

FS SONNE

FAHRTBERICHT SO118
CRUISE REPORT SO118

BIGSET

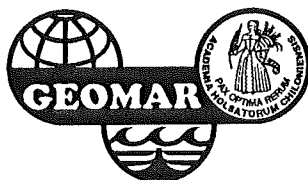
**BIOGEOCHEMICAL TRANSPORT OF
MATTER AND ENERGY IN THE DEEP SEA**

MUSCAT (OMAN) - MUSCAT (OMAN)
31.03 - 11.05.1997



71

GEOMAR REPORT



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Edited by
Olaf Pfannkuche and Christine Utecht
with contributions of cruise participants

GEOMAR
Forschungszentrum
für marine Geowissenschaften
der Christian-Albrechts-Universität
zu Kiel

Kiel 1998
GEOMAR REPORT 71

GEOMAR
Research Center
for Marine Geosciences
Christian Albrechts University
in Kiel

Redaktion der Serie: Gerhard Haass

Managing Editor: Gerhard Haass

Umschlag: GEOMAR Technologie GmbH

Cover: GEOMAR Technologie GmbH

GEOMAR REPORT
ISSN 0936 - 5788

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1. Introduction

The 118th voyage of FS SONNE started on March 31st 1997 in Muscat (Sultanate Oman) and finished on May 11th 1997 in Muscat. The expedition was dedicated to the research programmes „Biogeochemical Transports of Matter and Energy in the Deep Sea“ (BIGSET) and German Joint Global Ocean Flux Study- Arabian Sea (JGOFS-Arabian Sea).

BIGSET is a joint programme of 2 research institutes and 5 university institutions (coordination GEOMAR, Kiel) within the new national research focus „deep sea research“ sponsored by the Federal Ministry of Education and Research (Table 1). BIGSET is concerned with the biogeochemical processes in the ecosystem of the deep sea. Main objective is the fate of sedimenting organic matter. Investigations concentrate to the abyssopelagic and benthic realm with the benthic boundary layer (BBL) as a focal point. The BBL is operationally defined as a zone extending from the clear water minimum (about 500m above the sea floor) to about one metre into the sediment, containing the nepheloid layer, the bottom contact water and the bioturbated sediment horizons (Fig.4). The activity of various groups of organisms inhabiting the BBL from the bacteria to the megabenthos and the nekton acts as a generator of the chemical fluxes and partly also for the physical mixing processes. The quantification of biochemical and geochemical fluxes (esp. carbon compounds, opal) within the BBL, the identification of the role of different ecological groups and their interactions are key questions. The investigations will enlarge our knowledge of deep ocean fluxes and of the early diagenesis of pelagic sediments, thus also being important for a better interpretation of the geological record.

Main objectives of BIGSET are:

- I. Investigations on the functional interrelations within the ecosystem deep sea.
- II. Parameterization and quantification of the benthic-pelagic coupling to describe the net fluxes of inorganic and organic matter, esp. carbon compounds and opal, on different time and space scales within the benthic boundary layer.
- III. Enhancement of our knowledge and modelling of diagenetic processes of deep sea sediments.
- IV. Development and use of advanced deep sea technologies.
- V. Modelling of benthic fluxes on different scales (small scale, basin wide).

Tab.1: BIGSET programme. The joint programme is coordinated by GEOMAR and is comprised of the following subprojects (**SP**):

Coordination joint programme BIGSET (O. Pfannkuche, GEOMAR)	
SP-1	Fluxes of matter through the benthic community (GEOMAR)
SP-2	Benthic resuspension, bioturbation and irrigation (University Rostock)
SP-3	Microbial early diagenetic processes (Institut für Ostseeforschung, Warnemünde)
SP-4	The preservation potential of primary climatic and environmental signals in the deep sea (University Hamburg)
SP-5	Near bottom particle flux, habitat demands an early diagenetic processes in the benthic deep sea foraminiferal community (University Tübingen)
SP-6	Interactions between the seasonality in benthic turn over rates and the distribution of trace elements in deep sea sediments (University Bremen)
SP-7	Reactions and fluxes in surface sediments: Geochemical measurements and modelling of the biogeochemical system (GEOMAR)
SP-8	Biogenic, lithogenic, aeolic and hydrothermal signals of trace elements in deep sea sediments (University Oldenburg)

2. Objectives

The expedition SONNE 118 aimed to assess carbon, nutrient and trace metal fluxes in the benthic boundary layer of the deep Arabian Sea, an oceanic area with episodically largely enhanced biogeochemical fluxes. BIGSET investigations were executed at 5 permanent stations in the central basin of the Arabian Sea since 1995 (Fig 1).

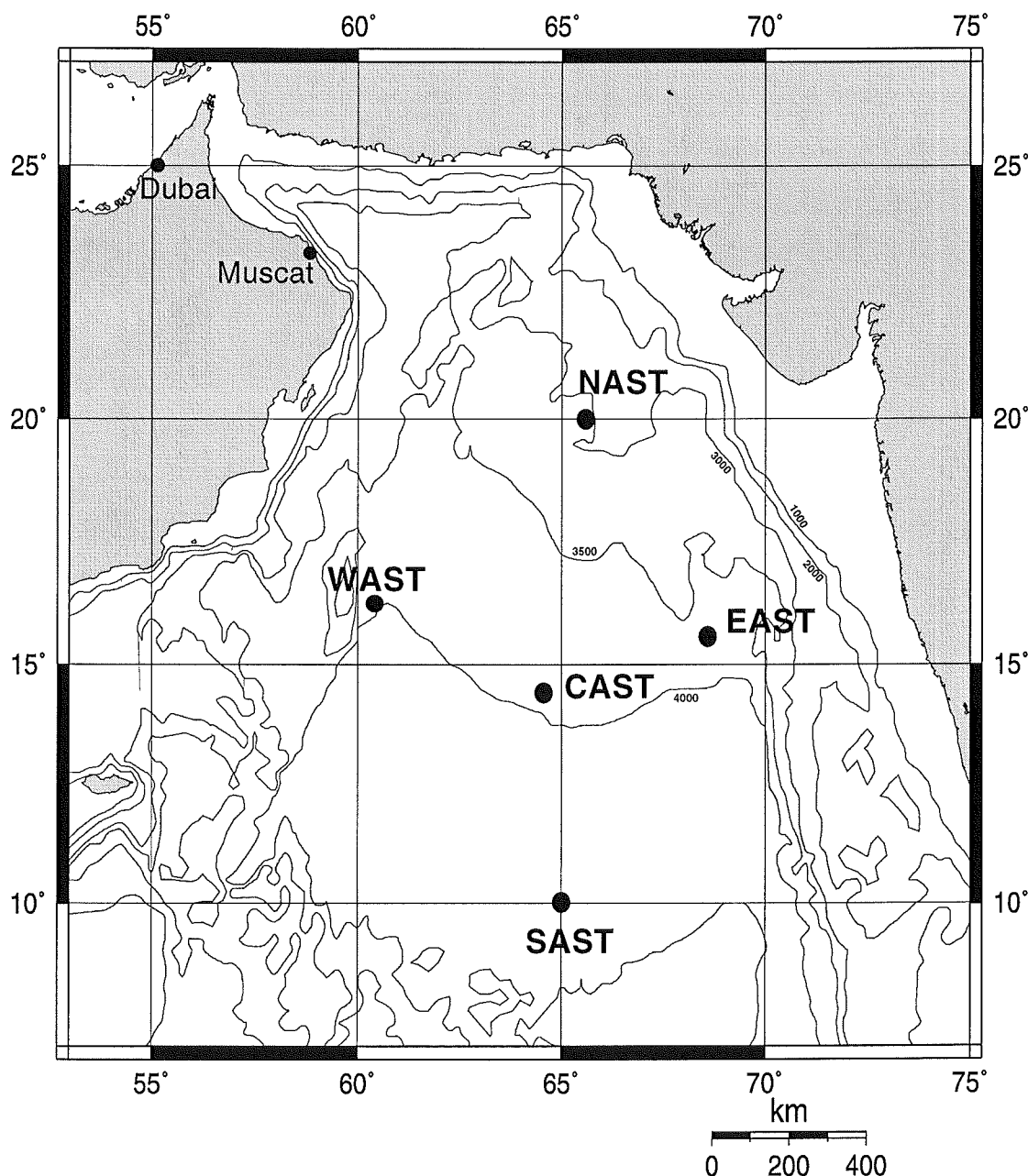


Fig.1: BIGSET main stations (Arabian Sea)

So far expeditions with RV METEOR were carried out in October 1995 (METEOR 33/1). This cruise covered all five stations (NAST, WAST, CAST, EAST, SAST). The cruise METEOR 31/3 (March 1995) led only to station WAST.

Since a couple of years investigations of particle flux with sediment traps have been also carried out at stations WAST, CAST and EAST by a joint Indian/German project. The area of WAST and CAST was also a focal point of international JGOFS research in 1995 and of German JGOFS in 1995 and 1997. JGOFS will provide data mainly on the processes and fluxes in the upper mixed layer (Fig.4).

The main driving force for hydrographical and biogeochemical processes in the Arabian Sea is the activity of the monsoon winds. The strong winds of the SW-monsoon (June-September) and the NE-monsoon (November-March) enhance new production in the euphotic zone resulting in an increased particle export from the upper mixed layer into the deep ocean. During the SW-monsoon upwelling areas develop along the coasts of Somalia and the southern Arabian Peninsula which result in an upflow of nutrient rich deep water into the open ocean west of the axis of maximum wind speeds (Findlater or Somali Jet). During this time the primary production is at its yearly maximum in the western part of the Arabian Sea with filaments of highly productive water masses reaching far into the open ocean (Fig. 2). During the intermonsoon phases oligotrophic conditions develop in the open Arabian Sea. The highest entry of allochthonous material occurs also during the SW-monsoon. Great quantities of dust and sand are blown from the Arabian Peninsula into the ocean. Also the major rivers that flow into the Arabian Sea such as Indus, Narmada and Tapti have their yearly effluent maxima.

A second production maximum appears during the NE-monsoon (Fig.2), with the NE-winds induced by the winter cooling of the northern hemisphere playing an important role for thermohaline mixing. Because of this highly seasonal variability and the enhanced particle fluxes during the monsoon periods, which belong to the highest known sedimentation rates into the deep sea the Arabian Sea represents a key area for our understanding of global biogeochemical fluxes into the deep sea. Samples from moored sediment traps (JGOFS-Indik, Indian/German cooperation) collected in time series provide us with information of the seasonal distribution and the amount of material transported into the deep sea (Fig.3). Above that, they reflect mixed surface layer processes (variations of the primary production, terrestrial entry) with little temporal delay and high temporal resolution. A comparison between primary productivity, export productivity, flux rates in different water depths and accumulation rates on the sediment surface therefore facilitate estimating the deposition at the sediment/water interface.

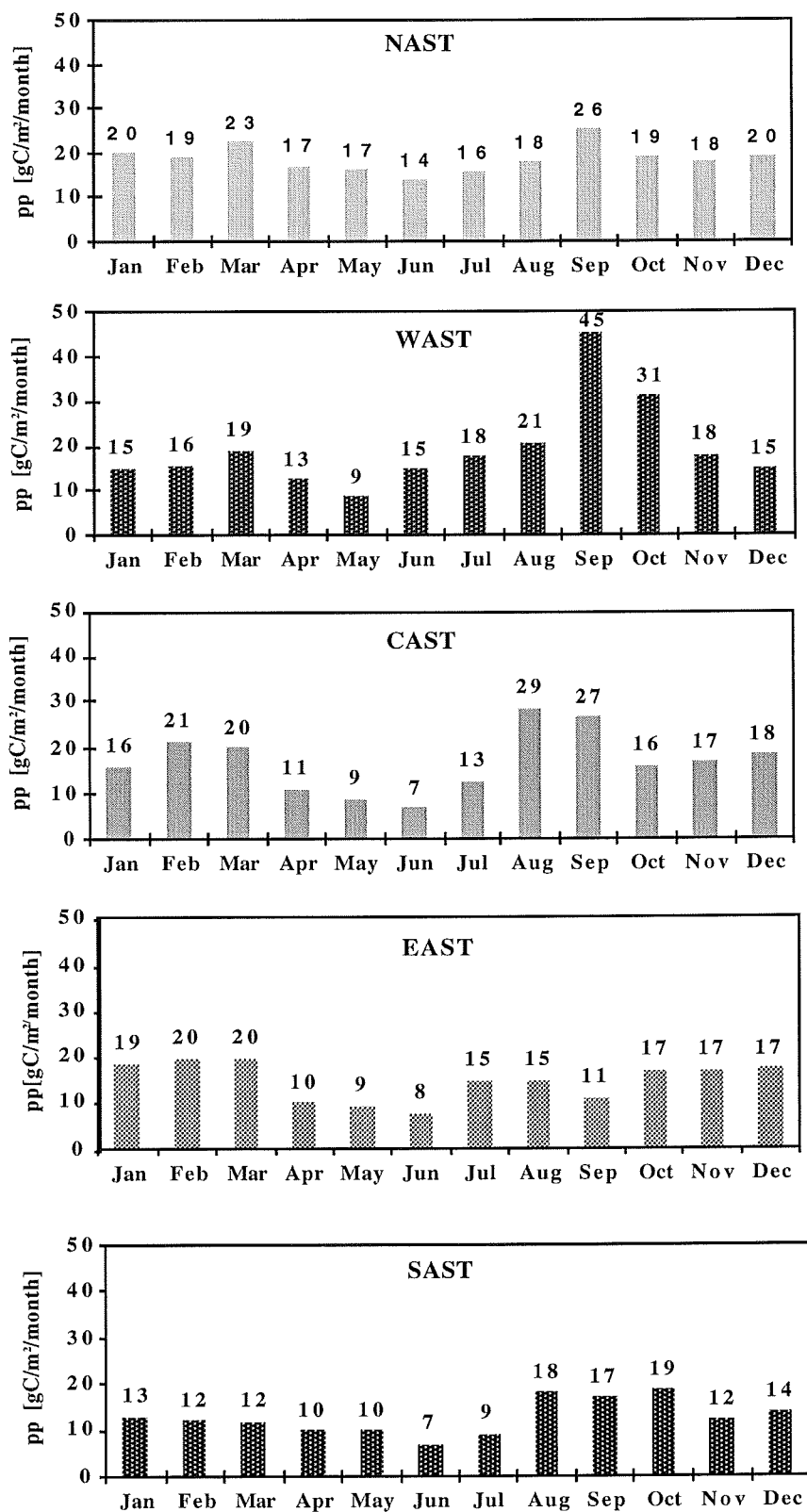


Fig.2: Primary production at stations NAST, WAST, CAST, EAST and SAST calculated by SAUTER (unpubl.) after satellite image data from ANTOINE et al (1996).

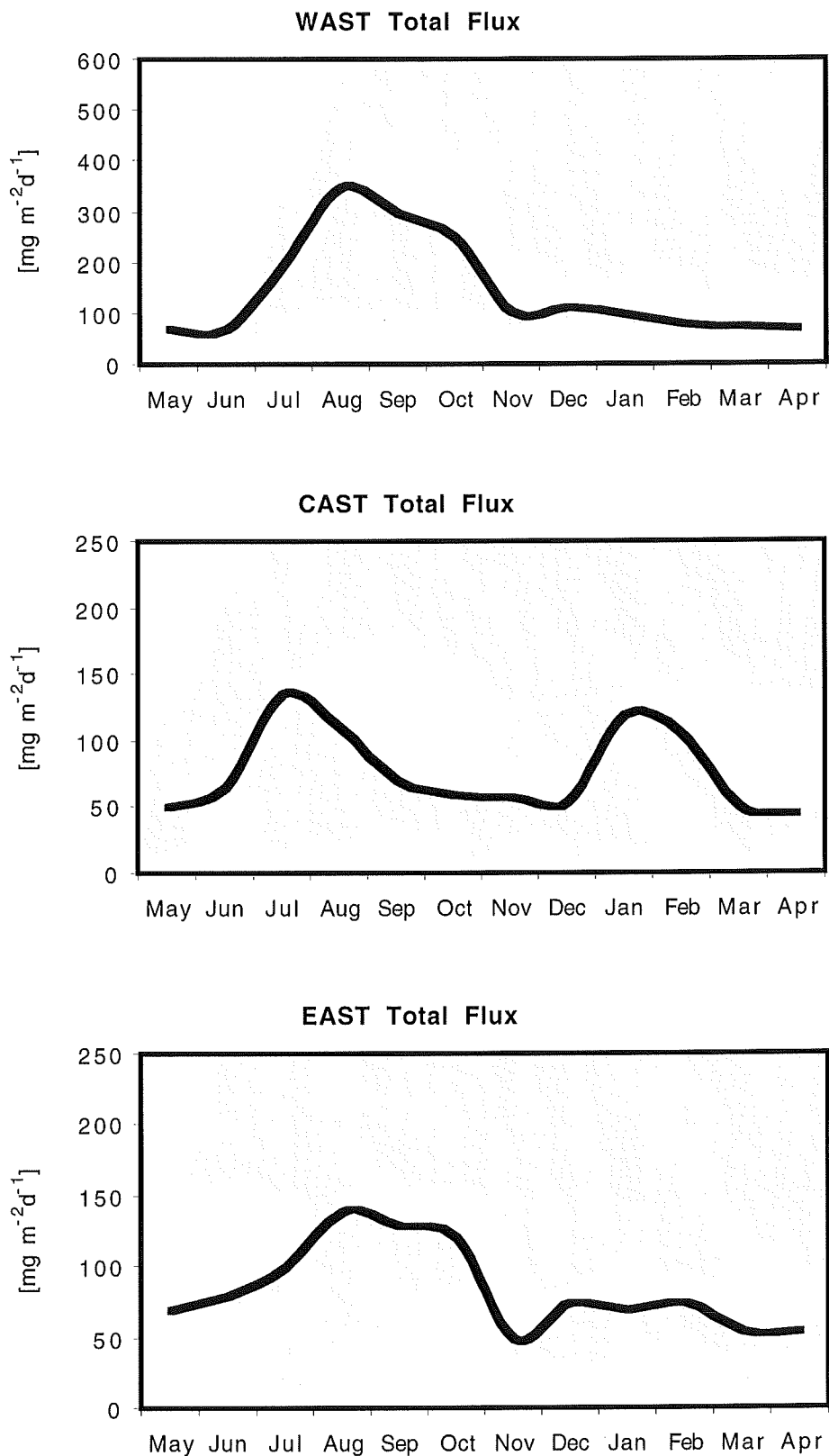


Fig.3: Seasonality of particle flux (total flux) at investigation stations WAST, CAST and EAST (arranged after HAAKE et al 1993). Mean values covering the period from 1986-1990.

The deep sea floor and the BBL are for investigations of oceanic material fluxes especially suitable because of various reasons. The sediment/water interface is a stable physical boundary, at which mass fluxes can be measured by different techniques. Two different methods are used in the BIGSET programme:

Modelling of pore water fluxes through measurements of nutrient concentration gradients and *in situ* measurements of benthic oxygen consumption rates in benthic chambers. The transport of dissolved material at the sediment/water interface originates from a combination of degradation processes of fast and slow decomposable organic material. The measured exchange rates can integrate variations of deposition rates, which facilitates estimating intermediate flux rates.

The sum of all carbon transport processes in the water column determine the rate of benthic deposition and mineralization. These processes include vertical and lateral transport of particles by physical properties as well as by organisms (Fig.4). Benthic investigations of early diagenetic processes mediate between short time scales of oceanic surface layer processes and the long time scales of processes in sediment layers beneath the bioturbated and bioirrigated sediment surface. Besides pore water fluxes the following aspects are of special interest in the BIGSET programme:

The amount of trace elements in the organic material, the knowledge of steering mechanisms of the elements' contribution between solid phase and porewater. Another important aspect is the reconstruction of the sedimentation entry paths (aeolic-seasonal, fluvial-seasonal up to episodic, turbidical-episodic) which can be quantified by the trace element relations.

Below the biologically active sediment layer the remaining material is buried for geological time scales. In consequence deep sea sediments represent the largest carbon storage of our planet. They also preserve the record of past climatic changes. Evidence has increased in the last years that global environmental changes happened much more rapidly and in the order of decades to centuries. In consequence the interpretation of carbon deposition under paleo-oceanographic and paleo-climatic conditions must consider the knowledge of the modification of the sedimentation signal by the „benthic filter“.

Regarding the carbon flux bathy- and abyssopelagic zooplankton and nekton inclusive its benthopelagic components act as a mediator between the productive oceanic surface layer and the benthos. This objective is investigated by

zooplankton subproject of German Indian Ocean JGOFS. Plankton organisms use carbon, fixed in sinking particles through ingestion, assimilation and in metabolic processes. Through ingestion and defecation of particles zooplankton contributes with a specific pathway to the transport processes. To estimate the influence of zooplankton and nekton organisms on the carbon flux a quantification of its carbon requirements in relation to the measurable carbon entry (from sediment traps) and in relation to the other fauna components is necessary.

The following three basic particle fluxes are to be investigated in the near-bottom interface in the deep sea, which is defined as a region reaching from the clear-water minimum zone (CWM) across the nepheloid layer down to app. 1m depth into the sediment (Fig.4).

- The particle flux into and in between the benthic boundary layer
- The remineralisation and solubilisation of particles in the BBL
- The deposition/ accumulation below the BBL

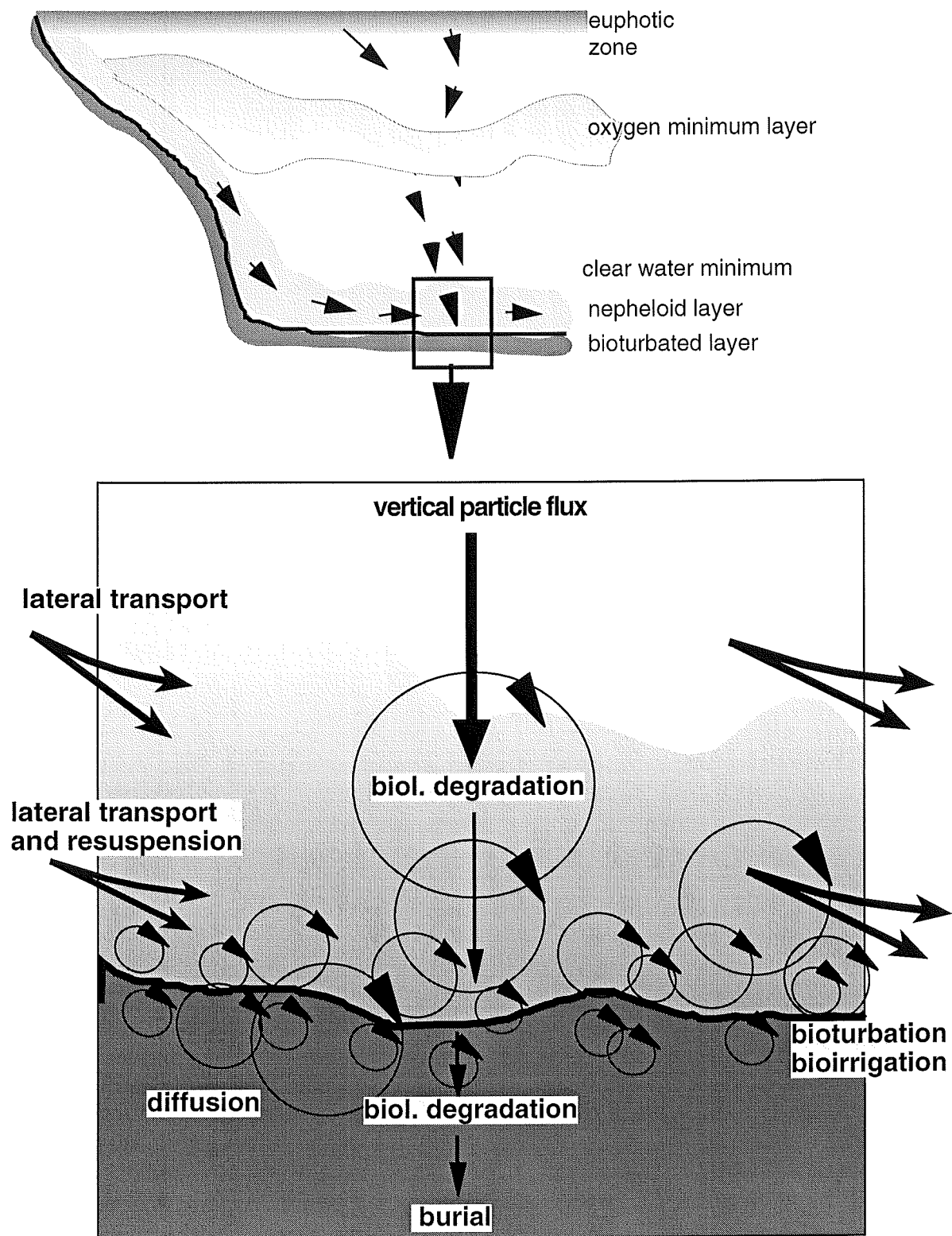


Fig.4: The near-bottom interface and schematic representation of the main transport and degradation processes.

The main scientific objectives of the SONNE cruise 118 were:

- I. Particle transport in the lower water column and the near-bottom interface
 - determination of the vertical particle flux 500m above ground
 - modification of the horizontal particle flux in the sediment-close bottom water
 - modification of the resuspension in the sediment-close bottom water
 - comparison of vertical and horizontal particle entries in the surface sediments
 - modification of controlling factors regulating the particle fluxes and their changes
- II. Deposition and degradation of particulate organic substance
 - measuring of *in situ* respiration rates of the sediment community.
 - microbial degradation of particles in the lower water column and in the surface sediments (aerobic degradation, nitrate reduction, sulfate reduction, methano-genesis).
 - determination of qualitative and quantitative interrelations between POM-deposition rates and biochemical activity parameters (ETS, ATP, hydrolysis-enzyme-activities).
 - investigation of the POM composition in sinking particles and surface sediment (POC, N, DOC, aminoacids, carbohydrates, HEXOSAMINE, C/N, $\delta^{13}\text{N}$, $\delta^{13}\text{C}$).
 - investigation of the relation between POM deposition rate and POM composition.
 - formulation of kinetic rules for the POM deposition (rate as a function of POM-age, POM-composition, electronacceptor availability, POM-flux at the sediment/water interface, sedimentation rate).
- III. Carbonate- and opal-solution
 - determination of the carbonate and opal solution rates at particles from the lower water column and surface sediments.
 - review and if necessary a new formulation of the kinetic rules of the carbonate and opal solution.
- IV. Biogenic transport processes in the surface sediment
 - quantification of the particle mixing by benthic organisms in the surface sediment (bioturbation, bioresuspension).

- quantification of the porewater and bottom water motion by benthic organisms (bioirrigation).
- review and if necessary a new formulation of the mathematic models of bioturbation and bioirrigation (Fick'sche Gesetze, nonlocal mixture).

V. Biology of the deep sea ecosystem.

- analysis of structure and distribution of organisms in the lower water column (zooplankton and nekton) and in surface sediments (megafauna, macrofauna, meiofauna, bacteria).
- analysis of the trophic relations between selected groups of organisms.
- description and quantification of biogenic structures and their role as intermediary of particle fluxes.

VI. Paleo-oceanographic proxies and tracers.

- determination of the trace element transports in particles from the water column into the sediment.
- modification of the interchange between particulates bound and dissolved trace elements in the water column as well as in the surface sediment.
- determination of the preservation potential of proxies during their transport through the water column and the early diagenesis in surface sediments.
- formulation of a model, that quantifies the preservation and resolution of trace elements in the sediment under different milieu-conditions and therefore facilitating an improved interpretation of the paleo-signals in the sediment

VII. Assessment and modelling of biogeochemical processes in surface sediments.

- assessment of material flux and turnover rates in the surface sediment.
- analysis of the functional relations between the important physico-chemical factors, reactions and material transport in the surface sediment.
- formulation of a kinetic model for the biogeochemical processes in the surface sediment based on the beforehand determined reaction kinetics and the beforehand achieved mathematic formulation of biogenic material transport.

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ANTOINE D., ANDRÉ J.-M. and A. MOREL (1996) Oceanic primary production

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- Seasonality and interannual variability of particle fluxes to the deep Arabian Sea. *Deep-Sea Research I*, **40**, 1323-1344.

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4. Narrative

In the late morning of March 31, 1997 the scientific party of SONNE Cruise 118 boarded RV SONNE in Port Sultan Qabos, Muscat, Oman. The group consisted of 25 scientists, technicians and students representing two programmes:

- BIGSET (Biogeochemical Transports of Matter and Energy in the Deep Sea: Arabian Sea)
- German JGOFS Indic (German Joint Global Ocean Flux Study; Indian Ocean).

The following institutions were participating:

BIGSET: GEOMAR Kiel; Institut für Ostseeforschung, Warnemünde; and working groups from the universities of Bremen, Hamburg, Oldenburg, Rostock und Tübingen.

JGOFS: Institut für Ostseeforschung, Warnemünde and University of Hamburg.

The research sites of SO118 have been previously investigated by the BIGSET group during METEOR 33/1 in September/October 1995.

During the morning of March 31 six containers with scientific equipment were unloaded and their contents were installed during the remaining day on the vessel. Another container with laboratory equipment and a temperature regulated laboratory container were taken over by the ship on the next morning. During the course of April 1 the installation of equipment on the working deck and in the laboratories was finished and RV SONNE departed at 22.30h from Port Sultan Qabos. The vessel headed in south-western direction towards the first location WAST on the western edge of the Arabian Basin (Fig.1).

The WAST location is divided into two contrasting sampling sites which lie 30nm apart. The site WAST-Top is located on the top plain of a deep sea mountain which extends about 70nm in length and 20nm in width in south to north direction rising about 2000m above the surrounding abyssal plain. The station WAST-Top is located in 16°10,5'N, 59°46'E (water depth 1920m). The station WAST-Plain is located on the abyssal plain in 16° 13'N, 60° 16'E (water depth 4045m). After a transit of 40h we arrived at WAST-Plain in the early afternoon of April 3. After a CTD/Rosette cast a series of multiple corer hauls were taken for geochemical and biochemical sediment analyses. A first inspection of the cores showed a substantial layer of relatively fresh and undegraded detritus on top of the sediment. Samples from the WAST-Top exhibited an even more extensive detrital layer on top of the sediment cores. These findings pointed at a relatively fresh sedimentation

pulse of particulate organic matter that had hit the WAST locality. First results of nutrient measurements from pore water and sediment contact water as well as measurements of biological activity potentials (electron-transport-activity ETSA) revealed surprisingly high porewater fluxes and biological activity. Station time at WAST was initially planned for two days with a second period of investigation about four weeks later. However, the possibility to study the geochemical and biological reaction in response to a fresh sedimentation pulse inclined us to reschedule our programme in order to get a time series of sediment samples. Therefore station work at WAST was prolonged until April 10, 1997.

