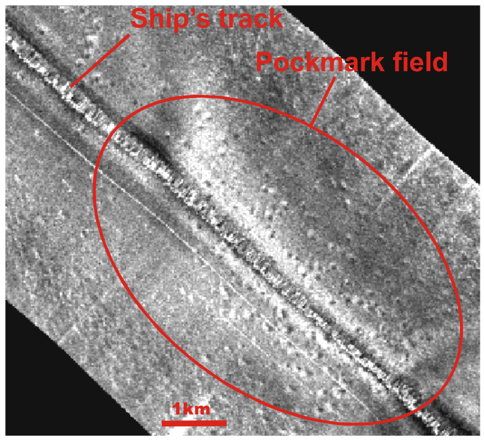
THE PORCUPINE AND ROCKALL MARGIN TOBI REGIONAL SIDE-SCAN SURVEY: PSG 00/019



2nd Preliminary Report

Submitted to: **Porcupine Studies Group, c/o CSA, CSA House, Unit 7, Dundrum Business Park, Windy Arbour, Dublin 14**

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Executive Summary

A 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).

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.

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 features surrounded by a homogenous seabed. 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. Significant accumulations are also surrounded by high backscatter areas suggesting an influence (coral colonisation?) on the surrounding seabed. 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 either due to enhanced local hydrodynamic conditions or possible fault associated fluid seepage. In the middle of the mosaic an enigmatic seabed backscatter is interpreted as broad, shallow erosional scours showing evidence of gullying downslope.

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, Southhampton Oceanography Centre (SOC). A full list of shipboard party is also presented in Appendix 1.

Funding and access to the TOBI facility was provided under the auspices of the European Union (EASSS III programme, ‘Improving Human Potential’, contract HPRI-CT-1999-00047) whose assistance is most welcome.

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 Rockall Trough and Hatton-Rockall Basins extensive sediment drifts are present which were formed under the influence of 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 2km. 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 thermohaline 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 buildups 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) 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). 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 gashydrate/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 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 5^{th} 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).

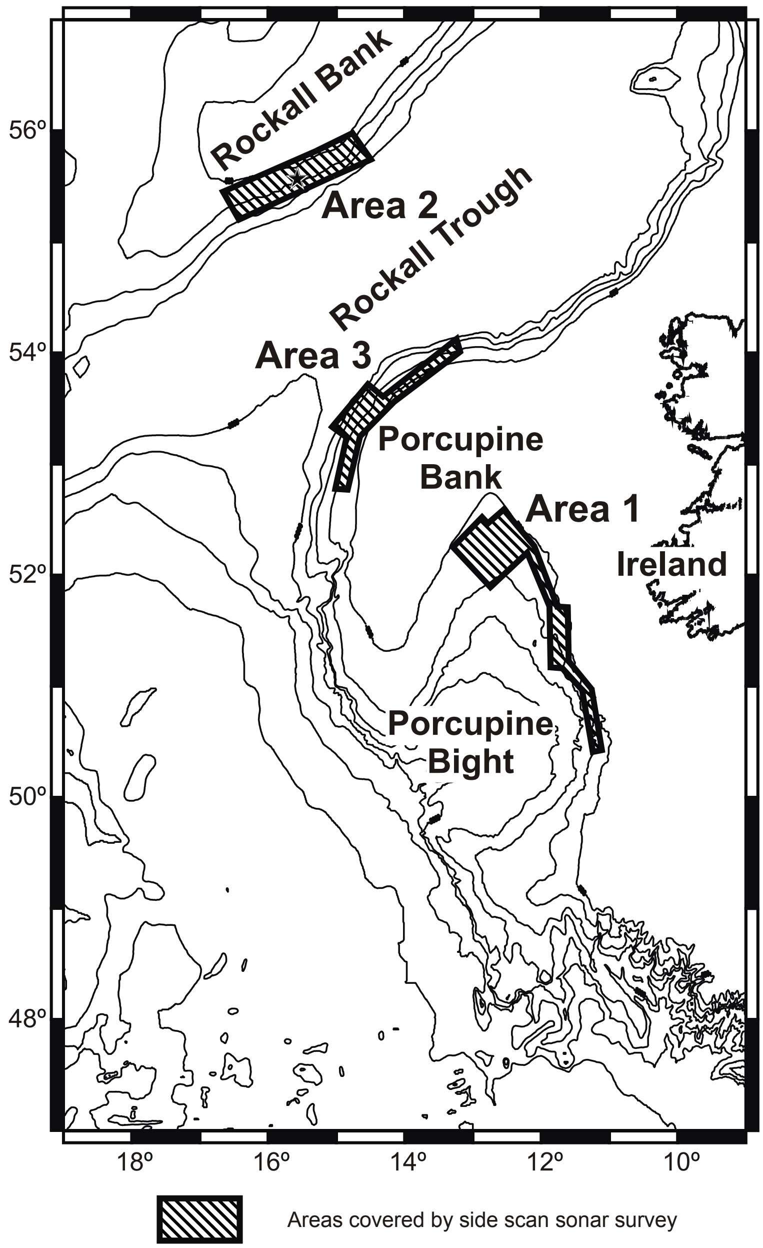


Fig. 1. *Map of the Porcupine Bight and Rockall Trough area with research areas indicated.*

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).

