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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
TWT	Two-Way Travel Time
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 substation survey area, the depth range varied between -41.26 meters in the shallowest part at the south-eastern region, to -45.02 meters in the northern region. The slopes are gentle, with average seabed gradients of < 0.1°, maximum values of 23.85º and minimum values of 0º.

Neogene sediments, comprising predominantly of sand occur throughout the OSS area. They vary between 3.5m and 21m in thickness, being thicker in the east. The underlying Palaeogene sediments all dip downwards to the north, at an angle of approximately 0.6°.
A thin layer of Bartonian sands occur in the north of the area, being underlain by Lutetian limestone sands, and Thanetian/Ypresian clays and sands. The Top Upper Cretaceous chalks are expected below this, at depths of between 75m in the south-east and 100m in the north-west of the OSS area.

No shallow gas, or other geohazards are expected within the OSS area.

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 Substation (OSS). The survey area is approximately 2.5 km x 1.7 km with water depths ranging from 41.3 – 44.5 m.

The following data were used in the study:

- 43.173 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.

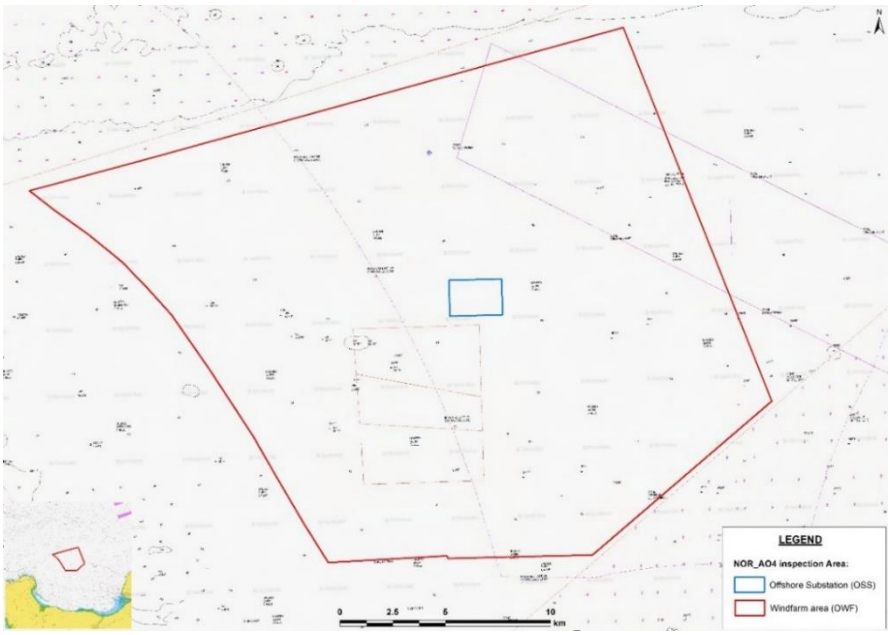


Figure 1-1: Windfarm area (OWF) and Offshore Substation (OSS) in the NOR_AO4 Survey area.

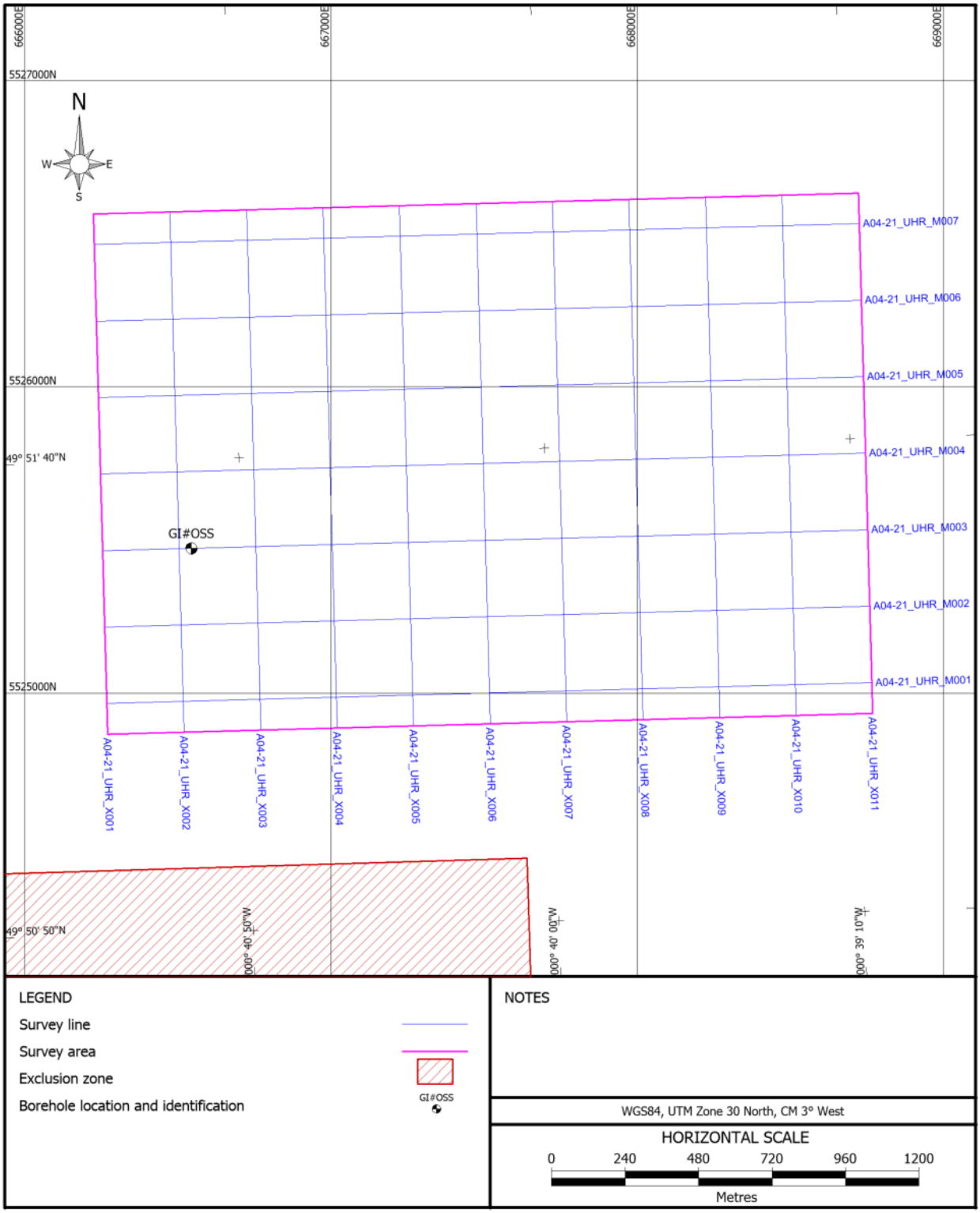


Figure 1-2: Line plan for NOR_AO4 Substation area (OSS).

1.2. SCOPE OF WORK

The objective of the site survey was to perform a geophysical survey over the proposed OSS 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

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 OSS 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

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

DATUM	
Inverse Flattening (1/f)	1/298,257223563

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)

1.3.2. 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 (Helmsmann 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.

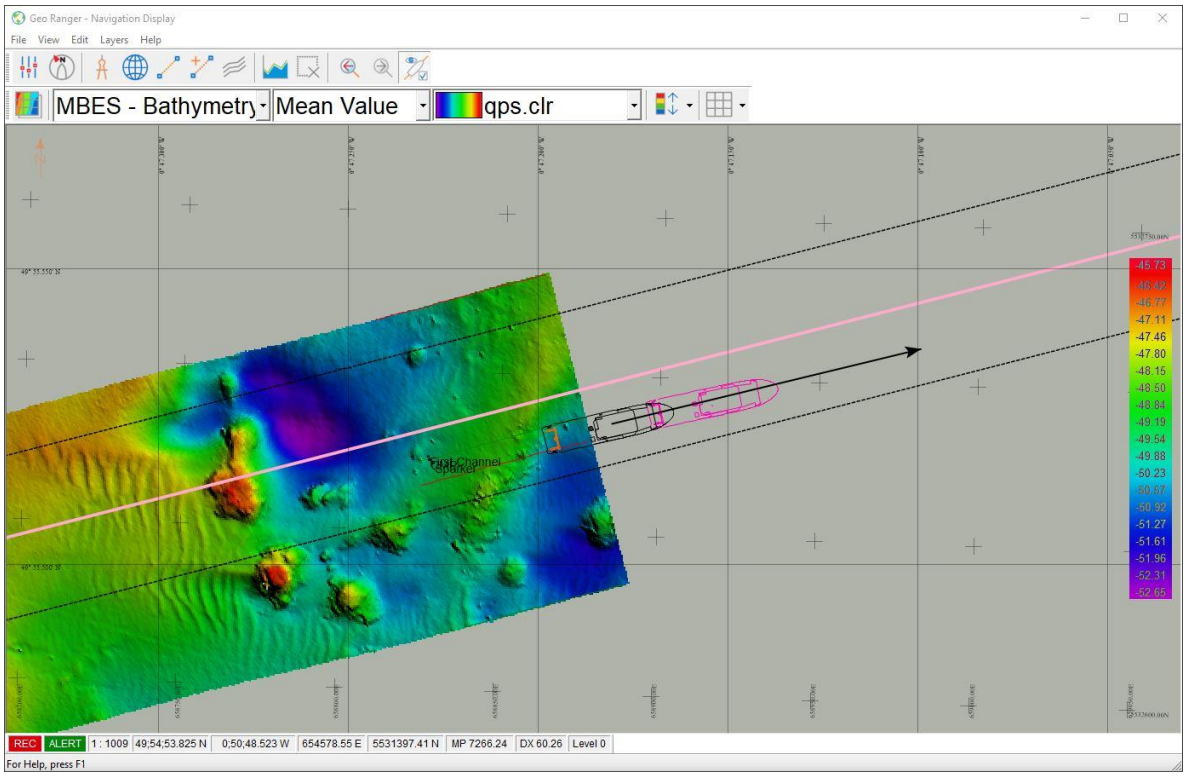


Figure 2-1: MBES bathymetry data acquisition with the QINSy software.

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.

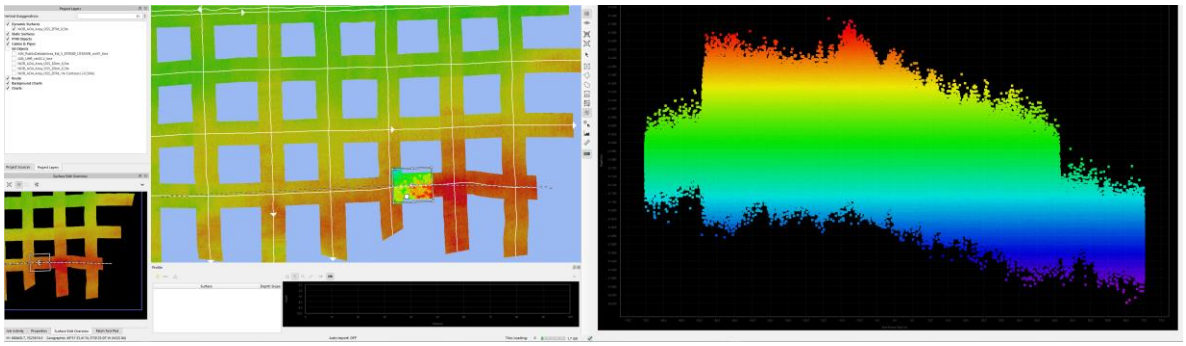


Figure 2-2: Processing screen of MBES bathymetry data with the Qimera software.

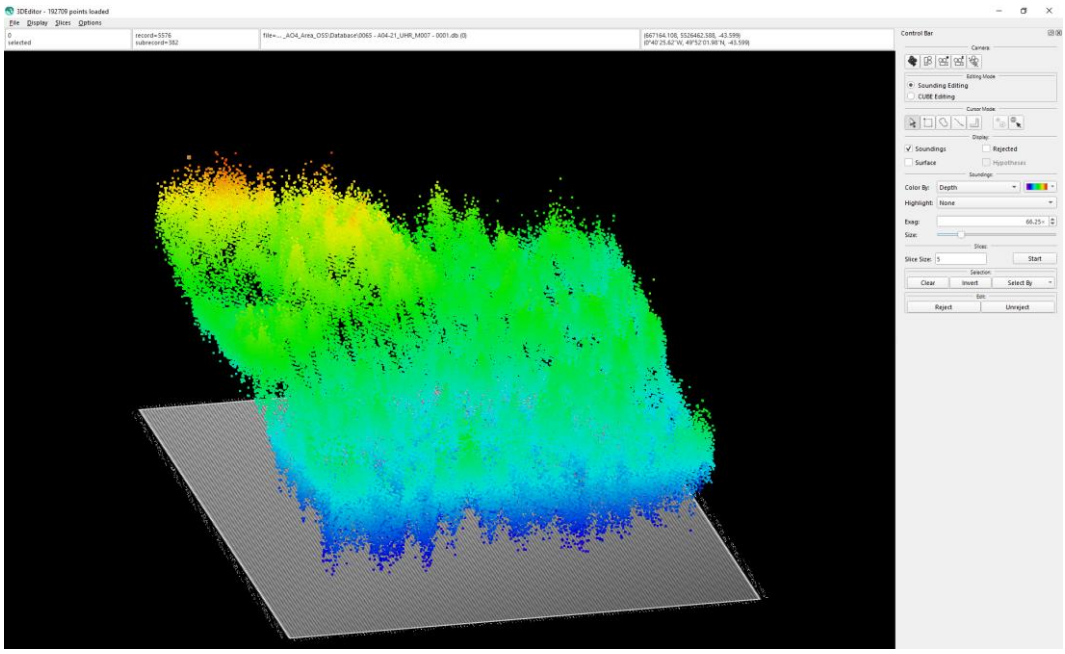


Figure 2-3: 3D image of the MBES bathymetry processing.

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) have 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 its susceptibility to scour, offshore platform should be emplaced on the seabed, so it is 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).

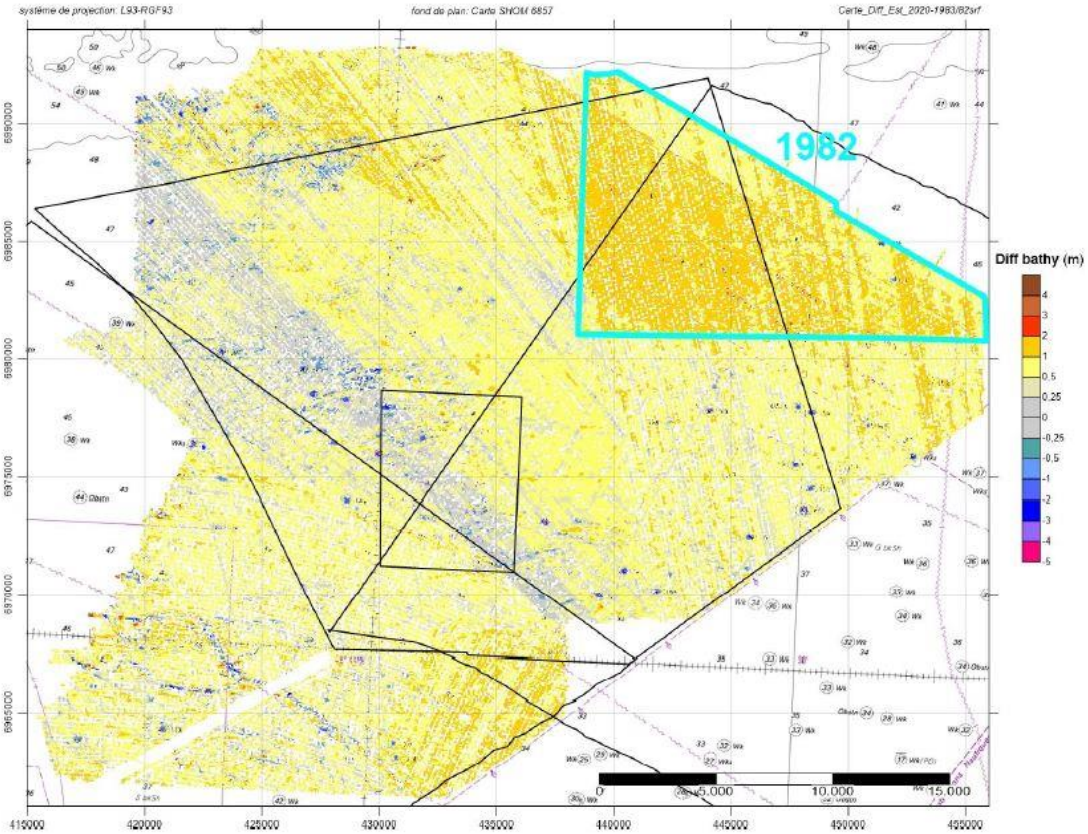


Figure 3-1: Bathymetric differentials 2020 to 1983 and 2020 to 1982.

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.

In the acquired lines of the offshore substation survey area, the depth range correspond between -41.26 meters in the shallowest part at the south eastern region, to -45.02 meters in the northern region. The slopes are gentle, with average seabed gradients of < 0.1°. A colour table for the representation of the three-dimensional terrain model was created, from red -41.26 metres depth and magenta for the maximum depth -45.02 meters.

NOR_AO4_Area_OSS_DTM Model (m):

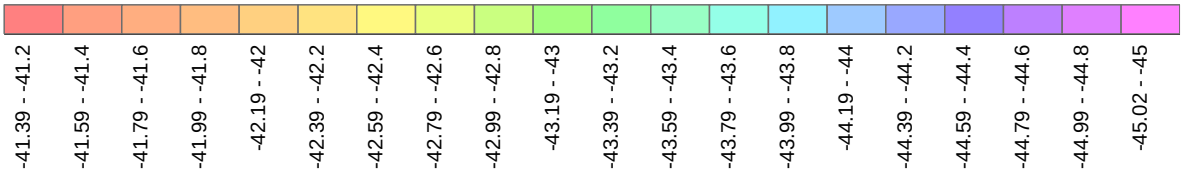


Figure 3-2: Color table for the representation of the MBES terrain model.

