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MESH South West Approaches Canyons Survey (MESH Cruise 01-07-01) Final Report

DAVIES, J., GUINAN, J., HOWELL, K., STEWART, H. & VERLING, E. (editor)

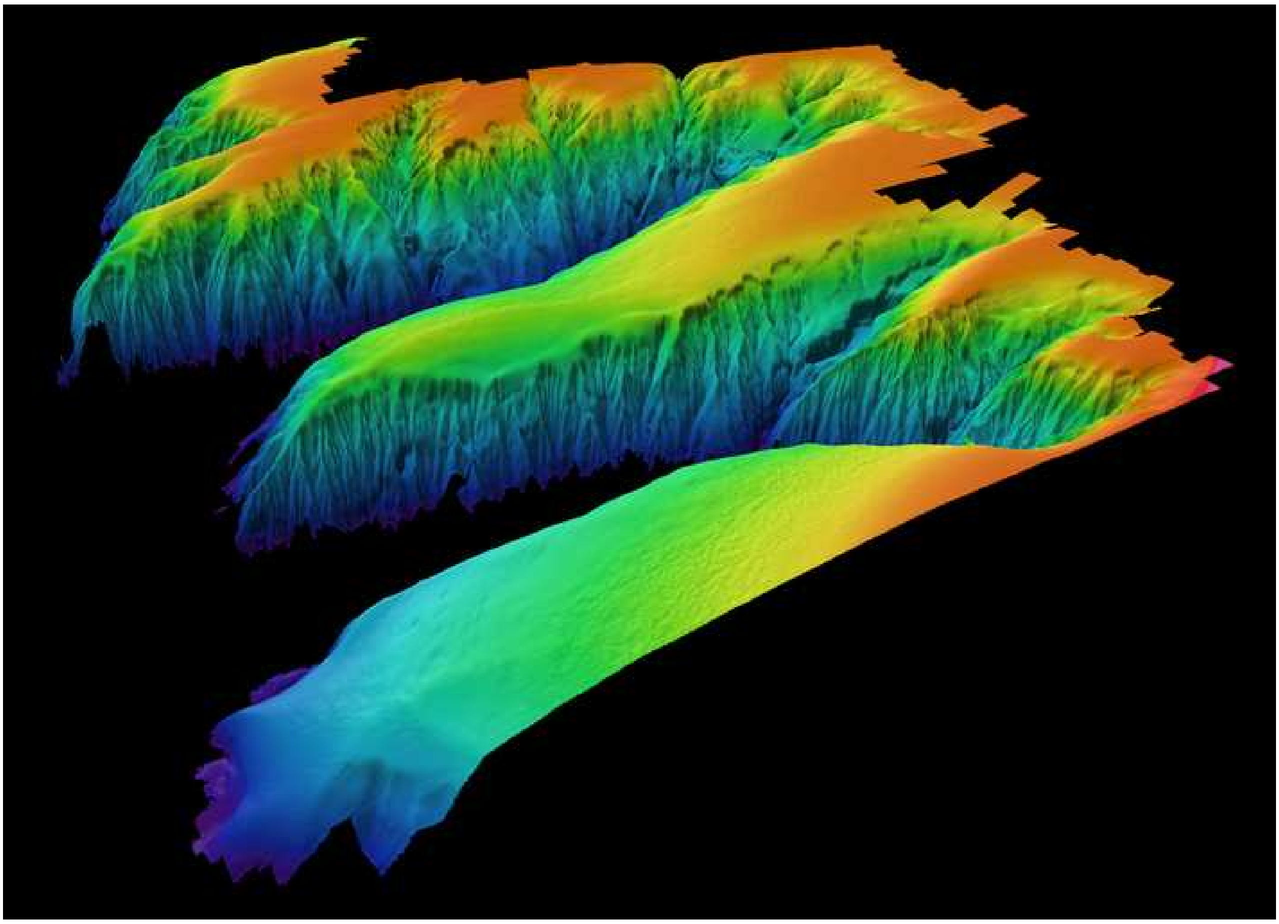

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Table of Acronyms used within this report

Acronym	Full Name
BGS	British Geological Survey
BPI	Bathymetric Position Index
BTM	Benthic Terrain Model
DEFRA	Department of the Environment, Food and Rural Affairs
DTI	Department of Trade and Industry
DTM	Digital Terrain Model
EU	European Union
EUNIS	European Nature Information System
GIS	Geographic Information System
HERMES	Hotspot Ecosystem Research on the Margins of European Seas
ICES	International Council for Exploration of the Sea
IFREMER	Institut Français de recherche pour l'exploitation de la Mer (French Research Institute for Exploitation of the Sea)
IHO	International Hydrographic Office
INSS	Irish National Seabed Survey
JNCC	Joint Nature Conservation Committee
MESH	Mapping European Seabed Habitats
MI	Marine Institute
MOW	Mediterranean Outflow Water
NADW	North Atlantic Deep Water
OSPAR	Oslo Paris Convention
POM	Particulate Organic Matter
PRIMER	Plymouth Routines in Multivariate Ecological Research
SAC	Special Area of Conservation
SEA	Strategic Environmental Assessment
USBL	Ultra Short Base Line
ICES WGDEC	Working Group on Deep Water Ecology

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1. Executive Summary

Submarine canyons are known to occur within European and UK waters, but have been the subject of few detailed studies. Although many marine studies have occurred on the European continental slope west and south-west of the British Isles, relatively little is known about deep sea submarine canyons in this area. The presence of canyons on the continental slope can significantly alter the hydrodynamic regime of the region. As a result, canyons may be highly unstable environments subject to periodically intense currents, debris transport, sediment slumps and turbidity flows (Shepard, 1973; Inman *et al*., 1976; Gardner, 1989). The great variability in the physical environment of canyons also creates differences in their faunal composition when compared to the neighbouring continental slope. Perhaps one of the most critical differences in the physical environment of canyons (in terms of its influence on the fauna) is the increased food supply found in these areas. Submarine canyons play an important role in the transport of sediments and organic matter from the shelf to the bathyal and abyssal zones (Shepard, 1951; Heezen *et al*., 1955; Monaco *et al*., 1990), and may serve as critical fish habitats (Stefanescu *et al.*, 1994).

Canyons found within the South West (SW) Approaches area (located at the Celtic Margin, approximately 320 km south of Cork, Ireland and south-west of Land's End, United Kingdom) were examined as part of this study. Two types of canyons occur along the Celtic margin, canyons with long, narrow upper reaches and V-shaped profiles that incise at the shelf-break; and canyons with short, broad upper reaches, U-shaped profiles and heads deeper than the shelf break on the continental slope. At the study area, the shelf-break occurred between a depth of 180 and 250m. Beyond the shelf, canyons occur densely spaced along the margin on the steep continental slope. In general, younger canyons are typically incised several hundred meters below the shelf break whilst older canyons tend to be more deeply recessed into the slope, and back across the shelf, suggesting that canyons have developed shorewards by headward erosion (Cronin *et al.*, 2005). The SW Approaches canyons area has been identified as an Area of Search (AoS) for the potential presence of Annex I reef listed in the EC Habitats Directive 92/43/EEC (EC, 1992). It was predicted that these submarine may contain bedrock and biogenic reefs formed by cold water corals (two of the three sub-types for Annex I reef). As this area is more influenced by southerly 'warmer' water bodies, it may contain biological communities very different from those Annex I reef AoS occurring in the far North-West of the UK offshore area which are influenced by 'cold' Arctic waters.

The study of the SW Approaches area had four key objectives:

- to collect high-resolution bathymetry, backscatter, sub-bottom and camera data from the submarine canyons located in the SW Approaches;
- to identify and map the extent of Annex I reef habitat (including all the sub-types of this habitat) listed in the EC Habitats Directive 92/43/EEC (EC, 1992), in particular Annex I Reef habitat (Johnston *et al*. 2002) within selected canyons in the SW Approaches area;
- to provide data to allow the assessment of potential Annex I reef habitat against the interpretation of Annex I reef according to the EU Habitats directive; and

- to test the application of the MESH Guidance framework for seabed habitat mapping, covering all stages of a project from planning through survey, analysis, map production and finally the practical application of maps for environmental management (www.searchmesh.net). This was the first thorough test for the recently completed MESH Guidance Framework, and so providing a 'proof of concept' from planning to completion.

The R/V Celtic Explorer vessel (The Marine Institute, Ireland) was used to survey the area over thirteen days in June, 2007. Both the Dangaard (also known as Dangeart) and Explorer canyons were covered, as well as the southern interfluve of a third canyon within Irish Waters. Multibeam bathymetric and backscatter data were acquired using the vessel's hull-mounted Kongsberg Simrad EM1002 system, which operates at a frequency of 93 to 95kHz and has the capability of acquiring swath bathymetry up to ~1,000m water depth. During the survey, acoustic data were also acquired using the keel-mounted precision hydrographic echo sounder, the Kongsberg Simrad EA600. Sub-bottom data were collected during the cruise to provide information from below the sea bed and allow the evolving history of the SW Approaches area to be assessed. Two systems were run simultaneously, the British Geological Survey (BGS) multi-tip sparker system and the BGS deep-tow boomer system. Biological sampling was conducted using a drop frame system with both digital video and stills cameras. The multibeam and backscatter response was used to stratify biological sampling as well as depth and position within the canyon. The flanks of the canyons were targeted preferentially, as these steep topographical features are exposed to strong currents and were considered more likely to support Annex I reef habitat. For each statistical image, substratum composition (type and percent cover) and textural classes were determined and classified by eye using the Wentworth and Folk Scales. All fauna visible in images were identified, and the resulting biological data analysed using PRIMER 6 (Clarke and Warwick, 2001) to enable images to be classified to EUNIS (European Nature Information System 2004 version) level 3/4.

The work programme was highly successful with 1106km^2 of multibeam data, 44 camera 'tows' and approximately 310 line km of sub-bottom data collected. The data revealed that the structure of the SW Approaches margin has been shaped by extension during the Early Cretaceous (approximately 130 mya) associated with the opening of the North Atlantic and its uplift, followed by erosion associated with Alpine orogenesis during the mid-Tertiary (Evans, 1990). Two main Alpine orogenic events controlled deposition during the Cenozoic. The first occurred in the middle Eocene and resulted in the compression and folding of Paleocene-Oligocene sediments during the Oligocene (Evans, 1990). The second occurred during the Late Miocene, resulting in a general uplift of approximately 100m in the Channel area (Evans, 1990). This second of the Alpine events is of most importance to the current interpretation. This event caused the seaward deposition of a prograding, deltaic wedge during the Miocene (Jones and Cockburn formations) which downlaps onto the Late Cretaceous Chalk followed by Pliocene incision of the canyons (the Pliocene to Pleistocene Little Sole Formation) (Bourillet *et al.*, 2003; Evans, 1990).

Previous studies and this survey have shown that the SW Approaches area is highly complicated in terms of sedimentary dynamics and evolution, and that the physiography and geology of the Celtic margin is diverse and complex (Cunningham et al., 2005; Evans & Huges, 1984). The study area revealed classic examples of erosional and depositional features consistent with submarine canyons elsewhere. The margin in this region is characterised by a highly dissected (erosional) continental slope interspersed with smooth (depositional) features and a relatively flat, smooth continental shelf. Evidence of mass wasting (gullying and landsliding) on the lower canyon's walls is contributing to sediment deposition at the lower canyon slope and floor. The backscatter mosaic could be divided into three types of broadly defined acoustic classes; (1) sharply defined areas of low backscatter reflectance (pale grey) occurring on the shelf, probably related to regions of mud and muddy sand (2) dark (high) backscattering seabed representing coarse grained sediment types occurring at the shelf-break, in the canyon gullies and on canyon interfluves (3) moderately backscattering seafloor with mottled lighter and darker patches generally associated with the outer shelf. The predominant ground type identified in the area comprised rippled, muddy sand with boulder and bedrock only cropping out on the canyon flanks and floors. The dominant sea floor composition identified was that of deep-sea mixed substrata, which comprised gravel and gravelly sediments in water depths >200m and was generally limited to water depth <500m. The deeper waters were dominated by muddy sediments.

Interestingly, the canyon interfluves, or canyon tops, comprised numerous mounds up to 10m in height and ~80m in diameter. These mini-mound features were not identified within the shallow sub-surface imaged by the seismic data and it was concluded that they are modern features possibly forming through colonisation and subsequent growth on a relict sea bed rather than accumulation over time. Significant amounts of coral rubble were observed coincident with these mounds. It is likely that this area once hosted diverse carbonate mounds similar to those found on Porcupine Bank (ICES WGDEC Report, 2005; Roberts *et al.*, 2003) and the northern Rockall Trough (Masson *et al.*, 2003; Roberts *et al.*, 2003) but have since been destroyed.

All three canyons exhibited a diverse array of substratum types supporting a range of epifaunal megafaunal species. Sea cucumbers (Holothurians), squat lobster (*Munida rugosa*), numerous anemone and several starfish species, sea pens, shell debris and fish species were encountered. Thirteen biotopes were described from the canyons, and of these, six were proposed as new EUNIS habitat types. Six clusters were identified during the multivariate analysis of biological data and were used to define new habitat types according to the EUNIS classification hierarchy (Davies and Moss, 1999). Ten new biotopes were defined from the six clusters, with video observation providing further faunal detail. A further three biotopes were identified from video observations as either no fauna were present on which to undertake cluster analysis or the communities were not sampled by the images. Table 1.1 provides a brief description of each of these biotopes. The most commonly occurring biotopes were Biotope 2, which was observed in all three canyons from 465-1013m, Biotope 6, which was found in all three canyons from 183-808m and Biotope 11, which was observed in all three canyons from 185-895m.

The biological communities observed in and around the canyons are similar to those observed at comparable depths and temperatures on other deep-sea features in the UK's offshore area. However the hard substrate communities observed at other offshore areas in the North West were, in general, more species-rich than those observed in the canyons of the SW approaches. It is possible that this may be a sampling error resulting from the poor-resolution images of bedrock and coral reef obtained in this survey and the limited observations of reef habitat obtained. However, video observations suggest sediment scour and smothering may prevent many species from colonising the available hard substrate. Importantly, one biotope observed in the SW canyons has not been observed during surveys of other deep-sea features. This biotope was found on muddy sand and characterised by the seapen *Kophobelemnon* sp. and cerianthid anemones. This biotope was similar to that of the shallow A5.36 EUNIS habitat type (Circalittoral fine mud). A5.36 is characterised by the seapens *Virgularia mirabilis* and *Pennatula phosphorea* together with the burrowing anemone *Cerianthus lloydii* and the ophiuroid *Amphiura* spp. This newly described biotope could be considered a deep-water version of this shallower habitat type although the sediment of A5.36 may be finer.

Table 1.1 A brief description of each of the 13 biotopes identified within the South West Approaches survey area

Biotope Name	Biotope Description
Biotope 1	Sand/mud with burrowing (Amphiura sp.) and surface dwelling ophiuroids
Biotope 2	Mud with sea pens (*Kophobelemnon sp.*), seastars (*Pseudarchaster* sp.), anemones (*Bolocera sp.*) and holothurians (*Benthogone* sp.)
Biotope 3	Bedrock ledges with annelids/hydroids and anemones.
Biotope 4	*Lophelia pertusa* reef, with predominantly sediment clogged *L. pertusa* and live *Madrepora oculata*
Biotope 5	Coral rubble with squat lobsters (*Munida* sp.), ophiuroids and crinoids
Biotope 6	Mixed sediments with squat lobsters (*Munida* sp.), ophiuroids and crinoids
Biotope 7	Bedrock with a sand veneer, little visible fauna
Biotope 8	Bedrock /boulders with little visible fauna
Biotope 9	Bedrock with sand veneer, with anemones
Biotope 10	Bedrock with barnacles (poss. *Bathylasma* sp.)
Biotope 11	Mud/sand with signs of bioturbation and the occasional cerianthid anemones.
Biotope 12	Mud with abundant cerianthids, and little other fauna
Biotope 13	Bedrock with reef like fauna (corals/crinoids)

Annex I biogenic reef (biotope 4), reef rubble (biotope 5) and bedrock reef (biotopes 3 and 13 and limited examples of biotope 6) were all observed within the canyons of SW Approaches. Annex I stony reef was not observed. Cold water coral (*Lophelia pertusa*) reef was observed within and at the seaward entrance to the Explorer Canyon between depths of 743-925m. It was associated with areas of sediment covered and exposed bedrock on the canyon flanks. In addition, areas of reef rubble were observed in the vicinity of intact reef within the canyon but more commonly on the interfluves of Dangaard Canyon associated with mini-mound structures.

It is likely that these mound structures support or once supported live *L. pertusa* reef. Bedrock supporting reef-like fauna was observed in all canyons. Bedrock reef communities were observed at the heads, on the flank and on the canyon floor from 237-1030m. The megabenthic fauna of the bedrock reef areas appear similar to bedrock reef areas on other UK offshore features at similar depths (Narayanaswamy *et al*., 2006; Howell *et al*., 2007b) although a combined analysis of both datasets would be required to establish this conclusively. In addition, much of the encrusting fauna of bedrock reef habitat is difficult to identify below phylum level without physical samples. Thus faunal differences may exist that are undetectable at the resolution achievable with video and image sampling.

The MESH guidance documentation (including Recommended Operating Guidelines (ROGs)) was fully tested throughout the planning and execution of this survey. The guidance available was found to be very useful, and provided a detailed framework for both the planning phases of the survey and during the cruise itself. In general the guidance provided was thorough, although a few additions to the text were identified to further improve its application to a wider range of circumstances. Of the guidance appraised, it was felt that guidance relating to survey metadata recording required the further development. Detail on the recommendations emerging from the appraisal are contained within a separate MESH report (see MESH SW Approaches Canyons Survey (MESH Cruise 01-07-01), MESH Guidance Appraisal Report http://www.searchmesh.net/Default.aspx?page=1935).

The survey of the canyons in the SW Approaches area has provided valuable geomorphological and biological data in an area with previously poor data and thus further enhanced our understanding of marine habitats found in UK offshore waters. During this survey, high quality multibeam bathymetry and backscatter data were successfully acquired over the study area and data from a range of habitats, including Annex I reef were collected. The data have enabled these habitats to be mapped and will allow an assessment against the interpretation of Annex I reef according to the EU Habitats directive which forms part of the process used to select sites for designation as offshore Special Area of Conservation (SACs).

2. Introduction

2.1. The study area and regional setting

2.1.1. Physical setting

The study area was located on the Celtic Margin, approximately 320 km south of Cork, Ireland and southwest of Land's End, United Kingdom (Figure 2.1) The margin trends west-northwest-east-southeast and is characterised by a relatively steep continental slope (Huthnance *et al*., 2001). Whilst the margin exhibits mean gradients of 11° in parts, steep vertical gradients along canyon walls have been recorded locally (Cunningham *et al*., 2005) and the margin is heavily indented by a number of canyons which form the major morphological features along the margin. Bourillet and Lericolais (2003) describe an incised paleovalley network occurring near the shelf break and indicate a connection between the incised valleys and the upper region of the canyons located on the Celtic margin.

Two types of canyons occur along the Celtic margin: 1) canyons with long, narrow upper reaches and V-shaped profiles that incise at the shelf-break; and 2) canyons with short, broad upper reaches, U-shaped profiles and heads deeper than the shelf break on the continental slope. In general, younger canyons are typically incised several hundred meters below the shelf break whilst older canyons tend to be more deeply recessed into the slope, and back across the shelf, suggesting that canyons have developed shorewards by headward erosion (Cronin *et al.*, 2005). At the study area, the shelf-break occurs between 180 and 250 m depth. Beyond the shelf, canyons occur densely spaced along the margin on the steep continental slope.

In this study two canyons and the eastern flank of a third canyon were surveyed on the margin revealing a complicated morphology at the canyon heads and flanks. The flat-topped interfluve areas between the canyons occur between approximately 140 and 400 m and are characterised by slope values not exceeding 8º. Cronin *et al*. (2005) describe how canyons are typically associated with large rivers and rarely occur on gentle slopes. It has been suggested that canyon heads at the shelf-break reflect the seaward expression of river mouths, supplying large amounts of sediment directly to the shelf edge (Bourillet *et al*., 2003; Cunningham *et al*., 2005) whilst terrigenous material has been transported from the north-western European continent to the deep sea via the English Channel to the Celtic deep fan during the Quaternary (Zaragosi *et al.*, 2000).

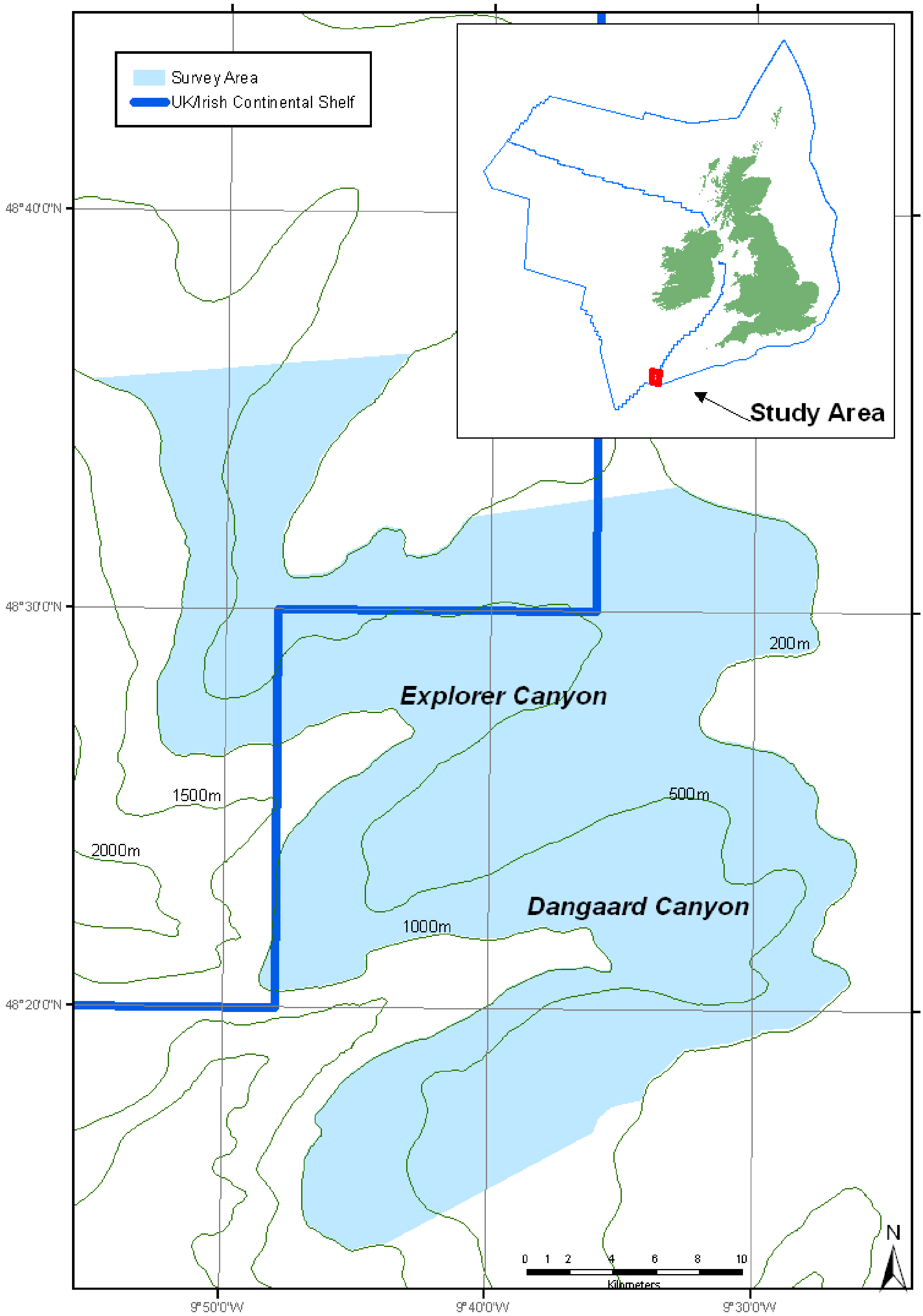

Figure 2.1. Map showing the study area and the location of the UK/Irish Median line. The Explorer Canyon (first named here) and the Dangaard Canyon are also indicated.

2.1.2. Hydrography

High-energy hydrodynamics characterise the Celtic Margin with spring tides and storm surges influencing the transport of sediment from the near shore to the shelf-edge (Cunningham *et al*., 2005). The study area is influenced by two main water masses, the North Atlantic Central Water from the thermocline down to 800 m, and the Mediterranean Outflow Water (MOW) from 800 to 1200 m. Below the MOW, the North Atlantic Deep Water (NADW), which includes a component of Labrador Sea Water, extends from 1200 m down to 3000-3500 m depth. Below the NADW, the Antarctic Bottom Water or Lower Deep Water is found with a low temperature and salinity content (van Weering *et al*., 1998). Along-slope currents move in a northerly and north-westerly direction (Pingree and Le Cann, 1989) and internal waves and tides are considered important to sediment transport and energy dissipation affecting sediment dispersal and sedimentation at the north east Atlantic Ocean margin.

Whilst long- and short-term current measurements on the Celtic Shelf and shelf edge are available, measurements of near-bed (lower 3 m of the water column) currents with direct relevance to sediment transport of resuspension are scarce. Results from the Ocean Margins EXchange Programme indicate along-slope residual velocities of 0.05 m s^{-1} exist at the shelf break and large tidal currents generate internal tides (>0.05 m s^{-1}) with vertical displacements of up to 150 m (Huthnance *et al*., 2001).

The study area is influenced by ebb-dominated tidal currents operating at the shelf edge. Reynaud *et al*. (1999) describe the interplay between tides and waves nearby at the Celtic Sea shelf edge in water depths similar to those at our study area. The area is described as being swept by tidal currents that reach 0.9 m/s 1 m above the seabed while the sedimentation rates are low in parts.

2.1.3. Geomorphology and sedimentary processes

The study area covers a portion of the outer continental shelf, shelf break and upper continental slope of the Celtic Margin which extends from the Goban Spur to the Berthois Spur (Figure 2.2). The outer continental shelf slopes gently southwest to a depth of ~200m where it passes down to the much steeper, deeply canyoned continental slope. The shelf break marks the boundary between the near horizontal sea floor of the continental shelf and the steeper slope.

The Explorer and Dangaard (also known as Dangeart) canyons were incised in the Pleistocene during episodic sea level low stands (Evans, 1990). Periods of low sea level resulted in intensification of wave and tidal action which transported sediment across the shelf and upper slope. This process initiated canyon cutting above sites of earlier buried canyons and natural depressions on the sea floor (Evans, 1990). There is no evidence to suggest that canyon cutting continues today although active retrogressive headwall erosion has occurred since the last glacial maximum (Cunningham *et al.*, 2005; Evans and Hughes, 1984).

The continental shelf hosts a number of major sandwave fields, which are located to the east of the area surveyed and extend laterally along the outer continental shelf (Evans, 1985;

Cunningham *et al.*, 2005). A number of tidal sand ridges, the Celtic Sandbanks, up to 60m in height and 200km in length with a trend of 030˚ are also located on the continental shelf (Evans, 1990). The proximity of the sandwave fields to the canyon heads (2.5km east of the Explorer Canyon head and 5km east of the Dangaard Canyon head) indicates that they are a path for transporting shelf sediment onto the slope (Cronin *et al.*, 2005; Cunningham *et al.*, 2005; Evans, 1985; 1990). The dominant process transporting the sediment through the canyons is turbidity currents triggered by retrogressive slope failure in the canyon head indicated by the presence of "cauliflower" or "amphitheatre" shaped rims in the head area (Figure 4.1; Cunningham *et al.*, 2005; Evans, 1990).

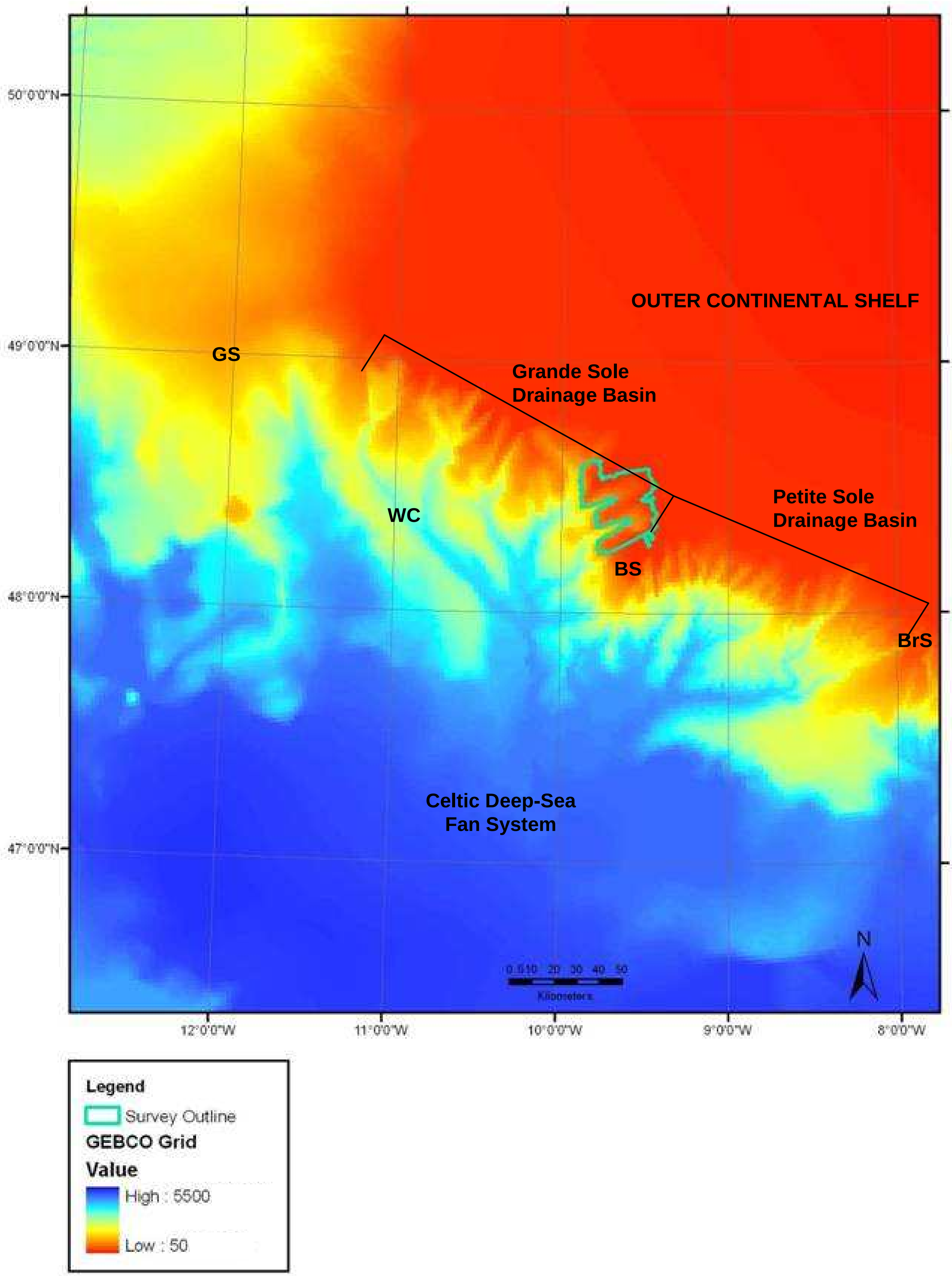

Figure 2.2. Physiographic features of the Celtic margin: BrS - Brenot Spur, BS - Berthois Spur, GS - Goban Spur, WC - Whittard Canyon.

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2.1.4. Biology

The structure of communities of organisms in submarine canyons is poorly known. In terms of the physical environment, submarine canyons can be markedly different to the neighbouring continental slope. They are topographically complex (Yoklavich *et al.,* 2000), contain diverse bottom types (Kottke *et al*., 2003) and may be characterised by benthic environments with high spatial heterogeneity (Schlacher *et al.,* 2007). The presence of canyons on the continental slope can significantly alter the hydrodynamic regime of the region. As a result, canyons may be highly unstable environments subject to periodically intense currents, debris transport, sediment slumps and turbidity flows (Shepard, 1973; Inman *et al*., 1976; Gardner, 1989). The great variability in the physical environment of canyons has led to differences in the faunal composition of canyons as compared to the neighbouring continental slope.

Perhaps one of the most critical differences in the physical environment of canyons compared to the adjoining continental slope (in terms of its influence on the fauna) is increased food supply. Submarine canyons play an important role in the transport of sediments and organic matter from the shelf to the bathyal and abyssal zones (Shepard, 1951; Heezen *et al*., 1955; Monaco *et al*., 1990). Organic matter in the form of macroalgae and/or Particulate Organic Matter (POM) may accumulate within canyons and in some cases canyon floors may be persistently covered with macrophyte detritus (Vetter and Dayton, 1999). Thus detritivores may be expected to flourish in canyon environments. Once in canyons, detritus is transported deeper by processes such as periodic resuspension by tidal flows, slumps and turbidity currents (Shepard, 1973; Inman *et al*., 1976; Gardner, 1989). Much of the organic carbon available to canyon benthos may arrive as flow along the seafloor as a result of resuspension, than as “rain” from the surface. Greatly amplified near-bottom flows (Rowe, 1971; Shepard *et al*., 1974; 1979) may enhance the delivery of particulate organic matter to the benthos and provide a favourable environment for suspension-feeding organisms.

In addition to the transport of organic matter into canyons, canyon consumers also potentially experience enhanced food supply through the trapping and aggregation of vertical migrators (Koslow and Ota, 1981; Hecker *et al*., 1988; Cartes *et al*., 1994; Macquart- Moulin and Patriti 1993; Genin, 2004). Dense layers of krill and zooplankton can become concentrated in canyons during their downward vertical migrations (Greene *et al*., 1988) much as occurs on seamount summits (Genin, 2004). The increased food supply to the benthos can result in elevated levels of secondary production, however this may vary between canyons and with the sediment size fraction examined. For example benthic infaunal biomass and density in canyons has been found to be higher (Gage *et al*., 1995; Vetter and Dayton, 1998), lower (Maurer *et al*., 1994), or similar to the adjacent slope (Houston and Haedrich, 1984).

The Megabenthos

Studies on the megabenthos have reported increased density or biomass in canyons than at comparable depths on the surrounding shelf and slope (Rowe, 1971; Headrich *et al*., 1975; Hecker *et al*., 1988; Cartes *et al*., 1994, Sarda *et al*., 1994, Vetter and Dayton 1999; Duineveld *et al*., 2001). Canyon megafauna have been found to be similar to, but distinct from, the local bathyal fauna (Rowe, 1971; Cartes *et al*., 1994; Stefanescu *et al*.,1994) as well as sharing similarities with sublittoral, coastal and continental shelf fauna for specific taxonomic groups

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such as the sponges (Schlacher *et al*., 2007). Typical megabenthic filter feeders such sea whips, sponges, basket stars, anemones and corals have been found in high densities inside canyons (Rowe, 1971; Hecker *et al*., 1988) and appear to benefit from the greater availability of hard substrate and the enhanced currents within the canyons (Hecker *et al*., 1988). Deposit feeding echinoderms such as holothurians, urchins and ophiuorids have been found in greater abundance (urchins, Dume Submarine Canyon) and density (urchins, La Merenguera, western Mediterranean), lower abundance (urchins, Scripps and La Jolla Canyons (Vetter and Dayton, 1999); ophiuroids, Hatteras Canyon (Rowe, 1971)) and similar abundance (holothurians, Whittard Canyon (Duineveld *et al*., 2001)) in canyons as compared to the neighbouring continental slope. Differences in faunal composition between canyons may be a result of the different disturbance regimes within individual canyons. A high incidence of disturbance by sediment movements from intense tidal currents, turbidity currents and detrital flows may be unfavourable to sessile invertebrate megafauna while favouring highly motile species (Ross, 1968; Rowe, 1971; Vetter and Dayton, 1999).

Canyons may serve as critical fish habitats. Stefanescu *et al*. (1994) found a much higher abundance and biomass of fish within a canyon in the Western Mediterranean than outside. The fish were slightly smaller in the canyon, and the size distributions of common species led to the conclusion that the canyon acts as a nursery ground for some species. Canyons can act as a refuge from fishing activities. Physical structures such as rock walls, boulders and ledges may provide shelter from bottom-contact fishing gear (Yoklavich *et al*., 2000).

The Regional Setting

The European continental slope west and south-west of the British Isles is one of the most intensely studied areas of the deep-sea. However data on the megabenthic fauna of this region has rarely been presented at a community level and has instead focused on specific faunal groups (Billett, 1991; Howell *et al*., 2002). In addition nearly all sampling of the megafauna from this region has been achieved using a trawl on soft sediment habitats. Video observations have however been made in the neighbouring Whitard Canyon (Duineveld *et al*., 2001) and Porcupine Bank (Tyler and Zibrowius, 1992), although not entirely from comparable depths. Within the UK Continental Shelf Limit two large scale video and stills image surveys of significant deep-water features at comparable depths to the present study have been undertaken. In 2005 the Department of Trade and Industry (DTI) Strategic Environmental Assessment (SEA) undertook survey of Rockall, Hatton and George Bligh Banks and the Anton Dohrn Seamount (Narayanaswamy *et al*., 2006). In 2006 the DTI SEA in association with DEFRA undertook a survey of Hatton, George Bligh and Rosemary Bank and the Wyville Thompson Ridge (Howell *et al*., 2007b).

Collectively these studies of offshore features and topographically complex regions of the continental slope west of the British Isles describe a diverse megabenthic fauna inhabiting a range of substratum types. Extensive areas of cold water coral reef have been observed on the Hatton, George Bligh and Rockall Bank and the Wyville Thompson Ridge. These coral-dominated areas support a rich associated sessile epifauna. Steep slopes and terraces of bedrock have been observed on George Bligh, Hatton, Rockall and Porcupine Banks supporting a sessile epifauna of encrusting sponges, scleractinians, antipatharians and gorgonians. The broad summits of the Anton Dohrn seamount, Rockall and George Bligh Bank and the Wyville

Thompson Ridge are covered by extensive sand plains with a low diversity epifauna dominated by echinoids.

2.1.5. Conservation interest

The UK government has a responsibility to implement the 1992 Directive on the conservation of natural habitats and of wild flora and fauna (92/43/EEC; also known as The Habitats Directive). As part of the implementation of the directive, the Joint Nature Conservation Committee (JNCC) provides advice to UK government on suitable areas in UK offshore waters that may qualify as Special Areas of Conservation (SACs; Johnston *et al*., 2002). These sites must contain habitats listed on Annex I and/or species listed on Annex II of the directive. Of the three Annex I habitat types known to occur in UK offshore waters, one (H1170, Reefs) has been identified as potentially present in the South West Approaches area. Further information on definitions and interpretation of these habitat types and their corresponding sub-types can be found on the JNCC website (http://www.jncc.gov.uk/page-1447).

Within Annex I reef habitat in the context of the Habitats Directive, there are three sub-types;

- Bedrock reefs (e.g. pinnacles, offshore banks);
- Stony reefs (cobble and boulder reefs, iceberg ploughmarks);
- Biogenic reefs made by cold-water corals (e.g. *Lophelia pertusa*), the Ross worm *Sabellaria spinulosa* and horse mussels *Modiolus modiolus*.

To qualify as Annex I reef, these features should ‘arise from the seabed’ or be topographically distinct. Importantly, reef can be either of geogenic or biogenic origin, the latter category of which includes concretions of corallogenic origin, including cold-water *Lophelia pertusa* reef which have been found in other parts of the UK offshore area (Howell et al., 2007b). Figure 2.3 shows the areas of potential Annex I reef (geogenic) habitat in the SW Approaches study area. The Dangaard Canyon in particular has been identified as a potential area of Annex I Reef habitat. The existence of Annex I habitat could lead to the area being recommended as an offshore SAC to the UK Government. Further information was required to fully assess the area in terms of its conservation importance, in particular to determine the existence and extent of Annex I reef habitat. However, data collected during this survey may also be used to contribute to the development of the EUNIS (European Habitat Classification System, 2004 version) and to inform national and international agreements on biodiversity and conservation such as OSPAR.

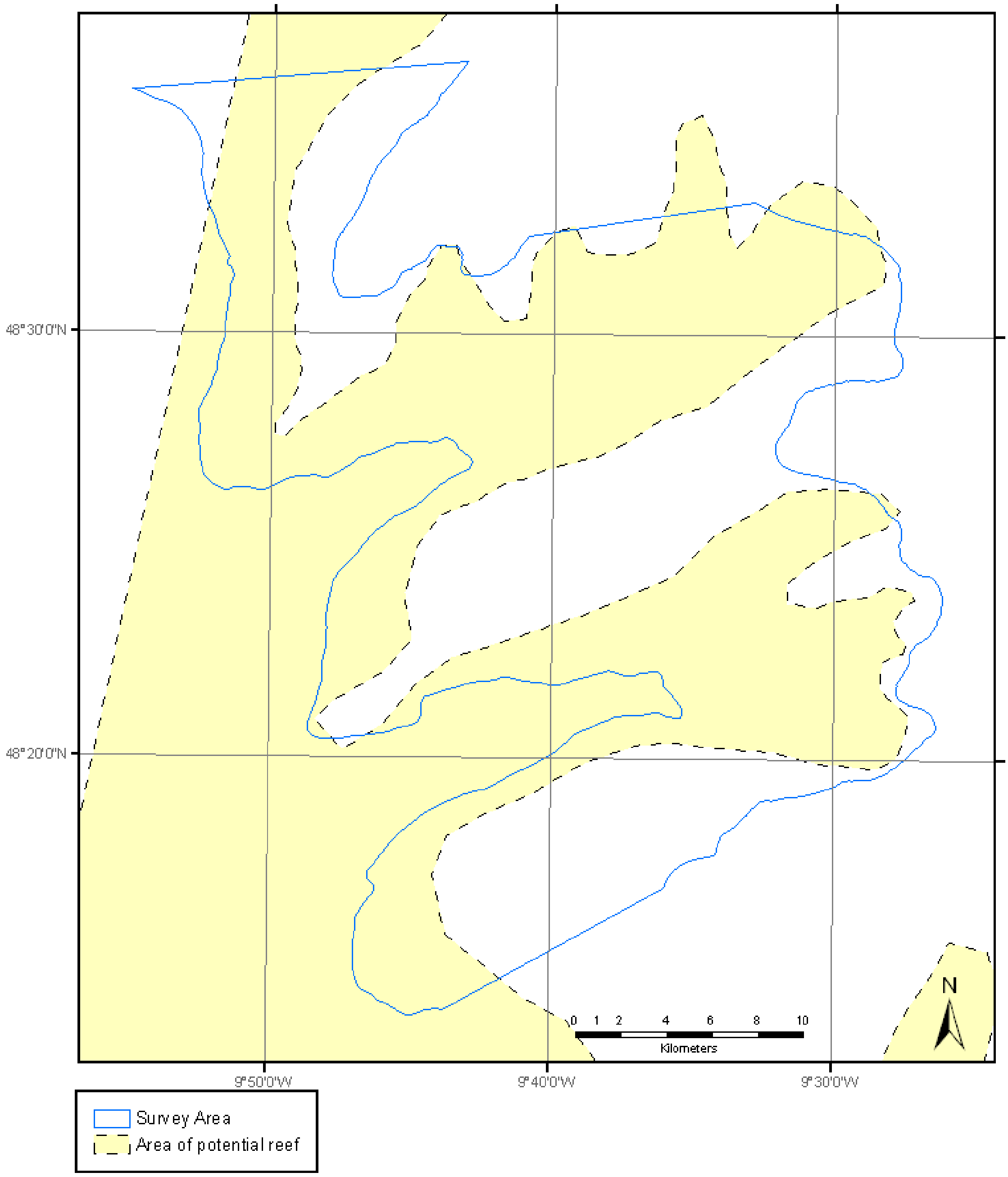

Figure 2.3. Map showing the study areas in relation to the location of areas of potential geogenic reef habitat (based on Graham *et al*., 2001)

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2.2. Study Objectives

The project goals were to better define the extent and morphological structure of the submarine canyon system located in the South West Approaches Regional Sea area, and to better define and distinguish the biological communities found within, and in the vicinity of the canyon system. Specifically, the objectives of the cruise were:

- to collect high-resolution bathymetry, backscatter, sub-bottom and camera data from the submarine canyons located in the SW Approaches
- to identify and map the extent of Annex I reef habitat (including all the sub-types of this habitat) listed in the EC Habitats Directive 92/43/EEC (EC, 1992), in particular Annex I Reef habitat (Johnston *et al*. 2002) within selected canyons in the SW Approaches area.
- to provide data to allow the subsequent assessment of potential Annex I reef habitat against the interpretation of Annex I reef according to the EU Habitats directive
- to test the application of the MESH Guidance framework for seabed habitat mapping, covering all stages of a project from planning through survey, analysis, map production and finally the practical application of maps for environmental management (www.searchmesh.net). This was the first thorough test for the recently completed MESH Guidance Framework, and so providing a 'proof of concept' from planning to completion. The results of this process are presented as an Annex to this report (see MESH SW Approaches Canyons Survey (MESH Cruise 01-07-01), MESH Guidance Appraisal Report http://www.searchmesh.net/Default.aspx?page=1935)

3. Methods

3.1. Survey vessel and survey details

The vessel used during the survey was the Marine Institute (Ireland) vessel the *R/V Celtic Explorer*, which is 65.5m in length and accommodates 31 personnel. The survey took place over thirteen days in June, 2007; the vessel left Cork Harbour on Tuesday, 5th June 2007 and returned to Galway on Monday, June 18th 2007.