During our stay at WAST the following gears were employed at both stations WAST-Top and WAST Plain: Sediment samples with multiple corer and gravity corer for biological and geochemical analyses, box grab samples for macrofauna investigations, EXPLOS-casts for megafauna studies, mesozooplankton catches with a double 1m²-MOCNESS (oblique hauls), plankton sampling (Foraminifera) with vertical multinet hauls, aggregate sampling with a WP2-net, CTD/rosette water sampler casts for hydrographical, geochemical and biological water analyses. A bottom water sampler with an integrated aggregate camera was employed to study near bottom particle dynamics. A mooring with a sediment trap 500m above the ground was deployed for 10 days. Two lander systems of the GEOMAR were deployed: a benthic chamber lander for the measurement of benthic community respiration and nutrient fluxes at the sediment/water interface and a lander housing a camera system for the observation of benthic bioturbative activity.

In the evening of April 10 we left WAST and headed in south-eastern direction to our southernmost station SAST.

During mid day April 12 RV SONNE reached the SAST station at 10°N, 65°E. The sampling locality is located on an abyssal plain at 4425m water depth. After the deployment of the GEOMAR benthic chamber lander one of our first goals was the retrieval of a sediment trap mooring which was deployed in late October 1995 during METEOR 33/1. The mooring contained of one sediment trap at 1000m above the sea bed and had sampled until early April this year. The acoustic release (BENTHOS model) could be activated immediately and gave correct distance measurements but failed to release the ballast weights. After several release commands and some hours of futile waiting for the mooring to appear at the surface we continued with sediment sampling.

During the next days we frequently tried to activate the release but it did not even respond with distance measurements. We therefore decided to dredge the mooring but the dredging attempts failed so that we had to abandon the system.

With exception of the MOCNESS the same gear as used at WAST was employed at SAST during the next days for sediment and water sampling. On April 14 the benthic chamber lander was due for retrieval. When trying to activate the release transponder (two MORS units) there was no response at all. Frequent release commands with two different deck units remained unanswered and the lander was not spotted on the sea surface. It was hypothesised that ballast weights might have been released in the frequent release attempts for the sediment trap mooring and that the lander had drifted away unnoticed. During our stay at SAST surface currents were steadily directed to the east with speeds up to 1knot. A search course of 50nm driven in current direction failed to spot the lander. Further frequent release attempt during our stay at SAST remained without any response so that we were forced to give it up.

In the early morning of April 17 we left the SAST station and took again course to the WAST location to continue our time series sampling.

The vessel stopped en route at 13° 05'N, 62° 45'E for a multiple corer deployment to enlarge our sampling grid for future basin wide extrapolation.

The WAST-Plain station was reached in the evening of April 18. After a Hydrosweep/Parasound survey in the course of April 19 we took a series of multiple corer, bottom water sampler and CTD/rosette water samples. In the afternoon of April 19 we steamed to the WAST Plain station, where we successfully recovered the GEOMAR camera lander. During the next days until the evening of April 21 we applied the same sampling routine as described for the first visit to the WAST site. In the morning of April 20 we successfully retrieved the sediment trap mooring deployed during our first visit to WAST. The GEOMAR camera lander was redeployed again carrying a shark carcass of 1,60m length for an experiment to study the degradation of large food falls by nekrophagous nekton organisms and megafauna.

In the evening of April 21 RV SONNE left WAST and headed east for the CAST sampling site. En route we took another multiple corer sample at 15° 20'N, 62° 20'E. CAST is located in the centre of the Arabian Sea on an abyssal plain at 14° 25'N, 64° 34'E (water depth 3950m).

In the evening of April 22 RV SONNE reached CAST. Station work at CAST was performed until early morning April 27. Besides a successful mooring and retrieval of the 500m-sediment trap which was deployed for three days the sampling programme was of the design of the WAST station including four successful MOCNESS hauls.

After 30 hours of steaming RV SONNE arrived at the NAST station on the morning of April 28. NAST as the northernmost sampling site of BIGSET is located at 20°N, 65°35'E (waterdepth 3190m). At NAST the 500m-sediment trap was successfully deployed for another three days period and besides two MOCNESS hauls the same sampling programme as performed at CAST was carried out. Station works at NAST were finished in the afternoon of May 1 and RV SONNE took course again to the WAST site. During the 33 hours transit the ship stopped at 18°N 62°48'E for a multiple corer deployment.

The WAST-Plain station at 16°13'N, 60°16'E was reached again in the late evening of May 2. We started stationwork with the retrieval of the camera lander (large food fall experiment). After a box grab deployment and near bottom CTD/rosette cast the sediment trap was moored again for a sampling period of 3 days. Afterwards RV SONNE headed for WAST-Top for a sampling series employing box grab, multiple corer, CTD/Rosette and bottom water sampler. In the evening of May 3 the camera lander was deployed on WAST-Top for another large food fall experiment. During the next days until May 7 samples were taken both at WAST-Plain and WAST-Top. The passages between the stations were used for MOCNESS-hauls and Hydrosweep/Parasound surveys. The sediment trap and the camera lander were retrieved successfully on May 7. Station work was finished in the afternoon of May 8 at 14.45h and RV SONNE took course to Muscat. RV SONNE docked at 8.00h on May 10 at Port Sultan Quabos. During the course of May 10 and 11 all scientific equipment was loaded into containers and the ship was prepared for the next campaign SO-119. The scientific party left RV SONNE on May 11 at 19.00h thus finishing SO118.

Favoured by good weather conditions and the calm sea state the cruise SO118 proved to be extraordinary successful. In total 101 stations were sampled with 214 individual gear deployments comprising of: 53 multiple corers, 21 boxgrabs, 6 gravity corers, 12 landers, 32 CTD/rosettes, 17 bottomwater samplers, 24 multiple opening/closing nets, 18 double 1m²-MOCNESSES, 12 WP2-nets, 10 EXPLOS

surveys and 8 sediment traps. 312nm were steamed for HYDROSWEEP / PARASOUND surveys.

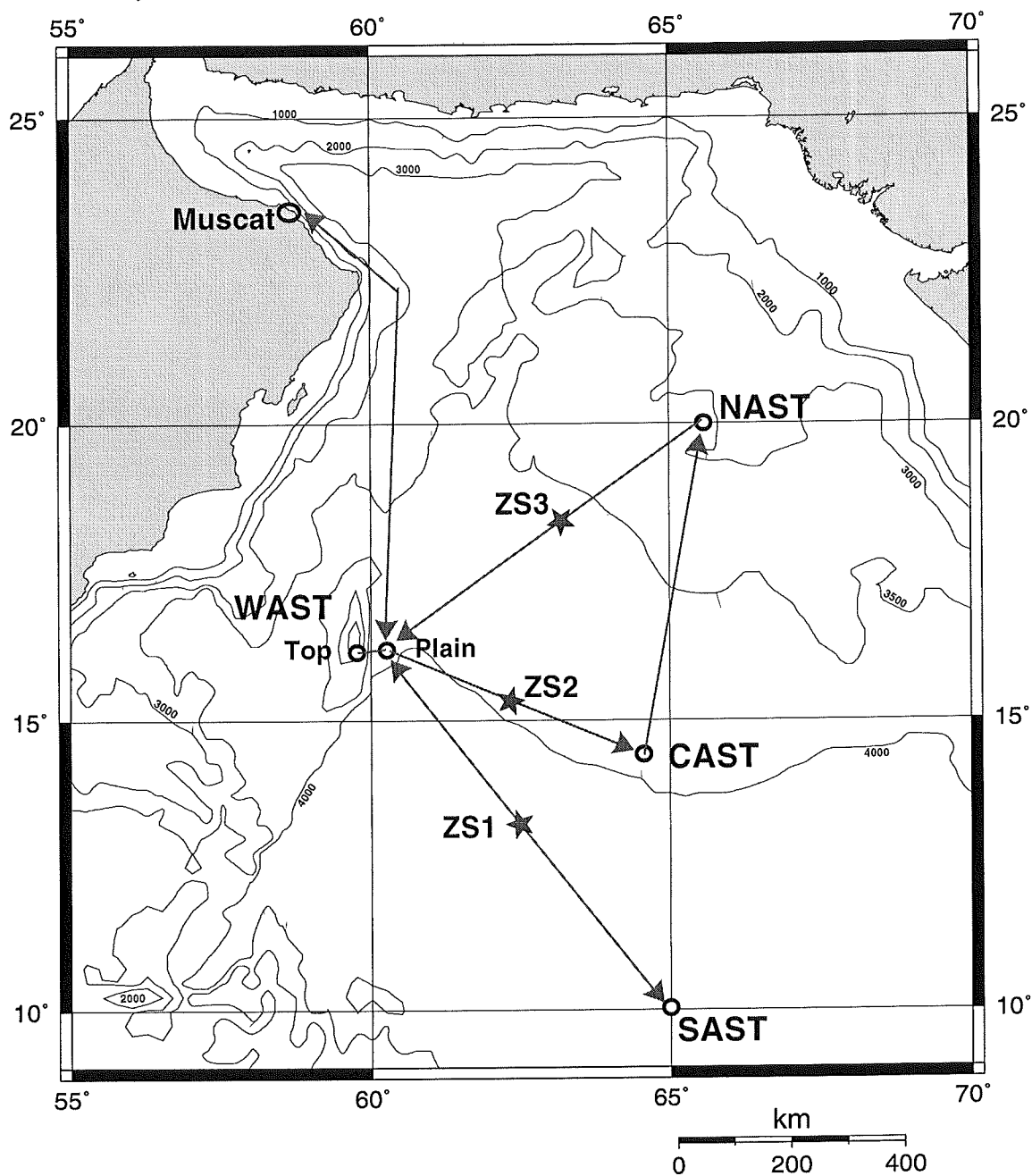


Fig.1: Cruise track and sampling stations of SO118
(Muscat-WAST-SAST-WAST-CAST-NAST-WAST-Muscat)
ZS = intermediate stations

5. Preliminary results

5.1. Bathymetry of the sampling stations, HYDROSWEEP swathmapping

Roger Luff

A bathymetric survey was carried out with the multibeam „HYDROSWEEP“-system at all main sampling stations. Parallel tracks, each surveying an area twice as wide as the water depth, were driven to determine the bathymetry around the main BIGSET stations. For a successful determination the measured areas have to overlap which reduced the netto track width to a factor of about 1.5 of the water depth.

The bathymetric maps shown in figures 1-6 had been prepared by the scientific technical services (WTD) on RV SONNE in different formates. The bathymetric maps are stored in the HPGL format (a vector based picture format which was transformed into WORD-files for this cruise report) for display, the raw data are tape-recorded for further evaluation. Plots with a scale of 1:100.000 are also available.

In total 37 hours of hydrosweep measurements resulted in about 1570km² of surveyed area divided into six subareas (Tab.1). CAST, NAST, SAST, WAST-Top, WAST-Plain and WAST-Area (map combining the bathymetry of WAST-Top and WAST-Plain). The contour levels in the maps are 10m, except for WAST-Top where the contour level is 20m. For the overall WAST-Area (Fig. 3) the contour level is 50m.

Table 1: surveyed area [km²] and depth [m] at the benthic sampling stations

Benthos station	Surveyed area [km ²]	Mean depth at station [m]
NAST	135	3180
WAST-Area	850	
WAST-Plain	171	4040
WAST-Top	270	1920
CAST	251	3850
SAST	331	4420

At several stations the HYDROSWEEP survey was combined with MOCNESS sampling transects, thus using the shiptime more efficiently. During the Hydrosweep transects the ship velocity was about 8 Kn. Most of the area between WAST-Top and WAST-Plain was surveyed during the frequent passages between these stations so that no extra time was required.

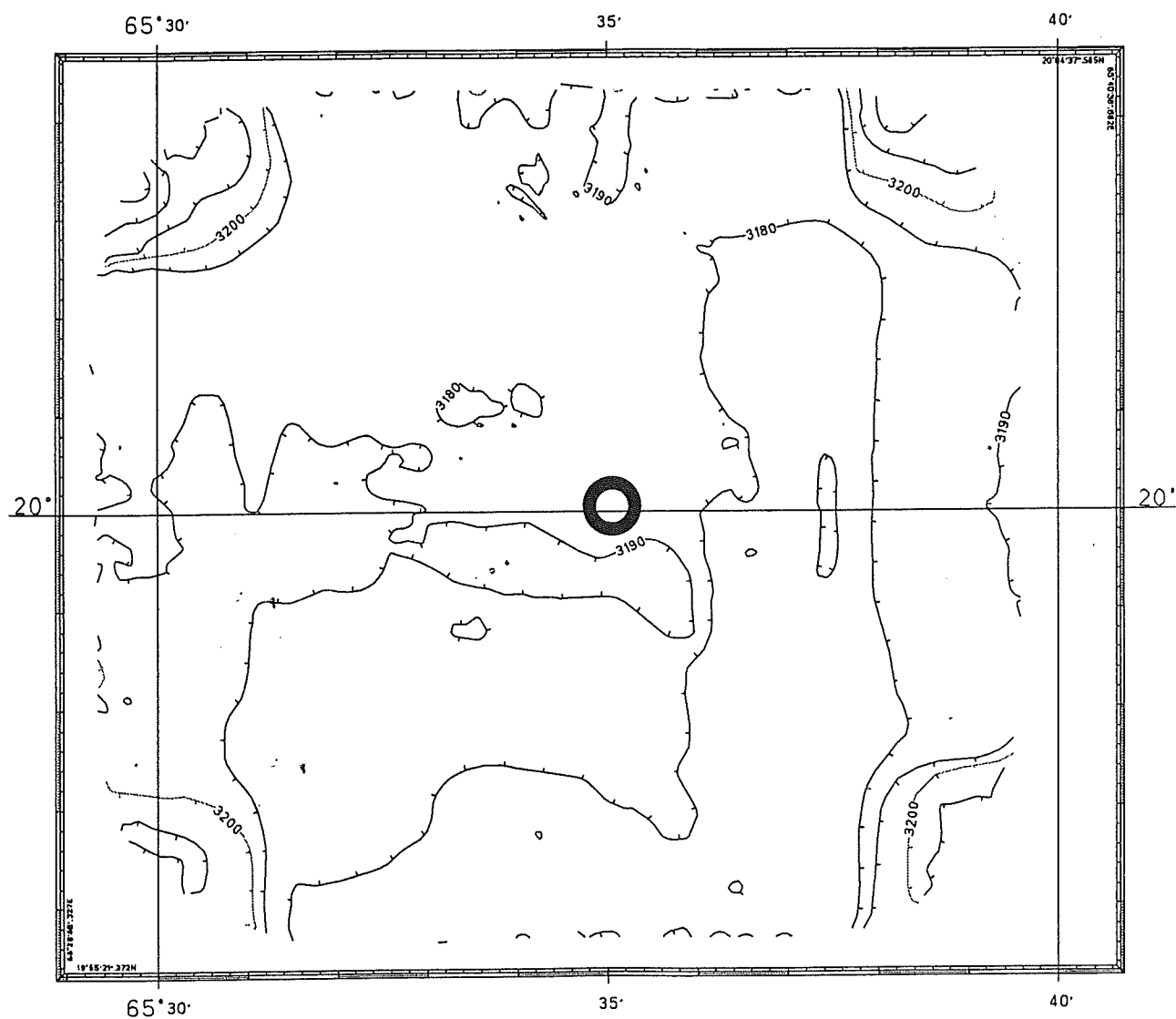


Fig.1: Bathymetry of NAST, Mercator projection at 20°N, contour interval 10m with the benthos station indicated at 20°00'N, 65°35'E at a depth of 3180m.

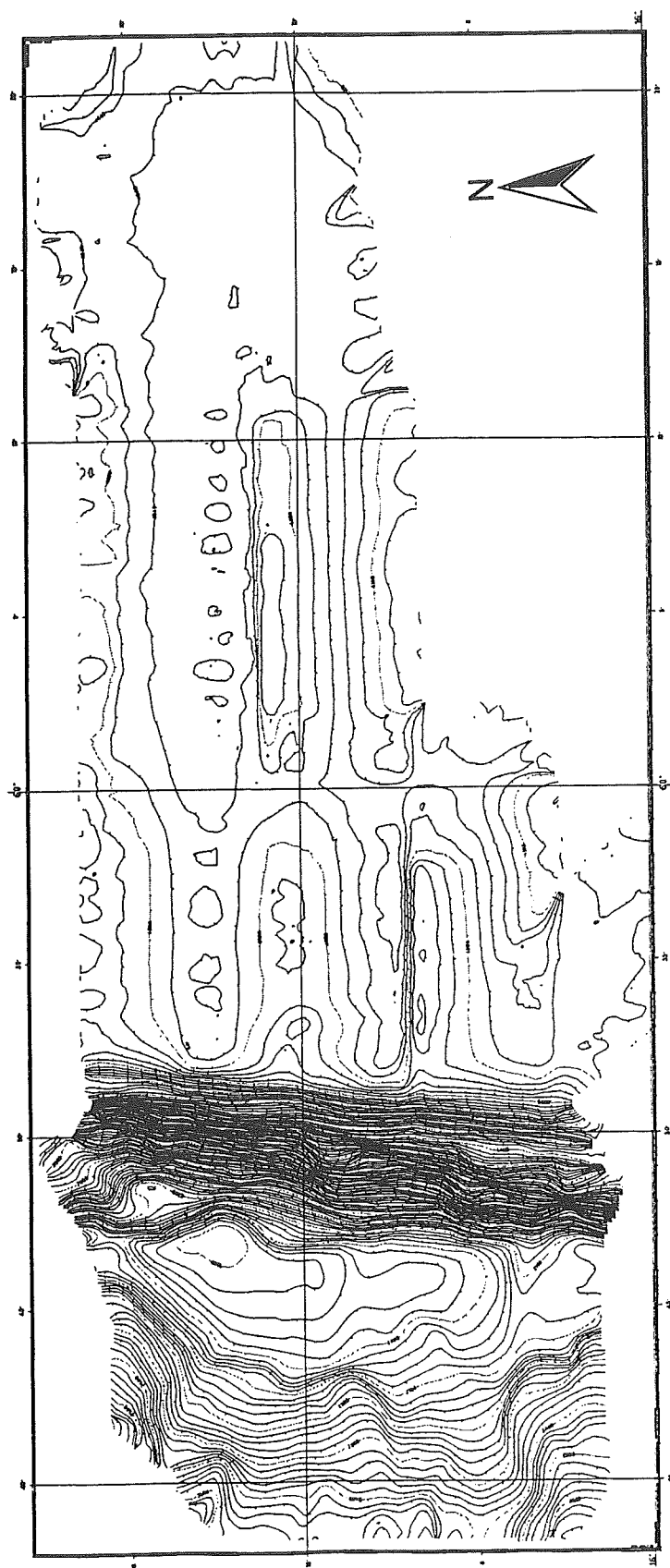


Fig.2: Bathymetry of the WAST-Area, Mercator projection at 16°N,
contour intervals 50m

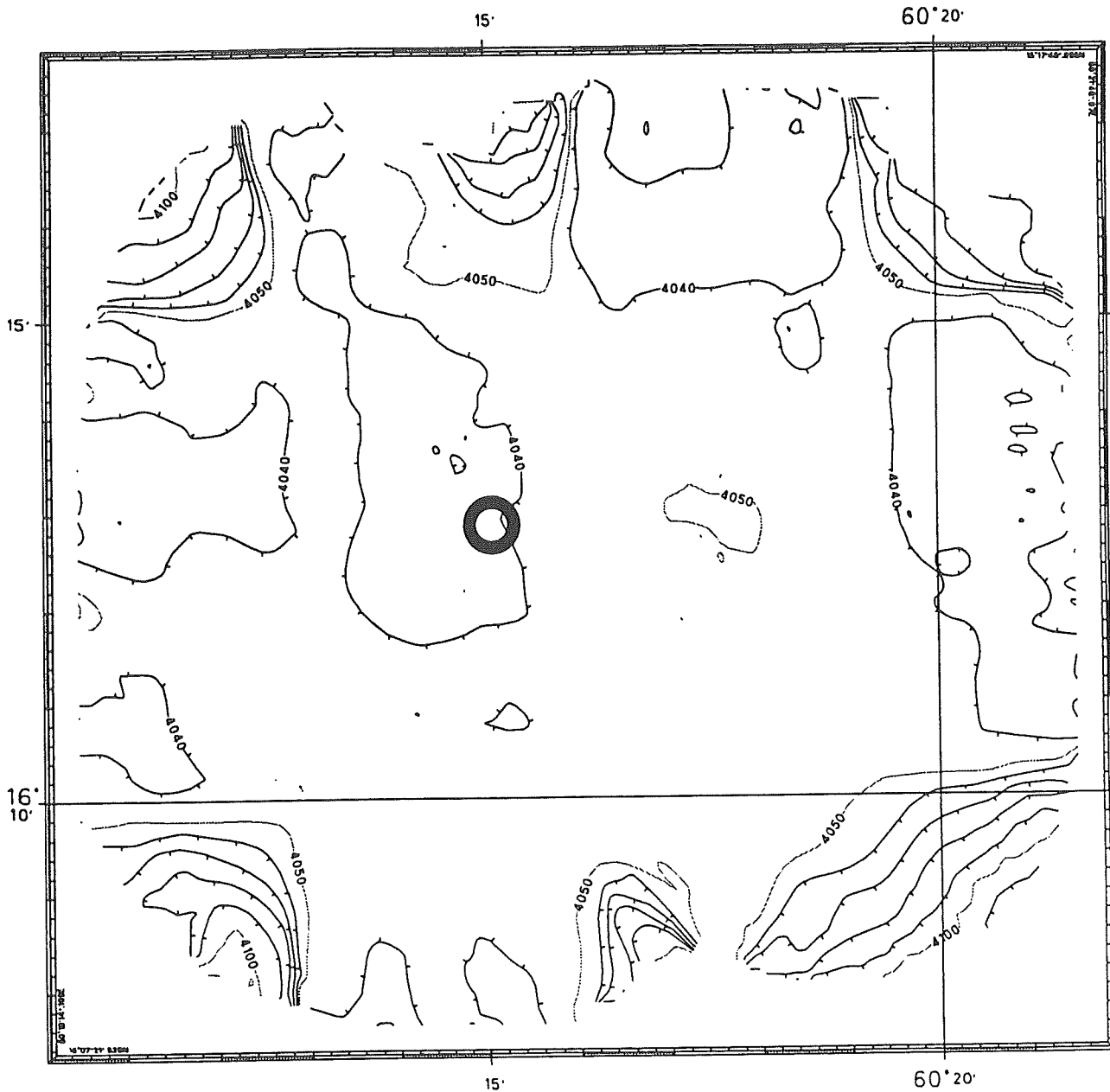


Fig.3: Bathymetry of WAST-Plain, Mercator projection at 16°N, contour interval 10m with the benthos station indicated at 16°35'N, 60°15'E at a depth of 4040m.

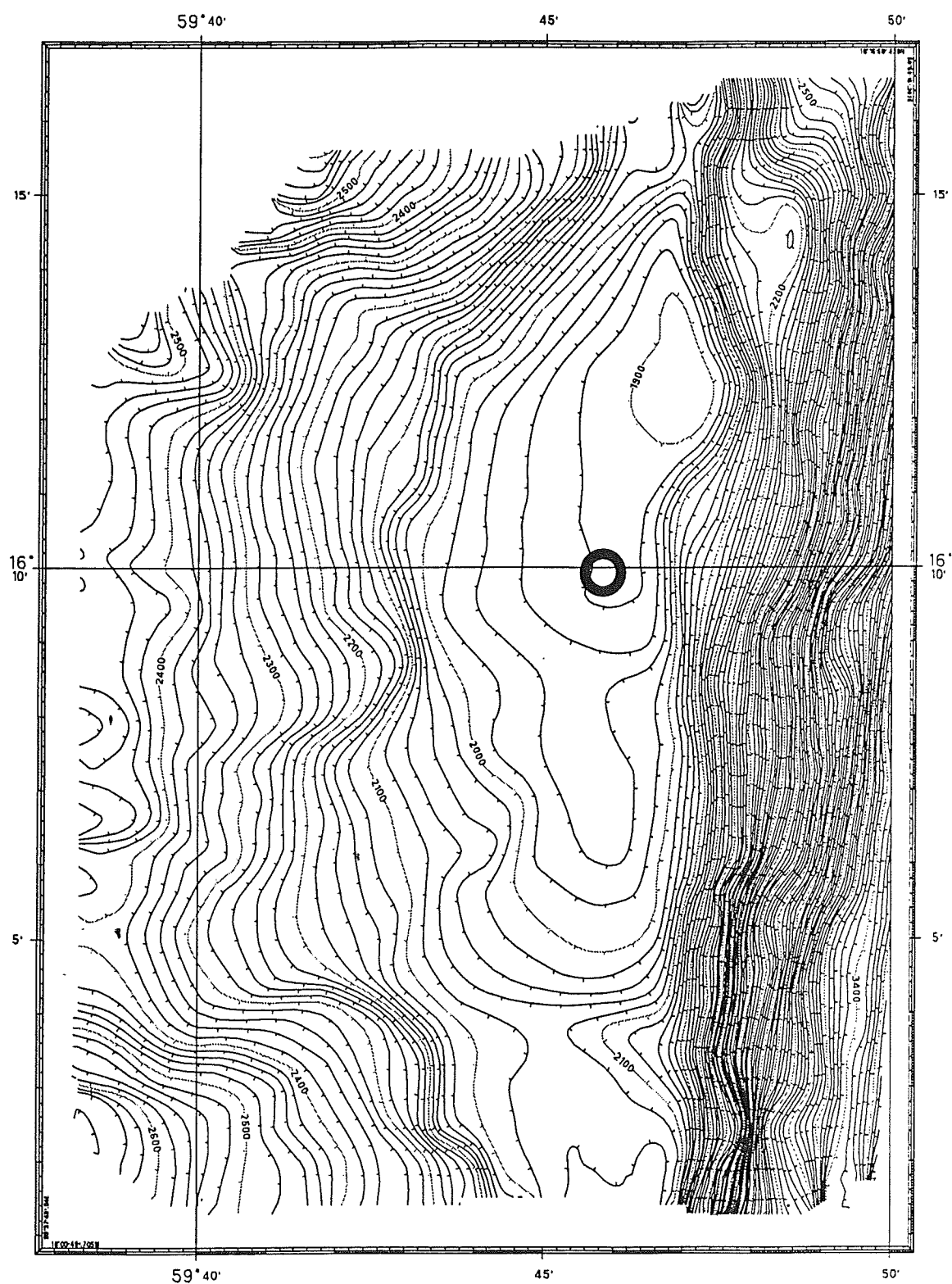


Fig.4: Bathymetry of WAST-Top, Mercator projection at 16°N, contour interval 20m with the benthos station indicated at 16°10'N, 59°46'E at a depth of 1920m.

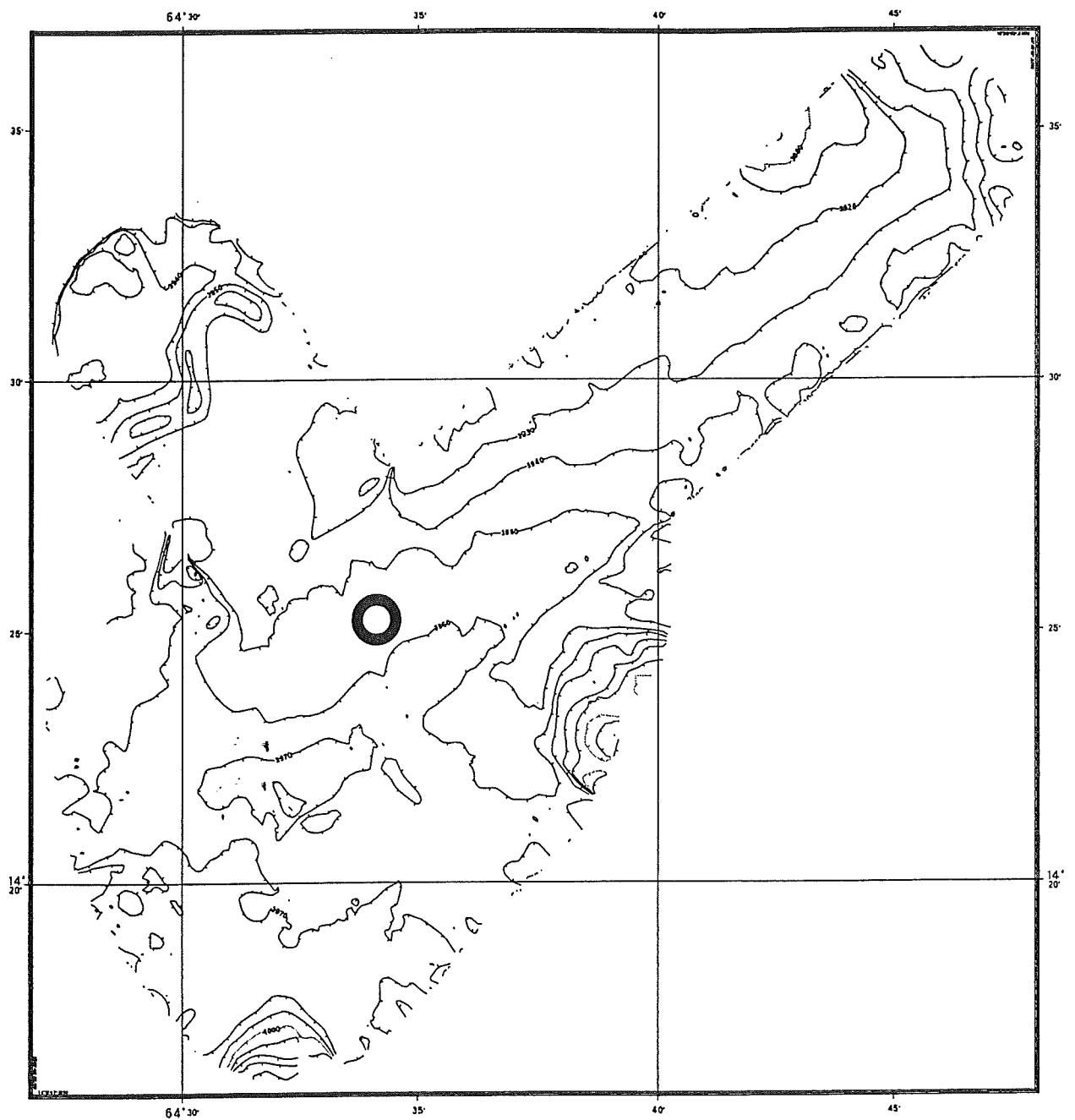


Fig.5: Bathymetry of CAST, Mercator Projection at 14°N. Contour interval 10m with the bathos station indicated at 14°25'N, 64°34'E at a depth of 3950m.

