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DGEC - BNO 2DUHRS Survey

UHRS Factual Report BNO - Accepted

Project Document Code	6168_4-RR-01-A

Revision	Date	Description of Revision	Author	Checked	Approved
2.0	16/09/2025	Accepted	PEAK/LSMA	EVA	BMCV

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REVISION HISTORY

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Rev.	Date	Reason for amendments	Section changes from previous version
1.0	28/08/2025	For Client review	N/A
2.0	16/09/2025	Client comments amended, Accepted	Comment sheet Ref. "6168_4-RR-01_UHRS Factual Report_Rev1.0.xlsx"

Author		Role and Function in the company
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DEFINITIONS AND ABBREVIATIONS

Throughout this document the following terminology is used:

DGEC	*Direction Générale de l'Energie et du Climat (DGEC) (Client)*
GEOxyz	*GEOxyz (Contractor)*
Peak	*Peak Processing (Sub-contractor) – processing and interpretation of the subseabed datasets*
OSC	*Ocean Science Consulting Limited (Sub-contractor) – providing visual surveys and subsequent interpretation of marine mammal and passive acoustic monitoring reporting and analysis*
TTS	*TTS Surveys Ltd (Sub-contractor) – providing 2DHR equipment and operations*

The abbreviations and units listed in the table below are used within this report. Where abbreviations used in this document are not included in this table, it may be assumed that they are either equipment brand names or company names.

Acronym	Description	Acronym	Description
2DHR	Two-Dimensional High Resolution	Port	Portside
ALARP	As Low As Reasonably Practicable	QC	Quality Control
ASCII	American Standard Code for Information Interchange	QINSy	Quality Integrated Navigation System
BSB	Below Seabed	QPS	Quality Positioning Services B.V.
EPSG	European Petroleum Survey Group	RGB	Red Green Blue
ETRS89	European Terrestrial Reference System 1989	RX	Receiver
FMGT	Fledermaus Geocoder Toolbox	Rev	Revision
GNSS	Global Navigation Satellite System	SBAS	Satellite-Based Augmentation System
GOVI	Geo Ocean VI	SBP	Sub-bottom Profiler
GRS80	Geodetic Reference System 1980	SEGY	Society of Exploration Geophysicists Y format
HSE	Health, Safety and Environment	SHOM	Service Hydrographique et Oceanographique de la Marine (PBMA in French)
IHO	International Hydrographic Organisation	SSS	Side Scan Sonar
IMU	Inertial Measurement Unit	SVS	Sound Velocity Sensor
INS	Inertial Navigation System	SWL	Safe Working Limit
J	Joules	THU	Total Horizontal Uncertainty
LAT	Lowest Astronomical Tide	TVU	Total Vertical Uncertainty
MAG	Magnetometer	UHR	Ultra-High Resolution
MBES	Multibeam Echosounder	UHRS	Ultra-High Resolution Seismic
MMO	Marine Mammal Observer	USBL	Ultra-Short Baseline
MRU	Motion Reference Unit	UTC	Universal Time Coordinated
N	Northing	UTM	Universal Transverse Mercator
NA	Not Applicable	UXO	Unexploded Ordnance
OSC	On-Scene Coordinator	WGS84	World Geodetic System 1984

Acronym	Description	Acronym	Description
PAM	Passive Acoustic Monitoring	ZH	Zero Hydrographic

REFERENCE DOCUMENTATION

Client Documents

Key project documentation from the Client is listed in Table 1.

Table 1: Client reference documents

Ref.	Document Number	Title	Owner
1.	2023-DGEC-07 CCAP.pdf	Administrative clauses	DGEC
2.	2023-DGEC-07-RC.pdf	Tendering rules	DGEC
3.	2023-DGEC-07 AE annexe 2.docx	Commitment on deadlines	DGEC
4.	2023-DGEC-07 CCTP.pdf	Technical proposal	DGEC
5.	Scenarios_Rochebonne_V2	Offshore surveys (3 options)	DGEC
6.	DTS_BRGM	Desktop studies (geological)	BRGM
7.	DTS_SHOM	Desktop studies (bathymetry)	SHOM
8.	DTS_UXO	Desktop studies (UXO)	6 Alpha Associates Ltd

GEOxyz Project Documents

Key project documentation created by GEOxyz is listed in Table 2.

Table 2: GEOxyz project documentation

Ref.	Document Number	Title	Owner
9.	6168_1-PDR-01	Project Document Register	GEOxyz
10.	6168_1-HSE-01	HSE Plan	GEOxyz
11.	6168_1-DDL-01	Data Deliverables List	GEOxyz
12.	6168_1-ERB-01	Emergency Response & Bridging Document	GEOxyz
13.	6168_1-PEP-01	Project Execution Plan	GEOxyz
14.	6168_1-PQP-0	Project Quality Plan	GEOxyz
15.	6168_1-PRA-01	Project Risk Assessment	GEOxyz
16.	6168_1-CM-01	Communication Matrix	GEOxyz

Standard Operating Procedures

Standard GEOxyz operating procedures that are relative to the project are listed in Table 3 for reference.

Table 3: Standard operating procedures

Ref.	Document Number	Title	Owner
17.	GEO-OPP-6028	Positioning Systems Operation Procedure	GEOxyz
18.	GEO-OPP-6029	Heading Sensor Operation Procedure	GEOxyz
19.	GEO-OPP-6030	MRU Operation Procedure	GEOxyz
20.	GEO-OPP-6031	SVP Operation Procedure	GEOxyz
21.	GEO-OPP-6032	USBL Operation Procedure	GEOxyz
22.	GEO-OPP-6033	MBES Operation Procedure	GEOxyz
23.	GEO-OPP-6038	SSS Operation Procedure	GEOxyz

Ref.	Document Number	Title	Owner
24.	GEO-OPP-3039	SBP Operation Procedure	GEOxyz
25.	GEO-OPP-6052	MBES Data Processing Procedure	GEOxyz
26.	GEO-OPP-6054	SSS Data Processing Procedure	GEOxyz
27.	GEO-OPP-6055	SBP Data Processing Procedure	GEOxyz
28.	GEO-OPP-6109	UHRS Operation	GEOxyz

Vessel Specific Procedures

Vessel Specific procedures that are relative to the project are listed in **Table 4** for reference.

Table 4 Vessel Specific procedures

Ref.	Document Number	Title	Owner
29.	GEO-GO08-OPP-6011	L&R Procedure USBL Pole	GEOxyz
30.	GEO-GO08-OPP-6003	L&R Procedure - SSS	GEOxyz
31.	GEO-GO08-OPP-6001	L&R Procedure SVP	GEOxyz
32.	GEO-GO08-OPP-6004-	L&R Procedure - Dual TVG	GEOxyz
33.	GEO-G009-OPP-6001	L&R Procedure SVP	GEOxyz
34.	GEO-GO09-OPP-6018	L&R Procedure - 2DHR and UHR	GEOxyz

Other references

Ref.	Document
35.	BRGM, 2024. Geological Overview of Façade North Atlantic – English Channel (desktop study). BRGM report number 73271.
36.	EMODnet (https://emodnet.ec.europa.eu/en/), European Commission Directorate-General for Maritime Affairs and Fisheries (EC DG MARE) and European Maritime Fisheries and Aquaculture Fund (EMFAF).
37.	Package F. 2024. Geological overview of the North Atlantic coast - Western English Channel. Final report - A. BRGM/RP-73271-FR, 62 p.
38.	BRGM, 2025. Geological overview of the macro-zones North-West Brittany and Rocks Dover – North-East Brittany. BRGM report 74348
39.	SHOM,2021a. Global Sedimentary Map.

EXECUTIVE SUMMARY

Survey	Geo Ocean IX	Start date: 07/05/2025
		End date: 21/05/2025
Sensors	MBES (Multibeam Echosounder), SBP (Sub-Bottom Profiler), UHRS (Ultra High Resolution Seismics)	
Coordinate system	Datum	European Terrestrial Reference System 1989 (ETRS89)
	Projection	UTM Zone 30 N (EPSG: 32630)
Bathymetry		
Depth	-93.79 to -71.04 metres (LAT)	
Site topography	Overall, depth increases from east to west. The western area of the survey area shows relatively uniform seabed levels with deepest point in the far western corner of the survey area, and the shallowest point in the southeast area of the survey.	
Geology overview		

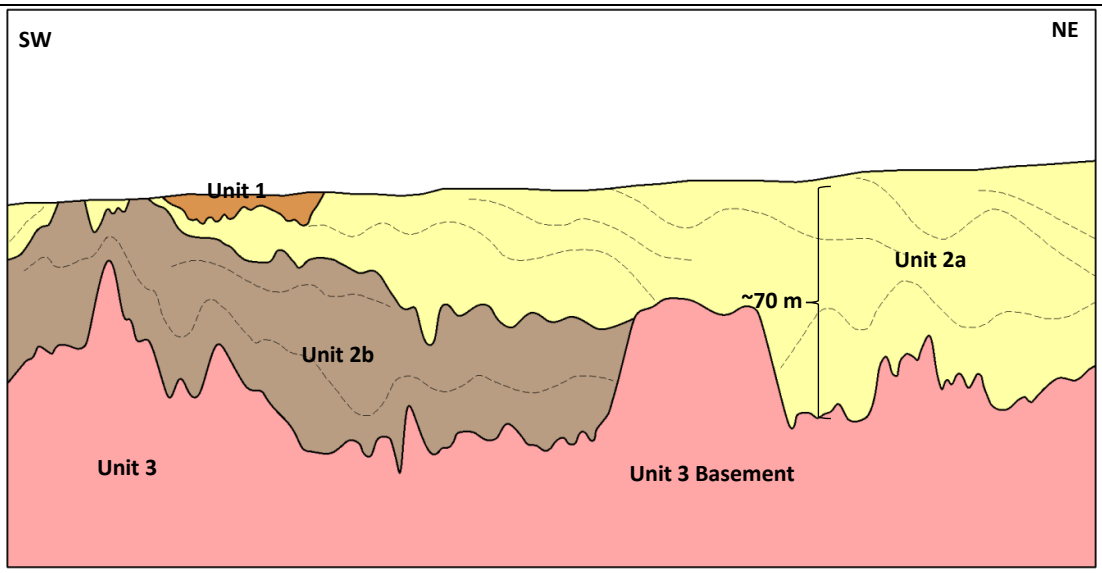
	Unit name	Age	Description
Unit summary	*Unit 1*	Late Eocene	Sandstone, limestone and mudstone (e2 in the stratigraphy of the BRGM desk study). Acoustically structureless
	Unit 2a	Late Eocene	Sandstone, limestone and mudstone (e2 in the stratigraphy of the BRGM desk study). Contains internal unconformities and bedded intervals. Predominates over NE of area
	Unit 2b	Mid to Late Eocene	Sandstone, limestone and mudstone (e2 in the stratigraphy of the BRGM desk study). Contains internal unconformities and bedded intervals. Predominates over SW of area
	Unit 3	Cambrian	Basement. Likely granite

Geology description

Unit 1: This interval is tentatively interpreted to represent Late Eocene deposits. The base is an erosion surface. It is generally around 10 m thick but in one small area it is 50 m thick. The unit has an erosive base a patchy distribution and is confined to the south-west and north-east of the area. Unit 1 may be younger than Eocene but is unlikely to be Quaternary.

Unit 2: Is a complex Eocene interval of sandstone, limestone and mudstone. The unit occurs throughout the area and is folded and draped over the ancient bedrock. The interval is typically 40 to 100 m thick. It contains numerous internal unconformities though the wide line spacing is not sufficient to enable their effective mapping. A single marker unconformity is mapped within Unit 2. The younger Unit 2a (above the marker) predominates to the north-east. Based on literature, there is no distinction in terms of type of rock between Unit 2a and Unit 2b.

Unit 3: This is ancient bedrock. The top of this interval is irregular and is the acoustic basement, there is no imaging of the internal structure of this unit. The top of the basement is between 12 and 150 m below seabed but is typically 40 to 100 m below seabed. This rock is probably Cambrian Granite.

	
Geohazards and installation constraints	There are no seismic indications of shallow gas or faults. Consideration should be given to the geological variation across the area: The likelihood is that Late Eocene sediments crop out over the entire area, under a thin discontinuous veneer of sand and gravel. There is significant variation within the Eocene sediments of Units 1 and 2. Reference data suggests that these units comprise a mixture of sandstone, limestone and mudstone. The project data are not calibrated to allow differentiation of these lithotypes. In terms of foundation conditions, the most significant variable may be the depth of the ancient basement granite. This ranges between 12 and 150 m below seabed. Where the granite is relatively close to the seabed then foundation design will probably extend to or within this very strong rock. In places where the granite is over 40 m below seabed it may be possible to design a foundation that resides entirely with the Eocene sediments. The bedrock is within 40 m of the seabed over parts of the south-west of the area.

1 INTRODUCTION

1.1 PROJECT OVERVIEW

As part of the development of offshore wind energy in France, the DGEC is responsible for the technical studies prior to the award of tenders for offshore wind farms. De risking studies of the seabed and sub-seabed are required for each prospective wind farm area.

The following four maritime façades cover the areas where the development of offshore wind power is envisaged:

- Eastern Channel North Sea (MEMN)
- North Atlantic Western Channel (NAMO)
- South Atlantic (SA)
- Mediterranean (MED)

The purpose of this contract is to carry out geophysical de-risking studies for approximately seven to eight sites spread throughout the metropolitan territory, which is divided into the four maritime façades. The sites are located in the continental shelf area, generally between 12 and 50 nautical miles from the coast (Figure 1-1).

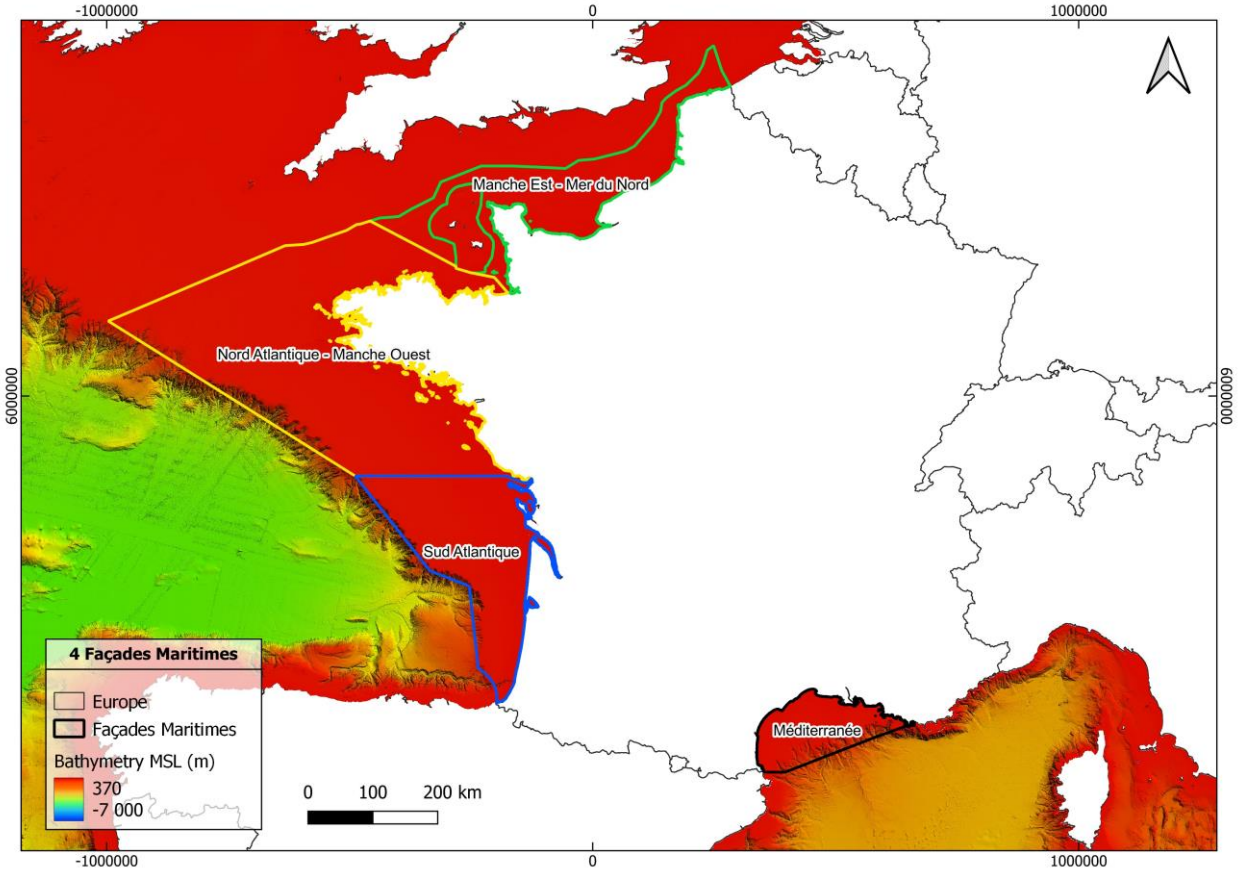


Figure 1-1: Project location overview

The main objectives of de-risking studies were to:

- Provide UHR seismic, MBES bathymetry, and Sub Bottom Profile data to better understand the seabed and sub-seabed conditions;
- Provide MBES/SSS data that will be used to issue ALARP certificates prior to the commencement of geotechnical testing.

