Cold water corals and carbonate mounds in the North Atlantic Ocean

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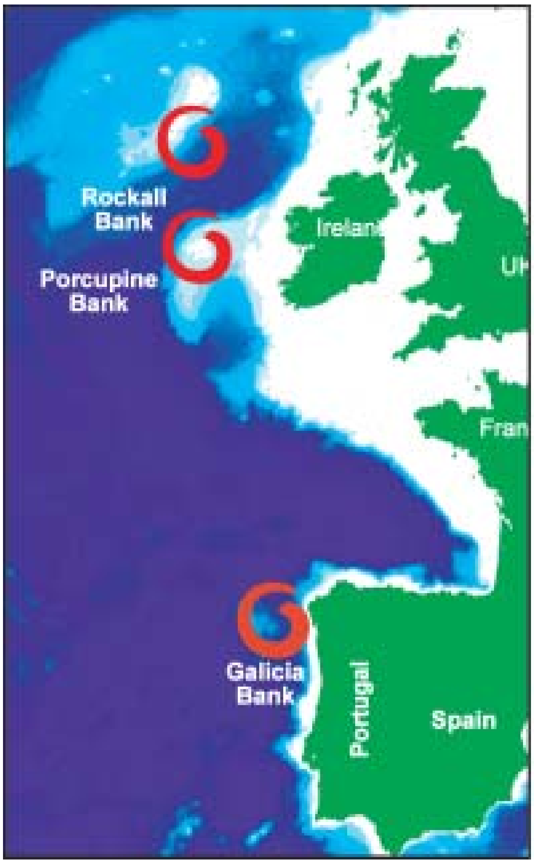
Coral reefs are usually associated with the sunlit tropical coastal waters of the world. Cold water corals (although described in scientific papers for over a century) were found to build reefs of similar dimension as the tropical reefs in cold, deep, and dark waters of continental margins only recently. Numerous recent occurrences of cold water corals are concentrated in a belt along the European Atlantic margin, stretching from southern Spain to northern Norway at several tens to more then thousand metres water depth.

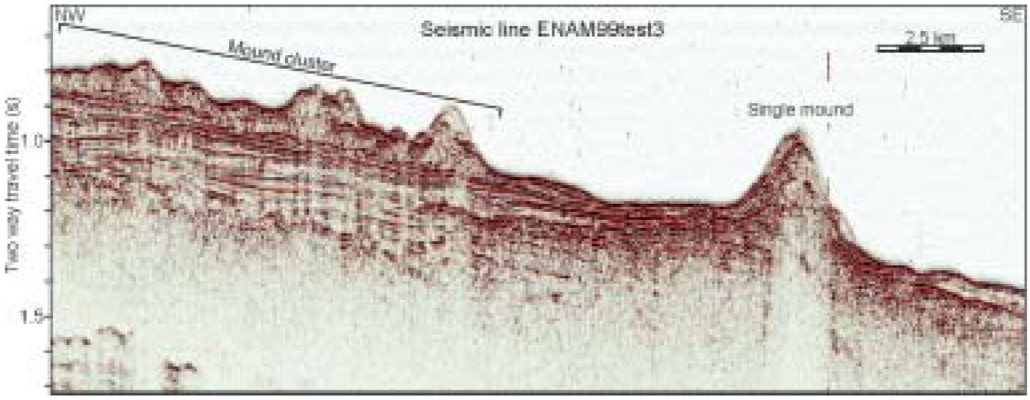
In the period 2000-2003, ecological, environmental and geological aspects of cold water corals found along the western European continental margin were investigated within the ACES, ECOMOUND and GEOMOUND projects, funded by the European Commission. The GEOMOUND project focused on the geological evolution of these mounds, while the major objective of ECOMOUND was to define their environmental controls and to study the processes involved in the development and distribution of these phenomena. The main goal of ACES was an environmental baseline assessment of the status of the deep-water coral community and to provide recommendations for future sustainable development of the European margin.

Within these international projects, the MCG department focused on the corals of giant carbonate mounds found on the margins of the southern Rockall Trough, situated W to NW of Ireland. In close co-operation with the European partners in these projects NIOZ, organised three cruises with R.V. Pelagia to the Rockall Trough. A NIOZ team also participated in the Caracole cruise with R.V. l'Atalante organised by IFREMER (Brest), during which the corals and carbonate mounds were studied using the ROV `Victor'. Within the framework of the ACES project the department of MEE made a study of the ecology of a cold coral community living at 800 m depth on top of Galicia Bank, a seamount off NW Spain. The area was visited during a number of cruises with the R.V. Pelagia.

The locations of the various research areas are shown on the map.



