NOR_AO4 AREA OFFSHORE WINDFARM UHR SEISMIC SURVEY	NOR_TEC_32_RESULTS REPORT – SEISMIC SURVEY - AO4 OWF AREA_0.4_A PROJECT No. 113401272
RESULTS REPORT	No. OF PAGES 118

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REV	***DATE***	***DESCRIPTION***	***BY***	***CHK***	***ENG***	***PM***	***CLIENT***

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ABBREVIATIONS

ASV	Assumed Seismic Velocity
BRGM	Bureau de Recherches Géologiques et Minières
BSB	Below Seabed
CM	Central Meridian
DGEC	Direction Générale de l'Énergie et du Climat
Km	Kilometre
LAT	Lowest Astronomical Tide
m	Metre
MD	Measured Depth
m/s	Metres Per Second
ms	Milliseconds
MSL	Mean Sea-level
MBES	Multibeam Echosounder
OWF	Offshore Windfarm
TWT	Two-Way Travel Time
UHRS	Ultra High Resolution Seismic
USBL	Ultra-short Baseline
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VR	Vertical Resolution
WGS84	World Geodetic System 1984

EXECUTIVE SUMMARY

According to the detected bathymetric results in the acquired lines of the offshore windfarm survey area, water depths vary between -32.9 m in the south-east and gradually deepen to -54.3 m in the north-west. The seabed slopes are moderate, with average seabed gradients of 1.62°, maximum values of 77.76º and minimum values of 0º.

The seabed gradient was computed at 22 planned borehole locations distributed over the range of water depths across the site. The slopes are gentle, with seabed gradients varying (as computed at the planned borehole locations) from <0.5 to 2°.

Shallow channels of unconsolidated sediment occur across the site, varying in thickness between 0 m and 58 m (in the north-west corner). The underlying sediments dip down gently (~0.6°) to the north-northwest, and comprise Bartonian sands in the north, Lutetian sands in the centre and Thanetian/Ypresian clays and sands in the south.

No evidence of shallow gas is observed.

Numerous faults occur within the site, generally trending from west-southwest to east-northeast. They terminate beneath the shallow channels, but they can be seen at seabed in the north of the site, where the channels are absent.

1. INTRODUCTION

1.1. PROJECT OVERVIEW

Tecnoambiente carried out a geophysical survey over the proposed NOR_AO4 lot located approximately 40 km off the coast of Normandy in the Bay of Seine. The site is under consideration for a windfarm and offshore substation.

The objective of this report is to present the data obtained in the seismic phase of the NOR_AO4 work area, focusing only on the Offshore Windfarm (OWF). The survey area is approximately 25 km x 23 km with water depths ranging from 20 – 60 m.

The following data were used in the study:

- 669.6 km of MBES and UHRS data.
- Background data as discussed in section 3.2 of this report.

Figure 1-1 shows the location overview. Figure 1-2 shows the survey line plan.

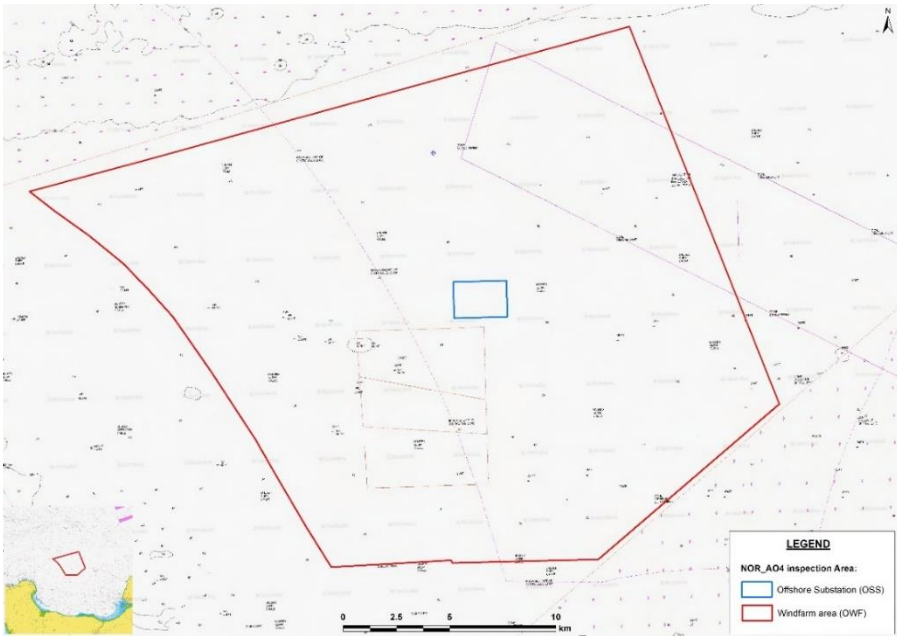


Figure 1-1: Windfarm area (OWF) and Offshore Substation (OSS) in the NOR_AO4 Survey area.

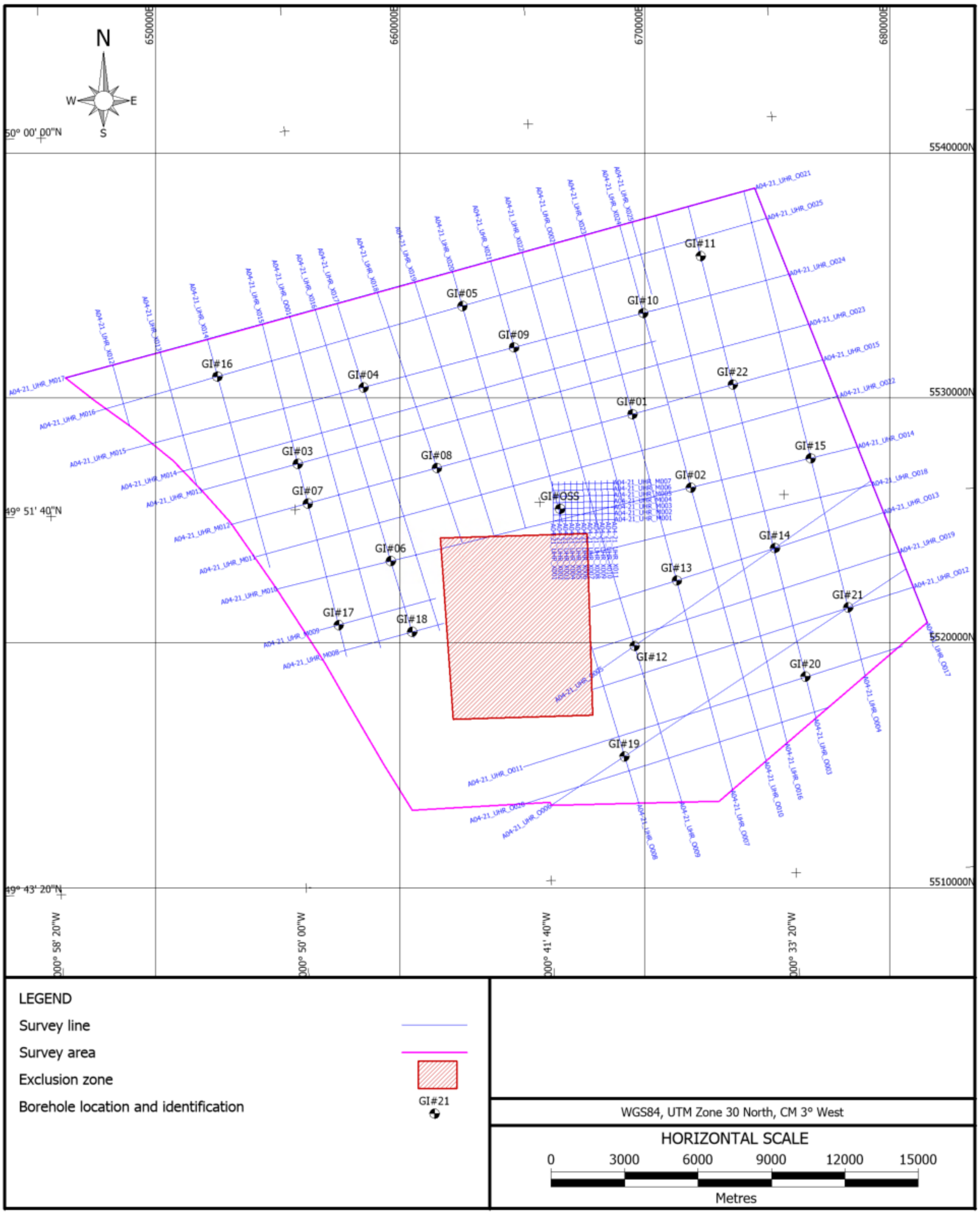


Figure 1-2: Line plan for NOR_AO4 Windfarm area (OWF).

1.2. SCOPE OF WORK

The objective of the site survey was to perform a geophysical survey over the proposed OWF site comprising MBES and UHRS datasets. The purpose of this was to:

- To define the water depths and seabed topography
- To define the shallow (nominally 100m BSB) subsurface geology
- Review proposed borehole locations for geohazards.

The main purpose of the study is to provide an interpretation of the geophysical data to provide a preliminary ground model over the NOR_AO4 OWF site.

Near-surface (shallow) geophysics investigations include engineering, environmental, geohazards, infrastructure and archaeological applications and are generally defined as the use of geophysical methods to investigate the upper few metres to hundreds of metres of the Earth's crust[1].

1.3. GEODETIC PARAMETERS

1.3.1. Survey datum

These parameters are detailed below.

Table 1: Datum parameters table

DATUM	
Survey Datum:	WGS 84
Spheroid	GRS 1980
Semi-Major Axis (a)	6.378.137,000
Semi-Minor Axis (b)	6.356.752,31424
Inverse Flattening (1/f)	1/298,257223563

[1] https://seg.org/News-Resources/Near-Surface/About

Table 2: Projection parameters table.

PROJECTION	
Projection	UTM
False Easting	500000
False Northing	0
Latitude of Origin	0º00'00.000000''
Central Meridian	3º00'00.000000''
UTM Zone	30 N
Scale Factor on CM	0.9996
Units:	Meters
VERTICAL DATUM	
Chart Datum	Bathyelli v2
Surface of reference	ZH/ell (Zero Hydrographic to the ellipsoid)

1.3.1. Vertical datum

Vertical datum applied in the QINSy navigation software is Bathyelli v2 geoid with zero hydrographic reference surface (ZH).

Le Havre is located in the N.CP-15 station, which is the reference station of the Bathyelli geoid model, and which belongs to the levelling network of the French IGN.

In order to transform datasets to LAT it would be necessary to apply a +0.3m offsets with regards to the Bathyelli hydrographic zero located N.CP-15 in Le Havre.

2. DATA ACQUISITION

2.1. MULTIBEAM ECHOSOUNDER

The objective during the data acquisition is the referencing of the acquired seismic data.

During the data acquisition, the vessel's master must follow the previously programmed routes of the project lines, governed by the indications of the computer screen (Helmsman indicator), which is shown, by means of visual and audible alarms, when it separates from its course more than a specified amount (variable according to weather conditions in the area, but never more than 2.5 metres from the theoretical line), and also when there is a problem in a peripheral, such as the loss of GPS corrections.

While the master follows the navigation lines, the acquisition module of the hydrography program captures all the position data sent by the GPS, as well as the soundings sent by the multibeam sounder for each transmission pulse, as well as the values of the heading, wave height, roll and head angles sent by the Hydrins III MRU. Parallel to the data entry, the data acquired by the equipment and peripherals is synchronized. This process is carried out by QINSy itself, complemented by the input of the time and the pulse per second (PPS) provided by the MRU, so that all the data is time synchronised.

The guidelines followed by Tecnoambiente during the surveying for MBES data acquisition were:

- IT-CM-01. Guidelines for Hydrography Project management, 5
- IT-CM-04. Bathymetric survey, 1
- IT-CM-14 Survey Basics Guidance, 1
- IT-CM-15 Online Surveying procedure, 3

These guidelines can be found in the quality plan document NOR_TEC_05_QUALITY PLAN.