1.2 SCOPE OF WORK

The overall scope of work consists of geophysical and UXO surveys in the Nord Atlantique Manche Ouest (BNO) zone as shown in (Figure 1-2).

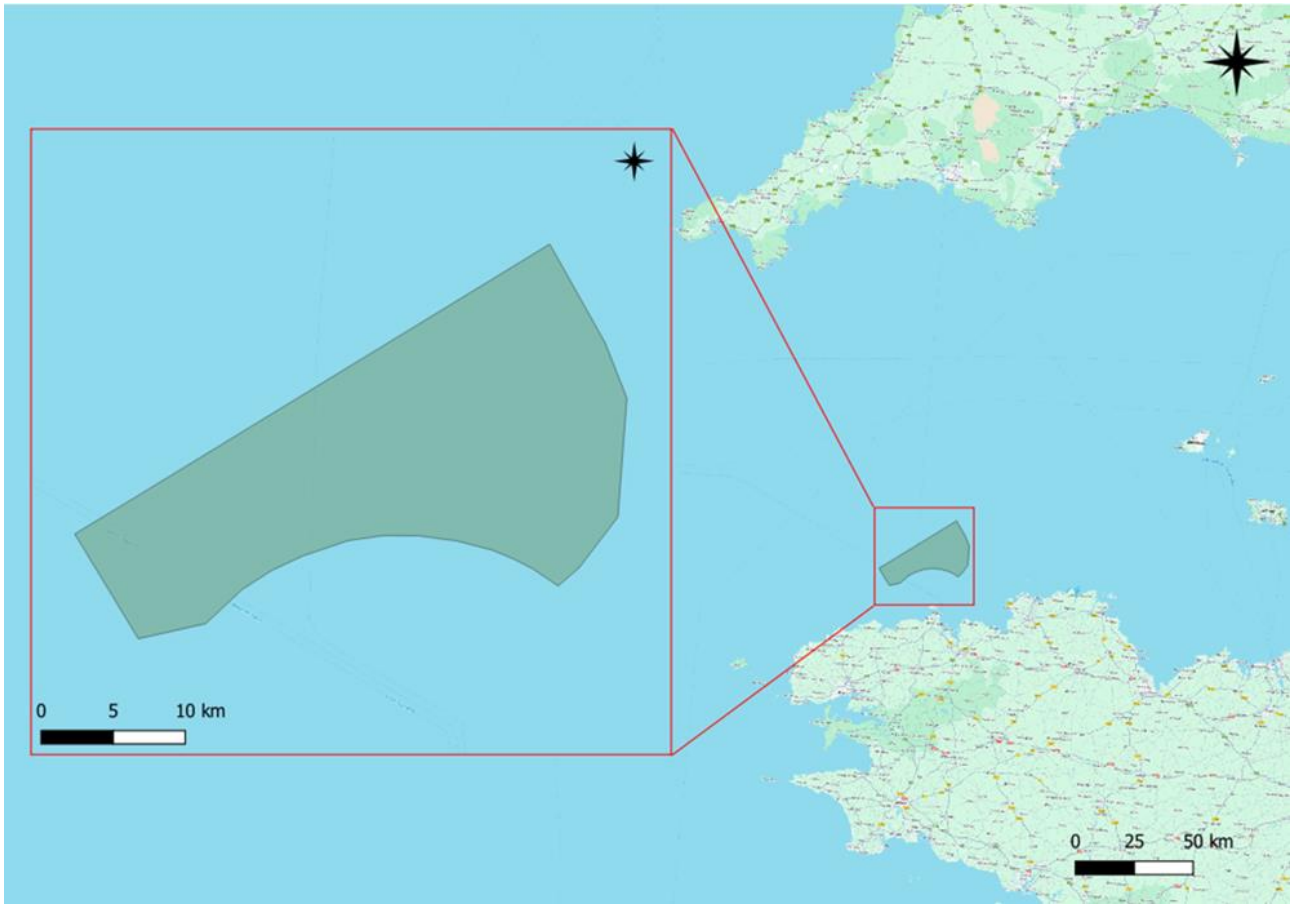


Figure 1-2: Scope of work area

The geophysical survey comprised the acquisition of Ultra High Resolution Seismic (UHRS), multibeam bathymetry (MBES), Sub Bottom Profile (SBP) sensor data by the GEOxyz vessel **Geo Ocean IX**. As far as possible, data from all sensors was acquired simultaneously, with line planning as per the Client specifications. The technical requirements for positioning and these individual components are defined in the client reference documents and summarised in the following sections.

1.3 SCOPE OF DOCUMENT

An overview of the reports submitted as part of the project are listed in Table 5 below. This report, the UHRS Factual Report, details the results of the geophysical survey.

Table 5: Project reports

Document Number	Title
6168_4-MCR-01	Mobilisation Report
6168_4-OR-01	Operations Report
OSC_2024_GEOxyz_MED_MMOPAM_v1.2	MMO & PAM Report
6168_4-RR-01	**UHRS Factual Report BNO (This Report)**
6168_4-RR-02	UXO Factual Report BNO

2 GEODETIC PARAMETERS AND TRANSFORMATIONS

2.1 HORIZONTAL DATUM

The geodetic datum and mapping coordinate system used for this project is WGS84 UTM Zone 30N. All coordinates used are referenced to the geodetic datum and grid parameters listed in Table 6 and Table 7 below.

Table 6: Datum parameters

Parameter	Details
Geodetic Datum	World Geodetic System 1984 (WGS84)
EPSG Coordinate Reference System	4326
Spheroid	GRS80
EPSG Ellipsoid Code	7019
Semi-Major Axis	6378137.000
Semi-Minor Axis	6356752.31424
Flattening	1/298.257223563
Eccentricity Squared	0.00669428002290

Table 7: Projection parameters

Parameter	Details
EPSG Coordinate Reference Code	32630
Projection	UTM
Zone	30N
Central Meridian	3° West
Latitude of Origin	0°
False Easting	500000.00 m
False Northing	0.00 m
Scale Factor at Central Meridian	0.9996
Units	Metres

2.2 VERTICAL REFERENCE

The vertical reference used is the Zéro Hydrographique (ZH) defined by the surface Lowest Astronomical Tide (LAT). Reduction was made via the SHOM Bathyelli (PBMA Plus Basses Mers Astronomiques in French) v2.1 model.

2.3 TIME AND LOG KEEPING

UTC (Universal Time Coordinated) has been used for record keeping during the project (including the Daily Progress Reports unless stated otherwise). The vessel was also maintained local time for operations.

Data time-tagging and synchronization was also used UTC. All data recorded in the online navigation software has been time stamped where appropriate using the time string and the pulse-per-second (PPS) from the GNSS.

2.4 SURVEY UNITS

The following survey units were used during the project and throughout this report:

- Distances are expressed in metres (m)
- Angles are expressed in degrees (°)

3 REGIONAL SETTING: MORPHOLOGICAL AND GEOLOGICAL CONTEXT

3.1 MORPHOLOGY AND SEABED NATURE

Based on EMODnet data, the seabed is expected to be shallower in the eastern section of the surveyed area, and greater depths (up to -95 m LAT) expected in the western part. A morphological overview of the area within the survey boundary shows a heterogenous seabed in the whole survey area with seabed features visible on the seabed, as shown in Figure 3-1.

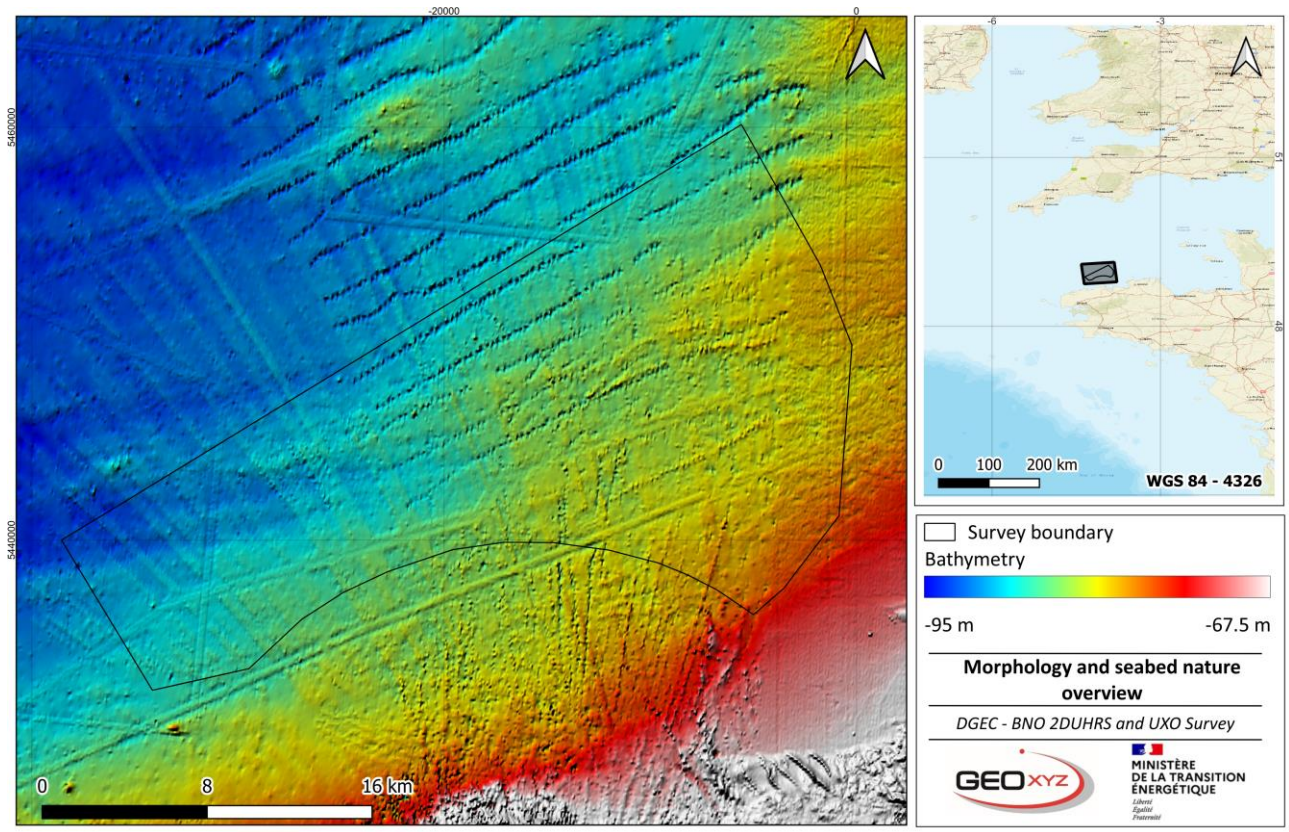


Figure 3-1: Morphology and seabed nature overview

The overall morphology of the area is characterized by a vast plateau exhibiting low roughness at the scale under consideration. A minor topographic elevation is located along the southeastern edge of the BNO region, rising approximately five meters above the surrounding plain. This relief extends in an east–west orientation for approximately two kilometres and is contiguous with the shoals of the Triagoz Plateau to the east, as illustrated in Figure 3-2.

Lineaments are observable in the bathymetric data, oriented in west-southwest to east-northeast, north to south, and northwest to southeast directions. However, these lineaments are interpreted as artifacts resulting from the bathymetric reference dataset employed. Additional lineaments are present within the northwestern macro-zone, although it is not possible to assign a definitive morphological interpretation to them at this scale.

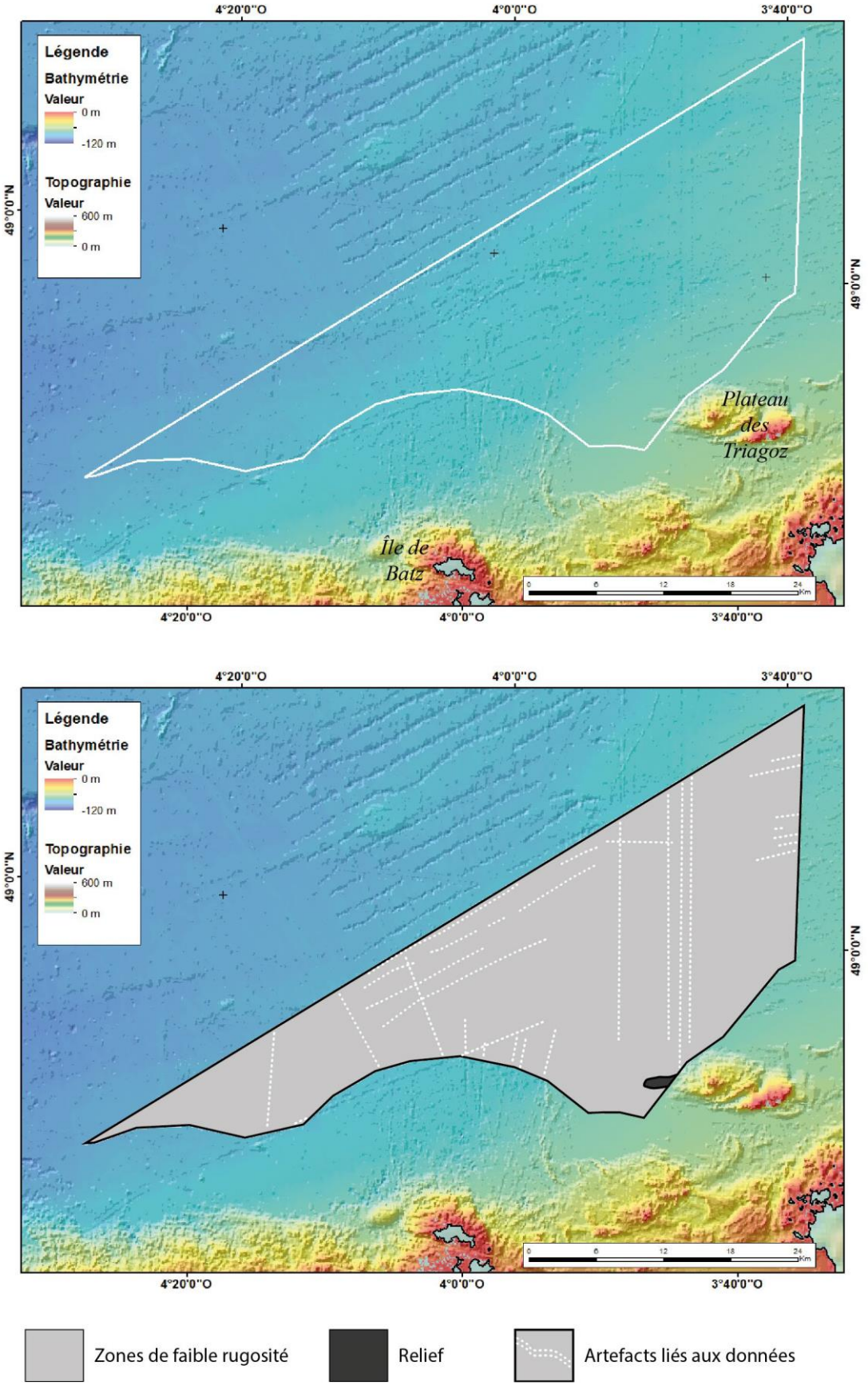


Figure 3-2: Bathymetric maps in the BNO area (EMODnet,2022; GEBCO,2023)

3.2 SEDIMENT MOBILITY

The BNO macro-zone is predominantly characterised by coarse sediments (including pebbles and gravel). A few restricted areas contain sand (ranging from fine sand to coarse sand with gravel). It is noteworthy that sandy deposits are mainly confined to areas near the coastline. The sandy zone (highlighted in yellow on the map in Figure 3-3) is located near the relief identified to the west of the Triagoz Plateau, as described in the large-scale morphological analysis. This relief is interpreted here as a sandbank. Outcropping rock zones were not identified within the area at the scale of the World Sedimentological Map (SHOM, 2021a).

