National Oceanography Centre, Southampton

Research & Consultancy Report No. 18

An appraisal of the surface geology and sedimentary processes within SEA7, the UK Continental Shelf

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2006

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DOCUMENT DATA SHEET

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PUBLICATION DATE

2006

TITLE

An Appraisal of the Surface Geology and Sedimentary Processes within SEA7, the UK Continental Shelf

REFERENCE

Southampton, UK: National Oceanography Centre, Southampton, 62pp. & 57 figs.
(National Oceanography Centre Southampton Research and Consultancy Report, No. 18)
(Unpublished manuscript)

ABSTRACT

This report describes some of the more significant geomorphology and sedimentary features within the SEA7 area of the United Kingdom continental shelf. The report makes use of specific targeted cruises undertaken for the UK Department of Trade and Industry as well as using data collected for other specific objectives. Data collected and used included multibeam bathymetry, processed for backscatter as well as depth, and seafloor photography. The most significant discoveries here were the occurrence of en-echelon fault scarps and mounds over areas of Hatton Bank which have subsequently acted as the focus for carbonate reef formation, polygonal faults delineated by their bathymetric expression at the seafloor in the centre of the Rockall-Hatton Basin, large-scale erosive features such as scours along the margins of George Bligh Bank and the northern margin of Rockall Bank, the definition of a highly eroded and sculpted upper continental slope/shelf edge along the eastern Rockall Bank margin and, lower on the slope the formation of the Feni Ridge, and the identification of sites of small-scale slope failure. Anton Dohrn Seamount was completely mapped using multibeam and reveals a domed summit with rock outcrop at its centre, and there is evidence of opposing currents on its east and western summit flanks. The summit of Rosemary Bank was also surveyed, meaning that the entire seamount is now surveyed to a high degree of accuracy. The summit of Rosemary is home to three distinct areas of parasitic cones, though there appears to be little outcrop.

KEYWORDS

acoustic backscatter, AFEN, bathymetric chart, cruise 2005, EM1002, EM120, Rockall Bank, Anton Dohrn Seamount, Hatton Bank, George Bligh Bank, Rosemary Bank, *Kommandor Jack*, *Lophelia*, carbonate mounds, multibeam bathymetry, seafloor mapping, sonar surveys

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This project was funded as part of the UK Department of Trade and Industry's offshore energy Strategic Environmental Assessment (SEA) programme. The SEA programme is funded and managed by the DTI and coordinated on their behalf by Geotek Ltd and Hartley Anderson Ltd.

1 EXECUTIVE SUMMARY

This report presents an interpretation of geophysical and image data collected as part of the Department of Trade and Industry's marine Strategic Environmental Assessment programme, which is the process of appraisal through which environmental protection and sustainable development may be considered, and factored into national and local decisions regarding Government (and other) plans and programmes – such as oil and gas licensing rounds (see http://www.offshore-sea.org.uk).

This report is largely based on the results of the *SV Kommandor Jack* cruises funded by the DTI during the summer of 2005, with some additional information gleaned from the few previous detailed studies within SEA7. The results are presented here as a non-technical report aimed at the educated reader, with where appropriate indications as to the confidence of interpretation and, where applicable, limitations. However, to allow a concise document, a basic knowledge of marine geology, hydrodynamics and physics is assumed.

The project goals were to map selected areas of the major offshore banks and shoals west of the northern United Kingdom with a view to investigating their geomorphology and sedimentary processes active over and around them. It has highlighted how few high resolution studies have been undertaken within the deep water SEA7 region and how variable the seafloor is within very small geographic areas.

The SAMS transects were planned as biological transects, but results overtook the planning and apart from where SAMS2 crossed the Rockall Plateau, effort was focused in the other survey blocks. SAMS1 was an unremarkable transect mostly over the deeper parts of SEA7 and there were no significant findings. SAMS2 crossed the Rockall Trough and Rockall Bank to the 370 m isobath on its western flank. Iceberg plough-marks are well-imaged on both flanks of the Bank, the central portion of the Rockall Bank being dominated by complex bedforms of sands, gravels with, in areas, significant bedrock outcrop. SAMS3 was very similar to SAMS1 in that nothing particularly new was revealed on this single transect and there were no photographic stations.

The NE Rockall Basin data collection exercise revealed some of the serious limitations that become apparent when trying to undertake habitat investigation with a relatively low resolution tool such as an EM120 swath system. The high resolution studies of 1996 and 1998 have proven exotic habitats and fauna in the centre of the basin, such as numerous colonies of the deep-water coral *Lophelia pertusa* and high density populations of the xenophyophore *Syringammina fragilissima*.

Anton Dohrn Seamount, has been known for a considerable time to be a steep-sided domed seamount standing alone in the centre of the Rockall Trough. It has a diameter of around 45 Km and a vertical relief of between 1,500 and 1,600 metres. Sheer walls are over 1,200 m in height, and the summit is domed, shoaling to ~550 m at its centre. Very high resolution studies suggest that there may be opposing currents affecting opposite sides of the seamount summit (northward to the west and southward to the east), and photographs indicate a generally high energy environment across the

summit of the Seamount, with coarse sands, gravel and broken shell common. Outcrops, where imaged and not encrusted, show common iron-staining and jointing.

The East Rockall Margin physiographic area can be dealt with as four distinct physiographic provinces, each of which has its own characteristics. The southernmost area runs to around 57º20'N and is characterised by iceberg plough-marks on the shelf with a break at 350-400 m, a steep (10-20º) highly incised upper slope dropping to around 550-600 m, and the crest of the Feni Ridge. Below the Feni Ridge the seabed is a mostly a smooth slope, with a contour-parallel step of about 100 m in height at 1,100 metres, reflecting deep geostrophic current activity. Elsewhere are a couple of small canyons, up to 100 m in depth and small sediment slumps or landslides. The second area lay between 57º20'N and 57º50'N where the orientation of the margin turns to the north. The steep upper slope drops to around 700m, and below 800 m, apart from a couple of small mid-slope canyons, the slope is much more regular and smooth. The third area runs from 57º50'N to 58º20'N and is where the orientation of the slope turns westward. The shelf-break is at about 350 m and the base of the steep (>20°) upper slope is at 600 m, below which are indications of slope failure deposits. The Feni Ridge is not developed along this part of the margin, which is imaged as a current-swept slope. There is evidence of old small slope failures. The final area is west of 13º50'W and includes the bathymetric saddle between George Bligh Bank and Rockall Bank, where the continental slope becomes topographically complex and has a slope angle lessens to around 2°. A series of curved erosive scours up to 120 m deep that form a long sweeping arc define the northern edge of the Rockall Margin.

Central Hatton Bank revealed a series of elongate, en-echelon lineated highs and troughs, focussed along two orientation planes, just south of E-W and NE-SW. Acoustic backscatter indicates outcrop over most of the scarp faces of the ridges, that was almost always covered in biological growth (corals and sponges). Photographic studies revealed a usual transect consisted of sands at the top of the scarp slopes, with outcrop and biogenic and rock rubble forming the scarp slopes, with rubbles and gravel lags at the base of the slopes. Also found were a series of perched basins that formed smooth sculpted hollows up to 100 m deep, and lay along a trend, extending for over 40 Km in a NE-SW direction. They appeared to be confined to a narrow slope parallel zone of only about 10 Km in width.

The West Hatton Bank Margin has been surveyed in detail though the data were not subject of an intensive interpretation for this study. North of 59º30'N the margin is likely dominated by geostrophic processes, with at depth ancient volcanic constructions being important. West of 16º30'W and above 1,800 m is a smooth, occasionally incised slope, though at dept, and especially south of 59ºN and west of 19º30'W, en-echelon features dominate the gross morphology.

George Bligh Bank has corals on its northern flank mounds and the summit has iceberg plough-marks above 500 m. On the eastern flank small step-faults are imaged by remote sensing and ground-truthing reveals coarse sands, gravels, boulders and outcrop. Around the southern margin of the Bank are a number of erosive scars indicating high current flow into the Rockall-Hatton Basin.

Rosemary Bank summit has discreet parasitic volcanoes formed into groups. The summit depth averages about 500 m, but individual parasitic cones take the shallowest areas to less than 350 m. The entire summit area appears covered by sediment, with no evidence on the acoustic backscatter of outcrop, and even though the flanks of some of the parasitic volcanoes show very strong backscatter. The Bank exhibits a well developed moat below steep walls, and on the northern side of the moat are scours showing the effect of the strong benthic current regime.

The Rockall-Hatton Basin is a bathymetric low where polygonal faults are imaged at the seabed, and the other significant Basin, the Rockall Trough, is a large basin separating Rockall Bank from the European continental shelf. Features of note here include on the lower Hebrides slope a series of superimposed, debris flows, to the southwest of Anton Dohrn Seamount, a sediment wave field, and indications of an old shallow channel system.

The Hebrides Terrace Seamount is an elliptical feature approximately 40 Km by 27 Km. It rises from the foot of the continental slope between 1,650 metres and 2,000 metres, rising to a minimum depth of around 1,000 metres. South of 57º15’N the Hebrides continental slope falls away at 5º-10º and the slope is extensively gullied. North of the gullied region the slope is smooth, though there is also a distinct notch paralleling the slope, similar to that seen on the East Rockall margin, at 1,000-1,100 metres waterdepth.

Seafloor mapping by hull-mounted multibeam systems provide the best terrain models, but due to the physics of acoustic propagation the resolution of such systems is less than ideal for detailed habitat identification. Nevertheless using both the topographic models and backscatter mosaics from such systems allows identification of areas that can be interpreted as probable areas of outcrop, iceberg plough-mark and other types of terrain where the likelihood of benthic reef communities (coral, sponges etc.) will be high.

The serendipitous discovery of polygonal fault traces at the seafloor in the Rockall-Hatton Basin proves that multibeam systems can detect exotic environments is areas of extensive sedimentation, however to define habitats in such areas requires higher resolution systems.

Other existing geophysical data in the SEA7 region could be analysed to enhance the Assessment of seabed conditions within the SEA7 area, and if combined with existing interpretations of well-studied areas could be used as supporting evidence for the identification of likely reef-like habitat areas.

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3 INTRODUCTION

Physiography

The physiography of the SEA7 area is summarised in Figure 1. The Hebrides Shelf gives way to the west at a shelf break of ca. 200 m into the Rockall Trough, a 2,700 m deep (shoaling northward) basin that separates the shoal areas of the Hebrides and Malin Shelves from Rockall Bank. Three large seamounts sit within the Rockall Trough, 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, and a large area of various shoals and ridges that include the George Bligh and Hatton Banks, which rise from 1,100 m to about 500 m. The northern Rockall Bank shoals to 200 m over much of its area and has the small pinnacle of Rockall Island.

Seafloor Sediments

Previous studies in parts of SEA7 have allowed a generalised overview of the types of sediments to be expected in various parts of the SEA7 area, and work undertaken for the AFEN consortium (Masson et al 1998, Geotek Ltd et al 2000) and academic studies (e.g. Bett 2001, Masson et al 2003, Wheeler and Masson 2005,) have allowed a further level of detail to be unveiled, especially within areas such as the NE Rockall Basin.

Generally speaking, in waters less than ca. 500 m deep relict iceberg plough-marks will be encountered, away from the main European shelf edge these will be from drifting icebergs as opposed to calved bergs from grounded ice sheets. In the NE Rockall Basin below the iceberg plough-marks, down to approximately 1,100 m there is a zone of predominantly gravely sand, but also some areas of sand and muddy sand, with Holocene deposits being of the order of 20 cm, thick over the entire Basin area. Lineations on sonar records suggest that there are strong bottom currents within the NE Rockall Basin at these depths. The lower continental slope is characterised by sand and silt contourite deposition, often in the form of sheets up to 25 cm in thickness. The centre of the NE Rockall Basin has sediment drifts and north or north-northeast migrating sediment waves with amplitudes of 10-15 m and wavelengths of 1.5 Km. Other features of note here are the *Lophelia*-topped 5 m high, ~70 m wide mounds, probably best characterised as sand volcanoes, and now known as the Darwin Mounds. To the east and south of the Darwin Mounds, is a field of pockmarks that individually range in size from 20-50 m across.

Further west, along the northwestern margin of the Rockall Trough, bottom water flow generates a large contourite formation known as the Feni Ridge (Roberts 1975a, Kidd and Hill 1987), which runs along the whole length of the western margin of Rockall Bank. The seabed at the northern edge of the Feni Ridge is dominantly erosive implying substantial bottom current accelerations as currents are deflected around George Bligh and Rockall Banks. Limited sampling in the region indicates that sediments are usually 20 cm or so of foram-rich marls overlying glaciomarine silty-clays with admixtures of sands and dropstones. Some science investigations at the northern end of Rockall Bank looking for thermogenic gas and gas-escape structures have proved so far inconclusive, though results suggest that faults may occur at the seabed near George Bligh Bank, however, the occurrence of sediment waves is also a possibility for small-scale surface irregularities.

Tides and Currents

Two main water masses can be recognized in the Rockall Trough, although both have complex origins. An upper water mass, referred to as Eastern North Atlantic Water (ENAW) occupies the upper 1,200 to 1,500 m of the water column. Below this, 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 northeasterly 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 northeasterly 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 (e.g. Ellett et al 1986, Holliday et al 2000).

Data and Interpretation

In virtually all cases, the data interpretation was undertaken post-cruise after further processing of the bathymetric data using advanced visualisation and mapping tools such as Fledermaus™ and GMT (http://gmt.soest.hawaii.edu/). The bathymetry data were re-gridded to a spatial resolution of 200 metres as the large area of SEA7 meant excessive processing times for full resolution grids to be used, and in fact, in deeper water the 15 or 20 m grids supplied by the 2005 *SV Kommandor Jack* survey contractor was an artificial creation as the individual acoustic sounding beams had a greater footprint separation. The bathymetry over the SEA7 study area was re-gridded post-cruise and maps produced with a contour interval of 50 m. This allows a regional view to be taken, with finer detail (where necessary) observed from the shaded relief 3-D images and/or the CHIRP profiles.

Backscatter data over most of the surveyed areas was processed from the raw multibeam data using CARIS HiPS™ or NOC PRISM software. The EM120 has a footprint size of about 30 m and the backscatter mosaic pixel size is ~15 m.

The 500 kHz sidescan sonar produces an image with an incredible amount of detail, although with an imaging range of 100 m per side, this detail is achieved only over a (relatively) small spatial area. It is possible to clearly “see” seafloor features at a sub-metre scale, which makes the picking of targets for sampling and/or photography very simple. However, there can be difficulties when trying to relate the backscatter targets from this survey system to the backscatter targets seen on either the EM1002 or EM120, due to their large footprint (The multibeam systems may have less than half-a-dozen pixels across the entire swath of the 500 kHz sonar).

Ground-truthing of the high-resolution sonar data was undertaken mostly by the use of photographic images, and although a limited number of samples were collected these were primarily for later biological examination. Furthermore there were some uncertainties in the location of the camera system (and sampling locations) caused by poor acoustic navigation, though the errors here were within the resolution limits of the EM120 bathymetry grids, and were thus acceptable.

4 KJ0105 CRUISE OBJECTIVES AND ACHIEVEMENTS

The scientific rationale behind this part of the SEA7 research programme is guided by potential future hydrocarbon exploration along this sector of the United Kingdom Continental Shelf (UKCS) in combination with the need to investigate areas deemed high priority/potential ANNEX I exclusion zones by the Joint Nature Conservancy Council (JNCC). The seafloor mapping exercise, with the sampling and photography studies to be carried out during a follow-up cruise, will allow a holistic picture to be obtained of the seafloor within this environmentally sensitive and globally important area.

The objectives of the *SV Kommandor Jack* 01/05 cruise (KJ0105) were to collect EM120 and where water depths permit, EM1002 multibeam and backscatter measurements and also high resolution sidescan sonar data over selected areas of Anton Dohrn Seamount, George Bligh and Rosemary Banks and, primarily, the eastern margin of Rockall Bank and selected areas of Hatton Bank (Jacobs 2006). The aims were to

- create high quality bathymetric maps of the survey areas
- create acoustic backscatter maps over the same areas
- where possible define the extent of any potential coral habitats
- create high resolution bathymetric and backscatter maps of specific features as may be discovered, such as carbonate mounds etc.
- complete, during the cruise, a preliminary interpretation of the above data, to be used as a guide for the sampling and seabed photography cruise which followed immediately
- produce an interpreted report post-cruise describing the surface geological conditions and active sedimentary processes within the SEA7 area

Virtually all of the cruise objectives were achieved, although poor weather and fishing activities restricted the amount and location of high-resolution sidescan sonar surveying.

5 "SAMS" TRANSECTS

These transects were named during the initial 2005 SEA7 project planning phase, when marine scientists from Scottish Associated for Marine Science (SAMS) indicated that they would like to see three transects undertaken as part of the biological investigations looking at spatial variation of species across the Rockall Trough and between the various offshore banks and seamounts.

SAMS1 is a transect between George Bligh Bank and the North Hebrides Shelf. The transect starts at the foot of George Bligh Bank where the seabed rises slightly to the top of a drift-like rise before gently sloping down over 180 Km to the moat skirting the southern flank of Rosemary Bank. A description of the moat surrounding Rosemary Bank can be found below in Section 12. Between Rosemary Bank and the Hebrides slope and below 1,500 m, the seafloor forms a uniform gentle (0.2-0.7º) slope, above 1,500 m the slope angle increases to 2º and above 800 m this increases again to 4º. The backscatter is mostly a uniform low level apart from near the eastern end (shallowest part) of the SAMS1 transect when the backscatter becomes more intense. There were no Camera or Sample stations along this transect.

SAMS2 was initially a transect between the Hebrides shelf, starting just north of the Hebrides Terrace Seamount, to the eastern margin Rockall Bank. This was modified to extend the transect across Rockall Bank to it's western shelf-break and back across the western Rockall Trough to Anton Dohrn seamount. During the second (west to east) transect, a very high resolution sidescan sonar survey was conducted across the entire Rockall Bank shallower than 300 m. This detailed survey is described at the end of this section, following the general bathymetric and CHIRP profile description.

The seafloor topography along SAMS2 is quite simple, being a transect from the Hebrides continental shelf break across the Rockall Trough, a basin that reaches just over 2,400 m in depth at its centre (~11°00'W) before gently becoming shallower as the Rockall margin is approached, the seafloor slope increasing up the Feni Ridge, becoming steepest over the uppermost 400 m of the East Rockall slope. On CHIRP profile data, the Hebrides Continental Slope above 1,000 m is characterised by a strong surface reflector, subsurface units vary in thickness and some show a relict surface topography indicating buried slope failure deposits, whereas in other areas the sub-bottom acoustic stratigraphy indicates the possible presence of sands. West of 10°34'W hummocky surface topography extends down-slope with a 5 m thick transparent layer covering a buried debris slide deposit. The sub-bottom debris deposit ends quite abruptly at 56°47'N 10°47'W and is replaced by up to 30 m of horizontally stratified reflectors which are butted against an acoustically transparent block outcropping at the seabed, forming a distinct 25 m scarp at 56°48'N 10°53'W. To the west of this scarp, the deposits of the deepest part of the Rockall Trough consist of a very well-bedded series of horizontal reflectors, some of which show very high acoustic impedance levels just below the seafloor. Tracing them to the west, these high amplitude reflectors abruptly die out as the eastern flank of the Feni Drift is reached (Figure 2).

Moving westward and higher up the Feni Drift, the CHIRP seafloor acoustic image is largely a single prolonged reflector with few sub-bottom returns suggesting a sandy contourite deposit. The true structural nature of the Eastern Rockall Bank continental slope is masked by the Feni Drift, with a steep (~100 m) scarp at 57°10’N 12°59’W formed by current sculpting. There are some small sediment failures on the upper reaches of the Feni Drift seen along the transect of SAMS2; these will be discussed later (see Section 8). The “true” structural Rockall Bank continental slope is imaged westward of 13°05’W, which is a very steep (10-15°) scarp from 300-700 m water depth.

The gross morphology across Rockall Plateau (above the shelf-break which is mostly around 300 m water depth in this region) shows a gentle convex surface, with a water depth minimum of around 150 m. In detail however, along the eastern flank of the plateau, there are 2-3 m variations in seafloor topography and the acoustic return echo strength on the CHIRP varies along the ship’s track indicating varying seafloor sediments. The acoustic backscatter mosaic from the EM1002 indicates that the acoustic variations seen on the CHIRP may be due to the imaging of probably degraded (by current activity) iceberg plough-marks. Over the upper western slope of Rockall Bank, as it begins to gently deepen toward the west, the CHIRP data generally show a continuing strong seafloor reflector with a single prolonged bottom echo and no sub-bottom reflectors. In detail, the seafloor exhibits a small-scale (< 2 m) topography with occasionally the seafloor reflector being hyperbolic (indicating significant surface roughness or small-scale yet steep topography). This small-scale surface topography becomes more and more pronounced toward the west, especially westward of 57°25’N 14°36’W where the small-scale roughness approaches 5 m in amplitude. This topography is difficult to see on the multibeam backscatter mosaic, but where imaged below 275 m waterdepth it becomes very apparent from the shaded bathymetry that this topography is due to glacial plough-marks.

The CHIRP data over the western Rockall Plateau exhibits a very prominent acoustic signature across the plough-mark terrain to about 57°27’N 14°31’W at about 250 m waterdepth (Figure 3). The hyperbolae and strength of the return echoes are due to the rough topography of the seafloor and the coarse-grained nature of the surficial sediments. To the East of this area the seafloor shows a very strong surface reflector and prolonged ringing, with just occasional hyperbolae very few sub-bottom reflectors. The multibeam reflectivity and shaded relief bathymetry indicate that this too is an area affected by iceberg plough-marks.

Toward the east the CHIRP data shows an even stronger seafloor reflector and although it has a prolonged sub-bottom ringing, the strength of the surface return and the sub-bottom ringing does vary spatially. Between 57°28’N 14°20’W and 57°29’N 13°20’W the multibeam backscatter also shows distinct lateral variations in reflectivity, possibly due to packets of different sediment types such as sand and/or gravel. These variations are very different in plan-form to the plough-marks noted above.

The multibeam backscatter patterns indicating variations in “sediment packets” continue to the east to ~200 m depth, where they are replaced typical plough-mark patterns. The CHIRP profiles also continue to show variation in seafloor return strength, with some backscatter variation boundaries on the profiles being coincident with backscatter changes on the multibeam mosaic, though without sufficient clarity and repetitiveness to enable unequivocal boundaries to be determined and mapped. This is likely due to the gradational nature of the sediment boundaries. Within the "sediment packet" area, there are areas on the CHIRP profiles that show ~1 m or so of sub-bottom penetration, though most of the area is characterised by a simple, single, prolonged seafloor reflector, suggestive of a coarse surficial sediment type and/or surficial ornamentation such as ripples. Below 250 m waterdepth on the eastern Rockall Bank margin, the plough-mark terrain is characterised on the CHIRP by an uneven though very strongly reflecting seafloor surface, with a roughness of 1-5 m and no sub-bottom reflectors.

At 57°29'N 12°58'W there is a very sharp drop to the East as the basement rocks fall away to form the eastern continental slope of Rockall Bank, with, at 57°29'N 12°52'W just on the 1050 m isobath, a distinctive small landslide scar 1.6 Km in length, a feature that is well-imaged on the shaded bathymetry. The Feni Drift is again encountered at 57°29'N 12°45'W, where its upper reaches show a strong surface reflector, with ~5 m sub-bottom penetration into probable contourite sands (little structure internally, almost acoustically transparent). By 1,750 m waterdepth there is sub-bottom penetration revealing typical drift deposits of regularly bedded reflectors, and the surface of the drift is gently undulating (possibly indicating an oblique crossing of a sediment-wave field). The drift surface rises by ~75 m to form a crest at 57°29'N 11°49'W, and eastward of this crest the seafloor gently slopes to a depth of 2020 m in the moat on the western flank of Anton Dohrn seamount. The CHIRP data show a horizontally-bedded sequence down to a sub-bottom depth of over 20 m sub-surface.

At the base of the steep flank of Anton Dohrn there is a talus slope covered by a thin transparent surficial layer (~ 2-3 m). The talus fan itself has a drop of 315 m between the almost vertical seamount flank and where the very finely bedded sediments are imaged onlapping upon the edge of the seamount base. The sediments here are flat and sub-bottom penetration images down to >30 m.

500 kHz Sidescan Sonar transect

This section describes in narrative fashion the major features imaged across Rockall Bank, starting on the western margin at a depth of ~350 m and running across the entire Bank. NOTE: This transit runs through both "western" and "eastern" areas on Rockall Bank that in 2005 were proposed for fisheries closure by the JNCC.

The transect begins at 57°27.0'N 14°48.75'W and runs just north of west-to-east to 57°29.25'N 12°58.85'W. At the western edge of Rockall Bank iceberg plough-marks are imaged that show a relatively low-level of acoustic backscatter, along with isolated boulders (dropstones) up to 2-3 m in size and higher backscattering features of uncertain origin. Moving east the plough-mark and dropstone density lessens, though the plough-marks become more highly backscattering around their margins. Between 14°45.0' and 14°40.5'W is a zone of well-defined iceberg plough-marks. Their boundaries are irregular highly backscattering zones, and that is coupled with a distinct infill in the central furrow of relatively low backscatter (finer sand?). They are extensive across the whole sonar track, usually 20-40 m wide (with ~20 m being most common), and the CHIRP profiler indicates that they are generally ~5 m deep, with some up to 10 m. The CHIRP also shows the boundary ridges to either side of the ploughed furrow are acoustically transparent with a prolonged echo return, suggesting there is no, or they have a chaotic internal structure. The sidescan images frequent highly-backscattering targets, with relief, usually outside of the central plough-mark furrows, that may be reefal structures though they are more likely boulders forming lag deposits from winnowed plough-mark edges (Figure 4).

The plough-marks and reef/boulders continue to be imaged along the transect to the east, and although the intensity of the acoustic backscatter from these features varies. The CHRIP reveals some areas that have a highly reflective single return echo that varies spatially in intensity and the length of the sub-bottom "ringing", whereas other areas show faint suggestions of sub-bottom reflectors at 2-3 m sub-surface, indicating a thin surficial veneer of sands. These variations may explain the unusual and patchy variations in backscatter intensity of the sonar records. The size of the individual plough-marks varies too, many with widths of up to 60 m, though most are 20-40 m across. The boulder/reef features are still present at irregular intervals, and the CHIRP profile shows that most of the rough (5-10 m) topography of the seabed has diminished, and instead the seafloor is now a gently sloping feature with just a few large steps in the surface.

East of 14°30'W, the plough-marks once again rapidly become much stronger in terms of the acoustic backscatter along their margins, however the CHIRP still shows a very smooth seafloor with almost no relief but with sub-seafloor reflectors at ~1 m sub-surface, suggesting a thin sediment drape over this area. This is in direct contrast to the westernmost area of plough-marks which although they appeared very similar on the sidescan imagery, they had a relief of 5-10 m. Within the plough-marks for the first time, reef/boulder targets are imaged (Figure 5).

Between 14°15.25' and 14°03.5'W is an extensive zone of increasing backscatter intensity along with increasing signs of current activity such as ripples, possibly small dunes, and current-parallel lineations. The plough-marks virtually disappear, although it is possible that their remnants are in places identifiable by the subtle alignments and differential backscatter levels on the sonar data. There are very few potential reef/boulder targets in this zone; in general ripples become more pervasive toward the East, though there are some areas where none occur. CHIRP profiles show a smooth seabed with a very strong surface reflector, though this varies laterally and subtly, reflecting a lateral variation of sediment types, presumably sands and gravels. Generally speaking, the higher the backscatter on the sidescan sonar, the more solid the return on the CHIRP profiler.

Toward the central part of Rockall Bank, the seafloor is dominated by high acoustic backscatter on the sidescan sonar, ornamented in many places by ripples of varying size, with patches of low-backscatter in discontinuous, irregular-shaped areas, possibly the furrows of (now degraded) iceberg plough-marks. All current features are indicative of a North to South flow direction. The area also has an increasing number of trawl-marks, more than any previous area; some are highly backscattering others not so, indicating that the seafloor current features imaged have been active since fishing began in these waters. In one or two areas trawl-marks can be traced crossing areas of outcrop/boulder fields. The CHIRP profiles show a smooth and highly reflective seabed with very subtle relief.

Over the eastern portion of the centre of Rockall Bank (for example around 57°28.5'N 13°45'W) high to very high backscatter is now dominant on the sidescan records, yet there are still significant low backscatter areas, mostly as irregular patches and as occasional sheets. Although the distribution of the backscatter types is rather chaotic and unpredictable, high backscatter sheets ornamented with ripples or small dunes begin to dominate the sonar mosaics toward the east, with low backscatter areas generally elongated in a North-South orientation. There are frequent current-parallel lineations superimposed onto both the high and low backscattering areas running northeast to southwest. The CHIRP profiles are inconclusive with a single prolonged seafloor return.

Moving yet further to the east there are a number of “zones” where distinctive types of acoustic facies occur, often with abrupt boundaries that, apart from very small increases in waterdepth and location, have no obvious explanation. Each distinctive “zone” may be from a few hundreds to a couple of kilometres in width. The first of these “zones” is one where high acoustic backscatter becomes overwhelmingly dominant, first taking the form of linguoid-shaped sheets with extensive northeast-southwest pervasive current-parallel lineations. Interestingly along the eastern or northeastern margins of the high backscatter sheets are halos of low acoustic backscatter. The CHIRP profiler shows varying surface intensities, but it is very difficult to correlate these directly with the sonar backscatter variations. In the adjacent backscatter “zone” the dominant high backscatter sheets show extensive and pervasive current lineations running northeast-southwest, with low-backscatter areas taking the form of “streams” running in the same direction. These low backscatter streams occur in discrete patches that are 500 m, 300 m, and 100 m wide, with about 150 m of high backscatter sheet between each. Trawl-marks are also imaged within this zone.

Over the next few hundred metres toward the east are extensive sheet-like deposits that change from east to west from medium through to high backscatter, with an almost total lack of low backscatter material, and where the pervasive current lineations become less and less pronounced toward the east. The CHIRP profile shows the high backscatter to be an area of very smooth seafloor. This sheet-like area of high backscatter merges (at about 57°28.75’N 13°29.5’W) into an area where the high backscatter deposits are formed into linguoid-barchan shapes which an increasing density of occurrence from east to west. Some of these barchan-shaped features show current directions of north-south, but mostly they are orientated northeast-southwest. Typically the wing of each upstream feature is connected to the centre of the next downstream, and along the eastern margin of each area of high backscatter is a halo of low-backscatter (Figure 6). At the extreme eastern edge of this zone the barchan-shaped bedforms give way to high backscatter streams, each about 10 m in width.

To the east of 13°25’W, these barchan-like features (they are not true barchans as they do not show relief) come and go to varying degrees, being interspersed with sheet-like areas of high or medium backscatter. The intensity (and occurrence) of current-parallel lineations also changes from very strong and pervasive, to none. The next distinct “zone” of seabed is just over 3 Km wide and consists of medium intensity backscatter sediments with various amounts of what appears to be rock outcrop forming 5-7 m high inliers (Figure 7). The individual outcrops vary in width from ~40 m to >300 m and, in line with the predominant bottom current directions, are exposed in northeast-southwest to north-south orientations. There are no readily identifiable geological structural features such as joints, bedding or faults that can be mapped from the sonar, though as in other areas low backscatter halos are visible mostly along the eastern flanks of the outcrop margins. Between each outcrop are medium-low acoustic backscatter areas between 80 and 200 m wide, a number of which appear to have ornaments of high backscatter “streams” orientated northeast-southwest.

Between the outcrops described above and 13°18.0’W is an area of seafloor exhibiting medium acoustic backscatter with 5-10 m wide elongate (northeast-southwest) streaks of higher backscattering material. To the east of 13°18.0’W iceberg plough-marks once again begin to dominate the seafloor, they are almost identical to the plough-marks on the western margin of Rockall Bank, having random orientations and medium-high backscatter margins along with low backscatter centre furrows. On this side of Rockall Bank however, the plough-marks have a degraded appearance and become more and more degraded toward the east. The boundaries between furrow and margin are not so sharply defined, likely due to the effect of bottom currents effectively eroding the plough-mark or partially obscuring (burying) the plough-marks under transported and re-deposited sediments. Also on this eastern flank of Rockall Bank, the high backscatter sediments that are common, or even dominate the seabed to the west of the rock outcrops described above, disappear altogether.

The high backscatter features imaged on this flank of Rockall Bank generally tend to be individual boulders (often with low backscatter halos), though occasionally other higher backscatter features between 10 and 20 m in diameter, often circular and not displaying any evidence of relief are also seen. These circular features are rather enigmatic and may be biological in origin or may simply represent very local differences in seabed geology such as a surficial firmground as opposed to loose sands (Figure 8).

At the end of the sonar transect (57°29.3’N 13°58.9’W) there are very few plough-marks showing on a medium-low backscattering seafloor.

In terms of ground-truthing, only 6 seafloor photography sites were occupied along the SAMS2 transect, all were on the eastern side of Rockall Bank.

SAMS2_L#5 at 57°28.8’N 13°27.7’W at a depth of 165 metres, was selected to examine an area of high acoustic backscatter on the 500 kHz sonar. The photographs record a transition from coarse sands with occasional shells and shell fragments to fine gravel with occasional shell and pebbles and back to uniform sand.

SAMS2_M#2 at 57°28.9’N 13°20.4’W at a depth of 165 metres, was selected to examine a possible outcrop. This transect showed a transition from a uniform sandy seafloor to firstly a pebble-strewn seafloor then onto to cobbles and boulders and possible sand-covered and outcropping bedrock.

SAMS2_M#3 at 57°28.9’N 13°20.2’W at a depth of 182-184 metres, continued the outcrop study and showed jointed (possibly igneous) outcrop and boulders inter-fingered occasionally by sand ribbons.

SAMS2_N#1 at 57°29.1'N 13°10.3'W at a depth of 220 metres was to look at a potential reef occurrence. The photographs showed a sandy seafloor with a probable relict partially buried rippled hard-ground (Figure 9). This exposed section of hard-ground is possibly what has caused the backscatter differences on the sidescan records such as in Figure 8.

SAMS2_O#4 at 57°29.1'N 13°08.7'W at a depth of 210 metres was another area of potential reef. The seafloor here is again dominated by sand, though with occasional biogenic material, cobbles and gravel, and a partially exposed hard-ground is interpreted as causing the backscatter changes.

SAMS2_P#1 at 57°29.2'N 13°06.0'W at a depth of 238 metres was another anomalous target that could be reef. In fact this too proved to be an exposed rippled hard-ground with occasional boulders.

SAMS3 starts approximately 10 Km south of Anton Dohrn seamount where the seafloor is almost flat (<1°) apart from a very shallow moat (~10 m) adjacent to the southern flank of the seamount. The CHIRP profiler gives good sub-bottom penetration to over 30 m, showing a well-stratified sequence of sediments, the return-echoes being laterally variable in terms of their echo-strength, with the uppermost 10-12 m (assumed to be Holocene) lying unconformably on the underlying material. However, the seabed reflection is not particularly well-defined and cannot be interpreted in terms of lithology or microtopography. The EM120 backscatter shows a slightly higher level of acoustic backscatter over the 2-3 Km of deposits nearest to the seamount, possibly indicating a slighter higher current speed (and hence coarser grained sediments) due to current deflection around the seamount base.

The description of SAMS3 across the summit of Anton Dohrn seamount can be extracted from the section describing the seamount (see below, Section 7).

The physiography of the northern side of Anton Dohrn seamount is very similar to the southern except that here the moat is slightly broader. The Rockall Trough sediments onlap onto the foot of the seamount, with, in the moat, an expanded section relative to the deposits that continue northward into the northern Rockall Trough. There is again a very slight increase in acoustic backscatter levels imaged by the EM120 over the area of the moat. Along the transect northward, there are few if any features of note. The EM120 backscatter is a uniform low level almost the whole length of the transect, and the CHIRP shows an unremarkable section (to about 30 m sub-bottom) of well stratified layers, although there is a hint of possible low-amplitude sediment waves (with a height of < 5 m) and a wavelength of several hundred metres. However, they do not show in the contours or shaded relief, and without additional profiles it is not possible to prove they are real features as opposed to directional artefacts.

As with the section over Anton Dohrn seamount, the section of SAMS3 across Rosemary Bank can be taken from that part of the report, see below Section 12.

To the north of Rosemary Bank, SAMS3 extends for approximately 25 Km. Similar to Anton Dohrn seamount, Rosemary Bank has a moat around its base, and at about 200 m deep, and about 2.5 Km wide the moat is well expressed in the contours, shaded relief and EM120m backscatter. The CHIRP profiles show that there are in fact a number of acoustically transparent blocks, either parasitic cones or fallen blocks, that form a dam in the moat against which the sediment sequences abuts. The floor of the moat is represented by a single highly reflective seafloor echo, with no coherent sub-bottom reflectors. To the north away from the seamount, the CHIRP data shows a similar well stratified sequence as per the whole of the Rockall Trough transect. The EM120 backscatter shows a uniform return from the sediment surface, and also detects as higher acoustic backscatter, the acoustic basement that is within the moat, however, this higher acoustic backscatter area does not easily lend itself to interpretation as acoustic basement without the aid of the CHIRP.

There were no photographic stations along SAMS3.

6 N E ROCKALL BASIN

Parts of this area had previously undergone intensive study during the AFEN projects in 1996 and especially 1998 (Masson et al 1998, AFEN 2000). The eastern end of the SAMS1 transect ended on the Hebrides shelf and the *SV Kommandor Jack* survey of 2005 included a short transect across the N E Rockall Basin to provide an invaluable data set for comparison between the SEA7 project and the AFEN studies.

The data collected as part of the SEA7 study show very little that can be of use in detailed habitat studies. The most notable features on the bathymetry are the sediments waves observed over the already mapped (to a large extent) field centred around 59°25'N 7°45'W, the varying sediment grain sizes over these features means that they are also detected (though barely) on the EM120 acoustic backscatter. Apart from the shallower parts of the continental slope (above about 1,000 m) where there are a few subtle backscatter variations, over the rest of the NE Rockall Basin transect, the backscatter is a more-or-less uniform intensity. The CHRIP data show a generally smooth seafloor with isolated small depressions in the seabed causing hyperbolae to be produced (possibly small rills), and penetration down to 30 m sub-bottom showing a series of parallel reflectors.

The AFEN surveys used a 30 kHz deep towed high resolution sidescan sonar as the primary survey tool that, due to its higher frequency and small insonification footprint proved much more suitable for habit mapping than the EM120 and EM1002 multibeam systems, with many differences observable on the acoustic backscatter (Figure 10). The principal discoveries and conclusions from the AFEN project as relevant to SEA7 were:

1. The present day sedimentary environment of the continental slope is dominated by low sediment input and deposition rates and reworking of surficial sediments by bottom currents.
2. The gross topography of much of the continental slope and basin floor was formed mainly during the last glacial, when high sediment input resulted in glacigenic debris fan formation on the eastern margins of both the Faeroe-Shetland Channel and the Rockall Trough. Holocene sedimentation has been dominated by along-slope transport by bottom currents.
3. In the northern Rockall Trough, bottom currents are the main agent of sediment transport at all depths on the continental slope down to at least 1,500 m. Coarse sediments on the upper slope indicate strong currents, with peak velocities probably >75 cm s^{-1} ; weaker currents on the lower slope are associated with the deposition of sand/silt contourite sheets. Currents are towards the northeast on the eastern margin of the trough. However, below the crest of the Wyville-Thomson Ridge, at about 500 m water depth, these currents are deflected to the west and then southwest by the ridge topography.
4. Carbonate mounds occur in the northern part of Tranche 36-53, but have not been found in the remainder of T36-53 nor in Tranches 19-22 and 30. No mounds have been discovered north of the Wyville-Thomson Ridge. The factors controlling the location of the carbonate mound fields are not understood at the present time.
5. Numerous colonies of the deep-water coral *Lophelia pertusa* were found on the carbonate mounds. Elsewhere in the areas surveyed during 1996 and

1998, *Lophelia* has only been encountered sporadically as small isolated colonies.

