National Oceanography Centre, Southampton

Research & Consultancy Report No. 24

MV *Franklin* Cruise 0206
03-23 Aug 2006
Habitat investigations within the SEA4 and SEA7 areas of the UK continental shelf

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2007

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DOCUMENT DATA SHEET

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PUBLICATION DATE

2007

TITLE

MV *Franklin* Cruise 0206, 03-23 Aug 2006. Habitat investigations within the SEA4 and SEA7 areas of the UK continental shelf

REFERENCE

Southampton, UK: National Oceanography Centre, Southampton, 95pp. & 71 figs.
(National Oceanography Centre Southampton Research and Consultancy Report, No. 24)
(Unpublished manuscript)

ABSTRACT

The objectives of the *MV Franklin* 0206 cruise were to collect EM1002 multibeam bathymetry and backscatter data, carry out on-board processing and use interpreted mosaics to identify variations in seafloor geology and morphology. Using these interpretations as a guide to distinguish variations in benthic habitat, when required, additional high resolution sidescan sonar transects would be run, and, in areas of interest, seafloor photograph and video imagery collected. The aims were to

- create high quality bathymetric maps of the survey areas
- create acoustic backscatter maps over the same areas
- when possible, define the extent of benthic habitats
- undertake photographic surveys of specific habitat areas to quantify the benthic ecology
- create high resolution bathymetric, backscatter and sonar maps of specific features as may be discovered, such as sponge reefs, carbonate mounds etc.
- complete, during the cruise, a preliminary interpretation of the above data

This was a highly successful cruise with all cruise objectives achieved. New erosive landforms were imaged over both George Bligh and the northern Hatton Bank, and numerous areas of rock outcrop mapped with multibeam and proved by photography to be reef. The epifauna were typical of could be expected of deep water oceanic areas, with encrusting sponges and corals over outcrop and other types of hard substrate, including pebbles on sands.

KEYWORDS

acoustic backscatter, bathymetric chart, cruise 0206 2006, EM1002, Hatton Bank, George Bligh Bank, cold water coral, cold water reef, *Franklin*, Lophelia, multibeam bathymetry, seafloor mapping, sonar surveys, SEA4, SEA7

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Pernilla Linne	Marin Mätteknik AB
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Joakim Strickner	Marin Mätteknik AB
Robert Venema	Marin Mätteknik AB
Karl Flink	Marin Mätteknik AB
Tony Cran	SEATRONICS Ltd

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Richard Olsson	Chief Officer
Kristoffer Bystedt	Second Officer
Conny Widfors	Chief Engineer
Arne Löfgren	First Engineer
Joakim Arvidsson	Motorman
Mikael Nilsson	Able Seaman
Peter Ågren	Able Seaman
Törner Hansson	Able Seaman
Lennart Jönsson	Cook
Julia Wisniewska	Steward

LIST OF FIGURES

FUNDING ACKNOWLEDGEMENT

This project was funded as part of the UK Department of Trade and Industry's offshore energy Strategic Environmental Assessment programme. The SEA programme is funded and managed by the DTI and coordinated on their behalf by Geotek Ltd and Hartley Anderson Ltd. Additional funds were also made available from the JNCC, U.K.

VESSEL

*Figure 1. The "business end" of the MV Franklin.**

Name:	FRANKLIN	Flag:	SWEDEN
Port of Registry:	GOTHENBURG	Call Sign:	SEIN
Class:	Lloyds Register (LR)	IMO.No.	8301797
Length:	55.6 m	Beam:	11.99 m
Draught:	3.8 m	Freeboard:	2.5 m
Gross Reg. Tons:	1179	Net Reg. Tons:	353
Displacement:	1218	Owner:	Shipriders AB Nya Varvet, Byggnad 84 426 71, Vastra Frolunda SWEDEN Tel: +46 31 695280

Primary Survey Equipment for this project:

SIMRAD EM1002 Multibeam
Benthos 100/384 kHz sidescan sonar
Geoacoustics 100/500 kHz (deeptowed) sidescan sonar
SEATRONICS Deep Sea Camera, inc. a Valeport MIDAS CTD system.
Primary Navigation: ARON 2000 DGPS
USBL: GAPS, France

ITINERARY

Sailed Kirkwall, UK	17:00 UTC, 3rd August, 2006
Docked Stornaway, UK	07:00 UTC, 23rd August, 2006

* *Thanks to Joakim Arvidsson for permission to use the photograph.*

BACKGROUND AND PROJECT OBJECTIVES

Seafloor Physiography and Geography

The continental shelf off northwest Scotland has been sculpted by the effects of a number of glacial events over the past million or so years. The current surficial sediments are the remnants of material deposited as the ice sheets waxed and waned; there is little present-day sediment input to the area. Typically the sediments are gravels, with sand sheets and also rock outcrop. In water depths of 20-100 m, shell-rich sand banks and ridges are formed by tidal current activity; further to the west, the Hebrides Shelf gives way to a shelf break at ca. 200 m, with along large parts of the shelf-edge, the unmistakable traces of iceberg plough-marks. To the west, the Rockall Trough is a 2,700 m deep (shallowing northward) basin that contains three large seamounts; from south to north they are the Hebrides Terrace Seamount, which sits adjacent to the UK continental slope and rises from 2,300 to 1,000 m, Anton Dohrn Seamount, a distinctive seamount that sits in the centre of the northern Rockall Trough and rises from 2,200 to 600 m waterdepth, and the Rosemary Bank, a very large moated seamount that sits at the northern end of the Rockall Trough and rises from around 2,200 m in its moat to 500 m. Further to the west is the Rockall Bank which shoals to 200 m over much of its area and has the small pinnacle of Rockall Island. Other shoals associated with Rockall include George Bligh Bank and Hatton Bank, both of which have been partially surveyed under previous DTI contracts and are known to have significant coral (*Lophelia pertusa*) colonies.

In terms of the tides and currents, in the SEA4 region the currents (both surface and benthic) are strongest over the inner shelf (> 1 ms^{-1}), though storm-induced benthic currents may increase this by up to tenfold. In the Fair Isle channel there are opposing tidal currents of approximately equal strength. Over the shelf-edge and in the deeper waters to the west, two main water masses can be recognized in the Rockall Trough, although both have complex origins. The upper water mass, (Eastern North Atlantic Water, or ENAW) occupies the upper 1,200 to 1,500 m of the water column, whilst at depth, the lower water mass consists primarily of water derived from the Labrador Sea. Overall flow patterns within the ENAW are complex, with irregular movements of eddies and gyres superimposed on an overall north-easterly transport. Consistent flow towards the northeast occurs only in a narrow zone along the Hebrides slope, between the shelf edge and depths of about 1,000 m. The deeper part of the north-easterly flow is blocked by the topography of the Wyville-Thomson Ridge and is probably deflected to the west, although there is little published evidence for this. The deeper water mass circulates in an anticlockwise direction around the Rockall Trough, constrained by the topography. In additional Norwegian Sea Overflow Water enters the Rockall Trough across the Wyville-Thomson ridge, and some of this flow is deflected southward along the western margin of Rockall Trough.

The objectives of the *MV Franklin* 02/06 (F0206) cruise were to collect EM1002 multibeam, backscatter and also high resolution sidescan sonar data over selected areas of the UKCS of interest to the DTI and JNCC that would help refine current models of the benthic topography, habitat and ecology. The areas of interest included the Papa and Horseshoe areas to the west of Orkney, the intersection of the Wyville-Thomson Ridge and the shallow continental shelf and the Hatton Bank (Figure 1). The scientific rationale behind this research programme is guided by potential future hydrocarbon exploration over the UKCS in combination with the need to investigate areas deemed high priority/potential ANNEX I exclusion zones by the JNCC, and whilst at this stage it is not possible to be definite about the actual locations of future seafloor installations and/or drill-sites, exploration wells are moving to ever deeper waters and further offshore into areas where little or no details are known about seafloor conditions except on the broadest of scales.

The first step in this type of detailed scientific study of the seafloor environment is to produce an accurate base-map of the topography, and, as a derivative, a seafloor acoustic reflectivity map which in turn will allow large-scale differentiation of the varying habitats within the diverse frontier areas under study. Where seafloor conditions are interpreted as being markedly different and/or unusual, or where expert interpretation of the data indicates probable sensitive and/or unusual areas of benthic habitat, a photo-reconnaissance mission to allow "ground-truthing" of the geophysical data and definitive description and quantification of the benthic biology and geology will be attempted, possibly if conditions are appropriate, followed by some carefully targeted, physical sampling.

Hatton Bank has never been a place of intense scientific study, indeed some of the best published bathymetry maps of the region are based on satellite altimetry and/or old (pre-GPS) single-beam echo-soundings that can be as much as 30 nautical miles apart. Thus a by-product and value-added aspect of this study is that it is not only important in the context of specific DTI and JNCC interests, but also in generally developing knowledge of the global oceans.

CRUISE NARRATIVE AND PRELIMINARY INTERPRETATIONS

(All Times UTC)

A detailed technical operations report was completed by the vessel operator (Marin Mätteknik). This section of the report describes seagoing activities and conditions encountered during the cruise as they affected the science priorities. An Observation and Preliminary Interpretation section begins on page 23.

Thursday 3 August (Day 215)

Whilst alongside, a safety briefing and tour of the vessel was given by the 2nd Officer. The vessel sailed from Kirkwall at 17:00 and began a transit to the EM1002 calibration and survey area to the west of Orkney, located around 59º05'N 3º40'W known as PAPA1. The vessel arrived at survey block at approx. 2100, and began SVP and then survey operations with a series of EM1002 lines designed to abut a previous industry survey. Figure 2 shows the "on-line" data acquisition area in the *Franklin*'s main laboratory.

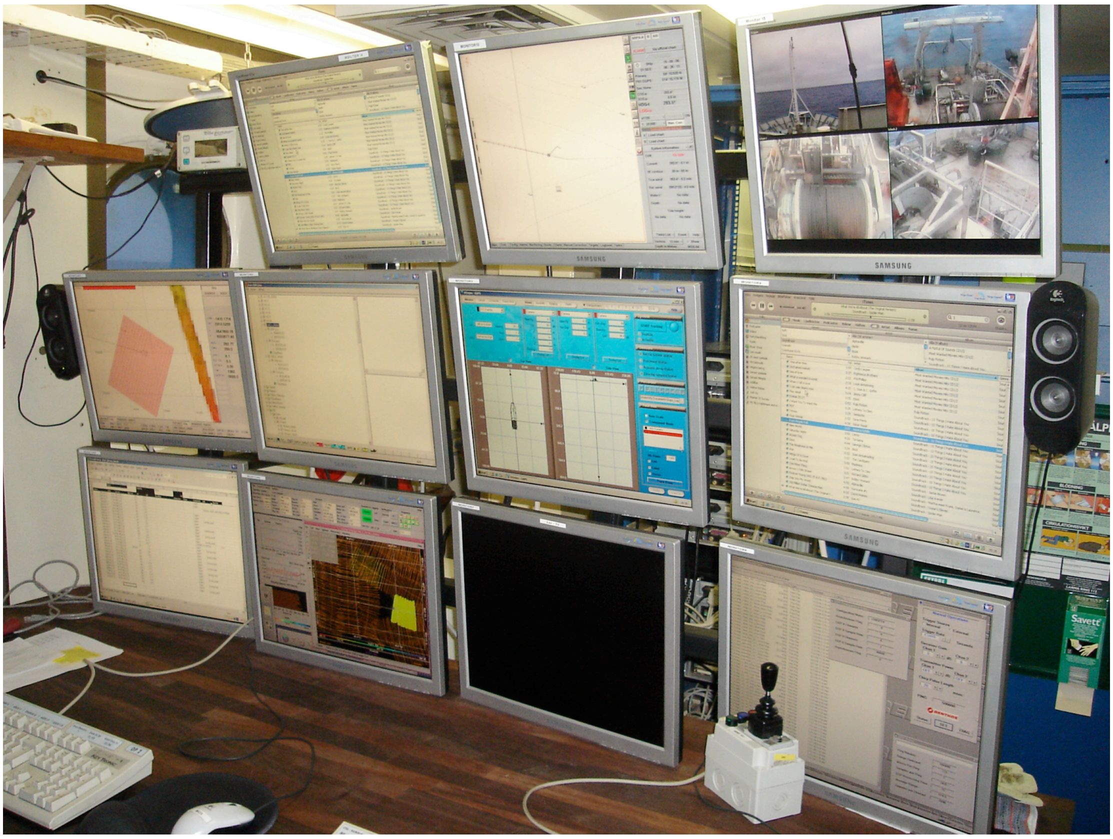


Figure 2. The "on-line" console area in the main laboratory of the Franklin.

Friday 4 August (Day 216)

A dual frequency (100 and 384 kHz) high resolution sidescan transect was run across the main part of the bank, which stood 40-60 m above the surrounding seafloor. This was used to target a photographic transect which crossed several distinctive areas of acoustic backscatter. The SEATRONICS sidescan was also tested on a reverse transect. It was decided that when using either fish the highest frequency (384 kHz Benthos or 500 kHz Geoacoustics) would be used to obtain the highest resolution data.

Following completion of this survey area a transit was run (with the EM1002 collecting data) to the "PAPA2" or "Horseshoe" area where an EM1002 box-survey was begun.

Saturday 5 August (Day 217)

The EM1002 survey in PAPA2 was completed and a 100/384 kHz sidescan transect made across the survey area.

Following the sidescan transect, the cameras system was launched (Figure 3) and five stations successfully completed. Following the camera surveys the transit to the northern Hatton Bank was commenced, though late in the day the vessel was forced to alter course due south to try and skirt a low-pressure area and the unexpected high sea-states that it caused.

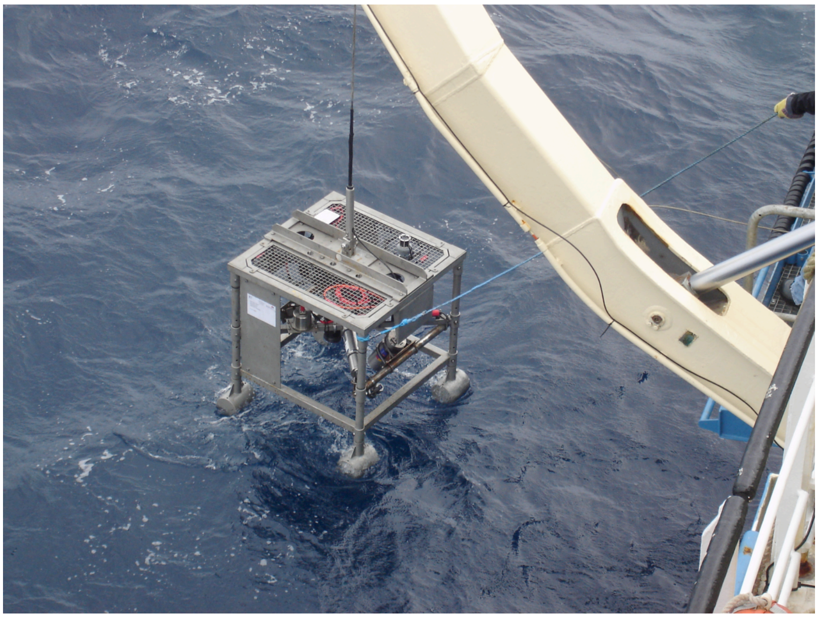


Figure 3. The SEATRONICS camera system being launched from Franklin.

Sunday 6 August (Day 218)

The vessel began the day in Broad Bay (Isle of Lewis) waiting on weather, using the time to re-configure the SEATRONICS camera so that it automatically stamps "ships time" on the digital log when each still photograph is taken. The camera was successfully tested before the vessel was underway heading for George Bligh – Hatton Banks.

Monday 7 August (Day 219)

Steady progress into a moderate 2 m swell allowed arrival at the EM1002 survey start point on the northern flank of George Bligh Bank in the early evening. In a waterdepth of 900 m, a swath of 0.9-1.0 km was achieved. Despite some vessel movement, the acoustic backscatter was acceptable for photographic target selection.

Tuesday 8 August (Day 220)

A reconnaissance line was run approximately NE-SW along the northern flank of George Bligh Bank, but no suitable targets were seen, so an alternative trackplan (using old GLORIA data as a guide) was started and immediately a series of seabed sculpted deeps were detected. Unfortunately the weather intervened with survey progress, gusting to 40kt by the middle of the day, and surveying had to be curtailed whilst the vessel made gentle headway into the wind and sea.

Wednesday 9 August (Day 221)
By late morning the vessel was located some 60 miles west of the George Bligh survey area, in water too deep for data collection with the EM1002, but the sea and wind had subsided and we were able to alter course to sail northward and begin collecting data when water depths allowed. An eastward survey line paralleling an EM120 multibeam survey line collected by the *Kommandor Jack* in 2005 was undertaken whilst we transited to our targeted survey area, which was a depth transect to 1,000 m across the northern margin of Hatton Bank between 15º50'-15º00'W.

Thursday 10 August (Day 222)
The survey over the northern arm of Hatton Bank continued in calm conditions.

Friday 11 August (Day 223)
Shortly after midday the EM1002 survey was suspended as coverage of the southern flank of this section of Hatton Bank had been completed, and the weather prognosis ideal for deep sea photography. Four sites were completed.

Saturday 12 August (Day 224)
The photography stations continued in excellent sea conditions, with a swell of <1 m and very light winds, and sites H_C8, 11, 5, 6, 10, 7, and H_C9 were successfully completed. Following the photographic survey, the EM1002 survey was resumed over the northern flank of this section of Hatton Bank.

Sunday 13 August (Day 225)
EM1002 surveying finished at the end of the day and the vessel moved to take up the first station position for the photographic transects across the northern flank targets whilst the multibeam data was being processed.

Monday 14 August (Day 226)
During the camera survey at station H_C12A, the winch developed a hydraulic problem which severely affected the haul and veer rates. Rather than risk total failure whilst the camera was still deployed it was decided to curtail the photographic survey after about 40 minutes of deployment (around 250 m horizontal distance) and recover the system. Whilst the winch was being attended to, the vessel began steaming to the next survey area over southeast Hatton Bank (sometimes known as Lyonesse Bank). The vessel arrived at the Hatton South survey area during the middle of the day and began EM1002 operations immediately.

Tuesday 15 August (Day 227)
By the early hours of the morning the seas that had been steadily building all day finally became too great and we suspended surveying and slowly headed due north into the sea, waiting for conditions to become more benign. During the day it became apparent that by the time the storm had passed and it was again sufficiently calm for us to continue multibeam mapping and camera surveys, we would probably be out of the immediate study area.

Wednesday 16 August (Day 228)
By just after 6am the weather had calmed enough that the vessel was able to turn and begin making way toward Hatton Bank (north) survey area. Along part of the route back to the study area a survey was conducted of possible scarp slopes on the southern flank of northern Hatton Bank (Hatton Transect), which would be further examined if time allowed. The swell was taking rather longer to deteriorate than had been expected and precluded attempting photography, so some of the transit swath lines were repeated to produce wider coverage.

Thursday 17 August (Day 229)
By early morning the swell still had not calmed sufficiently to allow camera station work, but swath mapping was possible: it was decided to continue to the George Bligh survey area and finish the mapping effort that weather had stopped at the beginning of the programme.

Friday 18 August (Day 230)
The George Bligh multibeam survey was completed half-way through the morning and the vessel occupied two camera stations in this study area, one along the (presumed) current axis into one of the smaller scours, and one orthogonal to the current into one of the bigger scours, GB_C1* and GB_C2*.

Once these were completed the vessel moved back to the north Hatton survey area to finish the photographic studies of the northern flank of the Bank, undertaking stations H_C12B* (continuation of the abandoned H_C12A), H_C18*, 17, and 14.
* The flash was not working for these stations.

Saturday 19 August (Day 231)
Photography stations continued with the successful completion of H_C13. Station 16 had some problems and had to be abandoned and re-started due to failure of the GAPS station-keeping positioning system. The vessel was controlled manually thereafter.

Once station H_C16 was successfully concluded, the vessel headed toward the Hatton Transect survey area in benign conditions and collected two more lines of multibeam to fully image a large scarp partially mapped on Day 228. Station HT_C1 had to be restarted after the camera lost the seafloor after crossing a very steep cliff edge. This station was followed by HT_C5, 2, 3 and 4, though the latter also had to be re-started as the camera lost focus and it was unable to be corrected with software. In the topography we were surveying it was considered too risky to re-boot at depth so the camera was recovered and redeployed after the re-boot, when Station HT_C4B was completed.

Sunday 20 August (Day 232)
Following the successful photography stations over the Hatton Transit area, the vessel headed to the Hatton South area and in the morning resumed the EM1002 survey that was halted there due to bad weather on day 227. Following completion of the swath survey, a sidescan transect across the area was planned. However, the Geoacoustics system supplied by SEATRONICS proved to be deficient, and the MMT Benthos sidescan system didn't have enough cable for surveying in 600 m water depths. After

tests it was decided to abandon the sidescan surveys and proceed with the photographic transects.

Monday 21 August (Day 233)

Transect HS_C2 was successful, but the next, HS_C3 had to be aborted early as the digital still camera developed a communications problem. The system was recovered and the problem turned out to be water in one of the camera connectors. The camera unit was replaced and the system redeployed. HS_C1, 4 and 5 were then completed without incident. A final camera run was made across one of the polygonal faults imaged in the Rockall-Hatton Basin by the *SV Kommandor Jack* in 2005, after which the vessel began the transit to Stornaway. Figure 4 shows the location of the main survey areas of F0206.

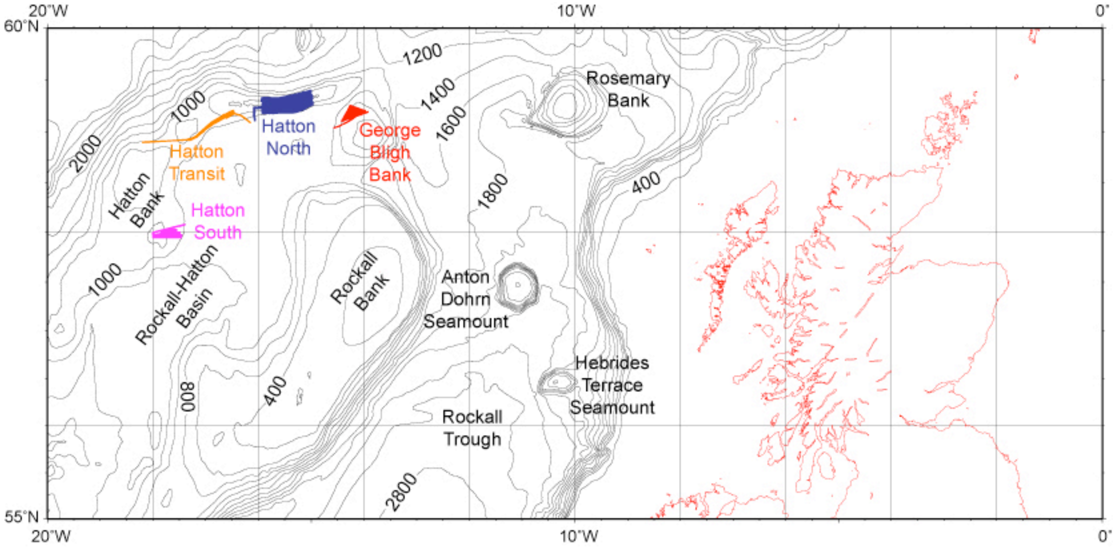


Figure 4. The multibeam survey areas completed during cruise F0206.

Tuesday 22 August (Day 234)

Transit to Stornaway.

Wednesday 23 August (Day 235)

The vessel docked in Stornaway at 0635.

TABLE 1 TABLE OF PHOTOGRAPHIC TRANSECT LOCATIONS*

* *NOTE: The stations were run in geographical order, which was not necessarily in numerical order.*

Site Label	Start Time	Start Latitude (North)	Start Longitude (West)	End Time	End Latitude (North)	End Longitude (West)	Notes
PAPA1_C1	0857/216	59°04.78'	03°41.19'	0957/216	59°04.46'	03°40.46'	61 images + video
PAPA2_C1	0420/217	59°33.31'	03°12.60'	0450/217	59°33.40'	03°12.67	33 images + video
PAPA2_C2	0547/217	59°33.94'	03°13.19'	0625/217	59°33.98'	03°12.89'	39 images + video
PAPA2_C3	0726/217	59°35.47'	03°14.26'	0749/217	59°35.50'	03°14.03'	29 images + video
PAPA2_C4	0844/217	59°35.78'	03°14.42'	0909/217	59°35.99'	03°14.53'	32 images + video
PAPA2_C5	0953/217	59°37.08'	03°14.24'	1013/217	59°37.07'	03°13.95'	21 images + video
H_C1	1418/223	59°17.52'	14°59.95	1507/223	59°17.04'	14°59.58'	54 images + video
H_C2	1743/223	59°12.47'	15°26.77'	1823/223	59°12.46'	15°27.31'	29 images + video
H_C3	2244/223	59°13.29'	15°51.42'	2310/223	59°13.03'	15°51.18'	32 images + video
H_C4	2052/223	59°13.92'	15°50.40'	2151/223	59°13.58'	15°50.06'	49 images + video
H_C5	0727/224	59°11.51'	15°25.84'	0757/224	59°11.61'	15°26.35'	32 images + video
H_C6	0949/224	59°15.51'	15°25.56'	1020/224	59°15.64'	15°25.97'	48 images + video
H_C7	1405/224	59°16.27'	15°19.11'	1451/224	59°16.32'	15°18.52'	54 images + video
H_C8	0036/224	59°11.32'	15°50.80'	0129/224	59°11.33'	15°51.35'	50 images + video
H_C9	1648/224	59°15.80'	15°00.88'	1735/224	59°15.99'	15°00.45'	34 images + video
H_C10	1150/224	59°16.47'	15°19.18'	1301/224	59°16.74'	15°19.27'	67 images + video
H_C11	0301/224	59°16.02'	15°47.24'	0348/224	59°16.31'	15°47.33'	66 images + video
H_C12A	0008/226	59°20.19'	15°02.42'	0054/226	59°20.13'	15°02.69'	26 images + video
H_C12B	1352/230	59°20.13'	15°02.68'	1504/230	59°20.04'	15°03.25'	70 images + video , no flash
H_C13	0021/231	59°17.25'	15°40.90'	0113/231	59°17.57'	15°40.78'	85 images + video
H_C14	2232/230	59°18.00'	15°37.72'	2318/230	59°18.30'	15°37.48'	50 images + video
H_C16A	0233/231	59°17.88'	15°51.41'	0251/231	59°17.97'	15°51.42'	19 images + video
H_C16B	0414/231	59°18.02'	15°51.42'	0448/231	59°18.17'	15°51.48'	30 images + video
H_C17	1924/230	59°19.96'	15°00.88'	1959/230	59°20.20'	15°01.04'	40 images + video
H_C18	1651/230	59°21.21'	15°14.19'	1749/230	59°20.95'	15°14.51'	49 images + video , no flash
GB_C1	0702/230	59°12.72'	14°10.80'	0802/230	59°12.54'	14°10.35'	53 images + video , no flash
GB_C2	1003/230	59°08.28'	14°22.96'	1037/230	59°07.99'	14°22.97'	32 images + video , no flash
HT_C1A	1105/231	59°08.50'	16°38.68'	1118/231	59°08.41'	16°38.66'	10 images + video
HT_C1B	1153/231	59°08.51'	16°38.63'	1248/231	59°08.24'	16°38.69'	53 images + video
HT_C2	1650/231	59°07.96'	16°44.57'	1803/231	59°07.69'	16°44.43'	105 images + video
HT_C3	1912/231	59°05.55'	16°48.91'	1958/231	59°05.70'	16°48.37'	38 images + video
HT_C4A	2152/231	59°01.41'	17°02.67'	2158/231	59°01.36'	17°02.65'	8 images + video
HT_C4B	2229/231	59°01.37'	17°02.67'	2318/231	59°00.98'	17°02.47'	48 images + video
HT_C5	1413/231	59°10.05'	16°32.40'	1526/231	59°09.75'	16°32.19'	74 images + video
HS_C1	0353/233	57°57.95'	17°40.62'	0458/233	57°57.95'	17°40.11'	66 images + video
HS_C2	2300/232	57°57.45'	17°46.15'	2352/232	57°57.18'	17°46.18'	38 images + video
HS_C3A	0055/233	57°58.34'	17°41.44'	0102/233	57°58.33'	17°41.44'	8 images + video
HS_C3B	0224/233	57°58.33'	17°41.41'	0307/233	57°58.15'	17°41.08'	68 images + video
HS_C4	0611/233	58°01.16'	17°36.41'	0726/233	58°00.89'	17°36.19'	64 images + video
HS_C5	0830/233	57°58.29'	17°35.90'	0906/233	57°57.99'	17°35.83'	49 images + video
PF_C1	1315/233	58°10.31'	16°26.10'	1517/233	58°11.01'	16°26.32'	96 images + video

Stations were labelled by study area and number as follows
PAPA1=PAPA1
PAPA2=PAPA2
H=Hatton North
HS=Hatton South (Lyonesse Bank)
HT=Hatton Transect (initially a passage)
GB=George Bligh Bank
PF=Polygonal Faults
C= Camera
1,2 etc = Station # (e.g. H_C1, HS_C3)

(N.B. Station H_C15 was removed as it overlapped with a previous station).