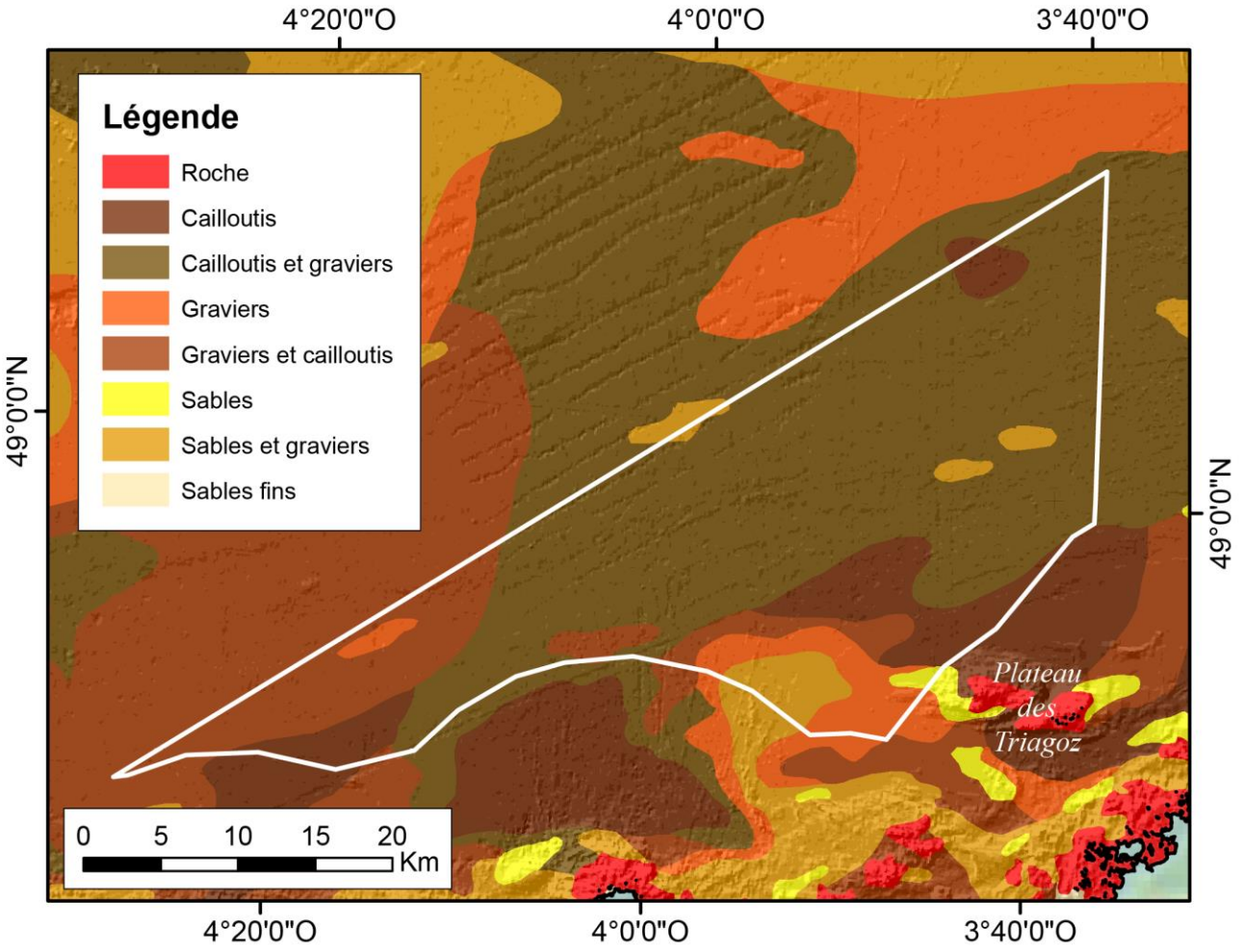


Figure 3-3: Seabed sedimentation in BNO area (SHOM, 2021a)

3.3 EXPECTED SUBSEABED GEOLOGY

The project UHRS data offer imaging of the geology to around 100 m below the seabed, exceptionally to 150 m. This interval comprises several distinct units separated by unconformities. The units are mapped and have been described based on their acoustic characteristics, patterns of superposition, the broad geological history of the area and the BRGM desk study.

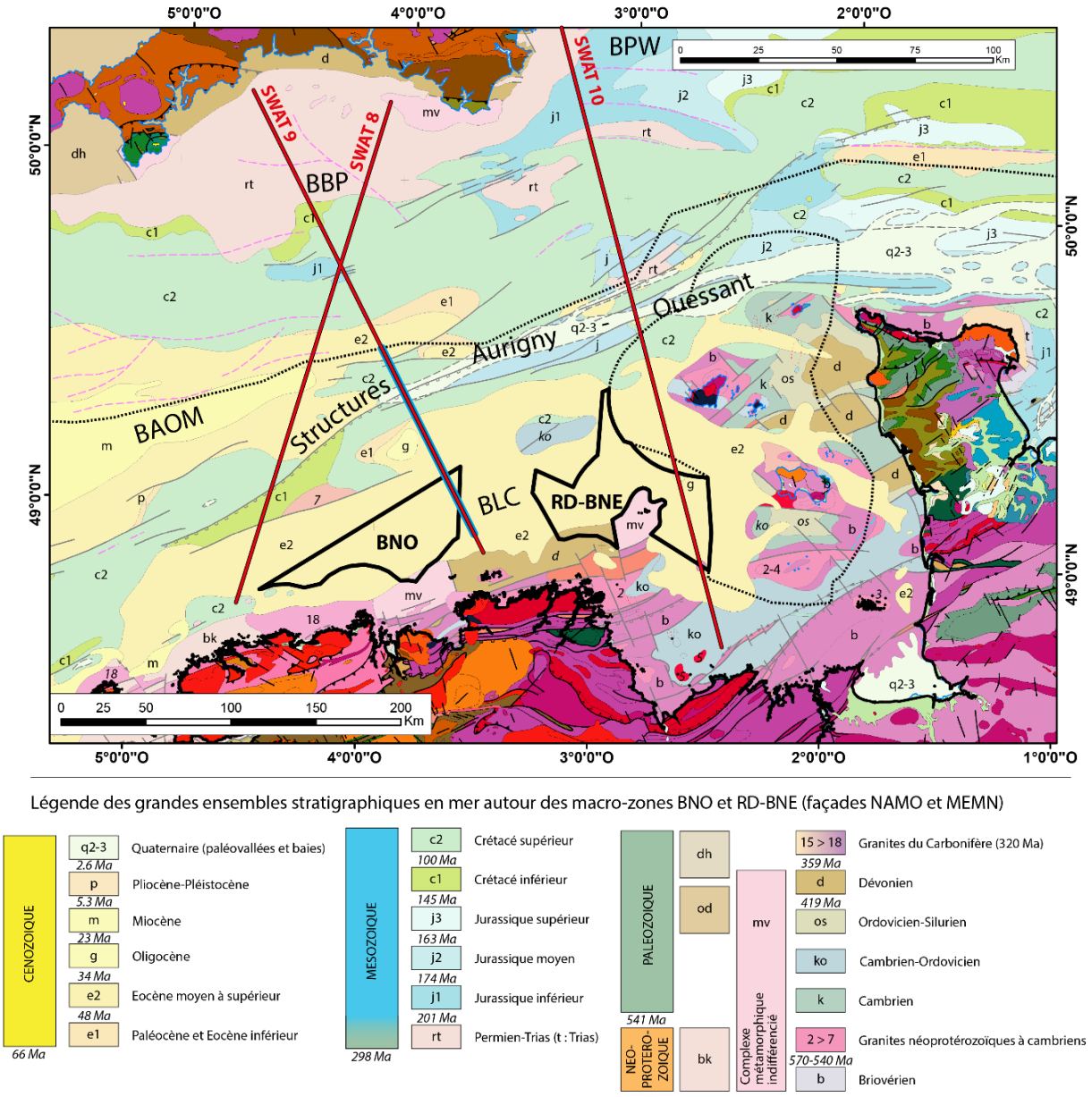
The desk study (and the EMODnet website) do not contain conclusive detail, but they do describe Late Eocene rocks (e2 in the desk study's stratigraphic nomenclature) over ancient basement rocks.

The data image a sequence that corresponds to the reference data:

Unit 1: This interval is tentatively interpreted to represent Late Eocene deposits, sandstone, limestone and mudstone. The base is an erosion surface (H10). The unit is generally around 10 m thick but in one area it is 50m thick. The unit has a patchy distribution and is confined to the south-west and north-east of the area.

Unit 2: Is a complex Eocene interval of sandstone, limestone and mudstone. The unit is folded and draped over the ancient bedrock. The interval is typically 40 to 100 m thick. It contains numerous internal unconformities though the wide line spacing is not sufficient to enable these to be effectively mapped. A single marker unconformity (H50) is mapped within Unit 2. The younger deposits of Unit 2a predominate in the north-west of the area.

Unit 3: This is the ancient bedrock. The top of this interval (H100) is irregular and is the acoustic basement, there is no imaging of the true internal structure of this unit. The top of the basement is between 12 and 150 m below seabed but is typically 40 to 100 m below seabed.



Légende des grandes ensembles stratigraphiques en mer autour des macro-zones BNO et RD-BNE (façades NAMO et MEMN)

Figure 3-4: Geological map of La Manche (BRGM,2025)

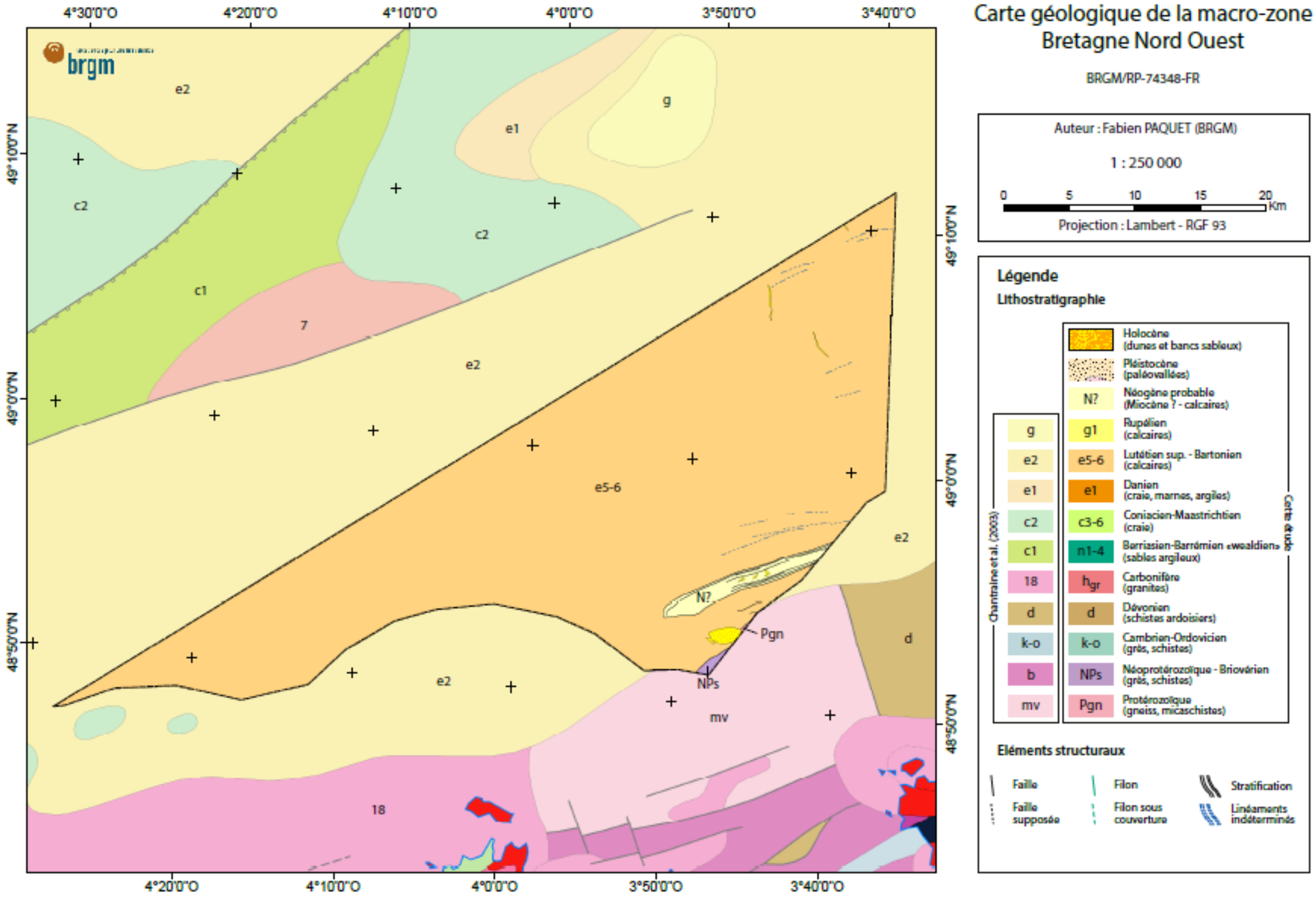


Figure 3-5: Geological map of BNO macro area (BRGM, 2025)

3.4 OTHER INFORMATION

In Figure 3-6, existing infrastructure and wrecks in survey area are presented. Four telecommunication cables are going through the survey area with 15 wrecks present as well. Out of those 15 wrecks, three are located inside planned acquisition lines of the UHRS survey.

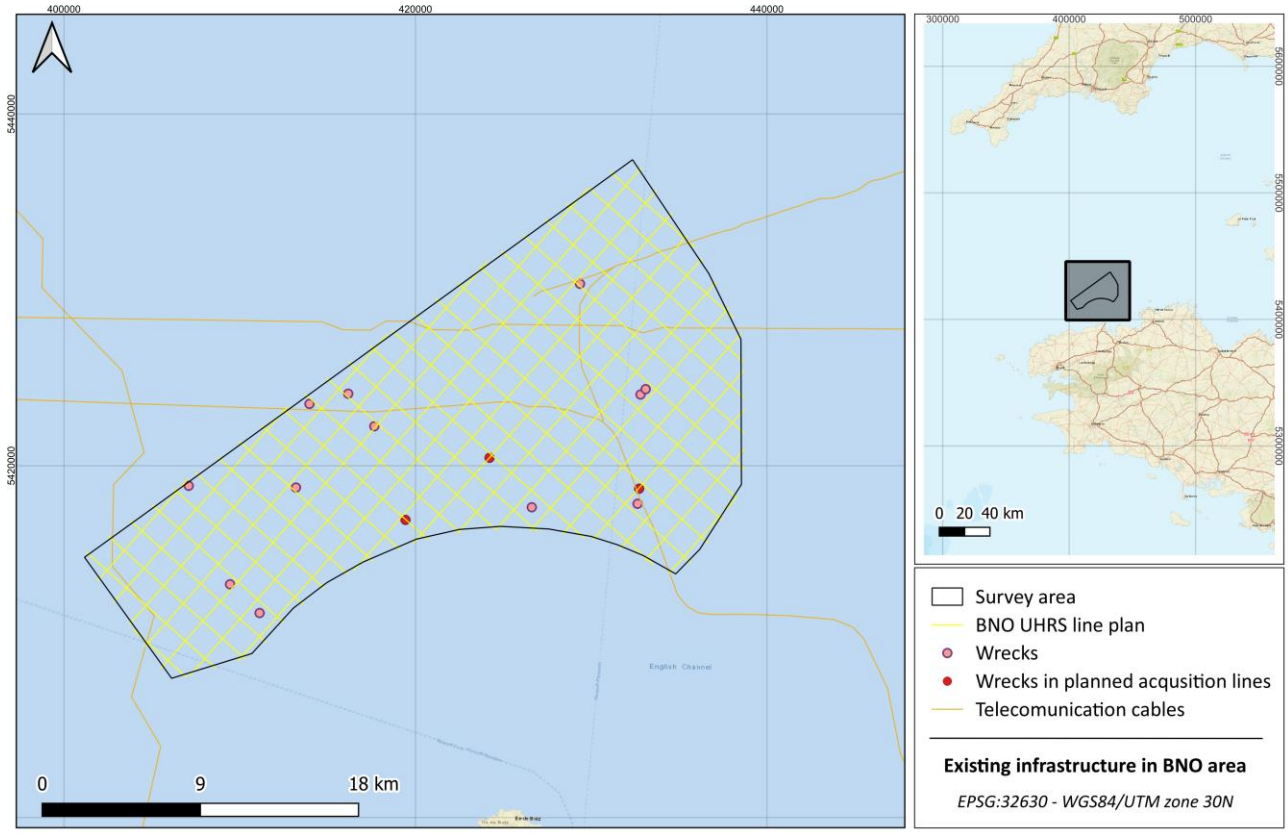


Figure 3-6: Existing infrastructure in BNO area

4 RESOURCES

4.1 VESSELS

GEOxyz's vessel Geo Ocean IX (GOIX) was used to conduct the survey. The specifications of the GOIX are summarised in Table 8.

Table 8: Survey vessel specifications

Geo Ocean IX	Specifications	
	Length	53.8 m
	Width	13.0 m
	Maximum draught	4.8 m
	Cruising speed	5 knots
	Main propulsion	2x Hybrid propulsion package on Berg CP propellers
	Endurance	24h day operations (28 days)
	Accommodation	30
	Positioning	Station Keeping/Autopilot
	A-Frame	A-frame (4.5 x 8.0 m) SWL 15 tonnes
	Crane	2.4 tonnes @ 8 m

4.2 EQUIPMENT

An overview of the equipment used during the project is listed in Table 9 below. More details are outlined in the Operations Report (6168_4-OR-01).