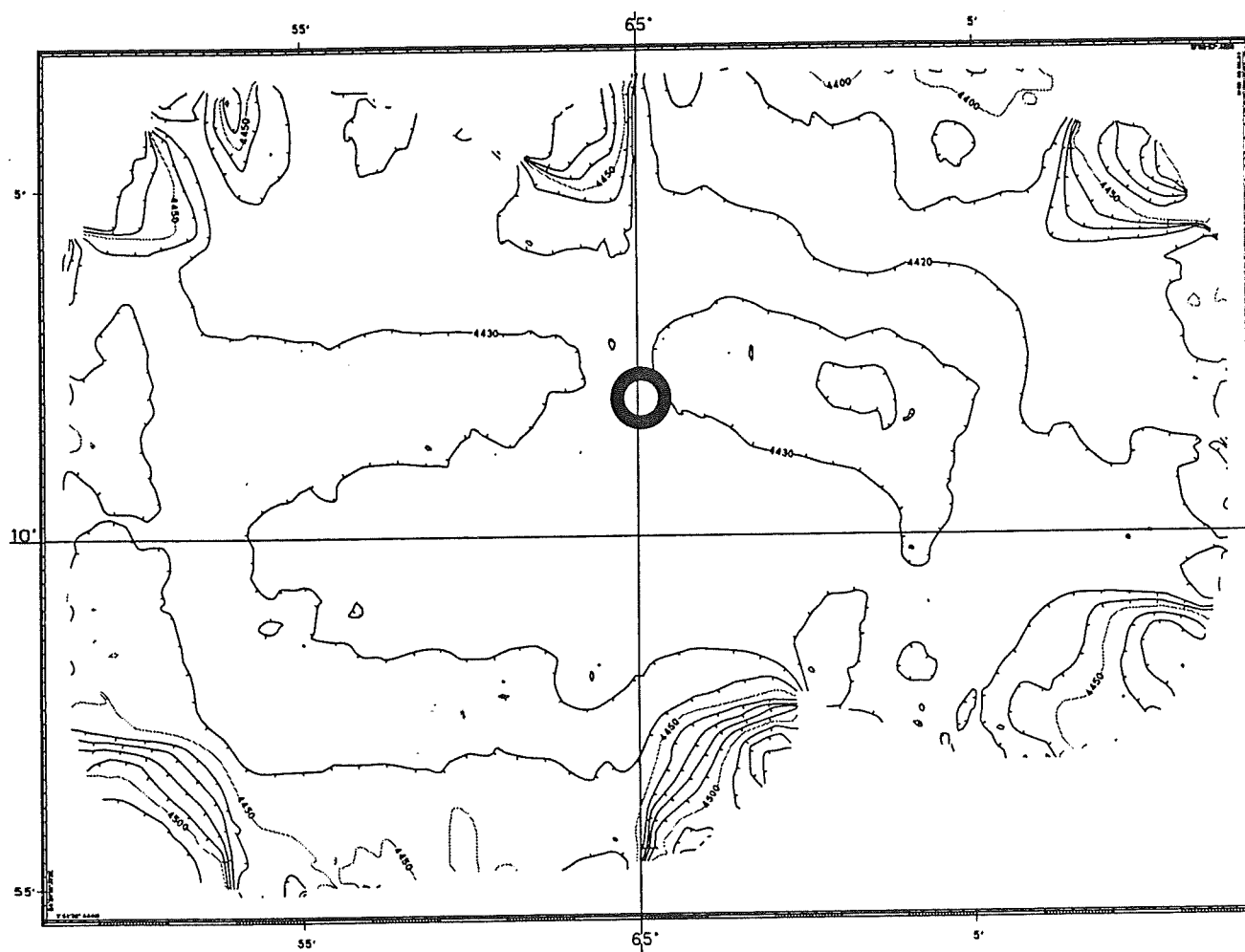


Fig.6: Bathymetry of SAST, Mercator Projection at 10°N. Contour interval 10m with the benthos station indicated at 10°02'N, 65°00'E at a depth of 4420m.

5.2. Hydrography at the sampling stations

Roger Luff

Introduction

In spring the northern part of the Indian Ocean undergoes a change of the wind and pressure system. The North-East monsoon which dominates the region between November and March has already lost its influence, while the South-West monsoon has not taken the predominance yet. The shift from one monsoon to the other can happen relatively rapidly over a period of 4-6 weeks. This intermonsoon period is characterized by calm winds. The general surface current pattern with a westward-flowing 'North Equatorial Current' and a southward current on the west side of the Arabian Sea breaks into a series of cold and warm mesoscale eddies which eventually transit into the reversed ocean circulation with an eastward 'North Equatorial Current' during the period of the South-West monsoon (PICKARD & EMERY 1990). During the South-West monsoon the circulation in the northern Indian Ocean is dominated by a strong westerly boundary current, the 'Somali' current.

Methodology and description of the work carried out

During the cruise SO118, 31 CTD-measurements were carried out at the five main stations with a Sea-Bird SBE 911 CTD-profiler. The CTD was combined with a 24x10 litre bottle rosette water sampler. The CTD carried sensors for pressure conductivity, temperature and oxygen. At shallow profiles (up to 600m) the CTD was additionally equipped with a fluorometer.

Minor problems with the CTD/Rosette system occurred only at two stations because of a leakage in the sampling unit of the rosette, which could be fixed by the WTD immediately. Because of the unreliable information from the CTD's bottom sensor a pinger was used on near bottom hauls to measure the distance to the bottom. This combination worked very precisely and we succeeded in getting water samples from 4-5m above the bottom.

CTD-No.	Station	Max. CTD-Depth [m]	Position (lat.)	Position (long.)	Date	Time [UTC]
CTD-01	WAST-Plain	800	16°13.02N	60°16.05E	03.04.97	10:25
CTD-02	WAST-Plain	4012	16°12.97N	60°15.99E	03.04.97	12:16
CTD-03	WAST-Plain	2521	16°12.98N	60°16.02E	04.04.97	19:27
CTD-04	WAST-Plain	12	16°13.28N	60°15.94E	05.04.97	12:23
CTD-05	WAST-Plain	4011	16°13.03N	60°16.00E	06.04.97	22:43
CTD-06	WAST-Plain	4031	16°12.99N	60°16.01E	07.04.97	14:28
CTD-07	WAST-Top	1906	16°10.49N	59°45.96E	10.04.97	04:05
CTD-08	WAST-Top	1802	16°10.47N	59°44.00E	10.04.97	06:09
CTD-09	SAST	4416	10°01.99N	65°00.00E	13.04.97	05:41
CTD-10	SAST	4386	10°01.94N	64°59.92E	13.04.97	08:56
CTD-11	SAST	2372	10°02.00N	65°00.00E	13.04.97	13:15
CTD-12	SAST	4415	10°02.00N	65°00.01E	16.04.97	17:11
CTD-13	WAST-Top	60	16°10.51N	59°45.98E	19.04.97	05:20
CTD-14	WAST-Plain	600	16°12.98N	60°15.95E	20.04.97	08:50
CTD-15	WAST-Plain	4038	16°13.00N	60°15.98E	21.04.97	07:19
CTD-16	WAST-Plain	3990	16°12.99N	60°15.98E	21.04.97	11:55
CTD-17	WAST-Plain	600	16°13.00N	60°15.96E	21.04.97	14:57
CTD-18	CAST	600	14°24.96N	64°34.00E	22.04.97	16:12
CTD-19	CAST	3946	14°25.05N	64°34.00E	23.04.97	06:09
CTD-20	CAST	2500	14°25.13N	64°33.95E	23.04.97	21:50
CTD-21	CAST	60	14°24.98N	64°33.97E	25.04.97	07:27
CTD-22	CAST	3956	14°24.98N	64°34.04E	26.04.97	13:46
CTD-23	CAST	3892	14°25.03N	65°34.06E	26.04.97	17:48
CTD-24	NAST	2500	19°59.99N	65°34.97E	28.04.97	15:07
CTD-25	NAST	60	19°59.99N	65°34.99E	29.04.97	05:15
CTD-26	NAST	3178	19°59.98N	65°35.00E	30.04.97	02:23
CTD-27	NAST	3183	20°00.00N	65°34.98E	30.04.97	10:39
CTD-28	NAST	3138	20°00.00N	65°34.99E	30.04.97	13:04
CTD-29	WAST-Plain	60	16°12.99N	60°16.01E	04.05.97	06:07
CTD-30	WAST-Plain	2500	16°12.99N	60°16.03E	05.05.97	21:28
CTD-31	WAST-Plain	4041	16°12.99N	60°16.00E	06.05.97	10:33

Tab. 1: List of the CTD-stations during SO118 with station, maximal depth, position and time.

Sampling depths of CTD-profiles depended on requirements of the working groups. Samples were taken for the calibration of satellite chlorophyll measurements (A. Boetius) at the surface and at 60m during satellite transits, for chemical analyses (O. Pfannkuche, R. Turnewitsch, and K. Wallmann) and for biological and particle analysis (P. Schäfer, B. Springer and C. Petry) in depth between 5m above the ground up to the sea surface. For planktonic foraminifera analyses (F. Kurbjeweit) samples were taken at depth between 2500m to the

surface prior to the multinet stations. Total water column profiles of temperature, salinity and oxygen from stations: WAST-Plain, SAST, CAST and NAST are shown in the figures 1 to 3. From the shallower station WAST-Top the temperature, salinity, oxygen and sigma profiles are shown in the figure 4.

Results

A selection of temperature, salinity and oxygen profiles from the main stations are shown in the figures 1 to 4. Salinity at the surface of the Arabian Sea reaches high values up to 36.5 due to high evaporation in combination with very small fresh water input. The sea surface temperature reaches values up to 30°C due to very low wind mixing during the intermonsoon period. The strong solar radiation and the low wind results in a small temperature difference of about 3°C between the air and the sea surface (see Figure 5a for details). The 3°C thermocline is located at a depth of about 250m-300m, while the halocline occurs in a depth of about 150m-200m. A well developed mixed layer with a uniform temperature and salinity distribution was not found. Below the surface layer and north of 10°S the 'Indian Equatorial Water' can be found (WYRTKI, 1973). This water mass has a salinity of 34.9‰ to 35.5‰ and is formed in the Arabian Sea with components originating from the Red Sea and the Persian Gulf with values up to 36.3‰. The Indian Equatorial Water had a strong influence at a depth of about 100m at the station SAST but was difficult to identify at the other stations because of the high surface salinity (Fig. 2). The layer of intermediate water can be identified by the oxygen minimum zone (Fig. 3). Below 200m at CAST and NAST, below 350m at WAST and below 500m at SAST oxygen concentrations of 0.2 mg/l to 0.7 mg/l were measured. This waterbody is part of the Indian Central Water. Local oxygen minima at 200m at stations SAST and CAST can be related to Red Sea outflow water, while its influence at the other stations seemed to be weaker. The deep and bottom water of the Indian Ocean are of Atlantic/Antarctic origin with a relatively uniform temperature and salinity (PICKARD & EMERY, 1990) of 1.2°C and 34.72 PSU at the bottom. The oxygen concentration at the bottom reaches relatively high values at SAST with 5.28 mmol/l at 4410m and relatively low values at NAST with 3.8 mmol/l at 3180m. This depletion represents a different age with the oldest water in the north-east of the Indian Ocean (STOMMEL 1958).

The CTD-data for the BIGSET project is online available at:

http://www.geomar.de/sci_dpmt/umwelt/bigset_7/bigset.html

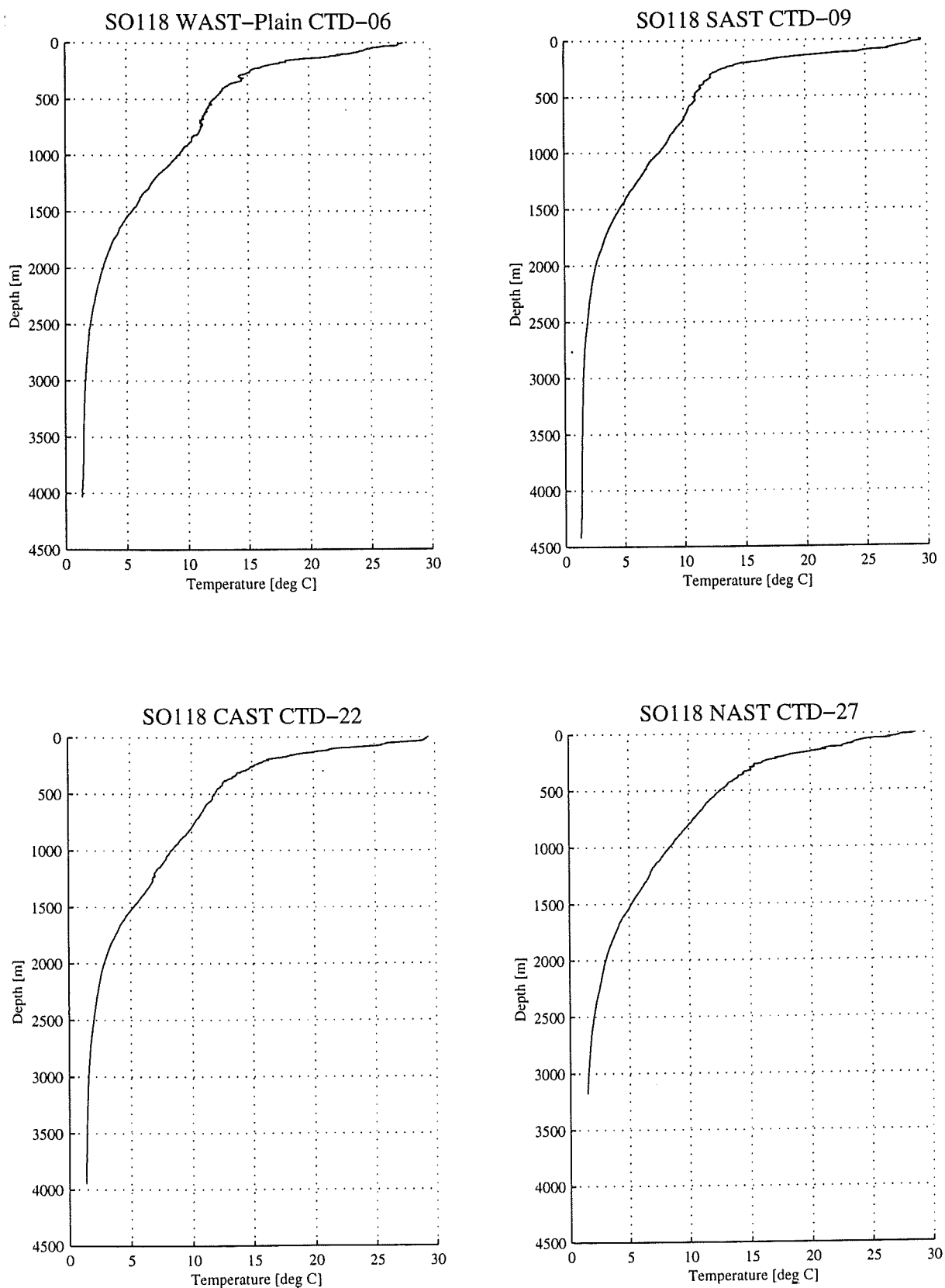


Fig. 1: Temperature profiles from the stations WAST-Plain, SAST, CAST and NAST

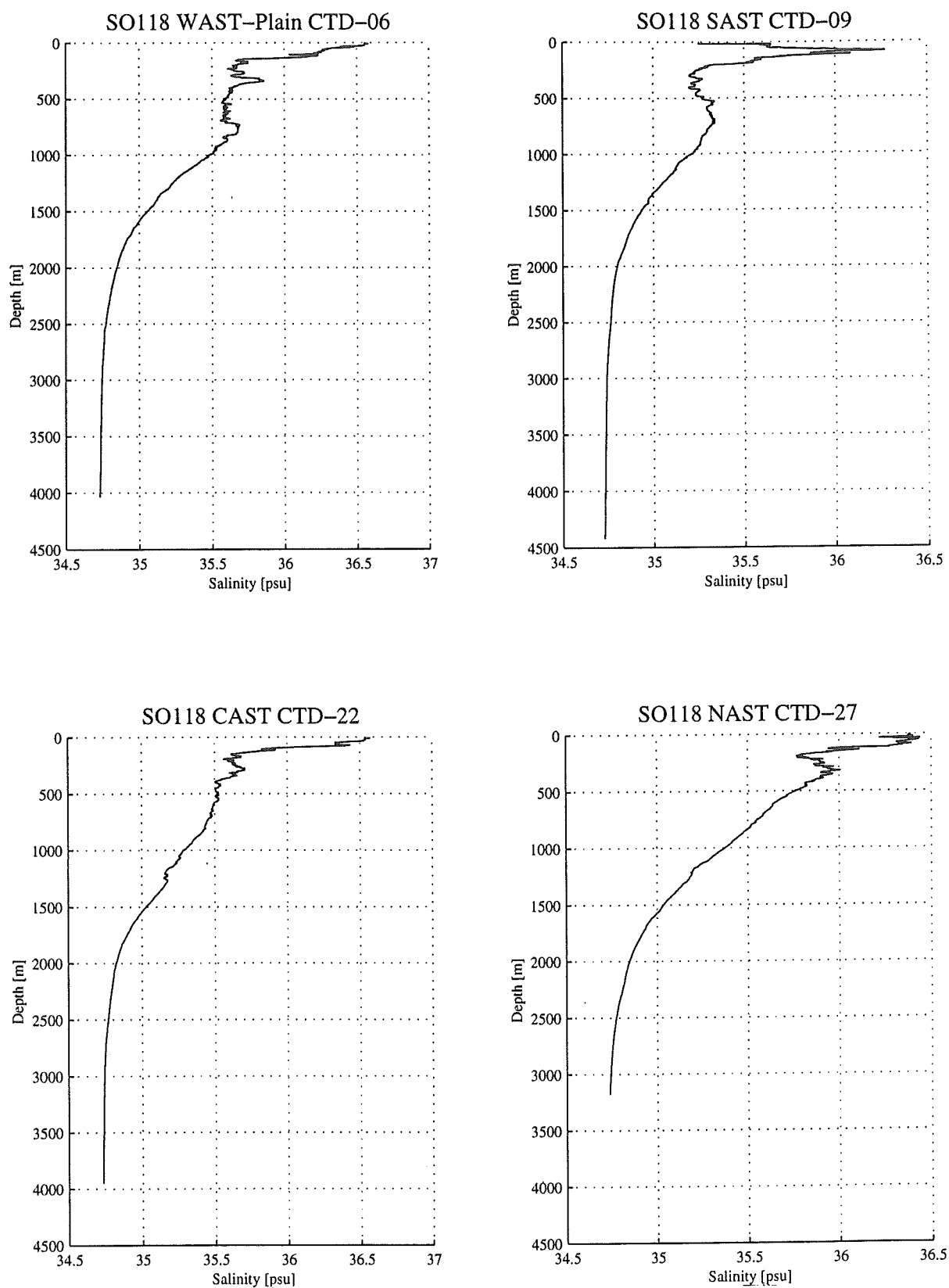


Fig. 2: Salinity profiles from the stations WAST-Plain, SAST, CAST and NAST

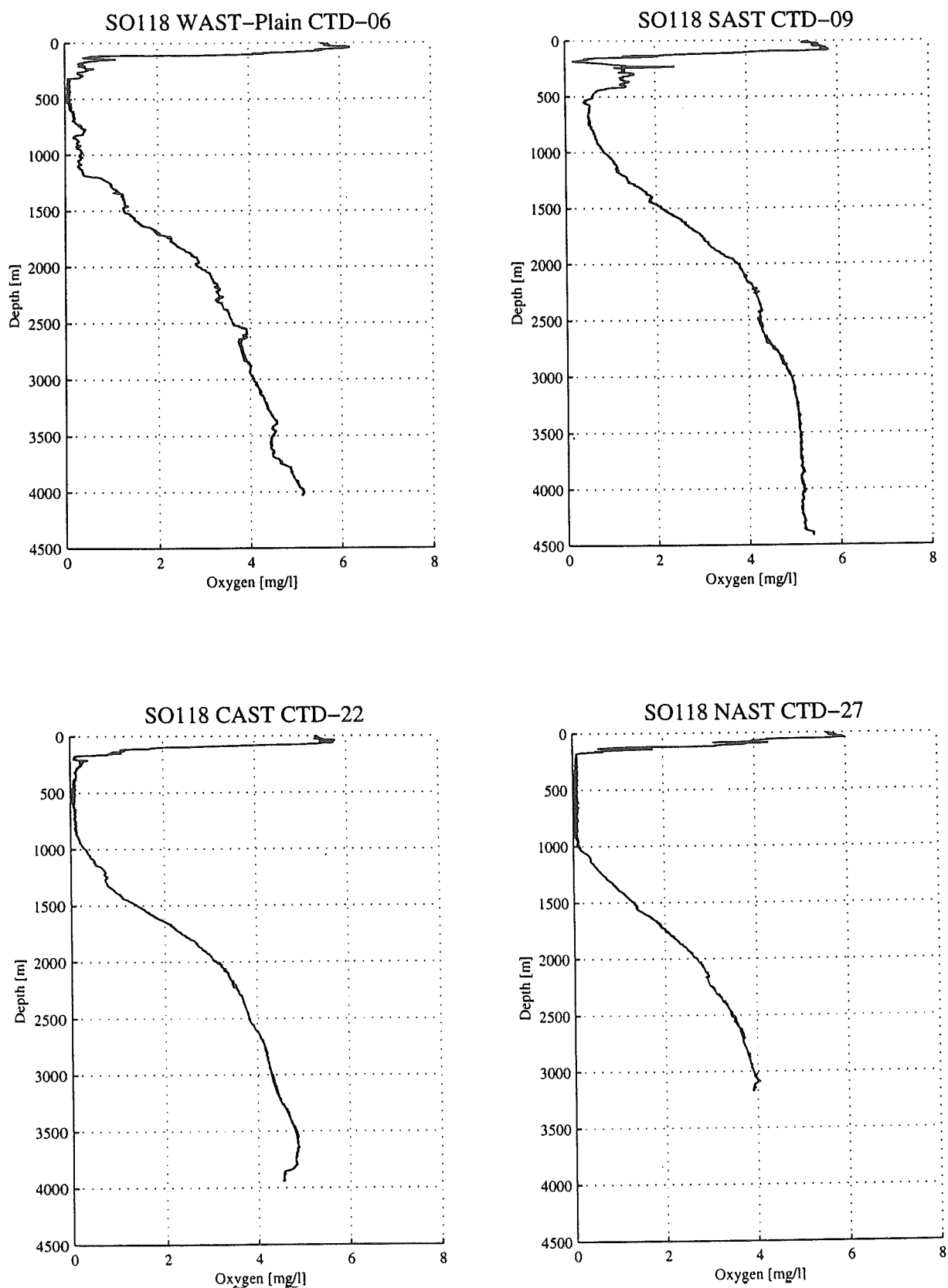


Fig. 3: Oxygen profiles from the stations WAST-Plain, SAST, CAST and NAST

Cruise SO118: WAST-TOP CTD-07

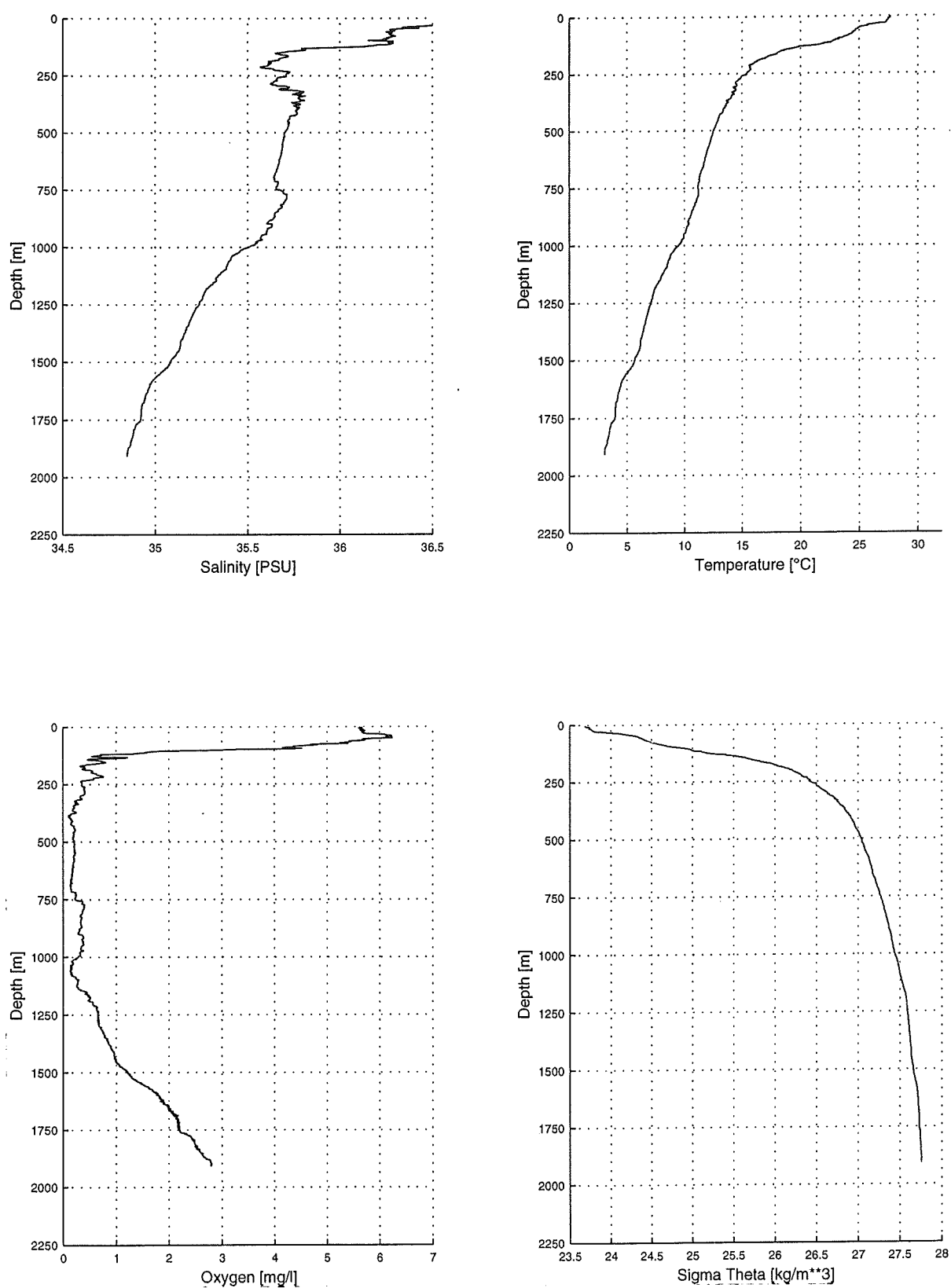


Fig. 4: Temperature, salinity, oxygen and sigma theta profiles from the station WAST-Top.

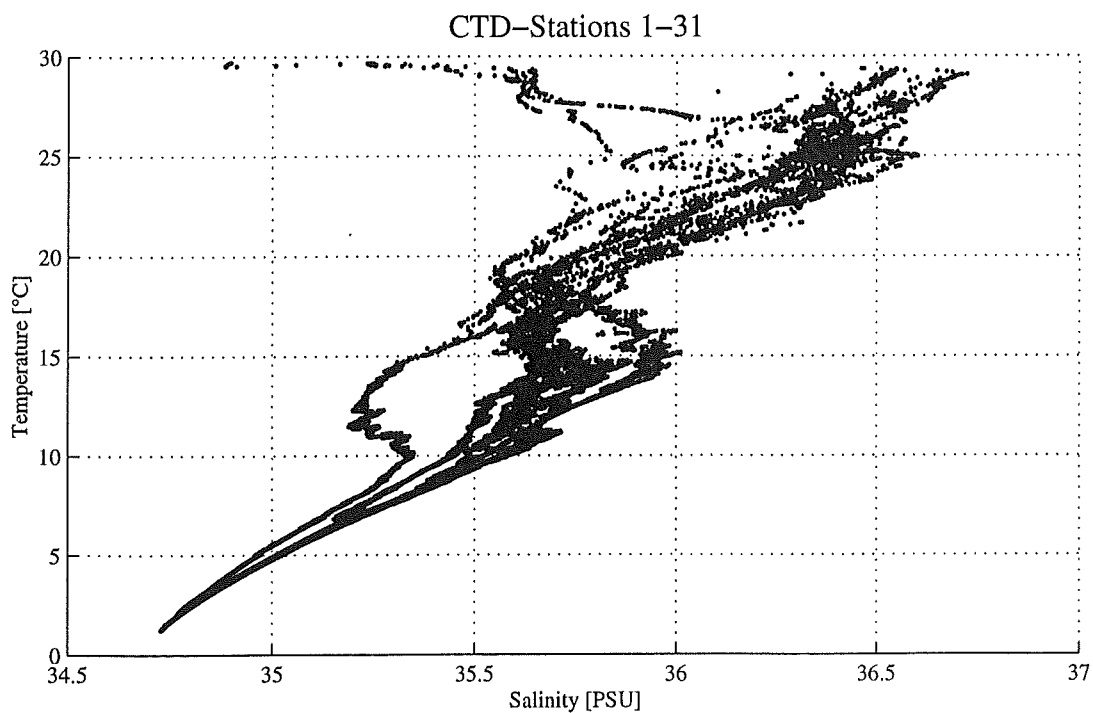
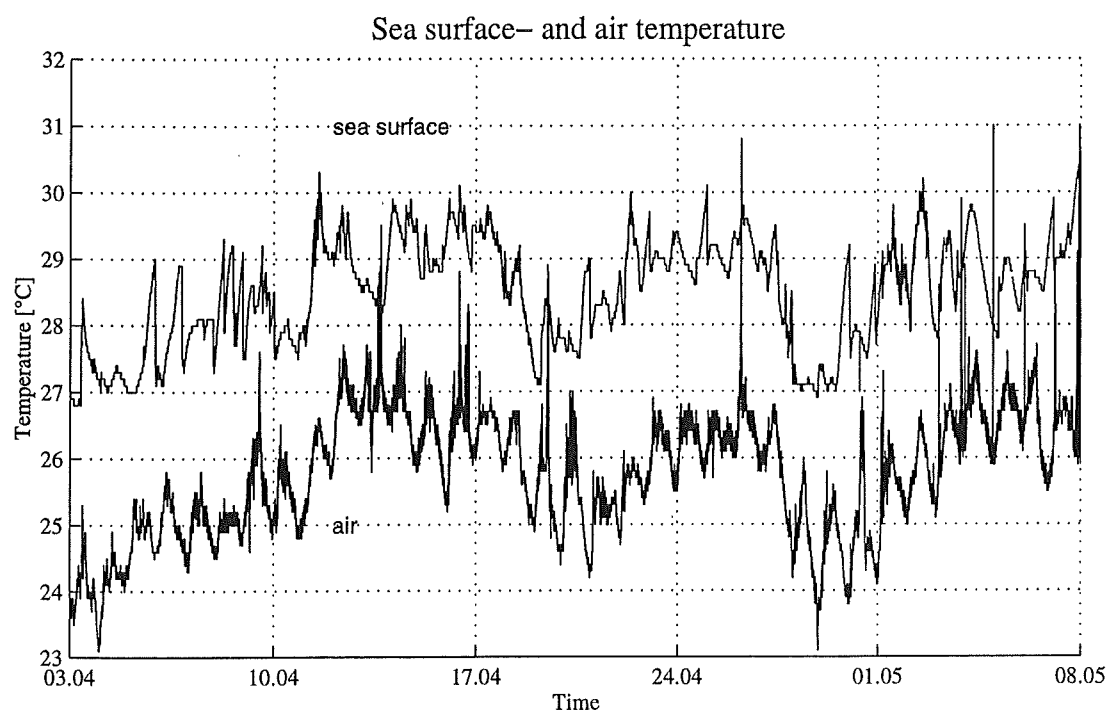


Fig. 5a and 5b:

- a: Sea surface and air temperature from the 3rd of April 1997 to the 8th of May 1997 from the ship data logging system DVS and
- b: Temperature and salinity relations from all SO118 CTD-stations.