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

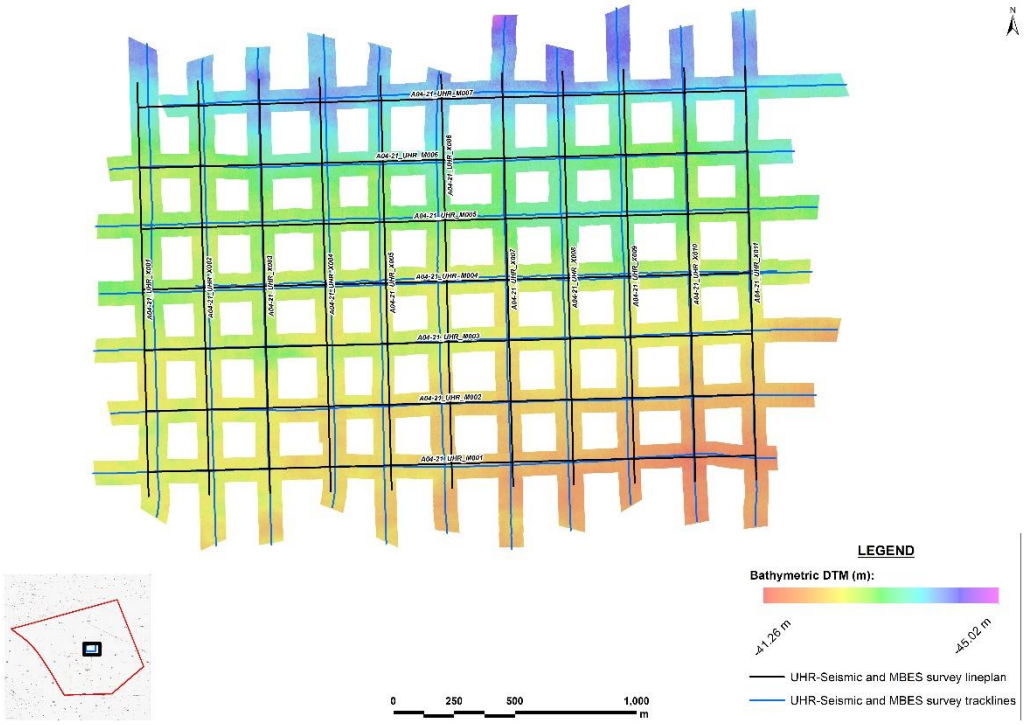


Figure 3-3: Whole bathymetric data grid model (0.5 x 0.5 m) with survey lines and tracklines for the offshore substation of the NOR_AO4 area.

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

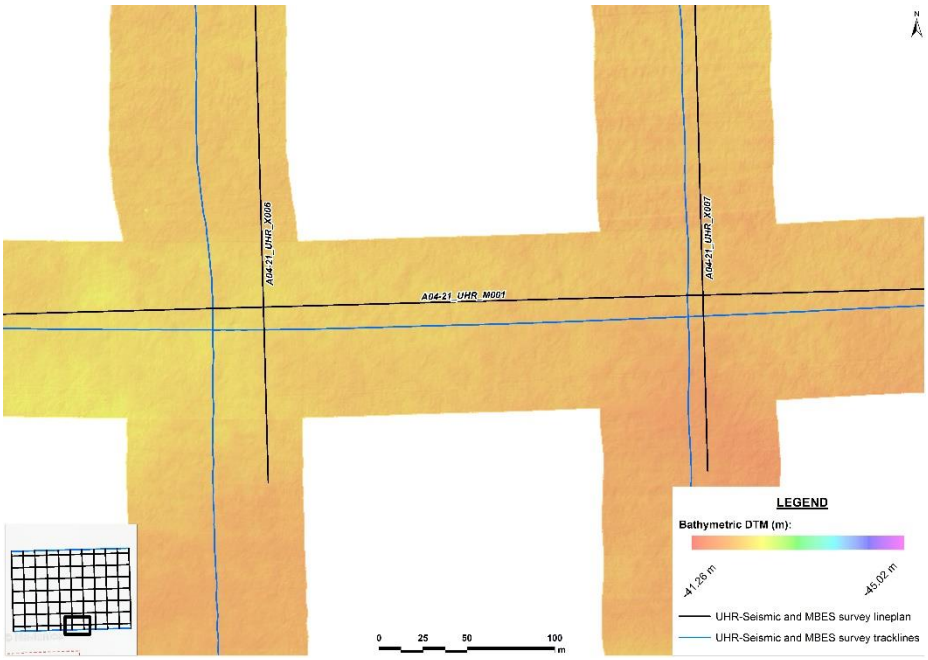


Figure 3-4: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the offshore substation of the NOR_AO4 area – Survey lines and tracklines AO4-21_UHR_M001 and AO4-21_UHR_X006-X007.

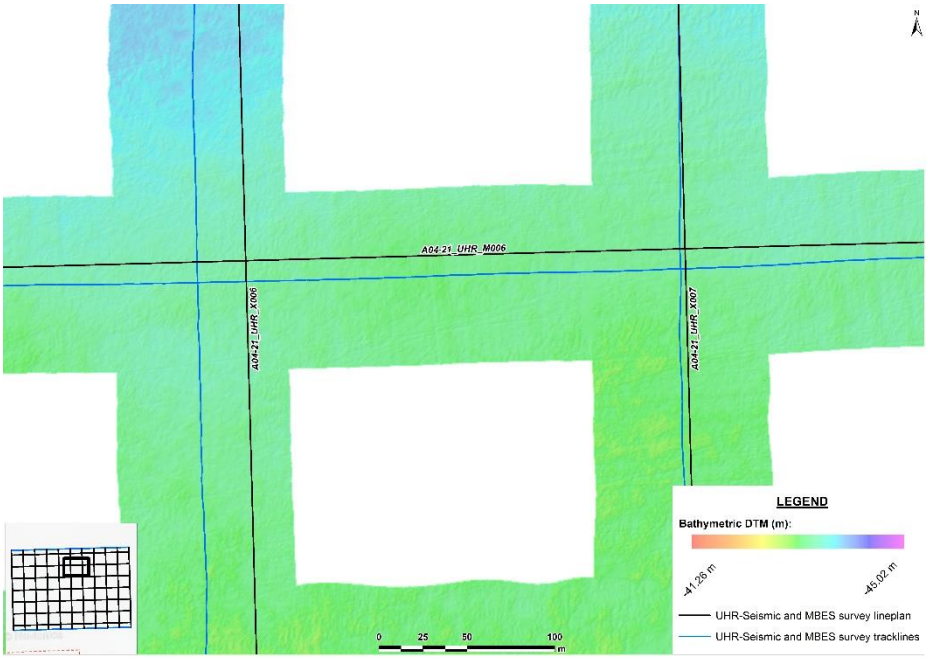


Figure 3-5: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the offshore substation of the NOR_AO4 area – Survey lines and tracklines AO4-21_UHR_M006 and AO4-21_UHR_X006-X007.

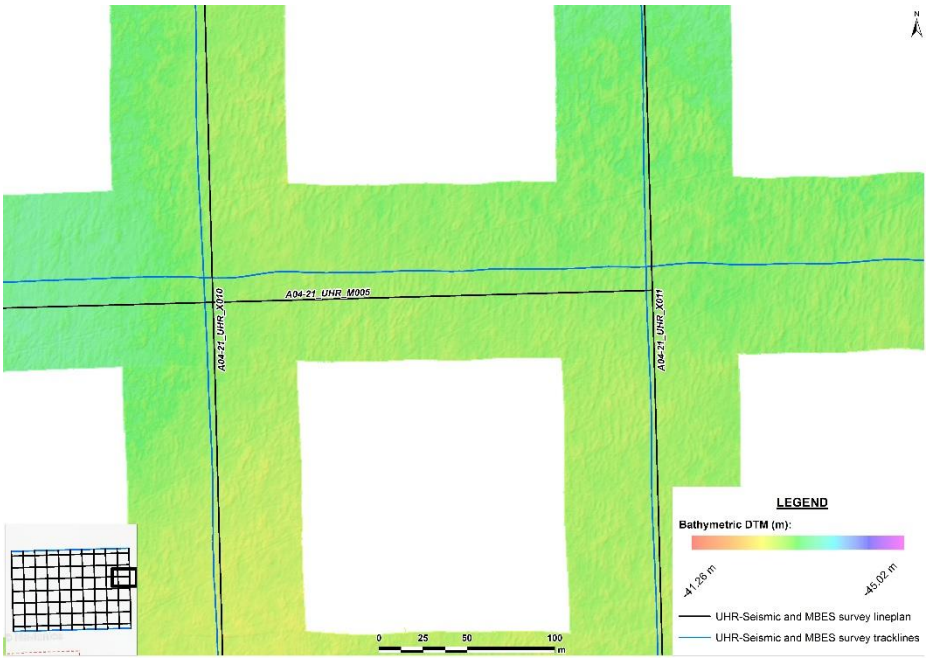


Figure 3-6: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the offshore substation of the NOR_AO4 area – Survey lines and tracklines AO4-21_UHR_M005 and AO4-21_UHR_X010-X011.

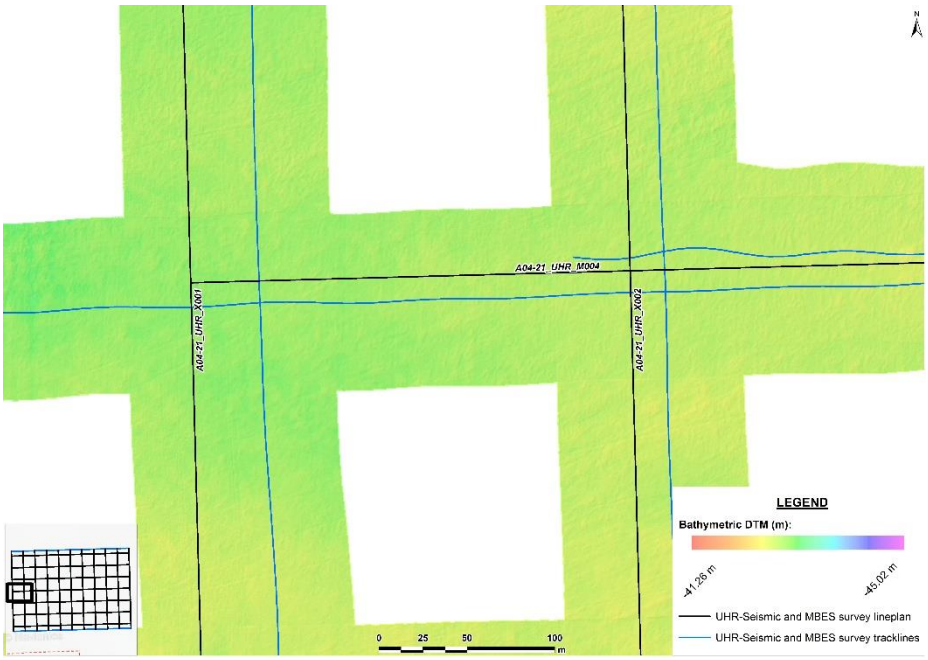


Figure 3-7: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the offshore substation of the NOR_AO4 area – Survey lines and tracklines AO4-21_UHR_M004 and AO4-21_UHR_X001-X002.

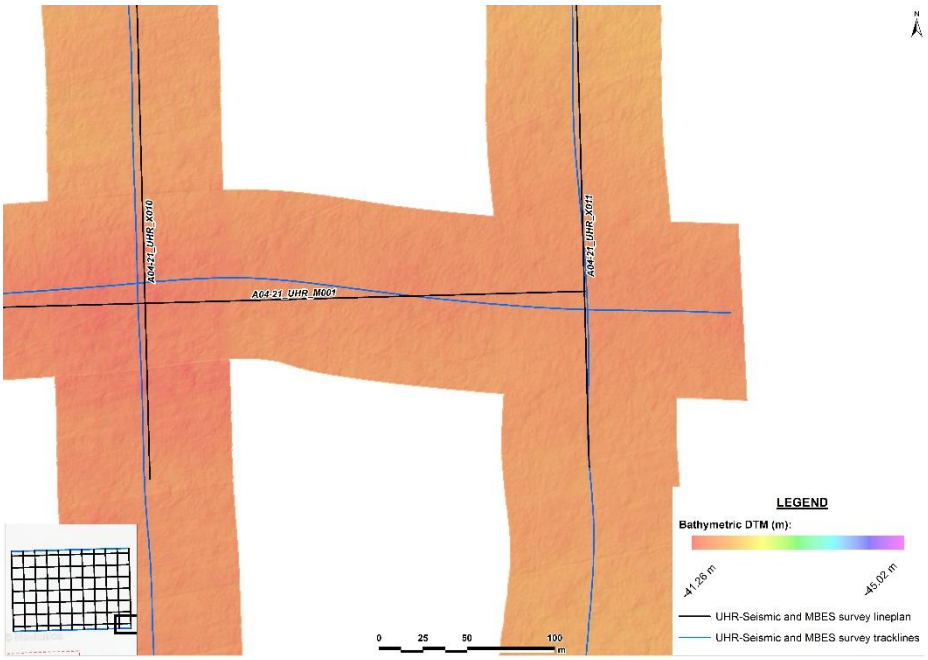


Figure 3-8: Detail of the bathymetric data grid model (0.5 x 0.5 m) for the offshore substation of the NOR_AO4 area – Survey lines and tracklines AO4-21_UHR_M001 and AO4-21_UHR_X010-X011.

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.

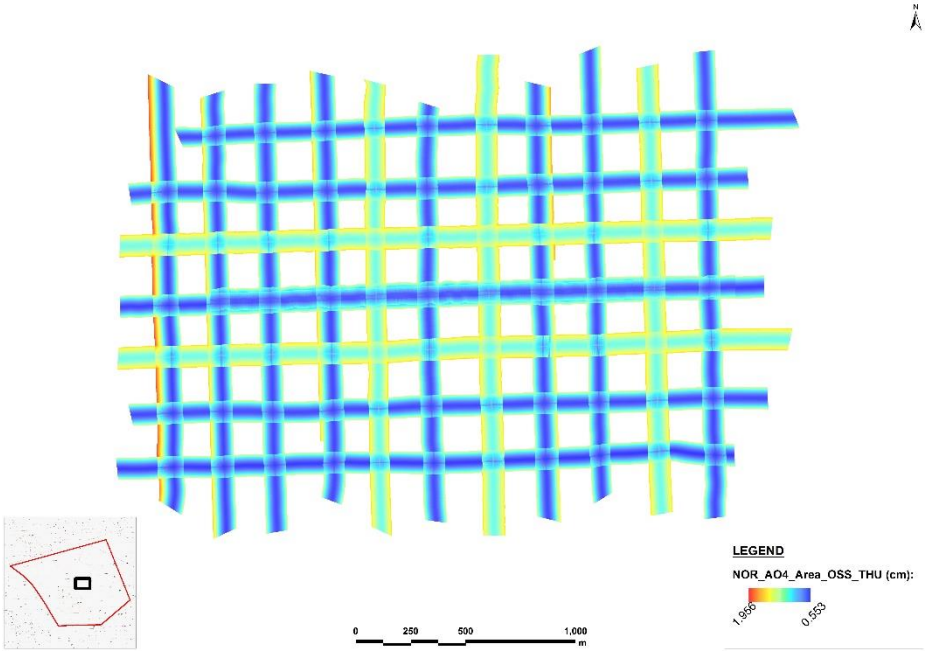


Figure 3-9: Results for the total horizontal uncertainty in the offshore substation of the NOR_AO4 area – General.

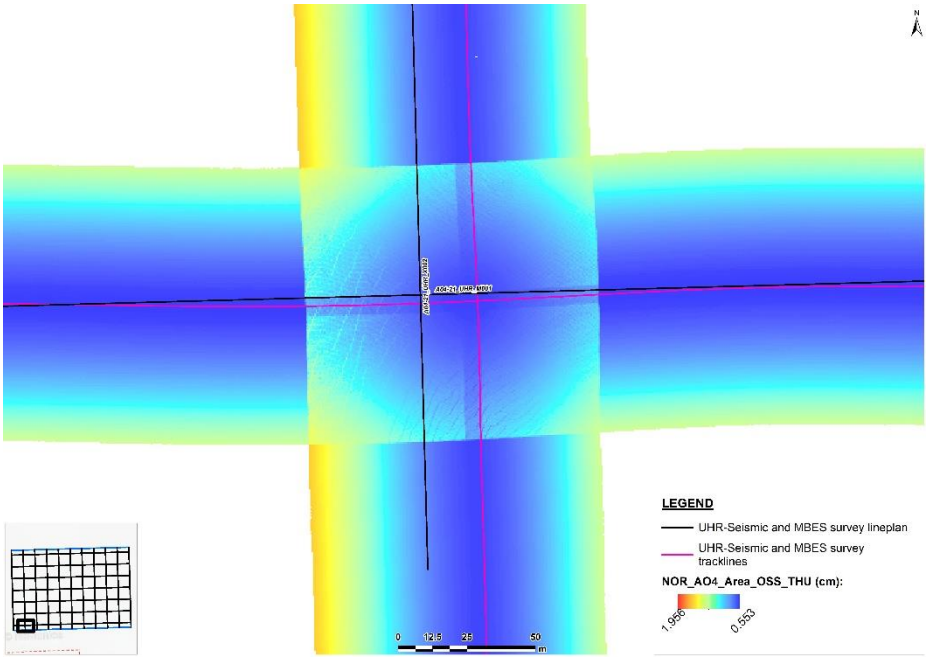


Figure 3-10: Example in detail of the results for the total horizontal uncertainty in the offshore substation of the NOR_AO4 area.

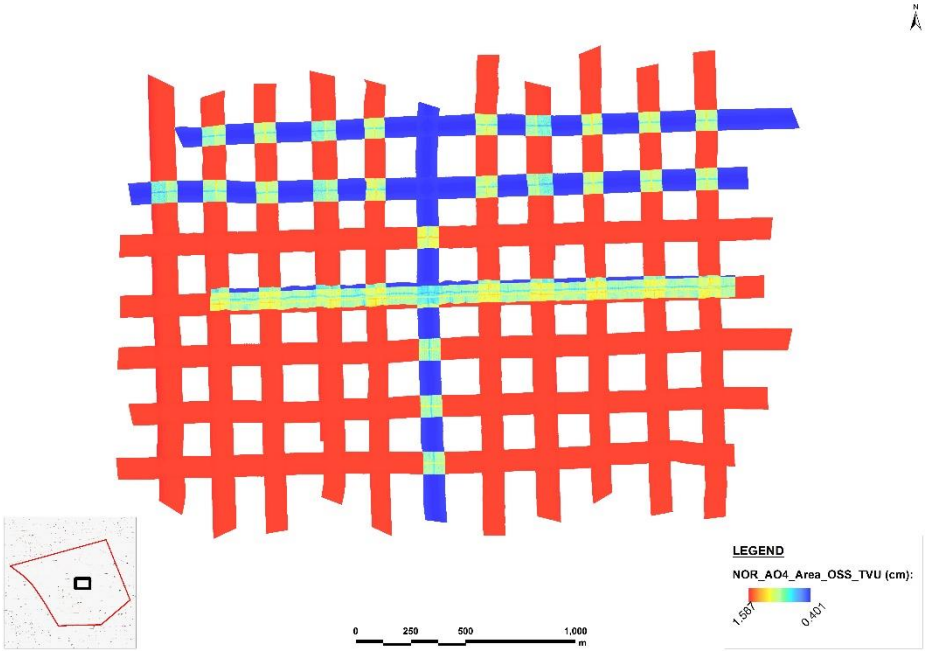


Figure 3-11: Results for the total vertical uncertainty in the offshore substation of the NOR_AO4 area – General.