Table 9: Survey equipment specifications

Type	Manufacturer	Model/type
GPS	2 x Trimble BX992 (1 x XP2 and 1 x G4 corrections)	Septentrio AsteRX-U3 Marine receiver with 2x Zephyr III
INS (motion, heading)	SBG IXBlue	Apogee INS Hydrins
Sound Velocity Profiler	Valeport	2 x Swift
USBL	Kongsberg HiPAP 352P	< 0.44% of slant range
Multibeam	Kongsberg EM2040 04 Dual head, Dual swath	Freq: 200 – 400 kHz Focus: 0.4° x 0.7° at 400 kHz
Sub bottom Profiler	Innomar SES2000 Medium	2-22 kHz 1-5 cm resolution
Seismic Source	AAE Duraspark 400 Sparker System (Stacked)	Includes 1x AAE CSP-N 2400j PSU for Operation 1x Spare PSU and Umbilical + All HV Connections

Type	Manufacturer	Model/type
Seismic Streamer	48 Channel GeoEel Streamer	Active Streamer Length: 98 m Configuration: 1x 65m Tow cable – 1x 5 m Stretch – 48ch @ 2 m Group Interval, 1x 5 m Tail stretch, 3x LH16 Digitiser Units
Seismic Streamer Balance Control	Digicourse System 3	Supplied with 3x 5011 Birds for depth control of streamer (2x online, 1x spare)
Seismic DGPS Positioning	AAE Minipod 101G	Head buoy, tail buoy & source positioning
Seismic Recording	Geometrics LH-16 with CNT-2 Controller	Digital Streamer and Recording system capable of sampling at 0.0625ms
IVS	ATN BINOX 4T	50mm, X7 Magnification
PAM	SmartPAM system	Geospectrum M36-900 Hydrophones 1 Hz -200 kHz

4.3 SOFTWARE

The software that was used for data acquisition and processing is outlined in Table 10 below.

Table 10: Project software list

Equipment / Data Type	Acquisition	Processing
Navigation, MBES, GNSS	QPS QINSy	n/a
MBES	QPS QINSy	Qimera QPS BeamworX Autoclean QGIS
SBP (sparker)	Coda Geosurvey	Shearwater Reveal Advanced Marine v.5.1 IHS Kingdom version 2016 64 bit
UHR Streamer	48 channel streamer (ch1-24@1 m int & ch25-48@2 m int)	Shearwater Reveal Advanced Marine v.5.1 IHS Kingdom version 2016 64 bit

4.4 SURVEY TIMELINE

The operational timeline for the survey is presented in Table 11.

Table 11: Survey timeline overview

Vessel	Dates	Activity
Geo Ocean IX	04/05/2025	Mobilisation and calibration
	07/05/2025 – 16/05/2025 20/05/2025 – 21/05/2025	Survey operations

5 DATA PROCESSING

5.1 MULTIBEAM ECHOSOUNDER

5.1.1 Data acquisition and settings

The primary settings used for the project are outlined in Table 12.

Table 12: MBES system settings

Kongsberg EM2040 (DH/DSW)	Head 1 port	Head 2 stbd
Survey speed	Average 4 knots	
High Frequency	400 kHz	400 kHz
Low Frequency	200 kHz	200 kHz
Bottom sampling	High Density Dual Swath (1024 beams)	
Operational Mode	Equidistant	
Range	50 m – 60 m	
Power	Maximum	
Pulse length	Auto	
Patch test roll	*TX -0.141°, RX 39.633°*	*TX -0.141°, RX -39.914°*
Patch test pitch	*TX 0.368°, RX 0.292°*	*TX 0.368°, RX 0.474°*
Patch test heading	*TX -0.05°, RX -0.467°*	*TX -0.05°, RX 0.367°*
Sector Width	60°	60°
Ping rate	Set to 20 Hz	
Software and version	Kongsberg Maritime K-Controller ver. 2.7.7.251	

The MBES project specifications are listed in Table 13.

Table 13: MBES specifications

Item	Specification
Minimum data density	>30 HC/m² between 0 – 50 m of water depth >15 HC/m² between 50 – 150 m of water depth > 9 HC/m² between 150 – 200 m of water depth
Bin size	0.2 m until 25 m of water depth 0.5 m between 25 – 50 m of water depth 1 m between 50 – 200 m of water depth
Grid	1 m cell size
Coverage	100 %
TVU	0.8 m (for 100 m water depth) / 1.5 m (for 200 m water depth)
THU	2 m
Backscatter	Recorded not processed

5.1.2 Overview of the methodology

Bathymetric data was recorded in QINSy as raw QPD files. All data acquired is being corrected online during the acquisition with QINSy for positioning and motion, including pitch, roll, heave, and acquiring in "accurate height status". The data was initially checked offline into the QPS processing software Qimera for quality, coverage, and density requirements. Data processing was carried out using Qimera and AutoClean. First, a rough cleaning was applied in Qimera to remove major spikes and noise. In addition, any SVP/refraction and GNSS drop out issues were fixed. Afterwards, FAU files were exported to continue processing with Autoclean. Bathymetric data was cleaned on a line-by-line basis and/or by using area-based cleaning tools in the processing software. A combination of basic filters applied to the entire data set and then individual QPDs manually cleaned by deleting any further outliers visible within the data.

Figure 5-1 outlines the general MBES processing workflow.

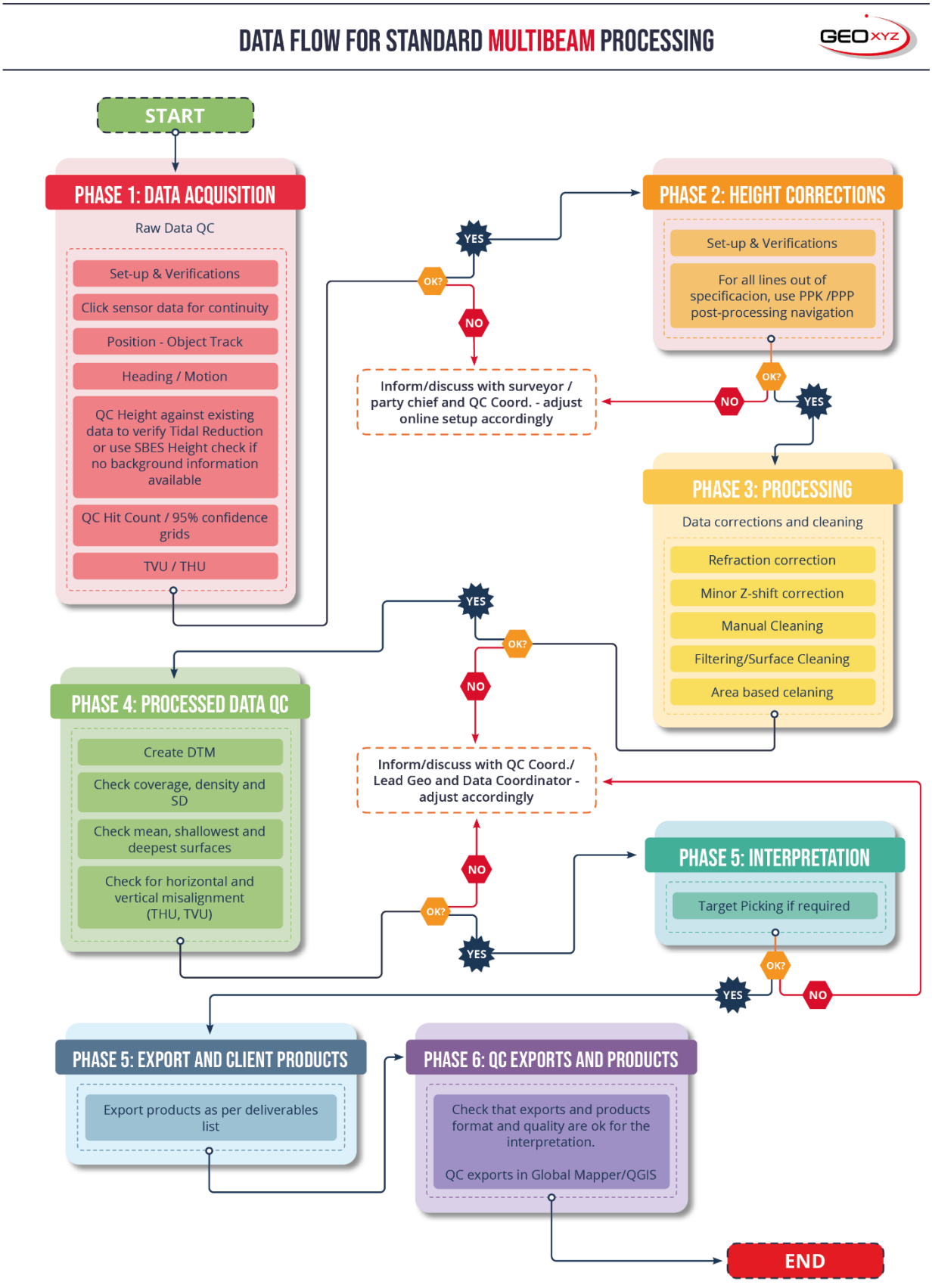


Figure 5-1: MBES processing workflow

5.1.3 Data quality assessment

The multibeam echosounder data was of high quality with very little acoustic noise. An example of the number of hits per metre over the required survey areas are presented in Figure 5-2. The TVU and THU values were within the project specification and are presented in Figure 5-3 and Figure 5-4, respectively.

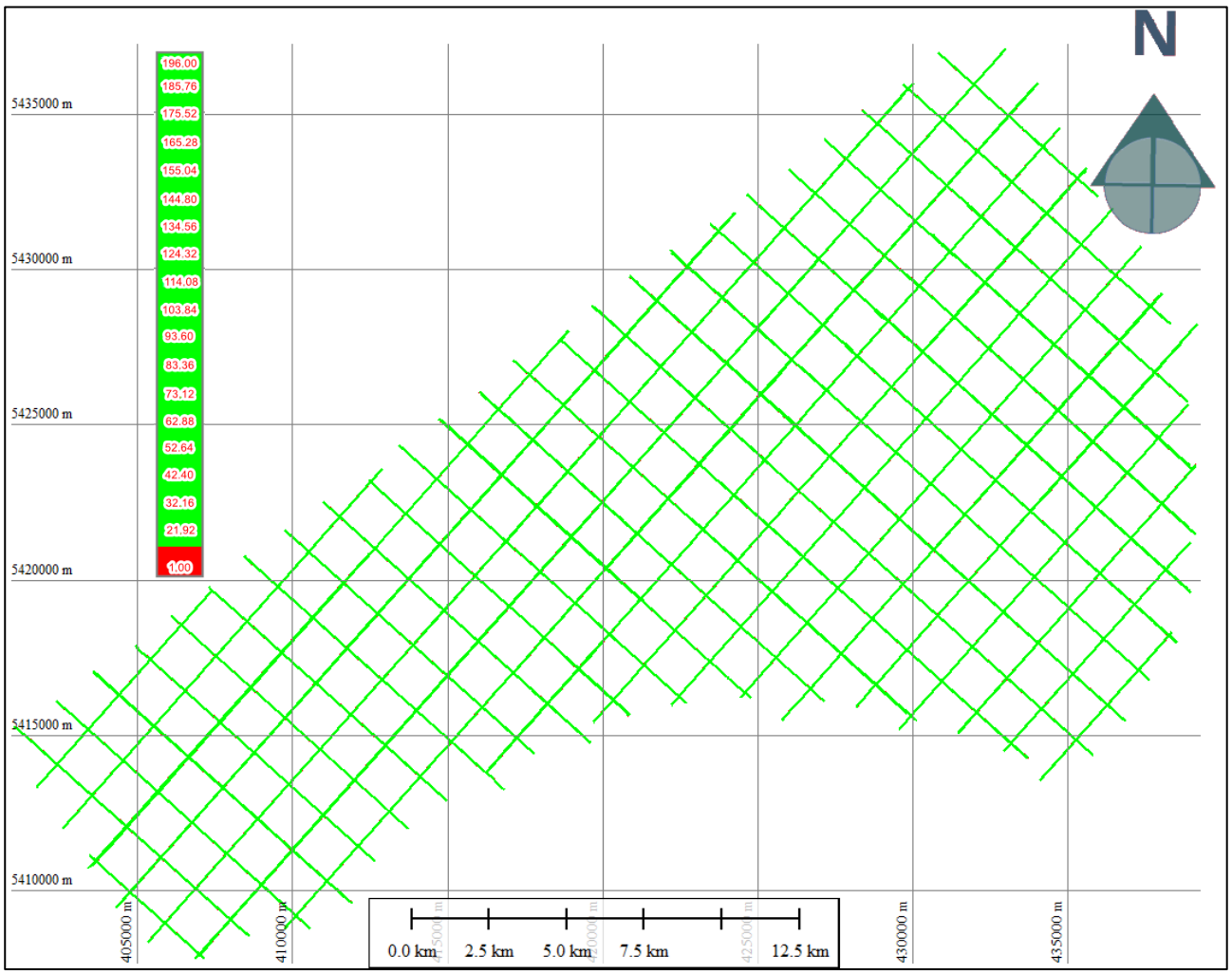


Figure 5-2: BNO bathymetric Data Hit Count per 1 m square (green is 15 > hits per bin)

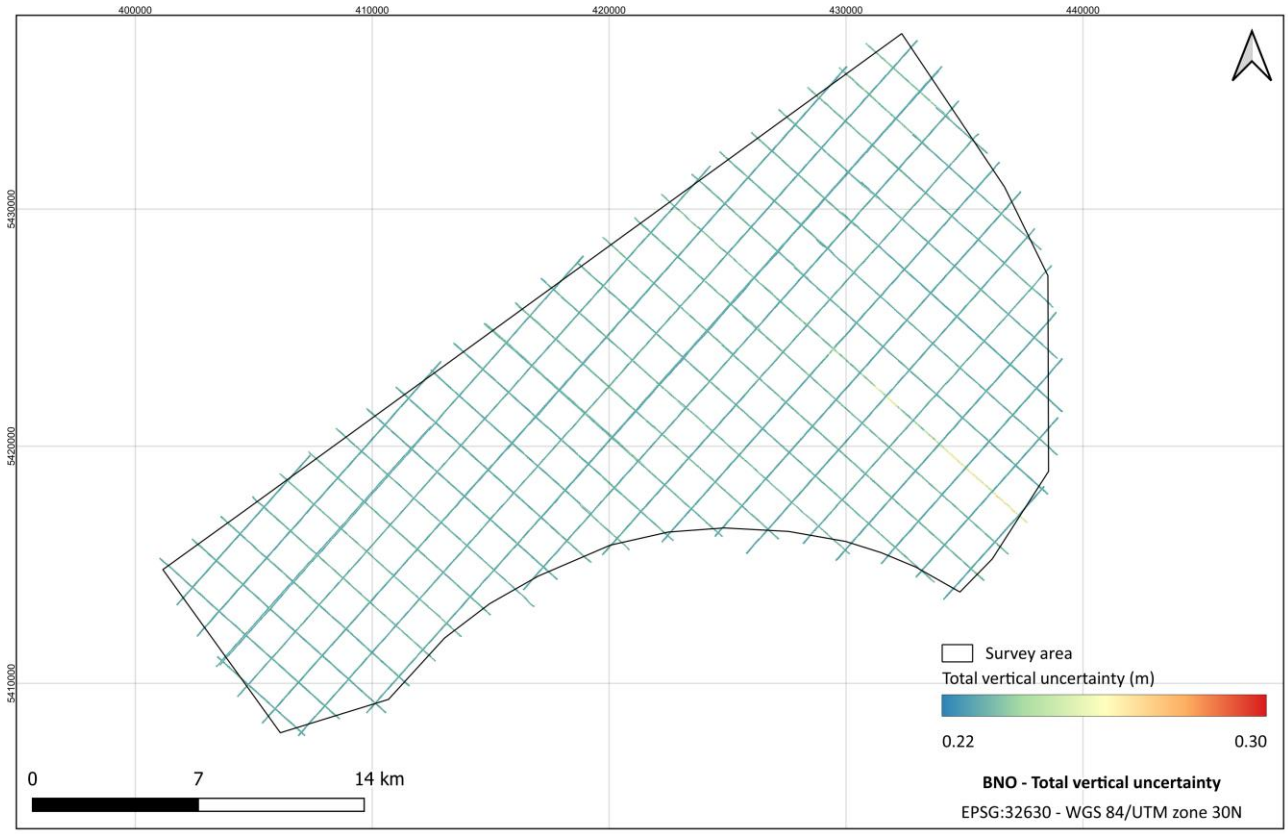


Figure 5-3: Total vertical uncertainty overview

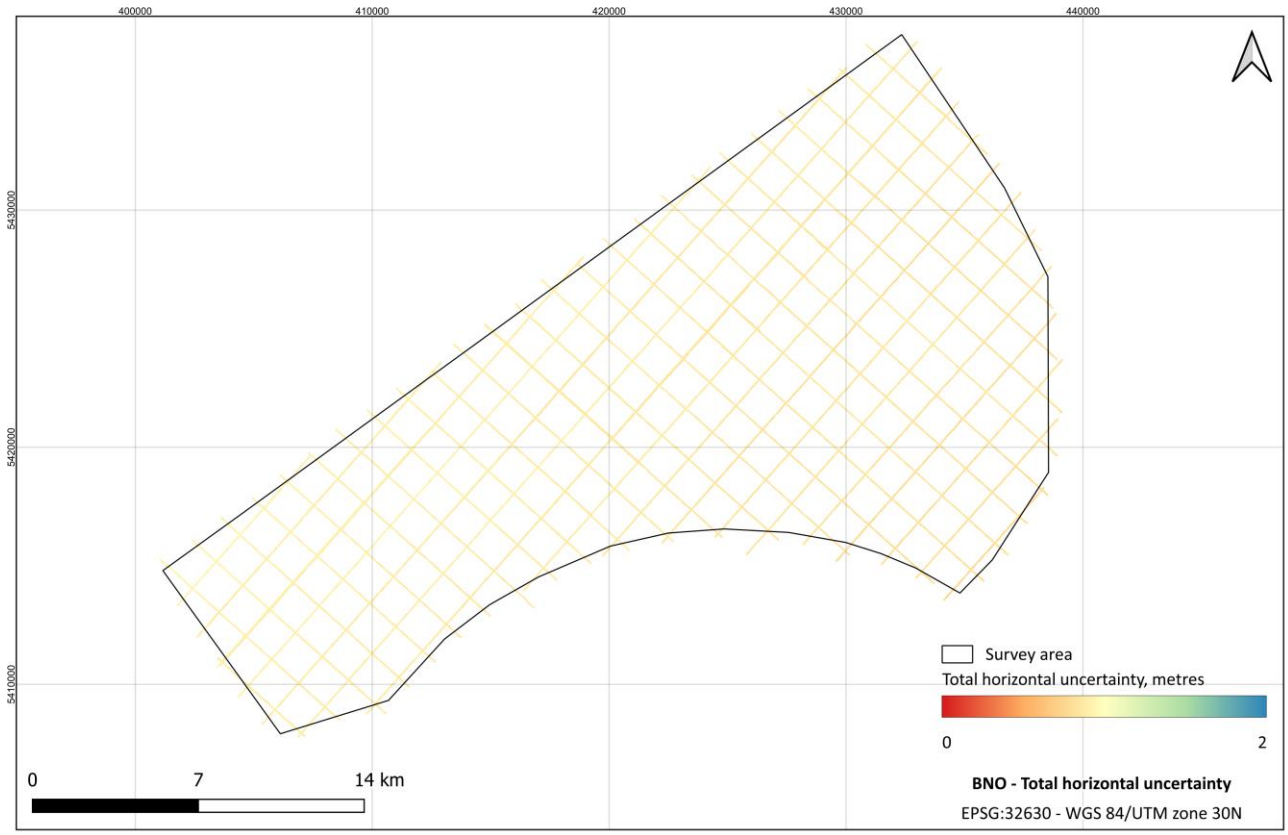


Figure 5-4: Total horizontal uncertainty overview

5.1.4 MBES deliverables

The MBES deliverables created as a result of the project are outlined in Table 14.

