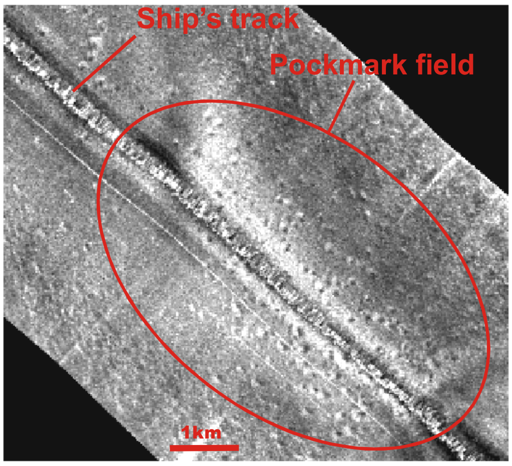
THE PORCUPINE AND ROCKALL MARGIN TOBI REGIONAL SIDE-SCAN SURVEY: PSG 00/019



Final Report

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Executive Summary

An interpretative summary of TOBI side-scan sonar coverage collected on-board cruise *RV Pelagia* M2002 under project PSG 00/019 of the Porcupine Studies Group is presented here. The purpose of this survey was to provide regional seabed mapping coverage of areas along the Irish continental margin where the occurrence of carbonate mounds had been noted. Furthermore, the survey provides details of seabed geomorphology, geology and processes operating in these areas and supplements existing TOBI coverage collected by the Rockall Studies Group (TRIM). The TOBI data has been integrated with TRIM dataset and also with a high resolution side-scan sonar dataset collected on-board RV Discovery cruise 248. The data are also described with reference to groundtruthing datasets including ROV video transects.

Three principle areas were surveyed along the margins of the Porcupine Seabight and the Rockall Trough that can be divided into a number of zones.

- Area 1: Porcupine Seabight margin
    - Zone 1: Gollum Channels (eastern margin)
    - Zone 2: Belgica Mounds (eastern margin)
    - Zone 3: Hovland/Magellan Mounds (northern margin)
- Area 2: SW Rockall Trough margin (Logachev Mounds - SE Rockall Bank)
- Area 3: SE Rockall Trough margin (Pelagica Mounds - NW Porcupine Bank)

Details from these areas are summarised below:

Area 1: Porcupine Seabight margin, zone 1 - Gollum Channels (eastern margin)

A single line, 6km wide, was run across the heads of the Gollum Channel canyon system that reveals a series of steep-sided channels. The flanks of the canyons are characterised by high backscatter implying coarse-grained and/or consolidated material with slide scarps and gullying implying slope failure and erosion of the canyon sides. Debris lobes in some canyons suggested reduced down-canyon activity at present. The canyon floors consist of coarser-grained material with meandering channels. Between-canyon areas are typified by homogenous muddy substrates.

A series of pockmarks was imaged between the Gollum Channels and the Belgica Mounds overlying the recently discovered buried Enya Mounds.

Area 1: Porcupine Seabight margin, zone 2 - Belgica Mounds (eastern margin)

In the Belgica Mound area, large ovoid mounds are arranged *en echelon* and surrounded by variable backscatter contourite drift deposits that sweep

around the mounds. The drifts consist of mainly of well-sorted sands with some sediment waves present. The drift sequences bury some of the upslope flanks of the carbonate mounds. Numerous small Moira Mounds (>50m across) are also imaged including a new discovery in a blind channel that forms the western limit of the Belgica mosaic. Smaller channels are also present to the immediate north of the Belgica Mounds.

Area 1: Porcupine Seabight margin, zone 3 - Hovland/Magellan Mounds (northern margin)

The side-scan mosaic in this area shows a homogeneous muddy seabed becoming gradually, slightly coarser-grained upslope to the north-west. In the south, the mosaic reveals the Hovland Mounds as large, multi-ridged mound structures (up to 4km long) and smaller rounder mounds and are the only prominent features. Some mounds are moated and high backscatter may also extend to near-mound areas. The Magellan Mounds are buried but leave subtle topographic effects detectable in the far-range side-scan sonar response.

Area 2: SW Rockall Trough margin (Logachev Mounds - SE Rockall Bank)

The SW Rockall Trough margin mosaic reveals numerous large-scale bedforms orientated parallel and perpendicular to the slope indicating a complex interplay between geostrophic and tidal current action. Elongated east-west orientated bedforms, several kilometres long and up to 500m wide, characterise the NW corner of the mosaic. Further east, these bedforms become less evident. Downslope, a 15km wide area is characterised by elongated clusters of predominantly downslope mounds, 100s of metres to kms across. Ground truthing suggest some of these are coral-colonised. Low backscatter channels exist between these mounds probably acting as conduits from funnelled (tidal) currents. East of these mounds, clusters of enigmatic, high backscatter, elongate, coarse-grained low relief features are present. Further downslope, at the southern limit of the mosaic, the seabed is characterised by low relief, very low backscatter seabed with slope parallel drift features and slide escarpments.

Area 3: SE Rockall Trough margin (Pelagia Mounds - NW Porcupine Bank)

SE Rockall Trough margin mosaic is typified by erosional features. Iceberg plough marks (up to 2km long) are common in the south of the mosaic (upslope) with numerous carbonate mounds (100-300m across and up to 200m high) widely distributed along the margin. These commonly occur in small clusters or alignments. Large mounds are also surrounded by high backscatter areas due to seabed erosion. An alignment of well-developed mounds exists on a topographic ridge between two canyon heads, presumably benefiting from increased food supply as currents wash over the ridge. A number of scarps are evident (up to 15km long) that possess a slight topographic rise upslope and a steep scarp face downslope. These are interpreted as either erosional features exposing internal bedding or fault scarps. Some carbonate mounds occur on scarps due to enhanced local hydrodynamic conditions. In the middle of the mosaic an enigmatic seabed backscatter is interpreted as broad, shallow erosional scours showing evidence of downslope gullying.

Acknowledgements

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The PSG comprises: Agip Ireland BV, Chevron UK Ltd, Elf Petroleum Ireland BV, Enterprise Energy Ireland Ltd, Marathon International Hibernia Ltd, Phillips Petroleum Company United Kingdom Ltd, Statoil Exploration (Ireland) and the Petroleum Affairs Division of the Irish Dept of Communications, Marine and Natural Resources.

The officers, crew and on-shore support team of the RV Pelagia are gratefully acknowledged as are all scientific personnel including Dr. Henk de Haas, NIOZ (chief scientist), Dr. Andy Wheeler, UCC (co-chief scientist) and Veerle Huvenne, Royal University of Ghent (RUG) (co-chief scientist) and the TOBI technical team, Southampton Oceanography Centre (SOC). A full list of shipboard party is also presented in Appendix 1.

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Data was processed at SOC by Jeremy Gault (UCC), Maxim Kozachenko (UCC), Veerle Huvenne (RUG) and Furu Mienis (Free University of Amsterdam).

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1. Introduction

1.1 Background

1.1.1. Geological setting

The present day morphology of the eastern Atlantic margin largely results from the rifting activities during the Mesozoic which resulted in the formation of the North Atlantic Ocean. The topographic highs and lows west of Ireland and the British Isles (Porcupine Seabight, Porcupine Bank, Rockall Trough, Rockall Bank, Hatton-Rockall Basin and Hatton Bank) are the product of several succesively failed attempts to extend the axis of mid-Atlantic seafloor spreading to the north east. The Porcupine Seabight, Rockall Trough and Hatton-Rockall Basin are the remainders of abandoned (initial) spreading centres, leaving the Porcupine, Rockall and Hatton Banks as topographic highs. Syn- and postrifting (Mesozoic to Quaternary) sedimentary covering finally resulted in the present day morphology of the area (Naylor & Mounteney, 1975). The Rockall Trough margins and basin floor sediments are effected by small to large scale slope failure processes (Flood *et al*., 1979; Dingle *et al*., 1982; Kenyon, 1987). In the Porcupine Seabight, Rockall Trough and Hatton-Rockall Basins extensive sediment drifts are present which were formed under the influence of Mediterranean Intermediate Water, North Atlantic Deep Water, Norwegian Sea Deep Water and Labrador Sea Water. The largest of these drift is the Feni Drift. The formation of these sediment bodies started during the Eocene (Stoker, 1998).

From the shelf edge west of Ireland and Britain, the continental slope deepens to a maximum depth of around 3000m in the southeast Rockall Trough and southwestern Porcupine Seabight. In the northern part of the Rockall Trough, between Scotland and the islet of Rockall the maximum water depth is about 2000m. The top of Rockall Bank, bordering Rockall Trough in the west, is between 500 and 200m below sealevel, with only Rockall islet emerging in the north. In the northern Rockall Trough, seamounts are present with their tops around 500-600m below sealevel. In the south, the Rockall Trough deepens into the almost 5 km deep Porcupine Abyssal Plain. The Feni Drift is located along the western Rockall Trough margin as a northeast to southwest elongated body. Its maximum width is in the order of 125km. The maximum crest height is about 2100m below the sea surface.

The Porcupine Seabight is a dynamic semi-enclosed basin where hydrocarbons have been found and good quality oils have been flowed from test wells (Croker & Shannon, 1995). Its sedimentary environment is characterised by drift deposits and an extensive channel-and-levee complexes (Gollum Channel) in the south of the basin (Kenyon *et al*., 1978), influenced by the northward flowing ‘slope current’ which follows the North Atlantic continental slope contours (White, 2001).

An overview of the oceanographic circulation in the northeastern Atlantic Ocean is given by van Aken & Becker (1996). The Rockall Trough forms one of the gateways of relatively warm surface waters flowing to the north, and cold deep water flowing south, and thus is an important transport path in the global thermo-haline circulation. Subpolar Mid Water flows northwards through the Rockall Trough. In the north this flow is split into two branches, one flowing across the Wyville-Thomson Ridge into the Faeroe-Shetland Channel and one flowing more to the northwest around the Faeroe Islands. The deep waters of Rockall Trough are composed of Labrador Sea Water between about 1200 and 1800m. At greater depth, cold Norwegian Sea Overflow Water, flowing over the Wyville-Thomson Ridge into the Rockall Trough, moves southwards along the western Rockall Trough margin over Feni Drift. Lower Deep Water partly enters the southern Rockall Trough along the eastern margin. Around 56°N it turns southwards to join the Norwegian Sea Overflow Water. The Mediterreanean Intermediate Water is also present in the Porcupine Seabight and southern Rockall Trough.

1.1.2. Carbonate mounds

Carbonate mounds are build-ups reaching up to 300m above the surrounding seabed consisting of mainly biogenic carbonate debris (principally from cold water corals *e.g. Lophelia pertusa*, *Madrepora occulata* and foraminifera). The summits of the mound are covered with patches of living *Lophelia pertusa*, *Madrepora occulata* and associated fauna. “Healthy” mounds may be completed covered in coral communities that may also seed the surrounding seabed.

Recent years have seen significant scientific and public attention focused on the occurrence of deep-water coral ecosystems (*e.g.* Edwards, 2000; Irish Skipper, 2001; Montgomery, 2001; MPA News, 2001; Siggins, 2001; Urquhart, 2001; Clarke, 2002; Dybas, 2002). These communities represent “biological hot-spots” of high biodiversity (Jensen & Frederiksen, 1992; Rogers, 1999) in water depths between *c.*50 and 1,100m on the European continental margin (*e.g.* Dons, 1944; Strømgren, 1971; Wilson, 1979a; 1979b; Zibrowius, 1980; Mikkelsen *et al*., 1982; Delibrias & Taviani, 1985; Hovland, 1990; Zibrowius & Gili, 1990; Frederiksen *et al*., 1992; Jensen & Frederiksen, 1992; Hovland *et al*., 1994; Mortensen *et al*., 1995; Freiwald *et al*., 1997; Hovland & Thomsen 1997; Freiwald, 1998; Freiwald & Wilson, 1998; Henriet *et al*., 1998; Hovland *et al*., 1998; Freiwald *et al*., 1999; Hovland & Mortensen, 1999; de Mol *et al*., 2002; Hall-Spencer *et al*., 2002; Kenyon *et al*., 2003; Masson *et al*., 2003; van Weering *et al*., 2003) and elsewhere (*e.g.* Teichert, 1958; Moore & Bullis, 1960; Stetson *et al*., 1962; Squires, 1965; Neumann *et al*., 1977; Cairns, 1979; Reed, 1980; Mullins *et al*., 1981; Genin *et al*., 1986; Griffin & Druffel, 1989; Messing *et al*., 1990; Keller, 1993; Rogers, 1999; Paull *et al*., 2000). The presence of the framework-building corals *Lophelia pertusa* and *Madrepora occulata* enables the development of carbonate mounds and reefs varying in height from a few metres (*e.g.* Wheeler *et al*., 2002; Masson *et al*., 2003) to several hundred metres (*e.g.* Henriet *et al*., 1998; De Mol *et a*l., 2002; Kenyon *et al*., 2003; van Weering *et al*., 2003). The role of these ecosystems as fisheries nurseries and refuges (Rogers, 1999), carbonate sinks of climate regulatory significance, indicators of hydrocarbon seepage (Hovland, 1990; Hovland *et al*., 1994; Hovland & Thomsen, 1997; Hovland *et* *al*., 1998; Henriet *et al*., 1998) and reservoirs of biodiversity (Jensen & Frederiksen, 1992; Rogers, 1999) have all been speculated.

Furthermore, carbonate mound have been features of Earth history ever since Cambrian times. These mounds frequently form giant reservoir rocks for hydrocarbon accumulations. However, their formation and environmental controls are the subject of much discussion and disagreement. The discovery of modern coral-covered carbonate mounds along the European continental margin provides an opportunity to study the processes that create carbonate mounds.

The exact process of mound formation is not entirely clear with several mechanisms proposed. One mechanism suggests the mounds represent modern carbonate knolls, made up of active bioherms or living carbonate reefs composed of ahermatypic corals, possibly developed through seepage of hydrocarbons from below through faults and fissures (Hovland *et al*., 1994). This cold seepage in turn would lead to a higher than normal concentration of bacteria and micro-organisms at the seabed and in the water immediately above, and would have a significant influence on local benthic community development (Hovland & Thomsen, 1989; 1997; Hovland, 1998). Prolonged seepage would result in local accumulation of organisms, the accumulation of skeletal debris and formation of authigenic carbonate, and ultimately in the development of the carbonate mounds. Recently, Hovland (1998) proposed that the cold water carbonate reefs with their numerous and rich fauna, would represent a final phase in a natural seep sealing process, after which the ecosystem would be maintained in equilibrium with extant conditions at the seabed.

A comparable relationship between hydrocarbon seepage and the formation of carbonate knolls, mounds and massive carbonate build ups, covered with corals and extensive, deviating from normal, benthic community development as advocated above, is well known from cold seeps and vents in the Gulf of Mexico (see overview in Aharon, 1994). Similar processes take place in the case of gas hydrate/clathrate dissociation, as recently illustrated by the studies of the Haakon Mosby Mud Volcano complex (Gardner & Vogt, 1999).

Another suggested mechanism is that currents support abundant living corals and organisms by causing enhanced particulate and organic matter concentrations in the benthic boundary layer. Kenyon *et al*. (1998) argue, on the basis of side-scan sonar and underwater TV records, that current-induced structures around the mounds are evident. They suggest that these currents would support abundant living corals and organisms by causing enhanced particulate and organic matter concentrations in the benthic boundary layer. The TOBI side scan sonar data collected in 1998 from the Porcupine Bank margin (TRIM) indeed show an erosional moat in the front and along the rim of the mounds, with subsequent sedimentation in the lee side of the mount (O'Reilly *et al*., 2000). Line ORAT 13 and derived side scan sonar mosaic collected by TTR-7 over part of the SW Rockall Trough carbonate mounds also shows current induced, westward directed sediment transport (Kenyon *et al*., 1998).

Similarly, the distribution of *Lophelia* (200-500m depth) around the Faeroe margin and banks is considered to be due to enhanced food supply by topography induced resuspension on the slope, forced by internal waves or strong currents (Frederiksen *et al*., 1992) rather than by hydrocarbon seepage. Near-bed current velocity- and turbidity measurements in any of the areas indicated above, however, are rare and show variation of current velocities between 1-100 cm s^{-1}. These observations *might* indicate that the SW and SE Rockall Trough mounds, after their initial formation due to seepage, have now reached a state of maturity and form a habitat for a specific benthic faunal community, supporting the opinion of Hovland (1998).

1.2. Objectives

The purpose of this cruise was to provide a regional coverage of areas along the Irish continental margin where the occurrence of carbonate mounds had been noted. Furthermore, the survey provides details of seabed geomorphology, geology and processes operating in these areas and supplements existing TOBI coverage collected by the Rockall Studies Group (TRIM).

The carbonate mounds are studied within the framework of the European Union 5th Framework research projects GEOMOUND, ECOMOUND and ACES that form part of the OMARC cluster. Various other national and EU-funded projects are also devoted to the study of these mounds including the present survey.

TOBI side-scan surveys where carried out in selected areas in the Porcupine Seabight and Rockall Trough (see Fig. 1). The areas where chosen based on the results of earlier cruises carried out within the framework of the GEOMOUND, ECOMOUND and ACES. Although a large data set on the mounds is available from previous cruises, the extensive study of this subject lacked a general overview map giving an idea of the setting of the mounds. Therefore this project was set up within the European Programme for Access to Large Scale Facilities/EASSS, on behalf of the partners of the European projects GEOMOUND and ECOMOUND. The *RV Pelagia* M2002 cruise, recording TOBI side-scan sonar data in the Porcupine Seabight and Rockall Trough filled the gap in the data. The main topics of this cruise were:

1) A full coverage of the 3 mound provinces in the Porcupine Seabight: the Belgica Mounds on the slightly steeper eastern flank of the Seabight; the Hovland province, containing fairly large and complex mound structures; and the Magellan province, comprising mainly buried mounds, of which many have a faint expression at the seabed (due to differential compaction and draping effects of the burying sediment).

2) A reconnaissance survey over the heads of the Gollum Channels, in the area covered by the Polarstern multibeam data set. This impressive canyon system has been studied briefly during the TTR 7 cruise

(Kenyon *et al.*, 1998) and also with a submersible (Tudhope & Scoffin, 1989).

3) A coverage of the mounds on the SW Rockall Trough margin, with the aim to investigate the morphology and relationship to local current conditions of the complicated clustered mound complexes in this area (de Haas *et al*., 2000; de Stigter & de Haas, 2001).

4) A coverage of the mounds on the SE Rockall Trough and study their morphology and the relationship to local current conditions. These are usually single mounds opposed to the mounds on the SW Rockall Trough margin (de Haas *et al*., 2000; de Stigter & de Haas, 2001).

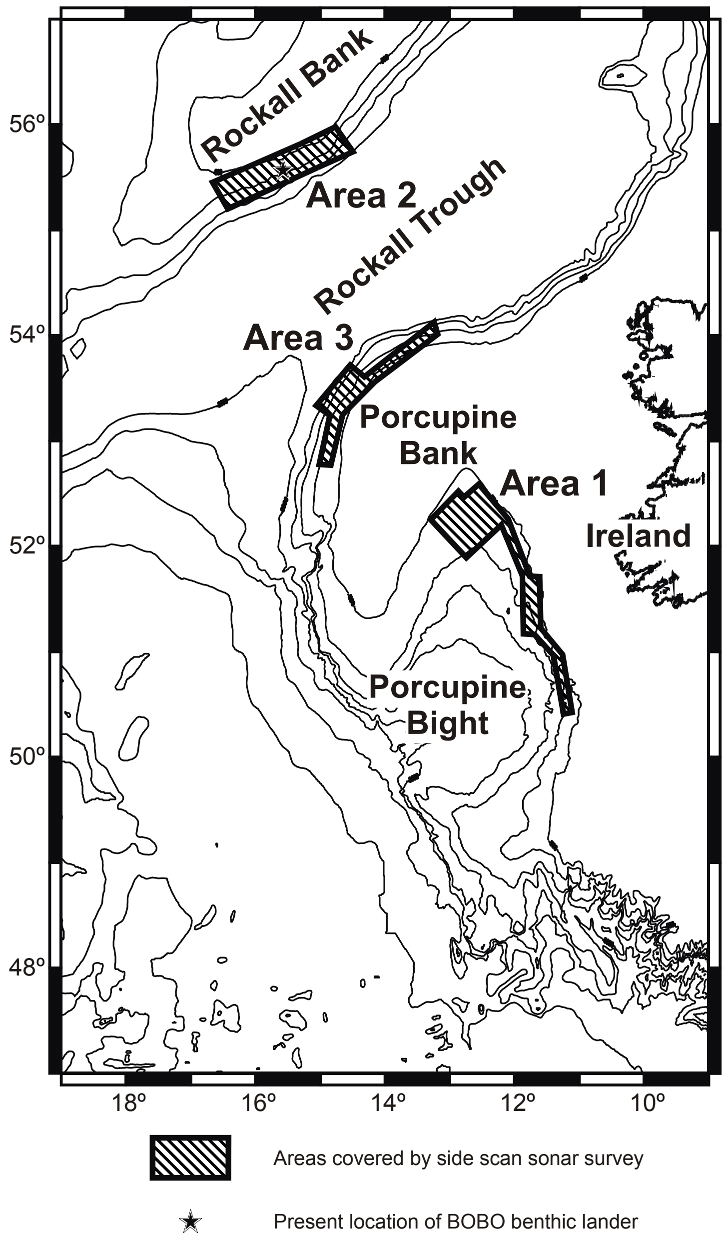


Fig. 1. *Map of the Porcupine Bight and Rockall Trough area with research areas indicated.*

2. Equipment and methods

2.1. TOBI side scan sonar

TOBI (Towed Ocean Bottom Instrument) is Southampton Oceanography Centre's (SOC) deep towed vehicle (Flewellen *et al*., 1993). It is capable of operating in 6000m of water. The maximum water depth encountered during the TOBI surveys during this cruise was around 1500m. Although TOBI is primarily a 30kHz side-scan sonar vehicle, a number of other instruments are fitted to make use of this stable platform. This particular TOBI system was built for RVS in 1995 and has a different instrument suite to that of the SOC TOBI. For this cruise, the instrument complement was:

- 30kHz side-scan sonar (Built by IOSDL)
- 8kHz chirp profiler sonar (Built by IOSDL/SOC)
- Three-axis fluxgate magnetometer. (Ultra Electronics Magnetics Division MB5L)
- CTD (Falmouth Scientific Instruments Micro-CTD)
- Pitch & Roll sensor (G + G Technics ag SSY0091)

A fuller specification of the TOBI instrumentation is given in Appendix 2. A Maplin GPS receiver provides the TOBI logging system with navigational data. An MPD 1604 9 tonne instrumented sheave provides wire out, load and rate information both to its own instrument box and wire out count signals to the logging system.

The TOBI system uses a two-bodied tow system to provide a highly stable platform for the on-board sonars. The vehicle weighs 1.8 tonnes in air but is made neutrally buoyant in water by using syntactic foam blocks. A neutrally buoyant umbilical connects the vehicle to the 600kg depressor weight. This in turn is connected via a conducting swivel to the main armoured coaxial tow cable. All signals and power pass through this single conductor.

For this survey, the SOC TOBI winch system was utilised. This system combines tow, launch and umbilical winches onto one standard 20' container-sized base plate enabling one driver to control all operations. The winch was secured to the aft deck using a custom made base plate that made use of the container fixings on the deck of the *RV Pelagia*. This fixing method has been used on the three previous occasions that TOBI has been used on *RV Pelagia* and provides a very strong and secure mount for the 28T winch. During the survey, the winch was controlled from a remote station in the TOBI laboratory.

The deck electronic systems and the logging and monitoring systems were set up in the small laboratory on the starboard side of the ship. The TOBI replay computer was mounted in the chemistry laboratory just forward of the TOBI laboratory. As TOBI has been used previously on the ship, mobilisation was easily accomplished in less than 12 hours.

2.2. TOBI Deployments

TOBI was launched and recovered a total of 3 times during the cruise:

Deployment	*Start time/day*	*End time/day*	*Comments*
1	11:28/176	18:28/183	Area 1
2	22:43/184	08:03/189	Area 2
3	00:28/190	07:55/193	Area 3

The *RV Pelagia* is equipped with a wide stern mounted hydraulic 'A' frame that allows TOBI to be deployed and recovered in an athwartships position. This gives good control of the vehicle during these operations. The main sheave was used for deploying and recovering the depressor weight, a smaller block used with a ship's winch was used to deploy and recover the TOBI vehicle. The main sheave was used for towing during the survey. No problems were encountered during any of the launch or recovery operations, which is a very great credit to the deck crews involved.

TOBI watch-keeping was split into three, four-hour watches repeating every 12 hours. Watch-keepers kept the TOBI vehicle flying at a height of ideally 350 to 400m above the seabed by varying wire out and/or ship speed. Ship speed was usually kept at 2.5 knots over the ground with fine adjustments carried out by using the winch. As well as flying the vehicle and monitoring the instruments watch-keepers also kept track of disk changes and course alterations.

The bathymetry charts of the work area were found to be accurate which helped immensely when flying the vehicle. The ship's ORETECH profiler was used with the SOC profiler display and control system mounted in the TOBI lab to give the watchkeepers a read out of water depth.

2.3. Overall Instrument Performance

2.3.1. Vehicle

The vehicle finished the cruise in good condition. Only a rubber bumper strip had to be taken off as it had become unstuck from the foam blocks. The only major problem was with the original umbilical. This exhibited an intermittent open circuit that caused the vehicle to reset itself. This occurred during the first survey run. At one point the depressor was brought back on board and some checks made but the fault had 'cured itself' by then – the open circuit only manifesting itself under tension and even then only once every 24 hours or so. During deployment at the start of the second survey the umbilical was found to be open circuit so the vehicle was recovered and the umbilical swapped for the spare. No problems were experienced with the spare. Also no fault could be found with the original once it had been replaced.

2.3.2. Profiler

The profiler provided excellent tracking of the seafloor to give height information for the TOBI vehicle. The results were not as good as expected although extensive processing could well improve upon the first replays.

2.3.3. Side-scan

This performed well throughout the cruise. Some slight noise was occasionally observed at far ranges usually from rain, shipping or water column stratification effects.

2.3.4. Magnetometer

The magnetometer functioned well throughout. The data had low noise – a few nT – and was smooth. The magnetometer data is used to give magnetic heading of the vehicle. This has to be adjusted for magnetic variation to give true heading. An incorrect reading of the x value was observed in the logged data every 12 seconds, which may be explained by the asynchronous nature of the A/D converter for the unit leading to readings during a sonar transmission.

2.3.5. CTD

The CTD unit gave no problems at all and was totally reliable: a major achievement given its recent history. The CTD data is used to give derived local sound speed and salinity.

2.3.6. Motion sensor

The motion sensor performed fine during the survey. It was noted that the raw output of this device is in the opposite sense to that of the SOC TOBI. This was easily overcome in software but needs to be repositioned so that there is compatibility between the systems.

2.3.7. Deck Unit

The system proved very reliable in operation throughout the cruise. A voltage of 320V was used to power the vehicle with a current of approximately 190mA.

2.3.8. Instrumented Sheave

The sheave performed mechanically very well throughout the cruise. The wire out meter proved extremely accurate, being less than 2m out at the end of each survey run.

2.3.9. Winch

The winch was reliable throughout the cruise. A hose was connected to the scroll of the winch to act as a washing system for the final recovery haul.

2.3.10. Data Recording and Display

Data from the TOBI vehicle is recorded onto 1.2Gbyte magneto-optical (M-O) disks. One side of each disk gives approximately 16 hours 9 minutes of recording time. All data from the vehicle is recorded along with the ship position taken from the GPS receiver and wire out from the sheave. Data was recorded using TOBI programme LOG.

As well as recording side-scan and digital telemetry data, LOG displays real-time slant range corrected side-scan and logging system data, and outputs the side-scan to a Raytheon TDU850 thermal recorder. PROFDISP displays the chirp profiler signals and outputs them to a Raytheon TDU850. DIGIO8A displays the real-time telemetry from the vehicle – magnetometer, CTD, pitch and roll – plus derived data such as sound speed, heading, depth, vertical rate and salinity. LOG, PROFDISP and DIGIO8A are all run on separate computers, each having its own dedicated interface systems.

Data recorded on the M-O disks were copied onto CD-ROMs for archive and for importation into the on board image processing system. A program called HITSCOPY was used to strip off magnetic and attitude data from the raw TOBI data files and store it in ASCII format for direct importation into a spreadsheet. Although old, the logging and display computer systems ran reliably throughout the cruise. During the third survey run it was noticed that the day number was not incrementing correctly on the logging computer. This should be updated by the GPS system. For these times the M-O data was corrected before being copied onto CD-ROMs. Further searching in the logging programme, an error was found in parsing the GPS string year information. This has now been corrected.

The replay computer suffered a corrupted registry during the first week of the cruise. Despite many efforts to re-install the software, due to a lack of a Windows 98 system disk, Windows 2000 had to be installed as the operating system. Although this was fine for regular tasks such as copying M-O disks to CD-ROM, it did not allow running of the old DOS replay programmes. A dual boot system was eventually installed to allow the older programmes to run under DOS.

2.4. TOBI Image Processing

Onboard processing equipment during this cruise consisted of a UNIX workstation (SUN ULTRA 10) with 36Gb of disk space. Final maps containing side-scan sonar imagery were plotted on an A0 plotter. All data were also archived using Exabyte tapes and CD-ROM (via a networked PC). Post-cruise, the data was reprocessed following the same protocols to improve quality.

