DGEC - Fécamp 2DUHRS and UXO Survey

UHRS Factual Report - Accepted

Project Document Code	6168_2-RR-01-A

3.0	20/02/2025	Accepted	PEAK	EVA	AMO
Revision	Date	Description of Revision	Author	Checked	Approved

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REVISION HISTORY

The table on this page should be used to explain the reason for the report revision and what has changed since the previous revision. It is the holder's responsibility to check that they hold the latest validated version.

Rev.	Date	Reason for amendments	Section changes from previous version
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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.
CP	Controllable Pitch / Cathodic Protection	RGB	Red Green Blue
EPSG	European Petroleum Survey Group	RX	Receiver
ETRS89	European Terrestrial Reference System 1989	Rev	Revision
FMGT	Fledermaus Geocoder Toolbox	SBAS	Satellite-Based Augmentation System
GNSS	Global Navigation Satellite System	SBP	Sub-bottom Profiler
GOVI	Geo Ocean VI	SEGY	Society of Exploration Geophysicists Y format
GRS80	Geodetic Reference System 1980	SHOM	Service Hydrographique et Oceanographique de la Marine (PBMA in French)
HSE	Health, Safety and Environment	SSS	Side Scan Sonar
IHO	International Hydrographic Organisation	SVS	Sound Velocity Sensor
IMU	Inertial Measurement Unit	SWL	Safe Working Limit
INS	Inertial Navigation System	THU	Total Horizontal Uncertainty
J	Joules	TVU	Total Vertical Uncertainty
LAT	Lowest Astronomical Tide	UHR	Ultra-High Resolution
MAG	Magnetometer	UHRS	Ultra-High Resolution Seismic
MBES	Multibeam Echosounder	USBL	Ultra-Short Baseline
MMO	Marine Mammal Observer	UTC	Universal Time Coordinated
MRU	Motion Reference Unit	UTM	Universal Transverse Mercator
N	Northing	UXO	Unexploded Ordnance

Acronym	Description	Acronym	Description
NA	Not Applicable	WGS84	World Geodetic System 1984
OSC	On-Scene Coordinator	ZH	Zero Hydrographic
PAM	Passive Acoustic Monitoring		

REFERENCE DOCUMENTATION

Client Reference Documents

Documentation provided by the Client for the project is listed below.

Document Code/Category	Title
2023-DGEC-07 CCAP	Administrative clauses
2023-DGEC-07-RC	Tendering rules
2023-DGEC-07 AE annexe 2	Commitment on deadlines
2023-DGEC-07 CCTP	Technical proposal
DTS_BRGM	Desktop studies (geological)
DTS_SHOM	Desktop studies (bathymetry)
DTS_UXO	Desktop studies (UXO)

Company and Project Documents

Document Code/Category	Title
6168_2-PEP-01	Project Execution Plan
6168-PF-01	Processing Flow
6168_2-PDR-01	Project Document Register
6168_2-HSE-01	HSE Plan
6168_2-DDL-01	Data Deliverables List
6168_2-ERB-01	Emergency Response & Bridging Document
6168_2-PQP-01	Project Quality Plan
6168_2-PRA-01	Project Risk Assessment
6168_2-CM-01	Communication Matrix

Other References

Paquet et al. 2024, Apercu geologique de la macro-zone Fecamp-Grand-Large.

EMODnet, https://emodnet.ec.europa.eu/en

EXECUTIVE SUMMARY

Survey	Geo Ocean VI	Start date: 09/09/2024	
		End date: 23/09/2024	
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 31 N (EPSG: 32631)	
Bathymetry			
Depth	-29.68 to -58.46 metres		
Site topography	Overall, depth increases from east to west. The eastern two-thirds of the survey area show relatively uniform seabed levels, with the shallowest point in the southeast. In contrast, the western third features greater depths, with the deepest point located in the southwestern part near the edge of the survey area.		
Geology overview			
Unit summary	**Unit name**	**Age**	**Description**
	Veneer	Holocene	Sand, gravel with clayey silt
	Quaternary/Neogene	Quaternary/Neogene	Mixed clastics
	E5-E4b	Upper Eocene	Sand and silt with local clays
	E4a-E3	Lower Eocene	Clay and sand with limestone in E3
	C5-C1	Upper Cretaceous	Chalk with flints
	N5-N6	Lower Cretaceous	Marl, clay and puddingstone
	N1-N4	Lower Cretaceous	Sand, sandstone and clay
	Jurassic	Jurassic	Marl, limestone and clay
Geology description	The truncated pre-Neogene geology generally dips at around 1 degree to the north-east with units becoming younger to the north-east, as well as upward. The arrangement of units is more complex in the west of the area. In the extreme south-west, a large strike-slip fault (the Fecamp-Lillebonne fault) places Jurassic sediments immediately against much younger Eocene deposits. There is a change in dip between the older Lower Cretaceous deposits (N1-4), which are relatively flat, and the more recent units that have greater dip, broadly parallel with the erosion surface that truncates the older Lower Cretaceous deposits. The Upper Eocene comprises sand and silt, Lower Eocene deposits are a mixture of clay and sand, becoming limestone. The Upper Cretaceous is chalk with flints. The Lower Cretaceous (which has lower dip) is carbonate rich towards the top, with marl, clay and puddingstone, become clastic in lower parts. The Jurassic rocks are marl, limestone and clay. Two Eocene and Upper Cretaceous units (E4a and C2) contain numerous low displacement faults. All these relatively ancient pre-Neogene rocks are truncated by a base Neogene unconformity that is partially infilled by clastic deposits. Over almost the entire area there is a seabed veneer of sandy gravel, though over large parts of the centre of the area this is too thin to clearly resolve.		
Geohazards and installation constraints	There are scattered indications of shallow gas. There are numerous faults that locally weaken the formation. Ground conditions are variable: a wide range of different units subcrop. In the		

	extreme south-west area, a major fault places Eocene deposits immediately against Jurassic rocks. In more detail, consideration should be given to the general geological variation across the area; chalk is close to seabed across a wide swathe of the centre of the site, elsewhere clastic sediments predominate. The chalk contains hard flints and the possibility of weathering effects may generate variable characteristics. The subcrop is most heavily structured in the south-west of the area and a major fault (with an associated anticline) crosses the site just east of the centre of the survey. These structures may generate abrupt changes in material characteristics and be weakened by fractures. All these relatively ancient pre-Neogene rocks are truncated by a base Neogene unconformity that is partially infilled by clastic deposits. These more recent clastics are best developed in the margins of the extreme west of the area and in the far east.

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. For each area identified as suitable for the development of wind farms, "de-risk studies" must be carried out in order to analyse the seabed on the surface and sub-surface.

The following four maritime façades have been identified to 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 was to carry out geophysical de-risking studies for approximately seven to eight sites spread throughout the metropolitan territory, which was 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).

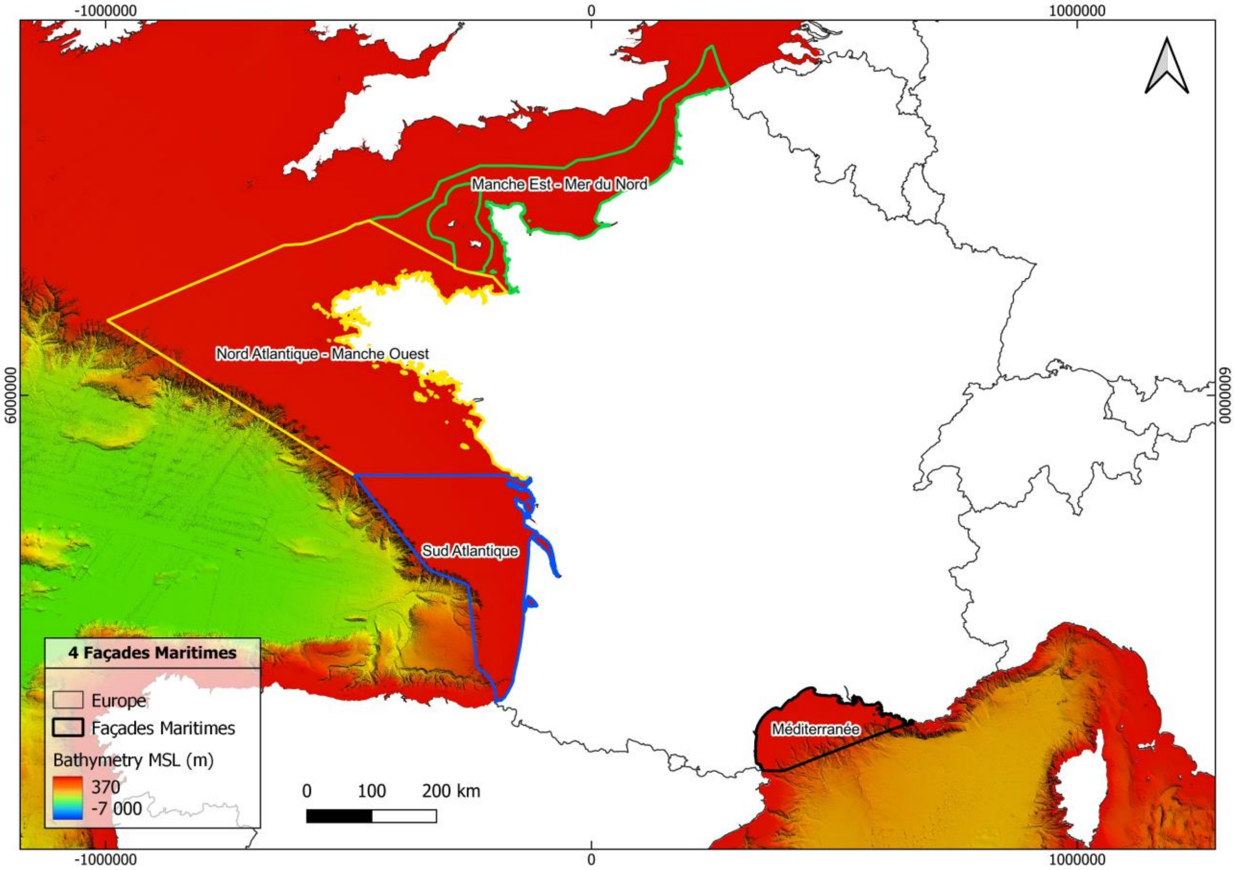


Figure 1-1: Project location overview

The main objectives of de-risk studies were to:

- Provide UHR seismic, sub-bottom profiler, MBES bathymetry, and side-scan sonar imaging data to better understand the seabed and sub-surface conditions.
- Provide magnetometer data that will be used to issue ALARP certificates prior to the completion of geotechnical testing.

1.2 SCOPE OF WORK

The overall scope of work consisted of geophysical and UXO surveys in the Fécamp zone (Figure 1-2).

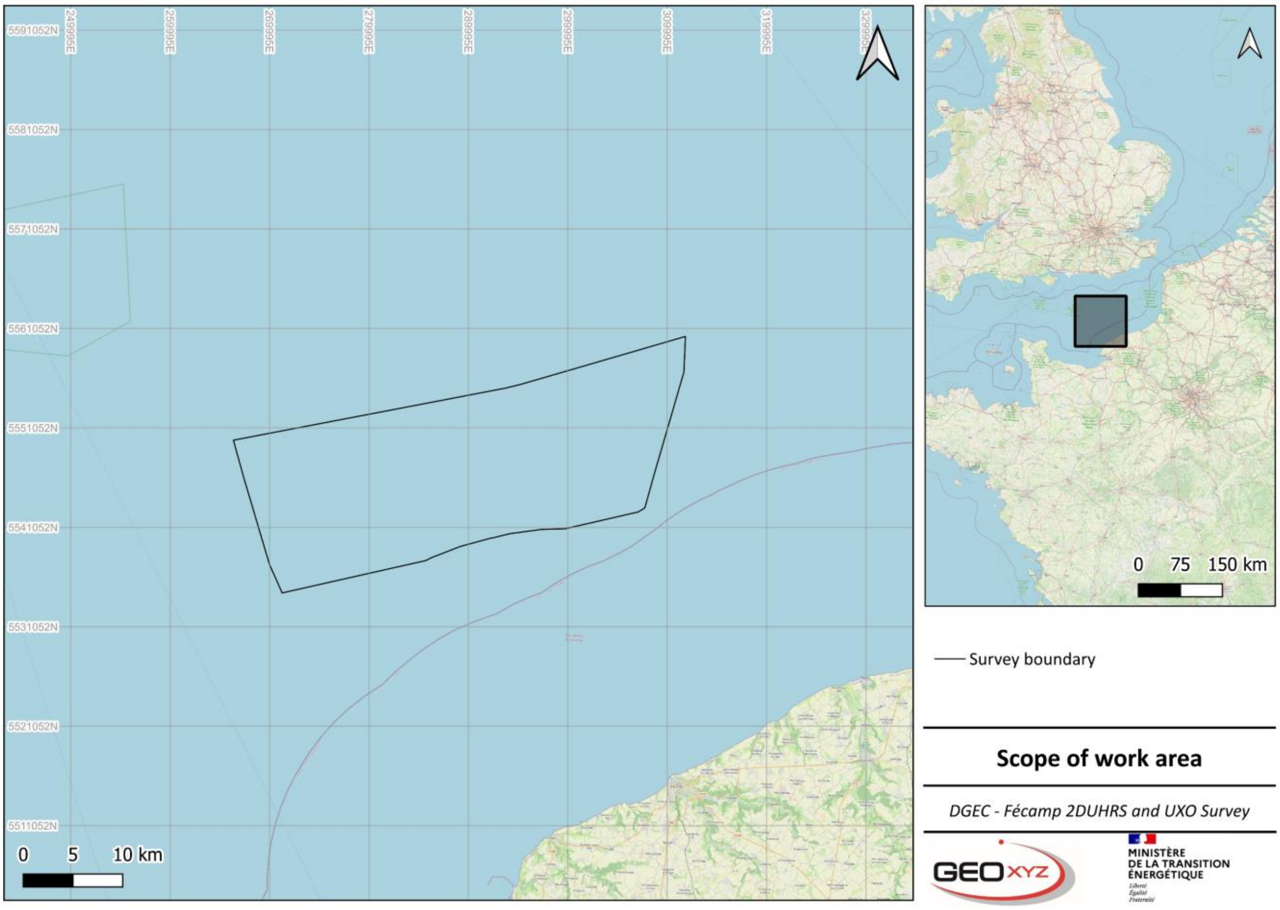


Figure 1-2: Scope of work area

The geophysical survey comprised the acquisition of Ultra-High Resolution Seismic (UHRS), Multibeam bathymetry (MBES), and Sub-Bottom Profile (SBP) sensor data.

The UXO survey comprised the acquisition of Magnetometer (MAG), Multibeam Bathymetry (MBES) and Side Scan Sonar (SSS) sensor data.

As far as possible, data from all sensors was acquired simultaneously, with line planning as per the Client specifications.

1.3 SCOPE OF DOCUMENT

An overview of the reports submitted as part of the project are listed in Table 1 below. This report, the UHRS Factual Report, details the results of the geophysical survey.

Table 1: Project reports

Document Number	Title
6168_2-MCR-01	Mobilisation Report 2DUHRS Survey
6168_2-MCR-02	Mobilisation Report UXO Survey
6168_2-OR-01	Operations Report 2DUHRS Survey
6168_2-OR-02	Operations Report UXO Survey
OSC_2024_GEOxyz_MED_MMOPAM_v1.2	MMO & PAM Report
6168_2-RR-01	**UHRS Factual Report (This Report)**
6168_2-RR-02	UXO Factual Report

2 GEODETIC PARAMETERS AND TRANSFORMATIONS

2.1 HORIZONTAL DATUM

The geodetic datum and mapping coordinate system used for this project is WGS84 UTM Zone 31N. All coordinates used are referenced to the geodetic datum and grid parameters listed in Table 2 and Table 3 below.

Table 2: Datum parameters

Parameter	Details
Geodetic Datum	World Geodetic System 1984 (WGS84)
EPSG Coordinate Reference System	4258
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 3: Projection parameters

Parameter	Details
EPSG Coordinate Reference Code	32631
Projection	UTM
Zone	31N
Central Meridian	3° East
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 datum for the project 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 has been used for record keeping during the project (including the Daily Progress Reports, unless stated otherwise). The vessel maintained local time for operations.

Data time-tagging and synchronization used UTC (Universal Time Coordinated). All data recorded in the online navigation software will be 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;

- Linear units are expressed in international metres (m)
- Angular units 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 -60 m LAT) expected in the western third. A morphological overview of the area within the survey boundary shows a more uniform seabed in the central and eastern regions, while the western part is expected to have a more complex seabed, as shown in Figure 3-1. The Figure 3-2 shows the interpretation of the morphological map. This interpretation shows an eastern section with sub-parallel escarpments and a western section presenting areas with a high roughness.

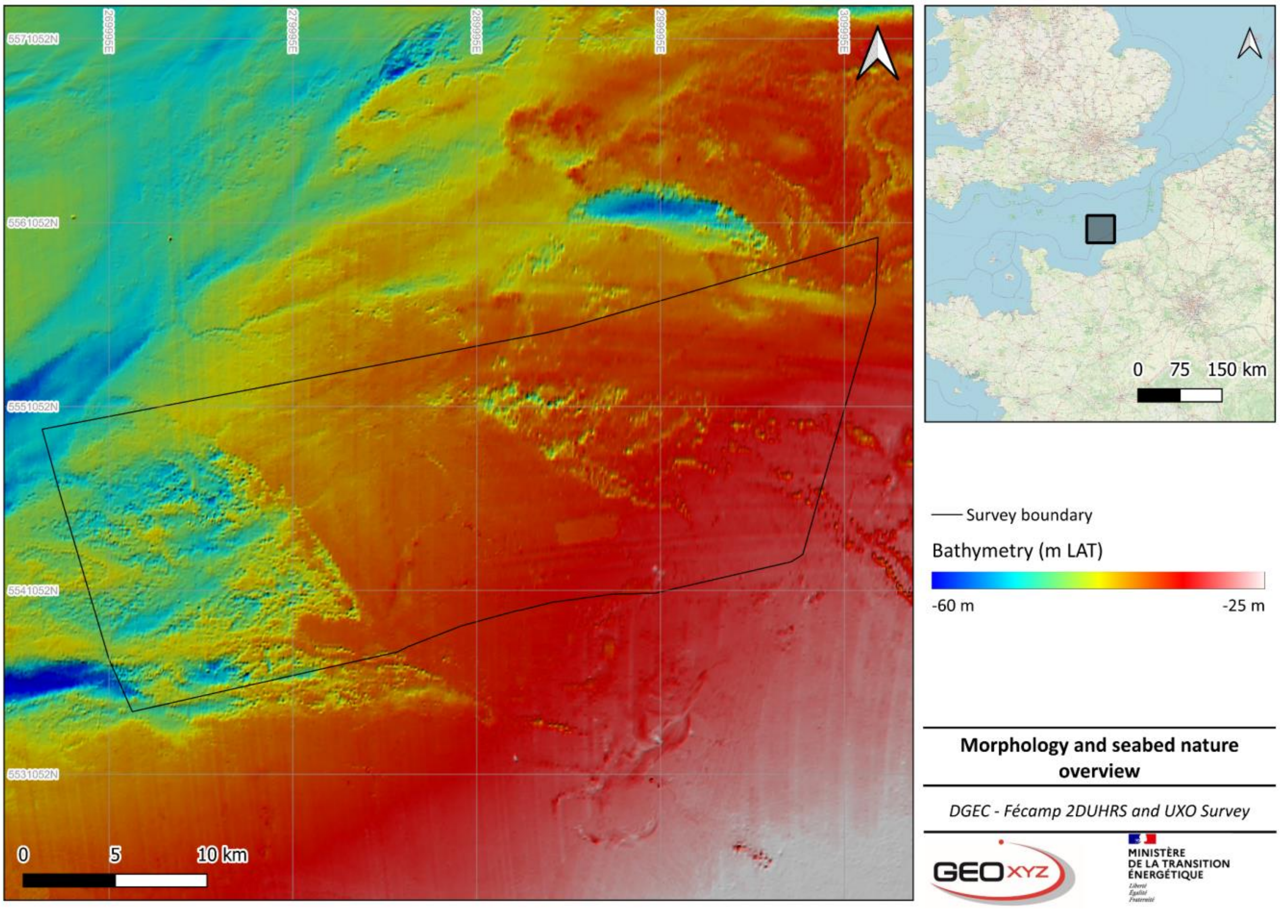


Figure 3-1: Morphology and seabed nature overview

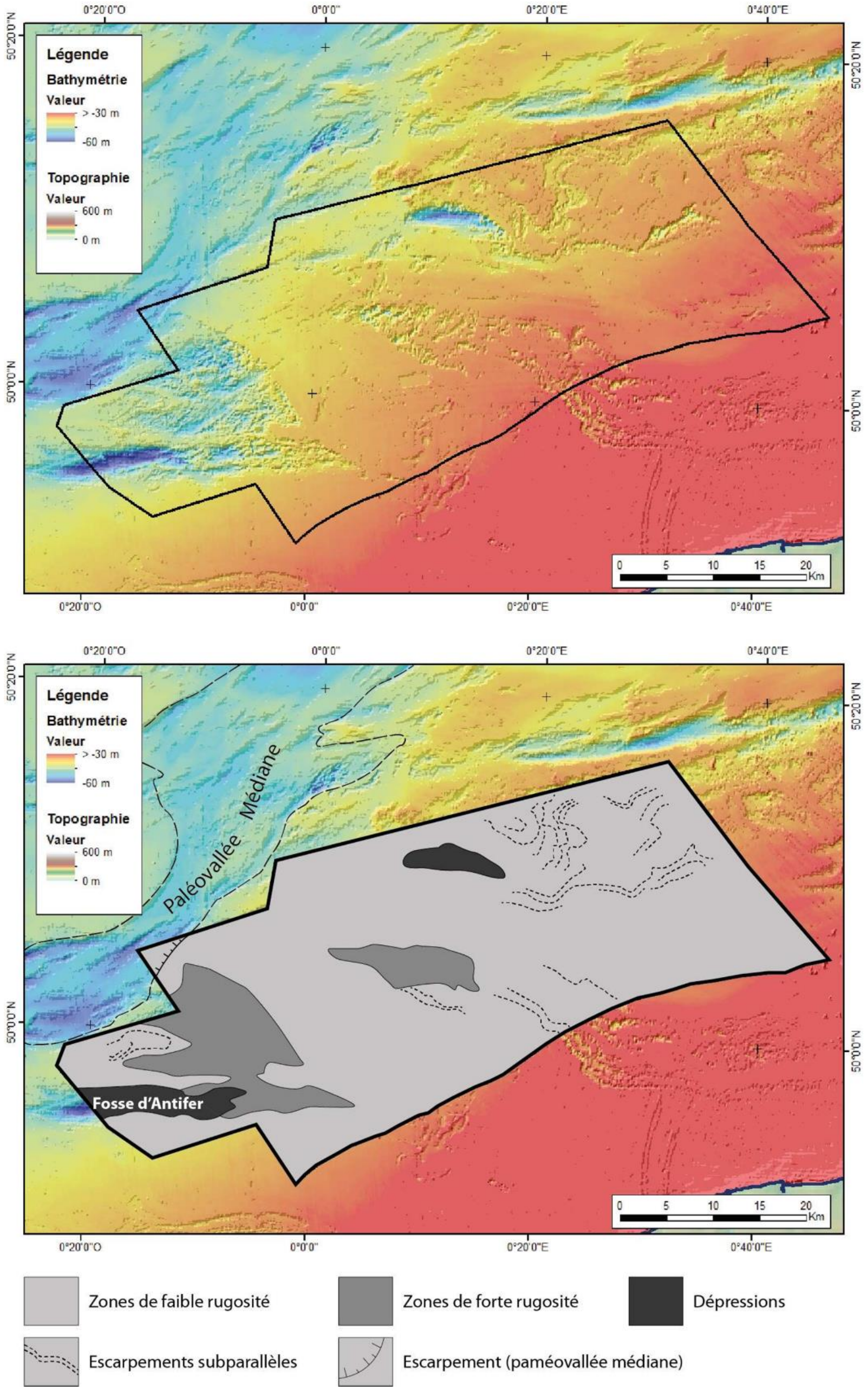


Figure 3-2: Bathymetric map from Fécamp-Grand Large macro-area (©EMODNet, 2022) and topography (©GEBCO, 2023). (Bottom figure: Simplified morphological interpretation map)

3.2 SEDIMENT MOBILITY

There are no indications of sediment mobility.

