DGEC - Mediterranean 2DUHRS and UXO Survey

UHRS Factual Report - Accepted

Project Document Code	6168_3-RR-01-A

2.0	13/03/2025	Accepted	ARE	EVA	AMO
Revision	Date	Description of Revision	Author	Checked	Approved

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REVISION HISTORY

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

Rev.	Date	Reason for amendments	Section changes from previous version
0.1	16/01/2025	First draft	N/A
1.0	17/01/2025	First issue to client	Minor changes
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DEFINITIONS AND ABBREVIATIONS

Throughout this document the following terminology is used:

DGEC	*Direction Générale de l'Energie et du Climat (DGEC) (Client)*
GEOxyz	*GEOxyz (Contractor)*
Peak	*Peak Processing (Sub-contractor)*

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

Acronym	Description	Acronym	Description
2D	Two-Dimensional	QINSy	Quality Integrated Navigation System
ALARP	As Low As Reasonably Practicable	QPS	Quality Positioning Services B.V.
ASCII	American Standard Code for Information Interchange	RGB	Red Green Blue
BSB	Below Seabed	RMES	Regressive Marine Erosion Surface
DTM	Digital Terrain Model	RX	Receiver
EMODnet	European Marine Observation and Data Network	Rev	Revision
EPSG	European Petroleum Survey Group	SBAS	Satellite-Based Augmentation System
ETRS89	European Terrestrial Reference System 1989	SBP	Sub-bottom Profiler
FMGT	Fledermaus Geocoder Toolbox	SEG-Y	Society of Exploration Geophysicists Y format
GIS	Geographic Information System	SHOM	Service Hydrographique et Oceanographique de la Marine
GNSS	Global Navigation Satellite System	SSS	Side Scan Sonar
GOVI	Geo Ocean VI	SVS	Sound Velocity Sensor
GRS80	Geodetic Reference System 1980	SWL	Safe Working Limit
HSE	Health, Safety and Environment	THU	Total Horizontal Uncertainty
IHO	International Hydrographic Organisation	TVU	Total Vertical Uncertainty
IMU	Inertial Measurement Unit	UHR	Ultra-High Resolution
INS	Inertial Navigation System	UHRS	Ultra-High Resolution Seismic
LAT	Lowest Astronomical Tide	USBL	Ultra-Short Baseline
MAG	Magnetometer	UTC	Universal Time Coordinated
MBES	Multibeam Echosounder	UTM	Universal Transverse Mercator
MRU	Motion Reference Unit	UXO	Unexploded Ordnance
PPS	Pulse per Second	WGS84	World Geodetic System 1984
Port	Portside	QINSy	Quality Integrated Navigation System
QC	Quality Control	ZH	Zero Hydrographic

REFERENCE DOCUMENTATION

Client Reference Documents

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

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

Company and Project Documents

Document Code/Category	Title
6168_3-PEP-01	Project Execution Plan
6168-PF-01	Processing Flow
6168_3-PDR-01	Project Document Register
6168_3-HSE-01	HSE Plan
6168_3-DDL-01	Data Deliverables List
6168_3-ERB-01	Emergency Response & Bridging Document
6168_3-PQP-01	Project Quality Plan
6168_3-PRA-01	Project Risk Assessment
6168_3-CM-01	Communication Matrix
6168_3_DGEC-FM-01	Unknown Wreck – Line X008

Other References

Information used for the project which was issued by third parties is listed below.

Document Code/Category	Title
Paper, Marine Geology 234	Shoreface migrations at the shelf edge and sea-level changes around the last glacial maximum (Gulf of Lions, NW Mediterranean). Jouet, et al., 2006.
EMODnet	Digital Bathymetry (DTM). https://emodnet.ec.europa.eu/en

EXECUTIVE SUMMARY

Survey	Geo Ocean VI	Start date: 09/10/2024	
		End date: 20/10/2024	
Sensors	MBES (Multibeam Echosounder), SBP (Sub-Bottom Profiler), UHRS (Ultra High Resolution Seismic)		
Coordinate system	Datum	European Terrestrial Reference System 1989 (ETRS89)	
	Projection	UTM Zone 31 N (EPSG: 32631)	
Bathymetry			
Depth	-88.24 to -121.36 metres		
Site topography	Overall, depth values increase from north to south. The bathymetry data analysis shows relatively uniform seabed levels throughout the survey area, with only minor variations in elevation. Significant changes in elevation are observed in the southern part of the route, where the seafloor transitions steeply from the continental shelf to the continental slope.		
Geology overview			
Unit summary	**Unit name**	**Age**	**Description**
	Veneer	Holocene	Sand, half a metre thick blanket
	Holocene	Holocene	Mixed clastics. Locally cemented sands. Less than ten metres thick
	Sequence S5	<150 k years	Progradational silt/sand over silt/clay
	Sequence S4	150-270 k years	Two cycles of progradational silt/sand over silt/clay
	Sequence S3	270-350 k years	Silt/clay, some wavy facies to south-east
	Sequence S2	350-440 k years	Progradational silt/sand over silt/clay
	Sequence S1	>440 k years	Mixed clastics, significant channel infill packages
Geology description	The pre-Holocene deposits extend from approximately 0.2 metres to ten metres below the seabed and are up to half a million years old. The five mapped sequences are at least 140 metres thick, reaching maximum thickness close to the south-east margin of the survey area, pinching out towards the north-west to a minimum thickness of around 80 metres. The precise thickness is undetermined as the oldest part of Sequence S1 extends beyond the penetration of the data. The individual sequences are cyclic and tend to contain less steeply-bedded PI facies (silt, clay) at their base and a more steeply-bedded PII facies (silt, sand) towards the top. These facies are separated by mapped Regressive Marine Erosion Surfaces. The units are aggradational/progradational (PI facies) or more progradational (PII facies), building out from the north or north-west. There is some evidence of transgressive reworking over the tops of some of the PII units.		

Geohazards and installation constraints	There are no indications of shallow gas or faulting. Scattered areas of cemented sand are interpreted in central parts which are hard/strong.

1 INTRODUCTION

1.1 PROJECT OVERVIEW

As part of the development of offshore wind energy in France, the DGEC is responsible for the technical studies prior to the award of tenders for offshore wind farms. For each area identified as suitable for the development of wind farms, "de-risk studies" must be carried out in order to analyse the seabed on the surface and sub-surface.

1.1.1 Areas of Study

Four maritime façades have been identified to cover the areas where the development of offshore wind power is envisaged (Figure 1-1). The purpose of this contract is to carry out geophysical de-risking studies for approximately seven to eight sites spread throughout the metropolitan territory. This territory has been divided into four maritime façades:

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

These sites will be located in the continental shelf area, generally 12 and 50 nautical miles from the coast.

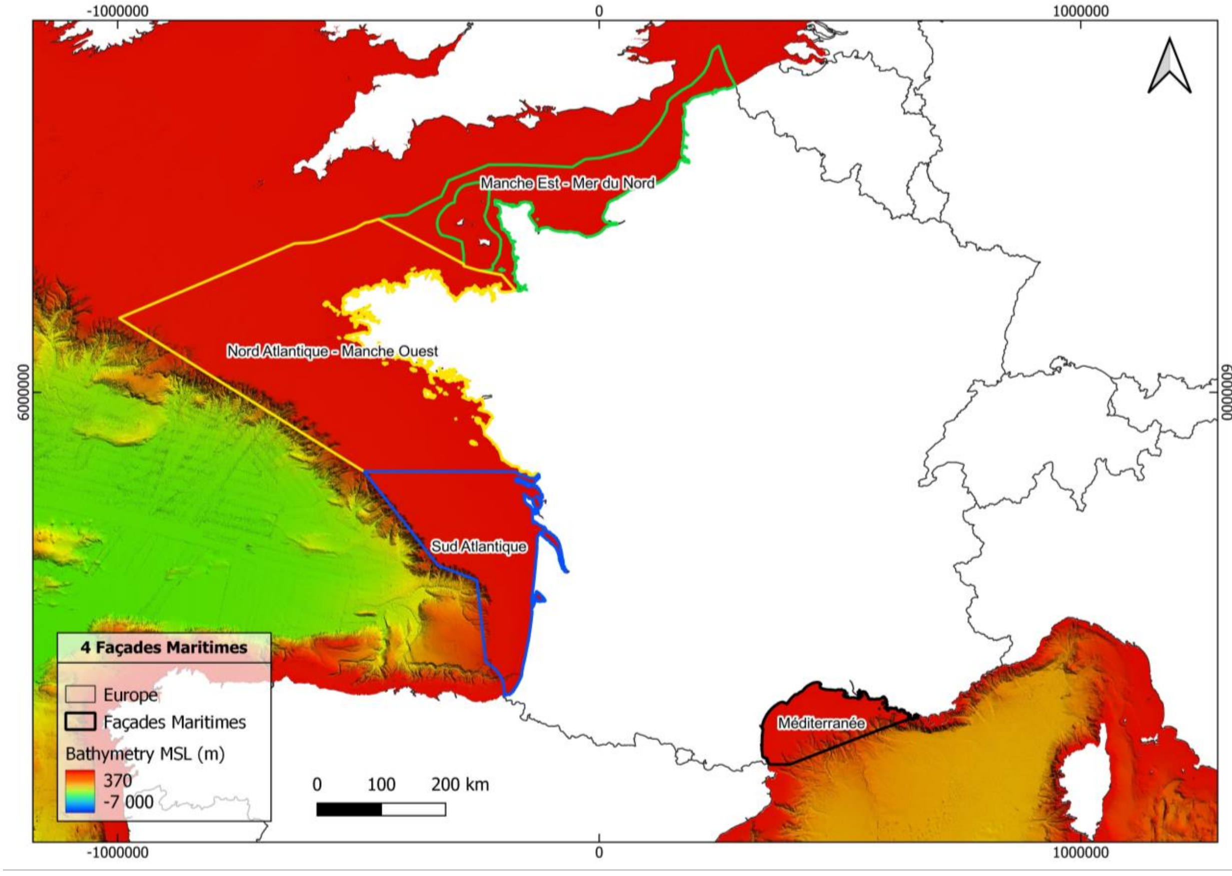

Figure 1-1: Project location overview - location of the four maritime facades

1.1.2 Objectives

The main objectives of the de-risk studies were to:

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

1.2 SCOPE OF WORK

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

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

The UXO survey comprised the acquisition of multibeam bathymetry (MBES) and side scan sonar (SSS) sensor data.

Data from all sensors was acquired simultaneously, with line planning as per the client specifications.

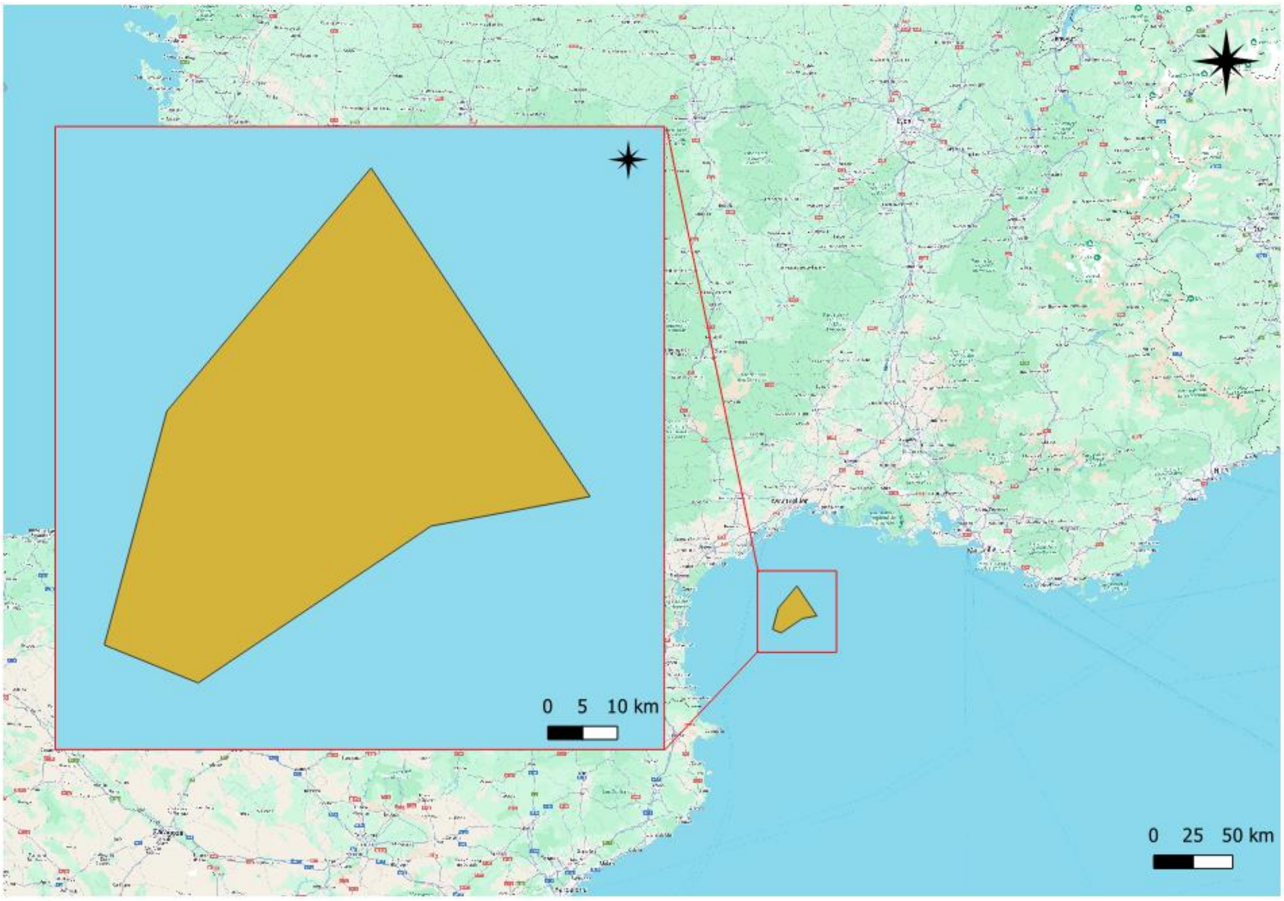

Figure 1-2: Scope of work area

1.3 SCOPE OF DOCUMENT

The Table 1-1 lists all the reports delivered as part of this survey, with this report highlighted in **bold**.

Table 1-1: Project reports

Document Number	Title
6168_3-OR-01	Operations Report - GOVI
6168_3-MCR-01	Mobilisation & Calibration Report - GOVI
6168_2-RR-02	UXO Factual Report
6168_3-RR-01	**UHRS Factual Report (This Report)**

2 GEODETIC PARAMETERS AND TRANSFORMATIONS

2.1 HORIZONTAL DATUM

The geodetic datum and mapping coordinate system used for this project is WGS84 UTM Zone 31N. All coordinates used are referenced to the geodetic datum and grid parameters listed in Table 2-1 and Table 2-2 below.

Table 2-1: Datum parameters

Parameter	Details
Geodetic Datum	World Geodetic System 1984 (WGS84)
EPSG Coordinate Reference System	4258
Spheroid	GRS80
EPSG Ellipsoid Code	7019
Semi-Major Axis	6378137.000
Semi-Minor Axis	6356752.31424
Flattening	1/298.257223563
Eccentricity Squared	0.00669428002290

Table 2-2: Projection parameters

Parameter	Details
EPSG Coordinate Reference Code	32631
Projection	UTM
Zone	31N
Central Meridian	3° East
Latitude of Origin	0°
False Easting	500000.00 m
False Northing	0.00 m
Scale Factor at Central Meridian	0.9996
Units	Metres

2.2 VERTICAL REFERENCE

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

2.3 TIME AND LOG KEEPING

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

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

2.4 SURVEY UNITS

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

- Linear units are expressed in international metres (m)
- Angular units are expressed in degrees (°)

3 REGIONAL SETTING: MORPHOLOGICAL AND GEOLOGICAL CONTEXT

3.1 MORPHOLOGY AND SEABED NATURE

Based on EMODnet data, the seabed is expected to be shallower in most of the survey area, while greater depths (up to -120 m LAT) are expected in the southernmost part of the survey. A morphological overview of the area within the survey boundary shows a relatively uniform seabed, however the southern part is expected to have a steep change in elevation, as shown in Figure 3-1.