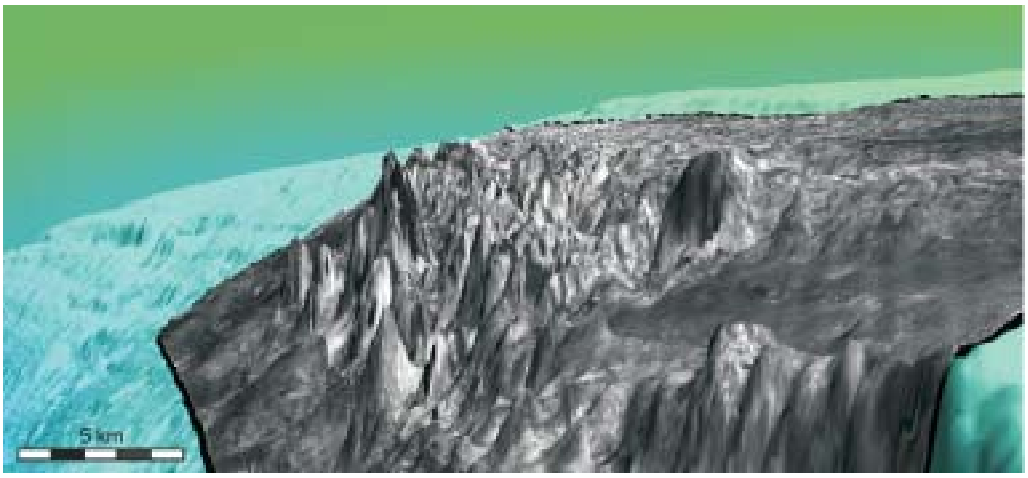
Map of the European margin with cold-water coral research areas indicated.



Part of seismic line ENAM99test3 located on the SW Rockall Trough margin showing a large single mound on the lower part of the slope and a cluster of mounds on the upper slope.

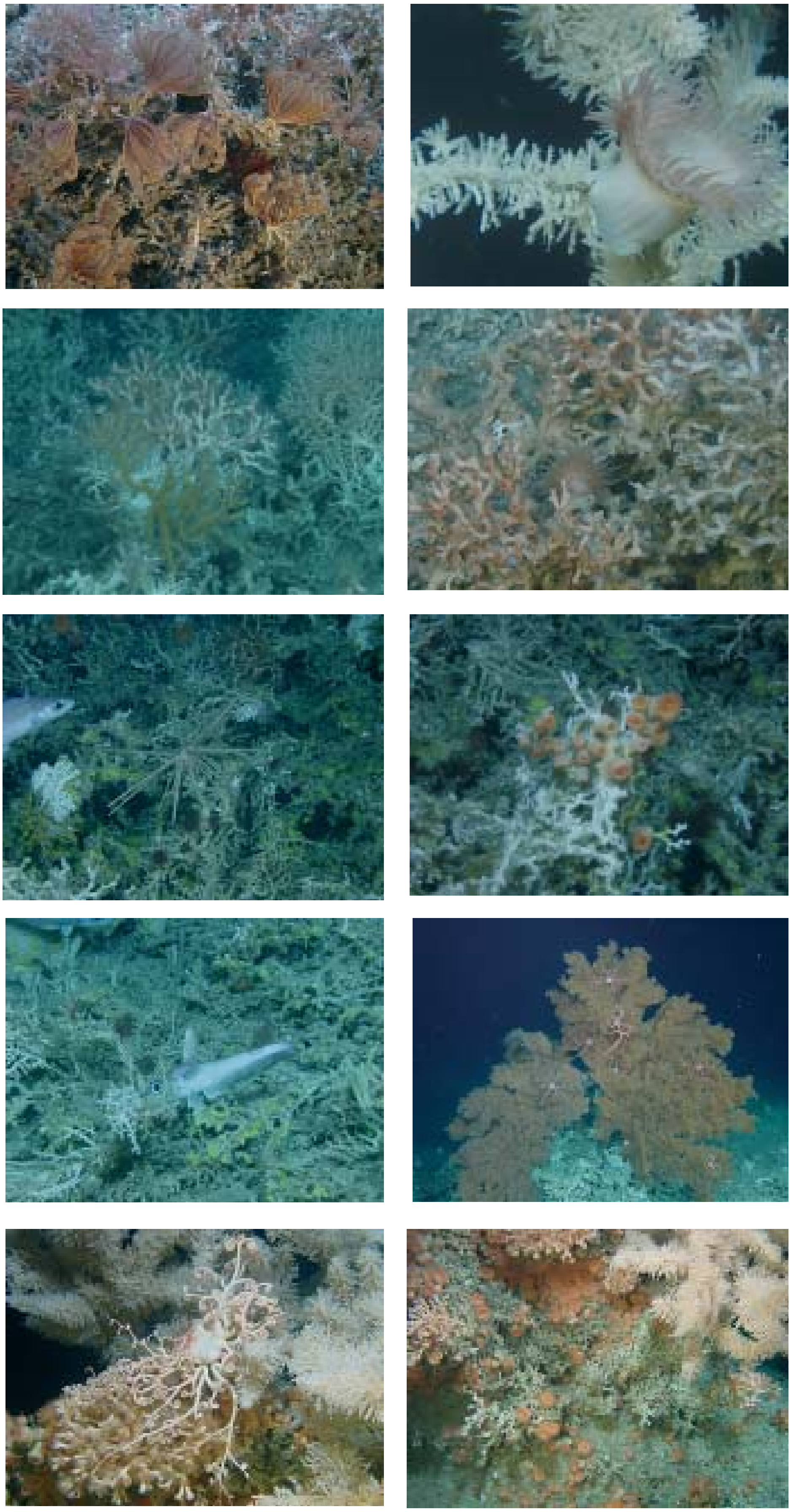
Giant carbonate mounds of the southern Rockall Trough