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5.3. Deep-sea zooplankton in the Arabian Sea

Rolf Koppelman, Heiner Fabian & Liesel Neugebohrn

Research programme

The global carbon cycle is one of the main topics of "IGBP-Global Change" programmes. Since the beginning of the industrialisation, the atmospheric carbon dioxide has been increased mainly by fossil fuel burning and deforestation. A global warming is expected caused by the "greenhouse" effect of this gas. A first estimate for the years 1980-1989 resulted in an enrichment of 5.4 Gt carbon per year in the atmosphere. About 2.0 Gt are absorbed by the world ocean of which 1.6 Gt remain in deep and intermediate waters (SCOR 1992).

Zooplankton contributes to the oceanic carbon cycle by modification and remineralisation of organic material. Deep-living zooplankton is involved in this processes by (1) carbon utilisation, (2) particle repacking, and (3) direct transport of material in their bodies (WISHNER & GOWING 1992).

There is a lack of quantitative data on the distribution of deep-sea zooplankton in the Arabian Sea at a depth below 1000 m, i.e. in the bathypelagic zone (see ANGEL 1984; SCOR 1995). In the frame of the Joint Global Ocean Flux Study (JGOFS) our project investigates the deep-sea zooplankton of the Arabian Sea on a temporal and spatial basis under the following aspects: (1) To determine the amount of carbon which is respired or stored as biomass and (2) to study the pathways of carbon by zooplankton within the pelagic foodweb.

Station works and preliminary results

Introduction

The Arabian Sea is bordered on the northern, eastern and western sides by the land masses of Asia and Africa and has a negative water balance with evaporation exceeding precipitation and land-runoff. Surface circulation undergoes a biannual reversal caused by the SW and NE monsoons leading to the greatest seasonal variability observed in any ocean basin.

A special feature is the vertically extensive oxygen minimum zone (OMZ) over wide areas of the central Arabian Sea (NAQVI 1987). Oxygen decreases strongly from more than 4 mlO₂l⁻¹ at the surface to less than 0.2 mlO₂l⁻¹ between 300m and 1000m. Below 1000m, oxygen concentration increases to 2 mlO₂l⁻¹ at 2000m and

to more than $3 \text{ mlO}_2\text{l}^{-1}$ below 3000m depth. An extension of the OMZ to surface waters may cause mass mortality of fish on a large scale (VINOGRADOV & VORONINA 1962). There is only one other oceanic area with a comparably extended and low oxygenated zone: the eastern tropical Pacific with an OMZ ranging between about 300 and 750m (KAMYKOWSKI & ZENTARA 1990, VINOGRADOV et al. 1991). The influence of the OMZ on the mesozooplankton distribution was intensively studied for the latter area; its upper and lower boundaries appeared to be zones of enhanced biological and biogeochemical activity (see WISHNER et al. 1995 and literature cited therein).

SO118 is the second of a series of cruises to examine the distribution of deep-sea zooplankton and its carbon utilisation. The cruise covers the time between the NE and the SW monsoon. The time span between SW and NE monsoon was investigated during METEOR 33/1 in October 1995 (KOPPELMANN & WEIKERT 1997). The NE and SW monsoon periods will be investigated in February 1998 and June 1999, respectively.

Material and methods

During the SO118 cruise, we used a 1 m^2 Double MOCNESS (WIEBE et al. 1985) with twenty $333 \mu\text{m}$ nets, to obtain horizontal and oblique mesozooplankton samples. Sampling speed amounted to 2 kn. The main stations investigated were WAST Plain and CAST, but additional samples were obtained at NAST and WAST Top.

Oblique tows (Table 1) were taken to quantify the standing crops of the mesozooplankton biomass and the abundance of different taxa and to describe the vertical distributions in the water column.

To determine the trophic level of different zooplankton size classes, two additional oblique hauls were taken, one at CAST and one at WAST Plain (Table 2). The samples were passed through a set of sieves resulting in fractions of >5 , $5-2$, $2-1$, $1-0.5$, and $<0.5 \text{ mm}$, then deep-frozen, and finally pulverised for the analysis of the $\delta^{15}\text{N}/^{14}\text{N}$ stable isotope composition. Individuals of single species were sorted from integrated nets over larger ranges of the water column (Table 3) for $\delta^{15}\text{N}/^{14}\text{N}$ and $\delta^{13}\text{C}/^{12}\text{C}$ analyses. At CAST, we additionally used a WP2 net with a mesh size of $55 \mu\text{m}$ to get phytoplankton samples from the upper 100 m of the water column.

Horizontal sampling (Table 4) was performed to get specimens for biochemical analyses. The fraction <5 mm of these zooplankton samples were split in 1/2 or 1/4 samples. One subsample was used to measure the electron transport system activity (ETSA). Another subsample was used to determine the wet, dry and ash-free-dry weights. At CAST and NAST a multiple closing net (MCN; WEIKERT & JOHN 1981; mesh size 100 μm) was deployed in addition to the MOCNESS to catch smaller microzooplankton. The ETS-activity is used to determine the potential respiration rate of zooplankton. The analysis was done following the method of PACKARD (1971), modified by KENNER & AHMED (1975). The enzymatic activity was corrected for *in-situ* temperature using the Arrhenius equation assuming an activation energy of 13.2 kcal mol⁻¹ for bathypelagic zooplankton (PACKARD et al. 1975) to determine the oxygen consumption in $\mu\text{lO}_2/\text{d}$ per m³, per g wet weight (WW), and per mg dry weight (DW). A respiration/ETS ratio of 0.5 was used to adjust the potential oxygen consumption measured by the ETS method for "real" respiration rates. The respiration/ETS ratio published by KING & PACKARD (1975) was modified by HERNÁNDEZ-LEÓN & GÓMEZ (1996) for the KENNER & AHMED (1975) method of the ETS assay.

Respiration rates of zooplankton from epipelagic layers were measured by oxygen consumption rates (Master thesis, Univ. Hamburg). For this purpose, splits of the samples for the biochemical analyses (Table 4) were transferred into a tub containing filtered seawater. These samples were kept dark except two corners of the tub, which were illuminated by cold light to attract living animals. These animals were sorted out by the use of a large pipette and transferred into "Karlsruher Bottles" with filtered sea-water (0.2 μm -filters) of predetermined oxygen saturation. The oxygen content of the bottles was measured in approximately 5 minute intervals over a period of 60 to 120 minutes. After incubation, the wet weight biomass of the samples was determined and the respiration rate per weight unit was calculated. Measurements were undertaken at 21-22°C, therefore, the calculated rates have to be corrected to the higher *in-situ* temperatures (25 °C) by means of the Arrhenius equation.

Preliminary results

Biomass distribution

The analyses of biomass and abundance of the zooplankton collected by oblique hauls are still in progress. Nevertheless, we can use available data sets from the horizontal samples to present some preliminary results on the zooplankton distribution in the bathypelagic zone, i.e. below 1000 m.

The vertical distribution of the zooplankton biomass expressed as wet weight is shown in Figure 1. The mesozooplankton shows an exponential decline with depth from 4500 mg/1000 m³ (CAST) and 8000 mg/1000 m³ (WAST-Plain and NAST) at 1000 m depth down to 200 mg/1000 m³ (CAST), 500 mg/1000 m³ (WAST-Plain), and 800 mg/1000 m³ (NAST) at 2500 m depth. At greater depths, the values were more or less constant between 200 and 700 mg/1000 m³.

ETS measurements and respiration rates

So far, ETS results are presented from bathypelagic depths only, since the upper ocean analyses are still in progress.

The respiration rates calculated from ETS measurements and standardised to zooplankton wet weight mass were around 250 µlO₂/gd at 1000 m depth at WAST-Plain and CAST. The rates decrease to less than 200 µlO₂/gd at 1500 m. At greater depth, the oxygen consumption increased to 320 µlO₂/gd (WAST-Plain) and 400 µlO₂/gd (CAST) at 2500 m. Between 2500 m and 4000 m the rates range between 300 and 400 µlO₂/gd with an exceptional high value of 500 µlO₂/gd at WAST-Plain at 3500 m depth.

The respiration rates calculated for NAST were higher than those at WAST Plain and CAST by a factor of two throughout the water column (Table 5, Fig. 4).

A first analysis of respiration rates by oxygen consumption measurements revealed a rate of 24.9 mlO₂/mgd in the 50 m layer. Further analyses are in progress.

Discussion

The pattern of an exponential decrease of mesozooplankton biomass and abundance between 1000 and about 2500m and more or less stable values below this depth was previously recorded in bathypelagic zooplankton samples around the world and is discussed in detail by KOPPELMANN & WEIKERT (1992) and WEIKERT & KOPPELMANN (1996). Also the plankton samples from the Arabian Sea obtained during METEOR Cruise 33/1 (LOCHTE et al. 1996) in October 1995 (Fig. 2; KOPPELMANN & WEIKERT 1997) show a similar distribution pattern. However, the concentrations measured during spring 1997 are lower than those measured in October 1995 as indicated by the WAST Plain and CAST profiles in Figure 3. This may give evidence for a seasonal response of bathypelagic zooplankton on changing flux rates, but the result has to be validated by a statistical analysis. Nevertheless, seasonal reactions of bathypelagic zooplankton have recently been found in the temperate NE Atlantic (KOPPELMANN 1995).

Our preliminary results from the Arabian Sea seem to conflict with the suggestion of MADHUPRATAP et al. (1996) who discuss recent data on epipelagic zooplankton, which indicate a rather constant mesozooplankton biomass throughout the year in the upper 300 m of the northern part of the Arabian Sea. The authors stated that, apart from upwelling in summer, convection processes during winter lead to the injection of nutrients into the surface waters, and that, albeit these mechanisms of nutrient supply establish different productivity regimes, these regimes are efficient enough to maintain a more or less invariable, high mesozooplankton biomass. The mesozooplankton in the upper 300 m is thought to feed on phytoplankton during the productive summer season and take advantage of the microbial loop during oligotrophic periods in winter.

The depth distribution of the respiration rates calculated from ETS data is different from the rates measured in October 1995 at CAST (Table 5). The values in April 1997 are much lower in the upper bathypelagic zone, between 1000 and 3000m. A possible explanation of the low rates may be a change in the taxonomic composition, which has to be confirmed by fine-taxonomical analyses. So far, only coarse taxonomical analyses have been done, which revealed no differences in the relative abundance of the main groups between the two intermonsoon periods.

However, it has been found that the amount of exoskeletons and carcasses was higher in the upper bathypelagic zone in April 1997 as compared to October 1995.

The analyses of the stable isotope composition is still in progress.

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Tab. 1: Oblique samples obtained with a 1 m² double-MOCNESS (333 µm) at different sites in the Arabian Sea taken for biomass and individual analyses.

Station	Haul	Bucket	Depth	Time		Date	filtered
				open	close		Volume (m ³)
WAST-Plain	1	L3	4000-3750	21:36	21:51	05.04.97	929
WAST-Plain	2	L3	4000-3750	07:12	07:27	08.04.97	902
WAST-Plain	2	L4	3750-3500	07:27	07:40	08.04.97	877
WAST-Plain	2	L6	3500-3250	07:53	08:05	08.04.97	760
WAST-Plain	2	L7	3250-3000	08:05	08:19	08.04.97	910
WAST-Plain	2	L9	3000-2750	08:32	08:45	08.04.97	845
WAST-Plain	3	L2	2750-2500	15:38	15:53	09.04.97	897
WAST-Plain	3	L4	2500-2250	16:05	16:20	09.04.97	981
WAST-Plain	3	L5	2250-2050	16:20	16:32	09.04.97	740
WAST-Plain	3	L7	2050-1850	16:44	16:54	09.04.97	618
WAST-Plain	3	L8	1850-1650	16:54	17:06	09.04.97	759
WAST-Plain	3	L9	1650-1450	17:06	17:17	09.04.97	792
WAST-Plain	4	R2	1450-1250	02:50	03:01	10.04.97	692
WAST-Plain	4	R3	1250-1050	03:01	03:13	10.04.97	744
WAST-Plain	4	L2	900-750	03:37	03:47	10.04.97	695
WAST-Plain	4	L3	750-500	03:47	04:01	10.04.97	937
WAST-Plain	4	L5	500-300	04:08	4:21	10.04.97	872
WAST-Plain	4	L6	300-200	4:21	04:26	10.04.97	393
WAST-Plain	4	L7	200-100	04:26	04:33	10.04.97	429
WAST-Plain	4	L8	100-50	04:33	04:37	10.04.97	243
WAST-Plain	4	L10	50-0	04:39	04:45	10.04.97	356
WAST-Plain	5	L2	1250-1050	00:12	00:22	20.04.97	598
WAST-Plain	5	L4	1050-750	00:33	00:50	20.04.97	102
WAST-Plain	5	L5	750-500	00:50	01:03	20.04.97	914
WAST-Plain	5	L7	500-250	01:13	01:29	20.04.97	982
WAST-Plain	5	L8	250-50	01:29	01:40	20.04.97	739
WAST-Plain	5	L10	50-0	01:43	01:50	20.04.97	357
WAST-Plain	6	R3	4000-3750	22:41	22:58	20.04.97	106
WAST-Plain	6	R4	3750-3500	22:58	23:15	20.04.97	108
WAST-Plain	6	R6	3500-3250	23:32	23:47	20.04.97	101
WAST-Plain	6	R7	3250-3000	23:47	00:05	20.04.97	107
WAST-Plain	6	R9	3000-2750	00:21	00:35	21.04.97	898
WAST-Plain	6	L2	2750-2500	00:35	00:49	21.04.97	939
WAST-Plain	6	L4	2500-2250	00:59	01:15	21.04.97	995
WAST-Plain	6	L5	2250-2050	01:15	01:27	21.04.97	677
WAST-Plain	6	L7	2050-1850	01:35	01:49	21.04.97	872
WAST-Plain	6	L8	1850-1650	01:49	02:02	21.04.97	841
WAST-Plain	6	L9	1650-1450	02:02	02:12	21.04.97	734
CAST	8	R3	3900-3750	00:58	01:06	25.04.97	458
CAST	8	R4	3750-3500	01:06	01:19	25.04.97	881
CAST	8	R6	3500-3250	01:35	01:49	25.04.97	936
CAST	8	R7	3250-3000	01:49	02:06	25.04.97	105

CAST	8	R9	3000-2750	02:16	02:31	25.04.97	979
CAST	8	L2	2750-2500	02:31	02:46	25.04.97	997
CAST	8	L4	2500-2250	02:56	03:14	25.04.97	115
CAST	8	L5	2250-2050	03:14	03:26	25.04.97	859
CAST	8	L7	2050-1850	03:37	03:49	25.04.97	871
CAST	8	L8	1850-1650	03:49	04:02	25.04.97	752
CAST	8	L9	1650-1450	04:02	04:16	25.04.97	104
CAST	9	R3	1450-1250	01:11	01:23	26.04.97	749
CAST	9	R4	1250-1050	01:23	01:38	26.04.97	971
CAST	9	R6	1050-900	01:46	01:56	26.04.97	620
CAST	9	R7	900-750	01:56	2:04	26.04.97	503
CAST	9	R8	750-600	2:04	2:12	26.04.97	532
CAST	9	R9	600-450	2:12	2:20	26.04.97	534
CAST	9	L3	450-300	02:27	02:37	26.04.97	680
CAST	9	L4	300-250	02:37	02:40	26.04.97	194
CAST	9	L5	250-200	02:40	02:43	26.04.97	206
CAST	9	L6	200-150	02:43	02:47	26.04.97	268
CAST	9	L7	150-100	02:47	02:50	26.04.97	183
CAST	9	L8	100-50	02:50	02:53	26.04.97	203
CAST	9	L10	50-0	02:56	03:01	26.04.97	271
CAST	10	R3	1450-1250	08:48	09:00	26.04.97	672
CAST	10	R4	1250-1050	09:00	09:12	26.04.97	742
CAST	10	R6	1050-900	09:20	09:29	26.04.97	573
CAST	10	R7	900-750	09:29	09:43	26.04.97	855
CAST	10	R8	750-600	09:43	09:51	26.04.97	530
CAST	10	R9	600-420	09:51	10:01	26.04.97	646
CAST	10	L3	420-350	10:06	10:15	26.04.97	556
CAST	10	L5	350-250	10:19	10:25	26.04.97	392
CAST	10	L6	250-150	10:25	10:33	26.04.97	499
CAST	10	L7	150-100	10:33	10:35	26.04.97	166
CAST	10	L8	100-50	10:35	10:38	26.04.97	167
CAST	10	L10	50-0	10:42	10:46	26.04.97	245
NAST	11	R3	3150-3000	01:08	01:16	30.04.97	487
NAST	11	R4	3000-2750	01:16	01:31	30.04.97	922
NAST	11	R5	2750-2500	01:31	01:47	30.04.97	103
NAST	11	R6	2500-2250	01:47	02:02	30.04.97	950
NAST	11	R7	2250-2000	02:02	02:18	30.04.97	100
NAST	11	R9	2000-1750	02:28	02:46	30.04.97	113
NAST	11	L2	1750-1500	02:46	03:01	30.04.97	105
NAST	11	L3	1500-1250	03:01	03:16	30.04.97	991
NAST	11	L4	1250-1000	03:16	03:32	30.04.97	103
NAST	11	L6	1000-500	03:41	04:11	30.04.97	204
NAST	11	L8	500-50	04:17	04:45	30.04.97	181
NAST	11	L10	50-0	04:48	04:52	30.04.97	290
NAST	12	R3	3150-3000	22:32	22:40	30.04.97	491
NAST	12	R4	3000-2750	22:40	22:54	30.04.97	899
NAST	12	R5	2750-2500	22:54	23:09	30.04.97	965

Table 1: continued

NAST	12	R6	2500-2250	23:09	23:27	30.04.97	109
NAST	12	R7	2250-2000	23:27	23:44	30.04.97	108
NAST	12	R9	2000-1750	23:54	00:10	30.04.97	102
NAST	12	L2	1750-1500	00:10	00:25	01.05.97	973
NAST	12	L3	1500-1250	00:25	00:40	01.05.97	103
NAST	12	L4	1250-1000	00:40	00:56	01.05.97	996
NAST	12	L6	1000-500	01:06	01:30	01.05.97	156
NAST	12	L8	500-50	01:38	02:09	01.05.97	199
NAST	12	L10	50-0	02:12	02:15	01.05.97	228
WAST-Plain	13	R3	4000-3750	03:30	03:41	04.05.97	703
WAST-Plain	13	R4	3750-3500	03:41	03:59	04.05.97	111
WAST-Plain	13	R6	3500-3250	04:11	04:31	04.05.97	124
WAST-Plain	13	R7	3250-3000	04:31	04:50	04.05.97	120
WAST-Plain	13	R9	3000-2750	05:01	05:20	04.05.97	119
WAST-Plain	13	L2	2750-2500	05:20	05:36	04.05.97	103
WAST-Plain	13	L4	2500-2250	05:46	06:05	04.05.97	130
WAST-Plain	13	L5	2250-2050	06:05	06:17	04.05.97	764
WAST-Plain	13	L7	2050-1850	06:27	06:39	04.05.97	839
WAST-Plain	13	L8	1850-1650	06:39	06:47	04.05.97	857
WAST-Plain	13	L9	1650-1450	06:47	07:05	04.05.97	838
WAST-Plain	14	R3	1450-1250	11:22	11:32	05.05.97	701
WAST-Plain	14	R4	1250-1050	11:32	11:49	05.05.97	100
WAST-Plain	14	R6	1050-900	11:59	12:08	05.05.97	579
WAST-Plain	14	R7	900-750	12:08	12:18	05.05.97	643
WAST-Plain	14	R8	750-600	12:18	12:30	05.05.97	767
WAST-Plain	14	R9	600-450	12:30	12:39	05.05.97	524
WAST-Plain	14	L3	450-300	12:42	12:57	05.05.97	746
WAST-Plain	14	L4	300-250	12:57	12:59	05.05.97	123
WAST-Plain	14	L5	250-200	12:59	13:03	05.05.97	228
WAST-Plain	14	L6	200-150	13:03	13:07	05.05.97	250
WAST-Plain	14	L7	150-100	13:07	13:09	05.05.97	155
WAST-Plain	14	L8	100-50	13:09	13:12	05.05.97	160
WAST-Plain	14	L10	50-0	13:16	13:21	05.05.97	293
WAST-Top	16	R2	1860-1750	16:02	16:08	07.05.97	399
WAST-Top	16	R3	1750-1600	16:08	16:17	07.05.97	515
WAST-Top	16	R4	1600-1450	16:17	16:25	07.05.97	544
WAST-Top	16	R5	1450-1300	16:25	16:34	07.05.97	553
WAST-Top	16	R6	1300-1150	16:34	16:43	07.05.97	586
WAST-Top	16	R7	1150-1000	16:43	16:52	07.05.97	564
WAST-Top	16	R8	1000-850	16:52	17:01	07.05.97	585
WAST-Top	16	R9	850-700	17:01	17:10	07.05.97	528
WAST-Top	16	L2	700-600	17:10	17:18	07.05.97	524
WAST-Top	16	L3	600-500	17:18	17:26	07.05.97	496
WAST-Top	16	L4	500-400	17:26	17:34	07.05.97	533
WAST-Top	16	L5	400-300	17:34	17:43	07.05.97	569
WAST-Top	16	L6	300-200	17:43	17:53	07.05.97	630

WAST-Top	16	L7	200-100	17:53	18:00	07.05.97	443
WAST-Top	16	L8	100-50	18:00	18:03	07.05.97	176
WAST-Top	16	L10	50-0	18:06	18:10	07.05.97	203
WAST-Top	17	R2	1860-1750	07:34	07:41	08.05.97	381
WAST-Top	17	R3	1750-1600	07:41	07:51	08.05.97	619
WAST-Top	17	R4	1600-1450	07:51	08:03	08.05.97	739
WAST-Top	17	R5	1450-1300	08:03	08:06	08.05.97	532
WAST-Top	17	R6	1300-1150	08:06	08:21	08.05.97	660
WAST-Top	17	R7	1150-1000	08:21	08:31	08.05.97	593
WAST-Top	17	R8	1000-850	08:31	08:38	08.05.97	461
WAST-Top	17	R9	850-700	08:38	08:46	08.05.97	538
WAST-Top	17	L2	700-600	08:46	08:52	08.05.97	365
WAST-Top	17	L3	600-500	08:52	08:58	08.05.97	423
WAST-Top	17	L4	500-400	08:58	09:04	08.05.97	448
WAST-Top	17	L5	400-390	09:04	09:08	08.05.97	238
WAST-Top	17	L6	390-300	09:08	09:15	08.05.97	460
WAST-Top	17	L7	300-200	09:15	09:23	08.05.97	505
WAST-Top	17	L8	200-100	09:23	09:27	08.05.97	291
WAST-Top	17	L9	100-50	09:27	09:30	08.05.97	144
WAST-Top	17	L10	50-0	09:30	09:34	08.05.97	185

Tab. 2: Samples obtained with a 1 m² double-MOCNESS (333 µm) and a WP2 (55 µm) at different sites in the Arabian Sea for stable isotope analyses of total zooplankton.

Station	Haul	Bucket	Depth	Time		Date	filtered
				open	close	1997	Volume (m ³)
CAST	7	R/L2	3900-3500	00:34	01:58	23.04.	1561
CAST	7	R/L3	3500-3000	01:58	01:41	23.04.	2240
CAST	7	R/L4	3000-2500	01:41	02:14	23.04.	2416
CAST	7	R/L5	2500-2000	02:14	02:50	23.04.	2312
CAST	7	R/L6	2000-1500	02:50	03:27	23.04.	2301
CAST	7	R/L7	1500-1000	03:27	03:54	23.04.	1790
CAST	7	R/L8	1000-500	03:54	04:32	23.04.	2435
CAST	7	R/L9	500-250	04:32	04:50	23.04.	1188
CAST	7	R/L10	250-0	04:50	05:08	23.04.	1031
WAST-Plain	15	R/L2	4000-3500	01:06	01:37	07.05.	1873
WAST-Plain	15	R/L3	3500-3000	01:37	02:14	07.05.	2310
WAST-Plain	15	R/L4	3000-2500	02:14	02:41	07.05.	1692
WAST-Plain	15	R/L5	2500-2000	02:41	03:21	07.05.	2430
WAST-Plain	15	R/L6	2000-1500	03:21	04:01	07.05.	2477
WAST-Plain	15	R/L7	1500-1000	04:01	04:37	07.05.	2340
WAST-Plain	15	R/L8	1000-500	04:37	05:21	07.05.	2830
WAST-Plain	15	R/L9	500-250	05:21	05:43	07.05.	1375
WAST-Plain	15	R/L10	250-0	05:43	06:02	07.05.	1134
CAST	WP2-01	B1	100-0	11:31	11:47	26.04.	

Tab. 3: Material from integrated samples over larger ranges of the water column obtained with a 1 m² double-MOCNESS (333 µm) for stable isotope analysis of zooplankton taxa.

Station	Haul	Bucket	Depth	Time		Date	Individuals
				open	close	1997	
WAST-Plain	1	R1	0-4000-0	17:30	01:58	05.04.	Ostracoda
WAST-Plain	2	L10	2750-0	08:45	11:12	08.04.	<i>Eucalanus</i> spp.
WAST-Plain	3	L10	1450-0	17:17	18:54	09.04.	<i>E. spp.</i> , Fishes
WAST-Plain	4	R1	0-1450	01:23	02:50	10.04.	<i>E. spp.</i> , Chaetognatha
WAST-Plain	5	R3	1450-0	00:01	01:50	20.04.	Calan., Fish, Chaetog.
WAST-Plain	6	R1	0-4000	18:33	22:22	20.04.	Nemertini
WAST-Plain	6	R10	2750-0	00:35	03:38	21.04.	Fish, Shrimps
WAST-Plain	6	L10	1450-0	02:12	03:38	21.04.	Tunicata
CAST	8	L10	1450-0	04:16	05:30	25.04.	Chaetognatha, Shrimps
NAST	11	R10	1750-0	02:46	04:52	30.04.	Aggregates

Tab.4: Horizontal samples obtained with a 1m² double-MOCNESS (333µm) and a MCN (100µm) at different sites in the Arabian Sea for biochemical analyses.

