Geophysical Surveys For Danish Offshore Wind 2030 - Kriegers Flak II North & South

Title	**Geophysical and Geological Survey Report For Kriegers Flak II North and South**
Number	BE5376H-711-03-RR
Revision	3.0

3.0	20/02/2024	Issue for Client	JWA/SKA	EVA	AMO/LRO
Revision	Date	Description of Revision	Author	Checked	Approved

REVISION HISTORY

The screen version of this document is always the CONTROLLED COPY. When printed it is considered a FOR INFORMATION ONLY copy, and it is the holder's responsibility that they hold the latest valid version.

The table on this page should be used to explain the reason for the revision and what has changed since the previous revision.

Rev.	Date	Reason for revision	Changes from previous version
1.0	24/11/2023	Issue for Client	N/A
1.1	09/01/2024	Revision based on Client comments	Ref. "Deliverable_Register_DOW2030_draft_WPA&C_WPAC_KFII_North&South_REPORT.xlsx"
2.0	02/02/2024	For Client Review	
3.0	20/02/2024	For Client Review	Ref. "Deliverable_Register_DOW2030_draft_WPA&C_WPAC_KFII_North&South_REPORT_Energinet reply"

TABLE OF CONTENTS

LISTS OF TABLES AND FIGURES

DEFINITIONS AND ABBREVIATIONS

Throughout this document the abbreviations are listed in Table 1. Where abbreviations used in this document are not included in this list, it may be assumed that they are either equipment brand names or company names.

Table 1: Abbreviations used in this document

Abbreviation	Definition	Abbreviation	Definition
2D	Two Dimensional	MBES	Multibeam Echosounder
3D	Three Dimensional	mE	Metres East
AS	Analytical Signal	mN	Metres North
BSB	Below Seabed	MRU	Motion Reference Unit
BSL	Below Sea Level	MSL	Mean Sea Level
CPT	Cone Penetration Test	NMEA	National Maritime Electronics Association
dB	Decibel	nT	Nanotesla
DGNSS	Differential Global Navigation Satellite System	QC	Quality Control
DTM	Digital Terrain Model	RES	Residual Magnetic Field
ECR	Export Cable Route	SBP	Sub-Bottom Profiler
EGN	Empirical Gain Normalisation	SEGY	Society of Exploration Geophysicists Y format
EPSG	European Petroleum Survey Group	SIMOPS	Simultaneous Operations
ETRF2000	European Terrestrial Reference Frame 2000	SP	Shot Point
ETRS89	European Terrestrial Reference System 1989	SSS	Side Scan Sonar
FMGT	Fledermaus Geocoder Toolbox	SVP	Sound Velocity Profile
GIS	Geographic Information System	THU	Total Horizontal Uncertainty
GOIV	Geo Ocean IV	TPU	Total Propagated Uncertainty
GOV	Geo Ocean V	TVU	Total Vertical Uncertainty
GRS80	Geodetic Reference System 1980	TWT	Two Way Time
Hz	Hertz	UHR	Ultra-High Resolution
IHO	International Hydrographic Organisation	USBL	Ultra-Short Baseline
INS	Inertial Navigation System	UTM	Universal Transverse Mercator
IOGP	International Association of Oil and Gas Producers	UXO	Unexploded Ordnance
ITRF	International Terrestrial Reference Frame	WPA	Work Package A
ka BP	kilo annum [thousand years] Before Present	WPC	Work Package C
KF II N	Kriegers Flak II North site	ZDA	NMEA-0813 Date Time Message String (UTC, day, month, year, and local time zone offset)

Abbreviation	Definition	Abbreviation	Definition
KF II S	Kriegers Flak II South site		

1 PURPOSE OF THE DOCUMENT

This report focuses on detailing the geophysical and geological results for the Kriegers Flak II North and Kriegers Flak II South survey sites. This report will detail the findings from the five sensors used to investigate the Kriegers Flak II North and Kriegers Flak II South areas, giving a detailed overview of the survey site, as well as listing any hazards meeting the functional requirements.

2 EXECUTIVE SUMMARY

Kriegers Flak II North			
Survey dates	Geological survey	Start	25/04/2023
		End	04/05/2023
	Geophysical survey	Start	28/02/2023
		End	22/03/2023
Sensors	Multibeam Echo Sounder (MBES), Side Scan Sonar (SSS), Magnetometer (MAG), Sub-Bottom Profiler (SBP), 2D Ultra-High Resolution seismic (2D UHR)		
Coordinate system	Datum		European Terrestrial Reference System 1989 (ETRS89)
	Projection		UTM Zone 33 N (EPSG: 25833)
Bathymetry			
Depth	21.8 m MSL – 34.5 m MSL		
Site topography	Within the northern section of the site, to the north of approximately 6117650 mN, the seabed initially deepens from north-east to south-west and then from north-west to south-east, with seabed levels ranging from 21.8 m MSL to 31.4 m MSL. Further south, the seabed deepens very gently from north-west to south-east, with three slightly raised areas of seabed, standing up to 3.0 m higher than the surrounding seabed, are separated by broad (500 – 1500 m wide), NW-SE orientated, truncated channel features. The truncated channel features are very shallow, with localised depths only 1.5 m – 2.5 m deeper than the surrounding seabed.		
Slope angles	No steep slopes are present within the northern section of the site, with maximum gradients of <1.0° noted. The northernmost of three raised areas exhibits a very localised slope gradient of up to 7.5°, deepening from north-west to south-east. Maximum slope gradients of up to 1.5° are present on the sides of the truncated channel features. The highest slope values (very steep slopes; >15°) are associated with seabed features, such as boulders and cable trenches, as well as smaller elevated features and especially wrecks.		
Seabed surface: Geology			
The seabed sediments across the north-western section of the site comprise a series of large, irregular outcrops of till/Diamicton, surrounded by large, irregular areas of sands and muddy sands (silty, clayey sands). Coarser patches of gravel and coarse sands are also present in the restricted areas in the northern part of this section. The seabed sediments across the south-eastern section of the site comprise mainly muddy sands (silty, clayey sands). To the south-east, the seabed sediments appear finer-grained, comprising areas of muds (silts/clay) and sandy muds (sandy silts/sandy clays), one of which extends into the north-western section of the site. A number of relatively minor areas of outcropping till/diamicton, as well as restricted areas of gravel and coarse sands are present, mainly near the southern border of the site.			
Seabed surface: Morphology			

Kriegers Flak II North	
In terms of seabed surface morphology, the western half of the site is dominated by patches of boulder field areas which vary in concentration between high and intermediate density. An area of possible sand-gravel patches or biostructures runs in parallel to the northeastern site boundary, reaching a width of over a kilometre in the southeastern segment of the site. Confined areas of ripples and sandwaves characterize the northernmost and south-westernmost edges of the site, respectively. The central part of the site is characterized by the afore-mentioned channel features, along with areas of disturbed seabed and seabed scars related to the construction of the Baltic Pipe. Most of the southern half of the survey area is covered in trawl marks with intermittent smaller boulder field areas.	
Seabed surface: Man-made features and site-specific hazards	
Wrecks	5 wrecks and 3 possible wrecks
Cables	5 known, 1 unknown cable
Pipelines	1 pipeline
Metallic objects	67
Other contacts	408
Sub-seabed soil units	
Unit I	Holocene deposits
Unit II	Late Glacial deposits
Unit III	Glacial deposits
Unit IV	Bedrock (likely Danian limestone)
2D UHRS: Geology	
The geological foundation zone extends to ~70 m below seabed. The rocks and sediments within this interval have been interpreted with reference to the supplied GEUS desk study. There is generally a good correlation between the shallow geology imaged in this project's sub-seabed data, and the desk study. In overview, the area has a glacial to post-glacial sequence of relatively recent sediments (Units I, II and III) over much older bedrock. The recent sediments are generally 3 – 8 m thick, though locally these recent sediments are interpreted to be much thicker. The seabed and top bedrock surface dips to the east, the younger post-glacial sediments (Units I and II) are better developed in the eastern part of the area. Unit I (Holocene deposits) comprises post-glacial silty, sandy CLAYS, which are less than 1 m thick across most of the area. These include a veneer of sandier seabed sediments, though these are seldom resolved in the SBP data. The Holocene sediments are widely distributed over the study area. The Holocene is very thin or absent (unmapped) over the centre/west of the area, over south-west to north-east trending zones, where till is close to the seabed. Small pockets of Holocene may occur in these areas and a <0.2 m thick seabed veneer may still be present. The Holocene deposits are thickest over a north-west to south-east trending ~2 km wide zone, which crosses the area from the centre/north to the extreme south-east. Here the deposits are up to 2 m thick. The sediments also thicken at the southern margin of the area. The base Holocene is mapped as horizon H05. Over broad areas, it is interpreted to be a mild erosion surface. Thickness variations are due to relief at this surface and a degree of mounding at the seabed. The	

Kriegers Flak II North
erosion at H05 may be related to the final regression of the area ~10 000 years ago, when sea level dropped. There are some narrow channels cut into the underlying Unit II deposits. These trend east-west across the centre of the site and may be due to a short-lived drainage system at the onset of the marine transgression. The Holocene unit (Unit I) has seismic characteristics that indicate that it is extremely soft/weak. The interval defining Unit II (late Glacial deposits) is complex, due to the area's range of glaciomarine environmental conditions during the Late Weichselian and earliest Holocene. Locally, upper parts show laminations indicative of interbedded clays and sands/silts, whilst lower parts may represent sandier deposits. The base of this unit is mapped as horizon H20. This is generally at the top of deposits which show clear signs of ice contact, true glacial deposits (tills). Unit II mainly occurs over central and eastern areas and is typically around 2 m thick, locally exceeding 5 m. In the west, and over many parts of the central and northern regions of the area, the Unit II glaciomarine sediments pinch out over the subcropping Unit III tills. The desk study divides this late glacial sequence into earlier and later parts. Unit III (Glacial deposits) occurs throughout the study area, except for a few very small areas scattered around the north/centre of the area. Unit III is interpreted to be a till deposited in association with the last major ice advance over the area, approximately 22 000 – 18 000 years ago. The till forms a 3 m to 6 m thick blanket over the site, with variations due to bedrock morphology, patterns of primary deposition and possible erosion at the later onset of glaciomarine conditions. Unit III is typically 3 to 6 m thick, but can locally range from 0 to 34 m. The till is thickest along a 500 m wide south-west to north-east trending low in the top of the bedrock. This feature may be due to bedrock fault displacement or erosion. Unit III is generally a glacial till which has been subjected to direct ice contact. The ice-contact facies may comprise a clay-prone diamicton, which is likely to contain subordinate silt, sand, gravel, cobbles and boulders. They will be overconsolidated. Consolidation levels may significantly vary over short distances. Seismically, the ice contact facies are structureless, with a very irregular upper surface, which probably forms a series of ridges. The bedrock is likely to be Danian limestone. Bedrock faults are not well imaged, though these are likely to be present. These ancient faults were reactivated during the Late Cretaceous/Early Palaeocene and, in this area, likely generated inversion. The high potential for erosion of the top of the bedrock (especially over the last 1.1 million years of ice advances) makes it difficult to attribute features at the top bedrock surface to tectonic activity. The top of the bedrock is generally 3 to 8 m below seabed, exceeding 25 m over a 500 m wide south-west to north-east trending zone, just south of the centre of the area. This feature may be related to faulting or erosion. The upper surface of the bedrock is a truncation surface with an angular unconformity between the ~60 million year old limestones and their much younger overburden. The bedrock may have been subjected to numerous phases of erosion during early glaciations.

<table>
<tr><th colspan="4">Kriegers Flak II South</th></tr>
<tr><td rowspan="4">Survey dates</td><td rowspan="2">Geological survey</td><td>Start</td><td>04/05/2023</td></tr>
<tr><td>End</td><td>15/05/2023</td></tr>
<tr><td rowspan="2">Geophysical survey</td><td>Start</td><td>11/03/2023</td></tr>
<tr><td>End</td><td>26/03/2023</td></tr>
<tr><td>Sensors</td><td colspan="3">Multibeam Echo Sounder (MBES), Side Scan Sonar (SSS), Magnetometer (MAG), Sub-Bottom Profiler (SBP), 2D Ultra-High Resolution seismic (2D UHR)</td></tr>
<tr><td rowspan="2">Coordinate system</td><td colspan="2">Datum</td><td>European Terrestrial Reference System 1989 (ETRS89)</td></tr>
<tr><td colspan="2">Projection</td><td>UTM Zone 33 N (EPSG: 25833)</td></tr>
<tr><td colspan="4">Bathymetry</td></tr>
<tr><td>Depth</td><td colspan="3">18.5 m MSL – 41.8 m MSL</td></tr>
<tr><td>Site topography</td><td colspan="3">Seabed levels across the western part of the area are generally <20 m MSL, becoming deeper towards the east at slopes of less than 0.1°, up to 24.0 m MSL contour, from which point slope gradients increase slightly, up to 0.25° up to 32.0 m MSL contour. To the north-east of the 32.0 MSL contour, up to the 34.0 m MSL contour, the seabed is almost completely flat, dipping imperceptibly towards the north-east at an average slope gradient of <0.02°. To the north-east of the 34.0 m MSL contour, the seabed continues to deepen very gently from W-E, then WNW-ESE, with seabed levels gradually deepening to reach a maximum of deeper than 41.5 m MSL, at an average slope gradient of <0.1°.</td></tr>
<tr><td>Slope angles</td><td colspan="3">The highest slope values (very steep slopes; >15°) are associated with seabed features, such as boulders, trawl scars, wrecks, and other smaller elevated features.</td></tr>
<tr><td colspan="4">Seabed surface: Geology</td></tr>
<tr><td colspan="4">The seabed sediments across the Kriegers Flak II South site become gradually finer grained, running from west-southwest to east-northeast across the site.

The shallowest section of the site lies at the south-western corner, where the seabed sediments comprise sands. Moving east-north eastwards, the seabed sediments grade into muddy sands (silty/clayey sands). Finally, in the extreme north-eastern corner of the site, the seabed sediments comprise mud (silts/clays) and sandy mud (sandy silts/clays).</td></tr>
<tr><td colspan="4">Seabed surface: Morphology</td></tr>
<tr><td colspan="4">In terms of seabed surface morphology, the Kriegers Flak II South site is less diverse than the KF II N site. The southwestern half of the site is dominated by Mytilus edulis beds stretching in patterns with a SW-NE orientation. In the whole central and eastern parts of the site, evidence of trawl marks was found, while in the central western part, several instances of seabed scaring and possible biostructures have been recorded. Several extensive patches of pitted seabed dominate the eastern half of the survey area, with spots of scour patterns and disturbed seabed in the easternmost stretches of the site.</td></tr>
<tr><td colspan="4">Seabed surface: Man-made features and site-specific hazards</td></tr>
<tr><td>Wrecks</td><td colspan="3">1</td></tr>
<tr><td>Metallic objects</td><td colspan="3">9</td></tr>
<tr><td>Cables</td><td colspan="3">1</td></tr>
</table>

Kriegers Flak II South	
Pipelines	0
Other contacts	139
Sub-seabed soil units	
Unit I	Holocene deposits
Unit II	Late Glacial deposits
Unit III	Glacial deposits
Unit IV	Bedrock (likely Cretaceous Chalk)
2D UHRS: Geology	

The geological foundation zone extends to ~70 m below seabed. The rocks and sediments within this interval have been interpreted with reference to the supplied GEUS desk study. There is generally a good correlation between the shallow geology imaged in this project's sub-seabed data, and the desk study.

In general, the area has a glacial to post-glacial sequence of relatively recent sediments over much older bedrock. The Quaternary sediments are generally 10 to 45 m thick. The seabed generally dips to the northeast. The top bedrock unconformity is an undulating surface that dips gently to the southwest, with the Quaternary sequence thinning as the water depth increases. Unit III is absent in large parts of the survey area and is present mostly in the central and northern parts.

Holocene unit (Unit I) is a package of post-glacial silty, sandy CLAY which is generally less than 1 m thick. The interval includes a thin veneer of sandier seabed sediments, though these are interpreted to be very thin and are seldom resolved in the SBP data. The Holocene sediments are widely distributed over the study area. The Holocene is very thin or absent (unmapped) over the northeastern part of the area, across a north-northwest to south-southeast trending zone, surrounding a mound of Unit II sediments. It is also locally absent in areas to the west and south-west where it appears to pinch out against Unit II. Small pockets of Holocene may occur in these areas and a <0.2 m thick seabed veneer may still be present.

The Holocene deposits are thickest in the north-east, where the water depths are greatest and Unit II is thinnest. Here, the deposits are up to 3 m thick. The sediments also thicken at the southern margin of the area. The seabed low in the northwest is related to depositional patterns of the glaciomarine sequence of Unit II and, possibly, the morphology of the top of the bedrock.

The base Holocene is mapped as H05. Over broad areas it is interpreted to be a mild erosion surface – thickness variations are due to relief at this surface and topography of the seabed. The erosion at H05 may be related to the final regression of the area around 10 000 years ago when sea level dropped. Holocene unit (Unit I) has seismic characteristics that indicate that it is extremely soft/weak.

The interval defining Unit II (late Glacial deposits) is complex, due to the area's range of glaciomarine environmental conditions during the Late Weichselian and earliest Holocene. Locally, upper parts show laminations indicative of interbedded clays and sands/silts, and downlapping sequences, where the lower parts are ambiguous but may represent a mixture of deltaic deposits.

The unit is mapped with H20 at its base, occurring throughout the survey area with a thickness of 10 to 25 m, with some local variations related to the topography of the top bedrock and top glacial surfaces. Unit II is generally developed from the south/south-west. The desk study divides this late glacial sequence into

Kriegers Flak II South
earlier and later parts: Unit IIa and Unit IIb. Unit IIa comprises the upper, higher amplitude, bedded parts of Unit II, while Unit IIb comprises the lower, more amorphous parts. Unit IIa is absent in the southwest of the site, where older Unit II deposits are thickest. Unit IIb is present throughout the survey area. Unit III (Glacial deposits) occurs mostly in the northern and central parts of the survey area. The deposits occur as a thin package of sediments between the top bedrock surface and the base of the Late glacial sediments. It is chaotic and structureless in appearance. Unit III is interpreted to be a till deposited in association with the last major ice advance over the area, approximately 22 000 years ago. Unit III is generally a glacial till which has been subjected to direct ice contact, though the unit may contain other facies which may have been laid down in ice-marginal environments during oscillations of the ice front. The ice-contact facies may comprise a clay-prone diamicton which is likely to contain subordinate silt, sand, gravel, cobbles and boulders and will be overconsolidated. Consolidation levels may significantly vary over short distances. Seismically, the ice contact facies are structureless with a very irregular upper surface, which probably forms a series of ridges. The bedrock is likely to be Cretaceous Chalk. Bedrock faults are not well imaged, though these are likely to be present. These ancient faults were reactivated during the Jurassic/Cretaceous and, within this area, likely generated subsidence. The high potential for erosion of the top of the bedrock makes it difficult to attribute features at the top bedrock surface to tectonic activity. The top of the bedrock is generally 7 to 45 m below seabed, it is shallowest, less than 10m below seabed, over the north/east of the area. The upper surface of the bedrock is a truncation surface with an angular unconformity between the Mesozoic rocks and their much younger overburden. The bedrock may have been subjected to numerous phases of erosion during early glaciations.

3 INTRODUCTION AND BACKGROUND

3.1 PROJECT OVERVIEW

Following a decision in the Danish Parliament in 2022, Denmark is on the path to establish offshore energy infrastructure in the Danish Baltic Sea to connect further offshore wind energy to the Danish mainland. The regional locations of the project are shown in Figure 1.

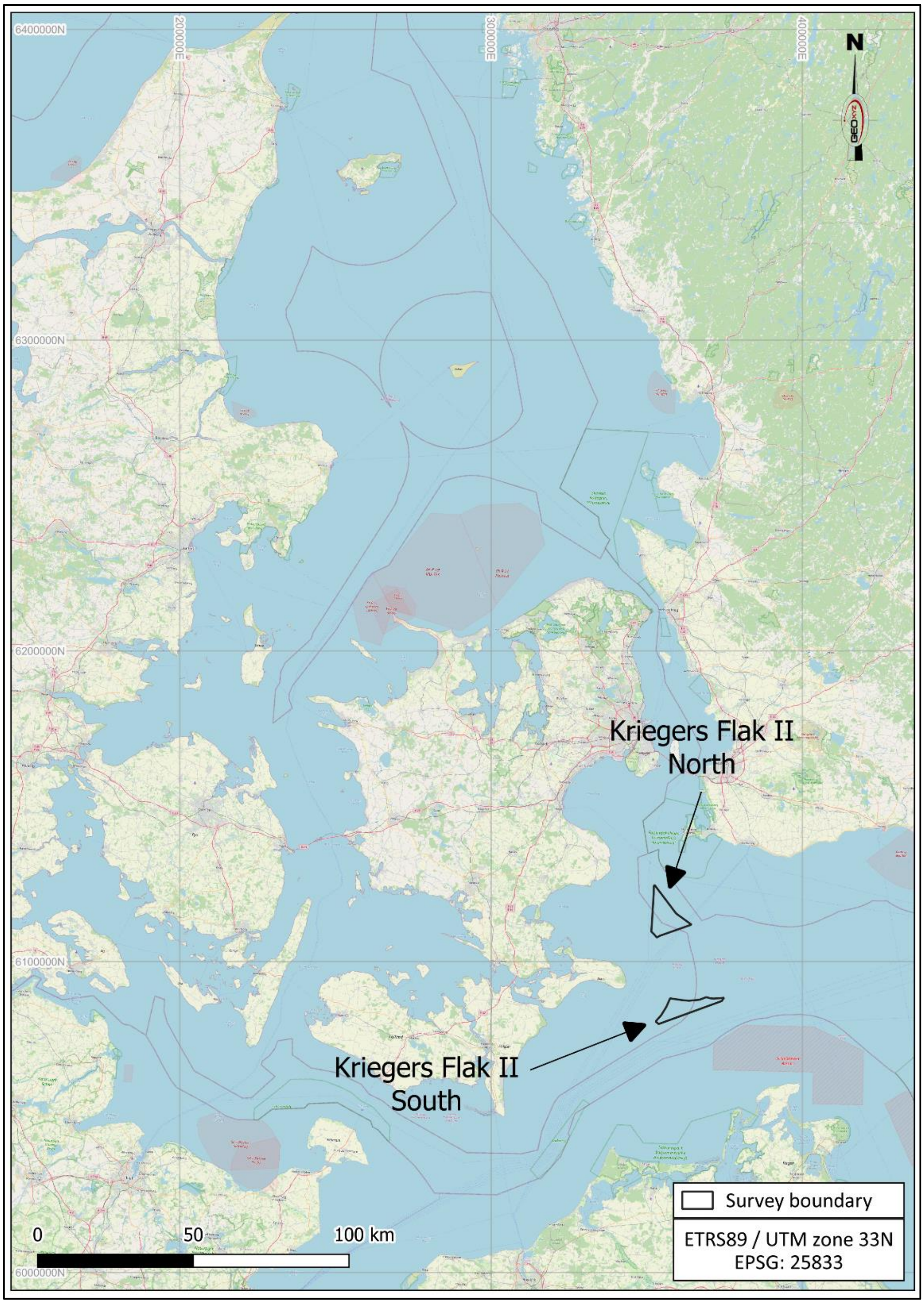


Figure 1: Project locations in the Baltic Sea

The offshore elements of the project comprise the following main parts:

- Two offshore wind farms in the Southern Baltic Sea (Kriegers Flak II North and Kriegers Flak II South)
- Offshore platforms for substations
- Export cables between offshore wind farms and the Danish mainland

The Danish Energy Agency has instructed the Client to initiate site investigations, environmental and metocean studies for the abovementioned main project elements.

The Client has awarded GEOxyz a contract for a geophysical survey of the Danish Baltic Sea project components, denoted in Figure 1.

The scope of the project includes the following work packages:

- Work Package A – Geological site survey
- Work Package C – Geophysical site survey

The scope of Work Package A and C includes the following:

3.1.1 Work Package A – Geological site survey

A geophysical site survey comprising Multi Beam Echo Sounder (MBES) including backscatter (BKS), Sub Bottom Profiler (SBP) and 2D UHR seismic system is to be performed to map the subsurface geological soil layers. Bathymetry should be mapped along the survey lines, as should the shallow geology.

The functional requirements of this work package are to:

- Map all major geological layers and structures to at least 100 m below seabed.
- 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.

3.1.2 Work Package C – Geophysical site survey

A full coverage geophysical site survey comprising MBES including backscatter, SSS, magnetometer, and SBP to map the bathymetry, static and dynamic elements of the seabed surface, and the subsurface geological soil layers to at least 10 m below the seabed. Grab sampling is also required to support the interpretation of the seabed surface geology.

The functional requirements of this work package are to carry out a detailed mapping of the seabed surface to provide:

- Accurate bathymetric data and charts in the surveyed areas
- The morphology and natural features of the seabed surface such as megaripples, 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 interest
- Identification of features of potential conservation interest including but not limited to; sandbanks, gravel reef, cobble reef, rocky reef and biogenic reef structures.

Mapping of the upper part of the seabed subsurface is required to 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, high boulder density, mobile sediments etc.

3.1.3 Area of investigation: Kriegers Flak II North and Kriegers Flak II South

The Kriegers Flak II North & South sites are located in the Baltic Sea region, situated between the Danish, Swedish, and German coastlines in Danish waters (Figure 2 and Figure 3). A summary of the areas is displayed in Table 2. The site extents for Kriegers Flak II North and Kriegers Flak II South are displayed in Table 3 and Table 4.

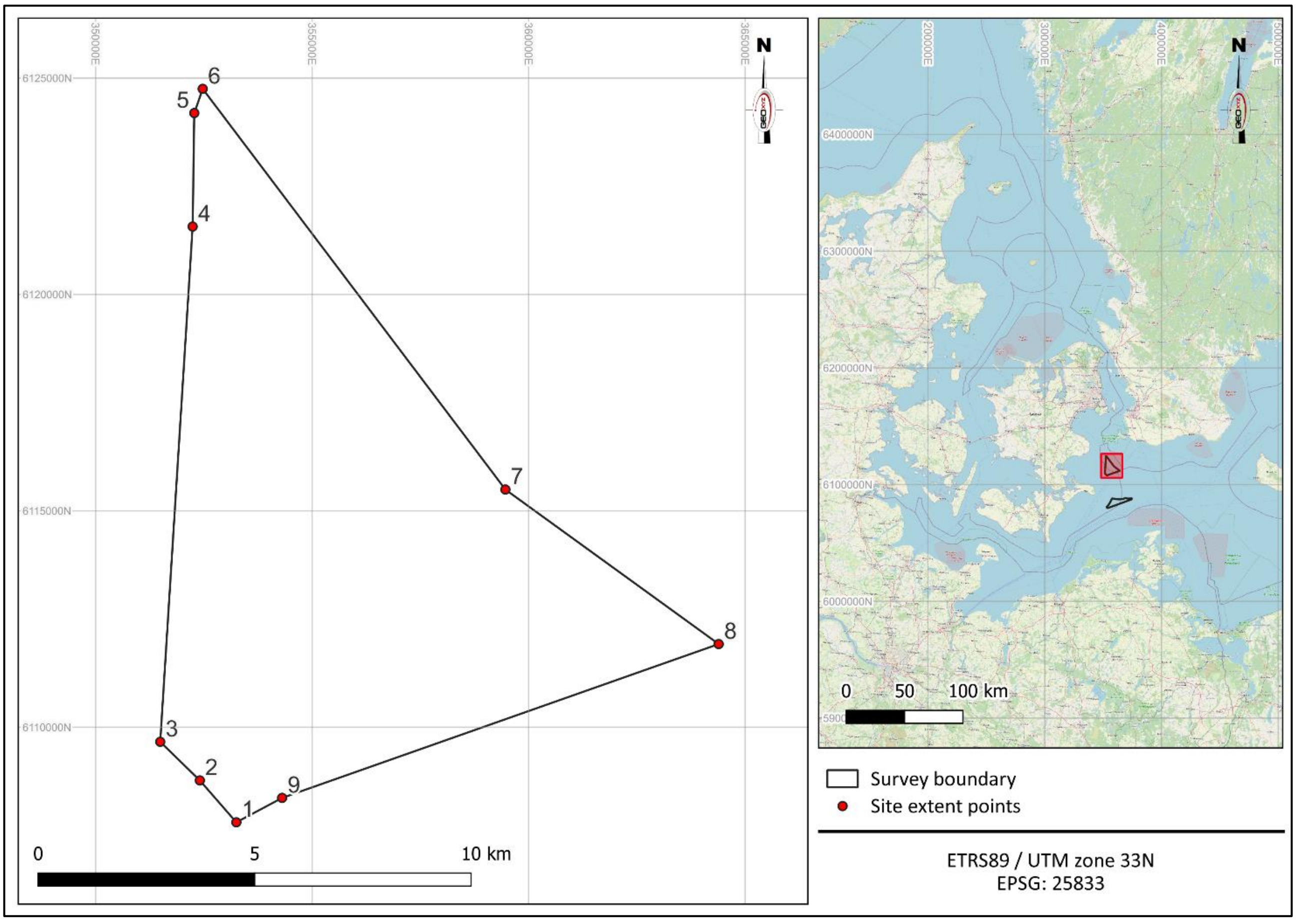


Figure 2: Overview of Kriegers Flak II North (with point IDs corresponding to those in Table 3)

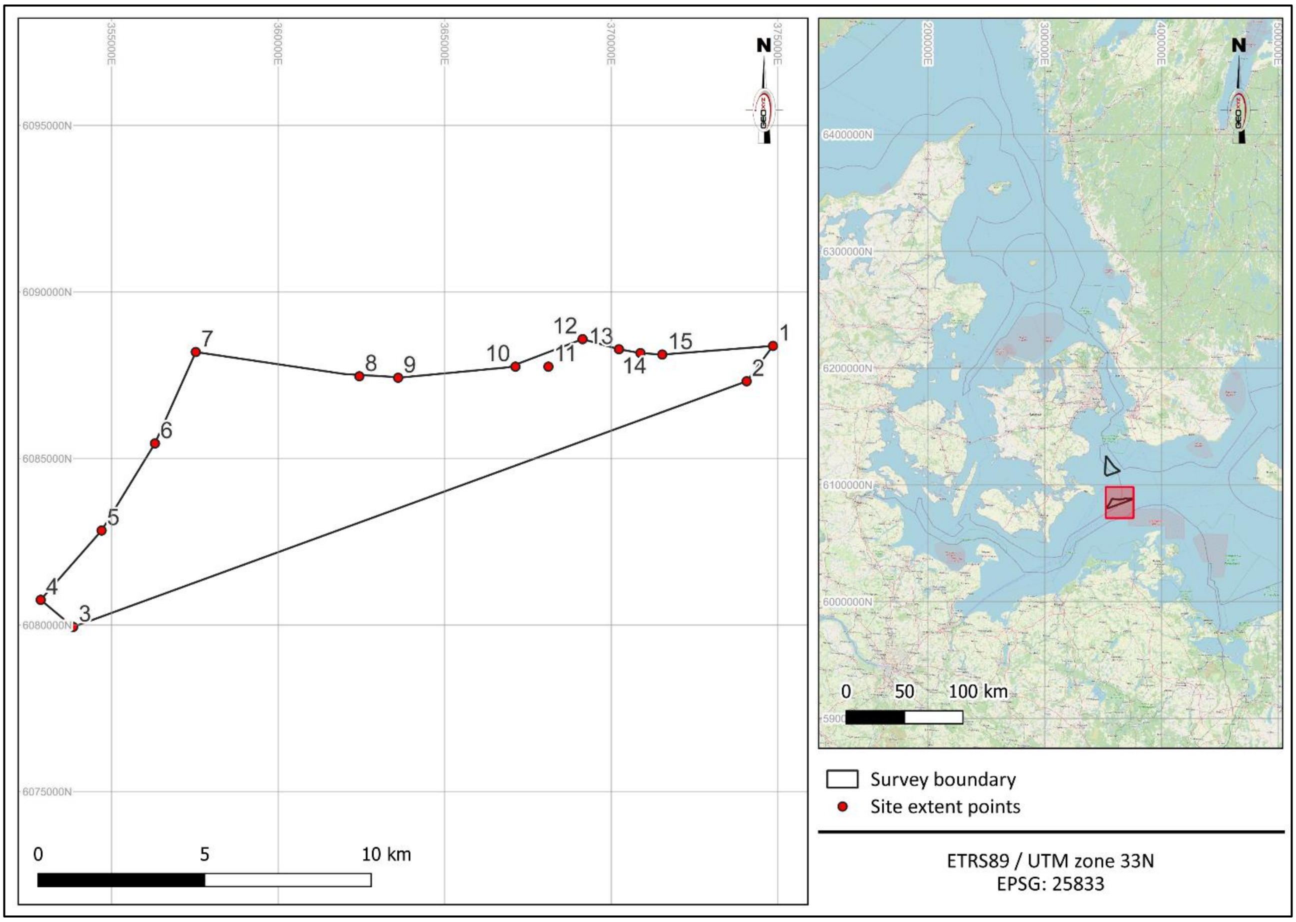


Figure 3: Overview of Kriegers Flak II South (with point IDs corresponding to those in Table 4)

Table 2: Summary of the Kriegers Flak II North and South areas

Site	Region	Survey Area Extent (km²)
Kriegers Flak II North	Baltic Sea	99
Kriegers Flak II South	Baltic Sea	76

Table 3: Kriegers Flak II North site extents

Point ID	Easting EUREF89 Zone 33N (m)	Northing EUREF89 Zone 33N (m)	Longitude EUREF89	Latitude EUREF89
1	353249	6107805	12°42.013'E	55°05.714'N
2	352406	6108773	12°41.192'E	55°06.221'N
3	351492	6109665	12°40.304'E	55°06.685'N
4	352240	6121568	12°40.635'E	55°13.110'N
5	352278	6124191	12°40.589'E	55°14.524'N
6	352472	6124750	12°40.754'E	55°14.829'N
7	359463	6115493	12°47.623'E	55°09.964'N
8	364387	6111923	12°52.360'E	55°08.123'N
9	354306	6108369	12°42.989'E	55°06.036'N

Table 4: Kriegers Flak II South site extents

Point ID	Easting EUREF89 Zone 33N (m)	Northing EUREF89 Zone 33N (m)	Longitude EUREF89	Latitude EUREF89
1	374855	6088381	13°02.824'E	54°55.602'N
2	374063	6087320	13°02.111'E	54°55.018'N
3	353844	6079945	12°43.424'E	54°50.715'N
4	352871	6080758	12°42.490'E	54°51.136'N
5	354699	6082840	12°44.136'E	54°52.289'N
6	356300	6085453	12°45.553'E	54°53.725'N
7	357526	6088197	12°46.617'E	54°55.224'N
8	362437	6087470	12°51.232'E	54°54.915'N
9	363601	6087425	12°52.323'E	54°54.910'N
10	367122	6087758	12°55.607'E	54°55.147'N
11	368112	6087758	12°56.524'E	54°55.326'N
12	369138	6088585	12°57.470'E	54°55.624'N
13	370229	6088281	12°58.499'E	54°55.478'N
14	370875	6088166	12°59.107'E	54°55.425'N
15	371530	6088121	12°59.721'E	54°55.412'N

3.1.4 Existing infrastructure

Existing infrastructure within the survey areas (as provided from the Client's database) is displayed in Figure 4 below. A total of seven known existing cables are crossing the Kriegers Flak North survey area. Two additional unknown linear infrastructure features are intersecting the survey area. Within the Kriegers Flak South site, the C-Lion1 cable is running through the survey area and one unknown infrastructure is crossing the western end of the survey area.

Figure 4: Existing infrastructure crossing the Kriegers Flak II North and South survey areas

3.2 SCOPE OF WORK

The surveys for the geophysical and geological scopes were undertaken using two vessels, Geo Ocean V and Geo Ocean VI. The vessels were mobilised at the end of 2022 and the surveys were undertaken in 2023 for both sites. The surveys achieved full coverage in the areas of investigation and mapped the bathymetry, the static and dynamic elements of the seabed surface, and the sub-surface geological soil layers to at least 100 m below seabed.

3.2.1 Objectives

The results of the survey will be used as basis for:

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

To accomplish these aims GEOxyz:

- Acquired high resolution bathymetric data to ascertain water depth and changes in topography across the sites using multibeam echosounder (MBES) data.
- Acquired high frequency (600 kHz) side scan sonar (SSS) data to identify seabed objects and features.
- Acquired low frequency (300 kHz) side scan sonar (SSS) data to distinguish seabed sediments.
- Acquired magnetometer data to identify cables, pipelines, potential UXOs and other ferrous objects on and below the seabed.
- Acquired high-resolution and 2D ultra high-resolution seismic data, in order 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, high boulder density estimation, etc.

3.2.2 Line planning

For the geological scope, the survey lines comprised of main lines were spaced at 250 m, and cross lines were spaced every 1000 m. Survey lines that were shorter than 4 km were extended outside the survey area to obtain this minimum length. Orientation of survey lines were determined to acquire main lines predominantly along the long axis of the site where this is apparent. Figure 5 and Figure 6 show schematic diagrams of the line plan for the geological scope for the Kriegers Flak II North and South area, respectively.

In Kriegers Flak II North and South, national borders were crossed in order to complete the survey lines. During the campaign, restrictions for sound emissions in non-Danish waters were lifted, however there is a requirement for data acquired in non-Danish waters to be deleted post-acquisition.

The Falsterbo traffic separation scheme is in place alongside approximately 3 km of the north-western edge of the Kriegers Flak II North work site. To mitigate restrictions and maximise coverage in this area, cross lines coincident with the traffic separation scheme have been replaced by an oblique survey line which remains outside of the separation zone. Due consideration will be given to marine traffic in the area when determining the safest and most efficient direction of survey for operations.

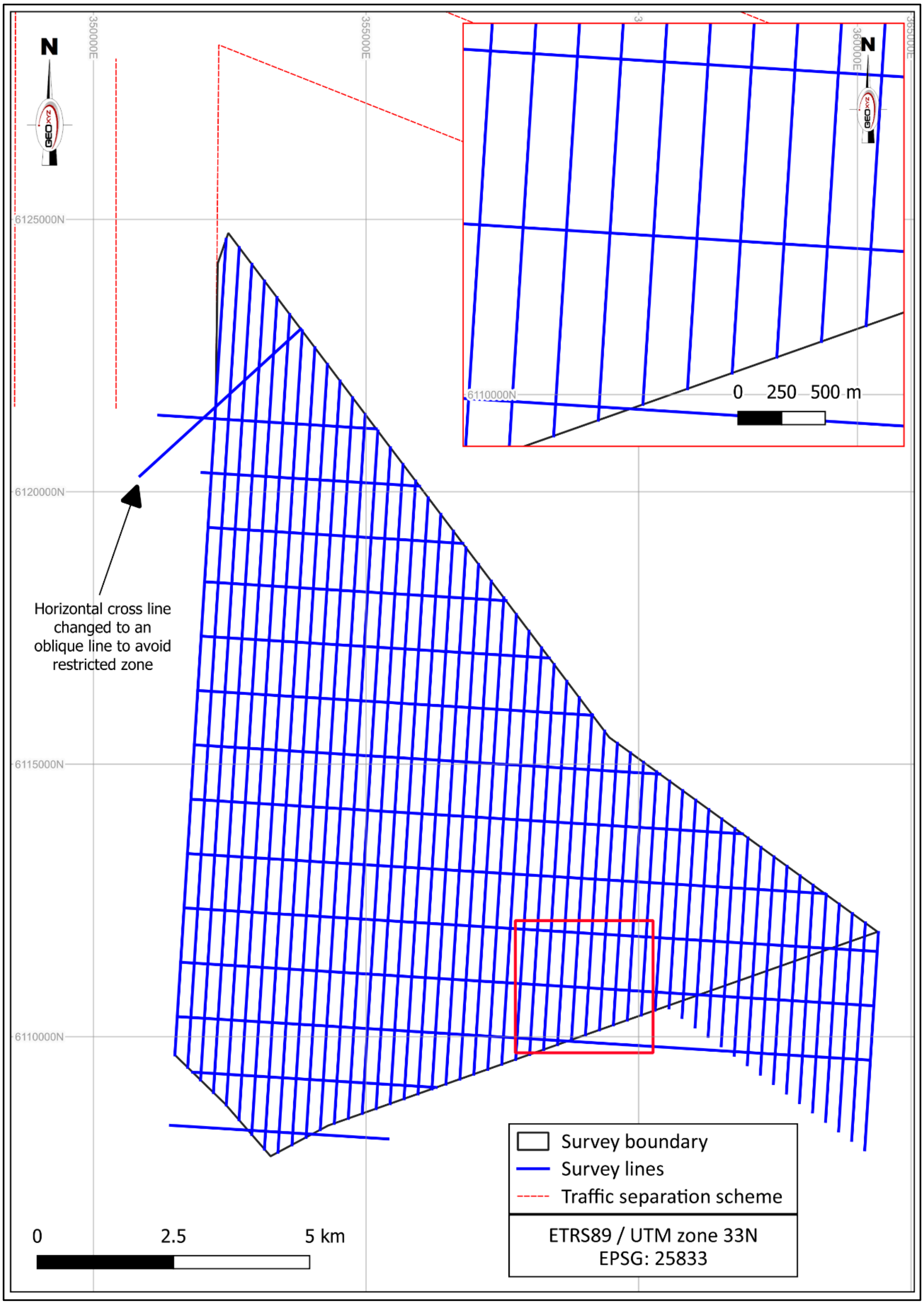


Figure 5: Kriegers Flak II North geological scope line plan (traffic separation scheme in red dash)

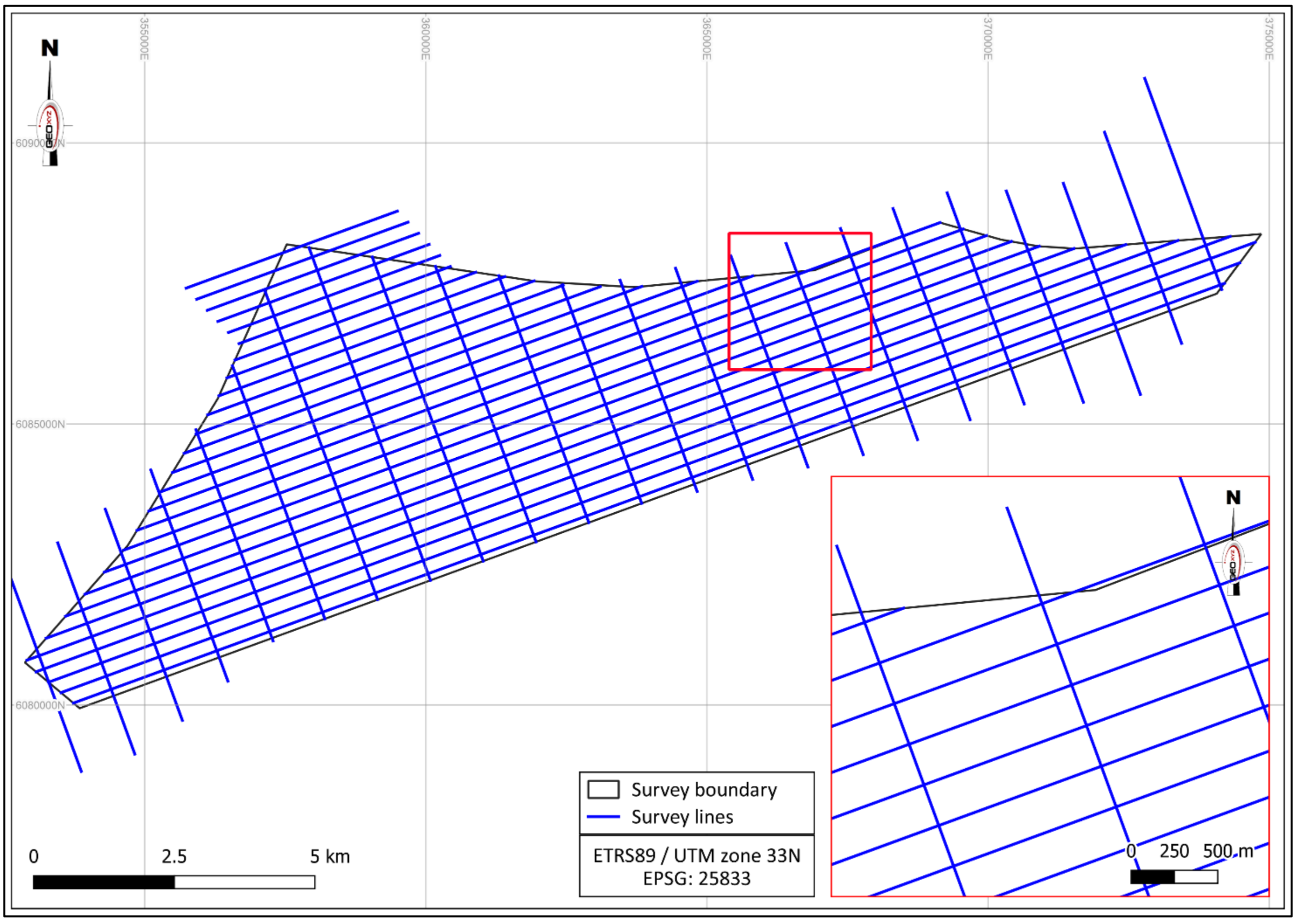


Figure 6: Kriegers Flak II South geological scope line plan

For the geophysical scope, the survey lines are spaced at 62.5 m apart, oriented predominantly along the long axis of the site where this is apparent. Figure 7 and Figure 8 show schematic diagrams of the line plan for the geophysical scope for the Kriegers Flak II North and South area, respectively.

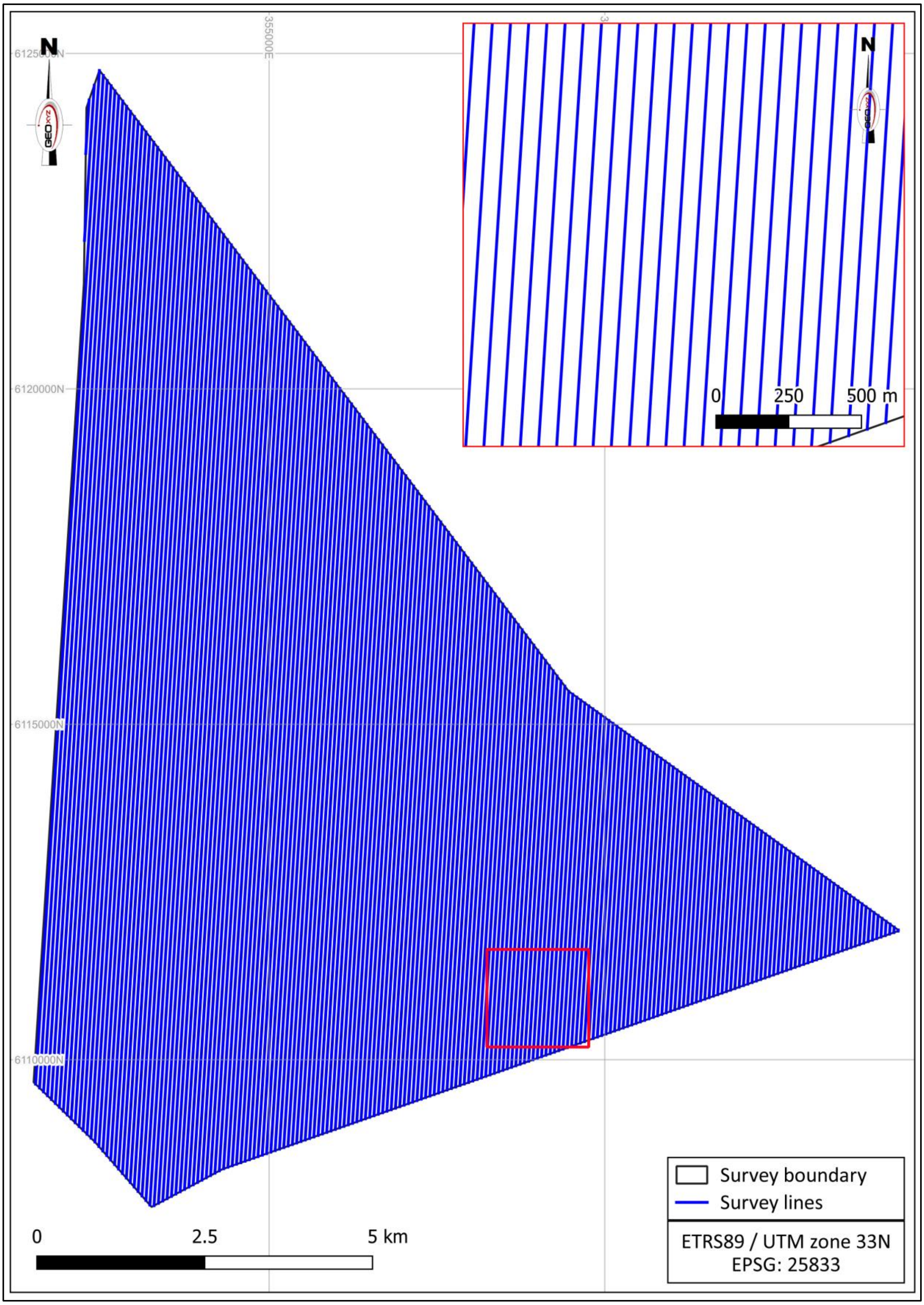


Figure 7: Kriegers Flak II North geophysical scope line plan

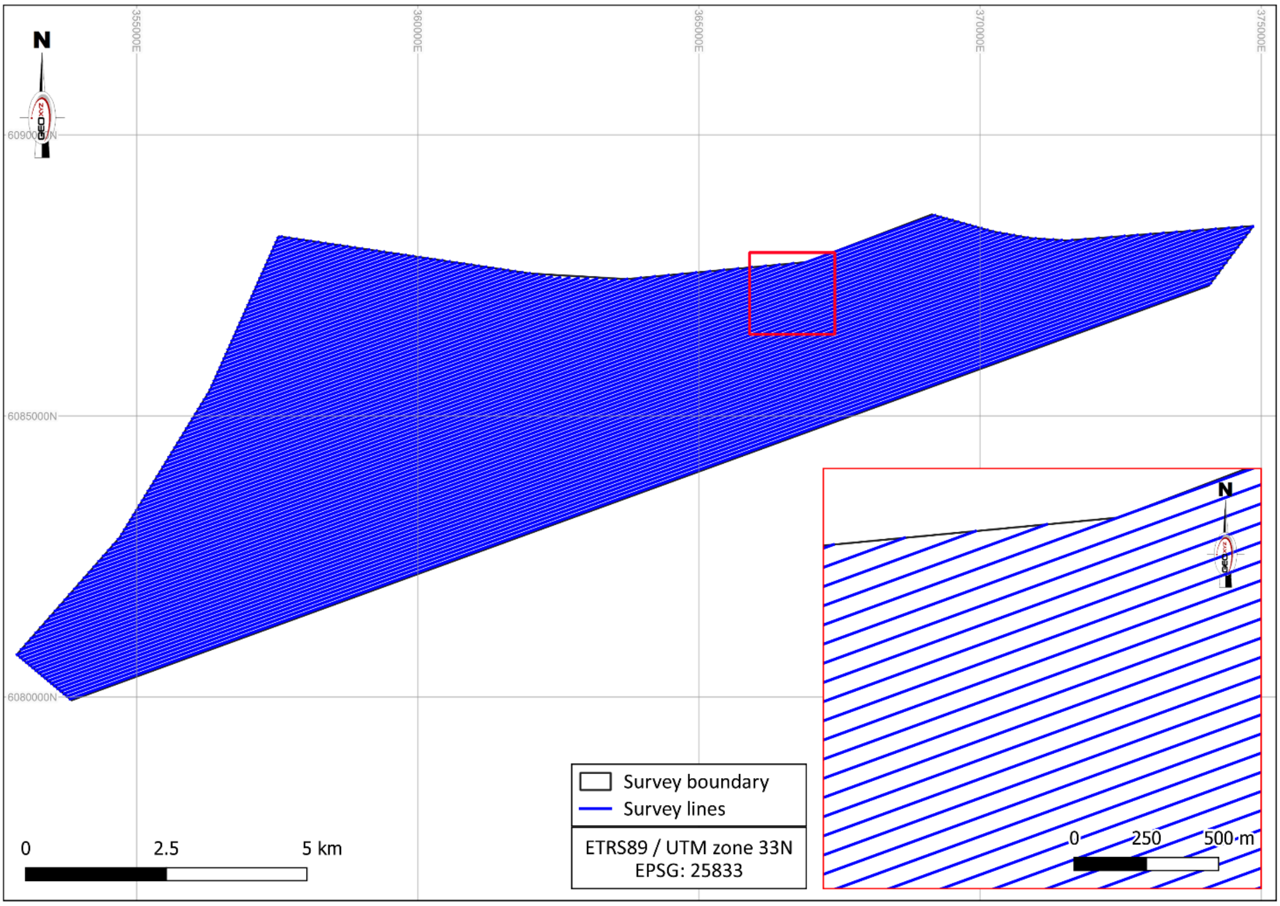


Figure 8: Kriegers Flak II South geophysical scope line plan

The Client specification and survey overview are detailed in Table 5.

Table 5: Client specifications and survey overview

Equipment	Specification	Survey Requirement
Vessels	Multi-vessel operations	Geo Ocean V (GOV) and Geo Ocean VI (GOVI)
Line Planning	Main Lines geological scope	Spaced at 250 m
	Cross Lines geological scope	Spaced at 1000 m
	Main Lines geophysical scope	Spaced at 62.5 m
	Cross Line geophysical scope	none
MBES Bathymetry/ Backscatter	Data density	16 hits/m^2 on 99 % of site
	Standard Deviation	0.20 m on 95 % of the site
	MBES Mode	Equidistant
	Gridded	0.25 m cell size
	Coverage	100 %
Side Scan Sonar	Resolution sufficient for detecting seabed object/features	0.5 m (length, width and height)
	Towing altitude	8 - 12 % of range (optimised for data quality)

Equipment	Specification	Survey Requirement
	Positional accuracy	± 2 m (using vessel course-over-ground and USBL)
	Operating mode	High Definition Mode
	Range	70 m
	Coverage	200 %
Magnetometer	Seabed altitude	≤ 3.0 m
	Measurement sensitivity	0.02 nT
	Sampling frequency	≥ 10 Hz
	Noise level	≤ 2 nT
	Coverage (in areas of operation)	100 %
Sub-Bottom Profiler	Penetration	10 m
	Vertical resolution	0.3 m
	System	Innomar SES 2000 or similar
2D Ultra High Resolution	Fundamental frequency	Between 1 and 3 kHz
	Vertical resolution	0.3 m to 40 m depth; 0.5 m to 100 m depth
	Minimum Penetration	100 m
	Fire rate	2 pulses/second
	Feather angle	<12° during 95 % of the shots
	Streamer depth	As per last PEP rev 1.4: 1.0 m ±0.5 m (although primarily determined by weather and data quality)
	Other acquisition parameters (dropped channels, noise threshold etc)	Source depth: 0.4 m ± 0.1 m. Noise thresholds: - Random noise: 7 µB (10 µB near/far traces & depth controller locations. - Coherent Noise ahead/astern: 15 µB. - Coherent noise abeam: 5 µB. Dropped bad shots threshold: No dead channels in the near 6 channels and a maximum of 2 non-consecutive dead channels from channel 6 to the far channel. Dropped/bad channels threshold: ≤ 2 channels.
	Variable energy levels	Between 100 and 1000 Joules
	System	A suitable multi-channel and multi-element hydrophone streamer with depth control plus depth measurement for continuous monitoring and recording of streamer depth

3.2.3 Parties involved

The parties involved in the project are represented by the organogram given in Figure 9.

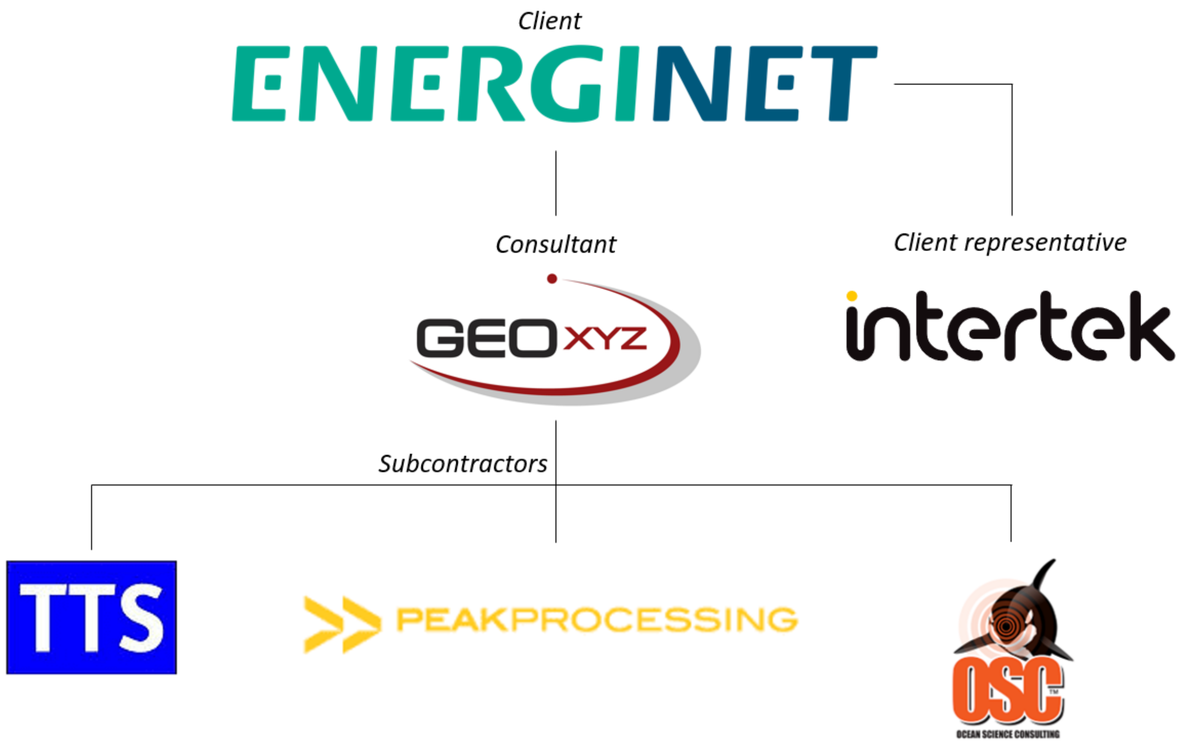


Figure 9: Parties involved in the project

3.3 REFERENCE DOCUMENTATION

Key project documentation from the Client is listed in Table 6.

Table 6: Reference documentation

Ref.	Document Number	Title	Owner
1.	22/02940-1	Scope of Services	Client
2.	22/02940-2	Scope of Services – Enclosure 1 – Technical Requirements	Client
3.	22/02940-5	Scope of Services – Enclosure 2 – Standards of Deliverables	Client
4.	22/02940-3	Scope of Services – Enclosure 3 – HSE Requirements	Client
5.	22/02940-4	Scope of Services – Enclosure 4 – Quality Management Requirements	Client
6.	16/19566-2	Requirements to TSG	Client
7.		TQ system (Energinet SharePoint site)	Client

Details on the conducted calibrations prior to the start of the survey and the operational aspects of the survey, including resources, event logs, etc., can be found in the Mobilisation and Calibration Report and the Operations Report, respectively. Information on the processing workflow and the interpreted results of the geophysical and geological datasets of the survey for the geological and geophysical scope on the Kriegers Flak II North and South sites are presented in this report.

Table 7 lists all the reports delivered as part of this survey, with this report highlighted in **bold**.

Table 7: Project reports

Ref.	Report Document Number	Title	Type of Report
8.	BE5376H-711-MCR-01	Mobilisation and Calibration Report Geo Ocean V	Mobilisation and Calibration Report
9.	BE5376H-771-MCR-02	Mobilisation and Calibration Report Geo Ocean VI	Mobilisation and Calibration Report
10.	BE5376H-711-OR-01	Operations Report geological scope	Operations Report
11.	BE5376H-711-OR-03	Operations Report geophysical scope	Operations Report
12.	**BE5376H-771-03-RR**	**Kriegers Flak II North and South Geophysical and Geological Report**	**Results Report**

4 GEODETIC PARAMETERS AND TRANSFORMATIONS

4.1 HORIZONTAL DATUM

The datum parameters for the survey are described in Table 8 and the projection parameters are given in Table 9.

Table 8: Datum parameters

Parameter	Details
Name	European Terrestrial Reference System 1989 (ETRS89)
EPSG Datum Code	6258
EPSG Coordinate Reference System	4258
Spheroid	GRS80
EPSG Ellipsoid Code	7019
Semi-Major Axis	6378137.000
Semi-Minor Axis	6356752.314140
Flattening	1/298.2572221010
Eccentricity Squared	0.00669428002290

Table 9: Projection parameters

Parameter	Details
EPSG Coordinate Reference Code	25833
EPSG Map Projection Code	16033
Projection	UTM
UTM Zone	33N
Central Meridian	15° East
Latitude of Origin	0°
False Easting	500000.00 m
False Northing	0.00 m
Scale Factor at Central Meridian	0.9996
Units	Metres

4.2 VERTICAL REFERENCE

The vertical datum for the project is Mean Sea Level (MSL) as defined by the Technical University of Denmark geoid model DTU21MSL. Height data was acquired relative to the ellipsoid and reduced to the project vertical datum. All reported depths in the current report are related to DTU21MSL.

4.3 TIME REFERENCE

The time frame set up in all survey systems on board the vessel as well as the reported time in any official form and document is provide in Coordinated universal time (UTC).

Online displays, overlays and logbooks are annotated in UTC as well as the daily progress report (DPR) and the Daily Processing Progress report (DPPR).

The synchronisation of the survey system is controlled by the ZDA NMEA time and date and the pulse per second (PPS) issued by the primary positioning system.

5 SURVEY RESOURCES

5.1 SURVEY VESSELS

For the geological and geophysical scopes, the survey vessels Geo Ocean V (GOV) and Geo Ocean VI (GOVI) were utilised to complete the work across the two sites. Both vessels are 54 m and equipped to perform a range of subsea surveys in the offshore renewables, and the oil and gas industries. Additionally, they can both operate 24 hours/day and can remain at sea for up to four weeks. The specifications of the GOV and GOVI are summarised in Table 10.

Table 10: Survey vessel specifications

Feature	Geo Ocean V	Geo Ocean VI
Owner:	GEOxyz	GEOxyz
Flag:	Luxembourg	Luxembourg
Length:	53.8 m	53.8 m
Width:	13.0 m	13.0 m
Draught:	4.0 – 4.8 m	4.8 m
Speed:	10 knots (cruising)	11 knots (cruising)
Main Propulsion:	Hybrid propulsion CP-propeller	Hybrid propulsion CP-propeller
Endurance:	28 days	28 days
Accommodation:	24	24
Positioning:	DGPS, HiPaP351 USBL	DGPS, HiPaP352P USBL NAVIS NavDP 4000
A-Frame:	10t Stern	13t Stern
Image of the vessel		

5.2 EQUIPMENT AND SOFTWARE

Details on the survey equipment used for this project onboard the GOV and GOVI are listed in Table 11 and Table 12, respectively.

Table 11: GOV survey equipment specifications

System	Manufacturer – Model	Equipment Specifications
GNSS	Trimble BX992 & BD982 (2x G4 corrections)	RTK: < 0.05 m; DGNSS: <0.10 m
INS (motion, heading)	IXBlue Octans V SBG Apogee Navsight	H: 0.1°; R&P: 0.01°; Heave: 5 cm H: 0.01°, R&P: 0.03°, Heave: 5 cm

System	Manufacturer – Model	Equipment Specifications
SVP	Valeport Swift	0.02 m/s
MBES	Kongsberg EM2040 Dual Rx, Dual ping	Freq: 200 – 400 kHz Focus: 0.4° x 0.7° at 400 kHz
USBL	Kongsberg HiPAP 351P	0.02 m range detection accuracy or < 0.3% of slant range
Magnetometer	Geometrics G882	Accuracy: < 2 nT throughout range. Freq: up to 40 Hz
SSS	2x Edgetech 4200 (300/600 kHz)	Horizontal beamwidth: 0.5° @ 300 kHz, 0.26° @ 600 kHz Resolution Across Track: 3 cm @ 300 kHz, 1.5 cm @ 600 kHz
SBP	Innomar SES-2000 Medium	2-22 kHz 1-5 cm resolution

Table 12: GOVI survey equipment specifications

System	Manufacturer – Model	Equipment Specifications
GNSS	2x Trimble BX992 (1 x XP2 and 1 x G4 corrections)	RTK: < 0.05 m; DGNSS: <0.10 m
INS (motion, heading)	IXBlue Hydrins SBG Apogee Navsight	H: 0.01°; R&P: 0.01°; Heave: 5cm H: 0.01°, R&P: 0.03°, Heave: 5cm
SVP	Valeport Swift	0.02 m/s
MBES	Kongsberg EM2040 MKII Dual head, Dual swath	Freq: 200 – 400 kHz Focus: 0.4° x 0.7° at 400 kHz
USBL	Kongsberg HiPAP 352P	0.02 m range detection accuracy or < 0.3% of slant range
Magnetometer	Geometrics G882	Accuracy: < 2 nT throughout range. Freq: up to 40 Hz
SSS	2x Edgetech 4200 (300/600 kHz)	Horizontal beamwidth: 0.5° @ 300 kHz, 0.26° @ 600 kHz Resolution Across Track: 3 cm @ 300 kHz, 1.5 cm @ 600 kHz
SBP	Innomar SES-2000 Medium	2-22 kHz 1-5 cm resolution

The primary software that was used to acquire and process the data is listed in Table 13.

Table 13: Primary software list

Type	Software	Related equipment
Acquisition	QPS QINSY	Navigation, MBES, GNSS, SSS, MAG
	Edgetech Discover	SSS Edgetech
	Innomar SESwin	SBP
Processing	Beamworx Autoclean	MBES
	QPS Qimera	MBES
	QPS FMGT	Backscatter
	Sonarwiz	SSS
	Oasis Montaj	MAG
	Kingdom or Silas	SBP
	ProMAX	2D UHR (processing)
	Kingdom	2D UHR (Interpetation)
	QGIS / AutoChart / ArcGIS	SSS, MBES, MAG, SBP

6 TECHNICAL QUERIES AND CHANGES TO SURVEY SCOPE

Geological, oceanographic, and technical site limitations resulted in necessary adjustments to the survey scope. These survey scope adjustments were made as Technical Queries (TQs) and were checked and validated by the Energinet (Client) and by GEOxyz. Table 14 outlines the project specific TQs related to the geophysical and geological scope. Below the table, their implications for the survey are outlined.

Table 14: Overview of the Technical Queries

TQ ID	Subject	Outcome
TQ - 004	SBP Interpretation geophysical scope	Where homogeneous geology is interpreted on SBP lines of the geophysical survey, interpretations are performed on every 2nd line
TQ - 007	Geological scope Kriegers Flak II North line plan v01	Line plan v01 was agreed by the Client.
TQ - 009	Boulder Field Criteria geophysical scope	Picking criteria within in boulder fields targets: Boulders ≥ 2 m in any direction & "Non-geological contacts" ≥ 0.5 m in any direction
TQ - 010	SSS nadir coverage	SSS Coverage of 200% acquired at entire site, except area affected by pycnocline effects

7 DATA PROCESSING AND INTERPRETATION METHODS

7.1 MULTIBEAM ECHOSOUNDER

7.1.1 Data acquisition

The system settings and Client specifications for the project are listed in Table 15 and Table 16, respectively.