3.2. Acoustic data collection

Prior to commencing the survey, Irish National Seabed Survey (INSS) bathymetry data were supplied to assist in survey planning and gap analysis. These data included multibeam bathymetric and backscatter data. Multibeam bathymetric contour data for the survey area were also made available from the French Research Institute for Exploitation of the Sea (IFREMER).

3.2.1. Multibeam bathymetric data acquisition

The multibeam bathymetric and backscatter data were acquired from the *R/V Celtic Explorer*, using the vessel's hull-mounted Kongsberg Simrad EM1002 system. The EM1002 is a hull mounted multibeam echo sounder operating at a frequency of 93 to 95kHz and has the capability of acquiring swath bathymetry data in up to ~1,000m water depth. Data collected during the cruise were acquired to a depth of 1,165m.

A fixed swath width of 660m was employed throughout the survey, maintaining a beam spacing of at least 5% the water depth. In this fixed survey mode, the EM1002 automatically adjusts the angular coverage so the required swath width is achieved. Multibeam echo sounder data were acquired to meet the International Hydrographic Organisation (IHO) S44 Order 2 standard. Full details on the EM1002 calibration exercise and data quality control performed during the survey can be found in the Operations Report (Stewart and Davies 2007).

During the survey, acoustic data were also acquired using the keel-mounted precision hydrographic echo sounder, the Kongsberg Simrad EA600. The multi frequency system installed on the *R/V Celtic Explorer* has three main transducers and a fourth transducer shared with another system. The three main frequencies are 12kHz, 38kHz and 200kHz with the shared transducer operating at 120kHz.

3.3. Collection of data using seismic techniques

Sub-bottom data collected during the MESH cruise provide information from below the sea bed and allow the evolving history of the SW Approaches area to be assessed. During the course of operations 320 line kilometres of seismic data were collected (see Figure 2.4). Two systems were run simultaneously, the British Geological Survey (BGS) multi-tip sparker system and the BGS deep-tow boomer system. Each system is summarised below but more comprehensive information for each can be found in the operations report for the cruise (Stewart and Davies, 2007). Please note that line 2007-06/02 from this cruise, collected in the deep-water area of Dangaard Canyon, was of poor quality due to water depth and has not been used for the interpretation.

3.3.1. Multi-tip Sparker System

A nine-candle, multi-tip array with 135 tips was used during the cruise, although at times during operations it was sufficient to operate with only 90 tips. The system ran at 1000 Joules per shot on lines 1-7, 1250 Joules per shot on lines 8-11, 750-1500 Joules per shot on line 12 and 1500 Joules per shot on lines 13-16. The sparker was fired once every 6 seconds, interleaved with the firing of the deep-tow boomer.

The summed output from the towed 10m hydrophone was fed into the BGS amplifier, which incorporates low pass and anti-alias filters and manually adjustable analogue gain to compensate for acoustic losses with water depth. The data were recorded using a CODA DA200 set up to digitally record two seismic sources simultaneously, in this case both the sparker and deep-tow boomer systems. The sparker signal was sampled at 5000Hz.

3.3.2. Deep Tow Boomer System

The BGS deep-tow boomer system is a deep-towed negatively buoyant fish comprising a 'boomer plate' transducer, high voltage storage and discharge system, a short hydrophone streamer and various sensors and controls. The system has variable output powers, on this project 500 Joules per shot was utilised. The deep-tow boomer was generally fired 3-4 times in every 6 seconds, depending on water depth and the height of the tow fish from the sea bed, interleaved with firing of the sparker.

A 2m, 6 element deep water BGS streamer was used during this cruise. The depth compensated analogue signal output was then fed into the BGS amplifier. The amplifier incorporates low pass and anti-alias filters and manually adjustable analogue gain to compensate for acoustic losses with water depth. The data were recorded simultaneously with the sparker system onto a CODA DA200 as described above. The deep-tow boomer signal was sampled at 10,000Hz.

3.4. *Seabed sampling*

3.4.1. Selection of sampling stations

The study site was divided into three areas, corresponding approximately to individual canyons. For each canyon, biological sampling, using both video and stills cameras (Figure 3.1), was stratified by interpreted ground-type / seabed features (using multibeam and backscatter response), depth, and position within the canyon The flanks of the canyons were targeted preferentially, with at least four transects positioned along each flank. These steep topographical features were assumed to be exposed to strong currents and thus more likely to support Annex I reef habitat. In addition, interesting features on the interfluve areas were targeted.

3.4.2. Collection of video and stills data

The Seatronics drop frame system was deployed from the starboard side of the vessel (see Figure 3.1). It comprised an integrated DTS 6000 digital video telemetry system, which provided a real time video link to the surface, and a 5 mega pixel Kongsberg and Imenco digital stills camera. Both video and stills cameras were mounted opposite each other at an oblique angle (video: 24º; stills: 22º) to the seabed to aid in species identification. Sensors monitored depth, altitude and temperature, and an Ultra Short Base Line (USBL) beacon provided accurate position data for some tows, but unfortunately malfunctioned for much of the survey. When the USBL failed, positional data were taken from the ships T-frame.

Figure 3.1. The Seatronics drop frame system onboard the *R/V Celtic Explorer*. Photo: Neil Golding © Crown Copyright.

Each transect was approximately 500m in length, although there were exceptions to this (i.e. if the terrain or currents became too difficult to control the camera). For the majority of tows, vessel speed was approximately 0.5 knots (min 0.3 and max 0.7 knots), with most tows lasting

between 0.3-1.5hrs. The drop frame was towed in the water column between one and three metres (dependant on substrate type and currents) off the seabed. At the beginning of each tow, starting from when the sea floor became visible, a 2-3 minute period was allowed, to enable the camera to stabilise before commencing the transect. At approximately 1 minute intervals the camera was landed on the seabed and a still image taken, exceptions were, 1) when the substratum was extremely soft (silt clouds) 2) when the substratum was extremely rocky, uneven, delicate (coral), or descending a cliff face; here the camera was not landed and images were taken off the seabed. These images are described throughout as 'statistical' images. In order to achieve representation of the biological communities present, images were also taken where habitat boundaries occurred. In addition opportunistic images were taken: to aid in species identification; to observe interesting geological features (e.g. sand ripples) and to capture evidence of anthropogenic activities/damage (e.g. fisheries).
A total of 44 video tows, totalling 23hrs of footage, and over 5000 stills images were obtained across the study area.

3.4.3. Calibration of the field of view

The fields of view of both the stills and video cameras were calibrated using a grided quadrat of known dimensions. Calibrations were made for 'on bottom' (drop frame fully landed on the seabed; Figure 3.2) and at 1m, 2m and 3m off bottom.

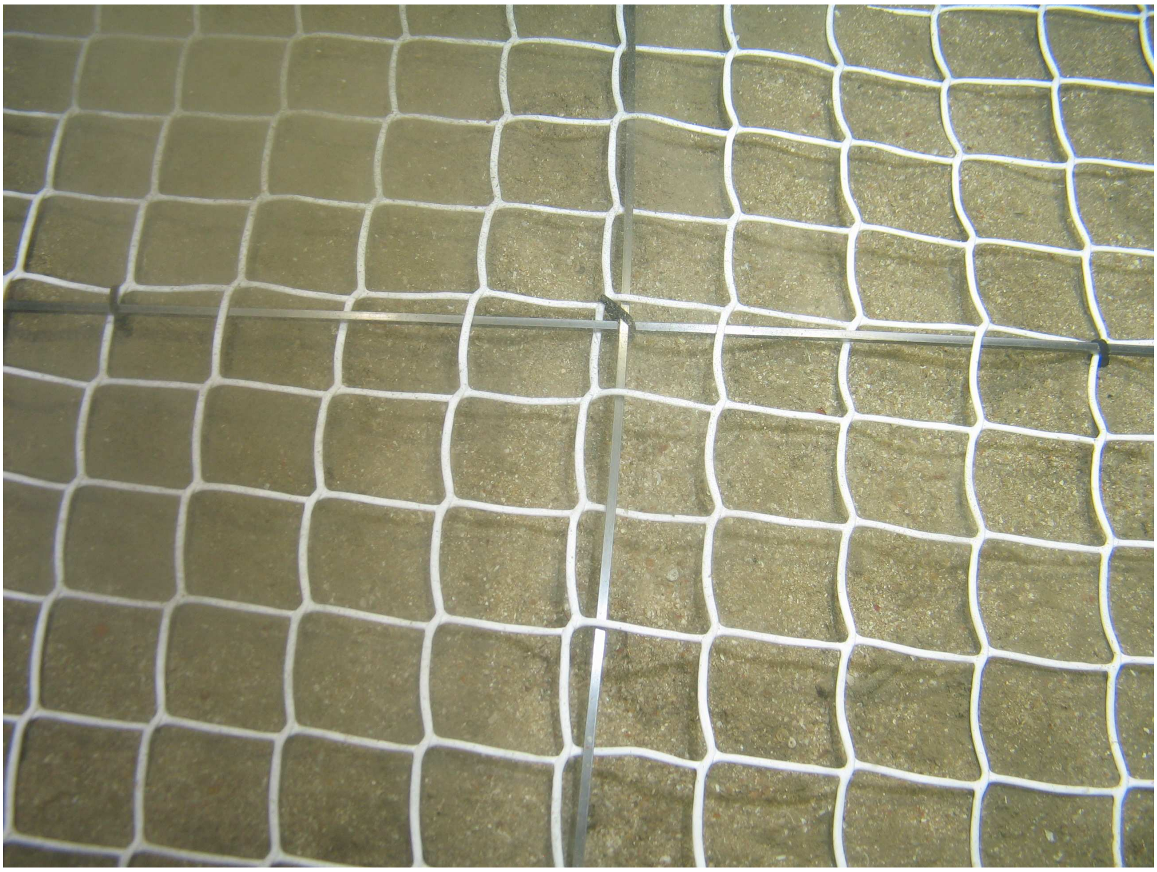

Figure 3.2. Calibration image, photograph of a mesh grid of known dimensions.

3.5. Data processing and *analysis*

3.5.1. Multibeam bathymetric data processing

Bathymetric and backscatter data were processed using CARIS HIPS & SIPS hydrographic data processing software versions 5.4 and 6.1. The raw data were first converted and imported using the 'import' command to an established CARIS HIPS project, containing the vessel file; which includes the information required for combining all sensor data to create final position/depth records. Bathymetric data were corrected for tidal variations using predicted tides generated from Polpred software. Polpred software, developed at the Proudman Oceanographic Laboratory, is an offshore tide and current computation system for PCs. The software uses one or more hydrodynamic models to allow users to compute and visualise tidal levels and currents in a number of ways. Once tidally corrected, the refraction editor within CARIS was then used to correct minor sound velocity discrepancies. On completion of data processing and cleaning, the export facility in CARIS HIPS & SIPS, which supports a variety of export options for multibeam echo sounder data such as CARIS map, ASCII file, image (e.g. geotiff), was utilised to export the data.

The raw data from the 200 kHz EA600 were processed in the CARIS environment and the same tidal variation correction, as used for the EM1002 data, applied.

Data visualisation

During the cruise, the CARIS-processed multibeam data were inserted into the Fledermaus® software for visualisation. Fledermaus® commercial software, distributed by Interactive Visualisation Systems, provides a powerful set of interactive tools for the preparation, analysis and presentation of a variety of spatial datasets in three dimensions (3-D) (Paton *et al*. 1997; Mayer *et al*. 2000). Fledermaus® is particularly suited to the visualisation of large datasets with multi-dimensional components, and enables import of a wide variety of data formats such as ASCII (*.*xyz*), binary (hydrographic transfer format) and Hydrographic Data Cleaning System (CARIS HIPS & SIPS) for the generation of 3-D models. Once the data have been imported, the profiling tool permits analysis of the terrain topography and has proved useful in providing information on height above seafloor of features relevant to benthic habitat. In addition, Fledermaus® enables georeferenced imagery (e.g. backscatter strength) data to be draped on other data sets, such as sub-bottom seismic data.

A digital terrain model (DTM) of the bathymetry data acquired during the survey was created and visualised using Fledermaus®. The DTM allowed for the interrogation of the data and proved invaluable during survey planning and identifying suitable locations for deploying the camera frame.

Surface grids were then exported from Fledermaus® in ESRI grid format for display in a geographic information system (GIS), ArcGIS (version 9.2).

Data integration and terrain analysis

Within GIS, data are stored in vector and raster format. A vector is a data structure used to store spatial data. The vector data model represents spaces as a series of discrete entity-

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defined point, line or polygon units which are geographically referenced (Burrough and McDonnell 1998). Each of these units is composed as a series of one or more coordinate points, for example: a line is a collection of related points, and a polygon is a collection of related lines. Examples of vector data represented in a GIS with relevance to habitat mapping, include locations of sampling records (point), survey transects (line) and geomorphological classes represented on a habitat classification map (polygon). The multibeam bathymetry and backscatter data were converted to ESRI raster grids using data conversion tools available in ArcGIS and referenced to UTM Zone 29N (WGS84). The values for each cell in a raster grid may be identified within the GIS; permitting the investigation of values at any location within the raster.

Seabed terrain plays an integral role in regulating seafloor processes and patterns of faunal distribution. In particular, the direct link between faunal distributions and the nature of the terrain can provide an understanding of these processes. Terrain analysis techniques characterising the seabed in terms of slope, aspect, complexity, etc., have wide applicability in habitat mapping for classifying and delineating faunal distribution and have recently been employed in shallow-water studies (Iampietro and Kvitek 2002; Dartnell and Gardner 2004; Lundblad *et al*. 2006). Techniques employing terrain analysis, also offer potential to deep-water habitat mapping where obtaining information on the physical environment is challenging given the inaccessibility of the benthic habitat.

Several slope, aspect, rugosity, etc., algorithms have been developed to calculate terrain parameters from DTMs. These algorithms are generally based on neighbourhood operations, with the difference between algorithms related to the number of neighbours used in the calculation, e.g. for a three by three cell neighbourhood, between two and nine grid cells may be used (Raaflaub and Collins 2006). Neighbourhood operations are often called “Focal Functions” since each operation generates a value for the ‘focus’ of a neighbourhood. The neighbourhood focus is called the scanning cell, and its neighbours (cells surrounding it) are known as the scanning neighbourhood. The scanning neighbourhood herein onward referred to as the analysis window, can take on various sizes and shapes depending on methods employed. Analysis window operations involve systematically moving across a raster grid, one cell at a time. As each cell is targeted, it becomes the focus cell and a new value is computed for that cell as a function of its analysis window. All values computed for the cells are then placed into the corresponding cells of the output theme.

In this analysis, the terrain parameters slope, aspect, rugosity and bathymetric position index have been derived for the study area.

Slope is a vector that has magnitude and direction (aspect) and is defined by a plane tangent to the surface as modelled by the DTM. It has been suggested that benthic fauna (particularly suspension feeding organisms) occupy positions on the terrain where they are exposed to benthic currents providing a food supply.

Aspect provides an indication of the direction a slope is facing and offers a clearer perspective of the terrain particularly in combination with shaded relief (Gallant and Wilson 2000). The distribution of benthic animals in the deep sea in relation to aspect has been largely unexplored and its influence on benthic community structure is likely to be connected to local and regional hydrodynamics, in turn influenced by the orientation of the seabed terrain. The parameters slope and aspect were readily derived using the Spatial Analyst extension tool in ArcGIS at the immediate neighbourhood analysis scale.

Terrain *rugosity* describes terrain roughness as a ratio of surface area to planar area. Measures of rugosity have recently been derived to quantify species distribution and biodiversity in relation to features of the terrain (Lampietro and Kvitek 2002; Kvitek *et al*. 2003, Lampietro *et al*. 2004; Lundblad *et al*., 2006). Rugosity analyses presented here are based on the methods of Jenness (2002) and have been implemented in ArcGIS within the Benthic Terrain Modeller (BTM) tool; where the ratio of the surface area to planar area of a surface is calculated across the three by three neighbourhood of the central pixel.

The *bathymetric position index (BPI)* is a second order derivative of bathymetry and the marine equivalent of the topographic position index used in terrestrial landscape studies (Weiss, 2001). Benthic fauna often colonise positions on the seafloor which are best suited to maintaining their existence. For example, the cold-water coral *Lophelia pertusa* is preferentially found at topographic highs, such as pinnacles, outcropping rocks and clay ridges (Freiwald, 2002) or on smaller-scale features, such as the crest of sand ripples and dropstones. The BPI is a measure of where a georeferenced elevation is relative to the surrounding terrain. Analysis of BPI is based on whether any particular grid cell forms part of a positive (e.g. crest) or negative feature (e.g. trough) of the surrounding terrain. The calculation is a raster grid-based method and involves evaluating elevation differences between a focal point and the mean elevation of the surrounding cells within a user defined rectangle, annulus, or circle (Lundblad *et al*. 2006). Our calculations were performed using the BTM tool available within ArcGIS based on the methods of Lundblad *(ibid)*.

3.5.2. Seismic Techniques

The recording parameters established within the CODA project for the cruise negated any requirement for any additional post-cruise processing.

The BGS carried out reconnaissance mapping of the SW Approaches between 1974 and 1981 (Evans and Hughes, 1984; Evans, 1990) establishing the stratigraphic framework for the area. More recent research carried out along the wider outer continental shelf and continental slope (for example Bourillet *et al.,* 2003) also utilise this stratigraphic framework.

The original BGS mapping carried out in the 1970s and 1980s used airgun and sparker sub-bottom profiling of a lower resolution than that obtained on this cruise. This coupled with the lack of geological ground-truthing in the SW Approaches study area, resulted in the interpretation of a number of seismic facies which has included 3 subdivisions of the Little Sole Formation. Table 3.1 summarises these seismic packages and suggests how they are related to the established Neogene stratigraphy. Further reading on the stratigraphy and structure of the SW Approaches area can be found in Bourillet *et al.* (2003), Evans (1990), and Evans and Hughes (1984).

Table 3.1. Relationship between seismic packages and stratigraphy of the SW Approaches area.

Seismic Facies	Stratigraphy	Age	Colour at Base of Facies (Figures 4.15-4.18)
I	Plio-Pleistocene paleovalley infill and slope failure - forms part of the Upper Little Sole Formation	Plio-Pleistocene	Red
II	Upper Little Sole Formation	Pliocene	Dashed Blue
III	Lower Little Sole Formation	Pliocene	Green
IV	Cockburn Formation	mid- to late Miocene	Yellow
V	Jones Formation	early to mid-Miocene	Base not identified

3.5.3. Video and stills samples

For each tow, the video was reviewed and a brief description given of the main seabed types and dominant species observed. 'Statistical' images (see Appendix 1 for further detail of these images) and images taken at habitat boundaries were reviewed and poor quality images removed. The remaining images were quantitatively analysed. Identification of species from images is difficult and in many cases impossible without physical samples. This is particularly problematic when working in the deep-sea where new species are regularly recorded. However, observed organisms can be identified as distinct morphospecies. Morphospecies may correspond to species, genus, family or higher taxonomic levels depending on the group. For this study all organisms >1cm were identified as distinct morphospecies and assigned operational taxonomic unit (OTU) numbers. The use of OTU numbers, rather than taxonomic ID's allows the data to be revisited in the future and identifications changed or the dataset combined with other datasets more easily. OTUs were subsequently identified to the lowest possible taxonomic level. All individuals were counted, however for encrusting and globose forms percentage cover was used.

For each tow, the video was reviewed and a brief description given of the main seabed types and dominant species observed. 'Statistical' images and images taken at habitat boundaries were reviewed and poor quality images removed. The remaining images were quantitatively analysed. All organisms >1cm were identified to the lowest possible taxonomic level and counted. For encrusting and globose forms percentage cover was used.

For each statistical image substratum composition (type and percent cover) was determined and classified by eye using the Wentworth and Folk Scales (Tables 3.2 and 3.3; Wentworth, 1922; Folk, 1954). Where sediment types could not easily be distinguished (e.g. fine sand, mud and silt) other indicators such as the appearance of disturbed sediment around cerianthid burrows, evidence from suspended sediment disturbed by the drop camera frame, and any apparent granular texture of the sediment visible from the images was also used. Additional data from BGS grab samples and published literature (for example Cunningham *et al.*, 2005; Evans, 1990; Evans and Hughes, 1984) was also used. Textural classes (Folk, 1954) were defined for each image (Table 3.3).

Table 3.2. Sediment particle sizes based on Wentworth (1922) and Folk (1954).

Particle size	Term
>256mm	Boulder
64-256mm	Cobble
4-64mm	Pebble
2-4mm	Gravel
0.0625-2mm	Sand
<0.0625mm	Mud
0.0625mm-2µm	Silt
<2µm	Clay

Table 3.3. Terminology used for mixtures of particle sizes based on Folk (1954). For the purposes of defining textural class any particle >2mm is termed gravel. Gravel and sand sized particles may be either lithic or biogenic in composition.

Major Textural Class	Mixture
Sand, Mud and Gravel	97.5-100% primary constituent
Slightly gravelly *mud or sand*	2.5-5% gravel sized particles
Gravelly *sand or mud*	5-30% gravel sized particles
Muddy *sand or gravel*	5-30% mud sized particles
Sandy *gravel or mud*	5-30% sand sized particles
Bedrock or bedrock with a sediment veneer	Bedrock or bedrock with a sediment veneer

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All images were also classified to EUNIS level 3/4. Image data was stored in an Access database prior to multivariate statistical analysis.

Biological data obtained from image analysis were analysed using PRIMER 6 (Clarke and Warwick, 2001). Prior to analysis highly mobile species (fish) were removed from the dataset. Cluster analysis with group averaged linking was performed on Bray-Curtis similarity matrix using square-root transformed, species count and percentage cover data to identify ecologically coherent benthic communities. Cluster analysis output was combined with available environmental parameters (depth, substratum type, temperature, position in canyon) to define new deep-water 'biotopes'. Video footage from each station was reviewed and classified using the newly defined biotopes. For some footage the observed habitat could not be allocated to a biotope defined from cluster analysis. This occurred where 1) no fauna were present and thus no species data on which to apply cluster analysis; 2) the habitat had not been sampled using images and thus the biological communities had not been included in the analysis. In these cases additional new biotopes were defined from video observation only. Video footage was also classified to EUNIS level 3 or lower. Changes to biotope and EUNIS habitat type within a video transect were mapped using GIS. Biotopes that could be considered Annex I reef habitat (stony, bedrock and biogenic) were identified and mapped.

3.6. *Data integration* and *habitat map production*

Classified video tows were overlaid on EUNIS classified multibeam backscatter, bathymetry, and derived layers (slope, benthic position index, aspect and rugosity) and habitat polygons drawn in GIS.

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4. Results

4.1. Multibeam bathymetry and backscatter interpretation

The general morphology of the Celtic margin/SW Approaches has been described from previous surveys (Zaragosi *et al*., 2000; Bourillet *et al*., 2003; Cunningham *et al*., 2005). During this survey, high resolution (25 m grid cell size) multibeam bathymetry and backscatter data were acquired over the study area in water depths ranging between ~140 m and 1165 m (Figure 4.1), revealing the morphology of two canyons and the eastern side of a third canyon at the northern limit of the study area. Multibeam data showed that the area was characterised by a series of features e.g. amphitheatre rims, slumps, slides and slump scars (Figure 4.1), and these are discussed below in detail for each of the canyons surveyed. The areas mapped consisted of the continental shelf, the continental slope and in parts the continental rise. Beyond ~950 m water depth the EM1002 system was operating at the upper-end of its limit in relation to data acquisition (<1000 m depth rated). As a result data from below this depth were sparse in much of the study area.

For the purpose of data analysis and interpretation, the study area was subdivided into the canyon areas of Dangaard Canyon and Explorer Canyon. The main aims of this interpretation were (1) to describe the morphology of the canyons from bathymetry and backscatter data and (2) to discuss the terrain attributes of the study area which are of relevance to understanding the distribution of benthic habitats. In order to gain an overall impression of the terrain at the study area, terrain analysis for the following attributes (1) slope (Figure 4.2), (2) rugosity (Figure 4.3) and (3) bathymetric position index (Figure 4.4) is presented.

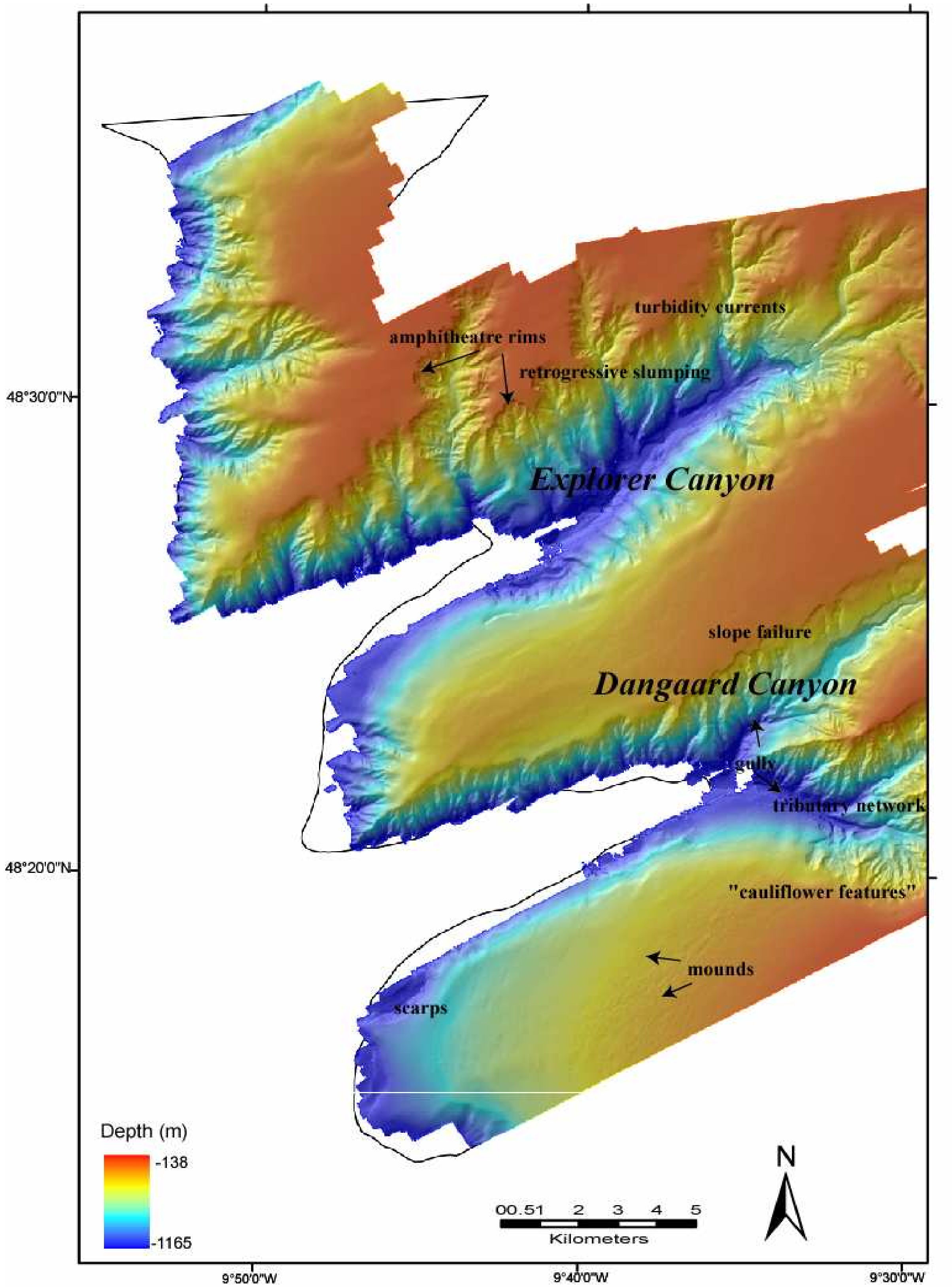

Figure 4.1. Canyons study area at the Celtic margin. Bathymetry data were acquired by the Kongsberg Maritime EM1002 swath bathymetry system. Shaded relief bathymetry reveals the morphology of the Dangaard Canyon and Explorer Canyon and the southern part of a third canyon.

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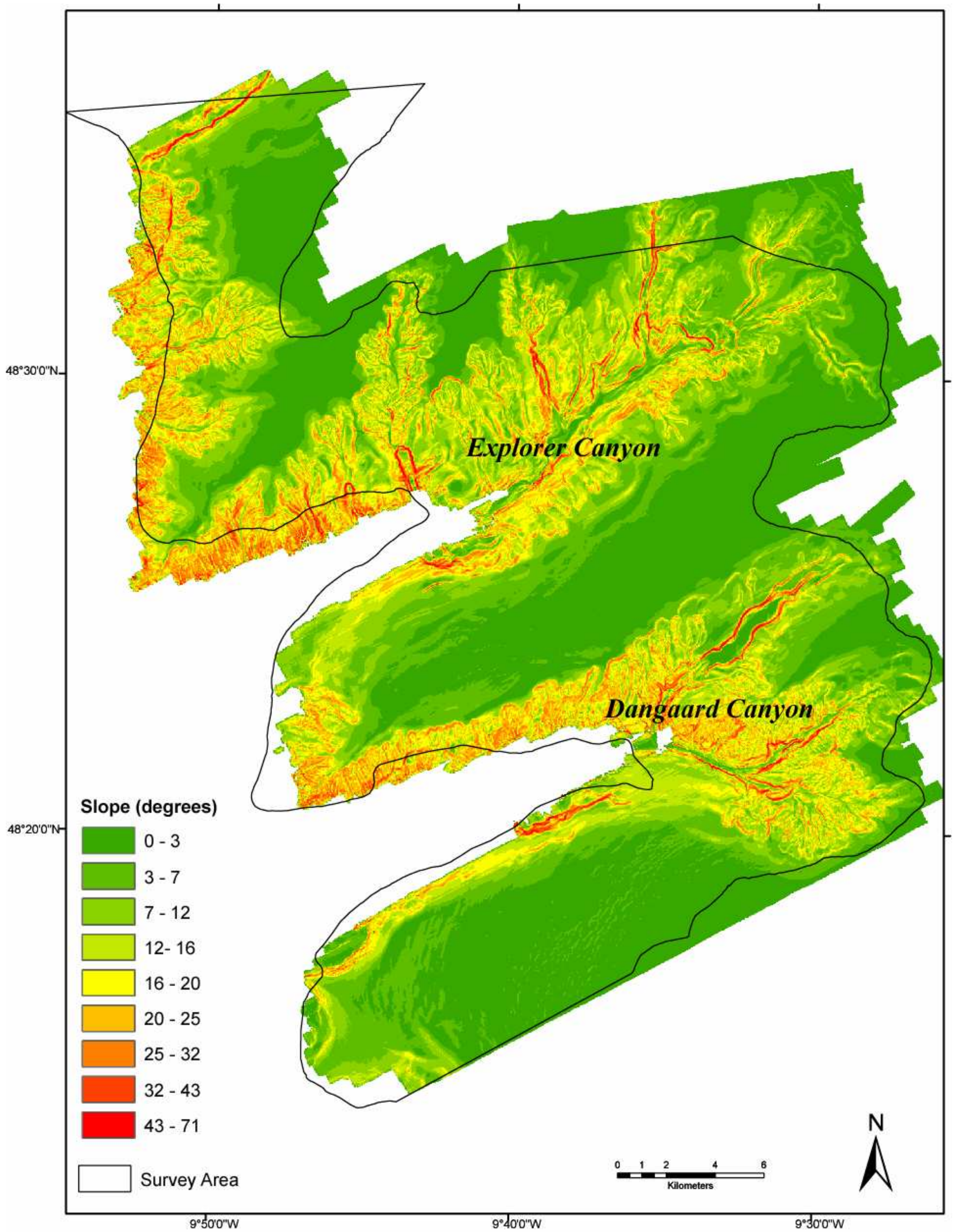

Figure 4.2. Slope analyses at the canyons study area. Grid cell size 25 m. Projection: Geographic, WGS84.

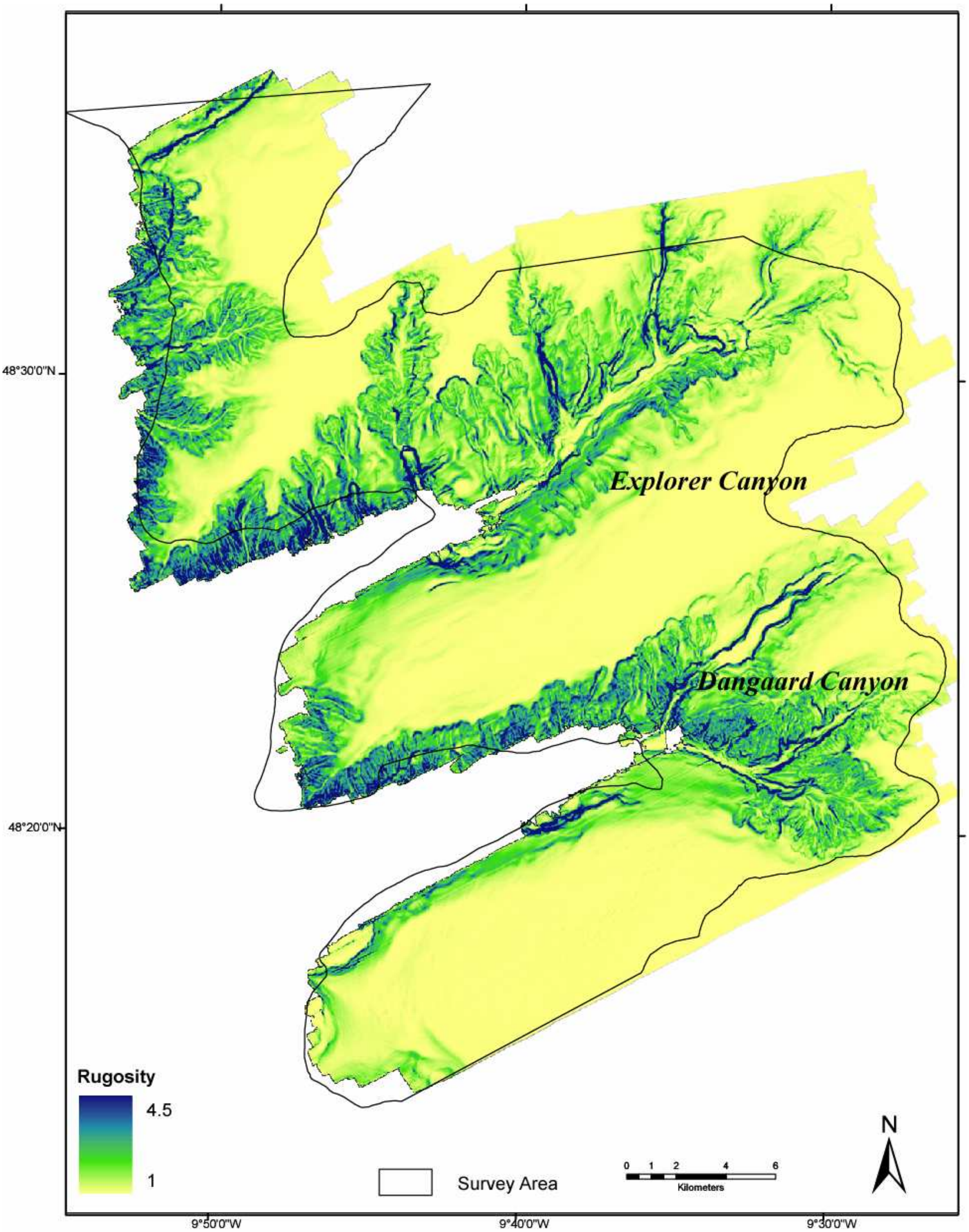

Figure 4.3. Rugosity analyses at the canyons study area. Grid cell size 25 m. Projection: Geographic WGS84.

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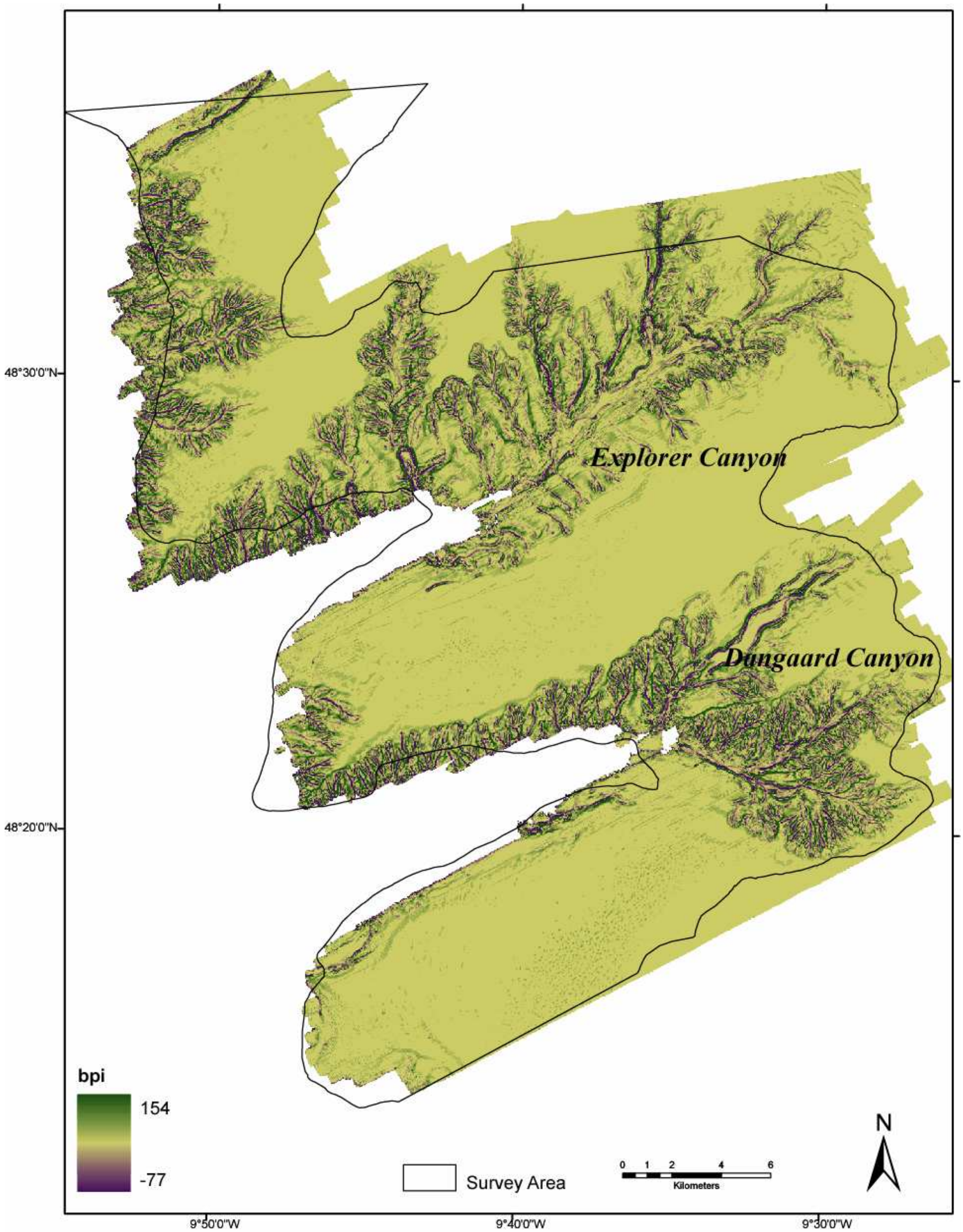

Figure 4.4. Bathymetric Position Index (BPI) analyses at the canyon study area. Grid cell size 25 m. Projection: Geographic, WGS84.

Terrain analyses

Slope values for the study area ranged between 0 and 71° with the highest slope gradients associated with steep canyon heads and canyon flanks (Figure 4.2). In general, the interfluve areas recorded slope values < ~8°. The dendritic patterns that are characteristic of the canyons indenting the shelf break were highlighted by the slope analyses showing these indentations to have higher gradients than the surrounding terrain. The extent of the tributary network feeding into the main canyon gullies was also reflected by the higher slope values observed at both canyon heads. At the Explorer Canyon, this tributary network was clearly well developed with the slope analysis revealing the extent of the channels incising away from the main gully onto the upper slope and shelf.

Rugosity analyses revealed values of between 0 and 4.5 for the study area (Figure 4.3). As may be expected, the terrain at the canyon flanks and head revealed the highest rugosity values, suggesting that the terrain there was highly complex and irregular. The lower gradients observed on the shelf and interfluve areas were characterised by the lowest rugosity values (~1). In general the highest rugosity values recorded from the study area showed a relationship with the high slopes and the low rugosity values with the low slopes.

The values recorded for *BPI* at the study area are between -77 and +154 (Figure 4.4). A BPI analysis has defined the parts at the study area where the terrain is lower than the surrounding terrain (negative BPI values). Lowest negative BPI values were associated with the walls of the canyon gully systems at the canyon heads incising towards the shelf indicating these areas are lower than the surrounding terrain. The BPI analysis showed the dendritic patterns at the canyon flanks were characterised by both positive and negative BPI values, suggesting the terrain was highly variable and was characterised by ridge tops, valleys and moderate-low slopes.

Canyon backscatter data

The study area was characterised by a range of backscatter intensities and patterns that can be related to different sediment types. The backscatter mosaic could be divided into three types of broadly defined acoustic classes; (1) sharply defined areas of low backscatter reflectance (pale grey) occurring on the shelf, probably related to regions of mud and muddy sand (2) dark (high) backscattering seabed representing coarse grained sediment types occurring at the shelf-break, in the canyon gullies and on canyon interfluves (3) moderately backscattering seafloor with mottled lighter and darker patches generally associated with the outer shelf and the network of gully tributaries suggesting medium grained sediment types, and coinciding with the area where mounds were recorded on the canyon interfluve at the southern limit of the study area (Figure 4.5). The acoustically distinct regions did not always have distinct boundaries and there was a degree of subjectivity associated with where the boundaries were placed.

The seafloor on the shelf to the east of the study area was relatively flat and distinguished by its low intensity backscatter return, which may be interpreted as fine-medium grained muddy-sand. Moving progressively to the west of the study area and away from the shelf, strongly reflective backscattering in each of the canyon gullies and tributary networks was evident. In these areas cobbles, boulders and bedrock outcrop were recorded from video records. The areas of higher reflective return were probably coarser, granular material and exposed bedrock surfaces in the main gully system and network of tributaries. The interpretation presented here is based solely on the backscatter data and could be improved by ground-truthing information from grab samples collected in the study area. A more detailed interpretation may be found in the geology section of this report (Section 4.2, 4.3 and 5.2).

