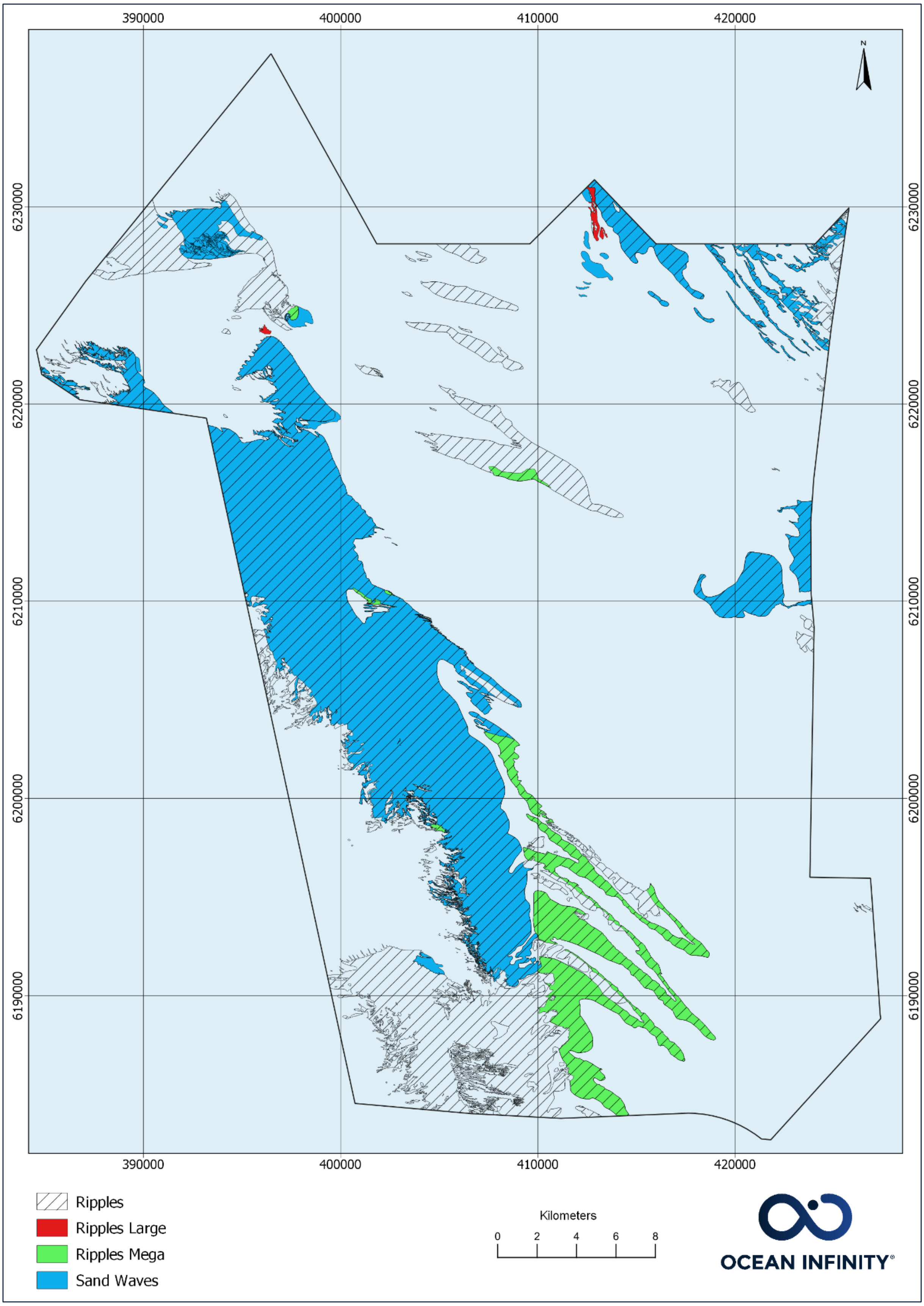


Figure 89 Distribution of Ripples, Large Ripples, Megaripples and Sand Waves in the NSA1 survey area.

Significant differences on the seafloor morphology and bedforms was detected between lines acquired before and after periods of weather stand-by (Figure 90). In some cases, the seabed showed low reflectivity patches of various sizes and orientations, these were interpreted as erosional features where the top sediment was removed, exposing the clay beneath (Figure 91).

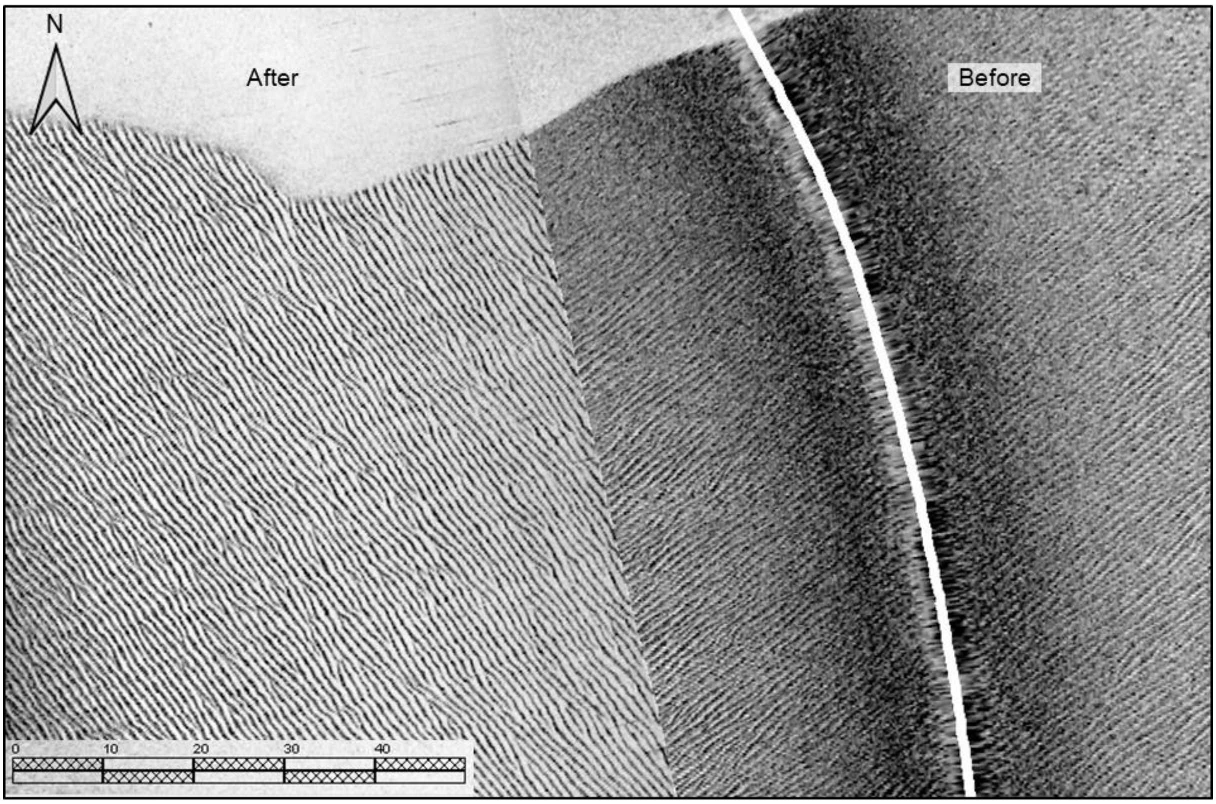


Figure 90 Example of different bedform size and direction before and after weather stand-by on BM11.

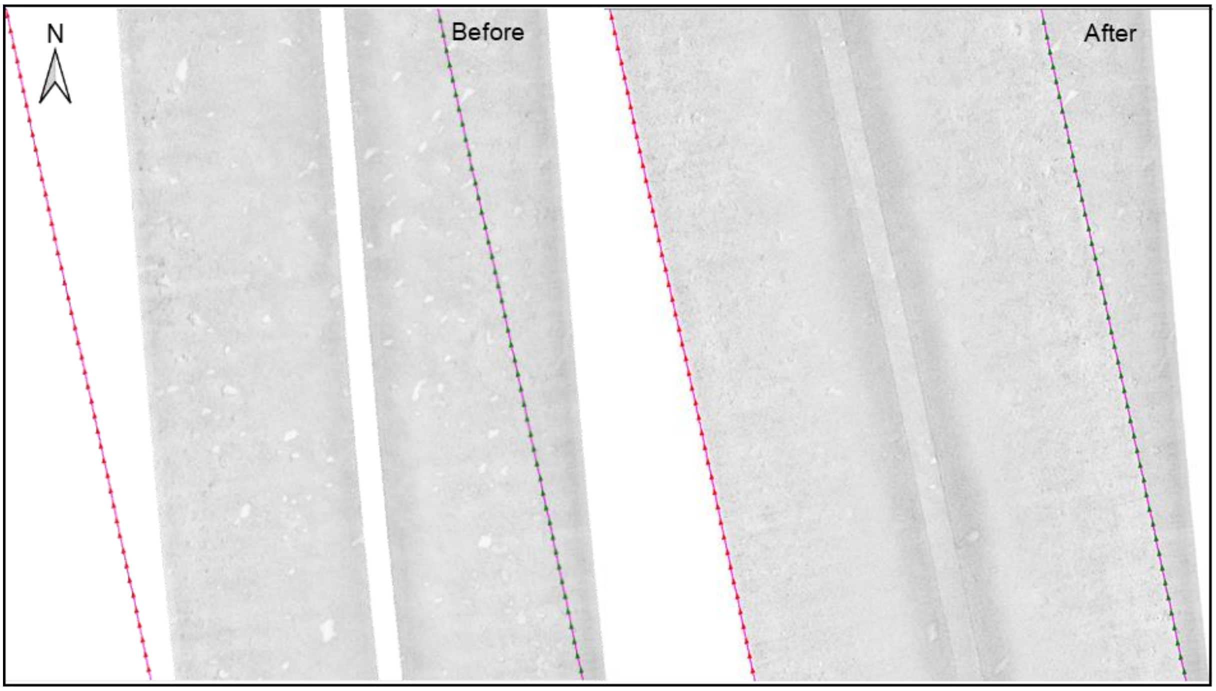


Figure 91 Example of exposed CLAY patches due to erosion of mobile top sediments before and after weather stand-by on BM10.

8.4.3 Areas of Depressions

Erosional depressions were observed within the NSA1 area with various shapes and depths ranging between 5 and 30 cm as visible in Figure 92. These have been interpreted as Rippled Scour Depressions (RSD) at the early formation stages. These features were discussed in TQ-022. Figure 93 shows the appearance of these depression in the SBP data. Figure 94 shows an overview of erosional depressions observed in the NSA1 area.

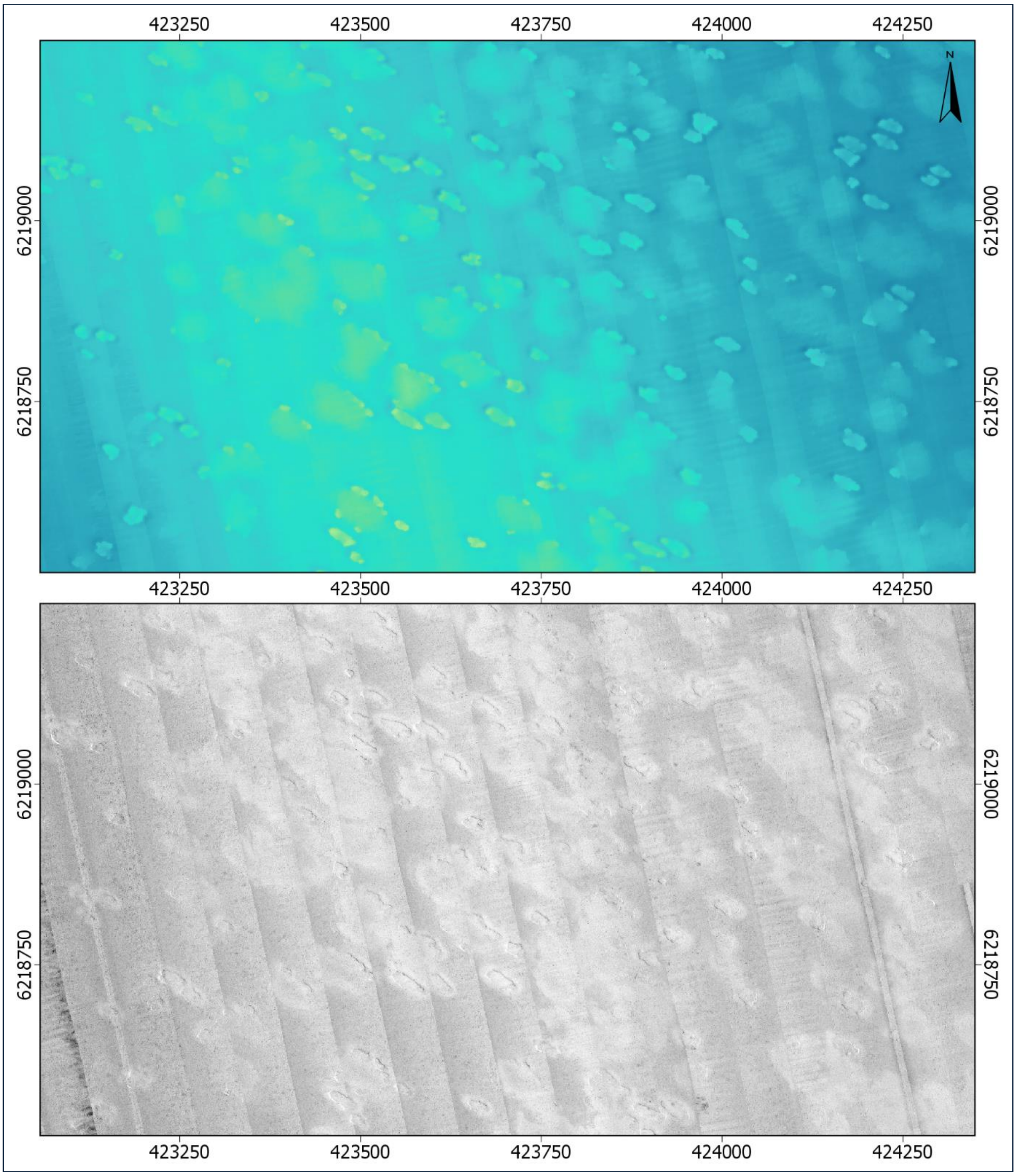


Figure 92 Erosional depressions on MBES (above) and SSS data (below). BM01.

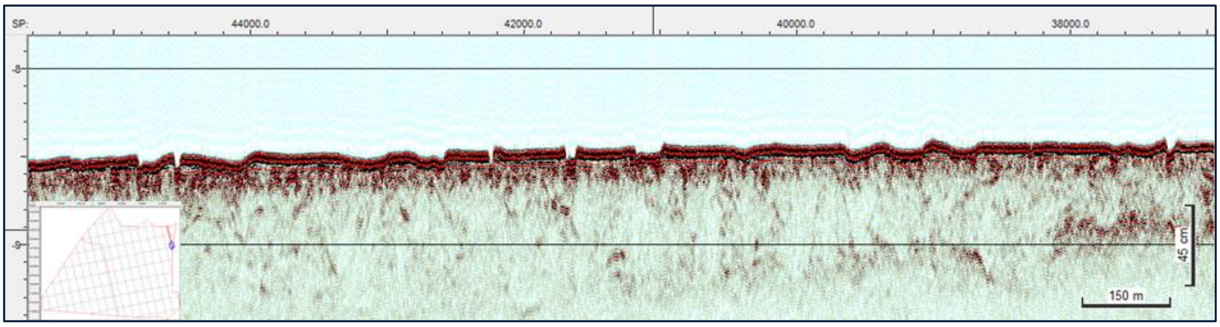


Figure 93 SBP example images of erosional depression visible in the seabed. Survey line BM01_04340, position 423700E, 6218847N (image mid-point).

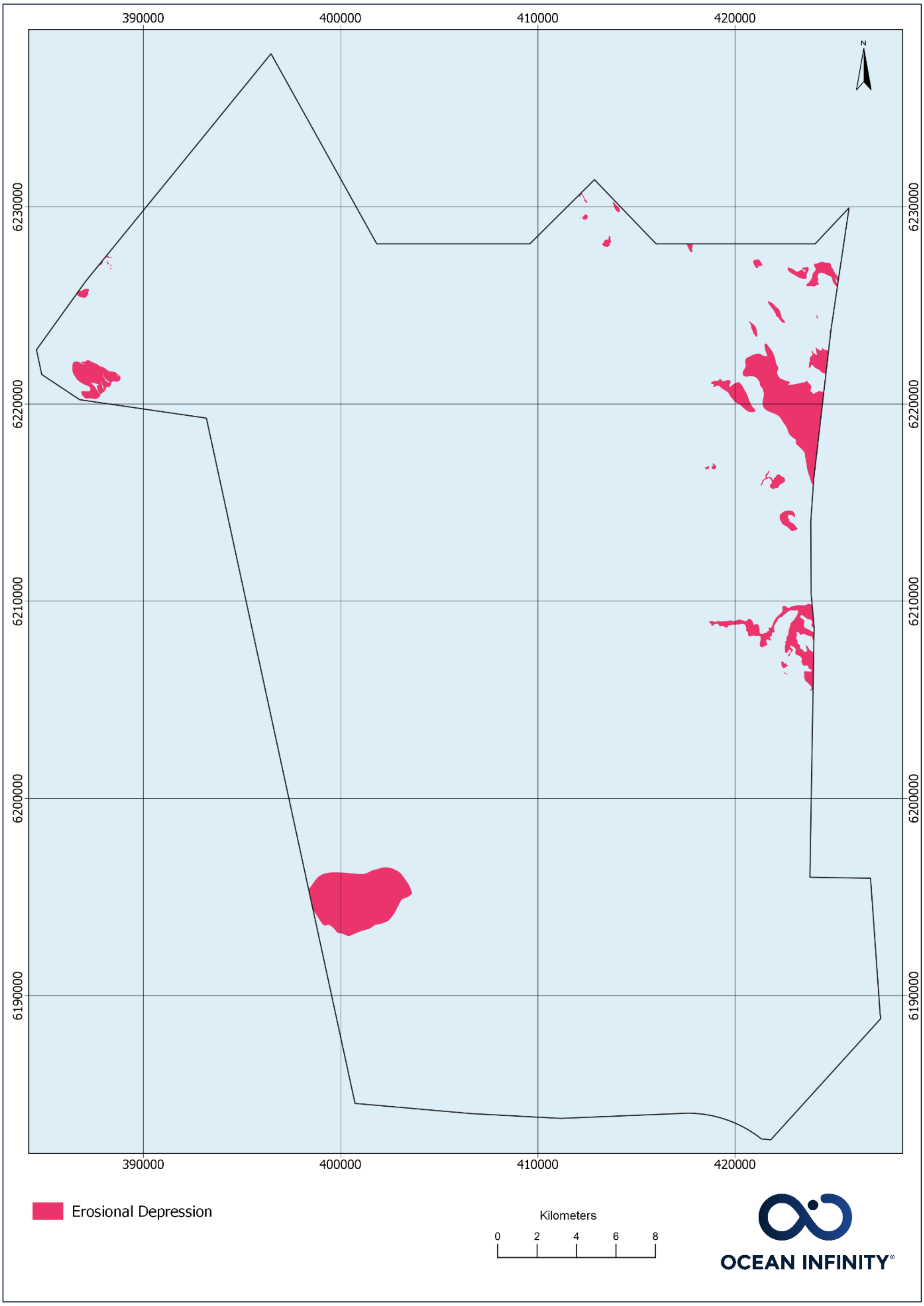


Figure 94 Distribution of erosional depression in the NSA1 survey area.

8.4.4 Boulders

Scattered boulders are present throughout the area from block BM04 to the west; small boulder fields (Figure 95) associated with areas of GRAVEL and coarse SAND and TILL/DIAMICTON were found in the southwest of NSA1 (BM10 and BM11) with individual boulders occurring in the vicinity of boulder fields.

Within the boulder field areas, boulders >2 m have been identified and are part of the TSG data set. For individual boulders, boulders >1 m outside boulder fields were picked.

Throughout the survey area a total of 1394 boulders have been picked both inside and outside boulder field areas. Boulders were picked manually within the SSS data sets and were cross checked against the MBES data. During the interpretation stage it was deemed the automated picking routine developed buy OI was not required as the distribution of boulders throughout the survey area was relatively low.

Figure 96 shows an overview of the boulder fields observed in the NSA1 survey area.

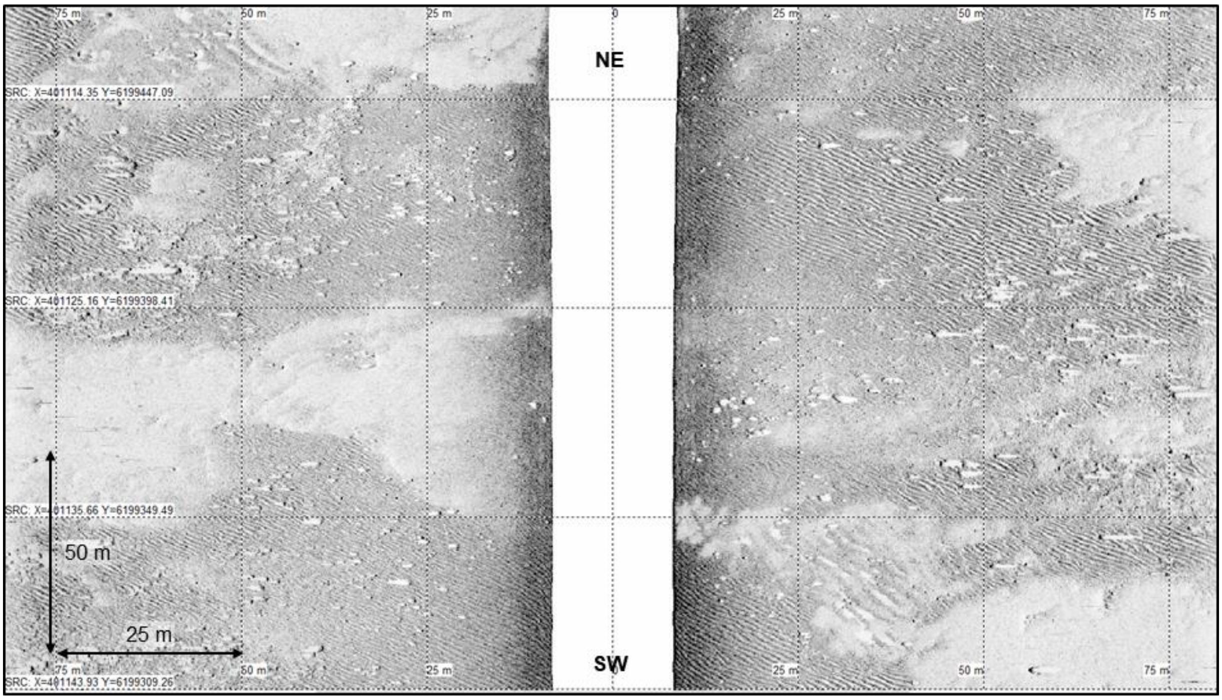


Figure 95 Example of boulder field area, Block BM10.

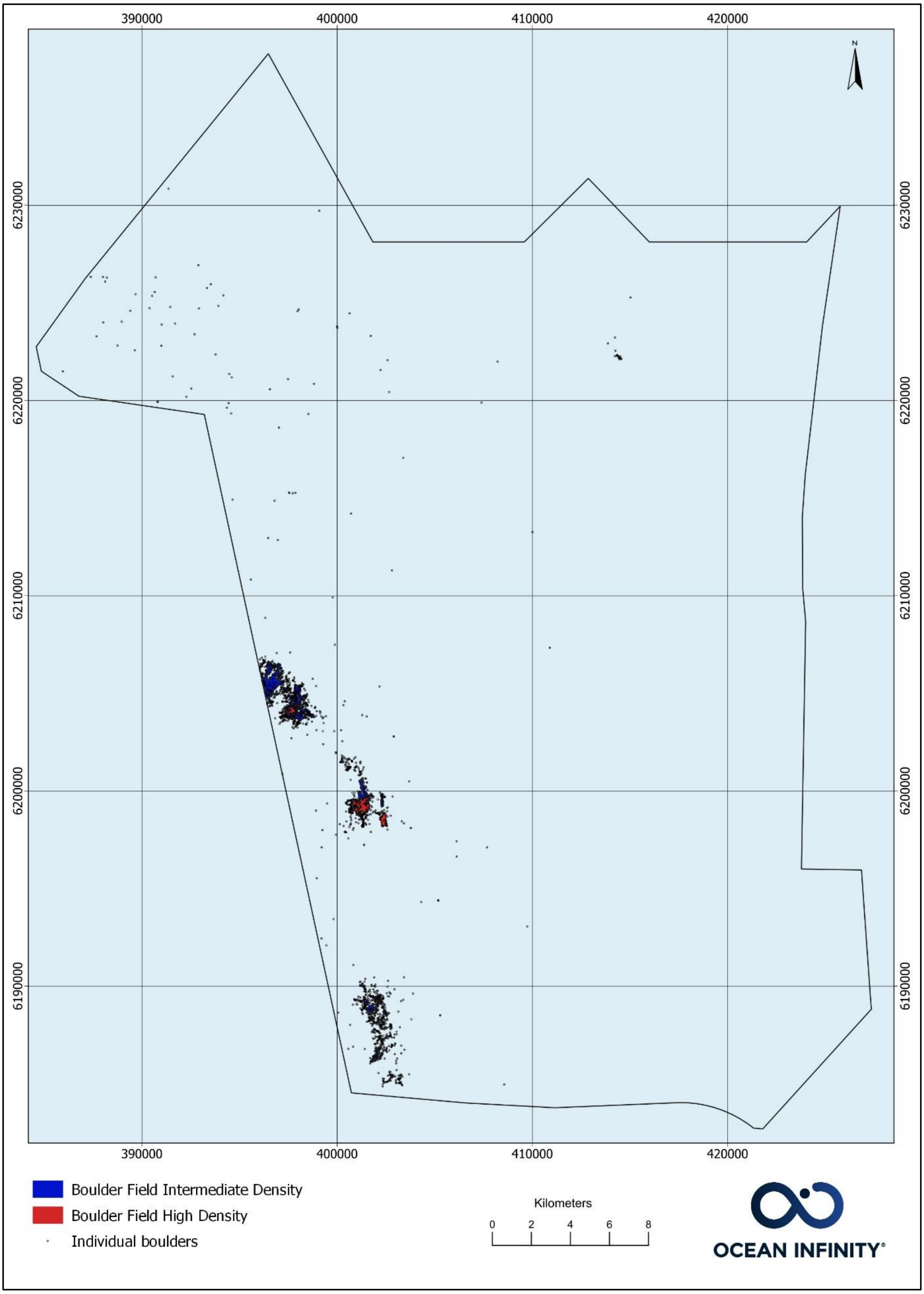


Figure 96 Distribution of individual boulders and boulder fields in the NSA1 survey area.

8.4.5 Trawl Marks

Evidence of trawling is observed across the majority of the survey area (Blocks BM03, BM04, BM05, BM07, BM08, BM09, BM10, BM12 and BM13), as seen in Figure 97 and Figure 98. Evidence of both older and more recent activity are observed with no predominant orientation identified.

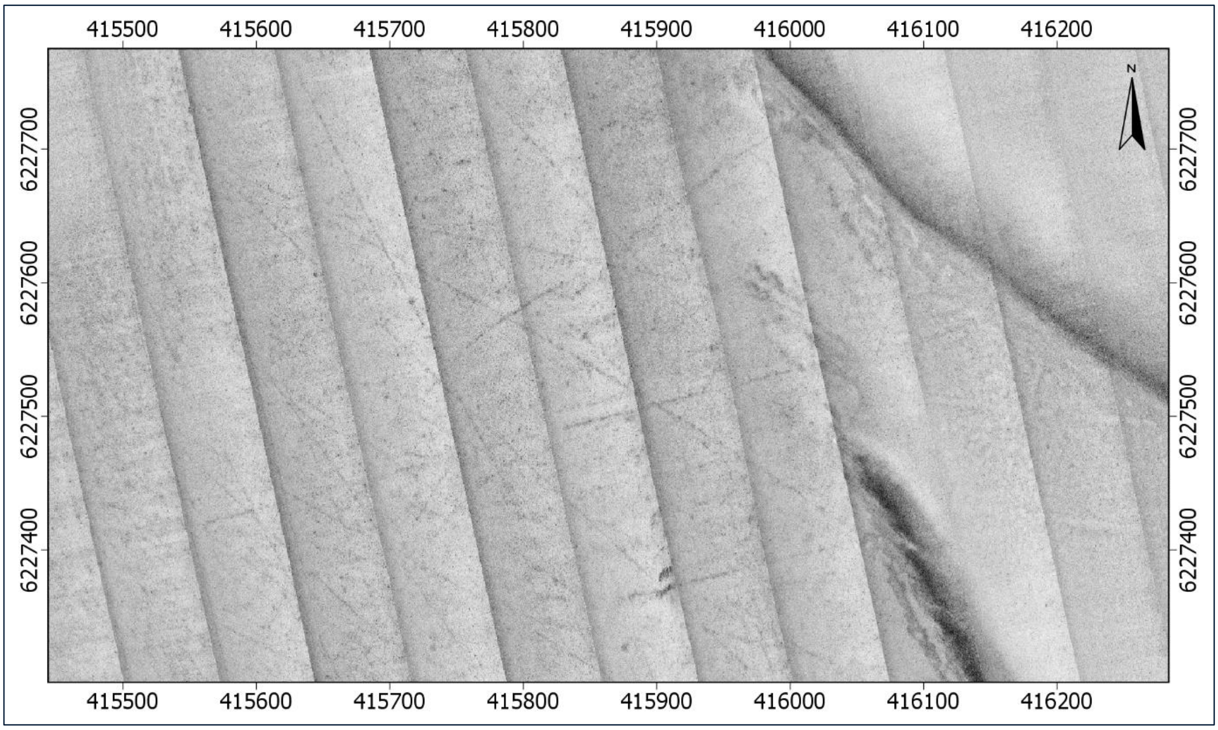


Figure 97 Example of trawl marks in SAND BM03.

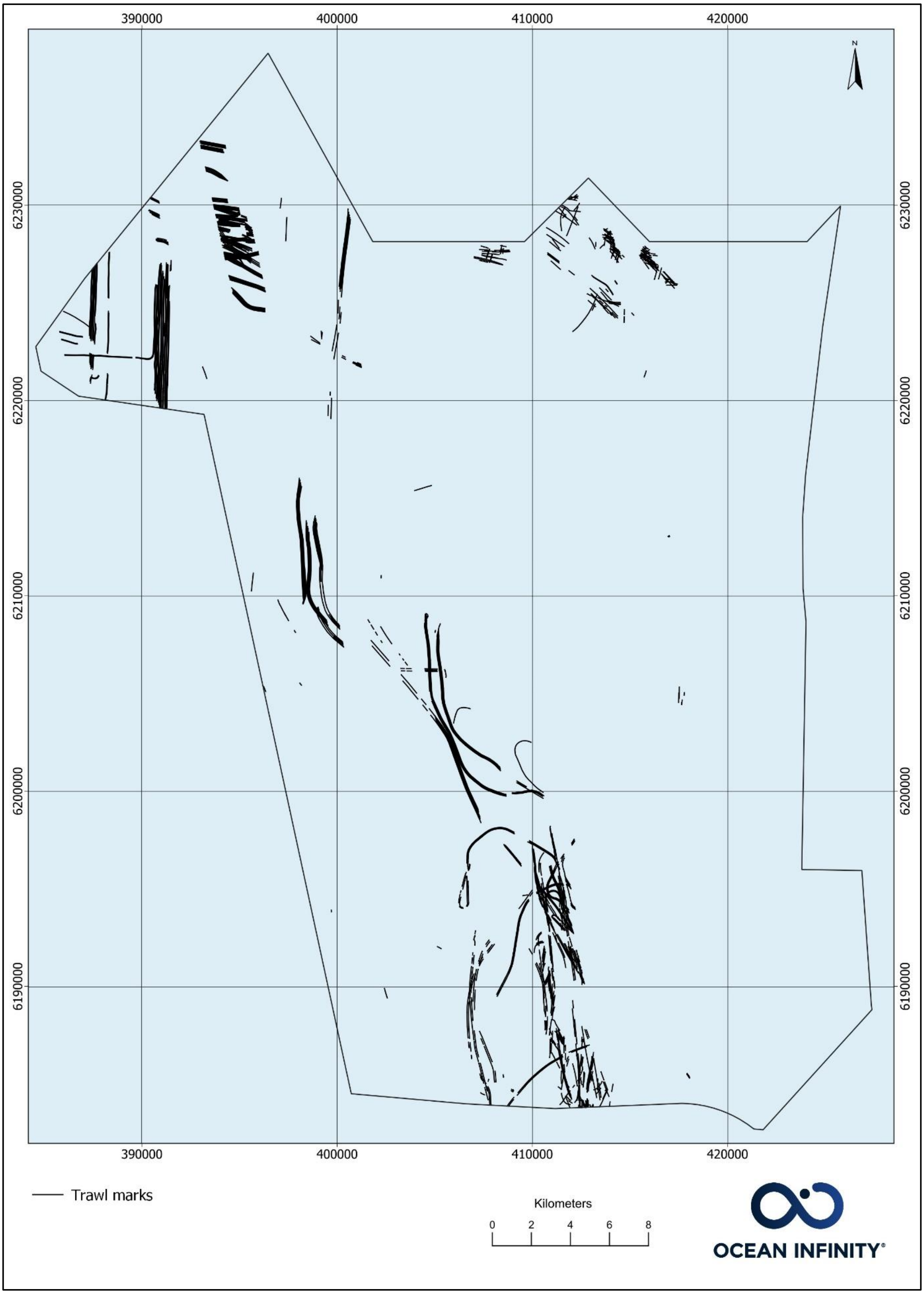


Figure 98 Distribution of trawl marks areas in NSA1 survey area.

8.5 Contacts and Anomalies

A total of 5021 individual seabed contacts were detected in the NSA1 survey area from SSS data. They were classified as: Anchor (5), Boulders (1394), Fish Net (2588), Soft Ropes (28), Wire (6), Wrecks (known, unknown and possible, 10), Scour marks (70) and Other (914). Items classified as Other were mainly possible Man-Made Objects that could not be placed in one of the specific debris classifications. Positional accuracy between contacts visible in the MBES and SSS data is good, less than 2 m.

SSS contacts are summarised in Table 35.

Table 35 Summary of SSS contacts.

CLASSIFICATION	NUMBER OF CONTACTS
Anchor	5
Boulder	1394
Fish net	2588
Other	914
Scour marks	70
Soft rope	28
Wires	6
Wrecks	10
Total	**5021**

8.5.1 Wrecks

A total of 10 items were identified as either charted wrecks (2), uncharted wrecks (4), or possible wrecks (4). A further two items were identified as possible debris within the NSA1 survey area. Of the 10 wrecks eight have been classed as high confidence and two as low confidence. Within the eight high confidence wrecks, two correlated to charted wrecks (ID, 007 and 013).