The ship's navigation was recorded online on a UNIX server of the ship. The data were transferred on a daily basis and then tested for time-continuity and abnormal speed values. It was noticed that the ship's GPS positions were not recorded with its GPS time. The time of the UNIX server storing the positions was recorded instead. Often the navigation file revealed gaps of up to 3 minutes during which no GPS position, nor any other ship's data was logged.

The winch data (wire-out) were also recorded online and stored in the side-scan raw data. The winch data were tested for abnormal wire-out values mainly caused by cable counter resets. Good navigation data is essential for processing, because the vehicle position and hence the side-scan image position is calculated from it.

The TOBI imagery was downloaded from the CD-ROMs using a subsample and average factor of 8. This gave a pixel resolution of 6 metres and an almost 3-fold improvement of the signal-to-noise ratio.

The survey was divided into three areas to facilitate processing (Fig. 1). As each survey in an area was completed the imagery was processed using the PRISM (v4.0) and ERDAS Imagine (v8.4) software suites to produce geographically registered imagery that could then be composed onto a series of mapsheets. These were initially produced at a scale of 1:25000. After initial on-board processing, the data was reprocessed at SOC where improvements to the navigation files could be overcome and full quality assurance guaranteed. Replotting was at 1:50000 to overcome data redundancy at 1:25,000.

The processing of TOBI imagery has two main phases: pre-processing and mosaicing. The pre-processing stage involves correcting of the side-scan sonar characteristics, removal of sonar specific-artefacts and geographical registration of each individual ping. This processing stage is solely composed of PRISM programs and runs from a graphical user interface. The PRISM software uses a modular approach to ‘correct’ the imagery, which is predefined by the user in a ‘commands.cfg’ file. For this data, the commands.cfg file contained the following command protocols:

- suppress_tobi -i %1 -o %0
- tobtvg -i %1 -o %0 -a
- mrgnav_inertia -i %1 -o %0 -t -u 236 -n navfile.veh_nav
- tobtvg -i %1 -o %0 -h -l 50
- tobslr -i %1 -o %0 -r res , res
- edge16 -i %1 -o %0 –m
- drpout -i %1 -o %0 -u -f -p -k 201
- drpout -i %1 -o %0 -u -f -p -k 51
- shade_tobi -i %1 -o %0 -t1,4095

These protocols performed the following processing operations:

- Removal of any surface reflection (i.e. from vehicle to the sea surface and back) – generally only a problem in shallower water depths, where a bright stripe or line is seen semi-parallel to the ship's track. Removal is only done when the imagery is unambiguous, whether the line is true artefact and not an actual seafloor feature. The result can sometimes be seen on the final imagery as a faint dark line.

- Smoothing of the altitude of the vehicle above the seafloor. The altimeter sometimes cannot locate the seafloor, possibly due to very soft sediment thus reducing the return profiler signal. Smoothing is done by a median filter of the given values, comparing this with the first return seen on the port and starboard sides, and applying a maximum threshold for altitude change if first return and altitude value differ. Generally first return values are used, as these values will be used in the slant-range correction too.

- Merging of ship navigation and cable data with the imagery and calculation of the TOBI position using an inertial navigation algorithm. The 'navfile.veh_nav' file contains ship position and cable values and an umbilical length of 200 metres is assumed (default) plus an additional 36 metre for the distance between the GPS receiver and the point where the cable enters the water. The recorded cable values in the TOBI data are used. Various assumptions are applied: the cable is assumed to be straight, the cable value is assumed to be correct, and zero cable is set when the depressor enters the water.

- Replacing the TOBI compass heading with track heading. A smoothing filter of 50 pings is applied. The heading values are used in the geographic registration process to angle each ping relative to the TOBI position.

- Slant-range correction assuming a flat bottom. This is a simple Pythagoras calculation assuming that the seafloor is horizontal across-track and sound velocity is 1500ms^{-1}. Each pixel is 8ms and generally equates to 6 metre resolution; any pixel gaps on the output file are filled by pixel replication.

- Median filter to remove any high or bright speckle noise. A threshold is defined for the maximum deviation for adjoining pixels over a small area above which the pixel is replaced by a median value.

- Dropout removal for large imagery dropouts. When the vehicle yaws excessively, it is possible for the 'transmit' and 'receive' phase of each ping to be angled apart. If this exceeds the beam sensitivity value (0.8º) little or no signal is received, creating a dark line on the imagery. The program detects the dropout lines and interpolates new pixel values. If more than 7 dropouts are present concurrently (28 seconds) no interpolation is done.

- More dropout removal but for smaller, partial line dropouts. If more than 7 partial dropouts are present concurrently (28 seconds) no interpolation is done.

- Across-track equalisation of illumination on an equal range basis. This assumes that the backscatter from a particular range should average a given amount for each piece of data. The near-range pixels and far-range pixels are generally darker than mid-range pixels. This is due to the transducer's beam pattern and differences in seafloor backscatter response in terms of angle of incidence. The result of this is to amplify the near and far-range pixels by about 1.5 and reduce the mid-range pixels by 0.8.

Once these calculations have been applied to the data the individual pings are placed on a geographic map. To emulate beamspreading the pixels are smeared over a small angle (0.8º) if no other data is present in those pixels. As survey tracks are designed to overlap the imagery at far-range, any overlapping data pieces are placed on separate layers of the same map. This allows user intervention to define the join where one piece touches the other. If small pixel gaps are visible between the geographically mosaiced pings, these are filled with an interpolated value plus a random amount of noise (but having the same variance as the surrounding data pixels).

The second phase (of mosaicing) allows the user to view all the 'layers' of data for an area. The software used is a commercial package named ERDAS Imagine (v8.4). Within this software the different layers can be displayed in different colours to distinguish the layers with data that will overlap data from another layer. In order to merge the different layers and their data together, polygons (Areas of Interest –or AOI) are drawn by the user to define the join lines between layers and then applied to create a single layer final image map. This procedure can also be used to remove shadow zones and areas of no data. The program that merges all data within selected AOIs into the final single layer image is called 'addstencil'. Several of these final images can then be mosaiced together into a big image from which maps can be created in different projections and spheroids, including scales, co-ordinates and text. Also annotation such as ship's track, vehicle track and dates and times can be added to the map. The map can then be plotted on the A0 plotter and/or converted into other format e.g. TIFF, JPEG, generic postscript etc. to be used for further analysis on PC, Macintosh or UNIX workstations.

3. Area 1: Results and interpretations from the Porcupine Seabight

The survey in Area 1, the Porcupine Seabight, is presented in a set of 15 maps (Fig. 2) and can be divided in 3 zones:

- Zone 1: Gollum Channels (eastern margin) – Maps 1-4
- Zone 2: Belgica Mounds (eastern margin) – Maps 5-9
- Zone 3: Hovland/Magellan Mounds (northern margin) – Maps 10-15

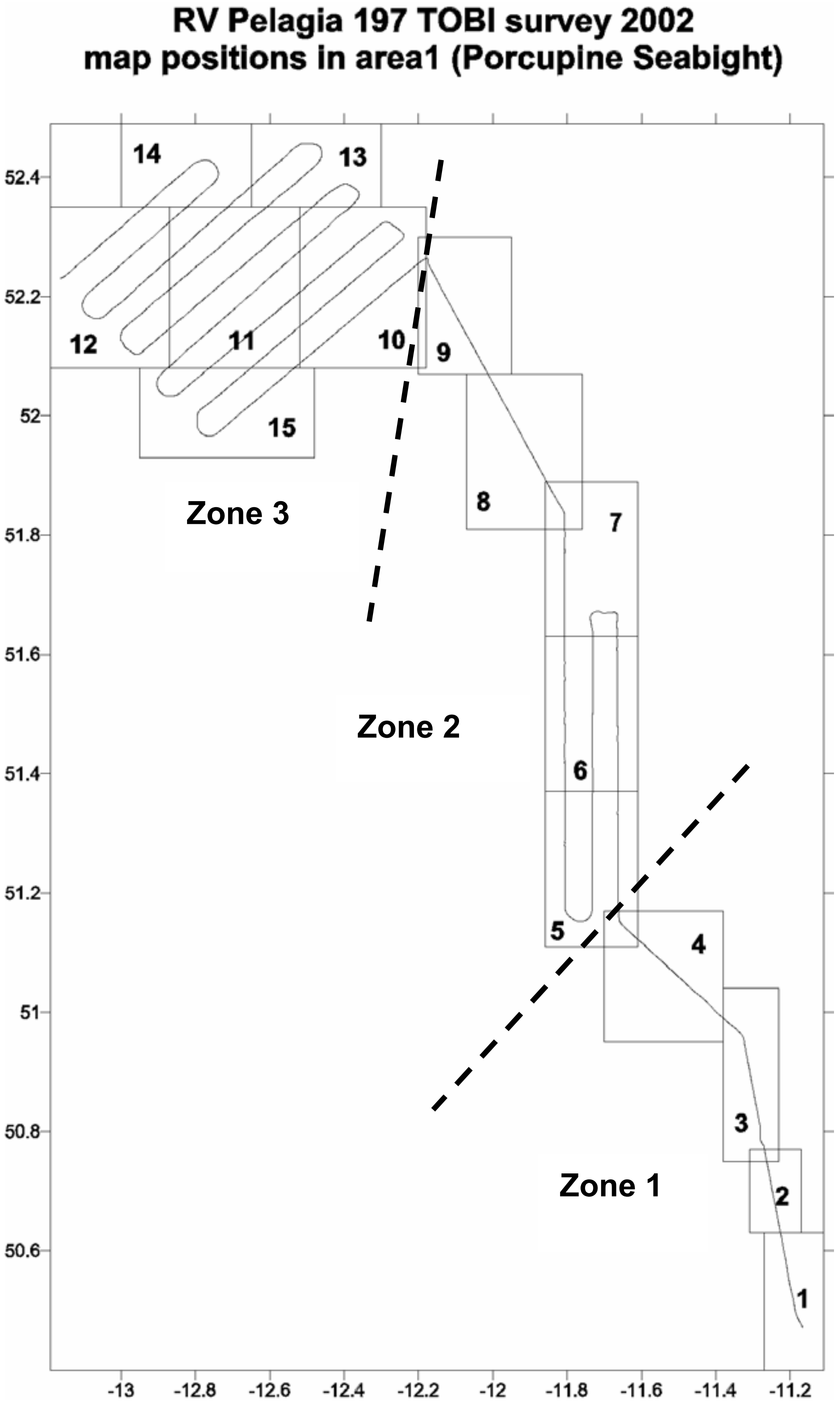


Fig. 2. *Map showing the mosaic maps of the Porcupine Seabight survey (area 1).*

3.1. Zone 1: Gollum Channels (eastern margin)

The Gollum Channels are pictured on maps 1 to 3 of Area 1. They are steep-flanked canyons of about 200m deep, as can be seen from the multibeam bathymetry (Fig. 3). The flanks show a strong backscatter on the side-scan sonar images because they face the instrument, but also probably because of their different nature: they might consist of more compacted material, or coarser sediments.

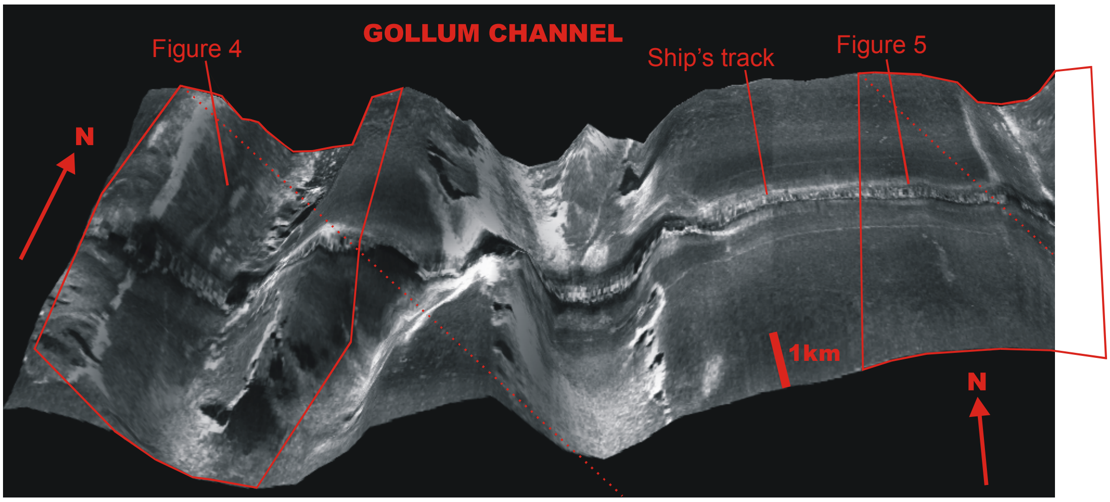


Fig. 3. *Example of TOBI side-scan sonar data draped over multibeam bathymetry showing the canyons of the Gollum Channel. The locations of figures 4 & 5 are also illustrated.*

Channels of different types can be recognised: V-shaped channels (e.g. the most southern channel surveyed) and U-shaped ones (further to the north). The U-shaped channel flanks are often affected by slope failure, such as sliding or gullying (Figs. 4 & 5). In some channels, depositional lobes can be seen on the channel floor, although this is not always the case. Generally, the channel floors seem to consist of coarser material than the areas between the channels. They show slightly higher backscatter, and high-backscatter features can be seen which could be large blocks of sediment or debris. Also on the rim of some channel flanks some positive features are seen. The widest channels seem to be affected the most by the debris flows, and, because of their width, are suggested to be the oldest ones. They also show lines on the channel floor, indicating the downslope current meandering on the fairly wide channel. In some cases, the steep channel flanks also are affected by sharp downslope gullies, clearly seem on the side scan-images (Figs. 4 & 5).

The areas between the channels generally show a much more homogeneous and lower backscatter. On the 3.5 kHz sub-bottom profiler, they can be recognised as depositional areas with smooth, parallel reflections. Some areas appear a little hummocky or undulating on the side-scan records. This probably suggests the presence of mud waves.

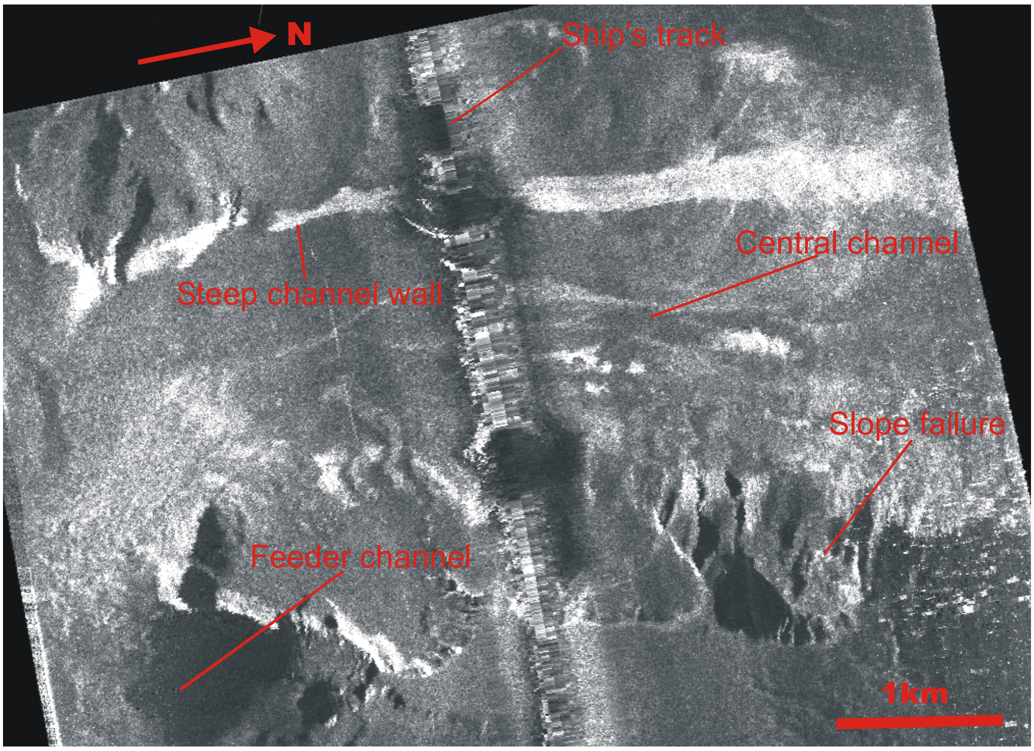


Fig. 4. *Gollum channel details showing canyon flank gullying and failure*

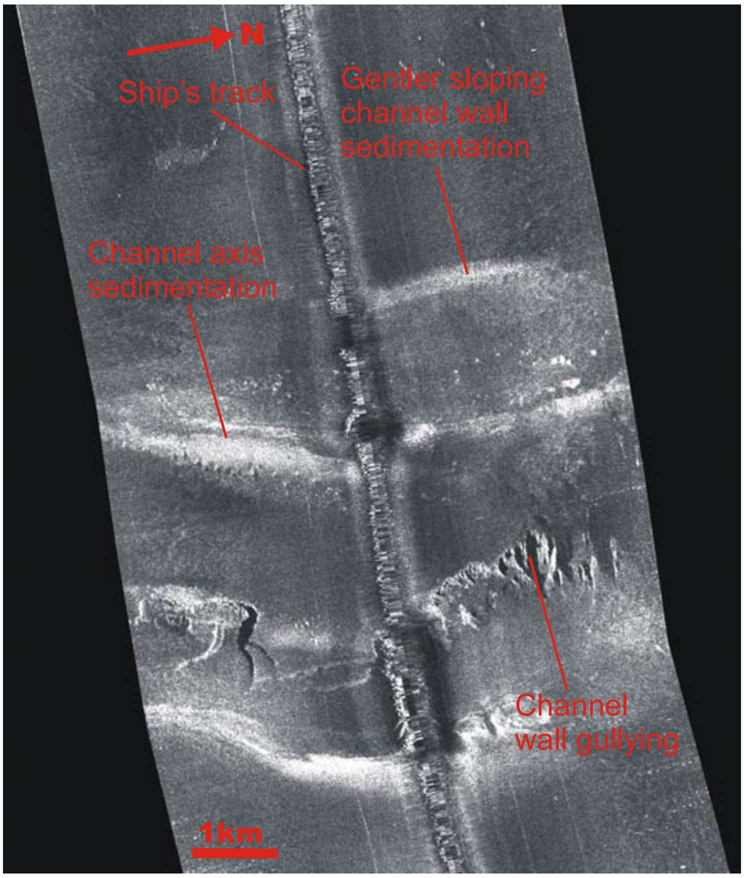
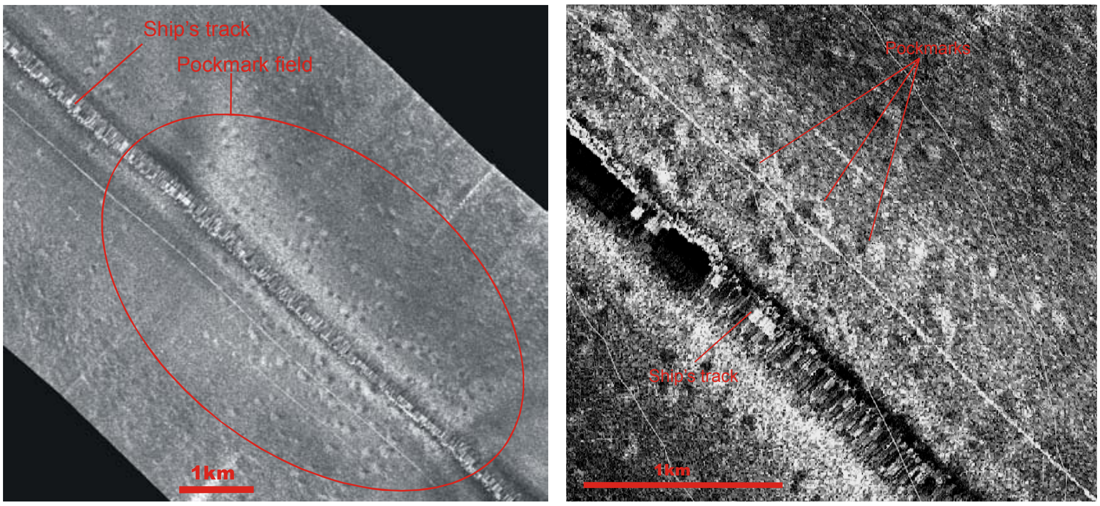


Fig. 5. *Gollum Channel details showing gullying*

Map 4 of Area 1 contain transit lines between the Gollum Channel and the Belgica Mounds Area (Zone 2). They generally show a homogeneous grey backscatter without many features. The most remarkable features are a field of depressions, probably pockmarks, seen on map 4 (Fig. 6). Recent survey results (Belgica 2003) found that these partly over buried carbonate mounds called Enya Mounds (Jean-Pierre Henriet, pers. comm.)



A B

Fig. 6. A: *pockmark field located north of the Gollum Channels and south of the Belgica Mounds (Map 5), and* B: *in detail*.

3.2. Zone 2: Belgica Mounds (eastern margin)

The Belgica Mound province is pictured on maps 5 to 7 of Area 1. Most of the mounds recognised from the bathymetry can easily be found on the side-scan sonar images as they have a high backscatter on their flanks and often a clear acoustic shadow. This is especially true of the mounds arranged in an *en echelon* pattern as they form prominent ridges (Figs. 7 & 8).

The Moira Mounds, expressed as small high-backscatter points, are also visible. They are placed against a background of darker backscatter material interpreted as well-sorted sand, as formerly recognised on the ROV images (Olu–Le Roy *et al*., 2002). Similar high-backscatter dots (sometimes a little elongated in a north-south direction) can be seen on other locations (*e.g.* on the western side of maps 5 and 6) (Fig. 9).

The very low backscatter seabed signatures are shown in various locations representing differing styles of sediment drift (Fig. 10). Low backscatter striations similar to those described by Kenyon *et al.* (1998) from the TTR7 side-scan sonar imagery can be found on map 5 and correspond to coarse substrates.

The western limit of the Belgica Mounds is defined by a relic channel identified both on the bathymetry and backscatter contrasts of the side-scan imagery. It meanders slightly, and in some locations low backscatter material seems to be concentrated in the bends. This is interpreted as sands, similar to those found around the Moira Mounds. Other smaller channels are present between the mounds, and north of them (maps 6 and 7) (Fig. 7). The northern ones show a lower backscatter on the slopes facing the side-scan instrument, than

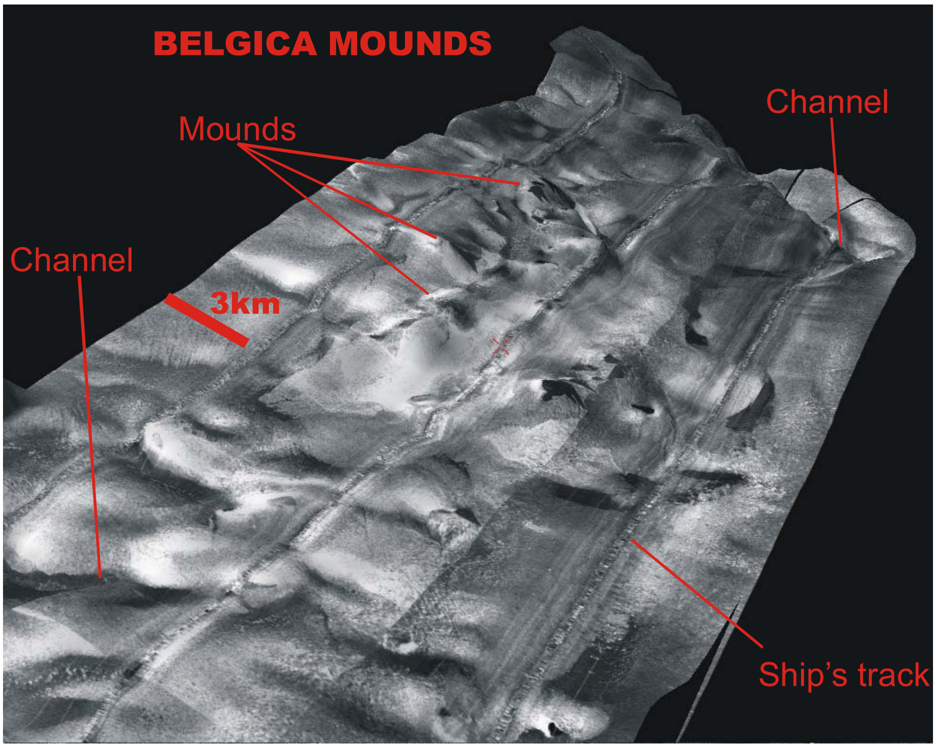


Fig. 7. *Southerly looking perspective of the Belgica Mounds: TOBI draped on multibeam bathymetry.*

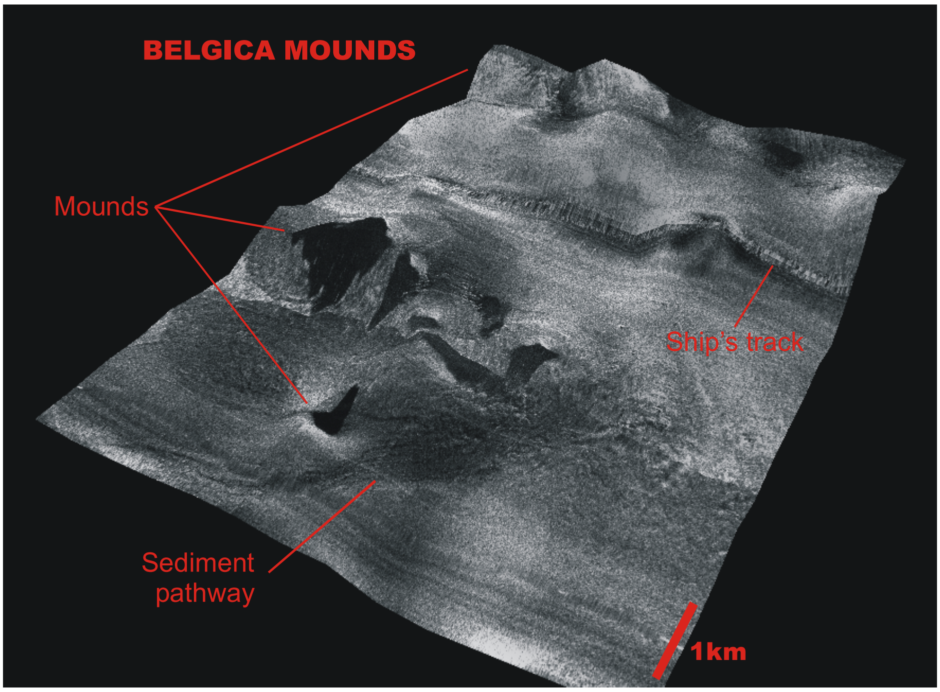


Fig. 8. *Easterly looking perspective of the southern Belgica Mounds area: TOBI draped over multibeam bathymetry showing mound and sediment drift features.*

on the opposite slopes. This is most probably due to the interaction between the sound frequency/wavelength and the sediment characteristics: *e.g.* compaction, texture, sorting, layering.

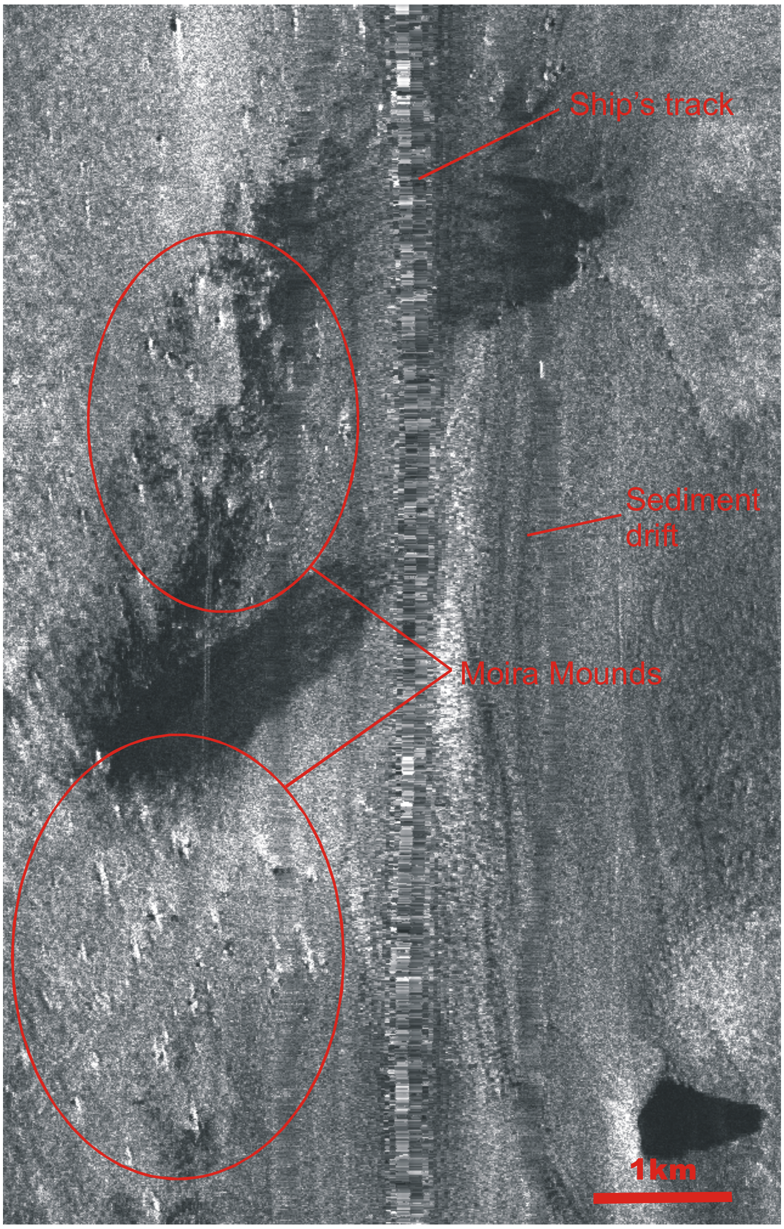


Fig. 9. *Small-scale carbonate mound features (Moira Mounds) existing between areas of extensive sediment drift*.