SURVEYING, DATA ACQUISITION AND OUTPUT

Navigation

Vessel navigation was by DGPS using the ARON 2000 system, a bespoke navigation system originally developed by Marin Mätteknik AB as the primary system. All other data acquisition systems took their time stamp from this navigation signal ensuring seamless positioning of every type of data collected during the cruise. The navigation system had a theoretical accuracy of better than 0.5 metres, which exceeded requirements for this survey. The positional data was run through navigation logging and display software, with continuous QC checks being run during each watch.

The USBL navigation system was based upon the French-designed GAPS. The system was fully integrated into the primary DGPS and proved very reliable, giving highly accurate fixes.

Bathymetry

EM1002 bathymety data - The performance of the survey crew, vessel and the survey equipment was of an exceptionally high standard and fully met the requirements of the survey. On-board processing was completed in near-real-time and output presented in whatever format was requested. Fledermaus ".sd" and ".scene" files were the primary data requested, but for some areas data was also produced in UTM coordinates (for direct importation into ArcGIS).

EM1002 backscatter data – The quality of the backscatter data obtained from the EM1002 system after on-board processing was suitable for determination of different seafloor types, even though it effectively just used the raw voltage amplitudes from the transducers on a scale from 0 to 50 (volts). The data were presented during the cruise as overlays on the bathymetry data as Fledermaus ".scene" files. This allowed the user to view and manipulate scales so that idealised perspectives could be seen and sites for photography determined precisely.

Overall the results from the *MV Franklin* EM1002 acquisition and processing system rank above any other comparable system seen by either of the authors.

Sidescan Sonar

There were two systems on-board, a switch-able 100-500 kHz Geoacoustics sidescan system on hire from SEATRONICS and MMT's own Benthos system; however only the SEATRONICS system had cable enough for deep (>500 m) deployments. Both systems were ran on the shelf surveys at the start of the cruise, however the results obtained from the EM1002 backscatter and the trade-off between speed and resolution meant that neither sidescan was used until the last survey area was reached. This was due to the above mentioned trade-off but also because the geomorphology of the other survey areas allowed relatively east target selection for the camera surveys.

During the Hatton South survey the Geoacoustics system proved to be very unreliable, signal levels were very low and there was a continual problem that caused the power supplies to the fish to fail at unpredictable times. We attempted to use the Benthos fish, but there was only 1,000 m of cable available and with a seafloor depth in excess of 600 m it was only possible to reach that depth by slowing the vessel to ~2 knots. This however caused problems as at such a low tow-speed the fish was unstable. The system was assessed for a while but the data were not suitable for our purposes.

Data Output

The major data output product was a hard drive containing all data collected in digital form (swath, backscatter, photographs, video and CTD). Paper products and PDF files will be delivered post-cruise.

OBSERVATIONS AND PRELIMINARY INTERPRETATIONS

Introduction

A map of the whole F0206 survey is presented in Figure 4. The geology and biology are discussed together in the PAPA survey boxes, as they are so localised, but in the other areas the description of each survey area begins with an interpretive overview, followed by detailed accounts of the observations made of the surface geology and then the biology during each of the photography transects.

PAPA1

A dual frequency (100 and 384 kHz) high resolution sidescan transect was run across the main part of the bank, which stood 40-60 m above the surrounding seafloor. This was used to target a photographic transect which crossed several distinctive areas of acoustic backscatter. Correlations of the photo-transect, sidescan and backscatter showed that highest acoustic response was produced by areas of bedrock and cobbles over bedrock, although high backscatter was also resulting from insonification of coarse gravely-biogenic sands (Figure 5). Identified biology included on a boulder and cobble substrate, encrusting species and occasional possible branching sponges. As the camera descended the Bank hydroids become more frequent but still fairly sparse, and other conspicuous epifauna included squat lobsters (possibly *Munida rugosa*) and the seastar *Porania pulvillus*. The areas of fine sand have few visible fauna: worm casts from infaunal polychaetes and siphons from infaunal bivalves with associated hydroid growths (Figure 6).

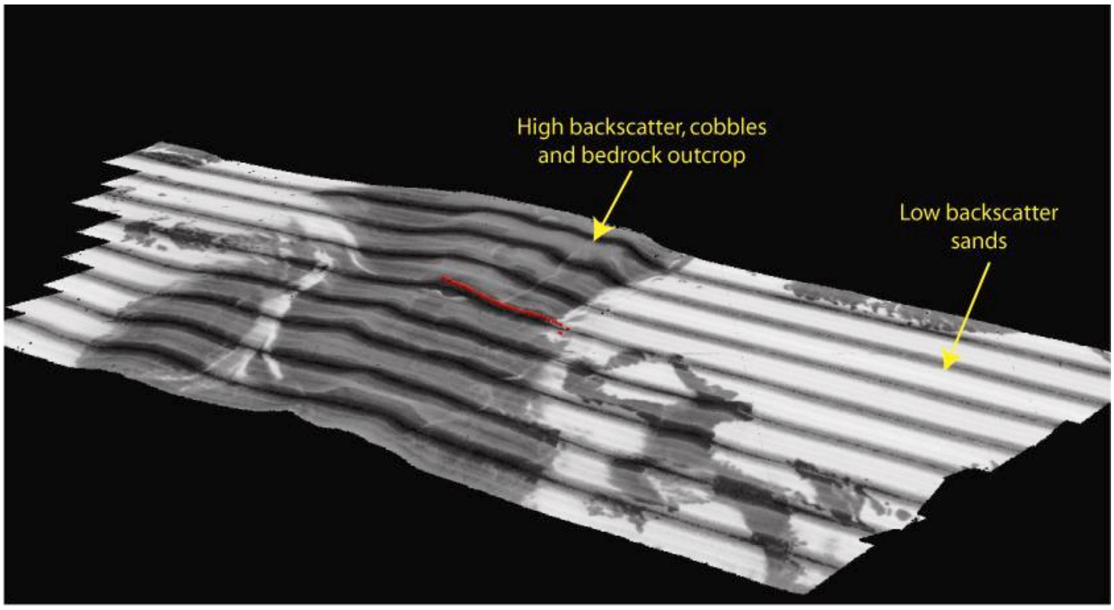


Figure 5. A DTM and draped backscatter image over the PAPA1 survey area with seafloor photograph locations also marked, viewed from the south. The dark stripes represent track-line artefacts, which in this survey were approximately 425 m apart.

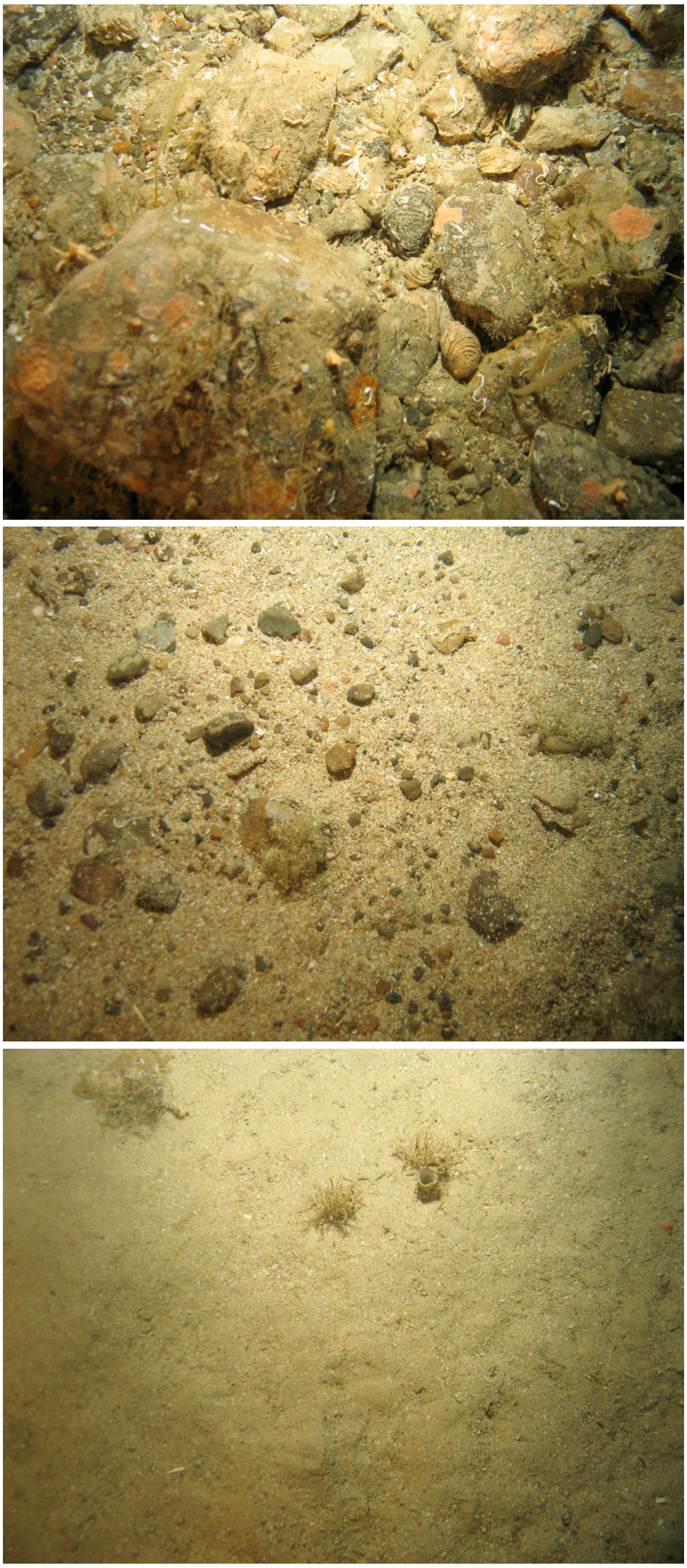


Figure 6. Seafloor photographs representative of the benthic biology of PAPA1

PAPA2 (Horseshoe)

The ten survey lines across the PAPA2 area showed the seabed to be a diverse area geologically (Figure 7), with the acoustic backscatter suggesting that outcrop, boulders and cobbles and sand sheets could b expected to be seen on the photographic transects. Sand waves of varying heights were also noted throughout the area, some were quite large, those in the northeast reaching 8 m in height. Five areas for examination by seafloor photography were identified.

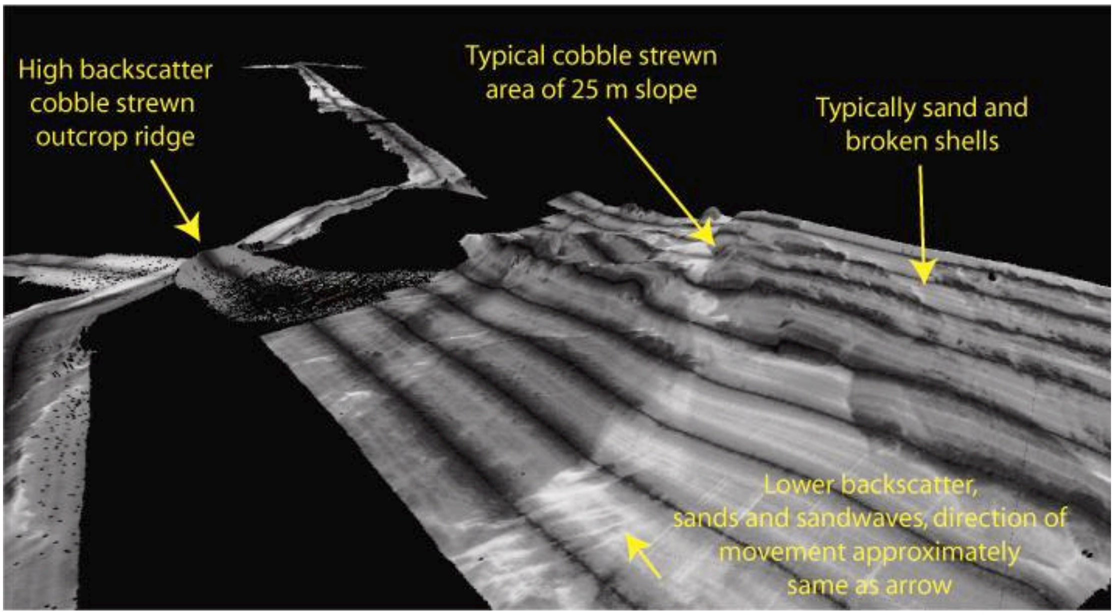
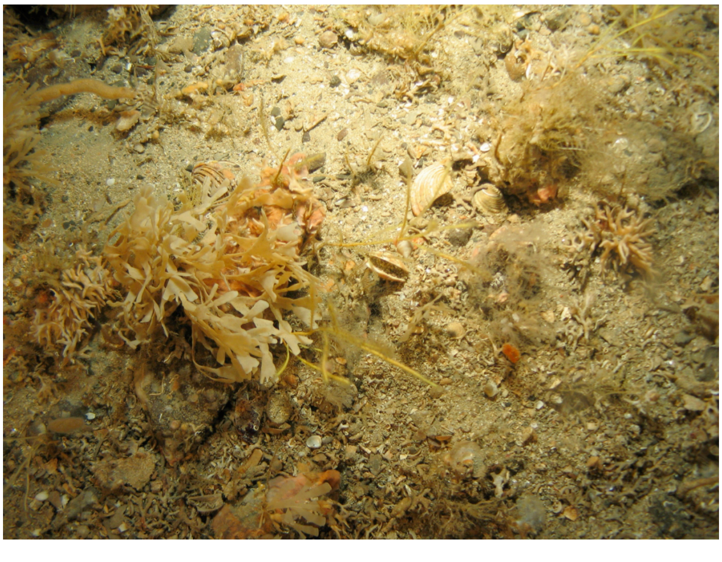


Figure 7. DTM with draped backscatter of PAPA2 (Horseshoe) area viewed from the northeast. The dark track-line artefacts are approximately 750 m apart.

PAPA2_C1 was a transect across the "Horseshoe" ridge near the south of the area, which showed bedrock outcrop and boulders on bedrock. The base of the topographic high was characterised on both sides by flustra, hydroids and encrusting sponges and asidians, that progressing upward to the pebble and cobble seabed became broadly characterised by flustra, hydroids, aggregations (carpets) of anemones, cup sponges (poss *Axinella sp.*), cup corals (*Caryophyllia sp.*), and numerous encrusting species. Conspicuous epifauna include the seastar *Stichastrella rosea*. Over the summit flustra become less abundant and cup corals (Caryophyllia sp.) and encrusting species became the most conspicuous fauna (Figure 8).



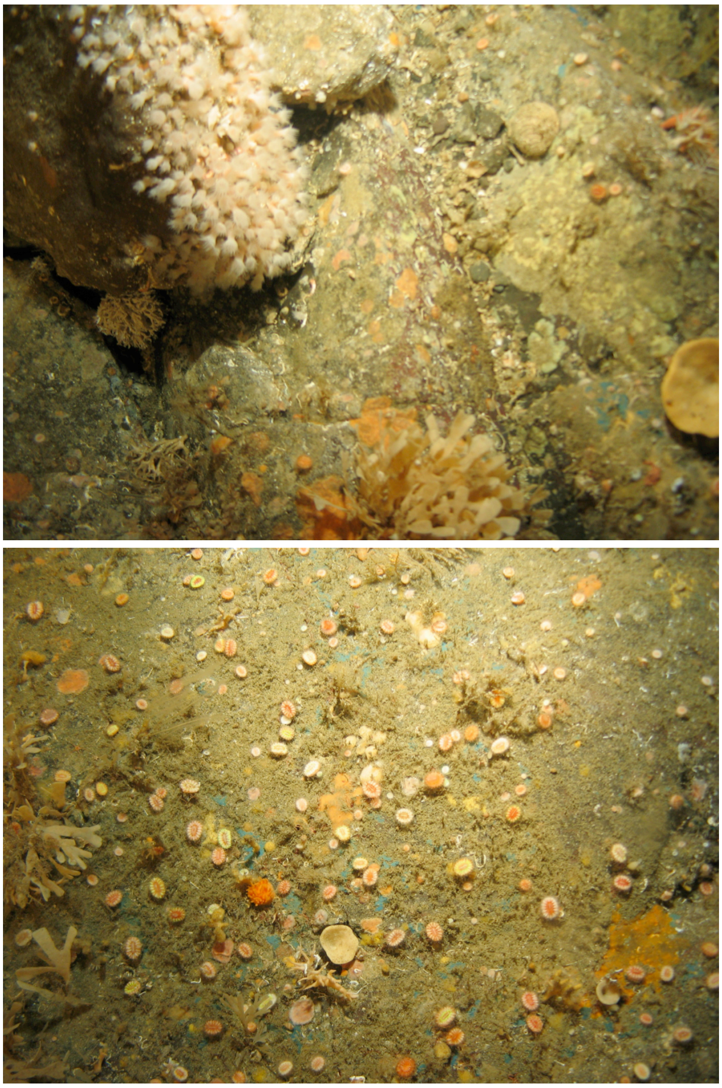
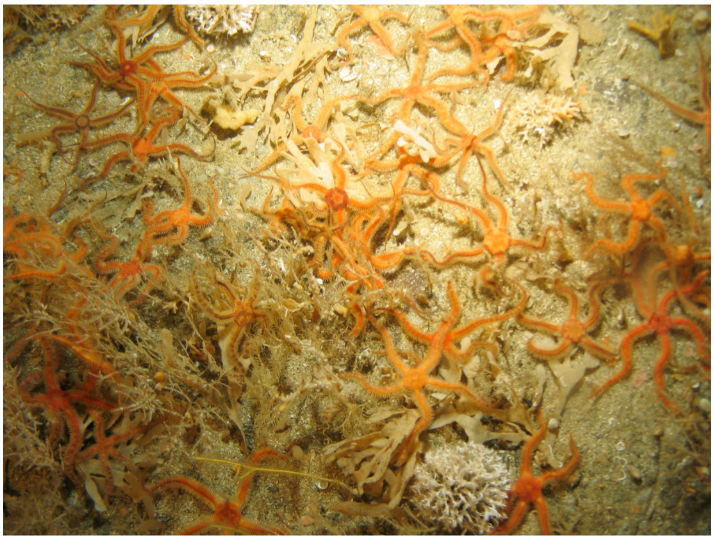


Figure 8. Seafloor photographs representative of the benthic biology of PAPA2_C1.

PAPA2_C2 was over a lower backscattering area which turned out to be an area of coarse biogenic sand, characterised by flustra and hydroid tufts covering approximately 30% of the seabed. Conspicuous mobile epifauna included occasional scallops. Evidence of infauna from protruding tubes (polychaeta) and siphons (bivalvia) (Figure 9).

Figure 9. Seafloor photograph representative of the benthic biology of PAPA2_C2.

PAPA2_C3 was targeted over an area interpreted as being large sand ripples and then up onto a potential outcrop area. This in fact turned out to be cobbles (possibly over bedrock) and a coarse sheet of biogenic (broken shell) gravel. An ophiuroid bed covered the rocks that were otherwise characterised by flustra, hydroids and encrusting species. Other conspicuous epifauna included squat lobsters (poss *Munida rugosa*). Over the area of pebble, shell gravel and coarse sand there was little conspicuous epifauna except serpulid worm tubes and very rarely the seastar *Porania pulvillus* (Figure 10).



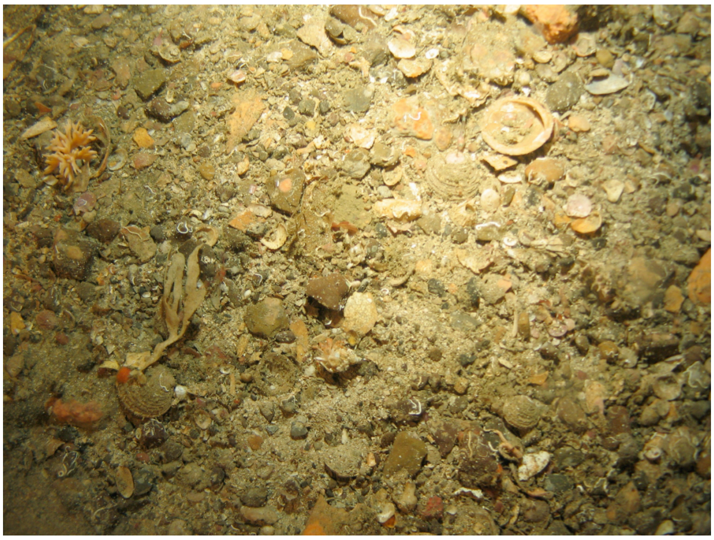


Figure 10. Seafloor photographs representative of the benthic biology of PAPA2_C3.

PAPA2_C4 looked at the boundary between a low backscattering area interpreted as a sand sheet (that was channelled between two areas of bedrock) and a 25 m-high area interpreted as bedrock outcrop, the photographs validating the interpretation. The sand sheet had little conspicuous epifauna. On the next habitat, the sand-strewn bedrock with boulders and cobbles, the characteristic fauna were flustra, hydroids and encrusting species. Conspicuous epifauna included the seastar *Stichastrella rosea*, squat lobsters (poss *Munida rugosa*) and brittlestars, which in places were dense enough to constitute a brittlestar bed. Fine sand that very quickly changed into a seabed of mixed whole shells had little conspicuous epifauna (Figure 11).

Figure 11. Seafloor photographs representative of the benthic biology of PAPA2_C4.

PAPA2_C5 looked at an area interpreted as intensively sand rippled, which consisted of areas of coarse sand and broken shell. In places occasional cobbles and flustra covered approximately 40% of the seabed, although when the camera then passed onto an area of sand waves (with course sand and shell debris in the sand wave troughs), there were few visible epifauna (Figure 12).

Figure 12. Seafloor photographs representative of the benthic biology of PAPA2_C5.

George Bligh Bank

The multibeam survey over this area revealed a series of erosive sculpted deeps in water depths between 700-900 m. The scours were either individual features or they had coalesced forming into sinuous steep-walled channel systems (Figure 13). The width of the deeps varies with a range of 1-1.5 Km, though they vary greatly in length between 2 Km for the smaller deeps, to over 12 Km for those that have coalesced and formed distinctive channel-like features. They are elongated along an axis of ~280º-100º and most have scarp slopes of around 50m in height at their western end, though in the larger scours these scarps may be up to 75 m in height and approach a slope angle of 30º.

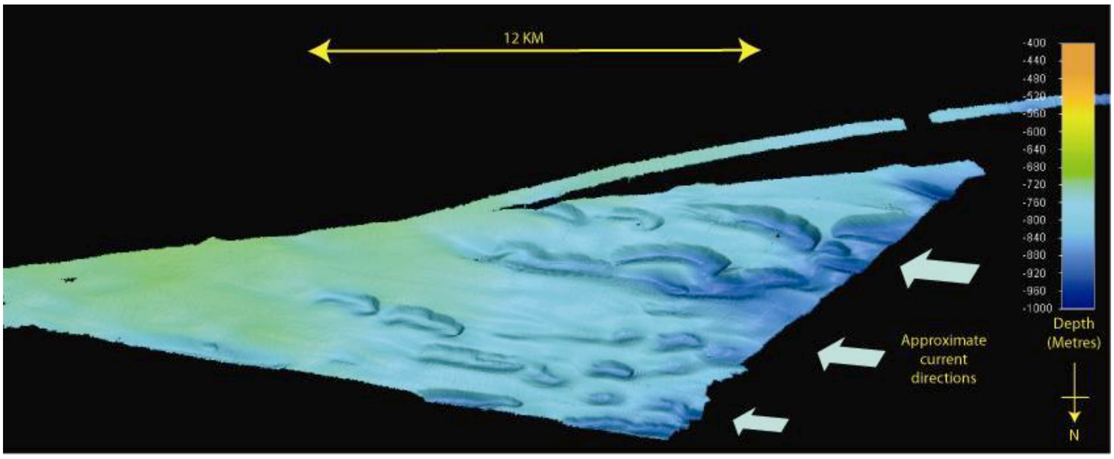


Figure 13. DTM of the northern flank of George Bligh Bank, viewed from the North. The sculpted hollows along the slope are interpreted as being due to benthic current erosion.

The backscatter mosaic is perhaps less informative than the morphological perspective given by the bathymetry alone. Overall the seabed exhibits a low regional acoustic backscatter, with higher backscatter within the sculpted deeps, probably due to an increase in surface roughness (Figure 14).

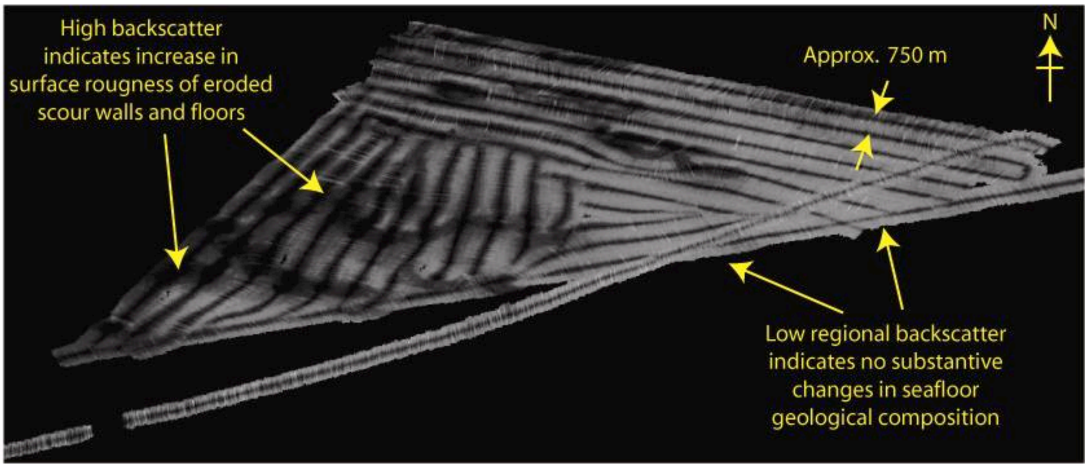


Figure 14. Acoustic backscatter mosaic over the northern flank of George Bligh Bank, viewed from the East. The sculpted hollows show a higher backscatter than the regional seafloor, but otherwise little extra information on either the geology or process of formation is revealed. The dark track-line artefacts are approximately 750 m apart.

GB_C1 This site was chosen to investigate the longitudinal variations of both seafloor composition and fauna at the upstream (strongest current) end of one of the scours, from just outside the scour, down the eroded scarp face and including a section of the deep scour bottom.

Geology: This site revealed a sandy with occasional gravel and cobble seafloor upstream of the erosive scour, thin broken shell fragments and clear feeding trails suggested that strong currents are not active at the present time. In the lee of many of the cobbles gravel streams were common. Near the edge of the scour, boulders and gravel became more common and what appeared to be washed outcrop of a fine-grained massive rock (igneous – basaltic possibly) was observed at the seafloor, with sand overlaying its edges. The outcrop formed an overhang over the steep scarp face of the scour wall, the face of which had boulders and cobbles in abundance laying on a sandy substrate that appeared at least partially lithified, and showed signs of bedding planes on the exposed surface. At the base of the erosive scarp the boulders and cobbles declined in number and a predominantly sandy bottom returned with cobbles sitting on the surface.