3.3 EXPECTED SUBSEABED GEOLOGY

The truncated pre-Neogene geology generally dips at around 1 degree to the north-east with units becoming younger to the north-east, as well as upward. The arrangement of units is more complex in the west of the area. In the extreme south-west, a large strike-slip fault (the Fécamp-Lillebonne fault) places Jurassic sediments immediately against much younger Eocene deposits.

There is a change in dip between the older Lower Cretaceous deposits (N1-4), which are relatively flat, and the more recent units that have greater dip, broadly parallel with the erosion surface that truncates the older Lower Cretaceous deposits.

The Upper Eocene comprises sand and silt, Lower Eocene deposits are a mixture of clay and sand, becoming limestone. The Upper Cretaceous is chalk with flints. The Lower Cretaceous (which has lower dip) is carbonate rich towards the top, with marl, clay and puddingstone, become clastic in lower parts. The Jurassic rocks are marl, limestone and clay.

Two Eocene and Upper Cretaceous units (E4a and C2) contain numerous low displacement faults.

All these relatively ancient pre-Neogene rocks are truncated by a base Neogene unconformity that is partially infilled by clastic deposits. Over almost the entire area there is a seabed veneer of sandy gravel, though over large parts of the centre of the area this is too thin to clearly resolve.

Geological maps of the Eastern Channel North Sea, which includes project survey area, are presented in Figure 3-3 and in Figure 3-4. For more information on expected subseabed geology, please refer to BRGM Geological Desktop Study: DTS_BRGM.

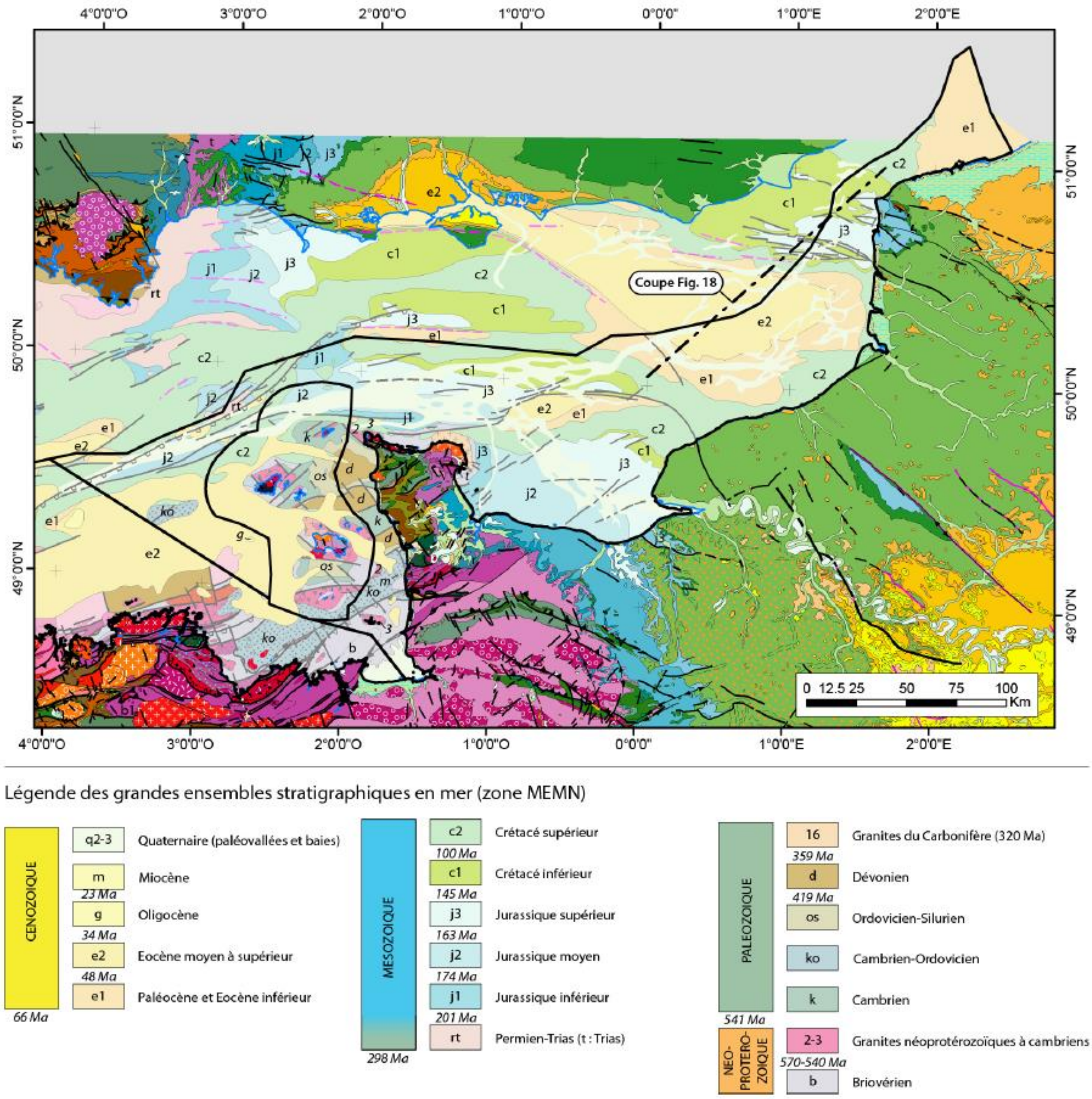


Figure 3-3: Geological map of the MEMN façade

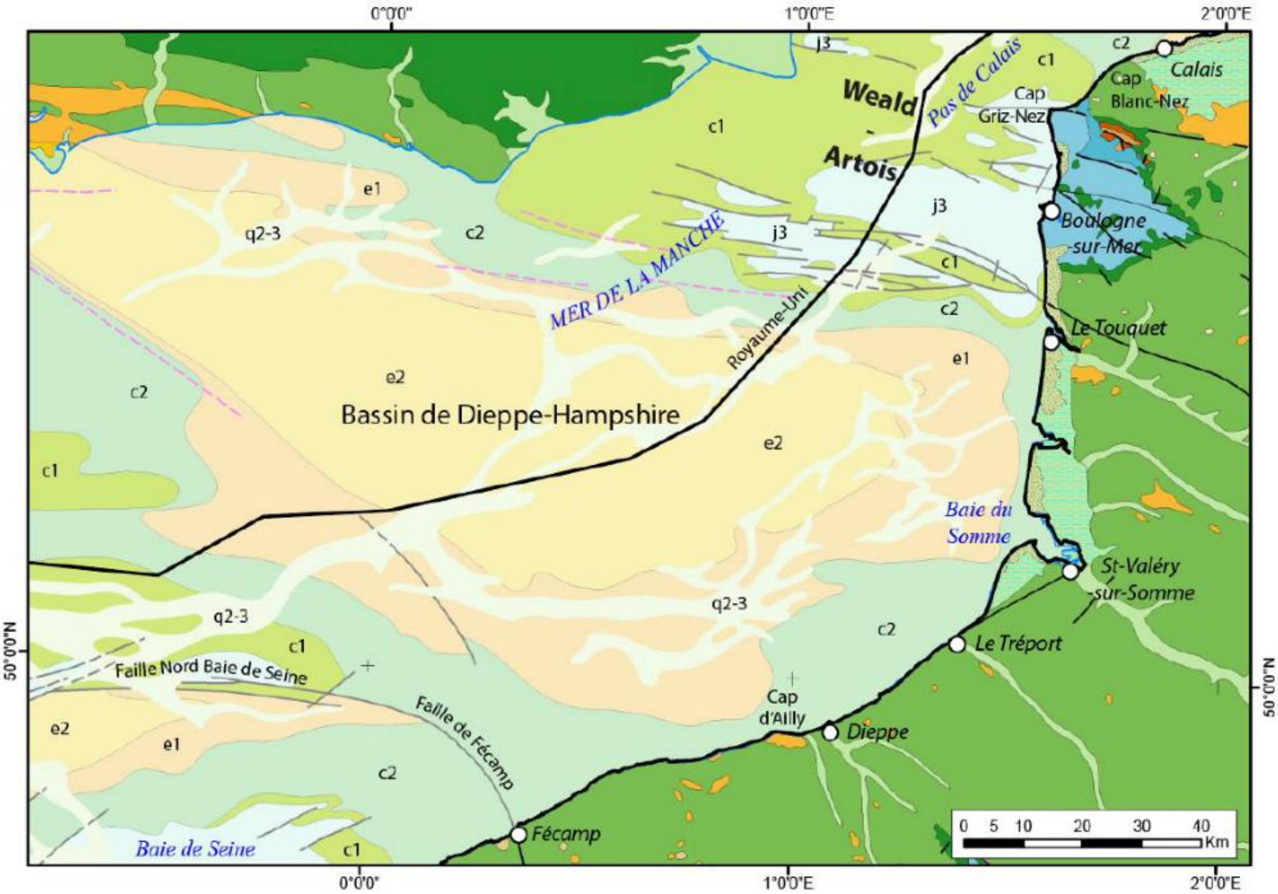


Figure 3-4: Geological map of the MEMN façade – Calais to Fécamp secto

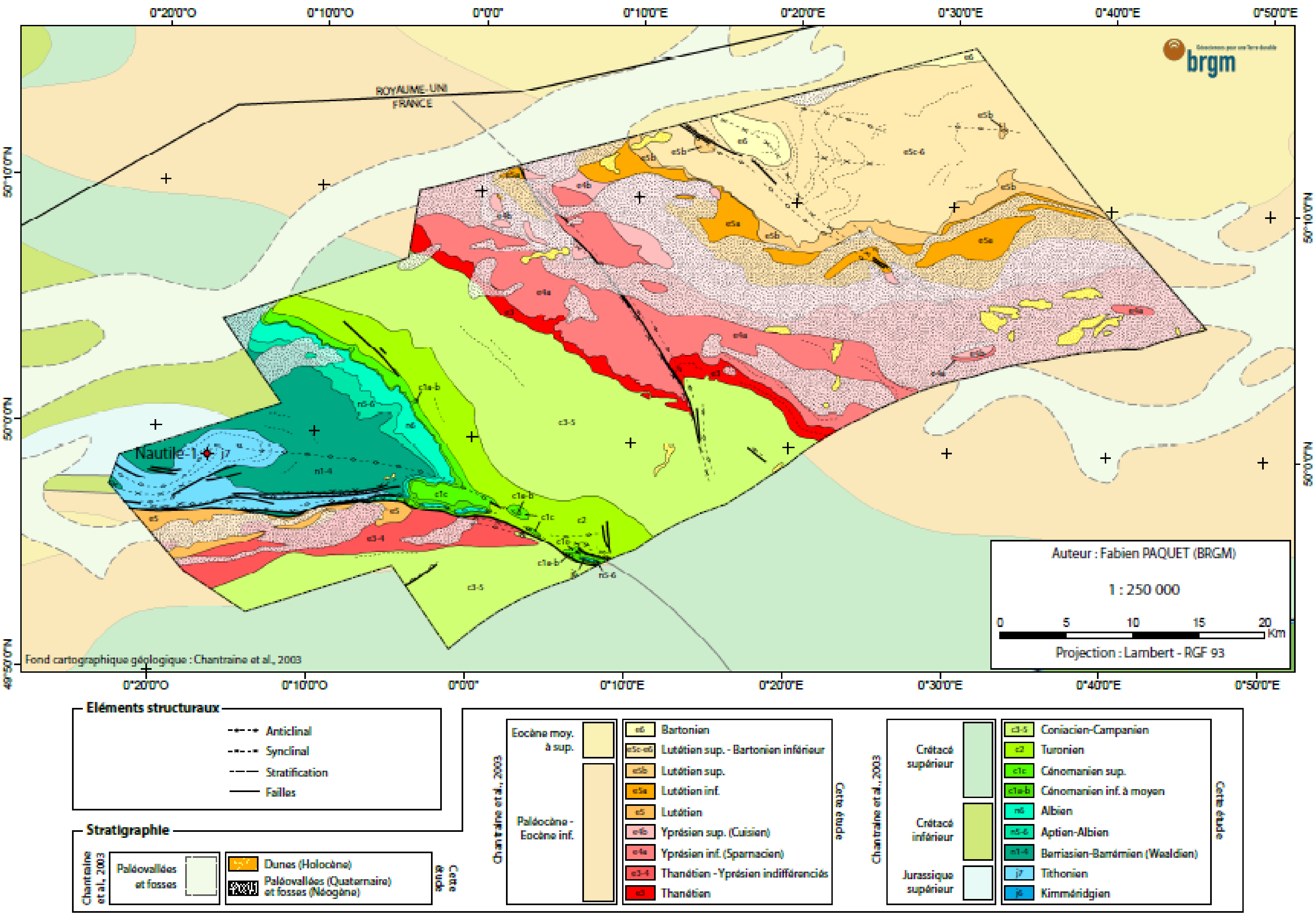


Figure 3-5 Geological map of Fécamp-Grand Large macro-area

3.4 OTHER INFORMATION

No existing infrastructure was found inside the Fécamp survey area, although a total of 11 wrecks are found within the survey boundary. Three wrecks are found within the planned acquisition lines (red dots in Figure 4), two of which are classified as dangerous wrecks and one as a non-dangerous wreck.

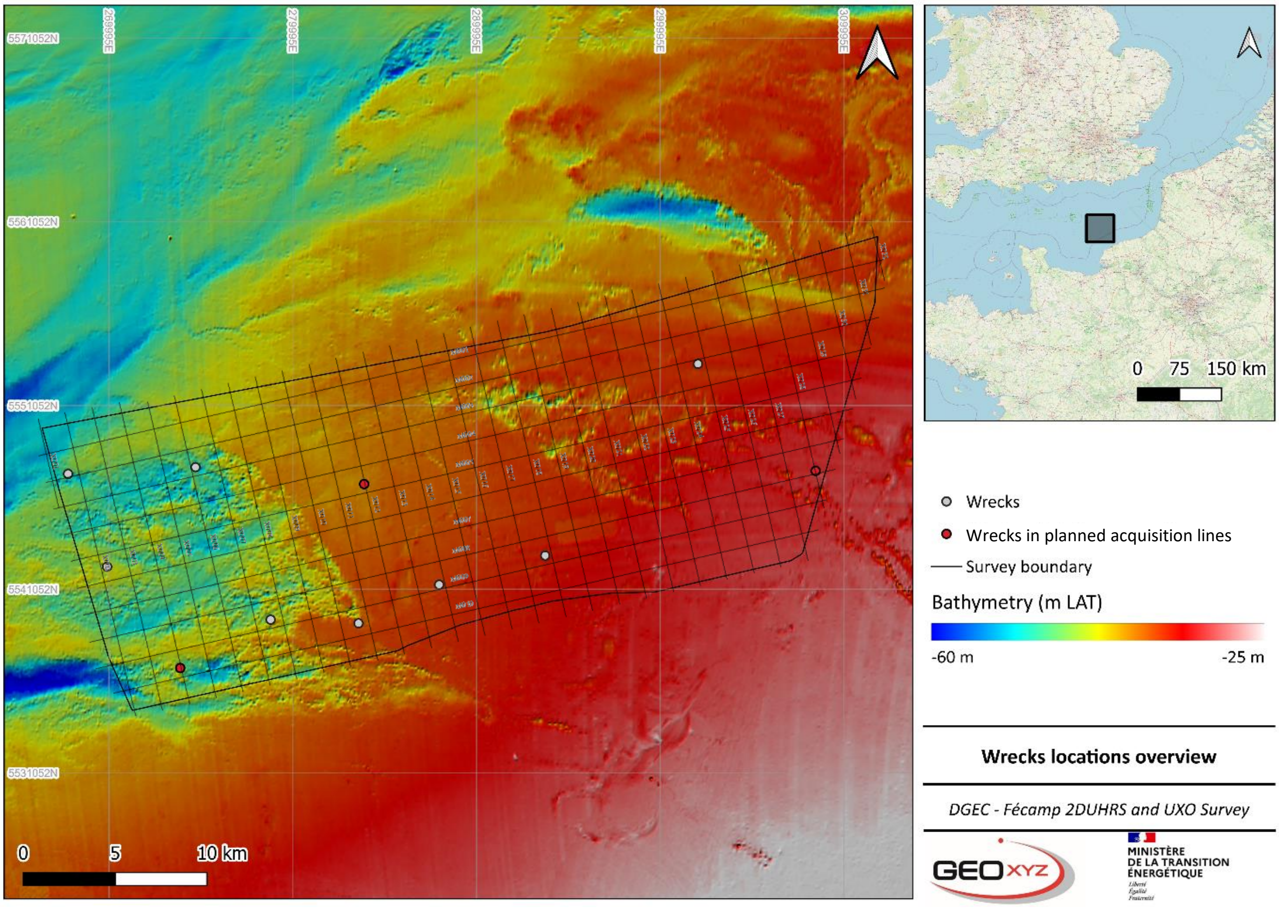


Figure 3-6: Wrecks locations overview

4 RESOURCES

4.1 VESSELS

GEOxyz's vessel Geo Ocean VI was used to conduct the survey. The specifications of the GOVI are summarised in Table 4.

Table 4: Survey vessel specifications

Geo Ocean VI	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	24 h 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 5 below. More details are outlined in the Operations Report (6168_2-OR-01).

Table 5: Survey equipment specifications

Type	Manufacturer	Model/type
GNSS primary GNSS secondary	Trimble Trimble	BX992 c/w OmniSTAR G4+ BX992 c/w OmniSTAR XP
Primary INS / MRU Secondary INS/MRU	iXblue SBG	Hydrins Apogee-I-B Surface IMU
MBES (Hull-mounted)	Kongsberg	EM2040 RX (Port) EM2040 RX (Stbd) EM2040 TX(Centre) EM2040 PU (Master) EM2040 PU (Slave)
Sound velocity	Valeport	Swift 500 Swift 500 Mini SVS (USBL pool mounted) Mini SVS+P (towed equip) Mini SVS+P (towed equip)
SBP	Innomar	SES-2000 Medium 100
Winches	Emce	EMCE UMB-305 (Stbd)
UHR streamer	Geoeel	Active Streamer Length: 96 m

Type	Manufacturer	Model/type
		Configuration: 1x 96 m Tow cable – 1x 5 m Stretch – 48ch @ 2m Group Interval, 1x 5 m Tail stretch, 3x LH16 Digitiser Units
Sparker	Duraspark	Duraspark 400
Sparker and Tail Buoy GNSS	Applied Acoustics	Minipod 101G (SBAS)

4.3 SOFTWARE

The software that was used for data acquisition and processing is outlined in Table 6 below.

Table 6: Project software list

Equipment / Data Type	Acquisition	Processing
Navigation, MBES, GNSS	QPS QINSy	n/a
MBES	QPS QINSy	Qimera / FMGT 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@1m int & ch25-48@2m int)	Shearwater Reveal Advanced Marine v.5.1 IHS Kingdom version 2016 64 bit
Passive Acoustic Monitoring (PAM)	Subacoustech, 4 broadband elements (up to 250khz) with PAMGuard (plus spare system)	n/a
DigiCourse Bird Controllers	ION System 3 v7.21	n/a

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 7.

