

Deep-water coral mounds on the Porcupine Bank, Irish Margin: preliminary results from the Polarstern ARK-XIX/3a ROV cruise

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Abstract. An overview of preliminary results from a series of recent Remotely Operated Vehicle (ROV) dives on the deep-water coral provinces of the Porcupine Bank, Irish continental margin, NE Atlantic is presented. The Porcupine Bank exhibits numerous giant carbonate mounds (up to 100s of metres in height) that occur predominantly, although not exclusively, on topographic ridges. The results revealed that, although these ridges have a tectonic origin, contemporaneous activity is typified by erosion due to strong hydrodynamic controls. The carbonate mounds are colonized by a variety of suspension feeders and associated fauna including framework-building corals (e.g., *Lophelia pertusa* and *Madrepora oculata*) although dense coral reef-like fauna coverage is not evident at present. The ecology of the carbonate mounds varied widely. Sessile megafauna, such as sponges, gorgonians and framework-building corals (e.g., *Lophelia pertusa*), were abundant on some of the carbonate mounds. Other mounds were relatively barren and appeared to be undergoing a natural senescence, with a much lower biomass of megafauna than is typical of shallow-water coral reefs. Some mounds had been damaged by demersal trawls, with smashed coral and lost gear common, whereas others appeared relatively pristine with occasional evidence of man-made litter.

Keywords. Carbonate mounds, cold-water coral, Irish margin, ROV, biodiversity, trawling impact, hydrodynamics

Introduction

Deep-water corals are widespread along the European continental margin where they are often associated with carbonate mounds. These elevated features are composed of carbonate mud, the skeletal remains of framework-forming corals (particularly *Lophelia pertusa* and *Madrepora oculata*) and material derived from associated fauna together with allochthonous sediment. Carbonate mound growth benefits from positive feedback whereby the corals grow preferentially in elevated positions where they can take advantage of faster flowing waters delivering organic particulate food supply, and avoid the higher concentration of inorganic sediment closer to the benthic boundary layer (Frederiksen et al. 1992; Freiwald 2002). The coral framework traps sediment and also, upon death, provides suitable substrata for renewed growth. This increases mound elevation which enhances environmental conditions and thus stimulates further coral colonisation and growth (see Genin et al. 1986; Freiwald et al. 1999).

Along the Irish margin, these carbonate mounds are massive features being 10s to 100s of metres high and often several kilometres across the base. Seismic investigations suggest that this may in part be due to the longevity of the carbonate mounds in this region with examples on the Porcupine Bank initiated on common erosion surfaces tentatively dated as Late-Early Pliocene (Kenyon et al. 2003; van Weering et al. 2003a, b). Previous studies (Kenyon et al. 1998; de Haas et al. 2002; Akhmetzhanov et al. 2003; Kenyon et al. 2003; van Weering et al. 2003a, b) also note that the Porcupine Bank carbonate mounds (Pelagia Mounds) are relatively isolated, discrete mounds existing in a strong current regime with intermediate nepheloid layers (Dickson and McCave 1986; Kenyon et al. 2003) providing an abundant food supply.

The influence of hydrodynamic processes peculiar to banks and seamounts seem to have an important role in carbonate mound growth. White et al. (2005) and White (in press) point out that circulation around banks along the Irish margin causes the accumulation of nutrient rich waters on the top of banks. This leads to high surface productivity values that in turn provide important enriched food sources to carbonate mound ecosystems. Furthermore, the presence of the banks causes an acceleration of contourite currents as they flow along the margin. Bank topography may also enhance internal wave dynamics (Frederiksen et al. 1992) and a strong (if not dominant) tidal current signal is evident. As these carbonate mounds exist at the boundary between two water masses, rigorous hydrodynamics may allow corals to take advantage of characteristics of both water masses.

