

METEOR-Berichte

PROSA

Process Studies in the Eastern South Atlantic

Cruise No. 76, Leg 1-3

April 12 – August 24, 2008,
Cape Town (South Africa) – Walvis Bay (Namibia)



Matthias Zabel, Antje Boetius, Kay-Christian Emeis,
Timothy G. Ferdelman, Volkhard Spieß

Editorial Assistance:
Senatskommission für Ozeanographie der Deutschen Forschungsgemeinschaft
MARUM – Zentrum für Marine Umweltwissenschaften der Universität Bremen

Leitstelle Deutsche Forschungsschiffe
Institut für Meereskunde der Universität Hamburg

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Editor:

DFG Senatskommission für Ozeanographie
c/o MARUM – Zentrum für Marine Umweltwissenschaften
Universität Bremen
Leobener Strasse
28359 Bremen

Authors:

Dr. Matthias Zabel	Telefon: +49-421-218-3392
Universität Bremen – FB 5 Geowissenschaften	Telefax: +49-421-218-4321
Klagenfurter Str.	e-mail: mzabel@uni-bremen.de
D-28359 Bremen / Germany	

Dr. Timothy Ferdelman	Telefon: +49-421-2018-632
Max-Planck-Institut für Marine Mikrobiologie	Telefax: +49-421-2018-690
Celsiusstr. 1	e-mail: tferdelm@mpi-bremen.de
D-28359 Bremen / Germany	

Prof. Dr. Kay-Christian Emeis	Telefon: +49-40-42838-4992
Inst. für Biogeochemie und Meereschemie	Telefax: +49-40-42838-6348
Universität Hamburg	e-mail: emeis@zmaw.de
Bundesstraße 55	
D-20146 Hamburg / Germany	

Prof. Dr. Volkhart Spieß	Telefon: +49-421-218-3387
Universität Bremen – FB 5 Geowissenschaften	Telefax: +49-421-218-7179
Klagenfurter Str.	e-mail: vspiess@uni-bremen.de
D-28359 Bremen / Germany	

Prof. Dr. Antje Boetius	Telefon: +49-421-2018-648
Max-Planck-Institut für Marine Mikrobiologie	Telefax: +49-421-2018-690
Celsiusstr. 1	e-mail: aboetius@mpi-bremen.de
D-28359 Bremen / Germany	

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Abstract

METEOR cruise M76 comprised of four legs to three working areas in the eastern South Atlantic the shelf and continental slope off Namibia, the deep-sea fan of the Congo River with the giant pockmark REGAB, and the DIAPIR area off Angola; Fig. 1). Due to a high security risk, originally planned investigations in the area of the Niger fan could not take place.

The main objective of the first leg (M76/1a,b) was to provide the scientific party with new samples for deep biosphere research. Microbial life in deeply buried sediments has only moved more and more into the focus of geoscientific and microbial research in the mid of the nineties. Main questions concentrate on the composition of the communities and the energy sources for the material cycles. With long sediment cores from the upper continental slope off Namibia sample material for a variety of interdisciplinary investigations should be gained. For this purpose the new wire-line drilling technique of the sea floor drill rig (MeBo) was tested for the in time in unconsolidated marine sediments. Unfortunately, but typical for the season, strong low-pressure areas around the Southern Ocean caused high swell up to 6m in the whole working area during most of the time, which very much restricted the time for deployments of MeBo. Nevertheless, very valuable information could be gained which led to important improvements for the next uses of the equipment, e.g. during METEOR cruise M78/3. Conventional devices were used to take a huge amount of new and very promising samples for subsequent analysis in the home labs. Furthermore, the waiting time for better weather conditions was used two times for intensive hydroacoustic surveys of a relatively small area (about 360 km²) in the southern working area, where very conspicuous pock mark structures could be identified.

During the second leg of this cruise (M76/2), reactions of geochemical environmental conditions on natural, temporal variations in the hydrodynamic circulation of the Benguela coastal upwelling off Namibia and Angola were investigated. Therefore a CTD station grid was occupied that consisted of transects perpendicular to the coast. Observations in the northern Benguela suggest that the summer season 2008 was characterised by exceptionally high surface temperatures and an increased frequency of coastal hydrogen sulphide outbreaks. Not only from the biogeochemical perspective, an on-line measuring system (FerryBox; 4H-JENA) could be used successfully to document spatial and temporal variations of the oceanographic and biogeochemical situation during the expedition M76/2. A very extensive data set could be generated which allows more detailed investigation on the complexity of the biogeochemical interrelations within an upwelling system. Especially, new information on the nitrogen cycle could be retrieved. With a suite of autonomous instruments, including benthic landers, conditions in the benthic boundary layer (BBL) were investigated. Additional velocity measurements show that surface waves induce high current velocities in the BBL even at water depths of about 100m. Oxygen measurements seem to correlate with wave frequency and indicate a possible vertical transport mechanism for solutes and resuspended matter.

The main objectives of the first of the expedition GUINECO (M76/3a) were to investigate the controls of fluid and gas migration, the accumulation of free gas in and beneath the gas hydrate stability zone, and the geochemical and microbiological interactions at the sediment-water interface, with the help of high-resolution seismo-acoustic mapping, video observations and sediment coring on the West African continental margin. Main questions include on one hand the influence of facies, grain size, and permeability variations within the sediment; and on the other,

the effect of salt tectonic deformation on gas accumulation and migration. Different lithological settings were selected for comparative multi-scale investigations with swath bathymetric, sediment echo-sounder, multichannel seismic, and backscatter systems as well as geological and bio-geochemical sampling. The immediate products of the cruise were a complete picture of the structural and sedimentary framework; near-3D images of vent sites, migration pathways and gas reservoirs; the identification of areas of recent vent activity, an overview information for subsequent ROV work during leg M76/3b and a quantification and characterization of active vent sites and shallow gas hydrate deposits in the light of different geological conditions.

During the second leg of the expedition GUINECO (M76/3b) the different target areas and active venting sites identified during the previous cruise were visited with ROV QUEST. Beside further visual observations, intensive sampling of escaping gas bubbles, sediments and organisms were carried out. Also in situ microsenors and a respiration chamber were used. Furthermore, several profiling instruments and carbonate colonization experiments were deployed, while some experimental moorings from former expeditions could be recovered.

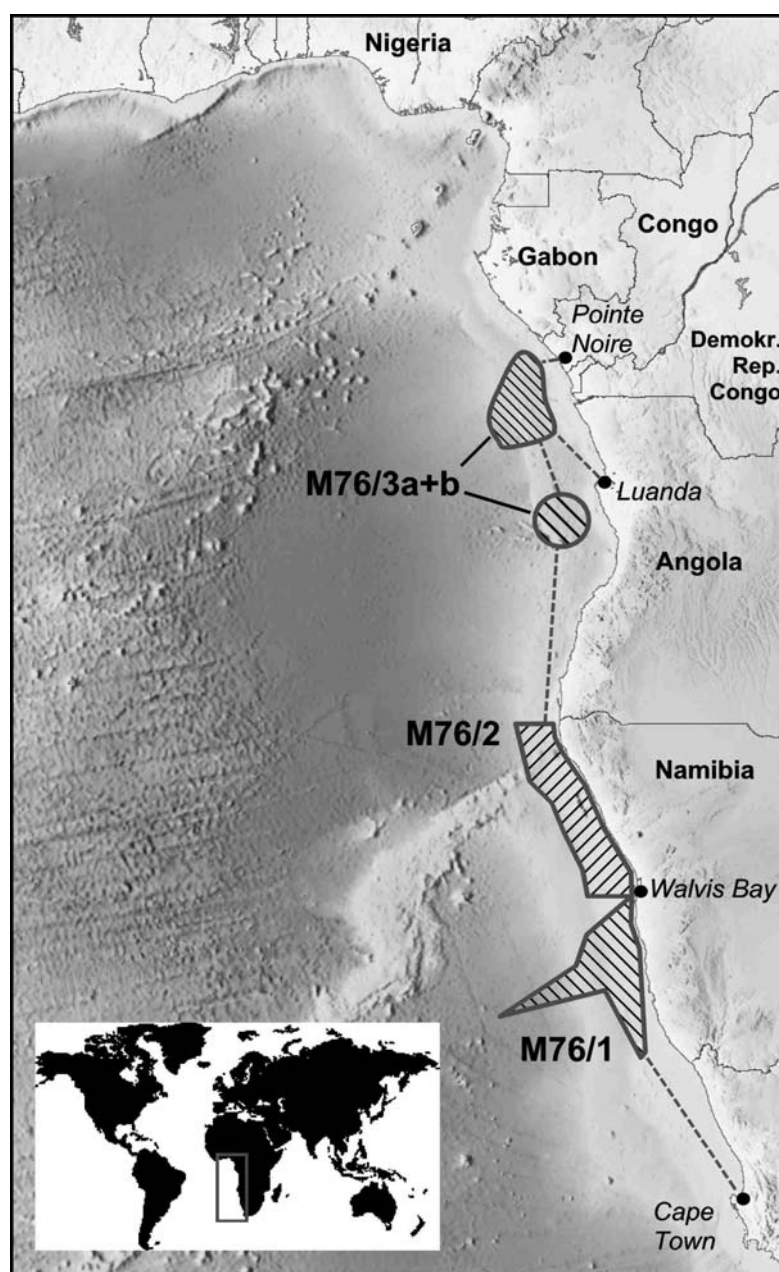


Fig. 1: Working areas (shaded) and harbors of METEOR cruise M76

Zusammenfassung

Die METEOR Reise M76 umfasste vier Fahrabschnitte in drei Untersuchungsgebiete im östlichen Südatlantik (Schelf und Kontinentalhang vor Namibia, Sedimentfächer vor der Kongo Mündungen, Diapir-Gebiet vor Angola). Aufgrund eines zu hohen Sicherheitsrisikos konnten die ursprünglich im Bereich des Nigerfächers geplanten Untersuchungen nicht stattfinden.

Im Zentrum des ersten Fahrabschnittes (M76/1) stand die Erforschung der tiefen Biosphäre, einem Bereich, der erst seit Mitte der 90er Jahre in den Fokus geowissenschaftlicher und mikrobieller Forschung gerückt ist. Anhand langer Sedimentkerne vom oberen Bereich des Kontinentalhanges vor Namibia sollten verschiedene aktuelle Fragestellungen bearbeitet werden. Mit chemischen und mikrobiologischen Verfahren sollen insbesondere biogeochemische Prozesse, die beteiligten mikrobiellen Gemeinschaften, und deren Wechselbeziehungen zur lokalen Ozeanographie und dem Sedimentationsmilieu untersucht werden. Auf dieser Forschungsreise wurde erstmalig das Tiefseebohrgerätes (MeBo) mit neuer, drahtgeführte Technik in unverfestigten marinen Sedimenten eingesetzt. Leider war die mögliche Einsatzzeit, aufgrund der jahreszeitlich bedingten Wettersituation mit hoher Dünung um 6m, auf wenige Tage beschränkt. Nichtsdestotrotz konnten sehr wertvolle Informationen zum Einsatz des Gerätes gewonnen werden, die schon zu wichtigen Verbesserungen des Systems und erfolgreichen Folgeeinsätzen führten (z.B. auf der METEOR Expedition M78/3). Während der Ausfahrt konnte mit konventionellen Geräten eine große Anzahl wertvollen Probenmaterials für nachfolgende Untersuchungen in den Heimplaboratorien genommen werden. Ferner wurden Wartezeiten auf bessere Wetterbedingungen zweimal dazu genutzt um im südlichen Arbeitsgebiet ein relativ kleinräumiges Areal mit sehr außergewöhnlichen Pockmark-Strukturen intensive mit den zur Verfügung stehenden hydroakustischen Verfahren zu vermessen.

Auf dem zweiten Fahrabschnitt (M76/2) wurden die Reaktion geochemischer Umweltbedingungen auf natürliche, zeitliche Variationen in der hydrodynamischen Zirkulation des Benguela-Küstenauftriebs vor Namibia und Angola untersucht. Zu diesem Zweck fanden Untersuchungen u.a. mit einem CTD-Kranzwasserschöpfer insbesondere entlang von 7 Transekten senkrecht zur Küste statt. Erste Untersuchungsergebnisse im nördlichen Benguela-Gebiet zeigen, dass die Sommersaison 2008 durch besonders hohe Oberflächenwassertemperaturen und eine zunehmende Anzahl an Schwefelwasserstoffausbrüchen gekennzeichnet war. Nicht nur aus biogeochemischer Sicht war der Einsatz eines Online-Messsystems (FerryBox; 4H-JENA) zur Dokumentation räumlicher und zeitlicher Variationen der ozeanographischen und biogeochemischen Bedingungen im Arbeitsgebiet während der Reise M76/2 sehr erfolgreich. So konnte ein überaus großer Datensatz generiert werden, der sehr detaillierte Untersuchungen komplexer biochemischer Wechselbeziehungen im Auftriebssystem erlaubt. Hierzu gehören in besonderem Masse neue Informationen zum Stickstoffkreislauf. Mit einer Reihe autonomer Instrumente, z.B. benthischen Landersystemen, wurde die benthische Grenzfläche (BBL) untersucht bzw. beprobt. Mit Messungen der Wassermassenbewegungen konnte gezeigt werden, dass Oberflächenwellen selbst in 100m Tiefe hohe Strömungsgeschwindigkeiten im Bereich der BBL indizieren können. Darüber hinaus lässt die Korrelation zwischen Wellenfrequenzen und Schwankungen in Sauerstoffgehalte einen möglichen vertikalen Transport von gelösten Komponenten wie resuspendiertem Material vermuten.

Auf den dritten Fahrabschnitt, dem ersten der GUINECO Expedition (M76/3a) sollten in erster Linie Kontroll- und Steuerungsmechanismen für Fluid- und Gasmigration und die Akkumulation freien Gases im Bereich der Gashydrat-Stabilitätszone, sowie geochemische und mikrobielle Wechselwirkungen an der Sediment-Wasser Grenzfläche untersucht werden. Hierzu wurden hochauflösender seismo-akustischer Messungen, Video-Aufzeichnungen, Bilderfassung und Auswertung, sowie Untersuchungen an Sedimentkernproben durchgeführt. Die Hauptfragestellungen bezogen sich einerseits auf den Einfluss von Variationen in Fazies, Korngröße und Permeabilität, andererseits auf Auswirkungen von Salztektunik und -deformation auf Gasansammlungen und dessen Migration. Für vergleichende, vielskalige Untersuchungen wurden zu diesem Zweck an unterschiedliche Lokationen bathymetrisch, tiefreichende lithologische, wie geologische und biogeochemische Arbeiten durchgeführt. Unmittelbare Ergebnisse bzw. Produkte der Ausfahrt waren komplette Abbildungen der strukturellen und sedimentären Untergrundcharakteristiken, Bilder von Vent-Lokationen, Migrationspfaden und Gasreservoirs in nahezu 3D-Qualität, die Identifikation aktiver Vent-Lokationen, die Generierung von Überblicksinformationen für nachfolgende ROV-Tauchgänge während des letzten Fahrabschnitts (M76/3b) und die Quantifizierung und Beschreibung aktiver Austrittsstellen und flacher Gashydratvorkommen.

Während des zweiten Abschnitts der GUINECO Expedition (M76/3b) wurden die unterschiedlichen Zielgebiete und hier insbesondere die auf der vorangegangenen Fahrt identifizierten aktiven Austrittsstellen mit Hilfe des ROV QUEST untersucht. Neben weiteren visuellen Beobachtungen erfolgten zumeist Tauchgänge mit sehr intensiven Beprobungen der Organismengemeinschaften, der Oberflächensedimente, sowie der austretenden Gasblasen. Auch in situ Mikrosensoren und eine benthische Respirationsskammer kamen zum Einsatz. Ferner wurden porfilierende Instrumente und Experimente zur Karbonatbesiedelung ausgesetzt. Einige experimentelle Verankerungen früherer Reisen konnten geborgen werden.

Research Objectives

The major objective of the first Leg of METEOR-Cruise 76 was the investigation of the deep biosphere. Due to the lack of cultured representatives our knowledge about the physiology and ecology of deep biosphere microorganism is still limited. Biomarker studies and the detection of certain marker genes in deep sediments indicated the presence of potentially chemolithotrophic bacteria and archaea, gaining their energy by metabolizing inorganic compounds. This cruise should provide us with sediment material from the deep subsea floor at the upper continental margin off Namibia. Specific biogeochemical processes, involved microbial communities, and their interrelations with the local oceanography and sedimentation regime should be investigated with a variety of chemical and microbiological methods and approaches. The main research questions were: 1) What are mechanisms controlling biogeochemical processes, their transfer rates and the composition of the microbial community in deeply buried sediments along the continental slope of Namibia. 2) Which kind of systematic correlations exist between microbial transfer rates, water depths, accumulation rates and the contents of organic carbon? 3) Is there an influence of the paleoceanographic regime and/or paleoclimate conditions on the composition of the benthic microbial communities, the biogeochemical processes and corresponding transfer rates?

Leg two was one of two initial expeditions in 2008 under the auspices of GENUS (Geochemistry and Ecology of the Namibian Upwelling System), a new research effort which aims to clarify relationships between climate change, biogeochemical cycles of nutrient elements, radiatively active gases, and ecosystem structure in a large marine ecosystem. The scientific aims of GENUS will be pursued by empirical studies into processes and rates of ocean circulation, biogeochemical cycling of nutrient elements between water column, biota and sediments, trophic interactions and energy flows, and a hierarchy of numerical models from regional climate, ocean circulation, ecosystems, and energy flows. GENUS also aims for a contribution to building capacity in marine sciences in Namibia by staging a joint scholarship programme with NatMIRC, UNAM, and German partner universities, by organising topical workshops in Namibia, and by participation of Namibian scientists on seagoing expeditions. During this expedition possible reasons for and consequences of variable oxygenation of shelf waters offshore Namibia in the Northern Benguela Coastal Upwelling System should be investigated. These variable oxygen conditions impact on the fluxes of dissolved constituents from sediments to the water column and are modulated by microbial communities. The main questions addressed during operations at sea were: 1) How does the physical circulation system affect oxygen conditions on the shelf? 2) How are nutrient element cycles and ratios between nutrients affected by variable oxygen conditions? 3) Which processes in the cycling of nitrogen are responsible for unusual nutrient ratios in the upwelling waters? 4) What is the magnitude of sediment-water exchange processes under variable oxygen condition? This expedition, with two Namibian participants, investigated the reasons for and consequences of variable oxygenation of shelf waters offshore Namibia in the Northern Benguela Coastal Upwelling System.

The main objectives of METEOR Cruise M76/3a were to investigate the controls of fluid and gas migration, the accumulation of free gas in and beneath the gas hydrate stability zone, and the geochemical and microbiological interactions at the sediment-water interface, with the help of high-resolution seismo-acoustic mapping, video observations and sediment coring on the West African continental margin. Main questions include on one hand the influence of facies, grain size, and permeability variations within the sediment; and on the other, the effect of salt tectonic deformation on gas accumulation and migration. Different lithological settings were selected for comparative multi-scale investigations with swath bathymetric, sediment echo-sounder, multichannel seismic, and backscatter systems as well as geological and bio-geochemical sampling. The immediate products of the cruise were a complete picture of the structural and sedimentary framework; near-3D images of vent sites, migration pathways and gas reservoirs; the identification of areas of recent vent activity, an overview information for subsequent ROV work during leg M76/3b and a quantification and characterization of active vent sites and shallow gas hydrate deposits in the light of different geological conditions. A close cooperation with IFREMER, Brest allows extended expertise especially in the fields of carbonate precipitation, biogeochemistry, microbiology, biology, monitoring and modeling.

The main objectives of the cruise leg M76/3b “GUINECO” were the comparative biological, geological and biogeochemical analyses of fluid and gas seepage at cold seep ecosystems of the West African continental margin. This includes the detailed mapping of gas and fluid venting as well as gas hydrates and their associated ecosystems. The remotely operating vehicle QUEST4000 of MARUM was the main working tool of this leg. Measurements of different physical, chemical and geological processes were combined with intensive observation and

sampling of seep communities, from micro- to megafauna. The program was developed in the framework of the cooperation between the MARUM (Bremen) and the French research institute IFREMER (Brest). The main research questions of GUINECO leg b were: 1) How does fluid and gas venting as well as diffusive seepage of gas influence biogeochemical processes at seeps? 2) How high is the net flux of fluids and gases and other chemical compounds at different types of cold seeps? 3) Which geochemical, geomicrobiological and sedimentological parameters control mineralization processes at gas and fluid vents? 4) How is the biodiversity of different size classes of cold seep organisms coupled to geological and geochemical processes?

Legs, sub-legs, chief scientists, and masters of R/V METEOR Cruise M76

<i>Leg / Sub-leg</i>	<i>Period</i>	<i>Ports</i>	<i>Chief Scientists</i>	<i>Master</i>
M76/1(a/b)	April 12 – May 13 '08	Cape Town – Walvis Bay	M. Zabel / T.G. Ferdelman	W. Baschek
M76/2	May 15 – June 4 '08	Walvis Bay – Walvis Bay	K.-C. Emeis	W. Baschek
M76/3a	June 7 – July 13 '08	Walvis Bay – Walvis Bay	V. Spieß	N. Jakobi
M76/3b	July 17 – Aug 24 '08	Walvis Bay – Walvis Bay	A. Boetius	N. Jakobi

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METEOR-Berichte

PROSA - Process Studies in the Eastern South Atlantic

PART 1

Cruise No. 76, Leg 1

April 12 – May 13, 2008, Cape Town – Walvis Bay



**Zabel M., Ferdelman T.G., Arnold G.L., Bender V.B., Bergenthal M.,
Buhmann S., Diekamp V., Düßmann R., Engelen B., Faust J., Formolo
M., Goldhammer T., Heuer V., Hielscher J., Hörner T., Hohnberg H.-J.,
Kalweit H., Klein T., Kleindienst S., Könnecker H.O., Lever M., Lin Y.-
S., Lunk T., Pape S., Rehage R., Renken J., Rosiak U.D., Sauer S.,
Schmidt W., Schnetger B., Siegert M., Truscheit T.**

Editorial Assistance:

Senatskommission für Ozeanographie der Deutschen Forschungsgemeinschaft
MARUM – Zentrum für Marine Umweltwissenschaften der Universität Bremen

Leitstelle Deutsche Forschungsschiffe
Institut für Meereskunde der Universität Hamburg

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1.1 Summary / Kurzfassung

The primary goal of this expedition was the coring of deeply buried sediments at five locations along the continental slope off Namibia. For this purpose the seafloor drill rig MeBo should be used, which has been developed under the leadership of the MARUM. Unfortunately, on several reasons, this goal could not be reached. Firstly, on many days to high swells prevented the deployment of the device. Furthermore, there were several technical problems with the technologically advanced instrument so that suitable sediment core material could not be recovered. Nevertheless, in many ways the first leg of the 76th METEOR cruise can be considered as successful. Extremely valuable experience in dealing with the MeBo system was collected, leading to its further development and improvement. Subsequent operations will benefit. Moreover, using conventional techniques, a great number of very good sample materials could be collected for further organic-geochemical, microbiological and biogeochemical investigations. In addition to the comprehensive analytical program onboard, first experiments were performed on the very intensely discussed topic of the importance of hydrogen in microbially catalyzed, geochemical processes, as well as to discover the benthic phosphorus cycle by using an innovative isotopic tracer technique. The time for processing the sample material and to bridge periods of bad weather conditions was used for detailed bathymetric surveys. Very spectacular was the detection of a huge set of giant pockmark structures on the upper continental slope.

Vorrangiges Ziel dieser Expedition war die Beprobung tiefvergrabener Sedimente am Kontinentalhang vor Namibia. Dies sollte an fünf ausgewählten Lokationen durch den Einsatz des am MARUM neuentwickelten Meeresboden-Bohrgerätes (MeBo) erfolgen. Leider konnte dieses Ziel aus verschiedenen Gründen nicht erreicht werden. Zum einen war ein Ausbringen des Gerätes an vielen Tagen aufgrund zu hoher Dünung nicht möglich. Ferner verhinderten technische Defekte mehrfach die Gewinnung guten Kernmaterials. Dennoch kann die Reise in vielfältiger Weise als erfolgreich bezeichnet werden. So wurden nicht nur extrem wertvolle Erfahrungen im Umgang mit dem MeBo gesammelt, die zu seiner Weiterentwicklung führen und nachfolgenden Einsätzen zugutekommen werden. Darüber hinaus konnte sehr gutes Probenmaterial für weiterführende, organisch-geochemische, mikrobiologische und biogeochemische Untersuchungen gesammelt werden. Neben einem umfangreichen analytischen Programm wurden insbesondere erste Experimente zur Erweiterung des aktuellen Kenntnisstandes hinsichtlich der Bedeutung von Wasserstoff bei mikrobiell katalysierten, geochemischen Prozessen, sowie zum benthischen Phosphorkreislauf durchgeführt. Die Zeit zur Bearbeitung des Probenmaterials bzw. zur Überbrückung von Schlechtwetterperioden wurde für bathymetrische Detailvermessungen genutzt. Erstmals wurde hierbei eine Vielzahl riesiger Pockmarkstrukturen im Bereich der oberen Kontinentalhanges entdeckt.

1.2 Participants

Table 1.1 List of scientific party

Name	Discipline	Institution
Zabel, Matthias, PD Dr.	chief scientist (M76/1a)	Marum
Ferdelman, Timothy G., Dr.	chief scientist (M76/1b)	MPI-MM
Bender, Vera B.	inorganic geochemistry	GeoB
Faust, Johan	inorganic geochemistry	GeoB
Pape, Silvana	inorganic geochemistry	GeoB
Sauer, Simone	inorganic geochemistry	GeoB
Goldhammer, Tobias	inorganic geochemistry	Marum
Heuer, Verena, Dr.	organic geochemistry	GeoB
Hörner, Tanja	organic geochemistry	GeoB
Lin, Yu-Shih	organic geochemistry	Marum
Siegert, Michael	Geomicrobiology	BGR
Lever, Mark	microbial ecology	UNC
Engelen, Bert, Dr.	Paleomicrobiology	ICBM
Kleindienst, Sara	biology, geochemistry	ICBM
Schnetger, Bernhard, Dr.	microbiogeochemistry	ICBM
Arnold, Gail Lee, Dr.	Biogeochemistry	MPI-MM
Formolo, Michael, Dr.	Biogeochemistry	MPI-MM
Bergenthal, Markus	MeBo-Team	Marum
Buhmann, Sitta	MeBo-Team	Marum
Düßmann, Ralf	MeBo-Team	Marum
Hielscher, Jens	MeBo-Team	Prakla
Hohnberg, Hans-Jürgen	MeBo-Team	GeoB
Kalweit, Holger	MeBo-Team	Marum
Klein, Thorsten	MeBo-Team	Marum
Könnecker, Heinz Otto	MeBo-Team	Marum
Lunk, Thomas	MeBo-Team	Prakla
Rehage, Ralf	MeBo-Team	Marum
Renken, Jens	MeBo-Team	Marum
Rosiak, Uwe	MeBo-Team	Marum
Schmidt, Werner	MeBo-Team	Marum
Diekamp, Volker	Curator	Marum
Truscheit, Thorsten	Meteorology	DWD

Participating Institutions

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe, Stilleweg 2, 30655 Hannover, Germany	www.bgr.bund.de
DWD	Deutscher Wetterdienst, Geschäftsfeld Seeschifffahrt, Bernhard-Nocht-Str. 76, 20359 Hamburg, Germany	www.dwd.de

GeoB	Dept. of Geosciences, Bremen University Klagenfurter Str., 28359 Bremen, Germany	www.geo.uni-bremen.de
ICBM	Inst. for Chemistry and Biology of the Marine Environment, Carl v. Ossietzky University Oldenburg, Carl-von-Ossietzky-Str. 9-11, 26111 Oldenburg, Germany	www.icbm.de
Marum	Centre for Marine Environmental Sciences Leobener Str., 28359 Bremen, Germany	www.marum.de
MPI-MM	Max Planck Institute for Marine Microbiology Celsius Str. 1, 28359 Bremen, Germany	www.mpi-bremen.de
Prakla	Prakla Bohrtechnik GmbH, Moorbeerenweg 3, 31228 Peine, Germany	www.Prakla-bohrtechnik.de
UNC	University of North Carolina at Chapel Hill, Dept. of Marine Sciences, Chapman Hall 351, CB 3300, Chapel Hill, NC 27599, USA	www.marine.unc.edu



Fig. 1.1 Scientific party on M76/1b

1.3 Research Program

(M. Zabel, T.G. Ferdelman)

The major objective of the first leg of METEOR cruise M76 was the investigation of the deep biosphere, an area that has come into the focus of geoscientific and microbiological research within the last decade. Previous studies on long sediment cores have demonstrated the existence of a marine deep biosphere. Due to the lack of cultured representatives our knowledge about the physiology and ecology of deep biosphere microorganism is still limited. Biomarker studies and the detection of certain marker genes in deep sediments indicated the presence of potentially chemolithotrophic bacteria and archaea, gaining their energy by metabolizing inorganic compounds.

This cruise should provide us with sediment material from the deep subsea floor at the upper continental margin off Namibia. Specific biogeochemical processes, involved microbial communities, and their interrelations with the local oceanography and sedimentation regime should be investigated with a variety of chemical and microbiological methods and approaches. This was the first cruise where the new wire-line drilling technique of the sea floor drill rig (MeBo) should be tested in unconsolidated marine sediments. Based on the necessary support for this operational and maintenance of the MeBo by a commercial enterprise (Prakla Bohrtechnik) which already has been involved in the development of the MeBo system, the cruise had to be split into two legs (M76/1a and M76/1b). Therefore, the cruise was interrupted on April 25 to exchange 3 scientists. On account of the large space requirements for the deployment of the entire MeBo system including winch and support containers, additional deployments of coring gear were limited to a 6 m-long gravity corer a multicorer.

1.4 Narrative of the Cruise

(M. Zabel, T.G. Ferdelman)

According to plan, RV METEOR left Cape Town with a very short delay of several hours at 5 pm on Saturday, April 12, 2008. Due to good weather and current conditions METEOR arrived at the first station at 28°S on April 14 (GeoB 12801; Fig. 1.2). Unfortunately, but typical for the season (austral autumn), strong low-pressure areas around the Southern Ocean caused high swell up to 6 m in the whole working area during most of the time. Because the dimensions of the MeBo system is close to the limit that can be handled on board of a ship like RV METEOR, and as well as for reasons of safety, MeBo was deployed only when the sea was below about 3 m. Despite the rough seas, several deployments of the gravity corer and the multicorer were successful. First preliminary investigations show the expected low microbial activities south of the known organic carbon depocentre on the upper continental margin between 24.5-26.5°S (cf. Fig. 1.2).

The waiting time for better weather conditions was used two times for intensive hydro acoustic surveys of a relatively small area (about 360 km²), where very conspicuous pock mark structures could be identified (s. Sect. 1.5.1). Afterwards, and based on previously existing results, a transect across the upper slope between 25,2°S and 24,6°S was chosen as the main working area during this expedition. Here, at about 800m water depth, the MeBo system could be deployed for the first time. A first hole with wire-line coring was drilled down to 14 mbsf. Nearly each of the 6 segments retrieved sediment, but continuous coring failed.

Again, deteriorating wave and wind conditions prevented further MeBo operations. In the meantime, we took valuable samples from the well-known mud belt off Namibia as well as from the continental rise. Even in the mud belt (cf. Fig. 1.2), two gravity cores could be obtained successfully. As expected, a series of multicorer cores contained filaments of the world's largest bacteria – *Thiomargarita namibiensis* – on the surface. A large number of samples were also taken for incubations and other special experiments to investigate microbially mediated element cycles. With good hope on improving weather we started looking on a site with more consolidated deposits. Such sediments, outcropping strata could be found in about 300 m wd at the shelf break. Unfortunately, several technical and electrical problems prevented further successful deployment of the MeBo system.

Considering the scientific goal of this leg, we decided to continue sampling down the slope. In about 3800 m water depth an excellent 5.6 m long core was retrieved. The whitish foraminiferal nannofossil ooze represents just the opposite of the organic rich sediments of the depocentre on the upper slope. Among other things these sediments reveal a big contrast in benthic life and microbial activity. However, pore water geochemistry indicates further on-going microbial activity in the deeper, dark layers of these sediments which let surmise the magnitude of this deep sub-seafloor microbial habitat.

On the morning of Friday April 25, we exchanged 3 scientists off in Walvis Bay, and took 2 scientists on-board. T. Ferdelman assumed chief scientist responsibilities at this point from M. Zabel. Due to deteriorating wave and wind conditions (swell at 3 to 3.5 m and wind to Bft. 5-6) further MeBo operations were postponed. In the meantime, we sailed to our proposed shelf site in the Namibian coastal mud-belt. On Saturday, April 26, Site GeoB12806 (25° 00'S and 14°23'E; 130 meter water depth) in the middle of the southern stretch of the mud-belt was extensively sampled by multi-corer and gravity corer operations. The surface sediment was, as expected, very soupy mud with minor amounts of foraminifera and accessory amounts of diatoms, small snails, fish bones and fish scales. On the surface of the cores filaments of *Thiomargarita* were quite easy to see with the naked eye. H₂S odour was present below the surface of the core. Further coring at the continental rise site GeoB12808 (26°22'S, 11°53'E, 3794 meter water depth) continued the mid-morning hours of Monday April 28th, where we obtained organic-poor, carbonate-rich sediments from beyond the continental margin depocentre. With the completion of work at Station GeoB12808 on Monday night and with a short reoccupation of Station 12803 to obtain surface sediments, we had nearly completed our planned non-MeBo coring program. While we were waiting on the wind and wave conditions to improve for deployment of MeBo, we used the days following 29 April to complete the PARASOUND survey in the area north of 25°30'S to 24°00'S.

Diminishing swell and wind conditions finally allowed us to deploy the MeBo on late morning on May 2. Unfortunately problems with electrical insulation on the cable and with the MeBo winch meant that we had to bring MeBo back on deck. The break in MeBo operations allowed us to obtain samples from an intermediate station along our depth-transect of nearly 3000 meter water depth. From there we returned to 28° South and the area of pockmarks. There, we completed mapping of this area, and obtained surface and sub-surface sediment from three additional structures.

After departing the region, the weather prognosis for Friday was not promising for another MeBo deployment, so we detoured to 10°E. This put us not only in the centre of the high

pressure system, but also well outside the continental slope sediment depocentre, and in deep water of over 4600 meters. With this, our deepest station, we have completed a transect of over 275 nautical miles, ranging from the hyper eutrophic sedimentary system that reigns on the Namibian shelf to the oligotrophic sediments of the Cape Abyssal Plain. The data collected during this expedition will add substantially to the current on-going quantification of biomass and microbial activity in the global sub-seafloor ocean.

On Saturday, after a several days of re-engineering and very hard work in the face of mounting difficulties, MeBo was ready for another deployment. Wire-line operations commenced Saturday evening and by Sunday morning, drilling had extended to 24 meters below surface. The recovery of sediment in the cores was only modest, but initial impressions are that the samples came from the proper depths. A second deployment was planned at Station GeoB12807 on the shelf break to test methods to optimize core yield. However, wind and wave conditions precluded prospects for safe recovery and MeBo operations were concluded. After thirty days on sea the cruise ended on May 13 in Walvis Bay.

Despite all the various difficulties with the new wire-line system on MeBo, this first test of this highly promising drilling technology provided important operational and technical experience under real, open-ocean conditions.

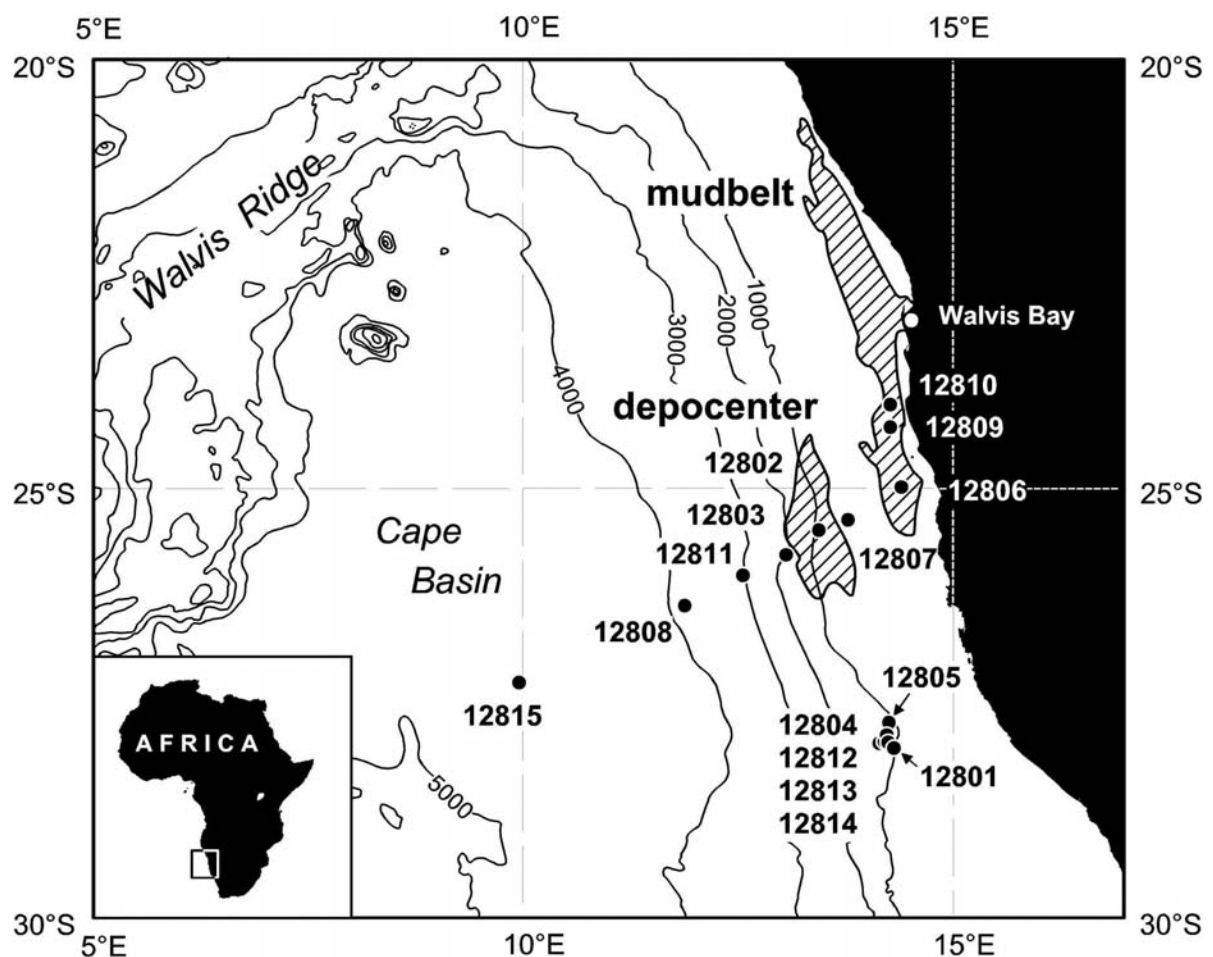


Fig. 1.2 Station map of R/V METEOR cruise M76/1. Shaded areas mark surface sediments with total organic carbon (TOC) concentrations higher than 5 wt%.

1.5 Preliminary Results

1.5.1 Acoustic Survey

(M. Zabel, T.G., Ferdelman)

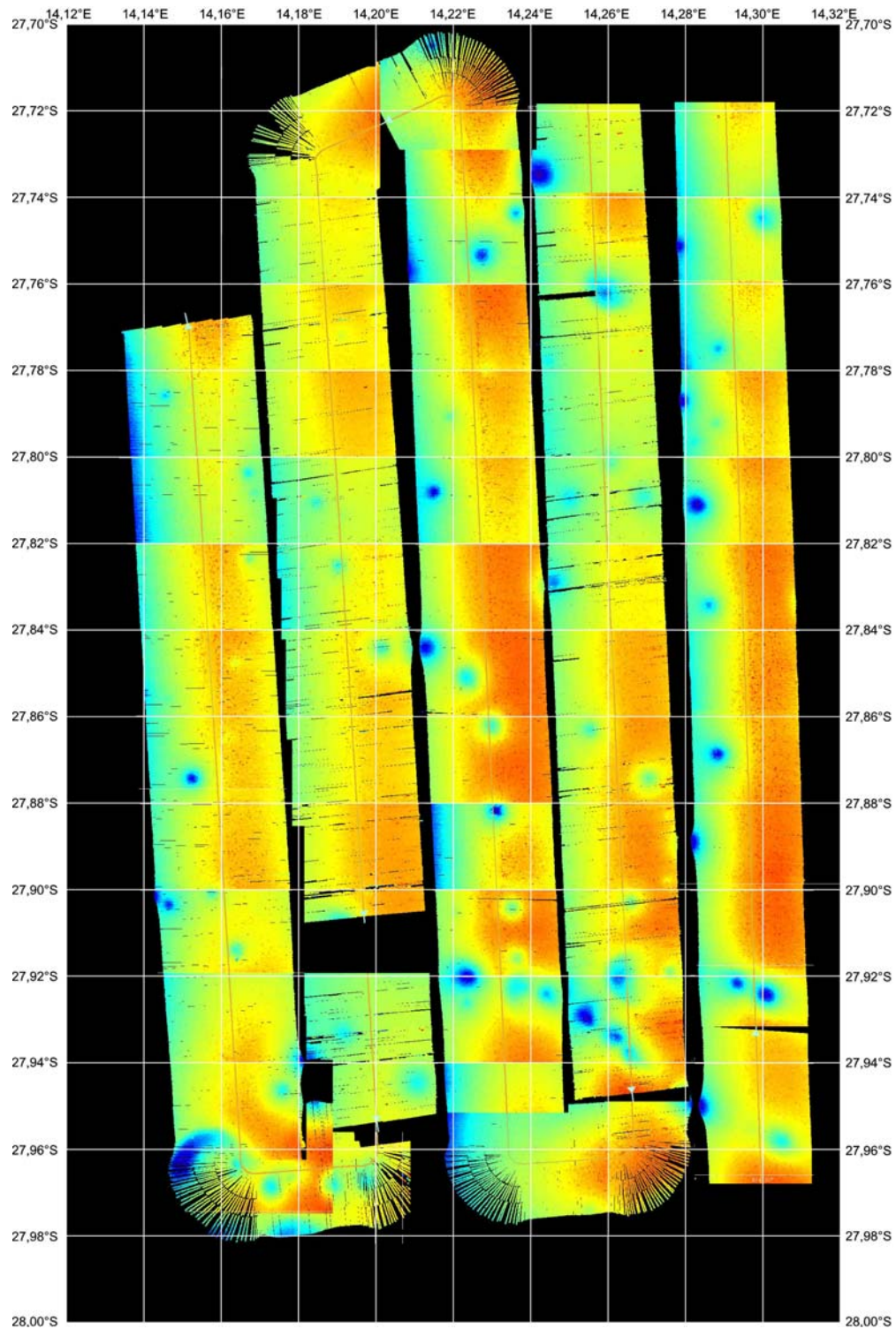


Fig. 1.3 Compilation of unprocessed EM120 multibeam echo sounder screenshots. Water depths arrange from ca. 1000 to 1400 m. Depressions have diameters of several hundred up to 1000m and depths below the surrounding sea floor of about 140 m.

Extensive acoustic surveys have not been in the research focus at the beginning of this cruise. But, unfavorable weather conditions for the deployment of the MeBo system gave us two times the opportunity for detailed bathymetric investigations at about 27.8°S, 14.2°E with multibeam echo sounder EM120. By passing this area, an unusual, circular depression has been observed already in 1996 during METEOR cruise leg M34/2 (Schulz et al. 1996). Now we could identify at least 68 of these structures with diameters of several hundred up to about 1000 m and maximum depths of 140 m below the surrounding seafloor. Active seepage of fluids or degassing could not be observed. Neither pore water concentration profiles show indication for active venting, nor carbonate dissolution could be diagnosed. We assume that these craters have been formed by massive blowouts of free gas produced and stored in the deep sub-seafloor.

1.5.2 Coring, Core Flow, and Curation

1.5.2.1 Coring with the sea floor drill rig MeBo

(M. Bergenthal, S. Buhmann, R. Düßmann, J. Hielscher, H.-J. Hohnberg, H. Kalweit, T. Klein, H.-O. Könnecker, T. Lunk, R. Rehage, J. Renken, U. Rosiak, W. Schmidt)

According to plan, R/V METEOR left Cape Town with a very short delay of several hours at 5 pm on Saturday, April 12, 2008. Due to good weather and current conditions METEOR arrived at the first station at 28°S on April 14 (GeoB 12801; Fig. 1.2). Unfortunately, but typical for the season (austral autumn), strong low-pressure areas around the Southern Ocean caused high swell up to 6 m in the whole working area during most of the time. Because the dimensions of the MeBo system is close to the limit that can be handled on board of a ship like R/V METEOR, and as well as for reasons of safety, MeBo was deployed only when the sea was below about 3 m. Despite the rough seas, several deployments of the gravity corer and the multicorer were successful. First preliminary investigations show the expected low microbial activities south of the known organic carbon depocentre on the upper continental margin between 24.5-26.5°S (cf. Fig. 1.2).



Fig. 1.4 The sea floor drill rig MeBo during deployment from R/V METEOR.

The mast with the feeding system forms the central part of the drill rig (Fig. 1.5). The drill head provides the required torque and rotary speed for rock drilling and is mounted on a guide carriage that moves up and down the mast with a maximum push force of 4 tonnes. A water pump provides sea water for flushing the drill string for cooling of the drill bit and for removing the drill cuttings. Core barrels and rods are stored on two magazines on the drill rig.

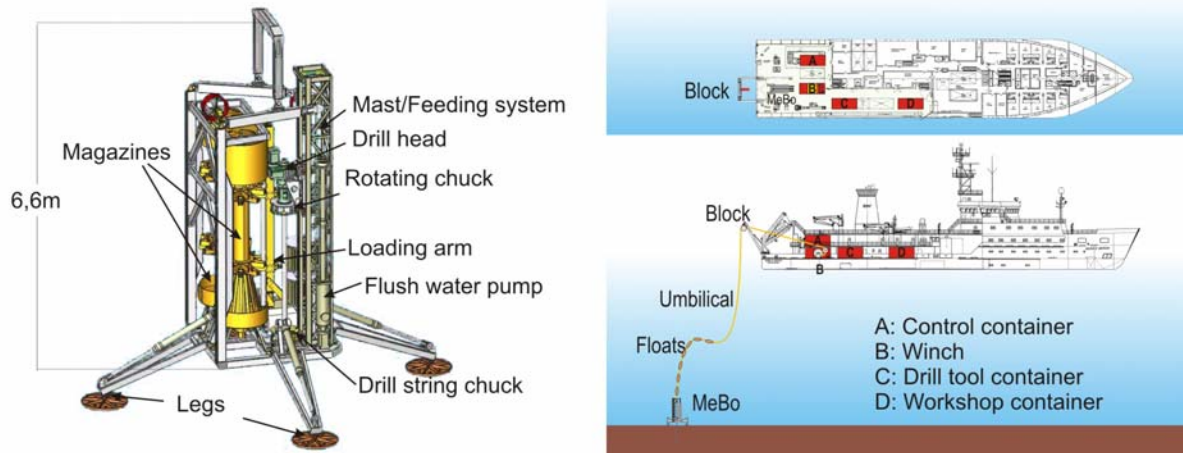


Fig. 1.5 Schematic overview on the MeBo drill rig (left) and its deployment from a research vessel (right).

The MeBo was developed in 2004/2005 at the Marum. After four expeditions between 2005 and 2007 we decided to upgrade the system in 2007/2008 with a new telemetry system and an adaption of the drilling system for wire-line coring technique. This state-of-the-art coring technique requires an overshot attached to a wire that is used to hook up the inner core barrel after drilling a stroke length (MeBo: 2,35 m) inside the drill string. The next empty inner core barrel is inserted into the drill string and a rod is attached to the drill string by thread connection before the next core section is drilled. This method is much faster than conventional drilling which requires repeated recovery of the entire drill string each time the end of stroke is reached. No casing is needed for wire-line drilling since the drill string stays in the drilled hole during the entire drilling process. This is especially important when drilling in soft formation since a collapse of the drilled hole during the recovery of the drilled core sections is prevented. Using wire-line technique the MeBo magazines can be loaded for a drilling depth of more than 70mbsf at a core diameter of 57-63 mm. Technical challenges of the adaption of the wire-line coring technique for the robotic MeBo system included inserting the overshot in the drill string by means of an additional manipulator, the decoupling of overshot and inner core barrel, a safe spooling of the winch for the steel wire, the development of a means to examine the correct landing of the inner core barrel before starting the coring process and the adaption of the core barrels to hemi pelagic deep sea sediments.

We were able to conduct eight deployments with the MeBo during M76/1 (Tab. 1.2). Minor technical problems related to the upgrade of the telemetry system and the implementation of wire-line coring technique was solved during the first deployments (ship ID 163 and 168). Bad weather conditions lead to more than 50% off time and to an abortion of the last deployment. Furthermore high dynamic loads caused an overload of the cable during deployment #32 (ship ID 175) with a serious insulation failure as consequence. Several water tests were necessary for locating the problem and for testing the subsequent modifications of the power system.

Reducing the tilt of the drill rig after landing was necessary for safely inserting the overshot into the drill string but required collection of experience for the landing phase in the extremely soft sediments at the continental slope off Namibia. The developed system for robotic decoupling of the overshot from the inner core barrel after recovery out of the drill string proved to be reliable. A safe spooling of the cable was difficult to achieve with the initial design and required some modifications during the cruise. Deeper drillings of 14,4 and 26,2 m were conducted after fixing the initial malfunction of the spooling system. The examination of the correct landing of the inner core barrel proved to be reliable. The time advantage of the wire-line coring technique with respect to the conventional drilling technique conducted during previous expeditions with the MeBo was shown during the last deployment that took about 7 hours for a drilling depth of 26 mbsf and that was about three times faster than drill string operations for conventional drillings with MeBo. However, the core recovery rate in the hemi pelagic sediments off Namibia was poor. Tests of different types of core catchers did not result in an improvement of the recovery rate. We assume that the valve that is required for the replacement of the water inside the inner core barrel during the coring process was undersized for the higher flow rates required for soft sediment sampling. Since we were not able to modify these valves on board of R/V METEOR future deployments with modified valves will show, how core recovery rates can be improved for sampling soft sediments with wire-line coring technique.

Table 1.2 Station list for MeBo deployments.

Ship ident	Date 2008	Deployment start / duration (hrs:min)	Latitude (°S)	Longitude (°W)	Water depth [m]	Drill No.	Drill depth (cm)	Recovery (cm/%)	Remarks
163	17.04. / 18.04.	15:16 / 16:47	25°30.03	13°27.01	784	#27	270	14 5%	Telemetry bandwidth limitation leads to drill stop.
						#28	270	0 0%	Stopped due to tilt of drill rig.
168	22.04.	08:26 / 13:41	25°30.03	13°27.01	786	#29	505	35 7%	Stopped due to fault in the feeding system
						#30	270	30 11%	Stopped due to unthreading wrong thread
169	23.04. / 24.04.	09:20 / 24:30	25°30.08	13°27.01	778	#31	1445	150 10%	Aborted due to leakage in compensation system
175	02.05.	09:21 / 07:19	25°30.08	13°26.76	801	#32			Winch end switch damaged
179	04.05.	11:22 / 00:59	25°30.09	13°26.92	795	#33			Insulation fault
181	05.05.	09:04 / 03:47	25°30.08	13°26.87	791				Several water tests for locating the insulation failure
187	09.05.	07:03 / 03:03	27°14.24	09°59.99	4664				Water test: Insulation and hydraulic check
188	10.05.	10:11 / 00:54	25°42.78	13°26.92	1995				Water test: Hydraulic check
189	10.05. / 11.05.	13:49 / 20:45	25°30.03	13°26.92	793	#34	2620	496 19%	Aborted due to weather conditions

1.5.2.2 Contamination test of MeBo cores

(M. Zabel, T.G. Ferdelman)

The sediments from MeBo core GeoB 12802-12 were microscopically inspected to detect a putative contamination by microorganisms that were introduced by the drilling process. Therefore, samples were taken from the core catchers of sections 1, 3, 4, and 6 as well as from the core of section 6 at a depth of 50-60 cm (total length 88 cm). This last core is proposed to originate from a depth of app. 14 mbsf. The core was cut horizontally and samples were taken from the innermost part to avoid core-liner effects. The samples were fixed overnight in glutardialdehyde, stained by SybrGreen and filtered onto a black 0.2- μ m-polycarbonate filter.

Total cell counts of the core catcher samples of sections 1, 3, and 4 were in the expected range which was determined before on the multi core GeoB 12802-1 and the gravity core GeoB 12802-3. They showed decreasing cell numbers from $5 \cdot 10^8$, $8 \cdot 10^7$, and $4 \cdot 10^7$, respectively. Both samples from section 6 were one order of magnitude higher ($2\text{--}3 \cdot 10^8$) and in the range of surface near sediment layers. These high numbers, the bright fluorescent signals and the high diversity of cell forms indicate a drilling-introduced contamination.

As this was only one sample from one core and as the cell counts from the core catcher were not too bad, the MeBo system still might retrieve sediments of a high quality. However, a drilling-introduced contamination should be avoided during the next operation. The next cores from the MeBo system should be tested for contamination before subjecting samples to biogeochemical and microbiological analyses.

1.5.3 Sediment Description

(V.B. Bender, B. Schnetger)

The preliminary, lithological summary of the sediments retrieved from multicorer and gravity corer during cruise M76/1 is based on only a basic visual description. No color scanner or microscopic inspection of smear slides was available. For color description MUNSELL Soil Color Charts were used. The gravity cores have been inspected after sampling gas by syringes, pore water with rhizons and after the sampling campaign for microbiological and organic geochemical analysis. From the remaining core halves the following description resulted.

GeoB 12801 “Reference”:

In both cores the sand fraction dominates and consists of foraminifera. The first 15 cm of the multicorer were soupy. Small copepods were found till 11 cm sediment depth. No smell of H₂S was present in the whole multicorer material. In the gravity core first H₂S smell has been detected in approx. 38 cm sediment depth.

In the upper part (308 cm), the GC consists of the same type of material as the multicorer but more dense. Deeper down the GC sediment grades into more clayish material with less amounts of foraminifera. Both cores are heavily bioturbated – no original stratification is visible. The general color in both cores is olive (5y 5/3). The GC core is marbled and contains mud clasts or more or less rectangle blocks (app. 1-4 cm in diameter or length) which are slightly lighter in color (pale olive, 5y 6/3) in the following depths (in cm): 93, 293-308, 312, 320, 327, 350, 354. Starting in a depth of about 107 cm, the sediment occasionally contains black grains (most pronounced in 107 cm and 235-293 cm), possibly glauconite.

GeoB 12802 (“Depocentre”):

The multicorer material consists of brown mud and is very soft until 20 cm depth. A consolidated 13 cm long worm tube has been found in 11 cm sediment depth. H₂S smell has been detected from about 20 cm downwards. Foraminifera mainly represent the sand fraction which is significantly lower in the whole core than at station 1. The general color in the GC is olive (5y 4/3) whereas the mud clasts, blocks or bands (e.g. 206-207 cm) have a lighter color (5y 6/4 to 6/4). The whole core had a strong H₂S smell and is bioturbated throughout, except from 245-264 cm. A higher occurrence of shell fragments has been found in 264-364 cm (bivalves). Small crystals, possibly barites, are present in the depth range from 325-340 cm.

GeoB 12803:

The sediment sampled by the multicorer is very soft until a depth of 13 cm. In this depth range starfish and tiny brown-red corals were found. The whole core is oxic or suboxic (no H₂S smell). The sand fraction is very low and mainly consists of foraminifera.

Most possibly a large fraction of the surface sediment of the GC has been lost (a significant amount of sediment has been found in the upper part of the GC weight). From pore water investigations it has been estimated that about 15 cm of the surface sediment is missing. The color in the GC sediments changes from olive (5y 4/3) in the upper 36 cm to olive grey (5y 3/2) until a depth of 175 cm and then grades into very dark grey (5y 3/1) till 345 cm. From this depth to the end of the core the color becomes lighter again (5y 3/2) possibly due to a slightly higher increase in sand fraction (foraminifera). Around the depth where the color changes (345 cm) there is a minimum in H₂ concentration, the maximum in H₂S and not far away from a strong increase in methane. A higher content of shell fragments and pteropods but also complete shells were found in the depth range 175-275 cm. Both cores (GC and MUC) are highly bioturbated.

GeoB 12804 (“The Hole”):

The cores were deployed from a seismic hole about 200 m below the general surface of this area (seep?). Beggiatoa mats were found on the surface of the multicorer sediment. H₂S odor has been detected just below the surface. The first 9 cm consist of olive colored mud forams in the sand fraction and with numerous large fragments of mussel shells as well as worm tubes and black very thin worms (which bleed when trying to extract them from the sediment by tweezers). The sediment grades from olive to black olive at about 11 cm. The sand fraction decreases in this depth. We discussed the possibility that the black part of the multicorer is the recent surface and is overlain by older material. At 20 cm the sediment color becomes olive again and the sand fraction increases again. Another change in color occurs at 28 cm and the color becomes a little lighter again with increasing sand fraction.

The gravity corer 12804-6 only sampled 110 cm. The upper 10 cm were used for collecting particles for microscopic investigations. Only foraminifera were found with accessories of glauconite and rarely quartz. The sediment has an olive color with a high proportion of sand fraction mainly containing forams. Sea urchin spines were found from the top to 70 cm. In the upper cm a complete mussel shell has been found, smaller fragments of shells were found the whole core. In 74-82 cm layer of more clayish material was found. In 95-100 cm small snails (1-3 mm) and ontoliths were found.

The second gravity corer from this station sampled material with a much longer geological record. From the surface to 283 cm and from 387-428 cm the sediment is olive colored (5y 5/3)

and consists of a high in sand fraction (forams). From 138-155 cm the color changes to olive grey and therefore bioturbation becomes obvious. From 283-387 cm the color changes to dark grey. Sand fraction is significantly lower in the dark sediment. From 428-510 cm the color is dark grey. Dark layers rich in clay are present in 463-465, 473-474, 480-482 cm, and brown layers are present in 467-472 and 490-492 possibly representing turbidite layers. H₂S odor is present from 250 cm until the end of the sediment core.

GeoB 12805 (“Daneben”):

The sediment sampled by the multicorer is very homogeneous throughout the complete length, consists of mud of pale olive color and a foraminifera-rich sand fraction. As accessories we found a few glauconite grains and quartz crystals have been under the microscope.

The upper 22 cm of the GC core is olive in color (5y 5/3) rich in forams. From 22-61 cm the sediment becomes slightly darker (5y 5/2) with a highly bioturbated transition zone (22-36 cm). The darker sediment is richer in the foram sand fraction. Between 61 and 267 cm these two colors change unevenly. A bleached clay-rich 20 cm bioturbated zone is present in 267-302 cm. Sec. 3 and 2 is light olive grey (5y 6/2) up to 395 cm. From 395-425 cm bioturbation is high. Below 425 cm the sediment becomes darker again (sand fraction increases). This dark color is present down to till 466 cm. Below, the sediment core becomes lighter again (5y 6/2). Darker sediment, unevenly distributed, occurs at 487/492/518 cm. At 543-544 cm a layer rich in forams has been found.

GeoB 12806:

The sediment sampled by the multicorer has a dark olive color and is very soupy for the first 20 cm where numerous white and black very thin „worms” have been recognized. Under the microscope these white “worms” have been identified as sulfur bacteria. The sand fraction of the sediment consists of mud with minor amounts of forams and accessory amounts of diatoms, small snails, fish bones and fish scales. During cell accounting a large proportion of diatoms were found. In 38-40 cm large mussel shells have been found; in a depth of 47-49 cm a larger amount of fish scales and in 54-55 cm fragments of mussel shells are present. H₂S odor was present almost right below the surface of the core.

A successful sampling with the 6 m gravity corer has been possible by lowering the device with 1.3 m/sec into the sediment, waiting 10 sec and retrieval with 0.5 m/sec. In the core catcher we used 0.3 mm steel strips while thicker strips lead to reduced recovery. The sediment sampled in the above described way has a black color (5y 2.5/2) from 0-29 cm, dark olive grey from 29-58 cm (5y 3/2) and dark olive grey (5y 4/2) from 58-297 cm. Large mussel shells (in 11, 142, 188 cm depth) and fragments (22, 101, 113, 170, 204, 218, 230-235, 163, 179-188 cm) are present in the whole core. In 262-263 cm a light band is present. The sand fraction is of very low quantity and consists mainly of forams with minor amounts of diatoms and snails.

GeoB 12807:

The multicorer material consists of mud with a high amount of sand fraction and is generally of dark olive in color. In the sand fraction the forams dominate. At 20 cm the content of forams and small shell fragments increases. Under the microscope the following components were found (in order of decreasing amount): forams, glauconite, shell fragments, fish scales and bones, quartz, small snails, green grains and diatoms.

The gravity corer starts with black mud (5y 2,5/2) exhibiting a pronounced sand fraction mainly bearing forams and occasionally small shell fragments (0-38 cm). From 38-68 cm the color is olive grey (5y 4/2) with high quantities of large and small mussel shells and fragments. From 68-83 cm the color changes back to black (5y 2,5/2). From 83-383 cm the color varies between 5y 3/2 and 5y 4/1 with lighter clasts 5y 4/4 showing strong bioturbation in the depth range from 77-183 cm. From 77 cm to the end of the core the sand fraction is much lower than the upper part of the core. Bands of lighter color than the surrounding sediment are present at 79-80, 207, 271, 244, 241, 366, and from 281-315 cm (5y 5/4 – 5y 5/4). From 67-77, 84, 101, 108, 133, 162, 280 cm black gravels consisting of consolidated sand occur with diameters between 0.2-2 cm. From 79-80 cm a pale olive band with glauconite is present (5y 6/3). Fish bones have been found at 96 (3 cm long), 320, and 324 cm.

GeoB 12808:

Multicorer sediment sampled at station 12808-4 from the top to 8 cm consists of brown carbonate-rich deep sea clay (10YR 6/6). Between 8 and 16 cm the sediment is light grey (5y 5/2). The sand fraction decreases slightly from the top to 16 cm. This surface has also been recognized in the gravity corer. For successful sampling it appeared necessary to remove half of the weight (from 1.5 to 0.7 t). The sediment color alternates between dark (generally olive gray 5y 5/2) and light (generally light grey 5y 7/1) intervals throughout the core (dark at 34-80, 110-147, 176-212, 263-279, 302-314, 406-469 cm).

Strong bioturbation is present between 34 and 80, 357 and 469, 489 and 546 cm. “Liesegang’sche Ringe” have been found between 314 and 357 cm core depths.

GeoB 12809:

The sediment sampled by the multicorer consists of dark olive colored mud. Due to the high water content the sediment is soupy from the surface down to 20 cm. *Thiomargarita* and *Beggiatoa* have been found in a high number till in approx. 10-12 cm sediment depth. The sand fraction is low and consists mainly of forams. Fish scales and bones are present throughout the core. Between 30 cm until the base of the multicorer sediment mussel shells and fragments have been found.

GeoB 12810:

For the sediment sampled by the multicorer the above description of GeoB 12809-2 is valid, except a slightly lower recovery.

GeoB 12811:

The surface sediment consists of light olive grey (5y 6/2) mud and is low in sand fraction (mainly forams). At the upper surface no brown color has been found indicating suboxic conditions. This has been validated by Fe^{2+} analysis where the maximum has been detected at 5-6 cm.

GeoB 12812 (“Putt 1”):

The sediment sampled by both multicorer deployments consists of light olive grey clay with a high content of forams. As accessories in the sand fraction quartz, mica (glimmer) and green grains have been found under the microscope. No H_2S odor has been recognized.

GeoB 12813 (“Putt 2”):

This surface core exhibits the same color as GeoB 12812-2 and -1. It possibly has a slightly lower sand content. In 3 cm sediment depth a small black horizon has been found. From 7 cm downwards the sediment is darker and has a lower content of sand fraction. No H₂S odor has been found.

GeoB 12814 (“The Bean hole”):

The surface of the sediment sampled by gravity coring was covered by slime. Below the surface the sediment exhibits a high sand fraction (forams). The whole core is more or less homogeneous with respect to variations in color and sand fraction quantity. The color varies only slightly from olive (5y 5/3) to olive grey (5y 5/2). In 175 cm sea urchin spines and in 224 cm and 247 cm some small black solid stripes (0,5 cm long, 2 mm width) of unknown origin have been found. In the core catcher no H₂S odor was present.

GeoB 12815:

The multicorer sampled surface sediment brown to light brown in color (0-10 cm brown, 10-26 cm transition zone, 26-38 cm light brown) and very low in sand fraction. No forams have been found any more. The sediment is heavily bioturbated.

The upper 7 cm of the sediment sampled by gravity coring consists of the same brown color as seen in the multicorer assuming that the surface is present in the GC core. Light yellowish brown layers (7.5YR 6/4) intercalate with very pale brown layers (10YR 7/4). Light yellowish brown layers have been found at 65-70, 82-89, 100-112, 120-132, 154-167, 179-183, 192-204, 214-240, 248-285, 305-347, 365-403, 440-556 cm. It was difficult to determine the sediment depth of the layers as they are heavily affected by bioturbation. At 440 cm a sharp boundary between very light colored material and brown deep sea clay was found. During METEOR cruise M34 a core similar in water depth and position (SL15) has been described back then this whitish horizon has been interpreted as a turbidite. In the sediment depth between 440 and 560 cm the brown sediment (7.5YR 5/3) is free of carbonate. Black spots with halos lighter in color and of unknown genesis have been found.

1.5.4 Inorganic Geochemistry

(G.L. Arnold, J. Faust, T.G. Ferdelman, M. Formolo, T. Goldhammer, S. Pape, S. Sauer, B. Schnetger, M. Zabel)

1.5.4.1 Objectives

Main research objectives of the Inorganic Geochemistry Group on this cruise were the acquisition of detailed down core profiles of inorganic pore water constituents to describe the sedimentary chemical environment with respect to redox zonation and mineralization processes, as well as additional sampling of pore and bottom waters for later investigations on phosphorus and sulfur biogeochemistry using diverse stable isotope techniques.

In this context a major interest was to study element redistribution processes, which take place at the sulfate-methane boundary (SMB). Since a couple of years it is well known that barite is formed in this zone. Also, dissolution of magnetic minerals like magnetite and other iron-bearing minerals are known to dissolve and/or precipitate under conditions of sulfate depletion and iron reduction (Riedinger et al. 2005). Coupled to this is the iron geochemistry in the sediments. The mineral fraction of iron and its reactivity with H₂S is an important control on the

dissolution and precipitation kinetics of iron in these sediments. To address this, a sequential iron extraction separating Fe-carbonates, Fe-oxides, magnetite and iron silicates will be performed (Poulton and Canfield 2005, März et al. 2008). Other elements, formally fixed in these minerals may play also an important role with respect to redistribution processes in the SMB but this has not been investigated to date. Such processes have a great effect if sedimentation rates change dramatically. In such cases the interpretation of magneto-stratigraphy is seriously compromised as well as barite or Ba in sediments as a proxy for productivity in ocean surface waters.

An important aspect with respect to trace element cycling can be inferred from sulfate-sulfide concentrations and sulfur reduction rates in surface sediments. Large trace element enrichments are often a product of intense sulfate reduction and production of hydrogen sulfide, which reacts with dissolved redox sensitive trace metals (Mo, U, V, U, Cd, Zn, etc.) to form solid sulfides or hydroxides. If this process takes place the pore water is depleted in these elements. A gradient in concentration exists which continuously transports via diffusion or advection dissolved metals from bottom water into the sediment, reacting from the dissolved to the solid state. If bioturbation is very high, as this is the case in some shelf areas off Namibia, almost no H₂S can be measured although bacterial sulfate reduction is high because H₂S is immediately re-oxidized (T. Ferdelman, personal communication). This may lead to redox conditions in the sediment not favorable for immobilization of certain trace metals. In this case a de-coupling between sulfate reduction rate and trace element enrichment in the sediment will take place.

Another goal was related to the reconstruction the upwelling regime from the glacial periods to the Holocene in undisturbed sediments and if age models will be available. Intense coastal upwelling induces high primary productivity in the surface water and thus the rate of supply of organisms to the sediment is high during such periods. Secondary processes induced by diagenetic reactions lead to the enrichment of metals thus providing a link to productivity. At selected stations we want to check the reliability of this approach.

A further aim of this cruise was tracing the trace metal composition of the sediments on a transect from the shelf to the deep sea. The lateral extension of the upwelling regime into the deep ocean will be traced using diagnostic major and trace elements typically for upwelling areas. We want to compare the results with those from the Peruvian margin (Böning et al. 2004) to find the key parameters for the enrichment and depletion processes.

An additional aspect is related to processes going on at sites on the seafloor significantly deeper than the surrounding surface. We still do not know the nature of these depressions. Most possibly these depressions represent active seeps having also an influence on the solid phase geochemistry.

Last but not least we wanted to search for dissolved Mn (III) in surface cores very low in re-mineralization rates in the suboxic regime of the pore water system (2000 m and lower water depths). Mn(III) could be detected and quantified by a new method (Schnetger et al. in prep.) in the suboxic part of the water column of the Black Sea during METEOR cruise M76-5. In sediments this Mn species was not be found to date. Mn (III) may play an important role in the (microbial) redox cycle as it can be reduced and oxidized by only one-electron transfer thus influencing the manganese, iron and nitrogen cycle.

1.5.4.2 Methods of Sampling

Aqueous samples were collected from multicorer tubes and gravity cores directly after core curation (sectioning and labeling). The multicorer tubes were brought to the geochemistry laboratory immediately and kept upright in the sink. Sampling depths were marked at the pre-drilled and taped holes every centimeter in the upper 10 cm and every 2 to 4 cm down to the bottom. The gravity core sections were stored securely in the 4°C cold room and 3.8 mm holes were drilled into the liner wall about every 25 cm, while maintaining a 10 cm distance from the section ends for microbiological sampling. Rhizon micro suction samplers (5 cm, 0.2 µm porous polymer, Rhizosphere Research) were carefully inserted through the sampling holes. Where the sediments were too dense, a 2.5 mm stainless steel rod was used to punch a hole before the sampler was inserted. Three way luer lock stopcocks were connected to the adapters of the rhizons to allow two syringes to be connected simultaneously and to ensure proper closing. First, a 20 mL syringe was attached, pulled and kept open with a spacer. After the first 0.5 mL was sampled, this sample was discarded (release vacuum, close stopcock to rhizon, discard sample through stopcock) and vacuum was reapplied. After 1 mL was sampled in most sampling positions, the pore water was transferred into 1 mL disposable syringes using the three way stopcock, sealed with a luer-lock cap, and instantly analyzed for dissolved iron. The syringes were then left connected to the rhizons until about 10 mL of pore water had been retrieved, which took 30 to 120 min.

On particular multi and gravity cores, we sampled large volumes of pore water (approx. 60 mL) for analysis of oxygen stable isotopes in dissolved inorganic phosphate using the rhizon technique described above. For obtaining such large volumes, we took integrated samples by using two rhizons beside each other and attributed the sample to the respective depth interval. Beside the aliquots used in onboard analyses of the parameters mentioned below, we collected the following sample splits for onshore laboratory analyses: 400 µL of sample preserved with Zn acetate solution for onshore sulfide detection, 1 mL of plain sample for onshore anion analysis, 1 mL of sample diluted with 9 mL of 1M HNO₃ for cation analysis, and 2 mL of sample preserved with ZnCl₂ solution for onshore DIC analysis. The rest of the sample was kept without addition of preservatives.

The large volume pore water samples for phosphate oxygen isotope analysis were filled into acid-washed (diluted supra pure grade HNO₃) HDPE bottles without additives.

1.5.4.3 Pore Water Analyses

Alkalinity was determined on a 1 mL split of the plain sample by titration with 0.01 M HCl. To allow accurate pH measurements, a pH electrode was used together with a special stirring device that magnetically rotates a 1.5 mL Eppendorf vial around the electrode without the need of a magnetic stirring bar. The acid was added using a 0.3 mm ID PTFE tube. The samples were titrated with a digital burette to a pH well below pH 3.9 and both titration volume and final pH were recorded. The alkalinity was calculated using a modified equation from Grasshoff et al. (1999).

Ammonium (NH₄⁺) was detected onboard with a flow injection Teflon tape gas separator technique after Hall & Aller (1992). About 200 – 300 µL of plain sample were injected into the analytical line by an auto sampler, there mixed with an alkaline solution (0.01 M NaOH + 0.2 M Na citrate) to form gaseous NH₃ which passed a PTFE membrane to cause a conductivity

signal in a receiving acid solution (0.001 M HCl, $34 \mu\text{S cm}^{-1}$). The conductivity was determined using a temperature compensated conductivity meter with flow-through-cell (Amber Science 1056 and 529) and recorded electronically.

Dissolved iron (Fe^{2+}) was detected photometrically (Hach Lange DR 5000 photometer) at 565 nm. An iron sensitive color complex was formed by adding 1 mL of plain sample to 20 μL of a ferrospectral receiver in disposable polystyrene cuvettes. In case of high iron concentrations, the original sample was diluted with oxygen free pure water to match the respective calibration range.