Whereas the first recordings of giant carbonate mounds on seismic profiles of the Rockall Trough (see example) seemed pure chance hits, more detailed echosounder surveying of the area showed that numerous mounds are present. These giant mounds range from a few tens to 350 metres in height and have a maximum diameter of several kilometres. The most striking images of the variety of mound morphologies present on the Rockall Trough margins were obtained during a survey with the TOBI side-scan sonar, operated by the Southampton Oceanography Centre, and carried out on board of the R.V. Pelagia. This survey showed a field of giant mounds on the SW Rockall Trough margin, stretching out more than 70 km between the 600 and 1000 m isobaths. To get an impression of the size of these mounds see the image of the side-scan sonar data draped over a 3D bathymetric map of the area. The mounds often occur in elongated clusters, separated from adjacent clusters by valleys oriented roughly perpendicular to the depth contours. Toward shallower depths a transition from giant to smaller mounds to coral-covered giant sand waves to active sand waves is observed. On the southeastern margin of the Rockall Trough mounds usually occur as isolated objects. Only one cluster of mounds has been observed on this part of the margin.



TOBI side-scan sonar image of the SW Rockall Trough margin draped over high resolution bathymetry of the area. View is towards the south-west. Water depth at top of the side-scan sonar image (grey) is 550 m, depth at lower boundary is 1300 m. The horizontal scale bar only applies for the front part of the image. Vertical exaggeration about 25 times. (Image in co-operation with the Southampton Oceanography Centre.)

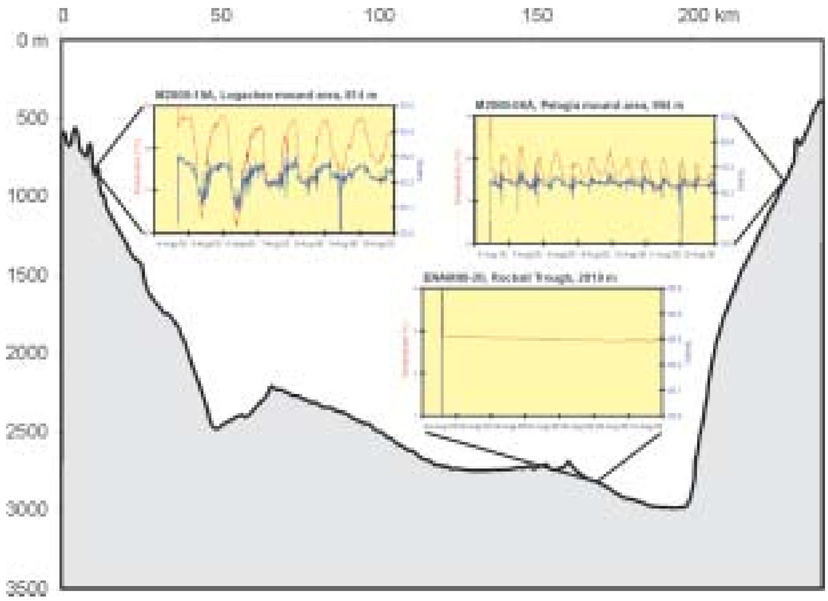
Photo and video imaging of the seabed reveals that the areas surrounding the mounds are often littered with pebble to boulder sized dropstones, derived from icebergs that drifted over the area during glacial times. The fact that these relicts from glacial times are not covered by recent sediments indicates that since the last glacial period no net sedimentation occurred. In the direct vicinity of mounds, dropstones are colonized by a variety of sessile fauna, such as sponges, octocorals, solitary hexacorals, bryozoans and brachiopods. Small isolated colonies of hexacorals are found. Travelling from the base towards the top of the mounds, the amount of coral debris and living coral increases. As is shown on the photographs, the summits of most mounds are marked by the presence of abundant living cold water corals (mainly *Lophelia pertusa* and *Madrepora oculata*) and associated fauna (other species of corals, brachiopoda, crinoids, pelecypoda, bryozoa, hydrozoa, echinoids, various types of shrimps, sponges, fish, etc.). Often the living corals are not evenly distributed but occur in decimetre to many metres sized patches alternating with dead colonies or coral debris. New coral colonies can settle on any hard surface present (dead corals, rocks, shells, hardgrounds, man-made objects dumped