6. Unique 'tail-like' sediment areas, visualised by sidescan sonar, downstream of the carbonate mounds were found to harbour high density populations of the xenophyophore ('giant protozoan') *Syringammina fragilissima*. Although infrequently recorded in the past, this species appears to be common in the Rockall Trough, and further afield, in depths of around 1,000 m.
7. The deep water areas of the Rockall Trough experience the seasonal deposition of phytodetritus, the degraded remains of microscopic surface ocean plants that may carpet the seabed to a depth of several centimetres during the summer months.
8. Contrary to general expectations, the abundance of animal life in the deep waters of both the Rockall Trough and Faeroe-Shetland Channel is not markedly lower than that encountered in shallower waters. In the Rockall Trough and the waters to the north of Shetland, animal abundance appears to increase with depth.
9. There is a very striking difference in the diversity of animal life north and south of the Wyville-Thomson Ridge. In the Rockall Trough diversity increases with depth (at least down to around 1,600 m or more). However, in the cold waters of the Faeroe-Shetland Channel, diversity drops rapidly with depth (to at least 1,600 m). As a consequence of these opposing trends, at around 1,600 m, the Rockall Trough has a diversity twice as high as that in the Faeroe-Shetland Channel.
10. A strong depth-related trend in faunal composition is apparent in the Rockall Trough. There is some evidence of enhanced rates of faunal change at around 1,200 m depth that may be related to hydrographic factors

7 ANTON DOHRN SEAMOUNT

The seamount stands alone almost in the centre of the Rockall Trough. It has a circular shape with a diameter of just over 45 Km and a vertical relief of between 1,500 and 1,600 metres, rising from an average seafloor depth of 2,000 m on its western side and 2,200 m on its eastern, it has a domed top with a "shelf-break" at 850 m and thus it has almost sheer walls of over 1,200 m in height, with a "dome" across the summit region shoaling to ~550 m in the centre of the seamount (Figure 11). The summit area is covered by up to 100 metres of sediments that bury a flat ancient erosional surface (Jones et al 1994).

There is a moat all around the seamount although it is most pronounced around its northwest flank where the seafloor is ~150 m below the regional depth. The flanks of the seamount have a simple slope apron that rises from the regional depth to the 1,500 m contour, which is where the walls become sheer. There are no significant canyons or gullies down the seamount flanks, the only "ornamentation" are a few small, steep hills, possibly parasitic cones that sit adjacent to the seamount on its eastern and north-western flanks. The relief across the summit area takes the form of a uniform dome across the whole area, although in detail there are one or two "steps" in the topography, mostly on the southern flank of the summit. Due to the overall thickness of sediments on the summit, they are unlikely to be due to primary structures such as flow-fronts, and are probably due to post depositional faulting or in some cases, sediment slides. Most of these "steps" are 25 m or less in height, with the largest step being on the southernmost part of the summit at ~60 m. Other areas for topographic expression the summit (again usually around 25 m or less) are acoustic basement pinnacle (parasitic cone) outcrops.

The acoustic backscatter (Figure 12) shows differences due to both rock outcrop (centre) and more subtle changes that indicate differences in sediment type and/or ornamentation. The sedimentary backscatter changes can be seen best over the north and western sectors of the summit area (Figure 13), however it is difficult to correlate these backscatter changes with changes noted on the CHIRP profiles. Acoustic basement outcrop near the seamount summit is easily defined as an area of darker acoustic backscatter than the surrounding seafloor. However, from the EM120 it is not possible to identify potential "biological" features.

To completely map the seamount required a series of transects across the summit region, which in turn allowed the collection of 21 lines of regularly-spaced CHIRP profiles. The CHIRP profiles that cross the northern summit area reveal a strong seafloor reflector with a laterally variable and discontinuous single sub-bottom sedimentary reflector that appears to drape an acoustic basement (or deeper transparent layer) at sub-bottom depths of 1-5 metres. The acoustic basement as imaged by the CHIRP profiler is likely to be a hard-ground of some sort, possibly an erosion surface from pre-Holocene time. Where the sub-bottom reflectors occur at <3 m sub-bottom depth, they overlie apparent basement highs. These buried "basement highs" may be either buried parasitic cones or, more likely remnants of old sediment wave or possibly even sediment slide topography. Frequently imaged by the profiler over the northern part of the seamount summit are a series of topographic "steps" with a down-side away from the summit, that vary in height up to over 20 metres. The shaded relief image (Figure 11) shows how the north and western areas of the summit are quite rough when compared to the southern and eastern flanks. The steps are sediment draped features, indicating that the steps are the result of ancient sediment failure, with the step faces being the slip-planes. The stepped topography is more common toward the south and southeast of the summit area, toward the seamount centre, the seafloor is quite smooth.

Moving further south over the central portion of the seamount summit, the western flank generally shows a shallow acoustic basement both near the surface and sometimes outcropping, usually with a few topographic step-downs toward the west. The seabed generally becomes smoother toward the central part of the summit region. Across the eastern flank of the seamount summit, the seafloor varies considerably, sometimes, over a narrow zone adjacent to the eastern margin, basement outcrop is noted, whereas in most other parts of the eastern summit sediments can be imaged at over 10 m sub-surface. Over most of the central summit area, the seafloor reflector is very strong and smooth, though in places it does gently undulate, however in centre of the seamount there is acoustic basement outcrop, rising steeply over 40 m above the summit sediments. This central outcrop is the largest area of basement outcrop on the summit of Anton Dohrn seamount.

Along the southern summit area, the western side of the seamount again has shallower acoustic basement imaged with the CHIRP than the eastern side, though toward the eastern flank, beginning 6 Km from the summit, there are several 15-25 m “steps” down exposing acoustic basement, as noted above, these may be slip-planes or shallow-buried (or now partially exhumed) steep flow-fronts. These step features are also clearly seen in the bathymetry and form several concentric semi-circular structures up to 15 Km in length. Generally speaking however, the southern parts of the seamount summit are smooth or gently undulating with very little outcrop.

500 kHz Sidescan Sonar transect

One deep-towed sidescan survey track was undertaken starting at 57°28.25’N 10°44.25’W and finishing at 57°26.5’N 11°22.75’W. The easternmost part of the summit displays medium-low backscatter seafloor with many scattered dropstones, some large enough to cast individual acoustic shadows, and most measuring 1-2 m across. Many of the dropstones show down-current (toward the south-southeast) backscatter contrasts in their lee, known as comet marks, indicating strong current flow across this part of the summit. Moving toward the summit area the general medium-low acoustic backscatter intensity remains and the trawl-marks greatly intensify, although the lee-marks disappear. Approximately three kilometres east of the summit outcrop area, a number of features displaying higher than usual backscatter are imaged, mostly circular in form and between 2-10 m in diameter (Figure 14). These features are apparently not occurring in any particular association with dropstones or other seafloor features, and are of uncertain origin.

Across the central area the summit outcrops are very distinctive and easy to recognise with their distinctly different reflection textures and large acoustic shadows indicating the relief of the outcrop (Figure 15). However, even amongst these outcrops there are examples of circular features that may not be geological in origin.

To the west of the summit outcrop area, the medium-low acoustic backscatter persists and outcrops become very rare as do trawl marks. Dropstones, though not so common as in the east are still imaged and there is a faint suggestion in the backscatter levels of northward elongation of sediment trails in the lee areas behind individual dropstones. Within 4 Km of the western edge of the summit, dropstones appear to be more common as does outcrop. Trawl marks also re-appear and the sediments have random patches of high backscatter of uncertain origin.

There were a number of photographic stations across the summit of Anton Dohrn Seamount and two on the lower western apron. These are described below, from east to west.

SAMS2 Geo1#1 at 57°27.9'N 10°50.0'W at a depth of 793-795 metres shows a sandy seafloor with gravel and occasional cobbles and boulders. The gravels are frequently orientated into streams, with finer gravels apparently in-filling the troughs of ripples.

SAMS2 Geo2#1 at 57°27.8'N 10°56.5'W and a depth of 660 metres reveals a coarse biogenic gravely sand with a few pebbles. There were no obvious current structures visible.

AD_A#1 at 57°27.5N 11°03.2'W at a depth of 591 metres shows the seabed here to comprise of sand with minor amounts of shell and broken shell debris, and rare gravel.

AD_H#1 at 57°27.4'N 11°05.0'W and a depth of 573-580 metres reveals a seabed consisting of sand with a large amount of biogenic material (especially empty brachiopod tests), and lesser gravel, though in some restricted areas, notably around dropstones, but possibly in other discrete patches, the gravels become dominant enough to form lag deposits. There is no evidence of current activity apart from the lags.

AD_J#1 at 57°27.3'N 11°06.7'W at a depth of 523-531 metres. This site was a mixture of jointed, iron-stained outcrop, with gravel lags and broken shell in association with outcrop and/or large dropstones, and elsewhere, ubiquitous biogenic sands, mostly with empty brachiopod and bivalve tests at the surface. Occasionally dropstones were evident. The occurrences of the empty tests suggest that strong currents were not actively sweeping this part of the seamount at the present, though the lags indicated that they did at times.

AD_B#1 at 57°27.3'N 11°07.2'W at a depth of 522-546 metres was located to image rock outcrop. There station is a progression from biogenic gravely sand through to iron-stained jointed rock outcrop (probably basalts, Figure 16) with boulder and pebble dropstones and washed gravel lags.

AD_C#1 at 57°27.3'N 11°07.7'W at a depth of 557-565 metres shows a transect across a small rock outcrop. To either side of the outcrop a similar pattern is observed, namely sands, then biogenic sands, gravely sands, broken shell, rock outcrop.

AD_K#1 at 57°27.2'N 11°09.1'W at 598-600 metres, biogenic sand and dropstones, with halos of gravel lag.

AD_K#2 at 57°27.2’N 11°08.9’W and a depth of 594-597 m shows the seabed to fine biogenic sands, with in places the empty brachiopod shells and other lighter detritus aligned into trails, which may be the troughs of sediment ripples. Also developed in patches are very clean gravel lags and dropstones.

AD_D#1 at 57°31.0’N 11°18.0’W at 724 metres depth is a gravely sand with dropstones that show well-developed downstream gravel lags (Figure 17).

AD_D#2 57°31.0’N 11°18.0’W and depth of 723-725 metres. This station was a continuation of AD_D#1, this photographic transect was to look for a probable lithological change that was imaged by the EM120 backscatter. The actual change in seafloor conditions was from a rippled seabed with coarser material in the ripple troughs (Figure 18a) to a gravely sand with no obvious current features (Figure 18b).

AD_G#1 at 57°28.9’N 11°27.0’W where the depth varied between 1740-1765 metres was occupied primarily to investigate the biology of the seamount apron. The sediment was primarily fine sand with dropstones and usually associated with the larger dropstones, some areas of gravel, which adjacent to the largest dropstones forms lags. Feeding trails are common on the sediment surface, suggesting weak benthic currents.

AD_F#1 at 57°28.9’N 11°28.0’W at a depth of 1420 metres was also primarily a biological station, and revealed the seabed to consist of a fine sandy layer that mostly obscured a gravely (?lag) deposit. Feeding trails are common and there is no evidence of current activity.

Figure 19 is a schematic interpretation of the geomorphology, surficial seabed geology and benthic current activity as derived from the 2005 SEA7 *SV Kommandor Jack* survey.

8 EAST ROCKALL MARGIN

Older studies of the Rockall Bank had tended to focus on the deeper geological structure and history of the opening of the northeast Atlantic (e.g. Roberts 1975b), although more recent studies have combined this approach with evaluations of hydrocarbon prospectivity (e.g. Roberts et al 1999, Spencer et al 1999). There have been relatively few modern studies of benthic habitats and fauna of Rockall Bank published in the open scientific literature (e.g. Wilson 1979a, Wilson 1979b, Wilson and Herbon 1998, Ivanov et. al. 1998).

The photographic stations are discussed at the end of this section, arranged in terms of their physiographic and geographic locations, so that the lower slope is first addressed moving from south to north, then the mid-slope and finally the upper slope stations. In terms of its geomorphology, the East Rockall margin survey area may be split into four distinct zones; from the UK-Ireland Boundary to 57°20'N, between 57°20'N and 57°50'N, between 57°50'N and 58°20'N and finally north of 58°20'N and west of 13°45'W.

In the southernmost region the shelf –break is at about 350-400 m with the upper slope dropping away quite steeply to about 550-600 m within only 1 Km of the shelf break. The slope itself is incised with bights up to several kilometres across and hundreds of metres deep spread at irregular intervals along the slope, though more especially focussed south of 56°55'N. Along the length of the entire slope in this area, at about 1-1.5 Km from the foot of the upper slope is the crest of a sediment drift, the northern part of the Feni Ridge. This crest stands 100-150 m above the moat that runs between it and the actual slope edge. At 56°45'N 13°46'W a promontory juts out from the Rockall shelf disrupting the drift, and adjacent to this small promontory, on its south side, a scour over 50 m in depth has formed, which along with the eroded bights into the upper slope described above, indicate the strength of the currents in this area.

South of this small promontory the drift begins to reform, though here coverage ends at the UK EEZ boundary. The crest of the sediment drift occurs at between 550-650 m waterdepth, with the contours showing for the most part an even slope down to 1,100 m, where the contours show a 100 m vertical drop in only 500 m of lateral distance, a bathymetric step that is more-or-less continuous through the area. Below this step the contours show a generally smooth slope to the edge of coverage at about 1,800-1,850 m waterdepth. The only exception to the mostly smooth slope is a sediment slump or small landslide, whose slip-plane is centred at about 56°44'N 13°39'W. The area affected is only 4 Km in width and its lower end is outside of the UK sector and not imaged. Other minor features of note are a few small slope-parallel scours, of the order of 1 Km across, occurring almost exclusively below 1,100 m.

The backscatter reveals many iceberg plough-marks on the Rockall Bank shelf, with a large (5 Km across) area of high backscatter just to the north of the small promontory described above at 56°45'N 13°46'W. The CHIRP shows this high backscatter to be the rough topography of the incised embayment walls (that are ~100 m high and contain an infill where the sediment drift follows the topography slightly infilling the embayment, Figure 20).

The steep upper slope down to about 600-650 m shows a number of similar, though much smaller areas of high backscatter that are each correlated with incisions/valleys into the shelf edge. The surface of the upper part of the sediment drift shows a uniform level of backscatter, though towards the southern extremity of UK territorial waters there are subtle patterns displayed that are suggestive of down-slope depositional events such as debris and/or turbidity flows. Lower on the slope, down to around 1,000 m, the backscatter remains at a uniform level until just north of the small sediment slide described above. Around 56°45’N 13°33’W are two areas of varying backscatter that merge down-slope, their lineations indicating that they may be the remnants of old slope failures, an interpretation confirmed by the CHIRP profile across the feature. Another noticeable area of backscatter variation lay approximately along the 1,100 m contour, which is where the bathymetric step reported above on the lower part of the sediment drift occurs. However this is also the region where much detail is lost due to processing artefacts and the large pixel footprint. Due to the survey layout there are few orthogonal CHIRP profiles across the bathymetric step, it may be that the backscatter differences here are due to the winnowing that has produced the step (Figure 21).

Between 57°00’N and 57°10’N the upper slope is not quite so highly incised as to the south, and the uppermost part of the sediment drift is very well developed although the depth of the crest of the drift deepens from less than 600 m around 57°00’N 13°25’W to over 750 m at 57°18’W 13°00’W. The lower eastern flank of the drift shows a similar current-scalloping to that seen further south, with the same 100 m step-down at about 1,100 m waterdepth. One of the few transverse CHIRP lines over the prominent step-down seen at 1,100 m images a very steep slope with a small ledge at its base, the poor weather at the time of survey preventing the collection of the highest quality records. North of 57°10’N the upper slope is once again very highly sculpted and has numerous steep and deep bights into the shelf edge. There are a number of small-scale sediment slips imaged that are degrading the upper sediment drift, mostly of the order of 1-3 Km in breadth, the largest being 5 Km wide centred at 57°18’N 13°00’W.

The acoustic backscatter mosaic of this area, down to the 1,100 m step, shows the same type of features as further south, with iceberg plough-marks on the shelf, a steep, highly-backscattering upper slope followed down-slope by the uniform backscatter of the upper sediment drift, and quite distinct backscatter contrasts along the bathymetric step-down, which itself is actually defined by a zone of lower acoustic backscatter (Figure 22). The small-scale sediment failures that ornament the upper part of the sediment drift and are distinctive on the shaded bathymetry are also seen on the acoustic backscatter mosaic, mostly defined by very thin arcs of high backscatter defining the slide back-walls, whereas the actual slide-plane displays a lower backscatter. Below the 1,100 m depth of the step and north of 57°00’N, there are a number of features on the backscatter mosaics that show indications of down-slope sediment failure and transport, some of these slope failures are seen on the surface in the shaded bathymetry, but others are masked by the lower reaches of the sediment drift. Examination of the CHIRP data shows degraded and draped sediment slide deposits (Figure 23).

An important area is the zone where the orientation of the Rockall slope changes, rather abruptly, at an “elbow” located at 57°22.5’N, from NE-SW to NNE-SSW. The steep upper slope now drops from the shelf-break down to 700-750 m, around 100 m deeper than further south, and whilst it is still eroded into small steep bights, these now exhibit a bias in that the bights are now elongated toward the north as opposed to almost slope-orthogonal. In places the upper slope is almost too steep to image, in some places dropping by 200 m vertically over just 150 m laterally. These ultra-steep slopes are only encountered between 400-750 m.

Another of the major effects of this change in slope orientation is that it changes the appearance of the upper section of the Feni Ridge. The shaded relief shows that the sediment drift is still present, though north of the elbow the crest of the drift becomes much more discontinuous. Approximately along the 800 m isobath, there are several small slope-failure scars, and apart from a couple of exceptions described below, the slope in general is much more regular and smooth.

Two small canyon systems are imaged along this key part of the margin, one at 57°17.5’N trending NW-SE, the other at 57°31’N trending almost E-W down-slope (Figure 24). Both canyons are about 100 m deep and appear to almost define the boundaries of an area of slope that exhibits small slope-parallel ridges, probably indicating past instability and sediment erosion. Both of the canyons are also in close proximity to small failure scars, and I suggest that the canyons have actually developed from previous slope failure events as neither canyon is traceable to the top of the continental slope.

Above the continental shelf-break, that in this area occurs at 450-500 m water-depth, the backscatter images excellent examples of iceberg plough-marks, and below the shelf-break the steep slope shows typical high-low acoustic backscatter contrasts of the sculpted slope. Below about 800 m the acoustic backscatter is mostly uniform, though between the two canyons the seafloor exhibits a generally higher level of backscatter than elsewhere in this area, and around the immediate areas of both the canyons, the backscatter show the distinctive down-slope patterns indicative of slide deposits (Figure 22).

Further north along the Rockall margin the orientation of the slope turns further to the west, becoming NW-SE at 57°55’N. The shelf-break shoals to about 350 m, though the upper slope remains extremely steep in places, often with slopes >20°. The base of the upper slope is at about 600 m water-depth and thereafter the mid and lower slope becomes gentle and smooth. The well-developed Feni Ridge sediment drift imaged south of 57°20’N has not yet formed along this part of the Rockall Bank. There are few mid-lower slope features imaged on the shaded relief, although on the lowermost part of the imaged slope, at about 1,000 m water-depth and between 57°45’N and 57°53’N, there is the faintest hint of a slope-parallel step that may be the degraded trace of a slope failure scar. Over this region the CHIRP data reveal a sediment drape of up to 5 m thickness over a buried topography that shows no internal structure, furthermore, the lineations and variations in acoustic backscatter suggest there has been down-slope deposition in this area in the past.

The steep scarp that has defined the upper Rockall continental slope to the south is here a smooth feature with a gradient of 20-30°. The upper slope has a number of small bights, but they are not as common or severe as those described along the southern UK zone of the eastern Rockall Bank continental slope. The base of the upper slope is marked by a break of slope at 900 m, after which is a gentler incline down to 1,100 m, which then steepens to 5-9°, down to 1,250 m after which a gentle <2° slope resumes. The backscatter typically shows the iceberg plough-marks on the shelf and along its edge, and mixed high acoustic backscatter features on the upper slope, whereas the area below this displays a uniform backscatter. There is however, a specific zone that stretches from 57°57’N 12°58’W to 58°07’N 13°12’W (about 25 Km by 3 Km) of mixed high and low backscatter, that the CHIRP profiles show is a region of thinly-buried (<2 m) debris deposits, the present topographic expression being a result of sculpture by currents.

As the shelf-break both curves further toward the west, it loses its identity and effectively disappears west of 13°50’W such that from the 500 m contour down to the 950 m isobath is a simple broad (7 Km) smooth slope. The upper part of this slope still shows the presence of iceberg plough-marks, imaged well on both the bathymetry and the acoustic backscatter, and along the shelf edge numerous small embayments and bights very similar to those that characterise the Rockall Bank slope further to the south are noted. The acoustic backscatter over upper-middle slope (500-900 m) shows an array of backscatter patterns that reflect the numerous small-scale (1-2 Km) sediment bodies associated with the bights and scours along this part of the slope.

On the mid-slope (1,100-1,250 m) between 13°30’ and 13°40’W, the shaded relief illuminates a slope-orthogonal 5-10 m topography at the seabed surface. These topographic lineations together form a slope-parallel bulge in the regional bathymetric contours and lie down-slope from a distinct 12 Km wide crescentric embayment high on the slope (that itself has been further sculpted with numerous small bights). The mid slope areas generally show a uniform medium level of acoustic backscatter, however over the area of bathymetric lineations described above, there area discrete variations in backscatter, which coupled with the sub-bottom topography revealed by the CHIRP profiler (Figure 25) indicates a buried slope failure deposit, presumably originating from the crescentric embayment high on the slope.

At 58°21’N 13°42.5’W there is a small (1 x 2 Km) isolated pinnacle just over 100 m in height, it could be a remnant part of a slide deposit or a distinct body such as an igneous intrusion.

This northernmost part of the Rockall Bank margin includes the bathymetric saddle between George Bligh Bank and Rockall Bank, which is the main, and deepest, entrance to the Hatton-Rockall Basin from the north and east. West of 14°W the continental slope becomes very complex topographically, the northern slope of Rockall having a much lower slope angle (2°) as it forms the bathymetric saddle mentioned above. The shelf edge is imaged at the limit of coverage at about 500 m water-depth, where a ridge runs parallel to the shelf-edge at 520-580 m water-depth (the crest of this small ridge plunges toward the west). The gross geomorphology of the slope from shelf-edge to below 900 m appears to be composed of a series of sloping, irregularly-stepped terraces, with each step and terrace occurring at various depths along the slope. Only below 800 m water-depth do the contours begin to persistently turn slope-orthogonal to form the saddle across the Rockall-Hatton Basin. Shallower than this they define a number of slope-parallel ridges, scours and a number of small slope-orthogonal “canyon-like” features, e.g. at 58°30’N 14°00’W, 58°28’N 14°08’W and 58°25’N 14°03’W (Figure 26). The shaded relief imagery in fact suggests that the “canyon-like” features mentioned above are more probably erosive scours. Their origins are always below the shelf edge, mostly at around 700 m, and over this part of the continental slope they disappear by 1,000 m water-depth.

A second area of erosive scours is imaged along the eastern flank of the saddle across the Rockall-Hatton Basin between George Bligh Bank and the eastern margin of Rockall Bank. These scours are very pronounced as together the individual features form a long sweeping arc from 58°23’N 13°56’W through 58°26’N 14°00’W and 58°35’N 14°07’W leading northwest away from the foot of the Rockall Bank slope. Each individual scour takes the form of an arcuate depression in the seafloor, the western wall being significantly steeper than the eastern, with individual scours being between 60 and 120 m in depth (Figure 27).

The backscatter in this area is quite surprising in that it shows very few features indeed. The iceberg plough-marks are still present on the shallowest parts of the coverage, but they are lost below 500 m. The stepped slope-increase between the uppermost slope and first mid-slope terrace, at around 650 m water-depth is seen, but apart from this, the rest of the slope displays almost uniform backscatter intensity. The exception being of course the mid and base-of-slope scours described above.

The lower East Rockall margin continental slope photographic stations from south to north show a generally benign environment in terms of sedimentary structure or features.

ER_E#4 at 57°01.5’N 13°04.0’W and 1599 metres depth shows a fine sandy seafloor, with some dropstones.

ER_G#1 at 57°15.0’N 12°50.0’W at 1546-1551metres again has a very fine sandy seafloor with rare shell fragments and even rarer dropstones.

The mid-slope stations from south to north are located across the Feni Ridge sediment drift that begins to be defined as a stand-alone bathymetric feature south of 57°N.

ER_D#1 at 57°00.0’N 13°20.0’W and a depth of 731-737 metres images the basal part of the sediment drift, where the seafloor is composed of loose medium gravely sand, with dropstones and associated with gravel lags, that apparently overlies a rippled possibly indurated surface (Figure 28).

ER_C#1 at 57°01.7’N 13°18.8’W was an attempt to image the upper portion of the drift deposit between 646-656 metres. The sediments are coarse sands with rare gravel-sized stones and biogenic material, along with randomly scattered larger dropstones. No current structures were noted during this transect.

ER_F#1 at 57°30.0’N 12°51.7’W was an attempt to look in detail at a probable recent slide-scar on the sediment drift between 1025-1030 metres waterdepth. Technical problems meant that no evidence of sediment sliding was imaged, but the sediment types were fine biogenic gravely sand with dropstones.

There were five sites photographically imaging the upper part of the Rockall continental slope, four located centrally (between 57° and 57°30'N) and one located on the northern margin.

ER_B#1 at 57°05.4'N 13°16.2'W was a depth transect between 552-580 metres. The predominant seafloor type was a conglomerate of rounded to sub-rounded fine to coarse gravel with cobbles and boulders in a coarse biogenic sand matrix.

ER_O#1 was a longer than normal transect, stretching between 57°12.9'N 13°07.2'W and 57°12.0'N 13°06.6'W, that had a depth range between 391-670 metres. Throughout the transect the seabed is characterised by a very rough texture, outcrop, boulders and cobbles are frequent, all surrounded by coarse gravely biogenic sands. In isolated patches and at varying depths along the transect, the seabed surface is entirely composed of biogenic material (whole and broken shell and urchin spines) whereas in others there are areas of clean sand.

ER_N#1 another long transect centred around 57°20.0'N 13°00.4'W and with a depth range of 407-635 metres. This was very similar to the previous site, with a rough surface texture comprising mostly coarse sands with biogenic gravels and pebbles, cobbles and boulders, with some areas of bedrock outcrop.

ER_M#2 at 57°29.3'N 12°57.3'W and 400-620 metres shows the typical upper slope agglomeration of coarse sands, biogenic and stony gravels, pebble to boulder sized blocks, and near the upper part of the transect at least one small area that appeared to be pale, indurated outcrop partially obscured by a surface layer of sand (Figure 29)

ER_L#1 is located away from the other sites on the northern margin of the Rockall Bank at 58°30.0 14°05.0 in water-depths of 1125-1127 metres. The seafloor here is very different from those described above; this is a much lower energy environment, with a seafloor composed of fine bioturbated sand and a lack of hard substrate.

Figures 30A,B and C show an interpretation of the geomorphology, surficial seabed geology and benthic current activity as derived from the 2005 *SV Kommandor Jack* surveys.

9 CENTRAL HATTON BANK

The vast majority of Hatton Bank is known from rather few widely-spaced single-beam echo-sounder, deep seismic and sparker profiles (e.g. White et al 1987, Neish 1992, Minshull 1993), and satellite-derived predicted bathymetry (Smith and Sandwell 1997), thus the shape and surface detail were, until the surveys undertaken here, virtually unknown. The occurrence and distribution of benthic fauna, and especially deep water corals over Hatton Bank has been reported sparsely, with one "modern" paper by Wilson (1979c) and other occurrences reported by anecdotal accounts largely from fishing vessels (K. Howell, Univ. Plymouth, pers. comm.).

The box-shaped survey over a small area of the Bank was undertaken to try and resolve what seafloor features were responsible for the appearance of some unusual topographic highs reported on sparker seismic profiles (D Long, BGS, pers. comm.). Two areas within the limited confines of the survey box provided images of the very different types of seafloor across this portion of Hatton Bank.

These two distinct seafloor types are firstly a series of elongate, en-echelon lineated highs (around 50-70 m above the surrounding seafloor) and associated troughs (approximately 80-100 m deeper than the adjacent high) which occur without any obvious relationship to the regional orientation of the Bank, its flanking slopes or depth. Secondly, lying slightly (15 Km) to the southeast of the lineated ridges are a series of lineated troughs or perched basins, again seafloor features that also show no relationship with the gross regional morphology of the Bank.

The en-echelon ridges and troughs lie across the crest of the Hatton Bank mostly at depths of 500-600 m though some can be seen as deep as 800 m on the western flank of Hatton Bank, and, within our survey box, they appear to be centred about 18°W. The north-south extents are uncertain because of the limits of the detailed survey area, but are clearly imaged between 58°39'N and 59°03'N. Although the following distinction may be due to our limited survey coverage, the features appear to be focussed along two discrete orientation planes, one disjointed group of ridges are imaged over 65 Km in length and are orientated just south of E-W, whilst a distinct second group are orientated NE-SW (Figure 31).

The individual ridges vary from 10 to >20 Km in length, and over their narrowest dimension the ridge-trough couplet are about 10-15 Km in width (Figure 32). However the ridges are not all associated with an adjacent trough, some, mostly those toward the west are smaller (in height) and have no bathymetric depression associated with them. Also the ridges on the western flank of Hatton Bank pass through a "field" that the shaded bathymetry indicates to be significantly rougher (on a scale of ~25 m in the vertical plane), especially around 58°42'N 18°25'W, than the overall smooth seafloor of the surrounding regional slope. This "field" of rougher topography is composed of a significant number of small positive bathymetric features, many circular shape and many tens to a hundred or so metres across in extent. Some of these groups of mounds display loose correlations that have orientations the same or very close to that of the ridges. The eastern group of ridges are much the same as described above except that their orientation is different and the smaller individual topographic highs tend to be much more clearly aligned along trends as opposed to forming loose “fields”. These features are seen to >800 m and also appear to continue to the east of the mapped area.

In terms of the acoustic backscatter, both the eastern and western groups of linear ridges and troughs show much the same characteristics. The surrounding seafloor shows a medium-low level of acoustic backscatter with almost no variation across the entire Hatton Bank survey block except for the linear ridges and small circular bathymetric highs themselves. Around many of these features is a halo of higher than normal backscatter that suggests a significant textural change in the surrounding sediments. Along the crests of the ridges the backscatter is at very high levels, indicating a major change in seafloor conditions, probably rock outcrop and/or major constructional biological features such as deep-water coral colonies or mounds that have a significantly different roughness from the surrounding seafloor. Also of note is the fact that a number (though by no means all) of the crests of the smaller individual rounded topographic highs display small areas of very high backscatter (Figure 33). This increase in backscatter signal level is likely to be due to a rough surface texture.

A number of photographic transects were made across the area of mounds and en-echelon ridges, and they are described below running from West to East.

HB_K#1 at 58°43.9’N 18°39.6’W has a depth range across a seafloor “hummock” of 740-771 metres. The seafloor appears to consist of sand with major reefal growths of coral and other associated fauna. In some places the corals appear to have been destroyed, probably by trawling, and in a few small areas there are patches of clean sand, though these are rare.

HB_L#1 at 58°41.0’N 18°32.0’W had a depth range of 645-652 metres. The seabed here consists of mostly of coarse sand with varying amounts of live and destroyed coral. The sands contain varying amounts of gravel though no larger clasts were noted.

HB_Q#1 at 58°42.7’N 18°29.4’W is a double-hummock, where the depth varies between 622-641 metres. Off the hummocks the seafloor is rippled sands, sometimes with scattered biogenic gravel. The hummocks themselves are a mixture of coral-covered sand (live, dead and destroyed) and exposed indurated material that shows the typical sculpted surfaces of submarine erosion on carbonate-containing rock, and rippled sands (Figure 34).

HB_A#1 at 58°42.7’N 18°21.5’W at 537-591 metres shows biogenic gravely sands which slowly become more covered by coral and are punctuated by large boulders and several types of outcrop, including what appears to be igneous (Figure 35a) and what appear to be indurated outcrops of massive sedimentary rock (Figure 35b, note the biogenic debris on the top of the block). These (likely) sedimentary rocks may actually be simple aggregations of biogenic debris that have formed a now-eroding talus deposit. Only carefully targeted sampling will answer this question.

HB_R#1 at 58°44.8’N 18°13.7’W and a depth of 519-525 metres reveals a clean, bioturbated, rippled sand with some small patches of gravel and irregular patchy outcrops of a jointed rock (probably basalt).

HB_C#1 at 58°44.2'N 18°08.0'W and 476-538 metres. The seabed is composed of irregular dropstones on a coarse biogenic sand and gravel matrix, with on the slopes, exposed jointed bedrock, probably basalt, that is, in some patches, encrusted and in others forms a bare rock pavement or slope, which may be a vertical scarp. In general however the slopes are composed either of bare (or colonised) rock, or they are blocky and rubble-strewn with, gravel, pebbles and larger material. Some of the ledges are covered by pebbles or other loose material, including masses of broken coral and some (infrequent) just have small patches of clean sand.

HB_M#1 at 58°45.4'N 18°04.5'W is another site running over a (double) slope, with depth ranges between 515-581 metres. The upper part of this site on a flat area of the seabed is characterised by a biogenic gravely sand with dropstones, that, near the edge of the first scarp gives way to iron-stained and jointed (basalt?) outcrop both at the edge and down the scarp slope. The base of the upper slope has a talus of broken coral and other debris, whereas the mid-slope shelf is covered by a clean gravely sand before outcrop again becomes dominant, forming overhangs at the top of the lower scarp slope (Figure 36a). The outcrop has the appearance of basalt, and the base of the scarp again has a talus slope, with a washed lag at its base (Figure 36b) before the seafloor once again becomes dominated by biogenic gravely sand.

HB_N#1 at 58°49.2'N 17°57.1'W and a depth of 542-646 metres follows a similar seafloor texture and composition pattern to the previous station. Above the scarp the seabed is coarse sand with a fine biogenic gravel, with boulders and coarser gravel on the surface toward the edge of the scarp, with on the slope itself a mixture of (basalt) outcrop and coarse sand/gravel/talus. Some of the ledges on the scarp are marked by a scree of broken biogenic material (mostly coral fragments), and the seafloor at the base of the slope is defined by a washed gravel lag.

HB_P#1 at 58°48.0'N 17°50.0'W and depth of 556-642 metres is another profile down a scarp slope, and shows the typical seabed assemblage of textures and sediment types. Sands and boulders at the top, then outcrop and scree, although at this site the outcrop displays a layering that (Figure 37a) gives a (probably false) appearance of sedimentary structure. At the base of the slope, the seafloor is not the typical gravel lag as seen elsewhere, but has the appearance of a chemically weathered sedimentary rock (Figure 37b).

HB_S#1 at 58°52.4'N 17°49.9'W and depth of 682-730 is another depth transect down a scarp slope. The upper part of the transect above the slope is predominantly sand which then becomes littered with encrusted (usually by coral) boulders and down the slope itself the seafloor is biogenic coarse sand and gravel with outcrop of mostly igneous bedrock although there is also some sedimentary outcrop too. At various intervals down the slope, the sedimentary and igneous outcrops appear to be inter-bedded (Figure 38). However, this may simply be an illusion, with the sedimentary material simply being an aggregation of ancient eroded biogenic scree that is now being chemically eroded by the seawater.

HB_E#1 at 58°57.0'N 17°41.9'W and depth of 798-854 is another depth transect. The sandy seafloor at the top of this slope is very clean and rippled, with little in the way of bioturbation (though there are Xenophyophores in this region). Gravel and larger material makes an appearance toward the edge of the slope, which is marked by an overhang (Figure 39a), just below which the outcrop shows distinct veins (Figure 39b). There is little biogenic rubble compared with most other transects, the slope comprising of either outcrop or rubble-strewn sand. The foot of the slope is gravely sand, again with remarkably little biogenic content.

HB_H#1 at 59°09.7'N 17°06.2'W and 466-483 metres was the most easterly site examined. Here the slope was characterised by veined, massive outcrop and boulders on coarse sand. The sand itself was a well-sorted with very little biogenic component, and in areas away from outcrop or large obstructions such as boulders, showed clear current ripples.

A second and very distinctive type of seafloor terrain was discovered on Hatton Bank, namely a series of bathymetric lows, the shaded bathymetry suggesting that they take the form of smooth sculpted hollows up to 100 m deep (Figure 40). They lay to the southeast of the mounds noted above, on the eastern flank of Hatton Bank, and lay along a trend, extending for over 40 Km in a NE-SW direction, yet being confined to a narrow zone of only about 10 Km in width. Limited transverse CHIRP sections across these features show that they are in fact a series of perched basins (Figure 41).

A single photographic transect was made in the perched basin area, HB_G#1 at 58°42.5'N 17°22.9'W ran from just outside of a basin to inside of one, with a depth range of 1096-1108 metres. The seafloor imaged over the transect consisted of a fine bioturbated sand (possibly silty) with rare gravel-sized dropstones.

Figure 42 is a schematic overview of the geomorphology, surficial seabed geology and benthic current activity around the central Hatton Bank region as derived from the 2005 *SV Kommandor Jack* surveys.

10 WEST HATTON BANK MARGIN

The UK sector of seafloor that encompasses Hatton Bank has been sparsely surveyed as mentioned in the previous section. However when the UK became a signatory to the United Nations Convention on the Law of the Sea (UNLCOS), the DTI commissioned a multibeam survey on the western margin of Hatton Bank, these data are considered "in confidence" until the United Kingdom submits its UNCLOS claim to the United Nations (Figure 43). The data collected for this survey have not been interpreted in detail for this study and no backscatter analysis has been undertaken, however, as this is such a high quality dataset it is described in brief here.

The northern part of the multibeam coverage extends from around 1,000 m down to in excess of 2,000 m. North of 59º30'N the gross morphology of the margin shows a semi-circular embayment to the south, with the contours shows at depths of 1,200-1,800 m a series of slope-parallel en-echelon structures indicating possible geostrophic activity, with further down slope a number of circular topographic highs between 2-8 Km in diameter and in excess of 200 m in height, which indicates that they are probably ancient extinct volcanoes.

To the west of 16º30'W where imaged above 1,800 m the contours indicate a smooth, though occasionally incised slope, whereas at depth the slope contours show in discrete areas, especially south of 59º and west of 19º30'W, en-echelon features that may be due to geostrophic activity or the primary deep geological structure. The rest of the margin to the southwest is dominated by the complex topography and volcanic edifices of the volcanic ridge of the Endymion Spur.

The topography along this part of the Hatton Bank is extremely variable, and the seafloor comprises both geostrophic and volcanic dominated areas, thus it is extremely likely that there will be many areas of diverse benthic faunas along this region, although the greater depth of the southern part of the surveyed are means that diversity may be restricted.