The Porcupine Bank (Fig. 1A for location of study area) is an upstanding block between the Rockall Trough (to the west) and Porcupine Seabight (to the east) formed during Mesozoic rifting associated with the opening of the proto-Atlantic (Naylor and Mountney 1975). The northeastern bank is connected to the continental landmass by overlapping western Irish continental shelf sediments. The bank's north-western flank overlies the Macdára Basin and basin boundary faults. Lower slopes (>1000 m water depth) on the margin are typified by submarine canyon systems

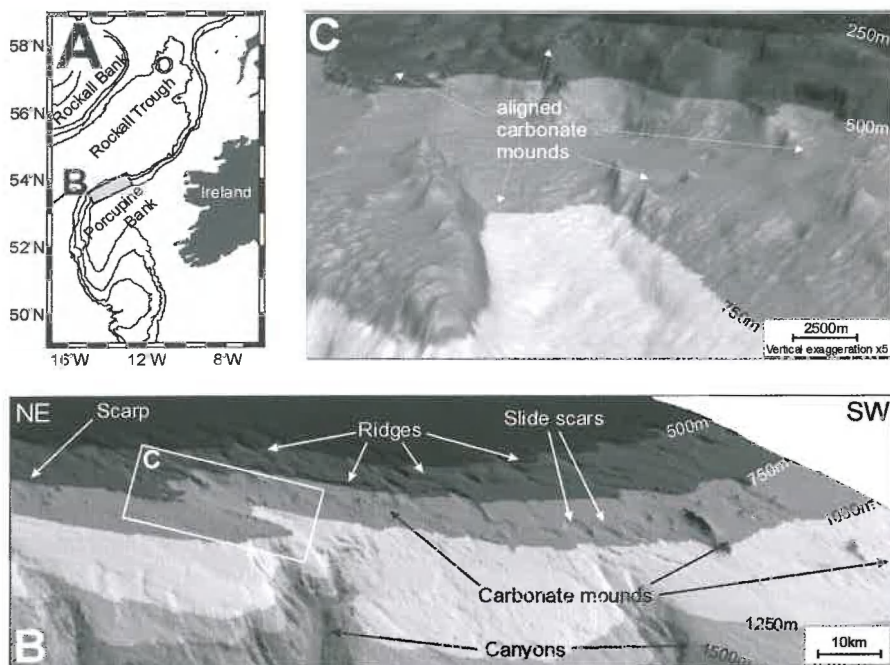


Fig. 1 Morphological setting of features discussed in the text. **A** Location map showing the Porcupine Bank and study area on the Irish continental margin. **B** Digital terrain model of the bank derived from multibeam echosounder data showing ridges, carbonate mounds, scarp and slide scars upslope of submarine canyons. **C** Detail showing carbonate mounds aligned along the crest of topographic ridges

and feeder systems (Fig. 1B). Carbonate mounds exist between 500–1200 m water depth. These occur predominantly on bank sub-parallel topographic ridges (Figs. 1B–C) that overlie boundary faults (Croker et al. 2003) and are interpreted as fault scarps (de Haas et al. 2002). Croker et al. (2003) suggested that a spatial relationship between boundary faults, fault scarps and carbonate mound occurrence might imply a cold seep origin to these mounds due to thermogenic hydrocarbon seepage (*sensu* Hovland et al. 1994) from underlying hydrocarbon reservoirs in the underlying Macdara Basin. Headwall scars due to submarine slides are also evident (Fig. 1B). Upslope areas (<500 m water depth) are dominated by iceberg ploughmarks (de Haas et al. 2002).

This paper presents *preliminary* results from the Remotely Operated Vehicle VICTOR6000 (ROV) deployments from the RV Polarstern in June 2003 that were performed to assess the following research questions.

- To what extent are carbonate mound growth processes influenced by hydrodynamic processes?
- What is the extent of biotic heterogeneity between carbonate mounds?

- Do we find evidence of deep-water trawling activity damaging the coral ecosystem?
- Are the ridges on which carbonate mounds are located a focus for thermogenic hydrocarbon seepage?