The confidence rating is determined by the likelihood that the contact is a wrecked ship. The shape and dimension of the contact are taking into consideration by assessing SSS, MBES and backscatter data, while also monitoring any magnetometer targets around the contact. Wrecks marked with “low” confidence have been deemed to be unlikely shipwrecks, either due to their shape and dimensions, or the lack of nearby magnetometer targets, such as IDs 012, 014, 017 and 020. All other wrecks have a high level of confidence of the presence of a shipwreck.

Table 36 Summary of all the wrecks and possible wrecks identified within NSA1 survey area.

OI Wreck ID	OI SSS ID	OI MAG ID	EASTING (m)	NORTHING (m)	CONFID-ENCE	COMMENT
007	S_NM_BM13_0255	M_NM_BM13_1380	388404.3	6221212.4	High	Wreck - charted
010	S_NM_BM11_0521	M_NM_BM11_0685	394677.4	6217762.3	High	Possible Wreck - uncharted
011	S_NM_BM11_0400	N/A	393796.4	6225778.2	High	Possible Wreck - uncharted

OI Wreck ID	OI SSS ID	OI MAG ID	EASTING (m)	NORTHING (m)	CONFID-ENCE	COMMENT
012	S_FR_BM08_0004 S_FR_BM08_0005 S_FR_BM08_0006 S_FR_BM08_0007 S_FR_BM08_0008 S_FR_BM08_0009 S_FR_BM08_0010 S_FR_BM08_0011 S_FR_BM08_0012 S_FR_BM08_0013	M_FR_BM08_0110 M_FR_BM08_0116 M_FR_BM08_0156 M_FR_BM08_0155	407115.3	6203323.2	Low	Possible Debris – debris field
013	S_FR_BM08_0059	M_FR_BM08_0306	409091.6	6189131.5	High	Wreck – charted (SIERRA CORDOBA) - outside buffer
014	S_FR_BM07_0301	M_FR_BM07_0451 M_FR_BM07_0551	413124.2	6185348.4	Low	Possible Debris - debris field
015	S_FR_BM06_0127	M_NM_BM06_0164	415481.1	6188337.9	High	Unknown Wreck - uncharted
016	S_NM_BM05_0142	M_NM_BM05_0320M_NM_BM05_0306	417285.5	6192061.6	High	Unknown Wreck - uncharted
017	S_NM_BM05_0056	N/A	417183.4	6196637.6	Low	Possible Wreck – uncharted Image is not conclusive that the target is a wreck.
018	S_NM_BM04_0120	M_NM_BM04_0072	415230.4	6222578.3	High	Unknown Wreck - uncharted
019	S_NM_BM03_0358	M_NM_BM03_0218	417503.0	6222693.7	High	Unknown Wreck - uncharted
020	S_NM_BM03_0530	M_NM_BM03_0370	417407.9	6219378.6	Low	Possible Wreck – or shipping container?

A visual overview of the identified wrecks is displayed in Figure 99 and text detailing the findings is below.

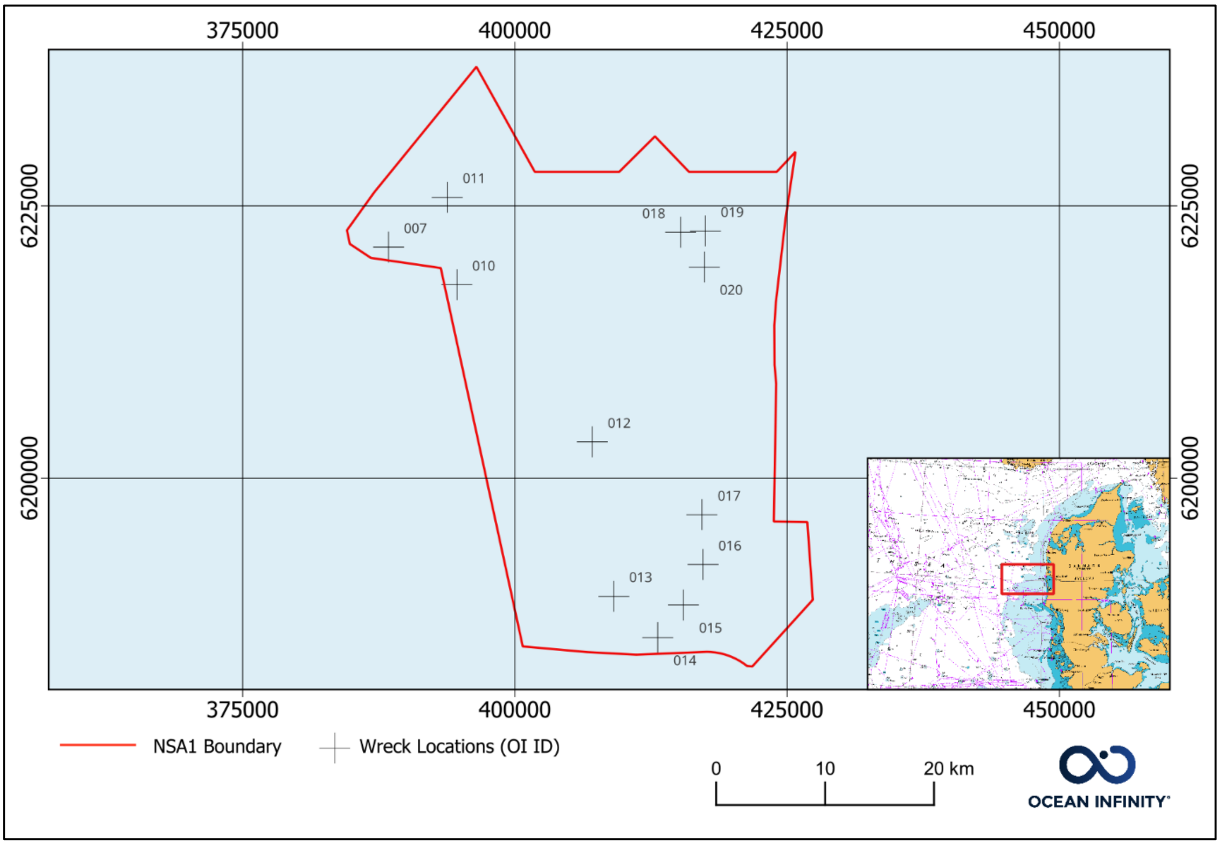


Figure 99 Overview of wreck locations within the NSA1 survey area

OI Wreck ID – 007. A charted wreck (Contact ID: S_NM_BM13_0255) was found at 388404.3 m E, 6221212.4 m N (Figure 100). One magnetic anomaly was observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 6.3 x 2.0 x 1.4 m.

OI Wreck ID – 010. An uncharted possible wreck (Contact ID: S_NM_BM11_0521) was found at 394677.4 m E, 6217762.3 m N (Figure 102). One magnetic anomaly was observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 50.9 x 9.8 x 3.3 m.

OI Wreck ID – 011. An uncharted possible wreck (Contact ID: S_NM_BM11_0400) was found at 393796.4 m E, 6225778.2 m N (Figure 104). No magnetic anomalies were observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 12.8 x 5.0 x 0.8 m.

OI Wreck ID – 012. An unknown possible debris field (Multiple SSS contact IDs) was found around 407115.3 m E, 6203323.2 m N (Figure 106). Four magnetic anomalies were observed in the vicinity. The SSS targets are linear in shape and have been interpreted as possible pipe debris.

OI Wreck ID – 013. A charted wreck (Contact ID: S_FR_BM08_0059) was found at 409091.6 m E, 6189131.5 m N (Figure 108). One magnetic anomaly was observed in the vicinity. On background information, the wreck is identified as the vessel SIERRA CORDOBA. The as-found dimensions (LxWxH) taken from the SSS data are 95.7x 41.7 x 2.1 m.

OI Wreck ID – 014. An unknown possible debris item (Contact ID: S_FR_BM07_0301) was found at 413124.2 m E, 6185348.4 N (Figure 110). Two magnetic anomalies were observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 12.8 x 5.0 x 0.8 m.

OI Wreck ID – 015. An uncharted wreck (Contact ID: S_FR_BM06_0127) was found at 415481.1 m E, 6188337.9 m N (Figure 112). One magnetic anomaly was observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 34.5 x 8.9 x 1.2 m.

OI Wreck ID – 016. An uncharted wreck (Contact ID: S_NM_BM05_0142) was found at 417285.5 m E, 6192061.6 m N (Figure 114). Two magnetic anomalies were observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 34.9 x 6.8 x 3.9 m.

OI Wreck ID – 017. An uncharted possible wreck (Contact ID: S_NM_BM05_0056) was found at 417183.4 m E, 6196637.6 m N (Figure 116). No magnetic anomalies were observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 7.2 x 6.0 x 0.2 m.

OI Wreck ID – 018. An uncharted wreck (Contact ID: S_NM_BM04_0120) was found at 415230.4 m E, 6222578.3 m N (Figure 118). One magnetic anomaly was observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 20.3 x 4.7 x 1.5 m.

OI Wreck ID – 019. An uncharted wreck (Contact ID: S_NM_BM03_0358) was found at 417503.0 m E, 6222693.7 m N (Figure 120). One magnetic anomaly was observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 34.8 x 7.0 x 2.0 m.

OI Wreck ID – 020. A possible wreck or debris item, possible shipping container (Contact ID: S_NM_BM03_0530) was found at 417407.9 m E, 6219378.6 m N (Figure 122). One magnetic anomaly was observed in the vicinity. The as-found dimensions (LxWxH) taken from the SSS data are 12.5 x 2.9 x 0.2 m.

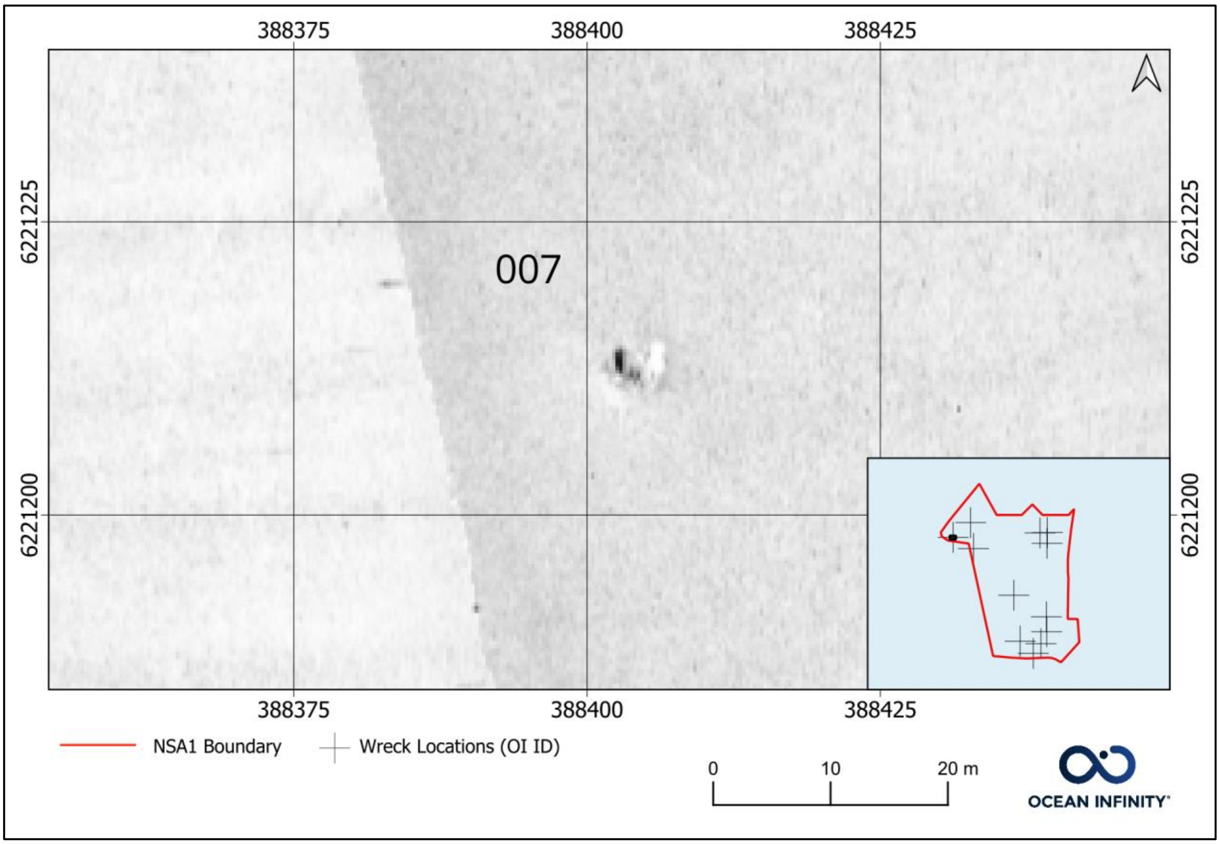


Figure 100 SSS image of charted wreck (OI-007).

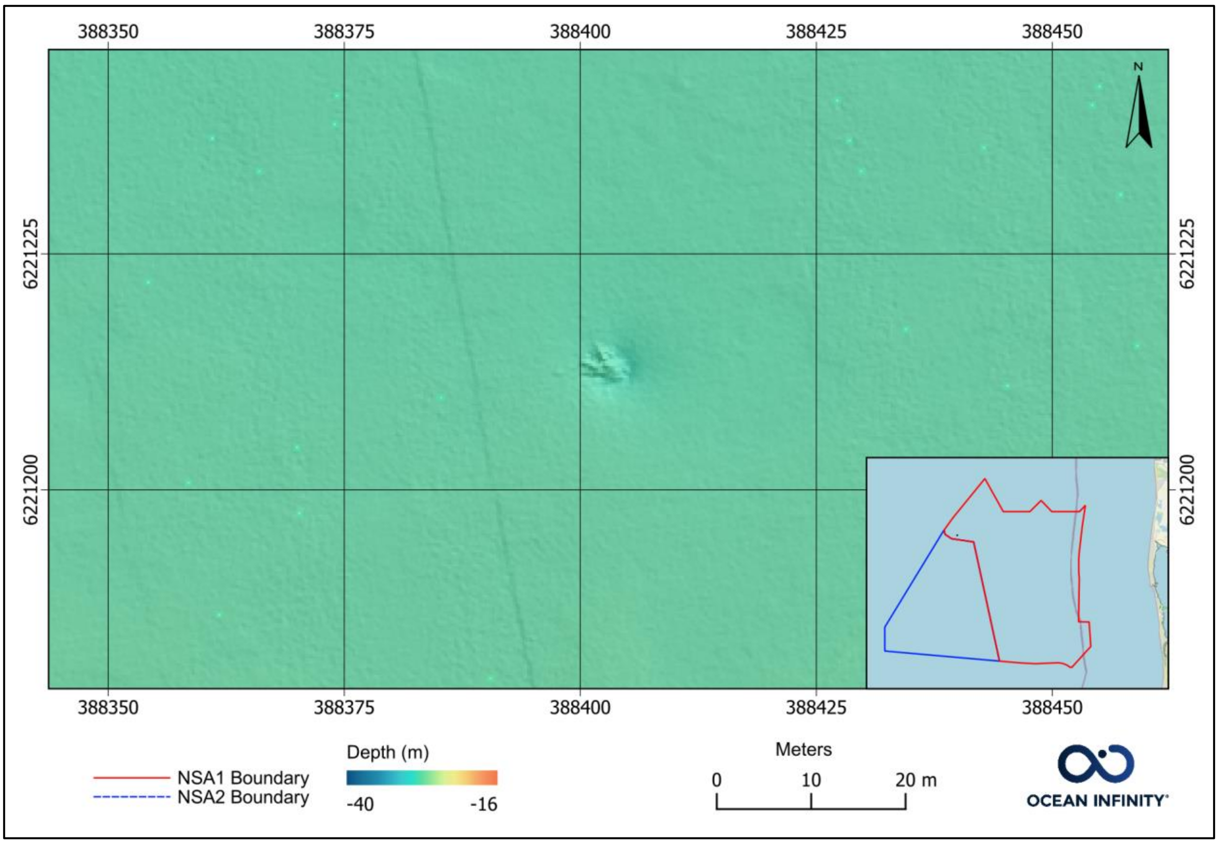


Figure 101 MBES image of charted wreck (OI-007).

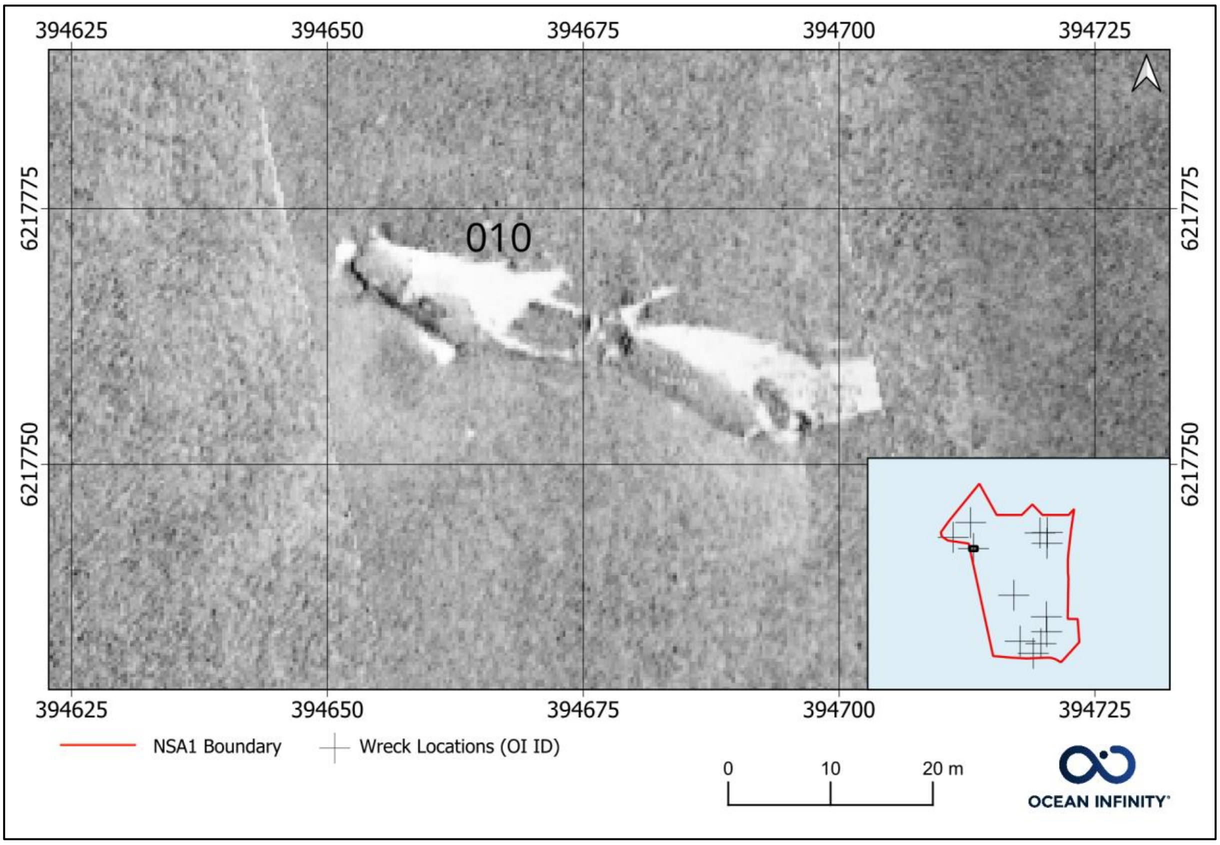


Figure 102 SSS image of uncharted wreck (OI-010).

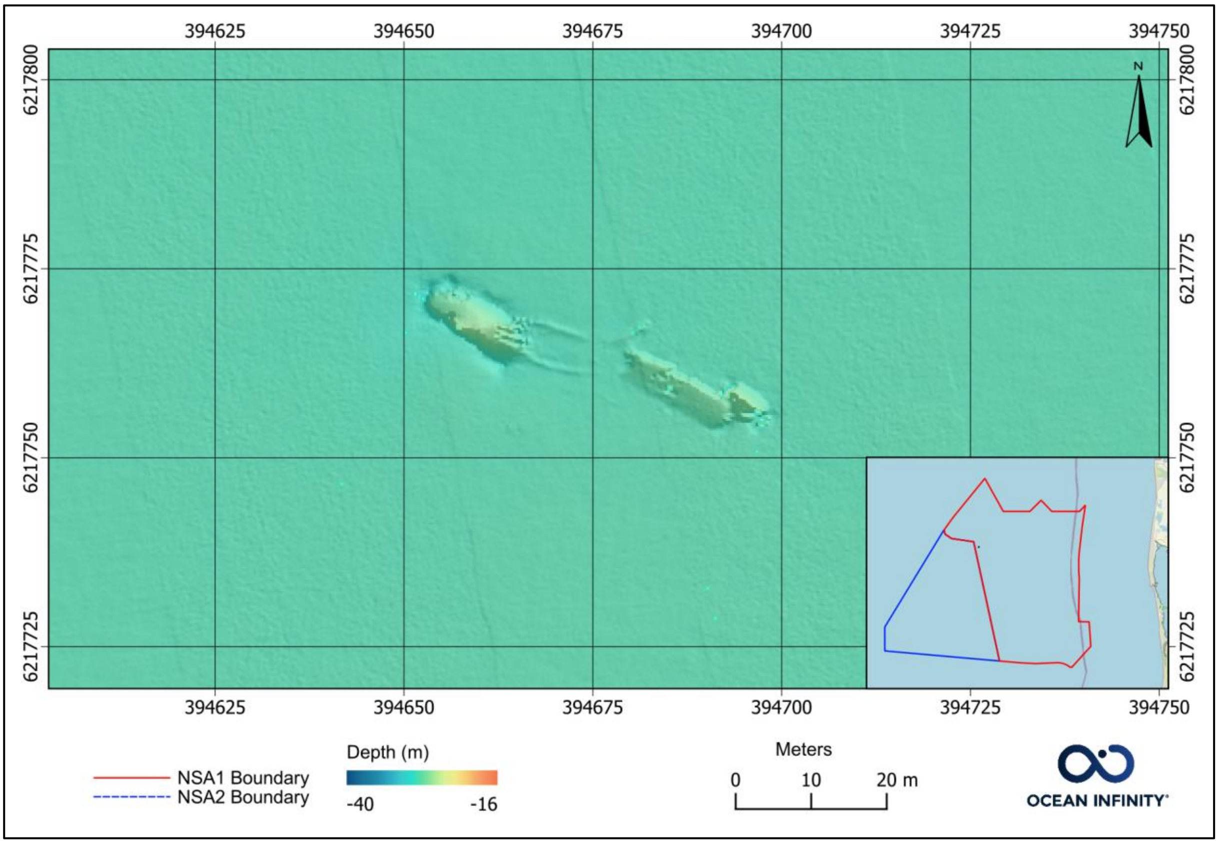


Figure 103 MBES image of uncharted wreck (OI-010).

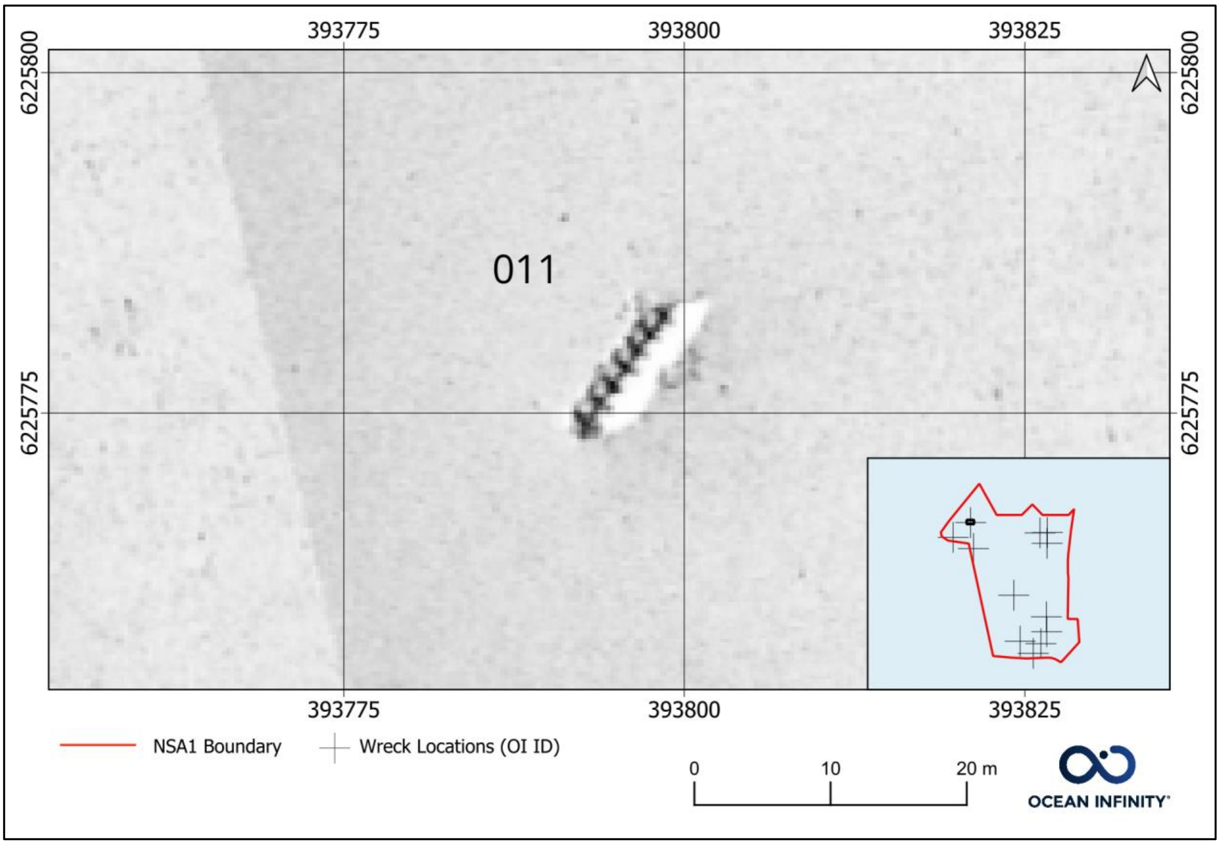


Figure 104 SSS image of uncharted wreck (OI-011).

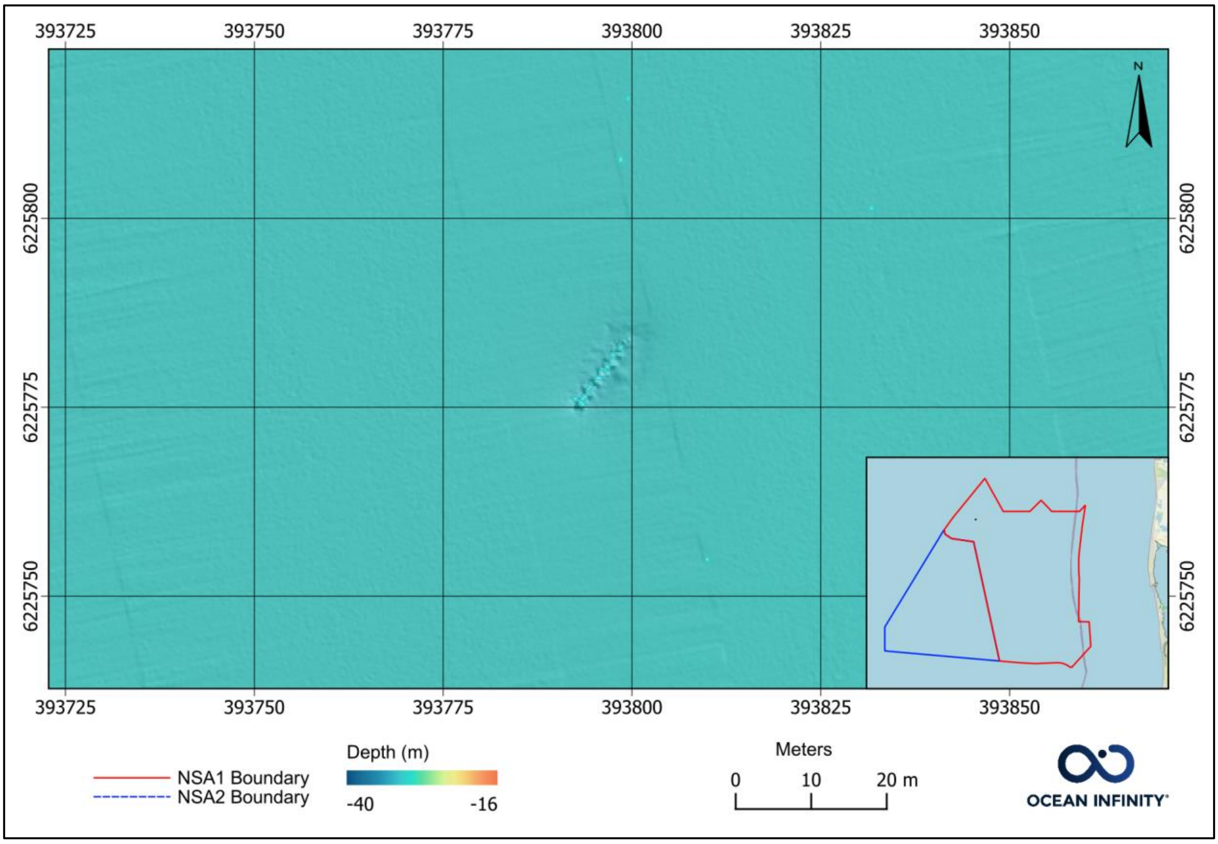


Figure 105 MBES image of uncharted wreck (OI-011).

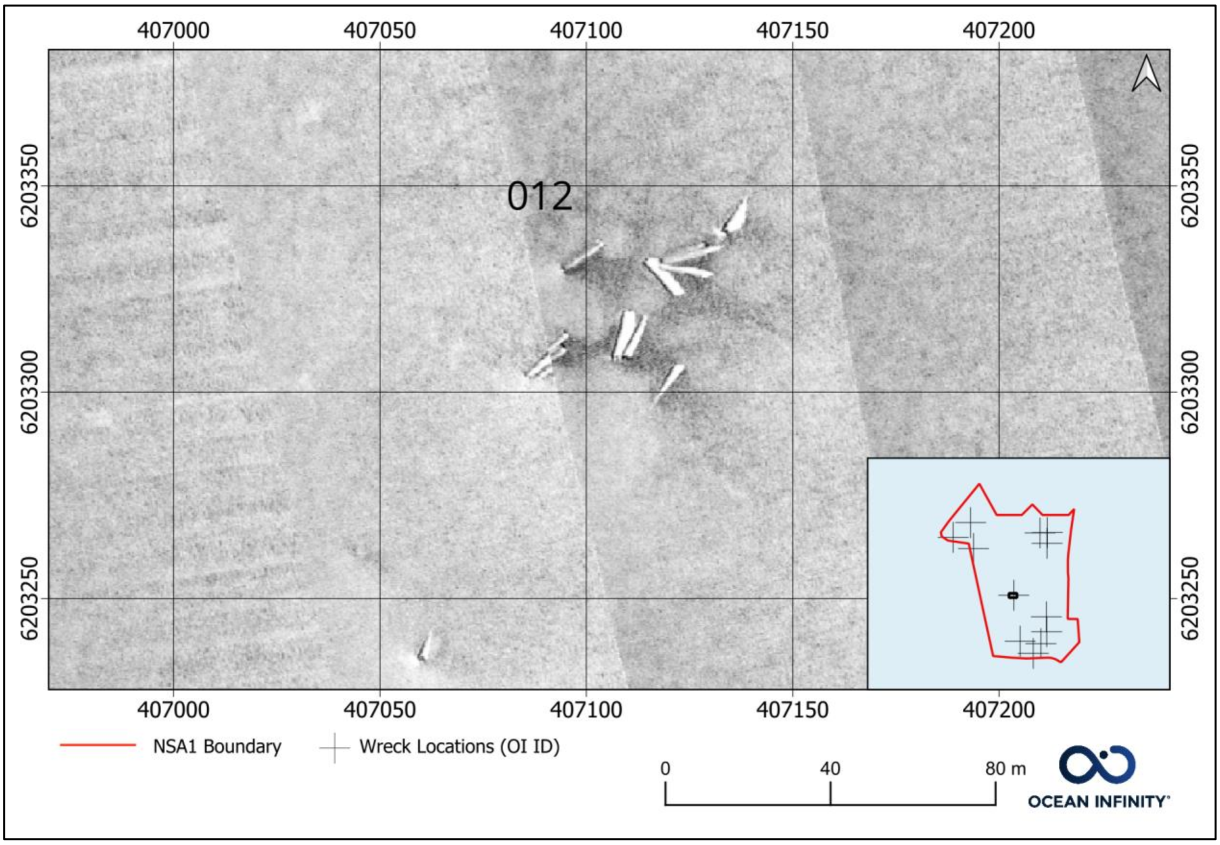


Figure 106 SSS image of unknown debris field (OI-012).

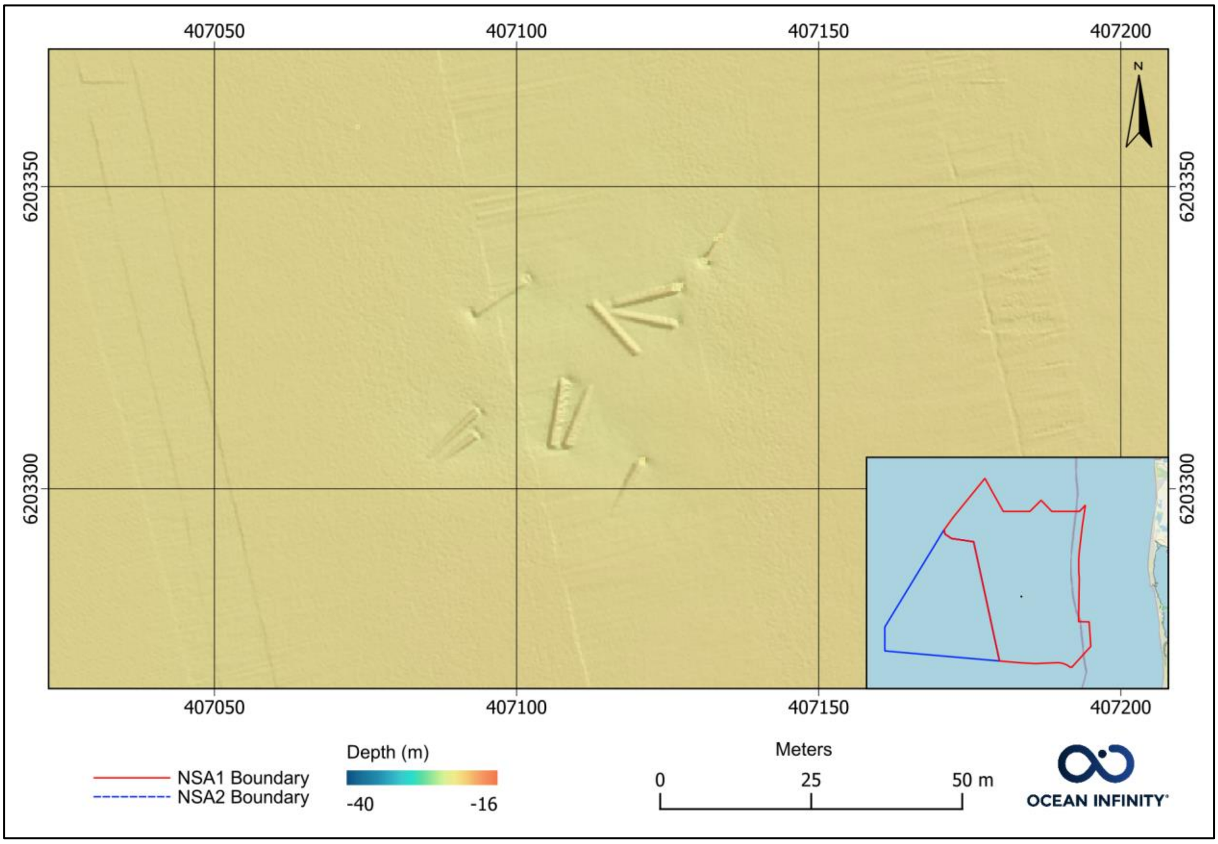


Figure 107 MBES image of unknown debris field (OI-012).