11 GEORGE BLIGH BANK

This Bank has received very little attention from researchers, mostly it has been referred to as an adjunct to other studies. Even so it is known to be a volcanic centre (Hitchen 2004) and Lophelia occurrences have also been reported (Wilson 1979c). For this study only the Bank was only partially mapped, with multibeam coverage confined to the east and south-east flanks. Features of note on the approach from the north are small-scale channels (~10 m deep) with possible outcrop exposed in the banks of the channels, and a couple of distinct 100m-high mounds which were examined by photographic stations.

GB_A#7 at 59°19.3'N 13°57.2'W and with a depth range of 808-920 metres. The top of this bank is a gravely sand, with evidence of destroyed coral (possibly trawl damage). The gravely sand is continuous over the whole transect, with varying amounts of coral growth, there is no outcrop visible at this site and relatively few dropstones.

GB_B#1 at 59°17.2'N 13°56.8'W at a depth of 780-797 reveals a sandy seabed with a minor gravel component and few dropstones. There is intermittent patchy coral growth over much of the seabed, although a large proportion of the coral is destroyed. No outcrop is seen, though at the base of the mound there appears to be a significant build-up of coral debris into a scree deposit (Figure 44) that appears to have become partially indurated.

The CHIRP data reveal an acoustic basement imaged at less than 5 m sub-bottom (though this is unlikely to be true "geological basement") as the northern flank of George Bligh Bank rises from 900 m to the summit at 450 m. Over the summit, iceberg plough-marks are restricted to areas shallower than 500 m, though they show two different types of acoustic character on the backscatter mosaics. One type has the same low-level acoustic return couplets as seen from plough-marks on Rockall and Rosemary Bank, but over a small part of the summit, the acoustic returns from the plough-marks are unusually high. The CHIRP data across the highly backscattering plough-mark area images the seafloor as a series hyperbolic "mounds", varying from 5-15 m in height (Figure 45). This type of feature on the relatively wide-beam CHIRP profiles usually indicates a very rough surface, often with a slope angle too steep to resolve accurately. This echo type is also considered a typical characteristic of carbonate mounds such as those imaged in the Porcupine Seabight (e.g. Wheeler et al 2005).

GB_C#1 at 58°57.6'N 13°49.6'W and a depth range of 426-437 metres was targeted at one of the high backscatter iceberg plough-mark targets on the summit of George Bligh Bank. However, the images revealed little, the seafloor consisted mostly of sands with a couple of clean, washed boulder trails that are probably the lag-deposits of washed-through iceberg plough mark boundaries.

GB_M#1 at 58°56.8'N 13°48.4'W and a narrow depth range of just 428-430 was also on the summit of the Bank. The seafloor here is entirely clean pitted (by biological activity) coarse sand, with rare and isolated dropstones, the largest of which have halos of gravel lags.

On the eastern flank at 700-800 m water depth (e.g. at 58°57’N 13°32’W) are several series of partial concentric rings and elongated striations showing marked backscatter change. These areas are very narrow in the E-W direction and elongated parallel or sub-parallel to the contours, suggesting that there is significant benthic (geostrophic) current activity in this direction. The actual seafloor type associated with these elongated features is unclear, though the backscatter level suggests that they may be of sedimentary origin rather than outcrop. Further down-slope at about 1,150 m (ca. 58°57’N 13°25’W) the backscatter shows distinct slope-parallel lineations of high backscatter, which on the CHIRP are imaged as a series of small (10-15 m) step-faults, the hanging walls are the high backscatter areas on the EM120 backscatter mosaic (Figure 46).

GB_J#1 at 59°04.1’N 13°29.1’W has a depth range of 1112-1152 metres. This site was focussed on an area of generally very high backscatter and the occurrence of many large blocks, possibly also outcrop, on the 500 kHz sidescan sonar. The upper part of the transect images a smooth biogenic sandy seabed that becomes populated with dropstones (including gravel halos) down-slope. Individual gravel-to-boulder sized clasts become more common further down-slope, and eventually a thin outcrop, forming an overhang is imaged (Figure 47a). Below this the seafloor is a mixture of outcrop mostly partially obscured by overlying sands, with large gravel-haloed boulders and eventually, near the end of the tow, massive outcrop (Figure 47b).

Further down-slope from the step-faults imaged by the CHIRP and backscatter mosaic and outlined above, the EM120 backscatter mosaic shows an area of high backscatter, approximately 7 Km across (east-west) running parallel to the contours. Where imaged by the CHIRP profiler, the high backscatter areas on the EM120 mosaic correlate with an area of steep slope and basement outcrop that upslope, merges into a zone of very high seafloor reflectivity and hyperbolic echoes (e.g. at 58°51.5’N 13°21.0’W). These characteristics strongly suggest a zone of intense current activity and it is likely that seabed erosion is occurring here (Figure 48).

GB_E#1 at 58°52.2’N 13°21.2’W and a depth of 1071–1291 metres is located over the east flank erosion zone described above and imaged in Figures 46 and 48. The camera reveals a seabed of coarse biogenic sandy gravel with outcrop and/or large boulders (Figure 49a) over the whole of the photo-transect. The outcrop mostly takes the form of massive, sometimes jointed rock, mostly blackened, but also with in places iron-staining, suggesting it is probably basaltic (Figure 49b).

The erosive zone described above is continuous around toward the southeast flank of George Bligh Bank, the backscatter mosaic imaging textures, and the CHIRP imaging topography again typical of that over an erosive area.

GB_F#1 at 58°47.9’N 13°24.1’W, was a transect down the flank of George Bligh Bank between depths of 1078–1338 metres. Over most of this transect the seabed is composed of massive iron-strained outcrop and/or large boulders, with coarse biogenic gravel and sand forming aprons around the outcrop (Figure 50a). Whilst much of the outcrop has varying amounts of sand deposited on the rock, many areas are also very clean, presumably a combination of slope angle and current washing (Figure 50b). At the base of the slope, the outcrop vanishes and the seabed is composed of coarse biogenic gravely sand (Figure 50c).

The moat around the base of GBB deepens from north to south, being in excess of 1,650 m where multibeam coverage ends in the south. At the eastern edge of coverage (and continued along SAMS1), the edge of the drift-like deposit is imaged, showing a uniform level of backscatter. The CHIRP images a well-stratified sequence of reflectors to over 30 m sub-bottom. An unusual feature is imaged on the backscatter mosaic centred at approximately 58°43.0'N 13°23.2'. It is an almost circular highly backscattering area approximately 500 metres in diameter, coincident with an indent in the contours. The CHIRP does not cross the feature, and although it runs close by it images just a slight depression in the seabed and an un-interpretable side-echo.

The size and number of slide-scars change considerably between the eastern and southern margins of George Bligh Bank. There is one large (~11 Km across) scar on the southeast flank at approximately 1,000 m depth, and along the southern slope of the Bank between 850 and 1,200 m are a number of smaller, crescent-shaped slide-scars, each with the apex of the crescent up-current (toward the east). Apart from the single long slide-scar on the eastern flank, the others are masked to a great extend on the EM120 backscatter by the general high backscatter levels so that their shapes are difficult to determine accurately. However, they are well defined on the shaded relief bathymetry maps.

At about 700 m on the southern flank of the Bank (58°48'N 13°45'W), the backscatter shows a complex pattern of medium-high backscatter (Figure 51). These backscatter features show an apparent random orientation, similar to, though less jagged than the patterns seen over plough-mark areas. They have a randomness to their orientation such that they appear like gigantic grazing trails; however these features are several hundreds of metres across. Their acoustic character on the CHIRP data is not particularly diagnostic showing both hyperbolic mounds and possible step-faults in a near-surface acoustic basement with just a thin veneer (~1 m or less) of sediment cover. A similar acoustic texture is also imaged at 58°44'N 13°37'W, which lay just above the zones of erosion discussed on the previous page. It is probable that the backscatter patterns are merely due to varying thicknesses of loose surficial sand over a firmground.

500 kHz Sidescan Sonar transect

For operational reasons the 500 kHz sidescan transect was begun just outside of the area of plough-marks over the George Bligh Bank summit. The sonar transect is remarkable for the overall low intensity of acoustic backscatter over the length of the single down-slope run[α]. There are just a few areas exhibiting any form of high backscatter and these are over areas of blocks (dropstones?) or outcrop. The low backscatter exhibited may possibly due to an overall high current regime and well sorted surficial sands.

Figure 52 is a schematic overview of the geomorphology, surficial seabed geology and benthic current activity over George Bligh Bank as derived from the 2005 *SV Kommandor Jack* survey.

[α] There is a possibility that the low backscatter levels were due to a technical problem, however, even if this were the case, it is the relative backscatter levels over this transect that are important.

12 ROSEMARY BANK

There have been a number of studies of Rosemary Bank, mostly dealing with the ancient geological history of the feature (e.g. Hitchen et al 1997), with one (Pudsey et al 2004) reporting the initial multibeam survey of the deep flanks of the Bank.

The 2005 *SV Kommandor Jack* survey encompassed most of the summit area above ~1,000 m, which overall forms a gentle dome with discreet parasitic volcanoes forming groups over 10 Km across. The summit depth averages about 500 m, however the individual parasitic cones take the shallowest areas to less than 350 m. Across the centre of the summit, especially between 59°10-15'N 10°10-20'W, shaded relief maps show subtle hints of what appear to be sediment waves, the CHIRP showing that these features are merely reflecting an acoustic basement topography. These "waves" do not have any expression on the backscatter mosaic (Figure 53).

The entire summit area appears covered by sediment, with no evidence on the acoustic backscatter of outcrop, and even though the flanks of some of the parasitic volcanoes show very strong backscatter, the CHIRP profiles across these volcanoes indicate that there is some degree of sediment cover (at least on all of the slopes that are resolved by the profiler).

Also clearly detected above 500 m are the distinctive trails left by iceberg plough-marks. The irregular, randomly orientated couplets of high and low backscatter are focussed in a small area right in the centre of the summit. Other changes in backscatter levels over the summit can be correlated with distinct changes on the CHIRP profiles, and these are interpreted as local lithological changes. Generally the CHIRP images a shallow acoustic basement at about 5 m, however toward the eastern flank the surface sediment thickness above the acoustic basement increases to about 12 m.

Multibeam data from the *RRS James Clark Ross* (Pudsey et al 2004) has been combined with that from the *SV Kommandor Jack* to give a complete image of the entire Bank (Figure 54). This shows that the summit area has a break of slope at about 1,050 metres on its northern flank, whereas it is at around 1,200 metres to the west and 1,400 m along most of the south flank. The eastern side of the Bank gently curves down so that it merges with the moat. The larger overview given by the additional data also shows that the parasitic cones actually form 3 loose groupings, that on the northeastern summit forming as deep as 1,300 metres up to 800 metres, those described above in the central summit region, and the third grouping on the western flank of the summit that form in 1,100-450 metres waterdepth. The Bank itself has very steep banks around most of its flanks, with slope angles of 20-40º common. These steep slopes are the inner bound of a dramatic moat that encircles the entire Bank, the southern part of the moat floor lay up to 400 metres below the surrounding seafloor of the Rockall Trough. On the northern side of the moat around 59º15'N 10º51'W, the effect of the benthic currents have produced deeps, here interpreted as erosional deeps. The "tails" that run to the southwest away from these deeps have been imaged by high resolution seismic profiling and interpreted by Howe et al (2006) as sediment waves. In this region however the bottom current dynamics are not well understood and from the various seismic lines that are available it is apparent that "cut and fill" sedimentary architecture is common, so that it is possible that both constructional sediment wave architecture and erosional scours can be adjacent and may even be coeval. However whether they are active or relict features will remain an open question.

Elsewhere within the moat the geomorphology appears quite smooth reinforcing that it has been sculpted by currents. Although the entire Bank is moated, the deepest part of the moat is on the west of the Bank where it reaches over 2,300 metres.

Figure 55 is a schematic overview of the geomorphology, surficial seabed geology and benthic current activity over and around Rosemary Bank as derived from the 2005 *SV Kommandor Jack* and the *RRS James Clark Ross* surveys.

13 ROCKALL-HATTON BASIN

There was a single transit across this bathymetric low that produced a stunning image, possibly the first, of polygonal faults at the seabed (Figure 56). The surface expression of the polygons are as a series of lineated seafloor depressions of up to 5 metres in depth , surrounding individual seabed 'plates' which are typically around 3 Km across.

Polygonal faults are known and have been mapped extensively in various marine geological settings, but only with seismic profiling, as sub-bottom features. This particular field of polygonal faults had been similarly mapped previously by the British Geological Survey (D Long, pers comm.), but the *SV Kommandor Jack* cruise produced the first plan views. In other areas polygonal faults are know to be pathways for fluid escape, therefore these features may potentially be sites of unique faunal assemblages.

14 ROCKALL TROUGH

The data for this overview was provided by the *RRS Charles Darwin* 174 survey run by the British Geological Survey (BGS), and only bathymetry data have so far been obtained. As these data are still being analysed by BGS this description must be limited to a brief overview only.

The lower Hebrides slope between Anton Dohrn and the Hebrides Terrace Seamount shows very clearly the impression of a series of superimposed, now buried, debris flows (Figure 57). To the south, and especially southwest of Anton Dohrn Seamount, a sediment wave field is brought into sharp focus by the DTM sun illumination, with the long axes of the sediment waves trending ~025º-205º, though by 12º30'W this field is replaced by a smooth seafloor that runs westward to the foot of the Feni Ridge. There are suggestions in the DTM of a limited shallow channel system around 57º03'N 12º20', but the channels seem to start and end without obvious reason and what is imaged may be a footprint of a relict system.

15 HEBRIDES TERRACE SEAMOUNT

Only a portion of the Hebrides Terrace Seamount lay within SEA7, the remained is in Irish waters. The data for this Seamount was obtained from IFREMER, France, and even though the survey was in UK waters they only provided a coarse grid of data (500 metre grid-cells), thus the description and conclusions here will be at best tentative.

The Seamount is an elliptical feature approximately 40 Km by 27 Km. It rises from the foot of the continental slope between 1,650 metres and 2,000 metres, rising to a minimum depth of around 1,000 metres. There are hints of gullies on the DTM however the coarse grid precludes identification of any further detail.

16 WEST HEBRIDES CONTINENTAL SLOPE

The multibeam data along the continental slope comes from two sources, the LOIS study (British Oceanographic Data Centre 1999) and the low resolution IFREMER grid (the same as for the Hebrides Terrace Seamount). Again only bathymetric data is available, no acoustic backscatter.

The overall slope of this part of the margin is 5º-10º. South of 57º15'N, which is the northern limit of the Barra slide, the slope is extensively gullied, though they are not that deep, mostly around50 metres. The heads of the gullies are formed at around 340 metres and they mostly lose their character by 1,600 m waterdepth where they feed into the slide deposits described above. North of the gullied region the slope is smooth, presumably due to a combination of geostrophic currents and the fact that the slope here has not been subject to large-scale mass-wasting. There is also a distinct notch paralleling the slope, similar to that seen on the East Rockall margin, at 1,000-1,100 metres waterdepth.

17 PREVIOUS STUDIES WITHIN SEA7

There have been numerous studies in the SEA7 area, mostly focussed upon the deeper geological structure, the opening of the North Atlantic Ocean and Rockall Trough, and looking at the potential for hydrocarbon formation and reservoirs. Virtually all of these type of studies have virtually ignored the surface and the active processes, or the few studies that have looked into these have done so on a regional basis using unsophisticated instrumentation and extrapolating features and processes to areas that the current detailed studies have shown to be perhaps rather speculative.

There have been a few focussed studies along similar lines as this, principally the AFEN studies of 1996 and 98 (GEOTEK LTD et al 2000), the conclusions and recommendations of which have been included in the relevant sections above. Other significant collections of surficial data are two GLORIA surveys run in the 1980’s. Both were a DTI-funded cruises (at least in part), one covered much of Hatton Bank and parts of the Rockall-Hatton Basin, and a second was a cruise that collected data along the western UK continental shelf and slope. Neither of these valuable data sets that use surface roughness (i.e. probable analogues for “reef” environment) have been worked up for use on the SEA studies.

Other studies have included significant effort by physical oceanographers looking at large-scale circulation and also by benthic biologists looking at specific areas and transects over many years (e.g. the “Ellett Line”, Ellett and Jones 1994, Holliday 2003), and the LOIS study (Land-Ocean Interaction Study) which took place on the west Hebrides shelf and slope in the mid-1980’s (e.g. Plymouth Marine Laboratory 1999).

18 OVERVIEW AND SUMMARY

This report is largely based on the results of the *SV Kommandor Jack* cruises funded by the DTI during the summer of 2005, with some additional information gleaned from the few previous detailed studies within SEA7. It has highlighted how few high resolution studies have been undertaken within the deep water SEA7 region and how variable the seafloor is within very small geographic areas. There have been a number of unexpected discoveries almost all through unusual geomorphology indicating the presence, at some time, of very strong benthic and/or geostrophic currents.

The SAMS transects were planned as biological transects, but results overtook the planning and apart from SAMS2 where it crossed the Rockall Plateau, effort was focused in the other survey blocks. SAMS1 was an unremarkable transect mostly over the deeper parts of SEA7 and there were no significant findings. SAMS2 crossed the Rockall Trough and Rockall Bank to the 370 m isobath on its western flank. The crossing of Rockall Trough revealed nothing significantly new about the geomorphology of the area, although the CHIRP data did provide an excellent illustration of buried slide deposits at the base of the Hebrides continental slope. In the area of the 2005 survey transect, Rockall Bank has a gently convex surface, with a water depth minimum of around 150 m. Iceberg plough-marks are well-imaged on both flanks of the Bank, the central portion being dominated by complex bedforms of sands, gravels with in areas significant bedrock outcrop. These interpretations of the remotely sensed data are reflected in the limited photographic stations that show typical high energy assemblage of coarse sands, broken shell, gravel and rock outcrop. SAMS3 is very similar to SAMS1 in that nothing particularly new was revealed on this single transect and there were no photographic stations.

The NE Rockall Basin data collection exercise revealed some of the serious limitations that become apparent when trying to undertake habitat investigation with a relatively low resolution tool such as an EM120 swath system. These limitations are especially highlighted in areas of subdued topography or extensive sediment cover. The studies of 1996 and 1998 have proven exotic habitats and fauna in the centre of the basin however none were detected by the low resolution (large) footprint of the EM120 multibeam system. Thus the principal summary of this region is taken from the AFEN reports. The present day sedimentary environment of the continental slope is dominated by low sediment input and deposition rates and reworking of surficial sediments by bottom currents. Carbonate mounds occur in the northern part of the NE Rockall Basin, the mounds had numerous colonies of the deep-water coral *Lophelia pertusa* and exhibited unusual ‘tail-like’ sediment areas, visualised by sidescan sonar, downstream of the carbonate mounds that were found to harbour high density populations of the xenophyophore (‘giant protozoan’) *Syringammina fragilissima*.

Anton Dohrn Seamount, has been known for a considerable time to be a steep-sided domed feature standing alone in the centre of the Rockall Trough. However this is the first time that modern navigation and sounding techniques have allowed its definition as having a diameter of around 45 Km, and a vertical relief of between 1,500 and 1,600 metres. It has almost sheer walls of over 1,200 m in height, with a “dome” across the summit region shoaling to ~550 m in the centre of the seamount. The seamount is moated to ~150 m below the regional depth of the Rockall Trough. There are no significant canyons or gullies down the seamount flanks, the only “ornamentation” are a few small, steep hills, probably parasitic cones that sit adjacent to the seamount on its eastern and north-western flanks. The relief across the summit takes the form of a dome with basaltic outcrop at its centre. Very high resolution studies suggest that there may be opposing currents affecting opposite sides of the seamount summit (northward to the west and southward to the east). Photographs indicate a generally high energy environment across the summit of the Seamount, with coarse sands, gravel and broken shell common. Outcrops, where imaged and not encrusted, show common iron-staining and jointing. Off-summit, there is a talus slope with a drop of 315 m and photographs reveal the sediments are finer grained, though gravel lags behind dropstones suggest currents are at least intermittently strong.

The East Rockall Margin physiographic area, though very large, can be dealt with as four distinct physiographic provinces, each of which has its own characteristics. The southernmost area runs from the UK-Ireland boundary to around 57º20’N and is characterised by a shelf break at 350-400 m, a steep (10-20º) highly incised upper slope that drops to around 550-600 m. Adjacent to and 100-150 m above the floor of a narrow moat at the base of the slope stands the crest of the Feni Ridge, a large and extensive sediment drift. Below the Feni Ridge the seabed is a mostly a smooth slope, with a contour-parallel step of about 100 m in height at 1,100 metres, probably reflecting deep geostrophic current activity. The only other significant features on the lower slope are a couple of small canyons, up to 100 m in depth that start approximately on the 1,000 m contour and stop above 1,500 m, and a 4 Km wide sediment slump or small landslide. Iceberg plough-marks are common above the shelf-break, and small areas of relict slope failure deposits are found below 1,000 m. The second area lay between 57º20’N and 57º50’N where the orientation of the margin turns to the north. The steep upper slope drops to around 700m, and the eroded bights are elongated to the north, but below 800 m, apart from a couple of small mid-slope canyons which may bound an area of historic slope failure, the slope is much more regular and smooth. The third area runs from 57º50’N to 58º20’N, and is the area where the orientation of the slope turns further westward. The shelf-break is at about 350 m and the base of the steep (>20°) upper slope is at 600 m, below which are indications of slope failure deposits. The Feni Ridge is not developed along this part of the margin, which is imaged as a current-swept slope. At about 13º45’W there is evidence of a slope failure on the upper slope, and below 850 m, a now-eroded slope failure deposit. The final distinct area is west of 13º50’W where the Rockall Bank margin includes the bathymetric saddle between George Bligh Bank and Rockall Bank, where the continental slope becomes topographically complex and has a slope angle lessens to around 2°. A series of curved erosive scours up to 120 m deep that form a long sweeping arc define the northern edge of the Rockall Margin.

Central Hatton Bank revealed two distinct seafloor types. Firstly a series of elongate, en-echelon lineated highs and (frequently associated) troughs, and secondly a series of lineated troughs or perched basins, neither feature showing any apparent relationship with the gross regional morphology of the Bank. The en-echelon ridges and troughs lie across the crest of the Hatton Bank mostly at depths of 500-600 m though some can be seen as deep as 800 m on the western flank of Hatton Bank, and, within our survey box, they appear to be centred about 18°W. The features appear to be focussed along two orientation planes, just south of E-W and NE-SW. Individual ridges vary from 10 to >20 Km in length, and over their narrowest dimension the ridge-trough couplet are about 10-15 Km in width. Acoustic backscatter suggests rock outcrop over along most of the scarp faces of the ridges; this outcrop was almost always covered in biological growth (corals and sponges). Photographic studies revealed that a usual transect across these features consisted of sands at the top of the scarp slopes, with outcrop and biogenic and rock rubble forming the scarp slopes, with rubbles and gravel lags at the base of the slopes. The perched basins formed smooth sculpted hollows up to 100 m deep, and lay along a trend, extending for over 40 Km in a NE-SW direction. They appeared to be confined to a narrow slope parallel zone of only about 10 Km in width.

The West Hatton Bank Margin has been surveyed in detail though the data were not subject of an intensive interpretation for this study. North of 59º30’N the margin is likely dominated by geostrophic processes, with at depth ancient volcanic constructions being important. West of 16º30’W and above 1,800 m is a smooth, occasionally incised slope, though at dept, and especially south of 59ºN and west of 19º30’W, en-echelon features dominate the gross morphology. The rest of the margin to the southwest is dominated by the complex topography and volcanic edifices of the volcanic ridge of the Endymion Spur.

Features of note on George Bligh Bank include on the northern flank a couple of distinct 100m-high mounds, both of which show gravely sand with varying amounts of coral growth. Over the summit, iceberg plough-marks are restricted to areas shallower than 500 m, some are highly backscattering others are not. Photographic transects show the seafloor consisted mostly of sands with clean, washed boulder trails that are probably the lag-deposits of washed-through iceberg plough mark boundaries. On the eastern flank small step-faults are imaged by remote sensing and ground truthing reveals coarse sands, gravels, boulders and outcrop. Around the southern margin of the Bank are a number of erosive scars indicating high current flow into the Rockall-Hatton Basin.

The summit area above ~1,000 m of Rosemary Bank forms a gentle dome with discreet parasitic volcanoes forming groups over 10 Km across. The summit depth averages about 500 m, however the individual parasitic cones take the shallowest areas to less than 350 m. The entire summit area appears covered by sediment, with no evidence on the acoustic backscatter of outcrop, even the flanks of some of the parasitic volcanoes do show very strong backscatter. Also imaged above 500 m are iceberg plough-marks. The summit area has a break of slope at about 1050 metres on it’s northern flank, whereas it is at 1,200 metres to the west and 1400 m along most of the south flank. The eastern side of the Bank gently curves down so that it merges with the moat. The parasitic cones actually form 3 loose groupings, on the northeastern summit, in the central summit region, and on the western flank of the summit. The Bank itself has very steep banks around most of its flanks, with slope angles of 20-40º common. These steep slopes are the inner bound of a dramatic moat that encircles the entire Bank, the southern part of the moat floor lay up to 400 metres below the surrounding seafloor of the Rockall Trough. On the northern side of the moat the scour effect of the benthic currents have produced a dramatic seafloor morphology.

The Rockall-Hatton Basin is a bathymetric low where polygonal faults are imaged at the seabed. The surface expression of the polygons are as a series of lineated seafloor depressions of up to 5 metres in depth , surrounding individual seabed ’plates’.

The Rockall Trough is a large basin separating Rockall Bank from the European continental shelf. Features of note imaged here include on the lower Hebrides slope a series of superimposed, now buried, debris flows, to the south, and especially southwest of Anton Dohrn Seamount, a sediment wave field and indications of a limited shallow channel system around 57º03’N 12º20.

The Hebrides Terrace Seamount is an elliptical feature approximately 40 Km by 27 Km. It rises from the foot of the continental slope between 1,650 metres and 2,000 metres, rising to a minimum depth of around 1,000 metres.

South of 57º15’N the Hebrides continental slope falls away at 5º-10º. The slope is extensively gullied, with the heads of the gullies forming at around 340 metres and the gullies disappearing by 1,600 m. North of the gullied region the slope is smooth, though there is also a distinct notch paralleling the slope, similar to that seen on the East Rockall margin, at 1,000-1,100 metres waterdepth.

19 CONCLUSIONS

The surficial sediments of Rockall Bank are extremely variable and are usually coarse-grained sediments such as sands and gravel (often biogenic), with a continuum of sizes ranging up to boulders.

Across the Bank, outcrop and drop-stones form ideal substratum for encrusting faunas that include coral and sponges, though trawling and current activity may disturb colonisation.

It may be that over certain areas of Rockall Bank habitats may migrate and be otherwise modified by the action of tide, storms and benthic currents. It would be useful if experiments were devised to investigate whether this is of significant importance, and if so the periodicity of habitat modification.

Iceberg plough-marks are common on the flanks of Rockall Bank, and relatively easy to map using multibeam acoustic techniques. Reconnaissance survey lines zigzagging along the upper part of the Rockall Bank margin would facilitate production of a definitive plough-mark distribution map.

Anton Dohrn seamount shows evidence of opposing current flow on its summit which is a high energy environment and displays evidence of intensive trawling activity.

The eastern margin of Rockall Bank has a steep upper slope beneath a shelf break which is mostly at about 350 metres. This steep upper slope is an area of bedrock outcrop and also heavily incised into numerous small bights. Should hydrocarbon activity take place in this area, detailed environmental, oceanographic, and geotechnical studies will be required.

All along the east Rockall Bank mid-lower continental slope is evidence of land-sliding, and although much of it is old and the deposits are now eroded, the instability along the margin should be noted and investigated in detail prior to any substantial structures being anchored.

The growth of the Feni Ridge and the presence of the ‘notch’ at 1,100 metres indicates significant geostrophic current activity at several depths along the east Rockall Bank margin. Furthermore, the surface of the Feni Ridge, especially near its crest shows evidence of instability and erosion.

The elongate en-echelon ridge-trough couplets found over central Hatton Bank and the mounds that extend to the west are host to diverse reef communities.

The origin of the ridges and mounds are unclear, as is their relationship to each other and the deeper geological structural features of Hatton Bank.

The individual central Hatton Bank reef communities are separated from each other sometimes by up to several tens of kilometres. Using acoustic mapping techniques it is likely that with further mapping effort their overall occurrence can be well-constrained.

Strong current activity is a key component of where the central Hatton Bank reef communities are found, with clean, often rippled sands at the top of the colonised scarp slopes and washed gravel lag deposits at their bases.

Perched basins forming smooth sculpted hollows were discovered lying to the southeast of the en-echelon ridges on central Hatton Bank. They appear to be constrained within a narrow zone trending NE-SW, however their actual distribution and affiliation to underlying geology or geostrophic activity requires further survey and examination.

The west Hatton Bank margin is likely to host significant exotic fauna displaying as it does steep irregular topography indicative of bedrock outcrop and volcanic constructions, and contour patterns suggestive of geostrophic current activity. Interpretation of the multibeam data in this area would greatly improve understanding of the benthic current activity and biological habitats associated with a margin-ocean interface, though this may have to wait until the data are released for public display

George Bligh Bank is sculpted by strong geostrophic activity and erosive features are seen on both remotely sensed and photographic images.

The erosive bights are pronounced along the eastern flank of George Bligh Bank where they indicate southward benthic current flow, and are even stronger along the southern margin of the Bank where they indicate very strong erosive benthic current flow into the Rockall-Hatton Basin.

Further multibeam mapping around George Bligh Bank would enable accurate descriptions of benthic current pathways to be determined and, along with long term (~1 year) benthic current meter moorings be a sensible pre-requisite of any hydrocarbon exploration activity in this area.

The boundaries of iceberg plough-marks over the summit of George Bligh Bank are marked by boulder trails with all the fine material now washed out.

Gravely-sand mounds to the north of George Bligh Bank show indications of trawl damage to the colonising reef communities.

Rosemary Bank is an ancient volcanic construction over 75 Km in diameter and 1,500 metres in height, ornamented with a series of grouped parasitic cones.

The low-resolution remotely-sensed geophysical data used for this study did not indicate any areas of potential outcrop over the summit area of Rosemary Bank, though it is likely down the steep flanks.

The geomorphology of the entire Bank and its surroundings suggest that there is a dominant benthic current from east-northeast to west-southwest. Factors here include the shallow moats developed around some of the summit parasitic cones as well as the major moat developed around the base of Rosemary Bank.

The deep benthic current around Rosemary Bank appears stronger along its northern flank, resulting in the development near the western tip of the Bank what appear to be scours, adjacent and outside of the main moat, of over 250 metres in depth.

The polygonal faults previously mapped by deep seismic profiling in the Rockall-Hatton Basin and known to be pathways of deep-seated gases and liquids, were imaged by their surface topography, a feature largely un-reported in scientific literature previously.

The serendipitous discovery of polygonal fault traces at the seafloor in the Rockall-Hatton Basin proves that multibeam systems can detect exotic environments is areas of extensive sedimentation.

Further surface exploration of the polygonal faults is required using high resolution system such as sidescan sonar and photography, to determine the habitat types and any potential exotic fauna and/or fluid or gaseous discharges from the fault zones.

Seafloor mapping by hull-mounted multibeam systems provide the best terrain models, but due to the physics of acoustic propagation the resolution of such systems is less than ideal for detailed habitat identification.

Nevertheless using both the topographic models and backscatter mosaics from such systems allows identification of areas that can be interpreted as probable areas of outcrop, iceberg plough-mark and other types of terrain where the likelihood of benthic reef communities (coral, sponges etc.) will be high.

A serious shortcoming of multibeam system in deep water (over 200 metres) is that their relatively low resolution (compared to, for example, sidescan sonar) makes detection of unique or unusual benthic communities in basinal areas almost impossible (e.g. the Darwin Mounds).

Other existing data such as the GLORIA data should be interpreted and combined with recent focussed studies of surficial processes to give guidance as to the type of seafloor that can be expected over a significant portion of the SEA7 area, and its likelihood of being potential reef habitat.

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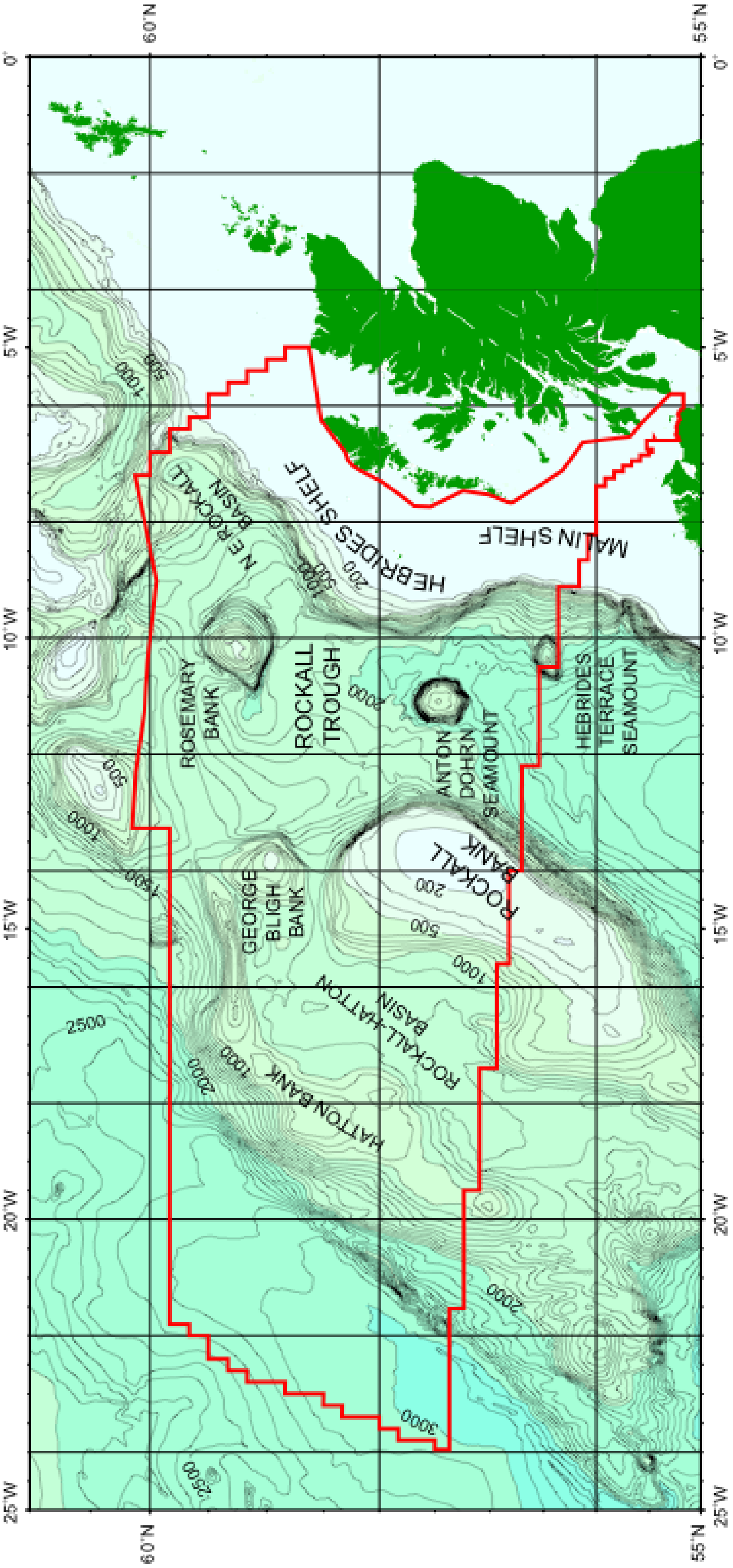


Figure 1. General physiography of the SEA7 area

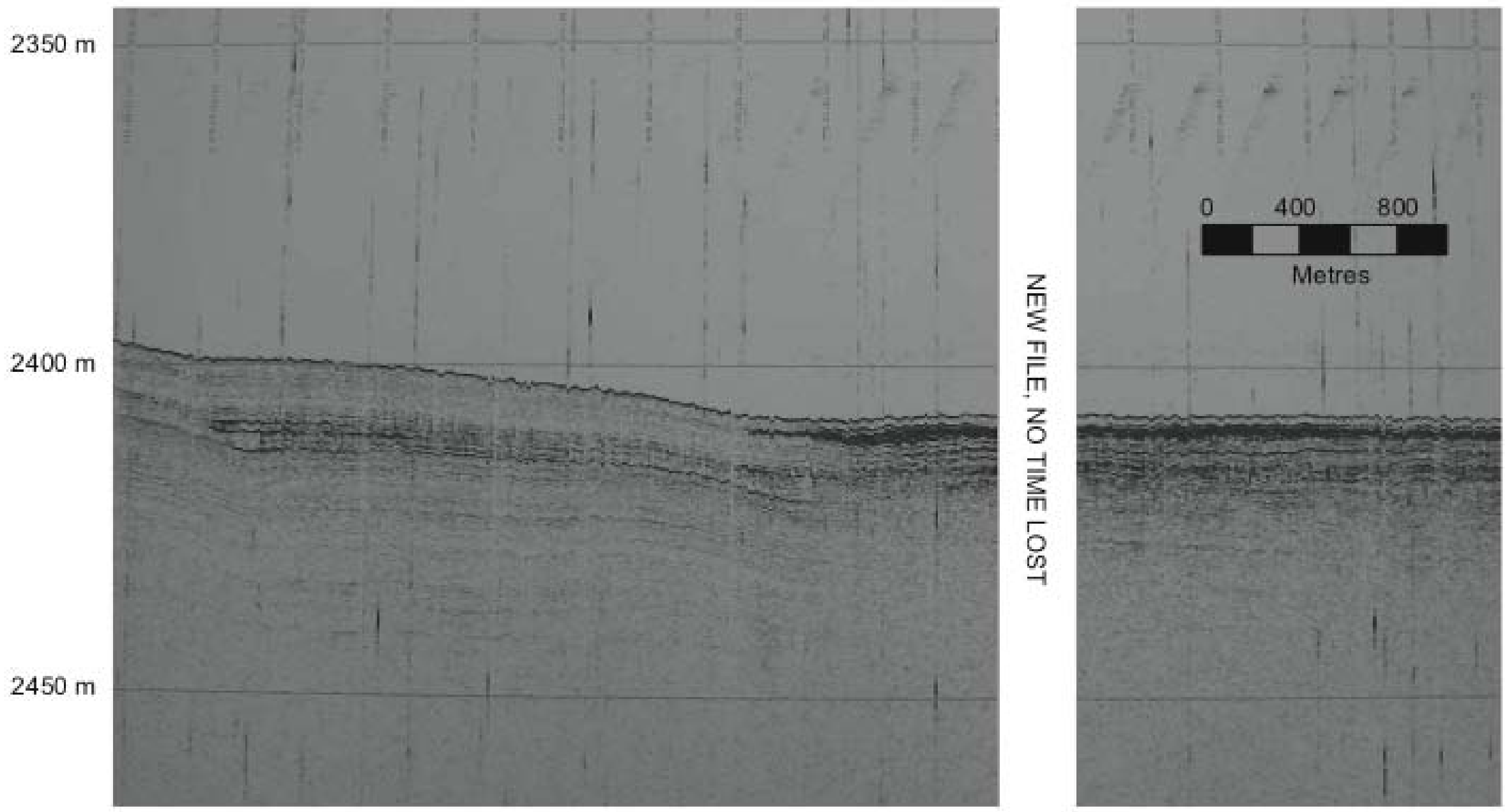


Figure 2. CHIRP profile showing high amplitude sub-bottom reflectors disappearing, and the almost acoustically transparent sediments that form the base of the Feni Drift

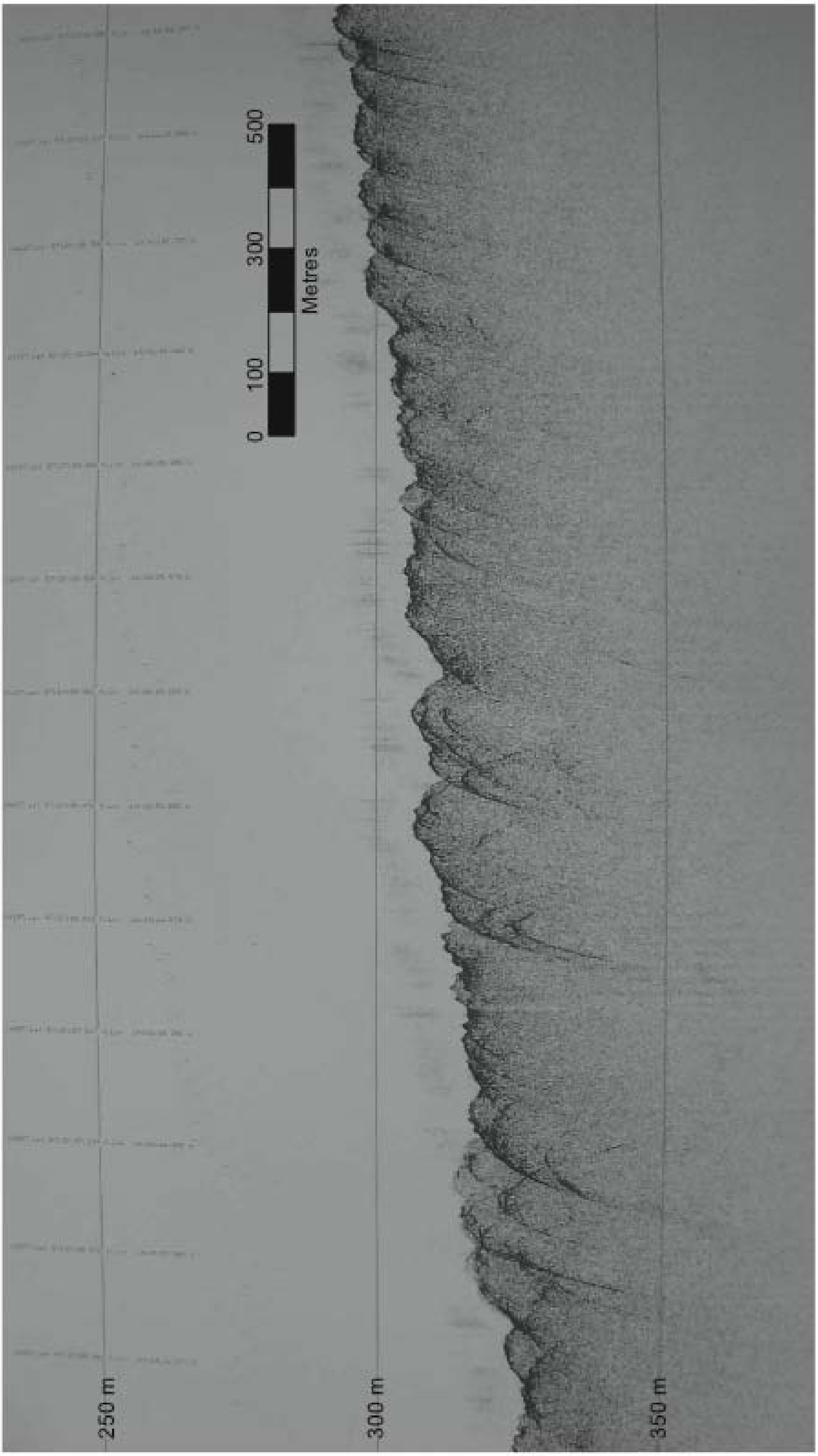


Figure 3. CHIRP profile showing prominent hyperbolae across the iceberg plough-mark terrain of the western Rockall Plateau at about 300 m waterdepth.