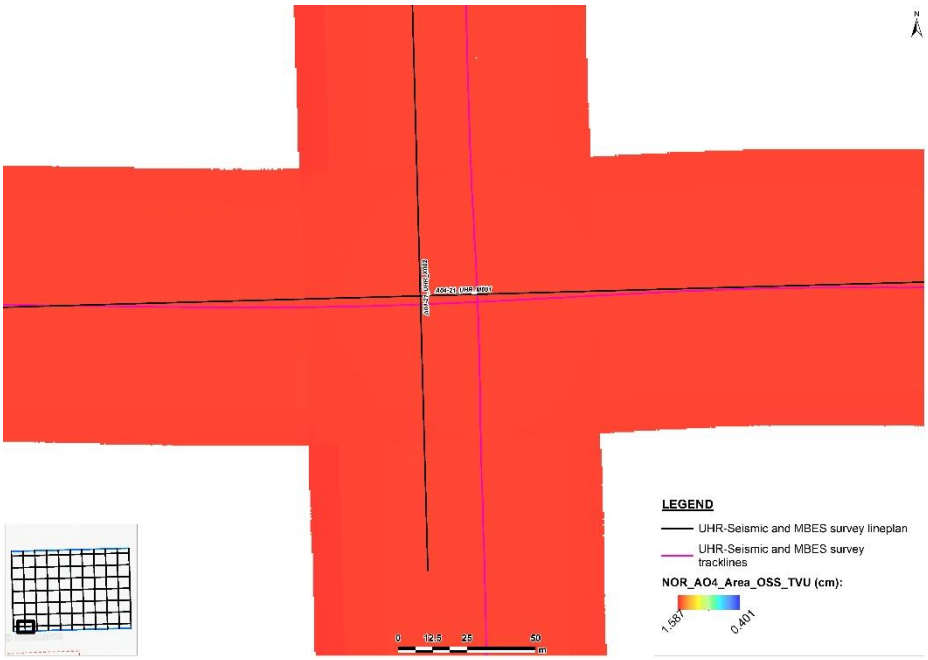


Figure 3-12: Example in detail of the results for the total vertical uncertainty in the offshore substation of the NOR_AO4 area.

The total horizontal uncertainty statistics are presented below:

- Maximum value: 1.9559 cm
- Minimum value: 0.5529 cm
- Average value: 0.9942 cm
- Standard deviation: 0.2701 cm

The total vertical uncertainty statistics are presented below:

- Maximum value: 1.5870 cm
- Minimum value: 0.4009 cm
- Average value: 1.3342 cm
- Standard deviation: 0.4214 cm

3.2. GEOLOGY

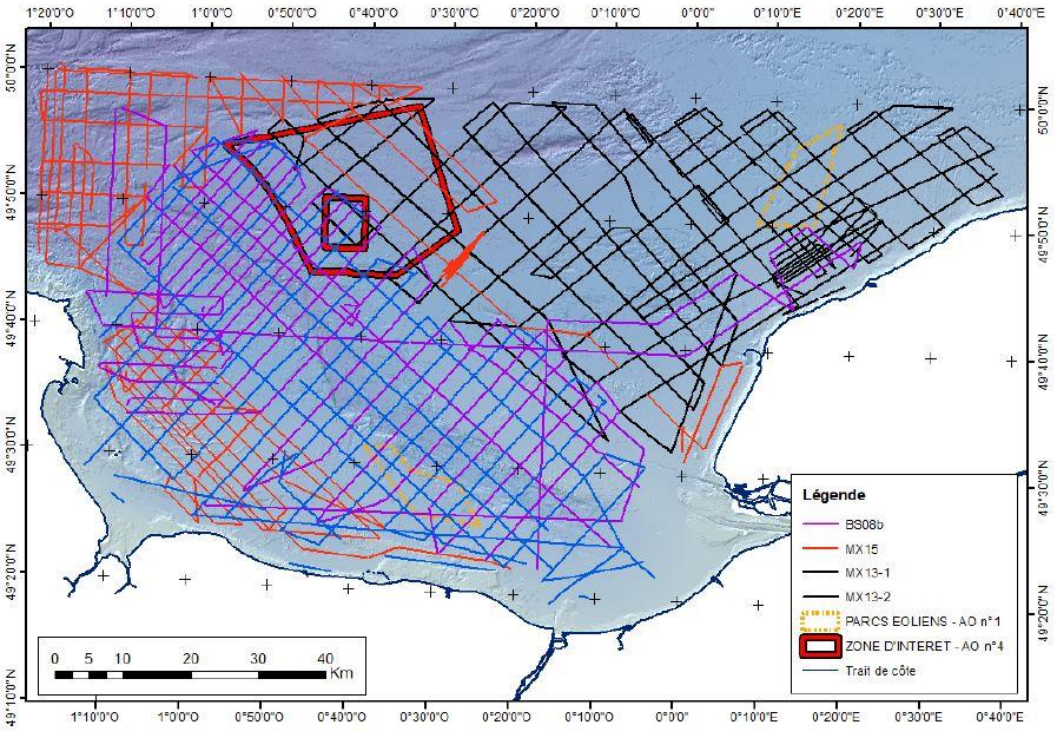
3.2.1. Data limitations

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, 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.



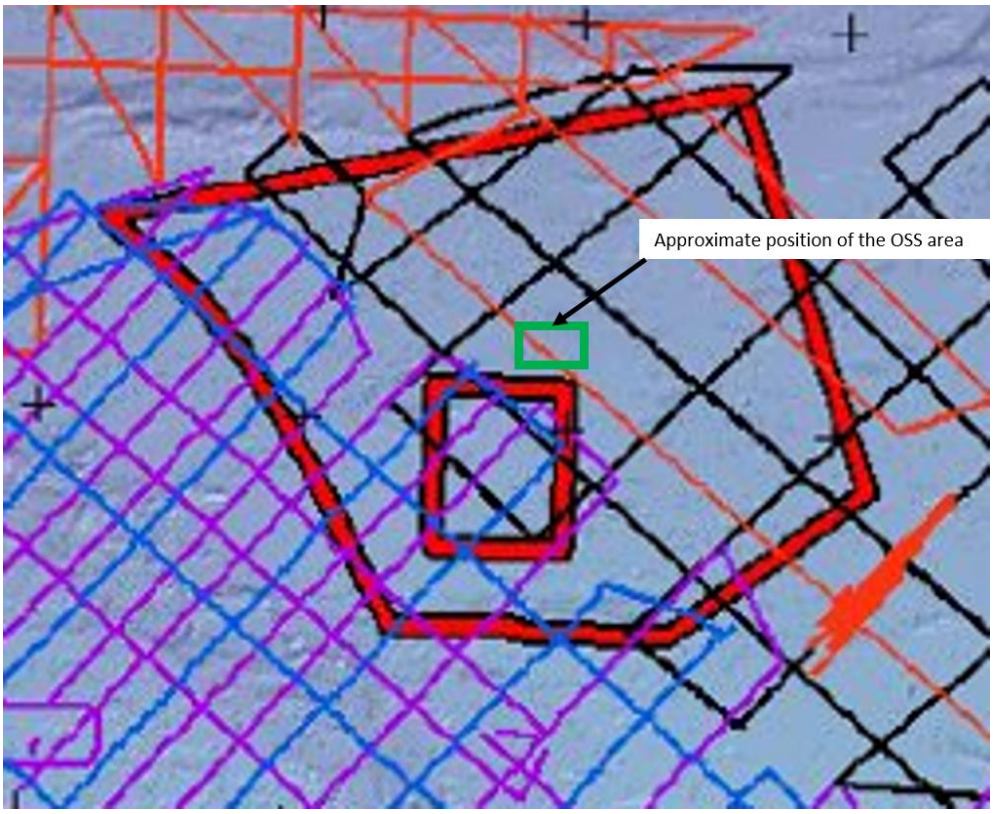


Figure 3-13: Map showing sparker seismic profiles of the four campaigns. (Thinon & Serrano, 2021).

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
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.

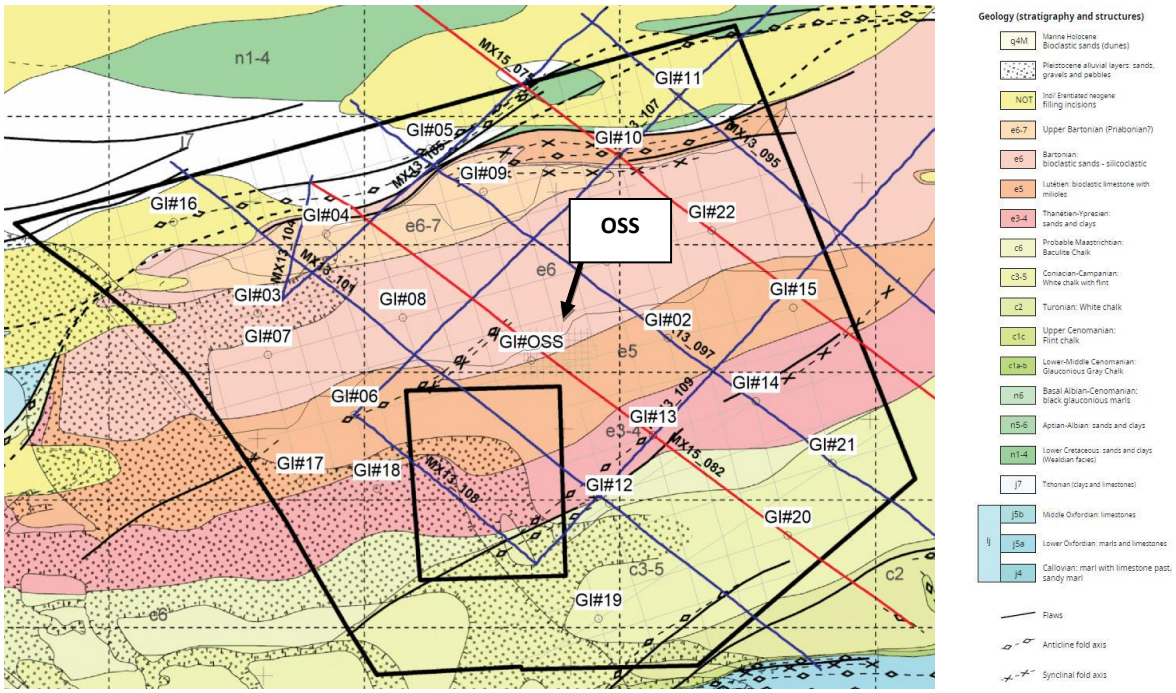


Figure 3-14: Extract from the Geological Map of France at 1:250,000 Bay de Seine Sheet (unpublished) modified after (Paquet, et al., 2021)

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.

The offshore substation (OSS) is in the approximate center of MX15_082 which illustrates expected shallow geology of the stratigraphic units.

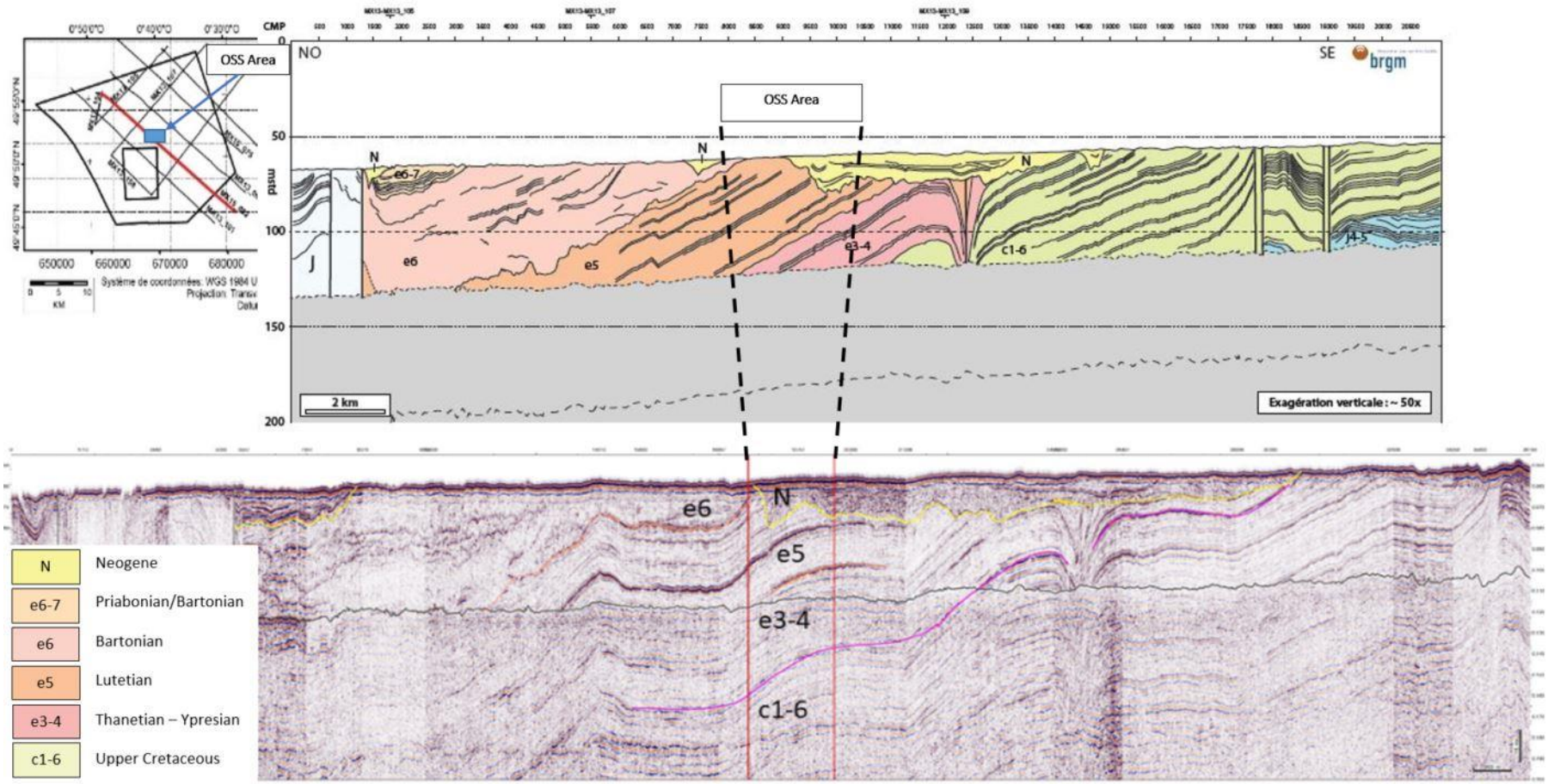


Figure 3-15: MX15_082 and representative UHR seismic section.

3.2.3. Geological sequence

The NOR_AO4 OSS 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 NOR_AO4 OSS area comprises a simplified sedimentary succession from the Paleogene to the Quaternary.

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

Across OSS, unit N / e6-7 ranges in thickness from about 3.5 to 21 m (BSB), with the thickest portion in the eastern half of OSS. Unit e6 pinches out in the west of OSS area (see Figure 3-17). Units e5 and e3-4 are each expected to be approximately 25 to 35 m thick across OSS. Although the deeper Cretaceous units (c3-5, c6) may not be encountered during geological investigations, they are included below for historical reference and awareness depending upon the accuracy of geophysical prognosis.

Below unit N / e6-7 (unconsolidated Quaternary paleovalleys, fluvial incisions and channel infill deposits) the expected subsurface nature is relatively homogenous. Unit N / e6-7 is illustrated in Figure 3-16 and 3-17 below as a time structure map (left) and interpreted horizon in yellow (right). The dark blue mapping in the eastern half of OSS portrays the thickest region of unit N / e6-7 up to approximately 21 m (BSB).

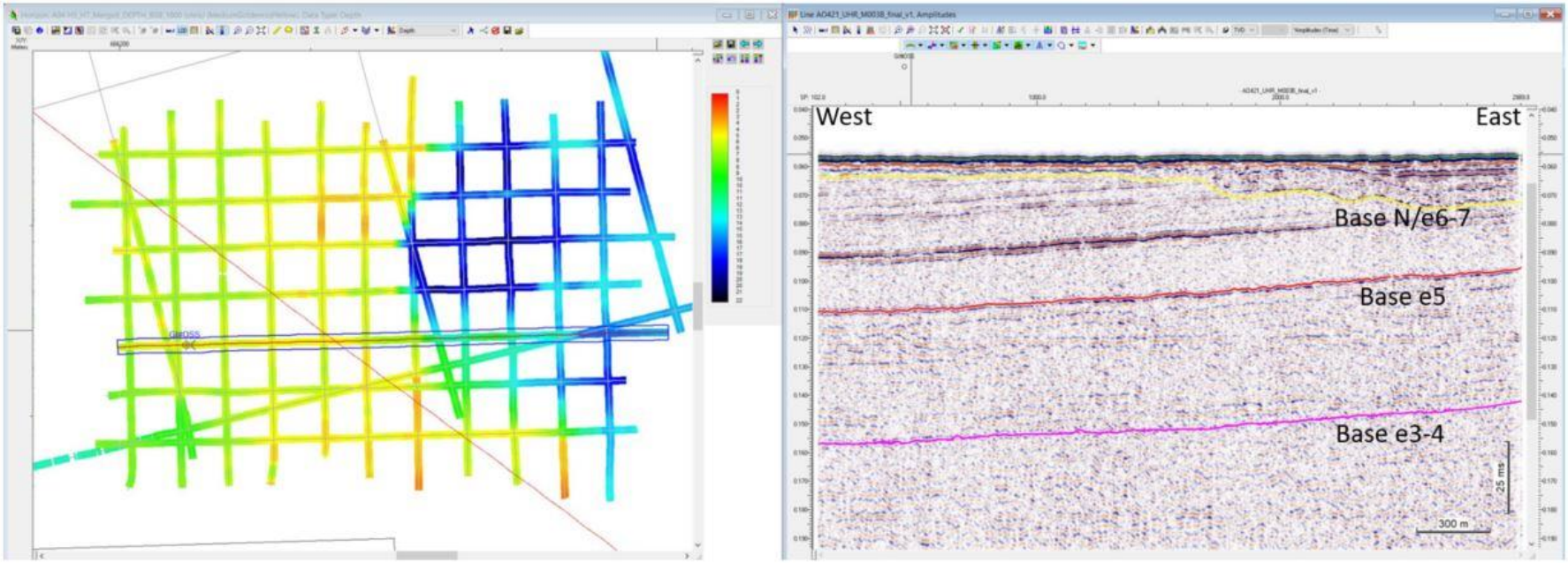


Figure 3-16: Time structure of unit N / e6-7 and Line AO4_UHR_M003B

Figure 3-16 illustrates the relatively chaotic nature of the subsurface in units N / e6-7, with the underlying homogeneous Paleogene. The Paleogene units are generally parallel bedded and dipping down to the north. Horizons shown on the figures have been correlated with the work of Paquet et al, but further ground truthing is required.