Some areas between the mounds show a very characteristic acoustic facies, with a very irregular texture (Fig. 10). Based on video results from the TTR7 (Kenyon *et al*., 1998) and CARACOLE cruises (Olu–Le Roy *et al*., 2002), they could possibly be interpreted as zones with an irregular seabed, consisting of fairly coarse materials, combined with dropstones and some coral debris.

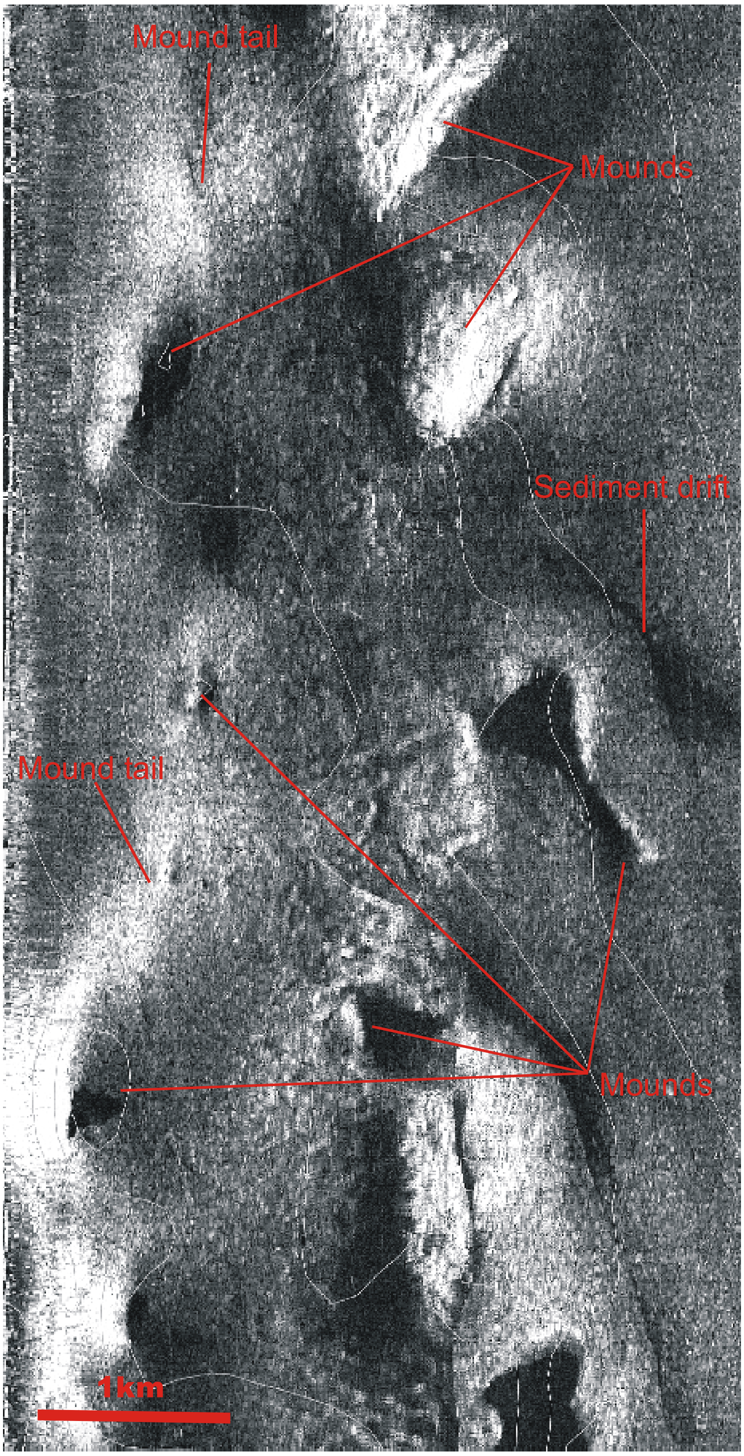


Fig. 10. *Interaction between sediment drift bodies are positive relief carbonate mounds.*

Maps 8 to 9 are transit lines from the Belgica Mounds area (Zone 2) to the Hovland Mounds Area (Zone 3). These show largely homogeneous featureless seabed although Map 9 shows 2 larger features consisting of dark backscatter patches with a high-backscatter point in the middle. They could be very small build-ups or incipient mounds.

3.2.1. Further analysis and comparison with other datasets

A detailed appraisal of the TOBI side-scan sonar within the context of existing data is presented by Huvenne et al. (subm.) with relevant text and observations are reproduced below:

The sidescan sonar mosaic of the Belgica mound province shows an entirely different pattern compared to the Magellan and Hovland provinces (Fig. 11). The image is less smooth, which is partly due to the more irregular bathymetry of the area. First of all, the eastern slope of the Porcupine Seabight is steeper (2 to 3° versus 0.2 to 0.5° in the Magellan/Hovland area). Furthermore, the province is bound to the west by a blind channel that runs approximately north-south, bending towards the SE in the southern part of the TOBI mosaic. Between the mounds, the slope is cut by several small, downslope directed channels or gullies. Van Rooij et al. (2003) attributed the large channel to the action of a northward directed bottom current, and interpreted the smaller gullies as minor turbiditic channels. The Belgica mounds on their turn are often arranged en echelon, generally in north-south trending ridges, more or less parallel to the bathymetry (especially to the south of the province). This way they create some sort of terrace-like morphology along the slope, as they tend to pile up sediments on their upslope flank (Wheeler et al., subm.). Their asymmetrical shape causes a lack of shadow formation when they are ensonified from the downslope direction. This, together with the fact that there are also other features with the same high-backscatter signature as the mound flanks facing the instrument, makes the mounds less easily recognisable than in the Magellan and Hovland province. In total 43 mounds were recognised in the combined sidescan sonar/bathymetry data set. This is similar to what is reported by De Mol (2002), who also found 20 more buried mounds on seismic profiles in the area. The mounds are between 300 and 2000 m wide, up to 100 m high above the present-day seabed and often have a slight NNE-SSW elongation (Wheeler et al., subm.a).

Overall, three types of backscatter pattern were recognised in the Belgica province, besides a range of specific features and bedforms (Fig. 11 & 12) :

- *A low backscatter facies of smooth texture (1) occurs mainly in the southern part of the TOBI mosaic. It also includes part of the large blind channel, and becomes darker (less backscatter) towards the south-east. On the echosounder profiles, a parallel stratified sediment was found, with an acoustic penetration of locally up to 50 m. The facies is interpreted as a package of hemipelagic sediments.*
- *A high-backscatter facies of irregular texture (2) is found mainly in the central and northern part of the image, between the mounds and around the gullies. On echosounder profiles of these areas the penetration reduces a little to ca. 30 m, and the amplitude of the seafloor and upper reflections is much higher, masking any underlying reflections. This facies is interpreted as indicative for current-swept areas, where the finest fractions are winnowed from the sediment and in some cases even non-deposition or erosion can occur. This results in a coarser, sometimes*

purely lag deposit. Core information describes foraminiferal sands and in some locations gravel or coral rubble.

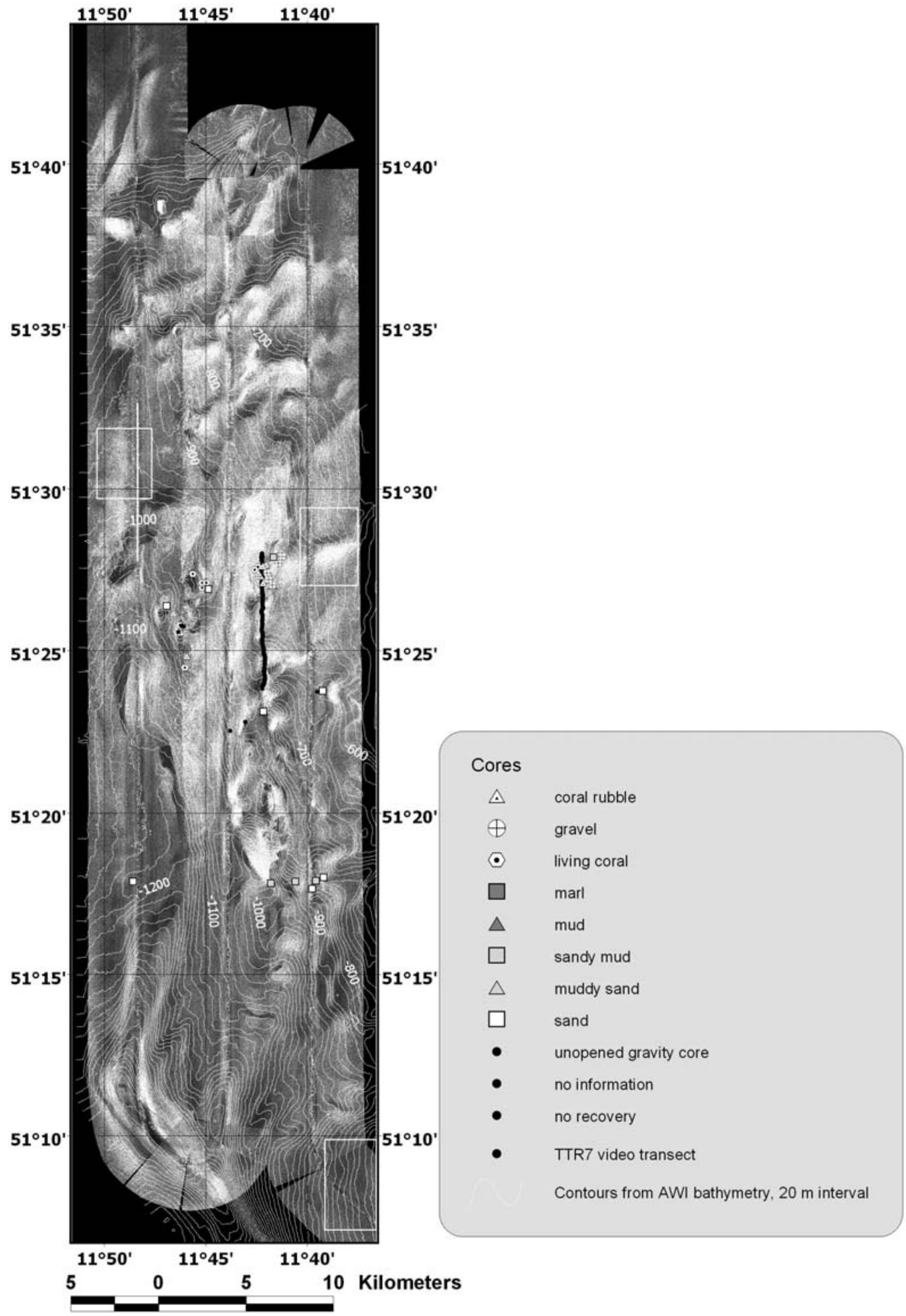


Fig. 11. *TOBI sidescan sonar mosaic of the Belgica mound province, with bathymetry data from the R/V Polarstern cruise (Beyer et al., 2003). Core information from different sources, mentioned in the text. The TTR7 video transect was described by De Bergé (2000). The rectangles and line indicate the locations of the details presented in Fig. 13.*

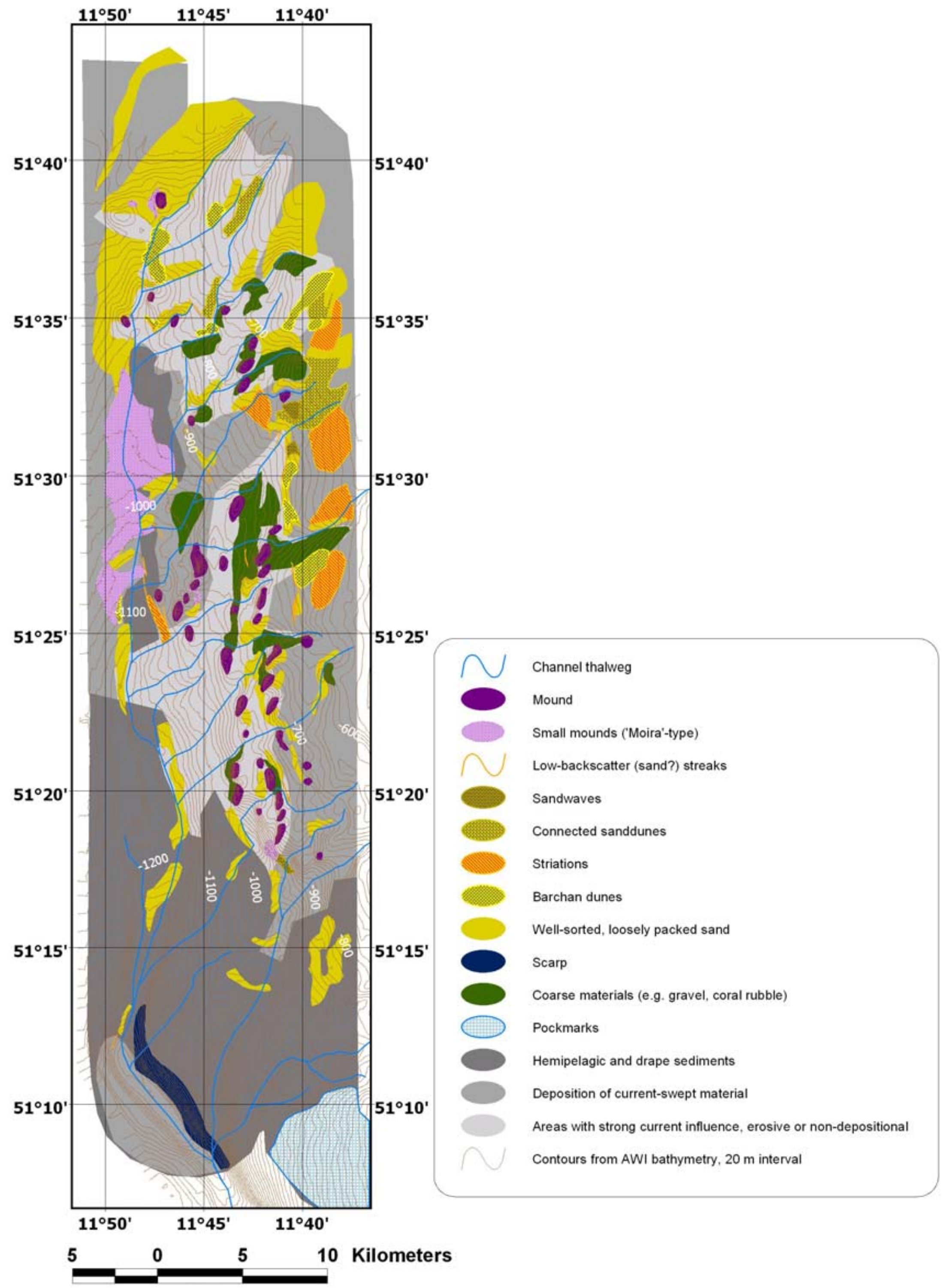


Fig. 12. *Interpretation of the TOBI sidescan sonar and bathymetry data in the Belgica mound province.*

- *A <u>medium backscatter facies with irregular texture</u> (3) occurs in the northern half of the TOBI image, more specifically east and west of the previous facies. It shows intermediate characteristics both on sidescan sonar and echosounder images. It is however also related to the area with irregular bathymetry, caused by the mounds and channels. Therefore this facies is interpreted as an area with a higher sedimentation rate than* *facies 2, but no drape sedimentation such as seen in facies 1. It probably also exhibits some kind of sorting or winnowing effect, although less strong than seen in facies 2.*

It has to be noted that the boundaries between these facies are indicated more or less arbitrarily on the map, as the facies change rather gradually.

Besides the overall backscatter pattern, some specific features have been recognised on the sidescan sonar records :

- *Mounds : the Belgica mounds were described above*
- *Small positive, high-backscatter features : in some locations, especially in the northern part of the blind channel, slightly elongated (N-S) positive features of some 30 to 50 m wide can be seen (Fig. 13a). In these areas small (up to 10 m), positive features can be identified on the echosounder data as well (Fig. 13b). Based on their similarity with a set of small mounds further to the east, these structures are interpreted as Moira-type mounds (Wheeler et al., 2000; Wheeler et al., subm.b).*
- *Towards the south-eastern corner of the mosaic, a whole set of depressions is found, with an average diameter of 140 m. Although no trace of them was seen on the echosounder profiles, they are interpreted as shallow pockmarks (Fig. 13c).*
- *Patches with very high backscatter (apart from facies 2) were found between the mounds and along the north-facing slopes of the gullies on the upper slope (Fig. 13d). They are also interpreted as areas with a very coarse seafloor, consisting of gravel lags or coral fragments. The echosounder profiles crossing the channels show that the north-facing flanks are rather eroded, which may have caused the higher backscatter in these areas*
- *Patches of very low backscatter occur at several locations, especially on the south-facing slopes of gullies, the large channel, mounds etc. (Fig. 13d). In some cases they are sharply bound, in other locations their boundaries are rather fuzzy. On some of the patches zones with a wavy pattern of higher backscatter can be recognised.*
- *Striations : lines of very low backscatter placed on a high backscatter background are found at several locations, especially along the higher slope between the gullies (Fig. 13d). The lines are often directed in a NNW-SSE direction, and are mostly connected with/starting from a patch of very low backscatter. They can be up to 1500 or 2200 m long and up to 40 m wide.*
- *Irregular patches of low backscatter on a high backscatter background exhibit different shapes, ranging from crescent-shaped to geometric patterns and 'blobs' of higher backscatter surrounded by lower backscatter lines. Some of these features occur directly besides a patch of very low backscatter, and gradually fade towards that signature.*
- *Single low-backscatter streaks occur especially in the central part of the TOBI mosaic. They are up to 1500 m long and between 30 and 60 m wide. Overall, they are directed more or less N-S, and often they are linked to one of the patches of very low backscatter.*

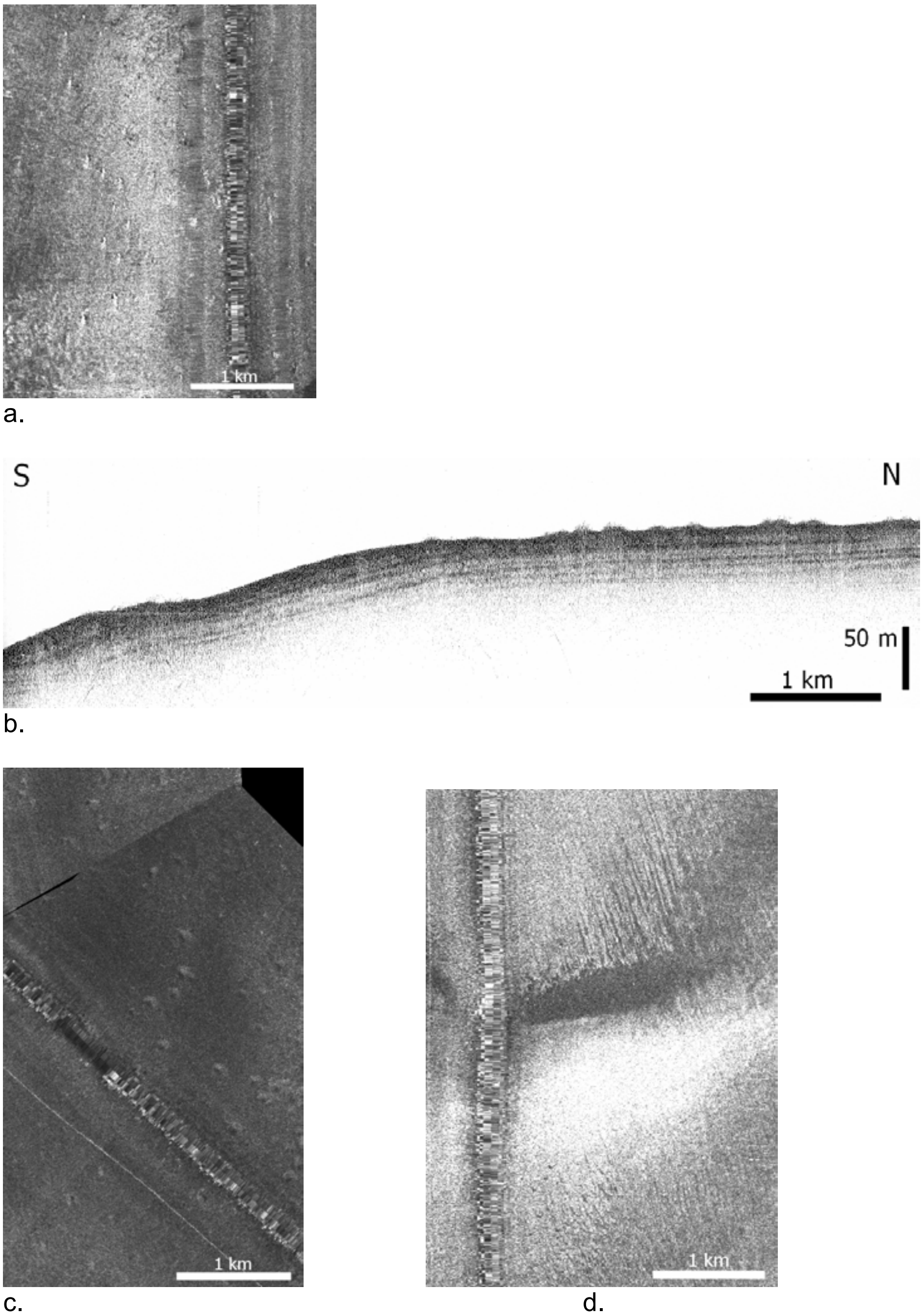


Fig. 13. *Details of the TOBI sidescan sonar and shipboard 3.5 kHz profiler data in the Belgica mound province (locations indicated on Fig. 7). Small positive structures (a & b), interpreted as small mounds; pockmarks (c); and a detail of a downslope gully (d) with high backscatter on the northward facing flank, and very low backscatter on the southward facing flank, interpreted as well-sorted sands. Striations depart from this patch of low backscatter, and to the south of the gully, some barchan dunes can be seen, associated with the sand patch of a second gully further to the south.*

Based on ROV video observations and core descriptions of one very low backscatter zone east of Thérèse Mound (see below), this type of acoustic facies is interpreted as well-sorted, loosely packed sands. A similar interpretation was described by Masson (2001), who found a large area with very low backscatter on TOBI imagery from the Faeroe-Shetland Channel. Through ground-truthing with boxcores and photographs, they concluded that *this facies was caused by a thin sheet of very well sorted sand or muddy sand, about 10 to 15 cm thick, covered with sand ripples. This interpretation can explain the other low-backscatter features as well. Probably all of these bedforms are caused by sands, shaped by the currents and deposited on a coarser or more compacted, higher reflective underlying seafloor. Both the striations and the individual streaks are ribbons of sand, elongated by the currents. The crescent-shaped patterns can be interpreted as barchan dunes, up to 90 m wide, while the geometric patterns probably are caused by barchan dunes, located closely enough to each other to be linked. The fact that all of these features occur very close to the deposits of sorted sands, supports the interpretation that these deposits acted as sediment sources for the bedforms to develop under the current action.*

The overall pattern of bedforms and sedimentary features relates quite well with the descriptions of single sidescan sonar lines in the area (TTR7 and TTR8-records, Wheeler et al., 1998; De Mol et al., 1999; Huvenne et al., 2002). A more detailed description of the sedimentary environment in the Belgica province, based on high-resolution sidescan sonar records, is given by Wheeler et al. (subm. b).

3.3. Integration with Discovery 248 side-scan sonar coverage

A 100kHz side-scan sonar mosaic spatially coincident with a section of the TOBI coverage in the Belgica Mounds area has been integrated with the TOBI coverage to provide a higher resolution of detail. The 100kHz mosaic covers an area of approx. 80km^2 and was surveyed using a GeoAcoustic (100 kHz) side-scan sonar onboard RRS Discovery 248 (Wheeler *et al*., 2000; Bett *et al*., 2000). Total approximate length of all lines is 215km with a swathe width of 800m. The side-scan sonar mosaic collected in the Belgica mounds area provided nearly full coverage of the area from 51º 21.0'N to 51º 32.0'N and from 11º 49.0'W to 11º 37.0'W.

Height of the side-scan fish above the seabed was controlled via a remotely operated electro-hydraulitic winch and flown at 25m off the seabed at 100kHz. To obtain optimum results, the speed of the vessel was kept at 3.5 knots. Hytech cable counter was used to calculate cable layback that was manually recorded every 5 minutes. The signal to the towfish was supplied by a GeoAcoustics transceiver (SS941) that was externally triggered from a CODA DA100 sonar processing system that supplied a real-time image recorded to DAT tapes. A hardcopy output of the side-scan record was also obtained directly from the GeoAcoustics transceiver using an Ultraelectronics Wideline 200 series 12 thermographic recorder with manual fixes. Navigation was supplied by the NaviPac survey software running on PC, providing the coordinate fix points and heading for the vessel from which the side-scan sonar image location was extrapolated using a layback calculation The distance of the towfish behind the vessel was calculated using trigonometry (based on water depth, towfish height above the seabed and wire out) with error correction for inertia movements around corners and wire catenation effects. Based on this method, accuracy of image navigation is +/- 50m.

Acquired digital side-scan sonar data was processed at the Southampton Oceanography Centre using the *PRISM* sonar software system (Le Bas & Huhnerbach, 1999). Processing involved data conversion from CODA to -netcdf format, the removal of the water column, slant range correction, navigation and mosaicing. The mosaics were then divided into a number of maps (tiles) whose spectral frequency distributions were then optimised. The side-scan sonar mosaics were then integrated within GIS using the ArcView GIS 3.2a and described and interpreted in relation to near seabed hydrodynamics and geological processes.

TOBI and 100kHz side-scan sonar coverages have been integrated within a GIS and are viewable as Imagine files within the viewer provided (Figure 14).

A detailed appraisal of the 100kHz side-scan sonar within the context of existing data is presented by Wheeler et al. (subm. b) with relevant text and observations are reproduced below:

Multibeam echosounder data (Beyer et al., 2003) reveals that carbonate mounds in the Belgica mound province are aligned along the slope in two parallel ridges. Some mounds rise above the seabed whereas others are buried or half buried within drift sediment. Mounds from the eastern ridge occur between water depths from 550 to 900m. The eastern flanks of these mounds are covered by the contourite drift deposits, and therefore possess a half or, in some cases, near-total buried morphology (Fig. 15b). Mounds located at deeper water setting, from 870 to 1030m water depth, form the western ridge and possess an outcropping morphology with a subtle difference in slope angles between their eastern and western flanks. Slope angles of individual mounds vary from 7 to 23°, with western flanks of the mounds being generally steeper then their eastern flanks. Individual mounds are also elongated in a general north-south direction parallel to the dominant current direction implying a hydrodynamic control on preferential coral growth and interstitial sediment accumulation.

Several interpretive facies are defined for the Belgica Mounds area and are described below. An interpretive facies map in presented in Figure 16.

<u>Background uniform backscatter facies</u>
Inter-mound areas especially in the eastern part of the province reveal homogenous uniform background backscatter pattern on the side-scan sonar imagery. This seabed facies occurs in relatively flat or gently sloping areas of the seabed, although in some cases may also characterise the flanks of carbonate mounds (e.g. the eastern flank of Poseidon Mound). Video truthing (Fig. 17) suggests that this facies is represented by smooth current swept sediment surface with occasional dropstones, or, in some places, by rippled sand sheets (Fig. 18). This facies possesses sharp boundaries with areas of sediment wave or barchan dune development and accommodates a number of sand ribbons and solitary Moira Mounds. This facies exists between the eastern and western mound areas and occurs only where bottom currents are

unrestricted. Once giant carbonate mounds provide obstacles to current flow, this causes acceleration in current speeds to form sediment wave fields.