Results

Influence of hydrodynamic processes

Abundant evidence is found of a strong benthic current regime in the study area. The seabed between carbonate mounds is typified by sands and exposed dropstones (deposited by melting icebergs) implying strong currents (Fig. 2A). These dropstones provide suitable attachments for sessile organisms including sponges, stylasterids, corals, gorgonians, antipatharians, anemones and barnacles (see Fig. 2A). The strong hydrodynamic regime and the exposed nature of carbonate mounds result in

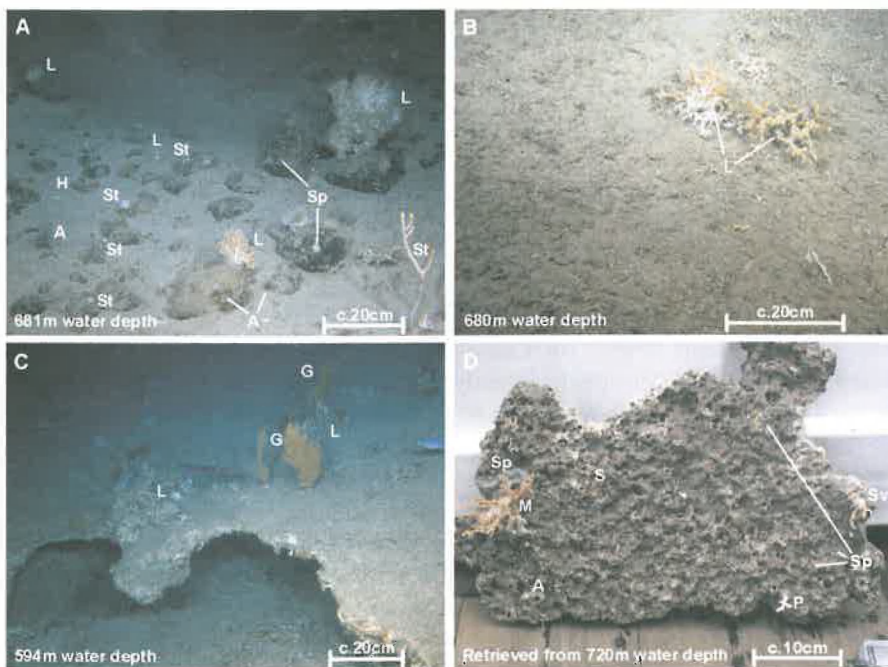


Fig. 2 Visible evidence of a strong hydrodynamic regime on the Porcupine Bank. **A** Typical seabed with sand sediment and exposed dropstones supporting communities of sponges (Sp), stylasterids (St), *Lophelia pertusa* (L) and anemones (A). **B** A typical carbonate mound surface showing exposed dead coral framework providing a firm substrate for attachment of *Lophelia pertusa* (L). **C** Seabed erosion exposing lithified sediments and providing a hardground for colonisation by *Lophelia pertusa* (L), other scleractinians and gorgonians (G). **D** Retrieved hardground showing extensive borings and colonisation by scleractinians including *Madrepora oculata* (M) and *Stenocyathus vermiformis* (Sv), stylasterids (*Pliothrus* sp.) (P), serpulids (S), sponges (Sp) and anemones (A)

very little sedimentary cover on the carbonate mounds themselves with sub-fossil coral frameworks often exposed. Figure 2B shows a typical view with sporadic colonisation of the carbonate mounds by cold-water corals by attachment directly onto dead skeletal material.

In many areas, intense current activity also resulted in physical erosion of the seabed and the carbonate mounds exposing lithified sediment which act as hard substrates (Fig. 2C). These provide firm substrata for colonisation and support a diverse fauna (e.g., *Lophelia pertusa*, *Madrepora oculata*, stylasterids, gorgonians, byssate bivalves (*Asperarca nodulosa* and *Chlamys sulcata*), serpulids and clionid sponges; Figs. 2C-D).

Examination of a 21 km ridge (680 m water depth) revealed carbonate mounds on top of the ridge provided its topographic expression although between mound areas were typified by a vertical escarpment (Fig. 1B). The exposure of soft sediment between hardgrounds exposed on the escarpment (Fig. 3A) suggests that the structure post-dates the last tectonic activity probably occurring as extensional fault reactivation in the Tertiary (e.g., Shannon et al. 2001) and was probably formed by seabed erosion. The alternation of hard and softer sediment may represent Quaternary climatic forcing of sedimentation patterns on the banks with glacial periods typified by sluggish current and high sediment rates and interglacial periods typified by fast currents causing seabed erosion. Preferential cementation of hardgrounds may be due to increased carbonate contents and biological productivity. Some hardgrounds are covered in a thin layer of black metallic oxides suggesting exposure at the seabed.