Table 7: MBES system settings

Kongsberg EM2040 (DH/DSW)	Head 1 port	Head 2 stbd
Survey speed	Average 4 knots	
High Frequency (used during survey)	400kHz	400kHz
Low Frequency	200kHz	200kHz
Bottom sampling	High Density Dual Swath (1024 beams)	
Operational Mode	Ultra-High density	
Range	2 x water depth	
Power	Maximum	
Pulse length	Auto	
Patch test roll	-41.288°	40.831°
Patch test pitch	-0.530°	-0.834°
Patch test heading	180.476°	180.192°
Sector width	55º	55º
Ping rate	9Hz - 14Hz dependant on range	
Software and version	QINSy 9.6.4	

The MBES project specifications are listed in Table 8.

Table 8: MBES specifications

Item	Specification
Minimum data density	30 HC/m² until 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 for <25 m of water depth 0.5 m for 25 m – 50 m of water depth 1 m for 50 m – 200 m of water depth
Grid	0.5 m cell size
Gridded standard deviation	≤0.20m per 1 m² bin
Coverage	100 % with 30% overlap between adjacent survey lines
TVU	0.8 m
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.

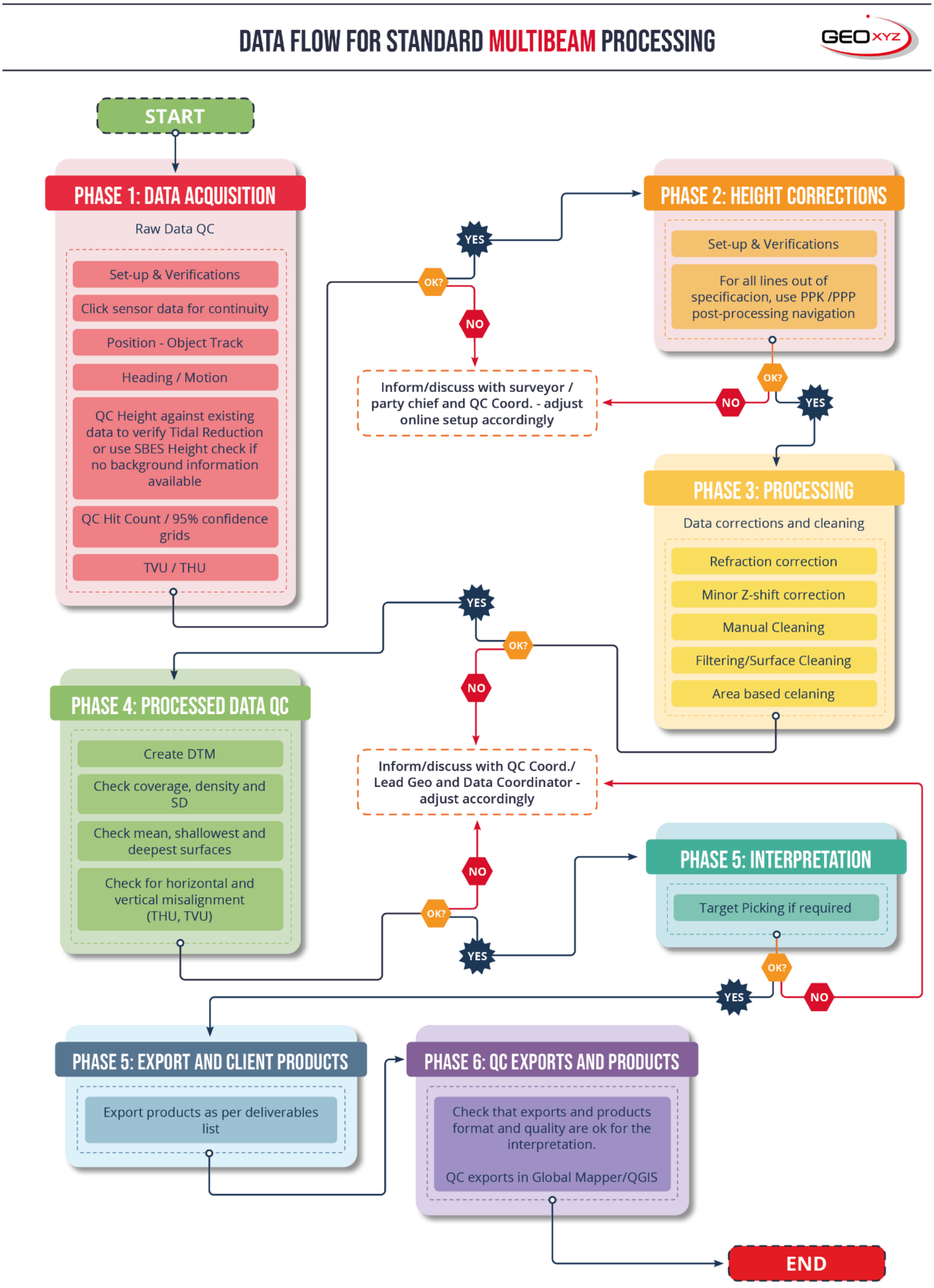


Figure 5-1: MBES processing workflow

5.1.3 Data quality assessment

The multibeam echosounder data was of high quality with very little acoustic noise. The THU and TVU values are within the threshold specified by the IHO Special Order S-44 and the specifications defined by the client. THU and TVU values are shown in Figure 5-2 and Figure 5-3.

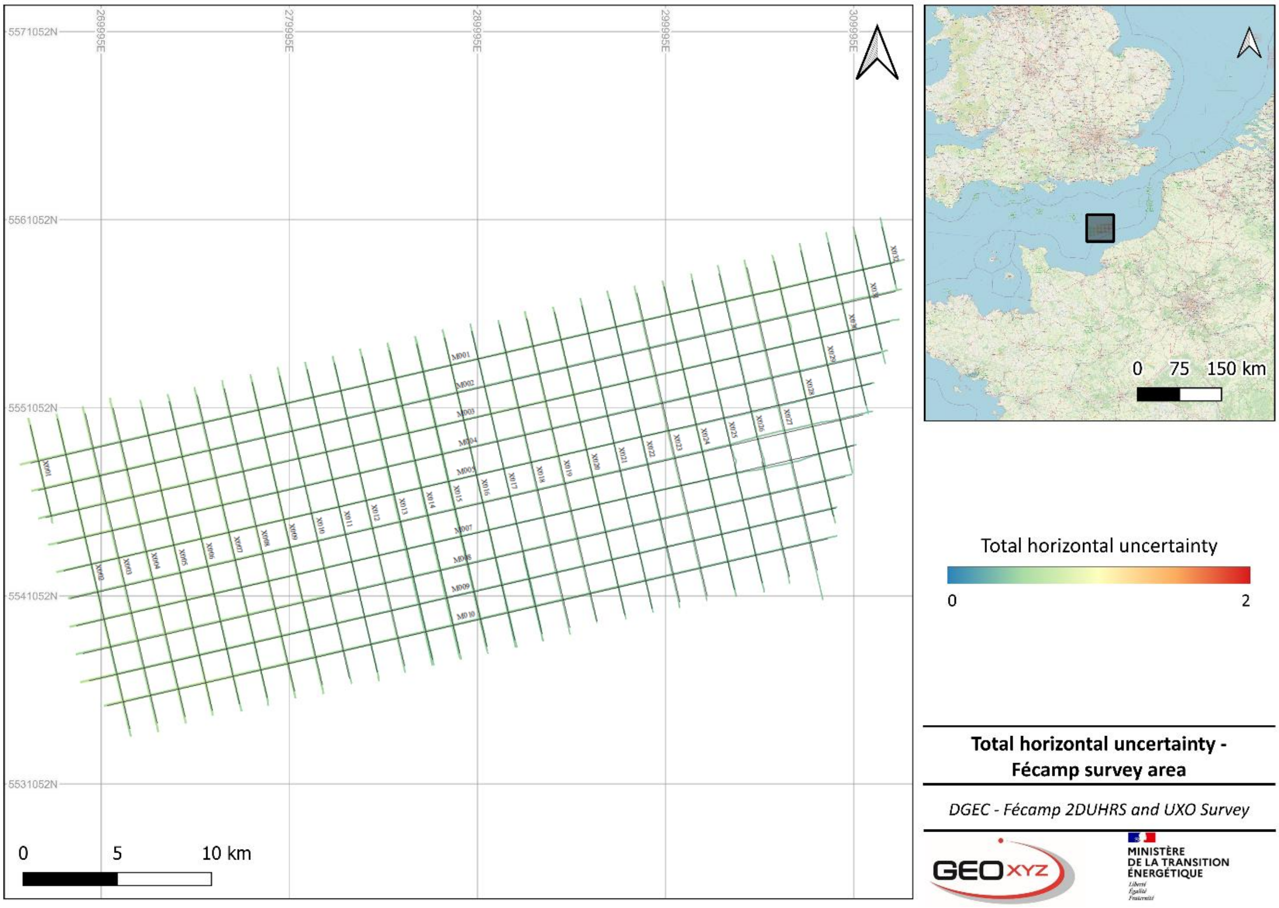


Figure 5-2: Total horizontal uncertainty (expressed in metres) for the Fécamp survey area

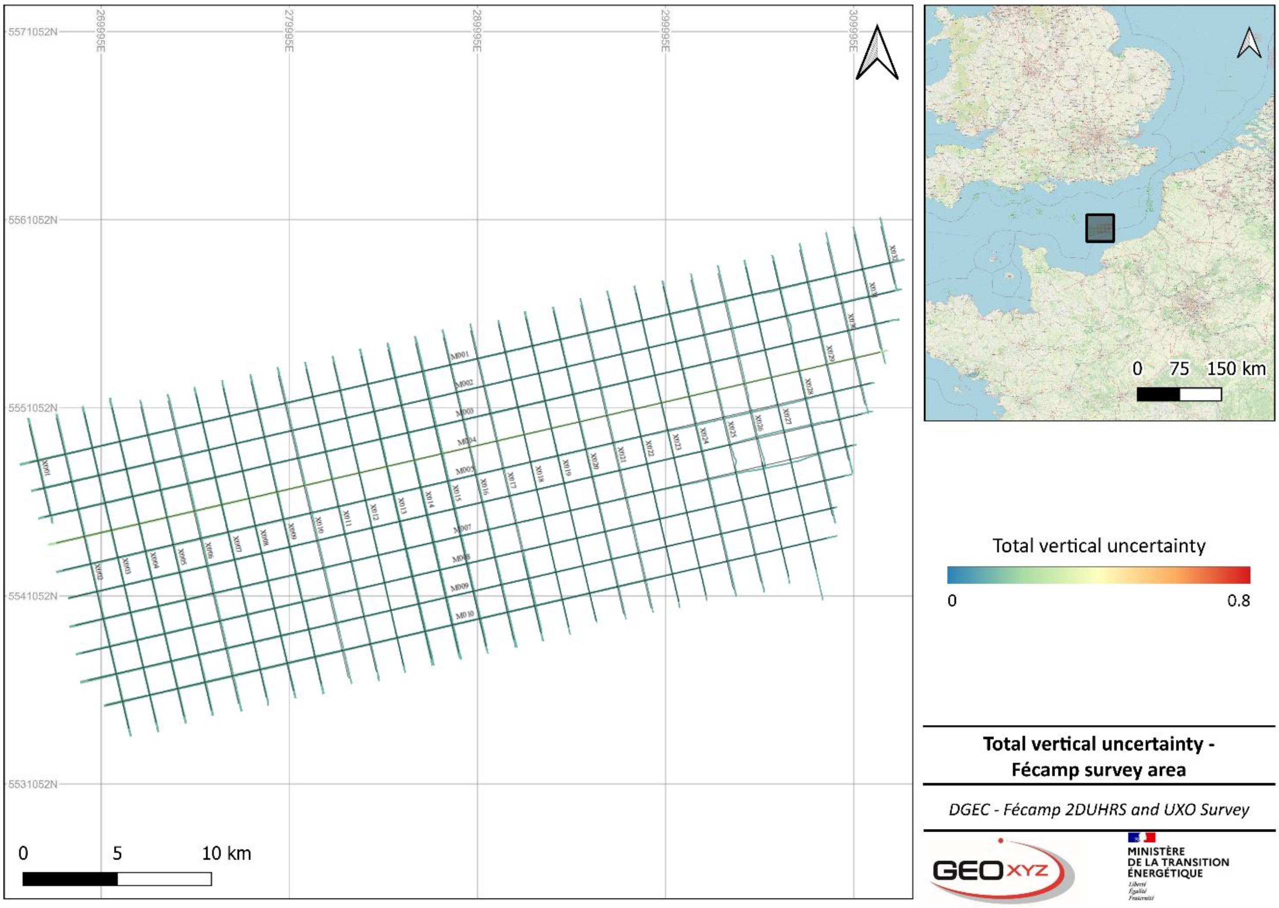


Figure 5-3: Total vertical uncertainty (expressed in metres) for the Fécamp survey area

5.1.4 MBES deliverables

The MBES deliverables created as a result of the project are outlined in Table 9.

Table 9: 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 10 below.

Table 10: SBP specifications

Item	Specification
Operating frequency	Chirp sounder: 2 to 10 kHz range Selectable ultrasonic transmitter frequencies: 3.5 and 7.0 kHz
Output power	From 4 kW to 10 kW
Penetration depth	5 m below seabed
Resolution	0.3 m

5.2.2 Overview of the methodology

Figure 5-4 below outlines the SBP processing workflow.

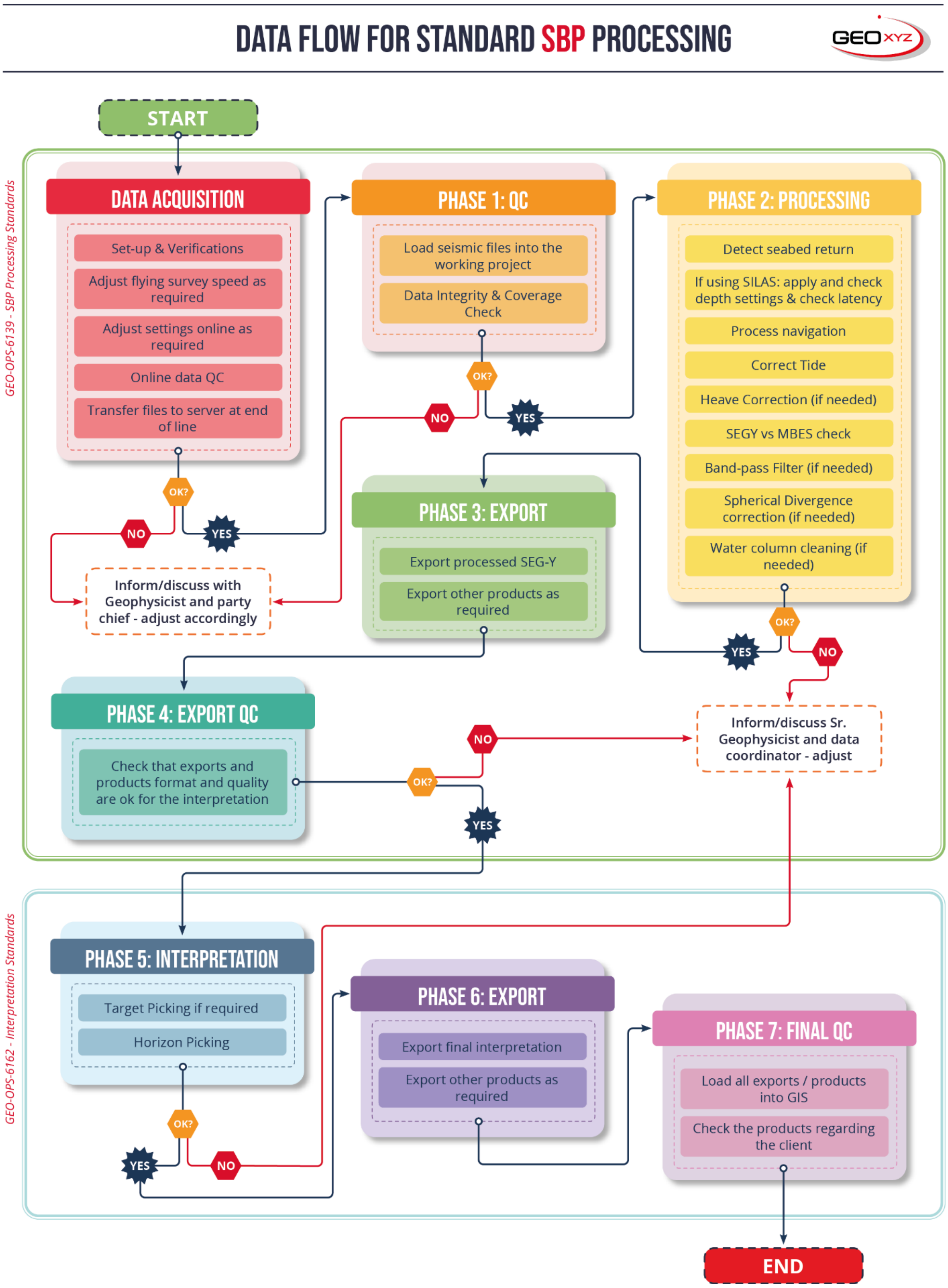


Figure 5-4: SBP processing workflow

5.2.3 Data quality assessment

The sub bottom profiler data are good quality and consistent (Figure 5-5). The data allow separation of reflectors as closely spaced as 0.15 m. Data penetration depend on the local geology – in some places relatively ancient rocks are very close to outcrop and imaging is limited. In areas with softer geology imaging is good to 8 m below seabed.

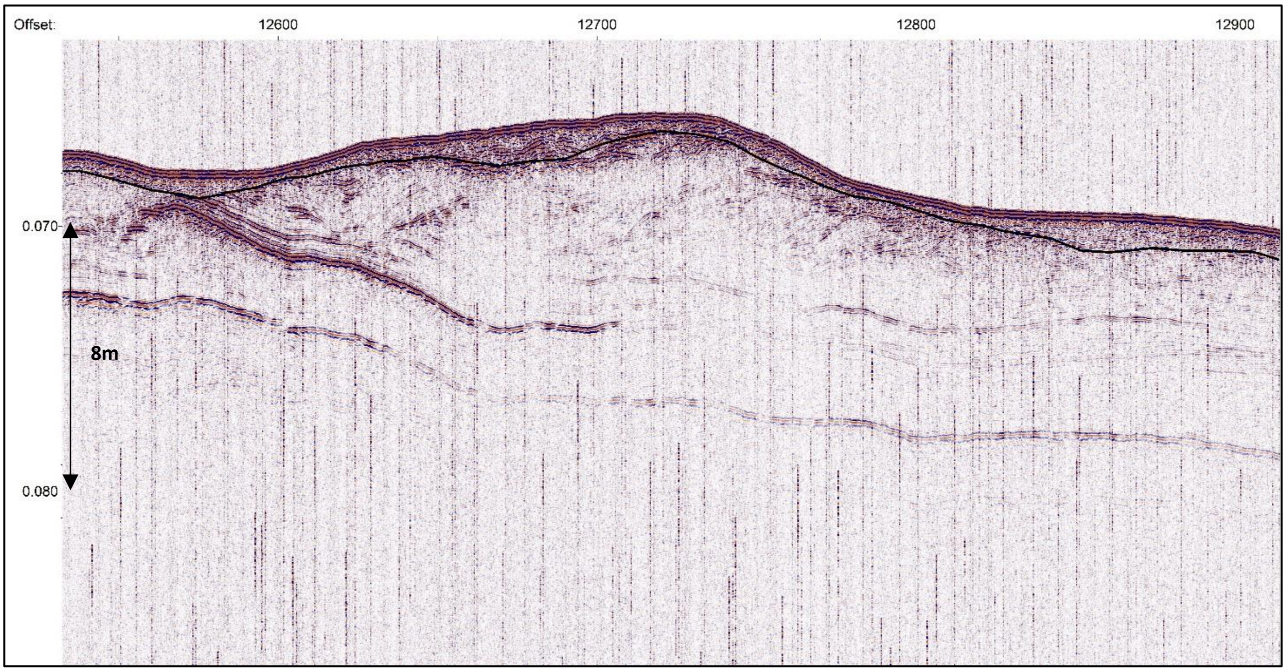


Figure 5-5: SBP data characteristics

5.2.4 SBP deliverables

Table 11: 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 12: 2DUHR specifications

Item	Specification
Source frequency	0.5 – 3.0 kHz
Source output	150 – 1500 J (up to 2500 J)
Source depth	0.5 m
Streamer channels	48
Shot point interval	At least half the distance between hydrophones
Minimum samples per measurement point	48
Resolution depth	0.5 m
BSB penetration	100 m
Distance between lines	1500 m
Interpolation	100 m

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.