Cold water corals and associated fauna at the Rockall Trough margins. Photographs taken with ROV Victor (copyright IFREMER).

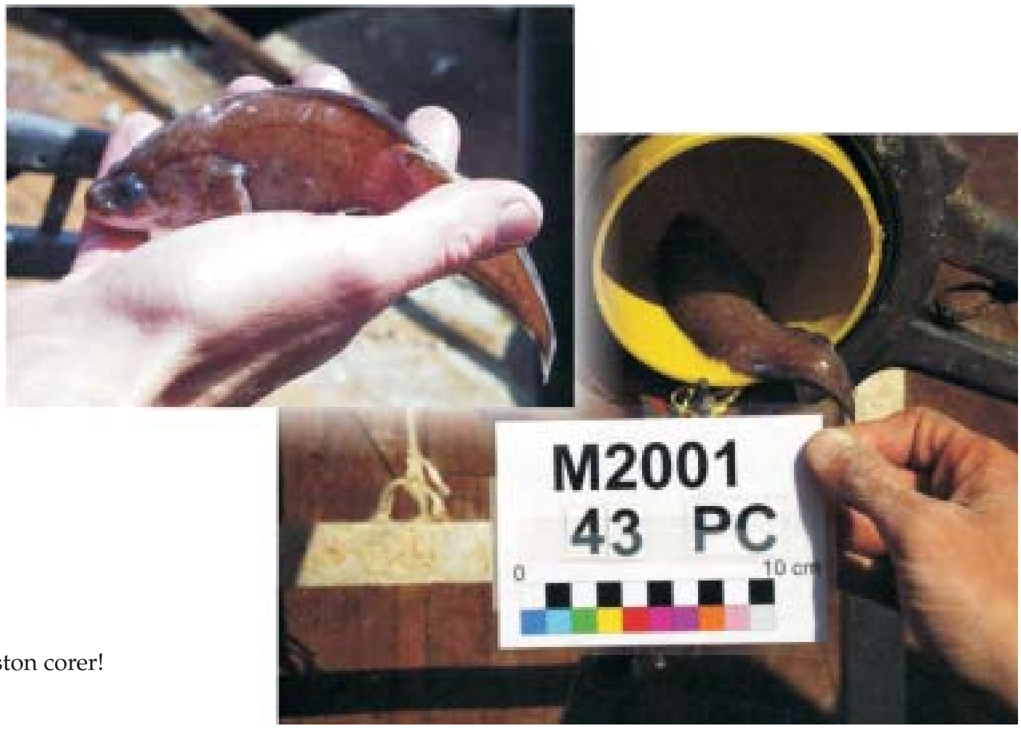
from ships, etc.). Seismic profiling, seabed photographs and video and core data suggest that the mounds are formed by baffling of sediment particles (predominantly skeletal debris of corals and other benthic animals and planktonic foraminifera) in the three dimensional coral framework. In this way sedimentation on the mounds occurs much faster than on the surrounding sea floor resulting in the vertical growth of the carbonate mounds.

The dominance of suspension feeding fauna on the carbonate mounds, and the presence of exposed glacial material on the areas surrounding the mounds, both indicate that the mounds are swept by relatively strong currents. This has been confirmed by observations made with free-falling benthic landers, recording near-bottom current velocity, temperature, salinity and turbidity on and in between mounds for periods of days up to one year. Examples of these measurements are shown plotted in relation to the position of the observations in the Rockall Trough. Instantaneous current speeds of between 10 and 20 cm s^{-1} on average were measured, with peaks exceeding 40 cm s^{-1}. Current directions showed a distinct tidal variation, of semi-diurnal frequency on the SE margin of Rockall Trough, and diurnal frequency on the opposite, SW margin. Associated with the tidal variations in bottom currents, temperature and salinity of the near-bottom water were found to fluctuate by more than 1°C and 0.1, respectively, on the SE margin, and by over 2°C and nearly 0.15, respectively, on the SW margin. CTD observations made concurrently with the benthic lander deployments showed that the near-bottom hydrodynamic regime is imposed by large tide-induced internal waves at the base of North Atlantic Current waters that flow northward through Rockall Trough. Observations on suspended particulate matter distribution over the mounds suggest that the tidal waves are active in transporting phytodetritus settled on shallower areas of the Rockall Trough margins downslope toward the mound areas. This phytodetritus is likely to be the prime food source for the cold water coral community.