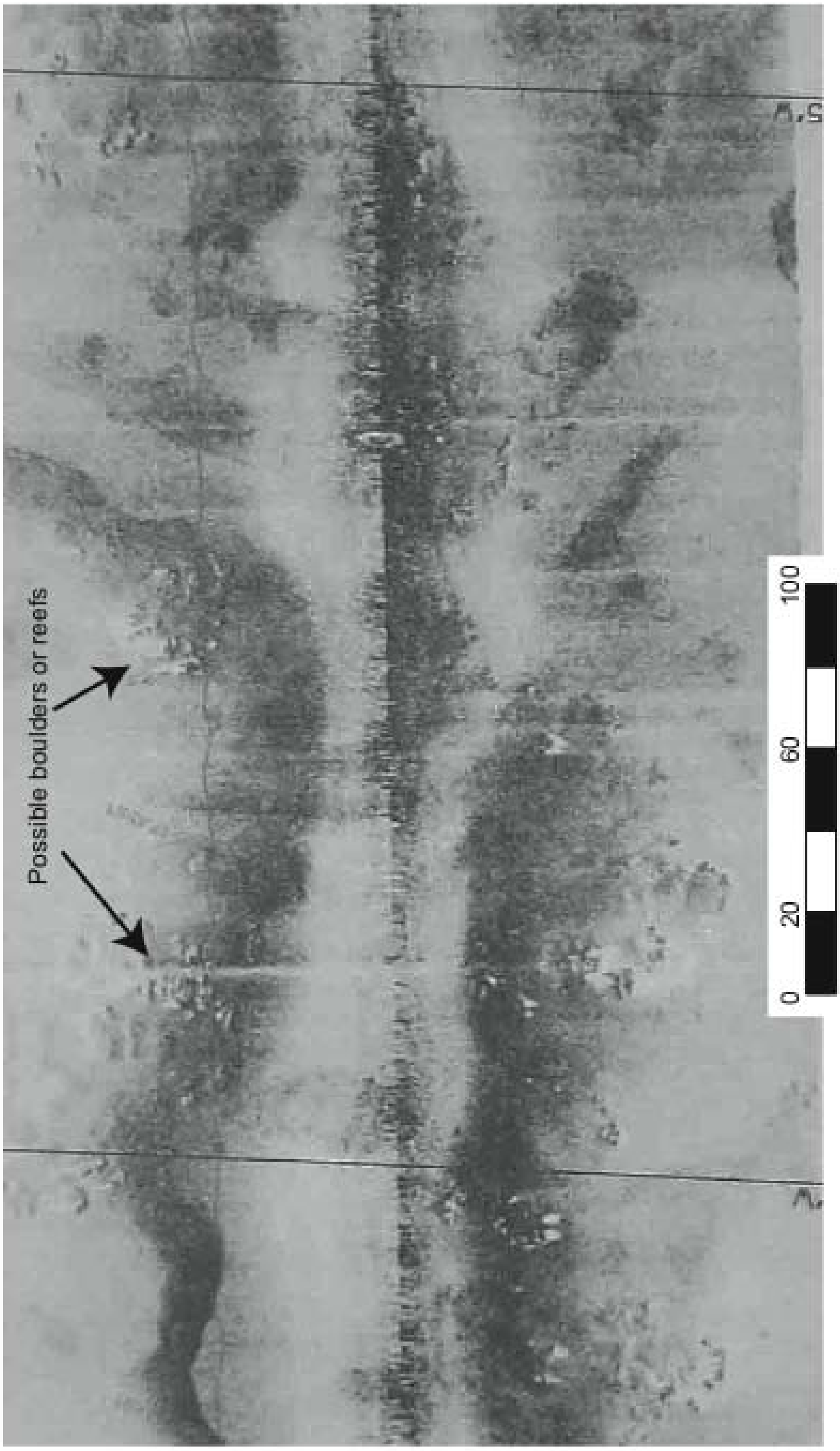


Figure 4. Iceberg plough-marks on western Rockall Bank delimited by irregular high-backscatter boundaries and low backscatter (light) infill, with structures that could be reefal or boulder

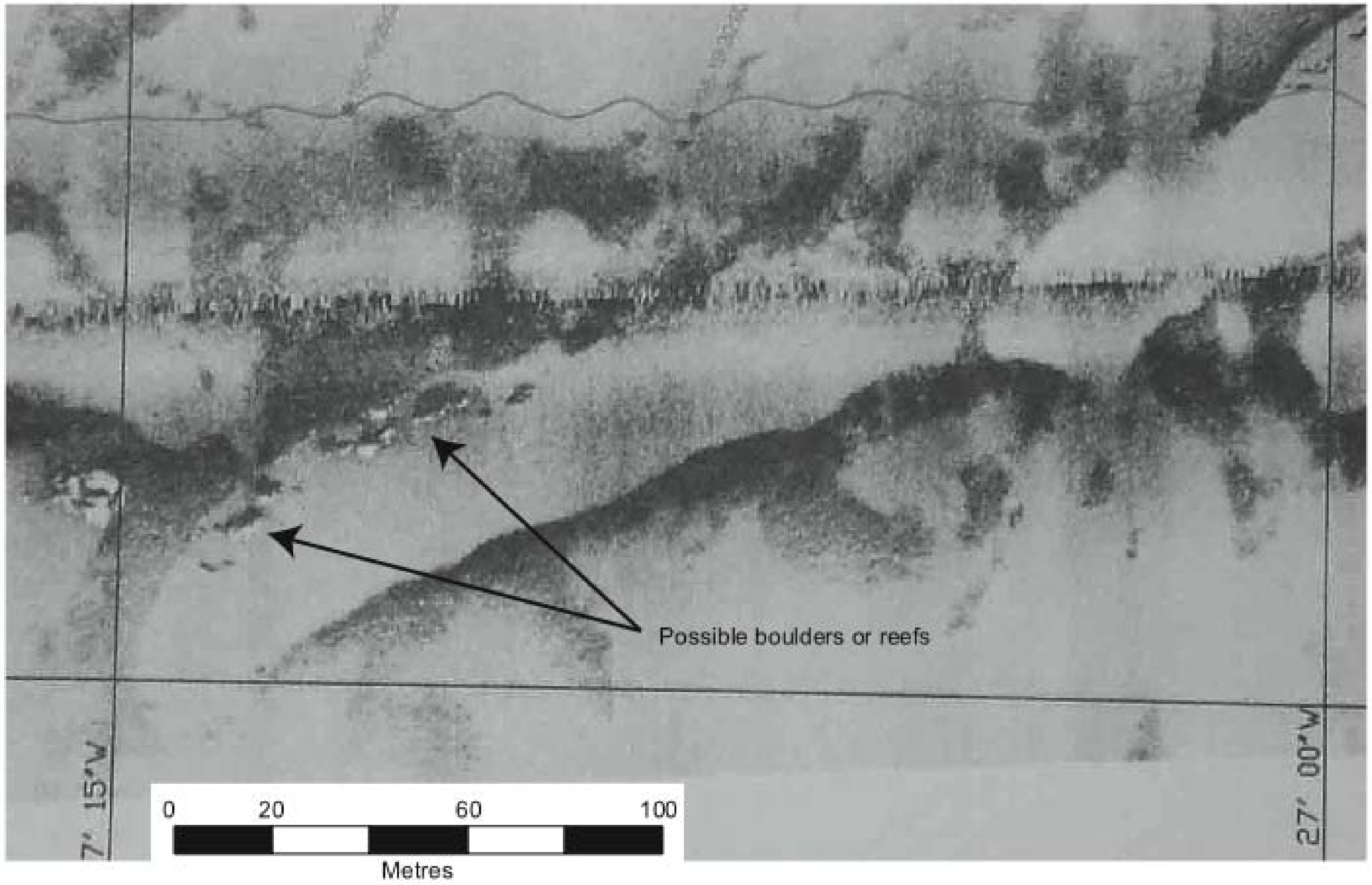


Figure 5. Example of well-developed iceberg plough-mark on the west-centre flank of Rockall Bank, with reef/boulder targets inside the central furrow.

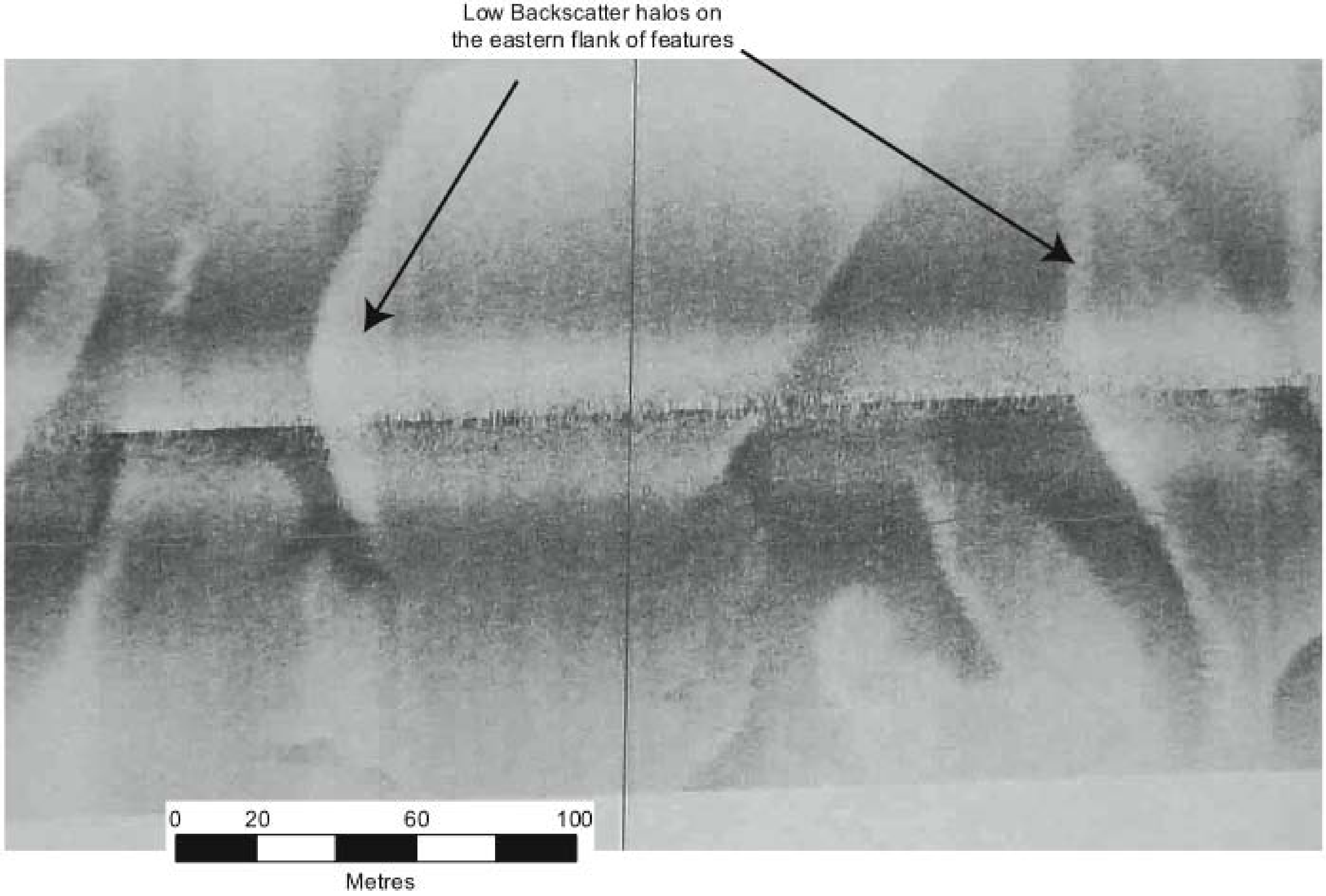


Figure 6. Barchan-shaped bedforms at about 200 m waterdepth on the eastern side of Rockall Bank, note low-backscatter halos along the eastern side of the features.

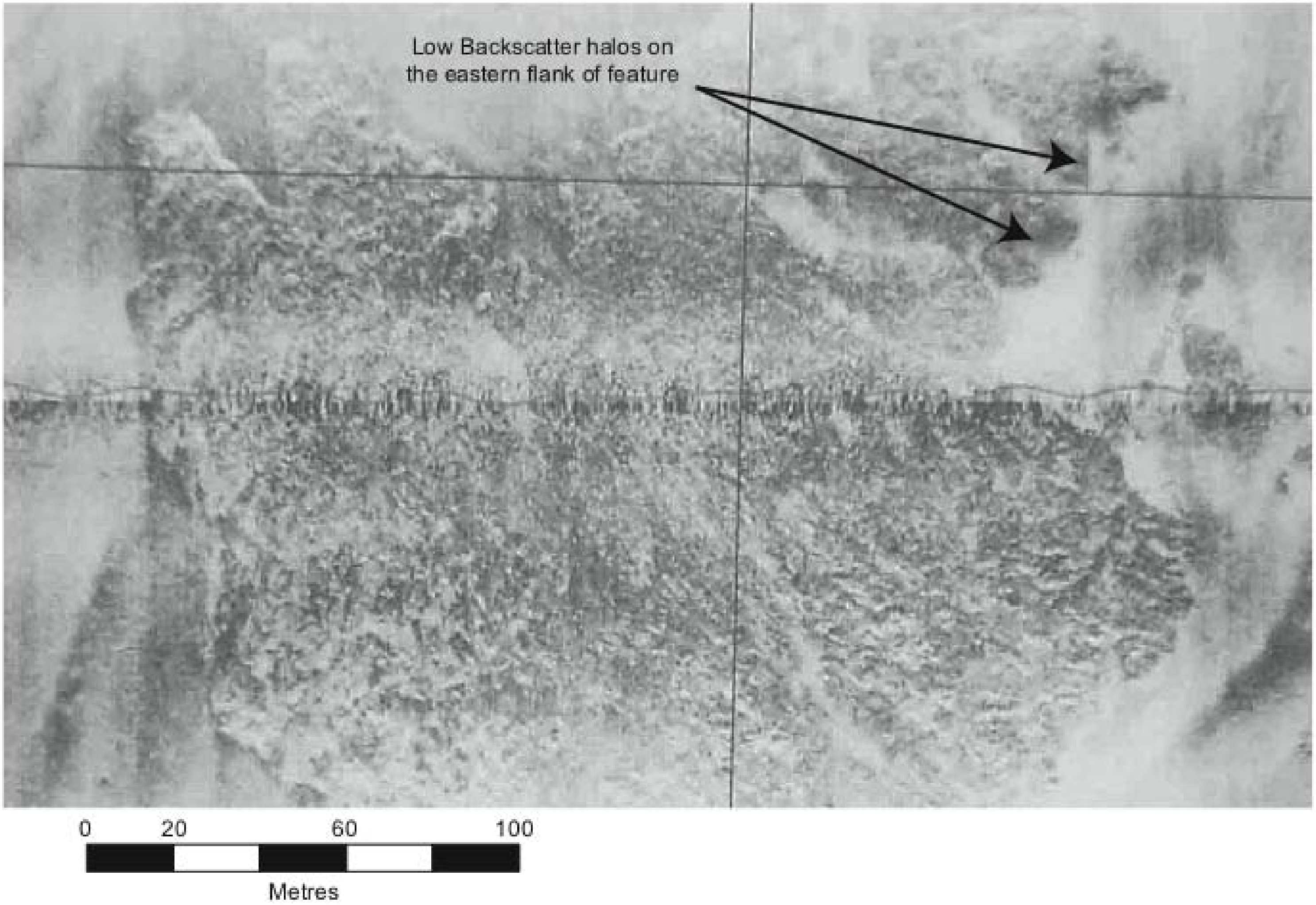


Figure 7. Inlier of rock outcrop on eastern Rockall Bank (57°29.0'N 13°20.25'W). Note the lack of structure and the low backscatter halos on the eastern side of the outcrop.

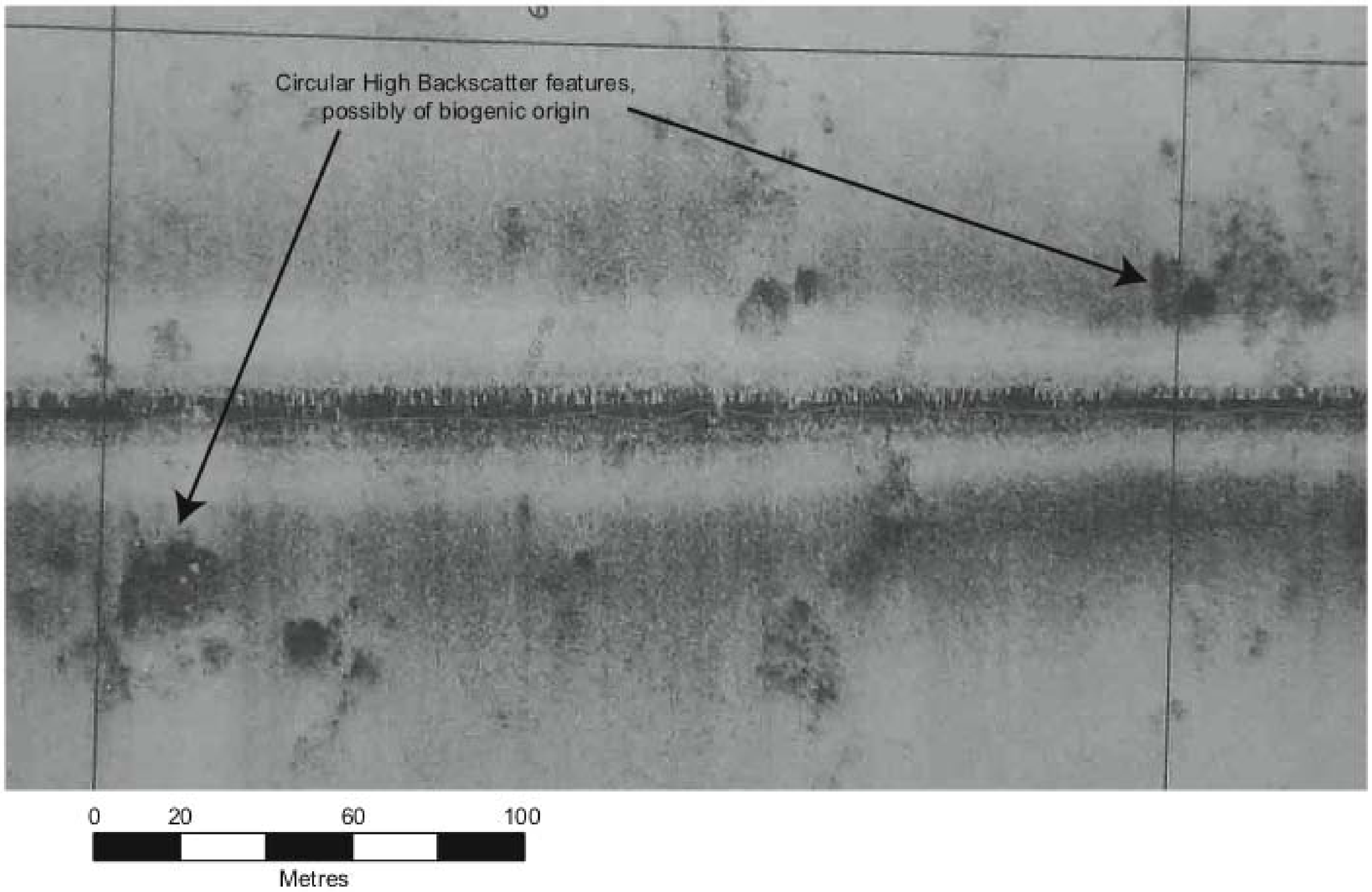


Figure 8. Circular (possibly biogenic) high backscatter features between 10 and 20 m in diameter within a generally medium backscatter zone on the eastern flank of Rockall Bank. There is a hint of a northeast-southwest fabric reflecting bottom current direction.

Figure 9. Sandy seabed with a probable relict partially buried rippled hard-ground, possibly the cause of the high backscatter zones illustrated in Figure 8.

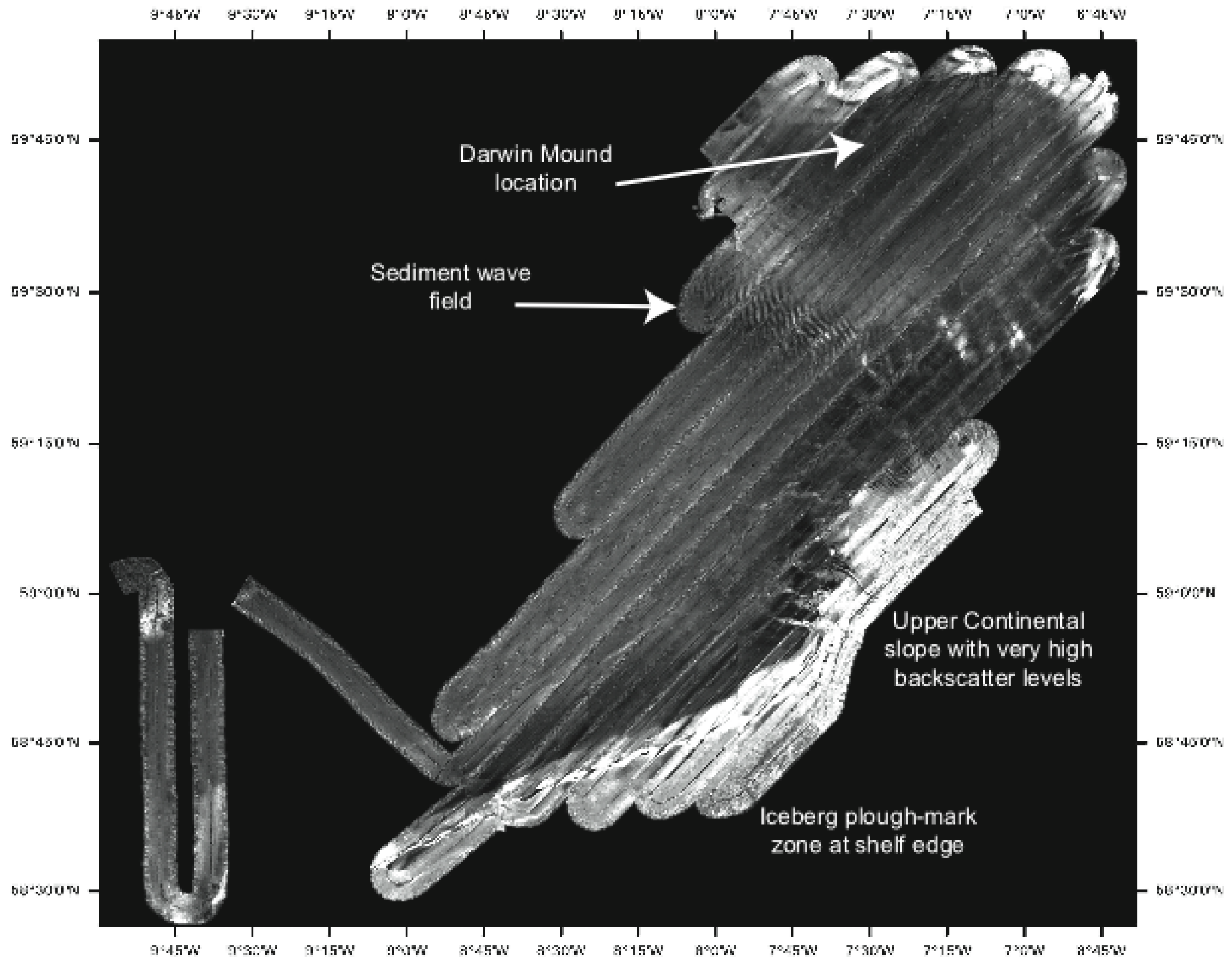


Figure 10. The mosaic of the 30 kHz TOBI sidescan sonar survey in the N E Rockall Basin. Note the huge variation in backscatter over the upper continental slope, the sediment wave field and (difficult to see at this scale) the coral colonies of the Darwin Mounds.

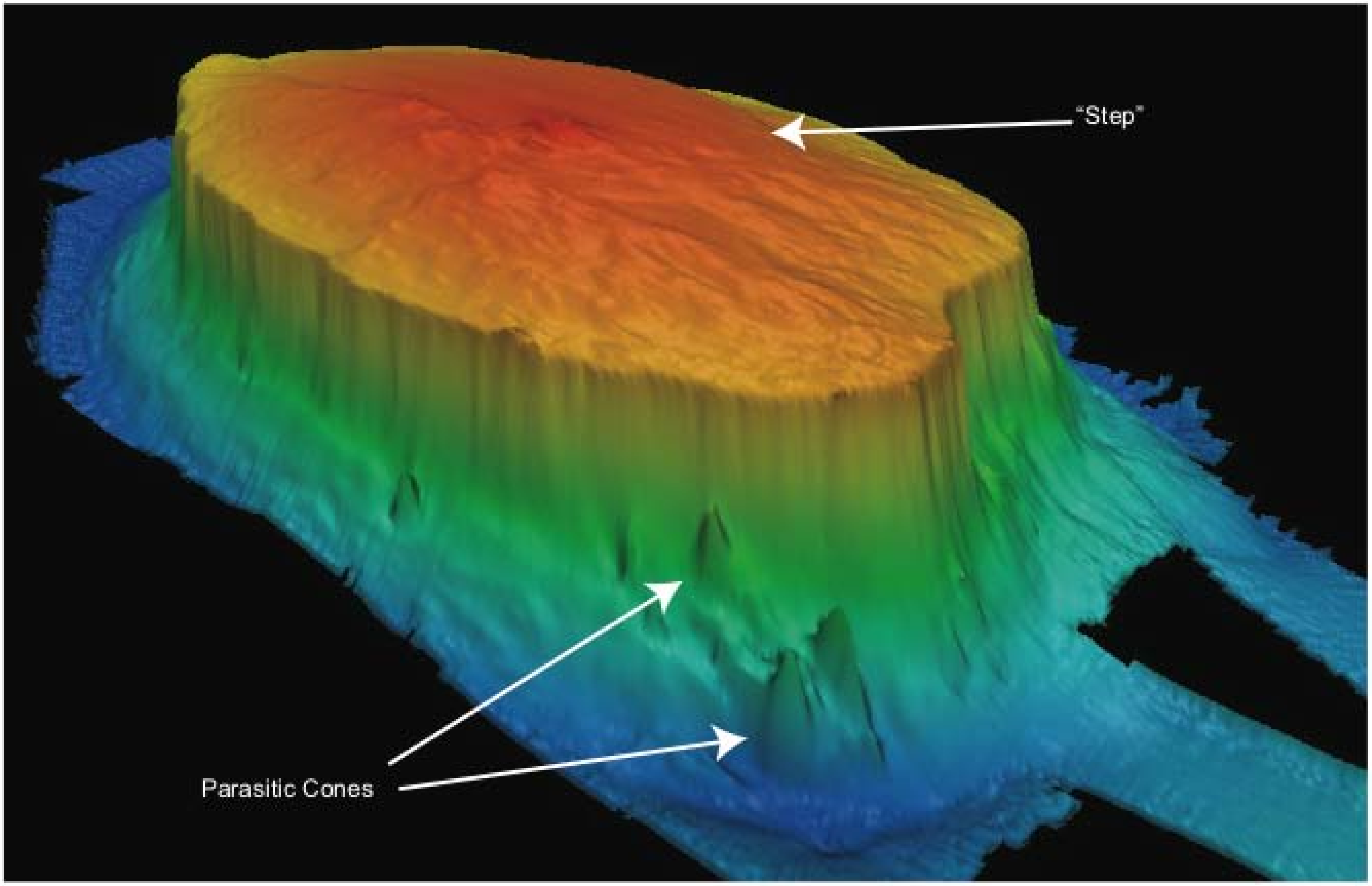


Figure 11. A 3D perspective of Anton Dohrn Seamount, showing the very steep walls and domed summit. The parasitic cones to the northwest are very clear is the rougher topography of the north-western summit area and "steps" on the southern part of the summit.

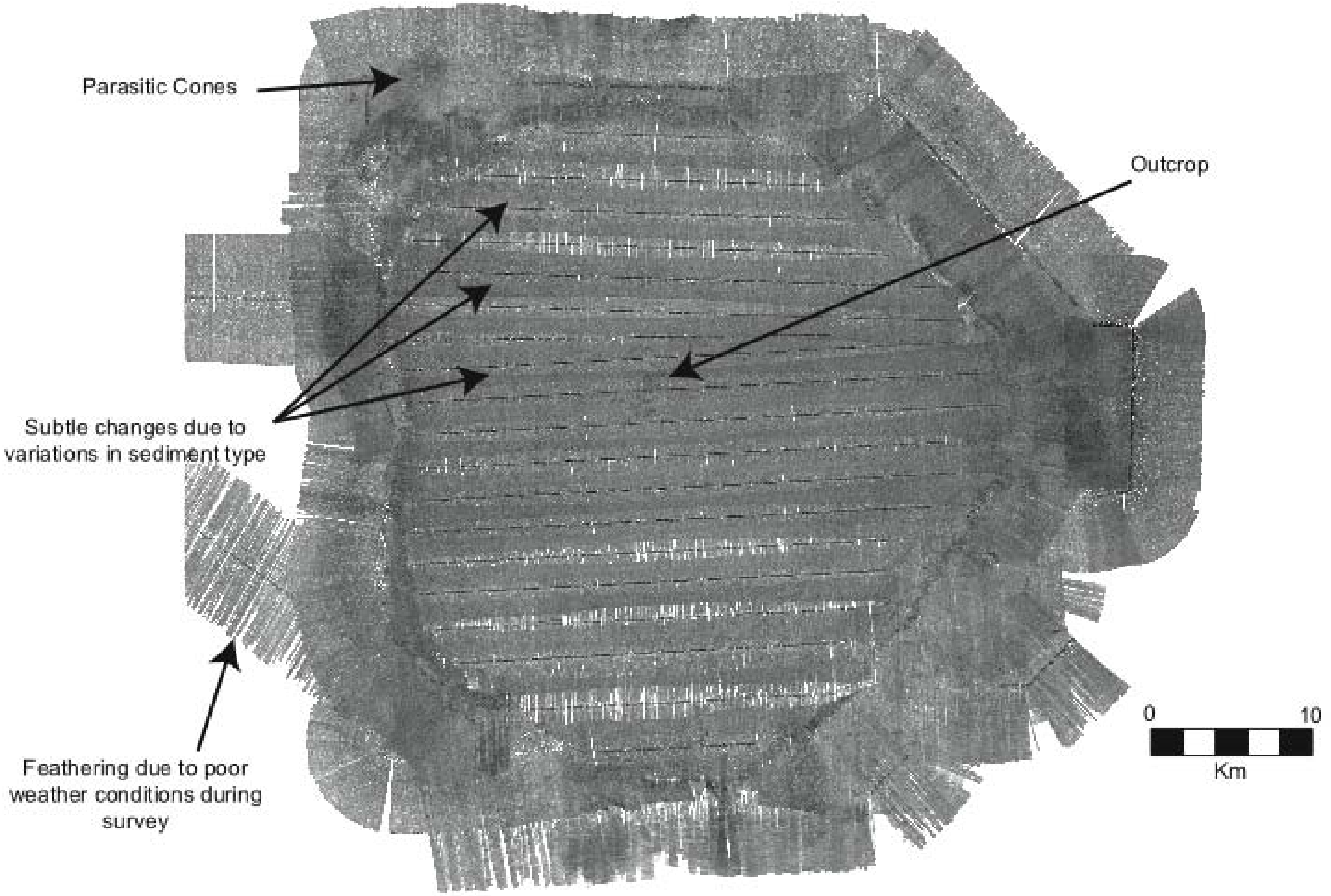


Figure 12 Acoustic backscatter over Anton Dohrn Seamount. The subtle changes over the north and west indicate changes in sediment type (see Figure 13). The "feathering" effect is due to bad weather during survey operations.

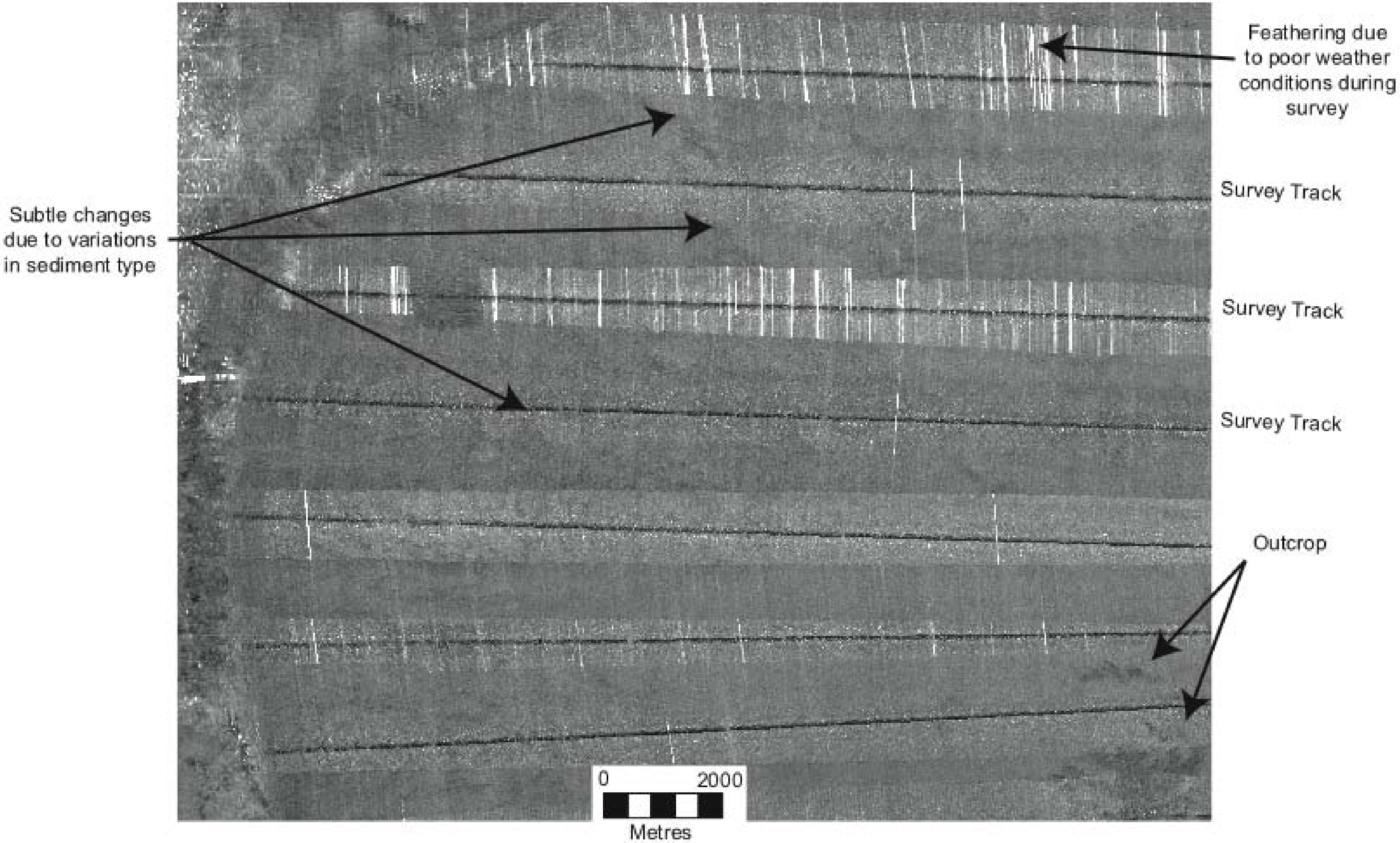


Figure 13 Close-up of acoustic backscatter variation on the summit of Anton Dohrn Seamount. The high reflectivity in the lower right is basement outcrop; the other more subtle variations are due to changes in sediment character.