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

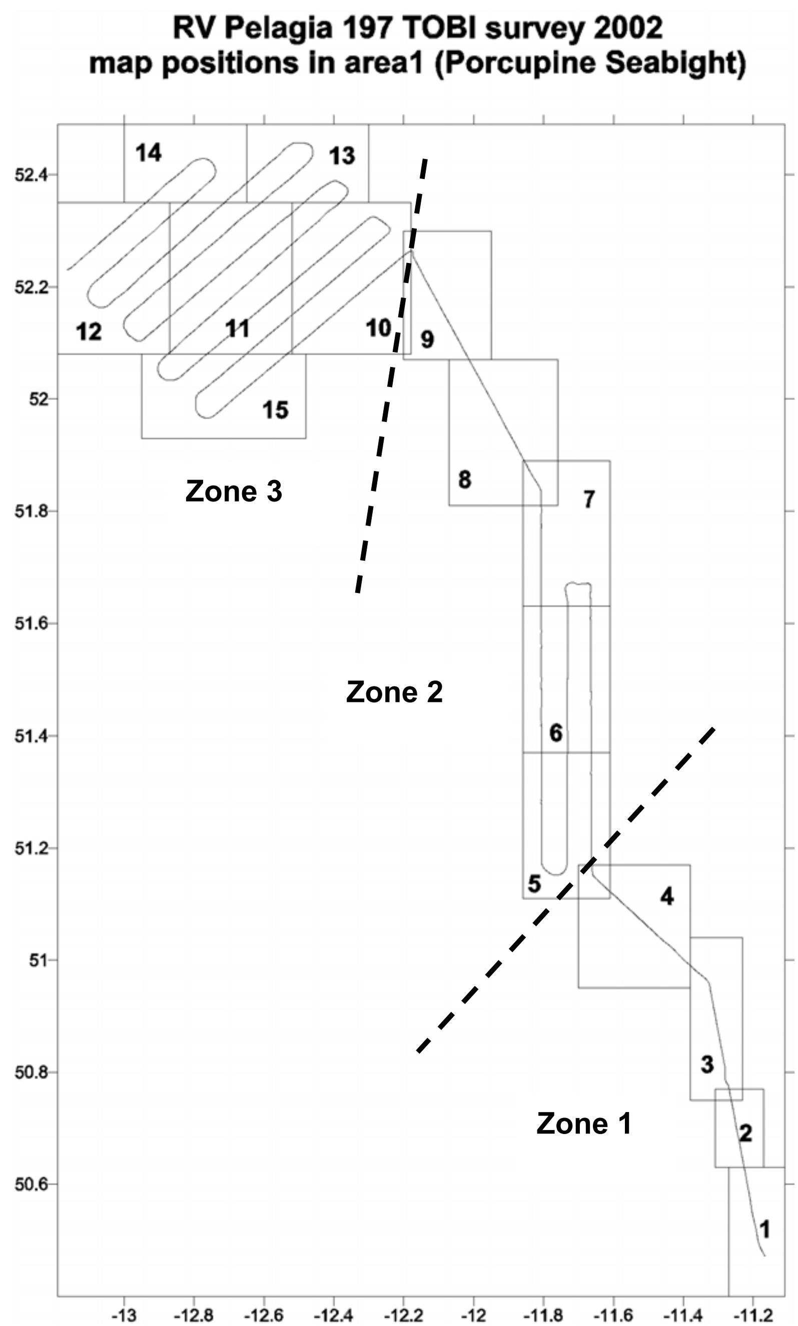


Fig. 2. *Map showing the mosaic maps of the Porcupine Seabight survey (area 1).*

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.

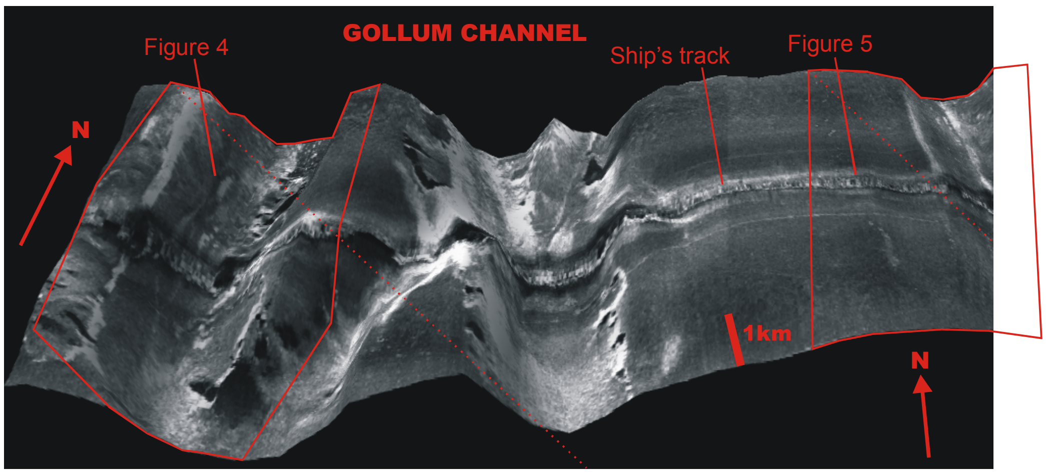


Fig. 3. *Example of TOBI side-scan sonar data draped over multibeam bathymetry showing the canyons of the Gollum Channel. The locations of figures 4 & 5 are also illustrated*.

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.

