MIDTERM-SUMMARY OF METROL RESULTS

(Public part of deliverable 2.2)

Abstract compilation of presentations by METROL participants on project results during the

1st. Annual METROL workshop, Copenhagen, 16/17 October 2003

EGU General Assembly 2004, Nice, 25-30 April 2004

METROL Mid-Term work shop, Utrecht, 2-4 June 2004

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METROL CRUISES:

Aarhus Bay fall and spring cruises, St.F. Henry (Henrik Fossing, NERI)

Participation: NERI, MPI

Research area: Five locations in the Aarhus Bay have been selected according to high resolution seismic data which were obtained by GEUS during an earlier survey. The five localities (M1-M5, 15-22 m water depth) were characterized by different gas bubbles distributions in the sediment. All five localities were sampled with gravity cores and Rumohr lot cores in spring 2003, while the program in fall 2003 and spring 2004 concentrated on the two contrasting localities M1 and M5. Parameters analyzed: concentrations of CH_4 and SO_4, density, water content, rates of sulfate reduction (SRR) and anaerobic oxidation of methane (AOM).

Find station lists for the spring cruise on web page:

http://www.pangaea.de/ddi?request=http://www.pangaea.de/Projects/METROL/Eventshn03s&format=html,

and for the fall cruise on page:

http://www.pangaea.de/ddi?request=http://www.pangaea.de/Projects/METROL/Eventshn03f&format=html.

Kattegat: Gunnar Thorson cruise 31 March - 11 April 2003 (Henrik Fossing, NERI)

Participation: NERI, GEUS, MPI, BRIS, GeoEcoMar, IBSS, Univ. Aarhus

Research area: Several stations around Læsø Rende, off Frederikshavn, and in the deeper northern Kattegat towards Göteborg, Sweden (water depths between <10 and 98 m). Purpose of the cruise: high resolution seismic survey of subsurface gas plumes and sampling of gassy sediments for geochemical and microbiological analyses.

For more information, download the station list for the Gunnar Thorson cruise from http://www.METROL.org (navigate via: Data, Cruises, then open Event list)

Skagerrak: RV Heincke (HE 191) 12-22 May 2003 (Christian Borowski, MPI Bremen)

Participation: MPI, AWI, BRIS, GeoEcoMar, Fielax Company, Univ. Hamburg.

Research area: Southern slope and central deep areas of the Skagerrak Trench (water depths between 50 and 680 m). Purpose of the cruise: Shallow hydro acoustic mapping of subsurface gas plumes. Sediment sampling across the slope and across pockmarks for geochemical and microbiological analyses. Search for and sampling of active methane seepages. Search for seeps and gassy sediments in deep central trench areas.

For more information, see METROL web site http://www.METROL.org (navigate via: Cruises, 2003 cruises, HE 191) and download the station list for the Heincke cruise (navigate via: Data, Cruises, then open Event list)

North Sea: Heincke Cruise (HE 208), 8-21 May 2004 (Antje Boetius, MPI Bremen)

Participants: MPI, AWI, Bristol and Cardiff. Guests were the group of Prof. G. Wendt from the University of Rostock for echosounder surveys of seeps and sediments, as well gas flares in the North Sea.

The cruise started in Bremerhaven on the 9th of May. The first stop was Aberdeen, to take the UK groups on board. 4 days were planned for sampling and surveying of UK pockmarks and gassy sediments. The work at UK block 15/25 identified a series of active seeps with gas ebullition from the center of the pockmarks at ca 160 m water depth. Camera surveys showed that the central parts of the pockmarks were covered with carbonate cements, making the sampling of the gassy sediments impossible. Outside the pockmarks, no gas was detected in

up to 4 m long gravity cores. Further surveys off other locations at the Scottish cost (20-100 m water depth) indicated by the British Geological Survey did not results in the detection of gassy sediments. However, active pockmarks were found on the Witch Ground area, especially in the vicinity of the famous pockmark Witch Hole. Several gravity cores were recovered and sampled. At the northern most station in the Gullfaks/Kvitebjorn platform area strong gas ebullition was detected with the echosounder. The seep area is covered with sand and gravel, but active and highly gassy sediments were recovered with a TV guided Multiple corer. These sediments were covered with sulfide oxidizing bacteria, and were smelling of sulfide. The samples of HE208 are currently under analysis.