Station	Haul	Bucket	Depth	Time		Date	filtered
				open	close		Volume (m ³)
WAST-Plain	1	L2	4000	21:24	21:36	05.04.97	667
WAST-Plain	2	L2	4000	06:59	07:12	08.04.97	659
WAST-Plain	2	L5	3500	07:40	07:53	08.04.97	705
WAST-Plain	2	L8	3000	08:19	08:32	08.04.97	701
WAST-Plain	3	L3	2500	15:53	16:05	09.04.97	697
WAST-Plain	3	L6	2050	16:32	16:44	09.04.97	706
WAST-Plain	3	R2	1450	17:18	17:28	09.04.97	622
WAST-Plain	4	R4	1050	03:13	03:21	10.04.97	494
WAST-Plain	4	L4	500	04:01	04:08	10.04.97	373
WAST-Plain	4	L9	50	04:37	04:39	10.04.97	178
WAST-Plain	5	R2	1450	23:51	00:01	19.04.97	541
WAST-Plain	5	L3	1050	00:22	00:33	20.04.97	576
WAST-Plain	5	L6	500	01:03	01:13	20.04.97	587
WAST-Plain	5	L9	50	01:40	01:43	20.04.97	158
WAST-Plain	6	R2	4000	22:22	22:41	20.04.97	114
WAST-Plain	6	R5	3500	23:15	23:32	20.04.97	101
WAST-Plain	6	R8	3000	00:05	00:21	21.04.97	918
WAST-Plain	6	L3	2500	00:49	00:59	21.04.97	617
WAST-Plain	6	L6	2050	01:27	01:35	21.04.97	613
CAST	8	R2	3900	00:43	00:58	25.04.97	815
CAST	8	R5	3500	01:19	01:35	25.04.97	888
CAST	8	R8	3000	02:06	02:16	25.04.97	604
CAST	8	L3	2500	02:46	02:56	25.04.97	637
CAST	8	L6	2050	03:26	03:37	25.04.97	647
CAST	9	R2	1450	01:02	01:11	26.04.97	459
CAST	9	R5	1050	01:38	01:46	26.04.97	487
CAST	9	L2	450	02:21	02:27	26.04.97	399
CAST	9	L9	50	02:53	02:56	26.04.97	200
CAST	10	R2	1450	08:40	08:48	26.04.97	447
CAST	10	R5	1050	09:12	09:20	26.04.97	480
CAST	10	L2	420	10:02	10:06	26.04.97	265
CAST	10	L4	350	10:15	10:19	26.04.97	270
CAST	10	L9	50	10:38	10:42	26.04.97	192
NAST	11	R2	3150	00:56	01:08	30.04.97	658
NAST	11	R8	2000	02:18	02:28	30.04.97	600
NAST	11	L5	1000	03:32	03:41	30.04.97	510
NAST	11	L7	500	04:11	04:17	30.04.97	382
NAST	11	L9	50	04:45	04:48	30.04.97	161
NAST	12	R2	3150	22:20	22:32	30.04.97	676
NAST	12	R8	2000	23:44	23:54	30.04.97	605
NAST	12	L5	1000	00:56	01:06	01.05.97	621

NAST	12	L7	500	01:30	01:38	01.05.97	521
NAST	12	L9	50	02:09	02:12	01.05.97	171
WAST-Plain	13	R2	4000	03:20	03:30	04.05.97	584
WAST-Plain	13	R5	3500	03:59	04:11	04.05.97	730
WAST-Plain	13	R8	3000	04:50	05:01	04.05.97	699
WAST-Plain	13	L3	2500	05:36	05:46	04.05.97	644
WAST-Plain	13	L6	2050	06:17	06:27	04.05.97	601
WAST-Plain	14	R2	1450	11:12	11:22	05.05.97	570
WAST-Plain	14	R5	1050	11:49	11:59	05.05.97	614
WAST-Plain	14	L2	440	12:39	12:42	05.05.97	377
WAST-Plain	14	L9	50	13:12	13:16	05.05.97	255
CAST	MSN 01	B1	2500- 2000	04:40	05:10	26.04.97	125
CAST	MSN 01	B2	2000- 1500	05:10	05:39	26.04.97	125
CAST	MSN 01	B3	1500- 1000	05:39	06:06	26.04.97	125
CAST	MSN 01	B4	1000- 500	06:06	06:36	26.04.97	125
CAST	MSN 01	B5	500-0	06:36	07:00	26.04.97	125
NAST	MSN 02	B1	2500- 2000	10:15	10:40	01.05.97	125
NAST	MSN 02	B2	2000- 1500	10:40	11:07	01.05.97	125
NAST	MSN 02	B3	1500- 1000	11:07	11:33	01.05.97	125
NAST	MSN 02	B4	1000- 500	11:33	12:05	01.05.97	125
NAST	MSN 02	B5	500-0	12:05	12:40	01.05.97	125

Tab. 5: Respiration rates ($\mu\text{l O}_2\text{d}^{-1}\text{ g wwt}^{-1}$) of deep-sea mesozooplankton
obtained from ETS and *in-situ* measurements

Parameter	WAST	CAST	NAST
Depth	1050 m	1050	1000 m
N	3	1	1
t (°C)	9.1	8.0	8.6
Mean	227	246	496
Range	191-284	-	-

Depth	1450 m	1450	
N	3	2	
t (°C)	6.0	5.6	
Mean	163	179	
Range	150-187	146-211	

Depth	2050 m	2050	2000 m
N	3	1	2
t (°C)	3.0	2.9	3.2
Mean	252	346	442
Range	212-324	-	440-444

Depth	2500 m	2500	
N	3	1	
t (°C)	2.2	2.2	
Mean	324	404	
Range	306-337	-	

Depth	3000 m		3150 m
N	3		2
t (°C)	1.8		1.7
Mean	295		613
Range	257-370		455-772

Depth	3500 m	3500	
N	3	1	
t (°C)	1.7	1.7	
Mean	484	341	
Range	388-548	-	

Depth	4000 m	3900	
N	3	1	
t (°C)	1.6	1.7	
Mean	364	398	
Range	301-418	-	

Literature data

Parameter	A Koppelman & Weikert subm.	B King et al.1978 Smith et al. 1986	C Smith 1982 Smith 1985
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Depth	1000 m	1000-2000 m	1300 m
N	1	3	8
t (°C)	8.9	4.5-2.1	3
Mean	980	5830	330
Range	-	2090-10130	240-490

Depth	2500 m	2000-3000 m	2615 m
N	2	1	5
t (°C)	2.3	2.1-1.6	1.7-1.8
Mean	580	440	560
Range	540-620	-	400-680

Depth	4000 m		3850 m
N	2		10
t (°C)	1.7		1.8
Mean	350		340
Range	320-380		240-480

A = Arabian Sea, October 1995, ETS data evaluated by the same method used in this study.

B = KING et al. (1978), calculated from ETS measurements based on 212 µm net-zooplankton from the North Pacific.

C = SMITH (1982), *in-situ* measurements, Santa Catalina Basin, 1300 m; Smith (1985), *in-situ* measurements, East Pacific Rise (Clam field and nonvent area), 2615 m; SMITH et al. (1986), *in-situ* measurements, Panama Basin, 3850 m.

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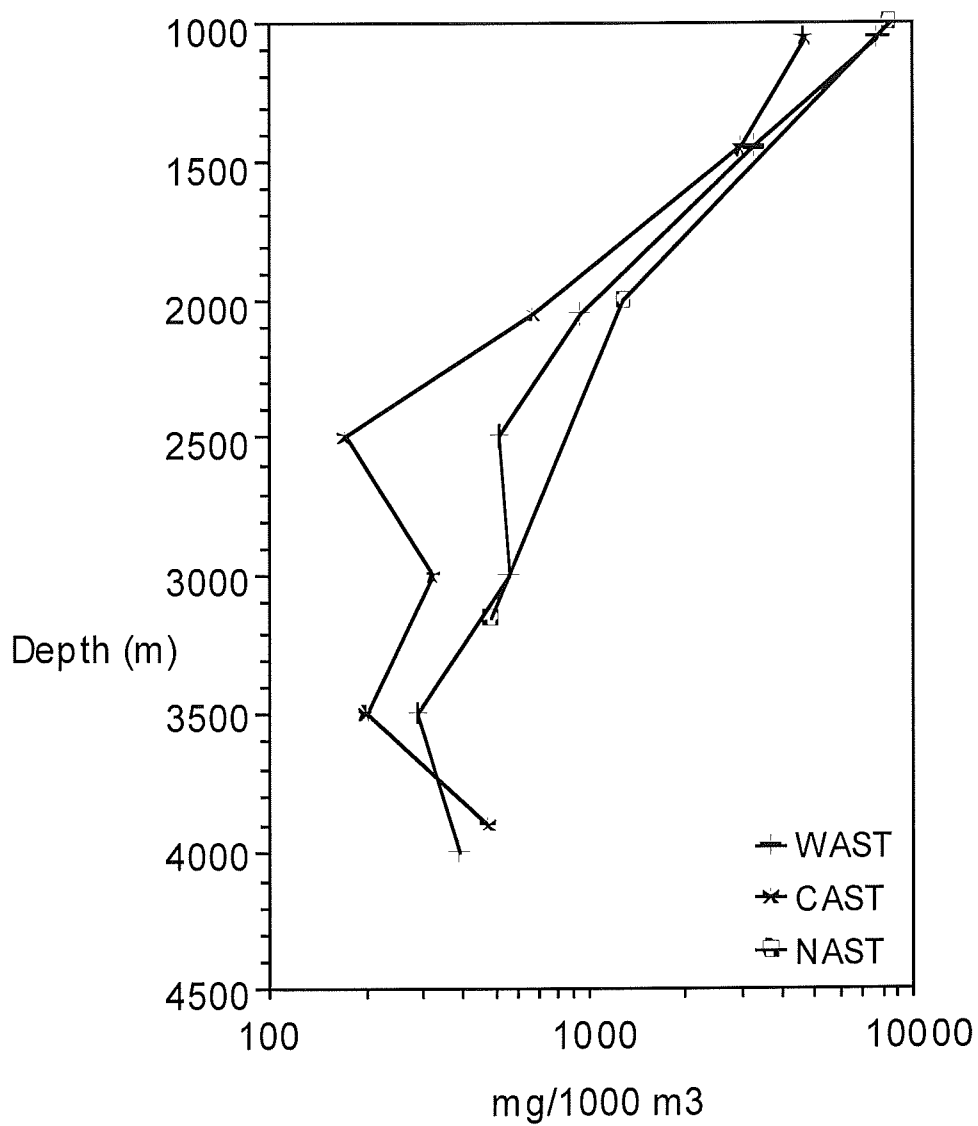


Fig. 1: Vertical distribution of bathypelagic mesozooplankton biomass (wet weights) in April/May 1997.

M33/1 October 1995

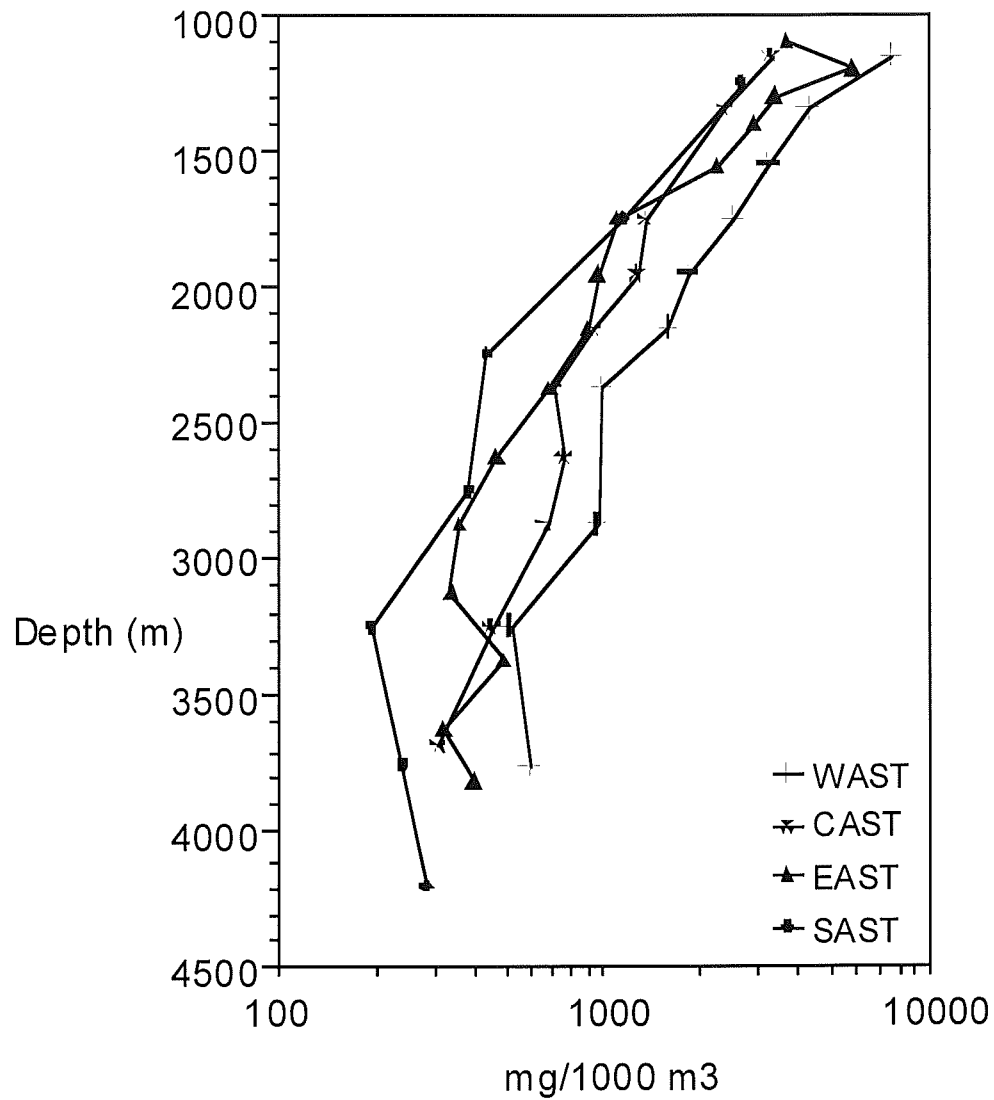


Fig. 2: Vertical distribution of bathypelagic mesozooplankton biomass (wet weights) in October 1995, METEOR 33/1 (modified after KOPPELMANN & WEIKERT, in press).

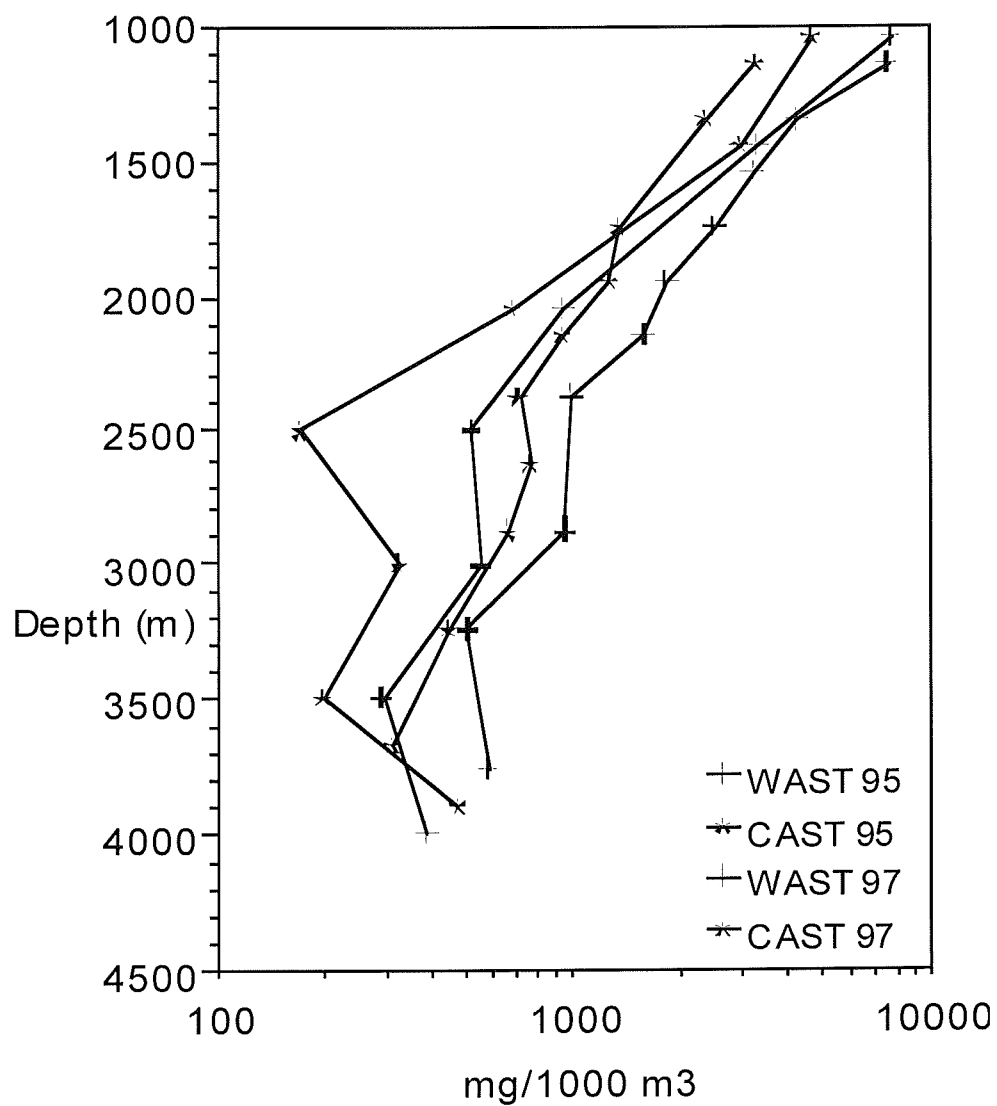


Fig. 3: Vertical distribution of bathypelagic mesozooplankton biomass (wet weight) in October 1995 and April/May 1997 at the stations WAST-Plain and CAST.

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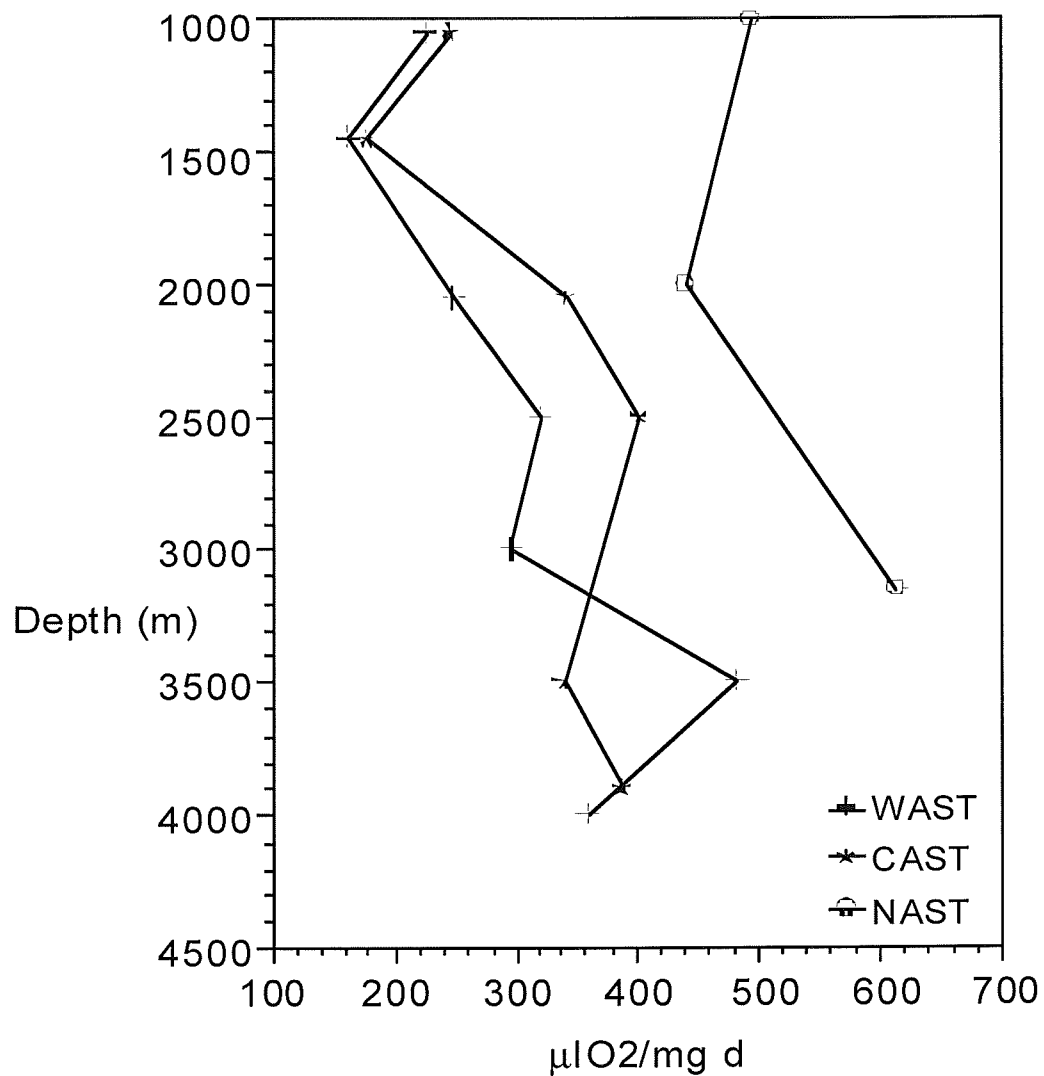


Fig. 4: Calculated respiration rates of bathypelagic zooplankton based on ETS measurements at different depths.

5.4. Microbial degradation of particulate matter in the deep water column

Carolyn Petry & Doris Setzkorn (IOW)

Research programme

Primary production in the euphotic zone and degradation processes in the deep water column determine the flux of particulate organic matter (POM) to the ocean floor. The turnover processes on these particles in water depths are therefore an important factor regarding the quality and quantity of POM reaching the deep sea floor. Sinking particles and the associated degradation processes are subject to different environmental conditions during their descent through the water column. Main objective of this project is to characterize the modifications of the sinking POM in dependence to these changing conditions. The degradation rates in different water layers are determined experimentally. The results are related to measurements of sediment trap material from long term moorings. Finally, the project aims to estimate the carbon flux from upper layers to the deep water based on the measured vertical fluxes (sediment traps) and the microbial degradation rates in different water depths (experiments).

The project „Microbial degradation of sinking particles in the deep water column“ of the Baltic Research Institute in Warnemünde, Germany, is part of the interdisciplinary research programme JGOFS-Indic. However, the project does not provide measurements of the JGOFS core parameters which are only intended for the oceanic surface layer, but focusses on experimental work connecting the processes in the surface layer with those in the deep water. Thus, the results of this study are also of great value for the investigation of input and turnover of POM into the benthic boundary layer of the deep sea (BIGSET).

Station work and preliminary results

Introduction

The fixation of CO₂ by phytoplankton cells in the euphotic zone and the subsequent sinking of these cells out of this zone is called the 'biological pump', because it removes CO₂ in the form of biogenic particles from the surface layer, the area where CO₂ exchange with the atmosphere takes place. Aggregates of phytoplankton cells and fecal pellets of zooplankton are large, rapidly sinking organic particles that contribute substantially to the vertical flux of POM (McCave

1975, ANGEL 1984, FOWLER & KNAUER 1986, ALLDREDGE & SILVER 1988, BATHMANN 1992). The remineralization of organic material occurs in the entire water column. So far investigations focussed mainly on the upper water column whereas investigations of microbial processes on aggregates in the deep water are scarce (ALLDREDGE & YOUNGBLUTH 1985, TURLEY & CARSTENS 1991, TURLEY 1992, 1993). The majority of the degradation rates in the bathyal were derived indirectly from the decrease of particulate organic carbon (POC) with depth captured in sediment traps and from the bacterial activity in these depths (CHO & AZAM 1988, SIMON ET AL. 1990).

Heterotrophic bacteria associated with sinking particles convert POM to dissolved organic matter (DOM) by extracellular enzymes (AZAM & SMITH 1991, KARNER & HERNDL 1992, SMITH ET AL. 1992). Enzymatic activity and bacterial growth depend on various environmental factors like temperature and pressure (HELMKE & WEYLAND 1986, LOCHTE 1992). Additionally, very low oxygen concentrations prevailing in the oxygen minimum zone (OMZ; in the Arabian Sea between approx. 200 and 1100 m; OLSON ET AL. 1993) presumably affect bacterial turnover processes of particles.

At this cruise experiments were conducted in which microbial degradation rates on POM from different depth levels were measured directly under changing temperature and oxygen conditions. To complete our understanding of bacterial degradation processes in the water column and at the sediment-water interface bacterial parameters were measured in water samples from the benthic boundary layer (SP-2, GRAF, and SP-3, LOCHTE). Measured rates are supposed to contribute, together with vertical flux data from long term moorings of sediment traps (SP-4, ITTEKKOT; ITTEKKOT 1991, 1993), to better of carbon cycling models.

Methodology and description of the work carried out

Experiments

Particulate organic material (POM, > 0,18 µm) from different depths (50 m, 250 m, 1200 m und 4040 m) was enriched in a ratio of 1:2 by tangential flow and incubated in the dark under simulated *in situ* temperature conditions. Additionally, POM from 50 m, 1200 m and 4040 m depth was incubated at other than *in situ* temperatures (Tab. 1).

To test whether the presence or absence of oxygen has any effect on the bacterial processes a second experiment was set up with water from the OMZ (500 m) and

from the euphotic zone (50 m; Tab. 1). POM was also enriched by tangential flow and aerated with a N_2/CO_2 gaseous mixture or shaken vigorously for the incubation without and with oxygen, respectively.

Another treatment was set up with POM collected with a 55 μm mesh size plankton net at WAST from surface water (150-0 m) and subsurface water (300-150 m) to compare POM degradation rates in water within the photic layer with those in water from just below. In addition, the results from the 'POM surface water treatment' allow the comparison with data from cruise M33/1 for the same area in October 1995. Particulate matter was incubated in the dark at both 28°C and 15°C, respectively (Tab. 1).

During the incubation period of 3 to 4 weeks different bacterial parameters were measured:

- The potential extracellular enzyme activities (EEA) of α - and β -glucosidase, chitinase, esterase and aminopeptidase with the use of fluorogenic model substrates at saturation concentrations (HOPPE 1983),
- bacterial secondary production (BSP) and bacterial protein production (BPP) were estimated by incorporation of 3H-thymidine (FUHRMANN & AZAM 1982) and 3H-leucine (SIMON ET AL. 1990), respectively,
- aliquots of the 'experimental water' were incubated in calibrated glass bottles and the oxygen concentrations were measured via Winkler titration (GRASSHOFF 1983).

Samples were taken for the determination of

- bacterial cell numbers (BCN) and biomass,
- POC/PON,
- DOC/DON,
- particulate and dissolved amino acids and carbohydrates,
- nutrients (NH_4^+ and NO_3^- ; measurements were provided by SP-7, WALLMANN.)

Besides fresh POM collected with a plankton net, material from unpoisoned sediment traps (500 m above bottom; SP-4) and from the "fluff layer" of sediment cores retrieved with a multicorer (SP-1, PFANNKUCHE) was incubated at 0-2°C.

In these experiments only the bacterial parameters EEA, BSP, BPP, BCN and nutrients were measured.

Fluff layer experiments were conducted together with SP-7.

The results of the experiments will be compared with data from the sediment trap studies (SP-4) and with data from different depths of the water column (i.e. in and below the euphotic layer, in the O₂ minimum and clear water minimum zone, 25 and 10 m above bottom, in the water collected at 10 to 60 cm above the sea floor, and in the water directly overlying the sediment cores; Tab. 1).

Tab. 1: Experiments. Listed are the layers and depths of origin of incubated POM and incubation temperatures.

Oxygen +/- = incubation with/without oxygen), * = in situ temperature.

Layer	Depth (m)	Temperature (°C)	Oxygen
<i>POM enriched via tangential flow (>0,18 μm, non quantitative)</i>			
Euphotic zone	50	28*	+/-
		15	
		8	
		2	
below euphotic zone, above OMZ	250	15*	
Oxygen minimum zone (OMZ)	500	15*	+/-
Clear water minimum	1200	8*	
		15	
Benthic boundary layer	4040	2*	
		15	
<i>POM collected with a plankton net (55 μm mesh size)</i>			
Euphotic zone	150-0	28*	
		15	
just below euphotic zone	300-150	15*	
		28	

Station work

In addition to the investigations in the water column conducted by the BIGSET groups from GEOMAR the JGOFS microbiology group from the IOW provided measurements of bacterial parameters to get an idea of bacterial degradation rates in the deep water. Sampling was closely linked to benthic boundary layer studies of SP-1 and -2 to measure EEA, BSP, BPP and BCN. Water samples from the bottom-near layer were taken with a bottom water sampler (BWS) and with a CTD rosette. SP-4 provided one splitted subsample from the short term sediment traps moorings 500 m above bottom at the stations WAST-Plain, CAST and NAST. Water overlying sediment cores from the multicorer was sampled only once on WAST-Plain (Tab. 2).

Tab. 2: Station works. List of sampling devices and sampled depths in the water column above bottom (a.b.) at each of the 5 stations. Samples were taken in all depths for the determination of the potential activities of extracellular enzymes (EEA), the incorporation rates of ^3H -thymidine (BSP) and ^3H -leucine (BPP), and bacterial cell numbers (BCN). BWS = bottom water sampler, MUC = multiple corer. Results of EEA measurements are shown in Fig. 1.

Depth a.b. (m)	WAST- Plain	WAST-Top	SAST	CAST	NAST
1000	CTD 06	-	-	-	-
500	CTD 06	-	-	-	-
300	CTD 06	-	-	-	-
100	CTD 06	-	-	-	-
50	CTD 06	-	-	-	-
25	CTD 05	-	CTD 12	CTD 22	CTD 26
10	CTD 05	-	CTD 12	-	CTD 26
5	CTD 06	-	CTD 09	CTD 22	CTD 27
	BWS 1	BWS 2+3	BWS 7	BWS 11	BWS 13
	0,65	0,65	0,65	0,65	0,65
Depth	0,50	0,35	0,35	0,34	0,34
a.b. (m)	0,43	0,20	0,20	0,21	0,21
	0,30	0,10	0,12	0,11	0,11
Water above sediment	MUC 7	-	-	-	-
Water depth (m)	4041	1915	4423	3957	3189

Results and conclusions

So far, only results from the EEA measurements in the benthic boundary layer are available (Fig. 1). Hydrolysis rates do not differ substantially between the 5 stations. Values range from 0-1.5 pM/h for α -glucosidase, 0-0.4 pM/h for β -glucosidase, 0-3 pM/h for chitinase, 500-2000 pM/h for esterase, and 0-40 pM/h for aminopeptidase.

On WAST-Plain hydrolysis rates of β -glucosidase, chitinase, and aminopeptidase reached higher values in the water above the sediment. This may be due to sediment particles mixed into the overlying water during the handling of the sediment core. At both WAST-Top and NAST EEA measurements were most reliable. Activities of all enzymes were measurable (except for β -glucosidase on WAST-Top I), whereas at WAST-Plain and at SAST only chitinase and esterase activities were detectable in all four layers but only in a few β -glucosidase and aminopeptidase activities were found. At CAST hydrolysis rates of esterase only could be detected in all four layers.

At none of the five stations EEA measurements suggest enhancement of enzyme activity within the benthic boundary layer. Due to turbulence in the benthic boundary layer particles from the sediment-water interface are mixed into the overlying water column. Particle concentration decreases with increasing distance from the bottom. Thus, one would assume higher hydrolysis rates near the sea floor decreasing with increasing distance from the bottom. Only esterase activities at NAST show an increase from 700 to 2300 pM/h towards the sea floor, but overall, data from the six BWS casts do not show uniform trends. Results of ^3H -thymidine and ^3H -leucine incorporation will give further evidence for bacterial activities in the water column up to 25 m above the sea floor.