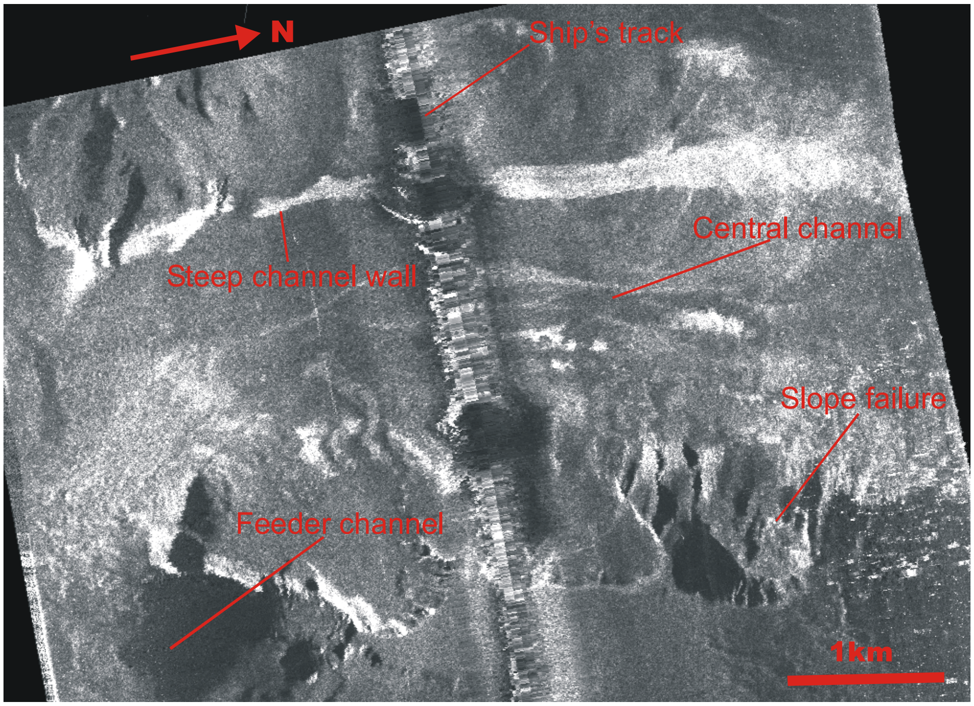


Fig. 4. *Gollum channel details showing canyon flank gullying and failure*

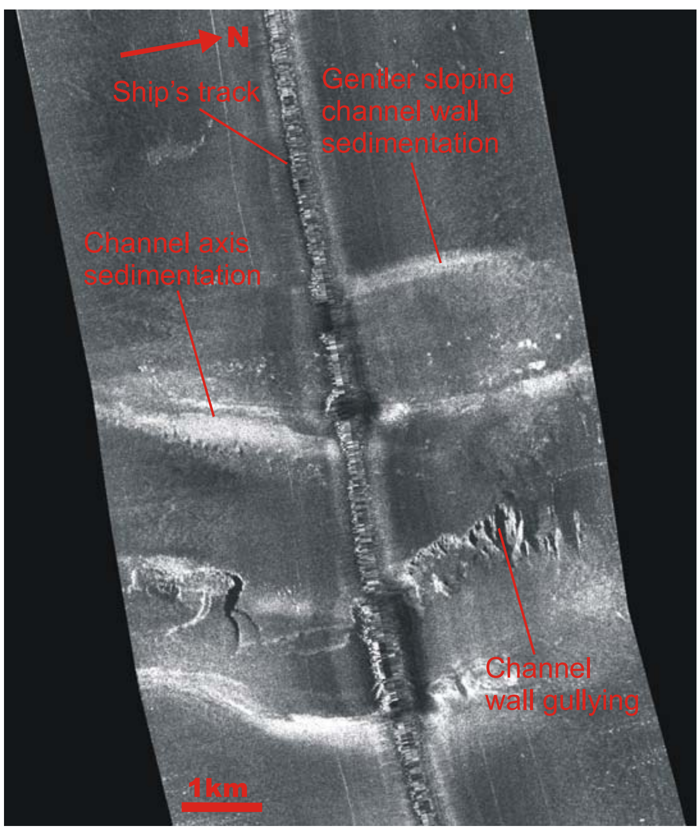
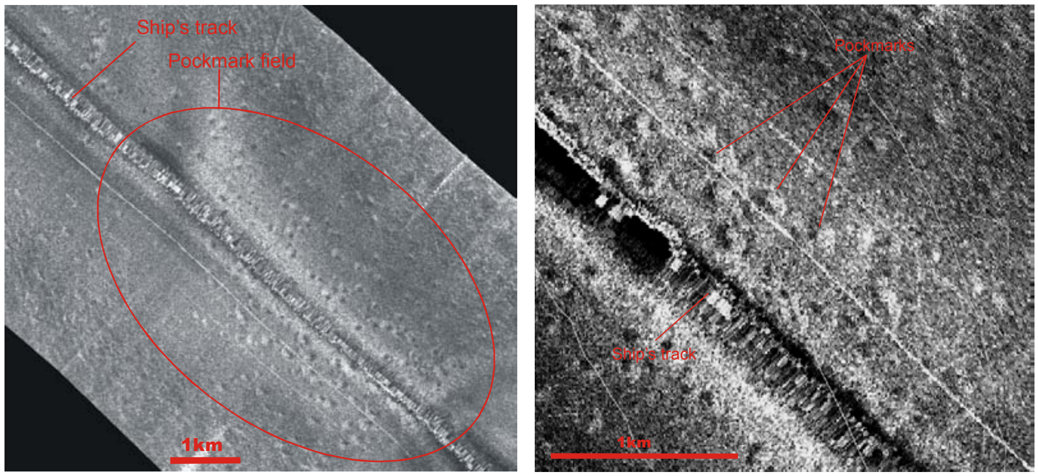


Fig. 5. *Gollum Channel details showing gullying*

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).



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

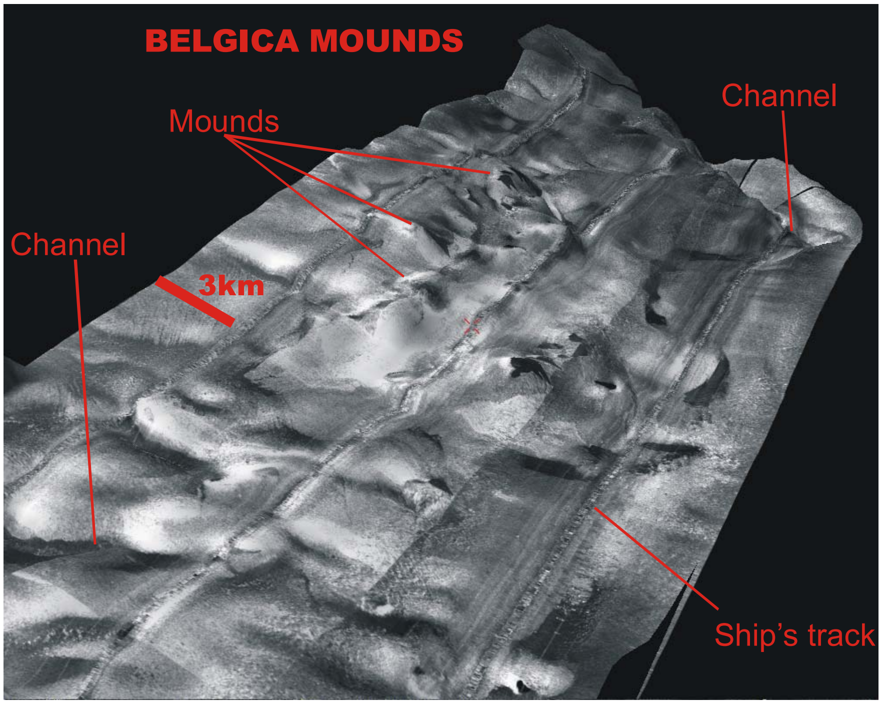


Fig. 7. *Southerly looking perspective of the Belgica Mounds: TOBI draped on multibeam bathymetry.*

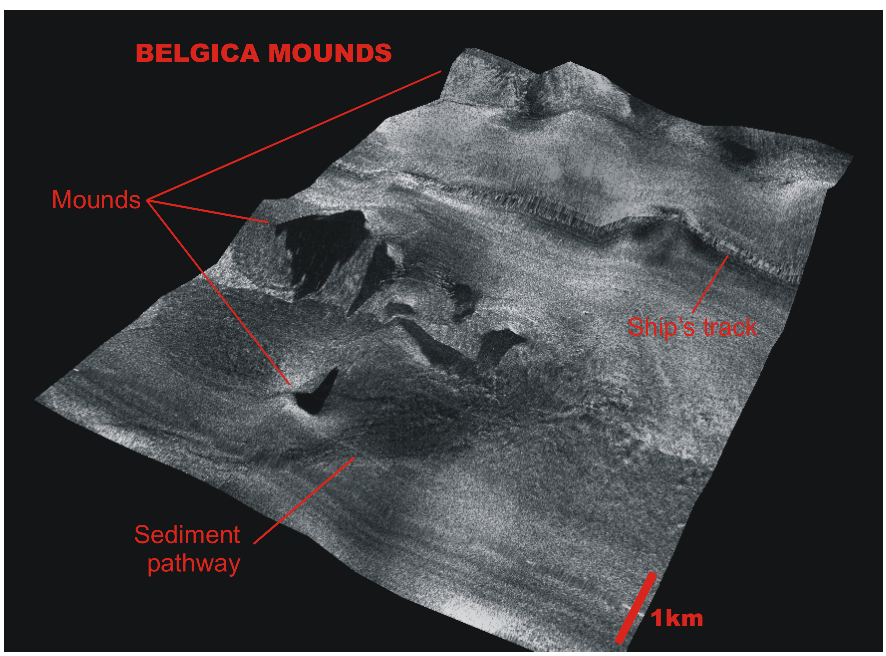


Fig. 8. *Easterly looking perspective of the southern Belgica Mounds area: TOBI draped over multibeam bathymetry showing mound and sediment drift features.*

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.