ONE-YEAR RESULTS

Seismic mapping results from Aarhus Bay (Jørn Bo Jensen, GEUS)

The present situation of the sediment distribution and bathymetry in Aarhus Bay area is demonstrated in the context of the historical development of the Western Baltic since the pre-quarternary, with respect to developments the water surface levels, sediment distributions, glacial ice coverage, succession of marine and fresh water stages etc.

Results of the seismic mapping performed with MS Line 2-7 March 2003 are presented. Locations of subsurface gas plume are demonstrated by selected Boomer and X-Star profiles and isobathic maps of subsurface gas distributions. Comparison of the results with data from the Great Belt.

Geological controls of methane seeps in the Kattegat area (Troels Laier, GEUS)

Distribution of gassy sediments and related gas seeps, surface sediments and holocene/pleistocene stratification in the northern Kattegat area. Special focus on the Frederikshavn Area: occurrence of gas in subsurface depth >100 m, and unusual sequence of Weichselian strata in on-land drills around Frederikshavn. Demonstration of the developments of coastlines, water depths and ice coverage during the past 125 ka. Gas with different origin according to ^{14}C dating in Kattegat sediments/seeps close to Frederikshavn. Hypothesis to explain this: “burial” of gas-charged sediments by glacialtectonic deformation. Evidence for this hypothesis provided by emerged cliff formations on the north-western Jutland coast.

Geochemistry: First results from the Aarhus Bay spring cruise 2003 and the Gunnar Thorson cruise (Henrik Fossing, NERI)

Explanation of core treatment on board and in lab (incl. cutting into meter sections, search for sulfate methane transition zone (SMT), sub-sampling techniques with mini cores vs. window technique etc.). Depth calibration of GC-samples (which regularly lack the top surface sediment) by alignment of SO_4^{2-} profiles obtained from of gravity cores (GC) and Rumohr lot samples (RL) from the same locality. Definition of SMTZ: the Sulfate-Methane Transition Zone spreads over the entire depth range in which sulfate and methane are simultaneously present.

Presentation of results from 5 locations in the Aarhus Bay (spring 2003) and 2 “detailed” locations in the Kattegat (Gunner Thorson cruise). Problem: the sulfate profiles measured in GC and RL sample do not always fit nicely. Possible reasons: heterogeneous surface sediments and/or ship drift between subsequent gear deployments.

Geochemical data and process rates from GT03 and HE191 (Nina Knab, MPI Bremen)

Presentation of Kattegat data from the Gunnar Thorson cruise: AOM rates measured at locations K9 (29GC) and K154 (58VC). Presentation of data from the Skagerrak cruise HE191 comprise: CH_4 and SO_4^{2-} profiles from 7 gravity cores sampled across the southern slope of the Skagerrak Trench (depth gradient 87 m – 535 m) and 5 GC cores sampled across

a pockmark on the upper trench slope. Rates for AOM and SRR were measured and analyzed in 4 detailed cores along the depth transect (one of them in the pockmark). Rates from two cores sampled on the upper slope within and outside of a pockmark are presented.

Methanogenesis and direct counts, Gunnar Thorson cruise (Barry Cragg, Cardiff University)

Presentation of data from the two "detailed" Kattegat locations K9 (26GC/28GC) and K15 (58VC/59VC): Depth profiles of total cell numbers determined by Acridine orange direct counting (AODC) and putative rates of acetate methanogenesis and bicarbonate methanogenesis are compared with methane and sulfate profiles. A comparison of near surface cell counts (0-0.5 mbsf) in METROL samples, ODP cores, "Bo's box cores", and Tamar Estuary samples reveals a fairly good fit of depth profiles obtained from different regions of the world.