Table 15: MBES system settings

Kongsberg EM2040 (DH/DSW)	Head 1 port	Head 2 stbd
Survey speed	Average 4 knots	
Frequency	400 kHz	400 kHz
Bottom sampling	High Density Dual Swath (1024 beams)	
Range	50 m	
Power	Maximum	
Pulse length	Auto	
Patch test roll	*TX -0.205.°, RX -40.005°*	*TX -0.270°, RX 42.530°*
Patch test pitch	*TX 0.340°, RX 0.340°*	*TX 0.242°, RX 0.242°*
Patch test heading	*TX –2.238°, RX 177.762°*	*TX -2.345°, RX 177.655°*
Sector width	80º	80º
Ping rate	25 Hz – 30 Hz (maximum)	

Table 16: MBES Client specifications

Item	Specification
Data density	16 hits/m^2 at 99 % of the site.
Standard Deviation	0.20 m on 95 % of the site.
MBES Mode	Equidistant
Grid	0.25 m cell size
Coverage	100 %

In TQ 008- MBES, it was requested and agreed to increase the MBES SD limit to 0.25 on 95 % of the site and to modify the hit count specifications to the following: A minimum of 99 % of site will show a hit count of at least 16 hits/m.

7.1.2 MBES methodology

The objective of the MBES processing workflow was to create a final digital terrain model (DTM) that provided the most realistic representation of the seabed.

The processing workflow is comprised of four general steps, which are summarized in the tables below:

Table 17: Loading MBES data in Qimera

Step 1	Load MBES data into Qimera
Set Up Project	Load in RAW multibeam files (*.db) as recorded by QINSy in a new project Grid cell size 0.25 m * 0.25 m
QC of coverage	Check completeness of data by cross-referencing the imported files with the Survey Log

Table 18: MBES positioning verification

Step 2	Positioning
All verification during the Positioning control was performed by checking the data with the 95% confidence option	
SVP correction	Applying the last SVP done into the data set
Overall statistics	Run Standard Deviation statistics. The standard deviation must be < 0.25 m
Verify horizontal positioning and Total Horizontal Uncertainty (THU)	Create a dynamic surface at 0.20 m. A .xyz file with THU values can be exported or a static surface can be created with THU values in it. The surface needs to be updated and a new export can be done (for the 24 hours QA deliverables)
Verify vertical positioning and Total Vertical Uncertainty (TVU)	Create a dynamic surface at 0.20 m. A xyz with TVU values can be exported or a static surface can be created with TVU values in it. The surface needs to be updated and a new export can be done (for the 24 hours QA deliverables)
FAU export	FAU files export to finalise the processing in BeamWorx Autoclean processing software (separate export per head)

Table 19: MBES data de-spiking and processing

Step 3	Data de-spiking
Quality assessment and data correction/filtering	Refraction and vertical mismatch issues due to pycnocline to be assessed and filtered when possible. Outer ranges to be trimmed when data cannot be properly filtered.
Manual De-spiking	Remove remaining substantial spikes manually using the 2D and 3D views. Correct where necessary
Filter De-spiking	Filters applied to de-spike the data
Coverage reassessment (SD and Hit count)	Coverage and specifications reassessment after processing

Table 20: MBES data quality control

Step 4	Quality Control
Shallowest/Deepest Areas	Special attention is needed for these areas to verify all spikes are removed.
Check for steps in data	Change plan view to the mean depth colour data to verify no steps are present in the data.
Statistics Control	Final statistics exports per block/area to track and save the final specifications.

Table 21: MBES target picking

Step 5	MBES target picking
Target picking	Targets picked manually in Qimera from the grid

The MBES data was initially brought into QPS processing software Qimera, to check that the coverage and density requirements were achieved before any further steps were taken. It was confirmed that a post-processed navigation solution was not necessary, as the dynamic PPP applied online provided the vertical and horizontal accuracy necessary for the survey. THU and TVU values were checked and confirmed to be within the specifications defined for the dataset. The DTU21MSL vertical model applied in QINSy online was confirmed to properly reduce the ellipsoidal heights to the project vertical datum. Subsequently, in Qimera, the bathymetry data for each data file is merged to create a dynamic surface, to review the standard deviation and sounding density results.

After this preliminary check and after confirmation that the data was within the project specifications, the process of removing outlying soundings, refraction and SVP corrections, as well as the refined cleaning routine, was performed.

The last step of processing was carried out in Autoclean, as it has been proven that, if no further processing was needed in the data coming from QINSy (post processing, computation recalculation, misalignments adjustments…), the Beamworx software manages high amounts of MBES data more quickly, which made the cleaning process more efficient and faster. In addition, it allows a more detailed statistical analysis to be performed at the end of the processing process.

Finally, MBES target picking was carried out after processing using the automatic tool in BeamWorx Autoclean software. Targets were detected based on a reference grid, which automatically measures the targets in Length x Width x Height. The detection process is fully automated and based on input parameters. These parameters could change per area depending on data quality, target numbers, size, and seabed complexity, but always in accordance with the specification of the project relative to minimum size and their interpretation as per TSG requirement. Detection and accuracy are greatly dependent on data quality. Artefacts such as thermocline, vertical alignment and complex morphology could impact the detectability of potential targets.

After running the detection process, a manual QC was conducted and any amendment were applied if needed e.g. false positives are removed, false negatives are added, and target dimensions were adjusted manually if required. The automated routine combined with a manual QC gave this output a reliable result.

Finally, a target correlation was done with the SSS and MAG contacts, and a final QC was done to ensure consistency on the target classification across the sites.

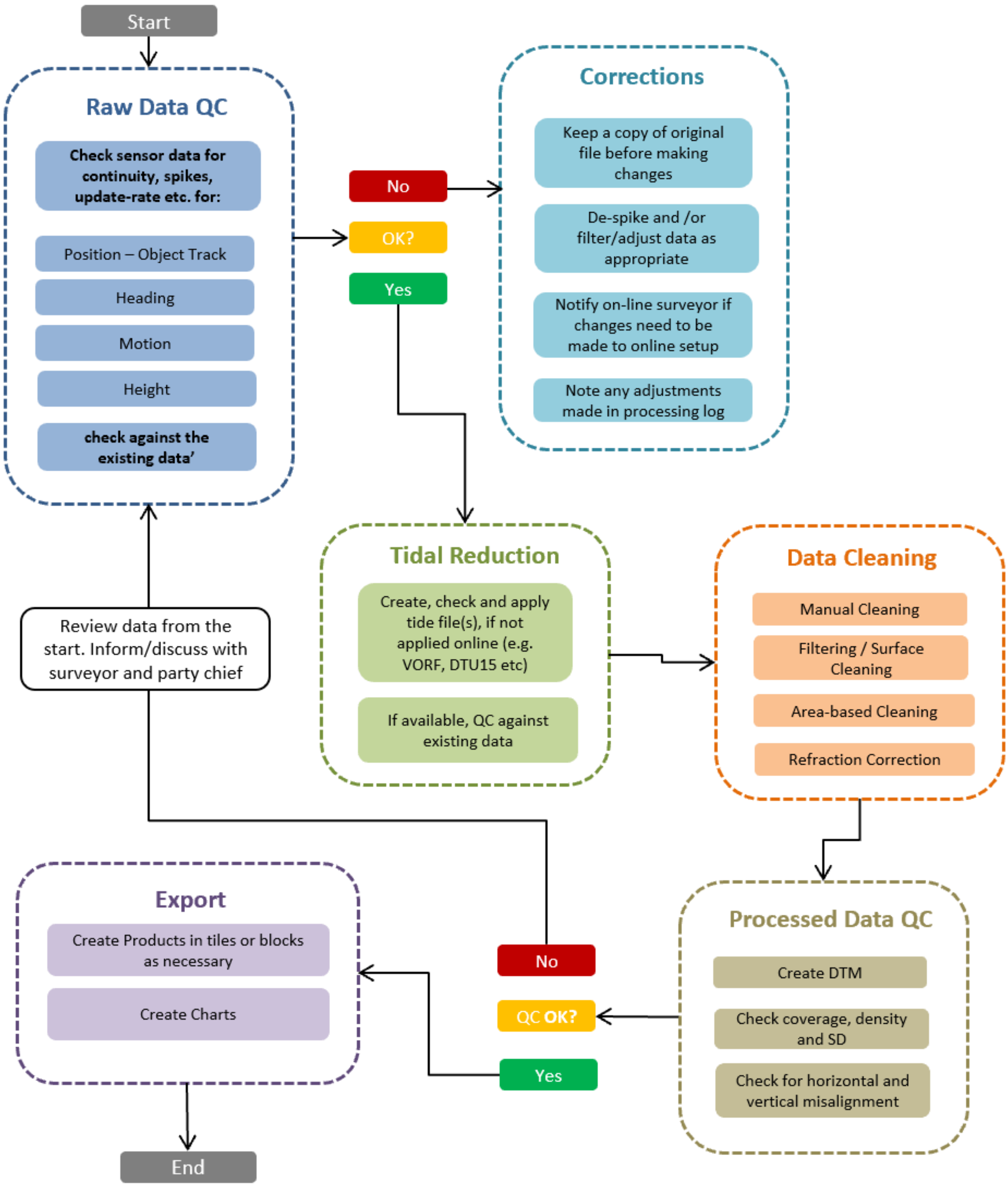


Figure 10: General MBES data processing workflow

7.1.3 Backscatter methodology

The backscatter data were processed and exported, using QPS Fledermaus GeoCoder Toolbox (FMGT) software.

Backscatter processing was carried out on the fully cleaned and processed MBES data files, from previous steps in the Qimera software. Combined GSF (both heads exported in the same file) were exported and then imported in FMGT along with a MBES reference surface.

The gain was modified to normalize the intensity over the survey area. It was also optimized to enhance changes in seabed sediment composition and morphological features on the seafloor.

Data from both vessels (GOIV and GOV) were processed in the same FMGT block projects to optimize the blending of overlapping data from the two vessels.

7.1.4 Data quality assessment

IHO Standards for Hydrographic Surveys define a maximum THU value of 2 m for a First Order Survey, and a 100 % of the THU values for Kriegers Flak II North & South are below this limit. In case of TVU, the maximum limit is defined by a relation between the uncertainty that varies with the depth and the uncertainty not dependent of the depth. For Kriegers Flak II North and South, a theoretical mean TVU max calculated for the sites is 0.65 m, being all TVU values below this theoretical limit. The TVU and THU values must be understood as an interval of ± the stated value. The TVU coverage maps for Kriegers Flak II North and South are displayed in Figure 11 and Figure 12, respectively. The THU coverage maps for Kriegers Flak II North and South are displayed in Figure 13 and Figure 14, respectively.

Figure 11: TVU coverage map Kriegers Flak II North

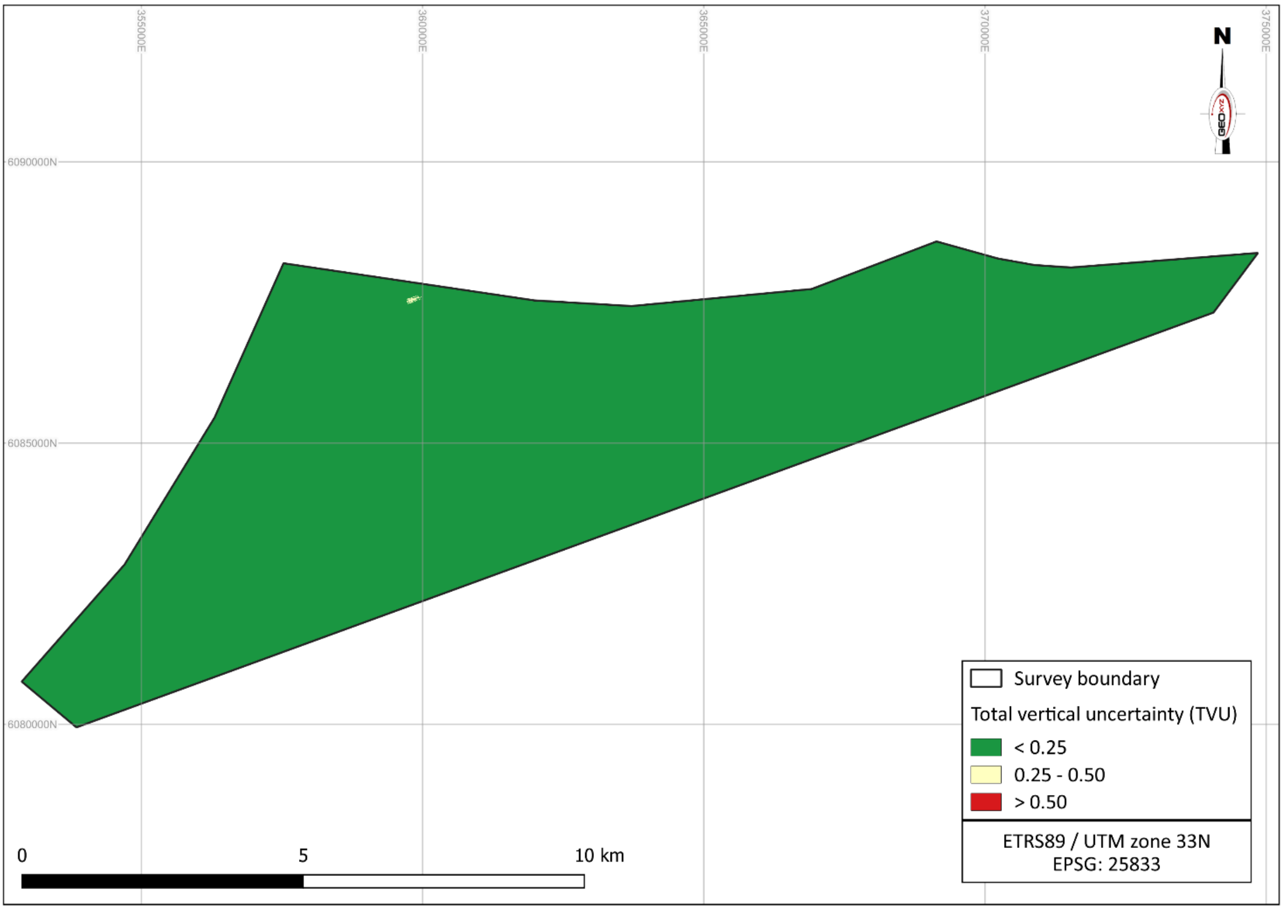


Figure 12: TVU coverage map Kriegers Flak II South

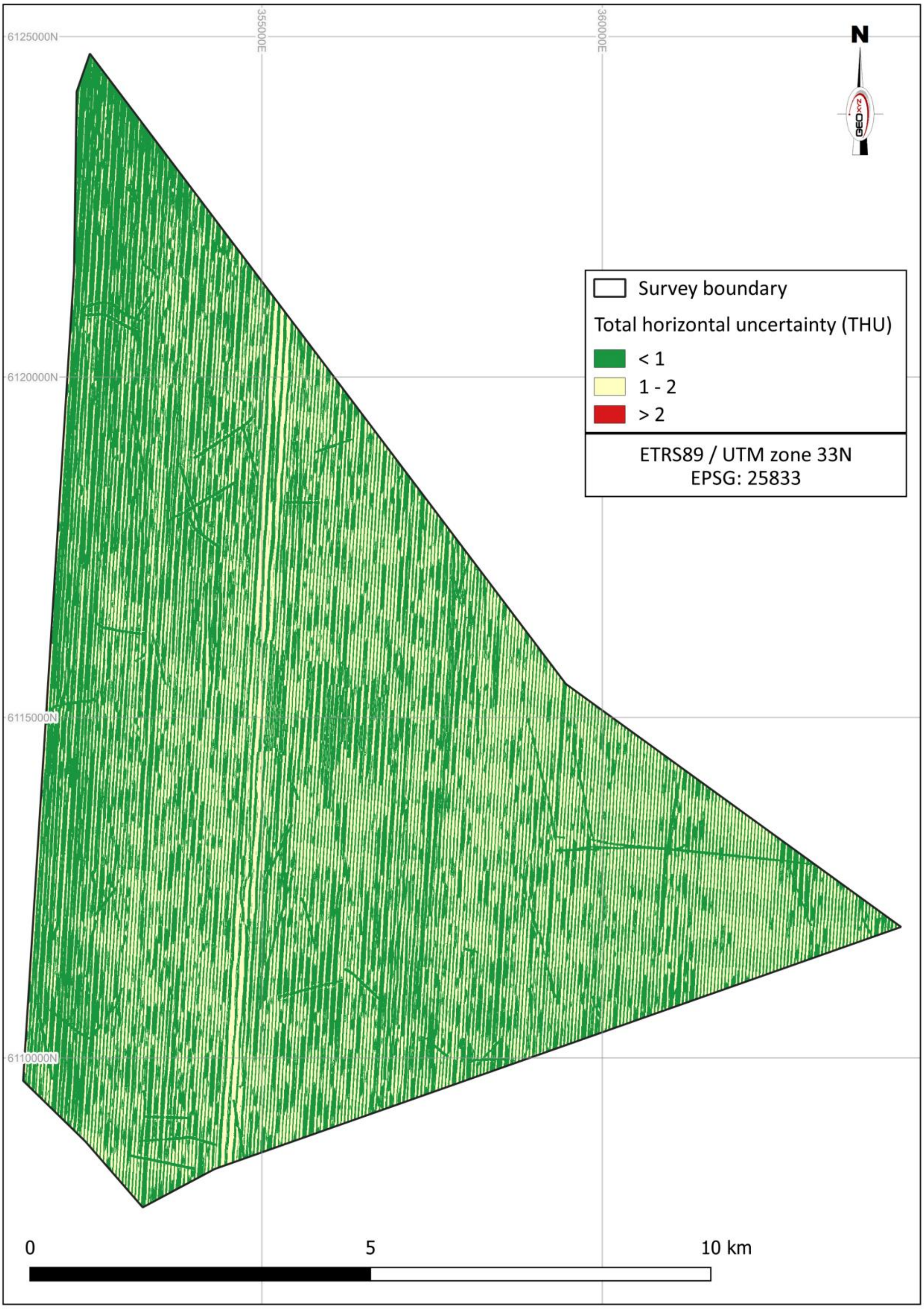


Figure 13: THU coverage map Kriegers Flak II North

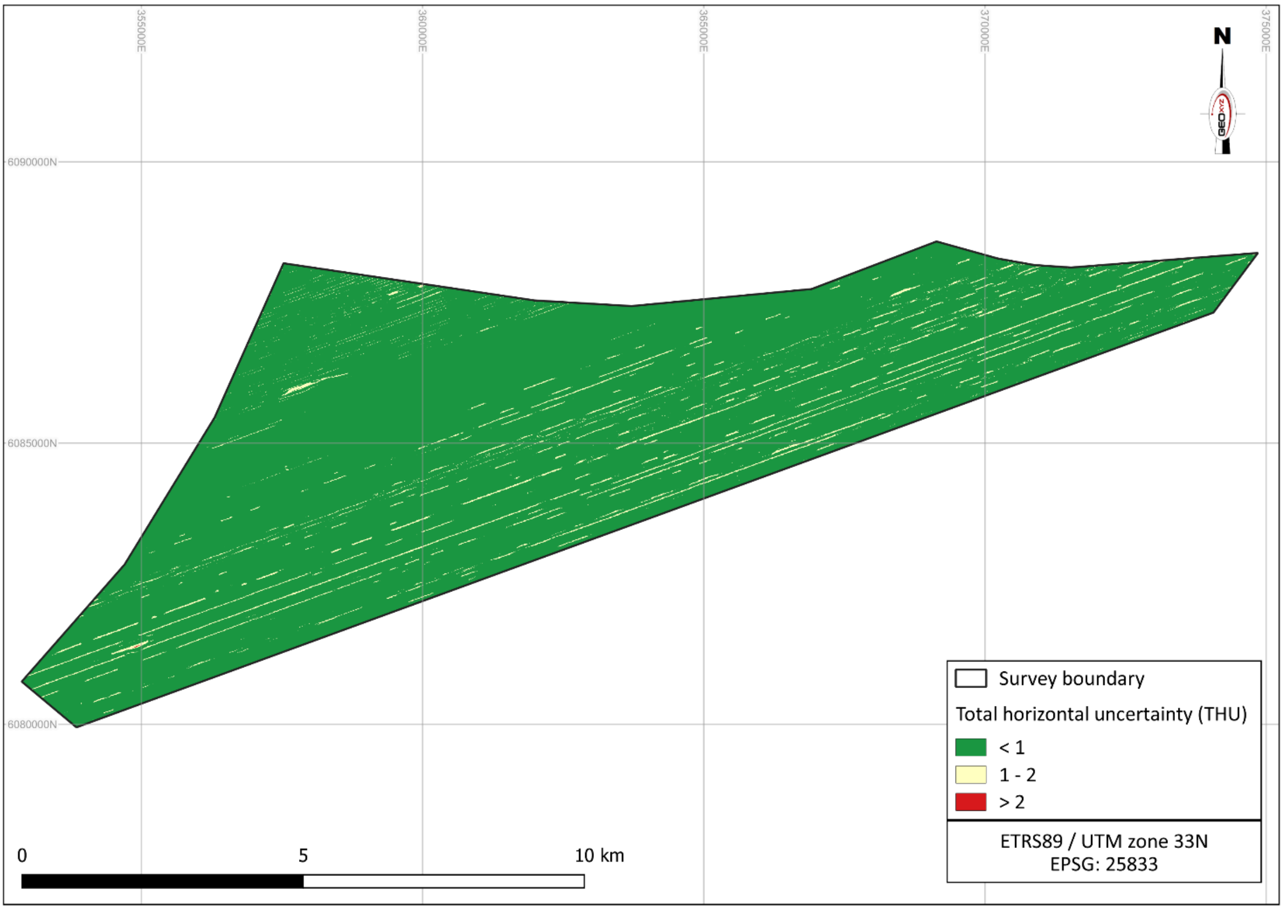


Figure 14: THU coverage map Kriegers Flak II South

The quality of the final processed backscatter was assessed in GIS software (QGIS and Global Mapper) after combining all processed blocks in one gridded surface as 1 m resolution backscatter mosaic (Figure 15 and Figure 16).

The aim of processing the backscatter data was to achieve a homogeneous colour scale between the survey blocks. The colour scale was normalised between blocks. This step was necessary, as it is not possible to process the entire survey area into a single mosaic due to the size of the dataset and the resolution specifications.

The backscatter mosaic assessment indicated that the boundaries between different sediment types were differentiated and therefore the results were fit for purpose.

Some artefacts are present which mostly manifest as stripes aligned with the survey line direction (Figure 17 and Figure 18). These artefacts also appear to be exacerbated during periods of poor weather. The MBES acquisition setup was preferential to the backscatter one.

Despite the presence of these artefacts, the backscatter data is of sufficient quality to derive sediment boundaries and aid the interpretation of the SSS dataset.

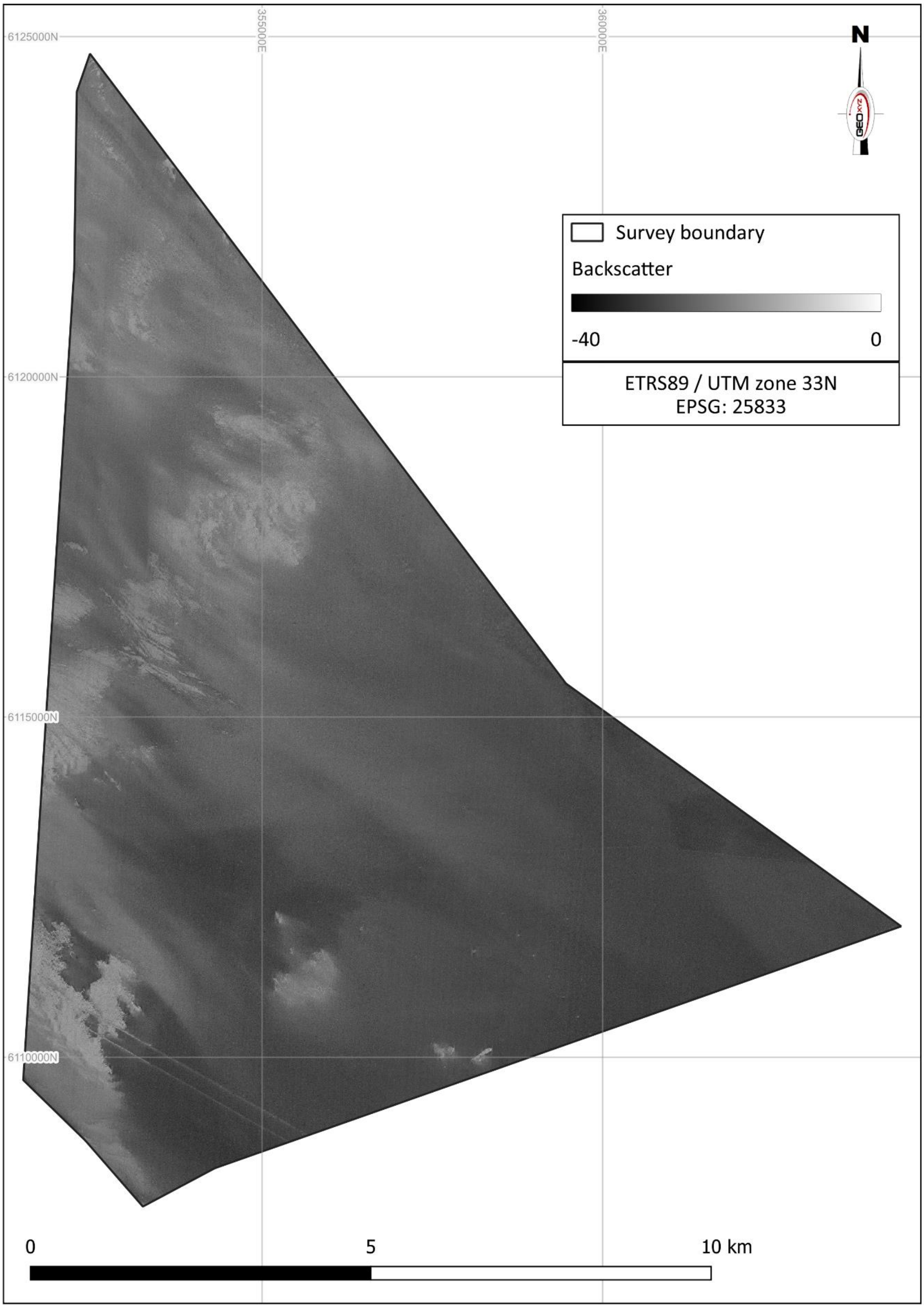


Figure 15: Backscatter map of Kriegers Flak II North

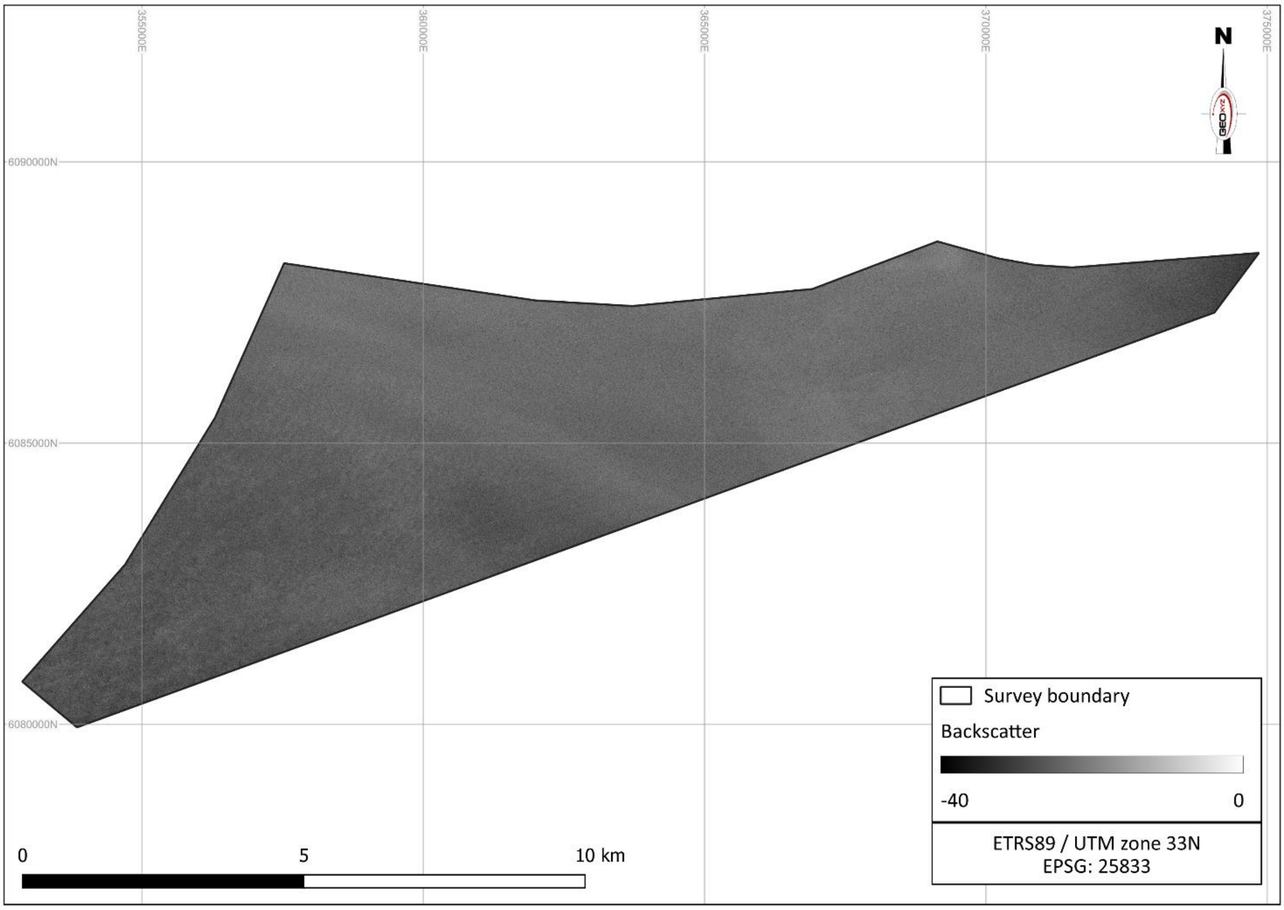


Figure 16: Backscatter map of Kriegers Flak II South

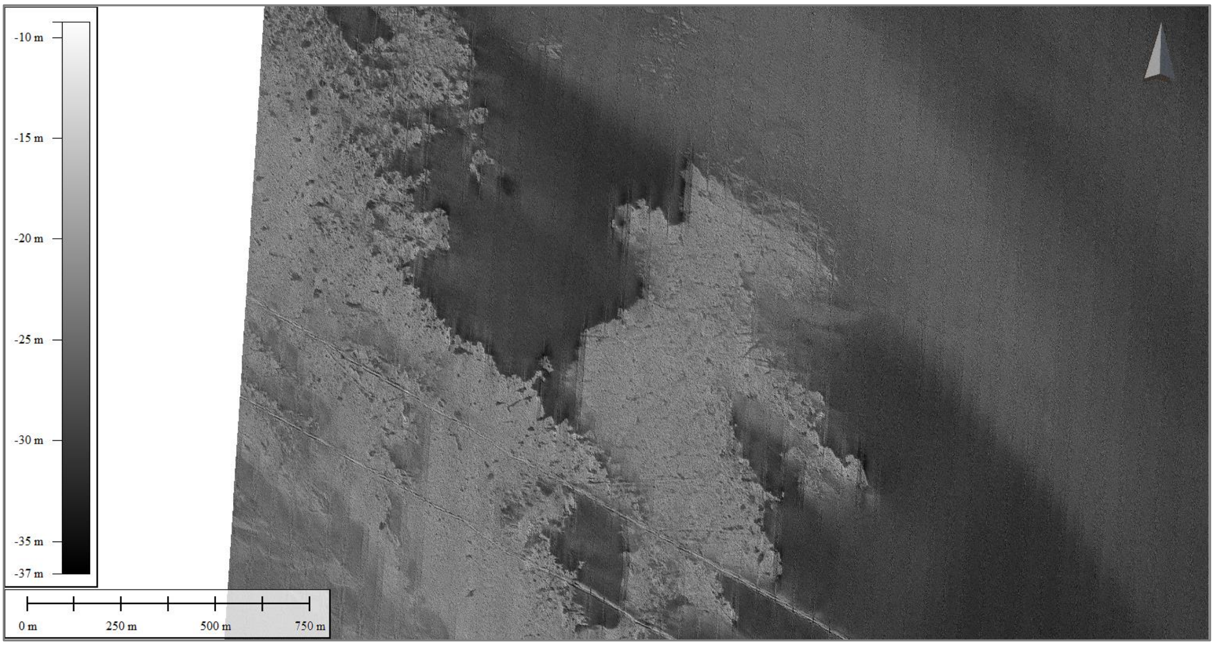


Figure 17: Example of stripe effect on the backscatter mosaic within the Kriegers Flak II North site

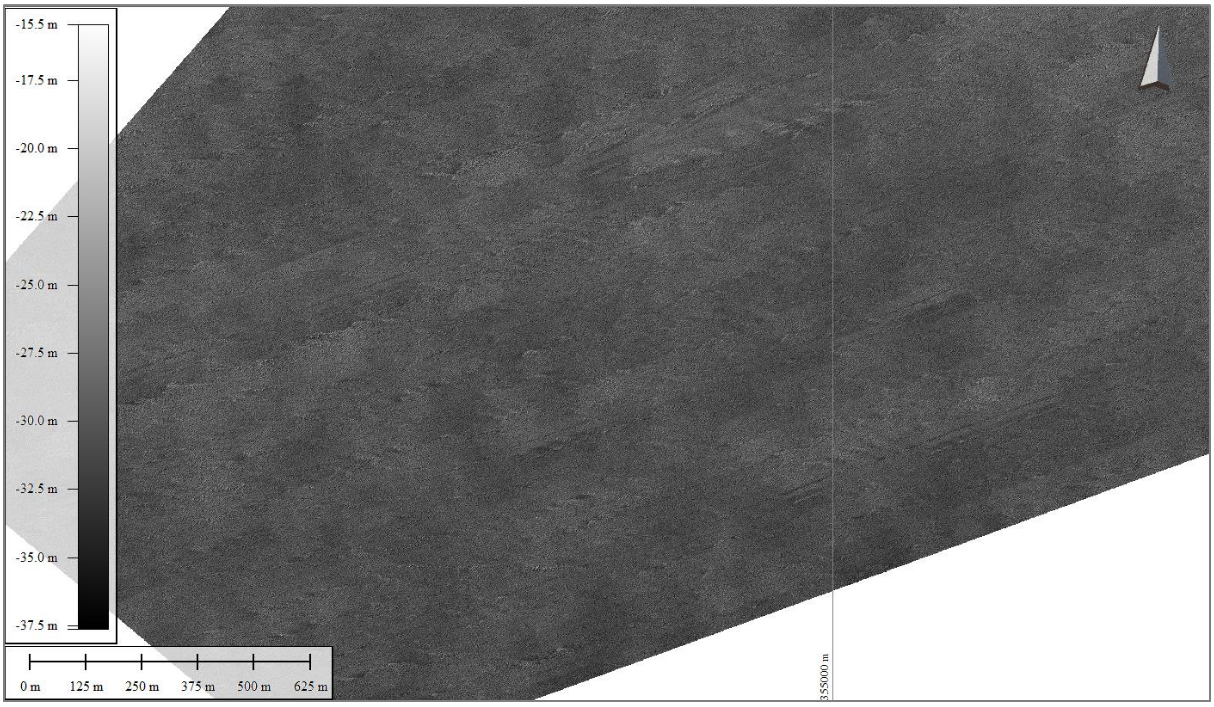


Figure 18: Example of stripe effect on the backscatter mosaic within the Kriegers Flak II South site

7.2 SIDE SCAN SONAR

7.2.1 Data acquisition

The SSS system settings and Client specifications are listed in Table 22 and Table 23, respectively.

Table 22: SSS system settings

Edgetech 4200 300/600 kHz	
Survey speed	Average 4 knots
Positioning	HiPAP 351 USBL
Mean fish altitude	Between 4.5 - 5 m
Trigger	High Frequency = Master
TVG / Gain	Recording RAW (*.jsf)
Range	HF = 70 m / LF = 70 m
Mode	High Definition Mode

Table 23: SSS Client specifications

Item	Specification	Achieved during survey
Resolution sufficient for detecting seabed feature/object	0.5 m (length, width and height)	< 0.5 m (length, width and height)
Towing altitude	8 - 12 % of range (optimised for data quality)	10 % of range
Positional accuracy	± 2 m (using vessel course-over-ground and USBL)	± 2 m (using vessel course-over-ground and USBL)

Item	Specification	Achieved during survey
Operating mode	High Definition Mode	High Definition Mode
Range	70 m	70 m
Coverage	200 %*	> 100 %

*Achieved by survey: 200%; except under nadir: 100% coverage.

7.2.2 SSS data processing

Side Scan Sonar (SSS) data were processed and interpreted using Chesapeake SonarWiz software. The SSS processing steps are outlined in Table 24 to Table 30. Figure 21 outlines the SSS processing workflow used for the project.

Table 24: Importing SSS data into SonarWiz

Step 1	Importing data: overview of the acquired lines
Set Up Project	The raw sonar files (*.jsf) had corrected navigation applied, using the SonarWiz NavInjectorPro utility, before being imported into Chesapeake SonarWiz software. The navigation data was de-spiked and exported from QINSy validator, to provide a smoothed position, with a bearing to towpoint heading solution. The processed sonar files (*.jsf) were imported into the SonarWiz project with the appropriate file type specific settings, as those were determined during the mobilization and calibration tests. A smoothing filter of 100 pings was applied during import. Once the parameters were agreed and checked with the Employer's Offshore Supervisor, they were used for the remainder of the dataset.
Bottom track	Using the automatic bottom tracking feature, SSS data were bottom tracked, line by line, and then, if needed, bottom track was manually adjusted.

Table 25: Navigation correction in SonarWiz

Step 2	Navigation correction
Check position	The SSS data were checked for positional accuracy against the MBES data, by locating clearly distinguishable features and contacts in both datasets and comparing their positions. If needed, the navigation data were re-processed and re-exported from QINSy as new navigation files (x, y, heading) and injected into the SSS data, using the SonarWiz NavInjectorPro utility. After that, positional accuracy was checked again.
Navigation	The towfish heading source was set to the fish heading to tow point. Using the SonarWiz ZEdit utility, navigation spikes were corrected and the positional accuracy was checked. The towfish heading was QC'd for small data jumps or artifact "vortex" effects.

Table 26: SSS signal processing

Step 3	Signal processing
EGN (Empirical Gain Normalization)	An EGN (Empirical Gain Normalization) table was calculated and applied to the data, creating a normalised gain, both along track and across track.
TVG (Time Variable Gain)	If the EGN table applied to the data did not have the desired effect, an Auto TVG was used.

Table 27: SSS infill assessment

Step 4	SSS infill assessment
Manual check for gaps	Manual check for data gaps, overlap and data loss during QC/QA.
Check for pycnocline interference	Quality control check for pycnocline interference towards swath edges. Affected areas were marked for infill and re-run if required.
SonarWiz coverage	Checked for 200 % coverage (100 % nadir coverage for pycnocline- thermocline affected data), using SonarWiz Coverage report.

Table 28: SSS contact picking

Step 5	SSS target picking
Target picking	Must include: H-L-W measurements Description of the target Confidence level The interpretation of contacts was performed in SonarWiz digitizing mode, in accordance with the specifications. Contacts were digitized alongside MBES data and confidence level was updated accordingly. Wrecks and cables were correlated to relevant databases.
Criteria of object detection	Minimum of 0.5 m (height, width or length) Object is identified as deviation from natural seabed forms The object is verified in wing line side scan image Position is verified with MBES data Man-made objects or very clear objects (even if only detected on one line only) Contact classification criteria defined with the Reporting Coordinator and sent to the Data Coordinator onshore.
Image picture	Colour grey inverted
Confidence level (Low, Medium, High)	Every contact has a confidence level attributed to it based on its detection in: • 1 SSS line -> Low, • 2 or more SSS lines -> Medium • 1 or more SSS lines and MBES data -> High
Boulder fields	Boulder field areas were outlined in SonarWiz map view whereas waterfall view was also used where needed. The boulder zone defining criteria are: • < 40 boulders: Not a boulder zone • 40 – 80 boulders: Boulder zone type 1: Intermediate boulder density • > 80 boulders: Boulder zone type 2: High boulder density • No minimum size requirement, all covered boulders count towards the minimum boulder amount to determine boulder zones The digitized polygons have been edited in QGIS and re-imported in SonarWiz. No manual target picking was performed within the boulder field polygons and a machine learning automatic picking algorithm was used instead. The results were confirmed to be representative and correct. Man-made objects have been manually picked within the boulder field areas

SSS contact picking was performed using two different methodologies related to the presence or not of boulder fields in the area.

Outside boulder fields:

Contacts were manually picked in the waterfall display in the Sonarwiz project, and measured for length (largest dimension of object), width (perpendicular to length) and height of the target.

Piking targets was in accordance with the specification of the project relative to minimum size and their interpretation as per TSG requirement. All contacts from 0.5 m were picked. Once all SSS targets were picked, they were correlated with MBES and MAG contacts.

Several QC steps are performed during the manual target picking and interpretation, and a final QC by the Lead Geo is done to ensure consistency on the target classification across the sites.

Inside boulder fields:

Automatic boulder picking was performed using an algorithm to analyse contacts from raster analysis. This methodology runs different scripts that detect and isolate the crucial components of reflections and shadows from the SSS data, which are fundamental for the representation, identification and measurement of boulders/targets.

Inside the mapped boulder fields, picking targets was in accordance with the specification of the project relative to minimum size and their interpretation as per TSG requirement. All contacts from 2 m and all MMO/debris were picked.

The detection process (Figure 19) was performed on each individual SSS line, and for each target the automated detection yielded a polygon that outlines the reflection and a line that outlines the shadow. When requested to identify the same target from several SSS lines, a specifically developed tool compared target position and dimension on different lines and created average values for one representative target. This task was especially challenging inside high-density boulder fields where target reflection varied between the lines and shadows overlaps between contacts.

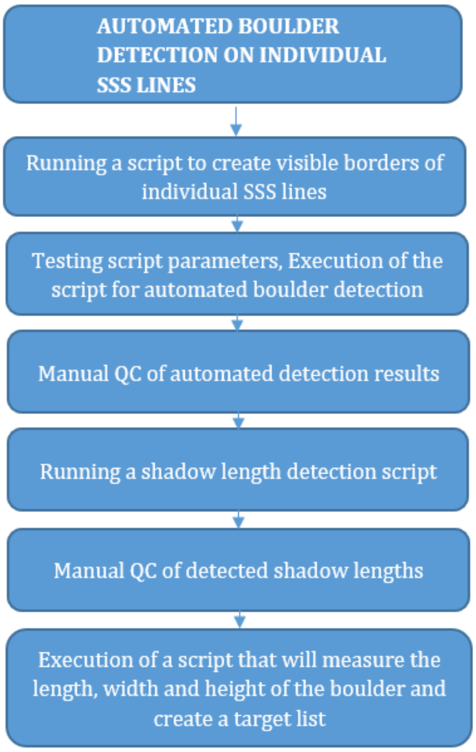


Figure 19: Automated boulder detection progress

A QC process was manually performed by a processor to check whether the detection results correspond to the real target by size and location, making adjustments if necessary to avoid false positive target detections (Figure 20). Manual quality control enabled the processor to ensure accurate and reliable detection results, adjust the results where needed, and improve the overall quality of the detection process.

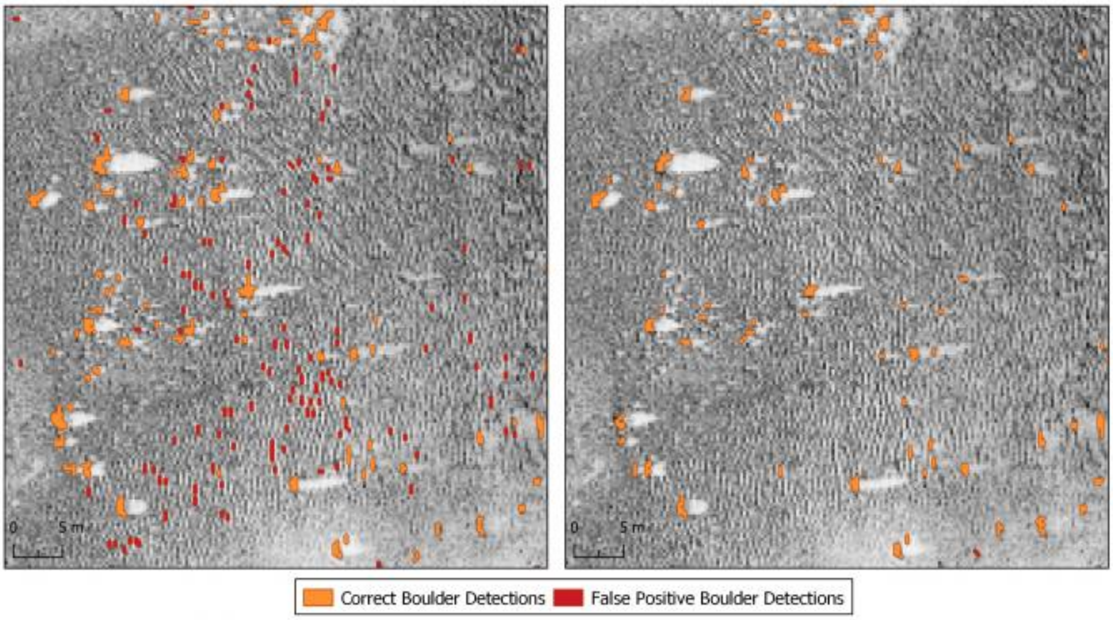


Figure 20: Automatic correct boulder detection vs false positive boulder detection

Once the algorithm was run and the QC was finished, a SSS boulder shapefile was exported and correlated with the MBES and MAG contacts. A final QC by the Lead Geo was done to assure the correct definition of contact.

The accuracy of this tool's detection varies between 90 % and 95 %, depending on the morphology of the seabed and the data quality.

Table 29: SSS mosaic creation

Step 6	SSS mosaic creation (HF and LF)
Adjust SSS line drawing order	SSS lines drawing order was adjusted to optimize the exported seabed image
Line grouping	Lines were grouped in: Approved, Rejected, Trials or Other
EGN and gain check	Final QC of EGN and gains was performed. If required, new EGNs and gains were recalculated and reapplied.
Inter file gap check	Data was checked for small inter-file gaps. SonarWiz inter-file gap tool was used when required.
Range check	Range was adjusted for optimized quality without compromising the 200 % data coverage.
Mosaic export	SSS mosaics were exported using the standardised project tile size and arrangement.

Table 30: SSS seabed classification

Step 7	Seabed classification
Seabed features	Seabed features have been created and QC'd using the exported SSS LF mosaics. SSS HF mosaics and the MBES exports were also taken into account.
Seabed Geology	The SSS LF and HF mosaics, as well as the MBES data and the SBP contours were used in order to outline the sediment differences, as those are represented by the

Step 7	Seabed classification
	reflectivity changes mainly on the SSS mosaics. Grab samples were the most useful for editing and confirming the outlined sediment boundaries

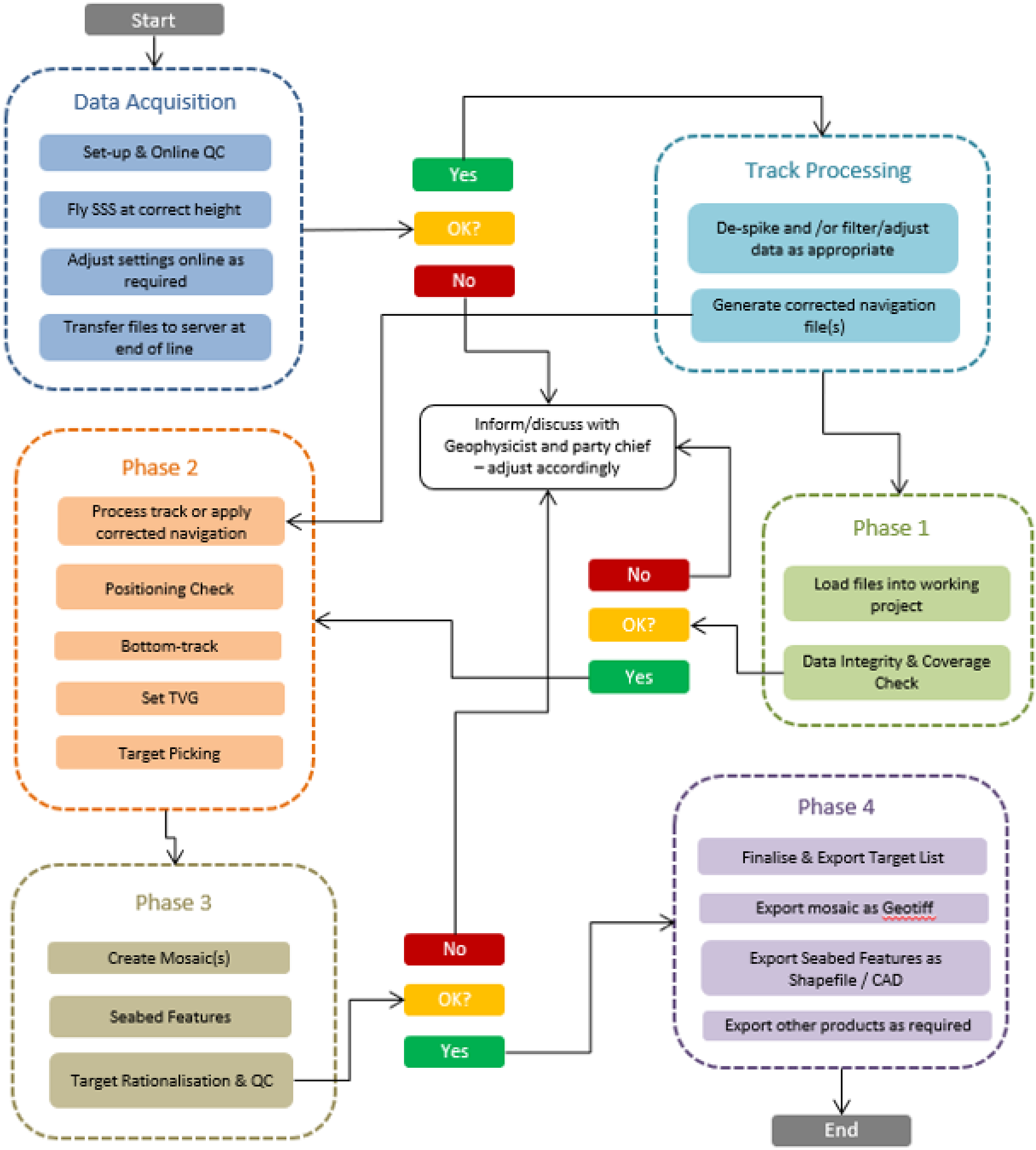


Figure 21: SSS data processing workflow

7.2.3 Data quality assessment

The SSS data quality was generally of high quality, meeting the Client specifications within the Kriegers Flak II North and South sites (Table 23).

Pycnocline effect resulted in marginal/bad data in the outer range of the SSS lines (Figure 22 and Figure 23). The affected parts have been removed during processing and good quality data has been used for mosaic exports and target picking.

The SSS coverage across the Kriegers Flak II North and South sites is displayed in Figure 24 and Figure 25. The requirement for 200 % SSS coverage was reduced to 100 %, due to the effect of the pycnocline on the SSS dataset.

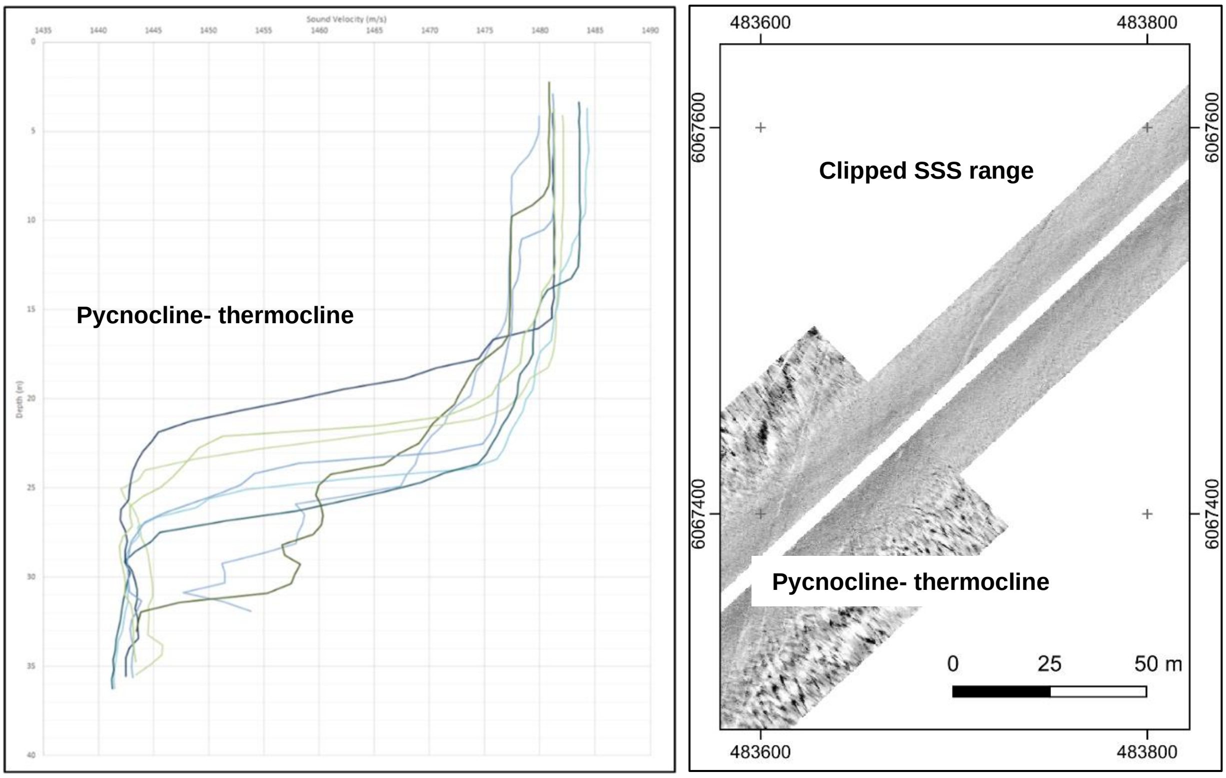


Figure 22: Pycnocline and effect on the SSS dataset

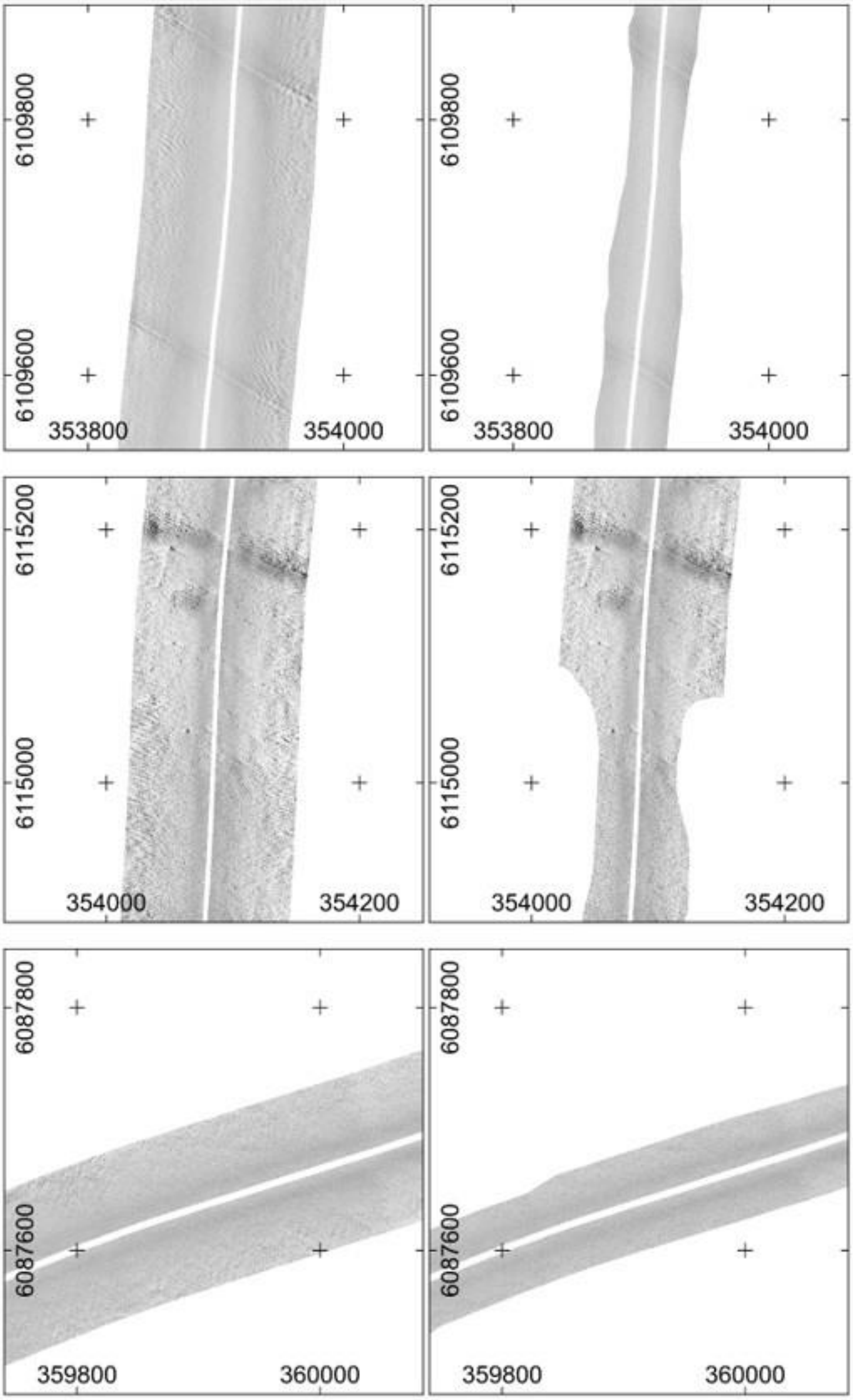


Figure 23: Pycnocline effect on the outer range of the SSS data (left) and trimmed-cleaned SSS data after Far Field Transparency function in SonarWiz (right)

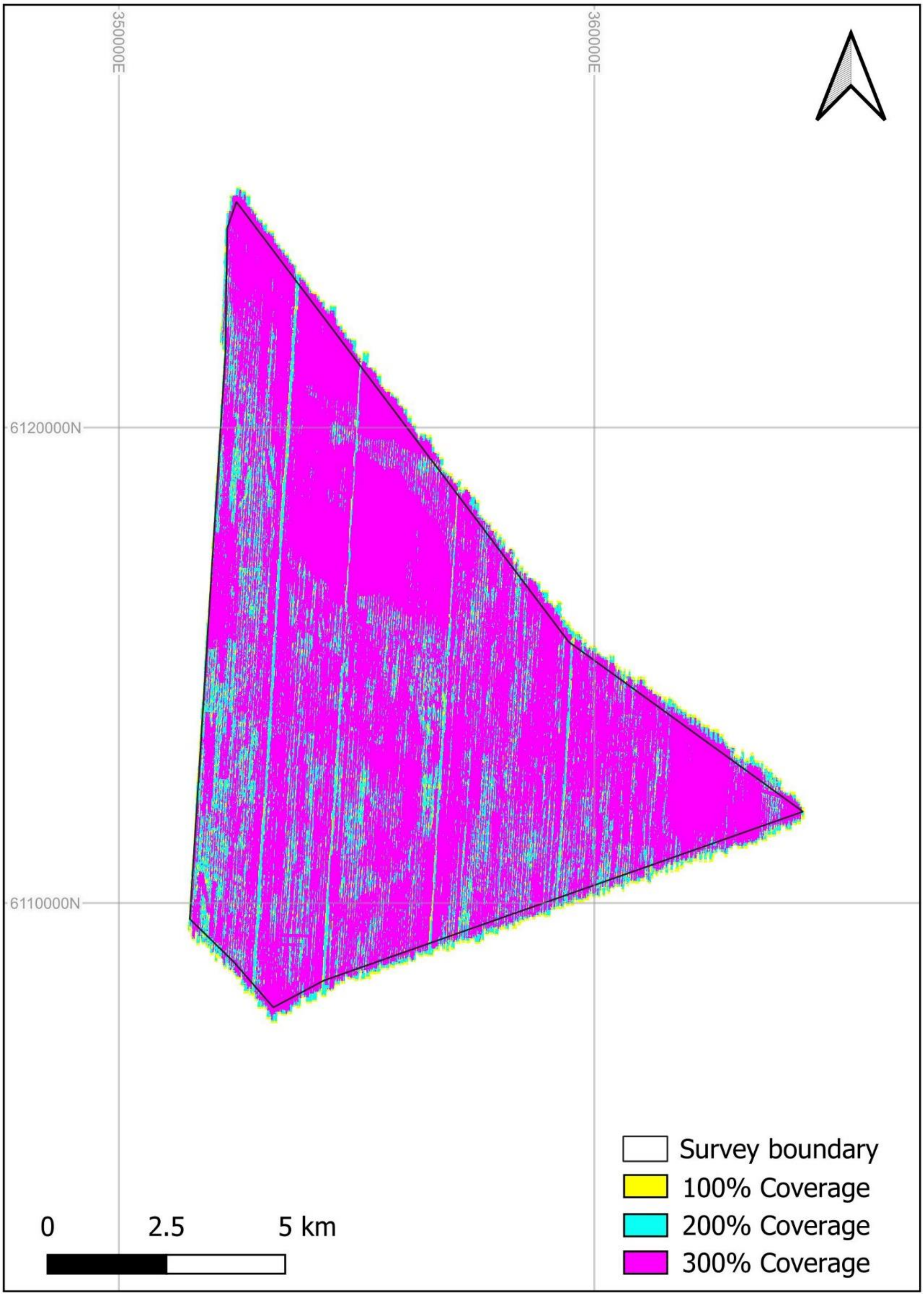


Figure 24: SSS coverage map Kriegers Flak II North

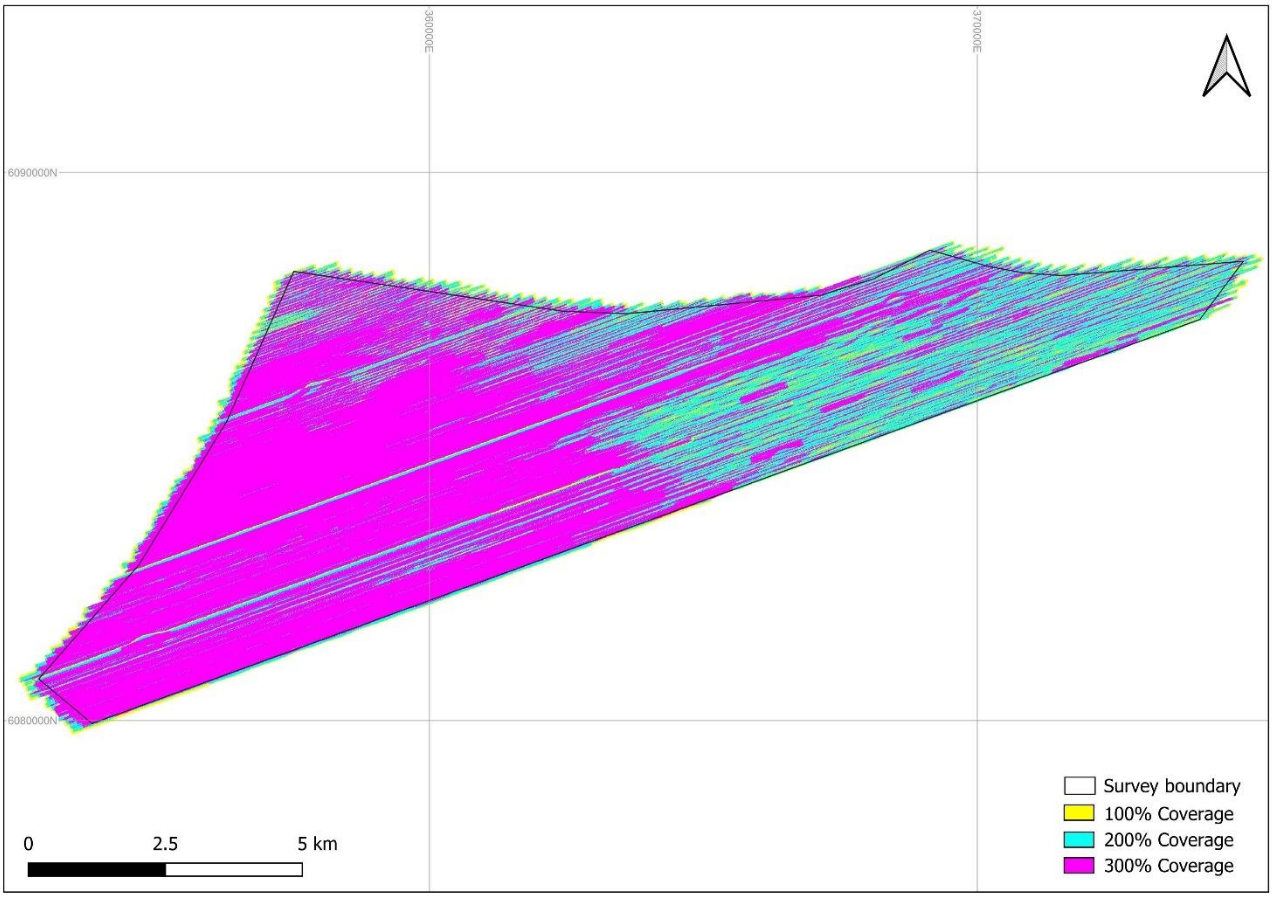


Figure 25: SSS coverage map Kriegers Flak II South

Data examples of good SSS data quality is presented in Figure 26. Shipwreck's details are clearly presented with good image definition.

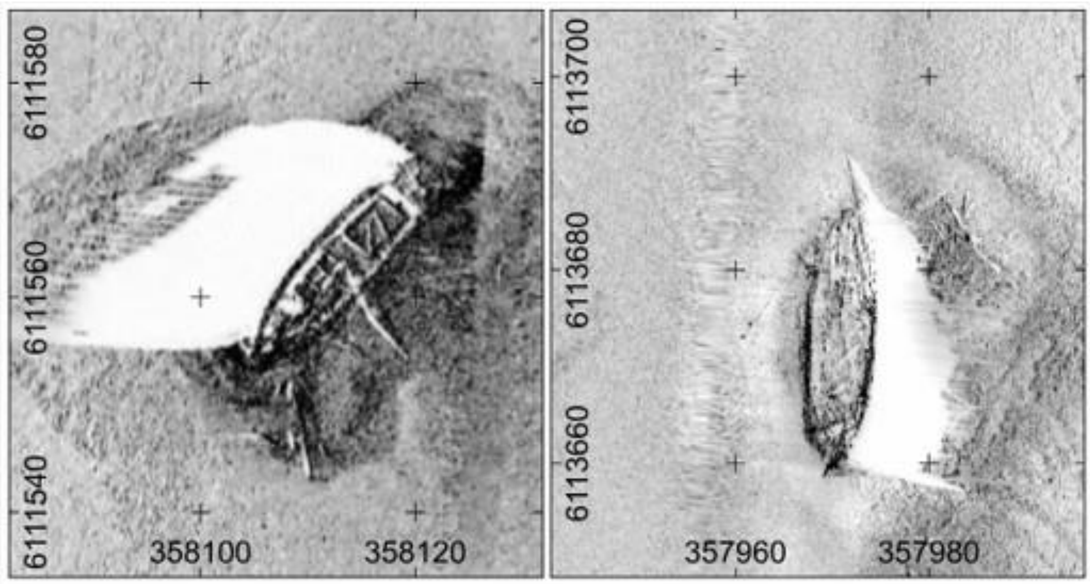


Figure 26: SSS data examples KFII_N_B04_SSS_GO6_0194 (left) and KFII_N_B04_SSS_GO6_0252 (right)

7.3 MAGNETOMETER

7.3.1 Data acquisition

The MAG system settings and Client specifications are listed in Table 31 and Table 32, respectively.

