EUG XI

Symposium RCM6

Carbonate Mounds, Fluids and Margin Architecture

Convenors

George Wolff
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Sunday PO Session

RCM6 : SUpo01 : PO
Giant Carbonate Mounds and Current Swept Seafloors on the Slopes of the Southern Rockall Trough

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Large mounds in the northern Porcupine Seabight were first described from seismic profiles by Hovland et al (1994) and proposed to be carbonate knolls. Higher resolution seismic showed some unusual shapes for these mounds (Henriet et al., 1998) and sidescan sonar and sampling proved them to be carbonate mud mounds, of various shapes and settings associated with abundant cold water corals (Kenyon et al., 1998).

A number of mounds from a similar setting, the upper continental slope, were investigated on the northern Porcupine Bank and the southeastern Rockall Bank. The mounds were found to occur in clusters in depths of about 500 m to 1000 m and are up to 350 m high. They vary in plan view shape from isolated, circular mounds to isolated mounds that are elongate in a preferred direction, to a near continuous field of mounds. The size of the mounds can be from a few tens of meters to 1.5 km in diameter. The taller mounds have very steep sides, typically up to 1 in 2 or 1 in 3, and have acoustically chaotic internal structure on seismic records. In all studied areas the mounds are often rooted along a well-marked unconformity. Many of them were found growing from tops of pre-existing basement highs or edges of escarpments. Rocky outcrops found on the northern Porcupine Bank are also believed to have provided the hard ground, advantageous for coral colonisation (Wilson, 1979) and as a consequence of this, and favourable environmental conditions, mature build-ups were formed above these outcrops.

Core samples and photographs (Kenyon et al., 1998) from the upper flanks and tops of the mounds show that there are abundant cold water corals, both Lophelia pertusa and Madreporan corals.

The mounds appear to be in ideal setting for the cold water corals of the north Atlantic Ocean (e.g. Rogers, 1999). All areas of carbonate mounds that we have investigated here are associated with relatively strong currents. Moats are found around some, often with a boulder strewn seafloor presumably due to non -deposition or winnowing of the finer sediments. The surface of the mounds on the Rockall Bank are moulded into presumed mud waves with a consistent wavelength of about 15-20 m and a consistent orientation along the general contours. The origin of the mud waves is not known but may be the result of internal tides e.g. New, 1987. Mobile sands are seen as fields of sand waves and as longitudinal bedforms such as sand ribbons and obstacle marks. The transport of sand is to the north east on the northern end of the Porcupine Bank, in depths of between 750 and 800 m, and to the south-west on the eastern Rockall Bank, in depths of between 700 and 800 m.

Henriet J-P, De Mol B, Pillen S, Vanneste M, Van Rooij D, Versteeg W, Crocker, PF, Shannon PM, Unnithan V, Bouriak S & Chachkine P, *Nature*, **391**, 648-649, (1998).
Hovland M, Croker PF & Martin M, *Marine and Petroleum Geology*, **11**, 232-246, (1994).
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Wilson JB, *J. Mar. Biol. Assoc. U. K*, **59**, 165-177, (1979).

RCM6 : SUpo02 : PO
Planktonic O Record and Sedimentological Characteristics near the Belgica Carbonate Mounds (Porcupine Seabight, SW off Ireland)

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In the Porcupine Seabight (SW off Ireland) 3 provinces of numerous carbonate mounds have recently been discovered (Henriet et al., 1998). The mechanisms and the timing of the formation of these mounds, where deep-water corals have been found, is still in discussion mainly because this area is 1) located on a structured continental margin and 2) under the influence of two water masses, the Mediterranean Outflow Water (MOW) and the overlying European North Atlantic Water (ENAW). Until now only short gravity cores were taken in the vicinity or on of the carbonate mounds hence limiting the interpretations.

During the last IMAGES-cruise a giant piston core has been collected in order to establish the chronological framework as well as the sedimentological characteristics a few kilometres east of the Belgica mound province, situated on a slope section in the Eastern part of the Seabight.

The core MD 992327 (26.25 m long) is located at 51°23 N and 11°39 W (651 m water depth). Two major lithological facies have been observed. The first one which is very homogeneous, corresponds to the first 12 m. It is represented by silty clay with few sulphid streaks and rare biogenic components. The second facies (from 12 to 26.25 m) is characterised by an alternations of medium to coarse grained sand with shell fragments and biogenic-rich layers. The base of the core correspond to a dark grey muddy fine sand. The lithological difference indicates probably a major change in the hydrology and/or a change in the sedimentary input at this location.

O-C isotopic analysis have been performed on *N. pachyderma s.* $\delta^{18}O$ and ^{13}C data are respectively in the range of 4.0 to 2.9 and 0.5 to -1.0 ‰ (PDB). O isotopic values are similar to those obtained in this part of the North Atlantic Ocean for the last glacial period. However, the signal is very 'flat' and it is quiet impossible to establish a chronology only based on the O-isotopic curve. Nevertheless, O and C isotopic values for the 12 first m are respectively depleted by 0.5 and 1 per mil compared to the lower part of the core. These shifts coincide also with changes in the lithological facies and foraminifera fauna and abundance.