Biotic heterogeneity between carbonate mounds

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

Preliminary observations (Fig. 4) suggest that the dominant sessile megafauna documented in the study area included corals (*Lophelia pertusa*, *Madrepora oculata*, *Desmophyllum cristagalli*, antipatharians, gorgonians (*Acanthogorgia* sp.) and others), and sponges. Mobile megafauna included conspicuous numbers of echinoderms, fish and crabs. The important habitat complexity provided even by sparse coral coverage showed an enhancement of faunal diversity. While some of the mounds surveyed had relatively low coral cover, there was clear visual evidence that the density and diversity of megafauna was greater on the mounds than on the surrounding seabed (Figs. 4A-C, E; see Olu-Le Roy et al. 2002; Foubert et al. 2005).

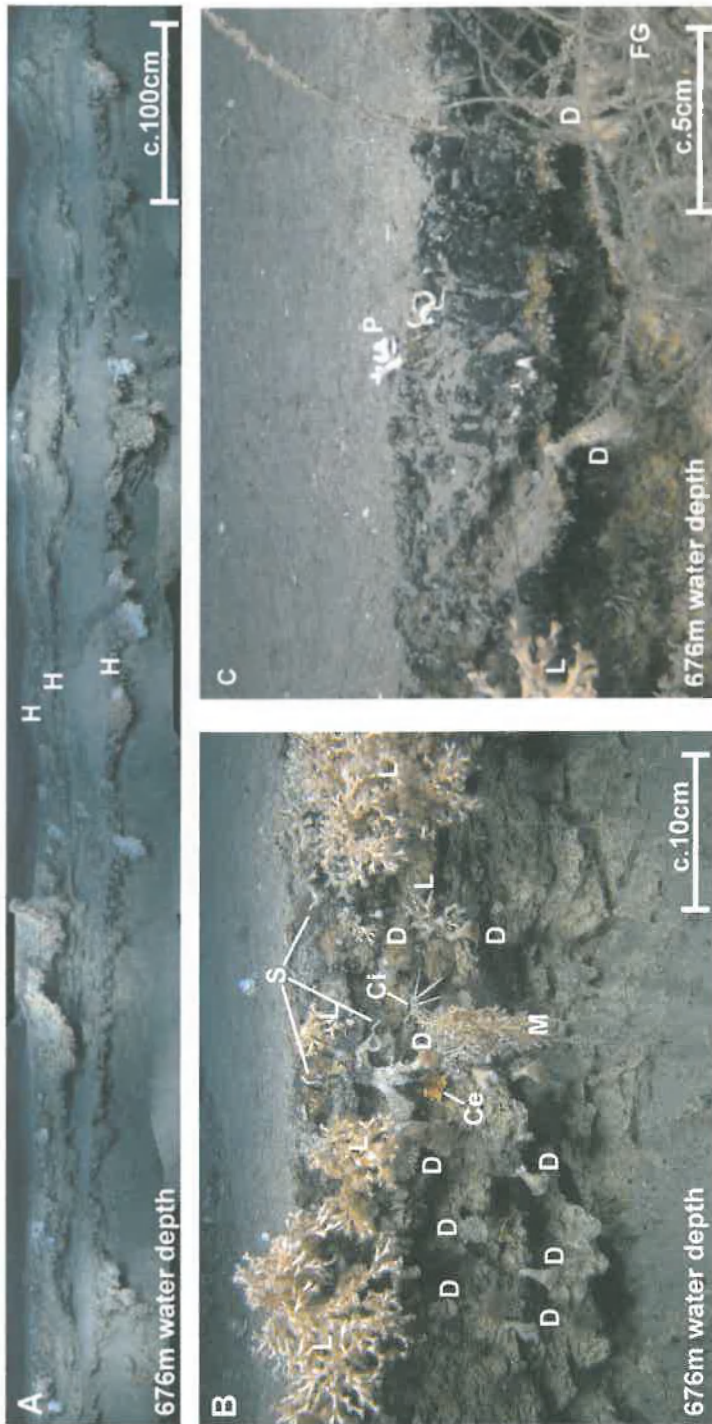


Fig. 3 Eroded seabed scarp colonised by cold-water coral: **A** Photo montage showing the face of the scarp. Several prominent resistant layers (?palaeo-hardgrounds) (H) are evident to which sessile organisms are attached. These prominent layers are separated by softer sediment. **B** Detail of colonisation on the upper hardground showing *Lophelia pertusa* (L), *Desmophyllum cristagalli* (D), *Madrepora oculata* (M), *Cidaris cidaris* (Ci), starfish (*Ceramaster* sp.) (Ce) and serpulids (S). **C** Closer detail of the hardground showing a thin black metallic oxide coating suggesting persistent exposure at the seabed. Some lost fishing gear (FG), *Lophelia pertusa* (L), *Desmophyllum cristagalli* (D) and *Pliobothrus* sp. (P) are also present