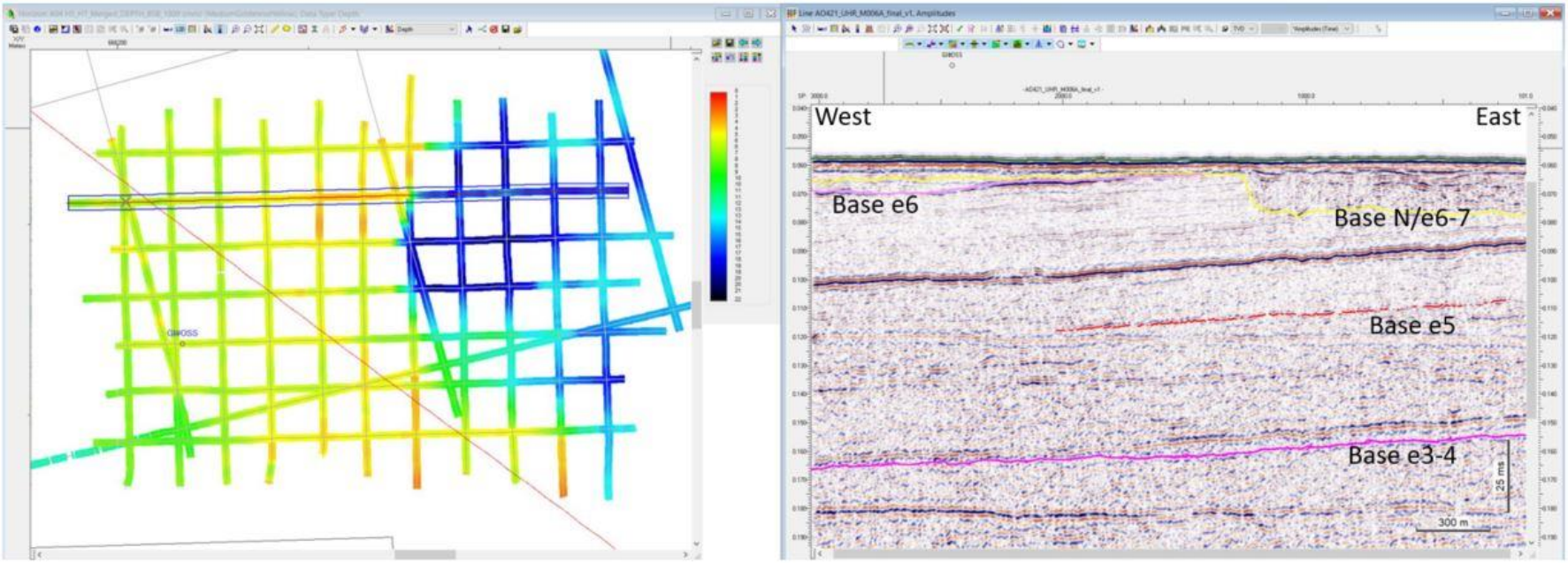


Figure 3-17: Time structure of unit N / e6-7 and Line AO4_UHR_M006A

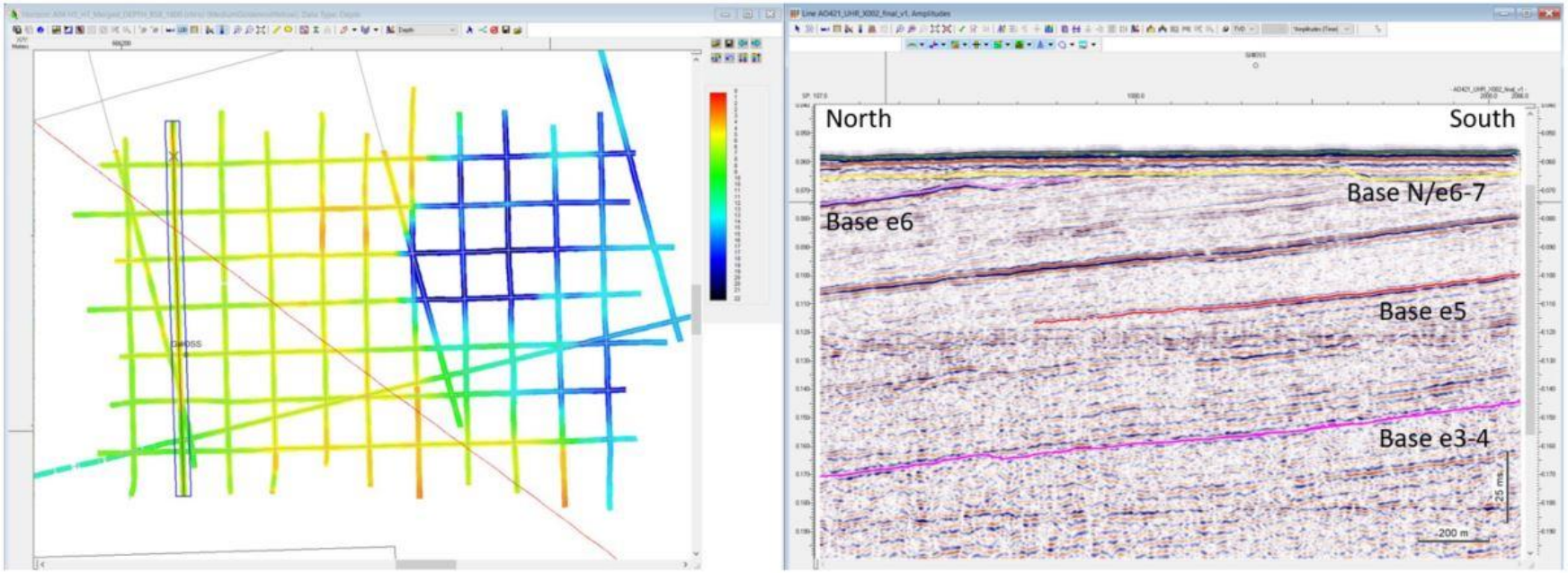


Figure 3-18: Time structure of unit N / e6-7 and Line AO4_UHR_X002

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 Thanetien-Ypresien (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)*

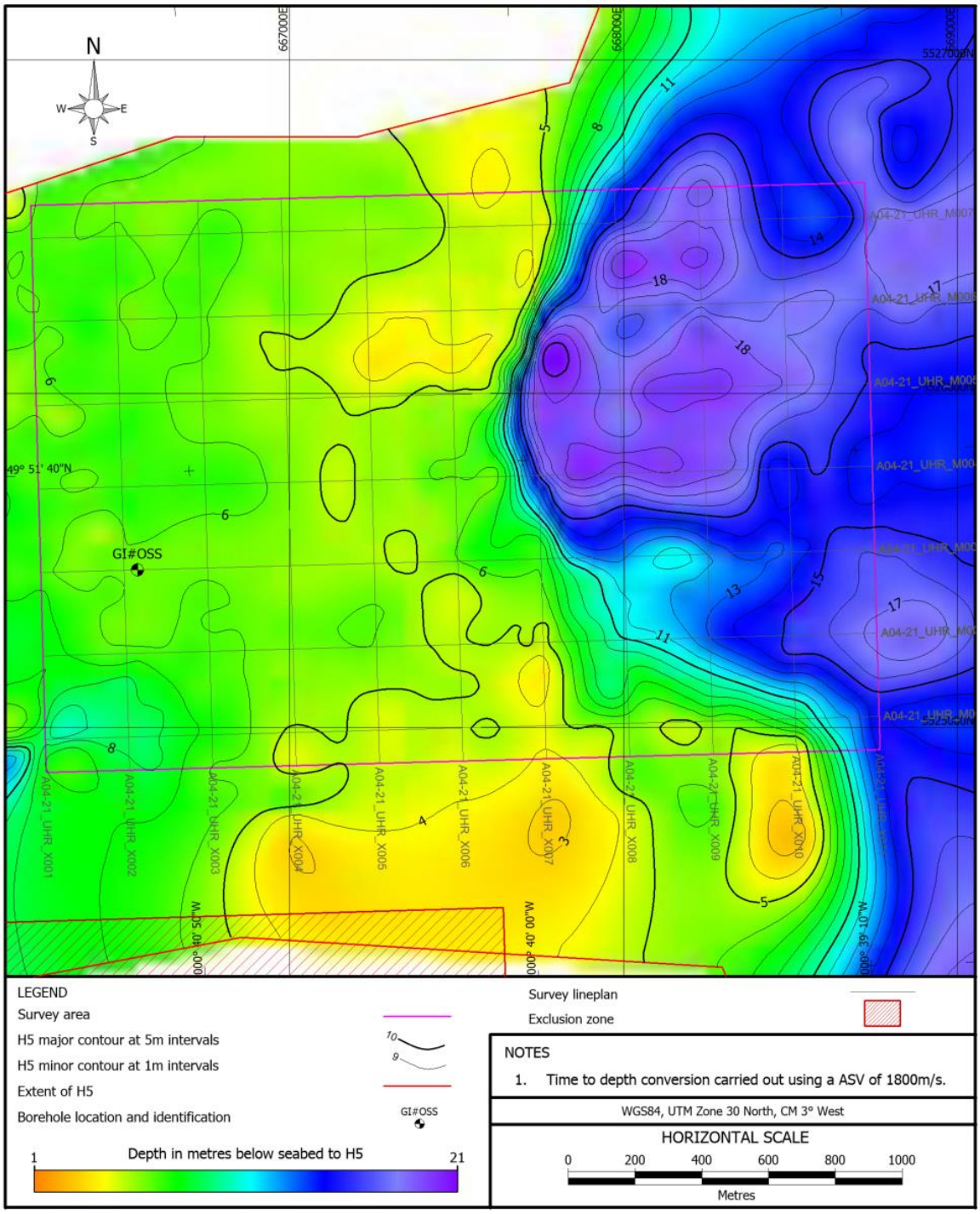


Figure 3-19: Isopach of Base Plio-Quaternary Uncosolidated sediments (H5).

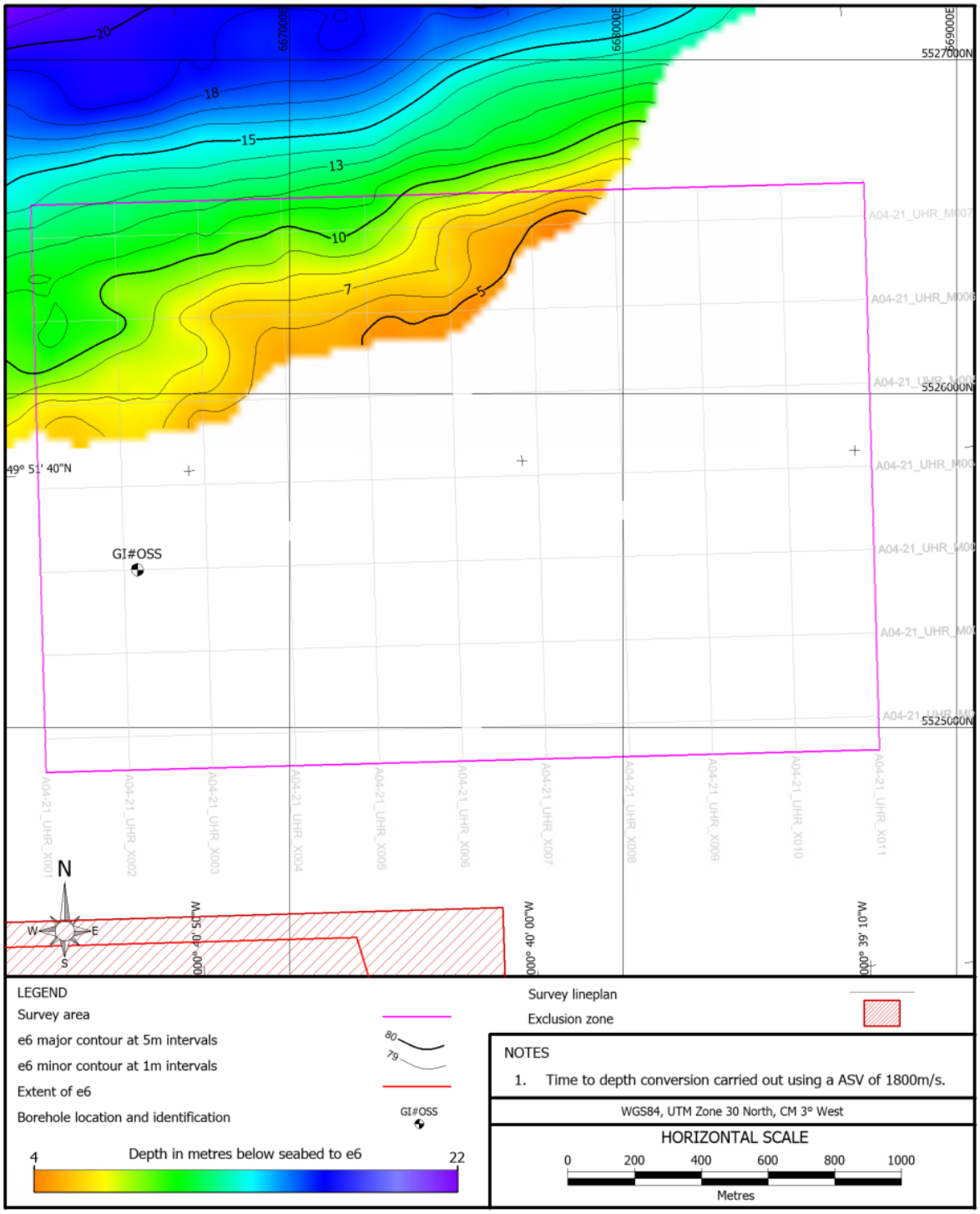


Figure 3-20: Extent of the base of the Bartonian (e6).

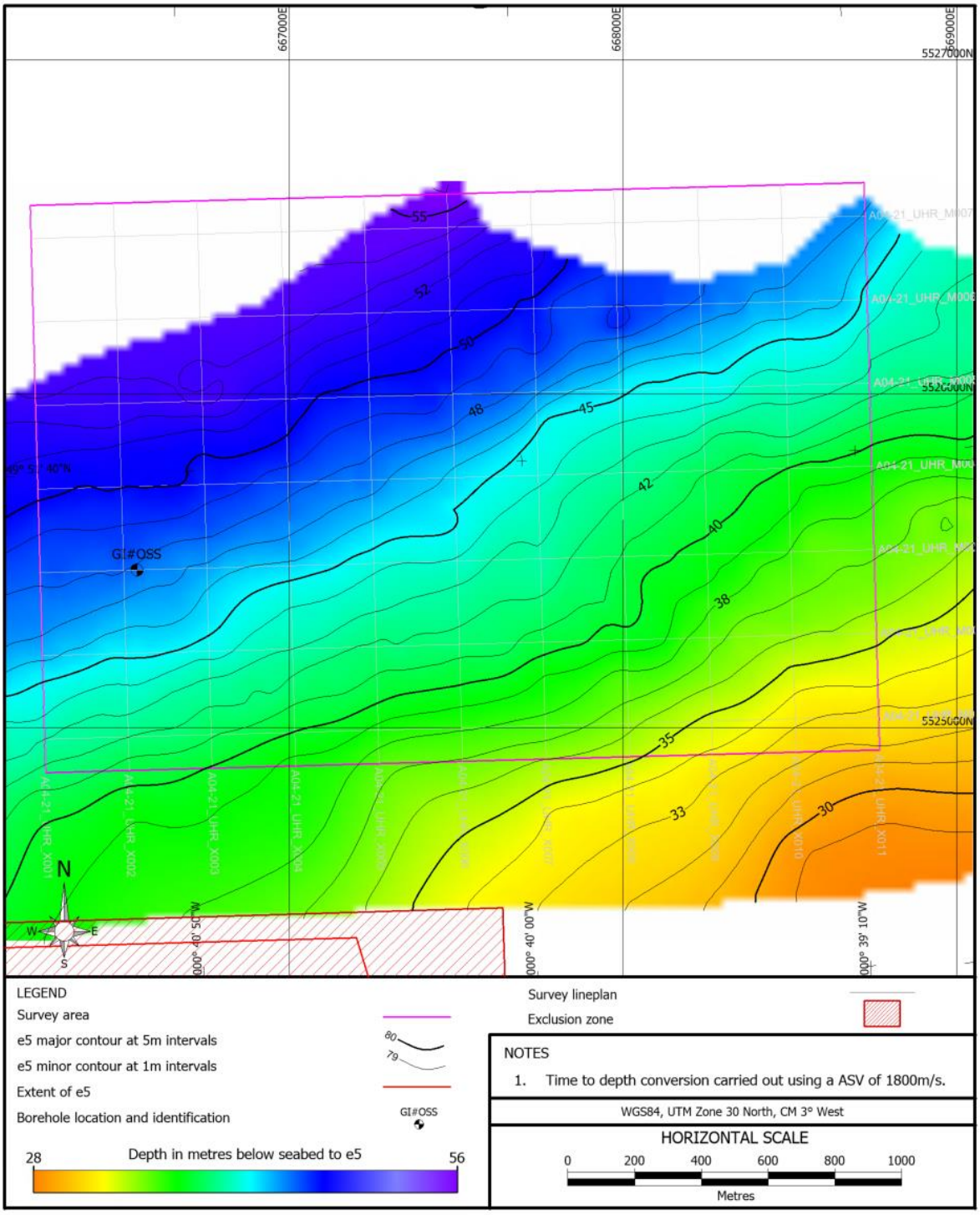


Figure 3-21: Extent of the base Lutetian (e5).

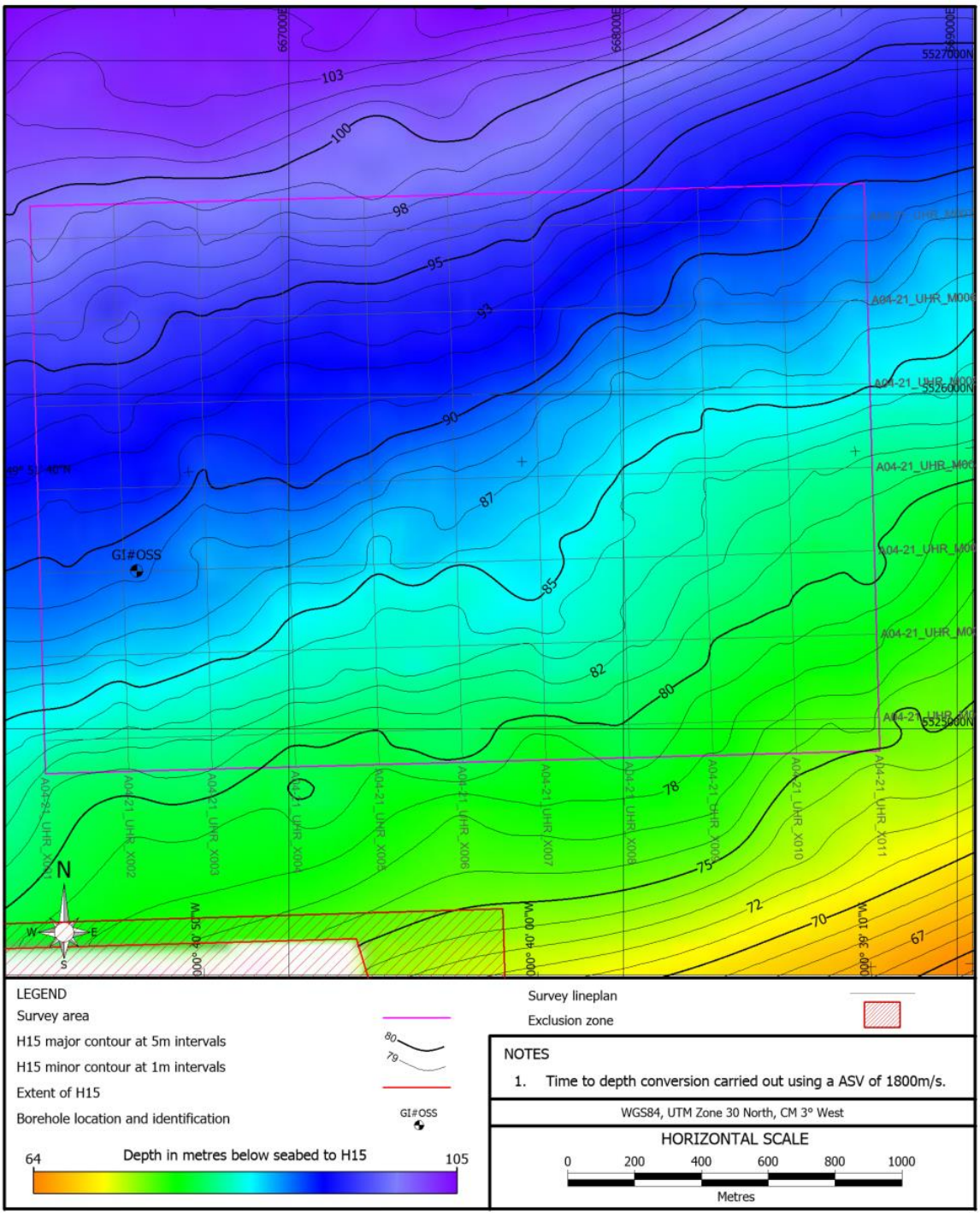


Figure 3-22: Isopach and extent of Intra Cretaceous unconformity (H15).