Table 14: Overview of the MBES deliverables

Deliverable	Format
RAW bathymetric data	QPD or bwxraw
Despiked, motion and tidal corrected point cloud	ASCII
Bathymetric average values gridded surface	ASCII, RGB TIF, Encoded TIF or FLT
Bathymetric density (Hit Count) values gridded surface	ASCII, RGB TIF, Encoded TIF or FLT
Bathymetric slope values gridded surface	RGB TIF, Encoded TIF or FLT
Bathymetric Contour Lines	SHP

5.2 SUB-BOTTOM PROFILER

5.2.1 Data acquisition and settings

Sub-Bottom Profiler data was acquired following specifications listed in Table 15 below.

Table 15: SBP specifications

Item	Specification
System type	Innomar SES-2000 Medium 100
Survey speed	~4 knots
Source frequency	8 kHz
Power setting	100 %
LF gain	4 dB
LF pulse	Single, 1p
Blanking time	Depth dependent
Trace length	20 ms
Ping rate	Average of 14.17 Hz with a minimum of 11.21 Hz (deep part) and a maximum of 22.65 Hz (shallow part)

5.2.2 Overview of the methodology

Figure 5-5 below outlines the SBP processing workflow.

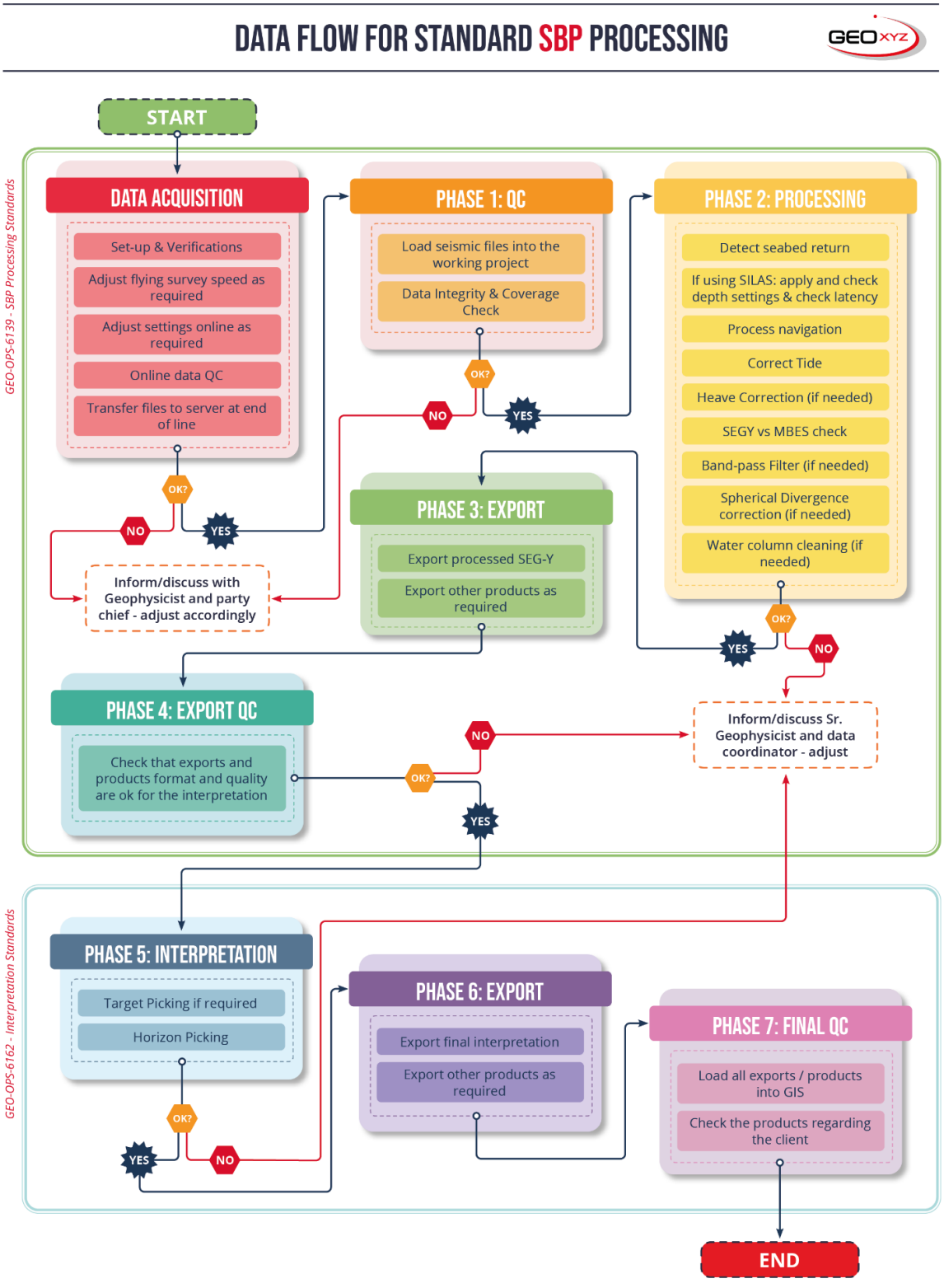


Figure 5-5: SBP processing workflow

5.2.3 SBP deliverables

Table 16: Overview of the SBP deliverables

Deliverable	Format
Kingdom project	Kingdom project files
Processed towed sensors (SSS, MAG, seismic positioning) trackplot line	SHP
Interim technical note	PDF
Raw SBP data	SEG-Y
P190 navigation	ASCII
Processed SBP data	SEG-Y
Longitudinal profile	ASCII
Horizon interpretation gridded surface	ASCII
Horizon contour lines (BSB)	SHP
Geologic feature points, polylines and polygons (if applicable)	SHP

5.3 ULTRA-HIGH RESOLUTION SEISMICS

5.3.1 Data acquisition and settings

Offshore, preliminary onboard processing was performed by Peak and included the following:

- NAV QC
- Creating Brute Stacks
- Creating Denoise Stacks
- QC'ing the P190 files processed by GEOxyz onshore

Final processing and interpretation on the datasets were done onshore by Peak.

Table 17: 2DUHRS specifications

Item	Setting
Source	
Sparker type:	Sparker
Source Unit type/capacity/number:	400 UHD Duraspark (stacked)
Frequency Bandwidth (Hz):	0.3-1.2kHz
Streamer type	
Streamer model / manufacturer	Geometrics GeoEel Gel
Streamer active length (m)	96
Number of channels	48
Group Interval (m)	2 m
Streamer Control	
Source, Tail buoy and Head buoy positioning (active)	
Controlling birds (no. Type & location)	2 x DigiCourse 5011 @ 32m & 72m
Acquisition Parameters	
Survey speed	

Item	Setting
Target penetration	100 m below sub-bottom
Shot Point Interval (m)	1.0 m
Record Length (s)[1]	300 ms
Sample Rate (ms)	0.062 ms/16 kHz
Source Depth (m)	0.5 m
Source Energy	1000 J
Streamer Depth (m) +/- allowance for front / rear	0.5 m front/ 2 m rear
Max. Feather Angle	Up to 15 degrees. Where over 12.5 degrees, data must be demonstrated to be well positioned and of good quality.
Noise Specifications (not specified by client)	@16 kHz 0-15Ubars deemed acceptable (with dynamic range 6-6200 Hz and 6 Hz low cut on raw data

5.3.2 Overview of the methodology

Onshore seismic processing produced final migrations using the processing sequence outlined below. More details on the methodology can be found in Appendix A. Parameters used for Time Variant Bandpass Filter are shown in Table 13.

[1] May be increased in line with the >100 m water depth

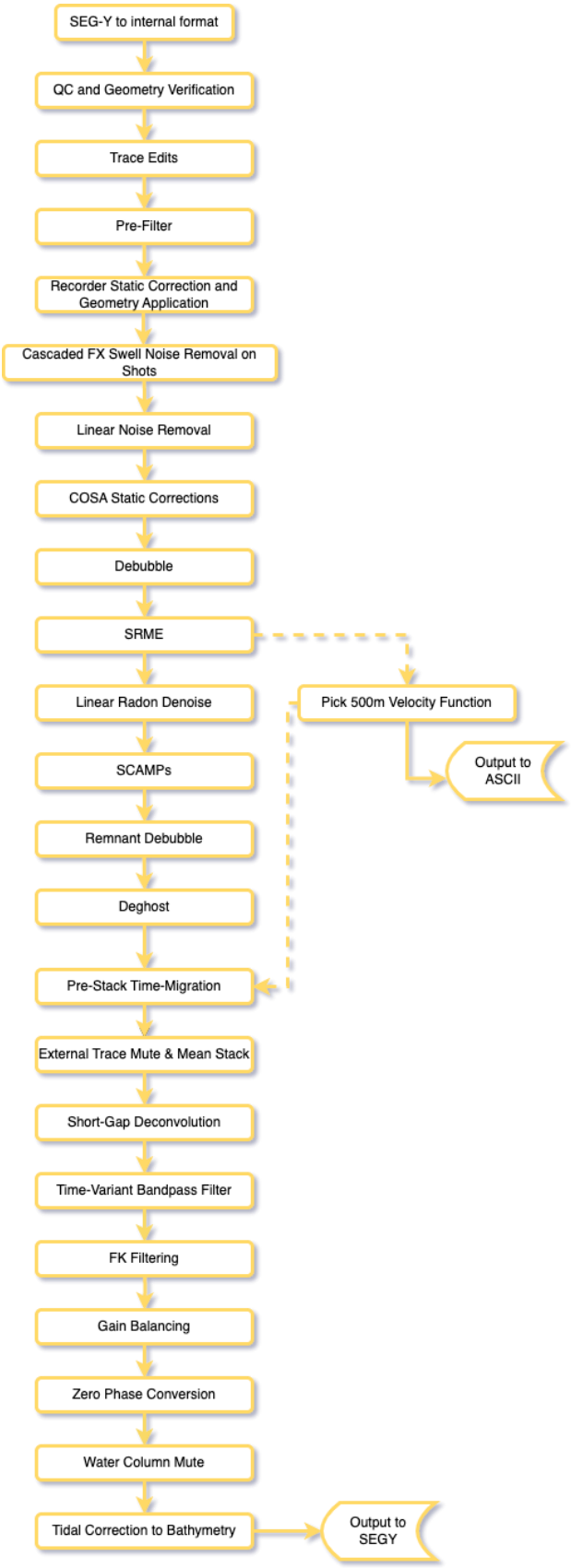


Figure 5-6: 2D UHR processing workflow

Table 18: Time Variant Bandpass Filter parameters

Time (ms)	Low cut	High cut
Above WB_time	160 Hz / 18 dB /oct	3000 Hz / 72 dB /oct
WB_time	160 Hz / 18 dB /oct	3000 Hz / 72 dB /oct
WB_time*2-20	160 Hz / 18 dB /oct	1200 Hz / 72 dB /oct
WB_time*2+20	160 Hz / 18 dB /oct	800 Hz / 72 dB /oct
290	60 Hz / 20 dB /oct	800 Hz / 72 dB /oct

5.3.3 UHRS deliverables

Table 19: Overview of the UHRS deliverables

Deliverable	Format
Kingdom project	Kingdom project files
Processed towed sensors (SSS, MAG, seismic positioning) trackplot line	SHP
Interim technical note	PDF
Raw UHRS data	SEG-Y
P190 navigation	ASCII
Processed UHRS data	SEG-Y
Longitudinal profile	ASCII
Horizon interpretation gridded surface	ASCII
Horizon contour lines (BSB)	SHP
Geologic feature points, polylines and polygons (if applicable)	SHP

5.4 DATA QUALITY ASSESSMENT SEISMICS

5.4.1 Shallow Profiler Data

Due to the outcrop of relatively old rocks the profiler data do not penetrate or image beyond the seabed. The data are consistent from line to line and statics correlate well (within 0.2 ms) with a time version of the multibeam echosounder data.

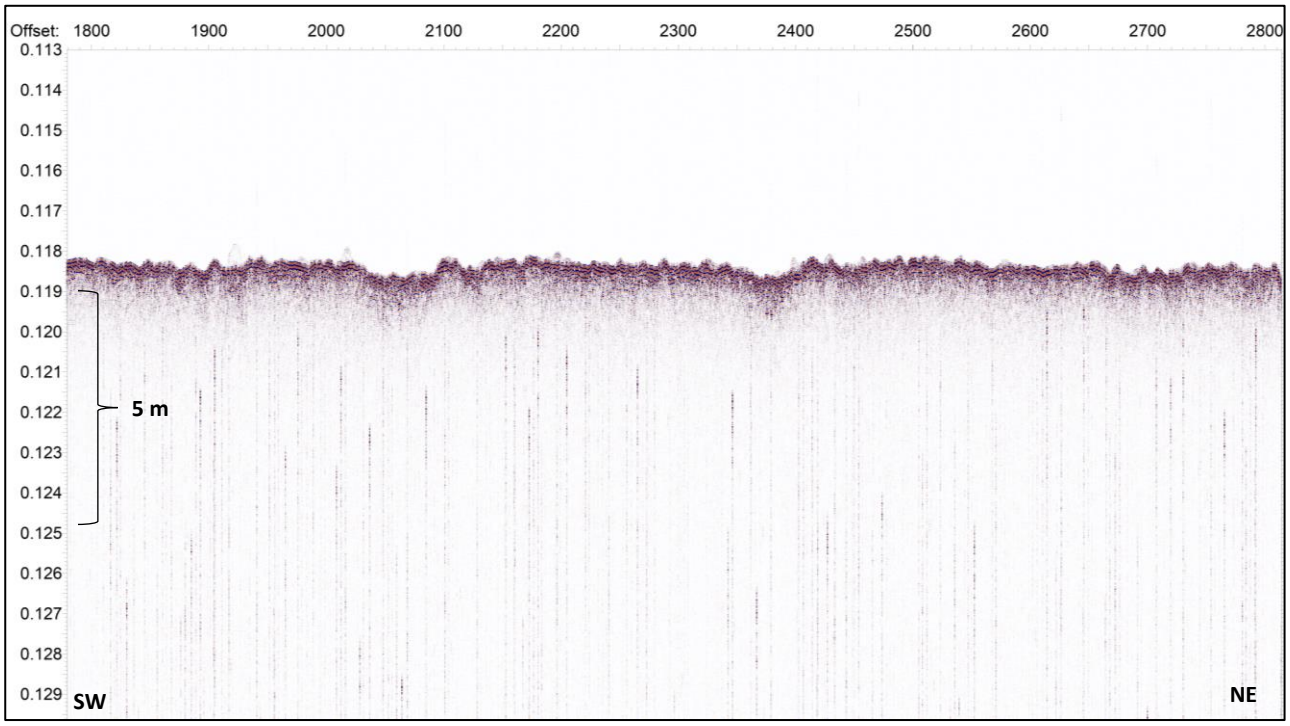


Figure 5-7: SBP line M04, data example

5.4.2 Ultra High Resolution Profiler Data

The UHRS data image the geology to approximately 80-100 m below seabed, though the penetration varies across the area depending on geology, the acoustic limit is imposed by the top of Unit 3, basement rocks (Figure 5-8). Where Unit 3 is deeper, penetration extends to 110-150 m below seabed. The data are consistent from line to line and statics correlate well (within 0.3 ms) with a time version of the multibeam echosounder data and the SBP data.