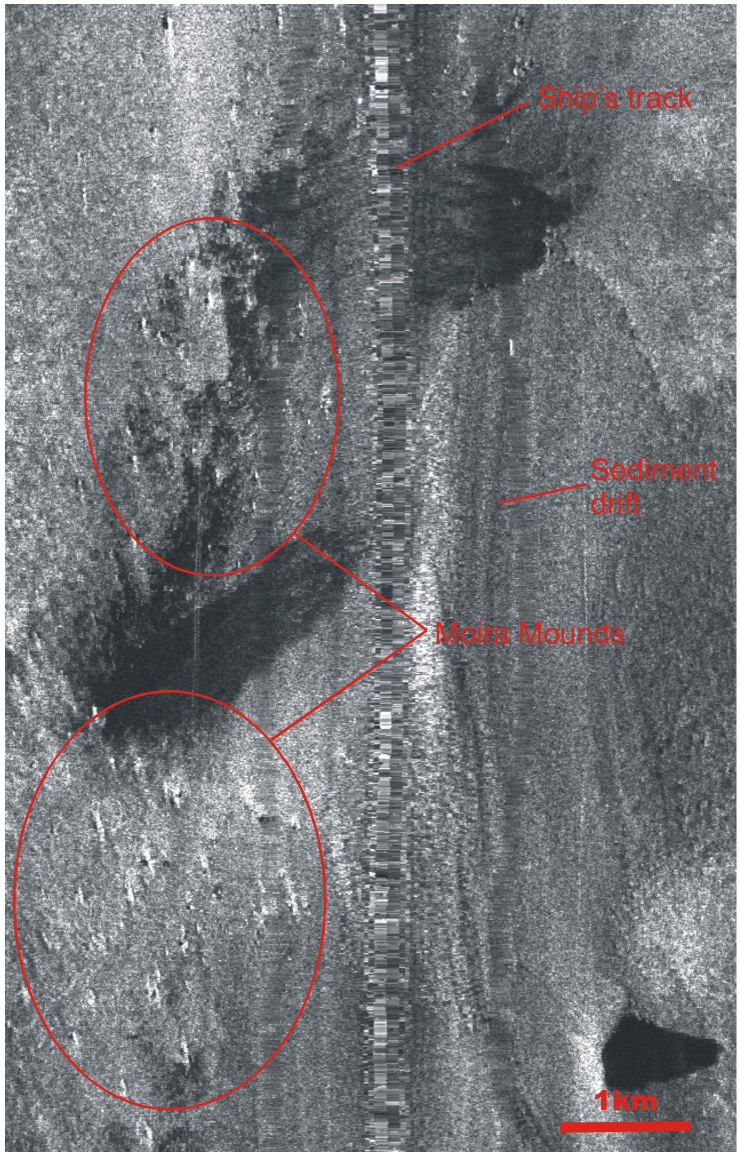


Fig. 9. *Small-scale carbonate mound features (Moira Mounds) existing between areas of extensive sediment drift*.

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.

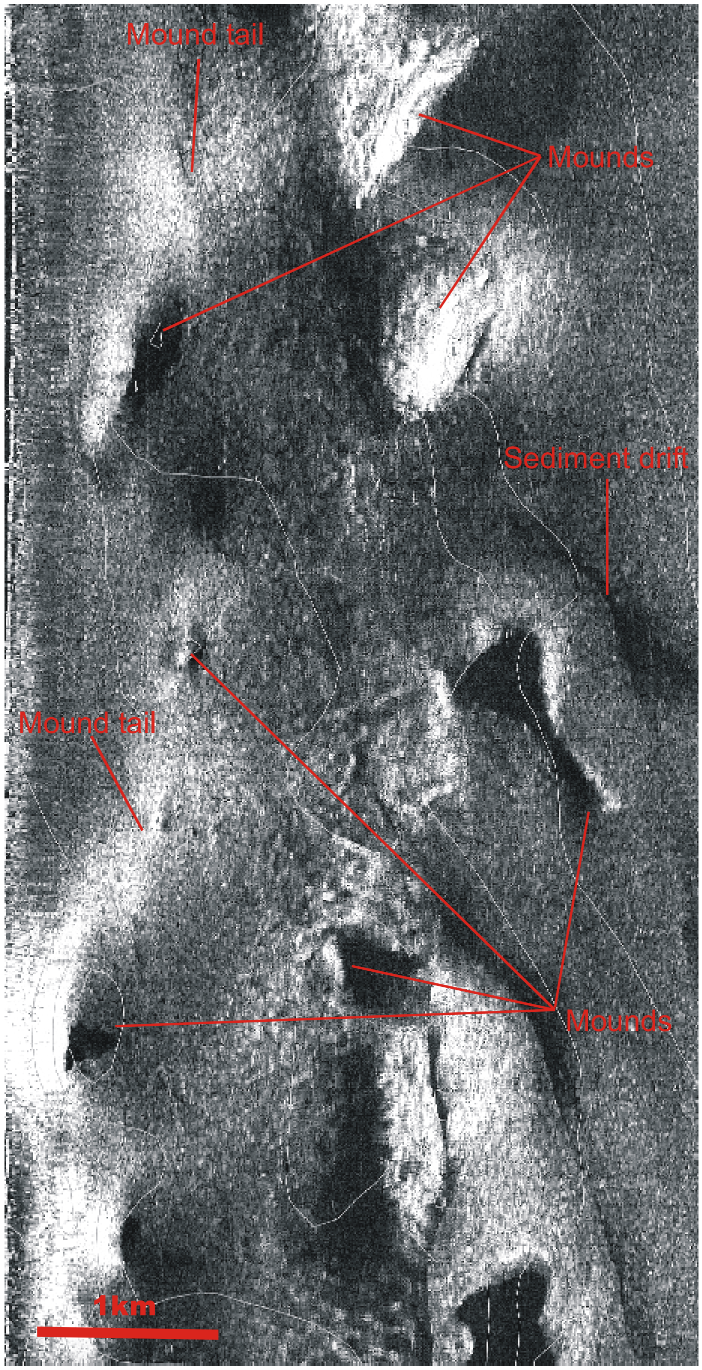


Fig. 10. *Interaction between sediment drift bodies are positive relief carbonate mounds.*

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.