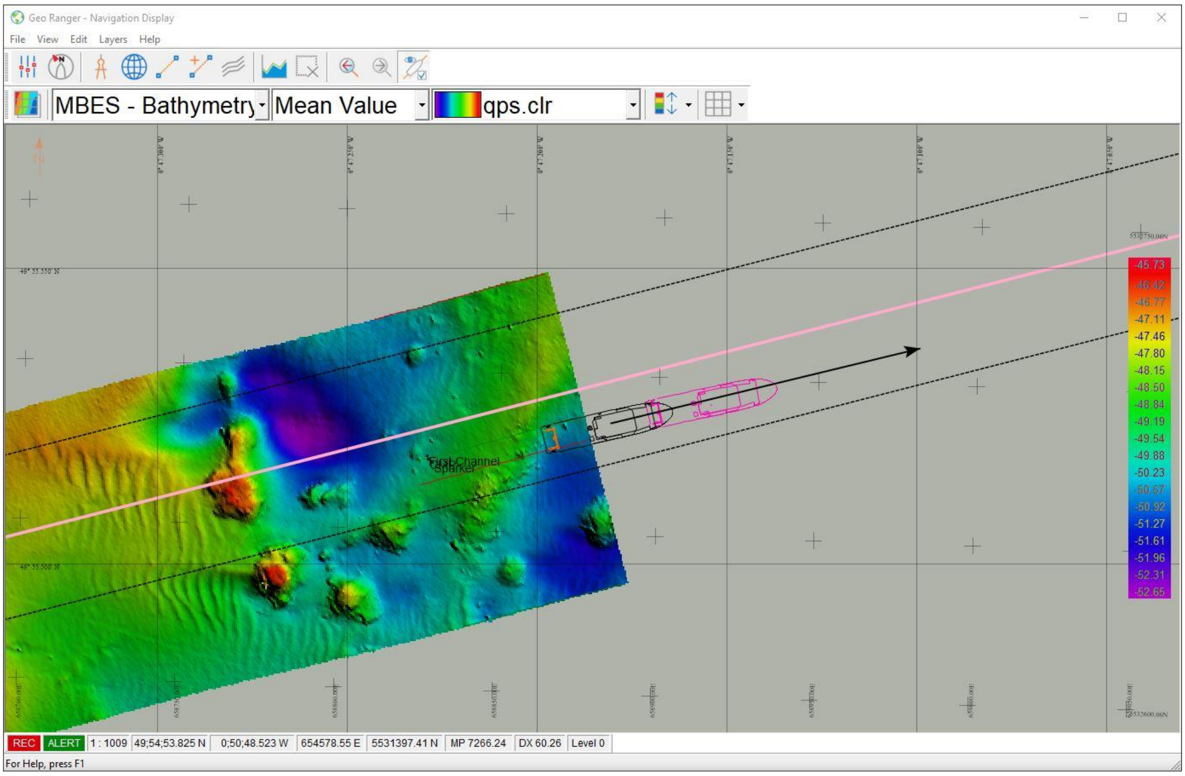


Figure 2-1: MBES bathymetry data acquisition with the QINSy software.

During data acquisition, limits have been applied to reduce the soundings noise. These limits in the recording correspond to static gates of the equipment software that reduce the acquired registers noise according to statistical calculations of vertical uncertainty.

Along the processing phase of the acquired data, the lines on the screen are processed in order to manually correct the noise that appears in the records, noise produced by multiple factors such as, multipath in position, air bubbles, cetaceans, motor interference of the boat, etc. in the digital register of soundings. To certify the complete removal of the noise in the soundings spike filters and spline filters have been applied.

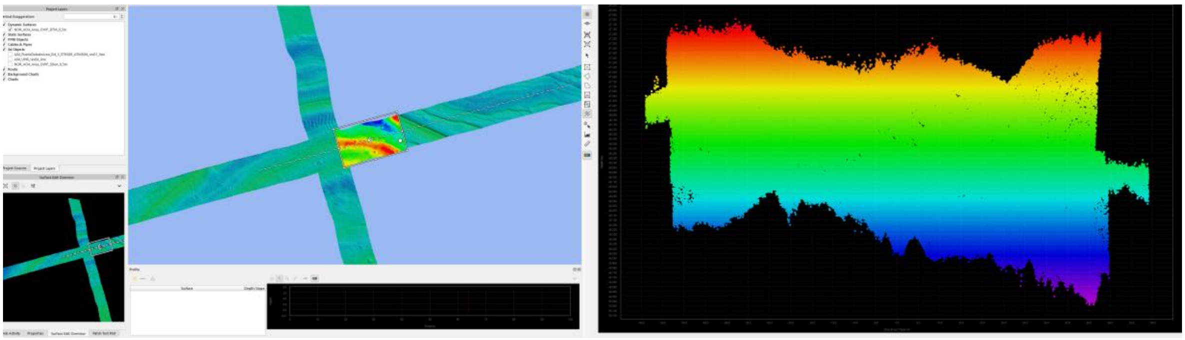


Figure 2-2: Processing screen of MBES bathymetry data with the Qimera software.

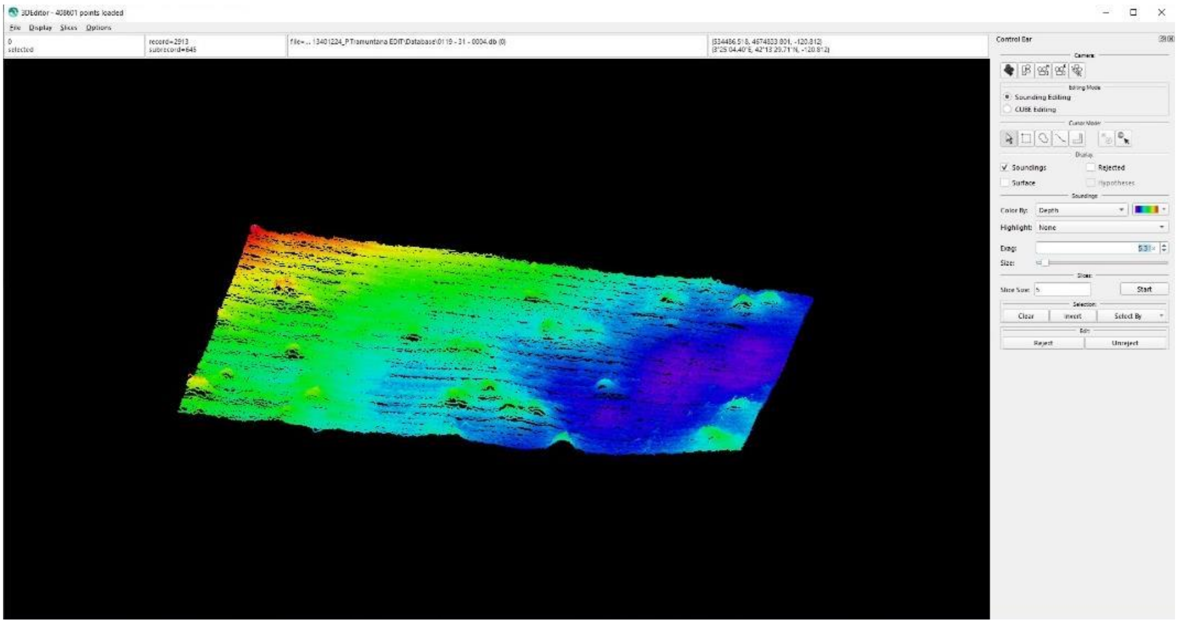


Figure 2-3: 3D image of the MBES bathymetry processing.

Once the possible existing errors in the records have been deleted, a digital model of the terrain with 0.5 x 0.5 m grid size is made with a minimum cell size to obtain the maximum resolution of the seabed.

2.2. UHR SEISMIC

The guidelines followed by Tecnoambiente during the surveying for UHR Seismic data acquisition are the ones provided from TTS, which are:

- IT-CM-17 Sparker Deployment Recovery, 1
- IT-TTS- 01_Geoeel Instrument Verification Procedure
- IT-TTS-02_Multichannel Seismic Streamer Procedure
- IT-TTS-03_Sparker Pulse Test Procedures
- IT-TTS-04_Streamer Recovery

These guidelines can be found in the quality plan document NOR_TEC_05_QUALITY PLAN.

The shallow geology/foundation conditions (0-80m BSB) has been interpreted and investigated from 2D UHR multi-channel seismic data. 2D UHR SEGY data has been recorded to 270ms TWT.

The 2D UHR data shows a dominant frequency of approximately 400Hz in the upper section.

<u>2D UHR – High Frequency</u>

Vertical Resolution	1.1 m (quarter wavelength based on an estimated dominant frequency of 400Hz and an assumed velocity of 1,800 m/s).
Horizontal Resolution	15 m (Radius of first Fresnel zone based on a dominant frequency of 400Hz and an assumed velocity of 1,800 m/s at a depth of 100m below sealevel).

The 2D UHR data has been zero phase converted and adjusted to the bathymetry, as such the central positive of the Ricker wavelet represents the seabed.

The raw field data was recorded in SEG polarity (positive acoustic pressure written as negative numbers on tape), but after processing the polarity is NON-SEG, with positive pressure as positive numbers.

SEGY data were loaded into a Kingdom workstation once processing had been completed and basic QC of the data took place. Seabed position was checked against time converted

MBES xyz data, a VatMAX amplitude extraction covering the seabed was used to check amplitude balance across the site and arbitrary lines between mainlines and crossline were checked. Key horizons were then picked, and all data was checked for possible shallow gas hazards using a combination of automated amplitude extractions and an iterative visual data assessment. Final exports for this site comprised structure map contours in DXF format / interpreted seismic sections.

3. RESULTS

3.1. BATHYMETRY

Bathymetry data have been reduced to Shom Bathyelli v2.0 and all depths are quoted to this. An overview of the bathymetry data is presented on Figure 3-3.

Most offshore energy infrastructure will be placed on the seafloor where small to very large, mobile, coarse-grained sand to gravel sedimentary bedforms may be moving. Considering their susceptibility to scour, wind turbines should be emplaced on the seabed so they are secured against movement. Seabed site characterization should include assessment of potential mobile sedimentary bedforms (Barrie & Conway, 2014).

Actimar undertook a sedimentary study to evaluate the amplitude of the potential vertical movements of sedimentary bedforms (i.e., seabed sediment mobility). Use of old data (< 1950) enabled quantification of dynamics on multi-decade time scales. Considering the long-term evolution trends of seabed at the NOR_AO4 site, regardless of the time scale differentials, the average evolution trends are within the error margins of the differentials (Figure 3-1). Actimar therefore concluded there are no identifiable evolutionary trends (sediment mobility) within the NOR_AO4 site (Actimar, 2021).

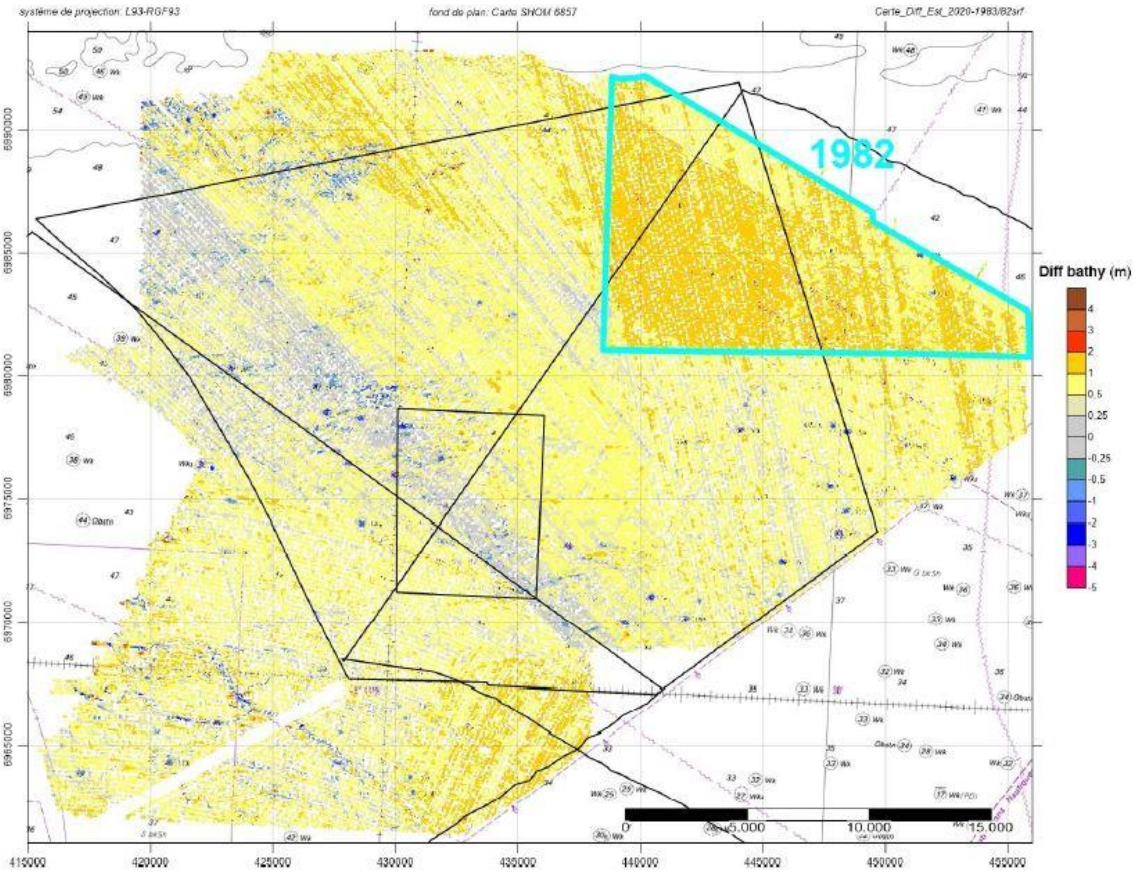


Figure 3-1: Bathymetric differentials 2020 to 1983 and 2020 to 1982.