There are areas where, because of steep dips and/or seabed gravel, the signal is scattered and imaging is poor.

The data are processed to zero phase with a peak (positive value) corresponding to a positive impedance contrast. The combination of relatively deep water and high primary velocities means that water bottom period multiple noise is unobtrusive and far down the section, it does not impose any limitation on imaging.

The vertical resolution of the ~600 Hz data allows separation of reflections ~1-1.5 m apart. The most significant practical limitation of the dataset is the 1500 m line spacing.

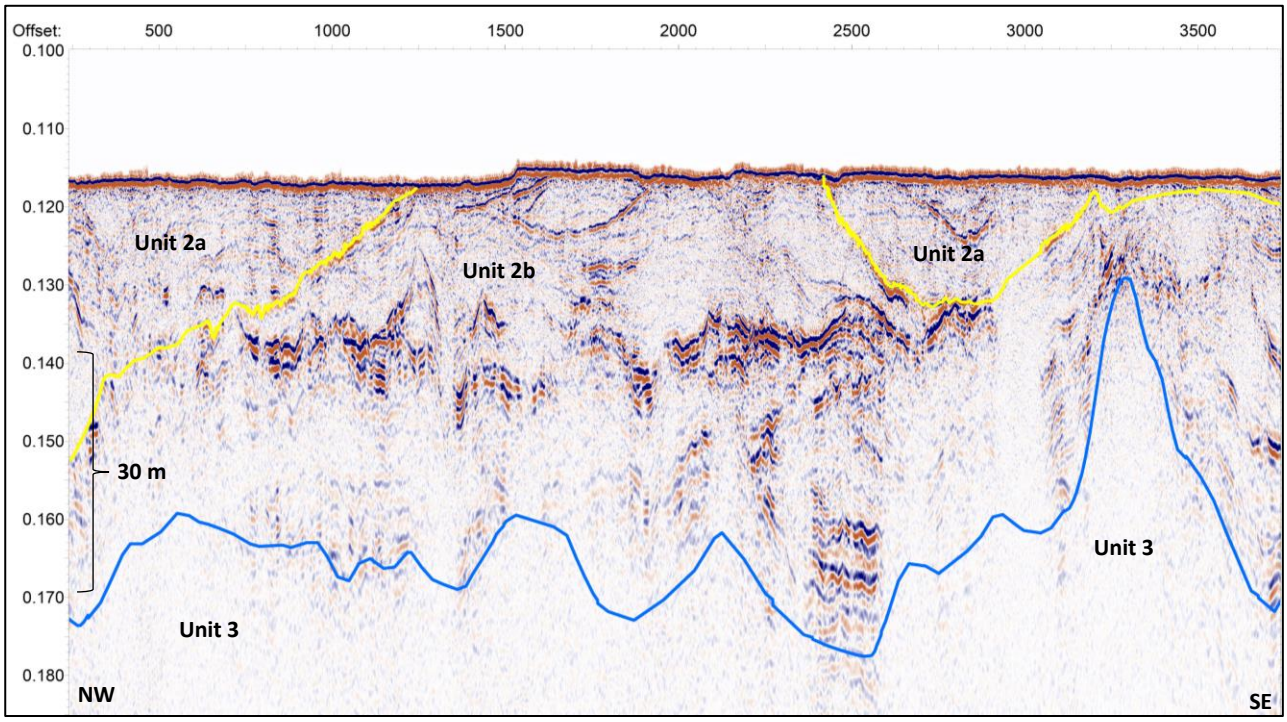


Figure 5-8: UHRS line M06, data example

6 RESULTS AND INTERPRETATION

6.1 BATHYMETRY

The water depths within the survey area varied between a shallowest value of -71.04 m LAT and a deepest value of -93.79 m LAT. Sea depth gradually increased from east toward west, with far western area being generally the deepest. The shallowest areas were concentrated in the far southeastern parts of the surveyed region where the shallowest point was calculated. The deepest point calculated is at far western corner of the survey area, close to the edge of the survey boundaries. General bathymetry overview is presented in Figure 6-1.

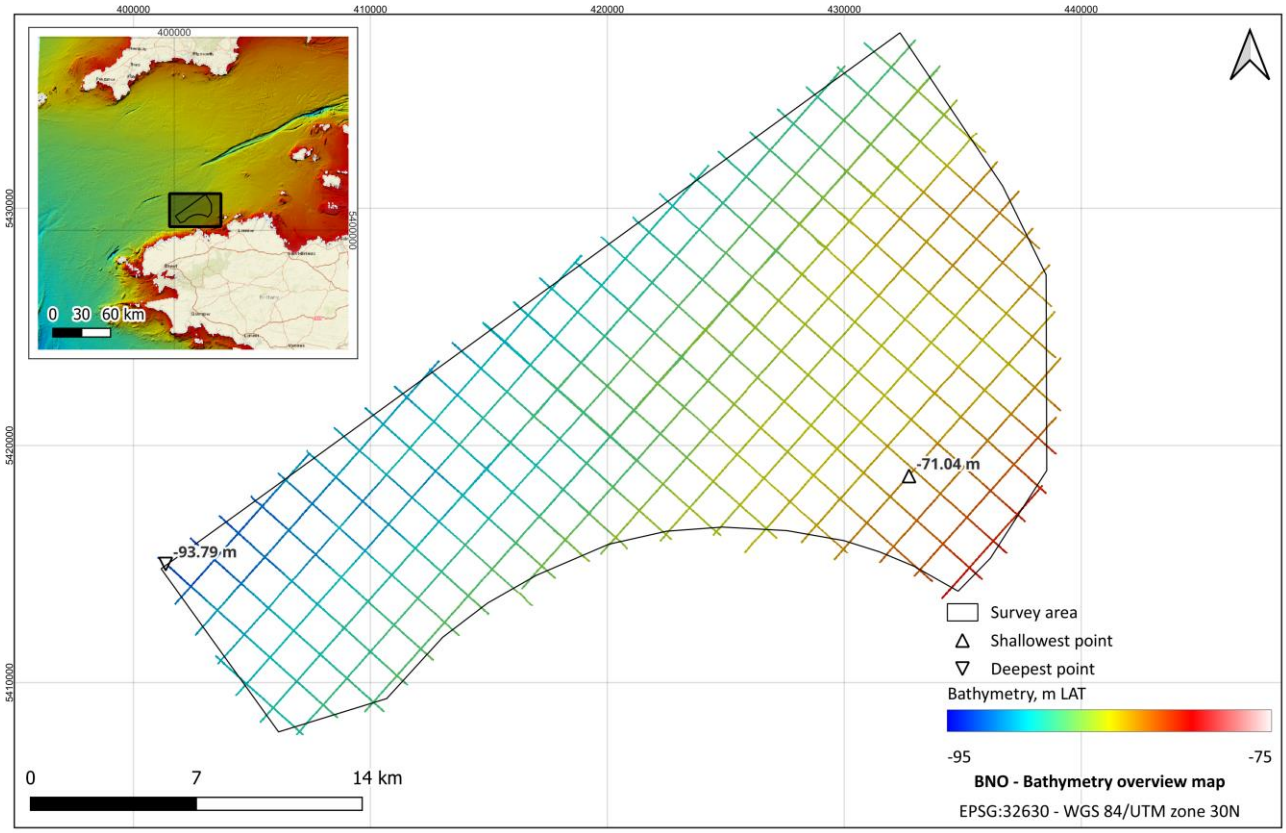


Figure 6-1: BNO bathymetry overview with EMODnet in overview map

The entirety of the survey area was characterised by very gentle slopes with high slope values only observed near morphological features such as rock outcrops (Figure 6-2) and one instance of an observed sandwave in the central part of the study area (Figure 6-3). Megaripples were only found sporadically throughout the northeastern part of the survey area (Figure 6-4).

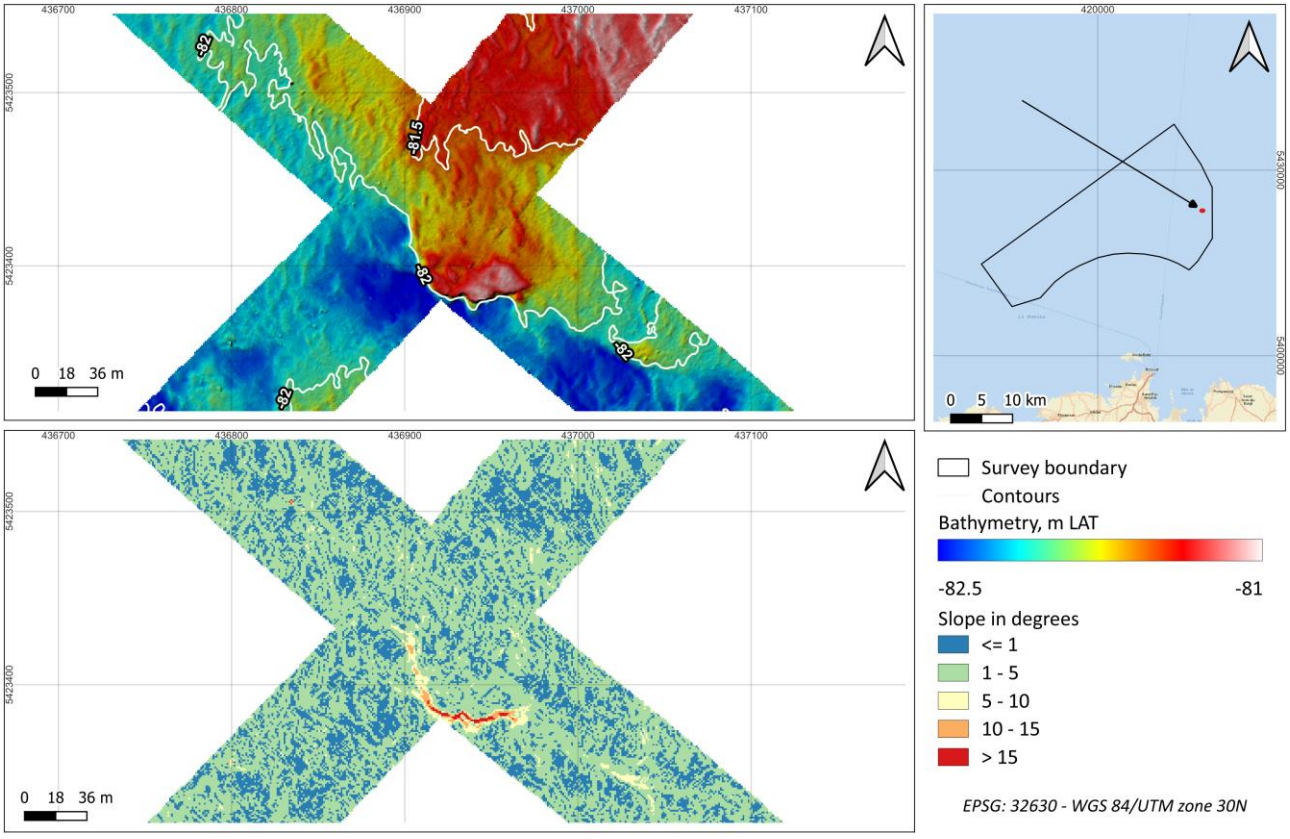


Figure 6-2: Bathymetry and slope - example 1

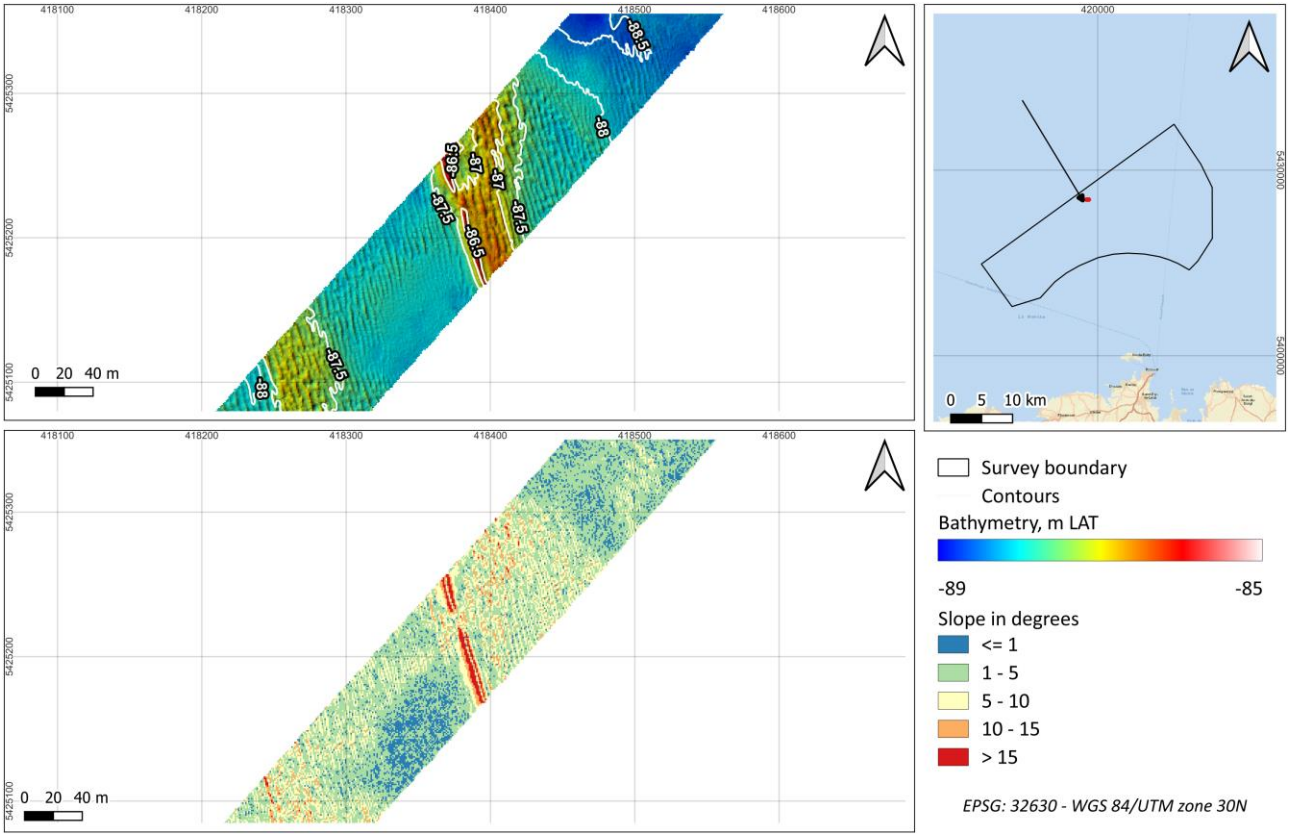


Figure 6-3: Bathymetry and slope - example 2

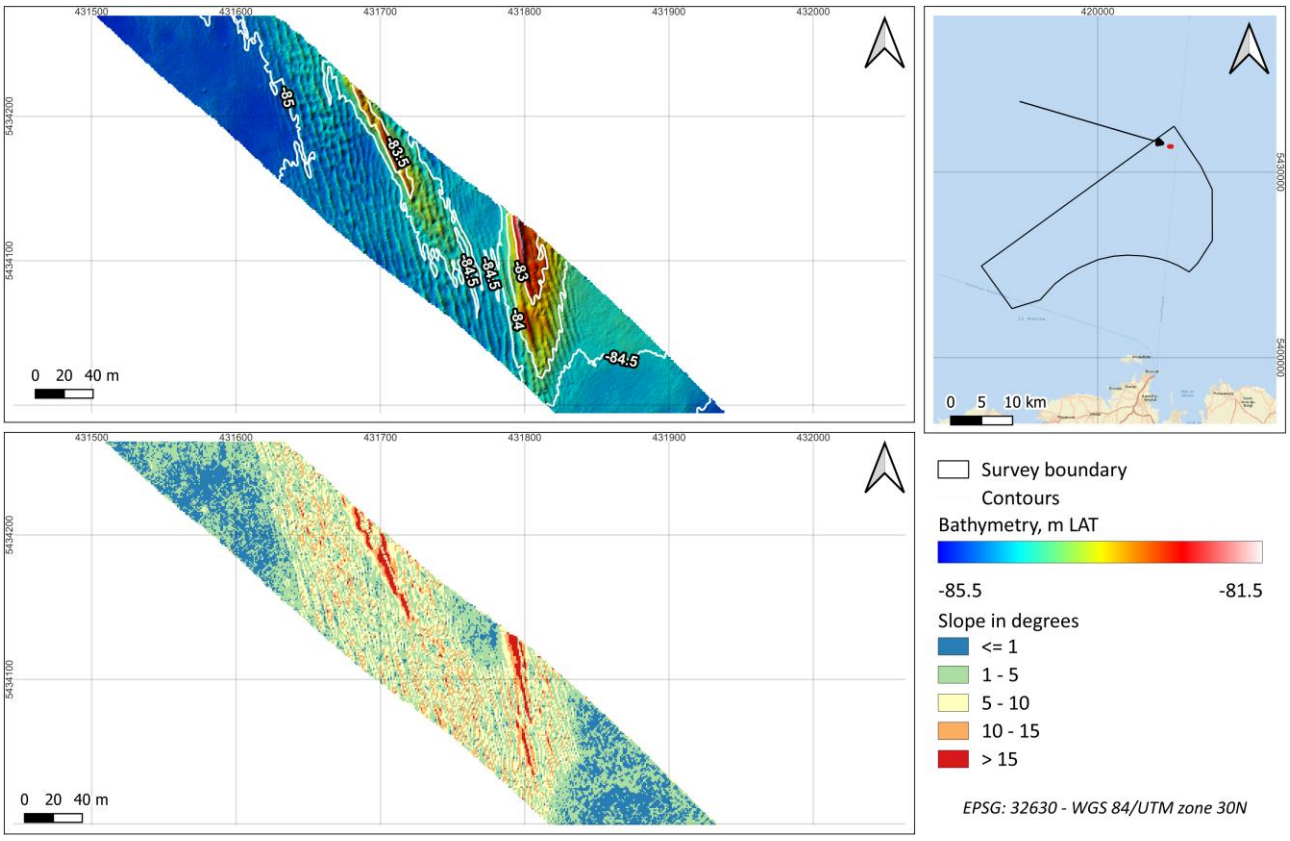


Figure 6-4: Bathymetry and slope - example 3

6.2 SUB SEABED GEOLOGY

6.2.1 Stratigraphy and general arrangement of the units

The UHRS data offer good imaging of the geology to around 100 m below the seabed, exceptionally to 150 m. This interval comprises several distinct units separated by unconformities (Figure 6-5). The units are mapped and have been described based on their acoustic characteristics, patterns of superposition, the broad geological history of the area and the BRGM desk study (Ref. 35).