(Preliminary) stable isotope results. Gunnar Thorson and Heincke 2003 cruises (Ed Hornibrook, Bristol University)

Description of the sampling methods for the analysis of stable carbon isotopes from sediments. Kattegat, Gunnar Thorson cruise: Presentation of $\delta^{13}C$-CH_4 depth profiles obtained from cores 58VC and 59VC (site K15) and additional selected $\delta^{13}C$-CH_4 values measured in cores 28GC (site K9) and 9GC (site K8). Skagerrak, HE191: $\delta^{13}C$-CH_4 depth profiles in cores 789GC ("below gas front") and 821GC (mid-slope) and additional data from 807GC (upper slope) and 816GC (pockmark). Summary: Stable carbon-isotope data confirm that CH_4 from all stations has a microbial origin (most likely CO_2/H_2 methanogenesis). Highly ^{13}C-depleted CH_4 should provide a good signal for tracing in biomarker work. "Sister" cores 58VC and 59VC contain CH_4 with very similar stable isotope compositions.

METROL working area North Sea seeps (Antje Boetius, AWI and MPI)

Report on the 2002 Heincke cruise HE180 to the North Sea gas seep sites at Tommeliten, Machar, and in the UK Block 15/25. Localization of gas flares in the water column and dome-shaped subsurface gas plumes by hydro acoustics and video surveys (seabed surface). Mapping with combined methods of gas bubbles in the water column, subsurface gas plumes and bacterial covers on seabed. Presentation of CH_4 profiles in water column; sediment profiles for concentrations of methane, sulfate, sulfide, and biomarkers, rates of SRR and AOM, and cell numbers by AODC counts.

Microbiological results from water analyses from North Sea seeps (Hans Kristian Kotlar, Statoil)

Presentation of results from comparative diversity analyses of microbial associations/communities at different North Sea seep sites, (e.g., Tommeliten, Kvittebjørn) based on 16S rDNA. Summary: Microbial associations clearly differ between sites; microbial seep populations contain bacteria which are related to hydrothermal vent symbionts.

Description of Black Sea seeps / results from Black-Sea underwater research in 2003 (Maksim Gulin, IBSS)

Report on past and recent work of IBSS in the NW Black Sea and the Kattegat:

- Hydro-acoustic mapping of gas seeps SW of Crimea and off the Romanian coast in water depths between 73 m and 445 m;
- mapping of methane seeps over the paleo delta of the Dnjepr river;
- underwater research on gas seeps and related carbonate formations with the submersible "Benthos-300 N-1", mapping and investigations on gas emission of shallow water seeps near Cape Yuret and Cape Tarkhankut;

- analyses of radio isotopes in carbonates collected near Frederickshavn during the Gunnar Thorson cruise 2003.

18-MONTHS RESULTS

ABSTRACTS PRESENTED AT THE EGU MEETING SESSION BG25 METHANE FLUXES ON CONTINENTAL MARGINS: BUDGETS AND CONTROLS

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PROJECT METROL: METHANE FLUXES IN OCEAN MARGIN SEDIMENTS - MICROBIOLOGICAL AND GEOCHEMICAL CONTROL

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Seepage and gas emission from the ocean margin seafloor provides a methane window between sub-surface sediments and the water column and, potentially, the atmosphere. Although important for the global methane cycle, this methane flux probably accounts for less than 10% of the entire methane production in the sea bed. The major sink for the sediment methane is its breakdown by anaerobic oxidation upon entry into the sulfate zone. The main objectives of the EU-funded project, METROL, is to understand and quantify the accumulation, transport and oxidation of methane in selected European margin sediments, and to determine the position and efficiency of the sub-surface methane barrier relative to the total carbon flux. Among nine European partner, the project brings together geophysicists, geochemists and microbiologists in field studies in the Baltic Sea ½ U North Sea region and in the Black Sea. Among the approaches used, the distribution of shallow gas is mapped concurrent with porewater analyses of gravity cores at strategic sites in order to model and map the relationship between depth of gas and flux of methane. New field data on methane and carbon fluxes are combined with existing data in the geoscience database PANGAEA and applied for transport-reaction modeling and GIS-based visualization of the methane flux and its controls. The presentation will give examples of early results of the project. Further information can be found in the web under www.metrol.org.