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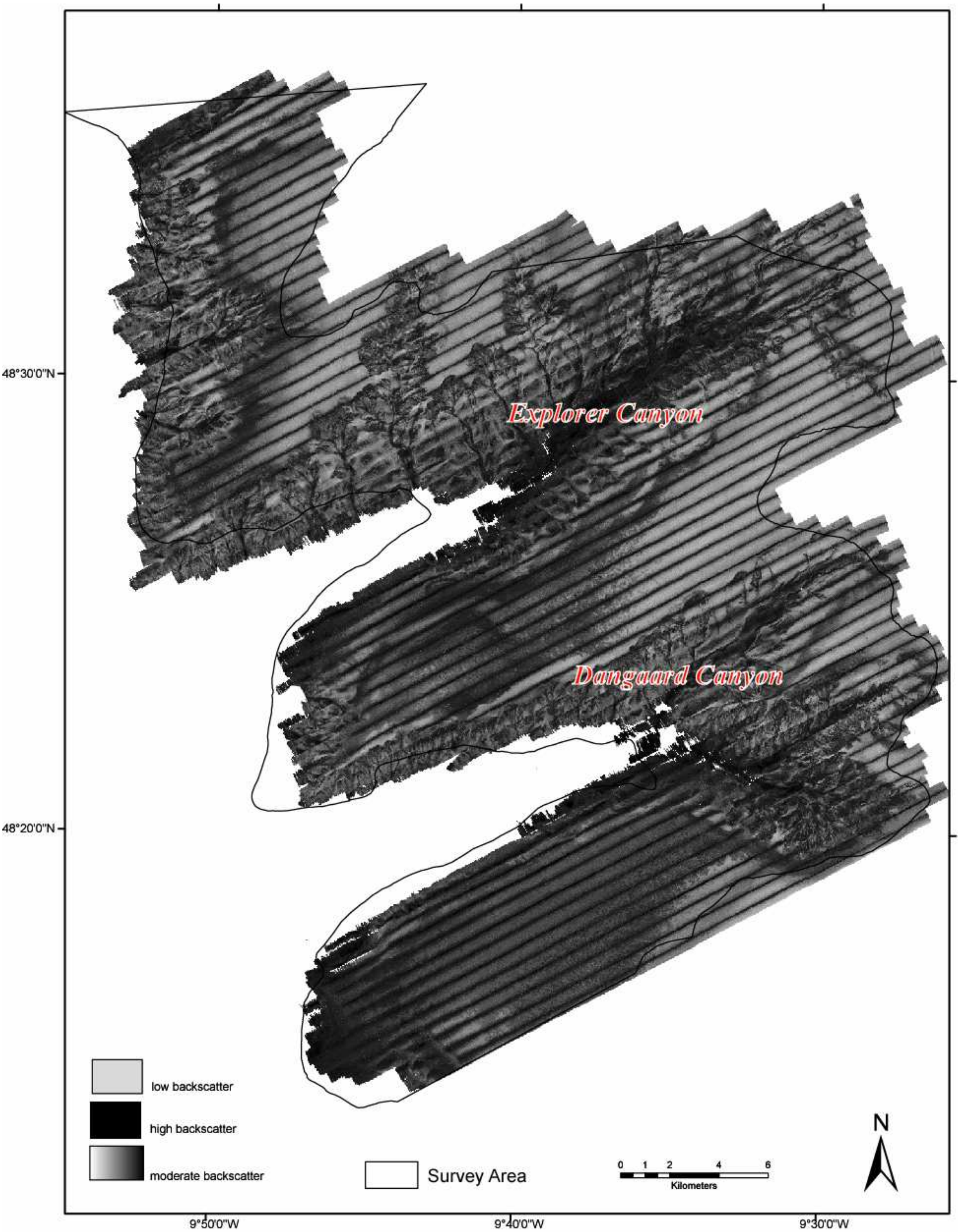

Figure 4.5. Backscatter data acquired at the canyons study area: strong acoustic reflectance (black regions), weak acoustic reflectance (grey regions) and medium reflectance (grey/black regions). Grid cell size 25 m. Projection: Geographic WGS84.

Dangaard Canyon

Data showed that the canyon head incised the slope between 1000 and 600 m water depth and was ~ 4 km wide. At the upper reaches of the canyon head, the multibeam data showed that two main gullies dominated the terrain with a network of tributary gullies feeding into the canyon, moving up-slope onto the continental shelf trending east-northeast. At the shelf-break, there was an extensive, well-developed 'cauliflower' shaped amphitheatre rim feature, ~ 4.5 km in diameter. The amphitheatre rims have been reported elsewhere (Belderson and Kenyon, 1976; Cunningham *et al*., 2005) and are thought to be drainage basins in which the catchment area is fed by a network of tributaries. Amphitheatre rims at the head suggested canyon headward erosion was taking place in the direction of the shelf. Turbidity currents generated down slope were likely responsible for the erosional features evident.

Gullies in the canyon head were characterised by a high backscatter reflectance suggesting that coarse-grained material has been deposited in the gully channels by mass-transport and the activity of turbidity currents down-slope. On the northern margin, the canyon slope was characterised by features indicative of mass-wasting, including slumps and slope failures (oriented parallel to the slope) suggesting sediment transport in the canyons heads and slopes is by slope failure in a seaward direction. While the northern margin of the canyon was heavily gullied and indented with these features, the southern margin was conspicuous by its lack of gullies and most noticeable was the largely smooth, featureless terrain of the area. The presence of fresh scars showed that mass movement (landsliding) was taking place along the southern wall of the canyon.

Dangaard Canyon terrain analysis

Slope analysis of the Dangaard Canyon head gully and tributary system showed high slope values (33-66°) associated with the incised channels and gullies (Figure 4.6). The network of gully tributaries at the canyon head was clearly defined by lower slope gradients with values falling in the range 17-26°. Sidewall and headwall gradients averaged ~10°, increasing in some areas to ~18°. The inter-canyon shelf area was characterised by lower slope values of < 9° suggesting it is relatively flat. *Terrain orientation* (aspect) at the southern wall of the canyon head had a northerly aspect whilst the centre of the canyon head showed a predominantly west south-west orientation (Figure 4.7). It is likely that the terrain orientation influences the direction of local currents, in turn influencing the benthic communities that live there. *Rugosity* analysis showed a range of values between 0 and 2.7 (Figure 4.8). Highest rugosity values were recorded from the main gullies at the canyon head, suggesting the terrain was highly complex there. Lowest rugosity values were reported for the shelf and interfluve areas, and the flat northern tributary channel within Dangaard Canyon.

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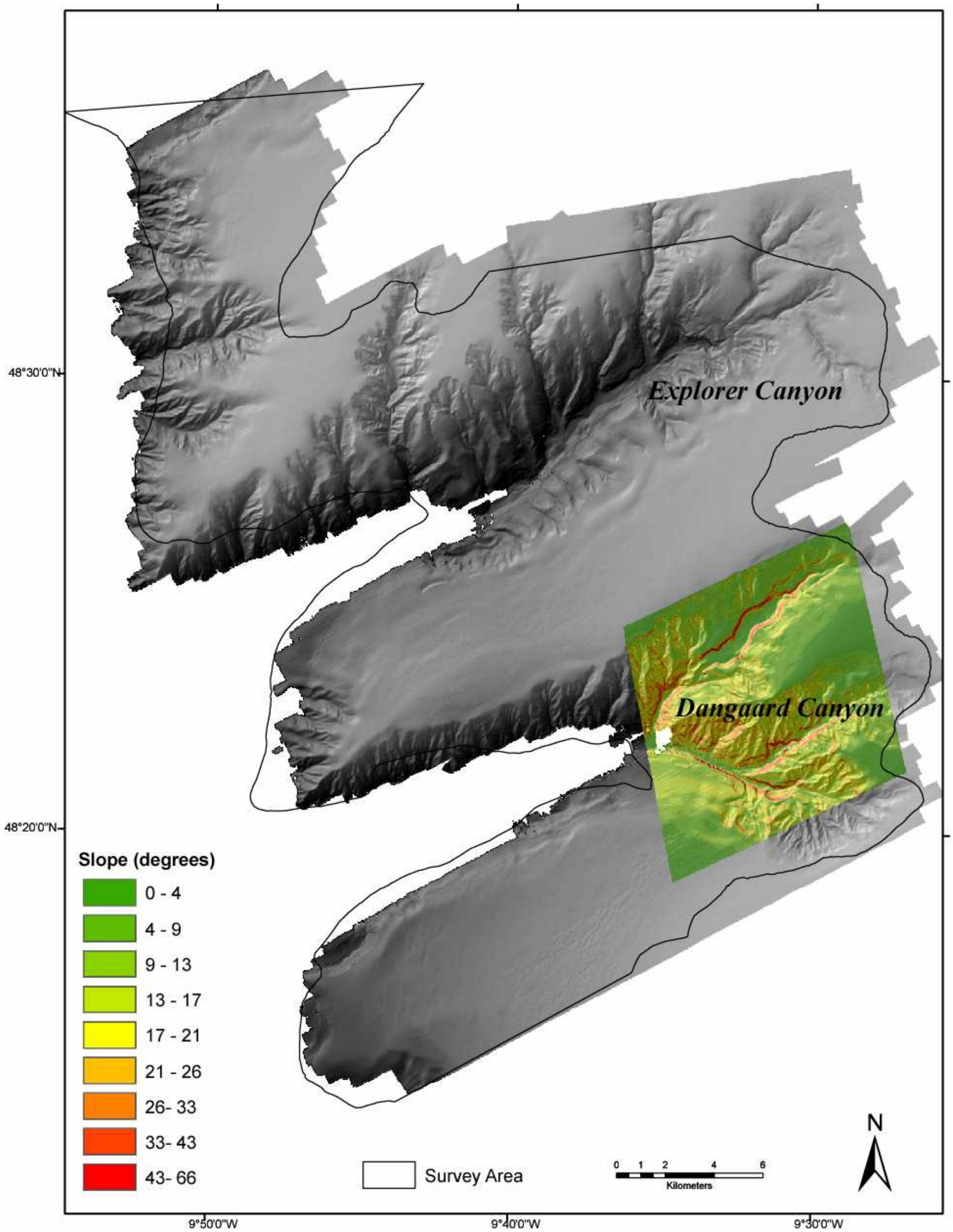

Figure 4.6. Shaded relief bathymetric map of study area showing slope analyses of the Dangaard Canyon head. Projection: Geographic WGS84.

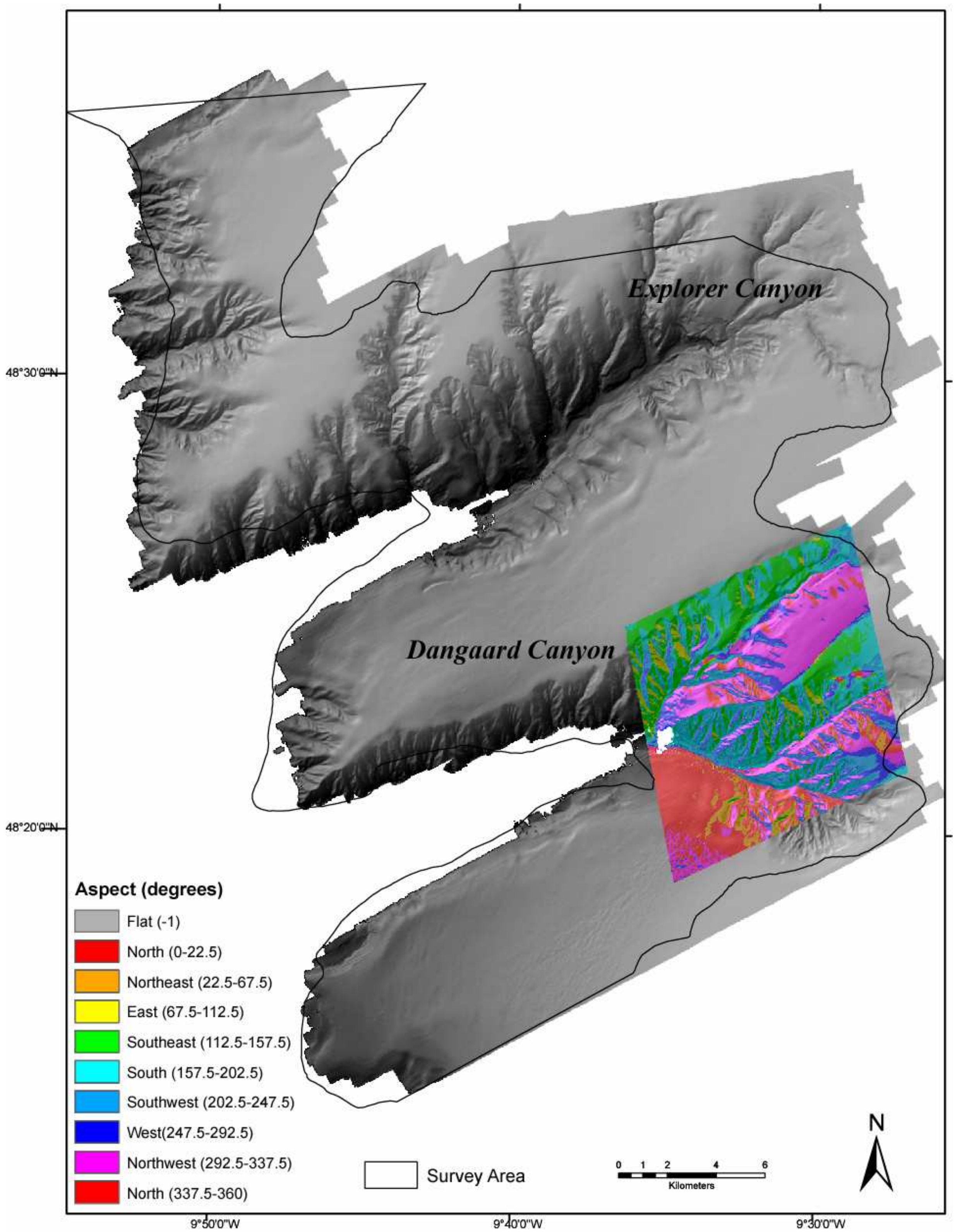

Figure 4.7. Shaded relief bathymetric map of study area showing aspect analyses of the Dangaard Canyon head. The southern wall of the canyon head has a northerly aspect whilst the centre of the canyon head is showing a predominantly west south-west orientation. Projection: Geographic WGS84.

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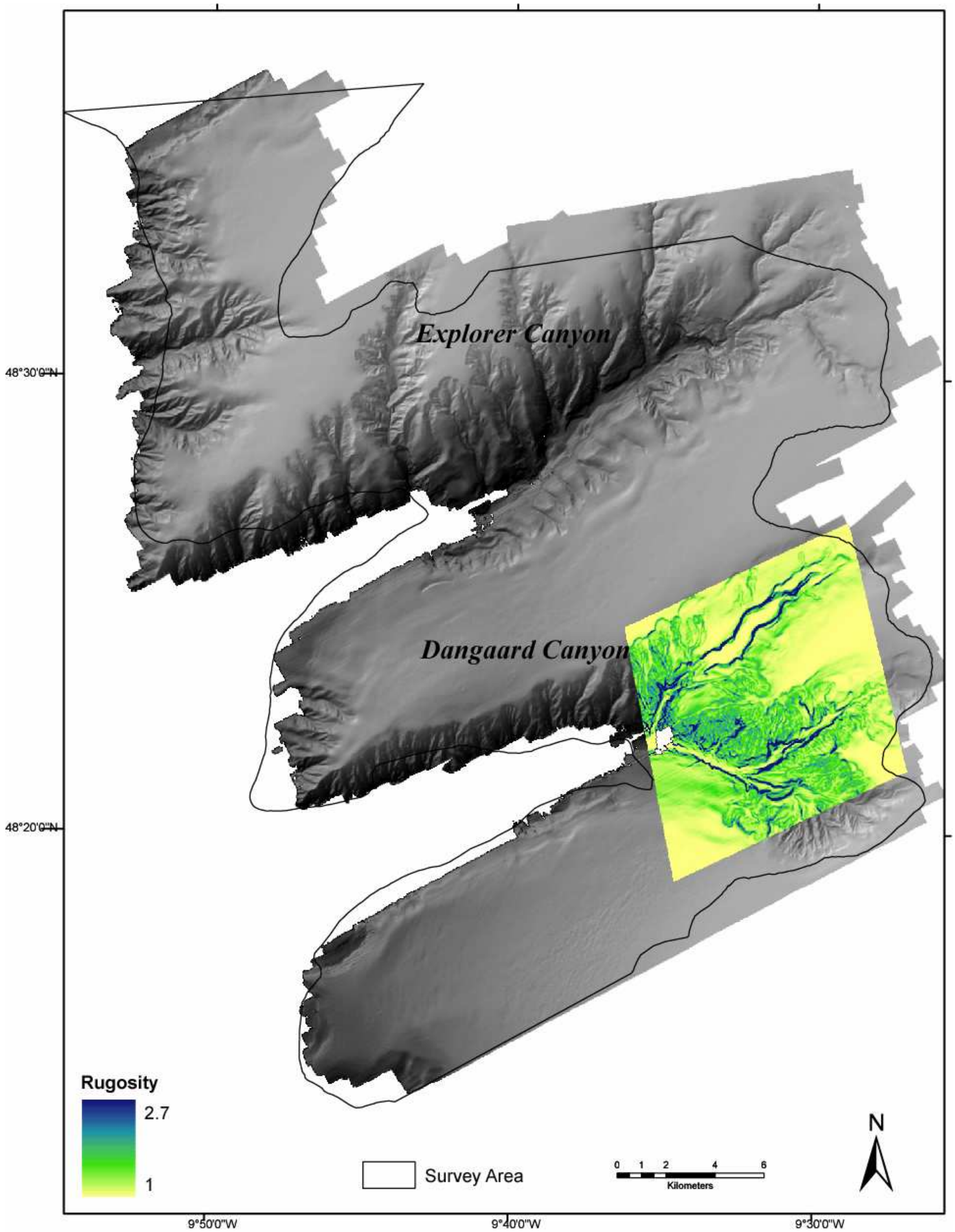

Figure 4.8. Shaded relief bathymetric map of study area showing rugosity analyses of the Dangaard Canyon head. Projection: Geographic WGS84

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Channel incisions

The Dangaard Canyon displayed a number of deeply incised channels associated with the steep channel walls that trend west-northwest. The channel to the north had a base diameter of approximately 120m, with the base of the channel lying 60m below the surrounding terrain. The channel to the south lay approximately 150m below the steep channel walls and was 200m diameter across at its base (Figure 4.9). These channels are likely acting as conduits for the transport of sediment from the shelf to the canyon lower flanks and canyon floor.

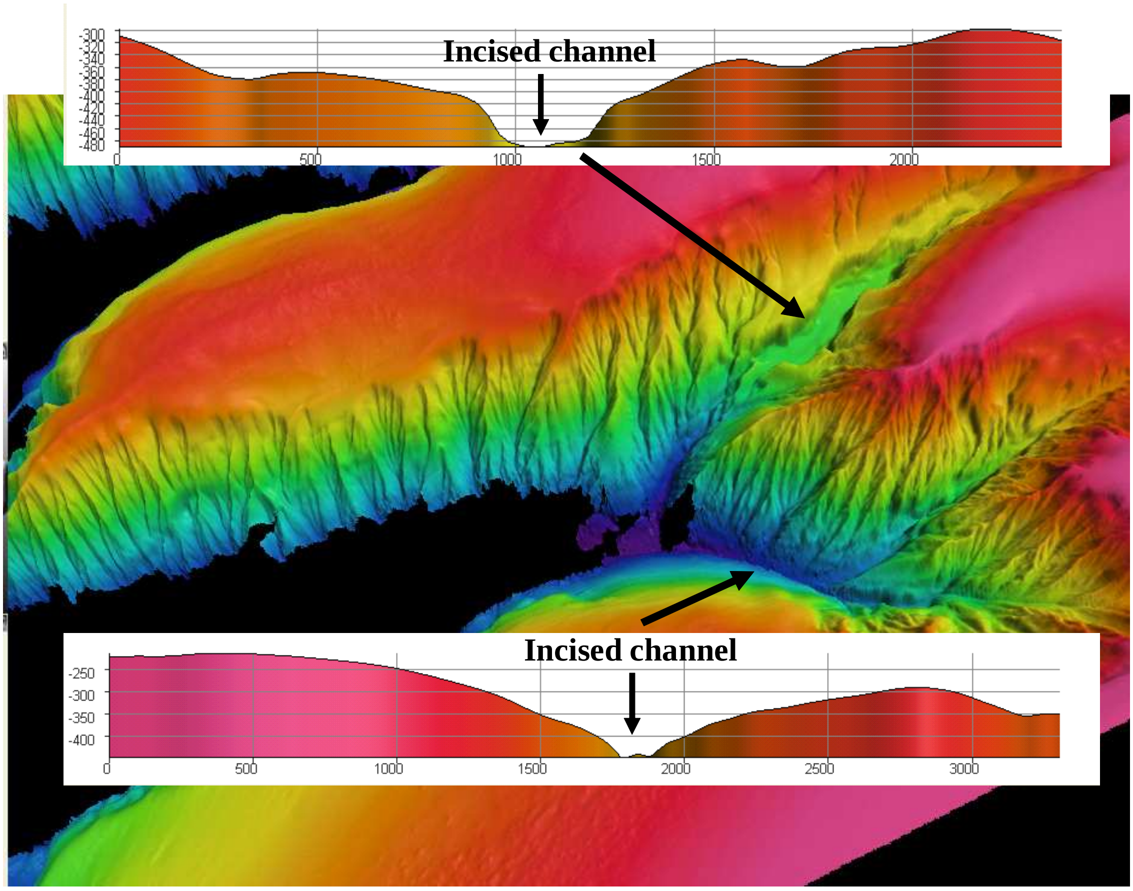
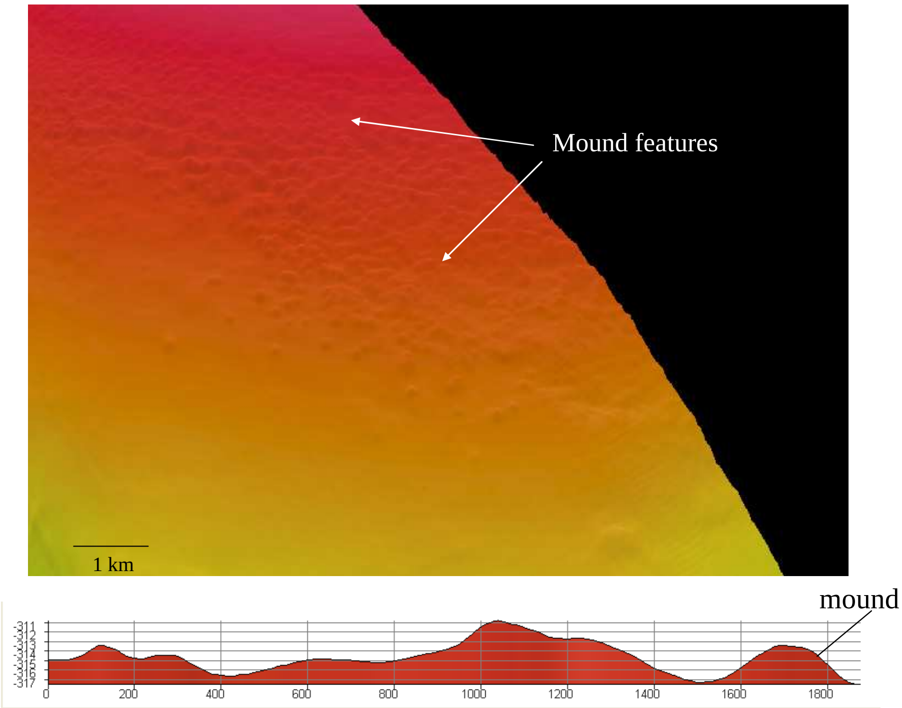


Figure 4.9. 3-dimensional (3-D) view of Dangaard Canyon in Fledermaus 3-D visualisation software. Vertical exaggeration is x6. Incised channels at the canyon head are shown and profiles of the channel indicate the channels are up to 60 m deep with steep channel walls.

Mound features on canyon interfluve

A large number of ‘mini-mound’ features were recorded in bathymetry data from the Dangaard Canyon interfluve to the south of the study area. The mounds occurred in a depth range of between 270 and 420 m (Figure 4.10). A profile across a section of the mounds indicated that the mounds were 2-4m high above the seafloor, with base diameters of between 50 and 150m. Patches of *Lophelia pertusa* were recorded in video data acquired at the mounds. Areas of strong reflectance in the form of ‘spotting’ were recorded at the area where the mounds occurred in the backscatter data. It is likely that these mounds are carbonate mounds and possibly once hosted a living cold-water coral habitat. The multibeam data suggested that there were an estimated 100 mounds or more in the area. Mounds of similar dimensions, the Darwin Mounds, have been recorded in sidescan data in the north east Rockall Trough (Masson *et al*., 2003). The Darwin Mounds are typically 75 m in diameter and 5 m high.

(a)



(b)

Figure 4.10. (a) A 3-D view of mound features identified at the southern interfluve of the Dangaard Canyon in bathymetry data, and (b) A cross section of part of the mound area

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Explorer Canyon

The upper reaches of the head of the Explorer Canyon were more deeply recessed into the continental slope and shelf than those of the Dangaard Canyon, suggesting that the Explorer Canyon is older than the adjacent canyon and has developed shorewards by headward erosion. The canyon was characterised by a meandering channel/gully trending east-northeast approximately 9km in length and which is fed by several tributaries. At the entrance, the canyon measured 9.5km distance from the north wall to the south wall in water depth > 1165m. A number of 'amphitheatre rims' were visible on the upper walls on the north wall of the canyon with local terracing whilst in contrast the southern walls of the canyon displayed less topographic expression and were similar in topography to the southern wall of the Dangaard Canyon, largely smooth and featureless in contrast to the highly indented northern canyon walls.

Explorer Canyon terrain analyses

Slope analyses at the canyon head Explorer Canyon (Figure 4.11) revealed slope values in the range 0-68°. As expected, highest slope values were associated with the incised channels and gullies bifurcating the northern canyon head. Medium to high slope values (between 15 and 42°) were characteristic of the southern canyon wall with higher slope values associated with the network of tributaries incising the wall. The *orientation* of the terrain at the southern wall of the canyon head was west-northwest whilst the opposite canyon wall trended in an east-southeast orientation (Figure 4.12). The terrain orientation influences the direction of local currents at the canyon head with implications for the location of benthic fauna on the terrain, which may benefit from a food supply carried by the currents. *Rugosity* analyses suggested the Explorer Canyon had higher rugosity values compared to the Dangaard Canyon head, with values ranging between 1 and 4 (Figure 4.13). The bifurcating gully at the northern wall showed highest rugosity values, as did the smaller channel incisions further along the head at the shelf-edge (Figure 4.14). The network of tributaries feeding into the canyon head had lower rugosity values.

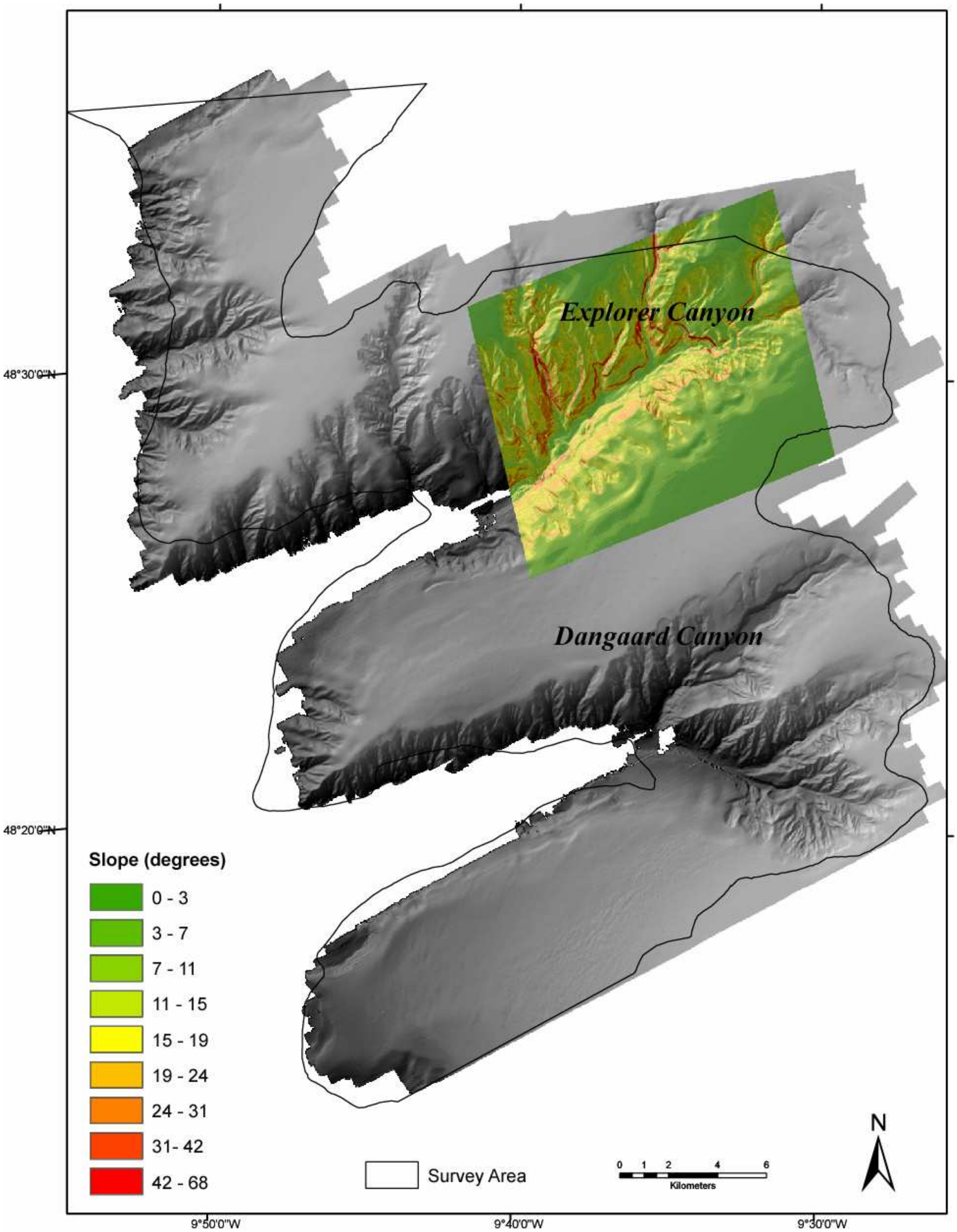

Figure 4.11. Shaded relief bathymetric map of study area showing slope analyses of the Explorer Canyon head. Projection: Geographic WGS 84.

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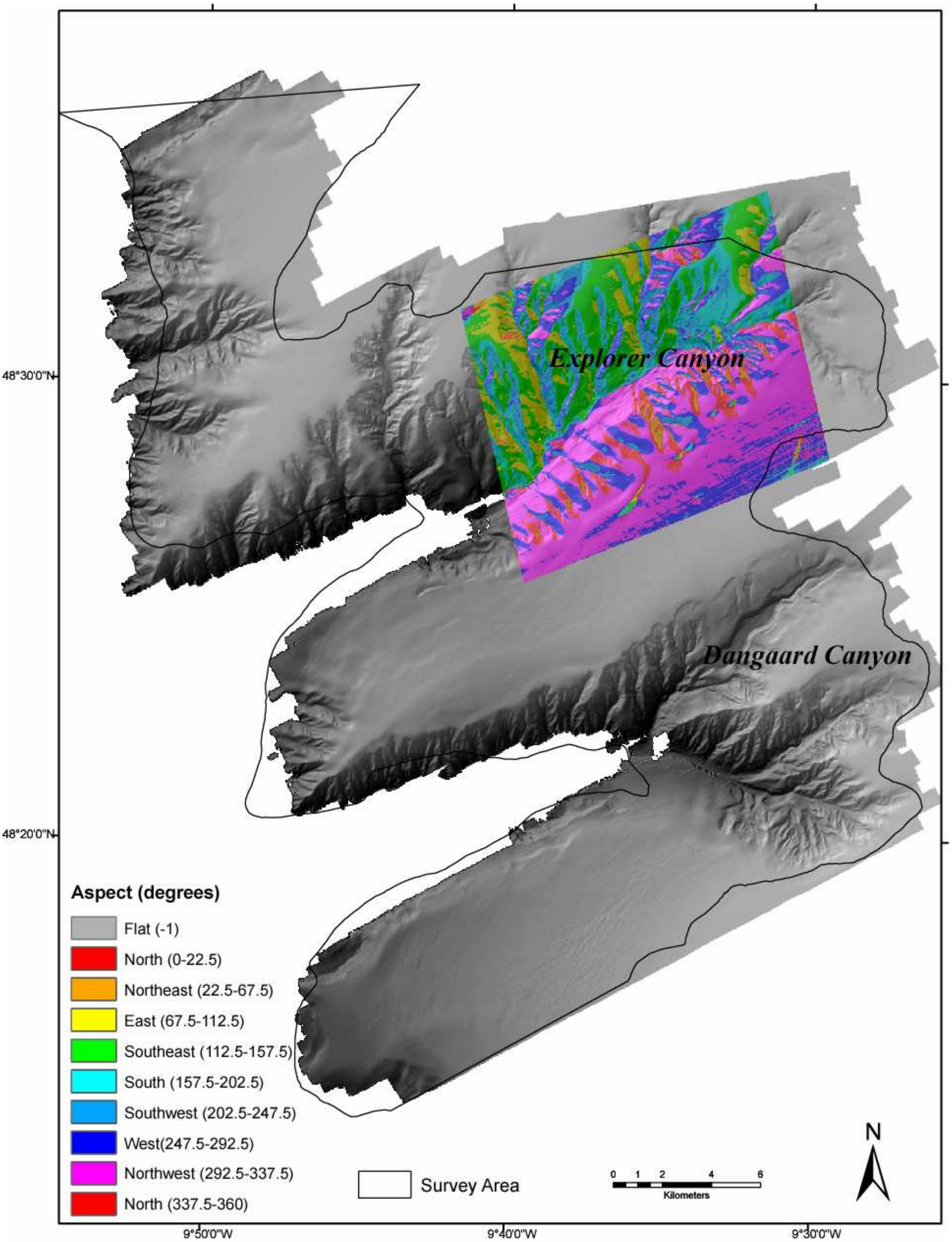

Figure 4.12. Shaded relief bathymetric map of study area showing aspect analyses of the Explorer canyon head. The southern wall of the canyon has a west-northwest terrain orientation. The northern wall reveals a predominantly east-southeast orientation. Projection: Geographic WGS 84.

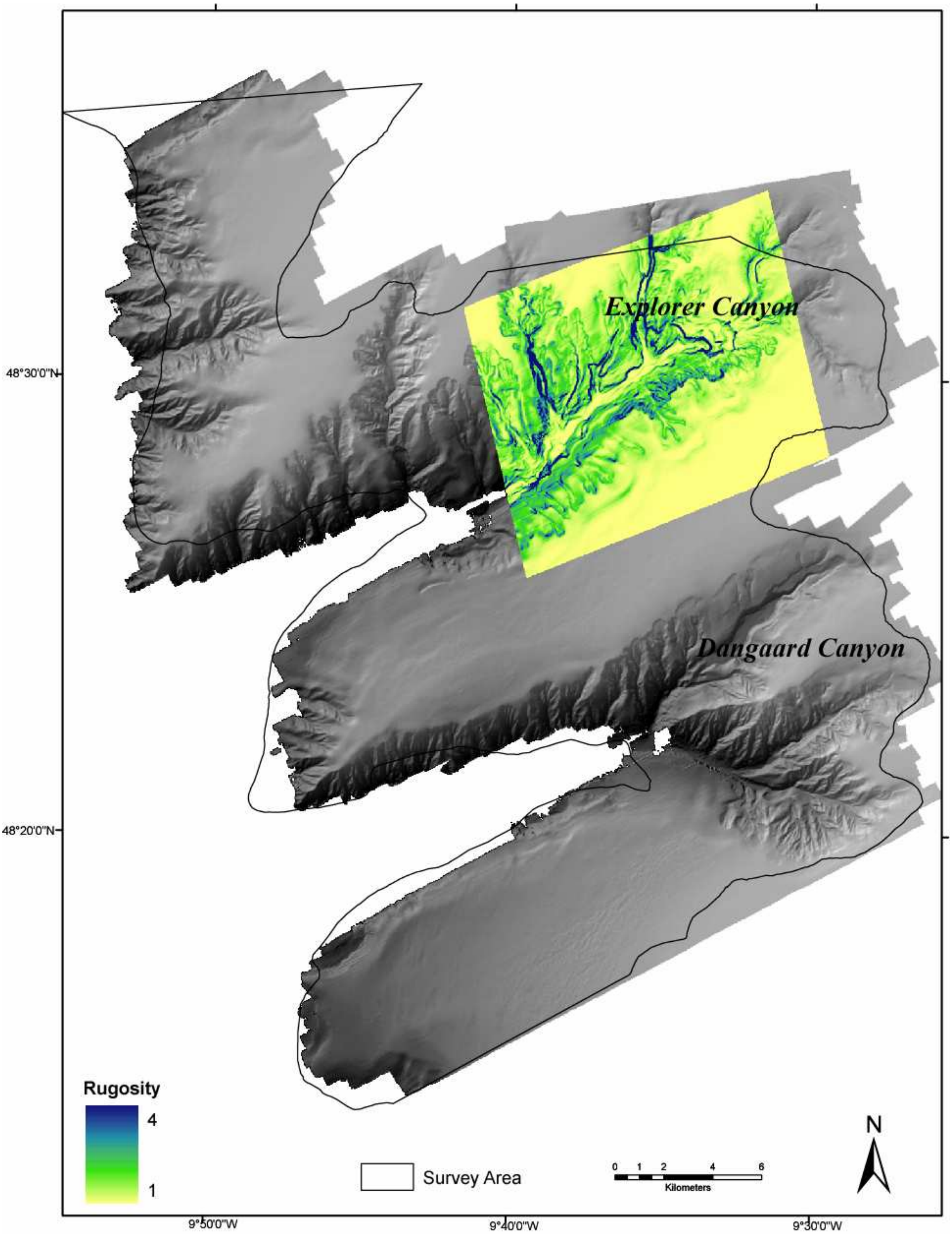

Figure 4.13. Shaded relief bathymetric map of study area showing rugosity analyses of the Explorer Canyon head. Projection: Geographic WGS84.

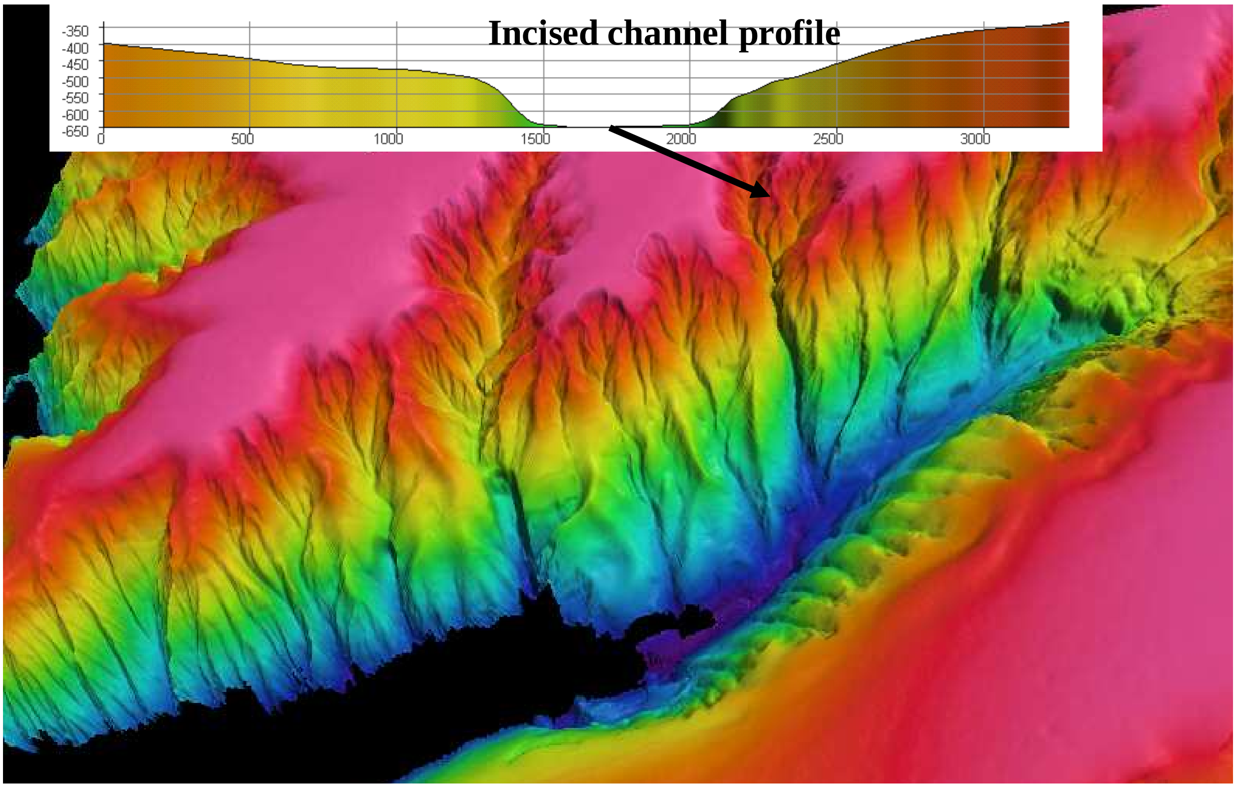

Figure 4.14. 3-dimensional view of Explorer Canyon in Fledermaus 3-D visualisation software. Vertical exaggeration is x6. Incised channels are presented and profiles of the channel indicate the channels are up to 60 m deep with steep channel walls.

4.2. Geomorphology and sedimentary processes

The outer continental shelf slopes gently southwest to a depth of ~200m where it passes down to the much steeper, deeply canyoned continental slope. The shelf break marks the boundary between the near horizontal sea floor of the continental shelf and the steeper slope. However, the position of the shelf break is not always easily defined firstly due to the gentle transition on the interfluves and secondly due to headward erosion of the canyon backwalls and incision of smaller v-shaped valleys into the continental shelf (see Figure 4.15).

A number of tidal sand ridges, the Celtic Sandbanks, up to 60m in height and 200km in length with a trend of 030˚ are also located on the continental shelf (Evans, 1990). The proximity of the sandwave fields to the canyon heads (2.5km east of the Explorer Canyon head and 5km east of the Dangaard Canyon head) indicates that they are a path for transporting shelf sediment onto the slope (Cronin *et al.*, 2005; Cunningham *et al.*, 2005; Evans, 1985; 1990). The dominant process transporting the sediment through the canyons is turbidity currents triggered by retrogressive slope failure in the canyon head indicated by the presence of "cauliflower" or "amphitheatre" shaped rims in the head area (Figure 4.1; Cunningham *et al.*, 2005; Evans, 1990)).

The overall distribution of sediment within the survey area has been established using data from existing BGS grab samples and shallow cores of the superficial sediments, photographic "ground-truthing" sites, multibeam and backscatter data collected during this survey (Figure 4.16). The EUNIS classification system was used for display purposes (Figure 4.17) http://eunis.eea.europa.eu/) due to the lack of physical samples to allow accurate classification of the sea-bed sediments using the Folk classification (Folk, 1954). Rock outcrop was commonly observed in areas with >20° slope values s uch as areas of amphitheatre rims, but not in areas of smooth canyon flanks of comparable slope angles (Figure 4.18)). Areas of biogenic gravel, comprising predominantly cold-water coral fragments derived locally, cover the tops of the interfluves coinciding with clusters of sea-bed mini-mounds. Areas of deep-sea mixed sub-strata comprise both lithic and biogenic sand and gravel, therefore biogenic gravel is not limited to the interfluve tops. Areas of deep-sea mixed substrata and sand were observed on the floors of the canyon heads and the interfluve flanks in water depths >500m, probably as a result of transport down the canyon heads and along-slope transport by contouritic currents. It was observed that predominantly mud and sandy muds were located below ~500m water depth (Cunningham *et al.*, 2005; Evans, 1990; Evans and Hughes, 1984). Sediment ripples were common on video data throughout the study area.

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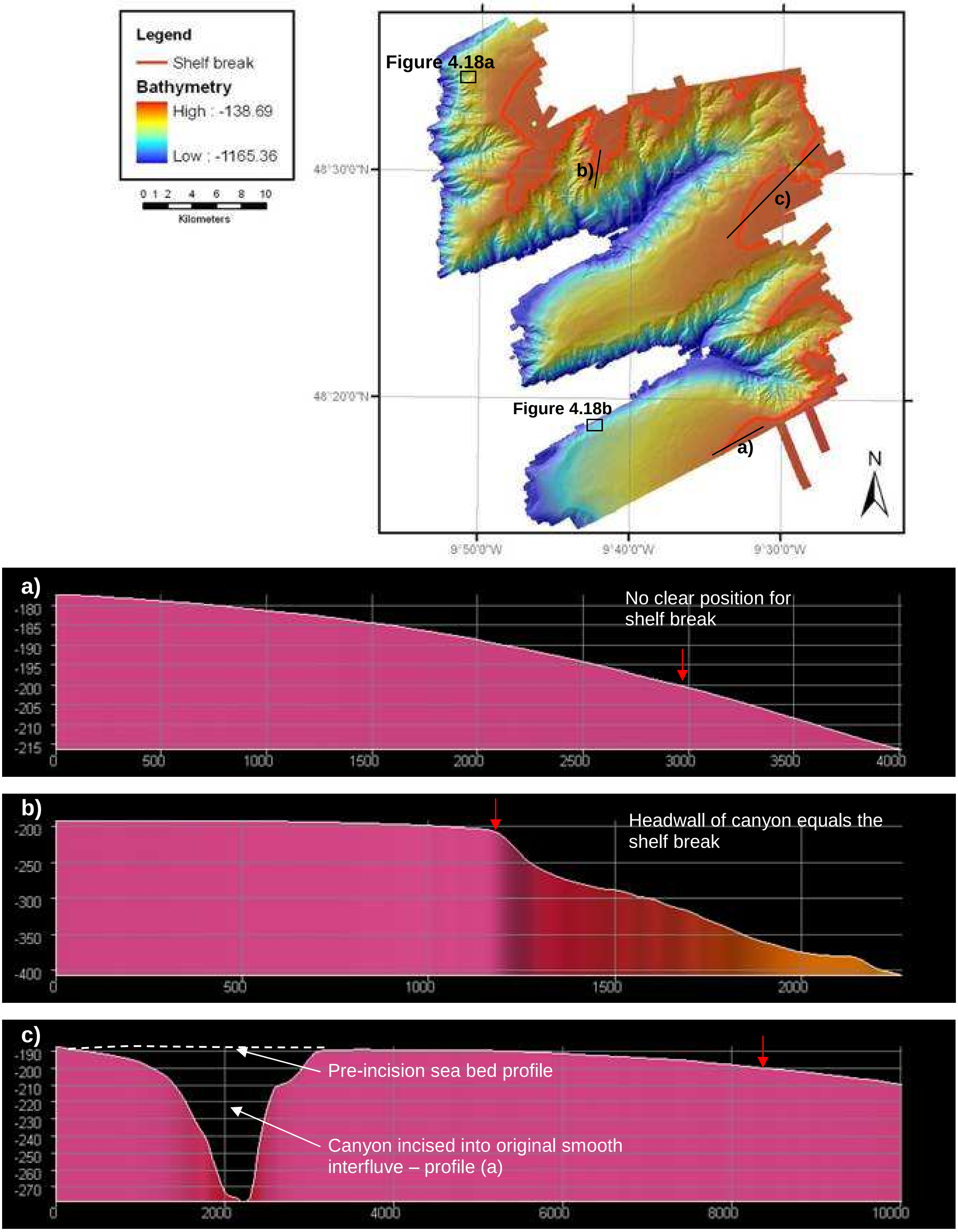

Figure 4.15. Profiles across the shelf break, indicated by the red arrow. See the inset diagram for the location of the profiles. Basemap showing the position of the shelf break at ~200m water depth. Profile (a) is located on a smooth interfluve. Profile (b) shows an amphitheatre rim. Profile (c) shows an incision extending into the continental shelf. Note the variation in horizontal and vertical scales on the profiles.