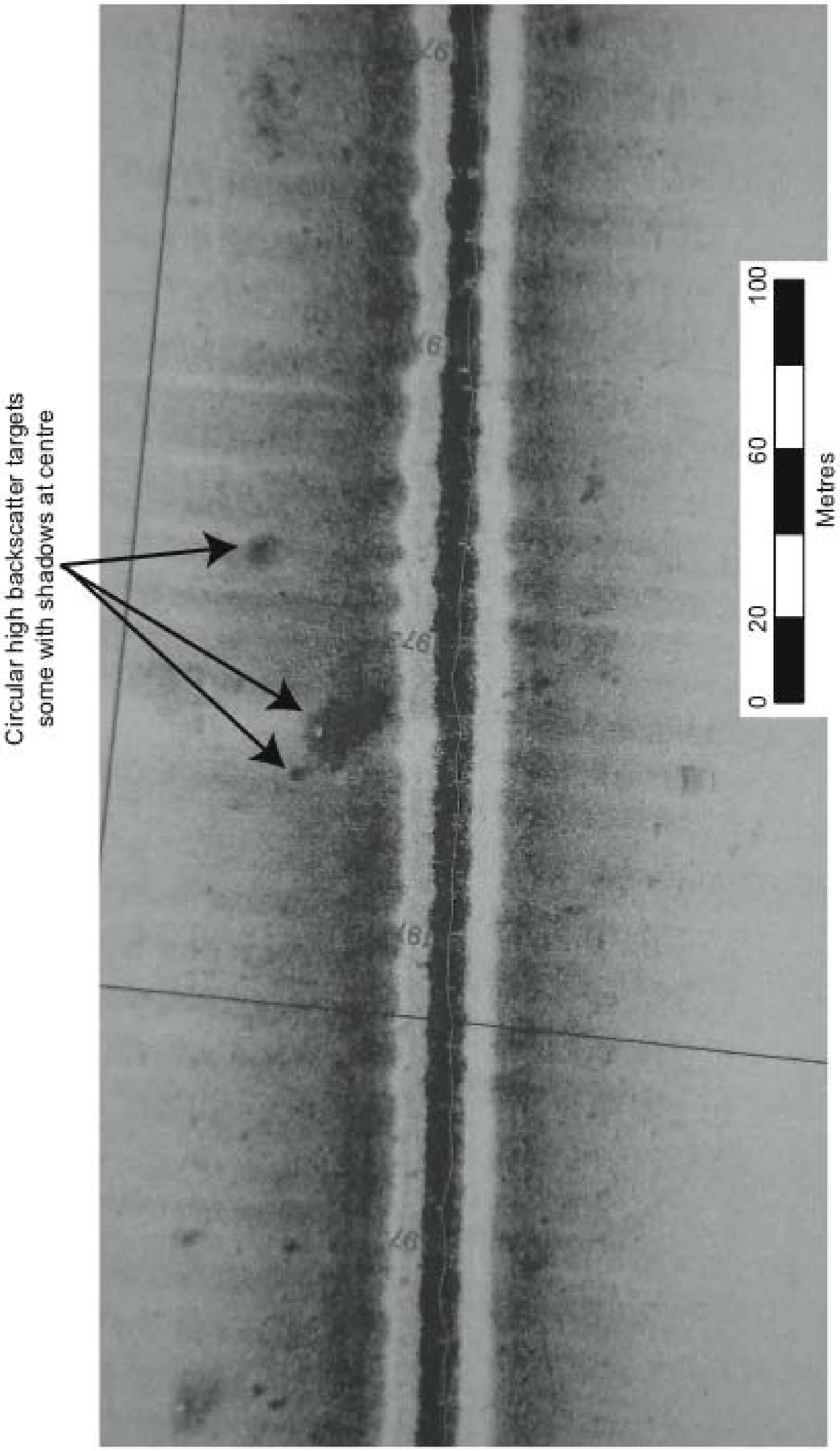


Figure 14. Circular high backscatter features just east of the summit outcrop of Anton Dohrn Seamount, they are between 2-10 m in diameter and of uncertain origin.

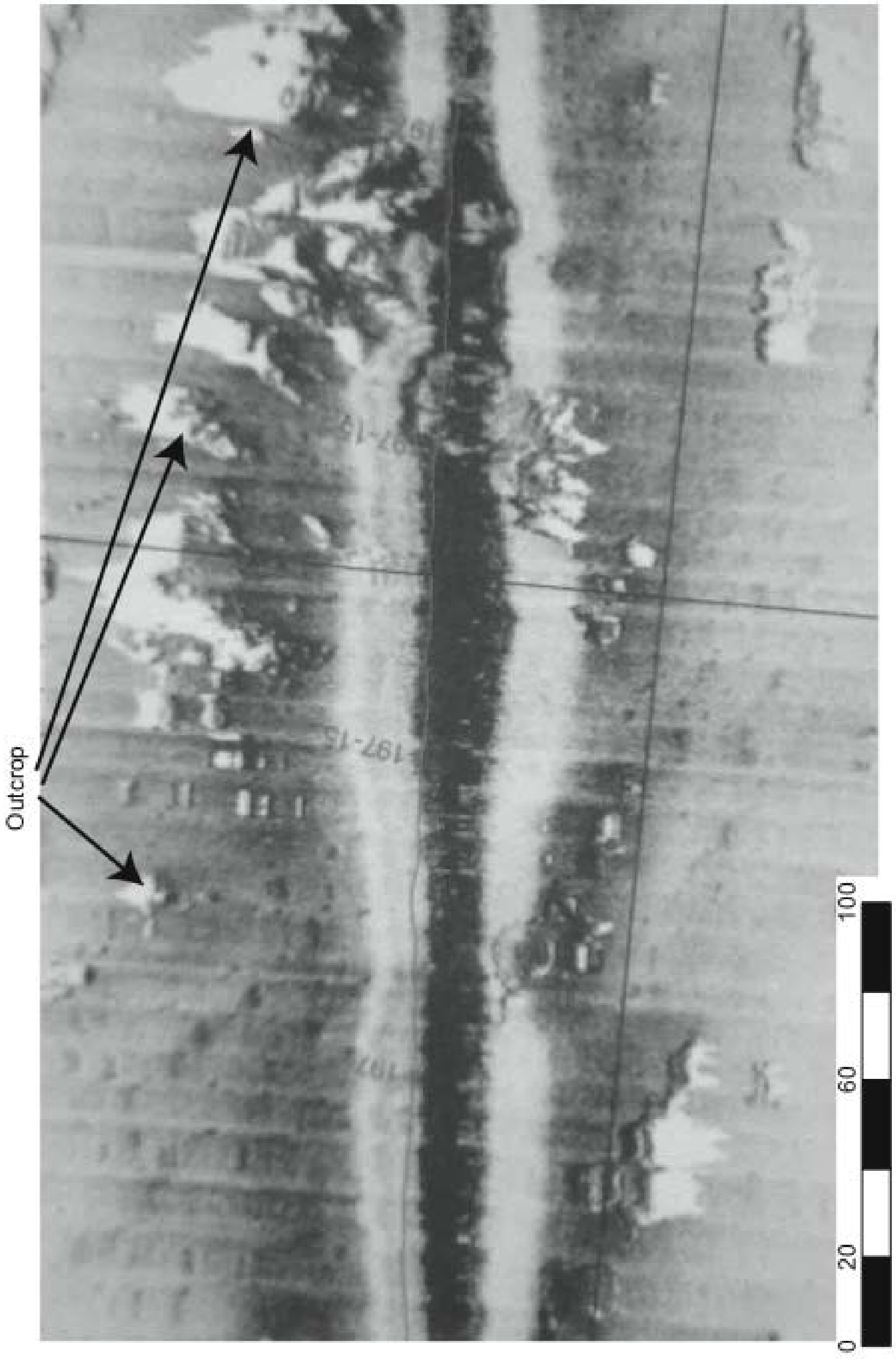


Figure 15. Rock outcrop over the central summit area of Anton Dohrn Seamount.

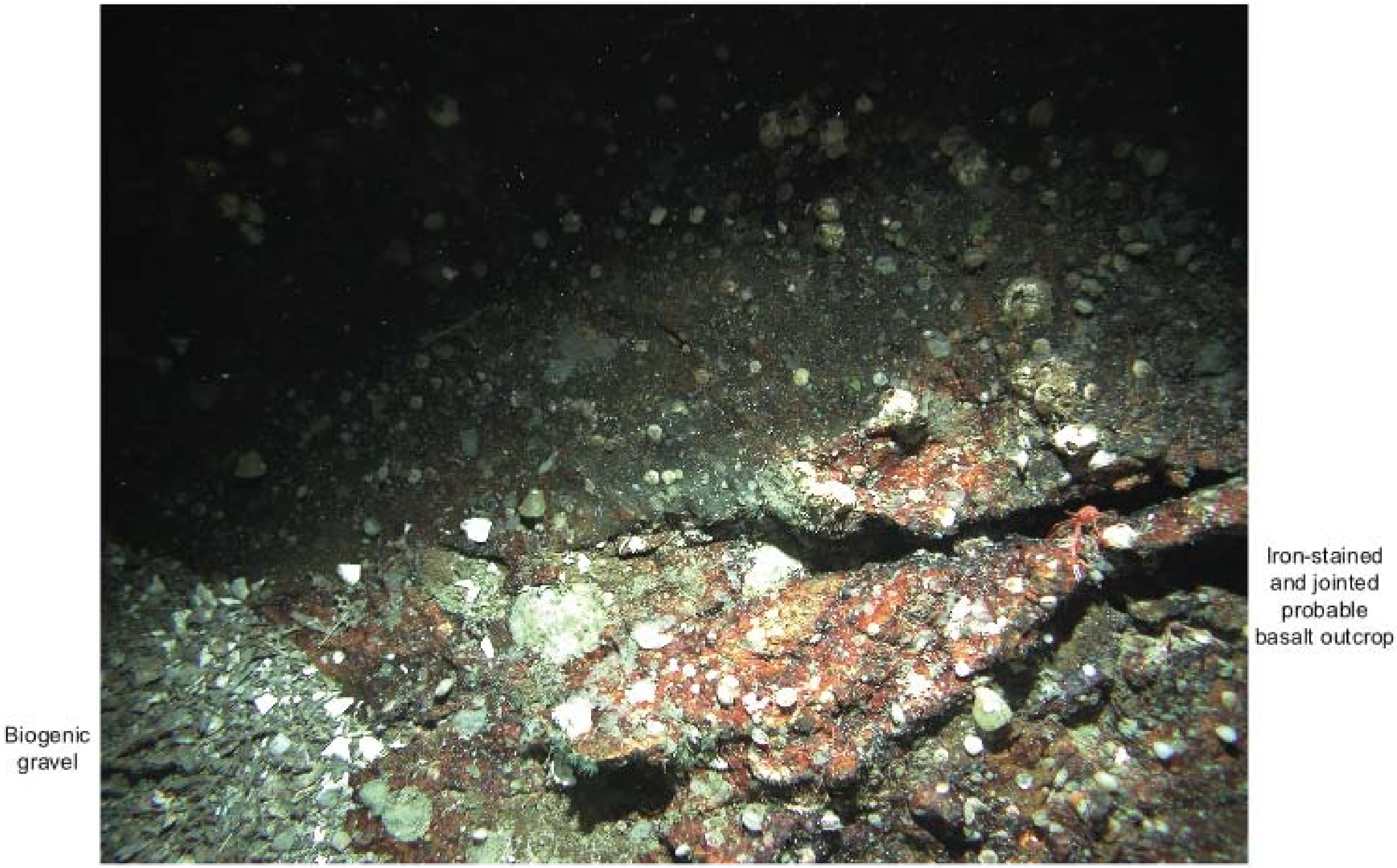


Figure 16. Seabed photograph showing iron-stained and jointed (probably basalt) outcrop at a depth of ~525 metres, with biogenic gravel and coarse sand lag deposits.

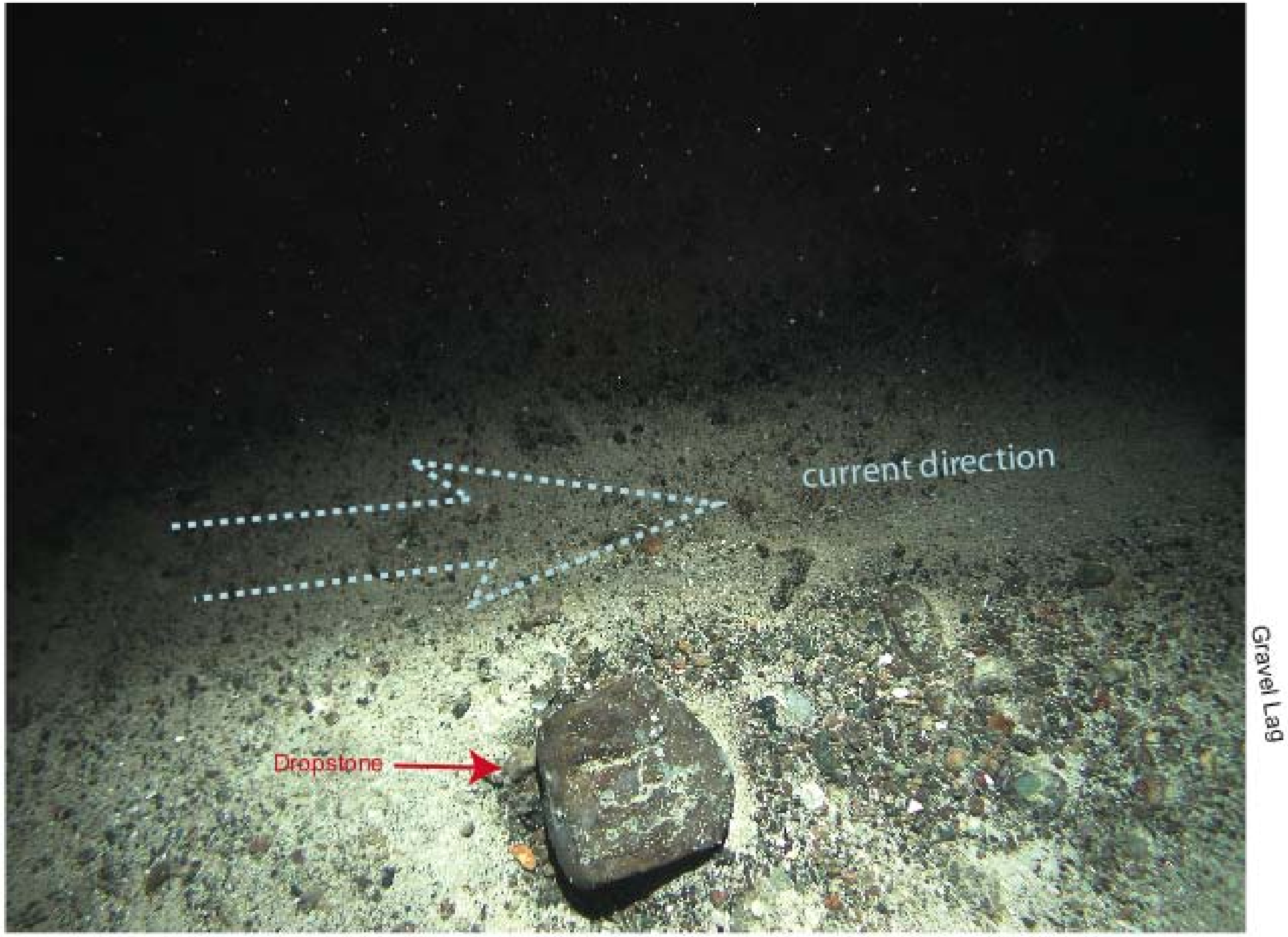


Figure 17. Seabed photograph at 724 metres depth on the northwest summit area of Anton Dohrn Seamount imaging a gravely sand with dropstones that show well-developed downstream gravel lag.

Photo a

Photo b

Figure 18. Seabed photographs from the northwest summit area of Anton Dohrn Seamount at 725 metres, trying to image the reason for the acoustic backscatter change on the EM120 data. Two types of seafloor were imaged along the transect; (a) a rippled seabed with coarser material in the ripple troughs, and (b) a gravely sand.

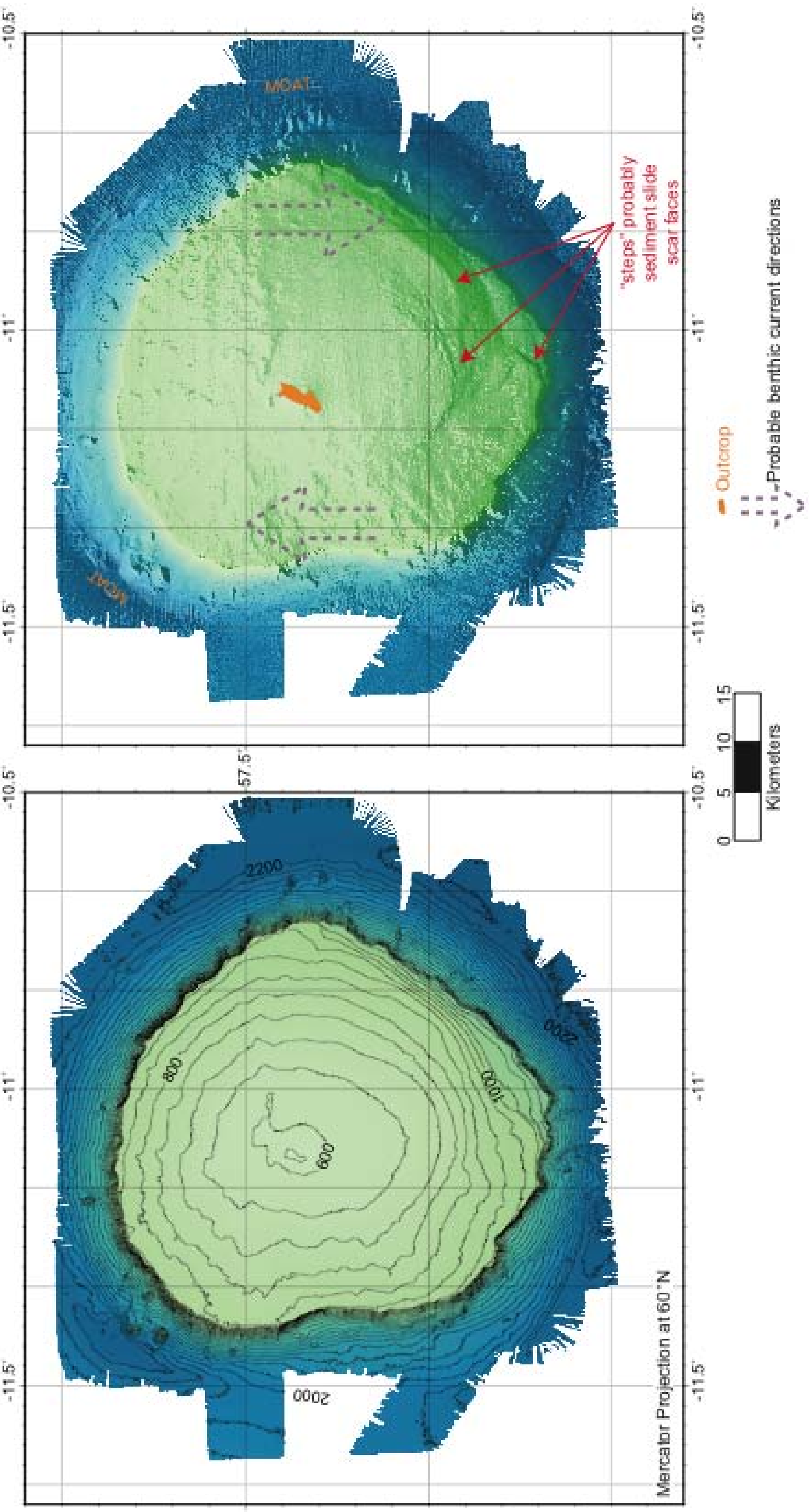


Figure 19. Schematic interpretation of the geomorphology, surficial seabed geology and benthic current activity on and around Anton Dohrn seamount as derived from the 2005 SV Kommandor Jack surveys.

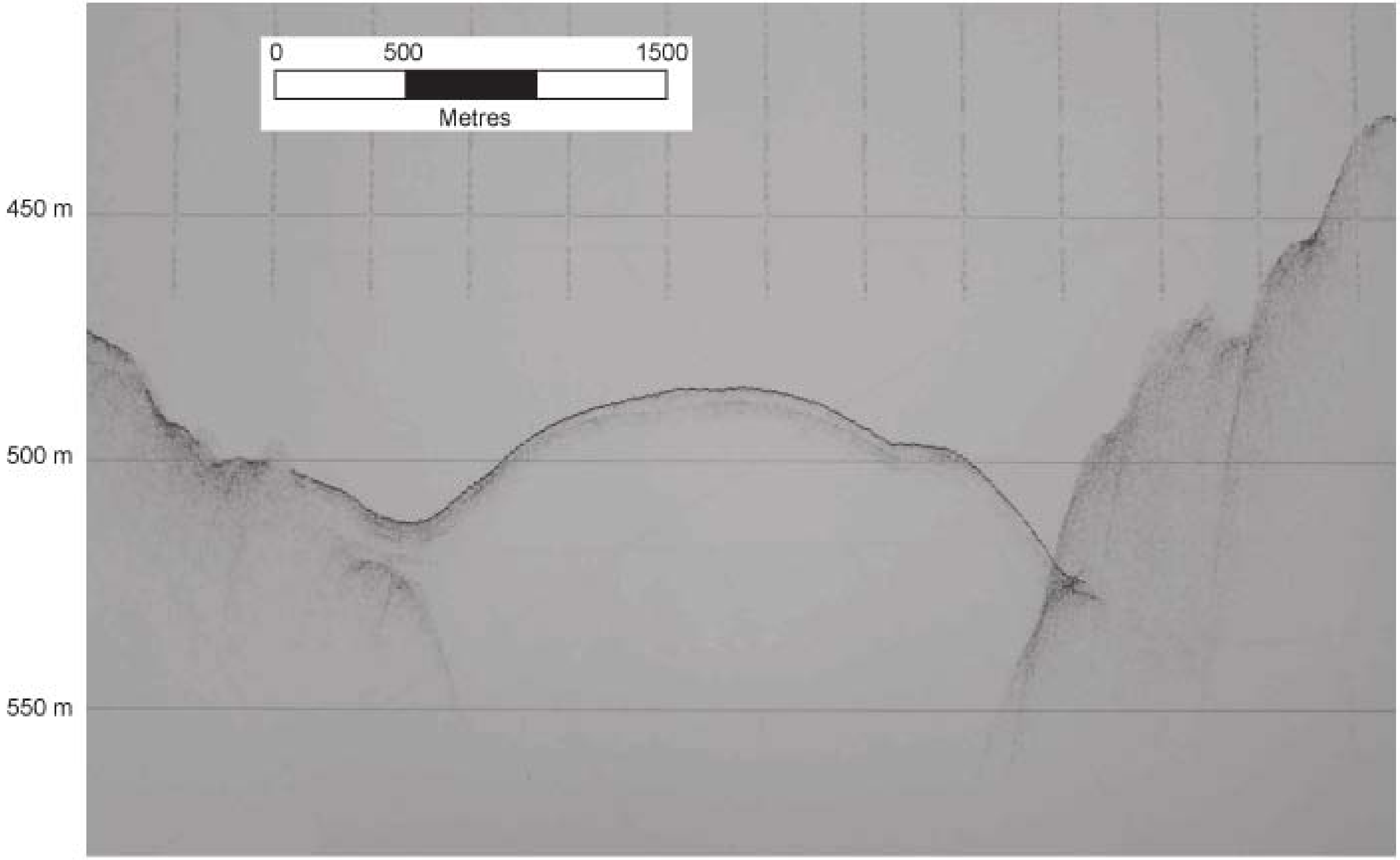


Figure 20. CHIRP profile showing the 100 m high incised embayment walls along the southern East Rockall margin, that here contains an infill where the adjacent sediment drift has followed the topography and begun to infill the embayment.

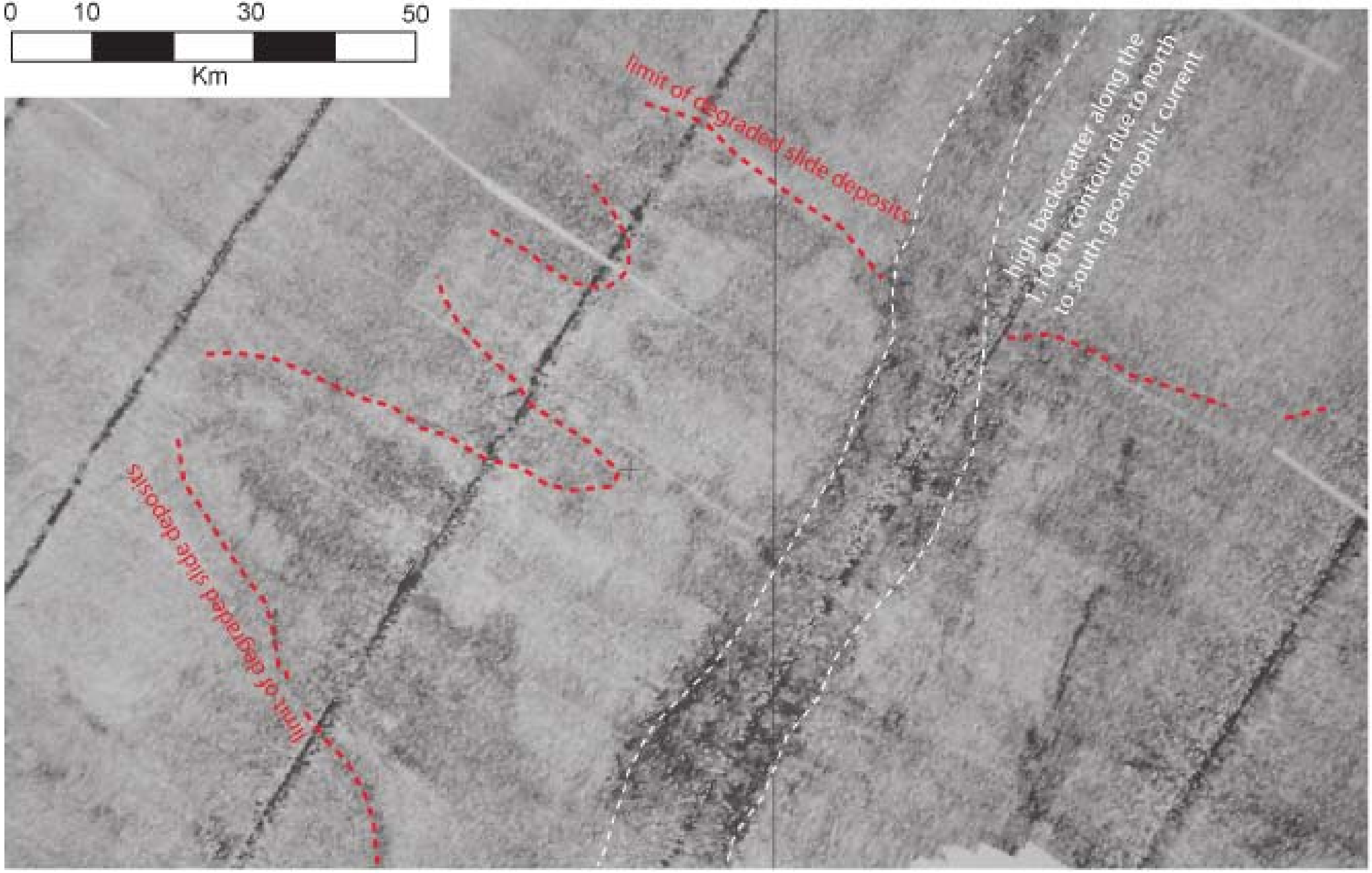


Figure 21. The acoustic backscatter mosaic over the south-eastern Rockall slope showing two areas of varying backscatter that combine down slope indicating that they may be the remnants of old slope failures, and the backscatter variation along the 1,100 m contour where the bathymetric step occurs.

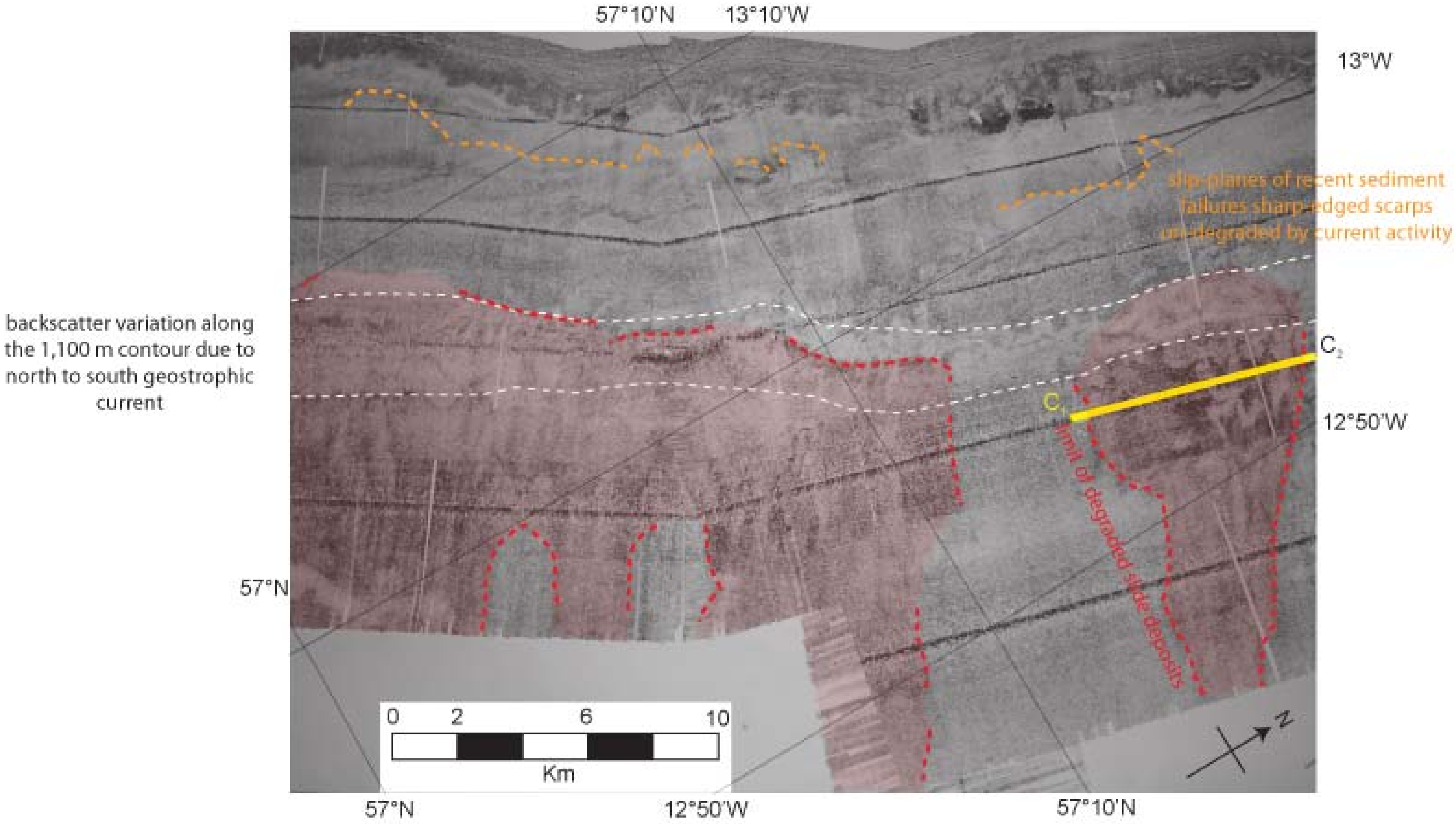


Figure 22. A section of acoustic backscatter mosaic showing small, possibly recent, landslides high on the sediment drift and a much older and degraded landslide deposit, the line C1-C2 shows the location of the profile in Figure 23.

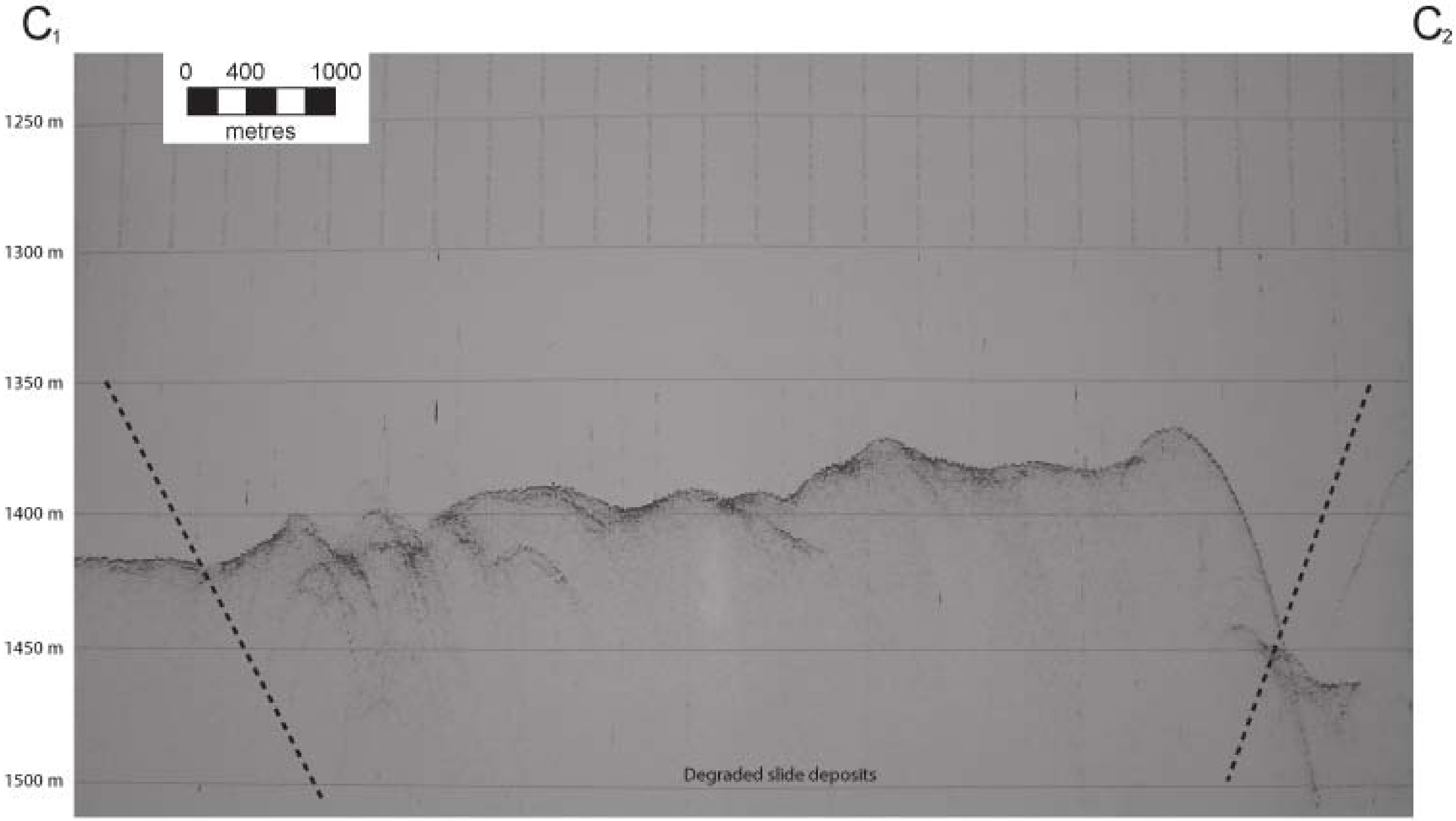


Figure 23. CHIRP profile showing the southern wall and floor of the 100 m deep canyon at 57°17'N 12°51'W and the adjacent degraded and thinly-draped sediment slide deposits.

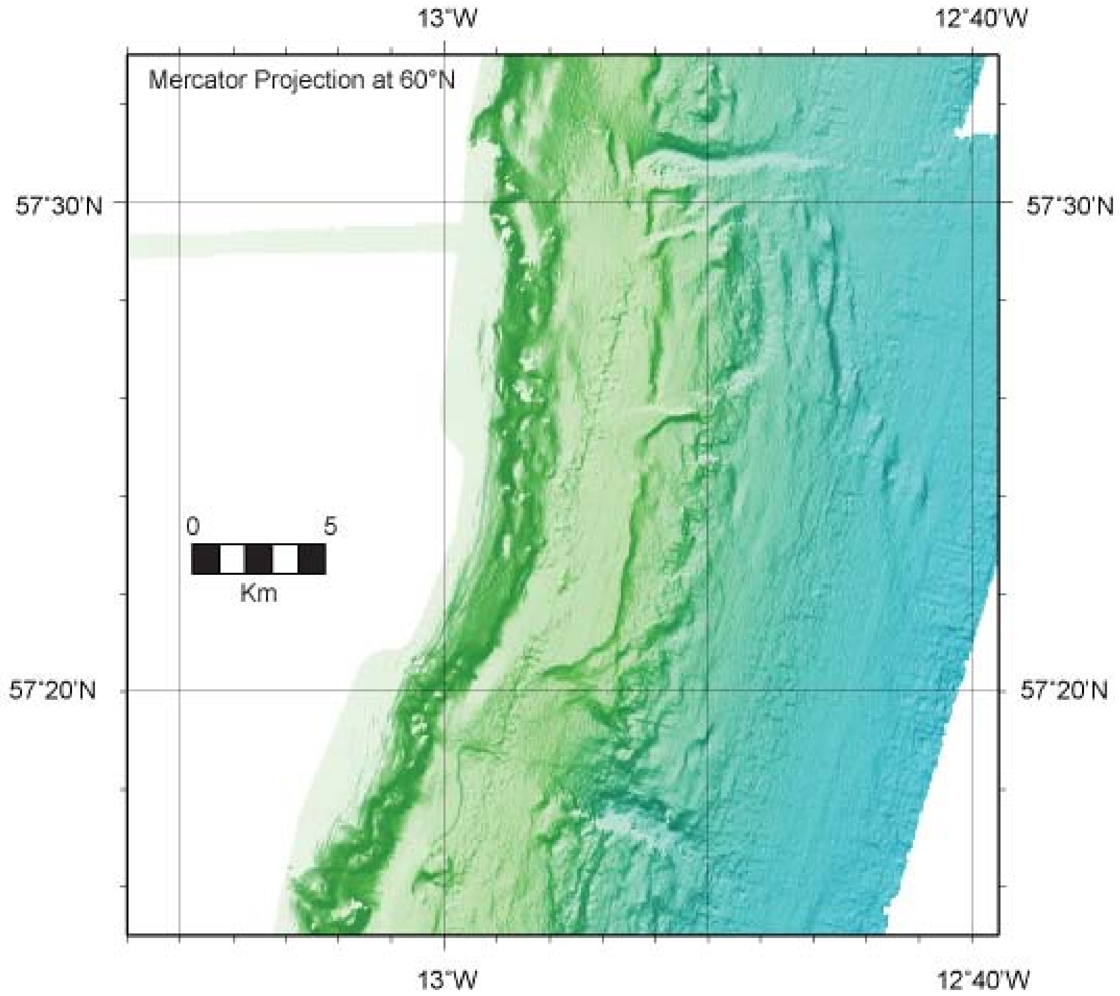


Figure 24. Shaded relief image of the "elbow" where the slope of Rockall Bank changes orientation from NE-SW to NNE-SSW, and the two ~100 m deep canyons, both with their origins on the middle slope, that probably define an area of previous slope failure events. The slope-parallel ridges are also likely indicators of slope failure events.

