



Survey Report: CV18_01
Area: Celtic Sea

For:
Marine Institute & Geological Survey Ireland

RV Celtic Voyager

May & June 2018

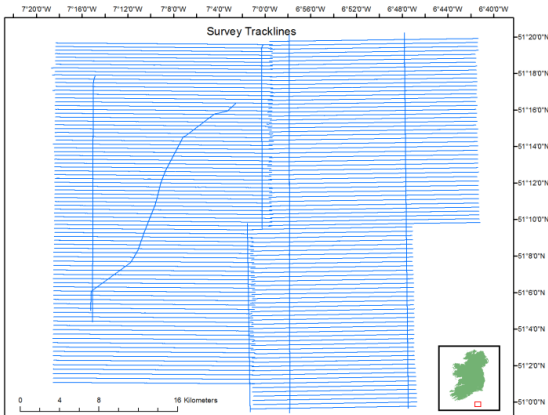
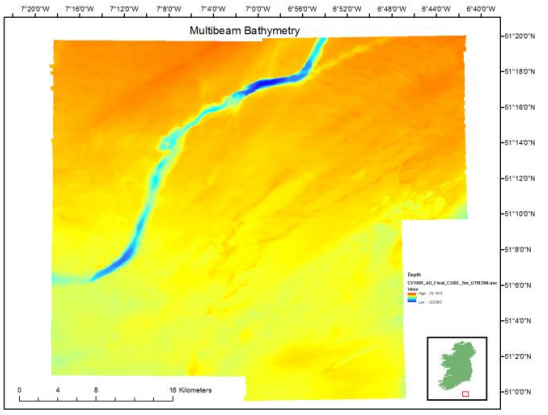
Prepared by Kevin Sheehan



Marine Institute Reference No:	Survey Report: CV18_01

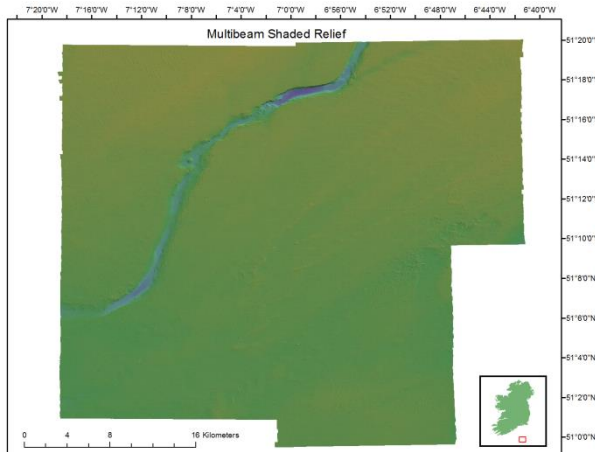
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Project Manager: Marine Institute / GSI			

Issue	Change	Date	Description	By	Approved
1		06/12/2018	Draft	K. Sheehan	
2		13/12/2018	Final	F.Sacchetti	

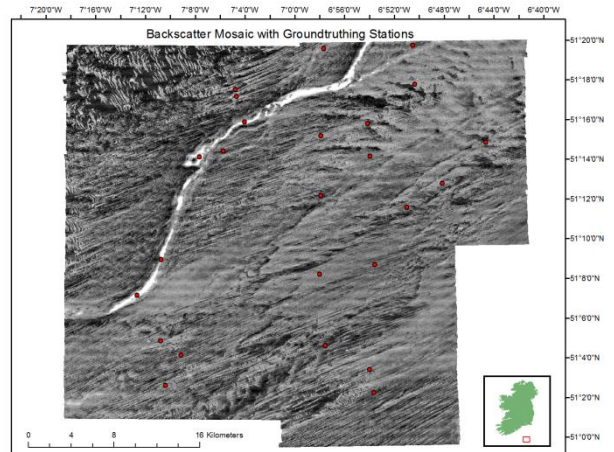
Executive Summary			
Survey Summary			
Survey Vessel:	RV <i>Celtic Voyager</i>	Survey Leg:	CV18_01
Mobilisation:	Cork	Demobilisation:	Cork
Survey Areas:	Celtic Sea	Start Date: End Date:	27/05/2018 08/06/2018
Northeast Boundary	51° 20.138N 6° 41.430W	Southwest Boundary	51° 1.629N 7° 19.302W
UKHO Admiralty	1123 (1:500,000)		
Key References	CV18_01 Survey Leg Report		
Equipment Used	EM2040 multibeam, Pinger sub-bottom profiler, EA400 singlebeam, SeaSpy magnetometer, AML MVP200, Valeport SVP Mini, C-Nav 3050 GNSS, Seapath 330+.		
Survey Statistics			
Minimum Water Depth (VORF LAT):	78 m	Maximum Water Depth (VORF LAT):	121 m
Area Covered:	1449 km ²	Survey Line Kilom:	3743 km
Approximate Operational:	84%	Approximate Downtime :	0%
Groundtruthing Stations:	25	Wrecks	9
H525 forms issues (wrecks)	9	H102 forms issued (shoals)	0
Survey Tracklines		Bathymetry	
			

Survey Images

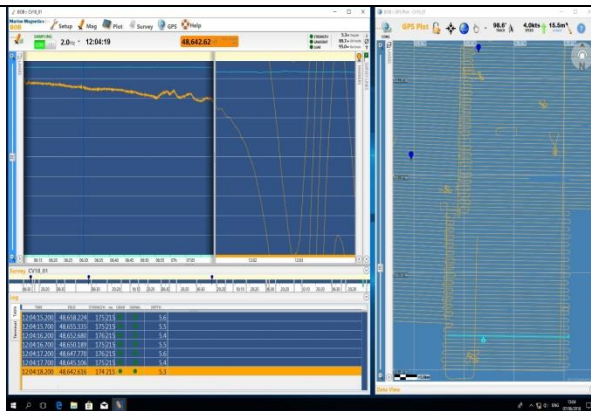
Shaded Relief



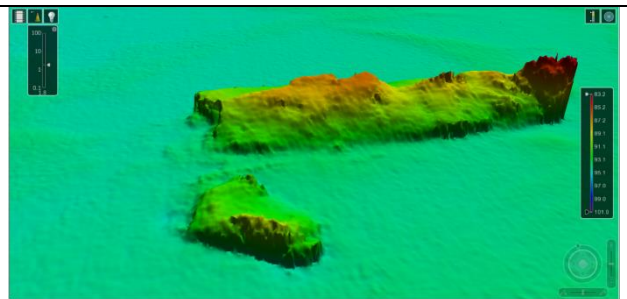
Backscatter with Groundtruthing



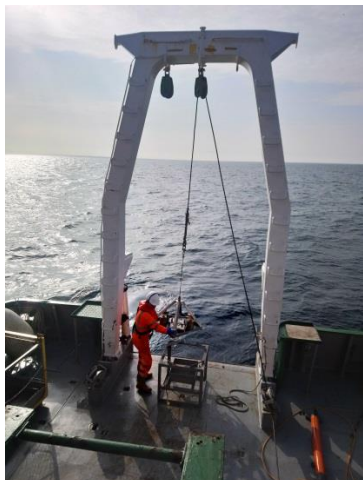
Magnetic Anomaly in Bob



Multibeam Image Wreck 9



Day Grab Deployment



Shipek Grab Deployment



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List of Acronyms Used Within This Report

Acronym	Full Name
AML	AML Oceanographic
CTD	Conductivity Temperature Depth
CUBE	Combined Uncertainty and Bathymetry Estimator
DCCAE	Department of Communications, Climate Action & Environment
DGNSS	Differential Global Navigation Satellite Systems
DPR	Daily Progress Report
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
GSI	Geological Survey Ireland
HSE	Health Safety & Environment
HVF	Hips Vessel File
IHO	International Hydrographic Organisation
INFOMAR	INtegrated Mapping FOr the Sustainable Development of Irelands MARine Resource
INSS	Irish National Seabed Survey
ITRF	International Terrestrial Reference Frame 2014 (ITRF2014)
LAT	Lowest Astronomical Tide
MVP	Moving Vessel Profiler
MBES	Multibeam Echo-Sounder
MI	Marine Institute
MMO	Marine Mammal Observer
MRU	Motion Reference Unit
NPWS	National Parks & Wildlife Service
PPE	Personal Protective Equipment
PPS	Pulse Per Second
PPP	Precise Point Positioning
QINSy	Quality Integrated Navigation System
RTG	Real Time Gypsy
RV	Research Vessel
SBP	Sub Bottom Profiler
SBES	Singlebeam Echo Sounder
SIS	Seafloor Information System

SVP	Sound Velocity Profile
TPU	Total Propagated Uncertainty
UKHO	UK Hydrographic Office
UTC	Coordinated Universal Time
VORF	Vertical Offshore Reference Frame
WGS	World Geodetic System

1. Introduction

1.1 Project Overview and Objectives

The Geological Survey Ireland (GSI) and Marine Institute (MI) conducted seabed mapping between 2003 and 2005 under the auspices of the Irish National Seabed Survey (INSS) and this has continued from 2006 to present day under the INtegrated mapping FOFor the sustainable development of Irelands MARine Resource (INFOMAR) programme. INFOMAR is a joint venture between the GSI and the MI. The INSS was one of the largest marine mapping programmes ever undertaken globally, with a focus on deep water mapping. INFOMAR is funded by the Irish Government through the Department of Communications, Climate Action and Environment (DCCAE).

INFOMAR Phase 1, 2006 to 2015 focused on mapping 26 priority bays and 3 priority areas around Ireland and creating a range of integrated mapping products of the physical, chemical and biological features of the seabed in those areas. INFOMAR Phase 2, 2016 to 2026 intends to map the remainder of Ireland's entire seabed. Figure 1 shows the extent of the continental shelf mapped area under INSS and INFOMAR and the outstanding areas as of January 2018. Grey have already been mapped, blue and coloured hatched areas are unmapped.

As of 2018 the remaining survey area has been split at the 30 nautical mile limit (Nm). The inshore survey fleet, managed by GSI is responsible for mapping inshore of the 30Nm limit and the MI vessels are responsible for mapping the offshore. Outstanding survey areas are defined into gridded survey units known as INFOMAR Survey Units (ISUs). ISUs are all 1000 km² in size and are uniquely identifiable by a letter on the x axis and number on the y axis. Each ISU is coloured in a shade of blue which indicates the modal water depth in that ISU. Colour scales are used, to denote the three depth bands; 50 to 100m, 100 to 150m and 150m plus.

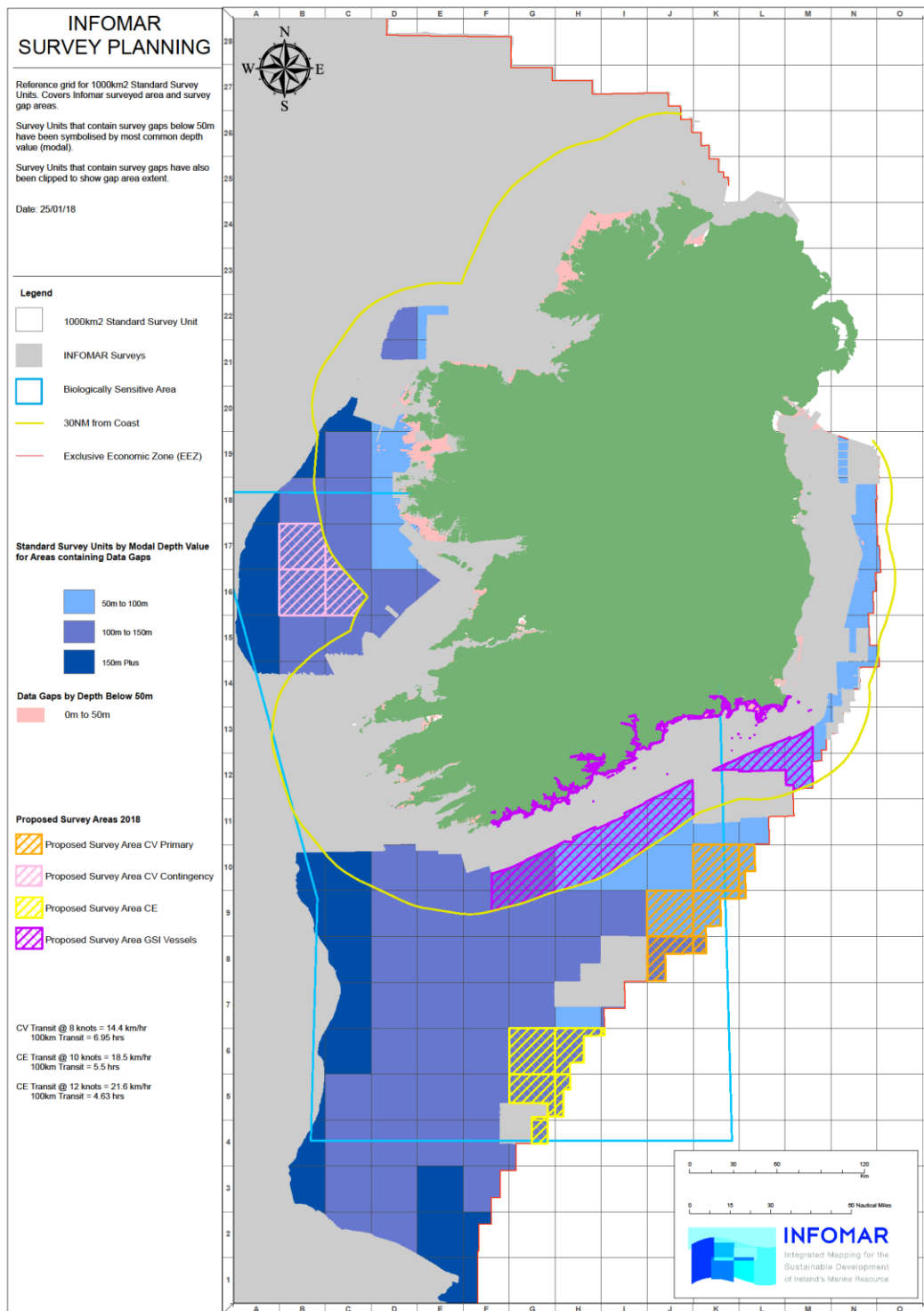


Figure 1: Survey coverage status January 2018.

MI supplied the research vessel *RV Celtic Voyager* and experienced personnel for the survey.

The scientific aims of the survey were to:

(i) Undertake a Multibeam Echo Sounder (MBES) hydrographic survey to International Hydrographic Organisation (IHO) Order 1A standard.

(ii) Produce bathymetry, shaded relief and backscatter mosaic products to provide depth, seabed features and seabed hardness/roughness information.