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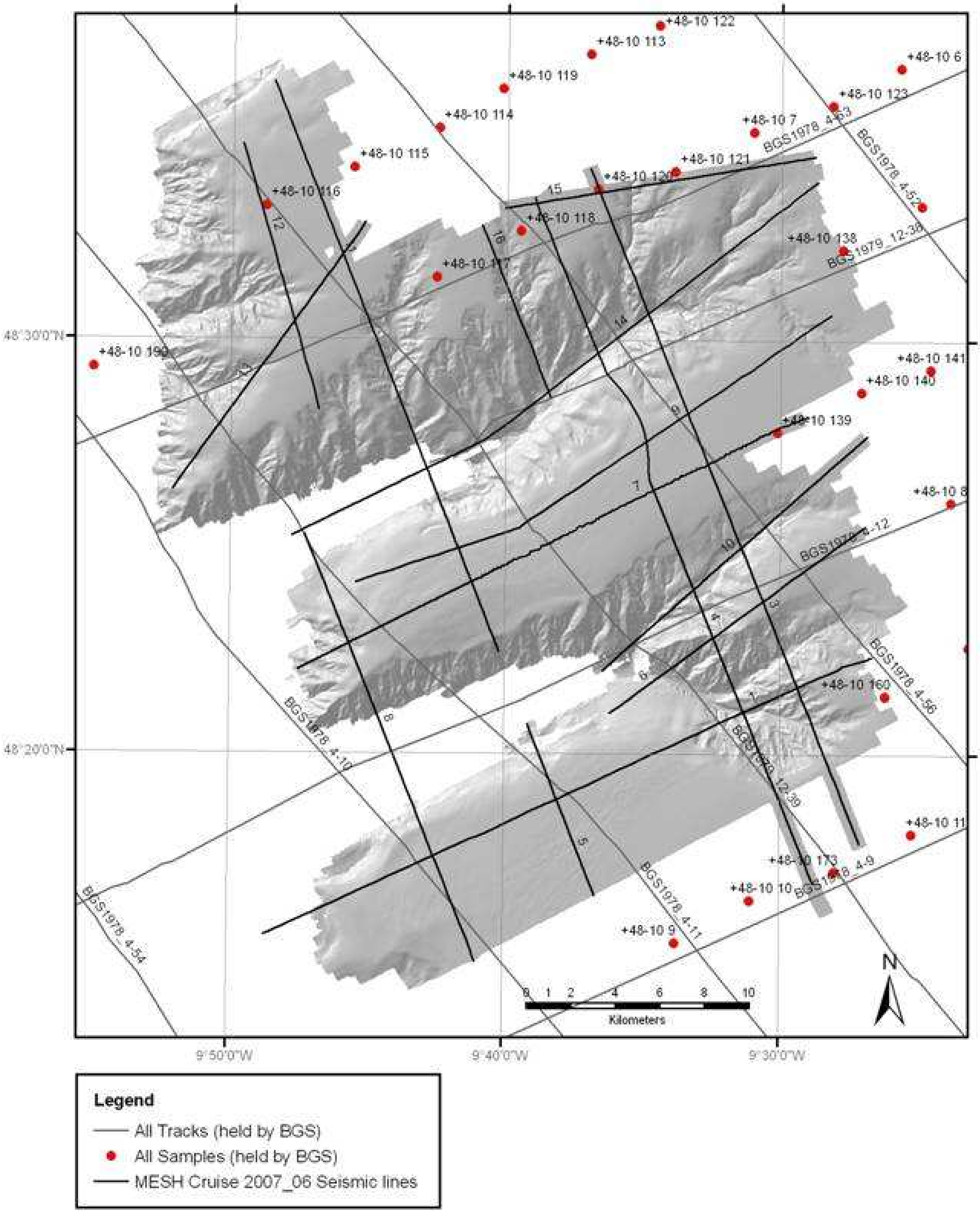


Figure 4.16. Station map showing existing BGS superficial sediment samples and seismic database along with the location of the seismic collected during the MESH cruise. For the location of all camera tows collected during this cruise please see Figure 4.20.

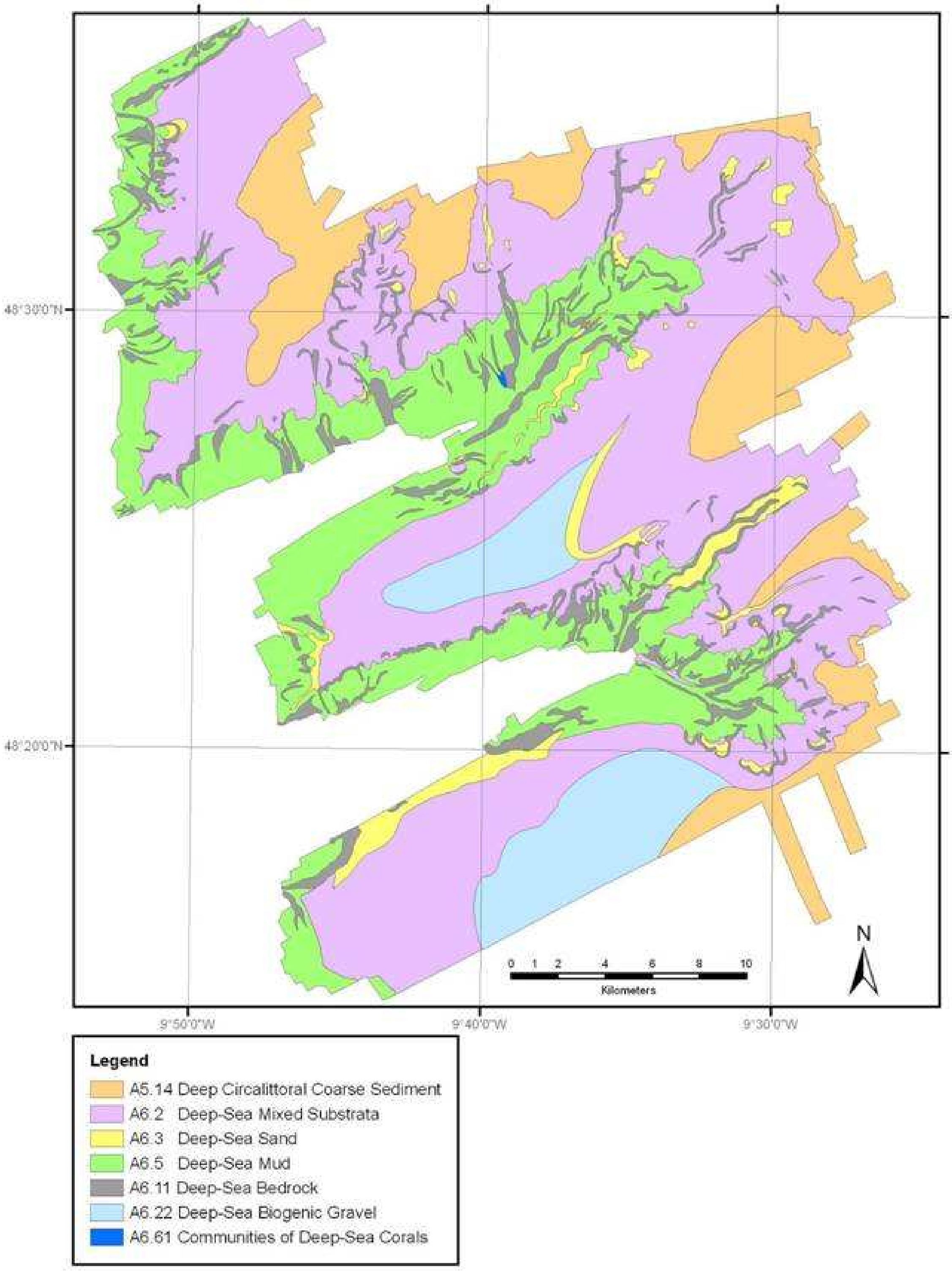
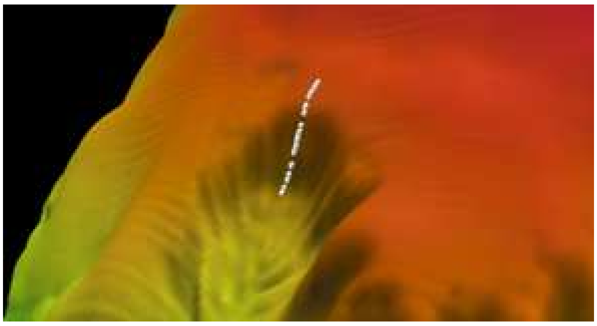
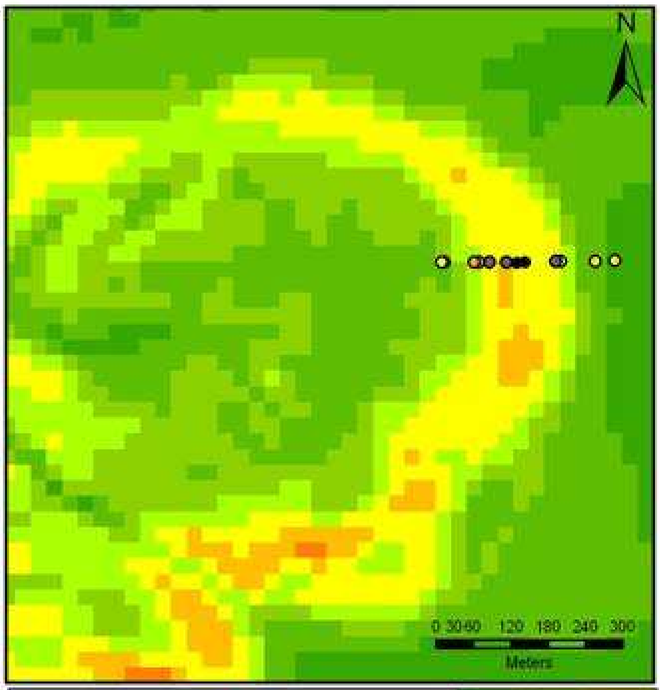
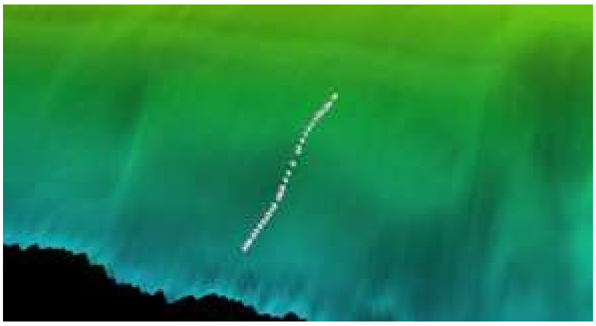


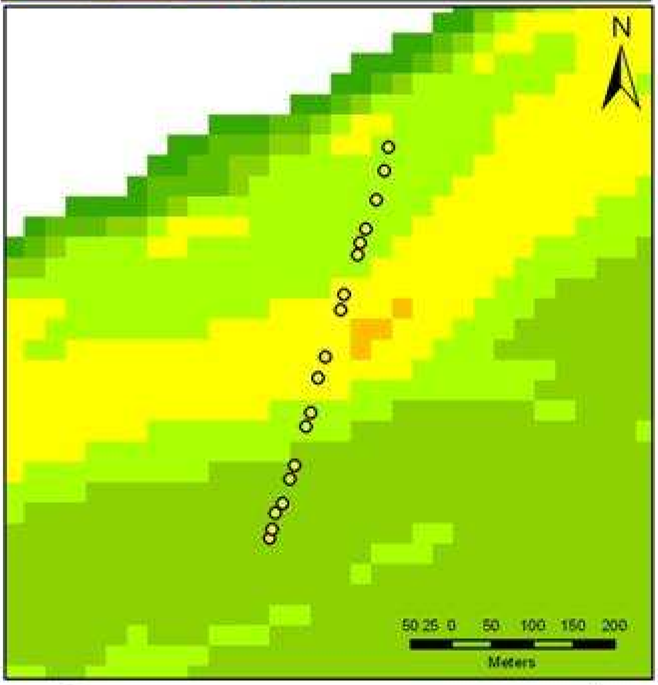
Figure 4.17. Interpretation of sea-bed sediments in the canyons study area represented in the EUNIS classification. The interpreted boundaries are derived from photographic "ground-truthing" sites, shaded bathymetry, backscatter, slope and existing reports (Cunningham *et al*. 2005; Evans, 1990; Evans and Hughes, 1984).





a) perspective view looking approximately east





b) perspective view looking approximately southeast

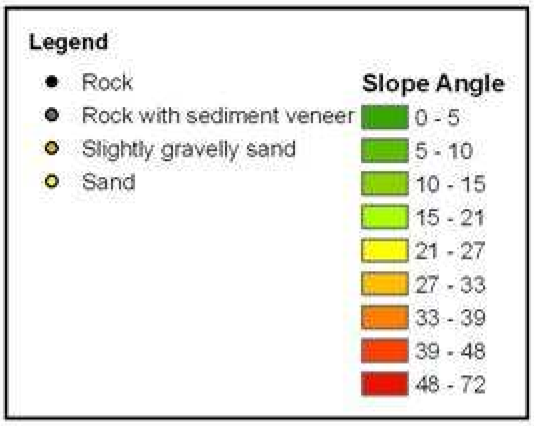


Figure 4.18. Perspective view of the bathymetry and plan view of the slope angle for camera tows C_1_3 (a) and C_3_9 (b) illustrating the occurrence of rock outcrop in the amphitheatre rims but not on smooth canyon walls of comparable slope values. For the location of all camera tows collected during this cruise please see Figure 4.24

4.3. Seismic data

The structure of the SW Approaches margin has been shaped by extension during the Early Cretaceous associated with the opening of the North Atlantic and uplift, followed by erosion associated with Alpine orogenesis during the mid-Tertiary (Evans, 1990). The Early Cretaceous strata comprise a thin sequence of shallow-marine clastics resting unconformably on Permo-Triassic or Jurassic sediments. Sea level rise associated with the opening of the North Atlantic changed the depositional environment from shallow- to deep-marine leading to the deposition of a thick Chalk sequence during the Late Cretaceous and Paleocene (Evans, 1990). Sea level remained high throughout the Cretaceous, approximately 200-350m above present day, and only began to fall during the Oligocene (Haq *et al.*, 1987). Two main Alpine orogenic events controlled deposition during the Cenozoic. The first occurred in the middle Eocene and resulted in the compression and folding of Paleocene-Oligocene sediments during the Oligocene (Evans, 1990). The second occurred during the Late Miocene, resulting in a general uplift of approximately 100m in the Channel area (Evans, 1990).

The second of the Alpine events are of most importance to the current interpretation. This event caused the seaward deposition of a prograding, deltaic wedge during the Miocene (Jones and Cockburn formations) which downlaps onto the Late Cretaceous Chalk followed by Pliocene incision of the canyons (the Pliocene to Pleistocene Little Sole Formation) (Bourillet *et al.*, 2003; Evans, 1990). Each of the three Neogene formations will be summarised and their relationship to interpreted seismic facies will also be discussed (see also Table 3.3).

The Jones Formation

The early to mid-Miocene age Jones Formation comprises progradational calcilutites with up to 25% sand-sized particles (Evans and Hughes, 1984). The Jones Formation rests unconformably on the blanket Chalk deposits of the Upper Cretaceous. The top of the Upper Cretaceous has not been identified in the MESH seismic dataset as it is located more than 1000m below sea level in the study area (Evans, 1990). This formation was deposited on a shelf with relatively uniform rates of deposition (Evans and Hughes, 1984).

This formation has been correlated with Facies V from this study (Figures 4.19-4.22; for the location of Figures 4.19-4.22, see Figure 4.23). The main seismic characteristics of this formation are reasonably parallel reflectors with a number of prominent reflectors located at the top of the facies package. Over the crests of the interfluves the top of the Jones Formation lies between 200-250m below sea bed and forms a break in slope on the smooth southern canyon flanks of the Dangaard and Explorer canyons (Figures 4.19 and 4.22).

The Cockburn Formation

The Cockburn Formation of mid- to late Miocene age comprises a deltaic sequence of calcarenites with predominantly fine sand-sized particles (Evans and Hughes, 1984). The Cockburn Formation represents an increase in the power of the hydraulic regime of the Celtic Margin suggested to be a result of increasing sea levels due to a connection made between the southern North Sea and the SW Approaches at this time (Evans, 1990). The unconformable relationship between this formation and the overlying Little Sole Formation suggests that the top of the Cockburn Formation was located at the limit of wave influenced sediment mobilisation during Pliocene times. This relationship is discussed below.

A characteristic of Facies IV, which is proposed to correspond to this formation, is the erosion surface which marks the base of this sediment package (Figure 4.22). The reflectors of Facies IV downlap onto the near-parallel reflectors of Facies V, this change is probably the result of an increase in hydrodynamics. A similar relationship exists between the top of Facies IV and the base of Facies III. This was due to peneplanation of the continental shelf between the late Miocene and early Pleistocene prior to deposition of the Little Sole Formation.

The Little Sole Formation

The Little Sole Formation was originally subdivided into the Upper and Lower members by Evans (1990); however it is informally divided into three facies in this study. Facies I comprises a discontinuous slump and palaeovalley infill deposit of Plio-Pleistocene age. Facies II comprises the sheet-like upper formation which rests unconformably on the peneplaned Cockburn Formation. Facies III is a discontinuous wedge-shaped member which is only found on the continental slope (Figures 4.19-4.22). The Lower Little Sole Formation (Facies III) is completely removed in areas of pronounced incision, so is absent on much of the outer continental shelf. However, it is preserved on the smooth interfluves between the canyons. The Upper Little Sole Formation (Facies II) is a relatively thin, featureless blanket deposit (Evans, 1990). Another seismic facies has been attributed to the Little Sole Formation, hereon called Facies I.

The three Facies that make up the Little Sole Formation were not always distinguishable from each other (Figures 4.19-4.22). Facies III, the wedge-shaped member, is characterised by a number of buried canyons (Figure 4.21), which have subsequently been re-excavated during the Pleistocene. Sigmoidal reflectors, which may represent buried sandwaves or contourite deposits, are also a characteristic of Facies III. This unit can be up to 300m in thickness and is well established on the canyon interfluves. It is harder to trace further back onto the continental shelf and instead becomes Facies II comprising a thinner package of sediments with less prograding units than Facies III. Facies II is 50-60m in thickness and is roughly parallel to the sea bed. In places Facies II is overlain by Facies I, which is characterised by the uppermost slump deposits (Figures 4.19 and 4.20) and an infilled palaeovalley located on the interfluve between Explorer and Dangaard Canyons. These have been highlighted on Figure 4.19.

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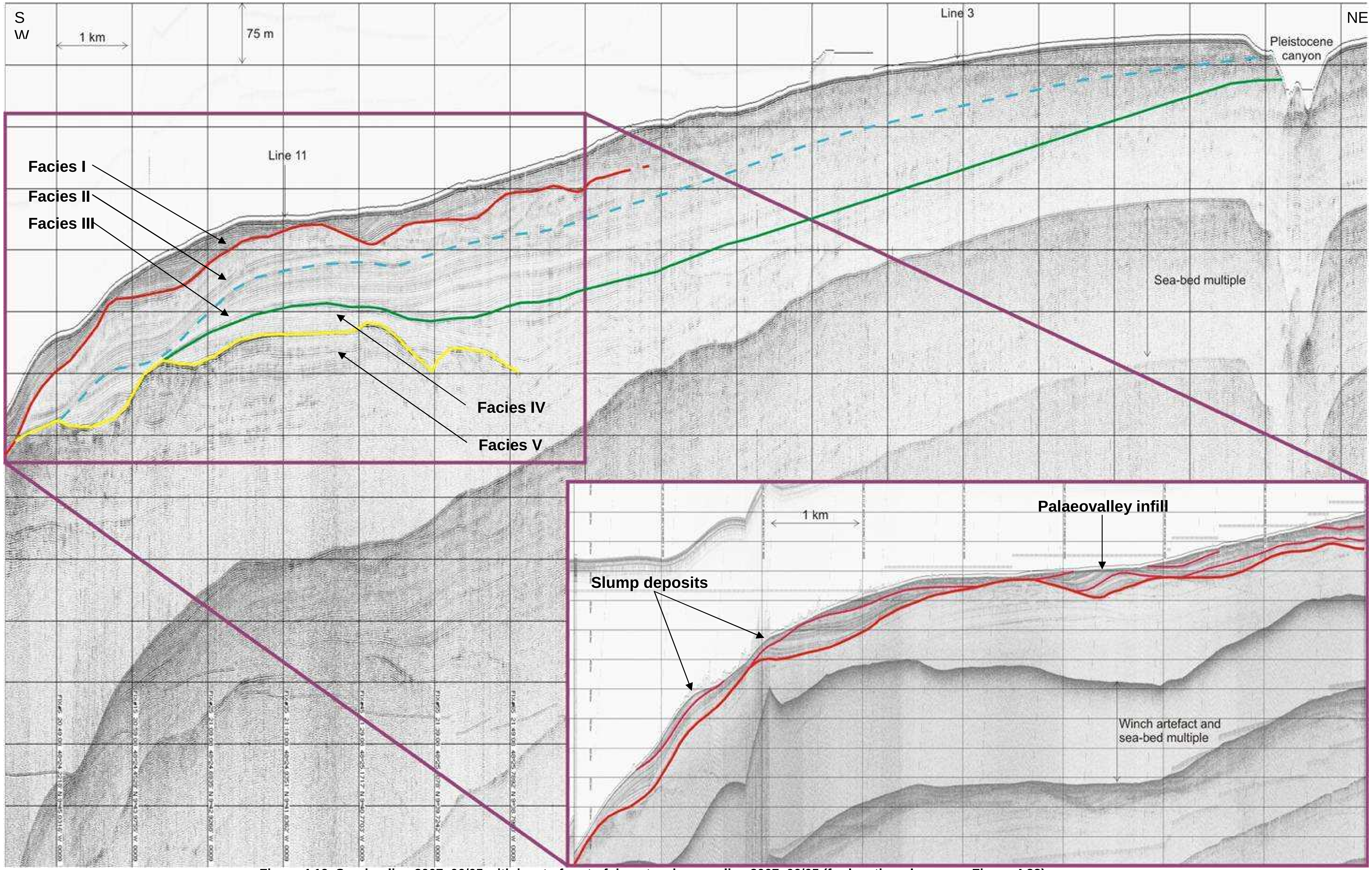

Figure 4.19. Sparker line 2007_06/05 with inset of part of deep-tow boomer line 2007_06/05 (for location please see Figure 4.23).

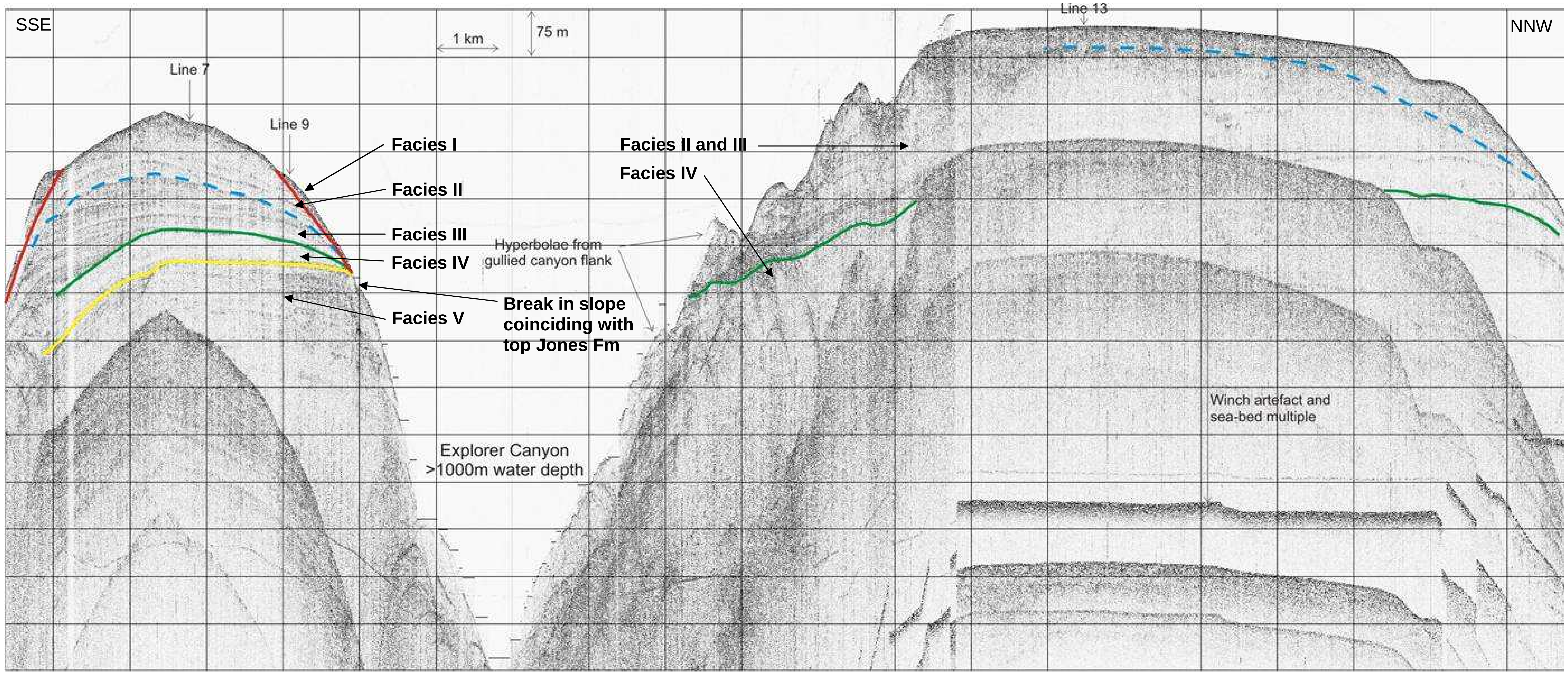

Figure 4.20. Sparker line 2007_06/11 (for location please see Figure 4.23).

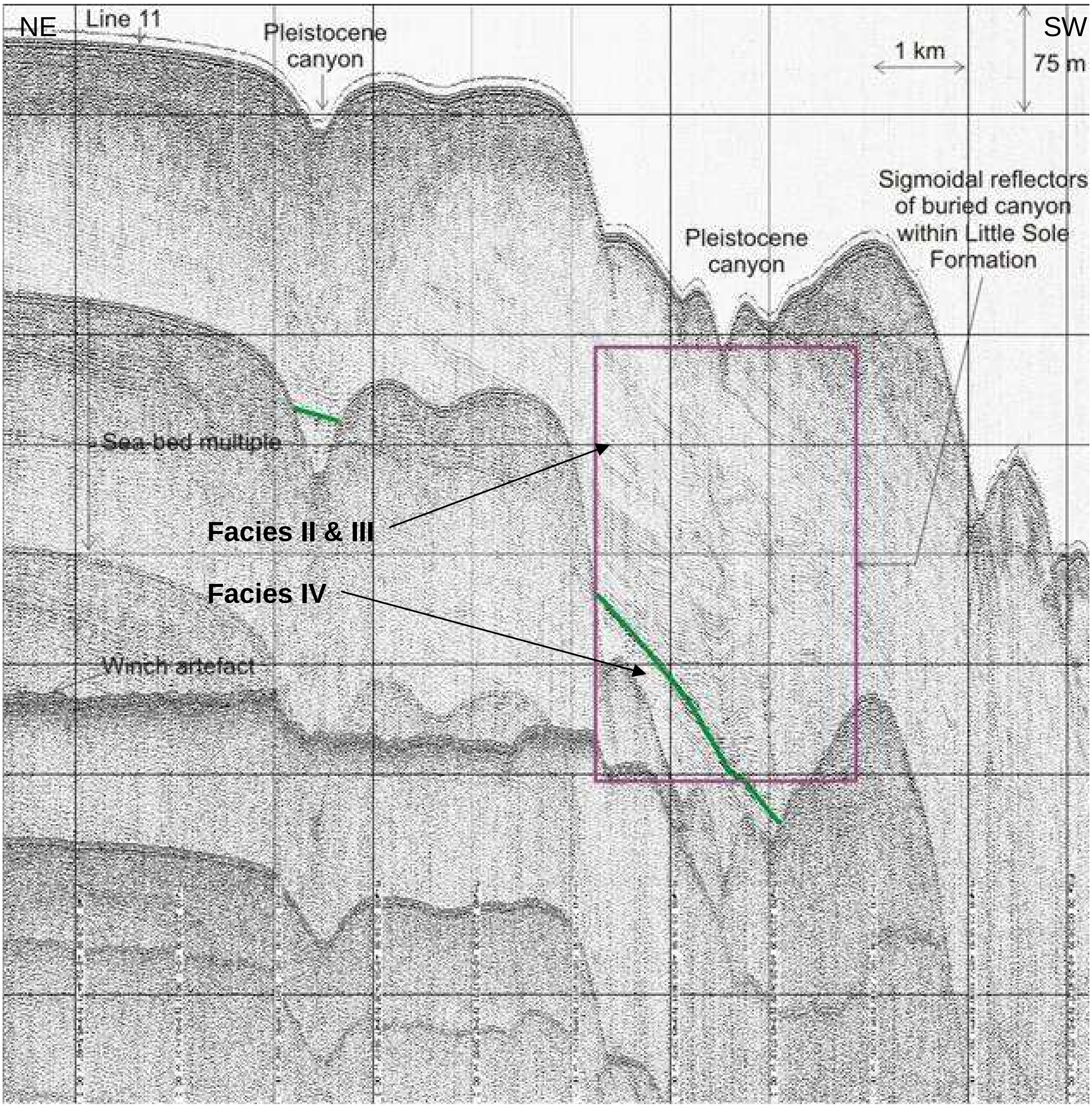

Figure 4.21. Sparker line 2007_06/13 (for location please see Figure 4.23).

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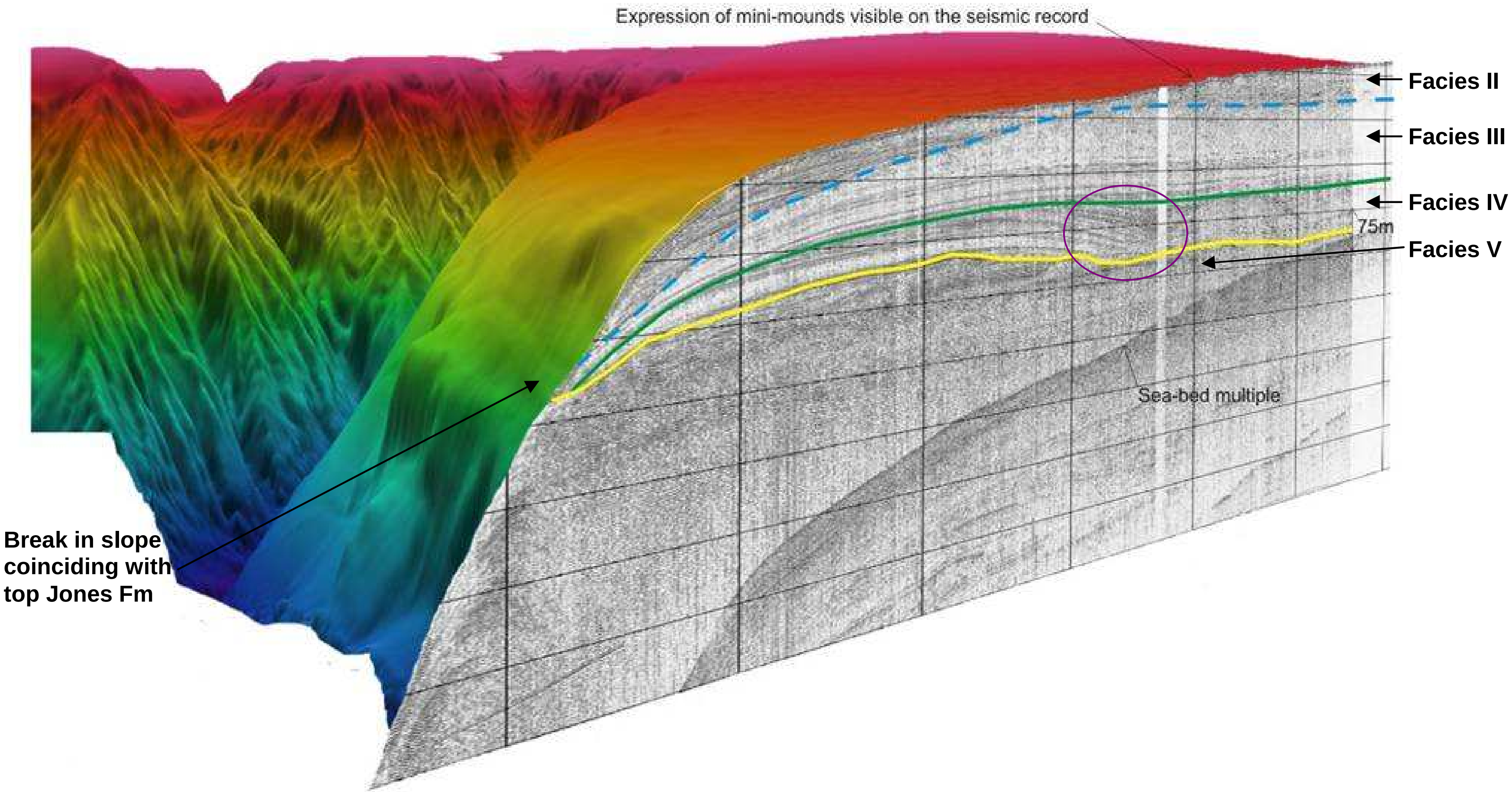

Figure 4.22. Sparker line 2007_06/05 combined with multibeam bathymetry view looking approximately west (for location please see Figure 4.23). Please note that the distance between each vertical line is approximately 1 km. The disconformity highlighted by the purple circle is a characteristic of Facies IV.

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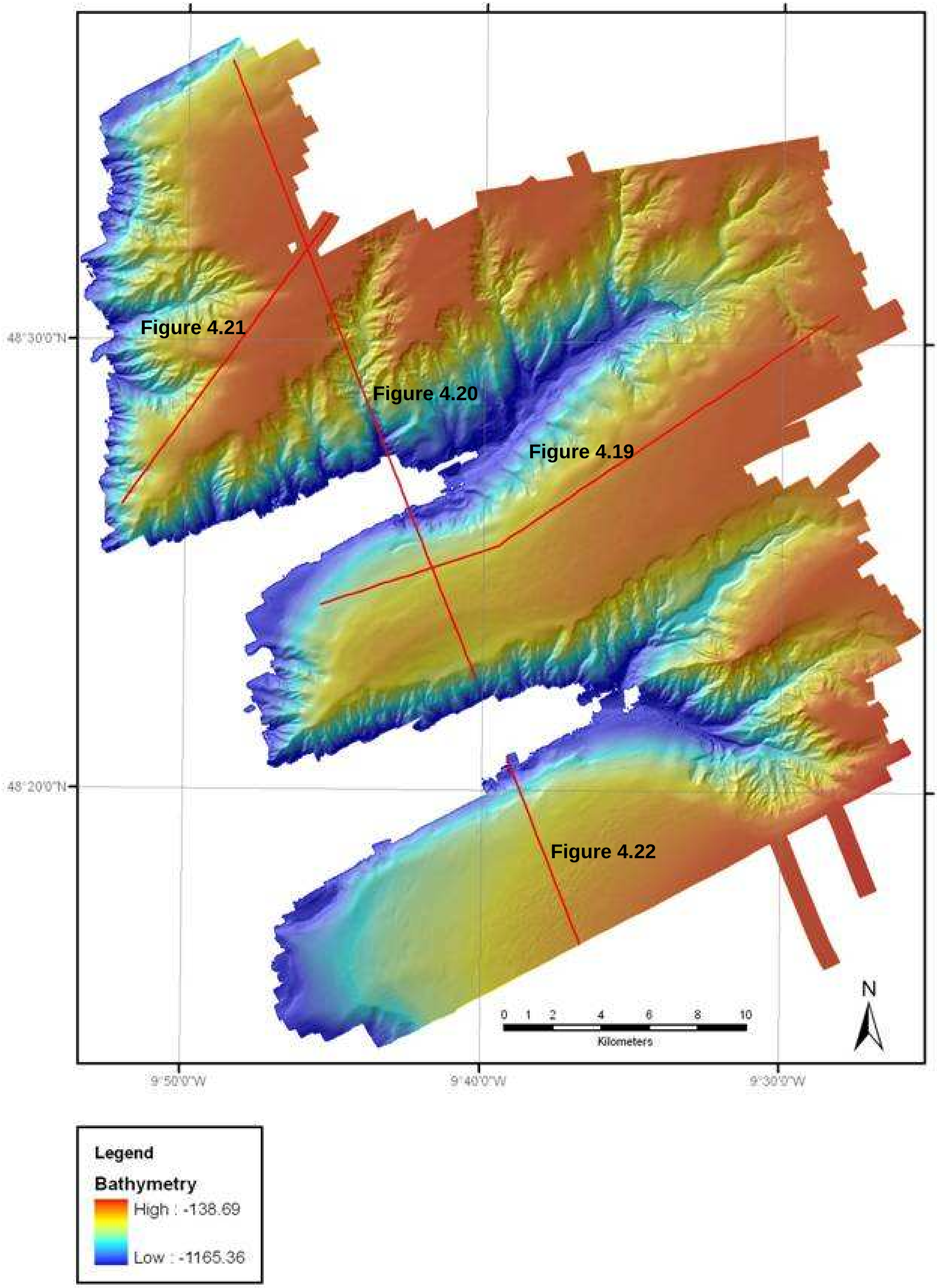

Figure 4.23. Location of seismic profiles shown in Figures 4.19-4.22. For information on additional seismic profiles in the survey area see Stewart and Davies (2007).

4.4. Epifauna – biotopes, distribution, epifauna map

4.4.1. Station Summaries

In total, 44 successful video tows were conducted. Table 4.1 summarises the video tows and Figure 4.24 shows their geographic locations. Appendix 1 provides further information about the still images taken along these video tows.

Table 4.1. Summary of video tows: canyon, position within canyon and depth in metres below sea surface

Station Number	Canyon	Position in canyon	Depth (m)
C_1_1	Irish canyon	Flank	722-991
C_1_2	Irish canyon	Flank	285-302
C_1_3	Irish canyon	Flank	351-436
C_1_4	Irish canyon	Flank	519-654
C_2_1	Dangaard canyon	Flank	247-323
C_2_2	Dangaard canyon	Canyon head	635-646
C_2_3	Dangaard canyon	Canyon head	759-824
C_2_4	Dangaard canyon	Flank	399-413
C_2_5	Dangaard canyon	Flank	542-698
C_2_6	Dangaard canyon	Flank	777-972
C_2_7	Explorer canyon	Flank	714-874
C_2_8	Explorer canyon	Flank	912-1064
C_2_9	Explorer canyon	Flank	563-635
C_2_10	Explorer canyon	Flank	390-441
C_2_11	Explorer canyon	Canyon floor	831-949
C_2_12	Explorer canyon	Canyon head	243-324
C_2_13	Explorer canyon	Canyon head	463-570
C_2_14	Explorer canyon	Flank	795-943
C_2_15	Explorer canyon	Flank	463-637
C_2_16	Explorer canyon	Flank	783-934
C_2_17	Explorer canyon	Flank	351-387
C_2_18	Explorer canyon	Flank	685-872
C_2_19	Explorer canyon	Flank	659-820
C_2_20	Explorer canyon	Canyon floor	827-1094

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C_2_21	Dangaard canyon	Interfluve	252-256
C_2_22	Dangaard canyon	Interfluve	328-343
C_2_23	Dangaard canyon	Flank	730-927
C_2_24	Dangaard canyon	Flank	685-824
C_2_25	Dangaard canyon	Flank	722-793
C_2_26	Dangaard canyon	Canyon head	306-399
C_2_27	Explorer canyon	Continental shelf	184-192
C_2_28	Explorer canyon	Canyon head	232-371
C_3_1	Dangaard canyon	Interfluve	204-221
C_3_2b	Dangaard canyon	Interfluve	303-309
C_3_3	Dangaard canyon	Canyon head	223-265
C_3_4	Dangaard canyon	Canyon head	239-246
C_3_5	Dangaard canyon	Canyon head	366-465
C_3_6	Dangaard canyon	Canyon floor	949-1000
C_3_7	Dangaard canyon	Interfluve	352-365
C_3_8	Dangaard canyon	Flank	459-612
C_3_9	Dangaard canyon	Flank	668-795
C_3_10	Dangaard canyon	Flank	711-869
C_3_11	Dangaard canyon	Flank	683-750
C_3_12	Dangaard canyon	Canyon head	671-919

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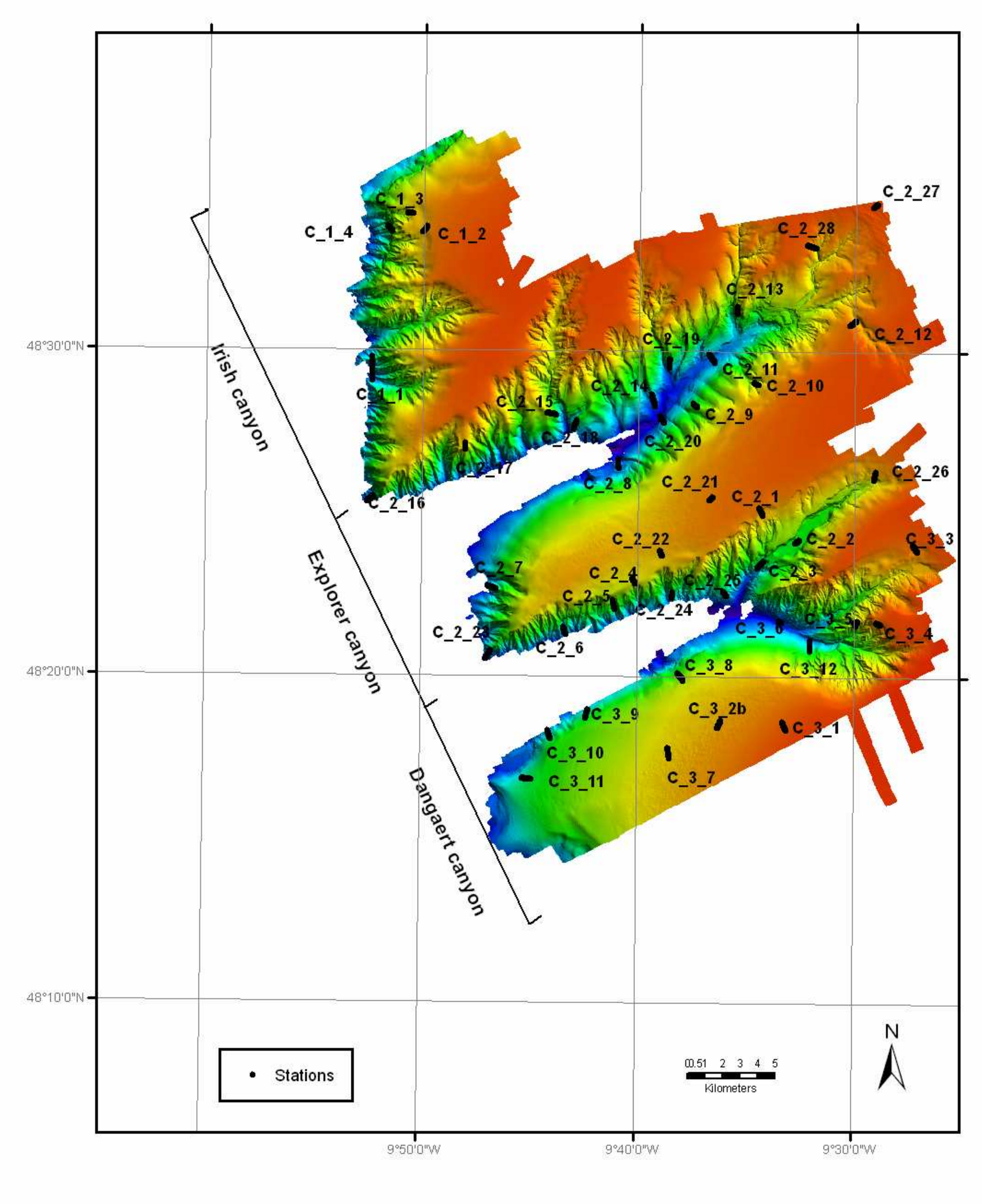

Figure 4.24. Map of the three canyons within the study area and the camera tows that were undertaken

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Irish Canyon

C_1_1

The transect crossed two ridges on the eastern canyon flank in Irish territorial waters. The transect was long (1.4km), sampling a variety of water depths, changes in topography and areas of high backscatter. The tow began on an area of soft sediment with holothurians (*Benthogone* sp.), asteroids (*Pseudarchaster* sp.) sea pens (*Kophobelemnon sp.*), cerianthids, anemones (*Bolocera* sp, and others), and fish (including Morids). As the transect continued, the sea bed sloped steeply, and a small number of isolated bamboo corals were observed, before the tow resumed to a soft sediment habitat as observed previously, although with slightly less epifauna. This habitat continued until the tow traversed a near vertical drop-off before resuming a habitat of soft sediment with distinct sand ripples. Throughout the tow, not all statistical images could be taken flat on the seabed due to the silt clouds stirred up by the drop camera frame.