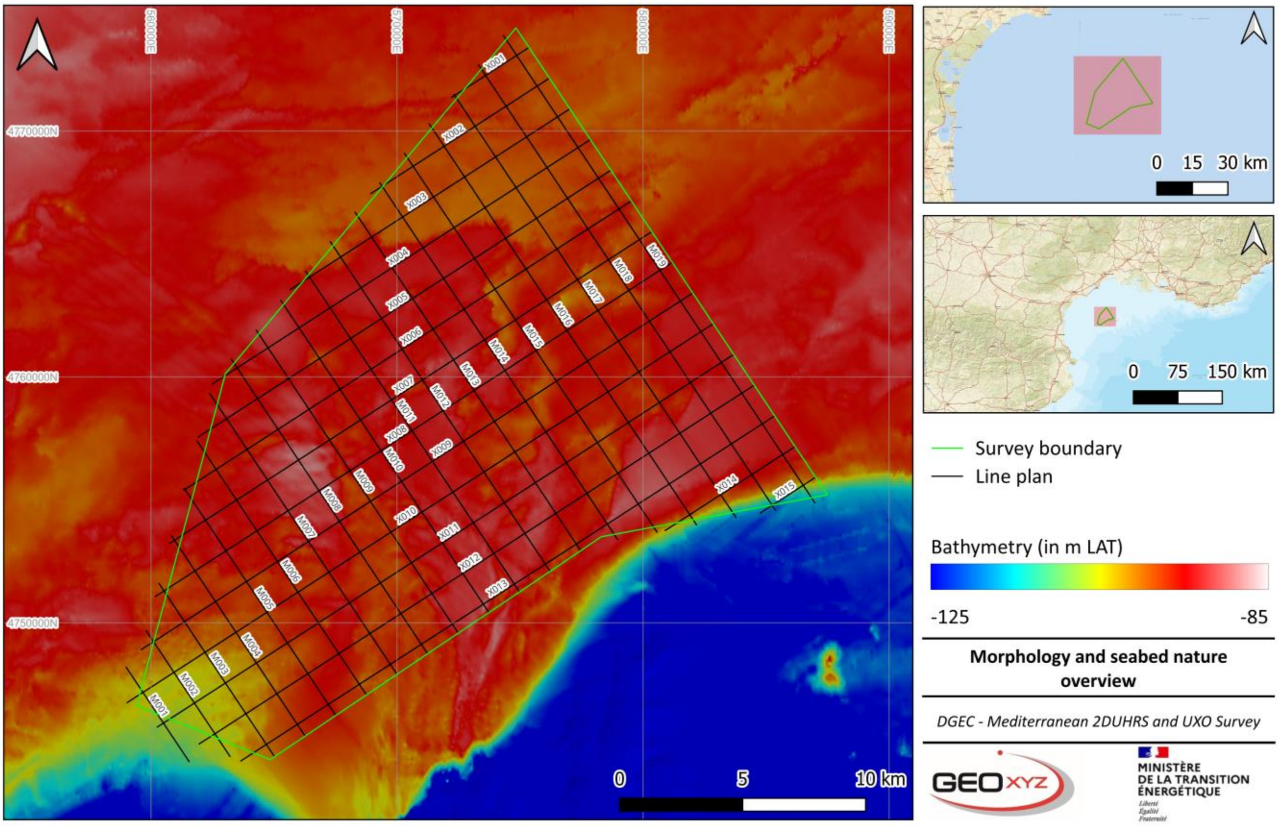

Figure 3-1: Morphology and seabed nature overview

3.2 SEDIMENT MOBILITY

There are no indications of seabed mobility.

3.3 EXPECTED SUBSEABED GEOLOGY

The top limit of the pre-Holocene deposits has been identified at a depth 0.2 metres from 10 metres below the seabed and are up to approximately half a million years old. The five mapped sequences are at least 140 metres thick, reaching this maximum thickness close to the south-east margin of the survey area, pinching out towards the north-west to a minimum thickness of around 80 metres. The precise thickness is undetermined as the oldest part of Sequence S1 extends beyond the penetration of the data.

The individual sequences are cyclic and tend to contain less steeply-bedded PI facies (silt, clay) at their base and a more steeply-bedded PII facies (silt, sand) towards the top. These facies are separated by mapped Regressive Marine Erosion Surfaces.

The units are aggradational/progradational (PI facies) or more progradational (PII facies), building out from the north or north-west. There is some evidence of transgressive reworking over the tops of some of the PII units.

3.4 EXISTING INFRASTRUCTURE

No existing infrastructure was found inside the Mediterranean survey area, although one unknown wreck was found. Figure 3-2 shows all wrecks that are near or within survey area, however, wreck circled in green is the unknown wreck. More information about the wreck can be found in 6168_3_DGEC-FM-01 Unknown Wreck – Line X008.

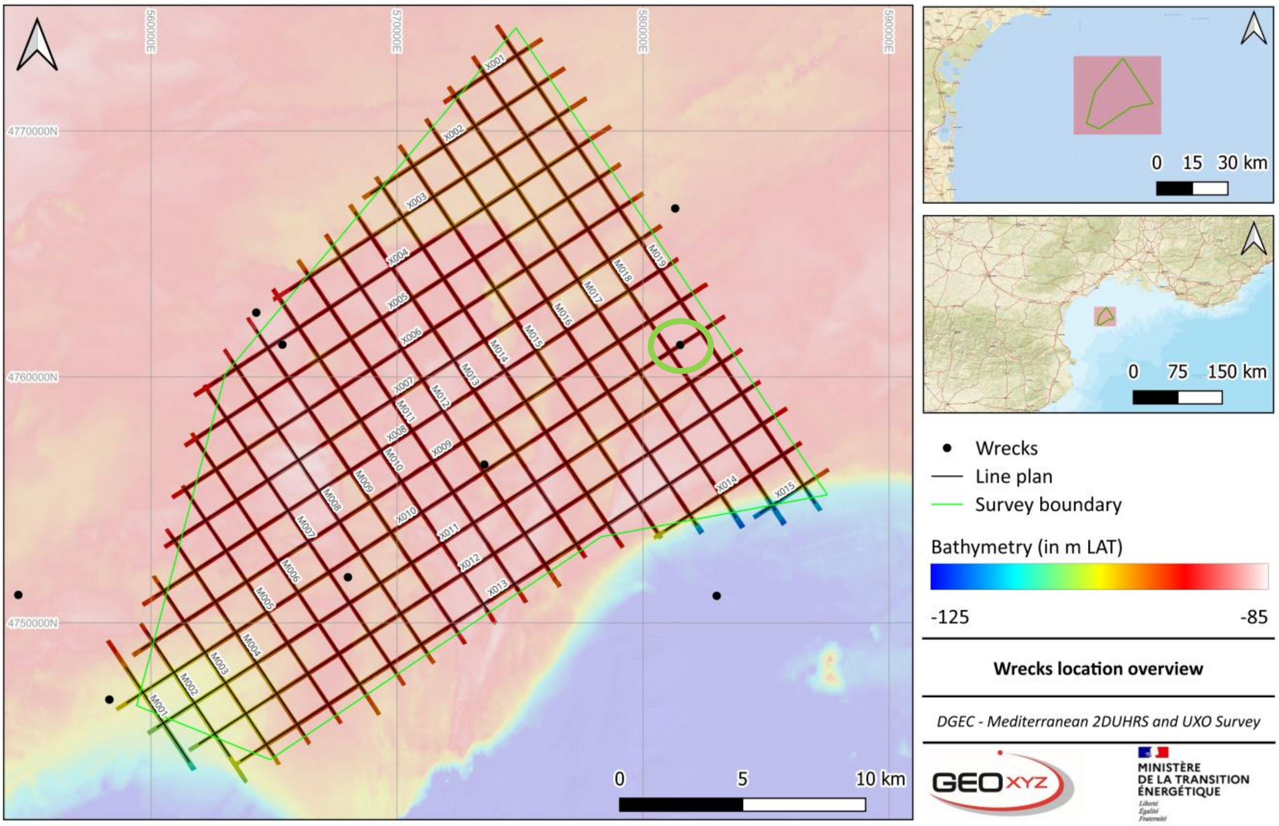

Figure 3-2: Wrecks location overview

4 RESOURCES

4.1 VESSELS

The survey vessel Geo Ocean VI (GOVI) used to conduct the survey. The specifications of the GOVI are summarised in Table 4-1.

Table 4-1: Survey vessel specifications

Geo Ocean VI	Specifications	
	Length:	53.8 m
	Width:	13.0 m
	Maximum draught:	4.8 m
	Cruising speed:	11 knots
	Main Propulsion:	2x Hybrid propulsion package on Berg CP propellers
	Endurance:	24 h day operations (28 days)
	Accommodation:	30
	Positioning:	Station Keeping/Autopilot
	A-Frame:	A-frame (4.5 x 8.0 m) SWL 15 tonnes
	Crane:	2.4 tonnes @ 8 m

4.2 EQUIPMENT

The equipment used for the survey is summarised in Table 4-2.

Table 4-2: Survey equipment specifications

Equipment	Manufacturer	Model / Type
GNSS primary GNSS secondary	Trimble Trimble	BX992 c/w OmniSTAR G4+ BX992 c/w OmniSTAR XP
Primary INS/MRU Secondary INS/MRU	iXblue SBG	Hydrins Apogee-I-B Surface IMU
MBES (Hull-mounted)	Kongsberg	EM2040 RX (Port & Stbd) EM2040 TX(Centre) EM2040 PU (Master) EM2040 PU (Slave)
Sound velocity	Valeport	Swift 500 Swift 500 Mini SVS (USBL pool mounted) Mini SVS+P (towed equip) Mini SVS+P (towed equip)
Winches	Emce	EMCE UMB-305 (Stbd)
UHR streamer	Geoeel	Active Streamer Length: 96m Configuration: 1x 65m Tow cable – 1x 5m Stretch – 48ch @ 2m Group Interval (ch1-

Equipment	Manufacturer	Model / Type
		48), 1x 5m Tail stretch, 3x LH16 Digitiser Units
Sparker	Duraspark	Duraspark 400
Sparker and Tail Buoy GNSS	Applied Acoustics	Minipod 101G (SBAS)

4.3 SOFTWARE

The primary software that was used to calibrate, acquire and process the data is listed in Table 4-3.

Table 4-3: Project software list

Type	Software	Version	Related equipment
Acquisition	QPS QINSy	9.6.4	Navigation, MBES, GNSS
Processing	Reveal	5.2	2D UHRS
	ISE	2.9.5	SBP
	Silas	V3.11.1.0 (x64)	
	Qimera/FMGT	2.6.2 / 7.11.0	MBES
	QPS BeamworX Autoclean	2023.3.1.1	
	QGIS	3.34	

5 OPERATIONAL SUMMARY

The survey vessel Geo Ocean VI (GOVI) was utilised to complete the MBES/UHRS/SBP survey. A summary of the survey operations is outlined in Table 5-1.

Table 5-1: Overview of survey operations

Vessel	Dates	Activity
Geo Ocean VI	Geophysical survey: 09/10/2024 – 20/10/2024 UXO survey: 20/10/2024 – 22/10/2024	SBP/MBES/2D UHRS/SSS acquisition survey, transit etc.

6 DATA PROCESSING

6.1 MULTIBEAM ECHOSOUNDER

6.1.1 Data acquisition and settings

The primary settings used for the project are outlined in Table 6-1.

Table 6-1: MBES system settings

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

The MBES project specifications are listed in Table 6-2.

Table 6-2: MBES specifications

Item	Specification
Minimum data density	30 HC/m² until 50 m of water depth 15 HC/m² between 50 – 150 m of water depth 9 HC/m² between 150 – 200 m of water depth
Bin size	0.2 m for <25 m of water depth 0.5 m for 25 m – 50 m of water depth 1 m for 50 m – 200 m of water depth
Grid	0.5 m cell size
Gridded standard deviation	≤0.20m per 1 m² bin
Coverage	100 % with 30 % overlap between adjacent survey lines
TVU	0.8 m
THU	2 m
Backscatter	Recorded not processed

6.1.2 Overview of the methodology

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

Figure 6-1 outlines the general MBES processing workflow.

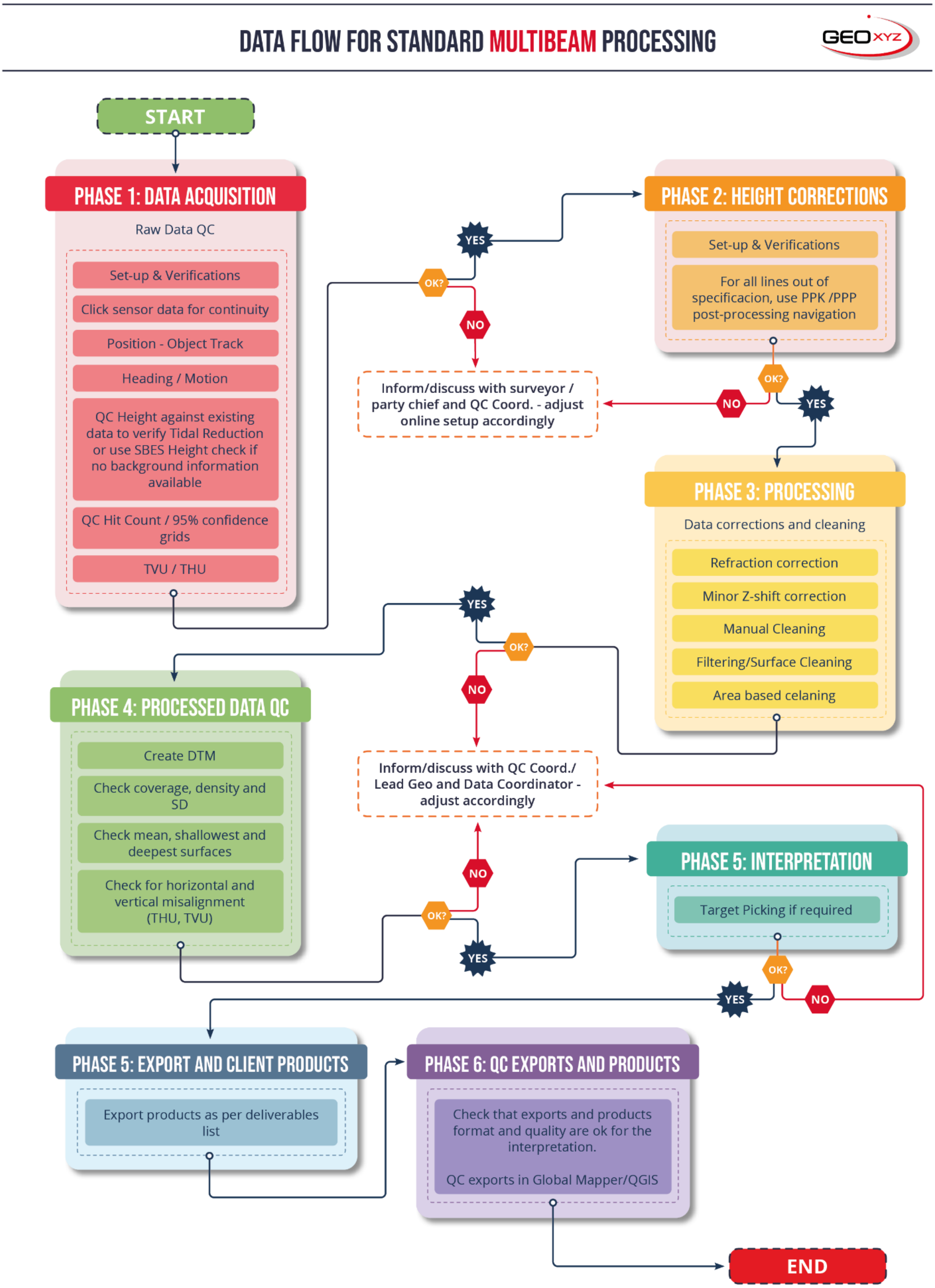

Figure 6-1: MBES processing workflow

6.1.3 Data quality assessment

The multibeam echosounder data was of high quality with very little acoustic noise.

The water depths in the survey area varied from 88 metres to 121 metres. An example of the number of hits per meter over the required survey areas are described below and illustrated in Figure 6-2. Seabed morphology was well defined in the processed Digital Terrain Models (DTMs) as illustrated in Figure 6-3.