Biology: Above the scarp, visible fauna include cerianthid anemones, urchins (*Calveriosoma sp.*), fish, and small growths of *Lophelia pertusa* on occasional pebbles and cobbles. Down-current the cobbles and boulders became more frequent and were colonised by fauna typical of this depth and region (encrusting sponges, serpulid tube worms, holothurians (*Psolus squamatus*)) and in places *Lophelia pertusa*, rarely soft corals and gorgonians). Just upstream of the erosive scarp where the seabed became coarser with gravel lags, cobbles and, in places bedrock, the fauna included anemones (*Phelliactis sp.*), antipatherian and stylasterid corals, and more typical encrusting fauna. The scarp slope with its boulders and cobbles was colonised by holothurians (*Psolus squamatus*), antipatherian corals, and rarely brisingid seastars in typical feeding pose. At the base of the slope the predominantly sandy seabed had few visible fauna except fish (eel pout) and urchins (Figure 15).

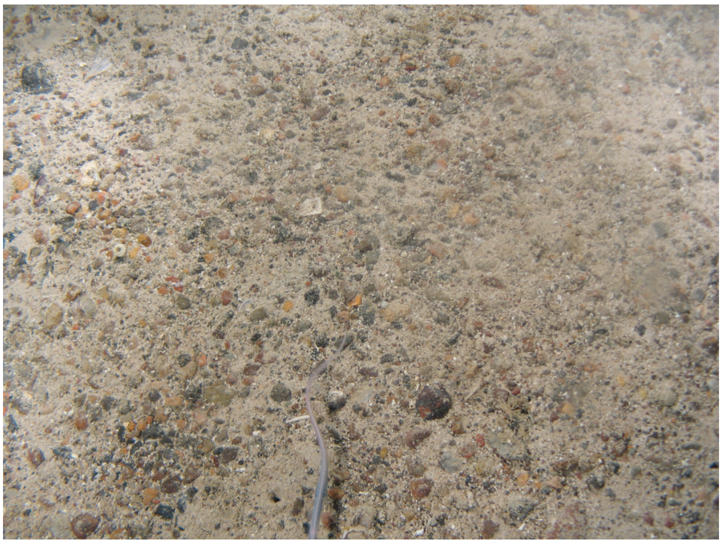


Figure 15. Seafloor photographs representative of the benthic biology of GB_C1.

GB_C2 This was a second transect to look at the changes inside and out of the erosive scours. This time the side of one of the larger scours was chosen.

Geology: A medium-coarse sand slope with dropstones and abundant biogenic material both fragmentary and growing apparently directly on the sand or, more likely, small dropstones. |The seabed then changes to a clean sand before the biogenic material re-appears, mostly as smaller clumps and broken fragments, and at the end of the tow the sand surfaces exhibit linguoid and straight-crested ripples.

Biology: The seabed was composed of sand and coral clumps with larger dead coral fragments, and occasional cobbles colonised by small growths of live *Lophelia pertusa* and *Madrepora occulata*, antipatherian, stylasterid and cup corals, anemones (*Phelliactis* sp. and others), ascidians, squat lobsters, small concealed ophiuroids (possibly *Ophicatis balli*). As the camera reached the top of the slope the sediment changed to sand with sparse cobbles and pebbles before becoming a clean fine sand on the descending slope. Visible fauna on the fine sand habitat were cerianthid anemones, eel pout, grenadiers and urchins (*Calveriosoma* sp.).

Figure 16. Seafloor photographs representative of the benthic biology of GB_C2.

Hatton Bank North

The shoal axis of Northern Hatton Bank trends East-West, with the summit rising to around 490 m between 15º18'-15º30'W. West of 15º30'W the summit depth is around 510 m, and it also plunges to below 500 m to the east of 15º18'. Morphologically, the most interesting features of note include an area of the summit exhibiting large iceberg plough marks, the very extensive erosive scarring (at various scales) that is evident over the vast majority of the Bank, a probable ancient dyke, and small slope-parallel channels that occur on both flanks of the Bank at its eastern end (Figure 17). The acoustic backscatter mosaic best exhibits the iceberg plough marks, and whilst some of the erosive scarring is also evident from backscatter differences, it is better seen in the 3D morphological DTMs. Also seen on the backscatter are more subtle changes in backscatter that reflect differences in surface texture and sediment types.

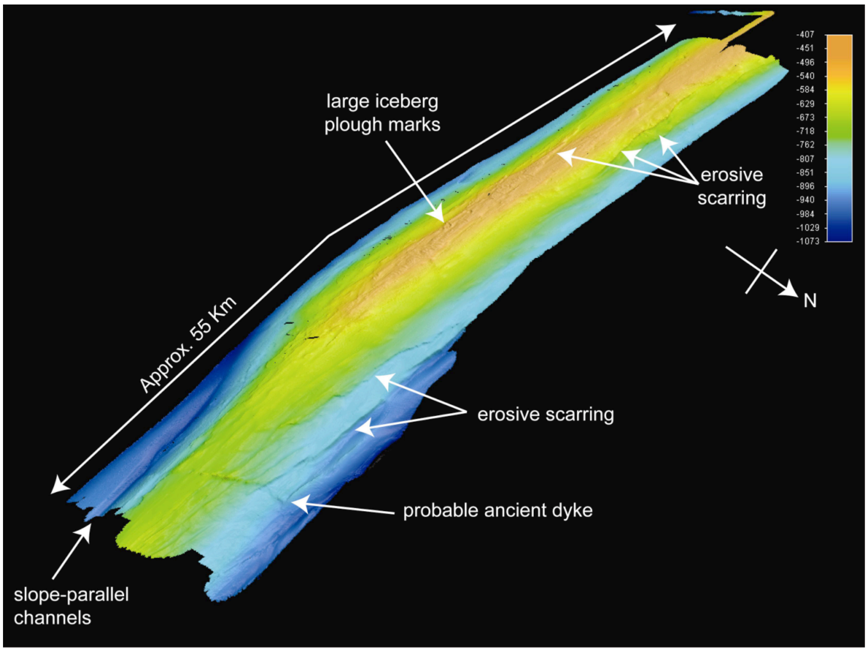


Figure 17. Fledermaus™ DTM of central northern Hatton Bank, showing extensive erosive scarring, an ancient dyke, and slope-parallel channels.

The northern flank of Hatton Bank in this area is rather different from the south in that the majority of the morphological fabrics run parallel to the contours of the Bank, whereas on the southern flank they tend to be oblique (Figure 17). This will be a direct reflection of the benthic current activity on either side of the Bank. However, the one exception is a series of rounded peaks that together make up a ridge up to 85 m in height and 6 Km in length that is orthogonal to the contours. This feature is interpreted as the remnants of a dyke. Mapping of the northern flank was restricted (by time) to around 800 m water depth over most of the northern flank of Hatton Bank, though east of 15º15’W coverage did extend down to below 900 m.

At the very eastern end of the survey area, the northern part of the summit displays a series of sharp-crested contour parallel ridges up to 10-20 m in height and sometimes bifurcating that disappear toward the west. To the west of the dyke, there is a marked difference in surface features in that a series of terraces are developed, separated by steep (>25º in places) scarps some of which reach over 100 m in height. There are five major scarps mapped (albeit incompletely in three cases), the shallowest occurring toward the east at about 550 m, and the deepest over the western end at about 800 m. The length of the scarps varies, from 10 Km at 720 m water depth in the east, to over 22 Km at 700 m waterdepth in the west. At the eastern edge of the survey area are two slope-parallel gullies, one on each flank of the ridge crest. Toward its western end the seafloor DTM of Hatton Bank generally shows a smoothness and morphology that is characteristic of areas of high geostrophic activity.

In terms of the overall acoustic backscatter, the levels are lower across the summit region than on the northern flank (Figure 18), but aside from the edges and faces of the scarps and the probable dyke described above, there are very few discrete high backscatter features.

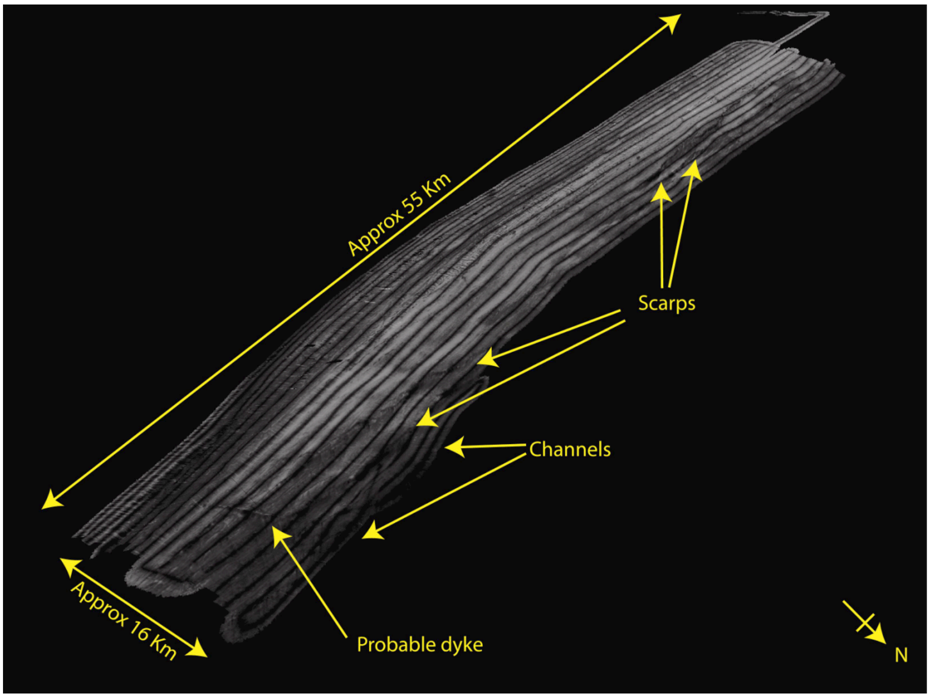


Figure 18. Acoustic backscatter mosaic of the northern flank of Hatton Bank. Apart from scarps and a potential dyke, discrete high-backscatter targets are few.

The overall backscatter level is lower than the southern flank, possibly indicating that the sediments are more homogenous (sandy contourites?). Even in the channels at the eastern end of the survey, the backscatter levels are not markedly different from the surrounding seafloor. Each of the above-mentioned features are discussed in more detail below in the order in which the photographic transects were run.

H_C1 was run over the channel axis near the eastern end of the swath coverage. The swath mapping covered a section of this channel over 12 Km long and in places it reached 30 m in depth. The axis of the channel was at 917 m water depth at the eastern end of our study area, running steadily along a trend of 250º to around 15º.06'N 59º.15'W where it turned further toward the south heading approximately 230º and deepening to over 1,000 m. The acoustic backscatter showed very little trace of the channel, possibly in part because the axis was partially obscured beneath one of the survey track-line artefacts. However to either side of the channel the general levels of acoustic backscatter are different, the upslope region having a marked higher backscatter than that down the slope. We interpret this as due to the channel catching any significantly coarser material that may be transported down-slope preventing it from reaching the lower part of the slope.

Geology: in general the whole transect showed coarse biogenic sands with small patches and trains of gravel and pebble, and the odd cobble and/or boulder. The sand surface showed what appeared to be old ripples, with the troughs in-filled with fine, often biogenic gravel or finer material. Video suggested that the southern bank of the channel has slightly finer-grained material than northern flank which appears to be mostly coarse sand (but this should be considered anecdotal, as the observation was derived from the sediment clouds thrown up when drop-camera was landed).

Biology: the transect began over coarse sand seafloor with pebbles and occasional cobble dropstones. Visible fauna included small (>10mm disc diameter) ophiuroids, the occasional urchin (poss *Calveriosoma sp.*), cerianthid anemones, fish (grenadiers) and occasional Xenophyophores. Fauna on the drop stones included anemones (*Phelliactis* sp. and sp. indet.), encrusting and globose sponge forms, and corals (*Caryophillia* sp., *Madrepora occulata*). As the camera descended the channel xenophyophores and the sponge *Pheronema carpenteri* became more abundant, with large sponge growths present occasionally. As the camera ascended the southern side of the channel, the sediment became finer and appeared rippled, xenophyophores and Pheronema were no longer visible and small ophiuroids again became the dominant visible fauna.

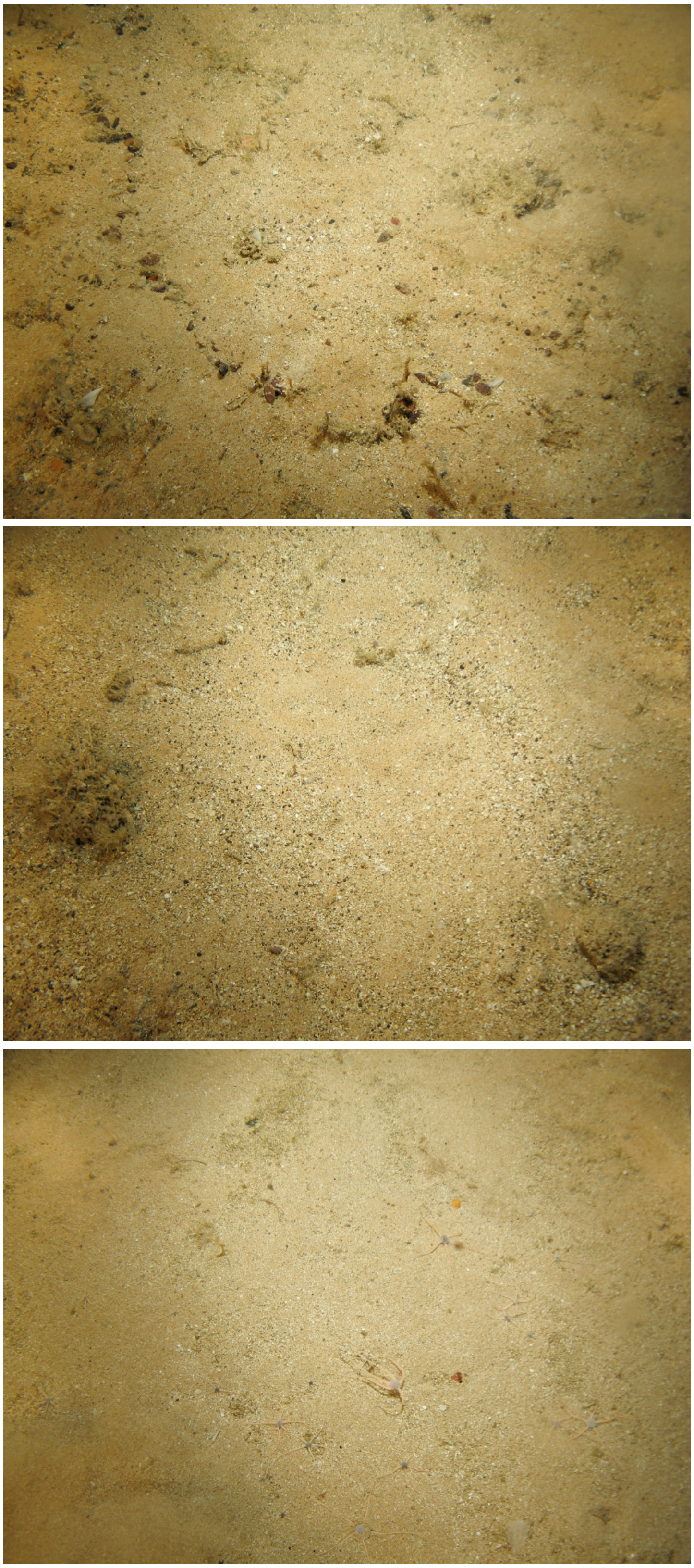


Figure 19. Seafloor photographs representative of the benthic biology of H_C1.

H_C2 was a mid-slope (760 m water depth) site primarily for biological characterisation. There are no noteworthy morphological or backscatter features in this region of the slope.

Geology: a mostly (old) rippled surface of coarse sands, with, in the ripple troughs, a slightly coarser loose biogenic matrix. Very few dropstones were noted on this transect. Indications are that the sand is partially consolidated in that very little to none is disturbed when the 450 Kg of the camera frame is landed.

Biology: the target was typical slope environment. The seabed was a coarse rippled sand. There were very few visible epifauna except small (>10mm disc diameter) ophiuroids, small cone shaped gelatinous organisms and occasional fish (*Chimaera monstrosa*).

Figure 20. Seafloor photograph representative of the benthic biology of H_C2.

H_C4 This site was chosen to examine specific acoustic backscatter targets and also for biological characterisation. The site is at 530 m water depth and lay on the uppermost geological unit on this part of the shelf (as opposed to other parts of the seafloor where the uppermost unit has been eroded and does not form part of the seabed). The morphology shows the site to be on a smooth area of gentle slope (~2º). The acoustic backscatter shows a very distinctive area of high backscatter surrounded by the generally low backscatter of the surrounding seabed (Figure 21). The high backscatter areas measure 220 m x 90 m and 130 m x 90 m, and both appear to be forming very gentle "humps" in the seabed of just a couple of metres height.

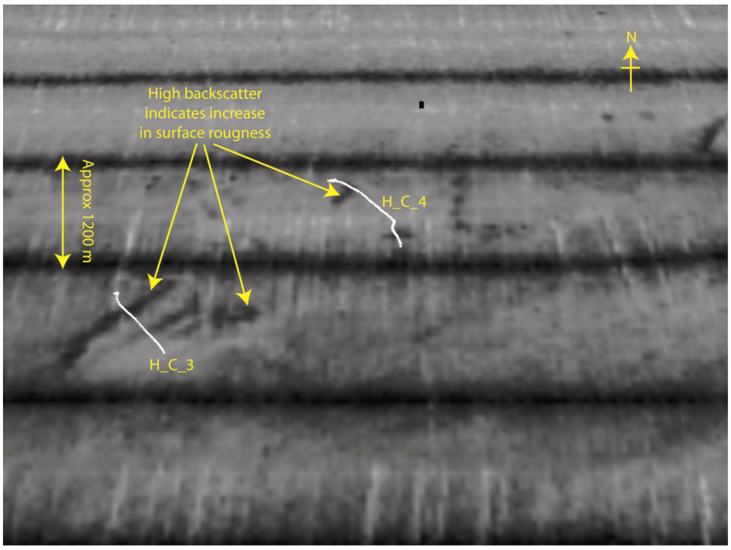


Figure 21. Acoustic backscatter mosaic showing the regional low backscatter and small targeted high-backscatter mounds examined during station H_C4.

Geology: a seafloor of sand with occasional singular pebbles and cobbles, interpreted as dropstones, and also a couple of areas of gravely sand. These were the only features that could be responsible for the acoustic backscatter differences, though their discrete nature is something of a puzzle.

Biology: the video transect began over an area of medium rippled sand. Visible epifauna included urchins (*Echinus acutus*, *Calveriosoma sp*), cerianthid anemones, holothurians (*Stichopus tremulus*) and fish (*Chimaera monstrosa*, an unidentified elasmobranch (possibly black-mouthed dogfish)). The transect then entered the first area of high backscatter, which revealed itself as an area of drop-stones of cobble and pebble size. Fauna present on the stones included small growths of *Lophelia pertusa*, globose and encrusting sponge forms and holothurians (*Psolus squamatus*). The sediment then returned to a medium sand with ripples and few visible epifauna, before crossing onto the second high backscatter target. This again was a discrete area of cobble and boulder drop-stones with species similar to the previous area.

Figure 22. Seafloor photographs representative of the benthic biology of H_C4.

H_C3 is located over a 20 m high erosion scar (Figures 21, 23 and 24). This scar appears to be part of a much larger erosive feature that is more-or-less continuous along the upper part of this area of Hatton Bank.

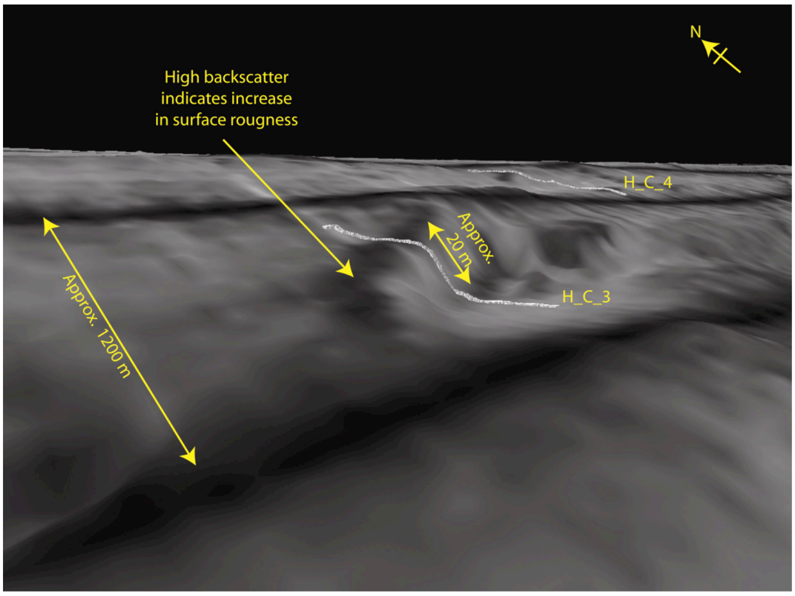


Figure 23. 3D perspective of acoustic backscatter draped over bathymetry showing the typical morphology of an erosive scar. Note the high backscatter fringe at the top of the scar. Superimposed over the mosaic is the track of station H_C3.

Geology: the seafloor is almost entirely coarse sand, with just an odd drop-stone with a gravel train in its lee. However, as the edge of the scarp is approached a hard surface is imaged, usually rust-brown to black in colour, though this is frequently obscured by surficial sand. This hard-ground spans the last few metres of seafloor before the scarp itself, at which point it is seen to form an overhang (Figure 24) with considerable biological growth. The hard-ground surface is interpreted as being an exposed (or exhumed) basalt, possibly an ancient lava or dyke. The biological growths along its edge suggest that the failure is historical rather than ancient. The scar surface itself appears partly stained and is partially obscured by unconsolidated surficial sands, whilst the base of the scarp appears to be uniform coarse sand.

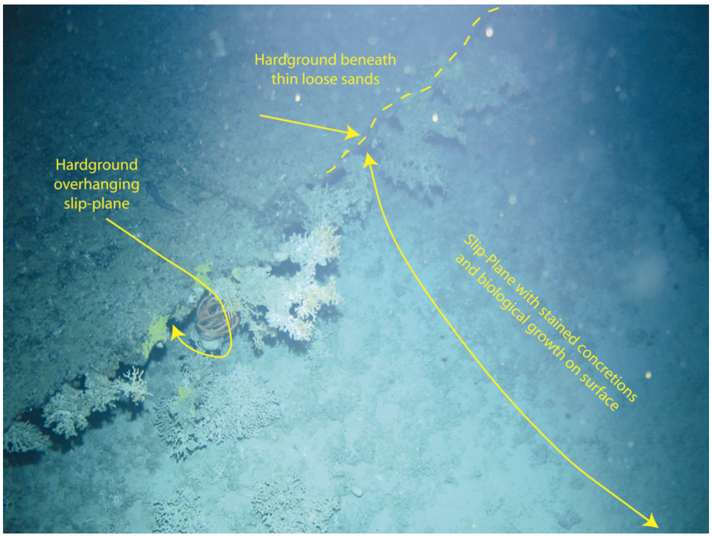


Figure 24. Photograph from the slip-plane area along transect H_C_3 showing a broken (?basalt) hard-ground at the seafloor that forms an overhang over the slip-plane of a sediment slide. The total height of the slip-plane below the hard-ground is of the order of 20 m.

Biology: the video transect began on a rippled sand seabed with occasional dropstones. Visible fauna included holothurians (*Stichopus tremulus*), urchins (*Cidaris cidaris*, *Calveriosoma sp*) cerianthid anemones and fish including *Chimaera monstrosa*, and blue-mouth red fish (*Helicolenus dactylopterus*). Fauna present on the cobbles and boulders at the scarp edge included brachiopods, encrusting and globose sponge forms, holothurians (*Psolus squamatus*), coral (small growths of *Lophelia pertusa*) and ascidians. The basaltic bedrock outcrops were encrusted with sponge, holothurians (*Psolus squamatus*), Serpulid worms, small growths of the corals *Madrepora occulata* and *Lophelia pertusa*, ascidians, brachiopods. Also at the scarp edge there were denser growths of *Lophelia pertusa, Madrepora occulata* and a distinct yellow sponge growth (Figure 24). At the base of the scarp slope the sediment again became medium rippled sand with few visible epifauna except occasional small cone shaped gelatinous organisms.

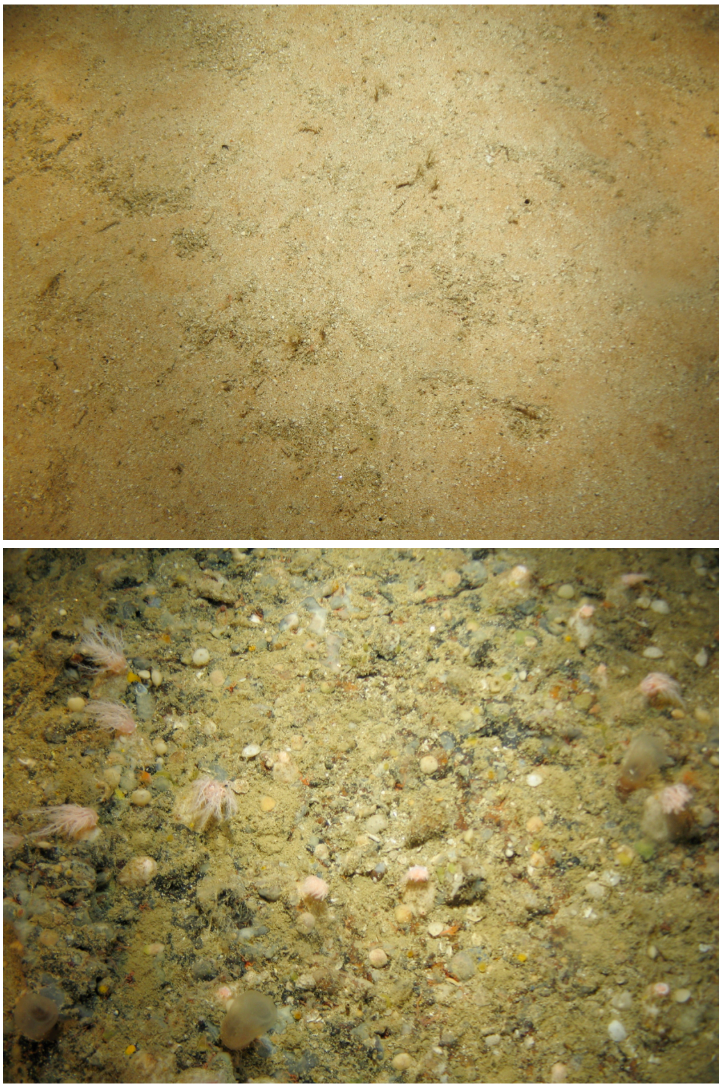


Figure 25. Seafloor photographs representative of the benthic biology of H_C3.

H_C8 This site was another chosen primarily for biological characterisation of the northern Hatton Bank slope. The site runs approximately east-west along the 700 m isobath in an area of smooth topography and with a uniform rather low level of acoustic backscatter.

Geology: The photography transect showed that this part of Hatton Bank is composed of a very uniform deposit of coarse slightly rippled sand, with detritus lying in the ripple troughs.

Biology: the transect revealed a fairly uniform habitat of rippled sand with few visible epifauna. Species encountered included hermit crabs, infaunal polychaete tube worms, small cone shaped gelatinous organisms, and fish (*Chimaera monstrosa*, and an unidentified ray).

Figure 26. Seafloor photograph representative of the benthic biology of H_C8.

H_C11 This transect was located almost on the crest of Hatton Bank, aligned to examine what appeared on the DTM to be a slip-plane (Figure 27).