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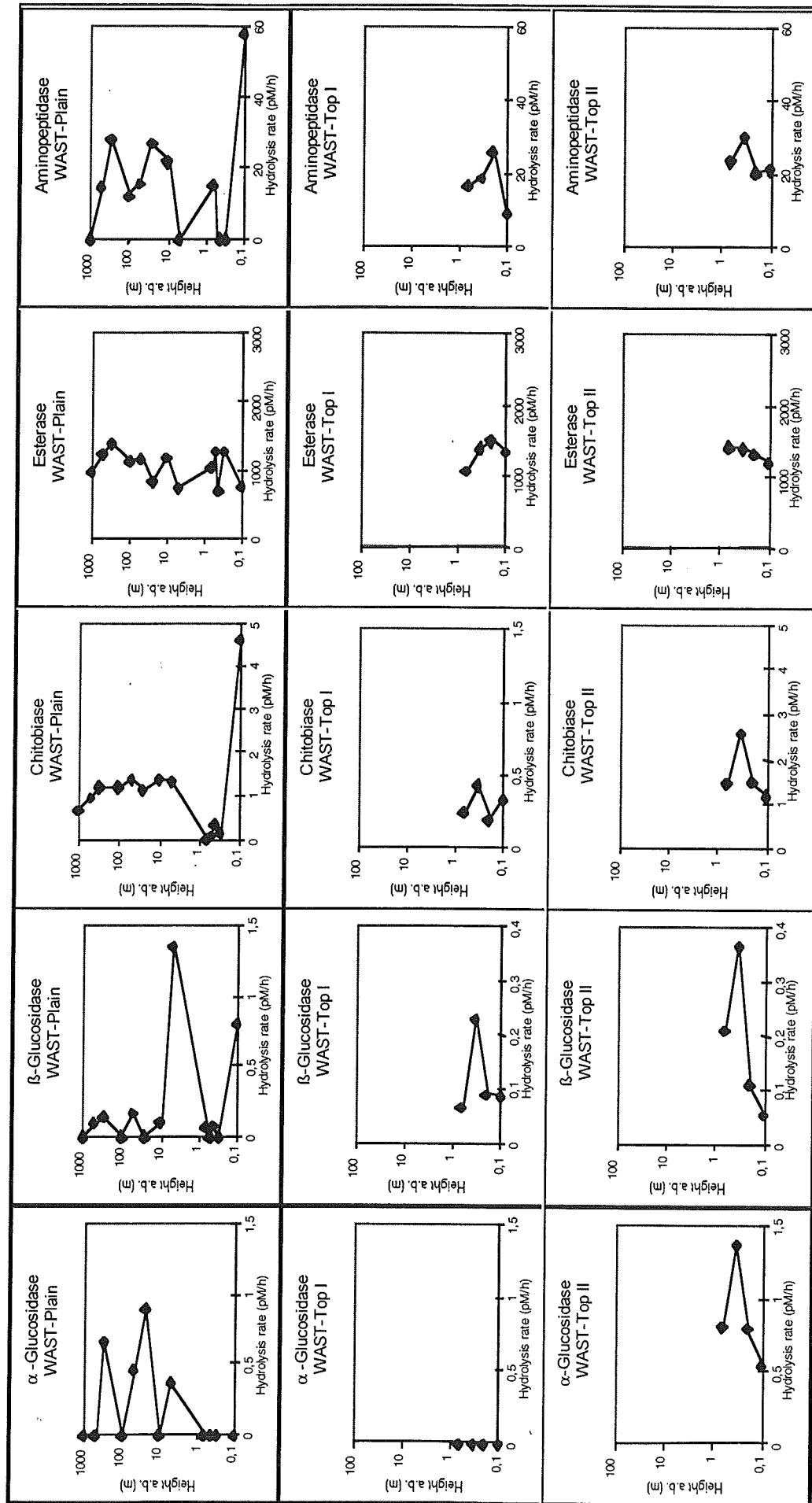


Fig. 1: Extracellular enzymatic activities in pM/h in different depths above the sediment surface (see Tab. 2). Note change of x-scale in plots *chitinase*, *WAST-Plain* and *WAST-Top II* and *β-glucosidase*, *WAST-Plain*. (Continued on next page).

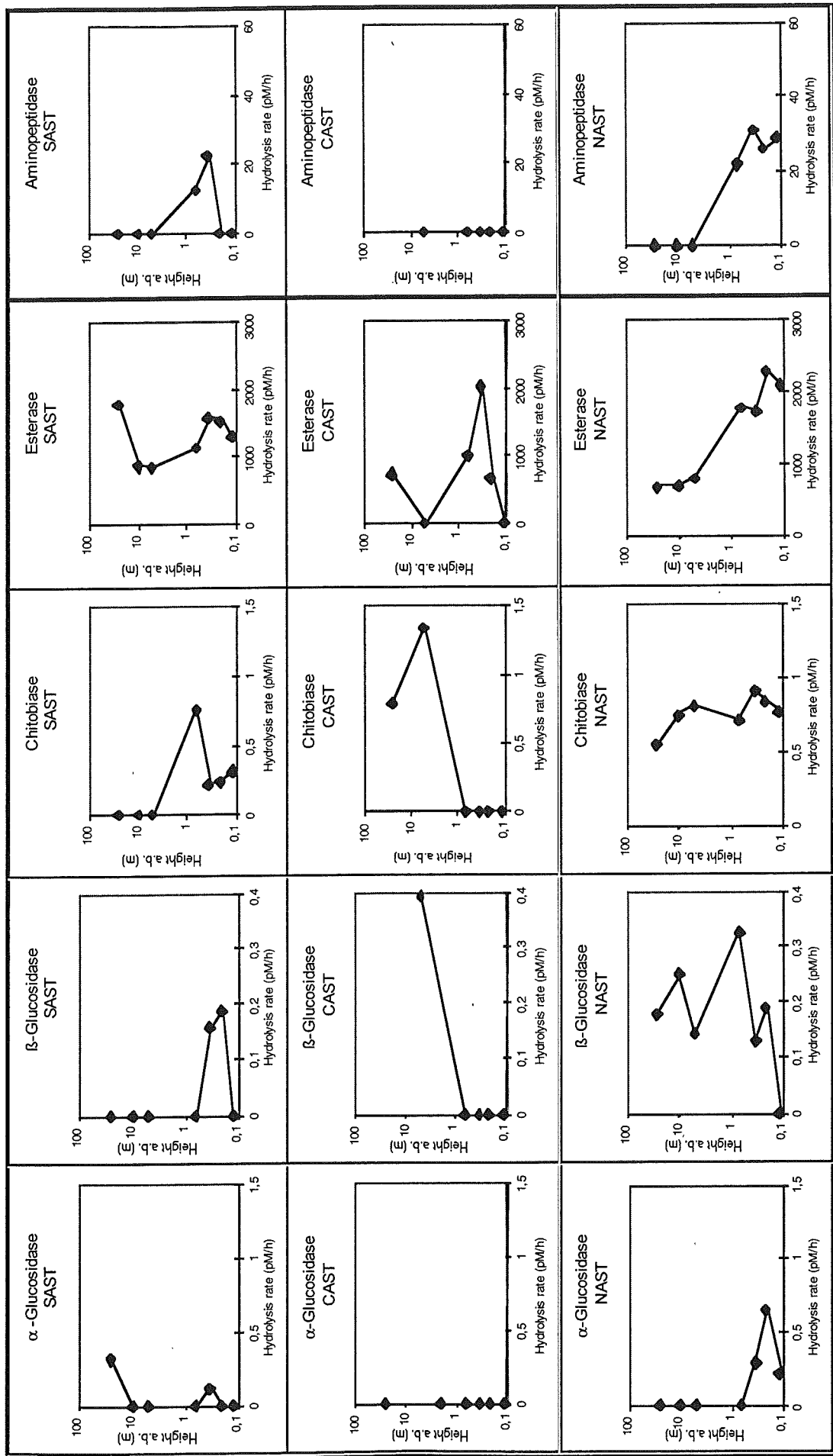


Fig. 1: Continued.

5.5. Preservation potential of primary climatic and environmental signals in deep-sea sediments

Petra Schäfer & Gunnar Schroll

Research programme

The subproject aims to assess the preservation potential of the environmental and climatic signals reaching the deep sea via particle sedimentation. This is to be achieved by characterizing the particle fluxes to the deep-sea benthic boundary layer and by comparing the biogeochemical composition between sinking particles, suspended particles and surface sediments. The carbon and nitrogen isotopic composition of sinking particles and sediments in combination with data on labile organic compounds in sediments and pore waters are expected to provide further information on early diagenetic processes. During cruise SO118 at 3 of the 8 stations a mooring system consisting of a sediment trap and a water transfer system was deployed and recovered. Sediment and pore water were sampled from cores taken by multiple corer. Water samples were taken from the depth of the sediment trap deployment and from the upper water column. Suspended particles were filtered onto glass microfibre filters.

Station works and preliminary results

5.5.1 Particle flux (500m traps short deployments)

The original plan of the subproject included the deployment of short-term moorings with a sediment trap and a deep-sea filtration system at each of the 5 main stations. Due to changes in the cruise schedule and due to the failed recovery of the long-term sediment trap mooring at SAST the mooring was deployed twice at WAST and once each at CAST and NAST. During the first deployment at WAST (WAST-ST-01, 08.-20.04.97) 3 samples of sinking particles were collected. One sample each was collected during the other 3 deployments at CAST, NAST and WAST(WAST-ST-02).

Methodology and description of the work carried out

Table 1 depicts the details of the mooring with one sediment trap and one water transfer system.

Tab. 1: Mooring system information, Arabian Sea, SO118

Region	WAST-Plain	WAST-Plain
Mooring name	WAST-ST-01	WAST-ST-02
Mooring position	16°14.17'N60°17.50E	16°13.91'N60°18.08E
Deployment	07.04.97, 15:15-16:53	03.05.97, 07:40-08:56
Deployment station	14	83
Recovery	20.04.97, 08:08-09:46	07.05.97, 10:11-11:30
Recovery station	49	96
Water depth (m)	4045	4045
Trap depth (m)	3478	3482
Distance to seafloor (m)	563	561
Sampling start	08.04.97, 06:00	03.05.97, 10:00
Sampling end	20.04.97, 06:00	07.05.97, 10:00
Duration (d)	3 x 4	4
Samples	WAST-ST-01 #1, #2, #3	WAST-ST-02 #1
Pump depth (m)	3989	3991
Distance to sea floor (m)	56	54
Sampling start	08.04.97, 06:00	03.05.97, 10:00
Sampling end	17.04.97, 08:48	07.05.97, 01:18
Sampling volume	3 x 80 l	1 x 52 l, 1 x 80 l
Region	CAST	NAST
Mooring name	CAST-ST-01	NAST-ST-01
Mooring position	14°22.95'N64°33.74E	19°56.71'N65°35.09E
Deployment	23.04.97, 08:00-09:39	28.04.97, 06:04-07:13
Deployment station	57	69
Recovery	26.04.97, 11:05-12:35	01.05.97, 13:10-14:24
Recovery station	66	79
Water depth (m)	3965	3173
Trap depth (m)	3398	2610
Distance to sea floor (m)	563	561
Sampling start	23.04.97, 10:30	28.04.97, 09:00
Sampling end	26.04.97, 10:30	01.05.97, 09:00
Duration (d)	3	3
Samples	CAST-ST-01 #1	NAST-ST-01 #1
Pump depth (m)	3909	3119
Distance to seafloor (m)	56	54
Sampling start	23.04.97, 10:30	28.04.97, 09:00
Sampling end	26.04.97, 09:50	01.05.97, 07:47
Sampling volume	3 x 60 l	1 x 45 l, 2 x 60 l

After initial macroscopic description of the sediment trap samples (Tab. 2) they were sieved, split and filtered.

Tab. 2: Description of sediment trap samples (visual)

Sample	WAST-ST-01 #1	WAST-ST-01 #2	WAST-ST-01 #3	CAST-ST-01 #1	NAST-ST-01 #1	WAST-ST-02 #1
Date of sample description	20.04.97	20.04.97	20.04.97	26.04.97	01.05.97	07.05.97
Supernatant volume (%)	95	95	95	98	95	93
Supernatant volume (ml)	230	230	230	235	230	233
Supernatant color	clear	clear	clear	clear	clear	clear
Subsample	x	-	x	-	-	-
Particle volume (ml)	10	10	10	5	10	7
Particle color	green-brown	green-brown	green-brown	green-brown	brown-green	brown-green
Large amorph. Aggregates	T	T	T	-	T	m
Small amorph. Aggregates	M	M	M	m	M	M
Fecal pellets (> 1 mm)	M	M	M	M	m	M
Fecal pellets (< 1 mm)	m	m	m	M	m	m

Amount: M = major (50 - 100%), m = minor (10 - 50%), T = trace (< 10%)

For the analyses of dissolved organic compounds the supernatant was filtered through glass microfibre filters (GF/F, 0.7 μ m, pre-combusted at 500°C) and filled in 10 ml glass ampoules (pre-combusted at 500°C). The ampoules were sealed under nitrogen and stored frozen. The particulate sample was wet sieved (1 mm) and split using a rotary splitter. The > 1 mm sample and three quarters of the < 1 mm sample were filtered on preweighed polycarbonate filters and dried (60°C) for further biogeochemical analyses. The processing and distribution of the sample splits for the various analyses of subproject 4 and 3 other subprojects of BIGSET (SP-1, SP-2 and SP-3) are listed below:

WAST-ST-01, #1, #2 and #3

> 1 mm, total	filtered and dried
< 1 mm 2/4	filtered and dried
< 1 mm 1/4	filtered and dried
< 1 mm 1/16	liquid and cool, grain size
< 1 mm 1/16	microbiology (SP-3)
< 1 mm 1/16	potential hydrolytic activity, FDA turnover (SP-1), microbiology (SP-3)
< 1 mm 1/64	chloroplastic pigments (SP-1)
< 1 mm 1/64	Thorium (SP-2)
< 1 mm 1/64	microscopy
< 1 mm 1/64	liquid and cool, free

CAST-ST-01, #1; NAST-ST-01, #1; WAST-ST-02, #1

> 1 mm, total	filtered and dried
< 1 mm 3/4	filtered and dried
< 1 mm 1/16	liquid and cool, grain size
< 1 mm 1/16	microbiology (SP-3)
< 1 mm 1/16	potential hydrolytic activity (FDA, SP-1)
< 1 mm 1/64	chloroplastic pigments (SP-1)
< 1 mm 1/32	Thorium (SP-2)
< 1 mm 1/64	microscopy

Results

Shipboard studies

One aliquot of the liquid sample (1/64) was investigated using the stereo microscope. The identified constituents are described below in order of their abundance:

WAST-ST-01, #1:

1. small amorphous aggregates containing fragments of diatoms
2. foraminifers (e.g., *Globigerinella digitata*, *Globigerinoides sacculifer*, *Globigerinella siphonifera*)
3. small fecal pellets (mostly oval-shaped)

WAST-ST-01, #2:

1. small amorphous aggregates containing fragments of diatoms
2. foraminifers (*Orbulina universa*, *Globigerinoides sacculifer*,
Globigerinella siphonifera)
3. fecal pellets in various sizes (mostly oval-shaped)

WAST-ST-01, #3:

1. small amorphous aggregates, some of them contain fragments of diatoms
2. foraminifers, small
3. fecal pellets in various sizes (nearly all oval-shaped)

CAST-ST-01, #1:

1. very small amorphous aggregates
2. and 3. fragments of diatoms and strings of cyanobacteria

NAST-ST-01, #1:

1. small amorphous aggregates
2. amorphous aggregates of medium size
3. foraminifers (*Globigerinoides conglobatus*, *Globigerinoides sacculifer*,
Globigerinella siphonifera, *Globigerinella digitata*)
4. pteropods (*Limacina*)

WAST-ST-02, #1:

1. small amorphous aggregates
2. large fecal pellets and fragments of large fecal pellets
3. small fecal pellets (oval-shaped) and foraminifers (e.g., *Globigerinoides sacculifer*, *Globigerinella siphonifera*)

Laboratory studies

The weight of the dried material (<1mm) from the filter was used to calculate the total flux (Fig. 1). The samples (<1mm) were analyzed for their bulk and detailed organic matter composition. Analyses of C_{org} , nitrogen, carbonate, biogenic opal and lithogenic material have been completed. Analyses of amino acids, hexosamines and carbohydrates as well as of stable carbon and nitrogen isotopes are being carried out. Total fluxes were highest at WAST during the first deployment in April ($89.3\text{--}10.4 \text{ mg m}^{-2} \text{ d}^{-1}$, Fig. 1). During the second deployment at the beginning of May the particle flux was much lower ($58.8 \text{ mg m}^{-2} \text{ d}^{-1}$). The lowest flux was measured at CAST ($46.2 \text{ mg m}^{-2} \text{ d}^{-1}$). These fluxes at WAST and CAST are in the

range of the fluxes recorded from long-term flux data of traps in similar depths (HAAKE *et al.*, 1993, RIXEN *et al.*, 1996). At NAST the total particle flux ($81.6 \text{ mg m}^{-2} \text{ d}^{-1}$) was lower than at WAST in April and higher than at CAST and at WAST in May 1997. The same regional trends are exhibited by the fluxes of biogenic opal, organic carbon and nitrogen (Figs. 2-4). Carbonate fluxes at WAST in April varied between 44.1 and $53.2 \text{ mg m}^{-2} \text{ d}^{-1}$ but decreased to 31.2 - $33.4 \text{ mg m}^{-2} \text{ d}^{-1}$ at the other 3 deployments (Fig. 1). Lithogenic matter fluxes varied between 14.3 and $18.6 \text{ mg m}^{-2} \text{ d}^{-1}$ at WAST in April and at NAST. At WAST in May and at CAST they were 8.3 and $5.3 \text{ mg m}^{-2} \text{ d}^{-1}$, respectively (Fig. 2). C/N ratios did not exhibit a regional trend. The values were around 7 (Fig. 3). The ratios of organic carbon to inorganic carbon ($C_{\text{org}}/C_{\text{carb}}$) varied at WAST between 1.10-1.25. The highest value was determined at NAST (1.64) and the lowest at CAST (0.51) (Fig. 4). Chlorophyll *a* fluxes varied between 1.40 and $8.76 \text{ } \mu\text{g m}^{-2} \text{ d}^{-1}$, pheopigment fluxes varied from 26.8 to $63.7 \text{ } \mu\text{g m}^{-2} \text{ d}^{-1}$ (Fig. 5) and total chloroplastic pigment (CPE = chlorophyll *a* + pheopigments) fluxes varied from 28.2 to $75.6 \text{ } \mu\text{g m}^{-2} \text{ d}^{-1}$ (Fig. 6). Lowest fluxes were measured at CAST. Phaeopigment and CPE fluxes were highest at NAST whereas the third sample at WAST in April exhibited the highest chlorophyll *a* flux. The 3 samples collected in April at WAST showed an increase in fluxes of chlorophyll *a*, phaeopigment and CPE. Also the ratio between chlorophyll and total CPE was increasing from 6.1% to 12.1% indicating an increase of fresh phytoplanktonic material in the BBL (Fig. 6). In May this value had decreased to 5.1% indicating the sinking of more degraded particles. The ratio of Chlorophyll and total CPE were in a similar low range at CAST (5.0%) and at NAST (6.4%). The potential hydrolytic activity (fluoresceindiacetat (FDA) turnover) varied between 30.9 and $99.1 \text{ fmol mg}^{-1} \text{ h}^{-1}$ (Fig. 7). At WAST FDA turnover values decreased from 59.0 to $30.9 \text{ fmol mg}^{-1} \text{ h}^{-1}$ in April. In May the value was higher ($60.5 \text{ fmol mg}^{-1} \text{ h}^{-1}$). The sample of NAST showed a similar value ($50.8 \text{ fmol mg}^{-1} \text{ h}^{-1}$) whereas the highest FDA turnover was encountered at CAST ($99.1 \text{ fmol mg}^{-1} \text{ h}^{-1}$).

Conclusions

The sinking particles consisted mainly of small amorphous aggregates, foraminifers and fecal pellets. The total fluxes of approximately $100 \text{ mg m}^{-2} \text{ d}^{-1}$ measured in April at WAST indicate a period of relatively high productivity. This is also valid for NAST with a total flux of $82 \text{ mg m}^{-2} \text{ d}^{-1}$. At CAST and in May at WAST a

more typical low productive intermonsoon situation was encountered (46 and 59 $\text{mg m}^{-2} \text{d}^{-1}$, respectively). Compared to the other stations CAST exhibited also the lowest fluxes of biogenic opal, lithogenic matter, organic carbon, nitrogen and chloroplastic pigments. The rain ratio of organic carbon to inorganic carbon pointed to a less effective biological carbon pump in the central Arabian Sea compared to the other stations during the time of investigation. In the samples of this station also the potential hydrolytic activity was at its maximum indicating a higher degree of organic matter degradation and a longer residence time in the water column (low settling speed, less ballast). The nature of organic matter will be further investigated with the help of amino acid and hexosamine analyses.

5.5.2 Suspended particles

Water samples for filtration of suspended matter were taken from water depths at which the sediment trap and the pump were deployed and in near-bottom profiles (Tables 3 and 4). Sampling was carried out in cooperation with subproject 2.

Tab. 3: Collection of suspended particles: Dates on which the various water depths were sampled at the 5 main stations

Station	Depth (m) = 5 m a.g.	Depth (m) = 50 m a.g.	Depth (m) = 500 m a.g.
WAST-Plain		03.04.97	03.04.97
WAST-Plain	21.04.97	21.04.97	21.04.97
WAST-Plain	06.05.97 (2x)	06.05.97	
WAST-Top	10.04.97	10.04.97	10.04.97
SAST	13.04.97	13.04.97	13.04.97 (2x)
CAST	26.04.97	26.04.97	26.04.97
NAST	30.04.97	30.04.97 (2x)	30.04.97 (2x)
Station	Depth (m) = 20,60,200,700	Depth (m) = 20,FM,60	Depth (m) = 50,250
WAST-Plain	04.05.97	04.05.97	03.04.97
SAST	13.04.97		
CAST	23.04.97	25.04.97	
NAST	28.04.97	29.04.97	

a.g.= above ground

FM:Fluorescencemaximum

Water samples were taken with a rosette water sampler equipped with 10-l NISKIN bottles from selected depths. For sampling of suspended matter seawater was filtered using preweighed glass microfibre filters (GF/F, 0.7 μm , pre-combusted at 450°C, 4.5 h). The filters were rinsed with double deionized water and dried at 60°C. At each of the main stations at least 1 filter with suspended matter from 3 near-bottom-depths (5, 50 and 500 m above ground) was taken for the analyses of

amino acids, hexosamines, carbohydrates and stable isotopes. The data will be interpreted together with the results of subproject 2 (C_{org}, N, Thorium).

Tab. 4: Water sampling

Region and date	Station	Position	Water depth (m)	Sample depth (m)	Volume (ml)	Above ground (m)
WAST-Plain 03.04.97	1/#1	16°13' N	4045	50	19000	
	CTD-01	60°15' E		250	36900	
	1/#2	16°13.0' N	4042	3520	38600	522
	CTD-02	60°16.0' E		3970	38150	72
WAST-Top 10.04.97	26/#1	16°10.5' N	1916	1860	58350	56
	CTD-07	59°46.0' E		1911	57700	5
	26/#2	16°10.5' N	1916	1400	58700	516
	CTD-08	59°46.0' E				
SAST 13.04.97	31/#1	10°02.00' N	4423	4375	59900	48
	CTD-09	65°00.00' E		4425	57500	-2
	31/#2	10°01.94' N	4422	3925	56250	497
	CTD-10	64°59.92' E		3925	58400	497
	31#3	10°02.01' N	4426	20	27750	
	CTD-11	65°00.00' E		60	27300	
				200	38000	
				700	48100	
WAST-PLAIN 21.04.97	53/#3	16°13.00' N	4044	3990	58500	54
	CTD-15	60°15.98' E		4038	59000	6
	53/#4	16°12.99' N	4042	3540	59050	502
	CTD-16	60°15.98' E				
CAST 23.04.97	59/#1	14°25.13' N	3958	20	28000	
	CTD-20	64°33.95' E		60	27950	
				200	38500	
25.04.97	62/#2	14°24.98' N	3955	20	18800	
	CTD-21	64°33.97' E		#44	6950	
				60	18900	
				60	18600	
26.04.97	67/#3	14°24.98' N	3956	3904	58200	52
	CTD-22	64°34.04' E		3952	58400	4
	67/#4	14°25.03' N	3958	3450	58600	508
	CTD-23	64°34.06' E				
NAST 28.04.97	71/#1	19°59.99' N	3189	20	19200	
	CTD-24	65°34.97' E		20	9400	
				60	28950	
				200	39000	
29.04.97				700	48400	
	73/#2	19°59.99' N	3186	20	19150	
	CTD-25	65°34.99' E		#33	18650	
				60	18700	
30.04.97	76/#1	19°59.98' N	3188	2688	58900	500
	CTD-26	65°35.00' E		3138	58200	50
	76/#6	20°00.00' N	3187	3138	58800	49
	CTD-27	65°34.98' E		3183	58950	4
	76/#7	20°00.00' N	3188	2688	57650	500
	CTD-28	65°34.99' E				
WAST-PLAIN 04.05.97	88/#2	16°12.99' N	4046	20	19400	
	CTD-29	60°16.01' E		#53	19350	
				60	19400	
				20	28950	
	88/#6	16°12.99' N	4044	60	28400	
	CTD-30	60°16.04' E		200	38500	
				700	48600	
06.05.97	92/#4	16°12.99' N	4043	3996	59650	47
	CTD-31	60°16.00' E		4041	59200	2
				4041	59700	2

#: Fluorescence maximum

5.5.4 Sediment and pore water

Sediment and pore water (from centrifuged sediments) were sampled from 13 cores taken by multiple corer at WAST-Plain, WAST-Top, SAST, CAST, NAST and at stations ZS 1, ZS 2 and ZS3 (Tab 5).

Sediment multicorer supernatant water was filtered and sampled as bottom water. Sediment was subsampled at selected intervals (Table 6). Pore water for the analysis of dissolved organic compounds was centrifuged from the sediment subsamples at a temperature of 2°C at 2000 rpm for 20 minutes.

Subsequently, the supernatant pore water was removed with syringes and filtered through glass microfibre filters (GF/F, 0.7 µm, pre-combusted at 500°C). The pore water was filled in 10 ml glass ampoules (pre-combusted at 500°C), the ampoules were sealed under nitrogen and deep frozen (-17°C to -23°C).

Tab. 5: Sediment and porewater sampling

Station	Station No.	MC	Position	Date	Water depth (m)	Core length (cm)
WAST-Plain	6	06	16°13'N, 60°16'E	05.04.97	4045	25
	46/#2	29	16°13.00'N, 60°16.01'E	19.04.97	4045	35
	88/#3	51	16°13.04'N, 60°16.01'E	04.05.97	4045	20
WAST-Top	11	08	16°10.5'N, 59°46.0'E	06.04.97	1916	14
	85/#2	49	16°10.49'N, 59°46.01'E	03.05.97	1917	10
SAST	31/#9	20	10°02.03'N, 64°59.99'E	14.04.97	4425	30
	35/#4	22	10°02.00'N, 65°00.00'E	15.04.97	4425	30
CAST	58/#2	34	14°25.00'N, 64°34.02'E	23.04.97	3957	13
	62/#4	38	14°25.00'N, 64°34.00'E	25.04.97	3952	30
NAST	70/#2	42	20°00.00'N, 65°35.00'E	28.04.97	3188	30
ZS 1	41	24	13°05.11'N, 62°45.00'E	17.04.97	4168	12
ZS 2	54	33	15°19.99'N, 62°19.99'E	22.04.97	3977	10
ZS 3	80	47	18°00.80'N, 62°48.81'E	02.05.97	3656	15

The sediment residue and the untreated sediment were dried at 60°C for 6-8 days and stored in glass vials. The sampling was done at 11°C, the filtration at 24°C.

Tab. 6: Sampling intervals of sediment and pore water

Sampling interval
Bottom water
0-0.5 cm
0.5-1 cm
1-1.5 cm
1.5-2 cm
2-2.5 cm
2.5-3 cm
3-4 cm
4-5 cm
6.5-7.5 cm
9-10 cm
14-15 cm
19-20 cm
24-25 cm
29-30 cm

Sediment samples are being analyzed for C_{org}, nitrogen, carbonate, biogenic opal, lithogenic material, amino acids, hexosamines, carbohydrates and stable carbon and nitrogen isotopes. Pore water samples are being analyzed for dissolved organic carbon, dissolved combined and dissolved free amino acids, hexosamines and carbohydrates

Literature

- HAAKE, B., ITTEKKOT, V., RIXEN, T., RAMASWAMY, V., NAIR, R. R. and W. B. CURRY (1993) Seasonality and interannual variability of particle fluxes to the deep Arabian Sea. *Deep-Sea Research I*, **40**, 1323-1344.
- RIXEN T., HAAKE, B., ITTEKKOT, V., GUPTHA, M. V. S., NAIR, R. R. and P. SCHLÜSSEL (1996) Coupling between SW monsoon-related surface and deep ocean processes as discerned from continuous particle flux measurements and correlated satellite data. *Journal of Geophysical Research*, **101**, 28569-28582.

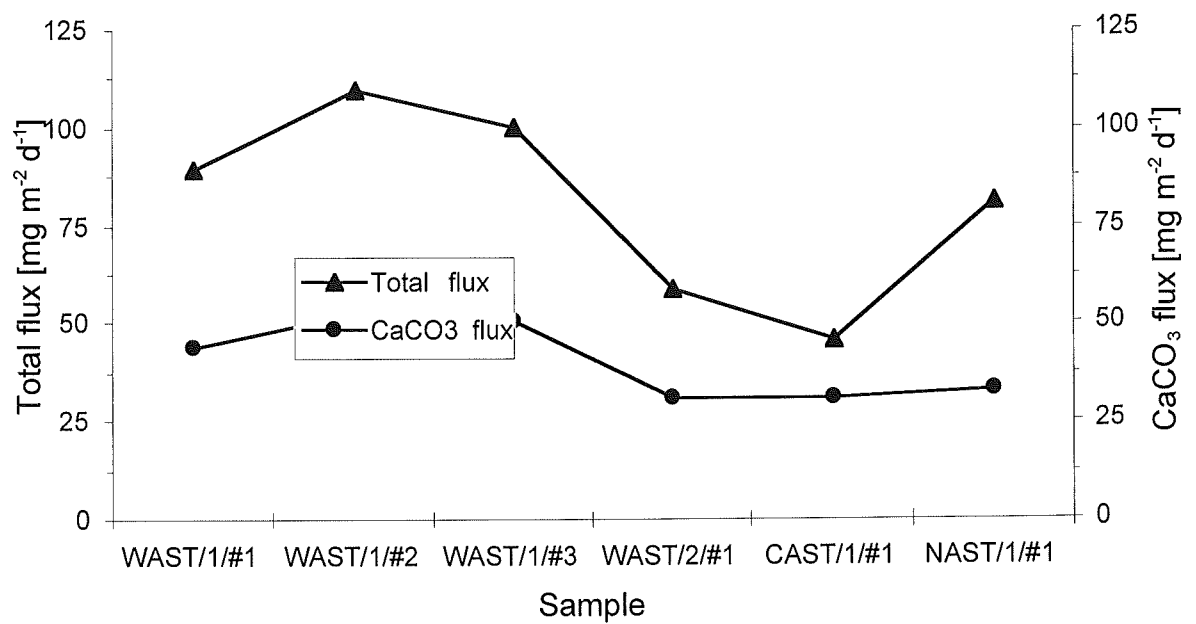


Fig. 1: Total and CaCO_3 flux in the Arabian Sea. Station and mooring descriptions see Table 1.