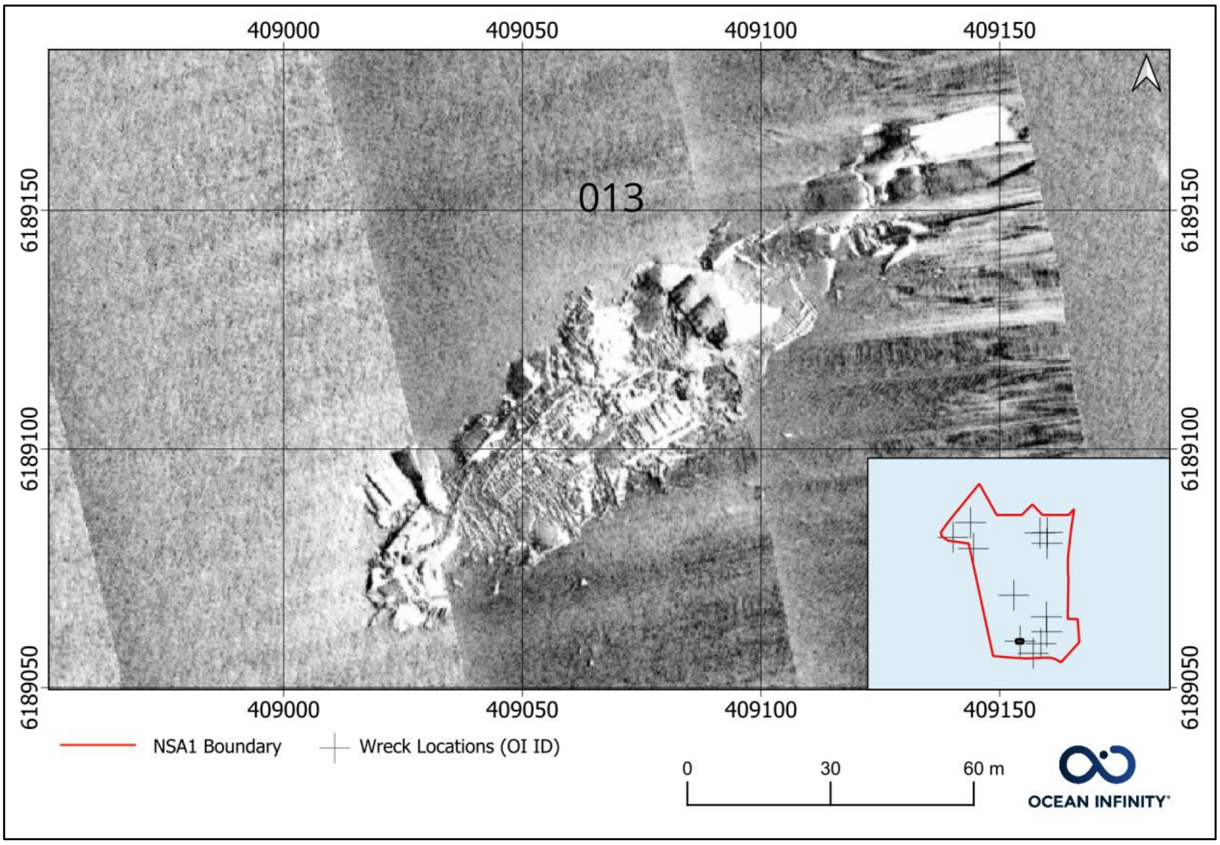


Figure 108 SSS image of charted wreck SS Sierra Cordoba (OI-013).

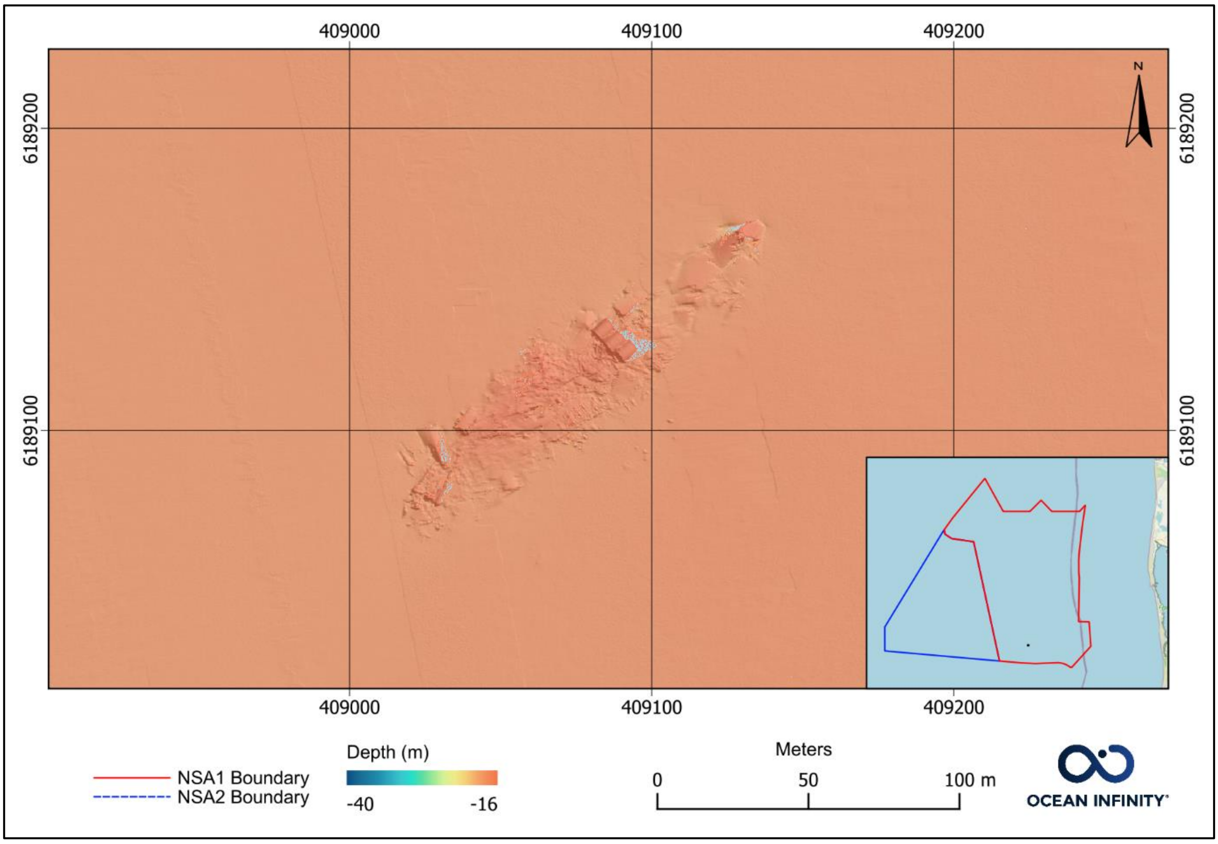


Figure 109 MBES image of charted wreck (OI-013).

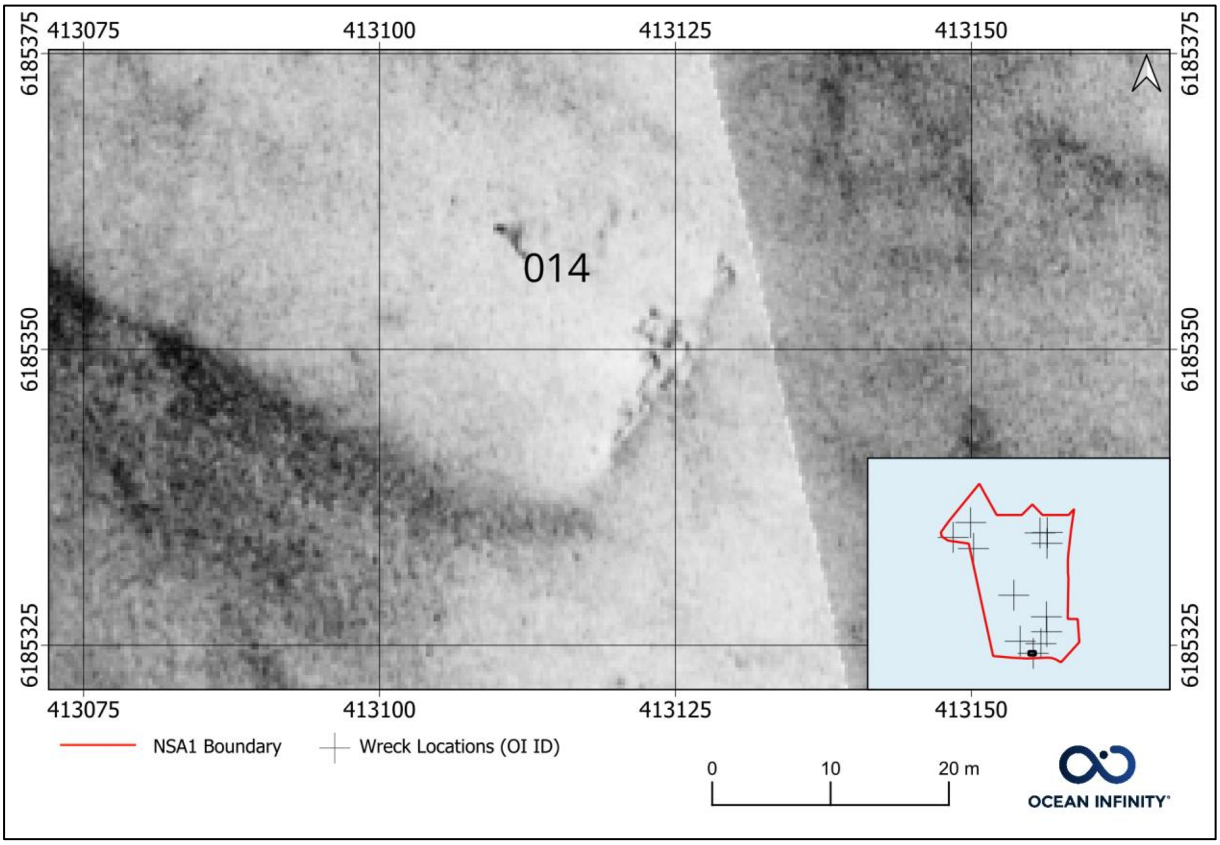


Figure 110 SSS image of unknown debris field (OI-014).

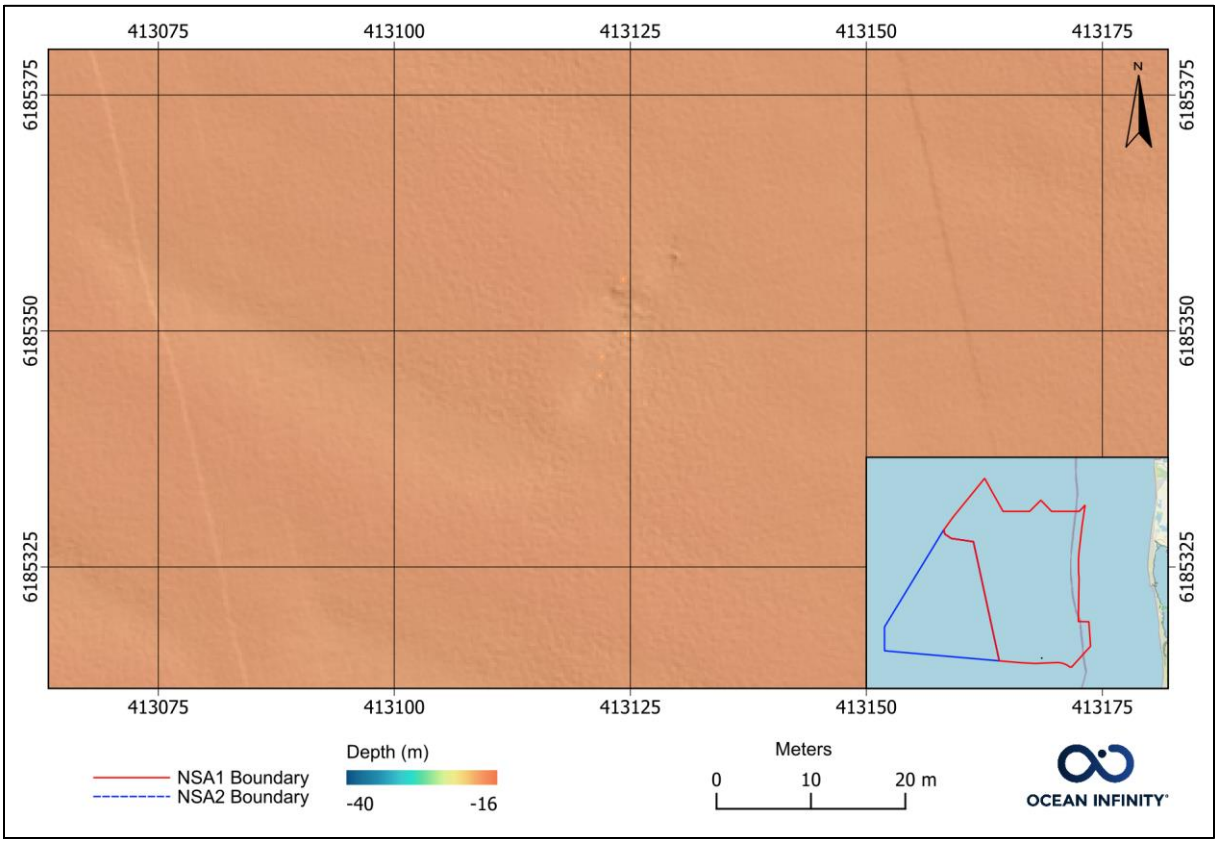


Figure 111 MBES image of unknown debris field (OI-014).

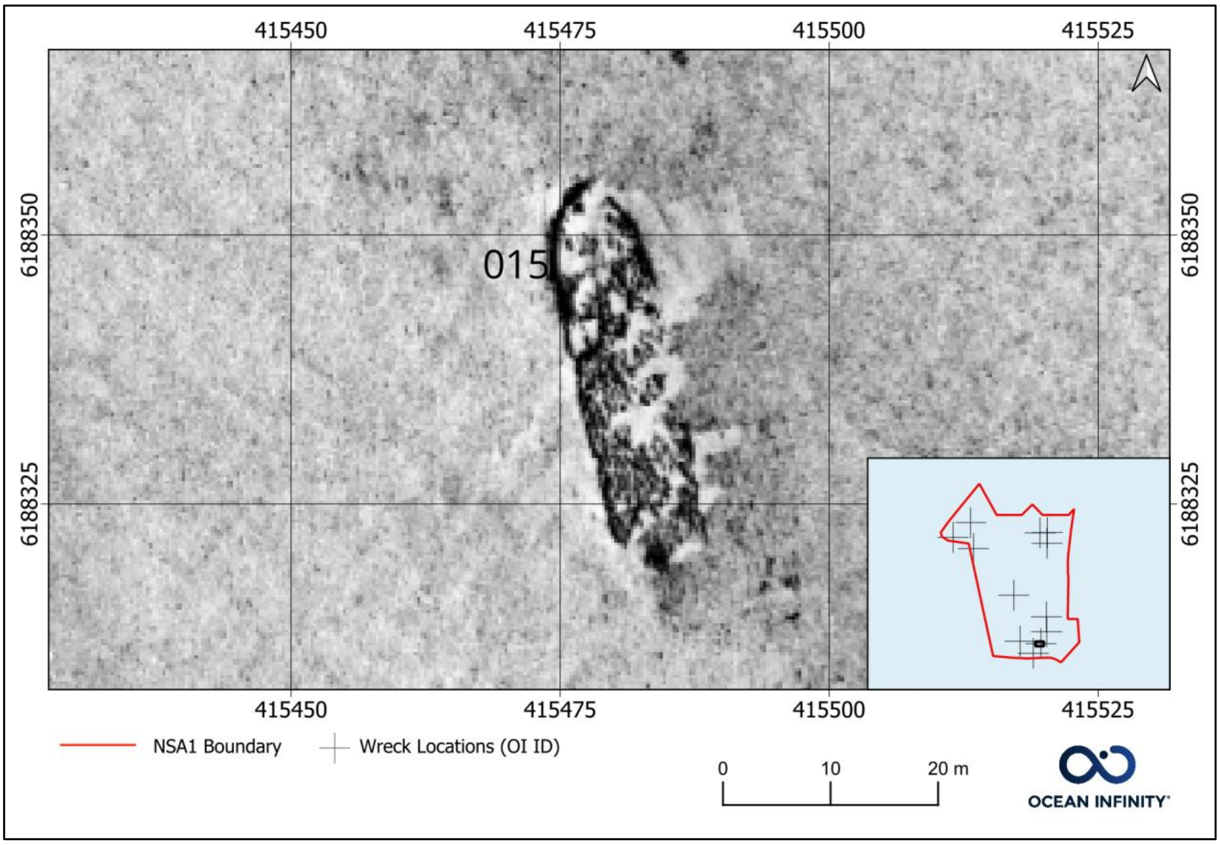


Figure 112 SSS image of uncharted wreck (OI-015).

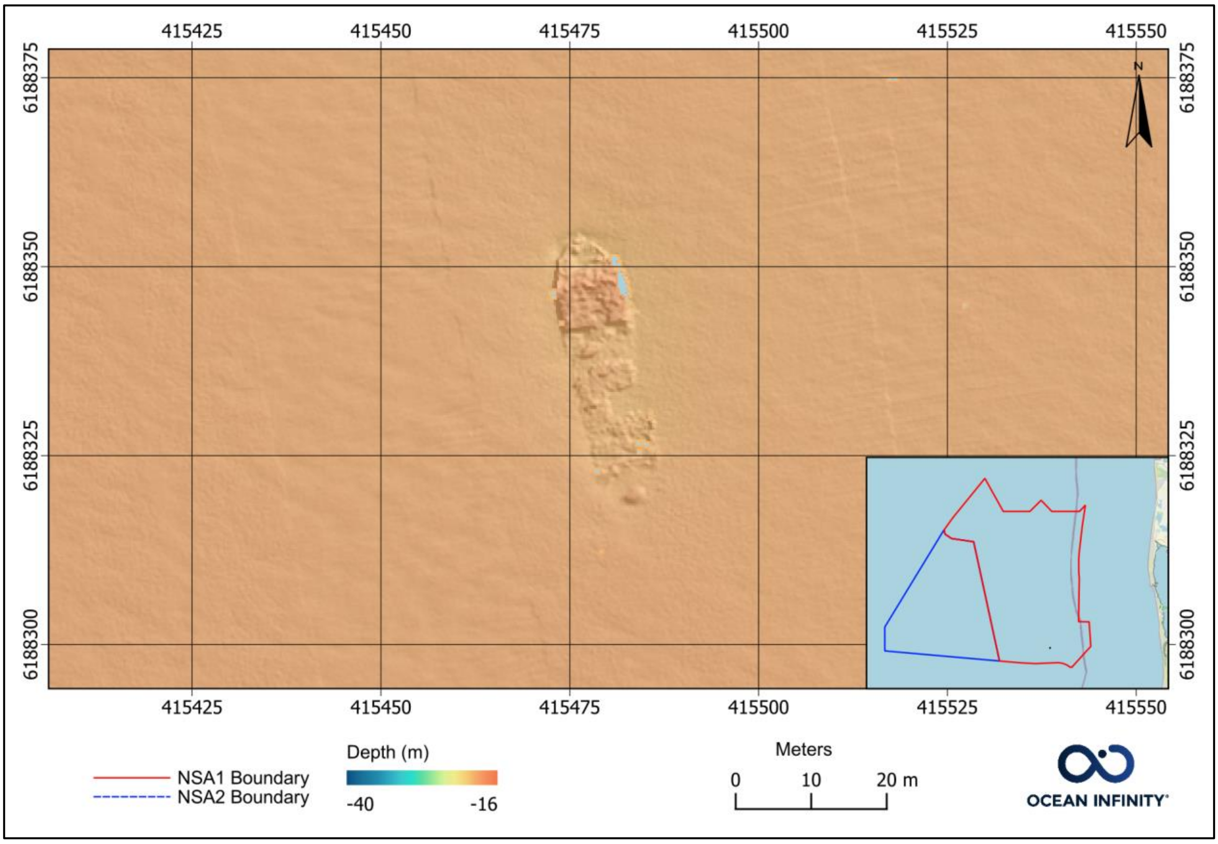


Figure 113 MBES image of uncharted wreck (OI-015).

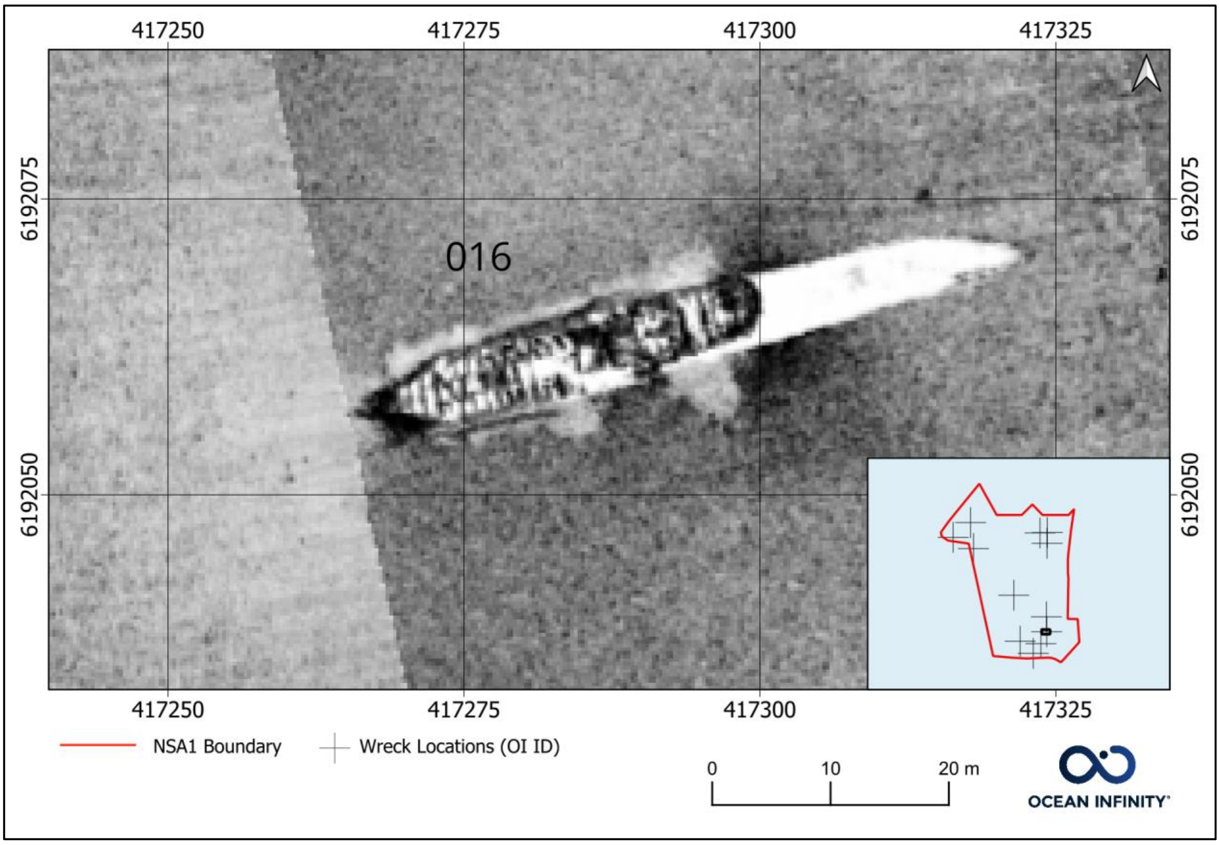


Figure 114 SSS image of uncharted wreck (OI-016).

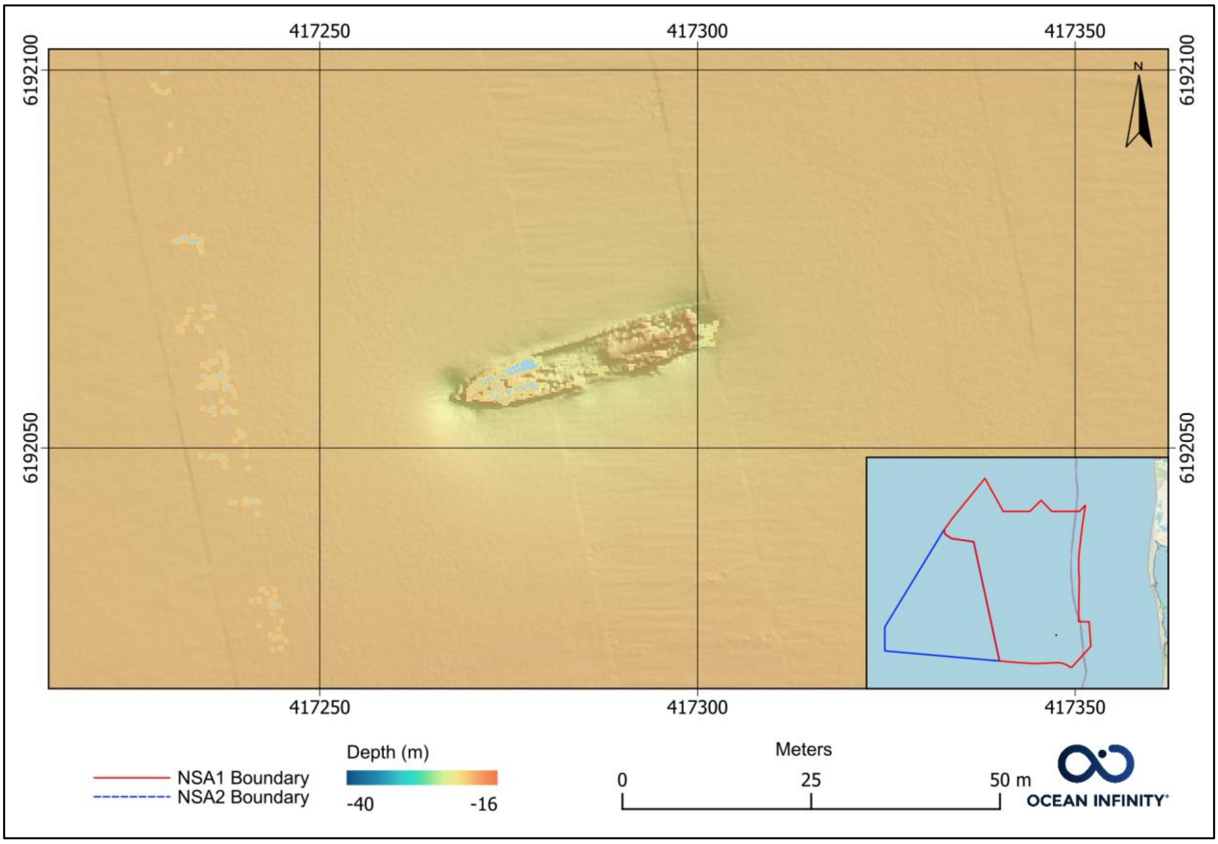


Figure 115 MBES image of uncharted wreck (OI-016).

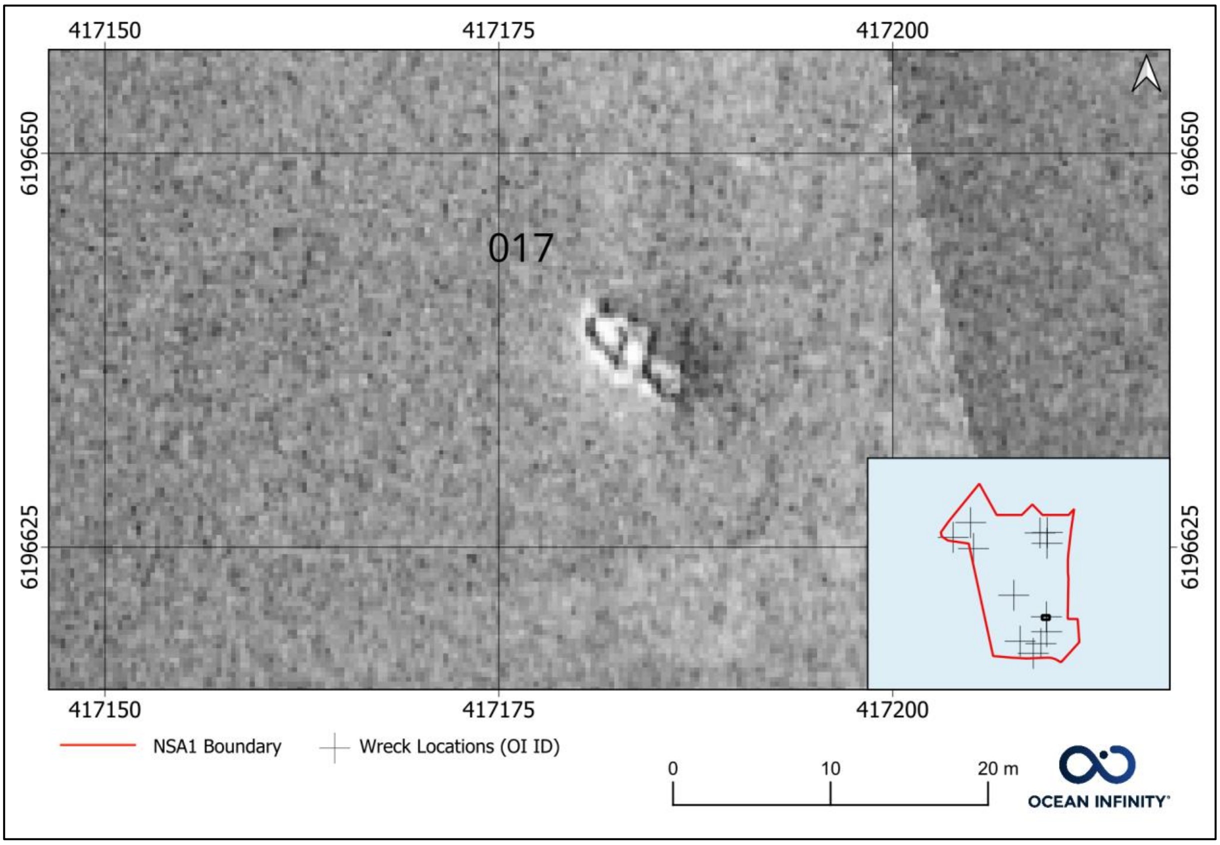


Figure 116 SSS image of uncharted wreck (OI-017).

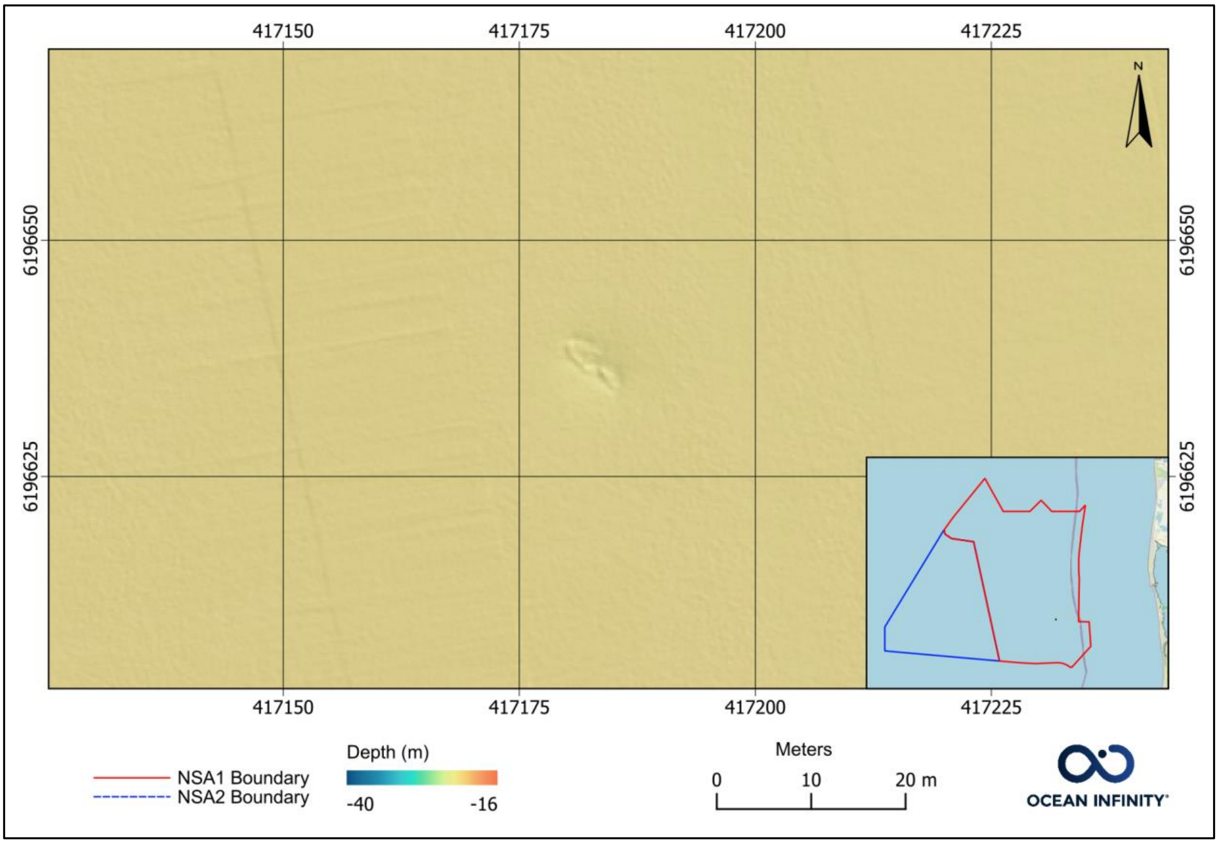


Figure 117 MBES image of uncharted wreck (OI-017).