The detailed resolution of the bathymetry grid (Digital Elevation Model for seabed data following QUA-01-B GIS specifications) allows for enhanced visualization of depth and interesting seafloor features. The main use of the multibeam data is to reference the seismic profiles to the real seafloor.

Water depths vary between -32.9 m in the south-east and gradually deepen to -54.3 m in the north-west. The seabed gradient was computed at 22 planned borehole locations distributed over the range of water depths across the site. The slopes are gentle, with seabed gradients varying (as computed at the planned borehole locations) from <0.5 to 2°. A colour table for the representation of the three-dimensional terrain model was created, from red -32.9 metres height and magenta for the maximum depth -54.3 height.

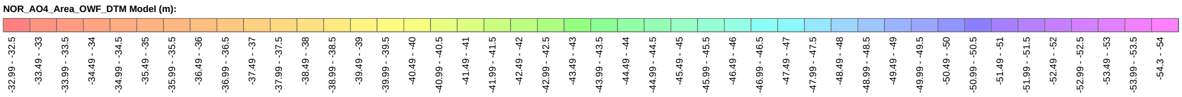


Figure 3-2: Color table for the representation of the MBES terrain model.

Bathymetric data from the vessel multibeam sensor has been processed into a 0.5 meters grid size bathymetry for all the acquired lines.

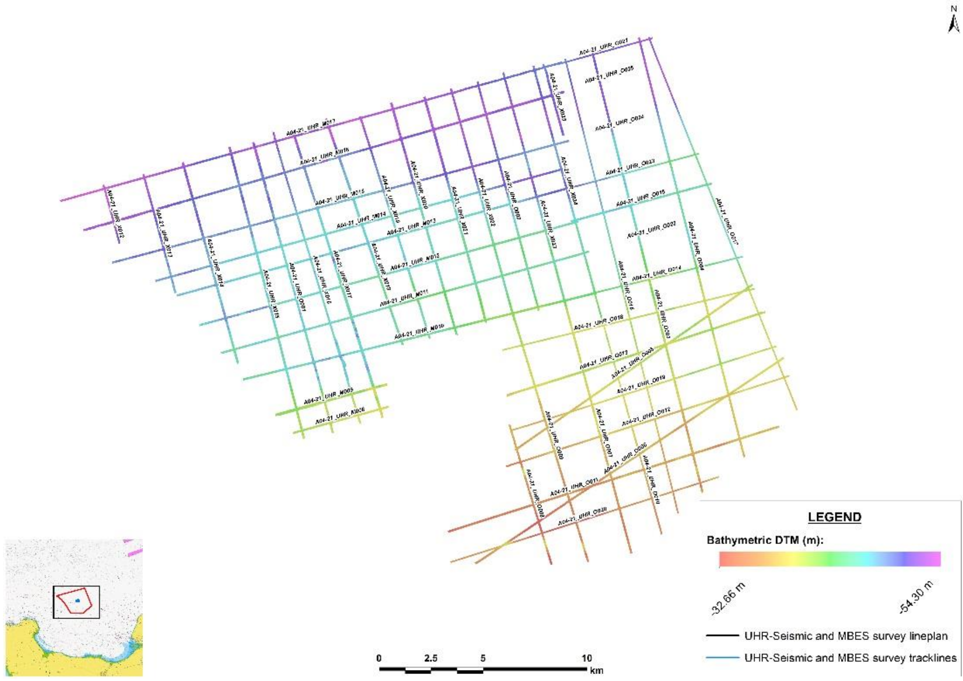


Figure 3-3: Whole bathymetric data grid model (0.5 x 0.5 m) for the Windfarm area of the NOR_AO4 area.

Several examples of the results of the MBES processed data are shown below:

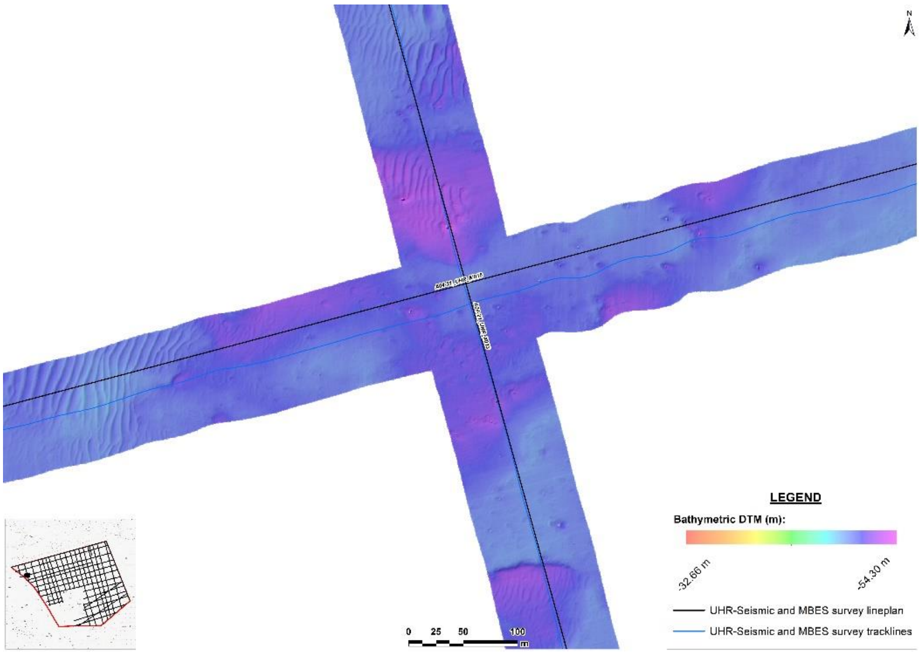


Figure 3-4: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the Windfarm area of the NOR_AO4 area – Lines AO4-21_UHR_M015 and – Lines AO4-21_UHR_X013.

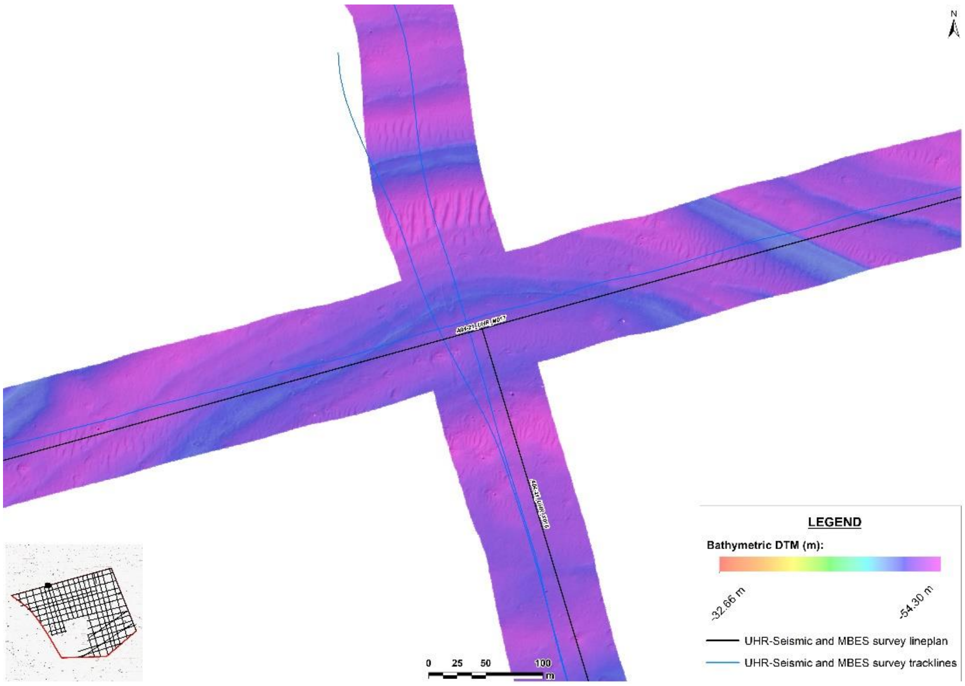


Figure 3-5: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the Windfarm area of the NOR_AO4 area – Lines AO4-21_UHR_M017 and – Lines AO4-21_UHR_X016.

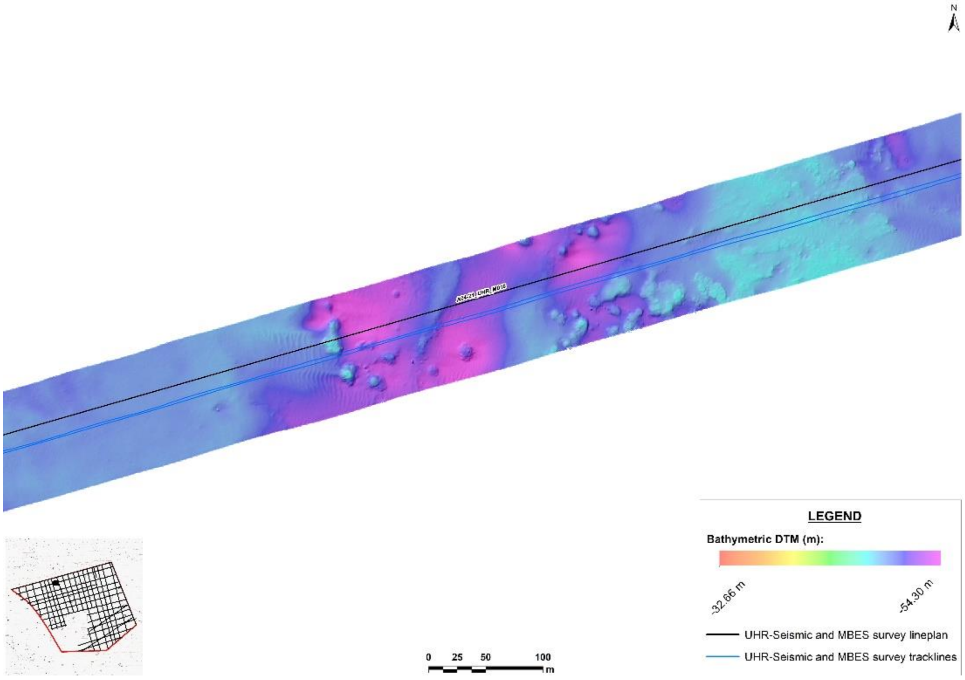


Figure 3-6: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the Windfarm area of the NOR_AO4 area – Line AO4-21_UHR_M016.

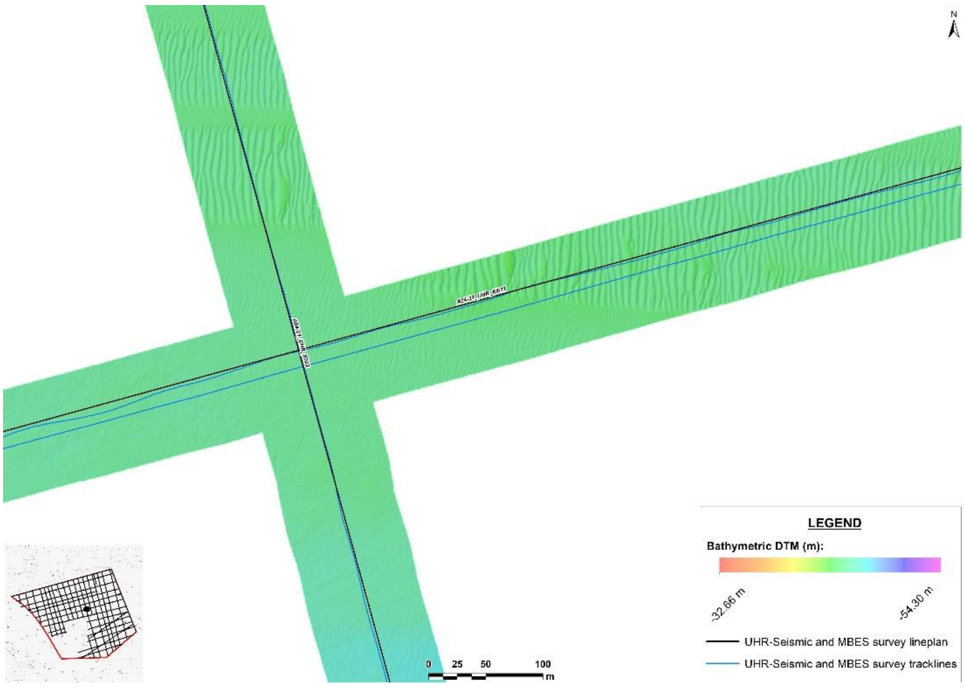


Figure 3-7: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the Windfarm area of the NOR_AO4 area – Lines AO4-21_UHR_M011 and – Lines AO4-21_UHR_X022.