(iii) Acquire Sub Bottom Profiler (SBP) data of the shallow (up to 30 m) sub seabed to determine the existence of buried objects and ascertain the sub-seabed character.

(iv) Acquire magnetometer data to investigate the sub seabed geology and provide information on manmade seafloor debris.

(v) Map in detail and provide hydrographic wreck reports on any wrecks.

(vi) Groundtruth the acoustic data with grab samples.

1.2 Survey Area

Figure 2 shows the area designated for mapping by the RV *Celtic Voyager* in 2018. The entire area is in the Celtic Sea in water depths ranging from 75 to 125 m depth and is bounded by the UK/Ireland border to the east. Predicted survey coverage for the RV *Celtic Voyager* 2018 survey season is 3400 km² based on survey rates achieved in the 2016 and 2017 seasons respectively. The actual hatched area in figure 2 is 3580 km² as hatched boundaries were drawn along existing ISU boundaries. Approximately 80% of the area lies in the 50 to 100 m depth zone and 20% in the 100 to 150 m depth zone. Survey coverage rates for these two zones are estimated at 80 km² and 113 km² per day respectively.

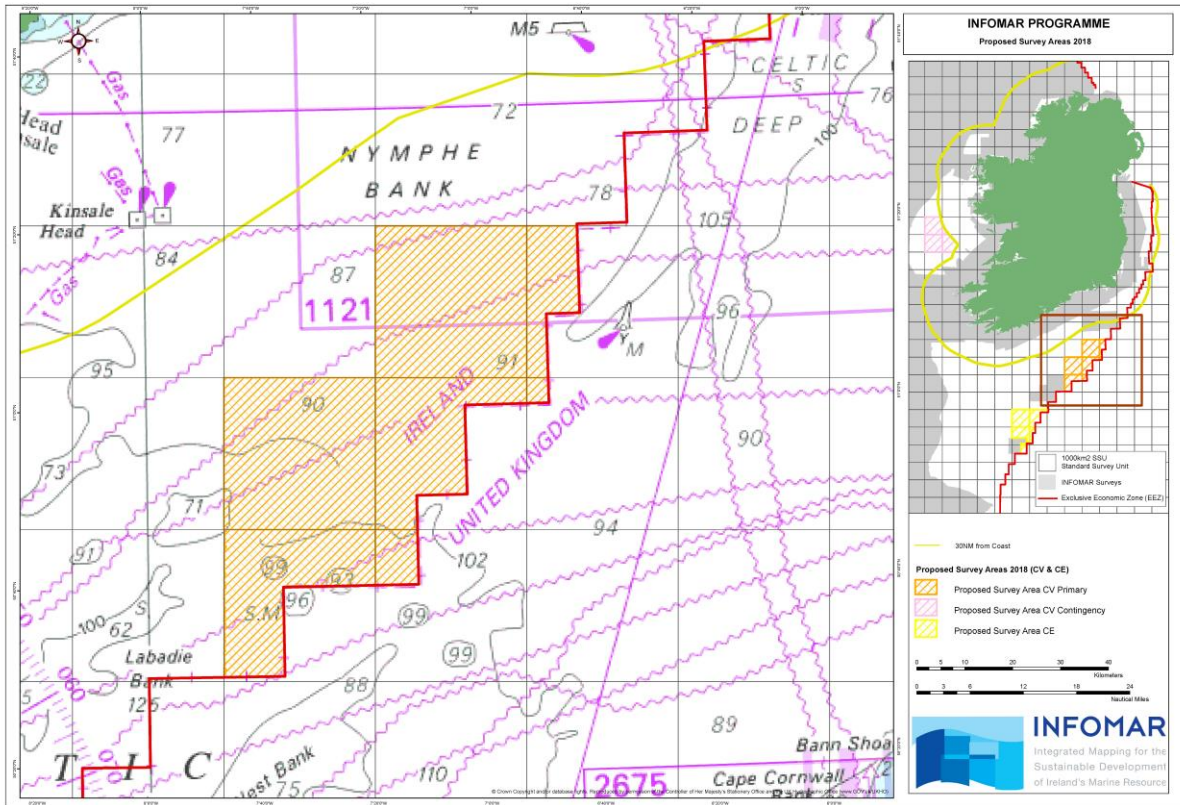


Figure 2: Proposed survey area for 2018.

2. Operations & Survey Setup

Mobilisation took place in Cork on 27th May. Data acquisition took place between 27th May and 13th June. Kevin Sheehan of the MI acted as Party Chief. The survey team comprised skilled personnel from the MI and a freelance contractor.

2.1 Survey Tracklines

The final survey trackline plot is contained in figure 3. Mainlines were acquired on east – west reciprocal headings.

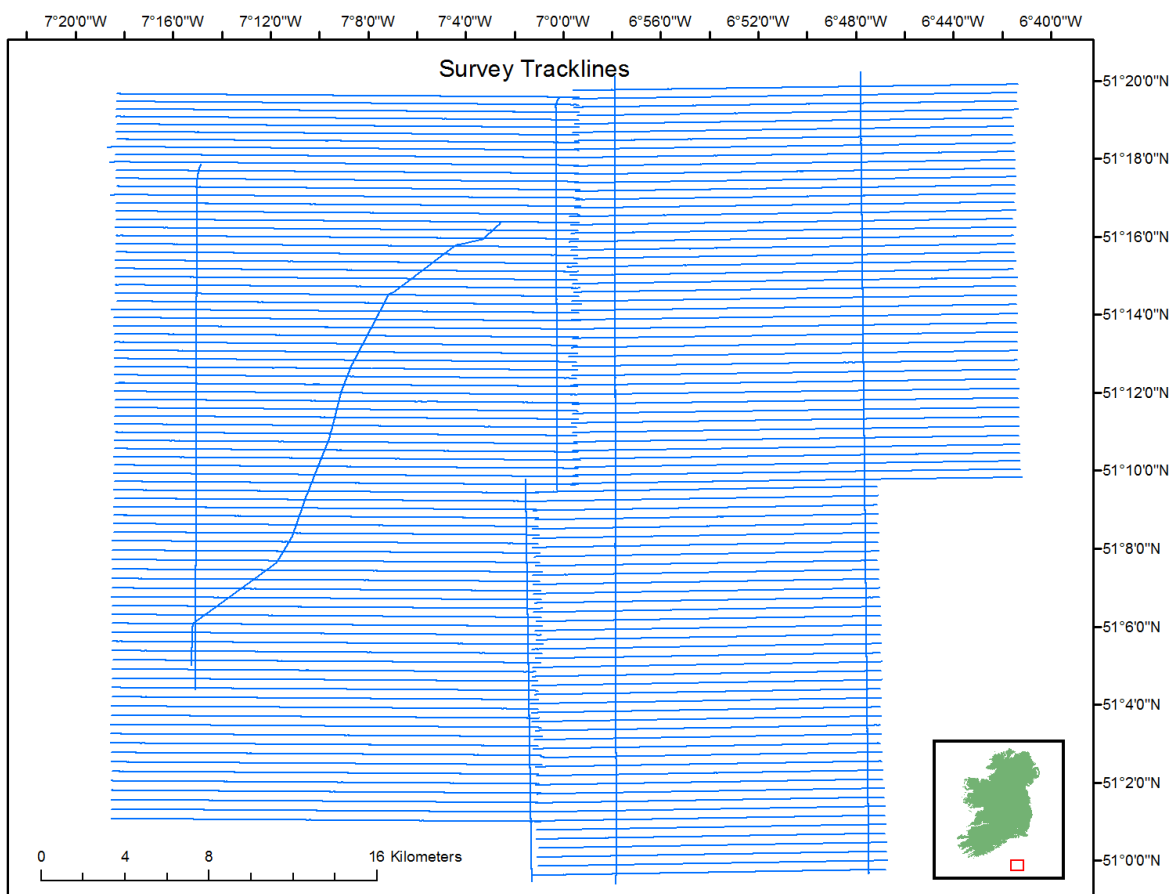


Figure 3: Survey trackline plot produced in Caris and ArcGIS software.

2.2 Summary of Events

A summary of the key events is presented in table 1. Times are in Coordinated Universal Time (UTC). Daily Progress Reports (DPRs) were distributed to management and INFOMAR personnel on a daily basis.

Date and time	Activity
27/05/2018 00:00	Portcall Cork City

27/05/2018 09:30	Mobilisation and troubleshooting
27/05/2018 13:00	Depart Cork and transit to calibration site in Cork Harbour
27/05/2018 15:00	Patch test EM2040 in Cork Harbour
27/05/2018 16:00	Transit to survey area
27/05/2018 22:04	Commence data acquisition
07/06/2018 21:28	Transit to Cork
07/06/2018 08:00	Alongside Cork / Demobilisation
07/06/2018 23:59	Demobilisation complete

Table 1: Summary of survey events.

2.3 Survey Personnel

Survey personnel, their affiliation and role are listed in table 2.

Name	Affiliation	Role
Kevin Sheehan	MI	Party Chief /Surveyor
Nicola O' Brien	MI	Surveyor
Slava Sobolev	Contractor	Data Processor

Table 2: Survey personnel details.

2.4 Health, Safety and Environment (HSE)

All personnel joining the vessel were given a safety induction tour which was recorded by the Second Mate. Medical and Personal Sea Survival certifications for all personnel were checked for validity prior to departure. A muster drill was held within 24 hours of departure from port. Magnetometer, grab and sound velocity profiler deployments were performed by vessel crew and without incident, with personnel wearing correct Personal Protective Equipment (PPE). There were no near misses or safety incidents to report.

2.5 Marine Mammal Observations

National Parks and Wildlife Service (NPWS) published a *Code of Practice for the Protection of Marine Mammals during Acoustic Seafloor Surveys in Irish Waters* in 2007. An updated document titled "Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters" was published in January 2014. Full details of both documents are published on the NPWS website. The code and guidance are applicable to all seismic, MBES and sidescan sonar surveys in bays, inlets or estuaries and within 1500 m of the entrance of enclosed bays/inlets/estuaries. All operations were outside of the areas covered under the above guidelines. No marine mammals were observed during the course of the survey.

2.6 General Survey Information

A summary of key survey statistics is contained in table 3.

Total Line Length (km)	3743
Area Covered (km ²)	1449
Operational (%)	84%
Downtime (%)	0%
Transit	6%
Port Call	8%

Table 3: Key survey statistics.

The pie chart presented in figure 4 presents the cumulative statistics from the final DPR. Survey data acquisition accounts for approximately 84% of the time.

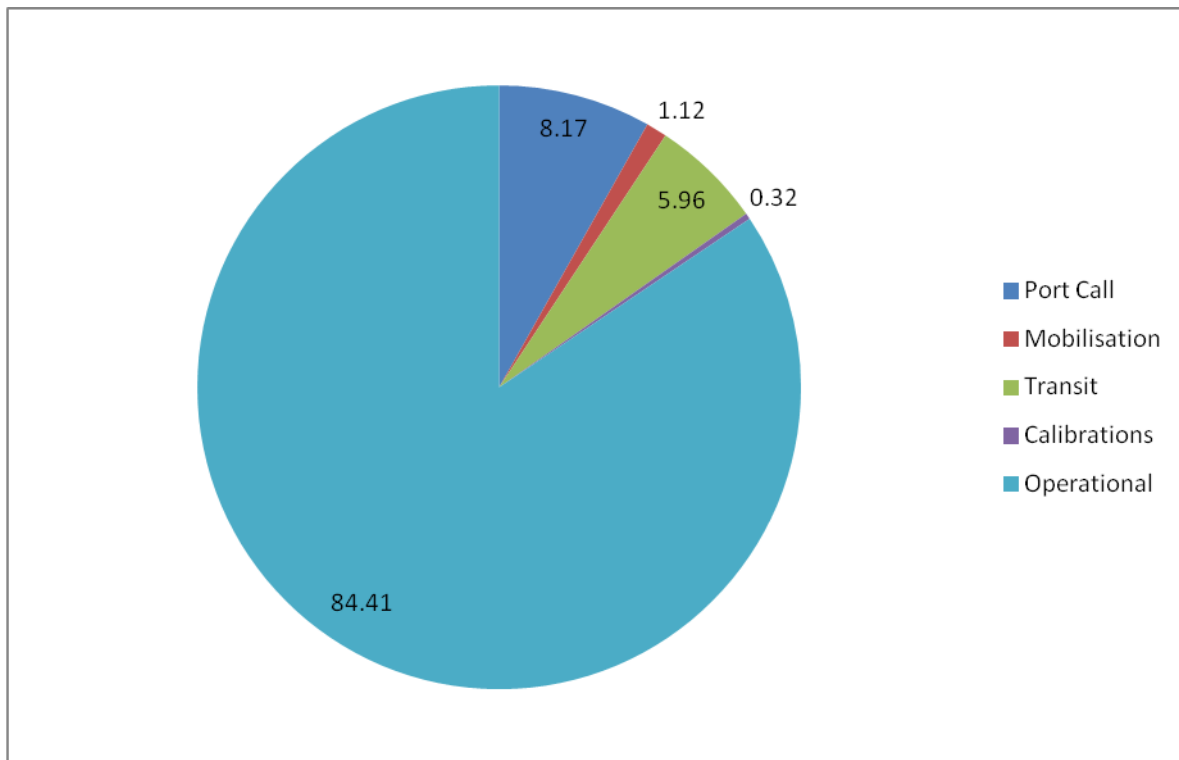


Figure 4: Survey statistics pie chart.

3 Survey Vessel Offsets, Equipment and Data Acquisition

The RV *Celtic Voyager* (figure 5) is a multipurpose research vessel owned by MI and managed by P&O Maritime. The vessel has wet, dry and chemical laboratories, which are permanently fitted with standard scientific equipment and can accommodate 8 scientists with a maximum endurance of 14 days. It has two hull mounted high resolution MBES systems, a Singlebeam Echo sounder (SBES), pinger source SBP and C-NAV Differential Global Navigation Satellite Systems (DGNSS) as primary navigation and a Seatex Seapath 330+ as secondary navigation and Motion Reference Unit (MRU).

All necessary geophysical and DGPS positioning equipment were pre-installed, calibrated and tested prior to commencement of survey activities.



Figure 5: The RV *Celtic Voyager*.

Detailed vessel information is contained in table 4.

Parameter	Numeric
Length	31.4 m
Beam	8.5 m
Draught	4.0 m
Engine	1 x Baudouin 26.2 655 kW

Power Output	640 kW/1200 RPM
Speed	10 knots
Fuel	38000 Lt MGO
Generator	2 x Daewoo 1x Deutz
Max Scientists and Crew	15
Passenger Licence	P5

Table 4: RV *Celtic Voyager* vessel information.

