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## Chapter 2

# AN OVERVIEW ON COLD-WATER CORAL ECOSYSTEMS AND FACIES

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## INTRODUCTION

Corals are often associated with tropical scenarios, like the Great Barrier Reef, bordering the north-eastern coasts of Australia, which is the largest reef in the world, or evoke the view of tropical atolls of which the Maldivian atolls are one of the most impressive examples. In this context coral bioconstructions thrive in warm-, well-illuminated and oligotrophic waters, and are a ‘hot spot’ for marine biodiversity. The full spectrum of biological and geological actors in these ecosystems has been the subject of scientific studies for many years. However, the investigation and public awareness concerning cold/deep-water coral ecosystems is a recent issue, which has been increasing in the last two decades.

Cold-water corals have been known since the eighteenth century. Pontoppidan (1755), Linné (1758), and Gunnerus (1768) first documented their occurrence in Norway and provided their taxonomic description. Their detailed investigation began only recently, fueled by the discoveries of giant deep-water coral mounds in the Porcupine Seabight (e.g., Henriet and others, 2002). Since then, the study of cold-water coral ecosystems has largely increased as a result of the development of latest generation technologies such as submarines (Figs. 2.1, 2.2) and Remote Operated Vehicles (ROVs) (Fig. 2.3, 2.5), that allow non-invasive investigations even at high depths.

The knowledge of the functioning of cold-water coral ecosystems is presently increasing in parallel with the awareness that they might be under serious threat and that damage and habitat losses may endanger their existence (Fosså and others, 2002). Fishing activity, hydrocarbon drilling, cable and pipeline placement, bioprospecting, destructive scientific sampling, and ocean pollution are perturbations influencing the coral ecosystems as documented in the UNEP-WCMC Report “Cold-water Coral Reefs” (Freiwald and others, 2004). Additionally, these ecosystems can be affected by climate change and ocean acidification (Guinotte and others, 2006). Cold-water coral buildups might be one of the most vulnerable marine ecosystem not only because the main reef builders (*Lophelia pertusa* and *Madrepora oculata*) are provided with aragonitic skeletons, but also

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Figure 2.1. Submarine operated vehicle developed for sampling within the coral branches without damaging them (Scale: ~20 cm). Picture taken by JAGO-Team, GEOMAR Kiel, from the Sula Reef, Norway.

because the solubility of $CO_2$ in the water is higher at low temperatures where these organisms develop (Guinotte and others, 2006). Although recent studies show that some cold-water corals can adapt to long-term environmental modifications (Form and Riebesell, 2012), still too little is known about the ecophysiology of these organisms. Further studies need to be promoted in order to obtain an efficient reaction from governmental institutions and policy makers for the protection of these vulnerable ecosystems.

The books "Cold-Water Corals and Ecosystems" (Freiwald and Roberts, 2005), "Deep-Water Coral Reefs: Unique Biodiversity Hot-spots" (Hovland, 2008) and "Cold-Water Corals: The Biology and Geology of Deep-Sea Coral Habitats" (Roberts and others, 2009), and the Special Issues of Marine Geology "Cold-water Carbonate Researvoir systems in Deep Environments – COCARDE" (Spezzaferri and others, 2011), and Deep-Sea Research II "The APLABES Programme: Physical Chemical and Biological Characterization of Deep-Water Coral Ecosystems from the Ionian Sea (Mediterranean)" (Corselli, 2010) and "Biology and Geology of Deep-Sea Coral Ecosystems: Proceedings of the Fifth International Symposium on Deep Sea Corals" (Mienis and others, 2014) contain a very detailed overview about our present knowledge on modern and ancient cold-water corals. Despite these summaries the functioning and the distribution of cold-water corals is far to be fully understood as it is for the warm-water reefs, although they occur at a worldwide dimension. The cold-water coral *L. pertusa*, the main reef builder (Figs. 2.2 A–C, E, 2.3 A, 2.4 A–D), is cosmopolitan but it occurs very frequently in the NE Atlantic Ocean and in Norway it reaches its highest known density giving rise to very extensive reefs (e.g., Zibrowius, 1980; Freiwald and others, 2004) (Figs. 2.2 A–C, E).