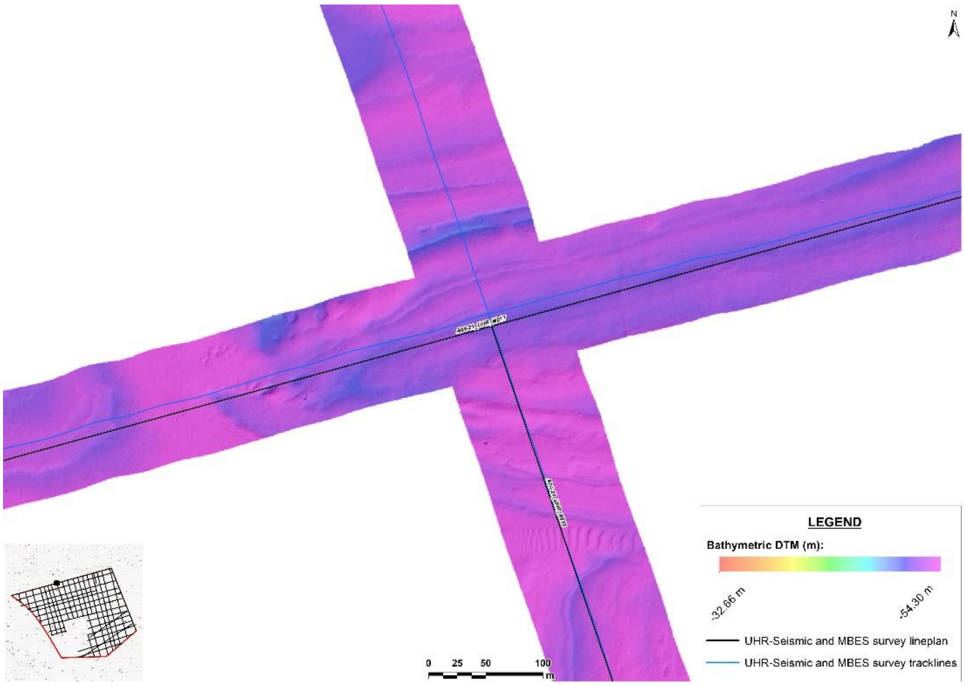


Figure 3-8: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the Windfarm area of the NOR_AO4 area – Lines AO4-21_UHR_M017 and – Lines AO4-21_UHR_X018.

Regarding the calculation of horizontal and vertical uncertainty in the MBES data acquired at the offshore windfarm, it has been calculated and rendered in the Qimera software. The following images represent these values for all acquired lines.

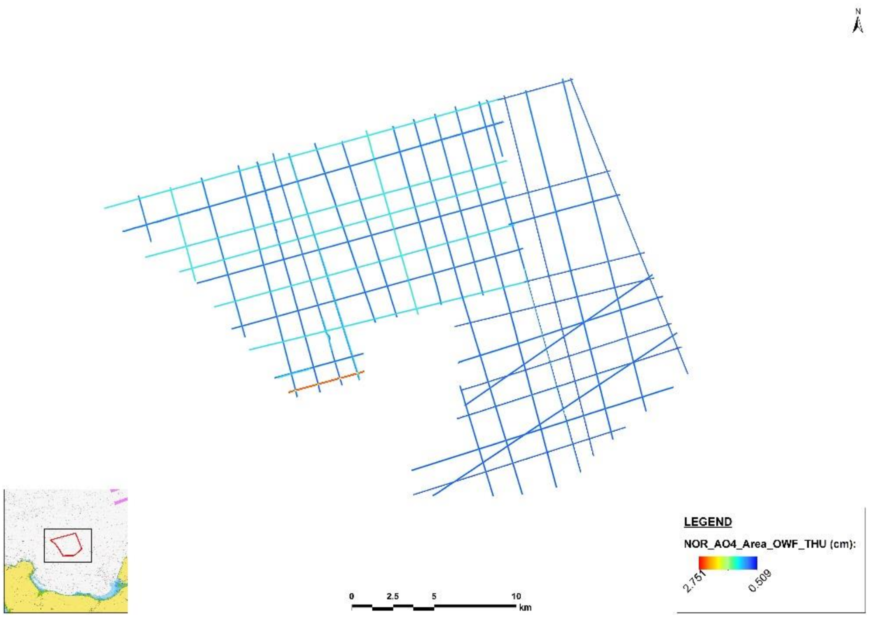


Figure 3-9: Results for the total horizontal uncertainty in the offshore windfarm of the NOR_AO4 area – General.

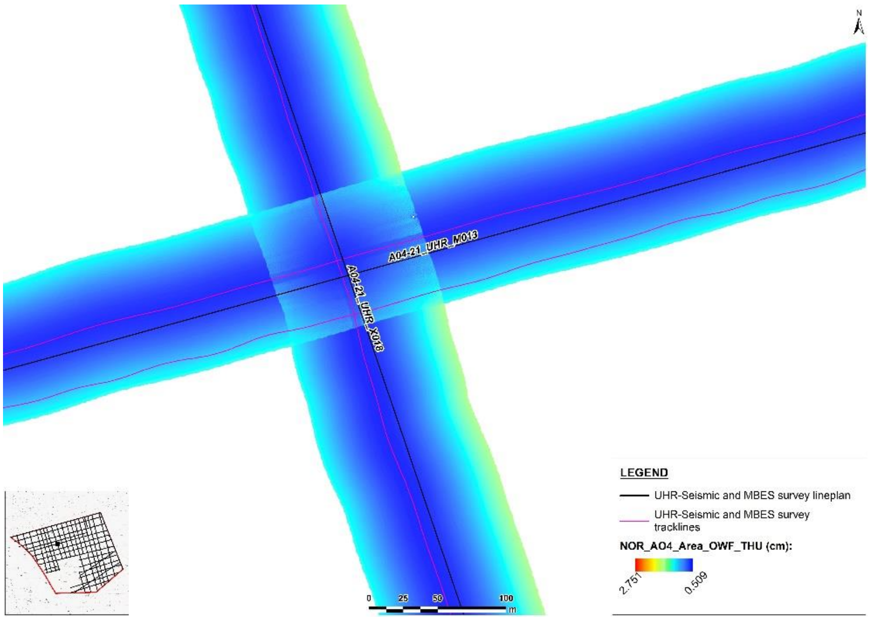


Figure 3-10: Example in detail of the results for the total horizontal uncertainty in the offshore windfarm of the NOR_AO4 area.

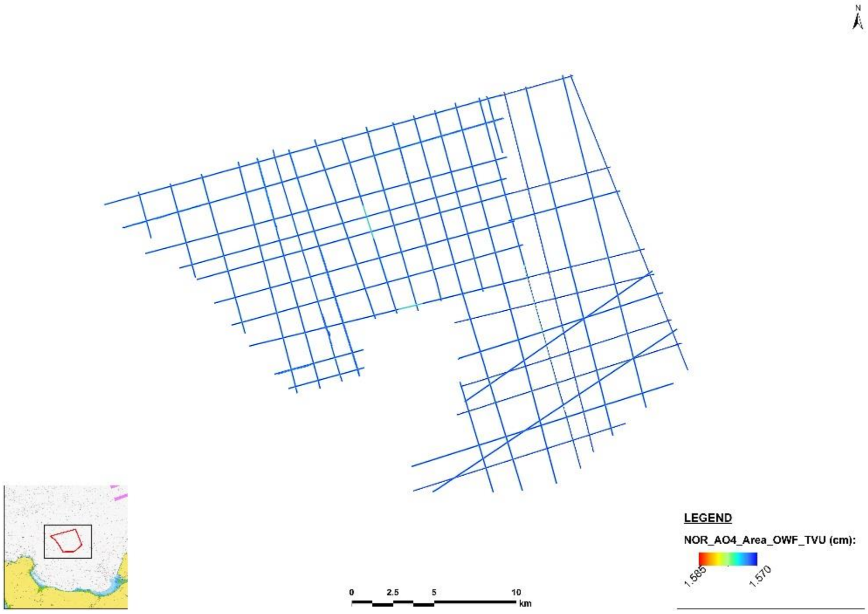


Figure 3-11: Results for the total vertical uncertainty in the offshore windfarm of the NOR_AO4 area – General.

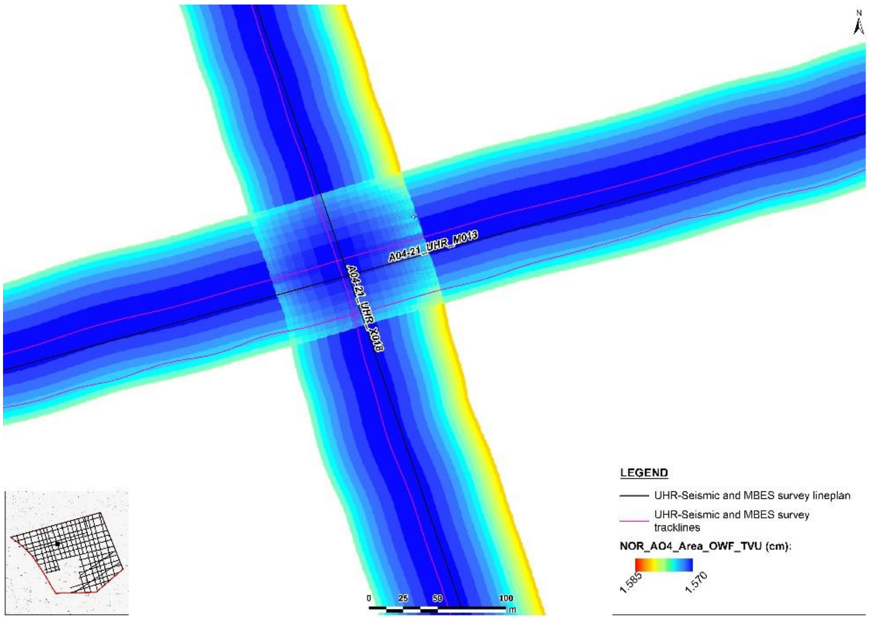


Figure 3-12: Example in detail of the results for the total vertical uncertainty in the offshore windfarm of the NOR_AO4 area.

The total horizontal uncertainty statistics are presented below:

- Maximum value: 2.7509 cm
- Minimum value: 0.5090 cm
- Average value: 0.9695 cm
- Standard deviation: 0.3132 cm

The total vertical uncertainty statistics are presented below:

- Maximum value: 1.5850 cm
- Minimum value: 1.5700 cm
- Average value: 1.5722 cm
- Standard deviation: 0.0022 cm

3.2. GEOLOGY

3.2.1. Data limitations

To support integration of the regional seismic stratigraphy (Thinon & Serrano, 2021) with the new (2021) NOR_AO4 UHR seismic survey data, seismic data from the MX13 and MX15 campaigns were imported into the Kingdom project. Unfortunately, the MX13 and MX15 seismic data provided in digital format is unusable without additional processing. However .tiff files showing the data and schematic interpretation were also provided and have been used to guide the framework of the interpreted stratigraphic units.

3.2.2. Geological setting from background data

To support a tender call for offshore wind power in area NOR_AO4, situated in the northwest of the Bay of Seine, the DGEC requested BRGM to prepare a geological summary comprising the area of interest, “Baie de Seine”.

Since 2007, BRGM acquired four new high-resolution sparker seismic data surveys to update the regional geological knowledge: BS07 (blue), BS08b (purple), MX13 (black), and

MX15 (red) (Thinon & Serrano, 2021). The NOR_AO4 area illustrated in Figure 3-13 covers both the OWF and OSS designated areas.