3.1 Vessel Offsets

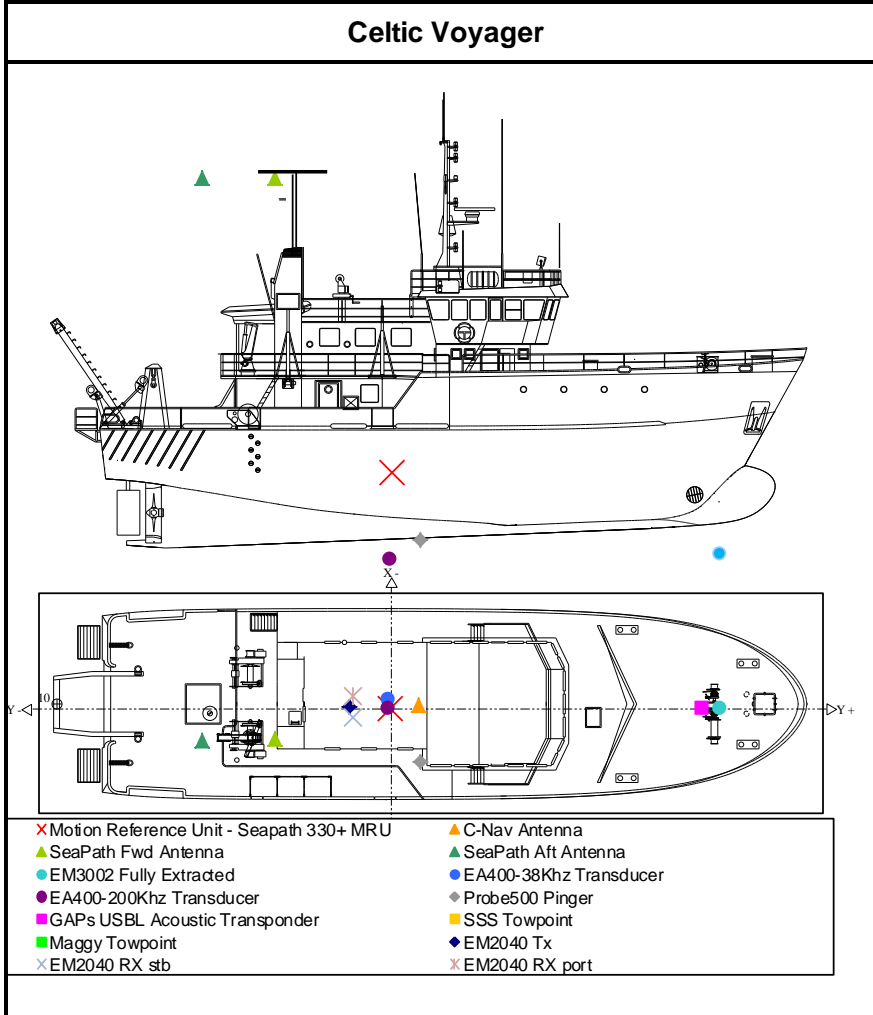
The EM3002 transducer was moved from a retractable pole amidships to the bow in August 2015. This coincided with the movement of the EM2040 transducers from their bow position to the retractable pole amidships. Bluepix performed an offset survey of the RV *Celtic Voyager* in August 2015 while in dry dock Killybegs. An additional offset survey was conducted by Bluepix in January 2016. Current vessel offsets are presented in table 5 below.

MARINE INSTITUTE

VESSEL OFFSET LOG

Project: **INFOMAR**
Client: **MI & GSI**
Project Title:

Date Last Surveyed: **10-11/01/2016 - Bluepix** Date: **11/01/2016**



No'	Offset Name	X	Y	Z	Reason for change
	Common Reference Point (CRP)	0.000	0.000	0.000	
1	Motion Reference Unit - Seapath 330+ MRU	0.000	0.000	0.000	
2	C-Nav Antenna	-0.114	0.965	14.396	
3	SeaPath Fwd Antenna	0.924	-3.993	13.292	
4	SeaPath Aft Antenna	0.984	-6.491	13.299	
5	EM3002 Fully Extracted	-0.078	11.190	-3.532	New Position 2015
6	EA400-38Khz Transducer	-0.343	-0.122	-3.783	
7	EA400-200Khz Transducer	-0.036	-0.115	-3.783	
8	Probe500 Pinger	1.636	0.989	-3.004	
9	GAPs USBL Acoustic Transponder	-0.077	10.633	-4.332	
10	SSS Tow point	0.000	-13.905	1.987	
11	Maggy Tow point	-3.835	-13.905	1.987	
12	EM2040 Tx	-0.064	-1.417	-4.863	New Position
13	EM2040 RX stb	0.279	-1.287	-4.693	New Position
14	EM2040 RX port	-0.411	-1.288	-4.696	New Position

Surveyor: Fabio Sacchetti Checked: Kevin Sheehan Date: 11/01/2016

EM2040 geometry	10-11/01/2016		
	X (forward)	Y (starboard)	Z(+Down)
Pos Com1(C-Nav)	0.965	-0.114	-14.396
EM2040 TX	-1.417	-0.064	4.863
EM2040 RX Port head	-1.288	-0.411	4.696
EM2040 RX Starboard head	-1.287	0.279	4.693
Seapath aft	-6.491	0.984	-13.299
Seapath fore	-3.993	0.924	-13.292
MRU 5+	0.000	0.000	0.000

Item	Yaw	Roll	Pitch
MRU 5+	0.57	0.07	0.21
EM2040 TX	-0.05	-0.37	0.74
EM2040 RX Port	-0.83	39.68	0.67
EM2040 RX Stb	0.69	-40.28	0.73
Seapath	-1.39	N/A	N/A
EM3002	0.68	-0.47	-0.14

Positive Yaw is clockwise. Positive Roll is starboard down. Positive Pitch is fore up.

Table 5: Vessel offsets and installation angles.

3.2 Survey Equipment

Table 6 contains information on the survey equipment both permanently installed and available for mobilisation onboard the RV *Celtic Voyager*.

System	Type	Comment
Multibeam Echo-Sounder	Kongsberg EM2040	200, 300 & 400 kHz
Multibeam Echo-Sounder	Kongsberg EM3002	300 kHz
Singlebeam Echo-Sounder	Kongsberg EA400	38 and 200 kHz
Sub-Bottom-Profiler	Sonar Equipment Services Pinger source	3.5 – 9 kHz
Sidescan Sonar	Edgetech 4200	100 and 500 kHz
Positioning	C-Nav DGNSS	Seapath330+ as secondary
USBL	IXsea-Gaps	Sonardyne Scout as secondary
Sound Velocity Profilers	Valeport SVX2	SV & Conductivity
Moving Velocity Profiler	AML MVP200	SV
Realtime Sound Velocity	Valeport / AML	SV
Magnetometers	SEASPY	Overhauser Effect

Table 6: RV *Celtic Voyager* available survey equipment.

3.3 Data Acquisition

3.3.1 Geodetic Parameters

Table 7 contains the geodetic parameters used for the survey.

Local Datum Geodetic Parameters	
Datum	ITRF2014
Spheroid	World Geodetic System 1984 (WGS-84)
Semi-Major Axis (a)	6378137.000 m
Semi-Minor Axis (b)	6356752.314 m
First Eccentricity Squared (e ²)	0.0066943800
Inverse Flattening (1/f)	298.257223563
Projection Parameters	
Grid Projection	Universal Transverse Mercator
Central Meridian Zone 29 (CM)	009° West
Origin Latitude (False Lat.)	00.0°
Hemisphere	North
False Easting (FE)	500000.0 m
False Northing (FN)	0.0 m
Scale Factor on CM	0.999600
Units	M

Table 7: Geodetic parameters.

3.3.2 Survey Datum, GNSS Tides and VORF Model

Table 7 above details the vertical and horizontal datum applied during operations. Global Navigation Satellite Systems (GNSS) tides do not require us to account for vessel draft or vessel squat values, as recorded depths are related directly to the World Geodetic System (WGS) 84 Ellipsoid. These values were reduced to Lowest Astronomical Tide (LAT) using GNSS tidal measurements and by then applying the VORF (Vertical Offshore Reference Frame) model (LAT/WGS84 separation) as illustrated in figure 6 below.

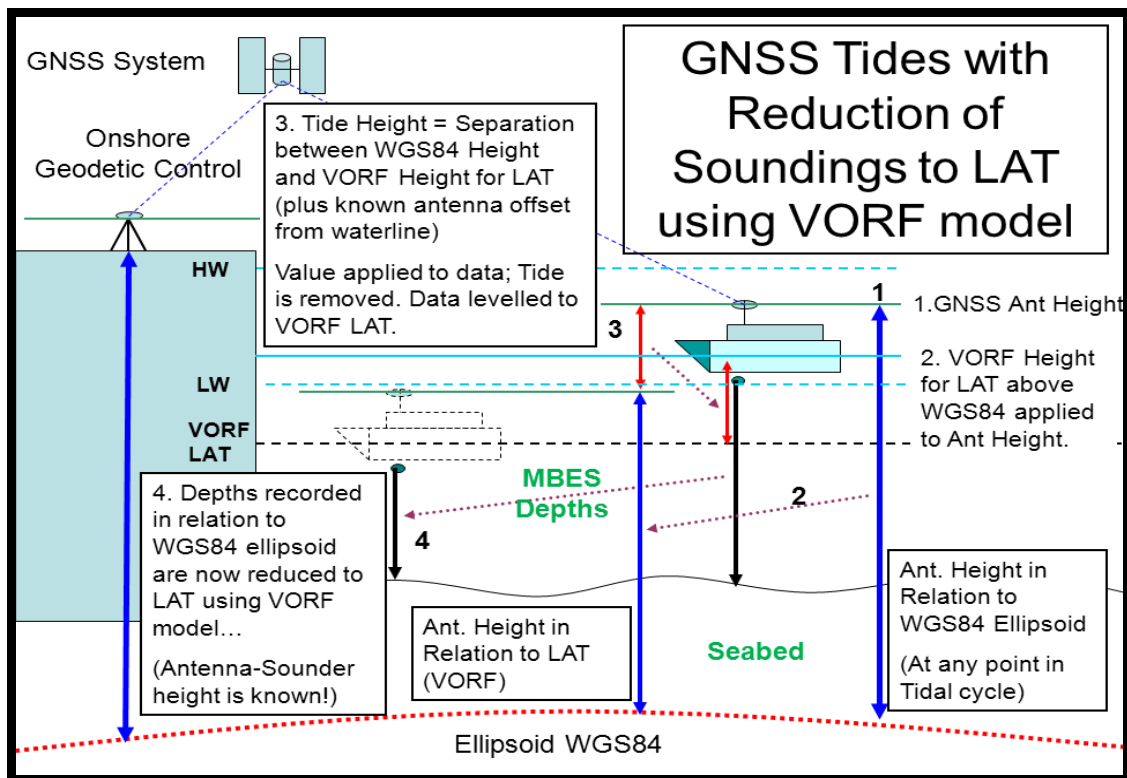


Figure 6: GNSS tides to LAT using VORF model.

3.3.3 Acoustic Systems

A Kongsberg EM2040 high resolution multibeam mounted on a retractable pole was used for swath acoustic acquisition. First bottom returns from the multibeam produce highly accurate bathymetric data. Additionally, backscatter acquired by multibeam sonars contains important information about the seafloor and its physical properties. This information provides valuable data to aid in seafloor classification and important auxiliary information for a bathymetric survey.

The configuration on the vessel consists of dual RX transducer (0.7° each) and a single TX transducer (0.7°). The system operates at frequency ranges of 200, 300 or 400 kHz with 800 soundings per ping and allows coverage of up to 10 times water depth on a flat bottom. It has a maximum ping rate of 50 Hz. The 200 kHz frequency was used for this survey. Positioning was provided by C-Nav 3050 DGNSS and these data were integrated with inertial measurement units by a Seatex Motion Reference Unit (MRU) model Seapath 330+ to give real time heading, heave, pitch and roll, position and velocity of the MBES system.

MBES data was recorded in raw.all format using Kongsberg's SIS software. The raw.all files were continuously backed up on the vessel server. Table 8 contains MBES metadata.

Descriptor	Metadata
Survey lines	NA
Data Files	389
Date Created	27-05-2018 to 07-06-2018
Dataset Size	92.7 GB
File Formats	.all

Table 8: MBES metadata.

United Kingdom Hydrographic Office (UKHO) guidelines were implemented when carrying out wreck investigations. Three survey lines along the wreck's primary axis with high overlap and one or more lines across its secondary axis to ensure full wreck coverage along both axes were acquired. The water column logging functionality in SIS was used throughout the investigation. Beam angles, survey speed, operational frequency and pulse length were configured for maximum resolution. Wrecks were reported to the UKHO using the standard UKHO "H-Forms". A total of nine wrecks were mapped in detail.

Water column data were acquired on all survey lines but only water column data acquired on wreck investigations were backed up to the vessel server and delivered on the final survey disk. Remaining watercolumn data were backed up to a separate disk that was connected directly to the EM2040 PC. Table 9 contains wreck investigation water column metadata information.

Descriptor	Metadata
MBES water Column Lines	38
Dataset Size	14.4 GB

Table 9: Wreck investigation water column logging files.

An EA400 hull mounted SBES provided additional depth and seabed character information. The EA400 is a dual frequency system with both 38 kHz and 200 kHz capability. The 38 kHz frequency was switched off throughout as it interfered with the MBES. MRU data was fed directly into the SBES.

SBES data was recorded in .raw format using Kongsberg's EA400 acquisition software. Data was backed up to the vessel server at the end of each line. Table 10 contains SBES metadata.

Descriptor	Metadata
Survey lines	NA
Data Files	1299
Date Created	28-05-2018 to 07-06-2018
Dataset Size	43.0 GB

File Formats	.out, .raw, .dg, .xyz
--------------	-----------------------

Table 10: SBES metadata.

A hull mounted pinger source 2x2 transducer array SBP operating at 3.5 kHz was used for sub-bottom data acquisition. The sweep time was varied appropriately with water depth to maximise ping rate and resolution. The pinger source is most effective in investigations of the top 20 or 30 m sub-seabed and where sediments are fine to medium grained. The signal will not penetrate bedrock. A Coda DA4G acted as the topside trigger and acquisition system. Raw data was recorded in native coda format along with tiff images of each survey line. Positioning data was provided from C-Nav DGNSS and MRU data was fed directly from the Seapath 330+. QC was maintained by the online engineers, with reference to the digital display; with sweep time, gains, filter parameters and transmit energy adjusted as required for optimal imaging. All data were backed up to the vessel server. Table 11 contains SBP metadata.