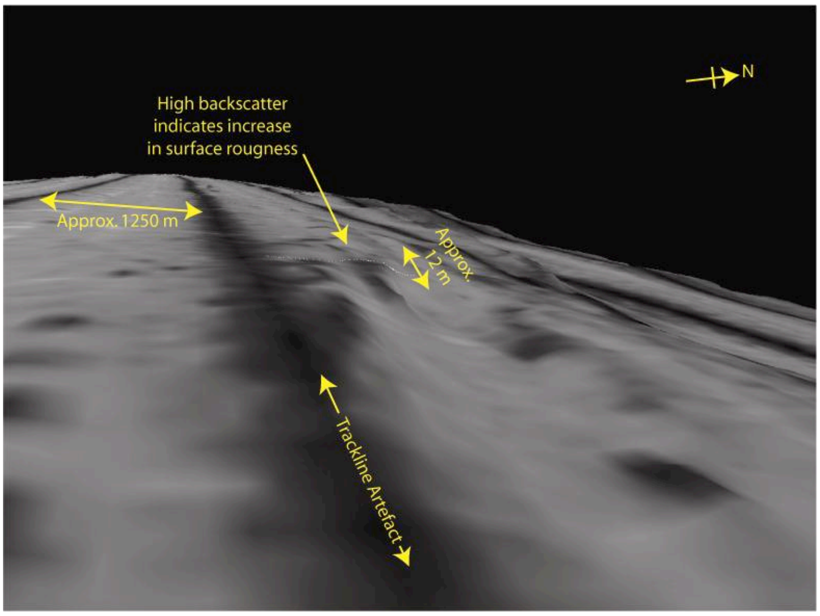
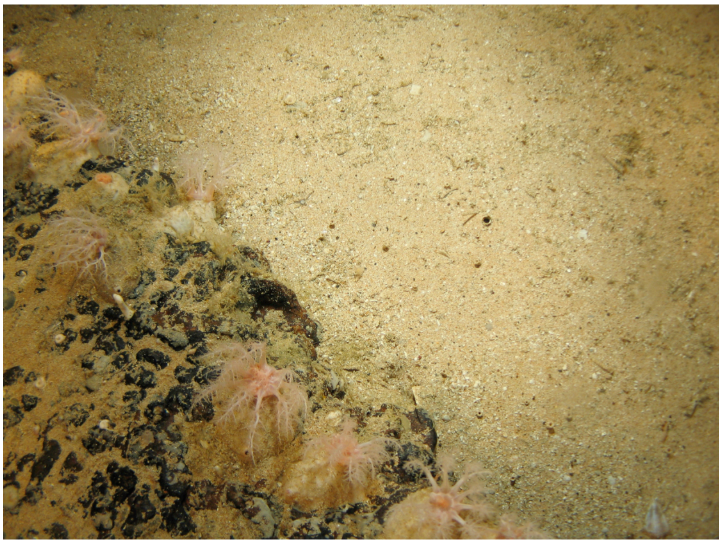


Figure 27. Draped backscatter mosaic and photograph locations (white dots) of station H_C11. The high backscatter indicates the seafloor exposure of the indurated basaltic "hard ground".

Geology: The transect was mostly over a sandy seafloor, with degraded ripples and detritus and biogenic fragments. There were however a number of areas where probable basaltic "hard grounds" are seen at the surface (Figure 28).



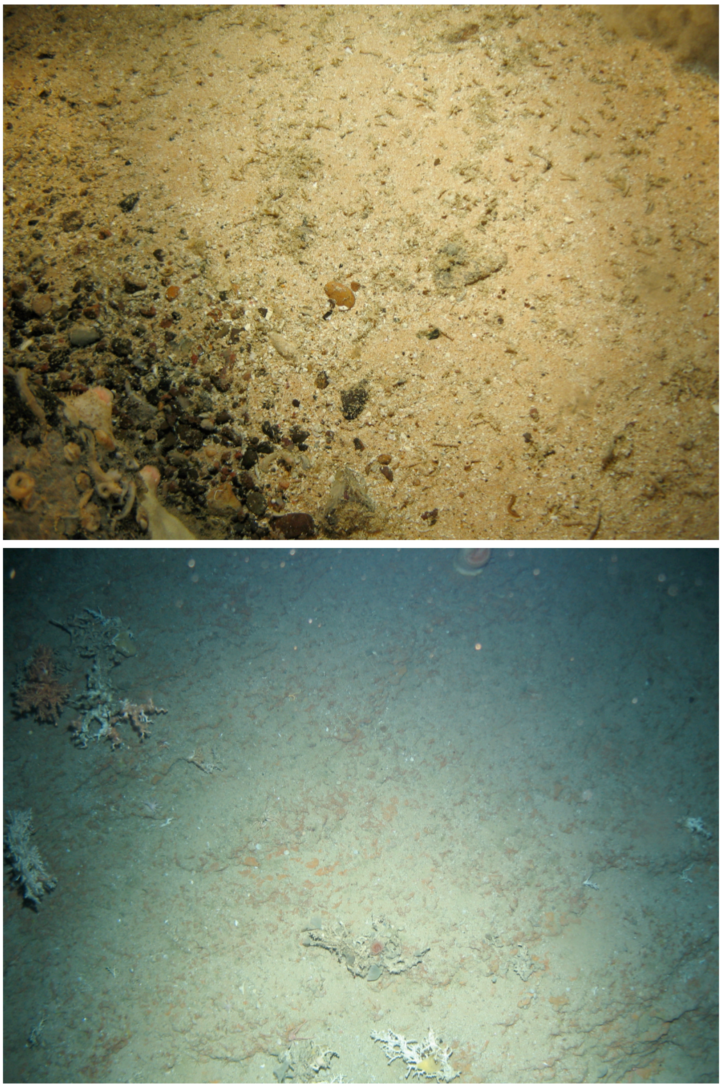


Figure 28. Photographs showing the reality of the seafloor geology at H_C11, with the basaltic hard ground exposed, and the slip-plane face.

Biology: The transect began in an area of medium sand, the few visible epifauna included occasional holothurians (*Stichopus tremulus*), urchins (*Calveriosoma sp. Cidaris sp.*) and fish. Occasionally a cobble dropstone was visible and was colonised by holothurians (*Psolus squamatus*), stylasterid corals, encrusting sponges, small growths of coral (*Madrepora occulata*), anemones (*Phelliactis* sp.), ophiuroids were often partly hidden in the cracks and crevices of stones (possibly *Ophiactis balli*), and squat lobsters (possibly *Munida rugosa*) and serpulid worms were also seen. A small piece of fishing net was encountered. At the edge and over the upper part of the slope, the habitat changed to an area of dense boulders and cobbles colonised by similar species to the drop stones with additional small growths of *Lophelia pertusa*, solitary corals (*Caryophillia sp*), brachiopods, gastropod molluscs, hydroids and rarely Brisingid sea stars. The scarp slope composed of outcrop covered with unconsolidated sand and encrusting sponge growth and colonised by coral (*Lophelia pertusa* and *Madrepora occulata*) thickets, globose sponges, decapods, squat lobsters (possibly *Munida rugosa*) polychaete tube worms, anemones (*Phelliactis* sp), holothurians (*Psolus squamatus*), stylasterid corals (probably *Pliobothrus*), and many ophiuroids hidden in the cracks and crevices of rock (possibly *Ophiactis balli*) (Figure 28). Over the lower section of the scarp slope was an area of boulders and cobbles again colonised by similar species and including possible colonies of the alcyonacean *Anthomastus grandiflorus*. At the base of the scarp the seabed again became rippled sand characterised by occasional holothurians (*Stichopus tremulus*), urchins (*Calveriosoma sp. Cidaris sp.*) and fish.

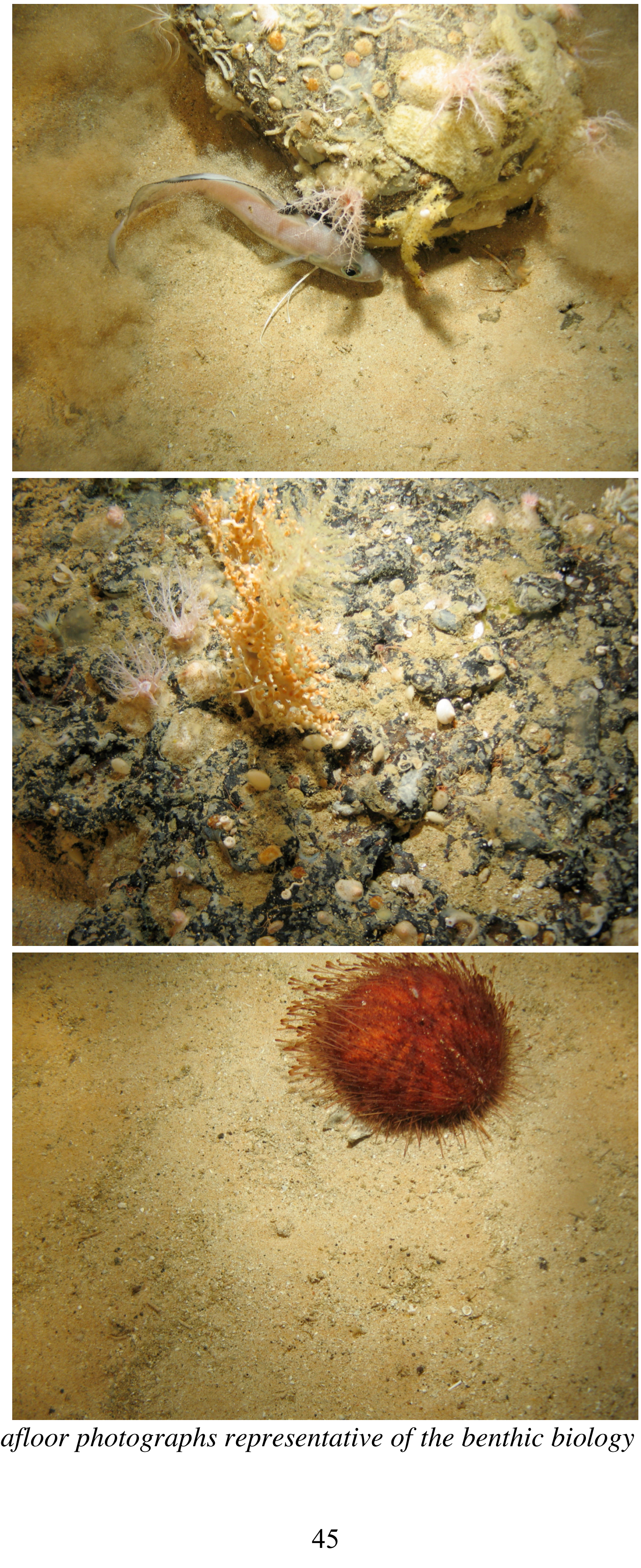


Figure 29. Seafloor photographs representative of the benthic biology of H_C11.

H_C5 The DTM suggests that this is another small sediment slide-scar. The feature is scar face is between 25-30 m high (Figure 30), facing to the east. The backscatter mosaic shows a slightly higher level than the surrounding seafloor, though it does not form a striking feature.

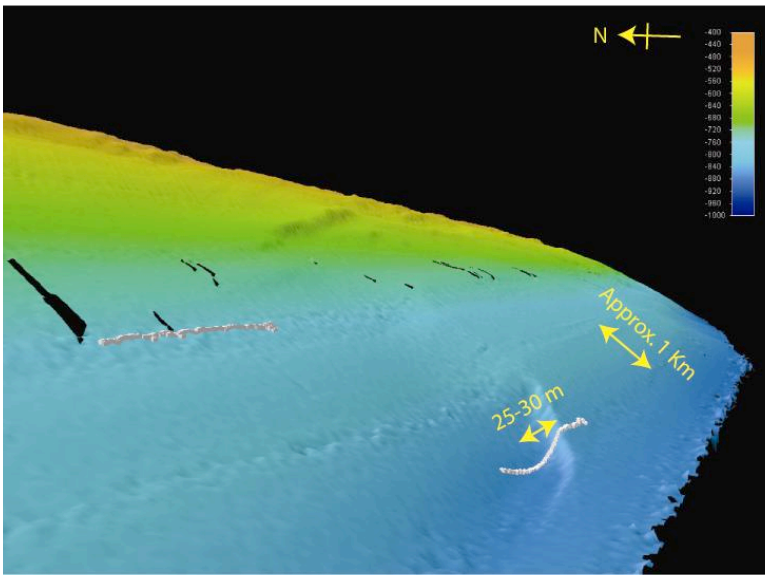


Figure 30. Location of transect H_C5 at about 850 m water depth on the southern flank of Hatton Bank.

Geology: Over the eastern part of the transect (above the scar), the sediments are degraded rippled sands, and at the scar are gravel lags and drop-stones, with an exhumed slab of basalt (Figure31). Below the scar the sediments are fine sands that tend to become coarser and rippled at the base of the scarp.

Figure 31. The exposed basaltic crust is seen at the very top of the slide scar.

Biology: The transect began over rippled sand with occasional dropstones, and few visible epifauna except small (<10mm disc diameter) ophiuroids and small cone-shaped gelatinous organisms. At the scarp edge pebbles and cobbles became more frequent and were colonised by encrusting and globose sponges, small growths of *Madrepora occulata*, cup (*Caryophillia sp.*) and stylasterid corals, serpulid worms, ascidians as well as other unidentified species (Figure 31). At the base of the scarp the sediment was finer sand but quickly returned to habitat similar to that at the start of the run with few visible epifauna except numerous ophiuroids. Toward the end of the transect pebbles became more abundant and xenophyophores were encountered.

Figure 32. Seafloor photographs representative of the benthic biology of H_C5.

H_C6 This station was run near the crest of Hatton Bank (Figure 33) to examine the details of the surface geology and biological communities that are found over the iceberg plough mark zone that is clearly visible over the summit area. The plough marks are restricted to a narrow zone measuring 19 Km in length by 3 Km in width and above 500 m water depth, which makes them some of the deepest recorded such features. The spatial restriction is due to large-scale erosion along both flanks of the Bank. Individual plough marks vary in width up to 400 m, and whilst most are 5-20 m wide, the deepest show a topography between furrow and border-ridge of up to 20 m, which in a couple of isolated cases takes the deepest absolute depth for a plough mark to around 520 m.

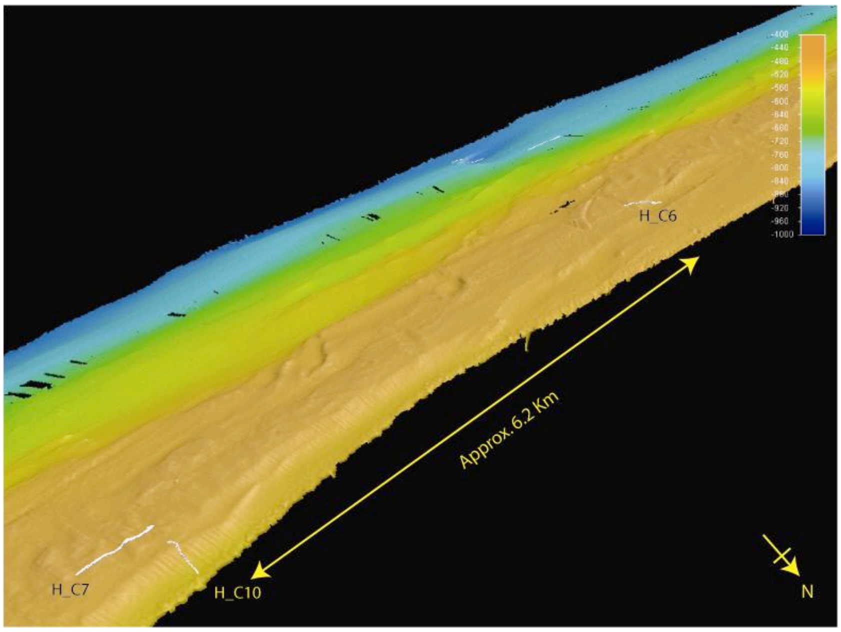


Figure 33. Location of transects H_C6, H_C7, and H_C10, all near the crest of northern Hatton Bank. Stations H_C6 and H_C7were ran for both geological and biological characterisation of the large iceberg plough marks that are found over the crest of the Bank, H_C10 was to look at the north-facing scarp slope.

Geology: generally the seabed is mostly rippled sand with a few pebbles and cobbles; however, there is excellent correlation between the high-backscatter plough mark edges and exposure at the surface of the basalt layer noted above at various locations over this part of Hatton Bank (Figure 34). Looking at the broken and disjointed occurrences of the basalt layer on the surface, it is evident that the layer was smashed during iceberg movements across the bank, with the ice gouging a central trough and pushing aside the basalt with a bulldozer effect (Figure 35).

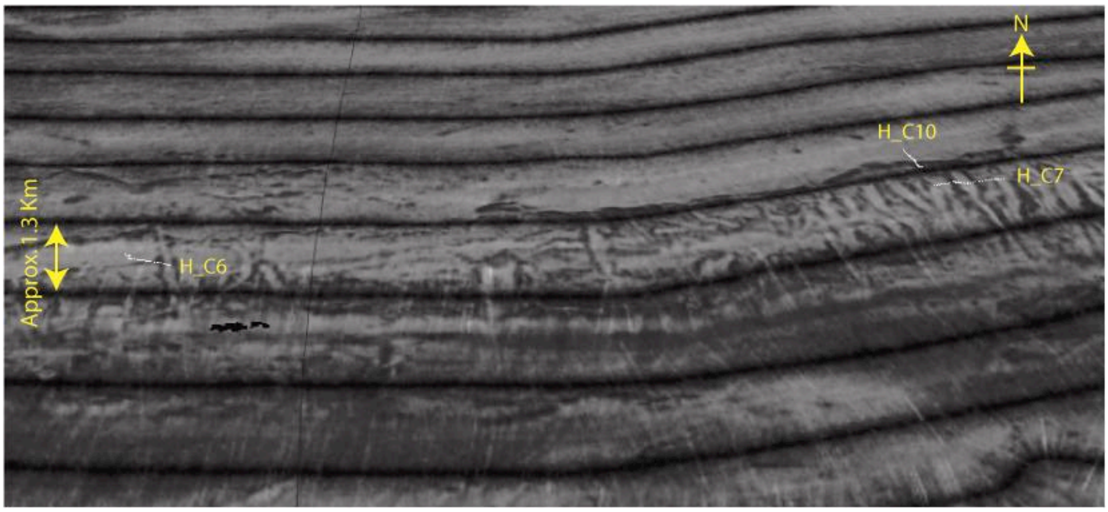


Figure 34. Acoustic backscatter mosaic showing high backscatter along the margins of all the iceberg ploughed areas

Figure 35. Some seafloor photographs from transect H_C6 showing details of the basalt crust which in places is bulldozed.

Biology: The transect began in an area of rippled sand habitat with few visible epifauna except the occasional urchin (*Calveriosoma sp*). Across the edge of the plough-mark the bulldozed region of dense cobbles and boulders was colonised by encrusting sponges, hydroids, holothurians (*Psolus squamatus*), decapods, stylasterid and solitary corals (*Caryophillia sp*). Visible mobile epifauna included squat lobsters (probably *Munida rugosa*), and ophiuroids hidden in the cracks and crevices of stones (possibly *Ophiactis balli*). As the tow progressed through the plough-mark the sediment changed to rippled sand with few visible epifauna, and the seabed changed again to sand-covered outcrop then again back into the cobbles and boulders that marked the edge of the plough-mark (Figure 35). Here visible fauna included encrusting sponges, holothurians (*Psolus squamatus*), solitary corals (*Caryophillia sp*), anemones, ophiuroids hidden in the cracks and crevices of stones (possibly *Ophiactis balli*), ascidians, decapods, urchins (*Cidaris sp*.) and brachiopods. Outside of the plough mark, the seabed then returned to rippled sands with few visible epifauna. A length of taut rope was visible on the seabed, most likely part of lost fishing gear.

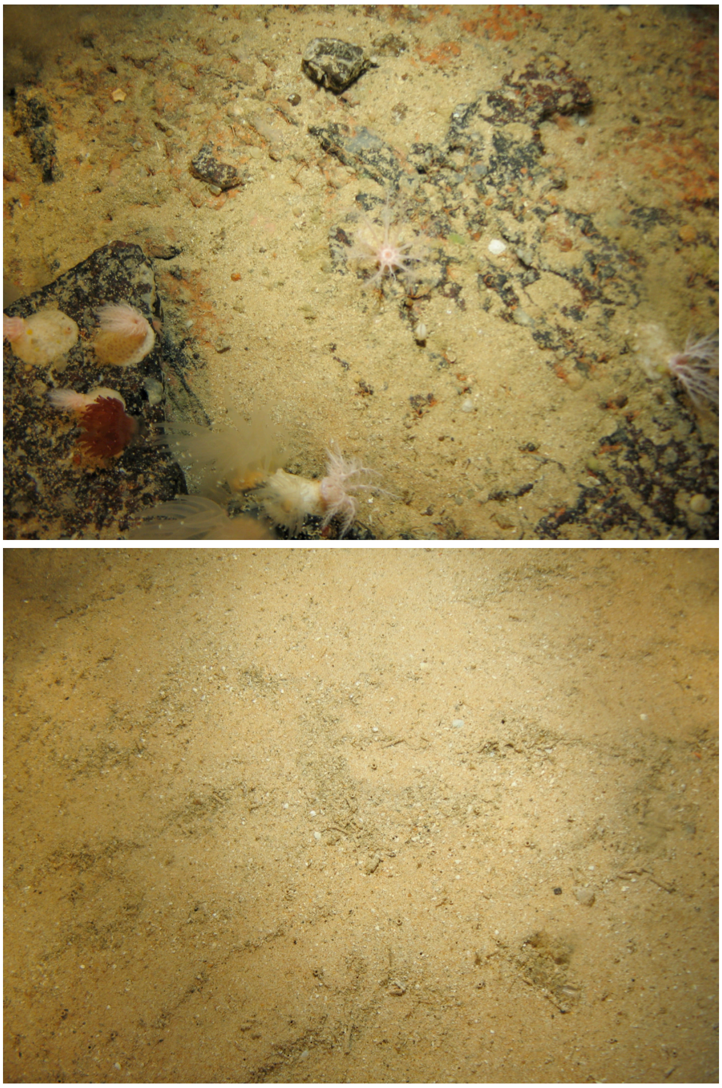


Figure 36. Seafloor photographs representative of the benthic biology of H_C6.

H_C10 This site was run to look at a northward-facing 30 m scarp slope on the axis of the Bank (Figures 33 and 34 for location).

Geology: Above (to the south of) the scarp, the seafloor is rippled sands, with occasional dropstones, but on the slope itself, and beginning just where the backscatter mosaic shows higher levels, the seafloor has a significant surface debris of what appears to be broken sections of basalt, sometimes the larger cobbles or small boulders have gravel trains on their lee sides. Away from the scarp to the north, the seafloor returns to a coarse sand overlying degraded ripples.

Biology: The transect began in an area of dense (>40% cover) cobbles on sand colonised by holothurians (*Psolus squamatus*), brachiopods, stylasterid corals (probably *Pliobothrus*) and small growths of *Lophelia pertusa*. The transect progressed onto an area of rippled sand with few visible fauna except occasional holothurians (*Stichopus tremulus*), urchins (*Calveriosoma sp*) and fish. A length of taut rope was visible on the seabed, most likely part of lost fishing gear. As the camera progressed toward the scarp slope the habitat changed to an area of occasional cobbles, characterised by similar fauna as described previously that became denser and boulders more frequent at the edge of the scarp. The fauna remained similar to that on the cobbled area, but with occasional thickets of *Lophelia pertusa*, blue-mouth red fish (*Helicolenus dactylopterus*) and urchins (*Cidaris cidaris*). Visible epifauna at the base of the slope on the rippled sand included holothurians (*Stichopus tremulus*), urchins (*Echinus acutus, Cidaris cidaris*) and fish (grenadiers and occasional flat fish).

Figure 37. Seafloor photographs representative of the benthic biology of H_C10.

H_C7 This was another look at an iceberg plough mark (Figures 33 and 34 for location), primarily for biological analysis and comparative studies with the plough mark faunas described (Howell et al in prep) over Rockall Bank.

Geology: The photographs here again showed the usual pattern of sands inside the plough marks, with the furrow edges being marked by boulders and cobbles predominantly of the broken basalt. There was an excellent correlation between acoustic backscatter and photography.

Biology: Transect began outside the plough mark on a rippled sand with few visible fauna except urchins (*Cidaris cidaris*), holothurians (*Stichopus tremulus*) and occasional fish (*Chimaera monstrosa*). The camera then crossed an area of sand with occasional cobbles colonised by encrusting sponges, holothurians (*Psolus squamatus*), solitary corals (*Caryophillia sp*), anemones and ophiuroids hidden in the cracks and crevices of stones (possibly *Ophiactis balli*), before passing back into a rippled sand habitat with few visible epifauna. As the camera approached the edge of a plough-mark the seabed changed to a region of dense cobbles and boulders colonised by a diverse range of species including encrusting and globose form sponges, holothurians (*Psolus squamatus*), solitary corals (*Caryophillia sp*), stylasterid corals (probably *Pliobothrus*) and small growths of *Madrepora occulata* and *Lophelia pertusa*, brachiopods, anemones and hydroids. Mobile epifauna included squat lobsters (probably *Munida rugosa*), shrimp and ophiuroids hidden in the cracks and crevices of stones (possibly *Ophiactis balli*). In the trough of the plough mark the seabed returned to rippled sand with few visible epifauna. Over the conjugate edge of the plough mark the habitat again returned to a region of dense cobbles and boulders colonised by a diverse range of fauna as described above and including a large yellow sea-fan (Gorgonian). Moving away from the plough mark the seabed was again rippled sand, which changed again as a second plough mark was encountered; the habitat here was identical in character to that described above.

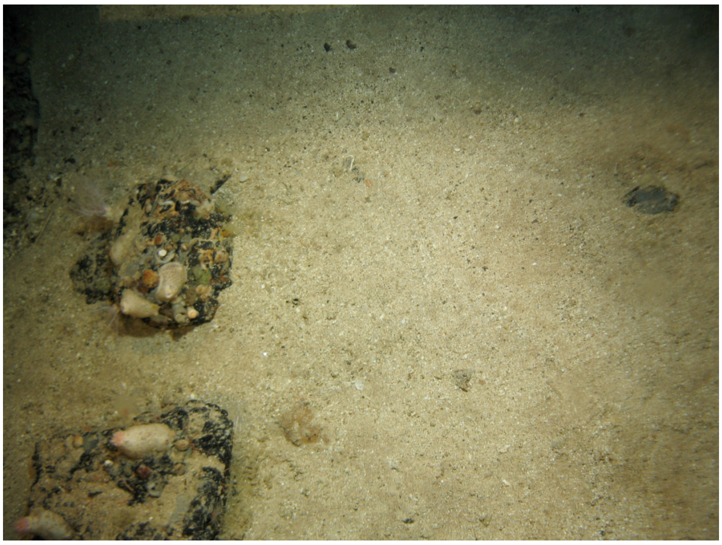


Figure 38. Seafloor photographs representative of the benthic biology of H_C7.

H_C9 This site was the deepest site on the south-eastern flank of Hatton Bank, lying just to the south of and above the slope-parallel channel described above in H_C1, and was targeted to examine whether there any sedimentological or biological changes from one side of the channel to the other.

Geology: The traverse showed the seafloor to consist entirely of coarse sand ripples with detritus infill. The acoustic backscatter levels were generally lower on the southern flank of the channel compared to the northern flank of the channel, however there was minimal sedimentological difference noted from the photographic survey.

Biology: The transect ran through a single habitat type of rippled sand with detritus in the ripple furrows. There were few visible epifauna but they included holothurians (Stichopus tremulus), urchins (Echinus acutus), small (<10mm disc diameter) ophiuroids, small cone shaped gelatinous organisms, a single occurrence of a zoanthid (Epizoanthus sp.), and many fish (*Chimaera monstrosa,* various grenadiers*,* unidentified ray, and the blue-mouth red fish (*Helicolenus dactylopterus)*.

Figure 39. Seafloor photograph representative of the benthic biology of H_C9.

H_C12A and B was a transect across the prominent N –S trending remnants of the large igneous dyke (Figures 17, 18 and 44).

Geology: Either side of the dyke the seabed is composed of rippled sands with coarser material in troughs, and rather few dropstones, though where they do occur, larger boulders have gravel trains down-current. Toward the edges of the dyke, part-buried outcrop occurs along with the boulders (e.g. Figure 40), and where the seabed is sandy, it becomes more pebble-covered. The outcrop itself was both a sheer wall and in places had the appearance of a stack of huge boulders, though the amount of encrustation makes identification of primary structures such as jointing difficult.