3.2.4. Geohazards

The correlation and mapped extent of a network of paleovalleys and fluvial terraces of the paleo-Seine has improved with this new data within the OSS area. As based on previous data no channelling was mapped within the OSS area. Paleovalleys and fluvial incisions within unit U20 are mapped using the new UHR seismic data set. The base of the combined channels of Unit N and Unit e6-7 have been mapped within the OSS area. An isopach of H5 represents the approximate thickness of unconsolidated Plio-Quaternary sediments (SAND, SILT, CLAY) (Figure 3-19). An isopach of H15 (intra Cretaceous unconformity) represents the approximate thickness of consolidated Cenozoic sediments resting unconformably on Upper Cretaceous sediments / bedrock CHALK (Figure 3-20).

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 100m below the seafloor. Although faulting (described in 3.2.6 Structural Geology) is clearly observed on the NOR_AO4 OWF area, it is not evident within the OSS area. Summaries of geological characteristics / processes and potential constraints expected at site NOR_AO4 OSS are provided in Table 4 and Table 6.

A geohazard prognosis for the planned geotechnical borehole at OSS is provided in Appendix A – GI SCREENING.

A summary of geological conditions and potential constraints on infrastructure and engineering activities, applied to NOR_AO4 site, is provided in (Table 6) modified after (Mellet, Long, Carter, Chiverell, & Van Landeghem, 2015).

Table 5: Geological characteristics / processes and potential constraints.

Geological characteristic / process	Potential constraint	NOR_AO4_OSS 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.	Not evident
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 (> 100 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.	Not 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	Not evident

The depth values were converted from time (TWT) using sound velocity of 1,800 m/s in sediments and 1,500 m/s in the water column (Thinon & Serrano, 2021).

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:

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 fillings 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 paleovalleys or fluvial terraces of the paleo-Seine in the cenozoic-paleogene deposits is plausible.

Figures 3-23 and 3-24 illustrate 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.

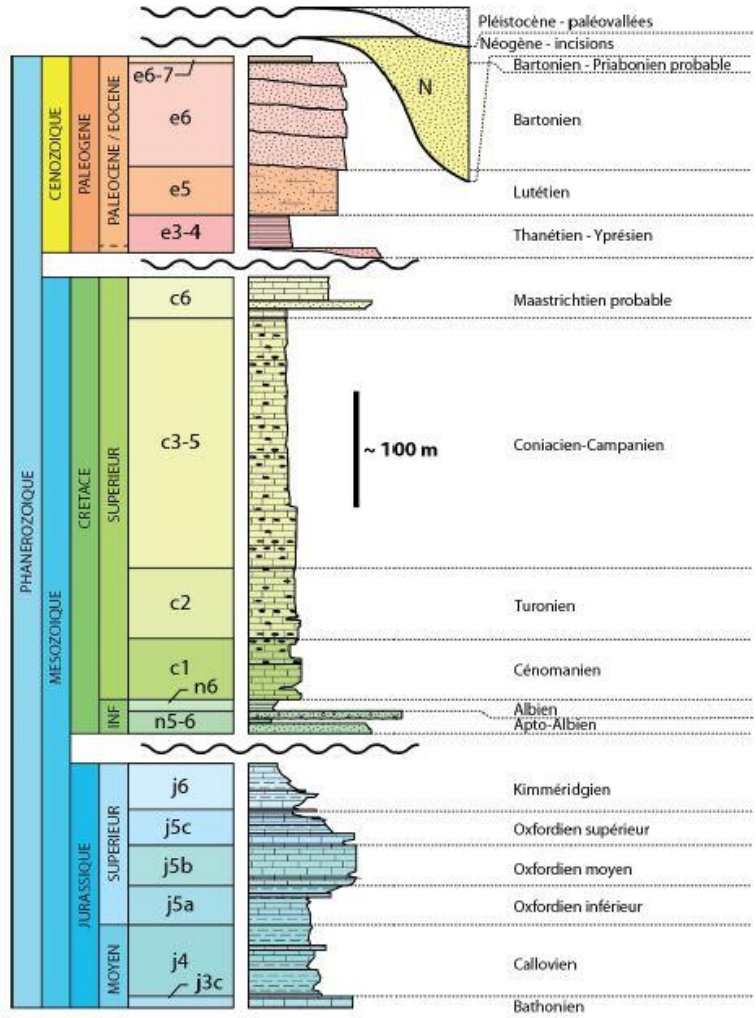


Figure 3-23: Schematic section of the stratigraphy (Thinon & Serrano, 2021).

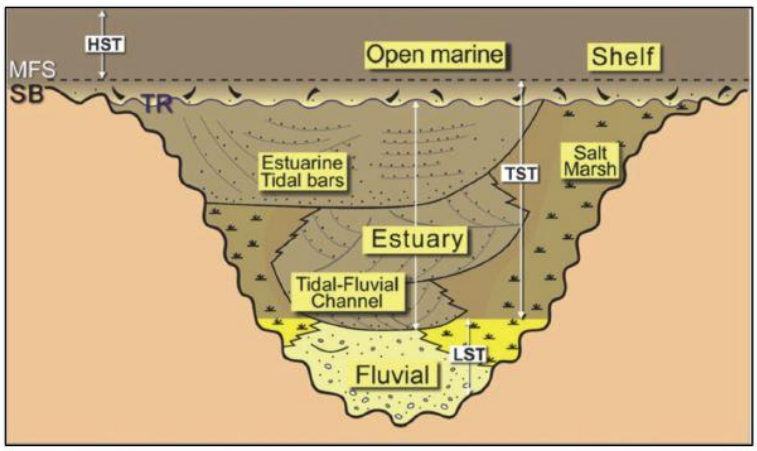


Figure 3-24: Schematic section of a paleovalley (Dalrymple and Choi, 2007).

3.2.6. Regional structural geology

The regional geological structure is illustrated below (Figure 3-25) 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).

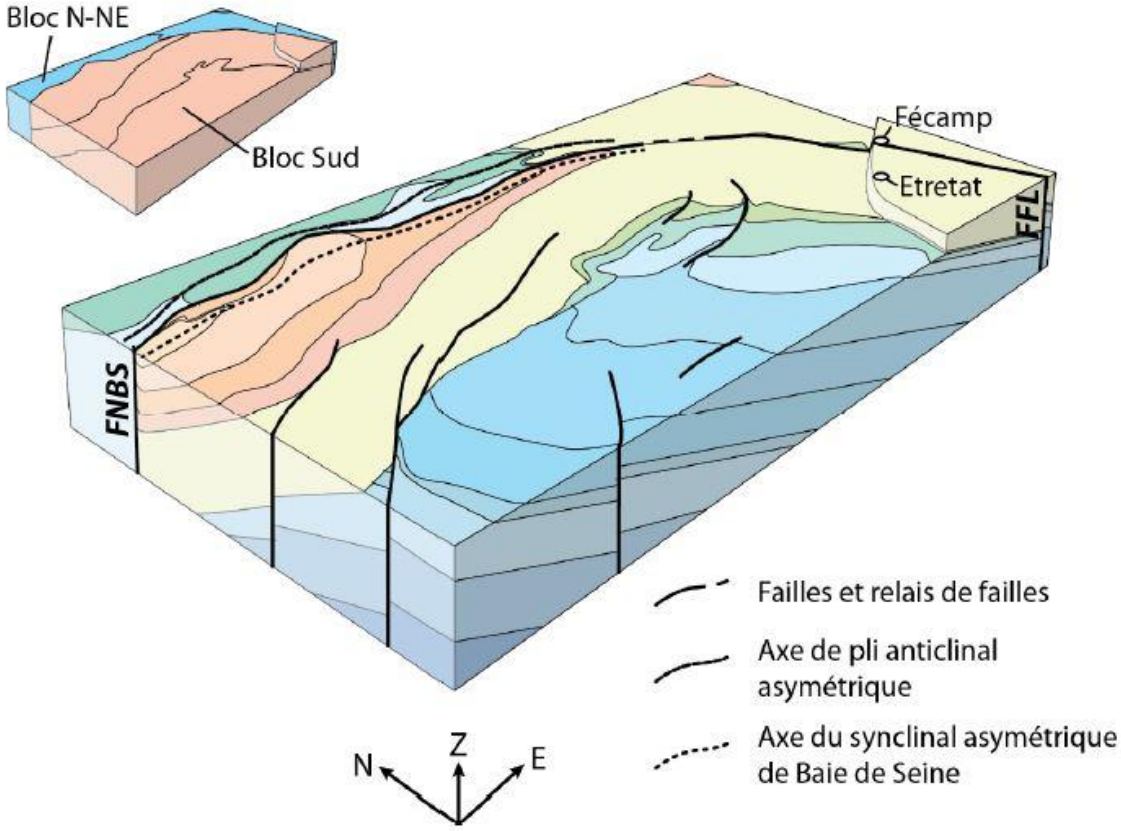


Figure 3-25: Schematic three-dimensional block diagram, viewed from the southwest (Chantraine et al., 2003; Benabdellouahed, 2011; Paquet et al. - b, in preparation).

3.2.7. Conclusions and recommendations/comments

Geological horizons and the spatial extent of Quaternary paleovalleys, fluvial incisions and channel infill were mapped to update and refine the seismic stratigraphy and geological model based on prior regional mapping. The correlation and mapped extent of the network of paleovalleys of the paleo-Seine has improved with this new data.

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 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.
3. 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 OSS site, monitoring for its potential could be beneficial for long-term development planning.
4. Acquire seabed ground-truthing “light” geotechnical data (e.g., grab samples) to confirm the variable seafloor composition illuminated with the sidescan sonar data.

4. REFERENCES

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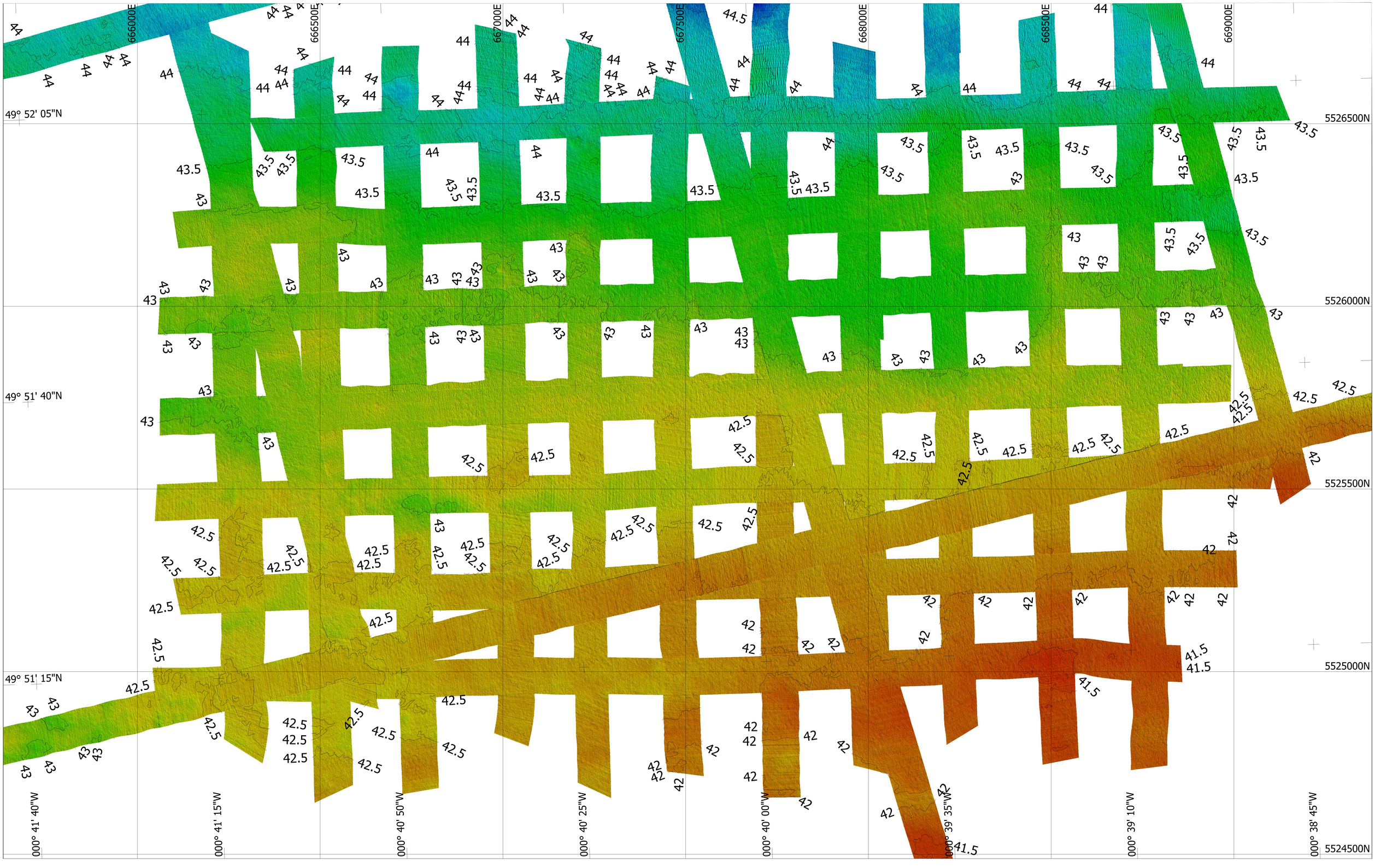
APPENDIX A – GI SCREENING

APPENDIX B – CHARTING

CHART NUMBER	CHART TITLE
1	AO4 OSS Bathymetry
2	AO4 OSS Isopach of H5 Horizon
3	AO4 Isopach of e6 Horizon
4	AO4 Isopach of e5 Horizon
5	AO4 OSS Isopach of H15 Horizon
6	AO4 OSS Geological Profile Line AO421_UHR_M004A
7	AO4 OSS Geological Profile Line AO421_UHR_X006
8	Arbitrary UHRS profile representing MX15_082



MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE

TECNOAMBIENTE A TRADEBE COMPANY

GEOQUIPMARINE

CARTOGRAPHIC INFORMATION:

ELEVATIONS REFERED TO BATHYELLI v2 GEOID

GRAPHIC SCALE: 0 50 100 150 200 250 m

DATUM	PROJECTION:
WGS84	UTM 30 N

DATE: JUNE 2022

COMMENTS: - - -

LEGEND:

42.5 — Bathymetric major contour with labels indexed at 2.5 m intervals

42 — Bathymetric minor contour with labels indexed at 0.5 m intervals

Depth in metres (SHOM BATHYELLI v2)
DTM data gridded at 1m cell size

41 43 45

PROJECT TITLE: Geophysical and UXO Survey - AO4 OSS Area

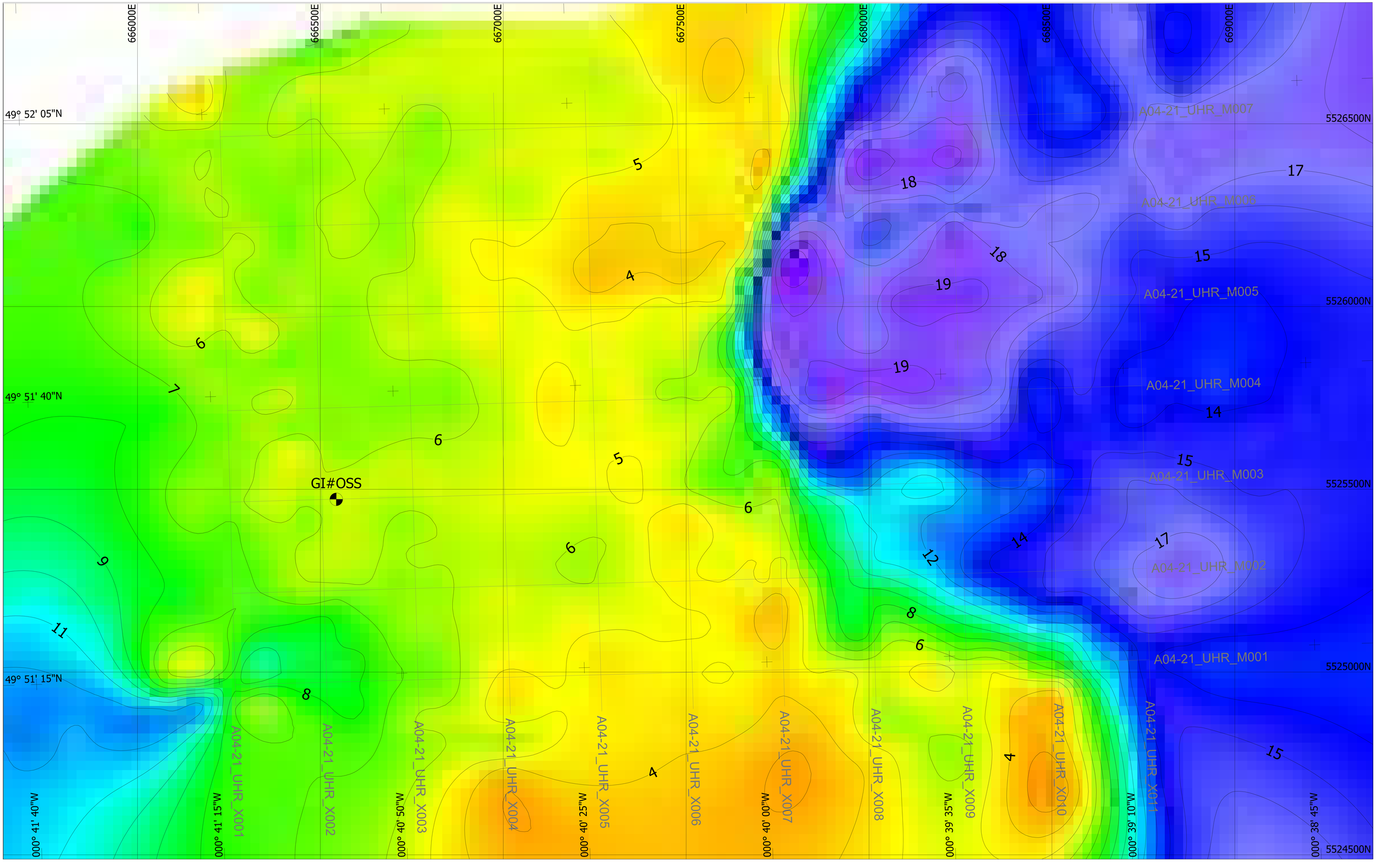
CHART TITLE: AO4 Bathymetry

AREA: GENERAL

CHART #: 1 OF 6

REFERENCE: - - -

SCALE: - - -



MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE

TECNOAMBIENTE

GEOQUIPMARINE

CARTOGRAPHIC INFORMATION:

ELEVATIONS REFERED TO BATHYELLI v2 GEOID

GRAPHIC SCALE: 0 50 100 150 200 250 m

DATUM: WGS84

PROJECTION: UTM 30 N

DATE: JUNE 2022

COMMENTS: - - -

LEGEND:

10 Major contour with labels indexed at 5 m intervals

8 Minor contour with labels indexed at 1 m intervals

AO4 OSS Survey Line

Depth converted using ASV of 1800m/s
Depth BSB to H5 in metres
2 — 21

PROJECT TITLE: Geophysical and UXO Survey - AO4 OSS Area

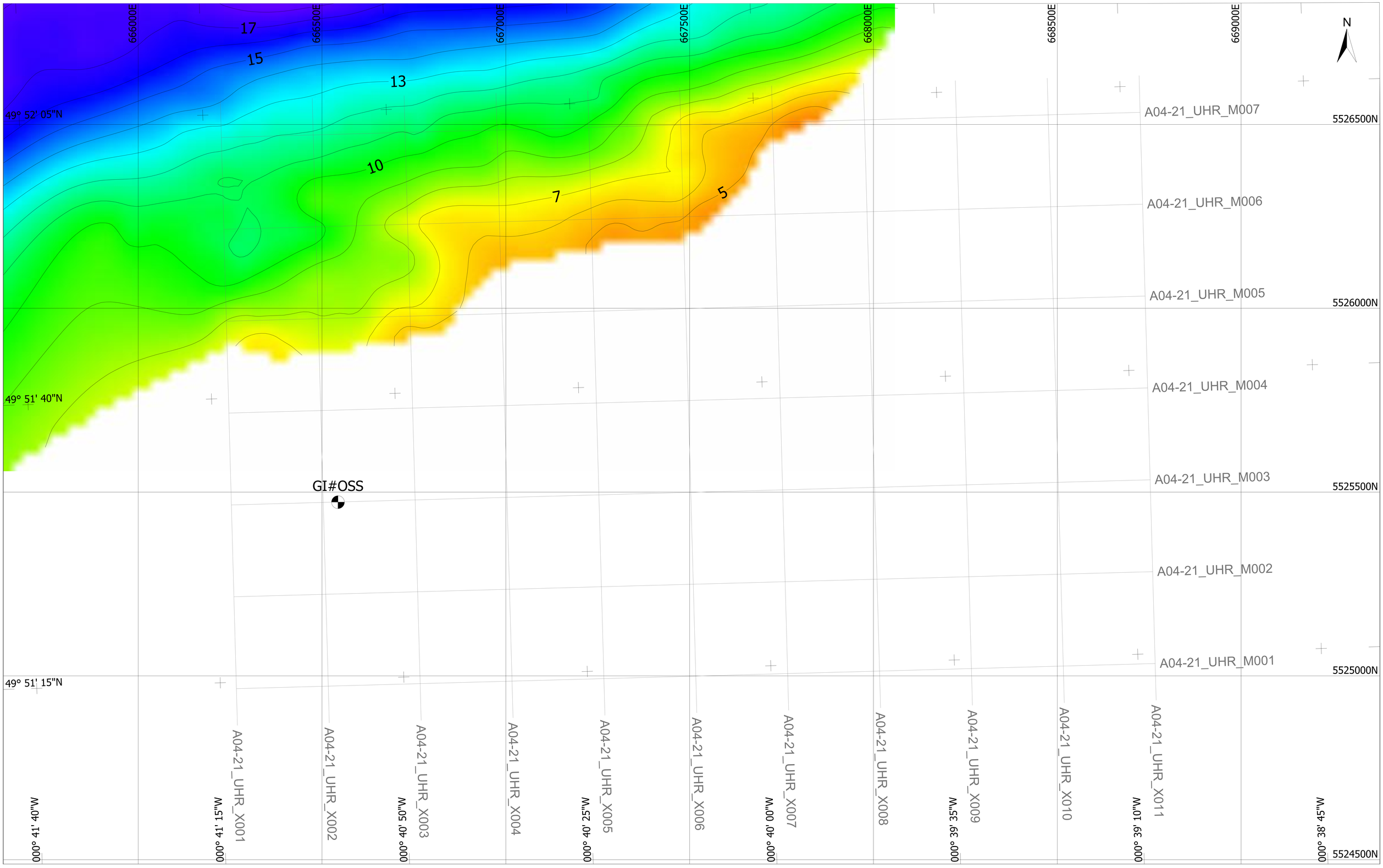
CHART TITLE: Isopach of H5

AREA: GENERAL

CHART #: 2 OF 6

REFERENCE: - - -

SCALE: - - -



MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE

TECNOAMBIENTE

GEOQUIPMARINE

CARTOGRAPHIC INFORMATION:

ELEVATIONS REFERED TO BATHYELLI v2 GEOID

GRAPHIC SCALE: 0 50 100 150 200 250 m

DATUM	PROJECTION:
WGS84	UTM 30 N

DATE: JUNE 2022

COMMENTS: - - -

LEGEND:

75 — Major contour with labels indexed at 5 m intervals

74 — Minor contour with labels indexed at 1 m intervals

AO4 OSS Survey Line

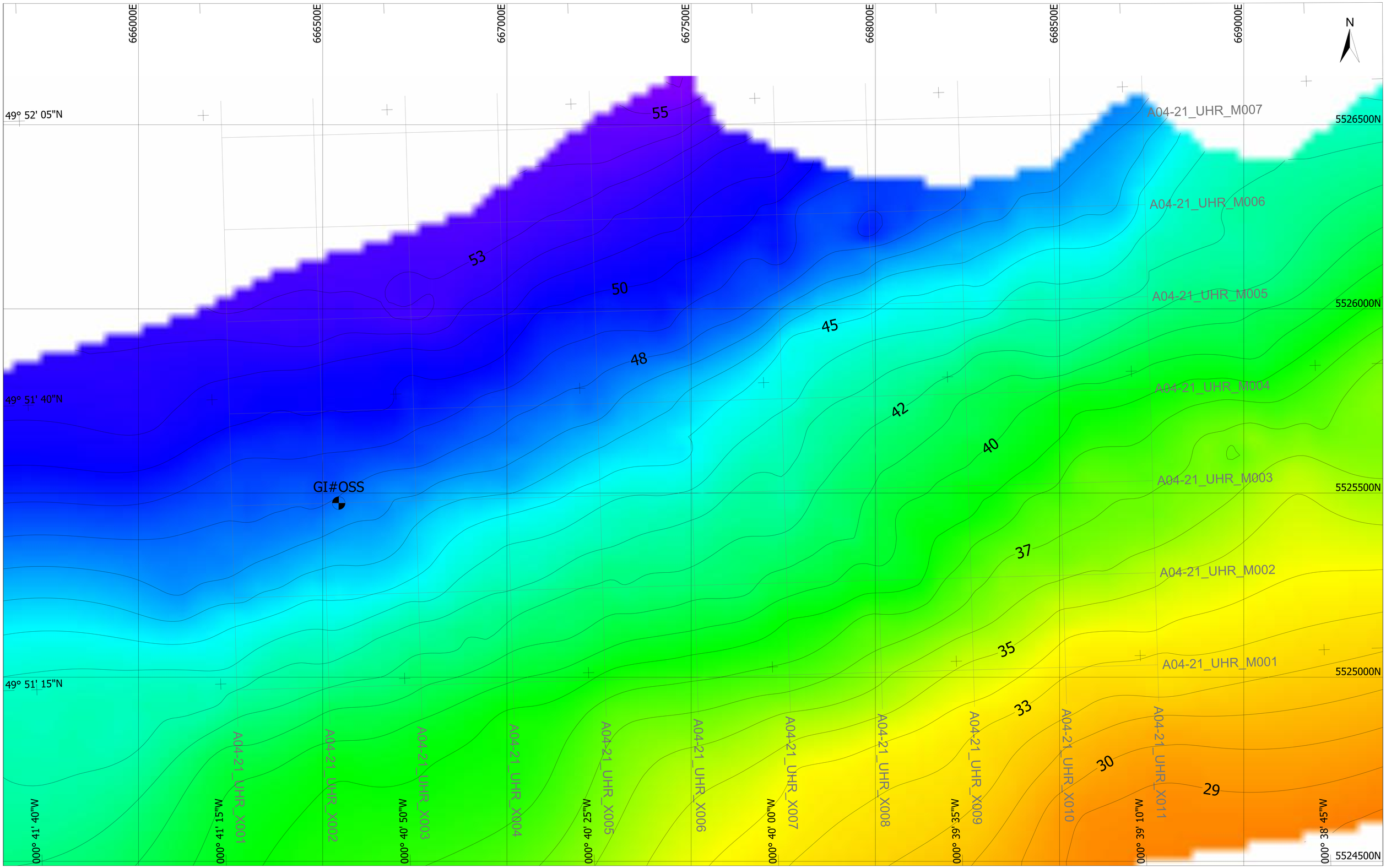
Depth converted using ASV of 1800m/s
Depth BSB to e6 in metres

4 — 19

PROJECT TITLE: Geophysical and UXO Survey - AO4 OSS Area

CHART TITLE: Isopach of e6

AREA:	CHART #:
GENERAL	3 OF 6
REFERENCE:	SCALE:
- - -	- - -



MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE

TECNOAMBIENTE — A TRADEBE COMPANY

GEOQUIPMARINE

CARTOGRAPHIC INFORMATION:

ELEVATIONS REFERED TO BATHYELLI v2 GEOID

GRAPHIC SCALE: 0 50 100 150 200 250 m

DATUM	PROJECTION:	COMMENTS:
WGS84	UTM 30 N	- - -

DATE: JUNE 2022

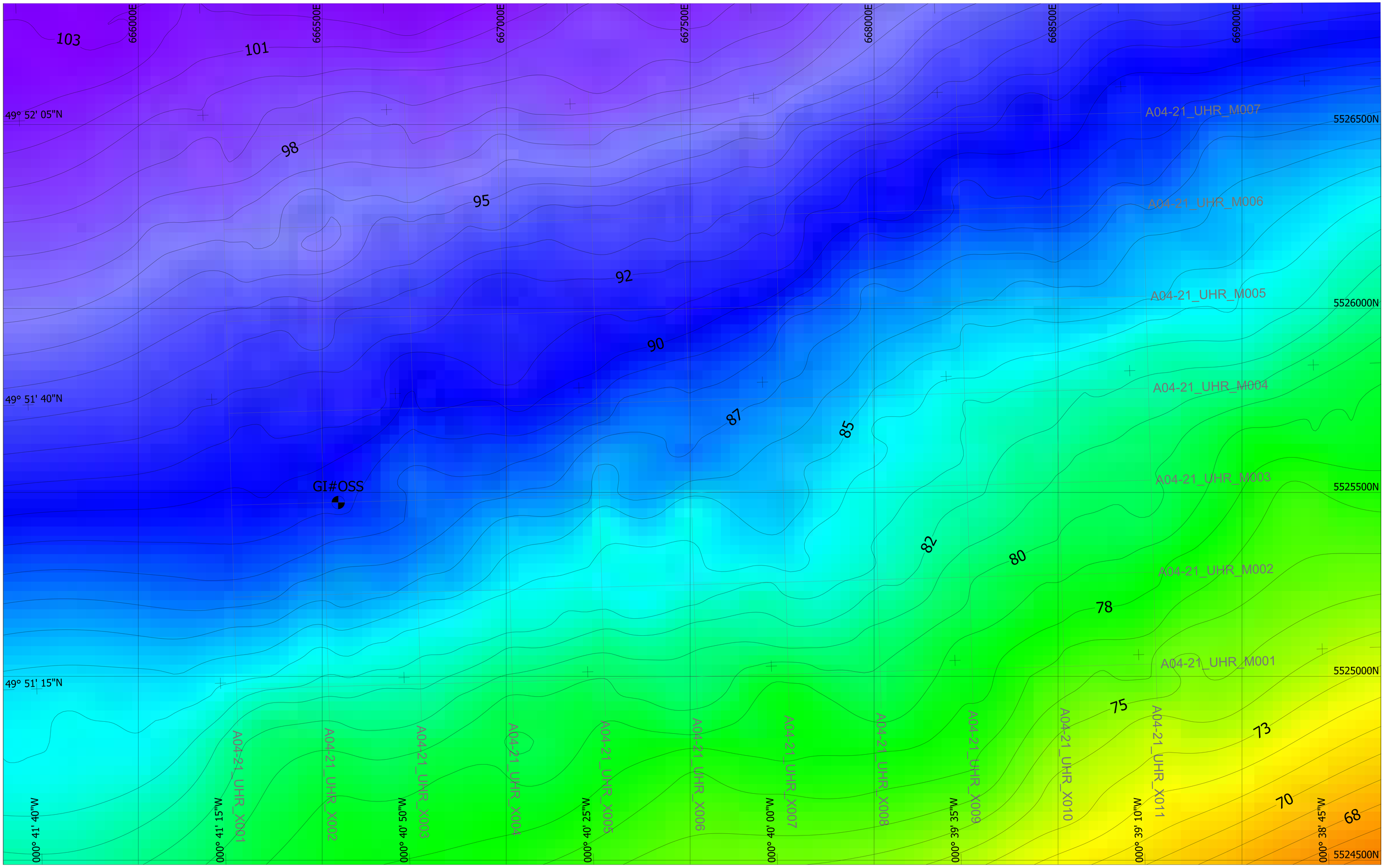
LEGEND:
- 75 — Major contour with labels indexed at 5 m intervals
- 74 — Minor contour with labels indexed at 1 m intervals
- AO4 OSS Survey Line

Depth converted using ASV of 1800m/s
Depth BSB to e5 in metres
28 — 56

PROJECT TITLE: Geophysical and UXO Survey - AO4 OSS Area

CHART TITLE: Isopach of e5

AREA:	CHART #:
GENERAL	3 OF 6
REFERENCE:	SCALE:
- - -	- - -



MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE

TECNOAMBIENTE

GEOQUIPMARINE

CARTOGRAPHIC INFORMATION:

ELEVATIONS REFERED TO BATHYELLI v2 GEOID

GRAPHIC SCALE: 0 50 100 150 200 250 m

DATUM	PROJECTION:	DATE:	COMMENTS:
WGS84	UTM 30 N	JUNE 2022	- - -

LEGEND:

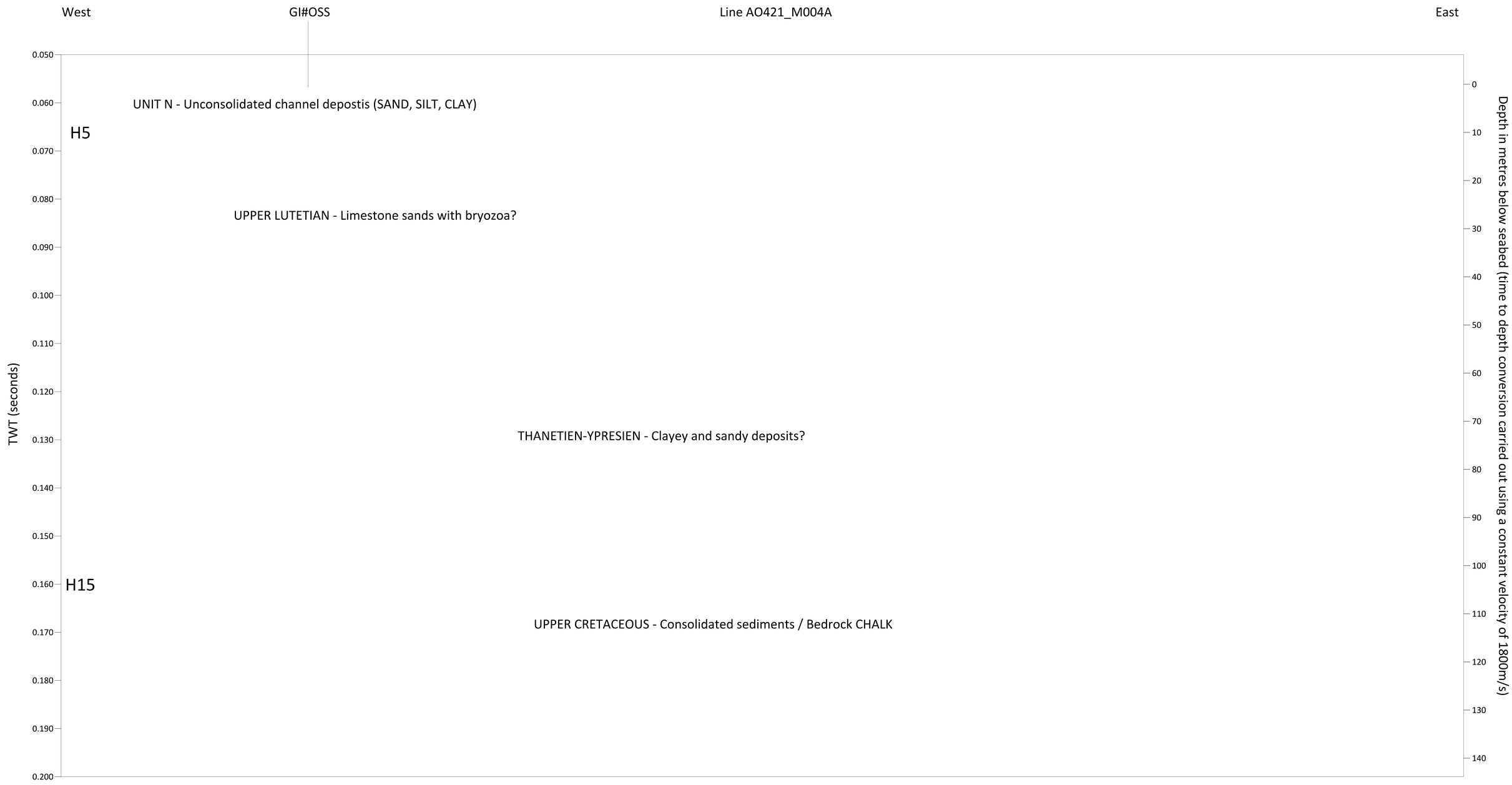
- 76 — Major contour with labels indexed at 5 m intervals
- 74 — Minor contour with labels indexed at 1 m intervals
- AO4 OSS Survey Line

Depth converted using ASV of 1800m/s
Depth BSB to H15 in metres
66 — 103

PROJECT TITLE: Geophysical and UXO Survey - AO4 OSS Area

CHART TITLE: Isopach of H15

AREA:	CHART #:
GENERAL	3 OF 6
REFERENCE:	SCALE:
- - -	- - -



MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE

TECNOAMBIENTE

GEOQUIPMARINE

CARTOGRAPHIC INFORMATION:	GRAPHIC SCALE:		DATE:	LEGEND:	PROJECT TITLE:	CHART TITLE:	AREA:	CHART #:
ELEVATIONS REFERED TO BATHYELLI v2 GEOID	DATUM: WGS84	PROJECTION: UTM 30 N	JUNE 2022 COMMENTS: - - -	H5 - Base of Unit N / e6-7 (comprising unconsolidated channel deposits (SAND, SILT, CLAY) H15 - Upper Cretaceous (comprising consolidated sediments / bedrock CHALK)	Geophysical and UXO Survey AO4 OSS Area	Profile of Line AO421_M004A	GENERAL REFERENCE: - - -	4 OF 6 SCALE: - - -

APPENDIX C – PROCESSING REPORT

Seismic Processing Report

Document Reference	PP2021-530 – Seismic Processing Report	
Issue Date/Version	3rd Nov 2021	Version: 1
Client	Tecnoambiente / RTE / DGCE	
Project	AO4 Windfarm	
Document Author	Tom Harrison / Hasan Abdat	
Approved By	Tony Bateson	
Reason for Issue	First issue for review.	