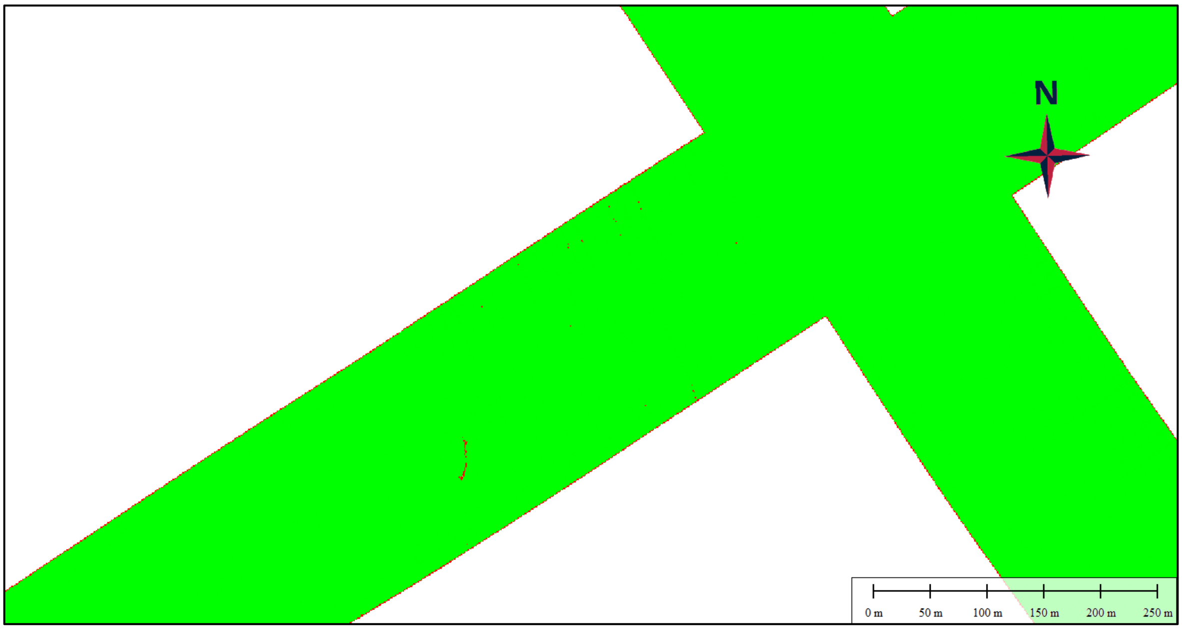

Figure 6-2: Bathymetric data hit count per 1 m square (green is > 15 hits per bin)

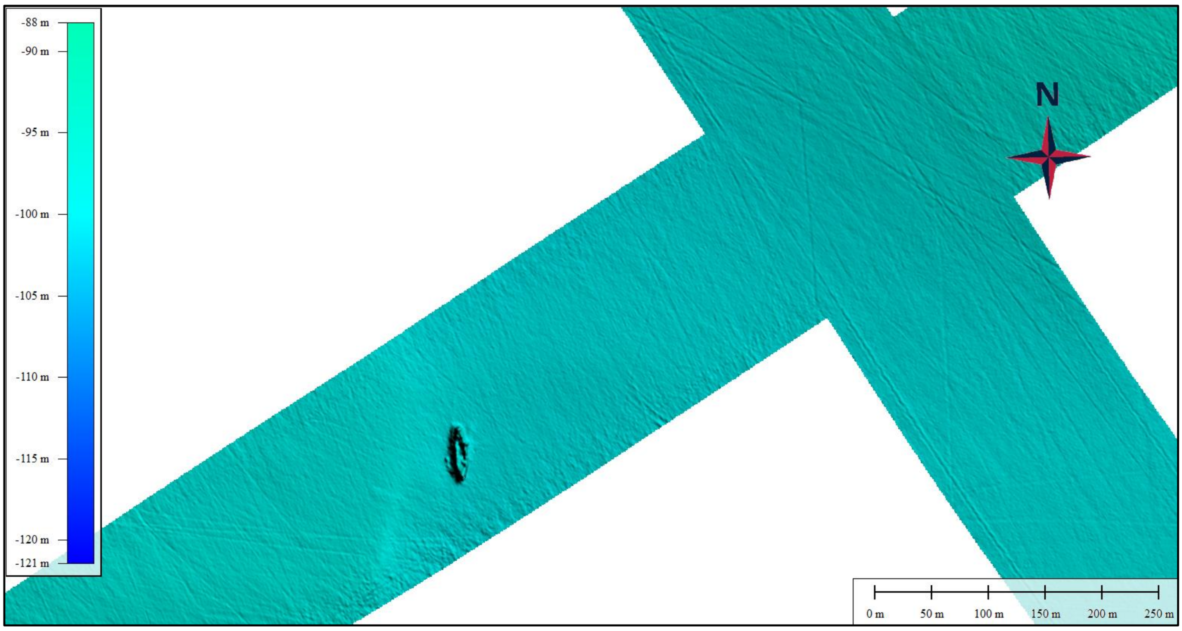

Figure 6-3: Bathymetric data DTM showing an unidentified wreck within survey area

The THU and TVU values for the survey are within the threshold specified by the IHO Special Order S-44 (Table 6-3) and the specifications defined by the client (TVU 0.8 m; THU 2 m). THU and TVU have been calculated according to the IHO S44 Special Order. TVU has been calculated according to this formula:

$$TVU_{max}(d) = \sqrt{a^2 + (b \times d)^2}$$

Where:

- **a** represents that portion of the uncertainty that does not vary with the depth (0.25m for Special Order);
- **b** is a coefficient which represents that portion of the uncertainty that varies with the depth (0.0075 for Special Order);
- **d** is the depth.

THU is, according to the IHO Special order, a fix value of 2 meters.

Table 6-3: THU and TVU values and threshold

Depth min	Depth max	IHO TVU threshold	IHO THU threshold	TVU of surveyed data	THU of surveyed data
88.24	121.36	0.93	2	0.11-0.26	0.81-1.62

6.1.4 MBES deliverables

The MBES deliverables created as a result of the project are outlined in Table 6-4.

Table 6-4: Overview of the MBES deliverables

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

6.2 SUB-BOTTOM PROFILER

6.2.1 Data acquisition and settings

Sub-Bottom profiler system settings are listed in Table 6-5.

Table 6-5: SBP specifications

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

6.2.2 Overview of the methodology

Figure 6-4 shows the SBP processing workflow.

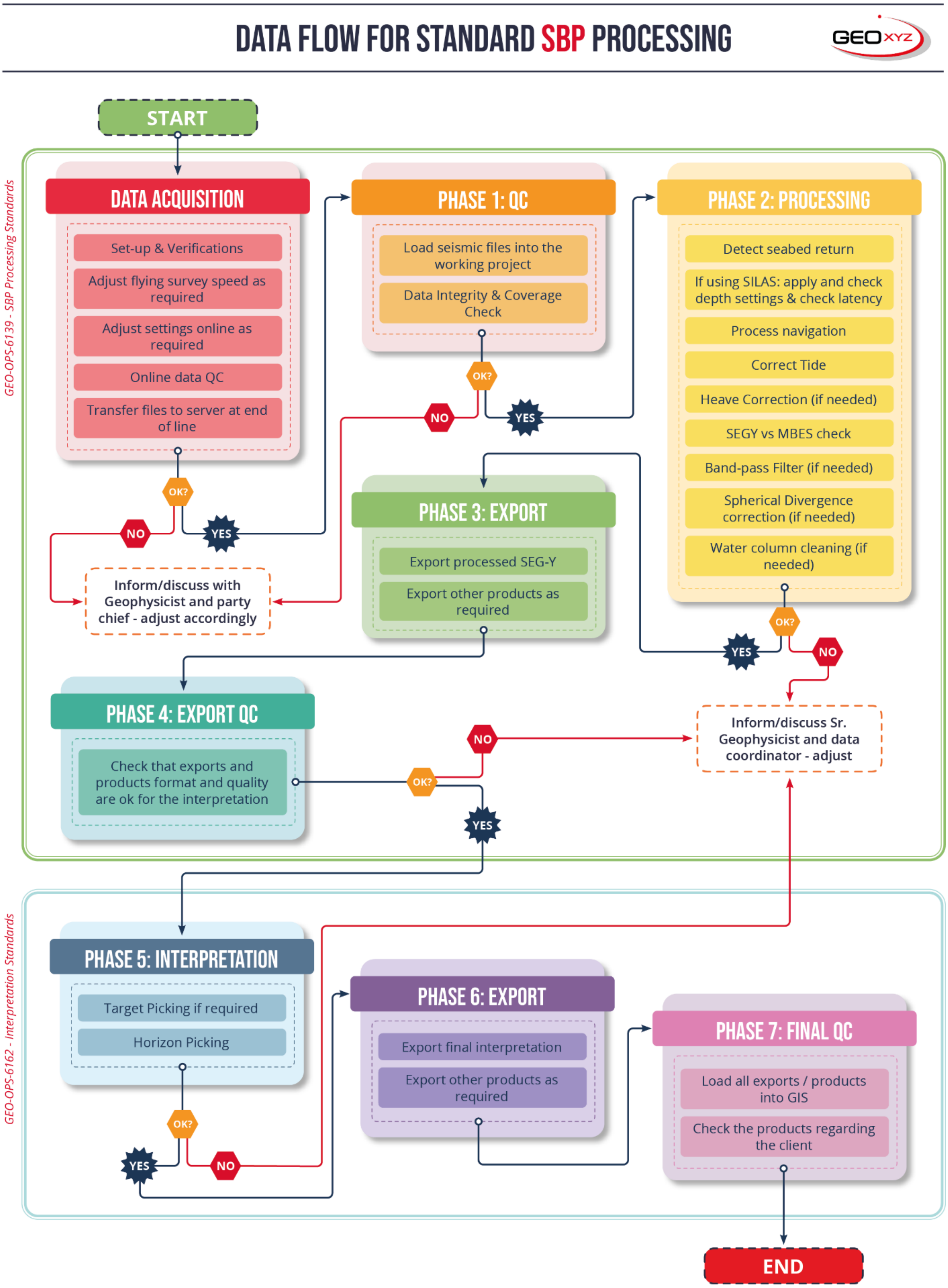

Figure 6-4: SBP processing workflow

6.2.3 Data quality assessment

The sub-bottom profiler data are good quality (Figure 6-5). The data allowed separation of reflectors as closely spaced as 0.15 metres. Data penetration depended on the local geology – in some places relatively amorphous sediments are very close to outcrop and imaging is limited. In areas with softer geology imaging is good to eight metres below seabed.

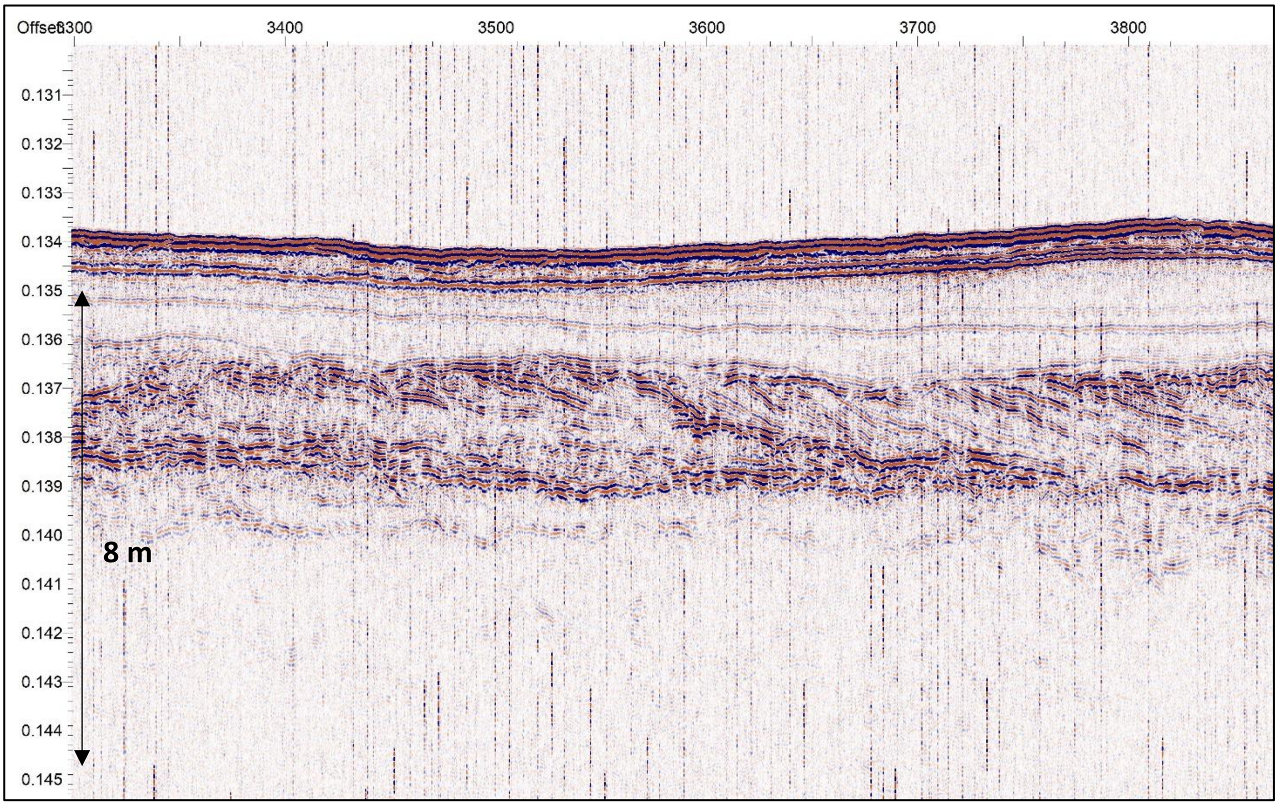

Figure 6-5: SBP data characteristics

6.2.4 SBP deliverables

The SBP deliverables created as a result of the project are outlined in Table 6-6.

Table 6-6: Overview of the SBP deliverables

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

6.3 ULTRA-HIGH RESOLUTION SEISMICS

6.3.1 Data acquisition and settings

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

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

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

Specifications for 2DUHR data are listed in Table 6-7.

Table 6-7: 2DUHR specifications

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

6.3.2 Overview of the methodology

Onshore seismic processing produced final migrations using the processing sequence is outlined in Figure 6-6. More details on the methodology can be found in Appendix A. Parameters used for Time Variant Bandpass Filter is shown in Table 6-8.

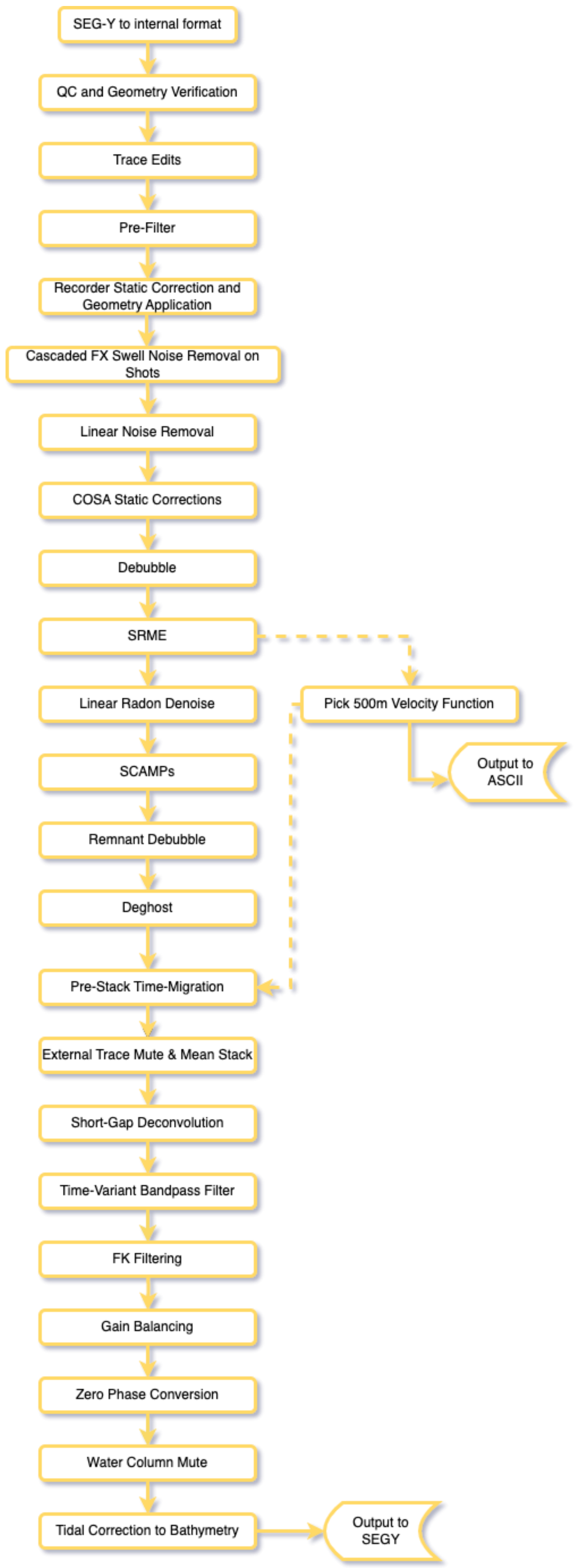

Figure 6-6: 2D UHR processing workflow

Table 6-8: Time Variant Bandpass Filter parameters

Time (ms)	Low cut	High cut
Above WB_time	320 Hz / 18 dB/oct	7500 Hz / 72 dB/oct
WB_time	320 Hz / 18 dB/oct	7500 Hz / 72 dB/oct
WB_time*2	60 Hz / 18 dB/oct	1200 Hz / 72 dB/oct

6.3.3 Data quality assessment

The UHR data are good quality and consistent (Figure 6-7) there are minor variations in noise and phase, these are likely due to variations in sea state during acquisition. Geological imaging does partly depend on the variable geology but often extends to beyond 140 metres below seabed. In favourable geological settings (at low travel times without signal scattering sand packages) the data can enable mapping of separate reflectors less than one metre apart.