Since the pioneering work of Hovland and others (1994), many studies have been conducted on the sedimentary setting of cold-water coral ecosystems. In particular, cold-water coral ecosystems are described and classified on the basis of their sedimentary facies and type of coral coverage. In general, two main groups of facies have been distinguished and named as (1) on-reef and (2) off-reef facies. The former are located on top/flanks of topographic highs (e.g., mounds, banks) and dominated by live and dead frame-building corals and coral fragments (Figs. 2.2, 2.3A-B). The latter are typical of inter-mound areas where sand, silt, silty clay locally associated with coarser elements, such as boulders and pebbles, represent the dominant seafloor features (Figs. 2.2; 2.3 C-D). In particular, Freiwald and others (2002) recognized five on-reef and two off-reef facies in the Sula Reef Complex (Norway). Foubert and others (2005) introduced 12 different sedimentary facies for seabed classification to interprete ROV video surveys in the Belgica Mound Province. The study of Dorschel and others (2007) reduced the number of the different facies to seven from Galway Mound top down to the basin. Margreth and others (2009) and Spezzaferri

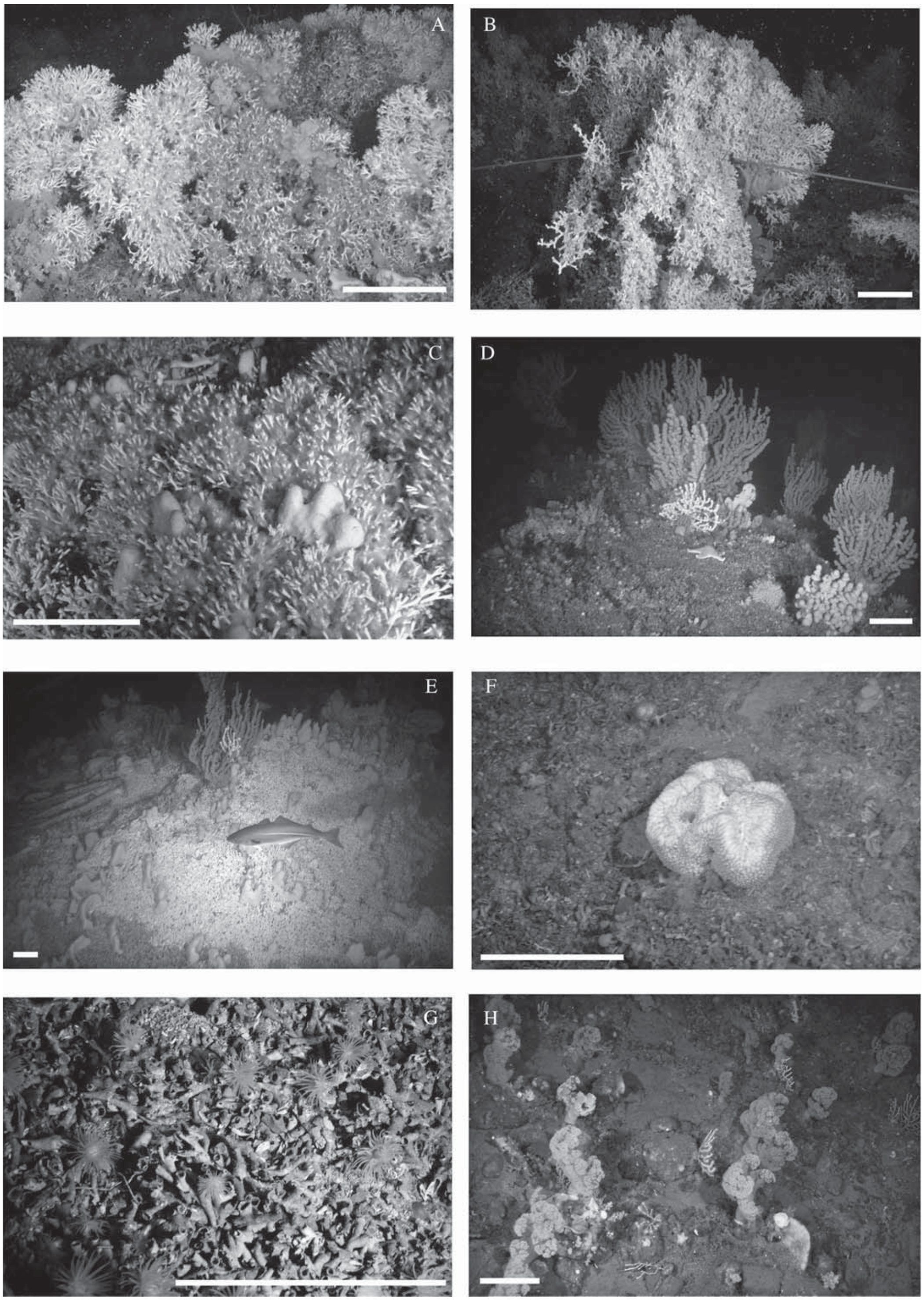