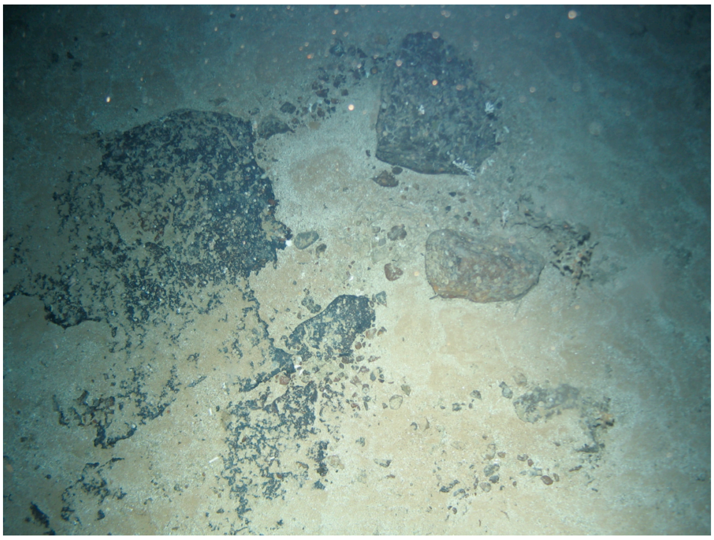
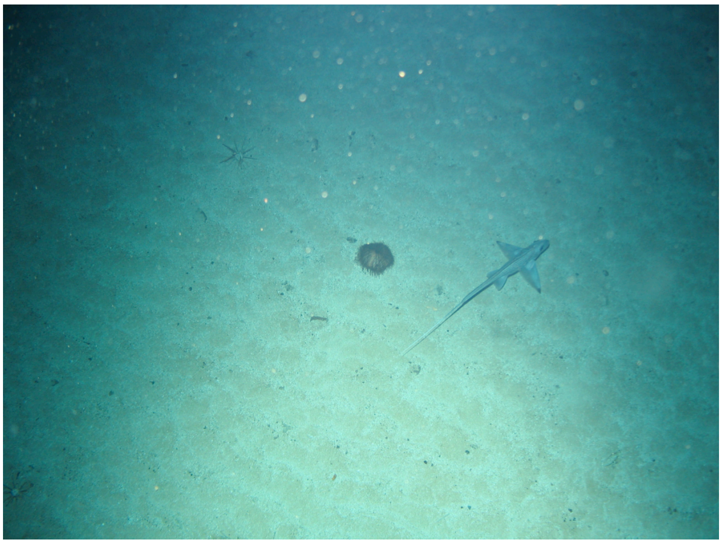


Figure 40. Outcrop and/or boulders at the seabed near the edge of the large dyke, note the rippled sands and gravel train.

Biology: Visible fauna over the rippled sand and occasional cobbles were few, consisting of holothurians (*Stichopus tremulus*), urchins (*Calveriosoma sp. Cidaris sp.*) and fish. Moving toward the ridge, the cobbles and boulders became more frequent with small growths of coral (*Lophelia pertusa* and *Madrepora occulata*) and encrusting fauna, with increasing gravel-lag deposits on the sand between rocks. Patches of dead coral skeleton were also visible and colonised by anemones

(*Phelliactis* sp), crinoids, Stylasterid corals (probably *Pliobothrus*), and both erect and encrusting sponges. Typical of the encrusting fauna in this area were *Psolus squamatus*, stylasterid corals (probably *Pliobothrus*), anemones (*Phelliactis* sp, and others), brachiopods, serpulid tube worms and encrusting sponges. At the ridge bedrock outcrop was covered with dense coral (*Lophelia pertusa, Madrepora occulata*, and soft corals) colonising the steep walls. Over the steep outcrop slope which consisted largely of boulders and cobbles, a diverse range of sessile species and fish including orange roughy were noted. The boulders and cobbles quickly became less frequent away from the dyke outcrop, though there were still typical encrusting fauna as described above present. The tow ended on sand with typical fauna including urchins (Cidaris cidaris) and fish.



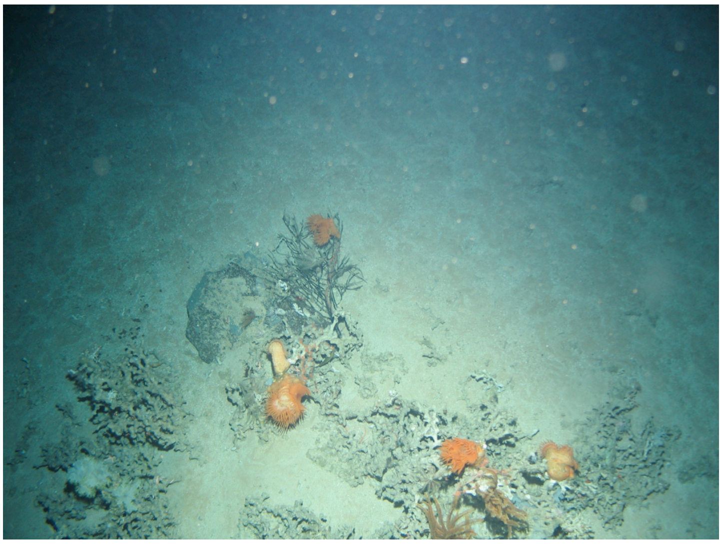


Figure 41. Seafloor photographs representative of the benthic biology of H_C12.

H_C18 This site is in the deepest of the channel-like features at the north-eastern corner of the survey area (Figure 42).

Geology: The deepest (>950 m) area of the seabed consisted of coarse, often biogenic rippled sand with rare, coral-encrusted boulders and cobbles, that covered most of the floor of the channel. The southern wall was extremely steep, vertical in some places, and consisted of bedrock outcrop and boulders for over 100 m of vertical face. At the top of the scarp face the seafloor returned to the usual coarse sand with gravel and encrusted boulders and cobbles on the surface.

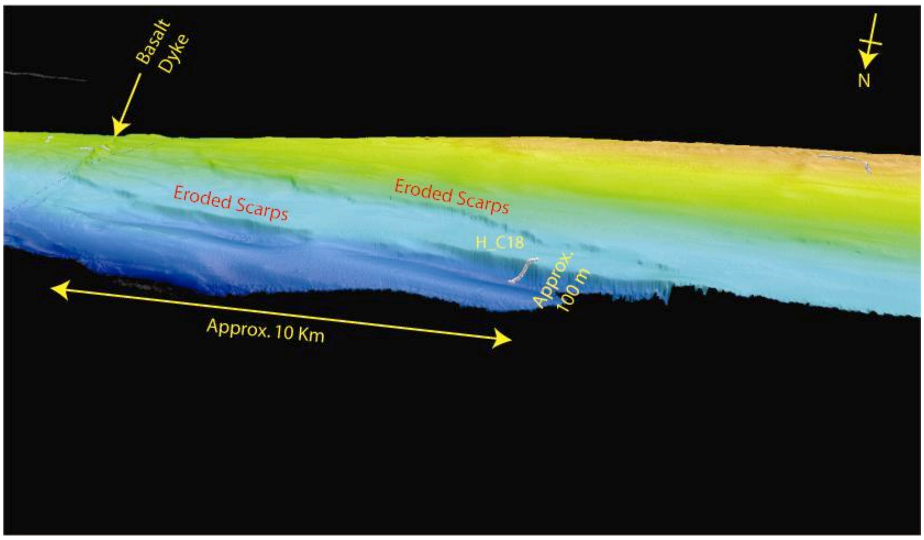


Figure 42. The location of camera transect H_C18 over a scarp slope acting as a channel bank in the north-eastern corner of the survey area.

Biology: Visible fauna over the area of sand with frequent pebbles at the start of the tow include small (<10mm disc diameter) ophiuroids, small cone shaped gelatinous organisms, occasional cerianthid anemones, and eel pout. As boulders and cobbles became more frequent they were colonised by encrusting sponges, cup sponges, anemones, Psolus, cup corals (*Caryophyllia* sp.), *Madrepora occulata* and stylasterid corals.

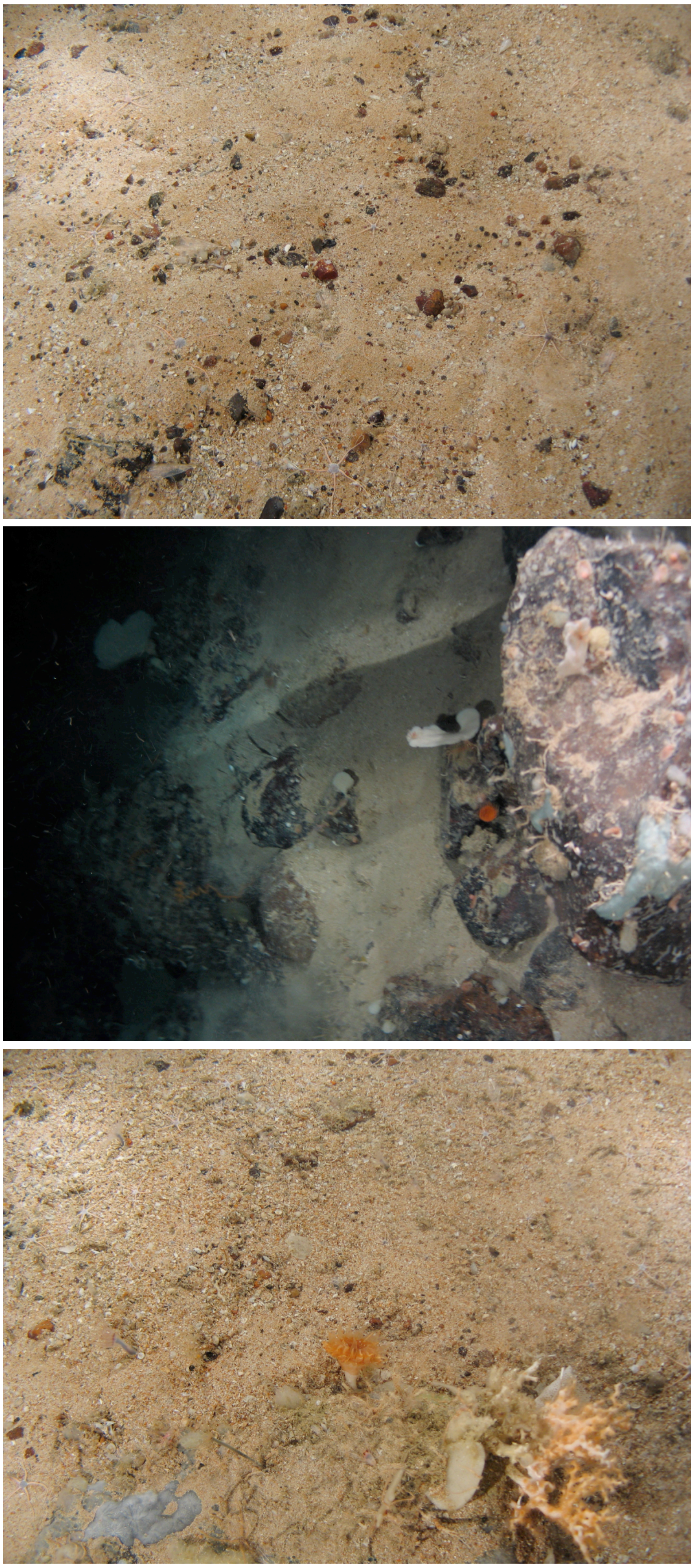


Figure 43. Seafloor photographs representative of the benthic biology of H_C12.

H_C17 This site was to look at features on the summit of Hatton Bank that appeared from the morphology to be large sand-ridges (Figure 44).

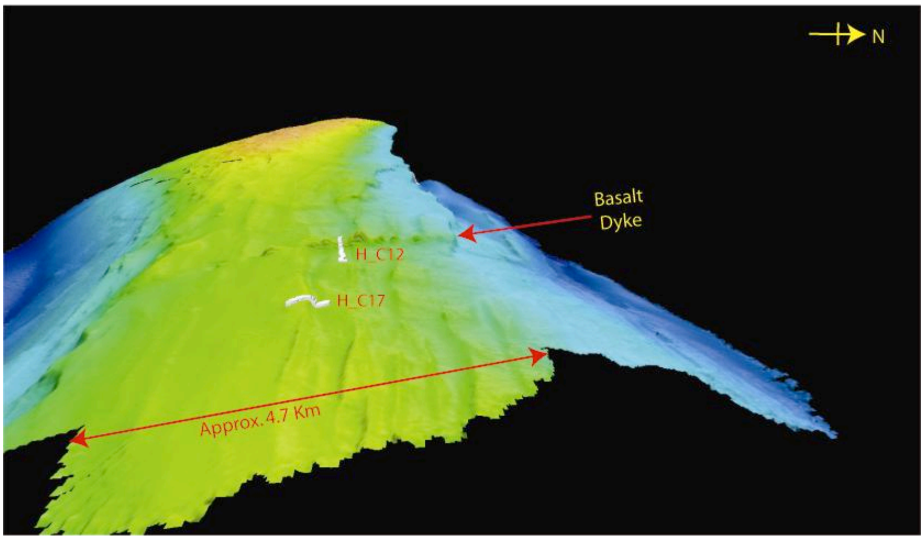
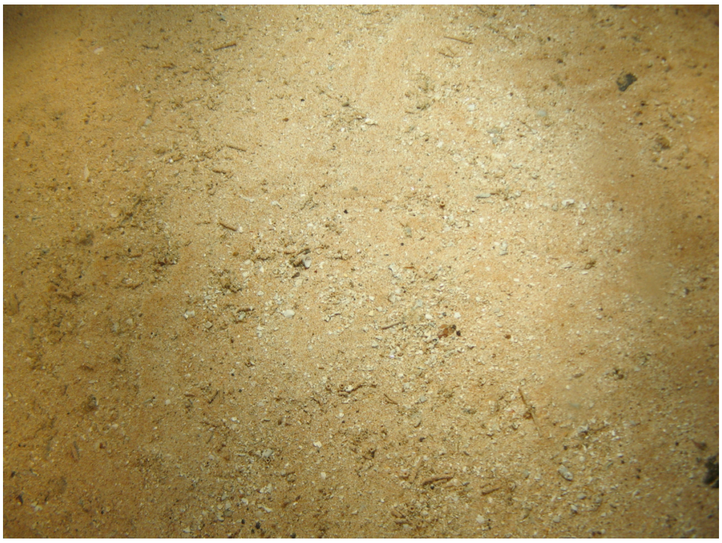
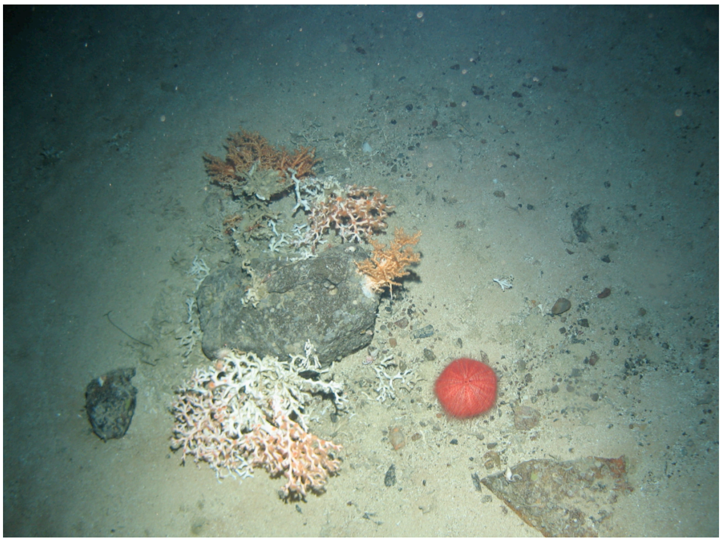


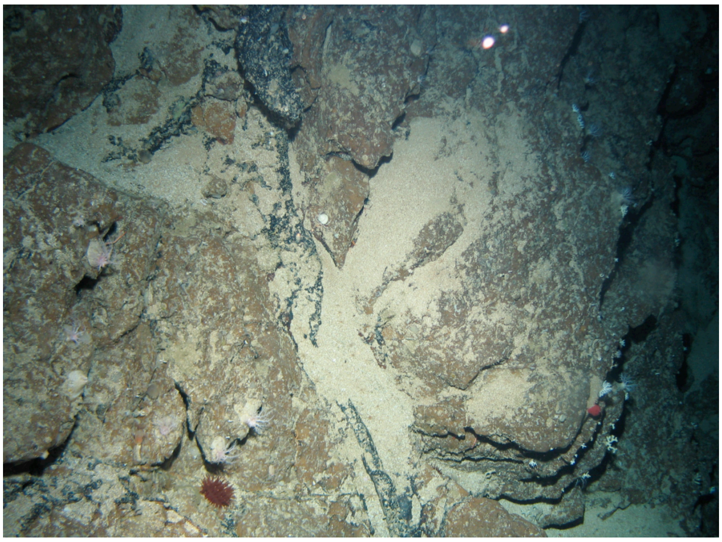
Figure 44. The location of H_C17 across one of the potential sand ridges at the eastern end of the Hatton Bank survey area.

Geology: The majority of the area here was composed of rippled sand with surface boulders and cobbles, though these tended to be in large patches with areas of clean rippled sand between. Toward the centre of the ridge the preponderance of boulders and gravels appears to increase, and an area of basalt outcrop was also visible, which was abruptly broken forming the top edge of a 20 m high almost vertical cliff. Immediately beneath this cliff toward the north the seafloor sediments consisted of a rippled sand and cobble field before changing abruptly to a very clean gravel lag, with no fine surface detritus. Toward the end of the transect, the seabed once again become littered with cobbles and boulders, possibly with sand-covered outcrop in places too, separated by gravel-covered sand.

Biology: The tow began on a sandy seabed with occasional cobbles and boulders and dead Lophelia skeleton. Fauna on the sand included holothurians (*Stichopus tremulus*), urchins (*Cidaris cidaris*, *Echinus acutus, Calverisoma sp.*), and fish (*Chimaera monstrosa* and Grenadiers). Outcrop and boulders were colonised by faunas similar to that seen in previous tows, including small growths of coral (*Lophelia pertusa, Madrepora occulata*), anemones (*Phelliactis* sp), stylasterid corals, holothurians (Psolus), brachiopods, and encrusting sponges. Brisingid seastars were visible occasionally perched on rocks in typical feeding pose. The almost vertical outcrop wall was sparsely colonised by cyclostome bryozoans, anemones, Psolus, *Lophelia pertusa* and *Madrepora occulata*. The sand and cobbles at the base of the wall had similar fauna to the cobbles earlier in the tow but including gorgonians (probably *Callogorgia verticillata*) and echiuran worms. Where the gravel-lags dominate the sea floor there were few fauna visible. Toward the end of the tow the bedrock and cobbles encountered are colonised by sparse fauna of similar composition to that described above.







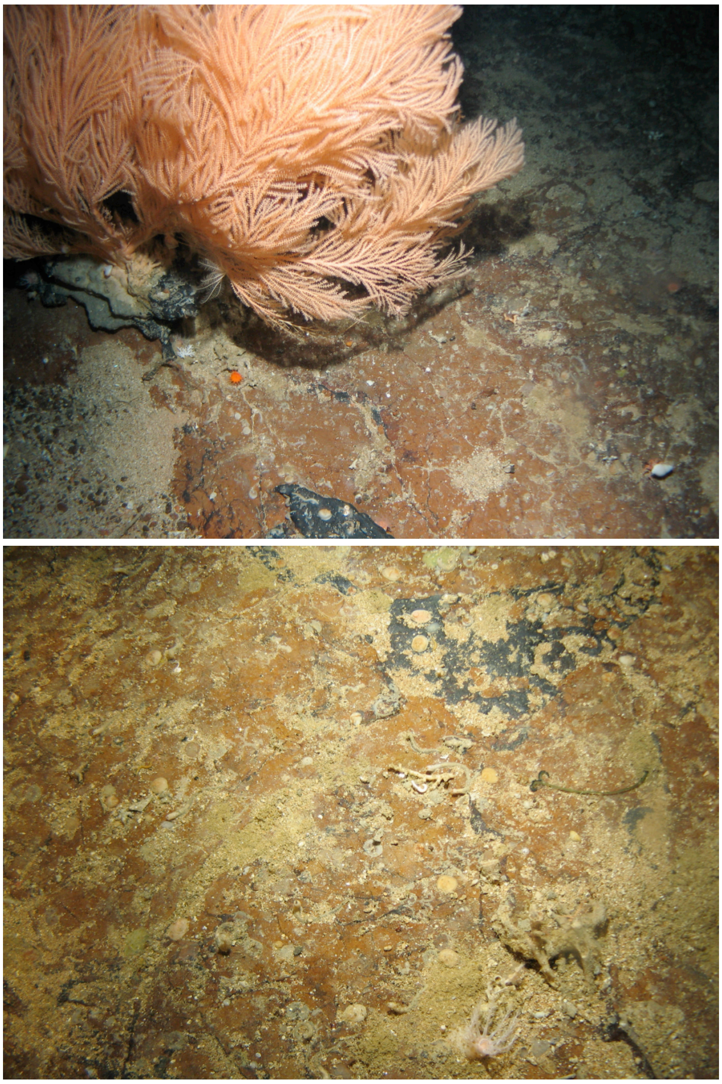


Figure 45. Seafloor photographs representative of the benthic biology of H_C17.

H_C14 This site was located to examine one of the very steep eroded scrap slopes on the northern flank of Hatton Bank (Figure 46).

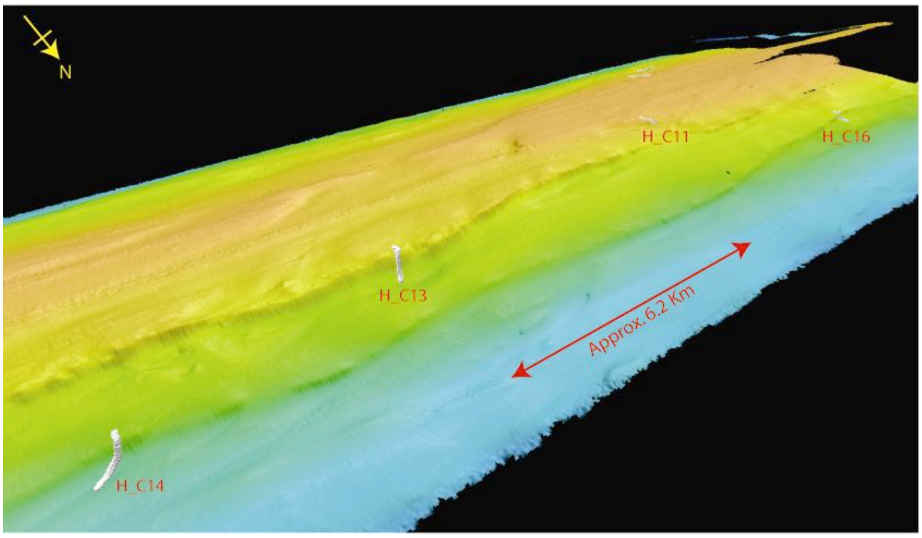
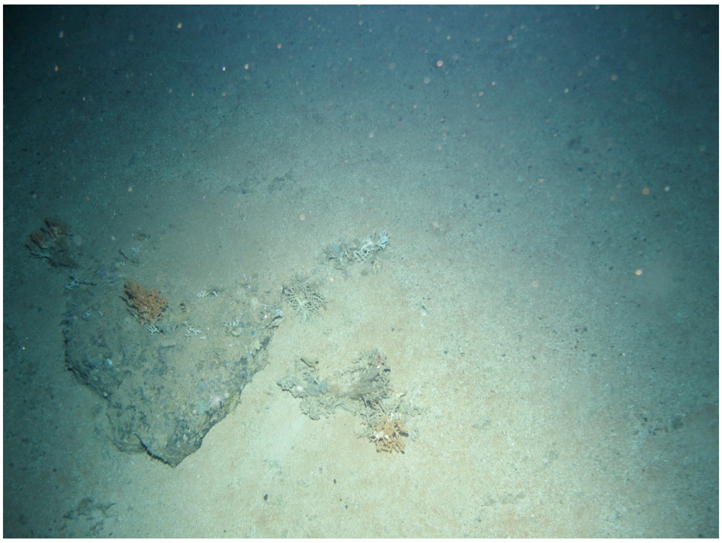


Figure 46. The location of sites H_C14, H_C13 and H_C16 (and H_C11) over the scarp slopes on the northern side of Hatton Bank.

Geology: At the beginning of the transect (southern end) the seafloor displays the usual mix of coarse sand with surface boulders and cobbles, with gravel trains appearing toward the cliff edge. On this transect, unlike many of the others, there is no pre-slope basalt outcrop evident; the upper scarp slope itself is composed of outcrop with overlying sand, and toward the base of the scarp the sand becomes vastly predominant with surface boulders and cobbles. At the base of the scarp the sediments change to a gravel lag, with no detrital or other fine-grained material. Just before the end of the transect, the seafloor shows and abrupt change to a coarse biogenic sand.

Biology: Sites H_C14 and H_C13 were faunally and topographically very similar to each other. The fauna over the sand and cobble area above the scarp was typical of the area and depth and included holothurians (*Stichopus tremulus*) and urchins (*Calveriosoma sp.* and *Echinus acutus.*). As the cobbles and boulders became more frequent they were colonised with small growths of coral (*Lophelia pertusa, Madrepora occulata*), anemones (*Phelliactis* sp), holothurians (*Psolus squamatus*), stylasterid corals, corkscrew-shaped antipatharian coral (*Stichopathes sp.*), brachiopods, and encrusting sponges. At the scarp edge the sea bed became rockier with bedrock and boulders colonised by species mentioned above, as were the outcrop and cobbles of the slope. As the boulders and cobbles became less frequent down the scarp front and the sea bed became more sandy, coral gravel with frequent lumps of Lophelia skeleton were colonised by similar fauna to the rock but including the erect bryozoan *Reteporella sp.* and cyclostome bryzoans, erect sponge growths and anemones. Toward the base of the scarp slope the seabed changed to a gravel lag deposit with few visible fauna, however numerous crabs (possibly *Paramola cuvieri*) were visible, distinctively in pairs. The seabed then returned to sands with fauna including *Echinus acutus* and small cone shaped gelatinous organisms.



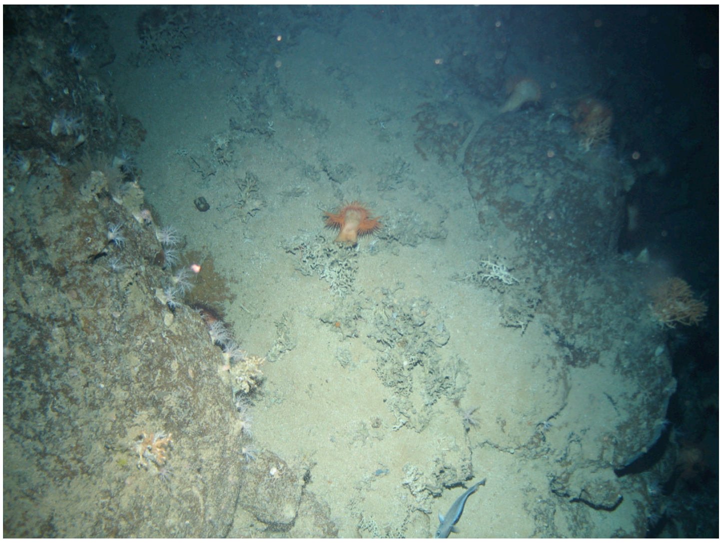
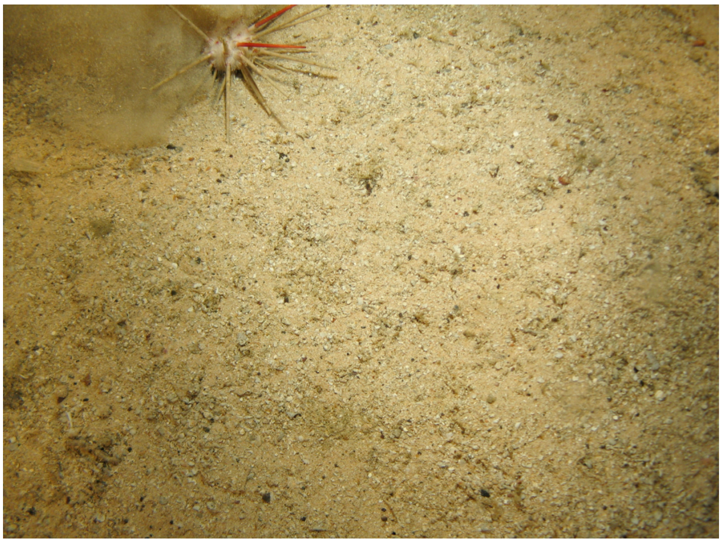


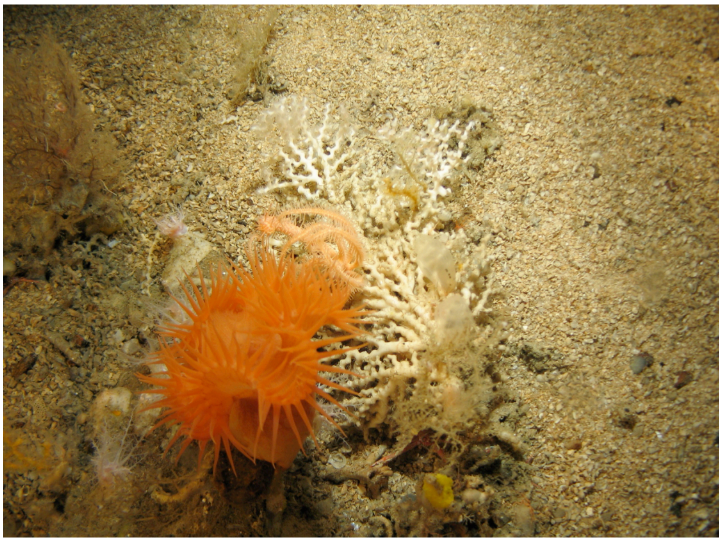
Figure 47. Seafloor photographs representative of the benthic biology of H_C14.