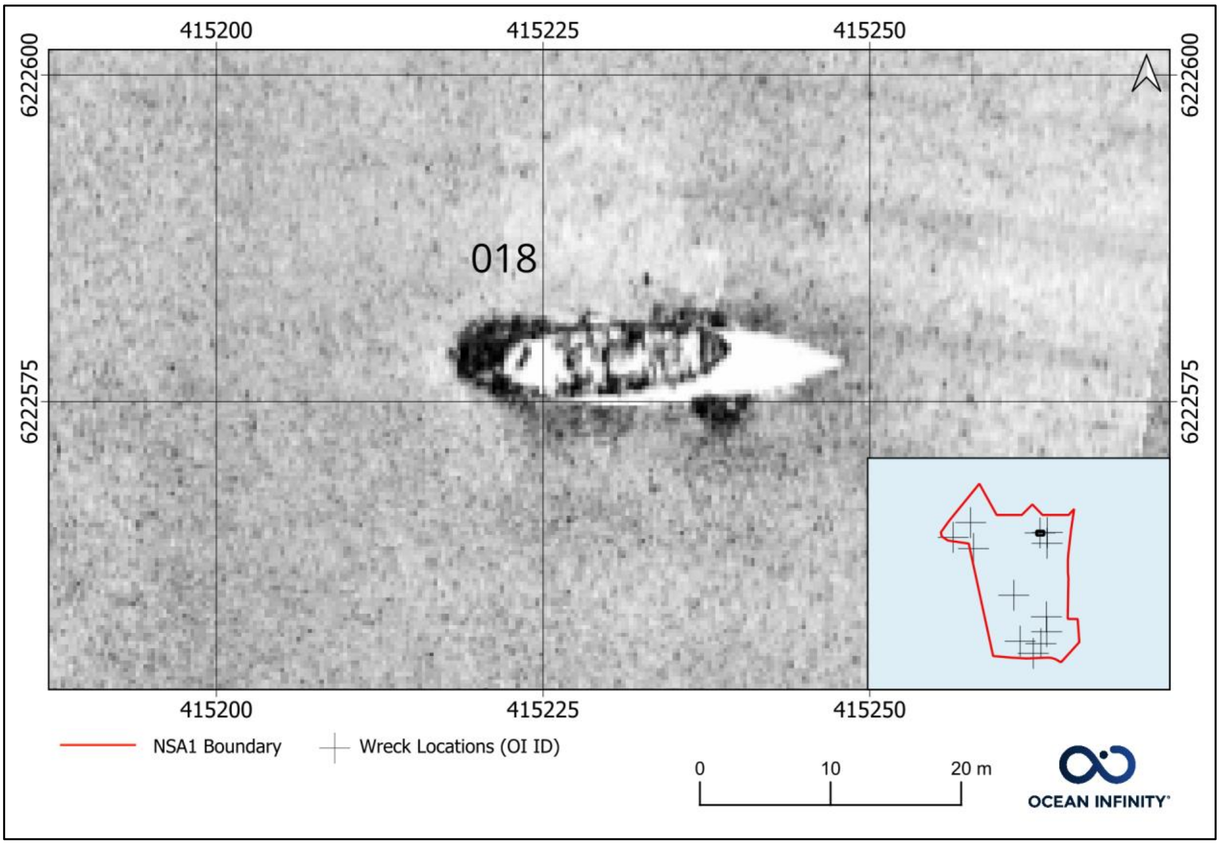


Figure 118 SSS image of uncharted wreck (OI-018).

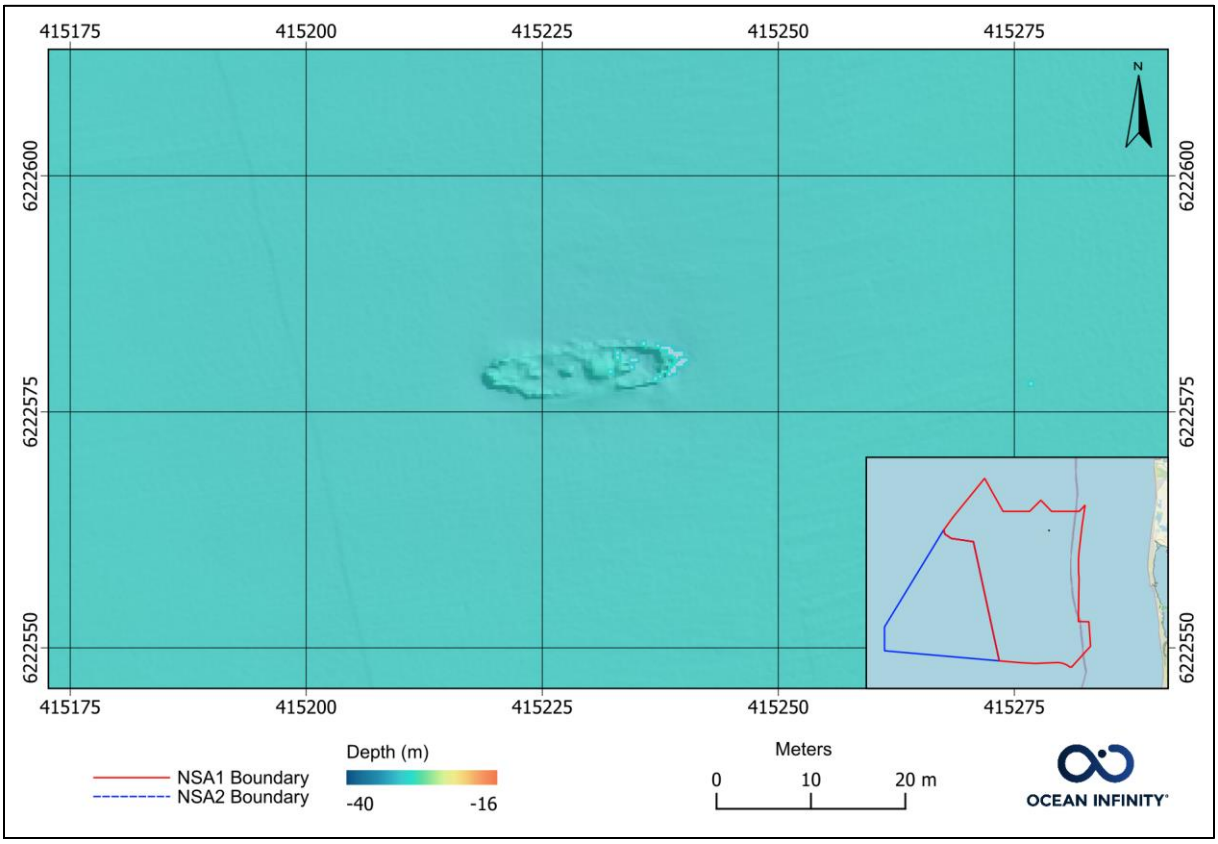


Figure 119 MBES image of uncharted wreck (OI-018).

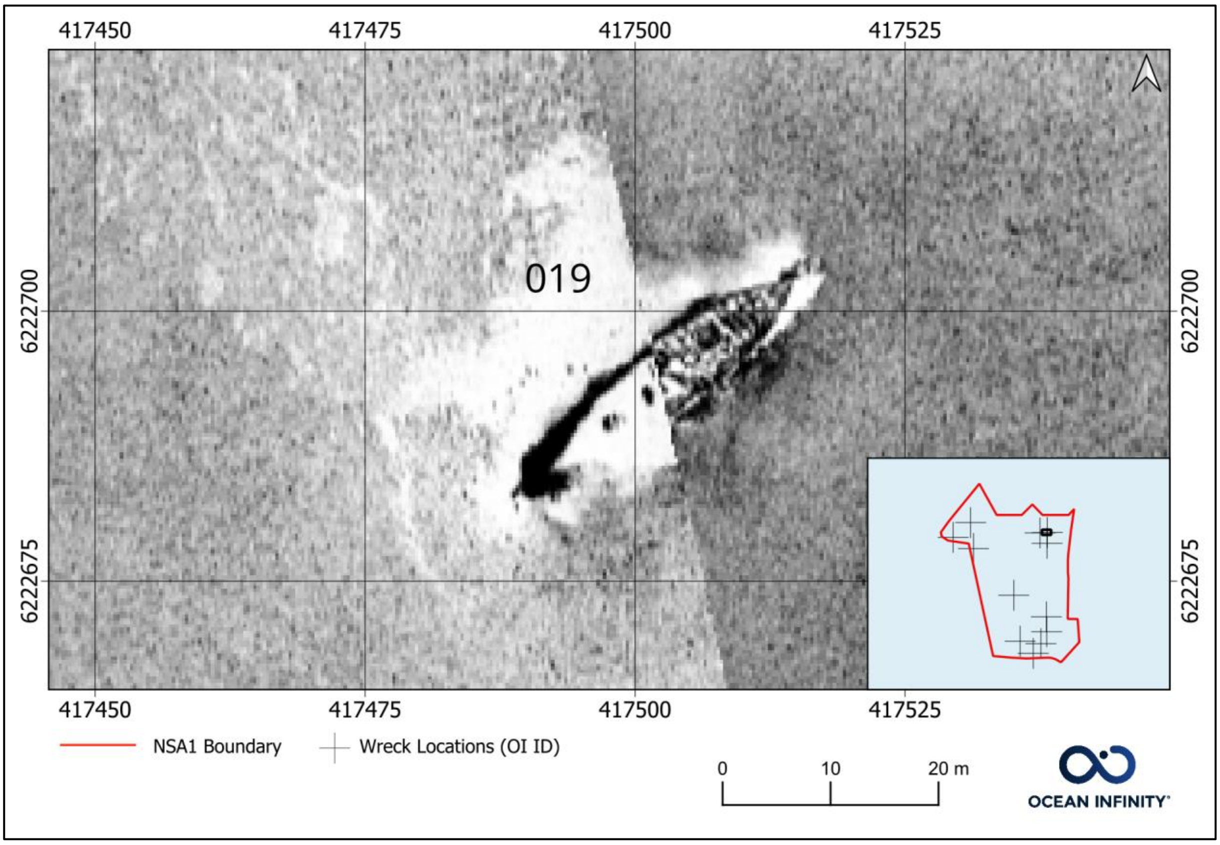


Figure 120 SSS image of uncharted wreck (OI-019).

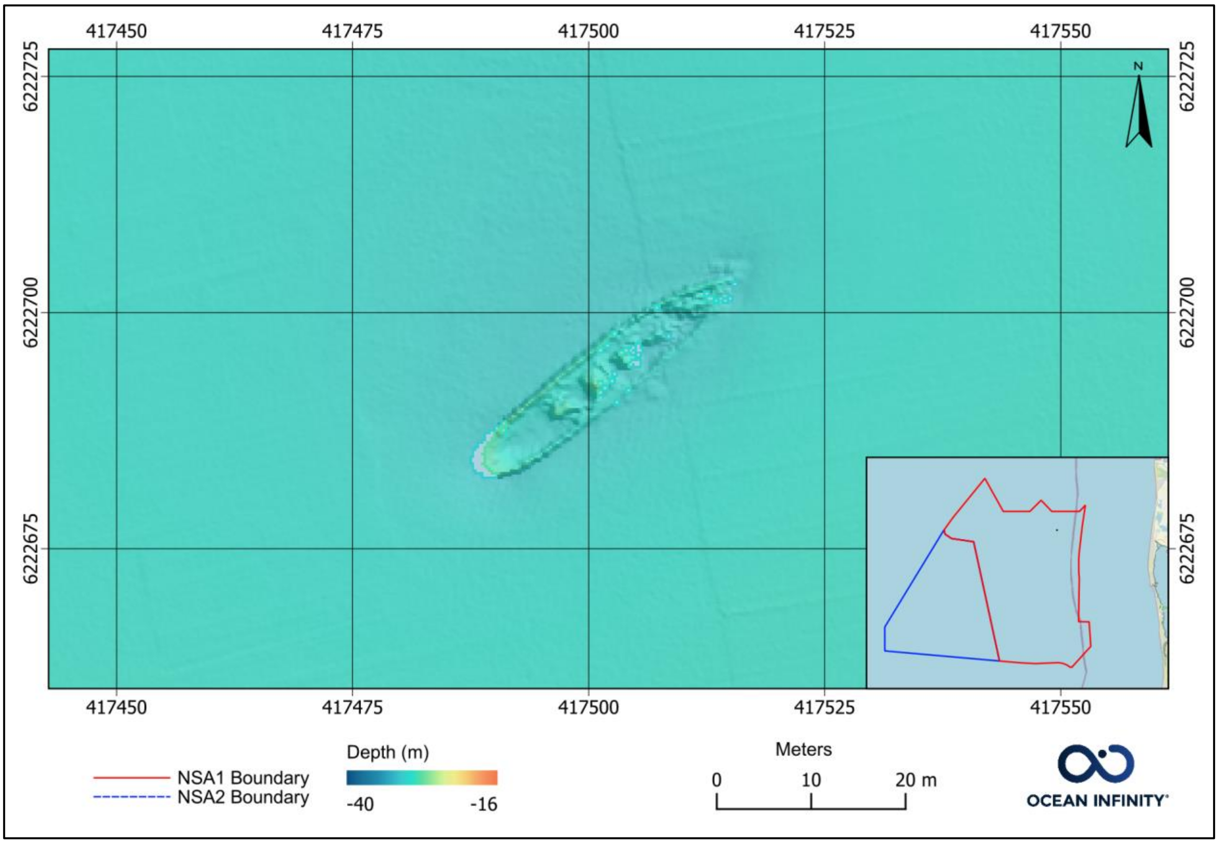


Figure 121 MBES image of uncharted wreck (OI-019).

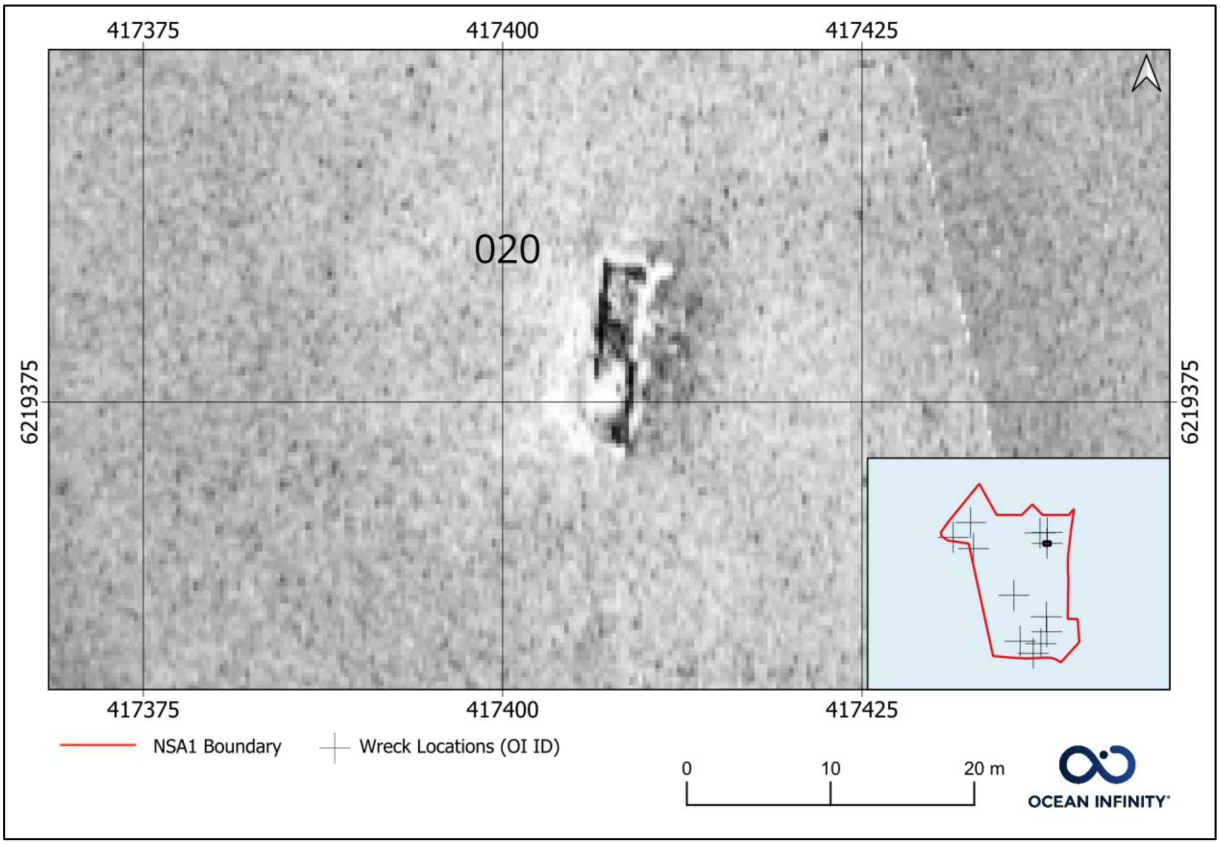


Figure 122 SSS image of possible shipping container (OI-020).

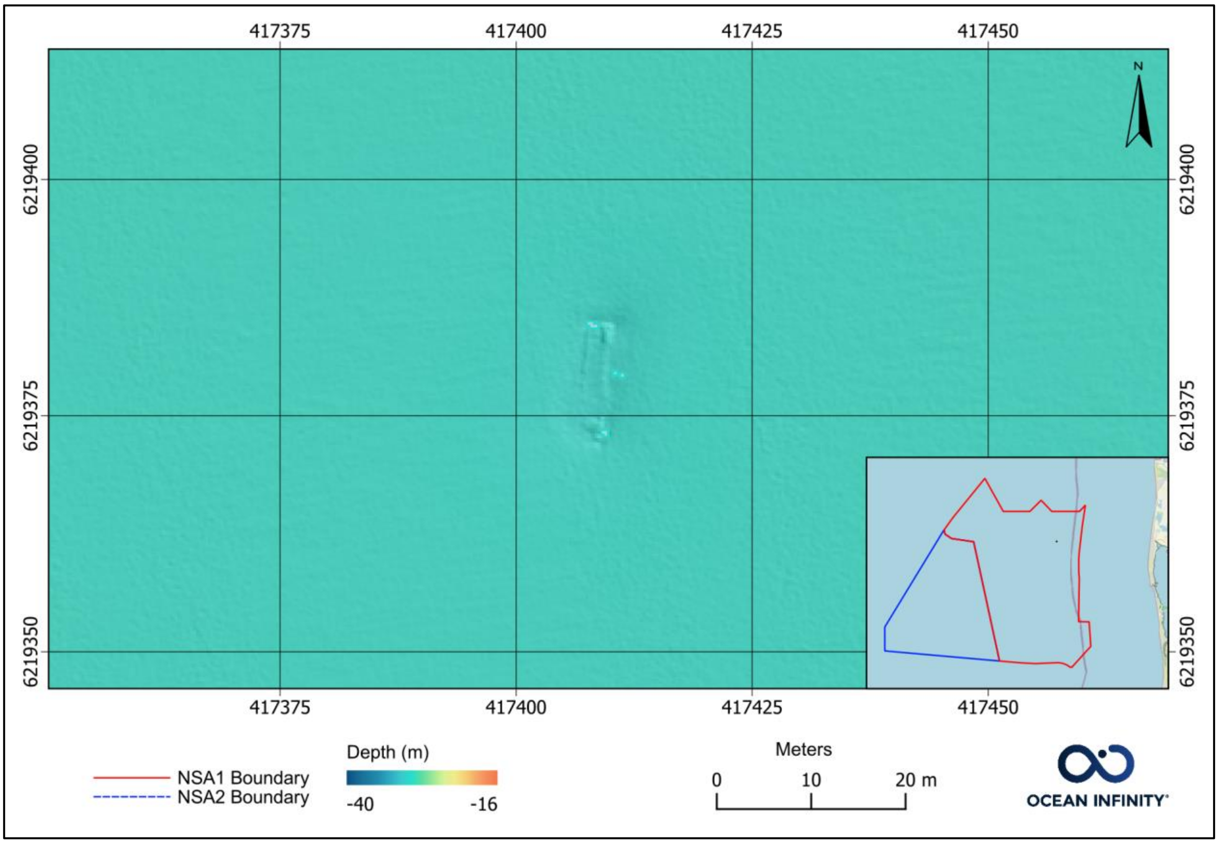


Figure 123 MBES image of possible shipping container (OI-020).

8.5.2 Existing Infrastructure

From background infrastructure data, 13 cables are believed to pass through the NSA1 survey area. Within the magnetometer data, 2798 picked anomalies have been associated with 10 existing cables. Polylines have been created from the observed magnetometer anomaly positions and displayed in Figure 124.

Due to the Nordlink cable (MAG_LIN_09) running parallel to the survey line orientation, the data was subject to masking from continuous complex anomalies. For this reason, the positing of the linear feature for this cable was acquired from three anomalies witnessed during cross lines.

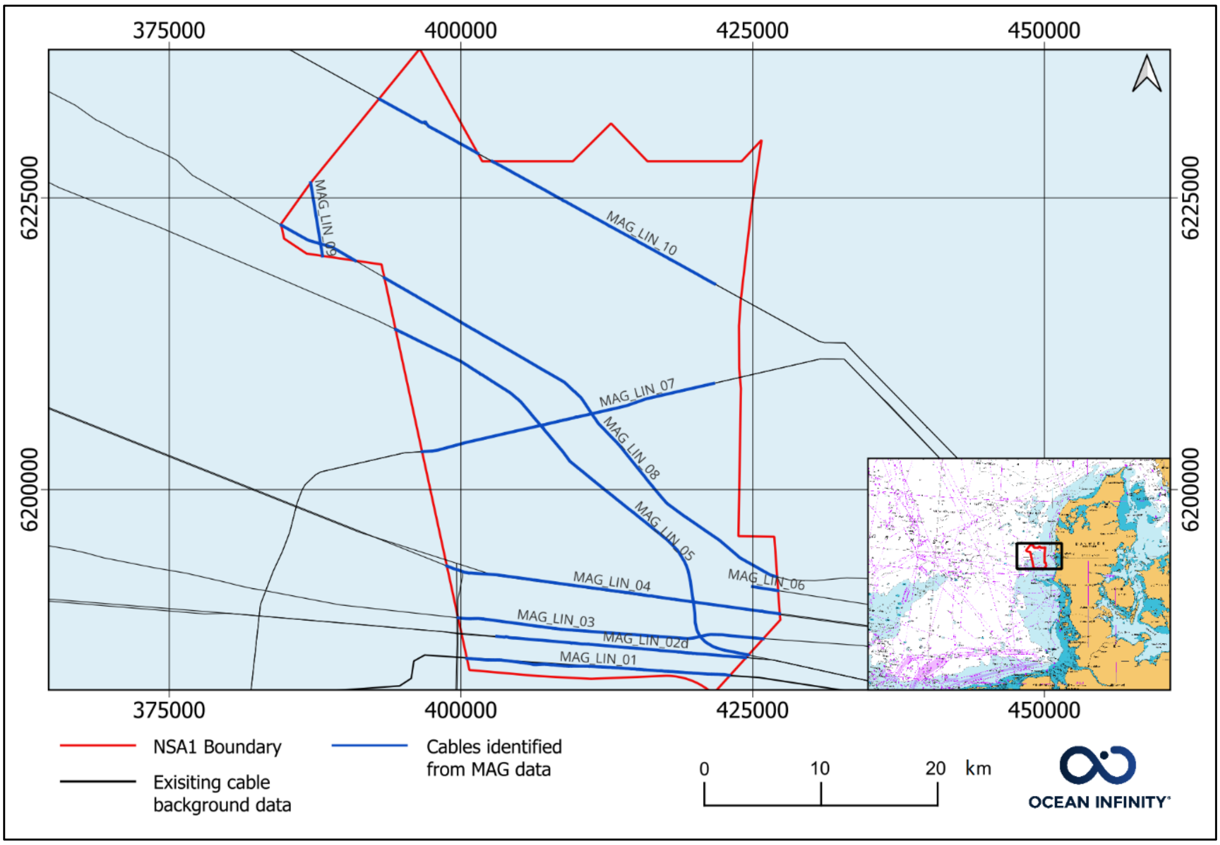


Figure 124 Magnetometer anomalies associated with existing infrastructure within the NSA1 survey area.

Details of the cables, and their associated magnetometer linear ID are detailed in Table 37 below.

Table 37 Existing known infrastructure within NSA1 survey area.

CABLE NAME	TYPE	OWNER	STATUS	TRACKED IN MAG DATA	MAG LINEAR ID
VIKING LINK	ELECTRIC CABLE	NATIONAL GRID VIKING LINK LTD / ENERGINET	ACTIVE	YES	MAG_LIN_01
UK-DENMARK 4	TELECOM CABLE	TDC	DECOMISSIONED	YES	MAG_LIN_02a-d
HAVHINGSTEN SEG 2.5	TELECOM CABLE	AQUACOMMS	ACTIVE	YES	MAG_LIN_03
CANTAT 3 SEG F5 F6	TELECOM CABLE	FAROESE TELECOM	ACTIVE	YES	MAG_LIN_04
DANICE SEG 2	TELECOM CABLE	FARICE	ACTIVE	YES	MAG_LIN_05

CABLE NAME	TYPE	OWNER	STATUS	TRACKED IN MAG DATA	MAG LINEAR ID
HAVHINGSTEN SEG 2.5A	TELECOM CABLE	AQUACOMMS	ACTIVE	YES	MAG_LIN_06
TAT 14 SEG N	TELECOM CABLE	ARELION	DECOMISSIONED	YES	MAG_LIN_07
HAVFRUE SEG 07	TELECOM CABLE	AQUACOMMS	ACTIVE	YES	MAG_LIN_08
NORDLINK	ELECTRIC CABLE	STATNETT SF	ACTIVE	YES	MAG_LIN_09
TAT 14 SEG K(1)	TELECOM CABLE	ARELION	DECOMISSIONED	YES	MAG_LIN_10
CANTAT 3 SEG F7	TELECOM CABLE	FAROESE TELECOM	ACTIVE	NO	N/A
CANTAT 3	TELECOM CABLE	BRITISH TELECOM	ACTIVE	NO	N/A
CANTAT 3a	TELECOM CABLE	BRITISH TELECOM	ACTIVE	NO	N/A

Disturbed sediments related to cable installation have been observed in isolated areas within the SSS data which appear as a linear feature as show in Figure 125.

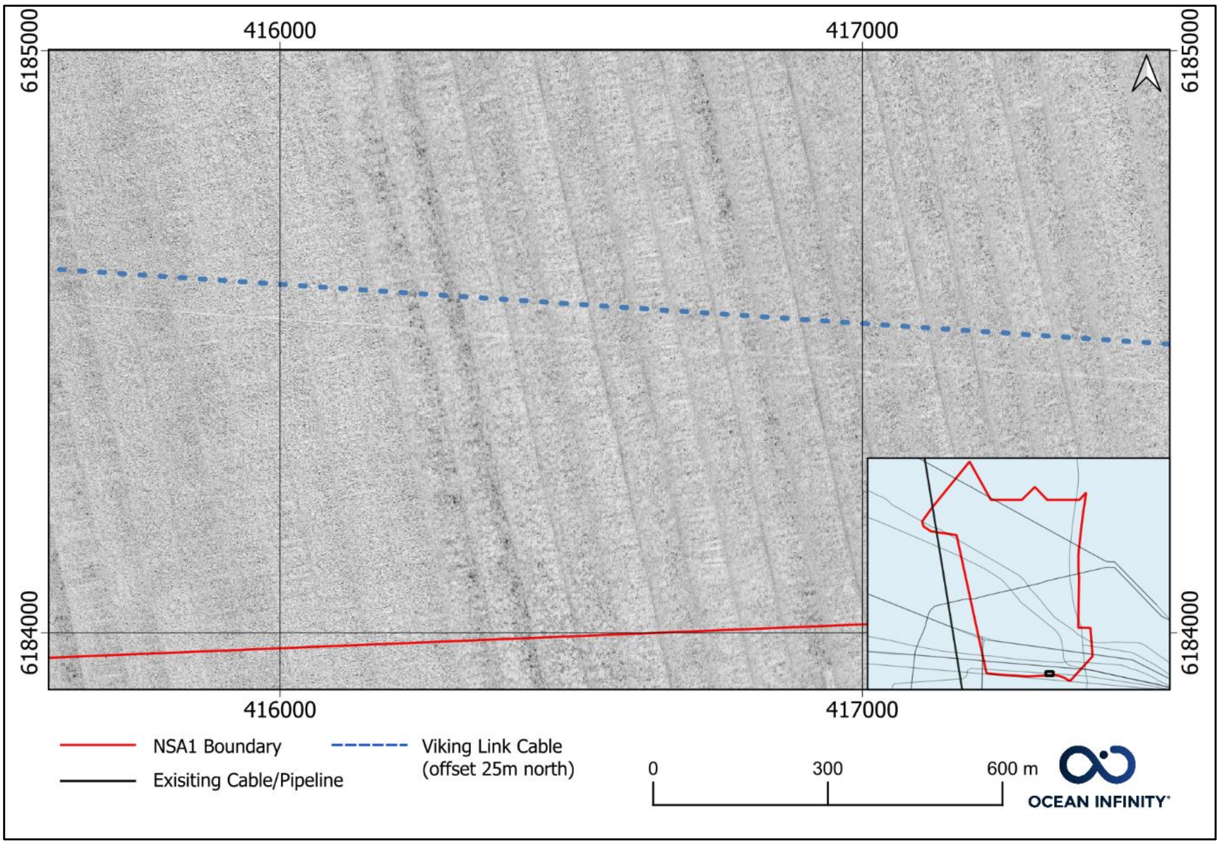


Figure 125 SSS images showing disturbed sediments related to the installation of the Viking Link cable.

Note the Viking Link cable has been offset 25m north in this image in order to view the disturbed sediment feature.

8.5.3 Linear MAG Features

Magnetometer anomalies that followed a linear sequence and not associated with existing infrastructure have been observed within NSA1 survey area. Eight magnetic linear features have been digitised from 181 anomalies to form polylines and are displayed below in Figure 126.

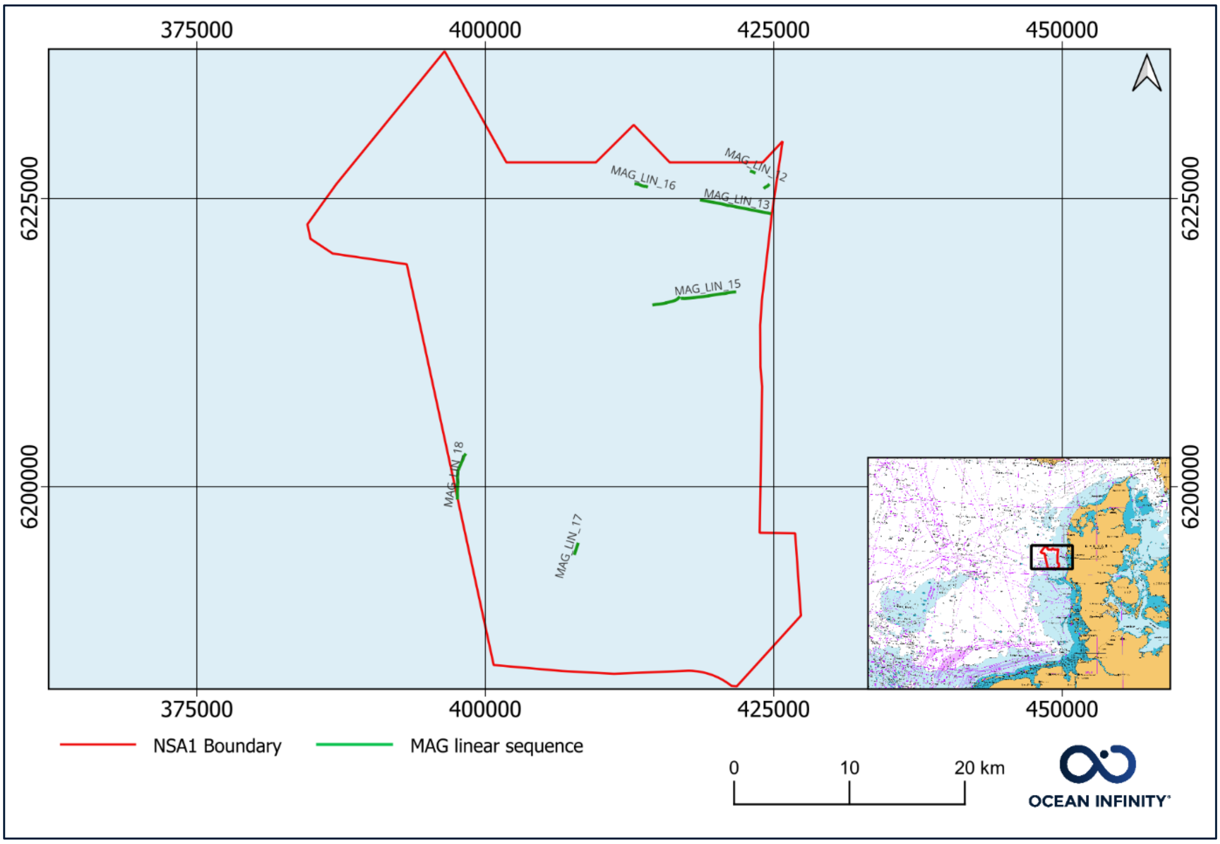


Figure 126 Digitised polylines from observed magnetic anomalies which form a linear sequence within NSA1 survey area.

8.5.4 Man-Made Objects

Different man-made objects were identified in the SSS data, ranging from anchor, fishing equipment with associated soft ropes and others that could not be placed in any specific category, but have been interpreted as possible man-made objects. The most common in the NSA1 site were the fishing equipment (Figure 127). All of the man-made objects can be found in the TSG geodatabase.

To define correlations between SSS contacts and MAG anomalies, a 5 m detection radius was used around each MAG anomaly. Any SSS contact that fell within this distance was categorised as being related to the corresponding magnetic anomaly. In some instances, where wrecks and or large debris fields were clearly visible on the SSS and MAG data, but was out with the 5 m radius threshold, (due to the line spacing of the MAG being 70 m), then these correlations were applied manually (Figure 128).