This work is within early stage of investigation and need to be combined with other sedimentological and biostratigraphical studies.

Henriet JP et al., *Nature*, **391**, 648-649

RCM6 : SUpo03 : PO
Sediment Distribution on a Carbonate Mound in the Porcupine Seabight

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The investigated Propeller Mound is located at 52°09'N/12°46'W. It is part of the Hovland Mound Province, named after MARTIN HOVLAND who in an earlier paper formulated the hypotheses that hydrocarbon seepage maybe the controlling factor for the growth of carbonate mounds west of Ireland (Hovland et al., 1994).

The base of the triangular-shaped Propeller Mound is in a water depth of 800 m. The top elevates 150 m above the seafloor. In latitudinal extension the mound measures 2 km. The longitudinal extension is 0.7 km. Three spur A, B and C point in NNW, NE and SSW direction. Spur A is 0.8 km long, spur B 0.6 and spur C 1.2 km. All distances correspond to the 800 m isobath. The slope inclination of the Mound varies between 25° on the western slope and 4° in the southern spur. Driftbodies in the east and the west of the Propeller Mound and a moat around the mound indicate an in general erosive hydrodynamic regime at present and/or in the past.

Boxcores were taken in transect over the flanks, spurs and the top to map different facies. All samples are from a depth range between 760 m and 650 m water depth. The samples from the top contain mainly dead coral material, mostly parts of the deep-water coral *Lophelia pertusa* in a matrix of sandy silty clay. On the NNW spur, sandy silty clays with dropstones (Ø < 2 cm) and debris < 5 mm have been retrieved. Only the boxcores from the spurs B and C comprise living corals. *Lophelia pertusa* is the dominant species, but also *Madrepora oculata* and *Desmophyllum cristagalli* has been identified. The matrix between the corals consists of sandy silty clay with abundant foraminiferas. *Globigerina bulloides* and *Neogloboquadrina pachiderma* (dex) are the dominant planktic foraminifera species. The most abundant benthic foraminifera is *Uvigerina peregrina* in different morphotypes. Also crustaceans, ophiuroids, bivalves, brachiopods, stylasterid hydroids and sponges have been found.

The poster will provide information on the sediment composition at and around the Propeller Mound. In addition, first data on the stable isotope composition of the benthic foraminifera *Uvigerina peregrina* will be presented.

Hovland M, Croker PF & Martin M, *Marine and Petroleum Geology*, **11(2)**, 232-246, (1994).

RCM6 : SUpo04 : PO
Coral Habitat Mapping and Groundtruthing on the Sula Ridge, Norwegian Shelf

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The major scientific target of a cruise carried out in summer 1999 was dedicated to retrieve high quality sponge samples from the seafloor for the sensitive detection and subsequent identification of marine natural compounds. In order to offer an economic method for the search of sponge-rich habitats within the very complex coral reef topography and to avoid damage on the benthic communities, the following strategy was chosen: 1. Echosounding and side-scan-sonar mapping of a defined seafloor grid on Sula Ridge. 2. Identification of sponge-rich target areas on the basis of the seafloor mapping surveys. 3. Dives with the manned research submersible JAGO for groundtruthing and sampling

On the Sula Ridge, the bathymetric range for the *Lophelia* reefs is from 330 - 233 m water depth. The reefs are concentrated along the summit near the escarpment of the asymmetric Sula Ridge. The length of the many *Lophelia* reef complex on the Sula Ridge is approxi-mately 13 km. The reefs on the Sula Ridge are 10 - 20 m high on average. The sonographs which were aquired with the deep-towed sidescan sonar along the strike line of the ridge allow the recognition of numerous individual 1 - 2 km long and 100 - 200 m wide reefs which often are arranged *en echelon*. Measurements carried out with the submersible confirmed the distinctive offset of 20° in the orientation of the reefs in relation to the northeast-southwest strike of the Sula Ridge. The corals can be seen to grow on the ridge and furrow systems which were produced by grounding icebergs.

RCM6 : SUpo05 : PO
3D Spatial and Morphological Analysis of a Buried Mound Province

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Mound structures were discovered in 3 provinces in the Porcupine Seabight, along the continental margin south-west of Ireland. One of them, the Magellan Province, contains mainly buried mound structures, although a few mounds also protrude up to the seabed, at 600 to 750 m depth. Comparison with other (seabed) mounds in the area allowed their identification as coral banks or carbonate mounds, associated with the growth of deep-sea coral species such as *Lophelia pertusa* and *Madrepora oculata*. The mounds in the Magellan Province were studied by means of high-resolution 2D and industrial 3D seismic data. The 3D data set consisted of the upper 400 ms TWT of a 830 km^2 industrial data block, provided by Statoil Exploration (Ireland) Ltd., and its partners, Conoco (U.K.) Ltd., Enterprise Energy Ireland Ltd. and Dana Petroleum plc. Time structure maps of key reflections and horizon slices were further processed in a GIS-system using mathematical morphology and geostatistical tools