Solid-phase iron samples were taken to be measured at the MPI. A sequential iron extraction (Poulton and Canfield 2005, März et al. 2008) will be used to separate the iron into the respective iron-bound mineral pools. These include Fe-carbonates, Fe-oxides, magnetite, and poorly reactive silicate bound iron. These samples are the same samples that will be used for carbon and sulfur analysis mentioned later in the report.

Phosphate (PO_4^{3-}) was determined photometrically (Hach Lange DR 5000 photometer) using the Molybdenum Blue method (Grasshoff et al. 1999). About 1 mL of sample was mixed with 50 μL of an ammonium molybdate solution in a disposable polystyrene cuvette and spiked with 50 μL of an ascorbic acid solution. The phosphomolybdate complex was thus reduced to molybdenum blue which was determined at 820 nm wavelength.

For dissolved pore-water sulfur species pore water sub-samples were immediately fixed using zinc acetate or zinc chloride solutions. Samples were measured directly onboard using the methylene blue method of Cline (1969). Errors due to pipetting and diluting ZnS suspensions were estimated to lead to a coefficient of variability of 8% for the analysis. Larger fractions of pore water (typically 4 to 6 ml) were also fixed with zinc containing solutions for shore-based analysis of stable sulfur and oxygen isotope composition in reduced and oxidized forms of dissolved sulfur.

Sampling for zero-valent sulfur species followed the protocol of Kamyschny et al. (2009). Pore-water samples were extracted in a N_2 -filled glove bag using rhizomes. Aliquots of pore water were partitioned and chemically fixed for polysulfides, thiosulfate, hydrogen sulfide, colloidal sulfur and elemental sulfur. Analysis and quantification using HPLC will be performed at the MPI for Marine Microbiology.

Pore waters for the analysis of the concentration and isotopic composition of *molybdenum* (Mo) were collected from a standard 8 cm MuC. Samples were treated with the addition of trace hydrofluoric acid to prevent shifts in the Mo isotopes during storage. Samples were stored in 20 ml (LDPE?) scintillation vials at 4°C.

Sediment samples were also collected from a 4 cm MUC (from the same deployment) for the analysis of the concentration and isotopic composition of Mo at intervals corresponding to the pore-water samples. Wet sediment was packed into 20 ml scintillation vials (completely filled). Pore water from these samples was then removed via rhizomes, collected and preserved for comparison against the standard MUC pore-water samples.

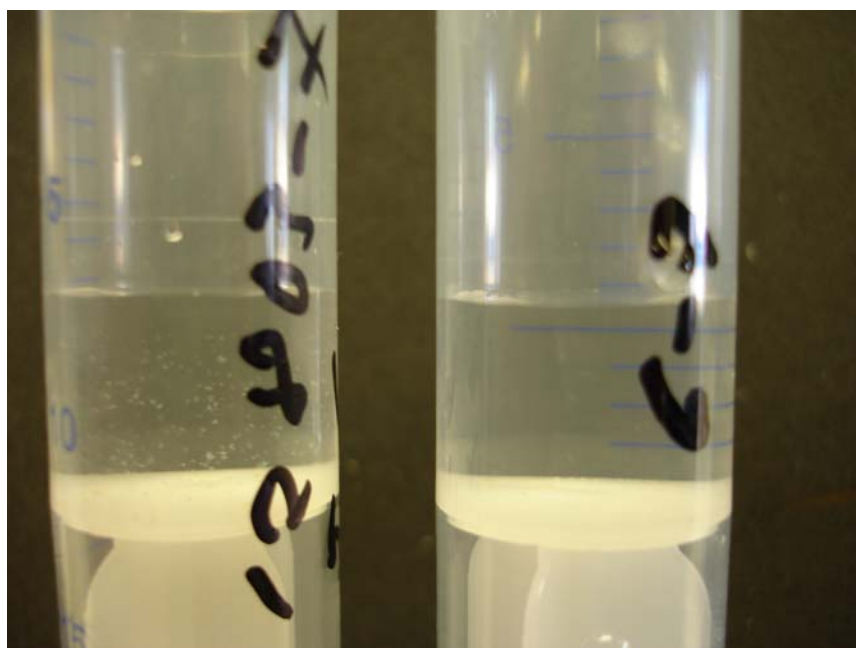
Dissolved oxygen at select stations was done on board by Winkler titration. Three to five samples of approximately 120 ml each were collected immediately from the bottom waters in the MUC cores after retrieval.

Table 1.3 Bottom water oxygen and hydrogen sulfide at stations GeoB12801-12804.

	12801	12802	12803	12804
Bottom water dissolved O ₂ (μM)	217 +/- 4 %	181 +/- 4 %	n.a.	193 +/- 4 %
Hydrogen sulfide detected?	no	yes	yes	n.a.
12802	Dissolved hydrogen sulfide was first detected (> 2 μM) at 0,20 mbsf (cm) and at 0,16 cm in the surface MuC cores (GeoB12802-3 and GeoB12802-7) respectively. Dissolved sulfide concentration linearly increased with depth to a concentration of 154 mM at 3,25 mbsf (GeoB12802-4) in the gravity core. With increasing depth, dissolved sulfide concentrations slightly declined to concentrations between 7 and 11.7 mM at depths of 4.33 to 4.53 mbsf in cores GeoB12802-4 and GeoB12802-8 respectively.			
12803	Dissolved hydrogen sulfide was first detected (6 μM) at 0,18 mbsf (cm) and only increased slightly with depth in the surface MuC core (GeoB12803-2). Below 1 mbsf the dissolved sulfide concentration linearly increased with depth to a concentration of 10,5 mM at 5,10 mbsf (GeoB12803-1) in the gravity core. With increasing depth, dissolved sulfide concentrations remained near 10 mM to the end of the gravity core (GeoB12803-1).			

Samples were collected from gravity cores every 10 cm for the shore-based analysis of total organic, inorganic carbon and solid-phase sulfur species. Samples were collected with cut-off 10 or 20 ml syringes and packed into either 15 or 50 ml centrifuge tubes or 20 ml scintillation vials. Samples were then frozen at -20°C.

Pore water for the investigation of reactive Mn (most probably Mn(III)) was sampled with rhizons from multicorer cores GeoB 12803-7 (18 samples in 1-2 cm distance), 12808-4 (16 samples in 1 cm distance), 12809-2 (8 samples in 2-10 cm distance), 12811-2 (16 samples in 1 cm distance), 12812-2 (6 samples in 1 cm distance), and 12815-2 (18 samples in 2 cm distance) from the same depths where pore water for Mo isotopes was sampled. Two ml were transferred immediately into pre-cleaned small PE-vials and acidified with suprapure HNO₃. Approximately 5 ml remained in the syringe for 36 h at approximately 18°C. It was assumed that after this time all soluble reactive Mn was oxidized to solid MnOx (Fig. 1.6). A filter disc (0.45 μm, SFCA, Millipore) was fitted to the syringe, the water was filtered, acidified and stored in vials. After quantification of Mn in the home lab in both solutions, the concentration of reactive Mn will be calculated by difference.

**Fig.1.6**

Search for Mn(III) in pore water from station GeoB 12803-7. Syringe right side: from 6-7 cm sediment depth, no precipitation. Syringe left side: from 5-6 cm sediment depth showing a precipitation after 36 h at room temperature, same as for 2-3, 3-4, and 4-5 cm.

1.5.4.4 Onboard Results

We sampled surface-near and deep sediments with multi- and gravity corer along a transect from the shallow shelf (mean water depth 120 m) to the foot of the continental slope (mean water depth 5000 m), comprising of seven singular stations. The order of stations was from shelf to deep sea: GeoB 12806, 12807, 12802, 12803, 12811, 12808, 12815. The ammonium (Figs. 1.7 and 1.8) and alkalinity (Figures 1.8 and 1.10) data clearly show differences between shallow shelf environments with sediments rich in organic matter (mudbelt station GeoB 12806) to poor deep sea clays (5000 m station GeoB 12811).

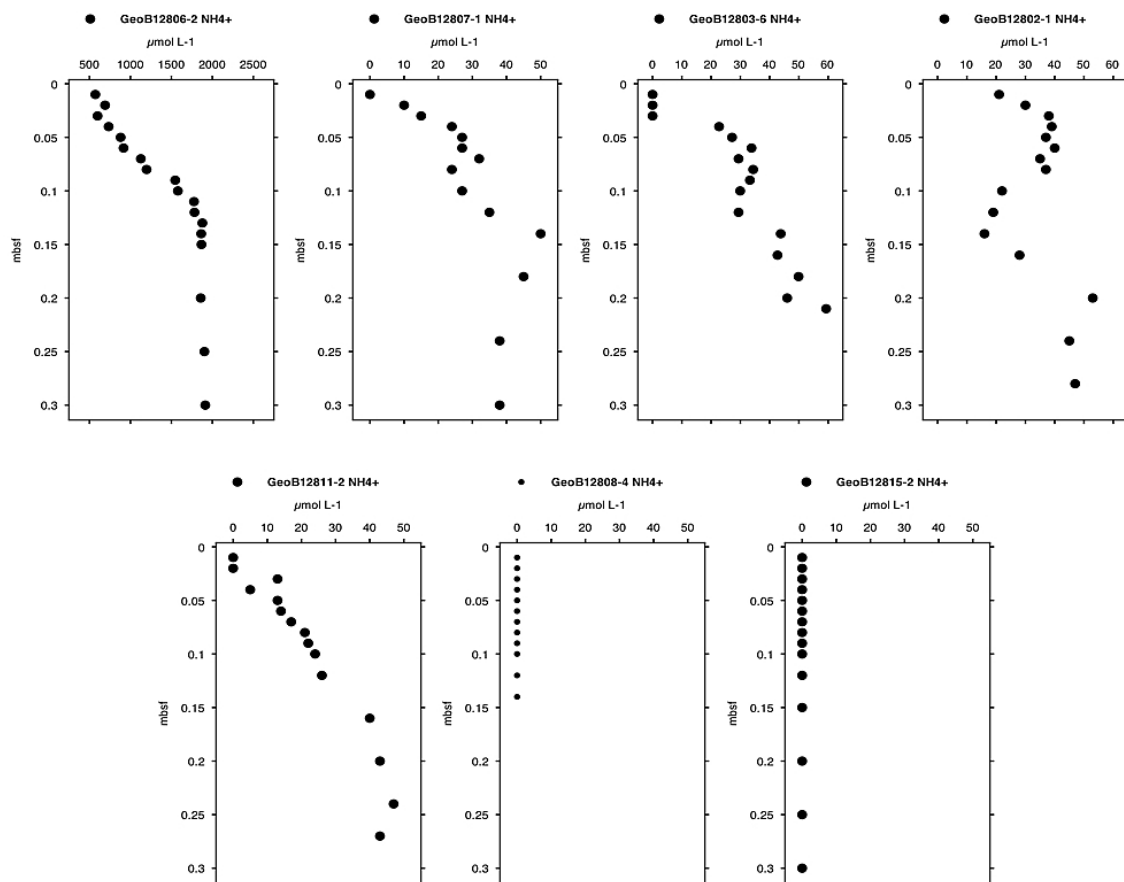


Fig. 1.7 Pore water ammonium data for surface-near multi cores from transect stations 12806, 12807, 12802, 12803, 12811, 12808 and 12815. Note the different scales of the x-axes

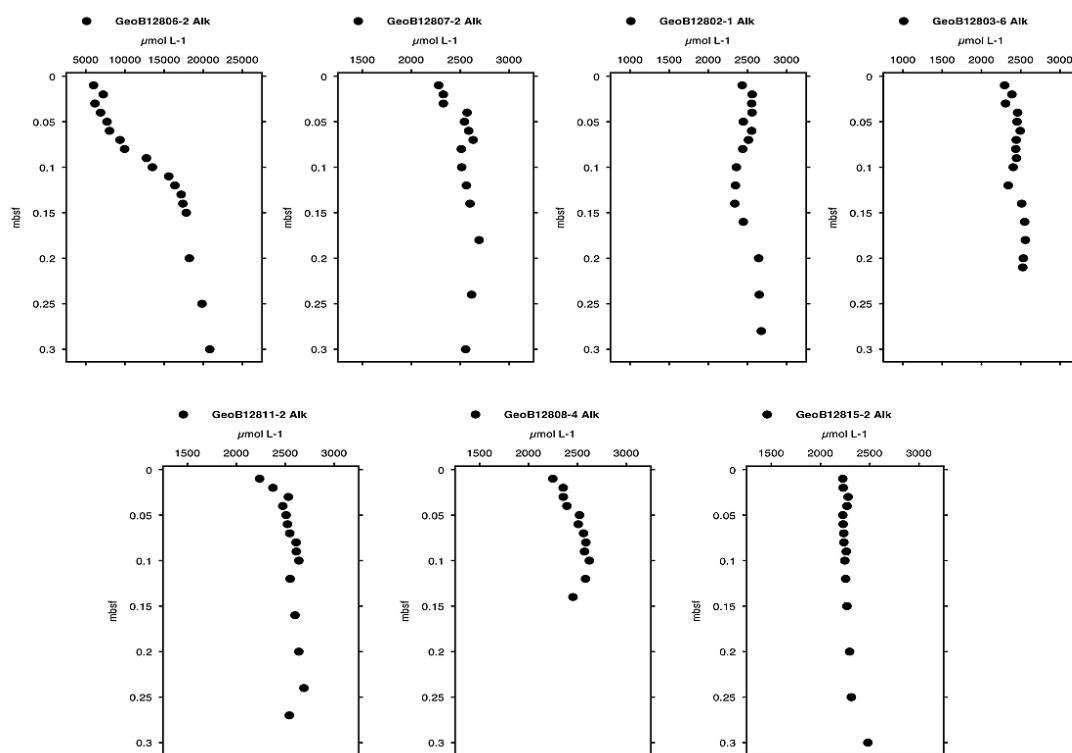


Fig. 1.8 Pore water alkalinity data for surface-near multi cores from transect stations 12806, 12807, 12802, 12803, 12811, 12808 and 12815. Note the different scales of the x-axes.

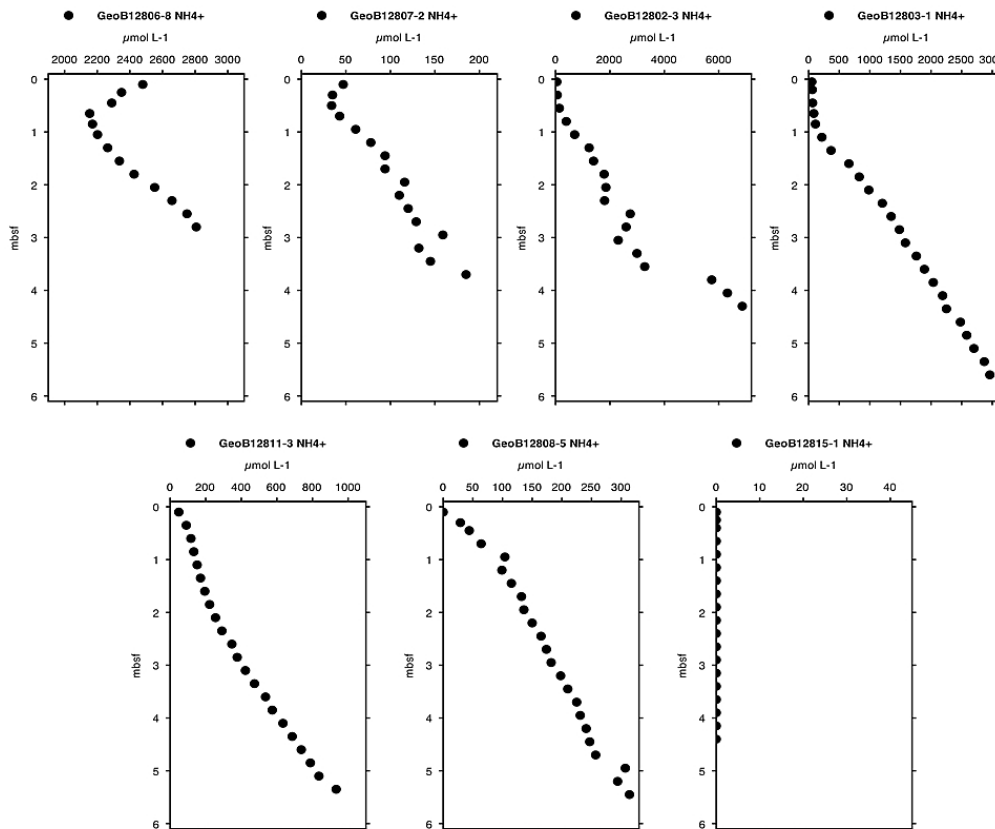


Fig. 1.9 Pore water ammonium data of gravity cores from transect stations 12806, 12807, 12802, 12803, 12811, 12808 and 12815. Note the different scales of x-axes.

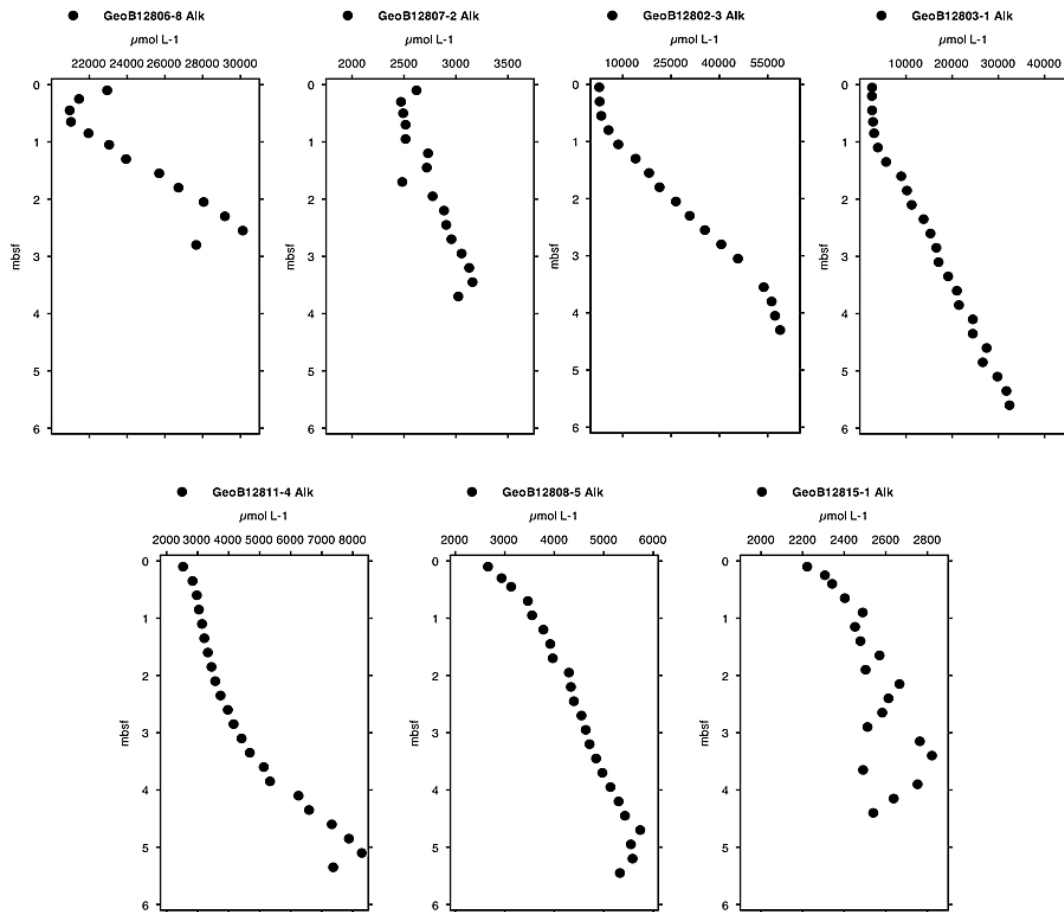


Fig. 1.10 Pore water alkalinity data of gravity cores from transect stations 12806, 12807, 12802, 12803, 12811, 12808 and 12815. Note the different scales of x-axes.

1.5.5 Experimental Biogeochemistry

(G.L. Arnold, M. Formolo, T.G. Ferdelman, T. Goldhammer, M. Zabel)

The availability and concentration of substrates set boundary conditions for microbial life. Information on this chemical milieu is usually obtained by measuring pore water profiles but is not sufficient to characterize the livelihood of the microbial communities alone. Data on formation and breakdown of relevant compounds over time is needed. Such turnover rates yield a better picture of prevailing process dynamics. Since they are subject to alteration after sample retrieval, onboard methods are not capable to produce actual in situ data, but still should deliver a mechanistic insight in the sedimentary environment. We investigated selected processes onboard in sediment incubations with or without radiotracer labelling.

Bag Incubation Experiments

To compare dynamics of sulfate reduction, phosphate turnover and molybdenum isotope chemistry between four sites (GeoB12801, 12802, 12803 and 12806) of different organic matter availability, we carried out incubations with representative surface and subsurface sediments subjected to different treatments (phosphate addition, molybdate addition, and a control without further treatment). Here we did not seek for actual station-related in situ dynamics, but for a comparison of sedimentary communities differing in activity and main metabolic pathways. All preparation of incubations, sampling and storage was done in a 4°C cooled laboratory, and sediment processing and later sampling was additionally done in a nitrogen filled glove bag.

We used incubation bags of an approximate volume of 1 L from two-ply gastight plastic foil, comprising a spout for convenient slurry sampling. About 4 L of surface sediment was collected from multi-core tops (upper 10 cm) and merged in a bucket. Subsurface sediment was prepared from 20 cm whole round gravity core sections of station GeoB12802 from 2.15 and 4.15 mbsf. Since the sediments were pretty compact and stiff in these depth layers, each liter of sediment was mixed with 0.5 L of station 12802 bottom water.

In the glove bag about 1 L of this sediment slurry was filled into each bag, making four bags for each station. The bags were provisionally closed with steel clips and thermo-sealed later. The respective replicates were amended with phosphate and molybdate and subsequently kneaded thoroughly to ensure even distribution of the spike solution.

On each of four sampling dates, 3*50 mL of wet sediment was squeezed into plastic centrifuge tubes. Six split samples of about 3 mL were filled into 5 mL disposable syringe barrels, closed with stoppers from each side and shipped to the isotope lab for later ^{35}S and ^{33}P radiotracer determination of sulfate reduction and phosphate uptake rates (see below). All accessible pore water was extracted from the centrifuge tubes using rhizone micro suction samplers, and splits were prepared for onboard alkalinity, ammonium and phosphate determination, as well as onshore anion, cation and DIC measurement and analysis of stable isotopes of sulfate, phosphate and molybdenum. The sediment remainder was kept for later solid phase analysis.

Determination of phosphate turnover with ^{33}P radiotracer

Phosphate is an essential molecule in cell metabolism. Hence, microbial productivity may be estimated by uptake rates of phosphate (Sorokin 1999). We tested the feasibility of a ^{33}P -based radiotracer method for uptake rate determination on bulk sediments. Therefore we used time-point samples of the bag incubation experiments (see above) and whole round subcores from surface-near multi-core tubes for further incubation and analyzed the distribution of radiotracer between inorganic pools (dissolved and solid phase adsorbed) and the incorporation into DNA as a cell-internal target molecule.

A spike of about 40 kBq of ^{33}P in a phosphate carrier solution was injected into about 3 mL of wet sediment sample and incubated for 12 to 60 h at 4 °C. After the incubation period, all accessible pore water was extracted with rhizone micro suction samplers. From 0.3 mL of solid sediment adsorbed phosphate and amorphous apatite was extracted using a modified SEDEX protocol (Ruttenberg 1992). After the addition of 20 mL of 1M MgCl_2 , the samples were shaken for 2 h and solution was separated from the sediment by 0.2 μm filtration. Another 0.3 mL of solid sediment were used for DNA extraction with a commercially available DNA extraction kit (MoBio PowerSoil). Phosphate concentration was determined photometrically (Molybdenum Blue method, Grasshoff et al. 1999) on pore water and SEDEX extract, and radioactivity was counted in a scintillation counter (Packard Inc.) on pore water, SEDEX extract and DNA.

The incorporation rate of ^{33}P into DNA will then be calculated from balancing the specific radioactivity of these three different pools. Therefore a few parameters remain to be examined onshore, such as bulk density (dry matter) of the sediment samples and DNA recovery rate of the extraction kit.

1.5.6 Organic Geochemistry

(V. Heuer, T. Hörner, Y.-S. Lin, M. Formolo)

1.5.6.1 Objectives

The major goal of organic geochemical studies in this cruise was to investigate microbial life and processes in the deep subsurface by deciphering the information encoded in structural and isotopic properties of sedimentary organic molecules. These molecules encompass (a) intact membrane polar lipids (IPLs) indicative of biomass from active subsurface prokaryotes and (b) low-molecular-weight organic compounds that act as central intermediates or terminal products in many metabolic processes. Route (a) leads to general taxonomic information on the active sedimentary community, estimates on the population density, and to constraints on the carbon fixation pathways and carbon sources utilized by prokaryotes in situ (Biddle et al. 2006, Lipp et al. 2008). Route (b) derives information on the dominant metabolic processes from the distribution, abundance, and isotopic composition of central intermediates, such as acetate (Heuer et al. 2006, 2009), and of terminal products, such as methane (CH₄; Whiticar 1999). Shipboard CH₄ analysis also served as a tool to rapidly screen the sediment for the depth of the SMB and to guide the subsequent sampling strategy for research projects focusing on this important geochemical zone. Bulk analyses including the content and stable carbon isotopic ratio of total organic carbon (TOC) and dissolved inorganic carbon (DIC) are part of the post-cruise investigations and provide background information for the interpretation of compound-specific data.

To complement information on metabolic processes, we also monitored the abundance of another key metabolite, hydrogen (H₂). H₂ is both produced and consumed by a wide variety of microorganisms during the decomposition of organic matter. It holds great potential in providing insightful information on the bioenergetics of the microbial ecosystem (e.g. Hoehler et al. 1998), but little is known about H₂ concentrations in sub-seafloor sediment. In this cruise, we wanted to examine the distribution of H₂ in a wide variety of sub-seafloor sediments and to compare the results with those from surface sediments.

1.5.6.2 Methods of Sampling

The multi corer (MUC) cores were processed on deck immediately after core retrieval. The sediment was extruded from the core by measured increments and the freshly exposed sediment surface was sampled. The first one cm of sediment was spooned into a glass vial for biomarker analysis. For determination of gas composition, porosity and TOC contents, a subsample set of 2-3 mL sediment was collected by cut-off plastic syringes, transferred to gas-tight vials and sealed according to the procedures described below. The depth resolution was about every four cm. A sediment sample (80-120 mL) dedicated for IPL analysis was collected from 1-5 cm. For pore water analysis, interstitial water samples were extracted from parallel cores using Rhizon suction samplers (cf. Section 1.5.4). Pore water sampling was carried out while cores were stored in the cold room at +4°C. Sampling was facilitated by small holes that were drilled into the core liners.

In the case of gravity cores, syringe samples for gas and solid-phase analysis were first taken on deck when the core was cut into 1 m long segments. Samples were taken from each freshly cut segment base. In order to improve the depth resolution, additional samples were taken at a later time, usually within a few hours, from intact whole round core segments that were stored in

a cold room at 4°C. Small sampling ports (ca. 2 × 3 cm) were cut into the core liner and syringe samples were retrieved from the freshly exposed sediments. After pore water extraction by the Rhizon suction samplers (cf. Section 1.5.4), the core sections were cut into two halves, and further pore water samples for volatile fatty acid (VFA) analysis were taken using a hydraulic press. Depth resolutions of the gas and VFA samples varied from a few cm to ~1 m, depending on geochemical zonation of the sediment. Samples for IPL analysis included the sediment remains (ca. 20 mL) after pore water squeezing and some large volume (80-120 mL) sediment samples collected from a few stations. Live sediments were quickly transferred into gas-tight glass bottles (250 and 500 mL) with the headspace flushed with N₂ and stored at +4°C for further investigations.

1.5.6.3 Metabolites of Anaerobic Biodegradation

Metabolic by-products can be useful indicators of the processes occurring during organic carbon remineralization in marine sediments. Sediment samples for the determination of metabolites from the anaerobic biodegradation of organic matter were fixed on-board with 0.1M NaOH to cease biological activity. Samples were stored at 4°C in pre-combusted amber glass bottles. Extraction and analysis of the samples will be performed at MPI for Marine Microbiology.

Table 1.4 Samples for analysis of metabolic by-products

<u>Location</u>	<u>Core #</u>	<u>Depths (cm)</u>	<u>analysis</u>	<u>Lat.</u>	<u>Long.</u>	<u>Depth(m)</u>
Site 1				27°59.965'S	14°18.040'E	1021.6
	12801-1 MUC	0-5	metabolites			
		10-15	metabolites			
		15-20	metabolites			
	12801-3 GC	340-345	metabolites			
		375-380	metabolites			
Site 2				25°30.300'S	13°30.00'E	793
	12802-1 MUC	0-5	metabolites			
		10-15	metabolites			
		25-30	metabolites			
	12802-6 MUC	3-6	metabolites			
		30-35	metabolites			
Site 3				25°45.594'S	13°04.201'E	1950.1
	12803-3 MUC	5-10	metabolites			
		20-25	metabolites			
Site 4				27°44.014'S	14°14.054'E	1251
	12804-2 MUC	5-10	metabolites			
		15-20	metabolites			
Site 6				24°59.999'S	14°23.345'E	132.3
	12806-2 MUC	5-10	metabolites			
		15-20	metabolites			
		25-30	metabolites			
		35-40	metabolites			
		45-50	metabolites			

Organosulfur Compounds

Sediment samples for organosulfur compounds were stored in pre-combusted glass jars. Samples were stored at 4°C. Extraction and analysis of the samples will be performed at MPI for Marine Microbiology.

Dissolved Organic Sulfur

Pore-water samples were extracted using rhizones in a N₂-filled glove bag. Aliquots of samples were treated with monobromobimane (Fahey & Newton 1987). The remaining pore waters were filtered using 0.2 µM Whatman filters and acidified with 50% HCl. Following acidification the samples were degassed with bubbling N₂ to remove any remaining hydrogen sulfide. Samples were stored at -20°C and will be analysed at the MPI for Marine Microbiology.

Table 1.5 Samples for analysis of polysulfides (PS), zerovalent sulfur (ZVS), dissolved organic sulfur (DOS) and organosulfur compounds (OSC)

<u>Location</u>	<u>Core #</u>	<u>Depths (cm)</u>	<u>analysis</u>	<u>Lat.</u>	<u>Long.</u>	<u>Depth(m)</u>	<u>Site Description</u>
Site 2				25°30.300'S	13°30.00'E	793	slope
	12802-4 GC	40	PS/ZVS/OSC				
		100	PS/ZVS/OSC				
		250	PS/ZVS/OSC				
		350	PS/ZVS/OSC				
		450	PS/ZVS/OSC				
	12802-6 MUC	0-3	OSC/OM				
		10-14	OSC/OM				
		25-30	OSC/OM				
	12802-8 GC	50-70	PS/ZVS				
		150-170	PS/ZVS				
		270-290	PS/ZVS				
		433-453	PS/ZVS				
		14	DOS/DOC/OSC				
		40	DOS/DOC/OSC				
		60	DOS/DOC/OSC				
		100	DOS/DOC/OSC				
		123	DOS/DOC/OSC				
		141	DOS/DOC/OSC				
		160	DOS/DOC/OSC				
		180	DOS/DOC/OSC				
		202	DOS/DOC/OSC				
		228	DOS/DOC/OSC				
		254	DOS/DOC/OSC				
		280	DOS/DOC/OSC				
		301	DOS/DOC/OSC				
		320	DOS/DOC/OSC				
		332	DOS/DOC/OSC				
		343	DOS/DOC/OSC				
		356	DOS/DOC/OSC				
		375	DOS/DOC/OSC				
		400	DOS/DOC/OSC				
		443	DOS/DOC/OSC				
		491	DOS/DOC/OSC				

Table 1.5 (continued) Samples for analysis of polysulfides (PS), zerovalent sulfur (ZVS), dissolved organic sulfur (DOS) and organosulfur compounds (OSC)

<u>Location</u>	<u>Core #</u>	<u>Depths (cm)</u>	<u>analysis</u>	<u>Lat.</u>	<u>Long.</u>	<u>Depth(m)</u>	<u>Site Description</u>
Site 6				24°59.999'S	14°23.345'E	132.3	"Mud Belt"
	12806-2 MUC	0-5	OSC				
		10-15	OSC				
		20-25	OSC				
		30-35	OSC				
		40-45	OSC				
		50-53	OSC				
	12806-9 GC	0 (1)	PS/ZVS/DOS/OSC				
		50 (2)	PS/ZVS/DOS/OSC				
		100 (3)	PS/ZVS/DOS/OSC				
		150 (4)	PS/ZVS/DOS/OSC				
		200 (5)	PS/ZVS/DOS/OSC				
		250 (6)	PS/ZVS/DOS/OSC				
Site 7				25°20.639'S	13°46.463'E	301.1	"outcrops"
	12807-2 GC	0-5	OSC				
		45-50	OSC				
		95-100	OSC				
		145-150	OSC				
		195-200	OSC				
		245-250	OSC				
		295-300	OSC				
		355-360	OSC				

In addition to taking samples for these organic measurements we also took samples for chlorin determinations from cores 12801-3, 12802-3, 12803-1, 12806-8 and 12808-5. Samples were taken at approximate 20cm intervals for these cores.

1.5.6.4 Gas Analysis

CH_4 – Concentrations of dissolved CH_4 were determined according to previously reported protocols (Kvenvolden & McDonald 1986, D'Hondt et al. 2003): 2-3 ml of wet sediment were enclosed in a gas-tight 22-ml glass vial and heated for 30 min at 60°C before 100 to 200 µl sub-samples were taken from the headspace gas with gas-tight syringes and analysed immediately by gas chromatography-flame ionization detector (GC-FID). The GC-FID was calibrated on a daily basis using a hydrocarbon gas standard (Scotty). Based on the partial pressure of CH_4 in the headspace gas and the headspace volume, the total amount of released CH_4 was quantified and normalized to the pore water volume of the extracted sediment sample, using the sample volume and corresponding porosity data of the solid phase sample.

H_2 – Concentrations of dissolved H_2 were determined using two different protocols, the headspace equilibration technique published in Hoehler et al. (1998) and an extraction-based method that was identical to that later described in D'Hondt et al. (2009). To prepare samples for the headspace equilibration technique, a sediment sample of 2-3 mL was extruded into a 22-mL headspace vial, immediately sealed with a thick black butyl stopper, crimp capped, and flushed with N_2 (purity = 99.999%) for at least 1 min. The samples were incubated directly after core retrieval onboard R/V METEOR in the dark at the in situ temperature of 4°C and the H_2 concentrations in the headspace gas were analysed every 1-3 days. All shipboard incubations were continued as long as possible to allow the establishment of a steady state, leading to total

incubation times of 2 to 25 days. To avoid evacuating the headspace by repeated removal of headspace gas, 1 mL of H₂-free N₂ was injected into the headspace immediately after the removal of headspace gas to ensure a constant gas pressure.

To prepare samples for the extraction-based method, a sediment sample of 2-3 mL was extruded into a 22-mL headspace vial, which was immediately filled with saturated NaCl solution to the top, sealed with a thin gray chlorobutyl stopper (VWR International LLC.), and crimp capped. The sampling and preparation steps typically took less than 1 min and the diffusive loss of gas is considered to be minimal. In the vial, a headspace was created by displacing 5-7 mL of the aqueous phase with an equal volume of H₂-free N₂ gas (the bypass gas out of the H₂ analyser, Peak Performer I). Once the headspace reached the intended volume, the gas-in needle was removed first, and the overpressure in the vial was allowed to escape through the liquid-out needle. The expelled liquid was collected in a syringe and the volume which corresponds to the generated headspace was recorded. The vial was then vortexed, turned upside-down, and allowed to sit for 20 min to let H₂ diffuse out of the interstitial water and equilibrate with the headspace. For H₂ analysis, the headspace gas was displaced into a N₂-flushed plastic syringe by injecting into the vial the same volume of saturated NaCl solution.

The concentration of H₂ in headspace gases was analysed by gas chromatography with mercury oxide detection, using a Peak Performer 1 (Peak Laboratories, LLC, USA). The instrument was calibrated with a 10 ppm H₂ primary standard (Air Liquide, Germany) on a daily basis. Typically, more than 3 mL and 1 mL of gas sample was injected to thoroughly flush the 1 mL and 0.1 mL sample loops, respectively, and the tubing between the injection port and the loop. The instrumental detection limit, evaluated statistically by a serial dilution of the primary standard with H₂-free N₂, was about 0.4 pmol H₂ (equivalent to ~10 ppb with the 1 mL sample loop).

1.5.6.5 Onboard Results

In the seven transect stations from the mud belt to the open ocean (Fig. 1.2), the pore water CH₄ concentrations in the upper six meter of sediment were generally low (<15 µM; Fig. 1.11). The exceptions are GeoB12802, where the SMB was penetrated at about 3.5 mbsf and pore water CH₄ concentrations reached up to ~8 mM, and GeoB12803, where ~110 µM of CH₄ was detected at the bottom of the core. The sediments retrieved inside or around the pockmarks also contained very low CH₄ concentrations (Fig. 1.12). However, we observed that for MUC cores retrieved from the one single deployment, some were bubbling rigorously on deck while the others were not. This could be an indication that CH₄ distribution in these sediments is highly heterogeneously and needs to be characterized with better coring techniques.

The H₂ concentrations obtained by the headspace equilibration technique ranged from 0.01 to 14.6 nM among the transect stations (Fig. 1.13). There was no apparent correlation between the H₂ concentrations and the redox processes inferred from the geochemical analysis. The lowest H₂ concentration within individual cores was often within the upper one meter. At station GeoB12803, there was a conspicuous subsurface minimum at ~3.8 mbsf. We also noted that the highest value of 14.6 nM, detected at ~2.8 mbsf at GeoB12802, coincided with the upper methanogenic zone.

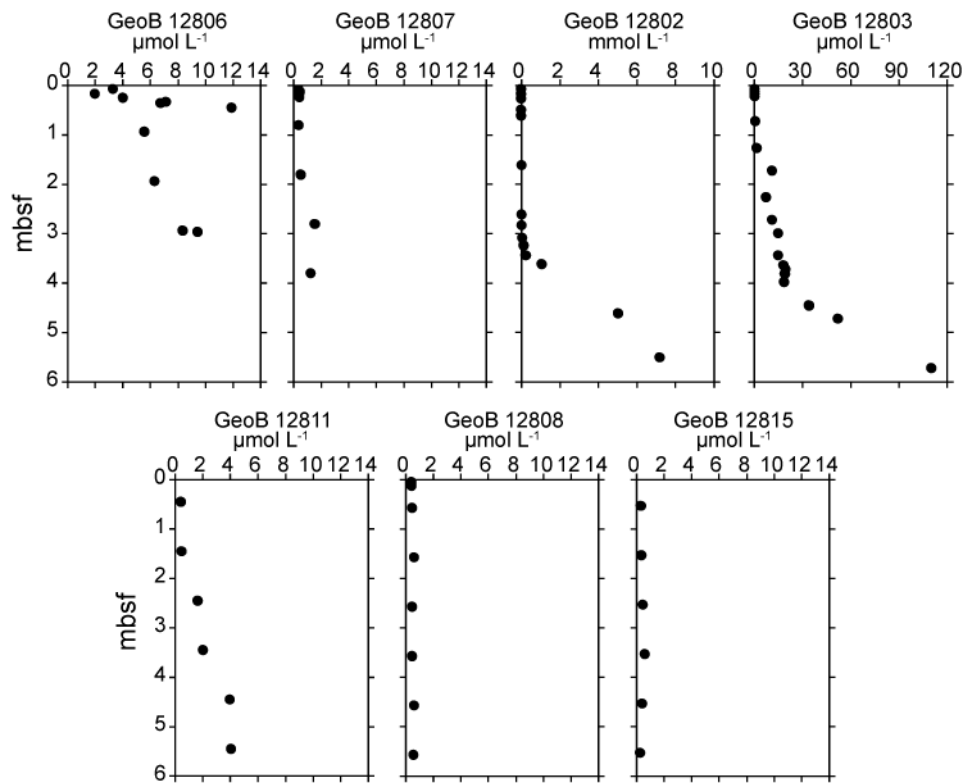


Fig. 1.11 Porewater CH₄ concentrations of multi corer and gravity cores from transect stations GeoB12806, 12807, 12802, 12803, 12811, 12808 and 12815. Note the different scales and units of x-axes.

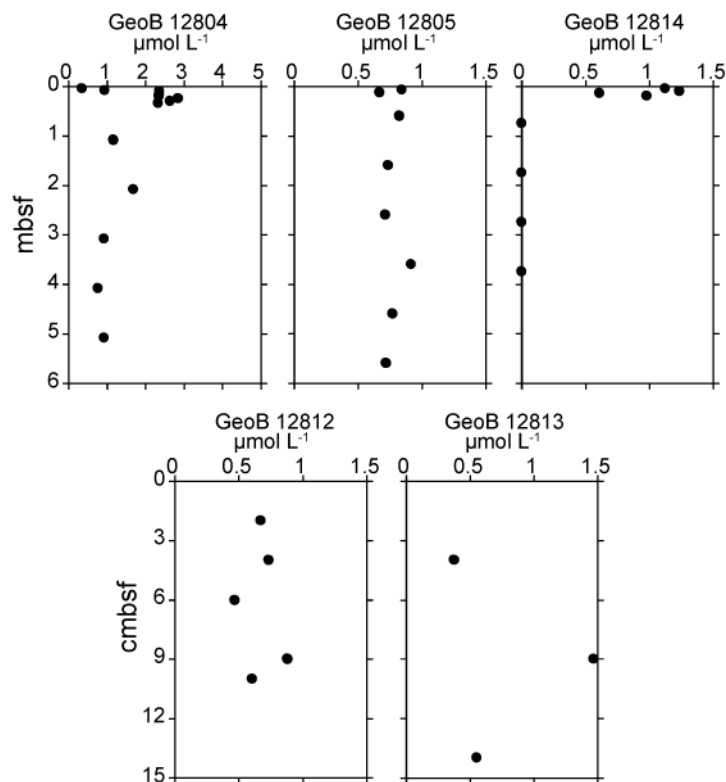


Fig. 1.12 Pore water CH₄ concentrations of multi corer and gravity cores from pockmark stations GeoB12804, 12805, 12812, 12813 and 12814. Note the different scales of x- and y-axes.

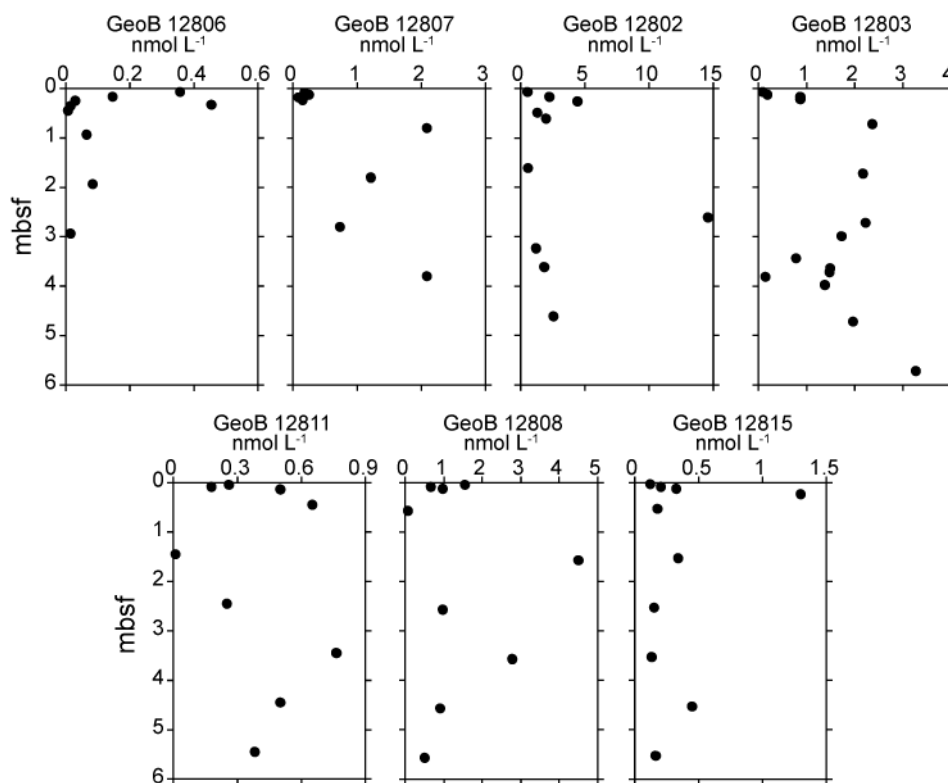


Fig. 1.13 The headspace equilibration technique-derived porewater H_2 concentrations of multi corer and gravity cores from transect stations GeoB12806, 12807, 12802, 12803, 12811, 12808 and 12815. Note the different scales of x-axes.

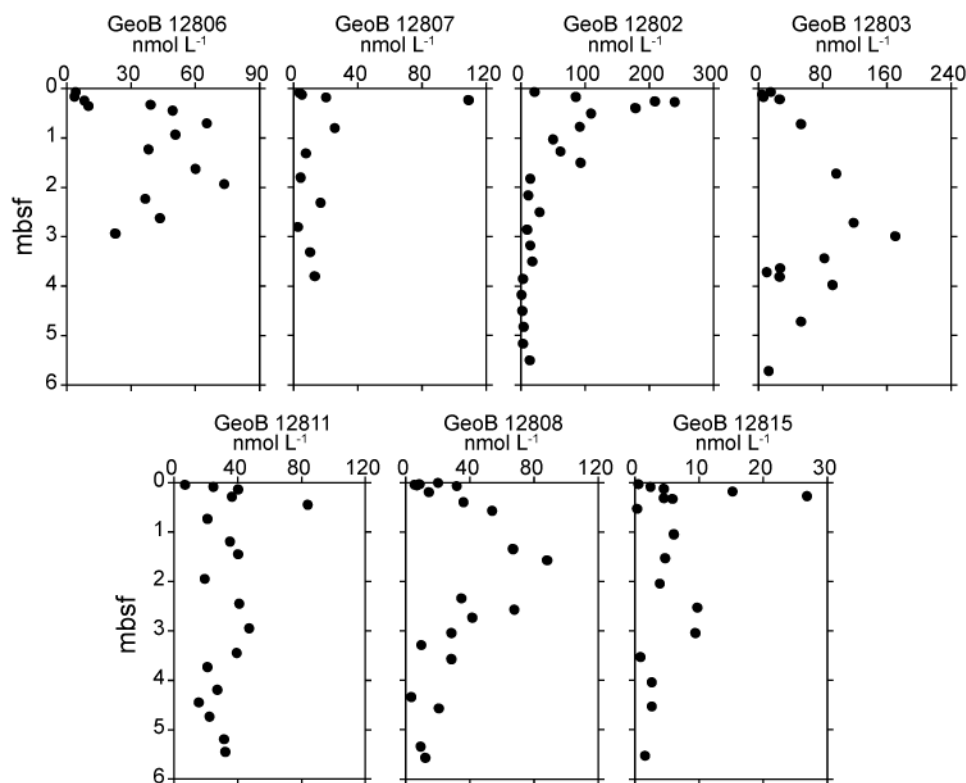


Fig. 1.14 The extracted pore water H_2 concentrations of multi corer and gravity cores from transect stations GeoB12806, 12807, 12802, 12803, 12811, 12808 and 12815. Note the different scales of x-axes.

The H₂ concentrations obtained by the extraction-based approach were much higher, ranging from 0.5 to 240 nM (Fig. 1.14). There was neither a clear correlation between the extracted H₂ concentrations and the inferred geochemical zones, but there were some similarities among the H₂ profiles generated by both methods. The extracted H₂ concentrations were usually low in the near-surface sediment, increased downward to reach a maximum, and decreased further downward or became scattered. Most interestingly, the subsurface minimum observed via the headspace equilibration technique was also depicted by the extraction-based approach. The sediment retrieved from the open ocean station (GeoB12805) had extremely low extracted H₂ concentrations, making it distinguishable in terms of H₂ geochemistry from other stations located at the continental margin. For a more detailed discussion of the H₂ data see Lin et al. (in prep.).

1.5.7 Microbiology

(B. Engelen, S. Kleindienst, M. Lever, M. Siegert)

1.5.7.1 Molecular-Guided Cultivation Assays

(B. Engelen, S. Kleindienst)

Objectives

Previous studies on long sediment cores have demonstrated the existence of a marine deep biosphere. Due to the lack of cultured representative our knowledge about the physiology and ecology of deep biosphere microorganism is still limited. Biomarker studies and the detection of certain marker genes in deep sediments indicated the presence of potentially chemolithotrophic bacteria and archaea, gaining their energy by metabolizing inorganic compounds. Our primary goal on METEOR cruise M76/1 is to assess the identity and abundance of potentially active, sulphidogenic and methanogenic microorganisms by selective cultivation approaches. Deep sediment of the Benguela Upwelling System off coast Namibia appears particularly suited since high microbial turnover rates result in depletion of pore-water sulfate and a pronounced sulfate-methane transition zone at a depth of several meters. Here the competition for hydrogen between sulfate-reducing bacteria and methanogenic archaea will be studied in different sediment layers and will be correlated to the corresponding geochemical settings.

Our secondary goal is to trace the occurrence of typical deep biosphere representatives: (1) The genus *Rhizobium* represents the most often cultured (non-spore-forming) deep-biosphere bacteria, (2) The *Chloroflexus* group appears to be the most abundant - but yet not cultured - deep-biosphere bacteria, (3): The genus *Photobacterium* was frequently isolated from deep sediments, (4) The *Roseobacter* clade is a worldwide distributed marine group and some isolates can grow by denitrification, or even by fermentation. For all of these, specific phylogenetic probes and primers are available. The results will be compared to our investigations on sediment cores from the Black Sea obtained during METEOR cruise M72/5. For the detection of these model groups it is especially interesting to sample deep penetrating MeBo cores to extend our studies further into the deep biosphere.

Sampling

From each site, sediments were sampled from multi cores, gravity cores and MeBo cores (if available, see Table 1.6). Additionally, bottom water samples from the multicores and surface waters from three stations of the transect were taken for cultivation studies. Bulk sediment samples were taken from two horizons of the multi cores: the top layer (0-5 cm) and 5 cm above

the bottom depending on core recovery. Gravity cores were sampled at three horizons: (1) above the proposed SMTZ (at app. 1.5 mbsf), (2) preferably within the SMTZ (at app. 3 mbsf), and (3) within the methane containing zone (from the lower most section). MeBo cores will be sampled at five horizons: one corresponding to the deepest sample from the respective gravity core and the other four equally distributed along the core.

All samples were taken aseptically by cut off syringes from the centres of the multi cores immediately after core retrieval. Due to the need for defining the SMTZ before sampling, gravity cores were sampled a few hours after storage at 4°C and after longitudinal opening. Sub samples were processed for molecular studies (50 ccm frozen at –20°C), onboard cell counting and fixation (4 ccm; 1 ccm each in different fixation solutions), onboard cultivation (20 ccm in reduced artificial seawater), and preservation for shore-based cultivation studies in different reducing agents: (1) Fe, (2) FeS and (3) H₂.

Table 1.6 Sample list for microbiological investigations

station	device	Lat	long	depth [m]	sediment layer [cmbsf]			
12801-2	MUC	28°0.001S	14°18.007E	1023.4	0-5			
12801-3	GC	28°0.022S	14°17.960E	1024.6	80-90	370-380		
12802-1	MUC	25°29.998S	13°27.008E	792.1	0-10			
12802-3	GC	25°29.999S	13°27.001E	787	140-150	420-440		
12802-11	Mebo	25°30.03S	13°27.01E	787	Sec.1 cc	Sec.4 cc	Sec.6 cc	Sec.6 50-60
12803-3	MUC	25°45.594S	13°04.202E	1938	0-5			
12803-1	GC	25°45.060S	13°04.200E	1942	140-160	450-460		
12804-2	MUC	27°44.131S	14°14.553E	1249	0-5			
12804-3	GC	27°44.131S	14°14.553E	1249.3	75-80			
12804-5	MUC	27°44.14S	14°14.54E	1250	0-5			
12804-6	GC	27°44.14S	14°14.54E	1250	150-155	470-475		
12804-7	MUC	27°44.14S	14°14.54E	1250	0-5			
12805-2	MUC	27°44.40S	14°15.04E	1133	0-5			
12805-1	GC	27°44.40S	14°15.04E	1133	5-10	285-290	535-540	
12806-2	MUC	25°00.00S	14°23.36E	133	0-10			
12806-8	GC	25°00.00S	14°23.36E	133	145-155			
12807-1	MUC	25°20.65S	13°46.47E	299	0-5			
12807-2	GC	25°20.65S	13°46.47E	299	150-155	350-355		
12808-1	MUC	26°22.13S	11°53.46E	3794	0-5			
12808-2	GC	26°22.13S	11°53.46E	3794	140-160	450-460		
12812-1	MUC	27°55.86S	14°15.35E	1286	0-5			
12814-3	MUC	27°57.84S	14°09.00E	1441	0-5			
12814-2	GC	27°57.84S	14°09.00E	1441	100-105	320-325		

Analyses

The first analyses will already be performed during the cruise. Total cells counts of the sampled sediments horizons will be determined by using the Acridine orange and the SybrGreen staining techniques. This will give first impressions if the study sites harbour a relatively large or small microbial community. The steepness of decreasing cell numbers with depth will roughly indicate the degree of microbial activities. The material preserved by glutar-dialdehyde and formaldehyde as fixing agents will also serve for the specific quantification of different microbial groups by CARD-FISH.

For the enrichment and isolation of strictly anaerobic microorganisms it is essential to keep the

sediments under their reduced stage. First onboard incubations in reduced artificial seawater will ensure that the sampled sediments are brought immediately under anoxic conditions. Microbial growth will be pre-stimulated before setting up shore-based enrichment cultures in selective culture media. Other enrichments of e.g. hydrogen consuming sulfate-reducers or methanogens will be performed shore based by using sediments preserved with different reducing agents.

Samples taken for molecular studies will serve to determine the original microbial community composition. The most abundant microorganisms within the different sediment horizons will be identified by DGGE. This molecular information will help to guide the cultivation strategy. The relative amount of specific microorganisms will be determined by using quantitative PCR. This technique will also be performed to trace the above described model organisms. Furthermore, detailed community profiles of sediments taken by gravity coring and corresponding layers from MeBo drilling will be compared. This will help to evaluate the capability of the MeBo system as a link between gravity coring of near-seafloor sediments and deep-ocean drilling.

1.5.7.2 Distribution and Quantification of Microbial Communities

(M. Sievert)

Sampling and methods

Samples from sites GeoB12801 to site GeoB12810 were taken to investigate the number and distribution of microbial communities in sediment depth profiles. The aim was to quantify the three domains *Bacteria*, *Archaea*, *Eukarya*, particular bacterial groups, i.e. JS1, *Geobacteraceae*, as well as the functional genes *dsrA*, *mcrA*, *aprA*, and *cbbL*. The latter functional genes are coding for key enzymes involved in major metabolic processes in marine sediments. We used molecular methods such as quantitative real time PCR, SYBR Green[®] and CARD-FISH staining. The first reference site GeoB12801 was sampled using a multicorer device (MUC) and sediment layers up to 30 cmbsf could be recovered. Samples from 0 and 30 cmbsf were taken from this core and 5 different samples from a gravity corer core (GC) could be retrieved to a water depth of 1023 m from the same site. Gravity corer cores from sulfide rich sediment at station GeoB12802 were sampled in zones of special interest as well as in regular zones beginning close to the surface and ending in the bottom of the core at 444 cmbsf. A multicorer core covered the top 30 cmbsf of this sediment and 9 samples at different layers of this core, with a higher resolution in the upper part, were taken. This sampling scheme was kept for all following cores with variations in dependence of the core depth. Special zones of interest such as the putative sulfate methane transition zone (SMTZ), i.e. the zone of anaerobic oxidation of methane (AOM) were sampled at stations GeoB12802 and GeoB12803, the latter in shallower sediments in about 1950 m water depth.

Additionally, two stations with wells in a water depth of 1249 m were sampled at stations GeoB12804 and GeoB12805 (reference station, water depth 1133 m), to study the microbial composition in relation to a putative gas seep. Here we could find zones with rich organic layers and strong sulfide odour. Eleven molecular samples were obtained to study the upper 30 cmbsf of a MUC core in a high resolution. Other stations in the so-called Neptune's Golf Course have been sampled, but microbial mats were found only at station GeoB12804. Also, one life sample from a suspected *Beggiatoa* mat at the surface of the sediment was taken. Life samples from other stations of this cruise were recovered for AOM incubation studies. Cultures to investigate the microbial reduction of organic matter with hydrogen as electron donor were set up for

cultivation experiments under mesophilic conditions from station with water depth ranging from 787 m (GeoB12802) to 3796 m (GeoB12808). A transect from sediments at a water depth of 116 m (GeoB12810), 1938 m (GeoB12803) to 3796 m (GeoB12808) was sampled in high resolution for SYBR Green[®] total cells counts, CARD-FISH and real-time PCR analysis. We used a method of cell detachment from sediment particles for cell counting (Kallmeyer, et al. 2008).

Samples for molecular studies and cell counts were taken from MUC cores and GC cores using autoclaved pre-cut syringes. DNA samples were shock frozen at -80°C immediately after collection in 15 ml PCR-clean centrifuge tubes. Samples for SYBR[®]-Green cell counts and CARD-FISH have been fixed in either 9 ml 2% formaldehyde in seawater (1 ml sample volume) and in 4% formaldehyde in phosphate buffered saline (PBS; 0.5 ml sample volume). The latter was incubated over night at 4°C, washed 2 times with PBS to remove the fixative from the suspension and stored for shipping and on-shore analyses at -20°C in 1:1 ethanol/PBS. Samples fixed with a 2% formaldehyde solution were not washed and stored at 4°C for on-shore analyses.

Results

Cells counts for a water depth of 116 m (GeoB12810), 1938 m (GeoB12803) and 3796 m (GeoB12808) are depicted in Figure 1.15.

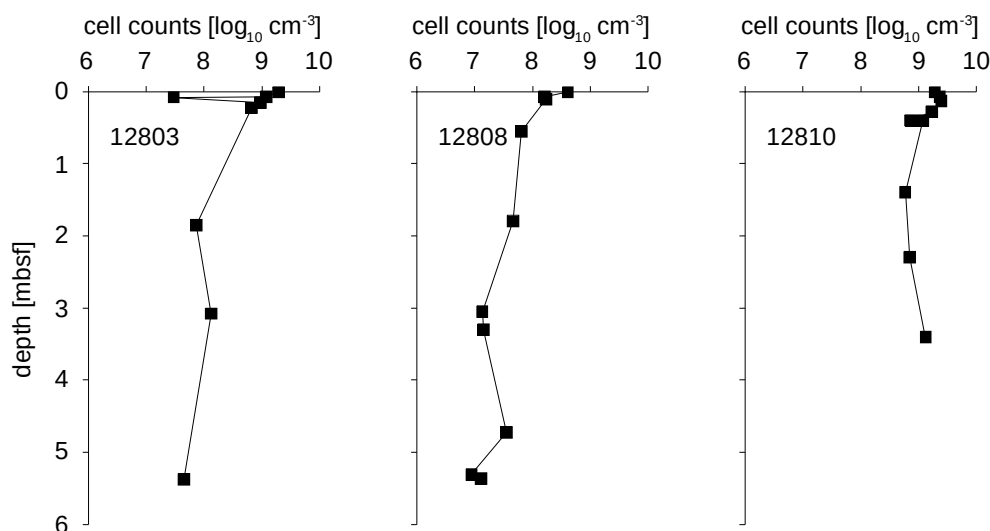


Fig. 1.15 SYBR Green total cell counts after cell detachment from sediment particles after (Kallmeyer, et al. (2008; data from Höft, 2009). These cell numbers are about half an order of magnitude lower than those without cell detachment (Höft, 2009, data not shown). For comparison also see Fig. 1.19 Engelen, Kleindienst of stations 12803 and 12808.

1.5.7.3 Community Zonation, Activity, and Genomics Based on Molecular Methods (M. Lever)

Sampling

Sediment samples for shore-based RNA/DNA analyses via PCR assays were taken using cut-off syringes immediately after arrival of cores on deck. Sediments were immediately placed on ice, and transferred to a -80°C freezer within 30 min. Fast handling was stressed to minimize degradative losses of RNA or changes in phylogenetic composition of RNA. Sampling was coordinated with sampling for gas phases, to allow correlation of microbial community

composition and activity with concentrations of the (1) key metabolic intermediate H_2 , and (2) metabolic waste product methane in analyses later on.

From each gravity core volumes of 100 mL were sampled at the cut. Multi-cores were sampled at the surface (0-1 cm), and at depth intervals of 5 cm below. Total number of samples taken depended on MUC length. Sediment volumes taken ranged from 5-30 mL and depended on the size of the MUC and volume of sediment sampled for gas analyses.

After initial gas analyses on samples had been completed, depth profiles of H_2 and methane concentrations were examined. Horizons of heightened interest, e.g. with H_2 peak or trough concentrations or sulfate-methane transition zones, were identified and sampled with higher depth resolution. Rectangular “windows” of $\sim 6 \cdot 10 \text{ cm}^2$ were cut out of the core liner of gravity cores, and 10-20 mL of sediment sampled. Again sampling was synchronized with sampling for gas analyses. Due to the duration of gas analyses, “window” sampling typically did not take place until several hours after sampling. Clearly, changes in RNA (and perhaps DNA) composition may have occurred as a result of differential degradation. Changes in RNA/DNA composition will be examined in the future, by comparing sediments sampled immediately after core arrival to ones stored in the cold room (4°C) and sampled hours to days later.

Analyses

The community composition and activity of microbes will be examined on shore in the context of (1) geochemical gradients (e.g. H_2 , acetate and other VFAs, sulfate, methane, TOC, DIC), (2) isotopes of metabolic substrates and end products (e.g. $\delta^{13}\text{C}$ -acetate and -methane), (3) *in situ* energy yields, (4) lithology, and (5) location in- or outside the depositional center. DNA and RNA will be extracted and used in (1) PCR assays and (2) genome sequencing (only DNA).

RNA work will be emphasized since RNA is not only a phylogenetic marker, but also indicates whether cells are alive (rRNA), or metabolically active (mRNA). The focus of our work will be on functional genes, functional gene mRNA, and 16S rRNA of methanogens, anaerobic methane oxidizers, acetogens, sulfate reducers, and CO_2 -fixing microbes. The distribution of poorly understood Archaea, such as Marine Benthic Group B, Miscellaneous Crenarchaeotal Group, South African Goldmine Euryarchaeotal Group, Marine Group I, or Terrestrial Miscellaneous Euryarchaeotal Group, will be examined. Moreover, we will investigate the likely existence of a ‘rare biosphere’ via genome sequencing (454 tag sequencing). Further projects may involve the characterization of sulfide oxidizers, nitrate reducers, and anaerobic ammonia oxidizers, and will depend on processes invoked based on preliminary geochemical analyses.

Analyses will be carried out at the University of North Carolina at Chapel Hill, USA, in the lab of Andreas Teske, and by Mark Lever at the Center for Geomicrobiology at the University of Århus, DK.

1.5.7.4 Microbiology: Preliminary Results

The sediment surface of some MUC cores from station GeoB12804 was covered by a microbial mat. The first microscopic inspection revealed a high abundance of filamentous bacteria (Fig. 1.16).

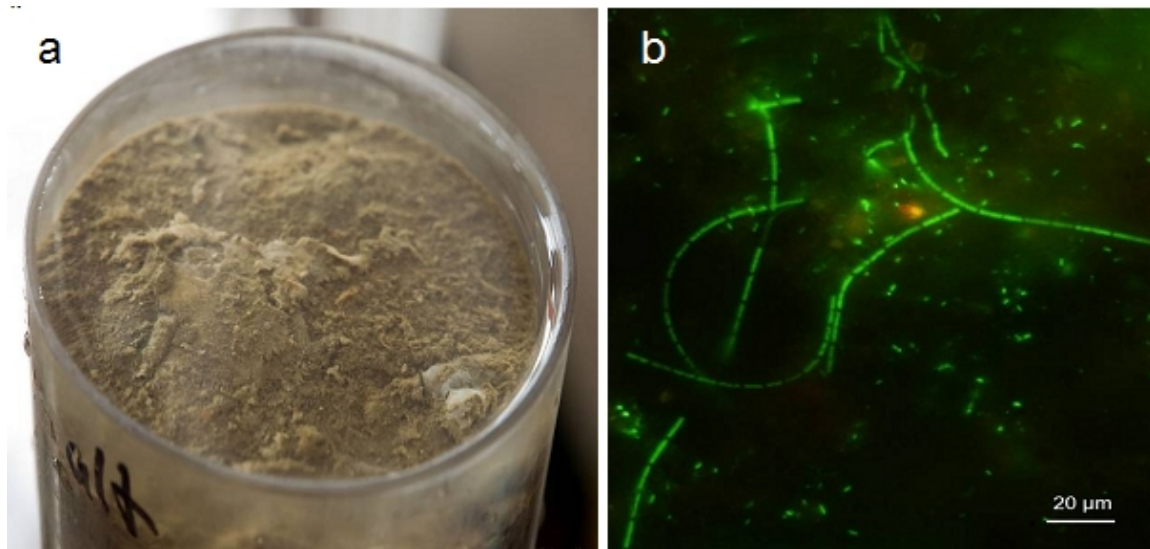


Fig. 1.16 a) Microbial mat on the sediment surface of station GeoB12804.
b) Microscopic image of the microbial mat sample after SybrGreen staining.

Thiomargarita cells were already seen by eye at the top sediment layers of station 12806. Under the microscope, the cells were easily recognizable by their enormous size, their typical “string of pearl” morphology and by large amounts of sulfur granules (Fig. 1.17).

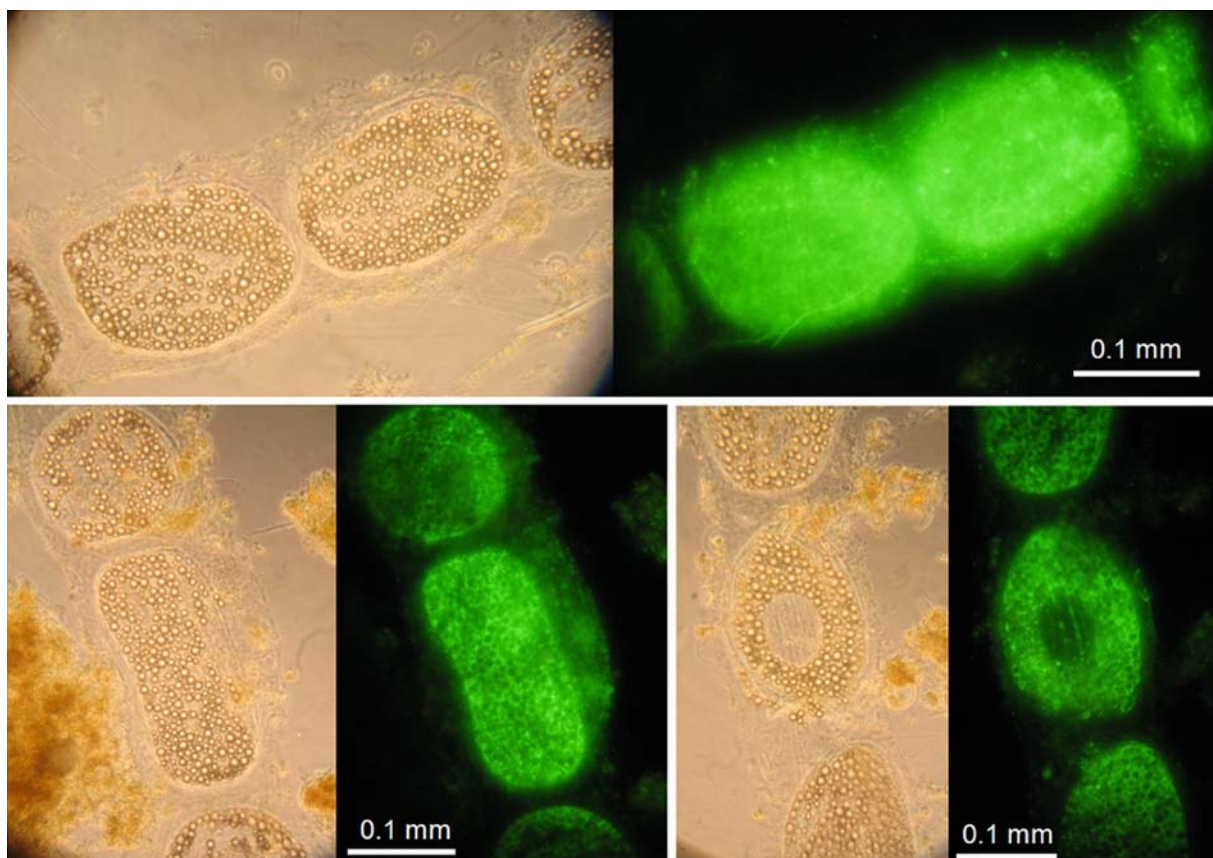


Fig. 1.17 Images of *Thiomargarita* cells. Top: Cells are filled with sulfur granules and are colonized by coccoid and filamentous microorganisms. Left: Dividing cell; Right: Cell showing a large vacuole. Phasecontrast and after SybrGreen staining.

The sediment surface and top layers of the MUC cores from station GeoB12809 harboured thick microbial mats with a filamentous structure (Fig. 1.18, left). After collecting surface material in

glas bottles, single filaments migrated actively to the sediment surface, or even glided up the glass wall (Fig. 1.18, right). Microscopically, the cells showed a typical *Beggiatoa*-like morphology. Some of the filaments were huge, showing a diameter of app. 0.2 mm. Many of them were packed with storage compounds, that are visible as dark spots in Fig. 1.18, bottom.

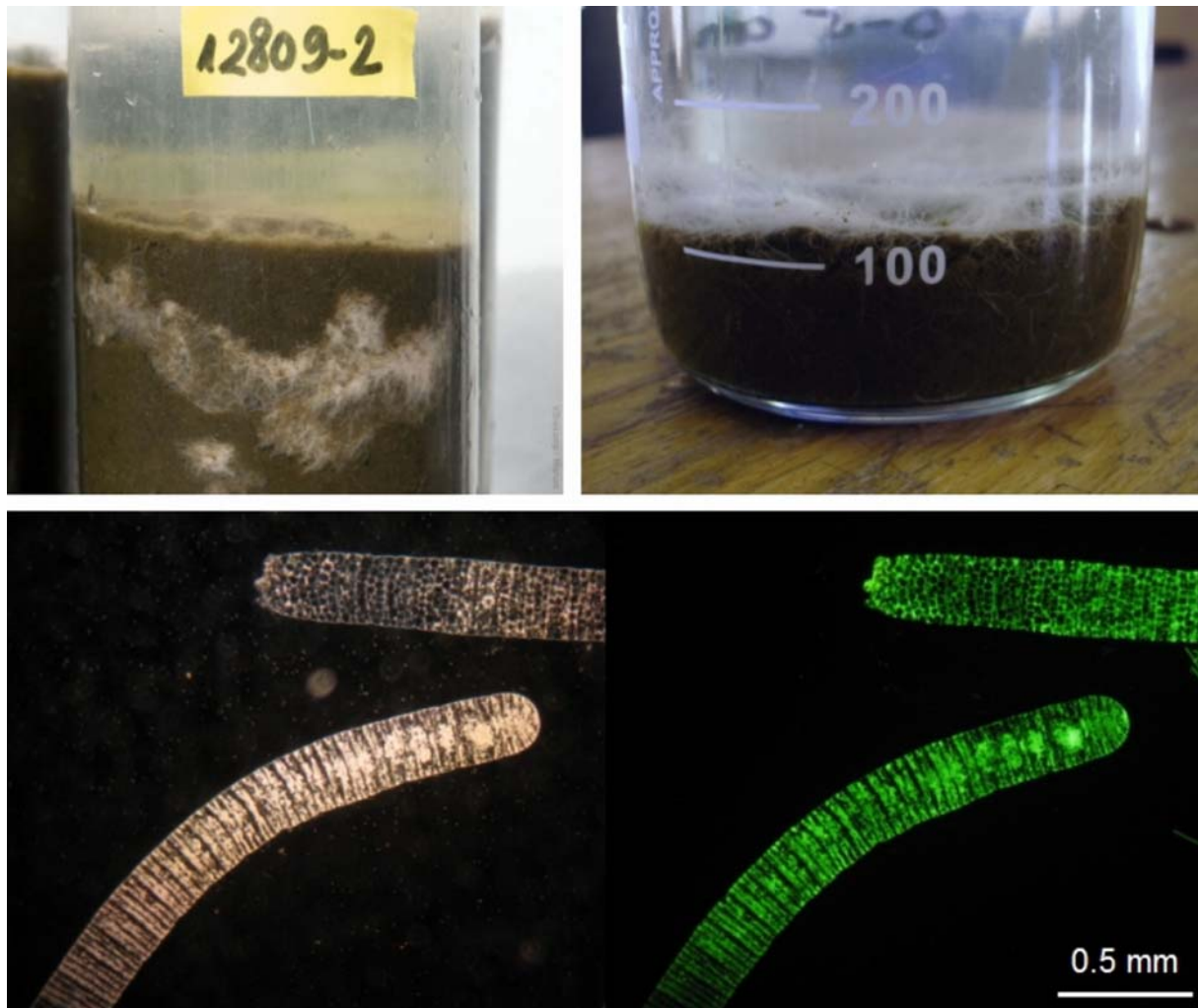


Fig. 1.18 Bacteria from the microbial mat of station 12809. Left: MUC core containing huge amounts of biomass in surface near sediment layers. Right: Colonization of the sediment surface within a sampling flask by large filaments. Bottom: The filaments show a *Beggiatoa*-like morphology. Phasecontrast and after SybrGreen staining.