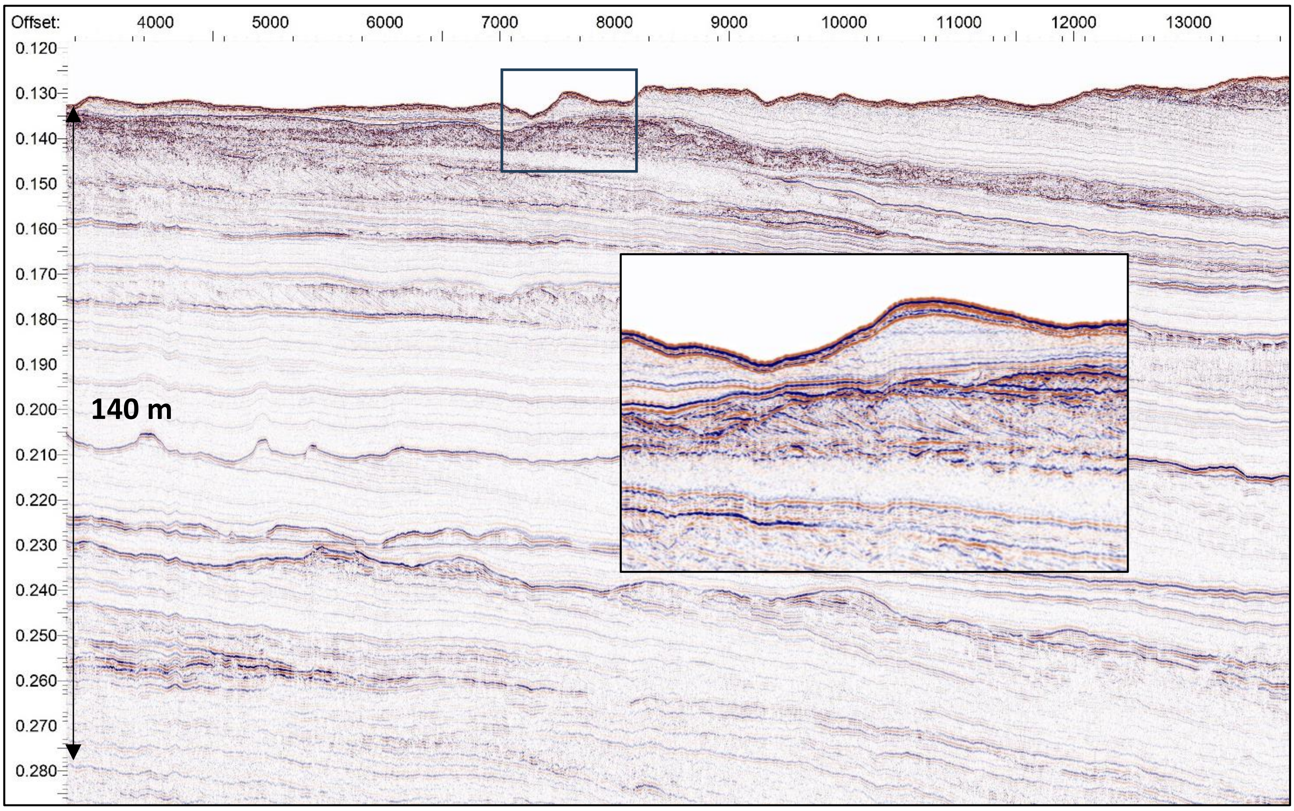

Figure 6-7: UHR data characteristics

6.3.4 UHRS deliverables

The UHRS deliverables created as a result of the project are shown in Table 6-9.

Table 6-9: Overview of the UHRS deliverables

Deliverable	Format
Kingdom project	Kingdom project files
Processed towed sensors (SSS, MAG, seismic positioning) trackplot line	SHP
Interim technical note	PDF

Deliverable	Format
Raw UHRS data	SEG-Y
P190 navigation	ASCII
Processed UHRS data	SEG-Y
Longitudinal profile	ASCII
Horizon interpretation gridded surface	ASCII
Horizon contour lines (BSB)	SHP
Geologic feature points, polylines and polygons (if applicable)	SHP

7 RESULTS AND INTERPRETATION

7.1 BATHYMETRY

Overall, depth values increase from north to south. The bathymetry data analysis shows relatively uniform seabed levels throughout the survey area, with only minor variations in elevation. Significant changes in elevation are observed in the southern part of the site, where the seafloor transitions steeply from the continental shelf to the continental slope. The shallowest point, at -88.24 metres, is located in the western part of the survey area, while the deepest point, at -121.36 metres, is found in the easternmost part of the survey area. Bathymetric overview of the survey area and the line plan are shown in Figure 7-1.

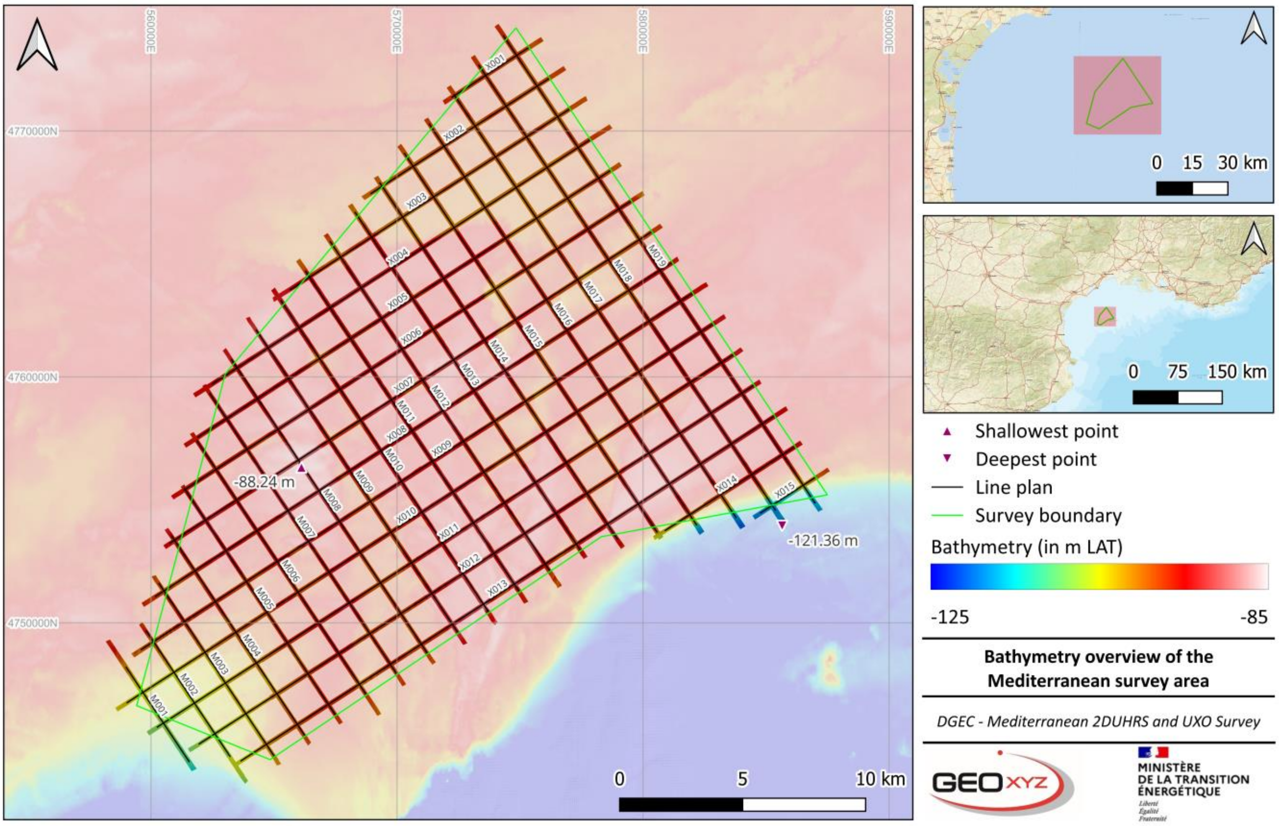

Figure 7-1: Bathymetry overview of the Mediterranean survey area (source background dataset: EMODnet)

The wreck mentioned in section 3.2 was found during the MBES data processing, it lies at a depth of 98.3 metres, and it has dimension length of 48 metres, width 11 metres and height 3.4 metres. The location of the wreck can be seen in Figure 3-2, circled in green. More information about the wreck can be found in 6168_3_DGEC-FM-01 Unknown Wreck – Line X008.

7.2 SUB SEABED GEOLOGY

7.2.1 Stratigraphy and general arrangement of the units

The geology is interpreted and described in the context of the stratigraphic model (Figure 7-2) used in the 2006 paper by Jouet et al. (2006). The following figure (Figure 7-2) is taken from that paper and the nomenclature of numbered S sequences and D surfaces as sequence boundaries are used in this report. Units and boundaries are numbered oldest first, from the bottom of the succession. The Jouet et al. (2006) paper serves as a good reference for this interpretation as it is geographically close to the survey area and shows strong visual correspondence between the survey data and several figures within the paper.

The main reference paper is broadly in line with other published work in the area, differences between the published stratigraphic papers mainly involve nomenclature and details of the relationship between sea level change and the deposition of particular facies.

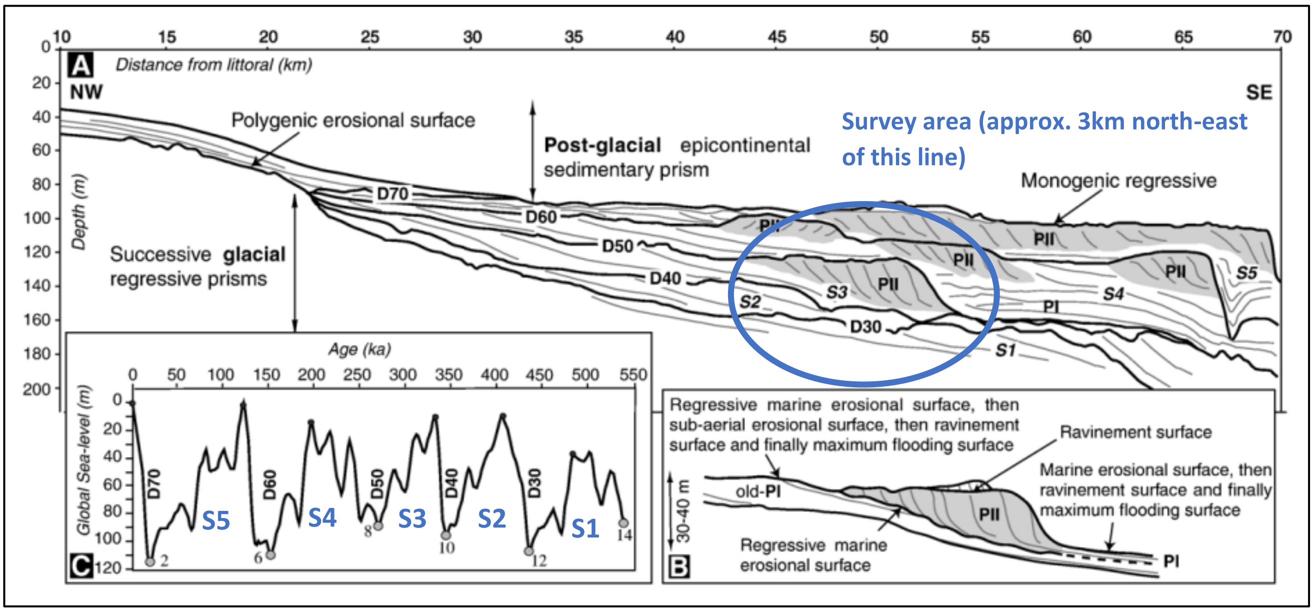

Figure 7-2: Stratigraphic interpretation diagram from Jouet et al. 2006 (additions in blue)

The area's shallow geology is complex as the succession contains numerous unconformities cut in association with sea level variations over the last half million years.

Many of the area's sediment packages are progradational, sourced from the coastline to the north and north-west. The succession is cyclic and repeatedly alternates between less steeply dipping clay/silt facies (PI) and more steeply dipping silt/sand facies (PII). The more aggradational PI sediments were laid down when the water was deeper, progradational PII facies were laid down in shallower water. The two facies are separated by Regressive Marine Erosion Surfaces (RMES surfaces in the horizon nomenclature).

Figure 7-2 shows these two facies and the sequence boundaries (D30, D40, etc.) that divide the sequences.

Insert C, at the bottom left of Figure 7-2, shows the correlation between glacial maxima/sea level lowstands (MIS stages 2, 6, 8 etc.) and the sequence boundaries.

The sequence boundaries relate to low stands, the even-numbered MIS stages.

Table 7-1 shows the interpretation synopsis for this survey.

Table 7-1: Interpretation synopsis

Sequence	Upper boundary	Lower boundary	Comments
S5	Seabed/D70 (MIS2)	D60 (MIS6)	Contains one cycle of PI/PII facies separated by S5 RMES1. Some transgressive deposits close to seabed

Sequence	Upper boundary	Lower boundary	Comments
S4	D60 (MIS6)	D50 (MIS8)	Contains two cycles of PI/PII facies separated by S4 RMES 1 and 2. Additional Top Sand picks map the tops of PII facies where not defined by D surfaces.
S3	D50 (MIS8)	D40 (MIS10)	Contains only PI facies. Wavy facies to south
S2	D40 (MIS10)	D30 (MIS12)	Contains two cycles of PI/PII facies separated by S2 RMES 1 and 2. Additional Top Sand picks map the tops of PII facies where not defined by D surfaces.
S1	D30 (MIS12)	-	Contains at least two phases of channel cut and fill

It should be commented on Jouet et al. (2006) paper that examination of this dataset suggests that the direct link of sequence-bounding D surfaces to relative lowstands/glacial maxima may only fully apply where PII facies are not present, that is, in more distal parts of the survey area.

Where PII facies are well-developed there is often good evidence for reworking of the uppermost parts and even additional progradational packages. Both features could be generated during initial marine transgression. This would mean that a sequence boundary tied to an absolute lowstand would have to be picked a little deeper to exclude this complex interval at the top of the PII facies. The best example of this situation is the pick of the base Holocene unconformity, a surface representing the most recent MIS2 lowstand. This is up to ten metres below the seabed, which in Jouet's model is the notional top of Sequence S5.

This is a minor observation, **the Jouet's model is very practical,** and the vast bulk of sediments seem to correspond to deposition during marine regression.

7.2.2 Geological overview

Reference data show that the geological sequences converge to the north-west, though this is difficult to make out over the limited extent of the survey area. The individual sequences are built out in a seaward direction. This means that the units become younger to the south/south-east as well as upward.

Based on the Jouet et al. (2006) paper, the pattern of sedimentation within each sequence is that:

- low angle (~1°) PI facies laid down during marine regression;
- continued sea level fall results in storm wave base erosion and the creation of Regressive Marine Erosion Surfaces (mapped in this report as RMES surfaces). These erosion surfaces cut the top of the PI facies;
- the higher angle (~2-4°) silt/sand PII facies is laid down over the RMES surface/facies PI deposits;
- the sequence top is then cut by sub-aerial erosion and ravinement;
- some sequences show thin reworked/transgressive deposits. These are present close to seabed in Sequence S5. **This is not fully in line with the paper, however the survey data show such deposits.**

In detail there are variations between the sequences. Sequence S1 (the oldest sequence) is strongly influenced by the cut and infill of at least two phases of channelling. Other sequences record some sea level fluctuations during regression; they contain more than one cycle of PI and PII facies.

Independent of the fluctuations of global sea level, the elevation of the seabed has risen over the last half a million years; water depth has generally reduced over this time, because of the buildup of sediment on the margin. Consequently, the succession may have become slightly more sand-prone over time; PII facies do seem thicker and better developed within the most recent sequences.

PI facies can be considered to be silt/clay prone and PII facies can be considered silt/sand prone.