The resulting images revealed 305 mounds (>30 m) within an area of 350 km^2. They all are rooted on the same reflection. Smaller buildups can be seen in the seismic profiles too, but were excluded from the statistical analyses. The mounds are significantly elongated in a N/S direction, and are associated with moat structures containing the same - even stronger- elongation. A N/S directed current influence seems to have played an important role in the mound history. The location and spatial pattern of the mounds however, is different. Investigations showed that mound positions are not linked to any fault information present in the shallow 3D data block. A possible relationship with the depth contours of key horizons or erosional unconformities, or with the morphology of an underlying enigmatic slope failure seems more promising. According to spatial trend analysis, the mounds are larger on the western edge of the province, while the burying sediment packages are thicker towards the (S)E. Sedimentation rates hence seem to have influenced the mound growth and vitality as well.

From the 2 and 3D seismic analysis of the Magellan Mound Province, one learns that the mounds started to grow at 1 confined moment in time and space. Their positioning does not seem to be influenced by shallow faults, but rather by the location of erosional unconformities and a deeper lying slope failure. Currents and sedimentation patterns on their turn clearly played a role in the mound development.

RCM6 : SUpo06 : PO
X-Ray Computer Tomographic Analysis of Sediment Cores from the Propeller Mound (Porcupine Seabight)

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Clusters of high relief mounds with a dimension of 5 by 1 km and a thickness of up to 100 m above the surrounding seafloor are the subject of intense debate on their genesis and internal structure. Many of the surveyed mounds show a high density of living and dead deep-water corals on the flanks. The contribution of coral frameworks to giant mound formation seems to be a major factor. These mounds are considered as analogues of Paleozoic Mud Mounds. In order to shed light into this spectacular topic, our group surveyed a particular mound the northern Porcupine Seabight - the Propeller Mound.

On the Propeller Mound in the Hovland Mound Area several sediment cores with a corelength of up to 5 m were recovered during POSEIDON cruise POS265 in September 2000 (see also Poster "Sediment distribution on a carbonate mound in the Porcupine Seabight", Dorschel *et al.*, this Journal). These sediment cores were analysed at the Universitäts-Klinikum at Kiel using a X-ray Computer Tomographer (Phillips Tomoscan LX) in order to evaluate the sediment structure and its components. The different core sections (up to 1 m) were according to depth and liner-diameter completly analysed. First insights clearly show parts with deep-water coral fragments in a fine sandy silty clay whereas other sections are dominated by the sandy silty clay with foraminiferal tests. 1 cm thick Cross-sections were also done in parts with interesting sediment strucutres and components.

Due to the still closed sediment cores (no visible core description available until January/February 2001) the first results will be presented in comparison with logging data (grape density, magnetic susceptibility) measured with Multi Sensor Core Logger (GEOTECH) at University of Bremen.

RCM6 : SUpo07 : PO
High Resolution Side-Scan Sonar Mapping of Deep-Water Coral Mounds: Surface Morphology and Processes Affecting Growth

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High-resolution deep-tow side-scan sonar (410 kHz: 200 m swathe and 100 kHz: 600 m swathe) and video (SHRIMP) imagery was collected on deep-water coral mounds at three locations in the NE Atlantic (areas A, B, & C) to determine biological and geological processes affecting mound growth. The spatial resolution of the high frequency side-scan sonars used here bridges the gap between video and lower frequency side-scan sonar mapping techniques (e.g. 30 kHz TOBI).

Area A - The Darwin Mounds (N Rockall Trough) exist in an area of strong bottom-currents and are relatively small (70 m diameter), low relief features (5 m height). All of the Darwin mounds possess discrete boundaries with a rubbly surface texture probably reflecting small accumulations of coral acting as nuclei for further coral growth. Internal structuring of the mound surface is irregular with a slight concentric arrangement of coral colonies. Distinctions can be made between undisturbed mounds (with well-developed coral patches) and other mounds that have become covered by sediment with no obvious coral stands. These may have been impacted by deep-water trawling activities.

The seafloor around the mounds is sandy (composing upper c.30 cm of sediment profile) and covered in sand ripples. Some mounds also occur in, or at the edge, of sediment wave fields. Within-mound sediment is sandy to a greater depth either due to sediment entrapment or because the Darwin Mounds represent colonised pockmarks associated with fluid escape (imaged at greater water depths during this survey).

There are abundant benthic trawl marks over the mounds and on the intervening seabed (up to 100% coverage).

Area B - Strong slope currents on the Porcupine Bank cause seabed scour and erosion resulting in a very coarse lag (including boulders) and exposed bedrock that offers a substrate for coral colonisation. The newly acquired data suggests that 'carbonate mounds' and colonised rock outcrops exist in this area.