Figure 2.2 A-H. Seafloor images of Norwegian coral reefs taken by JAGO Team, GEOMAR Kiel. A) *Lophelia pertusa*, living coral facies, Røst Reef, Northern Norway (ARK-XXII, dive 999), B) Living coral facies; note the rope and/or cable among *Lophelia* branches, Røst Reef (ARK-XXII, dive 1001); C) Detail of *Lophelia* branches and associated sponges (probably *Mycale lingua*), living coral facies, Stjernsund, Northern Norway (P325, dive 912); D) Large colonies of the octocoral *Paragorgia arborea* in a coral rubble facies, Stjernsund (P325, dive 912); E) Sponges, octocorals and live *Lophelia* branches, living coral facies, Stjernsund (P325, dive 912); F) Demospongiae, coral rubble facies, Røst Reef (ARK-XXII, dive 999); G) Coral rubble facies characterized by very common tiny anemones, Stjernsund (P325, dive 914); H) Dropstone facies dominated by Alcyonacea, Røst Reef (ARK-XXII, dive 1001). Scale bars: 20 cm in the foreground of images.

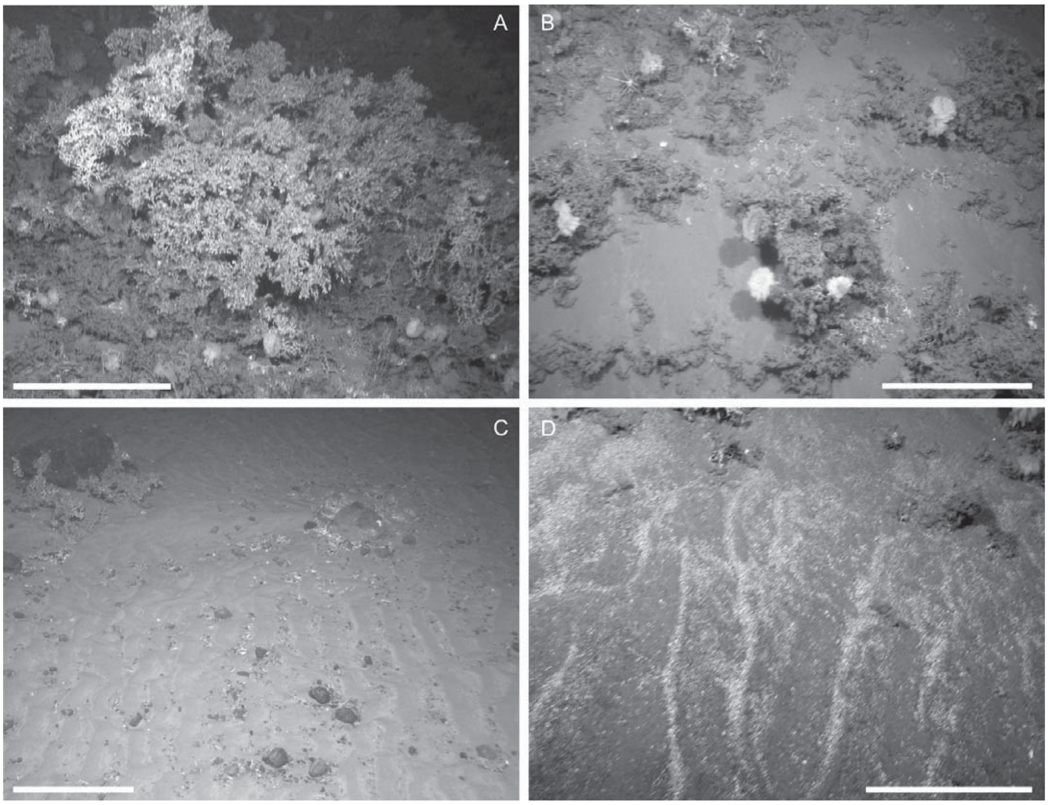

Figure 2.3 A-D. Seafloor images of the Moira Mounds (Porcupine Seabight) acquired by the Holland 1 ROV during the Venture cruise (Wheeler et al. 2011b). A) Live large colonies of *L. pertusa*, Living Coral Facies, dive 33. B) Coral rubble and dead coral colonies on rippled sandy seafloor, Coral Rubble Facies, dive 30. C) Rippled sand and dropstones, Sand and Dropstone Facies, dive 33. D) Sand and Biogenic Gravel Facies, dive 30. Scale bars: 50 cm in the foreground of images.