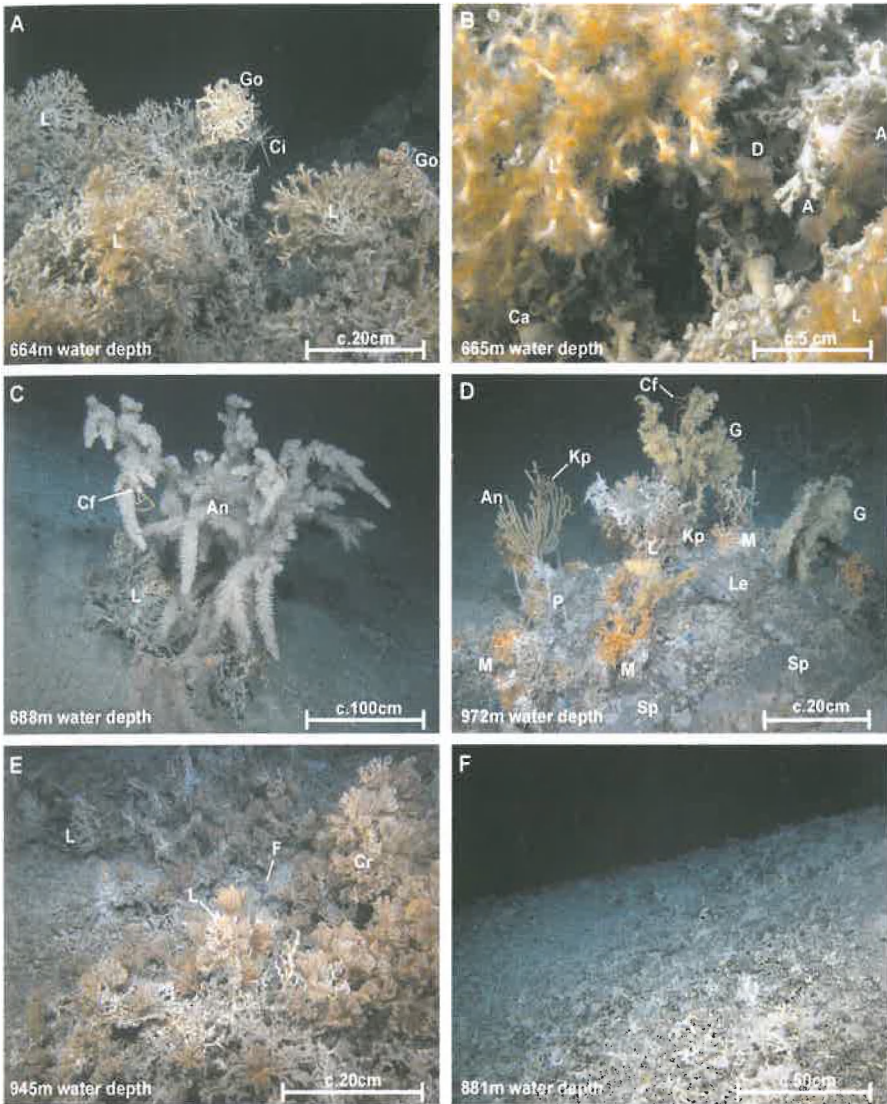


Fig. 4 Selected images showing the variety of organisms and their association encountered on the northwest Porcupine Bank. **A** *Lophelia pertusa* colonies (L) with *Gorgonocephalus* sp. (Go) and *Cidaris cidaris* (Ci). **B** Close up of *Lophelia pertusa* colonies (L) with polyps extended. An anemone (A), a gastropod (*Calliostoma* sp.) (Ca) and *Desmopyllum cristagalli* (solitary coral) (D) are also present. **C** An antipatharian (An) with spider crabs (*Chirostylus formosus*) (Cf) attached to a *Lophelia pertusa* colony (L). **D** Heavily colonised dropstone with several sponge-species (Sp), *Lophelia pertusa* (L), *Madrepora oculata* (M), antipatharians (An), sylasterids (*Pliobothrus* sp.) (P), crinoids (*Koehlerometra porrecta*) (Kp) and spider crabs (*Chirostylus formosus*) (Cf) attached to gorgonians (*Acanthogorgia* sp. and others) (G) as well as a fish (*Lepidion eques*) (Le). **E** Crinoids (Cr) attached to *Lophelia pertusa* colonies (L) with a fish (F) **F** Coral rubble field as a result of demersal trawling activity

Colonised dropstones represent an important habitat on the lower mound flanks and in off-mound areas (Fig. 4D), where they form oasis-like habitats providing hard substrate for many sessile organisms (see Oschmann 1990).

Certain fauna are found on all mounds (including most scleractinian coral species, e.g., *Lophelia pertusa*, *Madrepora oculata* and *Desmophyllum cristagalli*) whereas others seem only to be specific to or dominant on individual mounds (e.g., stylasterids with *Stylaster* sp., crinoids, gorgonocephalids; Figs. 4A, E).

Evidence of deep-water trawling activity

Destruction of the coral habitat by demersal trawling was noted (Fig. 4F; see also Grehan et al. 2003), clearly an even greater concern if certain mounds do harbour specific faunal assemblages. Trawled mounds are characterised by extensive coral rubble fields suggesting that coral cover may have been formerly more extensive here than on the other mounds surveyed in the area. This also suggests that demersal trawling activity (Hall-Spencer et al. 2002) may be targeting mounds with the most prolific coral growth (therefore of the highest conservation value) due to related high fish populations.