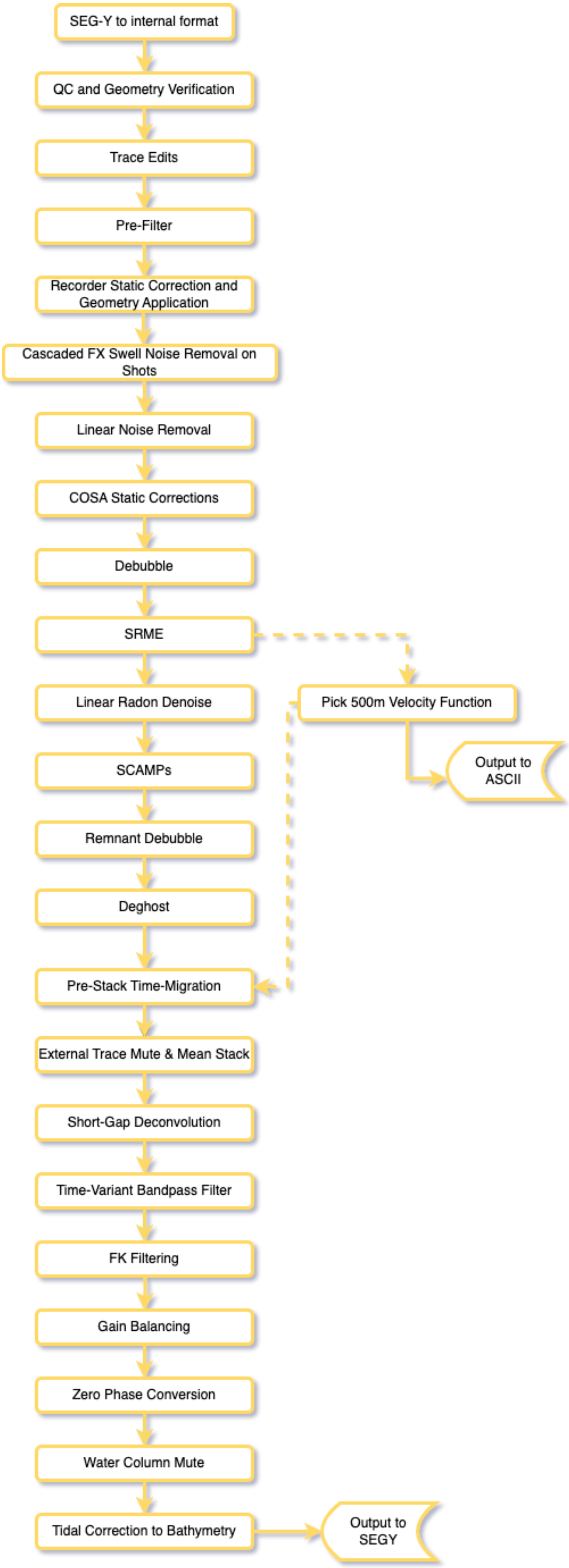


Figure 5-6: 2D UHR processing workflow

Table 13. 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 Data quality assessment

The UHR data are good quality and consistent (Figure 5-7). Geological imaging does partly depend on the variable geology but often extends to beyond 120 m below seabed. In favourable geological settings (at low travel times within the Upper Cretaceous chalk). The data can enable mapping of separate reflectors less than 1 m apart.

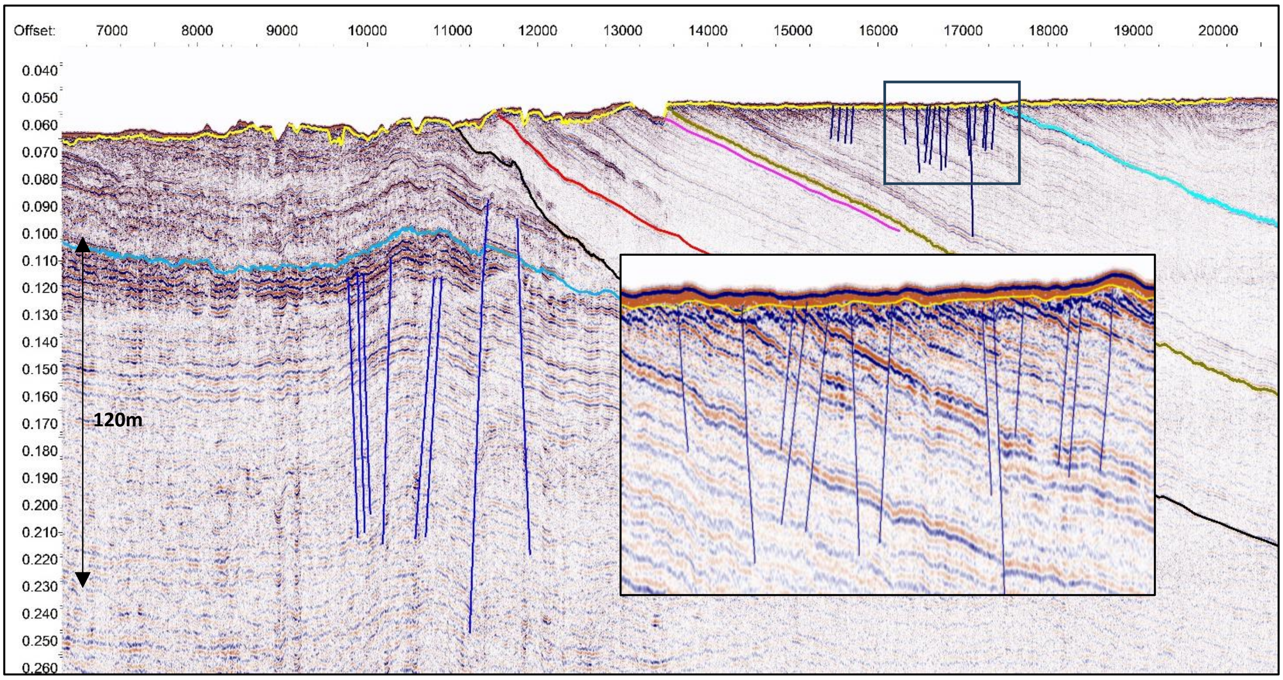


Figure 5-7: UHR data characteristics

5.3.4 UHRS deliverables

Table 14: 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

Deliverable	Format
Longitudinal profile	ASCII
Horizon interpretation gridded surface	ASCII
Horizon contour lines (BSB)	SHP
Geologic feature points, polylines and polygons (if applicable)	SHP

6 RESULTS AND INTERPRETATION

6.1 BATHYMETRY

In broader research area of Eastern Channel North Sea, morphological features with high roughness are found off rocky coasts. In their highest parts, they can be permanently emerged in form of islands, or they emerge at low tide as shallows and reefs, or they remain constantly submerged. They are of rocky composition, which is why they have eroded less than the adjacent lands, and that is also the reason for their roughness.

Morphology features with low roughness are also encountered throughout the general area. They are characterized by elongated shapes, more or less sinuous, whose relief, in relation to the surrounding lands varies by a few meters to tens of meters. They are made up of sedimentary deposits, predominantly sandy, and form isolated dunes, grouped into vast dune fields, or form larger structures called sand banks. Some of these structures may emerge at low tide.

Among the negative reliefs found in the general area, there is a network of connected sinuous depressions developed as an extension of the current river network. They are usually referred to as paleovalleys, referring to their fluvial origin. Their depth, relative to the surrounding plateau, can locally reach 25 m. These paleovalleys developed when sea level was lower than the current level for around 100 m. Furthermore, a series of rectilinear isolated depressions connected to the paleovalley network are also found in the general area. Their depth in relation to the surrounding plateau is 20 to 30 m but can reach up to 50 m. The one closest to the survey area is the Fosse d'Antifer, off the coast of the Antifer port terminal, which is found western of the survey area.

The bathymetry of the Eastern Channel North Sea can be seen in Figure 6-1. For more information on morphology of the area, please refer to BRGM Geological Desktop Study: DTS_BRGM.

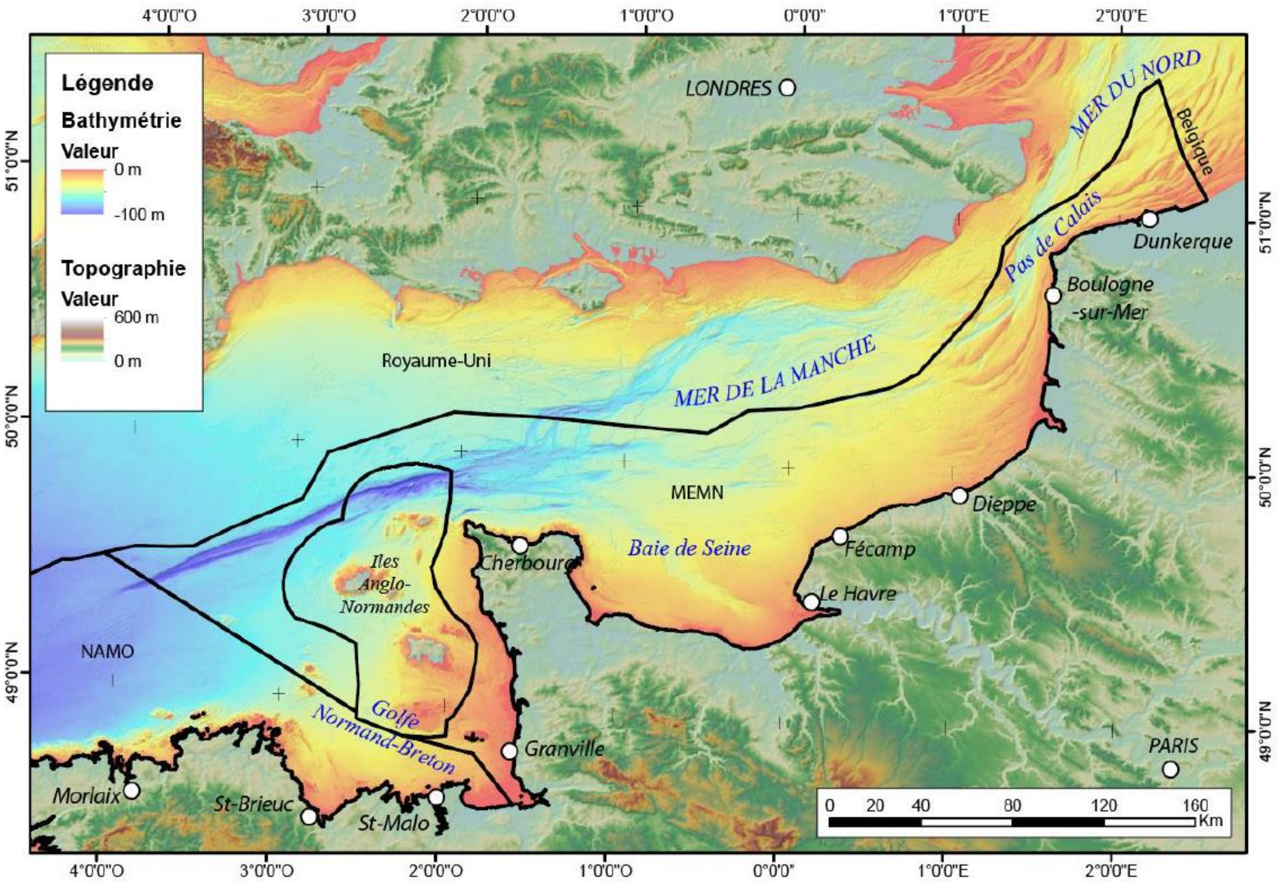


Figure 6-1: Bathymetry of the MEMN facade

In general, depth values increase from east to west. The MBES data analysis reveals relatively uniform seabed levels in the eastern two-thirds of the surveyed area, with the shallowest point, at -29.68 metres, located in the southeastern part. The more complex geology in the southwest of the observed area has potentially shaped a more dynamic terrain, thus determining the location of the deepest point. The western third of the surveyed area displays greater depths, with the deepest point, at -58.46 metres, found in the southwestern part, near the edge of the surveyed area. Bathymetric overview of the surveyed area is shown in Figure 6-2.

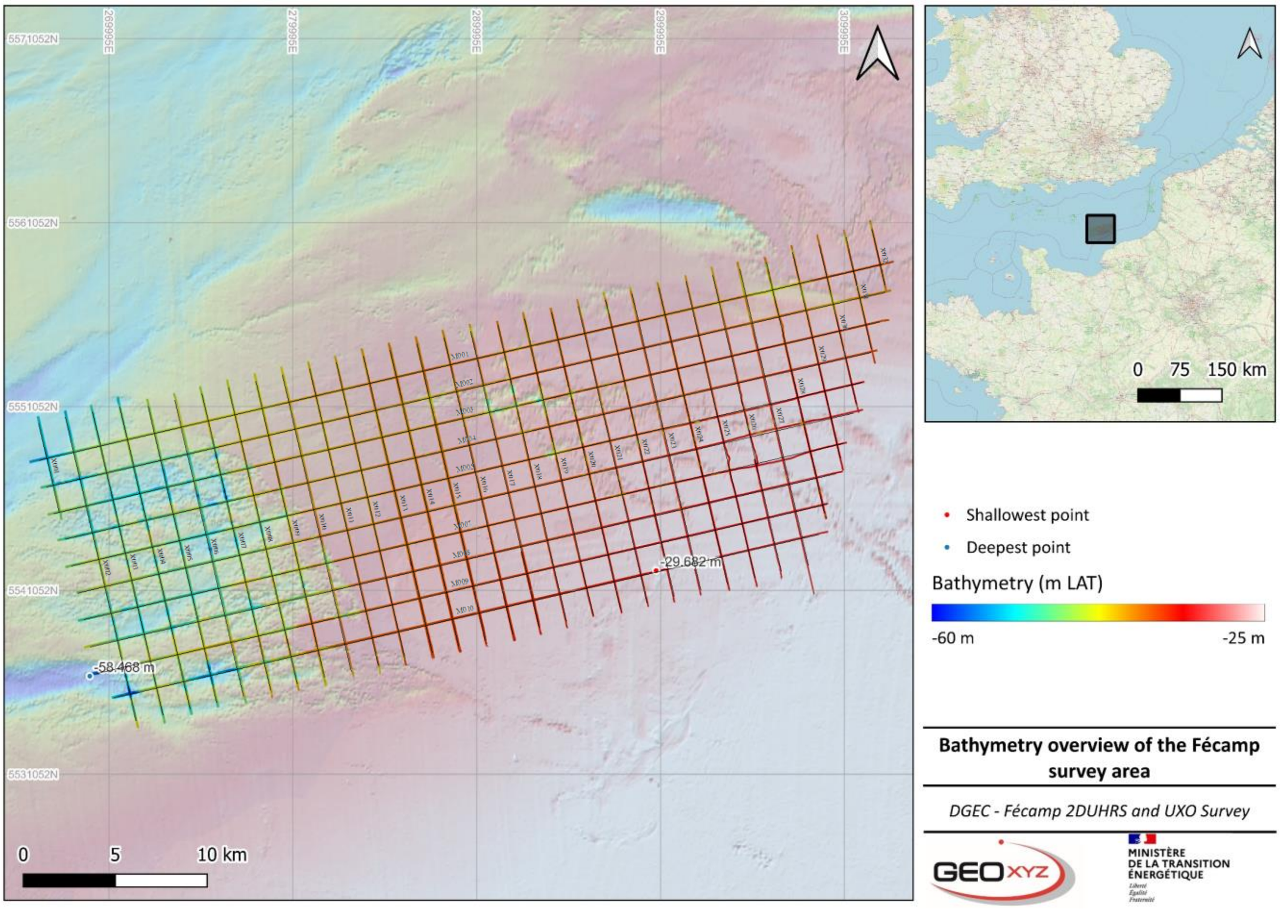


Figure 6-2: Bathymetry overview of the Fécamp survey area (source background dataset: EMODnet)

The western third of the survey area exhibits a more complex bathymetry, likely due to the presence of faults such as the Fécamp-Lillebonne major fault in the extreme southwest with the deepest point of the survey area near a developed anticline. The F-L fault (presented in Figure 6-10) probably creates the variations in seabed conditions visible in Figure 6-3. The difference in terms of seabed roughness between the western part and the rest of the site is probably due to soil characteristics. The protruding areas are probably of rocky composition, which have been eroded less than the areas adjacent to them, so it is the rocky structure of the reliefs which gives them their rough appearance.

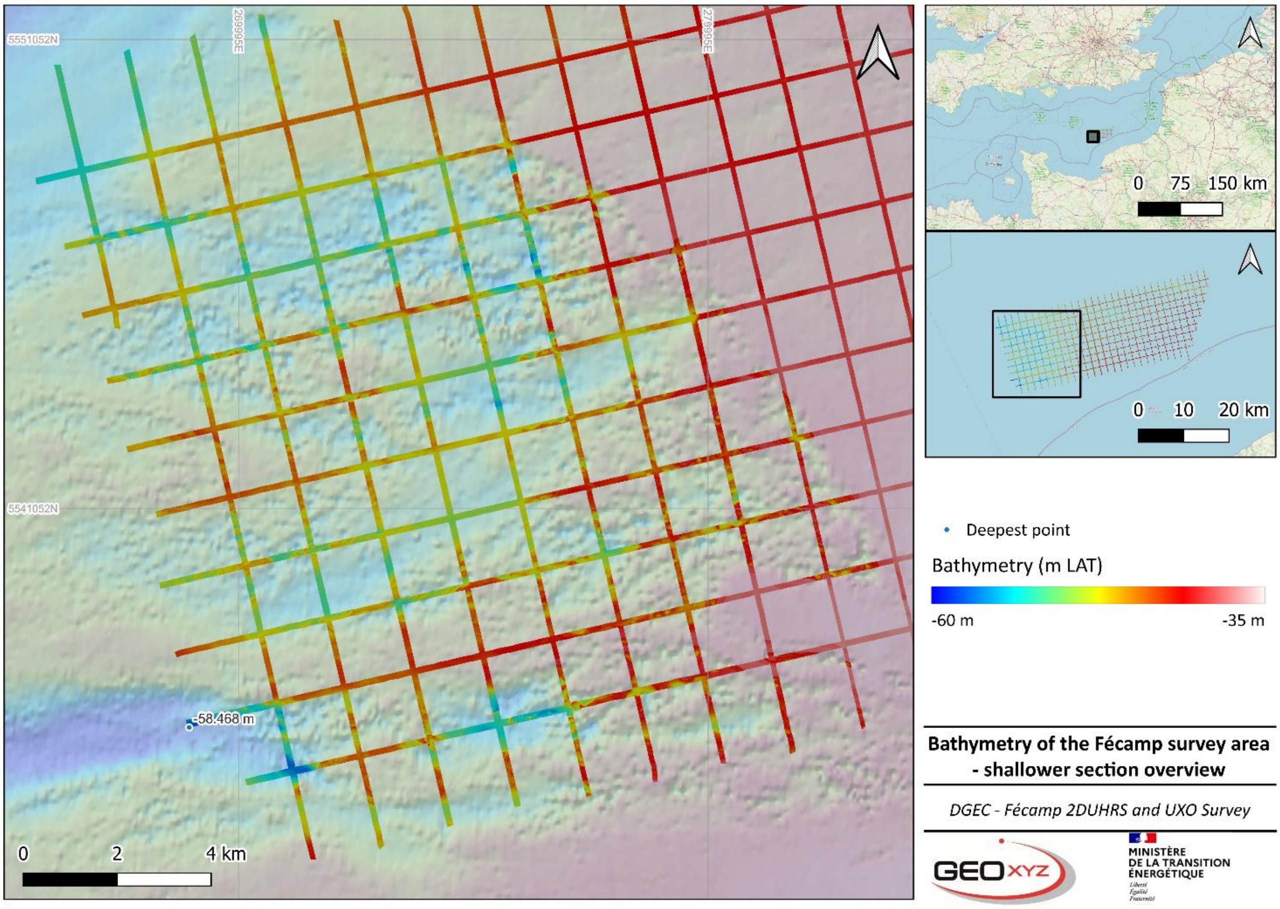


Figure 6-3: Western section overview

6.2 SUB SEABED GEOLOGY

6.2.1 Stratigraphy and general arrangement of the units

The geology is interpreted and described in the context of the stratigraphic model (Figure 6-4) used in the supplied desk study (Paquet et al., 2024). The following figure is taken from the desk study and links the area's units to chronostratigraphy and, on the righthand side, this study's picked surfaces and unit lithologies.

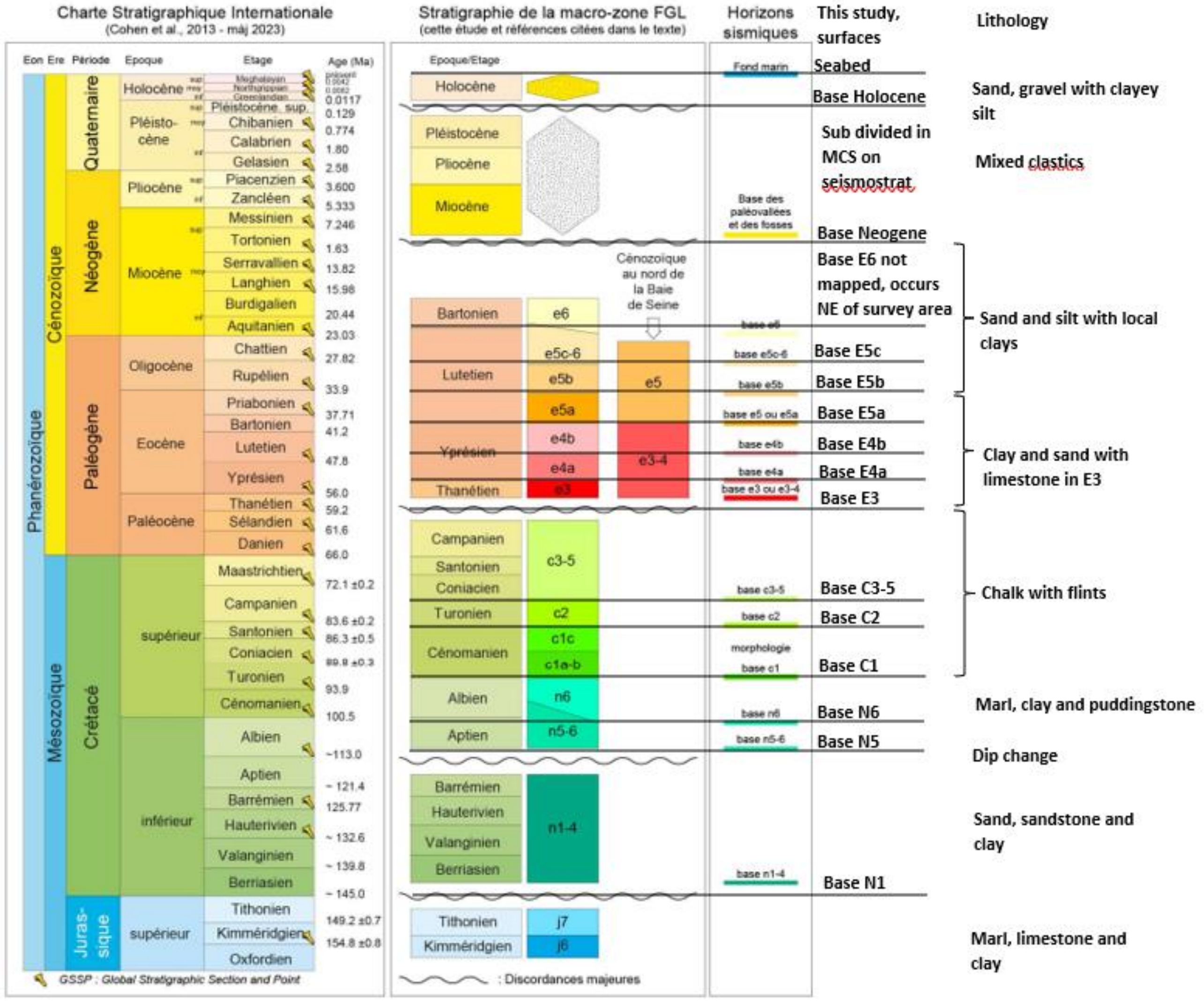


Figure 6-4: Stratigraphy and this study's picked surfaces

The area's shallow geology is complex as the sequence dips and is truncated, placing numerous different units close to seabed (Figure 6-5), there is an additional influence of tectonics, which is most pronounced in the extreme south-west of the area.