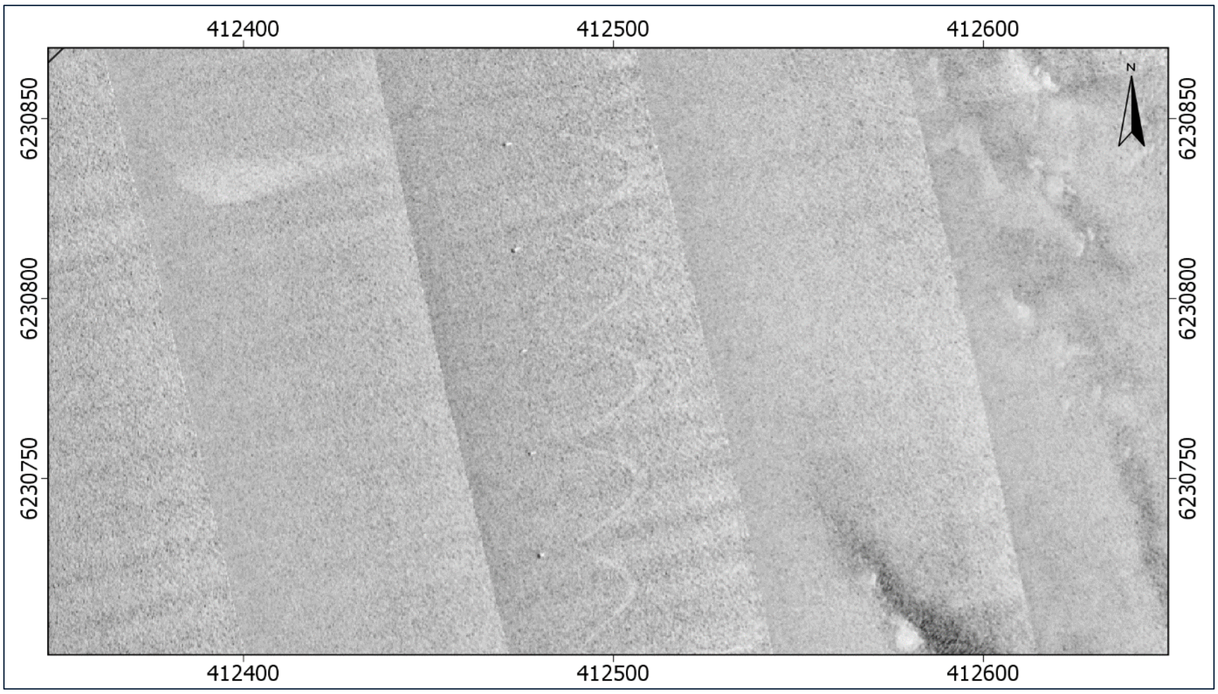


Figure 127 Example of fishing equipment with associated rope on SSS data, BM04.

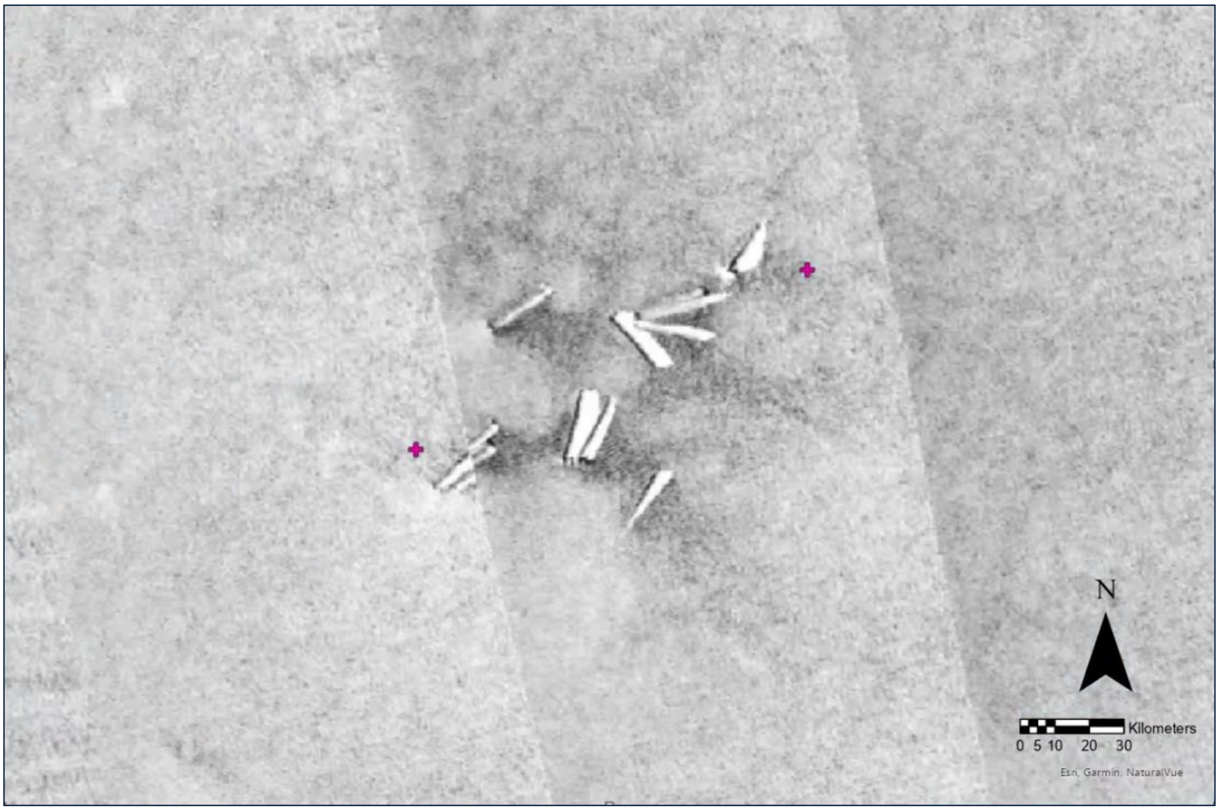


Figure 128 MAG anomalies correlated to discarded debris (likely pipes). The anomalies are manually correlated as they are 6 m and 10 m from the nearest debris item.

8.6 Sub-Seabed Geology

The Geological Ground Model was defined from the integration of geophysical survey and grab sample results acquired within the NSA1 survey area. A thorough revision of the available scientific literature was carried out to steer the SBP interpretation and ensure the formulation of a Geological Ground Model that is consistent with the known geologic evolution of the region. The seismic reflectors summary table (Table 38), is reproduced here to aid the readers understanding of each unit described below.

Seismostratigraphic interpretation of the single-channel SBP data was the basis for the geological ground model presented here. The geological ground model comprises 8 horizons that correspond to seismic reflectors and/or boundaries deemed significant to build the main sub-surface geological framework, distinct depositional and erosion events, marking relevant environmental changes, and shifts in sediment types. The criteria for horizon selection were spatial reflector continuity and delimitation of seismic facies interfaces. The mapped horizons represent the bounding surfaces of the 6 seismic units and 2 internal reflectors described here.

Alongside the model, a careful and detailed analysis of direct seismic indicators (e.g., diffractions, acoustic blanking, etc.) was carried out as part of the assessment of potential geohazards within the sub-surface. The sub-surface geological units which could be identified in the SBP data (in part or in full) generally correspond to sediment deposition or infill sediment, overlaying stiff sediments of glacial origin. The upper-most unit (H10) has a high level of mobility, forming megaripples and sand waves. Erosion of this unit can occur throughout the site and expose older sediments below. In some parts of the site, stiff sediments, such as glacial till, can approach the seabed and occasionally outcrop (Figure 143). Areas where stiff sediments encroach the seabed within 5 m have been mapped and depicted in Figure 158.

In areas with deep horizons, 2D UHRS grids from Fugro was used as a guidance. Surficial data and interpretation were used to ensure sediment boundaries at the surface were properly mapped to develop a full understanding of the geomodel. Refer to *Table* 38 for a description of the units described in the sections below.

Table 38 Summary of seismic reflectors.

Unit name (corresponding reflector)	Acoustic Facies and Internal Configuration	Expected Composition	Probable Geological Age	Kingdom Reflector Colour
GHz_Gas	High amplitude causing acoustic blanking			**Dark Red**
GHz_Peat	Medium to high amplitude	Organic material	Holocene	**Sienna**
Unit 10 (H10)	Low to medium amplitude and chaotic	SAND with local variations in grain size from silty to gravelly	Holocene	**Cyan**
H20_internal	Medium to high amplitude	SAND with local variations in grain size from silty to gravelly	Holocene	**Spring Green**
Unit 20 (H20)	Low to medium amplitude, semi-transparent, with strong chaotic or continuous to semi-continuous internal reflectors	SAND with local variations in grain size from silty to gravelly	Holocene	**Green**

Unit name (corresponding reflector)	Acoustic Facies and Internal Configuration	Expected Composition	Probable Geological Age	Kingdom Reflector Colour
H30_internal	Medium to high amplitude	SAND with local variations in grain size from silty to gravelly	Holocene	**Light Gold**
Unit 30 (H30)	Well layered unit with low to medium amplitude concordant internal reflectors	SAND with local variations in grain size from silty to gravelly	Holocene	**Yellow**
Unit 35 (H35)	Medium to high amplitude and well laminated	Channel infill. CLAY, SILT and SAND. Organic material	Holocene	**Dodger Blue**
Unit 37 (H37)	Low to medium amplitude showing some steeply dipping laminations	Channel infill. CLAY, SILT and SAND. Organic material	Weichselian	**Blue**
Unit 40 (H40)	Medium to high amplitude and chaotic with a mix of small channels, acoustically transparent and sub parallel reflectors	SAND/ SILT/ CLAY/ organic material	Weichselian	**Gold**

8.6.1 U10

Unit 10 is the uppermost unit throughout the majority of NSA1 with some minor areas where it is absent or unresolvable from the seabed (Figure 129). The unit ranges from 0.0 m to 4.4 m BSB, with a thickness range of 0.0 m to 4.4 m. Unit 10 is characterised by chaotic and sometimes concordant or semi-transparent internal reflectors. Generally, Unit 10 is a thin surficial package but thickens in areas of sandwaves (Figure 130). Unit 10 is interpreted to comprise SAND with GRAVEL and/or SILT.

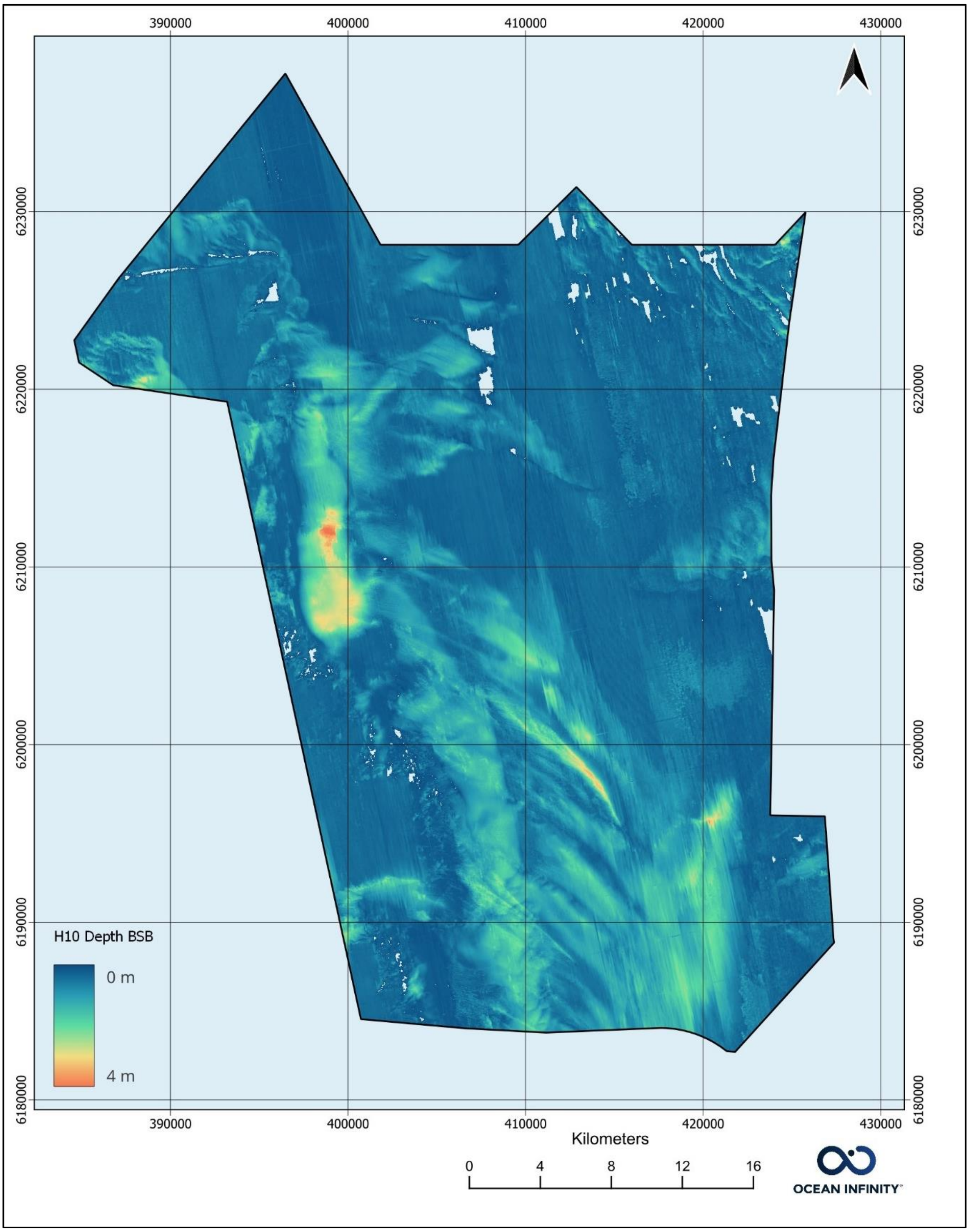


Figure 129 SBP Grid showing extent of Unit 10.

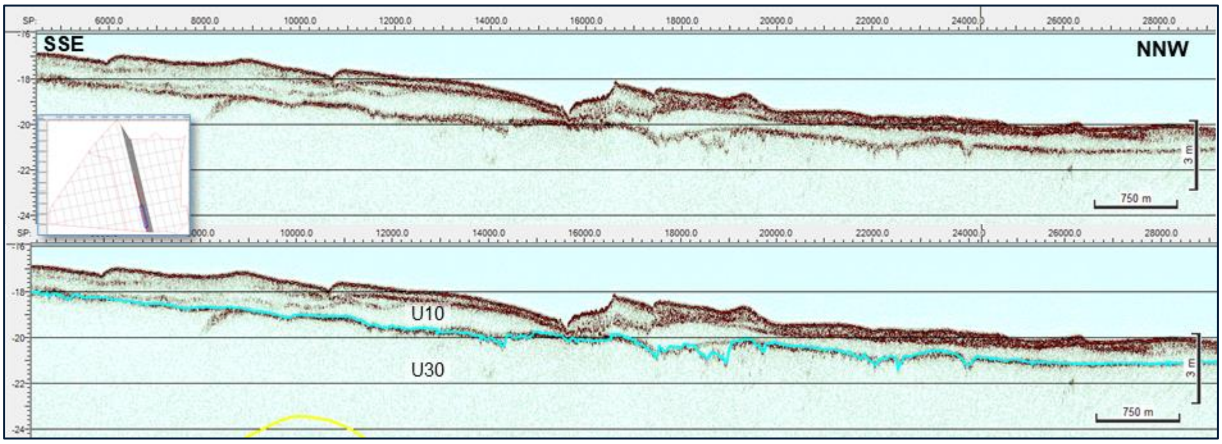


Figure 130 SBP example images of thicker Unit 10 in area of sandwaves. Survey line BM08_25620, position 407959E, 6191046N (image mid-point).

8.6.2 U20

Unit 20 is usually present underneath Unit 10 in the western part of NSA1 (Figure 131). The unit ranges from 0.0 m to 5.3 m BSB, with a thickness range of 0.0 m to 3.5 m. Unit 20 generally represents one phase of deposition (Figure 132), but in some areas Unit 20 is comprised of multiple phases (Figure 132). Occasionally, coarser sediments, chaotic in nature, are found at the base of Unit 20. This is associated with a sea level regression/ erosional event. Unit 20 displays some continuous internal reflectors as well as internal high amplitude reflectors extending up from the base (Figure 133).

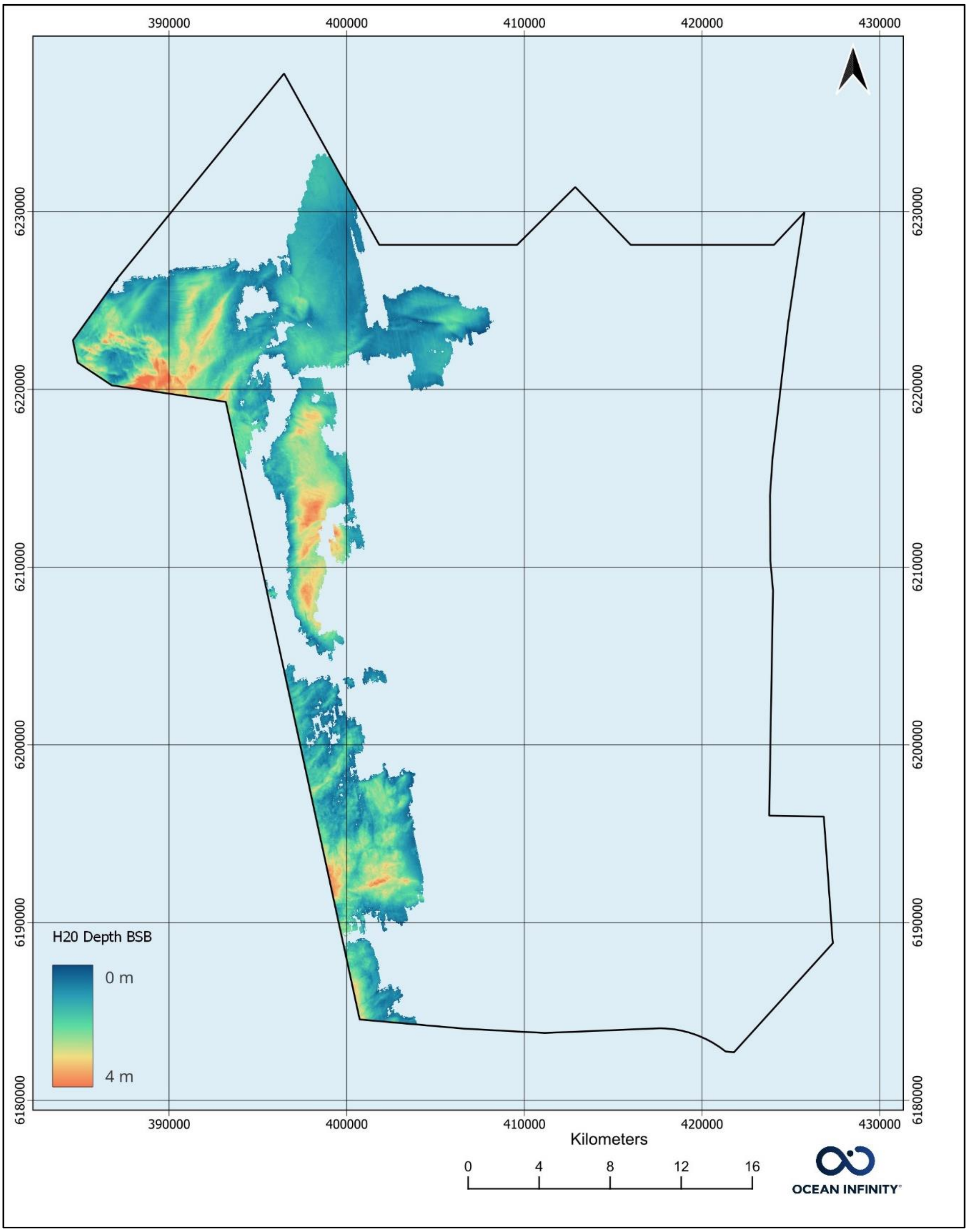


Figure 131 SBP Grid showing extent of Unit 20.

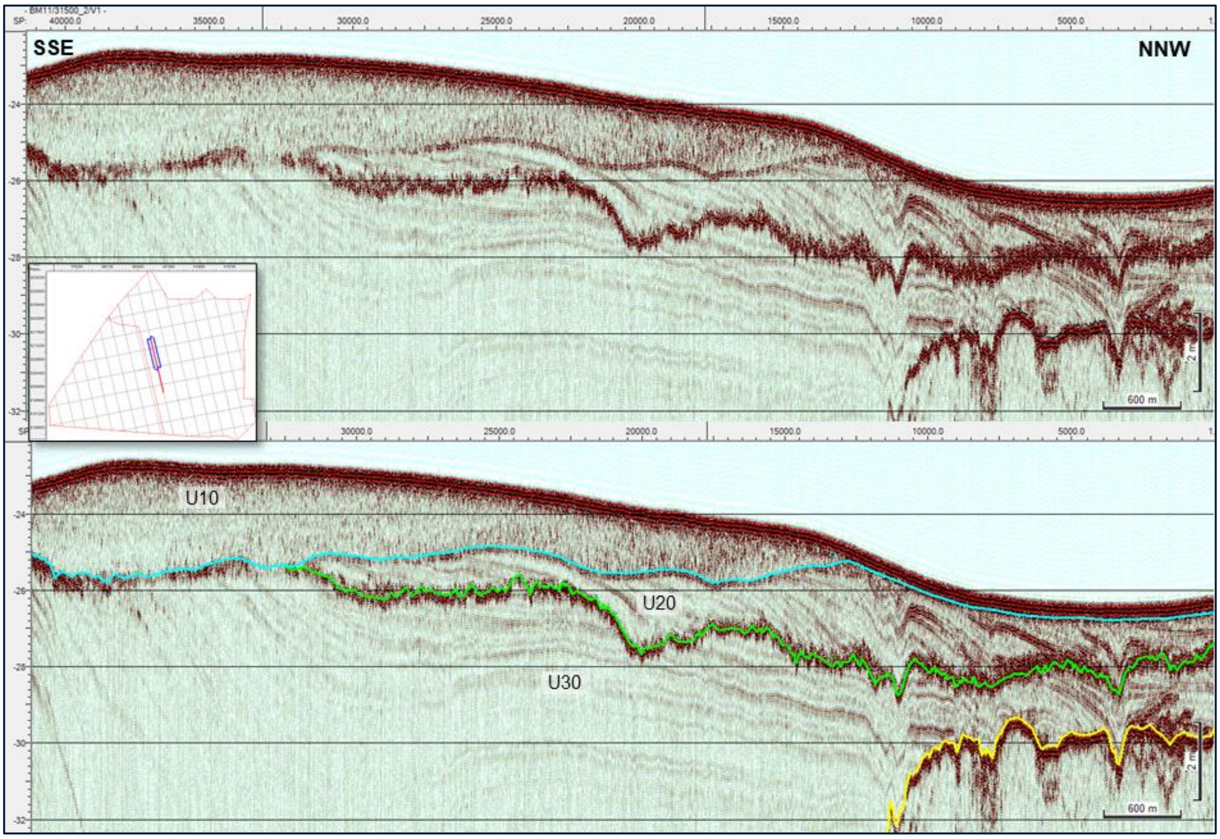


Figure 132 SBP example images of Unit 20. Survey line BM12_31500, position 397671E, 6210726N (image mid-point).

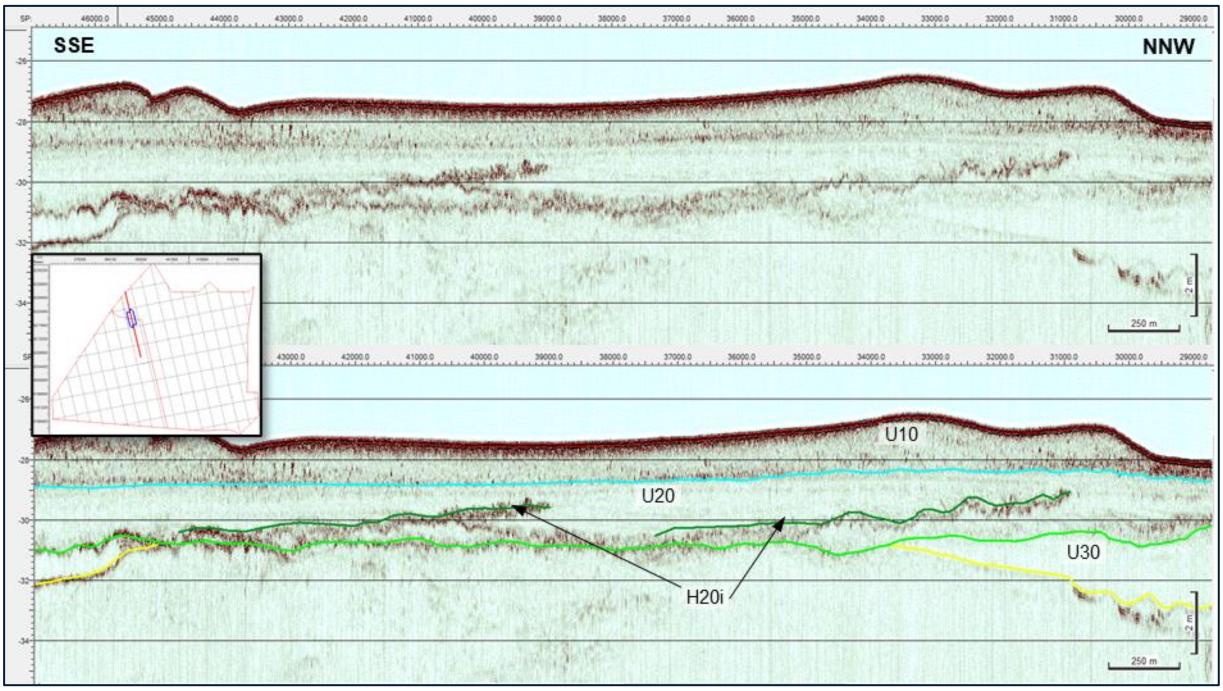


Figure 133 SBP example images of high amplitude discontinuous internal reflectors in Unit 20. Survey line BM12_36890, position 390207E, 6219735N (image mid-point).

8.6.3 U30

Unit 30 is generally a well layered unit with low to medium amplitude concordant internal reflectors. In areas, the base of the unit has some higher amplitude semi continuous reflectors (Figure 156). The interpretation of the Unit 30 basal reflector (horizon H30) is often impaired due to signal attenuation of uppermost coarser sedimentary deposits of Unit 35. Unit 30 is widespread throughout the NSA1 (Figure 134). In the central area Unit 30 fills a deep channel, here the base is unresolved (Figure 135). The upper reflectors of Unit 30 appear upturned in the western side of the deep channel, possibly folded, and possible acoustic blanking is obscuring the deeper areas (Figure 135). Unit 30 can be found either directly under Unit 10 (e.g. Figure 148, Figure 154) or underlying Unit 20 (e.g. Figure 132, Figure 155). An internal package of coarser sediment can be observed in some areas within Unit 30 (Figure 136). The unit ranges from 0.0 m to 17.0 m BSB (Figure 134), with a thickness range of 0.0 m to 14.5 m, although the unit is thicker in areas where the reflector is unresolved.

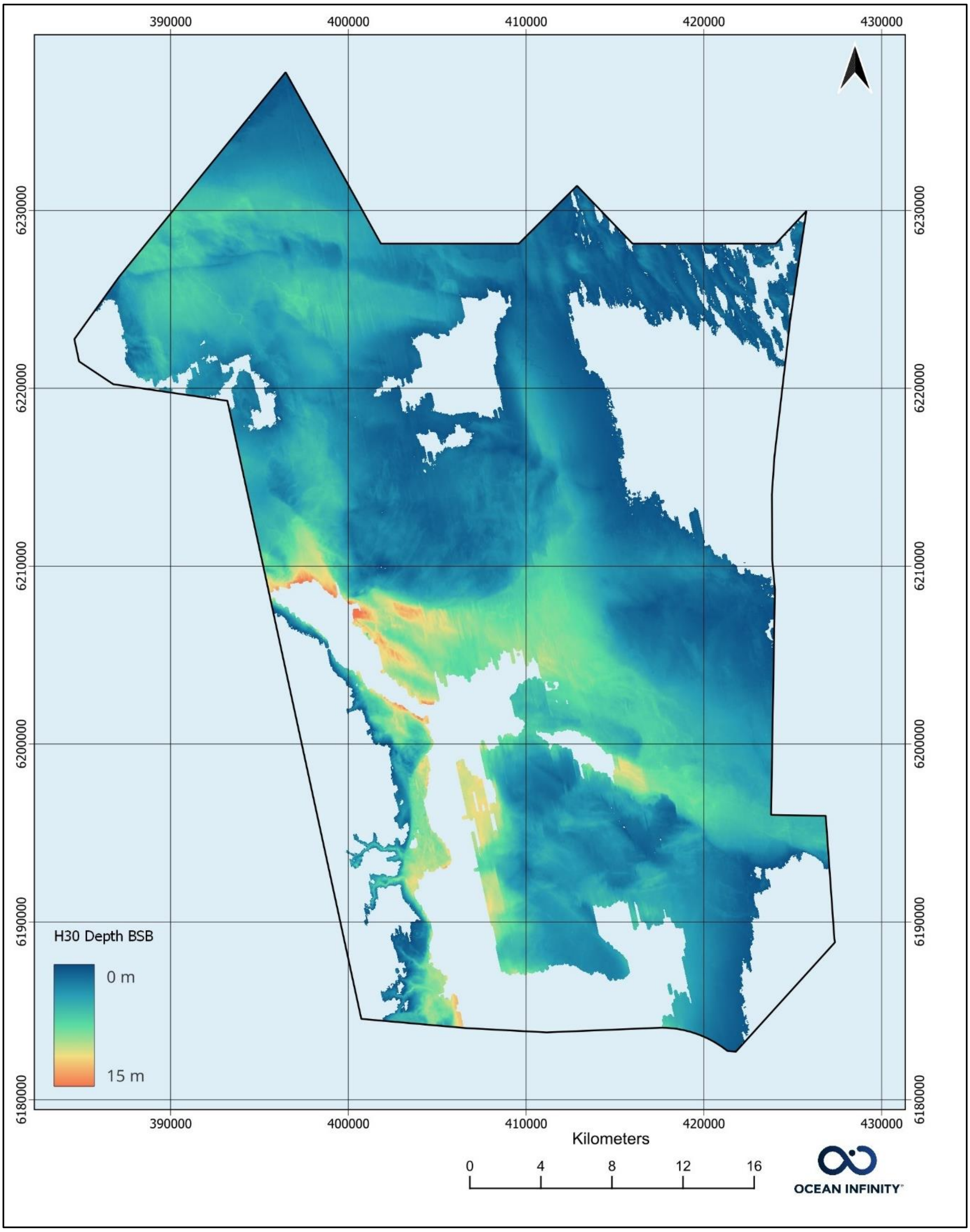


Figure 134 SBP Grid showing extent of Unit 30.

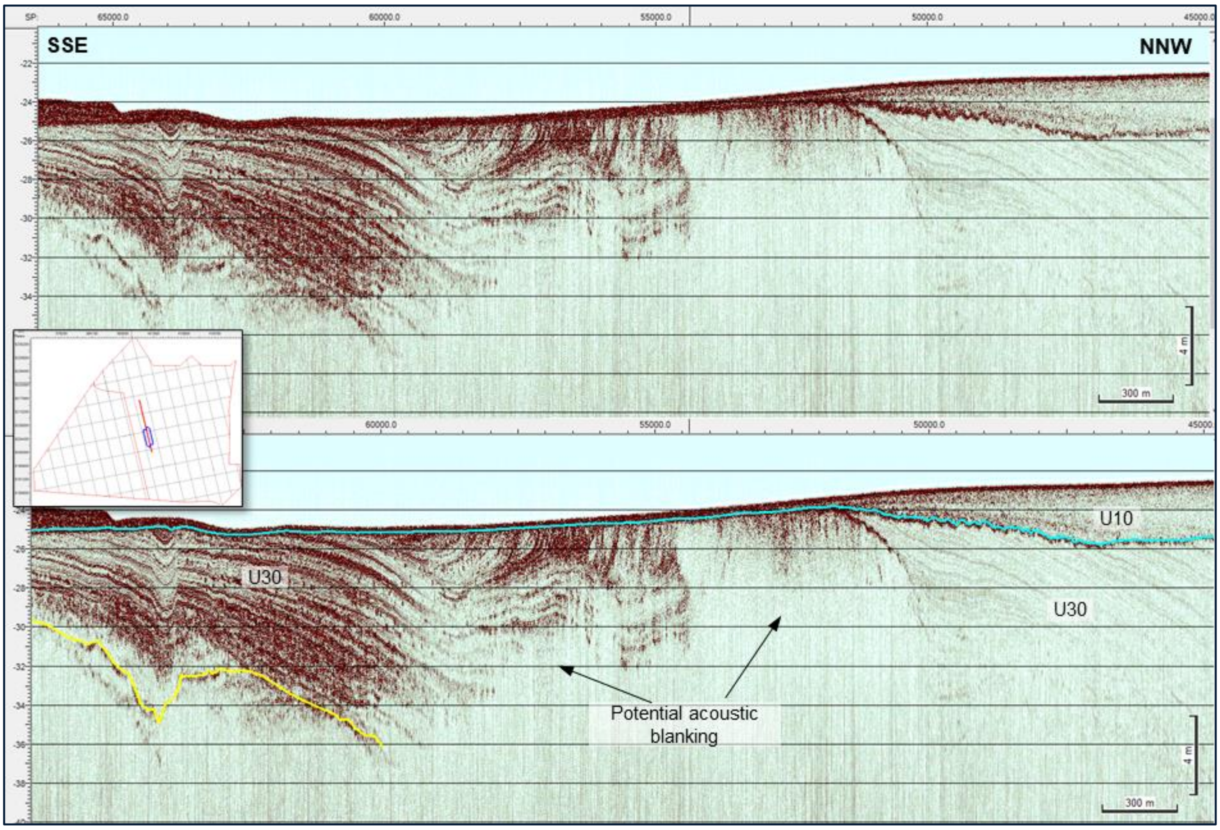


Figure 135 SBP example images of potential folding and acoustic blanking within Unit 30. Survey line BM10_30100, position 400347E, 6204985N (image mid-point).