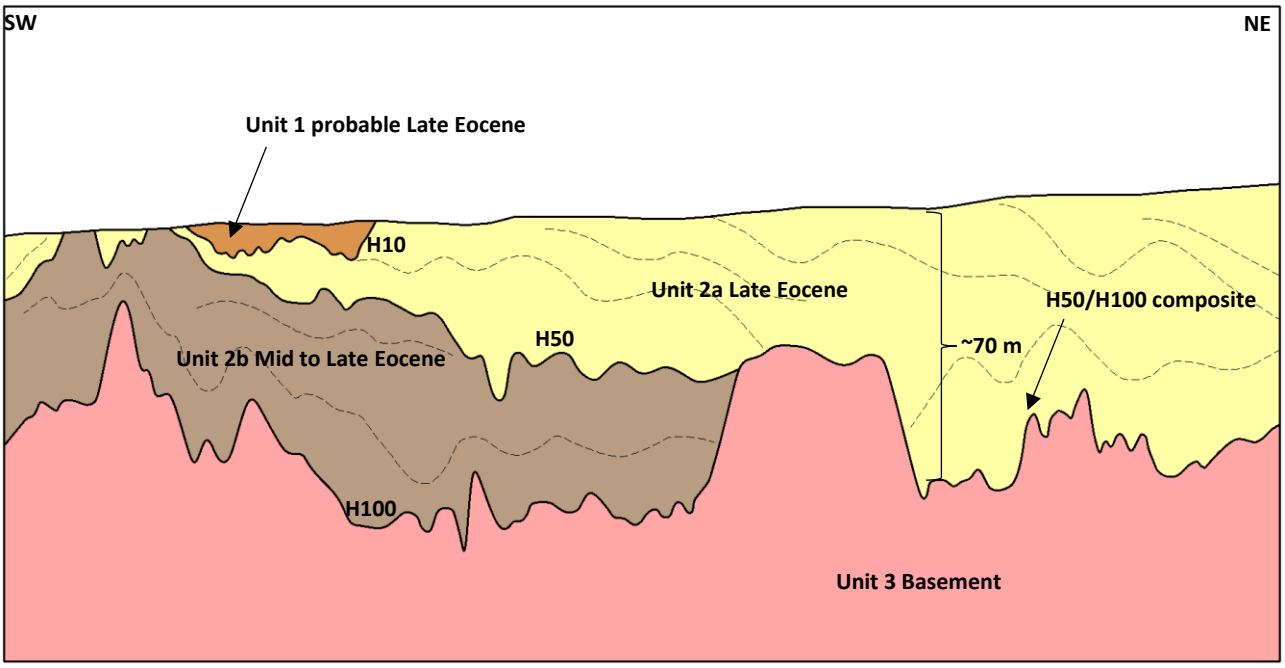


Figure 6-5: Geological schematic

Unit 1: This interval is tentatively interpreted to represent Late Eocene deposits (e2 in the stratigraphy of the BRGM desk study). The base is an erosion surface (H10). It is generally around 10 m thick but in one part of the south-west of the area it is 50 m thick. The unit has a patchy distribution and is confined to the south-west and north-east of the area.

Unit 2: Is a complex Eocene interval of sandstone, limestone and mudstone (e2 in the stratigraphy of the BRGM desk study). The unit is folded and draped over the ancient bedrock. The unit is typically 40 to 100 m thick. It contains numerous internal unconformities though the wide line spacing is not sufficient to enable their effective mapping. A single marker unconformity (H50) is mapped within Unit 2, younger Unit 2a deposits are predominant in the north-east of the area.

Unit 3: This is the ancient bedrock (seven in the stratigraphy of the BRGM desk study). The top of this interval is irregular and is the acoustic basement, there is no imaging of the internal structure of this unit. The top of the basement (H100) is between 12 and 150 m below seabed but is typically 40 to 100 m below seabed. This rock is probably Cambrian Granite.

6.2.2 Geological Overview

Interpretation synopsis is presented in Table 20.

Table 20: Interpretation synopsis

Unit	Upper boundary	Lower boundary	Comments
1	Seabed	H10	Late Eocene. Sandstone, limestone and mudstone (e2 in the stratigraphy of the BRGM desk study). Acoustically structureless
2a	Seabed or H10 where that exists	H50	Late Eocene. Sandstone, limestone and mudstone (e2 in the stratigraphy of the BRGM desk study). Contains internal unconformities and bedded intervals

Unit	Upper boundary	Lower boundary	Comments
2b	Seabed/H10/H50	H100 – top basement	Middle-Late Eocene. Sandstone, limestone and mudstone (e2 in the stratigraphy of the BRGM desk study). Contains internal unconformities and bedded intervals
3	H100	-	Basement. Likely granite

Seismic facies are described in Table 21.

Table 21: Seismic facies descriptions

Facies	Seismic facies description	Comments, distribution
Transparent/chaotic	Transparent with noise, occasional weak structure	**Unit 1**, confined to parts of the south-west and north-east
Bedded/chaotic	Irregular sub-parallel reflections with variable dip patterns, occasional transparent intervals	**Unit 2**, occurs throughout the area
Transparent/dipping noise	No clear indication of primary reflections, facies characterised by dipping noise and irregular upper surface	This is the facies of **Unit 3.** Subcrops the entire area, interpreted to be Cambrian granite

6.2.3 SUB SEABED Unit geology description

This section describes sub seabed geology. In this area all the units imaged in the profiler data are relatively old (pre-Quaternary, probably pre-Neogene) though there is expected to be a thin discontinuous seabed veneer of sand and gravel.

Unit 1 Upper Eocene

This interval is tentatively interpreted to be Upper Eocene, as this unit is at outcrop in the BRGM desk study where it is classified as ‘e2’. The package has a patchy distribution in the south-west and north-east of the area (Figure 6-6 and Figure 6-7). Given the resolution of the desk study this interval could be of Miocene age, or even Quaternary. The interval has a chaotic/transparent internal structure and an erosive base. These characteristics might suggest the clastic infill of a Quaternary erosion surface. However, the rough texture of the seabed is consistent either side of the margins of this unit, as is seabed elevation. These observations do indicate that the material properties of Unit 1 are very similar to those of Unit 2 meaning that the Unit 1 sediments are probably pre-Quaternary.

Unit 1 is generally up to 10 m thick though it reaches a maximum thickness of 50 m over a very small part of the central south-west of the area (Figure 6-6). The unit base is erosive; it is very clear in some areas where it truncates reflectors in Unit 2 and is indistinct in others.

If Unit 1 is Upper Eocene then it probably comprises a mixture of sandstone, limestone and mudstone. The combination of basal erosion and transparent internal structure may indicate that limestone is less likely to be present.

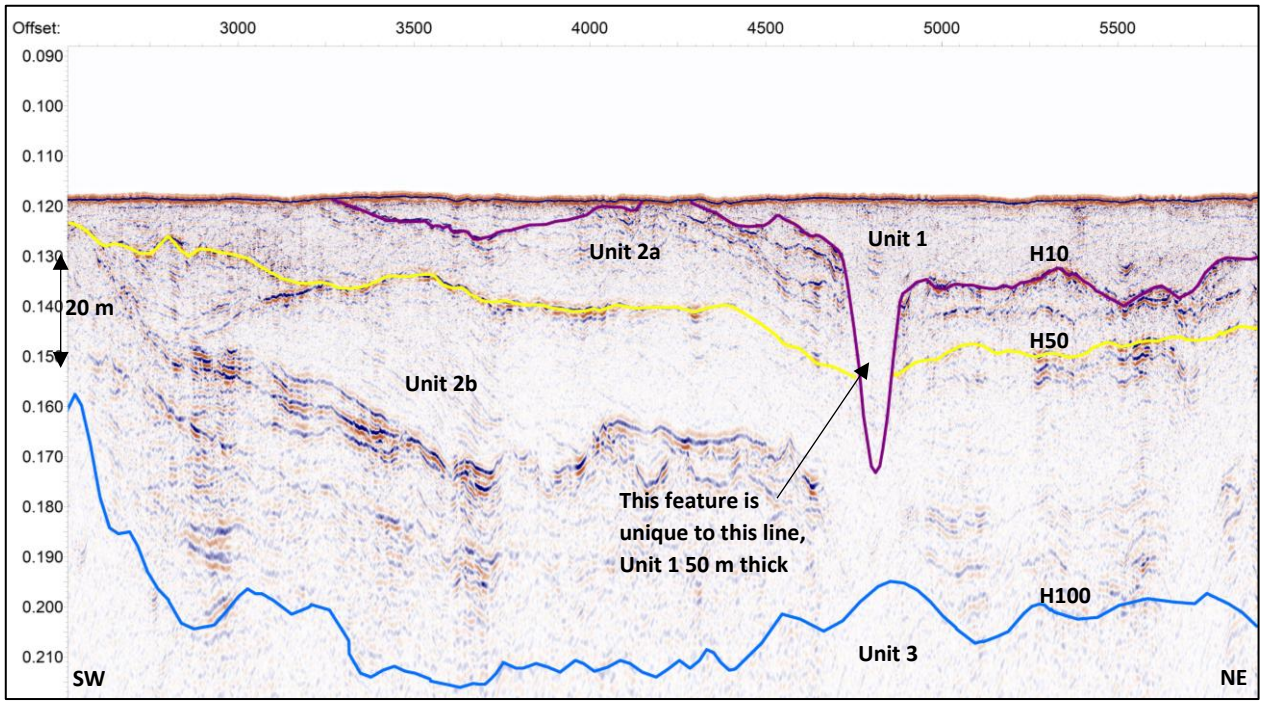


Figure 6-6: UHRS M04, Unit 1, south-west

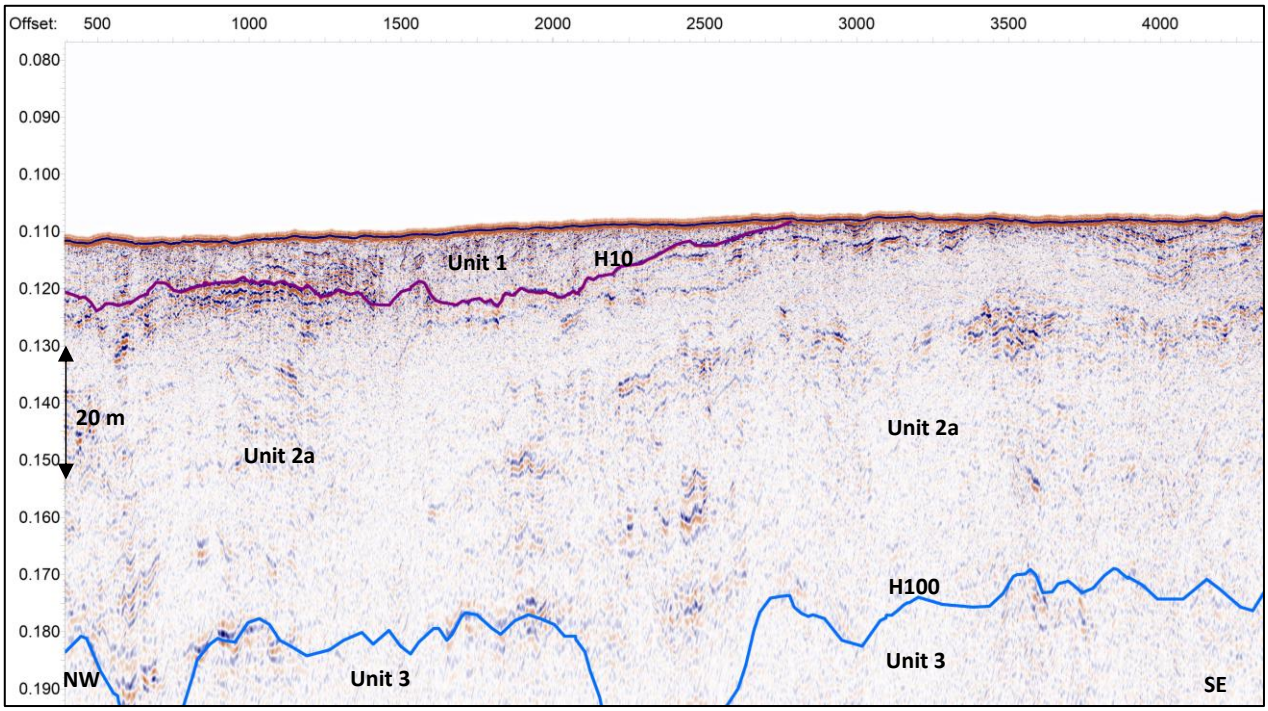


Figure 6-7: UHRS X39, Unit 1, north-east

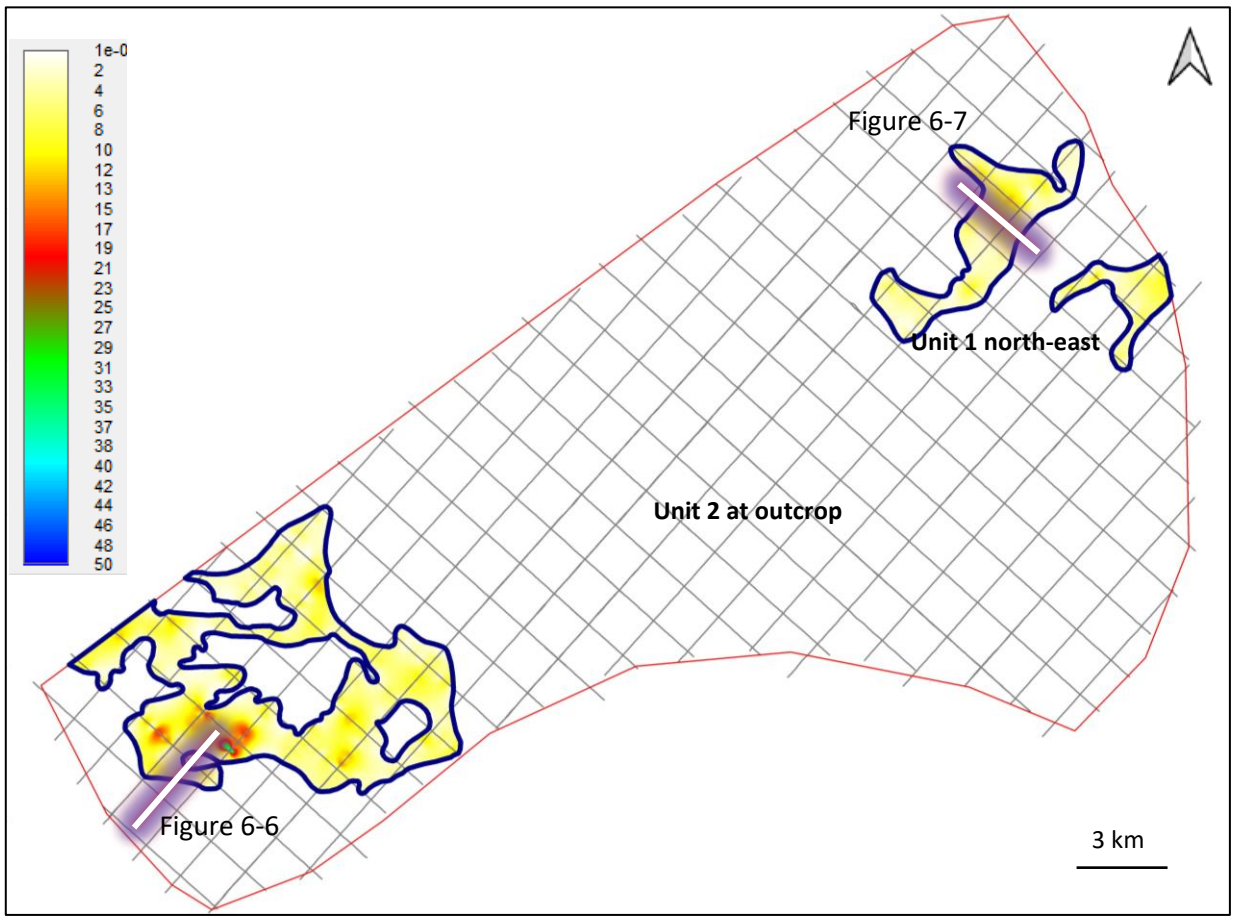


Figure 6-8: Depth to base Unit 1, in metres

Unit 2 Upper Eocene

Unit 2 is a complex Upper Eocene interval of sandstone, limestone and mudstone classified as 'e2' in the BRGM desk study (Figure 6-9). The unit occurs throughout the area and is folded and draped over the ancient bedrock. The interval is typically 40 to 100m thick. It contains numerous internal unconformities though the wide line spacing is not sufficient to enable their effective mapping.