Table 31: MAG system settings

Geometrics G882	
Survey speed	Average 4 knots
Positioning	Hipap 351 USBL
Fish altitude	2 to 3 m
Frequency	10 Hz

Table 32: MAG client specifications

Item	Client Specification	Achieved by survey
Seabed altitude	≤ 5 m	≤ 5 m
Measurement sensitivity	0.01 nT	0.01 nT
Sampling frequency	1-20 Hz (selectable)	10 Hz
Noise level	≤ 2 nT	≤ 2 nT

The magnetometer was towed behind the SSS in a "piggyback" configuration. The magnetometer data was collected together with all analogue data as a single pass.

7.3.2 Magnetometer data processing

The magnetometer data were processed using GeoSoft Oasis Montaj. The magnetometer processing steps used for the project are outlined in Table 33 to Table 39.

The general magnetometer processing workflow used in the project is outlined in Figure 27.

Table 33: Magnetometer navigation processing

Step 1	Magnetometer navigation processing
Backup of "CMP_Easting" and "CMP_Northing"	The raw easting and northing for the common mid-point (CMP), (*CMP_Easting* and *CMP_Northing)* of the Eiva Scan Fish were copied; all subsequent navigation processing were performed upon these copies.
De-spiking	Data windowed for survey site Non-linear filter applied, with a fiducial width of 5 (and tolerance of 1.5 m). The filter was used to remove small spikes present in the data.
Interpolation	Interpolation of the gaps created by removing the navigation spikes. This was done using a linear interpolation, for gaps over six fiducials (one more than the de-spike length).
Back up of smoothed navigation	The smoothed/interpolated/de-spiked data were backed up
Projection	Project projection is set

Step 1	Magnetometer navigation processing
Distance	Calculates the total distance along the track for each fiducial.
Distance Separation	The distance between each fiducial is calculated. This was done by applying a convolution filter to the distance. The settings were -1, 1, 0. The results were written to the *Dist_QC* channel. This helped to monitor the frequency (10 Hz) of the magnetometer, it helped to spot any “freezes” in the data acquisition. It was compared to the magnetometer signal. Any large jumps in distance separation could have caused a spurious anomaly or missed data.
Comparison	The raw navigation, de-spiked navigation, smoothed navigation, the distance separation and magnetometer signal had their profile plotted together within Oasis Montaj. This allowed the quality control (QC) of the navigation and its processing. The database view plots these profiles against each other.

Table 34: Magnetometer altitude processing

Step 2	Magnetometer altitude processing
De-spiking	The raw altitude of each magnetometer was de-spiked. The filter stripped out any data spike that is above 10 m (or the value of the altitude cut-off defined during the EVT). This was done within Oasis Montaj using channel tools and channel mathematics.
Interpolation	The interpolation restored the gaps created by removing the altitude spikes. This was done using a linear interpolation, for gaps over ten fiducials (approximately 2 m).
Smoothing filters	A set of filter (low pass and B-spline) was applied to the de-spiked/interpolated altitudes to produce a smooth, more realistic values for altitude.
Alt cut-off	Clipped any data above 4 m and below 1.5 m
Clip X and Y with Alt masked	Clipped the position according to the altitude cut-off
Copy Mask of interpolated altitudes to Easting and Northings	Not done at this step
Comparison	The raw altitudes, de-spiked, smoothed altitudes, averaged altitudes and smoothed average altitudes, the distance separation and magnetometer signal had their profile plotted together within Oasis Montaj. This allowed QC of the altitude and the processing.

Table 35: Magnetometer data QC

Step 3	Magnetometer data QC
De-spiking	A de-spiking filter was applied to the total magnetic TMF values.
Non-linear filtering	A non-linear filter was applied to attenuate any noise present in the data.
B-spline smoothing	A “B Spline” filter was applied to the non-linear filter. This helped to make the signal to appear more realistic (smooth).
Removal of data with poor magnetic signal	Any data with a magnetic signal strength below 200 was removed.
Copy Mask of interpolated TMF values and poor	The stripped magnetic data is used to mask the eastings and northings. The data gaps that are present in the interpolated TMI values were reintroduced by using these TMI

Step 3	Magnetometer data QC
magnetic signal to Easting and Northings	values to mask the eastings and northings. This is done because original gaps may have been reduced due by the previous smoothing filters.
Comparison	All the processing steps for the TMI are plotted along with the magnetometer signal for QC.

Table 36: Magnetometer background calculation

Step 4	Magnetometer background calculation
Background	To obtain the background magnetometer signal, a series of non-linear filters were applied. These were as per GeoXYZ's procedures. An additional geological filter was produced by using a variation of filter parameters to attenuate magnetic anomalies.
B-Spline	A "B Spline" filter was applied to the final non-linear filters to smooth the result.
Compare	The final data were compared with the raw data to identify over or under filtering of the data.

Table 37: Magnetometer residual field calculation

Step 5	Magnetometer residual field calculation
Residual (Anomalies)	Filtered magnetometer data minus the background signal (anomaly and geology).
Residual (Geology)	An additional geological residual field was also calculated using an additional non-linear filter set.
Gridding	Data were gridded using Minimum Curvature with a Cell Size of 0.5 m and a blanking distance of 6 m. Coverage assessment for infills were based in dynamic coverage analysis.

Table 38: Magnetometer dynamic range calculation

Step 6	Magnetometer dynamic range calculation
Detection ranges	Detection ranges were calculated from a pre-survey equipment evaluation test (EVT)
Coverage plot	Coverage plots were created through use of proportional symbols within Oasis Montaj rather than blanking data to various distances. Dynamic coverage calculation: C0 = 2*(sqrt(X.X**2-(C1+1.5)**2)) C0 =Dynamic Coverage X.X= Detection range depending on altimeter values. C1 = altitude 2 = the burial depth
Final grid blanking distance	Caution was required when selecting the final blanking distance, to ensure that the edge of survey results were not exaggerated.

Table 39: Magnetometer target picking

Step 7	Magnetometer target picking
Analytic Signal	AS grids were calculated as per calculation: $AS = \mathrm{sqrt}(dx^2 + dy^2 + dz^2)$ AS grids were produced using a 0.5 m cell size, blanking distance set at 6 m.
Target picking	Anomalies greater than 5 nT peak to peak were picked. The background removal was checked to be optimal for target picking and the pick-to-pick measures are correct. Residual field was checked against total field to help determine anomalies.

Step 7	Magnetometer target picking
De-duplication of targets	Compare targets with Altitude and Residual and TMI profiles. Targets were de-duplicated as required.
Target List	Magnetometer target list was compiled, as per client requirements

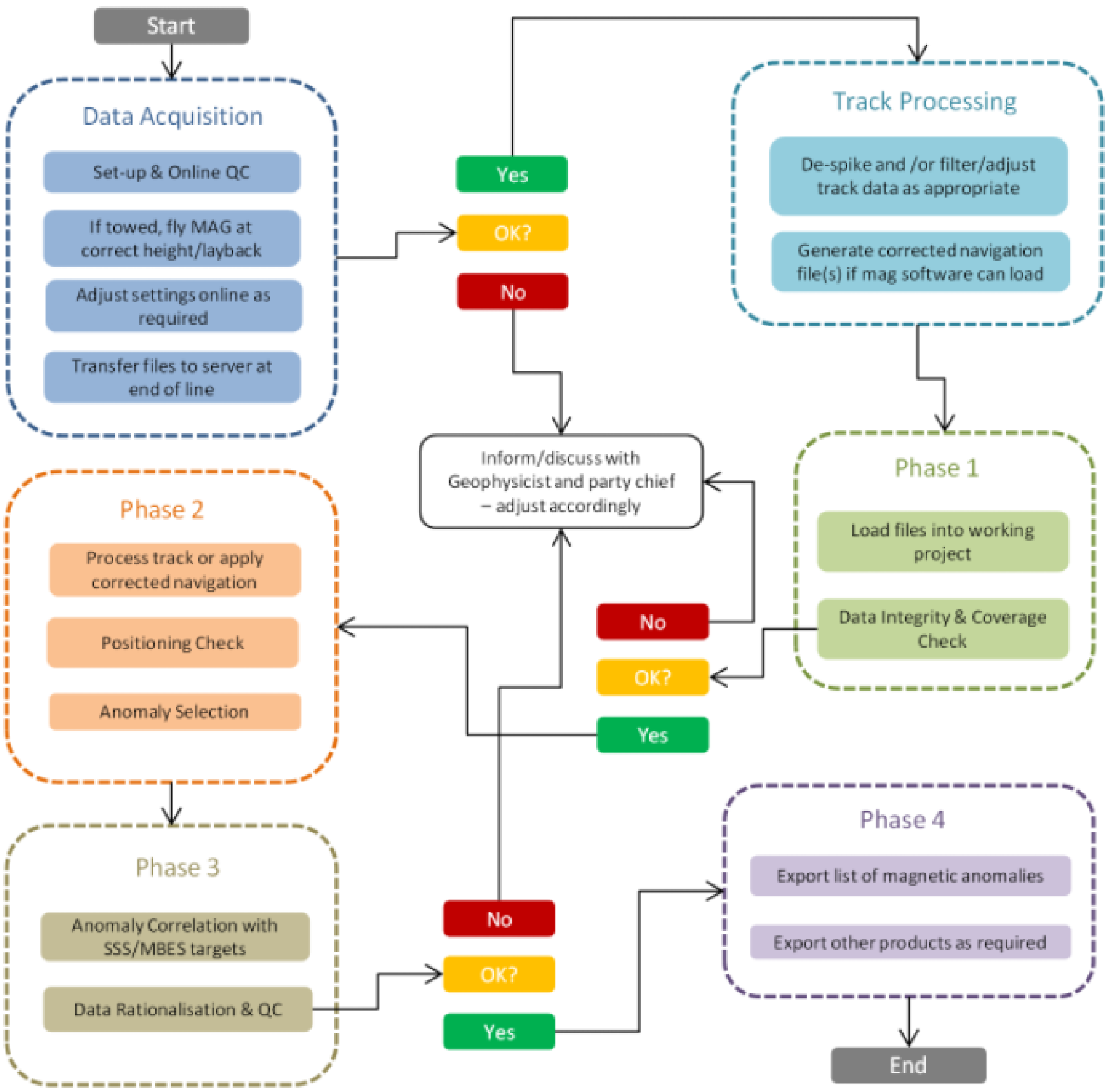


Figure 27: Magnetometer processing workflow

7.3.3 Data quality assessment

In general, data quality is good and meets the project requirements. Spikes occur within the data of the total magnetic field. Spikes are overall more frequent for the altitude channel. A comparison between raw and filtered and smoothed altitude values is presented in Figure 28.

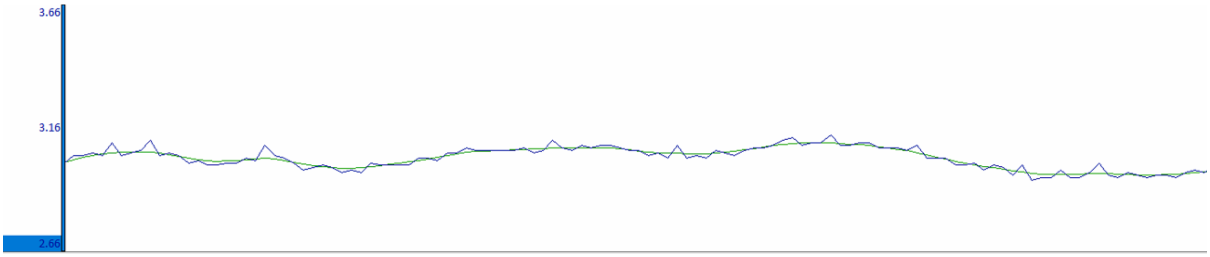


Figure 28: Data example showing comparison between raw and filtered altitude values

A non-linear filter was used for de-spiking and smoothing was achieved using the B-Spline filter. Further processing then continued on the filtered data.

Easting and northing coordinates were de-spiked and smoothed as well, however, only few jumps or spikes were present in navigation. Where gaps were present due to navigation drop out, interpolation to 20 m was performed. Infill or replayed lines were included in the data to solve any jumps in navigation (Figure 29).

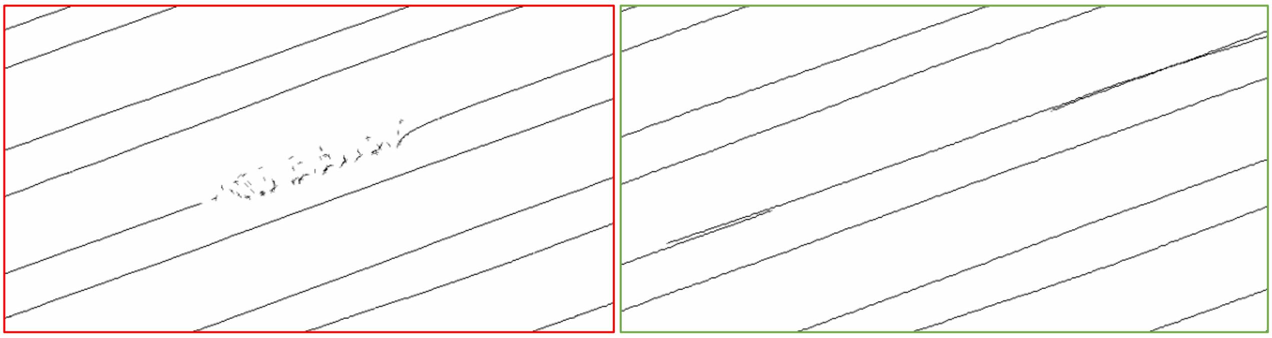


Figure 29: Data example on B02 Kriegers Flak II South site (line 1842- 5376_C_KS_GO5_L078V – MAG); Left image (framed in red) shows jumps in navigation, right image (framed in green) displays the same data, de-spiked and including the infill

Specially for line 1785 - 5376_C_KS_GO5_L023V – MAG in Kriegers Flak II South B03, an altitude spike occurs causing a gap in the data (Figure 30). The altitude spike is not creating a real anomaly. At the same spot, the spike is present in the total magnetic field. This part was masked from the final easting and northing coordinates and it was not used for further calculation of the analytical signal (blue profile) or generation of other grids.

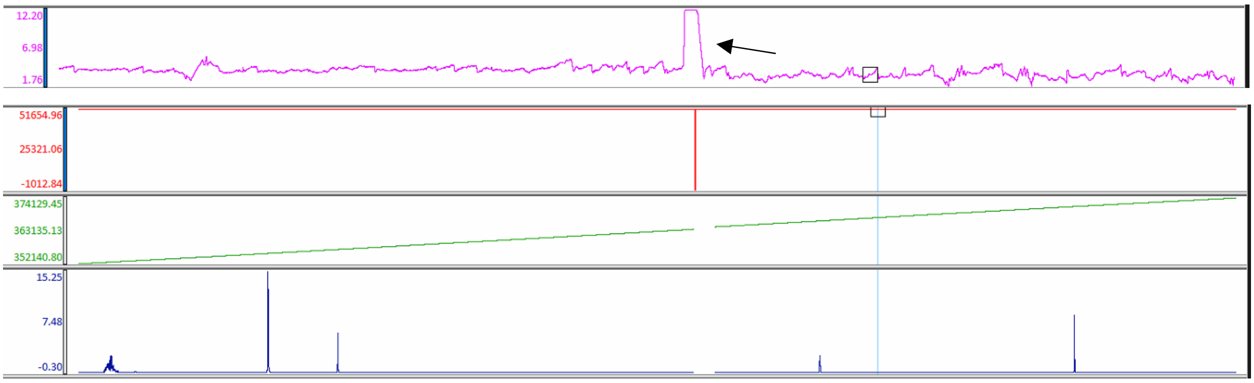


Figure 30: Data example from Kriegers Flak II South B03 showing a spike; in pink: altitude profile; in red: total magnetic field; in green: residual signal profile; in blue: analytical signal profile

Based on final Easting and Northing coordinates residual was generated as well. The Residual was generated from the measured total magnetic field and calculated background. The background field was calculated using a series of non-linear filters. Based on this calculation, anomalies were highlighted.

Signal strength values were mostly above 1000. Short drop out in signal strength values were present, yet these were under acceptable conditions. For Kriegers Flak II North site, for example, low signal values were observed over the Baltic Cable (Figure 31).

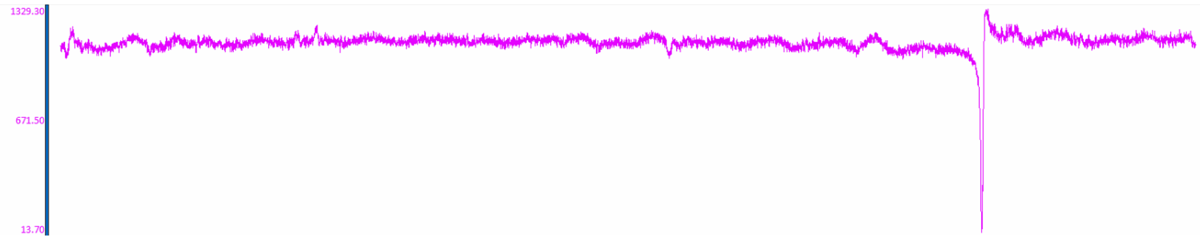


Figure 31: Signal strength values dropping over the Baltic Cable (Line 1285_C_KN_G06_L659V_MAG)

7.3.4 Magnetometer dataset profile example

An example profile for the MAG dataset within the Kriegers Flak II North site across a wreck and a metallic object within the Kriegers Flak II South site are displayed in Figure 32 and Figure 33, respectively.

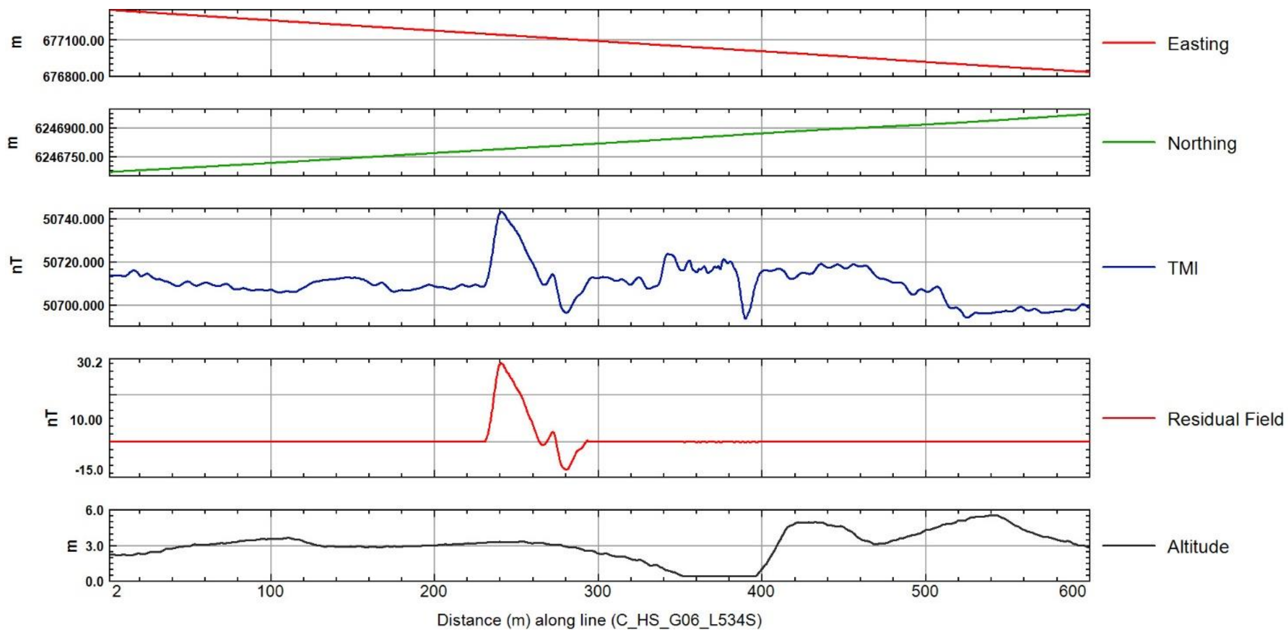


Figure 32: MAG profile example within Kriegers Flak II North, block 01, across MAG target KFII_N_B01_MAG_G06_0125

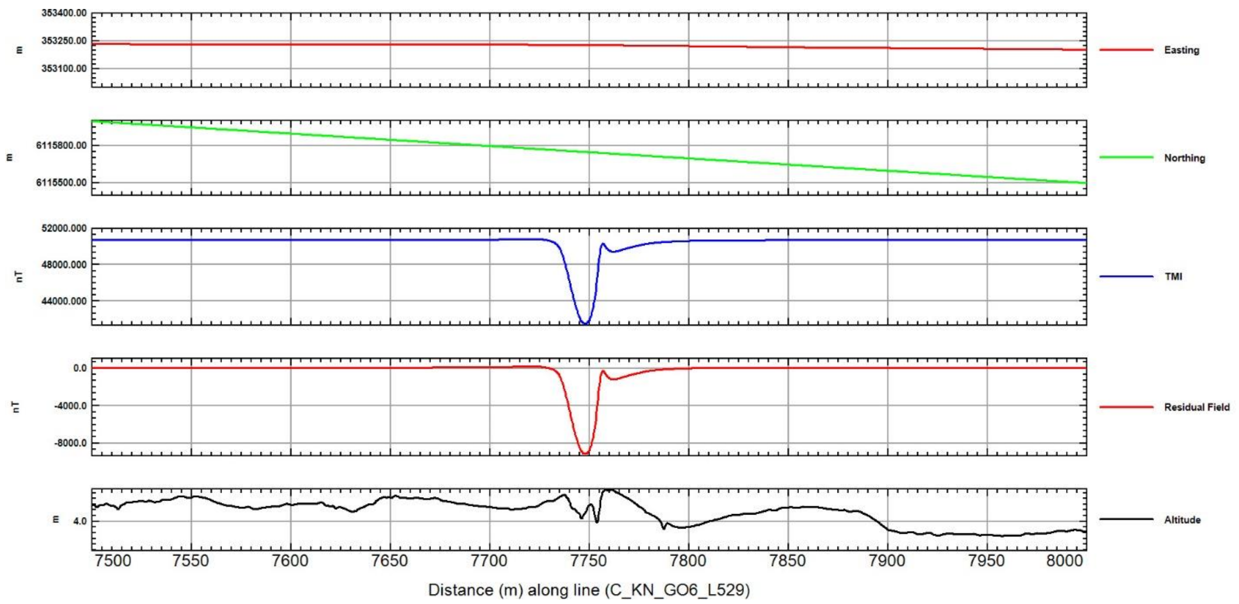


Figure 33: MAG profile example within Kriegers Flak II South, block 04, across MAG target MAG_KS_B4_0015

7.3.5 Magnetic residual anomaly grid

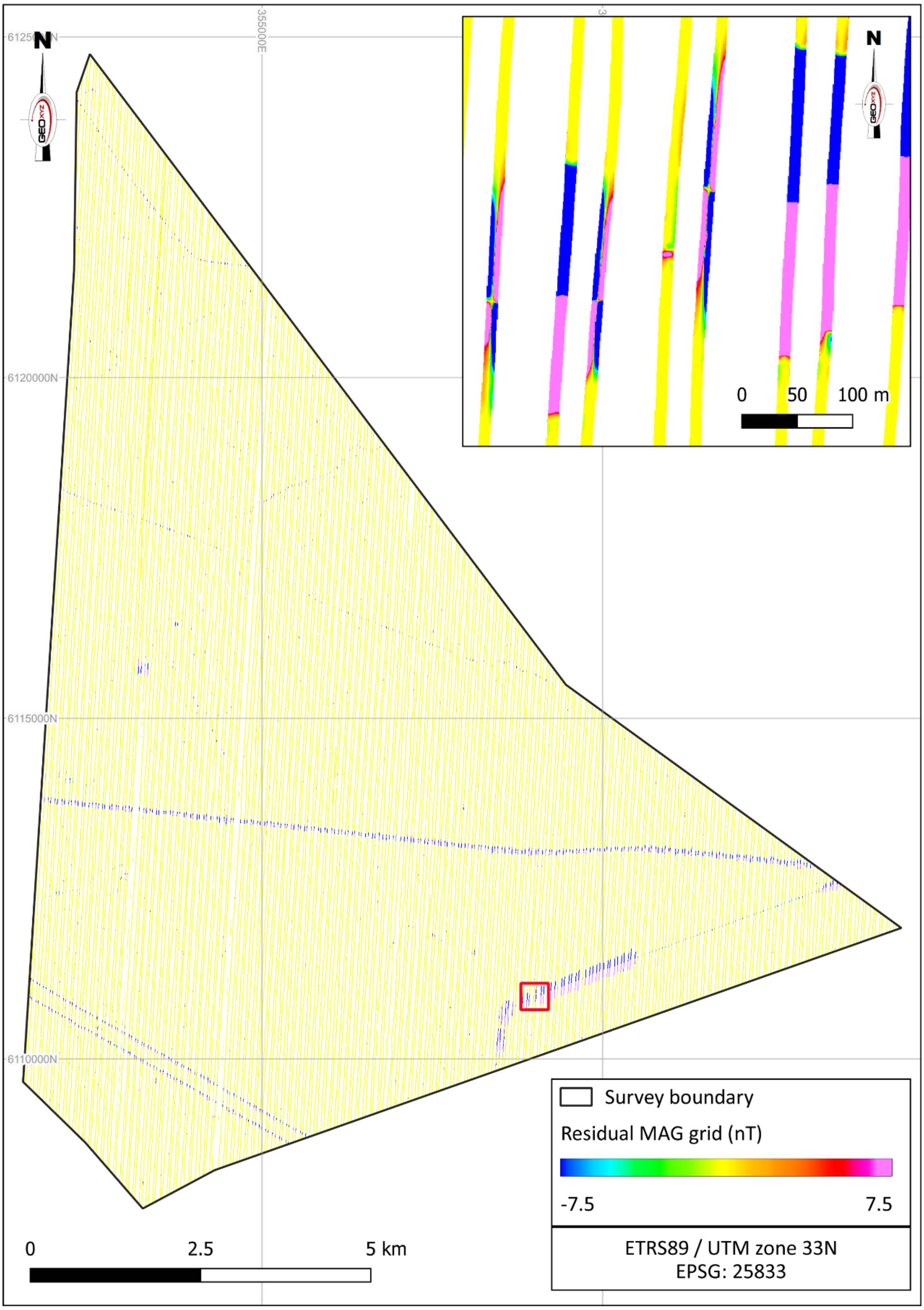


Figure 34: MAG residual anomaly grid across the Kriegers Flak II North site

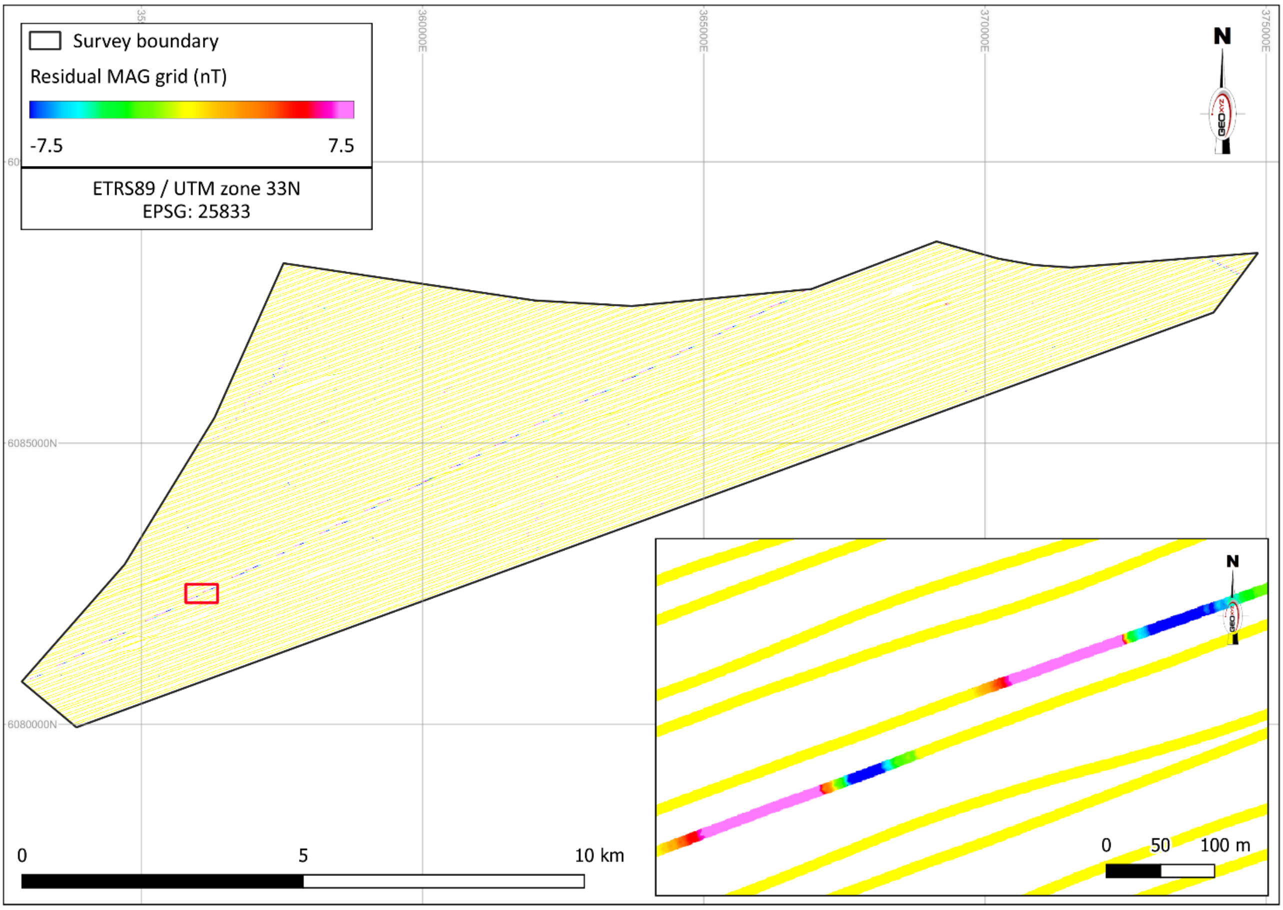


Figure 35: MAG residual anomaly grid across the Kriegers Flak II South site

7.3.6 Magnetic analytic anomaly grid

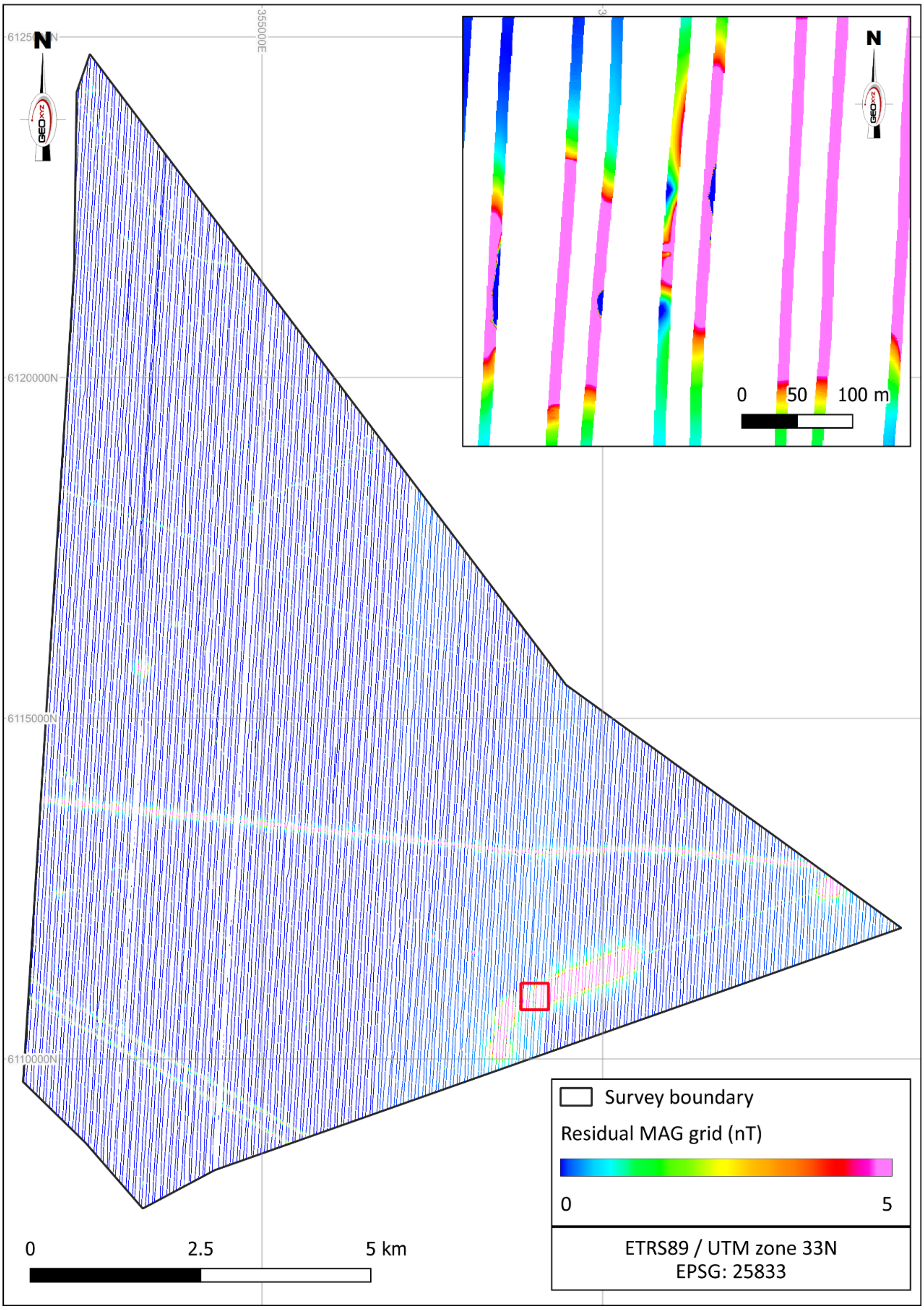


Figure 36: MAG analytic anomaly grid across the Kriegers Flak II North site

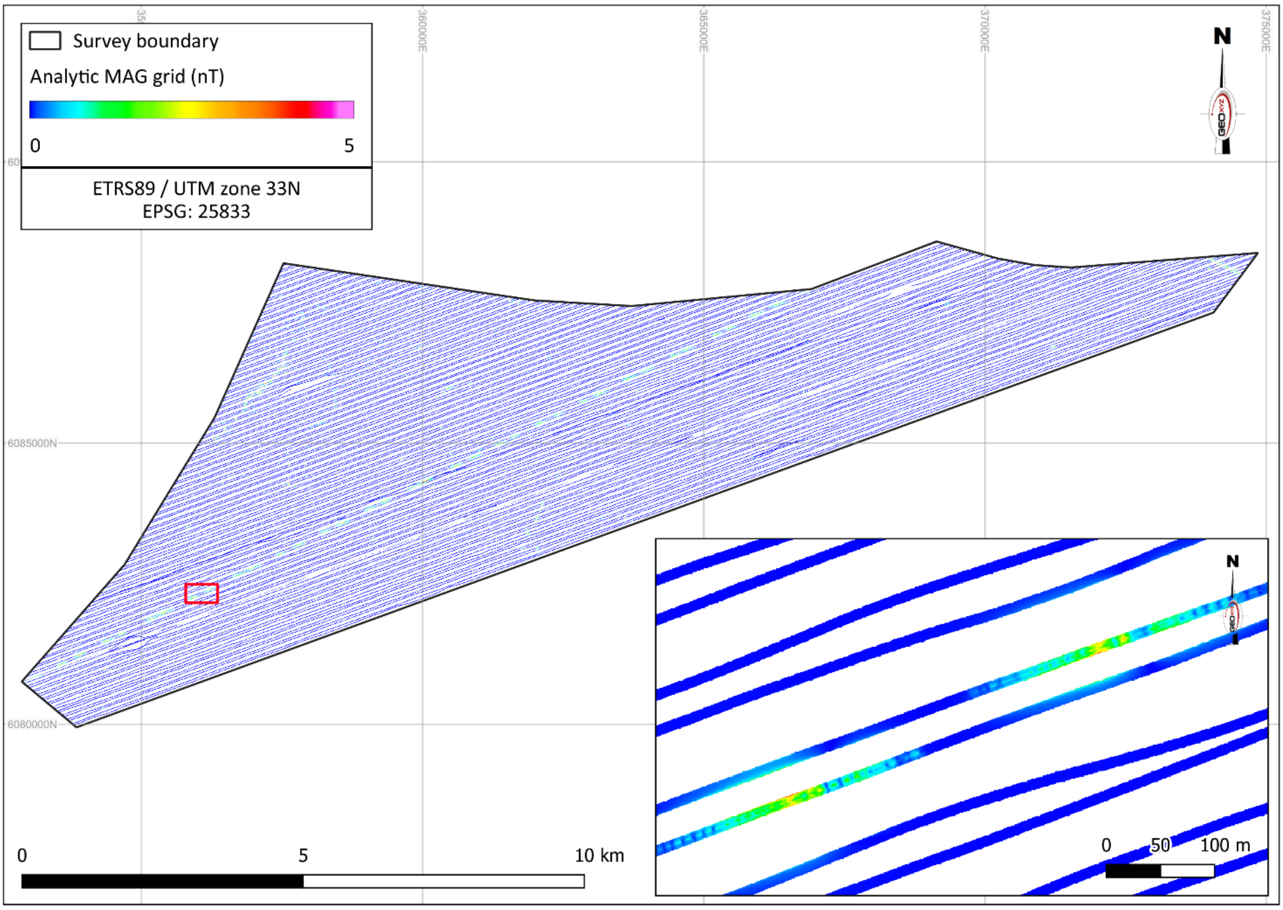


Figure 37: MAG analytic anomaly grid across the Kriegers Flak II South site

7.4 SUB-BOTTOM PROFILER

7.4.1 Data acquisition

The client requirements for the SBP survey are outlined in Table 40.

Table 40: SBP acquisition and processing methodology

Item	Specification
Penetration	10 m
Vertical resolution	0.3 m
System	Innomar SES 2000 Standard

7.4.2 Data processing

Sub-bottom profiler (SBP) data were acquired using an Innomar SES 2000 Standard System and recorded using SESWIN recording software. SBP data processing and data QC was performed using Innomar ISE, Innomar SES Convert and Stema Silas software.

The main SBP processing steps used for the QC are outlined in Table 41.

Table 41: SBP data import and data QC

Steps	SBP data import and QC
Import of SEGYs	Import SEGY Tide file applied
Data Quality	Lines checked for: No empty pings Correct bottom detection No motion influence No noise in the data No artefacts in data Good reflector visibility Good penetration (5 m)
Position check	Lines checked for: Data coverage Verification of the absolute height by importing the MBES grid (no manual offset is accepted, after tide/heave correction applied online)

7.4.3 Data quality assessment

In terms of data quality/utility, the general standard is very good. In general, good imaging of the shallow geology is produced. The vertical resolution allows separation of surfaces ~0.15 m apart.

The picked horizons were gridded to 5 m lateral resolution using the IHS Kingdom Flex Gridding algorithm default settings. The final project datum depth grids were created from thickness horizons, which were then added to the MBES bathymetry. This was to remove the effect of any static miss-ties and to provide the best gridded surface possible. Sub-bottom data and interpretations were depth converted using a velocity of 1600 m/s.

The depth grids show some very minor artefacts (<0.2 m) related to busts between adjacent lines. These artefacts are primarily caused by the high density of survey lines and slight variations in horizon picking between these lines.

7.5 2D UHR SEISMIC

7.5.1 Data acquisition

The client requirements for the UHR seismic survey are outlined in Table 42. A horizontal tow configuration (with the head and tail at 1 m water depth) was employed. This configuration was tested during the verification phase at the start of the project and adjusted to determine the optimal consideration to vertical resolution and weather dependency of survey operations. Sparker and streamer components were towed inline to optimise launch and recovery activities and line turns.

Table 42: UHR acquisition specifications

Item	Client specification
Fundamental frequency	Between 1 and 3 kHz
Vertical resolution	0.3 m at seabed (weather dependant)
Minimum Penetration	100 m

Item	Client specification
Fire rate	2 pulses/second
Feather angle	<12° during 95 % of the shots
Variable energy levels	Between 100 and 1000 Joules
System	A suitable multi-channel and multi-element hydrophone streamer (e.g. 48 channels @ 3.125 m), with depth control, plus depth measurement for continuous monitoring and recording of streamer depth

7.5.2 Data processing

The processing workflow applied to the datasets for Kriegers Flak II North and South are outlined in detail within APPENDIX A.

7.5.3 Data quality assessment

The multichannel seismic data are of good quality and resolve primary reflections to beyond 100 m below seabed. There is minor variation in signal phase in some of the lines and occasional missed shots. These faults have a negligible effect on interpretation. The most significant imaging problem is related to the shallow gas which is distributed over a large proportion of the north and central parts of the area. This blanks out the signal and gives rise to reverberations at the period between the seabed and the gas.

The data allow separate mapping of reflections ~0.5 m apart.

The data were depth converted using stacking velocities and a time grid of the top bedrock. The interpretation was depth converted using a velocity of 1600 m/s to Unit III, 1800 m/s was applied to Unit III.

7.6 SEABED SAMPLING

7.6.1 Kriegers Flak II North

The geotechnical ground-truthing phase of the survey was conducted, in order to provide initial surface sediment classifications and establish baseline physico-chemical parameters at specific locations across the site.

A total of thirty-three sampling stations were proposed by the onboard senior Marine Environmental Scientist and grab samples were collected at each of these stations. Samples were successfully acquired at all thirty-three of the proposed stations. A full suite of physico-chemical samples (PC1 and PC2) was obtained at all of the other stations.

One full suite of physico-chemical samples was acquired at each of the stations, using a 0.1 m² dual van Veen grab sampler or a 0.1 m² mini Hamon grab.

A basic suite of Physico-Chemical (PC) samples, comprising a single primary (PC1) and single secondary (PC2) were acquired at each location. Particle Size Analysis (PSA), Total Organic Matter (TOM) and Carbonate Content (CC) components were sub-sampled ex-situ once sent to the benthic laboratory. PSA1, TOM1 and CC1 were subsampled from the primary (PC) sample and PSA2, TOM2 and CC" were extracted from the secondary (PC2) sample, as required.

Any conspicuous benthic macrofauna and species of potential conservation value were noted.

Figure 38 below indicates the proposed grab sampling positions across the Kriegers Flak II North site.

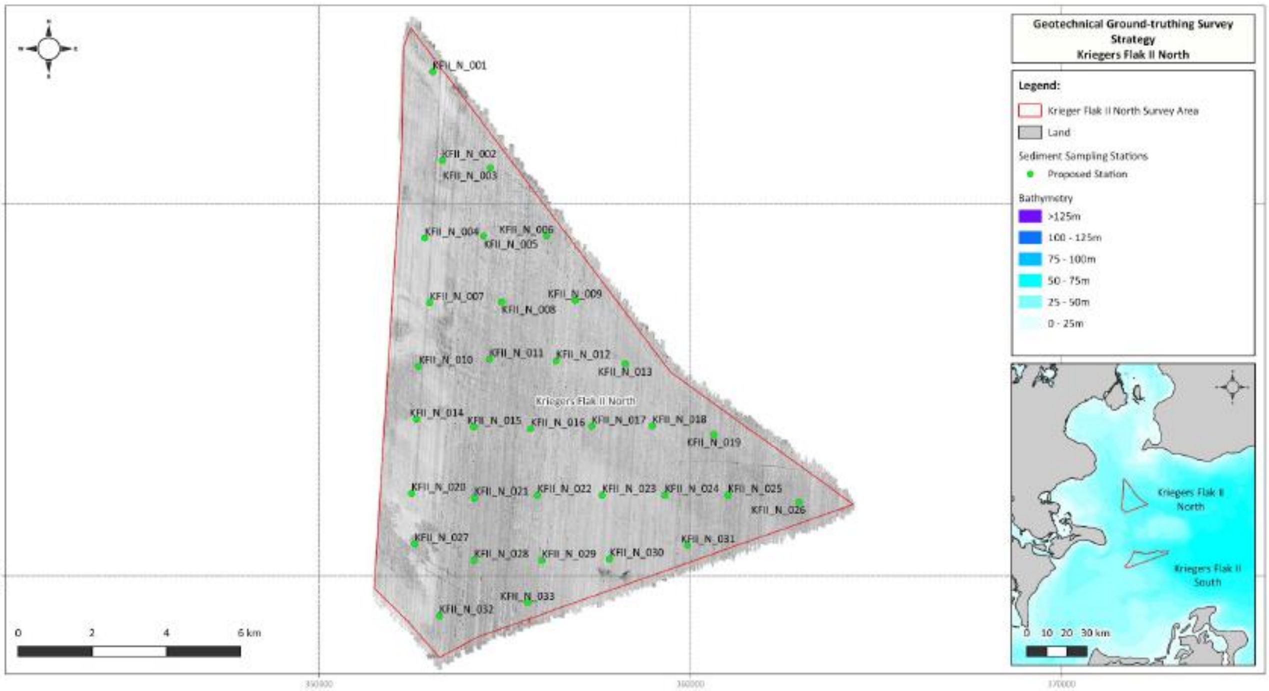


Figure 38: Proposed surficial geotechnical ground-truthing sampling locations within Kriegers Flak II North area

The full results of the geotechnical ground-truthing at the Kriegers Flak II North site can be found in APPENDIX B of this report: *Danish Offshore Wind, Kriegers Flak II North: Surficial Geotechnical Ground-Truthing Data Report,* prepared on behalf of GEOxyz, by Ocean Sciences Consulting (OSC).

7.6.2 Kriegers Flak II South

The geotechnical ground-truthing phase of the survey was conducted, in order to provide initial surface sediment classifications and establish baseline physico-chemical parameters at specific locations across the site.

A total of twenty-five sampling stations were proposed by the onboard senior Marine Environmental Scientist and grab samples were collected at each of these stations. Samples were successfully acquired at twenty-five of the proposed stations. A full suite of physico-chemical samples (PC1 and PC2) was obtained at all of the other stations.

One full suite of physico-chemical samples was acquired at each of the stations, using a 0.1 m² dual van Veen grab sampler or a 0.1 m² mini Hamon grab.

A basic suite of Physico-Chemical (PC) samples, comprising a single primary (PC1) and single secondary (PC2) were acquired at each location. Particle Size Analysis (PSA), Total Organic Matter (TOM) and Carbonate Content (CC) components were sub-sampled ex-situ once sent to the benthic laboratory. PSA1, TOM1 and CC1 were subsampled from the primary (PC) sample and PSA2, TOM2 and CC” were extracted from the secondary (PC2) sample, as required.

Any conspicuous benthic macrofauna and species of potential conservation value were noted.

Figure 39 below indicates the proposed grab sampling positions across the Kriegers Flak II North site.

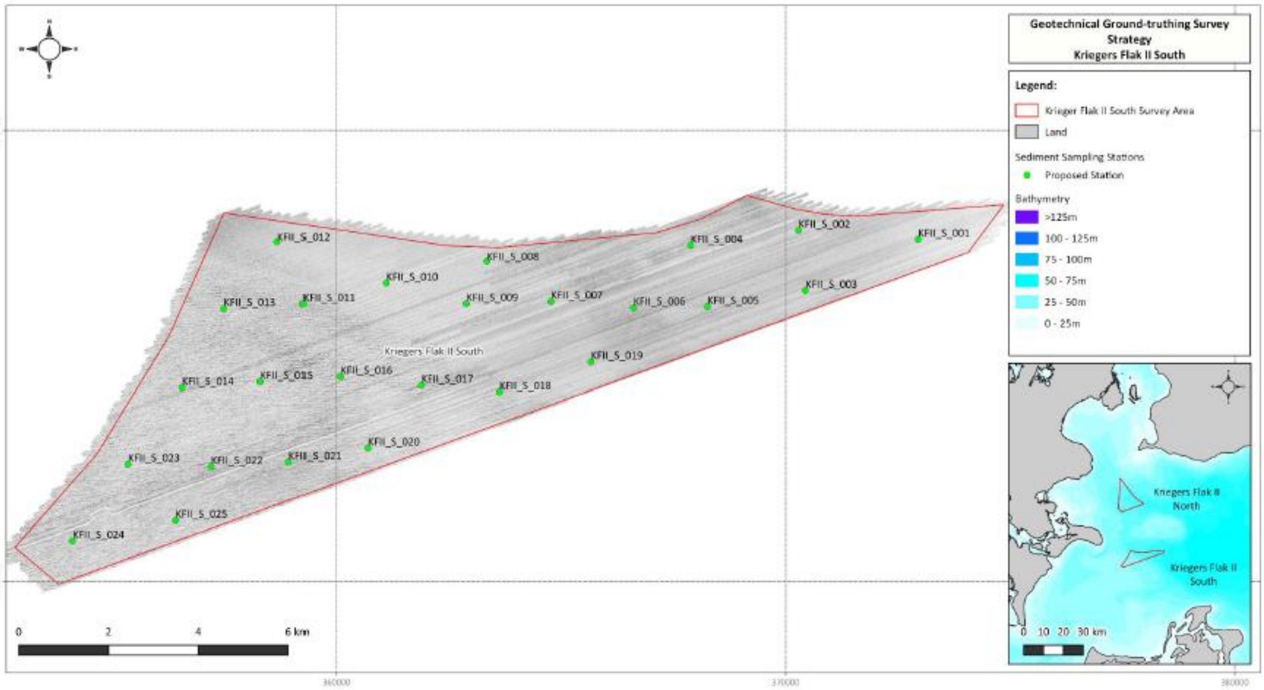


Figure 39: Proposed surficial geotechnical ground-truthing sampling locations within Kriegers Flak II South area

The full results of the geotechnical ground-truthing at the Kriegers Flak II South site can be found in APPENDIX C of this report: *Danish Offshore Wind, Kriegers Flak II South: Surficial Geotechnical Ground-Truthing Data Report,* prepared on behalf of GEOxyz, by Ocean Sciences Consulting (OSC).

8 RESULTS AND INTERPRETATION KRIEGERS FLAK II NORTH

8.1 CLASSIFICATION CRITERIA

8.1.1 Slope classification criteria

Seabed gradient has been classified as per Table 43 below.

Table 43: Slope classification

Classification	Slope
Very Gentle	< 1°
Gentle	1° - 5°
Moderate	5° - 10°
Steep	10° - 15°
Very Steep	> 15°

8.2 BATHYMETRY

Seabed levels across the Kriegers Flak II N site range from a minimum of 21.8 m MSL, in the northernmost section of the site near 353465 mE, 6123400 mN, to a maximum of 34.5 m MSL at the extreme eastern edge of the site, near 364360 mE, 6111930 mN (Figure 40).

An overview of the bathymetry within the Kriegers Flak II N survey area is shown in Figure 40, bathymetry profiles for several line plan segments are shown in Figure 41 and a detailed bathymetric overview of the northern and central part of the survey area is shown in Figure 42.

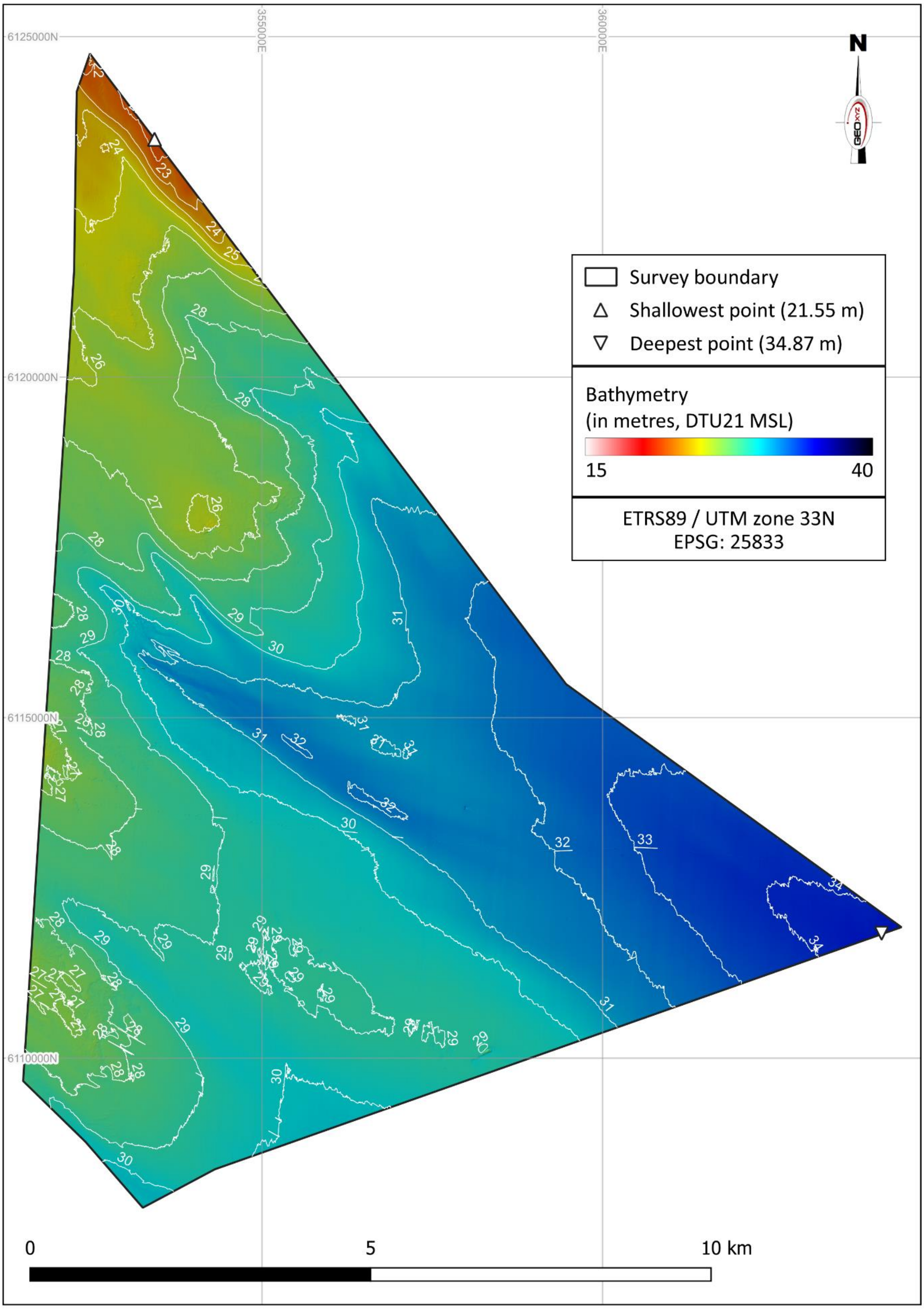


Figure 40: Bathymetry across Kriegers Flak II North area

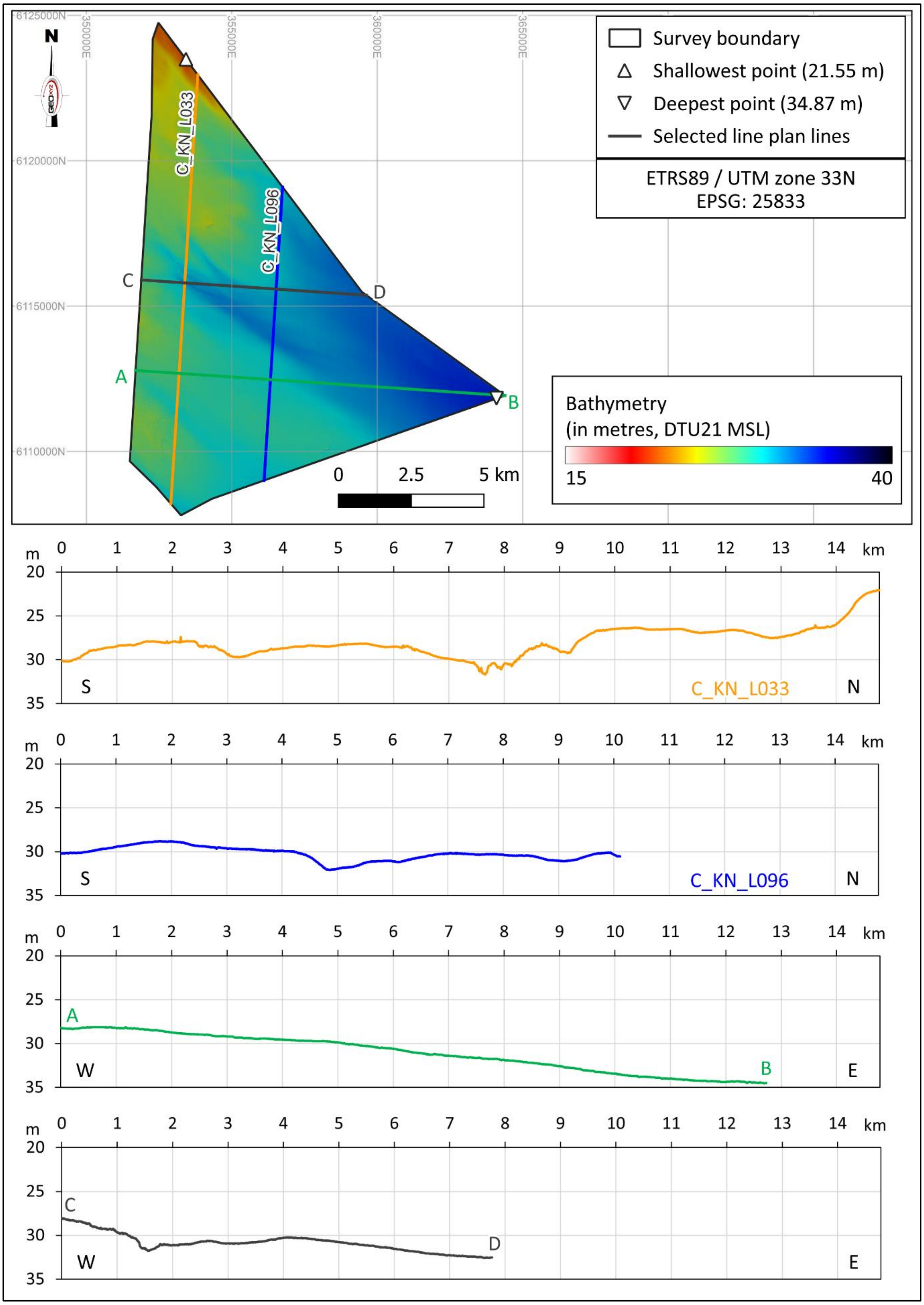


Figure 41: Bathymetry profiles based on selected line plan segments

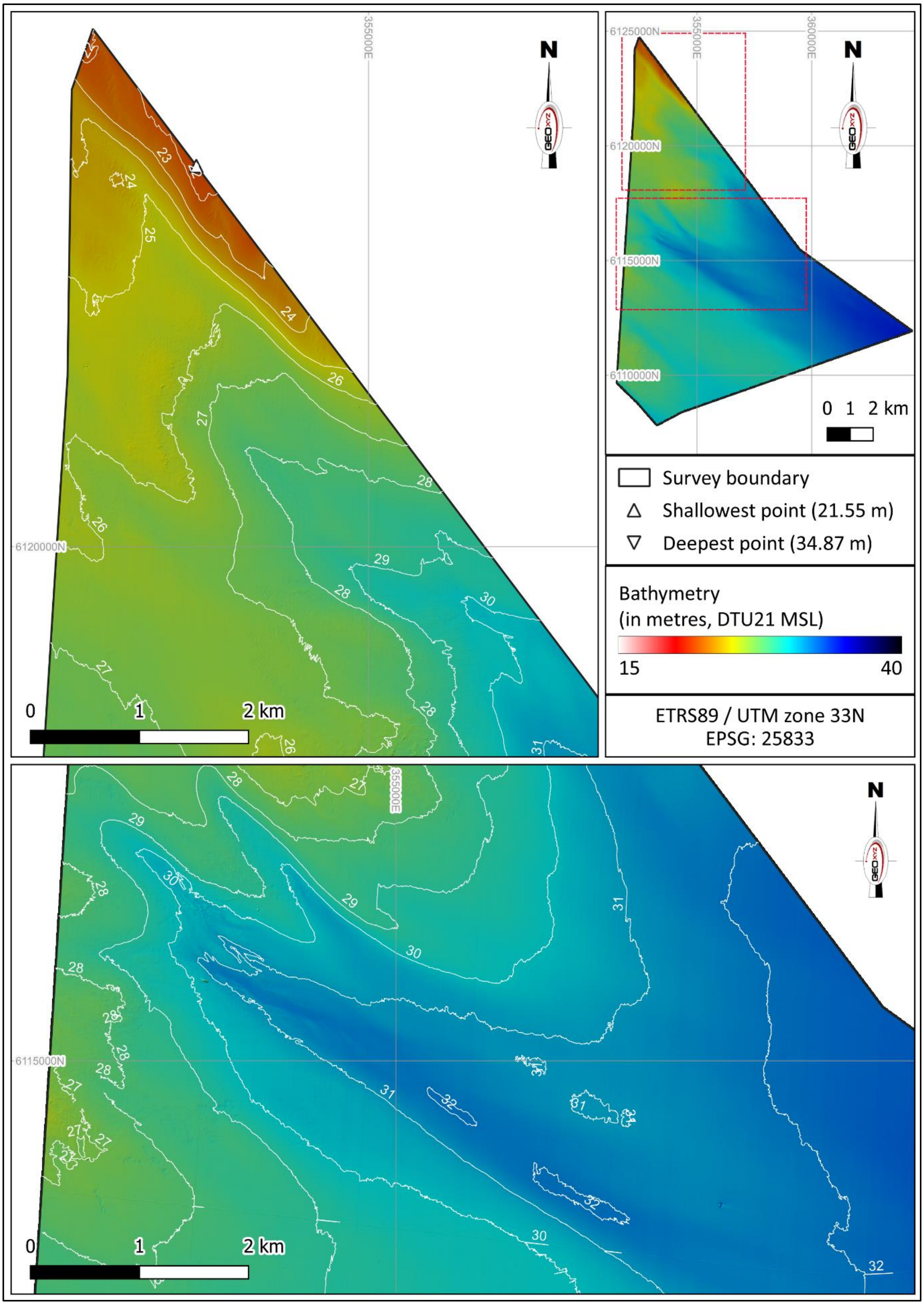


Figure 42: Detailed overview of bathymetry in the northern and central part of the survey area

Within the northern section of the site, to the north of approximately 6117650 mN, the seabed initially deepens from north-east to south-west and then from north-west to south-east, with seabed levels ranging from 21.8 m MSL to 31.4 m MSL (Figure 42, top chartlet). No steep slopes are present, with maximum gradients of < 1.0° noted.

To the south of approximately 6117650 mN, the seabed deepens very gently from north-west to south-east, with three slightly raised areas of seabed separated by broad (500 – 1500 m wide), NW-SE orientated, truncated channel features.

The raised areas only stand 2.0 m – 3.0 m higher than the surrounding seabed, with the northernmost raised area, centred at approximately 354270 mE, 6117775 mN, exhibiting a very localised slope gradient of up to 7.5°, deepening from north-west to south-east.

The truncated channel features are of variable width (~500 – 1500 m) and are very shallow, with maximum localised depths only 1.5 m – 2.5 m deeper than the surrounding seabed. Maximum slope gradients of up to 1.5° are present on the sides of these features.

The highest slope values (very steep slopes; >15°) are associated with seabed features such as boulders and cable trenches (top chartlet in Figure 43) as well as smaller elevated features and especially wrecks (as seen on various locations shown in the bottom chartlets in Figure 43).

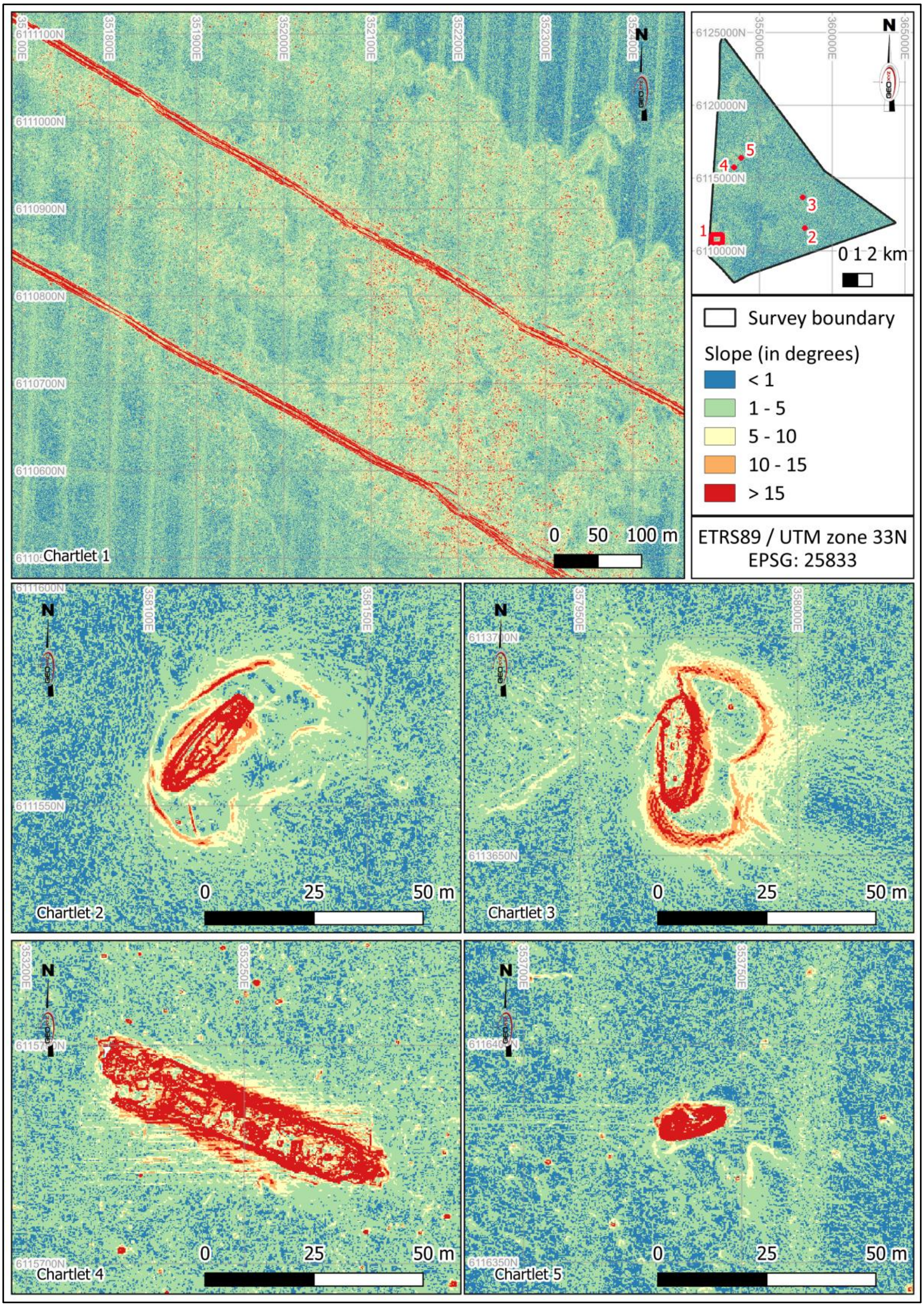
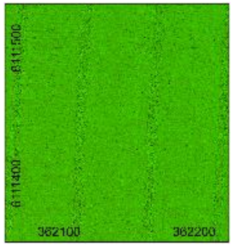
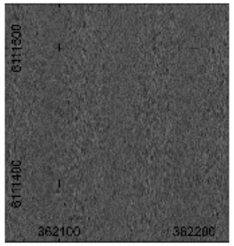
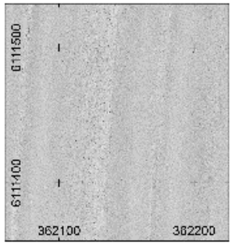
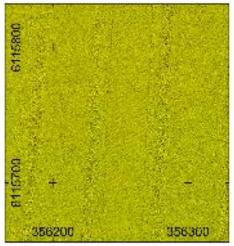
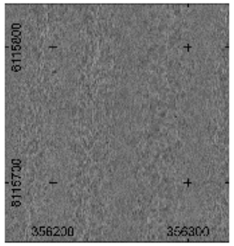
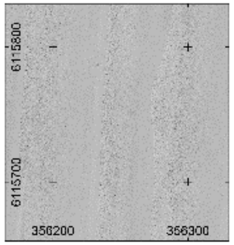
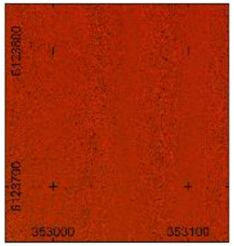
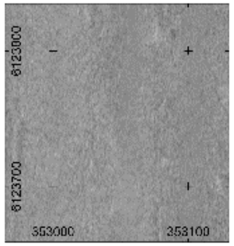
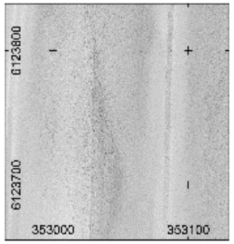
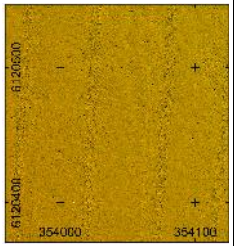
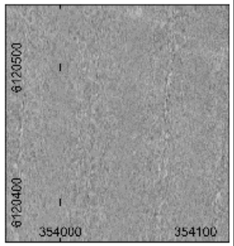
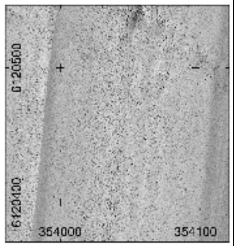


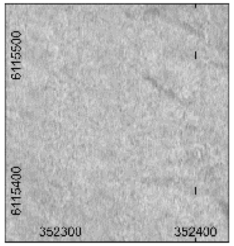
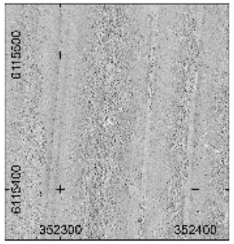
Figure 43: Slope map of several high-slope areas within the survey area

8.3 SEABED SURFACE CLASSIFICATION: GEOLOGY

The seabed geology for Kriegers Flak II North site was evaluated from the interpretation of the low and high frequency SSS data, the backscatter imagery and the MBES dataset. Data analysis and classification was performed using the seabed acoustic characteristics, such as reflectivity and backscatter strength, as well as the seafloor relief and the overall pattern. During the interpretation of the backscatter data, higher reflectivity areas – higher intensity sonar returns (darker grey to black colors) have been related to relatively coarse-grained sediments and lower reflectivity areas – lower intensity sonar returns have been related to relatively fine-grained sediments (Table 44). GEUS terminology was used to define the identified seafloor sediment in the survey area.