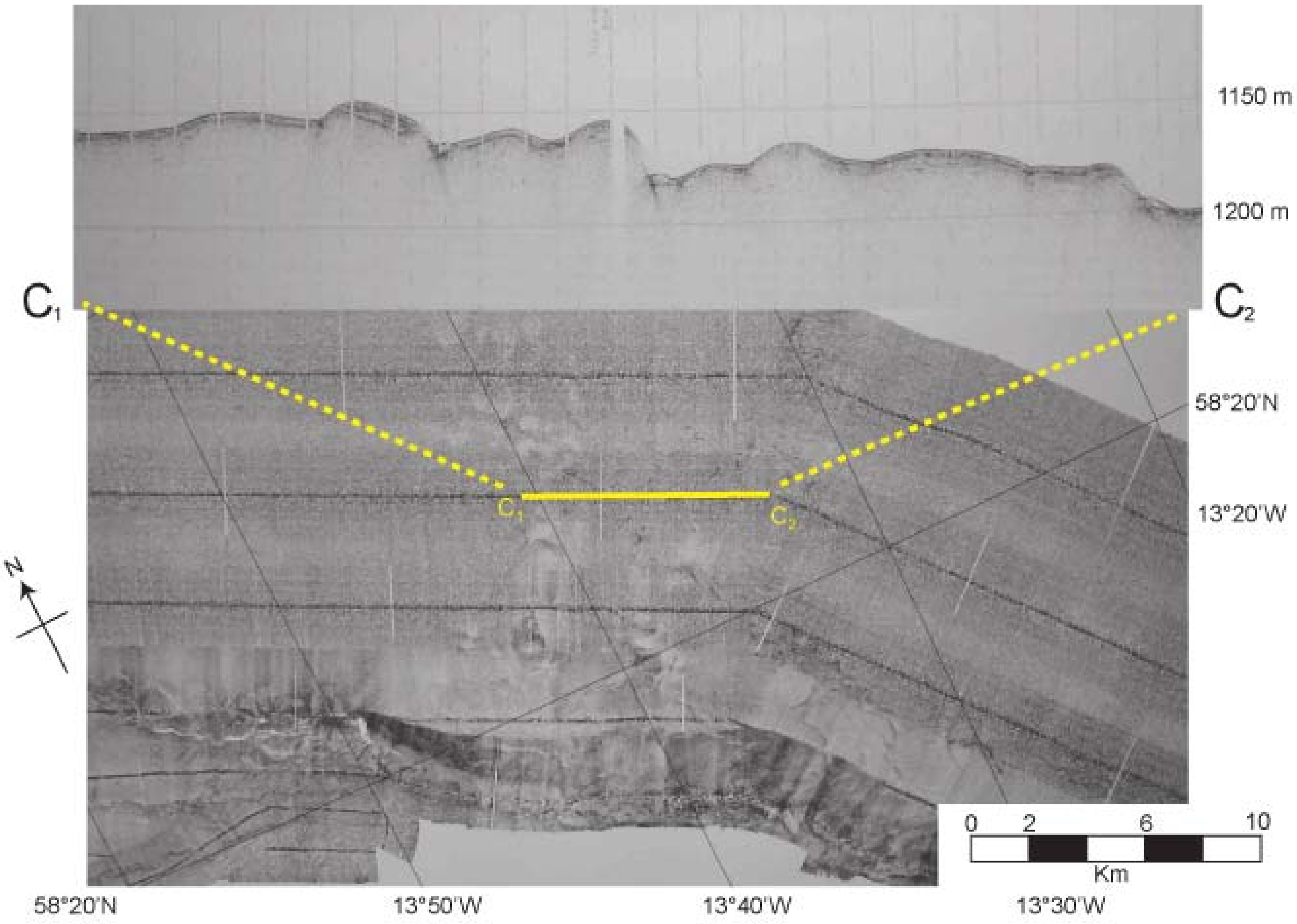
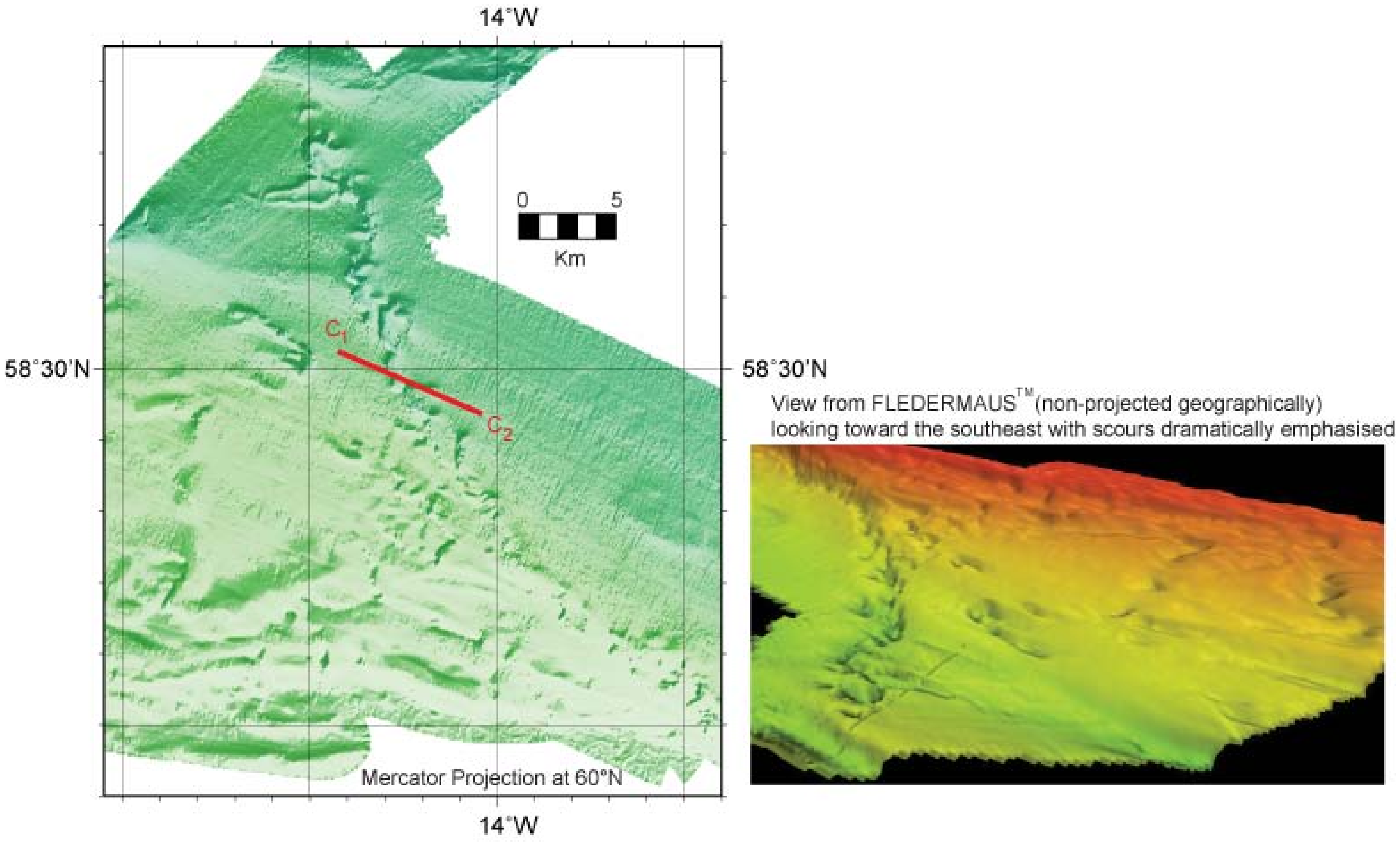


Figure 25. The backscatter mosaic and CHIRP profile across a slide deposit on the mid-slope off northern Rockall margin. The crescentic embayment in the Rockall continental slope is the likely origin of the slide. The various acoustic backscatter differences higher on the slope reflect the numerous small-scale sediment bodies associated with the bights and scours along this part of the slope.



View from FLEDERMAUS™ (non-projected geographically) looking toward the southeast with scours dramatically emphasised

Figure 26. Shaded bathymetry of the northern continental slope of Rockall Bank, showing the saddle across the entrance to the Rockall-Hatton Basin. The intra-slope scours are clearly imaged as is the elongated arc of scours at, and sweeping northwest away from, the foot of the Rockall Bank continental slope. C_1 - C_2 location of CHIRP profile in Figure 27.

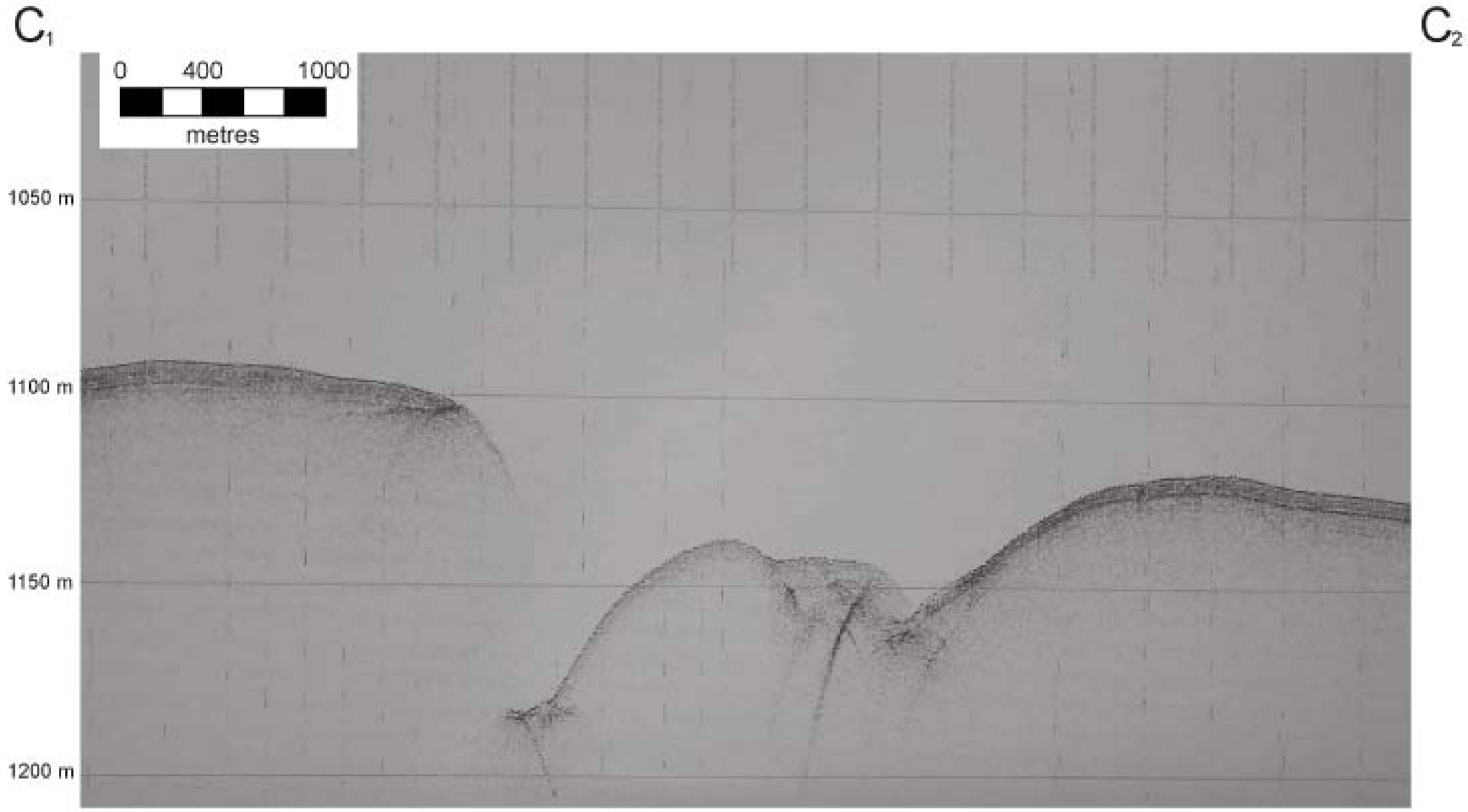


Figure 27. CHIRP profile across one of the erosional scours at the foot of northern margin of Rockall Bank (see Figure 26 for location). Note the higher western wall and the winnowed section on the eastern flank.

Figure 28. Mid-slope seabed photograph at a depth of 735 metres over the basal part of the Feni Ridge, where the seafloor is composed of gravely sand, with dropstones and their associated gravel lags. These appear to overlay a rippled, possibly indurated surface.

Figure 29. Upper continental slope photograph on the Rockall margin showing pale indurated outcrop partially obscured by a surface layer of sand.

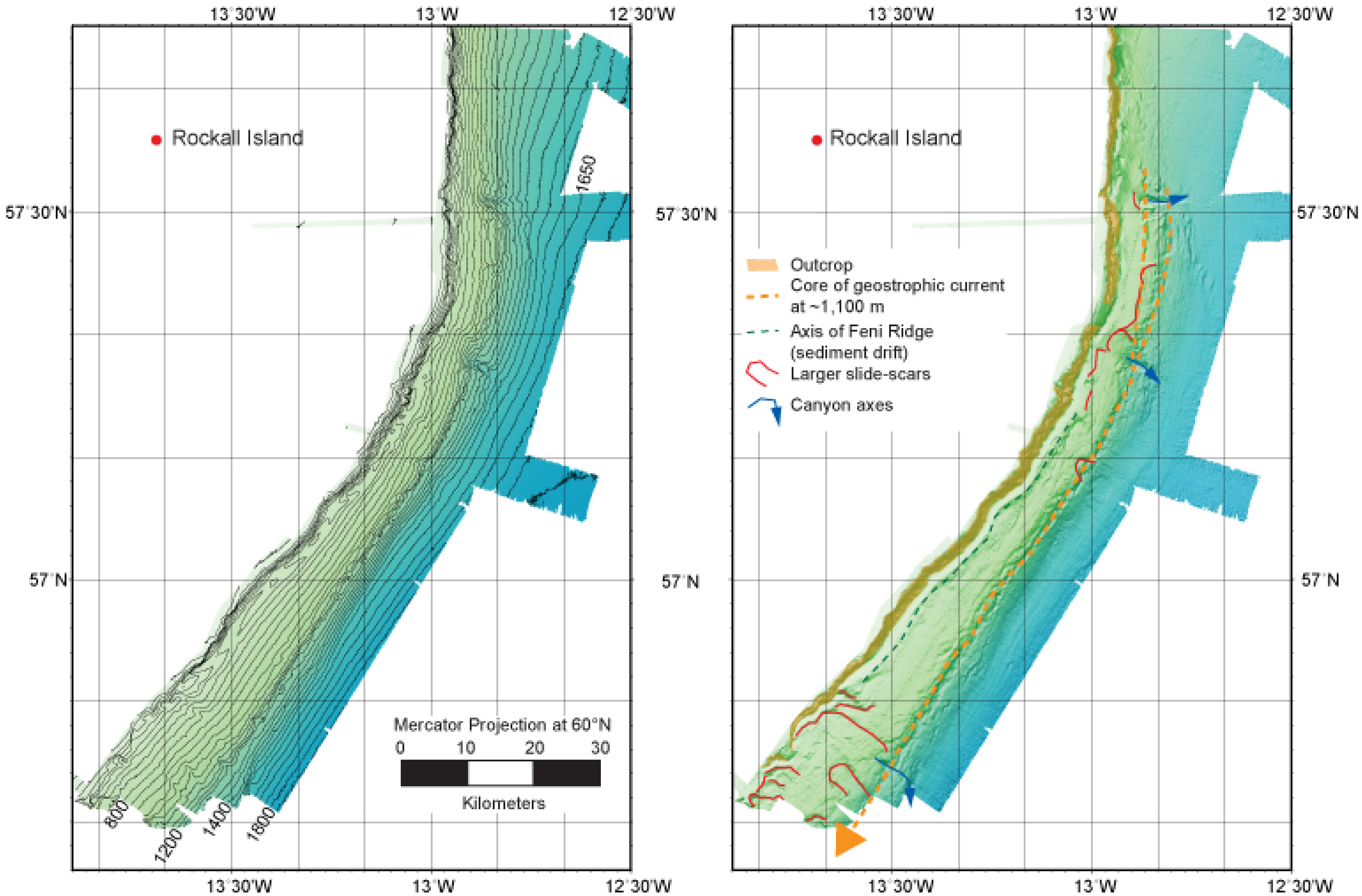


Figure 30A. An interpretation of the geomorphology, surficial seabed geology and benthic current activity as derived from the 2005 SV Kommandor Jack surveys. A = South of 57°45'N.

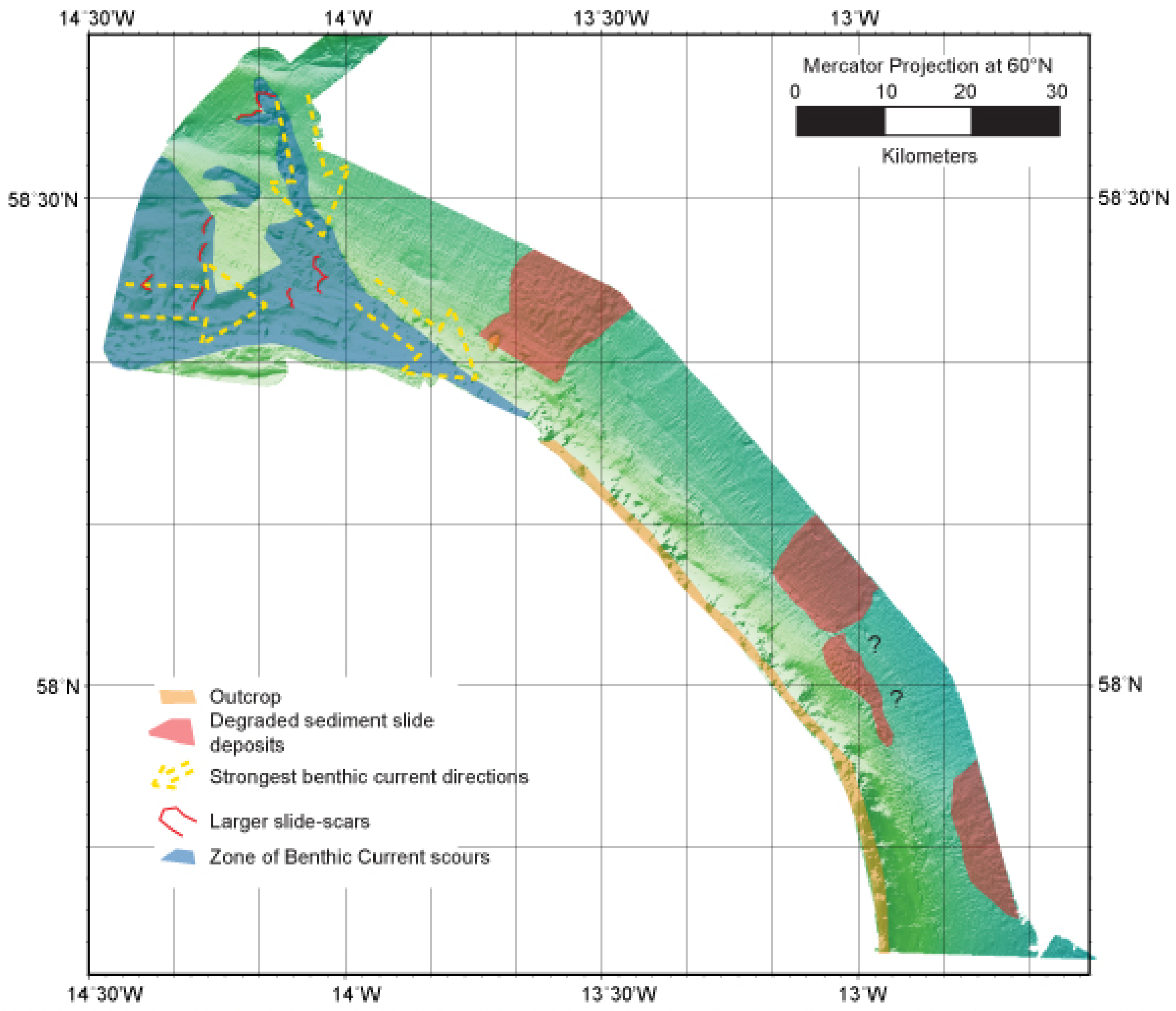


Figure 30B. An interpretation of the geomorphology, surficial seabed geology and benthic current activity as derived from the 2005 SV Kommandor Jack surveys. B = North of 57°45'N.

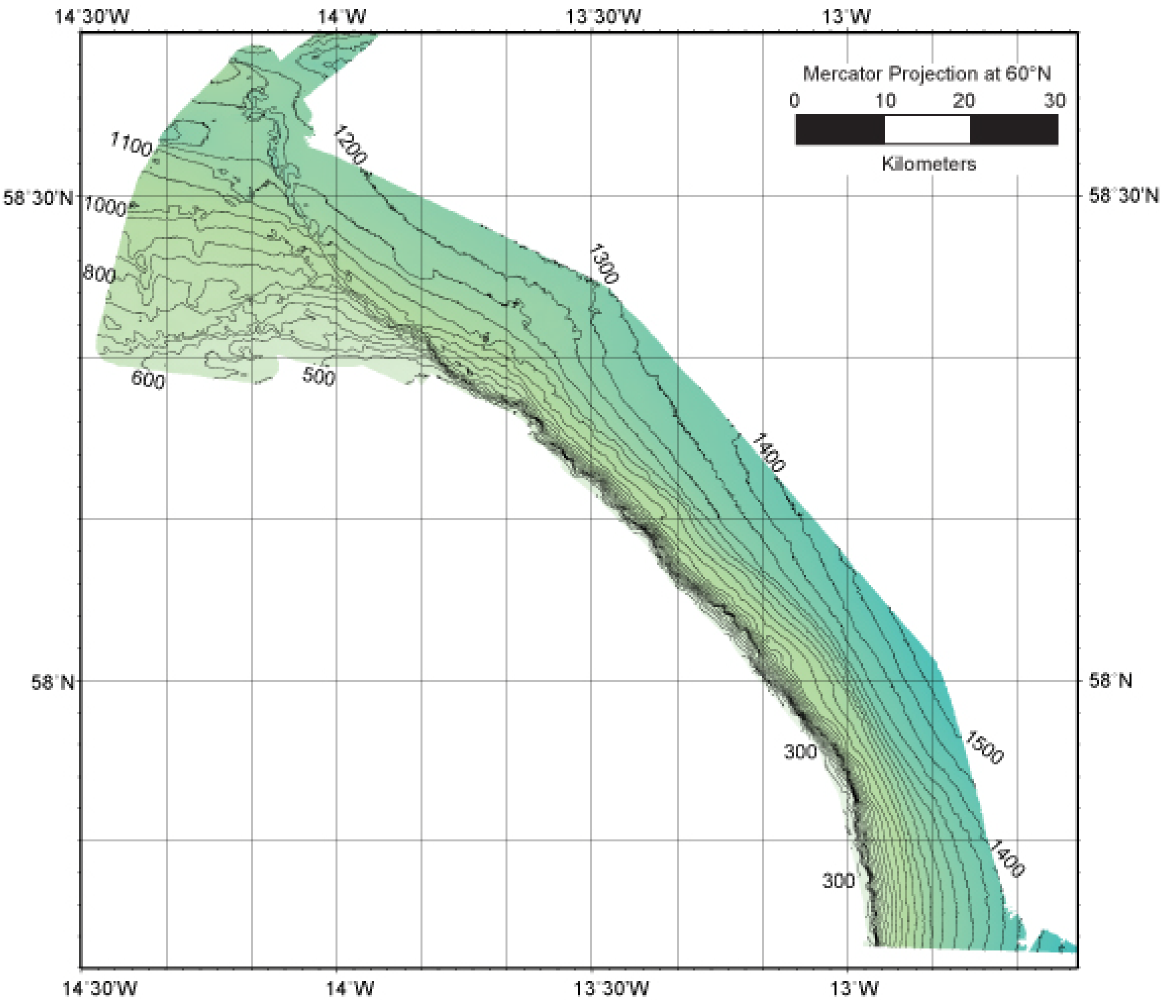


Figure 30C. An interpretation of the geomorphology, surficial seabed geology and benthic current activity as derived from the 2005 SV Kommandor Jack surveys. C = Bathymetry north of 57°45'N.

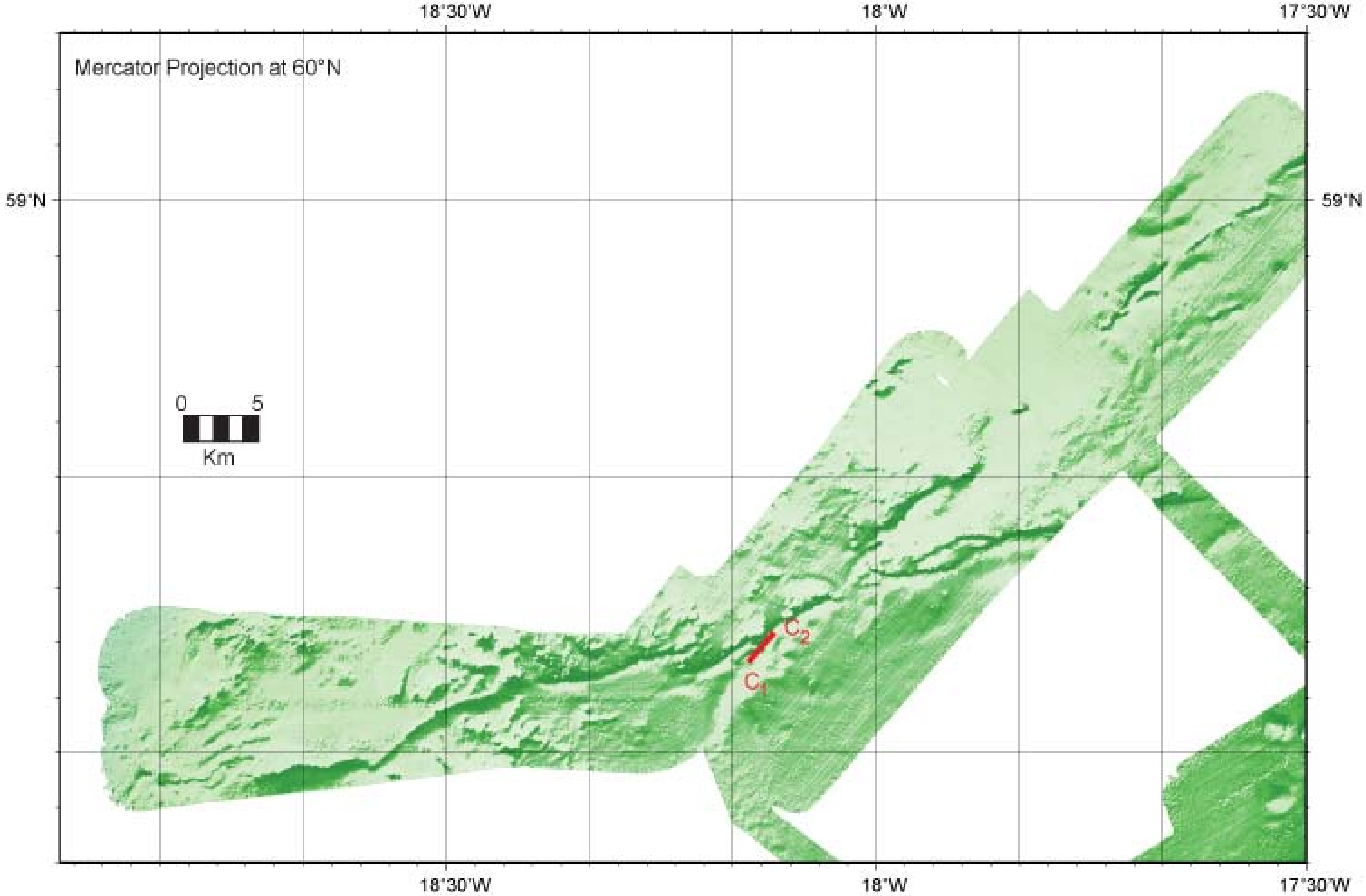


Figure 31. The en-echelon ridges and troughs across the summit of central Hatton Bank, with two clear trends (just south of E-W and NE-SW) imaged.

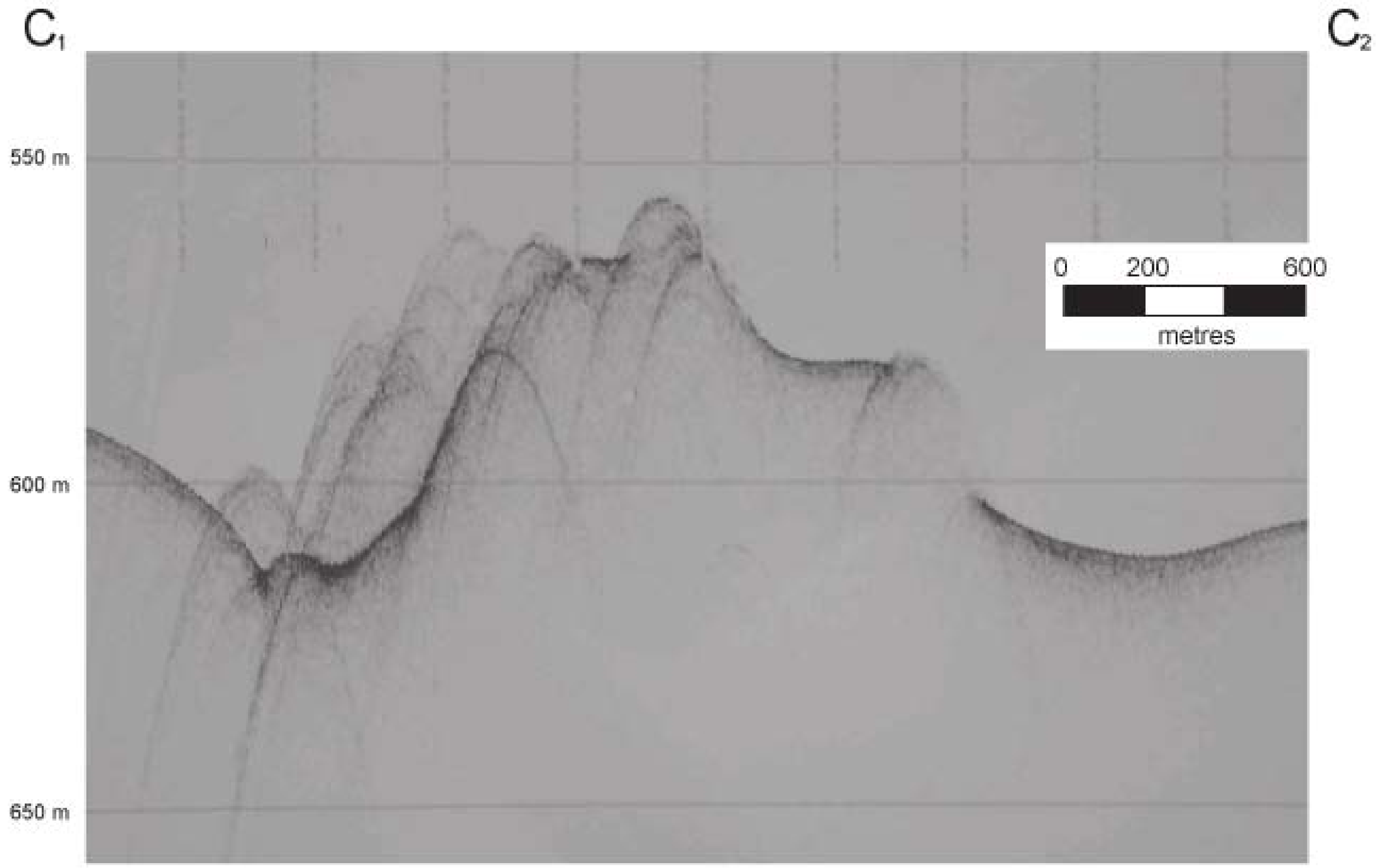


Figure 32. CHIRP profile showing a transverse section across one of the Ridge-Trough couplets (see Figure 31 for location). The hyperbolic echoes over the ridge crest and parts of it slope indicate the steepness and roughness of the slopes that are beyond the resolution capability of the profiler.

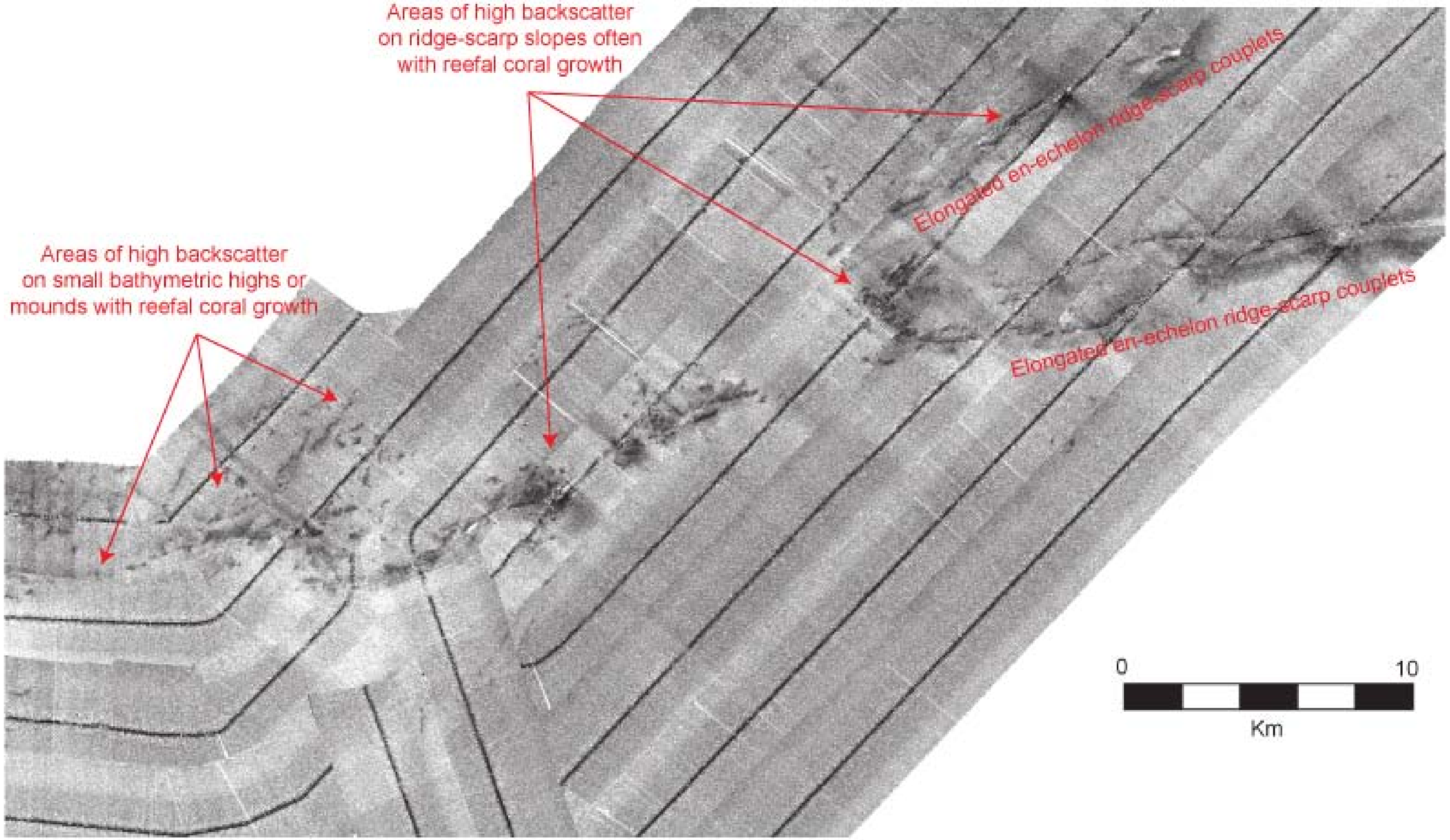


Figure 33. Part of the acoustic backscatter mosaic over Hatton Bank showing the variation in backscatter and the very high levels associated with rock outcrop and probable biological constructions.