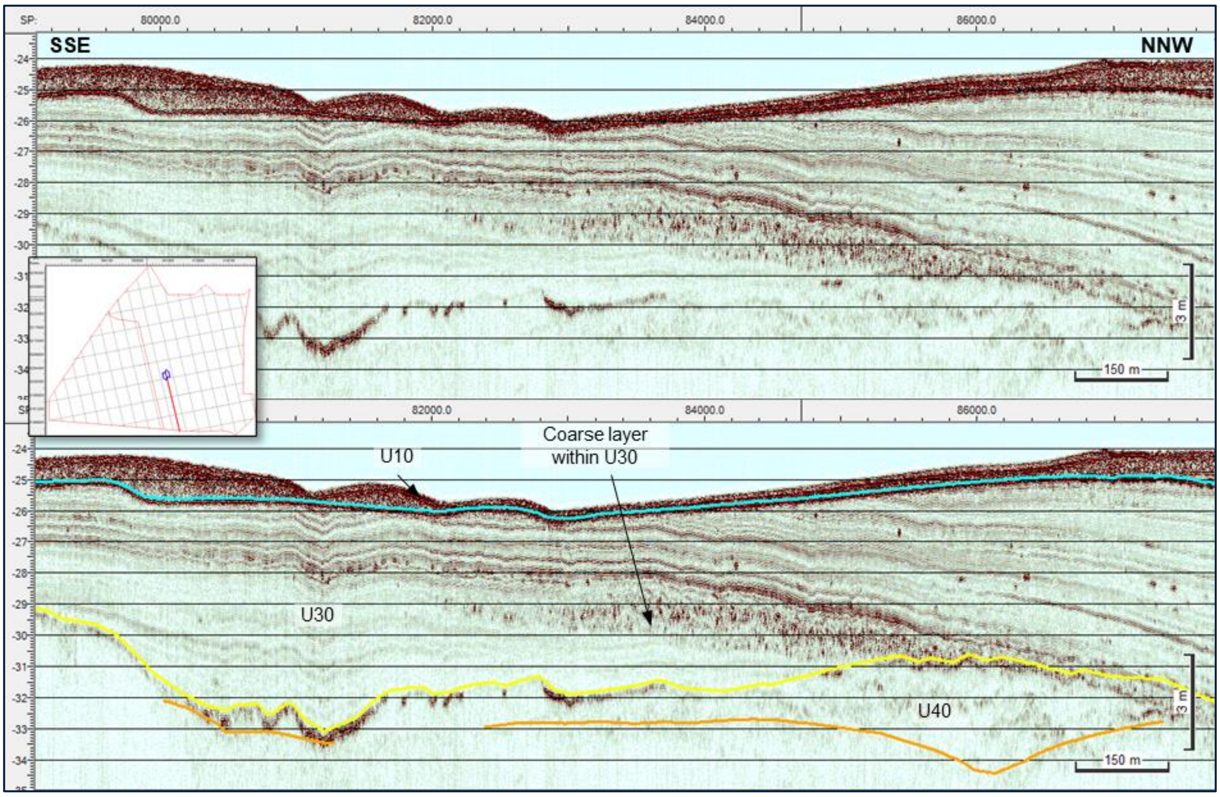


Figure 136 SBP example images of coarser layer within Unit 30. Survey line BM10_29750, position 401354E, 6201944N (image mid-point)

8.6.4 U35

Unit 35 is well laminated and medium to high amplitude. The unit represents channel infills underlying Unit 30. In some areas there are multi stages of channel infill (left side in Figure 148). In the northwestern part of the NSA1 area (Figure 137) the unit may have been deformed from compaction and dewatering and the sediments exhibit an unusual, vertical striped appearance (Figure 138). Acoustic blanking is occasionally observed within Unit 35 (Figure 139). The acoustic blanking is possibly indicative of the presence of gas saturated sediment. The unit ranges from 0.0 m to 16.6 m BSB (Figure 140), with a thickness range of 0.0 m to 15.4 m.

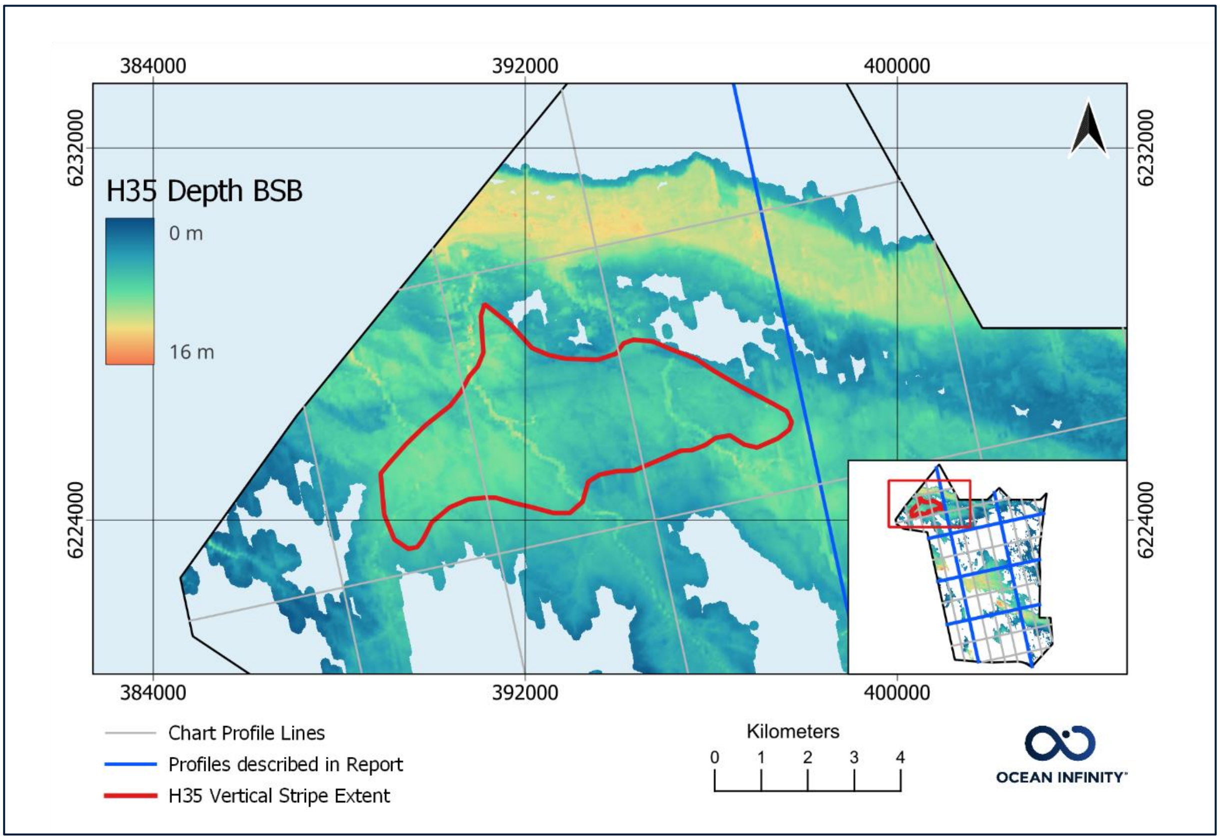


Figure 137 Extent of vertical stripes within Unit 35.

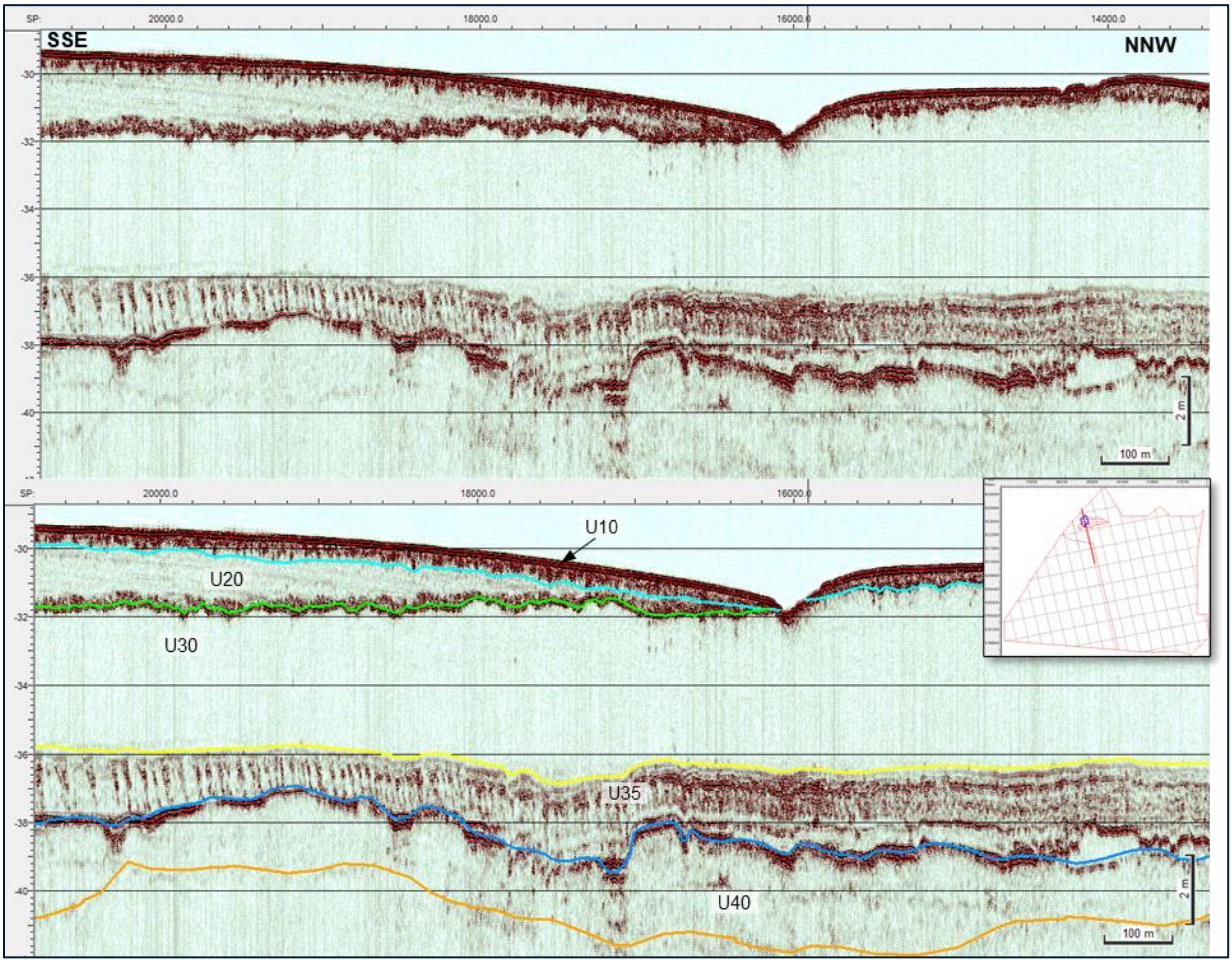


Figure 138 SBP example image of Unit 35 with (left) vertical stripes and without (right). Survey line BM12_34930, position 39739E, 6226515N (image mid point).

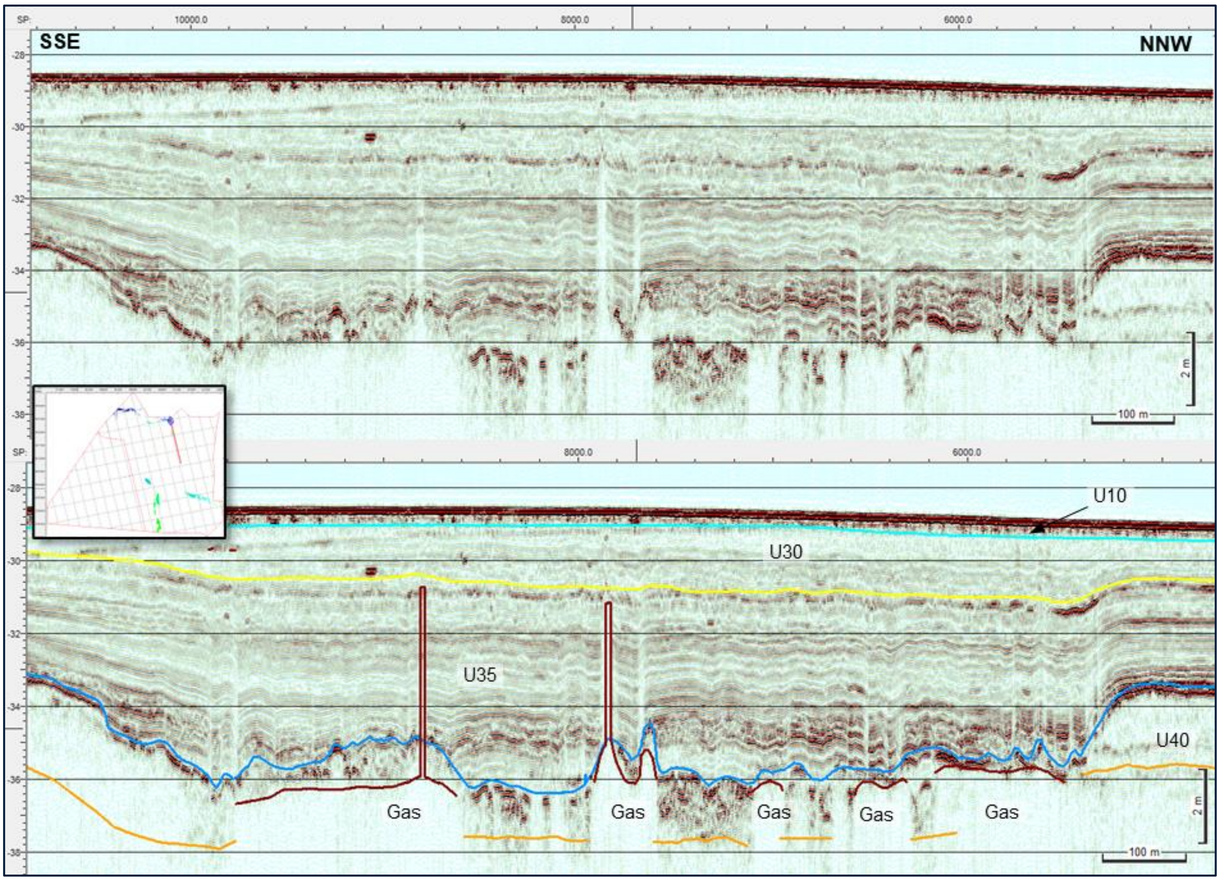


Figure 139 SBP example image of acoustic blanking (potential gas) at the base and within Unit 35. Survey line BM05_16870, position 409798E, 6226603N (image mid point).

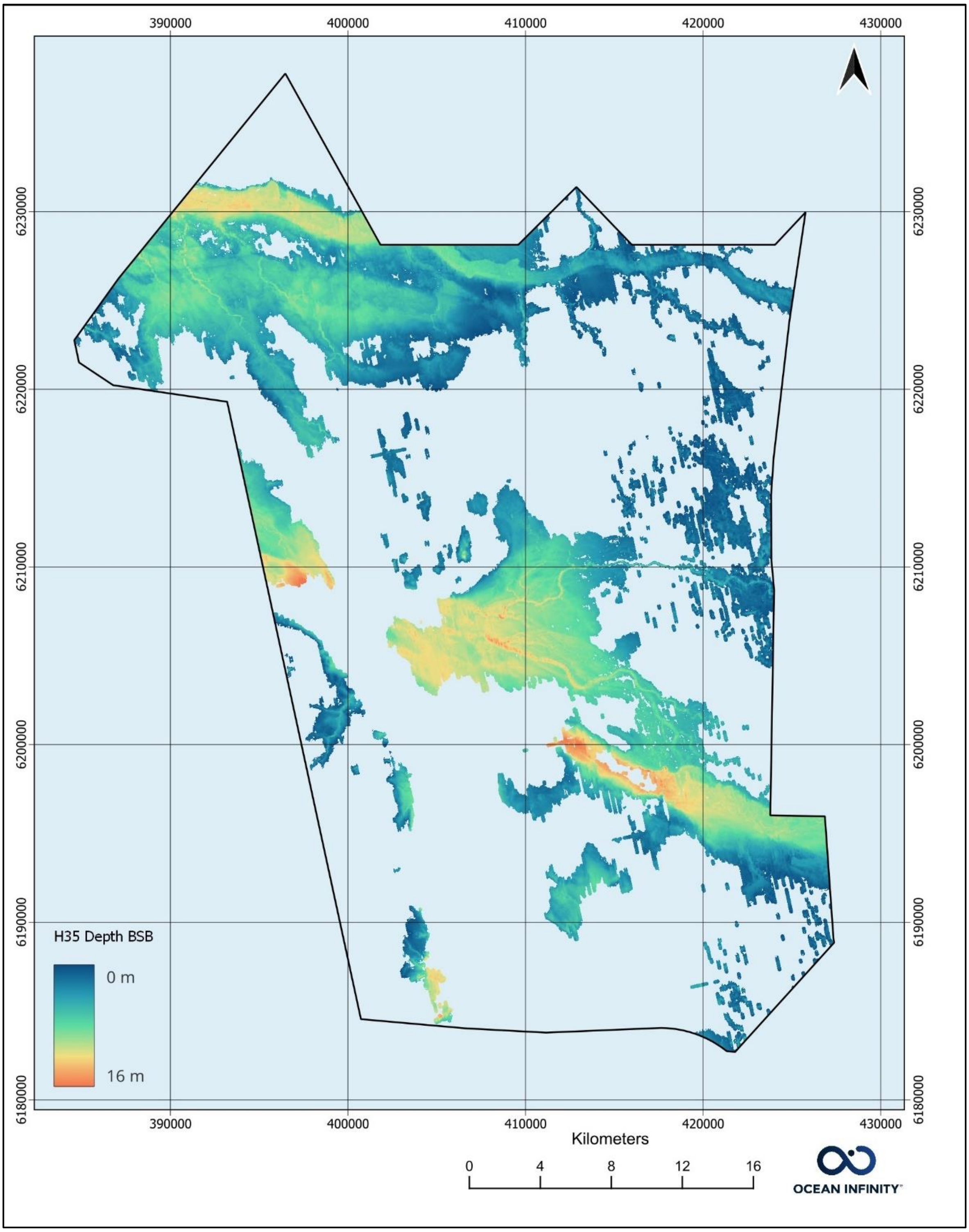


Figure 140 SBP Grid showing extent of Unit 35.

8.6.5 U37

Unit 37 comprises well laminated sediments which exhibit a medium acoustic amplitude. This unit represents older channel infill sediments. This unit has only been picked in NSA1 in 2 small, isolated areas in the south. The unit ranges from 0.5 m to 12.8 m BSB with a thickness range of 0.0 m to 11.5 m.

8.6.6 U40

The seismic character of Unit 40 is medium to high amplitude and chaotic with a mix of small channels, acoustically transparent and sub parallel reflectors. The unit is interpreted to be of glacial origin, however in some areas, the sediments are interpreted to be formed in a brackish/ lagoonal/ shallow marine environment with fine sand/ silt/ clay/ organic material present (Figure 141). This unit is only partly picked in the NSA 1 area due to lack of penetration.

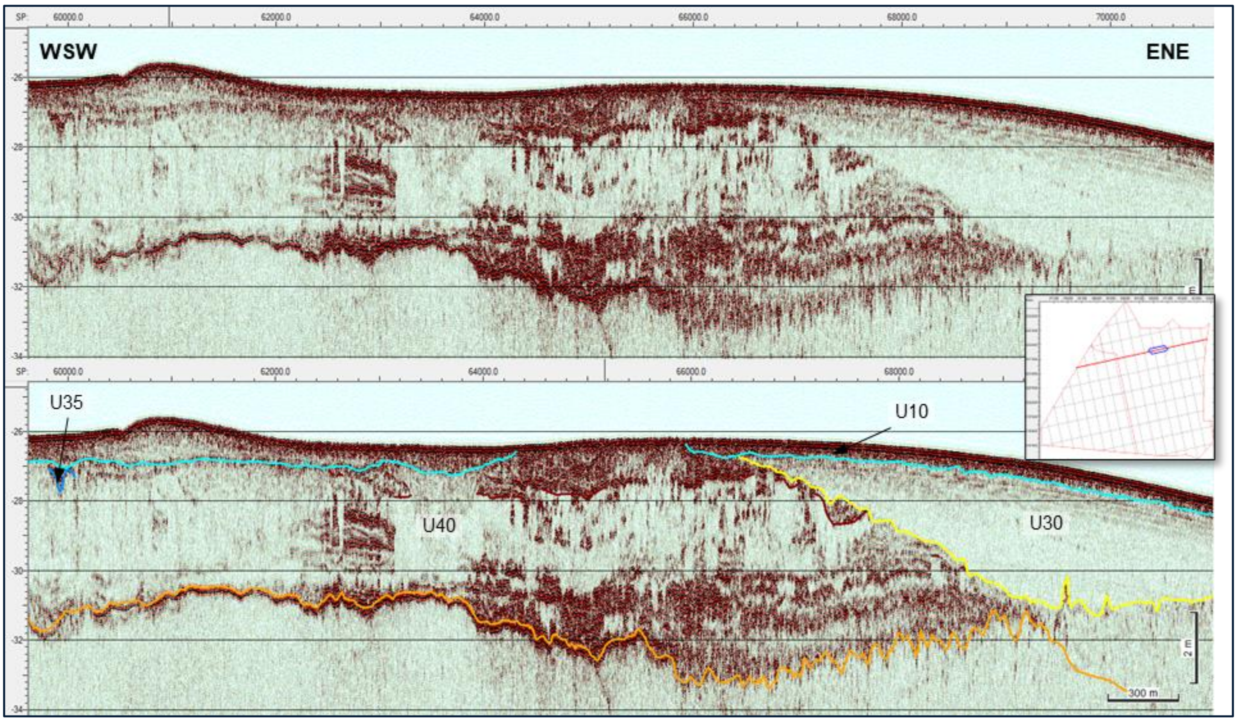


Figure 141 SBP example image of Unit40 Survey line BX01_15000, position 409985E, 6221158N (image mid-point).

In the western part of the NSA1 area some small areas of outcropping Till were interpreted (Figure 143). No base of this unit could be seen; therefore, this unit was not digitized. This unit represents potentially Saalian sediments of glacial origin. Where the reflector could be digitized, the unit ranges from 0.0 m to 16.9 m BSB with a thickness range of 0.0 m to 13.8 m, but the unit is assumed to be thicker in areas where it cannot be resolved.

The full extents of this unit should be determined from the UHRS data.

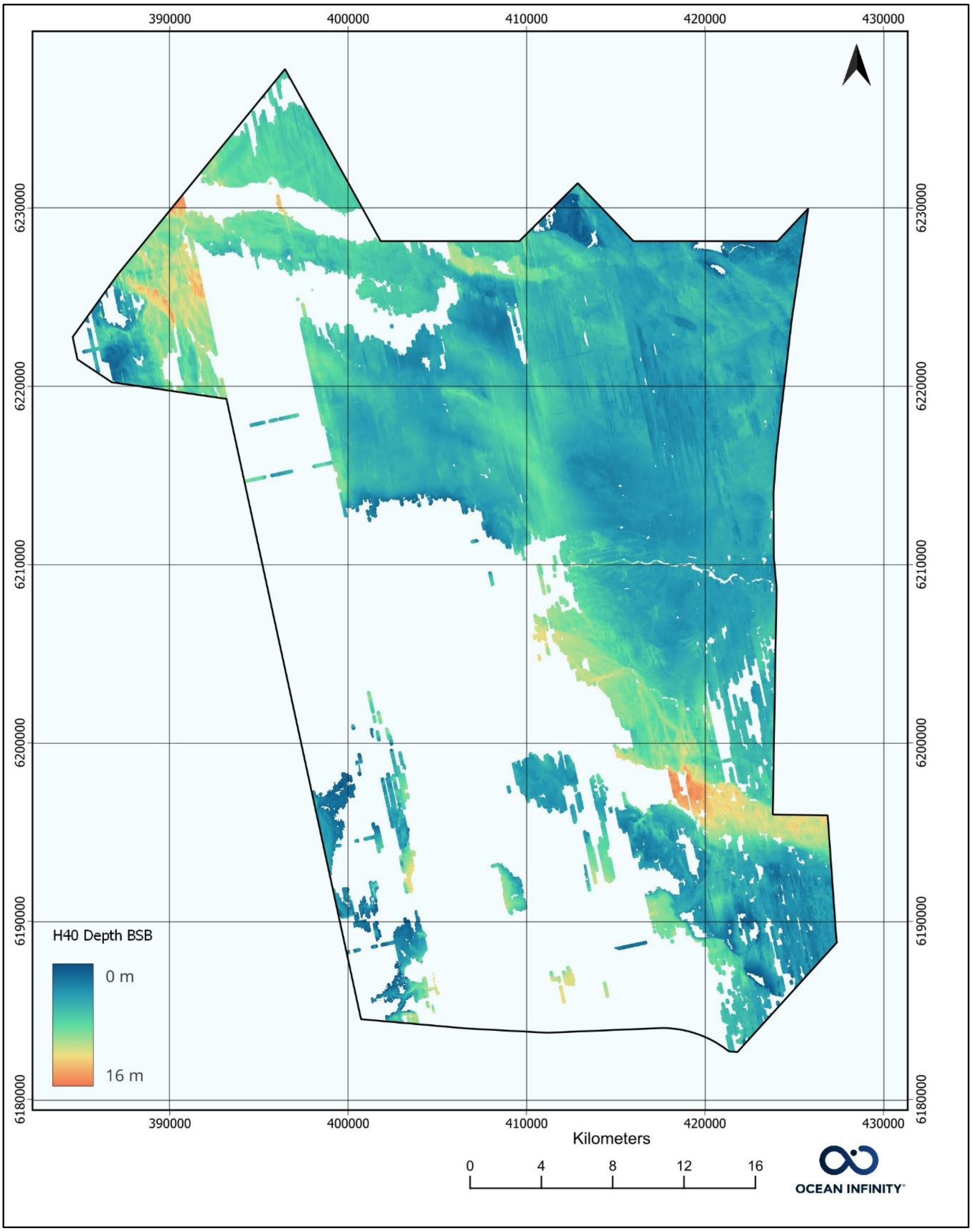


Figure 142 SBP Grid showing extent of Unit 40.

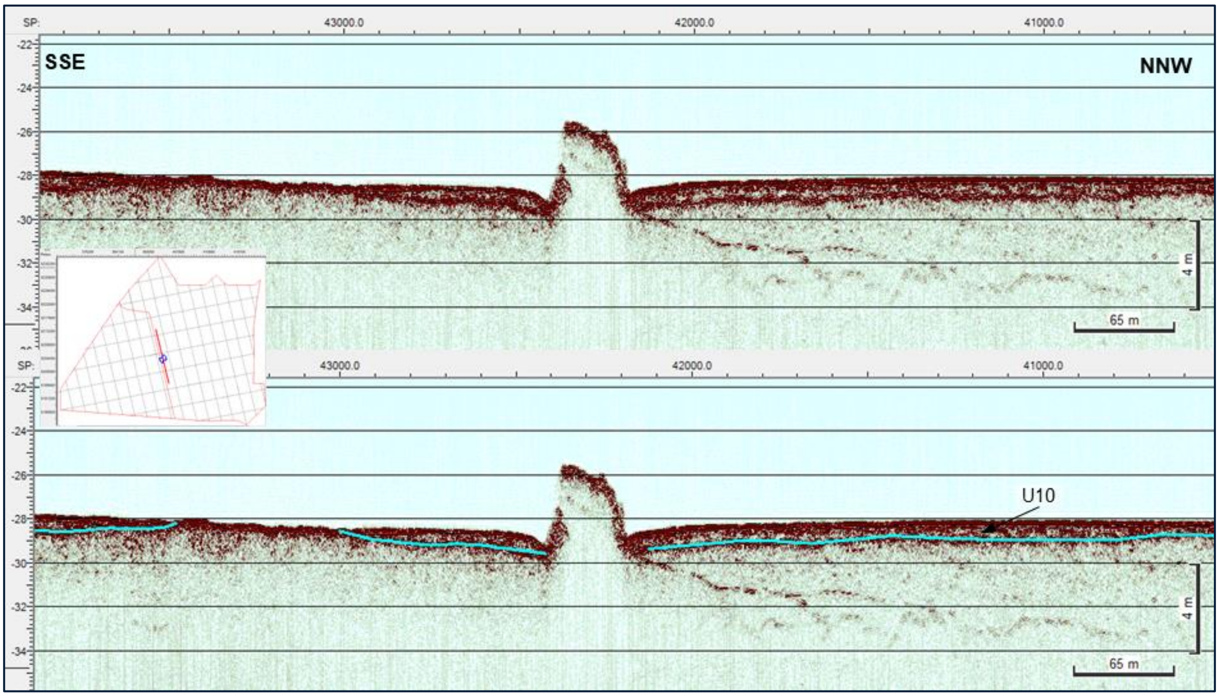


Figure 143 SBP image of outcropping Till. See also bathymetry image in Figure 76. Survey line BM11_33320, position 397253E, 6204060N (image mid-point).

8.6.7 Profiles

Twenty-one profiles were selected for charting purposes. Of these, five are presented in the following sections, see overview image Figure 144. The description that is presented in the following sections should be read in conjunction with the relevant profile chart; the images presented in these sections are a sample from each profile and do not constitute the entire line. In addition, the text uses KP values as well as coordinates as a reference to aid the descriptive text. The KP value is essentially the run line chainage of each profile which start at KP 0.0 and ends at the maximum extent of each profile line.

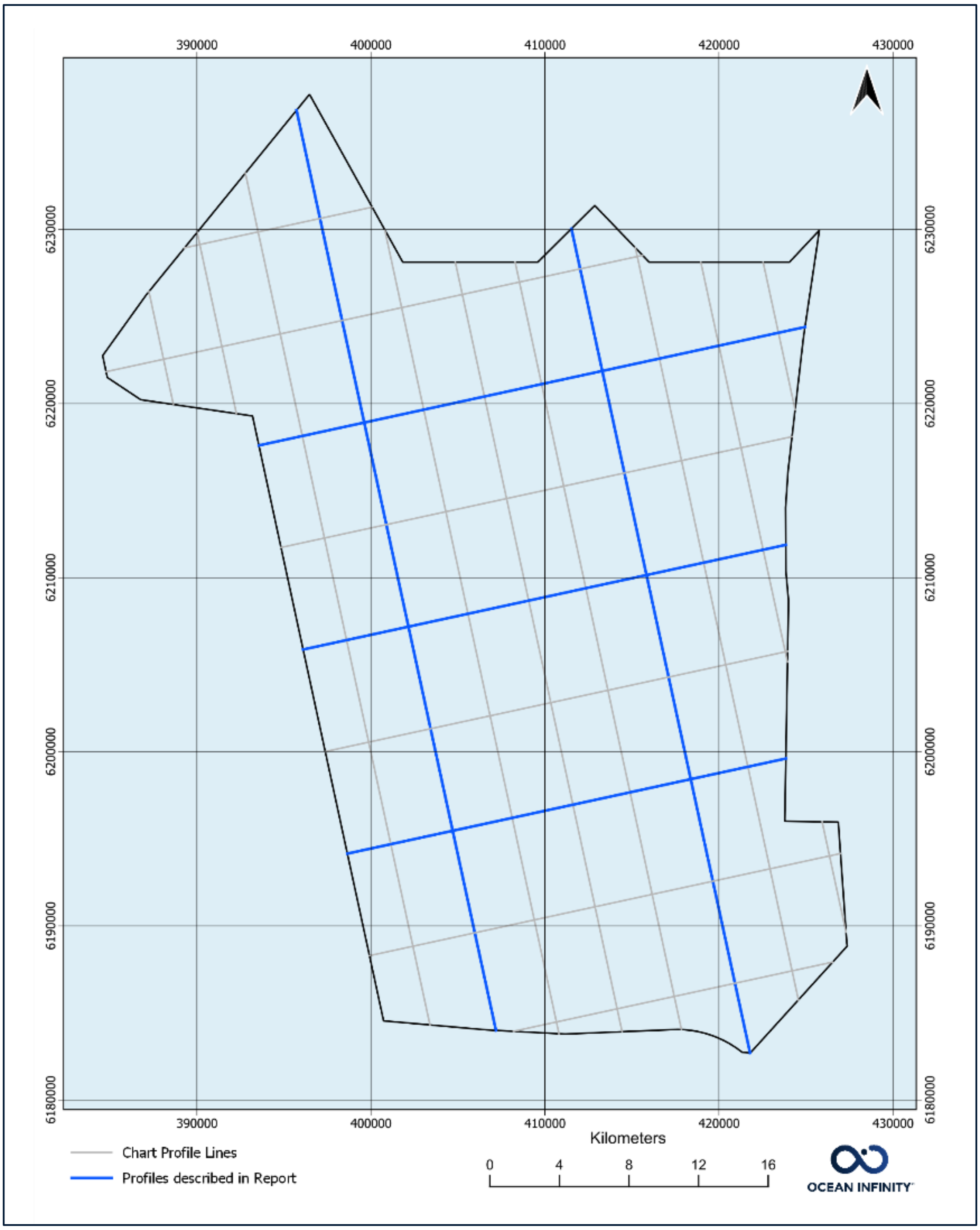


Figure 144 Overview Profile lines presented in charts and report with location of shown images.

8.6.7.1 BX01_15000 (WSW TO ENE)

In the east (Figure 145) U10 is overlying U35, U35 is outcropping around 424994 E, 6224411 N (KP46.4). Below U35, U40 is present. Towards the west, U10 rests upon U30 or U40. Below U30, U35 is often observed as channels cutting through U40.

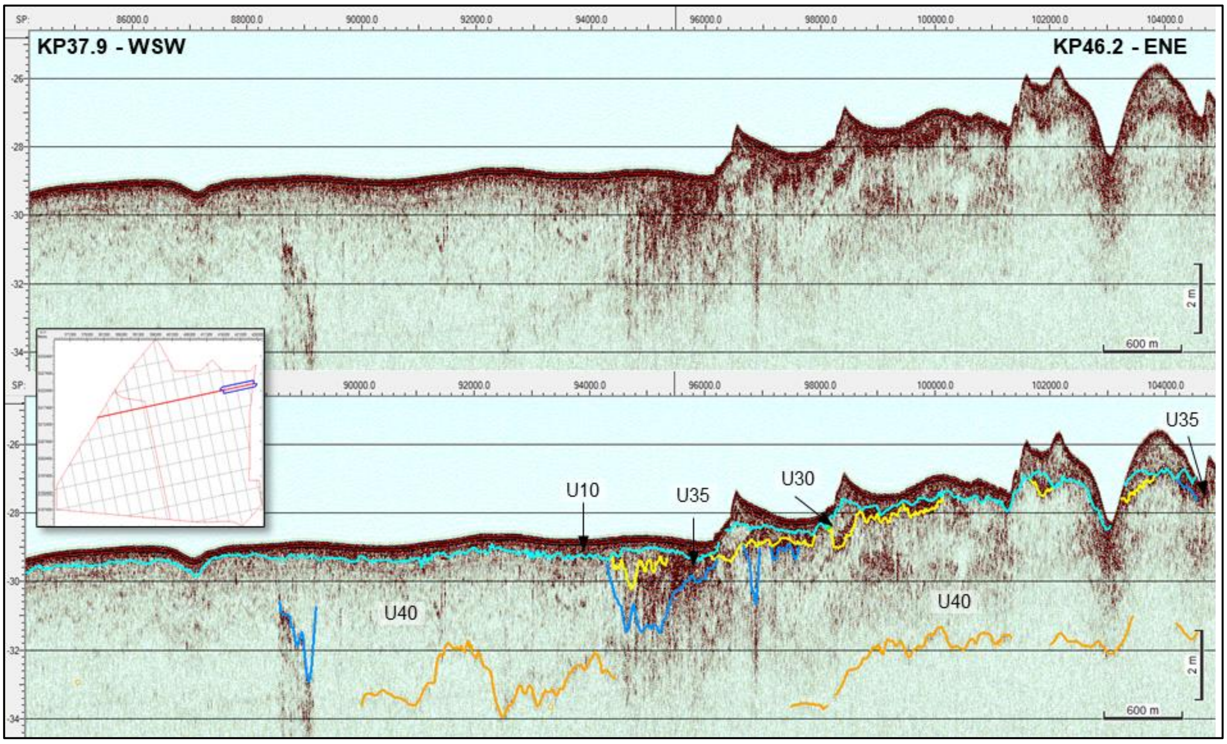


Figure 145 SBP example image of eastern part of Profile line BX01_15000. Position 418387E, 6198426N (image mid-point).