Area C - In the Belgica Mound area (E Porcupine Seabight), giant carbonate mounds have been identified that form slope-parallel ridges aligned to strong currents. Side-scan sonar imagery of lower mound slopes reveals that they are largely covered in sediment waves. Coral accumulations on mounds appear as patches of high backscatter up to a few metres across. Underwater video (SHRIMP) clarifies that these consist of both live and dead coral. The upper parts of mounds are covered by near continuous coral colonies. Further away from the foot of the mound, coral density decreases and coral colonies occur preferentially on the wave crests and upper flanks and not in the troughs.

Other mounds in the Belgica Mound area show no evidence of coral accumulations and may therefore be relic mounds or possess limited coral activity and are becoming buried by the sediment waves. Some of these sediment wave fields infrequently contain 'Darwin Mound'-size coral mounds on their peripheries. Trawl marks were also common in this area. In several cases SHRIMP videos showed trawls stranded on the coral mounds.

Monday AM Session

RCM6 : MOam02 : F3
Polygenetic Types of Seepage-Related Carbonate Deposits and Mounds

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Mounds in the basinal facies of marine and lacustrine environments associated with benthos communities are frequently of autochthonous origin. These organosedimentary deposits are often related to subaquatic springs and/or seeps. Fabrics, microfacies, and geochemical signatures indicate an origin of carbonate deposits related to disequilibria in the area of fluid emissions, e. g. divalent cation-rich water injected into an alkaline water body. Subaquatic spring water is commonly a nutrient source for microorganisms, and therefore a favourite place for the growth of biofilms. These biofilms may trigger carbonate formation and, therefore, induce mound growth. Remarkably, many build ups exhibit a chimney-like structure. Good examples are (1) spring mounds of the alkaline salt lakes of the Gobi desert (Arp et al., 1998) and (2) tufa towers of the Mono Lake (USA) and the Lake Van (Turkey). Fossil counterparts are carbonate spring mounds of the Miocene Ries Crater (Germany). Marine examples for seep-induced carbonate deposits are related to the hydrocarbon oxidation at cold seeps. Most of the known hydrocarbon-linked deposits occur at methane seeps, with carbonates recognisable by a strong depletion in carbon ^{13}C due to anaerobic methane oxidation (Peckmann, 1999; Thiel et al., 1999). Fewer seep carbonates are related to hydrocarbon seeps that have been dominated by longer chain hydrocarbons (e.g. Beauvoisin, Jurassic, France). However, seep carbonates preferentially form within the sediment and a relation to mound growth is often enigmatic. The seep core of the Devonian Hollard Mound (Morocco), which is surrounded by a marine-sourced mud mound facies, is interpreted to have acted as a nucleus for mound growth (Peckmann et al., 1999). H_2S-rich fluids at hydrothermal vents, or hot, nutrient-rich waters at geysers may favour the growth of biofilms and induce mound-shaped mineral precipitates. These mound-shaped deposits are formed of sulphides and cherts which are occasionally accompanied by carbonates.

All types of seepage-related build ups exhibit strong microbial signatures. Likewise, microbial activity, to varying extent, is a driving force for mound formation. In shallow water environments phototrophic bacteria dominate biofilms, whereas deep water seepage environments are dominated by chemolithotrophic bacteria, heterotrophic anaerobic bacteria, methanotrophic bacteria, and archaea. The various submarine seep and spring settings may favour the formation of carbonate mounds. Benthic communities, which filter nutrients from the open water column, take advantage of these substratum and, moreover, enhance mound growth. We suggest, that many complex mud mounds may exhibit a nucleus, which is seep-related. Consequently, both marine- and seepage-derived nutrient sources may contribute to mound formation in aquatic environments.

Arp G, Hofmann J & Reitner J, *Palaios*, **13**, 581-592, (1998).
Peckmann J, *Doctoral thesis, Univ. -Goettingen*, 126pp, (1999).
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RCM6 : MOam03 : F3
Coolwater Coral Reefs and Carbonate Mounds

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Existing data indicate that the existence of the largest coral reef province is not confined to the shallow-water subtropical to tropical climatic belt as is conventionally cited in textbooks. Instead, the largest coral reef province thrives in mid-depths from the high latitudes to the low latitudes of both hemispheres along continental margins and seamounts. Reef-constructing azooxanthellate corals are associated to many spectacular large-scale seabed structures along the NE Atlantic continental margin: (1) the numerous deep shelf reefs off Norway with the Sula Reef as the best known example, (2) the giant mounds in the Rockall Trough and Porcupine Seabight, and (3) the so-called Darwin Mounds on the Wyville-Thomson-Ridge. The participation of deep-water corals is substantial in all areas, however, mound formational processes are yet not understood due to the lack of drilling, The habitat requirements for framework-producing azooxanthellate corals such as Lophelia pertusa and Madrepora oculata are reasonably well known. The planula larvae need a hard substrate for settling and metamorphosis. Strong bottom currents prevent the deposition of fine-grained deposits and therefore, Lophelia is preferentially found on various kinds of topographic highs such as submerged moraine ridges, clay ridges, iceberg ploughmark levees, spurs, outcropping rocks and artificial substrates (oil rigs). In the strict ecological sense, the Lophelia ecosystems often form true coral reefs with respect to their framework-building capacity which lead to highly elevated structures on the seafloor, which support a highly diverse associated fauna with biodiversity indices similar to those found in tropical shallow-water reefs. Moreover, like their shallow-water cousins, the deep-water reefs have to withstand severe phy-sical disturbances. These disturbances do not occur in the form of tropical storms, but as ocea-nic internal waves, deep barotrophic internal waves and shock waves produced by submarine slide events.