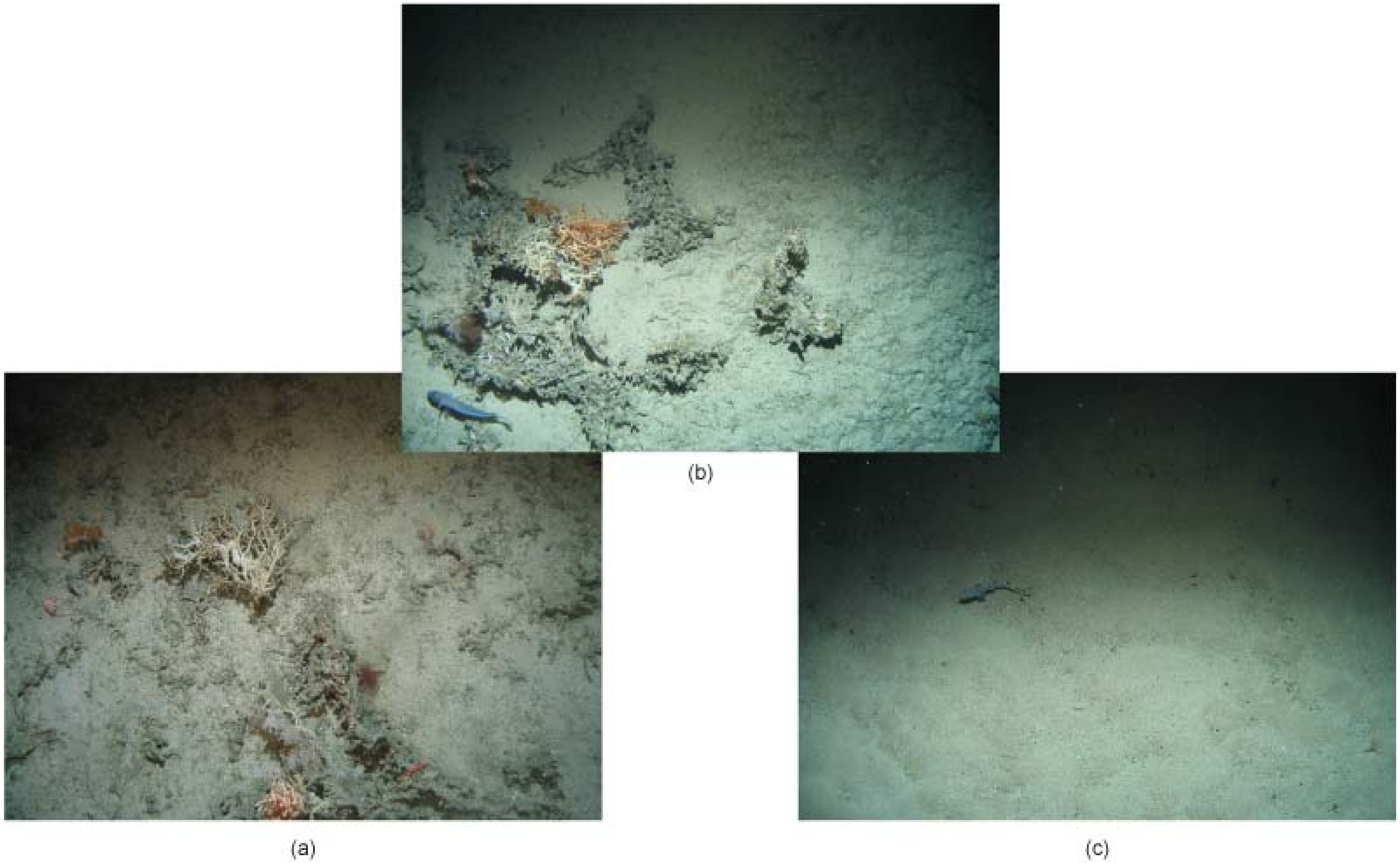
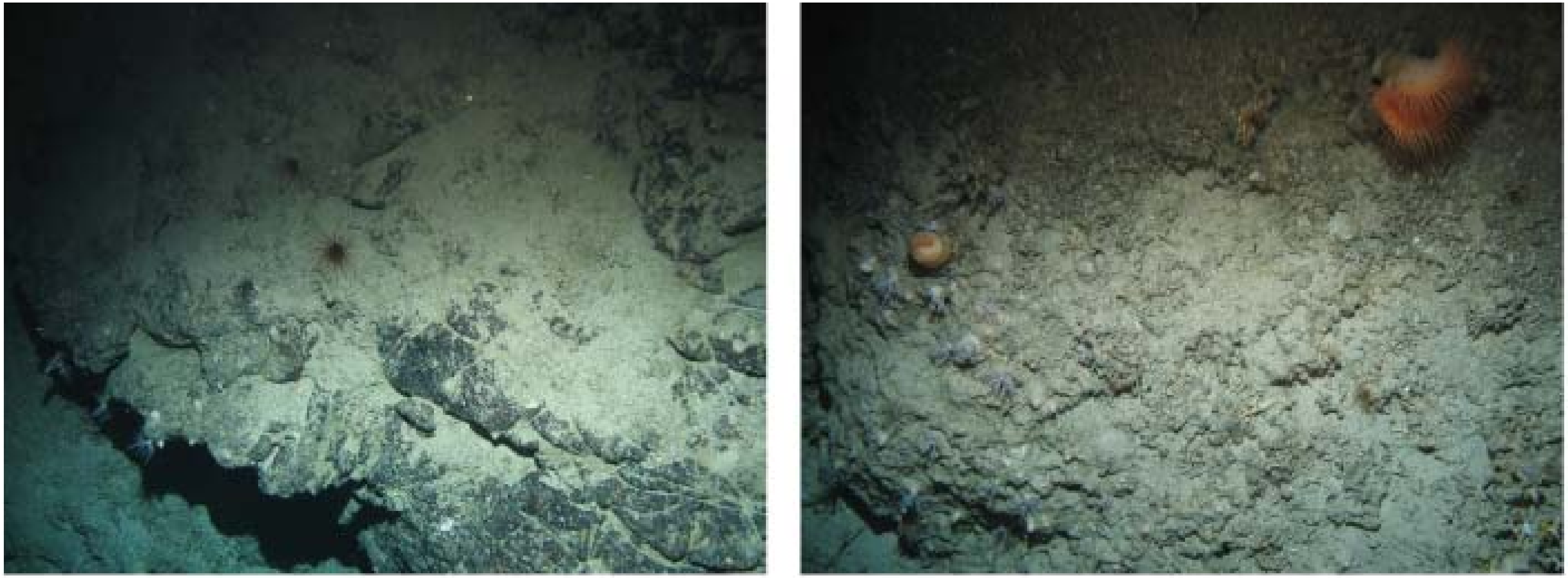
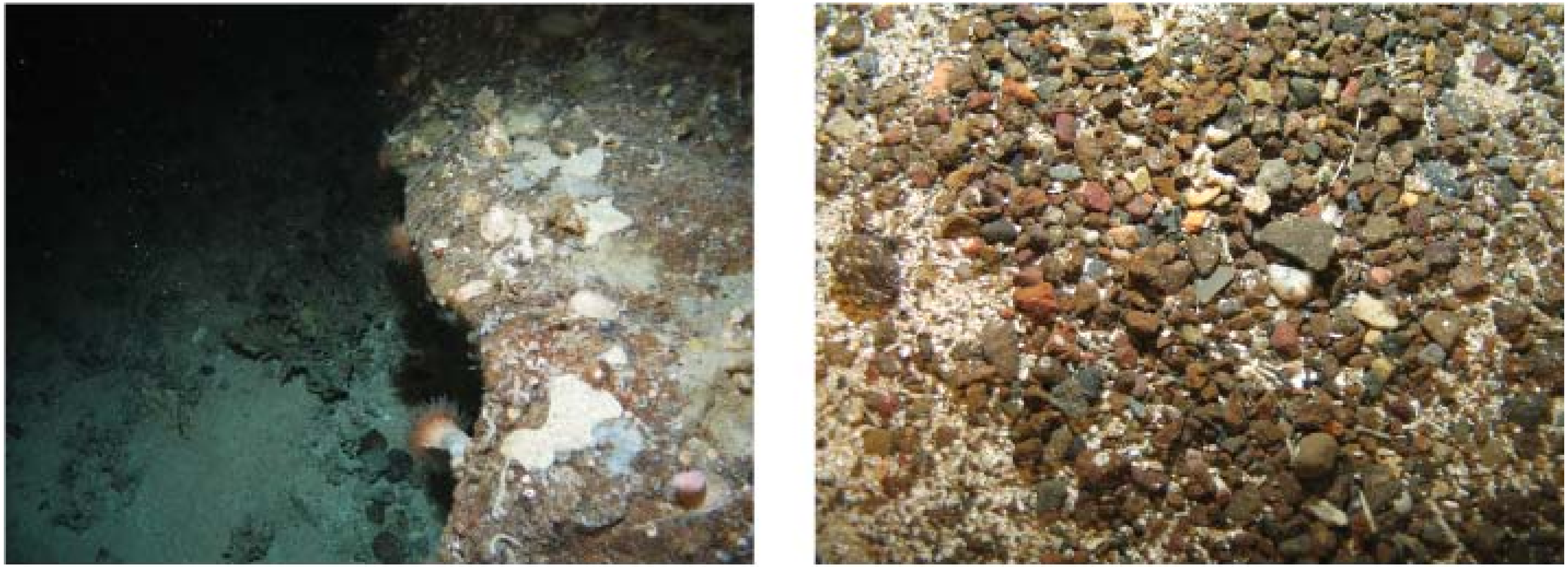

(a) (b) (c)

Figure 34. Seabed photographs from Hatton Bank showing a "double-hummock" feature at 622-641 metres showing that the hummocks are composed of varying amounts of coral-covered sand (a), indurated material (b), (the mounds' "body" perhaps) and rippled sands (c).



(a) (b)

Figure 35. Seabed photographs revealing probable igneous outcrop (a), and indurated massive probably sedimentary rock (b) that may be an aggregation of biogenic debris.



(a) (b)

Figure 36. Seabed photographs over a (double) slope, with a depth range of 515-581 m. The top of the lower slope is overhanging rock, probably basalt (a), and at the base of the slope is a very well-washed gravel.

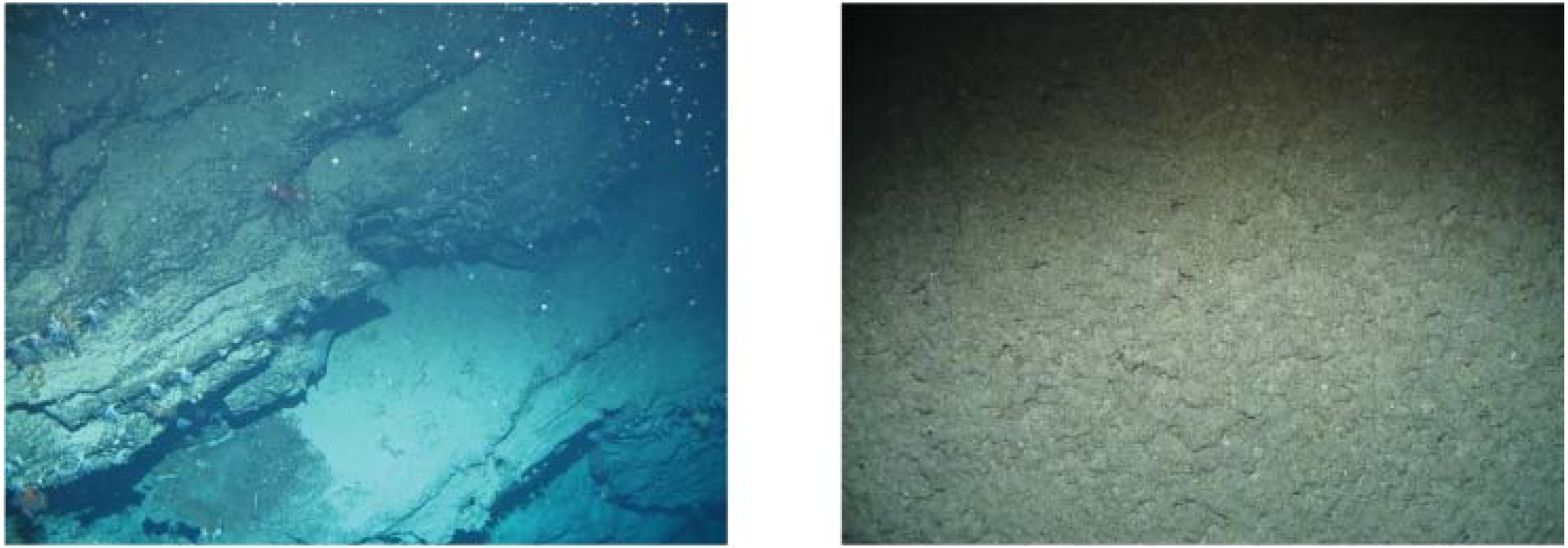

(a) (b)

Figure 37. Seabed photographs down a typical scarp slope (556-642 m) showing layered outcrop (a), and toward the base of the slope an outcrop of what appears to be a chemically weathered sedimentary rock (b).

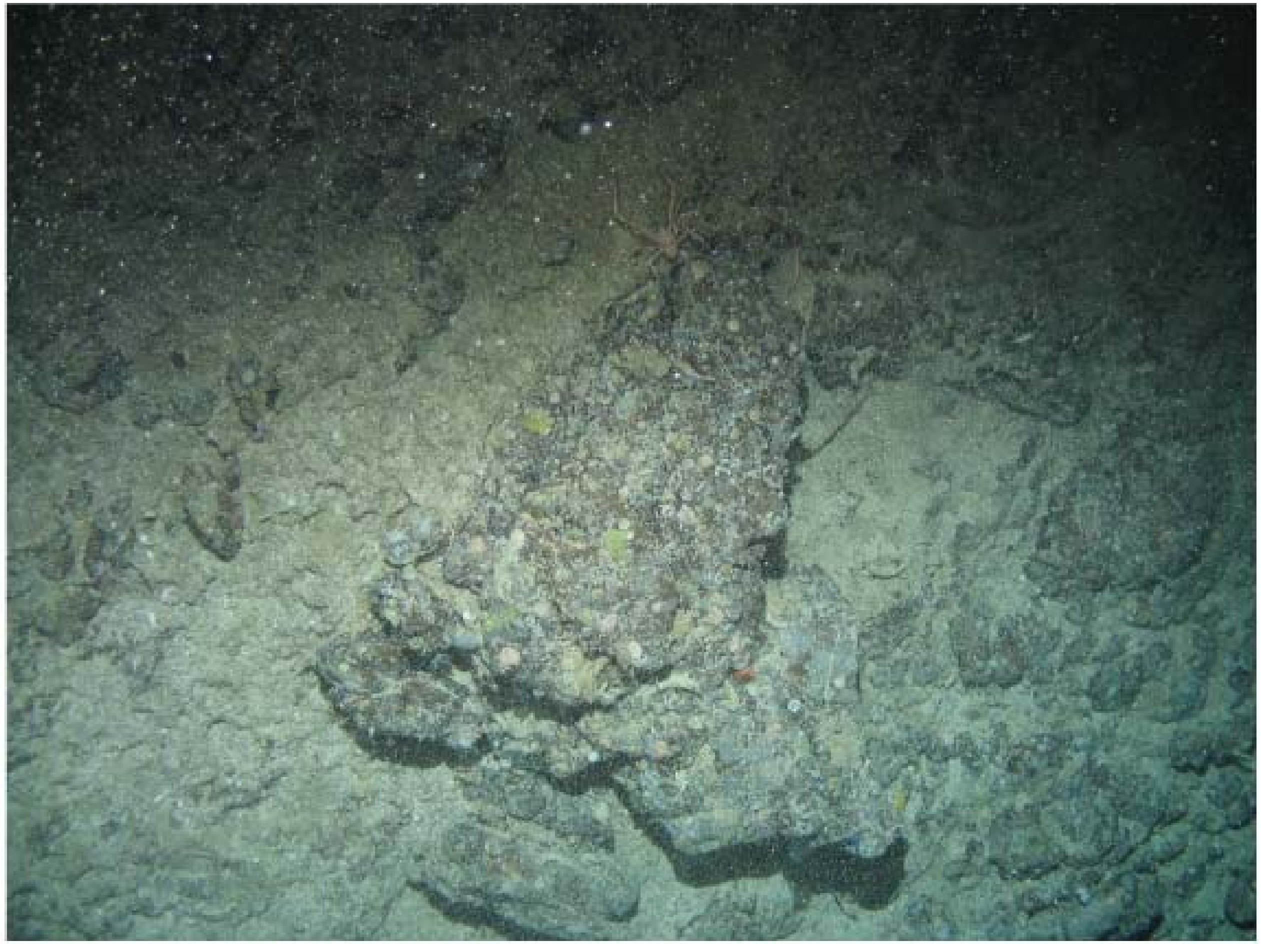
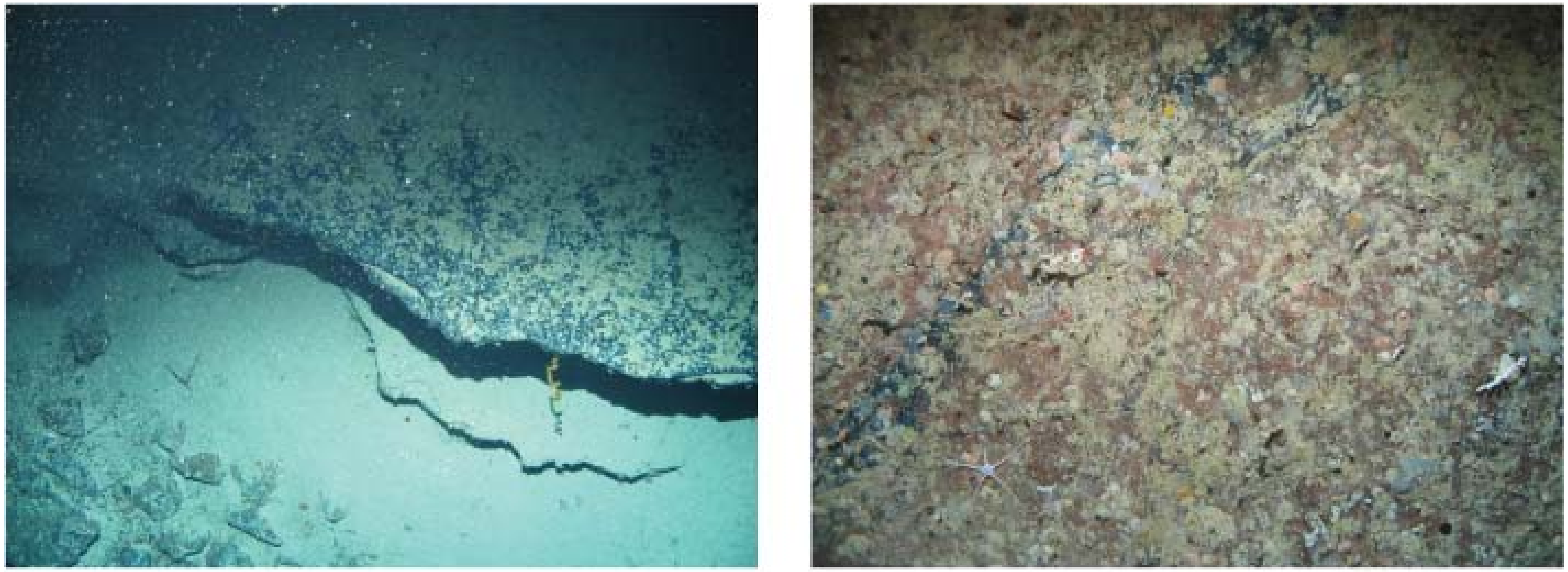


Figure 38. Seabed photographs of part of an outcrop encountered on one of the scarp slopes. Here the sedimentary and igneous outcrops appear to be inter-bedded.



(a) (b)

Figure 39. Seabed photographs between 798-854 metres. The top of the scarp here is marked by an overhang (a) just below which the rock displays a series of viens, suggesting it is igneous (basaltic) in origin (b).

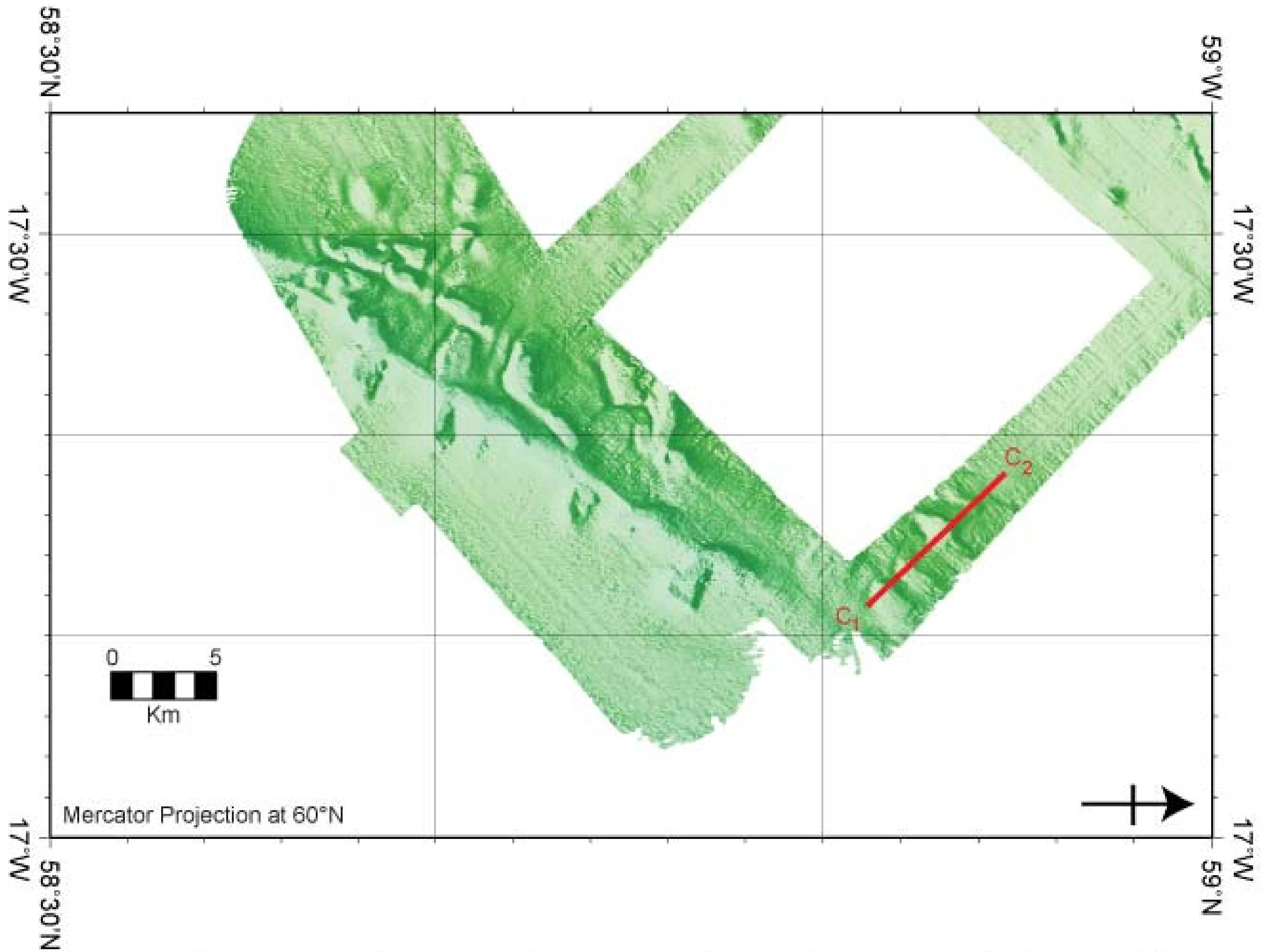


Figure 40. Shaded bathymetry image of the eastern flank of Hatton Bank showing the distinctive 40 Km long and 10 Km wide zone of northeast-southwest trending bathymetric lows that form a series of perched basins.

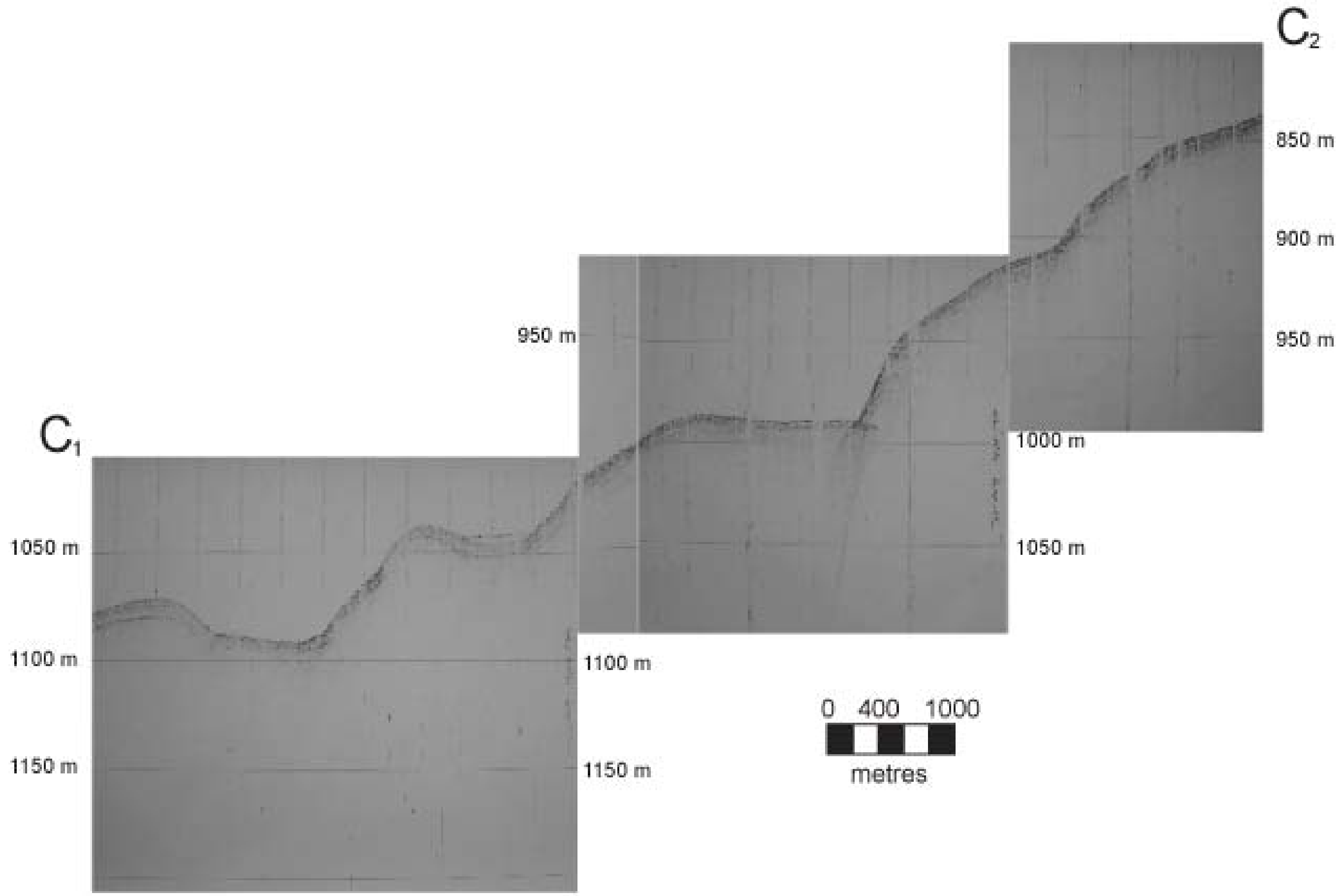


Figure 41. CHIRP section across the features bathymetric lows show that they are in fact a series of perched basins (see Figure 40 for location of profile).

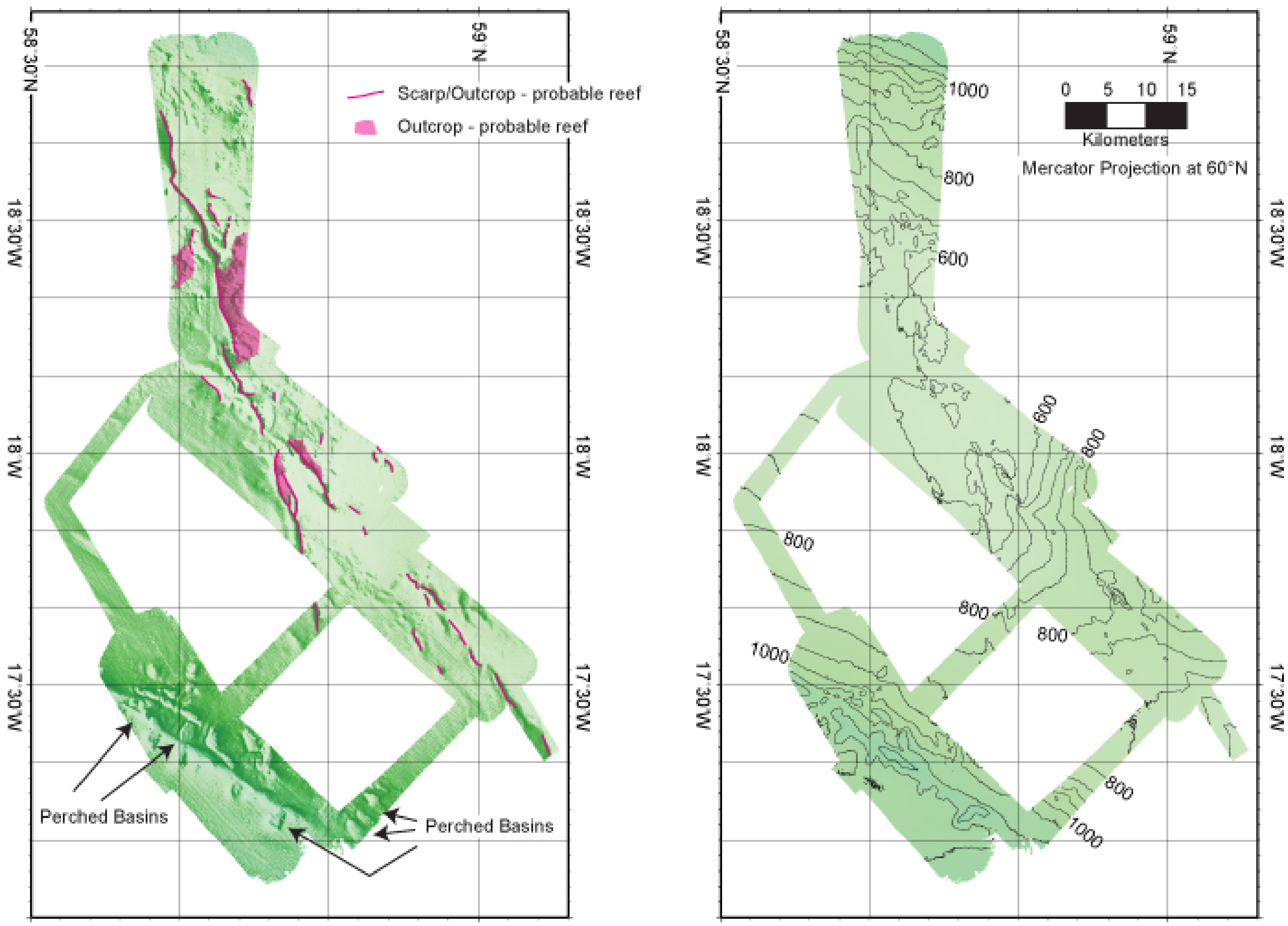


Figure 42. A schematic overview of the geomorphology, surficial seabed geology and benthic current activity around the central Hatton Bank region as derived from the 2005 SV Kommandor Jack surveys.

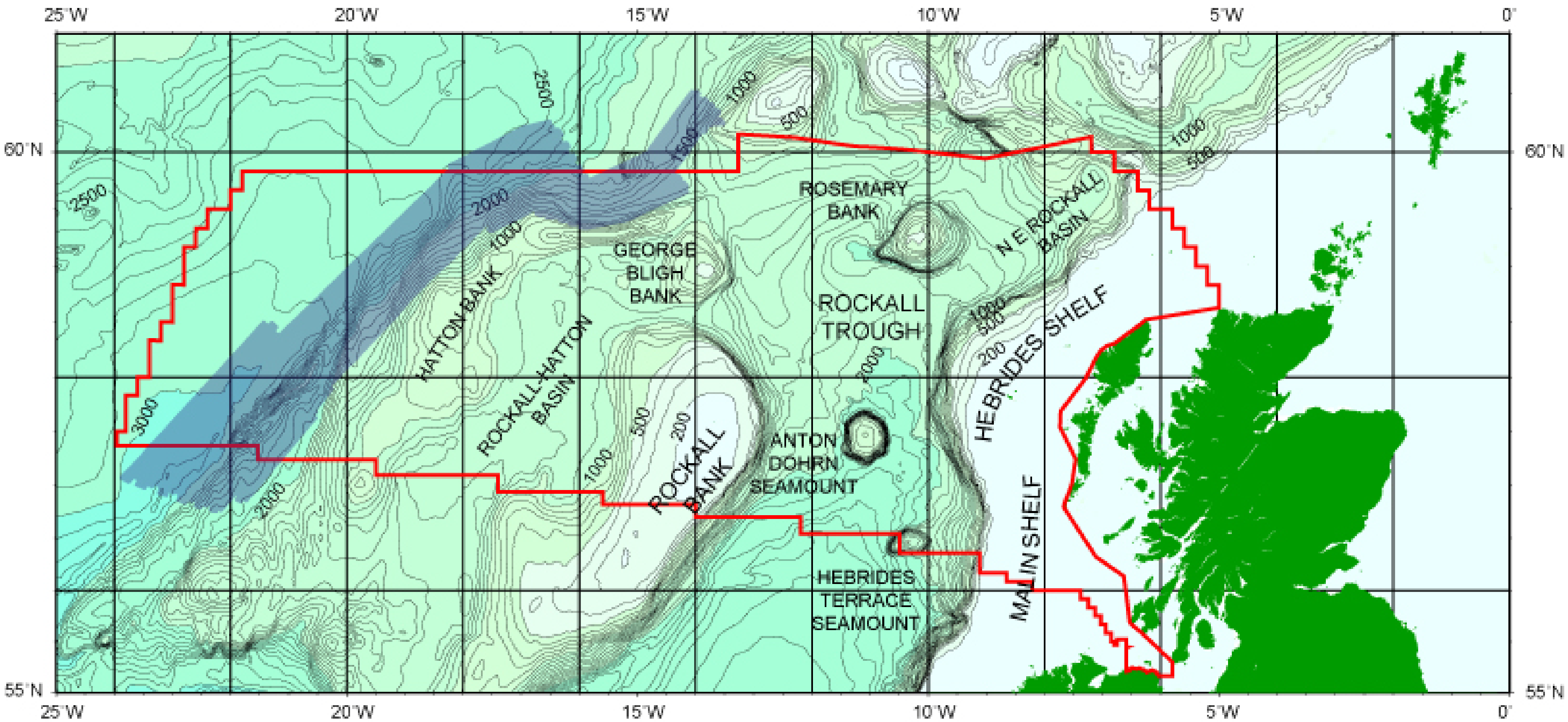


Figure 43. Area of coverage of EM12 multibeam over the west Hatton Bank margin. These data are considered "in confidence" until the United Kingdom submits its UNCLOS claim to the United Nations.

Figure 44. Seabed photograph taken over a 100 m high mound just to the north of George Bligh Bank. At the base of the mound there appears to be a significant build-up of coral debris into a scree deposit that may have become partly indurated.

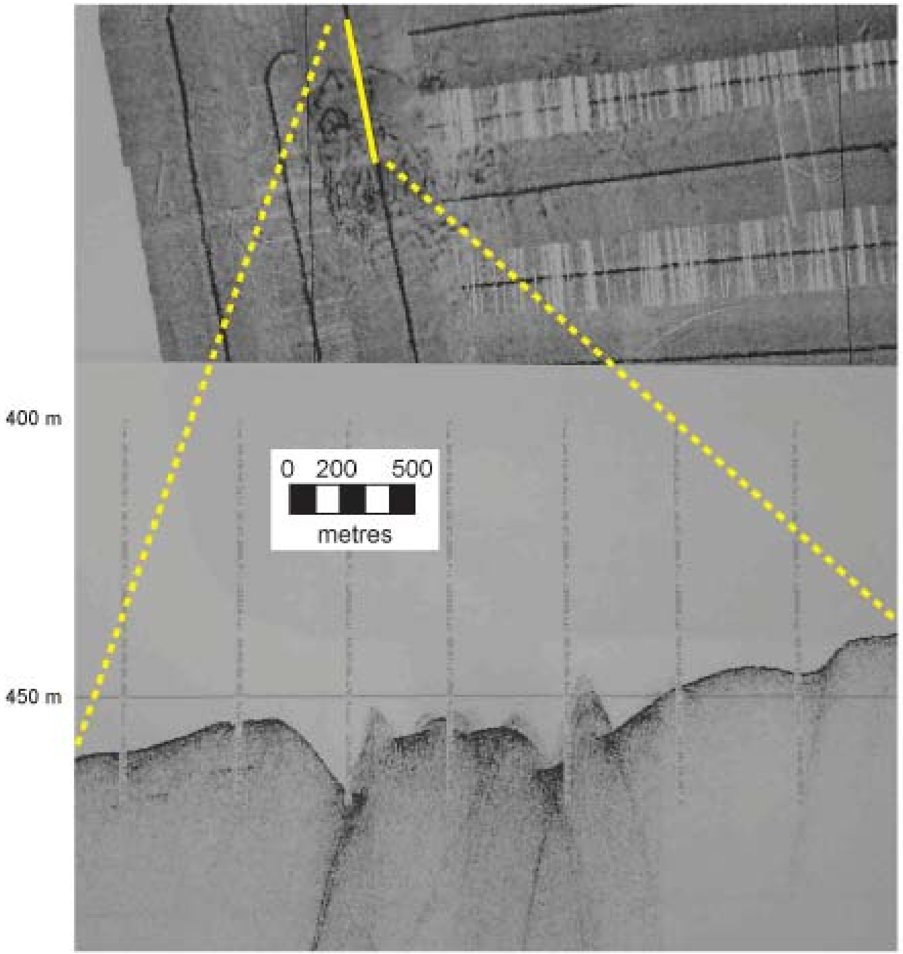


Figure 45. Summit area of George Bligh Bank with plough-marks showing both high and low levels of acoustic reflectivity, and a CHIRP profile showing characteristics typical of those seen over "coral mound" regions.

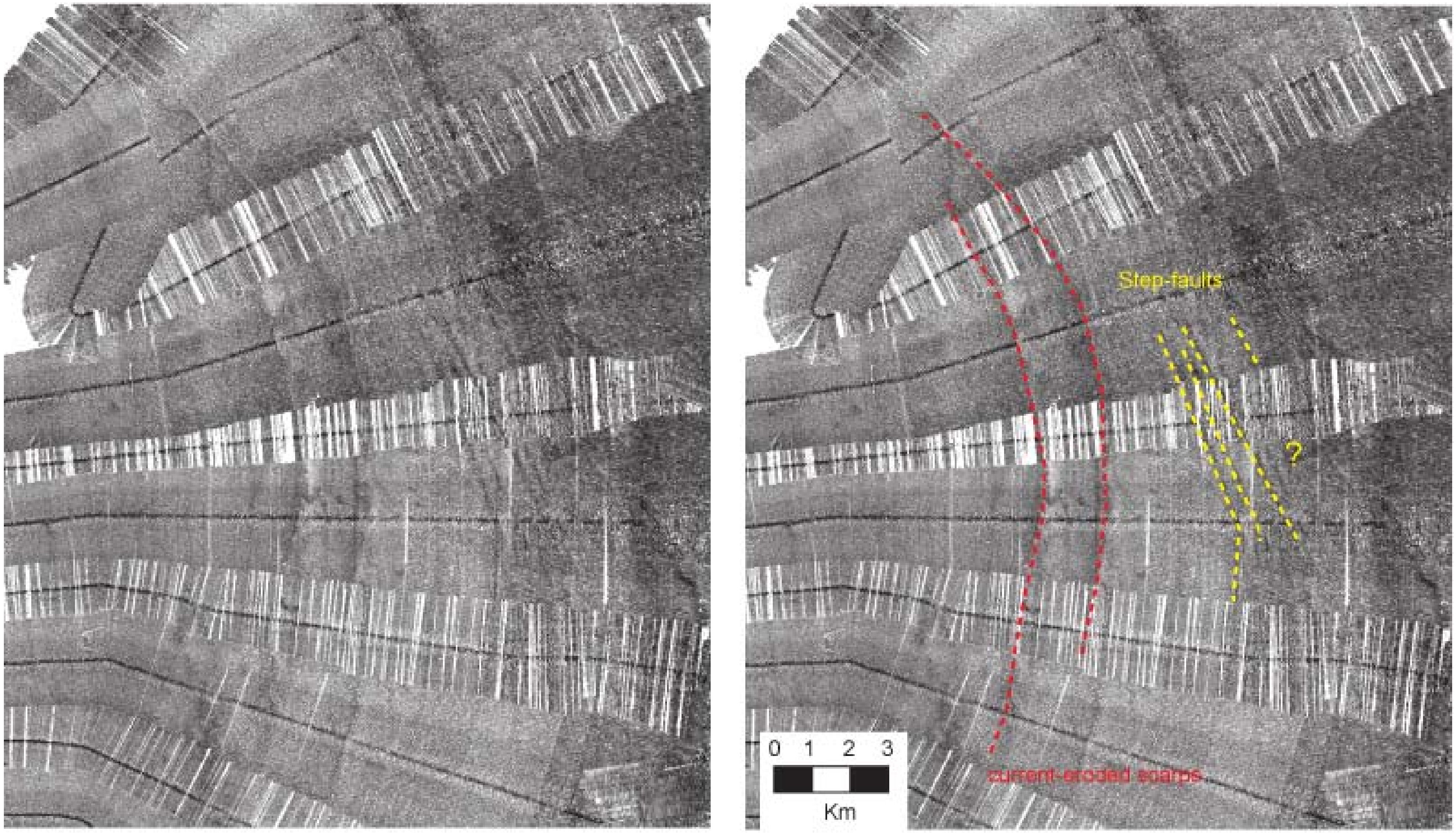
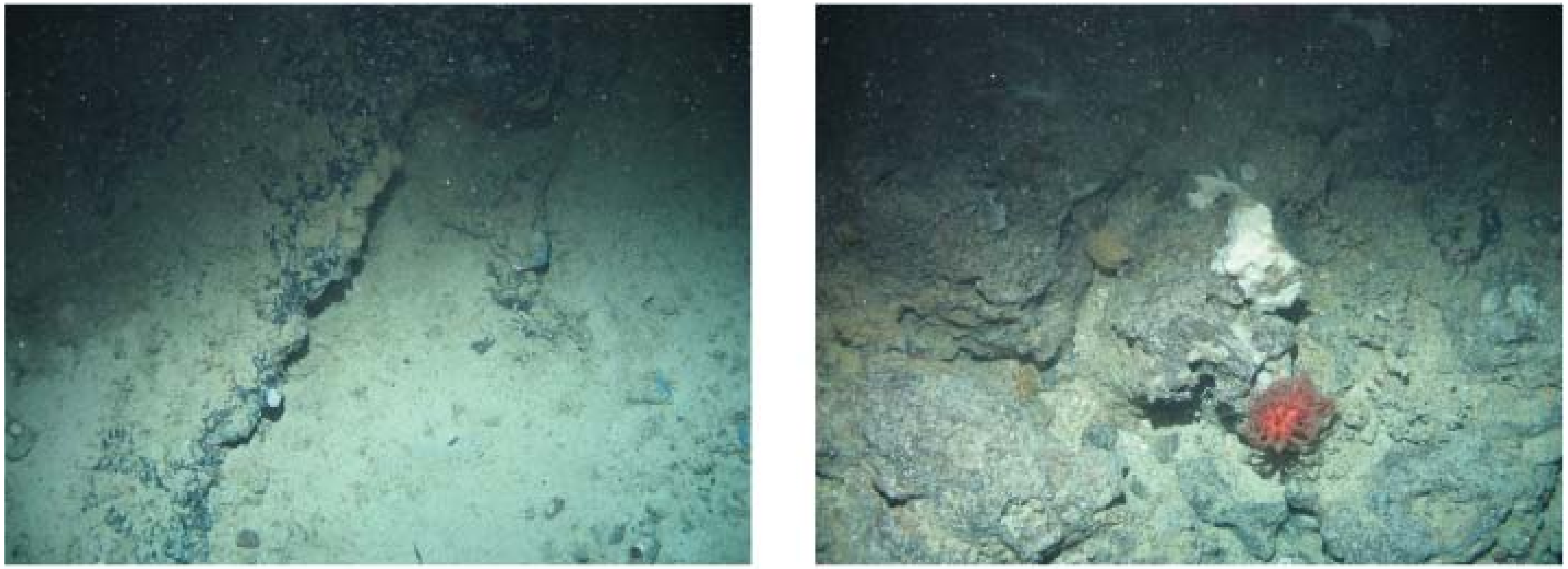


Figure 46. Acoustic backscatter mosaic showing a series of concentric rings scarps suggesting erosive current activity at 700-800 m, and at about 1,150 m, distinct slope-parallel lineations of high backscatter that are a series of small (10-15 m) step-faults.