C_1_2

The target was an area of high backscatter on the edge of the interfluve. The tow revealed an area of even sea bed with slightly muddy sand with varying cover of biogenic debris (shell and coral) and pebbles. Very little epifauna were visible, with the exception of squat lobsters (*Munida* sp.) and hydroids. At least two fishing nets were observed during the tow.

C_1_3

The target was a slumping feature forming an amphitheatre-like depression identified on the multibeam. At the start of the tow the sea bed comprised slightly rippled, fine-grained sand with a small proportion of shell debris. As the tow continued, a steep drop off was encountered. Further ledges of bedrock were encountered as the tow progressed. Approximately 250m along the tow the terrain sloped steeply, with slightly rippled muddy sand. Areas of bedrock (with sand veneer in places) were characterised by cerianthids (tube dwelling) and non tube-dwelling anemones. Other fauna observed were a single blue mouth redfish (*Helicolenus dactylopterus***)** and a rabbit fish (*Chimera monstrosa*).

C_1_4

The first 100m of the tow consisted of muddy sand with burrows in the sediment.. As the camera continued along the line, a vertical drop off was encountered, with a series of bedrock ledges. Typical fauna observed along the ledges were tube dwelling polychaetes and anemones. In places exposed bedrock was visible with abundant featherstars (Crinoidea) and antipatharian corals (*Stichopathes* sp). The remainder of the tow comprised a steep slope of fine-grained, muddy sand with shells, pebbles and occasional cobbles, which graded into an area with no shell debris or lithic fragments, but with more abundant fauna, including asteroids (*Pseudarchaster* sp.), cerianthids, and the sea pen *Kophobelemnon* sp. Discarded fishing line was visible.

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Explorer Canyon

C_2_7

The target was a ridge located at the end of the interfluve. The camera tow began on an area of rippled sandy mud. Fauna were not particularly abundant, with some cerianthids, large *Bolocera* sp., other anemones and seastars (*Pseudarchaster* sp.). As the tow continued, the substrate graded into clay, and with more abundant fauna, additional species observed included sea pens, the decapod *Bathynectes* sp. and bamboo corals.

C_2_8

The target was the deeper water section of the southern flank of the canyon. The camera tow began on an area of muddy sand with some silt cover and slight ripples with finer grained material in the ripple troughs. As the tow continued, occasional cobbles were visible. Fauna was sparse, with only a few cerianthids and asteroids. As the camera progressed along the tow, the substrate changed to clay. Further along the tow, a few urchins (*Cidaris cidaris*) and blue-mouth redfish were seen.

C_2_9

The target was a ridge on the southern flank of the canyon. The tow began on an area of muddy sand with abundant burrows.Fauna were very sparse, with only a few seastars (Asteroidea), cerianthid and other anemones.

C_2_10

The target was the upper part of the canyon flank. The tow revealed a continuous substrate of muddy sand, with sparse fauna. Holothurians, ophiuroids, an octopus and *Nephrops* were observed, with some burrowing anemones.

C_2_11

The target was an area of the canyon floor in the head of the canyon, which had a high backscatter response. The tow began on an area of rippled sand with underlying bedrock. Urchins (*Cidaris cidaris*) were visible. As the tow continued, ledges of bedrock became apparent with small growths of the coral *Madrepora oculata*. Between the ledges, areas of flat seabed comprising rippled sand were observed.

C_2_12 (Figure 4.25)
The target was a shallow water tributary of the canyon. The tow began on an area of sandy seabed. Fauna included abundant sea pens, squat lobsters (*Munida* sp.) and urchins (*Cidaris cidaris*). As the tow continued biogenic material (shell) was observed. A crinoid (*Leptometra celtica*) field was encountered, with abundant *Munida*. Further along the tow, a few boulders with small growths of coral were evident, which subsequently graded into an area of sandy, shelly gravel. As the tow continued, an area of bedrock (with shell debris) and abundant crinoids was encountered. Discarded fishing line was observed along the tow.

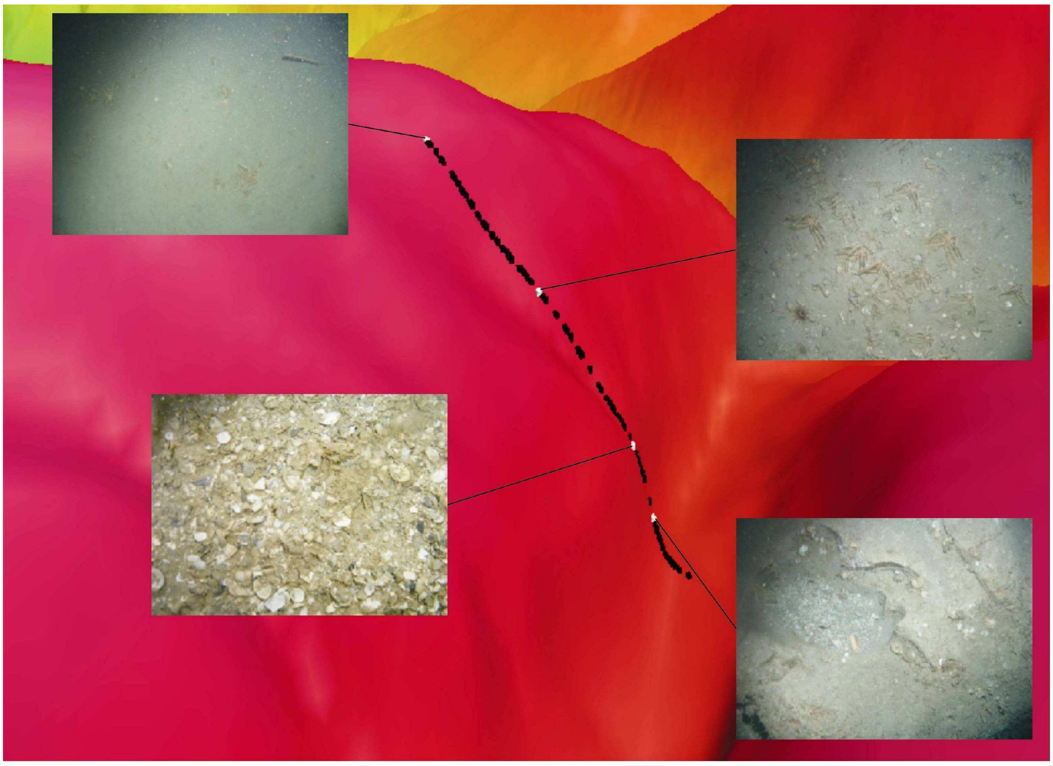

Figure 4.25. Camera tow of C_2_12 highlighting the change in habitats along the tow from sand through to bedrock.

C_2_13
The target was a ridge in the head of the canyon. The tow began on an area of muddy sand with abundant mysid shrimp observed in the water column. As the tow continued, bedrock outcrop was encountered with abundant ophiuroids and occasional hydrocorals (stylasterids). The bedrock, which formed planar outcrop related to bedding planes, was observed frequently along the tow, with corals (*Madrepora oculata*) and hydroids growing on the plane edges.

C_2_14 (Figure 4.26)
The target was a ridge in the deeper water section of the canyon flank. The tow began on an area of biogenic reef, comprising dead and live *Lophelia pertusa*, with abundant live growths of *Madrepora oculata*. The dead framework (with live growths) covered an area of approximately 50-90% of the field of view (and more locally) and was infilled with sand. As the tow proceeded it became apparent that the reef was extensive, and continued for the duration of the tow, before ending abruptly as the substrate changed to bedrock with few visible fauna. Typical organisms inhabiting the reef were: the pencil urchin (*Cidaris cidaris*), ophiuroids, anemones (including cerianthids), fish (*Lepideon* sp.), antipatharian coral (*Stichopathes* sp.) and crustaceans (*Bathynectes* sp., *Chaceon affinis* and *Munida* sp.). The fauna changed slightly further along the reef, with crinoids (*Koehlerometra porrecta*) and brisingids becoming more abundant.

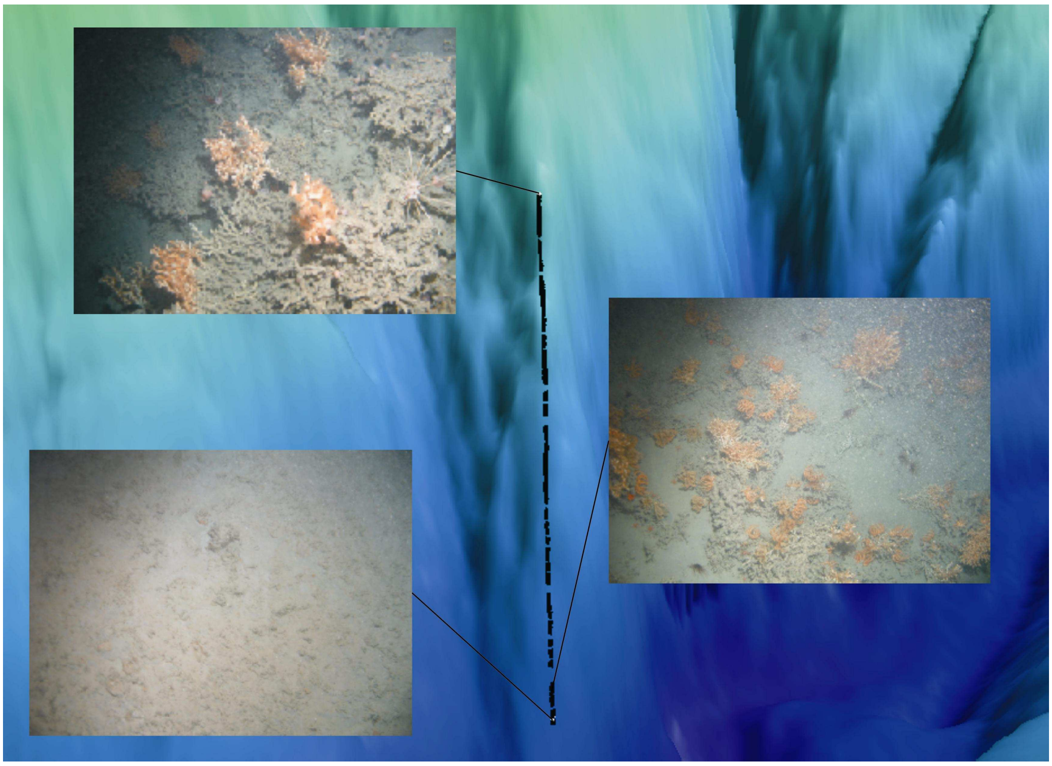

Figure 4.26. Camera tow of C_2_14 showing a biogenic reef.

C_2_15
The target was a change in backscatter along the flank of the canyon. The tow revealed one continuous substrate of muddy sand with sparse fauna throughout. Despite this, signs of bioturbation were obvious throughout the tow, with abundant small burrows and *Nephrops* burrows. Conspicuous fauna observed were holothurians (*Benthogone* sp.) and a few asteroids (*Pseudarchaster* sp.).

C_2_16
The target was a ridge on the end of the interfluve. The tow began on an area of soft sediment, probably composed of clay, with burrows and cerianthids. Other fauna observed were sea pens (*Kophobelemnon* sp. and an unidentified species), anemones (including *Bolocera* sp.),

asteroids (*Pseudarchaster* sp) and echinoids (*Calveriosoma fenestratum*). As the tow continued, bedrock with a thin veneer of fine sediment became visible, with the presence of a few bamboo corals, and small patches of coral rubble with small growths of live coral (*Madrepora oculata*). Subsequently, the substrate changed back to soft mud/clay and continued to the end of the tow.

C_2_17
The target was a shallow area of the canyon flank, where there were historical records for corals. The tow began on an area of soft clay, which had numerous small burrows. Fauna was sparse throughout the tow, with the exception of ophiuroids, and cerianthid anemones, that increased after approximately 300m.

C_2_18
The target was a ridge at a similar water depth on the canyon flank as tow C_2_14 where biogenic reef was observed. This tow was conducted to determine whether the distribution of the reef extended horizontally along the canyon flank. The tow began on an area of bedrock, with little visible fauna other than asteroids. As the transect descended the steep outcrop of bedrock, patches of coral (dead *Lophelia* with some live *Madrepora oculata*) were visible, with some fauna associated with it (*Cidaris cidaris*, echinoids and asteroids). As the transect continued, the patches of rubble graded back to bedrock, and then to muddy sand, with abundant ophiuroids, the sea pen *Kophobelemnon* sp., *Bolocera* sp. cerianthids and other anemones.

C_2_19
The target was a ridge 2km northwest of C_2_14 (biogenic reef) but at a shallower water depth to try to asertainthe extent of the reef. The camera tow revealed a continuous substrate of muddy sand, with very few visible epifauna, but signs of bioturbation in the form of burrows.

C_2_20 (Figure 4.27)

The target was the canyon flank opposite C_2_14 where the biogenic reef was observed, to investigate the occurrence of a reef at a similar position on the southern flank. The tow revealed a substrate of muddy sand, with numerous small holes. As the tow progressed, a slope with bedrock outcrop and a veneer of rippled fine-grained sand was apparent. The moderate slope became a steeper, stepped bedrock escarpment before levelling out, returning to bedrock outcrop with a veneer of sediment at approximately 1020m water depth. Fauna were not particularly abundant, and were concentrated along the edge of rock outcrop. Conspicuous fauna included anemones, and burrowing ophiuroids.

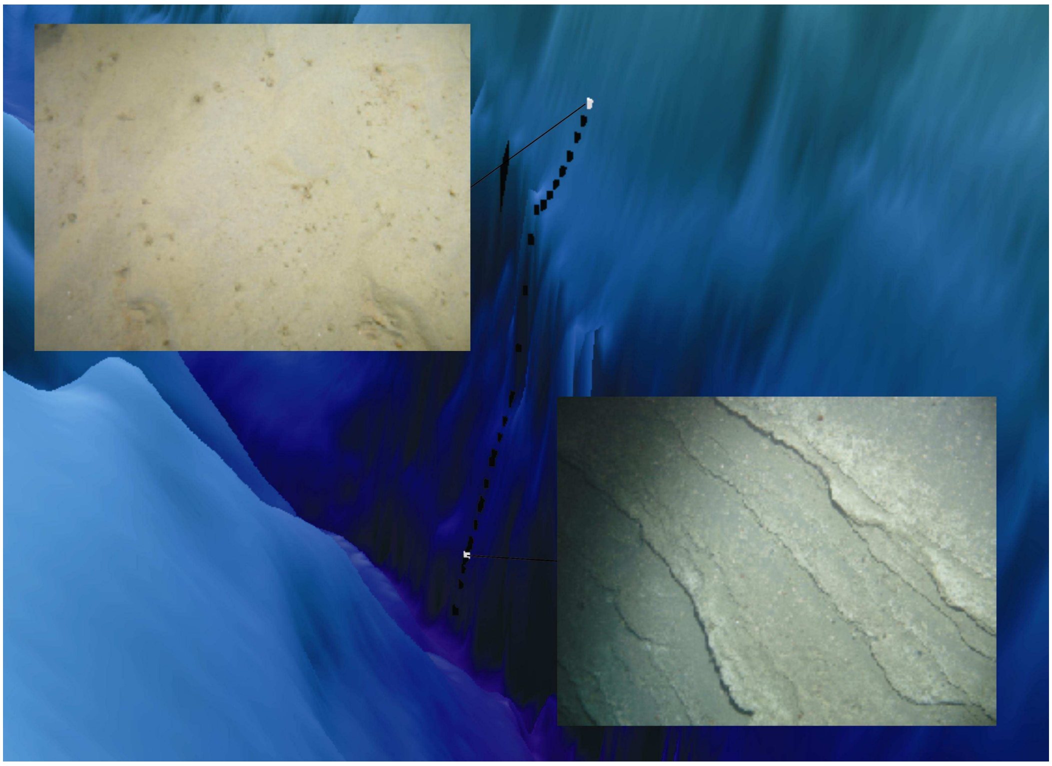

Figure 4.27. Camera tow of C_2_20 showing bedrock ledges.

C_2_27

The target was a shallow area on the continental shelf. The tow revealed a continuous substrate of rippled muddy sand with some coarser material visible in the ripple troughs, with occasional cobbles. Few epifauna were visible throughout, only occasional asteroids (*Porania pulvillus*), crinoids,flatfish and a single monkfish (*Lophius piscatorius*).

C_2_28

The tow began on an area of coarse biogenic gravel (shells), on muddy sand. Typical fauna included occasional holothurians (*Stichopus tremulus*), crinoids, asteroids, *Munida* sp. and ophiuroids. From approx 30m along the transect, the sediment became less shelly and supported less epifauna. Further along the tow, the substrate became progressively sandier. As the tow neared its end, bedrock with a veneer of sand became apparent prior to a series of bedrock ledges with associated ophiuroids and hydroids. Discarded fishing line was observed.

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Dangaard Canyon
C_3_1
The camera failed three times within the tow, thus there are gaps in the video/camera track. The target was a change in backscatter response. The tow revealed one continuous habitat of flat sea bed consisting of medium-grained sand with some biogenic material (predominantly shell debris). There were some signs of hydrodynamic activity, with the presence of small sand ripples, and bioturbation in the form of echinoid tracks. Typical fauna that were observed throughout the tow were echinoids (possibly 2 species), asteroids (including *Astropecten irregularis*), cerianthids, ophiuroids, polychaete tube worms, and abundant flatfish.

C_3_2b
The target was a mini-mound (approximately 10m high) located on the interfluve identified using multibeam data. The camera transect began on an area of slightly silty sand with shell debris. Throughout the tow there were patches of coral debris and occasional boulders. Towards the end of the tow, less biogenic material was apparent, but there were numerous burrows within the sediment. Dominant fauna were *Munida* sp., the holothurian *Stichopus tremulus*, numerous anemone species and flatfish (*Lepidorhombus* sp.).

C_3_3
The target was a change in backscatter and slope. The tow began on an area of muddy sand with occasional deposits of biogenic material (shells). Dominant fauna were sea pens, ophiuroids and *Munida*. As the track continued the sediment became more silty with noticeably fewer sea pens, but with more biogenic material (shells) pebbles and ophiuroids (*Ophiothrix fragilis*). The camera then transversed down a slope of approximately 21^{o}, before the terrain levelled off for the remaining part of the tow. The slope coincided with a break in slope interpreted on the multibeam data and some cobbles were visible in places on the slope. There were signs of bioturbation, with the presence of burrows. Discarded fishing line was observed.

C_3_4
The target was a change in backscatter within the canyon head. The tow began on an area of flat sea bed comprised of muddy sand with mud deposits and shell debris. Conspicuous fauna were cerianthids, squat lobsters (*Munida* sp.) ophiuroids (*Ophiothrix fragilis*) and abundant echiurans (*Bonellia viridis*). As the tow progressed, the substrate remained homogenous for approximately 200m. Subsequently, the camera reached a break in topography, in the form of a steep slope. As the camera progressed, both the current speed and the slope angle prevented landing of the camera. Dominant fauna that were visible throughout the latter part of the tow were mysid shrimp and *Munida*.

C_3_5
The target was a ridge and ridge flank within the canyon head. The first part of the tow began on the crest of the ridge with the second half traversing down the ridge flank. The tow revealed a continuous substrate of muddy sand with prominent silt. There were signs of some infaunal activity, with the presence of holes in the sediment. There were also signs of hydrodynamic activity in the canyon head comprising unidirectional sand ripples. The second part of the tow descended down the ridge flank into a gully in the canyon head. As the camera began to descend the flank, the ripples became more prominent and regular. Fauna were not abundant, with only a few *Nephrops* and anemones visible. As the tow progressed down the flank, the

substrate was unchanged, but there were visible signs of deposition of material (mud lumps and shell debris). There was no sign of hydrodynamic activity in the latter part of the tow.

C_3_6 (Figure 4.28)
The target was an area of high backscatter response, on the canyon floor. The tow began on an area of muddy sand with prominent ripples. Occasional boulders with attached epifauna (*Bolocera* sp. and other anemones) were also visible. As the tow progressed, the substrate remained homogenous, then changed from relatively flat sea bed to one of variable relief due to the presence of boulders. Fauna were not particularly abundant on the substrate, but were concentrated on the boulders. Typical fauna attached to the boulders were the holothurian *Psolus* sp., and the scleractinian coral *Lophelia pertusa*. Other fauna included large anemones (*Bolocera* sp.), cerianthid anemones and ophiuroids. The tow continued into an area with coral debris (rubble), with silt cover. As the camera continued into deeper water, the coral rubble became denser with larger rocks present. Again, the same fauna were observed on cobbles and boulders as seen previously. Discarded fishing net and plastic bags were observed.

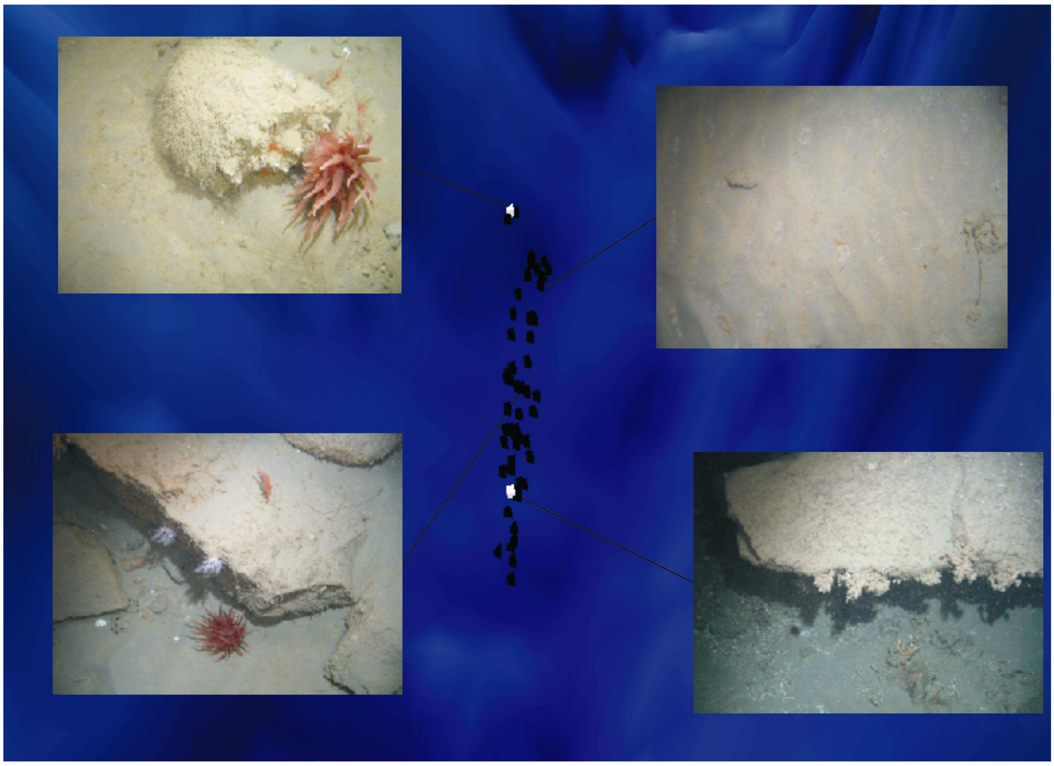

Figure 4.28. Camera tow of C_3_6 with selected images showing the various habitats encountered along the tow

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C_3_7
The target was an area of the mini-mounds with variable backscatter. The tow revealed two distinct habitats. The transect began at the edge of the mound field on an area of muddy sand with some biogenic material (shell). There were patches of bioturbation (small holes) and cerianthids. As the camera tow progressed (approximately 100m along) patches of coral (*Lophelia pertusa*) debris were visible, with *Munida* present. The debris had some silt coverage and was broken up. The camera then passed over another area of muddy sand with cobbles and pebbles, and abundant anemones. The tow continued into another area of coral debris, similar to that observed previously. Toward the end of the tow the proportion of coral debris decreased and the sea-bed composition returned to muddy sand with occasional cobbles with abundant anemones. Discarded fishing line was observed.

C_3_8
The target was the shallow section of the southern flank of the canyon. The transect began at the canyon edge on an area of very silty muddy sand with occasional cobbles, cerianthid anemones, and a few fish. As the camera continued along the tow, the slope descended fairly rapidly over clay dominated substrate. This substrate continued to an approximate depth of 550m, after which the substrate became sandier with fine biogenic (shell and coral) material in distinct bands, with burrows present. The slope angled downward for the remainder of the tow.

C_3_9
The target was approximately midway down the southern canyon flank in deeper water than C_3_8. The tow began on an area of rippled muddy sand with some biogenic material (shell). A few cerianthids were visible, with little other fauna. As the camera continued along the tow, the substrate became siltier with clay lumps (deposits) and a few isolated cobbles. Grenadier fish and asteroids were observed throughout the tow.

C_3_10
The target was located near the base of the southern canyon flank in deeper water than C_3_9. The tow revealed a homogenous substrate: muddy, silty sand with parallel ripples observed for the majority of the tow. Conspicuous fauna were cerianthids, echinoids (*Calveriosoma fenestratum*), asteroids (*Pseudarchaster* sp.), holothurians (*Benthogone* sp.) and fish.

C_3_11
The target was the end of the interfluve. The tow revealed one continuous habitat of muddy sand with some cobbles scattered throughout. Parallel ripples were visible during the latter part of the tow, with some gravel deposits located in the troughs of the ripples. Small burrows were visible throughout. A single monkfish (*Lophius piscatorius*) was seen. Other fauna observed included the echinoid *Calveriosoma fenestratum*, the decapod *Paromola* sp., brachiopods and asteroids (*Pseudarchaster* sp.).

C_3_12
The tow was located in the gullied canyon head. The tow began on an area of muddy sand with prominent ripples. Fauna were sparse, with a few pencil urchins (*Cidaris cidaris*), fish (*Synaphobranchus kaupii* and *Lepidion eques*), burrowing ophiuroids, echinoids and anemones. Approximately 270m along the tow, a slope was encountered, which dropped off to an area of what appeared to be either large mud deposits or cobbles covered in mud. Very few epifauna

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were visible. The relief of the sea bed continued to gradually slope downwards towards an area of bedrock outcrop with a thin veneer of sediment. Subsequently, the substrate graded back to muddy sand, with patches of underlying bedrock visible, with a more abundant cover of fauna. This continued until the end of the tow when a bedrock ledge with a veneer of sediment was encountered.

C_2_1
The target was a change in backscatter along the upper edge of the canyon. The tow began on an area of muddy sand with poorly defined ripples. Fauna were abundant, with dominant brisingid asteroids, crinoids (*Leptometra celtica*) and squat lobsters (*Munida* sp.). As the tow progressed the substrate became coarser with some biogenic material present. *Munida* and crinoids were again the dominant fauna observed. A few sea pens were also seen. As the tow proceeded, the gradient increased, coinciding with a decrease in the fauna observed. Once the break in slope was passed, the same fauna were observed as seen previously. Where more cobbles with a fine covering of silt cover were observed, fauna included holothurians, *Munida*, urchins and a few fish. The habitat graded into muddy sand with occasional cobbles, with little fauna other than *Munida*, grenadier fish and anemones. As the tow neared the end, the substrate became finer comprising muddy sand.

C_2_2
The target was a high backscatter response in the canyon floor area of the canyon head suggesting the presence of hard substrate. The tow began on an area of flat sea bed comprised of sand, with abundant fish. As the tow proceeded, the substrate became finer with slight rippling. Fish were again present, with some cerianthids, *Bolocera* sp., other anemones, asteroids and fish (*Synaphobranchus kaupii*). Further along the tow, occasional cobbles were present, but with little attached fauna. As the tow continued, the habitat changed to a homogenous muddy sand substrate.

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C_2_3 (Figure 4.29)
The target was an area of complex sea bed topography located at the foot of a flat bottomed canyon. At the beginning of the tow the substrate comprised fine-grained sand with coral fragments and occasional cobbles, little fauna were present other than fish. As the tow proceeded there were bedrock ledges with a veneer of fine-grained sediment, subsequently to which boulders and rock outcrop were encountered. The bedrock appeared to comprise softer lithologies rich in carbonate with no visible fauna, with the exception of one outcrop where coral was observed. Fauna were not particularly abundant throughout the tow, with the exception of fish. Other less abundant fauna included asteroids, anemones, and a few corals.

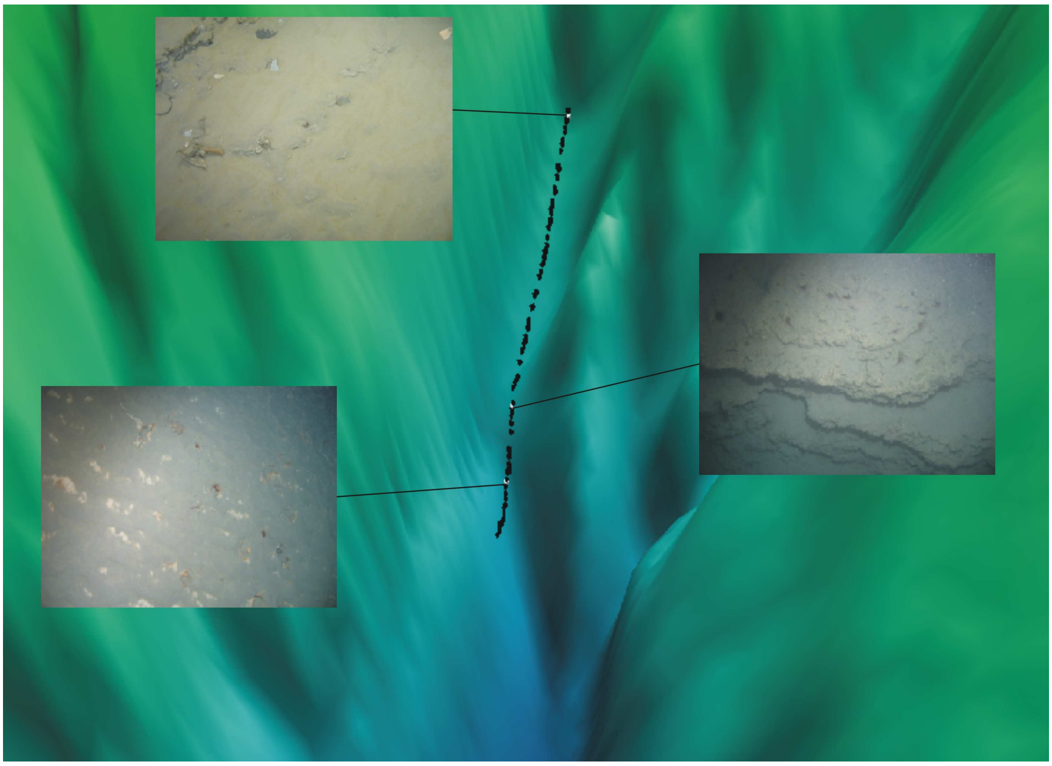

Figure 4.29. Camera tow of C_2_3.

C_2_4
The target was the top of the northern flank of the canyon. One continuous muddy sand substrate was observed. At the beginning of the tow, slight ripples were present, and as the tow continued, the ripples graded out to flat seabed with shell fragments. In some areas fauna were sparse, although in other areas abundant caryophyllid corals, flatfish (*Lepidorhombus* sp.) and grenadier fish were visible. Ophiuroids were visible throughout the tow.

C_2_5
The target was a ridge of a gully located on the northern flank of the canyon. The tow revealed a homogenous habitat of sandy mud. The tow began on an area with numerous burrows, *Bolocera* sp.and other anemones, burrowing ophiuroids and grenadier fish. As the tow proceeded, the faunal assemblage varied, with abundant sea pens (*Kophobelemnon* sp.) and asteroids.

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C_2_6
The target was a deep-water ridge of a gully on the northern flank of the canyon. The tow revealed a homogenous habitat of sandy mud. At the start of the tow, typical fauna were cerianthids and sea pens (*Kophobelemnon* sp.), and as the tow proceeded into deeper waters, fewer fauna were visible. Along the tow the sediment type seemed to become finer, making it more difficult to see the seabed and take statistical images.

C_2_21
The target was an area of mini-mounds located on the interfluve. The tow began on an area of sandy sediment with little epifauna, with the exception of *Munida* sp. and holothurians. Visibility was poor throughout the tow, due to silt cloud obscurities. Further along the tow, sea pens began to appear. As the tow neared the end, the sediment became slightly muddier.

C_2_22 (Figure 4.30)
The target was an area of the mini-mounds located on the interfluve and identified on the multibeam data. The tow revealed an area of muddy sand with coarser sediment and coral fragments. Typical fauna were the crinoid *Leptometra celtica*, *Munida* sp. and numerous Grenadier fish. As the tow continued, coral debris became less common and pebbles with some larger rocks became apparent. Subsequently, coral fragments became denser, with larger pieces, in distinct bands.

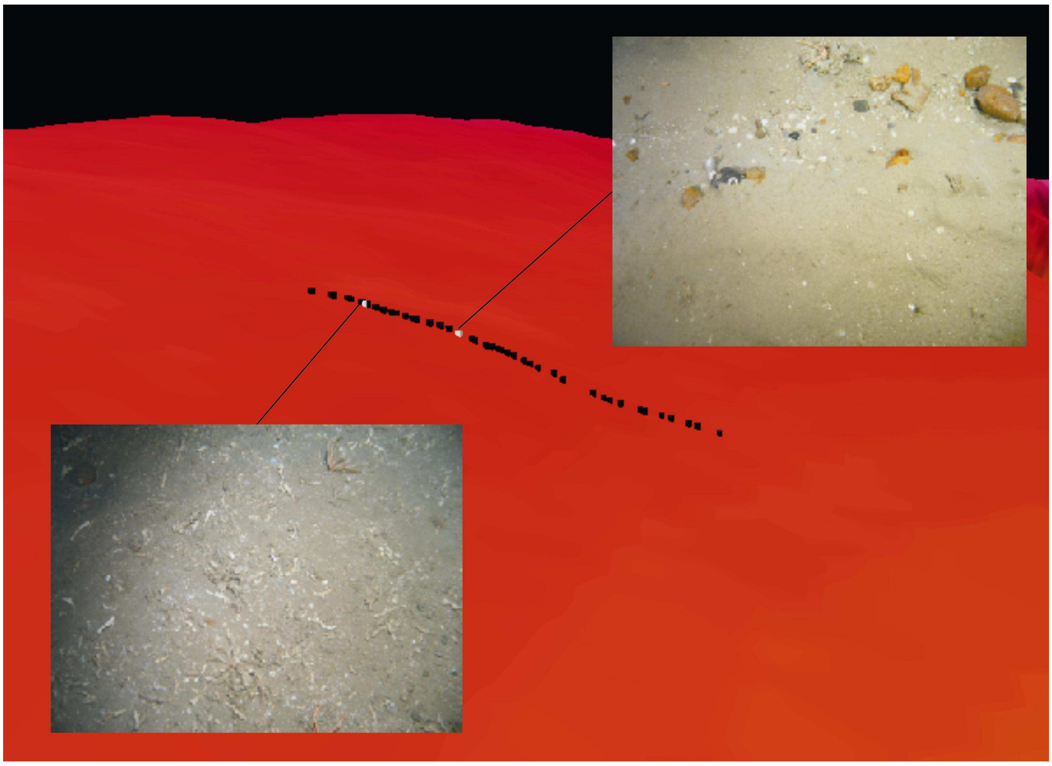

Figure 4.30. Camera tow of C_2_22 showing mixed substrata and coral gravel.

C_2_23
The target was a ridge at the end of the interfluve. The tow began on an area of muddy sand with abundant *Kophobelemnon* sp. and another unidentified sea pen. Other dominant fauna were a number of cerianthid species, asteroids (*Pseudarchaster* sp.), crinoids and bamboo corals. As the tow progressed, fauna became denser. Towards the end of the tow, a few steep ledges were encountered, subsequent to which a small area of dead *Lophelia pertusa* with associated fauna was encountered. The dominant fauna associated with the coral was the antipatharian coral *Stichopathes* sp*.,* cerianthids, bamboo corals and asteroids (possibly *Ceramaster* sp.).

C_2_24
The target was a deep-water ridge of a gully on the northern flank of the southern canyon imaged. The tow revealed a homogenous substrate of muddy sand, with burrows, anemones, occasional sea pens (*Kophobelemnon* sp.), holothurians (*Benthogone* sp.) and ophiuroids.

C_2_25
The tow consisted of rippled muddy sand. Fauna were sparse throughout, with only a few sea pens (*Kophobelemnon* sp.), asteroids (*Pseudarchaster* sp.) and the pencil urchin *Cidaris cidaris*.

C_2_26
The target was a shallow tributary to the canyon head. The tow began on an area of sand with pebbles. Fauna included *Munida* sp., a few fish (grenadiers and flatfish) asteroids and sea pens (with associated ophiuroid). After approximately 200m, a single boulder was observed, with some associated fauna (anemones). After 280m, a few boulders and cobbles and sediment deposits were apparent, with some attached fauna and abundant *Munida*. After which the substrate changed back to rippled sand. Discarded fishing net and line were seen frequently throughout the tow.

4.4.2. Image analysis

Image analysis was conducted over three stages as detailed below.

Analysis 1
Cluster analysis (Figure 4.31) revealed a number of distinct clusters at approximately the 2% similarity level. Analysis of these clusters using the SIMPER routine in PRIMER 6 (Clarke and Warwick 2001) identified the morphospecies that characterise each cluster as follows:

- Cluster A (4 images): Characterised by a species of burrowing anemone
- Cluster B (2 images): Characterised by an amphipod species
- Cluster C (6 images): Characterised by black coral (*Stichopathes* sp.), a crinoid species and an anemone
- Cluster D (6 images): Characterised by brachiopods
- Cluster E (8 images): Characterised by barnacles (poss. *Bathylasma* sp.)
- Cluster F (15 images): Characterised by sabellid tube worms
- Cluster G (16 images): Characterised by an unidentified tube worm
- Cluster H (33 images): Characterised by anemones (*Bolocera* sp.) and mysid shrimps

- Cluster I (238 images): Characterised by sea pens (*Kophobelemnon* sp.), cerianthid anemones, ophiuroids (prob. *Ophiactis balli*), unidentified anemones, dead and live coral (*Lophelia pertusa*)
- Cluster J (6 images): Characterised by an anemone, a gastropod (*Colus* sp.) and a stalked crinoid
- Cluster K (442 images): Characterised by ophiuroids and burrowing ophiuroids (*Amphiura* sp.)

Clusters A, B, D, F and G contained very few samples and/or clustered on the presence of only a single species. Therefore they were not considered to be robust clusters representative of 'true' ecological groupings and were disregarded from further analysis. Cluster C, H and J each contained few images, none of which (within a cluster) were similar in terms of their physical environmental properties. As a result no coherent biotope could be described from these clusters. These clusters were also removed from further analysis. Cluster E also contained few samples however upon inspection of the images a distinct habitat type was present in some images that could be consistently visually identified. This cluster was retained for further analysis. Clusters I and K contained many images and a number of sub clusters were present within each that merited further analysis (Analysis 2).

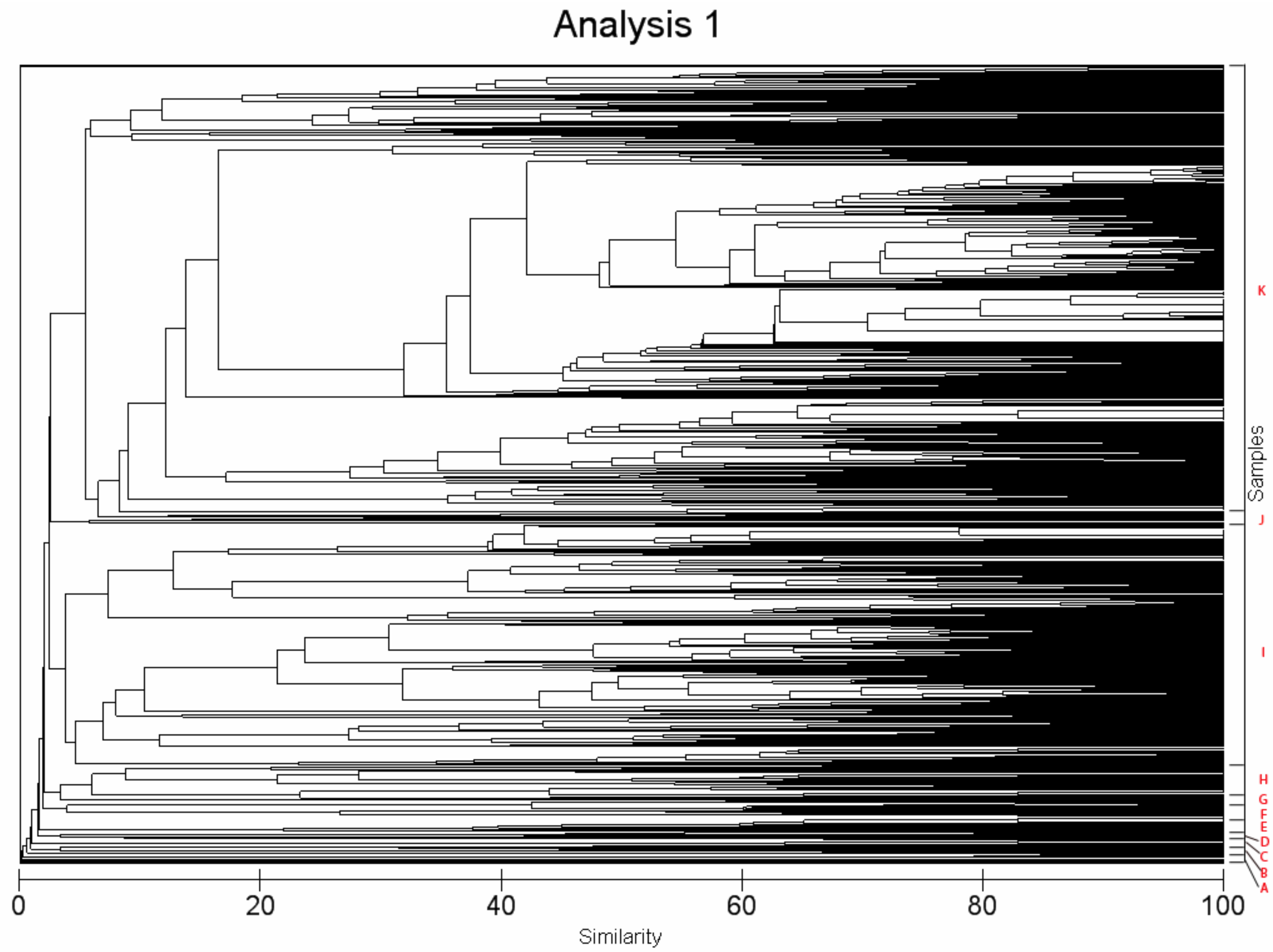

Figure 4.31. Cluster analysis of faunal composition of statistical images.