and others (2013) summarized the sedimentary facies in the Porcupine/Rockall region and along the Norwegian margin keeping into account the models proposed by Foubert and others (2005); Dorschel and others (2007); Mortensen and others (2001); Freiwald and others (2002) and related them to foraminiferal assemblages. Rosso and others (2010), Vertino and others (2010) and Savini and others (2014) highlighted the main features and spatial distribution of cold-water coral thanatofacies and video-detected macrohabitats from Mediterranean mounds (Ionian Sea).

All authors use the amount of living corals as a main parameter for “activity” of cold-water carbonate ecosystems. For instance, if living corals are abundant, the mound is considered as in a growing state - a so-called “active” or “active growing” mound (Henriet and others, 2002; Rüggeberg and others, 2007). If living corals are absent and pelagic sediment covers the mound, it is then defined as a “buried” mound and is only visible on seismic sections (De Mol and others, 2002; Freiwald and others, 2002).

Below we present an example of cold-water coral facies from active mounds: the Moira Mounds (MM), small-scaled reliefs located at ∼1000 m depth in the Porcupine Seabight, NE Atlantic and colonised by cold-water corals (e.g., Wheeler and others, 2011a, b; Foubert and others, 2011; Spezzaferri and others, 2012). Three main facies groups have been so far distinguished in the MM, but transitional facies are rather common: Living Coral (LC) and Coral Rubble (CR) Facies (Fig. 2.3 A-B); Sand and Dropstone Facies (SD) (Fig. 2.3 C); Sand and Biogenic Gravel (S-BG) Facies (Fig. 2.3 D). Further studies are currently underway for a more detailed description of both sedimentological and faunistic features of the Moira Mounds.

## LIVING CORAL AND CORAL RUBBLE FACIES

Living Coral (LC) and Coral Rubble (CR) Facies are typical of the Moira Mound tops. They are character-