Fig. 14. *Overlay of the 100 kHz side-scan sonar coverage on the TOBI side-scan sonar coverage in the Belgica area*

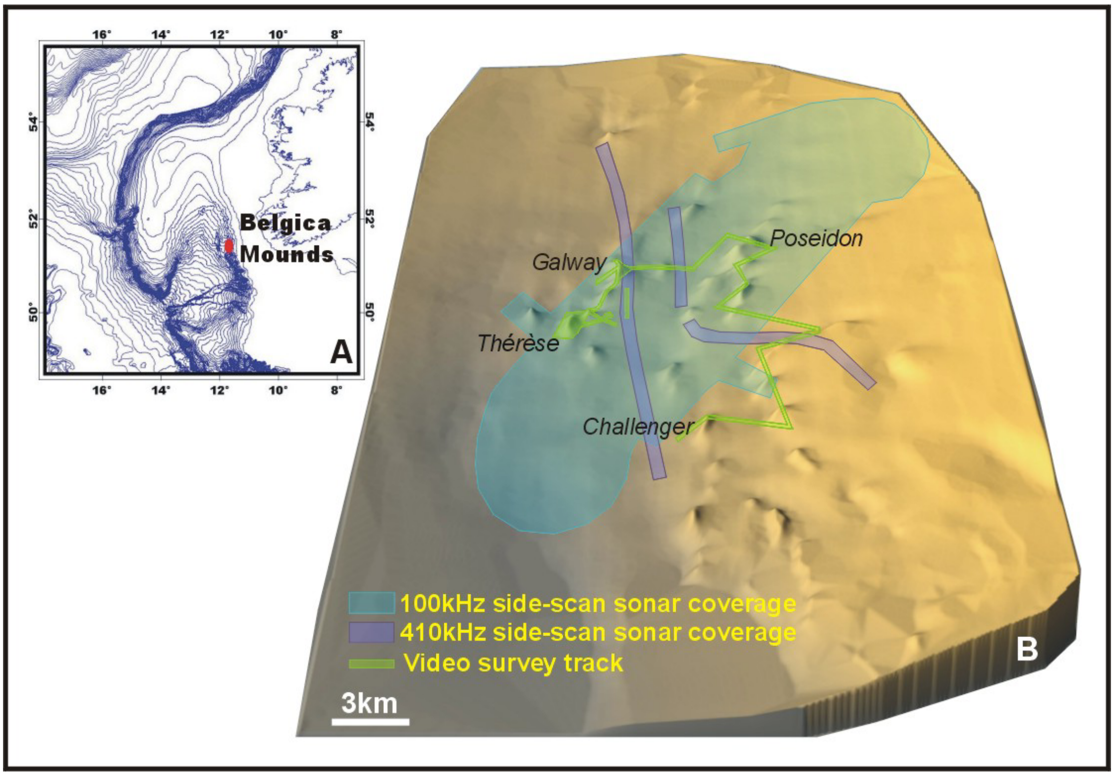


Fig. 15. *(a) Location map showing the location of the Belgica mounds study area on the regional scale, eastern Porcupine Seabight, NE Atlantic (contours from GEBCO 97); (b) Terrain model of the central part of the Belgica mound province based on multibeam bathymetry (AWI). Transparent layers show 100kHz and 410kHz side-scan sonar coverage and underwater video survey track. Names of individual mounds within the province are shown.*

Sediment wave facies

Side-scan sonar imagery shows that sediment waves are distributed throughout the mapped area, although more frequent in the western part of the province. Sediment waves shape the seabed in between mound areas and also develop on mound's flanks, indicating that mound surface morphology is strongly dictated by prevailing basal current activity. Sediment waves can be grouped in fields that possess sharp boundaries with the surrounding seabed. Boundaries between sediment wave fields are defined by differences in wave dimensions implying formation under different hydrodynamic conditions due to acceleration and deceleration of current flow caused by the local topography under present or former conditions.

The orientation and size of sediment waves is dependent on the location and in some cases follow the contours of the local topography. Sediment waves on mound flanks show larger dimensions on the stoss slopes of the mounds then on their lee sides. Orientation of sediment wave bedforms in between mound areas indicates currents directed to the north and north-west. Sediment wave bedforms vary in shape and size with a wavelength of 5 to 60m and a wave height of 1 to 10 m. The dimension of the sediment waves observed on the mound flanks range between 10 to 15m wavelength and 1 to 3m height. Orientation of sediment wave crests shows that currents change *their directions in the proximity of giant carbonate mounds as the mounds form obstacles to current flow.*

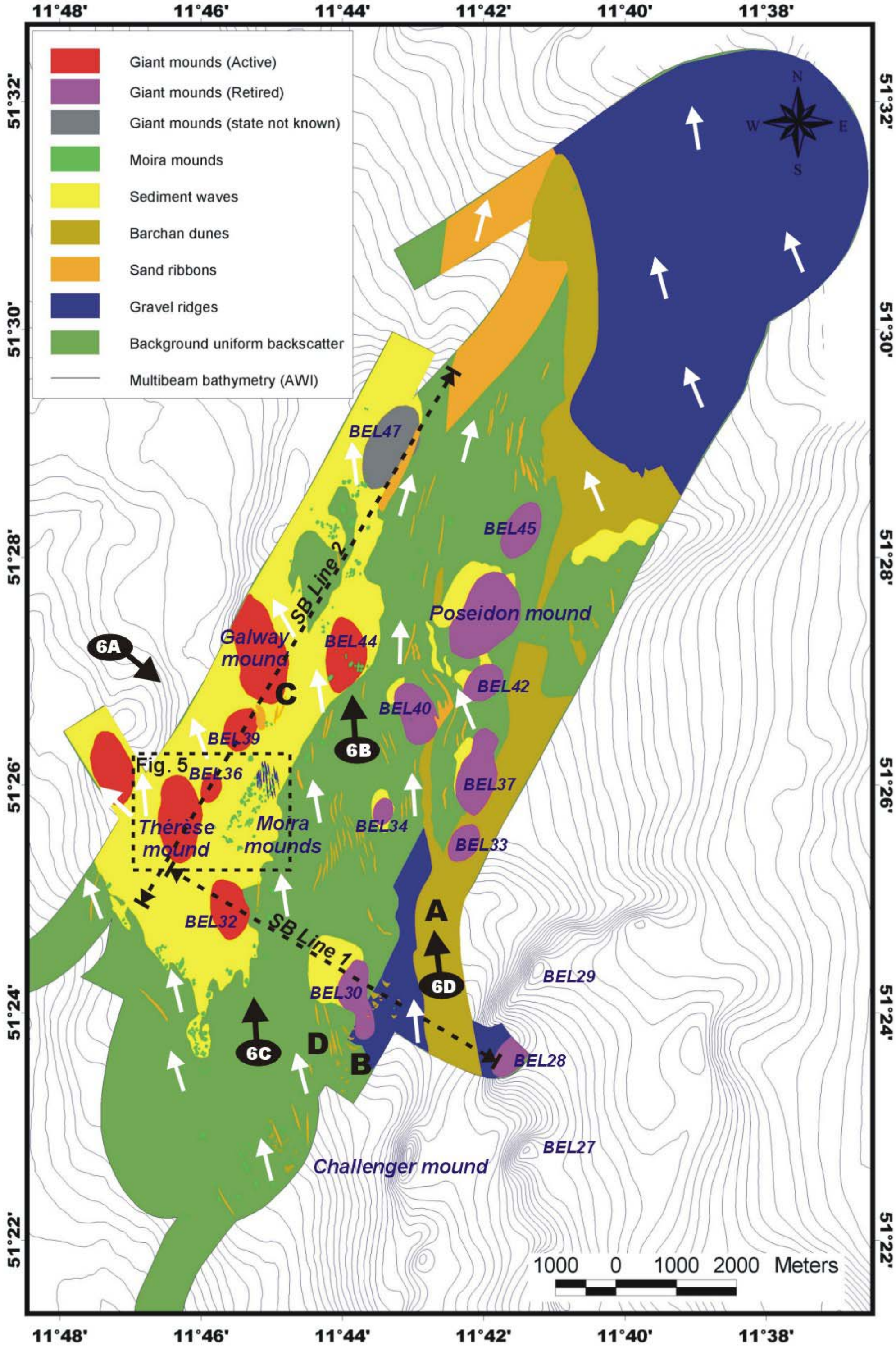


Fig. 16. *Interpretation (facies) map of the Belgica Mounds area based on side-scan sonar, sub-bottom profile and video data. Dashed lines indicate the location of selected 3.5kHz sub-bottom profiler lines (SB Line 1 & 2: see Fig. 23 for detail). A number of 3D views of the 100kHz side-scan sonar imagery draped over the multibeam bathymetry are located (e.g. 6A; see Fig. 20a). Location of 410kHz side-scan sonar highlight images is shown (A, B, C & D; see Fig. 21a-d). Dashed box outlines the area of Thérèse and Moira mounds that was extensively video truthed (see Fig. 18 & 22 for detail). White arrows indicate directions of benthic currents derived from bedforms orientation on side-scan sonar and video imagery.*

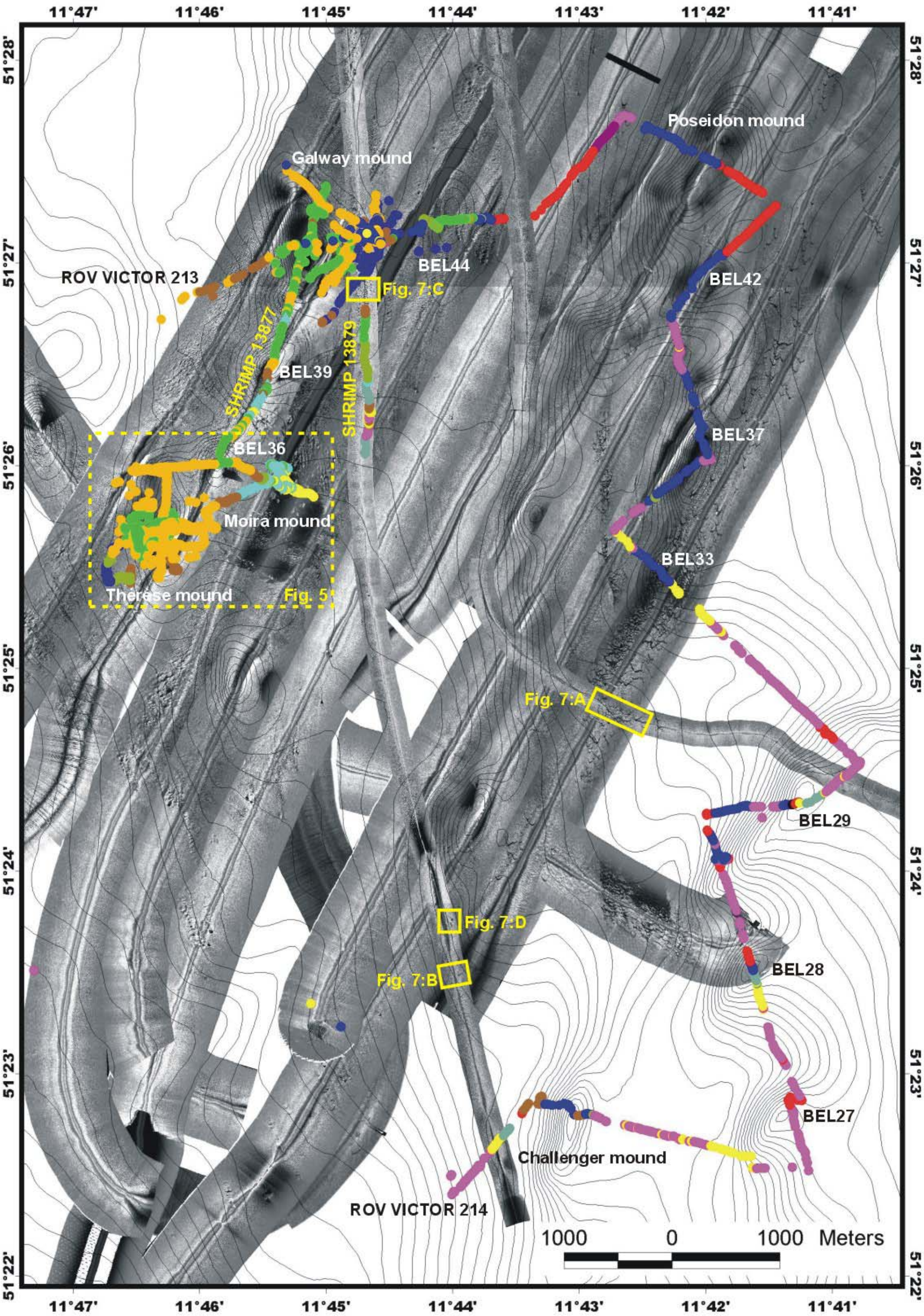


Fig. 17a. *This map presents facies interpretation of the video survey tracks overlaying remote-sensed imagery (100/410kHz side-scan sonar and multibeam bathymetry contours). Video data includes all video surveys undertaken in the study area with ROV VICTOR 6000 & SHRIMP video systems (see Appendix 3 for details).*

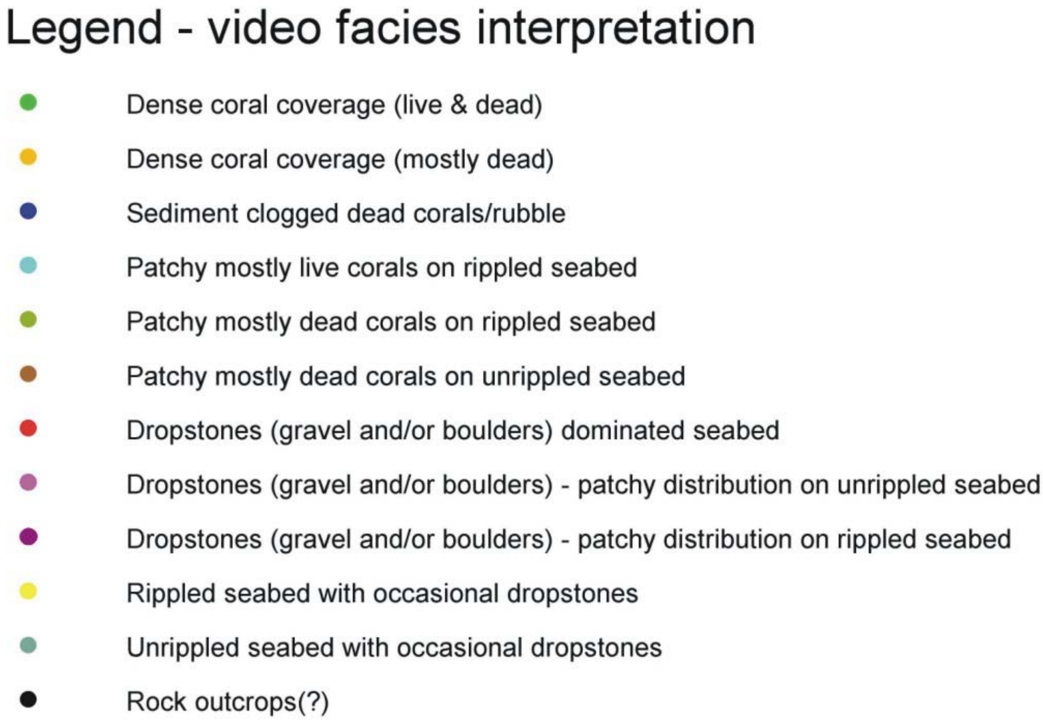


Fig. 17b. *Legend for the facies interpretation of the underwater video survey tracks presented on Fig. 17a.*

Video truthing allows an assessment of sediment wave mobility. Sediment waves that are active at present are superimposed by current ripples that show similar crest alignment, therefore indicating that both type of bedforms were formed under the same current direction and probably represent peak and normal flow conditions respectively. Most of the waves within the sediment wave fields at the lower and upper flanks of the giant mounds have been stabilised by corals and associated biocommunities, with corals growing preferentially on wave crests (Fig. 19b).

BEL44 shows a good example of a rapid transition from uniform backscatter representing rippled or current swept sand sheets to a sediment wave field at the lower flanks of the mound (Fig. 17 & 20b). Due to the low topography of this mound (c.40m) sediment waves migrate over the mound's summit. Moira Mounds can be observed on the lower south-eastern flank of this mound. These Moira Mounds possess long (c.150-500m) tail-like structures aligned in south-north direction representing down-current sediment wave trains.

<u>Barchan dune facies</u>
The distribution of barchan dune forms is limited to the eastern part of the Belgica mound province. Side-scan sonar imagery reveals an extensive barchan dune field stretched in a SSW-NNE direction along the eastern edge of the mosaiced area. This implies active sediment transport over the eastern flanks of the half buried mounds. Bedforms orientation provides evidence for strong northward flowing bottom currents. Dunes show larger dimensions at the lower stoss flanks of the mounds and decrease in sizes while migrating over the upper flanks and mound's crests (e.g. BEL33). Therefore

wavelengths of observed dune forms vary from 10 to 70m. Dunes show denser distribution in the proximity of BEL33 and become sparser to the north-east of BEL33. The main barchan dune field goes over the tope of BEL33, covers the eastern flank of BEL37 and continues as far north as the southern edge of the Poseidon Mound, followed by a sharp transition to the light toned uniform backscatter. Smaller areas of barchan dunes development are observed further to the north.

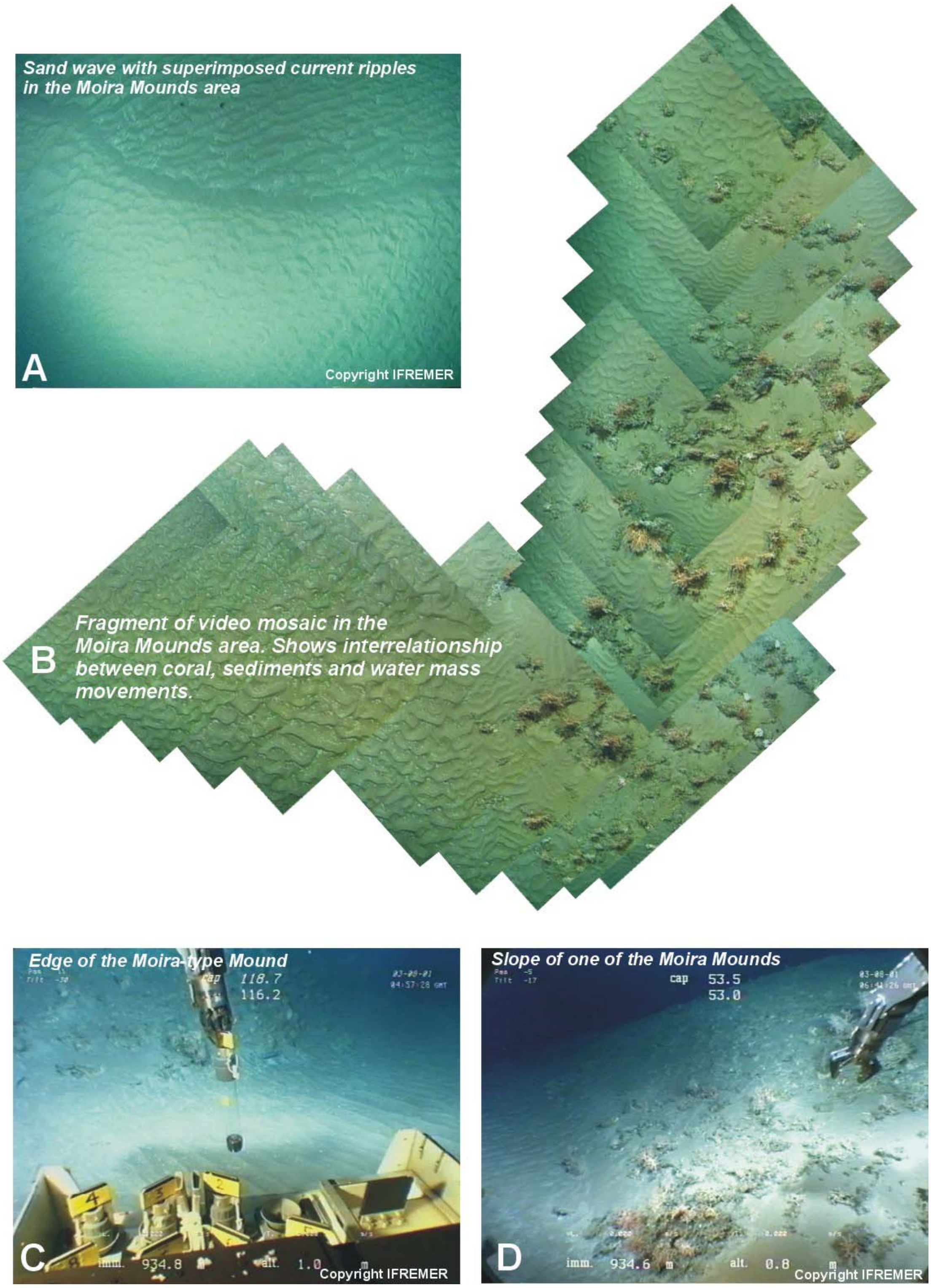


Fig. 18. *Fragment of video mosaic in the Moira mounds area and video highlights. (All images © IFREMER)*

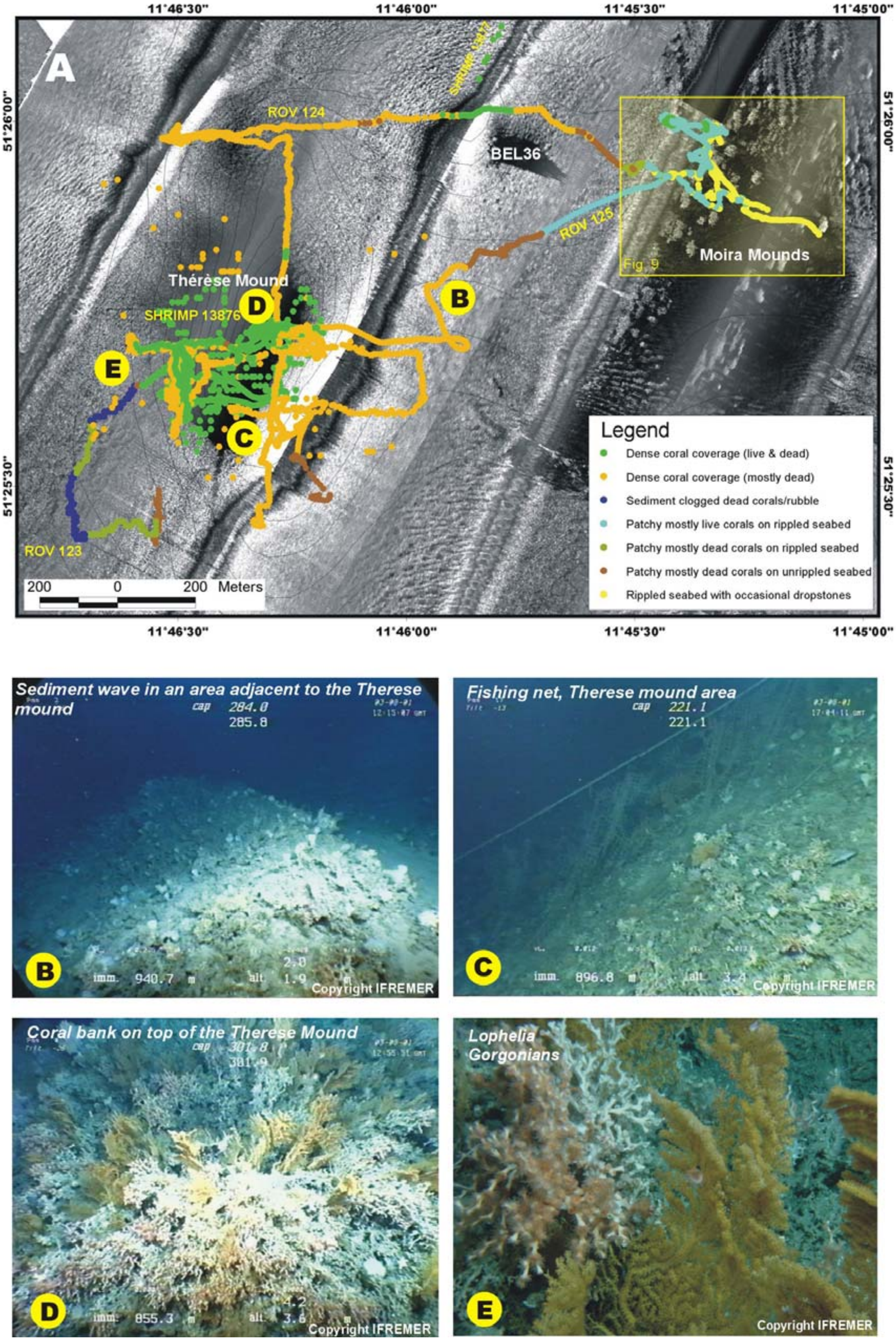


Fig. 19. *Thérèse and Moira video facies interpretation overlaid over 100kHz GeoAcoustic side-scan sonar mosaic. Analysed video data includes: ROV VICTOR dives 123, 124 and 125, and SHRIMP dives 13876, 13977. See also video highlight images (a - d © IFREMER).*

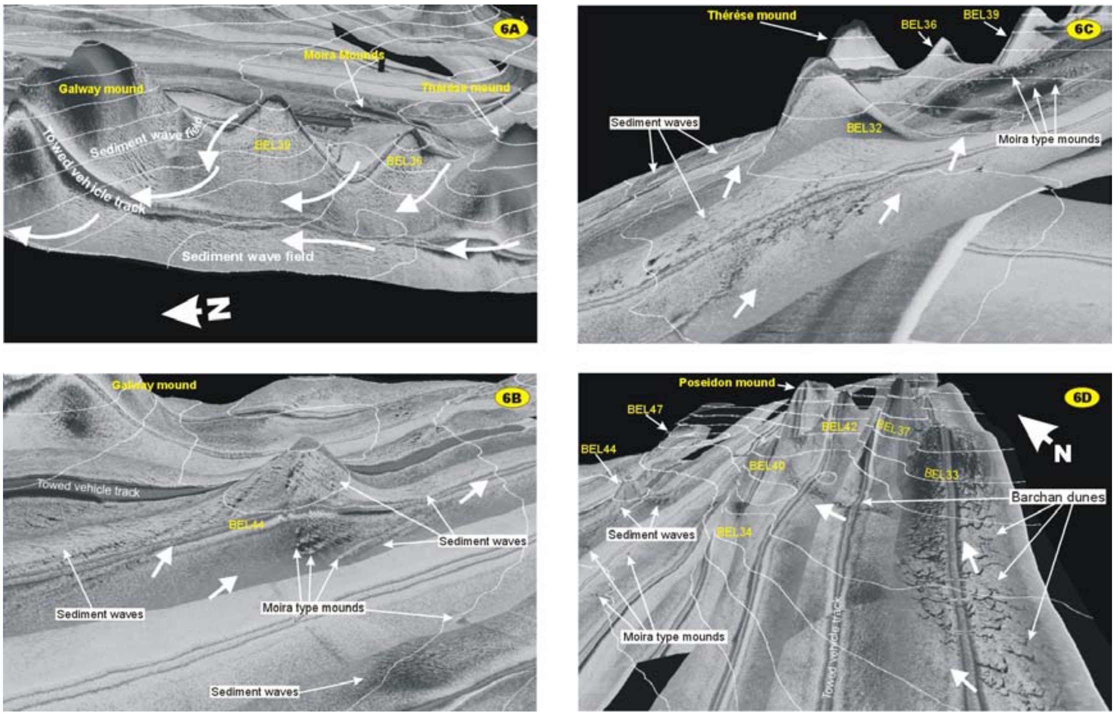


Fig. 20. *These images show a three-dimensional prospective of 100kHz GeoAcoustic side-scan sonar mosaic draped over multibeam bathymetry. Location and viewpoint for each of the 3D images is shown on Fig. 16. Notice distribution and variation in bedform type and dimensions on mound flanks and between mound areas. White arrows indicate benthic current directions derived from bedforms interpretation. Thin white curves show multibeam bathymetrical contours.*

A relatively narrow zone (c.150m) of barchan dunes runs in a south-north direction following the isobaths west of BEL33 and BEL37 to the base of BEL40 (Fig. 16). The orientation of dunes in the upper field (over BEL33 and BEL37) show a NNE sediment transport direction while in the field west of BEL37 it indicates a northern sediment transport.

A 410kHz side-scan sonar highlight (Fig. 21a; see Fig. 16 for location) shows a zone of barchan dune development. Solitary forms are evident at the edge of the field whereas the centre of the field shows the bedforms combining into ridges. Low points in the ridges occur where dunes meet so that the wings of the dunes feed sediment behind to the next row of dunes. At the southern edge of this barchan dune field, dunes migrate over gravel ridge dominated seabed. Gravel ridges are imaged as thin wavy lines of dark toned backscatter (Fig. 21a & 21b).

About 16 barchan dune forms migrate over the seabed directly to the east of BEL30. Wavelength varies between 30 and 70m, and height of few meters. More to the east and north-east barchan dunes develop into extensive fields as described above (Fig. 21b).