The sedimentary infill is dominated by imported pelagic muds consisting of either calcareous plankton, or by suspended terrigenous muds and silt-grade deposits. Coral rubble sheets locally dominate the internally produced reef debris. The diagnetic regime is poorly studied. Microbial micritisation caused by bacteria and fungi creates a characteristic micritic envelope around dead corals. Submarine cementation, if present, generally started with cryptocrystalline precipitation of magnesian calcite which converts a primarily grain-supported fabric into a mud-supported fabric rich in peloids with microspar rims and micritic limestones. Another early diagenetic process seem to be very common in deep-water coral reefs in the dysaerobic zone above the sediment-water interface where dead coral skeletons become infested by an iron and manganese precipitating microbial consortium consisting of Siderocapsa-like bacteria, fungi and protists such as stalked peritrichs. This biofilm seems to be involved in active baffling of suspended detritus which, in turn, cloggs the dead coral framework thus enhancing sediment accumulation rates in an otherwise erosive environment.

RCM6 : MOam04 : F3
Deciphering the Messages of Carbonate Mounds: The Porcupine Scientific Drilling Project

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Porcupine Basin displays - within the North Atlantic realm and perhaps in a global perspective - a unique association and diversity of carbonate mound provinces, which may yield the key to address the question of mound genesis and its significance in a global oceanic plot, from a process-oriented point of view. The giant mounds on the present seabed surface southwest of Ireland, up to 200 m high, the extensive cluster of over a thousand buried reefs embedded in drift sediments, the whole range of mounds towering from a deeply ravinating unconformity on the eastern slope of Porcupine Basin are not mere curios, but significant build-ups, which may put Man on the track of hitherto unknown Biosphere processes thriving at the confluence of fluxes from both internal (geological) and external (oceanic) origin. In many aspects and mutatis mutandis, carbonate mounds might be for the Margins what sulphide mounds are on the Ridges: the product of biologically controlled geological processes, of global significance. The 'Porcupine Drilling Project' is driven by four major research projects funded under the 5th Framework Programme of the European Union (GEOMOUND, ECOMOUND, Deep-Bug and ACES) and hence it mobilizes a multi-disciplinary consortium of 22 institutes and research centres. A range of provoking hypotheses will be tested: the role of gas seeps as a prime trigger for mound genesis, the role of bacteria as main mound builders, the role of reef-forming corals as major part of the mound community and their environmental record potential, the significance of mound 'events' in a paleoenvironmental plot, the identification of prominent erosional surfaces as product of global oceanic turn-overs, the potential of mounds as high-resolution palaeoenvironmental recorders, the value of the Porcupine-Rockall mounds as present-day analogs for Phanerozoic reef mounds and carbonate mud mounds, and the potential role of fluid flow as common source of both slope failures and mound growth. Finally, a virtual link to biological processes is provided by the widespread existence of cold and deep-water coral and sponge reef ecosystems which colonize the flanks of the mounds. Preliminary results of the many site preparation cruises up to summer 2000 are presented and discussed.

RCM6 : MOam05 : F3
Sedimentology of Cold Water Carbonate Mounds; Results from the Porcupine and Rockall Bank Margins

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During cruises with R.V. Pelagia in 1999 and 2000 cold, water carbonate mounds along the Porcupine and Rockall Bank margins where visited. These mounds are located on the SW and SE Rockall Trough continental margin between 500 and 1100 m water depth and are covered with sometimes extensive *Lophelia pertusa* and *Madrepora oculata* colonies and associated fauna. The mounds have a diameter of about 2-5 km at their base and can be up to 300 m high. On the mounds and on the surrounding seabed box- and piston cores were taken. In addition bottom photography and under water video recording was carried out. Box- and piston cores show that the recent sediment cover of the mounds is built up of carbonate sand and silt consisting of coral debris. The growth of the mounds results from the production of carbonate by the corals on top of the mounds. Carbonate debris is trapped in the 3-dimensional structure of coral branches, thus forming a baffled structure. However, the coral branches disintegrate downcore and the final type of sediment would be a bioclastic carbonate sand. Further away from the summits, on the flanks of the mounds coral growth is patchy or completely absent. Carbonate debris is transported from the summit to the flanks by currents and small and large scale slope failure processes (slumping). U/Th Sedimentation rates indicate that the average vertical growth rate of the corals is in the order of 10 mm per year, while the actual vertical sediment accumulation rate of a mound is less than 0.5 mm per year. The presence of hardgrounds indicates that at least locally, the sedimentation on the mounds (and thus most likely also carbonate production and thus coral growth) is not continuous in time. Observations on the lower slopes and in the intramound areas indicate that sedimentation rates are extremely low in these areas since numerous glacial pebbles and larger drop stones are present, indicating the absence of net sedimentation since the last glacial.