Analysis 2

During Analysis 2, clusters E, I and K were examined in more detail by further sub-dividing these clusters. At the 5% similarity level, six clusters were identified from clusters E, I and K (Figure 4.28). Analysis using the SIMPER routine in PRIMER 6 (Clarke and Warwick, 2001) identified the characterising species of each cluster as follows:

- Cluster E1 (4 images): Characterised by barnacles (possibly *Bathylasma* sp.).
- Cluster E2 (4 images): Characterised by cerianthid anemones, hydroids and hermit crabs (Paguridae)
- Cluster I1 (96 images): Characterised by cerianthid anemone and sea pens (*Kophobelemnon* sp.)
- Cluster I2 (142 images): Characterised by cerianthid anemone, dead and live *Lophelia pertusa*, ophiuroids (probably *Ophiactis balli*), and several anemone species
- Cluster K1 (369 images): Characterised by ophiuroids and burrowing ophiuroids (*Amphiura* sp.)
- Cluster K2 (74 images): Characterised by Munida sp., serpulid worms, cup corals (*Caryophyllia* sp.) and crinoids (*Leptometra celtica*)

The images contained within cluster E2 were not similar in terms of their physical environmental properties and, with so few images (4 images), could not be used to describe a coherent biotope. Those within cluster E1 however were similar in terms of their physical environment and could be used to describe a biotope that could be consistently visually identified. Cluster K1, K2 and I1 contained sufficient images to describe each as biotopes that could be consistently identified. Cluster I2 could be divided into a number of sub clusters and so further analysis of this cluster was undertaken (Analysis 3).

Analysis 3

During Analysis 3, cluster I was examined in more detail by further sub-dividing the cluster at higher similarity level to examine the smaller clusters within cluster I. At approximately the 7% similarity level Cluster I2 could be further subdivided (Figure 4.29) as follows:

- Cluster I2a (19 images): Characterised by an unidentified anemone species.
- Cluster I2b (123 images): Characterised by a cerianthid anemone, dead and live *Lophelia pertusa*, *Madrepora oculata*, ophiuroids (probably *Ophiactis balli*) and a polychaete worm.

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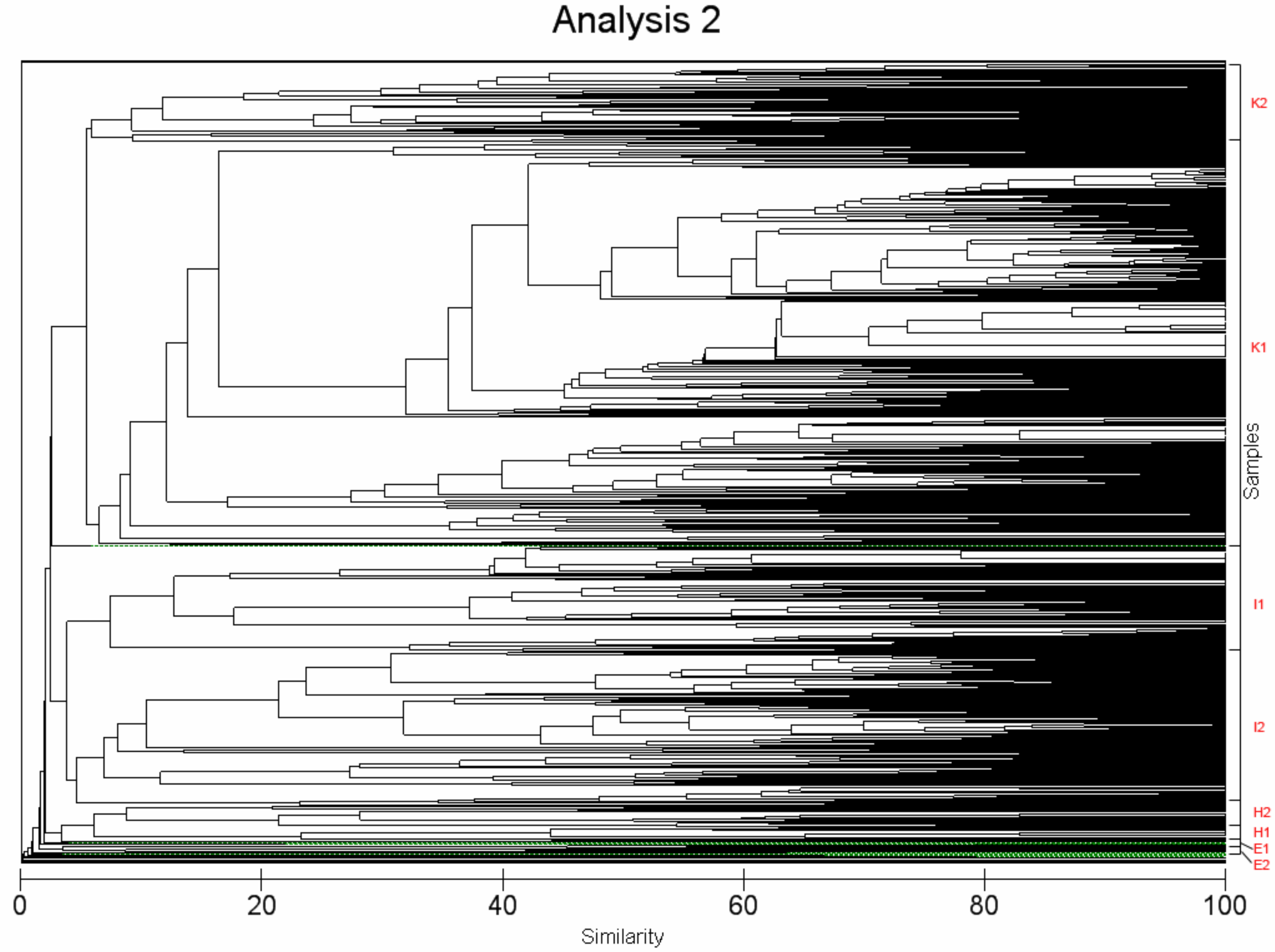

Figure 4.32. Cluster analysis showing subdivisions within clusters E, I and K, dashed lines are omitted clusters.

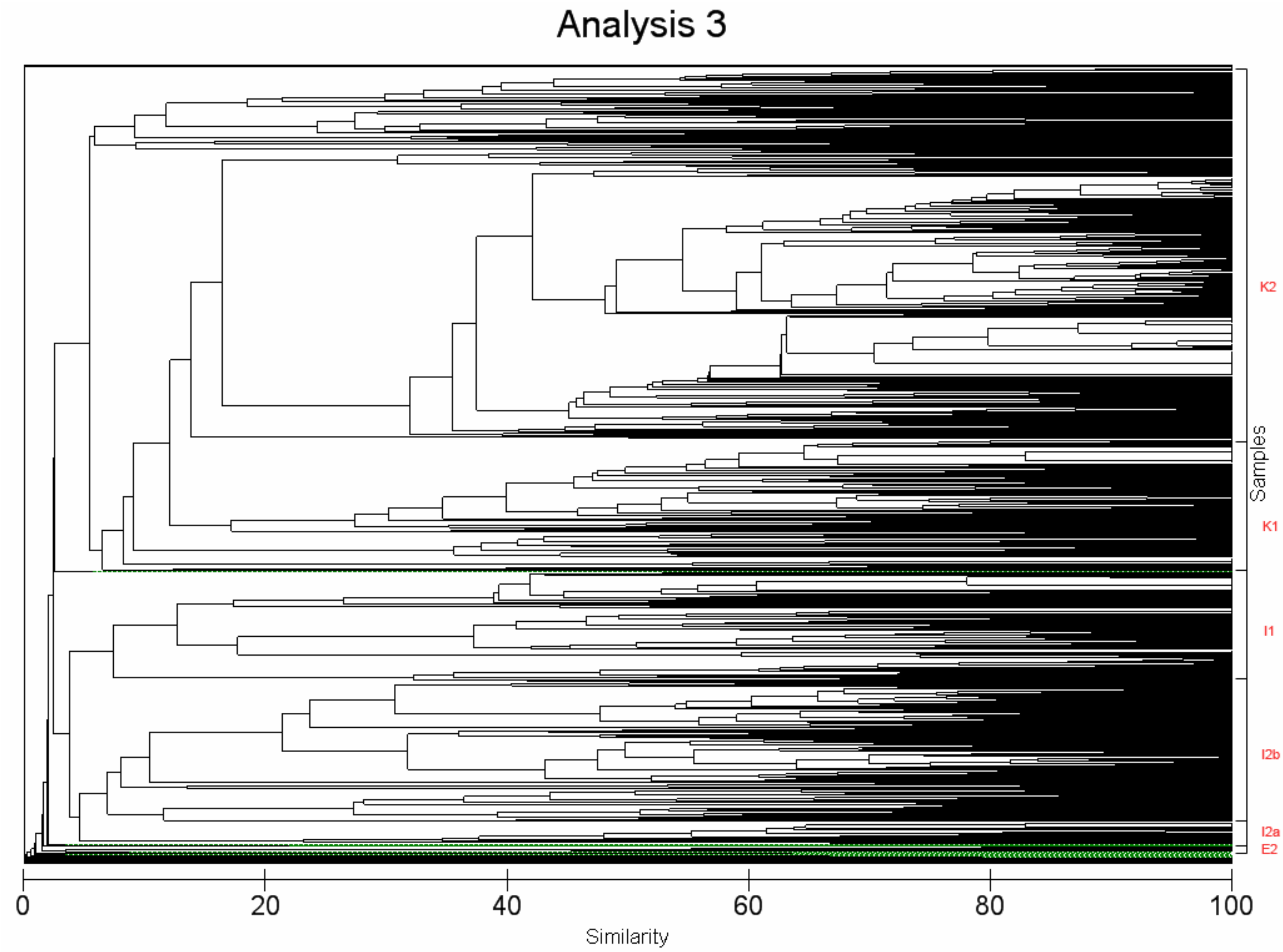

Figure 4.33. Cluster analysis showing further subdivision of cluster I, dashed lines are omitted clusters.

Conclusions of Analysis

Six clusters were identified as representing coherent ecological communities that could be sufficiently described and consistently visually identified from video observation. SIMPER analysis of these clusters identified the main species that characterise each cluster.

- Cluster E2: Characterised by barnacles (*Bathylasma* sp.), found on bedrock.
- Cluster I1: Characterised by the sea pen *Kophobelemnon sp.* and a cerianthid anemone, found on mud.
- Cluster I2a: Characterised by an unidentified anemone species, found on bedrock.
- Cluster I2b: Characterised by a cerianthid anemone, dead and live *Lophelia pertusa*, *Madrepora oculata*, ophiuroids (probably *Ophiactis balli*) and polychaete worms; found on rock ledges, bedrock outcrop and cold water coral reef.
- Cluster K1: Characterised by ophiuroids and burrowing ophiuroids (*Amphiura* sp.); found on sand.
- Cluster K2: Characterised by squat lobsters (*Munida* sp.), serpulid tube worms, cup corals (*Caryophyllia* sp), and crinoids (*Leptometra celtica*); found on mixed sediments and coral rubble.

4.4.3. Defining Biotopes

The 6 clusters identified above were used to define new habitat types according to the EUNIS classification hierarchy (Davies and Moss, 1999). Because EUNIS divides communities on the basis of substrate type, some clusters were further divided when describing the habitat types. 10 new biotopes were defined (Table 4.2 and Table 4.3) from the 6 clusters, with video observation providing further faunal detail. A further 3 biotopes were identified from video observations as either no fauna were present on which to undertake cluster analysis or the communities were not sampled by the images. Representative images of each of the biotopes identified are shown below.

Table 4.2. A brief description of each of the 13 biotopes identified within the South West Approaches survey area

Biotope Name	Biotope Description
Biotope 1	Sand/mud with burrowing (Amphiura sp.) and surface dwelling ophiuroids. Figure 4.34
Biotope 2	Mud with sea pens (*Kophobelemnon sp.*), seastars (*Pseudarchaster* sp.), anemones (*Bolocera sp.*) and holothurians (*Benthogone* sp.). Figure 4.35
Biotope 3	Bedrock ledges with annelids/hydroids and anemones. Figure 4.36
Biotope 4	*Lophelia pertusa* reef, with predominantly sediment clogged *L. pertusa* and live *Madrepora oculata.* Figure 4.37
Biotope 5	Coral rubble with squat lobsters (*Munida* sp.), ophiuroids and crinoids Figure. 4.38
Biotope 6	Mixed sediments with squat lobsters (*Munida* sp.), ophiuroids and crinoids Figure. 4.39
Biotope 7	Bedrock with a sand veneer, little visible fauna Figure. 4.40
Biotope 8	Bedrock /boulders with little visible fauna. Figure 4.41
Biotope 9	Bedrock with sand veneer, with anemones Figure. 4.42
Biotope 10	Bedrock with barnacles (poss. *Bathylasma* sp.). Figure 4.43
Biotope 11	Mud/sand with signs of bioturbation and the occasional cerianthid anemones. Figure 4.44
Biotope 12	Mud with abundant cerianthids, and little other fauna. Figure 4.45
Biotope 13	Bedrock with reef like fauna (corals/crinoids). Figure 4.46

Table 4.3. The relationship between identified clusters and newly defined biotopes.

Cluster	Biotope
E2	10
I1	2
I2a	9, 8
I2b	3,4,13
K1	1
K2	6, 5

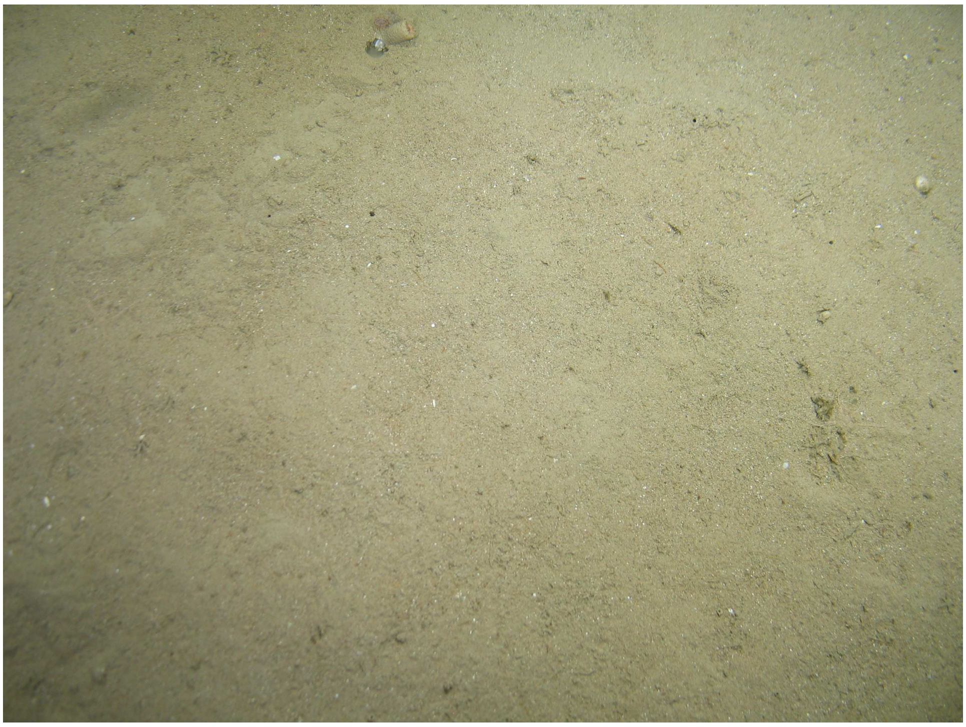

Figure 4.34. Biotope 1: Sand/mud with burrowing (Amphiura sp.) and surface dwelling ophiuroids.

Figure 4.35. Biotope 2: Mud with sea pens (*Kophobelemnon sp.*), seastars (*Pseudarchaster* sp.), anemones (*Bolocera sp.*) and holothurians (*Benthogone* sp.).

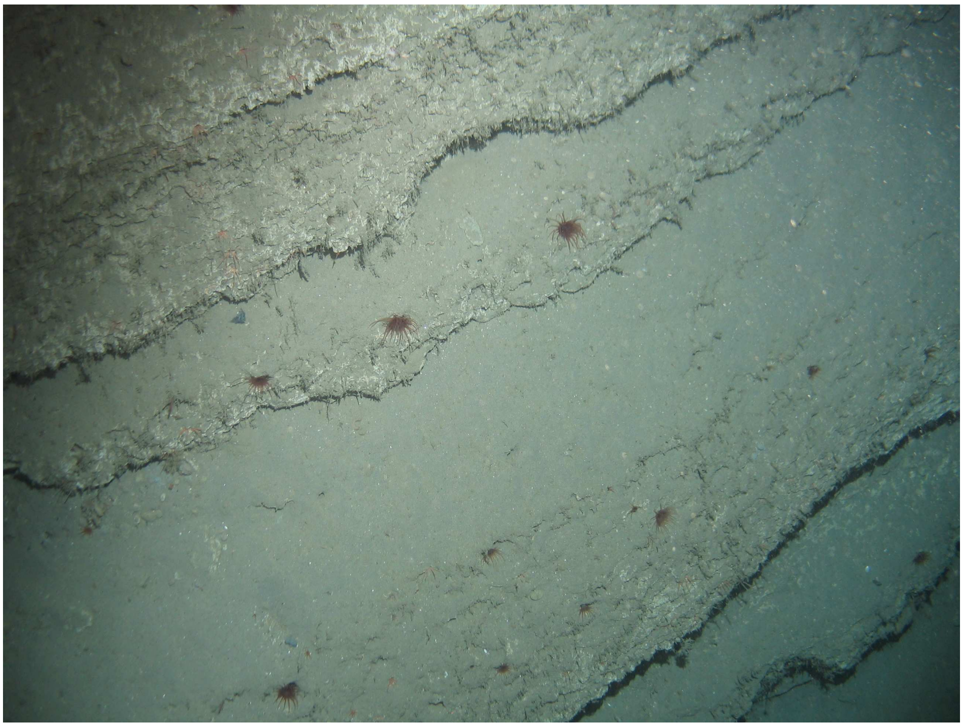

Figure 4.36. Biotope 3: Bedrock ledges with annelids/hydroids and anemones.

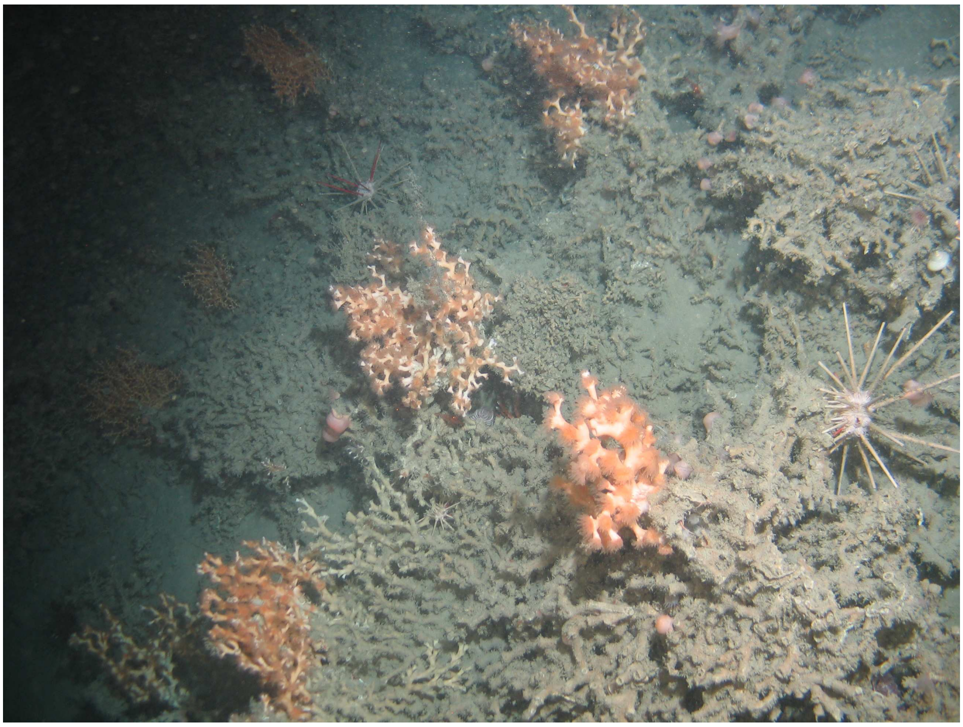

Figure 4.37. Biotope 4: *Lophelia pertusa* reef, with predominantly sediment clogged *L. pertusa* and live *Madrepora oculata*.

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Figure 4.38. Biotope 5: Coral rubble with squat lobsters (*Munida* sp.), ophiuroids and crinoids

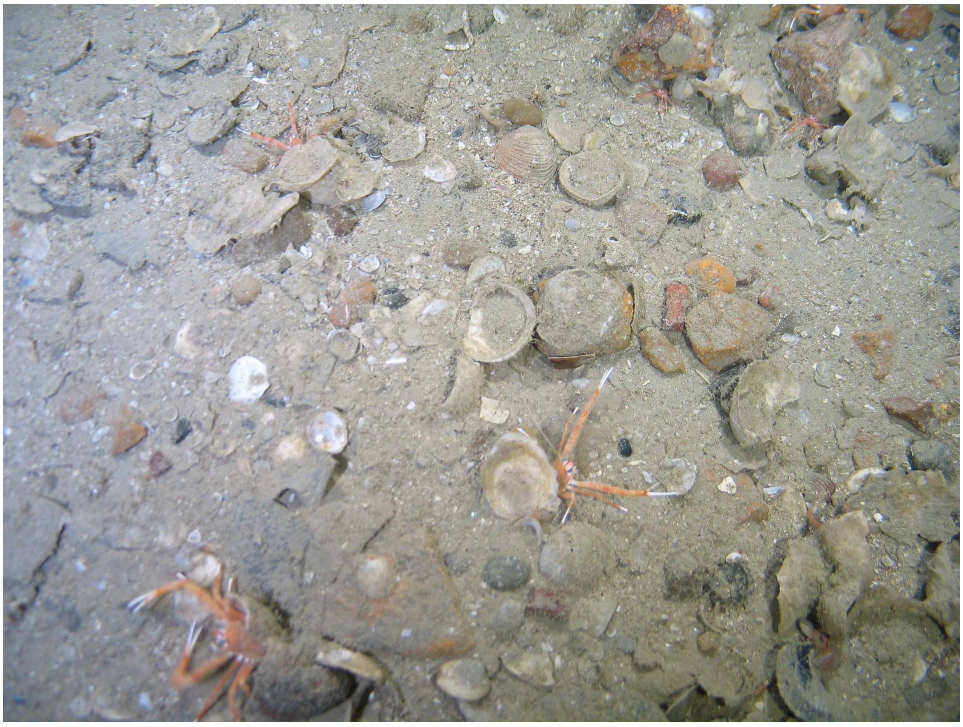

Figure 4.39. Biotope 6: Mixed sediments with squat lobsters (*Munida* sp.), ophiuroids and crinoids

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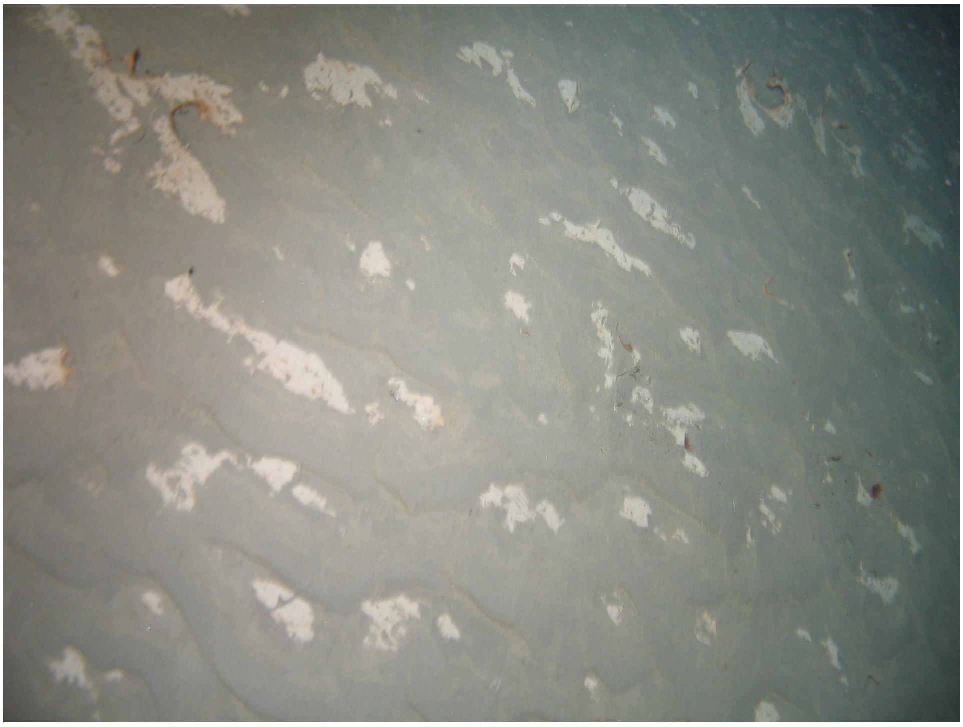
Figure 4.40. Biotope 7: Bedrock with a sand veneer, little visible fauna.

Figure 4.41. Biotope 8: Bedrock /boulders with little visible fauna.

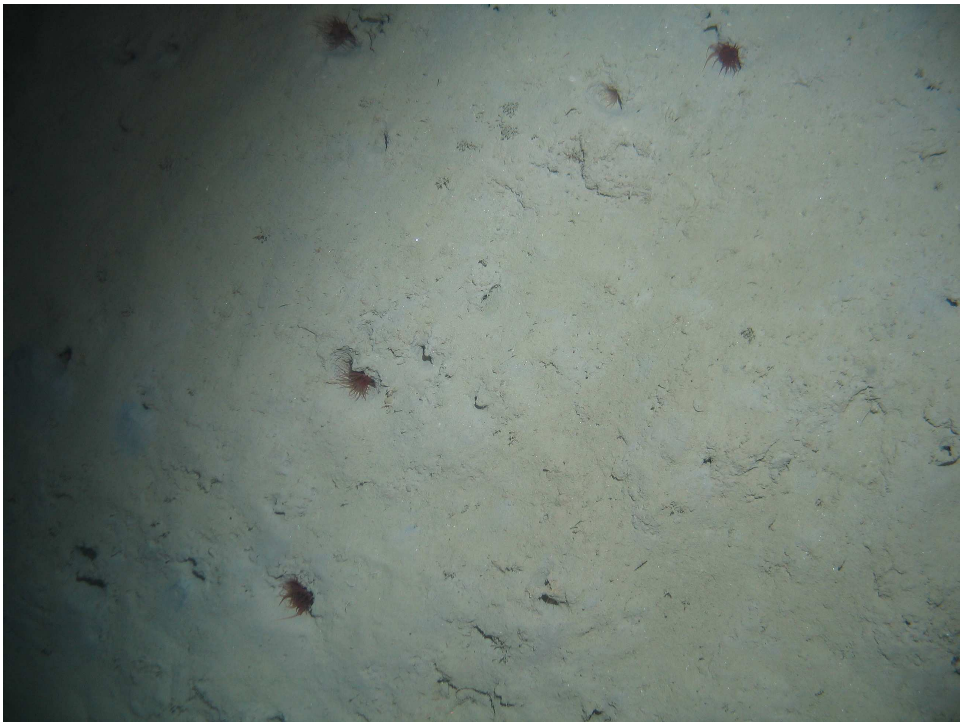

Figure 4.42. Biotope 9: Bedrock with sand veneer, with anemones.

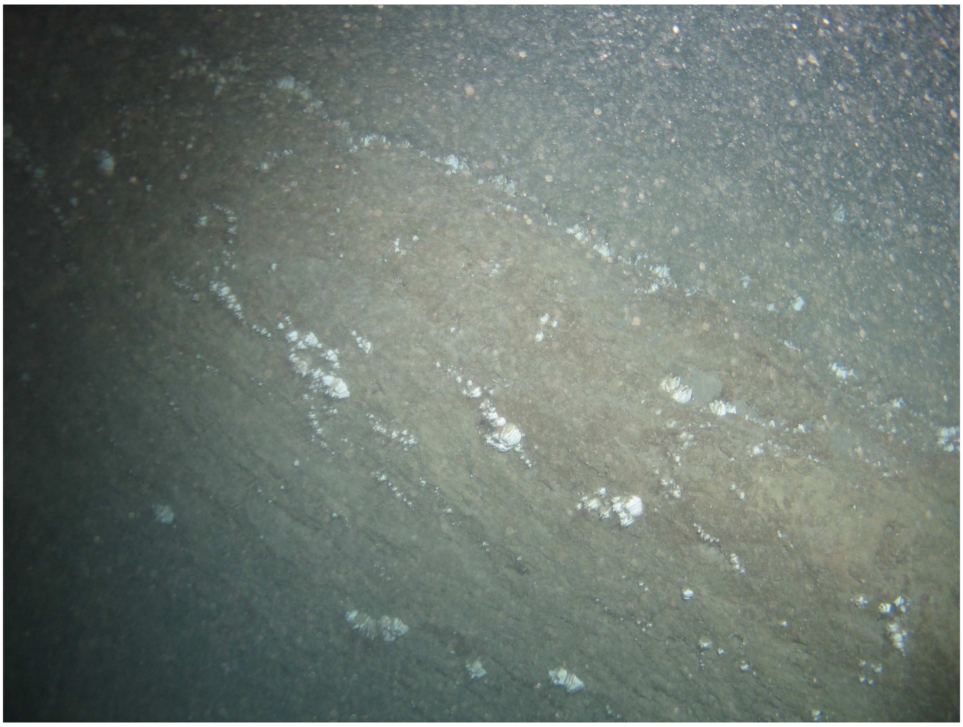

Figure 4.43. Biotope 10: Bedrock with barnacles (possibly *Bathylasma* sp.).

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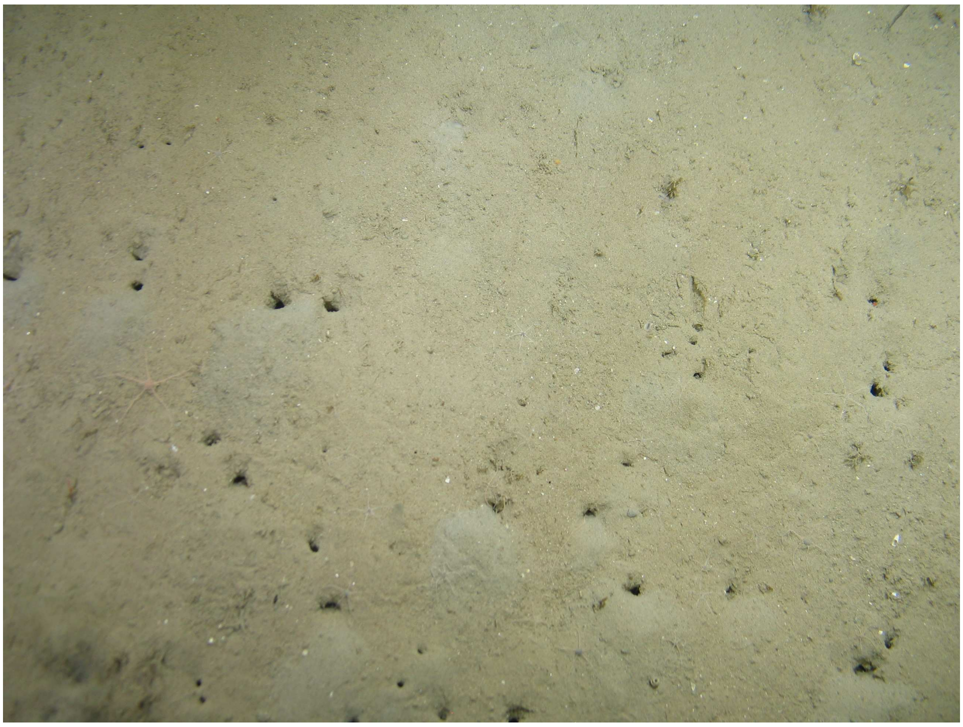

Figure 4.44. Biotope 11: Mud/sand with signs of bioturbation and the occasional cerianthid anemones.

Figure 4.45. Biotope 12: Mud with abundant cerianthids, and little other fauna.


Figure 4.46. Biotope 13: Bedrock with reef-like fauna (corals/crinoids).

4.5. Integrated Habitat Maps

Classified video tows were overlaid on EUNIS classified multibeam backscatter, bathymetry, and derived layers (slope, benthic position index, aspect and rugosity) and habitat polygons drawn in GIS and a series of integrated maps were produced.

4.5.1. EUNIS maps

Geologically classified statistical images from the video tows were classified to EUNIS level 3/4. Backscatter was classified into distinct acoustic types and broadly interpreted into sediment types using expert judgment. Sediment types were assigned to the appropriate EUNIS level 3/4 and polygons drawn in GIS. Classified image data were overlaid on multibeam backscatter and used to ground truth the expert interpretation of the multibeam backscatter. Where changes in interpreted backscatter corresponded to changes in the sediment classification of the images, habitat (polygon) boundaries were defined and/or validated. Where changes in the sediment classification of the images did not correspond to changes in the backscatter, no habitat (polygon) boundary could be defined. Table 4.4 shows the EUNIS habitats present, as classified from the video analysis. The map showing where each of these habitats is located is shown in Figure 4.47. Note that EUNIS Habitat type A6.14 does not appear on the map as it could not be mapped in this way.

Table 4.4. EUNIS habitats present, classified from video analysis

EUNIS code	Level 3	Level 4	Level 5
A6.11	Deep-sea rock and artificial hard substrata	Deep-sea bedrock	
A6.14	Deep-sea rock and artificial hard substrata	Boulders on the deep-sea bed	
A6.2	Deep-sea mixed substrata		
A6.22	Deep-sea mixed substrata	Deep-sea biogenic gravels	
A6.3	Deep-sea sand		
A6.5	Deep-sea mud		
A6.611	Deep-sea bioherms	Communities of deep-sea corals	Deep-sea [*Lophelia pertusa*] reefs

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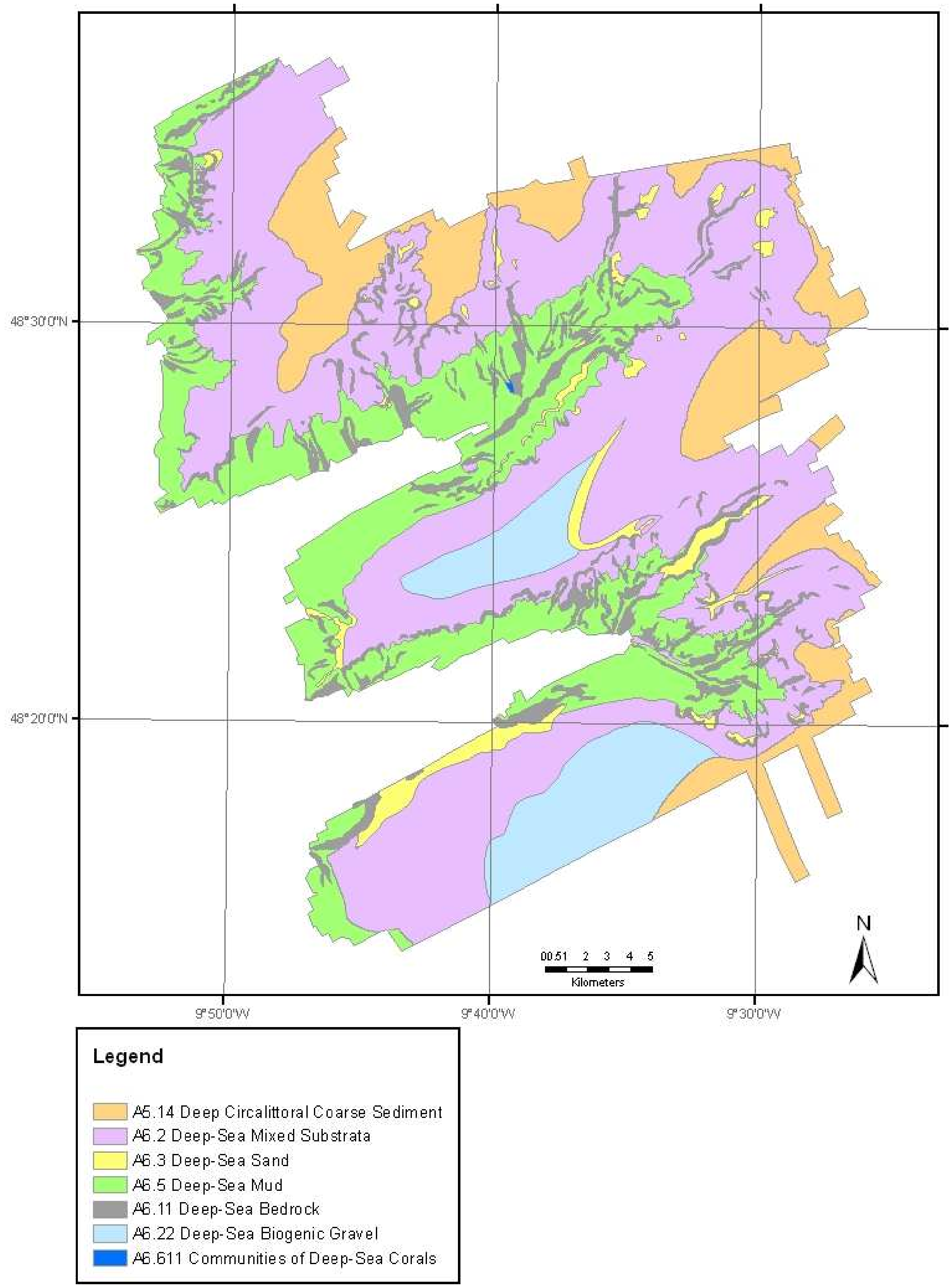

Figure 4.47. EUNIS habitats present in study area.

4.5.2. Biotope Maps

Classified video tows (biotope) were overlaid on the EUNIS map (Figure 4.47) and existing polygons classified according to the combination of biotopes contained within. The assumption has been made that where a biotope occurs within a polygon it is predicted to occur throughout the polygon and not just in the immediate vicinity of the video ground-truthing. It is vital that the implications of this underlying assumption are understood when using the maps produced. Multibeam backscatter, bathymetry and derived layers (slope, benthic position index, aspect and rugosity) were used to aid further division of polygons to individual biotope level.

Due to the difference in the resolution of the video and geophysical data, polygons could rarely be further divided to the individual biotope level. For example, no difference of backscatter or other factors (eg. slope) was observed to consistently distinguish between the bedrock biotopes 3, 8, 9 and 13. Consequently, for polygons interpreted as bedrock substratum (EUNIS A6.1), where no ground-truthing was present, any combination of these biotopes may occur and the map produced reflects this. Figure 4.48 illustrates the distribution of (combinations of) biotopes within the canyons. The polygon containing biotopes 1, 6, 11, and 12, was predominantly composed of biotopes 1, 6 and 11, while biotope 12 only occurred once and thus may not extend throughout this entire polygon. Biotope 10 only occurred once within the canyon system, and it appears to be on the very steep part of the canyon head. Biotope 4 only occurred once as an isolated reef, while in other parts of the canyon it occurs with bedrock biotopes 8 and 9.

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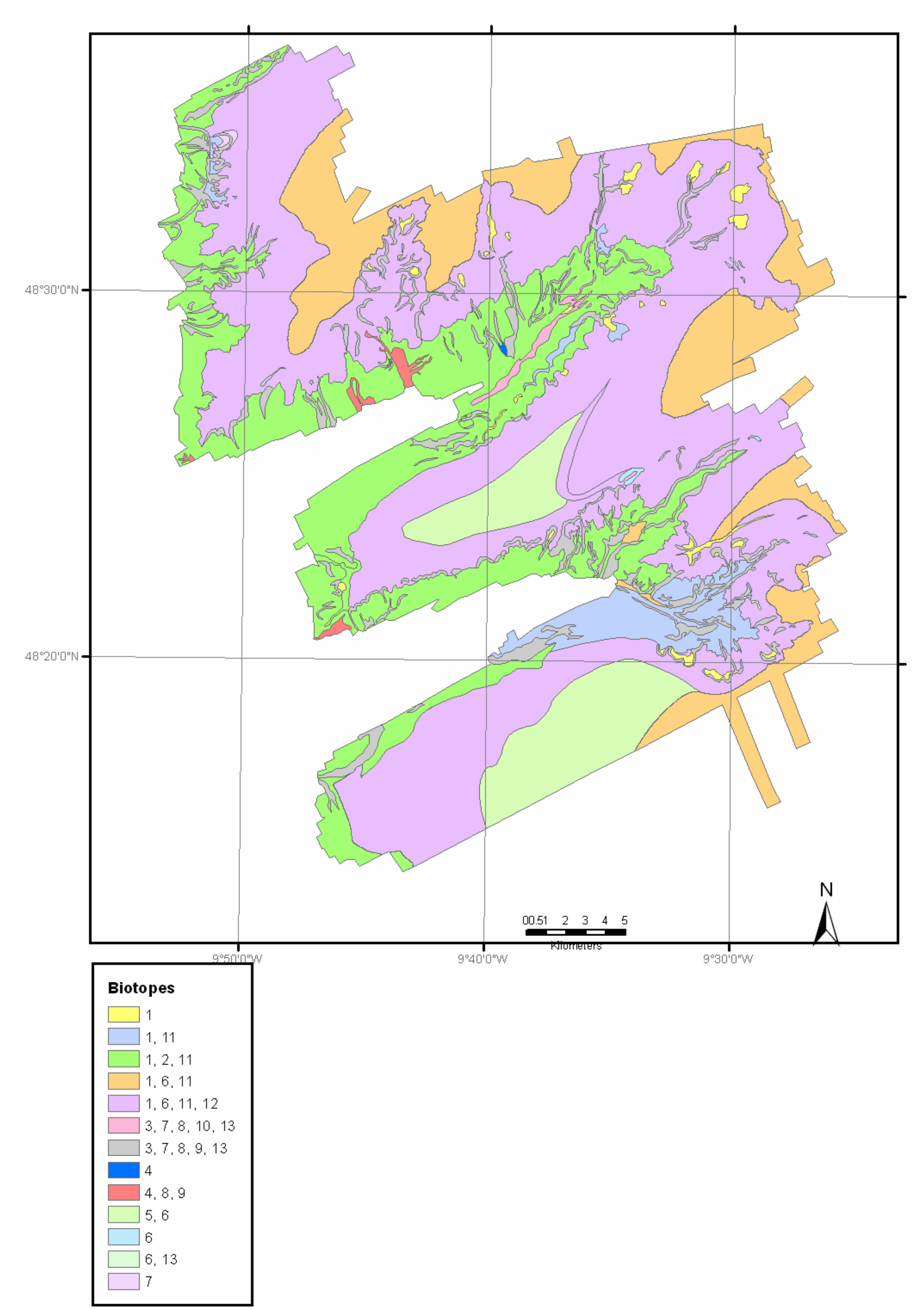

Figure 4.48. Biotopes present within study area, classified from the video data.

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4.5.3. Annex I Maps

In addition to classifying the video tows on the basis of biotopes, areas considered to be Annex 1 habitat were also noted. To constitute an Annex 1 habitat, an area of either biogenic, bedrock or stony substrate with reef-like fauna had to be present. The GIS layer produced for the biotope classification (Figure 4.48) was used as a base layer for the production of the Annex 1 maps. Polygons of bedrock and biogenic reef were classified and colour coded according to their substrate type. Bedrock polygons were further classified according to the presence of biotopes that constituted Annex 1 habitat (biotopes 3, 6 and 13). Where other bedrock biotopes (8, 9, and 10) could not be distinguished from the Annex 1 bedrock areas using the backscatter or the other layers (slope etc), these areas were classified as potential Annex 1 habitats. In addition bedrock areas for which ground-truthing was not available were classified as potential bedrock reef. Both categories were mapped to show areas of both bedrock and potential bedrock reef habitats within the study area (Figure 4.49).

Three categories were used to map the occurrence of cold-water corals within the study area, and these were defined as: biogenic reef, a large area of *L. pertusa* framework with abundant *Madrepora oculata* and other associated fauna; patches of cold-water coral, low-lying *L. pertusa* patches with sand infill with abundant epifauna such as cerianthids; and historical cold-water coral area, abundant coral rubble present on the mini-mounds found on the interfluves of the canyons. Polygons with biogenic reef present were classified as Annex 1, while the historical and patch coral areas could not clearly be defined as either Annex 1 or non- Annex 1 habitats, and thus left unclassified (Figure 4.50).

No Annex I stony reef was observed within the study area.