Cross-section through the Rockall Trough, with bottom water temperature and salinity records obtained with the BOBO lander over a 7 days period at three different locations. Large diurnal temperature and salinity fluctuations were observed on the SW Rockall Trough margin (left), smaller semi-diurnal fluctuations on the SE margin (right), and fluctuations were negligible in the deep Rockall Trough (lower right). The salinity record at the latter location was unreliable.

An alternative hypothesis, explaining coral growth and mound formation as the result of microbial production fuelled by hydrocarbon seepage from the subsurface, has failed to be supported by evidence so far. Stable carbon isotope analysis on cold water corals in co-operation with the Free University of Amsterdam did not produce anomalous isotopic ratios that would support the hypothesis of a hydrocarbon-based food web. However, the fact that the corals presently living on the summits of the carbonate mounds appear to derive their existence from recent rather than fossil food sources does not preclude the possibility that the foundations of these mounds were laid under different conditions. Seismic profiling has revealed that the base of most of the mounds is located on a reflector that is most likely Late Early Pliocene (± 4.5 million years) in age. The question remains about what changes occurred during this period in the Rockall Trough that initiated the abundant growth of cold water corals. We hope to answer this question by drilling through a mound. It is planned that during the MOUNDFORCE program, started this year, strategic future drill sites will be selected.



Deep-sea fishing……..by piston corer!

Cold corals of Galicia Bank

The upper part of Galicia Bank is relatively flat except for the easternmost part which consists of a series of steep peaks along the precipitous eastern slope of the Bank. The flat part is covered by a thick layer of foraminifera ooze with a low organic content. The surface of the sediment consists of numerous small current ripples and occasional megaripples of ~50 cm height indicating mobile sediment and high current velocities. Under water video images show that the cold corals (*Lophelia pertusa, Madrepora oculata*) grow as isolated patches amidst the ripples of foraminifera sand and serve as shelter and substrate for a variety of organisms. The particle supply and carbon mineralisation in the coral community were studied with two benthic landers deployed for 18 months at Galicia Bank. The landers were equipped with sediment traps, flux chambers, current and turbidity meters. The sample record of the sediment trap revealed a large seasonal and annual variability in the flux of phytodetritus and carbon. The daily carbon flux in the first 5 months of 2000 was on average 37 mg C m^{-2} while in the same period of 2001 this was only 17 mg C m^{-2}. Quantities of fecal pellets and swimmers collected in the trap were highly variable as well as between years. A comparison between the daily carbon flux and the sediment carbon oxidation rate, i.e. 7 mg C m^{-2} d^{-1}, measured by in-situ community oxygen consumption (SCOC) indicate that a surplus of carbon is not oxidized in the sediment. Most likely the strong tidal currents (max. 30 cm s^{-1}) and the mobile sediment lead to winnowing of the sediment and near bed transport of the organic material. The low biomass of the benthic community and the dominance of filter-feeding organisms support this. To determine whether the corals on Galicia Bank thrive on particles imported from the upper water column or on an autochtonous food source fueled by seeping hydrocarbons, we analysed stable isotope contents ($\delta^{15}N$, $\delta^{13}C$) of particles in the sediment trap and of the coral tissue. The $\delta^{13}C$ value of coral tissue, -20.55‰, excludes a carbon source supported by methane seepage as earlier suggested for corals off the Norwegian coast. The $\delta^{15}N$ signature of the phytodetritus in the trap (2.2‰) was more than one trophic level lower that of coral tissue (9.5‰) indicating that sinking algae are not the sole food source. As polyps of cold corals have been seen catching zooplankton, the $\delta^{15}N$ signatures of swimmers (copepods, amphipods) caught in the trap were analysed in addition. The resulting values, ~10‰, were close to those of coral tissue. Possibly corals have a mixed diet of zooplankton and algae which would be an advantage in a habitat with large year to year fluctuations. Future analysis of other (lipid) tracers in coral tissue will hopefully provide further insight into food sources of the cold corals on Galicia Bank.