In general, total cell counts of all investigated stations decreased with sediment depth. Highest numbers of app. 10^9 cells cm^3 were found at sediment surfaces, which was in the expected order of magnitude. The slope of decreasing cell numbers correlated to water depth along the transect from the shelf to down to about 4000 m wd (Fig. 1.19a). One exception are deeper sediment layers of the gravity core from site GeoB12807. Here almost no cells were detectable which might be due to the age of the outcropping sediments and thus the poor availability of organic matter.

The reference station (GeoB12801) and station “Daneben” (GeoB12805) showed an almost parallel decrease in cell numbers (Fig. 1.19b). At both stations, cell numbers were lower than at station 12802 with a comparable water depth. This indicates the lower microbial activity within sediments from stations GeoB12801 and GeoB12805. In comparison to the surrounding area,

cell numbers of sediments from the holes of “Neptune’s golf course” (Fig. 1.19b) were slightly elevated.

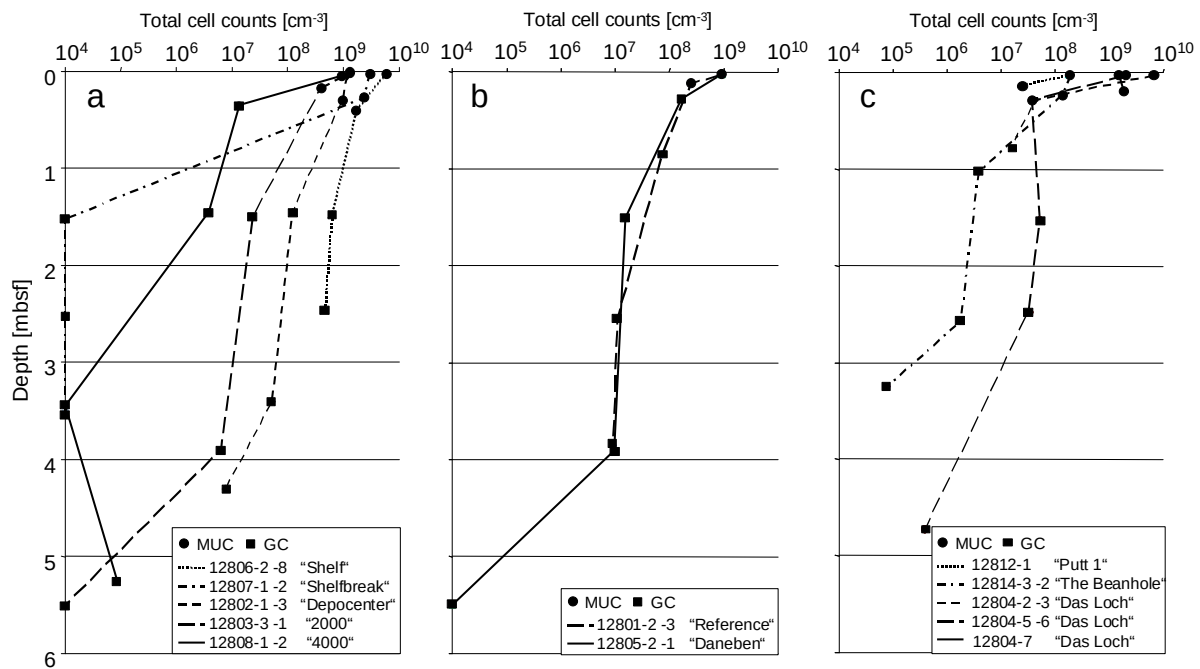


Fig. 1.19 Total cell counts from a) The transect (stations 12802, 12803 & 12806-12808); b) “Reference” & “Daneben” (stations 12801 & 12805); and c) “Neptune’s Golf Course”: “The Hole”, “Putt1”, and “The Beanhole” (stations 12804, 12812 & 12814). Cells were counted after SybrGreen staining.

1.6 Ship’s Meteorological Station

(T. Truscheit)

On the late afternoon of April 12th 2008 R/V METEOR left the port of Cape Town for the cruise M76/1 to the continental margin of Namibia. The synoptic situation in these days looked as follows:

An extensive high pressure system on a position 35°S 2°E moved south south eastward and increased. Therefore the wind direction moved to south easterly directions already on the day before. Simultaneous the wind force increased up to Beaufort 7. In these days the activity of low pressure systems were concentrated in the Antarctic waters. Their cold fronts affected the waters north of 40°S only temporary and have been not determining for the weather conditions in the working area of R/V METEOR. Two shallow low pressure systems over South Africa and the south of Namibia were responsible for warm air over wide areas of the South African continent and therefore an overcast sky. The strong south easterly winds of Beaufort 7 with gusts to Beaufort 8 were stable for the moment and the low pressure systems in the Antarctic waters were responsible for a south westerly swell up to 3.5 meters. Especially on April 15th the swell increased up to 4.5 meters temporary.

The south Atlantic subtropical high pressure system – on April 16th on a position approximately 32°S 3°E – was decreasing slowly. With reference to the South African Weather Service it should be replaced by a new high which was expected to be on a position 39°S 0°E/W on April 19th. A trough extended to the south western area of Namibia but was decreasing with approaching of the new subtropical high. On April 18th a low was analyzed over southwest of the

continent but was decreasing as well. The southern wind reached Beaufort 5 in these days and especially on April 17th the swell decreased to 2 meters, almost ideal conditions for MeBo.

With reference to the analysis of South African Weather Service the subtropical high should move eastward. With approaching of this high the gradient of pressure increased slowly and of course simultaneous the wind force. The maximum wind speed of Beaufort 9 with gusts to 10 was reached in the night from April 19th to 20th. On April 21st the subtropical high has already moved to a position southeast of Cape Town. Simultaneously two low pressure systems (one on a position 24°S 15°E, which increased and moved south westward and another low on a position 40°S 20°W which was moving eastward and decreasing) have been analyzed on this day. Consistent the gradient of air pressure decreased. In the following days until April 24th the wind speed reached Beaufort 4 at its maximum, temporarily just weaken variable. Contemporaneous the swell decreased to 1.5 to 2 meters during these days. On Friday 25th the low over the coast line of Namibia has been disbanded. Logical the working area of R/V METEOR got into sphere of influence of a stronger gradient of air pressure. These conditions caused of a low 1010 hPa over the south of Namibia and South Africa on the one hand. On the other hand the subtropical high was analysed on a position approximately 32°S 10°E. Constant the south easterly wind increased up to Beaufort 7 with gusts to 8 on Wednesday 27th. Against to the forecast of the South African Weather Service the above mentioned low moved westward. Consistent the gradient of air pressure predominated for a longer time than expected on the day before. The sea increased up to 4 meters in these days. However the swell came from south westerly directions. Already in these days it was clear that the synoptic situation would change fundamental. The subtropical high increased to 1028 hPa with its center on a position 38°S 3°W. At the same time a low pressure system 1011 hPa has been analyzed over South Africa. It was moving north ward and should combine with a low which was analyzed on a position 19°S 18°E. This would signify that the gradient of air pressure would be stable, even temporary increasing. But against all expectations this high decreased. In the result the wind force just reached 6 Beaufort at its maximum instead of up to 8 Beaufort.

Slowly the subtropical high moved eastward. Contemporaneous the emphasis of low pressure over Namibia moved westward. Assuming that these movements became true a significant change of the synoptic situation could be expected for May 2nd. Meanwhile the subtropical high was analyzed with two emphasis of air pressure 1029 hPa on a position 38°S 12°E and 36°S 28°E. It moved north eastward and was decreasing. Finally the wind subsided to Beaufort 2 on this day. Namely the swell reached 3 meters but decreased as well fast.

Simply these conditions have been stable until May 5th. A high 1016 hPa over South Africa moved eastward not very much and should increase to 1020 hPa in the further time. In the same time a low 975 hPa has been analyzed on a position 47°S 2°W, which was moving eastward rapid. A cold front from an accompanying secondary low should drift south eastward and would cross the working area. Logical the wind direction turned to northwest with approaching of the front and to south east on the reverse side after crossing. The wind speed increased to Beaufort 5 while crossing of the frontal system. The low pressure system moved eastward and high pressure influence predominated again. The wind direction turned back to south southeast and was weaken. Nevertheless a swell of up to 4 meters caused of the eastward moving low pressure system preserved on May 6th. On the following day an extended high pressure system with two emphasis 1022 hPa over the eastern South Africa and 1028 hPa west northwest of the working

area was responsible for fog temporarily with visibilities of 200 meters and drizzle on May 7th. Still the swell reached 3.5 meters on this day and the wind speed increased to Beaufort 5 again and was stable on this position. During the night from May 8th to May 9th R/V METEOR shifted to a position approximately 230 nm westward. On this position on the eastern flank of a high 1018 hPa on 27°S 8°E the wind conditions have been calm with only swell of 1,5 to 2 meters. Consequently nearly out of the influence of the Benguela current air temperature as well as water temperature rise from 15 to 20°C towards to the day before. A east south eastward moving low 992 hPa on a position 32°S 25°W was responsible for forcing the above mentioned high to northwest on Monday 12th. While passing and decreasing to 979 hPa the working area of R/V METEOR south at approximately 38°S and moving eastward the cold frontal system of it drifted up to the north of 26°S east south eastward and crossed the working area therefore in the morning of Monday 12th. This low and the position of high pressure caused wind speed of Beaufort 5 to 6 and direction south southeast. The significant sea (including swell) reached 2.5 to 3 meters on Sunday 11th and these conditions have been stable until arrival in the port of Walvis Bay/Namibia on Tuesday 13th.

1.7 Station List M76/1

(M. Zabel, T. Ferdelman)

Table 1.7 Station list M76/1

Station No.	GeoB No.	Date (2008)	Time (UTC)	Lat [S]	Long [E]	Water Depth [m]	Gear	max. rope tension [kN]
ME761/160	12801-1	14.04.	07:53	27° 59.99'	14° 18.01'	1019	MUC	19,4
	12801-2	14.04.	09:02	27° 59.99'	14° 18.01'	1023	MUC	20,2
	12801-3	14.04.	10:00	28° 0.00'	14° 18.01'	1023	GC	33,2
ME761/161	12801-4	15.04.	08:36	27° 59.73'	14° 18.03'	1024	MUC	18,8
	12801-5	15.04.	09:41	27° 59.75'	14° 18.04'	1023	MUC	22,7
ME761/162	12802-1	16.04.	11:59	25° 30.00'	13° 27.00'	795	MUC	16,0
	12802-2	16.04.	13:00	25° 30.00'	13° 27.00'	799	MUC	17,2
	12802-3	16.04.	13:52	25° 29.99'	13° 27.01'	792	GC	42,8
	12802-4	16.04.	14:57	25° 30.00'	13° 27.01'	786	GC	39,5
ME761/163	12802-16	17.-18.04.	Start 15:16	25° 30.03'	13° 27.01'	784	MeBo	
			End 08:03	25° 30.01'	13° 27.01'	788		
ME761/164	12802-6	18.04.	08:57	25° 30.00'	13° 26.98'	794	MUC	15,8
	12802-7	18.04.	09:53	25° 30.04'	13° 27.00'	794	MUC	16,6
	12802-8	18.04.	10:47	25° 30.03'	13° 27.01'	793	GC	42,0
ME761/165	12803-1	18.04.	14:35	25° 45.60'	13° 04.20'	1944	GC	50,1
	12803-2	18.04.	16:02	25° 45.59'	13° 04.20'	1938	GC	43,6
	12803-3	18.04.	17:27	25° 45.60'	13° 04.20'	1938	MUC	24,7
ME761/166	12804-1	21.04.	11:33	27° 44.13'	14° 14.55'	1251	GC	24,7
	12804-2	21.04.	12:36	27° 44.13'	14° 14.55'	1249	MUC	19,1
	12804-3	21.04.	13:50	27° 44.13'	14° 14.55'	1253	GC	34,2
ME761/167	12805-1	21.04.	15:08	27° 44.40'	14° 15.01'	1133	GC	28,9
	12805-2	21.04.	16:05	27° 44.39'	14° 15.01'	1132	MUC	23,6
ME761/168		22.04.	Start 08:26	25° 30.03'	13° 27.01'	786	MeBo	
			End 22:07	25° 30.06'	13° 27.01'	784		
ME761/169		23.-24.04.	Start 09:20	25° 30.08'	13° 27.01'	778	MeBo	
			End 09:50	25° 30.02'	13° 27.07'	784		
ME761/170	12806-1	26.04.	10:30	25° 00.00'	14° 23.34'	133	MUC	9,3
	12806-2	26.04.	11:04	25° 00.04'	14° 23.35'	133	MUC	9,3
	12806-3	26.04.	11:50	25° 00.05'	14° 23.35'	132	MUC	8,1
	12806-4	26.04.	12:29	25° 00.00'	14° 23.33'	133	GC	19,4
	12806-5	26.04.	13:25	25° 00.04'	14° 23.35'	133	GC	18,9
	12806-6	26.04.	14:02	25° 00.04'	14° 23.35'	133	MUC	5,9
	12806-7	26.04.	14:43	25° 00.04'	14° 23.35'	133	MUC	7,6
	12806-8	26.04.	15:23	25° 00.04'	14° 23.35'	133	GC	26,5
	12806-9	26.04.	15:51	25° 00.04'	14° 23.36'	133	GC	19,5
ME761/171	12807-1	27.04.	09:57	25° 20.66'	13° 46.48'	303	MUC	19,8
	12807-2	27.04.	10:32	25° 20.67'	13° 46.50'	301	GC	40,1
ME761/172	12803-4	27.04.	16:46	25° 45.91'	13° 03.66'	1965	MUC	29,1
	12803-5	27.04.	18:26	25° 45.91'	13° 03.65'	1965	MUC	26,5
	12803-6	27.04.	20:08	25° 45.91'	13° 03.65'	1966	MUC	29,0
ME761/173	12808-1	28.04.	10:49	26° 22.18'	11° 53.50'	3794	MUC	39,6
	12808-2	28.04.	13:20	26° 22.18'	11° 53.49'	3794	GC	59,9
	12808-3	28.04.	16:01	26° 22.18'	11° 53.50'	3795	GC	56,7
	12808-4	28.04.	18:26	26° 22.18'	11° 53.49'	3796	MUC	33,7
	12808-5	28.04.	21:01	26° 22.18'	11° 53.49'	3795	GC	47,6
ME761/174	12803-7	29.04.	15:19	25° 45.61'	13° 04.19'	1944	MUC	28,6
ME761/175	12802-13	02.05.	07:09	25° 30.06'	13° 26.76'	799	GC	18,6
			Start 09:21	25° 30.08'	13° 26.76'	801		
			End 16:40	25° 30.08'	13° 26.52'	810	MeBo	

Tab. 1.6 (continued) Station list M76/1

Station No.	GeoB No.	Date (2008)	Time (UTC)	Lat [S]	Long [E]	Water Depth [m]	Gear	max. rope tension [kN]
ME761/176	12809-1	03.05.	07:44	24° 17.15'	14° 16.09'	120	MUC	7,2
	12809-2	03.05.	08:08	24° 17.15'	14° 16.09'	119	MUC	9,0
ME761/177	12810-1	03.05.	10:03	24° 03.19'	14° 15.69'	121	GC	16,5
	12810-2	03.05.	10:26	24° 03.19'	14° 15.69'	120	MUC	11,2
ME761/178	12809-3	03.05.	12:20	24° 17.17'	14° 16.07'	114	GC	13,9
ME761/179		04.05.	Start 11:22	25° 30.09'	13° 26.92'	795	MeBo	
			End 12:21	25° 30.13'	13° 26.91'	795		
ME761/180	12811-1	04.05.	19:58	26° 00.62'	12° 34.39'	2975	MUC	33,1
	12811-2	04.05.	21:55	26° 00.62'	12° 34.39'	2976	MUC	40,7
	12811-3	04.05.	23:46	26° 00.62'	12° 34.39'	2975	GC	40,4
ME761/181		05.05.	Start 09:04	25° 30.08'	13° 26.87'	791	MeBo	
			End 12:51	25° 30.28'	13° 27.01'	789		
ME761/182	12812-1	06.05.	08:37	27° 55.83'	14° 15.27'	1304	MUC	18,9
	12812-2	06.05.	10:37	27° 55.80'	14° 15.27'	1309	MUC	23,2
ME761/183	12813-1	06.05.	15:57	27° 55.22'	14° 13.47'	1391	MUC	26,6
	12813-2	06.05.	17:48	27° 55.20'	14° 13.44'	1409	MUC	19,5
	12813-3	06.05.	19:02	27° 55.20'	14° 13.44'	1391	MUC	21,2
ME761/184	12814-1	07.05.	07:04	27° 57.84'	14° 09.00'	1440	MUC	26,0
	12814-2	07.05.	08:24	27° 57.84'	14° 09.00'	1440	GC	28,4
ME761/185	12804-4	07.05.	12:40	27° 44.12'	14° 14.62'	1251	MUC	18,5
	12804-5	07.05.	14:01	27° 44.10'	14° 14.59'	1255	MUC	17,8
	12804-6	07.05.	15:14	27° 44.10'	14° 14.60'	1253	GC	34,4
	12804-7	07.05.	16:32	27° 44.14'	14° 14.55'	1256	MUC	25,6
ME761/186	12814-3	07.05.	20:37	27° 57.77'	14° 08.90'	1431	MUC	22,7
ME761/187		09.05.	Start 07:03	27° 14.24'	09° 59.99'	4664	MeBo	
			End 10:09	27° 14.23'	09° 59.99'	4665		
ME761/187	12815-1	09.05.	11:22	27° 14.24'	09° 59.99'	4662	GC	59,0
	12815-2	09.05.	14:03	27° 14.24'	09° 59.99'	4668	MUC	56,8
ME761/188		10.05.	Start 10:11	25° 42.78'	13° 04.14'	1995	MeBo	
			End 11:05	25° 42.78'	13° 03.87'	2010		
ME761/189		10.05.	Start 13:49	25° 30.03'	13° 26.92'	793	MeBo	
			End 10:34	25° 30.05'	13° 26.80'	799		

1.8 Data and Sample Storage and Availability

All metadata were delivered to the PANGAEA World Data Center MARE and to the BSH (CSR). The ship station list is published together with the SCR on the homepage of the control station METEOR. Reference geological cores are stored in the MARUM core repository, these and the other geological samples have obtained GeoB ID numbers in addition to the PANGAEA event labels.

1.9 Acknowledgements

The overall successful course of this expedition needs to be attributed to the friendly cooperation and very efficient technical assistance of Captain Walter Baschek, his officers and crew. No matter in which area, we always were attentively cared for. It was always obvious that all people on board worked on a common task. For this we would like to thank everybody involved, last but not least also the Leitstelle METEOR Hamburg.

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METEOR-Berichte

Process Studies in the Eastern South Atlantic (PROSA)

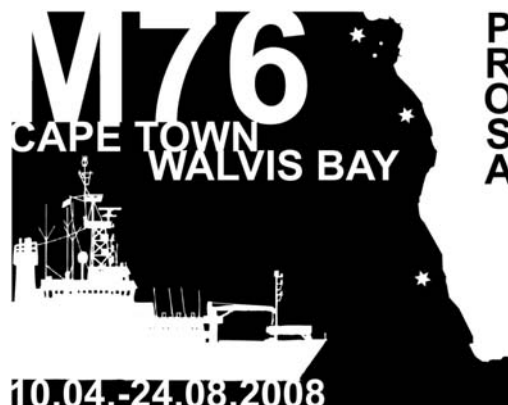
***Marine Nutrient Cycles Impacted by Global Change:
Physical Forcing on Biogeochemical Cycles in the Coastal Upwelling
System Offshore Namibia***

PART 2

Cruise No. M76, Leg 2

May 17 - June 04, 2008

Walvis Bay – Walvis Bay



**K. Emeis, P. Berger, V. Brüchert, C. Eickenrodt, P. Ellitson, A. Ellrott,
J. Fischer, D. Franzke, T. Heene, M. Holtappels, M. M. Jensen,
A. Johannsen, R. Jones, T. Köppen, P. Lam, F. Langenberg,
G. Lavik, V. Meyer, V. Mohrholz, B. Nagel, A. Nordhausen, S. Oesterle,
T. Pieplow, U. Struck, M. Tsuchiya, T. Truscheit**

Editorial Assistance:
Senatskommission für Ozeanographie der Deutschen Forschungsgemeinschaft
MARUM – Zentrum für Marine Umweltwissenschaften der Universität Bremen

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2012

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2.1 Summary / Kurzfassung

The expedition investigated the reasons for and consequences of variable oxygenation of shelf waters offshore Namibia in the Northern Benguela Coastal Upwelling System. These variable oxygen conditions impact on the fluxes of dissolved constituents from sediments to the water column and are modulated by microbial communities. The main questions addressed were: 1) How does the physical circulation system affect oxygen conditions on the shelf? 2) How are nutrient element cycles and ratios between nutrients affected by variable oxygen conditions? 3) Which processes in the cycling of nitrogen are responsible for unusual nutrient ratios in the upwelling waters? 4) What is the magnitude of sediment-water exchange processes under variable oxygen condition? The ship left Walvis Bay on May 17, 2008 and collected data from a series of stations aligned in 6 transects perpendicular to the coast (at roughly 23°S, 22°S, 21°S, 20°S, 19°S and 17°30'S). At all stations CTD casts (including water sampling with a rosette sampler) and multicore hauls were done. At 6 stations, we deployed autonomous benthic landers (chamber lander, bottom water profiler, bottom-water sampler) to measure benthic fluxes and an autonomous bottom-mounted ADCP, and we profiled the water column with a pumpcast CTD system and in-situ pumps. In addition, sediments were samples with a multicorer, and water-column microstructure was recorded by repeated casts with a free-fall microstructure profiler. Between stations, we collected bathymetric and seismic data, and an automated measurement systems was operated for nutrient analyses and physical water properties of surface waters (FerryBox by 4-H Jena). The ship returned to Walvis Bay on June 4, 2008.

Die Expedition untersuchte die Gründe für und die Folgen schwankender Sauerstoffgehalte von Wassermassen auf dem Schelf vor Namibia im nördlichen Benguela Auftriebsgebiet. Die schwankenden Sauerstoffgehalte steuern die Stoffflüsse zwischen Sediment und Wassersäule und werden durch adaptierte Bakterienvergesellschaften moduliert. Wesentliche Fragen waren: 1) Wie beeinflusst die physikalische Zirkulation die Sauerstoffversorgung des Schelfs? 2) Wie beeinflussen die Sauerstoffgehalte im Bodenwasser die Nährstoffgehalte und Nährstoffverhältnisse im Wasserkörper? 3) Welche Prozesse im Stickstoffkreislauf bewirken die ungewöhnlichen Nährstoffverhältnisse im Auftriebswasser? 4) Welche Spannbreiten haben Stoffflüsse zwischen Wasser und Sediment in Abhängigkeit von Sauerstoffgehalten im Bodenwasser? METEOR verließ Walvis Bay am 17. Mai 2008 und bearbeitete Stationen auf 6 Transekten senkrecht zur Küste (bei etwa 23°S, 22°S, 21°S, 20°S, 19°S und 17°30'S). Auf allen Stationen wurden die Wassersäule und die Oberflächensedimente beprobt. Auf 6 Stationen wurden zusätzlich autonome benthische Lander eingesetzt, um die Stoffflüsse an der Sediment-Wasser-Grenze zu beproben, und es wurden ein aufwärts blickendes autonomes ADCP-System sowie ein Bodenwasserschöpfer eingesetzt. Auf Transekten wurden Daten mit Fächerechlot und Parasound aufgenommen und Parameter des Oberflächenwassers wurden kontinuierlich mit einer FerryBox (4-H Jena) vermessen. Die Fahrt endete am 4. Juni 2008 in Walvis Bay.

2.2 Participants and Participating Institutions

Name	Vorname	Inst	Task
Emeis, Prof. Dr.	Kay-Christian	IfBM	Chief scientist
Berger	Philipp	IfBM	PARASOUND
Brüchert, Prof. Dr.	Volker	UStockholm	Sediment biogeochemistry
Eickenrodt	Cathrin	IfBM	DON isotopes
Ellitson	Paloma	MFMR	Meiofauna, Winkler
Ellrott	Andreas	MPI-MM	Pumpcast CTD
Fischer	Jan	MPI-MM	Microprofiler, benthic lander
Franzke	Daniela	NN	Nutrient analyses
Heene	Toralf	IOW	CTD, ADCP, microstructure
Holtappels	Moritz	MPI-MM	Benthic profiler, bottom-water
Jensen, Dr.	Marlene Mark	MPI-MM	Microbiology, pumpcast
Johannsen	Astrid	IfBM/GKSS	DIN isotopes
Jones	Rian	MFMR	Winkler, sediments, ornithology
Köppen	Timo	IfBM	Filtration
Lam, Dr.	Phyllis	MPI_MM	Molecular Ecology
Langenberg	Frauke	IfBM	Filtration
Lavik, Dr.	Gaute	MPI-MM	Pumpcast CTD
Meyer	Volker	MPI-MM	Pumpcast CTD
Mohrholz, Dr.	Volker	IOW	ADCP, CTD, microstructure
Nagel	Birgit	IfBM	Sediment, pore water
Nordhausen	Axel	MPI-MM	Benthic lander
Oesterle	Stefan	MFMR	CTD, microstructure
Pieplow	Tanja	GKSS-IfK	FerryBox
Struck, Dr.	Ulrich	HU Berlin	Sediment sampling
Tsuchiya, Dr.	Masashi	IFREE	Benthic Forams
Truscheit	Torsten	DWD	Weather technician

Participating Institutions

IfBM	Inst. of Biogeochemistry and Marine Chemistry, University of Hamburg, Germany
UStockholm	Stockholm University, Sweden
MPI-MM	Max-Planck-Institute for Marine Microbiology, Bremen, Germany
IOW	Leibniz-Institute of Baltic Sea Research, Rostock-Warnemünde, Germany
MFMR	Ministry for Fisheries and Marine Resources, Windhuk, Namibia
IFREE	Inst. For Frontier Research in Earth and Environment, Yokosuka, Japan
GKSS-IfK	GKSS Research Center, Institute of Coastal Research, Geesthacht, Germany
DWD	German Weather Service, Hamburg, Germany

2.3 Research Program

(K. Emeis)

Coastal upwelling systems are both active (as sources/sinks for CO₂ and nutrients) and passive (as sounding boards of changes in external forcing) components of global and regional climate change (Summerhayes et al., 1995; Summerhayes et al., 1992). Their specific importance for research on the consequences of global change for ecosystems stems from several factors: Firstly, their role in the global marine carbon cycle in terms of mass fluxes by far outweighs their modest regional extent. They are areas of substantial CO₂ degassing, and at the same time they are focal points for nutrient delivery from the sub-thermocline of the adjacent oceans to the euphotic zone and thus support an immensely powerful biological pump in the near and far field around the areas of physical upwelling (Berger et al., 1989; Diffenbaugh et al., 2004; Watson, 1995). Secondly, strong and direct links exist between physical forcing (e.g., intensity of trade wind forcing or changes in wind stress curl) and response in the physical system of coastal upwelling (f.e., intensity and spatial extent of upwelling, location of filaments) on the one hand, and on the chemical and biological upwelling systems on the other hand. Examples of such responses include changes in oxygen levels and spatial extent of suboxia/anoxia ; carbon dioxide versus methane degassing (is the latter demonstrated?); changes in organic carbon sequestration and burial; changes in the amounts and ratios of nutrients exported from the shelf upwelling system out to the adjacent pelagic ocean. Thirdly, in terms of consequences for higher ecosystem levels, variations in the physical forcing on local and regional space and interannual to interdecadal time scales are the prime suspect for changes in the biological structure, functioning and diversity of entire upwelling ecosystems, which greatly affects their value as a natural resource. Case in point are global and regional “regime shifts” seen in the geographical predominance and biomass of small pelagic fish in coastal other upwelling systems (Chavez et al., 2003; Schwartzlose et al., 1999).

These properties of and mechanisms in coastal upwelling systems mark them as prime candidates for studies under the auspices of IMBER, the Integrated Marine Biogeochemistry and Ecosystem Research initiative. Research under IMBER aims to understand, how biogeochemical cycles and ecosystems in the ocean react to global change, and how those reactions may in turn act on global change. Expedition METEOR 76-2 investigated one of these large coastal upwelling systems, the Northern Benguela Upwelling systems off shore Namibia (Fig. 2.1).

The Setting

Atmospheric and Oceanic Circulation

The coastal upwelling region offshore Angola, Namibia and South Africa is a classical example for an eastern boundary current system. It is driven by winds around the high air pressure cell that forms the South Atlantic Anticyclone (SAA) with a core position at about 30°S, 10°W (Schell, 1968). Together with the equatorial low pressure belt and highly variable continental low pressure cells over southern Africa (such as the Angola Low and Kalahari Low), these atmospheric centres of action control strength and direction of the Southeast Trades (SET) along south-west African coasts and thus the wind stress curl. The SET provides the driving force for the Benguela Current (BC) which feeds water masses into

the South Equatorial Current (SEC) as part of the basin-scale wind-driven oceanic circulation (Fig. 2-1).

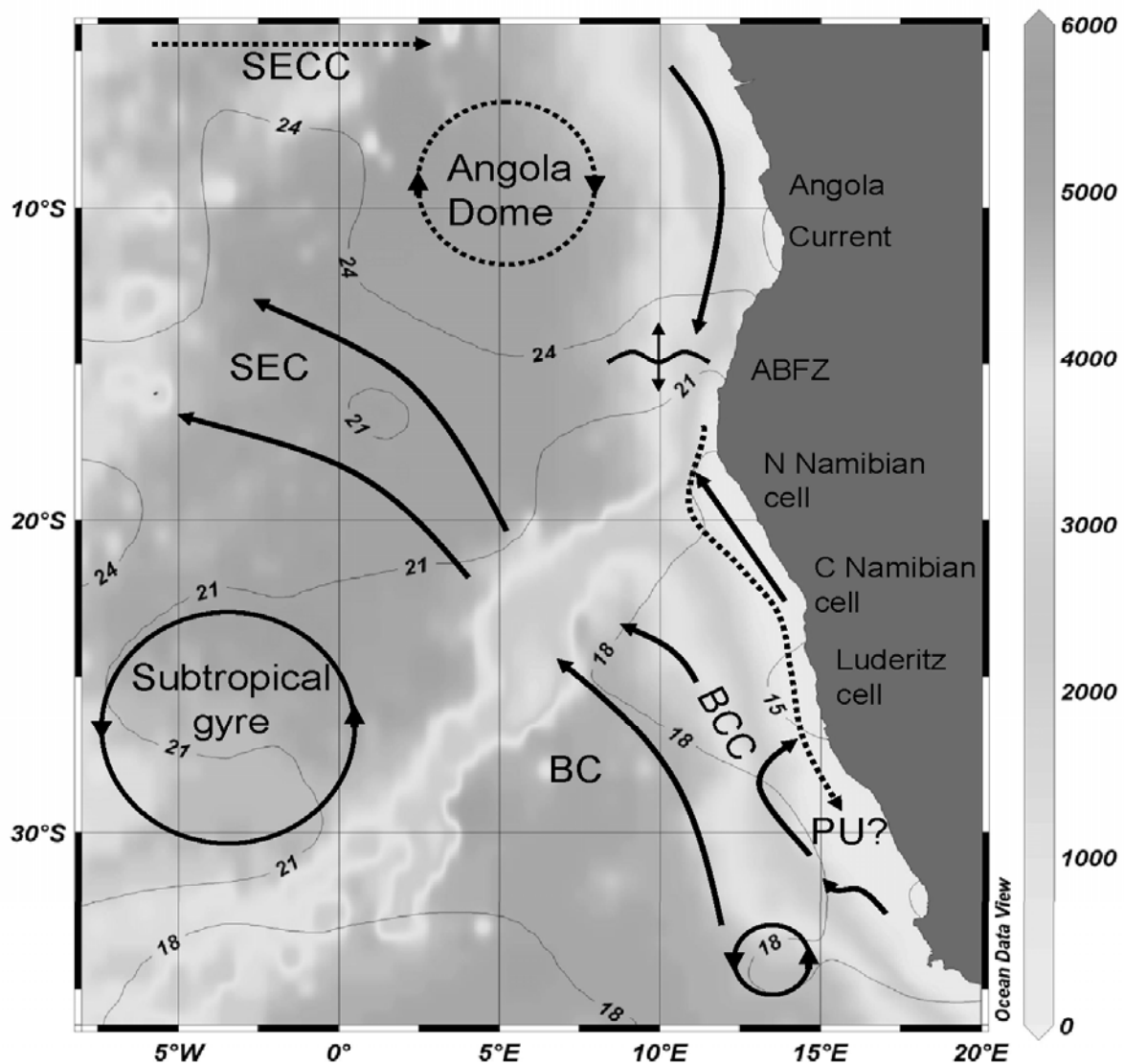


Fig. 2.1 Bathymetry of the South East Atlantic overlain with climatological sea surface temperatures (contour lines, in °C) (Gouretski and Koltermann 2004). Arrows show surface (solid) and subsurface (dashed) hydrographic features (Hardman-Mountford et al. 2003). SEC south equatorial current, SECC south equatorial counter current, BC benguela oceanic current, BCC benguela coastal current, ABFZ Angola-Benguela front, PU poleward undercurrent. Figure from Emeis et al., 2007.

The meridional component of the SET is responsible for the Ekman offshore volume transport in near-surface layers. The resulting mass deficit over the SW African shelf is partly compensated by onshore transport of Eastern South Atlantic Central Water (ESACW) from approximately 200 m depth. ESACW originates in the source region of the Benguela Current near the Cape of Good Hope and is transported northwards along the upper continental slope at water depths of <400 m. Water of deeper layers frequently carries the signature of Antarctic Intermediate Water (AIW) from up to 500 m water depth (Lutjeharms and Valentine, 1987; Stramma and Peterson, 1989). The overall coastal upwelling area is about 150–200 km wide and is composed of several locally fixed upwelling cells - determined by coastal morphology

and topography (Lutjeharms and Meeuwis, 1987) - extending up to 600 km offshore where upwelling filaments interlace with open ocean water (Lutjeharms and Stockton, 1987). The northern boundary of coastal upwelling is given by the Angola-Benguela-Frontal Zone (ABFZ) between 15°S and 17°S (Boyd et al., 1987; Lass et al., 2000). Its location is variable in space and in time and mainly depends on the constellation of air pressure gradients between the ITCZ and the SAA (Meeuwis and Lutjeharms, 1990; Shannon et al., 1987).

The southern boundary of the Benguela upwelling regime coincides with the retroflexion zone of the Agulhas Current (Boebel et al., 2003). In coastal zones south of approximately 33°S, relatively warm surface water originates from the Indian Ocean and its equatorward spreading forms a highly variable frontal zone which separates cold upwelling water in the North from relative warm water in the South (Defant, 1936). The Benguela upwelling regime thus is the only Eastern Boundary Current system with a poleward border of warm water.

Hydrography and Oxygen Balance

The chain of cause and effect from physical forcing to chemical environment and ecosystem response hinges on the oxygen supply and consumption (and linked to it, the nutrient balance) as the master variable. Three hydrographic features are important with respect to the oxygen supply for shelf waters offshore Namibia: (i) A poleward undercurrent compensates the effect of meridional Ekman transport which depends on the strength of the equatorward component of the SET (Lass et al., 2000). This poleward undercurrent of South Atlantic Central Water (SACW) originates in the Gulf of Guinea and entrains 'old' and oxygen-depleted waters of the Angola Dome (Chapman and Shannon, 1987). The mixed water mass arrives at the northernmost Namibian offshore zones with oxygen concentrations well below 90 $\mu\text{mol/L}$ and hugs the shelf break as a focused jet. (ii) ESACW is advected onshore (O'Toole, 1980) as an intermediate cross-shore compensation current that balances the Ekman offshore transport in near-surface layers. The resulting mixed water typically has oxygen concentrations of 178 $\mu\text{mol/L}$. (iii) A third water mass which has considerable effects on the hydrography, biogeochemistry and ecosystem states on the shelf offshore Namibia is warm tropical surface water normally found north of the ABFZ as described for case (i). Under specific conditions (during Benguela Niños, see below) it is advected southward along the coast to the area off Walvis Bay (and sometimes even further south).

Changes of SET strength and location disrupt the oxygen balance over the shelf via weakened upwelling and source water makeup. The cross-shelf compensation current of ESACW reacts instantaneously to changing trade-wind intensity and is immediately interrupted when the trade winds stop. In other words, the most important oxygen source for waters overlying the shelf is directly coupled to fluctuations in the coast-parallel component of the wind field on the time-scale of hours and/ or few days. Only the poleward undercurrent, which has a longer response time of weeks to months, remains to counteract oxygen consumption in the water column and the sediment. However, water in the undercurrent is already depleted in oxygen. In addition, oxygen demand is enhanced during slackening of the SET, because stabilisation of the water column promotes plankton blooms over the shelf (Bailey, 1991). Oxygen levels of near sea-bed layers over the shelf can only increase after the trade winds resume, again turning on the cross-shelf "conveyor" of oxygen.

Chemical and Biological Characteristics of Coastal Upwelling

The source waters of coastal upwelling on the Namibian Shelf have characteristic nutrient and oxygen concentrations, which are determined by processes that steer the relative proportions of the individual source waters. Aside from this, nutrient and oxygen regimes are also influenced by internal sources and sinks: by oxygen consumption, by gains of nutrients from sediments (Bailey, 1991) or – in the case of nitrate - by losses to suboxic and anoxic processes in the water column (Kuypers et al., 2005; Tyrrell and Lucas, 2002). Typical nutrient concentrations in the upwelled water offshore Namibia are 15-25 μM nitrate, 1.5-2.5 μM phosphate und 5-20 μM silicate; these concentrations increase over the shelf (to 10-30 μM nitrate; 2-3 μM phosphate, 20-50 μM silicate) and rapidly decline to <5 μM nitrate, <2 μM phosphate and <1 μM silicate in adjacent pelagic waters over the continental slope (Shannon and O'Toole, 2003). Primary production fuelled by these nutrient concentrations amounts to on average $1.2 \text{ gC m}^{-2} \text{ d}^{-1}$ in the northern Benguela (Brown et al., 1991). Phytoplankton is dominated by diatoms (Hentschel, 1936) with abundances of $> 10^6$ cells/L near the coast that rapidly decrease to 10^2 cells/L over the continental slope (Vavilova, 1990). Abundance patterns of diatoms in surface waters are well reflected by their abundance in surface sediments (Schuette and Schrader, 1981). High phytoplankton biomass ($1.2 \cdot 10^6$ tC in the area between 15°S to 28°S) is the basis for rich higher trophic levels (Shannon and Pillar, 1986). This includes small pelagic fish, which are the third largest source of income for Namibia.

An integrated project (GENUS: Geochemistry and Ecosystem Research in the Namibian Upwelling System) will address several key questions related to the reaction of coastal upwelling ecosystems to global warming over the coming years. This will be done by empirical and theoretical work; expedition METEOR 76-2 was one of several expeditions to enhance the observational basis. The focus was on the physical and biogeochemical processes at the interface between sediment and water column, and key questions of this expedition were:

1) What is the current field in bottom waters? Which processes determine the extent of and the energy in the benthic boundary layer? How do these processes affect the oxygen supply to the boundary layer? Vertical mixing in the benthic boundary layer is an important control on material exchange between the water column and underlying sediment, because it erodes vertical density gradients. We suspect, based on previous observations, that this boundary layer is elemental in restricting oxygen supply to the shelf sediment, and that it is highly variable in space and time. One main objective of work on METEOR 76-2 was thus to investigate the current fields in and the microstructure of the benthic boundary layer over the shelf and continental rise offshore Namibia. For this, we deployed an upward-looking ADCP at the sea floor and a microstructure profiling system, which supplemented CTD profiling combined with a lowered ADCP.

2) What are synoptic patterns of oxygen and nutrient element concentrations during the expedition, and what are nutrient element ratios in the surface layer? In combination with data obtained during expeditions with R/V MARIA S. MERIAN (expeditions MSM-7/2 and MSM-7/3) in austral summer 2008, measurements during METEOR 76-2 aimed to image conditions in the surface layer in high temporal and spatial resolution. We employed a

FerryBox-System to measure physical, chemical and biological parameters continuously at 5 m water depth (depth of the vessel's seawater inlet).

3) How efficient is the regeneration of nutrients from the sediments as a function of sediment type and oxygen content of the benthic boundary layer? Which microbial processes affect the release/uptake of nutrients and what are the rates of these processes? Mineralisation of organic matter at the sediment surface or in the lower water column returns nutrients in the ratios at which they were fixed in the photic zone to the dissolved pool, but processes in the sediment and at the sediment-water interface can modify these ratios and result in a significant N-deficit or P-excess in waters over the Namibian shelf. The sediment-water interface invariably shows the steepest gradients in kinetic energy, diffusion rates, particle concentrations, microbial activity and concentrations of dissolved constituents. *In-situ* measurements with bottom water sampling devices, benthic profilers and benthic chambers were made during METEOR 76-2 to obtain data from the sediment-water interface in high resolution, bracketing different types of sediments, water depths, and oxygen concentrations in bottom waters. Samples obtained from multicorer deployments were used to experimentally investigate the regeneration rates of N and P by incubations with stable and radiogenic isotope tracers.

4) What are controls on rates of denitrification and anaerobic ammonium oxidation, and how are these processes represented in the isotopic signatures of dissolved inorganic nitrogen in the water column and in sediment pore waters? The suboxic to anoxic environment on the shelf of Namibia that extends to the adjacent mesopelagic ocean is known to be a globally significant sink for nitrate. High rates of denitrification and anaerobic ammonia oxidation have previously been inferred ((Tyrrell and Lucas, 2002)) or measured ((Kuypers et al., 2005)), but the controlling mechanisms are far from understood. This deficit was tackled by various experimental approaches during METEOR 76-2. An additional approach was to sample the water column for determinations of the isotope ratios $^{15}\text{N}/^{14}\text{N}$ and $^{18}\text{O}/^{16}\text{O}$ in nitrate and $^{15}\text{N}/^{14}\text{N}$ of dissolved organic nitrogen and ammonium. Combined with analyses of reactive N-species, their isotope signatures will allow us to infer integrated rates of denitrification and anammox in the shelf system.

Factors that also are reflected in the isotope fingerprints of dissolved nitrate and ammonium are dinitrogen fixation (which might be expected to occur because of excess phosphate concentration, expressed either as P^* (Deutsch et al., 2007) or ΔN (Tyrrell and Lucas, 2002), in waters that have previously undergone denitrification) and nitrification ((Sigman et al., 2005) (see Fig. 2.2). For this reason, we performed simple incubation experiments with $^{15}\text{N}_2$ during the cruise that would indicate if diazotrophic dinitrogen fixation is indeed occurring. Together, the results of these diverse approaches will help us to quantify turnover of reactive nitrogen in the upwelling system, and will establish rates of processes affecting that turnover.

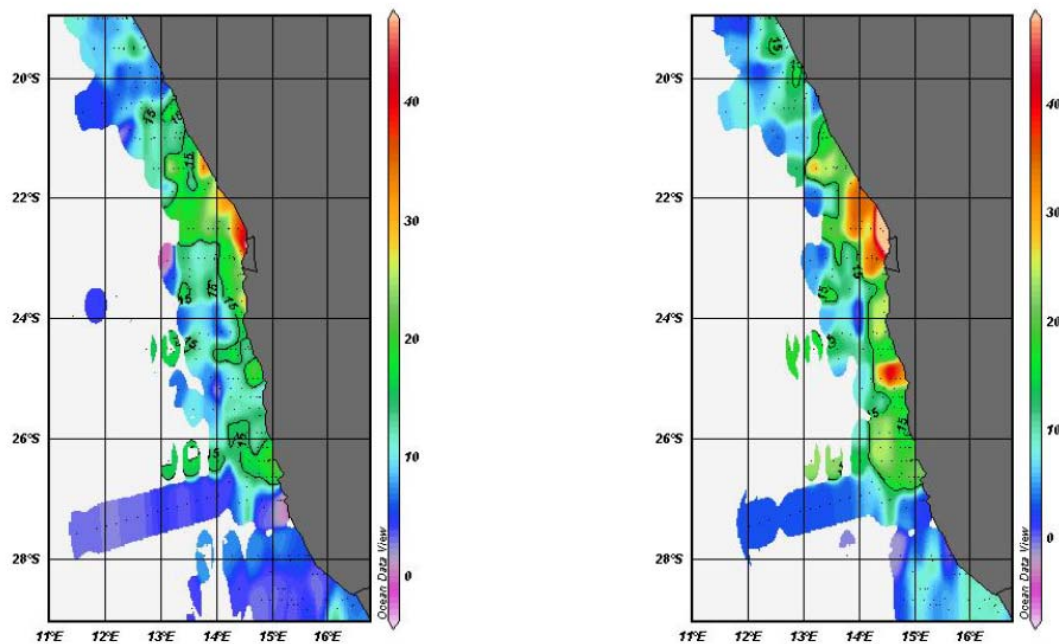


Fig. 2.2 Nitrate deficits in a) surface waters and b) bottom waters offshore Namibia. The parameter ΔN is calculated as $\Delta N = 16 \cdot [\text{PO}_4^{3-}] - [\text{NO}_3^-]$. Waters with high ΔN coincide with the distribution of organic-rich diatom oozes and with elevated $\delta^{15}\text{N}$ in surface sediments (Emeis et al., 2007).

5) What is the relationship between the isotope ratios $\delta^{15}\text{N}$ in DIN, biomass, suspended matter, and sediments and the degree of organic matter degradation? Although the isotope ratio $\delta^{15}\text{N}$ is widely used as a proxy for nutrient utilisation and as an indicator of global N-inventories on geological time scales, there is indication that organic matter diagenesis affects this ratio (Lehmann ref.). The sections occupied on METEOR 76-2 are aligned perpendicular to the coastline, and thus bracket spatial gradients in productivity, nutrient concentrations and degree of nitrate utilisation, sedimentation rates, and oxygen content of the bottom water. The data set will permit us to evaluate the influences of these parameters on $\delta^{15}\text{N}$ by analysing $\delta^{15}\text{N}$ in DIN and particulate matter in various stages of epi- and diagenesis. As a measure of degradation, the same samples of particulate matter will be analysed for their amino acid composition, which is used to establish organic matter reactivity.

2.4 Narrative of the Cruise

(K. Emeis)

METEOR departed Walvis Bay/Namibia on May 17, 2008 at 10:00 Z with a smaller than anticipated scientific crew, because two Angolan scientists did not arrive. At the first station (M762-190), situated just off Pelican Point in 50 m water depth, a first CTD cast showed anoxic bottom waters from 38 m to the seafloor, and on the transit to the next station, gas bubbles were registered in the water column by our PARASOUND system (see Fig. 2.3 for an overview of stations; cf. Sect. 2.7). We worked our way through a series of stations (192 to 205) on the transect at 23°S, after which station M762_206 was selected for a first intensive study of the water-column and the sediment-water interface. Here we deployed autonomous systems (bottom-mounted ADCP, benthic profiler, and benthic lander as well as a bottom-water sampler) to measure and sample the sediment-water interfaces and benthic boundary

layer, and collected samples from chemoclines in the water column by our pumpcast CTD. Operations here were successfully finished on May 19 at noon. The vessel set course to the second transect at 21°S, on the way occupying a station (M762_207 at 22°10'S and 014°05' E, where CTD and multicorer were deployed. The westernmost station on the transect at 21°S (station M762_208) was reached at 19:40 UTC on May 20. By that time, initial difficulties with the setup of the FerryBox on-line registration and measuring device had been solved, and from 20 May 20:00 onwards, the device monitored a series of physical and chemical parameters of the water at 5 m water depth (the inlet for the ship's seawater pumping system is located at this depth at the stern) in 1 minute intervals. We again worked our way towards shallower water with CTD and multicorer stations, anticipating that this would indicate where best to locate our next benthic station. When we had reached the shallowest station of that transect, however, winds of Bft 7 from 170° and a 4 m swell from 220° made it very difficult to position the ship and work safely with autonomous gear. Expecting that swell would be significantly lower further North, we abandoned the transect at 21°S after taking a final multicore at our intended benthic station at 21°05'S/013°15.2'E and set course to our northernmost transect at roughly 17°S.

We reached the seaward station of that transect (ME762_215) 24 hours later, during which PARASOUND, Hydrosweep, and FerryBox were operated. As predicted, the wind was still strong (6 to 7 Bft) from the SE, but the swell was somewhat lower and did not preclude operating CTD and multicorer on 5 stations (ME762_215 to 219) in water depths shallowing from 3260 m to 92 m in the time period from May 22, 11:30 UTC to May 23, 07:00 UTC. However, the weather situation did preclude the deployment of autonomous instruments, and we decided to move south to our fourth transect at roughly 17°S.

Station ME762_220 was occupied on May 23 at 22:00 UTC. It is the seaward station of a transect of in all 5 stations (ME762_220 to ME762_224) in 1200 m to 98 m water depth. All of these stations again had a program of CTD casts and successful MUC deployments. Based on these initial surveys, we selected station ME762_225 at 120 m water depth as the optimal site for a benthic station. Over the time from 24 May 14:00 UTC to 22 May 15:00 UTC, we successfully deployed the autonomous instruments at the seafloor, and operated the pumpcast CTD, bottom water sampler, in-situ pumps, multicorer, and microstructure profiler in the time until their recovery. Because the recovered water and sediment samples were used for time-consuming inoculations and experiments, we set our course to another open-water station to start operations on the fifth transect at roughly 19°S. The transit to station ME762_226 fortuitously coincided with the approximate middle of our cruise, and we took the opportunity to celebrate with the ship's personnel. When the party reached its climax at 22:00 UTC on May 25, everybody pitied those who had to go to work on a CTD cast and MUC deployment at station ME762_226 in 740 m water. Headaches and lack of sleep did not prevent us from working hard at the following stations (ME762_227 to _230), of which the last one in water 100 m deep again was chosen for intensive study of the water column and benthic fluxes. We deployed ADCP, benthic profiler and benthic lander, and continued with a program of bottom-water sampler deployments, pumpcast CTD, microstructure profiler and multicorer, until the autonomous instruments were raised again on May 27 by 06:50. After two multicorer deployments, we ended operations at station ME762-230 and set course to finish work on the transect at 21°S.

The only station of that transect (ME762-231) was a revisit of a previous station (ME762-212/214) which at that time could not be completed due to adverse weather, and was re-occupied on May 27 at 15:30 UTC. Again the benthic instrumentation was deployed, followed by a series of microstructure profiler and bottom-water sampler deployments, and high-resolution sampling of the water column by pumpcast CTD. The benthic instruments were recovered after 10 hours, and a regular CTD completed operations by May 28, 07:00 UTC. The ship offset appr. one mile to the South, and CTD casts were done on 6 stations (ME762-232- ME762-237) aligned in parallel to the transect at 21° in water depths ranging from 130 m to 1680 m; this lasted until May 29 at 04:50 UTC.

After a transit of 6 hours, we reached the westernmost station (ME 276-238) of a transect at roughly 22°S. On that transect of 6 stations, the CTD was operated, and multicores were taken at all stations except the deepest station in 1670 m. In the morning of May 30 at 05:30 UTC, we started our next intensive study of benthic processes at station ME762-243 with deployed autonomous instruments, pumpcast CTD, bottom-water sampler, and microstructure profiler, as well as multicores.

Here, the only critical incident of the cruise occurred: When approaching the buoy that marked the position of the benthic lander, the ship (guided by the first mate) sheared off both floats, which were later recovered drifting. Night had fallen, and after recovery the last mooring (bottom-mounted profiler), it was decided to try and dredge the lander on the next morning. During the night of May 30 to 31, the ship surveyed a profile perpendicular to the coast with PARASOUND and EM120 (a multibeam echosounder) and returned to the position of the lost mooring in the morning of May 31, at 06:00 UTC. The captain ordered a boat outside and dredging operations started with the so-called “Tuck” method, where the boat guards one end of a long rope with bottom-weights and hooks at the seafloor, and the vessel performs a full circle around the position with the other end of the rope, also weighted at the bottom. The first attempt was successful, and the lander was on board by 11:00 UTC. The ship then set course to the westernmost station of another CTD- transect at 23°S (station M76-2/244 reached by 20:00 UTC on May 31). Four stations with CTD deployments brought us to the position of an oceanographic mooring operated by IOW that needed to be removed. Recovery started at 07:00 in the morning of June 1 and was finished by 07:50, after which 2 additional CTD stations (ME762-250 and -251) were occupied to select the location of a final benthic station. At 10:00 on June 1, this second benthic station on the 23°S transect (ME76_2-252) was reached and after 2 initial CTD cast, the ADCP, profiler, and benthic lander were moored. During the day, pump-CTD profiles and bottom water samplers were run, followed by several deployments of the microstructure profiler, and 5 deployments of the multicorer. Unfortunately, the sediment was so soft that all cores over-penetrated, even after displacement of the ship, and so, our last benthic station has no good sediment coverage. Two deployments of the in-situ pumps completed the sampling program. The moorings were collected by 09:30 on June 2, and after a final CTD profile, the ship moved east to start a mapping program with multibeam ecosounder and PARASOUND in the area just offshore Pelican Point, where previous cruises had encountered gas eruptions. The survey was performed on a dense grid over suspected seabed structures, while instrumentation was packed and containers were readied for unloading. We left the survey area at 02:00 on June 4, and arrived in port at Walvis Bay on June 4, 2008 at 09:00 local time.

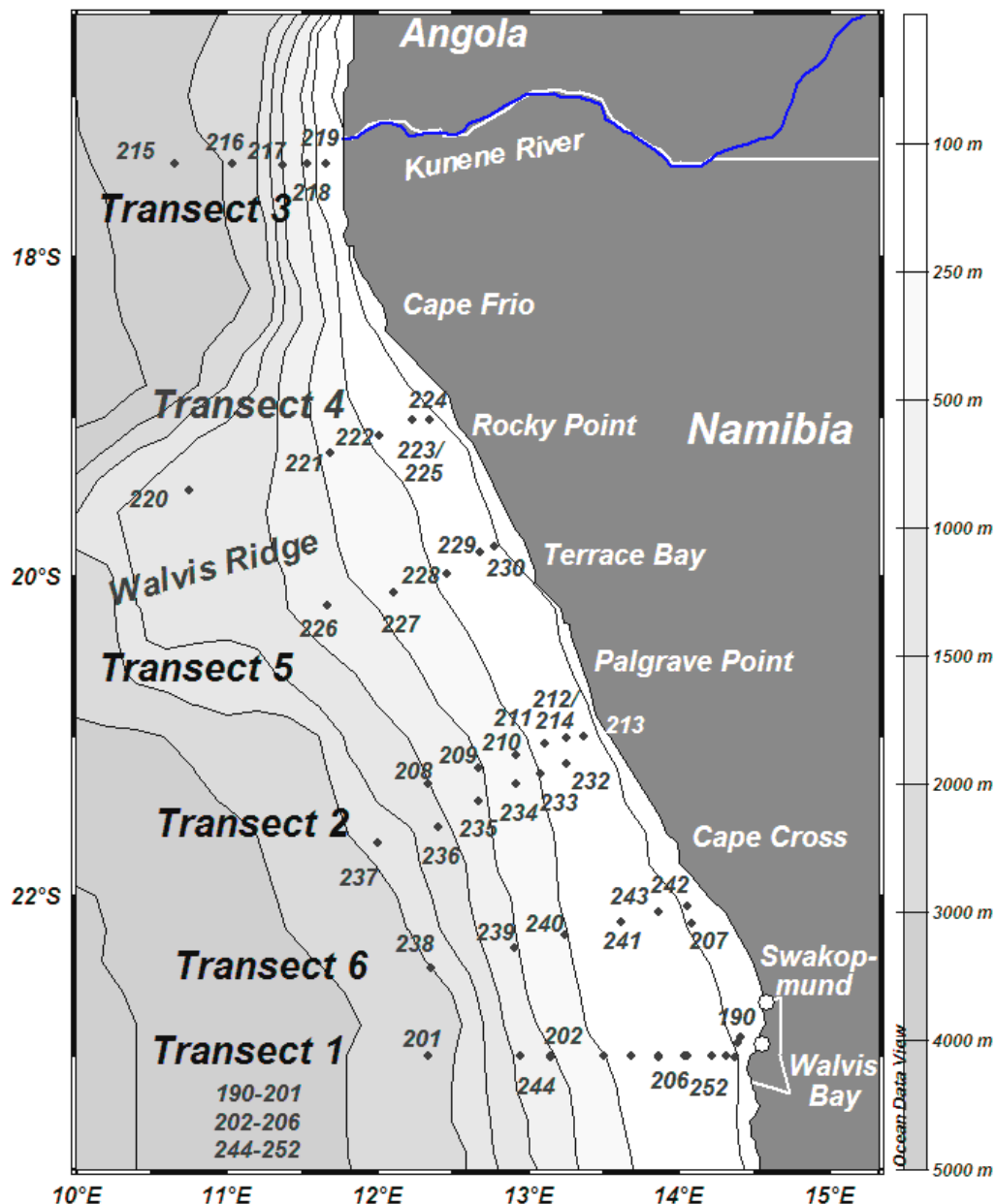


Fig. 2.3 Track and station map of M76-2

2.5 Preliminary Results

2.5.1 Large Scale Hydrography and Dynamics of the Bottom Boundary Layer

(V. Mohrholz, T. Heene, S. Oesterle)

The hydrographic investigations during the METEOR cruise M76/2 are focussed on two main topics. With respect to the large scale dynamics of the system a CTD station grid was carried out, that consists of transects perpendicular to the coast. Transects covered were the shelf between the shelf break and the coast between 17.5 and 23°S. These measurements will complement the existing data sets from the RV MSMERIAN cruises MSM7/2 and MSM7/3 in March/April 2008. Existing observations in the northern Benguela suggest that the summer season 2008 was characterised by exceptional high surface temperatures and an increased frequency of coastal hydrogen sulphide outbreaks. In view of global change it will be

important to clarify whether the uncommon conditions were caused by a usual Benguela Nino or can be attributed to a long term change.

The large scale investigations were accompanied by small scale process studies at selected stations on the mud belt that should clarify the role of turbulent mixing for vertical fluxes of nutrients and oxygen. Recent observations depicted a well mixed bottom layer of 10 to 30 m thickness on the shelf that could not be explained with the available current measurements. Using a bottom mounted ADCP in high resolution mode in combination with a Microstructure probe (MSS) for estimation of dissipation rates of turbulent kinetic energy (TKE), it will be clarified which processes determine the mixed bottom layer.

Methods

CTD/PCTD

A CTD-system "SBE 911plus" (SEABIRD-ELECTRONICS, USA) was used to measure the parameters pressure, temperature, conductivity, and oxygen. Additionally the probe was equipped with a two channel Dr. Haardt BackScat II fluorometer that supplies fluorescence (683 nm, chlorophyll-a) and turbidity data. The CTD-probe was mounted to a SeaBird Rosette water sampler with 13 FreeFlow bottles (IOW/HydroBIOS) of 5 l volume. Data are monitored and stored to hard disk with Seasave software Version 7. Generally the CTD was deployed with the single wire winch no. 3 of the R/V METEOR. At the key stations the CTD system was equipped with a high pressure pump and connected to a special pump cable in order to use it as a Pump-CTD system. This system was developed with new technological features in close co-operation of the IO Warnemünde instrumentation department and the MPI Bremen nutrient group in 2001 according to the ideas of Gernot Friedrich et. al. from MBARI California during the end of the 1980s.

Water sampling is carried out with the 13 5L FreeFlow bottles and a continuous water stream of approximately 2 litres per minute from the CTD through cable and winch into the analytics lab. The system consists of the submersible CTD-, Rosette-, pump probe unit, a special pump cable and a computer controlled winch. It allows the measurement of vertical profiles of the CTD parameters given above in combination with sophisticated online water sampling down to a depth of 400 m. For the high pressure pump unit, mounted to the CTD-rosette frame a PROCON Series 3 vane pump and a 0.5 kVA Franklin motor are used. The pump cable (FALMAT) consists of a nylon hose in the centre (inner/outer diameter: 6/8 mm), 9 electrical wires for pump and other power supplies in the probe, 4 twisted pairs for data transmission, a strengthening Kevlar layer and an outer PUR mantle (over all diameter: 18mm, breaking strength: 3 t). The individual pump function was stable during the cruise and the flow rate is usually constant in the range of ± 0.1 l/min.

The slip ring fluid output of the winch is connected to the lab outlet via a deck nylon hose 6/8 mm, 15 to 25 m long. Here the flow meter was installed to release the sample water at working places in the chemical lab. For data quality assurance comparison measurements were carried out for pressure, temperature, conductivity and the oxygen sensor. The deviations of the CTD sensors from the comparison measurements are summarised in Table 2.1.

Tab. 2.1 CTD comparison measurements

Sensor	Offset	Offset std	Slope	Slope std
Pressure			0.00	---
temperature			0.00	---
Salinity			0.00	---
Oxygen				
Fluorescence Chl-a	0.00	---	---	---
Turbidity	-0.07	---	---	---

Lowered ADCP

A LADCP-2 system was used to obtain full depth current velocity profiles at each CTD-station. Two ADCP WH-300s were mounted to the frame of the CTD-probe. The system was equipped with an external battery case for elimination of magnetic disturbances by battery packs. One ADCP was used in upward looking mode (serial number: 1129) and one in downward looking mode (serial number: 0586) in order to cover a range as large as possible. Prior the cruise both devices were calibrated in the port of Walvis Bay to minimize compass errors. After calibration the residual error in heading amounted to < 2.0 degree. The Workhorse LADCP produces profiles of velocity and echo intensity. Additionally, temperature inside the ADCP cases is recorded. The LADCP worked without instrument failures throughout the cruise. Post processing of LADCP data was carried out with MATLAB LADCP-2 software by Martin Visbeck. First the velocity profiles were differentiated with respect to depth to eliminate the CTD-package's motion. Then a depth record was obtained by integrating the vertical velocity in time. Then the shear profiles were averaged together within depth bins. The average shear profile was then integrated vertically to obtain a baroclinic velocity profile. The barotropic correction was calculated with start and end positions from GPS, which were recorded when the CTD-probe passed the 40 dbar depth level. The software package was extended routinely for calculating the acoustic backscatter cross section and a data export in Blueprint formatted file.

Vessel-mounted ADCP

During the entire cruise the VMADCP (RDI Ocean Surveyor 75 kHz) of the R/V METEOR was in operation. The data were recorded continuously with the VMDAS software. Bottom tracking was used if available. The data are partly affected by interference of the vessel's Doppler log. A detailed data analysis will be carried out after the post processing of the data set.

ADCP Bottom Frame

To obtain near bottom current data with high spatial and temporal resolution a bottom mounted ADCP frame fast used. The frame was equipped with an upward looking 600 kHz WH ADCP (RD-Instrument), operating in mode 12 for fast profile sampling and a SeaCat SBE16 thermaosalinometer from SeaBird Electronics for fast sampling of temperature and conductivity 15 cm above the bottom. The frame was deployed as a so called L-mooring. It consists of the frame connected via a 60 m ground rope with a secondary lead anchor that fixed the mooring rope with the surface buoy. This design will prevent any disturbances of the current measurements by the mooring rope. The ADCP frame was deployed at the key

stations for periods of about 12 hrs. The ADCP data cover the near bottom water column from 2 m to 20 m above the bottom with a vertical resolution of 0.5 m. The ADCP profile sampling rate was 2 s. Each profile consists of 15 subpings. The accuracy (standard deviation) of velocity estimates for a single profile was < 0.6 cm/s. The sampling interval of the thermosalinometer was 60 s.

MSS90 Microstructure Profiler

The microstructure-turbulence profiler MSS 90 is an instrument for simultaneous microstructure and precision measurements of physical parameters in marine and limnic water. The MSS profiler was used only at the key stations. It was equipped with 2 velocity microstructure shear sensors (for turbulence measurements), a microstructure temperature sensor, standard CTD sensors for temperature, conductivity and pressure, a vibration control sensor, and a two component tilt sensor. The sampling rate for all sensors is 1024 samples per second, the resolution is 16 bit. The raw data from the MSS profiler are directly transmitted via RS 485 data link to the on-board unit of the measuring system and then to a notebook for data registration. All sensors are mounted at the measuring head of the profiler, the microstructure sensors being placed about 150 mm in front of the CTD sensors. The profiler is balanced with negative buoyancy, which gave it a sinking velocity of about 0.6 m/s. It is operated via a dedicated winch, with disturbing effects, caused by cable tension (vibrations) and the ship's movement, excluded by a slack in the cable. The measurements interval for water depth of about 130 m was approx. 6 to 8 min. Due to the intermittency of turbulence five subsequent profiles are averaged to obtain robust dissipation rates.

The velocity shear variance is calculated by integrating the power spectrum in the wave number range from 2 to 30 cpm. The limitation of the high wave number cut off to 30 cpm is due to narrow band vibration peaks in the wave number range above 30 cpm resulting from eddy generation at the probe guard of the profiler. The low wave number cut off at 2 cpm is to eliminate contributions from low frequent tumbling motions of the profiler. The calculated dissipation rates have been corrected for the unresolved low wave number range (cut off at 2 cpm) and high wave number range (cut off at 30 cpm) of the spectrum, using correction coefficients obtained from the universal turbulence spectrum. The variance has been calculated in bins of 512 data records (corresponding to approx. 0.3 m depth intervals), with 256 records overlap of the depth bins. Finally, 0.5 dbar depth bins of the dissipation rates have been calculated. The dissipation rate calculation has been carried out for both shear sensors #1 and #2, and the calculated dissipation rates showed a good agreement. A mean dissipation profile has been calculated from both dissipation profiles. However, in some profiles spikes occurred in one of the two dissipation profiles. We assume a hit of larger particles to be a reason for these isolated spikes. To eliminate an influence of these spikes in the mean dissipation profile calculated from the two sensors, the following procedure was applied: A mean dissipation value has been calculated if the values of one sensor did not exceed the other by a factor of 5. If one sensor was larger by a factor of 5 in the respective depth interval, the smaller value was taken for the mean profile.

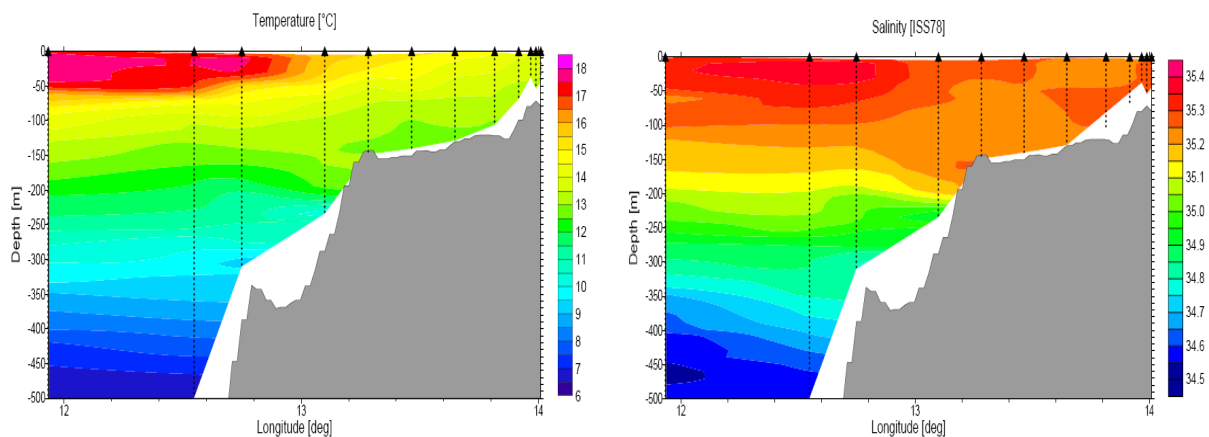
Preliminary Results

During the cruise a total number of 6 CTD/PumpCTD deployments were carried out. The LADCP was used during 49 of the CTD deployments (cf. Sect. 2.7). For the process studies in

the bottom boundary layer six intensive stations were carried out. At these the bottom mounted ADCP and the MSS were used (List of Stations).

Walvis Bay Transect 23°S

At the latitude of Walvis Bay (23°S) the CTD data depicted a clear upwelling situation, characterized by a cross shore circulation consisting of an Ekman offshore transport in the surface layer, active upwelling at the coast and an onshore compensation flow below the thermocline (Lass and Mohrholz, 2005). The compensation flow transports central water, originating from the upper central water layer between 50 and 200 m onto the shelf. Offshore, a strong thermocline was found at about 50 m depth. Above the shelf the thermocline is less pronounced (Fig. 2.4) and the isotherms crops out at the surface. At the inner shelf break near the 200 m depth isobath, slightly down sloping isotherms and isohalines indicates a southward current. The salinity minimum that is associated with the core of Antarctic Intermediate Water (AAIW) was found at 700 m depth. The lower water layer at the inner shelf is suboxic. Near the coast this water is lifted up to the surface by active coastal upwelling. The oxygen concentration in the near bottom layer rises with increasing distance to the coast (Fig. 2.5). At the westernmost station of this transect the central water

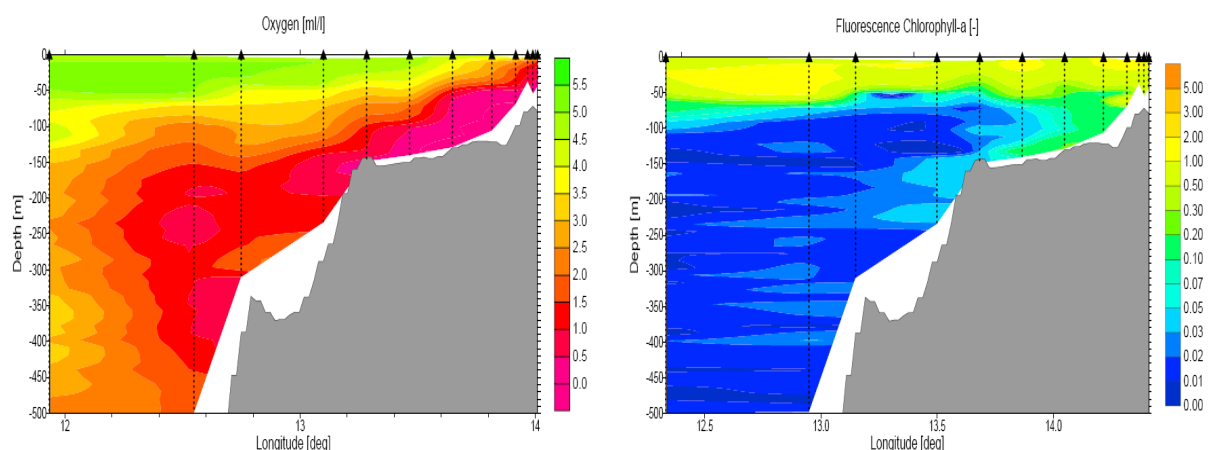


layer is well ventilated by ESACW.

Fig. 2.4 Temperature and salinity distribution at the Walvis Bay transect 23°S, 17/18 May 2008.

Fig. 2.5 Oxygen distribution and fluorescence at 683 nm (Chlorophyll-a) at the Walvis Bay transect 23°S, 17/18 May 2008.

At the time of the measurements the current pattern obtained with the LADCP (Fig. 2.6) did not reflect the upwelling dynamics described above. However, the LADCP data are not



synoptic. Spatial and short temporal fluctuations in the current field due to tides, inertial oscillations and continental shelf waves are superimposed to the upwelling dynamics.