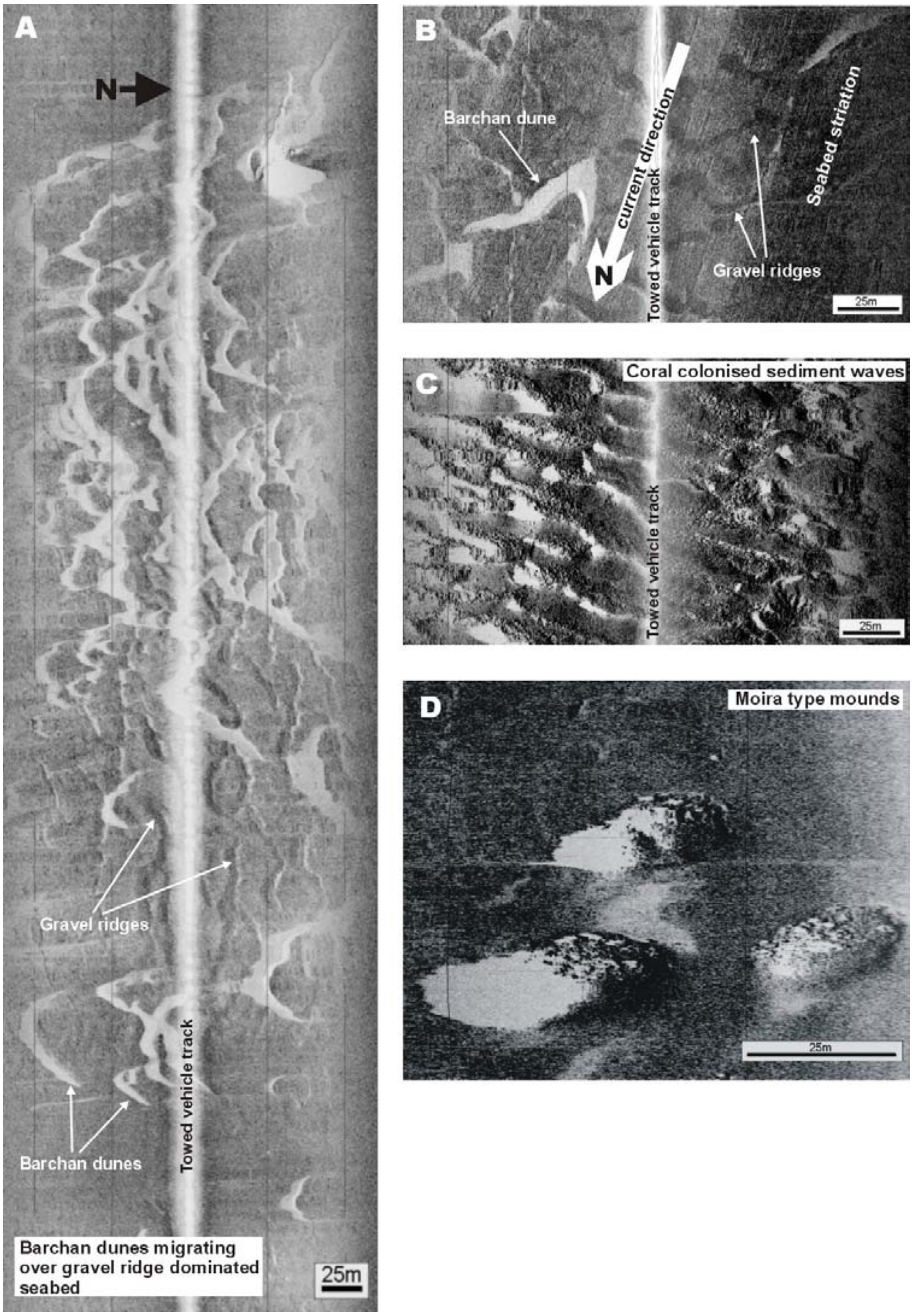


Fig. 21. *410kHz side-scan sonar highlight images. Location of images is shown on Fig. 16. (a) This image shows a zone of barchan dune (white backscatter) development migrating over gravel ridge (black backscatter) dominated seafloor in the area between carbonate mounds. (b) Image shows barchan dune forms composed of sandy material (white backscatter) migrating across gravel ridges (black backscatter), as well as seabed striation caused by intense current velocities. (c) This image shows that the surface morphology of the lower flanks of the carbonate mounds is strongly controlled by sediment waves. High backscatter spots on the surface of the waves are caused by coral and associated bioaccumulations. White backscatter represents acoustic shadows cast by wave crests. This image is from the south-eastern flank of the Galway mound. (d) Three closely spaced Moira type mounds are imaged in the area between giant carbonate mounds. Moira mounds possess a lumpy structure with spots of high backscatter indicative of coral colonisation. This example exists on a gravely substrate at the edge of a gravel ridge field. Areas of white backscatter represent acoustic shadows, implying that mounds are sufficiently elevated above the surrounding seabed*

<u>Gravel ridge facies</u>

Two types of gravel ridges were observed within the mosaiced area: ridges with lunate and linear crest alignment. Ridges with lunate crest alignments develop in the eastern part of the province, and in most cases coexist with superimposed barchan dune forms composed of sandy material (white backscatter on Fig. 21a & 21b). Gravel ridges are represented here by sinuous crested lines. They show predominantly sinuous out of phase plan pattern with some bifurcation and have a wavelength varying between 10 and 40m. The 410kHz imagery implies that some sandy sediment (white backscatter) is deposited on the leeward sides of the ridges. Gravel ridges occur in the areas with very active hydrodynamics, which is indicated by seabed striations (Fig. 21b).

Ridges with linear crest alignment were observed at the northern and north-western far ends of the Belgica mound province. The northern part of the mosaic area shows an extensive field of sand and gravel ridges (ribbons). These ridges possess a SE-NW elongation therefore indicating currents flowing from SSE to the NNW. In parts of this zone, sand ridges are replaced by barchan or transverse dune forms indicating fluctuations in the benthic current strength. An area of apparently buried linear gravel ridges also exists in the Moira Mounds area to the east of Thérèse Mound (Fig. 16 & 19a), where a series of SSE-NNW oriented features can be observed. These features are c.10-20m wide and distributed with an average spacing of 30m.

<u>Sand ribbon facies</u>

Sand ribbons are distributed throughout the mapped area. These are relatively narrow features with straight to wavy crest alignment. They normally elongated in the SSE-NNW direction indicating northern sediment transport direction and possess lengths from c.150 to 900m. Sand ribbons in the vicinity of mounds show basal currents directional change depending on the local topography. Most of sand ribbons tend to occur in groups, although 100kHz side-scan sonar shows that solitary examples may also take place. Video truthing shows that in some places current induced sand ripples are superimposed on the body of the sand ribbons. Ripple crests show orientation perpendicular to the elongation of the sand ribbon, therefore indicating the same direction of basal current that was responsibly for formation of bedforms of both scales. This suggests that sediment transport in the form of sand ribbons is an active process, which implies that currents with the speeds up to 100cm s^{-1} (Belderson et al., 1982) required for their formation might still be contributing to the hydrodynamic regime of the province.

<u>Moira Mound facies</u>

Moira Mounds are relatively small (tens of metres across and a few metres high) coral mounds that occur in the areas between giant carbonate mounds (Fig. 20c), with some apparent examples located near BEL44 on Fig. 16 & Fig. 20b. These features may represent an early stage of mound development and, based on seismic evidence, are much younger than their giant carbonate mound counterparts. Side-scan sonar imagery indicates that the Moira Mounds preferentially occur in the areas with active hydrodynamics: on the *upstream margins of sediment wave fields, and far end of gravel ridge or barchan dune dominated seabed. The facies map of the study area (Fig. 16) indicates that the majority of the Moira Mounds are located within the area of the western mounds where environmental conditions seems to be optimal for dense coral colonisation and contemporary coral growth. Most of the Moira Mounds are sub-circular in shape, showing elongation in the direction of the dominant current flow. Moira Mounds tend to occur in groups, although solitary examples were also documented (Fig. 16). Although only a limited number of Moira Mounds was mapped with 100 and 410kHz side-scan sonar, the survey with 30kHz TOBI side-scan sonar (Huvenne et al., subm.) showed that hundreds of Moira Mounds exist in the study area. This indicates the specific favourable environmental conditions existing within the western mound area that supports initiation and development of coral structures.*

By using high-resolution 410kHz side-scan sonar imagery the acoustic signature for coral accumulations on top of the Moira Mounds was detected. Figure 21d shows three closely spaced Moira Mounds, which possess a lumpy structure with spots of high backscatter indicative of coral colonies. The mounds are sub-circular with the uppermost mound showing bimodality in form suggesting that it may have formed as a result of intergrowth between two mounds. This example exists on a gravelly substrate at the edge of a gravel ridge field (see location of Figure 21d on Figure 16). Video imagery shows that mounds have a slope gradient of about c.15 degrees (Fig. 18d).

The most studied Moira Mounds are located to the east of the Thérèse Mound (see Fig. 16 & 19). This area was mapped with 100kHz side-scan sonar and truthed with detailed ROV "Victor 6000" video observations (Olu-Le Roy et al., 2002). These Moira Mounds occur within an area of sediment wave development that covers longitudinal gravel ridges. It is speculated here that the gravel ridges probably formed the original substrate for coral colonisation that has been subsequently buried. Wave crests within this field have an east-west orientation indicating that Moira Mound development occurs under a northerly flowing current regime. Most of the mounds show elongation with the regional current flow in the south-north direction.

An interpretation-facies map of ROV video ground-truthing is presented on Figure 22 that shows that the Moira Mounds represent accumulations of living and dead coral frameworks filled with sediment and occur in areas of active sand transport on rippled sand sheets and the upstream margins of sediment wave fields. Moira Mounds show patchy to dense mostly live coral coverage on their summits. Once coral colonies gained a “footing” in these areas, coral colonies trap sand and build positive features for further coral development on the seafloor. In doing so, corals become elevated above the benthic-boundary layer gaining access to fast flowing waters (with increased nutrient flux and lower bedload sediment transport) thus stimulating further biological growth, sand entrapment and increases in mound elevation.

Between mound areas are represented by rippled sand sheets with occasional small dropstones and, in places, patchy live coral cover. In some areas, current ripples are superimposed on larger scale current-induced *bedforms (low angle sand waves). Current ripples also shape the surface morphology of the sediment infilling coral framework on mound flanks and summits. Video imagery (Figure 18) show evidence of interactions between strong basal current flow regimes with active sand transport and coral sediment entrapment being the dominant mound growth mechanism. Development of extensive rippled sand sheets on mound flanks and in between mound areas provides evidences that mounds act as obstacles for bottom currents therefore enhancing their strength. Occurrence of the Moira Mounds in the areas of rippled sand sheets development within the sediment wave fields implies benthic current strength of approx. 60cm sec^{-1} (Southard & Boguchwal, 1990).*

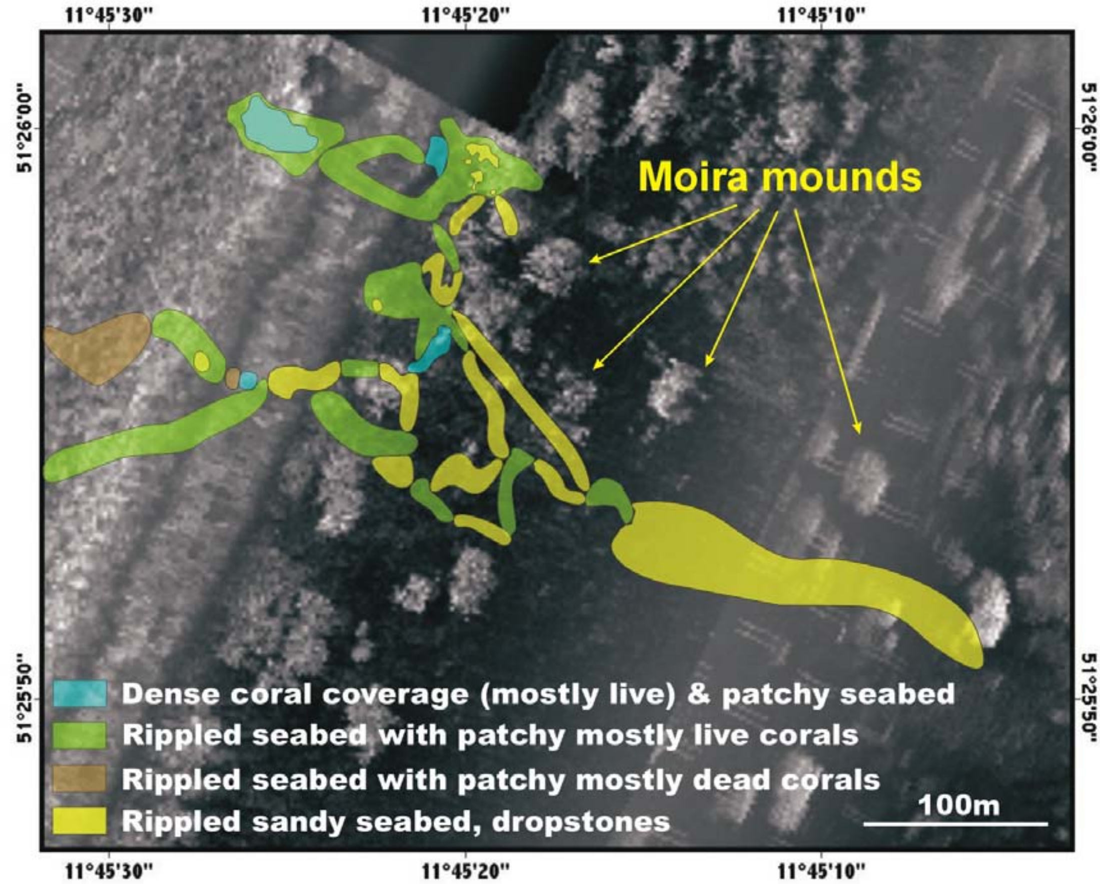


Fig. 22. *Moira mounds video facies interpretation (ROV VICTOR 6000 dives 124 & 125) overlaid over 100kHz GeoAcoustic side-scan sonar mosaic*

<u>Belgica mound facies</u>

The location of the giant mounds (and hence the giant mound seabed facies) is best documented from the multibeam and sub-bottom profiler data. Furthermore, sub-bottom profiler records interpreted together with the available ground-truthing information allows a distinction between active and retired mounds to be made (see also ROV-based conclusions in Foubert et al., subm.). This interpretation was based on the nature of the seabed reflector. Sub-bottom profiler records show two types of seabed reflectors of the mound's surface: a solid seabed reflector with the same characteristics as the surrounding seabed and a diffuse reflector. Video and sampling surveys of *several mounds suggest that a diffuse reflector occurs where mounds are topped with exposed coral framework (see below). In most cases this will imply the coexistence of both dead and live coral populations. Mounds possessing a solid seabed reflector normally show no evidence of coral life and are dominated by coral rubble or sediment clogged dead coral framework. In this way, the 3.5kHz sub-bottom profiler record provides a rough estimate of mound cover and coral ecosystem "health". Appendix 3 lists all mounds imaged on the 3.5kHz sub-bottom profiler in the central Belgica mound province, and summarises where available ground-truthing information on particular mounds. Ground-truthing information has been collected for 9 mounds imaged on the sub-bottom profiler that has been extrapolated to mounds that were imaged on the sub-bottom profiler only (Appendix 3).*

Side-scan sonar data provides details of the surface morphology of the upper and lower flanks of the mounds. Side-scan sonar imagery reveals that mound morphology is strongly dictated by prevailing basal current activity. Most of the outcropping mounds of the western mound belt are largely covered in sediment waves. The type and size of bedforms changes depending on the local topography related to mound proximity and position up the flanks of the mounds (Fig. 20a & 20b). 410kHz side-scan sonar data revealed sediment waves with coral accumulations (Fig. 21c). Mounds of the eastern mound belt possess a half buried morphology due to onlap of the contourite drift deposits. Drifting sediments are superimposed on the eastern flanks of the mounds in the form of barchan dunes, which in some cases (e.g. BEL33 on Fig. 20d) migrate over the mound summits.

Appendix 3 and the facies map of the study area (Fig. 16) clearly show that at present mounds of the eastern belt of the province are retired (purple facies) and mounds of the western belt are active (red facies) in terms of the health of the coral cover and hence mound growth. The two most representative 3.5kHz sub-bottom profiles are indicated by the dashed lines on the facies map (Fig. 16) and presented with some interpretations on Figure 23.

Line 1 (Fig. 16 & 23) images two carbonate mounds (BEL30 & BEL32) and contourite drift, which, on the sub-bottom profiler data, appear as a well-stratified sediment succession. The south-eastern flank of BEL30 is partly covered by this drift, another carbonate mound immediately to the east of BEL30 has been totally buried by this drift and the area between BEL30 and BEL32 is filled with the contourite drift deposits with sediments onlapping on the south-eastern slope of BEL32. This mound is bounded from north-west by a seabed depression (gully) between BEL32 and Thérèse Mound. The first mound on this line (BEL30) possess a solid seabed reflector, while BEL32 shows a diffuse seabed reflector, which implies that BEL30 is retired, and BEL32 is active at present (see Appendix 3).

Line 2 (Fig. 16 & 23) images the westernmost mounds of the Belgica province including the eastern flank of BEL47, an interval of gently sloping seabed and four outcropping carbonate mounds: Galway Mound, BEL39, BEL36 and Thérèse Mound. Each mound is nearly symmetrical in a NNE-SSW direction, showing highly diffuse seabed reflectors especially at their summits.

Groundtruthing reveals these mounds are heavily colonised by corals (see Appendix 3) and represent the best examples of active mounds within the province.

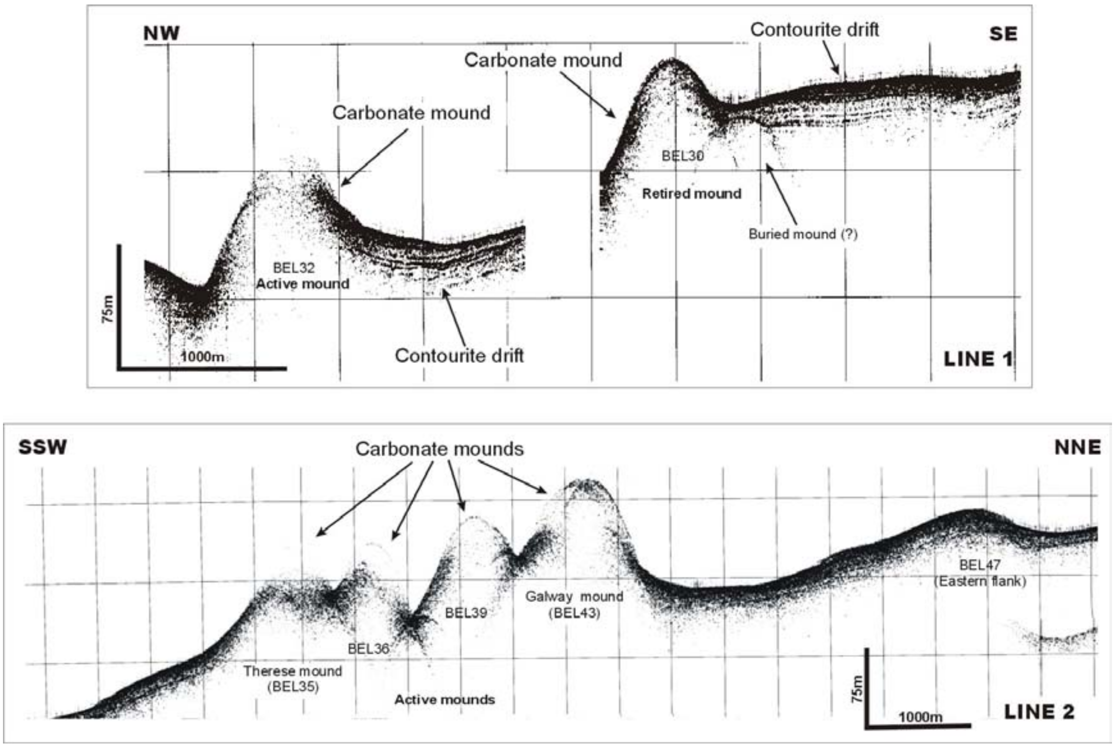


Fig. 23. 3.5kHz sub-bottom profiler lines. Location of profiles is shown on Fig. 16. LINE 1: images two carbonate mounds (BEL30 & BEL32) and contourite drift sequences that are characteristic for the study area. Solid seabed reflector of BEL30 suggests that this mound is retired at present, while diffuse reflector of BEL32 suggests that this mound is active. LINE 2: shows few active mounds of the western mound belt including Thérèse and Galway mounds.

Eight mounds were video ground-truthed within the eastern area of the province, which can be characterised as "retired" mound belt, as all mounds here show a lack of live coral cover. The mounds flanks and summits are mostly composed of sediment-clogged dead coral frameworks or coral rubble. A general description of video transects across these mounds is presented below paying particular attention to evidence for sediment transport (see Fig. 17 & 24). Video facies descriptions are also summarised by Foubert et al. (subm.).

The Challenger Mound is characterised by sediment clogged dead coral and coral rubble facies. No living framework-building corals were observed on this mound although gorgonians and sponges were found growing on dead corals on the flanks and summit of the mound. At the lower eastern flank patchy dead corals and coral rubble clogged within rippled sand sheet were encountered. The orientation of ripples indicates active sediment transport to the NNW, which implies that currents follow around the contours of the lower flank of the mound.

Lower south-western flank of BEL27 also showed rippled sands. The orientation of ripple crests indicates that currents are flowing to the NNE, *following the topographical contours of the lower western flank of the mound. The orientation of comet and scour marks at the lower southern flank of the mound shows westerly-directed currents implying that regional northerly flowing contour currents are being deflected and intensified to the west by the mound's topography. The northern upper flank of BEL27 shows a dense dropstones distribution, implying further active seabed erosion on this side of the mound also.*

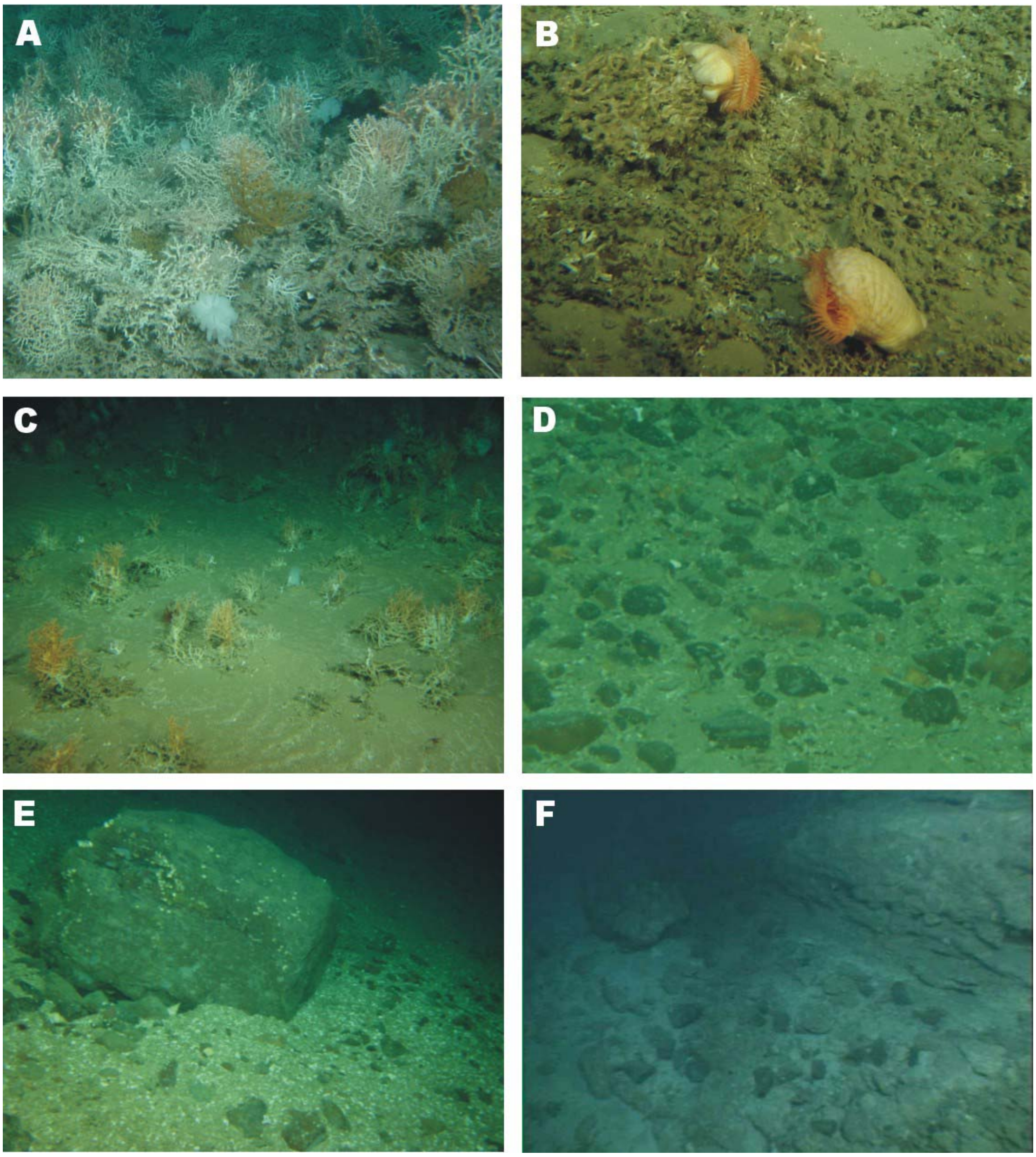


Fig. 24. Video highlights of different facies characteristic for the Belgica mounds study area. (a) Dense coral coverage (live & dead); (b) Sediment clogged dead corals/rubble; (c) Patchy mostly live corals on rippled seabed; (d) & (e) Dropstones (gravel and/or boulders) dominated seabed; (f) Hardground outcrops (All images © IFREMER)

The southern flank of BEL28 also shows rippled sands migrating in the form of low relief sediment waves over a current swept seafloor typified by a coarser gravel lag. The orientation of the current-induced ripples superimposed on *sediment waves and the orientation of comet marks behind dropstones in between wave areas indicates south-westerly flowing currents. The summit and flanks of this mound are represented by background uniform backscatter on 100kHz side-scan sonar. Video truthing suggests that the upper southern flank of BEL28 is represented by muddy bioturbated seabed, with the summit of this mound (c.690m water depth) possessing sediment-clogged dead coral cover. No live framework-building corals were observed on this mound although gorgonians and antipatharians growing on dead coral framework and dropstones were present. Video imagery shows the presence of dropstones on the mound's summit embedded within sediment-clogged coral cover implying strong seabed erosion by bottom currents. This may be one of the reasons for the mound's retirement.*

Lower south-western flank of BEL29 shows a dropstone dominated seabed. Areas between dropstones are filled with carbonate-rich sediment probably composed of broken shells and coral rubble. The western flank of BEL29 shows sediment-clogged dead coral cover. Mid-slope areas contains a c.200m area with patchy dropstones, that are embedded within coarse-grained carbonate rich sediment, suggesting erosion and reworking of previously existed coral cover. Extensive hardgrounds are exposed on the upper western flank of BEL29 suggesting strong seabed erosion and exposure of the lithified internal mound sediment. Erosive current may account for an absence of coral settlement in this area. The possible hardground outcrop is followed for c.40m to the east by very dense distribution of boulder size dropstones. Rippled sands drape dropstone-dominated seabed at the summit of the mound. Orientation of the ripple crests and current induced features surrounding exposed dropstones suggests northerly currents flowing over the mound's summit. Similar situation develops at the upper eastern flank of the mound.

To the northeast of the BEL29 summit, the dive track crosses the 410kHz side-scan sonar line. The light toned uniform backscatter on the side-scan sonar imagery with apparent boulder and ridge-like structures is represented on the video imagery with relatively flat muddy bioturbated seabed with patchy distribution of boulder size material.

Video imagery of the lower southeastern flank of BEL33 shows active sediment transport in the form of transverse and barchan sand dunes in accordance with 100kHz side-scan sonar data. The summit and western flank of the mound demonstrate dead sediment clogged corals and coral rubble cover. This mound does not reveal any framework-building corals only shows epifauna (e.g. actinians) that uses dead coral framework as an attachment substrate.

Flanks of BEL37 also show dead sediment-clogged coral coverage. The southern flank of BEL37 shows no evidences of live corals or epifauna. The northern upper and mid flank of the mound demonstrates the abundance of soft corals (e.g. gorgonians). BEL42 at its flanks and summit shows patchy to dense dead coral cover, which corresponds to background uniform backscatter on 100kHz side-scan sonar (Fig. 17). In some areas this is more *reminiscent of the coral rubble facies. Both corals and coral rubble are sediment clogged and show patchy growth of gorgonians.*

The Poseidon Mound is the biggest mound of the eastern mound belt, the eastern flank of which is covered in coarse gravel lag. The summit and the western flank of the mound show dense, mostly dead, coral cover. However, very sparse live Madrepora oculata *is found growing on the mound's summit. Mostly dead coral framework supports the growth of epifauna (e.g. antipatharians, sponges, anemones). Video imagery of the lower western flank of Poseidon Mound confirms 100kHz side-scan sonar interpretation that sediment waves are colonised by corals although corals are mostly dead at present. Coral preferentially grow on the sediment wave crests with the very limited growth in wave troughs. It is plausible to assume that these sediment waves are not active at present, as they have been stabilised by coral growth.*

In contrast to the eastern mounds, western mounds in the Belgica mound province showing dense coral coverage with a large percentage of live colonies of Lophelia pertusa *and* Madrepora oculata *on their summits. Lower flanks of the mounds show mostly dead coral cover with the sediment clogged corals and coral rubble at mound's basements (see also Foubert et al., subm.).*

Mapping of the Thérèse Mound (Fig. 17 & 19), suggests that the surface morphological details of this mound show distinct relationships to sediment waves that have become colonised and stabilised by coral and associated communities (Fig. 19b). On the lower flanks of the mounds, corals colonise the crests of sediment waves with limited growth in the troughs, therefore taking advantage of stronger current and nutrient flux. Coral density increases up the mounds (Fig. 19c) until sediment waves become fully stabilised and corals continue to grow into coral banks (Fig. 19d). Coral population is mainly represented by Lophelia pertusa *and* Madrepora oculata*. Coral growth supports extensive epifauna (e.g. sponges, gorgonians: Fig. 19e), and a wide range of benthic organisms, as well as deep-sea fishes (Olu-Le Roy et al., 2000). Underwater video imagery also provides evidences of the deep-sea fishing activities in the study area (e.g. stranded nets), which may affects the coral reef ecosystems vitality (Fig. 19c).*

The observations from the Thérèse Mound are also typical for most active mounds of the western mounds in the Belgica mound province (including BEL36, BEL39, BEL44 and the Galway Mound). BEL36 shows dense live and dead coral coverage with patchy unrippled seabed at its lower and mid flanks. Live coral are documented on the summit of the mound. The northern slope of BEL39 shows dense live and dead coral coverage. On the top of the mound a well-developed but predominantly dead coral framework is observed that may suggest limited erosion. The southern slope is characterised by a smooth seabed with patchy dead and living coral cover.