Thermogenic hydrocarbon seepage

Despite 88 hours of dedicated dive time on carbonate mounds, no gas bubbles, authogenic carbonate crusts, bacterial mats, chemosynthetic fauna (e.g., tube worms, pogonophorans or distinct molluscs species), pockmarks or any other evidence of cold seepage were found (see Dando and Hovland 1992; Sibuet and Olu 1998).

Preliminary conclusions

Fast-flowing currents along the Porcupine Bank at depths where cold-water corals and resultant carbonate mounds occur induces seabed erosion thereby providing hard substrata, in the form of exposed dropstones and hardgrounds, suitable for the colonisation by sessile megafauna. Paradoxically, at present seabed erosion seems to be the dominant process stimulating renewed colonisation of carbonate mounds by framework building corals and therefore mound growth. This mechanism may also explain the stratigraphy exposed on escarpments with climate controlled alternations in sediment and hydrodynamic regimes producing a repetition of soft sediment overlain by hardgrounds (see Fig. 3A).

Surveys of a variety of mounds showed that although megafaunal species cover was reduced in comparison with some other mound provinces (e.g., the Galway Mound; Foubert et al. 2005), biodiversity remained high with mounds offering an important habitat to corals, gorgonians, antipatharians, sponges, crustacea and fish. Demersal trawling has produced drastic alterations to the ecology of impacted carbonate mounds.

Previous studies have identified a number of ridges and scarps on the Porcupine Bank where carbonate mounds were preferentially located (de Haas et al. 2002). The coincidence of boundary faults overlying hydrocarbon reserves led to speculation

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

Acknowledgements

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