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1. Version Control

DATE	VERSION	CHANGE
3rd Nov 2021	1	First issue for client review.

2. Seismic Data Processing

2.1. Introduction

The dataset was processed offshore by Peak Processing (October-November) using a ProMAX™ R5000.8.3.0 system.

The objective was to provide a dataset for use in geological interpretation of the area to determine suitability for wind turbine and offshore sub-station placement.

The dataset comprised:
66 2DUHR lines
Total project kms = 669.6kms

The UHR lines were acquired with a 300ms record length using a 800J, 360 tip, sparker fired every 1m. The sample interval was 0.0625ms. The receiver array consisted of a 48 channel streamer with a varying group interval – 1m for channels 1-24 and 2m for channels 24-48.

2.2. Processing Sequence and Testing

The processing sequence was tested and devised by Peak Processing. Line X-023 was used as the test dataset.

After pre-processing; quality control and navigation loading stages, velocities were picked on semblance gathers every 500m using ProMAX Velocity Function Suite for each of the lines, which were then used to produce full fold stacks.

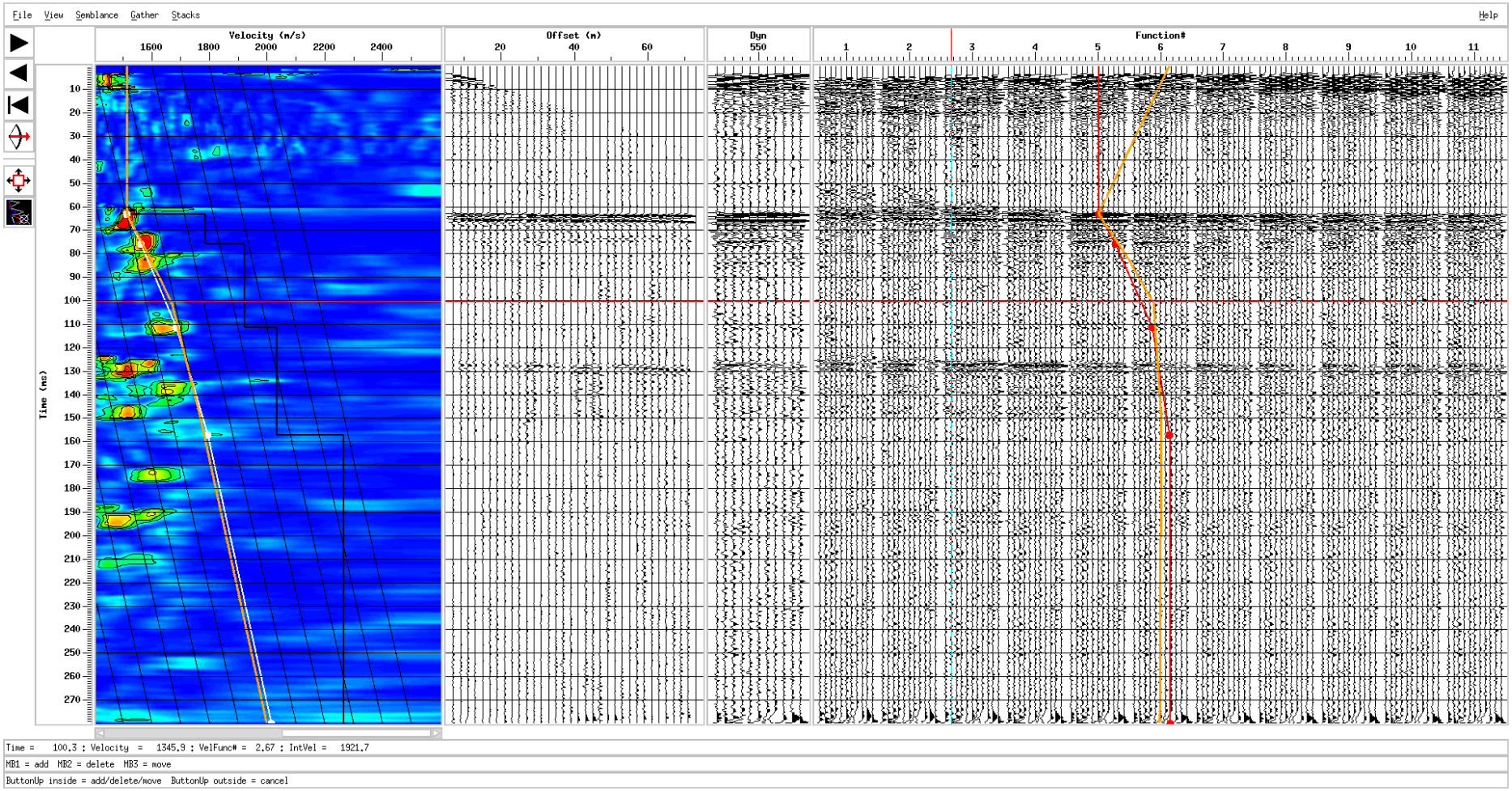


Figure 1 – Velocity Picks

The data was put through designature processing, using an ideal wavelet created from alongside signature testing, and intensive cleaning flows. Due to the short layback from the vessel and lack of boom towpoint high levels of vessel propellor noise were visible in the data, particularly on lines running into the strong current. Noise in the data was addressed with a combination of bandpass filtering, time-frequency domain (TFD) noise filter and Surface Wave Noise Attenuation.

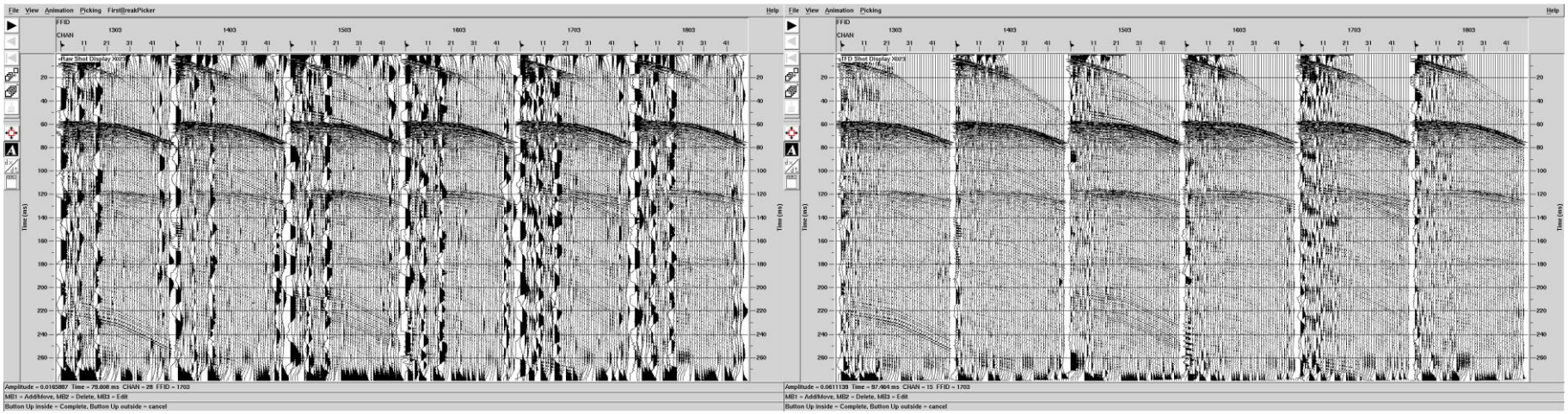


Figure 2 – TFD noise rejection at 50-450Hz with a 14ms sampling window over 7 traces – before and after display

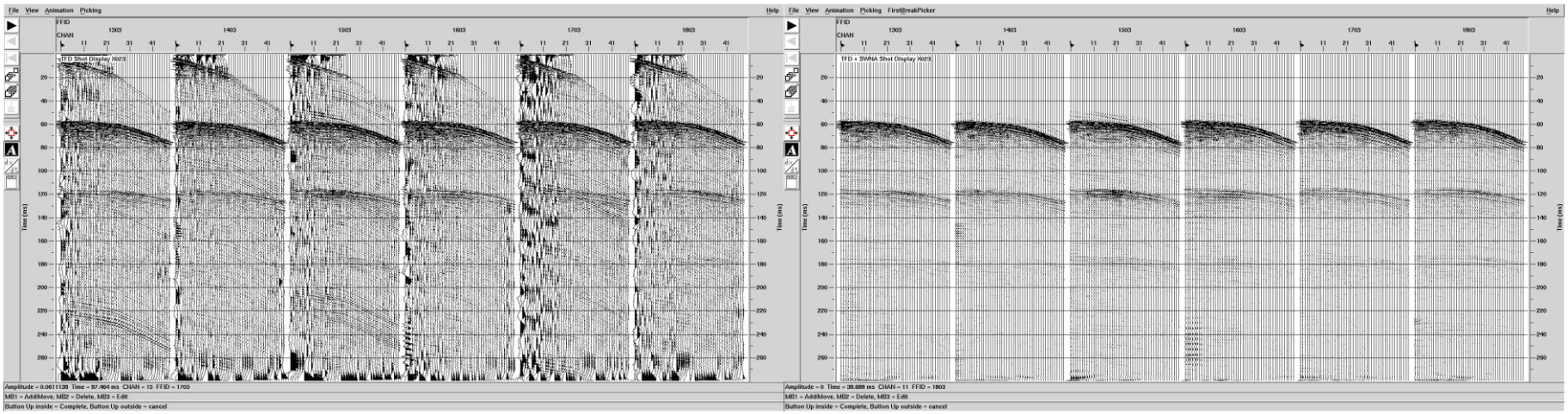


Figure 3 – SWNA noise rejection on shots 1-2000Hz with a 24-trace panel size – before and after displays

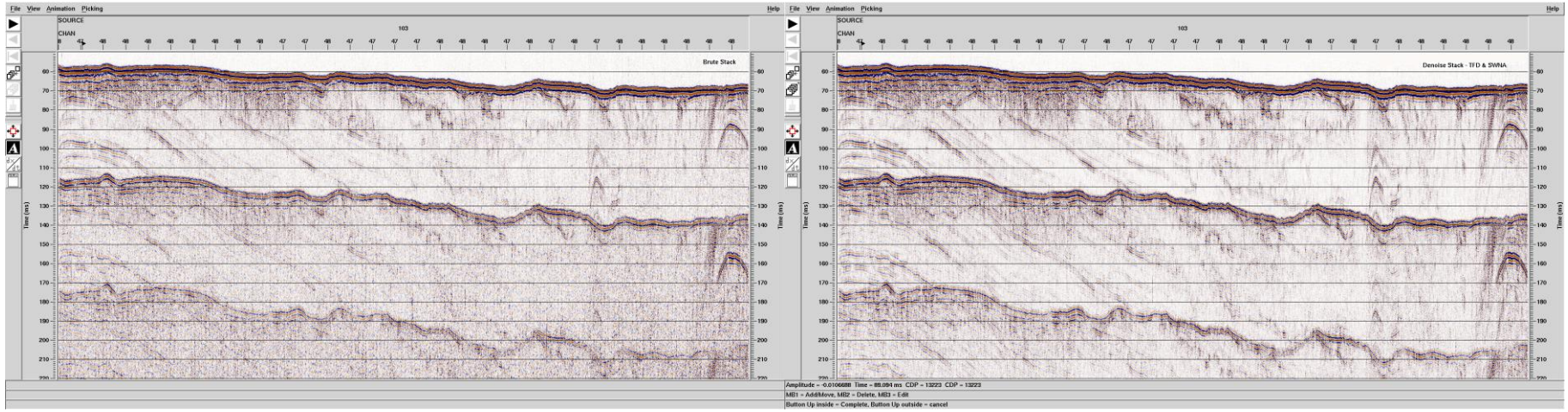


Figure 4 – Brute Stack (left), Denoise(TFD & SWNA) stack (right)

Surface Related Multiple Attenuation (SRME) was tested and applied to remove water surface multiples in the data. Best results were obtained as follows; using a spatial taper of 1.0 trace and frequency taper of 0.0 a model of the noise/multiple was obtained. A filter that matched the noise was derived and applied with a 200ms window length and a 5ms filter length. Finally, the modelled noise is subtracted in the channel domain, using a 20ms temporal window length and a 3ms filter length. The subtraction modules were quite efficient in attenuating surface multiples present in the data.

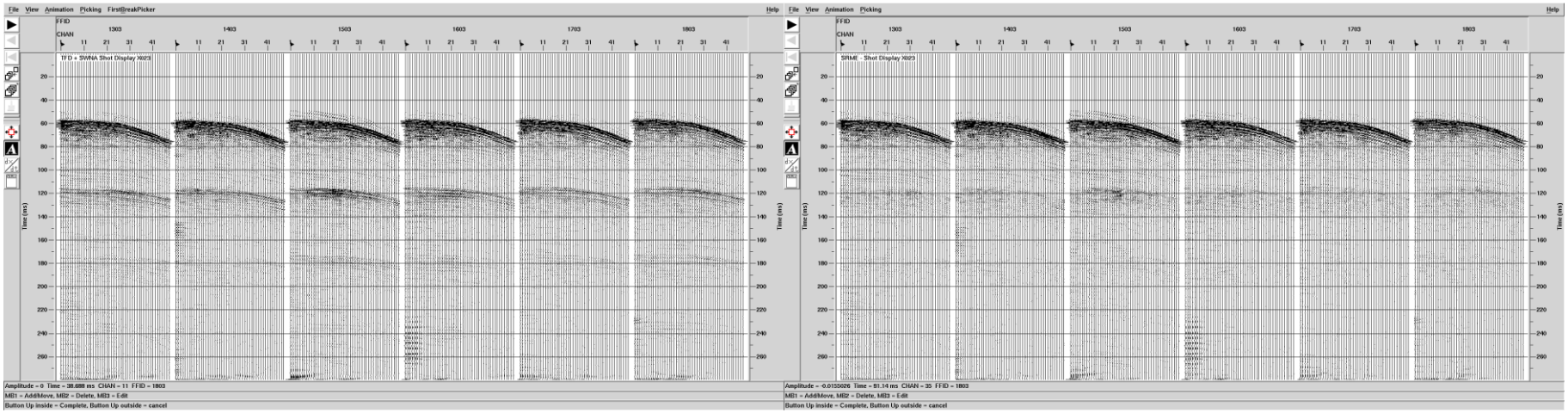


Figure 5 –Denoised shots (left) and SRME shots (right)

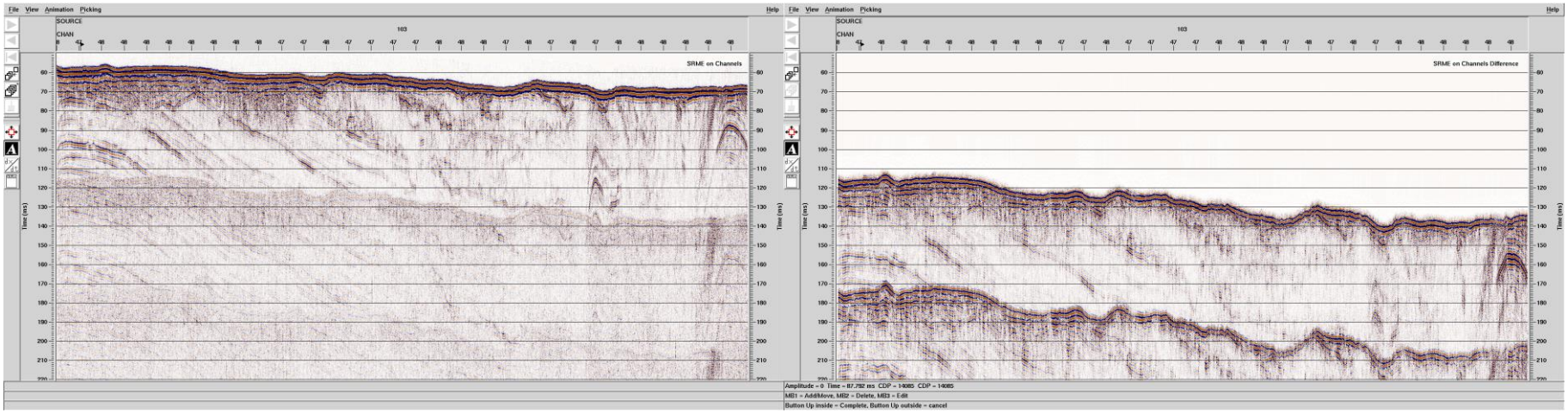


Figure 6 –SRME stack (left), difference display versus Denoise stack (right)

Further multiple removal was conducted using water bottom predictive deconvolution using CDPs with water velocity NMO applied. Optimum results were obtained with a single filter, 0.5ms operator length, with a water depth relative prediction distance.