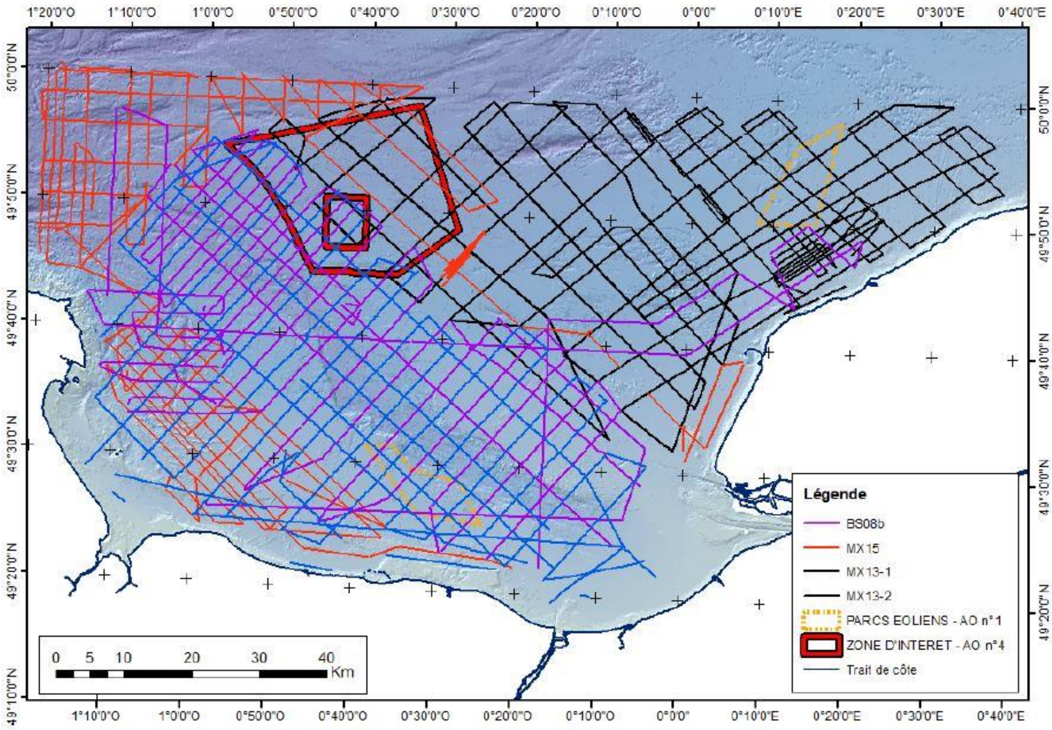


Figure 3-13: Map showing sparker seismic profiles of the four campaigns (Thinon & Serrano, 2021).

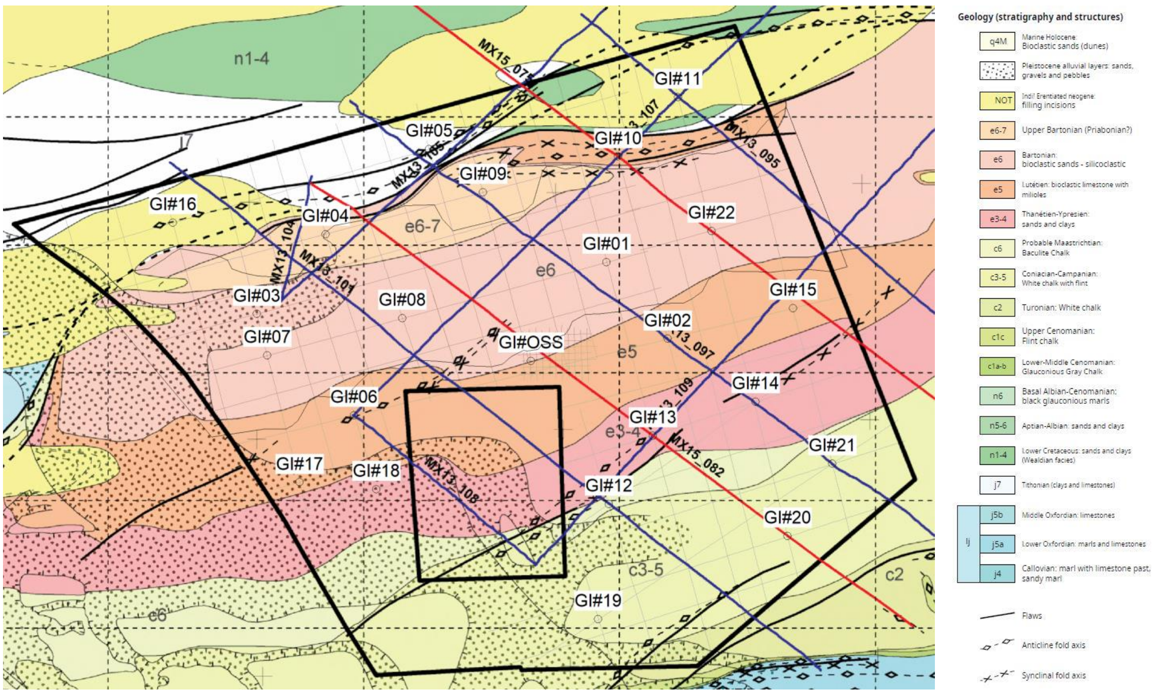
From the high-resolution sparker seismic data profiles DGEC selected ten profiles from the MX13 and MX15 surveys to produce interpreted seismic sections with stratigraphy.

Table 3: List of MX profiles for preparation of regional geology map 1:250 K (unpublished).

CAMPAIGN	PROFILE	LENGTH (m)
MX13	MX13_spk095	31,580
MX13	MX13_spk097	29,934
MX13	MX13_spk101	32,358
MX13	MX13_spk104	4,974
MX13	MX13_spk105	17,222
MX13	MX13_spk107	23,638

CAMPAIGN	PROFILE	LENGTH (m)
MX13	MX13_spk108	9,277
MX13	MX13_spk109	30,859
MX15	MX15_075	29,462
MX15	MX15_082	29,299

BRGM has interpreted this high-resolution sparker seismic data and is preparing a 1:250,000 geological map (Figure 3-14) for the Bay de Seine (Thinon & Serrano, 2021). MX13 (blue) and MX15 survey lines (red) are shown with this 2021 NOR_AO4 UHR seismic survey data (grey) and planned geotechnical borehole locations.



(Large black polygon marks the OWF area and light grey lines are the 2021 survey lines)

Figure 3-14: Extract from the Geological Map of France at 1:250,000 Bay de Seine Sheet (unpublished) modified after (Paquet, et al., 2021).

The selected profiles from the MX13 and MX15 surveys (Table 3) formed the basis for integration of seismic stratigraphy into this (2021) NOR_AO4 UHR seismic survey data.

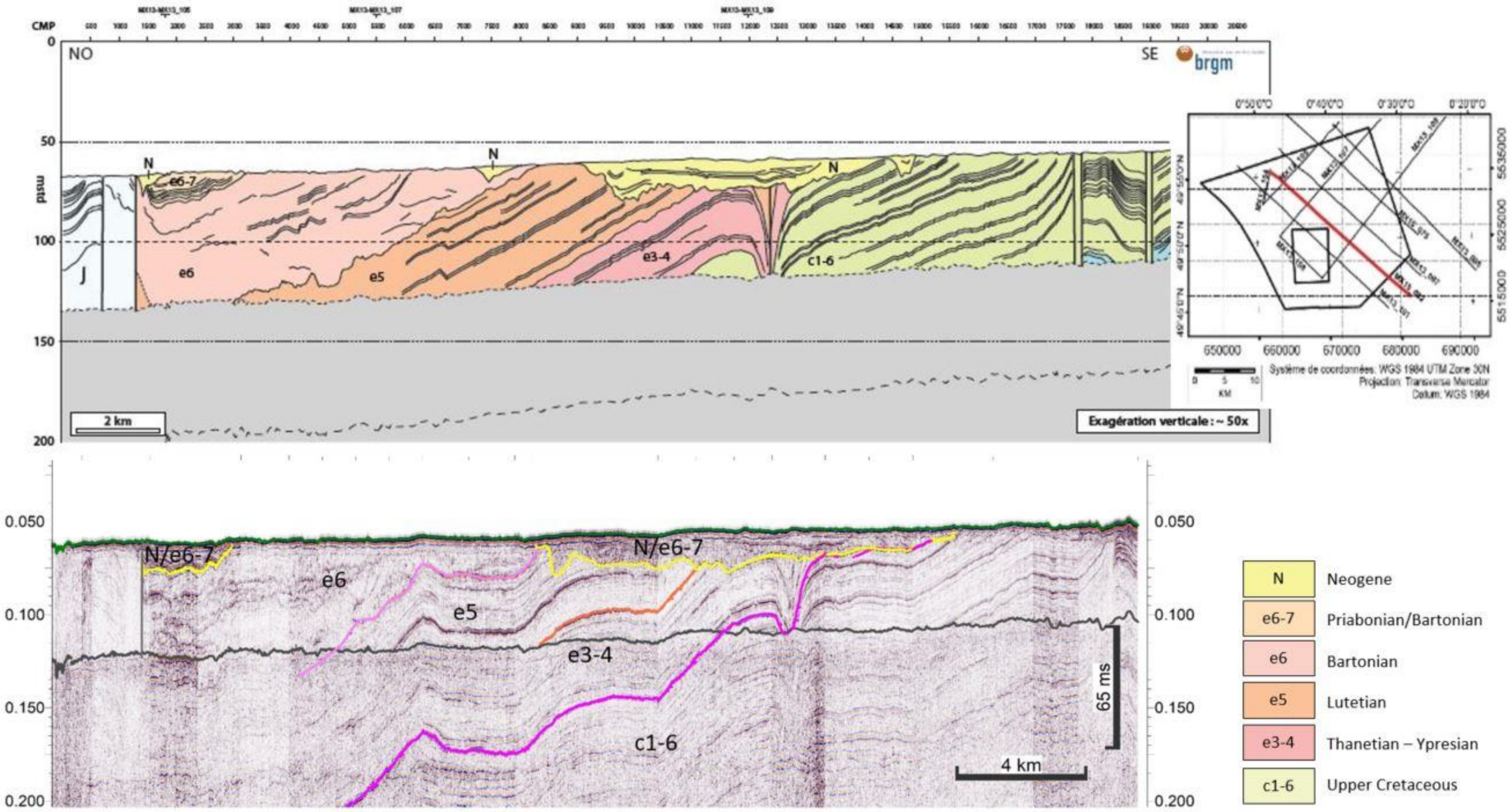


Figure 3-15: Above: MX15_082 unpublished from (Paquet, et al., 2021); Below: Zig-zag arbitrary line of AO4_UHR data

3.2.3. Geological sequence

The NOR_AO4 area of interest comprises a sedimentary succession from the Jurassic to the Quaternary, interspersed with large hiatuses, mainly erosive, punctuated by angular unconformities. Six coherent stratigraphic packages, over the first 50 to 100 m subsea are distinguished, with stratigraphy shown in (Figure 3-15) (Thinon & Serrano, 2021).

The shallow geology (100 m below seabed) within the NOR_AO4 site has been divided into units following those established by Paquet et al. (2021). These units are correlated in Table 4 to the background data providing detailed facies descriptions and horizons mapped for this report.

Four horizons are mapped over the AO4 OWF area which have been correlated with the established stratigraphy. Namely, the base of the shallow channels (Base of N/e6-7); the base of the Bartonian (e6); the base Lutetian (e5); and the base Thanetian/Ypresian / top Upper Cretaceous. Interpretation has generally been restricted to above the first seabed multiple for all but the top Cretaceous.

The distinction between the base of N and top of e6-7 remains challenging with the line spacing and data quality of this (2021) NOR_AO4 UHR seismic survey data. However; the correlation and mapped extent of a network of paleovalleys and fluvial terraces of the paleo-Seine has improved with this new data. Paleovalleys and fluvial incisions within unit U20 were mapped as combined channel infill extent (Figure 3-16). These were compared to the channel extent mapped on older sparse seismic data in Figure 3-17.

Neogene /Priabonian sands occur in incised channels generally trending west-southwest to east-northeast across the site. They are generally less than 20 metres thick, apart from in the north-east and north west corners where they reach thicknesses of over 50 metres (see Figure 3-16). The mapping indicates widespread unconsolidated channel infill affecting most of the planned boreholes.

An isopach of H15 (Top Upper Cretaceous unconformity) represents the approximate thickness of unconsolidated Cenozoic sediments resting unconformably on consolidated Upper Cretaceous sediments / bedrock CHALK (Figure 3-20).

The top Cretaceous horizon dips down to the north-northwest at an angle of approximately 0.6° The Cretaceous outcrops at seabed in the south-east corner of the survey area.

Table 4: Shallow Geological Units.