Video imagery of the Galway Mound shows that the sediment waves imaged on 410kHz side-scan sonar at the eastern lower flank of the mound are stabilised by coral growth (Fig. 21c). Corals are mostly dead at present, but in *places show rather dense coverage. Corals show a preference for colonisation on wave crests, and are very sparse in the wave troughs and coexist with abundant population of sponges and soft corals (e.g. gorgonians and antipatharians). The seabed between the coral-colonised sediment waves show unrippled sand. The lower north-eastern flank of this mound also shows dense but mostly dead coral cover whilst the upper flanks and the mound's summit show dense, mostly live coral cover. The dominant coral species on this mound are* Madrepora oculata *and* Lophelia pertusa*. Live corals grow on dead coral skeletons that also form a substrate for sponges, gorgonians and other epifaunal growth. The lower eastern flank of the mound is dominated by sediment-clogged corals and coral rubble facies. In some places, areas of sediment-clogged corals are surrounded by rippled sands whereas further a field active sand transport is in the form of rippled sand sheets and low relief sand waves. This implies that the health of the coral population in the vicinity of the mound was probably influenced by active sediment transport, and corals could not keep up to speed with the burial action of migrating sediment.*

BEL44 is the most easterly located mound of the western "active" mound belt (Fig. 16). The lower eastern flank of BEL44 shows sediment-clogged coral rubble facies with occasional dropstones (Fig. 17). This facies dominates the flank of the mound from c.910m to c.900m water depth. In places it is apparent that corals colonise previously mobile sediment wave structures. Further upslope from c.900 to c.860m water depth mound's upper flanks and summit show dense mostly live coral coverage. Live corals coexist with dead corals and support epifauna of sponges, gorgonians and antipatharians. Live coral population is dominated by Madrepora oculata*, although* Lophelia pertusa *was also observed. Rippled sands infilling the space between corals implies active sediment transport over the flanks of the mound and possibly in parts of the summit where coral coverage is not too dense. A combination of side-scan sonar and video imagery implies that active sediment transport in this area supports coral ecosystem with sand entrapment and further biological growth being the dominant driving factors of mound growth.*

3.4. Zone 3: Hovland/Magellan Mounds (northern margin)

Maps 10 to 15 of Area 1 comprise the Hovland and Magellan mound provinces. In general this side-scan mosaic shows a homogeneous grey seabed, with a slight gradation in backscatter from the SE to the NW (lower to higher backscatter) with isolated high relief, high backscatter features present in the south of the mosaic representing carbonate mounds (Hovland Mounds) (Fig. 25).

The Hovland Mounds are mostly large, multiple, complex structures. They can be divided in 2 types: one type of Hovland Mound appears as quite sharp ridges, often forked, with several summits, relatively steep flanks and a clear acoustic shadow. They can be up to 4km long. Propellor mound (Fig. 26) is a good example of these. The other type consists of rounder, smoother, less sharp mounds with a less obvious acoustic shadow. They are associated with extensive patches of high backscatter. One of this type of mound has been sampled through boxcoring. The boxcore taken on the top (M2002-02) contained several large dropstones, and coral debris in a muddy matrix. This seems to indicate that the mound top consists of older material that has been exposed by erosion. The box taken in the high-backscatter zone (M2002-03) contained sandy materials with shell fragments in the upper centimetres, but further down the core a very stiff clay was found and could be responsible for the high backscatter. Some of the Hovland Mounds are surrounded by clear moats, recognisable as a 'halo' or rim of slightly darker backscatter around them.

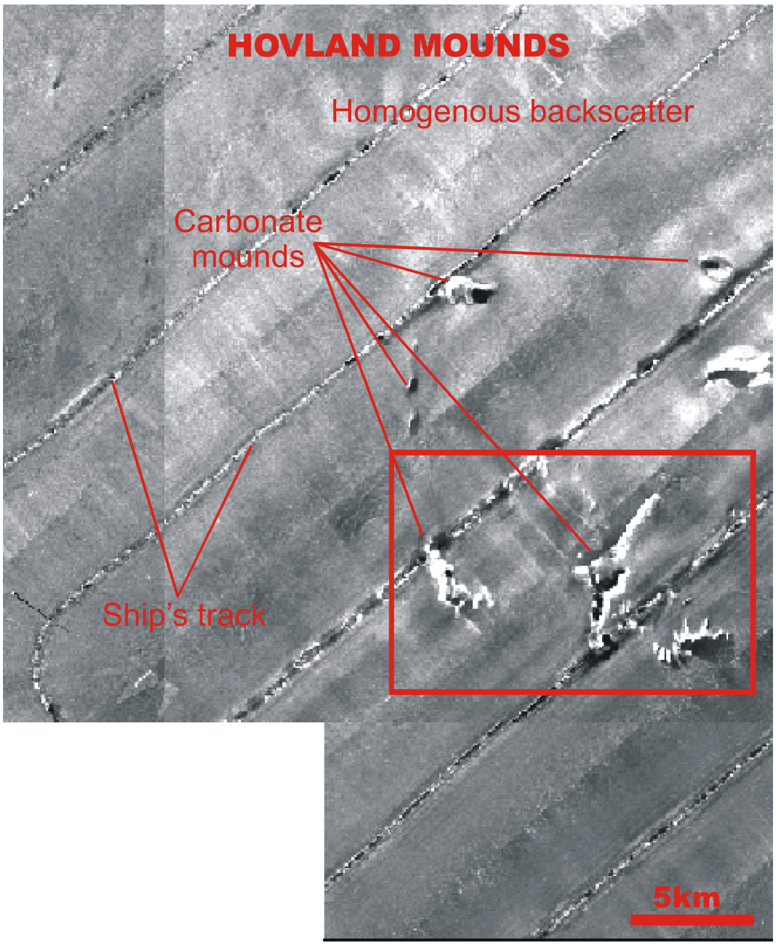


Fig. 25. *Uniform moderate backscatter seabed with high relief mound features evident.*

The moats are only vaguely discernible from slight variations in backscatter strength as the seafloor slopes away or towards the side-scan sonar. Also, further to the centre and the north of the Magellan province, comparable vague variations in grey levels can be interpreted, and with the help of the bathymetric information, as depressions, representing traces of filled moats located deeper in the sedimentary succession. Again, the general orientation of these patterns is north-south.

In general, the Magellan province appears on the TOBI side-scan imagery as an area with a homogeneous acoustic facies of medium, although rather 'grainy' backscatter strength. Boxcores and seabed photographs/video fragments identify this facies as bioturbated muddy or silty hemipelagic sediments (Kenyon *et al*., 1998). The seafloor seems to be more or less featureless, apart from the obvious mounds that reached the seabed. Evidence of present-day erosion or sedimentation patterns, such as bedforms, are absent. Against this background, the mounds are clear features, even if they are much smaller than the giant structures found in the Hovland province. Most of them have a strong backscatter on the flank facing the instrument, both due to their slope and to their composition. Some mounds are rather smooth and do not create a strong shadow. These structures are buried under a sediment drape, as can be interpreted from the seismic data.

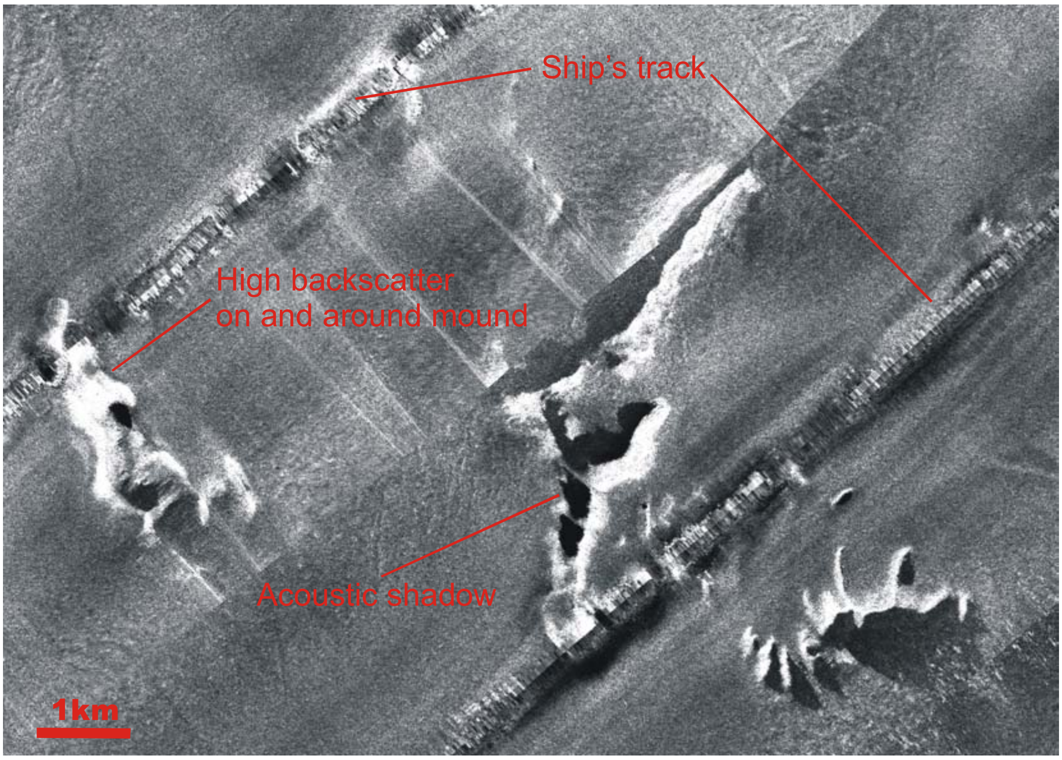


Fig. 26. *Hovland Mound details. The central mound is the Propellar Mound*

<u>*3.4.1. Further analysis and comparison with other datasets*</u>

A detailed appraisal of the TOBI side-scan sonar within the context of existing data is presented by Huvenne et al. (subm.) with relevant text and observations are reproduced below:

In general, the Magellan/Hovland region appears on the TOBI sidescan sonar imagery as an area with a homogeneous acoustic facies of medium backscatter strength (Fig. 27). The intensity seems to decrease slightly from the north to the south, while the backscatter texture becomes smoother in that direction. This facies could be identified as bioturbated muddy or silty hemipelagic sediments, often with a watery or 'soupy' upper layer of a few cm, containing a high concentration of foraminifera. The gradual change from north to south is probably due to a gradual change in grain-size, sorting and compaction of the sediments. In the Hovland province, the seafloor is cut by 6 depressions or blind channels, generally running N-S (except for one which bends towards the NW; Fig. 27). They were also reported by Hovland et al.

(1994) who attributed them to bottom current erosion or to the escape of pore water or gases through the seafloor. De Mol (2002) suggested they were caused by current scouring, and interpreted their elongation direction as the result of a northward directed current. Apart from these channels and the obvious mounds with their associated, scoured moats, the seafloor appears relatively featureless. Evidence of recent erosion or sedimentation patterns, such as bedforms, is absent between these structures. A few pockmarks were found around 52°15'N, 12°30'W and around 52°04'N, 12°55'W, but the overall environment of the Magellan and Hovland mounds seems relatively quiet.

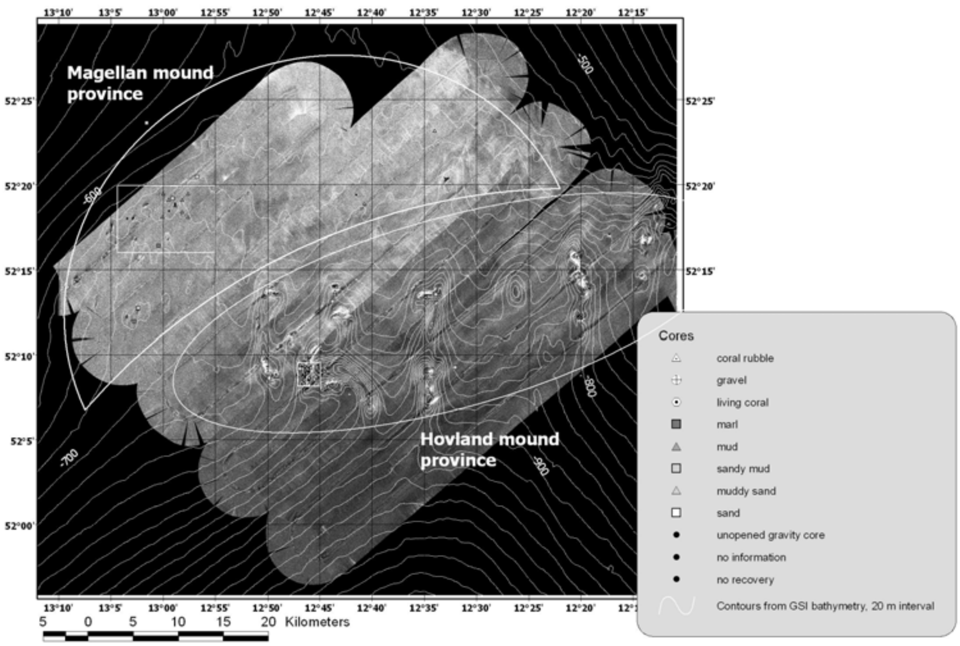


Fig. 27. *TOBI sidescan sonar mosaic of the Magellan and Hovland mound provinces. The bathymetric contours are derived from GSI data, and the core information was obtained from existing data sets, mentioned in the text. The rectangles indicate the positions of Fig. 28 and 30.*

Against this background the coral banks are clear features: they have a strong backscatter on the flank facing the sidescan, due to their slope towards the instrument and to their composition of (live) coral framework and coral debris (see below). An acoustic shadow can be seen behind the features. The Magellan mounds are relatively small (some 300 to 800 m across, and up to some 50 m above the present-day seabed), and some of them are less easily recognisable (Fig. 28). These mounds are smoother, have a less strong backscatter and do not create a strong shadow. They are interpreted as being buried already under a thin drape of sediments. In total, 19 covered mounds could be found, while 14 mounds still seemed to be active at the present-day seafloor. Seismic studies however, have shown that the Magellan province contains many more mounds (possibly more than 1000 structures, Huvenne et al., 2003), but that most of these are buried already under the embedding sediments.

The Hovland mounds on the other hand appear to be much larger, and in several cases they form elongated ridges. Their length can vary between 1700 and 3200 or even 5000 m, and their width ranges from 450 to 1200 m. The ridges have different orientations and may be forked, with spurs extending in different directions. Still, often there is a north-south directed component (spurs, or the ridge itself). Eleven large and 15 smaller mounds could be recognised on the sidescan sonar mosaics. De Mol (2002) studied seismic profiles through the province, which indicate that some of the mounds may have a common, subsurface base. He also found several buried Hovland mounds. Most of the mounds are located at the flanks or at the heads of the blind channels/depressions in the area. They can be grouped in 2 clusters : one on the northeastern flank of the area and one more to the centre.

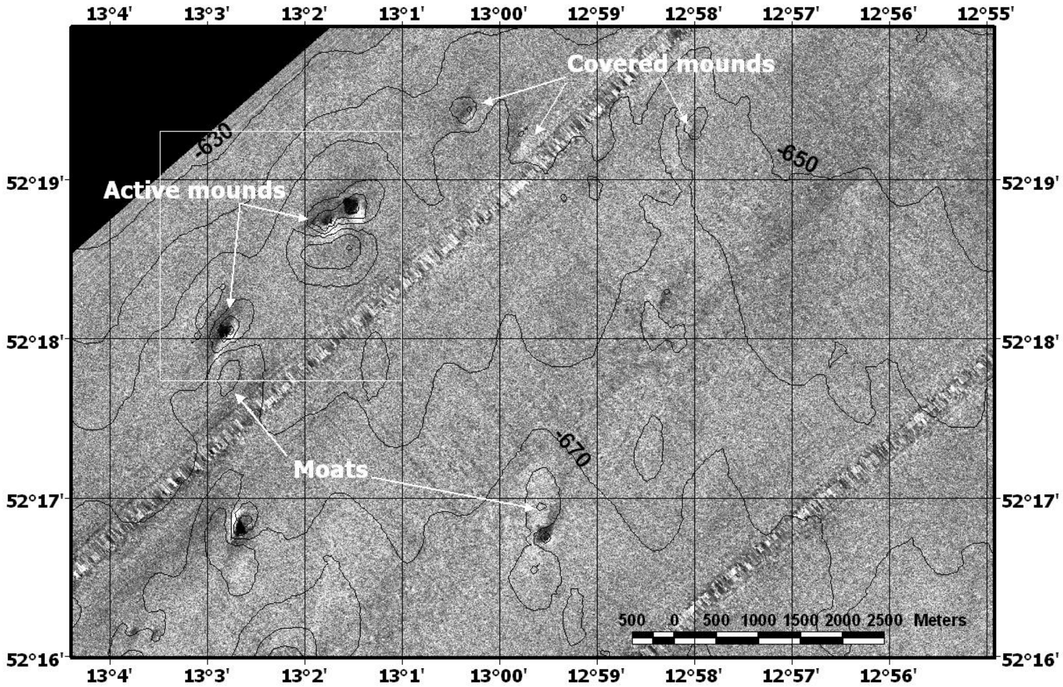


Fig. 28. *Detail of the TOBI sidescan sonar mosaic over the Magellan mound province, illustrating the seabed appearance of mounds and moats. Some of these are already covered by a drape of hemipelagic sediments. The bathymetry information is derived from the time-depth converted seafloor reflection mapped from 3D seismic data in the Magellan province (Huvenne et al., 2003). The box indicates the position of Fig. 29.*

Depressions, described as 'moats' can be found around most of the mounds. They were previously recognised from seismic data already (De Mol et al., 2002; Huvenne et al., 2003), and were attributed to the scouring action of currents. Especially around the Magellan mounds, the moats appear to be elongated in a N/S direction, possibly due to the action of a reversing current (Huvenne et al. 2003). And although most of these depressions are largely filled in nowadays, which indicates they might not be very active any more, with the help of the bathymetry data they still can be recognised in the sidescan images as subtle variations in backscatter (Fig. 28). Also some of the Hovland mounds have associated moats to their south and north, which *often merge with the blind channels. The most western depression even seems to be formed through the merging of several moats (Fig. 27).*

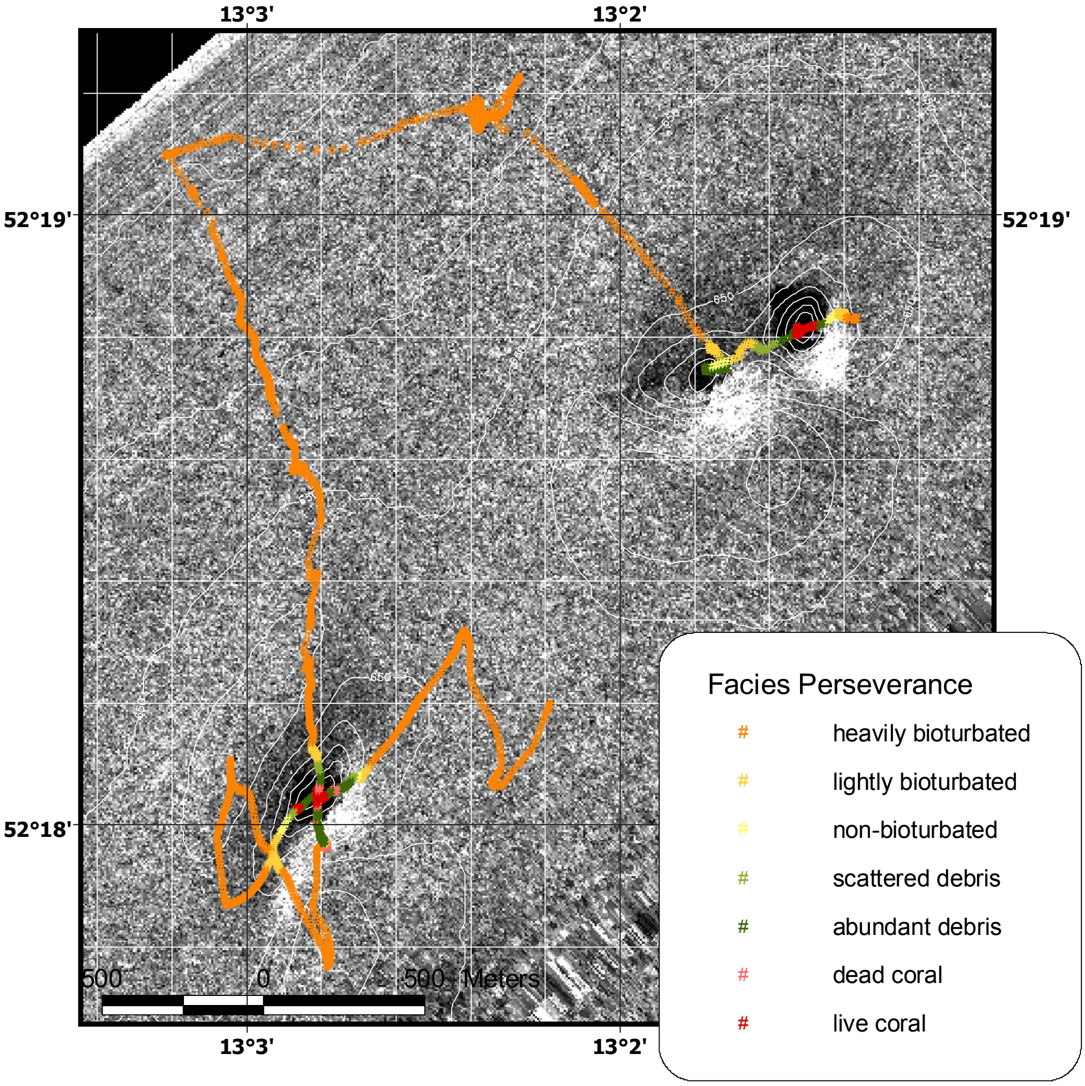


Fig. 29. *Overview map and seabed facies interpretation of Caracole dive 127 on Mound Perseverance and a nearby Magellan mound, overlaid on the TOBI sidescan sonar imagery. The bathymetric information is again derived from 3D seismic data (Huvenne et al., 2003).*

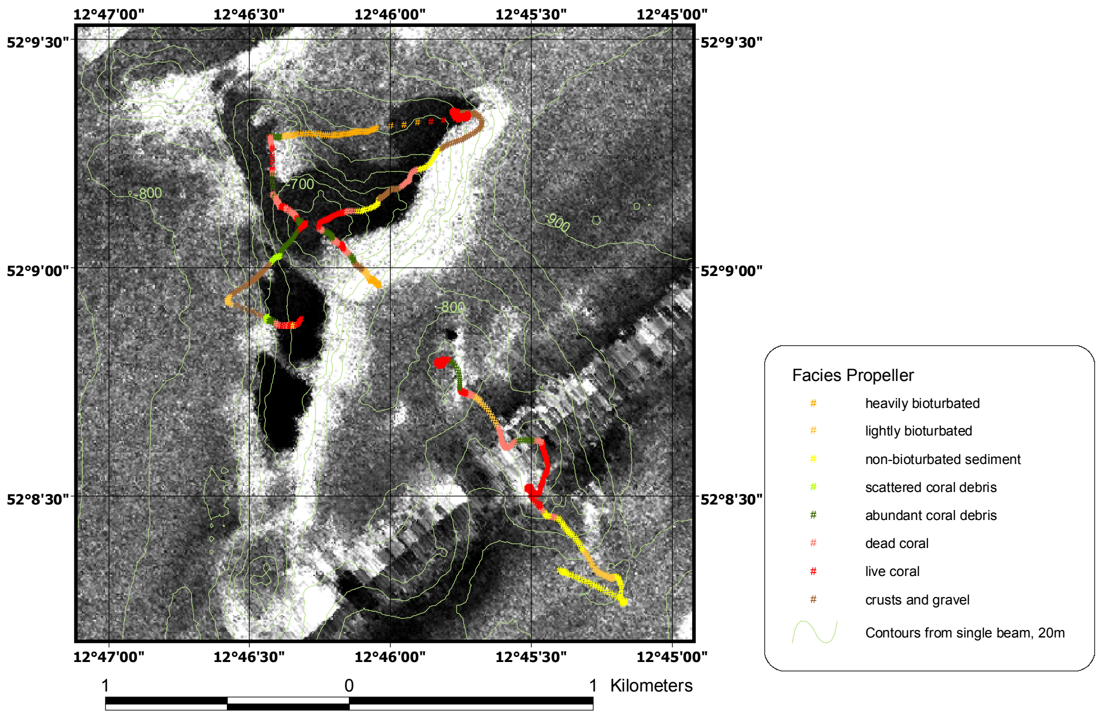


Fig. 30. *Overview map and seabed facies interpretation of Caracole dive 126 on Propeller Mound, overlaid on the TOBI sidescan sonar imagery. The bathymetry information is derived from single beam data, obtained during a cruise with the R/V Poseidon in 2000 (Freiwald et al., 2000).*

4. Area 2: Results and interpretations from the SW Rockall Trough margin

4.1 TOBI data interpretation

The side-scan sonar mosaic of the SW Rockall Trough margin (SE Rockall Bank) has a length of about 100 km and is in the order of 25 km wide (Fig. 31). It is oriented parallel to the slope. At a first glance the mosaic appears chaotic. The largest part of the area shows irregular patterns of strongly varying backscatter that has dimensions in the order of one hundred metres to several kilometers (Fig. 32).

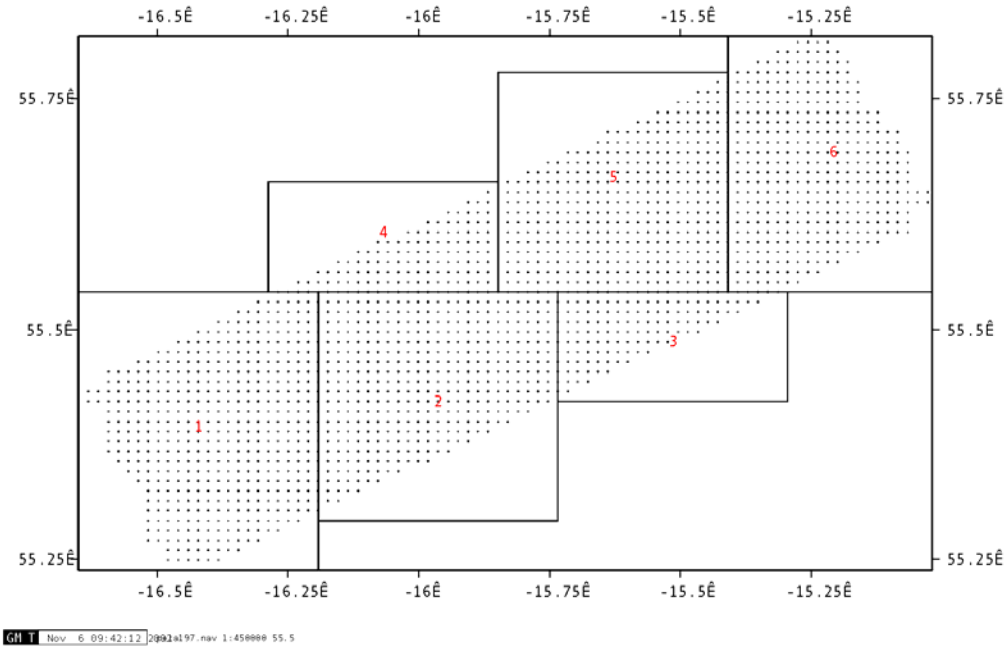


Fig. 31. *Map showing the mosaic maps of the SW Rockall Trough survey (area 2).*

In the NW part of the area (maps 1, 2, 4 and vaguely in 5), east-west elongated structures are present showing parallel lineaments of high and low backscatter. These structures are several kilometres long and up to 500m wide. They are interpreted as giant sediment waves which have an orientation that is slightly oblique to the general depth contours (Figure 42). Further to the east (map 5) these sediment waves grade into an area with a more patchy appearance, interpreted as a field of small mounds, eventually grading into a more featureless, low backscatter seabed (map 6). These structures are located in an area that runs parallel to the general depth contours from NW to NE in the mosaic and is at maximum about 4-5 km wide.

Downslope (southerly) the dunes grade into mounds present in the middle section of the mosaic within a zone that is about 15 km wide at maximum, and has an irregular pattern of low to high backscatter is present. This pattern is interpreted as mounds with diameters in the order of hundreds of metres to a few kilometres. Many of these mounds are grouped in more or less elongated clusters that show a downslope orientation of their longest axis (Fig. 15).