Unconformities are mapped in the order that they were cut, for example the base Holocene cuts the RMES in Sequence S5. The interpretation project contains boundaries and tops that delimit the sandier PII facies, as well as the D and RMES horizons.

Table 7-2: Seismic facies descriptions

Facies	Seismic facies description	Comments, distribution
Transparent	Transparent and featureless	This unit has consistent acoustic character, seabed veneer ~0.5 m thick
PI	Bedded with very low seaward dip, parallel or sub parallel moderate amplitude reflectors. Aggradational/progradational	This facies was laid down over initial regression of each of sequences S2-S5. The transition from this facies to PII facies is marked by a Regressive Marine Erosion Surface. In distal parts of S3 this facies shows a wavy reflector pattern, indicative of bottom current influence on deposition. Silt/clay prone.
PII	Bedded with discernible seaward dip, parallel or sub parallel moderate amplitude reflectors. In detail there can be numerous internal unconformities bounding separate delta-like packages. Progradational	This facies was laid down during the later parts of marine regressions, close to sealevel lowstands. Sediments largely bypassed the pre-existing shelf to be laid down on the slope. This facies occurs in sequences S2, S4 and S5. Silt/sand prone
Channel fill	Variable complex fill. Steeply dipping beds with some thin progradational subunits towards top. Older phase of channel infill is more amorphous	Limited occurrence in extreme south of area. Facies is at least 90 m BSB.

7.3 SHALLOW GEOLOGY

7.3.1 Seabed Veneer

The seabed veneer comprises of Holocene sand. The base of this interval is imaged and mapped on the profiler data. The interval is acoustically amorphous, its base is a truncation surface where reflectors within older units abruptly terminate (Figure 7-3 and Figure 7-4). The unit is typically about half a metre thick, exceptionally reaching one metre. It is likely to exist as a very thin discontinuous layer beyond those areas where it is mapped – in very restricted areas over steep seabed slopes the sand veneer is not clearly imaged.

The survey lines are widely spaced, and the unit is thin, however the surficial sand can be approximated as a continuous half a metre thick blanket deposit.

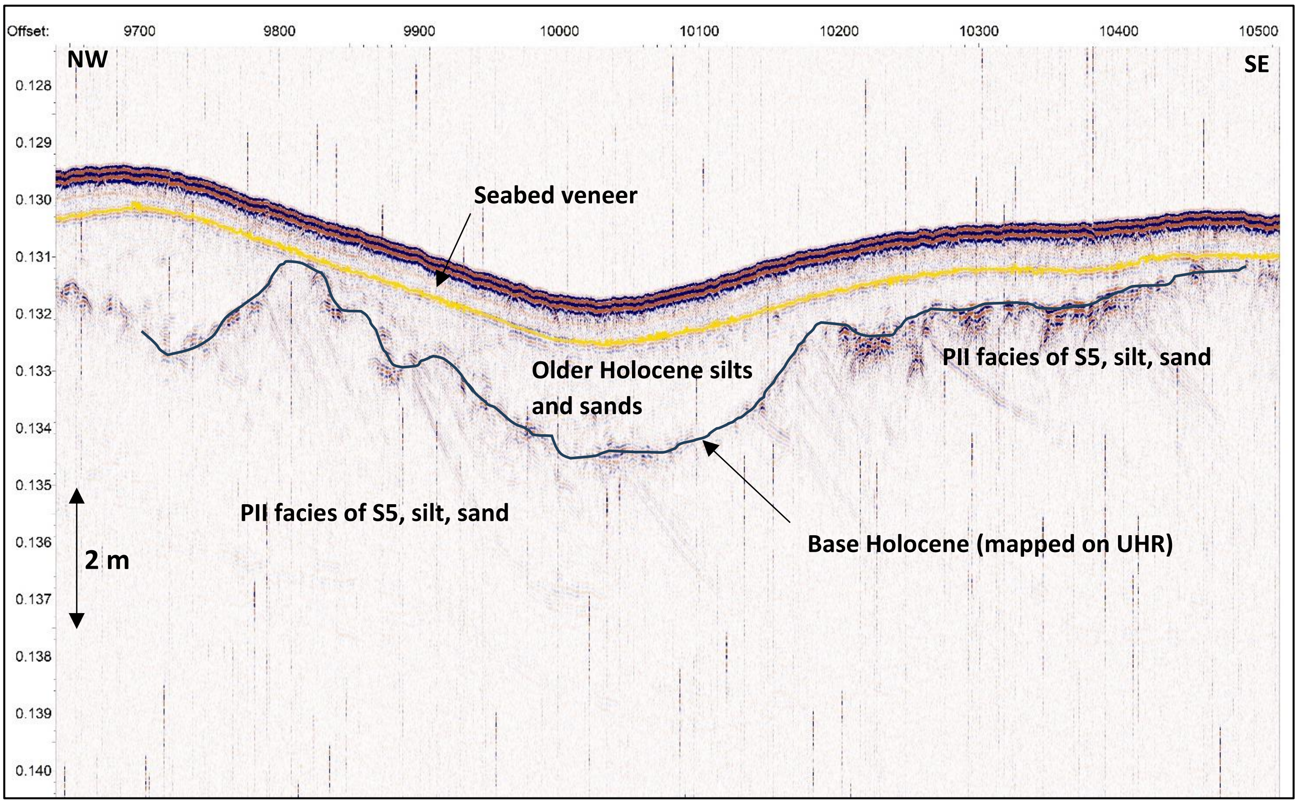

Figure 7-3: M009 SBP, seabed veneer

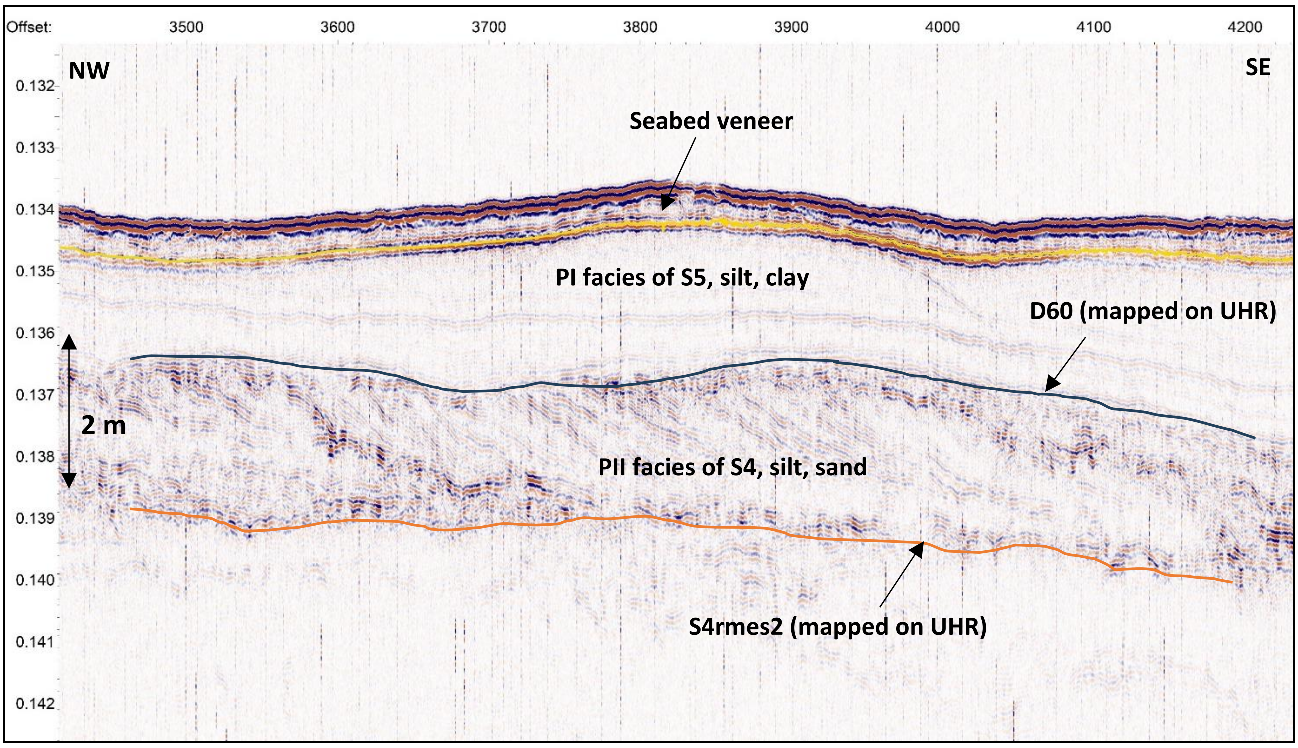

Figure 7-4: M016 SBP, seabed veneer

7.3.2 Holocene

The base Holocene is mapped in the UHR data. This is an irregular truncation surface of the dipping older beds, creating an angular unconformity. Over wide areas the Holocene interval is less than one metre thick and mostly comprises of the sand veneer.

The Holocene deposits are up to ten metres thick and are best developed over central/south-eastern parts of the area.

In these thicker areas the Holocene deposits include small progradational units laid down over the major S5 progradational PII facies sand package (Figure 7-5). These units are around three to five metres thick, have positive seabed relief and are likely to be silt/sand prone (Figure 7-6). They are interpreted to have been deposited during the most recent marine transgression.

In detail this interval is complex with numerous separate progradational packages. These have not been individually mapped, as their size approximates the survey line spacing. The individual units may result from the changing relationships of seabed morphology and positions of point sediment supply during the early phases of marine transgression.

The thickness of the Holocene is shown in Figure 7-7.

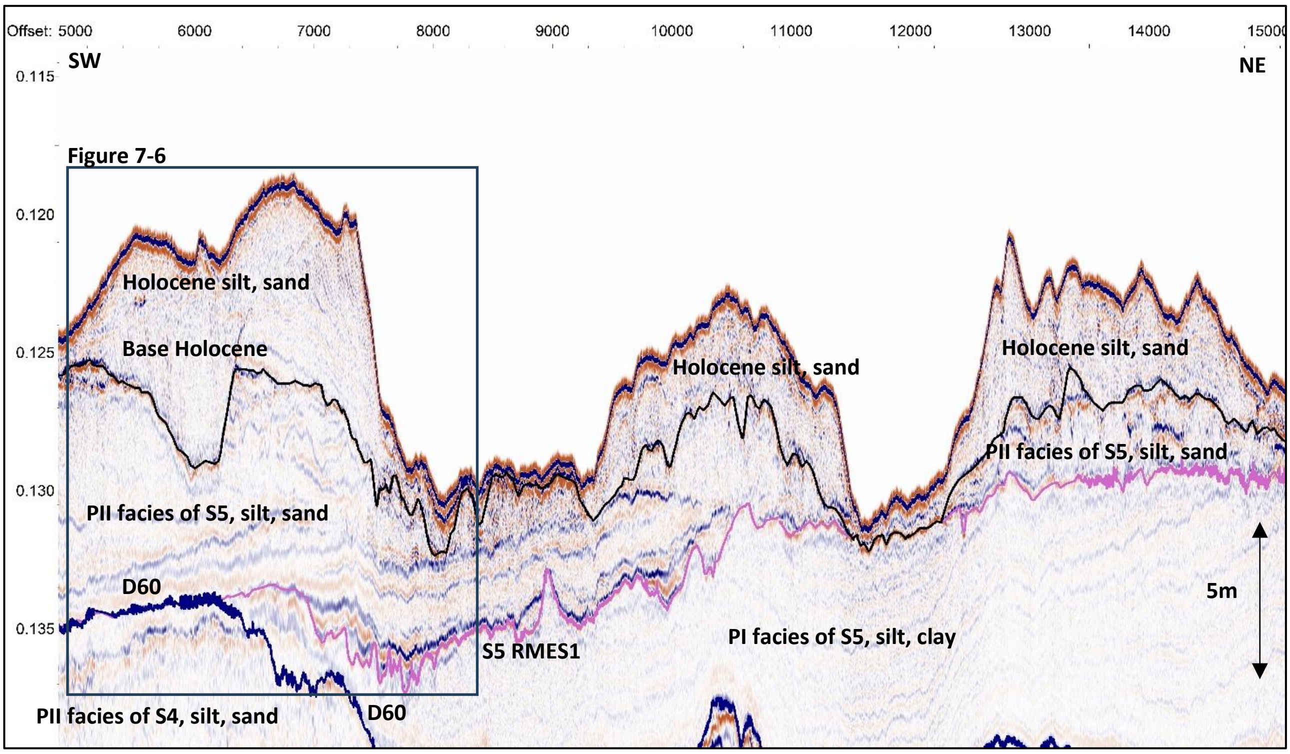

Figure 7-5: X007 UHR, Holocene across the centre of the area

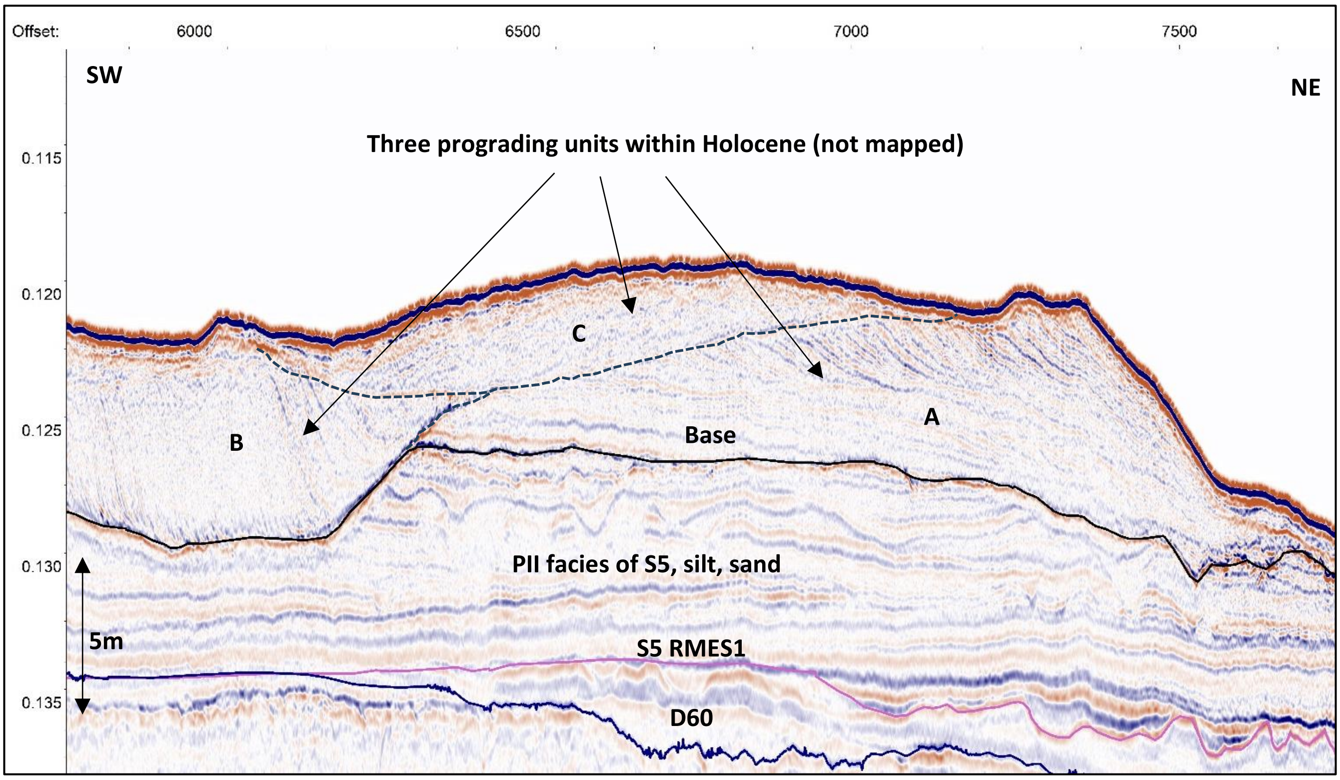

Figure 7-6: X007 UHR, Holocene across the centre of the area, zoomed in, three prograding units