A single marker unconformity is mapped within Unit 2. This is H50, the base of Unit 2a and top of Unit 2b. This surface meets the seabed over the southern margin of the area and over parts of the south-west – Unit 2a is not present where H50 is composite with the seabed.

Over the northern third of the area H50 is composite with the top of the basement rocks. Unit 2b is not present here.

The interval contains numerous internal unconformities and bedded packages. The 1.5 km line spacing is too wide to allow this complexity to be mapped.

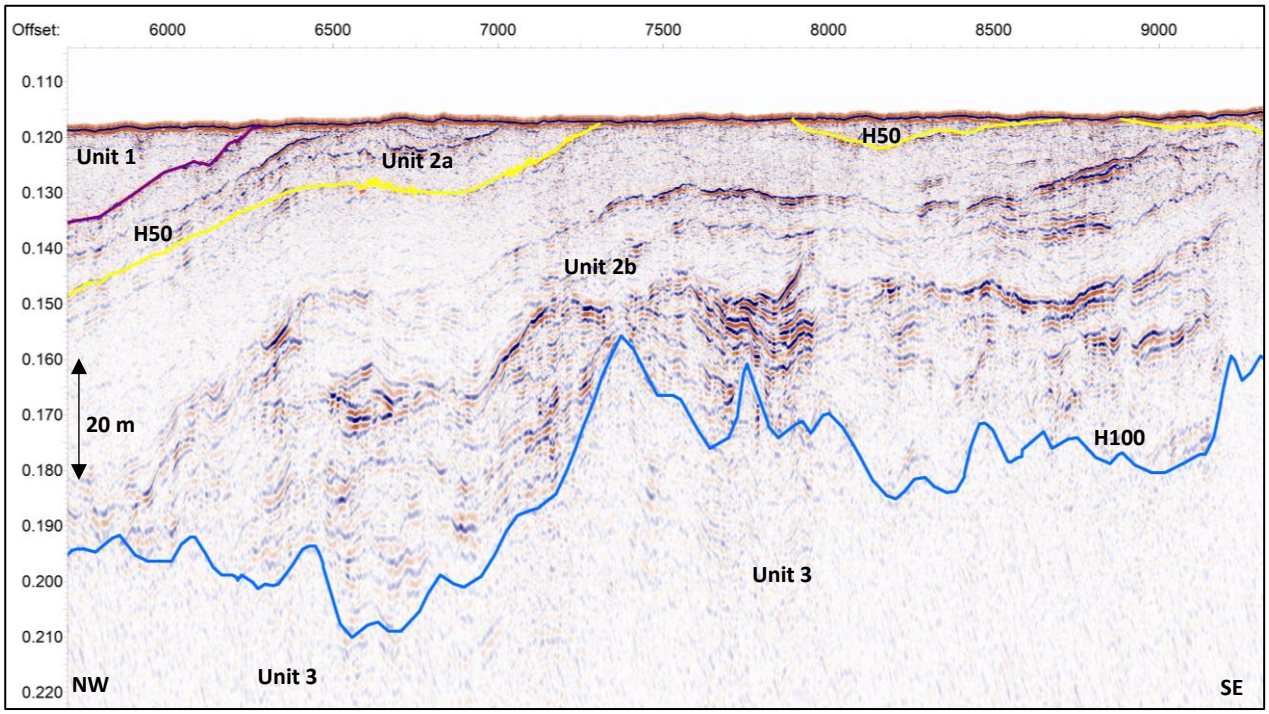


Figure 6-9: UHRS X04, Unit 2 internal unconformities

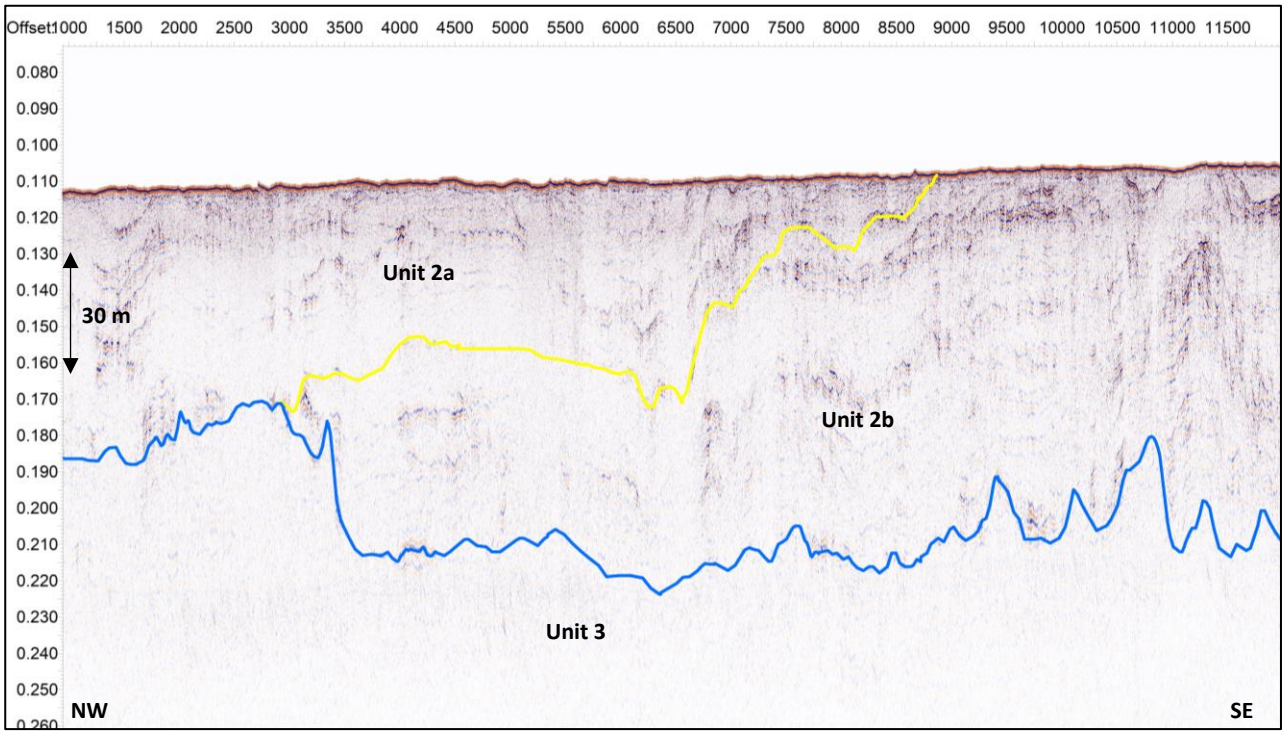


Figure 6-10: UHRS X29, Unit 2, north-east of area

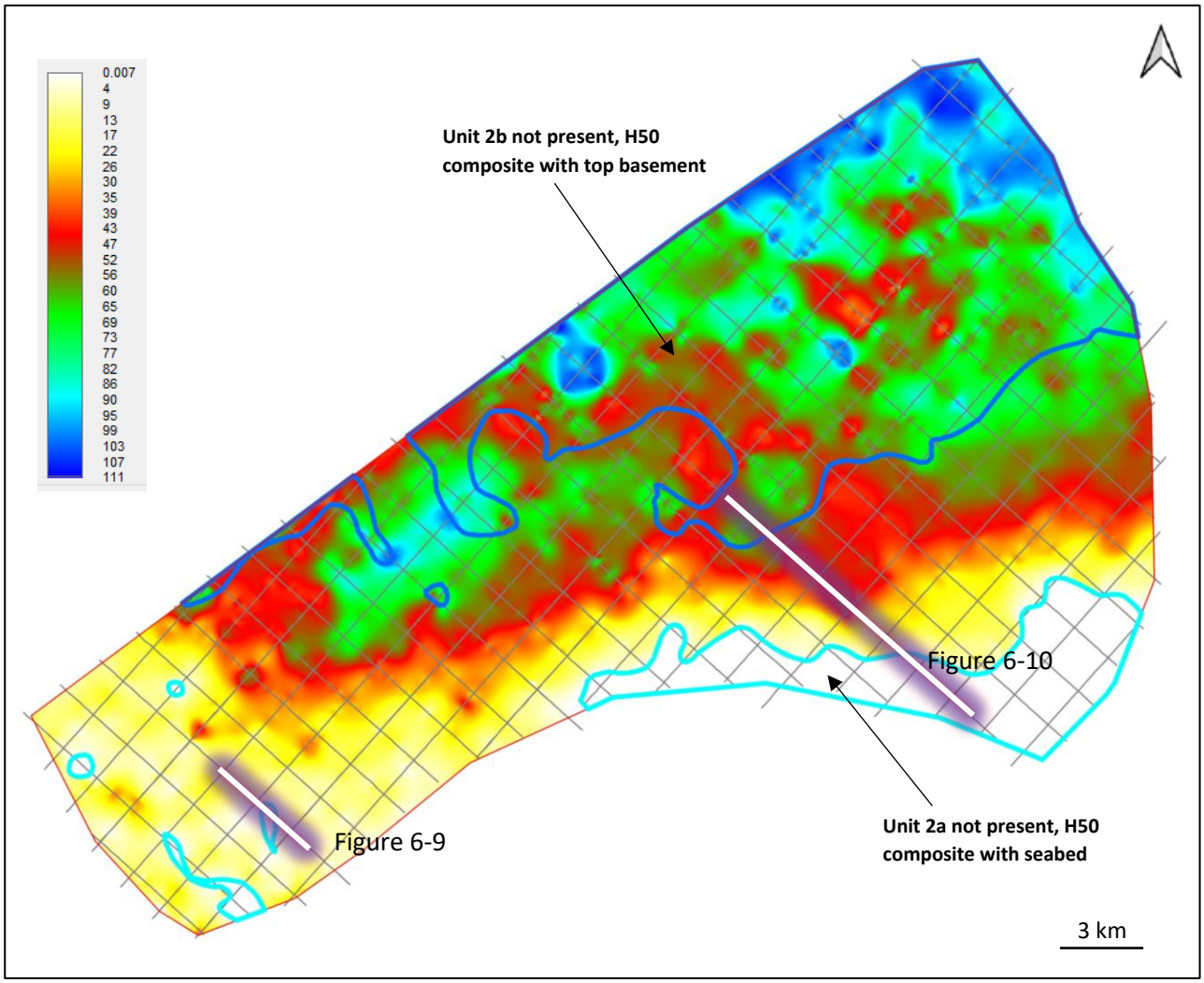


Figure 6-11: Thickness of Unit 2a, in metres

Unit 3 Cambrian

This is the ancient bedrock. The top of this interval is irregular and is the acoustic basement, there is no imaging of the internal structure of this unit. The top of the basement is between 12 and 150 m below seabed.

The BRGM desktop study indicates that this interval is Cambrian granite.

Over parts of the south-west of the area this ancient rock is within 40 m of the seabed. Unit 3 is over 70 m below seabed over the north and east of the area and over an area west of the centre of the site.

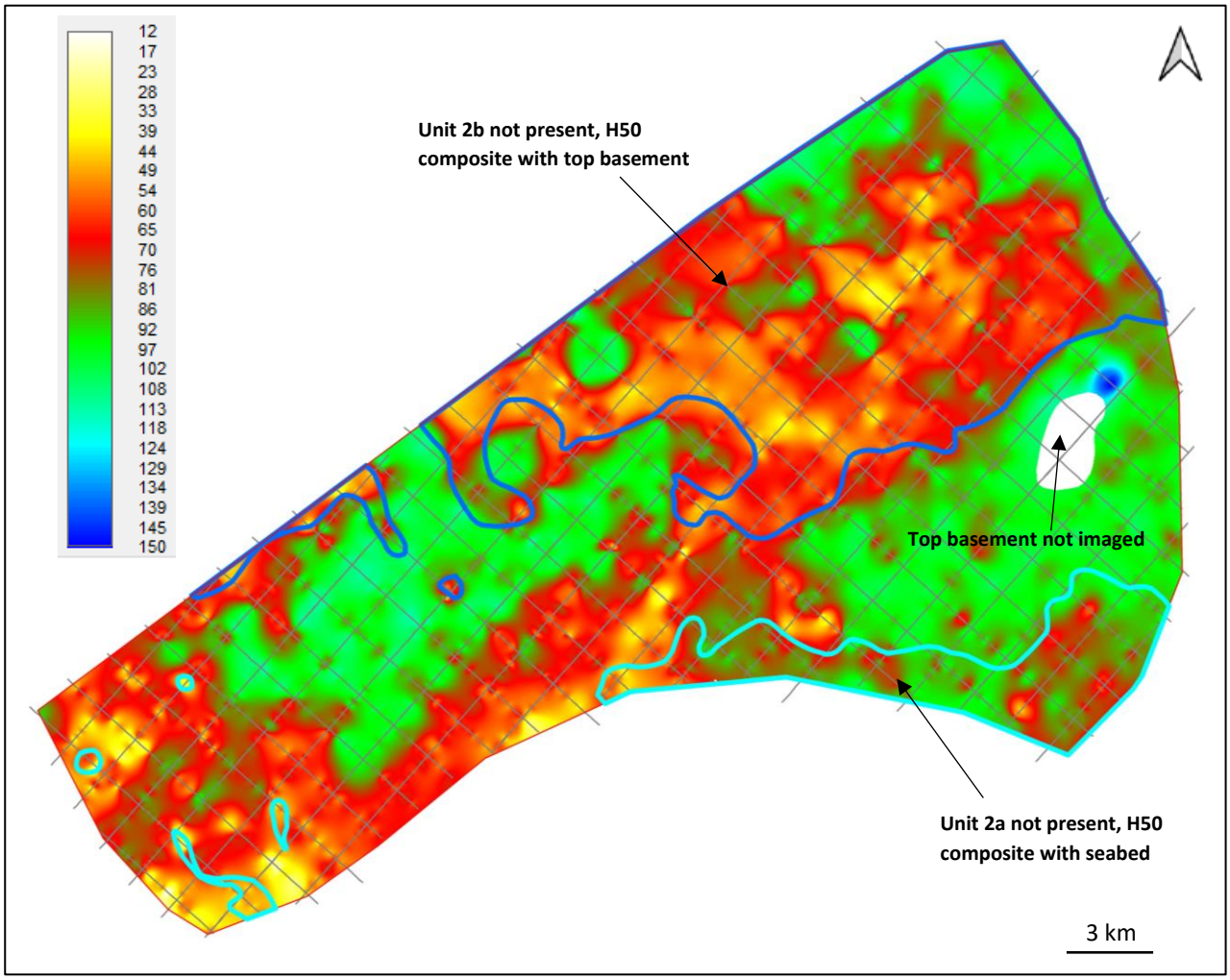


Figure 6-12: Depth to basement (top Unit 3, base Unit 2) in metres below seabed

6.3 GEOHAZARDS AND GEOLOGICAL INSTALLATION CONSTRAINTS

6.3.1 Shallow Gas

The survey line spacing is too great to enable a meaningful overall interpretation of the area's shallow gas potential.

There are no seismic indications of shallow gas in the UHRS data but it is recommended that a location-specific gas hazard assessment is done at any location where sub seabed operations (geotechnical testing, boring, engineering foundation installation etc.) are planned.

6.3.2 Faulting

There are no obvious faults within the post-basement sequence. The relief at the top of the bedrock may be due to a combination of erosion and fault displacements.

6.3.3 Geological Variation

The geological sequence shows significant variation within the depth range imaged in this project, a depth range like that of potential engineering works.

The likelihood is that Late Eocene sediments of units 1 and 2 crop out over the entire area, under a thin discontinuous veneer of sand and gravel.

There is significant variation within the Eocene sediments of Units 1 and 2. Reference data suggests that these units comprise a mixture of sandstone, limestone and mudstone. The project data are not ground truth calibrated to allow differentiation of these lithotypes. The acoustic heterogeneity of Unit 2 is expected to be a result of significant variations in the composition of the unit.

The most significant engineering variable may be the depth of the ancient basement granite. This ranges between 12 and 150 m below seabed (at a velocity of 1850 m/s). Where the granite is relatively close to the seabed then foundation design will probably extend to or within this very strong rock. In places where the granite is over 40 m below seabed it may be possible to design a foundation that resides entirely within the Eocene sediments. Figure 6-12 shows the depth of the basement granite.

The bedrock is within 40 m of the seabed over parts of the south-west of the area.

APPENDIX A. UHRS PROCESSING WORKFLOW

UHRS processing workflow is provided as a separate document.