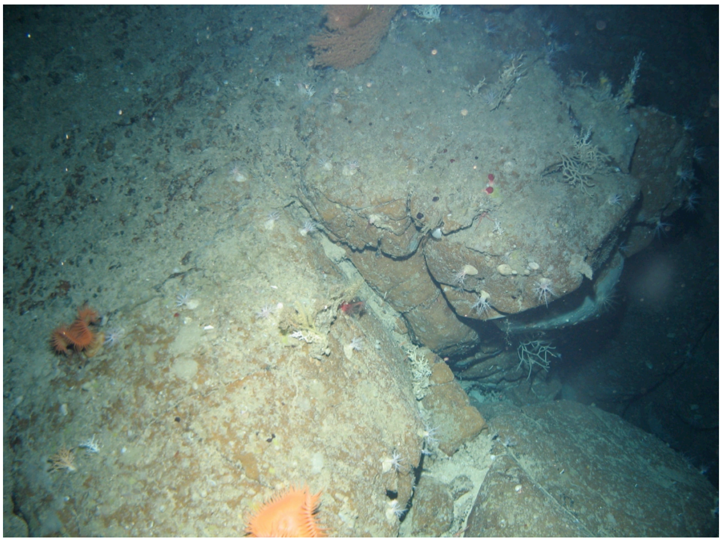
H_C13 This was an investigation of another of the steep scarp slopes, probably produced by extensive erosion, on the northern flank of Hatton Bank. This scarp was the shallowest investigated and formed a steep (< 20º) wall around 90 m in height dropping from 560-650 metres (Figure 46).

Geology: transect begins with coarse sand and surface boulders and cobbles, moving north toward the cliff edge, gravel trains become more common, eventually to be replaced by an basalt outcrop with many cobbles and boulders. The top of the scarp slope is an extremely steep outcrop slope replaced down-slope by sand covered by boulders and cobbles. The cobble and larger material becomes infrequent toward the base of the scarp, though gravel is still common, especially in laterally-restricted areas where very well-washed lag deposits are found, before sand returns as the dominant sediment type.

Biology: Fauna over the sand with occasional cobble seabed was typical of that seen elsewhere in the area at this depth and included holothurians (*Stichopus tremulus*) and urchins (*Calveriosoma sp.* and *Echinus acutus.*). As the tow progressed toward the scarp edge cobbles and boulders became more frequent and were colonised with small growths of coral (*Lophelia pertusa, Madrepora occulata*), anemones (*Phelliactis* sp), holothurians (*Psolus squamatus*), and encrusting sponges. At the scarp edge the sea bed became rockier with the bedrock and boulders colonised by species mentioned above and additional coral species including gorgonians (probably *Callogorgia verticillata*). Large sponge growths were visible occasionally, and cyclostome bryozoans. In general the fauna appeared more diverse near the ridge edge. The steep rock/boulder scarp wall was colonised by similar fauna (as above) but including corkscrew-shaped antipatharian coral (*Stichopathes sp.*) and the alcyonacean *Anthomastus grandiflorus*. Lower down the scarp, the sea bed became sand and coral gravel with occasional lumps of Lophelia skeleton colonised by Psolus, stylasterid corals, sponge and live Lophelia and Madrepora, occasional sea pens and brisingid seastars. Over the lag deposits there were few visible fauna, but in the punctuating the lags were sand/coral skeleton patches with similar fauna to that described above.







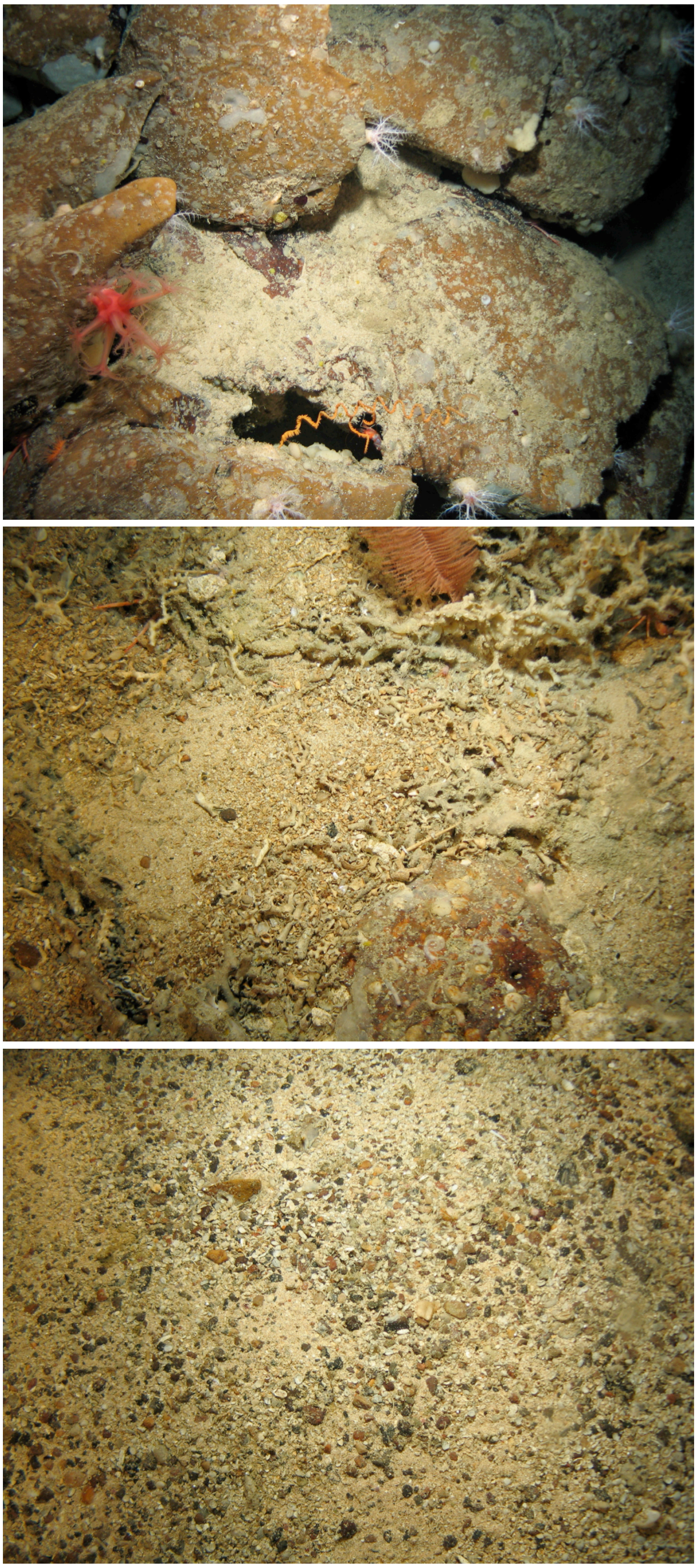
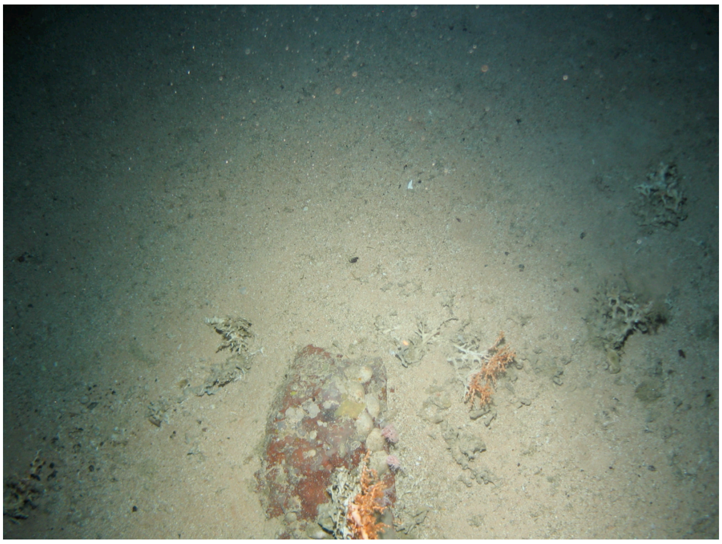


Figure 48. Seafloor photographs representative of the geology and benthic biology of H_C13.

H_C16 Was the furthest west of the steep northern flank scarp slopes examined. This particular scarp dropped from 585-615 metres at a slope angle of over 20º, before the base of the scarp flattened out to around 2º and falling away to about 640 metres (Figure 46).

Geology: Sheet sand and rare dropstones, with cobbles and boulders becoming more frequent toward the scarp edge. Technical problems meant that the scarp edge was not imaged, the transect resuming part-way down the scarp slope. Biogenic (coral fragment) gravel and outcrop occurs here, with some denser patches of gravel (no longer coral fragments, but stones) cover than others and cobbles appear on the lower part of the slope. Lithic gravels make up significant part (~20%) of seabed cover moving toward end of tow and then wane such that seafloor returns to gravely sand with dropstones.

Biology: C16 was very similar to both C13 and C14. The sand and occasional cobble area was colonised by small growths of coral (*Lophelia pertusa, Madrepora occulata*), holothurians (*Psolus squamatus*), and encrusting sponges. The scarp slope of sand and coral debris was colonised by small growths of live coral (*Lophelia pertusa, Madrepora occulata*), anemones (*Phelliactis* sp), stylasterid corals, and rarely gorgonians (probably *Callogorgia verticillata*). As the camera descended the slope cobbles and boulders became more frequent and colonised by similar species to those described above but including Psolus and encrusting sponges.



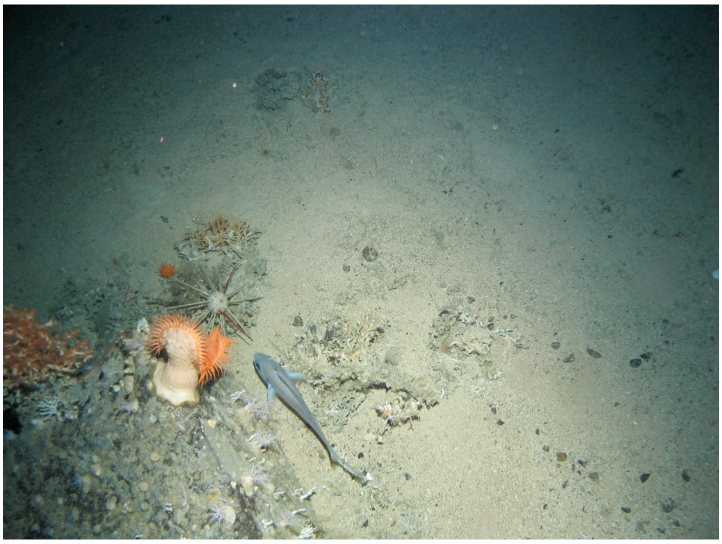


Figure 49. Seafloor photographs representative of the benthic biology of H_C16.

The CTD data across this part of Hatton Bank were examined and the average temperature taken whilst the camera was at the seabed (Figure 50).

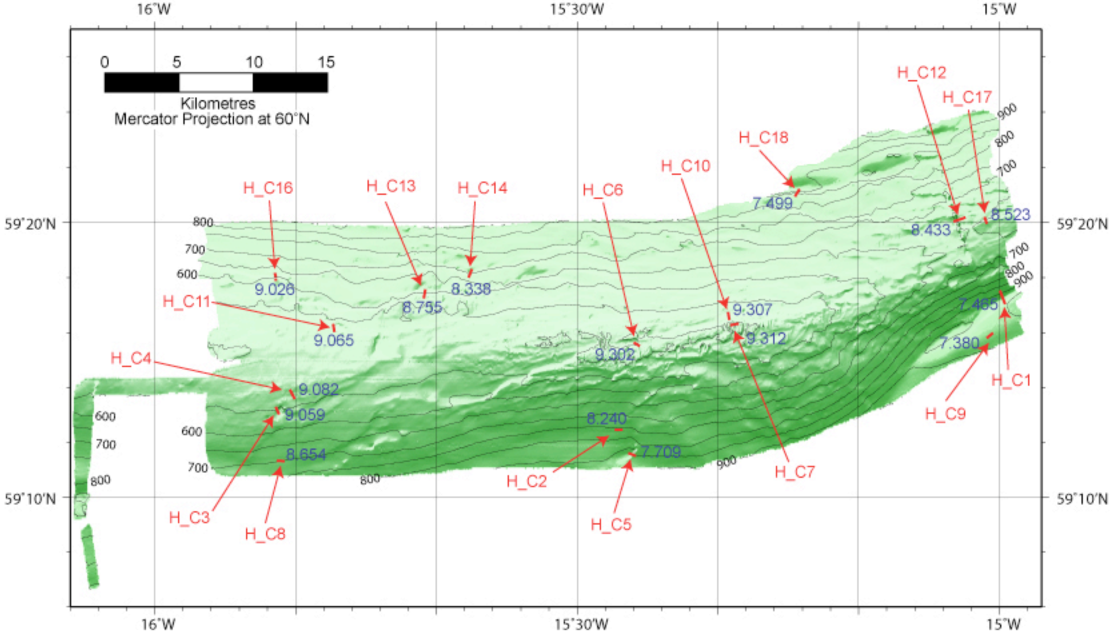


Figure 50. Positions of stations over North Hatton Bank and averaged bottom temperatures (blue).

These data (Figures 50 and 51) indicate that there is a single water mass flowing across Hatton Bank, the detailed geomorphology of this part of the Bank and large-scale physical oceanography studies of the area (REFS) suggesting that this is from the south or southwest toward the north and north-east.

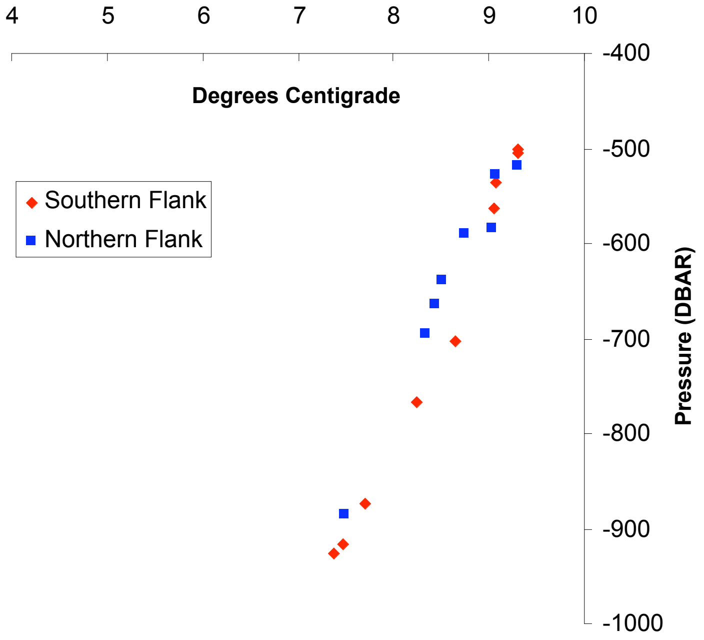


Figure 51. Graph of averaged bottom temperatures across northern Hatton Bank against depth, further split into the northern and southern flanks.

Hatton Bank South (Lyonesse Bank)

The EM1002 survey provided excellent data over this small abutment on the southeast flank of Hatton Bank. The seafloor in this region comprises a gentle dome topped by a series of small mounds standing 100-140 m above the surrounding seafloor, centred around 57º58'N 17º40'W. The DTM reveals that each mound varies in size from 1-5 Km, and each has numerous peaks, ledges and/or ridges, each slightly elongated in an E-W direction, with the roughest and craggiest topography toward the east and a less rough (sediment-covered) flank toward the west. Interpretation of the geomorphic structures presented by the regional overview (Figure 52) suggests that this is part of an exhumed and now eroded igneous intrusive centre described from seismic investigations. The regional seafloor is a smooth dome except for around 58º00'N 17º49'W where there are a series of small (~10 m deep) depressions up to 200 m across that trend ~045º-225º.

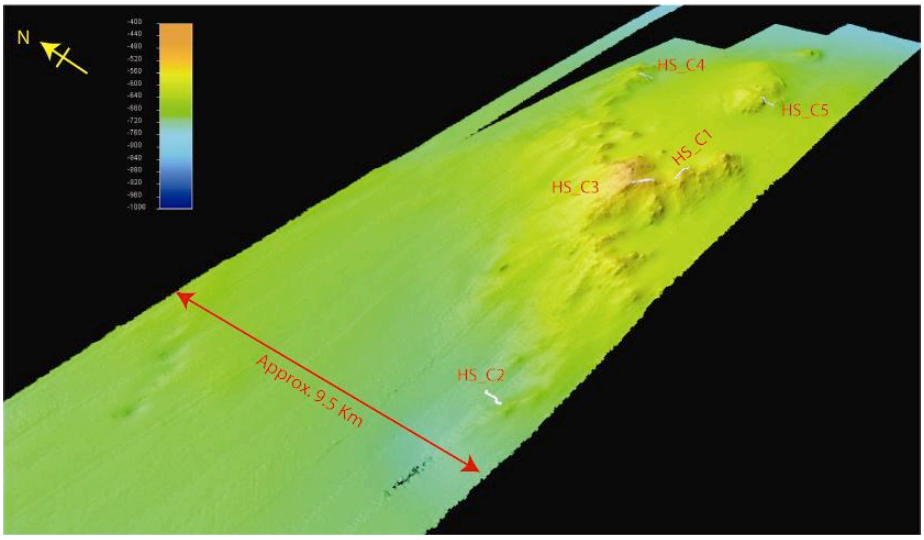


Figure 52. DTM of southeast Hatton Bank (Lyonesse) showing the East-West elongation of the individual mounds, and the "smoothed" topography they exhibit on their western flanks. The camera transects are also indicated.

The acoustic backscatter (Figure 53) shows that the crest and ledges/ridges of each of the peaks or ridges is a discrete area of very high acoustic backscatter (100-200 m across), interpreted as bedrock outcrop. The backscatter of the (mostly southern) flanks of the mounds is also higher than the surrounding seafloor, indicating a difference in surface conditions. Generally the surrounding regional seafloor shows a uniform low level of acoustic backscatter, but there are some areas of higher backscatter, for example just to the west of the southernmost imaged mounds around 57º56'N 17º45'W, and over the eastern extremity of the study area. The backscatter is also significantly higher within a couple of the small depressions noted above at 58º00'N 17º49'W, indicating possible unusual biogenic or sedimentary conditions.

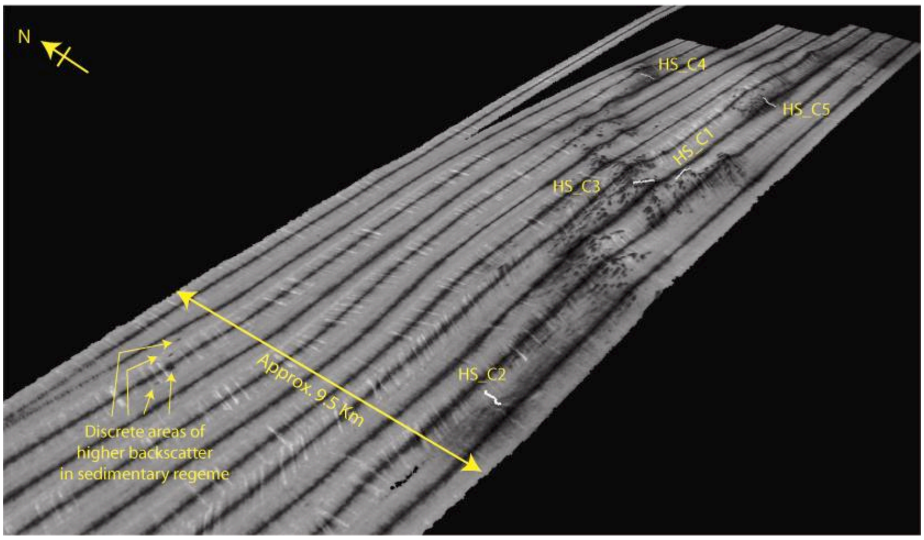


Figure 53. Acoustic backscatter mosaic from same viewpoint as Figure 52, of part of the southeast Hatton Bank (Lyonesse) survey area showing the very high acoustic backscatter rock outcrop on the summits and ridges of the individual mounds and the slightly higher level of acoustic backscatter on the southern flanks of these mounds.

HS_C2 This transect was run across the area of low topography that showed a transition from low to high acoustic backscatter.

Geology: The seafloor consisted entirely of clean rippled sands with very rare drop-stones. There was no immediate and obvious reason for the acoustic backscatter change unless it was an effect of the ripple type and orientation, though this will be very difficult to prove.

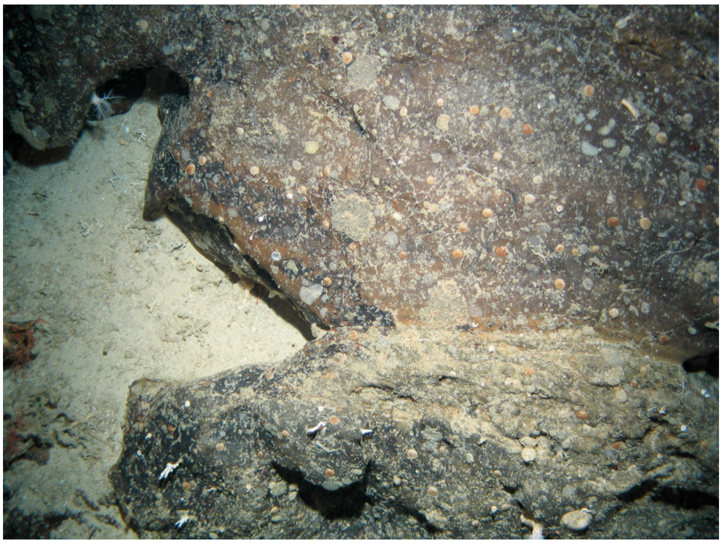
Biology: Visible fauna were those typical of this type of habitat and included urchins (*Calverisoma* sp.), small cone shaped gelatinous organisms and fish.

Figure 54. Seafloor photographs representative of the geology and benthic biology of H_C13.

HS_C3 This was one of the transects targeting one of the mound summit areas.

Geology: There is a large amount of bedrock outcrop, and two distinct types of probably ancient rock distinguished. The first and dominantly abundant outcrop type form large outcrops with vertical walls of over 20 m in height. It has rock surfaces that are discoloured and stained either brown or black and host a large amount of encrusting biota that obscures clear vision of any detailed structures they may contain. Having said that it is clear that a reasonably well-developed joint system is present, and where biota-free surfaces are seen the rocks appear to be composed of a fine matrix, these are the exposed basalts of the Lyonesse igneous centre (Figure 55). E.g.

HS_C 2,14,17,18. Between these large outcrops are "gullies" with sandy floors, from just a couple to several tens of metres in width. The second type of rock is buff-coloured (HS_C3B + 29+39) and although there are few examples clearly seen, it appears to occur at the base of the hard, darker pillar-like outcrops described above. The buff-coloured rock has a dimpled surface, usually a characteristic of submarine weathering in carbonate-rich material. The recent deposits are richly biogenic sands, with, near the outcrop pillars, surface boulders. A lack of ripples suggests current activity is not particularly significant.



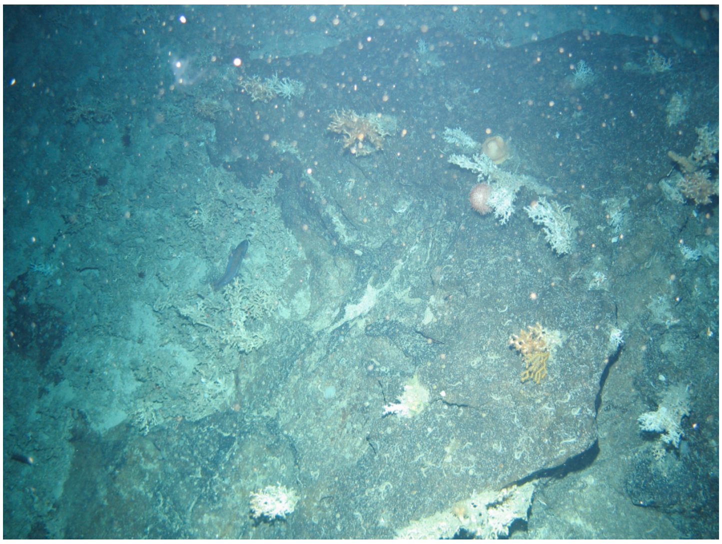
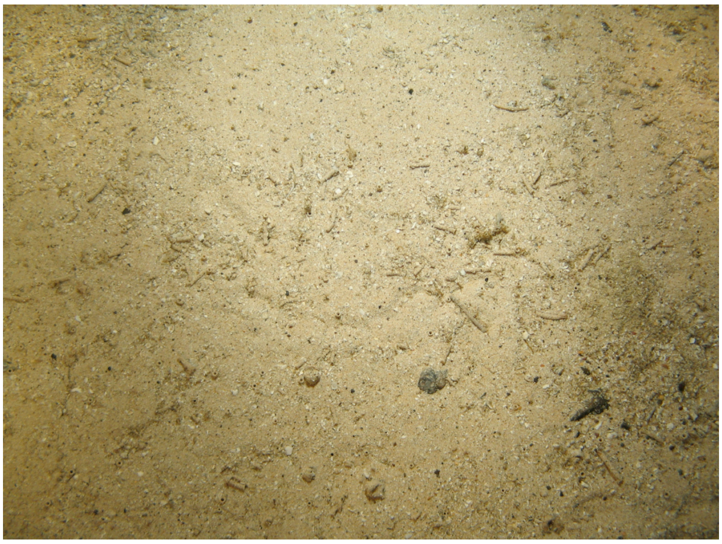
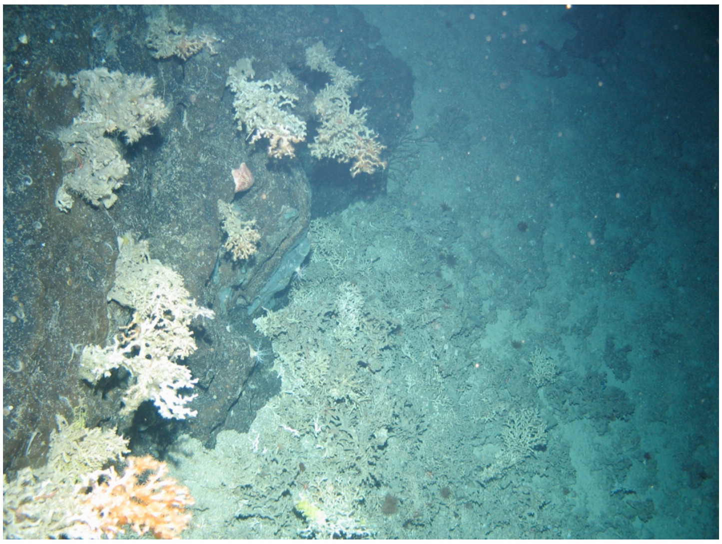
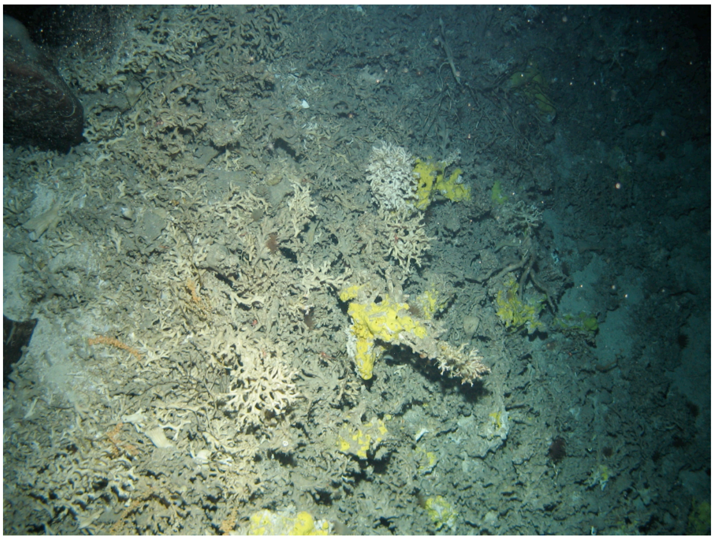


Figure 55. Basalt outcrop (dark) and probably the weathered (ancient) host sedimentary rocks through which the basalts intruded (light).