3.3. 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. 11).

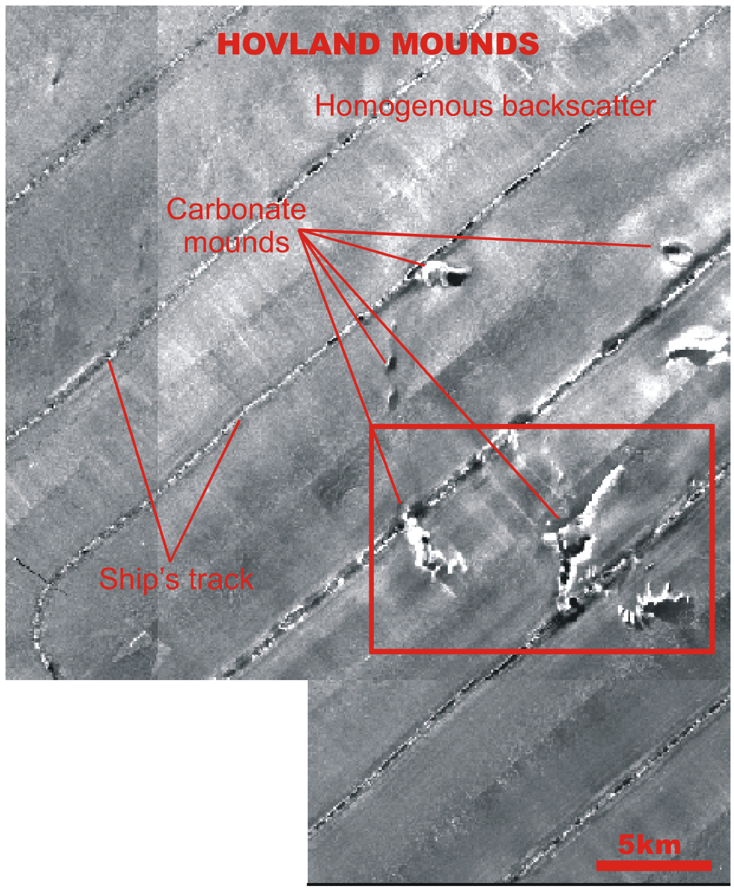


Fig. 11. *Uniform moderate backscatter seabed with high relief mound features evident.*

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. 12) 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.

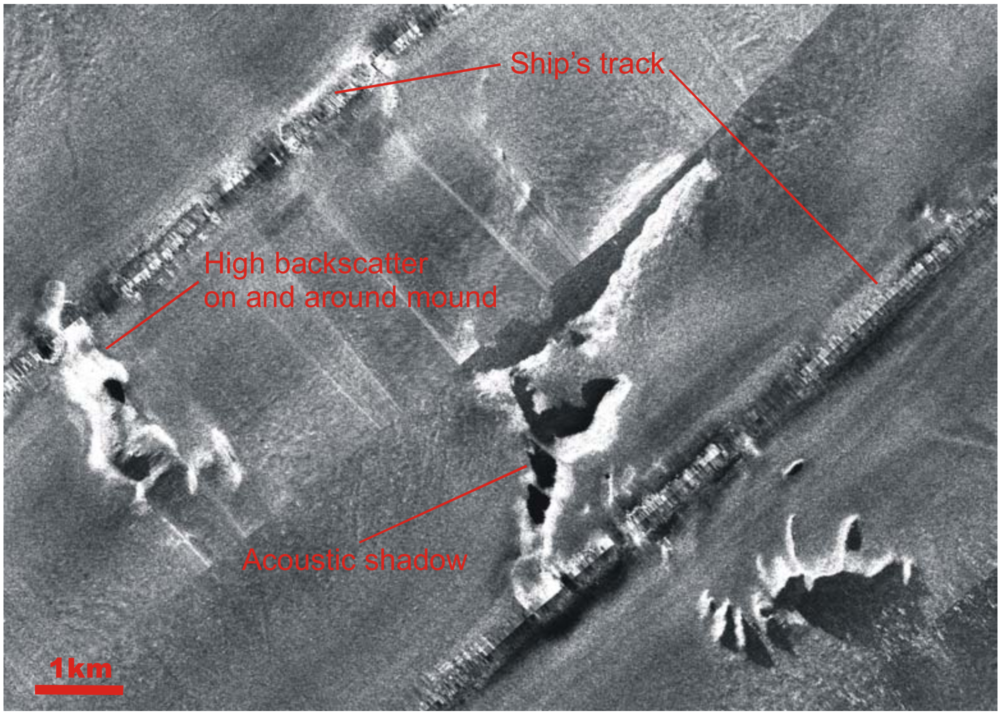


Fig. 12. *Hovland Mound details. The central mound is the Propellar Mound*

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.

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

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. 13). 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. 14).

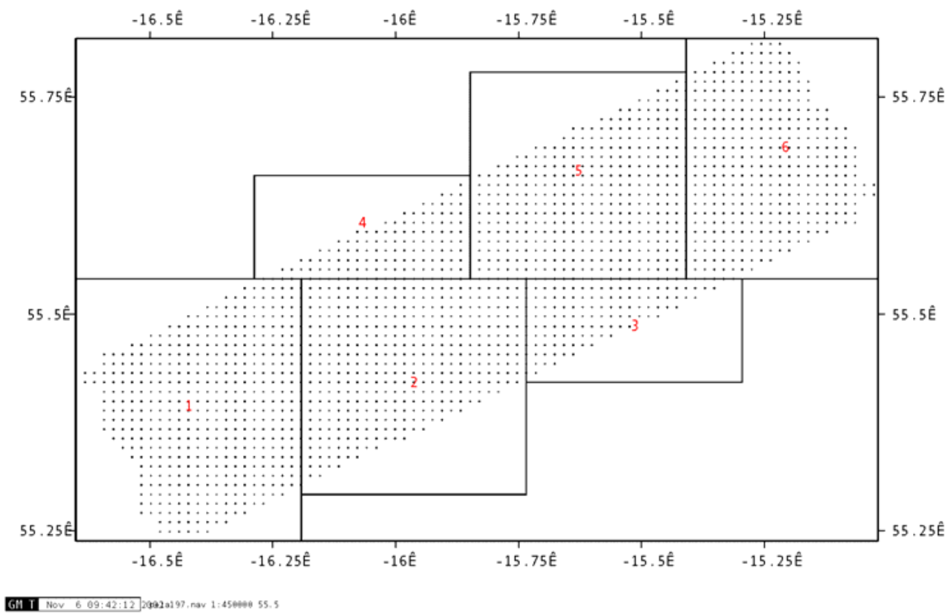


Fig. 13. *Map showing the mosaic maps of the SW Rockall Trough survey (area 2).*

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 14). 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).