Descriptor	Metadata
Survey lines	NA
Data Files	513
Date Created	28-05-2018 to 07-06-2018
Dataset Size	35.8 GB
File Formats	.cod & .tiff

Table 11: SBP metadata.

3.3.4 Magnetometer

A Marine Magnetics Corporation SeaSPY towed Overhauser Magnetometer was used to acquire magnetic field data. The system comprises a towfish, tow cable, deck lead and transceiver interfaced to a standard Windows based PC. Acquisition parameters and QC were controlled via BOB software.

The magnetometer was towed 100 m behind the vessel at a depth of less than 5 m beneath sea surface. Magnetometer and GPS data from the towfish were input to the control PC via separate serial ports and synchronised. Initial QC was performed via real-time graphing of the magnetic field trace and by monitoring real-time GPS data. Magnetometer data were recorded in a database using BOB software and output in proprietary BOB format as .mms file. Metadata is contained in table 12.

Descriptor	Metadata
Survey lines	NA
Data Files	2
Date Created	28-05-2018 to 07-06-2018
Dataset Size	901 MB

File Formats	.mms, .txt
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Table 12: Magnetometer metadata.

3.3.5 DGPS Systems

C-Nav DGNSS provided the primary navigation. The C-Nav 3050 is a dynamic DGNSS Precise Point Positioning (PPP) system providing accuracy of <0.1 metre horizontally and 0.2 metre vertically. It provides 66 channel tracking, including multi-constellation support for GPS, GLONASS and Galileo. C-Nav provided the primary navigation feed for the MBES, SBES, SBP and magnetometer sensors. C-Nav also provided a reliable GPS tide correction.

C-Nav has a range of QC output displays that were monitored in real-time including number of satellites in use, satellite attitude and angles, vertical accuracy, vessel speed, heading and precise position. GPS signal was always very good and the system never lost the Real Time Gypsy (RTG) solution. A hard disk connected to the C-Nav receiver provided real-time data storage.

Seapath 330+ provided the secondary navigation. Seapath and C-Nav data were continuously checked in Quality Integrated Navigation System (QINSy) software to ensure data integrity and comparison between the primary and secondary navigation systems remained within tolerance. Navigation data were recorded in .cnav3050 format using C-Nav software. One file per day was created. Metadata is contained in table 13.

Descriptor	Metadata
Survey lines	All
Data Files	12
Date Created	28-05-2018 to 07-06-2018
Dataset Size	2.64 GB
File Formats	.cnav3050

Table 13: C-Nav navigation metadata.

3.3.6 Online Navigation

QINSy software was used for navigation acquisition and QC. QINSy performs visual and QA data-feeds from the key acquisition systems. A project template database was created containing all survey configuration parameters relevant to the project. The project template contains the datum, projections, vessel shape, administrative information, as well as vessel offsets and I/O parameters. QINSy uses a sophisticated timing routine based on the Pulse Per Second (PPS) option from the GNSS receiver. All incoming and outgoing data is accurately stamped with a UTC time label.

Survey line and SVP positioning data were recorded in QINSy software in .db and .txt format. The QINSy navigation .txt file was input to the Multilog database for metadata recording of each survey system. QINSy metadata is provided in table 14.

Descriptor	Metadata
Survey lines	NA
Data Files	544
Date Created	28-05-2018 to 07-06-2018
Dataset Size	2.2 GB
File Formats	.db & .txt

Table 14: QINSy navigation metadata.

3.3.7 Sound Velocity

A Valeport Mini SVP instrument was used to obtain sound velocity for the echosounders. The Valeport instrument directly measures sound velocity. Fresh sound profiles were input to the echosounders as required. A Valeport sound velocity sensor positioned at the transducer head provided a real time sound velocity input directly to the EM2040.

Sound velocity profile data were recorded in asvp format and downloaded with DataLog X2 software. Metadata is contained in table 15.

Descriptor	Metadata
Survey lines	NA
Data Files	33
Date Created	28-05-2018 to 07-06-2018
Dataset Size	353 KB
File Formats	.asvp

Table 15: Sound velocity metadata.

3.3.8 Multilog

A Microsoft Access database was used for logging survey metadata. Data acquisition parameters, data QC, sound velocity and daily progress report information were input and recorded. A backup of the database was made regularly.

4 Online QC, Data Processing, Results and Interpretation

The hydrographic survey was performed to International Hydrographic Organization (IHO) survey standard Order 1a. This represents the minimum standard for position, depth accuracy and feature detection achieved during data acquisition and processing. Order 1a and Order 2 requirements are presented in table 16.

	Order 1a (S-44)	Order 2 (S-44)
Description of Areas	Shallower than 100m, features of concern to shipping.	Areas generally deeper than 100 m where a general description of the sea floor is considered adequate.
Max THU allowable (95%C)	Total Horizontal Uncertainty (THU) 5m+5% of depth	Total Horizontal Uncertainty (THU) 20 m+10% of depth
Max TVU allowable (95%C)	Total Vertical Uncertainty (TVU) a = 0.5 metre b = 0.013 $\pm\sqrt{a^2 + (bxd)^2}$	Total Vertical Uncertainty (TVU) a = 1.0 metre b = 0.023 $\pm\sqrt{a^2 + (bxd)^2}$
Full Seafloor Search	Required	Not Required
Feature Detection	Cubic Features > 2m (Depths < 40m) 10% depth > 40m	Not Applicable
Recommended Max line spacing	Full Seafloor search	4 x average depth

Table 16: IHO standards for hydrographic surveys

4.1 MBES Online Quality Control

4.1.1 Acquisition Parameters

Most of the important acquisition parameters are set in the Runtime Parameters module of SIS. Figure 7 shows an example of settings in the Sounder Main tab in Runtime Parameters. Max angle and max coverage parameters were adjusted to take account of depth, sea state, sound velocity conditions and seafloor character. Pulse type for survey mainlines and crosslines was maintained at FM and ping mode set to 200 kHz, which maximised swath width in the depths encountered. Wreck surveys were performed at Medium CW or Long CW and at 300 kHz to provide maximum resolution.

Max angle, sector mode, vessel speed and pulse type were adjusted to attain maximum resolution for wreck inspections. Water Column data were acquired for all survey lines and stored directly to external disk.

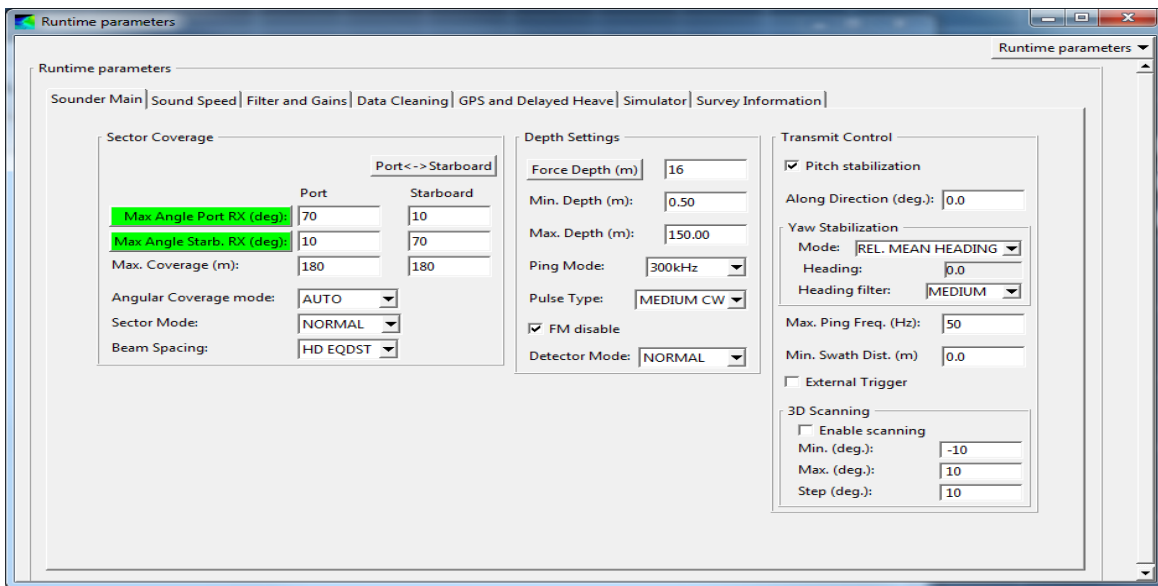


Figure 7: Runtime parameters window in SIS.

4.1.2 Crossline versus Mainline Statistics

Crossline data were acquired for QC of depth soundings. A total of 17 crosslines were acquired for statistical analysis in Caris Hips. Crossline data were compared with mainline data and all crossline data indicated that the soundings exceeded the 95% certainty required for Order 1a specification. Statistics for Order 2 specification were not calculated.

4.1.3 Feature Detection

The minimum standard for feature detection for an Order 1a survey are cubic features > 2 m in depths up to 40 m and 10% of depth beyond 40 m. Water depths ranged from 78 to 120 m meaning that the minimum sized cubic feature that needs to be detected is 7.8 m. Sounding density plots were made in Caris at 8 m (i.e. 10% of the least survey depth) and 5 m grids respectively. Figure 8 shows the 8 m grid plot. Green signifies that at least 9 soundings are found in an 8 m bin. The mean number of soundings in each bin is 59.

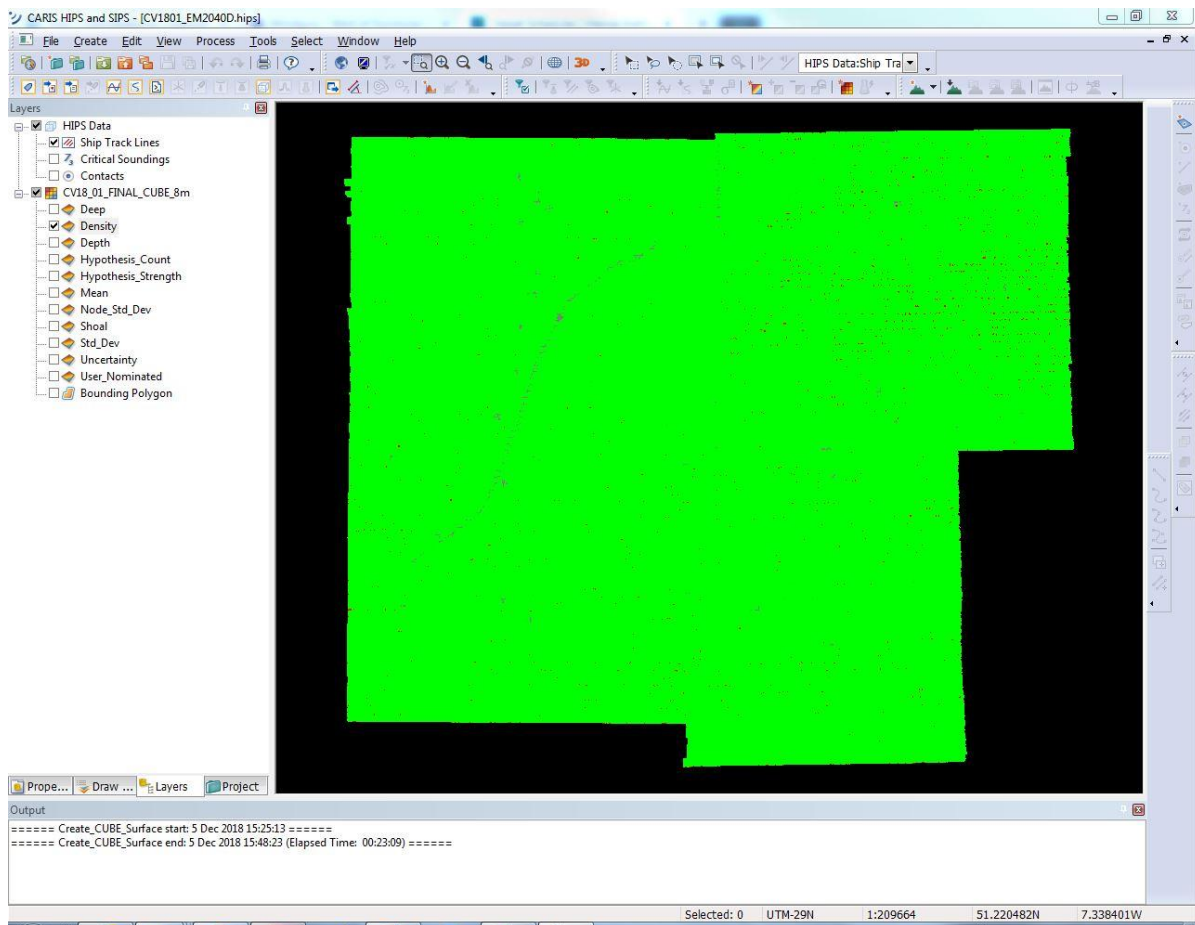


Figure 8: Sound density plot gridded at 8 m bin size.

Figure 9 shows the 5 m grid plot. Green signifies that at least 9 soundings are found in a 5 m bin. The mean number of soundings in each bin is 58. This greatly exceeds the sounding density requirement as per Order 1a.

Sounding density was regularly monitored during survey on the SIS geographical display. IHO feature detection requirements were maintained through using adequate detection systems, skilled personnel, appropriate vessel speed, high ping rate and appropriate swath overlap. Sounding densities were plotted and quality assured after creation of a finalised surface for the survey area.