Between 4200421 E, 6223419 N (KP41.8) and 413049 E, 6221821 N (KP34.2) a thin layer of U10 is overlying U40, the base of U40 is only observed in some places. Moving to the west U30 is underlying U10 and gets thicker towards the west. At 410510 E, 6221271 N (KP31.6) possible peat is observed (Figure 146). U30 thins out and disappears at 408349 E, 6220802 N (KP23.8), while U40 internal appearance changes from chaotic to sub parallel layers. This is interpreted as deposits from a brackish/ lagoonal/ shallow marine environment with fine sand/ silt/ organic material (Figure 141).

U30 is observed again at 402894 E, 6219621 N (KP29.4), between 399334 E, 6218850 N (KP20.3) and 396652 E, 6218268 N (KP17.4), overlain by U20. Around 397017 E, 6218347 N (KP18.0) a channel within U35 is observed. The western part of the line consists of U10 on top of U20 or U30, U20 above U30 or U40, and U30 above U40.

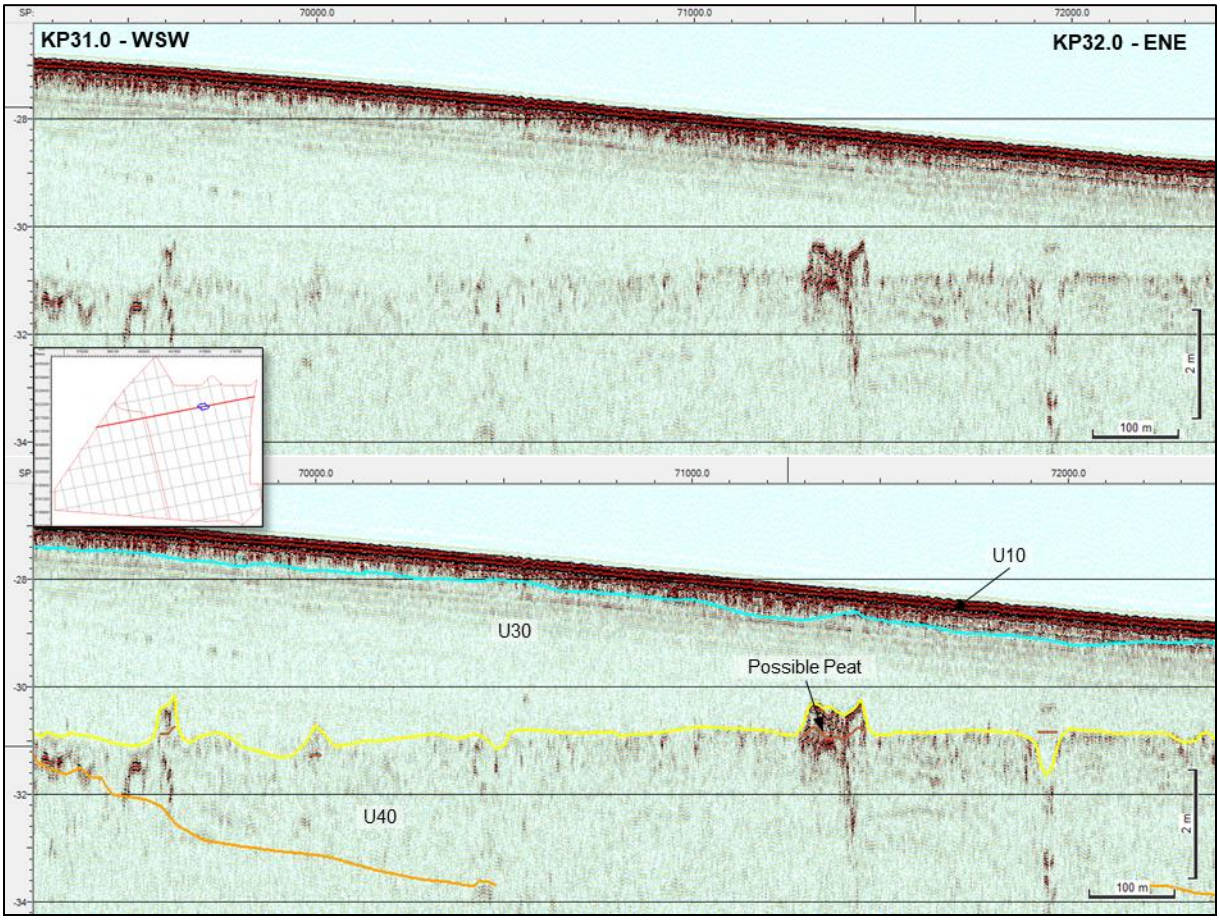


Figure 146 SBP example image of possible peat. Survey line BX01_15000, position 410281E, 6221223N (image mid-point).

8.6.7.2 BX01_27000 (WSW TO ENE)

In the eastern part of the line U10 is overlying U40 and in some places U35. Possible acoustic blanking can be observed in this section (Figure 147). At 419987 E, 6211042 N (KP50.2), U10 is on top of U30, U30 thickens toward the West (Figure 148). Below U30, channels are often observed. At 400323 E, 6206780 N (KP30.1), the base of U30 can no longer be seen due to the thickness of the overlaying sediments (Figure 149).

U20 is only observed around 398035 E, 6206283 N (KP27.6). After 397643 E, 6206198 N (KP26.8) only a thin layer of U10 is present above U40. U40 or older sediments are outcropping or close to seabed in the western part of the crossline (Figure 150).

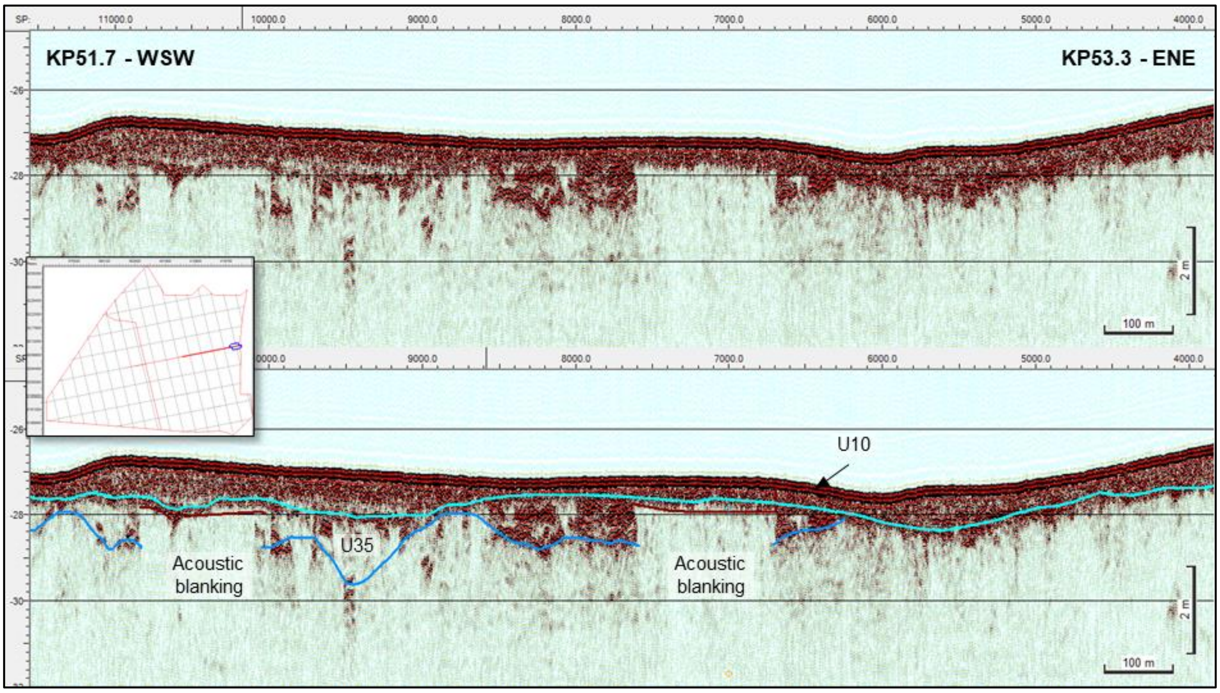


Figure 147 SBP example image of acoustic blanking. Survey line BX01_27000, position 422328E, 6211550N (image mid-point).

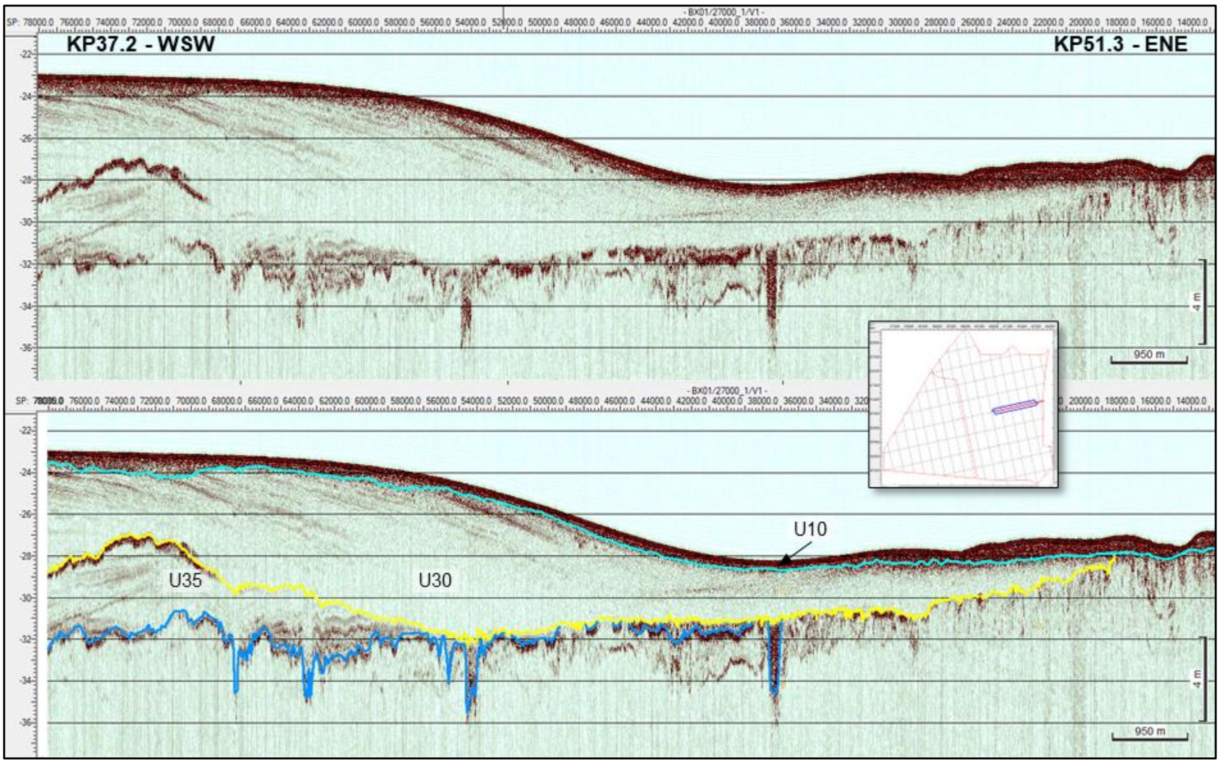


Figure 148 SBP example image of eastern part of Profile line BX01_27000. Position 413772E, 6209693N (image mid-point).

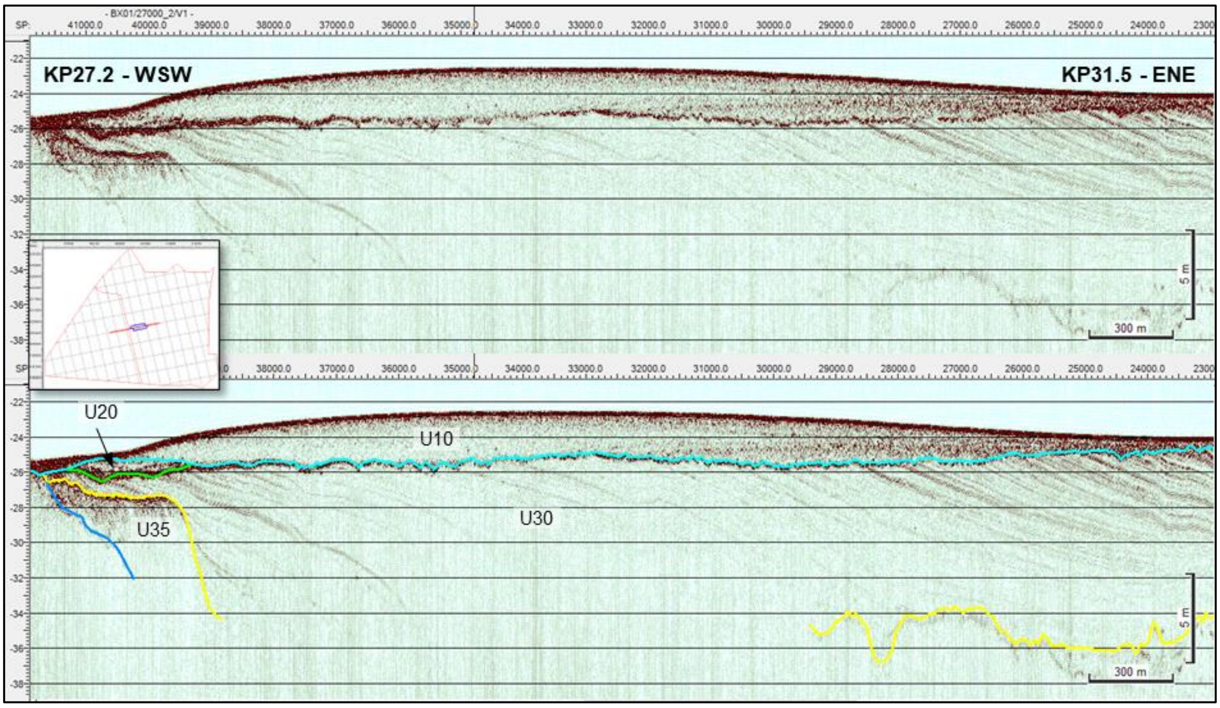


Figure 149 SBP example image of western part of Profile line BX01_27000. Position 399599E, 6206622N (image mid-point).

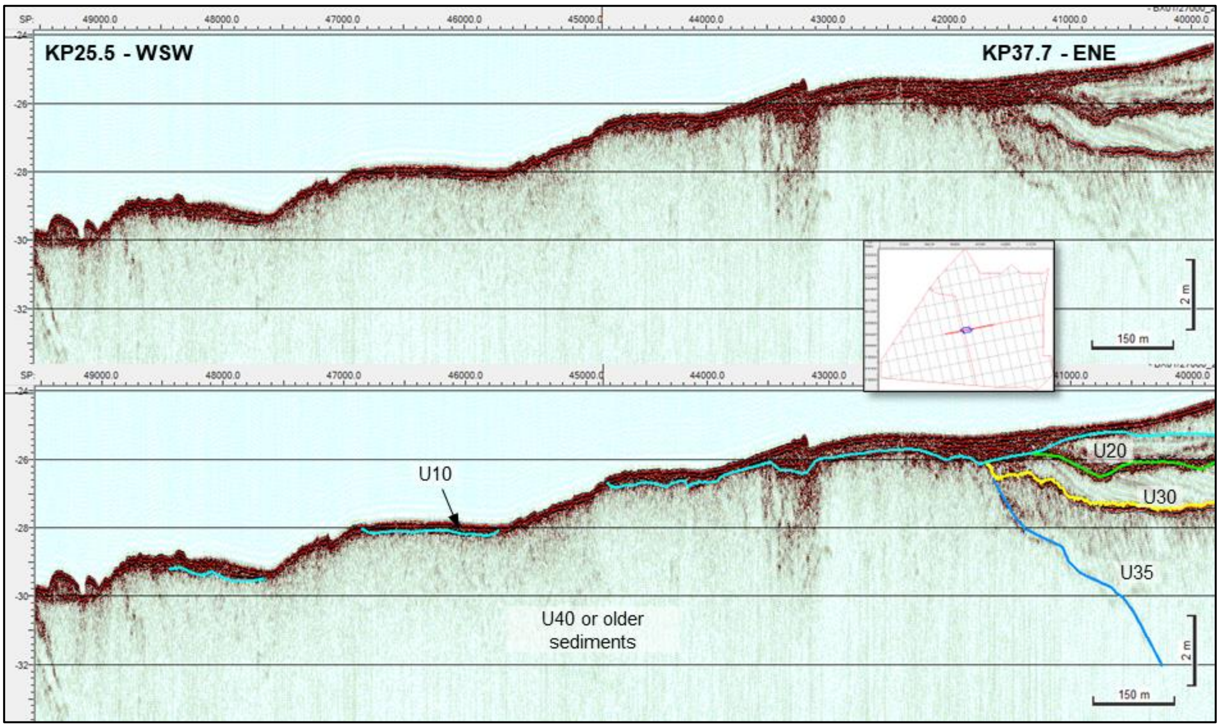


Figure 150 SBP example of outcropping U40 or older sediments in western part of Profile line BX01_27000. Position 396961E, 6206050N (image mid-point).

8.6.7.3 BX01_39000 (WSW TO ENE)

In the east part of the line, U10 overlies U30. An internal reflector, (H30i) is also present within U30 (Figure 151). Channels of U35 are often observed below U30 cutting into U40.

At 403617 E, 6195217 N (KP36.7), Unit 10 rests above U20, which becomes the main stratigraphy in this area. Below U20, small channels of U30 and U40 are observed (Figure 152).

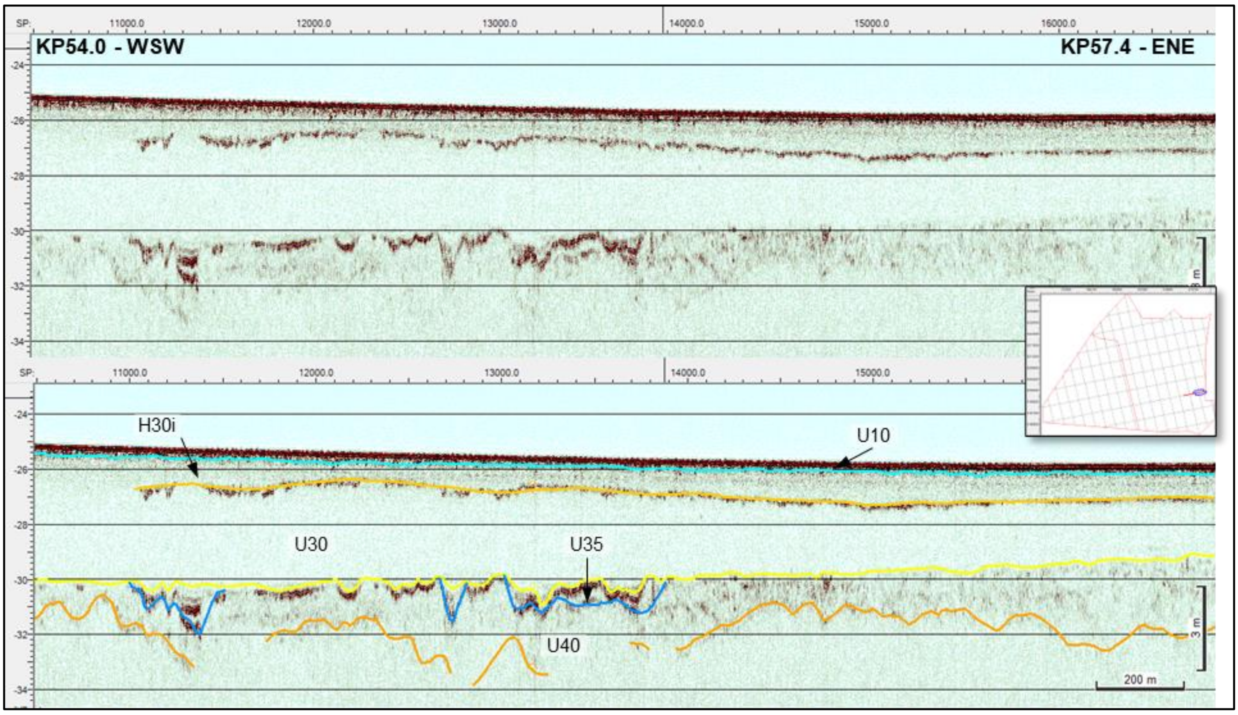


Figure 151 SBP example image of eastern part of Profile line BX01_39000. Position 421922E, 61991870N (image mid-point).

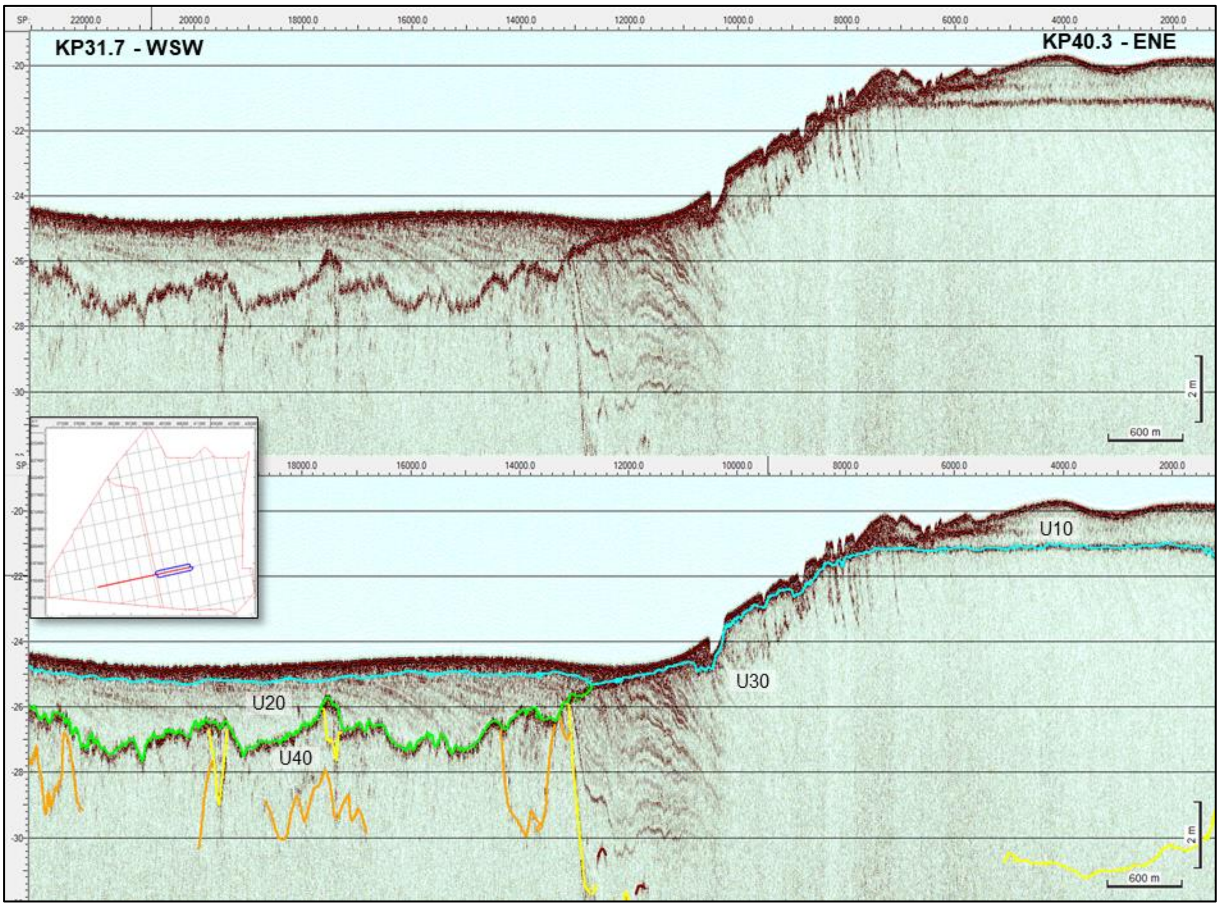


Figure 152 Profile BX01_39000.Change in the main stratigraphy, U10 on top of U30 to U10 above U20. Position 403918E, 6195280N (image mid-point).

8.6.7.4 BM04_13860 (NNW TO SSE)

In the north part of the profile the uppermost unit is U30, below which U40 is observed. U40 is only about 0.5 m thick and rests upon well layered older sediments (Figure 153). U40 thickens toward the south and channels of U35 is observed cutting though the unit. Between 411888 E, 6228406 N (KP1.6) and 412514 E, 6225515 N (KP4.7), U10 is present as the upper unit. Further south a thin layer of U10 overlies U40.

From 413562 E,6620687 N (KP9.5), the stratigraphy is U10, U30 and U40, as the lowest unit. U10 is thin and U30 thickens towards the south, at 419518 E, 6193211 N (KP37.6), U30 thins again and U10 increases in thickness (Figure 154). An internal reflector is present in U30 (Figure 154). At approximately 418636 E, 6197279 N (KP33.5), acoustic blanking is observed within U35.

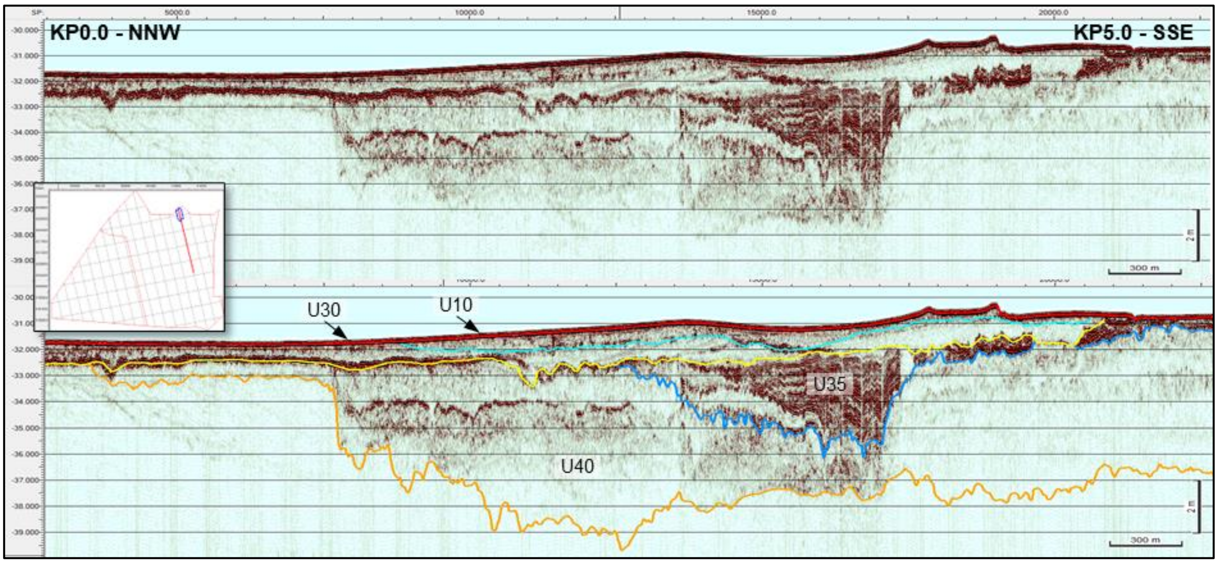


Figure 153 SBP example image of northern section of Profile line BM04_13860. Position 411952E, 6228108N (image mid-point).

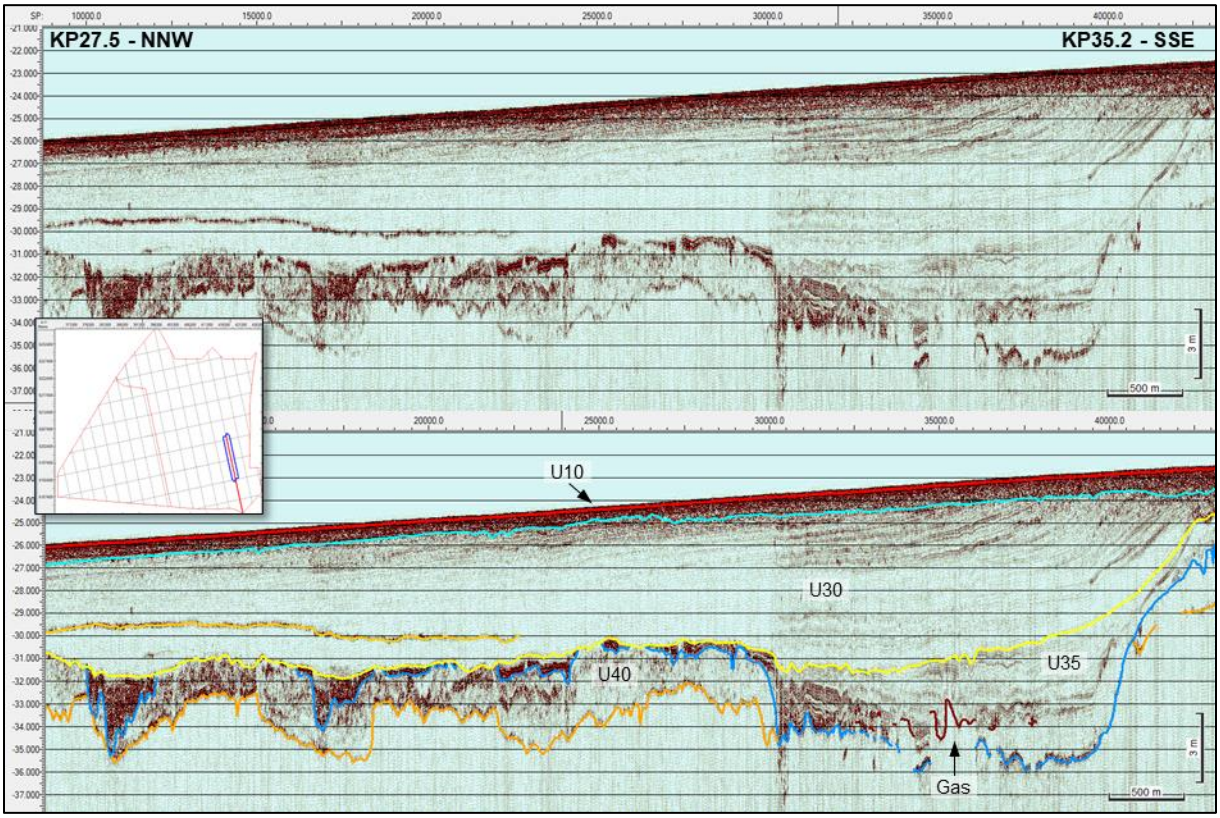


Figure 154 SBP example image of middle section of Profile line BM04_13860. Position 411952E, 6228108N (image mid-point).

8.6.7.5 BM09_27860 (NNW TO SSE)

A thin layer of U10 rests upon U30, below which, unit U40 is present. In proximity to 396999E,6230993N (KP5.7) a wide channel can be observed. The channel consists of U35 sediments, where gas blanking is also observed in the channel. Unit U20 is observed between 397300E, 6229585N (KP7.4) and 399061E, 6221475N (KP15.8), after which acoustic penetration is unable to resolve its base (Figure 155).

Around 399138E,6221120N (KP16.1) U10 gets thicker and U35 is no longer observed below U30. U30 deepens into a basin, occasional U35 can be seen at the base of U30 (Figure 156). Due to the presence of acoustic blanking combined with the thickness of sediment, the base of U30 can't always be observed.

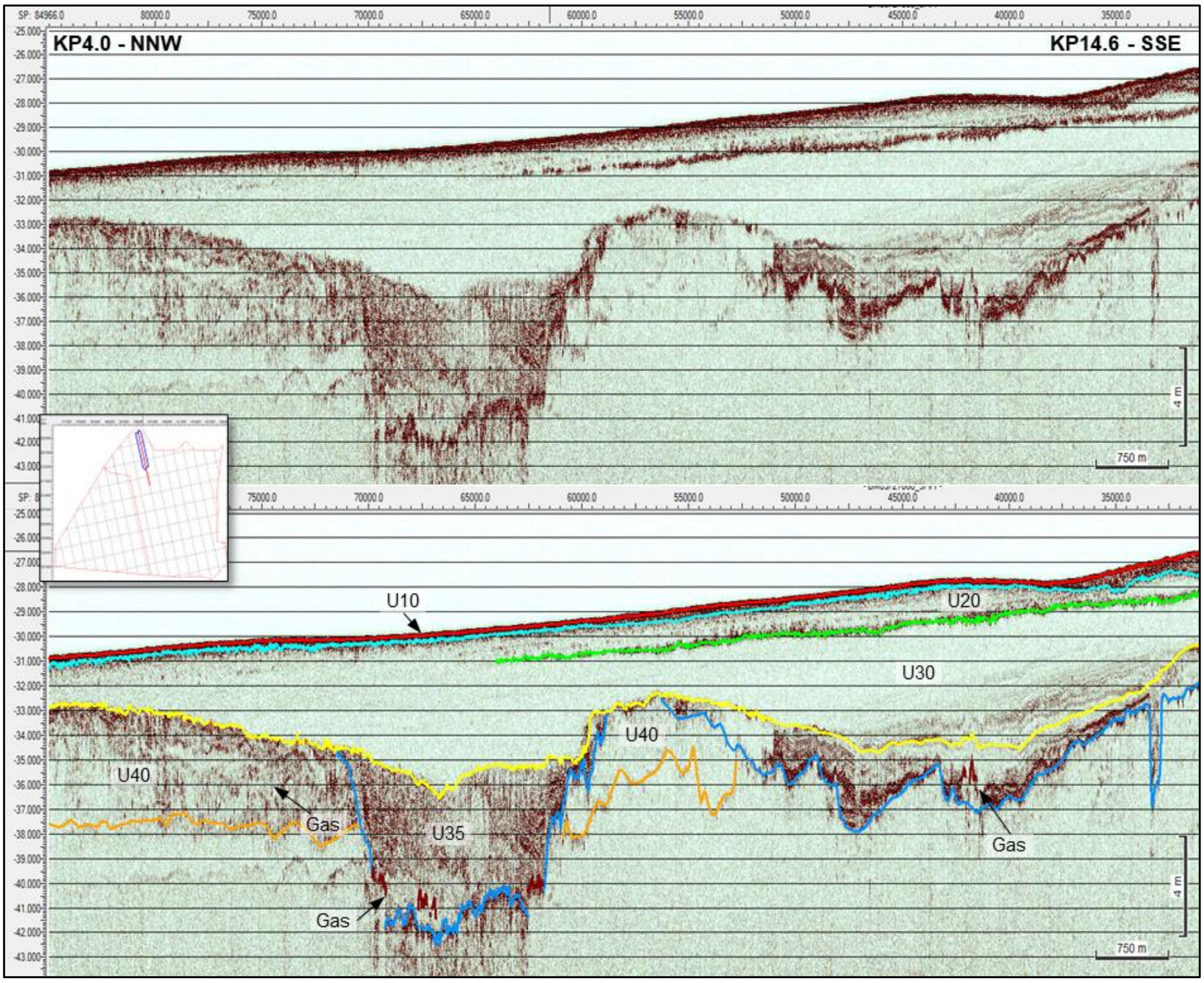


Figure 155 SBP example image of northern section of Profile line BM09_27860. Position 397593E, 6228250N (image mid-point).