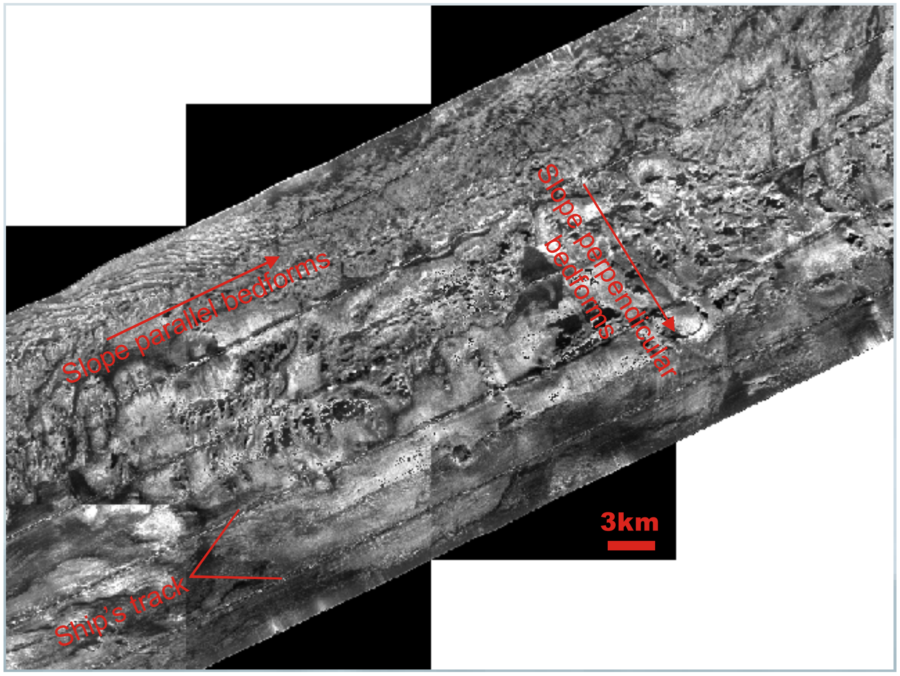


Fig. 14. *Central section of the SW Rockall Trough mosaic showing zonation. Downslope is to the south-east..*

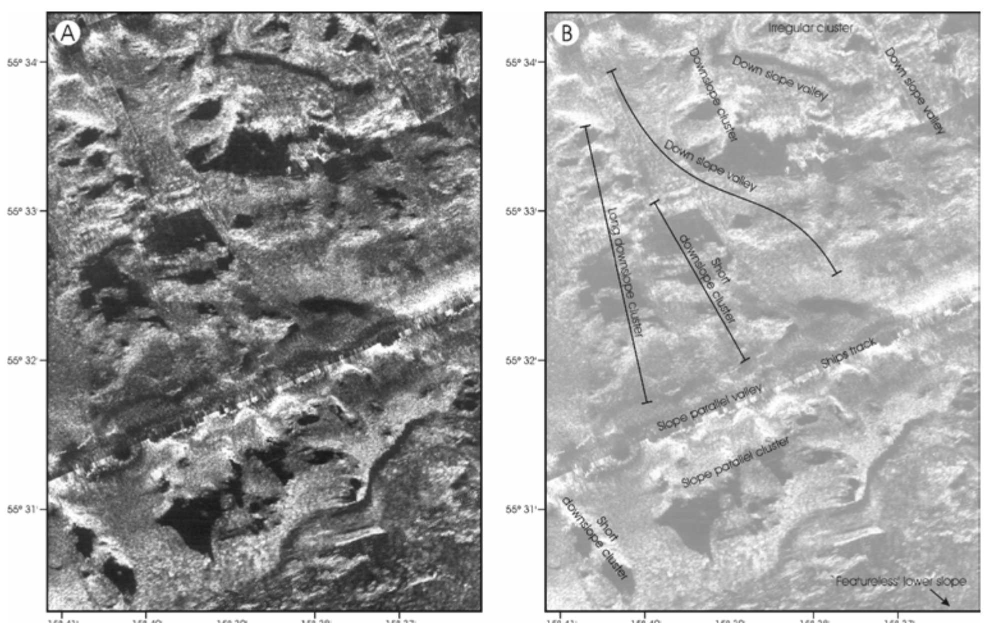


Fig. 15. *A: Data example of the SW Rockall Trough margin (area 2) showing the mound morphology in this area, and,* B*: Interpretation of* A *showing mound clusters and valleys*.

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. 15). 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. 16). 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).

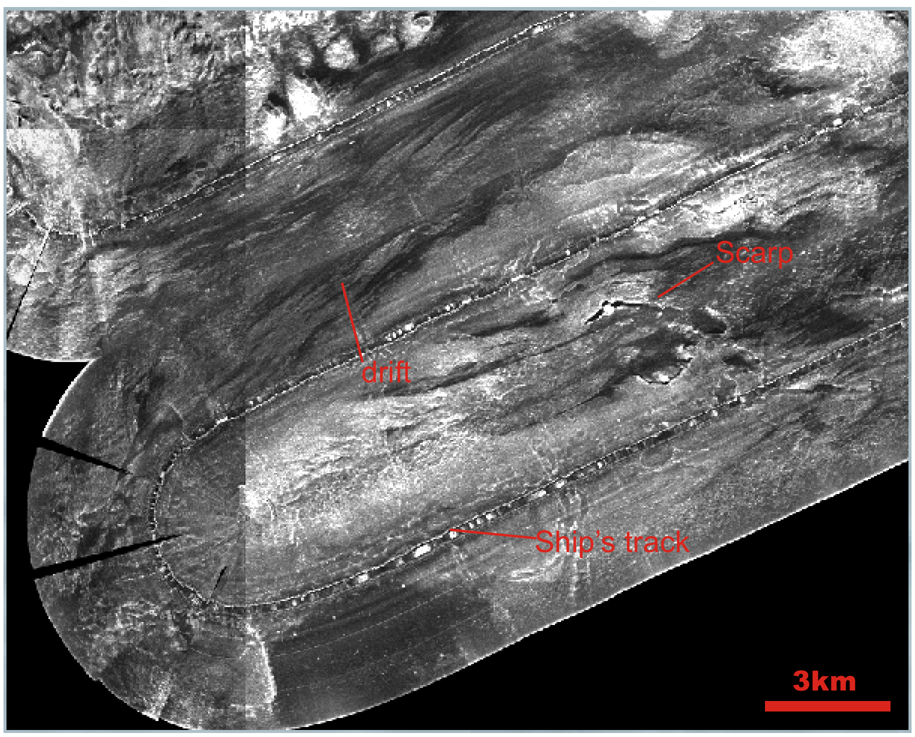


Fig 16. *The deeper water mosaic areas show drift features and evidence of slope failure. Downslope is to the south-east.*

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

The side-scan sonar mosaic of the SE Rockall Trough margin (northeastern Porcupine Bank area) (Figs. 17 & 18) 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.