(a) (b)

Figure 47. Seafloor photographs over northeast George Bligh Bank showing (a) thin outcrop forming an overhang on the eastern flank of the Bank, and (b) massive outcrop occurring further down slope.

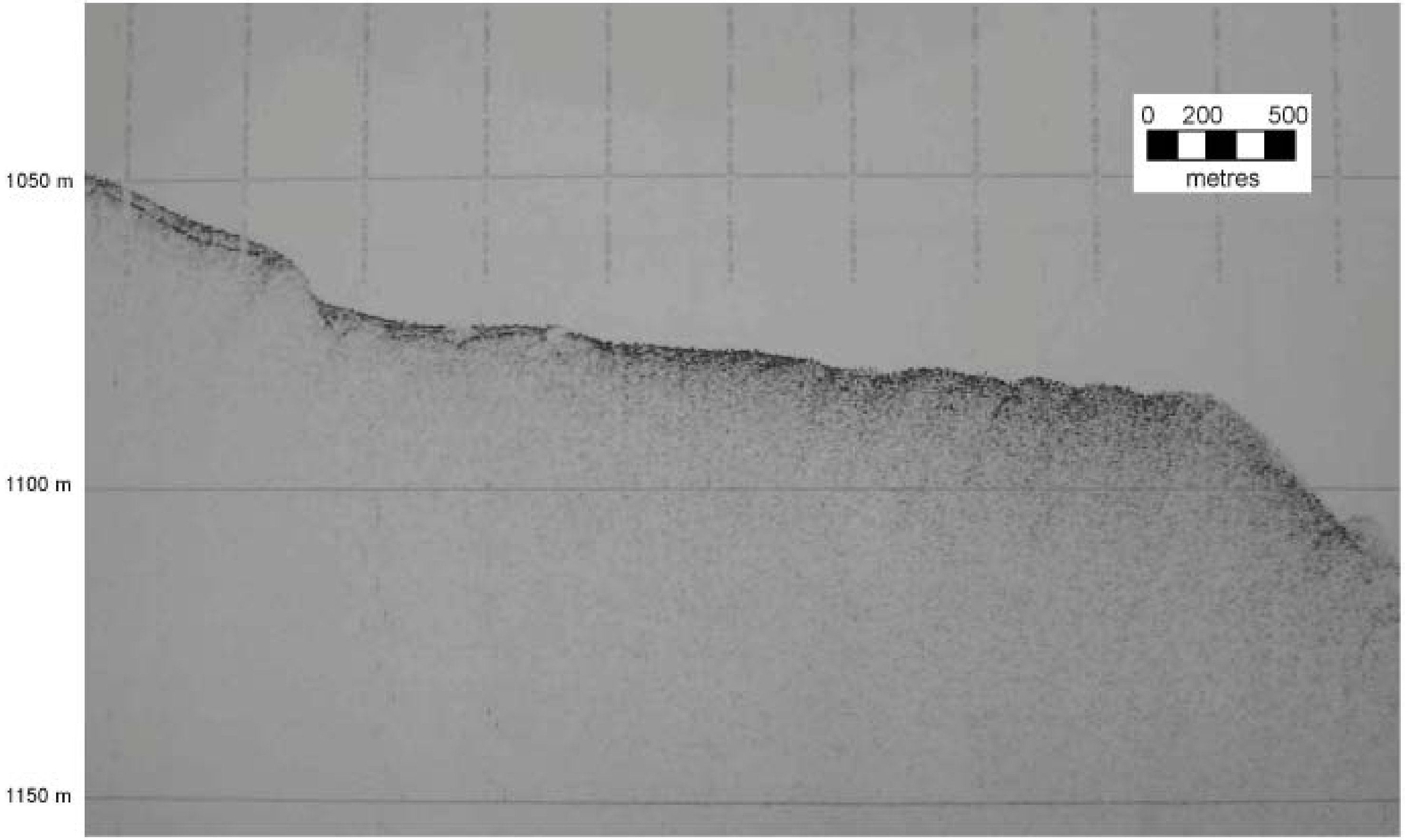
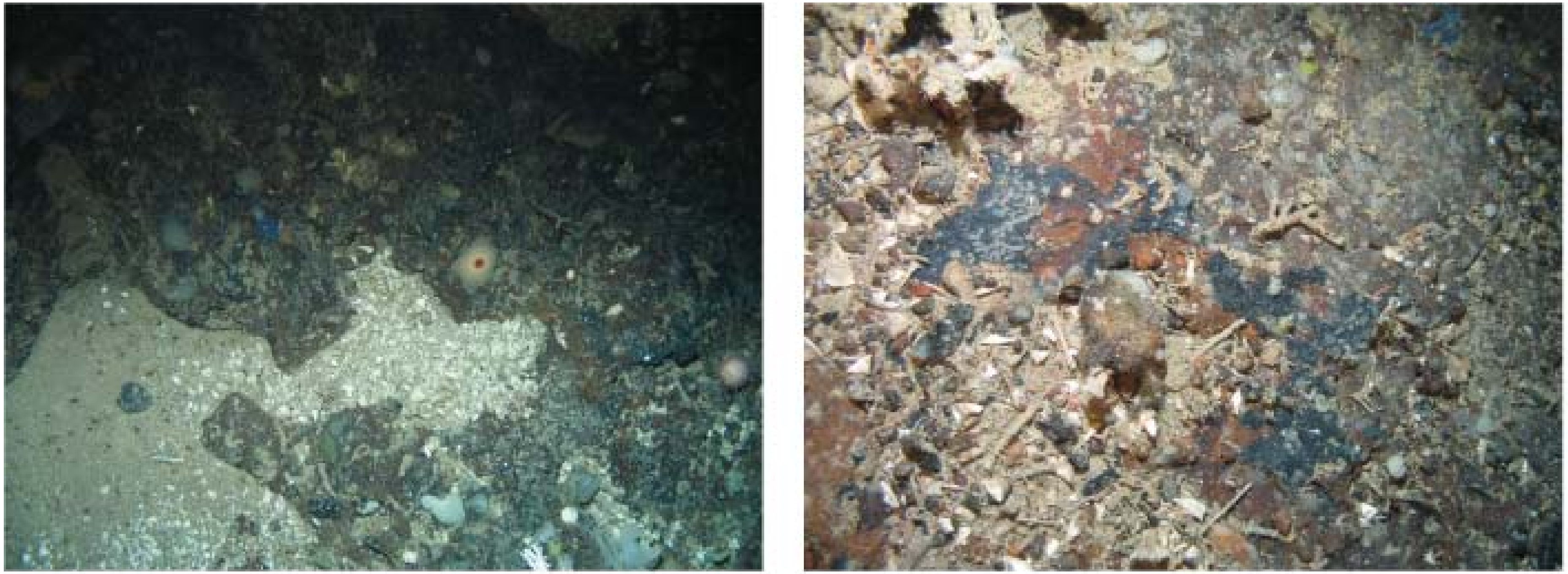
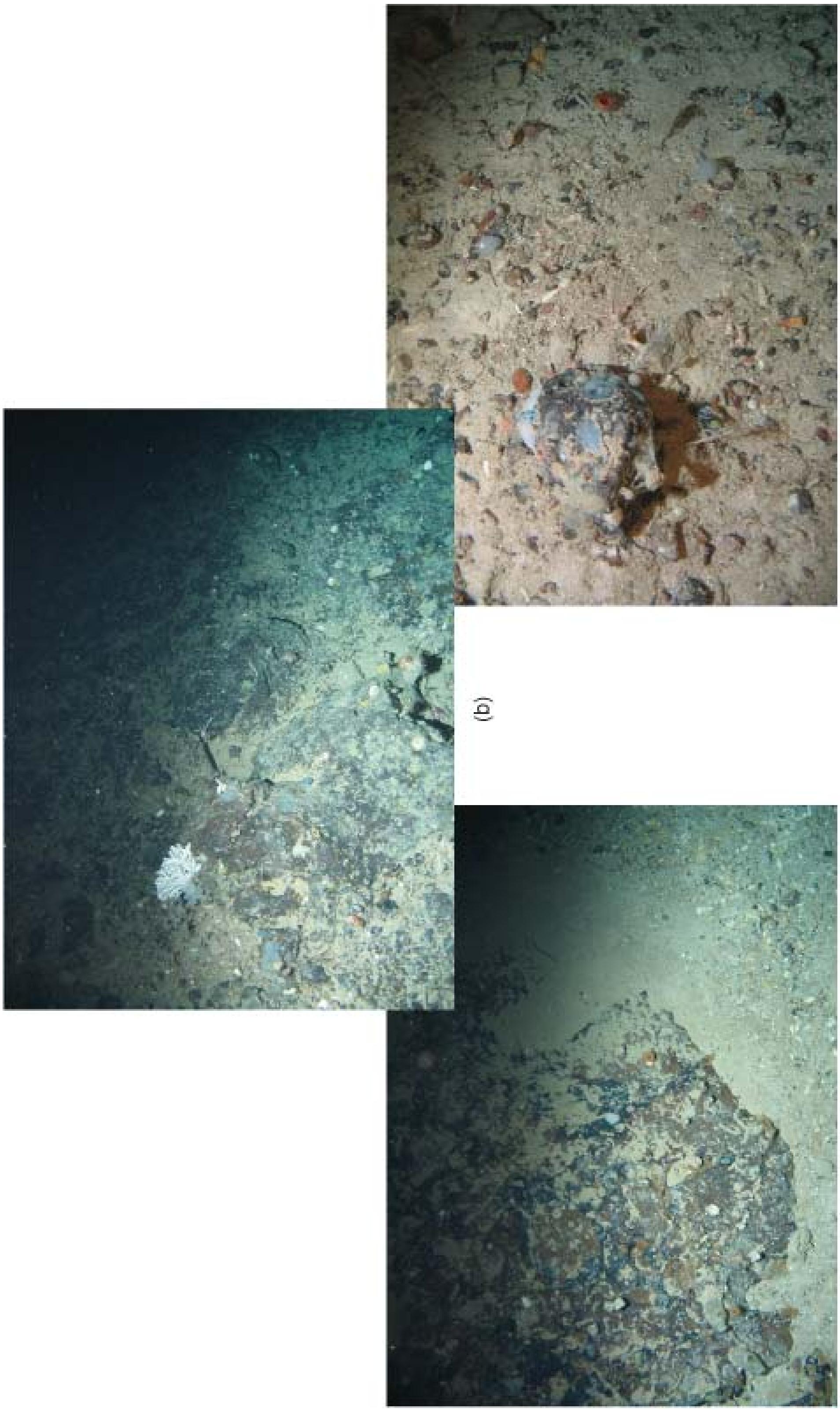


Figure 48. CHIRP profile showing very high seafloor reflectivity and hyperbolic echoes that indicate active seabed erosion over this region of eastern George Bligh Bank.



(a) (b)

Figure 49. Seafloor photographs over the east flank erosion zone on George Bligh Bank, showing the typical seabed of outcrop and/or large boulders (a), and detail of the massive outcrop areas, which usually exhibit a joint system and are either blackened or iron-stained.



(a)

(b)

(c)

Figure 50. Various types of seabed encountered on the eastern flank of George Bligh Bank, from (a) iron-stained boulders, to (b) washed outcrop and at the base of the slope, (c) biogenic gravelly sands.

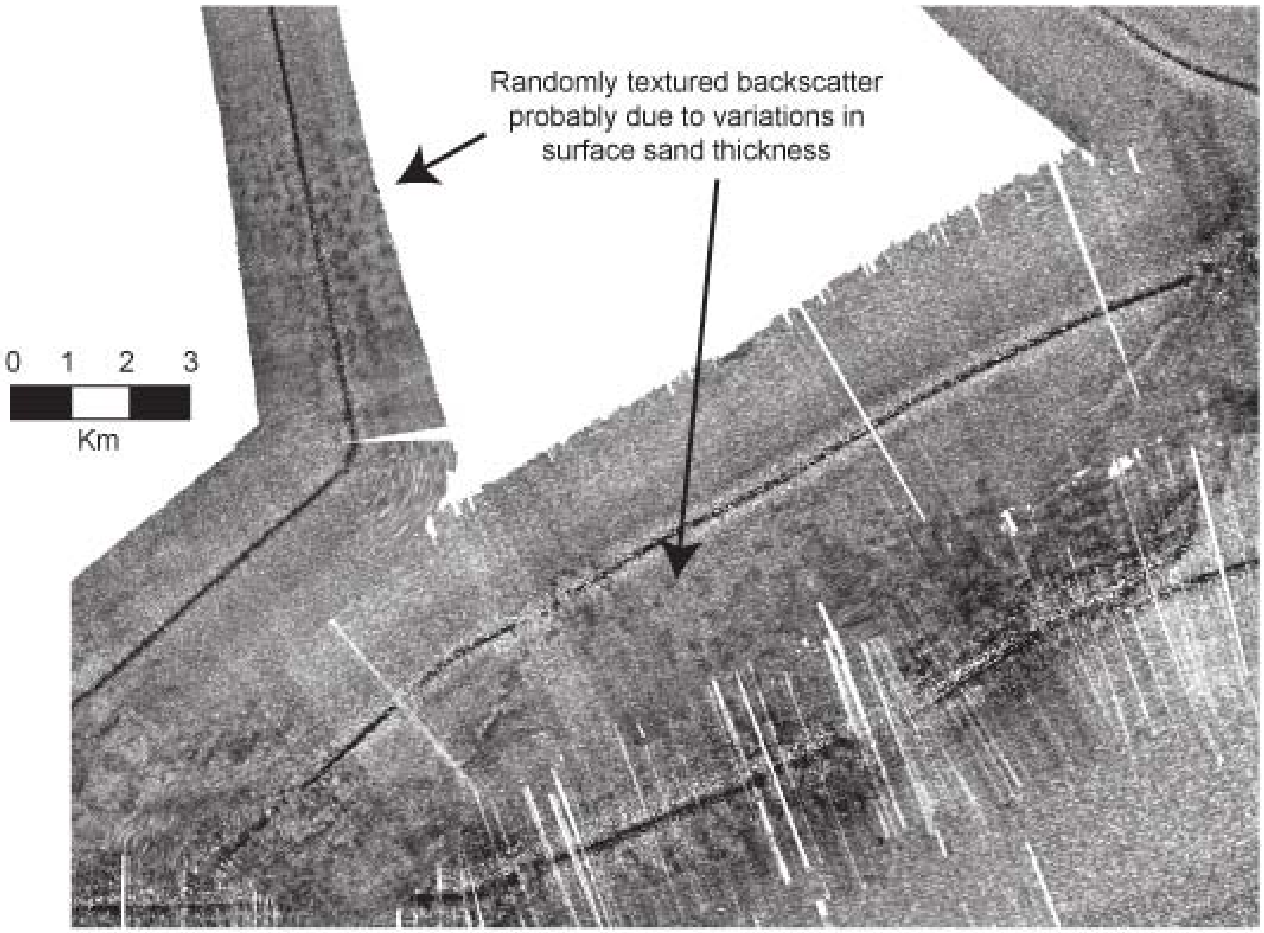


Figure 51. Section of backscatter mosaic from the southern flank of George Bligh Bank showing a random pattern of backscatter differences, probably due to varying thicknesses of surficial sands.

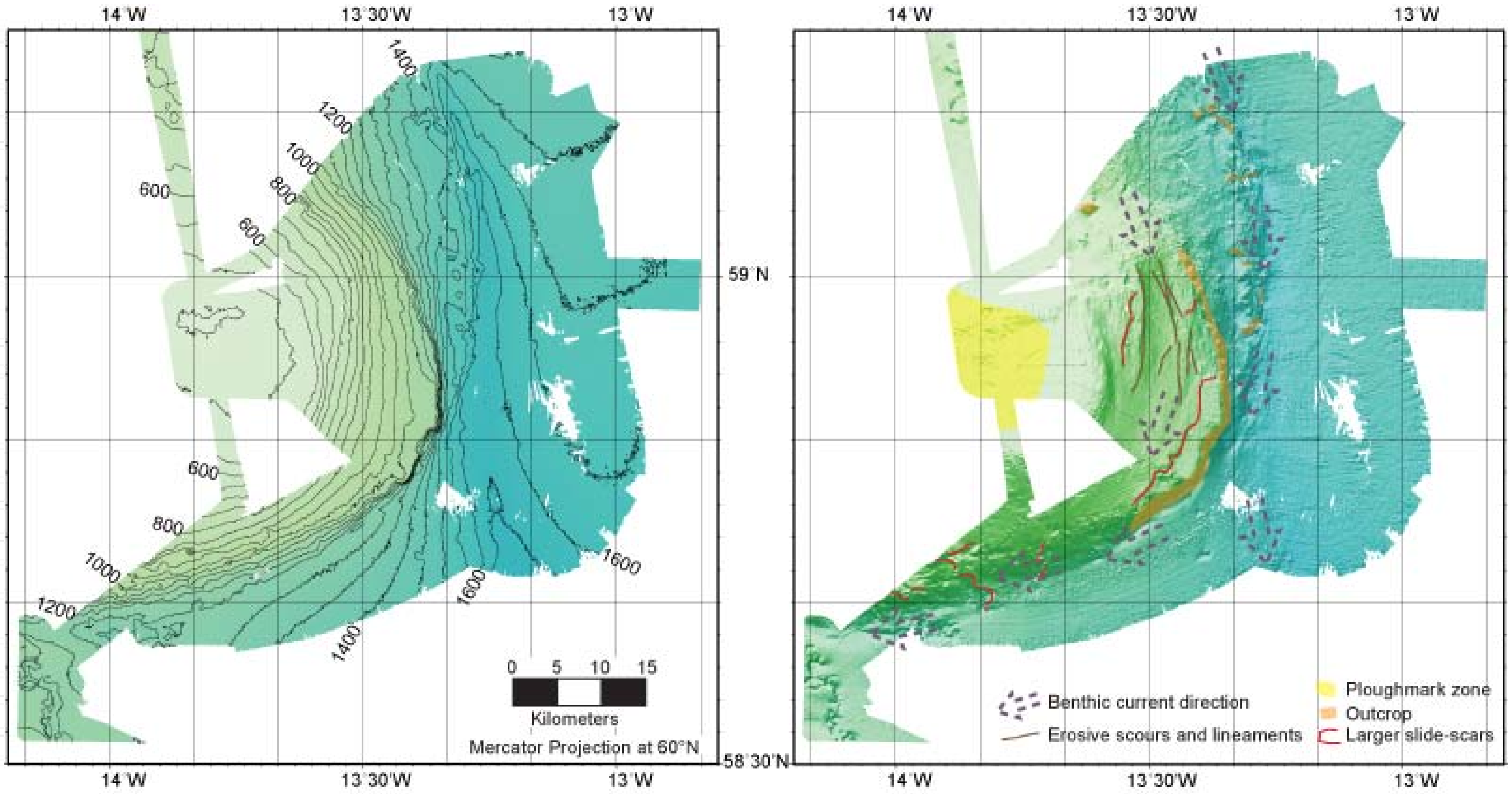


Figure 52. Schematic overview of the geomorphology, surficial seabed geology and benthic current activity over George Bligh Bank as derived from the 2005 SV Kommandor Jack survey.

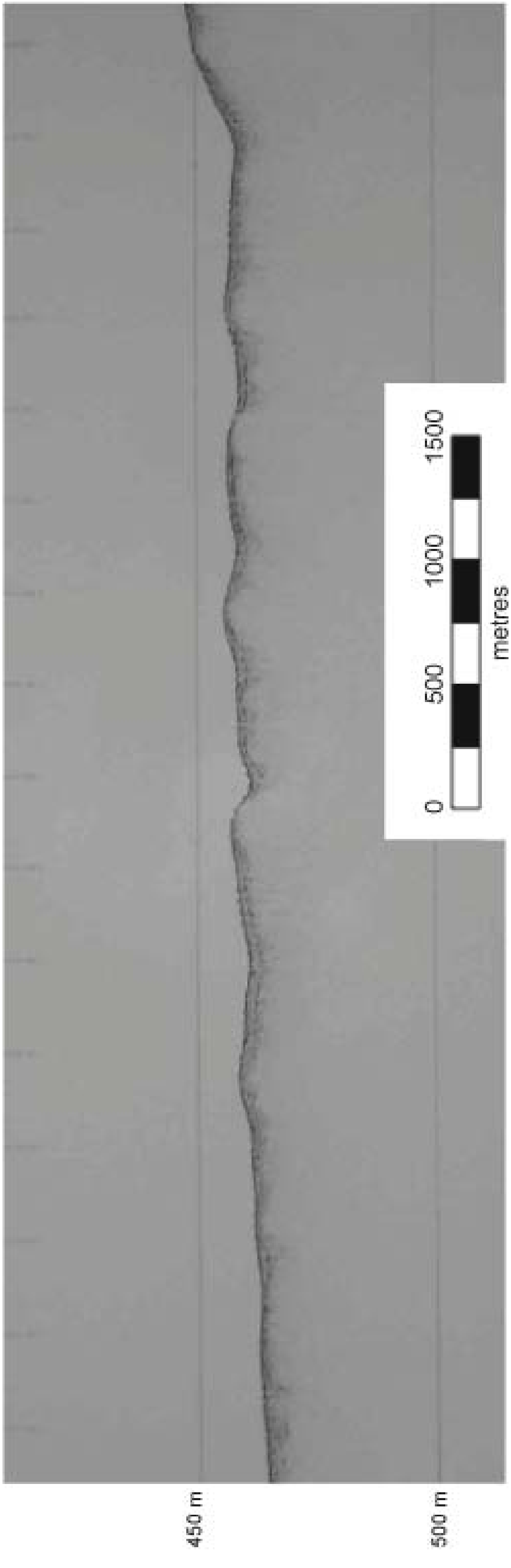


Figure 53. Part of a CHIRP profile over the summit area of Rosemary Bank which reveals that the "waves" seen on the shaded relief maps are actually draped acoustic basement topography.

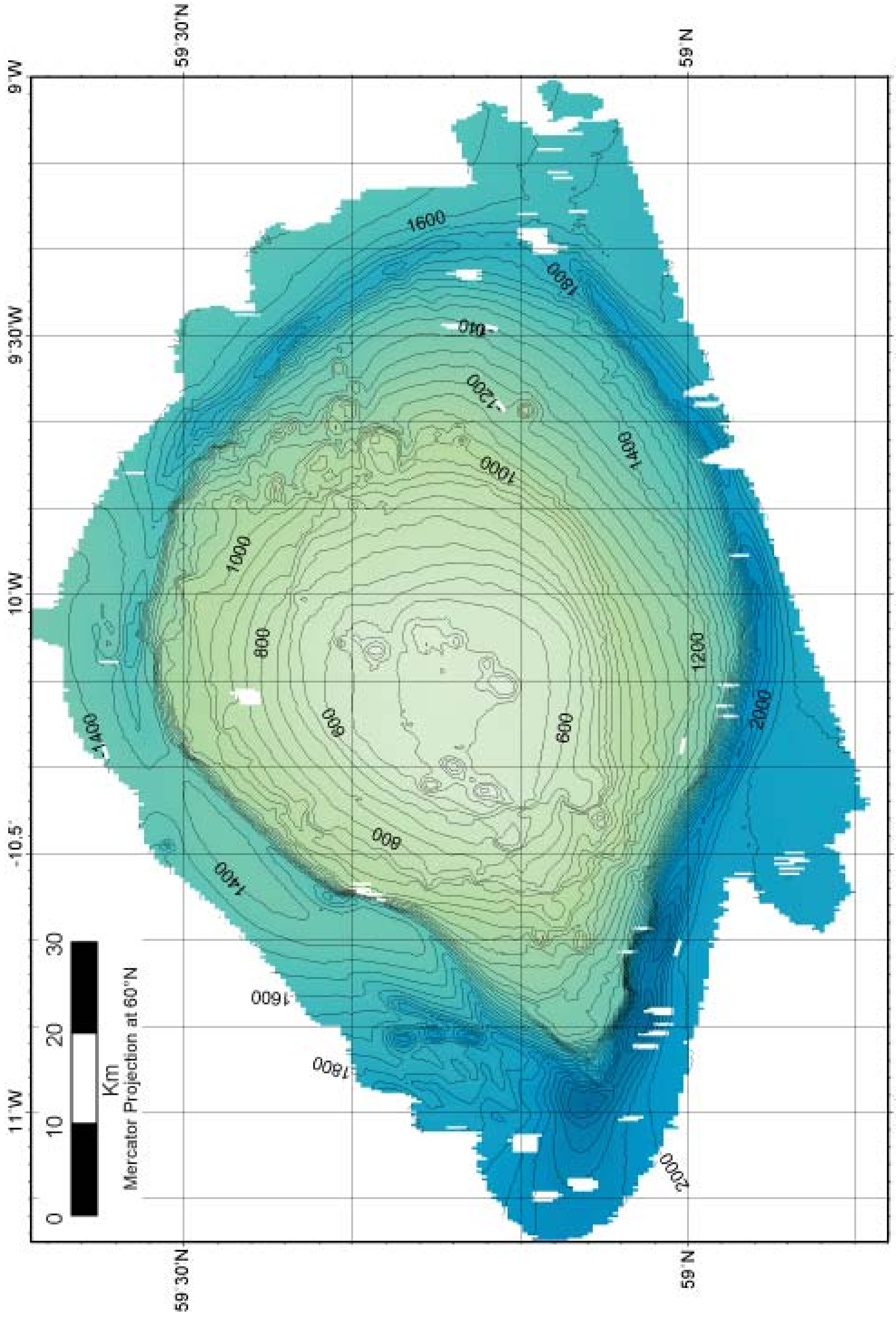


Figure 54. Bathymetry of Rosemary Bank compiled from the EM120 RRS *James Clark Ross* and SV *Kommandor Jack* surveys. Features of note include the groupings of parasitic volcanoes and the steep flanks and moat, and erosional deeps.

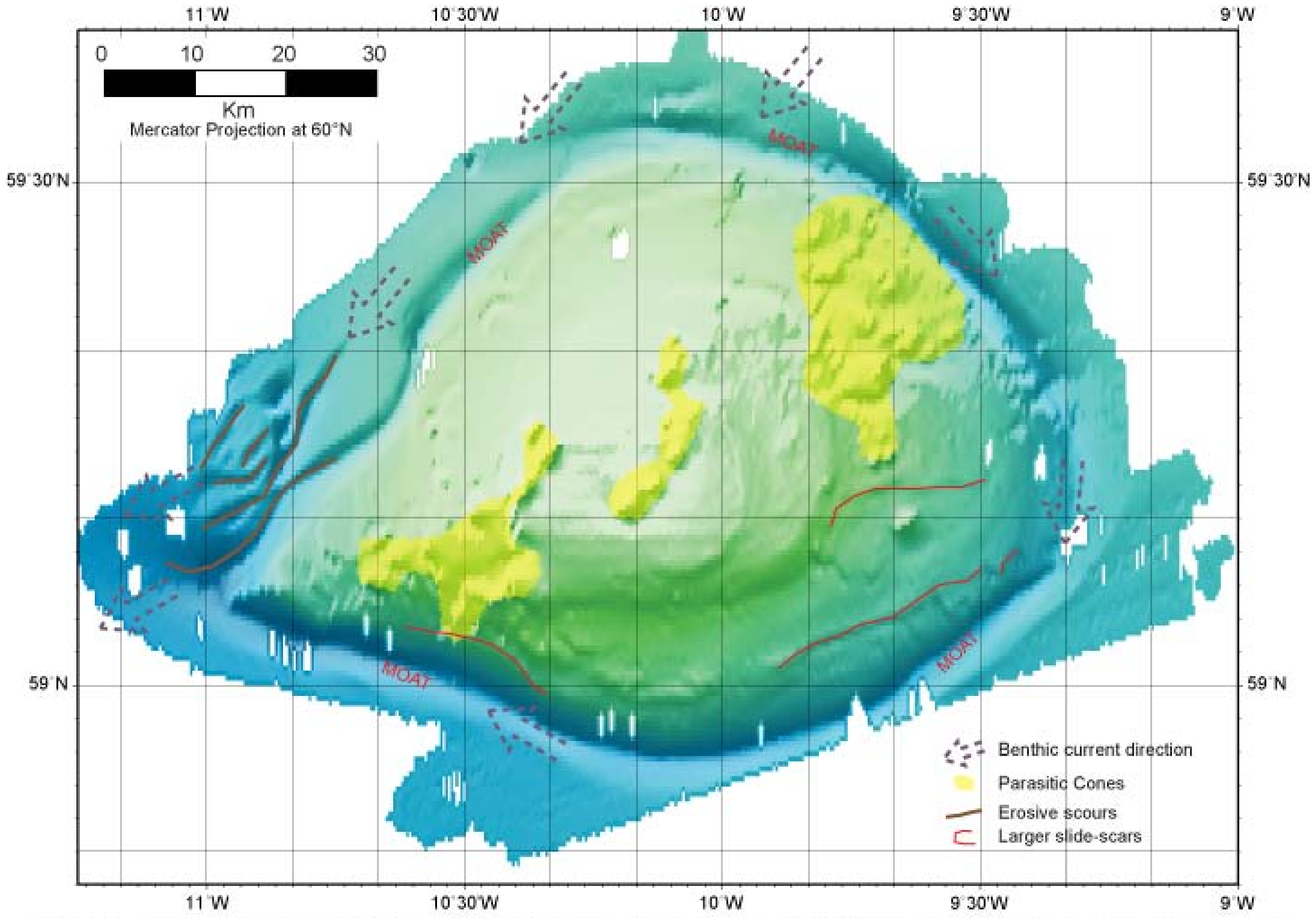


Figure 55. A schematic overview of the geomorphology, surficial seabed geology and benthic current activity over and around Rosemary Bank as derived from the 2005 SV Kommandor Jack and the RRS James Clark Ross surveys

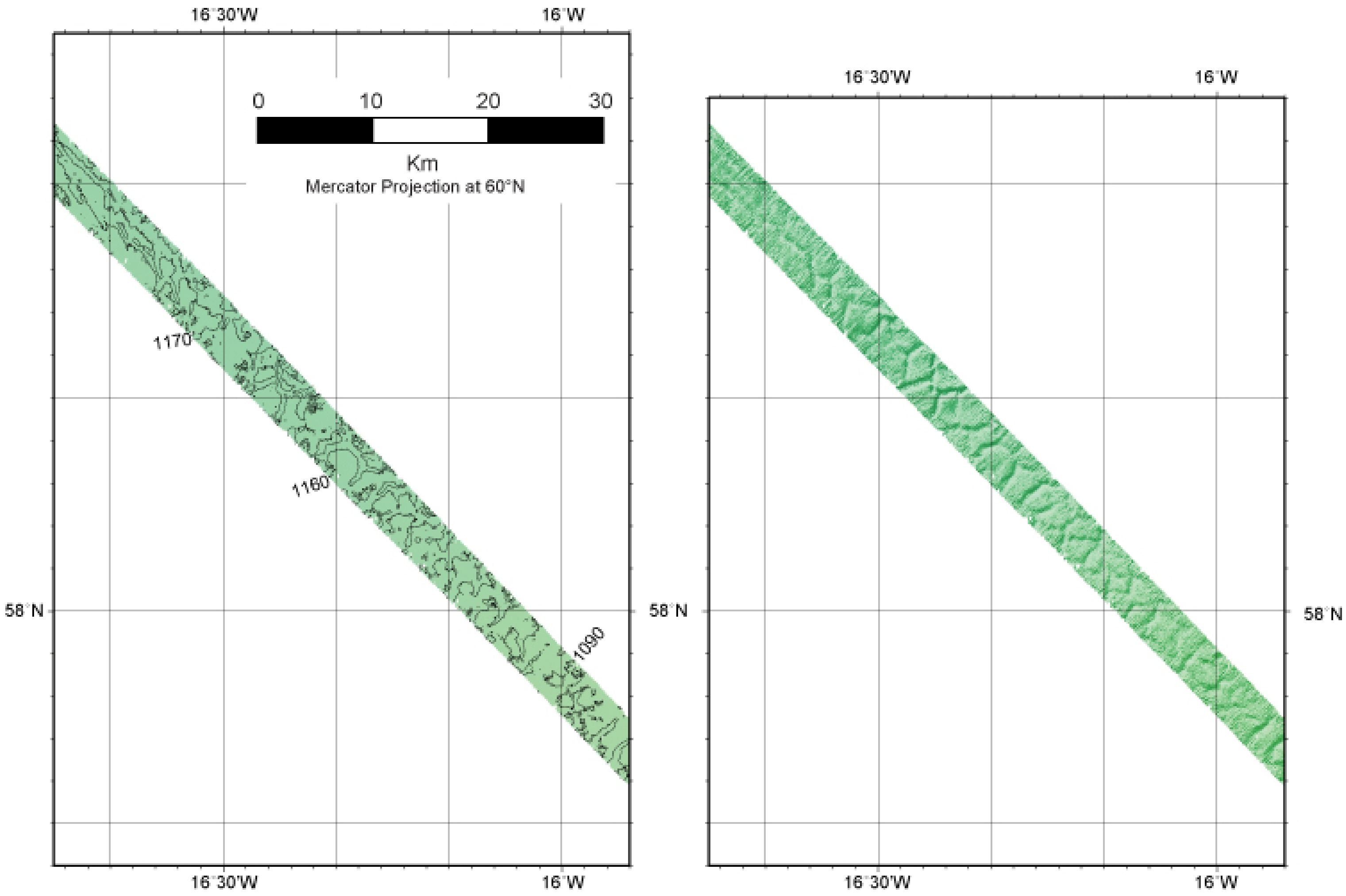


Figure 56. The surface expression of the polygonal faults that occur in the centre of the Rockall-Hatton Basin.

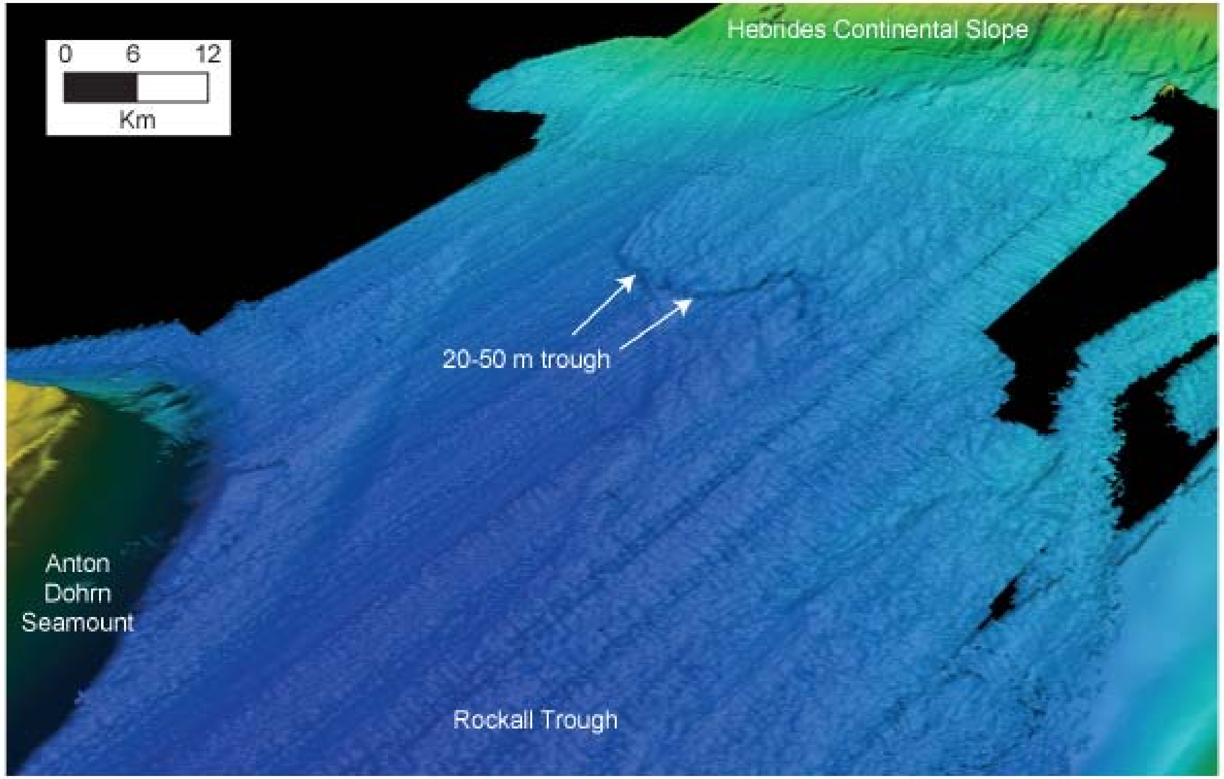


Figure 57. Fledermaus™ view of superimposed, now buried, debris flows on the lower Hebrides slope between Anton Dohrn and the Hebrides Terrace Seamount.