SEISMIC EVIDENCE FOR GAS ESCAPE FROM MESOCOIC ROCKS IN THE NORWEGIAN TRENCH / SKAGERRAK

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In order to investigate occurrence and migration of fluids and gas the central Norwegian Trench and its southern slope has been investigated in the Skagerrak region by means of high-resolution multi-channel seismics. The multi-channel seismic (MCS) gear consisted of a S15 watergun (Sodera) and a 24 channel high-resolution streamer of 150 m active length.

On the plateau south of the Norwegian Trench the boundary between Quaternary and Cretaceous strata is marked by a conformity. Where the seafloor steepens towards the Norwegian Trench the conformity changes into a prominent erosional unconformity. Signal attenuation and acoustic whitening indicate gas loading within the up to 150 m thick Quaternary succession of the upper slope in water depth between 80 and 420 m. Here, elongated depressions align on the upper shelf and slope as it was described by other authors. The alignments of these current-modified pockmarks correlate with the location of bright reflections within Cretaceous rocks which subcrop at the erosional unconformity. We

interpret the bright reflections as the top of porous and permeable conduits for thermogenic gas. Chaotic and contorted reflections between the pockmarks and the subcropping bright reflections mark vertical gas upflow towards the seafloor. Downslope of the gas front and in water depths of more than 420 m the seismic data reveal acoustic turbulence and bright spots beneath the unconformity. This observation points to gas accumulation within the Cretaceous rocks. The Quaternary deposits form a less permeable capping sequence for the thermogenic gas. The seismic data corroborate the thesis that thermogenic gas escapes from Cretaceous strata and thus supports the formation of elongate depressions on the upper southern slope of the Norwegian Trench.

GEOLOGICAL CONTROLS OF METHANE SEEPS IN THE KATTEGAT AREA BETWEEN DENMARK AND SWEDEN

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The presumptions of the methane seeps in the northern Kattegat area were examined as part of the METROL EU project on methane contribution from the marine environment.

Previous estimates on total gas escape from the whole of the Kattegat area were based on detailed measurements around sub-tidal seeps. These measurements were, however, carried out mainly to understand the near surface processes involved, biological as well as chemical and paid only little attention to the role of geology controlling the location of the seeps.

It appears that gas seeps mainly occur in areas where glacigene marine deposits are found at shallow sub-bottom depth, as has been shown by a number of shallow acoustic surveys. Furthermore, migration of gas preferably occurs where Eemian - Early Weichselian marine deposits were affected by glaciers to great depths during the expansion of the Scandinavian ice sheet prior to Late Glacial Maximum 20 ka. Knowledge of the deformation processes of older marine sediments by glaciotectonics could be obtained from previous on-shore drillings (up to 200 m deep) as well as from coastal cliffs exposures. Numerous wells were drilled in coastal areas of northern Denmark during the 1930'ties and 1940'ties in order to exploit the shallow gas occurrences existing in that part of the country.

Thus, it may be concluded that gas charged fine-grained deposits in the Kattegat and Skagerrak area were pushed to shallower localities by Scandinavian glaciers during the last - Weichselian - ice age. In near coastal areas these deposits are now covered by sand that allow the gas to escape to the sea-floor before it is consumed by methanothrophs. Carbonate crusts associated with the gas seeps, show that part of the methane has been oxidized, as crusts were depleted with respect to the carbon-13 isotope compared to normal marine carbonates. Subsequent erosion, partly due to isostatic rebound after glaciation, has exposed spectacular submarine "landscapes" like the bubbling reefs.

Radiocarbon dating of methane from different seep areas confirm that the gas is more than 40,000 years old (limit of the radiocarbon method). By contrast, shallow gas in muddy sediments outside the seepage areas was found to be less than 3000 years old.