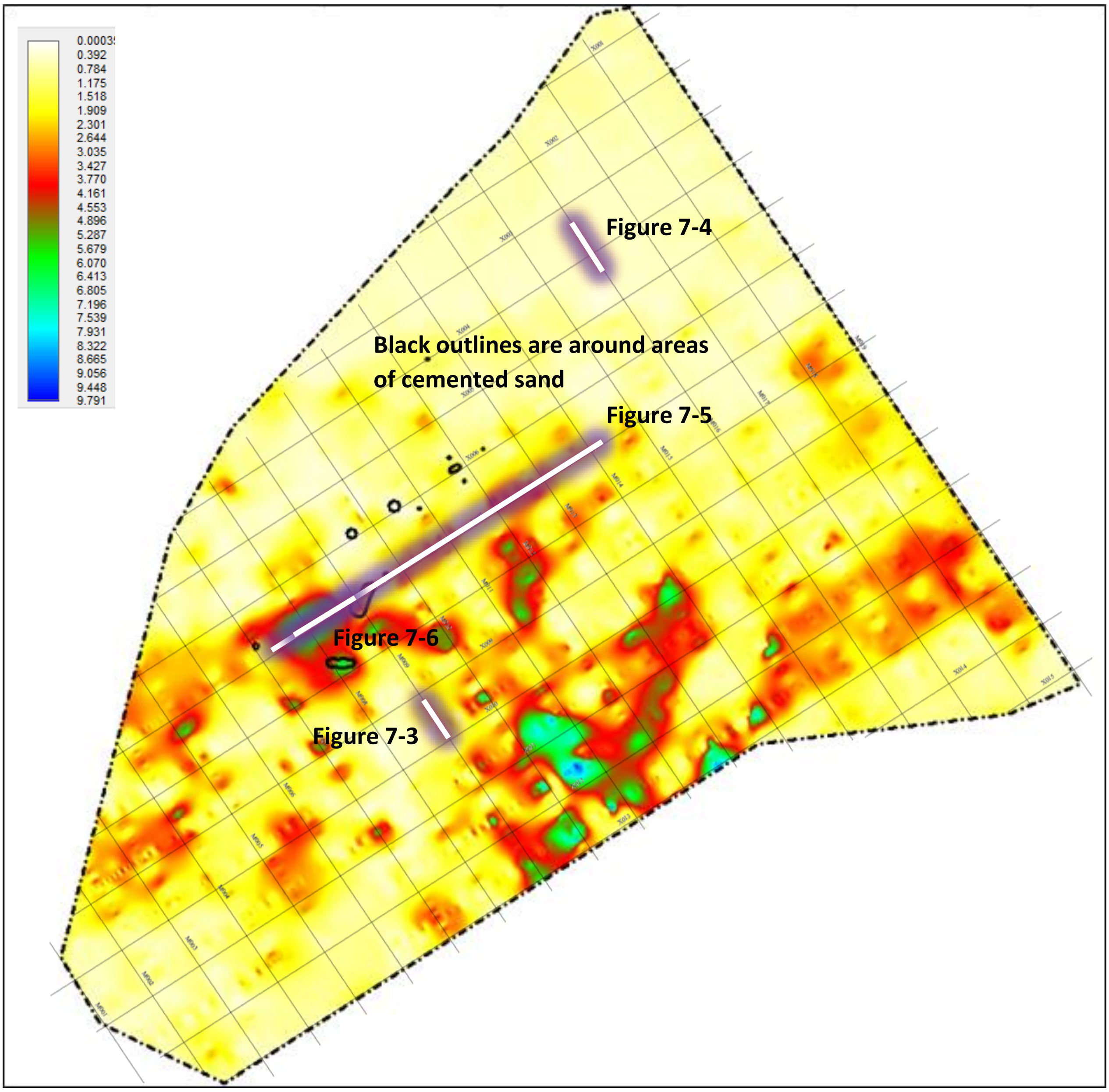

Figure 7-7: Thickness in metres, Holocene

7.4 DEEPER GEOLOGY

The top limit of the pre-Holocene deposits has been identified at a depth 0.2 metres from 10 metres below the seabed and are up to approximately half a million years old. Sequence boundaries are mapped, D surfaces, based on the stratigraphy of the Jouet et al. (2006) paper (Figure 7-2).

Together the five mapped sequences are at least 140 metres thick, reaching this maximum thickness close to the south-east margin of the survey area, pinching out towards the north-west to a minimum thickness of around 80 metres. The precise thickness is undetermined as the oldest part of Sequence S1 extends beyond the penetration of the data. The base of S1 is not defined in the reference paper or this project, it is ambiguous because the sedimentary patterns that define the later sequences break down in Sequence S1 and cannot be directly applied.

The individual sequences are cyclic and tend to contain less steeply-bedded PI facies (silt, clay) at their base and a more steeply-bedded PII facies (silt, sand) towards the top. These facies are separated by mapped Regressive Marine Erosion Surfaces.

The units are aggradational/progradational (PI facies) or more progradational (PII facies), building out from the north or north-west. There is some evidence of transgressive reworking over the tops of some of the PII facies packages.

The following subchapters describes the sequences in turn and includes some maps and data examples. The GIS deliverables will include all D and RMES maps with the footprint of the individual sandier packages represented by boundaries and/or D surfaces cropped back to the extent of sand.

7.4.1 Sequence S5

Sequence S5 (Figure 7-8) reaches a maximum thickness of 40 metres in the east of the area, where there is a thick, steeply-dipping package of PII facies silt/sand. S5 RMES1 is picked within S5 at the base of this facies unit (Figure 7-9). There is localised evidence of an infilled ravinement surface at the top of the progradational PII unit. The dipping south-eastern extremity of the facies PII package locally defines the bathymetry, over this zone; the seabed dips away to the south-east at approximately 2°.

S5 thins over the northern quarter of the area where the base Holocene unconformity cuts down around three to five metres into the sequence, truncating S5 RMES1. This area is north of the PII facies, which is located over the centre and south of the area.

Sequence S5 is absent over the northernmost nearly four kilometres of the survey area.

Jouet’s model uses the seabed as the top of Sequence S5 (D70). On this basis the previously described Holocene deposits and sand veneer would be regarded as part of Sequence S5. The base of S5, D60, is correlated to lowstand/glacial maxima MIS6, 150,000 years ago.

The true equivalent top, related to the most recent MIS2 lowstand, may be the base Holocene unconformity.

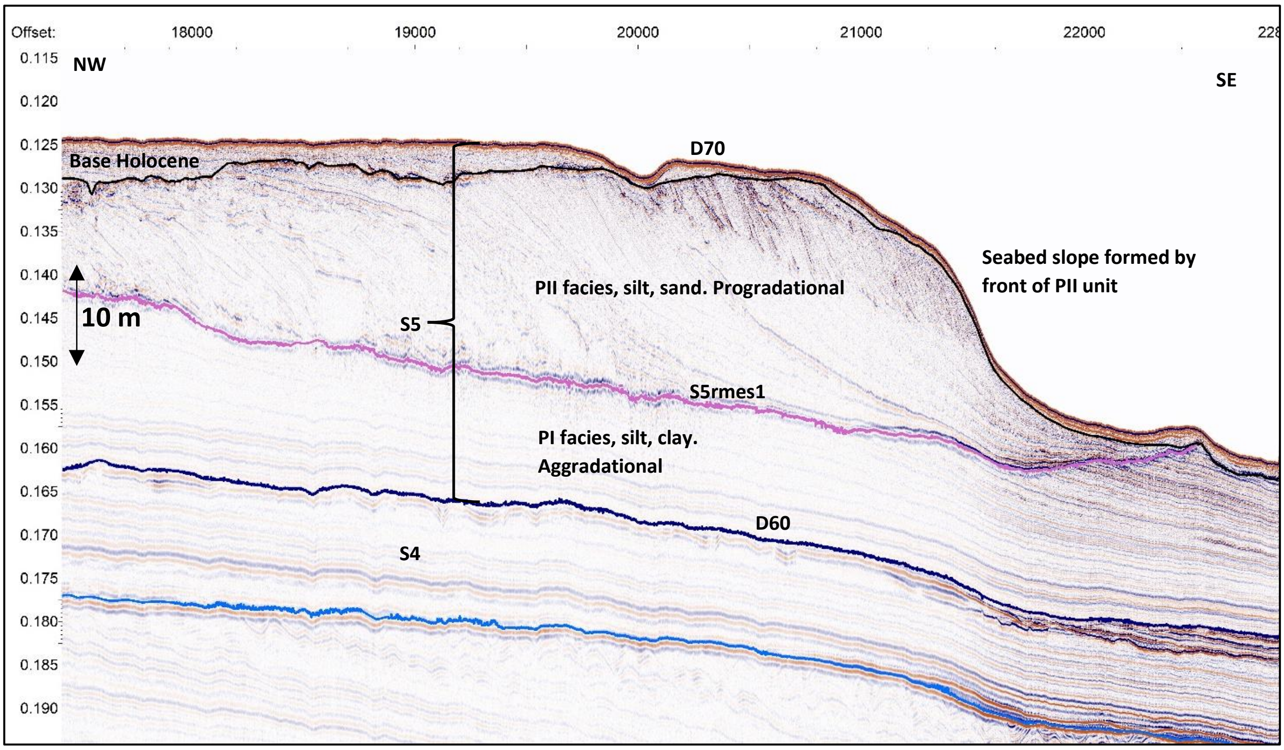

Figure 7-8: M018 UHR, Sequence S5, east of area

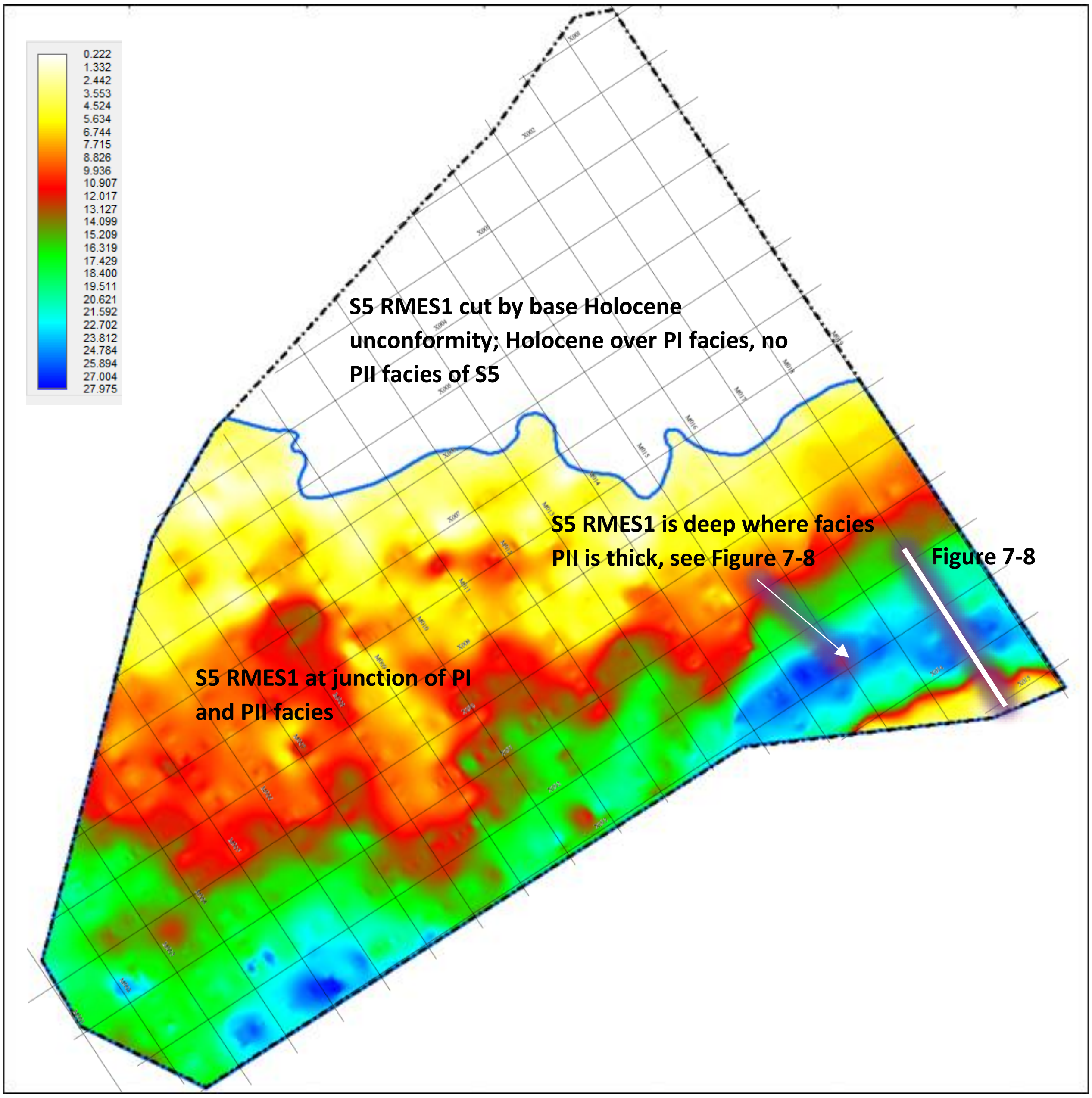

Figure 7-9: S5 RMES1, depth in metres below seabed (shows the junction of the PI and PII facies)

7.4.2 Sequence S4

Sequence S4 is thinner and more complex than S5. This interval contains two cycles of PI/PII facies. The thickest south-eastern part of the PII units is around ten kilometres north-west of the equivalent part of S5. S4 was deposited between MIS stages 6 and 8, 150-270 thousand years ago. The sequence is bounded by D60 and D50.

The two sedimentary cycles within Sequence S4 are shown on Figure 7-10. This complexity is also hinted at in Jouet et al. (2006) paper, Figure 7-2, shows that the authors represented more than a single progradational PII unit within S4.

In the north-west the PI facies between the progradational PII units pinches out and the two PII facies units are stacked on top of each other. At finer scale there is a further level of complexity; the tops of the PII facies units show some reworking and separate thin progradational units (Figure 7-11). These may have been deposited during the post MIS6 marine transgression.

The PI facies in the lower part of the second sedimentary cycle contains an additional subtle unconformity.

The regressive marine erosion surface within the lower sedimentary cycle is channelised in proximal areas (Figure 7-10, Figure 7-11). These channels cut through approximately five metres of PI facies subcrop. This is atypical of these regressive marine erosion surfaces, which are generally flatter truncations.

S4 deposits generally occur under both the Holocene and S5 deposits however S5 is eroded out over the northernmost approximately four kilometres of the area and S4 deposits are directly below the Holocene sediments.

Figure 7-12 shows the junction of the PI and PII facies in the upper cycle of S4.

The picked "S4_1_TopSand" and "S4_2_TopSand" can be described as follows:

- S4_1_TopSand is an additional pick that is neither a D sequence boundary or a RMES surface. It goes over the top of the SII sand facies in the lower part of S4. This facies transition is otherwise unmapped. Sequences with a single facies cycle have a D surface in this position.
- S4_2_TopSand is a duplicate of D60 but cut back to the area that it marks the top of SII sand facies.