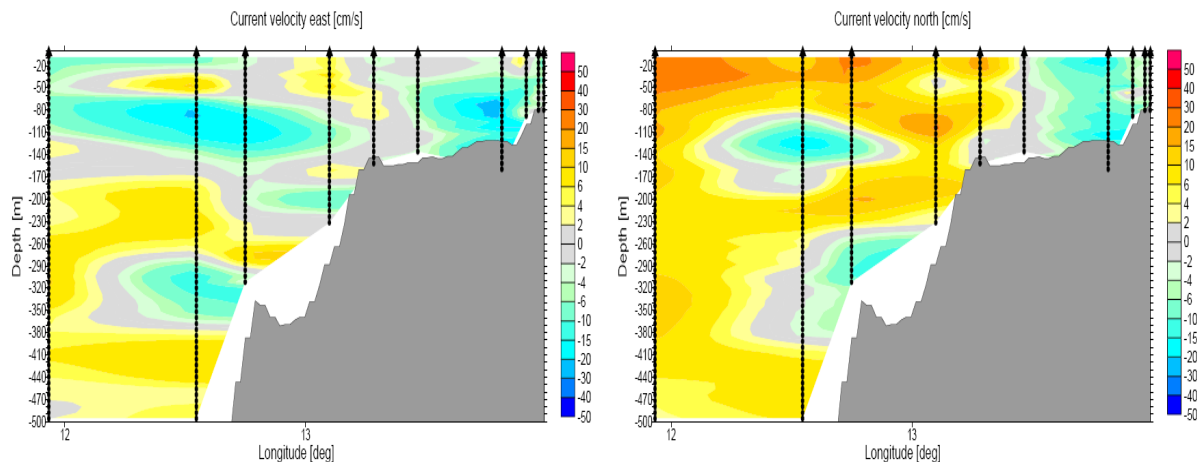
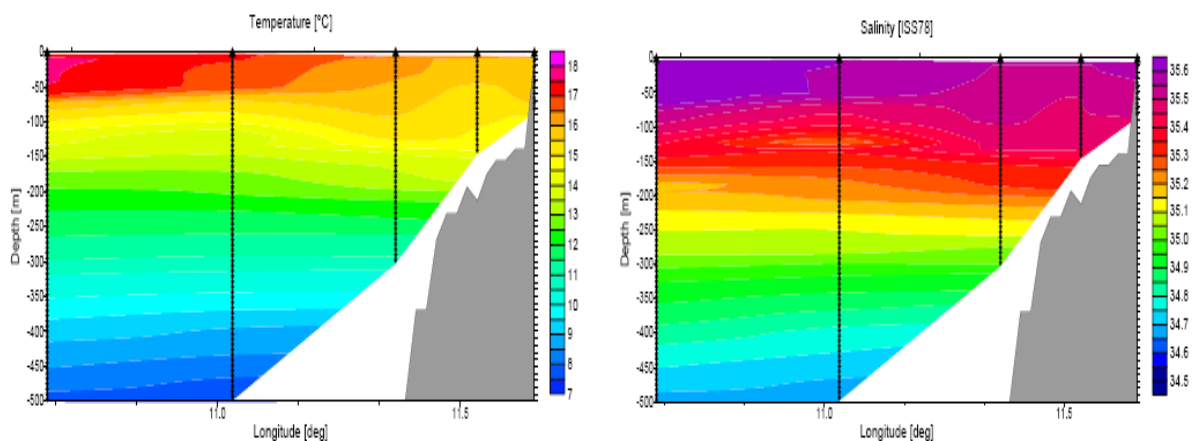


Fig. 2.6 LADCP measured current velocity east (left) and north (right) at the Walvis Bay transect 23°S, 17/18 May 2008.

Kunene Transect 17.5°S

The Kunene transect is located in the vicinity of the Angola Benguela Frontal Zone (ABFZ) which is usually found between 15°S and 17°S. Offshore, the warm and saline water in the surface layer can be linked to tropical water from the Angola Gyre (Fig. 2.7). However, towards the coast surface temperature and salinity are decreasing and that points to a former upwelling event in the Kunene upwelling cell. At the time of our observation no active upwelling was found here. Although near the coast the oxygen concentration in the surface was low. The center of the oxygen minimum layer was found between 200 and 400 m depth, covering the whole transect. Below 400 m the oxygen concentration is increasing (Fig. 2.8). The core of AAIW was found at 800 m depth.

Fig. 2.7 Temperature and salinity distribution at the Kunene transect 17.5°S, 21/22 May 2008.



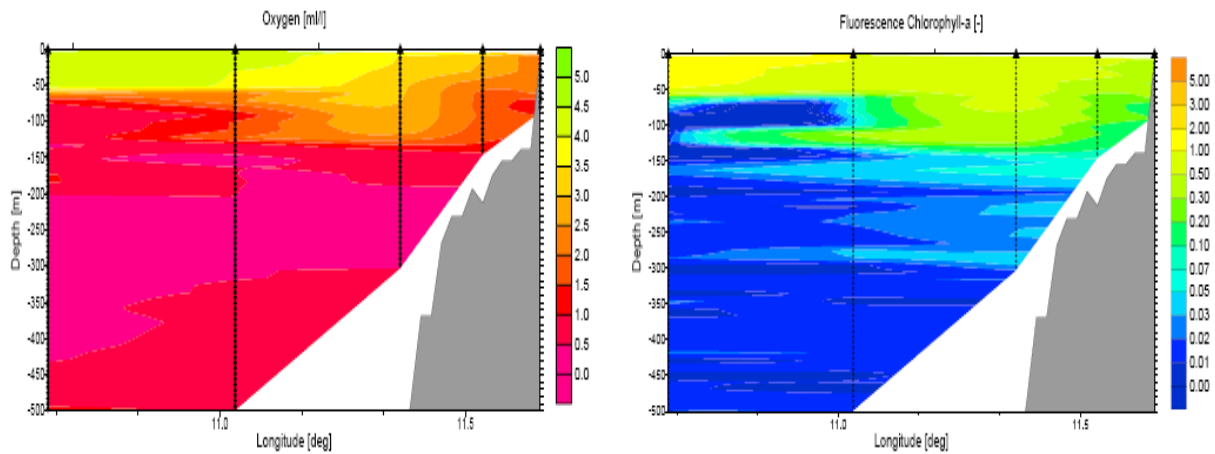


Fig. 2.8 Oxygen distribution and fluorecence at 683nm (Clorophyll-a) at the Kunene transect 17.5°S, 21/22 May 2008.

The off shelf currents depict a northward directed flow which transports central water towards the equator (Fig. 2.9). At the shelf edge a pole-ward flow dominated the central water layer.

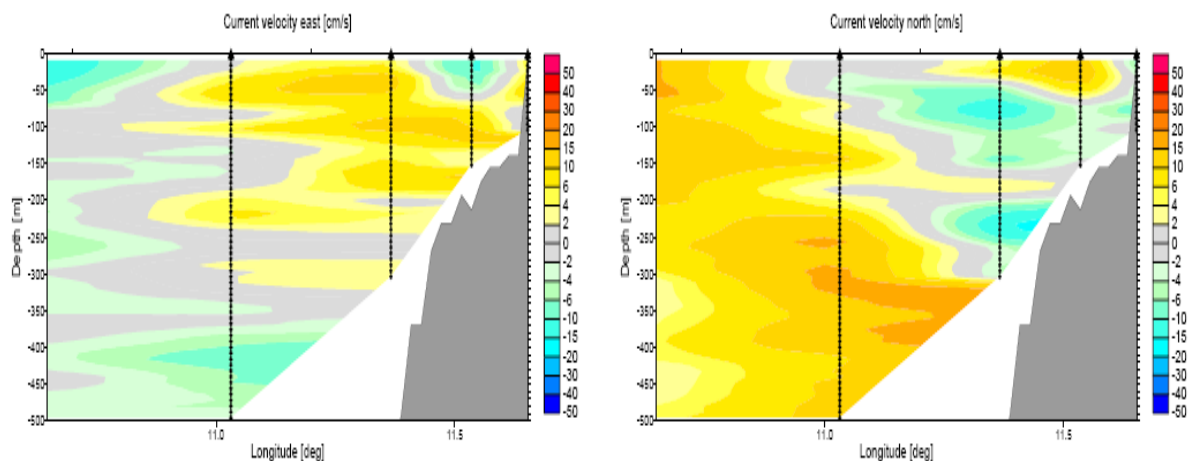


Fig. 2.9 LADCP measured current velocity east (left) and north (right) at the Kunene transect 17.5°S, 21/22 May 2008.

Surface and Subthermocline Distributions

At the Southwest African shelf the oxygen deficiency of the thermocline water is maintained by the local dynamics of coastal upwelling and oxygen consumption in the Benguela as well as by remote forcing, mainly the advection of the two central water masses of the region SACW and ESACW (Mohrholz et al., 2008). The water mass properties of the westernmost stations at the Walvis Bay and the Kunene transects are depicted in Fig. 2.10. The central water layer off the shelf at Walvis Bay is covered by ESACW with oxygen concentrations of 2 to 4 ml/l. In contrast, at the Kunene transect SACW with lower than 1 ml/l oxygen was found in that depth. The area in between is characterised by the transition between both water masses.

This is also supported by the horizontal distribution of salinity and temperature at 10 m (Fig. 2.11) and 70 m depth (Fig. 2.12). The temperature distribution at 10 m depth depicts a belt of cold water at the coast that becomes narrower towards the ABFZ. The temperature

increased from 13.5°C off Walvis Bay to about 18°C at the westernmost stations. The salinity reflects the distribution of both central water masses. The high saline water in the northwest is associated with SACW. Its fraction decreases southward and towards the coast. Low oxygen content in the coastal cool water belt indicates the former upwelling of water from below the thermocline. Comparable oxygen patterns were found in the 70 m depth layer close below the thermocline (Fig. 2.12). In contrast, the temperature and salinity distribution points to a southward transport of SACW along the shelf edge down to 22°S.

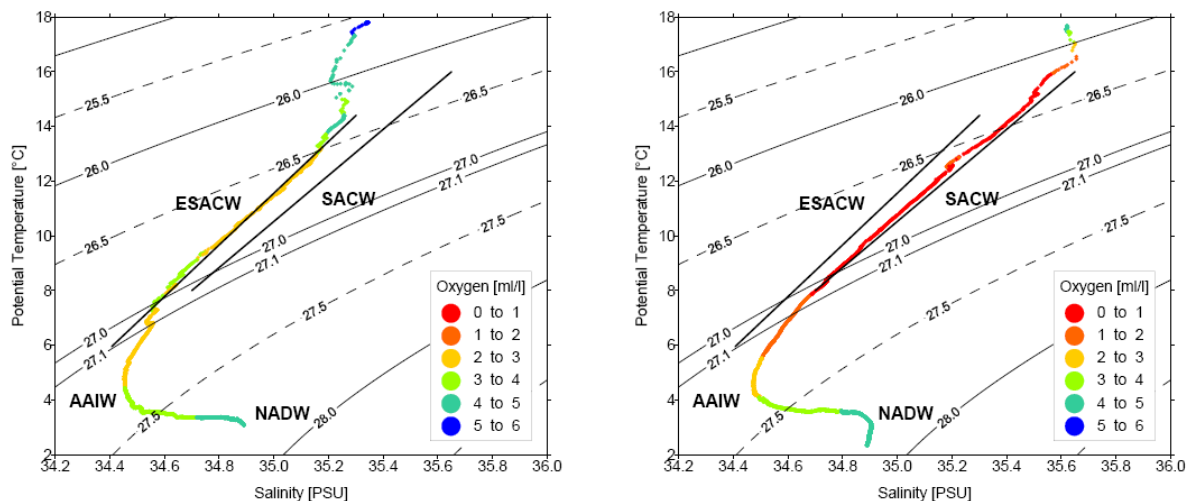


Fig. 2.10 TS-properties of water masses at the continental margin at 23°S (left) and 17.5°S (right).

Dynamics of the Bottom Boundary Layer

A first data analysis of the ADCP data reveals interesting new information on the bottom boundary layer (BBL) dynamics. Since the temporal resolution of the data was about 2 s, the current field of the long surface waves could be resolved. Fig. 2.13 shows an example of the observed patterns. The current velocity caused by the swell was in order of 10 cm/s. This value exceeds the observed mean current velocities near the bottom by the factor of 2 to 3 (Lass and Mohrholz, 2005). The consequences of this result for re-suspension of sediments and the vertical mixing in the BBL will be one of the key issues in the data analysis.

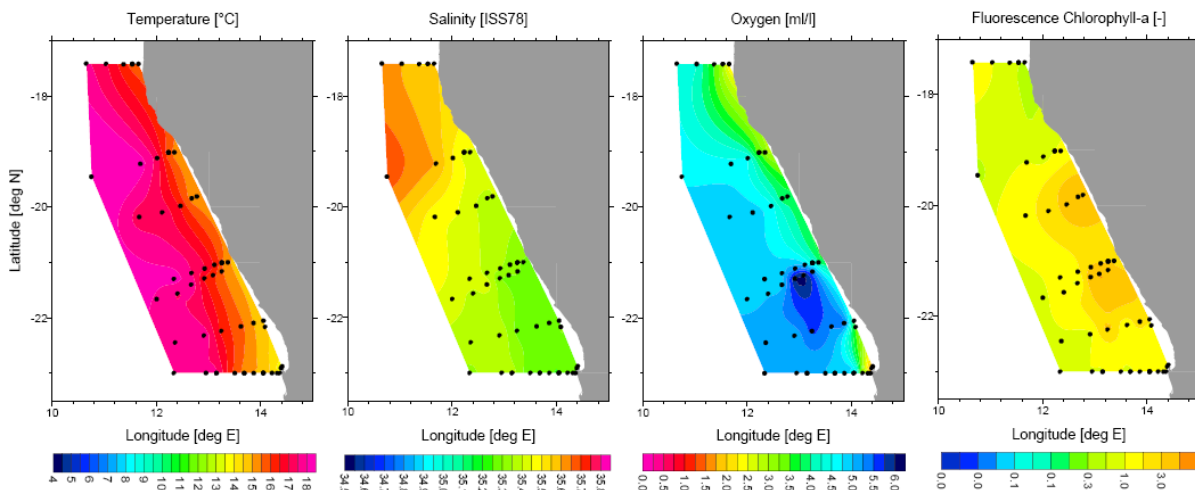


Fig. 2.11 Surface patterns (10 m depth) of temperature, salinity, oxygen and fluorescence 683 nm.

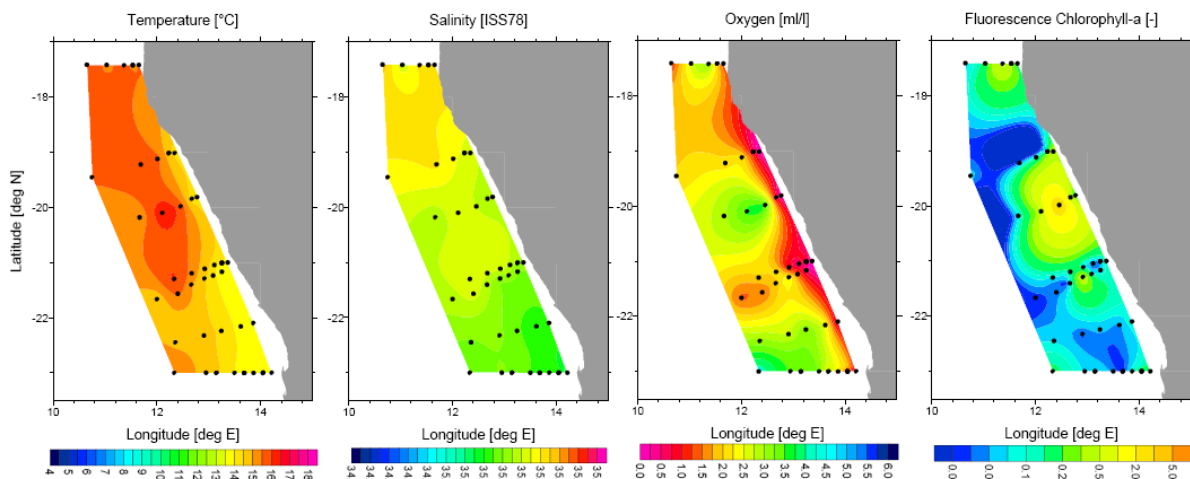


Fig. 2.12 Subthermocline distributions (70 m depth) of temperature, salinity, oxygen and fluorescence 683 nm.

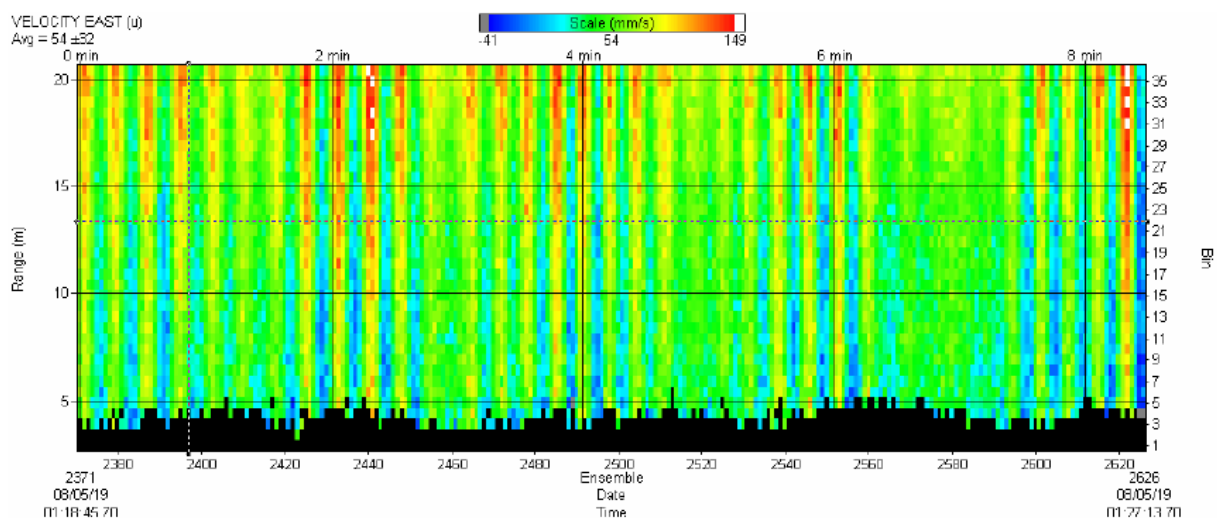


Fig. 2.13 East component of current velocity in the bottom layer at mooring station 20 nm off Walvis Bay (8 min section of the 14 hour time series). The most energetic short term fluctuations up to 10 cm/s were caused by the swell.

The data from the MSS deployments reveals an analogous pattern for all worked stations (Fig. 2.13). A thin surface layer (10 to 15 m) was well mixed. There dissipation rates of 10^{-4} W/kg are found. However, this high value will be generated mainly by ships induced turbulence. Below the surface layer a relatively strong linear density gradient was observed in depth down to about 60 m. Dissipation rates are small and amount to 10^{-8} W/kg. Between 60 m depth and the top of the bottom layer the density gradient remained nearly linear but it was lower than above. The probe measured dissipation rates of 10^{-9} W/kg or slightly more which is close to the noise level of the instrument at 10^{-9} W/kg. The true dissipation rates in that depth layer will be partly below this limit. In most profiles a well mixed bottom layer of 10 to 30 m thickness was present. There the dissipation rates increased from 10^{-9} W/kg at the top of this layer to 10^{-7} W/kg and more towards the sea bed. Unfortunately, the conductivity sensor of the MSS probe failed during the campaign. Thus, for the post-cruise processing of data, the density profiles obtained with the CTD will have to be used.

A very exiting observation was the detection of a solibore which passed the moored ADCP at station 42 during the first part of the deployment (Fig. 2.13). After the passing front the acoustic backscatter intensity showed a strong increase, which points to an increasing

concentration of suspended matter in the near bottom layer. Unfortunately no MSS data are available for this event.

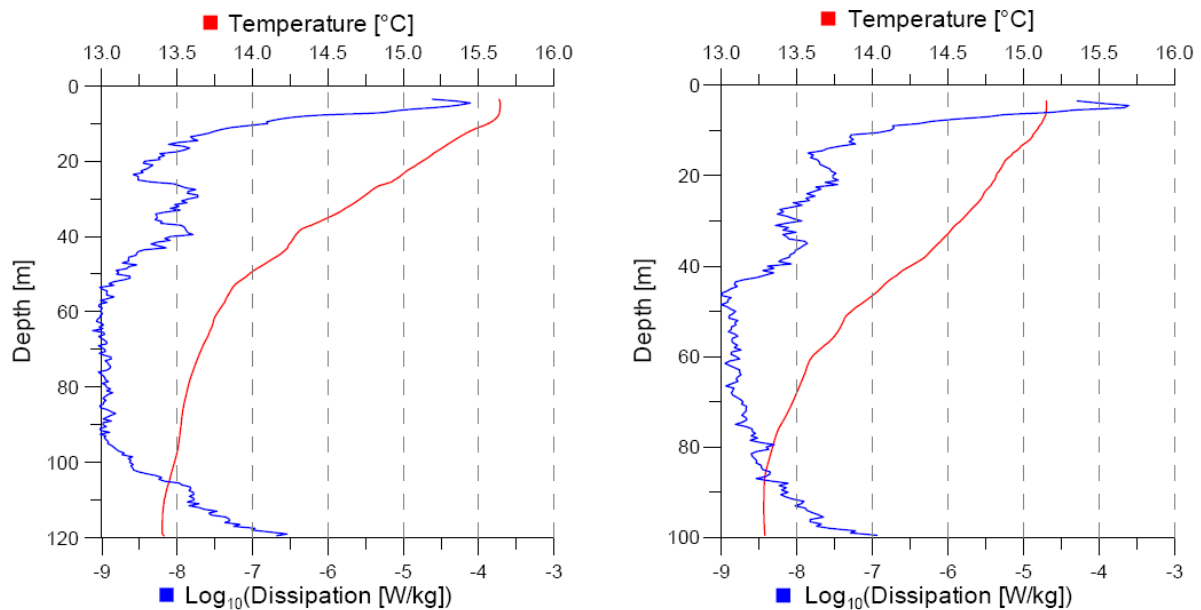


Fig. 2.14 Vertical profiles of temperature and TKE dissipation rate at station 43 (left) and station 55 (right). The graphs depict mean values of 25 profiles taken within 5 hours.

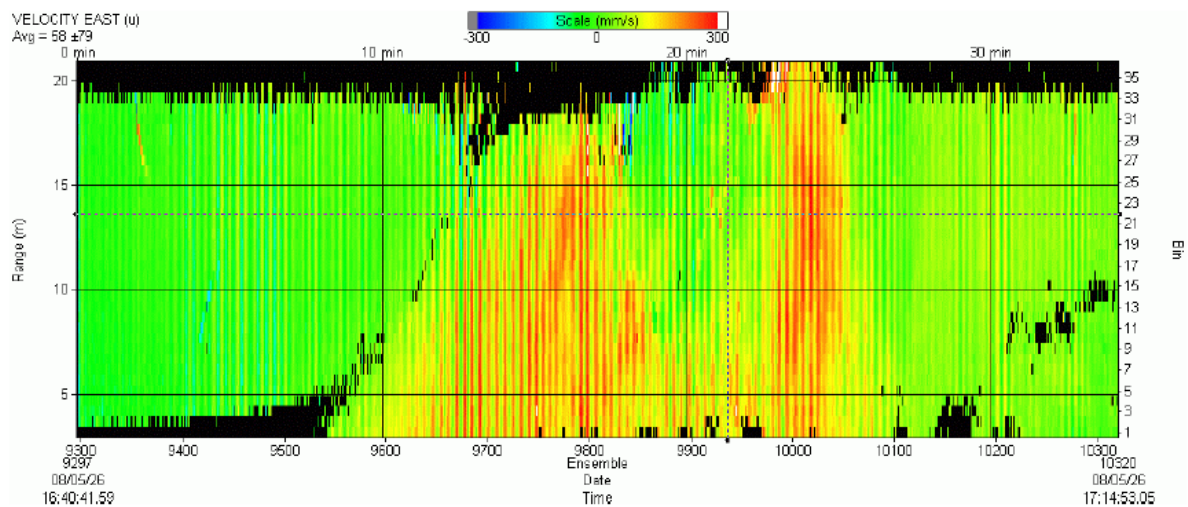


Fig. 2.15 Passing solibore at CTD station 42. The east component of current velocity showed a front and afterwards a strong increase of the eastward flow onto the shelf for 10 to 15 min.

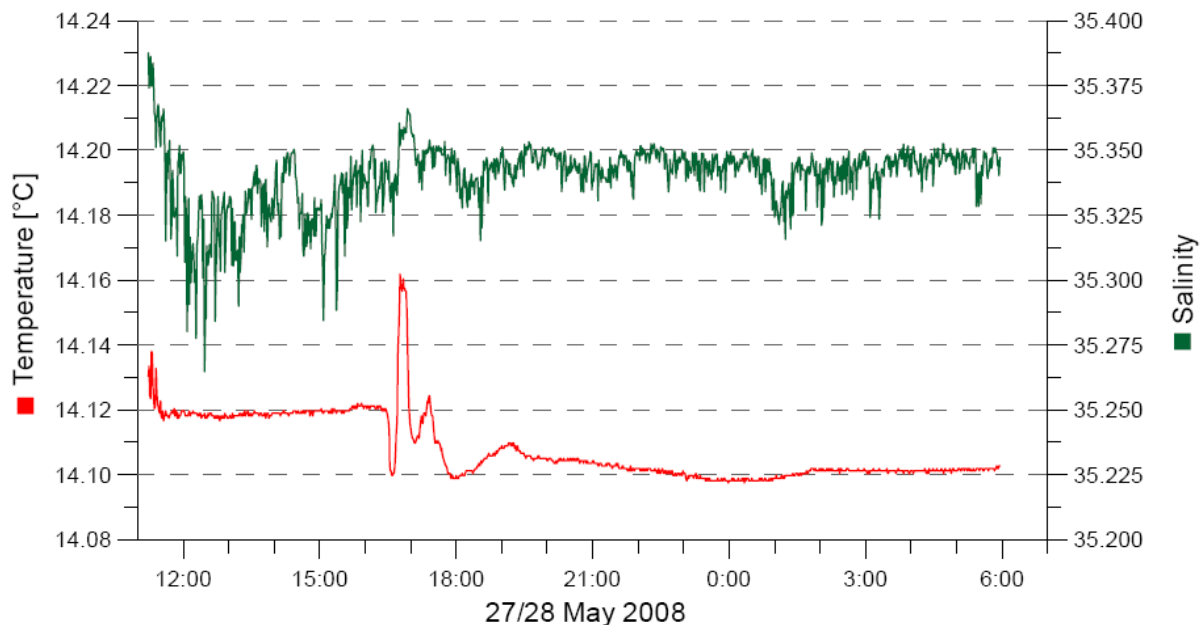


Fig. 2.16 Time series of temperature and salinity 20 cm above the bottom at CTD station 42.

2.5.2 **N₂-fixation Experiments** (U. Struck, F. Langenberg)

On eight selected stations, day-light incubations and one night-time incubation for nitrogen fixation rate estimates were performed following the method described in Montoya et al. ((Montoya et al., 1996)). We used surface water for the incubation and incubated it under daylight radiation conditions on deck.

The water samples were kept cool in a permanent flow of seawater pumped into the incubator. The samples were treated with 1 ml of 98 atom% pure ¹⁵N₂ per litre before the start of the experiment. 250 ml septum bottles were used for the experimental setup, into which sample water was filled without bubbles, ¹⁵N₂-gas was injected by using a gastight syringe. Incubation time was typically 8 hours during daytime and 12 hours during the night-time experiments. After the incubation the water was filtered on pre-combusted (4 hours at 450°C) Whatmann GFF glass fibre filters and dried in an drying oven at 40 ° over night. The nitrogen isotope measurements of the samples will be performed in the stable isotope laboratories at the Natural History Museum in Berlin and IfBM Hamburg.

2.5.3 **FerryBox** (T. Pieplow, K. Emeis)

To document the oceanographic and biogeochemical situation during the expedition METEOR 76-2, we used an on-line measuring system (FerryBox; 4H-JENA). This type of instrument is increasingly used for environmental monitoring on ships of opportunity and yields high-quality data in high temporal and spatial (on a moving vessel) resolution (e.g., Petersen et al., 2007). In our case, the instrument was fed with seawater from the ship's circular pump that draws water from 5 m water depth at the ship's bow. Our instrument was equipped with the following sensors and analysers:

- Flow-through-system: Temperature, conductivity, dissolved oxygen, pH, turbidity, chl-a fluorescence, yellow substance fluorescence,

- Analysers: automated analysis of phosphate, nitrate, nitrite, silicate, ammonium, after cross-flow filtration of seawater. The instruments were calibrated once per day with standards of known composition.
- external sensor: differential GPS output from the ship's system

In addition, an instrument to determine the $p\text{CO}_2$ of seawater (ProOceanus Systems, Inc.; PSI- CO_2 , with infrared detector, calibrated measuring range 0-600 ppmv, precision 0.01 ppmv; repeat rate 1 min) was linked with the data system of the FerryBox. Although this instrument has a built-in zero calibration, the calibrated measuring range was too low for the high $p\text{CO}_2$ concentrations in the upwelling waters off Namibia, and raw data from the IR detector that have been stored will have to be recalculated with a different calibration range after the cruise.

Operational remarks:

Water supply to the FerryBox turned out to be difficult initially, because the system has a high water demand (> 10 L/minute). A pump that had been constructed for deployment in the moonpool of the vessel and protruded out of the ship's hull was destroyed by an impact after one day. For a day after that loss we used a submerged pump in the moonpool, which also broke down after a few hours. Finally, we used the ship's pure seawater supply with good results in terms of pressure and flow-through; however, by the time it had reached the instrument, that water consistently was significantly warmer by a few degrees C than the ambient water temperature as recorded by the thermosalinograph. What the long path of the seawater through the ship did to bias other parameters is difficult to establish. Concentrations of nutrient elements will be checked on discrete samples in the home laboratory.

Preliminary Results

Figure 2.17 shows the track of the ship through the waters offshore Namibia in the time period from May 20 to June 3 (A). Stations and dates are indicated. Figures 2.17B and 2.17C depict salinity and temperature as measured by the ship's thermosalinograph that was synchronized to the FerryBox data system via GPS. Figures 2.17D and 2.17E show oxygen concentrations ($\mu\text{mol/L}$) and chlorophyll a fluorescence (arbitrary units). Note the high values of both parameters south of 22°S , where apparently a plankton bloom was recorded. In contrast, oxygen levels were low (below 200 ($\mu\text{mol/L}$)) in freshly upwelled and cold surface water N' of 18°S .

Tab. 2.2: Parameters and range of measurements of the FerryBox

Parameter	Instrument	principle	range	accuracy	resolution	time step
oxygen	Aanderaa Optode	optical	0-500 $\mu\text{mol/L}$	$<8 \mu\text{mol/L}$	$<1 \mu\text{mol/L}$	1 min
temperature	Aanderaa Optode	optical	$-7.5^\circ\text{C} - 41^\circ\text{C}$	$\pm 0.1^\circ\text{C}$	0.05°C	1 min
yellow substance	Turner Scufa II	optical	3 o.o.m.	n/a	n/a	1 min
turbidity	Turner Scufa II	optical	4 o.o.m.	n/a	n/a	1 min
chl a - fluorescence	Turner Scufa II	optical	4 o.o.m.	n/a	n/a	1 min
conductivity/ salinity	FSI Excell salino-meter	inductive	2 - 42 psu	0.030 psu	0.0001 psu	1 min
temperature	FSI Excell salino-meter	resistor	$-3^\circ\text{C} - 45^\circ\text{C}$	$\pm 0.01^\circ\text{C}$	0.0001°C	1 min
ammonium	Systea Micromac 1000	loop flow, optical (titration)	0- 1 mg-N/l	$5 \mu\text{g-N/l}$	10%	30 min
nitrite	Systea Micromac 1000	loop flow, optical (titration)	0-500 $\mu\text{g-N/l}$	$5 \mu\text{g/l}$	10%	30 min
silicate	Systea Micromac 1000	loop flow, optical (titration)	0-3 mg /l	$10 \mu\text{g/l}$	10%	30 min
o-phosphate	Systea Micromac 1000	loop flow, optical (titration)	0-600 $\mu\text{g-P/l}$	$10 \mu\text{g-P/l}$	10%	30 min
nitrate	Systea Micromac 1000	loop flow, optical (titration)	0- 1 mg-N/l	$10 \mu\text{g-N/l}$	10%	30 min

The spatial patterns of pCO_2 in surface waters are strictly antagonistic to concentrations of oxygen (see below) and were highest near the coast, and in particular in the freshly upwelled plume N' of 18°S (note that the concentrations exceeded the calibration range of the instrument). Phosphate and nitrate concentrations showed distinctly different patterns: Whereas both were high in the plume N' of 18°S , phosphate concentrations were high in the area around 2°S , while nitrate concentrations were depleted. This phenomenon has previously been noted (Tyrrell and Lucas, 2002) and was attributed to denitrification; it is most obvious in the frequently anoxic area around 22°S . Silicate levels were always high near the coast and coincided with colder water, and decreased rapidly as the water warmed and moved offshore.

Because the data set is so extensive, many variables are significantly correlated or anti-correlated to others. Most obvious is the strict ($r^2 = 0.81$) anti-correlation between oxygen levels and pCO_2 (Fig. 2.18). In the case of silica, the plot versus temperature shows the non-linear relationship expected from uptake of silicate by diatoms as the upwelling waters warm. Anomalous behaviour of nitrate is indicated by its low and non-linear ratio to phosphate, which may be either due to liberation of phosphate from anoxic seafloors (Bailey, 1991), or to massive denitrification (Tyrrell and Lucas, 2002), or to the extraction of its precursor, nitrite, by anaerobic ammonium oxidation (anammox) (Kuypers et al., 2005).

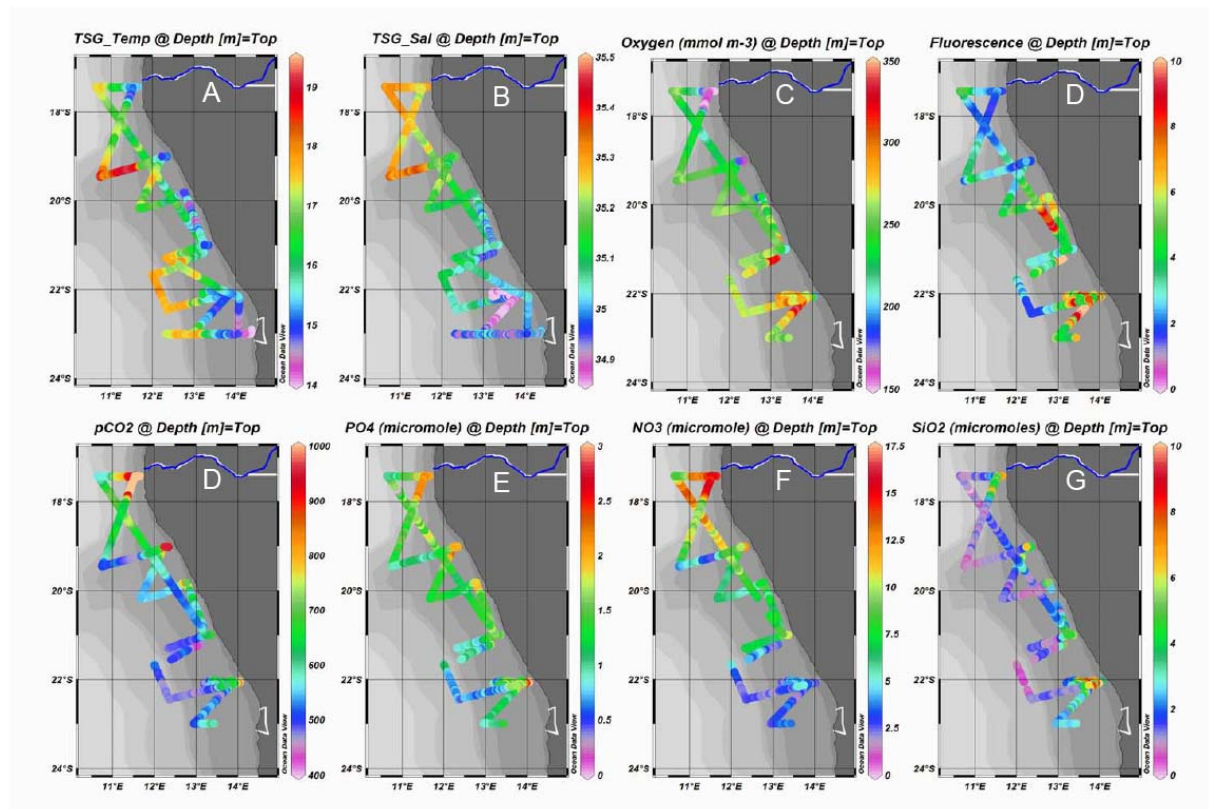


Fig. 2.17 Physical and chemical properties of surface waters offshore northern Namibia during expedition ME762 outline the proximity to and ageing of upwelling water along the coast. A) Temperature (°C) B) salinity, both from the thermosalinograph. C) Oxygen concentrations, D) Chlorophyll-a fluorescence, E) CO₂ partial pressure, F) o-phosphate concentrations, G) nitrate concentrations, H) silicate concentrations.

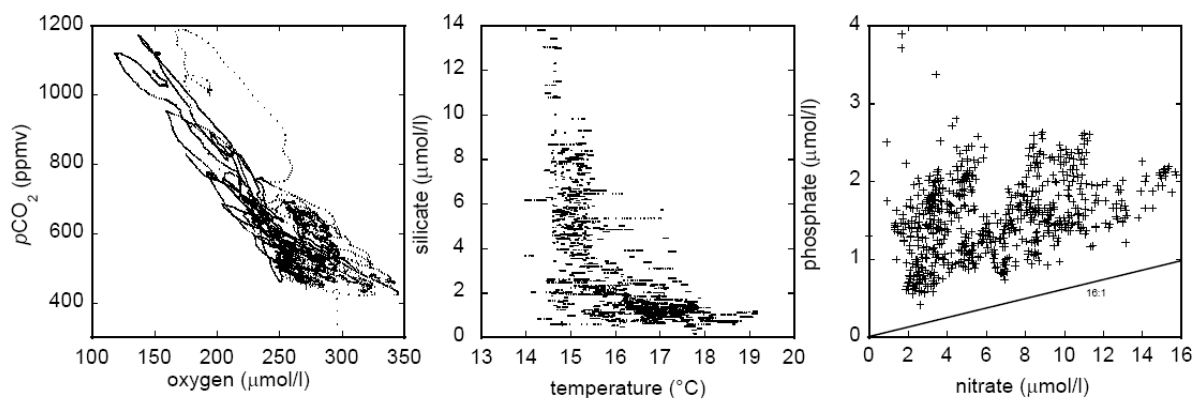


Fig. 2.18 Property-property plots of FerryBox data. A) As expected, $p\text{CO}_2$ is highly negatively correlated to the oxygen content of sea surface waters. B) Silicate decreases rapidly as temperature of freshly upwelled water warms and diatoms bloom in the plume. C) Nitrate loss (or phosphate gain) results in a pronounced nitrate deficit of the surface waters as compared to the Redfield ratio of 16:1 (molar).

2.5.4 Dissolved Oxygen Analyses

(P. Ellitson, R. Jones)

Samples for determination of dissolved oxygen concentration in seawater were collected from the CTD and pump CTD to enable calibration of the seabird sensor. The samples for dissolved oxygen were analyzed according to the IOW protocol for determination of oxygen (Department of Chemistry; G. Nausch). A total number of 196 samples were collected and

analyzed during the cruise. The seawater samples were collected as duplicates in 50 mL glass bottles and oxygen concentration values are reported in cm^3/dm^3 .

The linear regression between the between the CTD seabird sensor and the lowest dissolved oxygen concentration obtained by the Winkler titration method yielded a correlation of 0.986. The linear regression between lowest dissolved oxygen concentration values and the highest dissolved oxygen concentration values of each of the duplicates done with the Winkler method gives a very good correlation value of 0.999. Pump CTD water was sampled in duplicate to obtain calibration samples for the CTD seabird sensor. A strong correlation between the duplicate samples at each depth of 0.998 was found.

2.5.5 Sampling for Stable Isotopes of Nitrate

(A. Johannsen, C. Eickenrodt)

At all stations of the first transect and on all intensive stations where the CTD was deployed, water samples were taken for analysis of nitrate isotopes. The sampling was applied on four to five depths depending on the water depth of the corresponding station, including the surface water, the chlorophyll maximum and water from the beginning and the well-established oxygen minimum zone. The exact depths correspond to those sampled for $\delta^{15}\text{N}$ in suspended matter. At the intensive stations, water samples were taken in a high-resolution CTD profile every 10 to 30 m between 120 m water depth and the bottom. Additionally, water samples were taken with the BWS (Bodenwasserschöpfer), which samples bottom water at five different depths between 30 cm and 200 cm above the sediment surface. The intensive station included also the sampling with the Pump-CTD, from which we took samples at four to five different depths.

The samples were immediately filtered through precombusted GF/F filters and stored frozen. At the intensive stations, samples were also taken for $\delta^{15}\text{N-NH}_4$, these were filtered and mildly acidified before being frozen. At selected stations, samples were prepared for the analysis of $\delta^{15}\text{N-NO}_3^-$ and $\delta^{18}\text{O-NO}_3^-$ in DON (dissolved organic nitrogen). To do this, the filtered water samples were oxidized with Persulphate-Oxidation-Reagent in a microwave. Further analysis of the frozen samples will be done similarly to the samples for DIN (dissolved inorganic Nitrogen). All samples will be analyzed for nutrients (Nitrate, Nitrite, Ammonia) before being analyzed for $\delta^{15}\text{N-NO}_3^-$ and $\delta^{18}\text{O-NO}_3^-$ and $\delta^{15}\text{N-NH}_4$. The knowledge of the isotopic composition of Nitrate (including DIN and DON) should allow us to get a better insight of reactive Nitrogen processing in the Benguela upwelling system. So far, the nitrate isotopes in this area have not been examined at high resolution and to such a spatial extent in specific layers of the water column.

2.5.6 Filtration

(T. Köppen, F. Langenberg, G. Lavik)

In order to study the amounts and stable isotopic concentrations of suspended material in the water column, 182 samples at different water depths were taken with a CTD, pump-CTD and bottom water sampler (BWS) at 22 stations. The water samples were filtered using a filtration system consisting of five simultaneous filtration devices, two water pumps and a waste container (cap. 26 l). Suspended material was collected on pre-weighted and pre-combusted GF/F-filters ($\varnothing$ 47 mm) and dried in an oven at 40°C for at least two days. The total amount of

material in each sample can be estimated using the volume of water filtered and final weight of dried material. Further measurements are planned to be continued at the IfBM, University of Hamburg. For the analysis of coccolithophoridae 250 ml of seawater were filtered from surface and subsurface water level using Polycarbonate filters with a pore size of 0.4 μm . The filters of 47 mm diameter were frozen at -20°C . Large volume water filtrations for chlorophyll, stable isotopic analyses and metagenome library were carried out at stations #225, #231, #252. Samples were taken by McLANE WTS-LV Sampler (WTS 6-1-142LV) in-situ-pumps at four depth at each station. During each pumpcast water was filtered on a GF/F-filter ($\varnothing$ 150 mm) for 90 minutes with an average flow rate of 6 L/min. Samples were stored at -80°C .

2.5.7 Nitrogen Cycling in the Suboxic Water Column of the Benguela Upwelling System

(G. Lavik, M. M. Jensen, M. Holtappels, D. Franzke, V. Meyer, A. Ellrot, P. Lam)

In many oceanic regions, growth of phytoplankton is nitrogen limited because fixation of N_2 cannot make up for the removal of fixed inorganic nitrogen (NH_4^+ , NO_2^- , NO_3^-) by anaerobic microbial processes. Globally, 30-50% of the total nitrogen loss occurs in oxygen minimum zones (OMZs) in the world oceans and is commonly attributed to denitrification (reduction of nitrate to N_2 by heterotrophic bacteria). However, it has previously been shown that the anammox process (the anaerobic oxidation of ammonium by nitrite to yield N_2) rather than heterotrophic denitrification is mainly responsible for nitrogen loss in the OMZ waters of the Benguela upwelling system. With insignificant heterotrophic denitrification to N_2 and low sulphate reduction rates in the OMZ waters of the Benguela System, the remineralisation of organic matter in these waters is still an open question. Nitrate might still play an important role in organic matter remineralization by heterotrophic nitrate reduction to nitrite or dissimilatory nitrate reduction to ammonium (DNRA), supplying the required nitrate and ammonium to sustain the N-loss by anammox bacteria. Alternatively, the ammonium required to sustain the anammox activity in the suboxic water column might be supplied by diffusion from the underlying sediments as well as aerobic organic matter degradation, whereas the nitrite might be supplied by aerobic ammonium oxidation. The regulation of these aerobic and anaerobic processes as well as the relative importance of these processes under various conditions is poorly understood. Our main research objectives during this cruise included the identification and quantification of the microorganisms involved in the nitrogen cycling. In addition, we examined the relative importance of pelagic versus benthic processes in nitrogen cycling. We also investigate the dynamics of oxygen and nitrogen loss in the benthic boundary layer, which forms a link between the water column and sediments, but is so far poorly understood due to previous sampling challenges.

Methods and Preliminary Results

We used a combination of nutrient measurements, various $^{15}\text{N}/^{13}\text{C}/^{18}\text{O}$ -incubation experiments and DNA/RNA based techniques to investigate the processes responsible for nitrate/nitrite reduction, ammonium oxidation and oxygen consumption from the Benguela OMZ. In addition, we performed $^{15}\text{N}/^{18}\text{O}$ -incubation experiments and high precision O_2 -measurements to investigate the impact of molecular oxygen on anaerobic and aerobic processes in the Benguela OMZ waters. The pump-CTD system allows us to continuously

sample water for inorganic nitrogen compounds and gaseous compounds (N_2 , Ar , O_2 , CH_4) online by membrane inlet mass spectrometry at ~ 1 m resolution. The Pump-CTD was additionally equipped with microsensors for oxygen, pH and sulphide as well as a so-called STOX microsensor, which can detect oxygen concentrations down to 20-40 nM. The STOX microsensor was generously provided by Prof. Niels Peter Revsbech from Århus University. Preliminary results (Fig. 2.19) indicate that the uppermost part and the lower most part of the OMZ are characterized by regular incursions/mixing of oxygenated water whereas there was no detectable oxygen in the bottom waters at several stations.

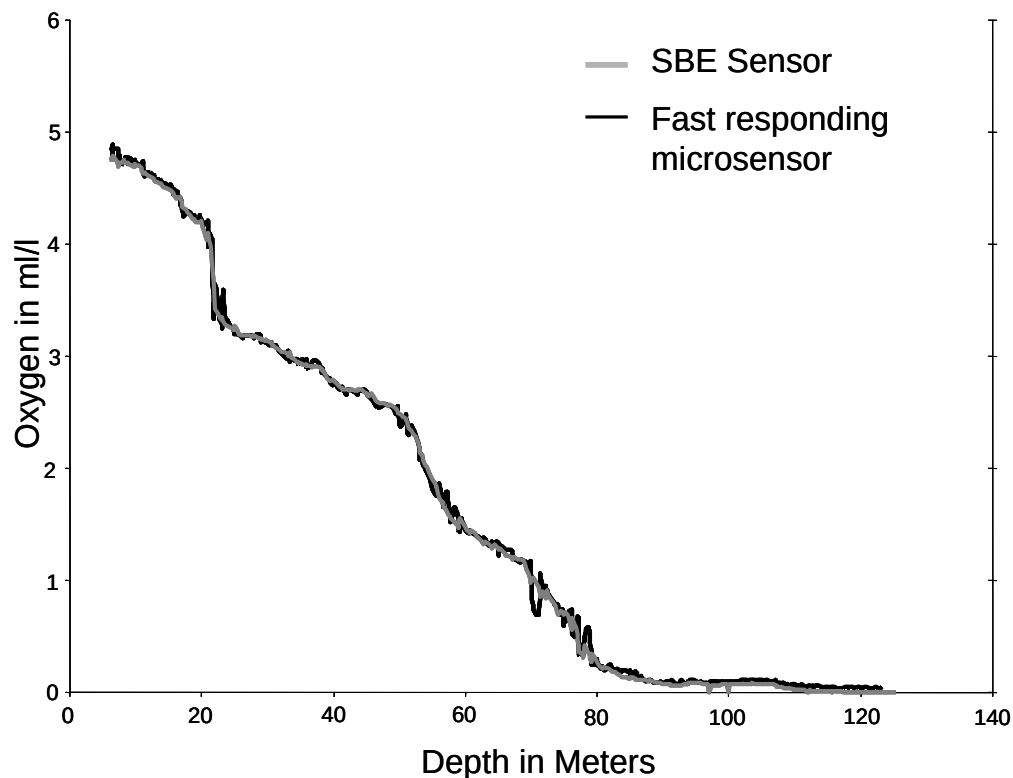


Fig. 2.19 Comparison between standard CTD oxygen sensor readings (SBE Sensor) and the STOX microsensor readings. The microsensor records significantly more fine detail in the oxygen concentrations.

Water samples were collected from 6 depths between 60 and 130 meter at six stations and incubated in 12 ml-Exetainers at *in situ* temperatures after the addition of ^{15}N -labeled substrates as well as ^{18}O -labelled oxygen. After 0, 6, 12, 24 and 48 h, Exetainers from experiments with ^{15}N -labeled substrates and $^{18}\text{O}_2$ were sampled by adding 100 μl saturated mercuric chloride. In the experiments with ^{15}N -labeled substrates, 2 ml from the Exetainers was replaced by helium. The samples were stored upside down to prevent gas leaking. The stable isotopic composition of the N_2 -gas as well as the $^{18}\text{O}_2$ and products of $^{18}\text{O}_2$ (i.e. NO_x , CO_2) will be analyzed by gas chromatography isotope ratio monitoring mass spectrometry at the Max Planck Institute for Marine Microbiology in Bremen (MPI Bremen). In addition to incubations with $^{18}\text{O}_2$, we used STOX sensors to investigate oxygen consumption at a defined depth at each station. The STOX sensors allow us to measure low oxygen respiration rates which cannot be detected by conventional oxygen sensors and the Winkler method.

To determine the total microbial abundance at each station where pumpcast-CTD was conducted, 1.7 ml samples were taken for flow cytometry at two-metre resolution. These samples were preserved with paraformaldehyde (1% final concentration) and stored at -80°C until further analyses at the MPI-Bremen. Meanwhile, at the same depths where incubation experiments were conducted, up to 250 ml of seawater was collected for 16S rRNA-targeted fluorescence *in situ* hybridization (FISH) to determine the abundance of specific groups of microbes involved in nitrogen cycling, such as aerobic nitrifiers and anammox bacteria. In addition, about 10 litres of water collected from each incubation depth were filtered through STERIVEX-filters (0.22 μm pore size) to obtain particulate organic matter for DNA and RNA extraction. These samples were stored at -80°C until further analysis at the MPI Bremen. After the extraction of the DNA and RNA, the abundance and expression, respectively, of functional genes encoding for the key enzymes of the nitrogen-cycle will be determined via (reverse-transcription-) quantitative polymerase chain reaction (qPCR). These functional gene analyses in combination with ^{15}N -incubation experiments could provide us with an unprecedented insight in the processes responsible for N-loss from the OMZ of the Benguela upwelling system.

Furthermore, in order to directly link the identities of microbes to cellular nitrogen fixation, anammox, nitrification, nitrogen assimilation and remineralization activities, we conducted incubation experiments with ^{15}N - and/or ^{13}C -labelled substrates to determine bulk reaction rates, while at the same time preserve samples for FISH-like analyses using the state-of-the-art nanoscale secondary ion mass spectrometry (nanoSIMS) at the MPI-Bremen. NanoSIMS analyses would enable us to simultaneously determine cellular activities and 16S rRNA identification on a single-cell basis. Using this novel technology, we would also determine the growth rates of marine anammox bacteria in the Benguelan OMZ.

Preliminary results show micromolar ammonium concentrations within or just below the chlorophyll maximum at all stations and in the bottom waters (1-4 μM). In the intermediate waters, the ammonium was generally submicromolar. High nitrite concentrations (1-5 μM) were found in the same zones as ammonium with the highest concentrations in bottomwaters with low oxygen concentrations (>5 μM).

2.5.8 Biogeochemistry of the Benthic Boundary Layer (BBL)

(G. Lavik, M. M. Jensen, M. Holtappels, D. Franzke, V. Meyer, A. Ellrot, P. Lam)

High exchange rates of nutrients and organic carbon between the sediment and the water column are expected in the Namibian upwelling system. The rates and transfer processes at this interface, the benthic boundary layer (BBL), remain poorly understood. Any solute that is exchanged between the sediment and the water column needs to be transported through the BBL by the means of turbulent diffusion. Concentration gradients measured within the BBL contain information about the flux across the sediment-water-interface. Besides the concentration gradients in the BBL little is known about turnover rates in the BBL itself. In the Namibian upwelling system the high particle and nutrient concentrations in this layer are a possible drive for enhanced mineralization rates.

The BBL was sampled with a Bottom Water Sampler (BWS) and a Benthic Boundary Layer Profiler (BBL-Profiler). The BWS is lowered to the seafloor. It consists of 6 horizontally aligned Niskin bottles to sample the bottom water over a depth range of 2 m

above sediment. The BBL-Profilier is an automatic sampling device that is deployed to the seafloor for several hours. It is equipped with an Acoustic Doppler Velocimeter (ADV), microsensors and optodes to measure current velocities and oxygen concentrations in the bottom water. A 12 channel peristaltic pump collects 70 ml samples of bottom water. The sample ports are distributed within 230 cm distance to the sediment.

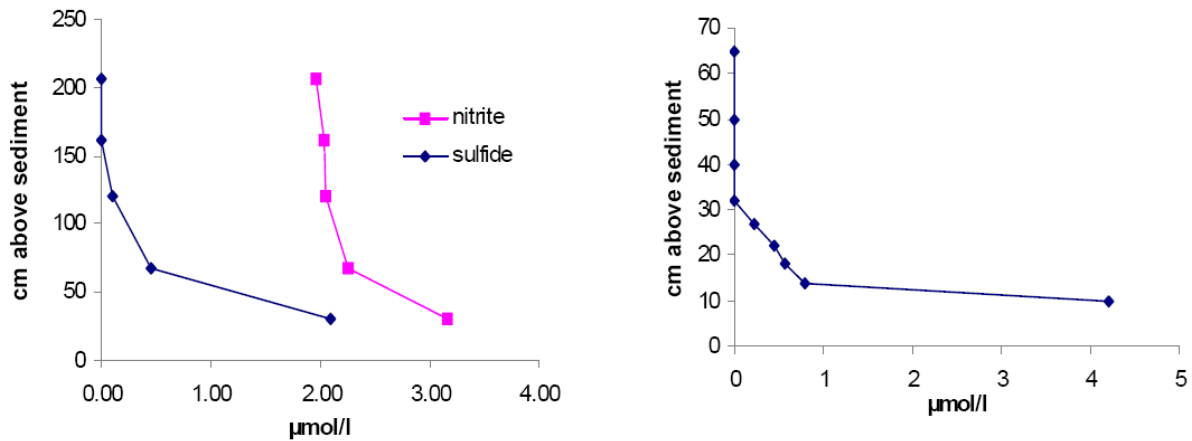


Fig. 2.20 Nitrite and sulfide concentrations above the sediment at station 206 (left) and sulfide concentrations above the sediment at station 230 (right).

The samples of the BWS were used for nutrient and gas analysis as well as for process studies whereas the samples of the BBL-Profilier are used for nutrient and gas analysis only. Oxygen consumption was measured on board with oxygen optodes and nitrogen turnover was traced with stable isotope experiments. Furthermore, water was filtered for molecular studies such as RNA and DNA analysis and Fluorescent In-Situ Hybridization (FISH). A total of 6 stations (206, 224, 230, 231, 243 and 252) between 90 and 150 m water depth were sampled.

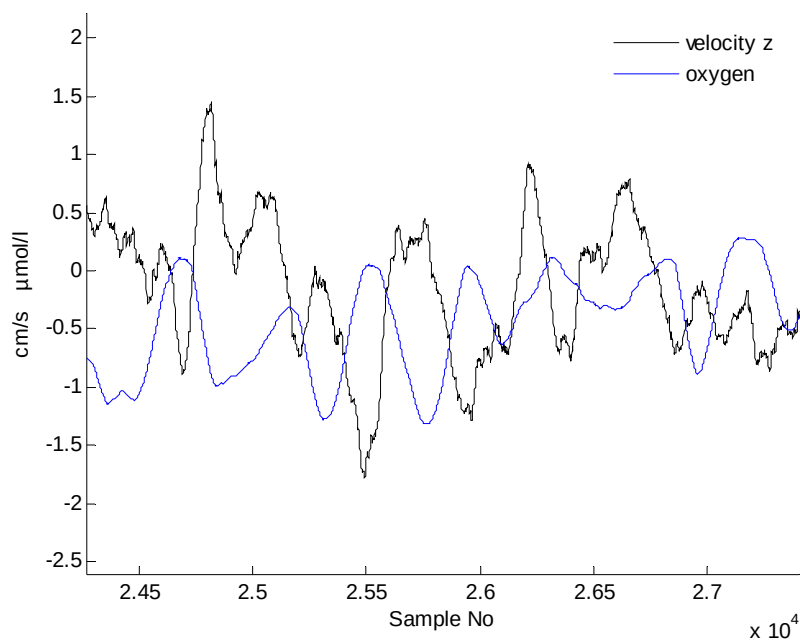


Fig. 2.21 Fluctuations of vertical current velocity and oxygen concentration at the seafloor (Station 231) over time (sample number in seconds)

In general, the BBL was well mixed and steep gradients of the on board measured nutrients were found only at station 206. Release of H_2S from the sediment was detected at stations 206 and 230 (Figs. 2.20). Further nutrient and gas samples need to be analyzed. The velocity measurements show that surface waves induce high current velocities in the BBL even at water depths of about 100 m. Oxygen measurements seem to correlate with wave frequency and indicate a possible vertical transport mechanism for solutes and resuspended matter. Rate measurements in the BBL were performed and the results will be compared with the rates in the upper water column.

2.5.9 Benthic Lander

(J. Fischer, A. Nordhausen)

High resolution profiles of chemical parameters like oxygen and sulfide concentration within the first few centimeters of the sediment contain information about the magnitude and spatial organization of benthic mineralization processes. Diffusive fluxes of sulfide from the sediment to the water column and of oxygen to the sediment can be calculated and zones of different activities can be identified. The incubation of sediment with some overlying water allows measuring the total diffusive flux directly. At the same time, uptake of nutrients, the release of DIC to the water, the change of N_2/Ar ratios as well as labeling and pulse-chase experiments can be performed. Doing these measurements in situ is the only choice to prevent coring artifacts due to mixing and changes in temperature and pressure.

Methods

A benthic lander equipped with two incubation chambers and a microelectrode profiler was deployed at 6 stations. Also designed as a free falling system with acoustic releases, we operated the lander attached to rope with a surface buoy at water depth below 150 m. This allowed for fast and reliable recovery at predetermined times. After the lander was placed on the sediment, a pre-programmed time of 2-3 h elapsed before the measurements started to allow eventually resuspended sediment to settle.

Incubation chambers

The square incubation chambers (20 cm · 20 cm) were lowered into the sediment and started recording oxygen concentration by two optodes in each chamber. Syringe samples (50 ml glass syringes) were taken every 1-2 h depending on total bottom time. At some deployments, ^{15}N labelled nitrate was injected into one of the chamber at the beginning of the incubation, while the other chamber remained unamended. After recovery of the lander, the syringe samples were processed immediately.

Microelectrode profiler

The microelectrode profiler was equipped with homemade electrodes for oxygen, H_2S , pH, conductivity and temperature. Profiles were recorded at 500 μm steps starting above the sediment. A resting time of 30 s at each depth ensured equilibration of the sensors. All data were stored in the lander and downloaded after recovery.

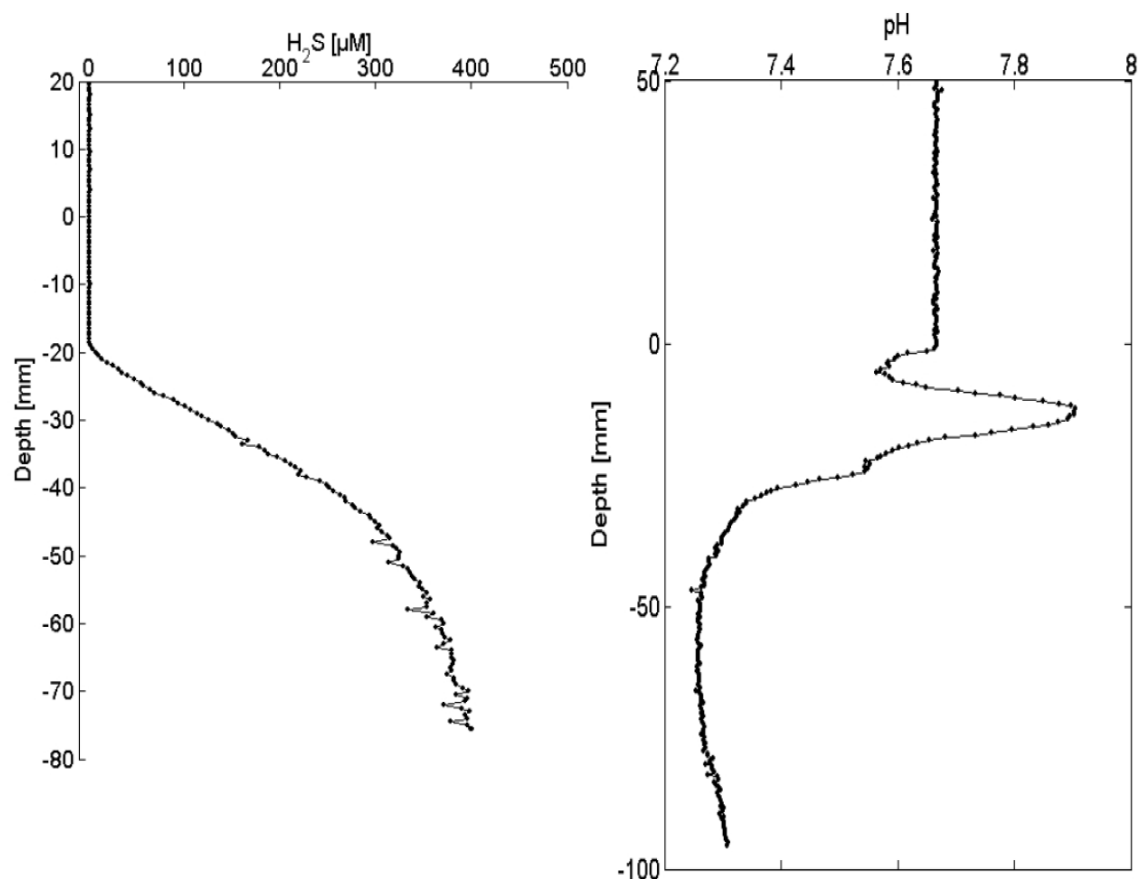
Preliminary results

Fig. 2.22 H_2S profile of Station 231. The z-value was calculated from the resistivity sensor which acted as surface detector (left). pH Profile of station 231 (right)

Microprofiles of H_2S , pH and sediment conductivity were successfully measured in high resolution at four different stations; oxygen was only present in one of the intense stations (number 231) within the bottom water and top sediment layer. The position of the sediment surface was determined by the conductivity sensor. However, since the other sensors were some centimetres apart, the actual surface may differ from sensor to sensor. The strong increase of sulfide concentration with depth is conspicuous. Fluxes of up to $1.3 \text{ mM/m}^2\text{d}$ were measured (Fig. 2.22). Most probably, the sediment surface was located at about -20 mm and there was a flux of sulfide into the bottom water.

The pH profile of station 231 showed a slight decrease in pH directly below the sediment surface, followed by a sharp increase to 7.9 and a decrease to 7.3 again (Fig. 2.22). The first peak could be explained by nitrate reduction, while the second one might have been caused by sulfide oxidation. Station 231 was the only station with oxygen in the bottom water (Fig. 2.22). A concentration of $2 \mu M$ was measured a few centimetres above the sediment surface. The oxygen penetration depth was only about 2 mm into the sediment. However, these low concentrations are close to the detection limit of the microelectrodes.

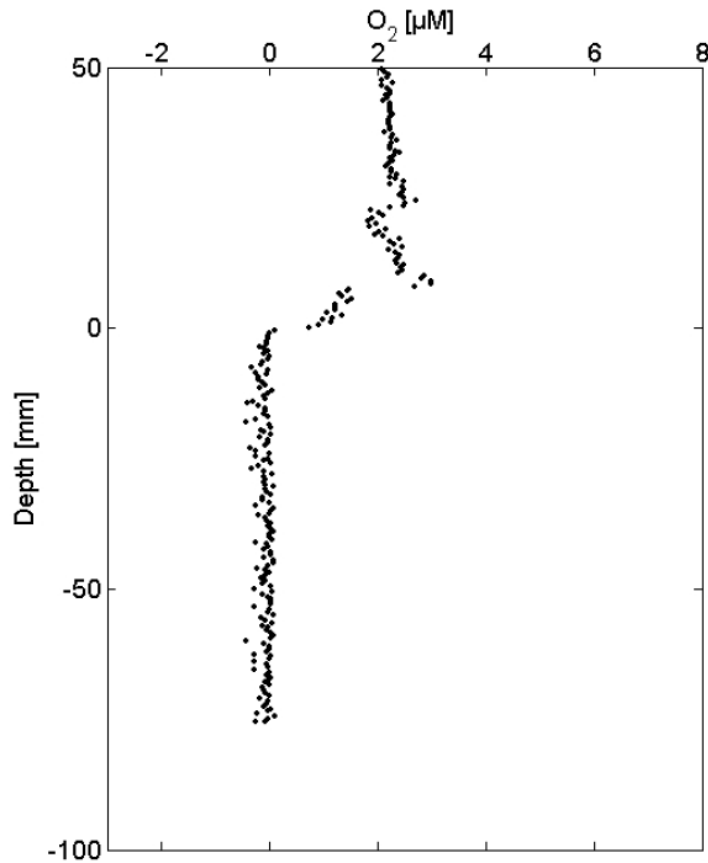


Fig. 2.23 Oxygen profile of station 231

Interestingly, the temperature within the sediment increased with depth. This was observed at all stations, where sediment profiles were measured. The effect was most pronounced at our last station (252; Fig. 2.23). Here, the temperature gradient was up to 0.6 K/m, leading to a heat flux of $\sim 0.3 \text{ W/m}^2$. Possible explanations for the elevated temperature would be either a recent change in bottom water, or the high microbial activity in the sediment.

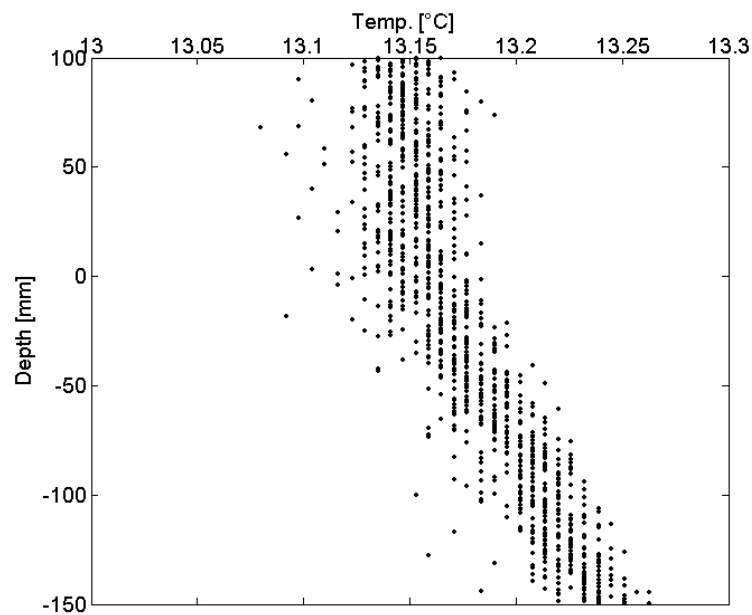


Fig. 2.24 Temperature profile of station 252

Tab. 2.3: Lander deployments on M76-2

Station Number	Deployment	Recovery	Parameters measured	Comments
206	19.05.2008, 01:35	20.05.08, 16:00	Microprofiles: O ₂ , H ₂ S, pH, conductivity Chamber: Syringe samples for Nutrients, DIC, O ₂	Release of weights failed, recovered by surface buoy. Profiles and chambers did not reach the sediment surface.
225	24.05.08, 14:23	25.05.08, 09:08	Microprofiles: O ₂ , H ₂ S, pH, conductivity Chamber: Syringe samples for Nutrients, DIC, O ₂	Sensors and chamber too deep in the sediment
230	26.05.08, 12:29	27.05.08, 06:42	Microprofiles: O ₂ , H ₂ S, pH, conductivity, temperature Chamber: Syringe samples for Nutrients, DIC, O ₂ ; Injection of ¹⁵ NO ₃ in chamber #1	good profiles, injection did not work
231	27.05.08, 18:43	28.05.08, 07:44	Microprofiles: O ₂ , H ₂ S, pH, conductivity, temperature Chamber: Syringe samples for Nutrients, DIC, O ₂ ; Injection of ¹⁵ NO ₃ in chamber #1	good profiles, injection did not work
243	30.05.08, 06:08	31.05.08, 10:53	Microprofiles: O ₂ , H ₂ S, pH Chamber: Syringe samples for Nutrients, DIC, O ₂ ; Injection of ¹⁵ NO ₃ in chamber #1	surface buoys got ripped off during approach of the vessel. recovered the lander by dragging lines over ground; good profiles, goby in chamber #1
252	01.06.08, 12:42	02.06.08, 09:14	Microprofiles: O ₂ , H ₂ S, pH, conductivity, temperature Chamber: Syringe samples for Nutrients, DIC, O ₂ ; Injection of ¹⁵ NO ₃ in chamber #1	good profiles, goby in chamber #1

2.5.10 Pore Water and Sediments

(U. Struck, P. Berger, M. Tsuchiya, P. Ellitson, R. Jones, V. Brüchert, B. Nagel)

The organic-rich sediments of the Namibian mud belt have been the focus of diverse studies over the past 10 years to better understand the biogeochemical and microbiological processes that regulate the carbon, nitrogen, and sulfur chemistry in this high productivity system. Publications include studies on the regulation of organic matter degradation rates (e.g., Brüchert et al., 2003; van der Plas et al., 2007), sulfur and methane cycling (Brüchert et al., 2003; Emeis et al., 2004), and the role of the large sulfur bacteria and their influence on the hydrogen sulfide flux from the sediment to the water column (Schulz et al., 1999; Brüchert et al., 2003). Sedimentary records of the stable carbon and nitrogen isotopes have been used to infer past variations in the intensity of denitrification and nitrogen loss from the shelf environment (Emeis et al., 2007). Fundamentally, the pore water chemistry of Namibian shelf sediments is characterized by the high rates of bacterial degradation of deposited organic matter. These rates result in steep pore water gradients of dissolved inorganic carbon, ammonium, hydrogen sulfide, and dissolved sulfate and reflect the large amount of fresh organic matter oxidized through bacterial sulfate reduction and later methanogenesis.

Recently, new hypotheses have been proposed for the regulation of the phosphorus cycle by the large sulfur bacteria (Schulz and Schulz, 2005), and the role of anammox for the N₂ loss from the upwelling system (Kuypers et al., 2005). These processes operate in the bottom

water and the near surface sediment, and may be responsible for the very low N/P ratios observed in the shelf bottom waters overlying the sediments (Kuypers et al., 2005). Stable nitrogen isotope results (Emeis et al., 2007) also suggest significant dinitrogen loss from the shelf environment. Together these findings provided the motivation to address nutrient transformation processes of nitrogen and phosphorus in the near-surface sediments and their impact for the overlying water column nutrient chemistry.

Pore waters and sediments were collected for chemical and stable isotopic analysis, enriched ^{15}N -nitrate experiments and for direct radiotracer experiments with ^{35}S -sulfate and ^{33}P -phosphate to further clarify the above findings and to quantify the role of individual bacterial processes.

Pore water sampling

Pore waters were collected with rhizones (Seeberg-Elverfehldt et al., 2005) from large 11 cm multicores tubes. Pore waters were extracted through ports drilled into the core in 1 cm intervals. Two sets of holes were drilled into the core at a right angle. In order to maximize the distance between two rhizones, pore waters were extracted for adjacent depths alternately from these two rows of holes so that the vertical distance between two rhizones on one line of the core was 2 cm. Pore waters were collected in 1 cm-intervals to a depth of 10 cm and in 2 cm intervals from 10 cm depth to the bottom of the core. The pore waters were collected in 10 ml plastic syringes and dispensed into vials for the chemical analyses listed in Table 2.4. Due to time constraints, pore waters were not analyzed on board. Analysis will be completed at the respective home laboratories. Gas voids were observed in the sediments at station 231 below 12 cm suggesting steep sulfate gradient and free gas just below the sediment surface.

Solid-phase sediment sampling

Additional sediment cores were collected to determine water content and for solid-phase chemical analysis (see Tab. 2.5). At selected stations, cores were sub-sampled to determine ^{210}Pb activities to calculate mass accumulation rates/sediment mixing coefficients, respectively.