Unit[2]	B2014[3]	Horizon	Upper surface	Lower surface	Description	Depositional Environment
N	**U20**	**H5**	**Seabed**	N	Non-reflective or poorly reflective seismic facies (Fs13). Internal arrangement of reflectors is complex, characterized by several internal surfaces of onlap and downlap resting on truncation surfaces. Its lower limit is a truncation surface locally deeply eroding the underlying formations. The upper limit is a pronounced erosion surface, sometimes corresponding to the seabed, sometimes at the base of plio-Quaternary fluvial incisions. Bartonian-(Miocene?) marly, quartz, shell and fossil sands (Benabdellouahed, 2014)	Shallow marine/lacustrine/fluvial
e6-7			**N/seabed**	e6-7		
e6			**e6-7/N/seabed**	e6		
e5	**U19**				Seismic facies Fs10. Limited at the base by an onlap surface and at the top by a truncation surface. Limestone sands with bryozoa of the Upper Lutetian (Benabdellouahed, 2014)	
e3-4	**U18**				Discontinuous reflectors, of low to medium amplitude and of low frequency. Limited at the base by a downlap surface and at the top by a truncation surface. Clayey and sandy deposits of the Thanetian-Ypresian (Benabdellouahed, 2014)	
c3-5, c6	**U17**	**H15**			Seismic facies Fs12 at the base (c3-5) and Fs4 at the top (c6). Limited at the base by an onlap surface and at the top by a toplap surface. Wavy reflectors. Whitish chalk of the Senonian. (Benabdellouahed, 2014)	Deep marine (Chalk Sea)

[2] *(Paquet, et al., 2021)*
[3] *(Benabdellouahed, et al., 2014)*

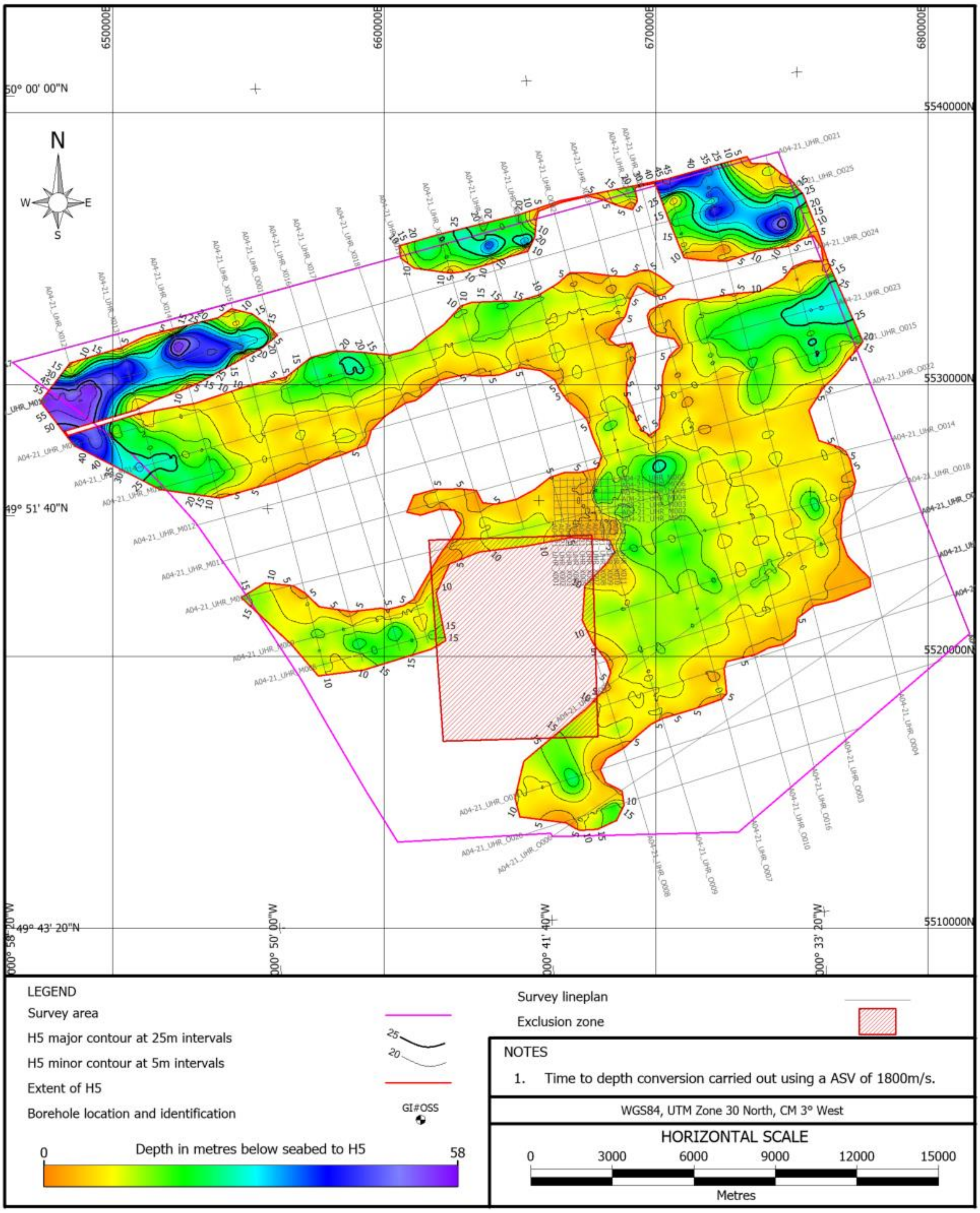


Figure 3-16: Isopach and extent of channel infill (H5)

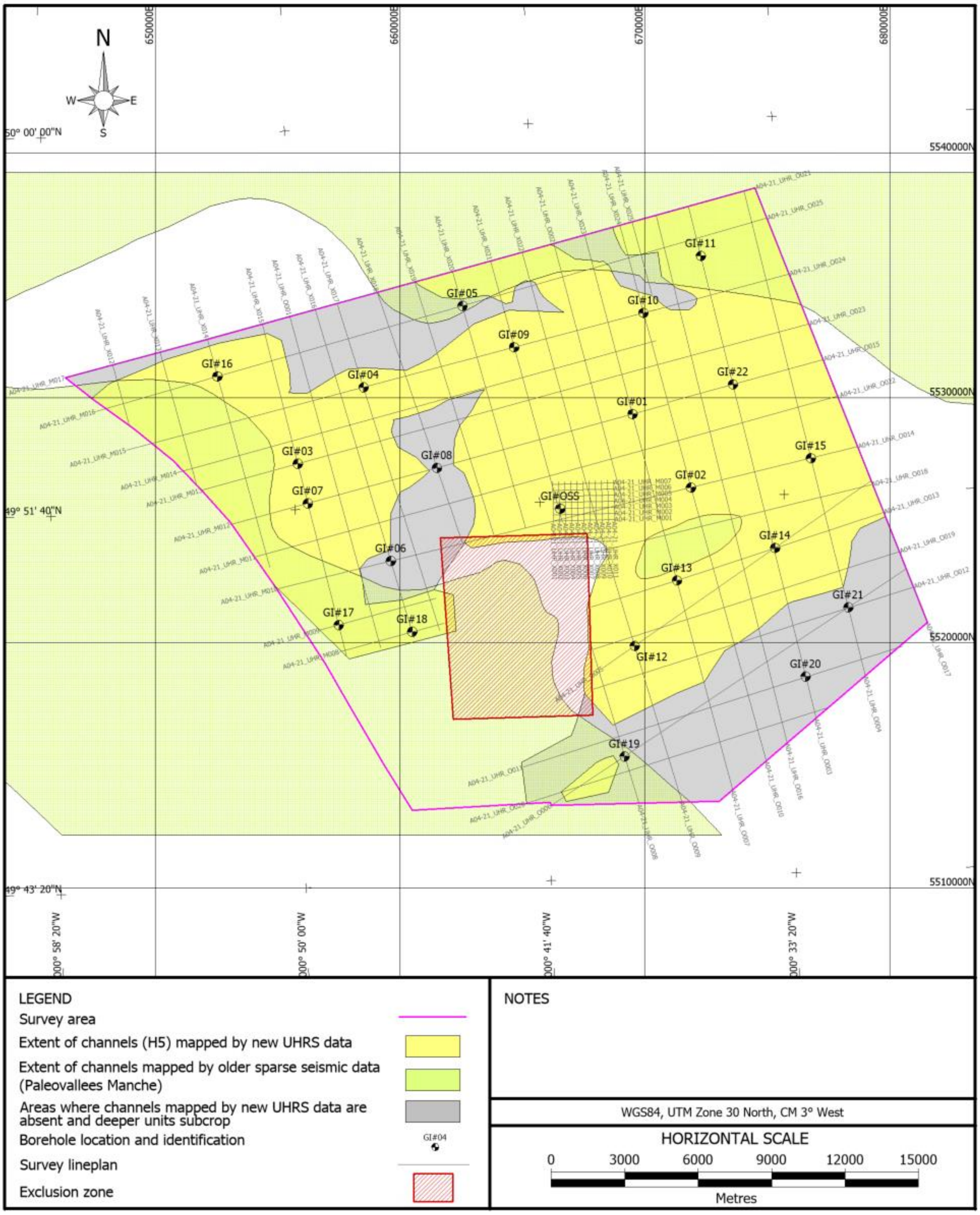


Figure 3-17: Extents of mapped channel infill (new UHR seismic vs older sparse seismic) related to planned boreholes.

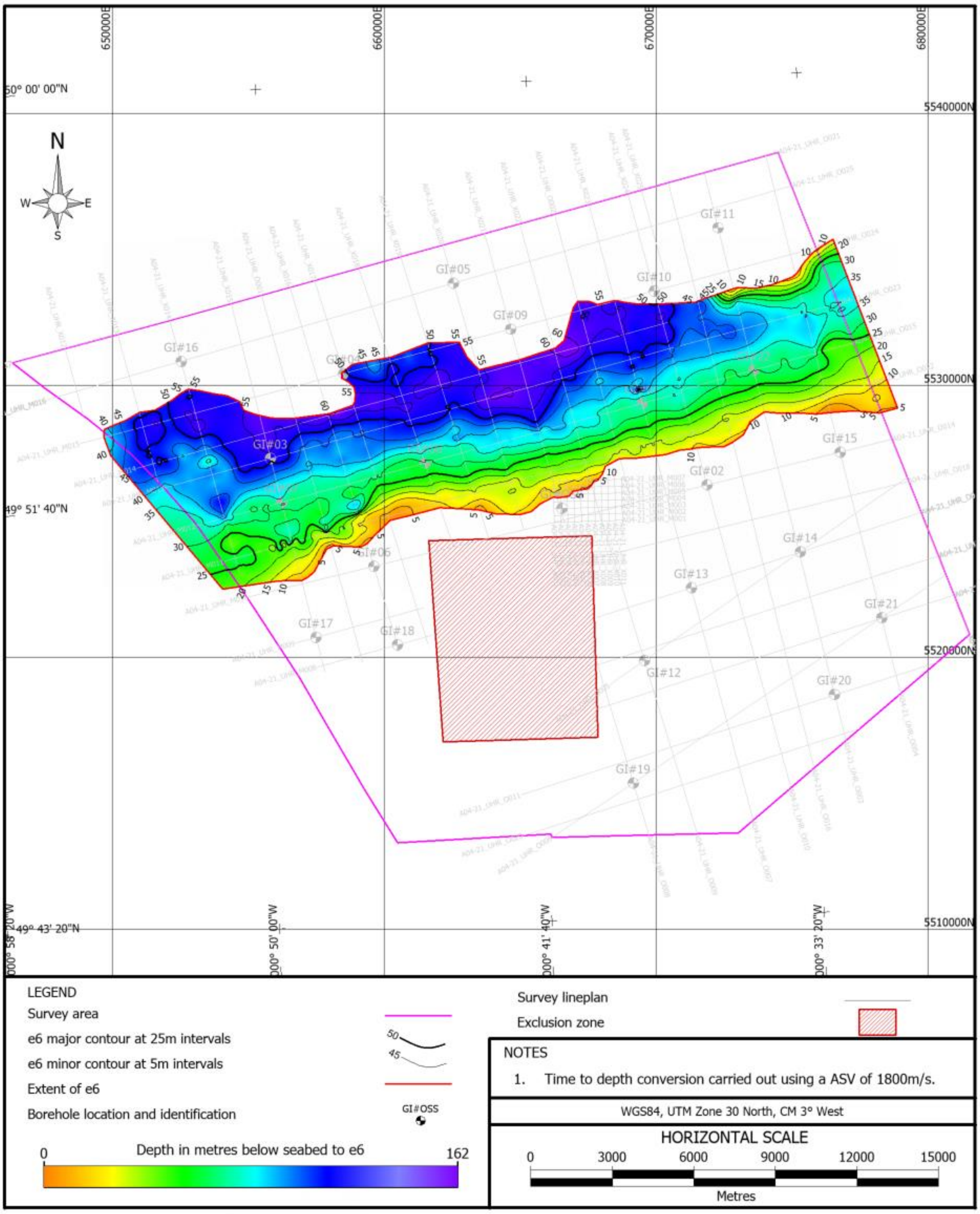


Figure 3-18: Extent of the base of the Bartonian (e6).