The geological history of the area is described in the desk study. This report is focused on describing the present-day geological conditions.

6.2.2 Geological overview

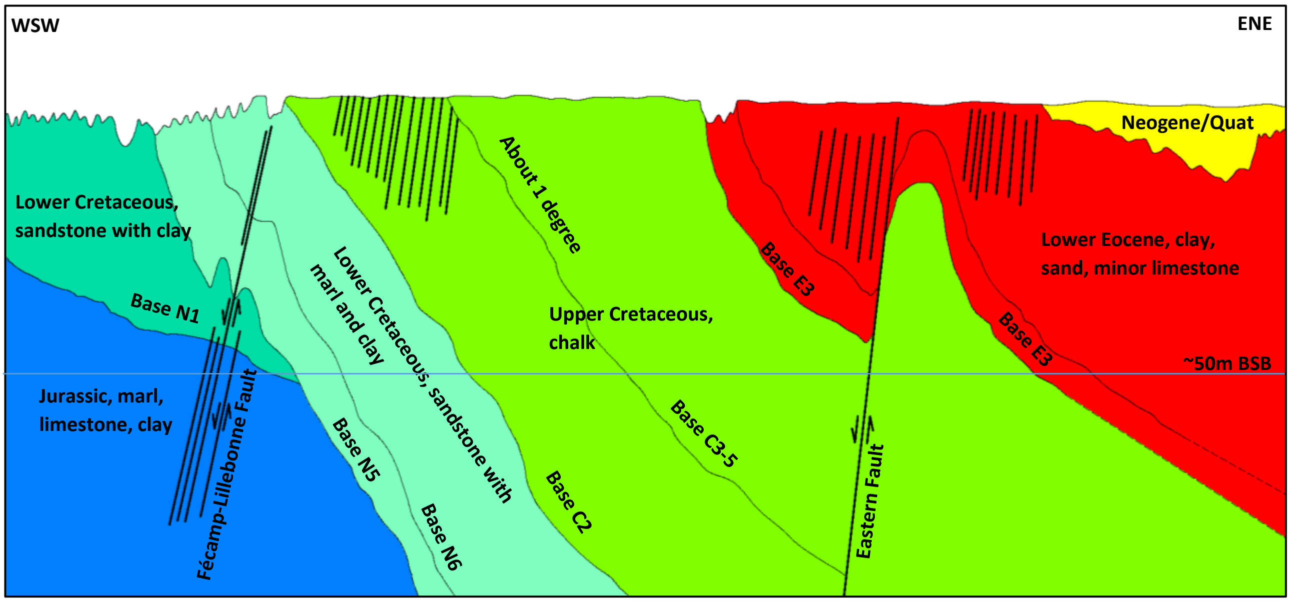
In some offshore areas, the shallow geological sequence is like a simple layer cake; successively older units can be expected at successively greater depths and similar ground conditions extend over many kilometres. This is not the case within the Fécamp survey area.

The truncated pre-Neogene geology generally dips at around 1 degree to the north-east with units becoming younger to the north-east, as well as upward (Figure 6-5). The arrangement of units is more complex in the west of the area. In the extreme south-west, a large strike-slip fault (the Fécamp-Lillebonne fault) places Jurassic sediments immediately against much younger Eocene deposits.

There is a change in dip between the older Lower Cretaceous deposits (N1-4), which are relatively flat, and the more recent units that have greater dip, broadly parallel with the erosion surface that truncates the older Lower Cretaceous deposits (base N5 on Figure 6-5).

The Upper Eocene comprises sand and silt, Lower Eocene deposits are a mixture of clay and sand, becoming limestone. The Upper Cretaceous is chalk with flints. The Lower Cretaceous (which has lower dip) is carbonate rich towards the top, with marl, clay and puddingstone, become clastic in lower parts. The Jurassic rocks are marl, limestone and clay.

Two Eocene and Upper Cretaceous units (E4a and C2) contain numerous low displacement faults.



	Neogene/Quaternary		Lower Cretaceous (sandstone with marl and clay)
	Lower Eocene (clay, sand, minor limestone)		Lower Cretaceous (sandstone with clay)
	Upper Cretaceous (chalk)		Jurassic (marl, limestone, clay)

Figure 6-5: Geological Schematic

All these relatively ancient pre-Neogene rocks are truncated by a base Neogene unconformity that is partially infilled by clastic deposits (yellow colour fill on Figure 6-5). Over almost the entire area there is a seabed veneer of sandy gravel, though over large parts of the centre of the area this is too thin to clearly resolve.

6.2.3 Seismic facies

The seismic expression of the geology does show some unit-to-unit variation. The following table describes the typical seismic facies of each unit. Several units show notable internal variations, for example, N1 contains distinct cross-bedded intervals, these are almost certainly sandier than the surrounding N1 deposits. Some intervals with contrasting lithotypes, for example the chalk-prone C units and the younger clay-prone E units, have very similar seismic expression. In this area seismic facies alone are not a good basis on which to make confident interpretations of the age or lithotype of the rocks.

An overview of the seismic facies by unit is presented in Table 15 below.

Table 15: Overview of seismic facies by unit

Unit	Seismic facies description	Comments, distribution
Holocene	Transparent and featureless	This unit has consistent acoustic character
Neogene / Quaternary	Variable channel fill facies. Draped continuous sub-parallel reflections in deeper sub-units. Shallower sub-units may be more chaotic. No faulting	This interval infills several separate eroded lows in the pre-Neogene sequence. Each of these mini basins contains a succession of sub-units with their own characteristics. The most consistent diagnostic seismic element associated with this interval is the lower surface; the erosive truncation of the subcrop
E5a	Moderate amplitude sub-parallel reflections, subtle internal unconformities. Limited faulting	Limited occurrence in extreme east of area, less confidently interpreted in extreme south-west in heavily structured zone. Description based on appearance in east
E5b	More amorphous than E5a, subtle internal unconformities. Limited faulting. Corresponds to eroded seabed at subcrop	Limited occurrence in extreme east of area, less confidently interpreted in extreme south-west in heavily structured zone. Description based on appearance in east
E5c	Moderate amplitude sub-parallel reflections, subtle internal unconformities. Limited faulting. Low frequency appearance	Limited occurrence in extreme east of area, less confidently interpreted in extreme south-west in heavily structured zone. Description based on appearance in east
E4b	More amorphous, internal unconformities. Limited faulting. May contain more sand-prone cross-bedded sub-units	East of centre
E4a	A thick complex unit with sub-parallel reflectors. The reflectors become more closely spaced towards the base of the interval. Numerous low-displacement faults	East of centre
E3	Characterised by 2-3 moderate to high amplitude internal reflections that represent unconformities. Limited faulting	East of centre
C3-5	Thick unit with parallel to sub-parallel low to moderate amplitude reflectors. Wavy bedding towards base of unit. Limited faulting	Subcrop over centre of area
C2	Moderate amplitude parallel to sub-parallel reflectors. Mounding and onlap of base. Numerous low-displacement faults, but not in the lower mounded part	Subcrop over centre of area
C1	Thin ambiguous unit, transparent	Subcrop over centre of area
N6	Moderate amplitude parallel to sub-parallel reflectors. Some low-displacement faults, hints of very low displacement faults at the limit of resolution	West of centre
N5	Poorly defined reflectors, noisy appearence	West of centre
N1	Complex unit with lower dip than overburden. Moderate amplitude sub-parallel internal reflectors. Cross-bedded sub-units, truncation of upper surface. Numerous faults	Subcrop over west of area, corresponds to seabed erosion

Unit	Seismic facies description	Comments, distribution
J	Moderate amplitude parallel to sub-parallel reflectors, numerous faults	Complex subcrop in west, heavily influenced by tectonics

6.3 SHALLOW GEOLOGY

6.3.1 Holocene Seabed Veneer

The seabed veneer comprises Holocene sand, gravel with clayey silt. The base of this interval is imaged and mapped on the sub-bottom profiler data. The interval is acoustically amorphous, its base is a truncation surface where reflectors within older units abruptly terminate (Figure 6-6 and Figure 6-7). The unit is typically less than 1 m thick and is likely to exist as a very thin discontinuous layer beyond those areas where it is mapped.

There is also likely to be relatively thick pockets of these sediments between the widely spaced survey lines. Due to the combination of the wide line spacings and the unit's thinness, the interval is not continuously gridded across the area.

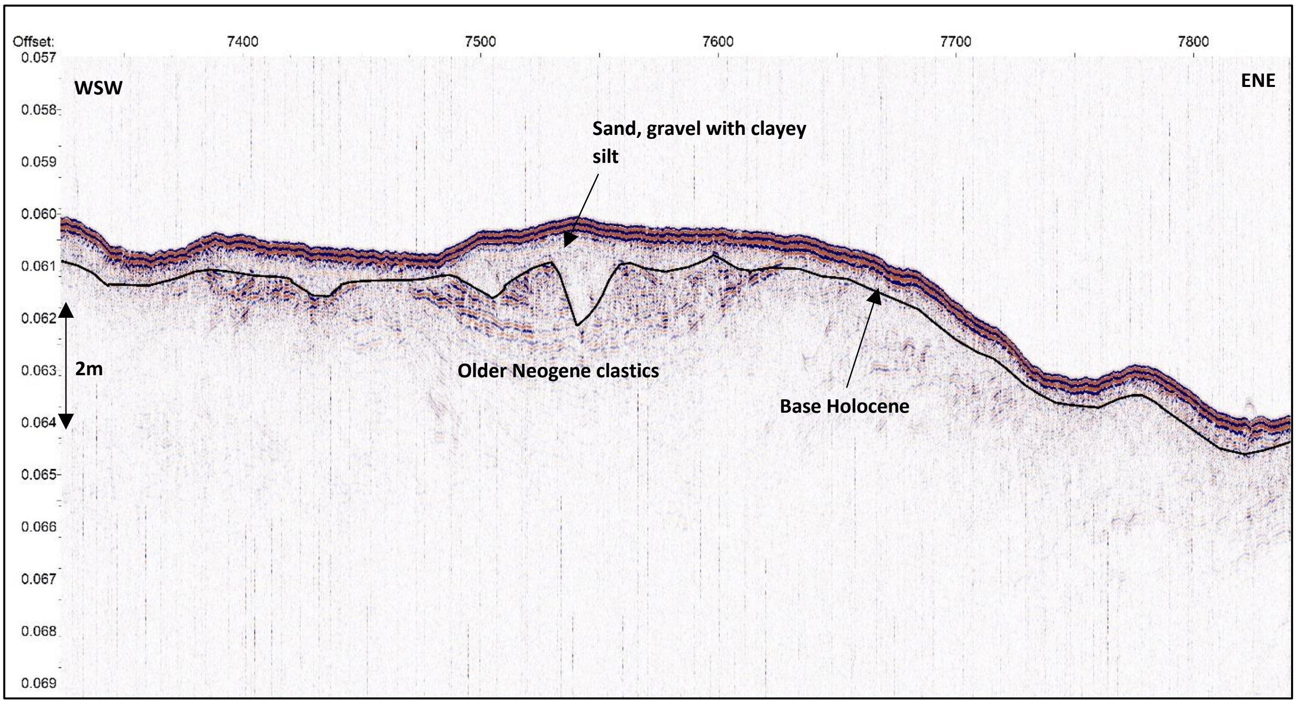


Figure 6-6: M006 SBP, sand, gravel veneer (location of the profile is presented Figure 6-9)

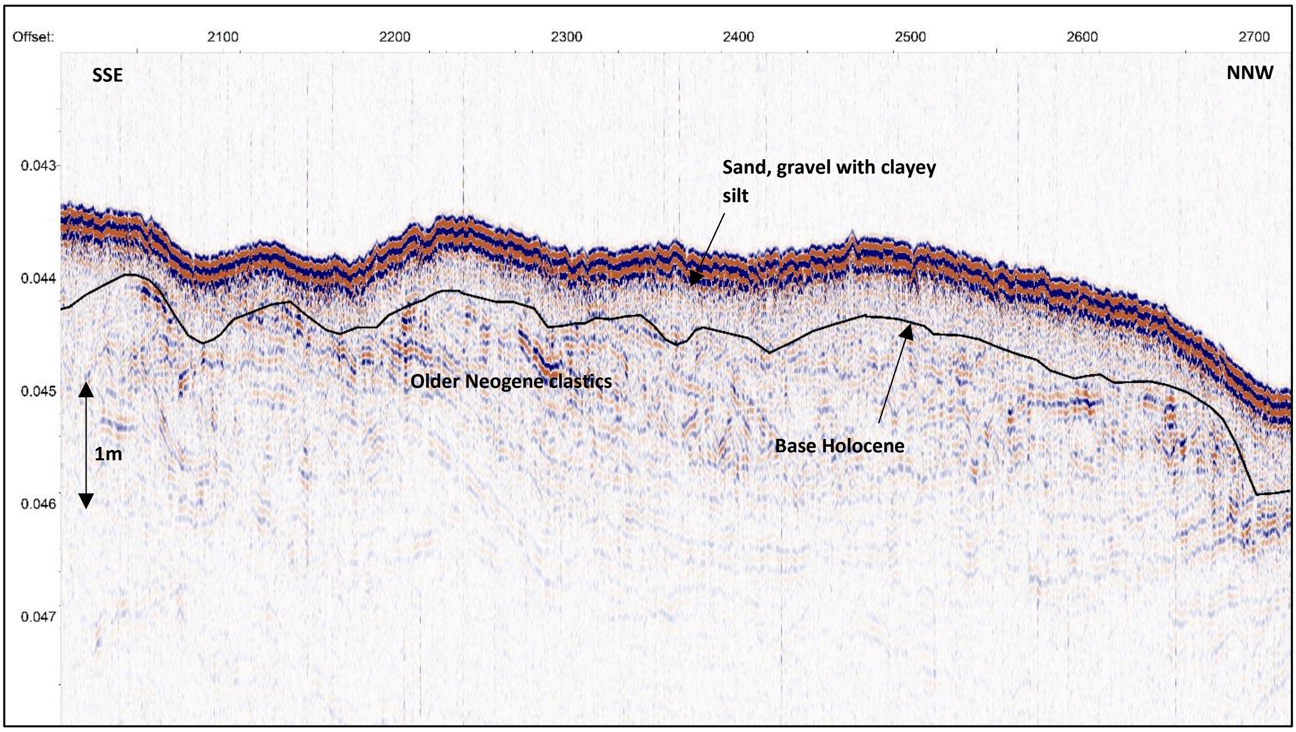


Figure 6-7: X028 SBP, sand, gravel veneer (location of the profile is presented in Figure 6-9Figure 6-10)

6.3.2 Neogene and Quaternary

The base Neogene is mapped in the UHR data. This is a strong truncation surface of the dipping older rocks, creating an angular unconformity. Over wide areas the Quaternary/Neogene interval is less than 3 m thick and may mostly comprise of the Holocene veneer.

The Neogene and Quaternary deposits are significantly thicker in the extreme north-west and south-west of the area and in the north-east. In these places the unit is generally over 20 m thick and is up to 60 m thick in the north-west of the area.

In these thicker areas the sequence is split into subunits based on shared seismic characteristics. In the west there are five sub-units and there are two in the north-east (Figure 6-8). The equivalence of these sub-units between the separate mini basins is uncertain.

The mini basins are generally cut into the pre-Neogene clastic units. The areas of chalk (over the centre of the area) have not undergone such incision; they are planed off quite flat. The erosion does not appear to correspond to the path of an ancient drainage system or to places where the older rock is shattered with faults. The erosion is likely a response to regional early Neogene tectonic uplift.

The age distribution of these Neogene/Quaternary deposits is unclear. It could be that the bulk of the deposits date from the onset of glacial activity over the last 0.5 to 1 million years when there was an increase in the flux of erosion products supplied to continental margins.

The thickness of the Neogene and Quaternary is shown in Figure 6-9.

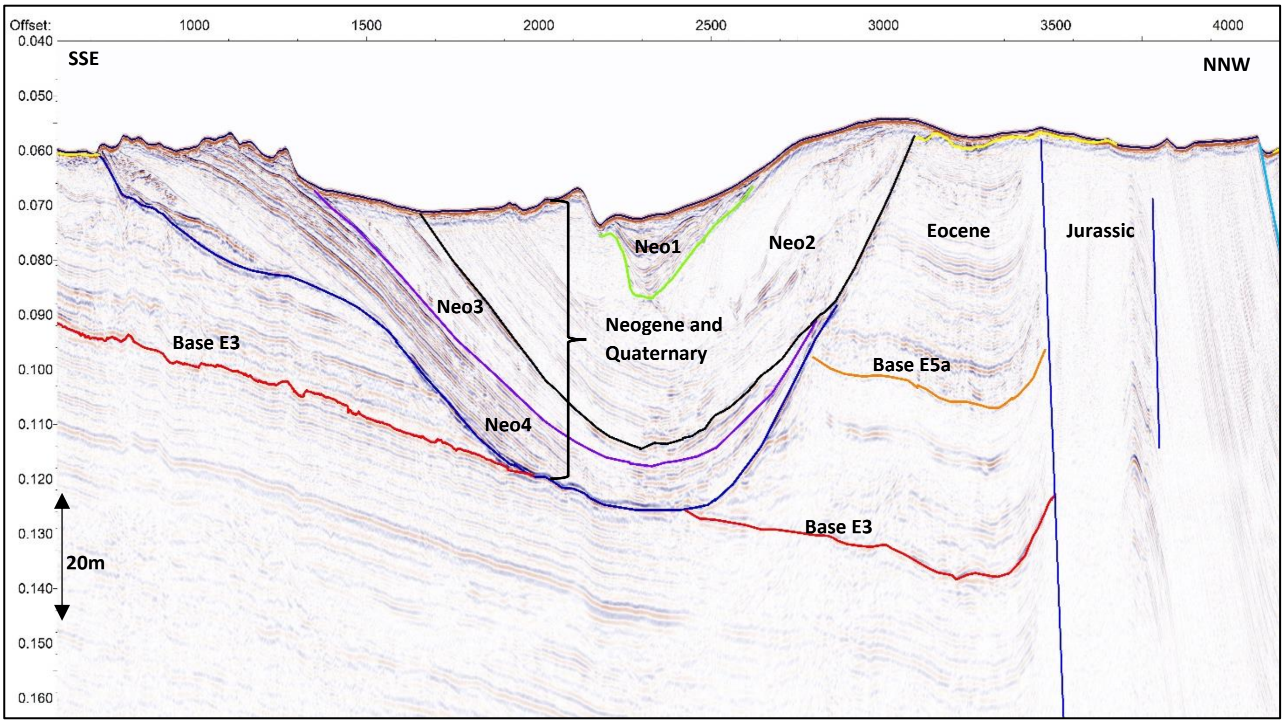


Figure 6-8: X005 UHR, Neogene and Quaternary, south-west of area (location of the seismic profile is presented in Figure 6-9)

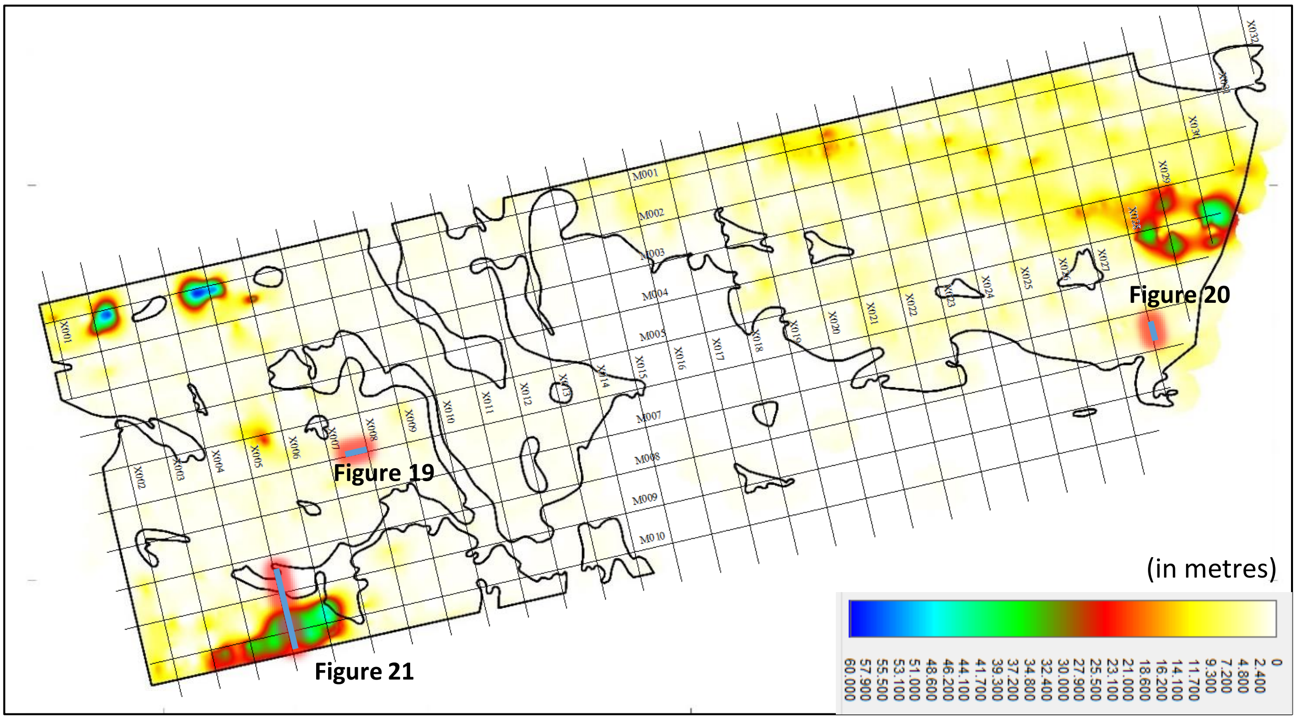


Figure 6-9: Thickness, Neogene and Quaternary

6.4 DEEPER GEOLOGY

The pre-Neogene deposits that extend to within ~50 m of the seabed range in age from Eocene to Jurassic. Various unit bases are mapped, based on the stratigraphy of the supplied desk study (Figure 6-5). The interpretation of subcrop patterns is at the unconformity that truncates the sequence. This surface is generally (over ~90 % of the area) within 3 m of the seabed but locally this truncation surface is up to 60 m below seabed, in these areas the truncation is infilled by Neogene/Quaternary deposits.