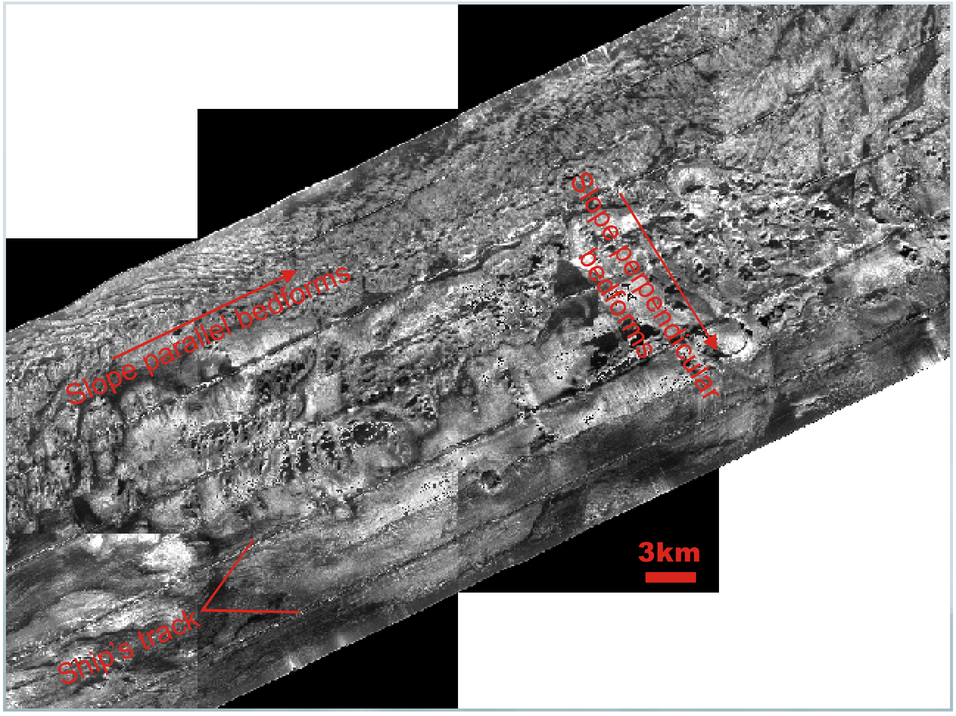


Fig. 42. *Central section of the SW Rockall Trough mosaic showing zonation. Downslope is to the south-east..*

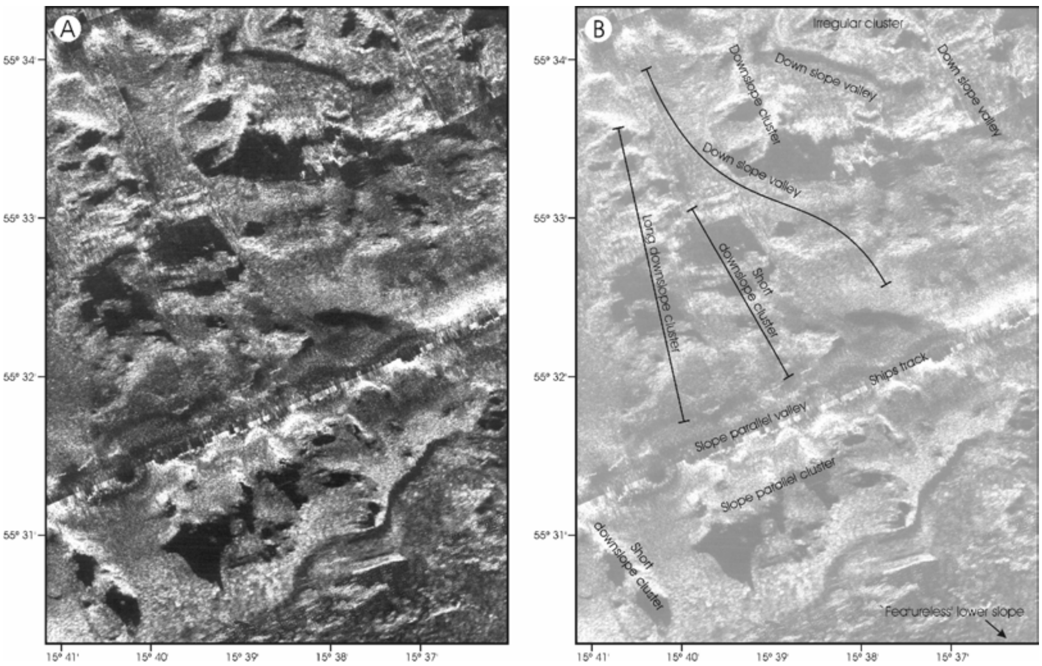


Fig. 43. *A: Data example of the SW Rockall Trough margin (area 2) showing the mound morphology in this area, and,* B*: Interpretation of* A *showing mound clusters and valleys*.

Between the mound clusters, narrow and elongated areas of low backscatter are present running perpendicular to or at a high angle to the general pattern of depth contours of the margin. Only sometimes do these structures run more or less parallel to the margin. The structures are interpreted as valleys in between the mounds acting as channels through which the (tidal) current is funneled between the mounds, resulting in high current velocities (Fig. 43). This also explains the pebbles and boulders found in box cores from these areas taken during earlier cruises (de Haas *et al*., 2000; de Stigter & de Haas, 2001). This interpretation of the topography agrees well with the results of the 3.5 kHz survey (located on maps 3 and 5) carried out during the M2000 and M2001 cruises (de Haas *et al*., 2000; de Stigter & de Haas, 2001). The southern boundary of the central zone of the mosaic is formed by relatively high mounds, sometimes grouped in cluster running parallel to the margin.

Downslope of the central zone, a 5km wide area of generally very low backscatter is present (Fig. 44). Only a limited amount of medium to higher backscatter features can be observed that are interpreted as slope parallel drift features (map 1) and slide escarpments (maps 1, 2 and 3).

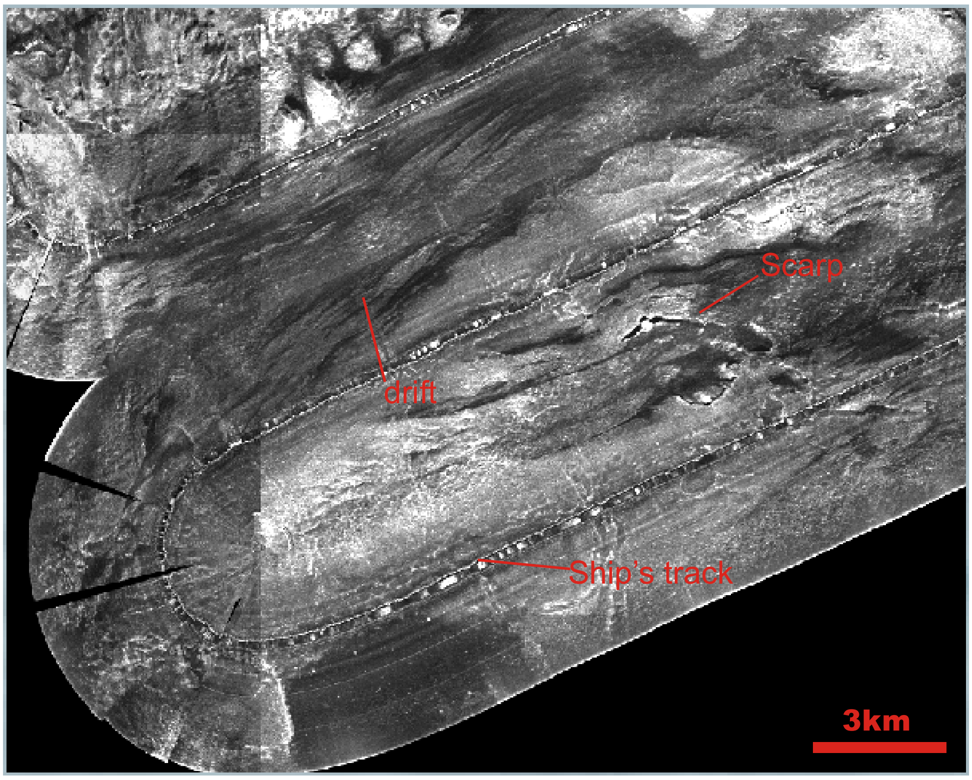


Fig 44. *The deeper water mosaic areas show drift features and evidence of slope failure. Downslope is to the south-east.*

4.2 Integration with TRIM side-scan sonar coverage

The TOBI and TRIM datasets for the Rockall Bank are also integrated and are viewable with the viewer on the CD-ROM. These datasets are not contiguous but separated by c.40km (Figure 45). However, this integration does show that both parts of this margin, although at similar water depths are dissimilar.

The TOBI data shows the dominance of carbonate mounds sculpting this margin that are largely absent further along the margin to the north-east (TRIM data).

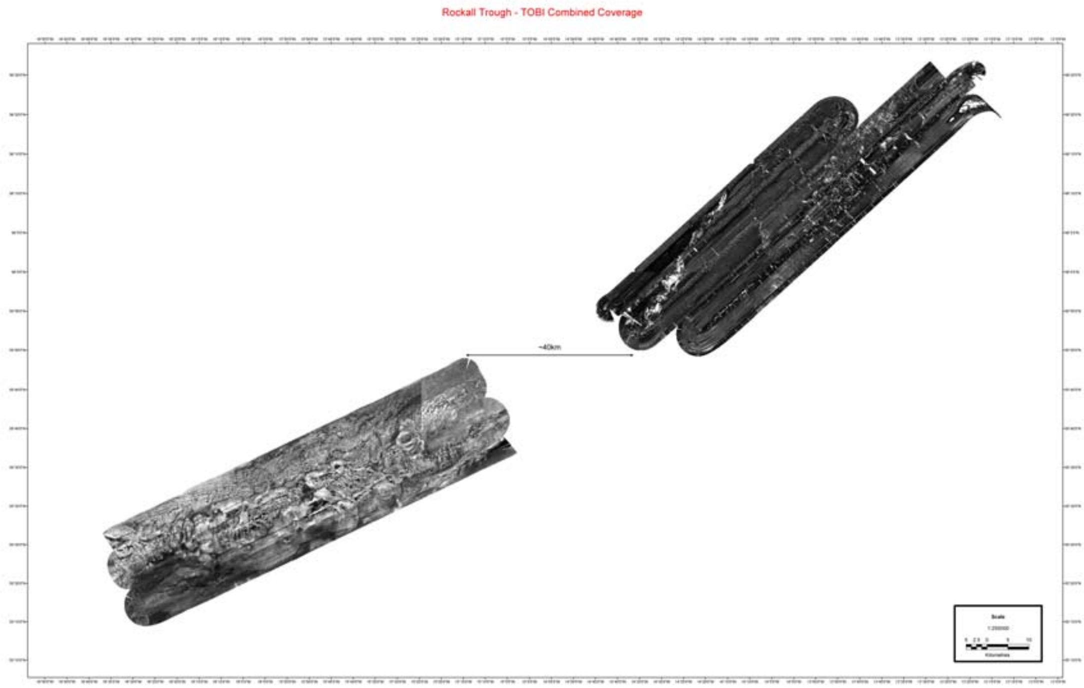


Fig. 45. *Integration of TOBI and TRIM data for the Rockall Bank showing different margin processes affecting these sections of the margin separted by c.40km.*

5. Area 3: Results and interpretations from the SE Rockall Trough margin

5.1. TOBI data interpretation

The side-scan sonar mosaic of the SE Rockall Trough margin (northeastern Porcupine Bank area) (Figs. 46 & 47) consists of a long NE-SW run-in line parallel to the existing TOBI TRIM98 data, a coherent mosaic of 4 lines in the middle of the area and a southerly 2-line mosaic extension. The mosaic covers the mid- to upper slope of the outer north-westerly Porcupine Bank covering areas of carbonate mounds, sediment drifts, erosional features and canyon heads.

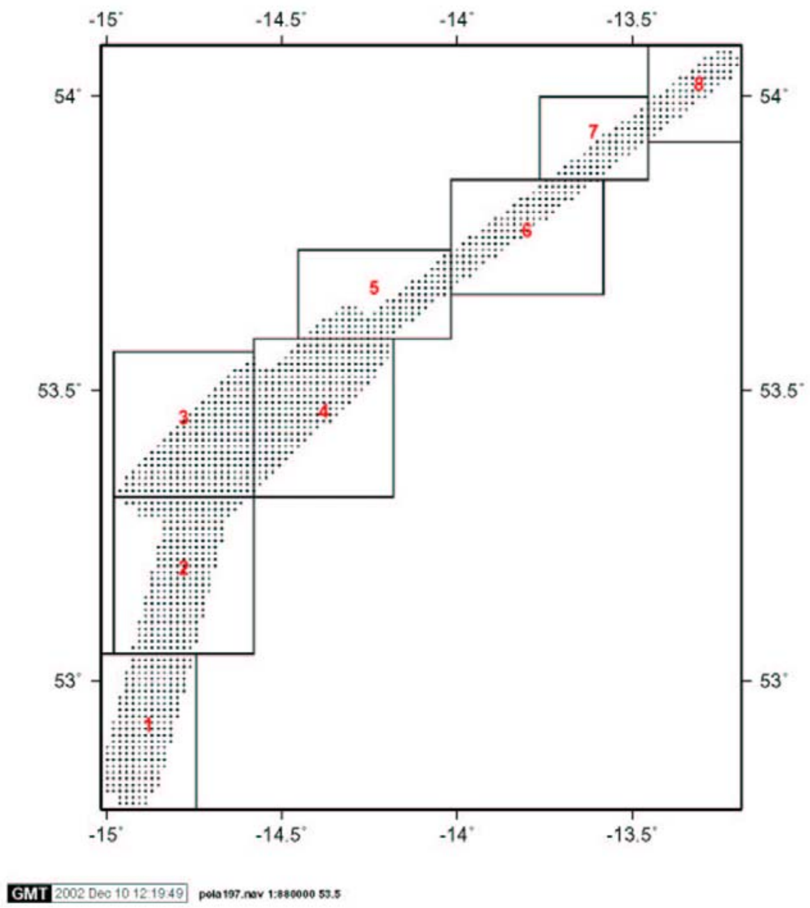


Fig 46. *Map showing the mosaic maps of the SE Rockall Trough margin (area 3).*

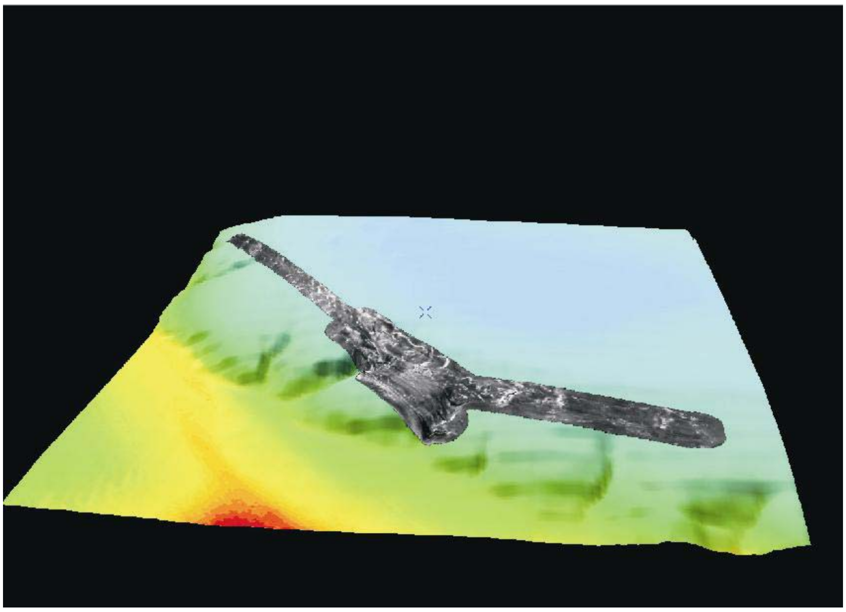


Fig. 47. *Overview mosaic coverage on the Porcupine Bank*

A number of sinuous scarps are identified on the mosaic that have a slight topographic rise upslope and a steep scarp-face downslope (Fig. 48). The shape and down slope acoustic facies suggest that these are not major slope failures but represent either the edges of erosional scours where shallow bedding planes are exposed or fault scarps. Comparable exposures of consolidated sediment exposures have been identified in this area during the CARACOLE ROV cruise (Olu–Le Roy *et al*., 2002) and previous imaged on high-resolution side-scan sonar (Wheeler *et al*., 2000). The scarps run sub-parallel to the isobaths and are more dominant in mid- to upslope areas. In the middle of the mosaic, the scarps coalesce to form “areas of exposed consolidated sediment” clearly defined as depressions with steep walls. These can be 500-700m across. Downslope, the “areas” become elongated to form shallow downslope gullies extending up to 1.5km. It is not clear if these are shallow failure scars or erosional hollows (Fig. 49).

A large number of carbonate mounds are identified on the mosaic being predominantly 100 - >300m across a ranging in height up to *c*.200m. These occur as both isolated features and associations with the scarps. Mound shapes range from ovoid, to ridge-shaped running sub-parallel to the isobaths, to complex forms. Some of the mounds, especially those occurring as groups, are also surrounded by zones of high backscatter seabed. A good example of such a feature is the east-west trending high backscatter region (4 km east-west, 2km north-south) in the southern part of the survey area (Fig. 50). A few mounds also show low backscatter moats, similar to those observed in the TRIM98 dataset.

There is a clear tendency for some mounds to be aligned along scarps (Fig. 48) and topographic highs. It is speculated that this is probably the result of a combination of suitable substrates for mound growth (formed by erosion of exposed high relief areas) as well as high currents speed accelerating over the topographic obstacle generating an increased biological food flux. One group of well-developed mounds are aligned along the crest of a topographic spur at the head of a canyon system and are probably also benefiting from hydrodynamically enhanced organic food supply (Fig 51). Alternatively, they could be associated with gas seepage along faults that a form the scarps.

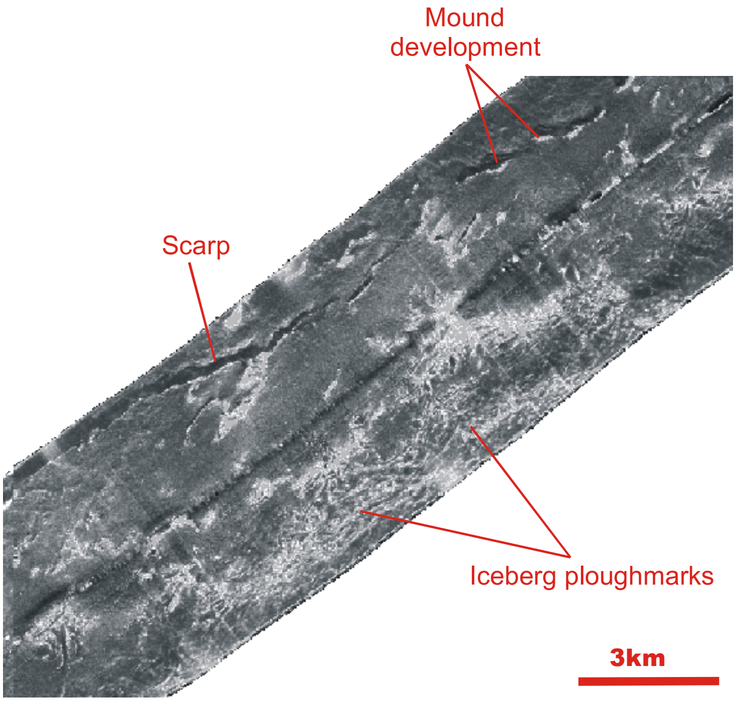


Fig. 48. *Sonar image showing scarps with small mound development aligned along the crest and an upslope zone of iceberg plough marks. Downslope direction is to the north-west.*

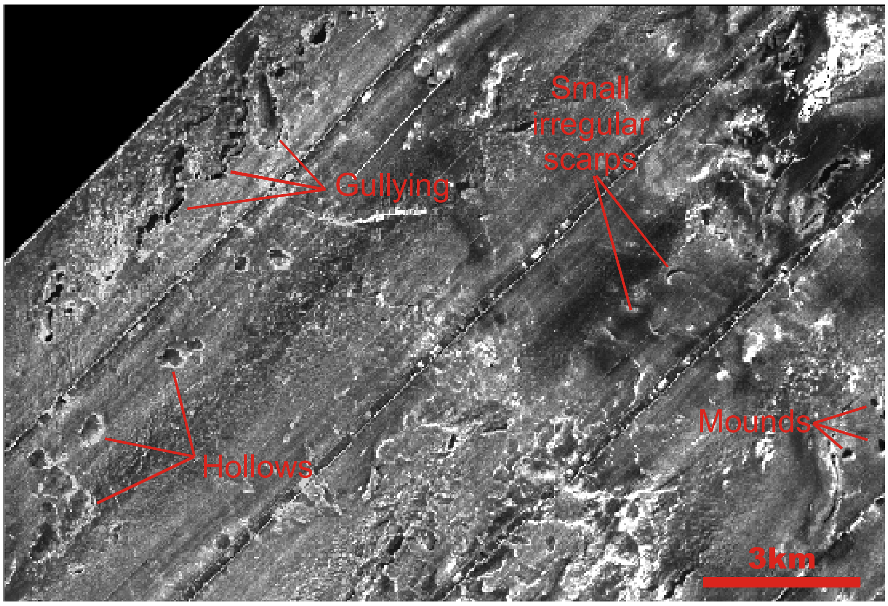


Fig. 49. *Sonar image showing small irregular scarps, hollows formed by erosion or shallow slope failure, downslope gullying and carbonate mounds. Downslope direction is to the north-west.*

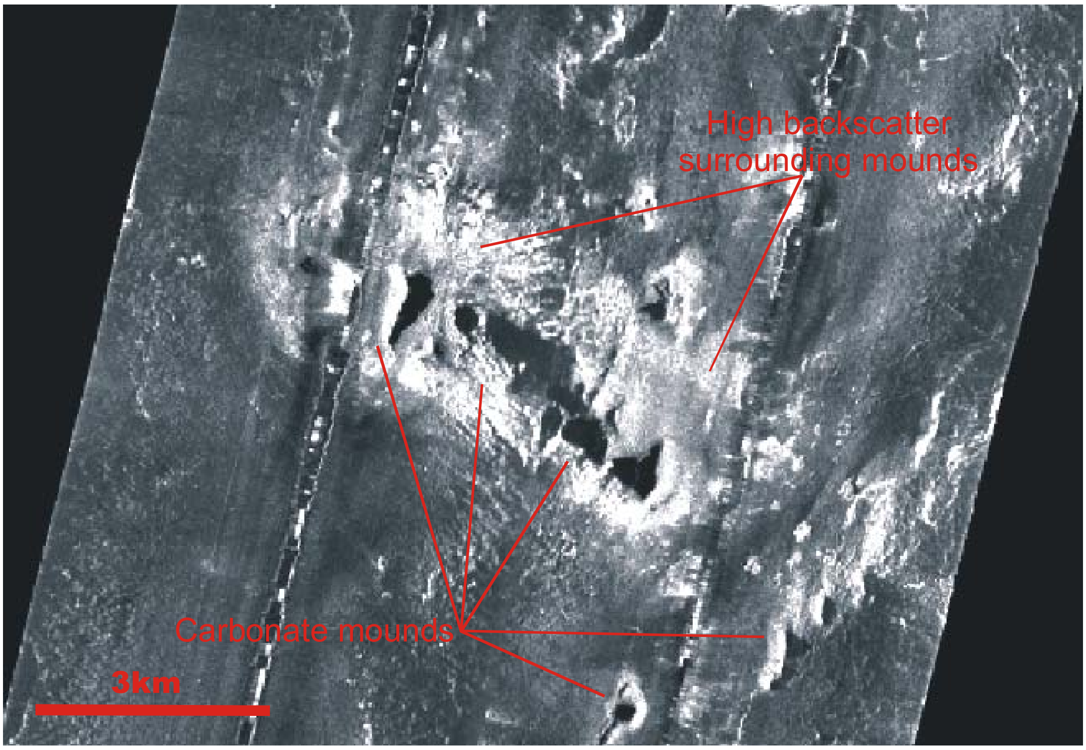


Fig 50. *Giant carbonate mounds cluster with smaller carbonate mounds and high backscatter signature on the surrounding seabed. Downslope direction is to the west*.

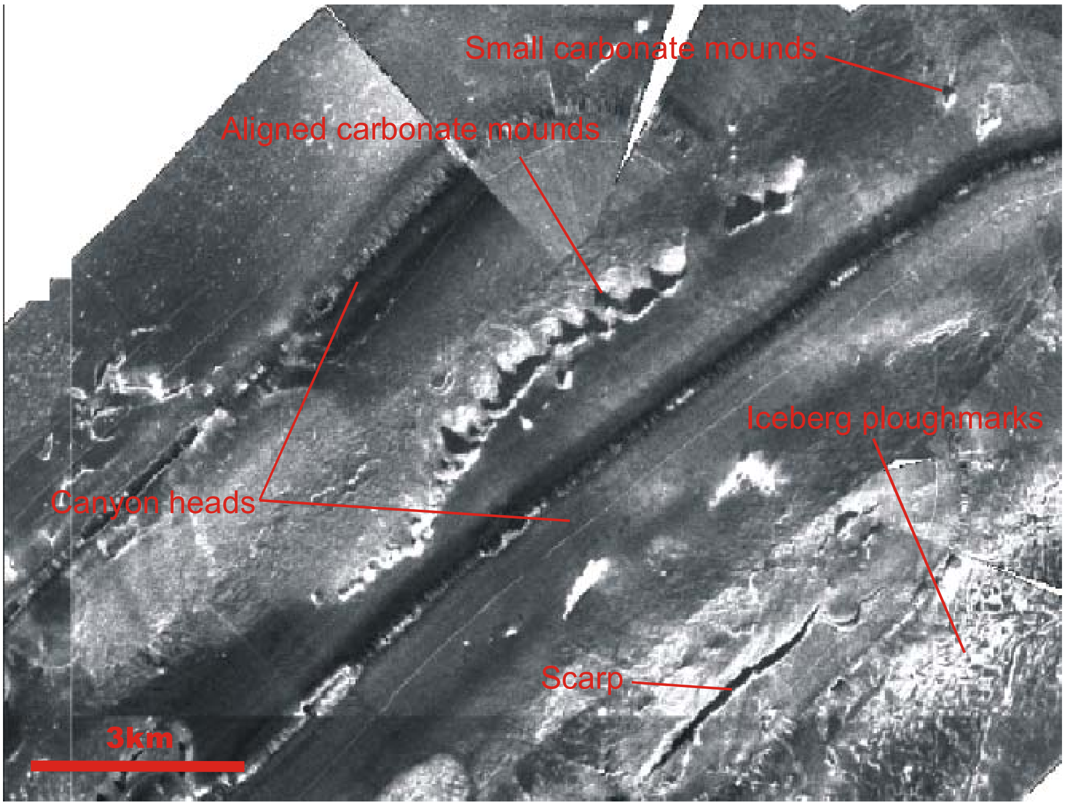


Fig 51. *An alignment of carbonate mounds along a topographic ridge between two canyon head feeder systems. Scarps and iceberg plough marks are also visible. Downslope direction is to the north-west.*

The heads of two canyon systems (*c*.2km across) are also imaged. These show scarp-faces bounding parts of the heads and very low backscatter sediment fills. Feeder "chutes" to the canyons are also observed and a low backscattering, sinuous channel (width *c*.125m) is also imaged at the head of the most northerly, and larger, of the two canyons.

A number of very small (12-15m wide) high backscatter features are also identified which may represent localised coral colonises, small mound features or large dropstones. These features are generally found downslope from the larger (>100m diameter) mound features. In the CARACOLE R1 site, a number of very large (>2.5m) boulders were observed on video data (Olu–Le Roy *et al*., 2002).

Upslope, in the middle of the mosaic, a large area of iceberg plough-marks is observed (Figs 48 & 51). The longest continuous iceberg plough mark is 2km long. The TOBI image from this region is very similar to those obtained in other glacially scoured regions such as the proximal areas of the Barra and Donegal fans (Armishaw *et al.,* 2000). These features occur at water depths slightly deeper than expected and may have implications for our interpretation of sea-level, palaeo-iceberg dimensions and the extent of past glaciation events on the Irish margin.

In the far north of the area, a board zone of high backscatter is noted crossing the mosaic east-west bounded by one of the scarps. This is probably a sediment drift. Other low backscatter drifts are also identified on the mosaic and seem to bend around mounds or abut against scarps.

In summary, the side-scan mosaic of the SE Rockall Trough margin provides detailed views of upper to mid slope features. The distribution of these features highlights a complex interplay between along-slope processes such as current scour, contourite drift sedimentation and downslope processes such as mass wasting and canyon formation.

Groundtruthing of the Porcupine Bank TOBI mosaic was recently undertaken and preliminary results published by Wheeler et al. (in press) with relevant extracts reproduced below.

Abundant evidence is found of strong benthic current regime in the study area. The seabed between carbonate mounds is typified by sands and exposed dropstones (deposited by melting icebergs) (Figure 52a) implying strong currents. These dropstones provide suitable attachments for sessile organisms including sponges, stylasterids, corals, gorgonians, antipatharians, anemones and barnacles (see Figure 52a). The strong hydrodynamic regime and the exposed nature of carbonate mounds result in very little sedimentary cover on the carbonate mounds themselves with sub-fossil coral frameworks often exposed. Figure 52b shows a typical view with sporadic colonisation of the carbonate mounds by cold-water corals by attachment directly onto dead skeletal material (Figure 52b).