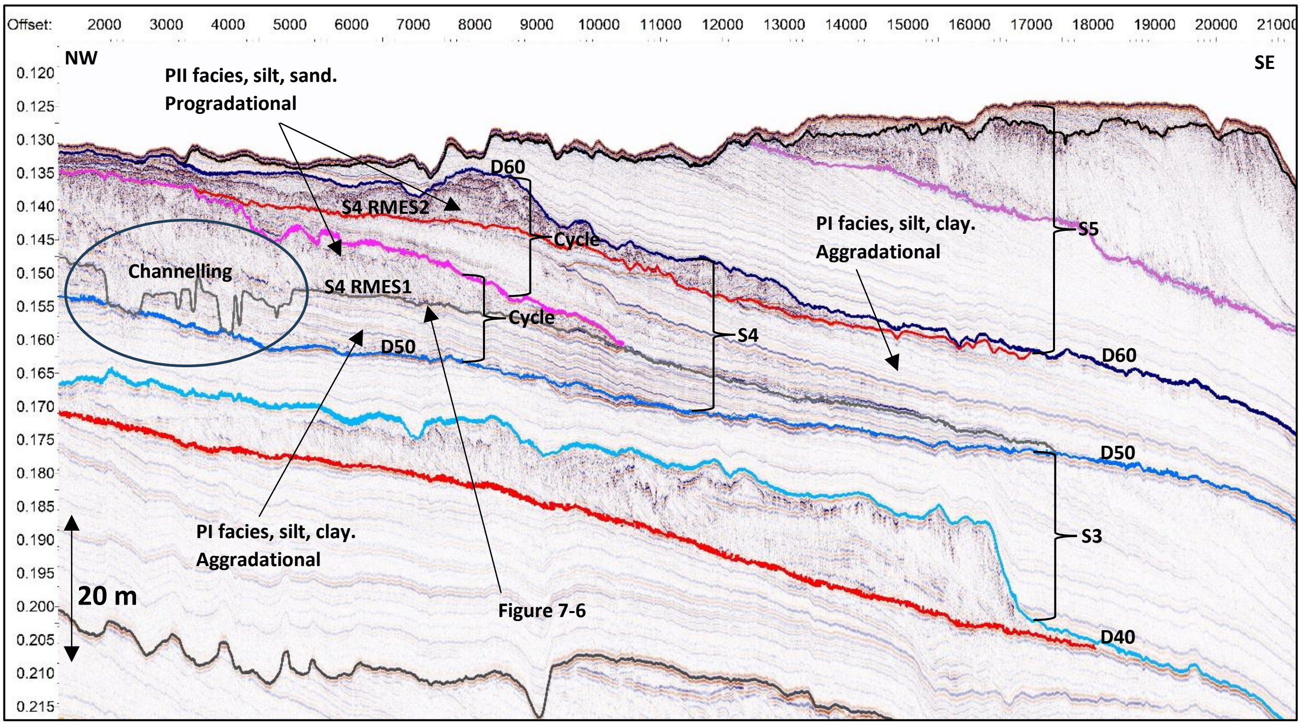

Figure 7-10: M018 UHR, Sequence S4

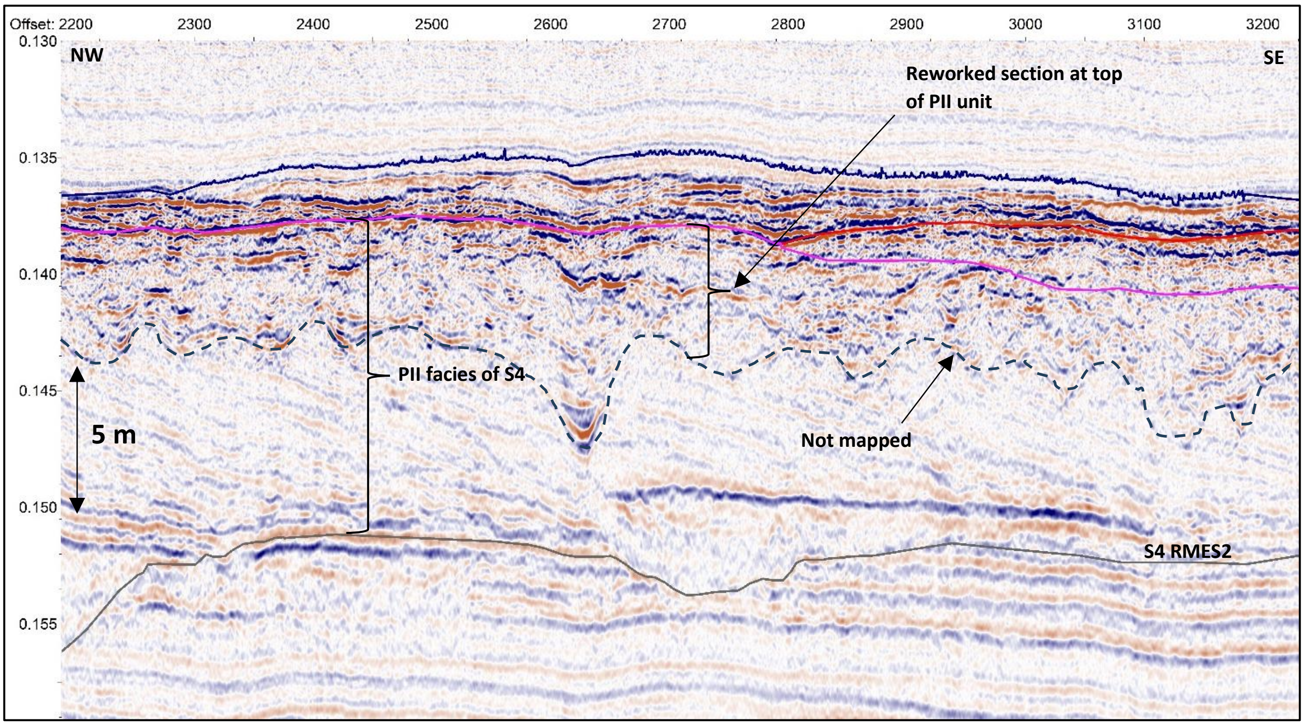

Figure 7-11: M013a UHR, Sequence S4, zoomed in

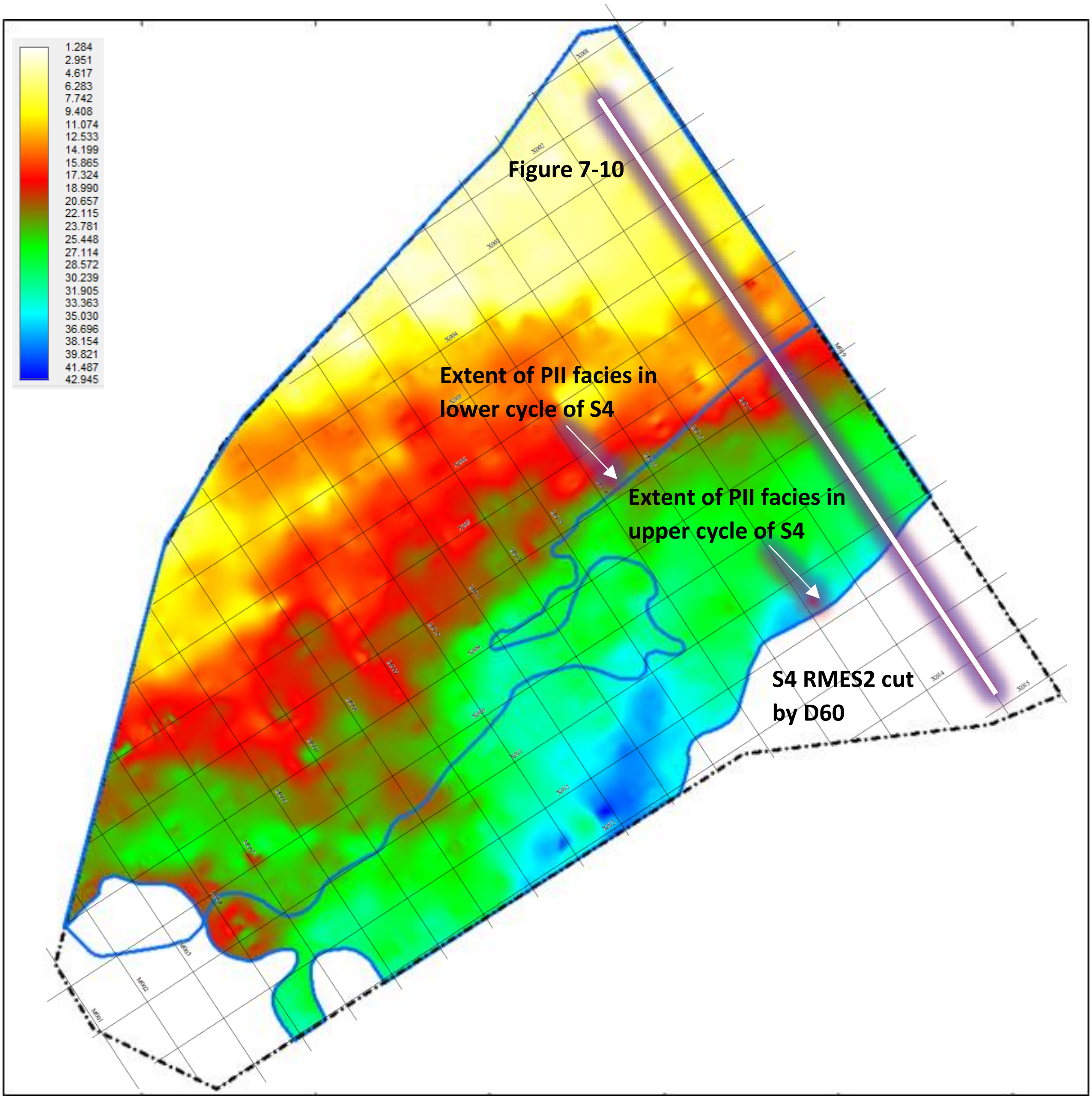

Figure 7-12: S4 RMES2, depth, metres below seabed (shows the junction of the PI and PII facies in the upper cycle of S4)

7.4.3 Sequence S3

Sequence S3 was deposited between MIS stages 8 and 10, 270 to 350 thousand years ago. It is bounded by D40 and D50. This sequence is composed of PI facies, there is no progradational PII unit.

In the south-east of the survey area the upper part of S3 has a wavy characteristic (Figure 7-13). The wavelength of these features is around 150 metres, and they developed northward (up dip) over time. This facies type is interpreted to represent a contour current influence on deposition.

This unit's thickness is influenced by the subcrop of the S2 PII facies. S3 thins out over the progradational bulge of S2 deposits, to around eight metres. South of this underlying structure S3 is generally around 40 metres thick (Figure 7-10).

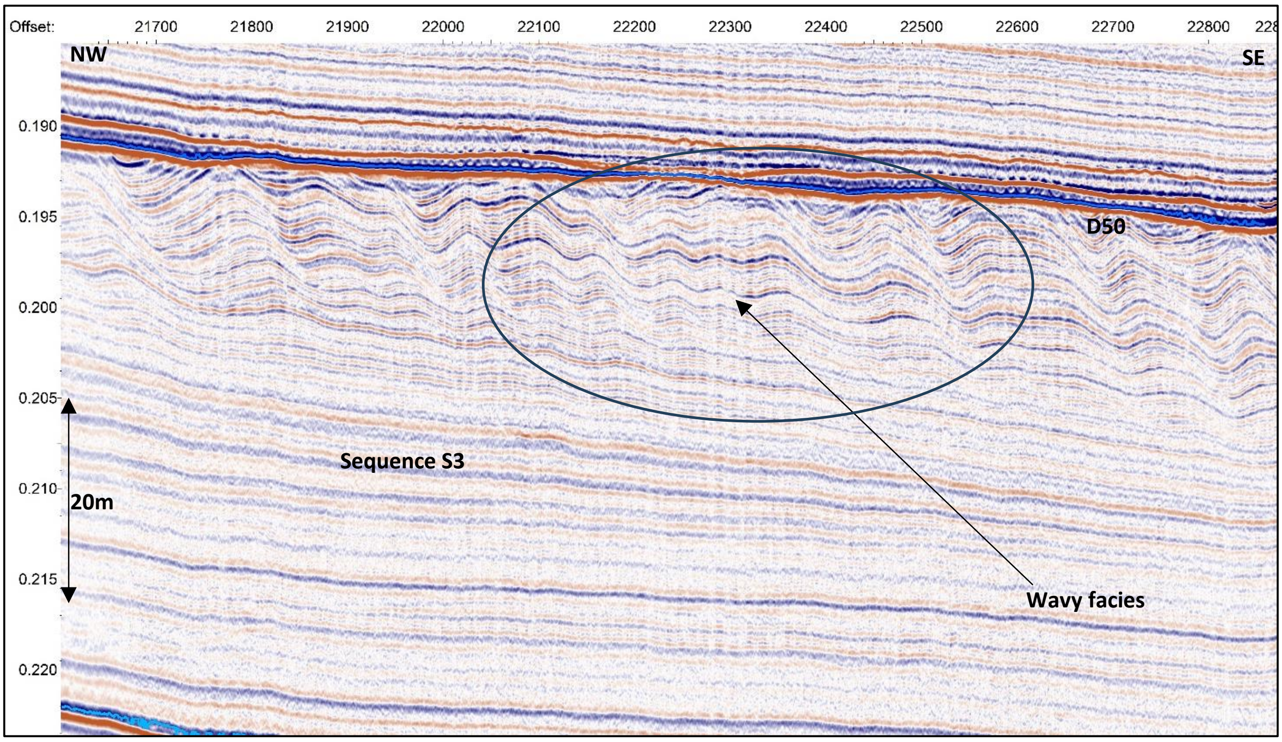

Figure 7-13: M018 UHR, Sequence S3, wavy facies

7.4.4 Sequence S2

Sequence S2 is thick (around 40 metres) and contains two regressive marine erosion surfaces (Figure 7-14). The lower of these surfaces is approximately at the centre of the sequence and does not mark a widespread transition to PII facies. There are some isolated progradational packages around this level.

The second surface, S2 RMES2, is more typical and separates PI and PII facies. Sandier PII facies associated with S2 RMES2 extend over the northern and central parts of the survey area. The upper parts of the PII facies show evidence of reworking and additional thin progradational packages.

S2 is bounded by D40 and D30, sequence boundaries linked to MIS10 and 12. This gives an age range of between 350 to 440 thousand years ago.

Figure 7-15 shows the junction of sequences S3 and S2.