The subcrop patterns are dictated by a combination of the regional dip (about 1 degree to the north-east) and strike of the older sediments, the influence of large faults and the erosion of the sequence. The following descriptions split the sequence based on their lithologies.

The text sections are reflected in the colour differentiation of Figure 6-10.

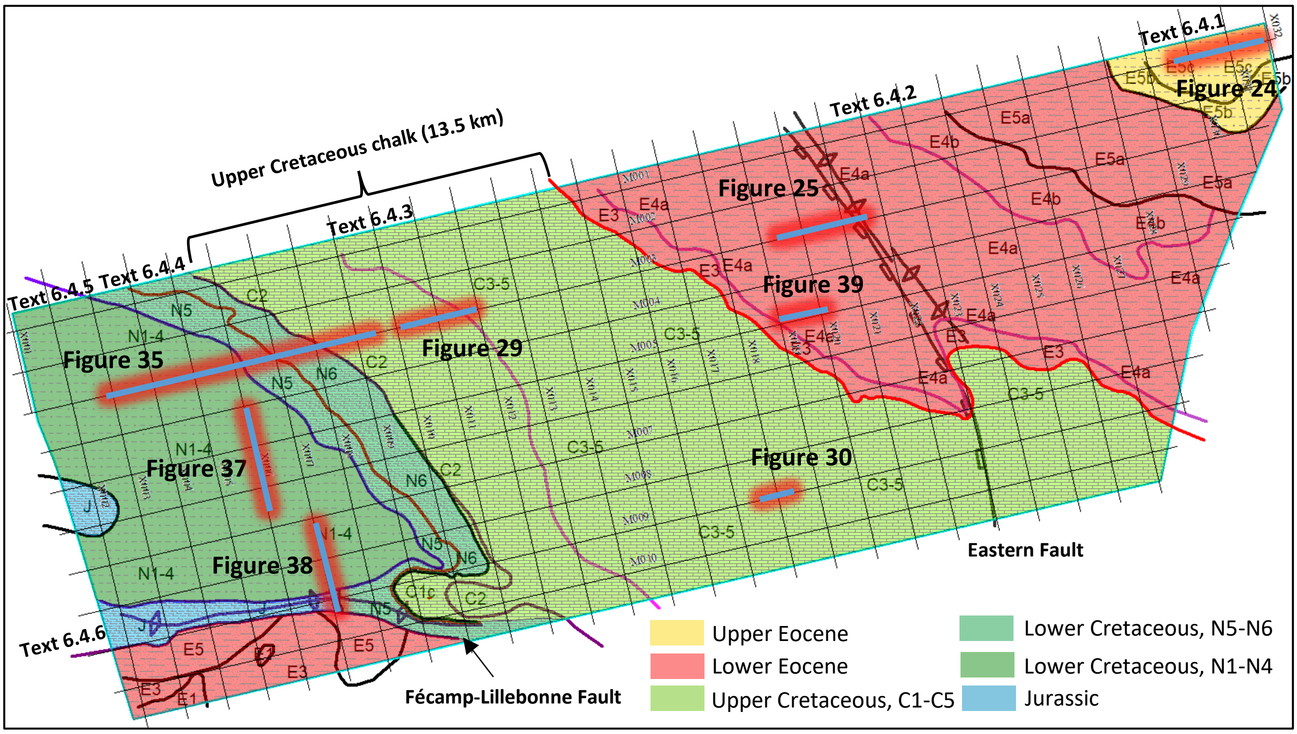


Figure 6-10: Subcrop patterns

6.4.1 Upper Eocene, E5b, E5c

The Upper Eocene E5b/c deposits subcrop in the far north-east of the area. This distribution is part of the general eastward younging of the sequence, a consequence of the regional north-east dip and the subsequent erosion.

These Upper Eocene deposits are sand and silt prone with subordinate clay layers. The seismic appearance is unexceptional; continuous reflections of moderate amplitude. These deposits are displaced by a normal fault in the north-east extremity of the site (Figure 6-11).

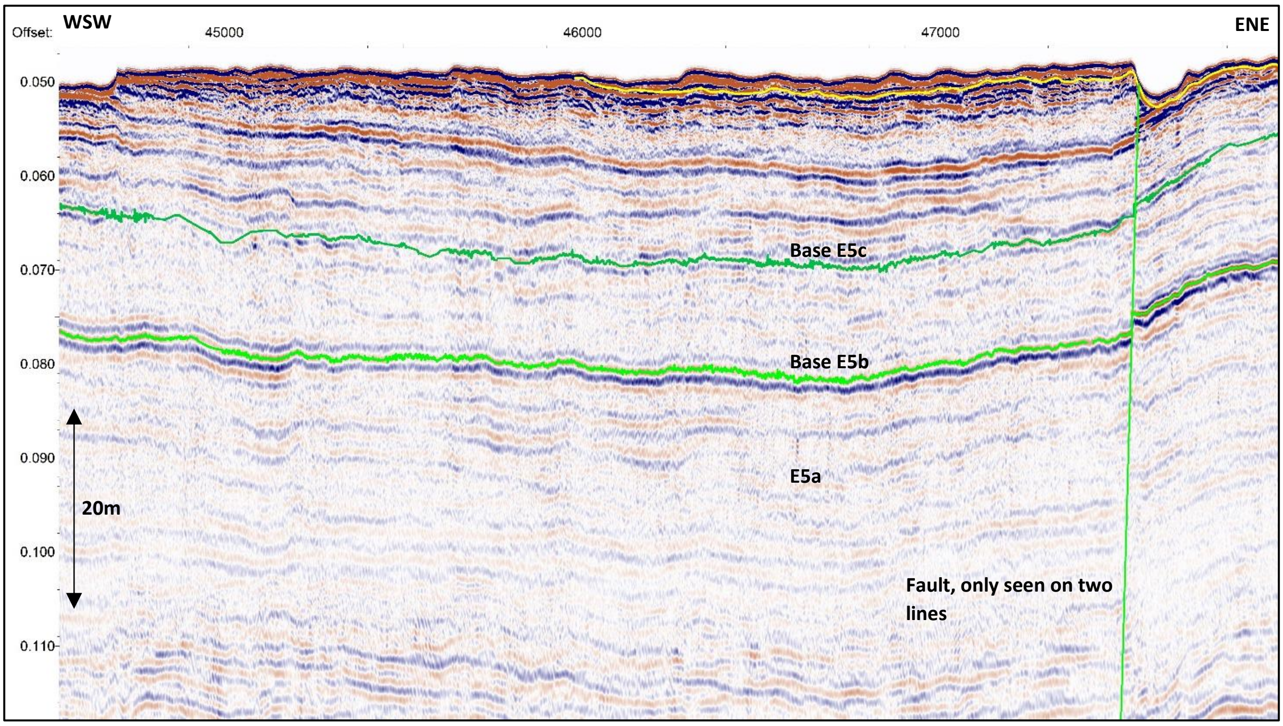


Figure 6-11: M001 UHR, Upper Eocene, north-east of area (location of the profile is presented in Figure 6-10)

6.4.2 Lower Eocene, Paleocene, E5a to E3

The Lower Eocene/Paleocene deposits subcrop over most of the north-east of the area. Their distribution generally conforms to the regional north-east dip of the sequence but is influenced by a large fault/fault trend striking north-west to south-east across the area (This is named the Eastern Fault in this report.)

There is a further Lower Eocene subcrop in the extreme south-west. This is a result of displacement by a large, very steep, east-west striking fault that places Eocene deposits against Jurassic sediments. This is probably the Fecamp-Lillebonne fault.

Sediments range from sand and limestone in E3, clay and sand in E4a and limestone in E5. The middle part of Unit E4a, has a thickness of ~30 m, is characterised by numerous low-displacement faults (Figure 6-12) and has a more finely bedded seismic appearance than the E3 subcrop.

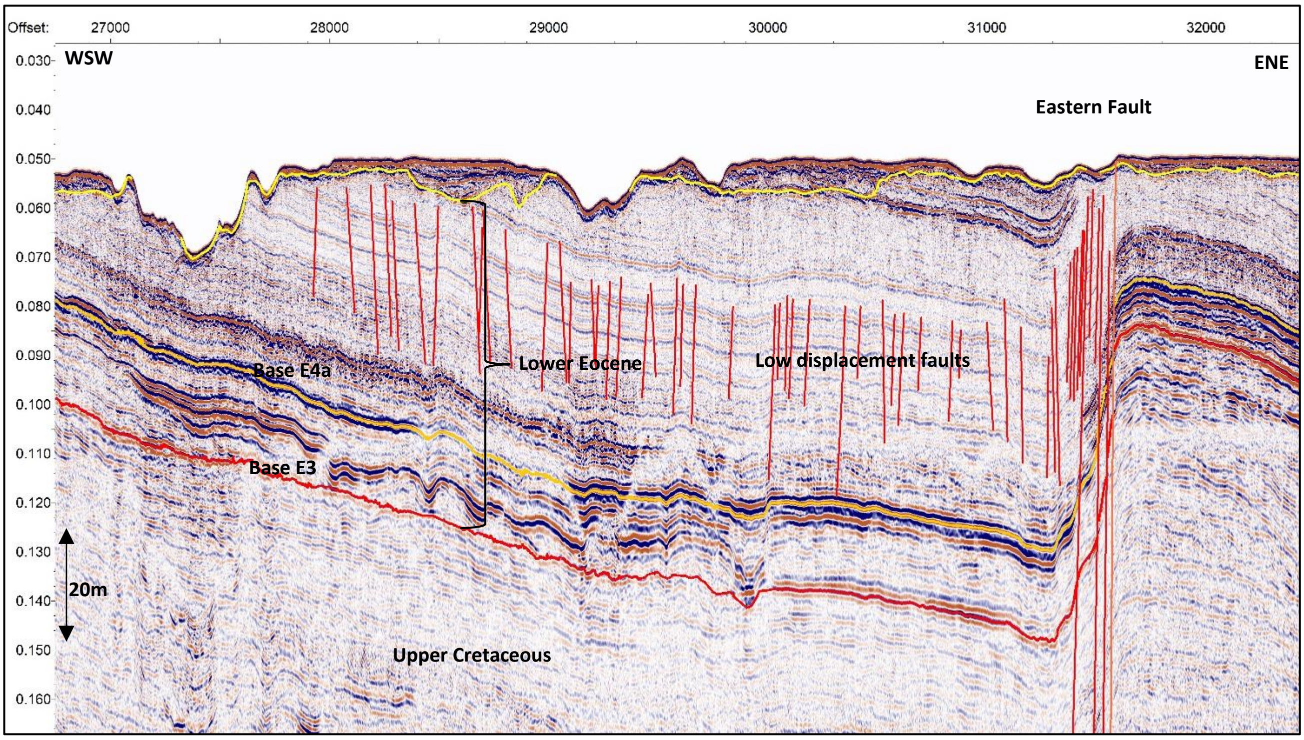


Figure 6-12: M003 UHR, Lower Eocene, north-east of area (location of the profile is presented in Figure 6-10)

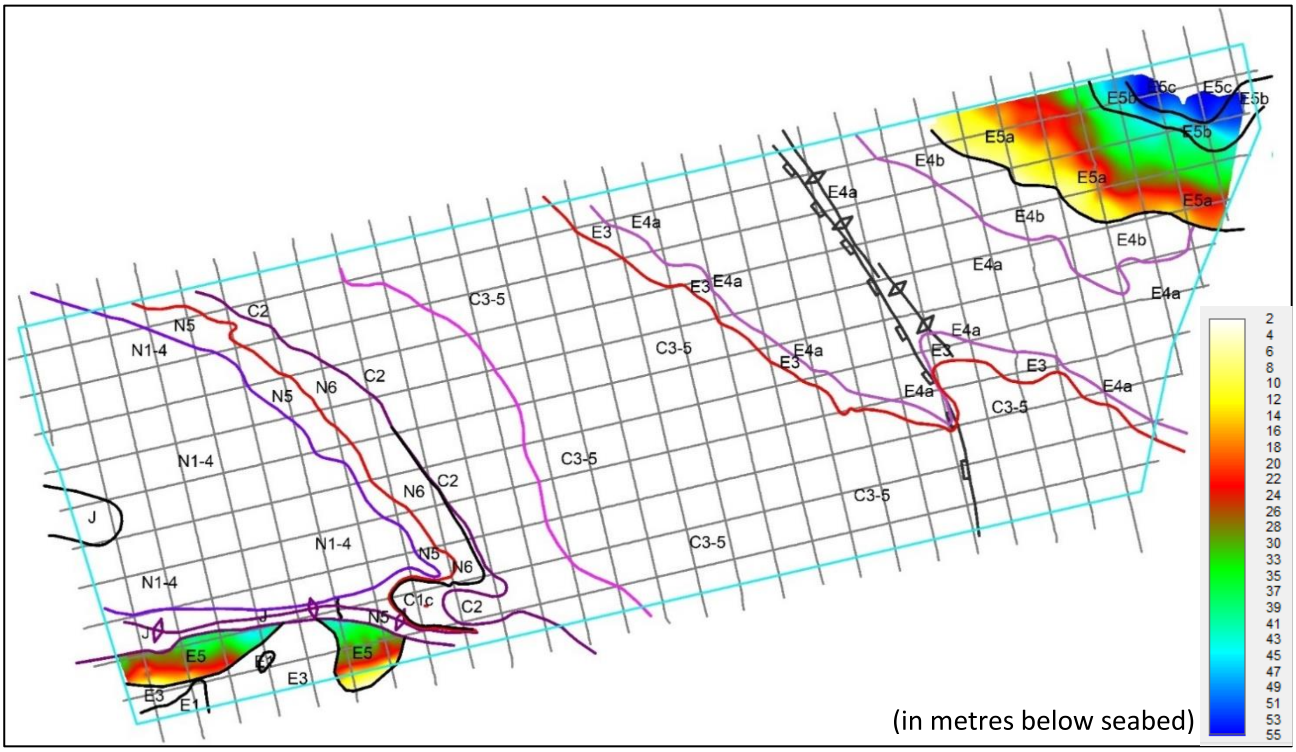


Figure 6-13: Base E5a

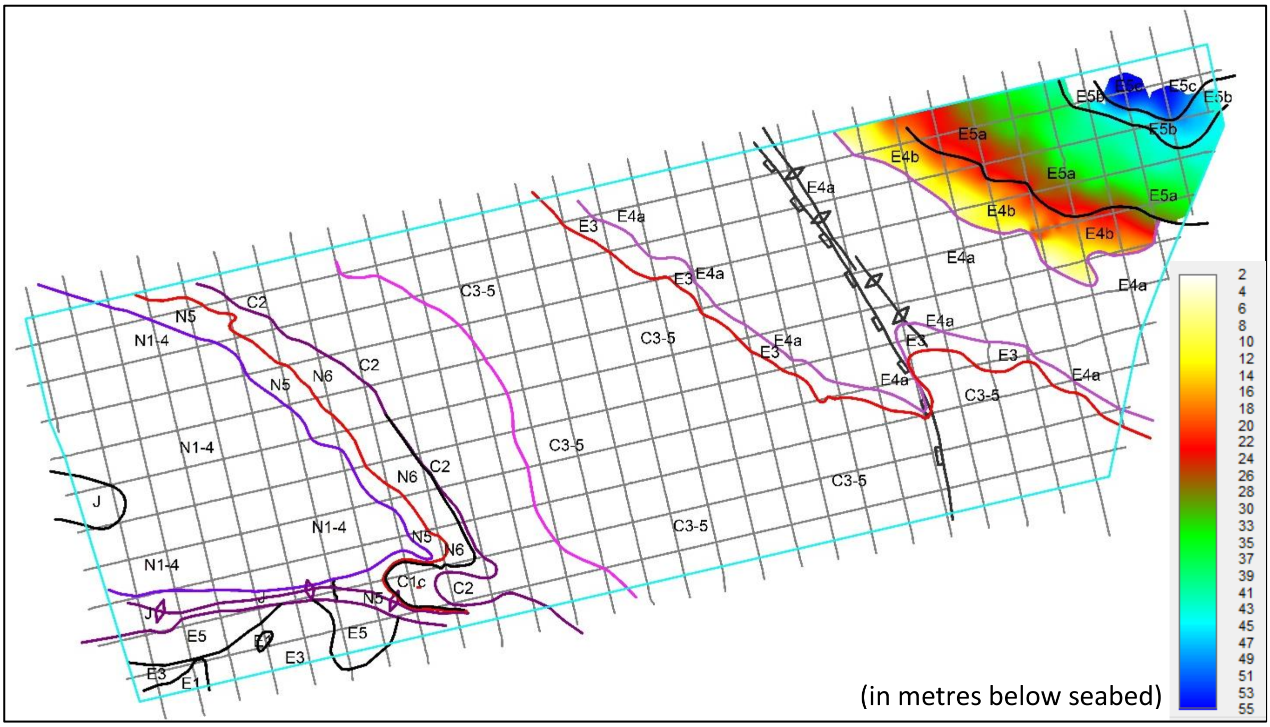


Figure 6-14: Base E4b

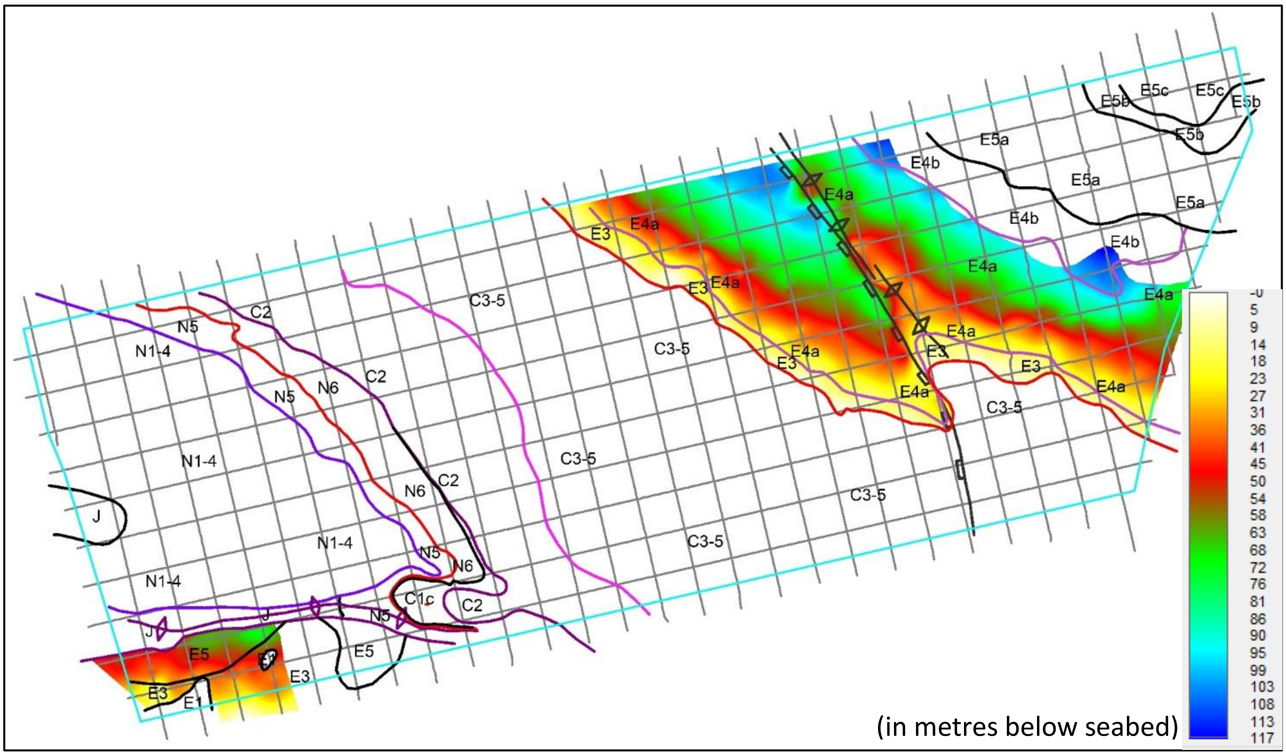


Figure 6-15: Base E3

6.4.3 Upper Cretaceous, C1 to C5

This part of the succession comprises chalk with flints. This chalk subcrops over a large part of the centre of the site, a swathe approximately 15 km wide. The upper truncation surface of the chalk is quite planar and smooth. The chalk is generally close to seabed under a very limited thicknesses of Neogene-Quaternary-

Holocene veneer. Dip patterns are similar to those of the Eocene sediments – approximately 1 degree to the north-east.