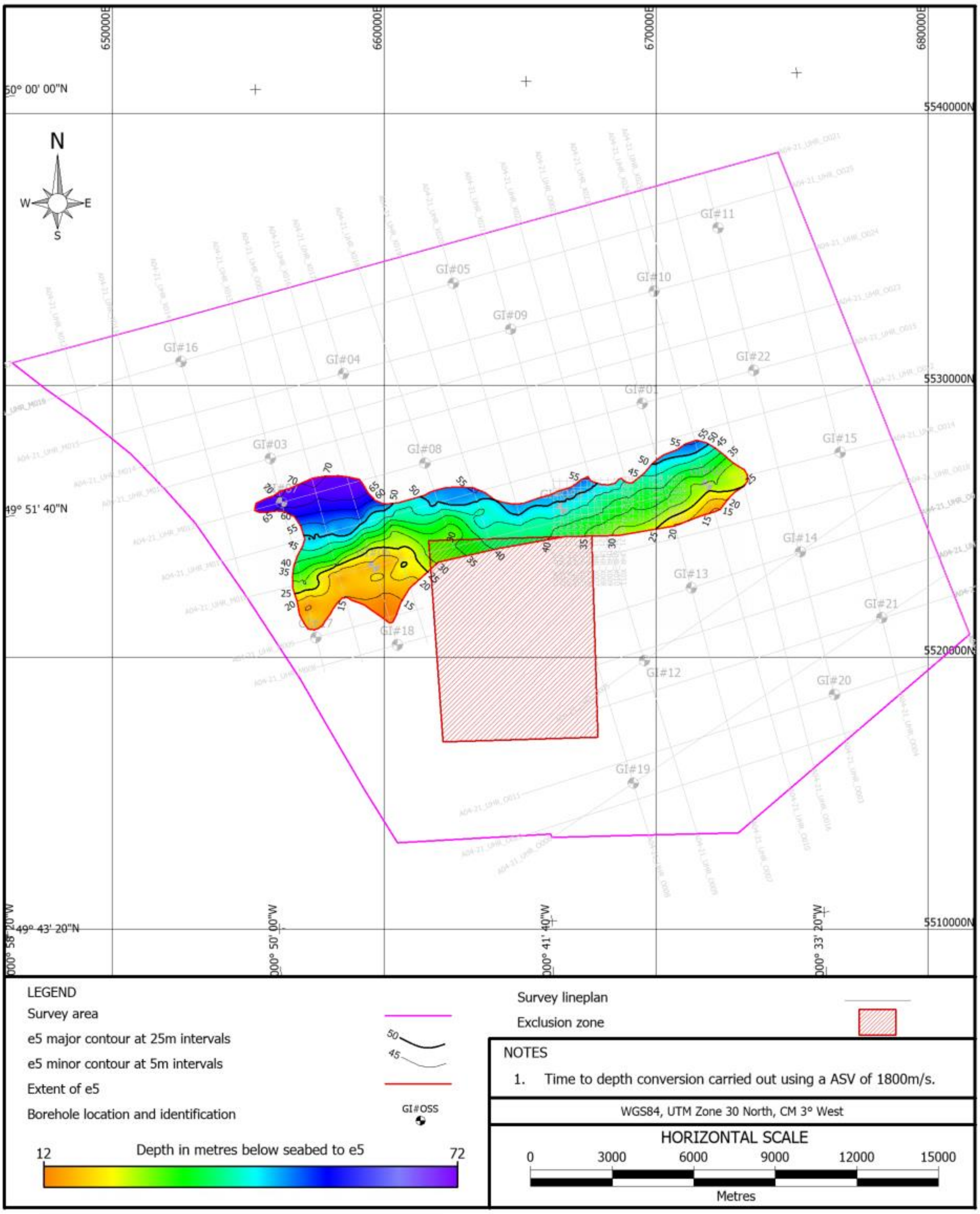


Figure 3-19: Extent of the base Lutetian (e5).

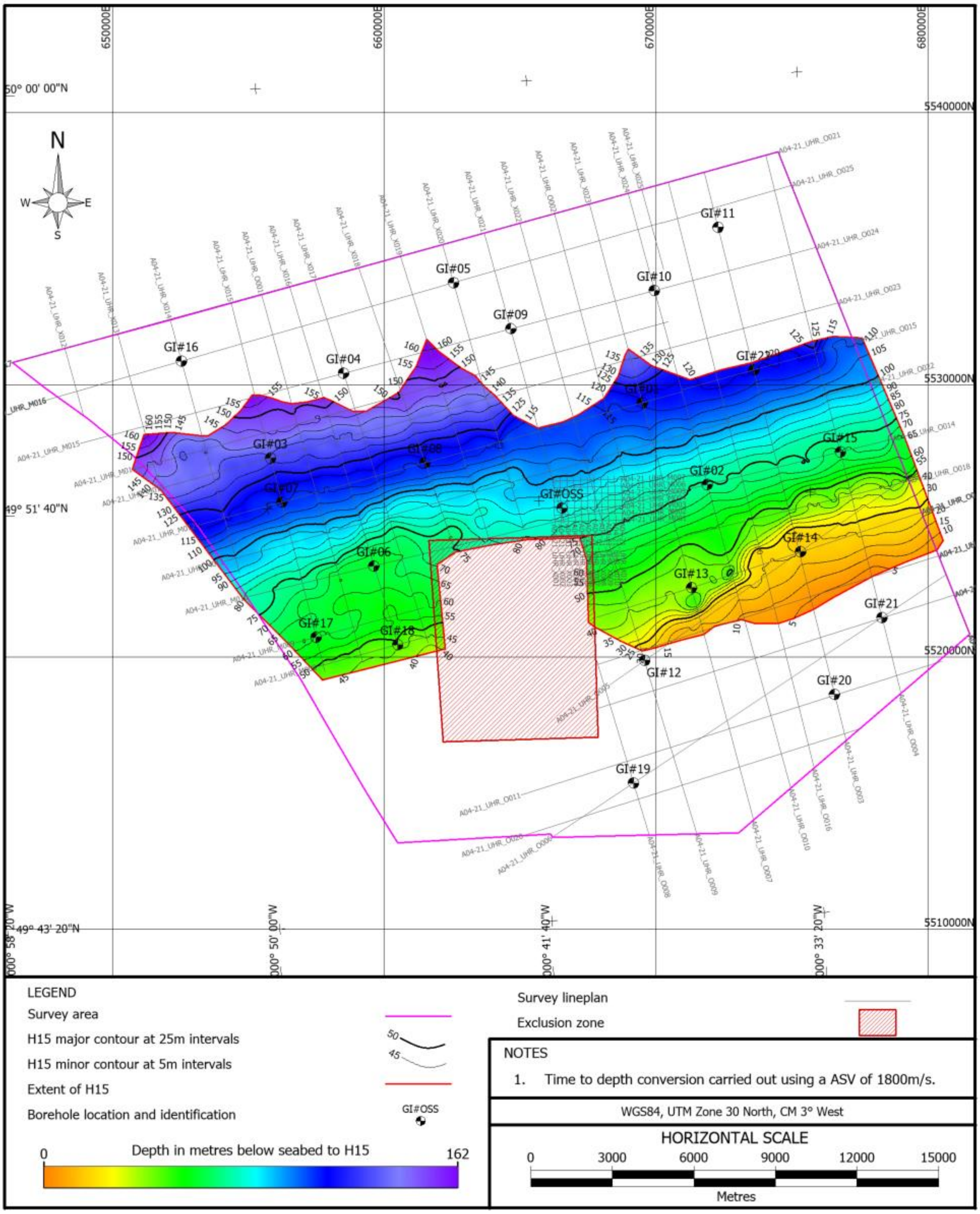


Figure 3-20: Extent of Top Cretaceous unconformity (H15).

3.2.4. Geohazards

The shallow geology can produce impacts and constraints on the design, installation and operation of seabed infrastructure and sub-seabed foundations. Constraints may relate to composition and distribution variability of sediments (at the seabed and in the subsurface) and bedrock within the first 80 m below the seafloor. Other constraints may relate to past or presently active geological processes, such as faulting described in 4.2.4 Structural Geology and illustrated on planned boreholes in Appendix A – GI SCREENING.

A summary of geological conditions and potential constraints on infrastructure and engineering activities, applied to the NOR_AO4 site, is provided in (Table 5) modified after (Mellet, Long, Carter, Chiverell, & Van Landeghem, 2015).

Numerous faults occur within the site, generally trending from west-southwest to east-northeast. They terminate beneath the shallow channels, but they can be seen at seabed in the north of the site, where the channels are absent. Since they do not extend into the shallow (Neogene) channels, the faults are thought to be inactive. However historic data (www.vcolcanodiscovery.com) shows numerous earthquakes from further south in the Baie de Seine, though none have been recorded within the site.

Table 5: Geological characteristics / processes and potential constraints.

Geological characteristic / process	Potential constraint	NOR_AO4 site
Seabed sediments		
Soft muds	Low strength means they will not bear large loads	Probable
Coarse lag (gravel to boulders) deposits	May be present below mobile sediment	Probable
Mobile sediment		
Migrating bedforms change topography (can create seabed features several metres height)	Can bury or expose structures or create a barrier to activities	Not evident
Mobile sediment can change sediment characteristics at seabed	Mobile sediment is constantly changing. Therefore, expect variation between samples taken from the same site at different times.	Probable
Bedforms can migrate in the opposite direction to that predicted from morphology and tidal residual	Do not assume sediment migration pathways from morphology. Repeat bathymetric surveys should be carried out.	Not evident
Gas/fluid escape and MDAC		
Gas or fluid present in shallow subsurface	Can lead to blowouts when drilling	Not evident
MDAC	Creates a hard substrate that is recognized as a special habitat that must be preserved	Not evident
Quaternary		
Variable sediment thickness	Locally, sediment thickness can change from thin (<5 m) to thick (> 50 m) over a short distance	Expected
Variable lithology (vertically and spatially)	Glacial processes rework and deposit sediments that are highly variable over large areas. This is problematic if using a single foundation design. Landforms and onshore analogues can be used to try to predict variability.	Expected
Heterogeneous sediment composition	Sediments are typically diamict which are poorly sorted mixtures of silt, sand, gravel, and clay. Diamicts can be interbedded with sands.	Probable
Overconsolidated sediments	Repeated loading by ice has overconsolidated sediment and shear strength values can exceed 900 kPa.	Probable
Bedrock		
Bedrock outcrop at seabed	Provides a hard substrate for emplacement of seabed infrastructure.	Expected
Faulting	Active faults are susceptible to ground surface ruptures that can compromise infrastructure; seabed forms that indicate pre-existing seabed instability, surface displacements, or fluid escapes are conditions that pose risk to infrastructure; Sub-surface fault zones may provide preferential conduits for gas migration, or may be hydraulically active during (or shortly after) earthquakes	Expected

3.2.5. Background Data Summary

To provide background context for regional stratigraphy and structural geology, relevant portions of text from Paquet, et al., (2021) are reproduced here (also see Figure 3.21):

Middle to Upper Jurassic

The Kimmeridgian is surmounted by the sandy Aptian from which it is separated by an erosion / non-deposition hiatus equivalent to the Tithonian-Barremian interval. This erosion corresponds to a period of uplift and emersion associated with tectonic movements linked to the opening of the Bay of Biscay (Ziegler, 1988). The Upper Jurassic is also present to the north of the map of the "Baie de Seine" zone, where the Tithonian marl limestone is recognized by drilling Nautile-1 and off the Cotentin. Here, the Jurassic is surmounted by the Wealdian facies of the Lower Cretaceous.

Upper Cretaceous (Cenomanian – Campanian / Maastrichtian probable)

The transgressive trend initiated in the Lower Cretaceous and which marks the return of marine sedimentation continued in the Upper Cretaceous and allowed creation of the Chalk Sea, from the Cenomanian (c1) to the Campanian (c5). Chalky deposits continue into the Maastrichtian (c6), but have often not been preserved due to subsequent erosions (Cretaceous and Paleocene).

Paleogene (Thanetian – Bartonian / Priabonian probable)

The Paleogene is preserved in the northern part of the Bay of Seine, in the form of an asymmetric syncline along the FNBS (Auffret et al., 1982). The series begins with an undifferentiated Thanetian-Ypresian interval (e3-4), which has an erosive base in the Upper Cretaceous (c3-5, c6). The deposits are predominantly sandy at the base and evolve towards a clay (lateral equivalent of the Ypres Argiles) (Larsonneur, 1971; Auffret et al., 1983). Above, the Lutetian (e5) is documented by the presence of bioclastic limestone with miliolida and faluns (Groupe Norois, 1972; Benabdellouahed, 2011; Benabdellouahed et al., 2014). The series is then marked by a surface of intra-Paleogene erosion, possibly marking the base of the Bartonian (e6). The filling is described there as marly, mixed siliciclastic and bioclastic sands (Benabdellouahed et al., 2014). This terrigenous component associated with basal erosion seems to bear witness to a phase of deformation and erosion of the edges *of the basin, attributed to the Pyrenean orogeny. The superficial part of the basin is marked by the presence of seismic facies with parallel, continuous and high amplitude reflectors, marking a change in the sedimentation. It is speculatively proposed that these deposits are of Priabonian age (e6-7), like what is observed in the Paris Basin (Briais, 2015).*

Neogene

The last deposits associated with the intracratonic basin context of the Paris Basin in the Bay of Seine area are those of the Upper Eocene (Bartonian - probable Priabonian). The geological history of the zone is then marked by an inversion on the inherited structures (FNBS) and an uplift of the zone, probably linked to lithospheric buckling, in response to the Pyrenean and Alpine collisions. Sedimentation is no longer a process extended over the whole of the region by a generalized subsidence specific to the context of the intracratonic basin (Western border of the Paris basin). It depends on the accommodation space available for sedimentation created either by a significant rise in sea level or by incisions creating morphological depressions that can receive sediment. Studies carried out in the Channel have shown the presence of one or more networks of incisions (Larsonneur, 1971, Alduc, 1979, Auffret et al, 1980, Benabdellouahed, 2013). These incisions are sometimes completely filled or completely free of filling. Recent work carried out by BRGM et al. within the framework of geological mapping projects seem to show that at least two distinct but superimposed main incision networks are present. The oldest, whose age could not be determined precisely (between Bartonien-Priabonien and Pleistocene) corresponds to a set of deep incisions (> 100 m) partially to fully filled.