Table 44: Acoustic characteristics of the sediment types within the Kriegers Flak II North site

Geological interpretation	Colour and Code	Sediment interpretation	Acoustic description	MBES image	Backscatter image	SSS image
Mud and sandy mud	21	Predominately mud with minor to significant fractions of sand. May contain minor fractions of or gravel.	Low reflectivity, visible in BKS			
Muddy sand	13	Predominately sand with significant fractions of mud and muddy sand. May contain minor fractions of or gravel.	Low to medium reflectivity, visible in BKS			
Sand	12	Predominately sand. May contain minor fractions of mud and/or gravel.	Medium reflectivity, visible in BKS			
Gravel and coarse sand	11	Mixed sediment. Predominately gravel and sand. May contain mud.	Medium to high reflectivity. Patches of high reflectivity interspersed in areas of low to medium reflectivity, visible in BKS			

Geological interpretation	Colour and Code	Sediment interpretation	Acoustic description	MBES image	Backscatter image	SSS image
Till/diamicton	41	Mixed sediment. Constituents range between mud and boulders.	Low to high reflectivity. Patches of high reflectivity interspersed in areas of low to medium reflectivity, visible in BKS. Usually, positive relief in MBES data			

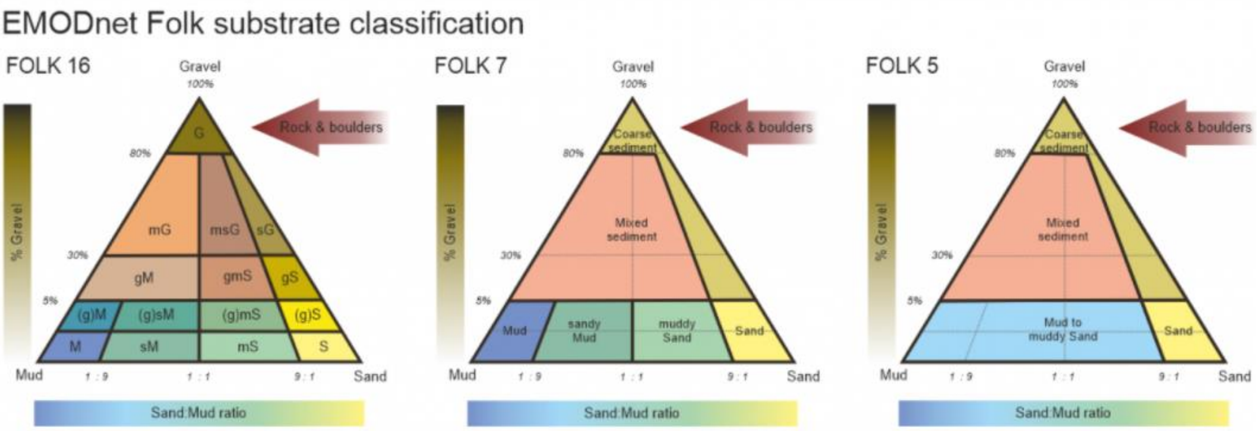
Bathymetric data aided the interpretation mainly in outlining of possible outcrops and the boulder field delineation.

The resultant seabed surface geology has been correlated to the soil description of the surficial grab samples and the onshore laboratory results. For the grab sample analysis, the definition of the particle sizes followed the Wentworth scale (Figure 44). For the needs of correlation, the results were further processed and reclassified, according to the Folk 7 classification system (Figure 45). For Sand, Muddy sand, and Mud and muddy sand seafloor sediment classes there is a direct correlation to the Folk 7 classification. Gravel and coarse sand, and till/diamicton sediment classes have been correlated to Mixed sediment grab samples and, for their separation, reflectivity, relief and sub-surficial geology have been considered. Finally, seafloor sediment classification has been integrated to the sub-seabed geology data. The resulting map is presented in Figure 46.

Major Grade	Phi (Φ) limits		Wentworth size class
	Lower	Upper	
gravel	<-8	-8	boulder
	-8	-6	cobble
	-6	-2	pebble
	-2	-1	granule
sand	-1	0	very coarse sand
	0	1	coarse sand
	1	2	medium sand
	2	3	fine sand
	3	4	very fine sand
mud	4	5	coarse silt
	5	6	medium silt
	6	7	fine silt
	7	8	very fine silt
	8	>8	clay

Scale by Wentworth (1922) classifying sediment particles according to the diameter expressed in units of N (phi, the negative log 2 of the diameter in millimeters).

Figure 44: Wentworth Scale – classifying sediment particles



FOLK, 16 classes	FOLK, 7 classes	FOLK, 5 classes
Rock & Boulders	Rock & Boulders	Rock & Boulders
Gravel - G	Coarse sediment	Coarse sediment *(Gravel >= 80% or (Gravel >= 5% and Sand >=90%)*
sandy Gravel - sG)		
gravelly Sand - gS		
muddy Gravel - mG	Mixed sediment	Mixed sediment *(Mud 95-10%; Sand < 90%; Gravel >= 5%)*
muddy sandy Gravel - msG		
gravelly Mud - gM		
gravelly muddy Sand - gmS		
(gravelly) Mud - (g)M	Mud *(Mud >= 90%; Sand < 10%; Gravel < 5%)*	Mud to muddy Sand *(Mud 100-10%; Sand < 90%; Gravel < 5%)*
Mud - M		
(gravelly) sandy Mud – (g)sM	sandy Mud *(Mud 50-90%; Sand 10-50%; Gravel < 5%)*	
sandy Mud - sM		
(gravelly) muddy Sand – (g)mS	muddy Sand *(Mud 10-50%; Sand 50-90%; Gravel <5%)*	
muddy Sand - mS		
(gravelly) Sand – (g)S	Sand *(Mud < 10%; Sand >= 90%; Gravel < 5%)*	Sand
Sand		

Figure 45: EMODNET Folk substrate classification

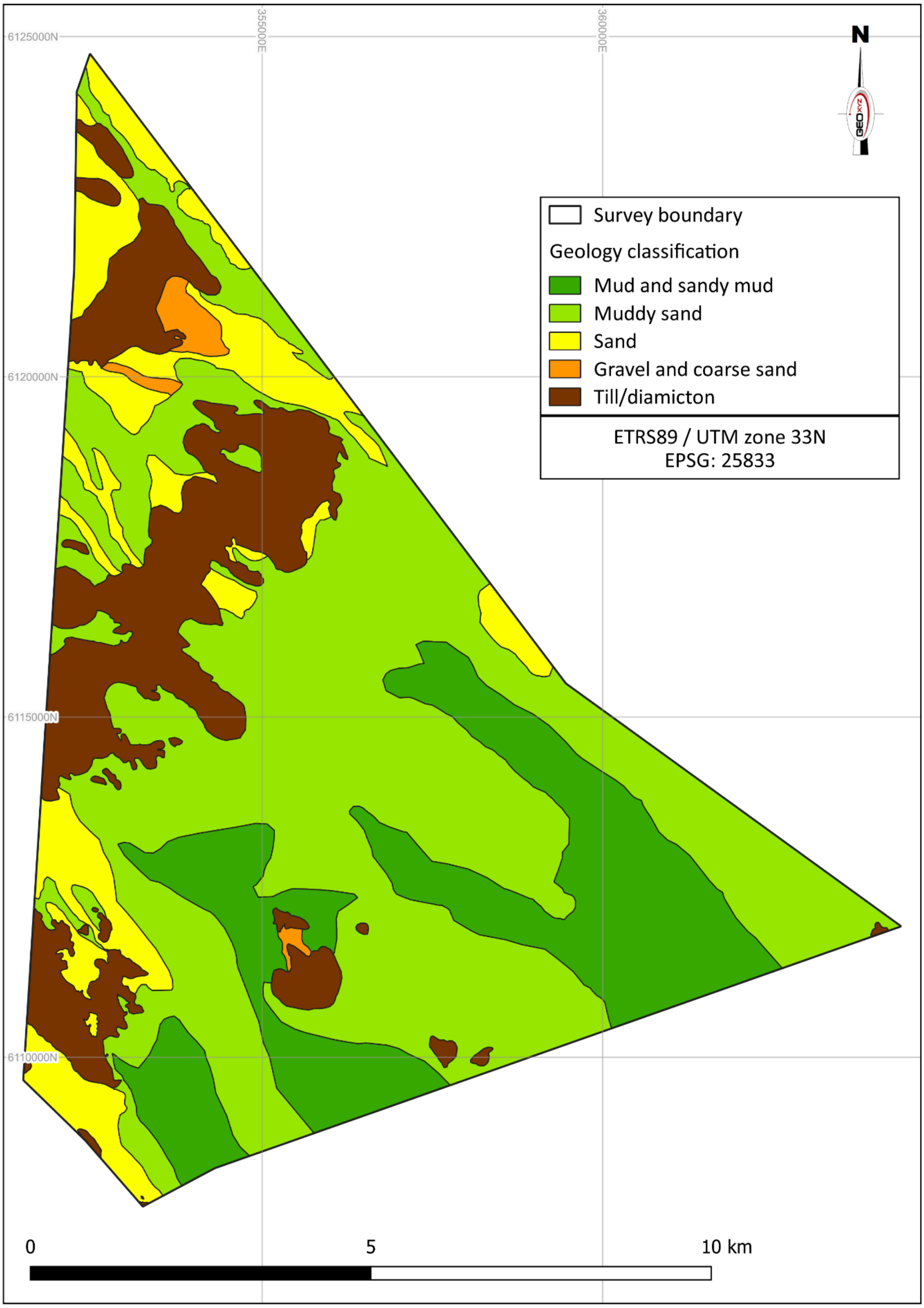


Figure 46: Seabed surface geology classification - Kriegers Flak II North

Muddy sand is predominant in Kriegers Flak II North site, with restricted regions in the northern part and widely extended areas across the north-central, central and south-central part.

The seabed sediments across the north-western section of the site comprise a series of large, irregular outcrops of till/diamicton, surrounded by large, irregular areas of sands and muddy sands (silty, clayey sands). Several coarser patches of gravel and coarse sands are also present in restricted areas in the northern part of this section.

The seabed sediments across the south-eastern section of the site comprise mainly muddy sands (silty, clayey sands). To the south-east, the seabed sediments appear finer-grained, comprising areas of muds (silts/clay) and sandy muds (sandy silts/sandy clays), one of which extends into the north-western section of the site. A number of relatively minor areas of outcropping till/diamicton as well as restricted areas of gravel and coarse sands are present, mainly near the southern border of the site.

8.4 SEABED SURFACE CLASSIFICATION: MORPHOLOGY

Seafloor morphology and seabed feature descriptions were based on the interpretation of SSS, BKS and MBES datasets whereas the results from the SBP have been considered. The resulting seabed surface morphology interpretation is presented in Figure 47 below. Some of them are the result of variable geological environment and past and present hydrodynamic conditions within the regime of sea level fluctuations (e.g., areas of boulders, ripples, etc.) whereas others have anthropogenic origin (e.g., trawl marks).

The acoustic characteristics of the interpreted seabed features across the Kriegers Flak II North area are summarized in Table 46.

The boulder field identification criteria for the survey are outlined in Technical Query TQ-009. Seabed objects, including boulders > 0.5 m in any direction were interpreted and classified. Areas with high boulder densities were provided as POL delineated from the SW projects and classified as per Table 47 below. Individual boulders within the boulder fields were picked using the automatic boulder picking algorithm, as outlined in the Processing Report. Debris objects larger than 0.5 m in any direction within the boulder fields were isolated from the auto-picked boulder fields and further investigated.

Table 45: Boulder field classification

Boulder density	Classification	Description
Intermediate	Class 1	Concentration of 40 – 80 boulders within an area of 100 x 100 m
High density	Class 2	Concentration of > 80 boulders within an area of 100 x 100 m

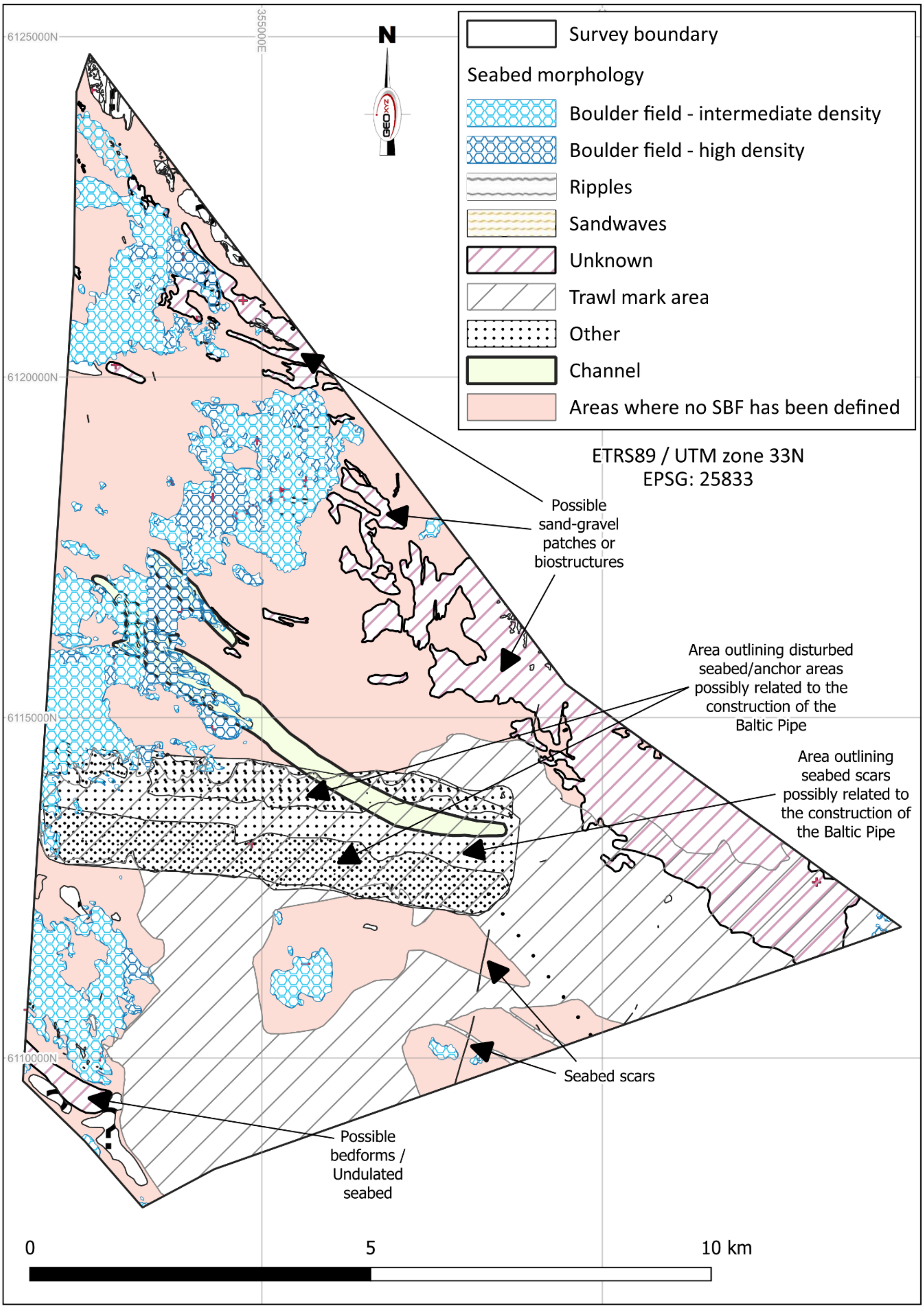
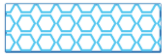
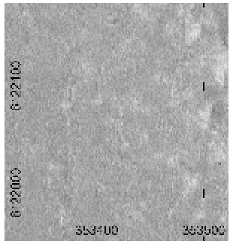
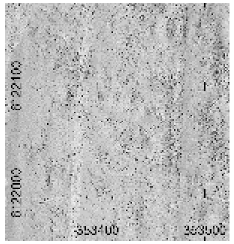
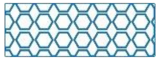
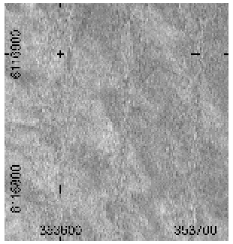
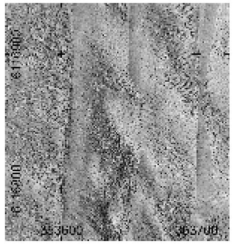
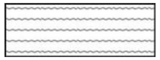
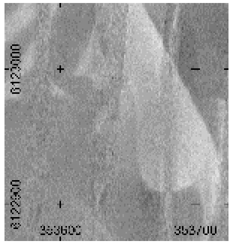
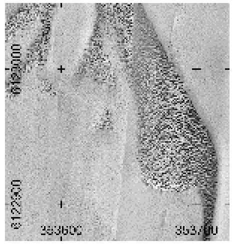
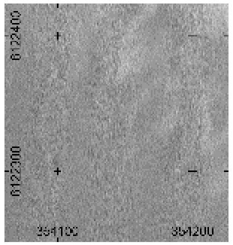
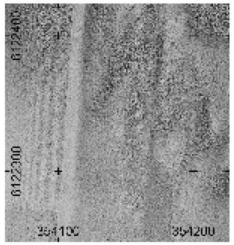
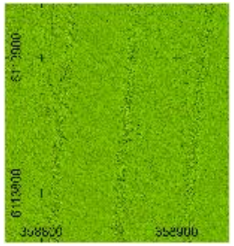
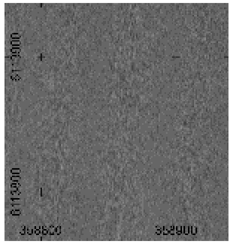
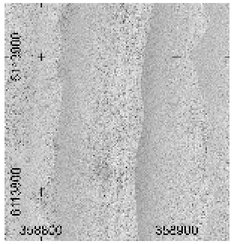
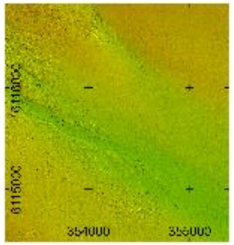
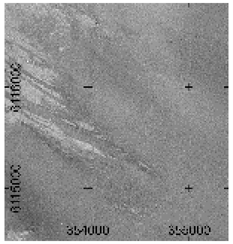
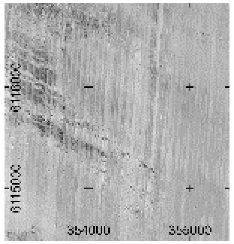
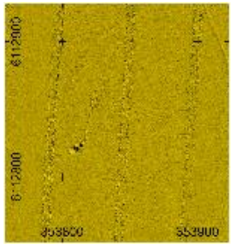
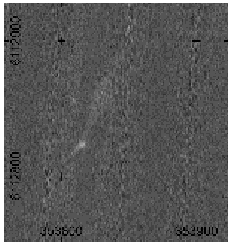
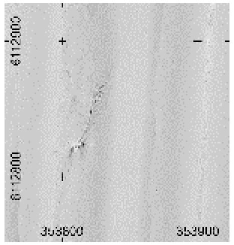
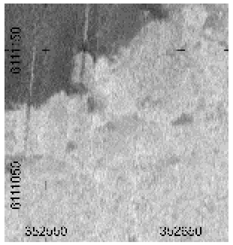
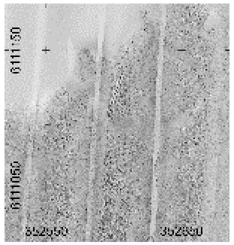
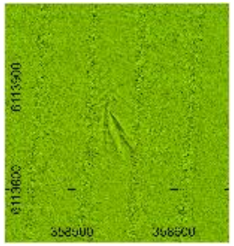
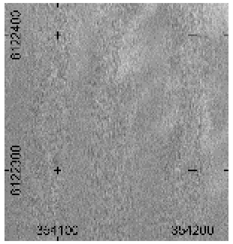
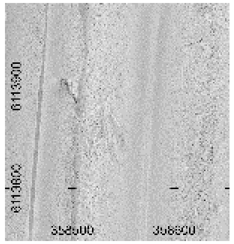
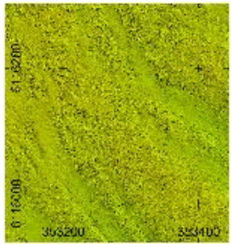
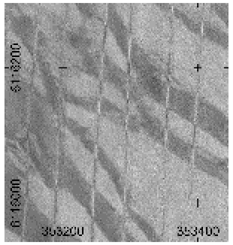
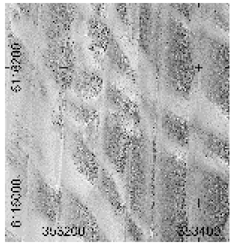
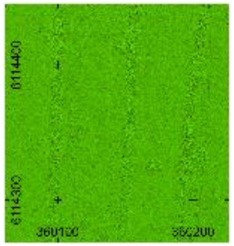
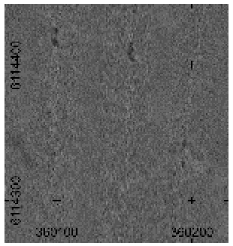
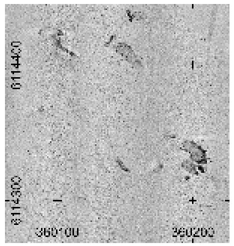
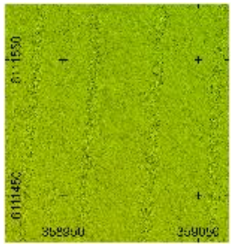
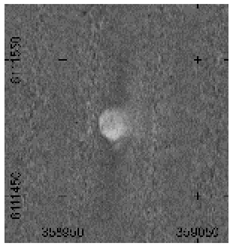
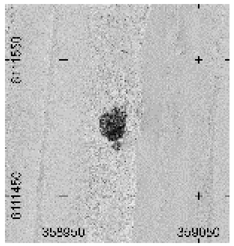


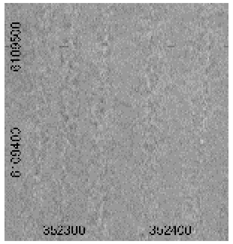
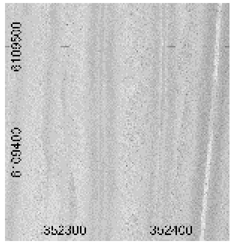
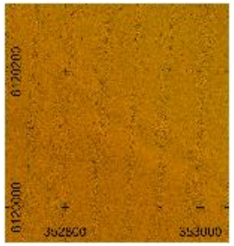
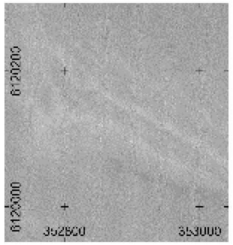
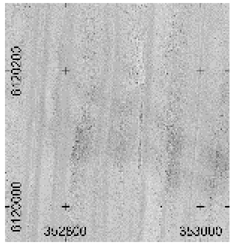
Figure 47: Seabed surface morphology classification

Table 46: Morphological interpretation

Seabed Feature	Symbology	Description	MBES image	Backscatter image	SSS image
Boulder Field – intermediate density (Class 1)		High reflectivity contacts of intermediate density (40 to 80 boulders in a 100 x 100 box), visible in MBES			
Boulder Field – high density (Class 2)		High reflectivity contacts of high density (more than 80 boulders in a 100 x 100 box), visible in MBES			
Ripples		Low to high reflectivity alternating areas. Visible in MBES. Wavelength, 0.5 – 1.5 m			
Sandwaves		Low to high reflectivity alternating areas. Visible in MBES. Wavelength, 5 m – 160 m. (Outlined polygons as well as linear features - sandwave crest)			

Seabed Feature	Symbology	Description	MBES image	Backscatter image	SSS image
Trawl Marks		Low to medium reflectivity linear features, visible in MBES			
Channel		Low to high reflectivity elongated area, visible in MBES and BKS			
Other – Seabed scars/disturbed seabed possibly related possible related to offshore operation activities (Baltic Pipe)		Low to medium reflectivity, visible in MBES. (Mapped area features – disturbed seabed, as well as linear features – seabed scars)			
Other – Seabed scars		Low to medium reflectivity, appear as elongated area, visible in MBES			

Seabed Feature	Symbology	Description	MBES image	Backscatter image	SSS image
Other – Scour pattern		Low to medium reflectivity linear scars forming a pattern, visible in MBES			
Other – Seabed scours within channel area		Low to high reflectivity. Clearly distinguishable in BKS and MBES			
Unknown – Possible Sand-Gravel patches or biostructures		Low reflectivity with irregular high reflectivity patches, distinguishable in SSS, MBES and subtle appearance in BKS			
Unknown - Eight linearly aligned along NW-SE direction, almost rounded shaped features		High reflectivity circular objects, distinguishable in SSS and BKS			

Seabed Feature	Symbology	Description	MBES image	Backscatter image	SSS image
Unknown – Possible bedforms / Undulated seabed		Low reflectivity, hardly noted in SSS, visible in MBES			
Unknown – Possible bedforms or erosional features		Low to moderate reflectivity areas, unclear in SSS, visible in MBES and distinguishable in BKS			

The intermediate density boulder fields are mostly outlined in the western half of the Kriegers Flak II North site, generally engulfing the boulder fields Class 2 (Figure 47).

Areas with ripples are observed at the northeastern edge and within few areas in the southern corner of the survey site. Some of these ripple areas occurred within till/diamicton area. Their wavelength varies between 0.5 m and 1.5 m. Similarly, areas with sandwaves are present at the northern and southern edge of the survey area. Their wavelength varies between 12 m and 16 0m. Occasionally, ripples are noted within the trough areas of the sandwaves.

A poorly defined channel is traced in the western centre of the Kriegers Flak II North site, with a NW-SE orientation. A smaller channel section with the same orientation is also observed slightly northwards of the main channel (Figure 47). Extended scours are observed in the western parts of both channel features. Their morphology as well as their position near the till/diamicton outcrop limits possibly imply an iceberg gouging origin.

Fishing activity with scattered trawl marks of different orientations are outlined in the southern half of the survey area (Figure 47).

Seabed scars and disturbed seabed areas (linear - seabed scars and polygon - disturbed seabed) are probably related to the construction of the Baltic Pipe as both features have been mapped in the vicinity of the pipeline (compare Figure 47 and Figure 60). The seabed scars are noted in various orientations and are likely caused by the anchor pattern from the construction barge during the Baltic pipeline laying operation. Aside from seabed scars associated with offshore activities, there are seabed scars observed in the survey area which are likely formed by natural or anthropogenic processes. Most of those features are not prominent in the SSS data but they have been mapped in the MBES data due to the measurable depth difference.

Within the Kriegers Flak II North site, there are five areas of scour pattern observed in the northern and eastern part of the site. All scour patterns are likely resulting from anchor chain abrasion on the seafloor during a vessel swing caused by wind and currents.

Possible sand-gravel patches or bio-structures are outlined in the northeastern part of the site (Figure 47). They are displayed as low reflectivity areas with numerous randomly scattered small to medium sized patches of high reflectivity. Those patches are identifiable on the SSS and the MBES records where the elevation difference is less than 10 cm approximately. The BKS data shows subtle patches of high intensity that tied well with the SSS high reflectivity patches. The latter could imply the present of coarse sediment (sand/gravel) or more likely the presence of bio-structures and the formation of benthic aggregations. Similar characteristics regarding MBES elevation and SSS imagery with patches, have been reported in relevant literature (e.g., Rabaut et al. 2009). The interpretation of this feature is uncertain.

Eight linearly aligned features with a NNW-SSE orientation are observed in the southeastern part of the site. Most of these features appear in rounded shape and are spaced 310 m to 400 m apart. The SSS reflectivity noted on these features is high and it is distinguishable in the BKS data. However, they are hardly visible in the MBES data. Their diameter is ranging from 24 m to 29 m. They have been interpreted as possible flat lying footprint left by offshore operation activities. The interpretation of this feature is uncertain.

An area of possible bedforms – undulated seabed, is observed in the southern part of the Kriegers Flak II North site. This area is barely distinguishable in the SSS data, but it is clearly visible in the MBES record. It is likely formed by the sea bottom currents, over sandy seafloor. The interpretation of this feature is uncertain.

In the survey area, an elongated area of alternating low to medium reflectivity, within an area of sand, gravel, and pebble substrate, is present (Figure 47). This WNW-ESE orientated feature has a difference in elevation of 0.7 m approximately. It is interpreted as possible bedforms related to bottom currents at a gentle slope seafloor, but it could also be related to erosional processes. The interpretation of this feature is uncertain.

8.4.1 Boulder field identification criteria

The boulder field identification criteria for the survey are outlined in Technical Query TQ-009. Seabed objects, including boulders > 0.5 m in any direction were interpreted and classified. Areas with high boulder densities were provided as POL delineated from the SW projects and classified as per Table 47 below. Individual boulders within the boulder fields were picked using the automatic boulder picking algorithm, as outlined in the Processing Report. Debris objects larger than 0.5 m in any direction within the boulder fields were isolated from the auto-picked boulder fields and further investigated.

Table 47: Boulder field classification

Boulder density	Classification	Description
Intermediate	Class 1	Concentration of 40 – 80 boulders within an area of 100 x 100 m
High density	Class 2	Concentration of > 80 boulders within an area of 100 x 100 m

8.5 SEABED SURFACE CLASSIFICATION: MAN-MADE FEATURES

Through the interpretation of the MBES, SSS, and MAG datasets, a total of 548 targets were identified within the Kriegers Flak II North site. An overview of the seabed surface objects is presented in Table 48 below. A total of 67 metallic objects were found within the survey area. Those objects were found as a single object, linear object, or a cluster of objects. Examples of metallic objects are presented in Figure 48 and Figure 49.

Table 48: Summary of man-made objects

Feature type	Total amount	Comment
Wrecks	8	A total of five unknown wrecks and three possible wrecks were found.
Cable and pipeline	<u>40 targets for 5 cables</u>: DK-RU 1, Baltic Cable, HK22008 Kriegers Flak BE-Rødvig, HK22007 A-Rødvig, Unknown-1 <u>5 targets for 1 pipeline</u>: Baltic pipeline	Two cables (Roedvig-Roenne & Unknown-2) were not found. Potentially, an Unknown-3 cable was found during survey.
Metallic	67	67 metallic contacts were found within a 5 m radius of a magnetic anomaly.
Soft Rope	20	20 contacts are related to possible soft rope item.
Other	408	A total of 408 sonar contacts were found.

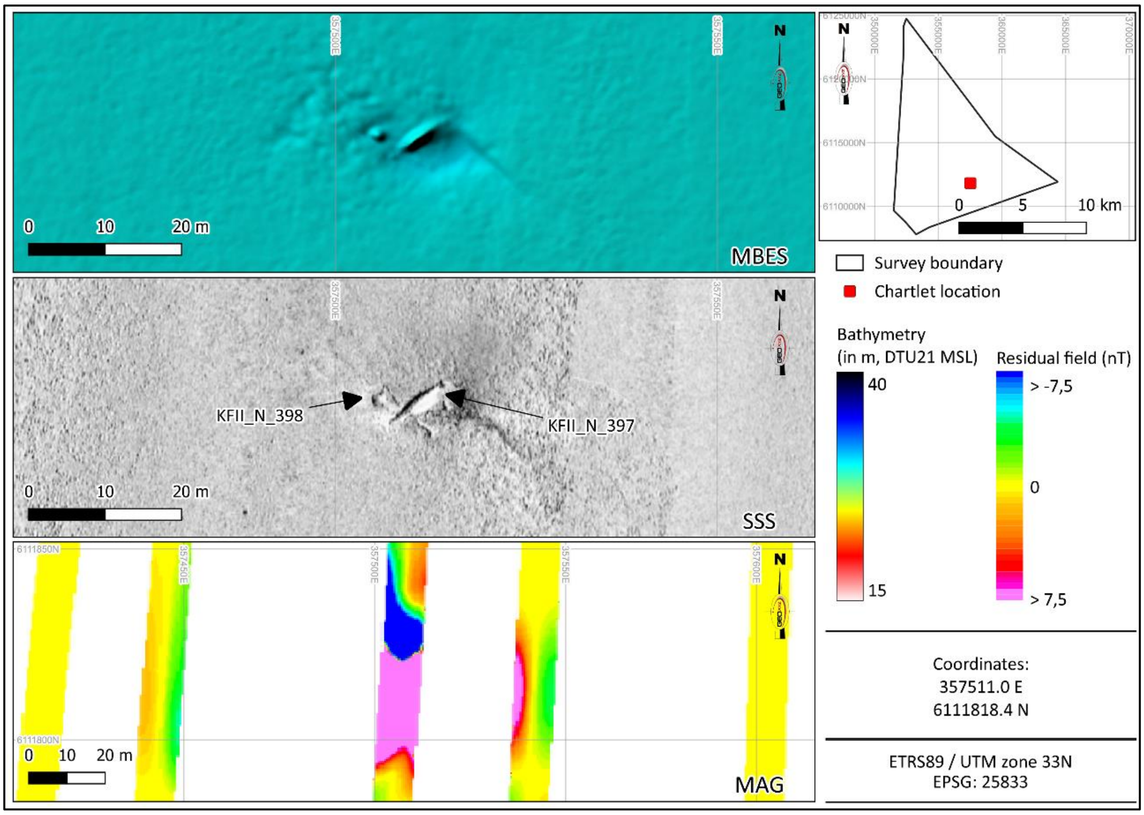


Figure 48: Data examples of a single metallic object (KFII_N_398) and a linear metallic object (KFII_N_397)

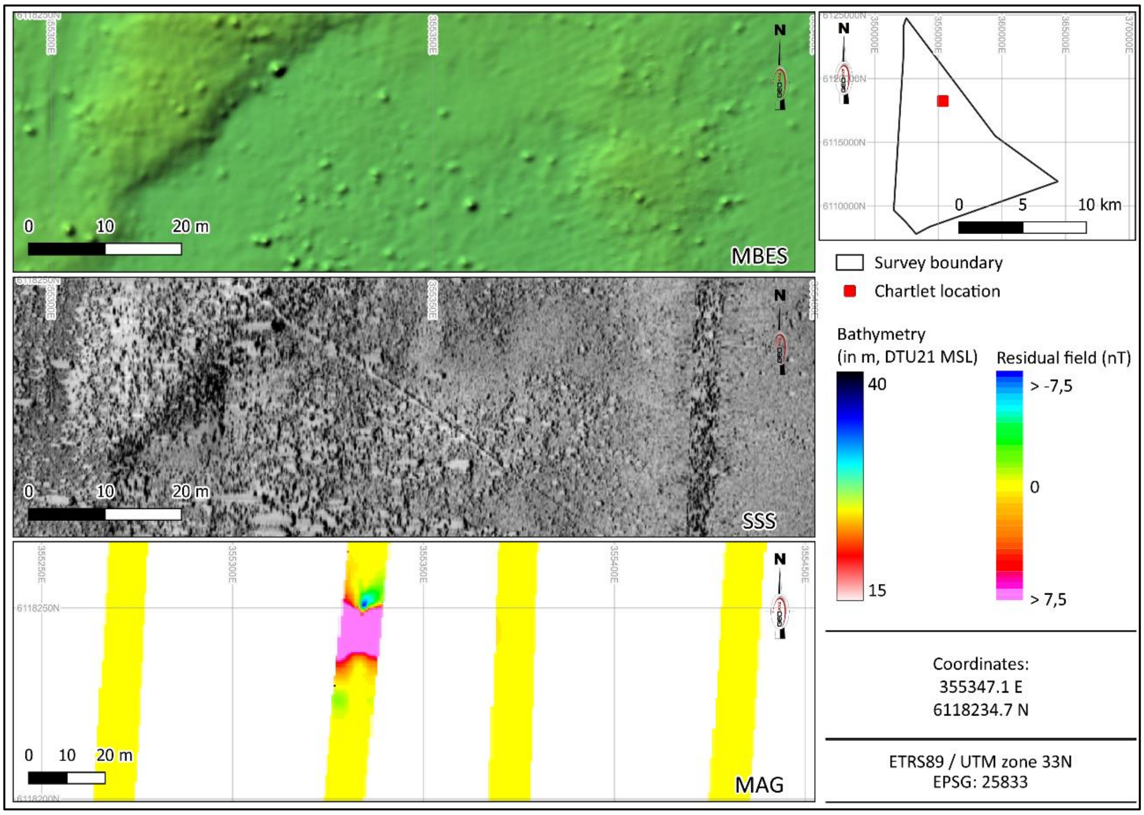


Figure 49: Data example of a linear metallic object (KFII_N_294)

A total of 408 sonar contacts were observed within the survey area. Figure 50 displays an example of a sonar contact found within 10 m of a magnetic anomaly. The latter could potentially be a ferrous object. The rest of the sonar contacts show high reflectivity but are not interpreted as debris.

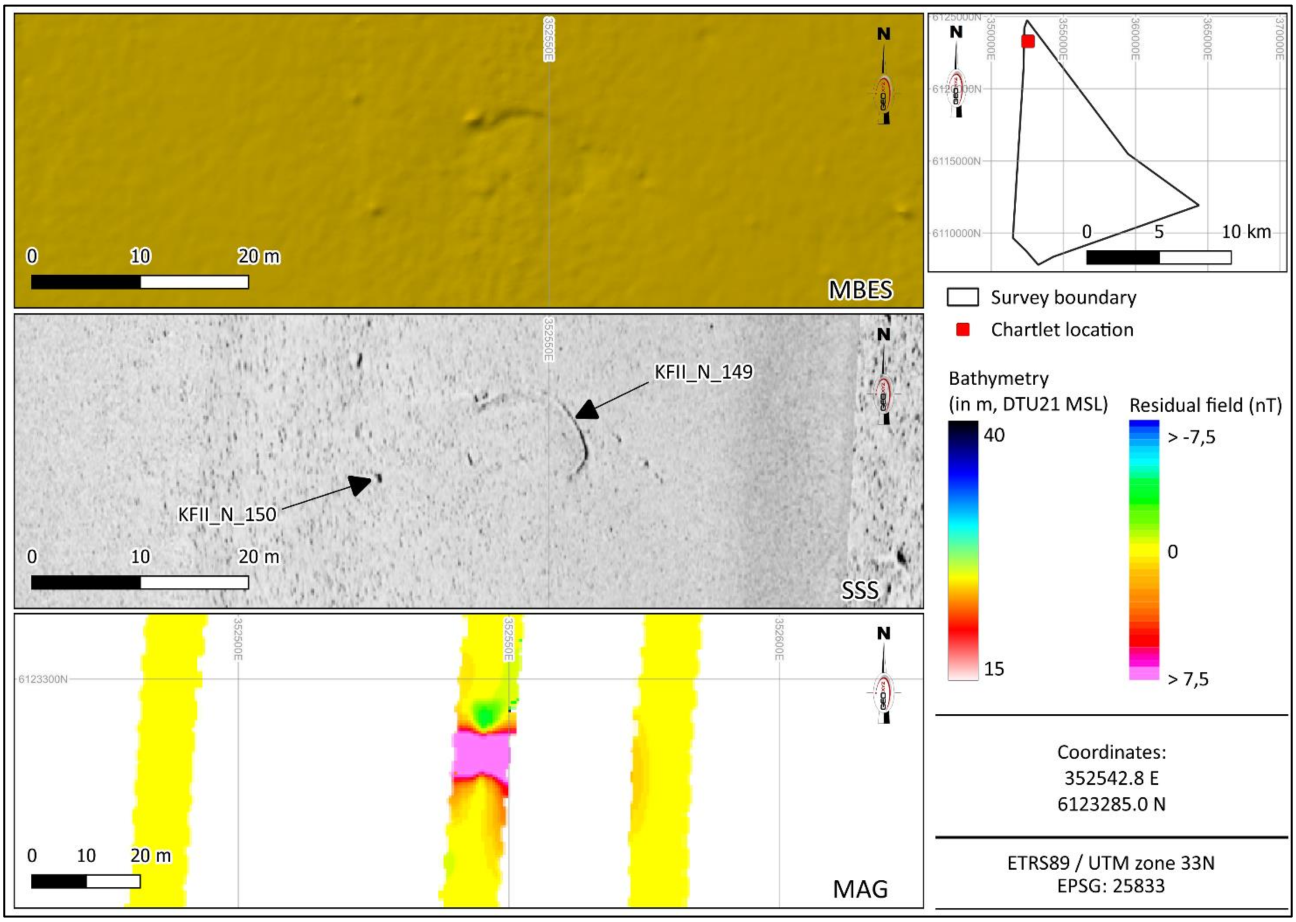


Figure 50: A metallic object (KFII_N_150) with a possible sonar contact (KFII_N_149) noted in close proximity (10 m) of a magnetic anomaly (KFII_N_B01_MAG_G06_0175)

Figure 51 presents an example of possible linear object identified within the Kriegers Flak II North site. There was no discernible linear magnetic response detected for all the linear objects. Some of these linear objects displayed a strong and sharp shadow in the SSS dataset which indicates a possible man-made object with significant height.

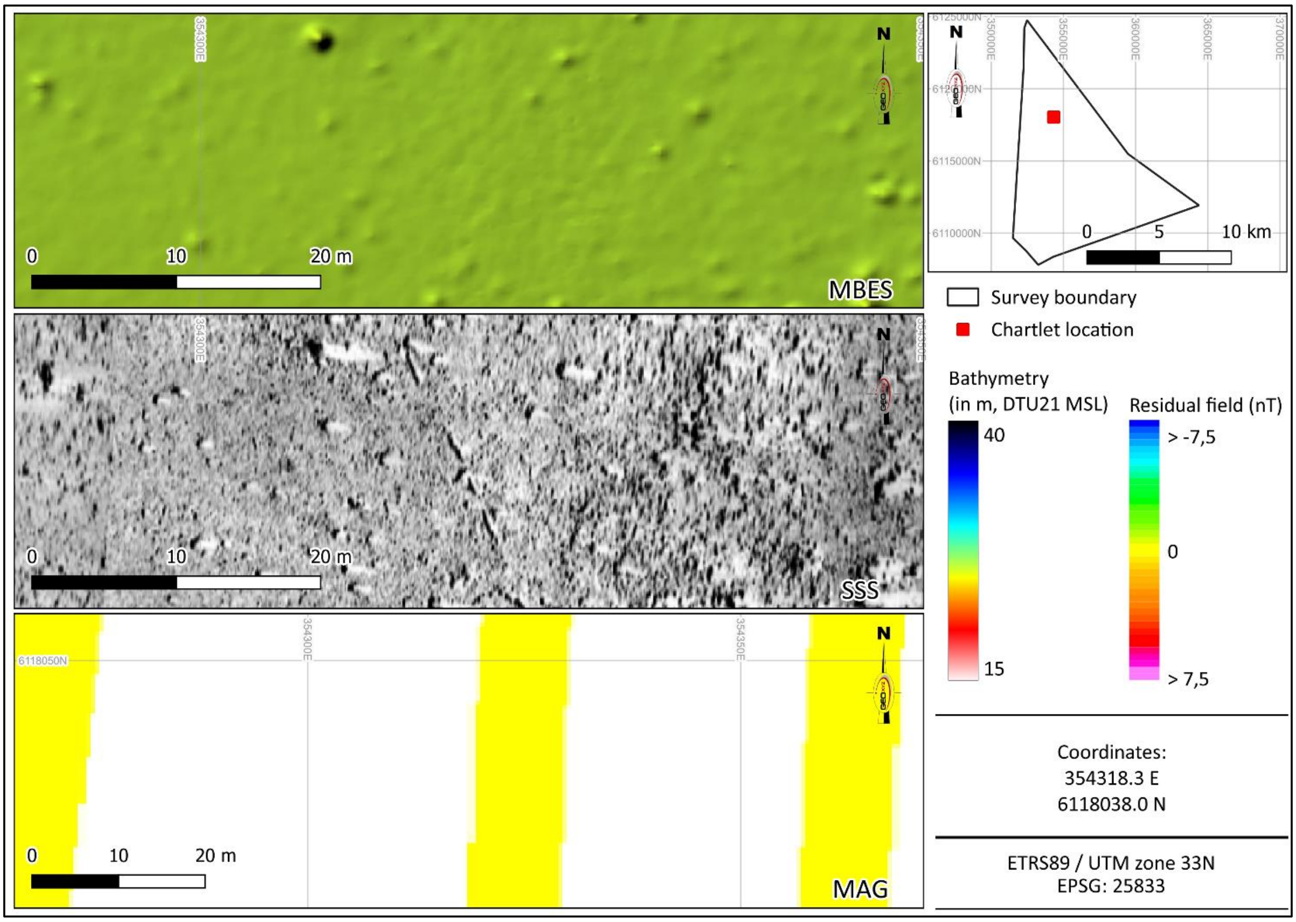


Figure 51: Data example of a possible linear object (KFII_N_196)

8.5.1 Archaeological findings

GEOxyz is not specialized in providing archaeological services. As such, the findings in this report are based on an interpretation of data which is a matter of opinion on which professionals may differ.

8.5.2 Wrecks and possible wrecks

A total of five wrecks and three possible wrecks were identified across the Kriegers Flak II North area, with an additional wreck located in close proximity of the survey area. The wrecks within the Kriegers Flak II North area are of unknown identity. Their locations are presented in Table 49 below. Of all the shipwrecks identified, four shipwrecks have not been detected by the magnetometer. This is likely due to the large distance between the wreck and the magnetic survey line. In the latter case, there are no intersects between the wreck and the magnetic survey lines for MMO ID KFII_N_033, KFII_N_034 & KFII_N_093. Aside from the distance, there is also a possibility that the shipwreck is not a ferrous metal wreck but rather a wooden shipwreck that generates a weak magnetic response even if the survey line intersects or is in close distance to the shipwreck (MMO ID KFII_N_392).

Table 49: Wrecks identified within the Kriegers Flak II North area and in its close proximity (wreck*)

MMO ID	Description	Wreck Name	Easting (m)	Northing (m)	Length (m)	Width (m)	Max. Height (m)	WD (m)	Comments
-	*Wreck* outside survey area*	*unknown*	*359614.0*	*6110155.0*	*10.2*	*3.2*	*1.4*	*30.0*	*Outside the survey boundary, 84 m to the south. Largely intact wreck. No magnetic signature*
KFII_N_033	Wreck	unknown	352608.2	6110452.7	28.0	9.2	1.8	27.5	Largely broken wreck. Small magnetic signature
KFII_N_093	Wreck	unknown	352413.6	6121655.1	19.1	7.2	1.5	25.3	Largely broken wreck. Small magnetic signature
KFII_N_122	Wreck	unknown	352175.7	6114095.5	16.4	7.5	2.6	27.3	Possibly upturned wreck. Very large magnetic signature.
KFII_N_034	Wreck	unknown	352226.3	6109232.4	18.5	6.0	1.4	28.9	South of survey boundary. Largely intact wreck. Possible wooden wreck. Very small magnetic signature.
KFII_N_018	Wreck	unknown	353251.1	6115728.9	71.0	11.6	5.0	30.1	Largely intact wreck. Very large magnetic signature.
KFII_N_202	Possible wreck	unknown	353738.5	6116381.0	16.4	7.0	4.5	29.5	Large magnetic signature.
KFII_N_392	Possible wreck	unknown	358114.4	6111563.6	27.2	7.9	3.3	30.1	Largely intact wreck. Very large magnetic signature.
KFII_N_414	Possible wreck	unknown	357972.4	6113673.8	27.0	7.7	2.9	32.9	Largely intact wreck. Large magnetic signature.

Wreck* outside the survey area

This wreck lies approximately 84 m to the south of the site boundary line.

As the wreck falls outside the survey area only general details were visible in the MBES data. Measurements were taken from the profiles and found to be 10.2 m x 3.2 m x 1.4 m (L x W x H). The water depth at the site is around 30 m.

Wreck KFII_N_033

Figure 52 presents the location of the unidentified wreck KFII_N_033.

This unknown wreck is located at 352608.2 E, 6110452.7 N and lies in WD of ~27.5 m, with dimensions of 28.0 m x 9.2 m x 1.9 m (L x W x H). The surrounding seabed is essentially a boulder field.

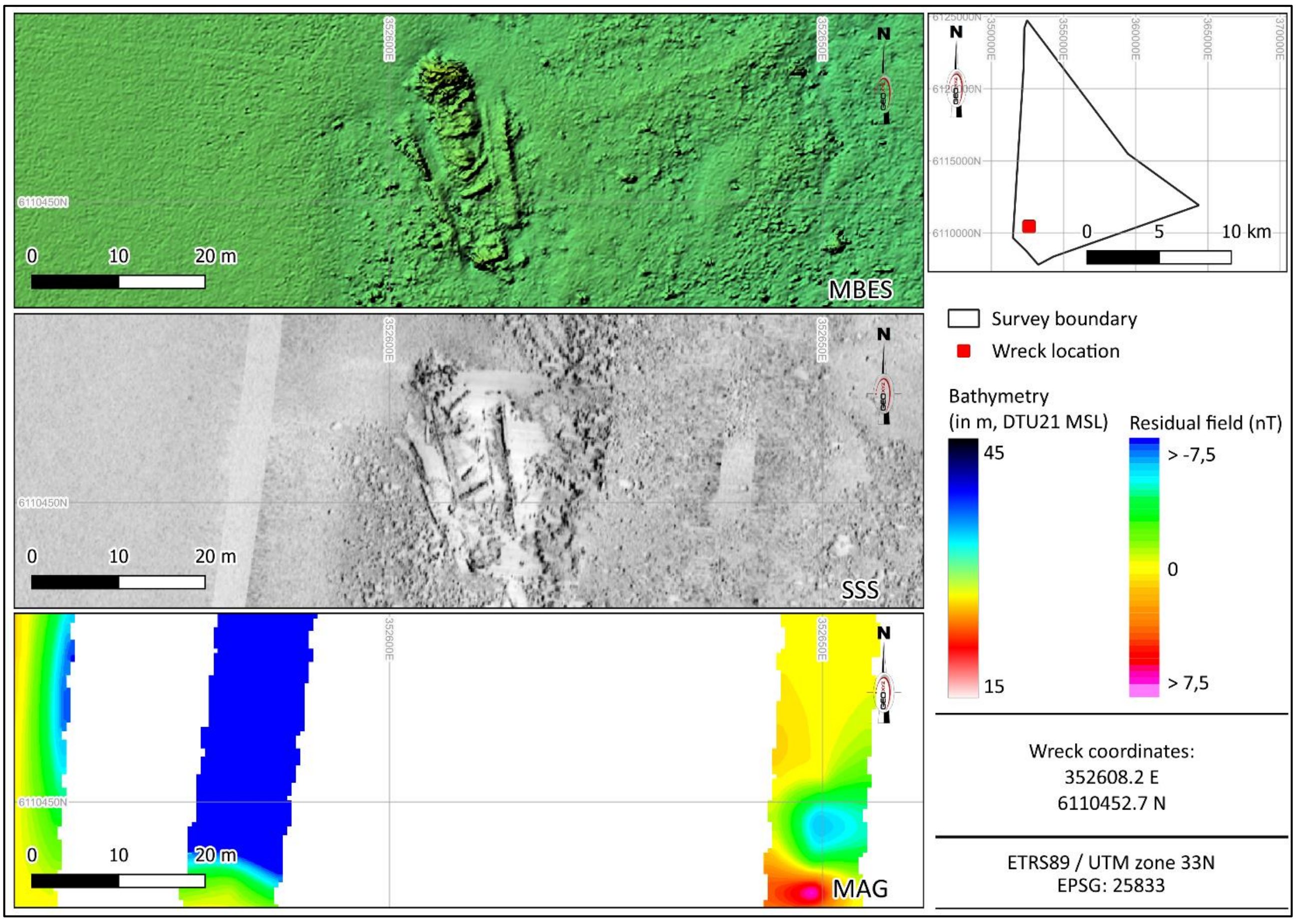


Figure 52: Location of wreck KFII_N_033

It appears that the vessel is in an upright position on the seabed, the stern with the wheelhouse at the top and bow pointing down. Adjacent to the hull are two booms, one on either side.

A MAG anomaly of about 50 nT is located on top of the feature.

Wreck KFII_N_093

Below is an overview of the location of the unidentified wreck KFII_N_093 (Figure 53).

This unknown wreck located at 352413.6 E, 6121655.1 N lies in WD of ~25.3 m, with the dimensions as follows: 29.1 m x 7.2 m x 1.5 m (L x W x H). Debris items lie close to the wreck, which lies upright on a flat seabed.

The vessel appears to be in an upright position on the seabed, with a mast extending from the bow. The seabed appears to be near featureless, with minimal small ripples.

The feature has a small anomaly of about 5 nT (peak to peak) confirming that part of the wreck is metallic.

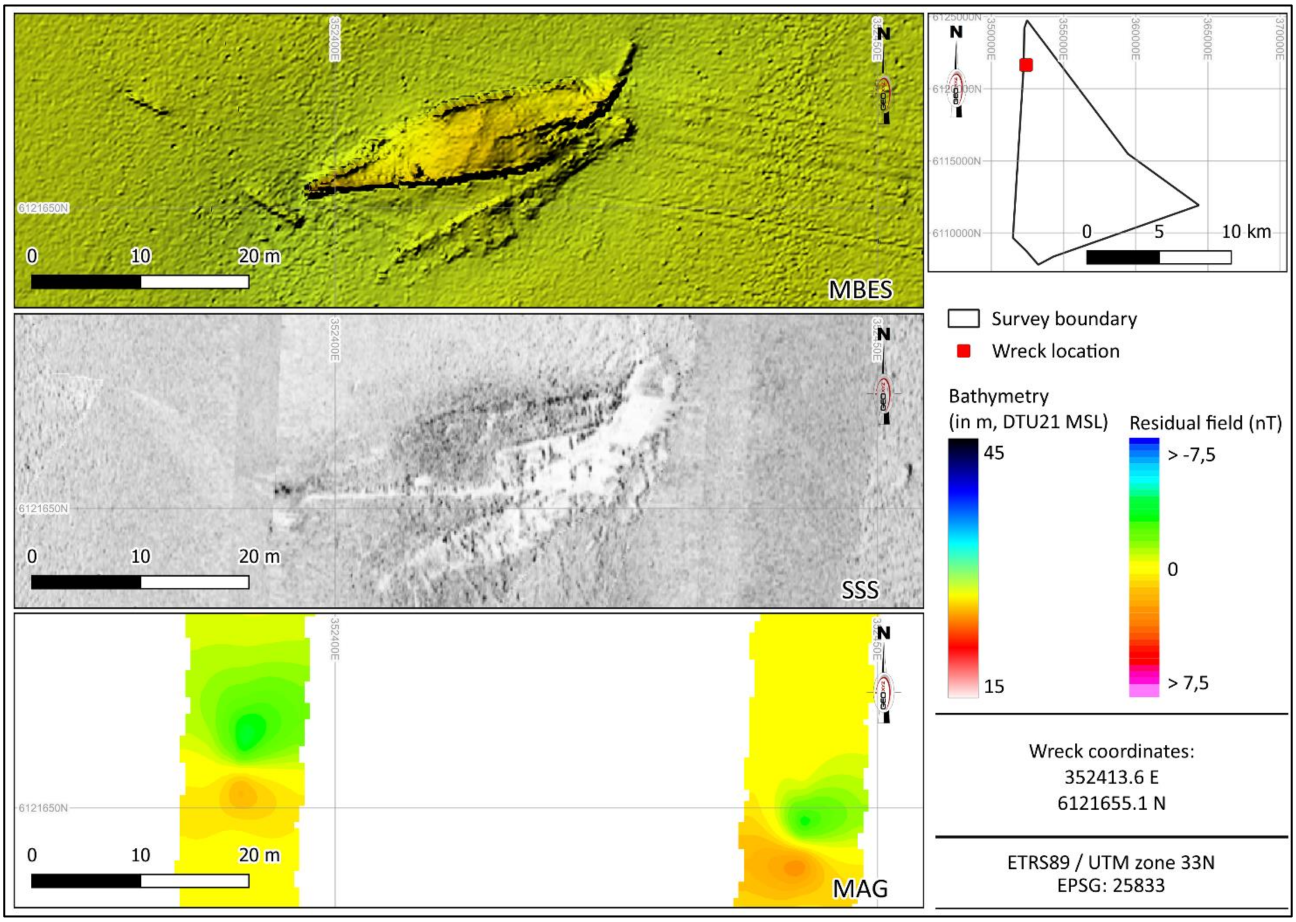


Figure 53: Location of wreck KFII_N_093

Wreck KFII_N_122

Figure 54 below displays an overview of the location of the unidentified wreck KFII_N_122.

This wreck is located at 352175.7, 6114095.5N, approximately 161 m north of the Baltic pipe in WD of ~27.3 m. The dimensions are as follows: 16.4 m x 7.5 m x 2.6 m (L x W x H). There appear to be some debris items close to the wreck.

It appears that the vessel is in an upturned position on the seabed. The seabed appears to be near featureless with minimal small ripples.

The mag profile over the wreck displays a massive anomaly of >5700 nT (peak to peak) which can only be associated with a metallic wreck.

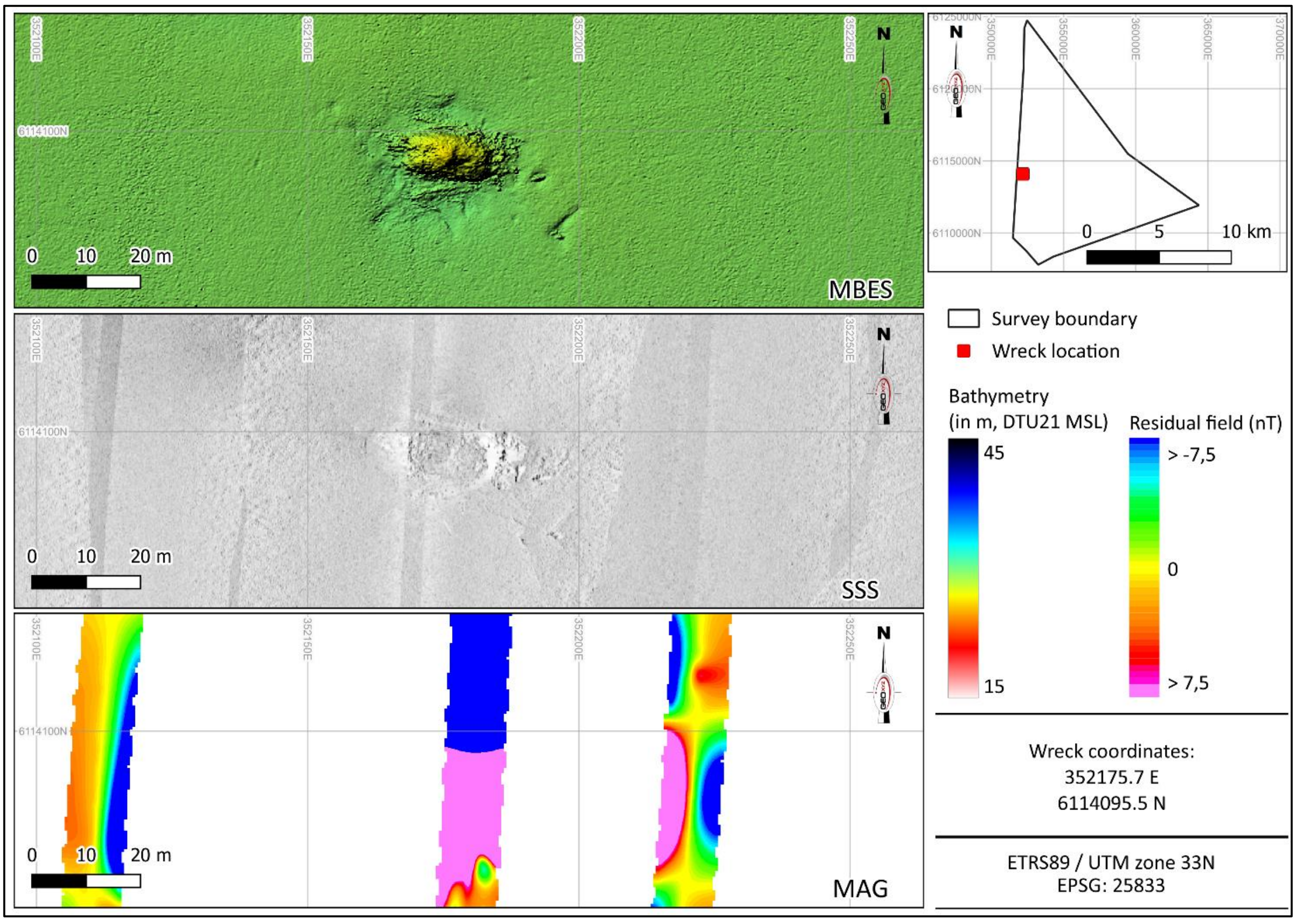


Figure 54: Location of wreck KFII_N_122

Wreck KFII_N_034

Figure 55 below displays an overview of the location of the unidentified wreck KFII_N_034.

This wreck is located at 352226.3E, 6109232.4N, in WD of ~28.9 m. The dimensions are as follows: 18.5 m x 6.0 m x 1.4 m (L x W x H). There are some small debris items lying close to the wreck.

The vessel is in an upright position on the seabed with the bow towards the west. There appears the be a cross beam spanning from the one side of the hull to the other side, as well as a rectangular object at an angle. The seabed around the wreck is flat, with no significant features.

The mag profile over the wreck has an anomaly of ~9 nT (peak to peak), which indicates that this wreck could be made of wood and was fitted with some metal items, like an anchor/chain and a metal chest.

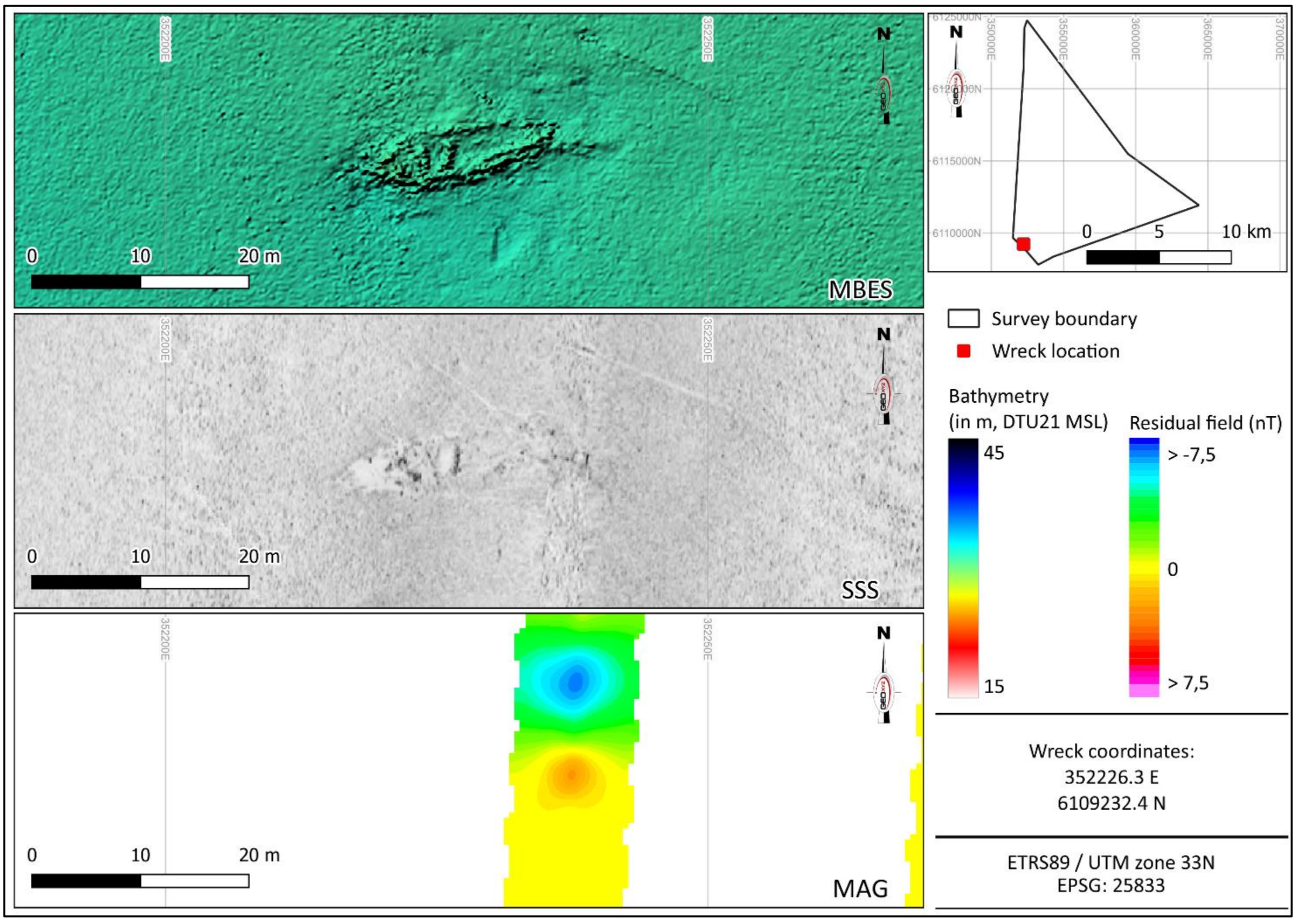


Figure 55: Location of wreck KFII_N_034

Wreck KFII_N_018

Figure 56 below displays an overview of the location of the unidentified wreck KFII_N_018.

This wreck is located at 352251.1 E, 6115728.9 N, in WD of ~30.1 m. The dimensions are as follows 71.0 m x 11.6 m x 5.0 m (L x W x H).

The vessel is in an upright position on the seabed with the bow towards the southeast. The seabed around the wreck is flat, with dispersed boulders.

The mag grid over the wreck shows an anomaly of >20000 nT (peak to peak), which can only be associated with a metallic wreck.