Unit C1 is very thin. C2 has a well bedded seismic appearance and contains numerous low-displacement faults. The lowermost part of C2 shows some structures indicative of a contourite influence on sedimentation; mounding and downlap. This could indicate that the ancient depositional surface had some dip, that the sequence's present-day dip is not entirely a result of early Neogene tectonics (Figure 6-16).

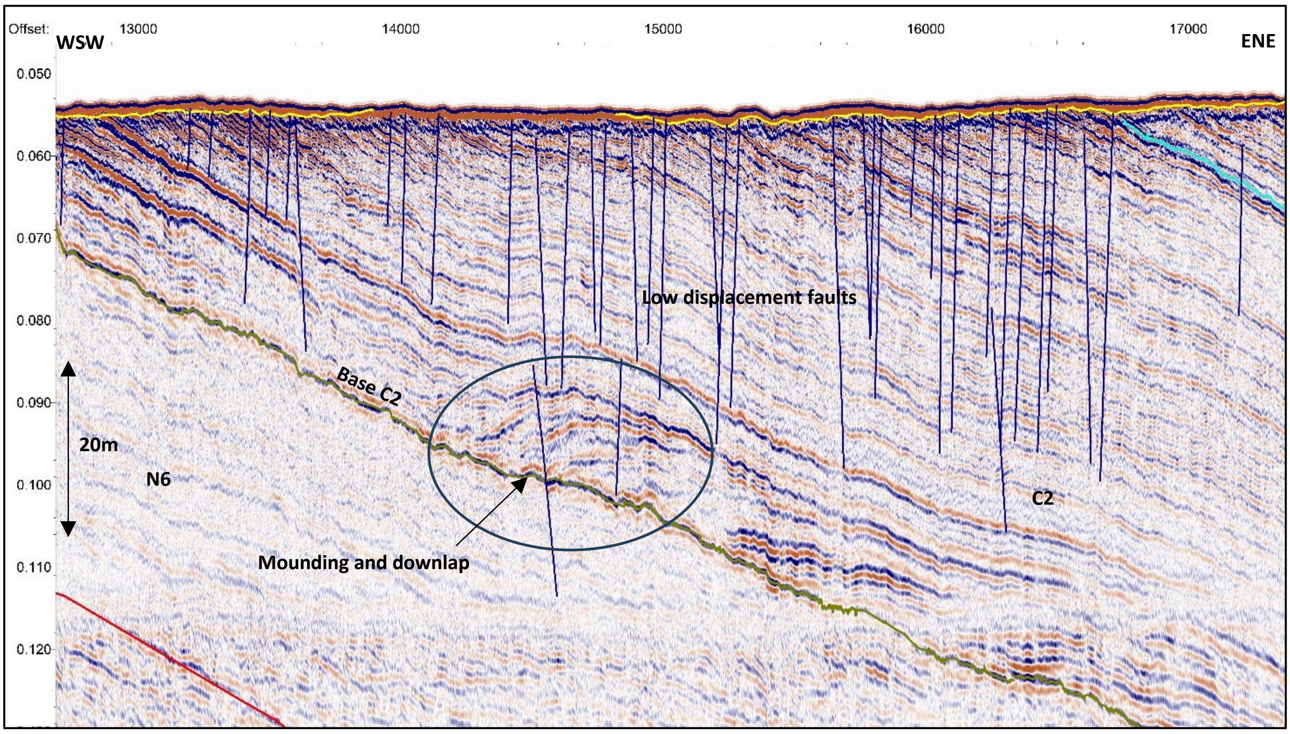


Figure 6-16: M003 UHR, Upper Cretaceous C2, centre of area (location of the profile is presented in Figure 6-10)

The C3-5 sequence has a less conformable internal structure. The lower part shows wavy bedded facies, this facies type is associated with bottom current influence on sedimentation (Figure 6-17).

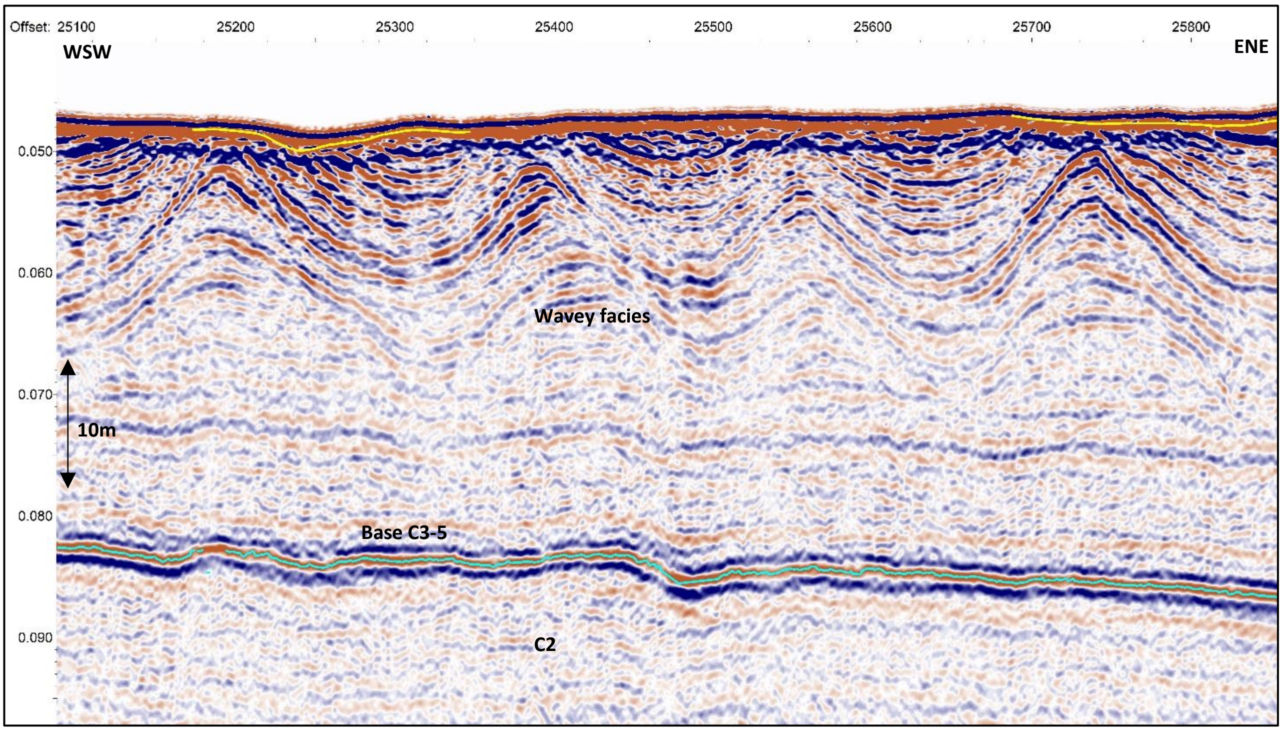


Figure 6-17: M009 UHR, Upper Cretaceous C3-5, south centre of area (location of the profile is presented in Figure 6-10)

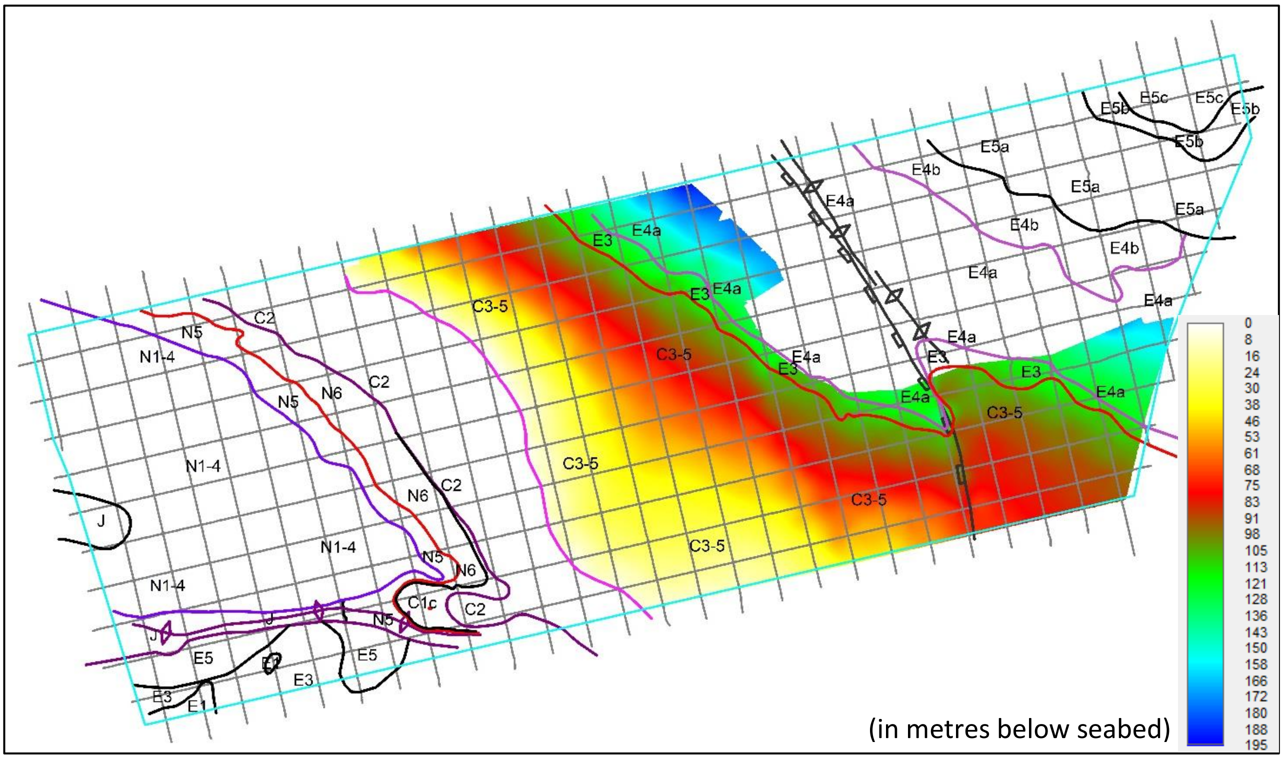


Figure 6-18: Base C3-5

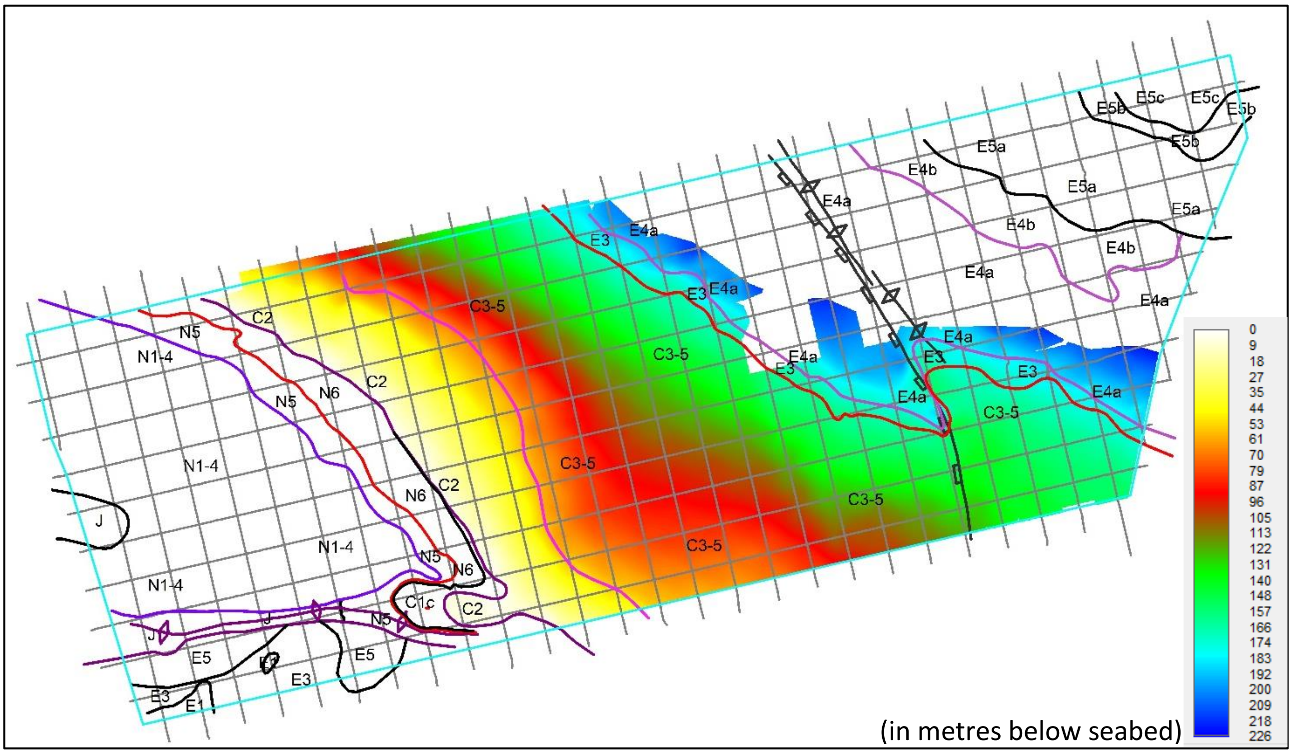


Figure 6-19: Base C2

6.4.4 Lower Cretaceous, N5 to N6

N5 and N6 subcrop over a ~2.5 km wide belt in the western part of the area. The Lower Cretaceous sediments are mostly sand and sandstone with subordinate clay layers. Marl, clay and puddingstone (pebbles in a finer matrix) occur with N6. N5 and N6 are the oldest deposits of the sequence that extends everywhere east of the N5-6 subcrop.

N6 has continuous low to moderate amplitude reflections, N5 is seismically amorphous (Figure 6-22).

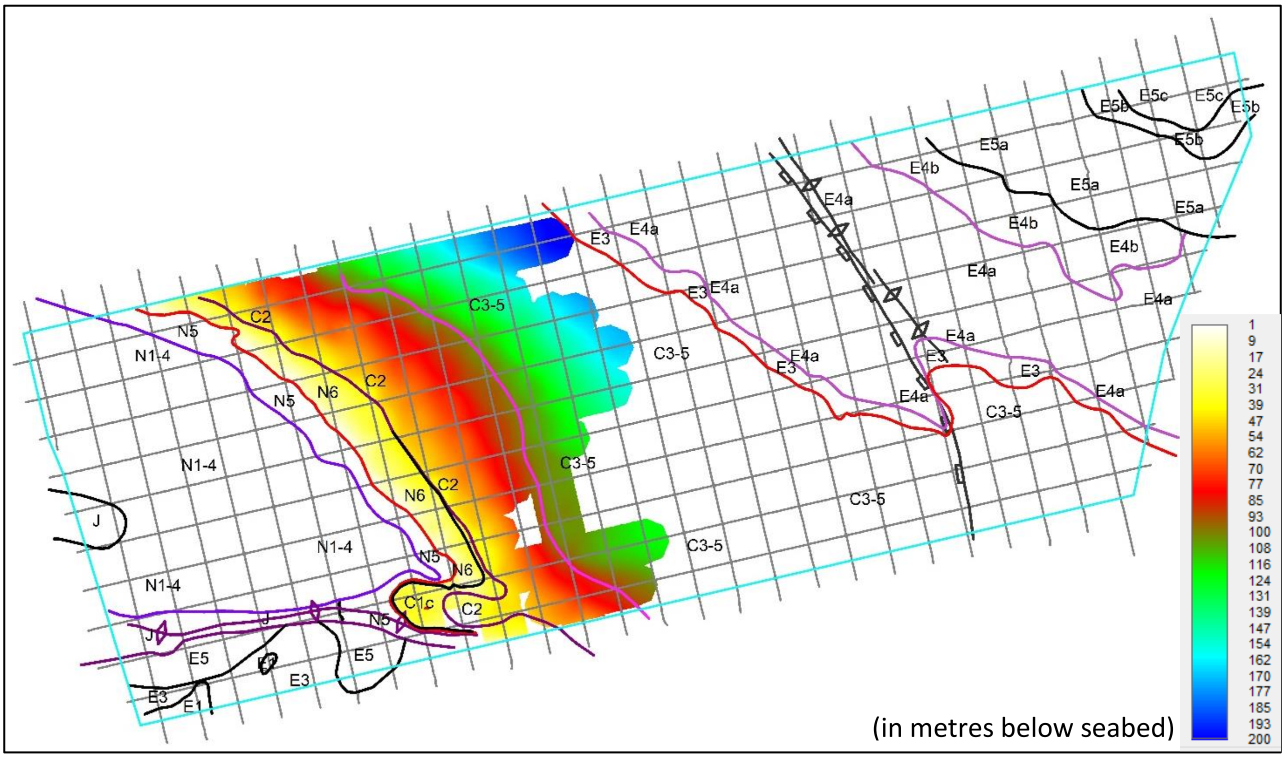


Figure 6-20: Base N6

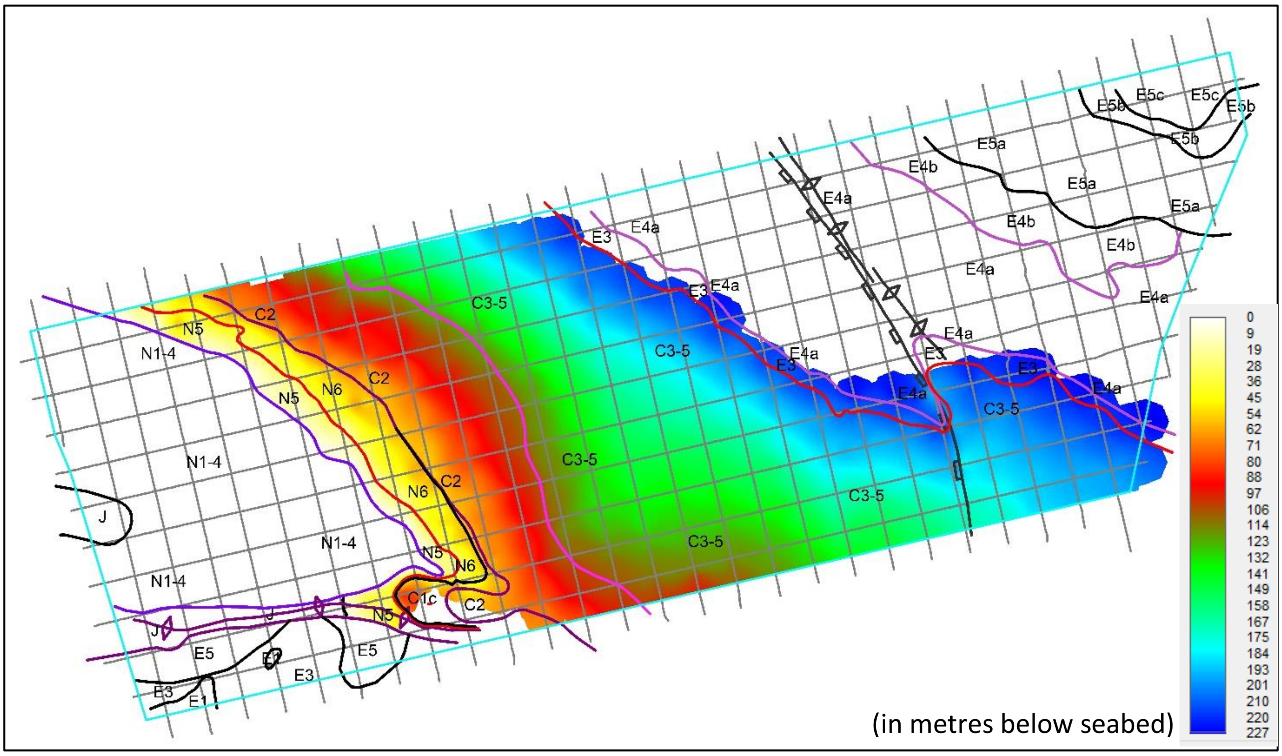


Figure 6-21: Base N5

6.4.5 Lower Cretaceous, N1 to N4

These deposits subcrop over most of the west of the study area. N5 and N6 sediments are mostly sand and sandstone with subordinate clay layers.