THE SULFATE-METHANE TRANSITION ZONE IN NORWEGIAN TRENCH SEDIMENTS (SKAGERRAK)

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Most of the methane formed in ocean margin sediments is degraded sub-surface by the process of anaerobic oxidation. This microbiological conversion is mostly confined to the Sulfate-methane-transition zone (SMTZ) which is the lower boundary to which seawater sulfate penetrates into the sediment and which constitutes a barrier against methane escape from deep sediment strata. The biogeochemical parameters characterizing the SMTZ and the

relationship between its sub-surface depth and environmental parameters, such as water depth and the occurrence of free gas in underlying sediments, are investigated by the EU project METROL. Gravity cores (5-6 m) were sampled across the southern slope of the Norwegian Trench (Skagerrak) in June 2003. Special focus was laid on sampling along the depth gradient and on sampling the up to 30 m deep elongated depressions (pockmarks) on the seafloor, which extend up to 2 km parallel to the depth contours. Geochemical profiles measured in upper slope sediments revealed high concentrations of pore water methane and indicate that the SMTZ usually was located within 0.5-1 m below the sediment surface. The shallowest SMTZ was found on the bottom of a pockmark, which supports the hypothesis of enhanced methane flux based on multi-channel seismic data. On the slopes of this pockmark, however, the position of the SMT was significantly deeper or methane was almost absent. No methane was found in a core retrieved from 535 m water depth in the central part of the trench.

EVIDENCE THAT ARCHAEA-SRB CONSORTIA ARE RESPONSIBLE FOR ANAEROBIC OXIDATION OF SLOWLY DIFFUSING METHANE

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Significant attention has been devoted to the study of the anaerobic oxidation of methane (AOM) due to its critical role in the mediation of methane fluxes from marine sediments. Most recent work - especially that employing microbiological and biomarker approaches - has focussed on cold seeps, where methane fluxes are high and methane-oxidizing communities are large. However, on a global scale AOM in ocean margin sediments characterized by relatively low diffusive methane fluxes is far more significant. Currently, there is little information on the biology of the organisms that mediate AOM in such settings and it is unclear whether they are the same as those found at cold seeps. As part of METROL, we examined biomarker distributions in marine sediments where methane is completely oxidized below the sediment-water interface (Benguela upwelling system, ODP core 1084; two sites in the Northern Kattegat and four sites in the Skagerrak, Baltic Sea). At all sites, we find archaeal and bacterial biomarkers similar to those observed in cold seep sediments, including archaeol (archaeal methanotrophs) and non-isoprenoidal diethers (sulphate-reducing bacteria). In some Skagerrak sites, sn-2-hydroxyarchaeol, thought to be particularly diagnostic for the archaea involved in AOM at cold seeps, is also present. Archaeol abundances vary from 25 to 400 ng g sediment^{-1}, considerably lower than those commonly found at cold seeps (up to 25 µg g sediment^{-1}), indicating that the AOM community was and/or is smaller. Nonetheless, the presence of the same biomarkers suggests that similar organisms mediate AOM in both continental margin and cold seep sediments.

MODELLING ANAEROBIC OXIDATION OF METHANE IN MARINE SEDIMENTS - PRELIMINARY RESULTS

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The widespread process of anaerobic oxidation of methane (AOM) in marine environments is currently being investigated as part of the multi-national METROL project (Methane Flux Control in Ocean Margin Sediments). Using data collected from the project cruises to European continental margins, we have devised a bioenergetic-based understanding of AOM and modeled the methane sink using a diagenetic reactive transport model. The ultimate role of the modeling studies is to underpin the main controls of methane flux to the oceans and the consequent impact on the global carbon cycle.

POSTERS PRESENTED AT THE EGU MEETING SESSION BG25 METHANE FLUXES ON CONTINENTAL MARGINS: BUDGETS AND CONTROLS

ACOUSTICAL MAPPING OF METHANE DISTRIBUTION IN THE HOLOCENE SEDIMENTS OF THE ÅRHUS BAY, DENMARK

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Within the EU project METROL, the overall purpose of the fieldwork in the Århus Bay is to track possible seasonal and inter-annual variations of the geochemical zonation in areas represented by variation in depth to the methane free gas zone. A M/S Line cruise was devoted to shallow seismic work in the Århus Bay, with the purpose to make detailed acoustic mapping of the acoustic blanking, representing the distribution of methane in the sediments and to attempt to establish the general stratigraphy of the Århus Bay, in order to be able to relate the gas formation to specific units. On basis of mapping of the areas that show acoustic blanking , a preliminary map of the distribution and depth to free methane in the muddy sediments has been produced. The combined information from the different seismic equipment's allowed a mapping of the distribution and depth to free gas in the intervals 0-0,5m, 0,5-2m, 2-4m and >4m.