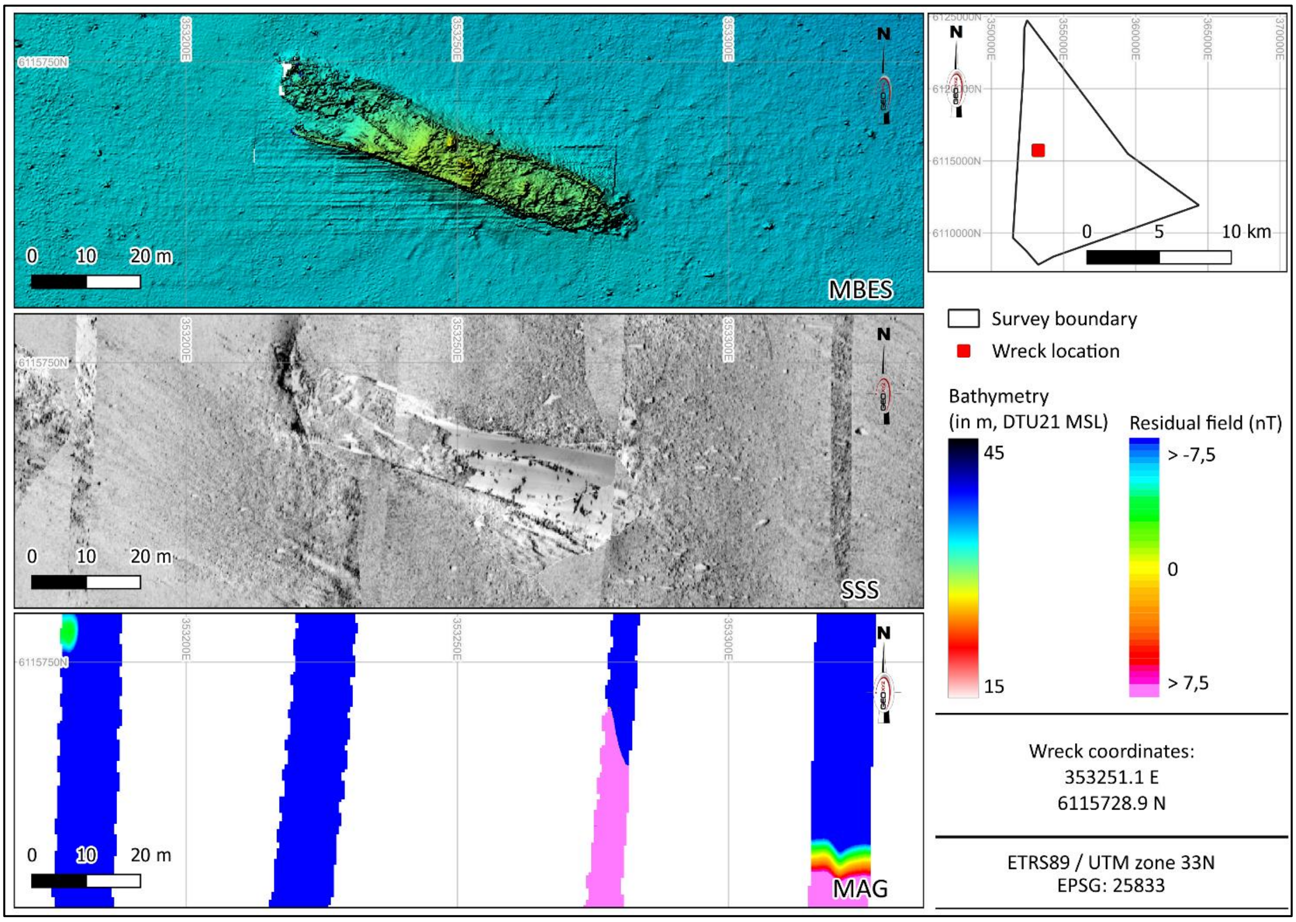


Figure 56: Location of wreck KFII_N_018

Possible wreck KFII_N_202

Figure 57 presents the location of the possible wreck KFII_N_202.

This unknown wreck is located at 353738.5 E, 6116381.0 N and lies in WD of ~29.5 m, with dimensions of 16.4 m x 7.0 m x 4.5 m (L x W x H). The surrounding seabed is flat.

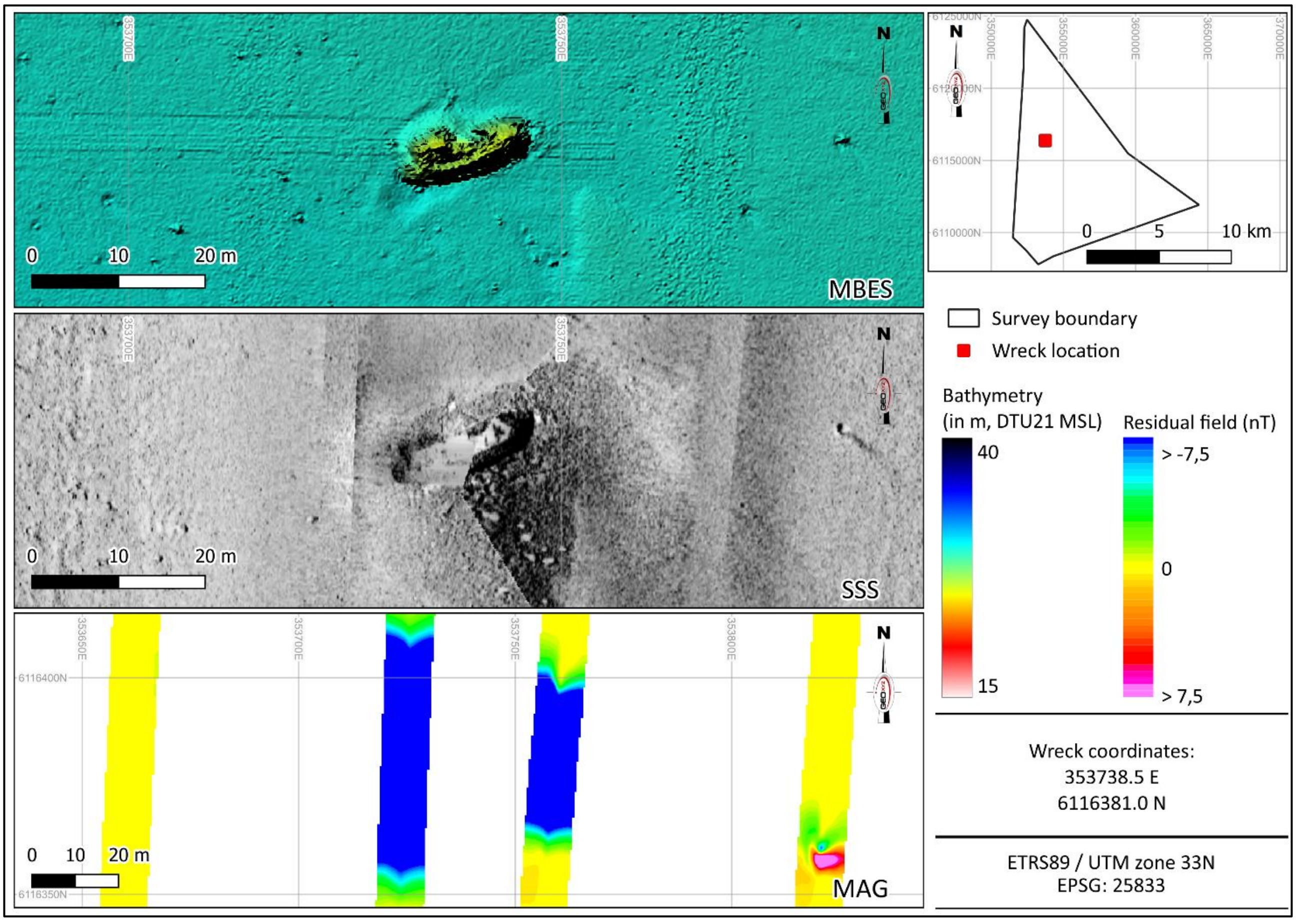


Figure 57: Location of wreck KFII_N_202

Possible wreck KFII_N_392

Figure 58 presents the location of the possible wreck KFII_N_392.

This unknown wreck is located at 358114.4 E, 6111563.6 N and lies in WD of ~30.1 m, with dimensions of 27.2 m x 7.9 m x 3.3 m (L x W x H). The surrounding seabed is flat.

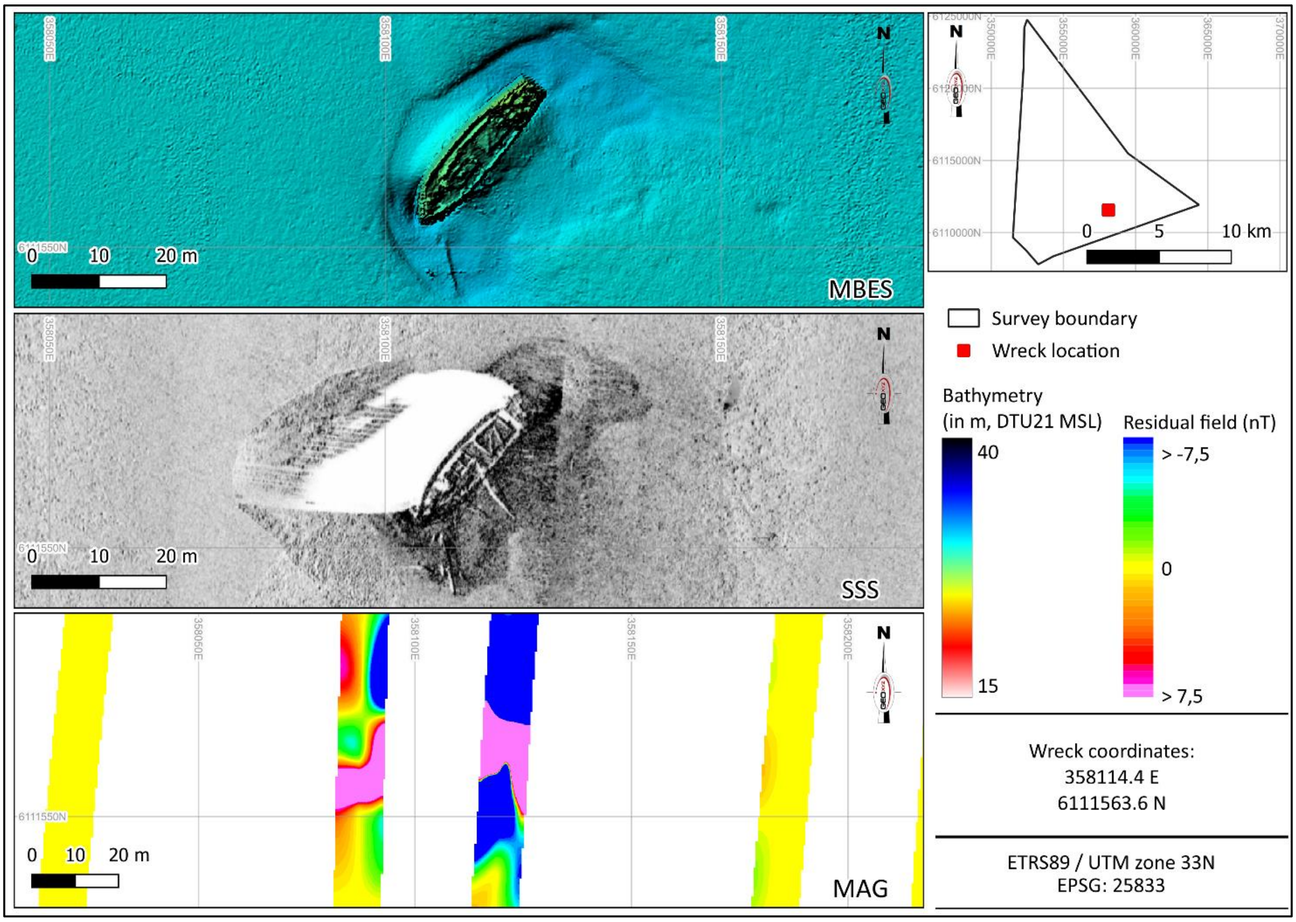


Figure 58: Location of wreck KFII_N_392

Possible wreck KFII_N_414

Figure 59 presents the location of the possible wreck KFII_N_414.

This unknown wreck is located at 357972.4 E, 6113673.8 N and lies in WD of ~32.9 m, with dimensions of 27.0 m x 7.7 m x 2.9 m (L x W x H). The surrounding seabed is flat.

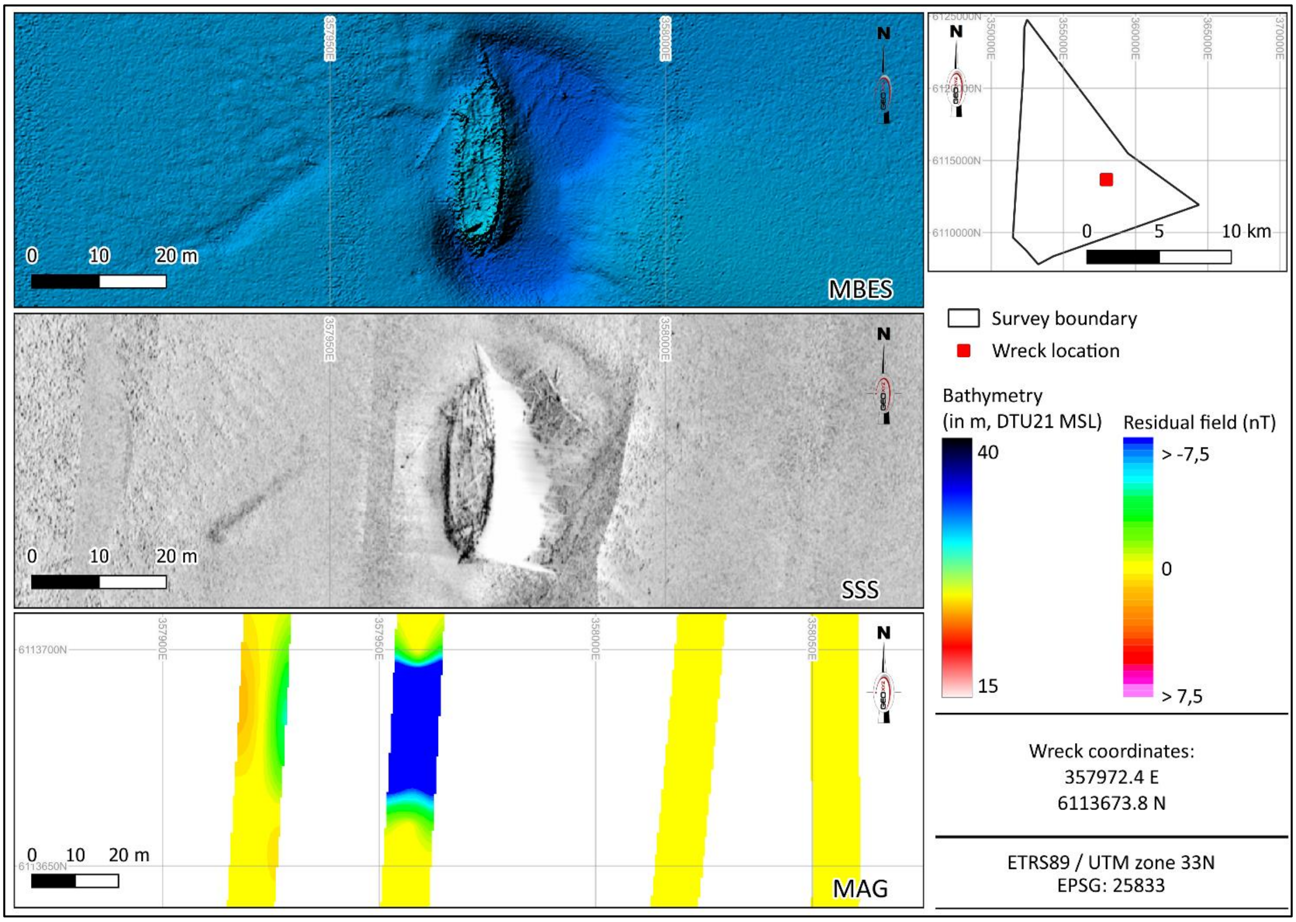
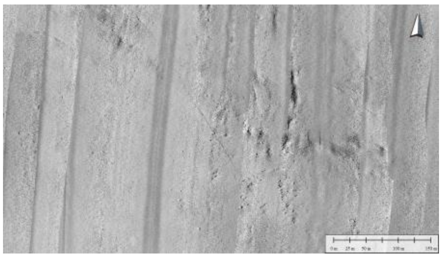
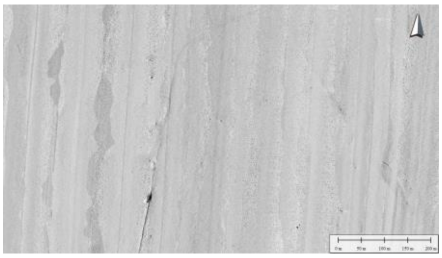
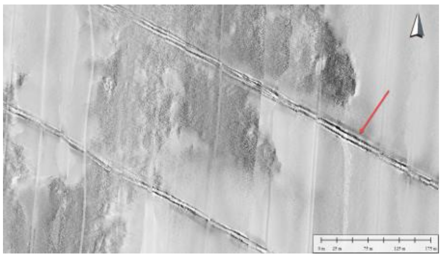


Figure 59: Location of wreck KFII_N_414

8.5.3 Cables, wires and ropes

Within the Kriegers Flak II North site, five cables (40 targets) have been identified. An overview is presented in Table 50 and Figure 60.

Table 50: Overview of the cables within the site

MMO ID	Cable	Description	SSS image
PTS: KFII_N_021, 158, 159, 265, 266 & 267 **LIN**: KFII_N_011, 016, 017, 034, 035 & 036	DK-RU 1 Cable	**Inactive Cable** **SSS**: KFII_N_B01_SSS_GO6_0485, 3700, 3708. KFII_N_B02_SSS_GO6_1150, 1151, 1152. **MAG**: -	
PTS: KFII_N_435 **LIN**: KFII_N_081	Baltic Cable (Observed position away from the database)	**Active Cable** **SSS**: KFII_N_B04_SSS_GO6_0387 **MAG**: KFII_N_B05_MAG_GO6_0003 to KFII_N_B05_MAG_GO6_0039 and KFII_N_B01_MAG_GO6_0008, 0007, 0006, 0004	
PTS: KFII_N_130, 268 & 330 **LIN**: KFII_N_024, 038 & 065	HK22008 Kriegers Flak BE-Rødvig Cable	**Active Cable** **SSS**: KFII_N_B01_SSS_GO6_3663 KFII_N_B02_SSS_GO6_1153 KFII_N_B03_SSS_GO6_1560 **MAG**: KFII_N_B01_MAG_GO6_0048, 0046, 0045, 0044, 0042, 0041, 0039, 0037, 0033, 0032, 0030, 0028, 0026, 0024, 00,21, 0019, 0016, 0014. KFII_N_B03_MAG_GO6_0002, 0004, 0009, 0011, 0013, 0014, 0016, 0017, 0018. KFII_N_B02_MAG_G06_0008 to KFII_N_B02_MAG_G06_0010,	

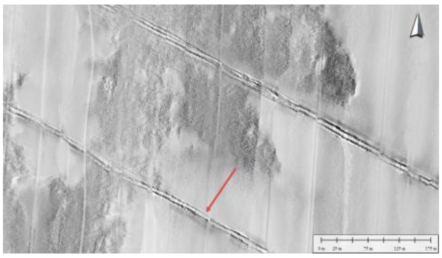
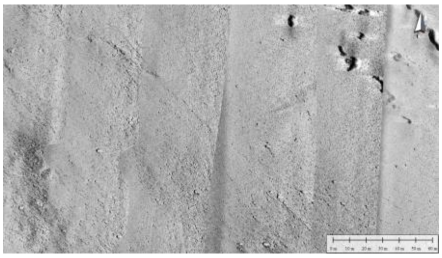
MMO ID	Cable	Description	SSS image
		0014, 0015, 0017, 0020, 0022, 0025, 0026, 0029 to 0037	
PTS: KFII_N_131, 269 & 331 **LIN**: KFII_N_023, 037 & 064	HK22007 Kriegers Flak A-Rødvig Cable	**Active Cable** **SSS**: KFII_N_B01_SSS_GO6_3664 KFII_N_B02_SSS_GO6_1154 KFII_N_B03_SSS_GO6_1561 **MAG**: KFII_N_B03_MAG_GO6_0001, 0003, 0005, 0006, 0007, 0008, 0010, 0012, 0015. KFII_N_B01_MAG_GO6_0040, 0035, 0034, 0031, 0029, 0025, 0023, 0022, 0020, 0018, 0015, 0012, 0011, 0010, 0009, 0008, 0007, 0006, 0005, 0004, 0003. KFII_N_B02_MAG_GO6_0001 to KFII_N_B02_MAG_GO6_0007, 0011 to 0013, 0016, 0018, 0019, 0021, 0023, 0024, 0027, 0028.	
PTS: KFII_N_020, 092, 142, 143, 145, 146, 147, 148, 151, 152, 153, 154, 155, 258, 259, 261, 262, 263 & 264 **LIN**: KFII_N_ 082	Unknown-1 cable (Observed position away from the database)	**Inactive Cable** **SSS**: KFII_N_B01_SSS_GO6_0484, 2458, 3675, 3676, 3678, 3679, 3680, 3681, 3685, 3686, 3687, 3688 & 3689 KFII_N_B02_SSS_GO6_1143, 1144, 1146, 1147, 1148, 1149 **MAG**: KFII_N_B01_MAG_GO6_0191, 0191, 0190, 0188, 0187, 0185, 0183, 0181, 0179, 0177, 0176, 0174, 0172, 0171, 0168, 0167, 0166, 0165,0164, 0161, 0160, 0158, 0153, 0152, 0149. KFII_N_B02_MAG_GO6_0118, 0117, 0116, 0114, 0112, 0111, 0110, 0109, 0108, 0107, 0101.	

Figure 60: A comparison of as-found cables and pipelines with existing data on their locations for the Kriegers Flak II North site

Existing cables that were not detected during the survey are the Roedvig-Roenne Cable and an Unknown-2 cable. Based on the database, the status of the Roedvig-Roenne cable and the Unknown-2 cable are active.

Finally, a section of a possible unknown cable (labelled as Unknown-3 cable) not registered in the database has been identified on SSS, MBES and MAG datasets. The possible Unknown-3 cable is located in the central region of the survey area (Figure 60). The MMO IDs associated with the possible Unknown-3 cable are LIN - KFII_N_033 and PTS - KFII_N_239, 240, 241 & 276. Numerous MAG targets were detected in the west section of the Unknown-3 cable, i.e., KFII_N_B04_MAG_GO6_0066, 0069, 0070, 0072 & 0071, KFII_N_B03_MAG_GO6_0073 up to 0076, KFII_N_B02_MAG_GO6_0081 up to 0086, KFII_N_B01_MAG_GO6_0132, 0133, 0135, 0136, 0137, 0138 & 0139. However, in the SSS data Unknown-3 cable has only been detected in a short section in Block 2 and the SSS anomalies picked on the cable are KFII_N_B02_SSS_GO6_1126, 1124, 1290 & 1125. Figure 61 shows a part of the possible Unknown-3 cable.

It could be that Unknown-3 cable is the Roedvig-Roenne Cable, as both the cables seem to be almost parallel to each other (Figure 60). The approximate distance between the Unknown-3 cable (observed) and the Roedvig-Roenne Cable (database) is 1.6 – 2.0 km. The Unknown-3 cable is visible in most of the residual and analytical magnetic data grids. Unfortunately, no MAG targets were picked as the Unknown-3 cable magnetic anomalies fall below the threshold value of 10 nT.

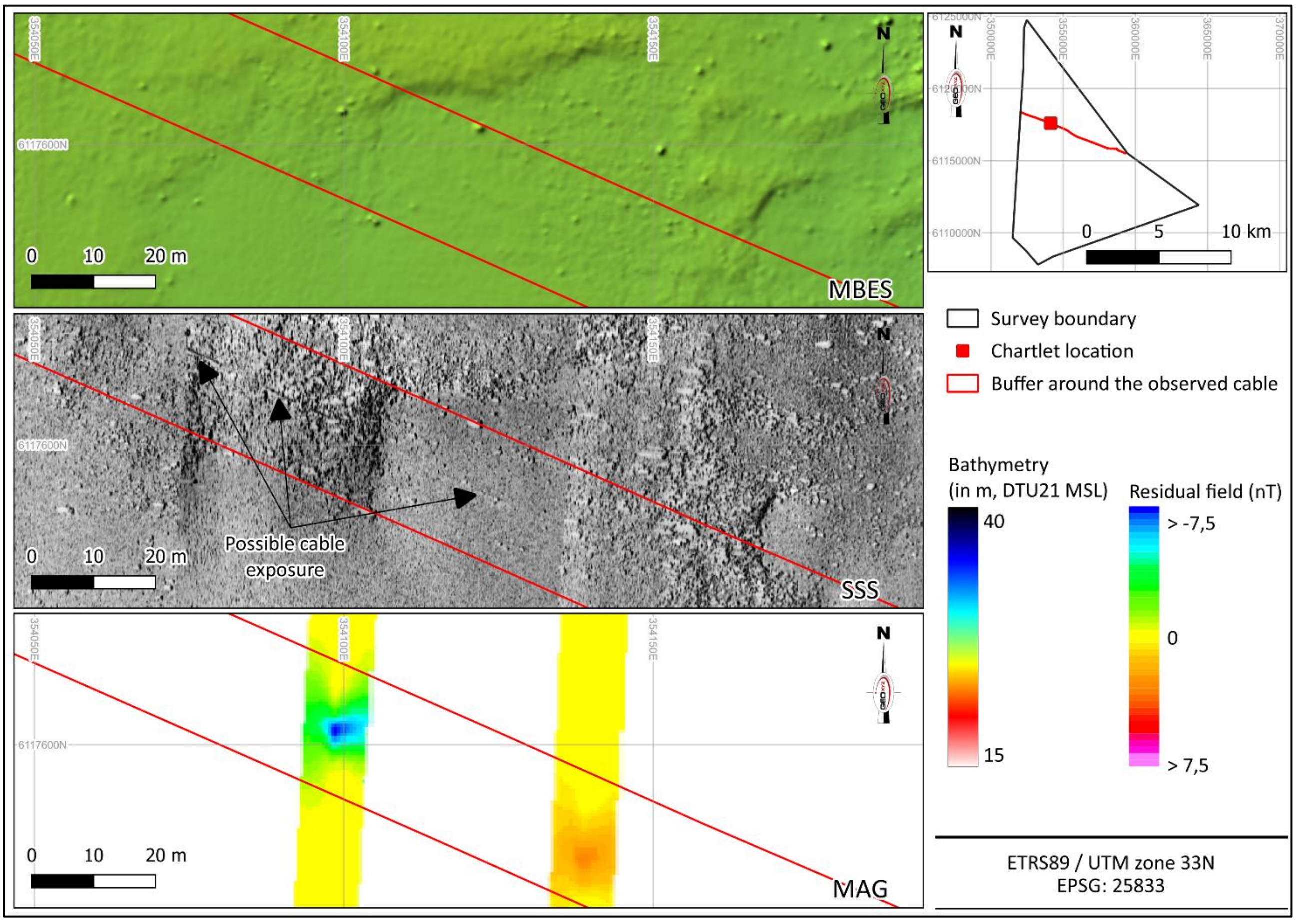


Figure 61: A portion of the possible Unknown-3 cable observed in MBES, SSS and MAG data

A total of 20 soft ropes with low to medium sonar reflectivity are observed in the SSS dataset. No discernible linear magnetic response is noted on all the linear objects. Among the soft ropes, KFII_N_022, 024 (Figure 62), 025, 129, 156 & 235 (Figure 63) are displayed in the MBES dataset due to their significant height.

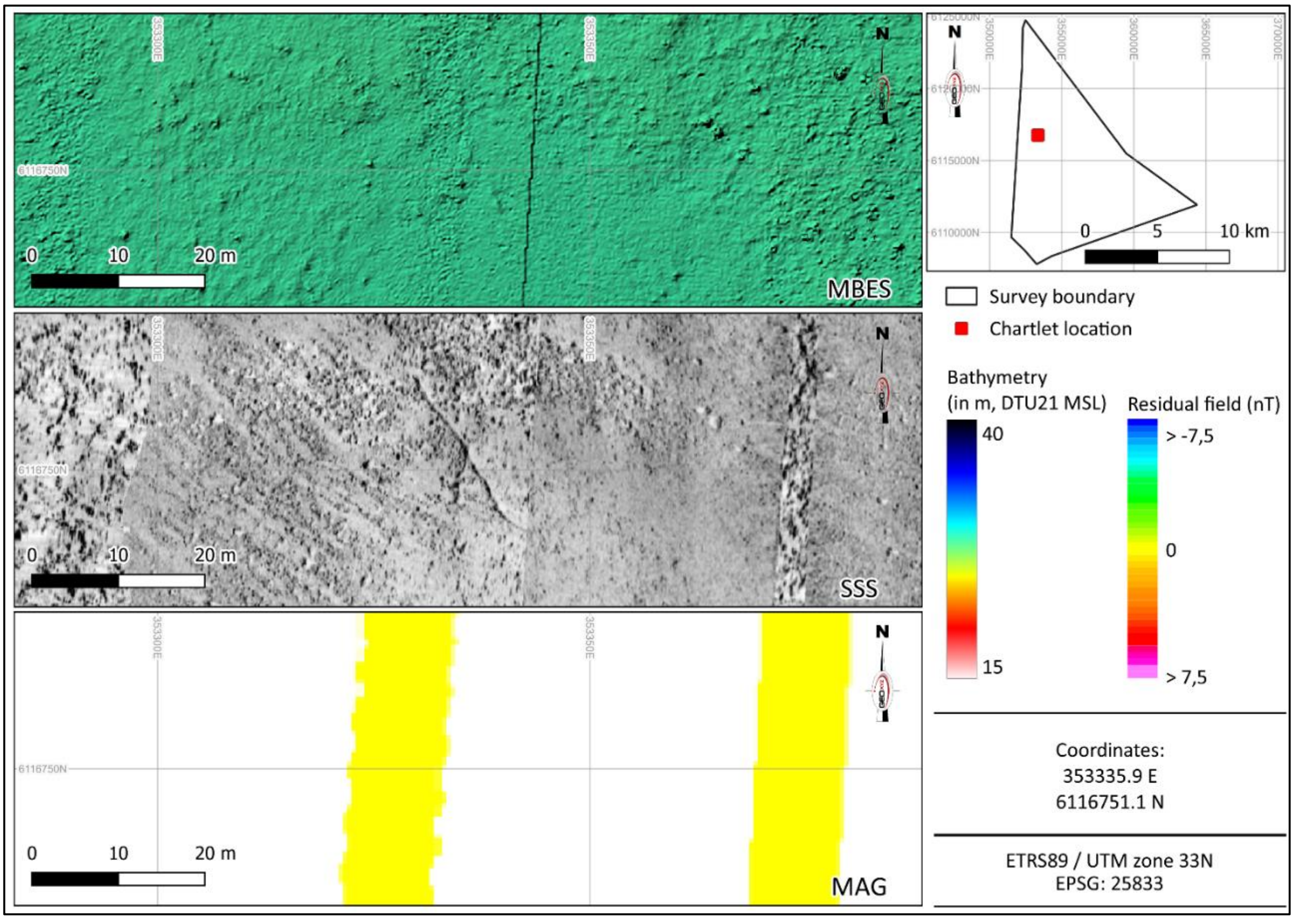


Figure 62: Soft rope observed within the Kriegers Flak II North site (KFII_N_024)

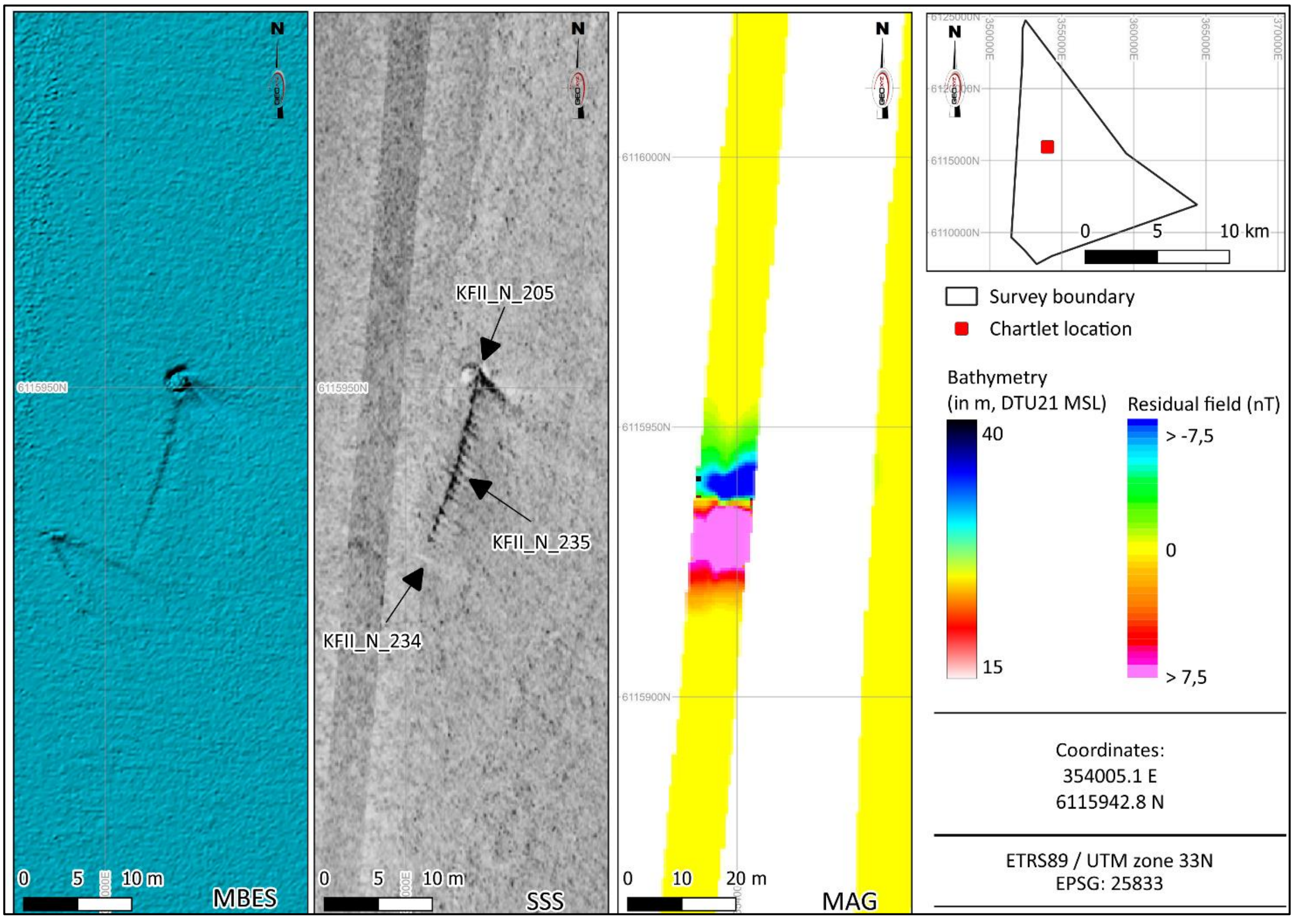
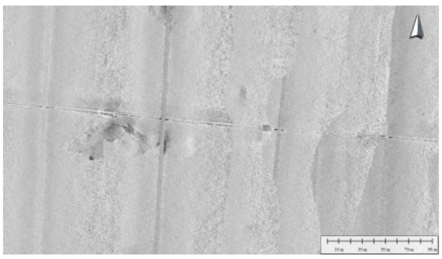


Figure 63: Possible soft rope (KFII_N_235) attached to a debris item (KFII_N_205). A metallic debris (KFII_N_234) is also noted to the south of the soft rope which has a subtle shadow

8.5.4 Pipelines

One pipeline (five targets) was detected within the Kriegers Flak II North site (Table 51 and Figure 60).

Table 51: Overview of the pipeline detected within the survey area

MMO ID	Pipeline	Description	SSS image
PTS: KFII_N_135, 270, 285, 433 & 447 **LIN**: KFII_N_018, 039, 066, 075 & 080	Baltic Pipe - Baltic Sea Pipeline (Observed position away from the database)	**Under Construction** **SSS**: KFII_N_B01_SSS_GO6_3668 KFII_N_B02_SSS_GO6_1155 KFII_N_B03_SSS_GO6_0301 KFII_N_B04_SSS_GO6_0385 KFII_N_B05_SSS_GO6_0034 **MAG**: KFII_N_B01_MAG_GO6_0115, 0114, 0113, 0111, 0109, 0108, 0106, 0105, 0103, 0102, 0097, 0096, 0094, 0093, 0089, 0088,	

MMO ID	Pipeline	Description	SSS image
		0087, 0086, 0080, 0081, 0078, 0077, 0073, 0072, 0069, 0067, 0064, 0063. KFII_N_B02_MAG_GO6_0038 to KFII_N_B02_MAG_GO6_0066. KFII_N_B03_MAG_GO6_0027 up to KFII_N_B03_MAG_GO6_0071. KFII_N_B04_MAG_GO6_0017 to KFII_N_B04_MAG_GO6_0064 KFII_N_B05_MAG_GO6_0041 to KFII_N_B05_MAG_GO6_0116	

8.5.5 Debris

A total of 218 debris items were identified from the interpretation of the MBES and SSS datasets in the Kriegers Flak II North site (Figure 64). All the debris items have been interpreted as non-ferrous objects.

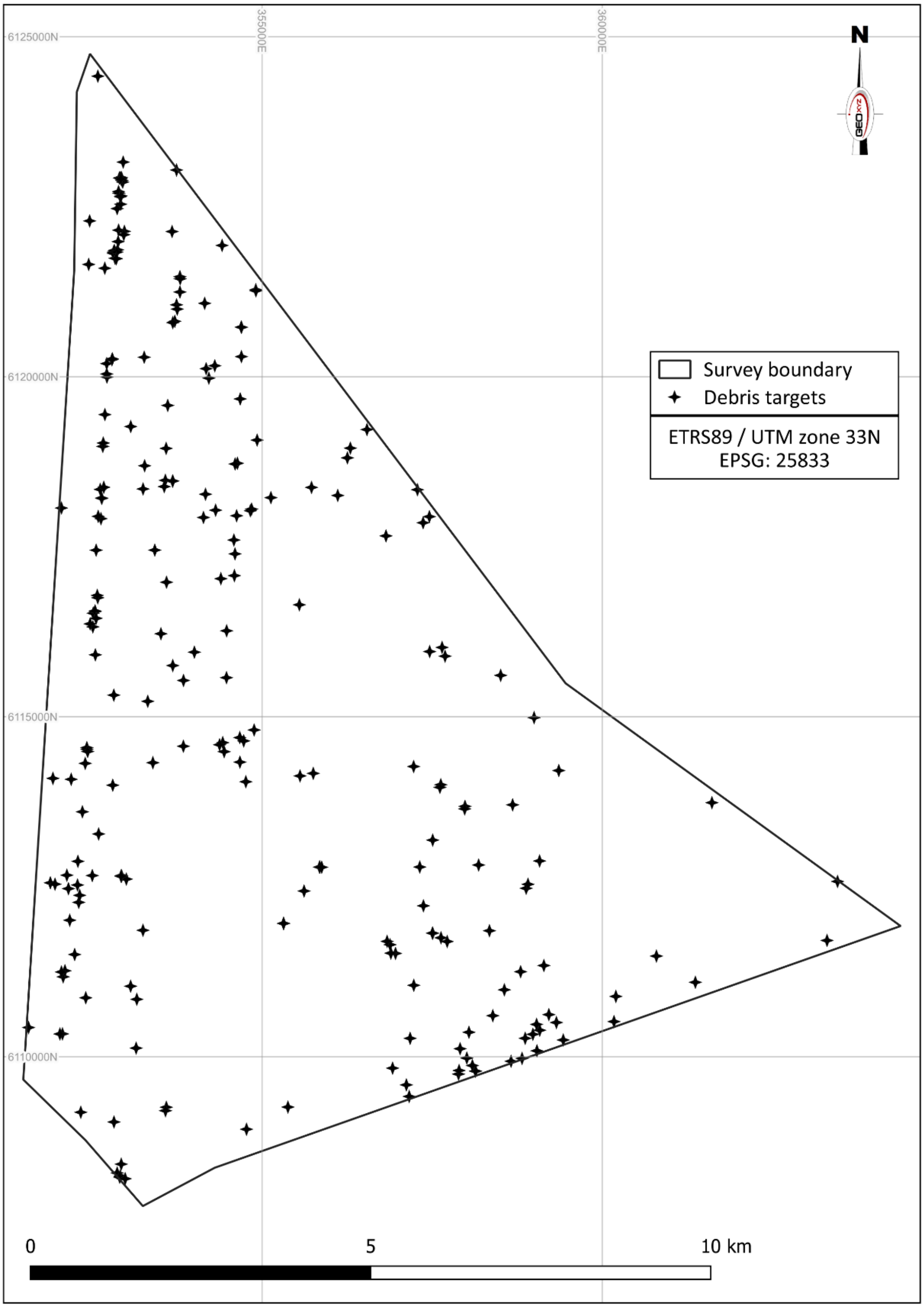


Figure 64: Overview of debris items within the Kriegers Flak II North site

9 SUB-SURFACE GEOLOGY

9.1 REGIONAL GEOLOGICAL HISTORY

9.1.1 Pre-Quaternary geology

The Kriegers Flak II North site is located just south of the south-western boundary of the Baltic shield between the southern part of Sweden, the Kattegat and the northern part of Jutland.

The area is underpinned by the west-north-west to east-south-east trending Sorgen-Frei-Tornquist structural zone (Geus 2024). This extensional/strike slip structure has been reactivated during Triassic, Jurassic and Early Cretaceous with dextral trans-tensional movements along the boundary faults. These movements inverted sedimentary basins.

In the Late Cretaceous – early Paleogene, the previously subsiding depocenter became inverted, due to a change in the regional stress orientation, dominated by compression associated with the Alpine Orogeny and the opening of the North Atlantic.

The uppermost bedrock of the Kriegers Flak II North OWF is expected to consist of Danian limestone, the oldest sediments of the Paleogene (GEUS 2024).

9.1.2 Quaternary geological developments

Four glacial maxima, dating from Late Saalian to Late Weichselian, have advanced across the Baltic region. The glacial maxima were separated by interglacial or interstadial marine or glaciolacustrine conditions.

In this report's area of interest, the sediments for earlier glacial cycles have been removed or reworked by the latest Weichselian ice advance. The Quaternary sediments reported here are those of the Weichselian glacial advance, the subsequent deglaciation and the latest marine Holocene conditions.

Developments over these last ~25 000 years, which have a sedimentary legacy, are covered in greater detail in Section 9.2.3.

9.2 SOIL UNIT INTERPRETATION

9.2.1 Shallow geological overview

The geological foundation zone extends to ~70 m below seabed. The rocks and sediments within this interval have been interpreted with reference to the supplied GEUS desk study (2024). This desk study applies a Quaternary stratigraphic model developed for the Bornholm Basin by Jensen et al. (2017) in conjunction with archive seismic data and limited ground truth information. Some of this information is derived from survey work for the Kriegers Flak OWF site, which is positioned between the Kriegers Flak South and North sites.

There is a good correspondence between shallow geology imaged in this project's sub-seabed data and the geology described in the desk study. This project's units are broadly equivalent with those in the desk study, this means that it will be easier for future workers to use these survey reports and the desk study together.

In overview, the area has a glacial to post-glacial sequence of relatively recent sediments over much older bedrock. The recent sediments are generally 3 – 8 m thick, though locally these recent sediments are interpreted to be much thicker. The seabed and top bedrock surface dips to the east, the younger post-glacial sediments (Units I and II) are better developed in the eastern part of the area.

9.2.2 Stratigraphy and general arrangement of units

The geological schematic (Figure 65) shows the arrangement of units within Kriegers Flak II North. Table 52 shows the basic characteristics of the stratigraphic units. Key surfaces are the top of Unit III (H20/H05/seabed) which is the top of potentially overconsolidated deposits and H30; the top of the bedrock.

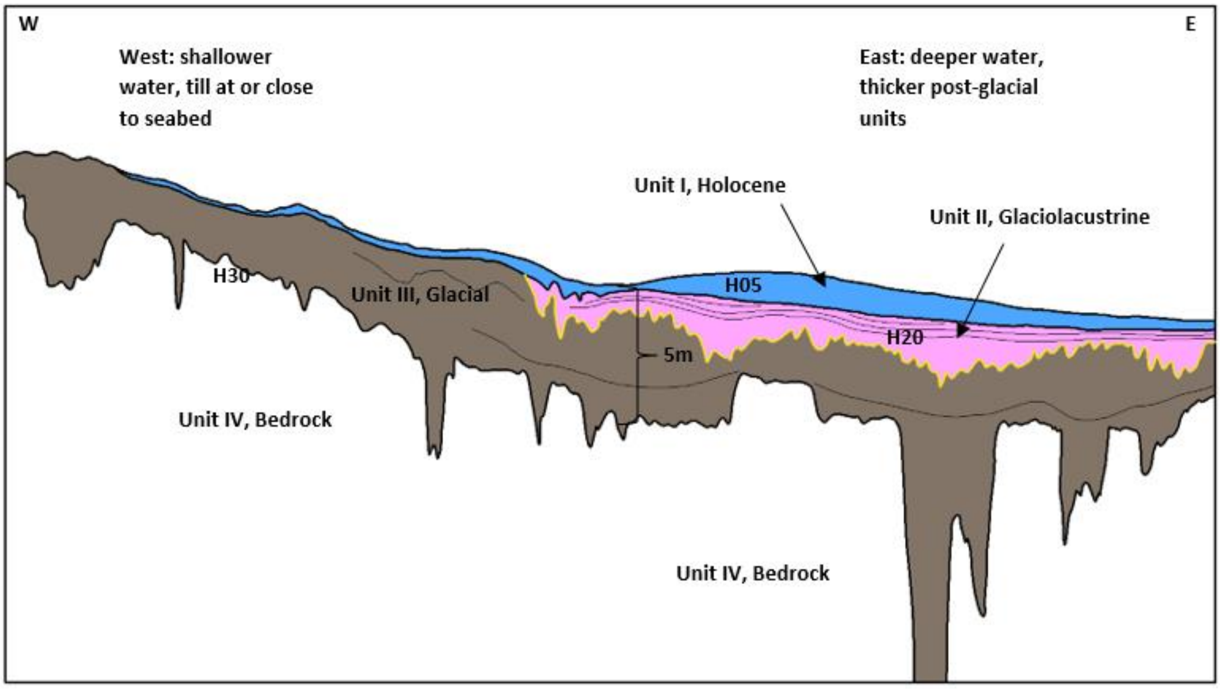


Figure 65: Geological schematic, general arrangements of units

Table 52: Shallow geological units

Unit	Upper surface	Lower surface	Main Soil Description	Depositional Environment
I, H, Holocene	Seabed	H05	Silty, sandy CLAY with thin veneer of SAND at seabed	Post-glacial marine
II, LG, Late Glacial	Seabed/H05	H20	Variable, includes intervals of laminated CLAY, SAND-prone packages	Glaciolacustrine
III, GL, Glacial	H05/H15	H30	Variable, CLAY-prone, locally overconsolidated	Glacial with localised direct ice contact, sandier outwash intervals
IV, BR, Bedrock	H20/H30	-	Chalk	Ancient shallow marine

shows the correlation between the project stratigraphy/nomenclature and Jensen et al.'s stratigraphy. The key difference is that Jensen et al.'s stratigraphy divides this project's Unit II into two units, II, the post-glacial transition and III, the glaciolacustrine.

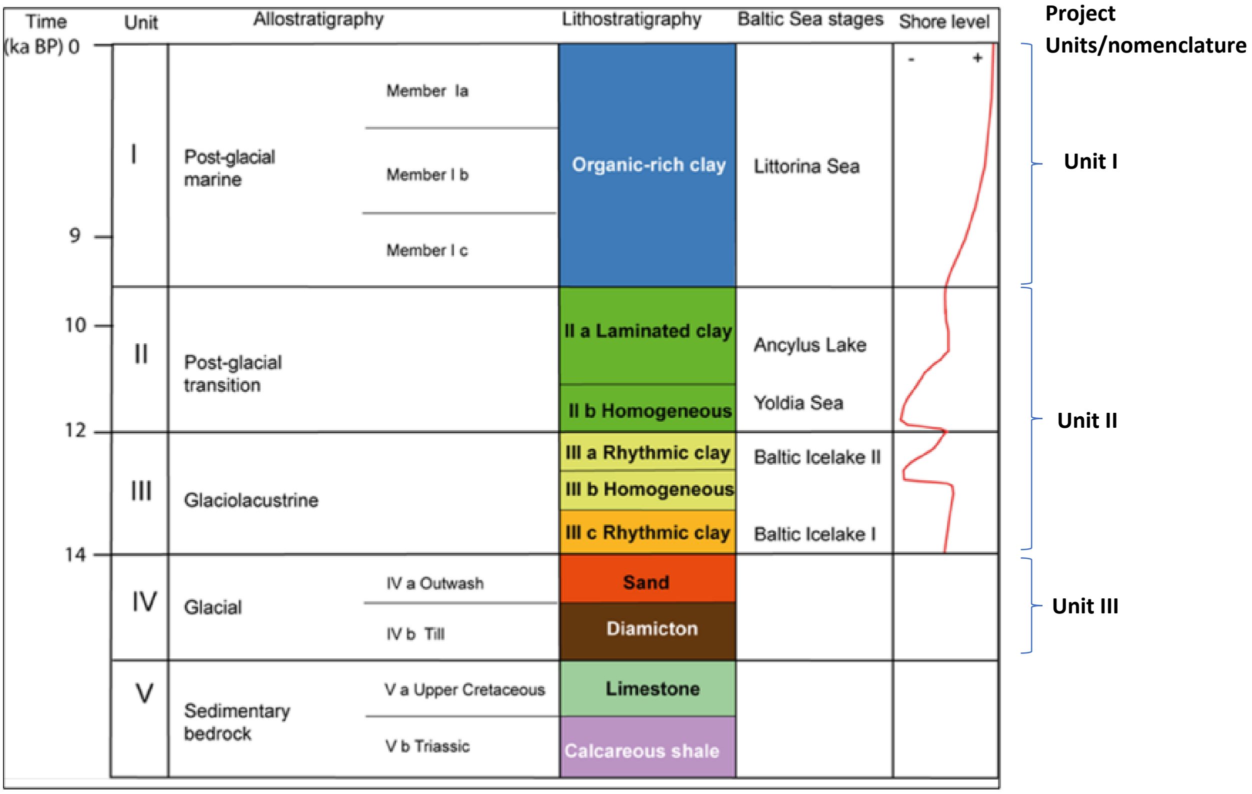
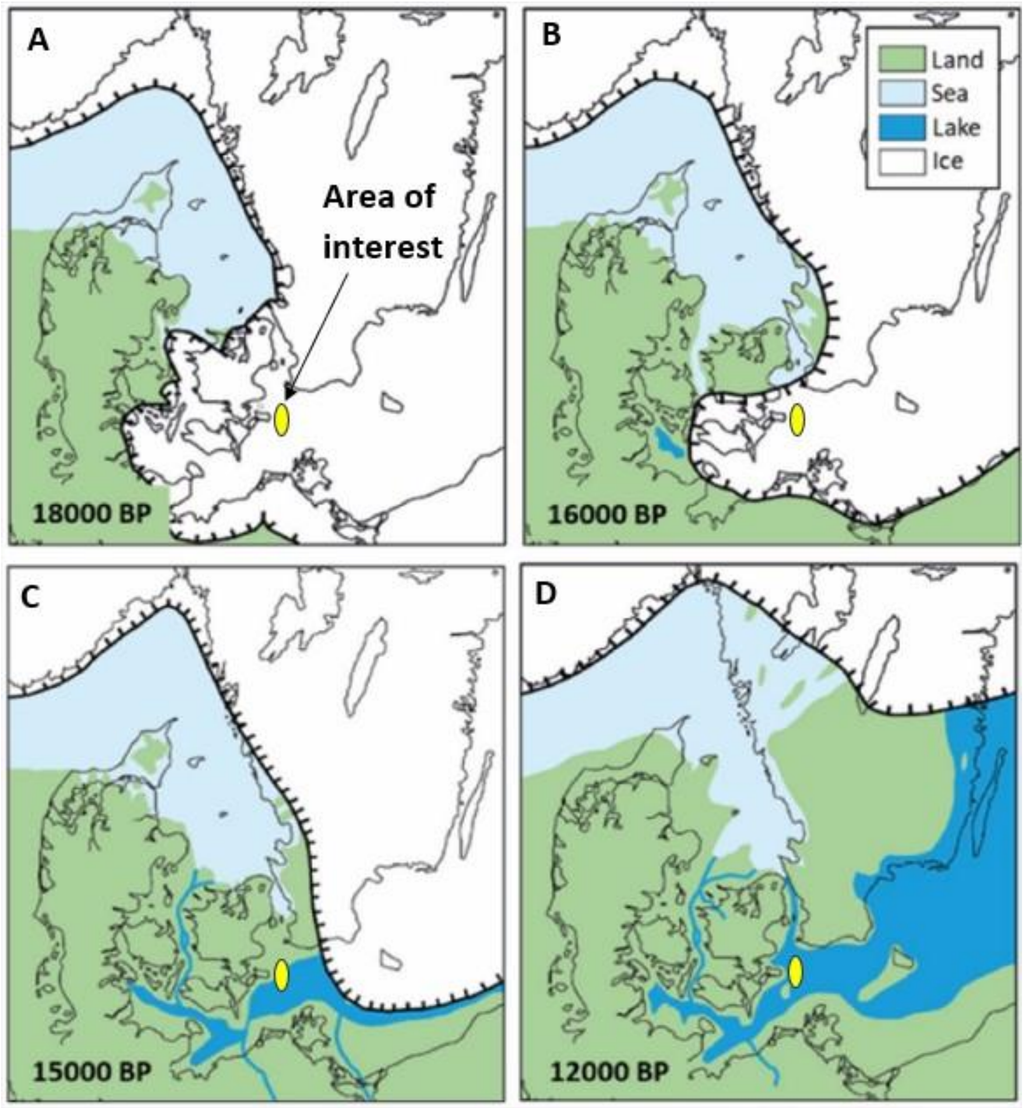


Figure 66: Correlation project stratigraphy/nomenclature and Jensen et al. (2023/2024) stratigraphy

9.2.3 Quaternary deglaciation history

These bullet points are largely derived from information in the GEUS desk study. Here, the stratigraphic units have been linked to the changing paleoenvironments. The letters in brackets refer to the following paleogeographic maps, which are extracts from the GEUS desk study.

- In Denmark the Scandinavian Ice Sheet reached its maximum extent ~22 000 years BP followed by retreat with evidence for short-lived advances over the following four thousand years.
- Marine transgression began around 18 000 years BP, (A) leading to rapid deglaciation and the establishment of glaciomarine conditions. In this early phase the region was not isostatically adjusted, sealevel was relatively high. By 15 000 years BP (C) the ice had retreated to the extent that the site was free of ice cover. The deposition of Unit III is associated with this ice sheet.
- After deglaciation (~15 000 years BP), the area generally experienced lacustrine conditions (Baltic Ice Lakes I and II, Yolida Sea) with an ever more distant ice front (C-E). Unit II was deposited in this dynamic lacustrine environment.
- About 10 000 years BP the Ancylus Lake water level dropped about 9m (E-F) and the area may have been close to subaerial exposure. Upper parts of Unit II were deposited in this environment.
- Around 9 100 years BP a fully marine environment existed in the western Baltic with the Ancylus Lake persisting farther east, in the study area (G-H). The sea broke though at about 7 000 years BP, establishing marine conditions at the site. Unit I was laid down in this marine environment.


A
Area of interest
18000 BP
B
Land
Sea
Lake
Ice
16000 BP
C
15000 BP
D
12000 BP

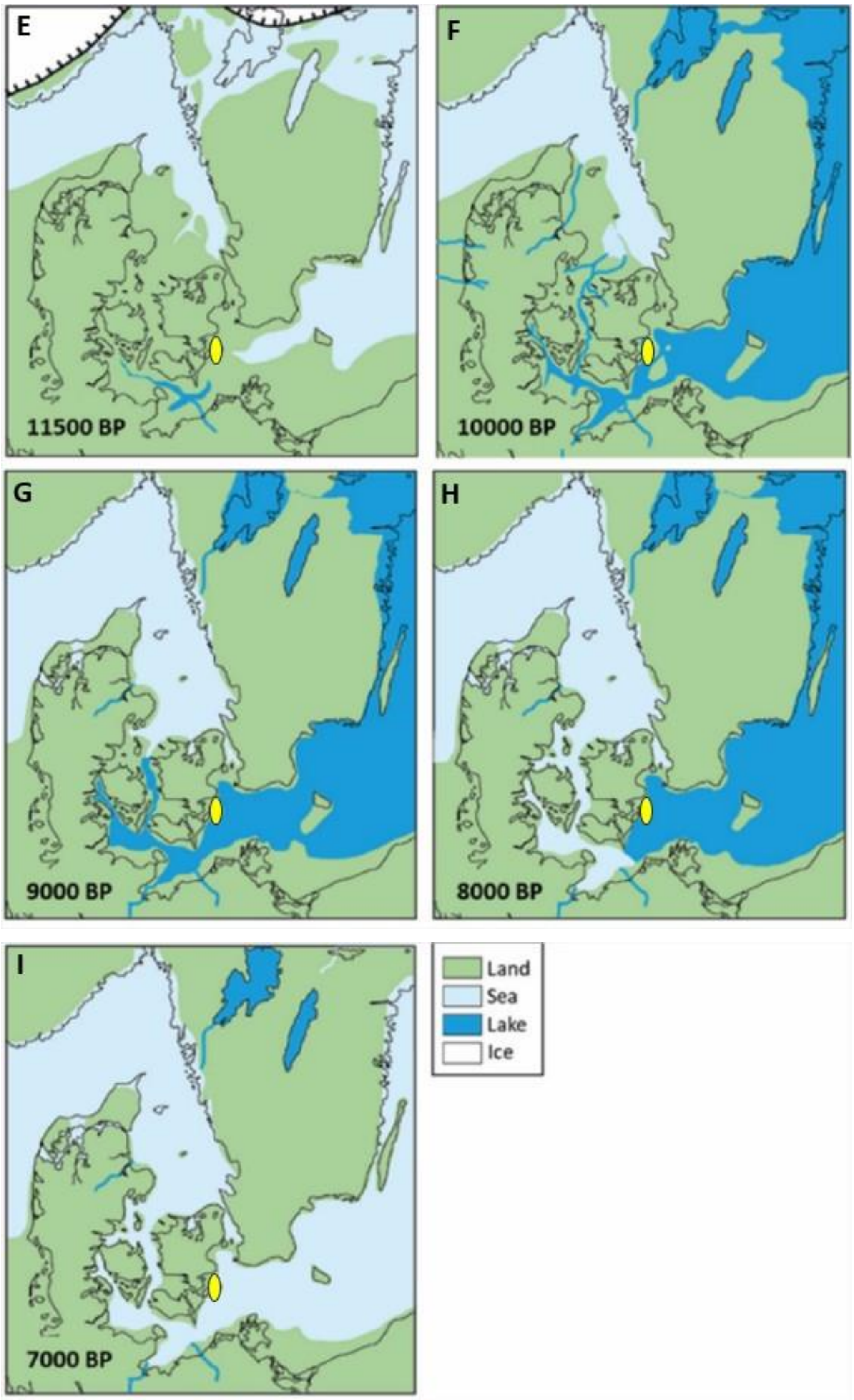


Figure 67: Paleogeographic maps

Unit I Holocene deposits

The Holocene unit is a package of post-glacial silty, sandy CLAY which is less than 1 m thick across most of the survey area. The interval includes a thin veneer of sandier seabed sediments, though these are interpreted to be very thin and are seldom resolved in the SBP data (Figure 68 and Figure 69). The Holocene sediments are widely distributed over the study area (Figure 71). The Holocene is very thin or absent (unmapped) over the centre/west of the area over south-west to north-east trending zones, where till is close to the seabed (Figure 70). Small pockets of Holocene may occur in these areas and a <0.2 m thick seabed veneer may still be present.

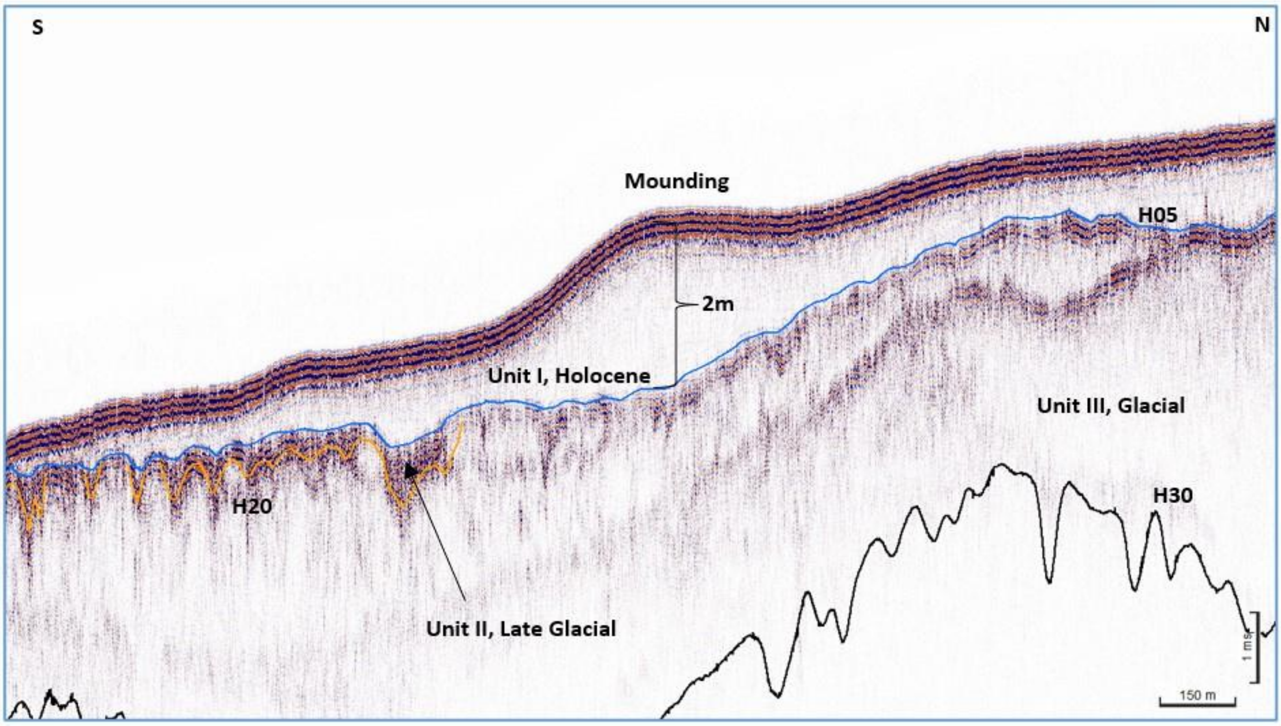


Figure 68: SBP data example, line L16, Holocene unit (Unit I), mounded, location is shown in Figure 71

The Holocene deposits are thickest over a north-west to south-east trending ~2 km wide zone which crosses the area from the centre/north to the extreme south-east. Here the deposits are mounded north of a seabed low and are up to 2 m thick (Figure 68). The sediments also thicken at the southern margin of the area. The seabed low is related to depositional patterns of the till and, likely, the morphology of the top of the bedrock.

Acoustically, the interval is almost featureless with very low amplitude, concordant internal reflections. Locally, there are very subtle internal unconformities, though these do not show amplitude increases. The latter suggests that material characteristics remain similar around these unconformities. The unconformities may represent sea level variations related to the interplay of isostatic rebound and background sea level rise.

The base Holocene is mapped as H05. Over broad areas, it is interpreted to be a mild erosion surface. Thickness variations are due to relief at this surface and a degree of mounding at the seabed (Figure 69 and Figure 70). The erosion at H05 may be related to the final regression of the area ~10 000 years ago when sea level dropped, potentially allowing wave-base storm erosion of the contemporary seabed. The erosion does not plane off the soft pre-existing sediments, as could be expected if the area became sub-aerially exposed.