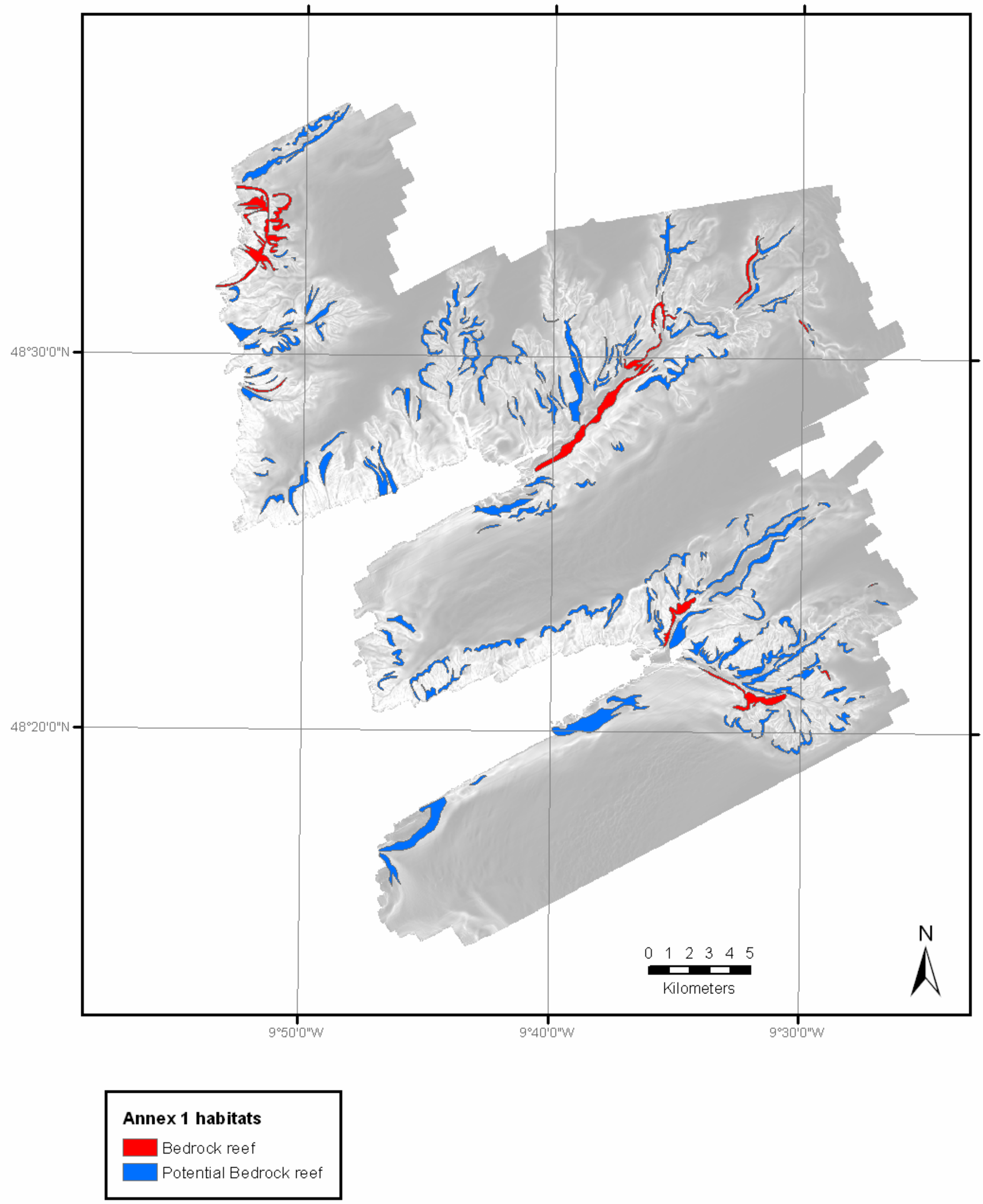

Figure 4.49. Map showing location of actual and potential bedrock reef

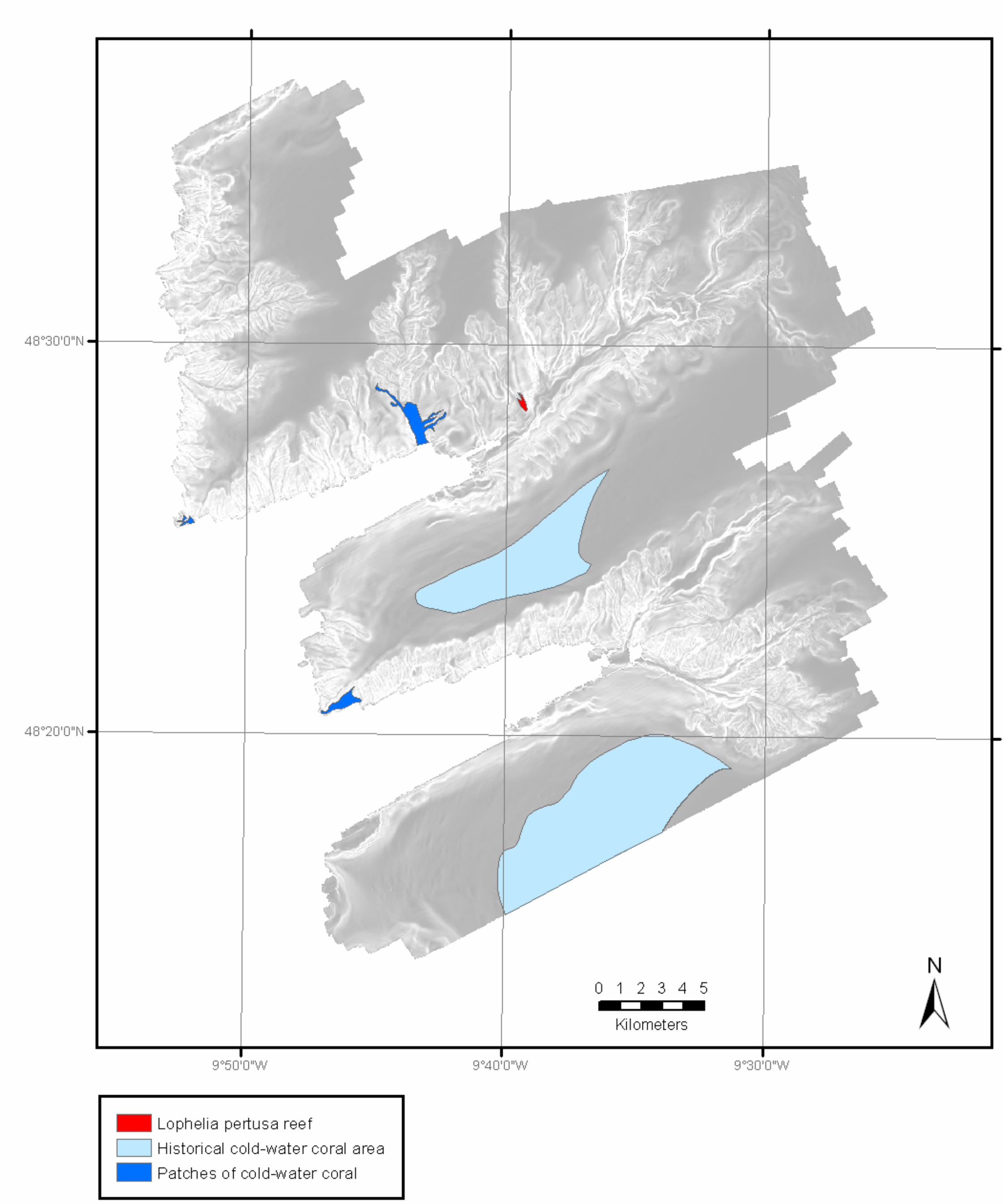

Figure 4.50. Map showing location of *Lophelia pertusa* reef, historical cold-water coral reef areas and patches of cold-water coral

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4.6. MESH Guidance appraisal

Detail of the MESH guidance appraisal can be found in a separate report (See MESH SW Approaches Canyons Survey (MESH Cruise 01-07-01), MESH Guidance Appraisal Report http://www.searchmesh.net/Default.aspx?page=1935), and is only summarised briefly here. Overall, the MESH guidance documentation (including Recommended Operating Guidelines) was found to be very useful, and provided a detailed framework within which surveys could be planned and executed. The recommended modifications to the ROGs were on the whole minor, seeking to either offer further clarity or to make the guidance applicable to a wider range of circumstances.

Of the guidance appraised, it was felt that guidance relating to survey metadata recording required the most development.

Whilst the guidance provides a very good start for a complicated topic, further clarifications are required to enable users to get the maximum benefit from it. The recommendations within the MESH Guidance Appraisal report will go some of the way towards improving the guidance; some have already been taken into account, and the guidance available on the MESH website reflects this.

5. Discussion

5.1. Overview of canyon morphology based on multibeam bathymetry and backscatter data interpretation

New multibeam bathymetry and backscatter data collected during this study have revealed the morphology of two canyons at the Celtic Margin in previously unprecedented detail. The high resolution bathymetry data (25 m grid cell size) has provided an overview of the study area morphology permitting the identification of a range of geomorphological features including drainage basins with amphitheatre rims occurring at the canyon heads, incised channels and gullies, retrogressive mass wasting and indention of the canyon heads at the shelf-break. During MESH cruise 01-07-01, video tows were conducted at 44 stations in the study area. The bathymetry data were vital in the selection of the video station locations. In addition to providing information on the seabed topography, bathymetry data has been used to provide information on the terrain attributes which have relevance to the benthic communities living there.

The data indicate both canyons are characterised by gullies and numerous tributaries incising the upper-slope towards the shelf-break between 180 and 400 m. Indications are that the Explorer Canyon, which appears more deeply recessed into the shelf, may be older than the Dangaard Canyon. Cunningham *et al*. (2005) suggest a canyon at the Celtic Margin which is less incised than other canyons is younger as a result of incision taking place on the slope as opposed to the further on the shelf.

The dendritic pattern observed at the study area is likely related to fluvial input from the shelf, sediment failure and or former melting of ice, which generated turbidity currents (see Stewart and Davies, 2007). Evidence of turbidity currents typically associated with submarine canyons is supported by the presence of erosional features occurring at the canyon margins and this is evident from both canyons investigated. The currents transport suspended material to the deep sea and act as important conduits of coastal detritus. Highest backscatter reflectance is observed from the canyon gullies. This suggests that they contain gravel, cobbles, boulders, or coarse grained sediment/sand, which were carried by turbidity currents from the shelf down-slope and deposited at the base of the canyon floor and gully features in the canyon head. Previous workers (Cunningham *et al*., 2005) suggest that sediment transport in this area is directed towards the canyon systems, which is consistent with our findings in relation to sediment-filled canyon gullies. Retrogressive failure is associated with both canyon headwalls resulting in the headward migration and indentation of the shelf. Data acquired over a 9-year study in the United States confirms that currents rarely cease flowing to transport sand-sized particles along valley axes of submarine canyons (Sheppard *et al*., 1979). Internal tides also act to carry re-suspended particles to the deep sea and are likely to contribute in part to erosion/deposition features in the canyon. These fluxes of particles represent important geological processes that interact with the canyon fauna and it is recognised that the organic material associated with these sediments provides a source of nutrients to deep sea organisms.

Each of the canyons mapped exhibits a juxtaposition of highly dissected canyon walls with smooth or lightly dissected walls. This phenomenon has been reported elsewhere (Greene *et al.*, 2002) and is thought to indicate lateral displacement along fault segments. Whilst a comprehensive discussion on mass wasting is beyond the scope of this study, we note evidence of this indicated in the multibeam bathymetric data, primarily identified by scars left by sediment flows.

Analysis of multibeam data has revealed interesting mound features observed on the shelf at the canyon interfluve in the southern part of the study area. The cluster of mounds have similar dimensions to small carbonate mounds previously identified in the Porcupine Seabight (Wilson, 2006) in similar water depths. Beyer *et al*. (2005) describe the acoustic response from which mounds were reported at the Porcupine Seabight. The mound cluster area is characterised by patchy high-backscatter regions with a complex grey-scale appearance and several isolated mounds exhibiting higher backscatter responses. These findings are consistent with the backscatter reflectance patterns observed from mounds at the current study area. The occurrence of cold-water coral fragments in the vicinity of the mounds would suggest that these mounds are carbonate in origin, perhaps once hosting live cold-water corals and similar to the carbonate mounds observed further north along the margin at the Porcupine Seabight and Rockall Trough (Kenyon *et al.*, 2003; van Weering *et al.*, 2003; Wheeler *et al.*, 2005). Masson *et al*. (2003) attribute high backscatter responses observed at the mounds to accumulations of coarse sediment and biological debris observed in video data. Whilst there is still considerable uncertainty relating to the factors which control the distribution of cold-water corals, the elevated topography associated with the mounds as a significant factor influencing the occurrence of the habitat. Video evidence from the mounds supports the possibility that the mounds have experienced anthropogenic impacts from fishing disturbance and the large number of coral fragments suggests the mounds have been damaged by such activity.

The terrain analysis techniques employed in this study have been successfully applied to other study areas to describe features of the terrain, particularly in relation to the distribution of benthic habitat (Wilson *et al.*, 2007; Guinan *et al.*, in press). Terrain parameters have provided information on the nature of the terrain at the canyon walls, headwalls and interfluve areas. Attributes such as slope, rugosity, orientation (aspect) and BPI have particular relevance to the diversity of benthic habitats associated with the canyons. For example, terrain showing higher gradients is likely to host a range of fauna which can benefit from a location where currents accelerate across gradients and thus provide a source of food to benthic suspension feeders. Highly irregular or complex terrain is likely to be occupied by fauna that are different to that of areas showing relatively low rugosity. The BPI is a useful attribute in relation to benthic habitat as it has been used to identify features of the terrain that are either elevated or lower than the surrounding terrain e.g. valleys, depressions and crests associated with seafloor topography (Lundblad *et al.*, 2006). In general the canyons study area is characterised by highly complex terrain and its influence on benthic community structure is also likely to be driven by local and regional hydrodynamics where benthic currents, steered by the seabed terrain, supply food, especially for suspension feeding fauna (Gage and Tyler, 1991).

The hydrography of the canyons is poorly understood. Nonetheless, it is likely that the present-day interplay between local scale near-bed currents, along slope currents, tidal currents, large scale water mass characteristics, along with the sediment supply from the shelf are key factors contributing to the erosional and depositional features observed at the study area. In addition storms and dense water cascading events are likely to influence the shelf-canyon sediment transfer and sediment fluxes in the study area.

Comparison to canyons elsewhere

Deep sea canyons have been extensively studied offshore in numerous locations worldwide, including northwest Europe, North America, Australia, New Zealand and Japan. Canyons investigated at the Monterey Bay National Marine Sanctuary in California with high resolution multibeam (Greene *et al*., 2002) show examples of highly dissected canyon walls together with smooth, relatively featureless walls similar to those observed at the canyons described in this study. It is possible that this is related to the direction of the dominant currents in both areas.

The Rockall Trough, north east Atlantic Ocean has a similar passive margin setting to the Celtic margin, also incised by multiple canyon systems. The canyons occurring at the Rockall Trough margin receive a limited supply of shelf-derived sediment due to their location with sediment supply associated with slope reworking unlike the Celtic margin canyons which are fed by a supply of shelf-derived sediments (Elliott *et al.*, 2006).

Canyons described along the eastern Canadian continental margin (Piper, 2005) show a similar morphology where a dendritic pattern is inferred as a result of fall-out of sediments creating small muddy turbidity currents that erode the seabed. Piper (2005) also describes large canyons leading headward across the shelf break, with converging patterns of tunnel valleys and attributes this to subglacial meltwater discharge contributing to the formation.

5.2. Overview of the geology of Dangaard and Explorer Canyons based on geophysical and sampling data

The data gathered has revealed not only the diverse and complicated morphology of the Explorer and Dangaard canyons, but also the influence the underlying structure has on the shape of the sea floor. The Neogene succession of the SW Approaches area reflects a number of erosive and constructive events. The early to mid-Miocene Jones Formation forms a progradational, fine-grained, carbonate rich deposit that rests unconformably on Chalks of Upper Cretaceous age (Evans, 1990). A subsequent increase in sea level resulted in the deposition of the Cockburn Formation during mid- to late Miocene times. This formation is characterised by reflectors downlapping onto the Jones Formation. The fine-grained, clay rich composition of these two Miocene formations is very similar although the proportion of fine sand-sized particles is higher in the Cockburn Formation (Evans and Hughes, 1984).

Due to a reduction in sea level during the late Miocene (Messinian) the continental shelf and upper continental slope were subject to erosion (Bourillet *et al.*, 2003). A deltaic, sandy, wedge-shaped sequence was deposited along the continental slope up to 300m in thickness (Evans, 1990). This sequence, the Lower Little Sole Formation, does not extend far to the east onto the outer continental shelf, but is overlain by the Upper Little Sole Formation which forms a thinner sedimentary blanket.

The major feature of this area is the incision of the continental slope by a network of canyons. The Dangaard and Explorer canyons form part of the Grande Sole drainage basin (Figure 2.2) which feeds the Celtic deep-sea fan. The canyons surveyed are located on the upper slope and are therefore and feed a sub-denrdritic, downward converging, tributary system transporting sediment from the outer continental shelf to the bathyal sediment sink. The canyons are separated by smooth interfluves comprising sections of undissected continental shelf and slope.

The canyons were incised in the Pleistocene during episodic sea level lowstands following deposition of the Little Sole Formation during the early Pleistocene. The Pleistocene is marked by a number of extensive glaciations. The reduction in sea level changed the hydrodynamic regime leading to a marked increase in the intensity of wave and tidal action across the outer continental shelf and upper slope. Subsequently, the Grande Sole drainage basin was fed by melt water from the Irish Sea sourced from the disintegrating British Ice Sheets (Zaragosi *et al*., 2000; 2006). The adjacent drainage basin to the Grade Sole, the Petite Sole drainage basin, was instead fed by the Channel paleoriver system (Bourillet *et al.*, 2003; Zaragosi *et al*., 2000; 2006). Large sand banks deposited on the outer shelf during these periods of reduced sea level form the sediment source for present day hydrodynamic transport of sediment from the shelf into the canyons (Zaragosi *et al*., 2000).

Modern day sediment transport processes are centred on the Explorer and Dangaard canyon heads. The proximity of the canyon heads to extensive sandwave fields located on the outer continental shelf and the Celtic Sea sandbanks indicates that the canyon heads provide a ready conduit for transporting sediment onto the slope (Cronin *et al.*, 2005; Cunningham *et al.*, 2005; Evans, 1985; 1990). Slumps originating from the interfluves also contribute to the bathyal movement of sediment (Figures 4.19 and 4.20). Today the dominant process transporting sediment through the canyons are turbidity currents triggered by retrogressive slope failure in the canyon heads (Cunningham *et al.*, 2005; Evans, 1990).

The distribution of grain size is controlled by a mixture of retrogressive slumping, today's hydrographic regime and the influence of the underlying Neogene formations. On the interfluve tops, biogenic gravel dominates. This is due to reworking of cold-water coral fragments sourced locally from mini-mounds. The mini-mounds are a feature of the modern sea floor and buried mounds have not been identified within the shallow sub-surface during this study. On the floors of the canyon heads, coarse-grained sediment has been found, probably transported from the outer continental shelf by slope failure in the canyon head. Shell rich sands and gravels can also be found on the floors of shallower tributary valleys such as those observed on camera tow C_2_ 12. The pattern of rock outcrop is influenced both by retrogressive slumping exposing rock in the amphitheatre rims and by cropping out of the top Jones and Cockburn formations forming elongated topographic breaks of slope (Figures 4.20 and 4.22). The Jones and Cockburn formations are commonly close to or at sea bed in water depths >500m. This coincides with an observed change in the dominant grain-size of the superficial sediment from sand to mud.

5.3. Overview of habitats found and their distribution

All three canyons exhibited a diverse array of substratum types supporting a range of epifaunal megafaunal species. Biotope 2 (mud with sea pens (*Kophobelemnon sp.*), seastars (*Pseudarchaster* sp.), anemones (*Bolocera sp.*) and holothurians (*Benthogone* sp.) was observed in all three canyons from 465-1013m. It was the most commonly observed biotope and was predominantly observed on the flanks of the canyons in areas where bedrock terraces were in-filled with muddy sand. In order for finer sediments to accumulate, these areas must be sheltered to some degree; however video footage of this biotope revealed sea pens (*Kophobelemnon* sp.) to be orientated into a mild current. These communities may undergo periodic disturbance as a result of sediment slumping although the timescales of these events are unknown.

Biotope 6 (mixed sediments with squat lobsters (*Munida* sp.), ophiuroids and crinoids) was the next most commonly observed biotope and was found in all three canyons from 183-808m. It was predominantly observed on the continental shelf and on the canyon interfluves and at the canyon head. In places, this biotope was dominated by feather stars (Crinoids). Crinoids are suspension feeding organisms that depend upon relatively fast bottom currents to supply them with particulate organic matter (POM). They feed by holding their arms up into the current and capturing small food particles from the water column. Crinoid-dominated examples of this biotope were observed at the heads of the canyon systems indicating the presence of strong local currents in this region. Biotope 11 (mud/sand with signs of bioturbation and the occasional cerianthid anemones) was the next most commonly observed biotope and was observed in all three canyons from 185-895 in all localities (canyon head, flank, floor and on the continental shelf). This biotope is similar to Biotope 2 but lacks *Kophobelemnon*. The absence of this suspension feeding species suggests this biotope occurs in more sheltered regions than Biotope 2.

Biotope 9 (bedrock with sand veneer, with anemones) was found on the flanks of all three canyons and towards the head of Dangaard Canyon. This biotope occurred where bedrock terraces were partially exposed with only a thin layer of fine sediment. It is poorly described as a result of the difficulty of landing the camera on the substrate. Biotope 1 (Sand/mud with burrowing (Amphiura sp.) and surface dwelling ophiuroids) was found in Dangaard and Explorer canyon and was distributed throughout the entire canyon system (heads, flanks, floor and on continental shelf). The ubiquitous occurrence of this biotope can be explained by its very general definition of a sand habitat characterised by ophiuroids. Soft sediment habitats are not well described when images are used as sample units because of the sparseness of epifauna within this habitat. Image size provides little biological data per sample to use in multivariate analyses. Biotope 7 (bedrock with a sand veneer, little visible fauna) was found throughout all three canyons from 343-1039m. This biotope is not characterised by any fauna and is described on the basis of geology alone. The distribution of Biotopes 4 (*Lophelia pertusa* reef, with predominantly sediment clogged *L. pertusa* and live *Madrepora oculata),* 5 (coral rubble with squat lobsters (*Munida* sp.), ophiuroids and crinoids), 13 (bedrock with reef-like fauna (corals/crinoids)) and 3 (bedrock ledges with annelids/hydroids and anemones), is discussed in Section 4.4. Biotope 8 (bedrock /boulders with little visible fauna) is not characterised by any fauna and is described on the basis of geology alone. It was observed in all three canyons from 559-1023m mainly on the floor of canyons and channels. Biotope 12 (mud with abundant cerianthids, and little other fauna) was observed at one station on the flank of Explorer canyon at 384-401m. Biotope 10 (bedrock with barnacles (possibly *Bathylasma* sp.)) was observed on the floor of Explorer Canyon at 950-956m.

5.4. Biological communities in the context of the wider area

The biological communities observed in and around the canyons are similar to those observed at comparable depths and temperatures on other deep-sea features in the UK's offshore area. Many of the species observed in this study were also observed in the joint DTI-DEFRA SEA-SAC surveys of Hatton Bank, Rosemary Bank, Wyville-Thompson Ridge and George Bligh Bank (hereinafter referred to as the SEA-SAC surveys) (Howell *et al*., 2007b) and the DTI SEA7 surveys of Hatton Bank, Rockall Bank, Anton Dohrn Seamount and George Bligh Bank (Narayanaswamy *et al*., 2006) with few new species recorded. In order to establish firm relationships between the communities of all the UK's offshore features a complete reanalysis of the entire dataset is required (currently being undertaken by University of Plymouth). The following are therefore subjective observations based on the results of separate cluster analysis of both the present and the SEA-SAC datasets.

The hard substrate communities identified here (those found to occur on bedrock, ledges, boulders, dead coral framework, and coral rubble) were characterised by the presence of *Lophelia pertusa*, urchins, and brittle stars (most likely *Ophiactis balli*). Within the SEA-SAC surveys a number of distinct hard substrate communities were identified through cluster analysis (Howell *et al*., 2007b). Some of these communities included one or more of the afore-mentioned species as characteristic species (identified through SIMPER analysis (PRIMER 5, Clarke and Warwick, 1994)) suggesting that there is some similarity between the hard substratum fauna of all the UK offshore features. However the hard substrate communities observed in the SEA-SAC surveys were, in general, more species-rich than those observed here. It is possible that this may be a sampling error resulting from the poor resolution of images of bedrock and coral reef obtained in this survey and the limited observations of reef habitat obtained. However, video observations suggest that the occurrence of sediment scour and smothering may prevent many species from colonising the available hard substrate.

A biological community occurring on pebble, gravel, shell gravel and coral rubble mixed sediment substrates and characterised by squat lobsters (*Munida* sp.) and serpulid tube worms was identified through cluster analysis. A similar community was also observed on other deep-sea features in the Rockall Trough as part of the SEA-SAC survey (Howell *et al*., 2007b) but the latter was also characterised by a more diverse range of species including sessile sea cucumbers (*Psolus* sp.) and sea squirts (ascidians). Within the SEA-SAC survey, examples of this community tended to cluster with communities on slightly coarser substrates (cobbles) not observed in the current study. The more diverse range of species characterising this community in the SEA-SAC surveys is therefore most likely a result of this clustering than any true difference in the biological communities between features.

Within the canyons, areas of bedrock covered with large barnacles (possibly *Bathylasma hirsutum*) were observed and formed a distinct cluster in the analysis. This community was also observed on a large rock outcrop on the summit of the Anton Dohrn Seamount (Narayanaswamy *et al*., 2006), suggesting again that this community is not unique to the canyons. Other biological communities identified in this study, which were not as well-defined, include sand characterised by brittle stars (Ophiuroidea) and heavily bioturbated sand characterised by infaunal polychaetes. Both of these communities were frequently observed on both offshore features and the continental slope in the Rockall Trough and again are not unique to canyons.

Importantly, one biotope observed in the South West canyons has not been observed during surveys of other deep-sea features. This community was found on muddy sand and characterised by the sea pen *Kophobelemnon* sp. and cerianthid anemones. This community was similar to that of the shallow A5.36 habitat type (Circalittoral fine mud) (EUNIS). A5.36 is characterised by the sea pens *Virgularia mirabilis* and *Pennatula phosphorea* together with the burrowing anemone *Cerianthus lloydii* and the ophiuroid *Amphiura* spp. This newly described habitat type could be considered a deep-water version of this shallower habitat type although the sediment of A5.36 may be finer. However, distinguishing between fine sand and mud by eye from image data is a challenge and is likely to lead to inaccuracies in sediment descriptions. Filter feeders such as sea pens, anemones and corals have been found in high densities inside canyons (Rowe, 1971; Hecker *et al*., 1988) and are thought to benefit from the enhanced currents (Hecker *et al*., 1988). The presence of a moderate current within this habitat was evident from video observations and may explain the abundance of both *Kophobelemnon* sp. and cerianthids.

Previous studies of canyon megafauna have found species composition to be similar to, but distinct from, the local bathyal fauna (Rowe, 1971; Cartes *et al*., 1994; Stefanescu *et al*., 1994). Although extensive sampling of the continental slope of the neighbouring Porcupine Seabight has been undertaken by the NERC Institute of Oceanographic Science (now part of the National Oceanography centre, Southampton) these data have not been reported at the community level, only at the level of distinct taxonomic groups (e.g. Asteroidea, (Howell *et al*., 2002), Holothurea (Billett, 1991)) and so do not provide a comparable dataset. However, observations of the megafauna of the neighbouring Goban Spur have been made from a submersible (Tyler and Zibrowius, 1992) and provide some indication of the species present on the continental slope in this area. Tyler and Zibrowius (1992) describe a diverse fauna dominated by sponges, echinoderms and gorgonians on the rocky deep western escarpments of the Porcupine Bank and Goban Spur. Many of the species identified in the 1992 study were observed in this study suggesting little difference in the megafaunal communities of the canyon and neighbouring continental slope (where comparable substratum types and environmental conditions are present).

At the resolution achievable using video and still imagery as sampling methods (>1cm, variable taxonomic level), the megafaunal communities of the south west canyons do not appear to be markedly different to those observed at comparable depths on other offshore features in the Rockall Trough region of the UK's Continental Shelf Limit. However, although these communities may be similar in terms of species composition, they may be very different in terms of genetic composition. The hydrographic regime of offshore features such as canyons and seamounts may be such that they inhibit or restrict larval dispersal resulting in reduced gene flow between populations (Parker and Tunnicliffe, 1994). Species with limited dispersal capabilities, such as sponges (Maldonado, 2006), may be isolated by distance between offshore features, while those with high dispersal potential (planktonic larvae eg *Munida* sp.) may show no significant genetic divergence between populations (Samadi *et al*., 2006). We can only speculate as to the genetic relationships between the communities of the UK's offshore features as at present, there are no data available. However, significant levels of inbreeding have been reported in *Lophelia pertusa* populations on the UK continental slope, and the recruitment of sexually produced larvae is thought to be strongly local (Le Goff-Vitry *et al*., 2004). Future outputs from the EU FP6 funded HERMES (Hotspot Ecosystem Research on the Margins of European Seas) project may provide greater insight into the importance of these features as biodiversity hotspots.

5.5. Relation of biological communities to EUNIS habitat types

The deep-sea bed section (A6) of EUNIS has fundamental flaws in its design that is beyond the scope of this report and will not be addressed fully here. In brief, level three of the hierarchy contains habitats defined at the scale of substratum (e.g. A6.3 deep-sea sand) and at the scale of large topographical features (A.6.8 Deep-sea trenches and canyons, channels, slope failures and slumps on the continental slope). The difference in spatial scales at comparable levels of the hierarchy within EUNIS needs to be addressed in order for this classification to be of greater use. Within the current EUNIS classification system, canyon habitats (those described within this study) should fall under section A6.81 – Canyons, channels, slope failures and slumps on the continental slope. However, the lower hierarchical levels in this section are defined on the basis of geomorphology (e.g. A6.811 – Active down-slope channels) with no further division at level 6. These level 5 divisions are not helpful, particularly from a biological perspective, and any division created below this would first have to be at the level of substratum (new level 6 habitat types), before being described at the level of biological communities (new level 7 and 8 habitat types). Therefore we have disregarded section A6.81 and mapped using EUNIS habitat types A6.1 to A6.6. New habitat types have also been proposed under the appropriate level 3 substratum scale habitats (e.g. A6.1-A6.6).

Thirteen biotopes were described and used in this study (see section 4.4.3 of this report). Of those 13, only one previously existed within the EUNIS Classification (A6.611 – Deep-sea *Lophelia pertusa* reefs). Six new EUNIS habitat types have been proposed (see Appendix 2 for a completed proforma describing these habitat types) based on the five clusters identified through PRIMER analysis of the biological data (see section 4.4.2) and the existing geological divisions within the EUNIS Classification System. The remaining six biotopes defined within this study were either defined based on geology alone, or were not sufficiently faunally resolved to allow a comprehensive description to be proposed.

Of the new habitat types only A6.4_UK01, A6.3_UK01 and A6.11_UK02 are likely to remain relatively unchanged following reanalysis of the complete UK offshore dataset (currently being undertaken by University of Plymouth). A6.22_UK01, A6.21_UK01 and A6.11_UK01 are likely to be modified, refined and subdivided in future. The faunal resolution achieved in this survey was significantly less than was achieved in the SEA7 and SEA-SAC surveys and thus discrimination of biological communities based on cluster analysis was weak.

It was not possible to produce GIS polygons at the biotope level from the acoustic data. The problem is one of scale. The acoustic data is at the scale of 1 pixel = 25mx25m. The biological data is at the scale of approximately 0.5x0.5m. The difference in the spatial scales between the two data types means that, more often than not, changes in the biological community observed on the video transect are not visible in the acoustic data and therefore cannot be mapped. While it is clear that it would not be practical to undertake acoustic survey at a finer resolution during exploration research, it must be acknowledged that the maps produced only provide an indication of the range of biotopes present within an acoustic facies.

5.6. Areas of conservation interest

Annex I biogenic reef (biotope 4), reef rubble (biotope 5) and bedrock reef (biotopes 3 and 13 and limited examples of biotope 6) were all observed within the area of study. Annex I stony reef was not observed.

Cold water coral (*Lophelia pertusa*) reef was observed within and at the seaward entrance to the Explorer Canyon between 743-925m. This is illustrated in Figure 4.50 within Section 4.5.3. It was associated with areas of sediment covered and exposed bedrock on the canyon flanks. Typical organisms inhabiting the reef were: the pencil urchin *Cidaris cidaris*, ophiuroids, anemones (including cerianthids), fish (probably *Lepidon sp.*), *Stichopathes sp.* (antipatharian coral) and crustaceans (*Bathynectes sp*., *Chaceon affinis* and *Munida* sp.). In certain areas, crinoids (*Koehlerometra porrecta*) and brisingids were observed. In addition, areas of reef rubble were observed in the vicinity of intact reef within the canyon but more commonly on the interfluves of Dangaard Canyon associated with mini-mound structures (See Figure 4.50). These mini-mound structures are of similar dimensions and acoustic response as small carbonate mounds identified in the neighbouring Porcupine Seabight (see Section 5.1). On the most southerly interfluve of the Dangaard Canyon, dense mini-mounds were found covering an

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area of 19km^2, whilst on the northerly interfluve, mini-mounds covered an area of 12km^2. Coral rubble was observed in the vicinity of the mini-mounds, and there was evidence of fishing activity in the area. However, no intact living coral was seen at the stations sampled, although it is likely that these mound structures once supported live *L. pertusa* reef.

Lophelia pertusa reef has been observed on Hatton, George Bligh and Rockall Banks in UK waters (Narayanaswamy *et al*., 2006; Howell *et al*, 2007a, b). In addition, the Darwin Mounds support clump formations of cold water corals (Bett, 2001). Within the neighbouring Porcupine Seabight and on the Porcupine Bank (Irish waters) carbonate mound associated cold water coral reefs have been described. Three well-delineated mound provinces are noted: the Belgica Mounds (500-1000m) on the eastern flank (De Mol *et al*., 2002; Van Rooij *et al*. 2003), the Hovland Mounds in the north (Hovland *et al*., 1994; De Mol *et al*., 2002) and a large number of buried Magellan Mounds further to the northwest (Huvenne *et al*., 2002, 2003). Species described from these reefs (and reefs in UK waters) are similar to those observed in the present study and include sponges (*Aphrocallistes* sp.), gorgonians (*Acanthogorgia* sp.), antipatharians and spider crabs (*Paromola cuvieri*). Coral rubble areas fringing these reefs are also similar (in terms of megabenthos) and are colonised by large anemones (*Phelliactis* sp.) and large alcyonarians (*Anthomastus* sp.).

Bedrock supporting reef-like fauna was observed in all canyons. Bedrock reef communities were observed at the heads, on the flank and on the canyon floor from 237-1030m. As discussed in Section 4.4 the megabenthic fauna of the bedrock reef areas appear similar to bedrock reef areas on other UK offshore features at similar depths (Narayanaswamy *et al*., 2006; Howell *et al*., 2007b) although a combined analysis of both datasets would be required to establish this conclusively. In addition, much of the encrusting fauna of bedrock reef habitat is difficult to identify below phylum level without physical samples. Thus faunal differences may exist that are undetectable at the resolution achievable with video and image sampling.

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6. Conclusions

The survey of the canyons in the SW Approaches area has provided valuable geomorphological and biological data and has greatly enhanced our understanding of the marine habitats found throughout the UK offshore area. By combining the seismic interpretation with the photographic ground-truthing and multibeam datasets an overall picture of the make-up of the superficial sediments has been achieved. Data obtained from this survey will be used in taking forward the identification of offshore Special Areas of Conservation (SAC).

Previous studies and this recent work have shown that the physiography and geology of the Celtic margin is diverse and complex. The study area reveals classic examples of erosional and depositional features consistent with submarine canyons elsewhere. The margin in this region is characterised by a highly dissected (erosional) continental slope interspersed with smooth (depositional) features and a relatively flat, smooth continental shelf. Evidence of mass wasting (gullying and landsliding) on the lower canyon's walls is contributing to sediment deposition at the lower canyon slope and floor. Future geophysical investigations in the study area would benefit from using a deep-water multibeam swath bathymetric system to investigate the canyon floor/continental rise, to further improve our understanding of the canyon morphology. The SW Approaches area is highly complicated in terms of sedimentary dynamics and evolution. To fully asses the sediment dynamics from source (continental shelf) to sink (Celtic Fan) extension of the multibeam, seismic and ground-truthing datasets (both stratigraphic and photographic) to the west and east of the MESH survey area would be required.

The Neogene formations play an important part in not only determining the evolution of the margin, for example its history of incision during the Plio-Pleistocene and series of marine transgressions and regressions during the Miocene but also its influence on sediment distribution and rock outcrop. Areas of rock outcrop are easily eroded as the comprising sediments are relatively young and only weakly cemented. The dominant sea floor composition identified was that of deep-sea mixed substrata. This comprises gravel and gravelly sediments in water depths >200m and were generally limited to water depth <500m, the deeper waters were dominated by muddy sediments. The mini-mound features observed on the interfluve tops were not identified within the shallow sub-surface imaged by the seismic data. Therefore it can be concluded that these are modern features possibly forming through colonisation and subsequent growth on a relict sea bed rather than accumulation over time.

Annex I bedrock reef, and biogenic reef were all observed within the area of study. Annex I stony reef was not observed within the study area. Cold water coral (*Lophelia pertusa*) reef was observed at the seaward entrance to, and within Explorer Canyon between 743-925m. It was associated with areas of sediment covered and exposed bedrock on the canyon flanks. In addition, areas of reef rubble were observed in the vicinity of intact reef within the canyon but more commonly on the interfluves of Dangaard Canyon associated with mini-mound structures. At the resolution achievable with video and image sampling, the biological communities observed in the canyons appear similar, in terms of species composition, to those observed on other offshore features in the UK Continental Shelf Limit. Thirteen biotopes were described from the canyons, and of these, six are proposed as new EUNIS habitat types (Appendix 2).

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Overall, the MESH guidance documentation (including Recommended Operating Guidelines) was found to be very useful, and provided a detailed framework within which surveys could be planned and executed. The recommended modifications to the ROGs were on the whole minor, and sought either to offer further clarity or to make the guidance applicable to a wider range of circumstances. Of the guidance appraised, it was felt that guidance relating to survey metadata recording required the most development.

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9. Appendices

Appendix 1. Statistical Images

Table showing the position and depth of the statistical images taken during the survey

Image number	Latitude	Longitude	Depth (m)
C_1_1_001	48.496263	-9.872838	734
C_1_1_004	48.49605	-9.872816	734
C_1_1_007	48.495878	-9.872843	732
C_1_1_010	48.495638	-9.872827	731
C_1_1_016	48.495407	-9.872813	733
C_1_1_017	48.495243	-9.872813	732
C_1_1_018	48.495049	-9.872772	731
C_1_1_020	48.494787	-9.8728	729
C_1_1_022	48.494704	-9.872783	730
C_1_1_024	48.494542	-9.872769	729
C_1_1_027	48.494231	-9.872753	731
C_1_1_030	48.494115	-9.872737	735
C_1_1_034	48.493776	-9.872683	742
C_1_1_037	48.4936	-9.872683	747
C_1_1_039	48.493391	-9.872676	750
C_1_1_043	48.492982	-9.872659	773
C_1_1_045	48.492826	-9.872638	782
C_1_1_049	48.492486	-9.872638	813
C_1_1_051	48.492386	-9.872628	816
C_1_1_055	48.492077	-9.87258	843
C_1_1_058	48.491943	-9.872574	839
C_1_1_062	48.491594	-9.872569	851
C_1_1_065	48.491337	-9.872543	866
C_1_1_066	48.491247	-9.872534	868
C_1_1_069	48.49085	-9.872511	862
C_1_1_071	48.490694	-9.872501	862
C_1_1_073	48.490515	-9.872481	861
C_1_1_074	48.490357	-9.872456	852
C_1_1_076	48.490114	-9.87248	860
C_1_1_077	48.490059	-9.872506	859

C_1_1_079	48.489953	-9.872489	857
C_1_1_081	48.489701	-9.872437	850
C_1_1_084	48.489353	-9.87243	860
C_1_1_086	48.489092	-9.872414	865
C_1_1_087	48.488895	-9.872399	863
C_1_1_089	48.488738	-9.872384	868
C_1_1_095	48.488319	-9.872349	870
C_1_1_096	48.488139	-9.872341	881
C_1_1_099	48.487821	-9.872339	890
C_1_1_100	48.4877	-9.872323	900
C_1_1_104	48.487411	-9.872316	920
C_1_1_106	48.487243	-9.872306	933
C_1_1_110	48.487056	-9.872259	934
C_1_1_114	48.486887	-9.872269	922
C_1_1_117	48.486719	-9.872265	928
C_1_1_122	48.486479	-9.872235	929
C_1_1_124	48.486394	-9.872226	928
C_1_1_128	48.486059	-9.872208	926
C_1_1_133	48.4859	-9.872215	966
C_1_1_135	48.485734	-9.872221	966
C_1_1_137	48.485642	-9.872198	954
C_1_1_140	48.48552	-9.872169	957
C_1_1_143	48.485335	-9.87219	951
C_1_1_144	48.485193	-9.872153	953
C_1_1_149	48.485006	-9.872181	951
C_1_1_150	48.484824	-9.872147	949
C_1_1_153	48.484666	-9.872136	923
C_1_1_156	48.484477	-9.872137	944
C_1_1_159	48.484269	-9.872114	942
C_1_1_162	48.484149	-9.872105	874
C_1_1_166	48.483981	-9.872083	877
C_1_1_167	48.483866	-9.872067	914
C_1_2_004	48.560165	-9.834129	301
C_1_2_008	48.560463	-9.833767	300
C_1_2_009	48.56065	-9.833563	299
C_1_2_012	48.560858	-9.833297	298

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C_1_2_015	48.56102	-9.833089	297
C_1_2_018	48.561604	-9.832403	293
C_1_2_021	48.561682	-9.832293	293
C_1_2_025	48.5619	-9.83207	291
C_1_2_026	48.562075	-9.831844	290
C_1_2_028	48.562292	-9.831604	290
C_1_2_031	48.56246	-9.831404	288
C_1_2_034	48.562724	-9.831092	287
C_1_2_035	48.56274	-9.831069	287
C_1_3_002	48.569403	-9.842213	353
C_1_3_004	48.569382	-9.842657	355
C_1_3_007	48.569383	-9.843408	361
C_1_3_009	48.569378	-9.843506	362
C_1_3_013	48.569362	-9.84418	381
C_1_3_018	48.569353	-9.844359	379
C_1_3_023	48.569363	-9.844594	387
C_1_3_026	48.569357	-9.844954	395
C_1_3_027	48.569359	-9.845168	401
C_1_3_028	48.569356	-9.84528	417
C_1_3_031	48.569349	-9.845948	432
C_1_3_032	48.569355	-9.845996	435
C_1_4_002	48.560453	-9.857723	
C_1_4_010	48.561023	-9.858491	599
C_1_4_012	48.561161	-9.858714	599
C_1_4_015	48.561232	-9.858845	599
C_1_4_017	48.56128	-9.858925	599
C_1_4_019	48.561335	-9.859016	600
C_1_4_020	48.561338	-9.859034	600
C_1_4_022	48.561384	-9.859098	601
C_1_4_025	48.561441	-9.859213	601
C_1_4_028	48.561486	-9.859279	602
C_1_4_032	48.561606	-9.859471	604
C_1_4_033	48.561712	-9.859655	606
C_1_4_035	48.561816	-9.859812	611
C_1_4_036	48.561924	-9.86	616
C_1_4_037	48.562057	-9.860187	620

C_1_4_040	48.562277	-9.860536	633
C_1_4_042	48.562387	-9.86072	639
C_1_4_043	48.562501	-9.8609	641
C_1_4_046	48.562605	-9.861091	645
C_2_1_010	48.4199	-9.57327	
C_2_1_012	48.41978	-9.57326	251
C_2_1_013	48.41964	-9.57314	252
C_2_1_014	48.41948	-9.57302	254
C_2_1_015	48.41936	-9.57293	256
C_2_1_016	48.41921	-9.57283	258
C_2_1_017	48.41907	-9.57273	261
C_2_1_020	48.41893	-9.57262	262
C_2_1_021	48.41879	-9.57251	267
C_2_1_024	48.41853	-9.57232	286
C_2_1_025	48.41838	-9.5722	291
C_2_1_028	48.41823	-9.57209	293
C_2_1_032	48.41813	-9.57201	296
C_2_1_037	48.41797	-9.57189	298
C_2_1_039	48.41781	-9.57179	301
C_2_1_042	48.41769	-9.57168	304
C_2_1_046	48.41752	-9.57155	309
C_2_1_048	48.41738	-9.57145	311
C_2_1_049	48.41724	-9.57136	312
C_2_1_051	48.41694	-9.57112	316
C_2_1_053	48.4168	-9.571	318
C_2_1_057	48.4166	-9.57086	318
C_2_1_061	48.41645	-9.57074	320
C_2_1_063	48.4163	-9.57064	321
C_2_1_068	48.41613	-9.57049	323
C_2_10_001	48.482913	-9.574309	391
C_2_10_004	48.482973	-9.574573	394
C_2_10_006	48.483104	-9.575065	400
C_2_10_007	48.483154	-9.575284	403
C_2_10_008	48.483224	-9.575524	406
C_2_10_009	48.483279	-9.575757	409
C_2_10_010	48.483345	-9.575997	412