RCM6 : MOam06 : F3
Giant Carbonate Mounds in the Rockall Trough, NE Atlantic Ocean

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During recent research carried out in the framework of the EU funded ENAM II, ECOMOUND and GEOMOUND projects, the presence of giant cold water coral covered carbonate mounds in waterdepths of 500-1100 m at the SW and SE Rockall Trough Margins was established. High resolution 2D and 3D seismic recording of the SW Rockall Trough mounds showed that mounds occur in clusters , on top of a relatively flat acoustic basement, with an unconformable cover of sediments of up to 0.5 sec TWT thickness. The seismic data provide no evidence for a direct relationship with underlying fault structures, although there is an obvious NNE-SSW alignment of some of the structures. Downslope from the main cluster of mounds these become rapidly smaller, and are absentbelow about 1000-1100 m depth at the SW and SE Rockall Trough flanks. It appears that two phases of major mound building can be recognized. We found no direct (seismic) evidence for a possible role of gashydrate dissociation and subsequent leakage through the sedimentary column for mound construction. Seen the elevated level (up to 300 m above seabed) of a number of the mounds, construction processes must have been taking place over a longer time span.

RCM6 : MOam07 : F3
Downcore Distribution Patterns of Cold-Water Corals, Porcupine Margin, NE Atlantic Ocean

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Two sediment cores (ENAM9828 and MD992326) were obtained from a carbonate mound at Porcupine Margin, NE Atlantic Ocean (54ºN 14ºW). Both cores consist dominantly of cemented foraminiferal sands containing scattered coral fragments (up to 10 cm large) and fine sandy, partially dissolved coral debris, with thin intercalations of darker-colored hemipelagic sediments. We report results of high-resolution geochemical measurements with the CORTEX corescanner, and mineralogical investigations of carbonate concretions from core ENAM9828. Evidence for the downcore distribution of corals is based on core description, abundance of aragonite in carbonate concretions, and on the Sr/Ca intensity ratio derived from corescanner data. Coral abundance is discontinuous; both cores show a maximum at or near the sediment surface and a broader variable subsurface maximum. Initial coral growth seems to be favored by suitable substrates (hardgrounds/ hiati) indicated by sharp Fe-Mn maxima and mixed (Fe-Mn?) carbonates. Subsequent continuing presence of corals might be related to bottom current supply of nutrients and/or particles suggested by minor, broad Fe peaks. The abrupt termination of the subsurface coral maximum implied by sharply decreasing Sr/Ca-ratios and disappearance of aragonite concurs with enhanced terrigenous input, controlling factors such as possible changes in paleocirculation presently remain elusive.

RCM6
Carbonate Mounds, Fluids and Margin Architecture

RCM6 : MOam10 : F3
Specific Cementation in Carbonate Mud-Mound Sediments, SE Rockall Margin, NE Atlantic Ocean

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We report results of a geochemical investigation of carbonate mounds sampled on the basis of geophysical data acquired during the 7th Training Through Research (TTR-7, 1997) and European North Atlantic Margin (ENAM-98, 1998) Cruises. Core ENAM-98-28 at the margin of two mud mounds in SE Rockall Trough was investigated in detail. This core consists of 710 cm of cemented carbonate sediments represented by cemented aggregates. The geochemical study of the cemented aggregates aimed to elucidate either their potential linkage with cold hydrocarbon (methane) seeps or with currents influenced on diagenetic processes on the mounds. Therefore, the sediments of the core were investigated with the following set of methods: (1) stable isotope analysis (down core determination of δ^{13C} and $\delta^{18}O$ from bulk sediments, corals brachiopods and gastropods, cemented aggregates); (2) isotopic analysis of δ^{13}Corg>3 determination of total organic carbon and total organic nitrogen contents; (4) GC and GC/MS analysis of total lipid extract from cemented aggregates and from surrounding sediments; (5) Scan electronic microscope study of cemented aggregates. Results indicate the absence of any evidence that sediments from core ENAM98-28 have been related to methane seeps. The aggregates appear cemented by amorphous silica rather than by carbonate. The silica possibly being derived by dissolution of siliciclastic sediments, skeletons of siliceous species, dissolved silica-rich bottom waters.