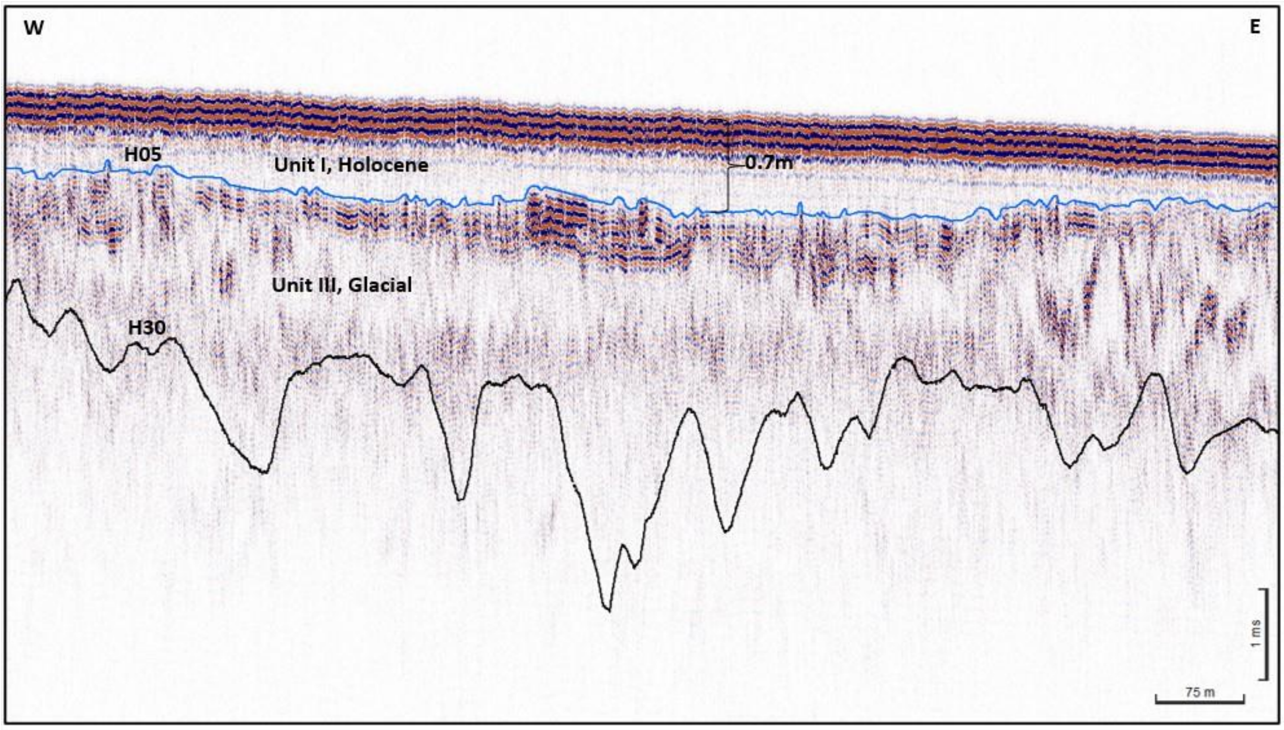


Figure 69: SBP data example, line X05, Holocene unit (Unit I), thin, location is shown in Figure 71

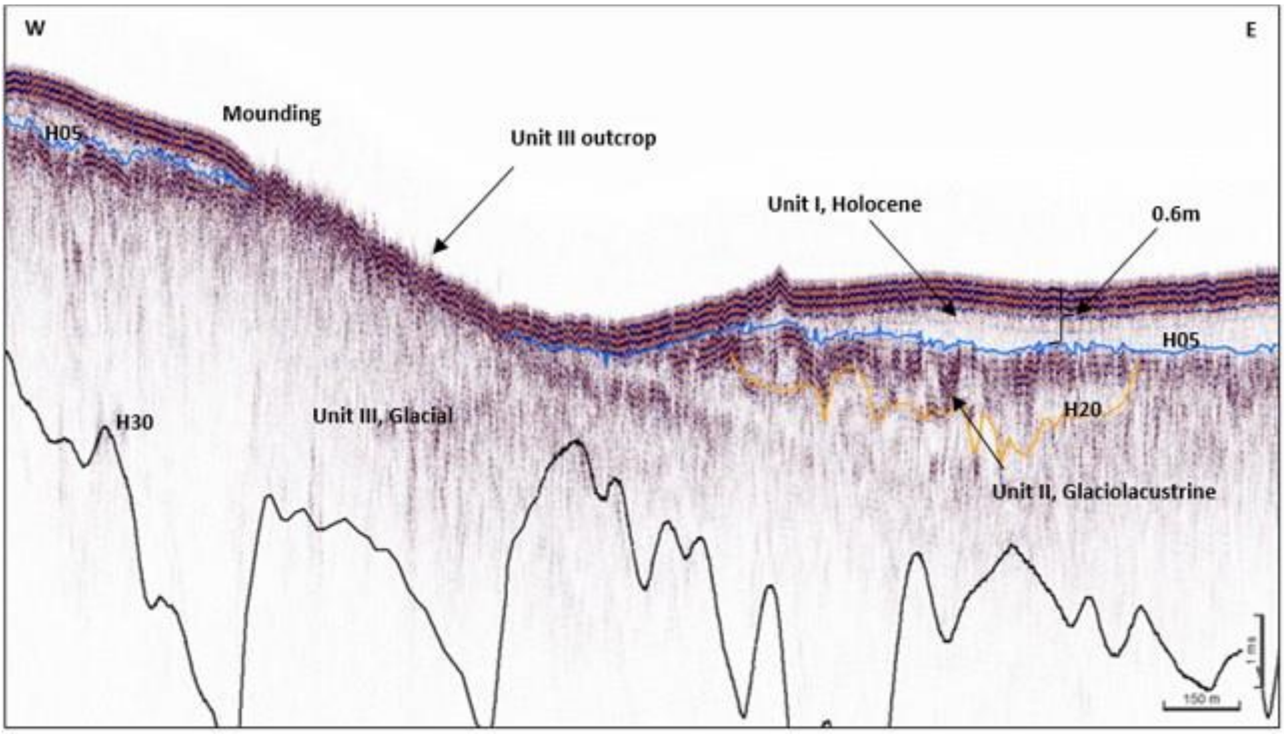


Figure 70: SBP data example, line X04, Holocene unit (Unit I), pinch out, location is shown in Figure 71

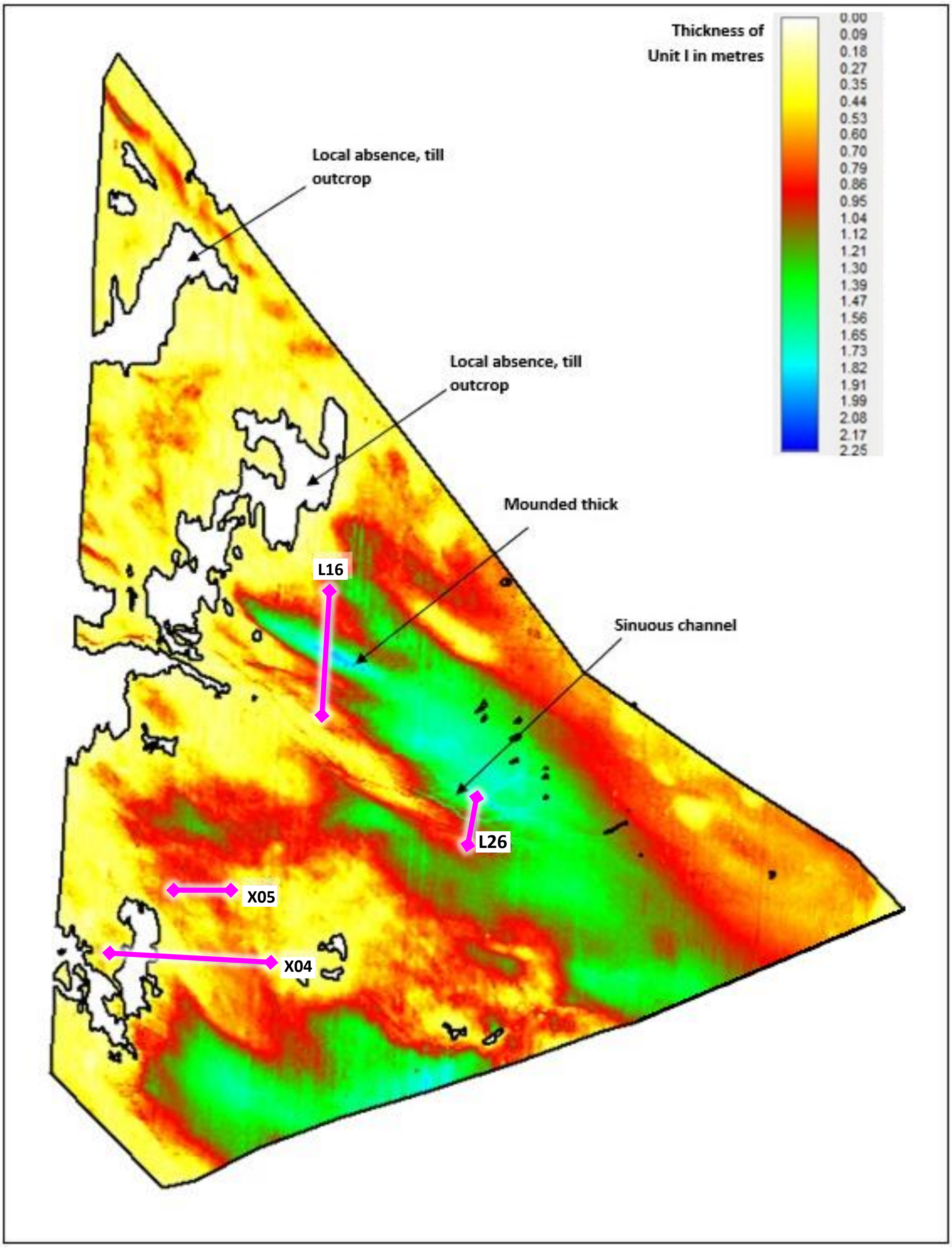


Figure 71: Thickness and distribution of Unit I Holocene deposits

There are some narrow channels cut into the underlying Unit II deposits (Figure 72). These trend east-west across the centre of the site and may be due to a short-lived drainage system at the onset of the marine transgression ~7000 years BP.

The Holocene unit has seismic characteristics which indicate that it is extremely soft/weak.

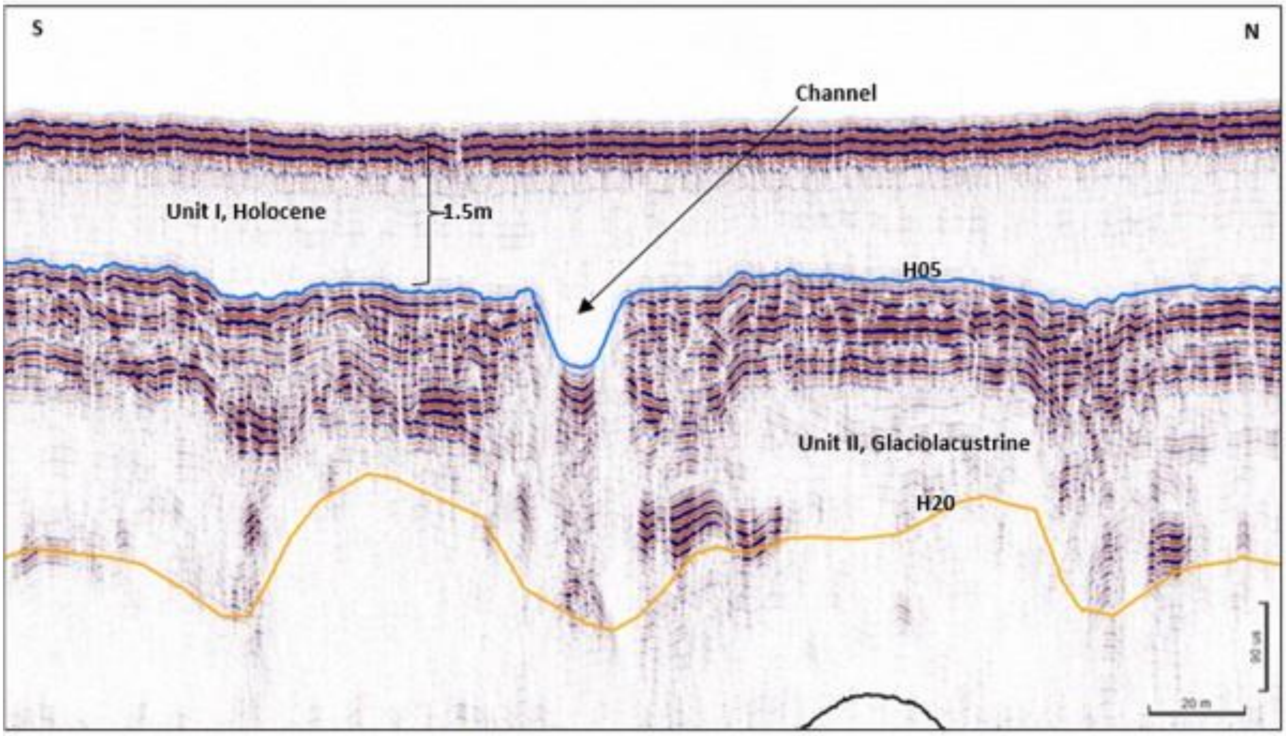


Figure 72: SBP data example, line L26, Holocene unit (Unit I), channel

<u>Unit II Late Glacial deposits</u>

This interval is complex due to the area's range of glaciolacustrine environmental conditions during the Late Weichselian and earliest Holocene. Locally, upper parts show laminations indicative of interbedded clays and sands/silts, while lower parts are ambiguous but may represent sandier deposits, perhaps outwash deposits or sediments redeposited from local moraines.

The unit is mapped with H20 at its base. This is generally at the top of deposits which show clear signs of ice contact, true glacial deposits (tills). The relief at this basal surface strongly influences the thickness and distribution of the Unit II sediments. Unit II mainly occurs over central and eastern areas and is typically around 2 m thick, locally exceeding 5 m (Figure 73). There may be a thin layer of bedded Unit II sediments beyond the mapped area.

In the west, and over many parts of the central and northern regions of the area, the Unit II glaciomarine sediments pinch out over the subcropping Unit III tills.

The desk study divides this late glacial sequence into earlier and later parts. There is scope to further sub divide this sequence using the existing geophysical database. Additional mapping work could involve dividing the upper, bedded, parts of Unit II from the more amorphous lower parts. Figure 72 and Figure 74 show these two facies types.

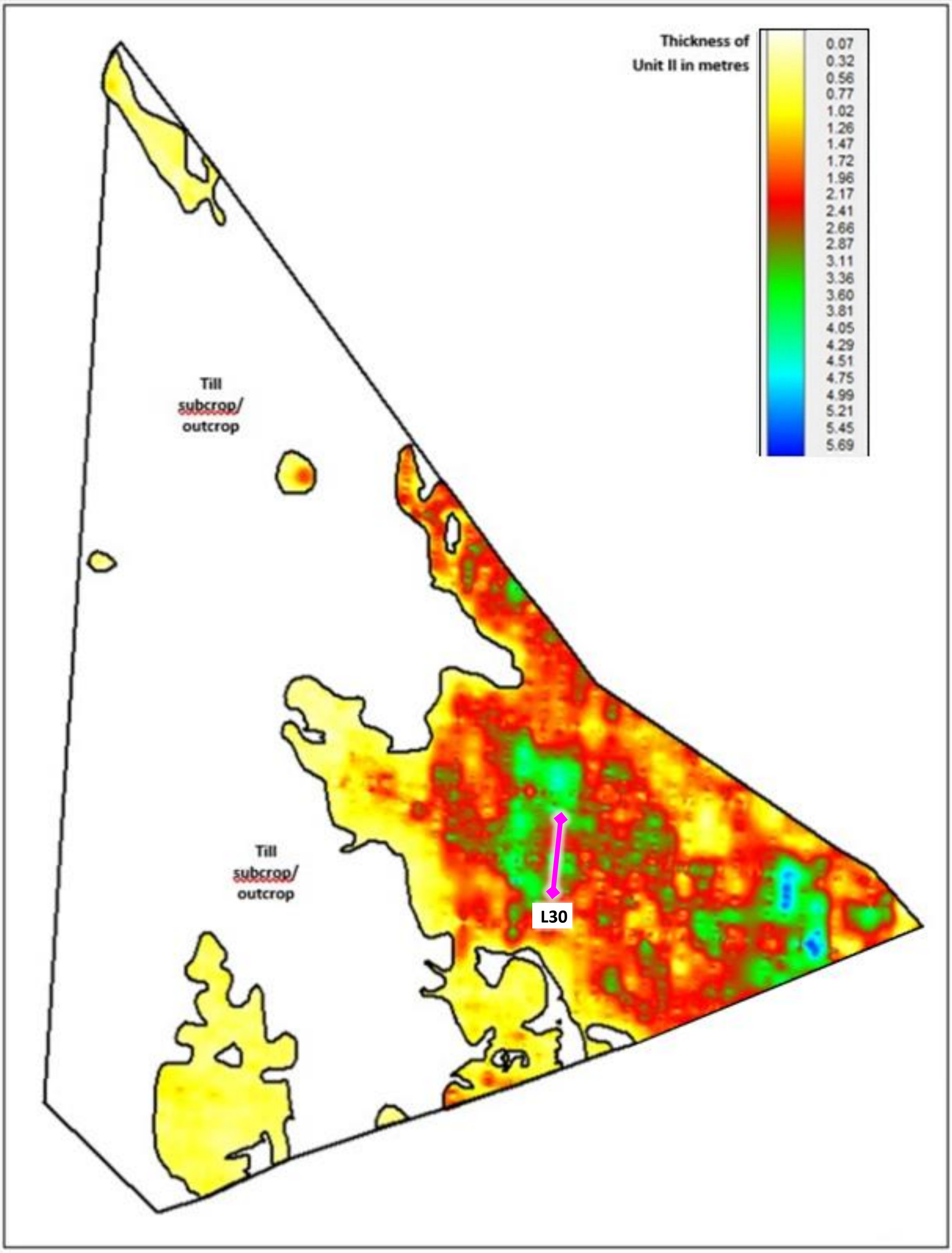


Figure 73: Thickness and distribution of Unit II late glacial deposits

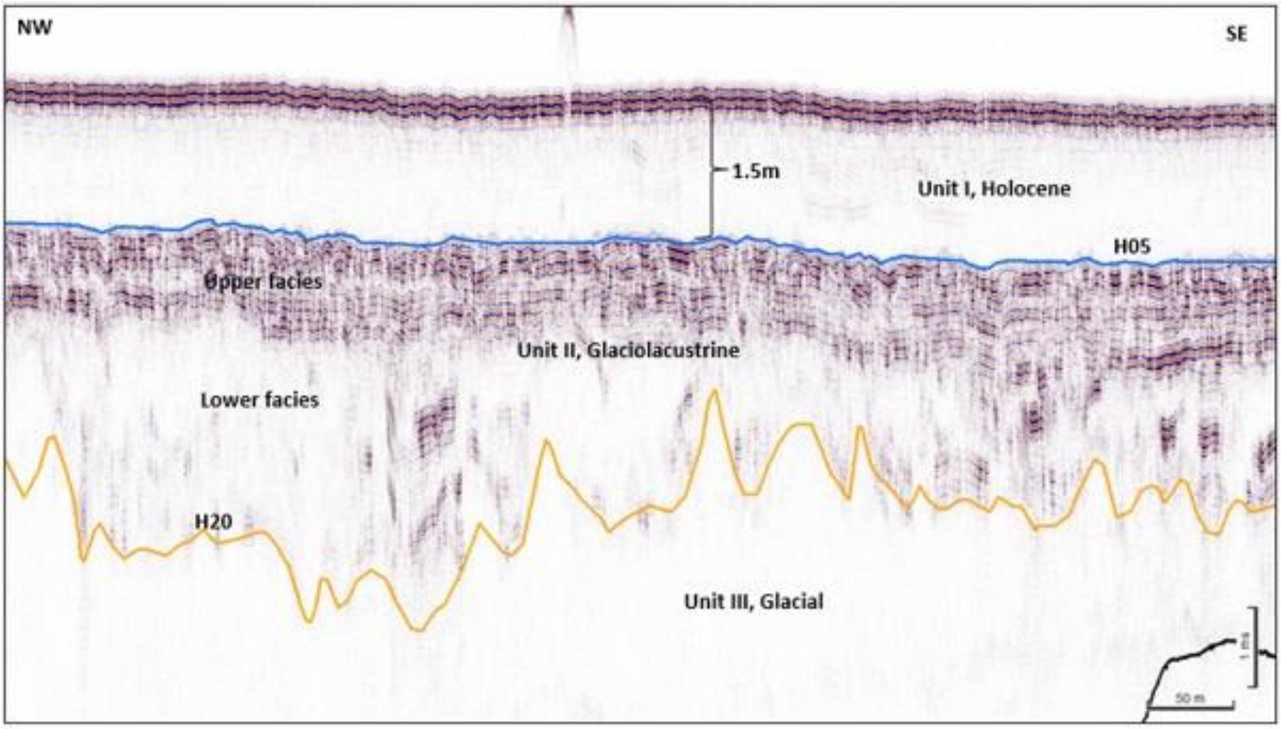


Figure 74: SBP data example, line L30, Unit II, upper and lower facies, location is shown in Figure 73

Unit III Glacial deposits

Unit III deposits occur throughout the study area (Figure 75), except for a few very small areas scattered around the north/centre of the area. Unit III is interpreted to be a till deposited in association with the last major ice advance over the area, approximately 22 000 – 18 000 years ago. The till forms a 3 m to 6 m thick blanket over the site with variations due to bedrock morphology, patterns of primary deposition and possible erosion at the later onset of glaciomarine/lacustrine conditions. Unit III is typically 3 to 6 m thick but can locally range from 0 to 34 m. The till is thickest along a 500 m wide south-west to north-east trending low in the top of the bedrock. This feature may be due to bedrock fault displacement or erosion.

The till of Unit III is at or close to outcrop in some parts west of the area, where the Holocene unit is not present.

Unit III is generally a glacial till which has been subjected to direct ice contact, though the unit may contain other facies which may have been deposited in ice-marginal environments during oscillations of the ice front. The ice-contact facies may comprise a clay-prone diamicton which is likely to contain subordinate silt, sand, gravel, cobbles and boulders. They will be overconsolidated. Consolidation levels may significantly vary over short distances. Seismically, the ice contact facies are structureless with a very irregular upper surface, which probably forms a series of ridges.

There may be scope to further divide Unit III, i.e., separating the ice contact facies from the ice-marginal or outwash packages. It should be noted that even the outwash intervals will have undergone some level of overconsolidation during the area's last ice advance. The complexity of Unit III can be seen in Figure 76 and Figure 77.

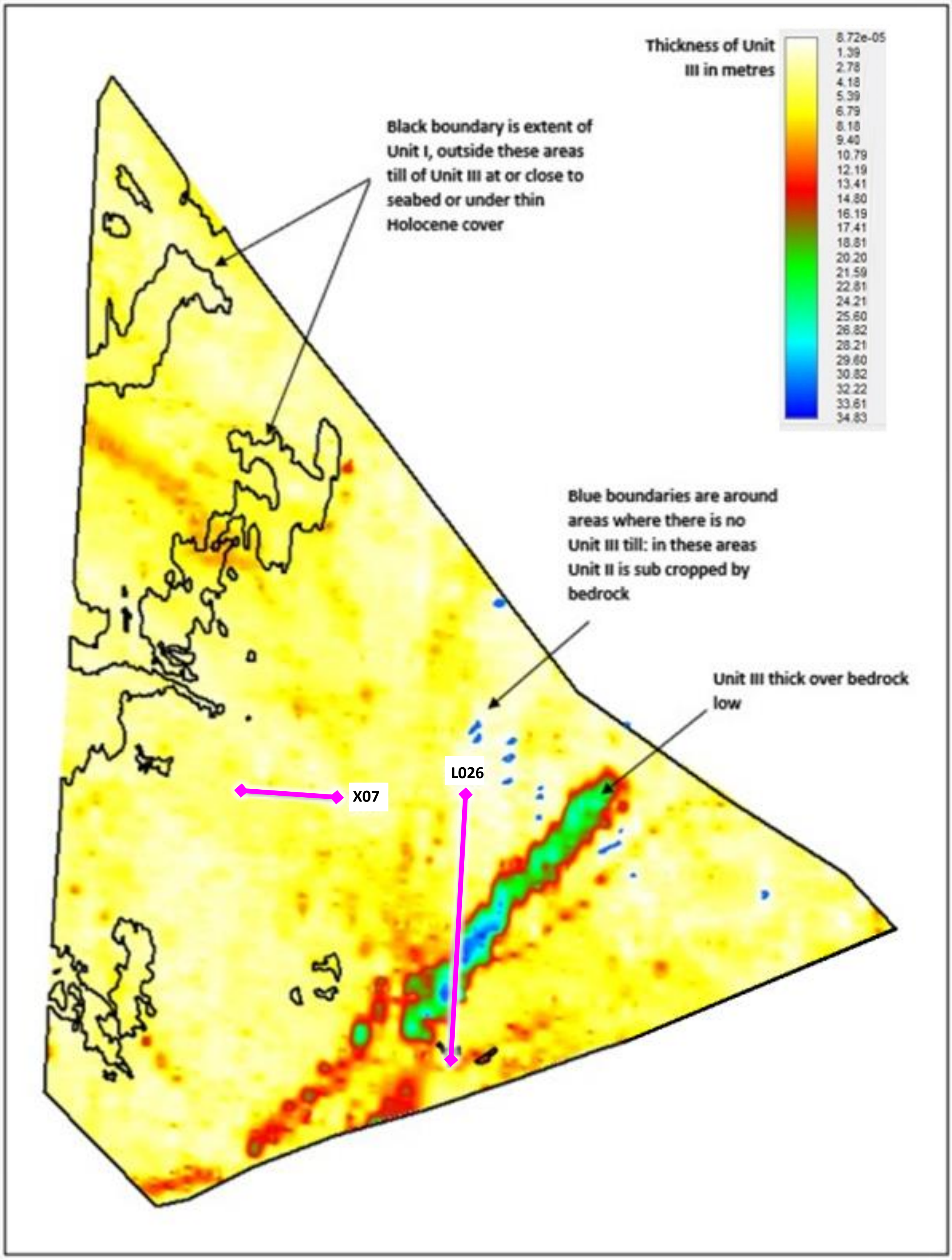


Figure 75: Thickness and distribution of Unit III Glacial deposits

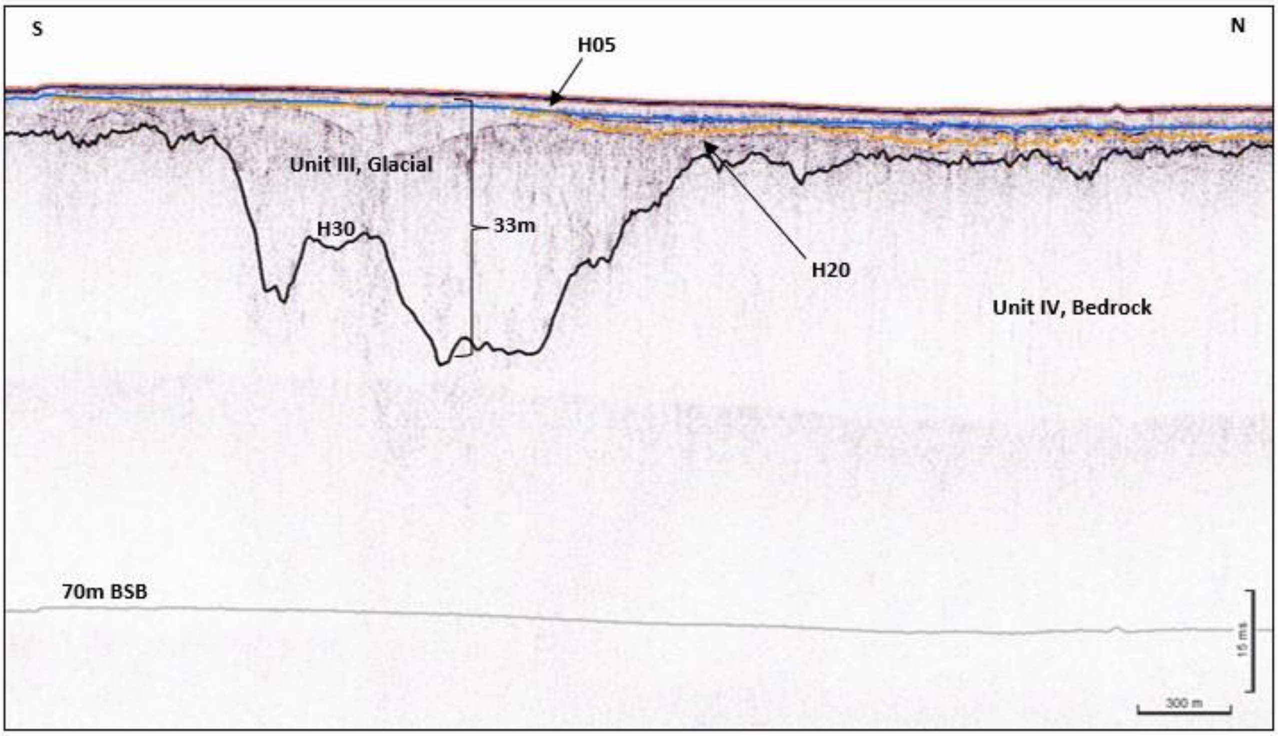


Figure 76: UHR data example, line L026, Unit III, till, bedrock low, location is shown in Figure 75 and Figure 78

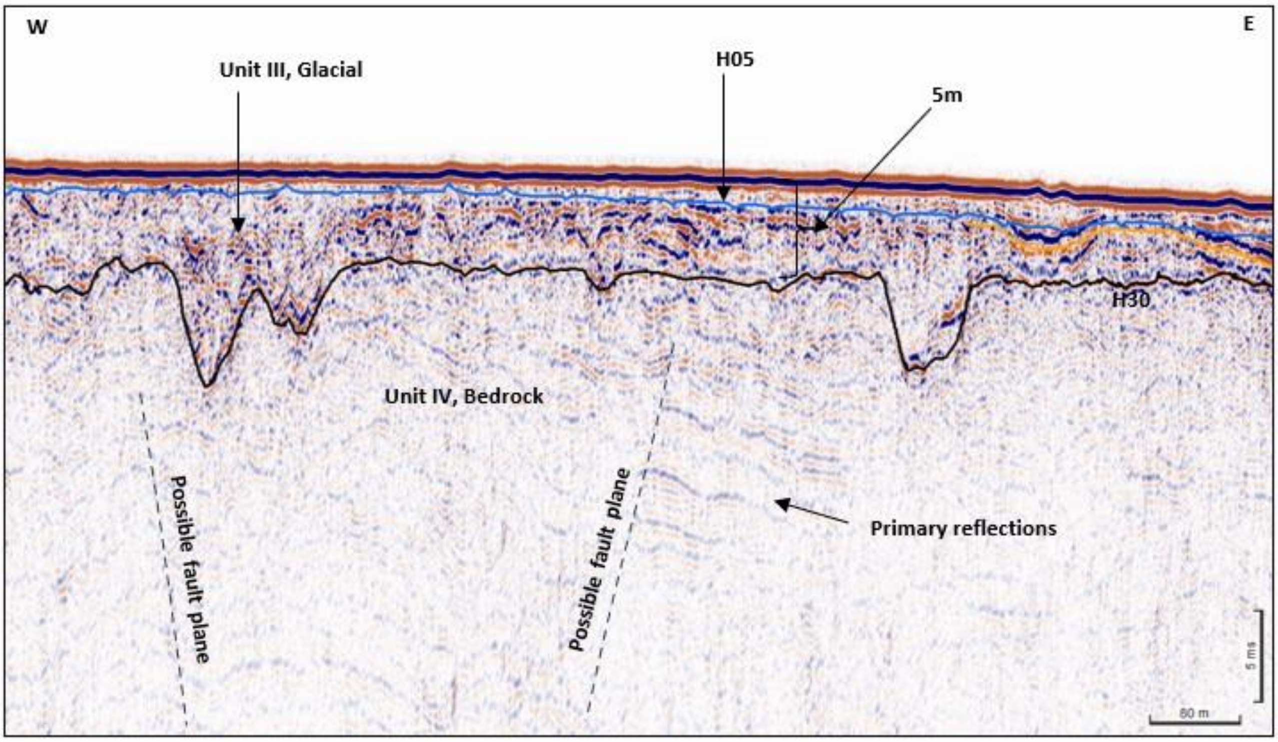


Figure 77: UHR data example, line X07, Unit III, till, south area, location is shown in Figure 75 and Figure 78

Unit IV bedrock

The bedrock is likely to be Danian limestone (GEUS 2024). Bedrock faults are not well imaged, though faults are almost certainly present (Figure 76 and Figure 77). Some UHR lines do show weak evidence for the position of fault planes. These ancient faults were reactivated during the Late Cretaceous/Early Palaeocene and, in this area, likely generated inversion. The high potential for erosion of the top of the bedrock (especially over the last 1.1 million years of ice advances) makes it difficult to attribute features at the top bedrock surface to tectonic activity. The tectonic relief may well have been planned off by ice.

The top of the bedrock is generally 3 to 8 m below seabed, exceeding 25 m over a 500 m wide south-west to north-east trending zone, just south of the centre of the area. This feature may be related to faulting or erosion.

The upper surface of the bedrock is a truncation surface with an angular unconformity between the ~60 million year old limestones and their much younger overburden. Figure 78 shows the depth of the bedrock below seabed.

The bedrock may have been subjected to numerous phases of erosion during early glaciations.

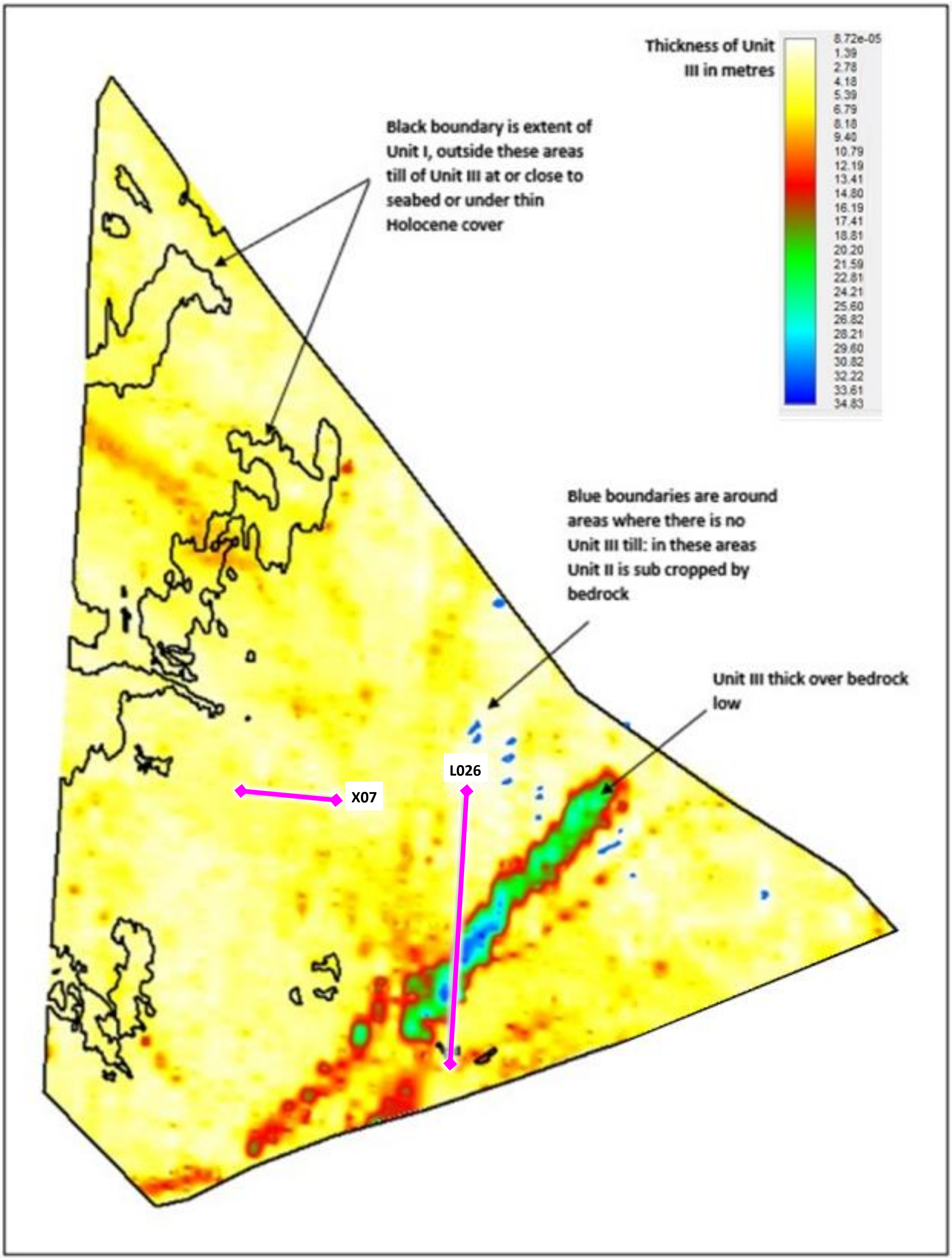


Figure 78: Depth BSB (Below Seabed) to H30 (bedrock)

9.2.4 Shallow geological installation constraints

The following considerations could be made regarding installation constraints based on assessment made from the geophysical dataset:

- The Holocene unit sediments are very weak/soft. Their bearing capacity will be negligible and could cause retrieval difficulties related to settlement of seabed frames etc.
- Unit III may have variable levels of overconsolidation.
- Unit III may contain numerous cobbles and boulders.
- Unit IV may have strength variations.
- Unit IV may be weathered at the upper truncation surface.
- Unit IV may locally be weakened by faulting and micro fractures.

Cobbles and boulders

There are very limited indications of sub-seabed boulders within the sub-bottom profiler data (Figure 79). These data have been optimized to resolve the shallow stratigraphy and do not readily generate diffraction hyperbola, which are the usual seismic indication of point contacts in the sub-surface. A further complication is that the units most likely to contain boulders, Units II and III, have been deformed and compressed by ice confusing any returns from individual point contacts. There is evidence for seabed boulders where Unit III crops out, showing that boulders are likely to be present sub-seabed.

These circumstances, and the great volume of data, make line-by-line assessment of point contacts impractical and potentially inaccurate.

A probability (Boulder Factor) grid has been generated to indicate where boulders are more or less likely to be encountered (Figure 78). This is based on the thicknesses of Units I, II and III:

- The thickness of the post-glacial Holocene unit is multiplied by 1: Boulders may rarely have melted from floating ice.
- The thickness of glaciomarine Unit II is multiplied by 3: There is a greater influence of ice.
- The thickness of Unit III is multiplied by 10, though this unit has few direct point diffractions it contains what are interpreted to be ice contact tills, the type of facies most likely to contain erratics. The overall probability of encountering boulders is driven by the presence and thickness of the Unit III tills. There is evidence of seabed boulders where this unit crops out.

The resulting grid is a unitless value but has been generated as depth, and is a product of the total thickness of the Quaternary sequence. A similar grid could be depth limited to the top 5 or 10 metres, such a grid would show a strong response where the Unit III tills are close to the seabed.

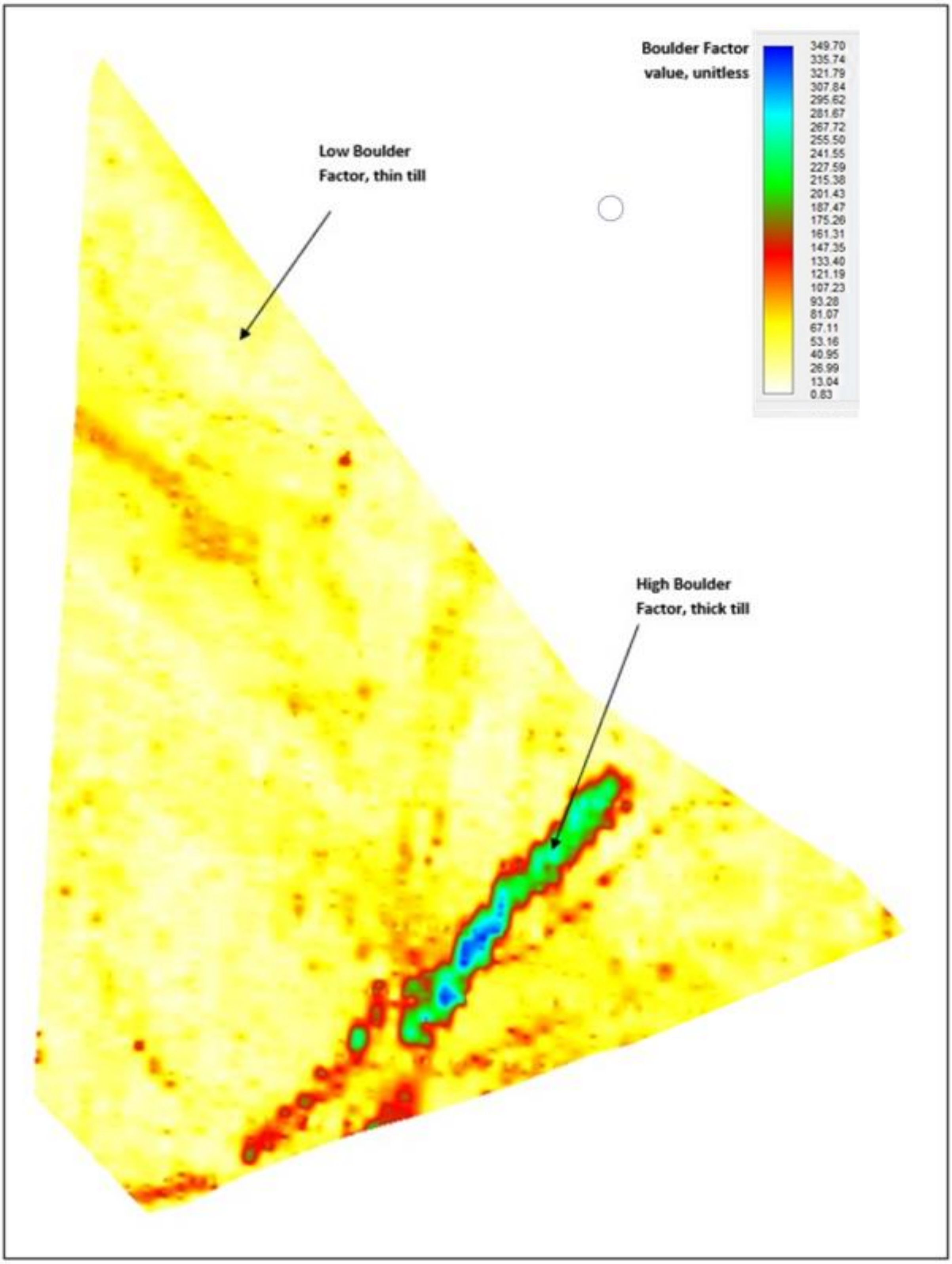


Figure 79: Boulder Factor, Quaternary

9.2.5 Sub-surface acoustic velocity model

SBP depth data

The SBP depth data are based on the final time segy files. The water column and recorder delay are depth converted at the water velocity. This velocity interval extends from the top of the record to a point just above the picked water bottom. This small offset ensures that the seabed return signal is not distorted by the transition from one interval velocity to another.

The remainder of the record is converted at an assumed velocity of 1600 m/s. This is because these shallow penetrating data only image normally consolidated, uncompacted, sediments and there are no associated processing velocities to consider.

This sub-seabed interval velocity was also applied to the thickness conversion of the interpretation of the upper two units: the depth SBP data match the supplied thickness/depth grids for units I and II.

UHR depth data

The UHR depth data have been built using an iterative approach. The limited range of acquisition offsets mean that there is little moveout in the raw data beyond 20-30 milliseconds below seabed. In turn, this means that the data are not especially sensitive to variations in velocity picking. This diminishes the consistency and strength of the relationship between velocity picks and the depth of primary reflections.

The time versions of the data have been depth converted with reference to a time grid of the base of the Quaternary sequence, based on interpretation of the final time data versions. This surface is the transition from relatively young sediments to relatively ancient rocks. The surface has been used to apply and control an interval velocity ramp from lower velocities, above, and higher velocities in the deeper bedrock.

There may be small miss ties at the intersection of depth segy lines which are not present in the parent time versions of the lines. This is due to differences in depth conversion velocities which, in time, only influence signal characteristics rather than vertical position.

Deployment of depth versions

The depth segy lines were loaded into the Kingdom projects as multiversions of the parent time lines. All interpretation is of the time data. These time interpretations have been thickness and depth converted and can be displayed on the depth lines as grids. There may be minor misties between these depth grids and events in the depth segy, especially with the UHR data, as the two depth products have been generated by separate workflows.

10 COMPARISON BETWEEN SEABED AND SUB-SEABED FINDINGS

In the final stage of interpretation, surficial geology has been correlated to the SBP results. Unit I Holocene sediments dominate the Kriegers Flak II North site (Figure 71), with thin parts surrounding mainly the till/diamicton surficial interpreted regions. The SSS interpreted till/diamicton regions (Figure 46) correlate well with the absence of the post glacial-marine Holocene unit and the periglacial-glaciomarine Unit II (Figure 71 and Figure 73). Nevertheless, there are parts where a thin layer of Unit I or Unit II (<0.5 m) occurs, implying a subcrop/outcrop of glacial Unit III till/diamicton. In the eastern tip of the site, a thin layer of the Holocene unit and Unit II occurs in the area that has been marked as till/diamicton in the SSS (considering the reflectivity, the relief in the MBES and the texture). The sediments are most likely clay, sand, gravel and boulders, implying diamicton facies (without direct genetic -glacial- connotation) of different age. On the other hand, the Unit III Till outcrops in the western site. This diamicton facies is most likely correlated to sub-cropping transitional glacial/glaciomarine ice-affected Unit II areas.

11 CONCLUSIONS

Seabed levels across the Kriegers Flak II North site range from a minimum of 21.8 m MSL, in the northernmost section of the site, to a maximum of 34.5 m MSL at the extreme eastern edge of the site.

Within the northern section of the site, to the north of approximately 6117650 mN, the seabed initially deepens from north-east to south-west and then from north-west to south-east, with seabed levels ranging from 21.8 m MSL to 31.4 m MSL. No steep slopes are present, with maximum gradients of <1.0° noted.

Further south, the seabed deepens very gently from north-west to south-east, with three slightly raised areas of seabed, standing up to 3.0 m higher than the surrounding seabed, are separated by broad (500 – 1500 m wide), NW-SE orientated, truncated channel features. The northernmost of these raised areas exhibits a very localised slope gradient of up to 7.5°, deepening from north-west to south-east.

The truncated channel features are very shallow, with localised depths only 1.5 m – 2.5 m deeper than the surrounding seabed. Maximum slope gradients of up to 1.5° are present on the sides of these features.

The highest slope values (very steep slopes; >15.0°) are associated with seabed features, such as boulders and cable trenches, as well as smaller elevated features and especially wrecks.

Muddy sand dominates the sediments across much of the Kriegers Flak II North site, with restricted regions in the northern part and widely extended areas across the north-central, central and south-central part.

The seabed sediments across the north-western section of the site comprise a series of large, irregular outcrops of till/diamicton, surrounded by large, irregular areas of sands and muddy sands (silty, clayey sands). Coarser patches of gravel and coarse sands are also present in the restricted areas in the northern part of this section.

The seabed sediments across the south-eastern section of the site comprise mainly muddy sands (silty, clayey sands). To the south-east, the seabed sediments appear finer-grained, comprising areas of muds (silts/clay) and sandy muds (sandy silts/sandy clays), one of which extends into the north-western section of the site. A number of relatively minor areas of outcropping till/diamicton, as well as restricted areas of gravel and coarse sands are present, mainly near the southern border of the site.

In terms of seabed surface morphology, the western half of the site is dominated by patches of boulder field areas which vary in concentration between high and intermediate density. An area of possible sand-gravel patches or biostructures runs in parallel to the northeastern site boundary, reaching a width of over a kilometre in the southeastern segment of the site. Confined areas of ripples and sandwaves characterize the northernmost and south-westernmost edges of the site, respectively.

The central part of the site is characterized by the afore-mentioned channel features, along with areas of disturbed seabed and seabed scars related to the construction of the Baltic Pipe. Most of the southern half of the survey area is covered in trawl marks with intermittent smaller boulder field areas.

A total of five wrecks and three possible wrecks were identified across the Kriegers Flak II North area, with an additional wreck located just outside the survey area boundary. The wrecks within the Kriegers Flak II North area are of unknown identity.

A total of 548 man-made targets were identified within the survey area. Eight of these were classified as wrecks, 67 as metallic contacts and 20 as soft rope. Five known cables have been found, along with an unknown one and a pipeline. In addition, 408 were identified as other, of which 218 contacts were defined as debris.

The geological foundation zone extends to ~70 m below seabed. The rocks and sediments within this interval have been interpreted with reference to the supplied GEUS desk study. There is generally a good correlation between the shallow geology imaged in this project's sub-seabed data, and the desk study.

In overview, the area has a glacial to post-glacial sequence of relatively recent sediments (Units I, II and III) over much older bedrock. The recent sediments are generally 3 – 8 m thick, though locally these recent sediments are interpreted to be much thicker. The seabed and top bedrock surface dips to the east, the younger post-glacial sediments (Units I and II) are better developed in the eastern part of the area.

Unit I (Holocene deposits) comprises post-glacial silty, sandy CLAYS, which are less than 1 m thick across most of the area. These include a veneer of sandier seabed sediments, though these are seldom resolved in the SBP data. The Holocene sediments are widely distributed over the study area. The Holocene is very thin or absent (unmapped) over the centre/west of the area, over south-west to north-east trending zones, where till is close to the seabed. Small pockets of Holocene may occur in these areas and a <0.2 m thick seabed veneer may still be present.

The Holocene deposits are thickest over a north-west to south-east trending ~2 km wide zone, which crosses the area from the centre/north to the extreme south-east. Here the deposits are up to 2 m thick. The sediments also thicken at the southern margin of the area.

The base Holocene is mapped as horizon H05. Over broad areas, it is interpreted to be a mild erosion surface. Thickness variations are due to relief at this surface and a degree of mounding at the seabed. The erosion at H05 may be related to the final regression of the area ~10 000 years ago, when sea level dropped.

There are some narrow channels cut into the underlying Unit II deposits. These trend east-west across the centre of the site and may be due to a short-lived drainage system at the onset of the marine transgression.

The Holocene unit (Unit I) has seismic characteristics that indicate that it is extremely soft/weak.

The interval defining Unit II (late Glacial deposits) is complex, due to the area's range of glaciomarine environmental conditions during the Late Weichselian and earliest Holocene. Locally, upper parts show laminations indicative of interbedded clays and sands/silts, whilst lower parts may represent sandier deposits.

The base of this unit is mapped as horizon H20. This is generally at the top of deposits which show clear signs of ice contact, true glacial deposits (tills). Unit II mainly occurs over central and eastern areas and is typically around 2 m thick, locally exceeding 5 m.

In the west, and over many parts of the central and northern regions of the area, the Unit II glaciomarine sediments pinch out over the subcropping Unit III tills.

The desk study divides this late glacial sequence into earlier and later parts.

Unit III (Glacial deposits) occurs throughout the study area, except for a few very small areas scattered around the north/centre of the area. Unit III is interpreted to be a till deposited in association with the last major ice advance over the area, approximately 22 000 – 18 000 years ago. The till forms a 3 m to 6 m thick blanket over the site, with variations due to bedrock morphology, patterns of primary deposition and possible erosion at the later onset of glaciomarine conditions. Unit III is typically 3 to 6 m thick, but can locally range from 0 to 34 m. The till is thickest along a 500 m wide south-west to north-east trending low in the top of the bedrock. This feature may be due to bedrock fault displacement or erosion.

Unit III is generally a glacial till which has been subjected to direct ice contact. The ice-contact facies may comprise a clay-prone diamicton, which is likely to contain subordinate silt, sand, gravel, cobbles and boulders. They will be overconsolidated. Consolidation levels may significantly vary over short distances. Seismically, the ice contact facies are structureless, with a very irregular upper surface, which probably forms a series of ridges.

The bedrock is likely to be Danian limestone. Bedrock faults are not well imaged, though these are likely to be present. These ancient faults were reactivated during the Late Cretaceous/Early Palaeocene and, in this area, likely generated inversion. The high potential for erosion of the top of the bedrock (especially over the last 1.1 million years of ice advances) makes it difficult to attribute features at the top bedrock surface to tectonic activity. The top of the bedrock is generally 3 to 8 m below seabed, exceeding 25 m over a 500 m wide south-west to north-east trending zone, just south of the centre of the area. This feature may be related to faulting or erosion. The upper surface of the bedrock is a truncation surface with an angular unconformity between the ~60 million year old limestones and their much younger overburden. The bedrock may have been subjected to numerous phases of erosion during early glaciations.

12 RESULTS AND INTERPRETATION KRIEGERS FLAK II SOUTH

12.1 CLASSIFICATION CRITERIA

12.1.1 Slope classification criteria

Seabed gradient has been classified as per Table 53 below.

Table 53: Slope classification

Classification	Slope
Very Gentle	< 1°
Gentle	1° - 5°
Moderate	5° - 10°
Steep	10° - 15°
Very Steep	> 15°

12.2 BATHYMETRY

Seabed levels across the Kriegers Flak II S site range from a minimum of 18.5 m MSL, in the south-western corner of the site near 353125 mE, 6080540 mN, to a maximum of 41.8 m MSL at the extreme north-eastern edge of the site, near 374300 mE, 6087630 mN.

An overview of the bathymetry within the Kriegers Flak II N survey area is shown in Figure 80, bathymetry profiles for several line plan segments are shown in Figure 81 and a detailed bathymetric overview of the eastern and central part of the survey area is shown in Figure 82.

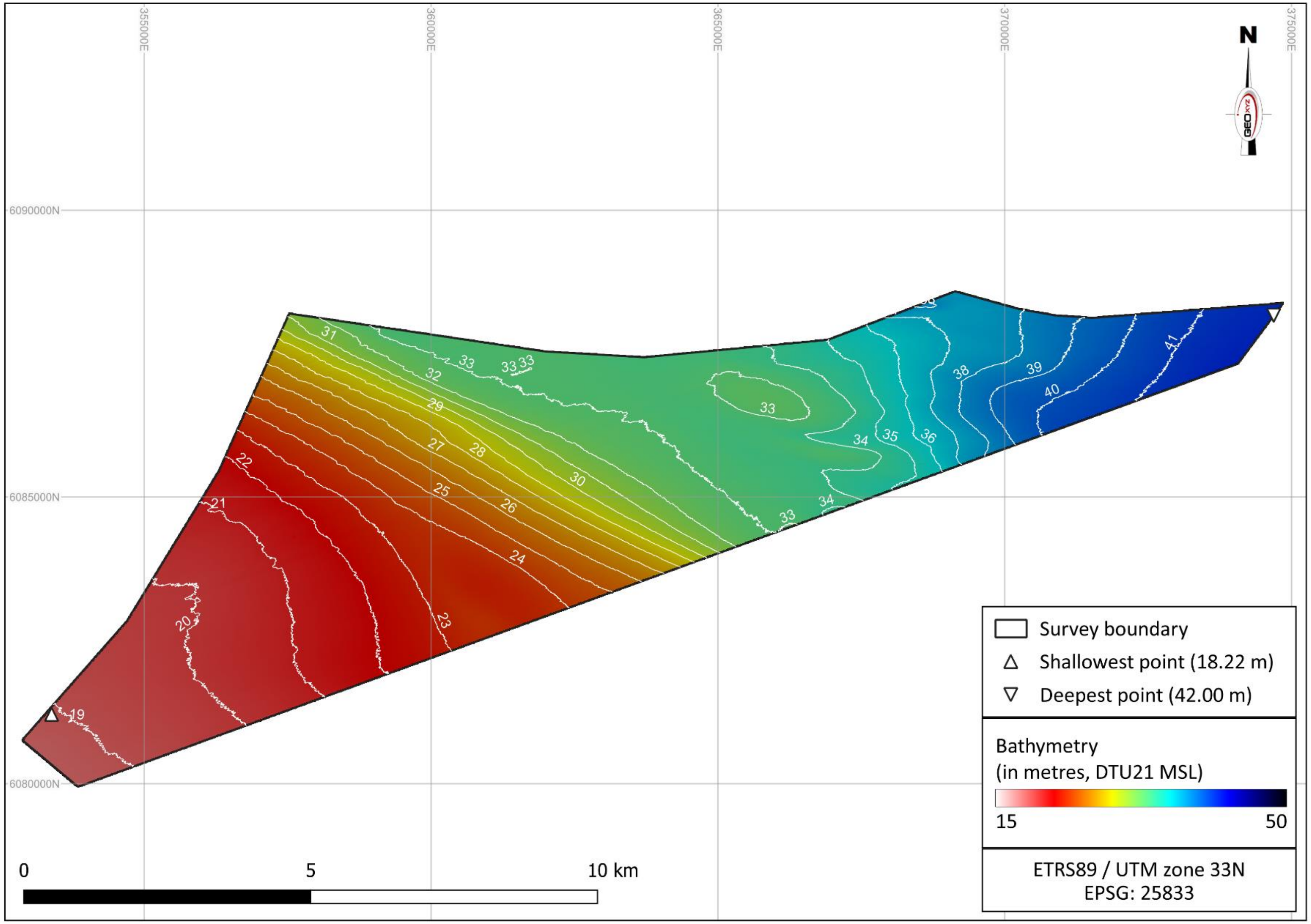


Figure 80: Bathymetry across Kriegers Flak II South area

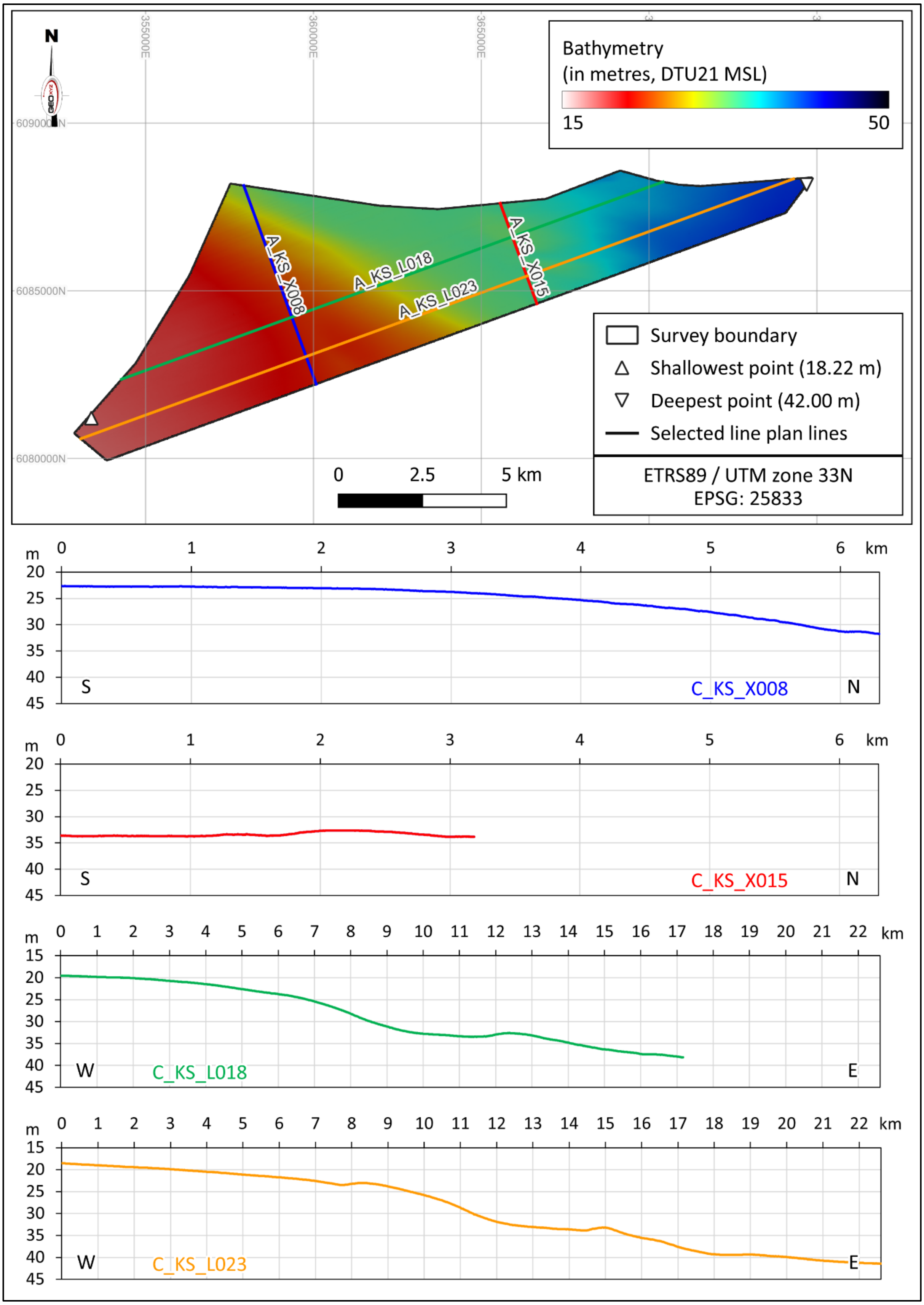


Figure 81: Bathymetry profiles based on selected line plan segments

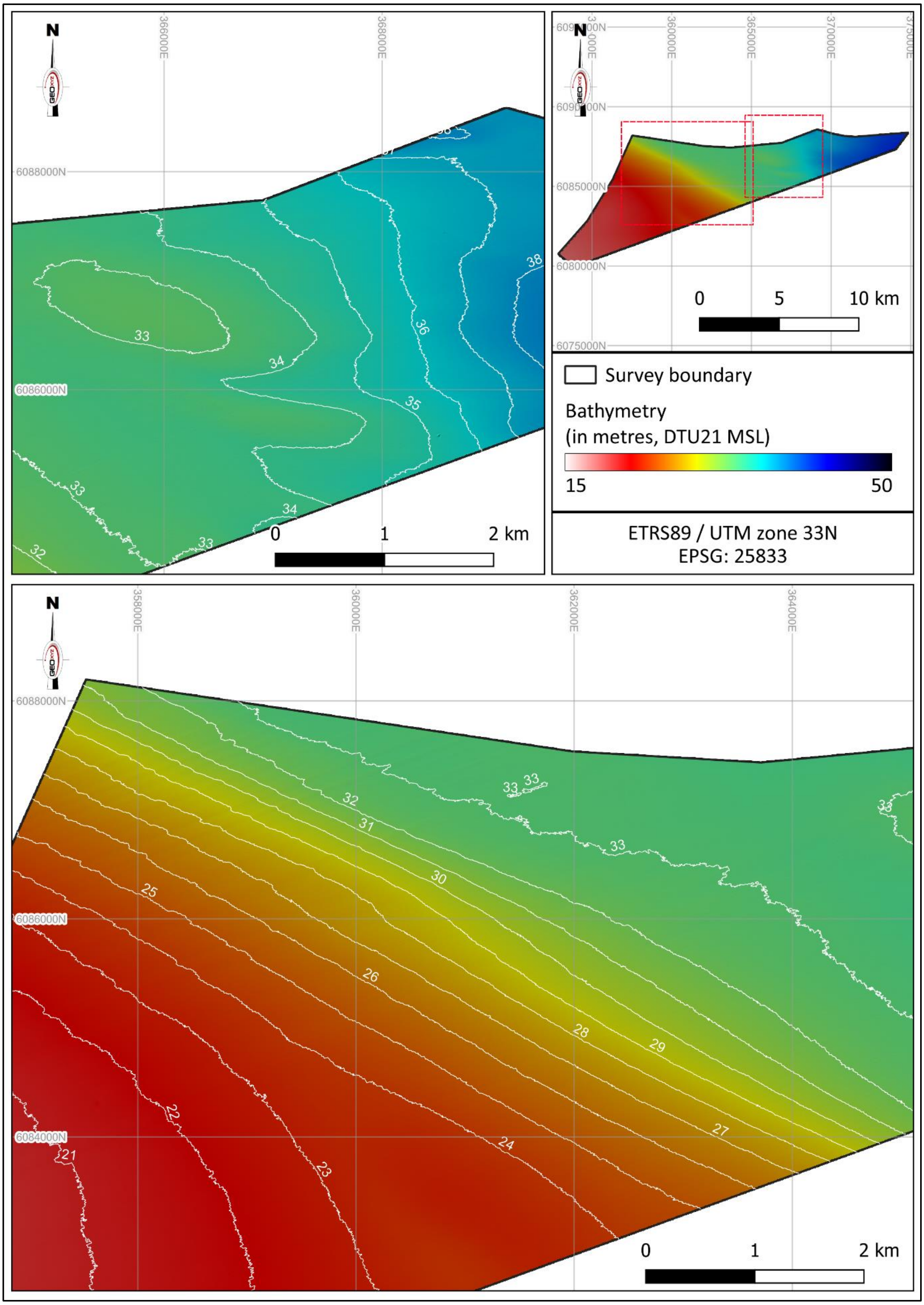


Figure 82: Detailed overview of bathymetry in the eastern and central part of the survey area

The westernmost part of the area has elevations of below 20 metres, growing deeper eastward at a slope of less than 0.1° until the 24-metre contour. At that point, the seabed gets more inclined, with slopes of up to 0.25° before reaching the 32-metre contour (Figure 82; bottom chartlet).

The central section of the site, to the north-east of the area mentioned above and bounded to the north-east by the 34.0 m MSL contour, is almost completely flat, with the seabed dipping imperceptibly towards the north-east at an average slope gradient of < 0.02° (Figure 82; bottom chartlet).

To the north-east of the 34.0 m MSL contour, the seabed continues to deepen very gently from W-E, becoming WNW-ESE, with seabed levels very gradually deepening to reach a maximum of deeper than 41.5 m MSL at an average slope gradient of < 0.1° (Figure 82; top chartlet).

The highest slope values (very steep slopes; > 15°) are associated with seabed features such as boulders, trawl scars, wrecks, and other smaller elevated features (Figure 83).

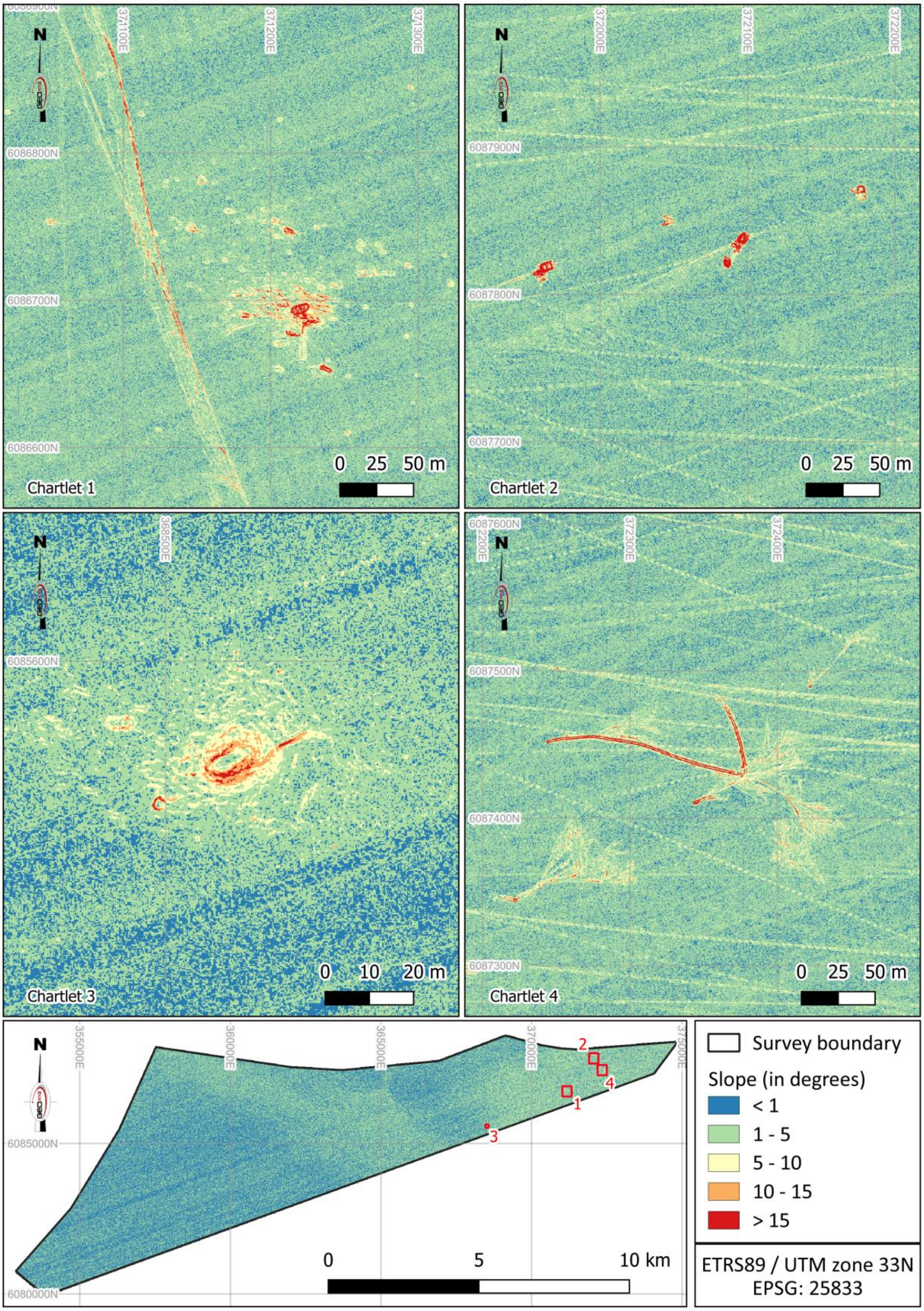


Figure 83: Slope map of several high-slope areas within the survey area

12.3 SEABED SURFACE CLASSIFICATION: GEOLOGY

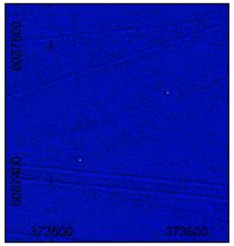
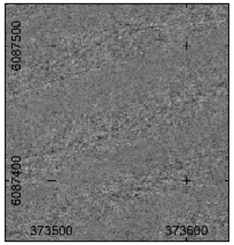
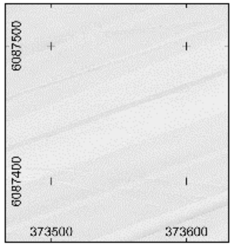
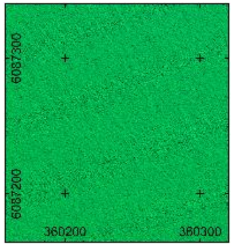
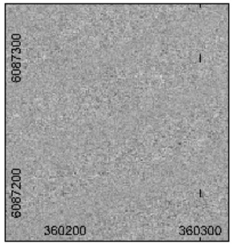
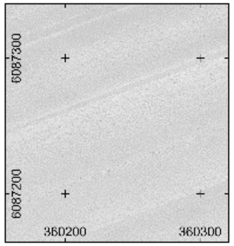
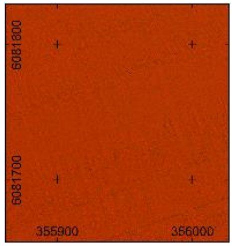
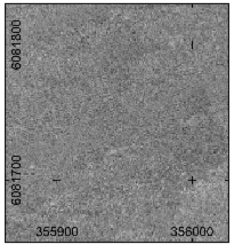
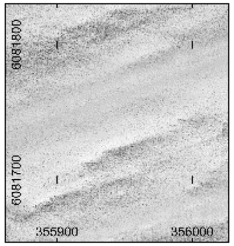
The seabed geology across the Kriegers Flak II South area was evaluated from the interpretation of the low and high frequency SSS data, the backscatter imagery and the MBES dataset. Data analysis and classification was performed using the seabed acoustic characteristics, such as reflectivity and backscatter strength, as well as the seafloor relief and the overall pattern. During the interpretation of the SSS data, higher reflectivity areas – higher intensity sonar returns (darker grey to black colors) have been related to relatively coarse-grained sediments and lower reflectivity areas – lower intensity sonar returns have been related to relatively fine-grained sediments (Table 54). GEUS terminology was used to define the identified seafloor sediment in the survey area.