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C_2_10_012	48.483416	-9.576273	416
C_2_10_014	48.483536	-9.576764	422
C_2_10_015	48.483615	-9.577012	425
C_2_10_016	48.483671	-9.577238	428
C_2_10_020	48.483821	-9.577785	436
C_2_10_021	48.483878	-9.57802	438
C_2_10_023	48.483956	-9.578256	441
C_2_11_001	48.499174	-9.613132	825
C_2_11_003	48.498806	-9.612996	834
C_2_11_007	48.498538	-9.612711	840
C_2_11_008	48.498482	-9.612644	842
C_2_11_013	48.498266	-9.612423	847
C_2_11_021	48.49793	-9.612063	856
C_2_11_026	48.497773	-9.611904	942
C_2_11_033	48.497529	-9.611663	942
C_2_11_039	48.497328	-9.611435	939
C_2_11_041	48.49725	-9.611365	940
C_2_11_043	48.497205	-9.611311	939
C_2_11_050	48.496847	-9.610957	937
C_2_11_051	48.496718	-9.610836	924
C_2_11_052	48.496583	-9.610683	925
C_2_11_055	48.496446	-9.61055	923
C_2_11_056	48.496358	-9.61045	921
C_2_11_057	48.495745	-9.609803	913
C_2_11_061	48.495538	-9.609592	909
C_2_11_065	48.495477	-9.609535	907
C_2_11_066	48.495442	-9.609504	902
C_2_11_069	48.495309	-9.60936	904
C_2_11_073	48.495177	-9.609218	922
C_2_11_078	48.494881	-9.608918	874
C_2_11_080	48.494838	-9.608873	873
C_2_11_083	48.494637	-9.608666	869
C_2_11_088	48.49454	-9.608564	866
C_2_11_089	48.494491	-9.608513	894
C_2_12_001	48.51333	-9.504628	242
C_2_12_011	48.513744	-9.503798	249

C_2_12_020	48.514008	-9.503197	257
C_2_12_022	48.514111	-9.502992	260
C_2_12_023	48.514165	-9.502896	261
C_2_12_026	48.514218	-9.502768	263
C_2_12_028	48.514318	-9.502582	265
C_2_12_031	48.514418	-9.502375	267
C_2_12_035	48.514553	-9.502098	270
C_2_12_036	48.514647	-9.501903	272
C_2_12_038	48.514736	-9.501704	274
C_2_12_040	48.514842	-9.501494	277
C_2_12_050	48.515238	-9.500679	285
C_2_12_053	48.51536	-9.500453	288
C_2_12_054	48.515387	-9.500387	289
C_2_12_056	48.515417	-9.500309	290
C_2_12_059	48.515441	-9.500247	291
C_2_12_061	48.515467	-9.500202	294
C_2_12_062	48.515537	-9.500075	294
C_2_12_063	48.515584	-9.499986	295
C_2_12_070	48.515674	-9.499784	298
C_2_12_073	48.515718	-9.499695	320
C_2_12_078	48.515846	-9.499445	320
C_2_12_079	48.515856	-9.499422	321
C_2_13_001	48.522986	-9.590885	463
C_2_13_003	48.522166	-9.590962	477
C_2_13_006	48.521818	-9.590993	484
C_2_13_008	48.521636	-9.591019	487
C_2_13_009	48.521458	-9.591043	506
C_2_13_010	48.521276	-9.591068	508
C_2_13_013	48.521168	-9.591084	516
C_2_13_016	48.521105	-9.591091	528
C_2_13_017	48.521082	-9.591101	521
C_2_13_018	48.520929	-9.591103	528
C_2_13_021	48.520764	-9.591108	534
C_2_13_022	48.520595	-9.59114	552
C_2_13_024	48.520442	-9.591164	549
C_2_13_026	48.520421	-9.591159	555

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C_2_13_030	48.520329	-9.591179	554
C_2_13_032	48.520258	-9.59119	555
C_2_13_035	48.520066	-9.591228	556
C_2_13_042	48.519731	-9.591256	558
C_2_13_047	48.519371	-9.591283	568
C_2_14_002	48.477709	-9.656533	797
C_2_14_005	48.477796	-9.656658	798
C_2_14_010	48.477703	-9.656627	797
C_2_14_016	48.47753	-9.656549	802
C_2_14_018	48.477486	-9.656524	802
C_2_14_020	48.477357	-9.656469	806
C_2_14_023	48.477212	-9.656399	809
C_2_14_026	48.477041	-9.656315	814
C_2_14_028	48.476823	-9.65624	816
C_2_14_033	48.476689	-9.656178	826
C_2_14_044	48.476275	-9.655982	839
C_2_14_049	48.476107	-9.655927	829
C_2_14_053	48.475975	-9.655869	827
C_2_14_059	48.475747	-9.655759	827
C_2_14_064	48.475559	-9.655677	843
C_2_14_067	48.475451	-9.655612	832
C_2_14_072	48.475161	-9.655501	845
C_2_14_076	48.47497	-9.655416	854
C_2_14_078	48.474822	-9.655345	871
C_2_14_081	48.474754	-9.655305	868
C_2_14_085	48.474721	-9.655327	872
C_2_14_089	48.474573	-9.655296	873
C_2_14_092	48.474407	-9.655215	874
C_2_14_097	48.474249	-9.655151	887
C_2_14_100	48.473975	-9.655045	887
C_2_14_102	48.473945	-9.655039	881
C_2_14_105	48.473789	-9.654945	891
C_2_14_107	48.473629	-9.654879	894
C_2_14_109	48.473493	-9.65481	895
C_2_14_115	48.473112	-9.654656	910
C_2_14_117	48.473014	-9.654601	917

C_2_14_119	48.472868	-9.654518	914
C_2_14_122	48.472708	-9.654442	917
C_2_14_125	48.472549	-9.654364	936
C_2_14_126	48.472379	-9.654259	938
C_2_14_129	48.472262	-9.654218	936
C_2_14_132	48.472213	-9.65419	938
C_2_14_136	48.472072	-9.654125	942
C_2_14_137	48.472054	-9.654103	938
C_2_15_002	48.467998	-9.736719	465
C_2_15_005	48.467947	-9.736143	473
C_2_15_007	48.467907	-9.735644	481
C_2_15_011	48.467839	-9.735092	492
C_2_15_014	48.467749	-9.734522	508
C_2_15_017	48.4677	-9.734162	525
C_2_15_020	48.467666	-9.733573	536
C_2_15_021	48.46764	-9.733294	554
C_2_15_027	48.467511	-9.73239	581
C_2_15_028	48.467498	-9.732255	580
C_2_15_034	48.467444	-9.731773	585
C_2_15_036	48.467408	-9.731466	590
C_2_15_038	48.467379	-9.731217	593
C_2_15_043	48.467314	-9.730576	602
C_2_15_047	48.467255	-9.730199	637
C_2_16_004	48.424819	-9.870922	799
C_2_16_007	48.424711	-9.871157	803
C_2_16_011	48.424586	-9.871388	804
C_2_16_024	48.424026	-9.872405	815
C_2_16_026	48.423958	-9.872545	817
C_2_16_029	48.423862	-9.872719	826
C_2_16_031	48.423756	-9.872871	822
C_2_16_036	48.423559	-9.873215	826
C_2_16_049	48.423241	-9.873848	833
C_2_16_057	48.42299	-9.874359	850
C_2_16_063	48.422883	-9.874497	845
C_2_16_065	48.422795	-9.874658	860
C_2_16_073	48.422579	-9.875098	879

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C_2_16_080	48.422303	-9.875586	885
C_2_17_001	48.452397	-9.80016	351
C_2_17_004	48.452031	-9.800155	352
C_2_17_010	48.451698	-9.800155	353
C_2_17_011	48.451536	-9.800179	354
C_2_17_014	48.451386	-9.800167	354
C_2_17_016	48.451205	-9.800174	356
C_2_17_020	48.451028	-9.80018	356
C_2_17_021	48.450844	-9.800174	358
C_2_17_025	48.450697	-9.800184	359
C_2_17_026	48.45052	-9.800207	360
C_2_17_027	48.45038	-9.800191	362
C_2_17_031	48.449986	-9.800216	367
C_2_17_033	48.449828	-9.800203	368
C_2_17_037	48.449277	-9.800221	378
C_2_17_042	48.449024	-9.800209	388
C_2_18_004	48.464143	-9.714525	689
C_2_18_006	48.463928	-9.714699	697
C_2_18_007	48.463793	-9.714766	699
C_2_18_009	48.463622	-9.714869	767
C_2_18_010	48.463568	-9.714897	746
C_2_18_014	48.463393	-9.714996	755
C_2_18_015	48.463312	-9.715031	753
C_2_18_018	48.462974	-9.715231	764
C_2_18_019	48.462796	-9.715344	764
C_2_18_020	48.462637	-9.715435	767
C_2_18_021	48.462571	-9.715487	770
C_2_18_023	48.462483	-9.715523	770
C_2_18_027	48.462257	-9.715649	776
C_2_18_028	48.462161	-9.715697	778
C_2_18_030	48.46153	-9.716066	790
C_2_18_033	48.460911	-9.716448	861
C_2_18_036	48.460612	-9.716657	831
C_2_18_037	48.460318	-9.716769	834
C_2_19_001	48.496112	-9.643017	659
C_2_19_002	48.495964	-9.643051	661

C_2_19_004	48.495629	-9.643095	666
C_2_19_005	48.495467	-9.643096	669
C_2_19_009	48.49498	-9.643182	678
C_2_19_011	48.494619	-9.643214	688
C_2_19_012	48.49446	-9.643271	691
C_2_19_017	48.494051	-9.643321	701
C_2_19_018	48.493877	-9.643322	704
C_2_19_021	48.493378	-9.643366	726
C_2_19_028	48.492232	-9.64355	772
C_2_19_029	48.492052	-9.643556	789
C_2_19_030	48.49183	-9.643568	793
C_2_19_031	48.491667	-9.643622	803
C_2_19_032	48.491457	-9.643667	805
C_2_19_033	48.491439	-9.64367	812
C_2_2_007	48.403658	-9.542351	651
C_2_2_009	48.40363	-9.54238	643
C_2_2_011	48.40357	-9.54251	642
C_2_2_014	48.40352	-9.54264	642
C_2_2_016	48.40342	-9.54281	642
C_2_2_019	48.40332	-9.543	643
C_2_2_022	48.40322	-9.54319	643
C_2_2_025	48.40313	-9.54335	644
C_2_2_028	48.40305	-9.5435	644
C_2_2_032	48.40296	-9.54365	644
C_2_2_036	48.40288	-9.54383	644
C_2_2_039	48.40266	-9.54424	645
C_2_2_041	48.40258	-9.54445	645
C_2_2_043	48.40243	-9.5447	645
C_2_2_046	48.4023	-9.54489	646
C_2_2_048	48.40221	-9.5451	645
C_2_2_049	48.40208	-9.54526	645
C_2_2_050	48.40198	-9.54548	645
C_2_20_003	48.463487	-9.647187	837
C_2_20_004	48.46364	-9.647292	840
C_2_20_006	48.463967	-9.647629	856
C_2_20_007	48.464107	-9.647765	863

C_2_20_009	48.464426	-9.648049	892
C_2_20_011	48.464717	-9.648334	899
C_2_20_017	48.465361	-9.64897	918
C_2_20_018	48.465501	-9.649085	956
C_2_20_020	48.465708	-9.649231	1048
C_2_20_027	48.466277	-9.649841	1022
C_2_20_028	48.466356	-9.64989	1020
C_2_20_031	48.466441	-9.649918	1023
C_2_21_003	48.425312	-9.609192	252
C_2_21_004	48.425304	-9.609249	252
C_2_21_007	48.425237	-9.609701	253
C_2_21_008	48.425194	-9.609776	253
C_2_21_013	48.424971	-9.610151	254
C_2_21_018	48.424763	-9.610516	254
C_2_21_020	48.424674	-9.610663	254
C_2_21_021	48.424641	-9.610703	254
C_2_21_023	48.424493	-9.610981	255
C_2_21_024	48.424405	-9.611147	255
C_2_21_025	48.424289	-9.611361	255
C_2_21_026	48.4242	-9.6115	256
C_2_21_027	48.424086	-9.611728	256
C_2_21_030	48.423948	-9.611964	256
C_2_22_004	48.397624	-9.649594	328
C_2_22_006	48.397499	-9.649512	329
C_2_22_008	48.397398	-9.649425	329
C_2_22_013	48.397247	-9.649349	330
C_2_22_017	48.397092	-9.649235	331
C_2_22_020	48.396949	-9.649119	331
C_2_22_022	48.396844	-9.649024	331
C_2_22_023	48.396787	-9.648995	332
C_2_22_027	48.396594	-9.648882	333
C_2_22_031	48.39648	-9.648752	334
C_2_22_034	48.396332	-9.648652	336
C_2_22_036	48.396191	-9.648535	337
C_2_22_040	48.395849	-9.648308	339
C_2_22_043	48.395609	-9.648103	340

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C_2_22_046	48.395395	-9.647946	341
C_2_22_047	48.395258	-9.647864	342
C_2_23_002	48.346638	-9.779156	730
C_2_23_005	48.346505	-9.779257	743
C_2_23_007	48.34636	-9.779408	749
C_2_23_008	48.346247	-9.779509	750
C_2_23_011	48.346072	-9.779694	755
C_2_23_014	48.345919	-9.779833	760
C_2_23_016	48.34578	-9.779972	763
C_2_23_018	48.345614	-9.780091	771
C_2_23_019	48.345598	-9.780115	776
C_2_23_023	48.345279	-9.780413	782
C_2_23_025	48.345164	-9.780539	782
C_2_23_028	48.345019	-9.780693	784
C_2_23_032	48.34485	-9.780855	787
C_2_23_043	48.343942	-9.781729	809
C_2_23_045	48.34386	-9.78179	826
C_2_23_046	48.34369	-9.78195	831
C_2_23_049	48.34351	-9.782099	836
C_2_23_054	48.343212	-9.782404	854
C_2_23_060	48.342675	-9.782946	881
C_2_23_061	48.342645	-9.782983	888
C_2_23_064	48.342575	-9.783029	893
C_2_23_066	48.342464	-9.783143	910
C_2_23_068	48.342388	-9.78323	894
C_2_23_070	48.34231	-9.783299	902
C_2_23_072	48.342217	-9.783356	907
C_2_23_077	48.341847	-9.783758	1059
C_2_24_002	48.376516	-9.639434	694
C_2_24_003	48.376343	-9.639467	699
C_2_24_004	48.376199	-9.639526	702
C_2_24_006	48.375903	-9.63969	722
C_2_24_009	48.375658	-9.639784	720
C_2_24_013	48.37522	-9.639954	753
C_2_24_014	48.375066	-9.640023	760
C_2_24_015	48.374912	-9.640094	764

C_2_24_016	48.374717	-9.64017	768
C_2_24_018	48.374373	-9.640265	786
C_2_24_022	48.373862	-9.640525	801
C_2_25_002	48.377362	-9.60101	722
C_2_25_005	48.376945	-9.600565	733
C_2_25_006	48.376816	-9.600425	736
C_2_25_012	48.376082	-9.599598	758
C_2_25_014	48.375765	-9.599245	767
C_2_25_019	48.375295	-9.598759	779
C_2_25_022	48.375206	-9.598667	781
C_2_25_023	48.375164	-9.598619	782
C_2_25_026	48.374971	-9.598387	788
C_2_25_028	48.374789	-9.59824	792
C_2_26_002	48.438534	-9.483885	307
C_2_26_003	48.438509	-9.483892	307
C_2_26_005	48.438191	-9.484041	310
C_2_26_006	48.438119	-9.484086	311
C_2_26_007	48.438046	-9.484116	312
C_2_26_013	48.437643	-9.484278	316
C_2_26_018	48.437176	-9.484485	321
C_2_26_019	48.437075	-9.48453	323
C_2_26_023	48.436897	-9.484605	325
C_2_26_025	48.436713	-9.484685	327
C_2_26_027	48.436564	-9.484726	329
C_2_26_029	48.436384	-9.484824	331
C_2_26_031	48.436347	-9.484843	0
C_2_26_039	48.436063	-9.48494	336
C_2_26_040	48.435935	-9.484996	339
C_2_26_043	48.435632	-9.485148	359
C_2_26_045	48.435475	-9.485213	366
C_2_26_046	48.435358	-9.485241	369
C_2_26_050	48.435236	-9.485292	381
C_2_26_052	48.435106	-9.485376	381
C_2_26_057	48.434772	-9.485511	392
C_2_26_059	48.434675	-9.485583	394
C_2_26_061	48.43464	-9.485594	396

C_2_26_062	48.43445	-9.485636	400
C_2_27_001	48.575601	-9.483186	186
C_2_27_002	48.575504	-9.483374	185
C_2_27_006	48.575408	-9.483643	184
C_2_27_007	48.575334	-9.483826	184
C_2_27_009	48.575316	-9.483867	184
C_2_27_012	48.575217	-9.484059	184
C_2_27_016	48.575143	-9.48427	185
C_2_27_017	48.575032	-9.484456	186
C_2_27_020	48.574833	-9.484858	187
C_2_27_022	48.574733	-9.48509	189
C_2_27_026	48.57458	-9.485396	190
C_2_27_030	48.574401	-9.485862	192
C_2_27_032	48.574303	-9.486073	192
C_2_27_033	48.5742	-9.486275	192
C_2_27_034	48.574095	-9.486463	192
C_2_28_002	48.554395	-9.537417	232
C_2_28_009	48.554395	-9.536905	238
C_2_28_011	48.554305	-9.536666	242
C_2_28_014	48.554252	-9.536433	246
C_2_28_019	48.554202	-9.536188	249
C_2_28_025	48.554124	-9.535767	256
C_2_28_034	48.554011	-9.535398	263
C_2_28_039	48.553966	-9.535087	269
C_2_28_040	48.553905	-9.53489	272
C_2_28_043	48.553827	-9.534626	278
C_2_28_046	48.553743	-9.53433	283
C_2_28_048	48.553696	-9.534073	286
C_2_28_049	48.553643	-9.53383	289
C_2_28_057	48.553525	-9.533285	295
C_2_28_059	48.55345	-9.533084	298
C_2_28_068	48.553335	-9.532509	307
C_2_28_069	48.553319	-9.532411	308
C_2_28_072	48.553295	-9.532256	311
C_2_28_075	48.55325	-9.532111	316
C_2_28_077	48.553215	-9.532011	317

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C_2_28_084	48.553115	-9.531564	329
C_2_28_086	48.553083	-9.531431	331
C_2_28_089	48.553053	-9.531238	371
C_2_28_090	48.553048	-9.531217	371
C_2_28_094	48.552978	-9.530914	370
C_2_28_095	48.552912	-9.530708	369
C_2_28_099	48.552858	-9.530395	370
C_2_3_002	48.392579	-9.570045	
C_2_3_005	48.3925	-9.57014	759
C_2_3_009	48.39241	-9.57031	760
C_2_3_011	48.39232	-9.57047	762
C_2_3_014	48.39222	-9.57062	763
C_2_3_016	48.39211	-9.57081	766
C_2_3_018	48.39202	-9.57091	768
C_2_3_021	48.3919	-9.57107	770
C_2_3_022	48.39183	-9.57123	774
C_2_3_023	48.3918	-9.57127	775
C_2_3_028	48.39168	-9.57144	778
C_2_3_031	48.39163	-9.57152	778
C_2_3_032	48.39156	-9.57163	781
C_2_3_034	48.39148	-9.57174	783
C_2_3_037	48.39138	-9.57191	786
C_2_3_039	48.39132	-9.57203	787
C_2_3_040	48.39129	-9.57211	788
C_2_3_042	48.39115	-9.57234	791
C_2_3_045	48.39105	-9.57256	793
C_2_3_047	48.39092	-9.57277	795
C_2_3_053	48.39071	-9.57311	797
C_2_3_055	48.3906	-9.57332	800
C_2_3_061	48.39039	-9.57369	798
C_2_3_063	48.39024	-9.57385	797
C_2_3_068	48.39008	-9.57403	816
C_2_3_071	48.38998	-9.57419	819
C_2_3_075	48.38989	-9.57431	820
C_2_3_082	48.38965	-9.57464	821
C_2_3_085	48.3896	-9.57469	823

C_2_3_092	48.38942	-9.57497	823
C_2_3_094	48.38936	-9.57508	822
C_2_4_001	48.383578	-9.670912	400
C_2_4_003	48.38342	-9.67074	400
C_2_4_005	48.38329	-9.67059	400
C_2_4_006	48.38312	-9.67044	399
C_2_4_012	48.38273	-9.66999	399
C_2_4_014	48.38255	-9.66984	399
C_2_4_016	48.38242	-9.66971	400
C_2_4_018	48.38229	-9.66958	400
C_2_4_022	48.382	-9.66929	401
C_2_4_024	48.38188	-9.66916	402
C_2_4_025	48.38175	-9.669	403
C_2_4_027	48.38161	-9.66887	404
C_2_4_030	48.38148	-9.66872	406
C_2_4_032	48.38133	-9.66856	408
C_2_4_035	48.3812	-9.66844	410
C_2_4_036	48.38105	-9.66826	412
C_2_5_001	48.37245	-9.68566	542
C_2_5_004	48.3722	-9.68557	557
C_2_5_008	48.37196	-9.68551	563
C_2_5_012	48.37153	-9.68539	572
C_2_5_016	48.37118	-9.68527	580
C_2_5_020	48.37071	-9.68513	599
C_2_5_021	48.37065	-9.68511	603
C_2_5_026	48.3704	-9.68503	609
C_2_5_032	48.37014	-9.68495	610
C_2_5_034	48.36996	-9.6849	614
C_2_5_039	48.36979	-9.68487	681
C_2_5_042	48.36963	-9.68482	635
C_2_5_047	48.36944	-9.68476	645
C_2_5_050	48.36926	-9.68469	644
C_2_5_053	48.36914	-9.68466	649
C_2_5_058	48.36893	-9.68459	657
C_2_5_064	48.36856	-9.68452	681
C_2_5_068	48.3683	-9.68443	689

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C_2_5_070	48.36822	-9.68441	696
C_2_5_073	48.36805	-9.68437	698
C_2_6_006	48.358344	-9.723597	785
C_2_6_012	48.35798	-9.723397	788
C_2_6_016	48.35764	-9.723225	794
C_2_6_031	48.356618	-9.722669	821
C_2_6_032	48.356479	-9.722611	824
C_2_6_040	48.355722	-9.72221	861
C_2_6_044	48.355378	-9.722025	877
C_2_7_003	48.3782	-9.77602	714
C_2_7_009	48.37832	-9.77654	723
C_2_7_014	48.37844	-9.77705	741
C_2_7_019	48.37847	-9.7773	743
C_2_7_023	48.37851	-9.77756	746
C_2_7_026	48.37858	-9.77786	752
C_2_7_028	48.37864	-9.77811	755
C_2_7_030	48.37867	-9.77835	758
C_2_7_033	48.37874	-9.77861	762
C_2_7_034	48.37877	-9.77876	764
C_2_7_036	48.37886	-9.77911	770
C_2_7_037	48.37889	-9.77939	776
C_2_7_039	48.37894	-9.77964	779
C_2_7_044	48.37905	-9.78015	787
C_2_7_051	48.37922	-9.78105	802
C_2_7_054	48.37925	-9.78131	806
C_2_7_055	48.37929	-9.78146	809
C_2_8_004	48.44037	-9.682	916
C_2_8_006	48.44073	-9.68203	914
C_2_8_007	48.44093	-9.68203	913
C_2_8_008	48.4411	-9.68207	913
C_2_8_010	48.44128	-9.68209	912
C_2_8_012	48.4416	-9.68212	913
C_2_8_015	48.4421	-9.68216	915
C_2_8_016	48.44226	-9.68217	917
C_2_8_017	48.44244	-9.68219	919
C_2_8_019	48.44277	-9.68224	924

C_2_8_020	48.44279	-9.68224	924
C_2_8_022	48.44316	-9.68229	931
C_2_8_023	48.44332	-9.68229	953
C_2_8_024	48.44349	-9.68232	963
C_2_8_026	48.44388	-9.68234	1021
C_2_8_027	48.44408	-9.68235	1006
C_2_8_029	48.44439	-9.68239	1054
C_2_8_030	48.44458	-9.68242	1027
C_2_9_003	48.471799	-9.622139	566
C_2_9_005	48.47195	-9.622422	569
C_2_9_007	48.472142	-9.622834	573
C_2_9_009	48.472353	-9.623264	578
C_2_9_011	48.47248	-9.623503	582
C_2_9_012	48.472576	-9.623722	585
C_2_9_013	48.472682	-9.62391	596
C_2_9_016	48.472946	-9.624455	613
C_2_9_017	48.47304	-9.624653	623
C_3_1_001	48.308271	-9.552125	55
C_3_1_003	48.306055	-9.552188	205
C_3_1_004	48.306586	-9.552221	206
C_3_1_006	48.306702	-9.552314	206
C_3_1_008	48.30689	-9.552441	208
C_3_1_014	48.307333	-9.552707	210
C_3_1_017	48.307493	-9.552818	210
C_3_1_018	48.30765	-9.552924	211
C_3_1_020	48.307801	-9.552989	211
C_3_1_022	48.307985	-9.55317	212
C_3_1_025	48.308132	-9.553238	212
C_3_1_026	48.308428	-9.55342	210
C_3_1_028	48.308395	-9.553275	256
C_3_1_030	48.308587	-9.553516	214
C_3_1_033	48.308728	-9.553582	214
C_3_1_034	48.308901	-9.553723	215
C_3_1_037	48.309577	-9.554154	215
C_3_1_040	48.309732	-9.554241	218
C_3_1_046	48.309975	-9.554419	218

C_3_1_049	48.310168	-9.554546	221
C_3_10_003	48.30149	-9.7328	712
C_3_10_005	48.30158	-9.73282	713
C_3_10_007	48.3017	-9.73294	716
C_3_10_009	48.30181	-9.73299	720
C_3_10_010	48.30192	-9.73306	724
C_3_10_012	48.30204	-9.7331	727
C_3_10_014	48.3022	-9.73321	732
C_3_10_016	48.3023	-9.73323	735
C_3_10_018	48.30245	-9.73335	740
C_3_10_022	48.30272	-9.7335	748
C_3_10_028	48.30312	-9.7337	761
C_3_10_032	48.30329	-9.73377	768
C_3_10_033	48.30338	-9.73384	772
C_3_10_035	48.30352	-9.73387	777
C_3_10_038	48.30367	-9.73396	783
C_3_10_041	48.30379	-9.73404	789
C_3_10_043	48.30396	-9.73415	795
C_3_10_044	48.30412	-9.73423	800
C_3_10_045	48.30425	-9.7343	806
C_3_10_050	48.30455	-9.73448	819
C_3_10_056	48.30486	-9.73463	832
C_3_10_058	48.30498	-9.73468	836
C_3_10_060	48.30512	-9.73476	842
C_3_10_063	48.30533	-9.73484	850
C_3_10_066	48.30547	-9.73491	855
C_3_10_070	48.30563	-9.73498	862
C_3_11_002	48.28055	-9.74771	684
C_3_11_004	48.28055	-9.74768	686
C_3_11_007	48.28055	-9.74773	686
C_3_11_013	48.28058	-9.7482	688
C_3_11_015	48.28061	-9.74868	691
C_3_11_017	48.28063	-9.74895	694
C_3_11_018	48.28064	-9.74916	695
C_3_11_019	48.28068	-9.7494	698
C_3_11_020	48.28071	-9.74964	700

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C_3_11_021	48.28071	-9.74992	702
C_3_11_022	48.28076	-9.75015	705
C_3_11_027	48.28081	-9.75064	710
C_3_11_029	48.28082	-9.75088	712
C_3_11_031	48.28084	-9.75117	715
C_3_11_033	48.28087	-9.75142	717
C_3_11_035	48.28091	-9.75171	721
C_3_11_037	48.28092	-9.75195	724
C_3_11_039	48.28095	-9.7522	727
C_3_11_040	48.28095	-9.7522	727
C_3_11_041	48.28097	-9.7523	729
C_3_11_045	48.281	-9.75273	733
C_3_11_050	48.28108	-9.75339	740
C_3_11_052	48.28109	-9.75361	741
C_3_11_054	48.2811	-9.75365	743
C_3_11_056	48.28116	-9.75412	747
C_3_12_001	48.347194	-9.534032	693
C_3_12_003	48.34735	-9.534058	673
C_3_12_005	48.347714	-9.534039	708
C_3_12_007	48.348088	-9.53403	712
C_3_12_008	48.348242	-9.534071	722
C_3_12_009	48.348383	-9.534051	722
C_3_12_012	48.34879	-9.53404	734
C_3_12_014	48.34913	-9.534026	744
C_3_12_016	48.349338	-9.534022	753
C_3_12_018	48.349537	-9.534038	761
C_3_12_020	48.349589	-9.534049	761
C_3_12_022	48.349723	-9.534055	774
C_3_12_024	48.349791	-9.534054	765
C_3_12_027	48.349871	-9.534044	785
C_3_12_034	48.350278	-9.534026	789
C_3_12_035	48.35038	-9.534014	787
C_3_12_036	48.350451	-9.534017	800
C_3_12_038	48.350643	-9.534015	800
C_3_12_040	48.350864	-9.533992	803
C_3_12_041	48.350922	-9.533986	804

C_3_12_042	48.351084	-9.534013	813
C_3_12_045	48.351551	-9.533992	874
C_3_12_048	48.351785	-9.533995	865
C_3_2b_002	48.307271	-9.604795	302
C_3_2b_006	48.307378	-9.604769	311
C_3_2b_013	48.307664	-9.604522	310
C_3_2b_018	48.307851	-9.604446	310
C_3_2b_021	48.30803	-9.604342	310
C_3_2b_025	48.30818	-9.604173	311
C_3_2b_028	48.308306	-9.604041	310
C_3_2b_029	48.308488	-9.603993	310
C_3_2b_032	48.30864	-9.603872	310
C_3_2b_033	48.308667	-9.603829	309
C_3_2b_036	48.308827	-9.603769	309
C_3_2b_041	48.308957	-9.60371	311
C_3_2b_043	48.309083	-9.603534	309
C_3_2b_046	48.309235	-9.603473	309
C_3_2b_048	48.309368	-9.603379	309
C_3_2b_049	48.309408	-9.603364	309
C_3_2b_051	48.311265	-9.599464	80
C_3_2b_058	48.311781	-9.599485	111
C_3_2b_060	48.310136	-9.602846	305
C_3_2b_062	48.310287	-9.602763	305
C_3_2b_063	48.310433	-9.602604	307
C_3_2b_067	48.310597	-9.602526	308
C_3_2b_070	48.310624	-9.602427	308
C_3_2b_073	48.310749	-9.602335	309
C_3_2b_077	48.310838	-9.602298	309
C_3_2b_079	48.311067	-9.602125	310
C_3_2b_081	48.311261	-9.601967	311
C_3_3_006	48.401267	-9.455041	244
C_3_3_009	48.401175	-9.454951	233
C_3_3_013	48.401067	-9.454874	232
C_3_3_014	48.400883	-9.454694	234
C_3_3_018	48.400757	-9.45453	234
C_3_3_026	48.40036	-9.454197	236

C_3_3_031	48.400082	-9.453916	238
C_3_3_034	48.40003	-9.453817	237
C_3_3_042	48.399736	-9.453579	254
C_3_3_048	48.399525	-9.45334	262
C_3_3_052	48.39938	-9.453203	263
C_3_3_055	48.399209	-9.453062	265
C_3_3_057	48.399055	-9.452887	266
C_3_3_060	48.398919	-9.452766	266
C_3_3_063	48.398802	-9.45263	267
C_3_3_067	48.398636	-9.452455	266
C_3_3_073	48.398372	-9.452173	266
C_3_3_077	48.398109	-9.451969	264
C_3_4_005	48.360551	-9.480067	1
C_3_4_009	48.360602	-9.480254	625
C_3_4_012	48.360687	-9.480455	1
C_3_4_016	48.360725	-9.480645	4
C_3_4_019	48.360805	-9.481002	1
C_3_4_024	48.36089	-9.481446	625
C_3_4_026	48.360912	-9.481635	1
C_3_4_032	48.361034	-9.482162	875
C_3_4_033	48.3611	-9.482356	125
C_3_5_001	48.362028	-9.497481	392
C_3_5_003	48.362123	-9.497578	379
C_3_5_006	48.362004	-9.497693	390
C_3_5_009	48.361939	-9.497915	394
C_3_5_010	48.361812	-9.498082	399
C_3_5_019	48.361385	-9.499013	407
C_3_5_028	48.361293	-9.499744	407
C_3_5_032	48.361369	-9.499662	415
C_3_5_035	48.361307	-9.49968	416
C_3_5_040	48.361053	-9.499568	427
C_3_5_045	48.360753	-9.499305	441
C_3_5_046	48.360603	-9.499128	447
C_3_5_049	48.360194	-9.49881	470
C_3_6_006	48.36158	-9.555944	1008
C_3_6_008	48.36138	-9.556153	1006

C_3_6_009	48.36133	-9.556037	1007
C_3_6_011	48.36149	-9.556206	1007
C_3_6_013	48.36144	-9.556242	1008
C_3_6_016	48.36139	-9.556207	1009
C_3_6_018	48.36159	-9.556386	1011
C_3_6_021	48.36165	-9.556545	1010
C_3_6_026	48.36162	-9.557062	1010
C_3_6_029	48.36174	-9.55702	1012
C_3_6_031	48.36176	-9.557029	1012
C_3_6_032	48.36175	-9.556985	1012
C_3_6_033	48.36175	-9.556985	1012
C_3_6_037	48.36179	-9.557236	1013
C_3_6_048	48.36176	-9.557478	1014
C_3_6_049	48.36181	-9.557632	1015
C_3_6_051	48.36178	-9.557797	1015
C_3_6_055	48.36167	-9.557546	1015
C_3_6_058	48.36181	-9.557862	1014
C_3_6_060	48.36186	-9.557892	1015
C_3_6_061	48.36178	-9.557983	1016
C_3_6_066	48.36201	-9.558294	1021
C_3_6_068	48.36191	-9.55823	1019
C_3_7_001	48.29185	-9.64142	356
C_3_7_002	48.29195	-9.64143	356
C_3_7_005	48.292	-9.64139	356
C_3_7_010	48.29209	-9.64154	355
C_3_7_013	48.2923	-9.64154	356
C_3_7_018	48.29242	-9.64153	354
C_3_7_022	48.29253	-9.6416	352
C_3_7_025	48.29287	-9.64169	357
C_3_7_028	48.29302	-9.64163	360
C_3_7_033	48.29322	-9.64173	361
C_3_7_035	48.29342	-9.64174	361
C_3_7_040	48.2936	-9.64182	362
C_3_7_043	48.2937	-9.64184	360
C_3_7_046	48.29388	-9.64196	360
C_3_7_047	48.29409	-9.64178	359

C_3_7_055	48.29444	-9.64204	362
C_3_7_060	48.29471	-9.64221	363
C_3_7_061	48.29478	-9.64226	362
C_3_7_066	48.295	-9.64209	361
C_3_7_070	48.29523	-9.64224	361
C_3_7_075	48.29536	-9.64224	363
C_3_7_080	48.29553	-9.64232	365
C_3_7_084	48.29583	-9.64237	367
C_3_7_089	48.29599	-9.64245	367
C_3_7_091	48.29613	-9.6424	367
C_3_7_096	48.29644	-9.64255	367
C_3_7_100	48.29681	-9.64268	367
C_3_8_001	48.33173	-9.63122	463
C_3_8_003	48.33173	-9.63127	463
C_3_8_004	48.33206	-9.63135	465
C_3_8_005	48.33206	-9.63164	466
C_3_8_006	48.33212	-9.63167	467
C_3_8_007	48.33213	-9.63176	469
C_3_8_008	48.33238	-9.63186	472
C_3_8_010	48.33248	-9.63203	477
C_3_8_013	48.33254	-9.63203	479
C_3_8_017	48.33283	-9.6323	488
C_3_8_021	48.33314	-9.63275	512
C_3_8_026	48.33334	-9.63305	534
C_3_8_032	48.3339	-9.6337	557
C_3_8_034	48.33404	-9.63368	560
C_3_8_035	48.33417	-9.63396	565
C_3_8_036	48.33432	-9.63399	570
C_3_8_040	48.33441	-9.63421	576
C_3_8_044	48.33467	-9.63442	584
C_3_8_046	48.33476	-9.63459	588
C_3_8_048	48.33492	-9.63516	598
C_3_8_050	48.33501	-9.63504	600
C_3_8_052	48.33513	-9.63518	604
C_3_8_053	48.33518	-9.63518	605
C_3_9_001	48.31193	-9.70631	668

C_3_9_003	48.31203	-9.70627	668
C_3_9_005	48.31221	-9.70622	673
C_3_9_007	48.31232	-9.7061	673
C_3_9_010	48.31259	-9.706	679
C_3_9_012	48.31273	-9.70591	682
C_3_9_015	48.31317	-9.70574	691
C_3_9_016	48.31332	-9.70566	693
C_3_9_020	48.31393	-9.70542	717
C_3_9_024	48.31446	-9.70517	742
C_3_9_027	48.31462	-9.70512	747
C_3_9_031	48.31506	-9.7049	763
C_3_9_033	48.3152	-9.70486	767
C_3_9_034	48.31535	-9.70476	771
C_3_9_036	48.31567	-9.70461	777
C_3_9_038	48.31599	-9.70448	786
C_3_9_041	48.31625	-9.70442	788

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Appendix 2. Proposed EUNIS habitat types

Table containing detail of the six proposed new EUNIS habitat types resulting from data collected during this project

Unique Id	Fits within higher EUNIS type	Change in definition of higher type	Why proposed habitat differs from other types?	Habitat title	Salinity	Wave exposure	Tidal streams	Substratum	Zone	Height/ depth band
					Salinity	Exposure	Exposure	Substrate	Altitude	Depth
A6.4_UK01	A6.4 (Deep-sea muddy sand)	None required	There are no sublevels described under this type	*Kophobelemnon* and ceriantheid anemones in deep fine sediments	Full (30-35ppt) Variable (18-35ppt)	very sheltered	moderately strong	Fine to very fine muddy sand	Circalittoral	
A6.22_UK01	A6.22 (Deep-sea biogenic gravels)	None required	There are no sublevels described under this type	*Munida* sp. and serpulids on deep-sea biogenic gravels	Full (30-35ppt) Variable (18-35ppt)	very sheltered	strong moderately strong	coral rubble shells	Circalittoral	
A6.21_UK01	A6.21 (Deep-sea lag deposits)	None required	There are no sublevels described under this type	*Munida* sp. and serpulids on deep-sea lag deposits	Full (30-35ppt) Variable (18-35ppt)	very sheltered	strong moderately strong	coral rubble shells	Circalittoral	
A6.11_UK01	A6.11 (Deep-sea bedrock)	None required	There are no sublevels described under this type	Scleractinian corals, anemones and *Ophiactis balli* on deep-sea bedrock	Full (30-35ppt) Variable (18-35ppt)	very sheltered	moderately strong	bedrock	Circalittoral	
A6.11_UK02	A6.11 (Deep-sea bedrock)	None required	There are no sublevels described under this type	Barnacles on bedrock outcrop	Full (30-35ppt) Variable (18-35ppt)	very sheltered	moderately strong	bedrock	Circalittoral	
A6.3_UK01	A6.3 (Deep-sea sand)	None required	This community is not characterised by the presence of *Grypheus vitreus*	Ophiuroids on flat deep-sea sand	Full (30-35ppt) Variable (18-35ppt)	very sheltered	moderately strong	sand	Circalittoral	

Appendix 2 (Contd.)

Unique Id	Features	Habitat description	Situation	Temporal variation	Anthropogenic influence	Geographic distribution	Reference(s)
EUNIS database table	Geomorphology						
A6.4_UK01				unknown	natural	NE Atlantic	
A6.22_UK01		At present the data are not clear enough to faunally resolve this biotope from the one described below. Modification to this biotope is expected following further analysis of UK offshore data.		unknown	natural	NE Atlantic	
A6.21_UK01		At present the data are not clear enough to faunally resolve this biotope from the one described above. Modification to this biotope is expected following further analysis of UK offshore data.		unknown	natural	NE Atlantic	
A6.11_UK01		At present the data are not clear enough to sufficiently faunally describe this biotope. Modification to this biotope is expected following further analysis of UK offshore data.		unknown	natural	NE Atlantic	
A6.11_UK02		The barnacle species is possibly *Bathylasma hirsutum*, although with physical samples it is impossible to say.		unknown	natural	NE Atlantic	
A6.3_UK01							

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Appendix 3. Glossary

Assemblage Collection of /group of

Bed-forms Any deviation from a flat bed, generated by the flow of an alluvial channel.

Biogenic Resulting from the actions of living organisms.

Biotope is an area of uniform environmental conditions providing living place for a specific assemblage of plants and animals

Broad scale Often used instead of small scale (e.g., 1:250,000), but also implies that the primary purpose of a map is to present an overview of a large area. As opposed to fine scale.

Calcarenites Calcareous sediment in which a high proportion of the sediment can comprise sand within a calcareous matrix or more commonly where both the clasts and matrix are calcareous.

Calcilutites A fine-grained limestone consisting of silt and clay-sized carbonate particles.

Classification A term commonly used to describe the process of interpreting remotely sensed data as habitat classes.

Community A large place or collections of plant or animal organisms sharing an environment.

Cretaceous A period of time between approximately 145.5 and 65.5 million years ago.

Epifauna Epifauna are animals that live upon the surface of sediments or soils.

Fine scale Often used instead of large scale (e.g., 1:10,000), but also implies that the primary purpose of a map is to explore the distribution of small scale features with a measurable degree of accuracy. As opposed to broad scale.

Geogenic Resulting from geological sources

Geographic information system (GIS) A computer assisted mapping system in which a number of data layers and coverages can be overlain and in which multi-layer queries and operations can be performed. Many GIS have special modules that allow spatial statistical operations and image processing. GIS are generally much more powerful than computer assisted drafting (CAD), although the distinction between them is not well defined.

Georeferencing or geo-referencing the process of adding geographic data to yield data or other field attributes either in real-time (on-the-go) or by post-processing or the process of associating data points with specific locations on the earth's surface.

Ground truth Direct observations and samples of the sea floor provide information that can be used to interpret remotely sensed images. Observations used in this way provide ground truth data. The process of using ground truth data for interpretation is often termed ground-truthing. During this process the relationship between properties of the remote images spatially associated with the sample sites (in the form of points, irregular digitised areas or buffer areas around points) are then applied to the whole image. Ground-truthing is distinct from ground validation.

Habitat The physical and biological environment that supports a particular biological community. Used synonymously with biotope and possibly synonymous with other terms such as coenosis.

Habitat classification The organisation of different habitats into specific class types

Habitat map Is a map representative of the type and abundance of species in a given area

Habitat type (EUNIS) Plant and animal communities as the characterising elements of the biotic environment, together with abiotic factors (soil, climate, water availability and quality, and others), operating together at a particular scale.

Heterogeneity The amount of diversity within a region.

Homogeneity The extent to which attributes are similar within a region.

Infauna Animals living within submerged sediments.

Map scale The ratio between a distance on the map and the corresponding distance on the earth

Miocene A period of time between approximately 23 and 5.3 million years ago.

Neogene A period of time between approximately 23 million years ago and modern times.

Oligocene A period of time between approximately 33.9 and 23 million years ago.

Orogenesis mountain-building.

Paleocene A period of time between approximately 65.5 and 55.8 million years ago.

Peneplanation Erosion to produce an extensive sub-horizontal surface.

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Pleistocene A period of time between approximately 1.8 million and 10,000 years ago.

Pliocene A period of time between approximately 5.3 million and 1.8 million years ago.

Prediction All maps derived from classification and modelling are predictive: The mapped distributions are based on statistical links, assumptions and hypotheses between the source data and the classes to be mapped. This underlying predictive nature of maps is often conveniently ignored, but all maps must be judged by their predictive power.

Resolution: Smallest distance separating two points on a map; dimensions of a pixel.

Scale the ratio between the size of something and a representation of it

Sediment type varies according particle size distribution, bulk density, moisture content, organic, content, erosion, transportation and accumulation.

Swath width side scan sonar projects a beam out to the side of the towpath it creates a wide region of insonified seafloor. Both right and left sonar channels make up the swath. Swath width changes with range settings and is a factor in determining coverage and lane spacing.

Tertiary A period of time between approximately 65.5 and 1.8 million years ago.

USBL Ultra-short baseline A position fixing method utilizing a transponder/ responder fitted to the deployed instrument and a transceiver mounted on a vessel at a known and surveyed position below the water line. The direction of origin of received signal from the instrument mounted transponder-responder indicates the towed instrument position relative to the support vessel, while the time delay between transceiver emitted signal and transponder/ responder return signal provides its distance. Positioning of the vessel mounted transceiver is related by survey to the position of GPS antenna, enabling accurate positioning relative the GPS defined position of the vessel.

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