RCM6 : MOam11 : F3
The Darwin Mounds- Possible Fluid Escape Features in the Northern Rockall Trough

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The Darwin mounds are located in the northern Rockall Trough in around 1000 m waterdepth. On 30 kHz sidescan sonar images, they appear as sub-circular, high-backscatter targets, typically 50-75 m in diameter and up to 5 m in height, although some 'mound-like' sonar targets have little or even negative relief. Several hundred mounds are observed in an area measuring less than 20x20 km. Many mounds are associated with distinctive 'tail-like' features consisting of elongate to oval patches of moderate backscatter up to 500 m in length. All tails have a consistent southwesterly orientation, suggesting that they are aligned in the direction of a prevailing bottom current. The tails have no topographic signature. High resolution 410 kHz sidescan sonar images of the mounds show a rough, variable backscatter surface. Comparison between high-resolution sidescan images and video footage indicates that the small high backscatter targets within the mounds, typically a metre or so in diameter, correspond to individual coral colonies.

Sediment cores up to 3 m in length, collected from the mounds, consist of terrigenous (mainly quartz) sand. With the exception of occasional coarse coral fragments and a few foraminifera, carbonate material is absent from these cores. 'Background' sediment from the seafloor between the mounds consist of a thin veneer (typically <20 cm) of sand overlying many metres of fine-grained mud. The cores show that the Darwin mounds are not carbonate mounds built up by the accumulation of coral and other biological debris. However they are clearly preferred sites for coral colonisation at the present day, since coral is only rarely observed on other possible coral attachment points (e.g. large glacial erratics) on the seafloor nearby. The variation of the 'mound-like' sonar targets between positive relief mounds and negative relief pockmarks is probably the key to understanding their origin, and leads us to suggest that all of these features are related to fluid escape from the seabed. Positive relief features may form where sub-surface sand is carried upwards by the escaping fluid and 'erupted' to create local mounds on the seabed. It is suspected that the fluid escape process may relate to sediment dewatering since no evidence of hydrocarbon seepage has been detected to date.

There is considerable evidence that trawling activity is causing damage to the mounds. Trawl marks, observed on 410 kHz sidescan sonar images, consist of a pair of strong grooves, typically 50 m apart, with a weaker linear fabric between, giving the seafloor a 'raked' appearance. Video footage shows large areas of fragmented, dead coral in the most intensely trawled areas.

RCM6 : MOam12 : F3
Biogeochemistry of the Darwin Mounds – Preliminary Results

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The 'Darwin Mounds' are small, sandy mounds in the Rockall Trough (1000 m, 59º 48' N, 07º 22' W) and are an important habitat for the deep-sea coral Lophelia pertusa and its associated fauna, as well as giant protozoans (Xenophyophorea). Little is known however about the relationship of these corals and xenophyophores and the mounds, although it has been suggested that they may be related to hydrocarbon seepage. In order to study the biogeochemical parameters controlling their development and to evaluate the possible links with hydrocarbons, organic geochemical investigations were carried out in the sediments from the mounds, their tails and surrounding areas (control), including samples from an adjacent field of seabed pockmarks. Thus far, two horizons (0-5 mm, 50-60 mm) from each of the sites were analysed.

Preliminary results from the sediments collected from a mound and its tail show a clear distinction between these and the control and pockmarked sites. Lipid concentrations were higher in the deeper horizon by as much as an order of magnitude at the mound and the same was true for its tail, albeit to a lesser degree. The lipid compositions were similar in both horizons at both locations and they were dominated by labile compounds such as poly-unsaturated fatty acids (PUFAs; C20:4, C20:5, C22:6) and other monounsaturated low molecular weight (<C20) fatty acids (e.g. C16:1 and C18:1). Cholesterol was the dominant sterol although cholesta-5,22-dien-3-ol (an invertebrate marker; Goad, 1978) was also abundant particularly in the deeper sediment at the mound. The abundance of labile 'fresh' organic matter and of the invertebrate marker at this depth, suggest that there is strong biological mixing (bioturbation) at the mound and tail sites, which is probably less intense in the tail. High molecular weight (<C20) hydrocarbons were present in low amounts and decreased in concentration with depth in all areas, implying an absence of hydrocarbon seepage.

In the control and pockmark areas the highest lipid concentrations were in the surface sediments, the most abundant being at the pockmark site. Although the surficial sediments from the these two areas had similar lipid compositions to the mound and tail sites, the deeper sections were largely depleted in labile material (PUFAs for example were absent) and relatively enriched in hopanoids (bacterial markers; Ourisson et al., 1987). This suggests less physical mixing (bioturbation) but relatively higher bacterial activity away from the mounds.

Overall, the preliminary organic chemistry data from the Darwin Mounds area seem to support visual observations of locally enhanced biodiversity and biological activity (i.e. bioturbation) in the vicinity of the mounds relative to the surrounding deep-ocean floor. There is, however, no evidence to suggest that this enhanced bio-diversity/-activity is linked with hydrocarbon escape from the seabed.