Bathymetric data aided the interpretation. The resultant seabed surface geology has been correlated to the soil description of the surficial grab samples and the onshore laboratory results. For the grab sample analysis, the definition of the particle sizes followed the Wentworth scale (Figure 84).

For the needs of correlation, the results were further processed and reclassified, according to the Folk 7 classification system (Figure 85). For sand, muddy sand, and mud and muddy sand seafloor sediment classes there is a direct correlation to the Folk 7 classification. Gravel and coarse sand, and till/diamicton sediment classes have been correlated to mixed sediment grab samples.

It should be noted that not only the grab samples (that might not be representative of the entire area outlined), but also SSS reflectivity, MBES relief, backscatter data, sub-surficial geology and the EMODNET classification have been considered for the Geology polygons.

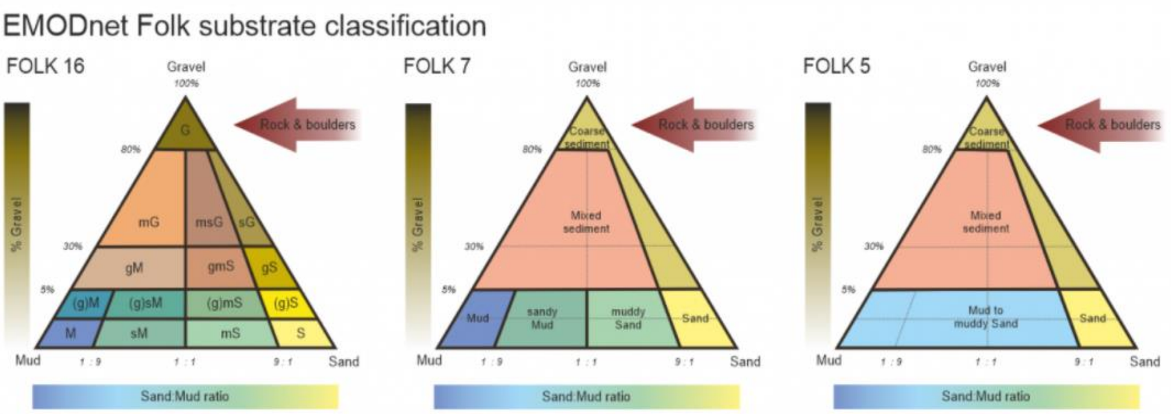
Table 54: Acoustic characteristics of the sediment types within the Kriegers Flak II South site

Geological interpretation	Colour and code	Sediment interpretation	Acoustic description	MBES image	Backscatter image	LF SSS image
Mud and sandy mud	21	Predominately mud with minor to significant fractions of sand. May contain minor fractions of or gravel	Low reflectivity, visible in BKS			
Muddy sand	13	Predominately sand with significant fractions of mud and muddy sand. May contain minor fractions of or gravel	Low to medium reflectivity, visible in BKS			
Sand	12	Predominately sand. May contain minor fractions of mud and/or gravel	Medium reflectivity, visible in BKS			

Major Grade	Phi (ϕ) limits Lower	Phi (ϕ) limits Upper	Wentworth size class
gravel	<-8	-8	boulder
	-8	-6	cobble
	-6	-2	pebble
	-2	-1	granule
sand	-1	0	very coarse sand
	0	1	coarse sand
	1	2	medium sand
	2	3	fine sand
	3	4	very fine sand
mud	4	5	coarse silt
	5	6	medium silt
	6	7	fine silt
	7	8	very fine silt
	8	>8	clay

Scale by Wentworth (1922) classifying sediment particles according to the diameter expressed in units of N (phi, the negative log 2 of the diameter in millimeters).

Figure 84: Wentworth Scale – classifying sediment particles



FOLK, 16 classes	FOLK, 7 classes	FOLK, 5 classes
Rock & Boulders	Rock & Boulders	Rock & Boulders
Gravel - G sandy Gravel - sG) gravelly Sand - gS	Coarse sediment	Coarse sediment *(Gravel >= 80% or (Gravel >= 5% and Sand >=90%)*
muddy Gravel - mG muddy sandy Gravel - msG gravelly Mud - gM gravelly muddy Sand - gmS	Mixed sediment	Mixed sediment *(Mud 95-10%; Sand < 90%; Gravel >= 5%)*
(gravelly) Mud - (g)M Mud - M	Mud *(Mud >= 90%; Sand < 10%; Gravel < 5%)*	Mud to muddy Sand *(Mud 100-10%; Sand < 90%; Gravel < 5%)*
(gravelly) sandy Mud – (g)sM sandy Mud - sM	sandy Mud *(Mud 50-90%; Sand 10-50%; Gravel < 5%)*	
(gravelly) muddy Sand – (g)mS muddy Sand - mS	muddy Sand *(Mud 10-50%; Sand 50-90%; Gravel <5%)*	
(gravelly) Sand – (g)S Sand	Sand *(Mud < 10%; Sand >= 90%; Gravel < 5%)*	Sand

Figure 85: EMODNET Folk substrate classification

Finally, seafloor sediment classification has been integrated to the sub-seabed geology data.

The seabed sediments across the Kriegers Flak II South site become gradually finer grained, running from west-southwest to eat-northeast across the site (Figure 86).

The shallowest section of the site lies in its south-western corner, where the seabed sediments comprise sands. This area indeed contains grab samples with >90 % (i.e., sand as per Folk 7 classification). Moving towards the east-northeast, the seabed sediments grade into muddy sands (silty/clayey sands). This muddy sand area contains mostly silty sand grab samples and three slightly gravelly silty sand grab samples (i.e., muddy sand as per Folk 7 classification). Finally, in the deepest section of the site, in the extreme north-eastern corner, the seabed sediments comprise mud (silts/clays) and sandy mud sandy silts/clays). No grab samples were acquired within the latter area, however the EMODNET data shows mud and sandy mud, which is in agreement to the lower reflectivity in SSS and backscatter data.

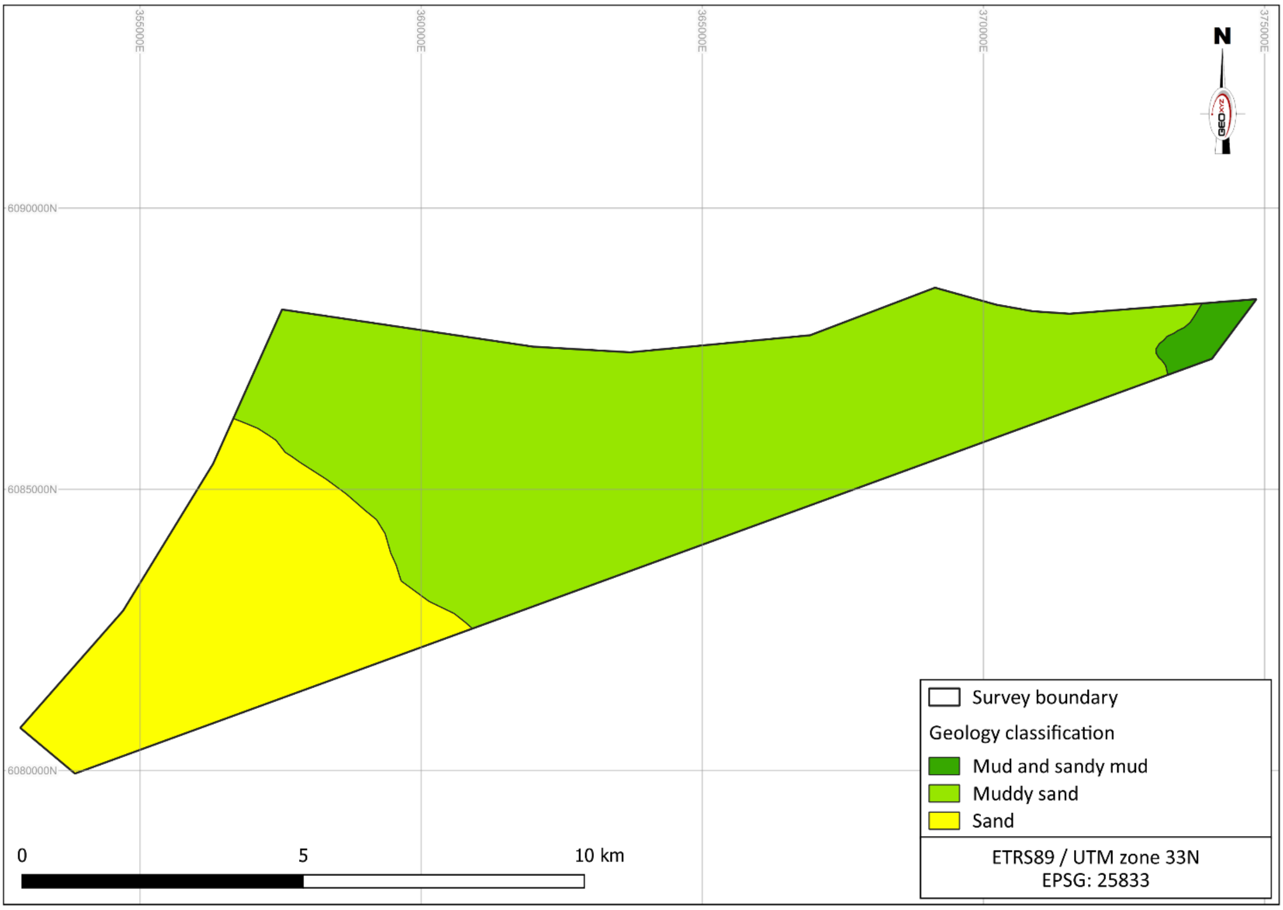


Figure 86: Seabed surface geology classification - Kriegers Flak II South

12.4 SEABED SURFACE CLASSIFICATION: MORPHOLOGY

Seafloor morphology and seabed feature descriptions were based on the interpretation of SSS, BKS and MBES datasets whereas the results from the SBP have been considered.

The resulting seabed surface morphology interpretation is presented in Figure 87 below.

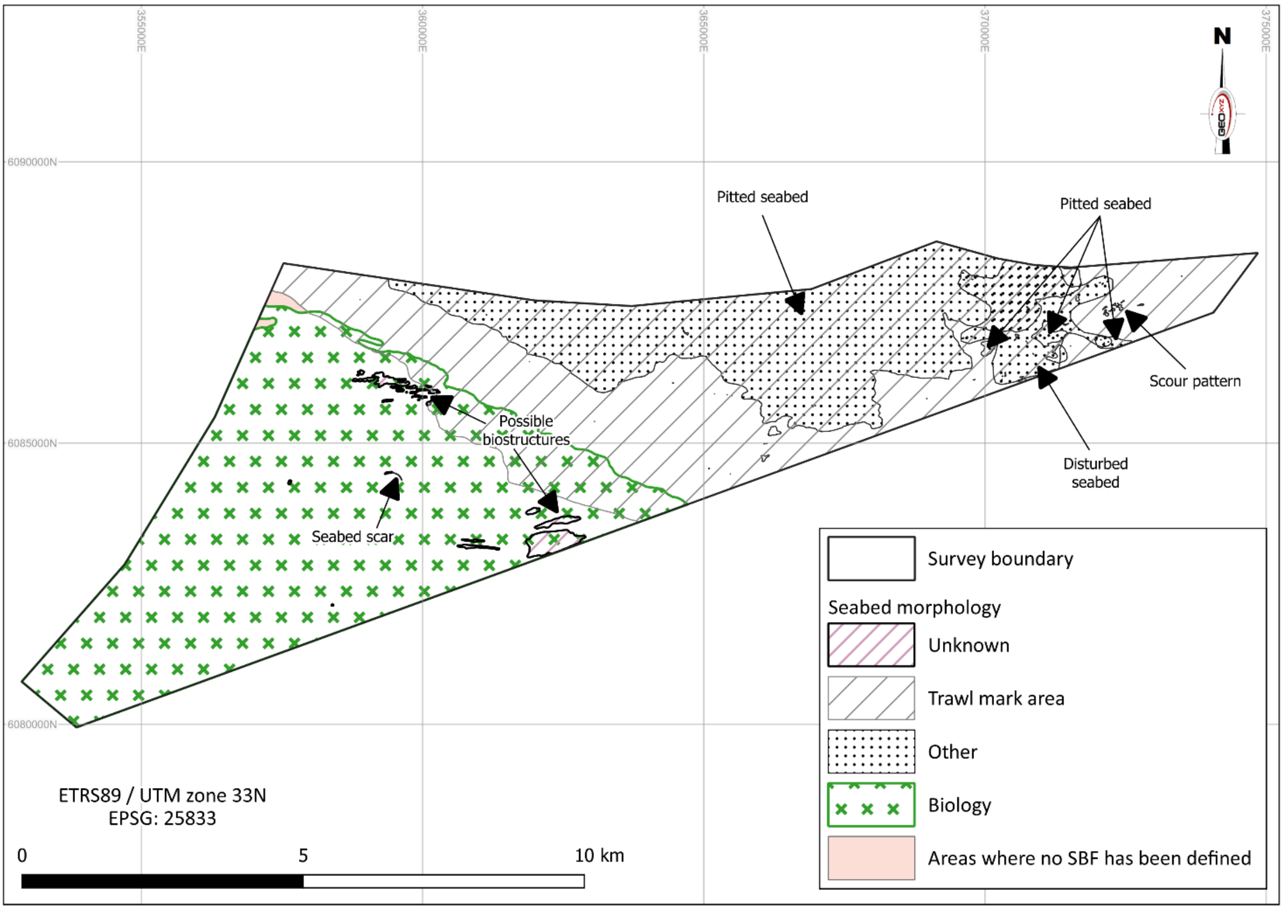
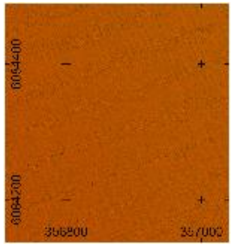
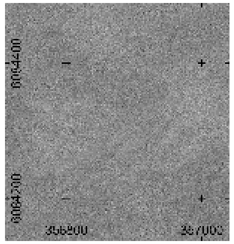
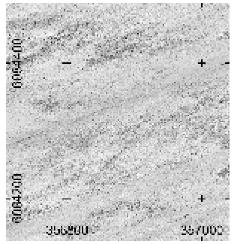
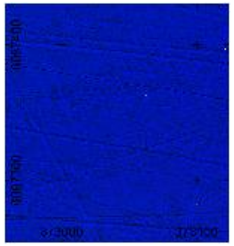
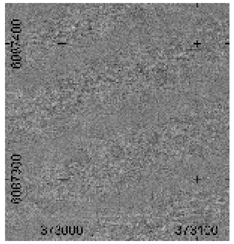
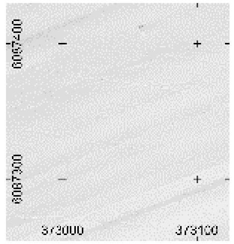
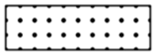
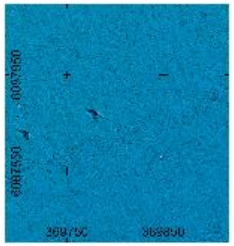
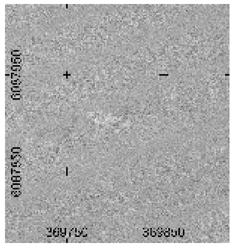
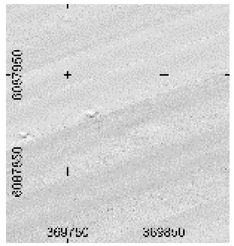
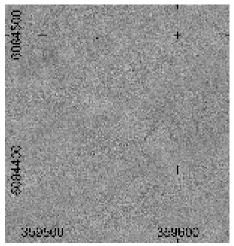
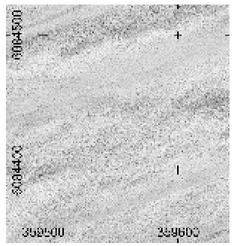
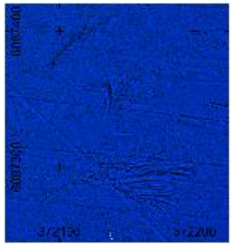
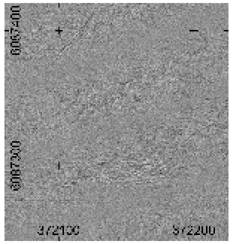
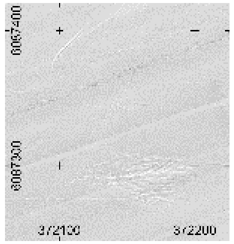
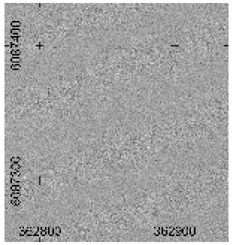
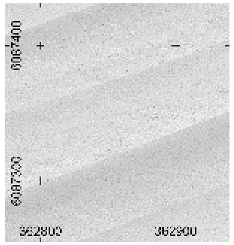
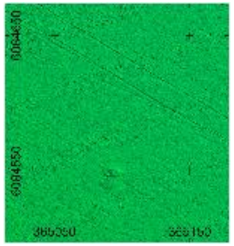
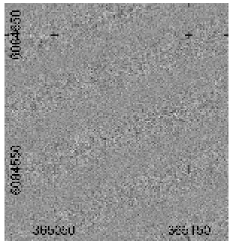
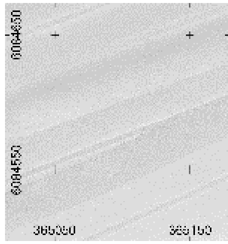
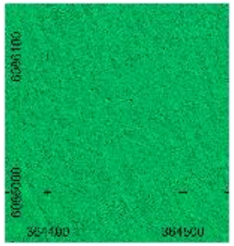
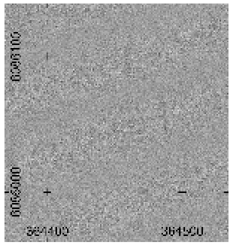
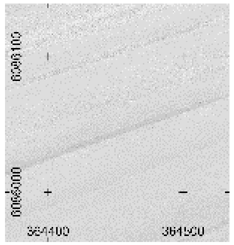


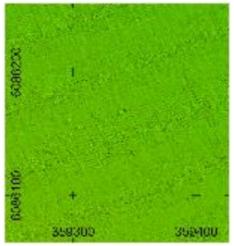
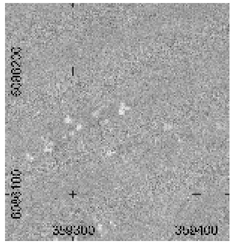
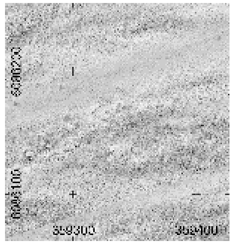
Figure 87: Seabed surface morphology classification

The acoustic characteristics of the interpreted seabed features across the Kriegers Flak II South area are summarized in Table 55.

Table 55: Morphological interpretation

Seabed Feature	Symbology	Description	MBES image	Backscatter image	SSS image
Biology – Area of Mytilus edulis beds		Low to high reflectivity alternating, SW-NE to W-E,elongated patches. Hardly visible in MBES. Subtle appearance in BKS			
Trawl marks		Low to medium reflectivity linear features, visible in MBES			
Other – Disturbed seabed - possible related to offshore operation activities		Low to medium reflectivity, visible in MBES			
Other – Seabed Scars		Low to medium reflectivity, visible in MBES.			

Seabed Feature	Symbology	Description	MBES image	Backscatter image	SSS image
Other – Scour pattern		Low to medium reflectivity linear scars forming a pattern, visible in MBES			
Other – Pitted seabed/Area of small depressions		Low reflectivity with numerous small spots of low to high reflectivity seabed			
Other – Seabed Mound		Low reflectivity, hardly noted in SSS. Visible in MBES			
Other – Depressions		Low reflectivity, hardly noted in SSS. Visible in MBES			

Seabed Feature	Symbology	Description	MBES image	Backscatter image	SSS image
Unknown – Possible bio-structures		Low to medium reflectivity, with irregular high reflectivity patches, visible in MBES and distinguishable in BKS in most of the area			

Fishing activity with scattered trawl marks of different orientations are outlined in the northeastern half of the Kriegers Flak II South site (Figure 87).

A wide area of SW-NE to W-E, low to high reflectivity alternating, elongated patches has been interpreted as area of possible Mytilus edulis beds and has been outlined in the southwestern half of the site. The existence of Mytilus edulis has been confirmed by ground truthing commenced within the area. Patches of higher reflectivity possibly accommodate far greater epifauna abundance, primarily attributed to the blue mussel (Mytilus edulis) which occurred in well-established beds across the majority of the southwest site. Those alternating patches show similar geometry to bedform-related features, however, the elevation difference is generally less than 5 cm and their crest part is rather flat.

The seabed scars and the disturbed seabed areas are likely associated with offshore operation activities as the scars appear to have an orientation towards and around a centre location. The disturbed seabed areas are mostly found at the end tips of the seabed scars. Both seabed features (linear - seabed scars and polygon - disturbed seabed) have been outlined within an extended area in the northeastern half of the survey area (Figure 87).

Aside from seabed scars associated with offshore activities, seabed scars are noted in the Kriegers Flak II South site which are likely formed by natural or anthropogenic processes. Most of these features are not prominent in the SSS data but they have been mapped in the MBES data due to the measurable depth difference.

A total of 11 scour patterns are outlined in the vicinity of the offshore operation area in the northeastern half of the site. All scour patterns are possibly resulting from abrasion of an anchor chain on the seafloor during a vessel swing caused by wind and currents.

An extended area with numerous, small depressions, is outlined in the northeastern half of the Kriegers Flak II South site (Figure 87). This area has a minimum size of 2.7 km to a maximum size of 12 km in width and length. Smaller areas are also outlined in the northeastern half of the site. A general localized depth observed over these areas is less than 0.5 m.

A total of three seabed mounds are observed in the northeastern half of the survey area. These areas have a minimum size of 7 m to a maximum size of 16 m in width and length. The maximum height observed on these seabed mounds is 0.25 m. In addition, 15 depressions, possibly related to physical processes, have been mapped in the survey area. Most of these features are prominently displayed in the MBES dataset.

Similarly to the Kriegers Flak II North site, possible bio-structure features are observed within the area of Mytilus edulis beds in Kriegers Flak II South site (Figure 87). They are showing high reflectivity/intensity returns in SSS and BKS data and they display an elevation of approximately 10 cm. They could possibly be interpreted as higher concentration of Mytilus edulis beds and/or likely reefs. The interpretation of this feature is uncertain.

12.4.1 Boulder field identification criteria

The boulder field identification criteria for the survey are outlined in Technical Query TQ-009. Seabed objects, including boulders > 0.5 m in any direction were interpreted and classified. Areas with high boulder densities were provided as POL delineated from the SW projects and classified as per Table 56 below. Individual boulders within the boulder fields were picked using the automatic boulder picking algorithm. Debris objects larger than 0.5 m in any direction within the boulder fields were isolated from the auto-picked boulder fields and further investigated.

Table 56: Boulder field classification

Boulder density	Classification	Description
Intermediate	Class 1	Concentration of 40 – 80 boulders within an area of 100 x 100 m
High density	Class 2	Concentration of > 80 boulders within an area of 100 x 100 m

12.5 SEABED SURFACE CLASSIFICATION: MAN-MADE FEATURES

Through the interpretation of the MBES, SSS, and MAG datasets, a total of 150 mad-made objects were identified within the Kriegers Flak II South site. An overview of the seabed surface objects is presented in Table 57 below. A total of nine metallic objects were found within the survey area. Those metallic objects were found as a single object, linear object, or as a cluster of objects. An example is presented in Figure 88.

Table 57: Summary of man-made objects

Feature type	Total amount	Comment
Wreck	1	One wreck was found within the survey area which was identified as the Brigit Ehlers shipwreck.
Cable and pipeline	1 cable: C-Lion1	
Metallic	9	Nine metallic contacts were found within a 5 m radius of a magnetic anomaly.
Other contacts	139	139 items were described as other.

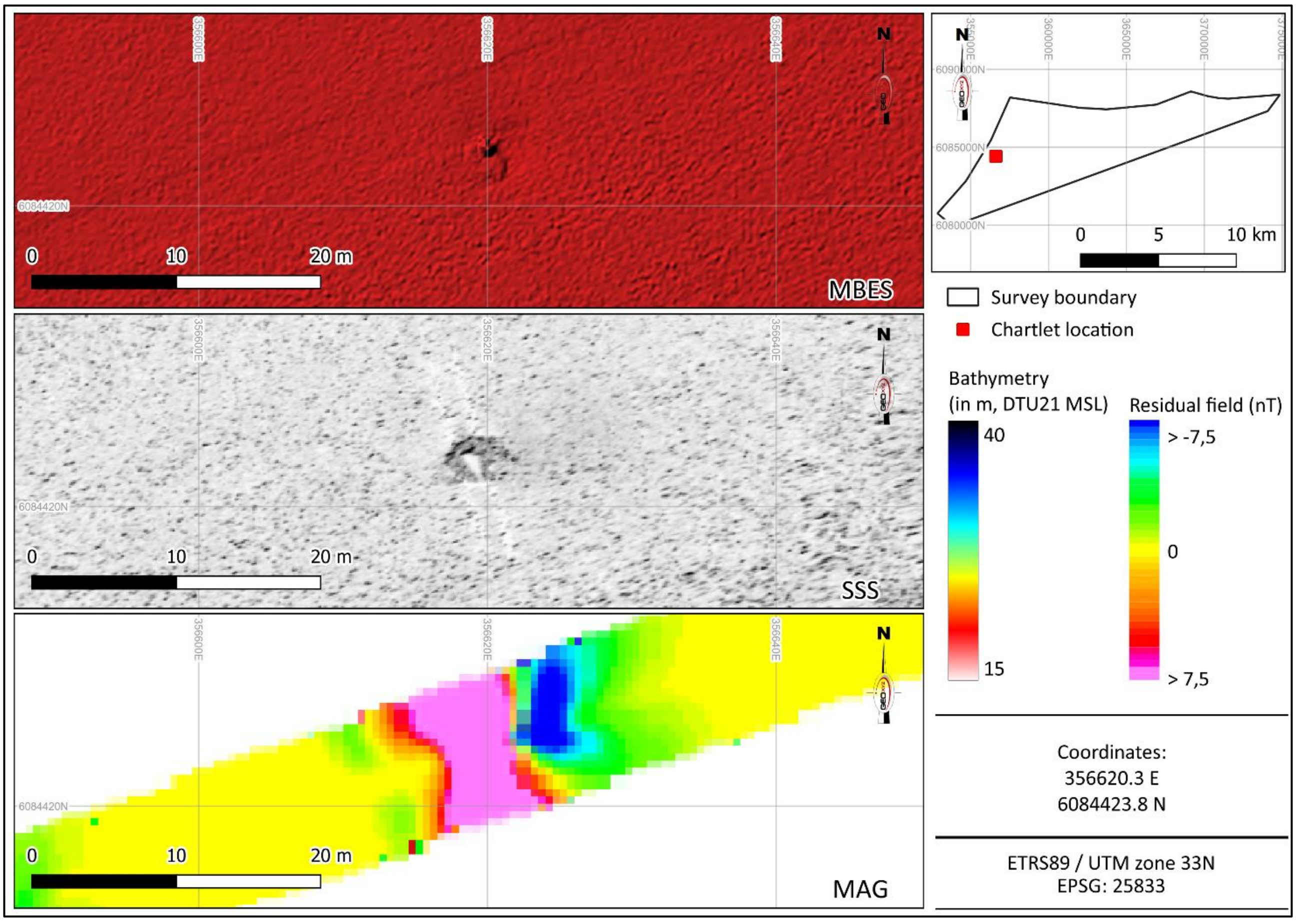


Figure 88: Data example of single metallic object (KFII_S_041)

A total of 64 sonar contacts were observed within the survey area. Figure 89 presents an example of a sonar contact found within a 10 m radius of a magnetic contact. Such contact could potentially present a ferrous object. The rest of the sonar contacts show high reflectivity but are not interpreted as debris.

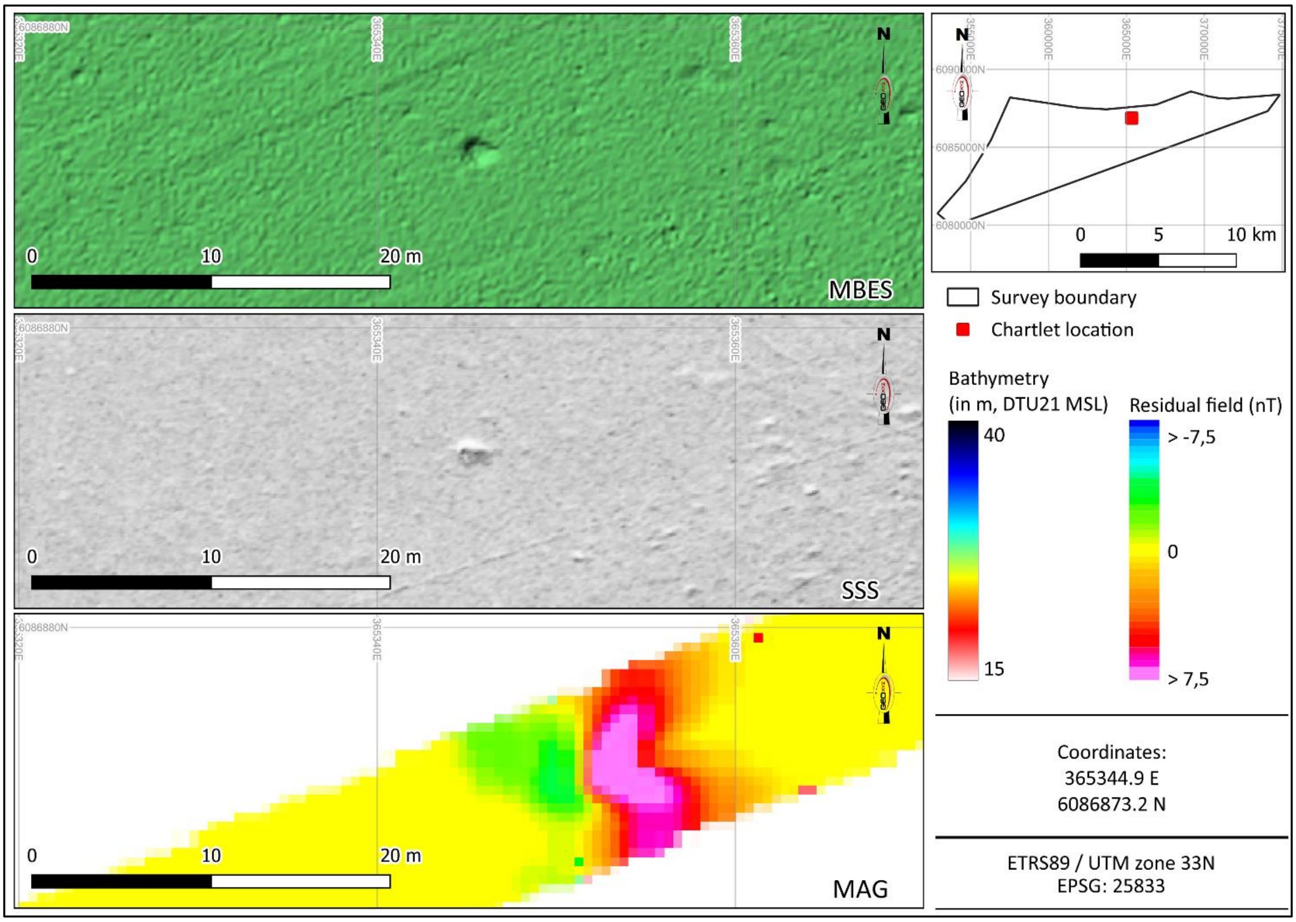


Figure 89: Possible sonar contact (KFII_S_061) in close proximity (10 m) to a magnetic anomaly (KFII_S_B02_GO5_0010)

A total of 18 possible linear objects, including elongated objects and objects with possible fragments of cable/wire/rope were identified within the Kriegers Flak II South site (Figure 90). There was no discernible linear magnetic response detected for all the linear objects. Some of these linear objects displayed a strong and sharp shadow in the SSS dataset which indicates a possible man-made object with significant height.

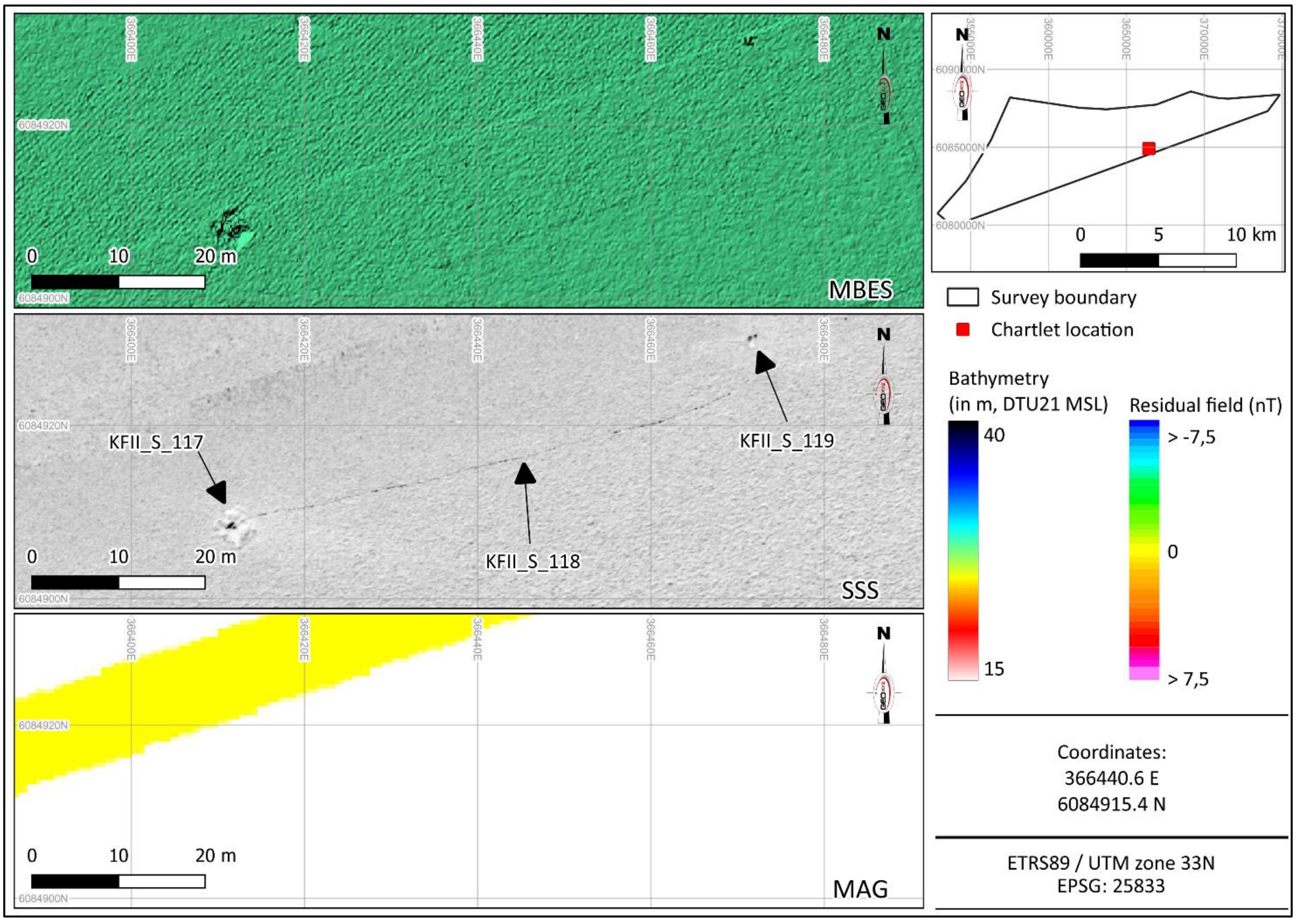


Figure 90: Data example of a possible linear object (KFII_S_118) attached to a debris item (KFII_S_117). A debris item (KFII_S_119) is also noted to the east of the linear debris

12.5.1 Archaeological findings

GEOxyz is not specialized in providing archaeological services. As such, the findings in this report are based on an interpretation of data which is a matter of opinion on which professionals may differ.

12.5.2 Wrecks

Within the Kriegers Flak II South area, a single wreck was noted. The wreck within the Kriegers Flak II South area was identified as the wreck of the Birgit Ehlers (Table 58).

Table 58: Wreck identified within the Kriegers Flak II South area

MMO ID	Description	Wreck Name	Easting (m)	Northing (m)	Length (m)	Width (m)	Max. Height (m)	WD (m)	Comments
KFII_S_148	Known wreck	Birgit Ehlers	370087.3	6086587.0	12.7	4.0	2.6	40.1	Broken up wreck

<u>Wreck KFII_S_148</u>

Figure 91 presents an overview of the location of wreck KFII_S_148, identified as the Birgit Ehlers wreck.

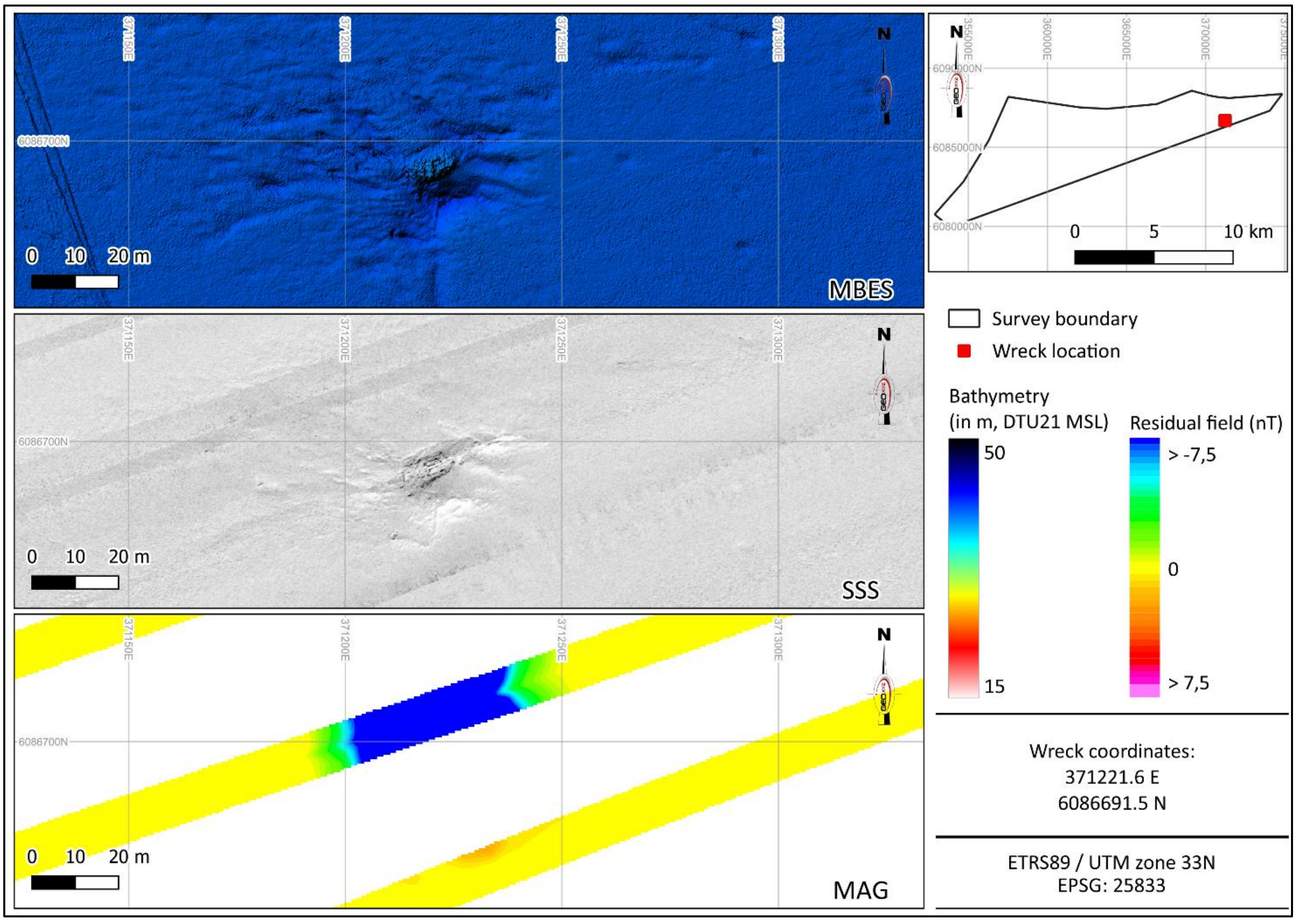


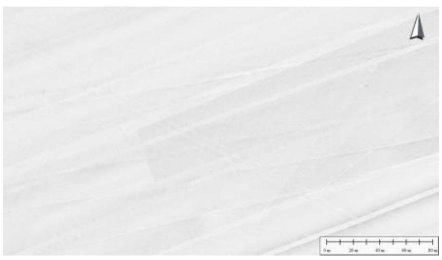
Figure 91: Location of wreck 10

This wreck is located at 371221.6 mE, 6086691.5 mN. The dimensions are approximately 12.7 m x 4.0 m x 2.6 m (L x W x H).

12.5.3 Cables, wires and ropes

Only one cable – the C-Lion1 cable – was found within the Kriegers Flak II South survey area (Table 59), and an existing cable that was not detected within the survey area is the Unknown-2 cable. Based on the database, the status of this cable is active. Both cables' locations are shown in Figure 92.

Table 59: Overview of the cable within the survey area

MMO ID	Pipeline / Cable	Description	SSS image
PTS: KFII_S_066 **LIN**: KFII_S_016, 021, 029 & 030	C-Lion1 Cable	**Active Cable** **SSS**: KFII_S_B02_SSS_GO5_0108 **MAG**: KFII_S_B03_MAG_G05_0002, KFII_S_B04_MAG_G06_0024, 0025, 0027, 0028, 0029, 0030, 0031	

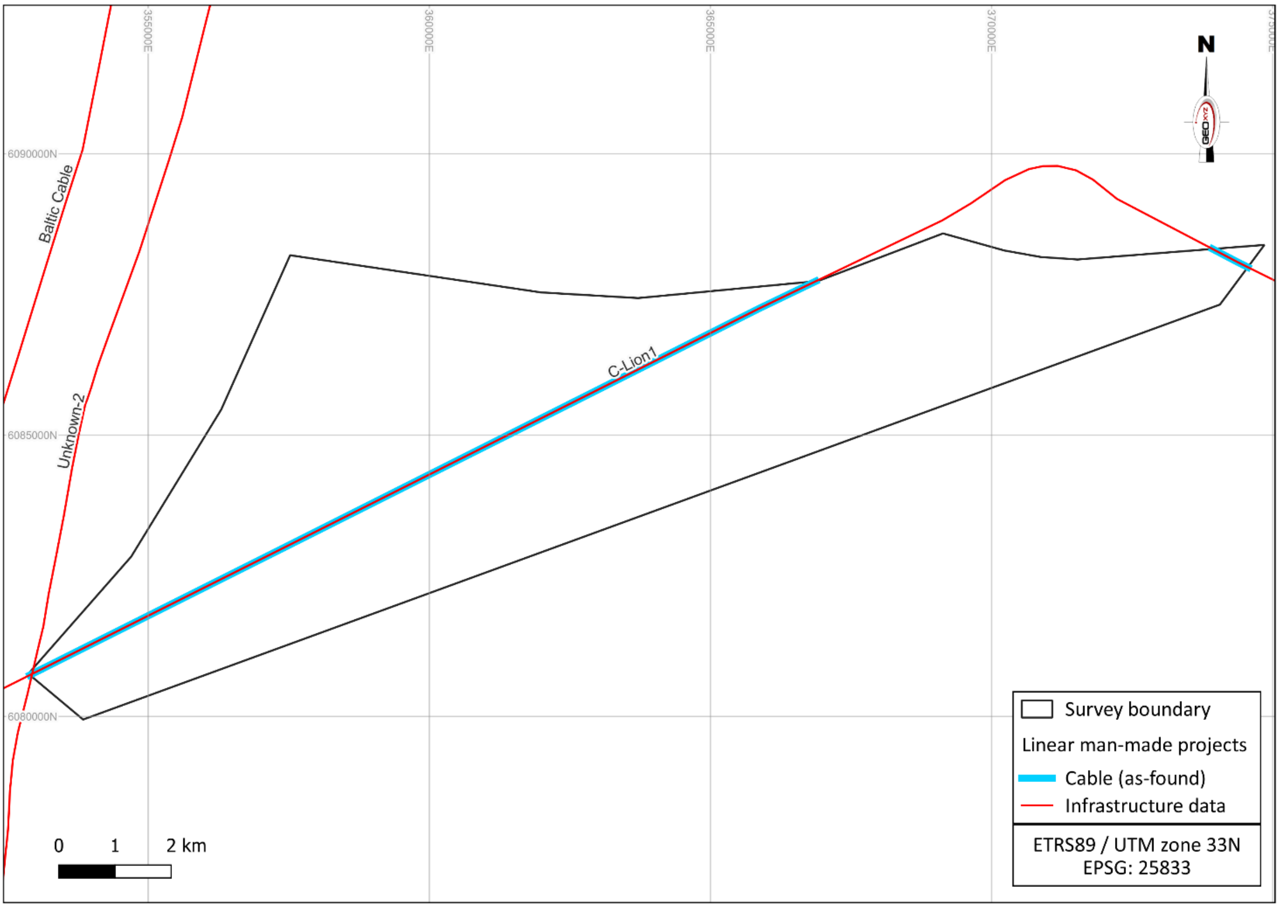


Figure 92: A comparison of as-found cables with existing data on their locations for the Kriegers Flak II South site

12.5.4 Pipelines

No pipelines were found within the survey area.

12.5.5 Debris

A total of 53 debris items were identified within the Kriegers Flak II South site from the interpretation of the MBES and SSS datasets (Figure 93). All the debris items were interpreted as non-ferrous objects. A data example of a possible debris object is shown in Figure 94.

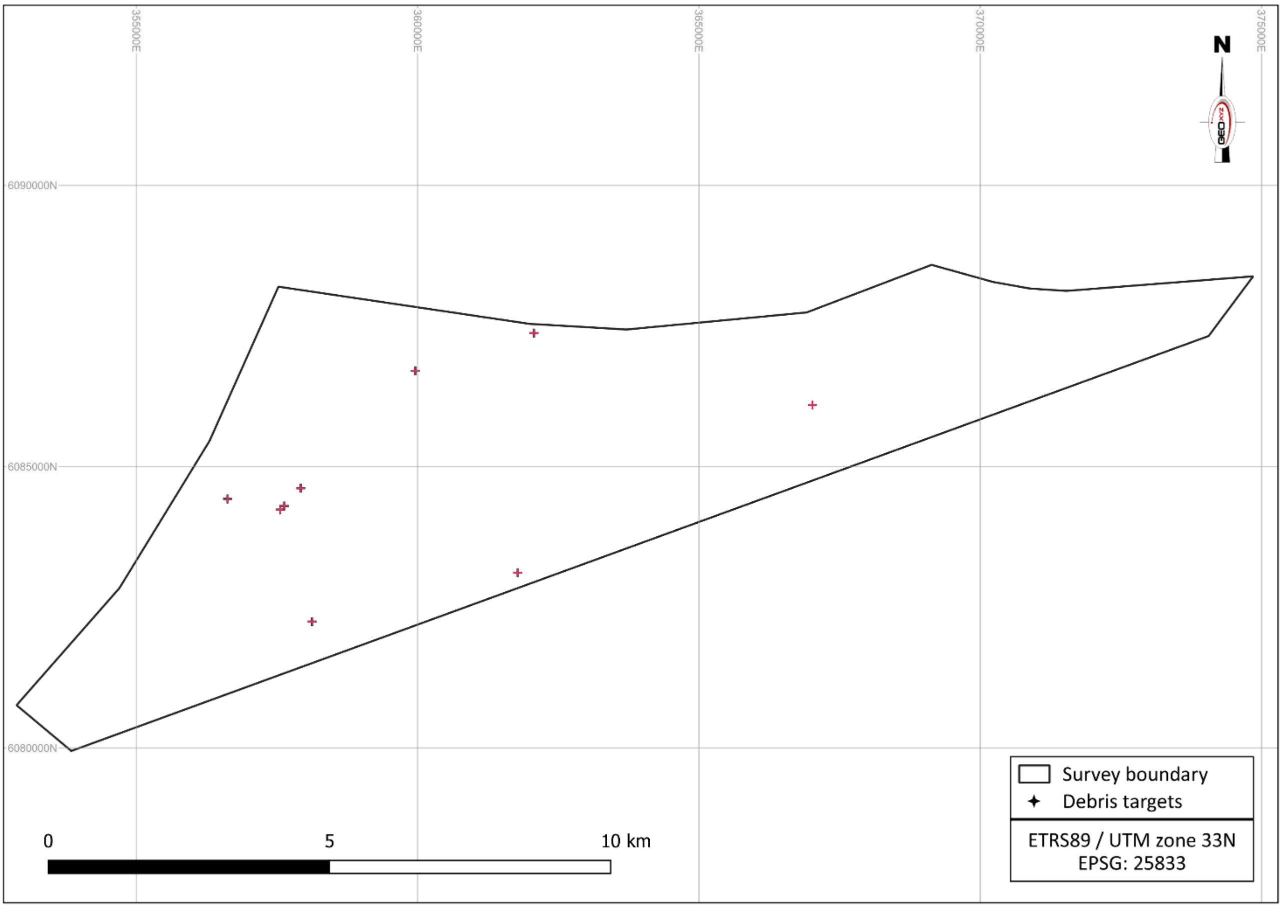


Figure 93: Overview of debris objects within Kriegers Flak II South survey area

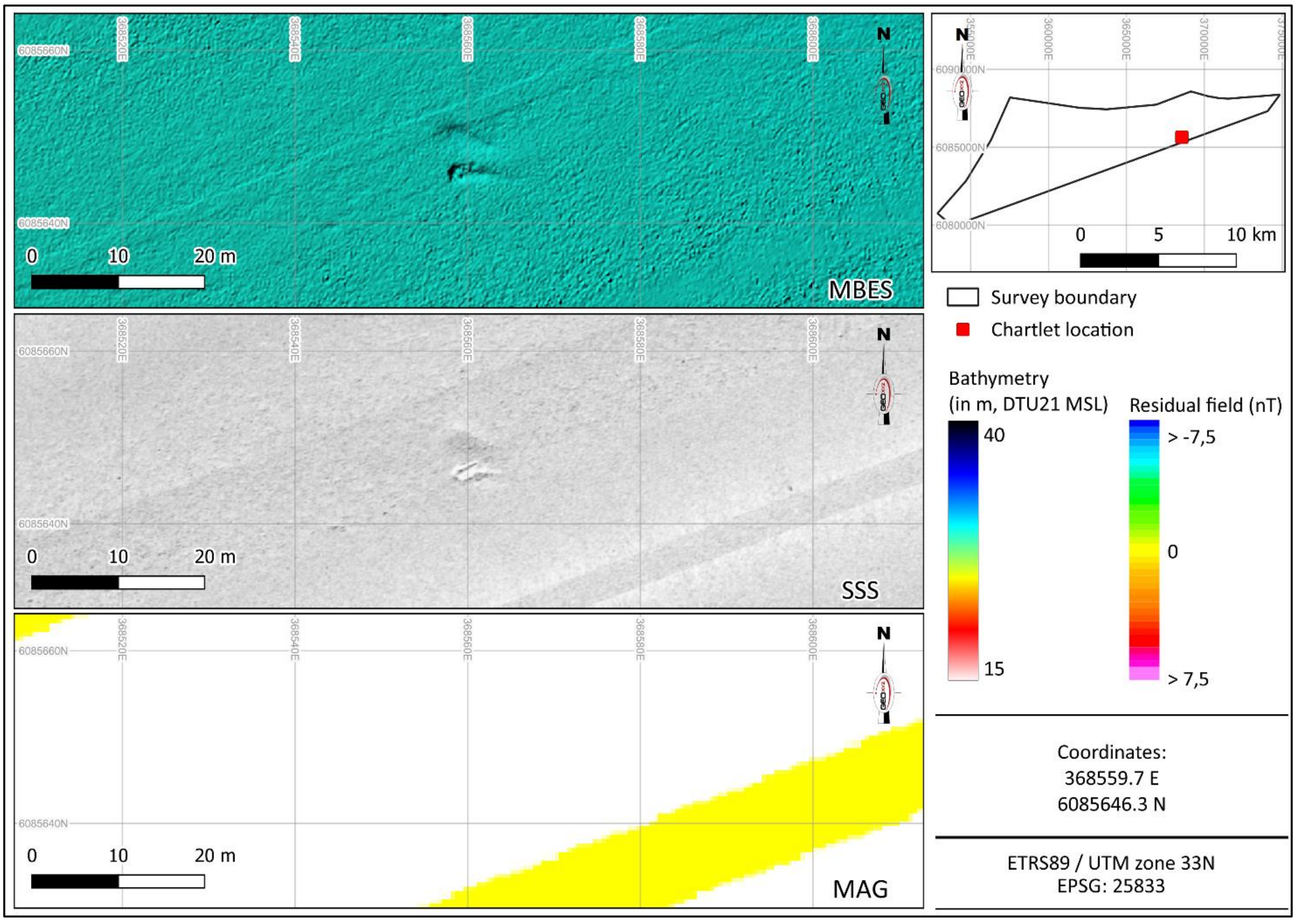


Figure 94: Data example of possible debris in the survey area (KFII_S_131)

13 SUB-SURFACE GEOLOGY

13.1 REGIONAL GEOLOGICAL HISTORY

13.1.1 Pre-Quaternary geology

The Kriegers Flak II South site is located just south of the south-western boundary of the Baltic shield between the southern part of Sweden, the Kattegat and the northern part of Jutland.

The area is underpinned by the west-north-west to east-south-east trending Sorgen-Frei-Tornquist structural zone (Geus 2024). This extensional/strike slip structure has been reactivated during Triassic, Jurassic and Early Cretaceous with dextral trans-tensional movements along the boundary faults. These movements inverted sedimentary basins.

In the Late Cretaceous – early Paleogene, the previously subsiding depocenter became inverted, due to a change in the regional stress orientation, dominated by compression associated with the Alpine Orogeny and the opening of the North Atlantic.

The uppermost bedrock of the Kriegers Flak II South OWF is expected to consist of Upper Cretaceous chalk (GEUS 2024).

13.1.2 Quaternary geological developments

Four glacial maxima, dating from Late Saalian to Late Weichselian, have advanced across the Baltic region. The glacial maxima were separated by interglacial or interstadial marine or glaciolacustrine conditions.

In this report's area of interest the sediments for earlier glacial cycles have been removed or reworked by the latest Weichselian ice advance. The Quaternary sediments reported here are those of the Weichselian glacial advance, the subsequent deglaciation and the latest marine Holocene conditions.

Developments over these last ~25 000 years, which have a sedimentary legacy, are covered in greater detail in Section 13.2.3.

13.2 SOIL UNIT INTERPRETATION

13.2.1 Shallow geological overview

The geological foundation zone extends to ~70 m below seabed. The rocks and sediments within this interval have been interpreted with reference to the supplied GEUS desk study (2024). This desk study applies a Quaternary stratigraphic model developed for the Bornholm Basin by Jensen et al. (2017) in conjunction with archive seismic data and limited ground truth information. Some of this information is derived from survey work for the Kriegers Flak OWF site, which is positioned between the Kriegers Flak South and North sites.

There is a good correspondence between shallow geology imaged in this project's sub-seabed data and the geology described in the desk study. This project's units are broadly equivalent with those in the desk study, this means that it will be easier for future workers to use these survey reports and the desk study together.

In general, the area has a glacial to post-glacial sequence of relatively recent sediments over much older bedrock. The Quaternary sediments are generally 10 to 45 m thick. The seabed generally dips to the northeast. The top bedrock unconformity is an undulating surface that dips gently to the southwest, with the Quaternary sequence thinning as the water depth increases. Unit III is absent in large parts of the survey area and is present mostly in the central and northern parts.

13.2.2 Stratigraphy and general arrangement of units

The geological schematic (Figure 95) shows the arrangement of units within the Kriegers Flak II South site. Table 60 shows the basic characteristics of the stratigraphic units. Key surfaces are the top of Unit III (H20/H05/seabed) which is the top of potentially overconsolidated deposits, and H20/H30; the top of the bedrock.

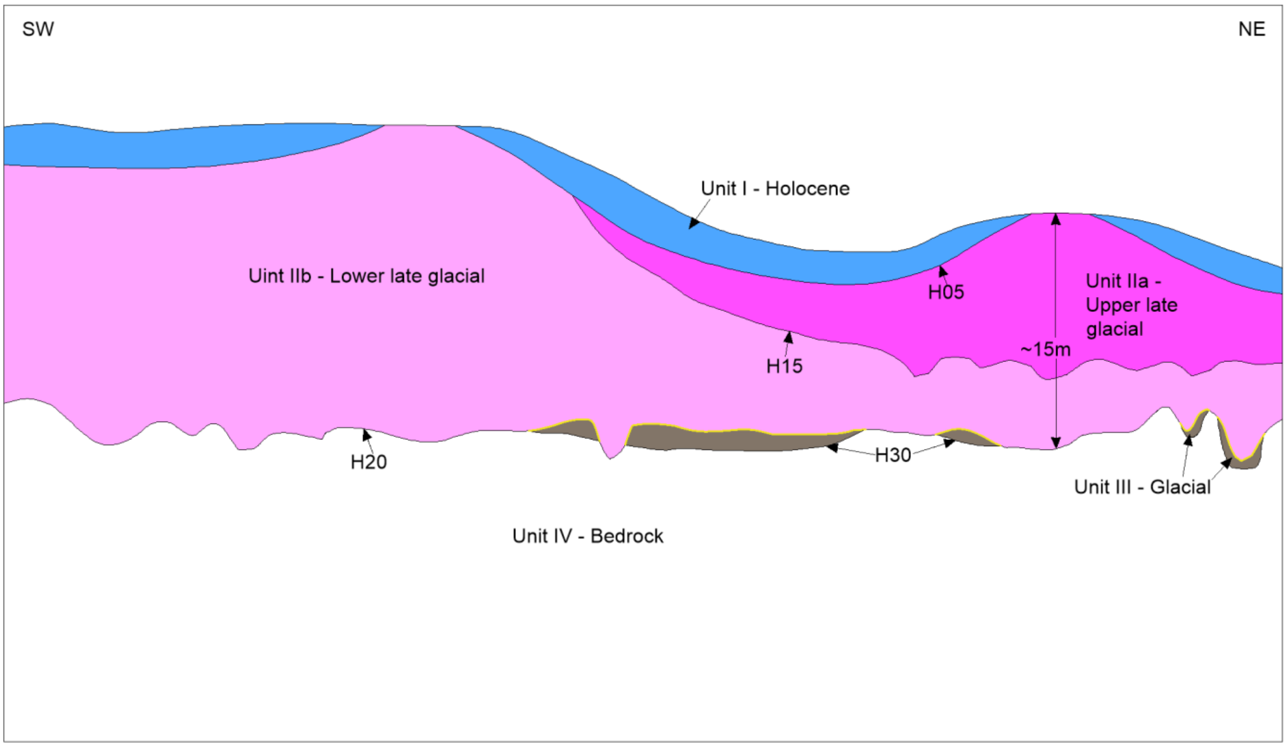


Figure 95: Geological, schematic, general arrangement of the units

Table 60: Shallow geological units

Unit	Upper surface	Lower surface	Main Soil Description	Depositional Environment
I, H, Holocene	Seabed	H05	Silty, sandy CLAY with thin veneer of SAND at seabed	Post-glacial marine
II (a and b), LG, Late Glacial	Seabed/H05	H20	Variable, includes intervals of laminated CLAY, SAND-prone packages	Periglacial, glaciomarine
III, GL, Glacial	H20	H30	Variable, CLAY-prone, locally overconsolidated	Glacial with localised direct ice contact
IV, BR, Bedrock	H20/H30	-	Chalk	Ancient shallow marine

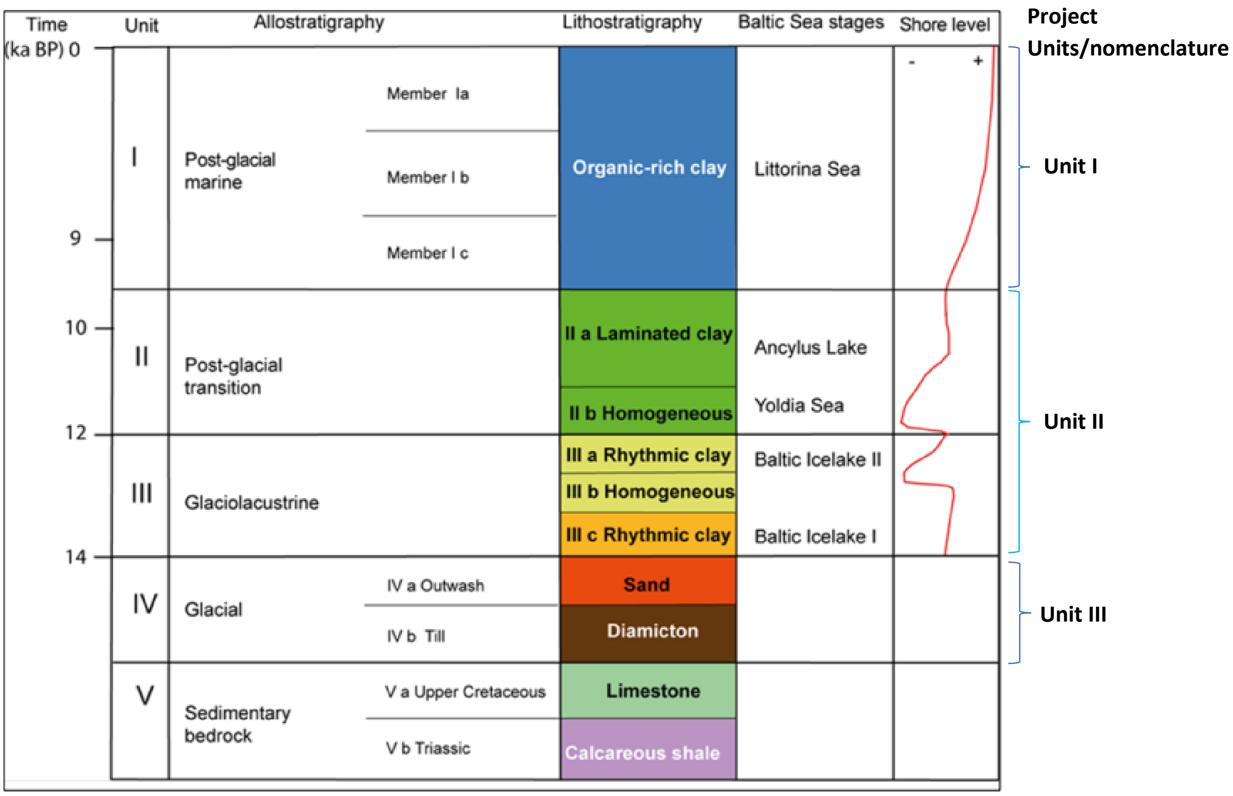
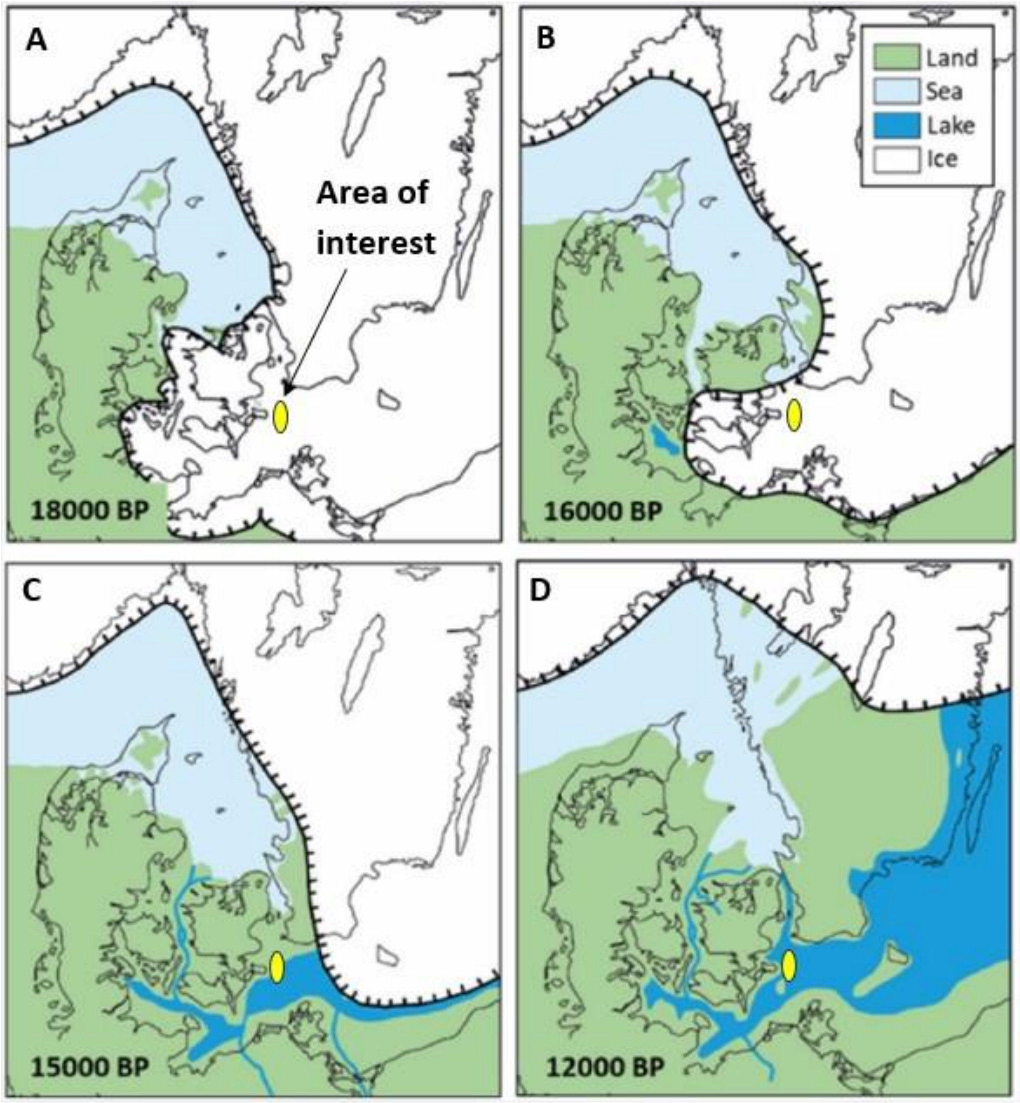


Figure 96: Correlation with Jensen et al.'s stratigraphy (GEUS 2024)

13.2.3 Quaternary deglaciation history

These bullet points are largely derived from information in the GEUS desk study. Here, the stratigraphic units have been linked to the changing paleoenvironments. The letters in brackets refer to the following paleogeographic maps, which are extracts from the GEUS desk study.