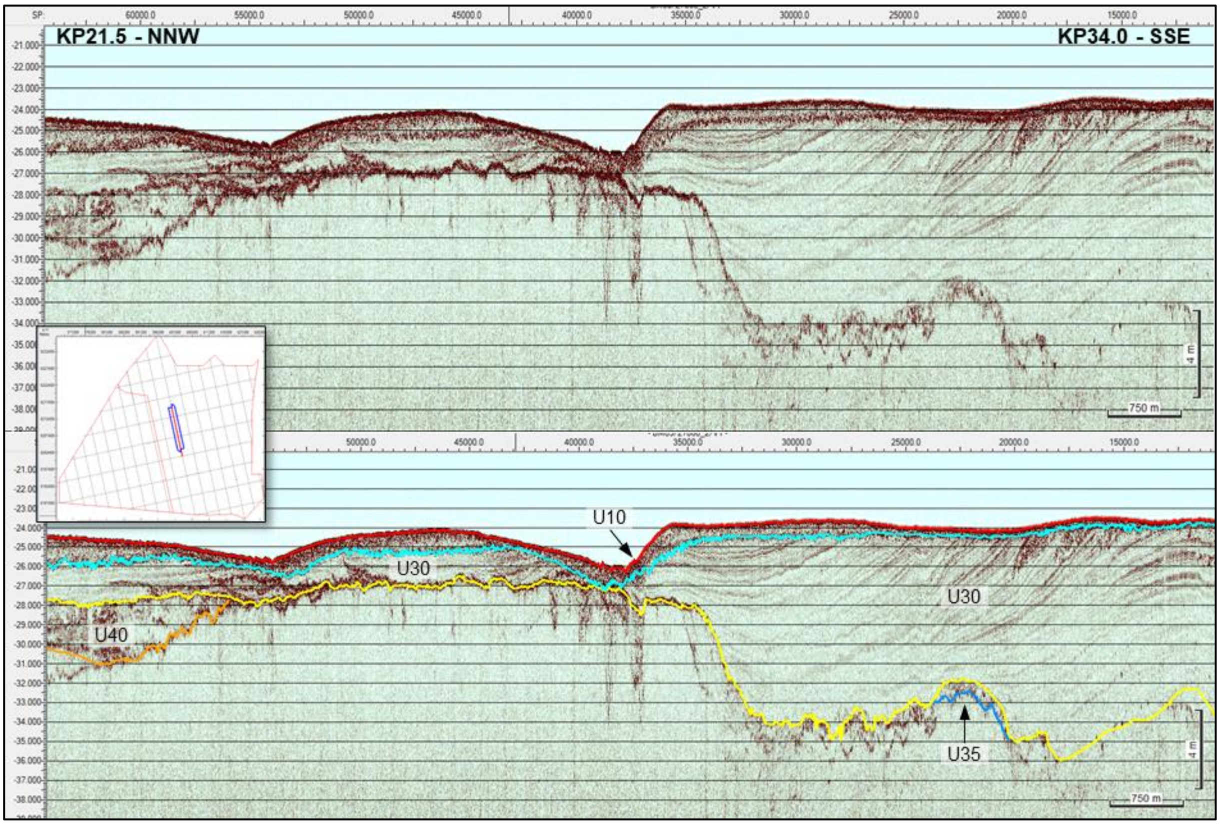


Figure 156 SBP example image of middle section of Profile line BM09_27860. Position 401601E, 6209753N (image mid-point).

8.7 Seabed Hazards

8.7.1 Gradients

Seabed gradient values of less than 1° are observed across the majority of the NSA1 site, with larger values (1° to 5°) corresponding to the sides of megaripple and erosional features. The largest reported slope values (> 20°) are formed from the wreck SS Sierra Cordoba (block BM08) and the sides of a prominent outcrop (block BM11). Outside of wrecks, the survey area comprises slopes that are very gentle to gentle and as such are not considered a major seabed hazard.

For complete details refer to Section 8.2 Bathymetry and Section 8.2.7 Slope Analysis.

8.7.2 Mobile Sediments and Bedforms

Areas of mobile sediments are present across the majority of the NSA1 site. The mobile sediments range from smaller wavelength bedforms such as ripples, large ripples, megaripples to larger scale sediment bedforms such as sand waves. As the mobile bedforms are quite extensive, particularly in the western and northern half of the site and given their transient nature, these could prove significant when considering burial depths for inter array cables and for turbine foundation design. Such areas exhibit periodic sediment removal and accretion.

For complete details refer to section 8.4.2 Mobile Sediments.

8.7.3 Boulders

Within boulder fields, a >0.5 m boulder picking threshold has been used to identify intermediate (10-20 boulders per 50 x 50 m) and high (>20 boulders per 50 x50 m), density areas. Boulders >2 m have also been picked within boulder fields, and these are part of the boulder contacts present in the TSG. Intermediate and high-density boulder fields were observed within the southwest area of the NSA1 site as shown in Figure 157. For further details of boulders within the area, refer to section 8.4.4 of this report.

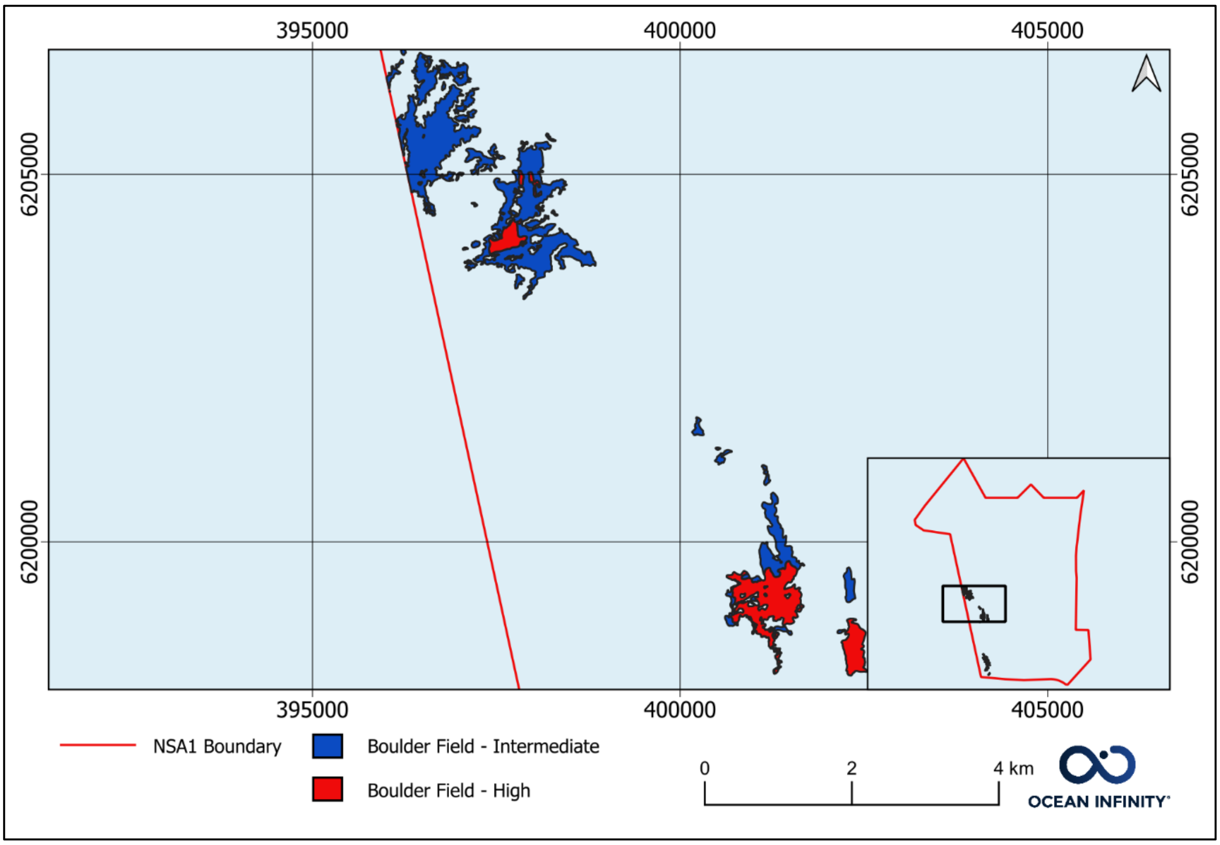


Figure 157 Areas of intermediate and high-density boulder fields within NSA1.

8.7.4 Existing Infrastructure and Wrecks

Existing infrastructure, unknown linear features and wrecks were identified from the survey data.

From background infrastructure data, 13 cables are believed to pass through the NSA1 survey area and 10 have been identified within the magnetometer data. Eight linear magnetic features have also been observed within the magnetometer data. None of these cables and features were observed within the SSS data therefore it is assumed that all cables and linear features are buried. The three not detected cables are various sub-sections of the Cantat-3 cable.

From the SSS and MBES data, 12 items have been identified as possible wrecks (10) or debris (2) associated with wrecks. These targets range in confidence value and include charted wrecks, unknown wrecks (targets that are clearly wrecks but are not present in any background data), possible wrecks (those that have some form resembling a wreck) and debris fields possibly related to wrecks. All the objects listed as wrecks protrude from the seabed and have been identified as a possible hazard.

For details refer to section 8.5.1 Wrecks, 8.5.2 Existing Infrastructure and 8.5.3 Linear MAG Features.

8.7.5 Sub-Seabed Hazards

Acoustic Blanking

Throughout the NSA1 survey area, we observe several examples of acoustic blanking due to gas migration, characterized by acoustically opaque zones in seismic reflection profiles (Figure 139, Figure 147). The gas mostly appears to inhabit the bedded facies of Unit 35 and is likely to be decomposition gas from the decay of in-situ organic matter. Potential gas is interpreted between 0.1 m and 17.3 m below seabed.

Possible Peat

Scattered possible Peat has been interpreted in NSA1 survey area, see example in Figure 146. Peat is geotechnically highly variable often highly inhomogeneous. Peat is generally interpreted to appear at the base of unit U30 and/or the top of unit U35 and is interpreted to be present from 0.1 m to 9.4 m below seabed.

Till outcrop

Till only outcrops within isolated, small areas within the central and southern part of blocks BM10 a BM11. A particularly prominent outcrop is observed within the central western part of BM11. For details refer to Figure 158 and Section 8.4.1.

Although till is only seen breaching the surface in a couple of isolated areas, stiff sediments are likely to occur frequently within 5 m of the seabed. The below figure depicts the areas where stiff sediments may be within 5 m of the seabed. It should be noted that outside of these polygons stiff sediments may occur within 5 m, and equally, sediments within these polygons may not be considerably stiff.

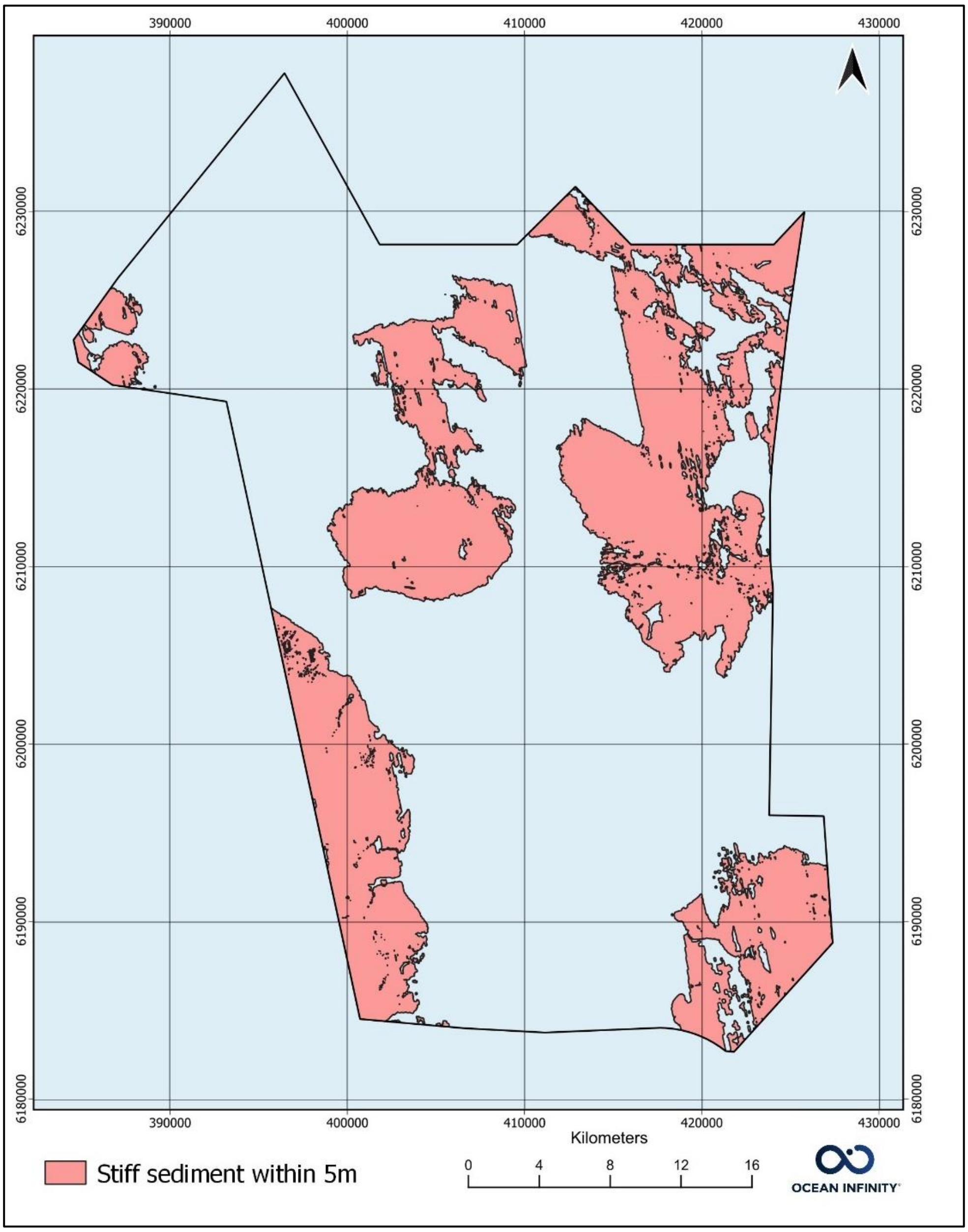


Figure 158 Areas where stiff sediments may be within 5 m of the seabed.

Due to the nature of gridding algorithms, in areas where the surface follows the seabed reflector (where till is outcropping), the resulting grid can change shape slightly relative to the seabed grid. When the surface is created, a blanking function is run to remove parts of the grid which are above the seabed, so that the "below seabed" grid does not have negative values. As an unintended result, the final surface can exhibit small holes in the surface, even though the presence of stiff sediment is known, as seen in Figure 159. Efforts were made to interpolate these gaps, but it often led to the surface extending above the seabed, and therefore providing negative BSB values. When assessing these grids or polygons, gaps in the main polygons should be disregarded, and knowledge of the inherent inaccuracies should be considered.

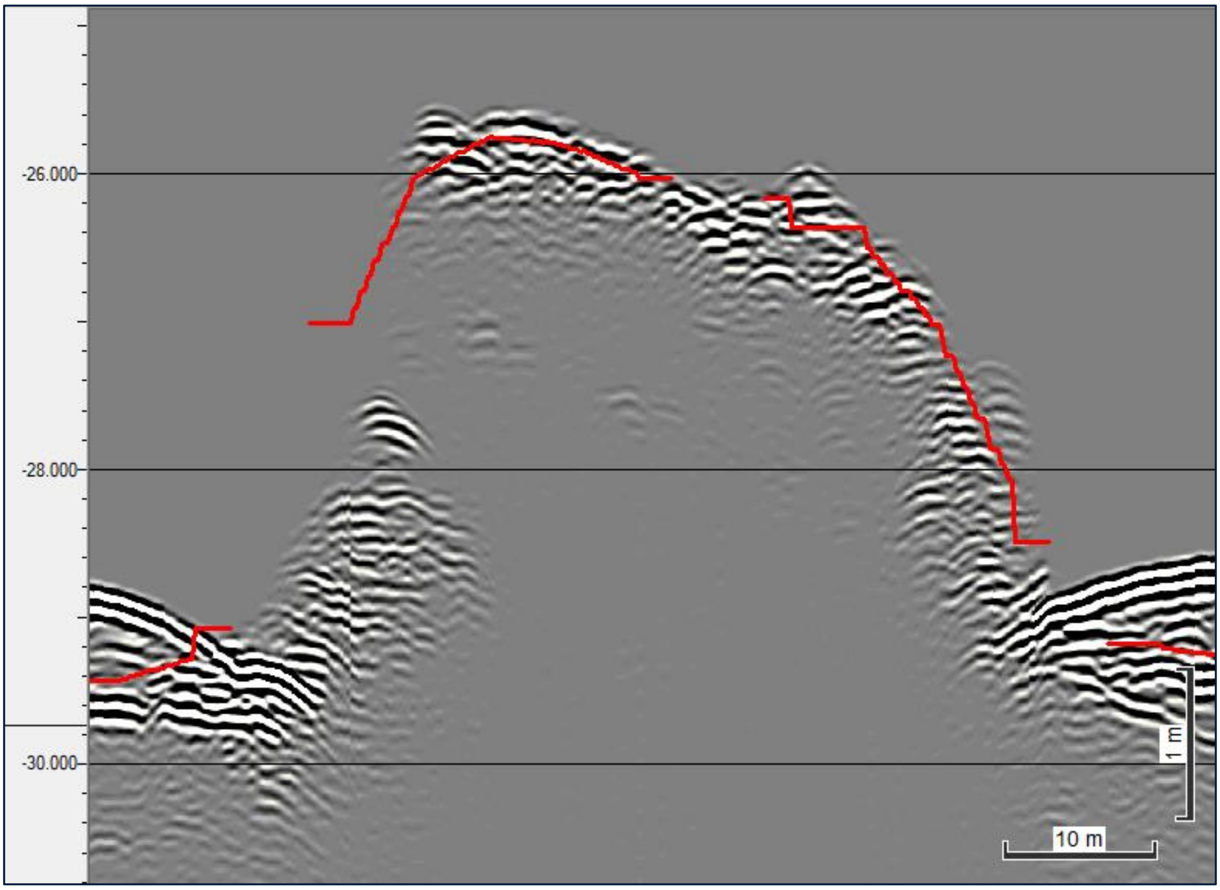


Figure 159 Example of stiff sediment grid error.

8.8 Archaeology Considerations

During the survey no obvious archaeological findings were observed. The most common MMO observed were associated with fishing activity in the area (fishing nets/pots).

A total of 10 charted, uncharted or possible wrecks were identified within the NSA1 survey area. A detailed description of the wrecks is described in Section 8.5.1.

8.9 Grab Sample Summary

The NSA1 survey area encompasses a variety of seabed conditions. Engineering within the investigated depth profile should consider the following general observations, which are neither exhaustive or prescriptive, and are related exclusively to the observed material presented in this report.

The results of the grab sampling provide good coverage of the surface seabed conditions, which are dominated by granular sediments, largely fine to medium SAND with occasional patches of GRAVEL and GRAVEL with COBBLES. The latter are observed mainly in the west of the survey area within BM11 and occasionally in the northeast in blocks BM04 and BM01 see Table 39 and Figure 160.

Table 39 Grab sample summary.

Lithology	Number of Samples
SAND	398
GRAVEL	18
GRAVEL & COBBLES	7
Total	**423**

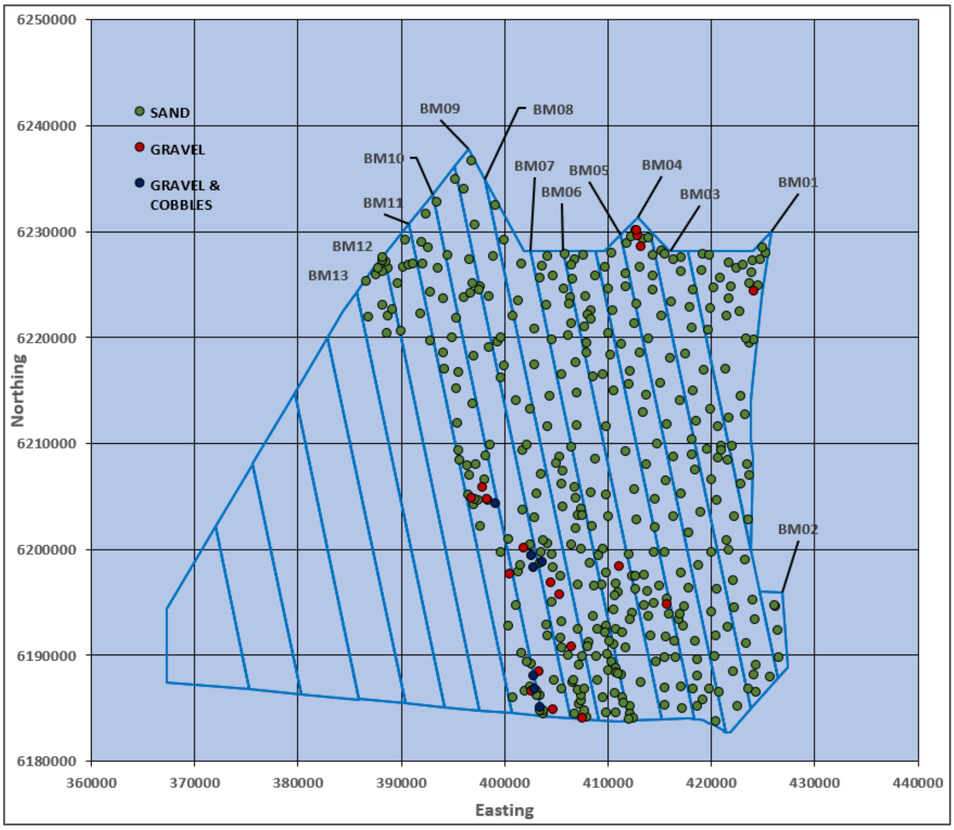


Figure 160 Distribution of SAND, GRAVEL and GRAVEL & COBBLES within NSA1.

Particular sediments within the survey area may affect shallow seabed engineering, i.e., highly organic material, high gravel and/or cobble contents. Within the survey area, SAND is common throughout and GRAVEL / COBBLES are encountered only in 25 of the 423 locations, occupying 6% of the samples taken. Due to the scattered nature of grab sampling, the geophysical data and interpretation should also be consulted as to whether there are significant deposits of coarse GRAVEL and/or COBBLES on the seabed. The presence of organic-rich CLAY and PEAT must also be taken into consideration, due to the undesirable thermal regime which such cohesive material can generate, together with their tendency for compressibility under load and typically low material strength. As part of the laboratory analysis, 31 of the samples were tested for their total organic matter which varied between 0.4-2.7 % for the total organic matter. Whilst the thermal regime of the seabed has not been a subject of investigation in this report, the potential high thermal resistivities in organic-rich material and low strength cohesive CLAY should be borne in mind, especially with regards to any electrical cable installation activities.

The majority of the seabed sediments sampled were of Recent age, whilst occasional samples were Post Glacial and Late Glacial in age.

For a full description of the grab sample results please refer to the lab report and logs in Appendix B.

9. Conclusions

Recorded water depths within the NSA1 survey area were between 15.56 m and 33.51 m, with depth generally increasing from the south to the north across the site. The site is dominated by the northern extent of the Horns Rev sandbank, with extensive areas of mobile sediments observed.

The surficial geology in the area is dominated by SAND and GRAVEL and coarse SAND with small areas of TILL/DIAMICTON. SAND is predominantly visible in the eastern and central parts of the area, while SAND and GRAVEL and coarse SAND are present in the western parts of the site. Small areas of TILL/DIAMICTON are found in the western part of the site. Isolated patches of Quaternary Clay and Silt are present outcropping North of BM06.

Areas of mobile sediments are present across the majority of the NSA1 site. The mobile sediments range from smaller wavelength bedforms such as ripples, large ripples, megaripples to larger scale sediment bedforms such as sand waves. Areas of ripples occur mainly associated with the GRAVEL and coarse SAND, the direction of these mobile sediments may vary along the survey area. Sand waves areas are visible particularly in the northeast and west of the survey area and are typically comprised of SAND or GRAVEL and coarse SAND.

A total of 5021 individual seabed contacts were detected in the NSA1 survey area from SSS data. They were classified as: Anchor (5), Boulders (1394), Fish Net (2588), Soft Ropes (28), Wire (6), Wrecks (10), Scour Marks (70) and Other (914). Intermediate and high-density boulder fields were observed within the southwest area of the NSA1 site.

A total of 5540 magnetic anomalies were detected within the NSA1 survey area. 2067 are possibly related to geology, 469 of these are individual discrete anomalies, 2798 relate to existing infrastructure which correlate to 10 known cables, 181 have a linear sequence which form eight unknown linear features and 25 related to wrecks or debris from possible wrecks.

10. Reservations and Recommendations

The results in this report, both geological descriptions and contact selection, are based on interpretations of geophysical data obtained during the survey. It should be considered that there is a natural limitation in the accuracy of interpretation. Results from grab sampling have been used for verification of the geological interpretations and is considered as ground truthing at those locations where collected. Where considered applicable, the sampling results have been extrapolated to constitute a base for verifications also in the surroundings.

Seismic interpretation presented in this report is based solely on seismic interpretation techniques. Unit definition is based on the identification and mapping of the most prominent reflectors and seismic facies shift that correspond to significant changes on depositional environments and sediment type. Seismic facies identification, internal reflector termination and geometry of the erosive surfaces are the basis for the unit's description, inferred depositional environments and sediment type. No type of subsurface ground truthing was incorporated into the present model. All units display a certain degree of vertical and horizontal variability and heterogeneity. This is due to intrinsic nature of the geological processes that took place, the rapidly changing environment and the great extent of the site. The interpretation derived from the geophysical data should be validated by means of ground sampling (bore hole, cone penetrometer test and any soil inspection technique). Key aspects to be investigated are (1) seismic units inferred soil composition, (2) geotechnical relevance of facies shift (laterally and vertically), (3) geotechnical relevance of internal erosive surfaces, (4) importance of linear features (channels) in terms of mechanical/lithological properties and its variability, (5) presence and potential hazard of the identified gas, and (6) presence of constrains in engineering and site development (boulders, coarse sediments).

Not all existing contacts are detectable in the SSS data due to resolution, material, and orientation of the object.

Ocean Infinity's recommendations for further planning within the NS1 survey area are:

- When the data is evaluated and more accurate positions of the planned NS1 turbine locations are decided, a more detailed survey is recommended over the selected sites.

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12. Data Index

The deliverables listed in Table 40 accompany this report.

For continuity, due to survey block extents or data tiling, some deliverable items were not clipped to the NSA1 boundary and may overlap into the NSA2 boundary. These items are delineated with an asterisk (*).

Table 40 Deliverables.

ENN Item No.	Group	Data Product
36*	Bathy data	Bathymetry - Un-gridded soundings, (X,Y,Z) values in ASCII format. The filenames reflect the vessel track ID's are corresponding one-to-one with contents of deliverable 44 (See 107 Feature_TSG). - Provided as depths relative to MSL (positive values)
37*	Bathy data	Bathymetry - Gridded soundings, 0.25m resolution, (X,Y,Z) values in ASCII format - Provided as depths relative to MSL (positive values) - Tiled 10x10 km following the UTM grid
38*	Bathy data	Bathymetry - Gridded soundings, 0.25m resolution, geotiff stored in esri file geodatabase. (provided in raster tsg as elevations - negative values) - GeoTIFF Grids are stored in a ESRI file geodatabase. - Spatial Reference has been configured. - Calculate Statistics has been performed. - Build Pyramids has been performed. - Tiled 10x10 km following the UTM grid
39*	Bathy data	Bathymetry - Gridded soundings, 1.00m resolution, (X,Y,Z) values in ASCII format. - Provided as depths relative to MSL (positive values) - Tiled 10x10 km following the UTM grid
40*	Bathy data	Bathymetry - Gridded soundings, 1.00m resolution, geotiff stored in esri file geodatabase. (provided in raster tsg as elevations - negative values) - GeoTIFF Grids are stored in a ESRI file geodatabase. - Spatial Reference has been configured. - Calculate Statistics has been performed. - Build Pyramids has been performed. No Tiling
41	Bathy data	Bathymetry - Gridded soundings, 5.00m resolution, (X,Y,Z) values in ASCII format - Provided as depths relative to MSL (positive values) No Tiling
42	Bathy data	Bathymetry - Gridded soundings, 5.00m resolution, geotiff stored in esri file geodatabase. (provided in raster tsg as elevations - negative values) - GeoTIFF Grids are stored in a ESRI file geodatabase. - Spatial Reference has been configured. - Calculate Statistics has been performed. - Build Pyramids has been performed. No tiling
45*	Bathy data	Bathymetry - TVU 1.00 m resolution, (X,Y, TVU) values in ASCII format. - Provided as depths relative to MSL (positive values) - Tiled 10x10 km following the UTM grid

ENN Item No.	Group	Data Product
46*	Bathy data	Bathymetry - TVU 1.00 m resolution, geotiff stored in esri file geodatabase. - provided in raster tsg as elevations (negative values) Untiled
47*	Bathy data	Bathymetry - THU 1.00 m resolution (X,Y,THU) values in ASCII format. - Provided as depths relative to MSL (positive values) - Tiled 10x10 km following the UTM grid
48*	Bathy data	Bathymetry - THU 1.00 m resolution, geotiff stored in esri file geodatabase. - provided in raster tsg as elevations (negative values) - Untiled
49*	Bathy data	Bathymetry - backscatter 32bit geotiff stored in esri file geodatabase (untiled) (amplitude populated channels). - Gridded sounding, 0.25m resolution
50*	Bathy data	SVP - sound velocity profiles as SVP comparison spreadsheet
23*	SSS data	Side scan sonar data as XTF-files with corrected navigation, High frequency
24*	SSS data	Side scan sonar data as XTF-files with corrected navigation, Low frequency
25*	SSS data	Navigation files, CSV-format
28*	SSS data	SonarWiz 7 project including: - bottomtracked and suitably processed .XTF files - SSS contacts - GIS/data: a) MBES_ANOMALY, as overlay or features b) MAG_ANOMALY, as overlay or features c) SURVEY_POL, as overlay or features d) SEABED_FEATURE_POL (Boulder fields), since picking strategi differs inside/outside boulder fields - MBES 0.25m tif (Provided in elevations - negative values relative to MSL) - Coverage maps (trimmed data only), as basemap - ReadMe file for included files and data
Additional	SSS data	HF Imagery by Survey Block in 1 m resolution - geotiff stored in esri file geodatabase (provided in raster tsg) Additional deliverable, requested in TQ-016.
52*	MAG data	MAG measurements, CSV-format a. Date (YYYY-MM-DD) b. Time (HH:MM:SS) c. Location ID (Unique location ID number) d. Magnetometer line ID (Unique line number) e. Survey line Heading f. Total magnetic field, measured values, raw magnetic measurements (nT) g. Residual field magnetic field (nT) h. Easting1, Northing1 (Measured coordinates, meters) i. Easting2, Northing2 (Processed coordinates, meters, filtered coordinates and reduced

ENN Item No.	Group	Data Product
		for obvious noise) j. Lay-back (Instrument lay-back distance, meters) k. Altitude (Instrument altitude above seabed, meters) One file covering the entire site
55*	SBP data	Processed SBP recordings, SEGY format. Processing include at least that l. SEGY headers are configured with geometry m. Traces are corrected for motion n. Traces are aligned with datum Delivered in Time, Depth and Velocity.
59	SBP data	Interpretation of the processed seismic data. These data include interpretation points for digitized horizons identified in the seismic recordings. The data must be delivered as a point list file in CSV-format with the following data columns: o. PointID Unique identification number p. Survey line ID Unique survey line identification q. SEGY_Name Filename of SEGY file r. Shotpoint ID s. Easting, Northing Coordinates, meters t. TWT Two-way-time, millisec u. Elevation Elevation, MSL, meters v. Depth BSB Depth Below Seabed, meters, based on constant velocity w. Type The interpretation points must be assigned "type value" to identify the observed layer boundaries, etc.
60x	SBP data	Generated elevation grids relative to vertical datum for each interpreted horizon in 5 m resolution as GeoTIFF grid (provided in raster tsg) The GeoTIFF grid format must satisfy the following requirements: - GeoTIFF Grids are stored in a ESRI file geodatabase. - Spatial Reference has been configured. - Calculate Statistics has been performed. - Build Pyramids has been performed
60y	SBP data	Generated elevation grids relative to vertical datum for each interpreted horizon in 5 m resolution as (X,Y,Z) values in ASCII format (Z as the horizon elevation in meter)
61z	SBP data	Generated depth below seabed (BSB) grids for each interpreted horizon in 5 m resolution as GeoTIFF grid (provided in raster tsg) The GeoTIFF grid format must satisfy the following requirements: - GeoTIFF Grids are stored in a ESRI file geodatabase. - Spatial Reference has been configured. - Calculate Statistics has been performed. - Build Pyramids has been performed
61aa	SBP data	Generated depth below seabed (BSB) grids for each interpreted horizon in 5 m resolution as (X,Y,Z) values in ASCII format (Z as the layer thickness in meter)
62bb	SBP data	Generated Isochore (layer thickness) grids for each interpreted soil unit in 5 m resolution as GeoTIFF grid (provided in raster tsg) The GeoTIFF grid format must satisfy the following requirements: - GeoTIFF Grids are stored in a ESRI file geodatabase. - Spatial Reference has been configured. - Calculate Statistics has been performed. - Build Pyramids has been performed
62cc	SBP data	Generated Isochore (layer thickness) grids for each interpreted soil unit in 5 m resolution as (X,Y,Z) values in ASCII format (Z as the layer thickness in meter)
63	SBP data	Kingdom project including SBP data from geological survey, both as TWT and as DEPTH conversion.
65	Grab sampling	Grab sample classification, MS-Excel spread sheet with the following data columns: dd. Unique sampling ID ee. Geological description of the recovered sample, i. Lithology

ENN Item No.	Group	Data Product
		ii. Depositional environment iii. Depositional age
66	Grab sampling	Grab sample laboratory analysis, overview table and result tables, MS-Excel spread sheet.
107a	GIS	Feature TSG geodatabase.
107b	GIS	Raster TSG geodatabase.
2*	Report	Operations Report
5.1*	Report	Charts (Overview, North-Up, and Profile*)

13. Appendices

Appendix A List of Produced Charts

Appendix B Grab Sample Lab Report

Appendix C Client Concession Forms and Memos