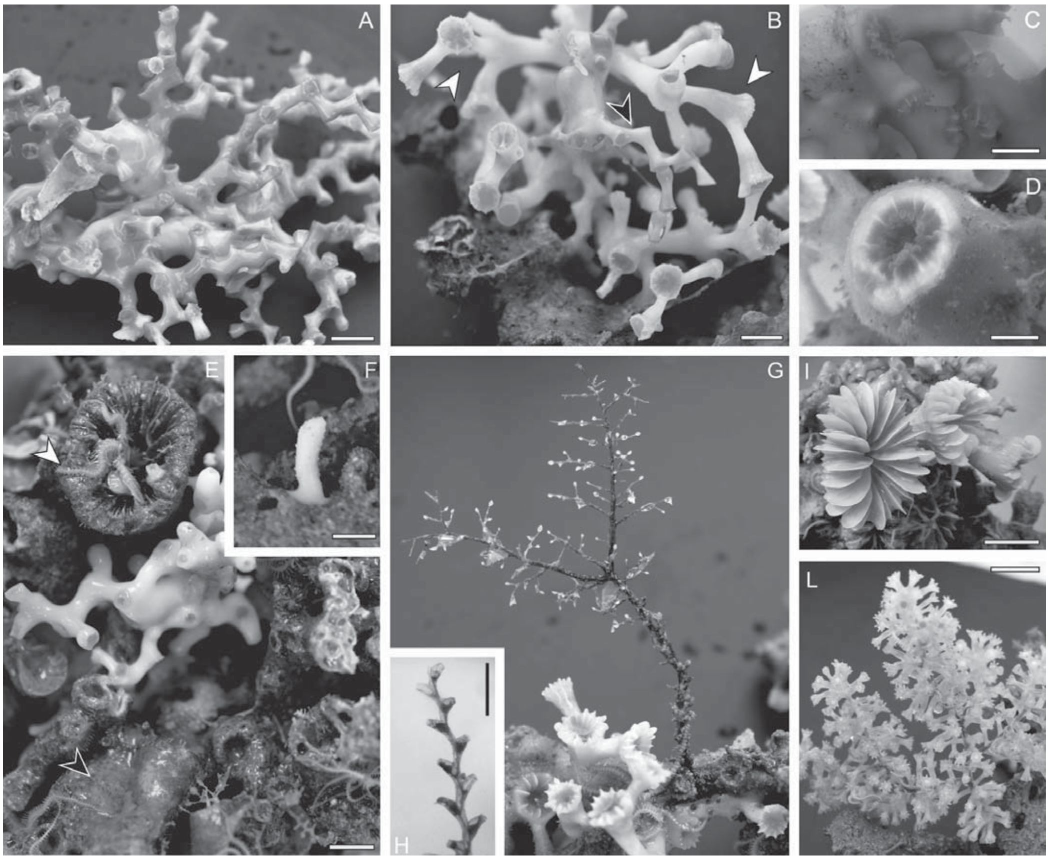

Figure 2.4 A-L. Images of seafloor samples collected during the Eurofleets CWC-Moira Cruise, 2012, from Living Coral (LC) and Coral Rubble (CR) Facies. A) Small colony of the frame-building scleractinian *Madrepora oculata*. B. Small colonies of the frame-building scleractinians *Lophelia pertusa* (white arrow) and *M. oculata* (black arrow). C-D) *Lophelia* corallites; flared (C) and swollen (D) morphotypes. E) Dead and black-coated scleractinian frame colonised by live epifauna: among which a tiny *Madrepora* colony (in the centre), encrusting sponges (black arrow), hydroids, brachiopods, ophiuroids (white arrow). F) Small branch of the stylasterid *Pliobothrus symmetricus*. G) Scleractinian corals as a substrate for hydrozoan colonies. H) Close-up of a hydrozoan. I) Live *Desmophyllum dianthus*. L) Tiny gorgonian colony. Scale bar: 2 cm (D, I); 1cm (A, B, C, E, F, G), 0.5 cm (H, L).

ized by dense coverage of live and dead colonies (and/or colony fragments) of frame-building corals (*L. pertusa* and *M. oculata*) and subordinate sandy to muddy sandy sediments (Figs. 2.3 A-B). In the LC Facies, *Lophelia* colonies can exceed 80 cm in size (Fig. 2.3 A). Their corallites show the typical flared shape (Fig. 2.4 C), but in some samples may display a peculiar swollen aspect (Fig. 2.4 D) (Beuck and others, 2007). In the CR Facies exposed coral branches are mostly dead, bioeroded and variably stained with brownish Fe/Mn oxides (Figs. 2.3 B; 2.4 E; 2.5 A). In both LC and CR Facies dead coral skeletons serve as substrate for many other sessile organisms: solitary corals, such as *Desmophyllum dianthus* (Fig. 2.4 I) and *Caryophyllia sarsiae*, hydrozoans (including rare and tiny colonies of the skeletonised species *Pliobothrus symmetricus*; Fig. 2.4 F-G), gorgonians (Fig. 2.4 L), actinians (Fig. 2.5 C), zoantharians, sponges (Fig. 2.4 E), agglutinant polychaetes, serpulids, bryozoans (mostly Cyclostome erect colonies), bivalves, brachiopods (Fig. 2.5 A), very tiny stalked crinoids (Fig. 2.5 D) and other sessile echinoderms (Fig. 2.5 E), cirripedes (Fig. 2.5 F) and foraminifera. Moreover several boring organisms, such as sponges, polychaetes and actinians (Fig. 2.5 A-B) may highly infest the coral skeletons. The vagile fauna of both LC and CR Facies is typically characterized by Ophiuroidea (Figs. 2.4 E, 2.5 G), locally very abundant, polychaetes such as the genera *Eunice* and *Lumbrineris* and several species of gastropods (Fig. 2.5 H).