- In Denmark the Scandinavian Ice Sheet reached its maximum extent ~22 000 years BP followed by retreat with evidence for short-lived advances over the following four thousand years.
- Marine transgression began around 18 000 years BP, (A) leading to rapid deglaciation and the establishment of glaciomarine conditions. In this early phase the region was not isostatically adjusted, sealevel was relatively high. By 15 000 years BP (C) the ice had retreated to the extent that the site was free of ice cover. The deposition of Unit III is associated with this ice sheet.
- After deglaciation (~15 000 years BP), the area generally experienced lacustrine conditions (Baltic Ice Lakes I and II, Yolida Sea) with an ever more distant ice front (C-E). Unit II was deposited in this dynamic lacustrine environment.
- About 10 000 years BP the Ancylus Lake water level dropped about 9m (E-F) and the area may have been close to subaerial exposure. Upper parts of Unit II were deposited in this environment.
- Around 9 100 years BP a fully marine environment existed in the western Baltic with the Ancylus Lake persisting farther east, in the study area (G-H). The sea broke though at about 7 000 years BP, establishing marine conditions at the site. Unit I was laid down in this marine environment.


A
Area of interest
18000 BP
B
Land
Sea
Lake
Ice
16000 BP
C
15000 BP
D
12000 BP

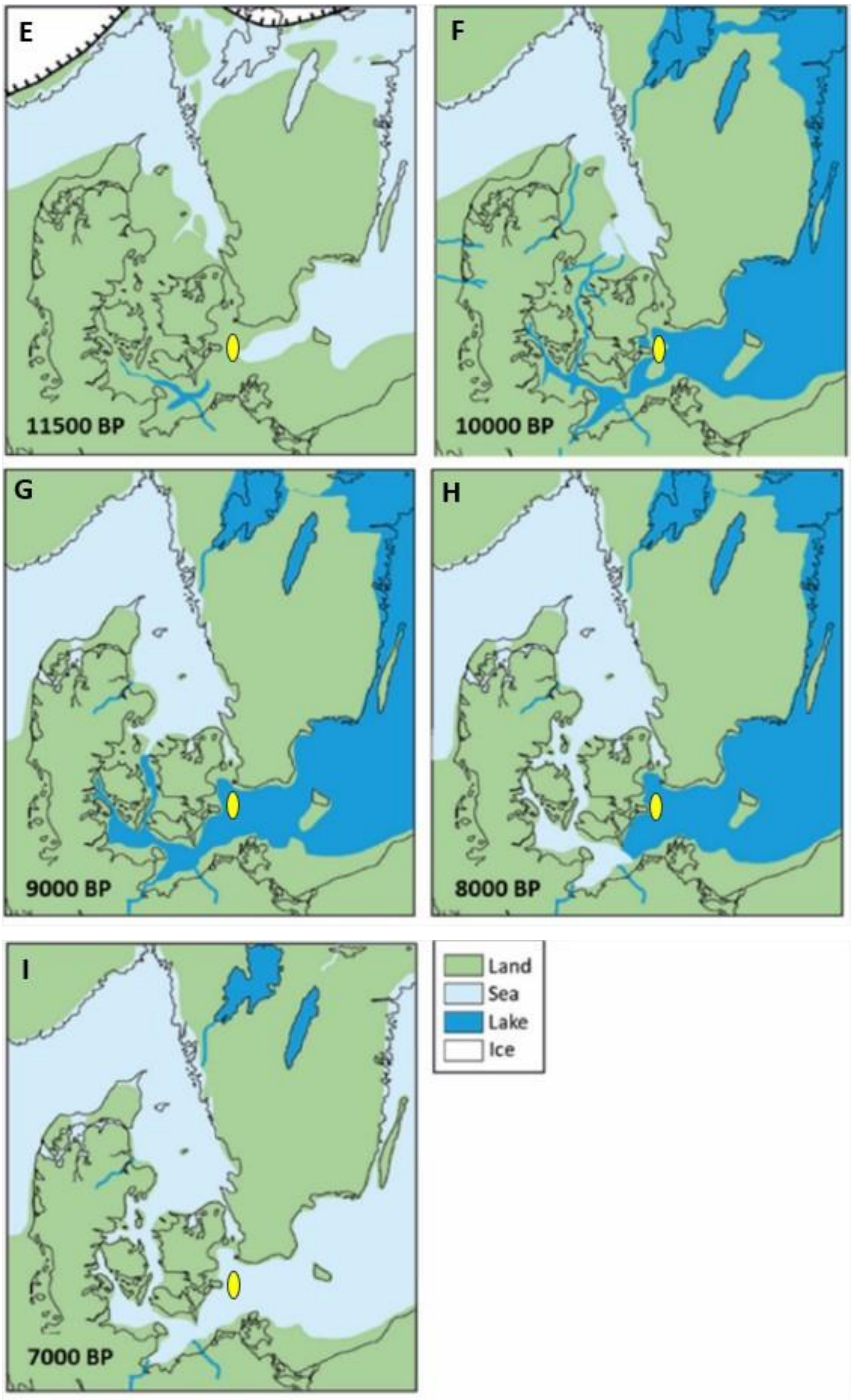


Figure 97: Paleogeographic maps

Unit I Holocene Deposits

Holocene unit (Unit I) is a package of post-glacial silty, sandy CLAY which is generally less than 1 m thick. The interval includes a thin veneer of sandier seabed sediments, though these are interpreted to be very thin and are seldom resolved in the SBP data (Figure 98 and Figure 99). The Holocene sediments are widely distributed over the study area (Figure 100). The Holocene is very thin or absent (unmapped) in the northeastern part of the area across a north-northwest to south-southeast trending zone, surrounding a mound of Unit II sediments (Figure 98). It is also locally absent in areas to the west and south-west where it appears to pinch out against Unit II. Small pockets of Holocene may occur in these areas and a < 0.2 m-thick seabed veneer may still be present.

The Holocene deposits are thickest in the north-east, where the water depths are greatest and Unit II is thinnest. Here, the deposits are up to 3 m thick. The sediments also thicken at the southern margin of the area. The seabed low in the northwest is related to depositional patterns of the glaciomarine sequence of Unit II and, possibly, the morphology of the top of the bedrock.

Acoustically, the interval is almost featureless with very low amplitude, concordant internal reflections. Locally, there are very subtle internal unconformities. However, the latter do not show amplitude increases, suggesting that material characteristics remain similar around these unconformities. The unconformities may represent sea level variations related to the interplay of isostatic rebound and background sea level rise.

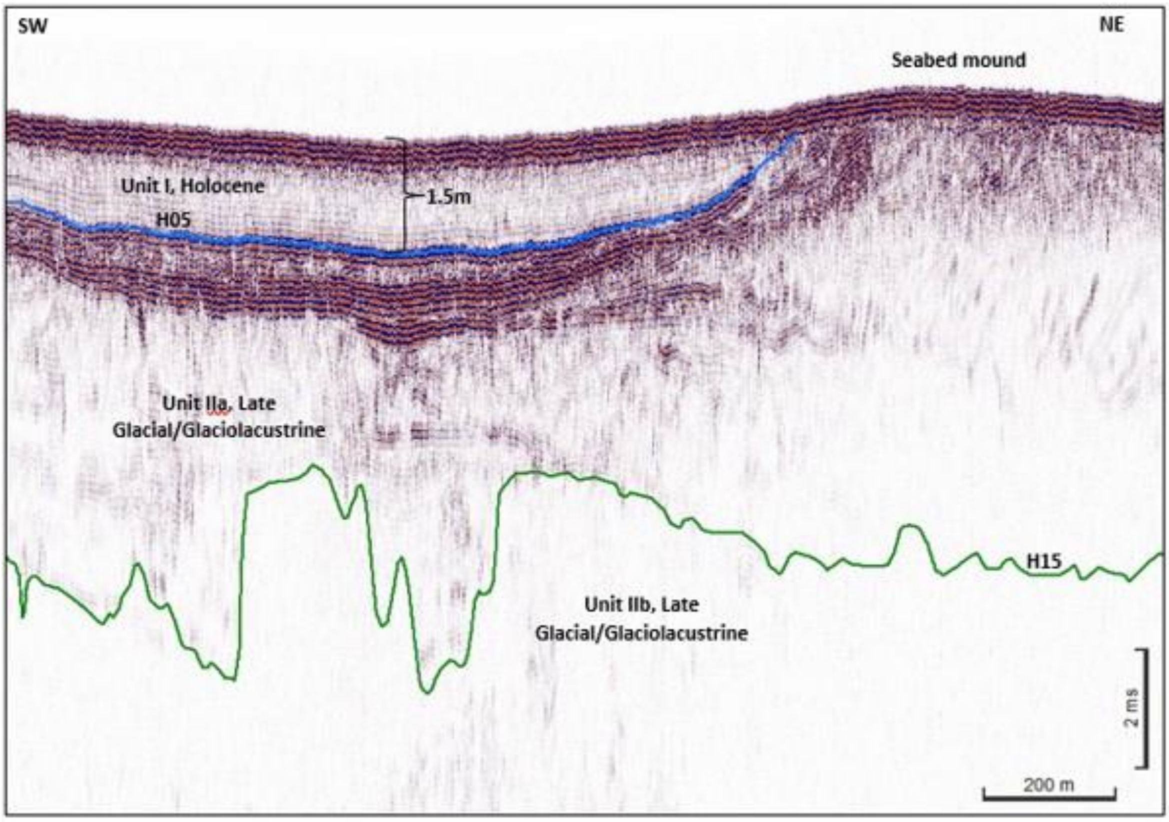


Figure 98: SBP data example, line L16, Holocene unit (Unit I), pinch out, location is shown in Figure 100

The base Holocene is mapped as H05. Over broad areas it is interpreted to be a mild erosion surface – thickness variations are due to relief at this surface and topography of the seabed. The erosion at H05 may be related to the final regression of the area around 10 000 years ago when sea level dropped, potentially allowing wave-base storm erosion of the contemporary seabed. The erosion does not plane off the soft pre-existing sediments, as might be expected if the area became sub-aerially exposed.

Holocene unit (Unit I) has seismic characteristics which indicate that it is extremely soft/weak.

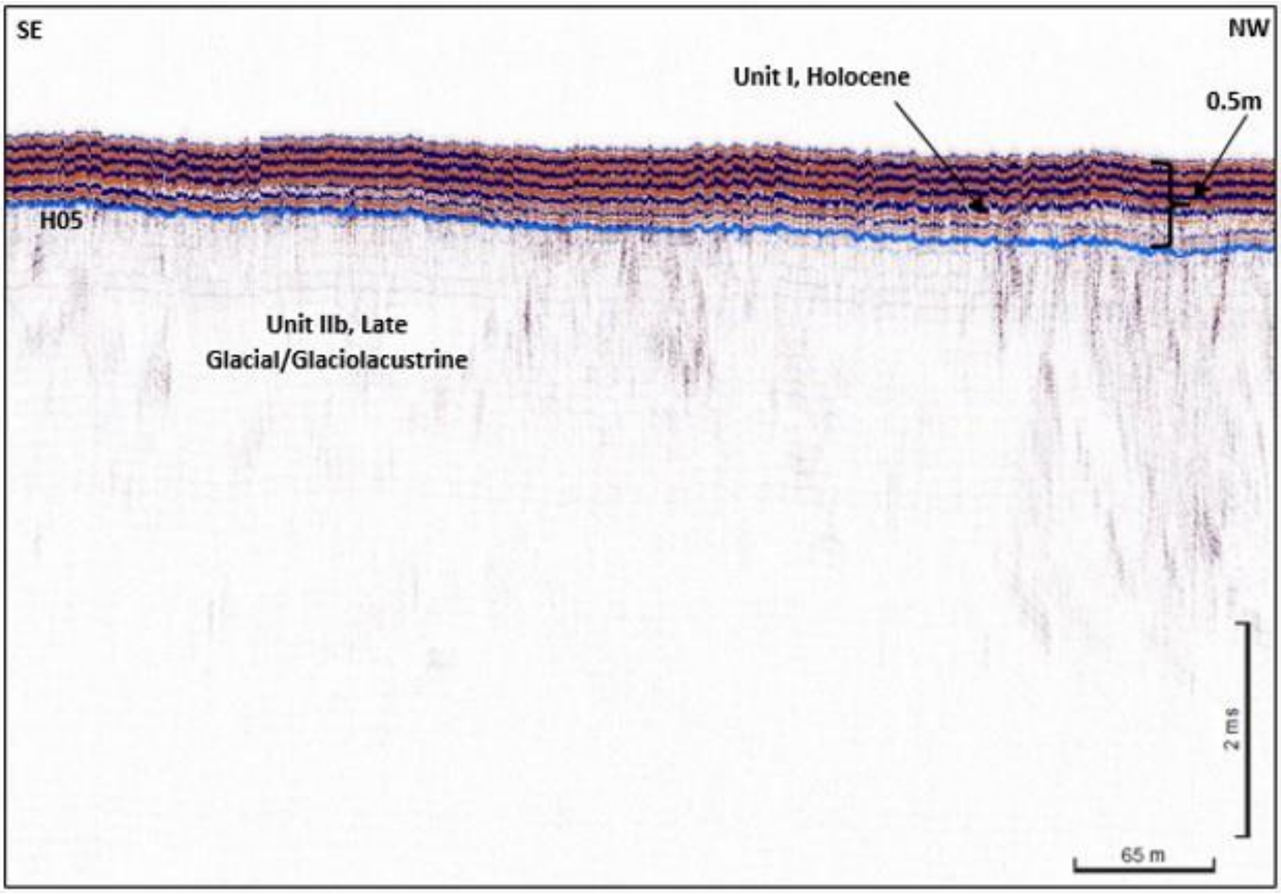


Figure 99: SBP data example, line X04, Holocene unit (Unit I), thin, location is shown in Figure 100

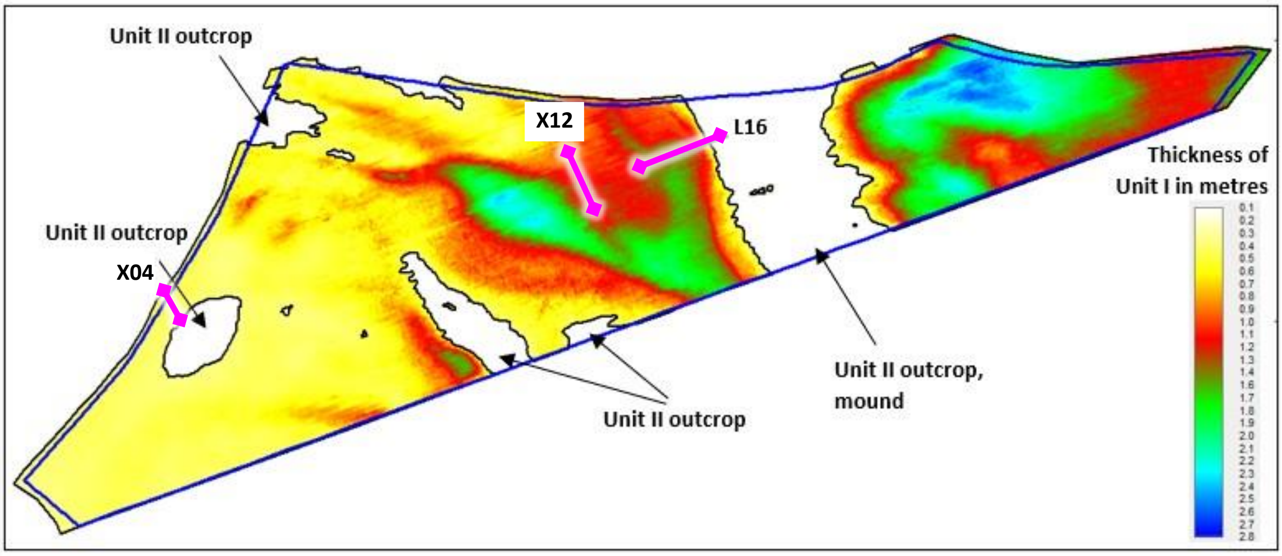


Figure 100: Thickness and distribution of Unit I Holocene deposits

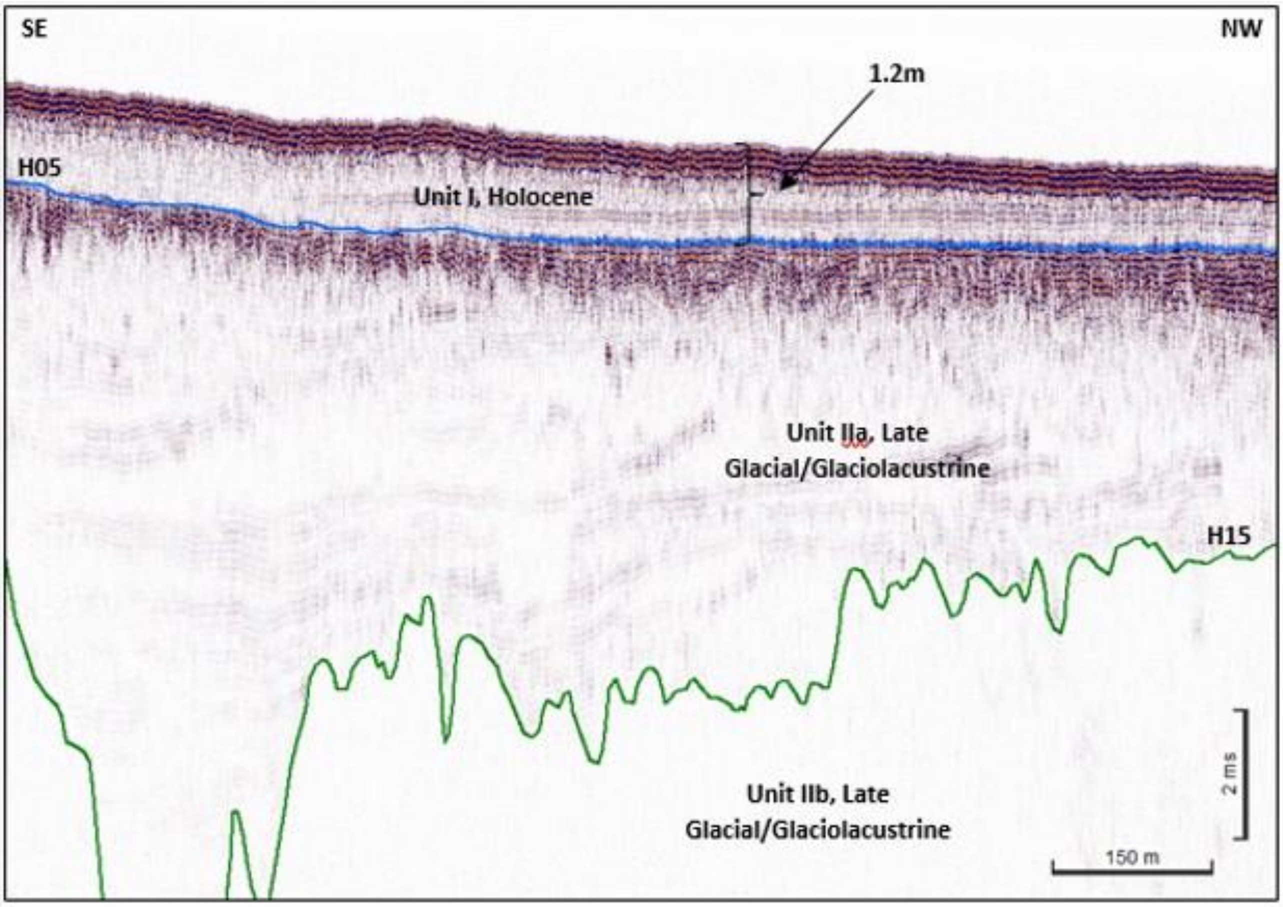


Figure 101: SBP data example, line X12, Holocene unit (Unit I), location is shown in Figure 100

Unit II Late Glacial Deposits

This interval is complex due to the area's range of glaciolacustrine environmental conditions during the Late Weichselian and earliest Holocene. Locally, upper parts show laminations indicative of interbedded clays and sands/silts, and downlapping sequences, where the lower parts are ambiguous but may represent a mixture of deltaic deposits, outwash deposits or sediments redeposited from local moraines.

The unit is mapped with H20 at its base. Unit II occurs throughout the survey area and is typically between 10 and 25 m thick, with some local variations related to the topography of the top bedrock and top glacial surfaces (Figure 102). The maximum thickness of 45m is in the extreme south-west of the area. Other variations are due the deposition patterns of Unit II and the pattern and depth of erosion during Unit II times.

Unit II is generally developed from the south/south-west (Figure 102 and Figure 103). Packages overstep each other, with younger Unit IIa deposits further north and north-east: Unit II becomes younger to the north-east as well as upward. The unit is thickest in the south-west. This geometry of Unit II has a great influence on bathymetric patterns and the distribution of Holocene unit (Unit I). The mound, which corresponds to an area of Unit II outcropping in Figure 100, is generated by a thickening of Unit II. This thickening may be an ancient beach deposit. The unit contains erosional unconformities which may correspond to changes in base level.

As in the provided GEUS desk study, the late glacial sequence at Kriegers Flak South has been divided into earlier and later parts. H15 marks the boundary between the upper and lower parts of Unit II. Unit IIa comprises the upper, higher amplitude, bedded parts of Unit II, while Unit IIb comprises the lower, more amorphous parts. Figure 103 and Figure 104 show these two facies types. Unit IIa is absent in the southwest of the site, where older Unit II deposits are thickest. Figure 105 shows the thickness and distribution of the upper unit IIa sediments throughout the survey area.

Unit IIb is present throughout the survey area. Unit IIb is expected to represent a highstand system tract of the late glacial glaciomarine sea of Kattegat. The thickness and distribution of Unit II (a and b) are shown in Figure 102.

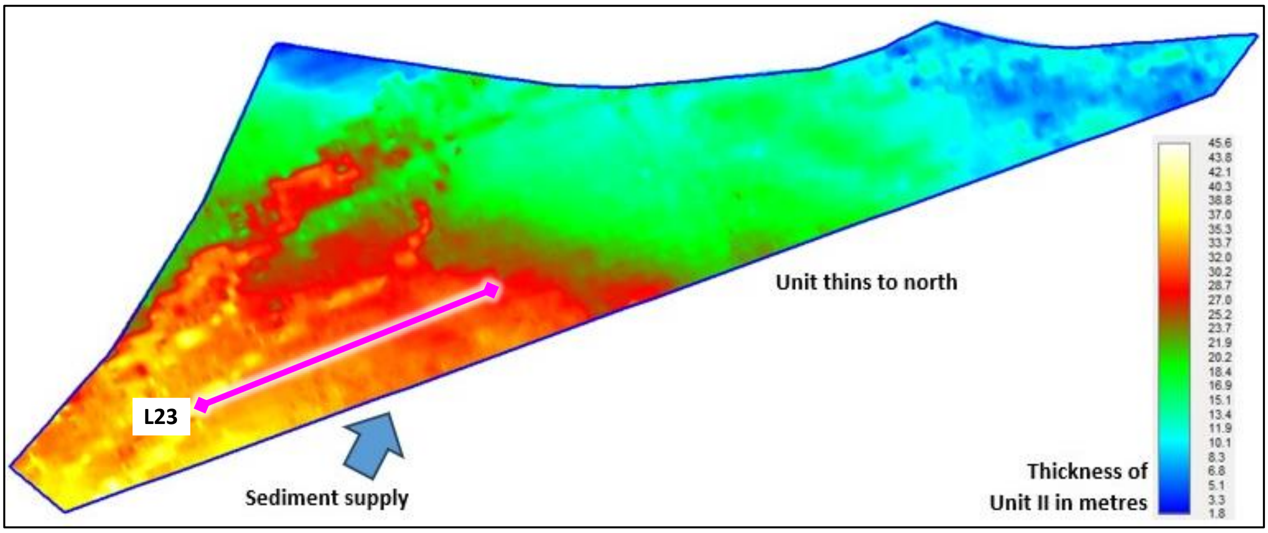


Figure 102: Thickness and distribution of Unit II (a and B) Late Glacial Deposits

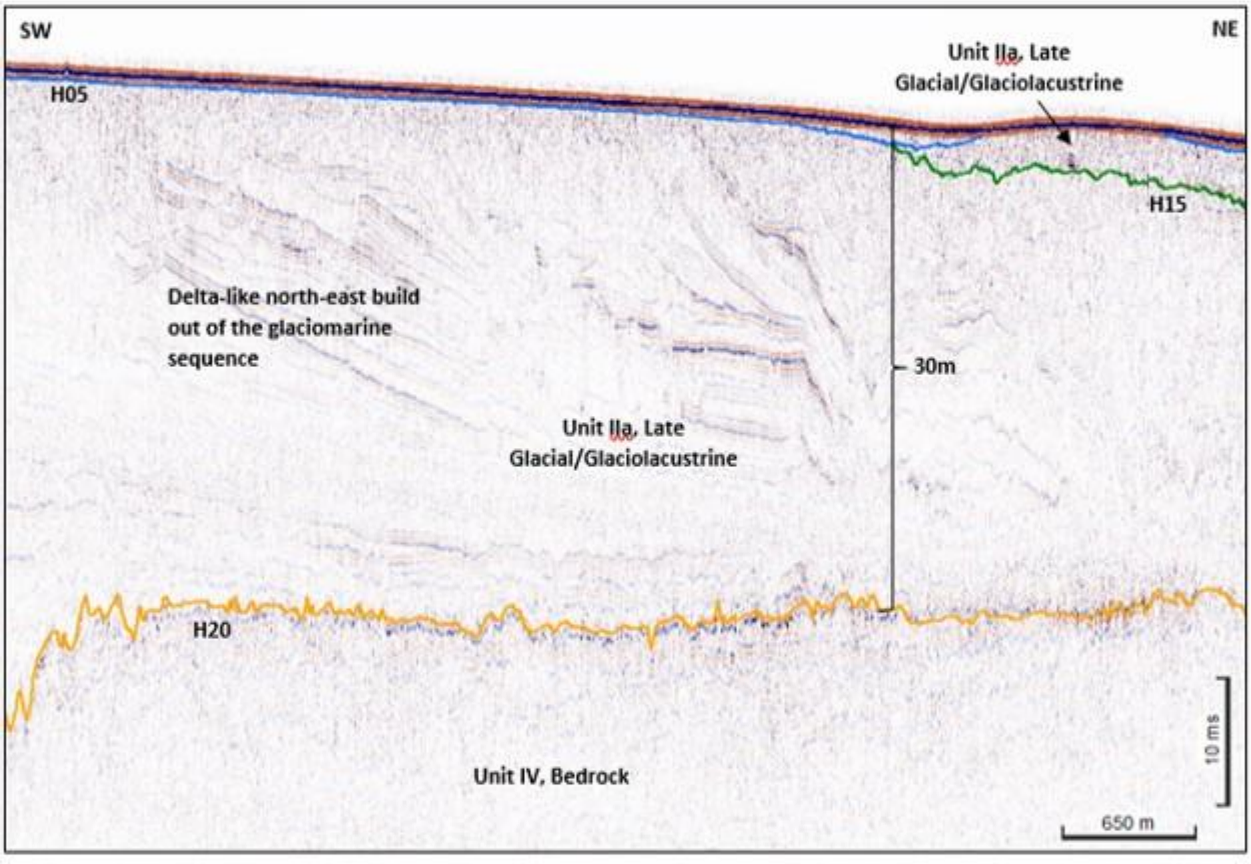


Figure 103: UHR data example, line L23, Unit II, upper and lower facies, location is shown in Figure 102 and Figure 105

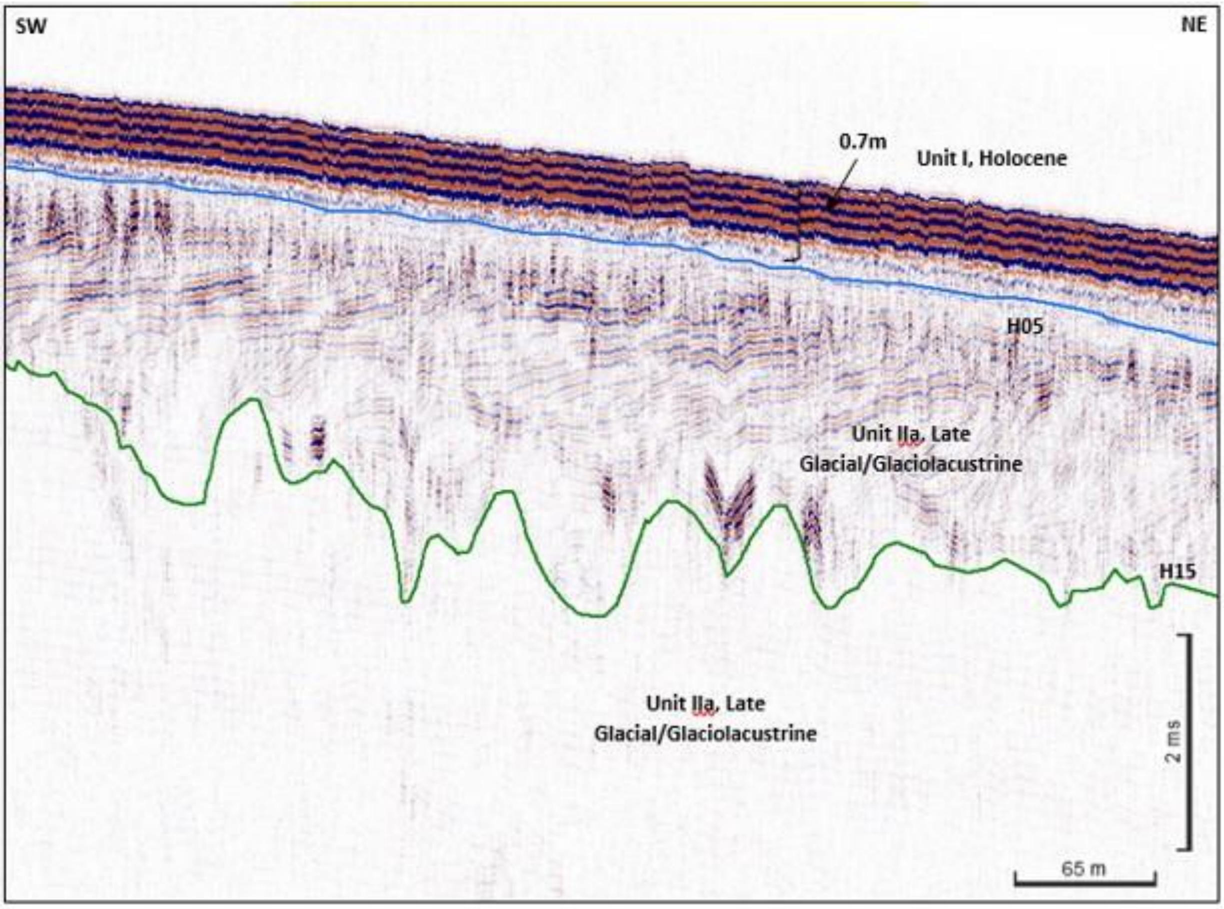


Figure 104: SBP data example, line L16, Unit II, upper and lower facies

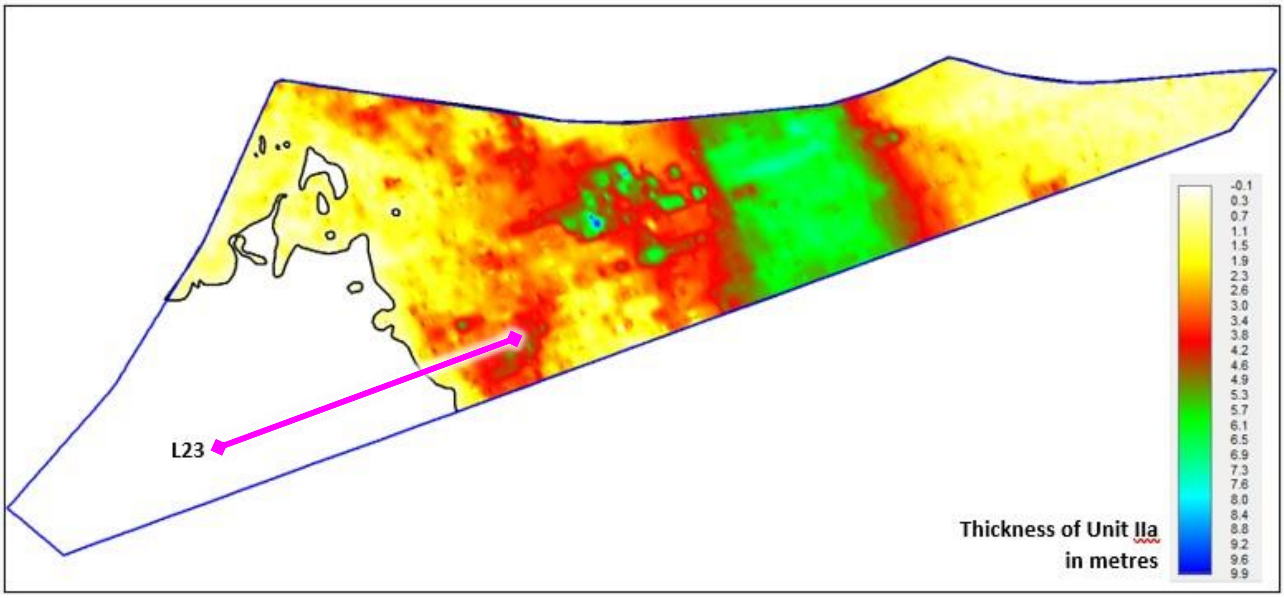


Figure 105: Distribution and thickness (m) of Unit IIa Late Glacial Deposits

Unit III Glacial Deposits

Unit III deposits occur mostly in the northern and central parts of the survey area (Figure 106). The deposits occur as a thin package of sediments between the top bedrock surface and the base of the Late glacial sediments. It is chaotic and structureless in appearance. Unit III is interpreted to be a till deposited in association with the last major ice advance over the area, approximately 22 000 years ago.

Unit III is generally a glacial till which has been subjected to direct ice contact, though the unit may contain other facies which may have been laid down in ice-marginal environments during oscillations of the ice front. The ice-contact facies may comprise a clay-prone diamicton which is likely to contain subordinate silt, sand, gravel, cobbles and boulders and will be overconsolidated. Consolidation levels may significantly vary over short distances. Seismically, the ice contact facies are structureless with a very irregular upper surface, which probably forms a series of ridges (Figure 107).

Unit III does not crop out within the survey area.

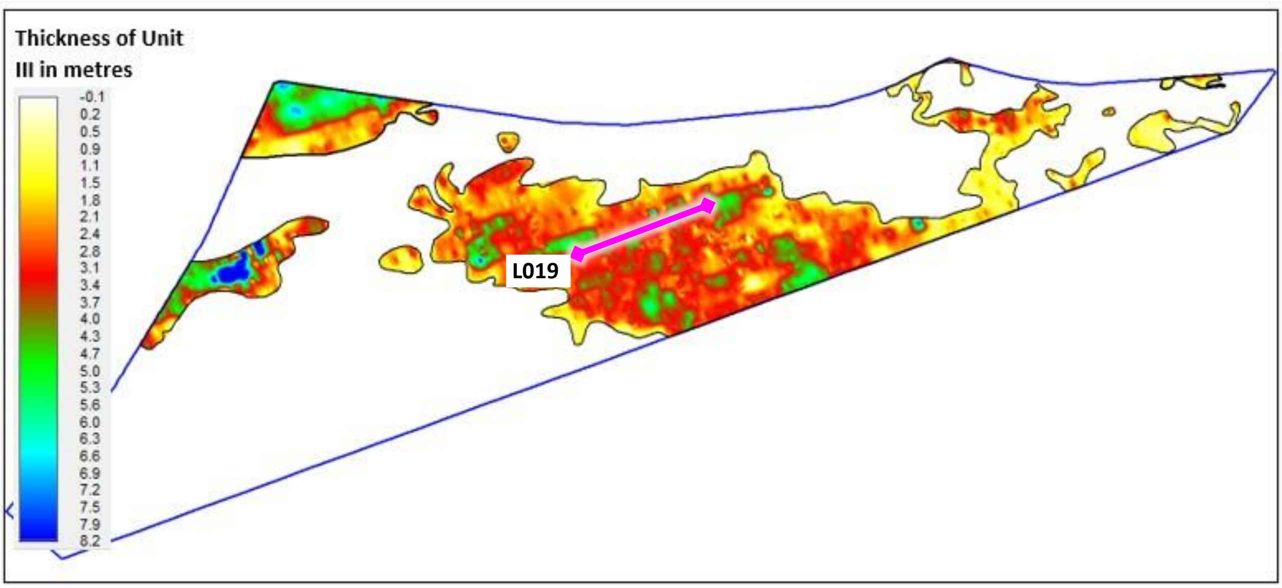


Figure 106: Thickness and distribution of Unit III Glacial Deposits

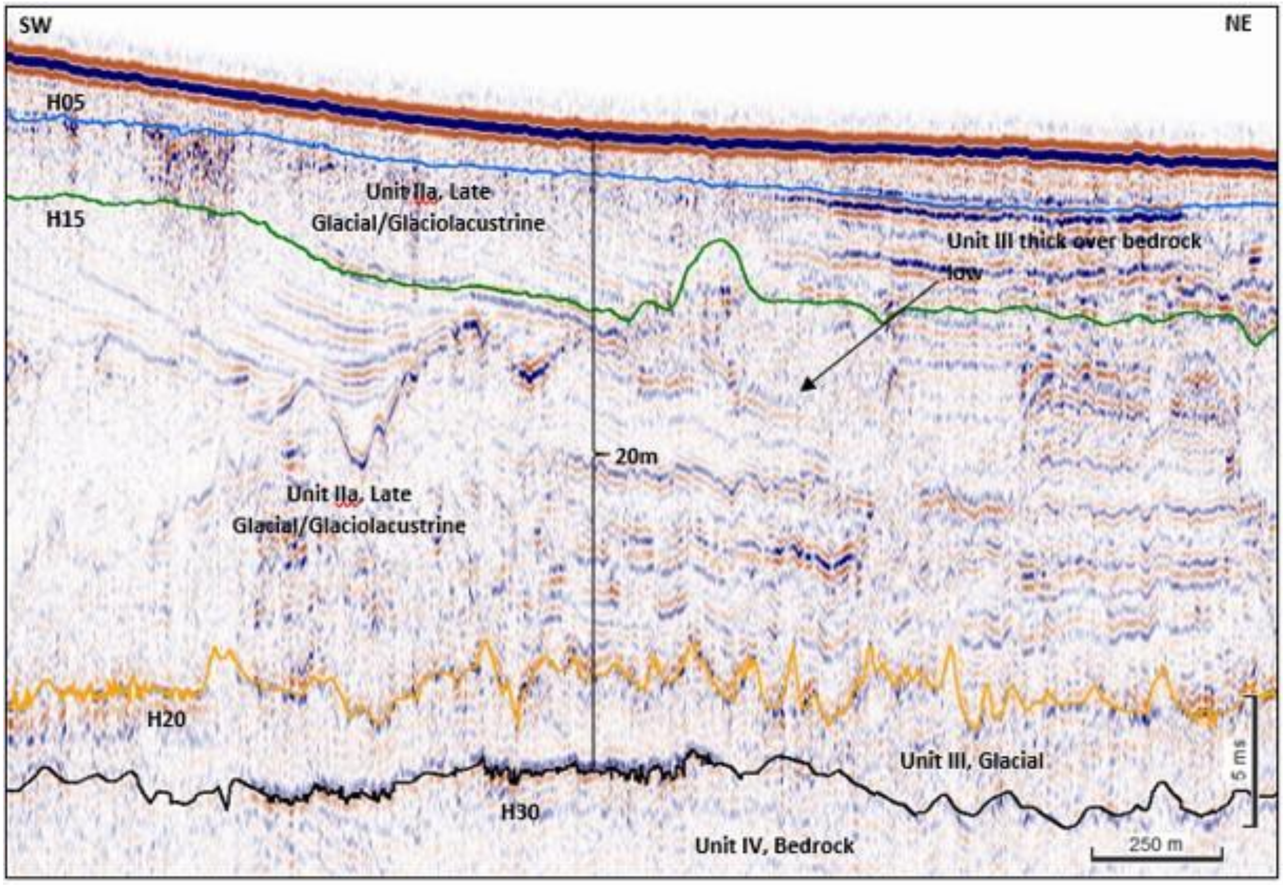


Figure 107: UHR data example, line L019, Unit III, till, location is shown in Figure 106

Unit IV Bedrock

The bedrock is likely to be Cretaceous chalk (GEUS 2024). Bedrock faults are not well imaged, though faults are almost certainly present. Some UHR lines do show weak evidence for the position of fault planes. These ancient faults were reactivated during the Jurassic/Cretaceous and, probably generated subsidence in this area. The high potential for erosion of the top of the bedrock (especially over the last 1.1 million years of ice advances) makes it difficult to attribute features at the top bedrock surface to tectonic activity: the tectonic relief may well have been planed-off by ice.

The top of the bedrock is generally 7 to 45 m below seabed, it is shallowest, less than 10m below seabed, over the north/east of the area.

The upper surface of the bedrock is a truncation surface with an angular unconformity between the Mesozoic rocks and their much younger overburden. Figure 108 shows the depth of the bedrock below seabed.

The bedrock may have been subjected to numerous phases of erosion during early glaciations. There is some uncertainty over the position of the top of the bedrock in the south-west of the survey area. A potential erosion surface has been mapped beneath H20, this interval may contain glacial sediments (Figure 109).

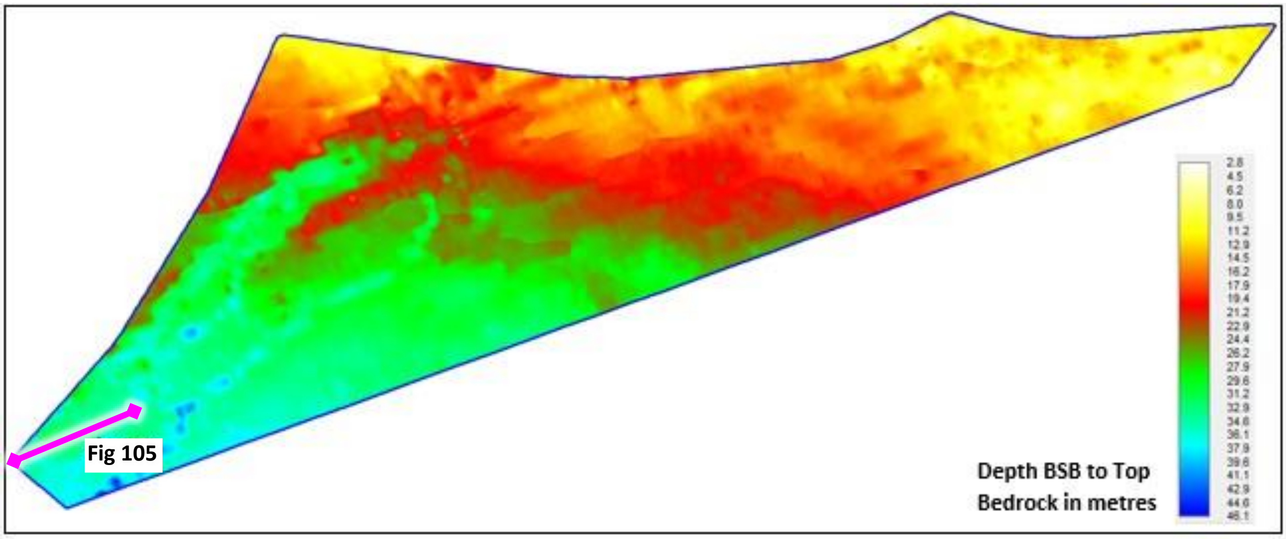


Figure 108: Depth BSB to top bedrock

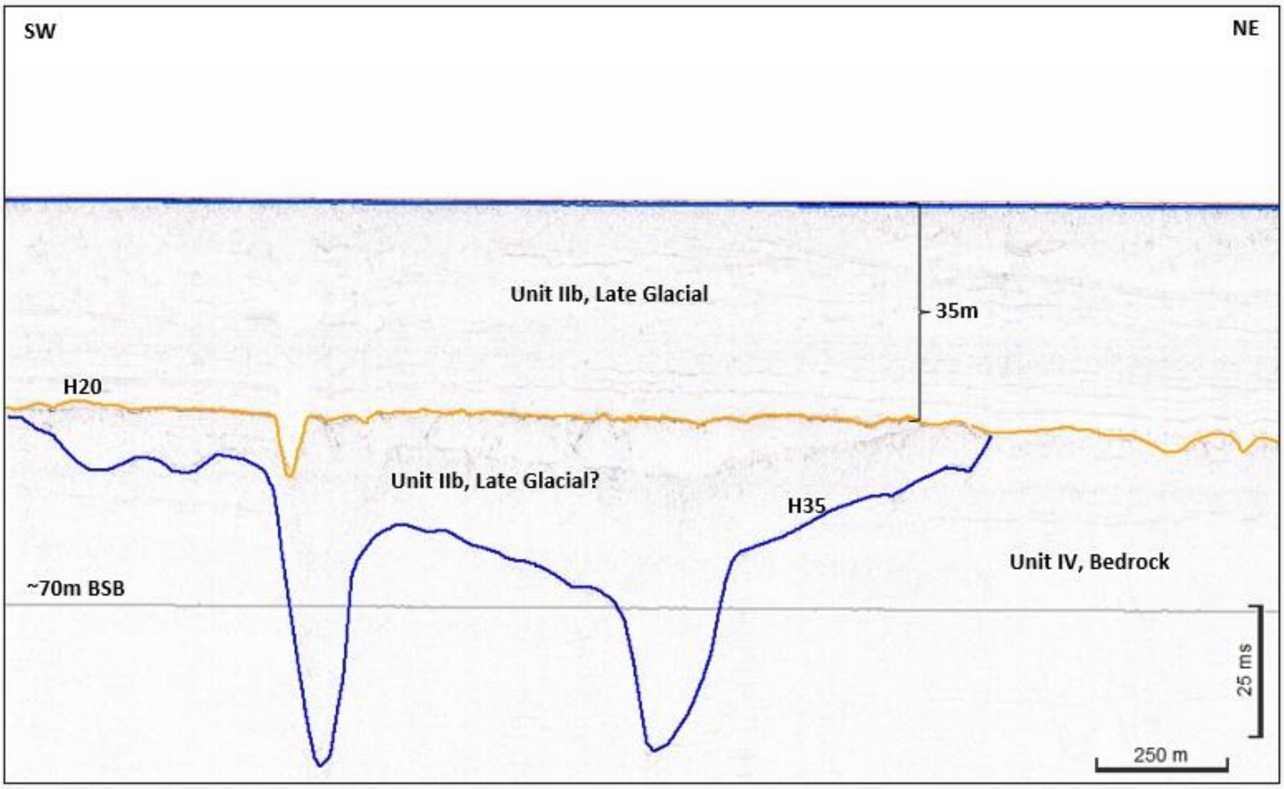


Figure 109: Potential deeper top bedrock

13.2.4 Shallow geological installation constraints

The following considerations could be made regarding installation constraints based on assessment made from the geophysical dataset:

- Holocene unit (Unit I) sediments are very weak/soft. Their bearing capacity will be negligible and could cause retrieval difficulties related to settlement of seabed frames etc.
- Unit III may have variable levels of overconsolidation.

- Unit III may contain numerous cobbles and boulders.
- Unit IV may have strength variations.
- Unit IV may be weathered at the upper truncation surface.
- Unit IV may locally be weakened by faulting and micro fractures.

Cobbles and boulders

There are very limited indications of sub-seabed boulders within the sub-bottom profiler data (Figure 109). These data have been optimized to resolve the shallow stratigraphy and do not readily generate diffraction hyperbola, which are the usual seismic indication of point contacts in the sub-surface. A further complication is that the units most likely to contain boulders, Units II and III, have been deformed and compressed by ice confusing any returns from individual point contacts. There is evidence for seabed boulders where Unit III crops out, showing that boulders are likely to be present sub-seabed.

These circumstances, and the great volume of data, make line-by-line assessment of point contacts impractical and potentially inaccurate.

A probability (Boulder Factor) grid has been generated to indicate where boulders are more or less likely to be encountered (Figure 110). This is based on the thicknesses of Units I, II and III. The thickness of the post-glacial Holocene unit (Unit I) is multiplied by 1: boulders may rarely have melted from floating ice. The thickness of glaciomarine Unit II is multiplied by 3: there is a greater influence of ice. The thickness of Unit III is multiplied by 10, though this unit has few direct point diffractions it contains what are interpreted to be ice contact tills, the type of facies most likely to contain erratics. The overall probability of encountering boulders is driven by the presence and thickness of the ice influenced units II and III.

The resulting grid is a unitless value, which has been generated as depth, and is a product of the total thickness of the Quaternary sequence. A similar grid could be depth limited to the top 5 or 10 metres. Such grid would show a strong response where the Unit III tills are close to the seabed.

Calibration and experience may allow replacement probability grids to be made in a GIS – this only requires each unit’s thickness to be multiplied by a revised figure.

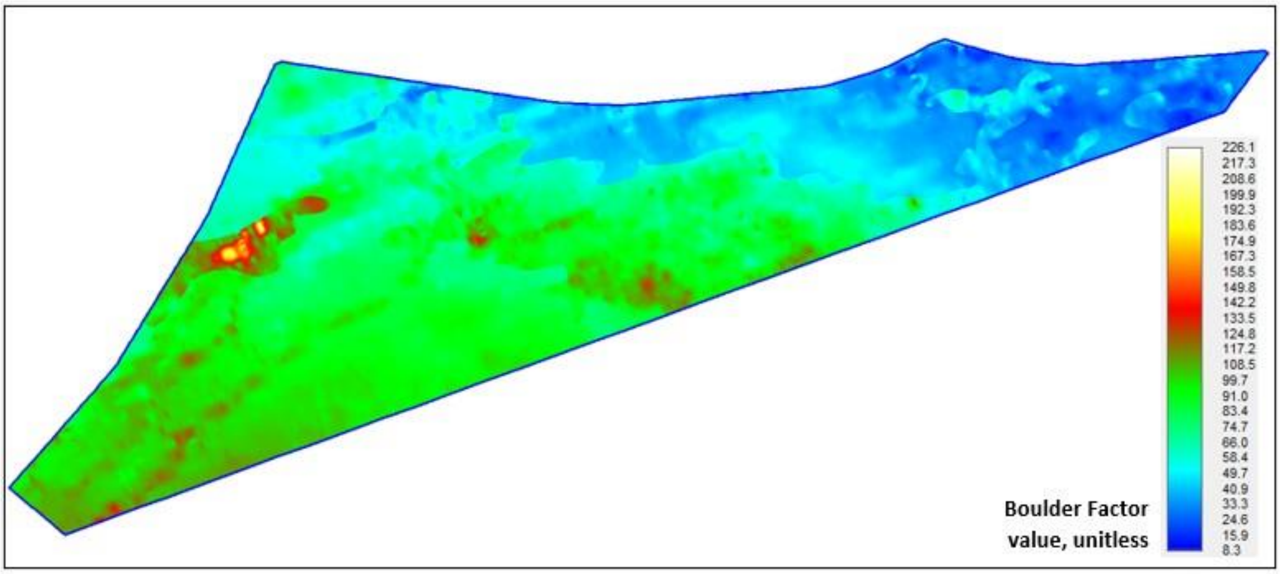


Figure 110: Boulder Factor, Quaternary

13.2.5 Sub-surface acoustic velocity model

SBP depth data

The SBP depth data are based on the final time segy files. The water column and recorder delay are depth converted at the water velocity. This velocity interval extends from the top of the record to a point just above the picked water bottom. This small offset ensures that the seabed return signal is not distorted by the transition from one interval velocity to another.

The remainder of the record is converted at an assumed velocity of 1600 m/s. This is because these shallow penetrating data only image normally consolidated, uncompacted, sediments and there are no associated processing velocities to consider.

This sub-seabed interval velocity was also applied to the thickness conversion of the interpretation of the upper two units: the depth SBP data match the supplied thickness/depth grids for units I and II.

Depth UHR data

The UHR depth data have been built using an iterative approach. The limited range of acquisition offsets mean that there is little moveout in the raw data beyond 20-30 milliseconds below seabed. In turn, this means that the data are not especially sensitive to variations in velocity picking. This diminishes the consistency and strength of the relationship between velocity picks and the depth of primary reflections.

The time versions of the data have been depth converted with reference to a time grid of the base of the Quaternary sequence, based on interpretation of the final time data versions. This surface is the transition from relatively young sediments to relatively ancient rocks. The surface has been used to apply and control an interval velocity ramp from lower velocities, above, and higher velocities in the deeper bedrock.

There may be small miss ties at the intersection of depth segy lines which are not present in the parent time versions of the lines. This is due to differences in depth conversion velocities which, in time, only influence signal characteristics rather than vertical position.

Deployment of depth versions

The depth segy lines are loaded into the Kingdom projects as multiversions of the parent time lines. All interpretation is of the time data. These time interpretations have been thickness and depth converted and can be displayed on the depth lines as grids. There may be minor misties between these depth grids and events in the depth segy, especially with the UHR data, as the two depth products have been generated by separate workflows.

14 COMPARISON BETWEEN SEABED AND SUB-SEABED FINDINGS

In the final stage of interpretation, surficial geology has been correlated to the SBP results. The SSS surficial interpreted sand, muddy sand and mud and sandy mud regions sufficiently correlate to the Unit I Holocene deposit thickness and distribution (Figure 100). SBP interpreted Holocene unit (Unit I), is a package of post-glacial silty, sandy clay that includes a thin veneer of sandier seabed sediments, though these are interpreted to be very thin and are seldom resolved in the SBP data. The Unit II Late Glacial deposit outcrops interpreted in the SBP, have not been outlined in the surficial sediments as no evidence of different sedimentary facies has been delineated in the BKS nor the SSS data. This can be justified by the presence of the aforementioned thin veneer of sandier seabed sediments, <0.2 m thick, that may still be present and cannot be resolved in the SBP.

15 CONCLUSIONS

Seabed levels across the Kriegers Flak II South site range from a minimum of 18.5 m MSL, in the south-western corner of the site, to a maximum of 41.8 m MSL at the extreme north-eastern edge of the site.

Seabed levels across the western part of the area are generally <20 m MSL, becoming deeper towards the east at slopes of less than 0.1°, up to 24.0 m MSL contour, from which point slope gradients increase slightly, up to 0.25° up to 32.0 m MSL contour.

To the north-east of the 32.0 MSL contour, up to the 34.0 m MSL contour, the seabed is almost completely flat, dipping imperceptibly towards the north-east at an average slope gradient of < 0.02°.

To the north-east of the 34.0 m MSL contour, the seabed continues to deepen very gently from W-E, then WNW-ESE, with seabed levels gradually deepening to reach a maximum of deeper than 41.5 m MSL, at an average slope gradient of <0.1°.

The highest slope values (very steep slopes; >15.0°) are associated with seabed features, such as boulders, trawl scars, wrecks, and other smaller elevated features.

The seabed sediments across the Kriegers Flak II South site become gradually finer grained, running from west-southwest to east-northeast across the site.

The shallowest section of the site lies at the south-western corner, where the seabed sediments comprise sands. Moving east-north eastwards, the seabed sediments grade into muddy sands (silty/clayey sands). Finally, in the extreme north-eastern corner of the site, the seabed sediments comprise mud (silts/clays) and sandy mud (sandy silts/clays).

In terms of seabed surface morphology, the Kriegers Flak II South site is less diverse than the KFIIN site. The southwestern half of the site is dominated by Mytilus edulis beds stretching in patterns with a SW-NE orientation. In the whole central and eastern parts of the site, evidence of trawl marks was found, while in the central western part, several instances of seabed scaring and possible biostructures have been recorded. Several extensive patches of pitted seabed dominate the eastern half of the survey area, with spots of scour patterns and disturbed seabed in the easternmost stretches of the site.

A total of 150 man-made objects were identified within the survey area. A single wreck was noted within the site, and it was identified as the 'Birgit Ehlers'. Nine objects were classified as metallic contacts and 53 as debris contacts. In addition, 18 linear objects and 64 other sonar contacts have been identified. Only one subsea cable has been recorded within the Kriegers Flak II South site – the C-Lion1 cable.

The geological foundation zone extends to ~70 m below seabed. The rocks and sediments within this interval have been interpreted with reference to the supplied GEUS desk study. There is generally a good correlation between the shallow geology imaged in this project's sub-seabed data, and the desk study.

In general, the area has a glacial to post-glacial sequence of relatively recent sediments over much older bedrock. The Quaternary sediments are generally 10 to 45 m thick. The seabed generally dips to the northeast. The top bedrock unconformity is an undulating surface that dips gently to the southwest, with the Quaternary sequence thinning as the water depth increases. Unit III is absent in large parts of the survey area and is present mostly in the central and northern parts.

Holocene unit (Unit I) is a package of post-glacial silty, sandy CLAY which is generally less than 1 m thick. The interval includes a thin veneer of sandier seabed sediments, though these are interpreted to be very thin and are seldom resolved in the SBP data. The Holocene sediments are widely distributed over the study area. The Holocene is very thin or absent (unmapped) over the northeastern part of the area, across a north-northwest to south-southeast trending zone, surrounding a mound of Unit II sediments. It is also locally absent in areas to the west and south-west where it appears to pinch out against Unit II. Small pockets of Holocene may occur in these areas and a <0.2 m thick seabed veneer may still be present.

The Holocene deposits are thickest in the north-east, where the water depths are greatest and Unit II is thinnest. Here, the deposits are up to 3 m thick. The sediments also thicken at the southern margin of the area. The seabed low in the northwest is related to depositional patterns of the glaciomarine sequence of Unit II and, possibly, the morphology of the top of the bedrock.

The base Holocene is mapped as H05. Over broad areas it is interpreted to be a mild erosion surface – thickness variations are due to relief at this surface and topography of the seabed. The erosion at H05 may be related to the final regression of the area around 10 000 years ago when sea level dropped. Holocene unit (Unit I) has seismic characteristics that indicate that it is extremely soft/weak.

The interval defining Unit II (late Glacial deposits) is complex, due to the area's range of glaciomarine environmental conditions during the Late Weichselian and earliest Holocene. Locally, upper parts show laminations indicative of interbedded clays and sands/silts, and downlapping sequences, where the lower parts are ambiguous but may represent a mixture of deltaic deposits.

The unit is mapped with H20 at its base, occurring throughout the survey area with a thickness of 10 to 25 m, with some local variations related to the topography of the top bedrock and top glacial surfaces. Unit II is generally developed from the south/south-west. The desk study divides this late glacial sequence into earlier and later parts: Unit IIa and Unit IIb. Unit IIa comprises the upper, higher amplitude, bedded parts of Unit II, while Unit IIb comprises the lower, more amorphous parts. Unit IIa is absent in the southwest of the site, where older Unit II deposits are thickest. Unit IIb is present throughout the survey area.

Unit III (Glacial deposits) occurs mostly in the northern and central parts of the survey area. The deposits occur as a thin package of sediments between the top bedrock surface and the base of the Late glacial sediments. It is chaotic and structureless in appearance. Unit III is interpreted to be a till deposited in association with the last major ice advance over the area, approximately 22 000 years ago.

Unit III is generally a glacial till which has been subjected to direct ice contact, though the unit may contain other facies which may have been laid down in ice-marginal environments during oscillations of the ice front. The ice-contact facies may comprise a clay-prone diamicton which is likely to contain subordinate silt, sand, gravel, cobbles and boulders and will be overconsolidated. Consolidation levels may significantly vary over short distances. Seismically, the ice contact facies are structureless with a very irregular upper surface, which probably forms a series of ridges.

The bedrock is likely to be Cretaceous Chalk. Bedrock faults are not well imaged, though these are likely to be present. These ancient faults were reactivated during the Jurassic/Cretaceous and, within this area, likely generated subsidence. The high potential for erosion of the top of the bedrock makes it difficult to attribute features at the top bedrock surface to tectonic activity. The top of the bedrock is generally 7 to 45 m below seabed, it is shallowest, less than 10m below seabed, over the north/east of the area. The upper surface of the bedrock is a truncation surface with an angular unconformity between the Mesozoic rocks and their much younger overburden. The bedrock may have been subjected to numerous phases of erosion during early glaciations.

16 OVERVIEW OF THE DIGITAL DELIVERABLES

16.1 GEOLOGICAL SURVEY

Table 61: Overview digital deliverables geological survey

Deliverable	Format	Data location
All sensors		
Trackplots (line)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Man-made objects (point)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Man-made objects (line)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Man-made objects (polygon)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Seabed features (point)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Seabed features (line)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Seabed features (polygon)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Seabed geology (polygon)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Catalogue of Seabed objects	PDF	108_GEOPHYSICAL_REPORT - WPA&C
SVP		
SVP logfiles	Raw and excel	101_MBES - WPA&C
SBP and UHRS		
Processed SBP data and UHRS recordings (Depth and Time)	SEGY	104_SBP_2D_URHS - WPA
SBP and UHRS instrument tracks	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Boulder Factor	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Interpretation of post-processed seismic data	ASCII	104_SBP_2D_URHS - WPA
Horizon interpretation depth BSL gridded surface	ASCII	104_SBP_2D_URHS - WPA
	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Horizon interpretation depth below seabed gridded surface	ASCII	104_SBP_2D_URHS - WPA
	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb

Deliverable	Format	Data location
Isochore gridded surface	ASCII	104_SBP_2D_URHS - WPA
	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Processing Project	Kingdom Project Files	104_SBP_2D_URHS - WPA
Reports		
Mob and Cal Report	PDF	Energinet SharePoint
Operations Report	PDF	Energinet SharePoint
Technical Report	PDF	Energinet SharePoint
Charts		
Overview	PDF	108_GEOPHYSICAL_REPORT - WPA&C
Trackplots	PDF	108_GEOPHYSICAL_REPORT - WPA&C
Sub-seabed Geology	PDF	108_GEOPHYSICAL_REPORT - WPA&C
GIS		
Trackplots (all sensors)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Boulder Factor	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon BSL Grids H05	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon BSL Grids H15	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon BSL Grids H20	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon BSL Grids H35 and H50	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon DBS Grids H05	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon DBS Grids H15	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon DBS Grids H20	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon DBS Grids H35	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Isochore Grids	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb

16.2 GEOPHYSICAL SURVEY

Table 62: Overview digital deliverables geophysical survey

Deliverable	Format	
All sensors		
Trackplots (line)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Man-made objects (point)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Man-made objects (line)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Man-made objects (polygon)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Seabed features (point)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Seabed features (line)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Seabed features (polygon)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Seabed geology (polygon)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Catalogue of Seabed objects	PDF	108_GEOPHYSICAL_REPORT - WPA&C
MBES		
Despiked, motion and tidal corrected point clouds	ASCII	101_MBES - WPA&C
Bathymetric average values gridded surface 0.25 m, 1 m and 5 m	ASCII	101_MBES - WPA&C
	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Bathymetry Total Vertical Uncertainty values gridded surface 1 m	ASCII	101_MBES - WPA&C
	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Bathymetry Contours 0.5 m	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
MBES Anomaly Points	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Vessel Tracks	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
SVP		
SVP logfiles	Raw and excel	101_MBES - WPA&C
Backscatter		

Deliverable	Format	
Gridded 1 m	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
	ASCII	101_MBES - WPA&C
SSS		
Processed SSS data	HF XTF	102_SSS – WPC
	LF XTF	102_SSS – WPC
Navigation Files	ASCII	102_SSS – WPC
SonarWiz 7 Project	SonarWiz Project Files	102_SSS – WPC
Target Images	Single band TIF	102_SSS – WPC
SSS Anomaly Points	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Magnetometer		
Processed Magnetometric Data	ASCII	103_MAG - WPC
Mag Anomaly Points	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Total Field Grid	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Residual Signal Grid	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Analytical Signal Grid	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Altitude Grid	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Oasis Montaj Project	Oasis Montaj Project	103_MAG - WPC
SBP and UHRS		
Processed SBP data and UHRS recordings (Depth and Time)	SEGY	104_SBP_2D_URHS - WPA
SBP and UHRS instrument tracks	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Boulder Factor	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Interpretation of post-processed seismic data	ASCII	104_SBP_2D_URHS - WPA
Horizon interpretation depth BSL gridded surface	ASCII	104_SBP_2D_URHS - WPA
	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Horizon interpretation depth below seabed gridded surface	ASCII	104_SBP_2D_URHS - WPA
	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
	ASCII	104_SBP_2D_URHS - WPA

Deliverable	Format	
Isochore gridded surface	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Processing Project	Kingdom Project Files	104_SBP_2D_URHS - WPA
Grab Sampling		
Grab Sample Positions	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Grab Sample Classifications	Excel Doc	108_GEOPHYSICAL_REPORT - WPA&C
Grab Sample Lab Analysis	Excel Doc	108_GEOPHYSICAL_REPORT - WPA&C
Onboard 48h deliverables		
MBES coverage	Shapefile	Onboard
Bathymetric average values gridded surface	ASCII	Onboard
Bathymetric density values gridded surface	ASCII	Onboard
Bathymetric standard deviation values gridded surface	ASCII	Onboard
MBES track	Shapefile	Onboard
SSS coverage	Shapefile	Onboard
SSS mosaic merged HF and LF	Single band TIF	Onboard
SSS mosaic per line HF and LF	Single band TIF	Onboard
SSS track processed	Shapefile	Onboard
MBES targetlist	ASCII	Onboard
SSS targetlist	ASCII	Onboard
Reports		
Mob and Cal Report	PDF	Energinet SharePoint
Operations Report	PDF	Energinet SharePoint
Technical Report	PDF	Energinet SharePoint
GIS		
Trackplots (all sensors)	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
MBES Contours	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
MBES Anomalies	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
MBES Grid 0.25m, 1.0m and 5.0m	Shapefiles	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb

Deliverable	Format	
MBES THU Grid 1.0m	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
MBES TVU Grid 1.0m	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Backscatter Grid 1.0m	Shapefile	SN2023_006_KFII_N_F_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_F_ETRS89_UTM33N_Rev01.gdb
Boulder factor	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon BSL Grids H05	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon BSL Grids H20	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon BSL Grids H30	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Gas BSL Grids	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon DBS Grids H05	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon DBS Grids H20	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Horizon DBS Grids H30	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Gas DBS Grids	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
SBP Isochore Grids	Encoded TIF	SN2023_006_KFII_N_R_ETRS89_UTM33N_Rev01.gdb SN2023_006_KFII_S_R_ETRS89_UTM33N_Rev01.gdb
Charting		
Trackplots and sampling locations	PDF	108_GEOPHYSICAL_REPORT - WPA&C
Bathymetry	PDF	108_GEOPHYSICAL_REPORT - WPA&C
Backscatter	PDF	108_GEOPHYSICAL_REPORT - WPA&C
Seabed Surface Classification	PDF	108_GEOPHYSICAL_REPORT - WPA&C
Seabed Objects	PDF	108_GEOPHYSICAL_REPORT - WPA&C
Seabed Features	PDF	108_GEOPHYSICAL_REPORT - WPA&C
Sub-seabed Geology	PDF	108_GEOPHYSICAL_REPORT - WPA&C

REFERENCES

Jensen, J.B., Moros, M., Endler, R. & IODP Expedition 347 Members. 2017: The Bornholm Basin, southern Scandinavia: a complex history from Late Cretaceous structural develop-ments to recent sedimentation. Boreas 46, 3–17

Jensen, J.B., Bennike, O., & Leth, J.O. (2023/2024) Screening of seabed geological conditions for the offshore wind farm areas Kriegers Flak II North and Kriegers Flak II South. Desktop study for Energinet. Danmarks OG Grønlands Geologiske Undersøgelse report 2023/2024

Rabaut, M., Vincx, M. & Degraer, S. Do *Lanice conchilega* (sandmason) aggregations classify as reefs? Quantifying habitat modifying effects. *Helgol Mar Res* **63**, 37–46 (2009). https://doi.org/10.1007/s10152-008-0137-4

APPENDIX A. KRIEGERSFLAKN+S - UHR SEISMIC PROCESSING REPORT

APPENDIX B. KRIEGERS FLAK II NORTH: SURFICIAL GEOTECHNICAL GROUND-TRUTHING DATA REPORT

APPENDIX C. KRIEGERS FLAK II SOUTH: SURFICIAL GEOTECHNICAL GROUND-TRUTHING DATA REPORT