Sediments collected within the mud belt are largely olive green diatom muds. At station 207 and station 243 tan-coloured concretions and tan-coloured bands were observed between 12 cm and 38 cm sediment depth. These were suspected to be phosphorite concretions. Chemical analysis in the home laboratories (IfBM) will further clarify the identity of these concretions. In the core at station 243, multiple tan-coloured layers alternated with the dark olive-green diatom mud. In addition, the top 10 cm of sediments contained abundant sulfur bacteria, which were identified as *Thiomargarita* and *Beggiatoa*. Qualitative inspection under the binocular microscope indicated that *Thiomargarita* dominated the sediments at 23 and 21 degrees S, whereas *Beggiatoa* dominated the surface at 20°S and 19°S. As expected, sediments below 5-10 cm depth smelled strongly of hydrogen sulphide. In comparison with earlier cruises (M 48/2 and M 57/3) the abundance of the large sulfur bacteria was conspicuously lower. Sediments at the shelf edge and on the continental slope were sandy and contained abundant planktonic and benthic foraminifera.

Tab. 2.4: Pore water sample subsets for chemical analysis

Porewater species	SO ₄ ²⁻ /HS ⁻	PO ₄ ³⁻ , NO ₃ ⁻ , NO ₂ ⁻ , SiO ₄ ⁴⁻	DIC; NH ₄ ⁺	Fe ²⁺ , Mn ²⁺	δ ¹⁵ N of NH ₄ ⁺	Ca ²⁺	CH ₄	Max. sediment depth (cm)
Volume (ml)	1.5	1.5	1.8	1.5	5-15	1	3	
Storage location	MPI	MPI	MPI	MPI	IfBM	MPI	MPI	
Station								
205					X			10
206	X	X	X	X	X			27
207		X			X			13
214								
215								
216								
219	X	X	X	X	X			29
222					X			10
225	X	X	X	X	X			23
230	X	X	X	X	X			33
231	X	X	X	X	X	X	X	44
243	X	X	X	X	X	X		48

MPI: Max-Planck Inst. for Mar. Microbiology, Bremen; IfBM: Inst. for Biogeochem. and Mar. Chem., Univ. Hamburg, SU: Dept. of Geochem., Stockholm University

Tab. 2.5: Summary table for sediment sampling

Station	Core length (cm)	Water content/Porosity	Pb-210	Bulk CNS analysis, amino acids	Sulfur, iron, manganese, phosphorus δ ³⁴ S	δ ¹³ C, δ ¹⁵ N	Suspected phosphorite concretions
Storage location		MPI/IfBM	MPI/IfBM	IfBM	MPI/SU	IfBM	IfBM, MPI/SU
202	35	X		X		X	
205	40	X		X		X	
206	40	X	X	X		X	
207	22	X		X		X	X
209	12	X		X		X	
210	1	X		X		X	
214	10	X		X		X	
216	11	X		X		X	
217	1	X		X		X	
218	1	X		X		X	
219	20	X		X		X	
221	19	X		X		X	
224	10	X		X		X	
225	19	X		X		X	
227	Surface	X		X		X	
228	Surface	X		X		X	
229	Surface	X		X		X	
230	40	X		X		X	
231	44	X	X	X	X	X	
239	10	X		X		X	
240	Surface	X		X		X	
241	Surface	X		X		X	
242	Surface	X		X		X	
243	40	X	X	X	X	X	X

Experiments

Three sets of experiments were conducted with intact surface sediment. Tab. 2.6 lists the stations at which experiments with sediments were conducted.

Tab. 2.6: Station list of sediment experiments

Station	³⁵ S- Sulfate reduction rates	¹⁵ N-whole core incubations	³³ P-uptake experiments
Processing and storage location	MPI Bremen	MPI Bremen	MPI Bremen
206	X	X	X
225	X	X	X
231	X	X	X
243	X	X	X

³⁵S-Sulfate reduction rates

Intact sediment was sub-sampled with 26 mm inner diameter tubes with silicone-sealed ports in 1 cm intervals. Core lengths varied between 25 and 35 cm. Cores were stored closed at 13°C in an incubator before injection. Between 30 MBq and 50 MBq of carrier-free ³⁵S-sulfate was injected through each port and the sediment was incubated between 4 and 12 hours, and then sectioned in 1 cm intervals and preserved with 20 ml 20% zinc acetate and stored frozen. Further processing of the sediment for the calculation of sulfate reduction rates will take place in the laboratory at the MPI Bremen.

¹⁵N whole core incubations

15 plastic tubes (36 mm inner diameter) were inserted in large multicore tubes. The supernatant was removed and replaced with ¹⁵NO₃⁻-amended bottom water from the lowermost CTD rosette bottle or water overlying sediment when available. Cores were pre-incubated for 12 hours before the time series for measurement of ¹⁵N₂ and ¹⁵N-ammonium accumulation started. After 2, 4, 6, and 10 hours, 3 vials containing 5 ml of slurry from different 3 cores were fixed with 2 ml 20% zinc acetate and 200 µl of a saturated HgCl₂ solution to stop bacterial activity and to fix excess hydrogen sulfide. Samples were stored without headspace in 5 ml-Exetainers. Nutrient samples were removed at the respective time points over the course of the experiment. Isotope analysis of the samples from the individual samples will take place at the MPI Bremen.

³³P-phosphate uptake experiments

Two sets of ³³P-phosphate uptake experiments were conducted – (A) an intact anoxic core incubation and (b) an oxic and anoxic incubation in Exetainers. For experiment (A) ³³P-labeled phosphate (50 kBq) was injected to intact cores every cm to 20 cm depth. 4 cores were injected. One core each was sectioned after 12, 24, 36, and 48 hours. From each section, one sample was fixed with 4% formaldehyde to a final concentration of 2% and stored cold. The second sample (2 ml) was fixed with 2 ml 20% zinc acetate and frozen to rupture cells.

In the oxic experiment, two 36 mm sub-cores were sectioned to 8 cm depth. Each sample (2 ml) was mixed with an equal amount of ¹⁵N-nitrate and ³³PO₄³⁻ and ¹⁵NO₃⁻-amended

bottom water from the lowermost CTD rosette bottle or from water overlying the multicores when available. The mixture was regularly bubbled and stirred with a pipette. A control was immediately fixed with 1 ml 2% formaldehyde and stored cold. The remaining 3 sets of samples (8 samples per set) were fixed after 12, 24, 36, and 48 hours. For station 225, 231, and 243, the incubation was run for 48 hours, and one time point was taken at the end of the experiment. 1 ml of sample was fixed with formaldehyde (final concentration 2%) to pick bacteria and the other 2 ml were fixed with zinc acetate (2 ml) and frozen to stop bacterial activity. Further processing, bacterial counting and intracellular phosphate uptake will be completed at the MPI Bremen.

2.5.11 Benthic Foraminifera

(M. Tsuchiya)

Many benthic foraminifers can persist in sediment in dysoxic environments. Some of them probably live in symbiosis with bacteria that can denitrify and also putatively oxidize sulfide. A benthic foraminifer *Virgulinella fragilis* is apparently restricted to dysoxic environments in both modern and fossil records. In modern oceanic environments, *V. fragilis* mainly arise in dysoxic conditions related to coastal upwelling, to the oxygen-minimum zone, or during strong stratification of the water column. These examples clearly show that fossil and modern *Virgulinella* provide a good proxy for oxygen-depleted environments. Altenbach and Ertan (2003) reported *V. fragilis* and also other benthic foraminifers from Walvis Bay area. Some of them have been analysed for molecular phylogenetic analyses (Ertan et al. 2004). They reported a phylogenetic position of *V. fragilis* based on only small subunit (SSU) of ribosomal DNA (rDNA) sequences.

Virgulinella fragilis can survive in oxygen-depleted environments, but it depends on the multiple symbioses of bacteria and kleptoplast in such environments (Bernhard, 2003). According to this study, endosymbiotic bacteria were identified as sulfide oxidizers and the morphology of the kleptoplast suggested diatom origins. Bernhard (2007) suggests that the endobionts consume the respiratory inhibitor hydrogen sulfide without using all available oxygen, therefore allowing oxidative phosphorylation to proceed in mitochondria. For these reasons, the coexisting *Beggiatoa* bacterial mats in the sediment, and endobionts of sulfide-oxidizing bacteria, probably aid in the suppression of sulfide concentrations in pore waters surrounding *V. fragilis*. However, the origins of both endobionts and kleptoplast are still unknown.

Our previous observations of scanning electron microscope (SEM) analyses and molecular analyses revealed that oxygen (and also hydrogen sulfide) concentration affected to the foraminiferal shell structures, especially in shape and densities of pores, although they have same SSU rDNA sequences (Tsuchiya et al. submitted). This is a case of adaptation in low-oxygen environments (Moodley and Hess, 1992).

Materials and methods

We used multiple corer to collect undisturbed sediment cores (diameter=99mm). Prior to process sediments, sedimentological observation including sediment facies and color were described and photographed. Multiple cores will use for three different observations. Sampling methods for each observation are as follows:

For faunal analyses both for benthic (living and dead) and planktonic (dead specimens), 2 multicores were collected. Three tip-cut 50ml syringes were inserted into sediment and sliced 0.5 cm interval down to 3 cm sediment depth, and sliced 1.0cm interval below 3cm sediment depth. Sediments were fixed with 10% neutralized seawater formalin or ethanol.

A total of 21 multicores were sampled for genetic analyses, stable isotopes, TEM observation and soft-X observation. The sediment from 5 stations was used to collect living foraminifers. Other sediments were fixed with ethanol to pick out dead specimens of foraminifers both analyses for stable isotope (O, and C), and trace element (Mg/Ca, and Sr/Ca). Prior to collect living benthic foraminifers, a plastic box (1 cm · 45 cm · 25 cm) was inserted into the sediment, and retrieved sediment sample for soft-x observation. Overlying bottom water was replaced with gelatin to avoid for drying that contains 4% formalin in final concentration. Three tip-cut 2.5 ml syringes were inserted into the surface sediment for environmental DNA (envDNA) analyses. 6 multicores were collected for analysis of nitrogen isotope ratios in chlorophylls/pheopigments. For this, sediments were sliced (scooped) every 5cm and put the sediments in baked-glass bottle. Each glass bottle is stored in -20°C.

Preliminary Results and Future work

26 multiple cores were collected during the expedition. The sediment from 5 stations was used to collect living foraminifers. 30 specimens of *V. fragilis* (from station 224) were picked out under binocular microscope; 15 out of these 30 specimens will be used for molecular phylogenetic analyses for host foraminifer, and both endobionts of bacteria and kleptoplast. Another 15 specimens will be used for TEM observation. Specimens were dried on the slide and stored in -20°C for molecular analyses. For TEM observation of benthic foraminifers, collected foraminiferal specimens were fixed with appropriate fixation method, such as EtOH or formalin/glutaraldehyde.

Living specimens of *V. fragilis* were also found from well-oxygenated stn. 219 (a single individual specimen), only few specimens existed other than at stn. 224. Dead specimens of *V. fragilis* could be found from several stations, e.g. stations 224, 225, and 231.

4 soft-x samples and 12 environmental DNA samples were collected. Onshore analyses are planned for soft-x samples that observed to understand foraminiferal microhabitat and sedimentation process. Environmental DNA samples were taken from 2 layers (0-1 cm, 1-2 cm) and retrieve 3 aliquots per core (retrieved from 2 stations), and then the samples were stored in -20°C that used for clone analyses of bacterial/microalgal assemblages to understand origin of endobionts within foraminiferal cell.

2.5.12 Sampling for Investigations on Meiofauna (P. Ellitson)

Sediment samples were collected by means of the multicorer to investigate the macrofauna (organisms seen with naked eye) and meiofaunal (microscopic organisms) species composition and to determine large sulphur bacterial biomass. Additional samples were collected from bacterial-rich sediment for Dr. H. Schultz (MPI) who intends to culture *Thiomargarita namibiensis*. The sediment samples intended for meiofauna analyses were collected for Bronwen Currie for identification of macrofauna and meiofauna species *and their distribution* patterns of with specific interest in the samples from the diatomous mud belt

area at 21° S to 22°S. Surface water was drained from the core and collected in a container. The surface was examined for organisms and then the first 10 cm of the cores (diameter=99 mm) were sectioned. Large organisms (e.g. large polychaetes, and mollusks) were removed and separately preserved in buffered formalin. Each of the sections was sieved through 1000 µm, 53 µm and 25 µm aperture sieves and the resulting fractions were preserved with buffered formalin. Subcores were taken from the cores for bacterial counts, and sectioned into centimeter sections from surface to 10cm depth for bacterial biomass estimation. Samples were preserved with 2% gluteraldehyde. *Thiomargarita namibiensis* sampling was done by removing the overlying core water until 5 cm of water is left, then mixing the surface of the core (the fluffy sediment) and dispensing the mixture into a sample flask. Samples were stored fresh at 4°C.

2.6 Ship's Meteorological Station (T. Truscheit)

On May 17th 2008 R/V METEOR left the port of Walvis Bay/Namibia for the cruise 76/2. The synoptic situation looked as follows in these days.

A stationary thermal low 1015 hPa over Namibia was analysed by the South African Weather Service. On its westerly flank humid air mass came from the south especially to the coastal waters of Namibia. This circumstance was responsible for fog in the morning time as well as in the days before. But to the opposite of the previous days the fog disbanded rapidly on the day of departure. The emphasis 1016 hPa of the subtropical high pressure zone was located in front of the south coast of South Africa. It was moving south eastward and increasing. At the reverse side weakened cold frontal system of an extensive low south of 50°S was approaching. Immediately from departure the wind conditions have been variable but increasing to Beaufort 3 to 4 during this day. Some miles offshore a swell of 3 to 4 meters from south west could be expected caused by the above mentioned low. In time the high pressure system south east of the continent was increasing to 1030 hPa while a new South Atlantic subtropical high west of Namibia was approaching. In between a channel of low pressure developed caused by charging but decreased temporarily. For the moment the southerly winds increased to 5 Beaufort as well as the swell reached still 3 to 4 meters from south west. Especially on May 19th and 20th several thermal lows along the coast of Namibia have been responsible for fog with visibilities < 200 meters. During May 20th the wind direction turned to south and increased to Beaufort 6 while the above mentioned frontal system touched the working area of R/V METEOR while moving south eastward rapidly. Following the subtropical high was approaching. In connection with a low south of Cape Town it was responsible for increasing of gradient of air pressure temporarily over the South African coast line. The wind increased to Beaufort 6 to 7, even Beaufort 8 in the night from May 23rd to 24th while further approaching of the subtropical high. Therefore the working area was located in between the subtropical high pressure system west of it and a trough 1012 hPa which was analysed to the south part of Angola. Especially on May 22nd and 23rd the sea including its part of swell from south west reached up to 5 meters. The trough was decreasing faster than expected and consequently the wind decreased as well to Beaufort 4 to 5 on May 24th. Likewise the swell decreased to 3 meters on this day. Even on the following day these conditions were stable. Already on May 26th a new powerful low 990 hPa was approaching

moving eastward and decreasing meanwhile but just indirect it had an effect to the working area. Cause of this low the usual subtropical high west of Namibia decreased or rather forced to the northwest. Contemporaneous low pressure on a position 25°S 20°E was analysed so that the gradient of air pressure over the coast line of South Africa and Namibia persisted weaken. The wind from south- southeast reached Beaufort 4 in its maximum, temporarily just variable very close to the coast line. Wind conditions as well as the swell conditions were stable until May 29th. On this day finally a low has been analysed on a position 40°S 12°E which was moving eastward while decreasing. A trough of this low pressure system extended northwest to 35°S 10°E but was decreasing as well while swivelling eastward. Consequently high pressure could recuperate along the Southwest African coast line. This fact was responsible for increasing of wind force at the coast line. The process of increasing was forced additional by the subtropical high 1035 hPa on a position 45°S 10°W which was moving eastward slowly. The south easterly wind increased to 5 Beaufort and reached even 6 Beaufort in the evening of May 31st. But altogether the wind force didn't reach the predicted values. The sea with its part of swell from southwest reached up to 3 meters temporary but decreased rapid. As well as for the days before the wind force should increase to Beaufort 5 but against to the forecast the real conditions have been much more moderate. Especially in the morning time of June 1st the wind conditions have been calm as well as the sea just reached 1.5 meters. On June 2nd the emphasis of high pressure was located on a position 48°S 25°E finally and should be stationary for a short time. A ridge of this high pressure system extended to a position approximately 33°S 0°E and was stationary as well but decreasing slowly. Therefore until the arrival in the port of Walvis Bay/Namibia conditions of up to Beaufort 5 could be expected.

2.7 Station List M76/2

Station#	date (m/d/y)	time start	latitude S	longitude E	water depth [m]	CTD	MUC	MSS	ADCP	MER	Lander	PCTD/ RO	BWS	ISP	Mor
ME762/190	17.05.08	11:07	22° 52.67'	14° 24.57'	48	1									
ME762/191	17.05.08	11:51	22° 54.62'	14° 23.38'	60	1	2								
ME762/192	17.05.08	13:39	23° 0.02'	14° 22.06'	37	1									
ME762/193	17.05.08	14:24	23° 0.03'	14° 18.99'	67	1									
ME762/194	17.05.08	15:39	22° 59.95'	14° 12.95'	101	1									
ME762/195	17.05.08	17:18	23° 0.00'	14° 2.93'	128	1	1	1							
ME762/196	17.05.08	20:07	22° 59.99'	13° 51.94'	140	1									
ME762/197	17.05.08	21:47	22° 59.98'	13° 40.95'	142	1									
ME762/198	17.05.08	23:22	23° 0.00'	13° 29.93'	227	1									
ME762/199	18.05.08	01:52	22° 59.98'	13° 8.95'	304	1									
ME762/200	18.05.08	03:40	22° 59.91'	12° 56.98'	9	1									
ME762/201	18.05.08	07:55	22° 59.99'	12° 19.99'	2017	1									
ME762/202	18.05.08	14:18	23° 0.01'	13° 8.91'	313	1									
ME762/203	18.05.08	17:36	22° 59.94'	13° 29.91'	234		1								
ME762/204	18.05.08	19:53	23° 0.00'	13° 41.00'	147	1									
ME762/205	18.05.08	22:00	23° 0.03'	13° 51.96'	145		1								
ME762/206	19.05.08	00:20	22° 59.87'	14° 3.12'	131	1	1	4	1	1	1	1	2		
ME762/207	20.05.08	06:57	22° 10.00'	14° 5.00'	64	1	4								
ME762/208	20.05.08	19:44	21° 17.96'	12° 20.04'	792	1									
ME762/209	20.05.08	23:05	21° 11.68'	12° 40.19'	365	1	1								
ME762/210	21.05.08	02:27	21° 6.84'	12° 55.36'	273	2									
ME762/211	21.05.08	04:56	21° 2.66'	13° 6.50'	129	1	1								
ME762/212	21.05.08	06:41	21° 0.46'	13° 15.16'	121	1									
ME762/213	21.05.08	08:09	20° 59.94'	13° 21.97'	100	1	2								
ME762/214	21.05.08	10:00	21° 0.47'	13° 15.19'	122	3	1								
ME762/215	22.05.08	11:38	17° 24.93'	10° 38.99'	3248	2									
ME762/216	22.05.08	18:20	17° 25.24'	11° 1.86'	1509	2	1								
ME762/217	22.05.08	23:56	17° 25.58'	11° 22.03'	302	1	1								
ME762/218	23.05.08	02:24	17° 25.30'	11° 32.09'	150	2	1								
ME762/219	23.05.08	03:46	17° 25.17'	11° 39.15'	93	1	1								
ME762/220	23.05.08	21:53	19° 27.46'	10° 44.88'	1183	1									
ME762/221	24.05.08	05:02	19° 13.36'	11° 41.32'	339	1	1								
ME762/222	24.05.08	08:14	19° 7.34'	12° 0.68'	236	1	1								
ME762/223	24.05.08	10:49	19° 1.01'	12° 13.75'	119	1									
ME762/224	24.05.08	11:59	19° 0.96'	12° 20.61'	97	1	1								
ME762/225	24.05.08	14:02	19° 1.0'	12° 13.74'	119	1	3	4	1	1	1	1	2	2	
ME762/226	25.05.08	22:34	20° 10.96'	11° 40.03'	739	1	1								
ME762/227	26.05.08	02:37	20° 6.00'	12° 6.47'	307	1	1								
ME762/228	26.05.08	05:58	19° 59.09'	12° 27.55'	171	1	1								
ME762/229	26.05.08	08:22	19° 50.67'	12° 40.49'	120	1	1								
ME762/230	26.05.08	10:27	19° 48.83'	12° 46.37'	100	1	2	5	1	1	1	1	2		
ME762/231	27.05.08	15:30	21° 0.47'	13° 15.20'	123	2	3	5	1	1	1	1	4	2	
ME762/232	28.05.08	16:08	21° 10.00'	13° 15.19'	133	1									
ME762/233	28.05.08	17:45	21° 14.12'	13° 4.98'	152	1									
ME762/234	28.05.08	19:30	21° 17.55'	12° 54.99'	289	1									
ME762/235	28.05.08	21:47	21° 24.20'	12° 40.01'	363	1									
ME762/236	29.05.08	00:07	21° 34.00'	12° 24.21'	892	1									
ME762/237	29.05.08	03:28	21° 39.96'	11° 59.97'	1678	1									
ME762/238	29.05.08	10:23	22° 26.95'	12° 21.48'	1673	1									
ME762/239	29.05.08	15:00	22° 19.41'	12° 54.55'	325	1	1								
ME762/240	29.05.08	18:01	22° 14.45'	13° 14.58'	228	1	1								
ME762/241	29.05.08	22:25	22° 9.49'	13° 37.10'	134	1	1								
ME762/242	30.05.08	01:50	22° 3.36'	14° 3.07'	56	1	1								
ME762/243	30.05.08	05:05	22° 5.74'	13° 51.69'	103	3	2	5	1	1	1	1	2		
ME762/244	5/31/08	19:53	22° 59.98'	12° 57.01'	593	1									
ME762/245	5/31/08	21:53	22° 59.99'	13° 8.95'	319	1									
ME762/246	6/1/08	00:30	22° 59.93'	13° 29.98'	239	1									
ME762/247	6/1/08	02:14	23° 0.00'	13° 40.94'	153	1									
ME762/248	6/1/08	04:48	22° 59.98'	13° 51.95'	147	1									
ME762/249	6/1/08	06:59	22° 59.90'	14° 2.30'	137	1									1
ME762/250	6/1/08	08:54	23° 0.00'	14° 12.96'	111	1									
ME762/251	6/1/08	09:58	23° 0.00'	14° 19.00'	73	1									
ME762/252	6/1/08	11:04	23° 0.00'	14° 12.96'	111	2	6	5	1	1	1	1	2	2	
Totals						71	46	29	6	6	6	6	14	6	1

MUC: multicorer; MSS: Microstructure profiler; ADCP: Acoustic Doppler Current Profiler; MER: benthic profiler; BL: Benthic chamber lander; PC: Pump-CTD; BWS: Bottom water sampler; ISP: in-situ pump. An oceanographic mooring operated by IOW was recovered at the end of operations at station 249.

2.8 Data and Sample Storage and Availability

The data raised during the cruise will be published in the frame of individual research projects of the participating groups, either in the form of publications in the scientific literature, or as parts of academic theses. Those data that have been acquired for physical parameters (CTD casts, ADCP results), chemical parameters (nutrient and gas concentrations, isotopic composition of reactive N, bulk sediment chemistry) are collected in the GENUS database (<ftp://genuser@ftp.io-warnemuende.de/>) that will be transferred to the Pangaea database at WDC Mare (at the end of phase I in spring 2012). Samples of sea water, pore water, suspended matter and surface sediment will generally be exhausted during shore based analyses, but in many instances, duplicate samples have been taken and archived, either frozen or freeze-dried. These materials are available at IfBM for external researchers and can be requested from the chief scientist. Acoustic data have been archived on DVD and mass storage devices, and can also be requested by interested researchers.

2.9 Acknowledgements

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2.10 References

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Process Studies in the Eastern South Atlantic (PROSA)

PART 3a

Cruise No. M76, Leg 3a

June 07 – July 13, 2008

Walvis Bay – Walvis Bay



**V. Spieß, C. Bourry, C. Breton, C. Caparachin, F. Ding, K. Enneking,
N. Fekete, J.-P. Foucher, J. Franke, R. Gehrman, F. Harmegnies,
T. Himmler, E. Kopiske, F. Kretschmer, S. l'Haridon,
U. Lütticke, G. Meinecke, J. Metzen, T. Pape, C. Pierre,
M. Raab, J. Renken, H. Riepshoff, E. Rongemaille, L. Toffin,
T. Truscheit, A. Trampe, A. Wülbers**

Editorial Assistance:

Senatskommission für Ozeanographie der Deutschen Forschungsgemeinschaft
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Institut für Meereskunde der Universität Hamburg

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3.1 Summary / Kurzfassung

R/V METEOR Cruise GUINECO M76/3a results from a cooperation between IFREMER, Brest, and MARUM, Bremen. Main objectives of the ongoing research objectives of both institutions in the area were dedicated to giant deep sea pockmark structures, which represent sites of significant fluid and gas seepage, occurrence of gas hydrates and carbonate precipitates, and they host large seep-related ecosystems.

During M76/3a, mainly geophysical and geological investigations were carried out including seismic and acoustic profiling, swath mapping, seafloor sampling of sediment, gas hydrates and carbonates and microbiologic studies on the samples.

The region is characterized by widespread occurrence of hydrocarbons in the subseafloor. Different geologic conditions in the shallow subseafloor, as sedimentary facies, salt tectonics, local gas trapping by lithology and gas hydrates influence the migration of gas towards the seafloor. The research is intended to study the external controls of seepage by structural seismic and acoustic studies and sampling.

The cruise was very successful in the identification of active seep sites by imaging numerous gas flares in the water column with the new PARASOUND system, identifying high backscatter patches in multibeam data, and locating migration pathways and shallow gas reservoirs in multichannel seismic data. Dedicated sampling provided gas hydrates and carbonates with a success rate of more than 50%. Shorebased studies of the samples and the gravity core heat flow data will provide further details on the nature and evolution of seepage. These data will be used to characterize seepage on the margin scale.

FS METEOR Fahrt GUINECO M76/3a ist das Ergebnis einer Kooperation zwischen dem IFREMER, Brest, und dem MARUM, Bremen. Hauptziele der laufenden Forschungsaktivitäten beider Institutionen in der Region zielen auf große Pockmarkstrukturen in großen Wassertiefen, die durch Fluid- und Gasaustritte, Vorkommen von Gashydraten und Karbonaten charakterisiert sind und deshalb seepbezogene Ökosysteme beheimaten.

Während M76/3a wurden geophysikalische und geologische Untersuchungen durchgeführt, u.a. seismische und akustische Profilmfahrten, bathymetrische Vermessungen, Beprobung von Sedimenten, Gashydraten und Karbonaten sowie mikrobiologische Studien.

Das Arbeitsgebiet ist durch großflächige Vorkommen von Kohlenwasserstoffen in großer Tiefe charakterisiert. Verschiedene geologische Randbedingungen wie die Sedimentfazies, Salztektunik, lokale Gasfallen durch Lithologie und Gashydrate beeinflussen die Gasmigration. Die Forschungsarbeiten zielen darauf ab, durch seismische und akustische Strukturuntersuchungen und Beprobung die externen Faktoren zu verstehen, die die Gas- und Fluidmigration kontrollieren.

Die Expedition war besonders im Hinblick auf die Identifikation von Lokationen mit aktiven Gas- und Fluidaustritten sehr erfolgreich. Zahlreiche Blasenströme von freiem Gas wurden in der Wassersäule nachgewiesen, entsprechende Flächen mit hohen Rückstreuwerten im Multibeam kartiert, und mit Mehrkanalseismik Migrationswege und flache Gasakkumulationen nachgewiesen. Gezielte Beprobungen lieferten mit einer Erfolgsquote von über 50% Gashydrate und Karbonate. Weitere Untersuchungen des Daten- und Probenmaterials und der Wärmeflussdaten sollen ein besseres Verständnis von Art und Entwicklung der Fluidaustritte

liefern und die externen strukturellen Kontrollmechanismen klären helfen, um eine Charakterisierung des Gas- und Fluidflusses am Kontinentalrand zu erreichen.

3.2 Participants

Name	Working group	Affiliation
Spieß, Volkhard, Prof. Dr.	Chief scientist	MARUM, Bremen
Bourry, Christophe	Gas hydrates	IFREMER, Brest
Breton, Cécile	AUV mapping	IFREMER, Brest
Caparachin, César	Bathymetry	MARUM, Bremen
Ding, Feng	Seismics	MARUM, Bremen
Enneking, Karsten	Pore water analysis	MARUM, Bremen
Fekete, Noémi, Dr.	Seismics	MARUM, Bremen
Foucher, Jean-Paul, Dr.	Heat flow	IFREMER, Brest
Franke, Jennifer	Pore water analysis	MARUM, Bremen
Gehrmann, Romina	Seismics	MARUM, Bremen
Harmegnies, François	Heat flow	IFREMER, Brest
Himmler, Tobias	Pore water analysis	MARUM, Bremen
Kopiske, Eberhard	AUV	MARUM, Bremen
Kretschmer, Falko	Seismics	MARUM, Bremen
l'Haridon, Stephane	Microbiology	IFREMER, Brest
Meinecke, Gerrit, Dr.	AUV	MARUM, Bremen
Metzen, Jan	Seismics	MARUM, Bremen
Pape, Thomas, Dr.	Gas hydrates/TV-sled	MARUM, Bremen
Pierre, Catherine, Prof. Dr.	Carbonates	UPMC, Paris
Raab, Marius	Seismics	MARUM, Bremen
Renken, Jens	AUV	MARUM, Bremen
Riepshoff, Hannes	Seismics	MARUM, Bremen
Rongemaille, Emmanuelle	Carbonates	IFREMER, Brest
Toffin, Laurent, Dr.	Microbiology	IFREMER, Brest
Truscheit, Thorsten	Meteorology	DWD, Hamburg
Trampe, Anna	Seismics	MARUM, Bremen
Wülbers, Alexius	AUV	MARUM, Bremen
Lütticke, Ulrich	PARASOUND technician	ATLAS, Bremen

ATLAS: Atlas Hydrographics, Kurfürstenallee 130, 28211 Bremen, Germany

DWD: Deutscher Wetterdienst, Geschäftsfeld Seeschifffahrt, Bernhard-Nocht-Straße 76, 20359 Hamburg, Germany

IFREMER: Ifremer Centre de Brest, Marine Geosciences, B.P. 70, 29280 Plouzané, France

MARUM: Center for Marine Environmental Sciences, University of Bremen, Leobener Str., 28359 Bremen, Germany

UPMC: Université Pierre et Marie Curie, 4 Place Jussieu, 75252 Paris, France

3.3 Research Program

(V. Spiess)

Project area E of the Center of Marine Environmental Sciences seeks to gain deeper insight into migration and venting processes of gases and fluids at the seafloor on different spatial and temporal scales. Multi-frequency seismic-acoustic imaging in two or three dimensions provides the missing link between flow-related surface observations and sub-seafloor processes that define the physical and chemical controls of fluid-gas migration systems. Increasingly higher resolution of the survey methods, from multichannel seismics to swath and backscatter profiling to video mapping, provide access to appropriate sampling sites for expelled fluids and gases, for the geologic remains of precipitation and for the biologically mediated exchange processes at the sediment-water interface. Our investigations on the West African margin, primarily in the lower Congo Basin, have focussed on different types of seep systems, associated with gas hydrates and shallow gas occurrences.

Deposition in the Congo Fan area is characterized by a substantial sediment influx from the continent. The hemipelagic input originates primarily from the fine grained suspended material of the river and a high biologic productivity, providing significant flux of organic matter to the sea floor. ODP Leg 175 Drilling and a pre-site seismic survey north of the Congo Canyon confirmed that the upper few hundred meters of the sediment column are dominated by hemipelagic sediments, which represent the host facies for gas and gas hydrate occurrences within the GHSZ around the pockmark area. Further downslope, fan deposition causes a change in the dominant sedimentary facies, introducing channel-levee structures and associated sand deposition. Furthermore, while the deposition of the shallow sediment column is dominated by uniform input from riverine sources and primary production, the overall structure of the continental margin is mainly shaped by salt diapirism and rafter tectonics. Thus the main goal of the cruise is a comparative analysis of fluid and gas seepage systems, including migration pathways, gas and fluid venting, hydrate distribution, and the ecosystem patterns and processes associated with these focused gas sources.

Preliminary work in the area during R/V METEOR Cruises M47/3 (2000) and M56A/B (2002) included the mapping and sampling of several seep sites in the Congo pockmark area. Based on these observations, the control parameters of fluid and gas migration systems and the associated vent communities and ecosystems were investigated. Given the widespread riverine input of fine-grained, organic-rich sediment, variations of sedimentary facies and tectonic deformation and its influence on the vent system can be studied in different working areas on the margin. In comparison with the pockmark area, which consists of fine-grained sediments with moderate to minor deformation, the following end-members were surveyed:

- Strong deformation above salt diapirs, creating pronounced faulting with higher transport capacity (tectonic control), probably promoting the focussing of fluid/gas migration;
- Sand-rich sediments, which have a higher permeability, supporting enhanced throughput and higher reservoir capacity (facies control);
- Regab pockmark site, a location of probable large amounts of fluid/gas expulsion but moderate solid material transport. Here, previous work of French biologists was complemented by geological - geophysical investigations to identify the main processes.

The Niger Cone pockmarks target had to be given up for security reasons.

3.4 Narrative of the Cruise

(V. Spiess)

R/V METEOR left the port of Walvis Bay, Namibia, on June 7th, 2008. Several pieces of luggage were still missing, but at least the delayed service suitcase for the PARASOUND technician turned up just in time. An essential extended maintenance and upgrade work for the PARASOUND system had originally been planned in port, but now the technician had to accompany us during the following days of transit to ensure the scientific goals of the cruise, which were intimately depending on the ability to reliably image gas flares and seep-related sediment structures. It was planned to drop off the technician during an extra call in a West African port, when the functionality of the sediment echosounder was secured. Following an AUV test just off Walvis Bay, transit to the north commenced in the evening of June 7th. The scientific crew consisted of German, French, Peruvian, Chinese, and Hungarian colleagues.

The first area of investigation was reached on June 10th, a region of intense salt tectonics at 11°S. Underway bathymetric data had revealed an interesting polygonal surface morphology, and as the PARASOUND system was still not running properly at this time, we spent a day with bathymetric surveying and subsequent seismic profiling. On June 12th, we sailed with seismics in the direction of the port of Luanda (Angola), where we studied fluid seepage structures on the upper slope, associated with deformation, numerous small pockmarks, faulting as well as mounds covered with corals, using seismic and video observations. The site appeared suitable for a first AUV test, which had however to be stopped due to technical problems.

As technical problems on the echosounder functionality continued, R/V METEOR sailed on June 14th towards the first main working area in Angolan waters ("Salt Diapirs"), reaching it in the evening of June 15th. It is located at the western border of the continental margin, its morphology is controlled by salt and raft tectonics. Upward moving salt in the subsurface has created a rough seafloor topography of several hundred meters elevation. Our goal was to find active fluid and gas vent sites with the help of seismic, bathymetric and sediment echosounder systems, as well as to verify their activity by video observations and coring. To that end, seismic profiles were recorded along tracks complementary to those acquired during two previous R/V METEOR expeditions.

At one location, a rugged seafloor with massive carbonate blocks and plates as well as single tube worms were seen in the video observation, indicating low but recent seep activity. A second video survey above a diapir revealed normal deep sea sediments with traces of venting. Gravity coring at both locations supported the video results. At another diapir, where pockmark-like features were selected for sampling with the help of the now functioning PARASOUND system, sediment cores showed indications of seep activity over longer time periods. After a final 2-day test of the echosounder and the acquisition of further seismic profiles, work was interrupted on June 19th for a transit and port call in Luanda. Research was continued in the working area on June 21st. Following an unsuccessful AUV test, several diapiric structures were video-surveyed. Visual observations could not confirm seep activity indications from sediment cores and from seismic data. The clearest indication of seepage was delivered by the PARASOUND system in form of a gas flare (free gas bubbles in the water column) on the seaward side of the deformation zone.

On the way to the deeper Congo Fan, a seismic transit profile was shot and an ikaite-containing core was successfully taken at the westernmost position of the cruise. Subsequent bathymetric and echosounder profiles were then recorded in Gabonese waters within the "sand facies" area after another half-day transit, starting on Tuesday 24th. This region is characterized by a widespread presence of sandy layers in shallow depths imaged by PARASOUND, displaying high reflection amplitudes possibly due to elevated gas charge. As we find it likely that such shallow gas occurrences cause frequent and widespread seep activity, we searched for appropriate sampling sites. Due to a major failure of the seismic compressor, originally planned seismic profiles had to be replaced by an echosounder overview survey on June 25th. This was followed by gravity coring at pockmark sites further to the east, which had been discovered during previous R/V METEOR cruises. Coring was quite successful by collecting large pieces and volumes of gas hydrates.

The "Pockmark" target area received its name from numerous unique giant pockmark structures, depressions on the seafloor of some tens of meters depth and several hundreds of meters diameter. Bathymetric data provided a handle on the size and number of these pockmarks, and allowed to identify a number of new ones, to subsequently characterize them with PARASOUND subseafloor imaging, and to identify several gas flares. At the site of an intense gas plume, the shallow occurrence of gas hydrates as well as living chemosynthetic fauna further documented recent and ongoing activity. Profiling until June 28th raised the number of newly-discovered flares to 5 - a sign of continuous and widespread seepage.

Several gravity cores were taken between June 30th and July 3rd. The cores were quite successful in recovering carbonates, hydrates and traces of fauna, but revealed an extreme spatial variability. Core lengths varied at one location between 0 and 8 m, and core material ranged from purely hemipelagic sediment to material mixed with massive carbonate and gas hydrate; even though the corer was positioned to the same coordinate with just a few meters of positioning inaccuracy. Six stations served to confirm hydroacoustic vent indications as well as to recover seep-related, shallow sample material. Two of them were free of gas hydrates, others at the pockmarks provided carbonates and gas hydrates. In three cores these were found primarily close to the surface, down to approximately 3 m depth. In-situ temperature measurements at the gravity corer revealed anomalies which indicate active fluid flux and hydrate instability within the surface deposits. Another last attempt to deploy the AUV failed at Hydrate Hole on July 3rd.

Research permission for Congolese waters arrived just in time to enable a short working period at the Regab pockmark site. It took full effect with the embarkation of a Congolese observer on July 4th in the port of Pointe Noire after a half-day transit, where a replacement compressor had arrived from Germany via airfreight. We left port within a few hours, heading for a one-day seismic survey across the pockmark and sand-facies areas, before departing for the Regab site.

The last days of the expedition were spent at Regab. The afternoon of July 5th brought two successful gravity cores of up to 2 m each, which recovered gas hydrates and carbonates. The remaining time was used to track vent mechanisms with the help of a network of seismic profiles. The immediate vicinity of the Congo Canyon, the complex local tectonics, and the variable distribution of different sediment types make it a challenge to interpret the data; the circumstances appear to differ principally from those in the pockmark area in the north and

thus make the site optimal for a comparison. We concluded our work with a seismic transit profile towards the south in the night of July 8th. Despite bad weather and heavy seas, R/V METEOR arrived in Walvis Bay on July 12th in time, but departure from the working area had to be rescheduled to half a day earlier.

In total, 29 very good cores were recovered with sediments containing large amounts of carbonates and gas hydrates, more than 7 gas flares were verified in the water column, and 8 days of seismic profiling (out of 14 planned days) were carried out during M76/3a. Furthermore, 7 TV-sled missions and 10 AUV deployments were included, the latter unfortunately without success. Our results demonstrated that seep activity is widespread and typical of this continental margin, and subsequent research will both focus on the seismo-acoustic characterization of seepage in the region as well as the study and the intercomparison of several seep locations with the help of carbonate, gas hydrate and microbiological samples.

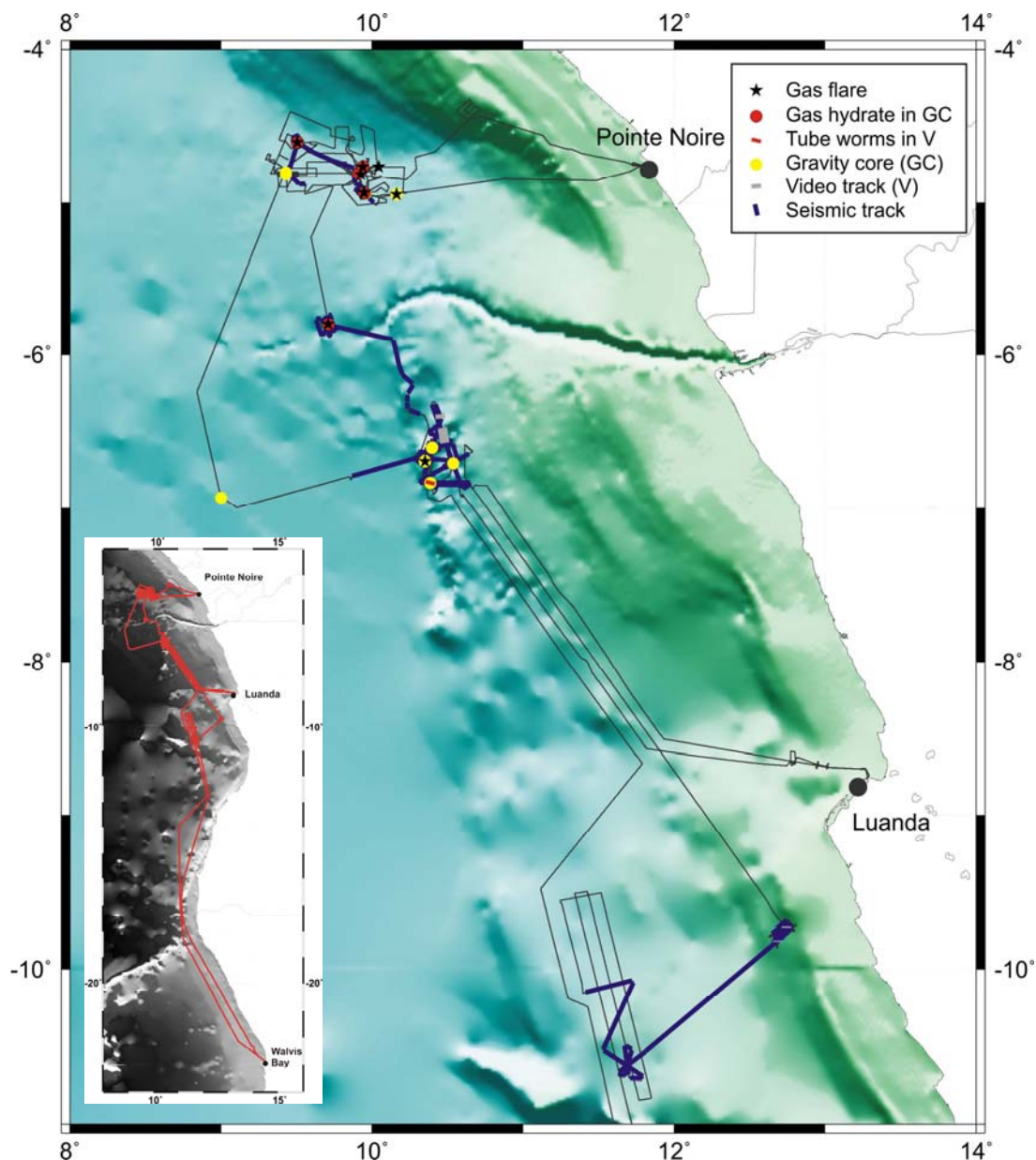


Fig. 3.1 Location of seismic profiles, sampling work, and seafloor video observations, as well as sites with indication of active seepage during Cruise M76/3a. Insert: overview map of working area and track lines of R/V METEOR during the cruise.

3.5 Preliminary Results

3.5.1 Multibeam Swath Mapping

(V. Spiess, C. Caparachin)

The KONGSBERG SIMRAD EM 120 and EM 710 multibeam echosounders are installed in the hull of R/V METEOR. The EM 120 emits a frequency of 12 kHz and can cover full ocean depth. The EM 710 uses a frequency range from 70 to 100 kHz and is optimized to survey with higher resolution in water depths shallower than 1,000 m depth. As most of the working area during M76/3a was deeper than 1000 m, the EM 710 system was not used very often. The SIMRAD EM 120 generates 191 beams with a maximum opening angle of 140°. The mode was set to obtain equally spaced soundings on the sea floor. Yaw movements of the ship were compensated automatically by the software by transmitting the swath perpendicular to the track rather than to the ship's axis. The opening angle was limited either by the maximum angle possible, a maximum angle set, or a maximum coverage in meters on the sea floor. Those values were adjusted to the requirements of individual surveys.

Bathymetric data were among the most important data set for this cruise to identify seep locations, as often highly special morphologies and/or high backscatter signals were associated with active seep locations. Pockmarks on 100m to kilometre scales and ridges were among promising features.

In addition to interesting data collected on transit between Walvis Bay and the working areas along the South and West African continental margin, the working areas offshore Angola had to be chosen because of technical maintenance issues with the PARASOUND system (Fig. 3.2).

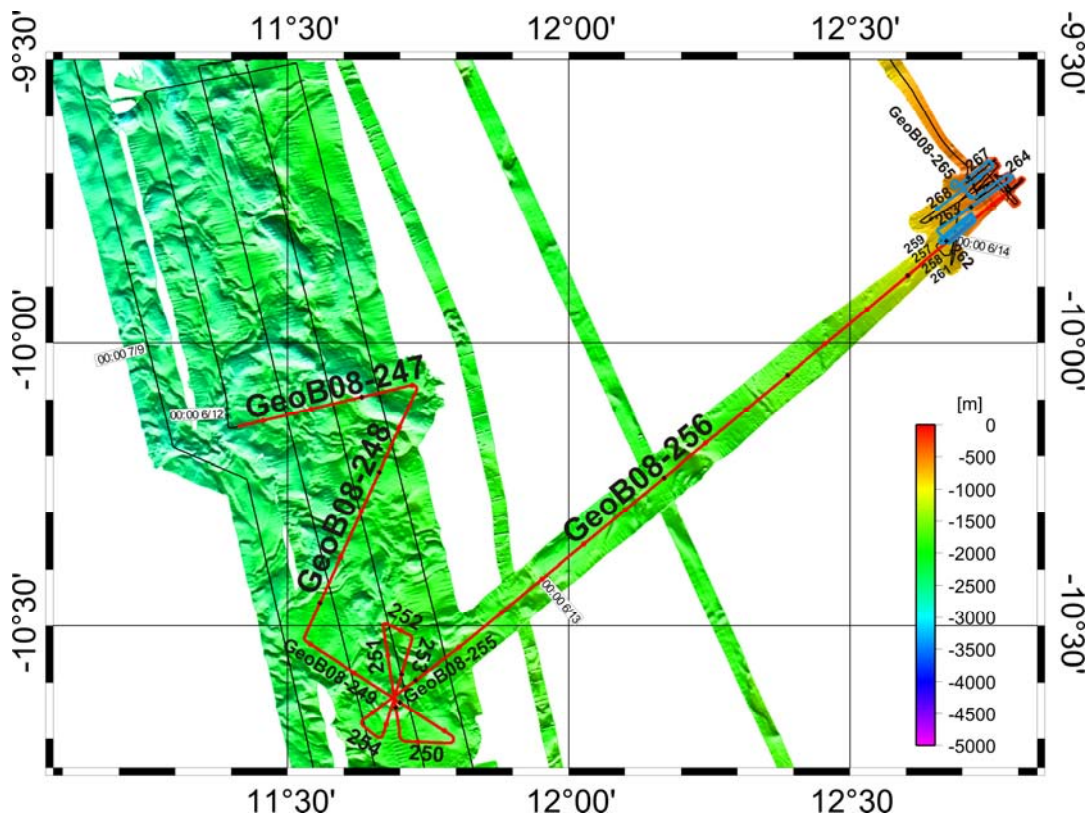


Fig. 3.2 Bathymetry and location/names of seismic profiles offshore Angola near the zone of massive salt tectonics (west) and within the extensional domain, where carbonate mounds were investigated.

Here, polygonal features on the seafloor were studied using swath bathymetry and multichannel seismics, while the sediment echosounder was not operational. Rugged terrain is characterizing the western part of this working area (Fig. 3.2), caused by active salt movement within a compressional domain. Morphology near the shelf edge in the East is in general flat, with mound structures of some 10 meters height, small pockmarks and enhanced sedimentation and faulting in an extensional domain of the margin.

A main objective of the cruise was to study the relationship of local tectonics and fluid seepage, which in the case of the Diapir Area (Fig. 3.3) is dominated by salt diapirism, leaving distinct topographic features on the sea floor of several hundred to more than thousand meters height. Diapiric ridges appear mostly in NNW-SSE orientation, associated with wider (depressional) basins accumulating thick sedimentary units. Bathymetric data were particularly used to identify topographic anomalies as well as spots of high backscatter anomalies, which may represent non-sedimented seafloor, carbonate precipitates or just fractured surfaces due to extension and faulting.

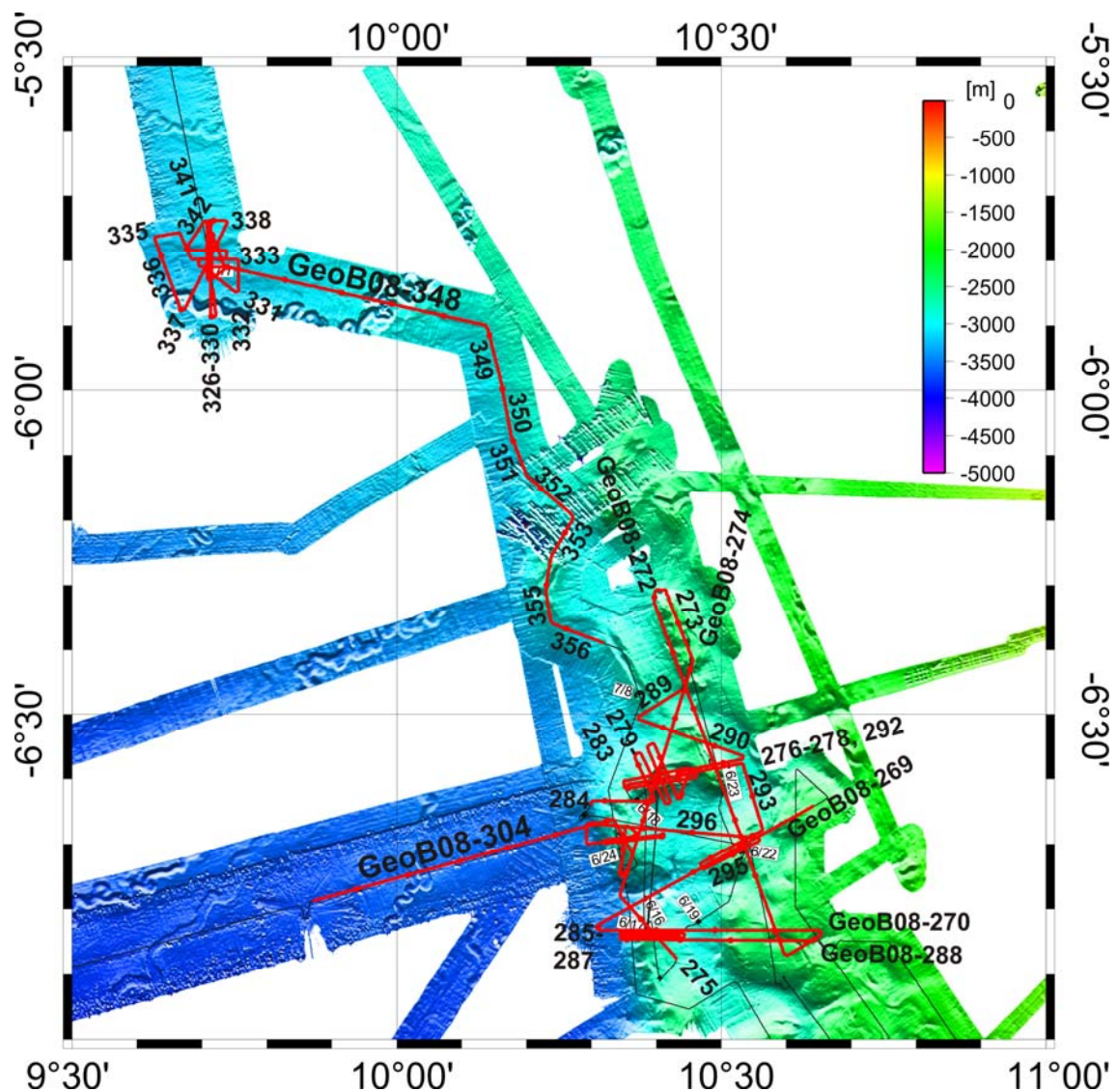


Fig. 3.3 Bathymetry and location/names of seismic profiles in the Diapir Area and around the Regab pockmark. The pronounced topography is caused by active salt diapirism, the very top of ridge is deformed by extension, faulting and slumping

The second main working area was located north of the Congo Canyon, where during previous cruises giant deep water pockmarks had been found. Because of the failure of the compressor at the arrival in this working area, the available ship time was used to extend the coverage with bathymetric and sediment echosounder area and to confirm potential seep sites by coring (Fig. 3.4)

Bathymetric data revealed the location of circular sea floor depressions, most of which were associated with high backscatter patches. Based on this information, dedicated PARASOUND lines were acquired and sampling sites based on these data were to more than 50% successfully cored retrieving seep related material (e.g. carbonates and gas hydrates).

As a result of bathymetric, sediment echosounder and water column surveying, more than 16 major seepage sites were mapped, as shown in Figure 3.5.

3.5.2 Subbottom Profiling

(N. Fekete, V. Spiess)

The ship-mounted parametric sediment echosounder PARASOUND from ATLAS HYDROGRAPHICS was used during M76/3a to image shallow subsurface structures. The Primary High Frequency (PHF) of the acoustic signal is 18 kHz and allows the detection of gas venting into the water column. Emitting a secondary high-frequency signal (e.g. 22 kHz), the difference (SLF, secondary low frequency) with 4 kHz is also generated - this is the so-called parametric effect. The 4 kHz frequency is used to image shallow subsurface structures. The beam of PARASOUND has an opening angle of 2°, therefore a footprint of 7% of the water depth. For online processing, the software ATLAS PARASTORE was used. This software allows the colour-coded visualisation of the various frequencies in a freely chosen number of windows with various scales and processing steps. Two different transmission sequences (single pulse or quasi-equidistant) were run during the cruise, depending on the target structures. For efficient flare detection in a certain area, the PARASOUND was set to the single pulse mode: a pulse is first emitted after reflections from the previous one were recorded. The result is a visualisation of the complete water column, where it is possible to detect a flare even if it is not connected to the seafloor. For dedicated echosounder surveys of special subsurface targets, the quasi-equidistant mode was performed, in which the ping rate is slowly varied by the software depending on the water depth and pings are emitted within the breaks between echo receptions. In this mode, the horizontal resolution is kept quasi-uniform, but the horizontal coverage is higher than in single pulse mode, since subsequent pings are emitted sooner than the echo from the previous one arrives. A disadvantage of this data acquisition mode is that it is strongly dependent on correct automatic water depth detection - which can be avoided by setting the water depth to be the beginning of display window. This way, water depth detection becomes a task of the watch keeper.

PARASOUND surveys were carried out simultaneously with bathymetric and seismic profiling after a starting period of technical problems. Their purpose was twofold: to image shallow subsurface structures, thus providing the link between surface information and the seismic data as well as helping identify potential seepage-related features (SLF), and to detect active vent sites by revealing gas bubbles in the water column (PHF). The approach had been successfully utilized during previous R/V METEOR cruises (e.g. M72/3, M74/2).

The first reliable operation in terval of the echosounder syst em provided profiles in the Diapir Area offshore Angola. The region is characterized by significant salt diapirism and raft tectonics and displays a set of margin-parallel ridges. Indications of ongoing venting were searched for near the highest topography first, but this remained unsuccessful. An active site was finally found on the western-m oost edge of the ridge area. The cl earest indication for current seepage was an approxim ately 2000 m tall gas flare in the prim ary high frequency (PHF) signal (Fig. 3.6). The subsurface (SLF; Fig. 3.6) data reveal ru gged and elevated topography with a vertical offset at the locatio n of the flare as well as a high -amplitude package in variable sub-bottom depths. The anomaly appears shallowest under the seep site.

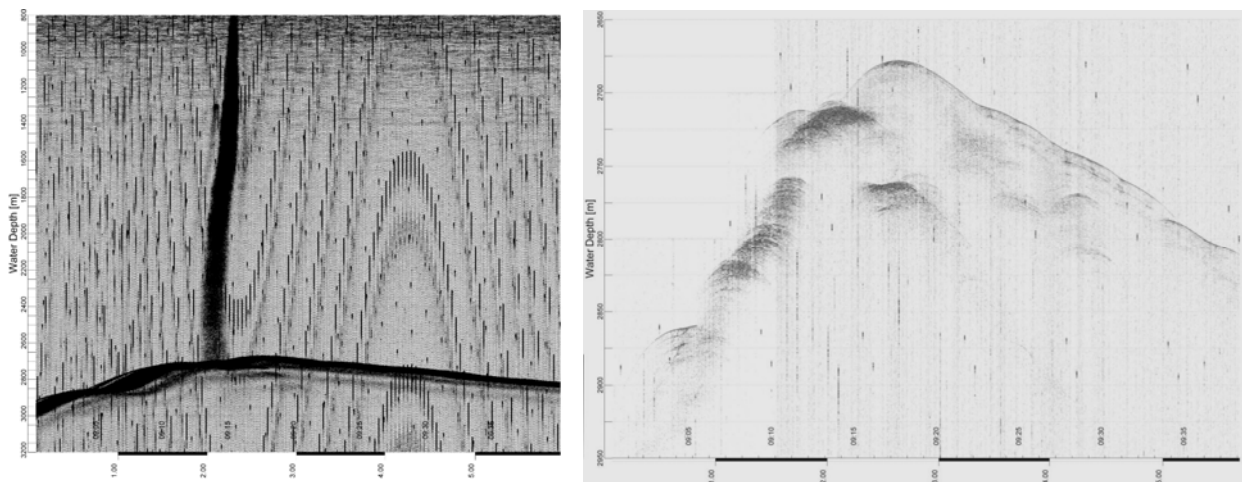


Fig. 3.6 PHF (left) and SLF (right) PARASOUND images of an active vent site in the salt diapir area, showing gas bubbles in the water column of approx. 2000 m height and the corresponding subsurface structure, characterized by acoustic amplitude anomalies of varying depths.

Subsequent investigations were carried out furt her north-west, in the vicinity of an buried meandering channel (Fig. 3.7) in the Sand Faci es Area. A widely obs erved acoustic feature here is a chaotic package of high reflectivity, some 50 m below seafloor, which is in contrast to the well-layered material of moderate reflection amplitudes on top and restricts penetration of acoustic energy towards greater depths. The feature may be caused by the elevated content of coarse grained sediment, resulting from material transport along the channel. Sandy layers have different acoustic properties than norm al (hemi-) pelagic sedim ents. In addition, increased pore space is like ly to allow the a ccumulation of free gas, which also m ay contribute to the acoustic anom aly. However, no direct evidence of ongoing seepage was found in the area.

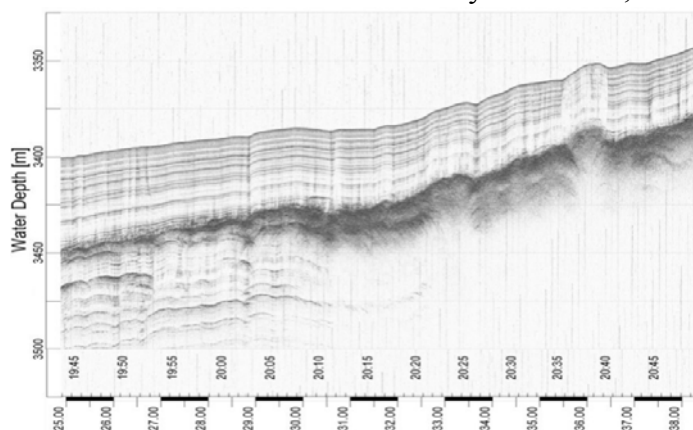


Fig. 3.7 SLF (4 kHz) PARASOUND image in the sand facies area in the vicinity of a submarine channel. Strong acoustic amplitude variations indicate the change in facies from fine-grained hemipelagic to a more sandy lithology, and probably also indicate an increase of the gas content in the pore space.

East of the Sand Facies Area, a pockmark field is found in similar water depths. Several of them were discovered during previous expeditions (e.g. M47/3, M56), and brought in connection with venting processes through the link of gas hydrate and carbonate precipitate presence on or near the surface. Over newly identified or known pockmark structures (e.g. Fig. 3.8), more than half a dozen instances of gas flares were imaged, often accompanied by subsurface acoustic anomalies such as high-amplitude zones below the seafloor. PARASOUND data among others prove the importance of these features in contributing to fluid seepage and may allow quantification on the margin-scale.

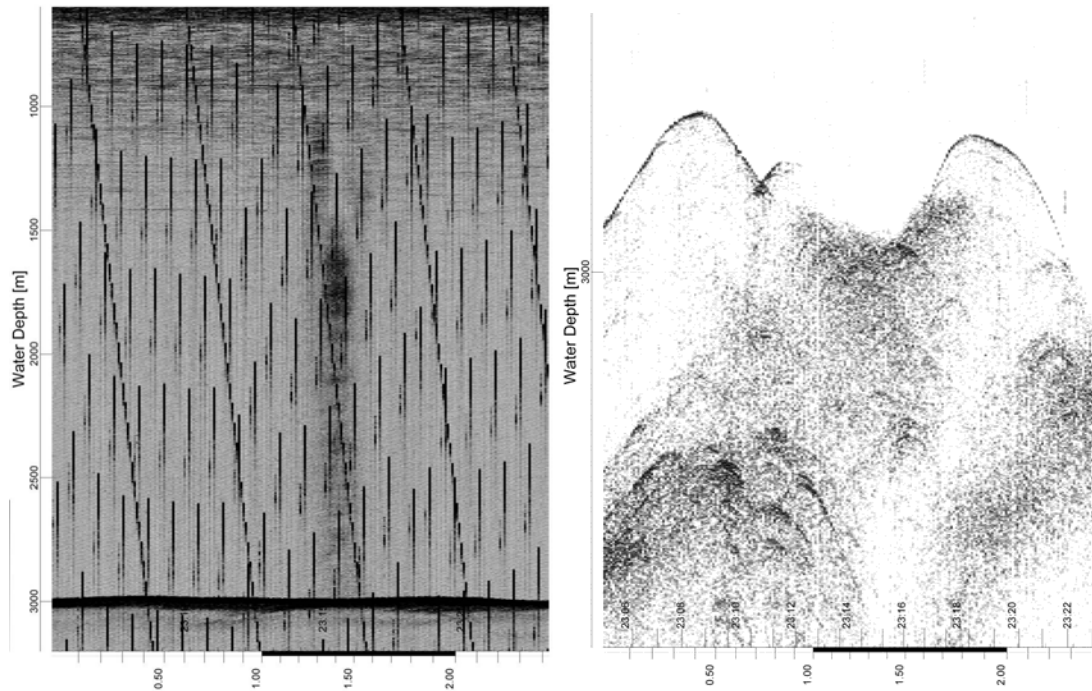


Fig. 3.8 PHF (left) and SLF (right) PARASOUND images of a pockmark and active seep site. The gas flare in the water column is almost 2000 m in height. The subsurface structure of the pockmark is characterized by high acoustic amplitudes in different depths, the shallowest being near the vent site.

The last scientific target of the cruise, the Regab pockmark, is a single large, flat feature near the Congo Canyon (Fig. 3.9). Its location is one of complex interrelationships between sedimentary processes, mass transport, and tectonic effects. The feature's venting activity is documented by a gas flare. Details of the vent mechanism are however yet to be deciphered.

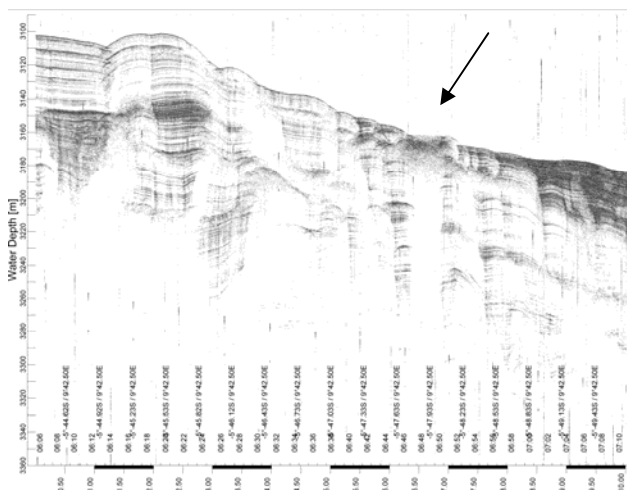


Fig. 3.9 4 kHz image of Regab pockmark. While the vicinity of the structure displays acoustic layering to subsurface depths exceeding 100 m, the pockmark itself (arrow) is characterized by a shallow, chaotic acoustic facies which scatters reflection energy strongly and allows no penetration underneath. The scattering effect may be caused by a mixture of elevated fluid and gas content as well as carbonate fragments.

3.5.3 Multichannel Seismic Measurements

(V. Spiess, F. Ding, N. Fekete, R. Gehrman, F. Kretschmer, J. Metzen, M. Raab, H. Riepshoff, A. Trampe)

The GeoB high-re resolution multichannel seismic equipment serves to image small-scale subsurface structures, usually irresolvable with conventional systems, on a meter scale. It consists of one or more acoustic sources, a multichannel streamer, a depth control system (birds), a recording unit, and a trigger system, which are described below (Fig. 3.10).

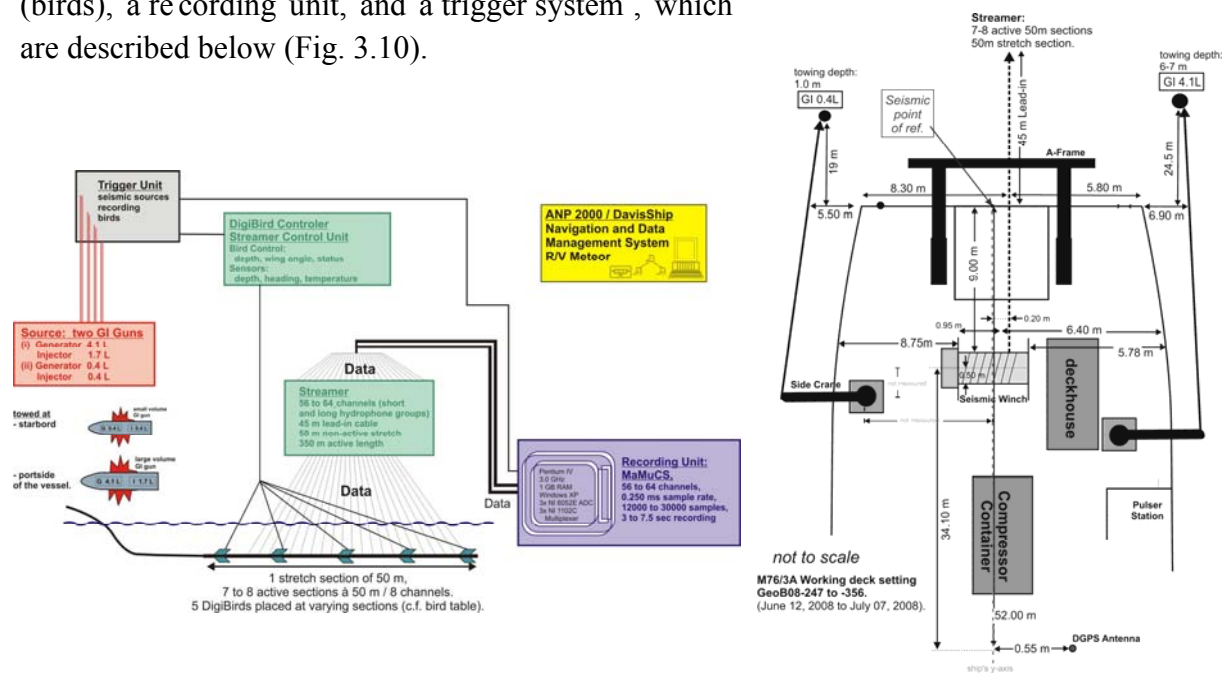


Fig. 3.10 (left) Seismic system setup during cruise M76/3a.

Fig. 3.11 (right) Deck setting and towing geometry during seismic profiling on cruise M76/3a.

During M76/3a, a Sodera Generator-Injector (GI) airgun with reduced chamber volume (0.4 L generator and injector, frequency range approx. 100-800 Hz) was towed on the starboard side of the vessel at a depth of 1.5 m. Another Sodera GI gun with extended chamber volume (4.1 L generator and 1.7 L injector, frequency range approx. 30-300 Hz) was towed on the port side of the vessel at a depth of 7 m, and shot alternately with the smaller GI gun during profiles GeoB08-247 through -303. Shot rate varied from 7 s to 9 s, achieving an approximate shot distance of 18 to 25 m at a profiling speed of 5 to 5.5 kn. The sources were shot at an air pressure of approximately 150 bar provided by the compressor container until profile GeoB08-305, and at a pressure of 120 - 135 bar after the failure of this, due to the smaller capacity of the auxiliary Junkers compressor used. The horizontal towing geometry of the seismic sources is shown in Figure 3.11. The two GI guns were towed with the help of cranes on the port and starboard side at a sideways distance of 6.90 m and 5.50 m from the ship, respectively. The along-track distances were 19 m and 24.50 m, resp.

The SYNTRON multichannel seismic streamer used during M76/3a consisted of a lead-in cable, 45 m of which was towed behind the vessel, of one 50 m stretch section, and of up to eight active sections of 50 m length. These contained 8 hydrophone groups each, at 6.25 m group separation. A 30 m long rope with a buoy at the end was connected to the streamer's tail swivel, resulting in a total tow length of 525 m. A 30 m long deck cable connected the

streamer to the recording system. During seismic profiling, the streamer was kept at an average depth of 3 m below the water surface with the help of 5 DigiBirds distributed evenly along its length. These had difficulties communicating with the control PC and were set manually to keeping 3 m depth / 0° fin angle. The streamer was towed midships between the acoustic sources. Its lateral separation to the port and starboard side guns was 13.80 m and 12.70 m, respectively.

For data recording, the custom -designed 96-channel seismograph MARine MULti-Channel Seismics (MaMuCS) was used. It is based on a Pentium IV PC (3 GHz, 1 GB RAM) with Windows XP operating system and was operated at a sampling rate of 0.250 ms at 16 bit resolution. It is equipped with three 32-channel multiplexers (NI 1102C) and three analogue-to-digital converters (NI 6052E). The seismograph provides online data display of shot gathers as well as a brute stack section of the range of channels of the user's choice, and stores data in SEG-Y format on the internal hard disk drive. Anti-aliasing was fixed to 10 kHz on the AD converter. Gain for each channel was set to 100 (measurement range 0.1 V). During the cruise, 56 channels of data were recorded, except for the profiles GeoB08-247 to -256, where 64 channels were acquired. Recording length varied between 3 and 7.5 s, allowing alternating shots from the two sources to be recorded in the same seismogram. The trigger unit used during M76/3a controlled shot and recording times as well as bird data acquisition. The unit is set up on an IBM compatible PC with a Windows XP operating system and includes a real-time controller interface card (SORCUS) with 16 I/O channels, synchronized by an internal clock. The unit is connected to an amplifier unit and a gun amplifier unit. The PC runs custom software, where arbitrary combinations of trigger signals can be defined, and changed during profiling without interrupting data storage. This was made use of in target areas encompassing a large range of water depths, to optimize acquisition efficiency. Time synchronization of all systems was done based on GPS time, which is directly acquired from the satellites through a Hopf GPS-DCF77 radio clock apparatus. This consists of a GPS aerial, a radio clock (Hopf modul 6870), a multi-aerial amplifier (modul 4446), and a radio clock PC card (modul 6039). This last item is built into the trigger PC. GPS time is distributed via LAN, and all other PCs are synchronized through the NTP (network time protocol) service.

In spite of difficulties with compressor and streamer, data quality is good to very good. Onboard processing of seismic data was carried out with the commercial software package VISTA 7 (Seismic Image Software Ltd.). A large portion of data underwent preliminary processing during the cruise. Brute stack profiles were filtered, debiased, and migrated in order to help selecting an optimal profiling strategy, to enable evaluation of data quality, and to give a first impression of the subsurface geology.

Altogether a set of 110 multichannel seismic profiles were acquired during M76/3a. Apart from some transit lines, these were distributed in six target areas: the Polygon Area (10 profiles / 195 nm), Angola Upper Slope (12 / 50 nm), Diapir Area (34 / 380 nm), Sand Facies Area (10 / 25 nm), Pockmark Area (10 / 85 nm), Regab (22 / 145 nm) (c.f. Figure 3.1). Data from previous cruises are available near the pockmarks and supplement freshly acquired information in a constructive way.

The Diapir area offshore Angola is characterized by extreme deformation due to salt tectonics. Active venting was documented through a gas flare in the water column (Chapter

3.4.2) as well as the presence of chemosynthetic organisms (Chapter 3.4.5) at the western margin of the area. High reflection amplitudes beneath the venting zone indicate a laterally discontinuous gas trap in the subsurface (Fig. 3.12). The location of venting is probably controlled by the age of deformation, in that seepage is most likely in the vicinity of most recent vertical movement.