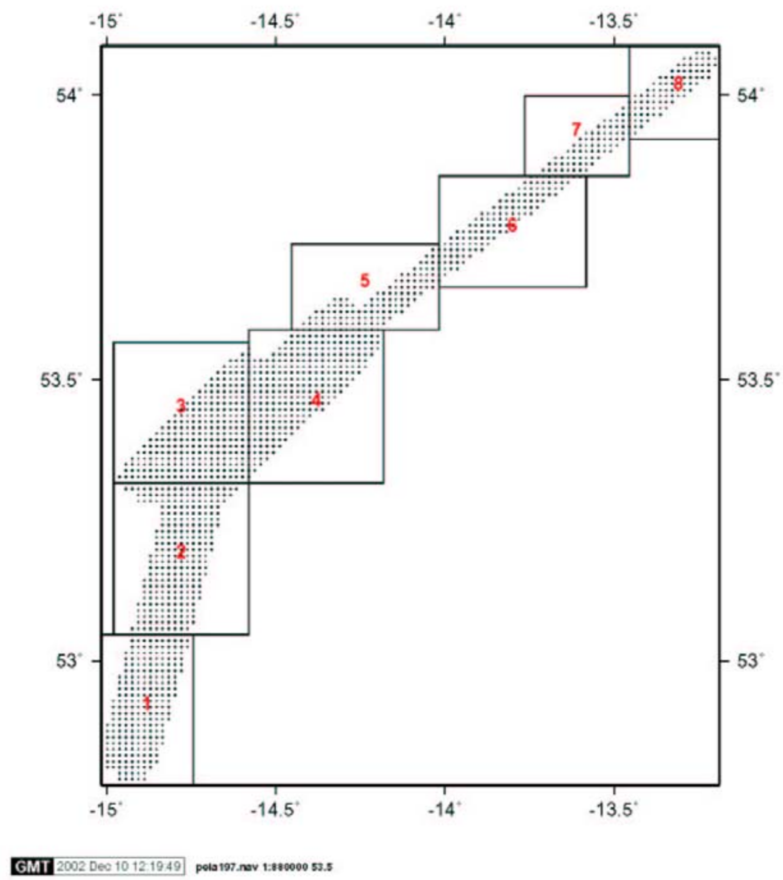


Fig 17. *Map showing the mosaic maps of the SE Rockall Trough margin (area 3).*

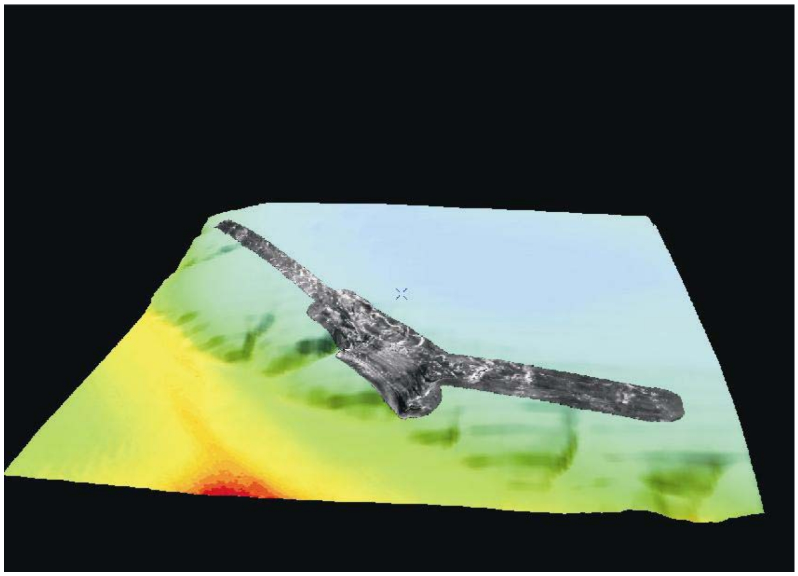


Fig. 18. *Overview mosaic coverage on the Porcupine Bank*

A number of sinuous scarps are identified on the mosaic that have a slight topographic rise upslope and a steep scarp-face downslope (Fig. 19). 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. 20).

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. 21). 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. 19) 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 22). Alternatively, they could be associated with gas seepage along faults that a form the scarps.

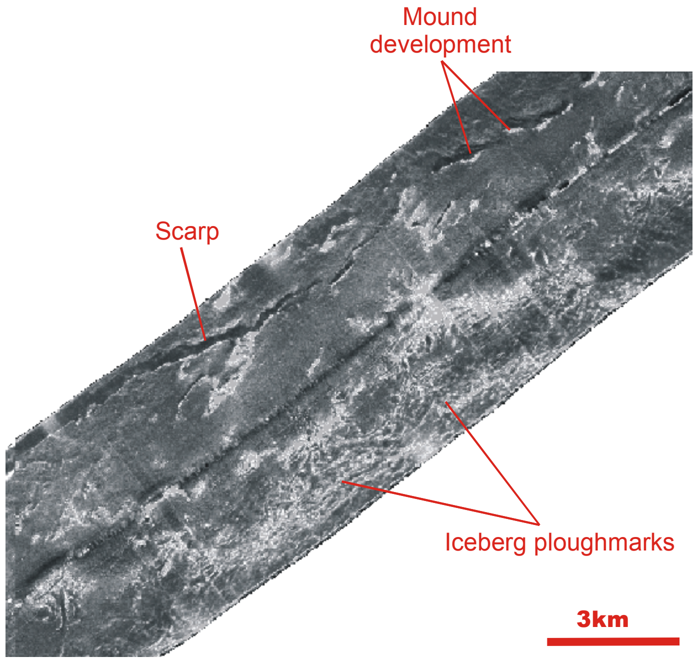


Fig. 19. *Sonar image showing scarps with small mound development aligned along the crest and an upslope zone of iceberg plough marks. Downslope direction is to the north-west.*