Goad LJ, *Marine Natural Products, Academic Press London*, 75-172, (1978).
Ourisson G, et al, *Annual Review of Microbiology*, **41**, 301-333, (1987).

RCM6 : MOam13 : F3
Characteristics of an Active Vent in the Fore-Arc Basin of the Sunda Arc, Indonesia

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RV SONNE cruise SO-139 was part of a joint German-Indonesian campaign to investigate the accretionary margin south of Java and Sumatra. During this cruise a site of active methane venting was discovered in the thickly sedimented fore-arc basin. The site was surveyed with sediment echosounding, swath mapping, photo sledge profiles, and subsequently sampled with a rosette water-sampler, a TV-controlled crab, and a gravity corer. Venting occurs 60 km south of Java in 3 km water depth. The site is located on top of a huge anticline structure which has evolved in the sedimentary basin fill. The crest of this fold can be traced bathymetrically, as it forms a 50-60 m high ridge striking parallel to the basin's axis. Spread over an area of approximately 300-400 m diameter at the potentially fault-controlled eastern end of the ridge we observed patches of dark massive carbonate precipitates associated with clusters of vent fauna. Molluscs of the families Solemyidae, Vesicomyidae, Thyasiridae and tube worms were sampled. Prominent methane anomalies of up to 5000 ml/l were discovered in the vicinity of the site in water depths corresponding to the top of the above ridge. Both, the biological and geochemical findings prove recent emanation of methane loaded fluids. This is corroborated by heat flow measurements at the ridge where heat flow appears 3 times elevated relative to regional heat flow data. Large buccinide snails (predators) where observed several hundred meters away from the vent site indicating an excessive food supply. We interpret this as an indirect sign of significant vent and seep activity. The authigenic carbonates ($\delta^{13}C$ = -40‰) cement the muddy sediment. Slabs recovered from the sediment surface display tube-like holes of 2 cm diameter, interpreted as fluid outlets. Concentrations of chloride in the pore waters decrease significantly with depth in the sediment cores of the vent site. We interpret this decrease as a result of mixing of pore water with a freshwater component from destabilized gas hydrates. Geothermometry, based on the solute concentrations in pore fluids from the upper 40 cm of the sediment allows to estimate temperatures which the pore fluids have experienced: there are strong indications for temperatures of about 210-230°C. We take the combined above two arguements as confirmation that the fluids arose from a minimum depth of several hundred meters below sea floor.

RCM6 : MOam14 : F3
Growth Dynamics and Ecology of Upper Jurassic Mounds, with Comparisons to Mid-Palaeozoic Mounds

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The Late Jurassic was a time not only of widespread coral reef growth but also of pronounced mound formation, encompassing coral, siliceous sponge and microbial mounds. Similarly, the Mid-Palaeozoic also is rich not only in framework reefs but also in mud-rich buildups, including coral mounds, stromatactis mounds, microbolite mounds and mixed types. A comparison of mound features and their general setting highlights, despite all differences, general similarities in overall growth dynamics. Mound formation is frequently not a continuous process but is often driven by discontinuous patterns, particularly by regularly or irregularly changing background sedimentation rates. In many examples, episodes of mound stabilisation by early, superficial lithification, growth of microbolite crusts and winnowing of fines is followed by growth episodes of benthic, adapted fauna under reduced to noticeable background sedimentation. This is superceded by episodes of accelerated sedimentation, filling up the irregular surface provided by benthic associations and microbial crusts, and piling up unstable muds, which in turn may become stabilised, hardened and further accreted by microbial activity in a subsequent episode of strongly reduced sedimentation. This pattern of variable sedimentation and organically induced precipitation may occur in different orders and magnitudes, giving some of the mounds a fractal pattern of control mechanism and fabrics. Most mounds therefore reflect control by oscillating mechanisms positioned within a broad band between boundary settings. Such 'sediment-oscillation mounds' evidence a more dynamic control than the growth of framework-rich reefs, the latter of which generally show more continous growth, less often interrupted by events. Less common pure microbolite mounds are a certain exception to this rule, requiring stable conditions, particularly strongly reduced background sedimentation ('sediment-starved mounds') and other controls excluding other benthic organisms (salinity extremes, eutrophication, or dysoxic settings), and in terms of growth dynamics are more similar to other framework reefs. The rare muddy reef metazoan mounds are also transitional to framework reefs, for sediment-adapted baffling organisms may be able to cope with largely continuous background sedimentation ('sediment-continuum mounds'). Elevated sedimentation rates kill or prevent growth of both reefs and mounds. The general control over the correct bandwidth and oscillations of sedimentation rate may be achieved by either position on a ramp-type shelf in the correct distance from a carbonate factory, or by a transition from transgression to sea-level high-stand. Frequently, transgression allows for establishment of mound growth by favouring microbolite formation in a sediment-starved regime, whereas initial moderate highstand-shedding from remote carbonate factories helps mounds to build up; only when bottom-level sedimentation accelerates during late highstand, mounds might suffocate from sediment and die off.