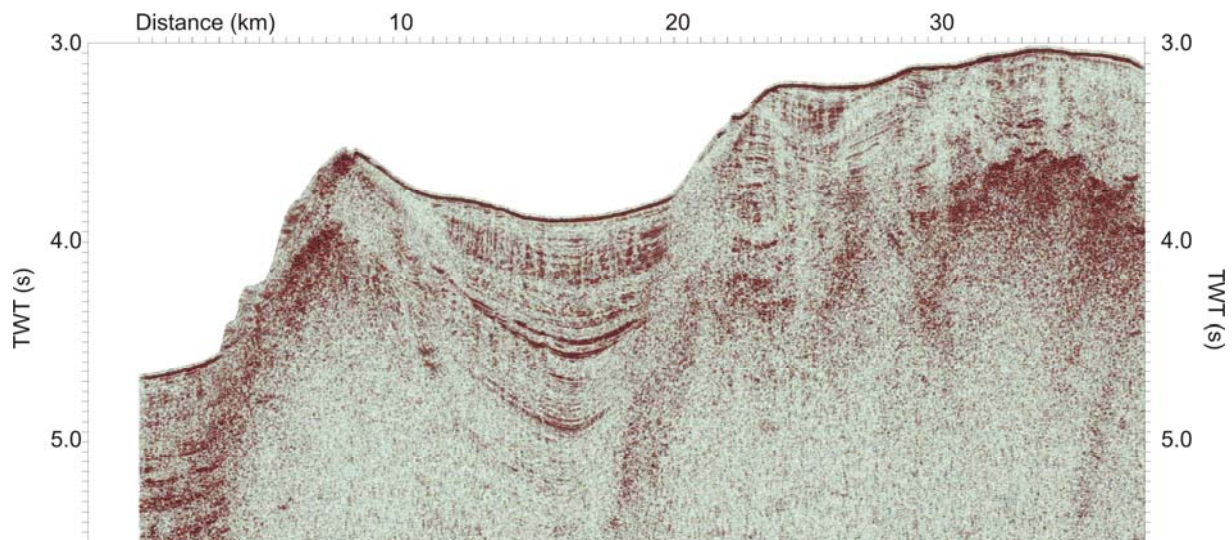


Fig. 3.12 GeoB08-270 multichannel seismic profile across the active seep site in the Diapir Area. High-amplitude chaotic reflection packages probably indicate gas accumulation, e.g. near profile distance 8 km and beyond 30 km.

Further north near the Congo Canyon, the Regab Pockmark is a large, flat feature with active venting taking place at its top, documented by gas hydrate and carbonate samples in gravity cores. Similarly to the echosounder data, reflection seismic images of the feature reveal acoustic blanking below a shallow, chaotic cover, which is in contrast to its relatively well-layered vicinity. Complex tectonics and variable lithology will make a detailed interpretation of the area a challenge.

The Sand Facies area is the vicinity of an offshore channel and is characterized by locally sand-dominated sediments. In consequence, grain size and pore space variations may allow the accumulation of significant amounts of free gas, supporting venting through the lithology where sand is present. Although this seems likely from the seismic structure (Fig. 3.13), no direct indication of seepage was found in the area. We speculate that venting here may be dispersive.

The number of pockmarks discovered on previous R/V METEOR expeditions (M49/1, M56) was increased during M76/3a. Several of these were found to be actively venting. Such are also the pockmarks in the Baboon cluster (Fig. 3.14) where seismic data indicate gas or gas hydrate accumulation in the subsurface in varying depth (shallower near the pockmark). The spatial extent and importance of venting in the region is more widespread than previously expected on variable horizontal and vertical scales.

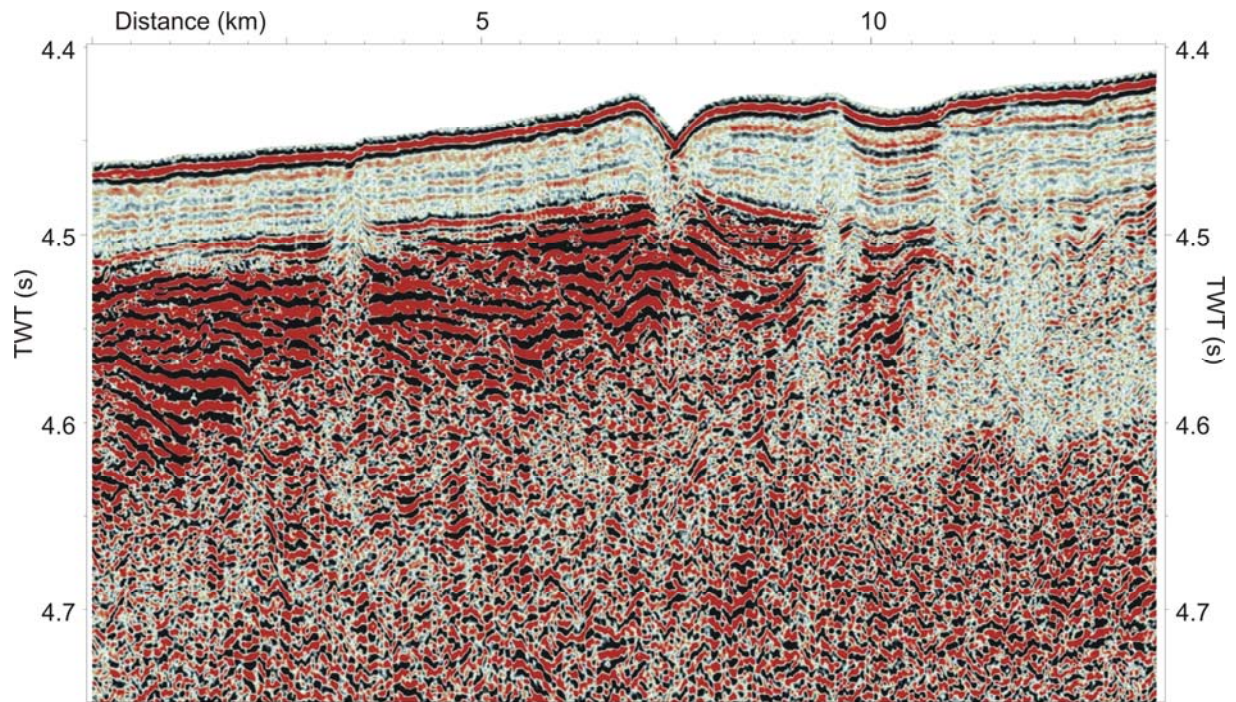


Fig. 3.13 GeoB08-324 multichannel seismic profile across the Sand Facies Area. High-amplitude, low-frequency reflection packages probably indicate shallow gas accumulation in the NW (left) segment of the profile.

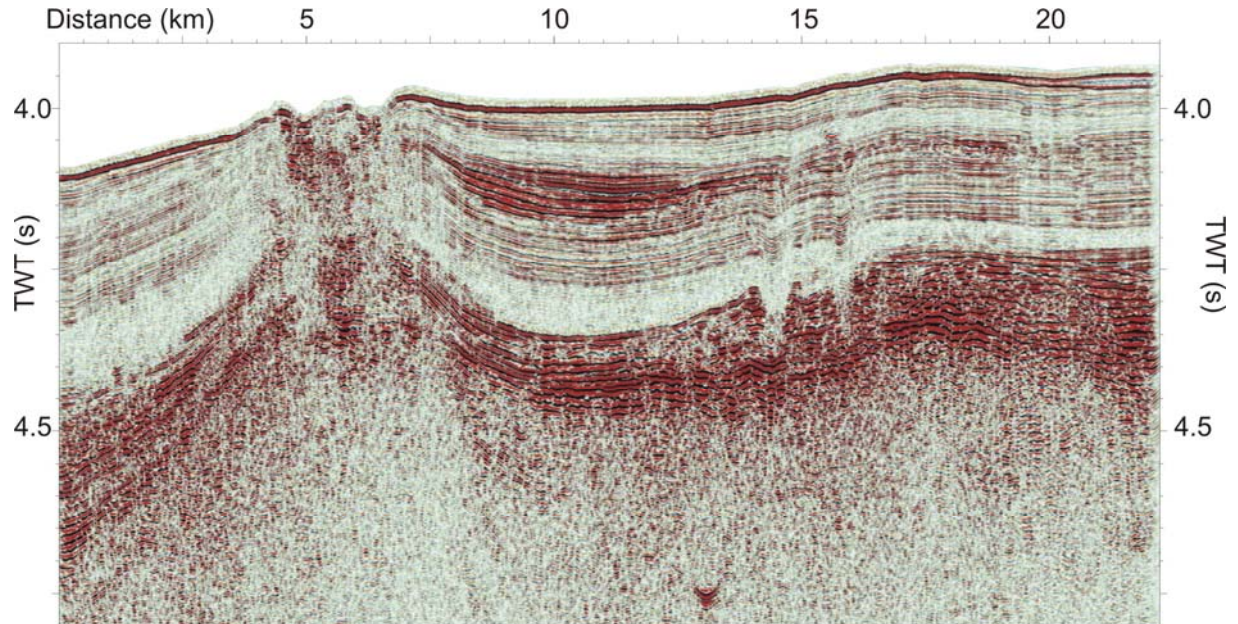


Fig. 3.14 GeoB08-306 multichannel seismic profile across the Baboon pockmark cluster. These structures may be the result of the focussing effect of salt diapirism.

3.5.4 Station Work with the Autonomous Underwater Vehicle SEAL 5000

(G. Meinecke, E. Kopske, J. Renken, A. Wülbers)

The AUV SEAL is built by the company International Submarine Engineering (I.S.E.) and has a depth range of 5000 m. The vehicle is 5.75 m long, with 0.73 m diameter and a weight of

1.35 tons. It consists of a modular atmospheric pressure hull designed from 2 hull segments, and a front and an aft dome. Inside the pressure hull, the vehicle control computer (VCC), 14 lithium batteries and spare room for additional “dry” payload electronics - the inertial navigation system PHINS and the RESON multibeam-processor - are located. The tail and the front section are flooded wet bays. In the tail section the motor, beacons for USBL, RF-radio, Flash light, IRIDIUM antenna, DGPS antenna and the pressure-sensor are located. In the front section the Seabird SBE 49 CTD, the Sercel MATS acoustic modem, the DVL, KONGSBERG Pencil beam and the RESON MBES 7125 are placed. The AUV SEAL has a capacity of approximately 14.6 KWh. Several hard- and software-mechanisms are installed on the AUV to minimize the risk for malfunction, damage and total loss, which work based on fault response tables. An emergency drop weight can be released by the user or automatically by the AUV.

On the vessel, a surface control computer (SCC) is installed. It is an Intel based standard PC, running with QNX and a Graphic User Interface (GUI) to control and command the AUV. Direct communication with the vehicle is established by Ethernet-LAN, either by hardwired 100mb LAN cable plugged to it on deck, or by Ethernet-RF-LAN modem once the vehicle is off deck. The typical range of RF-communication is around 1 – 2 km distance. Within this range the user has all options to operate the AUV in Pilot-Mode, e.g. to manoeuvre the AUV on water or change settings. Once it is under water, all communication links are shut down automatically and the AUV goes in Mission-Mode, i.e. carries out a specific pre-defined mission. Communication hereafter is limited to an acoustic underwater modem with dunking transducer (Sercel MATS modem) and limited acoustic bandwidth.

The station work during M76/3a started with the installation of the control van. After unpacking the AUV, first pre-dive system checks showed a malfunctioned aft-plane, possibly an effect of transportation. The plane was replaced. The first two test dives in 300 m water were aborted prematurely because of a fault of the PHINS inertial unit. During subsequent deck tests, the PHINS fault could not be reproduced. Manufacturers from both the AUV and of the PHINS unit were involved in the trouble-shooting, and IXSEA was asked for replacement of the INS but declined this due to strict export regulations of such devices. Finally, interference between PHINS power supply and the MATS communication was found and eliminated.

The next AUV launch targeted 3100 m water depth and aborted at 1150 m due to insufficient compensation at the thruster motor. The fault occurred repeatedly, indicating that, compared to compensator volume, too much air was in the pockets of motor and gearbox inside the thruster unit. The success of an overnight evacuation could not be certified due to the lack of station time.

The AUV SEAL is in the test phase with little or no operational experience. In spite of lack of acquired scientific data, launch and recovery on R/V METEOR proved successful and yielded valuable insight. The open architecture of the AUV allowed the AUV team to interfere with the internal VCC to an extent necessary to find faults related to PHINS and MATS communication. To prevent compensator faults, a more powerful compensator will be installed in the AUV for further cruises.

3.5.5 TV-sled (T. Pape)

Objectives of TV-sledge deployments during M76/3a were seafloor explorations of areas potentially harbouring sites of hydrocarbon seepage as expected from current ship-based echosounder data and multichannel seismic profiles, as well as external information. Subsequently, sites promising for ROV-inspections and seafloor experiments during the consecutive Leg M76/3b areas should be proposed. For this, a detailed documentation of the distributions of specific benthic organisms and carbonates, which could serve as sea bottom indicators of fluid and gas discharge into the water column, was performed by means of TV-sledge operations during M76/3a.

The TV-sledge consists of a steel frame (80 · 120 · 110 cm, W·L·H) and is equipped with video-data telemetry, a spotlight (HID), and a b/w camera. The video-data telemetry consists of an underwater unit connected to the deck unit via the deep-sea cable. The deck unit is linked to monitors for continuous seafloor observations and adjustments of the cable length and to a TV-video system for permanent recordings of the seafloor images. During M76/3a the video-sledge was hauled about 2 m above ground with an average ship velocity between 0.5 and 0.9 knots. For accurate underwater positioning, an USBL (ultra-short baseline) navigation system (IXSEA, Posidonia) was mounted on the wire 50 m above the TV-sledge.

The site of TV-sledge station #3 in the area of the ‘Angola diapirs’ was chosen for seafloor investigations because strong shallow reflectors were recognized by sediment echo sounding. The scheduled track followed a general NE/SW trend in water depths between 2,615 and 2,770 m.

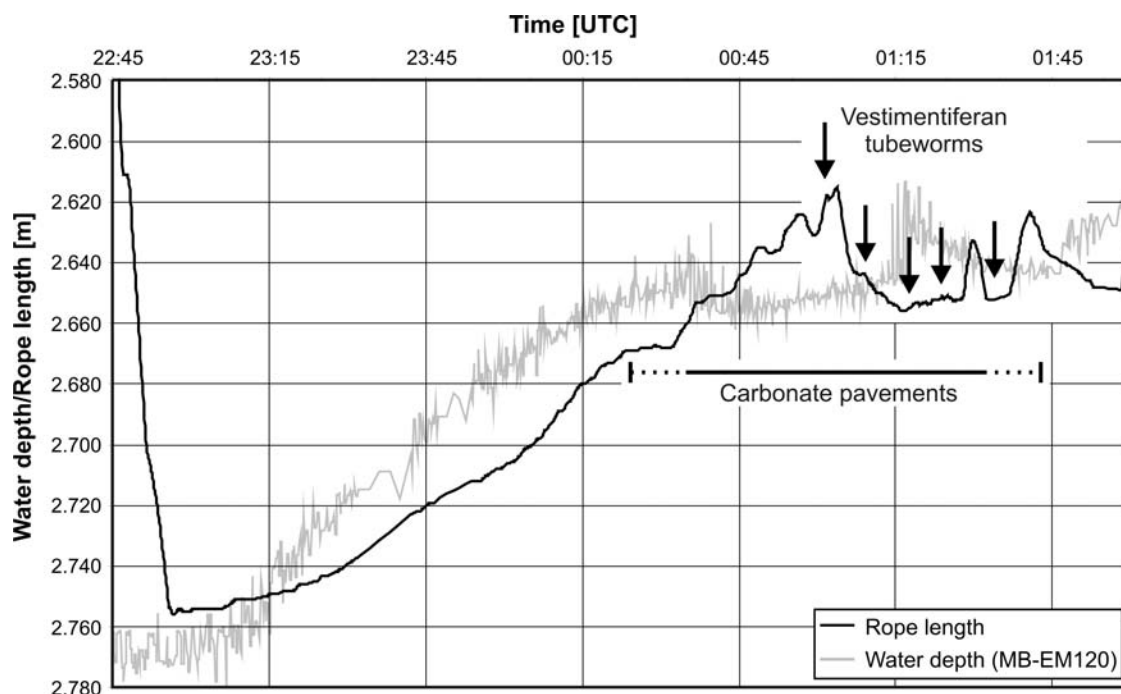


Fig. 3.15 Crossplot showing time vs. water depth (as determined with the EM120 echosounder) and the length of the cable during deployment of TV-Sledge Station #3 (GeoB13103-1).

Seafloor observations started in about 2,770 m bsl ($6^{\circ}82.175$ S; $10^{\circ}38.790$), where a smooth topography, virtually undisturbed sediments, and no features attributed to hydrocarbon seepage was observed. This general picture did not change very much for the subsequent about 80 mins of the station. However, at 00:23 ($6^{\circ}82.947$ S; $10^{\circ}38.623$), when a local plateau in about 2,653 m bsl was approached, authigenic carbonate slabs, indicating (sub-)recent hydrocarbon seepage from the seafloor were identified. Following the track, the area became increasingly rough in topography and massive carbonate pavements covered the seafloor. Probably due to tectonic movement and erosion, carbonaceous rocks were dislocated and created incisions with steep flanks and several meters in depth. Sometimes whitish patches on the seafloor which might have indicated microbial mats were recognized. First vestimentiferan tubeworms, indicating recent seepage activity, were observed at 01:01 ($6^{\circ}83.392$ S; $10^{\circ}38.535$) close to the top of a morphological high in about 2,615 m (cable length) water depth. In conclusion, seafloor inclined on average by $\sim 12\%$ from the carbonate covered plateau towards the top additionally settled by vestimentiferans.

Although bubble streams and clam fields were not observed in the course of TV-S#3, both, the presence of massive carbonate blocks and alive vestimentiferan tube worm bushes demonstrate active and long-term hydrocarbon seepage in that area. Preferential settlement of vestimentiferan tube worms on morphological highs was previously reported by Sahling et al. (2008). Individual or bush-forming tubeworms were recognized until 01:34 ($6^{\circ}83.778$; $10^{\circ}38.450$; 2,644 m), while carbonate slabs decreased significantly in density in the area investigated between 01:40 and 01:49 and were virtually absent afterwards. Thus, seafloor observations were completed at 01:57 after 182 mins seabottom time in about 2,647 m water depth (cable length).

3.5.6 Heat Flow Measurements

(J.P. Foucher, F. Harmegnies)

During the M76/3a cruise, sediment temperature measurements were routinely made at coring stations by attaching thermometers to the external wall of the core barrel. Thermometers are self-recording NKE-manufactured thermistor temperature sensors accurately calibrated in the Ifremer laboratory prior to the cruise. Five to ten thermometers were attached to the core barrel, depending on the length of the barrel that was used. Sensors are mounted on outriggers at a distance of 6 cm from the barrel wall so as to minimize thermal disturbances produced by frictional heating at penetration time. Sediment equilibrium temperatures were extrapolated from the transient curves recorded for a period of 8 minutes following penetration while the corer was kept in the sediment prior to pull out.

Thermal conductivity was measured in the ship laboratory on selected recovered cores using the needle probe method. The measuring device uses a Fenwal I-G874 manufactured thermistor sensor, a power supply delivering a stabilized heating voltage of 5 volts (± 2 mV), a multimeter Keithley 2000-20 for the heating voltage/current and thermistor resistor value measurements. Thermal conductivity was derived from temperature records at a sampling rate of 5 seconds over a total heating time of two minutes and a needle heating rate of 8 W/m.

A total of 23 successful temperature gradient measurements were made in combination with gravity coring operations during the M76/3a cruise. Measurements were made either at

sites of previous investigations (Ondreas et al., 2005; Sahling et al., 2008) or at newly explored sites (diapirs off Angola, Bear Hole, Deep Hole, Sand Facies area, Ikaite site).

Based on results obtained, two groups of measurements can be distinguished. A majority of measurements show linear temperature profiles with depth. These measurements have well defined gradients. They are observed on the diapiric structures, in Worm Hole, at the Ikaite site, in the Sand Facies area. It will be however noted that the calculated mean gradients are highly variable, ranging from 56°C/km to 146 °C/km. They define the thermal regime of the deep basins off Angola, Congo and Gabon, at the limited scale of the region where measurements were taken. A relatively higher heat flow on salt diapiric structures off Angola is likely to be caused by heat flow refraction through the higher thermal conductivity salt bodies.

Table 3.1 Summary list of measurements

Station	Site	Latitude S	Longitude E	Depth m	Gradient G (Nb) (mK ⁻¹)	Conductivity K (Nb) (Wm ⁻¹ K ⁻¹)	G x K Total (mWm ⁻²)
13106-1	Angola Diapir 1	06°36,300	010°23,726	2576	(2) 124,4	(7) 0,702	87,3
13107-1	Angola Diapir 1	06°36,275	010°23,820	2581	(2) 145,7	(6) 0,693	101,0
13108-1	Angola Diapir 2	06°42,459	010°32,148	2484	(5) 108,6	(20) 0,759	82,4
13109-1	Angola Diapir 2	06°42,399	010°32,146	2476	(5) 111,2	(19) 0,783	87,1
13112-1	Angola Diapir 3	06°41,575	010°20,968	2702	(3) 59,4		
13112-2	Angola Diapir 3	06°41,452	010°21,022	2703			
13113-1	Ikaite Site	06°55,916	008°59,984	3957	(10) 64,5		
13114-1	Hydrate Hole	04°48,564	009°54,483	3092	(12) 82,0	(6) 0,703	57,6
13114-2	Hydrate Hole	04°48,570	009°54,500	3090	(12) 73,3	(6) 0,703	51,5
13114-3	Hydrate Hole	04°48,641	009°54,512	3095	(4) 213,9	(6) 0,703	150,4
13115-1	Baboon Hole	04°56,272	009°56,993	2989	(5) 161,9		
13115-2	Baboon Hole	04°56,266	009°56,984	2989	(5) 95,4		
13115-3	Baboon Hole	04°56,300	009°56,993	2989	(13) 93,3		
13115-4	Baboon Hole	04°56,280	009°57,025	2988	(3) 61,8		
13116-1	New Site	04°56,586	009°57,366	3003	(5) 86,7		
13117-1	Astrid slump	04°56,862	010°09,716	2843			
13117-2	Astrid slump	04°56,905	010°09,744	2844			
13118-1	Worm Hole	04°45,605	009°56,423	3104	(5) 100,3	(22) 0,686	68,8
13119-1	Sand Facies	04°48,880	009°25,805	3326	(13) 69,9	(48) 0,666	46,6
13119-2	Sand Facies	04°47,954	009°25,750	3334	(13) 68,2	(48) 0,666	45,4
13120-1	Deep Hole	04°36,203	009°30,395	3436	(3) 166,1		
13120-2	Deep Hole	04°36,156	009°30,565	3436	(4) 91,8		
13120-3	Deep Hole	04°36,195	009°30,397	3436	(4) 581,2		
13120-4	Deep Hole	04°36,206	009°30,395	3436	(4) 421,7		
13121-1	Regab Pockmark	05°47,835	009°42,736	3156	(3) 102,2		
13121-2	Regab Pockmark	05°47,881	009°42,805	3156	(4) 56,2	(9) 0,718	40,4

Another group of measurements show complex, non linear temperature profiles, such as at several coring stations in Hydrate Hole, Deep Hole and Regab. The combination of heat flow measurements with gravity coring operations allowed us to observe that in many cases those stations with complex temperature profiles are also those where gas hydrate was found in the recovered cores. Non-linear temperature profiles suggest active fluid flow and fast time-evolving gas hydrate occurrences.

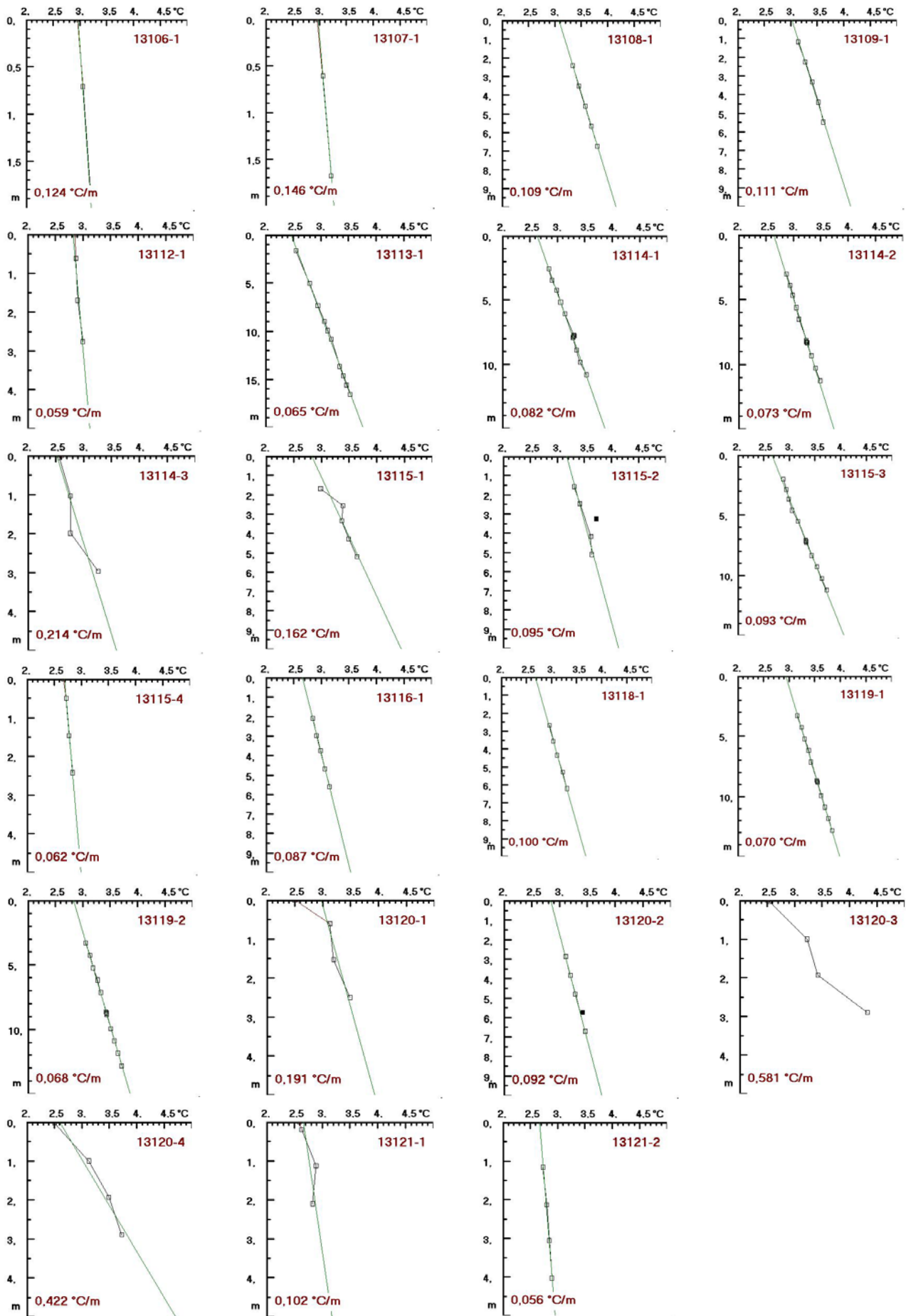


Fig. 3.16 Heat flow measurements at gravity coring stations. Temperature vs. sub-bottom depth

3.5.7 Geological Sampling

(T. Pape, T. Himmler, F. Harmegnies, J.-P. Foucher, C. Bourry)

During expedition M76/3a, seafloor sampling of seep- and non-seep associated near-surface sediments was performed with a gravity corer and a multicorer. Primary targets of those stations were hydrocarbon seep-associated shallow sediments as detected by sediment echosounding and flare imaging (chapter 3.5.2), and multichannel seismic investigations (chapter 3.5.3). In addition, cores from sites characterized by conspicuous shallow reflectors were collected. The cores were used for visual descriptions (chapter 3.5.5) as well as extraction of pore water (chapter 3.5.10), seep-associated authigenic carbonates, macrobiota, gas hydrates (chapter 3.5.8) and sediments for microbiological investigations (chapter 3.5.11). Heat flow measurements were performed during most of the gravity corer deployments (chapter 3.5.6). During M76/3a a total of 29 gravity corer stations were carried out in water depths between 2,475 and 3,935 m (Table 3.2). Complementary to gravity coring, one multicorer station was carried out for high-resolution surface sediment sampling at 'Worm Hole' in about 3096 m water depth.

Gravity coring stations were carried out with a weight of about one ton connected to cutting barrels of 13.2 cm ID and 6 to 18 meters length, respectively (Table 3.2). At sites where shallow authigenic carbonates and/or near-surface gas hydrates were expected to occur in high density, 3 m barrels were used instead. For recovery of sediments dedicated for geochemical, microbiological and sedimentological investigations, the cutting barrel was equipped with rigid PVC liner, whereas either flexible plastic foils or pre-cut and taped PVC liners were used for rapid gas hydrate sampling.

For accurate underwater positioning, an USBL (ultra-short baseline) navigation system (IXSEA, Posidonia) was mounted to the wire 50 m above the gravity corer or multicorer. During nearly all stations, in situ temperatures were measured simultaneously to the sediment sampling procedure. Therefore, a series of five to ten temperature sensors and a pressure sensor were welded to the cutting barrel (see chapter 3.5.6). For sediment sampling, the gravity corer was deployed via R/V METEOR's winch W 10 and lowered with a rope speed of 1.5 m s^{-1} . With respect to expected sediment texture, the penetration velocity was set between 0.8 and 1.5 m s^{-1} , respectively, except for station GeoB13120-4 which was run with a maximum speed of 1.8 m s^{-1} . For reaching equilibrium during in situ temperature measurements the device was left in the sediment for 8 min at least. Subsequently, it was pulled out from the sediment with a velocity of 0.3 m s^{-1} and recovered on deck with 1.5 m s^{-1} .

The multicorer was equipped with a set of twelve (8 x 10 cm ID, 4 x 6 cm ID) plastic liners of 50 cm length each. It was deployed at Worm Hole via winch W 10 with a rope speed of 0.8 m s^{-1} and penetrated into the sediment with 0.5 m s^{-1} .

Table 3.2 Specifics of gravity corer and multicorer stations during M76/3a. Positions given are POSIDONIA coordinates recorded during sediment penetration.

GeoB	GC#	Location	Water Depth	Lat.	Long.	Rope speed (penetration)	Length cutting barrel
			[m]	[°S]	[°E]	[m s ⁻¹]	[m]
13105-1	1	Angola diapirs	2653.3	6°50.11	10°23.11	1.5	3
13105-2	2	Angola diapirs	2656.7	6°50.10	10°23.11	1.5	3
13106-1	3	Angola diapirs	2575.9	6°36.30	10°23.73	1.0	6
13107-1	4	Angola diapirs	2580.5	6°36.27	10°23.82	1.3	6
13108-1	5	Angola diapirs	2479.8	6°42.46	10°32.15	1.4	6
13109-1	6	Angola diapirs	2475.0	6°42.40	10°32.15	1.3	6
13112-1	7	Angola diapirs	2703.6	6°41.59	10°20.96	1.5	6
13112-2	8	Angola diapirs	2704.9	6°41.53	10°21.03	1.5	6
13112-3	9	Angola diapirs	2704.3	6°41.43	10°20.97	1.5	6
13113-1	10	Ikaite site	3953.2	6°55.92*)	8°59.98*)	1.2	18
13114-1	11	Hydrate Hole	3086.8	4°48.56	9°54.48	1.5	12
13114-2	12	Hydrate Hole	3089.1	4°48.57	9°54.50	1.5	12
13114-3	13	Hydrate Hole	3092.0	4°48.57	9°54.53	1.5	12
13115-1	14	Gas Flare 2	2988.7	4°56.26	9°56.98	1.3	6
13115-2	15	Gas Flare 2	2988.6	4°56.27	9°56.98	1.3	6
13116-1	16		2999.0	4°56.58	9°57.36	1.3	6
13117-1	17	Astrid Slump	2841.7	4°56.92	10°09.81	1.3	6
13117-2	18	Astrid Slump	2844.8	4°56.91	10°09.75	1.3	6
13118-1	19	Worm Hole	3101.9	4°45.60	9°56.42	1.3	6
13115-3	20	Gas Flare 2	2993.0	4°56.30	9°56.99	1.4	12
13115-4	21	Gas Flare 2	2988.7	4°56.28	9°57.00	1.4	12
13119-1	22	Sand facies	3325.9	4°48.88	9°25.81	1.0	12
13119-2	23	Sand facies	3333.4	4°47.95	9°25.75	0.8	12
13120-1	24	Deep Hole	3434.6	4°36.20	9°30.40	1.3	6
13120-2	25	Deep Hole	3438.5	4°36.16	9°30.56	1.4	6
13120-3	26	Deep Hole	3435.3	4°36.20	9°30.40	1.4	6
13120-4	27	Deep Hole	3433.8	4°36.20	9°30.40	1.8	6
13121-1	28	Regab pockmark	3155.7	5°47.84	9°42.74	1.5	6
13121-2	29	Regab pockmark	3155.0	5°47.76	9°42.83	1.5	6
13118-2	MUC # 1	Worm Hole	3096.4	4°46.28	9°53.35	0.5	

*) no USBL, ship position

3.5.8 Gas Hydrates and Hydrate-bound Volatiles

(T. Pape, C. Bourry, J. Franke)

Previous investigations revealed accumulations of near-surface gas hydrates associated to cold seeps in the study area of M76/3a. These included pockmarks in the Northern Congo Fan area (R/V METEOR cruises M47/3 (2000) and M56 (2002; Sahling et al., 2008)) and the Regab pockmark located in the Congo-Angola Basin (cruise ZAI-ROV with L'Atalante (2000); Charlou et al., 2004).

Objectives of the works during M76/3a were to sample substantial amounts of gas hydrates from several hydrocarbon seep sites for on-shore analyses (e.g. cryo-stage Field-Emission Scanning Electron Microscopy, X-ray diffraction, and chemical composition of hydrate-bound gases (Bohrmann et al., 2007; Klapp et al., in press)). For this, a gravity corer with a 3, 6 or 12 m -cutting barrel equipped with PVC liners or flexible plastic foil was used

(chapter 3.5.7). For rapid access to gas hydrates recovered with PVC liners, they were pre-cut and re-taped prior to deployment. Gas hydrates were additionally taken from the core catcher.

Sampling strategies followed two procedures: pieces sufficient in size for long-term storage and subsequent analysis by microscopic techniques were extracted from the core catcher and the core liner and were immediately transferred into liquid nitrogen (-196°C) for preservation and long-term storage. Small gas hydrate pieces were cleaned carefully in ice-cooled water, transferred into syringes and left at room temperatures for controlled dissociation and immediate collection of hydrate-bound gases. Volatiles released by this procedure were transferred into 20 mL glass serum vials, sealed with saturated NaCl solution and capped with butyl stoppers. During M76/3a gas hydrates were found in ten gravity cores from five cold seep sites. A list of gas hydrates and hydrate-bound gas gathered during M76/3a is given in Table 3.3. Except for those in a core taken at Worm Hole, hydrate pieces were sufficient in sizes for on-shore analysis.

Gas hydrates collected during M76/3a differed strongly with respect to their vertical distributions, fabrics, structures, sizes, and shapes. For instance, hydrates resembling former fillings of tube worm tubes or bivalve shells were in particular present very close to the seafloor of Hydrate Hole and Regab pockmark, but were not observed at Deep Hole. Pictures of selected gas hydrate pieces from Hydrate Hole, Deep Hole, Baboon Hole and Regab pockmark are exemplified in Figures 3.17 a through f.

During M76/3a hydrates were found in gravity cores from pockmarks in the Northern Congo Fan area and the Congo-Angola Basin, which already revealed the presence of shallow hydrates during previous studies in 2000 and 2002, respectively. This indicates that the individual pockmarks still provide sufficient amounts of light hydrocarbons for precipitation of near-surface gas hydrates, and thus, are still active. Compared to the findings of these earlier investigations, hydrate accumulations at Hydrate Hole and Deep Hole in the Northern Congo Fan area appeared to start at shallower sediment depth, suggesting a somewhat higher seepage activity. In contrast, similar to observations made in 2002, the upper hydrate limit in the only core from Worm Hole was several meters bsf.

Hydrates at all sampling sites showed remarkable differences with regard to e.g., distributions, fabrics, and sizes. On-shore analyses of the hydrates stored will include several mineralogical and gas chemical approaches in order to clarify factors controlling the variances observed.

Table 3.3 Specifics of gas hydrate samples and hydrate-bound gases collected during M76/3a

GeoB	GC no.	Location	Corer	Lat [° S]	Long [° E]	Water depth [m]	Description of hydrates	GH / gas samples for on-shore analyses
13114-1	11	Hydrate Hole	12 m, PVC liner	4° 48.563' S	9° 54.483' E	3086.8	GH > 585 cm b.s.f. (core recovery 700 cm); tubular and shell-shaped, possibly fillings of cavities, encapsulating free gas; in addition cm-sized chunks	y / y
13114-3	13	Hydrate Hole	12 m, PVC liner	4° 48.565' S	9° 54.529' E	3092.0	GH uniformly distributed over entire core (recovery 196 cm), very close to the surface (few cm); spatially associated with tubeworm roots and carbonates, tubular, shell-shaped; chunks forming mm to cm thick vertical veins	y / y
13115-1	14	Baboon Hole	6 m, PVC liner	4° 56.263' S	9° 56.984' E	2988.7	GH distributed over entire core (recovery 280 cm); small chunks very close to sediment surface (few cm), spatially associated with bivalve shells; > 200 cm b.s.f. very dry sediment and significant lower GH density; massive, irregular cavernous clusters, cm-thick diagonal veins	y / y
13115-2	15	Baboon Hole	6 m, flexible liner	4° 56.266' S	9° 56.985' E	2988.6	GH uniformly distributed over upper 270 cm b.s.f. (recovery 380 cm); small chunks very close to the surface (few cm), spatially associated with bivalve shells; > 270 cm b.s.f. very dry sediment and significant lower GH density; occasionally massive horizontal GH layers	y / y
13118-1	19	Worm Hole	6 m, PVC liner	4° 45.603' S	9° 56.422' E	3101.9	tiny GH pieces only in core catcher (recovery 447 cm)	n / y
13120-1	24	Deep Hole	6 m, PVC liner	4° 36.201' S	9° 30.395' E	3434.6	GH nearly uniformly distributed > 20 cm b.s.f. (recovery 300 cm), between 20 and 230 cm b.s.f. co-occurring with or even attached to carbonates; porous and massive structures, occasionally layered or vein-forming, often hollow GH pipes	y / y
13120-3	26	Deep Hole	6 m, PVC liner	4° 36.201' S	9° 30.395' E	3435.3	GH nearly uniformly distributed > 20 cm b.s.f. (recovery 295 cm), between 95 and 105 cm b.s.f. and 180 and 240 cm b.s.f. co-occurring with carbonates, massive veins and irregular chunks in high density; often hollow GH pipes	y / y
13120-4	27	Deep Hole	6 m, PVC liner	4° 36.196' S	9° 30.404' E	3433.8	GH uniformly distributed over entire core (recovery 330 cm), between 50 and 90 cm b.s.f. and 190 and 205 cm b.s.f. co-occurring with carbonates; chips and cm-thick porous tubes; diagonal veins; hollow GH pipes	y / y
13121-1	28	Regab pockmark	6 m, PVC liner	5° 47.759' S	9° 42.831' E	3155.7	GH uniformly distributed > 30 cm b.s.f. (recovery 193 cm), chunks and small chips in high density; co-occurring with carbonates and fragments of tubeworm tubes and mussel shells; GH filling in tubeworm tube	y / y

GH = gas hydrates; b.s.f. = below seafloor



Fig. 3.17 Photograph of hydrates from: a) Hydrate Hole: cavernous, vesicular hydrate chunk; b) Baboon Hole: accumulation of cavernous hydrates in high density; c) Hydrate Hole: vertically orientated massive hydrate chunks of several cm lengths; d) Deep Hole: tubular, porous hydrate chunk; e) Hydrate Hole: tubular, fragmented hydrate pieces and hydrate chunks in close spatial association; f) Deep Hole: cylindrical to conical hydrate chunk.

3.5.9 Authigenic Carbonates

(C. Pierre, E. Rongemaille, T. Himmler)

The main objectives of sampling authigenic carbonates were to study their geochemistry and mineralogy.

There were six gravity cores deployed at different sites in the Diapir Area from the Angola margin. Only two of these recovered pieces of massive carbonates and porous aragonitic crust fragments in the core catcher. One core of 4.9 m length was opened and described on board. Bivalve shell fragments were found as isolated specimen and accumulated in cm to dm thick layers, the uppermost one being observed 8 - 10 cm below the surface. Below 3.7 mbsf, these bivalve shell layers were also containing carbonate concretions and mm-thick whitish carbonate crusts. These observations indicate that this site was probably an active venting site until recently as evidenced by bivalve shells occurrence very close to the surface.

At the Ikaite site, the gravity corer successfully retrieved 15.44 m of a sedimentary succession consisting of olive grey/medium to dark grey/medium grey green/brownish silty clay moderately to highly burrowed down to ~10.5 m bsf; downwards, the sedimentary succession consisted of alternating fine grained to slightly coarser grained layers that are most probably turbidites (Zabel & Schulz, 2001). Small (mm sized) white dots of felted needle-like

crystals of a soluble mineral were disseminated within the sediment from 10.9 mbsf down to 15.04 mbsf; we postulate that these crystals were the product of decomposition of former ikaite crystals since similar crystals were seen to be formed when a piece of ikaite was maintained after a few hours in the laboratory at room temperature. Ikaite was found as a single big cluster of amber/ brownish translucent crystals in the interval between 14.33 mbsf and 14.38 mbsf (Figure 3.18).

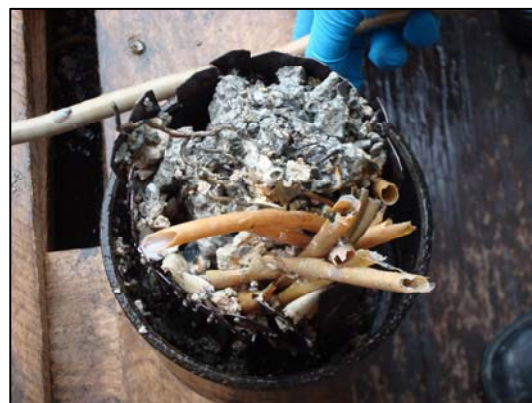


Fig. 3.18 (left) Cluster of ikaite crystals from the interval 14.33-14.38 mbsf of core GeoB 13113-1.

Fig. 3.19 (right) Gas Flare 4 (Astrid slump): Core catcher: fragments of carbonate rock and of carbonate crusts, broken tube worms.

Gravity cores in the Pockmark Area have been deployed at six pockmarks sites, two of them (Worm Hole, Hydrate Hole) having been discovered during M47 and M56 cruises (Sahling et al., 2008) whereas the others (Gas Flare 2, Astrid slump, Deep Hole) were new sites identified during this cruise by PARASOUND profiles as potential active venting sites. All sediment cores strongly smelled of H_2S . Sediment recovery was from 1.96 m to 7.0 m. At Astrid slump, only carbonate crust fragments and macrofauna (bivalve shell fragments, live and dead tube worms) were recovered in the core catcher, indicating that at this site, sea floor was hardly cemented and hosted the common cold seep faunal communities (Figure 3.19). In two cores from Bear Hole and Gas Flare 3 site, authigenic carbonate concretions were also very abundant in sediments with or without gas hydrates; they were mostly concentrated in the upper 2 meters as very hard concretions with various shapes (rounded or angular surface, flat, elongated to contorted structures resembling burrows) and with various sizes (a few mm to a few cm) (Figure 3.20); they were sometimes draped with a yellowish thin crust composed of acicular crystals (probably aragonite) which upper faces were covered with tiny pyrite crystals. Authigenic carbonate occurrences were also present at depth as yellowish to olive-grey disseminated nodules and discontinuous layers (Figure 3.21).

Two cores at the Sand Facies site recovered 9.5 and 11.5 meters of a continuous sedimentary succession of alternating layers of dark olive grey/ medium grey/ olive grey silty clay with various intensities of bioturbation. There was neither gas hydrates nor authigenic carbonates in these sediments that could testify for gas venting at this site.

Two gravity cores within the central part of the Regab pockmark yielded 1.92 m of sediments with gas hydrates occurring below 30 cm depth, and 2.12 m of gassy sediments without gas hydrates, both having a very strong H_2S smell. Authigenic carbonate concretions

were very abundant in both cores from the surface down to 2 m bsf. They were of various morphologies (small rounded pieces, fossilized tube worms and burrows, big pieces cementing bivalve shells) and were sometimes covered by a mm-thick white crust of palisadic aragonite crystals (Figure 3.22).



Fig. 3.20 (top left) Hydrate Hole: Cm-sized carbonate concretions (cemented burrows).

Fig. 3.21 (top right) Worm Hole: Carbonate layer from the interval 390-410 cm.

Fig. 3.22 (bottom left) Regab: Big carbonate concretion from the interval 84-90 cm.

3.5.10 Pore Water Analysis

(K. Enneking, J. Franke, T. Himmler)

The main focus of geochemical investigations during M76/3a was on pore water from sediments at newly discovered and previously known sites of methane seepage, pockmarks, and gas-hydrate bearing sediments. The aim of these studies is to characterize the biogeochemical processes at methane seeps and within sediments containing gas hydrates. Furthermore, reconstruction of the variation in methane fluxes and the migration of the zone of anaerobic oxidation of methane over time is a major aspect of these studies. In this context authigenic minerals (e.g., carbonates, barite, and iron sulphides) play an important role because they have a high potential to serve as biogeochemical archives and trace the past changes in redox conditions and reaction fronts over time.

In total, eight gravity cores and one multicorer tube were sampled for pore water analysis (Table 3.4) during this cruise. Samples from new sites of active methane seepage include the stations GeoB 13115-3 (Gas Flare2) and GeoB 13120-3 (Deep Hole). The station GeoB 13113-1 (Ikaite site) is in close vicinity to the GeoB station 1401-4 (c.f., Zabel and Schulz, 2001). GeoB stations 13114-2/-3, 13118-1/-2, and 13121-2, are located at pockmark structures with indication of active methane seepage which were recently described by

Sahling et al. (2008) (Hydrate Hole, Worm Hole) and Ondréas et al. (2005) (Regab pockmark).

Table 3.4 Overview of the stations with analysed pore water during M76/3a (GC: gravity corer; MUC: multicorer).

GeoB Station	Working area	GC/MUC
13108-1	Angola diapirs	GC
13113-1	Ikaite site	GC
13114-2	Hydrate Hole	GC
13114-3	Hydrate Hole	GC
13115-3	Gas Flare2	GC
13118-1	Worm Hole	GC
13118-2	Worm Hole	MUC
13120-3	Deep Hole	GC
13121-2	Regab pockmark	GC

Pore waters were collected with rhizon-technique (Seeberg-Elverfeldt et al., 2005), either through small ports drilled into the core segments or by directly sticking the rhizons into the sediments on open core segments. Samples were taken on each core segment in 25 cm intervals, beginning at 10 cm (continued at 35 cm, 60 cm, and 85 cm) from the upper part of the core. After a few hours of extraction, the pore waters were transferred into 20 ml polyethylene bottles. On-board analysis included E_H /pH values, alkalinity, ammonium-, phosphate- and iron (II) concentration (Table 3.5).

Table 3.5 Summarized parameters of on-board pore water analysis (ALK = alkalinity).

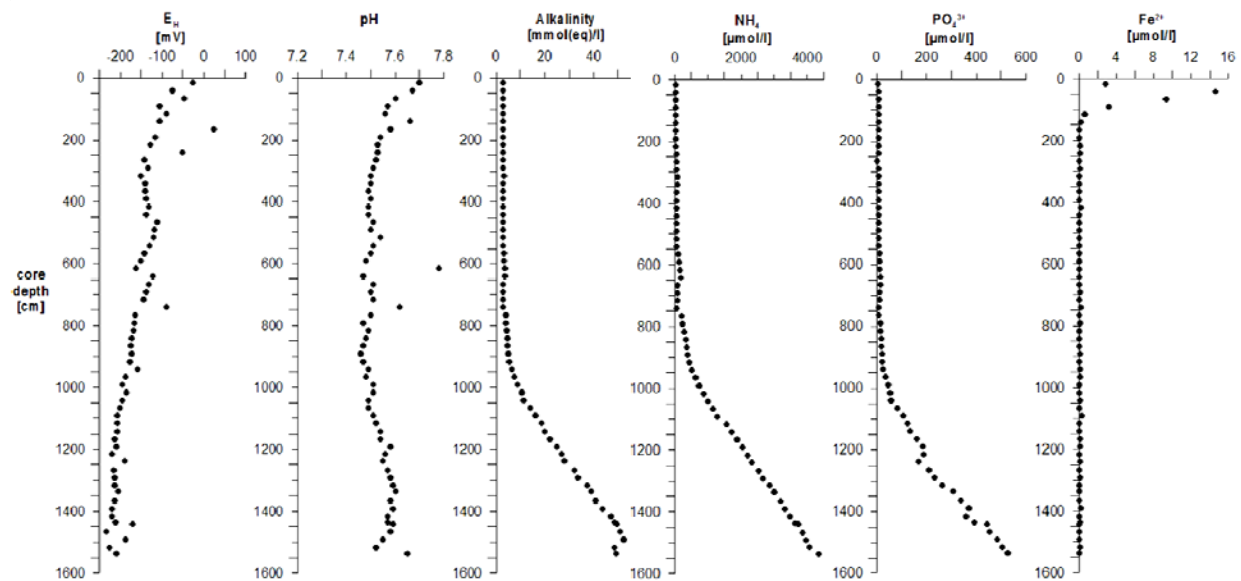
GeoB station	GC	MUC	E_H /pH	ALK	NH_4^+	Fe^{2+}	PO_4^{3-}
13108-1	x		x	x	x		
13113-1	x		x	x	x	x	x
13114-2	x			x			
13114-3	x		x	x			
13118-1	x		x	x	x	x	x
13118-2		x		x	x	x	x
13115-3	x		x	x	x	x	x
13120-3	x		x	x	x	x	x
13121-2	x		x	x	x	x	x

The redox potential (E_H) and pH value was measured with punch-in electrodes directly stuck into the sediment. Alkalinity was calculated by titration of 1 ml sample with HCl. Ammonium was determined via conductivity measurements. Phosphate and iron (II) concentration was detected by photometrical analysis. For further analysis at the University of Bremen, aliquots of the remaining pore water were prepared (Table 3.6) and stored in PE bottles. Subsamples for chloride and sulphate determinations were diluted 1:100 with deionised water (conductivity $<0,1 \mu S/cm$). Aliquots for sulphide measurements were prepared with ZnAc solution (0,3%) to fix all sulphide present as ZnS. ICP samples for determination of cations and rare earth elements were diluted 1:10 with deionised water (conductivity $<0,1 \mu S/cm$) and acidified with 65% HNO_3 - (suprapure).

Table 3.6 Aliquots prepared for further studies at the University of Bremen.

GeoB station	Alq. Cl ⁻	Alq. SO ₄	Alq. H ₂ S	Alq. ICP
13108-1	X	X		
13113-1	X	X	X	X
13114-2	X	X		
13114-3	X	X	X	X
13118-1	X	X	X	X
13118-2	X	X	X	X
13115-3	X	X	X	X
13120-3	X	X	X	X
13121-2	X	X	X	X

Five gravity cores (GeoB 13113-1, GeoB 13118-1, GeoB 13115-3, GeoB 13120-3, and GeoB 13121-2) were selected for detailed geochemical investigations.

**Fig. 3.23** Pore water concentration profiles from core GeoB 13113-1 (Ikaite site).

At the Ikaite site (GeoB 13113-1, Fig. 3.23), a single ikaite ($\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$) crystal was found at 14.35 cm below sea floor (m bsf) but no gas hydrates were observed. The E_H value decreases with increasing depth, indicating more reducing conditions in the deeper sediments. The pH value decreases down to 9.00 m bsf and then increases over a short interval down to 13.59 mbsf before decreasing again. At 9.00 mbsf, increasing alkalinity, ammonium and phosphate concentrations reveal enhanced degradation of organic matter. The measured methane concentration (Fig. 3.28) shows a significant peak at around 14.00 m bsf due to increased microbial (?) methane production. We therefore assume that we penetrated through the sulphate-methane transition zone with this core. The upcoming sulphate profile of this site will tell us more. Iron (II) is observed in the uppermost layers to 1.00 mbsf and further downwards beneath detection limit (0.05 mg/l).

The coring station GeoB 13118-1 (Fig. 3.24) is located at the Worm Hole pockmark which was already studied during M47/3 (2000) and M56 (2002).

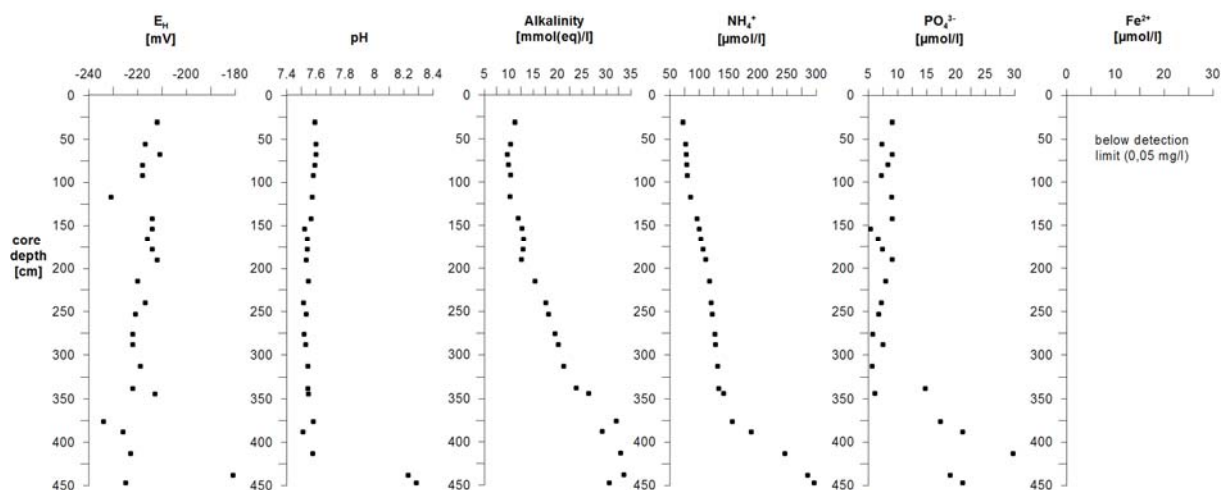


Fig. 3.24 Pore water profiles from GeoB 13118-1 (Worm Hole).

Here, carbonate concretions were found from the surface down to 1.49 mbsf and from 3.29 mbsf down to 4.08 mbsf. Remarkably, the pH value increases below 4.25 mbsf to a significantly higher level. Small pieces of disseminated gas hydrates were only found beneath 4.41 mbsf in the core catcher. The relatively high alkalinity values in the deeper part of the core, beginning from 350 cmbsf, are most likely related to the process of anaerobic oxidation of methane (AOM) which liberates large amounts of hydrogen sulphide and HCO_3^- into the pore water. Below 3.50 mbsf, a significant increase of ammonium and phosphate concentration appears which might be related to microbial activity (AOM).

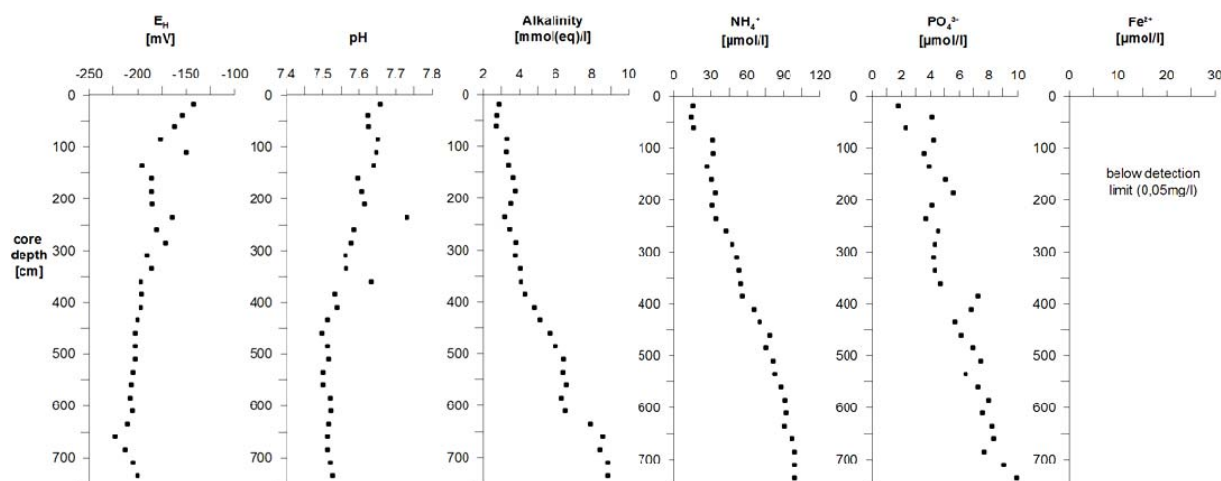


Fig. 3.25 Pore water profile of GeoB 13115-3 (Gas Flare2).

The station GeoB 13115-3 (Fig. 3.25) corresponds to a newly discovered active seepage site with a pronounced gas flare (Gas Flare2) detected by the PARASOUND system during M76/3a. We assume that this core is not in close vicinity to the actual active site of seepage. The concentration levels and shapes of the pore water profiles of alkalinity and ammonium at this site are characteristic for normal hemipelagic sediments. A single living bivalve (chemosymbiotic?) was found on the surface of the gravity core. Relatively small carbonate

concretions were found between 4.18 mbsf and 4.80 mbsf. No gas hydrates were observed in this core.

Another newly discovered active site corresponds to the coring station GeoB 13120-3 (Fig. 3.26) from the “Deep Hole” pockmark structure. The core contained gas hydrates from near the surface down to 2.95 m bsf. Numerous carbonate concretions were found in the interval from 0.50 mbsf to 2.40 mbsf. Due to gas hydrate dissociation during core recovery from the seafloor on deck, primary signals of pore water concentrations might be diluted by the hydrate waters. However, relatively high alkalinity values indicate high concentration of hydrogen sulphide and HCO_3^- most probably resulting from AOM. Pore water chloride concentration, which will be analyzed at the University of Bremen, will allow quantifying the amounts of gas hydrates initially present *in situ*.

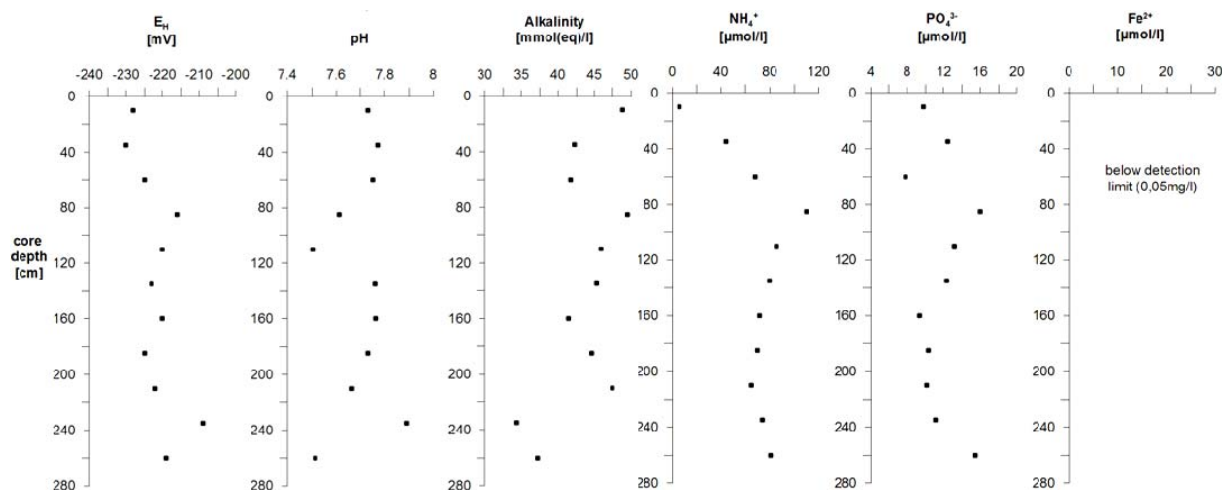


Fig. 3.26 Pore water concentration profiles from the core GeoB 13120-3 (Deep Hole).

Comparable signatures in the pore water profile were observed for GeoB13121-2 (Fig. 3.27) at the Regab pockmark site. This core contained carbonate concretions down to 1.74 mbsf. Here, no gas hydrates were found but gas cracks were observed in the lower part of the core.

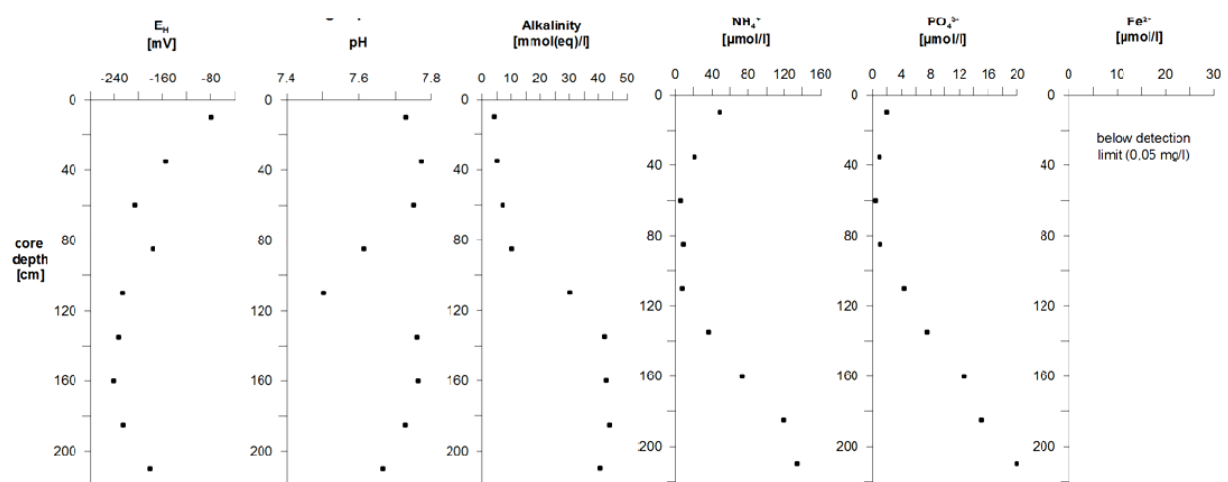


Fig. 3.27 Pore water concentration profiles from the core GeoB 13121-2 (Regab pockmark).

3.5.11 Exploration of Methanogenic Communities in Marine Sediments of the West African Margin

(L. Toffin, S. L'Haridon)

High amounts of methane are temporally stored at continental margins as free gas, dissolved or as solid hydrate. Despite that most of methane sink to atmosphere is mainly regulated by anaerobic methane oxidation (AOM) processes in marine sediments, large scale decomposition of gas hydrates and increase of methane concentrations in the atmosphere have influenced the global climate and probably caused global warming events. Isotopic and molecular data suggest that most methane in the ocean is of biogenic origin, i.e. it is produced by microbial methanogenesis. Although that methanogens play an important role in the anaerobic degradation of organic matter in marine sediments, the identity, activity and the role of methanogens in such ecosystems remains not completely understood. Indeed, only few methanogen species have been isolated in pure culture and characterised from marine sediments. Uncultivated lineages of Archaea closely related to methanogens groups have been identified in marine sediments as well. Methanogenesis is the last step of anaerobic degradation of organic matter. They are strict anaerobes and occur only in anoxic habitats. They can use a narrow range of substrates, primarily H_2/CO_2 and acetate. However, methylamines such as trimethylamine also serve as substrates for methanogenesis and may be a particularly important source for the methane in marine sediment. Such substrates have been termed “non-competitive” because, unlike hydrogen and acetate, methanogens have a competitive advantage over sulfate-reducing bacteria, the dominant process in marine sediment.

Only a very small percentage of Archaea identified in marine sediment samples by using molecular tools grow in traditional media. In order to study their physiological characteristics, limits, requirements, and performance in laboratory, the cultivation of methanogens members from the marine sediment remains a challenge. Even though cultivation remains essential to understand the microbial ecosystems functioning, molecular methods offer an alternative approach to identifying prokaryotes in crude samples without the need to culture. Explosive developments in microbial ecology have occurred in recent years, notably at the molecular level. The ribosomal RNA based analyses, in particular 16S, allows a phylogenetic identification of microorganisms, even of those which have not yet been isolated and studied in laboratory cultures. Methanogenic Archaea may be studied more specifically using a characteristic ‘functional’ marker gene. A specific marker for methanogens is the methyl coenzyme-M reductase (*mcrA*), the key enzyme of methanogenesis. Molecular phylogenetic surveys of methanogens and methanotrophs have been conducted in several methane seep environments targeting a functional gene for the *mcrA*.

The specific aim of the cruise GUINECO Leg M76/3a is to identify and cultivate *Archaea* involved in methane production in marine sediment associated to West African continental margin.

The major objectives of the GUINECO Cruise M76/3a are :

- Culturable methanogenic diversity in marine sediments of the West African margin
- Structure and distribution of methanogenic communities in West African margin
- Active microbial communities based on molecular methods

The aim of the cruise GUINECO Leg M76/3a is to explore the phylogenetic diversity and physiological potential of Archaea involved in methane production in marine sediments of the West African continental margin. Cultivation-independent and –dependent techniques will be employed to characterize the methanogenic populations at various depths and therefore along geochemical gradients and also to characterize the active methanogens in marine sediments. The diversity and the distribution of methanogen communities in marine sediments will be monitored by using molecular methods such as Denaturing Gradient Gel Electrophoresis (DGGE) with the subsequent construction and sequencing of archaeal (16S rRNA) and methanogenic (*mcrA*) clone libraries. In order to elucidate the abundance and the dominant nutritional group of methanogens in marine sediments, we will develop a molecular technique using fluorogenic PCR (quantitative PCR, Q-PCR) to quantify *mcrA* genes specific to the various phylogenetic groups of methanogenic Archaea. In addition, active microbial fraction of the community will be estimated by total RNA extraction and Reverse transcription assays of the 16S rRNA. Culturable methanogens will be studied by using selective media. Positive enrichments, based on microscopic observation of fluorescent cell under UV, will be monitored by DGGE in order to guide the isolation of new species.

Sediment samples were collected by multicorer (MUC) and gravity corer (GC) and are listed in Table 3.7. For methane concentration in pore water, it is essential to collect sediment immediately after the core arrived on deck. On board relative abundance of dissolved methane in sediments was deduced from Trace GC (Thermo Finnigan) by using the Headspace technique. Sample volumes of 3 cm³ were immediately transferred into a 10 mL headspace vial filled with 6 mL of NaOH 2.5% solution. After homogenizing and shaking, methane measurements were conducted by injecting 200 µL of the headspace gas into a Trace GC gas chromatograph. The retention time of methane was at 1.37 min. Peaks were quantified. Additional samples for total DNA and RNA extractions were collected from the center of the core of every 1 meter section or in less contaminated parts of the liner (for pre-cut liners with windows) by using autoclaved cut-end 2 cm³ syringes. Gas hydrates were collected from GeoB 13114-1 and centrifuged. Pore water in supernatant was removed and sediment was stored at –20°C.

Samples for DNA and RNA will be stored at –20°C back to the laboratory. Fixed samples (1 cm³) will be used for FISH (Fluorescent In Situ Hybridization) analysis in order to confirm the occurrence of microbial communities detected by molecular tools. For the enrichment of methanogens, 10 cm³ of sediment samples were re-suspended in reduced artificial seawater and stored at 4°C. Structure and distribution of Archaea methanogens from crude sediments and enrichments cultures will be compared by DGGE (Denaturing Gradient Gel Electrophoresis) based on the 16S rRNA genes analysis. In addition, identification of phylogenetic groups of microbes involved in methanogenesis pathway will be performed by using selected functional gene such as Methylcoenzyme M reductase (*mcrA*).

In order to study the interaction between methanogenic diversity and activity with geochemical gradients of potential metabolic substrates for methanogenesis, subsamples of pore water were collected for TOC (Total Organic Carbon), DIC (Dissolved Inorganic Carbon) in order to evaluate the dissolved CO₂ and volatile fatty acids (acetate, formate, ...). In addition, sediment samples were stored for analysis of methylated compounds such as

methylamine, dimethylamine and trimethylamine involved in methylotrophic methanogenesis pathway.

Table 3.7 Sample list for microbiology

Core	Latitude	Longitude	Water depth (m)	Remarks
GeoB 13113-1	06°55,918 S	008°59,984 E	3956	Ikaite Site
GeoB 13114-1	04°48,564 S	009°54,483 E	3091.6	Hydrate Hole
GeoB 13114-2	04°48,570 S	009°54,500 E	3090.2	Hydrate hole
GeoB 13114-3	04°48,641 S	009°54,512 E	3095.2	Hydrate hole
GeoB 13115-1	04°56,265 S	009°56,982 E	2988	Gas flare #2
GeoB 13118-1	04°45,605 S	009°56,423 E	3103.9	Worm hole
MUC 13118-2	?	?	?	Worm hole
GeoB 13120-3	04°36,195 S	009°30,397 E	3435.9	
GeoB 13121-1	05°47,835 S	009°42,736 E	3156	REGAB centre
GeoB 13121-2	05°47,881 S	009°42,805 E	3155.6	REGAB North-East

Gravity core GeoB 13113-1 was recovered from location 06°55,918 S 008°59,984 E with a 17.30 m of liner. The gravity core was cut into 1 meter long sections. Samples for methane determination were taken at 1 m intervals from the core segments directly on deck before capping and sections were stored at 4°C. Only one Ikaite crystal (calcium carbonate hexahydrate, $\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$) was observed at 14.35 m of depth in sediment. The methane profile depicted in Figure 3.28 shows a continuous increase of methane from 10.45 mbsf to the bottom of the core. The potential sulphate-methane transition zone (SMT) is located at a depth of 13 m which is in accordance with previous data from gravity core containing Ikaite crystals collected in the vicinity (Zabel and Schulz, 2001). The presence of authigenic calcium carbonate (Ikaite) in the SMT, where anaerobic oxidation of methane (AOM) occurs, suggest that microbial communities might be involved in Ikaite formation in anoxic sediments.

A second gravity core GeoB 13114-2 was collected at Hydrate Hole in the Gabon pockmark area. Based on previous bathymetric mapping, the core was recovered from the North West edge of the shallow high amplitude reflector of the pockmark observed on the PARASOUND sediment echosounder and side scan data (04°48,570 S. 009°54,500 E; Sahling et al., 2008). Results presented in Figure 3.29 suggest that the SMT occurs at 3 to 4 mbsf. Beneath the SMT, methanogens might be dominant. Gas hydrates have been observed at Hydrate hole (GeoB 13114-3) and Worm hole (GeoB 13118-1), but not from GeoB 13114-2.

Previous studies of the giant REGAB pockmark have shown that the centre is dominated by Mytilidae bivalves. High concentrations of methane (130 $\mu\text{L/L}$) were measured in the water column close to the seafloor (Olu et al., 2007). In the north-east of the pockmark, methane concentrations were around 1 $\mu\text{L/L}$ and the surface sediment is dominated by Vestimentifera field. During GUINECO Cruise M76/3a, two gravity cores were collected from both areas. The center of the REGAB pockmark is represented by GeoB 13121-1. This core contains stratified hydrates from 0.40 mbsf down to the core catcher (1.90 mbsf). A second core GeoB 13121-2 was collected in the North-East part of the REGAB pockmark. GeoB 13121-2 did not contain gas hydrate but gas bubbles from 1.60 to 2.10 mbsf. Methane profiles suggest that SMT is localized at 1.00 to 1.30 mbsf (Figure 3.30).