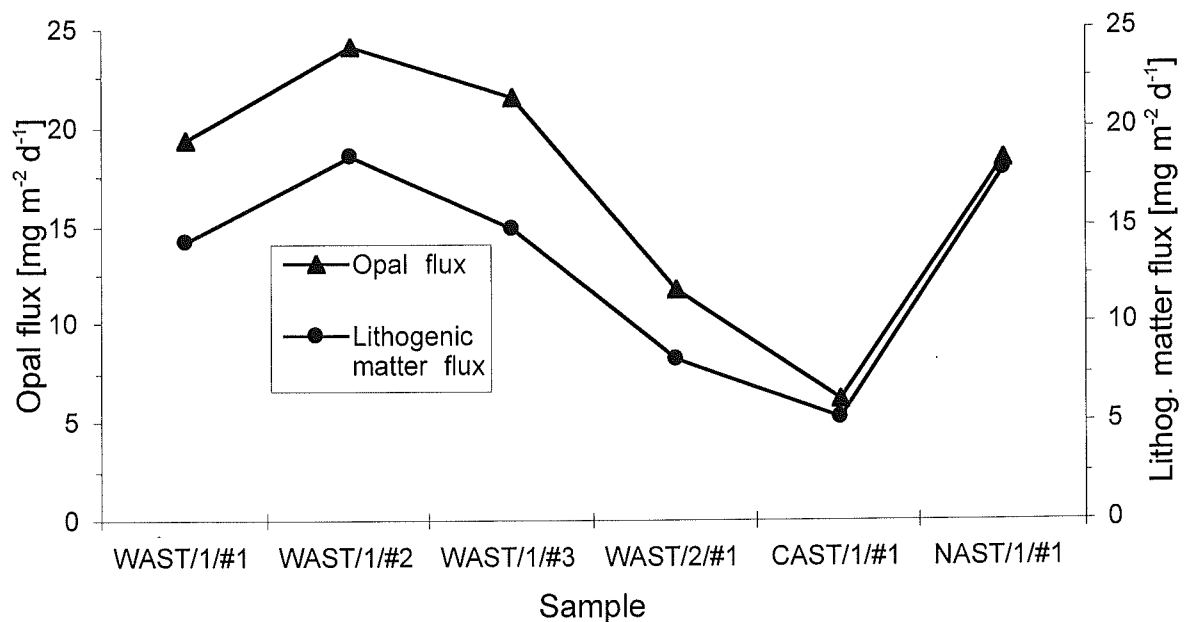


Fig. 2: Biogenic opal and lithogenic matter flux in the Arabian Sea. Station and mooring descriptions see Table 1.

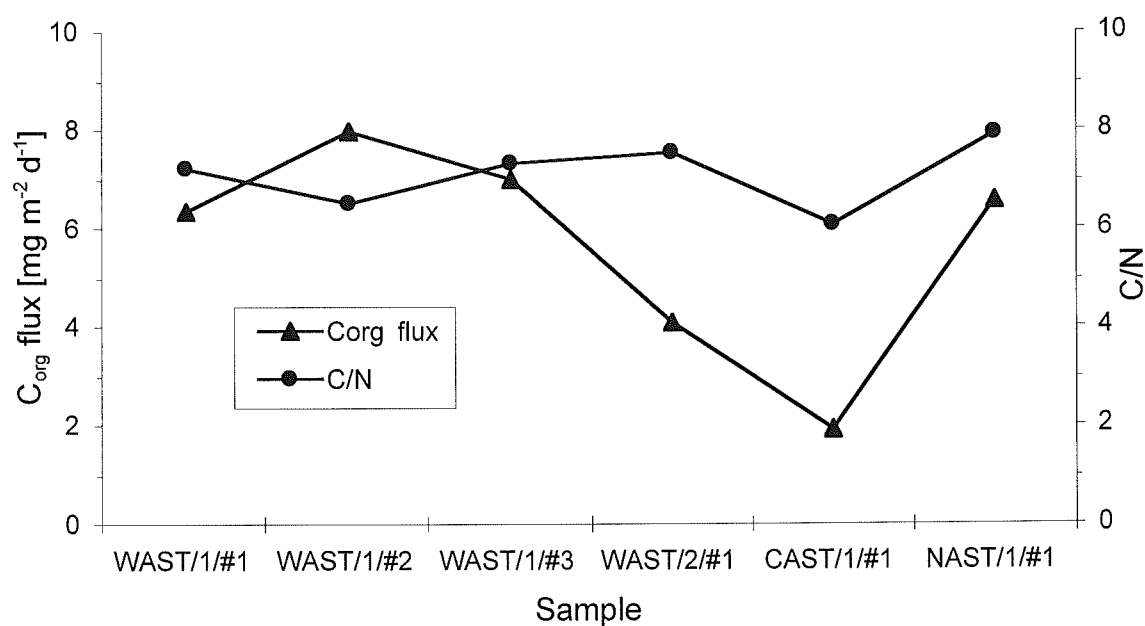


Fig. 3: Organic carbon flux and organic carbon/nitrogen ratios (by weight) in the Arabian Sea. Station and mooring descriptions see Table 1.

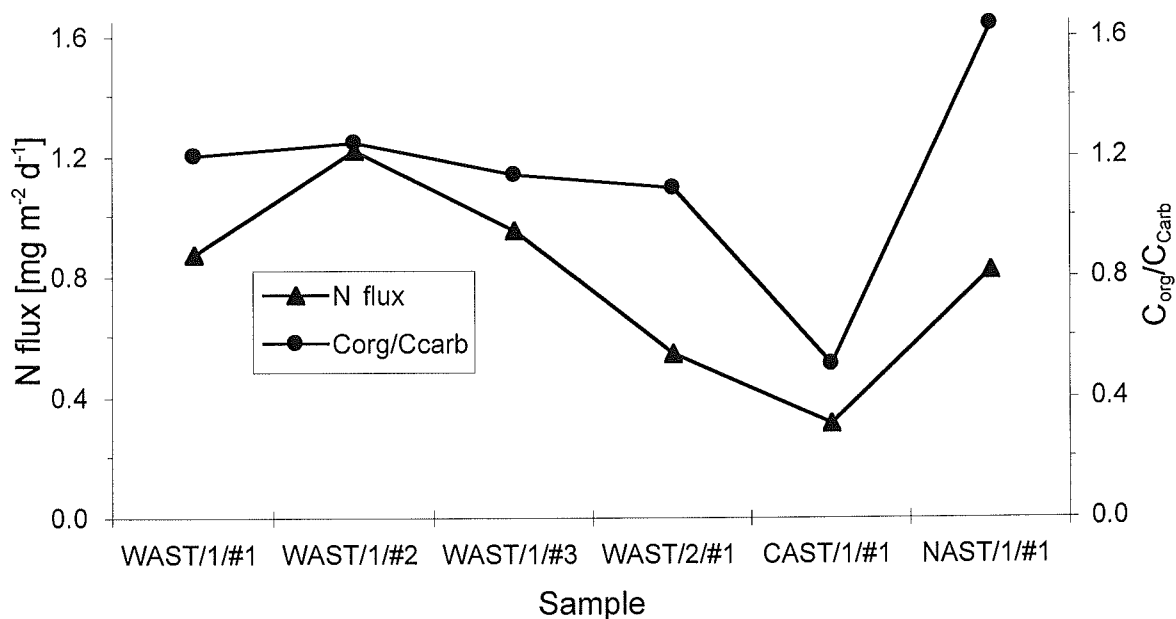


Fig. 4: Nitrogen flux and organic carbon/inorganic carbon ratios in the Arabian Sea. Station and mooring descriptions see Table 1.

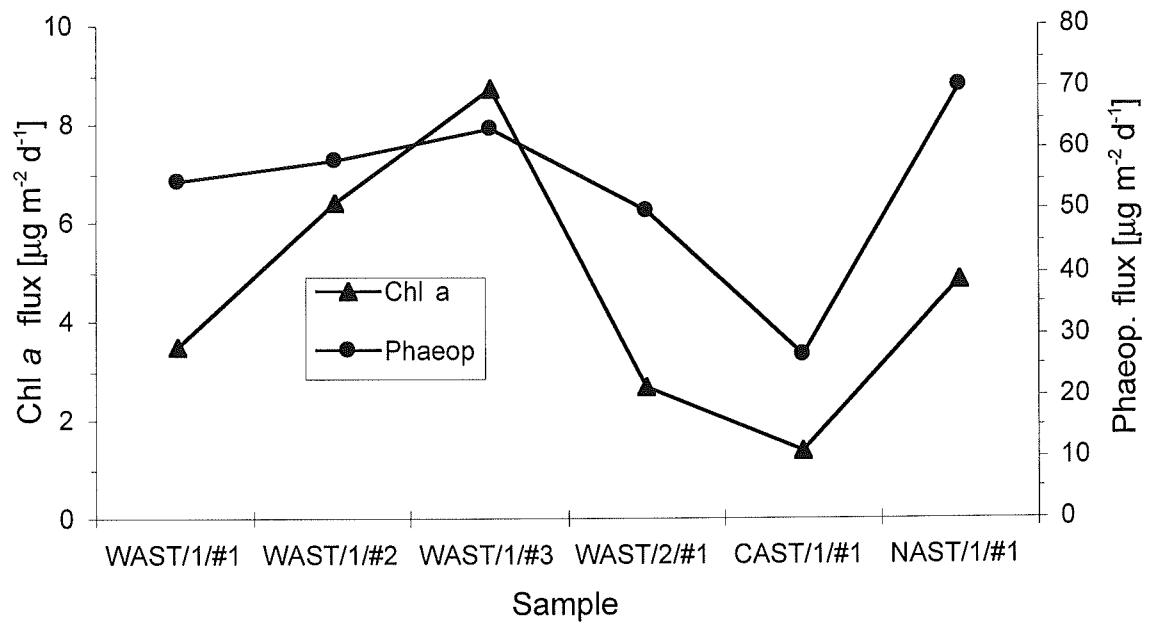


Fig. 5: Chlorophyll *a* and phaeopigment fluxes in the Arabian Sea. Station and mooring descriptions see Table 1.

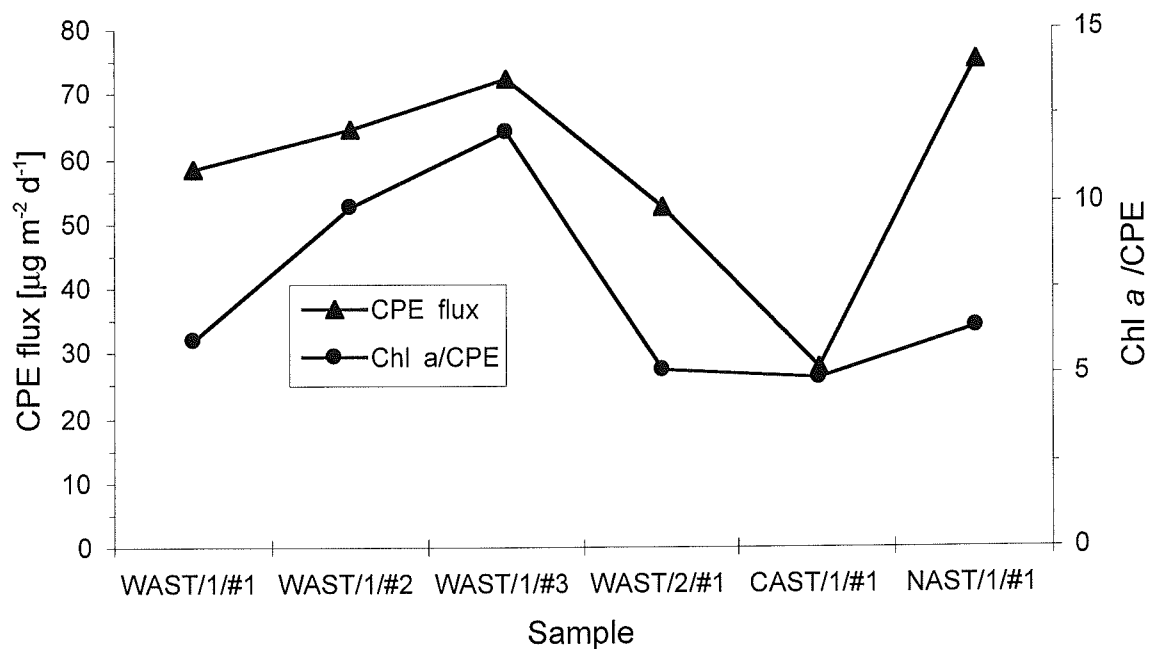


Fig. 6: Chloroplasic pigment (CPE, chlorophyll *a* equivalents) flux and chlorophyll *a* to total CPE (in %) in the Arabian Sea. Station and mooring descriptions see Table 1.

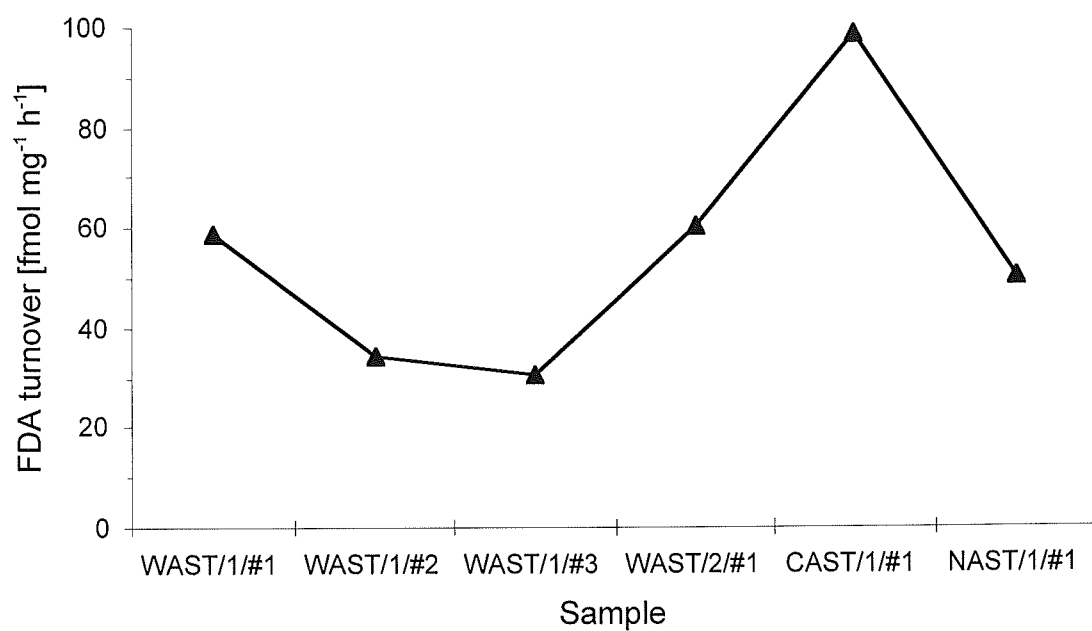


Fig. 7: Potential hydrolytic activity in sinking particles measured using the turnover of fluoresceindiacetat(FDA). Station and mooring descriptions see Table 1.

5.6 The role of foraminifera: Particle flux and early diagenetic processes

Frank Kurbjeweit & Petra Heinz

Research programme

Objectives were to study deep sea benthic foraminifera at five stations (WAST-Top, WAST-Plain, SAST, CAST, EAST and NAST) in the Arabian Sea. More detailed information on their ecology and biology will help to understand the biogeochemistry on the deep sea floor. In addition, the calcareous phyto- and zooplankton were investigated, continuing our long term survey in the area (JGOFS-Indic).

Evaluation of samples from METEOR cruises M 31/3 and M 33/1 in the Arabian Sea indicated regional differences in foraminiferal biomass (C_{org}) and faunal composition from north to south and from east to west (C_{org} : WAST-Plain > WAST-Top > NAST > CAST > EAST > SAST). This shift may be caused by different food conditions. On WAST-Top and WAST-Plain the calculated foraminiferal biomass (C_{org}) was 5-30 times greater than at stations SAST and EAST. Furthermore, depending on oxygen and other biotic and abiotic parameters different vertical distribution patterns in the sediment are observed. High abundance, biomass and turnover of benthic foraminifera can be related to sedimentation rate of organic matter, which stresses the importance of measurements during different seasons. On SO118 we focused on: species composition (recent and fossil) and their distribution, on the biomass, food web, habitat preferences, growth, reproduction, bioturbation, new production of organic material and pore water chemistry.

5.6.1 Abundance, composition and carbonate flux of planktonic foraminifera and coccolithophorids

Introduction

The spatial and temporal distribution of the calcareous plankton fauna (planktonic foraminifera and pteropods) and flora (coccoliths) and their export into deeper waters was investigated. The seasonal and the interannual changes will be studied to integrate samples into our previously collected data set. The data will serve for comparison of different monsoonal periods and for comparing the same seasons of different years. This investigation will lead to better understanding of

the carbon flux, and will improve interpretation of fossil assemblages for reconstructing the Quaternary development of the monsoonal system.

Material and methods

A multinet was used equipped with five nets (100 μm mesh size). At stations WAST-Top, WAST-Plain, SAST, CAST and NAST we tested every second to third day in depth layers of 100-80-60-40-20-0m to sample the productive zone to document short term changes. The depth layer of 700-500-300-200-100-0m and 2500-2000-1500-1000-700-0m were sampled to measure the export flux. From CTD/rosette casts, performed in combination with a net haul series, we took water samples at all depth intervals (2500, 1500, 700, 500, 300, 200, 100, 60 and 20m) for the sampling of calcareous nanoflora. Plankton samples were immediately examined for foraminiferal species composition and subsequently fixated in 4% hexamin buffered formaldehyde. Water samples were filtered through a 0,45 μm regenerated cellulose filter using a vacuum pump (200 mbar) to investigate coccolithophores. About 5 litres of water were filtered. The filters were dried over night and stored in petri dishes for further SEM examination and countings.

Results

The plankton tows contained only few foraminifera at almost all depths. Especially in the upper 100 m, they occurred very rarely. *Globigerinella siphonifera*, *Globigerinoides sacculifer* and *Orbulina universa* "dominated" this zone. In the upper export zone (<700m) these species were still dominating, but species like *Gallitellia vivans*, *Globigerina falconensis* and *Globorotalia scitula* also occurred. Especially the latter species was abundant on CAST. In the lower export zone (>700m -2500m) the diversity increased significantly and at least 11 species could be distinguished. Besides *G. sacculifer* and *G. siphonifera*, *Hastigerina digitata* and *Globorotalia menardii* became the most abundant species. The latter was very abundant on CAST (Tab. 1).

Table 1: Occurrence and relative abundance of foraminifera in the productive (upper 100 m), upper export (<700 m) and the lower export zone (<2500 m).

species/zone	productive zone (> 100 m)	upper export zone (< 700 m)	lower export zone (< 2500 m)
<i>Globigerinoides sacculifer</i>	xx	xx	xxx
<i>Gobigerinella siphonifera</i>	xx	xx	xxx
<i>Orbulina universa</i>	xx	xx	xx
<i>Globigerinoides ruber</i>	x	x	x
<i>Gallitellia vivans</i>	-	x	x
<i>Hastigerina digitata</i>	-	-	xxx
<i>Gobigerinella calida</i>	-	-	x
<i>Globorotalia scitula</i>	x (WAST-Plain)	xx	x
<i>Globorotalia menardii</i>	-	-	xx (CAST)
<i>Globigerina falconensis</i>	x	x	xx
<i>Globigerinoides conglobatus</i>	x (NAST)	-	x (WAST-Plain)

- = not found; x = only very few; xx = few; xxx = abundant

5.6.2 Abundance and composition of benthic foraminifera

Material and methods

At all main stations multicorer sediment samples were taken to investigate the benthic foraminiferal assemblage, stable isotopes (foraminiferal and pore water tests) and to obtain sediment for experimental work. Immediately after arriving on deck, the cores were transferred to the cool room (6-10°C). The sediment cores were filmed and/or photographed to document the original fabrics. Subsequently, the upper 1 or 2 cm of sediment mixed with bottom water were transferred into 250 ml DURAN flasks, which were kept in darkness under deep-sea temperature (4°C). The samples were regularly inspected every 3-4 days for foraminifera and their tracks in the sediment.

A second core was used for fixation (TEM) of foraminiferal cytoplasm to investigate food particles. The upper 2 cm of the sediment were sieved over a 125 µm- and a 63 µm-screen and washed with filtered seawater. Subsequently, the living foraminifera were picked under the stereo microscope, fixated and stained. The top two centimeters of a third core were sliced into half centimeter intervals in one centimeter slices. All slices were stained with a solution of ethanol and Rose Bengal to distinguish between living and dead specimens. Three replicates were taken at all stations to investigate the spatial heterogeneity of foraminiferal assemblages.

From a fourth core benthic foraminifera, pore water and water from the bottom nepheloid layer (BNL) were taken for ^{13}C - and ^{18}O - analysis to record microhabitat processes. Additionally, water from the water column and the BBL were taken with CTD/rosette-casts (20, 100, 500, 1000, 1500, 2000, 2500 and about 4000 m) and/or bottom water sampler (12, 21, 35, 65 cm above the sea-floor. The pore water was obtained by extracting it from cores sliced in cm intervals down to 14 cm by an Argon flow for twenty minutes (3 at). All samples were poisoned with HgCl_2 to stop bacterial growth and therefore sequestration of CO_2 . Special attention was paid to keep transfer times as short as possible and to avoid contamination by atmospheric CO_2 during compression. The remaining sediment ("press cake") was transferred into plastic dishes, sealed and stored at -30°C for determination of species and their ^{13}C - and ^{18}O - composition.

Preliminary results

Regular observations (every 3-4 days) of all cultures showed that no foraminifera had survived a sampling from 3100 m depth or deeper. Only few foraminifera had survived a sampling from 1950 m at WAST-Top.

Preliminary data from TEM prepared specimens (sediment layer 0-2cm, Tab.2) showed the following species composition: *Lagenammina difflugiformis*, *Ammobaculites agglutinans* and *Reophax* spp. These species were recorded from all stations in rather high numbers independent from water depth and particle flux. Calcareous species like *Epistominella exigua* belong to the epifauna and occur frequently at most stations. In contrast to MC-samples from METEOR cruise M33/1 at the end of the SW-monsoon they seem to play a minor role during the investigated intermonsoonal phase.

Infaunal species like the *Uvigerina peregrina-hispida* group, occur only at the more eutrophic stations WAST-Top and WAST-Plain where large amounts of phytodetritus were observed on top of the sediment.

A preliminary inspection of the core samples from WAST-Plain (Tab. 3) shows that living benthic foraminifers occur down to at least 24 cm in the sediment but are sharply decreasing in abundance below 2 cm. In layers below 10 cm only very few specimens were found and in most cases only single individuals are recovered.

Individuals $>125\ \mu\text{m}$ appear to have a wider depth distribution range than the smaller (63 - $125\ \mu\text{m}$) specimens. A positive correlation of the vertical distribution

with oxygen in the sediment exists only for small foraminifera (30-63 μm). They appear to survive only in well oxygenated sediments. From this observation the question arises how can pre-adult and adult specimens manage to survive in poorly oxygenated sediments? What kind of microenvironment has to be generated for this kind of survival.

At WAST-Top large Allogromiids (0.3 to 1.2 cm) dominated the phytodetritus enriched surface layer with up to 1000 individuals per m^2 . At least three different morphotypes could be distinguished. It seems that Allogromiids can respond quickly within a few days to weeks to phytodetritus pulses from the euphotic zone because within a time period of about 3 weeks the phytodetritus was already sequestered and nutrients declined significantly (SP-7).

Tab. 2: Occurrence of benthic foraminifera in the upper 2 cm at WAST-Top, WAST-Plain, SAST, CAST and NAST.

species/station	WAST-Top	WAST-Plain	SAST	CAST	NAST
<i>Ammobaculites agglut.</i>			X		
<i>Ammodiscus sp.</i>				X	
<i>Astrononion echolsi</i>				X	
<i>Bolivina sp.</i>	X				
<i>Cibicidoides sp.</i>	X				
<i>Cibrostomoides bradyi</i>				X	X
<i>Eggerella</i>	X			X	
<i>Eggerelloides</i>				X	X
<i>Epistominella exigua</i>	X	X		X	X
<i>Eponides bradyi</i>		X			
<i>Eponides tenuiformis</i>		X			
<i>Gavellinopsis</i>	X				
<i>Gyroidina sp.</i>				X	
<i>Gyroidinoides sp.</i>	X				
<i>Hormosina nodulosa</i>	X				
<i>Hormosina sp.</i>		X	X	X	
<i>Lagenammina difflugif.</i>		X	X	X	
<i>Lagenammina laticollis</i>		X			
<i>Lenticulina sp.</i>		X		X	
<i>Liebusella sp.</i>		X	X	X	
<i>Melonis barleeianum</i>				X	
<i>Oridorsalis tenera</i>				X	X
<i>Pullenia bulloides</i>	X				
<i>Pullenia sp.</i>	X	X			
<i>Pyrgo murrhina</i>	X				
<i>Reophax dentaliniformis</i>			X	X	
<i>Reophax micacaeus</i>	X		X		
<i>Reophax scorpiurus</i>	X		X		
<i>Reophax subfusiformis</i>	X		X		
<i>Rhizammina algaeformis</i>	X		X		
<i>Triloculina sp.</i>	X				
<i>Trochammina sp.</i>		X		X	X
<i>Uvigerina peregrina</i>	X	X			

5.6.3 Grazing and bioturbation experiments

Introduction

The knowledge about the qualitative and quantitative grazing of benthic foraminifera in the deep-sea is rather limited (TURLEY et al. 1993; LINKE et al. 1995; HEMLEBEN & KITAZATO 1995). Phytodetrital material sedimented from the euphotic zone is used by most foraminifera. However, we do not know how much is ingested on which time scales and how much organic material is produced in terms of biomass, for sustaining their microhabitats (e.g. cysts) and waste product release.

Our knowledge about the role of meiofauna for bioturbation and bioirrigation is presently very limited (HEMLEBEN & KITAZATO 1995; GROß in prep.). Most authors (i.e. MAHAUT & GRAF 1987, WHEATCROFT et al. 1994) suggest that mainly macrofauna is responsible for bioturbation, despite the dominance of meiofauna in terms of abundance and biomass in deep sea sediments. Benthic foraminifera often contribute to more than 50 % of the benthic biomass (GOODAY 1994). They could potentially play an important role in bioturbation and bioirrigation.

In this respect, we need quantitative data from in situ and laboratory experiments with benthic foraminifera to model the energy budget in deep sea sediments. In addition to natural radiotracers artificial tracers can be used to quantify ingestion and bioturbation (SHERR & SHERR, 1993). For that reason fluorescently labelled microbeads and bacteria were used.

Material and methods

Six different kinds of experiments were performed using living specimens from WAST-Top (1915m): under in situ (4°C, 192 bar and 445 bar, darkness) or under semi in situ (4°C, 1 at, darkness) conditions to investigate their grazing potential or their influence on bioturbation.

At the end of all experiments the foraminifera were stained with Rose Bengal to distinguish between dead and living specimens. The samples were subsequently wet sieved over 63 and 125 µm screen and sorted under a stereo microscope (Zeiss SV 11). Foraminiferan specimens were examined with an epifluorescence microscope (LEITZ Axioplan) for attached fluorescently labelled microbeads (FLM) and/or bacteria (FLB) and their test diameters were measured. Subsequently the tests were crushed to determine the total numbers of FLM and/or FLB. For FLB the carbon content was determined by using the conversion factor $30 \times 10^{-12} \text{g C}_{\text{org}}$ per

cell (LOCHTE, BOETIUS pers. comm.). Biomasses converted into organic carbon content were calculated by applying the equations by ALTENBACH (1985) for various calcareous and agglutinated species.

Experiment 1

This experiment was conducted to discriminate between deep-sea foraminifers, fluorescently labelled bacteria (FLB) and fluorescently labelled microspheres (FLM; i.e. food quality) and to estimate the speed of particle ingestion. Two parallel sets of experiments were run in a time series for about 152 hours (\gg 6 days) under semi in situ conditions (see above). In a first set 910 μ l of a suspension of FLB (initial concentration: $8.9 \cdot 10^9$ cells ml^{-1}) were added to 20 ml of a 1:1 sediment-water suspension from the top 2 cm of a sediment sample in a plastic bag. In a second experiment both, FLB and FLM, of similar size and form (1 μm), were added in identical concentrations. Samples were taken at 24, 60, 72, 96 and 152 hours.

The stained samples are still under investigation.

Experiment 2a/b

The experimental set-up was similar to the one described above, but under in situ pressure (192 bar, 4°C). The experiment was done in cooperation with Dr. A. Boetius who made the fluorescently labelled bacteria (FLB) available. A time series from 0 to 12 hours with five sampling times (after 1, 2, 4, 6 and 12 hours) was performed. In addition, the same experiment was run on a long term basis for 7 days, 15 days and 30 days.

Results

The percentage of body carbon ingested as bacteria is extremely low ranging from 0 to maximal 0.42 %. Nevertheless, FLB are ingested in higher numbers than FLM. Most of the larger foraminifers (>125 μm) contained very few labelled bacteria and some microbeads. In contrast, only a small fraction of the smaller foraminifera (63 - 125 μm) ingested FLB and FLM, respectively. No general difference was found in ingestion rates between the three different sampling intervals 7, 15 and 30 days. Due to the low number of individuals for each species at each sampling time no trend can be found. The short time experiments show slightly higher incorporation rates, however, not large enough to sustain the organisms.

Experiment 3

The third experiment was conducted to test if and how fast agglutinated foraminifera incorporate FLM into their tests and which size (1, 3, 6 and/or 10 μm \varnothing) they prefer. In addition FLB were offered in similar concentrations to see if and how much bacteria are ingested.

The stained samples are still in the evaluation process.

Experiment 4

To investigate the influence of pressure and food concentration on grazing rates a dilution series of FLM and FLB (1:1) was prepared and added to 20 ml sediment-water suspensions with living foraminifera for 24 hours under in situ (192 bar, 4°C, darkness) and semi in situ conditions (1 at, 4°C, darkness).

The stained samples are still in the evaluation process.

Experiment 5

In cooperation with subprojects 1 and 7 an in situ experiment with FLM of different size classes (1, 3, 6 and 10 μm) and bromide as additional tracer was designed to investigate bioturbation and bioirrigation in one experimental set up. Microbeads and bromide were injected into the incubation chambers of the lander at the stations WAST-Plain and SAST. A 50 cm^3 syringe was filled with a bromide/FLM solution. FLM of 1, 3, 6 and 10 μm were used in concentrations which corresponded with natural bacteria densities (BOETIUS pers. comm.).

The first lander experiment lasted for one day at WAST-Plain (station 15, free fall respirometre (FFR) 1). Unfortunately, the syringe system failed to inject the solution into the chamber. In a second trial the syringe worked but the sediment was lost during retrieval. Thus, no data are available. At SAST (station 28, FFR 3) the third experiment failed as well because the lander could not be retrieved.

Experiment 6

In order to determine the concentration of bacteria within the sediment and in the BNL under laboratory conditions subsamples of the topmost layer of the sediment (0-1 cm) and of the water from MC 481 (station 43) were taken and fixiated with 2% formaldehyde (04/19/97). The residual sediment and bottom water was then transferred into DURAN flasks to culture living foraminifera (see above). The

development of bacteria in these cultures has been followed in the forthcoming weeks in the home base laboratory. A first sample set of the sediment and the water was already taken on board after 1, 3, 6 and 12 days.