The map shows that acoustic blanking is found in the central part of Århus Bay about 4m below the seabed. A rather dense seismic grid and a key sampling station M1 document this. In areas where the sedimentation rate is assumed to be high, the acoustic blanking is found with gradually more methane towards the sediment surface. From the selected key station M2 with no free methane in the top 4m of the sediment to M5 with free methane within the surface 1-meter. The mapping results show that the oldest seismic unit is glacial till, probably related to the latest glacial advance in the region. The glacial till is covered by lateglacial icelake clay-silt reaching a thickness of up to 10m. The existence of the clay-silt is documented by descriptions of old vibrocores from the region. The glacial till and the lateglacial clay-silt contain insignificant amounts of organic matter and can not be regarded as the source of the methane gas.

In the deeper part of the Bay, early Holocene organic material and peat has been described in few cores. A thin seismic unit is observed probably representing an early Holocene lowstand period, when most of the Århus Bay was dry land. The 3 uppermost seismic units are related to the Holocene transgression of the region representing different hydrographical conditions. The lowermost unit partly drapes the basin area with clay sediments and partly shows prograding sandy coastal deposits around glacial ridges. Some shells are reported in old cores but it is unclear if it is brackish or marine deposits. The next unit consists in general of marine mud to sandy mud covering most of the central part of the Århus Bay and some places reaching the present seabed in areas of erosion or non-deposition. The distribution of the youngest seismic unit illustrates the sub-recent to recent sedimentation basin areas in the central part of the basin. The acoustical mapping shows that the methane production takes place in all the Holocene seismic units.

METHANE AND SULFATE DYNAMICS IN THE SEDIMENTS OF AARHUS BAY (DENMARK)

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Methane is observed in Aarhus Bay sediments in a wide concentration range from near saturation (i.e. gas bubble formation) close to the surface sediment to no detectable CH_4 in the top 4 m of the sediment. Therefore Aarhus Bay sediment is an interesting study area to learn

more about what controls methane concentrations in marine sediments and thus the CH_4 flux towards the surface sediment - key questions in the EU project: METROL. Methane and sulfate concentration profiles were determined at five stations that was sampled by gravity coring (max. 4m) and Rumohr lot coring (max. 80 cm). One station was chosen in the central part of Aarhus Bay where the sulfate-methane transition zone (SMTZ, i.e. the depth where SO_4^{2-} and CH_4 coexist) was observed at 150 - 220 cm over a wide area. The other four stations were sampled along a 1.5 mile transect where gas bubbles appeared gradually closer to the sediment surface with a concomitant raising of the SMTZ towards the sediment surface (i.e. from 200 to 20 cm below the sea floor). The chemical analyses of the SO_4^{2-} and CH_4 concentrations profiles were compared to acoustic/ seismic studies of the sea floor where gas bubble formation were observed from their reflection of the acoustic waves. The closer methane saturation (i.e. gas bubble formation) was observed towards the sediment surface the shorter the distance to the methane front above. The dimension of the SMTZ revealed no obvious dependency on the depth of the gas bubble front.

INTERMITTENT GAS SEEPAGES CAUSED BY SEDIMENT SLUMPING ON THE SOUTHERN SLOPE OF SKAGERRAK - RESULTS OF RADIOCARBON DATING

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The presence of gas seeps on the southern slope of the Skagerrak is indicated by distinct methane anomalies in the water column above a limited area at approximately 350 m water depth. Furthermore, patches of black sulfide layers on the seafloor obtained by boxcoring confirm that strongly reducing conditions exist in localised spots of this area. Despite these indications, it has been difficult to obtain more exact information as to nature as well as to the cause of these seeps. In seeking an answer to these questions, radiocarbon dating was carried out on a number of gravity cores, approximately 2 m long, obtained from this area as well as the neighbouring areas. The material for radiocarbon dating included methane, shells, foraminifera as well as organic matter.