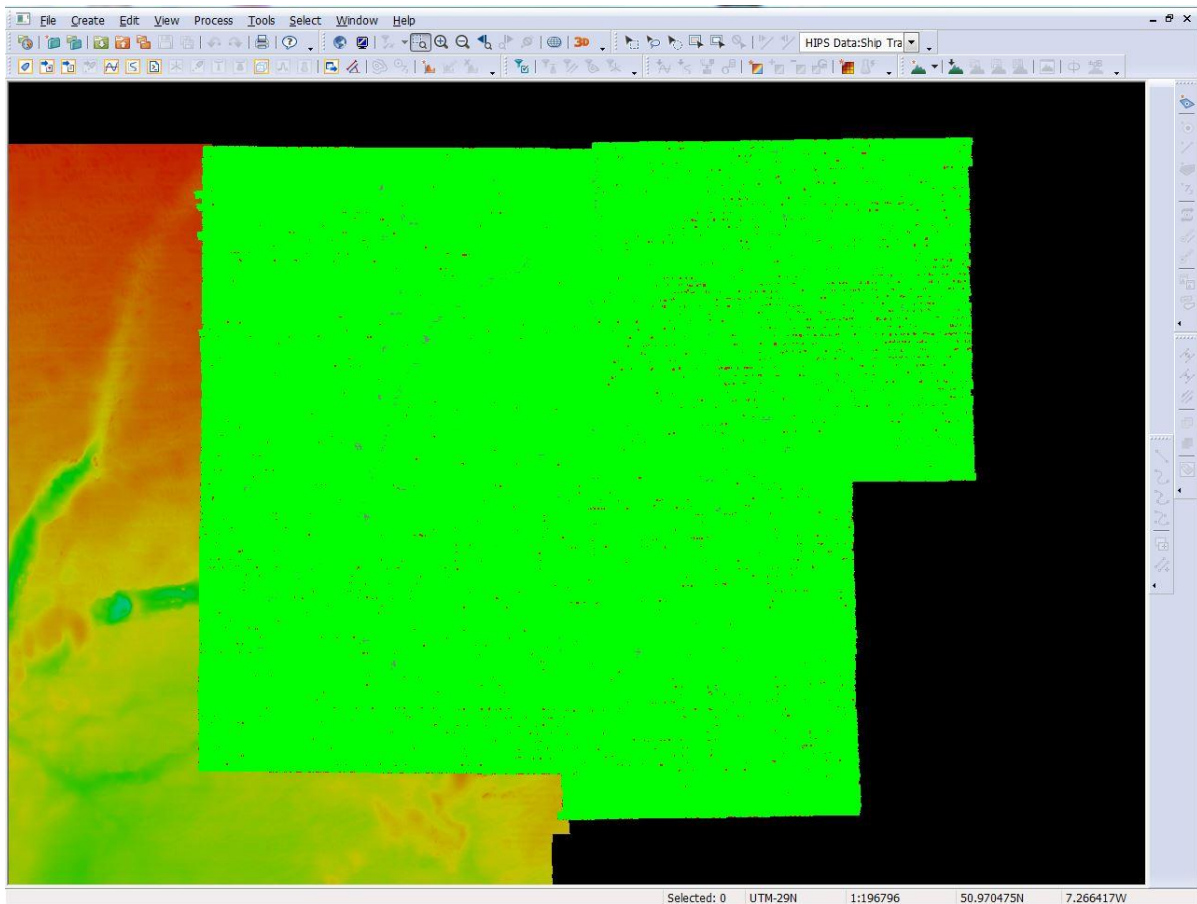


Figure 9: Sound density plot gridded at 5 m bin size.

A full seafloor search was achieved in areas shallower than 100 m in accordance with IHO Order 1a requirement.

4.1.4 Error Budget and Uncertainty Model

Manufacturer values for positioning and sounding errors were factored into the vessel error budget. Vessel offsets were established through an onshore dimension control survey (see section 3.1). In addition; uncertainty levels over positions of soundings were improved through good sound velocity control while surveying. Calibration of the MBES through a standard patch test, combined with good online quality control, ensured that the vessel's error budget fell within IHO 1a specifications.

Table 17 below details standard deviation values applied in the calculation of the vessel's Total Propagated Uncertainty (TPU) model. TPU is an estimate of the uncertainty of any individual sounding, taking into account the uncertainty estimates of the component measurements (tide, sound speed, draft, range measurement, angle measurement, attitude,

offsets etc). TPU is expressed as a separate value in horizontal and vertical planes. The uncertainty of each sensor was entered in the HIPS Vessel File (HVF) and the TPU calculated.

Heading Accuracy	0.05°
Heave	5 cm or 5 % Amplitude
Roll	0.01°
Pitch	0.01°
Pitch Stabilised	0.00°
Position Navigation	0.1 m
Timing Transducer	0.00 s
Timing Navigation	0.00 s
Timing Gyro	0.00 s
Timing Heave / Pitch / Roll	0.00 / 0.00 / 0.00 s
Sound Velocity Measured	0.001 m/s
Sound Velocity Surface	0.001 m/s
Offsets X / Y / Z	X=0.01 / Y=0.01 / Z=0.01
MRU Alignment	Gyro=0.1 / Pitch=0.1 / Roll=0.1
Vessel Speed	0.03
Vessel Loading	0.00
Vessel Draft	0.00 (Use of GPS tides)
Delta Draft	0.00

Table 17: Standard deviation values used in TPU calculation.

4.1.5 Sound Velocity Control

SVP's were monitored by QC in SIS of the Crosstrack window, by comparison of the sound profile versus the realtime sound velocity reading in the Numerical window and by feedback from the data processors. The initial plan was to use a Moving Vessel Profiler (MVP) but a technical fault prevented this. SVP's were acquired regularly and applied in the SIS software. Data from each cast are plotted in figure 10. Each cast is named by date and number. Sound velocity in m per second is plotted on the x axis and depth in m on the y axis.

Most profiles show a large difference between near surface sound velocities and velocities at depth with a range of up to 25 m/s. Sound velocity is fastest near the surface where water temperatures are highest. A distinct thermocline is present at between 10 m and 45 m water depth. The water body beneath the thermocline is much colder than above. Sound velocity increases linearly beneath the thermocline where pressure is the dominant variable affecting it.

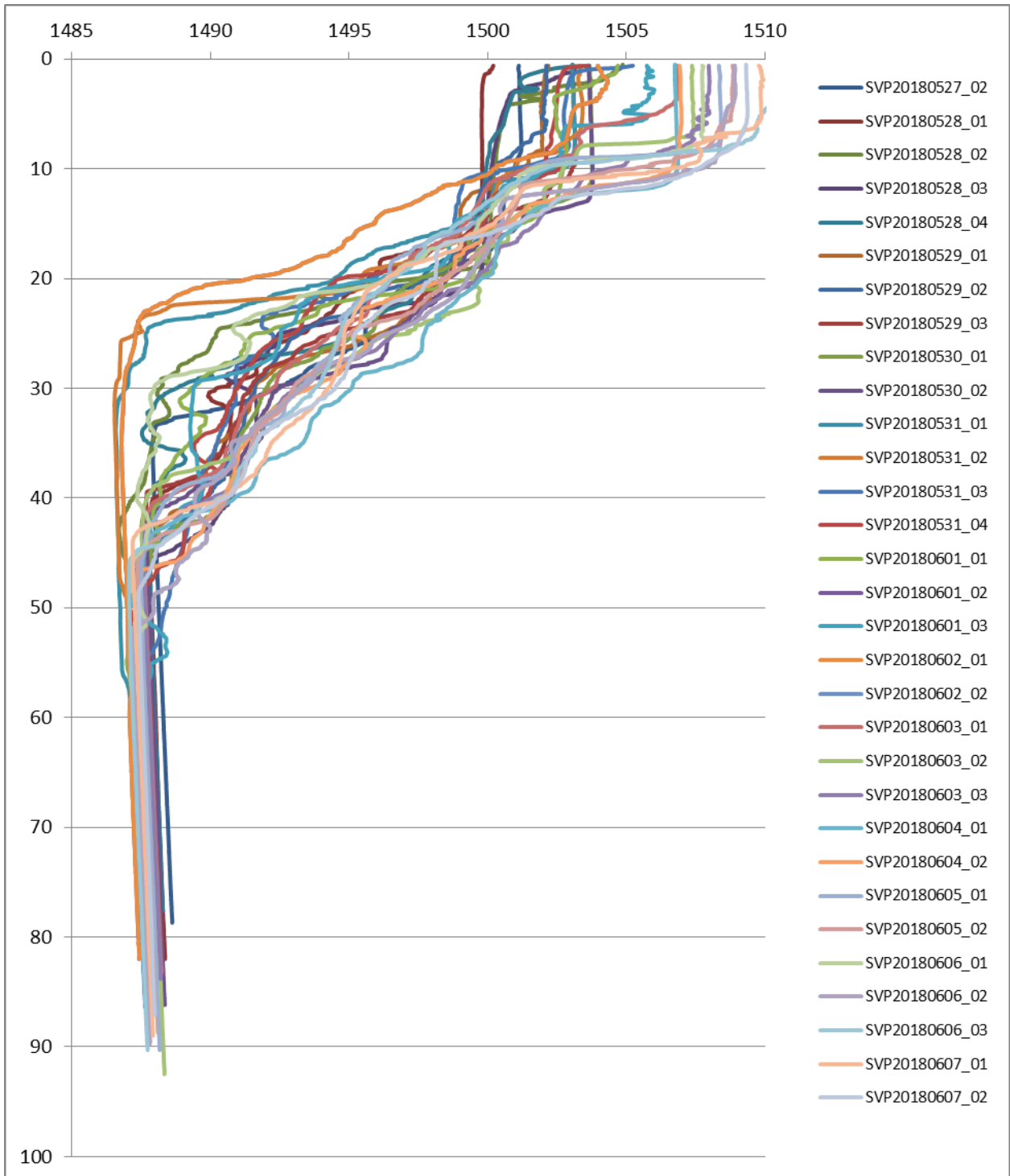


Figure 10: Composite SVP profile plot.

4.2 Post Processing Methods

4.2.1 Navigation

Navigation data was logged in standard C-Nav format. Real time positioning data quality from C-Nav was of sufficient quality to exceed IHO Order 1a standard requirements. Vertical

errors on the GPS heights are also low (+/- 15 cm) and provide a robust solution for computation of GPS tide.

Navigation data and in particular GPS heights were despiked and smoothed in Caris HIPS. GPS tide was computed using the separation model between International Terrestrial Reference Frame (ITRF) datum and VORF LAT.

4.2.2 Depth Soundings Data Processing

Soundings were edited in Caris HIPS software against an existing chart background. Combinations of automated and manual processing procedures were applied by experienced data processors to remove systematic errors and obvious outliers. Uncertainty results were examined to ensure they fell within IHO specifications for Order 1a and Order 2 surveys. Processed and cleaned data were subjected to final validation by an experienced and qualified hydrographer. The following is a simplified list of steps undertaken during sounding data processing:

1. Navigation data were checked and spikes removed.
2. GPS tides were computed using the UKHO's VORF model. This reduced the MBES depth soundings to LAT. GPS tide results were then checked for quality and consistency.
3. TPU values were calculated.
4. Swath Editing was performed in CARIS to clean large "noise" spikes from the data.
5. SVP data were applied to correct for refraction errors caused by water column heterogeneity. A range of SV Algorithms were used to determine the most suitable method of applying SV corrections. (Example: nearest in distance verses nearest in time).
6. A CARIS Combined Uncertainty and Bathymetry Estimator (CUBE) base surface was then created to allow CUBE automatic filtering.
7. Final verification of sounding consistency and absence of spikes was carried out using subset editing.
8. Export of final products from Caris: Multibeam Bathymetry grids, Shaded Relief grids, and Backscatter Mosaics. XYZ and trackline grids were also output.

4.2.3 Backscatter Mosaic Generation

Backscatter is a function of the hardness and roughness of the seafloor. Multibeam backscatter mosaics were produced using QPS FlederMaus Geocoder Tool (FMGT),

backscatter analysis software with advanced functionalities capable of providing an enhanced backscatter mosaic.

4.3 Survey Results and Data Interpretation

A preliminary interpretation of MBES and SBP data was used to assess bathymetry, seabed texture, seabed features, and shallow geology.

4.3.1 Multibeam Images

Grids and geotiff images were created in Caris Hips software of MBES bathymetry. Backscatter mosaics were created in FMGT. Geotiffs and grids were imported into ArcGIS and images (figures 11 to 13) output for this report.

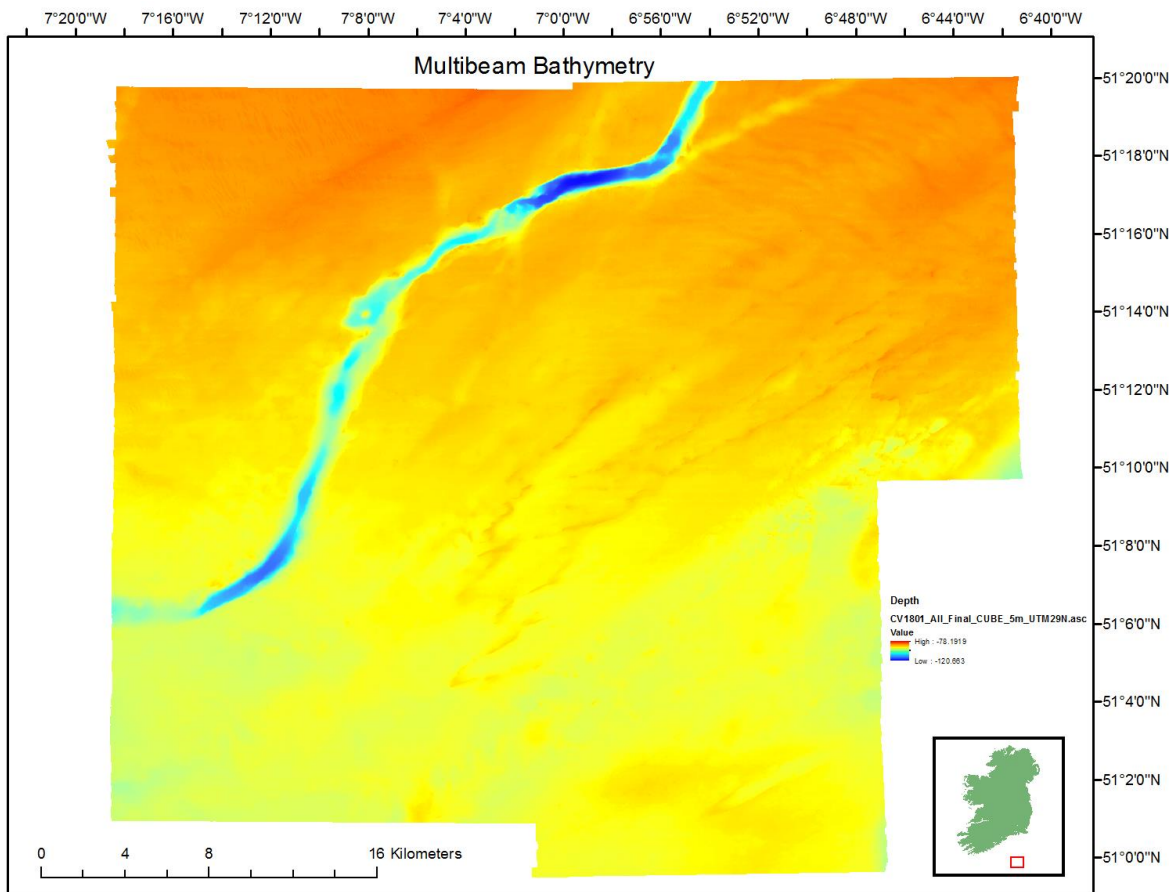


Figure 11: Multibeam bathymetry image.