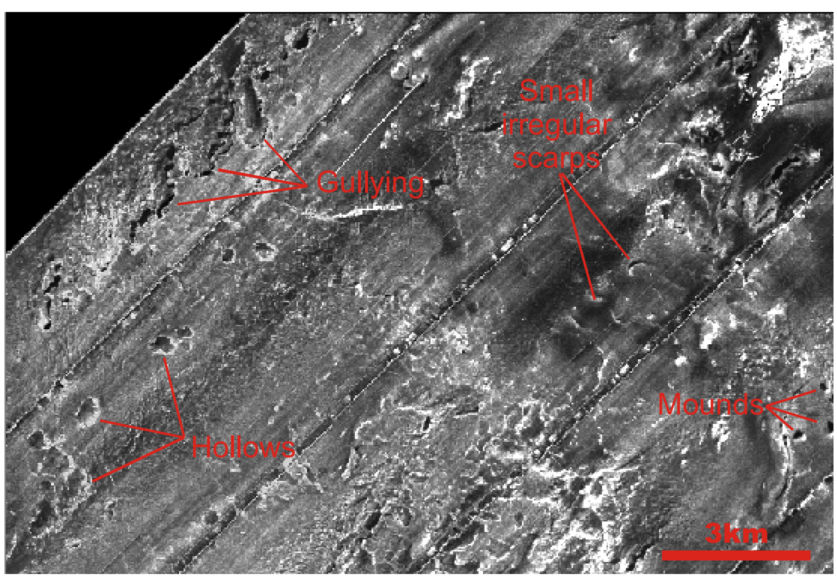


Fig. 20. *Sonar image showing small irregular scarps, hollows formed by erosion or shallow slope failure, downslope gullying and carbonate mounds. Downslope direction is to the north-west.*

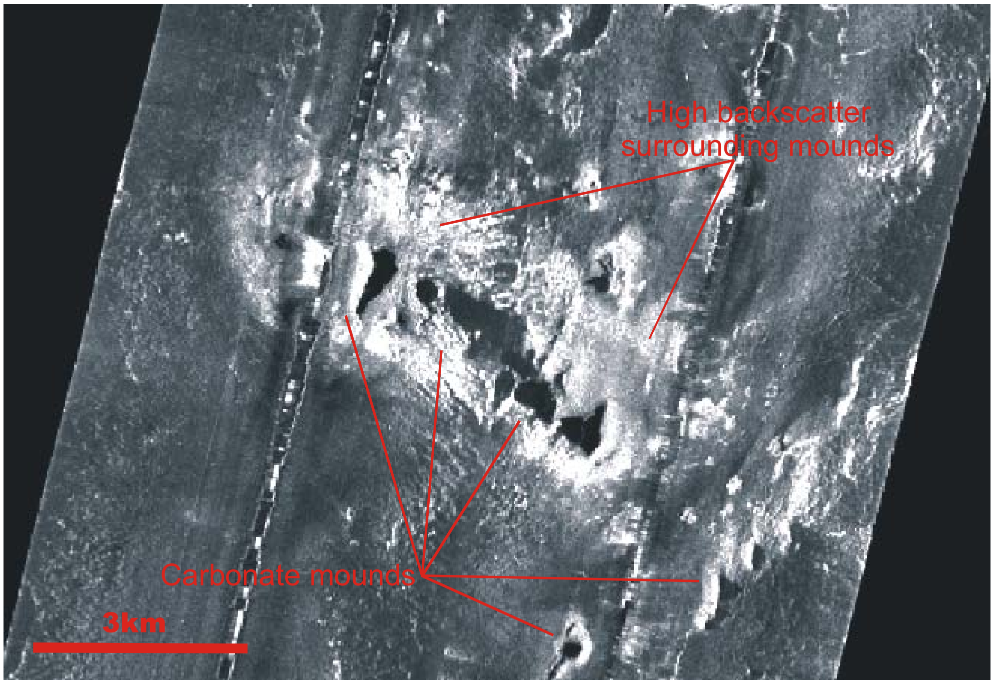


Fig 21. *Giant carbonate mounds cluster with smaller carbonate mounds and high backscatter signature on the surrounding seabed. Downslope direction is to the west*.

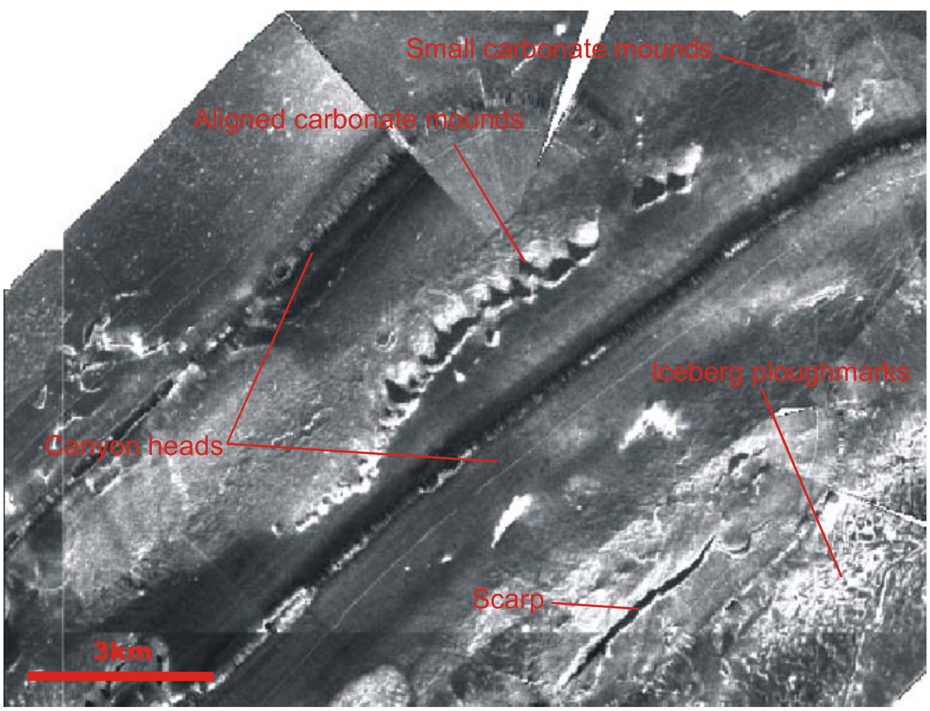


Fig 22. *An alignment of carbonate mounds along a topographic ridge between two canyon head feeder systems. Scarps and iceberg plough marks are also visible. Downslope direction is to the north-west.*

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 19 & 22). 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.

6. References

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Appendix 1. Shipboard party

Scientific party

Name	Institute
Henk de Haas (Chief scientist)	Royal Netherlands Institute for Sea Research, Texel, The Netherlands
Andy Wheeler (Co-chief scientist)	Dept. of Geology & Env. Res. Inst., Univ. College Cork, Cork, Ireland
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
Veit Hühnerbach (Data processor)	Southampton Oceanography Centre, Southampton, United Kingdom
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
Furu Mienis (Student)	Dept. of Earth Sc., Free Univ. Amsterdam, Amsterdam, The Netherlands
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.