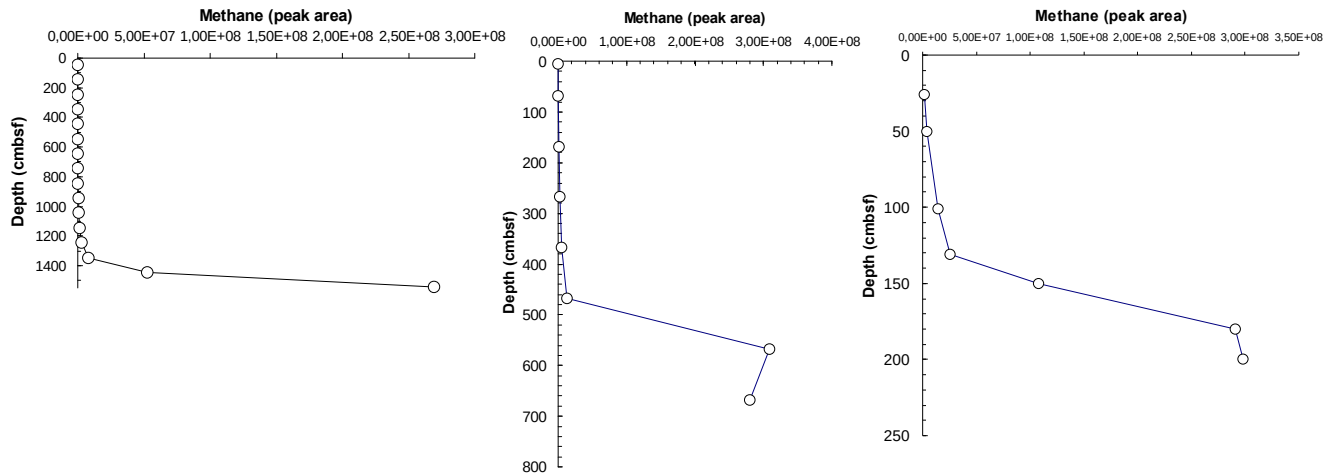


Fig. 3.28 (left) Methane profile of core GeoB 13113-1. Ikaite crystal was collected at 14.35 mbsf.

Fig. 3.29 (middle) Methane profile of core GeoB 13114-2 (Hydrate Hole).

Fig. 3.30 (right) Methane profile of core GeoB 13121-2 North-East of the REGAB pockmark.

3.6 Ship's Meteorological Station

n/a

3.7 Station list, Seismic profile list

ME763/264-1	17/06/2004		SEISREFL		12:04				6° 39.48' S	10° 17.26' E	3388.6
ME763/265-1			AUV-2	12:11	14:52	6° 39.66' S	10° 17.15' E	3401.1	6° 39.22' S	10° 17.45' E	
ME763/266-1		13108-1	GC-5	18:04	19:48	6° 42.43' S	10° 32.15' E	2482.0	6° 42.47' S	10° 32.15' E	2476.6
ME763/266-2		13109-1	GC-6	20:54	22:38	6° 42.42' S	10° 32.15' E	2475.7	6° 42.41' S	10° 32.14' E	2476.2
ME763/267-1			SEISREFL	23:41		6° 48.83' S	10° 28.36' E	2867.9			
ME763/267-1	18/06/2004		SEISREFL		08:59				6° 51.26' S	10° 39.19' E	2339.9
	19.06.-21.06.2008		Port call Luanda								
ME763/268-1	20/06/2004		AUV-3	13:15	15:40	6° 54.43' S	10° 35.86' E	2472.9	6° 54.98' S	10° 35.21' E	
ME763/269-1		13109-2	VS-5	17:20	01:46	6° 41.94' S	10° 32.17' E	2410.8	6° 42.55' S	10° 31.45' E	2401.0
ME763/270-1	21/06/2004	13110-1	VS-6	03:07	09:49	6° 34.46' S	10° 28.92' E	2397.9	6° 28.55' S	10° 27.88' E	2638.6
ME763/271-1		13111-1	VS-7	10:42	17:00	6° 23.40' S	10° 26.90' E	2434.7	6° 25.12' S	10° 27.12' E	2387.7
ME763/272-1			SEISREFL	17:15		6° 25.44' S	10° 27.06' E	2424.4			
ME763/272-1	22/06/2004		SEISREFL		13:53				6° 44.45' S	10° 20.63' E	3064.4
ME763/273-1		13112-1	GC-7	15:30	17:25	6° 41.60' S	10° 21.00' E	2704.1	6° 41.60' S	10° 20.96' E	2701.3
ME763/274-1		13112-2	GC-8	18:12	20:19	6° 41.64' S	10° 20.93' E	2704.2	6° 41.54' S	10° 21.03' E	2704.3
ME763/274-2		13112-3	GC-9	21:51	23:22	6° 41.38' S	10° 21.03' E	2704.3	6° 41.44' S	10° 20.97' E	2701.0
ME763/275-1			SEISREFL	23:50		6° 42.10' S	10° 20.86' E	2703.6			
ME763/275-1	23/06/2004		SEISREFL		08:38				6° 48.57' S	9° 51.69' E	3716.6
ME763/276-1		13113-1	GC-10	14:23	16:40	6° 55.91' S	9° 51.69' E	3716.6	6° 55.92' S	8° 59.98' E	3956.2
ME763/277-1	24/06/2004		SEISREFL	10:00	15:50	4° 46.54' S	9° 22.29' E	3354.2	4° 37.19' S	9° 37.80' E	3321.8
ME763/278-1	25/06/2004	13114-1	GC-11	12:37	14:41	4° 48.53' S	9° 54.46' E	3088.2	4° 48.57' S	9° 54.48' E	3093.2
ME763/279-1		13114-2	GC-12	18:56	20:50	4° 48.57' S	9° 54.48' E	3087.1	4° 48.58' S	9° 54.50' E	3088.9
ME763/280-1	26/06/2004		AUV-4	07:12	10:14	4° 47.72' S	9° 57.96' E	3077.8	4° 47.75' S	9° 56.33' E	
ME763/281-1		13114-3	GC-13	10:44	12:41	4° 48.57' S	9° 54.52' E	3090.5	4° 48.58' S	9° 54.53' E	3093.9
ME763/282-1			AUV-5	13:47	14:40	4° 47.77' S	9° 55.91' E	3088.5	4° 47.72' S	9° 55.26' E	3092.8
ME763/283-1		13115-1	GC-14	18:00	19:58	4° 56.30' S	9° 56.97' E	2986.0	4° 56.27' S	9° 56.99' E	2991.5
ME763/283-2		13115-2	GC-15	20:40	22:29	4° 56.27' S	9° 56.99' E	2991.0	4° 56.27' S	9° 56.99' E	2997.0
ME763/284-1	27/06/2004	13116-1	GC-16	07:00	08:53	4° 56.58' S	9° 57.36' E	2997.9	4° 56.66' S	9° 57.30' E	3003.5
ME763/285-1		13117-1	GC-17	13:15	15:00	4° 56.91' S	10° 9.73' E	2844.6	4° 56.87' S	10° 9.74' E	
ME763/285-2		13117-2	GC-18	15:13	17:20	4° 56.88' S	10° 9.74' E		4° 56.91' S	10° 9.76' E	2842.1
ME763/286-1	28/06/2004	13118-1	GC-19	01:20	03:26	4° 45.63' S	9° 56.43' E	3101.8	4° 45.60' S	9° 56.43' E	3096.1
ME763/286-2		13118-2	MUC-1	04:10	06:45	4° 45.60' S	9° 56.43' E	3096.9	4° 45.60' S	9° 56.42' E	3098.3
ME763/287-1		13115-3	GC-20	08:34	10:34	4° 56.32' S	9° 56.89' E	2988.6	4° 56.29' S	9° 57.00' E	2984.6
ME763/288-1		13115-4	GC-21	14:09	16:00	4° 56.26' S	9° 56.96' E	2997.9	4° 56.19' S	9° 56.88' E	2992.7
ME763/288-2			AUV-6	16:20	16:40	4° 56.15' S	9° 56.82' E	2988.7	4° 56.26' S	9° 56.81' E	
ME763/289-1	29/06/2004		AUV-7	15:13	15:35	4° 48.96' S	9° 22.42' E	3351.3	4° 48.97' S	9° 22.43' E	3343.5
ME763/290-1		13119-1	GC-22	19:58	22:00	4° 48.88' S	9° 25.81' E	3325.9	4° 48.88' S	9° 25.81' E	3328.3
ME763/291-1	30/06/2004	13119-2	GC-23	00:28	02:31	4° 47.96' S	9° 25.74' E	3362.3	4° 47.94' S	9° 25.76' E	3333.6
ME763/292-1			AUV-8	09:19	12:19	4° 49.17' S	9° 53.91' E		4° 49.17' S	9° 53.62' E	
ME763/293-1	01/07/2004	13120-1	GC-24	04:28	06:47	4° 36.34' S	9° 30.42' E	3427.8	4° 36.18' S	9° 30.54' E	3441.8
ME763/293-2		13120-2	GC-25	07:33	09:37	4° 36.16' S	9° 30.57' E	3436.1	4° 36.17' S	9° 30.56' E	3434.0
ME763/294-1			AUV-9	13:35	17:27	4° 49.06' S	9° 53.94' E	3089.5	4° 49.00' S	9° 53.83' E	
ME763/295-1	02/07/2004	13120-3	GC-26	04:34	06:45	4° 36.20' S	9° 30.36' E	3433.6	4° 36.14' S	9° 30.02' E	3407.8
ME763/296-1		13120-4	GC-27	07:10	09:11	4° 36.20' S	9° 30.32' E	3434.2	4° 36.21' S	9° 30.39' E	3442.5
ME763/297-1			AUV-10	12:30	16:00	4° 49.06' S	9° 53.59' E	3087	4° 49.11' S	9° 53.86' E	
	03/07/2004		Port call Pointe Noir								
ME763/298-1	04/07/2004		SEISREFL	06:50		4° 58.34' S	10° 2.43' E	2950.8			
ME763/298-1			SEISREFL		05:52				4° 56.45' S	9° 33.21' E	3252.8
ME763/299-1	05/07/2004	13121-1	GC-28	13:06	15:02	5° 47.82' S	9° 42.71' E	3156.1	5° 47.82' S	9° 42.80' E	3157
ME763/299-2		13121-2	GC-29	16:00	18:14	5° 47.94' S	9° 42.64' E	3156.4	5° 47.81' S	9° 42.80' E	3154.5
ME763/300-1			SEISREFL	18:20		5° 47.92' S	9° 42.81' E	3156.5			
ME763/300-1	06/07/2004		SEISREFL		23:28				6° 23.95' S	10° 20.66' E	2859.6
End of station work											
		Abbreviations:	SEISREFL:			Multichannel Seismics					
			GC:			Gravity corer					
			VS:			TV-sled					
			MUC:			Multicorer					
			AUV:			Autonomous Underwater Vehicle					
			USBL:			Ultra-short baseline underwater positioning (IXSEA, Posidonia)					
										</	

Profile number	Date	Time UTC	Latitude south	Longitude east	MaMuCS FFN	Date	Time UTC	Latitude south	Longitude east	MaMuCS FFN	Profile duration	Number of shots	Distance [km]	Distance [nm]	average course
GeoB08-247	12/6/08	00:27	10°08.88	11°24.71	386	12/6/08	4:00	10°04.44	11°43.31	1804	03:33	1418	34.895	18.84	76.6
GeoB08-248	12/6/08	04:11	10°05.08	11°43.70	1881	12/6/08	09:45	10°31.18	11°31.79	4460	05:34	2579	52.985	28.61	204.5
GeoB08-249	12/6/08	09:54	10°31.76	11°32.09	4520	12/6/08	13:10	10°41.70	11°47.55	5824	03:16	1304	33.628	18.16	122.7
GeoB08-250	12/6/08	13:23	10°42.45	11°47.22	5913	12/6/08	14:14	10°42.28	11°42.52	6254	00:51	341	8.559	4.62	272.1
GeoB08-251	12/6/08	14:33	10.68415	11.69882	6323	12/6/08	16:36	10°29.9	11°40.18	7195	02:03	872	20.892	11.28	351.1
GeoB08-252	12/6/08	16:43	10°29.88	11°40.70	7242	12/6/08	17:11	10°31.03	11°43.06	7432	00:28	190	4.796	2.59	116.0
GeoB08-253	12/6/08	17:20	10°31.71	11°43.19	7492	12/6/08	19:13	10°41.65	11°40.14	8243	01:53	751	19.228	10.38	197.1
GeoB08-254	12/6/08	19:23	10°41.67	11°39.35	8309	12/6/08	19:40	10°40.57	11°37.98	8421	00:17	112	3.220	1.74	308.8
GeoB08-255	12/6/08	19:48	10°39.92	11°38.11	8475	12/6/08	22:02	10°32.15	11°48.51	9370	02:14	895	23.780	12.84	53.2
GeoB08-256	12/6/08	22:03	10°32.10	11°48.58	9378	13/6/08	11:21	9°44.24	12°46.62	16351	13:18	6973	138.032	74.53	50.5
GeoB08-257	14/6/08	01:31	9°49.01	12°40.05	16823	14/6/08	02:08	9°46.80	12°42.74	17314	00:37	491	6.392	3.45	50.6
GeoB08-258	14/6/08	02:23	9°47.16	12°42.87	17506	14/6/08	03:03	9°49.49	12°40.03	18043	00:40	537	6.744	3.64	230.6
GeoB08-259	14/6/08	03:18	9°48.79	12°39.94	18240	14/6/08	03:55	9°46.62	12°42.58	18730	00:37	490	6.274	3.39	50.6
GeoB08-260	14/6/08	04:02	9°46.62	12°43.06	18833	14/6/08	04:08	9.78204	12.72215	18943	00:06	110	0.745	0.40	138.3
GeoB08-261	14/6/08	04:13	9.78788	12.72132	18999	14/6/08	04:50	9°49.51	12°40.63	19471	00:37	472	6.367	3.44	229.8
GeoB08-262	14/6/08	04:54	9°49.40	12°40.36	19519	14/6/08	05:10	9°48.24	12°39.36	19735	00:16	216	2.819	1.52	319.2
GeoB08-263	14/6/08	05:14	9°47.98	12°39.50	19795	14/6/08	06:55	9.71358	12.78406	21154	01:41	1359	16.766	9.05	55.6
GeoB08-264	14/6/08	07:09	9°42.30	12°46.62	21320	14/6/08	07:54	9.74368	12.72181	21945	00:45	625	7.417	4.00	235.0
GeoB08-265	14/6/08	08:00	9°44.46	12°42.78	22008	14/6/08	08:24	9°42.85	12°41.36	22326	00:24	318	3.951	2.13	318.6
GeoB08-266	14/6/08	08:32	9.71764	12.68153	22437	14/6/08	08:35	9.72209	12.68119	22489	00:03	52	0.496	0.27	184.4
GeoB08-267	14/6/08	08:45	9.72265	12.69298	22600	14/6/08	09:28	9°40.79	12°44.77	23180	00:43	580	7.522	4.06	51.2
GeoB08-268	14/6/08	09:42	9°41.45	12°45.11	23360	14/6/08	11:04	9°46.11	12°38.94	24471	01:22	1111	14.189	7.66	232.9
GeoB08-269	15/6/08	20:27	6°38.53	10°38.45	123	16/6/08	00:55	6.82261	10.31313	3509	04:28	3386	41.350	22.33	241.2
GeoB08-270	16/6/08	01:06	6.83223	10.31696	1953	16/6/08	04:44	6.83235	10.64805	3108	03:38	1155	36.529	19.72	90.0
GeoB08-271	16/6/08	04:54	6°50.55	10°38.96	3165	16/6/08	05:31	6°52.23	10°36.17	3385	00:37	220	6.000	3.24	238.9
GeoB08-272	16/6/08	05:38	6°51.90	10°35.72	3428	16/6/08	11:54	6.32712	10.39668	5739	06:16	2311	63.665	34.38	339.7
GeoB08-273	16/6/08	12:37	6.32606	10.4208	5856	16/6/08	13:46	6.4139	10.45522	6363	01:09	507	10.475	5.66	158.6
GeoB08-274	16/6/08	13:49	6°25.07	10°27.36	6371	16/6/08	18:23	6°46.59	10°20.65	8013	04:34	1642	41.723	22.53	197.3
GeoB08-275	16/6/08	18:27	6°46.92	10°20.77	8039	16/6/08	19:57	6°52.48	10°25.79	8581	01:30	542	13.829	7.47	137.9
GeoB08-276	18/6/08	00:31	6°36.44	10°21.86	134	18/6/08	01:31	6°35.53	10°27.22	494	01:00	360	10.004	5.40	80.4
GeoB08-277	18/6/08	01:46	6°35.94	10°27.17	584	18/6/08	02:59	6°36.84	10°21.44	1019	01:13	435	10.672	5.76	261.1
GeoB08-278	18/6/08	03:19	6°36.10	10°21.50	1142	18/6/08	04:23	6°35.02	10°26.73	1523	01:04	381	9.828	5.31	78.3
GeoB08-279	18/6/08	04:33	6.59109	10.45003	1588	18/6/08	05:02	6°37.55	10°26.35	1757	00:29	169	4.043	2.18	197.4
GeoB08-280	18/6/08	05:14	6°37.42	10°25.81	1833	18/6/08	06:11	6°33.11	10°23.94	2175	00:57	342	8.692	4.69	336.5
GeoB08-281	18/6/08	06:31	6°33.50	10°23.33	2296	18/6/08	07:29	6°37.94	10°25.23	2645	00:58	349	8.935	4.82	156.8
GeoB08-282	18/6/08	07:43	6°37.84	10°24.61	2724	18/6/08	08:37	6°33.75	10°22.61	3050	00:54	326	8.421	4.55	333.9
GeoB08-283	18/6/08	08:53	6°34.25	10°22.11	3149	18/6/08	09:47	6°37.87	10°23.79	3472	00:54	323	7.382	3.99	155.1
GeoB08-284	18/6/08	09:55	6°38.09	10°23.36	3516	18/6/08	11:14	6°38.00	10°18.28	3990	01:19	474	9.347	5.05	271.0
GeoB08-285	19/6/08	01:01	6°50.16	10°25.77	136	19/6/08	02:05	6°50.16	10°21.09	521	01:04	385	8.606	4.65	90.0
GeoB08-286	19/6/08	02:22	6°50.56	10°21.13	625	19/6/08	03:20	6°50.57	10°26.04	973	00:58	348	9.029	4.88	90.1
GeoB08-287	19/6/08	03:43	6°50.36	10°25.68	1111	19/6/08	04:45	6°50.36	10°20.84	1482	01:02	371	8.900	4.81	90.0
GeoB08-288	19/6/08	04:58	6°50.78	10°21.18	1561	19/6/08	08:43	6°50.92	10°38.76	2909	03:45	1348	32.327	17.46	90.5
GeoB08-289	22/6/08	18:27	6.46283	10.43838	50	22/6/08	19:26	6°30.18	10°22.41	407	00:59	357	8.440	4.56	238.2
GeoB08-290	22/6/08	19:34	6°30.56	10°22.61	455	22/6/08	21:32	6.56326	10.53122	1161	01:58	706	18.067	9.76	109.3
GeoB08-291	22/6/08	21:40	6°34.21	10°31.72	1207	22/6/08	22:51	6°35.27	10°26.23	1635	01:11	428	10.290	5.56	259.1
GeoB08-292	22/6/08	23:06	6°35.54	10°26.57	1724	23/6/08	00:14	6°34.57	10°31.85	2133	01:08	409	9.879	5.33	79.6
GeoB08-293	23/6/08	00:20	6°34.80	10°32.04	2164	23/6/08	01:43	6.67545	10.56306	2677	01:23	513	11.081	5.98	163.1
GeoB08-294	23/6/08	01:48	6°40.82	10°33.64	2694	23/6/08	03:14	6.7284	10.46976	3208	01:26	514	11.366	6.14	242.1
GeoB08-295	23/6/08	03:27	6°44.25	10°28.52	3284	23/6/08	04:32	6°41.78	10°33.43	3677	01:05	393	10.123	5.47	63.3
GeoB08-296	23/6/08	04:40	6°41.41	10°33.23	3728	23/6/08	08:05	6.66839	10.29651	4970	03:25	1242	28.503	15.39	274.8
GeoB08-297	23/6/08	08:13	6°40.45	10°17.56	5005	23/6/08	08:31	6°41.82	10°17.55	5115	00:18	110	2.537	1.37	180.4
GeoB08-298	23/6/08	08:36	6°41.96	10°17.90	5146	23/6/08	09:57	6°41.16	10°24.43	5633	01:21	487	12.102	6.53	83.0
GeoB08-299	23/6/08	10:13	6°41.38	10°23.97	5728	23/6/08	11:11	6°41.88	10°19.69	6072	00:58	344	7.927	4.28	263.3
GeoB08-300	23/6/08	11:29	6°41.55	10°19.76	6182	23/6/08	11:59	6.68806	10.36624	6369	00:30	187	4.103	2.22	83.1
GeoB08-301	23/6/08	12:06	6.68185	10.36836	6437	23/6/08	12:17	6°40.36	10°21.40	6467	00:11	30	1.645	0.89	308.1

Profile number	Date	Time UTC	Latitude south	Longitude east	MaMuCS FFN	Date	Time UTC	Latitude south	Longitude east	MaMuCS FFN	Profile duration	Number of shots	Distance [km]	Distance [nm]	average course
GeoB08-302	23/6/08	12:25	6°40.59	10°21.12	6518	23/6/08	13:04	6°42.81	10°20.90	6751	00:39	233	4.131	2.23	185.7
GeoB08-303	24/6/08	01:16	6°42.13	10°21.35	222	24/6/08	01:50	6.66373	10.33475	436	00:34	214	4.864	2.63	331.3
GeoB08-304	24/6/08	01:55	6°39.75	10°19.75	456	24/6/08	07:51	6.78783	9.86995	3389	05:56	2933	52.556	28.38	254.7
GeoB08-305	25/6/08	11:11	4.80627	9.3757	254	25/6/08	11:14	4.80606	9.3799	300	00:03	46	0.466	0.25	87.1
GeoB08-306	5/7/08	08:21	5°0.092	10°0.519	327	5/7/08	09:39	4.8983	9.90645	908	01:18	581	16.111	8.70	315.3
GeoB08-307	5/7/08	09:46	4.90258	9.90092	960	5/7/08	10:09	4.93235	9.89114	1138	00:23	178	3.481	1.88	198.2
GeoB08-308	5/7/08	10:18	4.93529	9.89798	1200	5/7/08	11:35	4.93806	9.9882	1800	01:17	600	9.994	5.40	91.8
GeoB08-309	5/7/08	11:41	4°55.89	9°59.39	1825	5/7/08	12:48	4.86983	9.88255	2341	01:07	516	13.713	7.40	299.9
GeoB08-310	5/7/08	12:52	4°51.91	9°52.85	2362	5/7/08	13:49	4.77691	9.88571	2793	00:57	431	9.822	5.30	3.2
GeoB08-311	5/7/08	13:54	4°46.28	9°52.73	2823	5/7/08	15:08	4°43.16	9°43.78	3379	01:14	556	17.500	9.45	289.2
GeoB08-312	5/7/08	15:10	4°43.16	9°43.78	3388	5/7/08	16:11	4°40.188	9°36.723	3851	01:01	463	14.141	7.64	292.8
GeoB08-313	5/7/08	16:13	4°40.188	9°36.723	3866	5/7/08	17:41	4°34.740	9°28.008	4524	01:28	658	18.990	10.25	302.0
GeoB08-314	5/7/08	17:50	4°34.392	9°28.110	4591	5/7/08	18:29	4°33.270	9°30.947	4883	00:39	292	5.635	3.04	68.4
GeoB08-315	5/7/08	18:37	4°33.690	9°31.143	4945	5/7/08	20:58	4.77644	9.4536	6000	02:21	1055	24.960	13.48	196.9
GeoB08-316	5/7/08	21:04	4°47.25	9°26.863	6050	5/7/08	21:39	4°50.388	9°25.248	6307	00:35	257	6.531	3.53	207.2
GeoB08-317	5/7/08	21:54	4.8337	9.41775	6420	5/7/08	22:16	4°47.611	9°25.092	6586	00:22	166	4.467	2.41	0.6
GeoB08-318	5/7/08	22:33	4.79748	9.42659	6671	5/7/08	23:00	4°49.54	9°27.17	6910	00:27	239	4.272	2.31	137.0
GeoB08-319	5/7/08	23:19	4°49.63	9°26.94	7055	5/7/08	23:49	4°48.30	9°23.69	7258	00:30	203	6.484	3.50	292.3
GeoB08-320	6/7/08	0:10	4°48.23	9°23.64	7431	6/7/08	01:07	4°48.24	9°28.00	7870	00:57	439	8.046	4.34	90.1
GeoB08-321	6/7/08	01:12	4.80832	9.47071	7911	6/7/08	01:22	4.82526	9.47021	7986	00:10	75	1.883	1.02	181.7
GeoB08-322	6/7/08	01:27	4°49.64	9°27.77	8018	6/7/08	02:02	4°47.64	9°24.09	118	00:35	219	7.736	4.18	298.5
GeoB08-323	6/7/08	02:13	4°47.31	9°24.57	198	6/7/08	02:27	4°47.32	9°25.62	303	00:14	105	1.938	1.05	90.5
GeoB08-324	6/7/08	02:30	4°47.46	9°25.82	326	6/7/08	04:05	4°52.66	9°30.85	1041	01:35	715	13.376	7.22	136.0
GeoB08-325	6/7/08	04:08	4.87763	9.51665	1055	6/7/08	04:40	4.87789	9.55765	1345	00:32	290	4.540	2.45	90.4
GeoB08-326	6/7/08	19:24	5.84251	9.71689	15	6/7/08	19:52	5.88075	9.72108	242	00:28	227	4.274	2.31	173.7
GeoB08-327	6/7/08	20:04	5°52.81	9°42.82	318	6/7/08	21:24	5°44.909	9°42.803	916	01:20	598	14.633	7.90	359.9
GeoB08-328	6/7/08	21:42	5°45.125	9°42.581	1051	6/7/08	22:25	5°49.082	9°42.576	1378	00:43	327	7.328	3.96	180.1
GeoB08-329	6/7/08	22:37	5°49.040	9°42.899	1466	6/7/08	23:09	5°45.94	9°42.90	1702	00:32	236	5.741	3.10	0.0
GeoB08-330	6/7/08	23:27	5°46.04	9°42.67	1835	7/7/08	00:00	5.81626	9.71154	2088	00:33	253	5.437	2.94	179.6
GeoB08-331	7/7/08	00:03	5°49.16	9°42.90	2108	7/7/08	00:35	5.84782	9.75084	2349	00:32	241	5.071	2.74	128.5
GeoB08-332	7/7/08	00:40	5°50.65	9°45.36	2389	7/7/08	01:08	5.80043	9.75611	2600	00:28	211	4.860	2.62	0.1
GeoB08-333	7/7/08	01:12	5°47.86	9°45.05	2623	7/7/08	01:48	5.79769	9.68543	2915	00:36	292	7.230	3.90	270.0
GeoB08-334	7/7/08	01:51	5°47.68	9°40.93	2916	7/7/08	02:14	5.7605	9.66735	3098	00:23	182	4.134	2.23	336.5
GeoB08-335	7/7/08	02:19	5°45.47	9°39.57	3127	7/7/08	02:36	5.7629	9.63062	3262	00:17	135	3.242	1.75	260.0
GeoB08-336	7/7/08	02:40	5°46.09	9°37.68	3291	7/7/08	03:59	5°52.486	9°40.037	3878	01:19	587	12.616	6.81	159.8
GeoB08-337	7/7/08	04:06	5°52.347	9°40.481	3929	7/7/08	05:38	5°45.05	9°44.092	4618	01:32	689	15.063	8.13	26.3
GeoB08-338	7/7/08	05:50	5.73818	9.73425	4680	7/7/08	06:04	5°44.292	9°42.67	4812	00:14	132	2.552	1.38	270.0
GeoB08-339	7/7/08	06:08	5°44.57	9°42.50	4846	7/7/08	07:09	5°49.644	9°42.508	5305	01:01	459	9.397	5.07	179.9
GeoB08-340	7/7/08	07:15	5.82959	9.71312	5377	7/7/08	07:35	5°48.818	9°44.076	5493	00:20	116	2.964	1.60	53.4
GeoB08-341	7/7/08	07:38	5°48.528	9°44.075	5521	7/7/08	08:25	5°44.422	9°42.480	5874	00:47	353	8.152	4.40	338.8
GeoB08-342	7/7/08	08:34	5°44.703	9°41.956	5942	7/7/08	09:00	5°46.775	9°40.597	6139	00:26	197	4.582	2.47	213.3
GeoB08-343	7/7/08	09:08	5°47.067	9°40.974	6198	7/7/08	09:44	5°47.075	9°44.144	6464	00:36	266	5.841	3.15	90.1
GeoB08-344	7/7/08	09:50	5°47.429	9°44.255	6511	7/7/08	09:52	5°47.655	9°44.279	6530	00:02	19	0.421	0.23	173.9
GeoB08-345	7/7/08	09:58	5°47.820	9°43.890	6572	7/7/08	10:17	5°47.821	9°41.845	6712	00:19	140	3.768	2.03	270.0
GeoB08-346	7/7/08	10:23	5°48.145	9°41.713	6756	7/7/08	10:26	5°48.395	9°41.708	6780	00:03	24	0.463	0.25	181.1
GeoB08-347	7/7/08	10:34	5°48.575	9°42.192	6840	7/7/08	10:58	5°48.58	9°44.28	7021	00:24	181	3.847	2.08	90.1
GeoB08-348	7/7/08	11:00	5.81004	9.73981	7036	7/7/08	15:46	5°53.951	10°8.138	9178	04:46	2142	44.862	24.22	102.7
GeoB08-349	7/7/08	15:52	5°54.315	10°8.426	9224	7/7/08	16:46	5°58.83	10°9.565	9629	00:54	405	8.621	4.65	165.8
GeoB08-350	7/7/08	16:46	5°58.83	10°9.565	9632	7/7/08	17:52	6°04.145	10°10.58	10127	01:06	495	10.019	5.41	169.2
GeoB08-351	7/7/08	17:53	6°04.145	10°10.58	10130	7/7/08	18:42	6°7.943	10°12.045	10497	00:49	367	7.534	4.07	158.9
GeoB08-352	7/7/08	18:43	6°8.014	10°12.124	10507	7/7/08	19:38	6.19001	10.26828	10919	00:55	412	9.636	5.20	130.4
GeoB08-353	7/7/08	19:46	6.20107	10.26977	10979	7/7/08	20:26	6.25239	10.2399	11279	00:40	300	6.588	3.56	210.2
GeoB08-354	7/7/08	20:35	6.26456	10.23637	11346	7/7/08	21:06	6.30774	10.23026	11579	00:31	233	4.845	2.62	188.1
GeoB08-355	7/7/08	21:12	6.31577	10.23076	11624	7/7/08	21:39	6.352	10.23666	11826	00:27	202	4.079	2.20	170.8
GeoB08-356	7/7/08	21:50	6.3626	10.24784	11909	7/7/08	22:51	6.38943	10.31962	12363	01:01	454	8.469	4.57	110.5

3.8 **Data and Sample Storage and Availability**

Data sets of different kinds had been collected. While conventional cores will be stored in the MARUM core repository, gas hydrate samples and carbonates will be handled by the individual PIs of the cruise to ensure proper use for scientific projects. As a result of the cooperation with the IFREMER, some of the material will be stored at IFREMER.

Seismic and acoustic data are of large volume, and will be handled by the PIs of the project. While a reduced data set of bathymetry and PARASOUND has to be passed on to the BSH, the full data sets are archived in MARUM by the responsible scientist. Data volumes are on the order of several TeraByte.

3.9 **Acknowledgements**

We thank Captain Jakobi and the crew of R/V METEOR for the excellent support.

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Process Studies in the Eastern South Atlantic (PROSA)

Part 3b

Cruise No. M76, Leg 3b

July 17 – August 24, 2008
Walvis Bay – Walvis Bay



A. Boetius, V. Asendorf, C. Bienhold, F. Brinkmann, C. Decker, D. Fischer, P. Franke, A. Gassner, J. Groger, D. Huettich, C. Le Gall, H.A. Mai, J.P. Meyer, Muller, N. Nowald, K. Olu, O. Oluwatobi, P. Pop Ristova, V. Ratmeyer, M. Reuter, F. Steen, R. Stiens, F. Tardeck, J. Tonnius, M. Viehweger, C. Villaverde, F. Wenzhöfer, T. Wilkop, M. Zarrouk

Editorial Assistance:
Senatskommission für Ozeanographie der Deutschen Forschungsgemeinschaft
MARUM – Zentrum für Marine Umweltwissenschaften der Universität Bremen

Leitstelle Deutsche Forschungsschiffe
Institut für Meereskunde der Universität Hamburg

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4.1 Summary/Kurzfassung

The main objectives of cruise leg M76/3b “GUINECO” were the comparative biological, geological and biogeochemical analyses of fluid and gas seepage at cold seep ecosystems of the West African continental margin. This includes the detailed mapping of gas and fluid venting as well as gas hydrates and their associated ecosystems. The remotely operating vehicle QUEST4000 of MARUM was the main working tool of this leg. Measurements of different physical, chemical and geological processes were combined with intensive observation and sampling of seep communities, from micro- to megafauna. The program was developed in the framework of the cooperation between the MARUM (Bremen) and the French research institute IFREMER (Brest). Important observations were made during the GUINECO Leg b with regard to the co-existence of fluid and gas venting at water depths >3000m, the net flux of diffuse seepage of gas at different types of cold seeps and the biodiversity of different size classes of cold seep organisms coupled to geological and geochemical processes.

Hauptziel des Abschnitts M76/3b waren vergleichende biologische, geologische und biogeochemische Analysen von Fluid- und Gasaustrittsstellen („Cold Seeps“) am West-Afrikanischen Kontinentalhang. Dabei wurde eine Kartierung der Gas- und Fluidaustritte, sowie der assoziierten Ökosystemen durchgeführt. Die Messungen der verschiedenen physikalisch-chemisch-geologischen Prozesse wurden verknüpft mit umfangreichen biologischen Untersuchungen der speziellen „Cold Seep“-Lebensgemeinschaften. Das Gesamtvorhaben fand im Rahmen einer Zusammenarbeit zwischen dem Forschungsfeld E des DFG-Forschungszentrums Ozeanränder (RCOM) und dem französischen Forschungsinstitut IFREMER statt. Vergleichende Beobachtungen sind gelungen zu dem gleichzeitigen Austritt von gelöstem und gasförmigen Methan in der Gashydrat-Stabilisationszone bei >3000m, den geochemischen, geomikrobiellen und sedimentologischen Eigenschaften der Gasaustritte, der Nettoemission von diffusen Fluidaustritten und der Biodiversität verschiedener Größenklassen der „Cold Seep“-Gemeinschaften in Beziehung zu geologischen und geochemischen Prozessen.

4.2 Participants

Table 4. 1 List of scientific party

Name	Discipline	Institution
Boetius, Antje, Prof. Dr.	chief scientist	MPI-MM
Wenzhöfer, Frank, Dr.	in situ biogeochemistry	MPI-MM
Pop Ristova, Petra	in situ biogeochemistry	MPI-MM
Bienhold, Christina	biogeochemistry, microbiology	MPI-MM
Stiens, Rafael	biogeochemistry, microbiology	MPI-MM
Wilkop, Tomas	biogeochemistry, geotechnique	MPI-MM
Villaverde, Cesar J.C.	geophysics	Marum
Brinkmann, Florian	carbonates, GIS	GeoB
Gassner, André	porewater analysis	Marum
Tonnius, Jörn	porewater analysis	Marum
Gröger, Jens	porewater analysis	GeoB
Fischer, David	porewater analysis	Marum
Olu, Karine, Dr.	Biology	Ifremer
Le Gall, Christian	biology, geochemistry	Ifremer
Decker, Carole	Biology	Ifremer
Muller, Felix	Biology	CNRS
Asendorf, Volker	LIFT	MPI-MM
Steen, Frederique	microbiology	GU
Oluwatobi, Oni E.	microbiology	JU
Tardeck, Frederic	GIS	FIELAX
Ratmeyer, Volker, Dr.	ROV	Marum
Franke, Philip	ROV	Marum
Nowald, Nicolas, Dr.	ROV	Marum
Zarrouk, Marcel	ROV	Marum
Mai, Hoang Anh	ROV	Marum
Huettich, Daniel	ROV	Marum
Reuter, Michael	ROV	Marum
Meyer, Jörn Patrick	ROV	MPI-MM
Viehweger, Marc	ROV	MPI-MM



Fig. 4.1 Scientific party on M76/3b.

Participating Institutions

CNRS	Centre National de la Recherche Scientifique Siège:3, rue Michel-Ange, 75794 Paris cedex 16, France	www.locean-ipsl.upmc.fr
GeoB	Dept. of Geosciences, Bremen University Klagenfurter Str., 28359 Bremen, Germany	www.geo.uni-bremen.de
FIELAX	FIELAX GmbH Barkhausenstr. 4, 27568 Bremerhaven, Germany	www.fielax.com
GU	Ghent University Sint-Pietersnieuwstraat 25, 9000 Ghent, Belgium	www.ugent.be/en
Ifremer	Institut français de recherche pour l'exploitation de la mer B.P. 70, 29280 Plouzané, France	www.ifremer.fr
JU	Jacobs University Campus Ring 1, 28759 Bremen, Germany	www.jacobs-university.de
Marum	Centre for Marine Environmental Science Leobener Str., 28359 Bremen, Germany	www.marum.de
MPI-MM	Max Planck Institute for Marine Microbiology Celsius Str. 1, 28359 Bremen, Germany	www.mpi-bremen.de

4.3 Research Program

The main objectives of the cruise leg M76/3b “GUINECO” were the comparative biological, geological and biogeochemical analyses of fluid and gas seepage at cold seep ecosystems of the West African continental margin. This included the detailed mapping of gas and fluid venting as well as gas hydrates and their associated ecosystems. The remotely operating vehicle QUEST4000 of MARUM was the main working tool of this leg. Measurements of different physical, chemical and geological processes were combined with intensive observation and sampling of seep communities, from micro- to megafauna. The program was developed in the framework of the cooperation between the MARUM (Bremen) and the French research institute IFREMER (Brest).

Seep fluids transport methane and other hydrocarbons to the seafloor where they form the energetic basis of a rich microbial life and attract a variety of chemosynthetic organisms

acting as primary producers in the cold seep ecosystem. For this cruise leg, target areas were pockmarks of the deep West African margin, which are connected to deep subsurface gas reservoirs. We were especially interested in the study of the giant pockmarks of the deep Congo margin, which are known to host enormous gas reservoirs and dense and diverse biomasses of chemosynthetic organisms. Main objectives besides the comparative analyses of those different cold seep systems were to understand which factors cause the differences in the geo-physical transport of gas and other chemical components, and how these influence biogeochemical processes and biological patterns in the ecosystem. At regional scale another objective was to compare chemosynthetic communities according to the geological context; at local scale – especially at the Regab site - we have studied the role of habitat heterogeneity on biological assemblage structure and distribution. The Regab site off the Congo margin has been selected for long term monitoring in international cooperation. The collected data will be used to address questions of the phylogeography of chemosynthetic fauna at global scale. The contribution of RCOM E is linked to the French ANR program DEEPOASES and the Census of Marine Life program CheSS (Atlantic equatorial belt hypothesis).

The main research questions of GUINECO cruise M76/3b were:

- How does fluid and gas venting as well as diffusive seepage of gas influence biogeochemical processes at seeps?
- How high is the net flux of fluids and gases and other chemical compounds at different types of cold seeps?
- Which geochemical, geomicrobiological and sedimentological parameters control mineralization processes at gas and fluid vents?
- How is the biodiversity of different size classes of cold seep organisms coupled to geological and geochemical processes?

Specifically, leg M76/3b investigated for the first time the biogeochemical structure and functioning of cold seep ecosystems on the West-African margin. A main objective was the quantification of fluid flow rates and biogeochemical processes together with the investigation of mineral precipitation. To achieve these goals, we have developed sampling and in situ measurement strategies based on ROV video transects. The Regab giant pockmark lies at a water depth of ca 3000 m. It is characterized by abundant gas seeps with large accumulations of giant *Escarpiatubeworms*, symbiotic mussels, carbonate concretions, outcrops of gas hydrates, fluid flow and free gas ebullition. We have determined different microhabitats within pockmark, facies and diapir systems of the Regab area. Microhabitats of different seepage activity have been sampled by pushcores and water samplers, and have been analysed with a variety of in situ tools to obtain a quantitative understanding of biogeochemical processes. We have investigated how chemical, physical and geological parameters influence the composition and structure of seep ecosystems and the flux and consumption of the potential greenhouse gas methane. High resolution mapping and videomosaicking have been used to define a sampling strategy for assessing the relationship between fluid fluxes, gas ebullition, gas hydrate and carbonate distribution, transport of electron acceptors, differences in sedimentology and the distribution, structure and activity of seep communities. The investigations also comprised detailed studies of the in situ

biogeochemistry of oxygen, sulphur, methane, and other microbial process measurements. Valuable targeted samples of organisms and microbial populations were obtained from well-characterized habitats for the assessment of biodiversity and functioning of chemosynthetic communities. We will also resolve temporal variation by deploying moorings with ecological observation modules including camera systems, temperature as well as chemical sensors. This module will be recovered during the French expedition WACS.

4.4 Narrative of the cruise

The second leg of the expedition GUINECO started 11:00 am on Thursday, 17 July with leaving the port of Walvis Bay. We had to steam 1100 nautical miles to our main target area, the giant pockmarks and diapirs off Congo, Angola and Gabon. The previous leg M76/3a had provided us with bathymetry maps of different target areas as well as the positions for giant gas flares marking the escape of free gas from sites as deep as 3100 m. We aimed at exploring several of these sites with the ROV QUEST, to learn more about the geological, geochemical and biological consequences of such vigorous gas escape.

Unfortunately, on the second day of our departure, in the early hours of the 18 July, we were informed of a tragic loss in the family of one member of the ship's crew and it was decided immediately to disembark him at the nearest harbour, namely Walvis Bay. We left Walvis Bay again in the morning of the 19 July. Due to excellent weather conditions, the ship reached our first target, the Diapir Area off Angola, in the morning of the 23 July.



Fig. 4.3 Respiration measurements with the benthic chamber



Fig. 4.2 Sampling of gas bubbles from a mussel bed (DIAPIR site; all Photos source: Marum)

Here we carried out the first exploratory dive of this area (QUEST4000 dive 207), to obtain seafloor images of the source of the gas escape mapped by PARASOUND on the previous leg at 2800 m water depth. By using a combination of acoustic wayfinding with the forward looking sonar of the ROV and regular checks of characteristic features on the seafloor, we were able to track at least one of the sources of free gas emission at this diapir site. Following the sonar image of gas bubbles, we landed on a giant bed of chemosynthetic mytilid bivalves (Fig. 4.2). Unfortunately the dive lasted

only a few hours, because a major oil leak was discovered that forced us to recover QUEST.

We continued to the giant pockmark Regab off Congo and carried out four short dives between the 24 and the 28 July due to continuous problems with oil leakage. The dives 208, 209, 211 and 212 provided us with net and pushcore samples from bacterial mats and clam fields (Fig. 4.3), as well as with a first in situ microsensor and respiration chamber measurement. In alternation with dives and during repair times we carried out PARASOUND

and Multibeam transects as well as gravity coring, for the geophysical and geological characterization of the area (see station list). The coring aimed at retrieving carbonates and hydrates for a characterization of the gas system and associated processes of the Regab pockmark. The dives focused first on habitats dominated by a species of vesicomid bivalves, which dwell the sediments for sulphide to nourish the thiotrophic symbionts hosted in their gills. These vesicomid clams are often found at cold seeps and in association with hydrate bearing sediments. At Regab the healthy clams form typical assemblages in the reduced sediments close to the central area of the pockmark. We also came across large fields of dead bivalve shells witnessing previous areas of gas emission, which went extinct. After having measured the respiration of the clams and their associated community (Fig. 4.4), we sampled the patches with blade and push cores for biogeochemical and biological analyses.

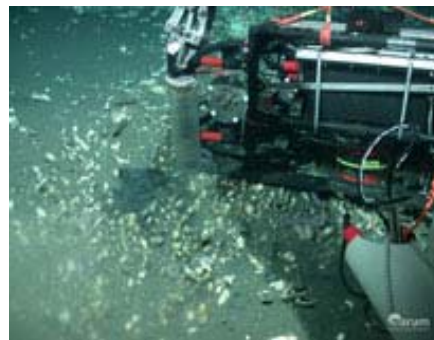


Fig. 4.4 Pushcore sampling in front of the benthic chamber on a field of living vesicomids.

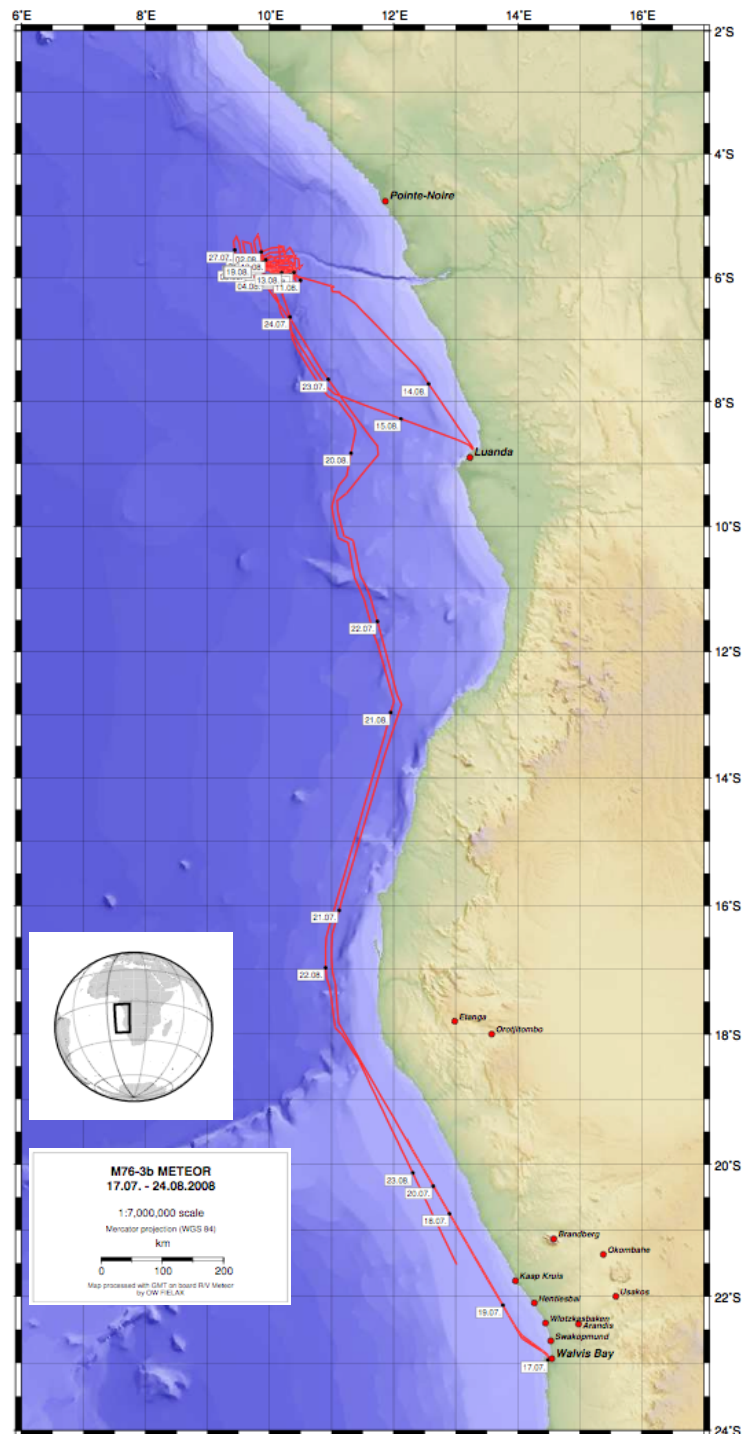
The problem with the oil leakage improved from dive to dive, however, we also encountered a major problem with the cable of the ROV. After dive 212, the cable came up strongly distorted and needed cutting and refitting work. We continued with dive 214 and 215 on the 30 and 31 July to finish the work at the first habitat site. Targets for the PARASOUND and Multibeam mapping were three previously unknown mud volcanoes (MV) between the Regab and the DIAPIR site (Fig. 4.8). We carried out videoguided Multicorer transects to detect potential gas seepage activity, but neither the visual inspection nor the coring on some central sites gave evidence for recent seepage. However, large fractions of the mud volcanoes were covered with carbonate cements indicating probably strong ancient seepage activities. Interesting, a gas flare was mapped on one of the MVs, showing that very locally parts of the MVs maybe active.

The fourth week was dedicated to exploration and measurements on the eastern part of the Regab pockmark. In 2000, dives of IFREMER's BIOZAIRE expedition found that the eastern part of the pockmark was characterized by a flat and sedimentary seafloor, covered by large mussel beds associated with gassy sediments. The first overview of this area 8 years later (Dives 217, 218 on 3 and 4 August) indicated considerable changes over time. The extension of the mussel beds was strongly reduced and they seem to be replaced by assemblages of vesicomid clams, potentially indicating a decrease in the gas flux. Still the benthic activity associated with the small mussel patches was very high, and indicated strong gas emissions.

After further maintenance, QUEST dives 222 and 223 (08-09 August) allowed us to carry out a series of benthic flux measurements on the remaining mussel beds as well as the vesicomid assemblages in the eastern area of the pockmarks, and we were able to deploy a series of carbonate colonization experiments as well as to collect more megafauna for the investigation of the diversity of chemosynthetic symbioses at Regab. Also, we found areas of gas bubble escape where they were not expected – away from the center and not associated with carbonate formation or benthic assemblages.

Unfortunately, between 10-14 August, we had to stop the ROV operations because the ROV suffered a complete black out. This forced us to steam to a close by harbour (Luanda, Angola) to receive spare parts from Bremen by courier. We arrived in Luanda to pick up the needed parts in the afternoon of the 14 August and after further repairs were able to dive again at Regab on the 15 August (dive 225). This dive allowed for retrieval of samples, in situ measurements and interesting video footage at another habitat with clam beds (bivalves of two families of Vesicomidae) in the Southwestern part of the Regab pockmark. This site was previously described as the largest clam field of the Regab pockmark, during its first exploration by the ROV VICTOR in 2001. Faced with another cable failure, we were able to carry out only one further dive (226) from the 18 to 19 August. The tasks included deployment of several profiling instruments, recovery of some experimental moorings, biological samples, water chemistry and “videomosaicking” to produce

visual maps for quantitative estimates on the areal coverage of the benthic habitats. Finally, we also carried out some measurements in the central pockmark area. A peculiar feature of this habitat is the attachment of mytilid bivalves to the tubes, as well as the dense colonization by hydroid polyps. The dive ended at 5:15 am in the morning of the 19 August with the recovery of the ROV QUEST before starting a final, long PARASOUND transect in the direction of Walvis Bay (Namibia). The expedition M76/3b ended in Walvis Bay (Fig. 4.5) port in the morning of the 24 August.



4.5 Preliminary Results

4.5.1 Geology of cold seeps

(C.J.C. Villaverde, F. Tardeck, V. Ratmeyer, P. Franke, D. Huettich, H.A. Mai, J.P. Meyer, N. Nowald, M. Reuter, M. Viehweger, M. Zarrouk, A. Boetius, A. Gaßner, Tomas Wilkop, F. Brinkmann)

During M76/3b cruise, geological hydro-acoustic surveys were performed in order to investigate the topography and acquire sediment structure information of known cold seeps e.g. Regab and Diapir area, as well to explore for potential new cold seep structures via detection of gas flares. For this purpose two hydro-acoustic systems were used, a Multibeam Echosounder Hydrosweep and a PARASOUND Sediment Echosounder. The first one was used to acquire real time image from the topography of the seafloor, while the second one was used to acquire sedimentary information from the upper 50 to 200 m layers below the seafloor and also for the gas flare mapping in the areas of interest. Two multibeam echosounders were available for this cruise: EM-710, which operates at 15.5 kHz and is designed for shallow water depths (up to 1000 m) and EM-120, which operates at 12.0 kHz and is designed for deeper areas (up to 4000 m). The principle of both echosounders is similar: a transducer system mounted parallel with the ship's keel line projects sonar frequencies with an angular coverage up to 150° perpendicular to the ship direction and up to 4° parallel to it, afterwards the reflected signals are detected by the receiver which is mounted in the athwart ship direction. The beam spacing can be equidistant, equiangular, or in-between depending on the water depth. The area coverage can go up to 6 times the water depth or 20 km depending on the echosounder used. The PARASOUND sediment echosounder system projects a sound beam with an opening angle of 2° with a pinging rate controlled by the water depth. In order to penetrate into the sediments the system works with two frequencies, a Primary High Frequency (PHF) of 18 kHz and a Secondary Low Frequency (SLF) of 4 kHz. This last one travels inside the cone produced by the PHF and passes through the sediments giving not only information about the sedimentary structure but also about their reflectivity. On the other hand the PHF is used generally for the recognition of gas flares in the water column as well as other changes in the composition of water.

During cruise M76/3b, there were 26 stations in total and more than 265 transects, from which 200 PARASOUND profiles could be obtained. Aforementioned systems operated simultaneously during all transit routes and during break times of the ROV, accumulating in total more than 450 hours of recording for bathymetry and 390 hours of recording for PARASOUND. These short statistics include hours and transects from the following transit routes: Walvis Bay - Diapir Area, Diapir Area - Regab, Regab - Luanda, Luanda - Regab and Regab – Walvis Bay. Whenever it was possible, transects were designed to be parallel to transects from leg M76/3a in order to improve the bathymetry and knowledge about sediment structures of these areas. Occasionally some minor failures were present in both systems, which were repaired in short time. However at the beginning of station 336 (on 1 August at 01:00 am) the PARASOUND system had a major failure, which obligated us to change the original route of the station to another area and acquire only bathymetry for the following days. At the beginning of station 365 (on 9 August 05:00 pm), with a great effort from

METEOR's electronics technicians, it was possible again to utilize the PARASOUND system. Short surveys, usually from 6 to 10 h, and one long survey of almost 35 h were performed around the Regab cold seep. The main objective of these surveys was to recognize features of interest, from bathymetry, and acquire PARASOUND profiles across the Congo Canyon - Diapir Area, in order to understand the lithological transitions and internal sediment deformation. Apart from Diapir and Regab, other locations of interest were the mud volcanoes area, located 40 miles east of Regab and the 3 pockmarks (Fig. 4.6), app. 5 miles to the north east of the same reference point. Additionally, at both areas a gas flare mapping was performed. The first target for PARASOUND was to locate the gas flare at the Diapir Area using as reference the coordinates of a gas flare detected during the previous leg M76/3a. The gas flare was found (S 06° 41.613', E 10° 20.888'), and the new coordinates were used for the first diving test of the ROV (Fig. 4.7).

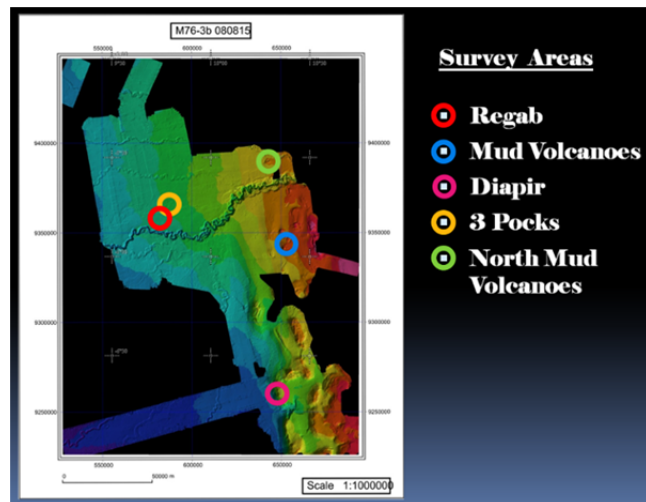


Fig. 4.6 Bathymetry of surveyed area during M76/3b (Note: Diapir Area was surveyed during leg M76/3a).

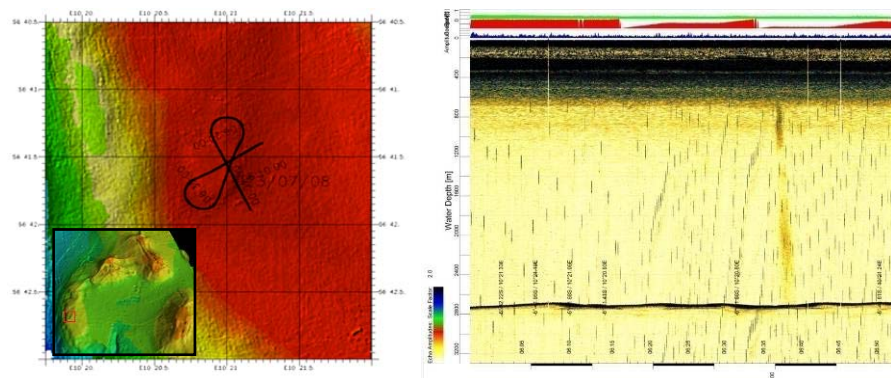


Fig. 4.2 Left: Track for gas flare mapping (left corner box: regional picture). Right: Gas flare at Diapir Area.

Transects acquired during the transit from Diapir to Regab through a ridge, revealed some pockmarks located in the northern part of the Diapir Area. Important contribution to this leg was the discovery of a new interesting area located east of Regab and north of Diapir area, using hydroacoustic methods. In this area apparently a young deformation in the sediments, probably caused by salt diapirism, created several mud volcanoes and other surrounding features. The mud volcanoes, preliminarily called Pichu Pichu (S 05° 57' 36", E 10° 22' 12"), Misti (S 05° 54' 40", E 10° 23' 30") and Chachani (S 05° 52' 12", E 10° 21' 18") are at least 1.5 km wide and 100 m high (Fig. 4.8). The last two are surrounded by collapsed sediments and have small depressions at the flat top. The first one shows a peak at the top and seems to be related to 3 faults, which have SE-NW orientation. The gas flare mapping in this area took

place during station 382. During the third track over Misti Mud Volcano, at S 06° 41.613' E 10° 20.888', a weak signal of a probable gas flare was identified (Fig. 4.9). Additionally, bathymetry and SHF profiles around this area showed strong reflectors approaching the top, giving indications for a small fault in the ground. To confirm the presence of gas flare, further mapping over this area is suggested. TV-MUC transects (station 354 and 352) were performed at Misti Mud Volcano and Pichu Pichu. Other aligned features could be recognized in this area. In the western and northwestern part two families of pockmarks exist, 15 km deep and at least 500 m wide. Westward, apparently younger deformation is taking place with orientation S – N, which has produced two depressions that show strong reflections in PARASOUND profiles. In the eastern part, more prominent features related to a fault, also aligned S – N, are present. Although the eastern chain of features seems to have more mature deformation than the western part, it is likely that gas seepage still take place there, since some PARASOUND profiles revealed stronger reflectivity at the top of them.

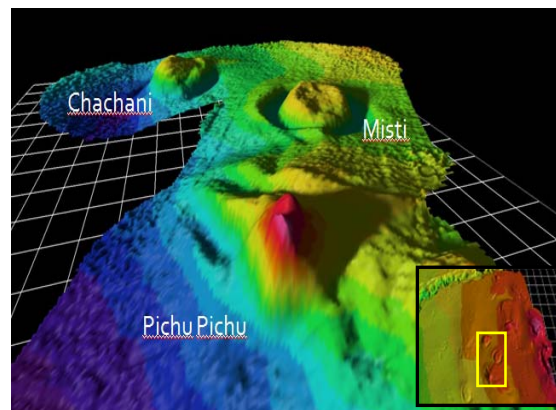


Fig. 4.3 3D view of three mud volcanoes discovered during M76/3b (lower right corner: regional map of the area, depicting aligned features).

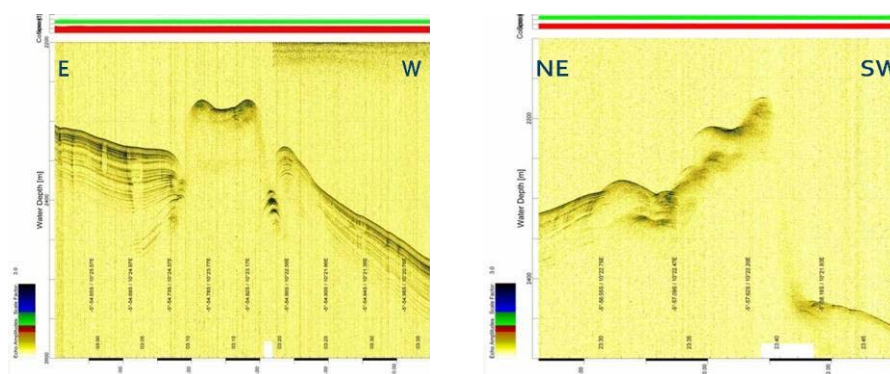


Fig. 4.4 PARASOUND profiles throughout Misti and Pichu Pich mud volcanoes. Collapse of sediments is easily recognized as well as steep walls of 100 m and 200 m, respectively.

As revealed from the bathymetry data acquired during this cruise the Regab pockmark cold seep is a very flat area, hence difficult to identify (Fig. 4.11). Only the SHF profiles over this area show acoustic anomalies at the seafloor. Regab is located close to the Congo Canyon and is situated above extended strong reflector layer, found 50 m below the seafloor. Two cross profiles recorded during M76/3a gave new ideas for the possible route of migration of fluids to the bottom surface. The profiles show parallel faults breaking the sediment layers and creating small pieces of strong reflector in different levels. There also seems to be a lateral variation of the shallower sediment facies, with stronger reflectivity towards the Congo canyon (Fig. 4.12)

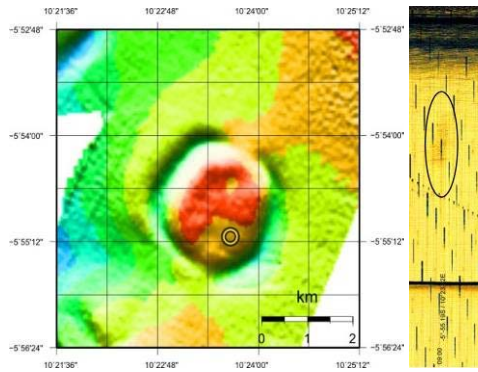


Fig. 4.6 Signal of gas flare at Misti Mud Volcano.

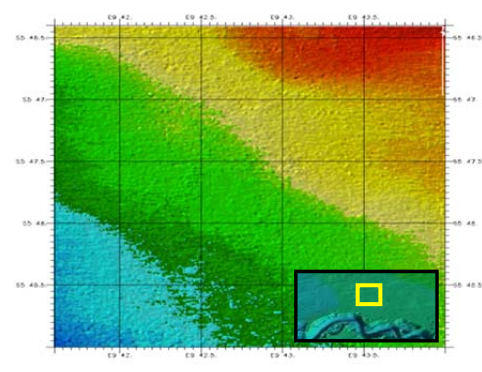


Fig. 4.5 Bathymetry of Regab.

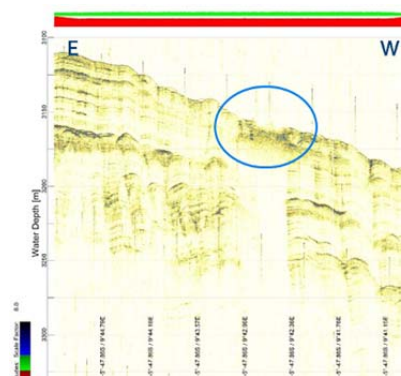
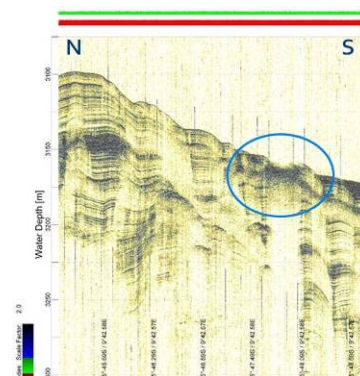


Fig. 4.7 SHF profiles showing strong reflector layer cut into pieces by several faults. Lateral variation in sediment facies is observed at the right of the left picture.

Originally, five areas had been selected for ROV dives, but due to technical problems we focused on the Regab pockmark, which lies at a water depth of ca 3000 m. It is characterized by abundant gas seeps with large accumulations of giant *Escarpi* tubeworms, symbiotic mussels, carbonate concretions, outcrops of gas hydrates, fluid flow and free gas ebullition. The ROV was used for ecosystem mapping and photomosaicking as well as for a high resolution sampling program of sediment and water column, based on several in situ tools (profiler, chamber, rhizone sampler, Insinc, gas flow meter, pressure tight samplers, push cores, blade cores, suction pump) (Table 4.2). We have used a shuttle to transport larger payloads to the bottom. Because dive time was limited, we used two subsequent dives to exchange the payload at the seafloor with the elevator. The ROV sampling concentrated on areas characterized by different microhabitats of chemosynthetic communities. It was attempted to sample each microhabitat (mussels, clams, tubeworms, bacterial mats) with push cores, blade cores, Insinc, water samples and slurp gun, and by in situ measurements with the profiler, Optode, Chamber and Rhizone sampler. We managed to sample different clam habitats in the centre, south and west of the Regab pockmark, and were able to probe both the clam patches as well as the area outside the clams for a comparison of the role of the sulphide-dwelling clams. Additional reference samples were obtained with TV MUC and box corer. Some dives included an ecosystem mapping part as well as bottom time to deploy long

term experiments and colonizers for future recovery by the WACS cruise. The detailed observations of all dives are provided in the dive summaries and protocols in the electronic version of the cruise report.

The deepwater ROV “QUEST 4000m” used during M76/3b aboard RV METEOR, is installed and operated at MARUM at the University of Bremen, Germany since May 2003. The QUEST ROV is based on a commercially available 4000 m rated deepwater robotic vehicle designed and built by Schilling Robotics, Davis, USA. During M76/3b, QUEST performed a total of 22 deployments (20 counted dives) to depths between 100 and 3166 m. Due to a number of technical problems from the beginning of the cruise, a total of only 14 dives resulted in 118 hours usable scientific bottom time. The remaining dives had to be disrupted at different stages and depths due to major problems with the compensation system, thruster failures, manipulator system failures and repetitive damage of the umbilical cable. Nevertheless, the majority of these issues could be repaired and eliminated instantly or during the expedition. In this regard, we are grateful for the ship’s assistance in providing alternative compensation oil as well as performing an extraordinary harbour stop in Luanda to acquire fibre-optic connectors. The latter were used more than usual due to severe problems with the umbilical cable and the need for cutting roughly 500 m of cable during 6 terminations at sea. QUEST was operated by a team of 9 pilots/technicians on a 24 hour basis with a resulting mean dive time of 10 hours, ranging from 4 to 27 hours total dive time per deployment. However, due to the originally anticipated 24 hour dive operations the crew was prepared to cope with long dives, as well as the unusual situation of regular intermediate dive and maintenance operations often round-the-clock. Close cooperation between ROV team and ship’s crew on deck and bridge allowed a smooth and professional handling during deployment and recovery. During diving, this cooperation allowed precise positioning and navigation of both the ship and the ROV, which was essential for accurate sampling and intervention work such as handling of the lift, instrument deployment and recovery. The ROV team is very grateful for this kind of steady support from the entire ship’s crew during the cruise.

The total QUEST system weighs about 45 tons (including the vehicle, control van, workshop van, electric winch, 5000 m umbilical, and transportation vans) and can be transported in four standard ISO 20 foot vans. A MacArtney Cormac electric driven storage winch is used to manage up to 5000 m of 17.6 mm NSW umbilical cable. The QUEST vehicle uses a Doppler velocity log (DVL, 1200 kHz) to perform underwater dynamic positioning, computer controlled displacement, and other automatic control functions. Absolute GPS based positioning is performed using the shipboard IXSEA Posidonia USBL positioning system. The QUEST SeaNet telemetry and power system provides a convenient way to interface all types of scientific equipment, with a current total capacity of 16 video channels and 60 RS-232 data channels. The scientific data system used at MARUM feeds all ROV- and ship-based science and logging channels into a commercial, adapted real-time database system (DAVIS-ROV). During operation, data and video, including HD (High Definition), are distributed in real time throughout ship’s laboratories to minimize crowding in the control van. This allows topside processing equipment to perform data interpretation and sensor control from any location on the host ship. Additionally, the pilot’s eight-channel

video display is distributed to client stations into the laboratories on the ship via simple CAT7 cable. This allows simple setup of detailed, direct communication between the laboratories and the ROV control van. Post-cruise data archival will be hosted by the information system PANGAEA at the World Data Centre for Marine Environmental Sciences (WDC-MARE). As a new approach for dive participation from the laboratories, computers were setup in the science laboratory to improve the access to, online ctd and intentionally other sensor data as well as extended planning and dive tracking using GIS. In accordance to GIS data preparation using ArcGIS version 9.1 by the scientific party, the software tool MIMOSA developed at IFREMER was successfully used to display and follow ROV and ship tracks upon GIS based map layers in real time. Dive maps and ROV station list from each dive is provided in the appendix (Fig. 4.9 and Table 4.11).

Table 4. 2 Scientific suite handled by Quest during M76/3b.

In situ instruments, handled during deployment/recovery operations by vehicle	ROV based tools installed on vehicle
MPI Lift system MPI Benthic Chamber MPI Benthic Microprofiler MPI Eddy horizontal profiler MPI XY Microprofiler MPI RCM autonomous current profiler MPI wood colonization experiment recovery GeoB ISPS Rhizone sampler GeoB Carbonate dissolution experiments IFREMER Blade Corer and dedicated racks IFREMER Calmar respiration chamber IFREMER Trac and Smac colonization experiments	ROV interchangeable draw-box basket Sea and Sun CTD real-time probe with turbidity sensor Pushcores, max. 16 INSINC incubation pushcores max. 4 T-Stick real-time 8 channel T-Lance KIPS discrete 9 sample water probe MPI handheld H2S sensor Hand-Nets Quantitative Gas Pressure Sampler Simple site markers

The space inside the QUEST 5 toolskid frame allows installation of mission-specific marine science tools and sensors. The initial vehicle setup includes two manipulators (7-function and 5-function), 7 colour video cameras, a digital still camera (Insite SCORPIO, 3.3 Mega-Pixel), a light suite, a Sea&Sun online CTD, a tool skid with draw-boxes, and an acoustic beacon finder. A forward looking sonar (Kongsberg 675 kHz) and a sidescan sonar (Benthos) were used for detection of seep sites, gas emissions, acquiring information on the bottom morphology and mapping seafloor structures. Continuous PAL video footage was recorded with two colour-zoom cameras (Insite PEGASUS or DSPL Seacam 6500). For extremely detailed video close up filming, a near-bottom mounted broadcast quality 3CCD HDTV 14 x Zoom video camera was used (Insite Zeus). Additionally, a custom built high definition still camera was used, based on a combination of a 70 mm Photosea optics and housing with a standard Kodak ProBack Plus digital 16 MegaPixel Camera Backside. As a standard still image camera an Insite Scorpio Digital Still camera was used. For the task of videomosaicking, a broadcast quality downward looking camera with dedicated corrected

underwater optics – Insite ATLAS - was installed for the first time in this functionality on the toolskid in conjunction with one high power HID wide angle flood light. Mosaicking was performed using the vehicles autopilots whenever possible, based on DVL bottom tracking at either 3 or 2 m altitude, and during horizontal speed between 0.1 to 0.15 m/sec. Further information is available at: http://www.marum.de/en/ROVs_.html.

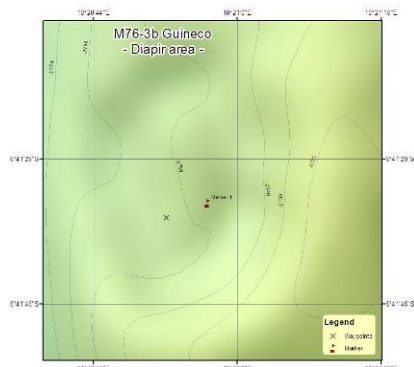


Fig. 4.9 ROV dive map from Diapir Area.

previous leg. The datasets had to be edited and converted into a map in order to serve as an orientation for the ROV pilots. The dive maps were also used for an online mapping system (MIMOSA) by the scientists. Within this platform every data record from the previous dives was transformed and included. Supported by the clarity and interactivity of this online system dives were operated safely and with a better overview. The Diapir area was the first region of interest on this cruise, where one dive operation was performed. On the map in Fig. 4.13 the maker and waypoints of the ROV are shown. Thirteen successful dives were carried out at the Regab area. The position of markers and targets are displayed on the map in Fig. 4.14.