## SAND AND DROPSTONE FACIES

The Sand and Dropstone (SD) Facies can be found in the basal part of the mound flanks but it is typical of

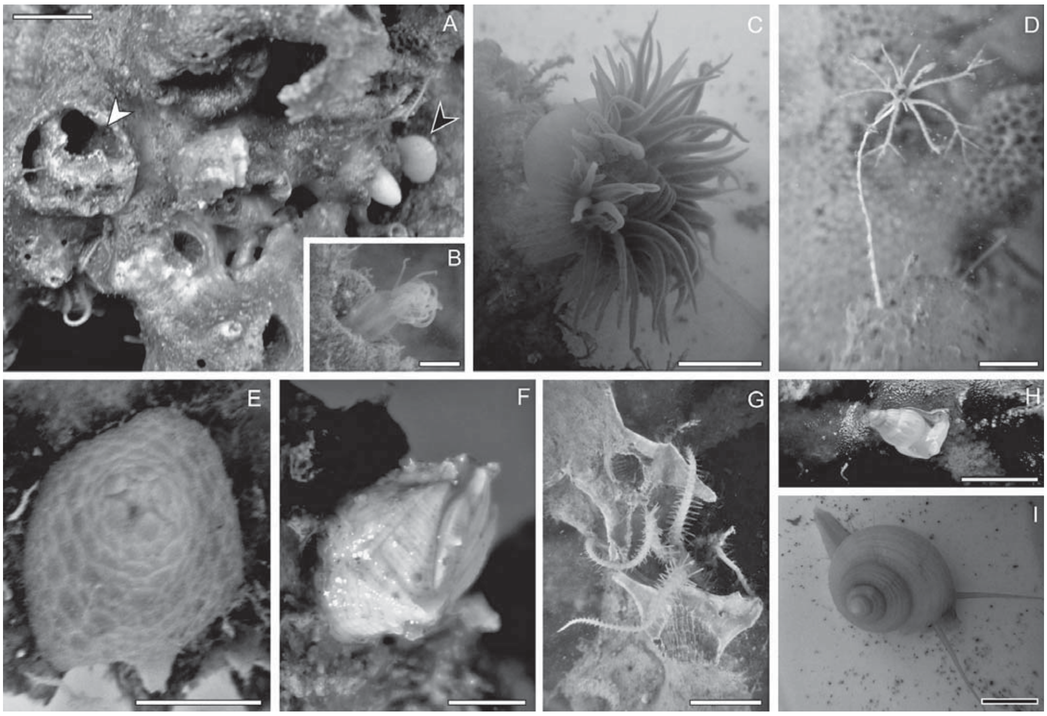

Figure 2.5 A-I. Images of seafloor samples collected during the Eurofleets CWC-Moira Cruise, 2012, from Living Coral (LC) and Coral Rubble (CR) Facies. A) Bioeroded and dark-coated coral frame showing cavities created by boring sponges (white arrow) and several epizoans among which the brachiopod *Terebratulina retusa* (black arrow). B-C) Actinians, note the boring *Fagesia* sp. in B. D) Tiny stalked crinoid on the sponge *Aphrocallistes bocagei*. E) Sessile echinoderm (*Psolus* sp.). F) Cirriped of the family Verrucidae. G-I) Vagile fauna: an ophiuroid within a coral branch hole. G) The gastropods *Amphissa acutecostata*. (H) *Calliostoma* sp. Scale bar: 1cm (A, E, F, G, I), 0.5 cm (B, C, D, H).

intermound areas. It is characterized by sandy to muddy sediments and heterometric dropstones (from 1–2 cm up to 13 cm in maximum diameter), from densely to loosely distributed on the soft sediment (Figs. 2.2 H; 2.6). Dropstones are mostly colonised by hydrozoans, agglutinant polychaetes, benthic foraminifera and secondarily by bryozoans and rare chitons. On the surface of the sandy sediments mm- to cm-sized biogenic fragments are generally common and locally abundant, mostly characterized by cirriped and echinoid plates, gastropods,