Methane from the seep area is distinctly younger (335 - 540 y) than methane from neighbouring sites (1030 - 1425 y). This excludes the possibility of a deeper older source for the gas, furthermore, the youngest gas was found at the shallowest depth. Radiocarbon dating of shell material indicated that the sediments of the seepage area were younger than sediments of similar depths in the neighbouring areas, suggesting higher sediment accumulation rates in the seepage area. However, accumulation rates may have changed considerably over time, as a sudden shift in age from 130 y to virtually recent occurred from 153 cm to 137 cm below surface. A shift in lithology at this depth was also evident visually. The shift in accumulation rate indicates that sediment slumping may have taken place in the surroundings of the seepage site. Slumping may have lead to very fast burial of fresh easy degradable organic matter, resulting in methane production when pore water sulphate had been exhausted. In analogue, elsewhere in Danish waters it has been observed that methane with a modern carbon signature started to seep from artificial sediment slumping only two months after the slumping took place. The slumping occurred by an unfortunate incident during a tunneling operation, when water from the sea above entered the tunnel. Adding more seafloor sediment into the hole quickly sealed the hole. Shallow gas has not otherwise been observed in the area of the incident. After another 3 months seeping of gas ceased to occur at this location. Comparing with observations made after the tunnel incident, it is possible that gas seeps caused by slumping in the Skagerrak are only short lived and therefore difficult to detect from time to time.

METHANE SEEPS IN THE NORTH SEA : TOMMELITEN REVISITED

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Germany

North Sea sediments from pockmarks often contain high amounts of gas and oil buried in 3 to 5 km below sea floor. In the framework of the EU project METROL, the former exploration site Tommeliten was visited in 2002. The goal was to identify potential target sites with gas seepage for further study of methane emission and its control. At Tommeliten we found active venting in the form of rising gas bubbles from small seeps. Tommeliten is characterized by the presence of carbonate reefs, which are populated by a diverse benthic community. Parasound reflectivity indicated gas mounds reaching up to sediment surface. Sediment and water column samples were obtained along a transect. In the water column gas plumes (20-100 m in width reaching up to 20 m below sea surface) were observed acoustically and sampled with a CTD. Within the gas plume, high concentrations of methane were found, decreasing to background values outside of the seep area. Cores of up to 4 m length were sampled with the vibrocorer. The cores from the seeps contained free gas in the form of bubbles within sandy sediments. Along the transect, the methane sulfate transition zone deepened away from the point source, from surface to > 200 cm sediment depth. Free gas was trapped in bubbles between layers of marl and carbonates. Within the methane-sulfate transition zone, clear peaks in lipid abundance and stable isotope depletion were recognized and indicate the presence of a community of anaerobic methanotrophs. Distribution and diversity of the methanotrophic community is currently investigated.

MODELING BIOGEOCHEMICAL FLUXES USING A KNOWLEDGE-BASED REACTIVE TRANSPORT APPROACH. ANAEROBIC OXIDATION OF METHANE AS A CASE STUDY

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The rapid increase in observational data of biogeochemical transformation processes in natural environments requires efficient assimilation into predictive models. Reactive transport models provide a powerful tool for global cycle prediction, provided that the observational data are integrated into a robust and realistic model framework. To meet these demands, the Biogeochemical Reaction Network System (BRNS) has been developed from a knowledge base (KB) of physical and biogeochemical processes integrating reaction mechanisms and rates. A Graphical User Interface (GUI) on a web-based 'runtime' server allows the user to select any number of KB processes required for their modeling task. With this approach it is no longer the model itself, but an easily accessible, open resource element, the KB, which contains the conceptual and quantitative understanding of biogeochemical pathways and their interactions.

Our results demonstrate that the BRNS allows reaction networks of increasing complexity, evaluates alternative process formulations, and develops diagnostic indicators of biogeochemical pathways that can be measured in the field or in experimental set-ups. A case study of anaerobic oxidation of methane has been developed to highlight the main features of the BRNS.