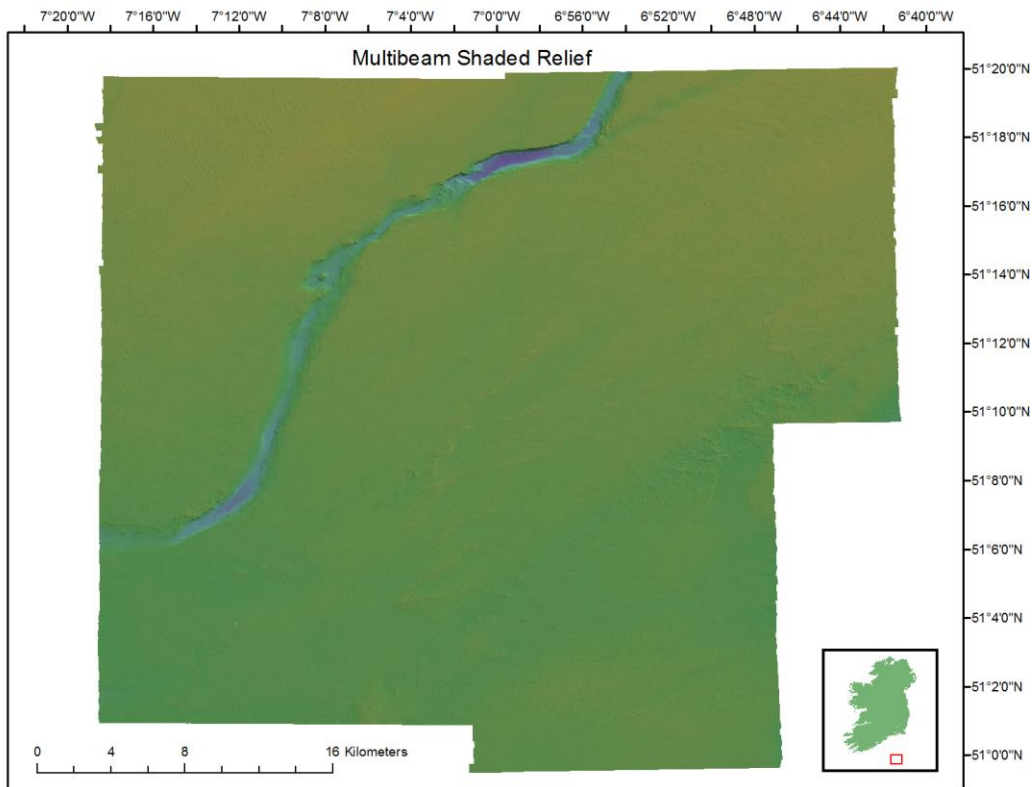


Figure 12: Multibeam shaded relief image.

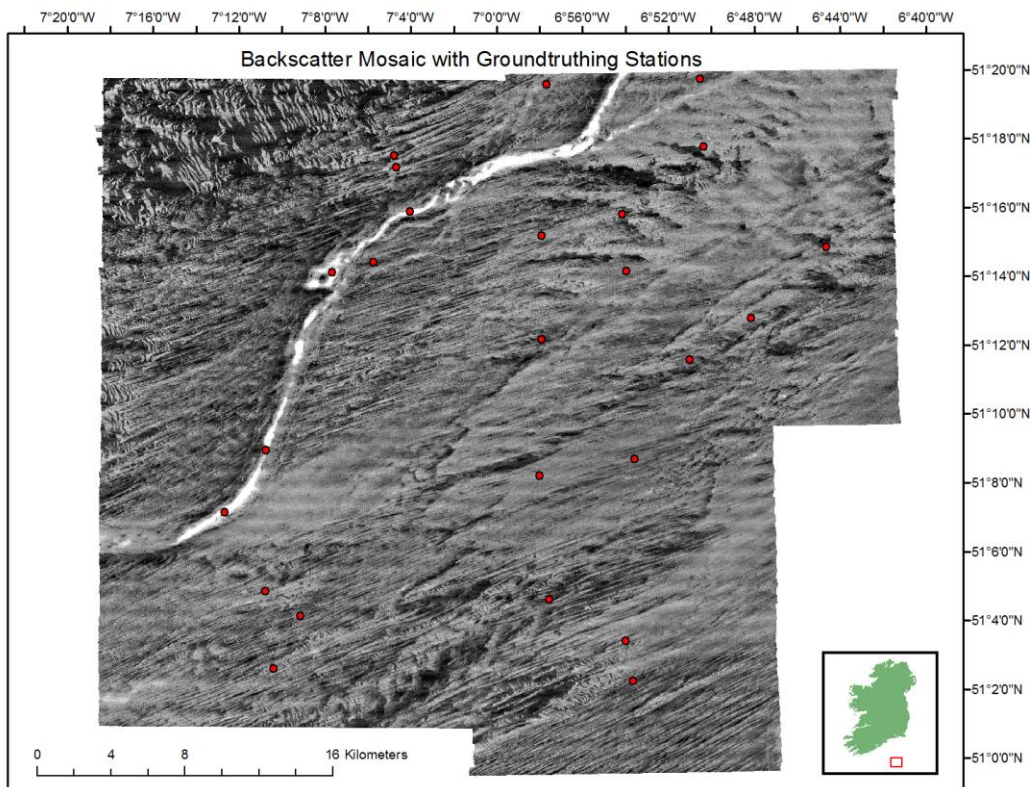


Figure 13: Multibeam backscatter mosaic image.

4.3.2 Shallow Geology Analysis

Data quality and penetration varied depending on prevailing sea state, survey direction and sub-bottom hardness. Survey speed (4-9 knots) was dictated by the ability of the MBES to meet its data density and data quality requirement. This is faster than the optimal maximum speed of 4 knots for sub bottom data integrity. Sea state was very good for much of the survey but in general the seabed is hard apart from a large scale channel feature and some sand ribbons.

Tiff images and coda format seismic files were recorded for all SBP lines. Profile lines 219 and 282 are selected for discussion here. Their geographical locations are shown in figure 14 where the profile extents have been overlain on the bathymetry data. Profile 219 was acquired on an easterly heading and profile 285 acquired on a north east heading over a channel.

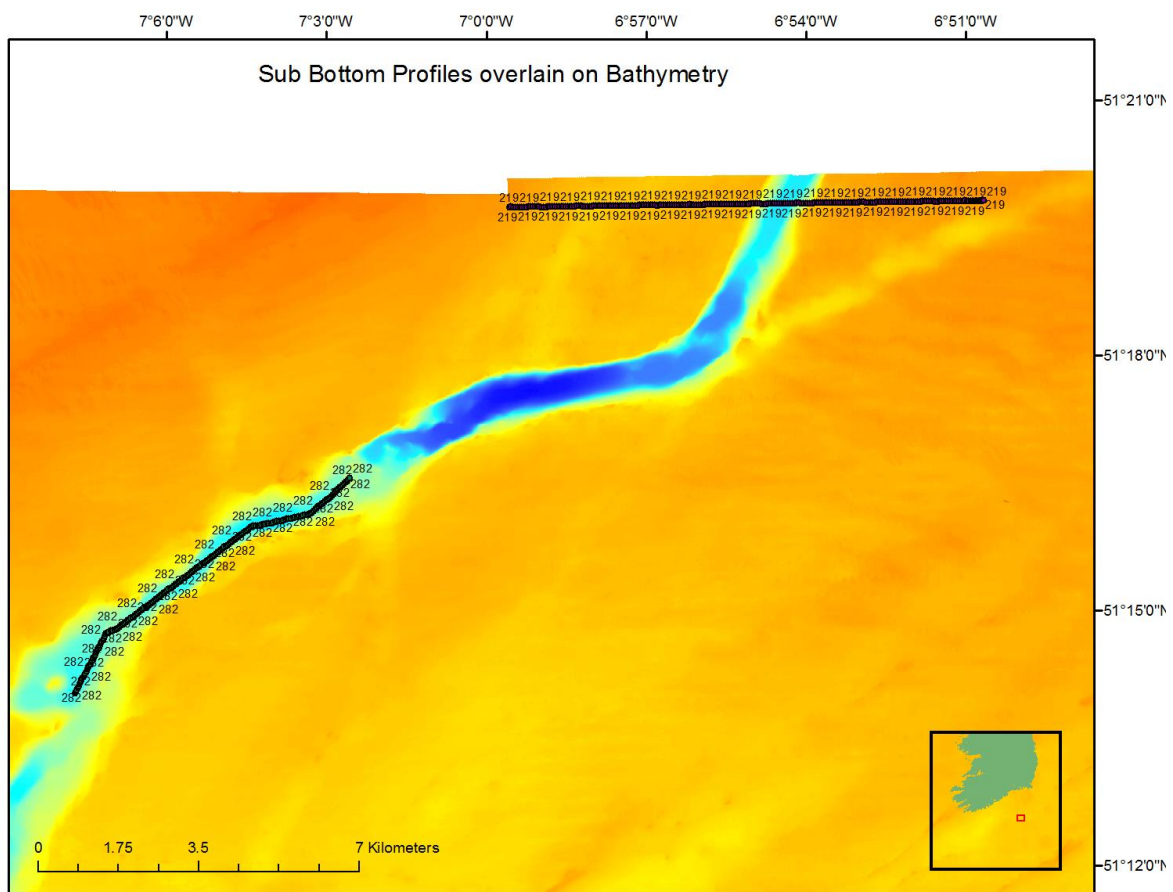


Figure 14: Sub bottom profile lines 219 & 282 overlain on multibeam bathymetry.

Interpreted sub bottom profiler tiff images of lines 282 and 219 are shown in figures 15 and 16 respectively. A bandpass filter with low cut 2.2 kHz and high cut 4.7 kHz was applied in

processing, along with a suitable gain. Heave compensation is applied to the images displayed. Horizontal scale lines are at 10 metre intervals for both sub bottom images below.

Profile 282, acquired along the centre of a large scale channel feature is 7.9 km in length. This profile was selected for discussion because it is one of the few survey lines acquired over relatively soft sub bottom where signal penetration is good. Seabed topography varies considerably across the profile with up to 15 m relief evident. Bedrock outcrops at several locations along the profile and can be seen at depth across most or all of the profile. The top of bedrock has an undulating character. The top of bedrock denotes an unconformity.

Topographic lows in the unconformity surface are overlain by sediment sequences of up to 12 m thickness. These sediments pinch out against the top of bedrock. Groundtruthing of the channel indicates that the sediments are fine grained and contain a high percentage of mud. Bedrock is unconformably overlain by coarser sediment at the southwest end of the profile. These sediments are less well penetrated by the pinger signal. The sediments are up to 3.5 m in thickness.

Profile 219 is 10.3 km in length and acquired from west to east. The seabed topography is very gently sloping apart from one section where it crosses the channel, but even here the slope angle is less than 3 degrees. Different vertical and horizontal scales on the image below acts to greatly exaggerate the channel slope. The channel has a width of approximately 1.2 km from its western to eastern high points. It is U-shaped so that it narrows at its base to less than 1/3 of its maximum width. The seafloor in the centre of the channel is approximately 20 m deeper than the seafloor along its margins. The channel floor is very gently sloping. It is underlain by soft sediment of up to 7 m in thickness. Sediment thickness is greatest at the centre of the channel. The sediments thin out towards the channel margins. The remainder of the profile away from the channel section is marked by sporadic reflectors. The hard seabed and near surface sediments inhibit signal penetration. Bedrock appears to be within 2 or 3 m of the seabed across the profile except for the centre of the channel.

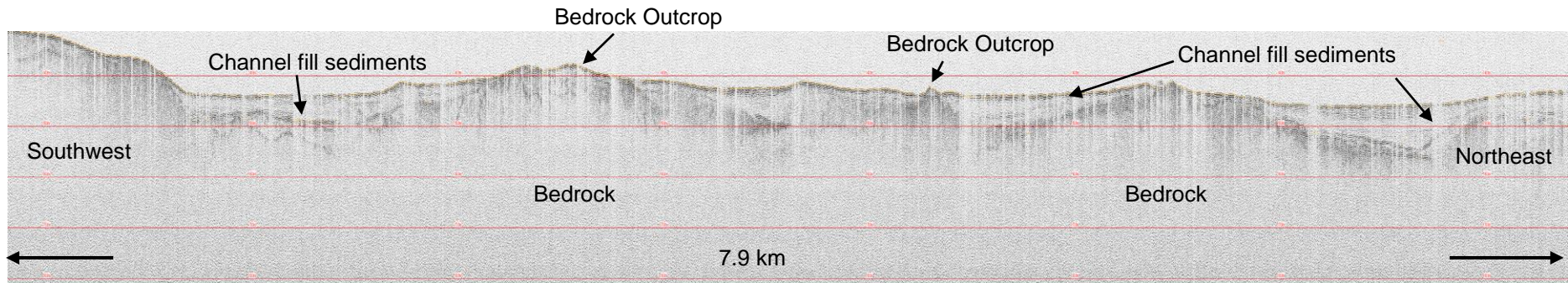


Figure 15: Sub bottom profile interpreted image, line 282.

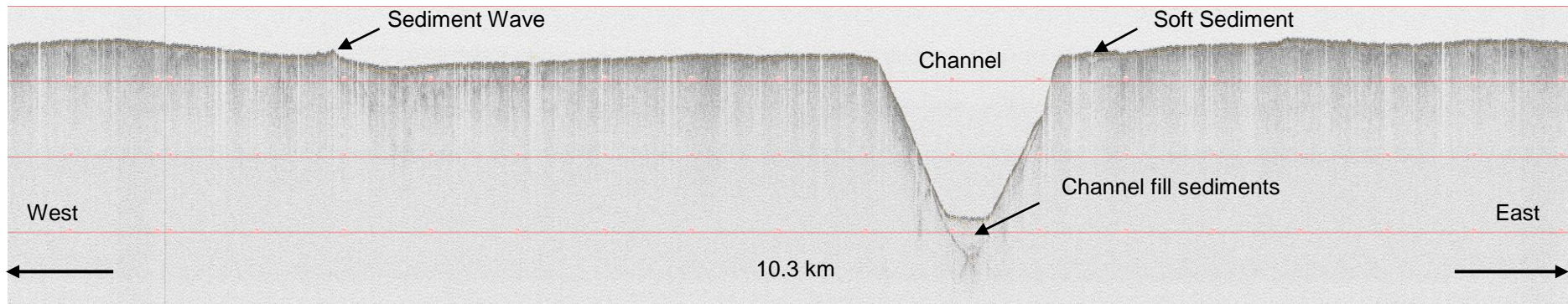


Figure 16: Sub bottom profile interpreted image, line 219.