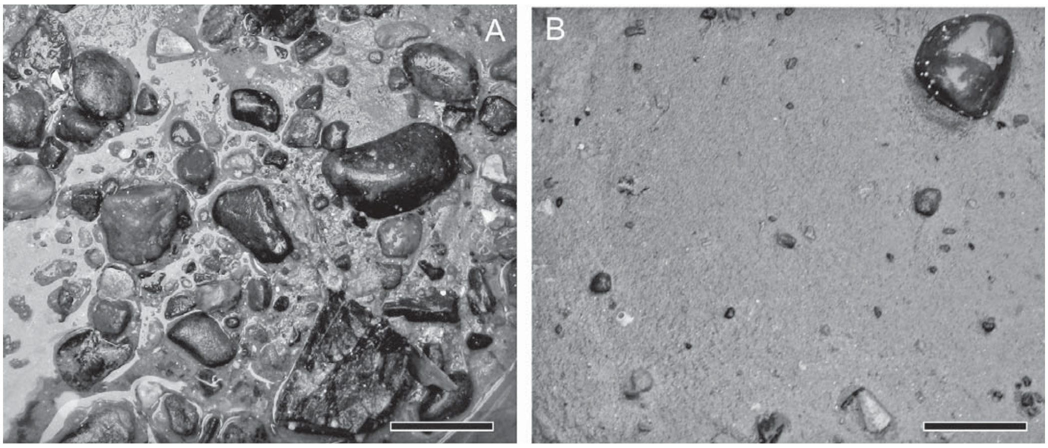

Figure 2.6 A-B. Images of seafloor samples collected during the Eurofleets CWC-Moira Cruise, 2012, from the Sand and Dropstone (SD) Facies with A) densely and B) loosely packed dropstones. Scale bars: 4 cm.

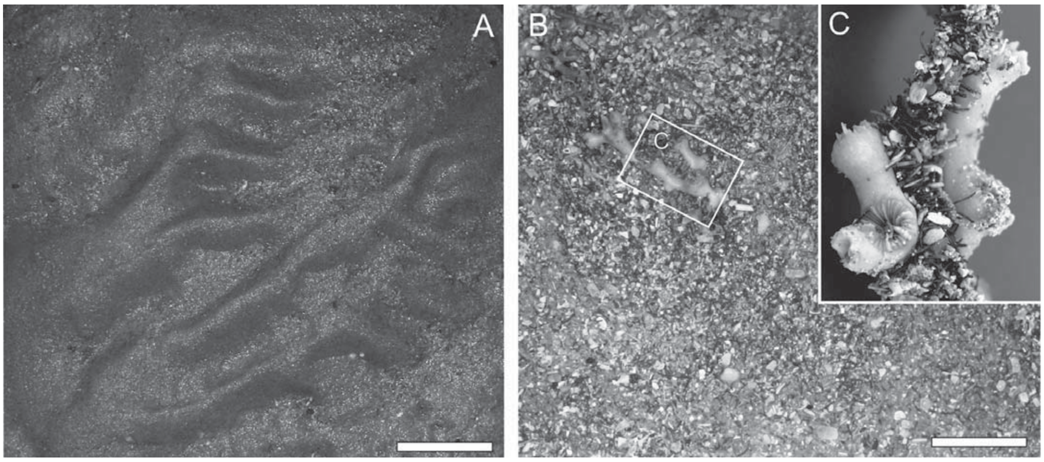

Figure 2.7 A-C. Images of seafloor samples collected during the Eurofleets CWC-Moira Cruise, 2012, from the Sand and Biogenic Gravel (S-BG) Facies. A) Micro-rippled sandy surface of a box-core. B) Biogenic gravel facies. C) Close-up showing an agglutinant polychaete tube encrusting a dead *Lophelia* branch. Scale bars: 4 cm.

bivalves and dentaliids. *Madrepora* and *Lophelia* fragments, as well as echinoid spines, can be rather abundant in the millimetric fraction of the sediment.

## SAND AND BIOGENIC GRAVEL FACIES

The Sand and Biogenic Gravel (S-BG) Facies is typical of inter-mound areas but can be found also along the mound flanks. It is dominated by sandy to muddy sediment and/or by bioclastic gravel (Figs. 2.3 D; 2.7 A-B) locally including relatively large coral fragments (Fig. 2.7 B-C). In the Moira Mound region the sandy facies commonly show well developed ripples (Fig. 2.3 C; see also Foubert and others, 2011). They can even be detected as micro ripples in box-corer samples with up to 3 cm wavelengths (Fig. 2.7 A). The mm- to cm-sized bioclastic fraction of the sediments belonging to the S-BG Facies is normally dominated by coral fragments, echinoid spines but includes also rather common *Cidaris* and cirriped plates, benthic molluscs (typical of both hard and soft substrates), pteropods and otolithes. Peculiar agglutinant polychaete tubes (Fig. 2.7 C) may encrust large coral fragments.

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