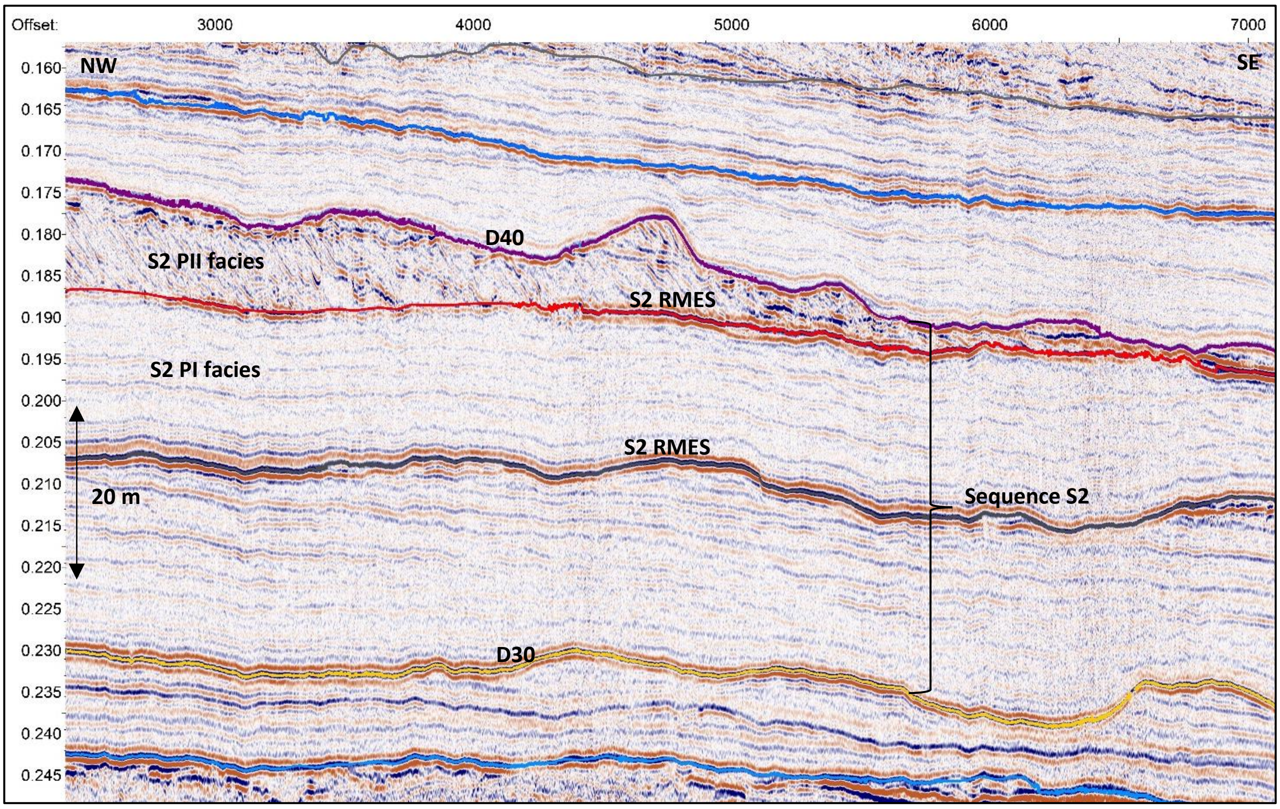

Figure 7-14: M009 UHR, Sequence S2

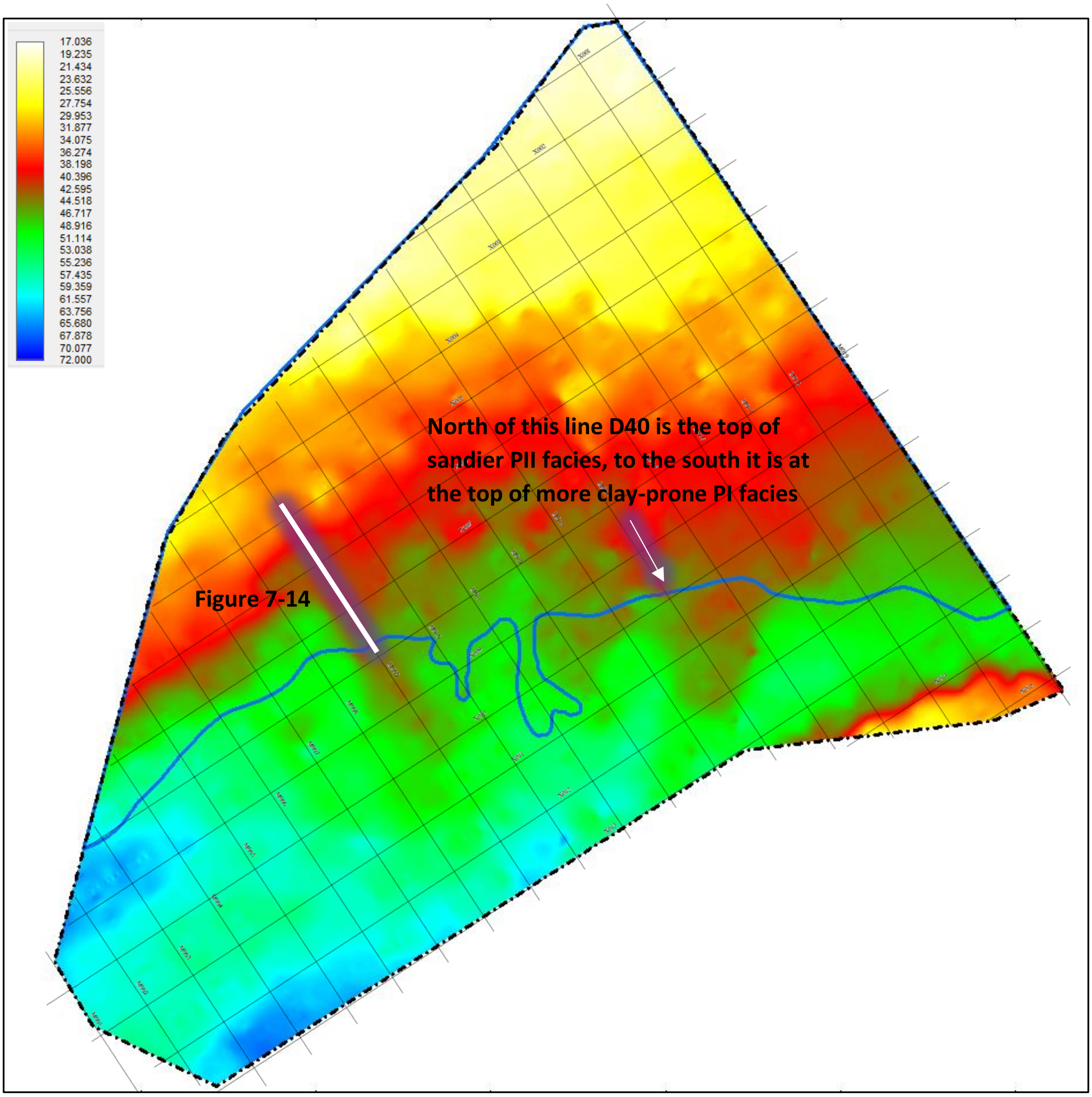

Figure 7-15: D40, depth in metres below seabed (shows the junction of sequences S3 and S2)

7.4.5 Sequence S1

These deposits, below D30 (MIS12), show some contrast with the younger deposits. This package is more than 440 thousand years old and contains numerous thin sub-units and erosion surfaces. Notably, the interval contains two major phases of cut and fill (Figure 7-16). This channelling is best developed in the extreme south of the area where the youngest channel is a five kilometres wide cut which extends past the lower limit of the data. D30 sags downward over the axis of this large channel. The channels trend approximately north to south for around eight kilometres, to the southern limit of survey. The channel fill packages are complex; they contain numerous sub units.

The youngest channel cut is at the top of sequence S1 – the channel fill is the youngest part of S1. This unconformity is only mapped in the south of the survey area. The deeper, older channel cut is mapped throughout the area, apart from where it is eroded out by the younger channel. Away from the south-east edge of the survey area it is a non-descript mild erosion surface.

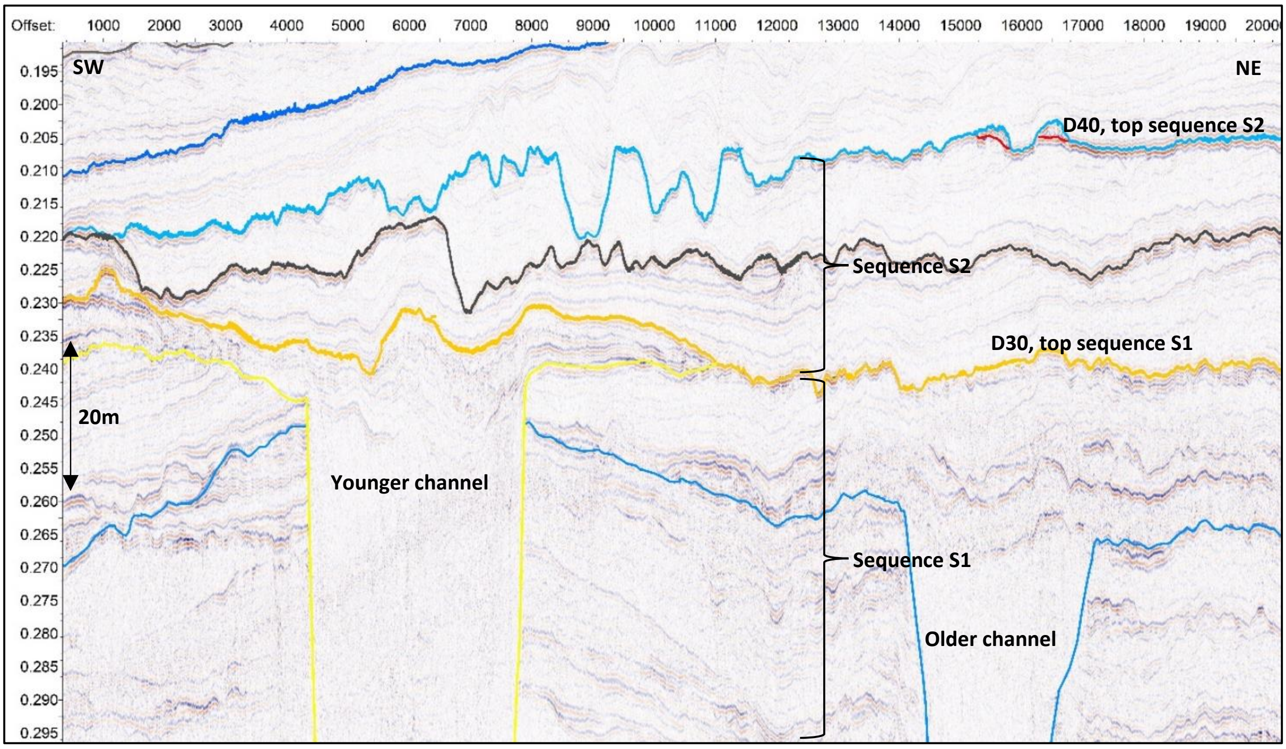

Figure 7-16: X011 UHR, S1 channels

The younger sequences do not contain any channels equivalent to these. Even if the channels are ignored, the sedimentary regime during S1 times was different to that which developed over the succeeding cycles of sea level rise and fall. S1 has a more aggradational style of construction, sequences S2 to S5 have a greater level of progradation. Over S1 time the sequence built up, whereas over S2 to S5 times the sequence built out, especially during deposition of the PII facies.

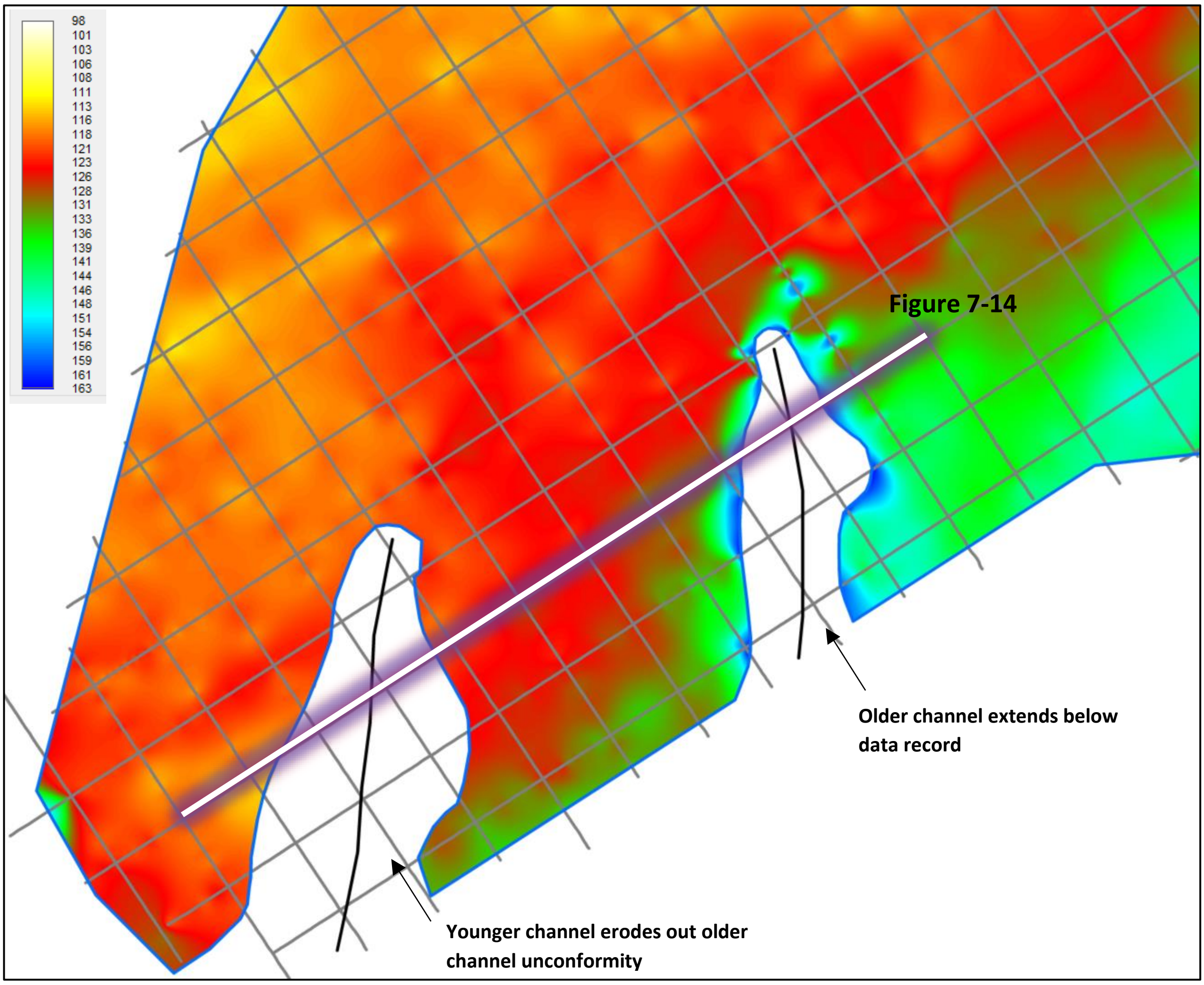

Figure 7-17: Older channel unconformity, depth in metres below seabed

It might be that the elevation of the contemporaneous seabed was so low that the water depth was always too great for the construction of progradational units.

The lithology within S1 is uncertain, it is likely to be a mixture of clastics, perhaps clay-prone with sandier layers and pockets.

7.5 GEOHAZARDS AND GEOLOGICAL INSTALLATION CONSTRAINTS

7.5.1 Shallow gas

The survey line spacing is too great to enable a definitive overall interpretation of the area's shallow gas potential. There are no clear indications of potential shallow gas on any of the profiler or UHR lines. This means that it is unlikely that there are any large, gasified areas, however it is possible that small pockets of gas exist between the survey lines.

It is recommended that a location-specific gas hazard assessment is done at any location where sub seabed operations (geotechnical testing, boring, engineering foundation installation, etc.) are planned.

7.5.2 Faulting

There are no indications of faulting in any of the data.

7.5.3 Slope Stability

There are no indications of post depositional sediment remobilization, slides, debris flows or similar.

There are significant seabed dips in the south of the area, however these are within sand facies; such sediments drain freely and maintain full effective stress, making failure unlikely.

There are short seabed slopes elsewhere. If works are planned to take place on one of these features, then seabed stability may need to be considered, especially if the slope is constructed of clay prone sediment.

7.5.4 Variable Ground Conditions

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

At any location within the survey area the baseline for understanding ground conditions is determination of the vertical and lateral distribution of facies PI (silt/clay) and facies PII (silt/sand) and the depths of the interfaces between these facies. The mapping has been done in such a way to make this possible, either though the GIS or directly from the Kingdom interpretation project.

There are some indications of cemented sands (Figure 7-18). In scattered parts of the centre of the survey area there are patches of high amplitude response in the profiler data, generally at the base of the surficial sand, often within a metre of the seabed. The distribution of these patches is mapped, nevertheless this interpretation is largely a function of the wide survey line spacing – these areas may be far more extensive than indicated. The distribution of the cemented sand is shown on Figure 7-7.

Jouet et al. (2006) describe the cemented sands as: “coarse siliclastic sands cemented by small crystals of high-magnesium calcite…”. They interpret that these are cemented beach sands that underwent diagenesis in a lagoon type environment. These areas will be very hard/strong.

There are distinct channel-fill facies with Sequence S1. This facies is restricted to the southern margin of the area and is at least 90 m below seabed.

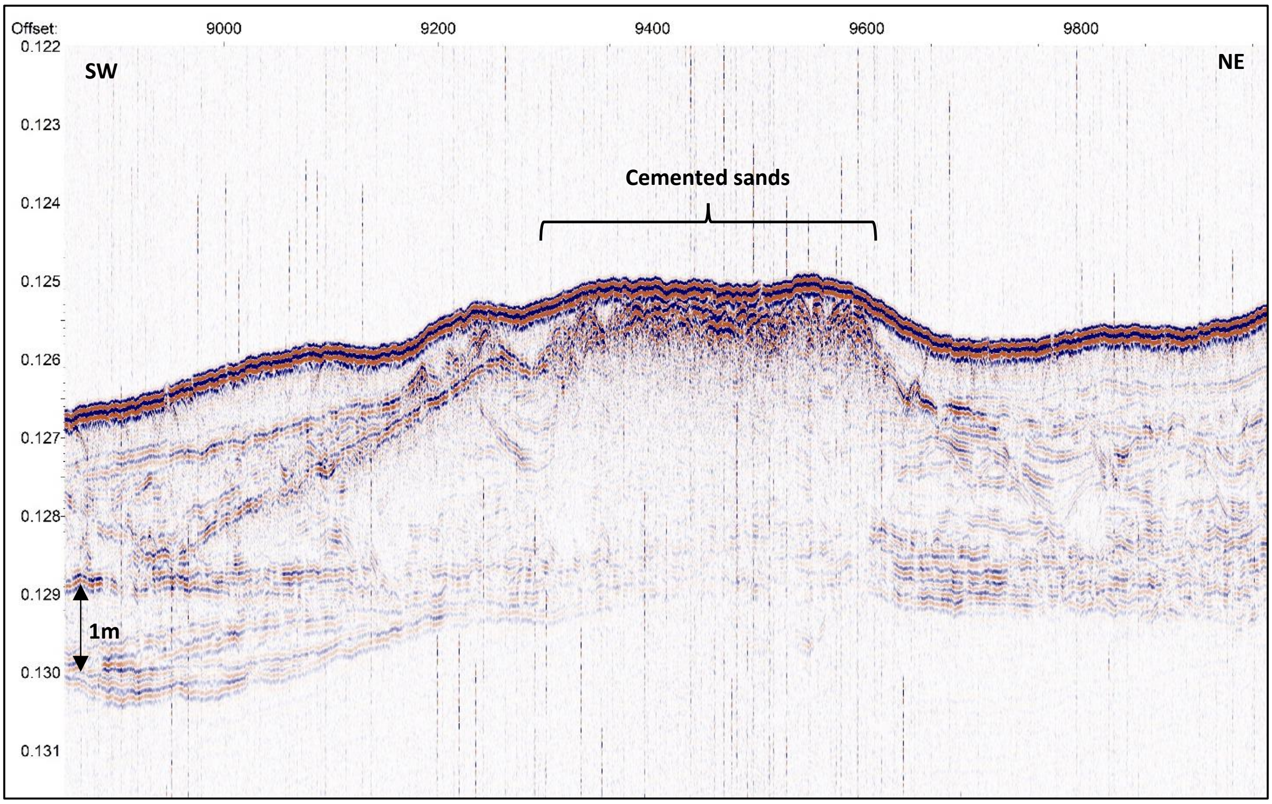

Figure 7-18: X006 SBP, cemented sands

APPENDIX A. UHRS PROCESSING WORKFLOW