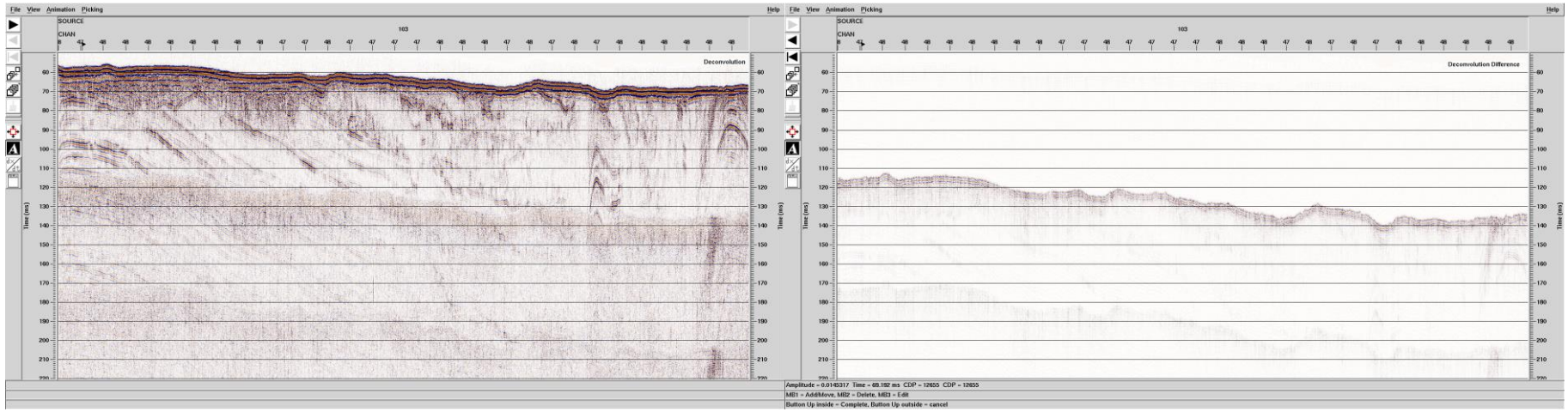


Figure 7 – Predictive Deconvolution stack (left), difference display versus SRME stack (right)

Channel static corrections were then performed on the data using automatically generated trim static shifts. Once this compensation for vertical movement of the streamer in the water had been performed, an external trace mute was also picked and applied across the dataset.

Following channel static corrections, a second pass of SRME was performed. As before, a model of the noise/multiple was obtained using a spatial taper of 1.0 trace and frequency taper of 0.0. A filter that matched the noise was again derived and applied with a 200ms window length and a 5ms filter length. This time the modelled noise is subtracted in the shot domain, using a 20ms temporal window length and a 3ms filter length.

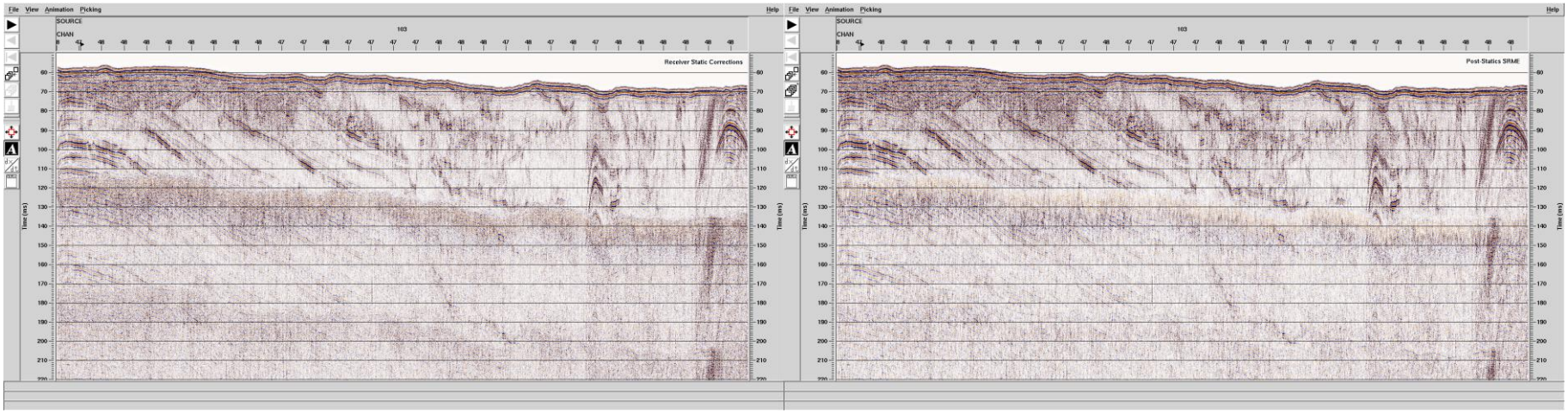


Figure 8 – Receiver Static Corrections and External Trace Mute (left), 2nd Pass of SRME post-static-corrections (right)

Post-stack, the gain was balanced throughout the record using a Time-Variant Gain function, generated and applied on a line-by-line basis, using a 50ms function. A combination of deconvolutions were then applied to further attenuate any remnant multiple, and crispen the shallow horizons. Best results were obtained with a 2ms operator and 2ms prediction distance, applied with a single gate of 0-200ms, and a 1ms operator length and water depth relative prediction distance, applied with a single time gate through the whole record.

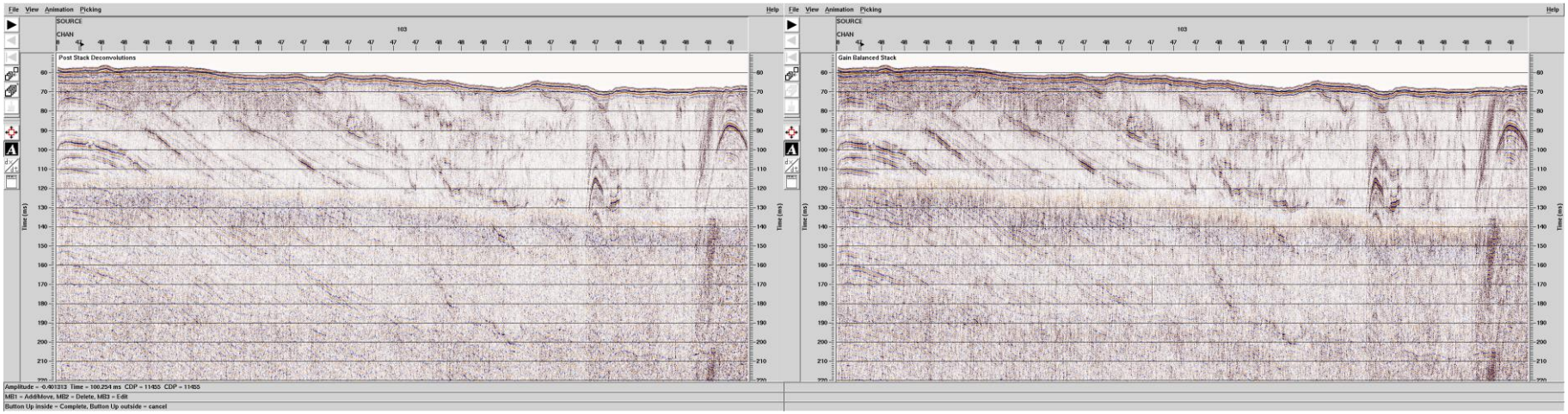


Figure 9 – Gain Balanced Stack (left), Post Stack Deconvolutions (right)

Noise levels were further reduced in the data using a combination of FK polygonal filter, and time variant bandpass filtering.

Time (ms)	Bandpass Filter Frequency Range (Hz)
70	160-1800
150	160-800
250	160-500

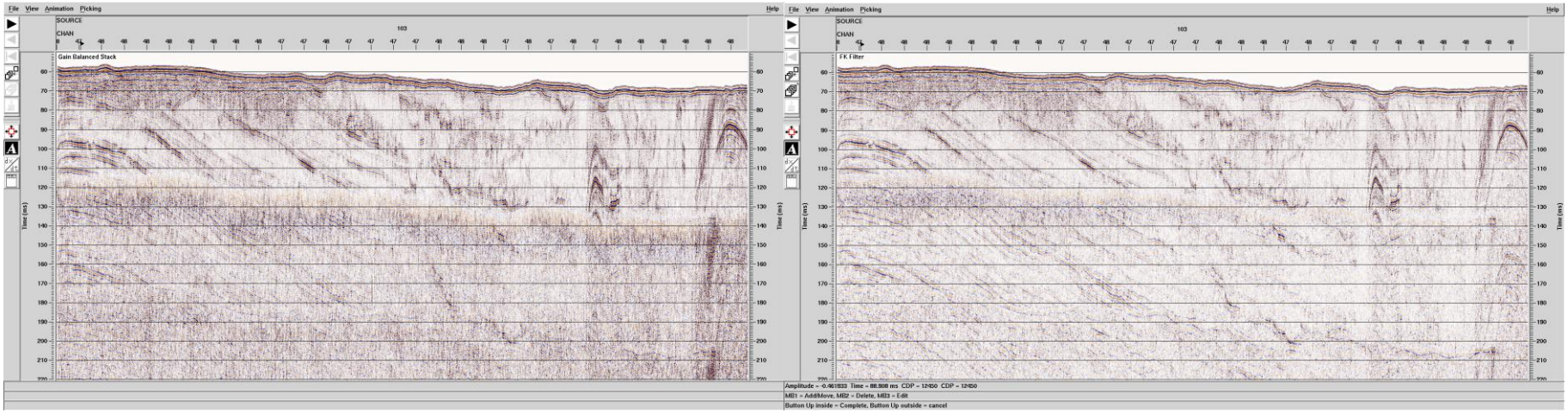


Figure 10 – Post Stack Deconvolutions (left), FK and Time-Variant Bandpass Filters (right)

After cleaning the data was migrated using ProMAX's Steep Dip Explicit algorithm, with up to 70 degrees with smoothed final velocities. Post Migration, a time variant bandpass filter was reapplied.

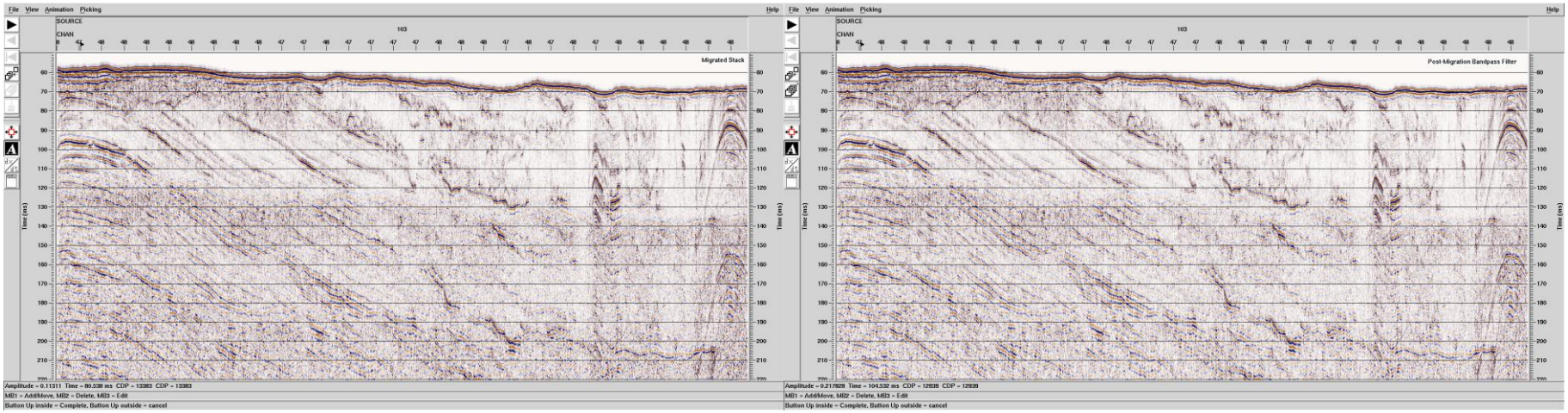


Figure 11 – Final migrated stack (left) and with Time Variant Bandpass Filter Reapplied (right)

Lastly, prior to export of the final SEGYs, static corrections were performed to correct for tide, and source & channel tow depths.

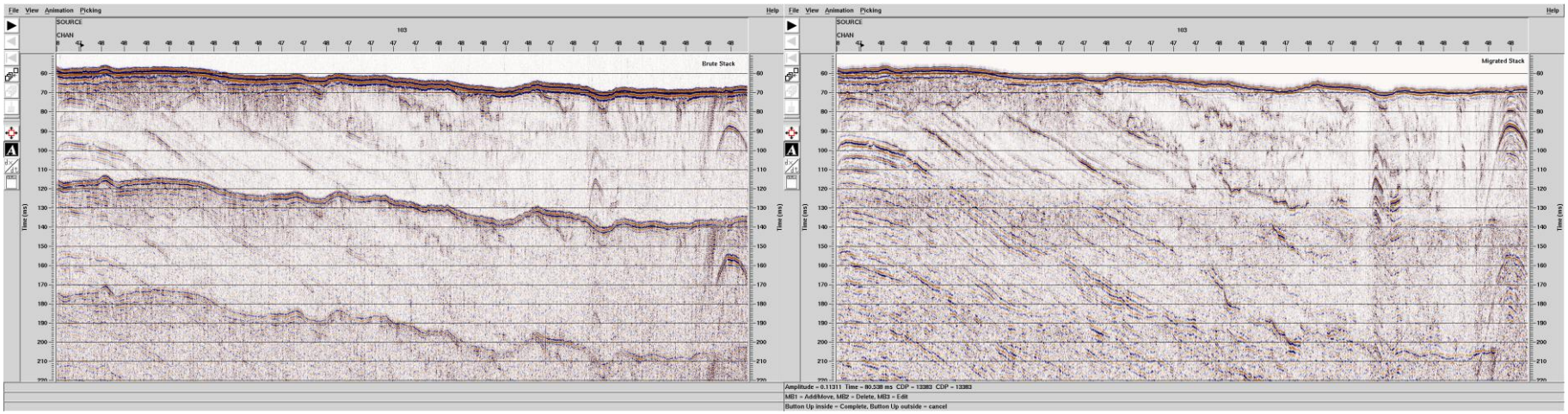
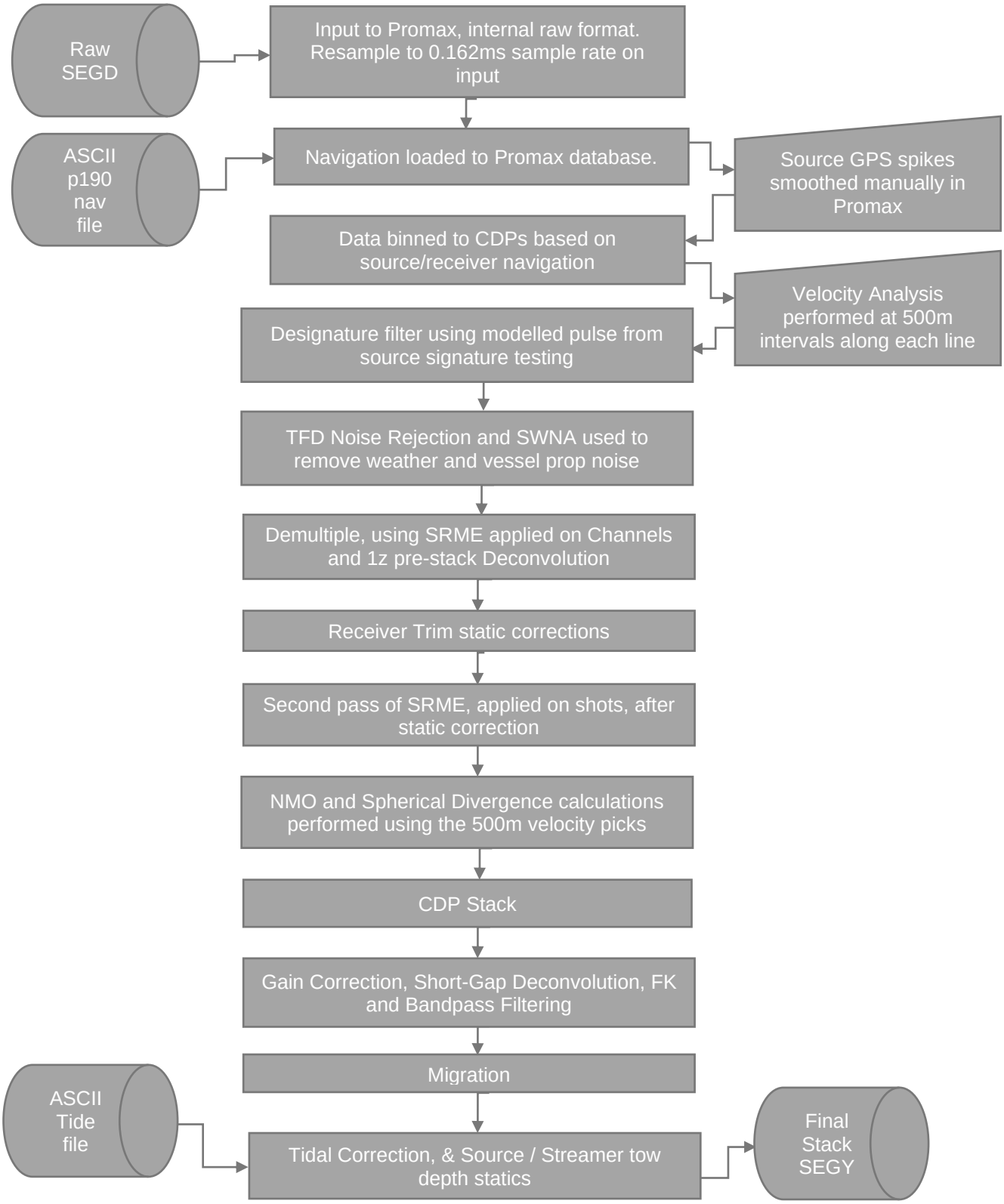


Figure 12 – Brute Stack (left) versus Final Processed Stack (right)

2.3. Processing Flow



Appendix A - Line Listing

Line Name	SOL Shot	EOL Shot	Length (km)
M001A	106	2954	2.8
M002A	129	2866	2.7
M003B	102	3000	2.9
M004A	105	3031	2.9
M005	101	3066	3.0
M006A	101	3060	3.0
M007B	108	2956	2.8
M008A	109	5006	4.9
M009A	102	5692	5.6
M010	105	17870	17.8
M011A	108	18458	18.4
M012	113	18998	18.9
M013A	107	19798	19.7
M014	105	20676	20.6
M015	108	22846	22.7
M016A	110	24015	23.9
M017	101	25135	25.0
O001A	108	14602	14.5
O002	108	11498	11.4
O003	109	21921	21.8
O004	107	20891	20.8
O005	103	14024	13.9
O006	121	17923	17.8
O007	108	9250	9.1
O008	101	7106	7.0
O009	105	12796	12.7
O010	101	13232	13.1
O011	112	16801	16.7
O012	108	14421	14.3
O013	101	13138	13.0
O013_1	106	4258	4.2
O014	108	7629	7.5
O015	107	7123	7.0
O016	106	22630	22.5
O017	101	19404	19.3
O018	108	12853	12.7
O019	107	13518	13.4
O020	101	13624	13.5
O021	110	4864	4.8
O023	111	6908	6.8
X001	108	2042	1.9
X002	107	2102	2.0
X003	101	2140	2.0

Line Name	SOL Shot	EOL Shot	Length (km)
X004	108	2041	1.9
X005	101	2147	2.0
X006	110	1993	1.9
X007	107	2288	2.2
X008	101	2082	2.0
X009	101	2138	2.0
X010	101	2138	2.0
X011A	107	2224	2.1
X012	107	3033	2.9
X013	103	6020	5.9
X014	101	10136	10.0
X015A	108	14593	14.5
X016C	101	14720	14.6
X017A	108	14521	14.4
X018	115	11604	11.5
X019	109	11304	11.2
X019_01	106	2454	2.3
X020	107	11697	11.6
X021	108	11343	11.2
X022	103	11659	11.6
X023	103	15128	15.0
X024	104	11527	11.4
X025	109	3674	3.6
		Total KM:	669.6