4.3.3 Bathymetry

Figure 17 shows the colour coded multibeam bathymetry image. Water depth varies from 78 to 120 m. Depth generally increases from north to south with the exception of a channel running from north-east to south-west. Greatest depths are found within the channel. The channel floor is at a depth of between 100 and 120 m. It is between 0.5 km and 2 km in width. Maximum slope angle of the channel walls is approximately 12 degrees but commonly it less than this. The seabed is very gently sloping apart from around the channel margins.

A number of ridge features are evident on the east central part of the area. These ridges have a relief of less than 3 m. They are orientated north-east to south-west and north north-east to south south-west. The ridges are 100 to 500 m in width.

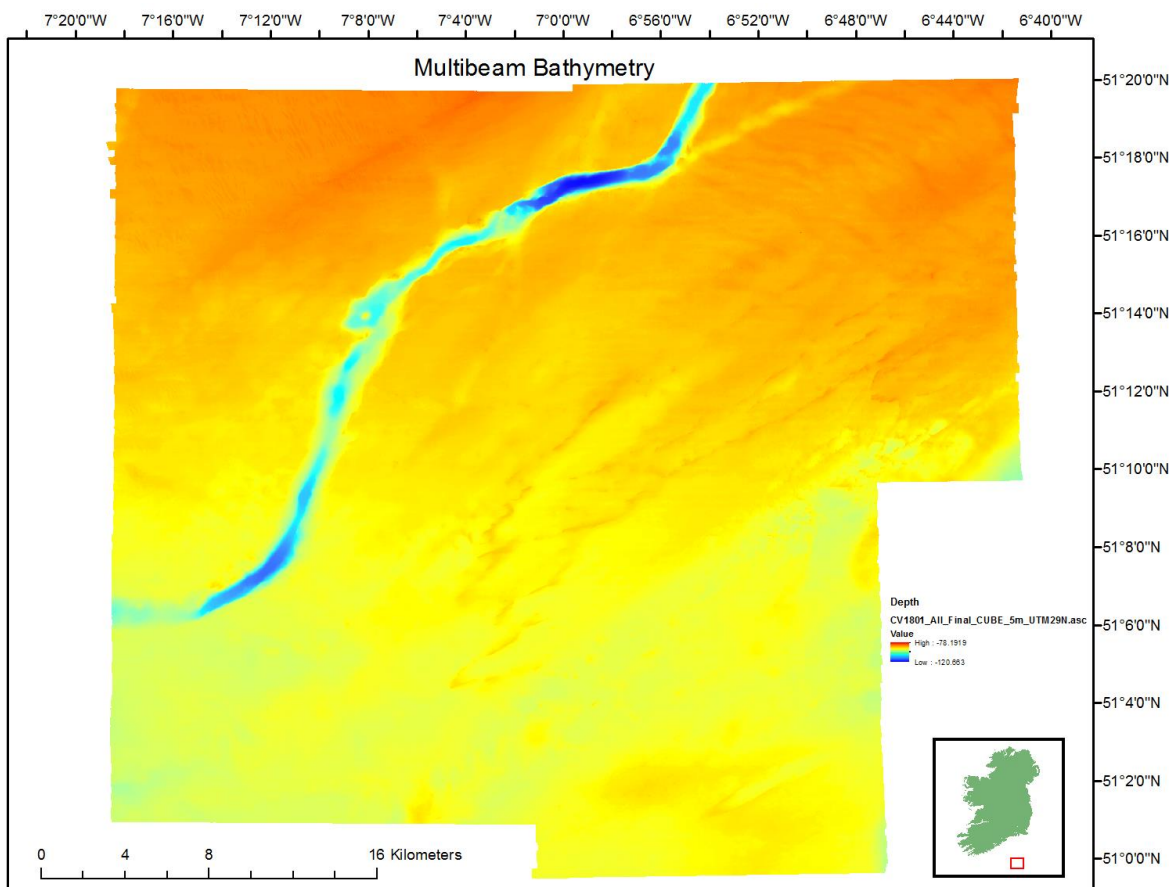


Figure 17: Multibeam bathymetry image.

4.3.4 Seabed Texture

Multibeam backscatter is the amount of acoustic energy being received by the sonar after a complex interaction with the seafloor. By analysing the amplitude of the returning sound waves it is possible to extract information about bottom structure and hardness, allowing for identification of bottom types. Seabed reflectivity properties depend on the hardness and roughness of the seafloor surface. In simple terms a strong return signal indicates a hard and/or rough surface and a weak return signal indicates a soft, smooth surface.

Figure 18 shows the backscatter mosaic. The convention used in this image is that dark coloured areas represent relatively stronger returns than light coloured areas. Sand ribbons are apparent as elongated areas of low backscatter in the northwest interspersed with dark patches which are gravel and shell lag deposits.

The channel feature described in the bathymetry and sub bottom profiler sections is clearly evident on the backscatter mosaic. It is defined by having very low backscatter with small patches of high backscatter. Groundtruthing indicates that the very low backscatter substrate comprises sediments with a moderate to high percentage of mud. Sub bottom profiler data shows that the high backscatter areas within the channel are outcropping bedrock.

The majority of the remaining area has a wide variety of backscatter types with locally rapid changes in backscatter values. Moderate to high backscatter types dominate. A north east to south west orientated fabric dominates. The ridges mentioned in the previous section show up as narrow areas of high backscatter. Small areas of sand ribbons are found in the south.

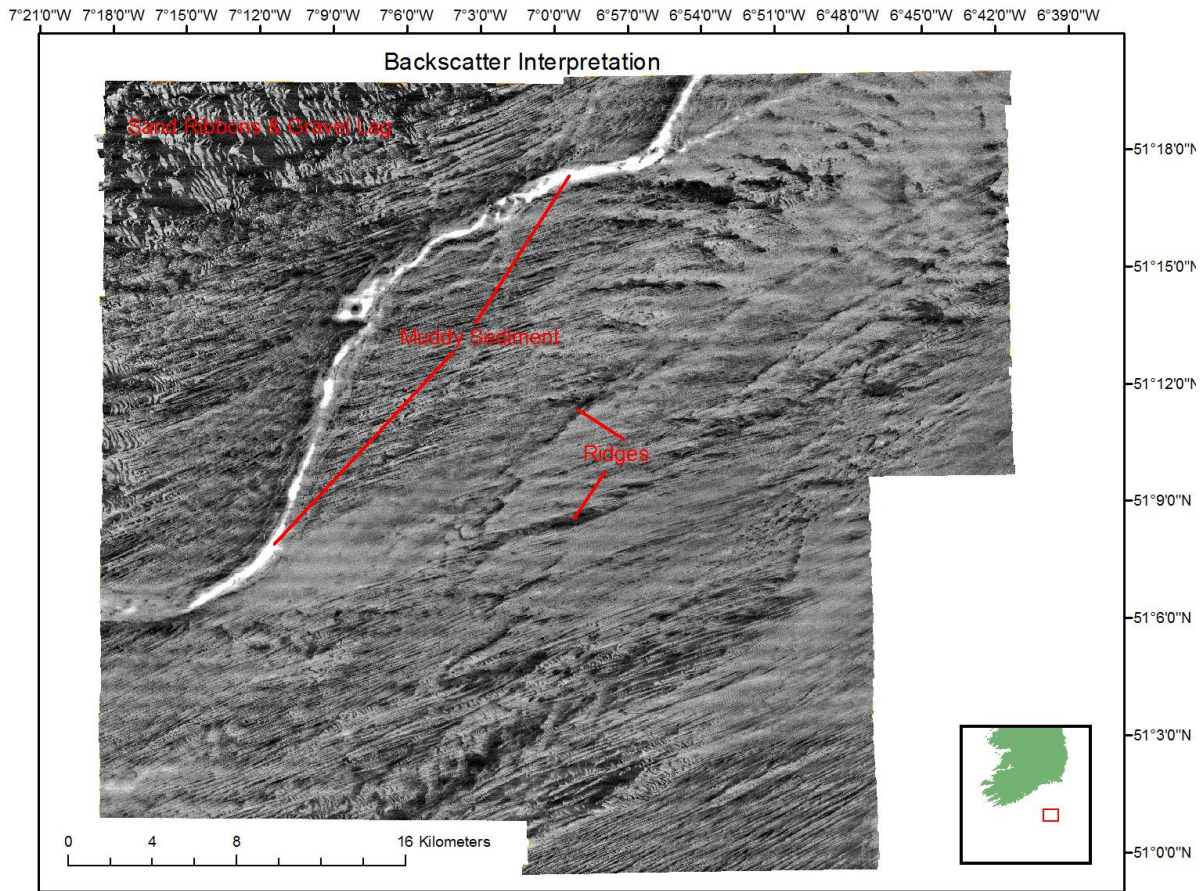


Figure 18: Multibeam backscatter mosaic with interpreted features.

4.3.5 Seabed Features

Description of seabed features is based on analysis of bathymetric, shaded relief and backscatter data. It is possible to make valid inferences on seabed character and composition by correlating these datasets. Shaded relief data are used to illustrate the features discussed in this section. Shaded relief imagery is produced in Caris by shining an imaginary sun at 35° angle over the depth colour coded multibeam bathymetry dataset.

Figure 19 is a shaded relief image with northwest sun azimuth. The ridges identified on the bathymetry data are clearly evident. They are characterised by having narrow width, low amplitude and axes trending northeast - southwest.

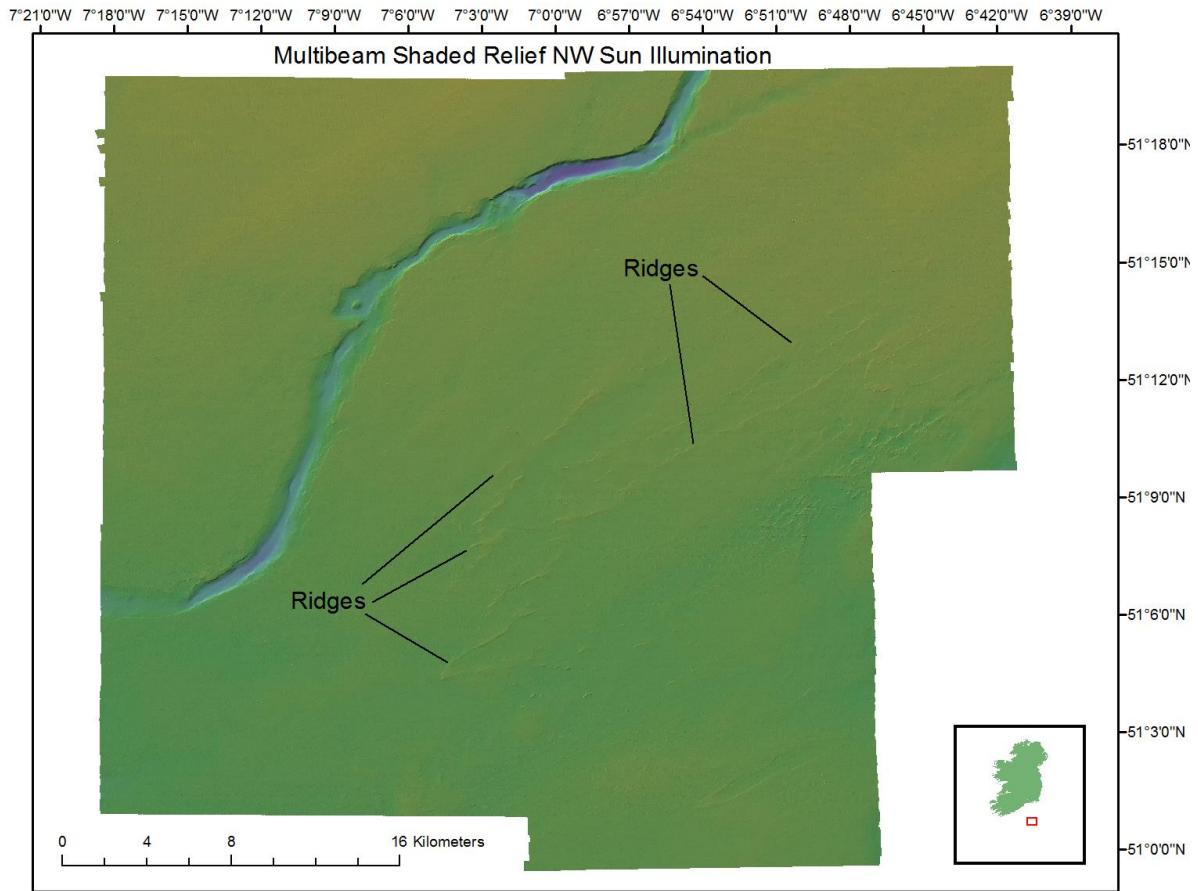


Figure 19: Multibeam shaded relief illustrating ridge features.

Figure 20 shows a multibeam shaded relief image of a segment of the channel. The channel floor varies in width from between approximately 350 m and 2600 m. It is predominantly smooth, indicative of fine grained sediments but outcropping bedrock is also identified. It meanders from northeast to southwest with its margins defined principally by outcropping bedrock.