Biology: The tow began over a large area of rock outcrop, fringed by coral rubble. The rock was sparsely colonised by typical encrusting fauna such as Serpulid worms, saddle oysters, encrusting sponge, occasional anemones, and holothurians (Psolus squamatus), and a diverse array of coral species including *Lophelia pertusa*, *Madrepora occulata*, corkscrew-shaped antipatharian corals (*Stichopathes sp*.), alcyonaceans (*Anthomastus grandiflorus*), stylasterids (probably *Pliobothrus*) and gorgonians. Anemones (Phelliactis sp.) and erect sponge growths were also observed on the rock outcrop. Fauna inhabiting the coral rubble fringing included small growths of live corals, anemones, encrusting and erect sponge forms, squat lobsters (poss *Munida rugosa*), ophiuroids (probably *Ophiactis balli*), decapods (*Paramola cuvieri*) and ascidians. Between each large rock outcrop were areas of sand with few visible fauna, and regions of frequent cobbles and boulders as the camera approached the next outcrop. The cobbles and boulders were colonised by typical encrusting fauna and holothurians (*Psolus squamatus*). Two separate lengths of taut rope/wire were visible on the seabed, most likely part of lost fishing gear.







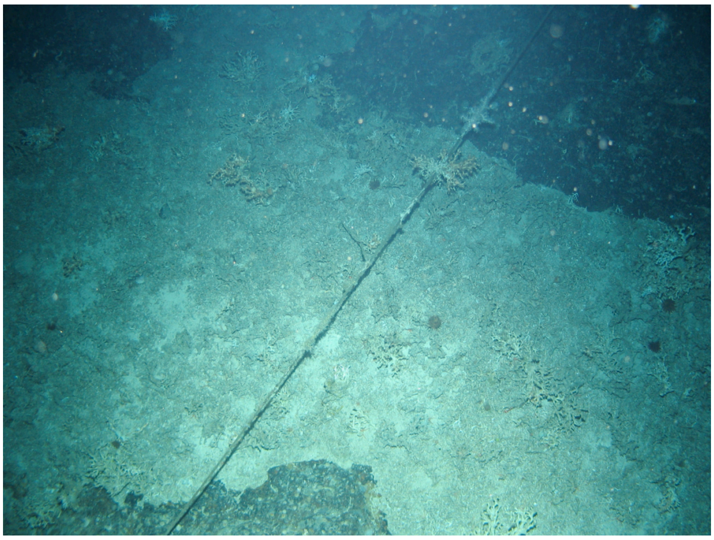
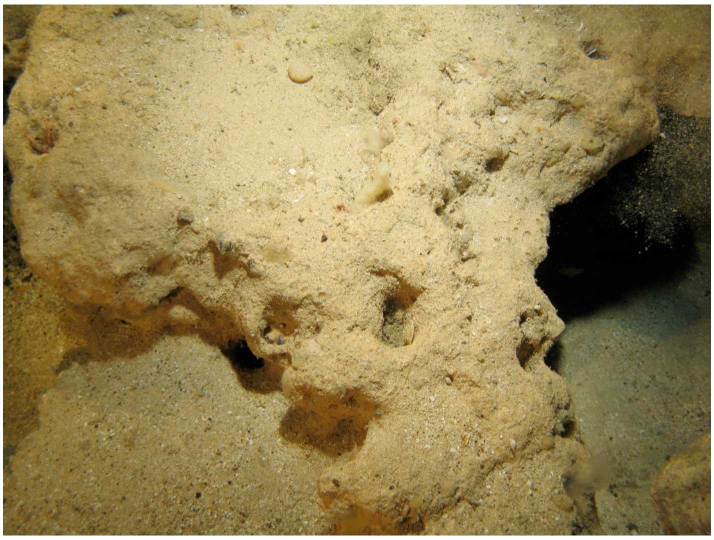


Figure 56. Seafloor photographs representative of the benthic biology of HS_C3.

HS_C1 This was a second transect across a summit area of the mounds to try and characterise the full range of faunal types.

Geology: This transect proved very similar to the previous in terms of the geology, with large outcrops surrounded by biogenic sands. Some of these sands are partly indurated and show evidence of bedding structures and/or sedimentary concretions (Figure 57). The pervasive iron-staining on the pillar-like outcrops suggesting that they are Fe-rich basalts. The recent deposits again were biogenic sands, again without obvious ripples or other active current indicators.



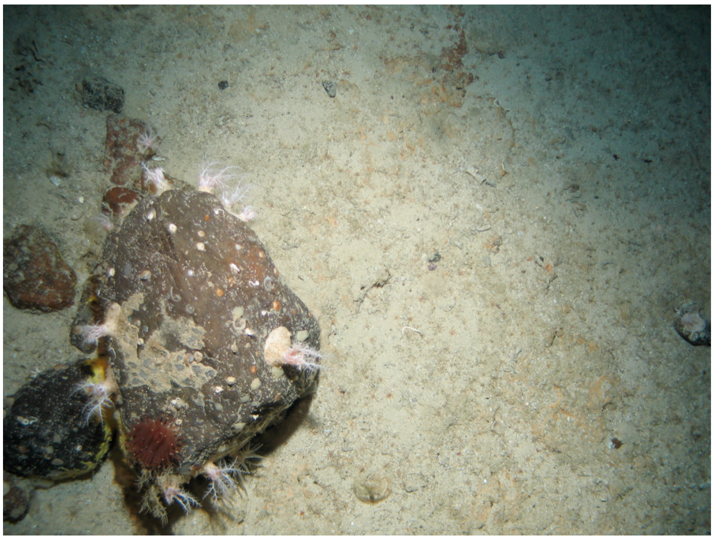
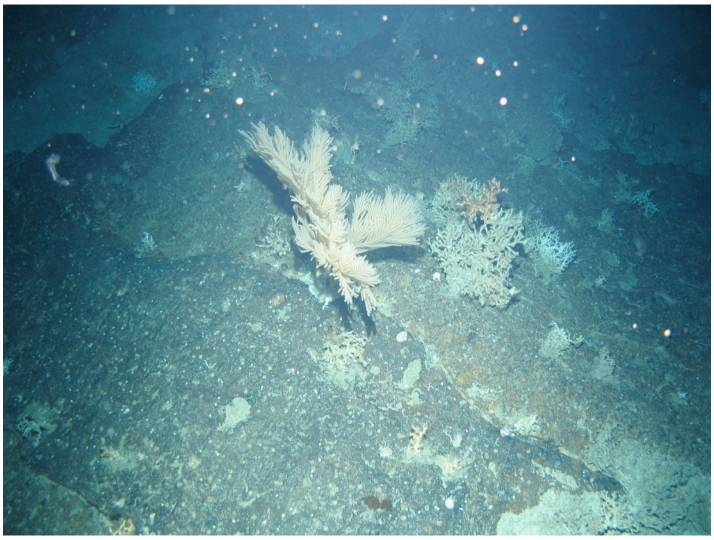


Figure 57. Possible concretions and primary bedding structures in the ancient sediments that surround the igneous intrusion at HS_C1.

Biology: The tow began over sand with few visible fauna except occasional cerianthid anemones. As the transect progressed, occasional cobbles, boulders and coral debris were encountered, becoming more frequent as the camera neared the rock outcrops. Cobbles and boulders were colonised by typical encrusting fauna and holothurians (*Psolus squamatus*), rarely sea pens were visible. Rock outcrop was fringed by coral rubble, boulders and cobbles and interspersed with areas of sand. The outcrop was sparsely colonised by typical encrusting fauna such as Serpulid worms, saddle oysters, encrusting sponge, occasional anemones, and holothurians (*Psolus squamatus*), and a diverse array of coral species including *Lophelia pertusa*, *Madrepora occulata*, corkscrew-shaped antipatharian corals (*Stichopathes sp.*), stylasterids (probably *Pliobothrus*) and gorgonians (possibly *Callogorgia verticillata*. Anemones (*Phelliactis* sp.) and erect sponge growths were also observed on the outcrop. Fauna inhabiting the coral rubble fringing the outcrops included small growths of live corals, anemones, encrusting and erect sponge forms, squat lobsters (poss *Munida rugosa*), ophiuroids (probably *Ophiactis balli*) and ascidiansHS_C1_056, HS_C1_060).



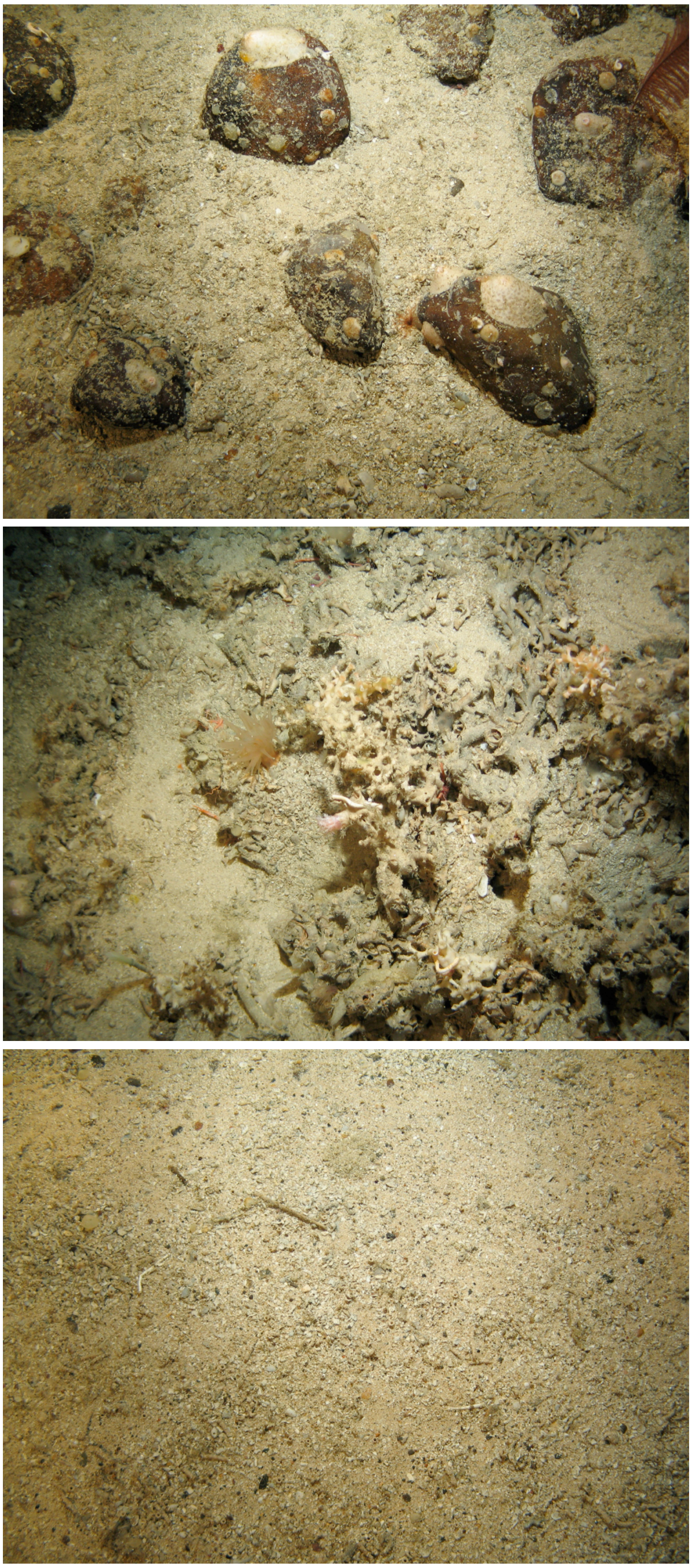
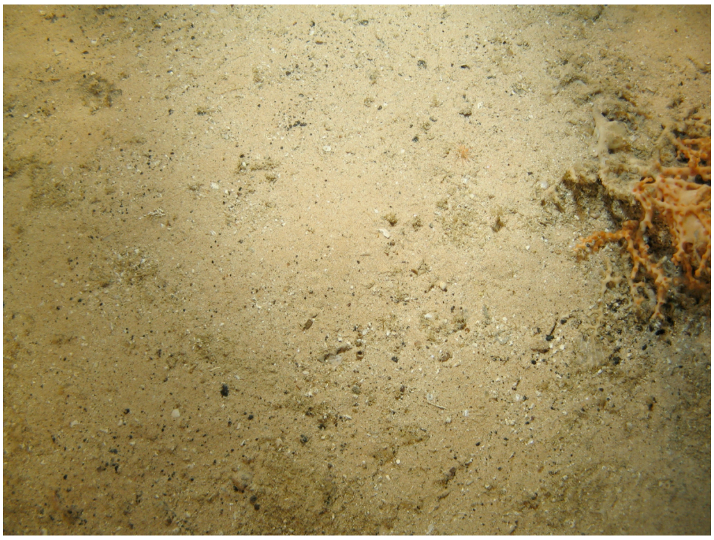


Figure 58. Seafloor photographs representative of the geology and benthic biology of HS_C1.

HS_C4 This transect was run over the southern flank of one of the mounds to quantify and categorise the fauna and to investigate the possible causes of higher acoustic backscatter levels compared to the sediments the rest of the survey area.

Geology: The flank of the mound centred on 58º06'N 17º36'W is composed of rippled sand with (mostly biogenic) detritus in the ripple troughs or otherwise spread across the seabed. In patches there are growths of coral on the sand, presumably anchored to small pebbles, and also outcrop of a buff-coloured indurated (ancient?) sedimentary rock. The majority of the loose recent sands that cover the slope is either mixed with, or has laying on its surface a very coarse biogenic gravel made from broken coral and shell fragments. It is concluded that it is the coarser nature of these surficial sediments that are the primary cause of the higher levels of acoustic backscatter on the mosaic when compared to sediments elsewhere in this survey area.

Biology: Over the sand with occasional cobbles and coral rubble, visible mobile fauna included holothurians (*Stichopus tremulus*), urchins (*Cidaris cidaris*) and fish. Cobbles were colonised by typical encrusting fauna including Serpulid worms, saddle oysters, encrusting sponge, occasional anemones, and holothurians (*Psolus squamatus*) and small growths of live coral as well as occasional large gorgonians. There were discrete areas of dense coral (Lophelia) rubble reef in-filled with sand and colonised by a diverse array of species including *Lophelia pertusa*, *Madrepora occulata*, corkscrew-shaped antipatharian corals (*Stichopathes sp.*), alcyonaceans (*Anthomastus grandiflorus*), stylasterids (probably *Pliobothrus*), gorgonians, anemones (*Phelliactis* sp. and others) and many erect sponge growths. Outcrop was sparsely populated with typical encrusting fauna as listed above and corals.



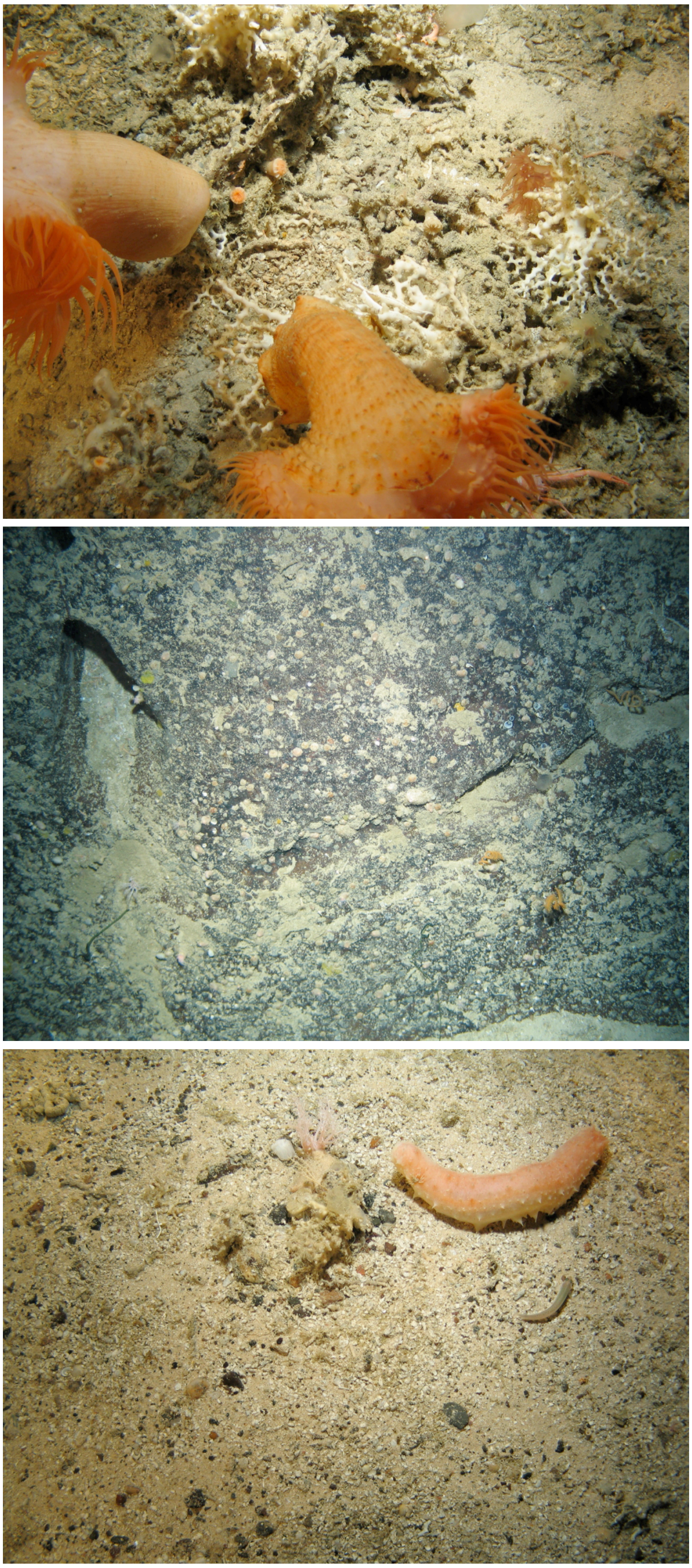
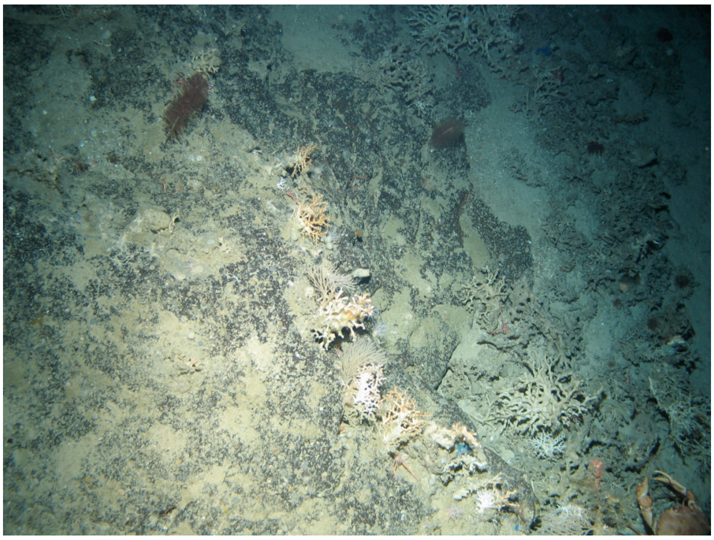


Figure 59. Seafloor photographs representative of the geology and benthic biology of HS_C4.

HS_C5 This transect was over the easternmost of the mounds in this part of the survey area, run primarily to look at the lateral distribution of fauna.

Geology: The seafloor here is very similar to the previous three transects, the same type of igneous outcrop, surrounded by richly biogenic gravely sands, that, away from the immediate vicinity of the outcrops, both loose the very high biogenic gravel fraction and appear to show ripples.

Biology: Outcrop was sparsely colonised by typical encrusting fauna such as Serpulid worms, saddle oysters, encrusting sponge, occasional anemones, and holothurians (*Psolus squamatus*) and a diverse array of coral species including *Lophelia pertusa*, *Madrepora occulata*, corkscrew-shaped antipatharian corals (*Stichopathes sp*., Leiopathes sp.), alcyonaceans (*Anthomastus grandiflorus*), stylasterids (probably *Pliobothrus*), gorgonians, and sea pens. Visible mobile fauna included numerous fish species, decapod crustaceans (*Chaceon affinis*) and seastars (Brisingidae). In places the bedrock gave way to large areas of coral rubble debris in-filled with sand and colonised by a diverse range of fauna as described for the rock areas but including many erect sponge growths (including *Aphrocallistes* sp), ascidians, squat lobsters and other coral species. Within the sands, cobbles and patches of lag gravel that surrounded the outcrop visible fauna were typical of this depth and included holothurians (*Stichopus tremulus*) and urchins (*Cidaris cidaris, Calveriosoma* sp.).



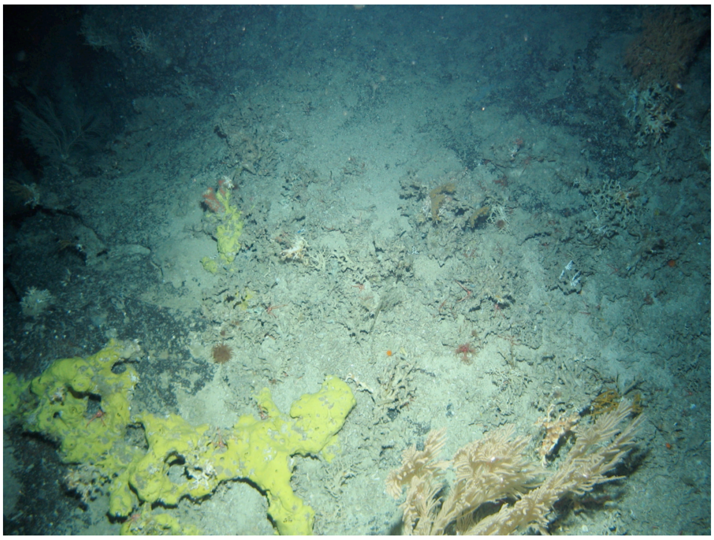


Figure 60. Seafloor photographs representative of the geology and benthic biology of HS_C4.

Hatton Transit

The Hatton Transit survey which was planned to run approximately either side of the 800 m contour on the southern flank of Hatton Bank from 58º54'N 18º12'W to 59º06'N 59º11'W produced some excellent results. The DTM and locations of the photograph transects is presented in Figure 61, showing a spectacular image of a steep, in places scalloped, scarp slope. In the west the slope is 100 m in height with a slope angle of ~15º, which increases steadily in height to 120 m in the central section of the mosaic, and at its highest and steepest (up to 150 m and 34º) at the eastern end of the mosaic. Above the scarp slope is a smooth plateau at about 600-650 m water depth.

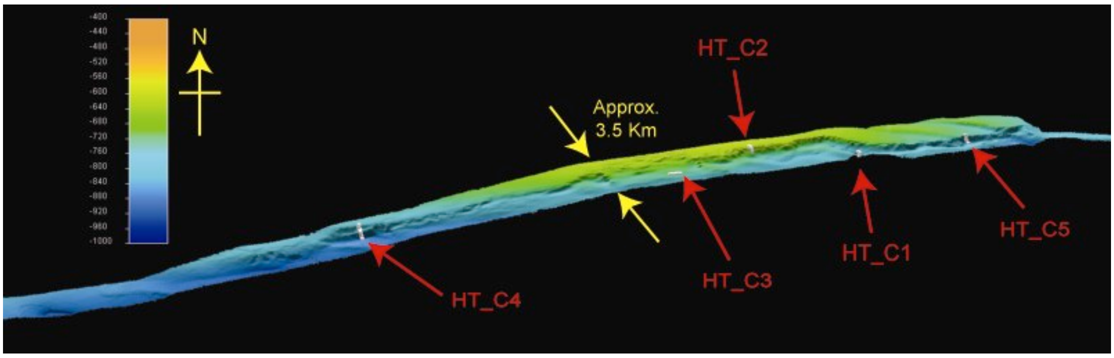
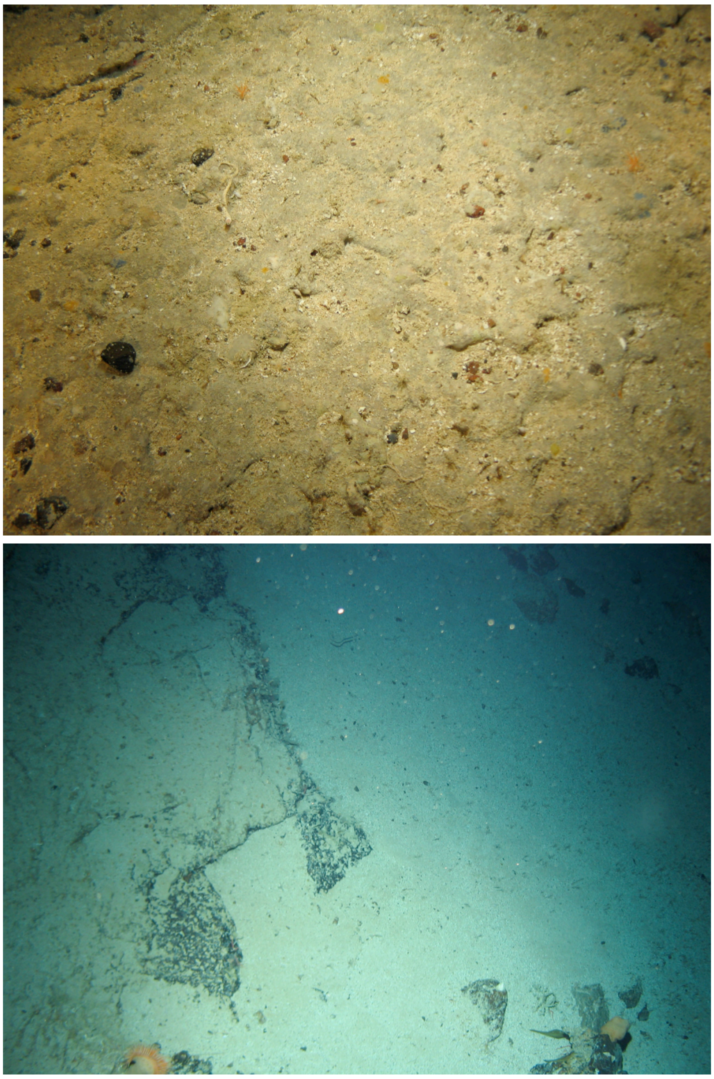


Figure 61. DTM of the Hatton Transit survey line(s running just above the 800 m contour) and the camera station locations. Note the steep scarp slope, up to 15º in the west and 34º in the east.

The backscatter mosaic shows as expected a higher signal level over the areas of steep slope, presumably due to increased surface roughness (of outcrop). Apart from these easily understood backscatter differences, there are few areas of interest on this mosaic. Thus photographic transect targets were selected on the basis of requirements for biological characterisation of the area, rather than any specific geological priorities which would be gained anyway as a by-product of the biological studies.

HT_C1 was chosen to examine the small channel at the foot of the escarpment at 59º08’N 16º38’W.

Geology: Working down-slope, a gravel lag on sand was the first type of deposit encountered, with, down the channel flank, boulders and cobbles showing sand halos on their lee sides. The side of the channel suddenly becomes very steep (>20º) with sedimentary outcrop displaying a dimpled surface, characteristic of chemically weathered carbonate-rich sediments. Down-scarp, bedrock, cobbles and boulders become common, and at the base of the steepest part of the scarp, a coarse gravel lag with no fine material at all forms the bed of the channel. There are no cobbles or larger particles in this part of the channel, it is probably the thalweg (Figure 62). Moving upward on the far side of the channel (the side distal from the main part of the Hatton Bank slope), about 10 m above the thalweg, gravel is still dominant but more and more coarse sand is also seen. Further up the flank of the channel, sand again become dominant with surface deposits of gravel, cobbles and boulders becoming common.