One of the major objectives during R/V METEOR cruise M76/3b has been the recovery of geological samples. Depending on the sampling target different coring devices have been used, i.e. a gravity corer with up to 6 m length and a shorter multicorer with a maximum core length of 50 cm. For focused sediment sampling push cores were deployed by the ROV Quest4000 at selected habitats. Gravity cores (GC) were either deployed with a 6 m or a 3.5 m-core barrel, both with an outer diameter of 14 cm and an inner diameter of 13.2 cm. The coring was conducted either with a PVC liner or with a soft plastic hose inside, which has been used if gas hydrates were sampling target. The gravity corer was deployed using the ship's winch W11. The winch speed was commonly set to 1.0 m/s to slack and 1.3 m/s to heave the GC in the water column. Heaving out of the sediment was done with 0.2 to 0.5 m/s. The head of the gravity corer was equipped with approx. 1.5 tons of lead. The multicorer (MUC) was used to sample undisturbed surface sediments. The MUC is equipped with a head for deployment of 8 liners with a diameter of 10 cm and length of 50 cm. The same winch W11 was used for the deployment of the MUC. The slacking was set to 0.7 m/s and the

For each area of interest dive maps were created that include recorded data of the ROV Quest4000 tracks, points of targets, markers and samples. The raw navigation data of the ROV, which was recorded via POSIDONIA (acoustic positioning system) as well as the track from the Research Vessel METEOR (GPS), plus coordinates of points of interests were cleaned, converted and merged into a geographic information system (GIS) to display and emphasize important conclusions. Base for all maps were the bathymetry datasets recorded by the

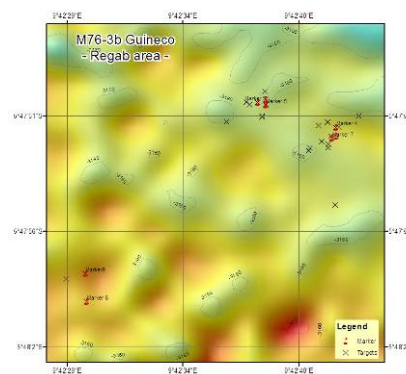


Fig. 4.8 ROV dive map from Regab area.

lifting speed was set to 1.0 m/s; depending on the sediment, the coring speed varied from 0.3 m/s to 0.7 m/s. To achieve an optimal sampling precision, GC and MUC stations were run with the POSIDONIA (USBL) underwater navigation system. Push Cores (PC) were operated by the ROV to sample undisturbed sediment surface at different microhabitats at Regab, e.g. mussel or clam patches. PCs are short plastic liners (length 30 cm) with an inner diameter of 8 cm. The PCs have a sealing on the topside to prevent outflow of the sampled sediment.

The 800 m wide Regab pockmark is situated at the passive Gabon–Congo–Angola margin which was formed by the break-up of South America and Africa during the early Cretaceous (Ondréas et al., 2005). The post-rift sedimentary sequence was described by Séranne et al. (1992). An aggradational seismic superunit (Aptian–Eocene) of siliceous and clastic deposits is separated from a progradational superunit (Miocene–Present) of siltysand turbiditic sediments by a major Oligocene erosional unconformity. Fluid migration processes and the isolated situation of the Regab pockmark on oceanic crust is still not fully understood, but Charlou et al. (2004) mark that methane is the major chemical component of the emitted fluids. They suggest that its origin is very likely a shallow reservoir of bacterial methane and not thermogenic gas formed in and migrated from deeper sediments. According to a fundamental overpressure and migration pathways, Ondréas et al. (2005) suggest an unsealed 300 m deep paleo-channel below the Regab pockmark to act as a shallow reservoir. It is connected to the pockmark by a pipe rooted in the paleo-channel.



Fig. 4.10

Carbonates sampled with GC;

a) from Diapir site

(GeoB13123);

b) at sediment depth 37 – 44 cm

(GeoB 13129-2);

c) at sediment depth 70 – 85 cm

(GeoB13129-2);

d) sediment depth 0 – 23 cm

(GeoB 13147).

One distinctive geological feature occurring within the sediments at Regab pockmark is the presence of authigenic carbonates. They form due to an increase in alkalinity caused by microbial oxidation of methane (Boetius et al., 2000). The produced bicarbonate leads to precipitation of carbonate minerals, which consequently act as a sink for methane. Hence, authigenic carbonate precipitates, also called seep carbonates, influence the global carbon budget and reveal an excellent archive of the biogeochemical processes that led to their

formation. Authigenic carbonates at the Congo Pockmark have been reported before Congo deep-sea fan (e.g. Ondréas et al., 2005 or Pierre and Foquet, 2007).

Authigenic carbonates were most abundant in the centre of the pockmark. They principally occurred as small nodules and pieces within the upper sediment layers (mainly underneath areas covered with vesicomyid patches or bacterial mats), as crusts densely covered by tube worms and mytilids (mytilid shells are also incorporated in the crusts), as likely sub-recent, rather extensive crusts which seem to be exposed due to erosion (occasionally as fractional slabs). Carbonate samples were recovered with gravity coring (appendix Figs. 4.1–4.8). Altogether 14 carbonate samples (or sets of carbonate samples) from different depth levels were recovered (appendix Table 4.1), most of which are rather small (less than 5 cm in diameter). Only a few bigger pieces with more than 10 cm in diameter of the crusts were retrieved (Fig. 4.15).

4.5.2 Geochemical characterization of cold seeps

(A. Gaßner, D. Fischer, J. Gröger, J. Tonnius, C. Le Gall, F. Brinkmann, F. Wenzhöfer, P. Pop Ristova, K. Olu, C. LeGall, C. Bienhold)

The focus of geochemical investigations carried out during this cruise in the frame of RCOM projects E3 and the MPI-MM was a detailed examination of the influence of methane seepage on geochemical processes in and at the seafloor as well as quantification of gas/fluid fluxes across the sediment/water interface at the Regab pockmark off Congo. The Regab pockmark is characterized by overall oligotrophic surface water conditions. However, the focused and diffuse seepage/upward migration of methane (hydrocarbons) stimulates high turnover rates of geochemical and biogeochemical processes close to the seafloor – in particular, influencing the cycling of carbon, sulphur and iron - also known from other cold seep/pockmark environments. One of the research objectives is to investigate and quantify geochemical processes, mineral formation and their dissolution at these hydrocarbon - seepage influenced sites. The second major task is quantification of fluid/gas fluxes across the sediment-water interface. This would allow identifying the significance of these unique hydrocarbon seeps and pockmarks on the carbon cycle and budget in the Eastern equatorial Atlantic Ocean, as well as the significance of geochemical parameters on benthic life at different micro habitats at Regab.

To prevent warming of the sediments on board the sediment cores were transferred to a cooling room immediately after recovery and maintained at a temperature of about 4°C. Only the gravity core (GeoB 13130, plastic foil) was sampled on deck at ambient temperature. The TV-MUC cores and the ROV push cores were processed within a few hours by means of Rhizon moisture samplers (Seeberg-Elverfeldt et al., 2005; pore size 0.1 µm). One sample of the supernatant bottom water was taken by means of Rhizons for subsequent analyses. During vertical subsampling of the cores into slices for solid phase analyses, pH and Eh measurements were performed with a minimum depth resolution of 1 cm. All other gravity cores were taken with a plastic liner and holes were drilled subsequently into the liner to perform Eh, pH and conductivity measurements. Additionally Rhizons were pushed into the sediment to obtain the pore water. Syringe samples of wet sediment were taken for methane

(5 ml) and solid phase analysis (10-20 ml). For the extraction of pore water, Rhizon samplers were used. Methane and solid-phase sampling (every 20 cm) was performed by cutting windows into the plastic liner. Depending on the porosity and compressibility of the sediments, the amount of pore water recovered ranged between 5 and 20 ml (upper samples). Solid phase samples for total digestions, sequential extractions and mineralogical analyses were taken at 20 cm intervals, kept in gas-tight glass bottles under argon atmosphere and stored at 4 °C. Pore water analyses of the following parameters were carried out during this cruise: Eh, pH, ammonium, alkalinity, phosphate, iron (Fe^{2+}) and methane. Eh and pH were determined with punch-in electrodes before the sediment structure was disturbed by sampling for the solid phase and methane. Ammonium was measured using a conductivity method. Alkalinity was calculated from a volumetric analysis by titration of 1 ml of the pore water samples with 0.01 or 0.05 M HCl, respectively. For the analyses of dissolved iron (Fe^{2+}) subsamples of 1 ml were taken directly from pore water extracted by Rhizons, immediately complexed with 50 μl of “Ferospectral” and determined photometrically. The analyses of phosphate were also performed photometrically. For further analyses in the home laboratory (Uni Bremen and AWI), aliquots of the remaining pore water samples were diluted 1:10 and acidified with HNO_3 (suprapure) for determination of cations (Ca, Mg, Sr, K, Ba, S, Mn, Si, B, Li) by ICP-AES and AAS. Additionally, 1.5 ml subsamples of the pore water were added to a ZnAc solution (600 μl) to fix all hydrogen sulphide present in the samples, as ZnS for later analysis – including stable sulphur isotopes. Subsamples for sulphate and chloride analyses were diluted 1:100 and stored frozen for ion chromatography (IC) analyses in the home laboratory. Further aliquots of the pore water were taken to determine the concentration of sulphate and sulphide and their $\delta^{34}\text{S}$ values as well as the concentrations and $\delta^{13}\text{C}$ of DIC and acetate. A complete overview of the sampling procedures and the analytical techniques used on board and in the laboratories at the University of Bremen is available at <http://www.uni-bremen.geochemie.de>.

During this cruise 9 TV-MUC cores from 5 locations, 17 ROV push cores, 4 gravity cores, 10 KIPS water samples were sampled and investigated in detail for pore water chemistry. For all sediment cores pore water extraction was performed applying the Rhizon technique. All sites sampled geochemically, including parameters analysed on board as well as aliquots of pore-water and solid-phase samples taken and stored for further analyses at the University of Bremen and at the Alfred Wegener Institute (AWI) in Bremerhaven are shown in the appendix in Tables 4.2 and 4.3. Gravity core GeoB 13142 and MUC core GeoB 13147 were retrieved approximately 50 km southwest of the Regab pockmark, from an area not influenced by hydrocarbon / gas seepage. These sediment cores did not contain any gas hydrates. Alkalinity measured at this site is relatively low, with maximum values of 4 to 5 mmol(eq)/l. Pore water analysis showed that nutrients reach concentrations of 50 $\mu\text{mol/l}$ NH_4 and 12 $\mu\text{mol/l}$ PO_4 . Highest concentrations of dissolved iron were measured in the top 10 cm (55 $\mu\text{mol/l}$). Dissolved iron content decreased with depth and total depletion was measured at 110 cm. At this site, hydrogen sulphide could be detected, by smell, below a depth of approx. 210 cm (Figs. 4.16 and 4.17).

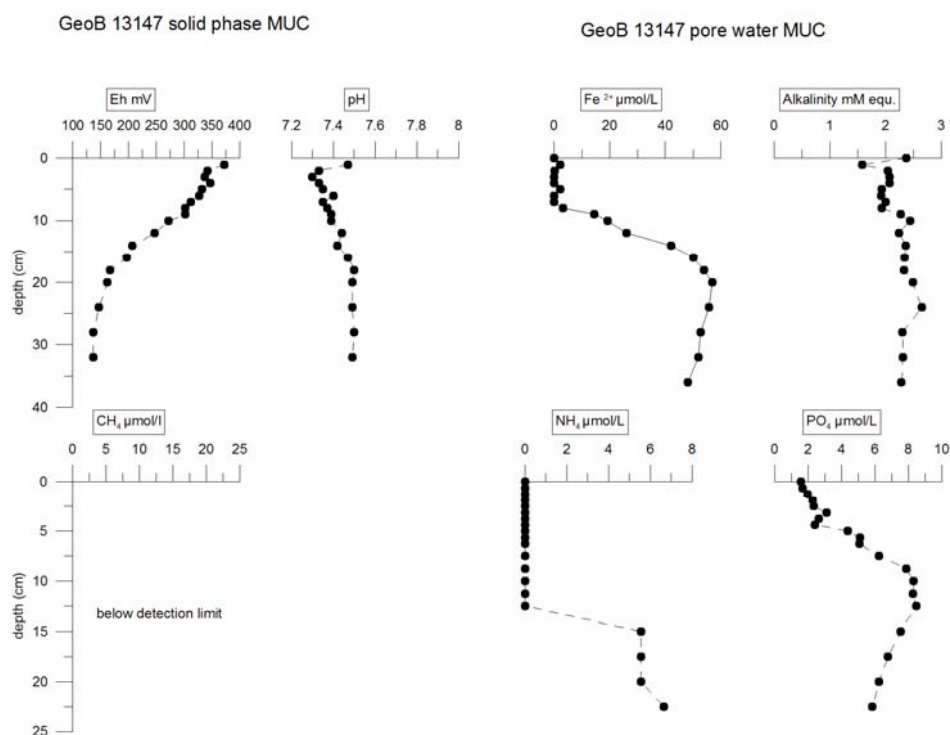


Fig. 4.11 Pore water concentration profiles of MUC core GeoB 13147.

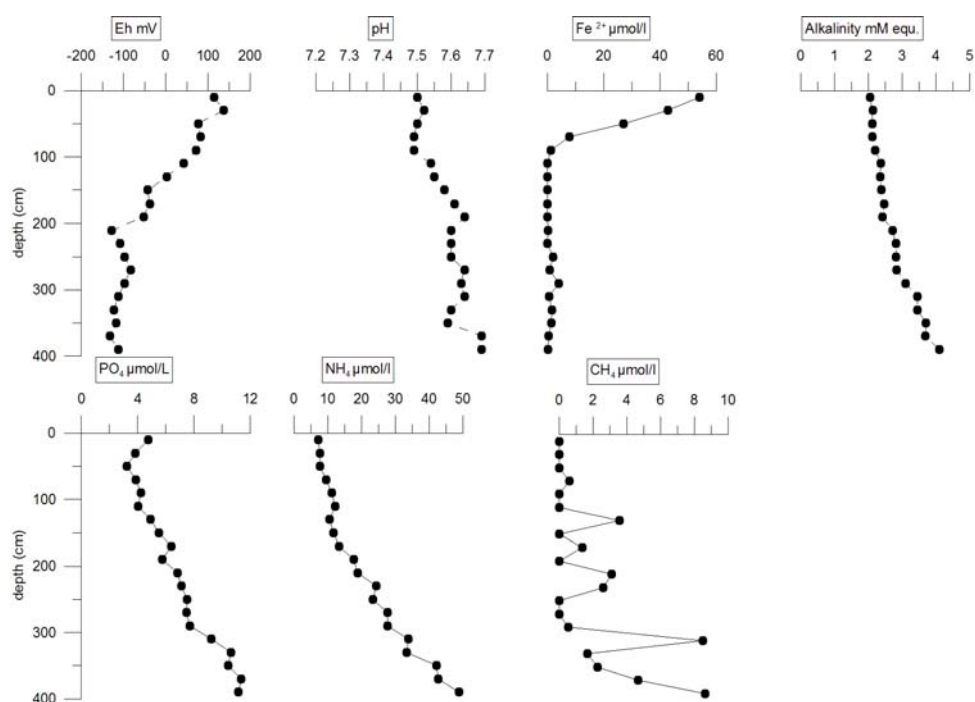


Fig. 4.12 Pore water concentration profiles of GC GeoB 13142.

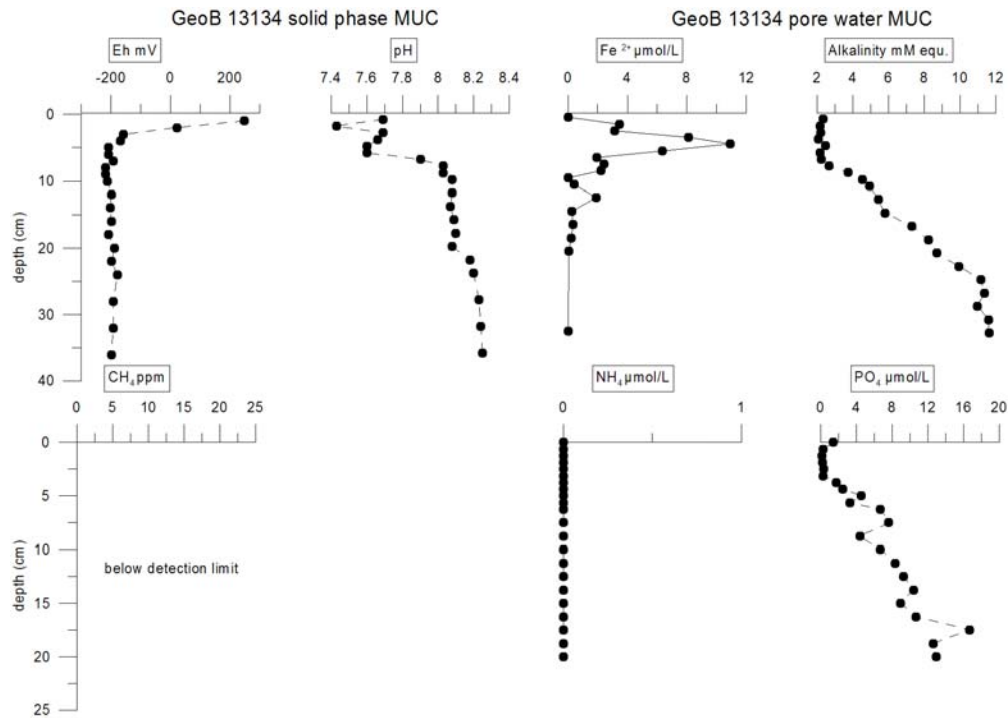


Fig. 4.13 Pore water concentration profiles of MUC core GeoB 13134.

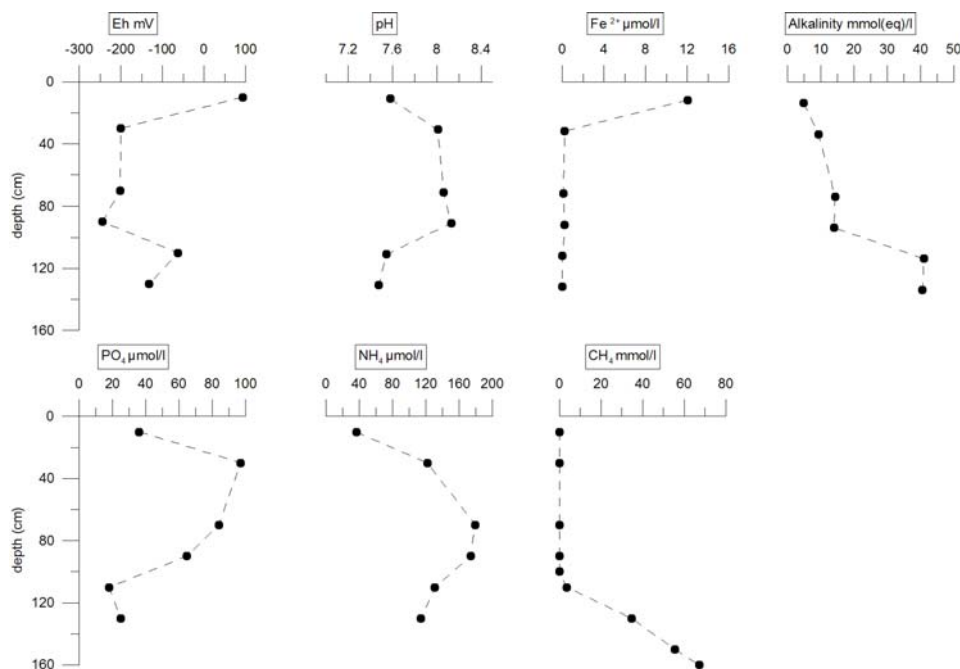


Fig. 4.14 Pore water concentration profiles of GC core GeoB 13125.

Gravity core GeoB 13125 and MUC core GeoB 13134 were taken in the inner active area of the Regab pockmark. Both cores were characterized by an intensive smell of hydrogen sulphide smell and had a very dark colour. Both cores had similar increase of pH with depth

with maximum values of approximately 8. Eh values decreased with decreasing sediment core depth, from +200 (oxic) to -200 (sulfidic). At 8 cm sediment depth the ferrous iron was completely depleted, while at the same depth measurements showed steep increase of alkalinity with maximum values of approx. 40 mmol(eq)/l at 120 cm (GeoB 13125). Methane concentration, measured in the same core, increased from 120 cm depth layer and reached maximum values of 72 mmol/l at approximately 160 cm (Figs. 4.18 and 4.19).

During earlier cruises in the Congo deep sea fan area, hydrocarbon gas seepages and shallow-buried gas hydrates were observed. The programme of M76/3b gave us further opportunities to recover gas samples, especially focussing on volatile hydrocarbons. Gas samples were obtained in several ways: (a) sediment samples recovered with PC, MUC and GC b) bottom water samples taken with KIPS. To certain extent, gas was also sampled by (c) controlled dissociation of a gas hydrate pieces out of gravity cores, and (d) gas collected with the gas bubble sampler (GBS), an *in situ* pressure-sampling-device for sampling gas-bubbles escaping from the seafloor. Methane analyses from sediment and water samples were carried out on board applying the headspace technique. The rest of the samples were stored for future analysis in the home laboratory. List of sediment and water samples from which subsamples for CH₄ analysis were taken is given in the appendix, Table 4.2 and Table 4.3.

Preliminary results of CH₄ concentration in sediments taken with push core from the vicinity of a bacterial mat and a gravity core (S 5° 47.8494', E 9° 42.6384') are given in Fig. 4.20.

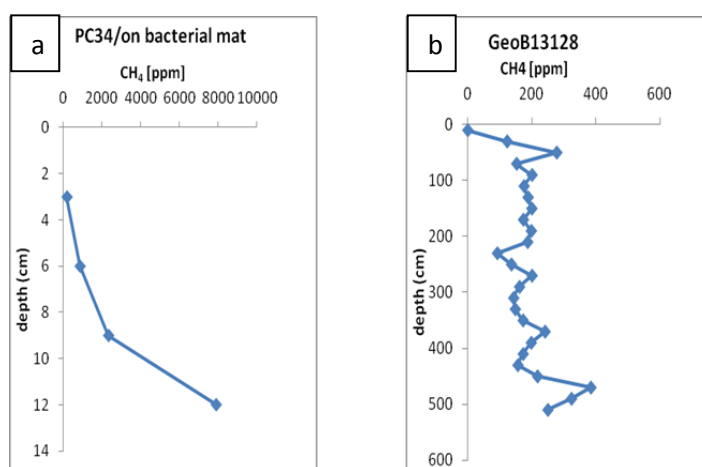


Fig. 4.15 CH₄ concentration in the sediment a) next to bacterial mat b) at S 5° 47.8494', E 9° 42.6384'; pc34=pushcore34)

The GBS is a tool for gas sampling retaining an *in situ* pressure, handled by ROV's manipulators. The main component is a steel tube having a valve on each end. One of them can be opened by ROV in order to collect gas bubbles at the sea floor by means of an attached funnel. As the GBS is closed under atmospheric pressure prior to deployment, gas is practically sucked in upon opening the valve in the water. The other valve is used to recover gas sample in the laboratory. GBS was used only at the Diapirs area (GeoB 13122 – 4; S 6° 41.575, E° 10 20.944; water depth 2707 m) due to the operational limitations of the instrument to withstand pressure no higher than 300 bars. All recovered subsamples were

transferred into glass vials prefilled with concentrated NaCl solution and taken back to the home laboratory for further analysis.

Gas hydrate samples were recovered from two gravity cores (Table 4.3). The main part was stored directly in liquid nitrogen. A small piece of the hydrate from each core was filled into a gas tight syringe and stored at room temperature for dissolution. Subsamples of the escaping gas were transferred into several glass vials and stored further analysis in the home laboratory.

Table 4. 3 Escaping gas subsamples from gas hydrates

GeoB No.	Area	Device	Lat.(S)	Long.(N)	Depth [m]	Type of sample	No. of subsamples
13124	Regab	GC	5° 47.804'	9° 42.740'	3.111	released gas	6
13130	Regab	GC	5° 47.850'	9° 42.737'	3.155	released gas	4

For the determination of rates for anaerobic oxidation of methane (AOM), sulphate reduction (SRR) and methanogenesis (MOG, only for gravity cores), radioactive tracer experiments were conducted in the Isotope Container on board. Radioactive tracers were injected every cm over the whole core length. The samples were then incubated at 4 °C for 10-12 hours and the reactions were stopped by transferring 1 cm slices of the cores into 20 ml 20 % Zinc acetate for SRR and into 25 ml of 2.5 % NaOH for AOM and MOG. Experiments were conducted in triplicate for all stations. The used tracers were radioactively labelled methane ($^{14}\text{CH}_4$) for AOM, labelled sulphate ($^{35}\text{SO}_4^{2-}$) for SRR and labelled carbon dioxide ($^{14}\text{CO}_2$, as bicarbonate) for MOG. Measurements for the determination of rates will be conducted in the home laboratories. The in situ incubation (INSINC) cores were deployed during three ROV dives (222, 223 and 226) covering four different habitats (appendix Table 4.9). The injection of the radioactively labelled tracer ($^{35}\text{SO}_4^{2-}$) occurs already at the seafloor under in situ temperature and pressure. Back on board the cores are sampled in centimetre slices and the reactions stopped by transferring the sediment into 20 ml 20 % zinc acetate.

The main objective of cruise M76/3b was quantification of fluid flow rates and biogeochemical processes together with investigations of the habitat structure and composition. Research questions were: what is the net exchange of solutes and gas at different types of seep habitats, and what is the spatial and temporal distribution of the related fluxes; how do fluid flow and gas ebullition influence solute gradients and biogeochemical process rates; how fluid flow and fluxes are related to fauna composition and distribution. For these goals a variety of in situ measurements using the ROV Quest were performed. Different microhabitats within the Regab pockmark were analysed and compared to obtain a quantitative understanding of the biogeochemical processes. We will investigate the flux and consumption of the potential greenhouse gas methane and how chemical and physical parameters influence the composition and structure of seep ecosystems. These measurements improve our insights into the pore water chemistry of these sediments as well help us to understand the small scale characteristics of the different habitats.

Ex situ microprofiles of O_2 , H_2S and pH were measured on retrieved PC and MUC cores from reduced sediments. Immediately after recovery the cores were kept at in situ temperature and transferred into an aquarium also set to in situ temperature to

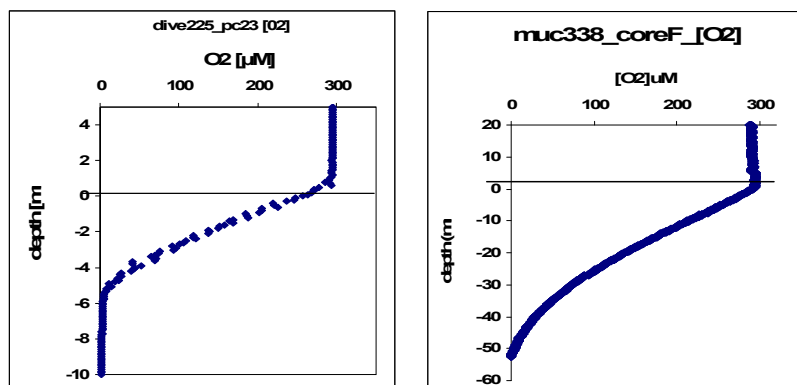


Fig. 4.16 Ex situ O_2 microprofiles from retrieved from: a) Two to three concentration profiles across the sediment water interface with a vertical resolution of 100 μm were measured in each core.

In situ measurements of fluxes and pore water concentration profiles were performed with the ROV-operated instruments - the microprofiler and XY-profiler (Fig. 4.22). Both in situ microprofiling instruments carried 10 microsensors which had a tip diameter of 10-50 μm . The following sensors have been used: O_2 , H_2S , pH and T. After placing the profiler at the targeted site the measuring routine was started by the ROV and subsequently the set of microsensors was lowered with a step size of 200 μm into the sediment.

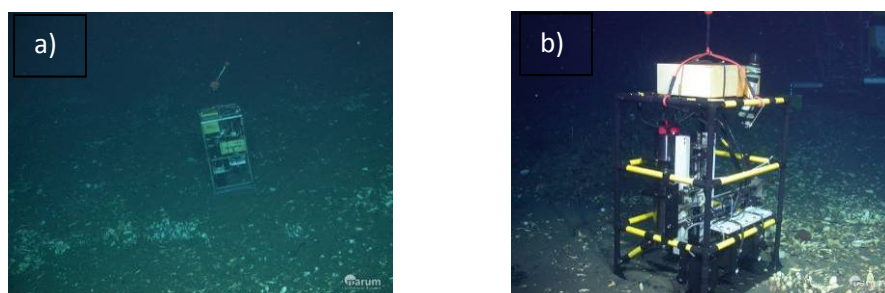


Fig. 4.17 a) Microprofiler next to vesicomyid patch b) XY-Profiler next to vesicomyid patch

While the microprofiler (Fig. 4.22a) measures only one profile per measuring routine, the XY-Profiler (Fig. 4.22b) is able to perform several vertical profiles along a 30 cm horizontal axis. During this cruise the XY-Profiler was set to measure 16 vertical profiles each separated by 2 cm.

During this cruise we were able to perform several microprofiler measurements in different seep habitats (appendix Table 4.10). Preliminary results from in situ microsensor measurements at a bacterial mat reveal that oxygen penetrates only 1 mm into the sediment (Fig. 4.23) indicating high consumption rates at this spot. There is, however no overlap between the H_2S and oxygen profile indicating an additional oxidant for the removal of the upwards diffusing sulphide. In comparison to the shallow oxygen penetration in the bacterial mat, ex situ profiles from a vesicomyid patch and a reference site show a deeper penetration of oxygen with 5 and 50 mm, respectively (Fig. 4.21).

During this cruise two different benthic chamber systems have been used to investigate the mussel/clam respiration as well as total exchange rates: the Ifremer Calmar and the MPI Benthic Chamber. Both benthic chambers follow the total exchange of solutes through the sediment water interface over time in an enclosed water volume overlying the sediment. A small support frame, capable of being operated by the ROV, is equipped with a circular (ID 19 cm) chamber to cover a larger area. During the incubation a central stirrer mixes the overlying water simulating the natural hydrodynamic conditions. The O₂ concentration of the enclosed water is followed continuously by 1 mini-electrode and 1 optode while sulphide is monitored with 1 H₂S mini-electrode. All sensors are mounted on the chamber lid. Other compounds (DIC, methane and nutrients) will be analyzed on retrieved water samples taken at pre-programmed time intervals during the incubation.

The MPI benthic chamber (Fig. 4.24) was deployed several times during the cruise (appendix Table 4.10). As an example of total oxygen consumption rates measurements of two incubations at and next to a vesicomyid patch are shown in Fig. 4.25. Clearly a high O₂ decrease is

seen at the vesicomyid site as compared to the surrounding sediment. This indicates a much higher total oxygen consumption rate by the clams inhabiting the seep-influenced sediments.

The Ifremer benthic chamber CALMAR (Fig. 4.26) is used to estimate oxygen uptake rates from the benthic fauna (respiration rate), and methane fluxes across the sediment interface. It has been deployed 3 times on 3 different vesicomyid bivalves' sites at Regab:

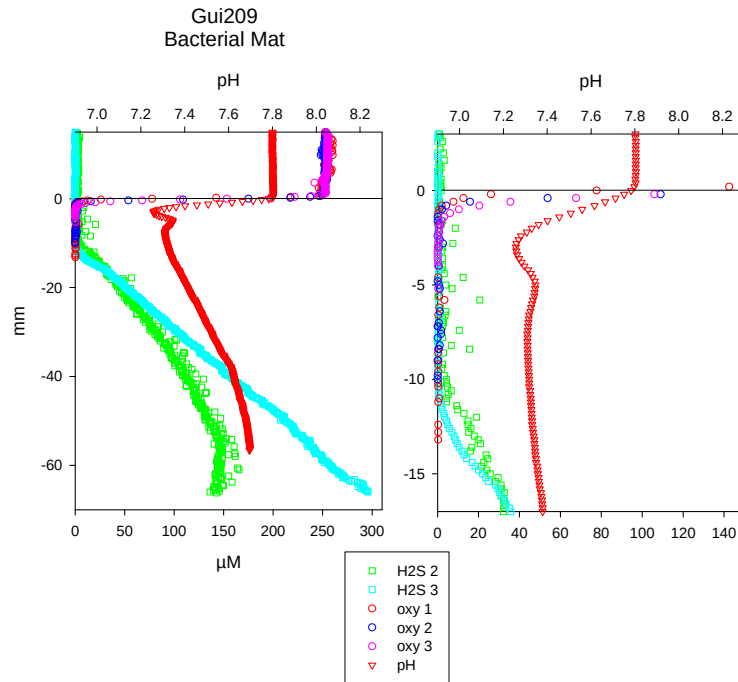


Fig. 4.18 In situ microprofiles from a bacterial mat

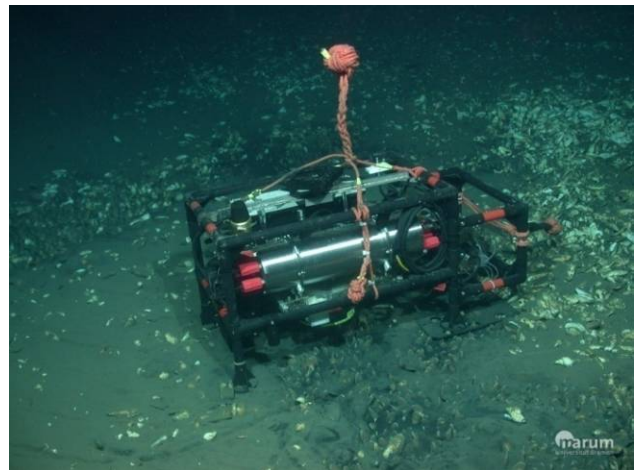


Fig. 4.19 MPI Benthic chamber on a vesicomyid patch.

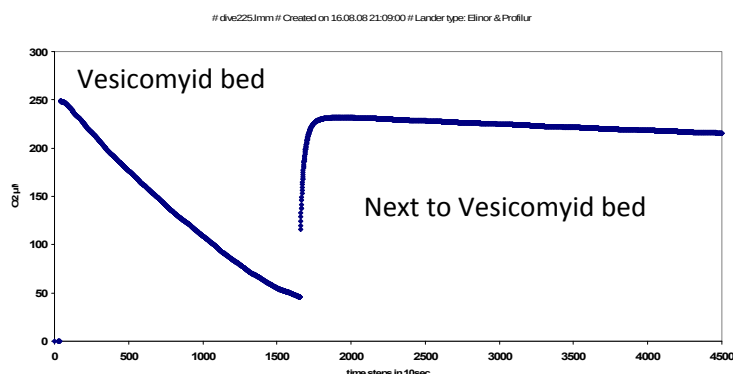


Fig. 4.20

Oxygen concentration during two deployments; first on top of a vesicomysid patch and second next to vesicomysid patch.

1. dive 211 (*Calypptogena* sp. Marker 3; North part of Regab)
2. dive 218 (*Calypptogena* sp. Marker 7; South part of Regab)
3. dive 225 (*Calypptogena* sp. + “*Vesicomysa*” *chuni* Marker 10; SW part of Regab)

For each deployment the total incubation time was 5 h 25 min. Inside the chamber an optode is continuously measuring the dissolved oxygen concentration in the enclosed bottom water; a measurement is taken every 5 seconds. Also 6 water samples are taken during the deployment; one every 60 min. These water samples of 100 ml are divided into subsamples for measuring:

1. O₂ concentration (winkler titration) – 2 subsamples.
2. CH₄ concentration – 3 subsamples
3. CO₂ measurement – 1 subsample
4. pH and temperature – 1 subsample

After each deployment, the bivalves (megafauna) and associated macrofauna was quantitatively sampled by one blade core taken at the same place. The total number of bivalves will also be estimated from the ROV images.

A new system - Eddy - to study the total oxygen uptake completely non-invasive was deployed 6 times during this cruise (appendix Table 4.10). Vertical transport of O₂ in the water column results exclusively from turbulent motions. The typical pattern of these turbulent motions, that the O₂ concentration on average is higher when the vertical velocity is pointing toward the sediment and lower when the velocity is pointing upward, gives over time a net transport of O₂ toward the sediment. Eddy correlation relies on measuring the vertical velocity and the oxygen concentration fast enough to calculate the momentary advective flux due to turbulent motions. Integrated over time for a period long enough to get a statistically sound average, it gives a net O₂ transport

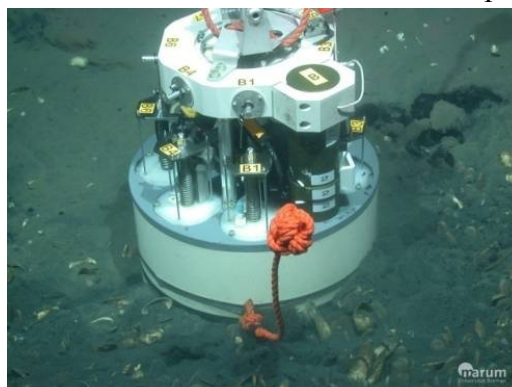


Fig. 4.21 CALMAR placed on a vesicomysid patch.

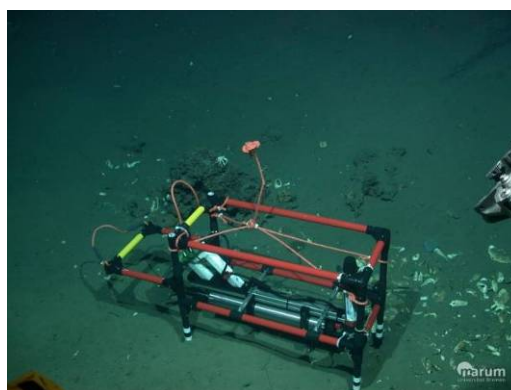


Fig. 4.22 Eddy on the seafloor.

directed towards the sediment. Eddy is an instrument developed to measure the vertical oxygen flux in the water column via eddy correlation (Fig. 4.27). The measuring plane is placed only 0.2 m above the sea floor and the measured flux can therefore be ascribed to the sediment water interface. Eddy measures oxygen concentration with a Clark-type micro-electrode and the flow velocity with an acoustic Doppler velocimeter (ADV). Data is acquired at 16 Hz in 15 min series, separated by 1 min breaks

A self-recording current meter (RCM11, Aanderaa Instruments, Norway, www.aanderaa.no) was placed on the seafloor at Regab to provide 2-minute interval information on the amplitude and direction of the bottom currents as well as the water temperature, salinity and oxygen during the deployments (appendix Table 4.10). Water currents are measured in one point

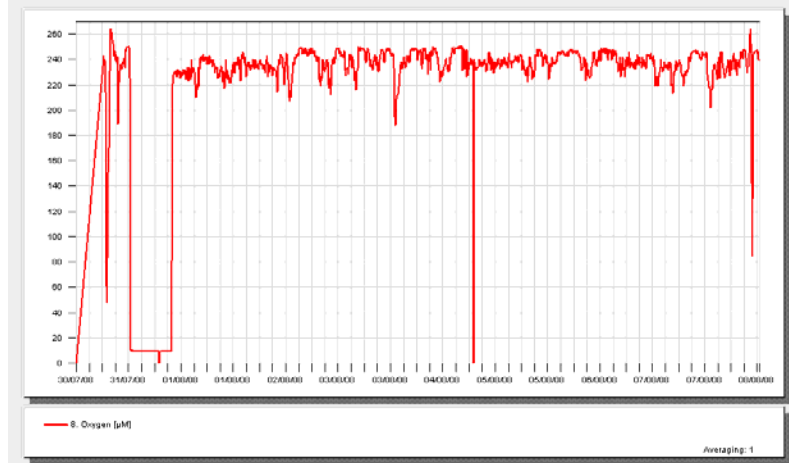


Fig. 4.28 Oxygen concentration in the bottom water at Regab.

with the acoustic backscatter technique, which is recognized to be a robust and reliable way of measuring currents. An internal tilt sensor compensates the current recordings if the instrument is tilted. On the top plate of the instrument optional sensors to monitor temperature, conductivity (which is used to calculate the salinity), pressure and oxygen optode were mounted. The recorded data is internally stored and downloaded from the instrument with a specific software, named 5059, to a PC after the deployment. An example of the variation in the oxygen concentration in the bottom water is shown in Fig. 4.28. A slight oscillation can be observed with an average of around 240 μM .

4.5.3 Biological characterization of cold seeps (K. Olu, C. Bienhold, C. Decker, F. Muller)

Seep communities in the Gulf of Guinea are known from the Biozaire program (1998-2003) led by Ifremer. The most active and diversified seep area discovered during several ROV cruises is the Regab pockmark located 8 km north from the Congo river deep channel, at 3170 m depth. The spatial distribution and composition of benthic communities associated with methane emissions was described from these first dives. The objectives of this cruise are to further characterize the biological communities, in particular, the symbiont-

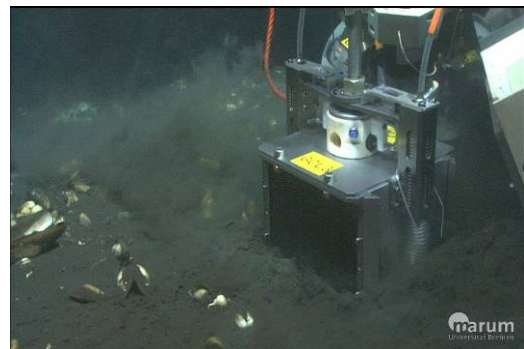


Fig. 4.29 Sampling with blade core.

bearing species, by (a) comparison of population structure, reproduction patterns, and physiological adaptations of the symbiotic bivalves, particularly of the Vesicomidae family, (b) study of macrofauna associated with different bivalve species, (c) study of symbiosis with focus on bivalves (mostly, mytilids, ludinids and thyasirids) and siboglinid tubeworms, and (d) colonization experiments with different substrata.

Bivalve patches from three different sites have been sampled using blade cores (triplicates were taken from each site) in order to estimate the bivalve and associated macrofaunal diversity and density. Additionally, two samples were also taken outside the bivalve patches. Blade corer is made of a rectangular box 20 cm long, 18 cm wide and 30 cm deep (Fig. 4.29). The corer is gently pushed in sediments by the arm of the ROV and closed by two blades, armed by spiral springs and released by a quarter turn of the handle. The samples were separated in different sections to study the vertical distribution of the megafauna (> 1 cm) and macrofauna, passed through different sieves (250 μ m to 1 mm) and fixed in formaldehyde or alcohol for taxonomic investigations and genetics, respectively, in the home laboratory. At each site, one blade core sample was taken from under the Calmar chamber in order to determine the respiration rates. Three sites have been sampled:

- Dive 212 (*Calyplogena* sp. Marker 3; S 5° 47.836' E 9° 42.617', North part of Regab) 1 blade core (Fig. 4.30)
- Dive 215 (*Calyplogena* sp. Marker 3; S 5° 47.836' E 9° 42.617', North part of Regab) 4 blade cores
- Dive 220 (*Calyplogena* sp. Marker 7; S 5° 47.867' E 9° 42.688', South part of Regab) 4 blade cores
- Dive 225 (*Calyplogena* sp. + “*Vesicomya*” *chuni* Marker 10, S° 5 47.976' E 09° 42.482', SW part of Regab) 3 blade cores (Fig. 4.31a,b and Fig. 4.32)

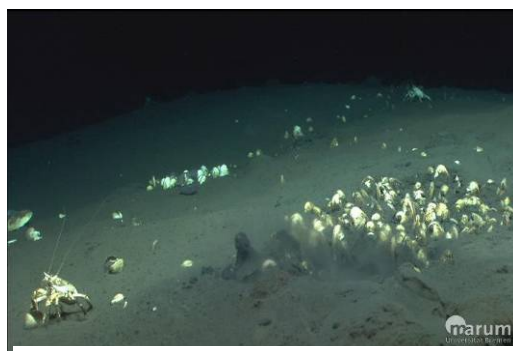


Fig. 4.30 Vesicomidae cluster sampled at Marker 3.

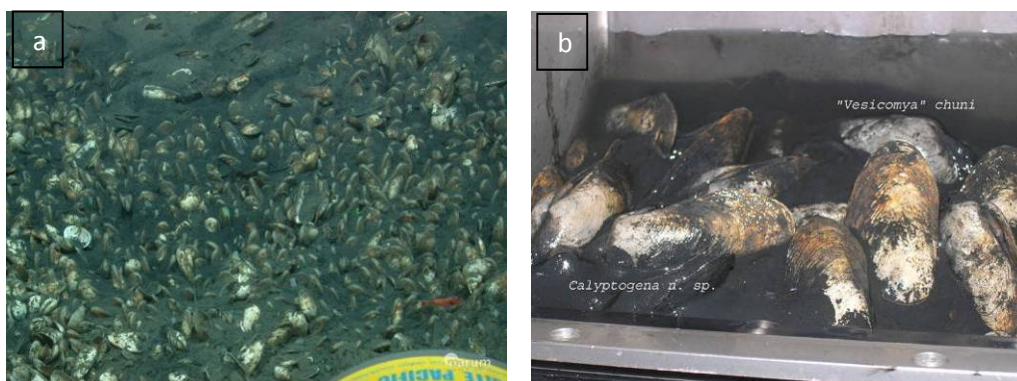


Fig. 4.31 a) Vesicomid cluster sample at Marker 10
b) Two vesicomid species at the surface of a blade core.

The bivalves sampled using blade cores and MPI sampling nets of 20 cm in diameter will be

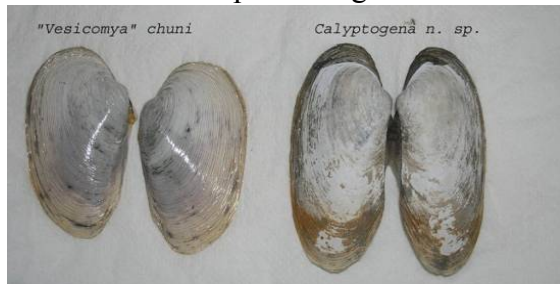


Fig. 4.32 Shells of the two vesicomyid species after dissection of the soft parts.

also used for population structure analyses (size frequency distribution) and reproduction pattern studies (gametogenesis stages). Two other symbiont-bearing bivalve families have been sampled in the Vesicomysidae clusters: Solemyidae and Thyasiridae (Fig. 4.33a,b). Other megafauna samples include one sea urchin commonly observed around vesicomyid beds in the south western field, holothurians of the family Synaptidae sampled in the north and

central part of Regab, and gastropods Provannidae associated with vesicomyids. In the mussels commensal polychaetes of the family Polynoidae have been found and stored in ethanol for genetic analyses.



Fig. 4.33 Two bivalves sampled at Marker 3: a) Solemyidae b) Thyasiridae

The seep and vent vesicomyids are characterized by physiological adaptations to sulphide-rich environment, in particular by the presence of different respiratory pigments that have high oxygen affinity and are able to bind sulphide. However, these pigments have been characterized in only one vesicomyid vent species. The oxygen and sulphide binding proteins in different vesicomyid species will be characterized and their affinity for sulphide and oxygen determined by dialyse experiments in the home laboratory (collaboration with Ann Andersen, UPMC Roscoff).

Specimens of different species of bivalves and tubeworms (siboglinid polychaetes) have been sampled for symbiosis studies. Within the scope of this study the following objectives will be addressed: a) identification of bacterial symbionts using molecular techniques, b) quantification of bacterial symbionts using FISH techniques on specimens collected from distinct areas, preferentially contrasted habitats, and c) determination of nutritional role of bacterial symbionts using stable isotope analyses. The study of Vesicomysidae will be done in collaboration with Ifremer (Karine Olu; Carole Decker) and Ann Andersen (UPMC; Roscoff) for a complete study of the biological and physiological adaptations of the different species. Samples taken during the M76/3b cruise include:

- Vesicomysidae: *Calyptogena* n. sp. (Vesicomysidae) from different sites of the Regab pockmark (Marker 3; 7; 10) and “*Vesicomys*”*chuni* (Vesicomysidae) from one site of the Regab pockmark (M10)

- Mytilidae: *Bathymodiolus aff. boomerang* from Regab sampled at two different environments: attached to carbonate covering an hydrate layer, and semi-buried in sediment at (Marker 6 = Biozaire M3 site). Some individuals from the Diapir area (likely *B. aff. boomerang*)
- Siboglinidae: *Escarpia southwardae* from Regab and Siboglinidae sp. from DIAPIR area. Different parts of the animals (particularly the tissues hosting the bacterial symbionts (bivalve gills and siboglinid trophosoms) were stored in ethanol, glutaraldehyde, and formaldehyde or frozen according to further studies.

Microbiological sampling of sediments was conducted with push cores, multicorer and gravity core (appendix Tables 4.5-4.8). The fixed samples will enable a thorough description of the microbiological communities in this area as well as the biogeochemical processes that the microorganisms are driving. Vertical subsampling of push cores and multicores was conducted with smaller subcores (diameter: 3 cm and 1 cm) in the cold room (4 °C). Gravity cores were sampled on deck and every metre was sampled with cut-off syringes. Sampling of the PC and MUC was done in 2 cm vertical intervals except for biomarker, which was sampled in 3 cm intervals. Sediment samples were fixed for different types of microbiological analyses, which will be conducted in the home laboratory (Table 4.4 and in appendix Table 4.4).

Table 4. 4 Overview of microbiological analysis and fixation methods for which sediment samples were taken

Microbiological analysis	Fixation
DNA extraction	- 20 °C
RNA extraction	- 80 °C
Acridine Orange cell counts (AODC)	4% Formalin/Seawater, -4
Fluorescence in situ hybridisation (FISH)	(PBS/Ethanol, - 20 °C)
Cultures	(glass bottle, headspace flushed with nitrogen, 4 °C)
Biomarker	(aluminium foil, -20 °C)

4.5.4 Colonization Experiments

(C. Bienhold, K. Olu, C. Decker)

Deep-sea sediments are usually highly oligotrophic and therefore nutrient limited. Sunken wood (similar to whale carcasses) provides a concentrated, locally restricted input of organic material to the deep sea where intensive local processes can lead to reducing conditions and high sulphide concentrations. Large organic food falls can therefore lead to the development of chemosynthetic environments in the deep sea that might act as stepping stones in the evolution of chemoautotrophic communities found in habitats such as hydrothermal vents and cold seep systems. To date little is known about the microbial diversity on large organic food falls in the deep sea. Important questions are: When and how do sulphidic environments develop? Which microorganisms colonize the wood and what is the function of microbial communities in the wood degradation? By comparing long-term wood colonization experiments in chemosynthetic active versus non-active areas as well as in different oceans we will try to find out whether the microbial communities are habitat specific and whether we find biogeographic differences in the community structures. For a comparative sampling wood experiments have also been deployed in the Barents Sea, the Mid-Atlantic Ridge (Logatchev vent), the Black Sea and the Mediterranean.

The wood colonization experiments consist of one large log (length: 200 cm; diameter: 30 cm) with 10 smaller logs (length: 25 – 30 cm; diameter: 10 – 15 cm) of Douglas fir tied to it (Fig. 4.34). During the M76/3b cruise two wood colonization experiments were deployed. Wood 1 was deployed in a chemosynthetic active area and wood 2 on a non-active sediment area to see whether differences can be observed in the quality and quantity of colonization of the wood according to biogeochemical differences in the surrounding habitat (Table 4.5).



Fig. 4.34 Wood colonization experiment before deployment during cruise M76/3b



Fig. 4.23 Wood 1 after 3 weeks on the seafloor. Shrimps and crabs could be observed on the wood.

Table 4. 5 Positions of the two wood colonization experiments deployed during M76/3b

wood experiment	environment	Lat (S)	Lon (E)
wood 1	chemosynthetic area	5°47.84	9°42.64
wood 2	reference site	5°48.01	9°42.68

Wood 1 was sampled during this cruise after 3 days (dive 217) and 3 weeks (dive 226) of deployment (dive 3.38). Each time one small wood piece was cut off with the help of the ROV. After recovery of the wood pieces, subsamples were taken for different molecular biological analyses (DNA, AODC, FISH). Microprofiler measurements were conducted at the wood experiment (wood 1) during dive 226 (appendix Table 4.10). First observations during the dives showed high abundances of shrimps and crabs on the wood. Holothurians were observed on the seafloor close to the wood (Fig. 4.35). The wood experiments will be revisited during the WACS cruise in 2010. The research is integrated into the European Research group of the Centre National de la Recherche Scientifique (CNRS) and the Max Planck Society (MPG) in the project DIWOOD (Diversity, establishment and function of organisms associated with marine wood falls) as well as the project CHEMECO (Monitoring colonization processes in chemosynthetic ecosystems) of the EUROCORES EuroDeep Program of the European Science Foundation.

Titanium Ring of Alvinellid Colonization Experiments (TRACs), initially developed for vent organism colonisation experiment (especially Alvinellid polychaetes) are now also used in cold-seep environments. Three TRACs have been deployed in the vicinity of a site with carbonate floor, close to tubeworms and mussels bed at 3170 m depth on the Regab site (S 5° 47.86', E 9°42.69) (Fig. 4.36). The 3 substrates of the TRACS composed of wood, carbonate rock, and Medicago stayed for an experiment time of 21 days and 7 hours. The recovered TRACS have been split for different analyses like Isotope, FISH, TEM (Transmission Electron Microscopy), and Taxonomic studies.

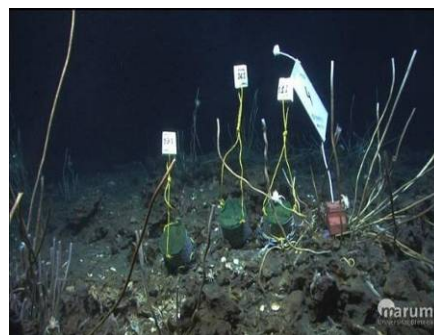


Fig. 4.24 TRAC on the seafloor

The aim of this Small Module Autonomous Colonization Experiment (SMAC) long-term experiment is to study the colonization of soft artificial enriched substrata by seep species living in sulphide rich sediment. Four pots are filled with a mixture of glass balls and fishmeal resulting in different concentrations in organic matter. For the highest concentrations, the artificial sediment becomes anoxic and sulphidic. Such experiments have previously allowed collecting vesicomid bivalve larvae and polychaetes. One SMAC was deployed in the south of Regab, close to Marker 7 (S 5° 47.87', E 9° 42.68') (Fig. 4.37). This area is colonised by vesicomid and mytilid bivalves on soft sediment, and by siboglinid tubeworms. The SMAC will be recovered in 2010 (WACS French cruise).



Fig. 4.25 SMAC on the seafloor

4.6 The Weather During R/V METEOR Cruise M76/3b (W.-T.Ochsenhirt)

METEOR left the port of Walvis Bay (Namibia) for the leg M 76/3b on the forenoon of the 17 July. During the outward voyage the weather was calm and the sky clear. North of zone of high pressure between 20 and 30°S, southerly winds of 3 or 4 Bft were encountered. The following day the vessel had to return to Walvis Bay due to a tragic family incident of a crew member.

On the 19 July the cruise started once more and same weather conditions were present. During the following night, the southwesterly wind increased to 6 Bft and decreased to 2–3 Bft towards the morning. On its way towards the research areas, on the 20 July METEOR crossed an area of dense fog, which slowly dissipated in the afternoon. Until the 23 July, when the first study area (05.9 °S, 10.3 °E) was reached, the wind came from southwest with 2–4 Bft and a long swell from southwest of 2 to 2.5 m. During the next days, new developing high pressure systems moved eastwards across the South-Atlantic along about 30°S to South-Africa and the Indian Ocean. METEOR remained in an area of weak pressure gradients sometimes under high pressure ridges, reaching out up to the equatorial region. The intertropical convergence zone (ITCZ) with significant thunderstorm activity extended from Guinea over Nigeria, to East-Africa. Some flat troughs with poor weather activity affected the southwest coast of Africa down to Namibia, and the operational area of METEOR was in the vicinity of flat low pressure systems. The corresponding winds were southerly with 3 or 4 Bft. These southerly trade winds were very constant with a speed between 1 and 3 Bft. The cloud cover changed often, but the precipitation was poor. The swell with a period of about 10 seconds and height of 1 to 1.5 m came nearly constantly from 190 degrees, and only on some days with a height of 2 to 2.5 m and a period of 14 seconds. On the 14 July METEOR entered the harbour of Luanda. Anchoring on road, an easterly wind of only 1 or 2 Bft was measured. The weather was rather misty. On the following day METEOR returned to the study area, where the visibility was better and southerly wind of 3 to 4 Bft was present.

After detailed calculation of the route back to Walvis Bay with the program METMASTER and additional routeing advice from the German National Weather Service in Hamburg, it was decided to leave the research area in the forenoon of the 19 August. Between a trough spreading over North-Africa, extending as far as Namibia (1015 hPa) and a ridge further to the west (1015 hPa as well), the transit began with southerly winds of 2–3 Bft and a swell from south of 1–2 m. At the latitude where the border of Angola to Namibia lays the south – southeast wind increased to 5 and 6 Bft and the sea swell rose to 2–3 m. The voyage ended in the morning on the 24 August in the harbour of Walvis Bay (Namibia).

4.7 Station List M76/3b

Table 4.6 Station list M76/3b cruise.

Station No. M	GeoB	Area	Gear	Gear No.	Start of Station / Gear at Bottom				End of Station				Remarks
					Date/Time (UTC)	Lat [N]	Lon [E]	Depth [m]	Date/Time (UTC)	Lat [N]	Lon [E]	Depth [m]	
300a	-	Transit	MB-PS	1	16/07/04 11:46	-22°45.65'	14°16.80'	83.0	22/07/04 06:00	-6°42.47'	10°21.45'	2713	Transit to Diapir
301	-	Diapir	PS	2	22/07/04 06:00	-6°42.49'	10°21.46'	2712.6	22/07/04 06:49	-6°41.6'	10°21.33'	2670.8	Searching Flare
302	13 1 2 2	Diapir	ROVQ	207	22/07/04 10:24	-6°41.62'	10°20.87'	2705.0					Successful dive
303	-	Diapir	SP	1	22/07/04 17:12	-6°41.58'	10°20.94'	2696.9	22/07/04 18:54	-6°41.6'	10°20.94'	0	No Depthinformation at end of station
304	-	Diapir	GC	1	22/07/04 20:03	-6°41.57'	10°20.94'	2702.0					USBL Subposition
305	13 1 2 3	Diapir	GC	2	22/07/04 22:28	-6°41.59'	10°20.87'	2672.0					Karbonatprobe, USBL Subposition
305a		Transit	MB-PS	3	22/07/04 23:46	-6°40.86'	10°20.65'	2710.0	23/07/04 06:57	-5°47.54'	9°42.73'	3139	
306	-	Regab	SP	2	23/07/04 07:19	-5°47.86'	9°42.91'	3148.4	23/07/04 08:32	-5°47.86'	9°42.91'	3149.2	
306a	-	Regab	PS	4	23/07/04 08:47	-5°47.85'	9°43.05'	3149.0	23/07/04 10:03	-5°47.77'	9°42.71'	3140.3	
307	-	Regab	GC	3	23/07/04 11:05	-5°47.80'	9°42.68'	3129.0					USBL-Subposition
308	13 1 2 4	Regab	GC	4	23/07/04 14:11	-5°47.80'	9°42.68'	3111.0					USBL-Subposition, Hydrat
309	13 1 2 5	Regab	GC	5	23/07/04 16:26	-5°47.82'	9°42.68'	3151.2					USBL-Position. Liner 1.5m
310	13 1 2 6	Regab	ROVQ	208	23/07/04 21:25	-5°47.91'	9°42.69'	3163.0					USBL-Subposition, Successful dive
311	-	Regab	MB-PS	5	24/07/04 01:46	-5°47.2'	9°43.07'	3131.9	24/07/04 16:34	-5°47.77'	9°42.77'	3148.9	
312	13 1 2 7	Regab	ROVQ	209	24/07/04 19:27	-5°47.9'	9°42.64'	3166.0					USBL-Subposition, Successful dive
313	-	Regab	MB-PS	6	25/07/04 00:57	-5°46.76'	9°43.42'	3103.4	25/07/04 07:46	-5°47.82'	9°42.74'	3155	
314	13 1 2 9-1	Regab	GC	6	25/07/04 08:47	-5°47.83'	9°42.63'	3120.0					Karbonatprobe, USBL Subposition
315	-	Regab	GC	7	25/07/04 10:45	-5°47.83'	9°42.63'	3120.0					USBL-Subposition
316	13 1 2 8	Regab	GC	8	25/07/04 12:33	-5°47.83'	9°42.63'	3156.0					USBL-Subposition - Liner, 5.5m
317	13 1 2 9-2	Regab	GC	9	25/07/04 15:12	-5°47.83'	9°42.74'	3156.0					Karbonatprobe, USBL Subposition
318	-	Regab	GC	10	25/07/04 18:21	-5°47.83'	9°42.73'	3119.0					USBL-Subposition
319	-	Regab	MB-PS	7	25/07/04 19:54	-5°51.56'	9°42.05'	3162.0	26/07/04 06:43	-5°47.63'	9°42.61'	3154.7	
320	-	Regab	LIFT	1	26/07/04 09:22	-5°47.84'	9°42.63'	3138.0					USBL-Subposition
322	13 1 30	Regab	GC	11	26/07/04 16:14	-5°47.85'	9°42.74'	3156.2					USBL-Subposition, Hydrat, Rhizon
323	13 1 31	Regab	ROVQ	211	26/07/04 20:02	-5°47.84'	9°42.68'	3147.0					USBL-Subposition, Successful dive
324	-	Regab	WOOD	1	27/07/04 07:41	-5°48.00'	9°42.67'	3138.0					USBL-Subposition, Woodpack2
325	-	Regab	ROVQ	212	27/07/04 13:44	-5°47.87'	9°42.61'	3156.3					USBL-Subposition, Successful dive
321	-	Regab	ROVQ	210	26/07/04 11:00	-5°48'	9°42.78'	3158.3	26/07/04 14:40	-5°47.88'	9°42.56'	3156.3	Dive canceled
326	-	Regab	MB-PS	8	27/07/04 22:03	-5°52.74'	9°44.91'	3400.5	28/07/04 07:29	-5°49.78'	9°43.78'	3169.9	
327	-	Regab	WOOD	2	28/07/04 10:20	-5°47.84'	9°42.63'	3051.0					USBL-Subposition

Station No. M	GeoB	Area	Gear	Gear No.	Start of Station / Gear at Bottom					End of Station					Remarks
					Date/Time (UTC)		Lat [N]	Lon [E]	Depth [m]	Date/Time (UTC)		Lat [N]	Lon [E]	Depth [m]	
328	-	Regab	ROVQ	213	28/07/04	12:23	-5°47.94'	9°42.63'	0.0	28/07/04	17:15	-5°47.87'	9°42.59'	3156.9	Dive canceled
329	13 1 32	Regab	TV-MUC	1	28/07/04	19:45	-5°47.84'	9°42.63'	3156.0						USBL-Subposition
330	-	Regab	MB-PS	9	28/07/04	23:39	-5°48.07'	9°42.9'	3156.4	29/07/04	09:00	-5°47.6'	9°42.71'	3155.1	
331	-	Regab	TV-MUC	2	29/07/04	12:09	-5°47.82'	9°42.68'	3155.0						USBL-Subposition
332	13 1 33	Regab	ROVQ	214	29/07/04	15:40	-5°47.87'	9°42.61'	3155.3						USBL-Subposition, Successful dive
333	-	Regab	MB-PS	10	29/07/04	23:22	-5°45.27'	9°44.59'	3081.1	30/07/04	05:15	-5°47.53	9°42.75'	3145.8	
334	-	Regab	LIFT	2	30/07/04	08:00	-5°47.84'	9°42.64'	3150.0						USBL-Subposition
335	-	Regab	ROVQ	215	30/07/04	11:36	-5°47.82'	9°42.64'	3148.0						Successful dive
336	-	Regab	MB-PS	11	31/07/04	00:57	-5°47.01'	9°42.68'	3133.2	31/07/04	07:31	-5°41.91'	9°47.84'	3008.2	
337	13 1 34	Regab	TV-MUC	3	31/07/04	09:46	-5°47.81'	9°42.67'	3111.0						USBL-Subposition
338	13 1 35	Regab	TV-MUC	4	31/07/04	20:40	-5°47.00'	9°42.67'	3081.0						USBL-Subposition
338a		Regab	MB	12	31/07/04	22:40	-5°47.45'	9°43.05'	3132.0	02/08/2008	05:57	-5°47.74'	9°42.94'	3143	
339	-	Regab	TV-MUC	5	01/08/04	08:11	-5°47.98'	9°42.50'	3101.0						USBL-Subposition
340	-	Regab	ROVQ	216	01/08/04	09:30	-5°47.88'	9°42.63'	3155.0	01/08/04	16:54	-5°47.87'	9°42.64'	0	Dive canceled
341	-	Regab	TV-MUC	6	01/08/04	18:57	-5°47.97'	9°42.51'	3110.0						USBL-Subposition
342	-	Regab	TV-MUC	7	01/08/04	21:49	-5°47.99'	9°42.5'							NO USBL-Position
343	-	Regab	MB-PS	13	01/08/04	22:59	-5°48.45'	9°42.64'	0.0	02/08/04	06:50	-5°47.67'	9°42.96'	3138.1	
344	13 1 36	Regab	ROVQ	217	02/08/04	07:39	-5°47.87'	9°42.63'	3164.0						USBL-Subposition, Dive successful
					02/08/04	10:21	-5°47.84'	9°42.64'	3149.0						
345	-	Regab	MB-PS	14	02/08/04	21:14	-5°48.2'	9°42.62'	3162.9	03/08/04	06:45	-5°	9°43.34'	3149.8	
346	-	Regab	LIFT	3	03/08/04	09:59	-5°47.87'	9°42.69'	3146						USBL-Subposition,
347	13 1 37	Regab	TV-MUC	8	03/08/04	14:23	-5°47.99'	9°42.52'	0						
348	-	Regab	ROVQ	218	03/08/04	18:00	-5°47.87'	9°42.65'	3151.0						USBL-Subposition, Dive successful
349	-	Regab	MB-PS	15	03/08/04	23:21	-5°48.18'	9°42.47'	3167.3	04/08/04	04:20	-5°48.29'	9°42.33'	3171.9	
350	-	Regab	ROVQ	219	04/08/04	05:40	-5°47.92'	9°42.76'	3155.0	04/08/04	09:00	-5°47.99'	9°42.6'	3159.3	Dive canceled
351	-	Regab	MB-PS	16	04/08/04	09:09	-5°48.53'	9°42.97'	3163.0	04/08/04	15:30	-5°57.26'	9°22.3'	2202	Regab - Mud-Vulcanos
352	13 1 38	MudVol	TV-MUC	9	04/08/04	19:00	-5°57.66'	10°22.11'	2183.2						8 Samples, USBL-Sub Position
353	-	MudVol	MB-PS	17	04/08/04	20:00	-5°58.08	10°21.89'	2427.1	04/08/04	22:30	-5°55.7'	10°23.42'	2322.4	
354	13 1 39	MudVol	TV-MUC	10	05/08/04	01:37	-5°54.37'	10°23.78'	2275.0						USBL-Sub Positions
354a		MudVol	MB	18	05/08/04	02:35	-5°54.37'	10°23.80'	2274.0	05/08/04	06:43	-5°47.89'	9°43.03'	3152	
355	13 1 40	Regab	ROVQ	220	05/08/04	07:34	-5°47.91'	9°42.71'	3157.1	05/08/04	23:33	-5°47.94'	9°42.49'	3157.3	Dive successful
356	-	Regab	MB-PS	19	06/08/04	00:37	-5°48.43'	9°44.44'	3134.5	06/08/04	04:18	-5°53.32'	10°12.34'	2691.7	
357	-	Regab	LIFT	4	06/08/04	10:08	-5°47.88'	9°42.69'	3148.0						USBL Subposition
358	-	Regab	ROVQ	221	06/08/04	11:46	-5°47.87'	9°42.7'	0.0	06/08/04	14:22	-5°47.9'	9°42.71'	0	Dive canceled
359	13 1 41	Regab	GC	12	06/08/04	15:52	-5°47.98'	9°42.52'	3120						USBL Subposition

Station n No. M	GeoB	Area	Gear	Gea r No.	Start of Station / Gear at Bottom				End of Station				Remarks		
					Date/Time (UTC)		Lat [N]	Lon [E]	Depth [m]	Date/Time (UTC)		Lat [N]		Lon [E]	Depth [m]
360	13 1 42	Regab	GC	13	06/08/04	18:58	-5°47.98'	9°42.52'	3115.0						USBL Subposition
361	13 1 43	Regab	ROVQ	222	06/08/04	22:21	-5°47.87'	9°42.68'	3166.4						Dive successful
362	-	Regab	MB-PS	20	07/08/04	13:00	-5°47.26'	9°41.68'	3162.8	07/08/04	18:05	-5°47.5'	9°42.67'	3143.9	
363	-	Regab	LIFT	5	07/08/04	20:52	-5°47.89'	9°42.68'	3152.7						
364	13 1 44	Regab	ROVQ	223	07/08/04	22:03	-5°47.93'	9°42.72'	0.0	08/08/04	10:35	-5°47.93'	9°42.69'	0	Dive successful
365	-	Regab	MB-PS	21	08/08/04	14:00	-5°47.87'	9°43.65'	3134.2	09/08/04	23:00	-6°9.89'	9°27.53'	2471.9	
366	-	Regab	MB-PS	22	09/08/04	23:30	-6°7.79'	10°27.86'	2436.7	10/08/04	06:15	-5°47.13'	9°43.05'	3138.2	
367	-	Regab	GC	14	10/08/04	07:45	-5°47.02'	9°42.69'	0.0						No Samples, NO USBL-Subposition
368	-	Regab	LIFT	6	10/08/04	12:48	-5°	9°42.51'	3153.0						
369	-	Regab	ROVQ	224	10/08/04	14:29	-5°48'	9°42.55'	0.0	10/08/04	17:29	-5°48.04'	9°42.48'	0	Dive canceled
370	-	Regab	GC	15	10/08/04	19:10	-5°47.01'	9°42.67'	3143.5						No Samples, USBL-Subposition
371	-	Regab	GC	16	10/08/04	21:35	-5°47.01'	9°42.67'	3132.0						No Samples, USBL-Subposition
372	-	Regab	MB-PS	23	10/08/04	22:46	-5°46.83'	9°43.16'	3115.7	11/08/04	05:45	-5°47.38'	9°43.78'	3119.9	
373	-	Regab	GC	17	11/08/04	09:12	-5°46.93'	9°42.72'	3143.0						No Samples, USBL-Subposition
374	-	Regab	GC	18	11/08/04	11:59	-5°45.17'	9°42.74'	3099.1						No Samples, USBL-Subposition
375	13 1 45	Regab	TV-MUC	11	11/08/04	14:38	-5°45.16'	9°42.74'	3099.9						8 Samples, USBL-Subposition
376	-	Regab	GC	19	11/08/04	17:05	-5°45.17'	9°42.74'	3101.1						No Samples, USBL-Subposition
377	13 1 2 4-2	Regab	GC	20	11/08/04	20:09	-5°47.84'	9°42.73'	3155.1						Some Carbonates, USBL-Subposition
377a		Transit	MB-PS	24	11/08/04	21:23	-5°48.49'	9°43.54'	3150.0	14/08/04	18:32	-5°48.62'	9°43.04'	3160	
378	-	Regab	LIFT	7	14/08/04	21:12	-5°48'	9°42.5'	3154.0						USBL-Sub-position
379	13 1 46	Regab	ROVQ	225	15/08/04	00:21	-5°48.02'	9°42.49'	3154.0						Dive successful
380	13 1 47	Regab	GC	21	15/08/04	22:22	-5°47.80'	9°42.74'	3155.0						USBL-Sub-position

Station No. M	GeoB	Area	Gear	Gear No.	Start of Station / Gear at Bottom					End of Station					Remarks
381	13 1 48	Regab	GC	22	16/08/04	00:34	- 5°47.81'	9°42.74'	3153.6						USBL-Sub-position
382	-	Regab	MB-PS	25	16/08/04	02:10	- 5°47.75'	9°43.01'	3152.6	16/08/04	13:16	- 5°54.91'	10°23.62'	2280.9	
383	13 1 49	Regab	MUC	12	16/08/04	18:50	- 5°47.99'	9°42.52'	3155.2						USBL-Sub-position
384	-	Regab	LIFT	8	16/08/04	23:02	- 5°47.83'	9°42.62'	3154.2						USBL-Sub-position
385	-	Regab	ROVQ	226	17/08/04	00:08	- 5°47.86'	9°42.81'	3154.8	18/08/04	04:14	- 5°49.02'	9°42.08'	3180.1	Dive successful
386		Transit	MB-PS	26	18/08/04	05:01	- 5°51.15'	9°49.02'	3122.0	23/08/04					

Abbreviations (devices)

MB	Multibeam Echosounder (depth)
PS	PARASOUND Sediment Echosounder (depth)
ROVQ	Remotely Operated Vehicle Quest 5
GC	Gravity corer
LIFT	Large lift Colossos
WOOD	Colonisation Wood
TV-MUC	TV-Multicorer

4.8 Data and Sample Storage and Availability

All metadata including those of the ROV QUEST dives were delivered to the PANGAEA World Data Center MARE and to the BSH (CSR). The ship station list is published together with the SCR on the homepage of the control station METEOR. All geophysical observations carried out during leg M76/3b and the ship tracks as well as the ROV tracks were also deposited at PANGAEA. The biogeochemical data have been processed and are shared between the MARUM and IFREMER PhD students and scientists involved in the scientific processing of the data. The videomosaicking data have been handed over to IFREMER for further processing, a student of MARUM is involved in the scientific use of the data. The samples have been split between MARUM, MPI, AWI, University Gent, IFREMER, University Paris according to the workplan. Reference geological cores are stored in the MARUM core repository, these and the other geological samples have obtained GeoB ID numbers in addition to the PANGAEA event labels. All photo and film data are stored in the MARUM QUEST data base. Reference microbiological samples are stored at MPI. Gene sequences submitted to the international data bases will receive accession numbers and can be related to the PANGAEA event labels. Reference biological samples are stored at IFREMER and at the University of Paris.

4.9 Acknowledgments

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