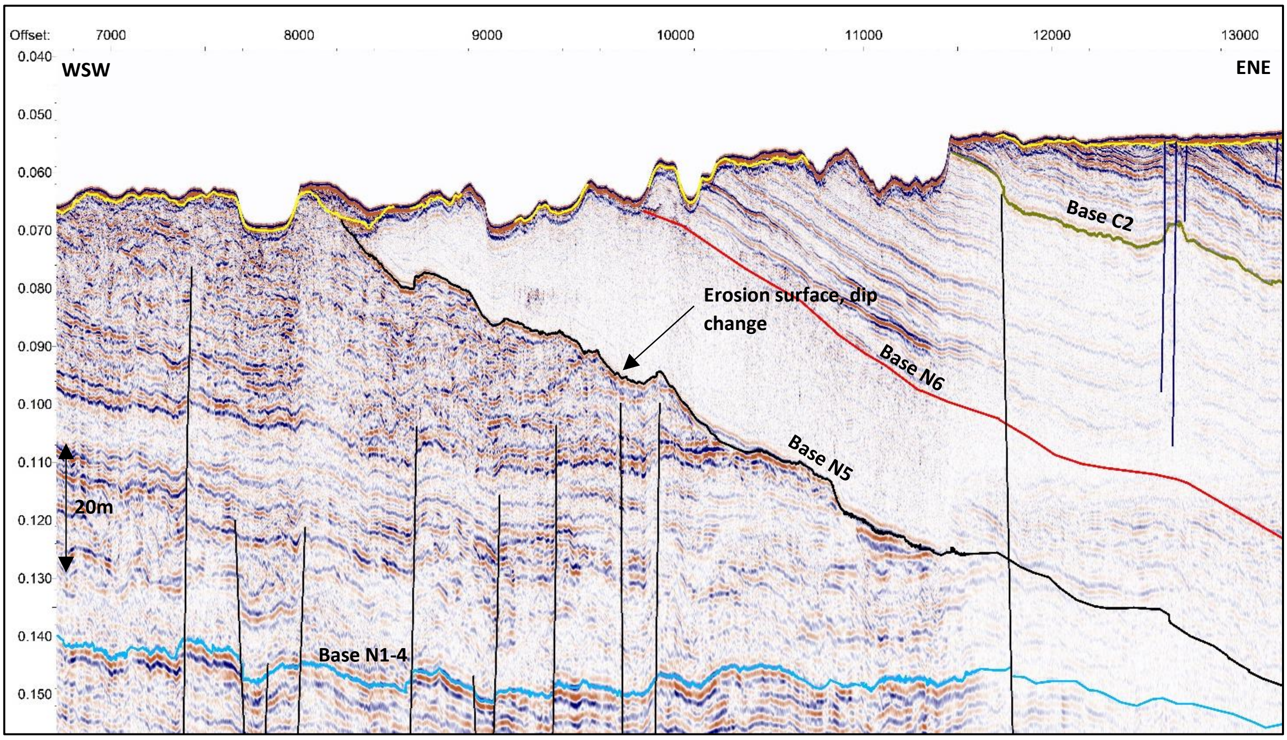


Figure 6-22: M003 UHR, Lower Cretaceous N1-4, west of area (location of the profile is presented in Figure 6-10)

This Lower Cretaceous sequence is cut by a major erosion surface that separates N5 sediments from all older sediments (Figure 6-22). Base N5 is the bottom of the succession that dips at about 1 degree to the north-east. The older N1-4 deposits have much lower dip angles, the Base N5 erosion surface cross-cuts these rocks, this surface is in the stratigraphic diagram (Figure 6-5).

N1-4 deposits are quite distinct with lower dip and much higher amplitude internal reflections. This may indicate a greater level of induration. The N1-4 interval contains cross-bedded intervals that likely comprise clean sand/sandstone (Figure 6-24).

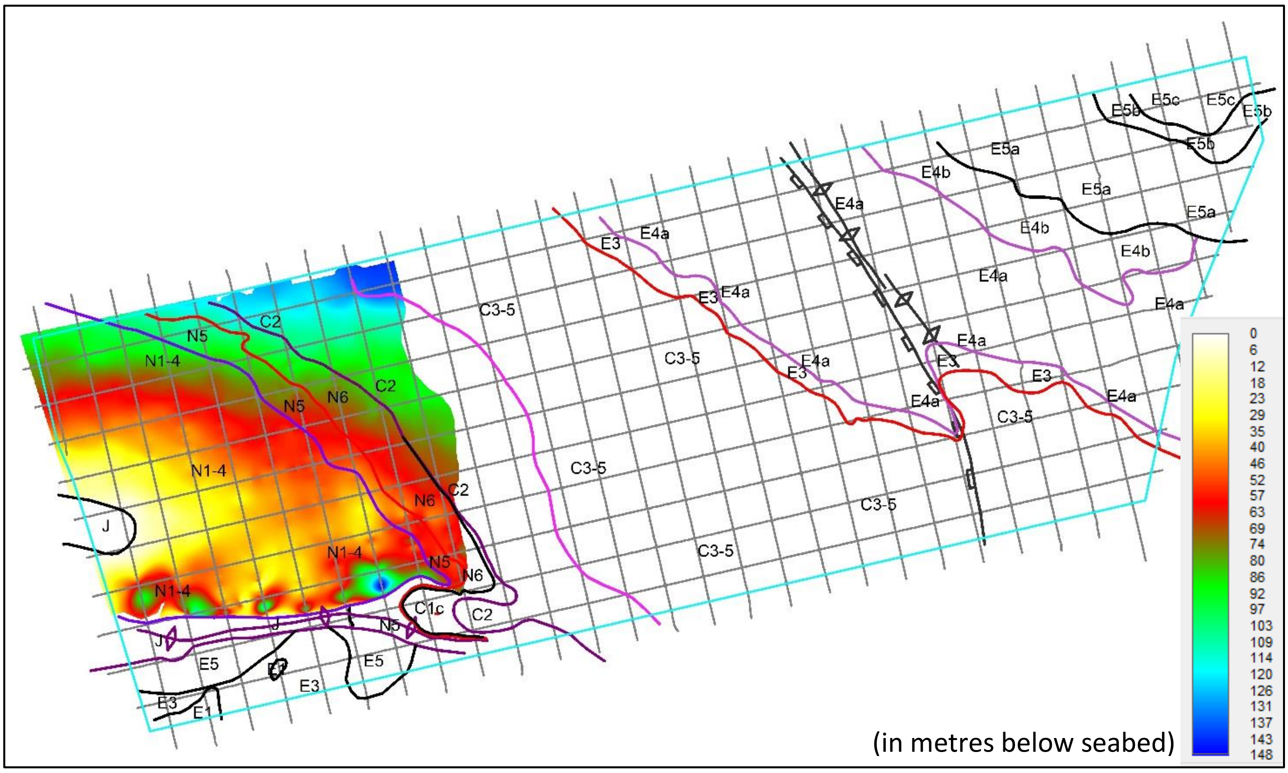


Figure 6-23: Base N1-4

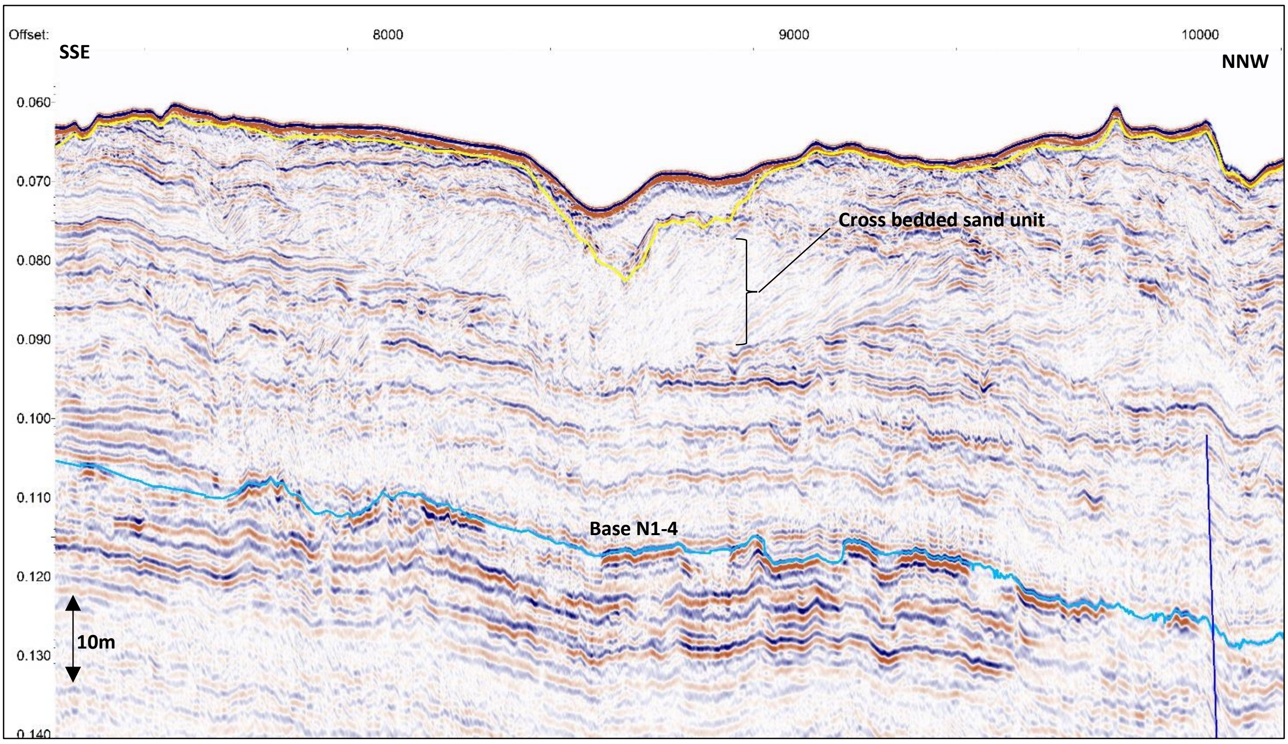


Figure 6-24: X006 UHR, Lower Cretaceous N1-4, west of area, sand unit (location of the profile is presented in Figure 6-10)

6.4.6 Jurassic

Jurassic deposits subcrop over a ~1 km wide east-west trending strip in the south-west of the area. The rocks are close to seabed along the northern side of the Fécamp-Lillebonne fault. The unit is steeply dipping and imaging is poor, these beds are likely to be faulted. Imaging improves slightly further north of the major fault the Jurassic beds form an anticline and are faulted.

There is an additional area of Jurassic subcrop in the central western part of the area. The Jurassic rocks comprise marl, limestone and clay, a predominantly carbonaceous interval.

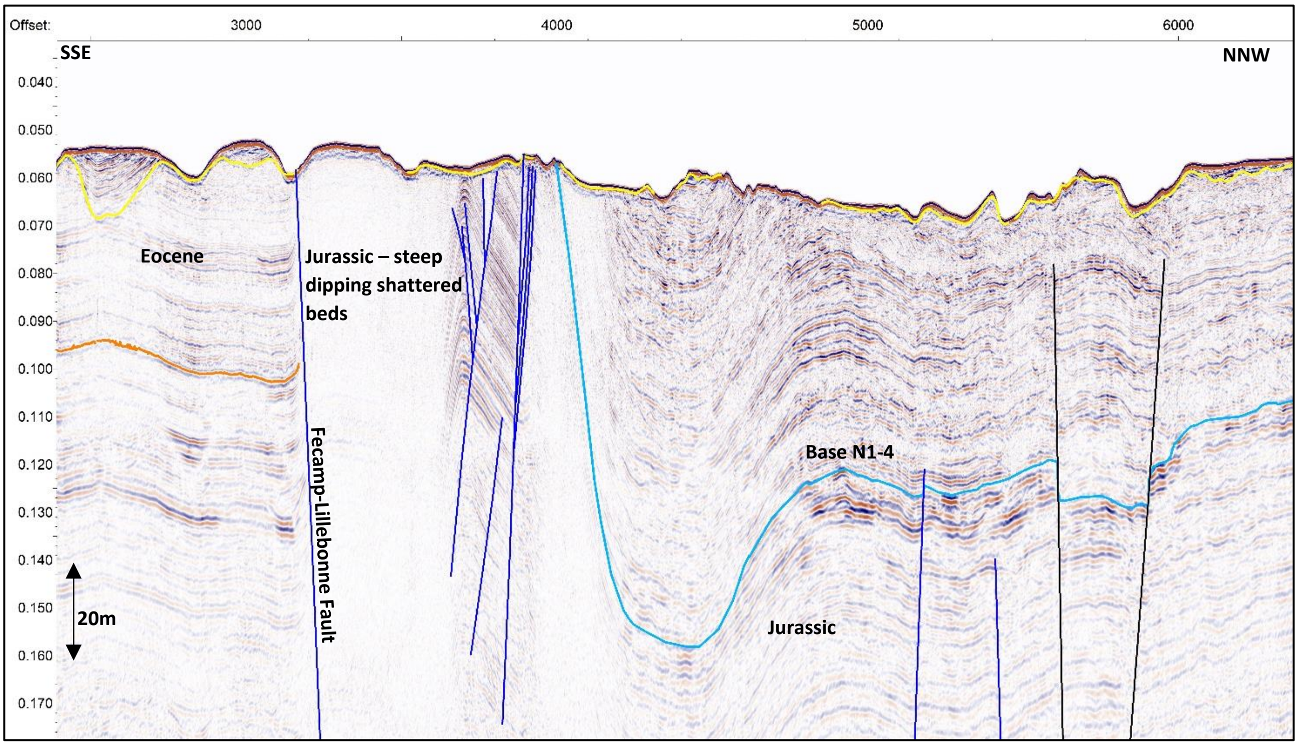


Figure 6-25: X007 UHR, Jurassic subcrop, south-west of area (location of the profile is presented in Figure 6-10)

6.5 GEOHAZARDS AND GEOLOGICAL INSTALLATION CONSTRAINTS

6.5.1 Shallow gas

The survey line spacing is too great to enable a meaningful overall interpretation of the area's shallow gas potential. There are scattered seismic anomalies, potentially representing shallow gas, on some of the UHR lines. These anomalies are interpreted to have a moderate probability of representing shallow gas.

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.

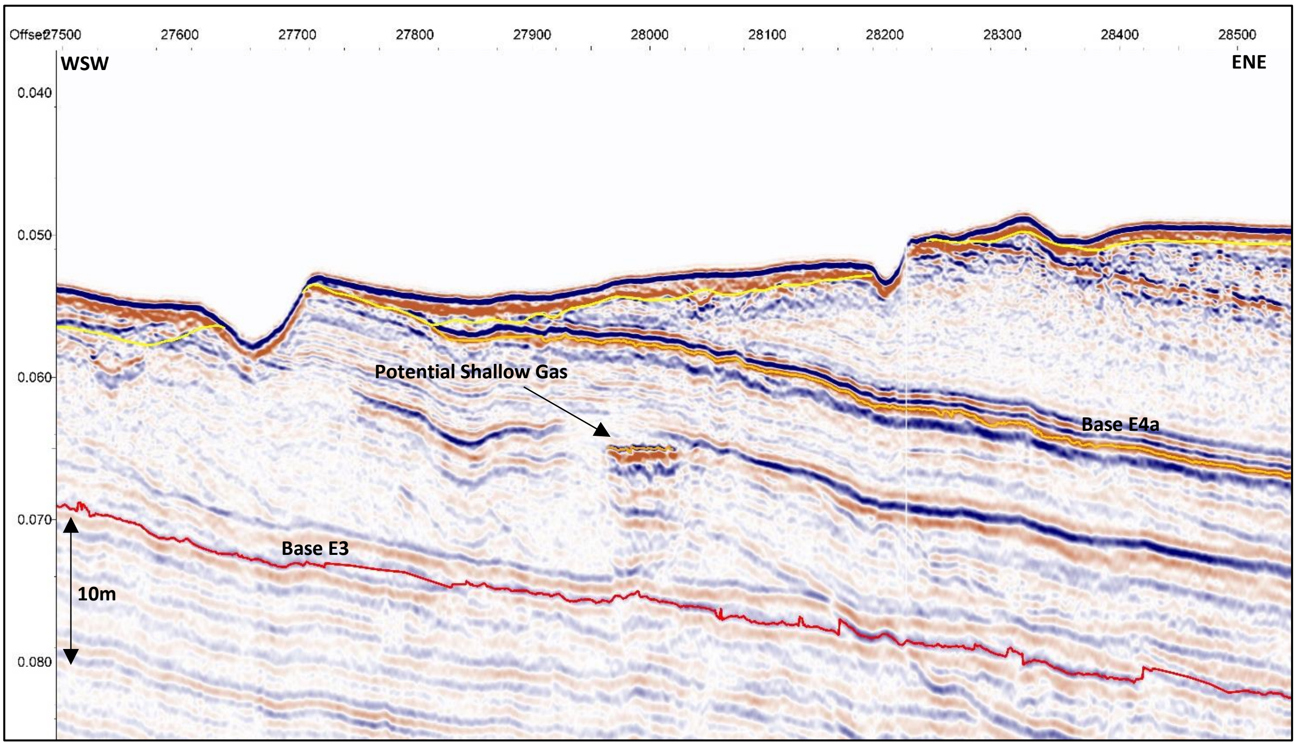


Figure 6-26: M005 UHR, Potential Shallow Gas, east of area

6.5.2 Faulting

Small faults

Two pre-Neogene units are characterised by low displacement normal faults. These are C2 and E4a. C2 chalk sub crops over a ~4 km wide band just west of the centre of the area. E4a sub crops in two areas either side of the major fault east of the centre of the area.

These faults may be accommodating general tectonic stress (especially perhaps those in E4a) or they may be related to dewatering/shrinkage of the affected formations. There are scattered minor faults in other units.

These small faults will locally reduce formation strength.

Large faults

The major faults are the Fecamp-Lillebonne fault in the extreme south-west and the large normal fault/fault trend (here called the Eastern Fault) running north-west to south-east just east of the centre of the area (Figure 6-6).

The F-L fault trending east-west is very ste.ep dipping and abruptly places Jurassic rocks beside Eocene sediments. Within 500 m of the fault Jurassic sediments are at a high angle and, as a result, poorly imaged. They are likely to be heavily faulted. 0.5 to 1 km north of the fault the Jurassic beds are faulted and form an anticline. The main practical impact of this fault is probably the immediate contrast in ground conditions that it creates.

The other large fault, the Eastern Fault, influences the distribution of Eocene units. Displacement seems to be shared across a few closely spaced faults with similar characteristics. This fault trend has an associated anticline which is immediately east of the fault.

There are numerous other faults that displace the older rocks but have limited influence close to the seabed and are difficult to trace from line to line.

There is no evidence that the large faults are acting as conduits for fluid flow through the sequence.

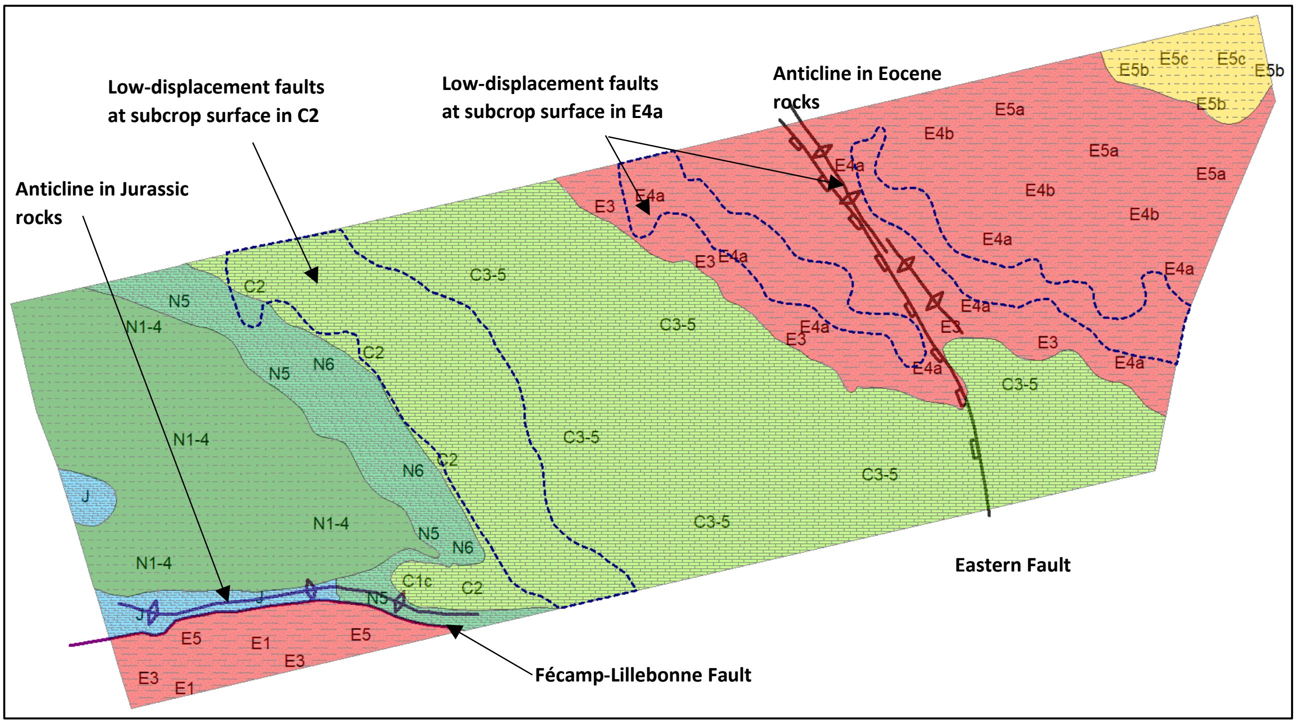


Figure 16: Subcrop patterns and structure

6.5.3 Variable Ground Conditions

The major practical consideration for operations may be the variety of sediments within the shallow sequence. These different geological units may require differing engineering foundation design and different development approaches.

Some key considerations may be:

1) How thick are the Neogene/Quaternary cover sediments?
2) Is the pre-Neogene sub crop chalk, Lower Cretaceous/Jurassic rock or Eocene sediments?
3) Is the pre-Neogene sequence faulted?

APPENDIX A. UHRS PROCESSING WORKFLOW