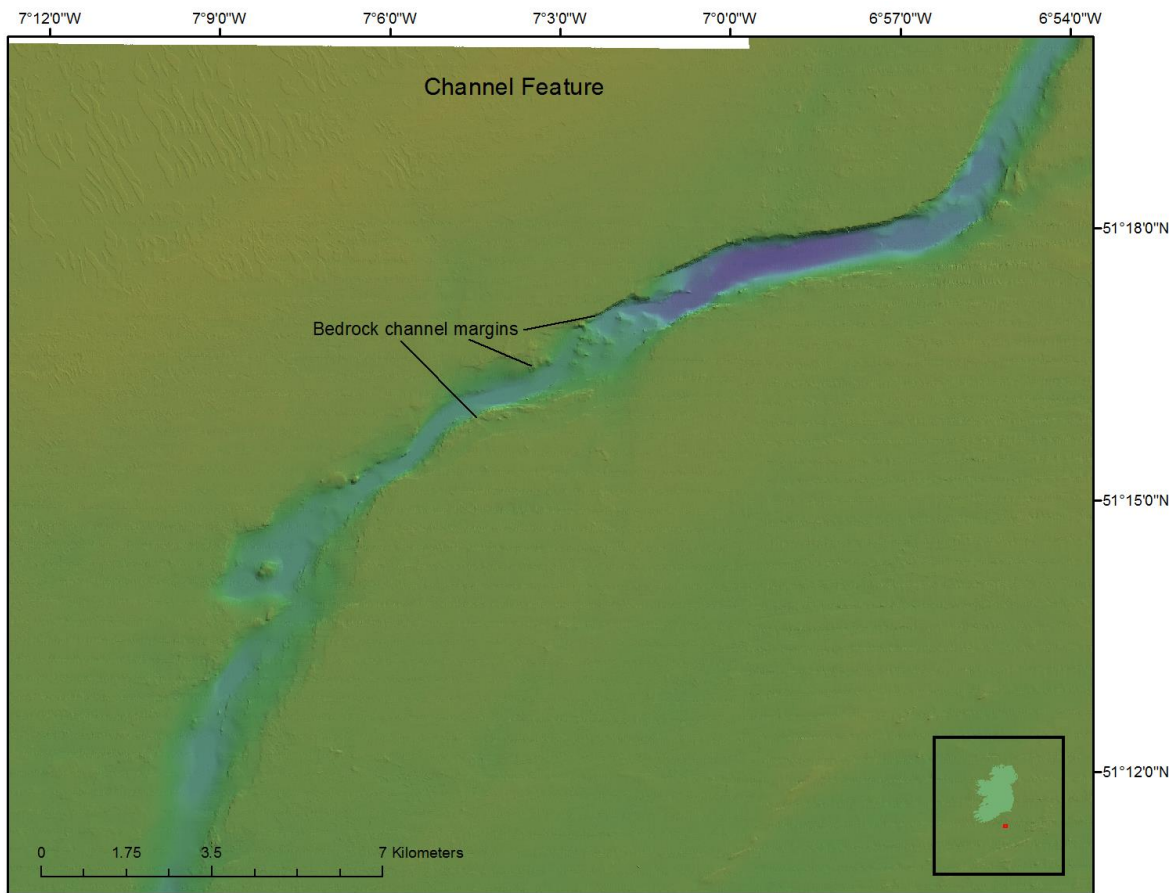


Figure 20: Multibeam shaded relief image of channel.

Figure 21 shows a shaded relief image of the eastern part of the area, midway between the northern and southern survey coverage extents. The area is dominated by ridge and mound topography. Ridges and mounds correlate with high backscatter returns.

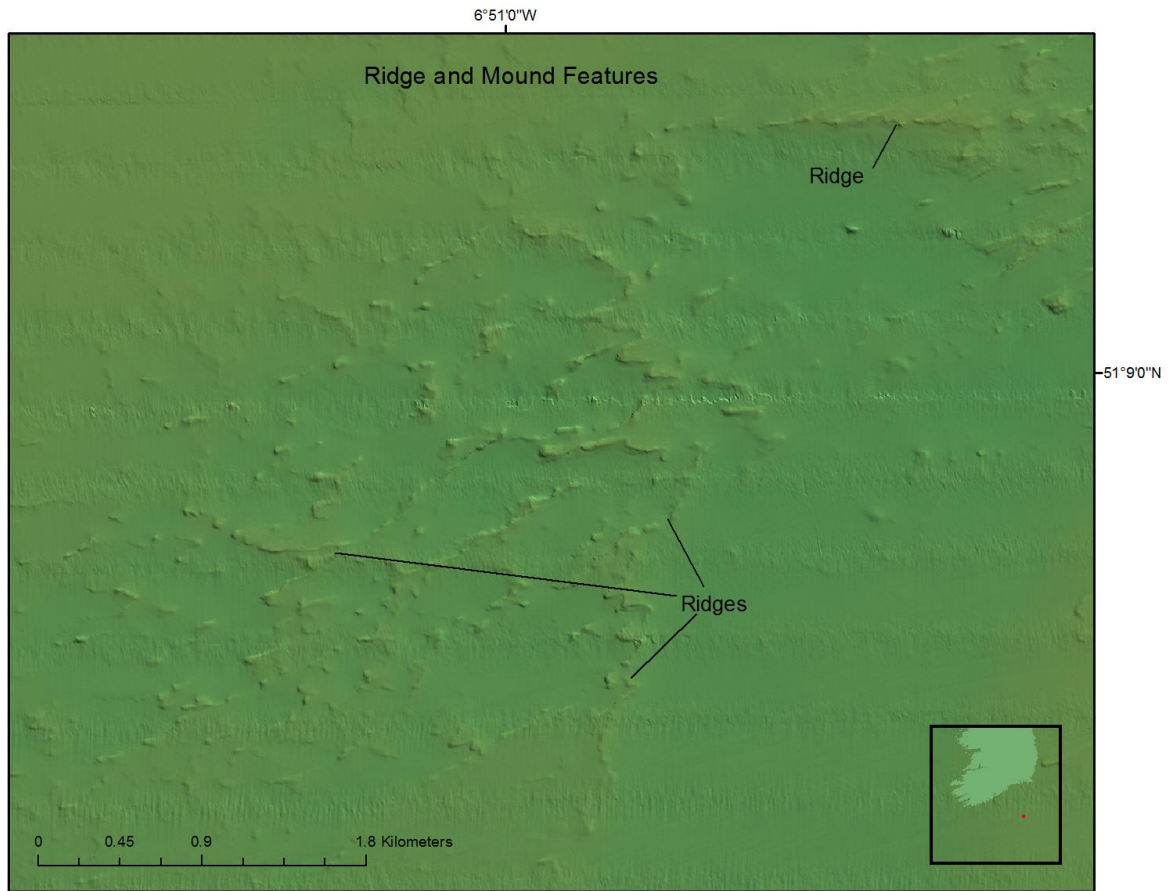


Figure 21: Multibeam shaded relief image showing ridge and mound topography.

Figure 22 is a multibeam shaded relief image of the northwest corner. It shows extensive sand ribbon formation on the seabed. Sand ribbons major axes are orientated northwest – southeast. The ribbons tend to be narrower than 500 m, up to 2 km in length and less than 1 m in height. Ribbons correlate with low backscatter type and are surrounded by much higher backscatter areas.



Figure 22: Multibeam shaded relief image showing sand ribbons.

4.4 Groundtruthing

Groundtruthing stations were acquired using Shipek and Day grabs respectively. We commenced with the Shipek grab deployed off the starboard side but due to some poor returns we switched to the Day Grab. The Day Grab was deployed from the aft deck and gave consistently good returns. Grab locations were selected based on the multibeam backscatter data and geographic spread when possible but opportunistic samples were acquired at SVP stations occasionally. Samples were photographed, described and data entered into a bespoke database. Samples were bagged and will be sent to a laboratory for particle size analysis, the results of which will be used to create substrate maps. Groundtruthing stations are plotted overlain on the shaded relief data in figure 23.

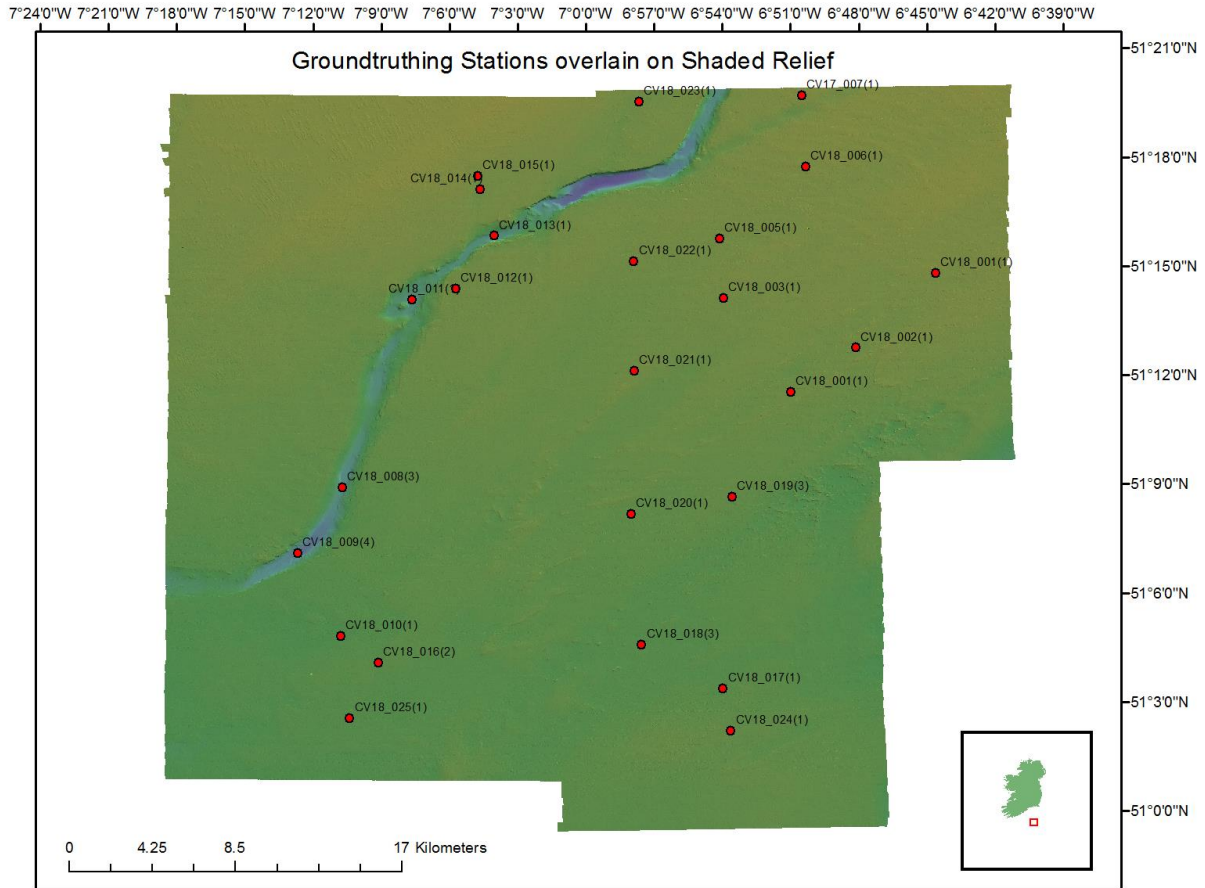


Figure 23: Groundtruthing stations plotted on shaded relief data.

4.5 Wrecks

A total of nine wreck sites were identified from multibeam and magnetometer data and detailed wreck surveys were completed for each. Watercolumn data was logged on each wreck survey line. Survey speed was reduced to 3 or 4 knots for the wreck investigations. Table 18 lists the associated metadata. Hydrographic wreck reports were created for each wreck and sent to the UK Hydrographic Office.

Number	Wreck No	Latitude	Longitude
1	11630	51° 16.2438 N	-007° 18.0148 W
2	11629	51° 11.0867 N	-007° 02.0193 W
3	11826	51° 13.4500 N	-006° 49.0000 W
4	11822	51° 16.3093 N	-006° 50.4974 W
5	11830	51° 18.0520 N	-006° 58.0377 W
6	NA	51° 10.2525 N	-007° 09.4914 W
7	11464	51° 07.8673 N	-007° 12.0098 W

8	NA	51° 00.7600 N	-006° 59.1782 W
9	NA	51° 04.4200 N	-007° 12.8042 W

Table 18: Wreck investigation metadata.

Figure 24 shows the wreck sites plotted on top of the multibeam shaded relief data.

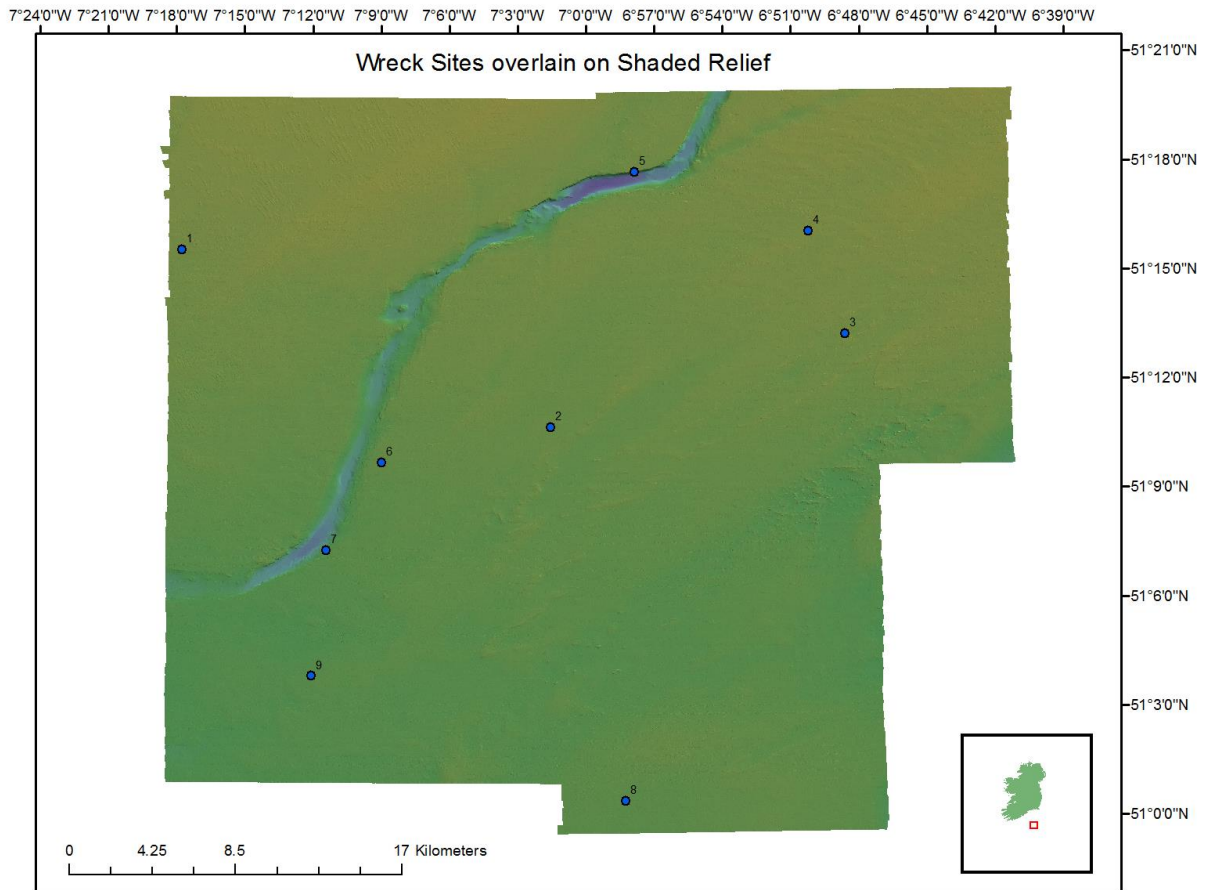


Figure 24: Wreck locations plotted on shaded relief data.