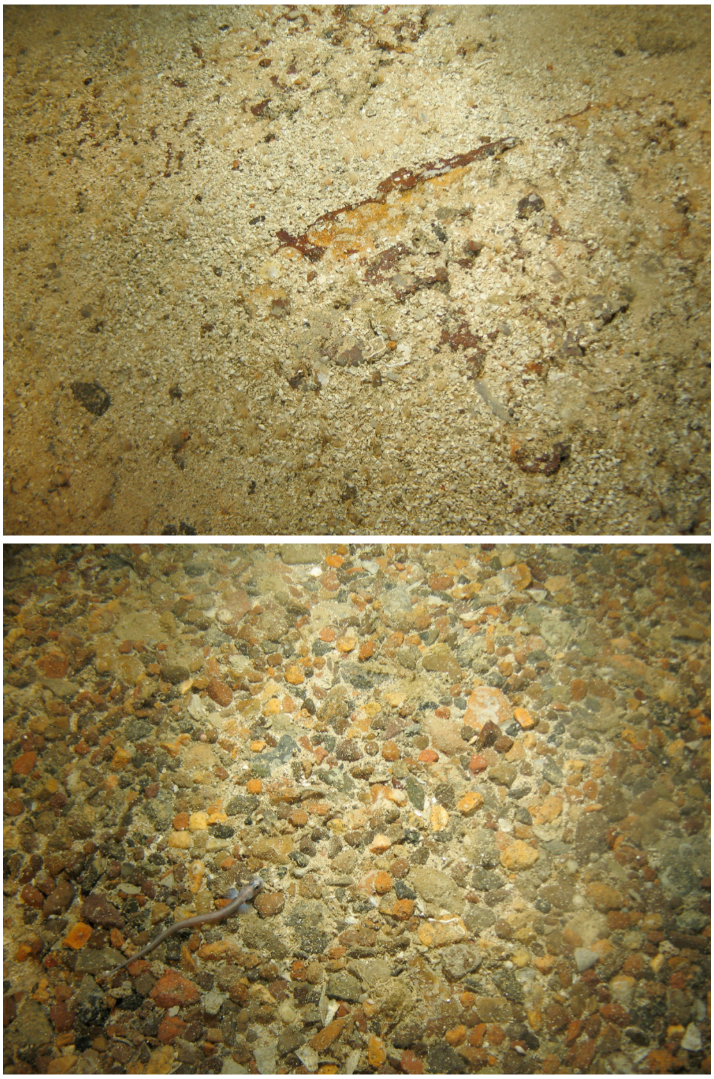


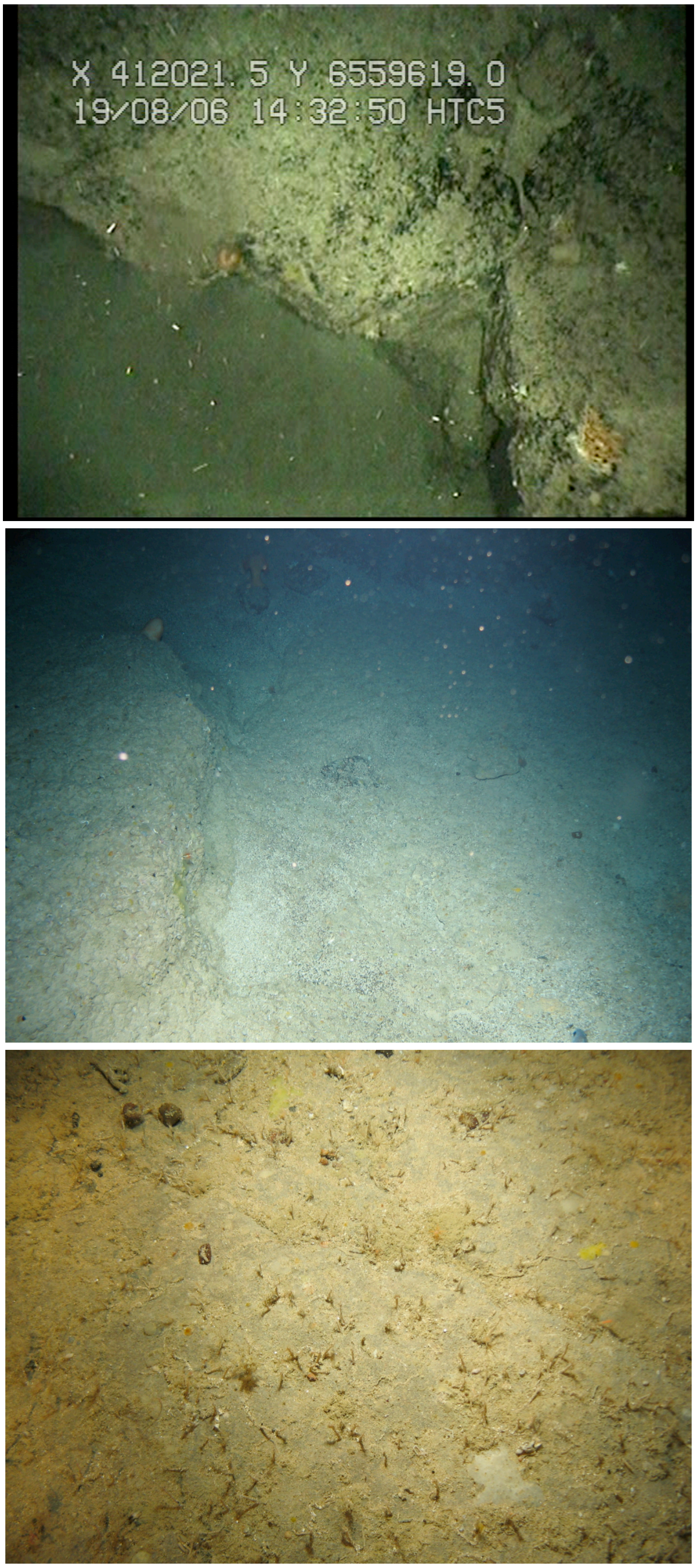
Figure 62. Outcrop showing dimpled surfaces, characteristic of chemically weathered carbonate-rich sediments on northern channel flank, and coarse gravel lag over the thalweg.

Biology: The sand with occasional cobbles was colonised by anemones (*Phelliactis* sp. and others), holothurians (*Psolus squamatus*), stylasterid and corkscrew-shaped antipatharian coral (*Stichopathes sp*.). Mobile epifauna included urchins (Cidaris cidaris) and ophiuroids. Visible fauna on the indurated sediment outcrop wall included corkscrew-shaped antipatharian coral (*Stichopathes sp*.), ascidians and ophiuroids. Few fauna were visible on the lag gravel except anemones, urchins (Echinus sp.), small cone-shaped gelatinous organisms, serpulid worms, occasional encrusting sponge, and eel pout. Over the far (southern) slope out of the channel the seabed became more sandy with occasional cobbles and boulders colonised by anemones (*Phelliactis* sp.), coral (*Madrepora occulata*, stylasterids, *Caryophillia* sp, corkscrew-shaped antipatharians (*Stichopathes sp*.), encrusting sponges, ascidians and brachiopods.

Figure 63. Seafloor photographs representative of the geology and benthic biology of HT_C1.

HT_C5 was a transect down the northernmost section of slope to investigate whether or not outcrop was present, if so what the geology was, and how it was being colonised and by what types of fauna.

Geology: At the start of the transect, on the mid-slope plateau, the sediments are sands with coral-encrusted cobbles and boulders (but no gravel). The seafloor adjacent to the cliff edge is marked by gravel halos around boulders and the large surface rock apparently becoming more numerous, with at the very edge of the cliff a distinct hard-ground, with a jagged edge forming an overhang, possibly a basalt crust (sill) on top of a sediment pile. The uppermost parts of the scarp are almost vertical, and appear to be composed of indurated fine-grained sediments exhibiting a dimpled surface, and larger sculpted erosion features. Down the face of the scarp (as the slope angle lessens) boulders and cobbles become common, though apart from the exposed sedimentary bedrock there is no finer material (gravel nor sand), though some of the larger boulders appear to be embedded into the fine outcrop matrix. At about 820 m gravel again begins to appear, and within another 10 m depth the gravel and sand surface with cobbles and boulders typical of Hatton Bank once again becomes dominant. There is still almost no fine detrital material, suggesting significant current activity, and the gravel appears to be embedded within the sand rather than sat upon it (Figure 64).



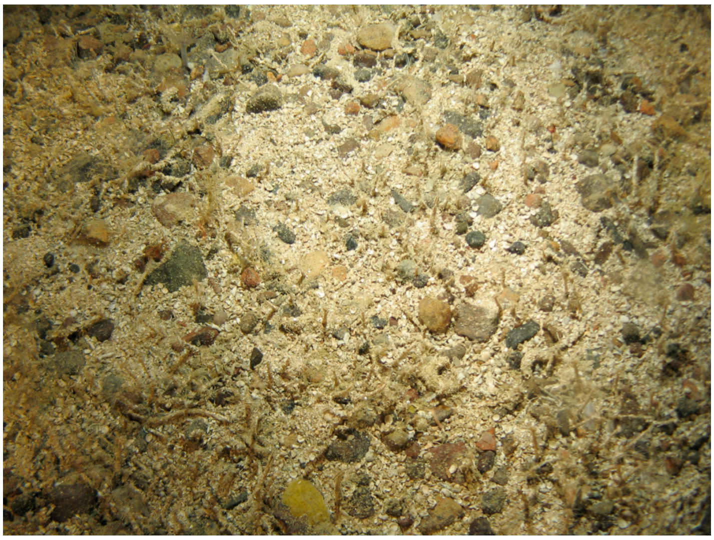


Figure 64. Possible basalt sill forming overhang at cliff edge on site HT_C5, with sedimentary outcrop forming eroding scarp face, and gravel sitting on top of sand at the base of the slope.

Biology: On sand with occasional pebbles and cobbles above the scarp slope, the visible mobile fauna included fish, and urchins (*Cidaris cidaris*). Visible fauna attached to cobbles included small growths of coral (*Lophelia pertusa, Madrepora occulata*), anemones (*Phelliactis* sp and others), holothurians (*Psolus squamatus*), stylasterid corals, brachiopods, and encrusting sponges. Over the overhang and down the steep slope the visible fauna were similar to that described above. Cobbles and boulders on the slope and were colonised by small growths of reef forming corals (*Lophelia pertusa, Madrepora occulata*), anemones (*Phelliactis* sp and others), corkscrew-shaped antipatharian corals (*Stichopathes sp.*), holothurians (*Psolus squamatus*), stylasterid corals, brachiopods, and encrusting sponges. Mobile fauna included hermit crabs (Paguridae) and seastars (*Stichastrella rosea*). As the cobbles and boulders became more frequent, gorgonians, erect sponges (*Aphrocallistes* sp.) and cup corals and echiuran worms (*Bonellia viridis*) became visible. Toward the base of the slope the gravel lag and sand had few visible fauna except ascidians, ophiuroids, anemones, squat lobsters (*Munida rugosa*), and urchins (*Echinus* sp.).

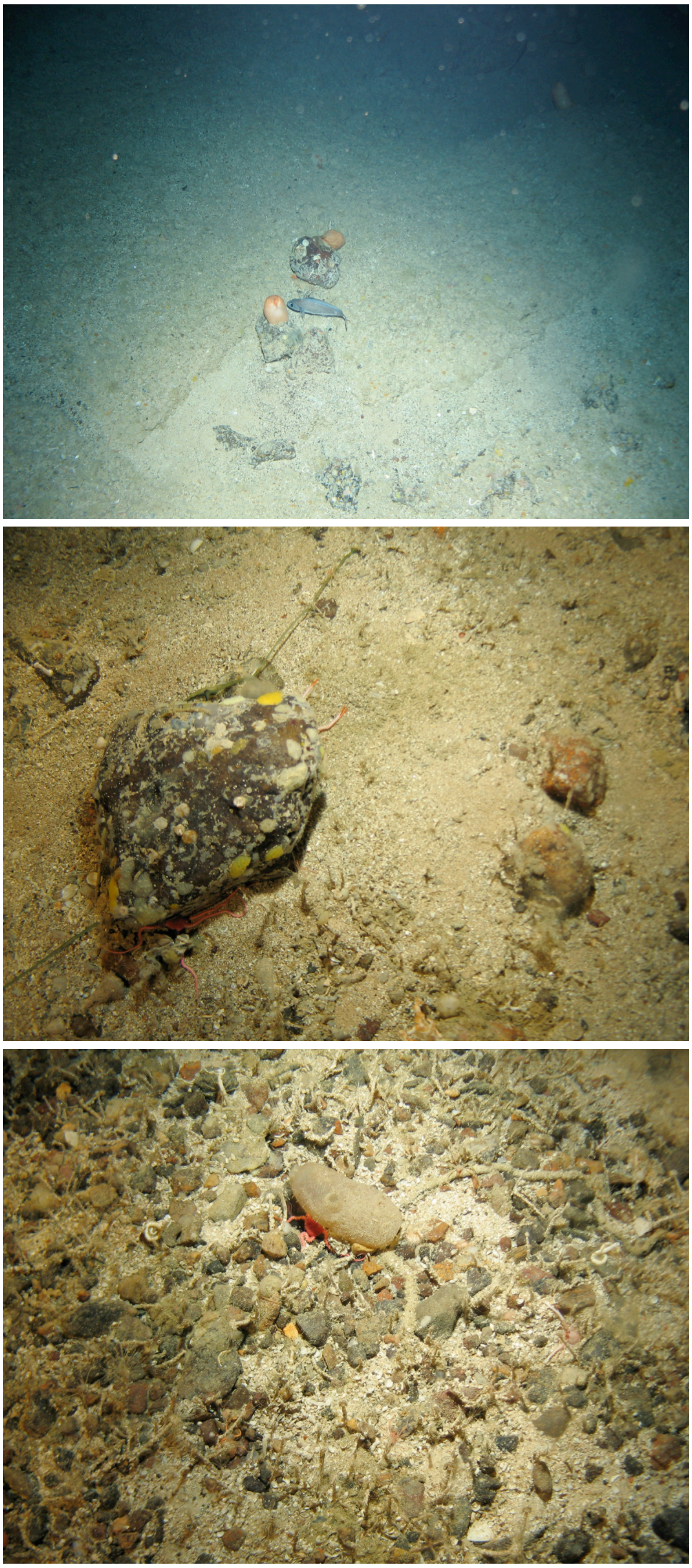


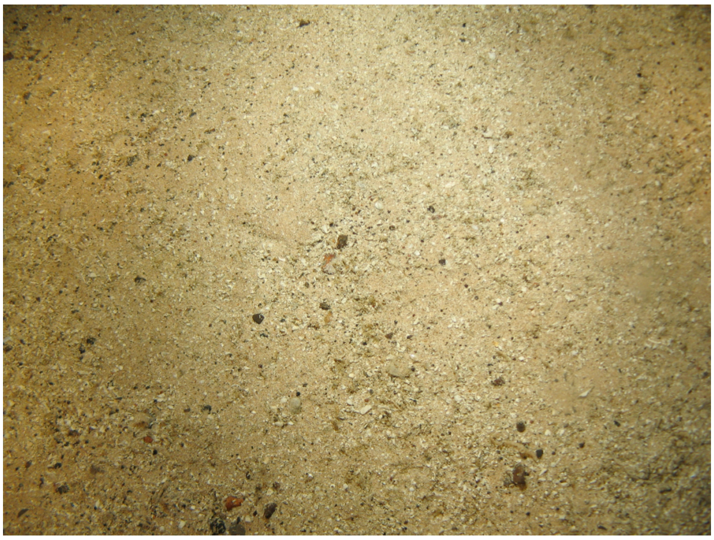
Figure 65. Seafloor photographs representative of the benthic biology of HT_C5.

HT_C2 A transect across around 300 metres of the shelf at 600 m, and then down the 70 metre scarp of central part of the cliff.

Geology: A sand and cobble seafloor, and following a similar pattern to the previous station the seafloor changes character to have boulders and cobbles more common, then a biogenic gravel (made up from >90% broken coral debris) with larger boulders. At the edge of the cliff a hard-ground is encountered which shows a vertical fracture surface, below which is the face of the scarp slope. On this slope the seafloor is swept clean to show a fine-grained weathered indurated surface, which continues down the scarp-face showing the characteristic dimpled pattern on its surface. Part-way down the scarp face there is a second break of slope where the slope becomes considerably steeper for a time. Moving down the scarp face (which was 10-20º) cobbles and boulders once again become frequent, as does biogenic gravely sand toward the base of the slope (which incidentally was not reached on this tow).

Figure 66. The fracture surface at the edge of the scarp slope and the typical scarp face at site HT_C2.

Biology: On the sand with occasional cobbles, visible fauna included fish (*Chimera monstrosa*), cerianthid anemones, urchins (*Echinus acutus*), and bivalves of the family Pectinidae. Cobbles were colonised by small growths of coral (*Madrepora occulata*, stylasterids), holothurians (*Psolus squamatus*), and other encrusting species. Coral debris and where they became more common, the cobbles were colonised by *Lophelia pertusa*, anemones (*Phelliactis* sp.), gorgonians, stylasterid corals, ascidians, and antipatharian corals (*Stichopathes sp*.). Mobile species include fish, hermit crabs (Paguridae) and seastars (Brisingidae, Stichastrella rosea), and along the indurated layer of the scarp fracture, cup sponges were also visible. Down the scarp face where the seabed consisted of sand and coral gravel, the fauna became more diverse with additional species apparent including large red soft corals, the alcyonacean *Anthomastus grandiflorus*, and a "Cauliflower-shaped" coral, plumose anemones, cyclostome bryozoans and erect sponge growths. Where the scarp steepens part-way down, it is colonised by *Psolus squamatus*, stylasterid corals, anemones and encrusting sponge. As the slope angle decreased, and became sandy with cobbles, boulders and a dead *Lophelia pertusa* framework, it was colonised by similar fauna as described for this habitat elsewhere.



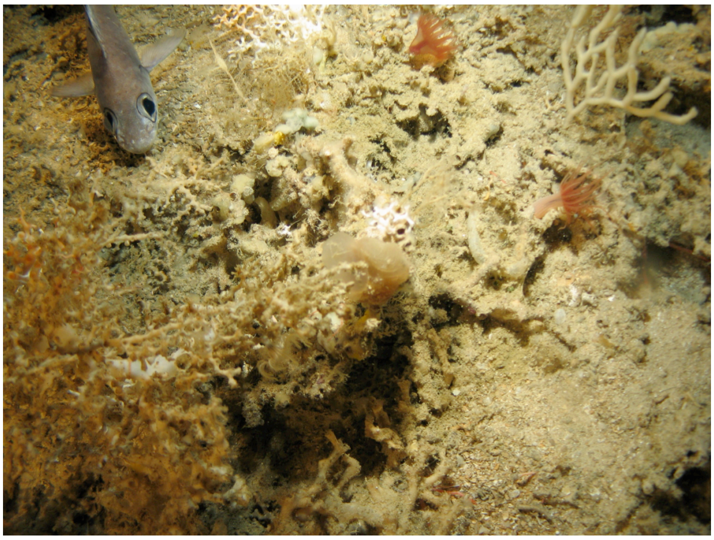


Figure 67. Seafloor photographs representative of the benthic biology of HT_C2.

HT_C3 This site was run along a slope-parallel track to characterise the benthic biology.

Geology: The seabed here is washed biogenic sands with surface cobbles and boulders.

Biology: There was a single broad habitat of sand with occasional cobbles. Visible fauna included small growths of coral (*Lophelia pertusa, Madrepora occulata*), anemones (*Phelliactis* sp), holothurians (*Psolus squamatus*), stylasterid corals, brachiopods, and encrusting sponges.

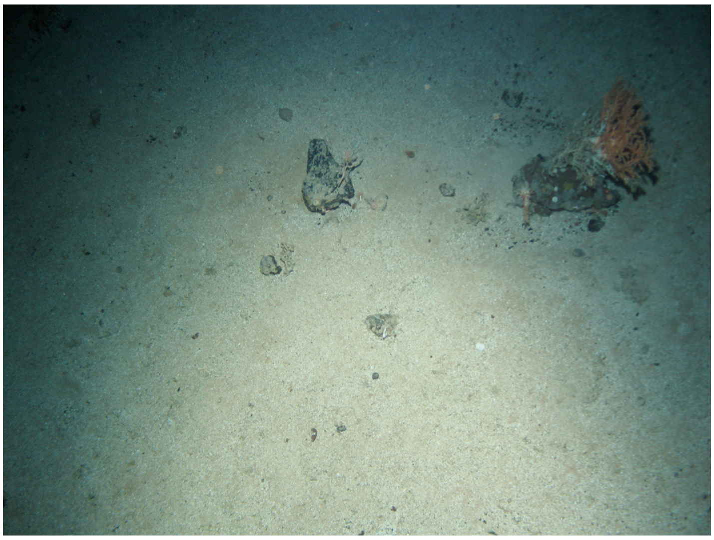


Figure 68. Seafloor photograph representative of the benthic biology of HT_C3.

HT_C4 The southernmost camera transect in this study area was a "double" slope comprising an upper slope (ca. 8º) that dropped about 55m in height, then a flat ledge of around 120 metres, then a second steeper (16º) slope that dropped around 80 metres.

Geology: The uppermost sand-dominated shelf is terminated by a broken basalt(?) sill, below which is ancient sedimentary outcrop as seen elsewhere along this ridge.

The shelf situated half-way down the overall slope is composed largely of biogenic rippled sand with surface cobbles and boulders. Below this the slope is dominated by biogenic gravely sand with rounded dropstones of varying size and angular boulders that are presumably derived from the slope above.

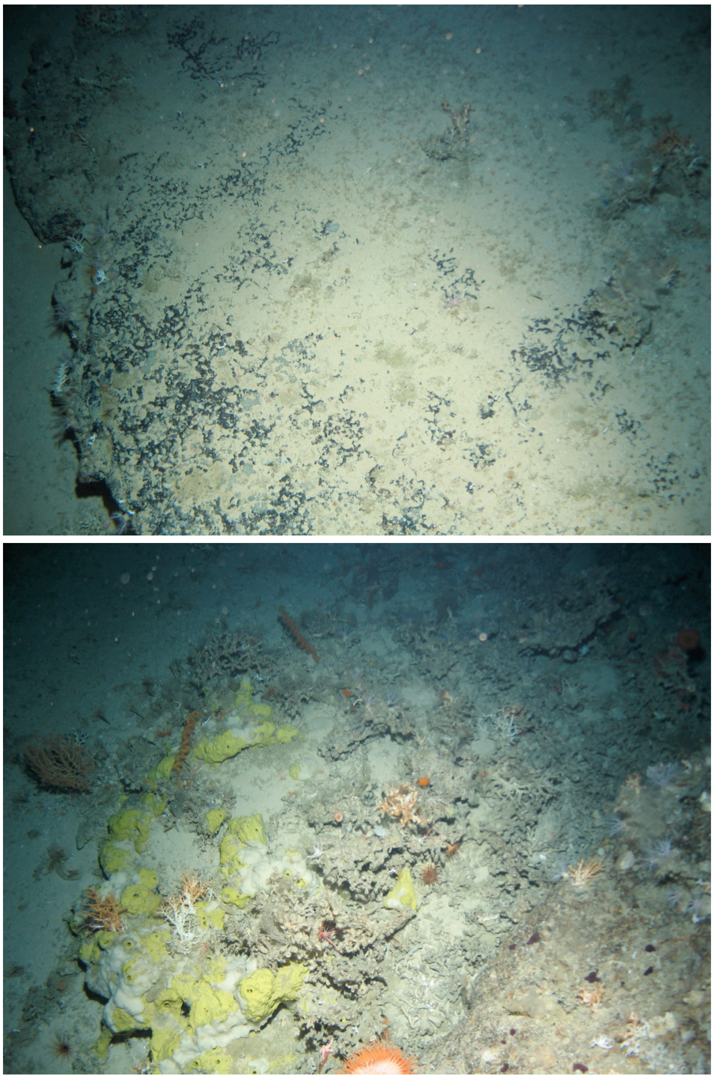


Figure 69. Broken basalt sill forming upper scarp edge and exposed sedimentary rock (covered by coral and coral debris) forming the scarp face at HT_C4.

Biology: On the upper area of sand, visible mobile fauna included fish (*Chimera monstrosa*), cerianthid anemones and urchins (*Cidaris cidaris*). Attached fauna included small growths of coral (*Lophelia pertusa, Madrepora occulata*), anemones (*Phelliactis* sp), holothurians (*Psolus squamatus*), stylasterid corals, brachiopods, and encrusting sponges. Through the predominantly sand habitat with occasional cobbles and boulders of the shelf half-way down the slope, the cobbles and boulders were colonised by cyclostome bryozoans, anemones (including *Phelliactis* sp.), *Psolus squamatus*, *Lophelia pertusa* and *Madrepora occulata*, gorgonians (possibly *Callogorgia verticillata*), corkscrew-shaped antipatharians (*Stichopathes sp.*) as well as more general encrusting fauna. Where the scarp steepened below the mid-slope shelf, the scoured outcrop had few visible fauna. Toward the base of the slope, cobbles became rare and visible fauna included small (>10mm disc diameter) ophiuroids, small gelatinous organisms and xenophyophores. Urchin tests were numerous in places.

Figure 70. Seafloor photographs representative of the benthic biology of HT_C4.

Polygonal Faults

The single station PF_C1 was an opportunity to look at the surface expression of a single polygon within the Rockall-Hatton Basin polygonal fault zone.

Geology: The surface sediments were very fine-grained, probably silts, with considerable, largely soft-bodied epifauna and burrows. Despite the polygon boundaries being defined by surface depressions of up to 15 m, no evidence of fluid flow or other noteworthy geological phenomenon was seen.

Biology: The aim was to pass the camera over the length of an entire polygon. The tow began on the edge of the polygon, over an area of muddy seabed populated by xenophyophores and the sponge *Pheronema carpenteri*. Other visible fauna included squat lobsters, globose sponge growths, ascidians, ophiuroids, occasional sea stars, holothurians and cerianthid anemones. An unusual stalked sponge species was also present, where the stalks appear to be colonised by zoanthids. Large burrow structures were also apparent. Across the polygon xenophyophores and Pheronema gradually became less frequent and eventually were rarely seen. The sediment became covered with a fine layer of silt or possibly marine snow. Visible fauna included unusual stalked sponges, fish, squat lobsters and occasional cerianthid anemones. Towards the far edge of the polygon xenophyophores and the sponge *Pheronema carpenteri* again became the dominant fauna with squat lobsters, decapod crabs, and hydroids also visible.

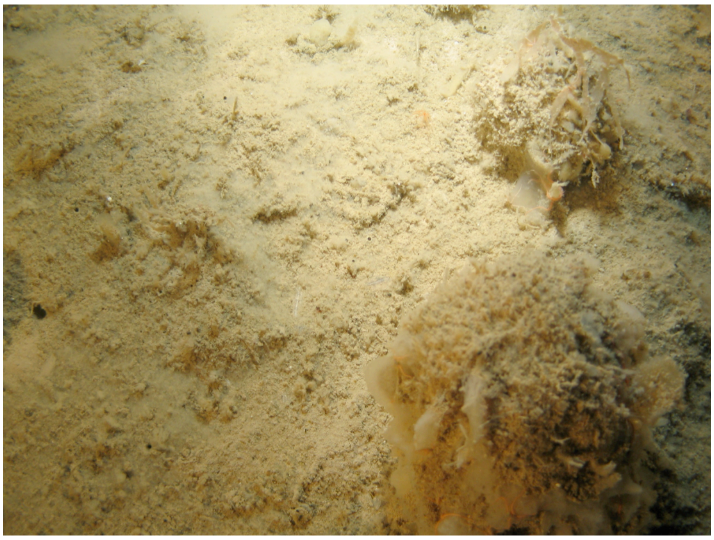


Figure 71. Seafloor photographs representative of the benthic biology over the polygonal faults area.

ACKNOWLEDGEMENTS

We thank the officers and crew of the *MV Franklin* for their accommodation and warm welcome aboard, and also the survey team from Marin Mätteknik AB for their dedication and professionalism. We would also like to thank the staff at Geotek Ltd.