FURTHER RESULTS AFTER 18 MONTH PRESENTED ONLY DURING UTRECHT MEETING

Bicarbonate and acetate methanogenesis in Kattegat and Skagerrak sediments (Barry Cragg, Cardiff University)

Data were presented showing the bicarbonate methanogenesis rate for cores from a cruise to the Kattegat/Skagerrak area named GC 26/28 and VC 58/59.

In GC 26/28 methanogenic activity increases from around the CH_4/SO_4 transition or sulfate-methane transition zone (SMTZ), around 1.3 mbsf however, sustained increases in activity do not start until 2 mbsf. Bacterial population numbers show no change at the transition but show a local increase at around 1.7 mbsf co-incident with an increase in methanogenesis. The percentage of dividing cells increases significantly with the sustained increase in methanogenesis at 2 mbsf. In VC 58/59 There is a significant occurrence in methanogenesis at 3.7 mbsf. This is coincident with the SMTZ and an increase in total bacterial numbers.

Data were presented for bicarbonate methanogenesis for four cores from the Heincke 191 cruise to the North Sea. A notable observation here is the variability of the methanogenic activity profile between cores. In Core GC 789 activity is zero within the transition zone, increasing significantly below this depth. In Core 807 activity increases significantly throughout the transition zone. In Core 816 the greatest rate of methanogenesis occurs within the transition zone. A lower peak of methanogenesis (1.25 – 2 mbsf) is associated with a local peak in methane concentrations. Core 821 is similar to Core 789 with significant methanogenic activity not recorded until below the transition zone.

Provisional acetate methanogenesis rates are also presented for the Heincke 191 data. Preliminary interpretation suggests that acetate methanogenesis is not a significant process in these sediments as rates are some four to five orders of magnitude smaller than those for bicarbonate methanogenesis.

^{210}Pb and ^{137}Cs activities in Kattegat sediments (Tim Ferdelman, MPI Bremen)

^{210}Pb, ^{226}Ra, and 1^{37}Cs data obtained from ultra-low gamma spectroscopic analysis of surface sediments from Kattegat stations K6 and K9 (Gunnar Thorson 2003) were shown. The peak in the ^{137}Cs activity at 7 cm at Station K9 (68RL), ostensibly due to fallout from the Chernobyl accident in 1986, gives an approximate sediment accumulation rate of 0.4 cm/a. The distribution of excess ^{210}Pb (unsupported by ^{226}Ra) with depth at K9 indicates a well-bioturbated zone of 10 to 15 cm. K6 (72RL) shows extremely high sediment accumulation rates of ca. 1.5 cm/a, based on the ^{137}Cs peak at 25 cm. This is supported by the very deep penetration of ^{210}Pb to depths of >40 cm. Samples for Site K10, selected Skagerrak sites, and two Aarhus Bay sites are being or will be counted.

Availability of bathymetric data for Metrol (Andreas Beyer, AWI)

Bathymetry serves as basic information for all marine sciences. Morphological structures can represent subsurface structures such as faults or oceanographic conditions such as flow regimes. A bathymetric map was compiled based on data from ICES, Mudab, BODC, AWI (collected within the framework of the MARGIS project) and depth contours from Statoil (10m contour interval) and GEBCO (100 m contour interval). The Statoil contours have been extracted from printed charts via scanning, georeferencing and digitizing. The Statoil contours proved to be very accurate and GEBCO contours were not used for gridding in those areas. The data were processed to determine a 2500m grid of the North Sea and the adjacent part of the Baltic Sea. Micro bathymetry is also available along 3 parts of a pipeline. They show detailed bathymetric structure and the southern flank of the Norwegian trough is dominated by pockmarks (e.g. ca. 7 pockmarks per square kilometre).

Short glossary of terms

GC: gravitycorer

Mbsf: metres below sea floor

RL: Rumohr lot

SMTZ: the Sulfate-Methane Transition Zone

SRB: sulfate reducing bacteria

VC: vibrocorer