Middle-Upper Pleistocene

The Pleistocene is also characterized by the presence of a network of fluvial paleo-valley type incisions corresponding to the outlines of rivers (Seine, Orne, Vire, etc.) during successive low sea levels from the middle to upper Pleistocene. This submerged hydrographic network is thus an extension and is connected to the current hydrographic network. These 40-meter-deep incisions are completely or partially filled. The deposits in these incisions were sparsely sampled. Based on the models of filling of valleys during Pleistocene sea level fluctuations (eg. Dalrymple et Choi, 2007), the deposits are either of the fluvial type (fall phase, low level glacial maxima), estuarine (during transgression), or marine (end of transgression and high sea level of interglacial stages).

(Thinon & Serrano, 2021) noted challenges with interpretation due to seismic facies resemblance for specific units and sparse line spacing:

1. The surface separating the Bartonian (e6) from the Neogene incisions and fillings (N) is uncertain because of the resemblance between the seismic facies of these two formations.
2. Incisions and infill are observed above the Paleogene (e3-4 to e6-7) on several profiles. These incisions could not be correlated with each other with certainty due to the low density of profiles, however the existence of a network of paleo-valleys or fluvial terraces of the paleo-Seine in the cenozoic-paleogene deposits is plausible.

Figure 3-20 illustrates the theoretical distribution of the different types and environments of sedimentation in an incised valley, and the corresponding periods in terms of relative sea level change.

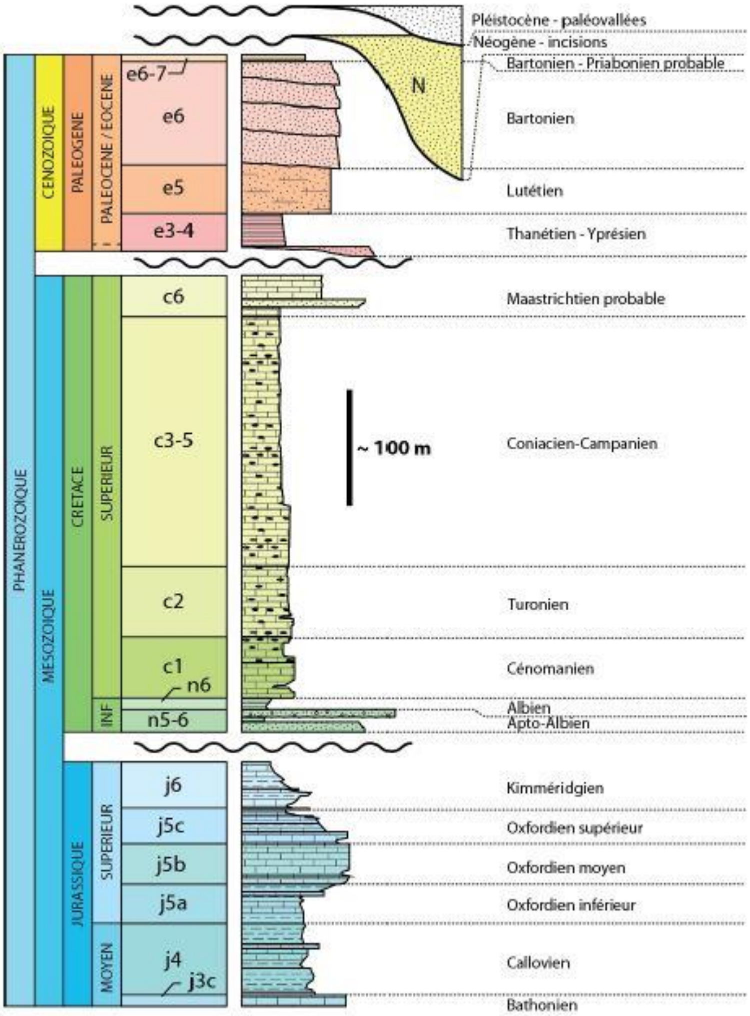


Figure 3-21: Schematic section of the stratigraphy (Thinon & Serrano, 2021).

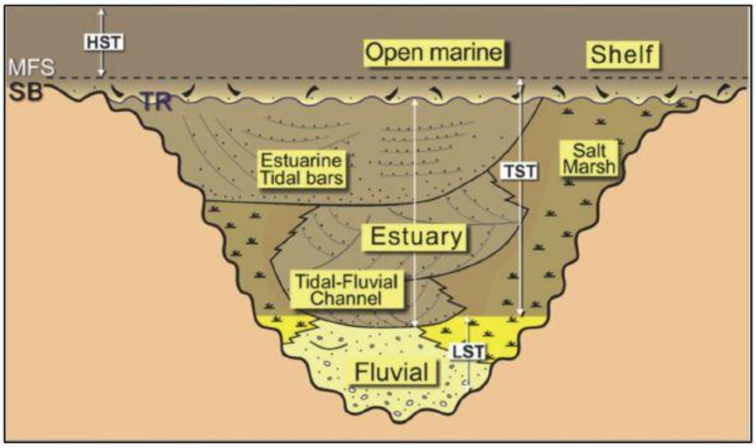


Figure 3-22: Schematic section of a paleo-valley (Dalrymple and Choi, 2007).

3.2.6. Regional structural geology

The regional geological structure is illustrated below (Figure 3-23) by a simplified block diagram. The major tectonic feature of the Bay of Seine is an east-west complex fault structure, "North Bay of Seine", (FNBS) and is currently observed on or near the seabed as a meso-cenezoic reactivation of a Variscan oceanic suture at depth. The FNBS system separates a sequence from Upper Jurassic to the Lower Cretaceous comprising the northern block, from the Paleogene (mainly Bartonian) sequence, comprising the southern block (Thinon & Serrano, 2021). The block diagram illustrates the configuration of the north and south blocks either side of the North Baie de Seine fault system (FNBS) and the Faille de Fecamp-Lillebonne (FFL), the monocline arrangements (Jurassic of the southern block), and the folds along the FNBS (asymmetric synclines).

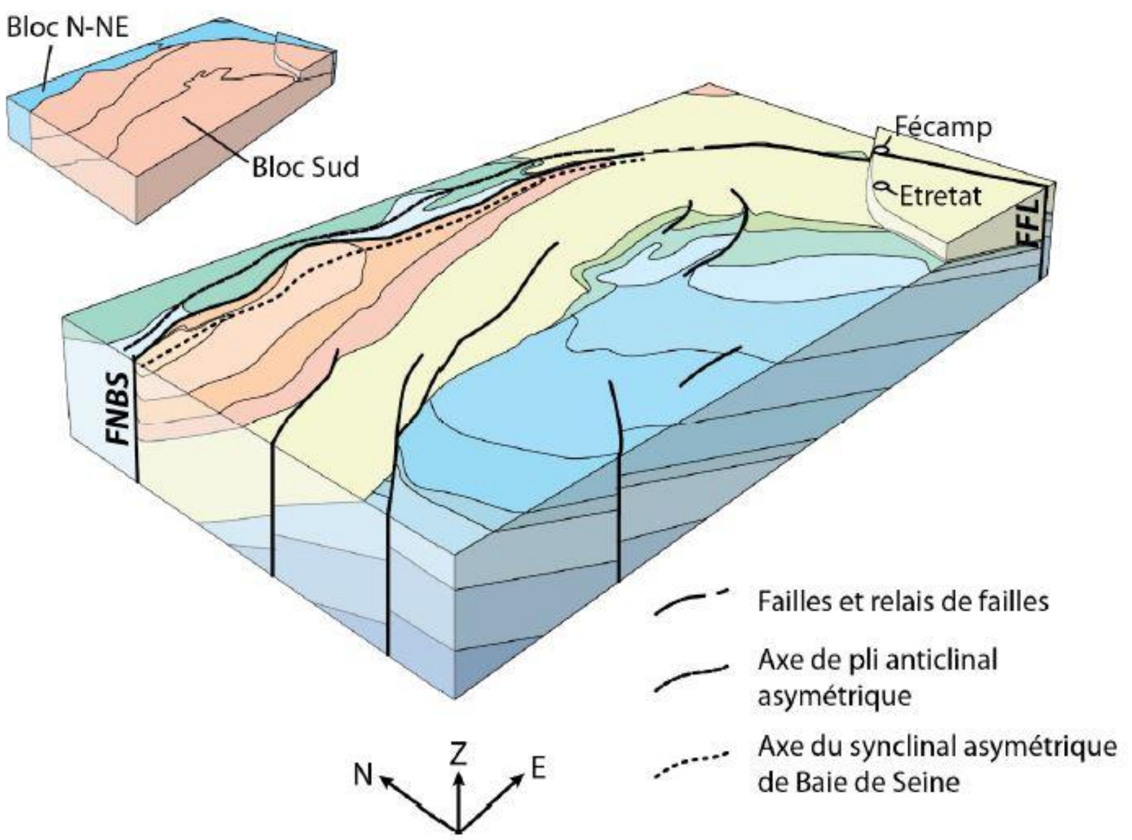


Figure 3-23: Schematic three-dimensional block diagram, viewed from the southwest (Chantraine et al., 2003; Benabdellouahed, 2011; Paquet et al. - b, in preparation).

3.2.7. Conclusions and recommendations/comments

Geological horizons were mapped to update and refine the seismic stratigraphy and geological model based on prior regional mapping. The spatial extent of Quaternary paleo-valleys, fluvial incisions and channel infill were mapped. The correlation and mapped extent of the network of paleo-valleys of the paleo-Seine has improved with this new data. This new information provides important input for planning geotechnical boreholes.

Shallow channels of unconsolidated sediment occur across the site, varying in thickness between absent and 58m (in the north-west corner). The underlying sediments dip down gently (~0.6°) to the north-northwest, and comprise Bartonian sands in the north, Lutetian sands in the centre and Thanetian/Ypresian clays and sands in the south.

No evidence of shallow gas is observed.

Numerous faults occur within the site, generally trending from west-southwest to east-northeast. They terminate beneath the shallow channels, but they can be seen at seabed in the north of the site, where the channels are absent.

To improve knowledge of potential geological constraints the following data acquisition could prove beneficial.

1. Acquire high-resolution sub-bottom (e.g., sparker) seismic data to coincide with the multichannel seismic data.
    a. This higher resolution sub-bottom seismic data will increase mapping resolution for near-surface geological constraints such as faulting.
2. Acquire additional high-resolution seismic data at a closer line spacing to improve spatial mapping of faults and stratrigraphic units.
3. Acquire sidescan sonar imagery data to coincide with the (2021) multibeam bathymetry and backscatter data.
    a. A detailed seafloor mapping with sidescan sonar data will identify potential natural and anthropogenic seafloor geohazards.
4. Acquire repeat multibeam bathymetry and backscatter data during sidescan sonar data acquisition

a. Use this comparative multibeam bathymetry data to assess potential for sediment mobility.

b. Although a recent study concluded that sediment mobility is not apparent at the NOR_AO4 site, monitoring for its potential could be beneficial for long-term development planning.

5. Acquire seabed ground-truthing "light" geotechnical data (e.g., grab samples) to confirm any variable seafloor composition illuminated by the sidescan sonar data.

4. REFERENCES

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APPENDIX A – GI SCREENING

APPENDIX B – CHARTING

CHART NUMBER	CHART TITLE
1	AO4 Bathymetry
2	AO4 Isopach of H5 Horizon
3	AO4 Isopach of H5 Horizon Comparison
4	AO4 Isopach of e6 Horizon
5	AO4 Isopach of e5 Horizon
6	AO4 Isopach of H15 Horizon
7	AO4 Geological Profile Line AO4-M010 and O014
8	AO4 Geological Profile Line AO4-X022, M010, X023 and O007
9	Arbitrary UHRS profile representing MX15_075
10	Arbitrary UHRS profile representing MX13_097
11	Arbitrary UHRS profile representing MX15_082
12	Arbitrary UHRS profile representing MX13_101

APPENDIX C – PROCESSING REPORT