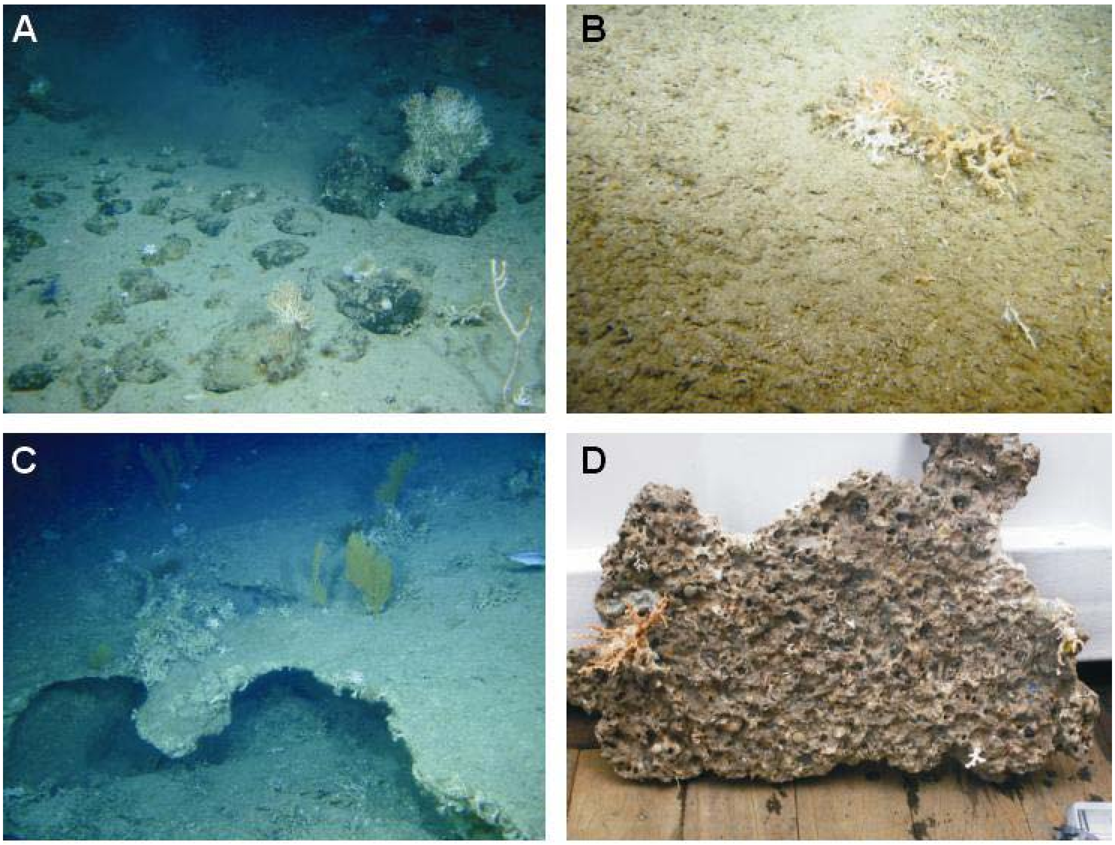


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Fig. 52. *Visible evidence of strong hydrodynamic regime on the Porcupine Bank. A: typical seabed with sand sediment and exposed dropstones supporting communities of sponges, stylasterids, holothurians (*Psolus *sp.),* Lophelia pertusa *and anemones. B: a typical carbonate mound surface showing exposed dead coral framework providing a firm substrate for attachment of* Lophelia pertusa*. C: Seabed erosion exposing lithified sediments and providing a hardground for colonisation by* Lophelia pertusa*, other scleractinians and gorgonians. D: retrieved hardground showing extensive borings and colonisation by scleractinians including* Madrepora oculata *and* Stenocyathus vermiformis*, stylasterids (*Pliobothrus *sp.), serpulids, sponges and anemones.*

In many areas, intense current activity also resulted in physical erosion of the seabed and the carbonate mounds exposing lithified sediment which act as hardgrounds (Figure 52c). These provide firm substrata for colonisation and support a diverse fauna (e.g. Lophelia pertusa*,* Madrepora oculata*, stylasterids, gorgonians, byssate bivalves (*Asperarca nodulosa *and* Chlamys sulcata*), serpulids and clionid sponges: Figure 52c & d).*

Examination of a 21 km ridge revealed carbonate mounds on top of the ridge provided its topographic expression although between mound areas where typified by a vertical escarpment. The exposure of soft sediment between *hardgrounds exposed on the escarpment (Figure 53a) suggests that the structure post-dates the last tectonic activity in the Tertiary and was probably formed by seabed erosion. The alternation of hard and softer sediment may represent Quaternary climatic forcing of sedimentation patterns on the banks with glacial periods typified by sluggish current and high sediment rates and interglacial periods typified by fast currents causing seabed erosion. Preferential cementation of hardgrounds maybe due to increased carbonate contents and biological productivity. Some hardgrounds are covered in a thin layer of black metallic oxides suggesting exposure at the seabed.*

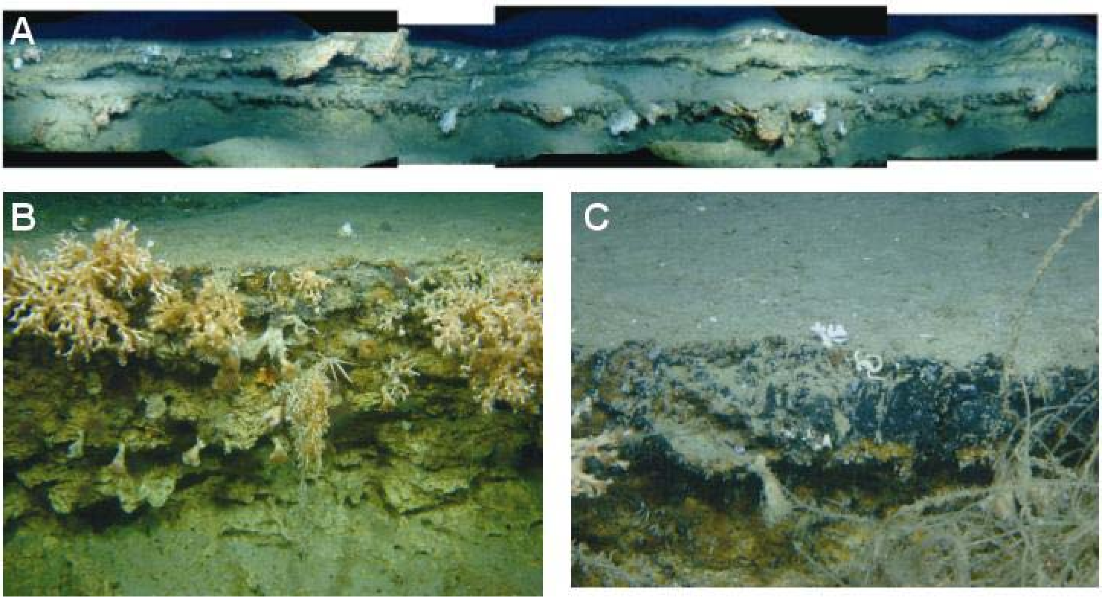

Fig. 53. *Eroded seabed scarp colonised by cold water coral A: Photo montage showing the face of the scarp. Several prominent resistant layers (?palaeohardgrounds) are evident to which sessile organisms are attached. These prominent layers are separated by softer sediment. B: Detail of colonisation on the upper hardground showing* Lophelia pertusa*,* Desmophyllum cristagalli*,* Madrepora oculata*,* Cidaris cidaris*, starfish (*Ceramaster *sp.) and serpulids. C: Closer detail of the hardground showing a thin black metallic oxide coating suggesting persistent exposure at the seabed. Some lost fishing gear,* Lophelia pertusa*,* Desmophyllum cristagalli *and* Pliobothrus *sp. are also present.*

A limited number of carbonate mounds in the study area where studied on a previous survey using the VICTOR6000 robotic submersible (CARACOLE cruise: Olu-Le Roy et al., 2002). The survey presented here purposely covered a greater variety of mounds in order to assess whether a typical faunal assemblage can be defined as truly representative of all the mounds on the Bank. Some observations are in accordance with CARACOLE findings, for example sessile megafauna covered only an average of about >5% the coral facies. Most ROV observations were made a few metres from the seabed, to cover a wide area quickly, butmacro- and microfaunal (evidence based on box-coring) were present in abundance on coral facies wherever close-up observations were made.

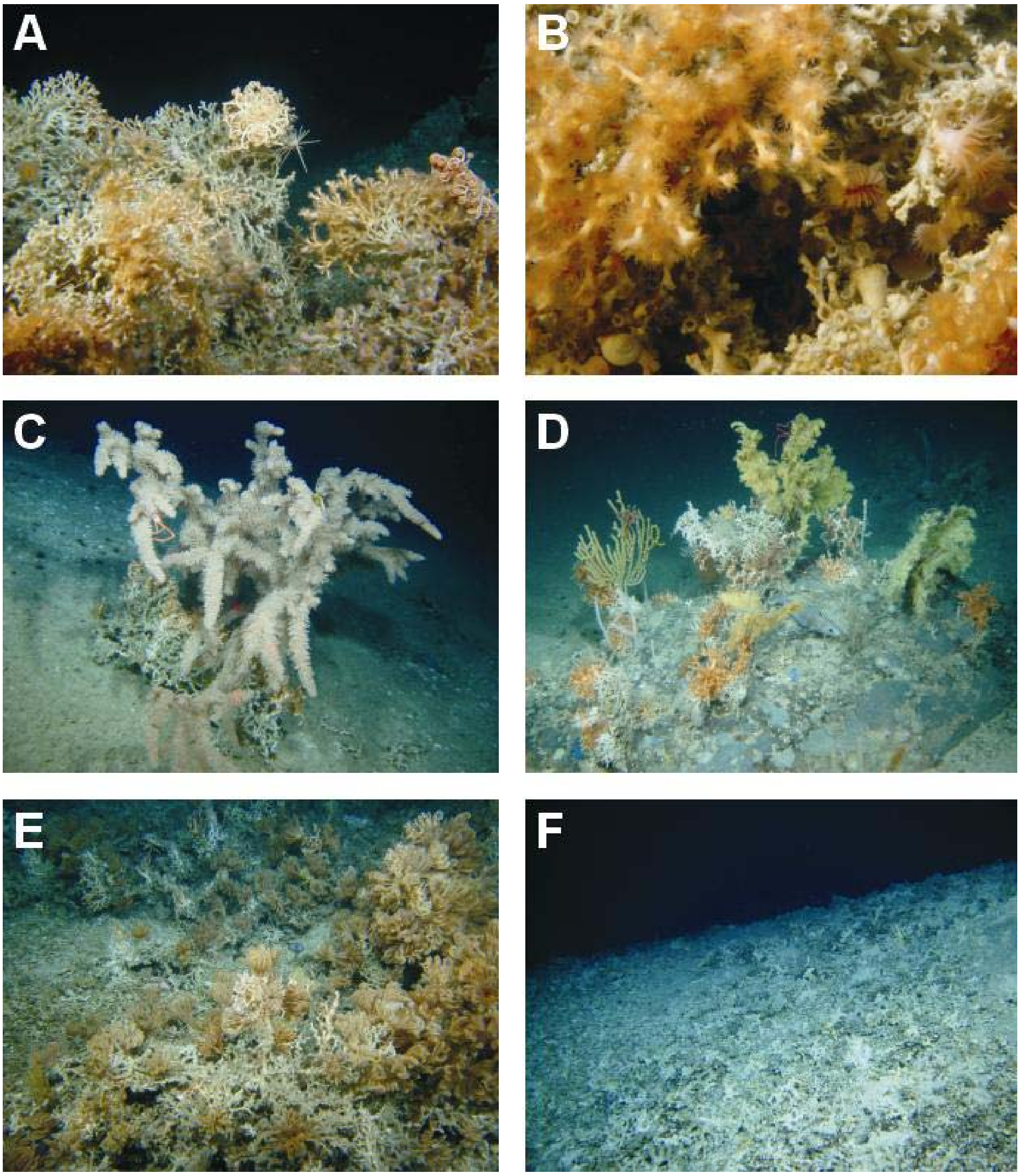

Fig. 54. *Selected images showing the variety of organisms and their association encountered on the northwest Porcupine Bank. A.* Lophelia pertusa *colonies with* Gorgonocephalus *sp. and* Cidaris cidaris*. B. Close up of* Lophelia pertusa *colonies with polyps extended. An anemone, a gastropod (*Calliostoma *sp.) and* Desmopyllum cristagalli *(solitary coral) are also present. C. An antipatharian with spider crabs (*Chirostylus formosus*) attached to a* Lophelia pertusa *colony D. Heavily colonised dropstone with several sponge-species,* Lophelia pertusa, Madrepora oculata*, antipatharians, sylasterids (*Pliobothrus *sp.), crinoids (*Crotalometra *sp.) and spider crabs (*Chirostylus formosus*) attached to gorgonians (*Acanthogorgia *sp. and others) as well as a fish (*Lepidion eques*) E. Crinoids attached to* Lophelia pertusa *colonies with a fish F. Coral rubble field as a result of demersal trawling activity*

*Preliminary observations (Figure 54) suggest that the dominant sessile megafauna documented in the study area included corals (*Lophelia pertusa*,* Madrepora oculata*, antipatharians, gorgonians (*Acanthogorgia *sp. and others),* Desmophyllum cristagalli*) and sponges. Mobile megafauna included* *conspicuous numbers of echinoderms, fish and crabs. The important habitat complexity provided even by sparse coral coverage showed an enhancement of faunal diversity. While some of the mounds surveyed had relatively low coral cover, there was clear visual evidence that the density and diversity of megafauna was greater on the mounds than on the surrounding seabed (Figure 54a, b, c & e) (see Olu-Le Roy et al., 2002; Foubert et al., subm.). Colonised dropstones represent an important habitat on the lower mound flanks and in off-mound areas (Figure 54d), where they form oasis-like habitats providing hard substrate for many sessile organisms (see Oschmann, 1990).*

Certain fauna are found on all mounds (including most scleractinian coral species e.g. Lophelia pertusa*,* Madrepora oculata *and* Desmophyllum cristagalli*) whereas others seem only to be specific to or dominant on individual mounds (e.g. stylasterids (*Stylaster *sp.), crinoids - Figure 54e, gorgonocephalids – Figure 54a).*

Destruction of the coral habitat by demersal trawling was noted (Figure 54f – see also Grehan et al., subm.), clearly an even greater concern if certain mounds do harbour specific faunal assemblages. Trawled mounds are characterised by extensive coral rubble fields suggesting that coral cover may have been formerly more extensive here than on the other mounds surveyed the area. This also suggests that demersal trawling activity (Hall-Spencer et al., 2002) may be targeting mounds with the most prolific coral growth (therefore of the highest conservation value) due to related high fish populations.

Despite 88 hours of dedicated dive time on carbonate mounds, no gas bubbles, authogenic carbonate crusts, bacterial mats, chemosynthetic fauna (e.g. tube worms, pogonophorans or distinct molluscs species), pockmarks or any other evidence of cold seepage were found.

Fast-flowing currents along the Porcupine Bank at depths where cold water corals and resultant carbonate mounds occur induces seabed erosion thereby providing hard substrata, in the form of exposed dropstones and hardgrounds, suitable for the colonisation by sessile megafauna. Paradoxically, at present seabed erosion seems to be the dominant process stimulating renewed colonisation of carbonate mounds by framework building corals and therefore mound growth. This mechanism may also explain the stratigraphy exposed on escarpments with climate controlled alternations in sediment and hydrodynamic regimes producing a repetition of soft sediment overlain by hardgrounds (see Figure 53a).

Surveys of a variety of mounds showed that although megafaunal species cover was reduced in comparison with some other mound provinces (e.g. the Galway Mound – Foubert et al., subm.), biodiversity remained high with mounds offering an important habitat to corals, gorgonians, antipatharians, sponges, crustacea and fish. Demersal trawling has produced drastic alterations to the ecology of impacted carbonate mounds.

Previous studies have identified a number of ridges and scarps on the Porcupine Bank where carbonate mounds were preferentially located. The coincidence of boundary faults overlying hydrocarbon reserves led to speculation that the carbonate mounds may be associated with cold seeps (Croker et al., 2003.). After 88 hours of ROV observation where this was suspected, we conclude that as no evidence of hydrocarbon seepage was found, thermogenic hydrocarbon seepage does not account for mound growth. Furthermore, the strong influence of fast currents on the benthic environment, coupled with probable high surface productivity, implies that hydrodynamic influence on food supply is probably a major factor contributing to coral growth. However, it is also noted that present conditions are not optimal for the prolific growth of cold-water coral which may be due to high present day current speeds as suggested by Kenyon et al. (2003).

4.2. Integration with TRIM side-scan sonar coverage

The TOBI side-scan sonar data has been integrated with contiguous previously acquired TOBI data (TRIM). Figure 55 shows the spatial relationship between the two coverages. The TOBI data is located upslope (north-east) of the TRIM datasets. Both coverages are available on the CD-ROM and can be simultaneously uploaded using the viewer.

Figure 56 shows an area of overlap between the two coverages that images an escarpment that is present on both coverages. There is no apparent offset to the escarpment as it goes from one coverage to the next demonstrating the accuracy and compatibility of the navigational components of both surveys.

Differences exist in the backscatter intensity of each survey with the TRIM survey appearing darker. This is because each coverage is independently, internally-balanced to show maximize the spectrum distribution for each coverage. Standardising the spectrum distribution for the combined coverages would remove this artifact but decrease the internal resolution of both coverages. The difference in backscatter intensity has therefore been retained as an acceptable artifact. Figure 49 also demonstrates a difference in outer swath interference with the TRIM data appearing more noisier. This probably a result of differences in the intensity of stratification of the water column between the two surveys as opposed to improvements in the operating system.

Figure 57 shows a cluster of carbonate mounds that span both the TOBI and the TRIM datasets. The integration of the datasets how allows this cluster to be viewed in its entirety.

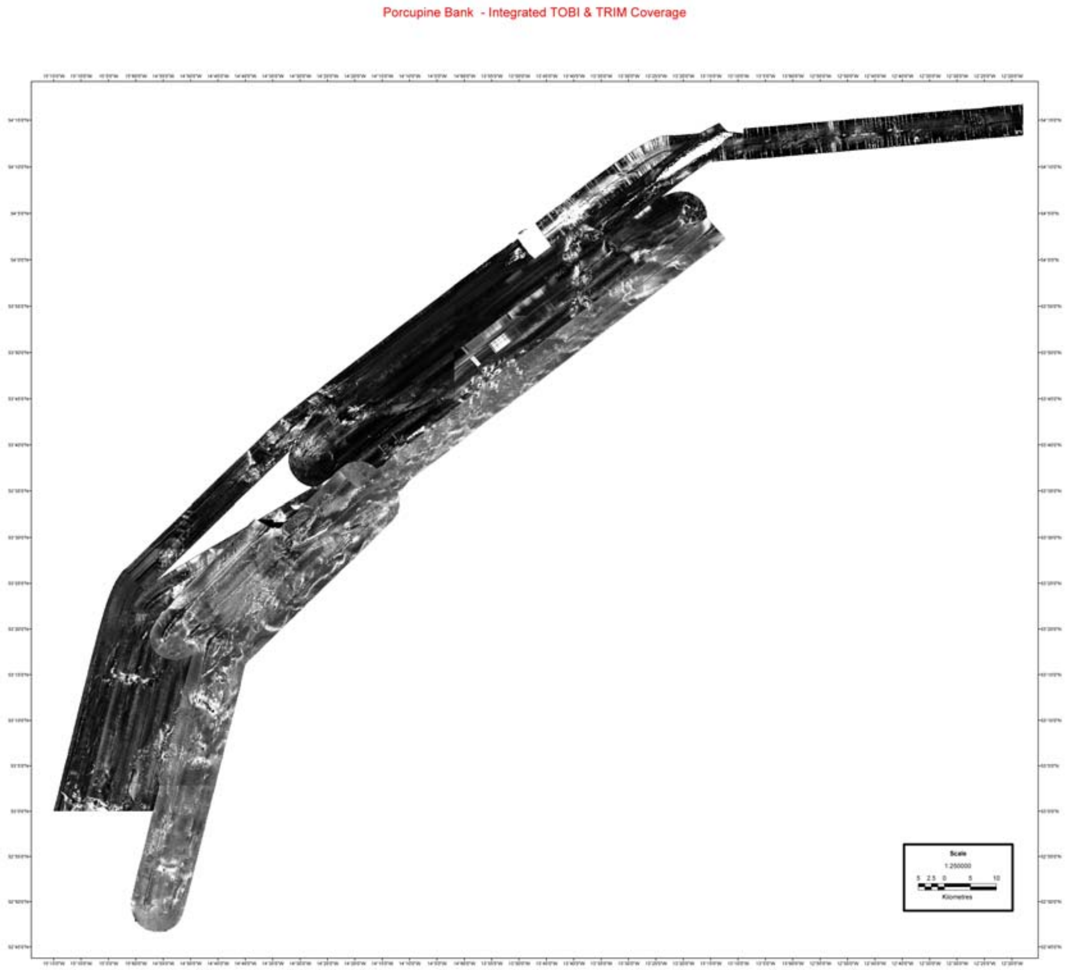

Fig 55. *Combined TOBI and TRIM coverages*

Fig 56. *Detail of the join between the two coverages showing good quality navigation*

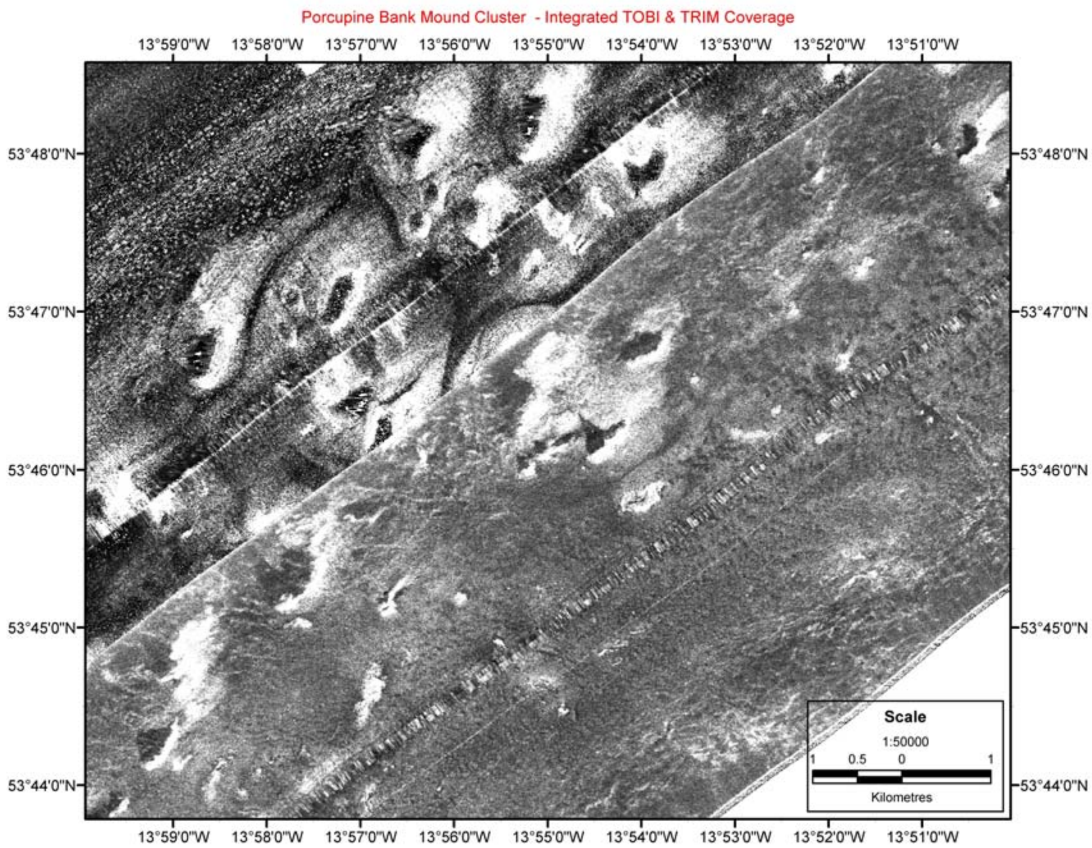

Fig. 57. *A cluster of carbonate mounds and drifts imaged at the margins of TOBI and TRIM coverages. The combined datasets now shoes the full extent of mounds in this area*.

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Appendix 1. Shipboard party

Scientific party

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Veerle Huvenne (Co-chief scientist)	Renard Centre of Marine Geology, University of Ghent, Ghent, Belgium
Vincent Hinsinger (Student)	Renard Center of Marine Geology, University of Ghent, Ghent, Belgium
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Chris Flewellen (Technician)	Southampton Oceanography Centre, Southampton, United Kingdom
Serkan Kulaksiz (Student)	International University of Bremen, Bremen, Germany
Colin Jacobs (Scientist)	Southampton Oceanography Centre, Southampton, United Kingdom
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Ian Rouse (Technician)	Southampton Oceanography Centre, Southampton, United Kingdom
Vikram Unnithan (Scientist)	Department of Geology, University College Dublin, Dublin, Ireland
Steve Whittle (Technician)	Southampton Oceanography Centre, Southampton, United Kingdom

Ships crew

Name	Rank
Feite Bos	Captain
Bert Puijman	First officer
Henk Douma	Second Officer
Menno Hogeweg	Engineer
Joris Valentijn	Engineer
Cor Stevens	Sailor
Guilherme Santos Cardoso	Sailor
Jan de Kraker	Sailor
John Betsema	Sailor
Felix Prins	Cook

Appendix 2. TOBI2 brief technical specification

Mechanical

Towing method:	Two bodied tow system using neutrally buoyant vehicle and 600kg depressor weight.
Size:	4.5m x 1.5m x 1.1m (lxhxw).
Weight:	1800kg in air.
Tow cable:	Up to 10km armoured coax.
Umbilical:	200m long x 50mm diameter, slightly buoyant.
Tow speed:	1.5 to 3 knots (dependent on tow length).

Sonar Systems

Sidescan Sonar

Frequency:	30.414kHz (starboard) 32.904kHz (port).
Pulse Length:	2.8ms.
Ouput Power:	600W each side.
Range:	3000m each side.
Beam Pattern:	0.8° x 45° fan.

Profiler Sonar

Frequency:	6 to 10kHz Chirp.
Pulse Length:	26ms.
Output Power:	1000W.
Range:	>50ms penetration over soft sediment.
Resolution:	0.25ms
Beam Pattern:	25° cone.

Standard Instrumentation

Magnetometer

System:	Ultra Electronics Magnetics Division MB5L.
Range:	+/- 100,000nT on each axis.
Resolution:	0.2nT.
Noise:	+/- 0.4nT.

CTD

System:	Falmouth Scientific Instruments, Micro CTD.

Conductivity

Range:	0 to 65 mmho/cm.
Resolution:	0.0002 mmho/cm.
Accuracy:	+/- 0.005 mmho/cm.

Temperature

Range:	-2 to 32° Celcius.
Resolution:	0.0001° C.
Accuracy:	+/- 0.005° C.

Depth

Range:	0 to 7000 dbar.
Resolution:	0.02 dbar.
Accuracy:	+/-0.12% F.S.

Pitch/Roll

System:	Dual Axis Electrolytic Inclinometer.
Range:	+/- 20 degrees.
Resolution:	0.2 degrees.

Altitude

System:	Taken from profiler sonar.
Range:	1000m.
Resolution:	1m.

Appendix 3. *Summary of ground-truthing information for the Belgica mounds imaged on 3.5kHz sub-bottom profiler lines and video imagery*

List of mounds imaged on 3.5kHz sub-bottom profiler lines	***Seabed reflector type on 3.5kHz profiler***	***Ground-truthing information***	***Mound type (active/retired)***
Thérèse Mound (BEL35)	*Diffuse*	*Dense coral coverage (live & dead)* *Video data: ROV Victor dives 123, 124, 125; SHRIMP 13876#1;* *Box core samples: PS64/271-2, PS64/271-1, PS64/271-3, 13881#1, 13881#2, 13881#3, 13874#1, 13874#2, 13874#3*	*Active*
Galway Mound (BEL43)	*Diffuse*	*Dense coral coverage (live & dead)* *Video data: ROV Victor dives 213, 214* *Box core samples: PS64/254-1, PS64/254-2, PS64/254-3, PS64/257-2*	*Active*
BEL36	*Diffuse*	*Dense (live & dead) coral coverage on the mound's summit* *Video data: ROV Victor dive 124, SRIMP13877#1*	*Active*
BEL39	*Diffuse*	*Dense (live & dead) coral coverage on the mound's summit* *Video data: SRIMP13877#1*	*Active*
BEL32	*Diffuse*	*Coral framework* *Box core samples: see Van Rooij et al., 2003*	*Active*
BEL38	*Diffuse*	*n/a*	*Active (?)*
BEL44	*Not crossed at the summit, but shows diffuse reflector on the western flank*	*Dense (live & dead) coral coverage on the mound's summit* *Video data: ROV Victor dive 214*	*Active*
BEL29	*Solid*	*Mound's summit is dominated by unrippled seabed with patchy dropstones; with sediment clogged dead corals/coral rubble on the western flank of the mound* *Video data: ROV Victor dive 214*	*Retired*

List of mounds imaged on 3.5kHz sub-bottom profiler lines	**Seabed reflector type on 3.5kHz profiler**	**Ground-truthing information**	**Mound type (active/retired)**
BEL33	*Solid*	*Sediment clogged dead corals/coral rubble* *Video data: ROV Victor dive 214*	*Retired*
BEL37	*Solid*	*Sediment clogged dead corals/coral rubble* *Video data: ROV Victor dive 214*	*Retired*
Poseidon Mound (BEL41)	*Solid*	*Sediment clogged dead corals/coral rubble on the western flank, and dropstones dominated seabed on the eastern flank* *Video data: ROV Victor dive 214* *Box core samples: PS64/276-2, PS64/276-3*	*Retired*
BEL30	*Solid*	*n/a*	*Retired (?)*
BEL34	*Solid*	*n/a*	*Retired (?)*
BEL40	*Solid*	*n/a*	*Retired (?)*
BEL42	*Solid*	*n/a*	*Retired (?)*
BEL45	*Solid*	*n/a*	*Retired (?)*