Results

The concentration of bacteria in the core tube water was approximately 9.4×10^5 cells/ml (see Fig.1a). One day after transferring to the culture flask, the concentration of bacteria decreased to 2.0×10^5 cells/ml and was more or less stable during the following weeks (2.4×10^5 to 9.0×10^4 cells/ml). In the next weeks the bacteria cell concentration remained rather constant (8.9×10^4 to 1.1×10^5). The concentration of bacteria in the sediment was 2.7×10^8 cells/ml.

After incubation the numbers of bacteria stayed fairly constant (1.6×10^8 to 6.4×10^8 cells/ml) during the following weeks. Even under home based laboratory conditions, the bacteria cell concentration in the sediment remained relatively constant (5.8×10^8 to 3.7×10^8).

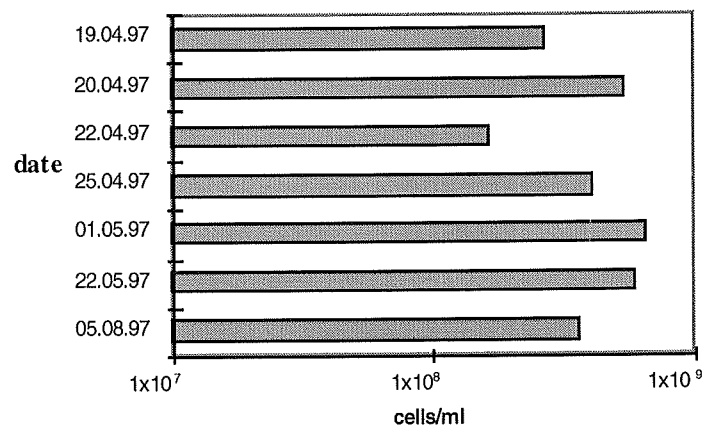
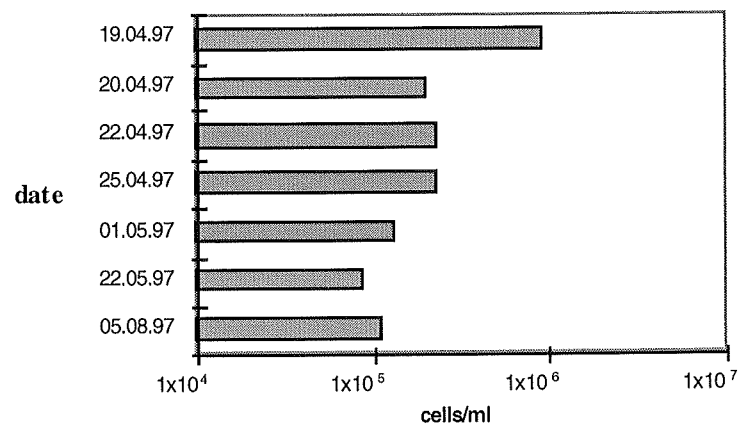


Fig.1: Concentration of bacteria (cells/ml) in sediment contact water (Fig.1a) and the toplayer of the sediment (0-1cm, Fig.1b) under laboratory conditions.

Discussion

Preliminary results of experiment 1 indicate that benthic deep-sea foraminifera can select their food according to food quality. Ingestion rates and thus the turnover of POM seem to be low when expressed as percentage of cytoplasmic carbon. Several reasons may be responsible for the low ingestion rates:

- a) Foraminifera were already damaged by decompression and recompression and/or
- b) they were damaged by warming during their recovery from bathyal depths (app. 7°C) to the surface (app. 25°C).
- c) The foraminifera were influenced by decreasing oxygen concentrations in the plastic bags during longer incubation periods.
- d) Foraminifera ingest bacteria, but only in small amounts as surplus. Their main food source being phytodetritus which occurs in form of aggregates but only sporadically in dense pulses at the sea-floor (see LINKE et al. 1995).

Preliminary assessments of the other experiments indicate that some benthic deep-sea foraminifera as i.e. *Tinogullmia riemanni* and *Allogromia* spp. (BERNHARD & BOWSER, 1992 and literature therein) ingest large amounts of bacteria. The proportion of different food sources at certain times during the year is still not known, which need further investigation of grazing and bioturbation of foraminifera under in situ conditions and in the laboratory.

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5.7 Microbial processes of the early diagenesis

Antje Boetius & Doris Setzkorn

Research programme

An important aspect of early diagenesis of organic matter (OM) in the deep-sea benthic boundary layer are microbial processes, since they determine the velocity of the turnover of OM as well as the chemical gradients in the sediment column (DEMING & BAROSS 1993). The first step in the utilization of POM is the extracellular hydrolysis of polymeric compounds, since only products with small molecular weight can pass through bacterial cell pores. In deep-sea sediments, the greatest part of the organic carbon is respired by the bacteria (>70%) and a smaller fraction of the organic C and N is utilized for growth (ROWE & DEMING 1985). Additionally, some of the hydrolyzed molecules may escape from uptake by the bacteria and enter the DOC pool. However, only few investigations were carried out to quantify microbial processes in the deep sea and the key factors which regulate microbial standing stock and degradation rates (LOCHTE & TURLEY 1988, LOCHTE 1992, VETTER & DEMING 1994, BOETIUS & LOCHTE 1994, 1996).

The objective of this subproject is the quantification of bacterial degradation of sinking particles and deposited organic matter as well as the investigation of the key factors regulating microbial activity in the benthic boundary layer. Field sampling and experimental studies are carried out during cruises in the Arabian Sea and the NE-Atlantic and include measurements of microbial biomass and growth, enzymatic degradation, respiration and incorporation rates of organic molecules as well as grazing rates. The results will be used to identify regional and seasonal variability of microbial processes. Further, they will be compared to the data on POC flux and remineralisation rates obtained by the geochemical investigations to improve the understanding of the processes of early diagenesis in the deep-sea benthic boundary layer.

Station works and preliminary results

Introduction

In the upper centimetres of sediment, the distribution pattern of bacteria and of hydrolytic enzymes provide indirect evidence for the level of organic matter (OM) input (DEMING & BAROSS 1993). One of the first reactions to a short-term increase in the supply of OM are changes in the production rates and the enzymatic activity adapting to the new food availability (BOETIUS & LOCHTE 1994). In addition to determination of standing stocks and activity of bacteria in the benthic boundary layer, degradation of OM is studied in shipboard experiments. Concentration and composition of added OM, oxygen content and pressure can be changed in the experiments allowing an assessment of the effects of these external parameters on degradation rates and modes (BOETIUS & LOCHTE 1996). These data will be compared to OM flux rates from sediment traps and to benthic respiration rates determined in situ.

Methodology

Samples for extracellular enzyme activities (EEA), microbial biomass and availability of specific organic compounds were collected at 41 ship stations (Tab.1). Hydrolytic activities of α -, β -glucosidase, chitinase, esterase, lipase, peptidase, phosphatase, sulphatase were measured on board using fluorescence-labelled MUF-substrates (BOETIUS 1995). For the determination of microbial biomass, bacterial numbers, cell volumes, phospholipid concentrations are measured in the home laboratory as well as availability of various organic compounds. Total microbial biomass can be estimated from measurements of phospholipid concentrations in the sediments (FINDLAY & DOBBS 1993). Bacterial biomass is measured by epifluorescence microscopy (MEYER-REIL 1968). Bacterial production rates are estimated by measuring the incorporation of ^3H -labelled thymidine and leucine into DNA and bacterial protein, respectively (KEMP 1994).

Tab. 1: List of samples. Enzyme activities were measured on board, the other samples are analysed in the home laboratory

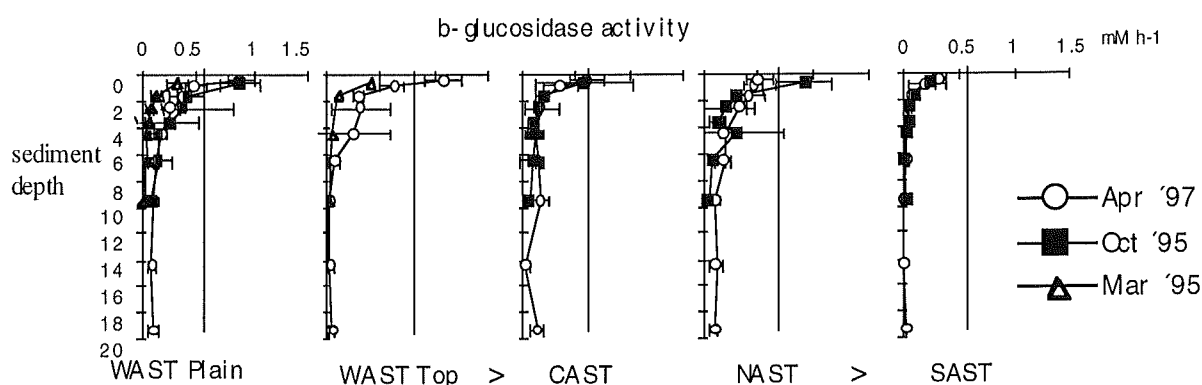
Station	MC No	Methods				
		Enzymes	Phospho- lipids	Bacterial Biomass	Bacterial Production	Organic Compounds
WAST- Plain	3			experiment		
	6					x
	7	x	x	x		
WAST- Top	8	x	x	x		
WAST- Plain	10	x	x			
	11	x			x	
WAST- Top	12	x	x			
WAST- Plain	14	x	x			
WAST- Top	15	x				
WAST- Plain	16	x				
SAST	17			experiment		
	18	x			x	
	19	x	x	x		
	20	x	x			
	21	x				x
	23	x				
WAST- Top	25	x				
	27	x	x	x		
	28	x			x	
WAST- Plain	30	x	x	x		
	31	x				
	32	x			x	
CAST	34	x			x	x
	35	x	x	x		
	36	x				
	37		x			
	38	x				
	39	x	x			
	40	x				
NAST	41	x				
	42	x				x
	43		x	x		
	44	x	x		x	
	45	x	x			
	46	x				
WAST- Top	48	x	x	x		
	49	x				
WAST- Plain	50	x	x	x	x	
WAST- Top	52	x				
WAST- Plain	53	x				
	54	x			x	

Results

Microbial enzyme activities in the sediments

In deep-sea sediments, bacterial enzymes are the primary agents of the early diagenesis of organic matter (OM). Most extracellular enzymes are produced when respective substrates become available (substrate induction), others are constantly produced but repressed in the presence of readily available nutrients. A comparison of the average activity potentials of β -glucosidase, one of the enzymes involved in the degradation of polysaccharides, at the five stations NAST, WAST-Top and Plain, CAST and SAST shows that highest microbial activities were present at WAST (Fig.1). Activity potentials at NAST and CAST were similar and about one third lower than at WAST, consistent with the differences in the average annual particle fluxes at these stations (HAAKE et al. 1993). The lowest activities were recorded at SAST.

Fig. 1: β -glucosidase activity (mM h^{-1}) in sediments of the Arabian Sea. Error bars indicate 95% confidence level of the average of 3-7 multiple corer

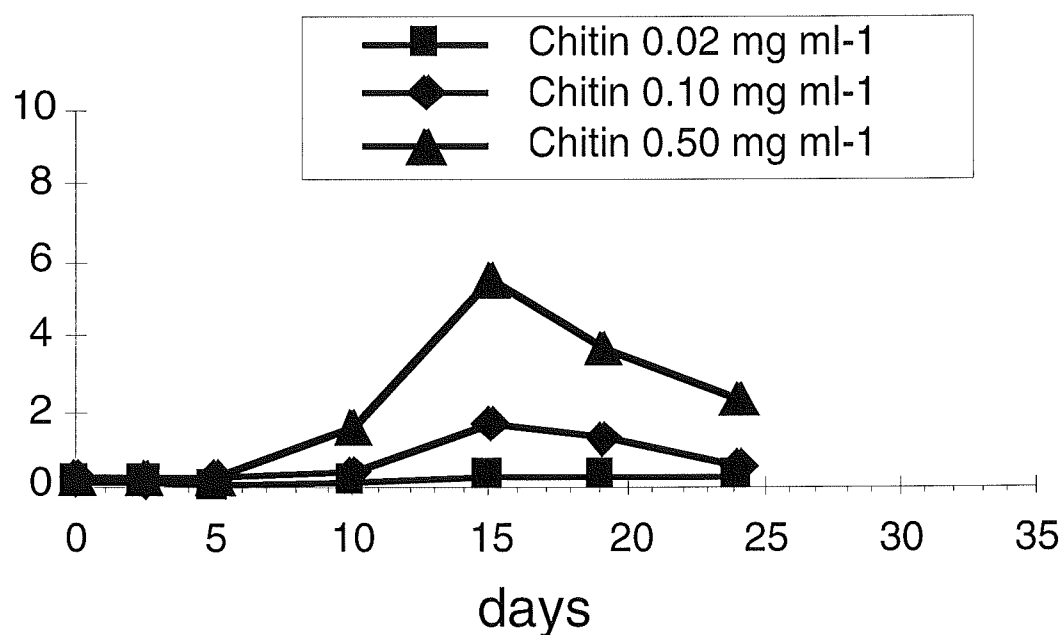


Most strikingly, the activity potentials of all enzymes measured in the deep-sea sediments of the Arabian Sea did not reflect the seasonal difference in POC fluxes after the SW-monsoon (Oct 1995) and during the oligotrophic phase during the intermonsoon (Apr 1997). In contrast, enzyme activity in the surface sediments was higher during the intermonsoon at WAST-Plain.

An experiment was performed to test whether the amount of enzymes produced by the natural microbial assemblages is relative to the supply with specific organic compounds. Three different concentrations of chitin were added to subsamples from one sediment slurry, which were incubated under *in situ* temperature and

pressure. After 10 days, activity of chitinase in the enriched samples increased substantially, depending on the amount of substrate added (Fig.2). Thus, the distribution of such substrate inducible enzymes in deep-sea sediments most likely indicates differences in the availability of their respective substrates. After 15 days, enzyme activity declined again, probably because part of the substrate was turned over as indicated by the relatively high production rates of $>2 \text{ mg ml}^{-1} \text{ d}^{-1}$.

Fig. 2: Enrichment experiment at station SAST: Chitinase activity

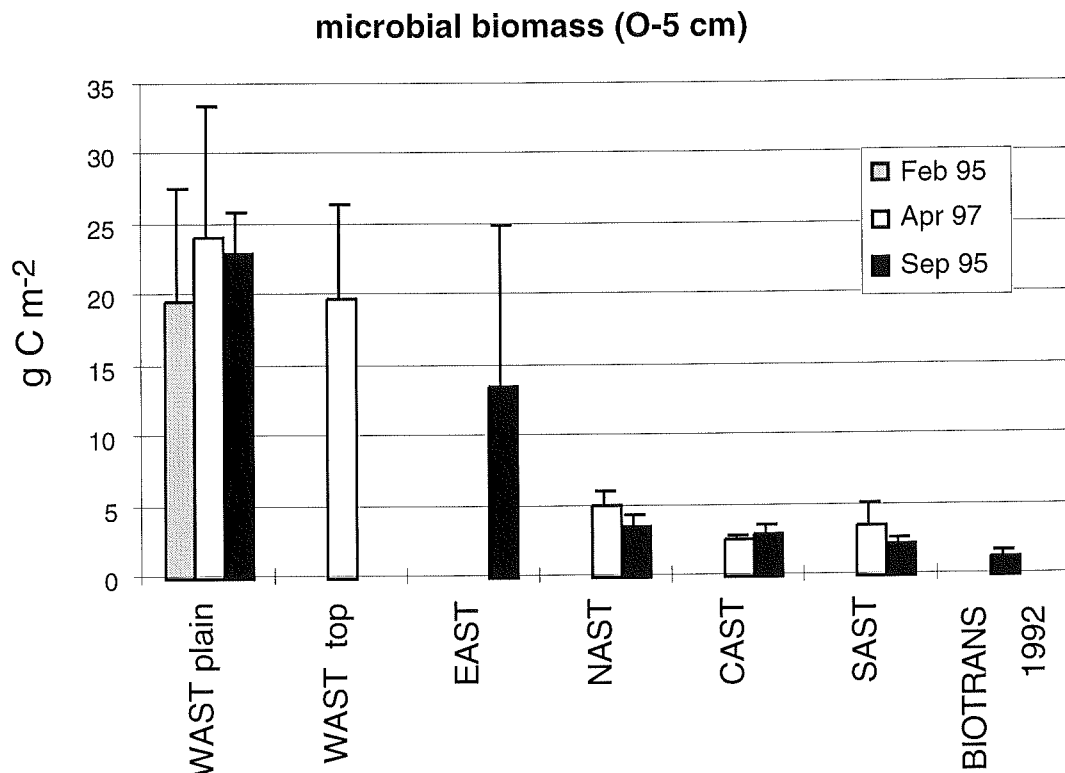


Microbial biomass in the sediments

Highest microbial biomass was detected at station WAST, stations NAST, CAST were at a similar level and SAST was slightly lower. Microbial biomass was higher at all stations in the Arabian Sea compared to the station BIOTRANS in the NE-Atlantic. Again, no significant seasonal differences were detected, but biomass in the surface sediments were slightly higher in April 1997 compared to October 1995 at station WAST-Plain, NAST and SAST.

Fig. 3: Total microbial biomass in the surface sediments (0-5 cm integrated).

Error bars indicate 95% confidence level of the average of 3 multiple corer



Conclusions

Comparing the two cruises to the Arabian Sea after the SW monsoon in October 1995 (M33/1) and in the Intermonsoon in April 1997 (SO118) we found the same trend in the regional differences with SAST as the most oligotrophic station, CAST and NAST at a medium level and WAST as a very rich station with high benthic turnover rates. This is also confirmed when the bacterial production rates at these stations are compared, which are fourfold higher at WAST compared to SAST. However, the expected seasonal decline in microbial activity and biomass in the oligotrophic Intermonsoon period was not found. Probably the NE-monsoon, which also increases particle flux to the deep-sea, did not end in February as observed in earlier years (HAAKE et al. 1993) but extended to March/April 1997.

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5.8 Benthic resuspension, bioturbation and bioirrigation

Barbara Springer & Robert Turnewitsch

Research Programmes

Principal aims of subproject 2 are to quantify particle-associated processes in the bottom nepheloid layer (BNL) and in the upper layers of the sediment. Another point of interest is diffusional and bioirrigational transport of porewater. Processes in the BNL form an essential 'intermezzo' between processes in the upper water column and processes below the bioturbated zone of the sediment (e.g. GRAF, 1989). They are important for diagenetical changes of settling and settled/resuspended particles before burial (RUTGERS VAN DER LOEFF & BOUDREAU, 1997). Recent sediment trap data from the deep Arabian Sea (LEE et al., submitted) indicate that particle fluxes do not change very much between the euphotic zone and 500 meters above bottom (mab); but between 500mab and the seafloor there was an obvious decrease in carbon flux.

A principal aim in this study is the determination of the mean residence time of resuspended particles, particulate organic carbon (POC) and particulate organic nitrogen (PON) in the BNL (< 1000 meters above bottom, mab). BACON & RUTGERS VAN DER LOEFF (1989) demonstrated that particle-associated processes in the BNL can be very dynamic and estimated the mean residence times of 25 days for resuspended particles in the BNL at the HEBBLE site (NW-Atlantic). Samples were to be taken very close to the bottom (<25 mab) to obtain more information on mechanisms of resuspension. A time series with the Bottom Water Sampler (BWS) <1 mab was to yield information on changes of the resuspension loop on time-scales of a few days.

RUTGERS VAN DER LOEFF & BOUDREAU (1997) emphasize that the resuspension loop can not be explained without information on mixing processes in the sediment. Therefore the natural radionuclides ^{234}Th and ^{210}Pb were used to determine the bioturbation intensity.

To get information on the particle and ^{234}Th flux into the BNL sediment trap samples were to be analyzed for particulate ^{234}Th in co-operation with subproject 4. The whole set of data of the composition of organic matter combined with the ^{234}Th data (sediment trap, water samples, sediment) will be used to gain information on the dynamics of the resuspension loop.

Station Works and preliminary Results

5.8.1 Investigations of the bottom nepheloid layer

Introduction

DEGENS (1989) emphasized that boundaries in general are often zones of enhanced activity and crucial for the determination of features of the adjacent compartments. Located above the seafloor, one of the major ocean boundaries, the bottom nepheloid layer (BNL) is a layer of elevated turbidity due to increased concentration of suspended matter, described as zone of increased light scattering near the sea floor (BACON & RUTGERS VAN DER LOEFF, 1989). According to BACON & RUTGERS VAN DER LOEFF (1989) local or nearby resuspension of surficial sediment accounts for this observation. Modelling results reveal the importance of the BNL for biogeochemical processes like decomposition of labile organic carbon and dissolution of calcite (RUTGERS VAN DER LOEFF & BOUDREAU, 1997). Bioturbational processes span time scales much shorter and space scales much longer than sedimentation. Bioturbation can move old particles from deeper sediment layers back to the sediment surface where they can be resuspended again. Therefore a sedimentary particle can cycle many times in the resuspension loop before being finally buried for geological timescales below the zone of bioturbation. Thus there is the possibility for diagenetic processes to affect the chemical characteristics of particles before burial. To obtain information on these links between upper water column and sediment water and sediment trap samples (in cooperation with subproject 4) for the determination of parameters characterizing the particles in the BNL (cf. Research Programmes) have been taken.

Materials and methods

All BIGSET main stations have been sampled at least once with the BWS and the CTD-rosette (Table 1 in the appendix). The sampling parameters are shown in Tables 3-14 in the appendix. Particulate ^{234}Th was also measured in samples from 4 short time sediment trap moorings in cooperation with subproject 4 (Table 2 in the appendix).

3-6 liters of water samples from the BWS (normally from 12, 20, 35 and 65 cm above bottom) and from the CTD-rosette were filtered on pre-weighed GF/F filters (previous heat treatment for 12 h at 500°C) for determination of total particulate

matter (TPM) according to LENZ (1971). Chlorophyll *a* and phaeopigments were also determined fluorometrically with a TURNER fluorometer according to SHUMAN & LORENZEN (1975). Blank filters for both methods have been measured. Additional filters will be measured for pigments with the HPLC method (in cooperation with subproject 3). For bacterial abundance and cell size determination 100ml-samples of water preserved with buffered formalin were taken which will be stained with DAPI and analyzed with an epifluorescence microscope and an image analysis system modified after THOMSEN (1991). While sampling near-bottom water with the BWS a particle camera (a camcorder with a close up lens in a pressure housing) mounted on the BWS filmed aggregates (about 20 minutes per deployment). The videotapes of the particle camera will also be analyzed with the image analysis system for amount, size classes and velocity of aggregates.

The methods for the measurement of dissolved and particulate ^{234}Th described below will be described in detail by RUTGERS VAN DER LOEFF & MOORE (submitted).

For the measurement of dissolved and particulate ^{234}Th 30 liters of water at each depth (5, 10, 25, 50, 100, 500, 1000 or 5, 10, 25, 50, 100, 250, 500 meters above bottom) were sampled with three 10-liter bottles of a CTD rosette (cf. Tables 3-14 in the appendix). The samples were drawn into PE-canisters and filtered immediately. 142mm diameter NUCLEOPORE™ polycarbonate filters with a pore-diameter of $0,4\mu\text{m}$ were used to filter the particulate matter in a pressure filtration device (pressure up to 400 mbar). The filters were folded in a reproducible way while wet, dried, wrapped in MYLAR™ foil and directly counted in a beta-counter on board. The volume of filtered water (generally about 26 liters) was determined with volumetric flasks and graduated cylinders. Blank filters have been measured. To 20 liters of filtrate $100\mu\text{l}$ of concentrated MnCl_2 , 6 drops of concentrated ammonia and $250\mu\text{l}$ of saturated KMnO_4 were added to form a MnO_2 precipitate that encloses thorium. The particles have to grow for at least 8 hours to achieve an almost 100% extraction efficiency. Then the MnO_2 precipitate was filtered on 142mm diameter NUCLEOPORE™ polycarbonate filters with a pore-diameter of $1,0\mu\text{m}$ in a pressure filtration device. The filters were half dried, folded in a reproducible way, completely dried, wrapped in MYLAR™ foil and directly counted in a beta-counter on board. Again the volume of filtered water was determined with volumetric flasks and graduated cylinders. In the new filtrate another precipitate was formed and processed like the first one in order to determine a blank for the MnO_2 -filters.

The filters have to be counted several times during the weeks following the first measurement to check whether the activity decreases with the half-life of ^{234}Th . Furthermore a standard-filter has to be counted to determine the self-absorption of the filters. The profiles shown in this report are not corrected for these values yet but since all samples have been treated the same way the profiles can be compared with each other.

Results and conclusions

All samples of the BWS and the deep CTD-rosette are still in the progress of analysis. First results suggest that at WAST-Top and WAST-Plain the amount of TPM in the near-bottom water column was highest during the first days of the cruise (more than 1 mg/g) supporting the hypothesis of a recent sedimentation event. Then TPM decreased and remained in the same range for all stations (data still have not been corrected for blank values).

In order to obtain a first impression of the profile shapes of dissolved and particulate ^{234}Th WAST-Top and SAST have been sampled with a small spatial resolution. It became obvious that the profiles become more or less asymptotic 500 meters above bottom (mab). Therefore the following profiles were only sampled up to 500 mab. All profiles of dissolved ^{234}Th show a reduced activity below 100 mab (Fig.1). Near the seafloor stations SAST, CAST, NAST and WAST-Top show an increase in particulate ^{234}Th activity (Fig.2). Since the activity of dissolved ^{234}Th is much higher than the activity of particulate ^{234}Th the profile of total ^{234}Th is determined by the former. These results suggest that there is radioactive disequilibrium between ^{234}Th and its parent ^{238}U which agrees with the results of BACON & RUTGERS VAN DER LOEFF (1989). But for a final proof self-absorption of the filters has to be determined. Radioactive disequilibrium is the basis for the calculation of the residence time of resuspended particles in the BNL.

A new phenomenon is the minimum of dissolved ^{234}Th in the WAST-Plain, NAST and CAST profiles and the maximum of particulate ^{234}Th in the WAST-Top, SAST and CAST profiles (Fig.1 & 2). A corresponding pattern was detected in high-resolution profiles from one of the BIGSET stations in the NE-Atlantic in July 1997. A reason for these shapes of the profiles might be a combination of resuspension and colloidal effects. The other parameters measured in the BNL and further, more detailed evaluations will help to understand this phenomenon.

For WAST-Plain a short time series for the ^{234}Th flux has been determined (Fig.3). A maximum was detected in the middle of April. At the beginning of May the flux has decreased to the lowest value measured at WAST-Plain on this cruise. In contrast to the flux measured at CAST, that fits the trend at WAST-Plain, the flux measured at NAST is comparatively low (Fig.3).

5.8.2 Natural radionuclides as tracers for bioturbation

Introduction

To achieve a broad understanding of the near-bottom boundary layer sedimentary mixing was another principal topic of the cruise. The mixing intensity can be estimated through profiles of the natural radiotracers ^{234}Th (for mixing on timescales of up to 100 days) and ^{210}Pb (for mixing on timescales of up to 100 years) assuming a steady state situation for these nuclides (e.g. SMITH et al., 1993). Furthermore the ^{234}Th dataset (samples from CTD-Rosette, sediment traps, sediment) will yield comprehensive information on short-time dynamics of particles in the near-bottom boundary layer. ^{210}Pb profiles from cruise M33/1 show regional differences between the BIGSET main stations. On cruise SO118 both the main stations and the intermediate stations were sampled for ^{210}Pb to evaluate these findings and to achieve a better spatial resolution.

Materials and methods

All sediment samples for the measurement of the natural radionuclides ^{234}Th and ^{210}Pb were taken with a multiple corer (10cm core diameter).

For ^{210}Pb the main stations WAST-Top, WAST-Plain, SAST, CAST and NAST and the intermediate stations SAST-WAST, WAST-CAST and NAST-WAST have been sampled (Tab. 3 in the appendix). At least two sediment cores per station were sectioned vertically immediately after the retrieval of the multiple corer. The whole cores were sliced: from 0-3cm in 0.5cm steps, from 3-10cm in 1cm steps, from 10cm down to the deepest parts in 2cm steps. The slices were sealed in tubular foil and stored frozen. For methodological reasons (reaching radioactive equilibrium between ^{210}Pb and its granddaughter ^{210}Po , which is determined with an alpha-spectrometer) the samples have to be stored for about one year before being processed (acid digestion, plating) and measured.

The main stations WAST-Plain, CAST and NAST were sampled for ^{234}Th (two cores per station): Fluff layer and/or 0-0.5cm, 0.5-1cm, 1-1.5cm, 1.5-2cm, 3-4cm. At WAST-Top and SAST only the fluff layer was sampled (Table 3). The sediments were subsampled with cut off syringes, the subcores were sectioned vertically and processed according to ALLER & COCHRAN (1976) and ANDERSON & FLEER (1982): acid leaching, co-precipitation, ion exchange columns and electroplating. The ^{234}Th activity was measured with a beta-counter. Raw data have to be corrected for extraction and detector efficiency at GEOMAR. ^{229}Th was used as a spike. Furthermore the sedimentary activity of its parent ^{238}U has to be measured at GEOMAR in order to calculate excess ^{234}Th (that is introduced into the sediment by settling particles).

Results and conclusions

For methodological reasons there are no results for sedimentary ^{234}Th and ^{210}Pb yet (cf. Materials and methods). However some ^{234}Th raw data from the fluff layer show high activities supporting the hypothesis that very young material from the watercolumn had reached the seafloor shortly before sampling.

On cruise M33/1 stations WAST, NAST, SAST and EAST showed regional differences in ^{210}Pb : The steepness of the profiles decreased in the ranking of WAST, EAST, NAST, SAST. This finding implies that bioturbation intensity increases in this ranking. In the upper 2-3cm ^{210}Pb activities span much larger ranges than in deeper sediment layers indicating an increased horizontal patchiness in the upper sediment layers. Since ^{210}Pb bears information on processes taking place on timescales of about 100 years, horizontal patchiness can only be maintained if horizontal mixing acts on a timescale >100 years. But there is evidence that horizontal mixing occurs on timescales of several days up to a few weeks (WHEATCROFT ET AL., 1989). This suggests that the assumption of a steady state situation for ^{210}Pb might be incorrect. This would have consequences for the biodiffusive calculation of bioturbation coefficients (D_b). The new samples will help to evaluate this problem more closely.

5.8.3 *In situ* experiments on bioirrigation and bioturbation

Besides natural radiotracers artificial tracers can be used to quantify bioturbation. For this cruise an *in situ* experiment with fluorescing microspheres of different size classes was designed in cooperation with subproject 5. The microspheres were to be injected into incubation chambers of the GEOMAR Lander.

Together with the microspheres a bromide solution for the quantification of bioirrigation (MARTIN & BANTA, 1992; SAYLES & MARTIN, 1995) was to be injected into the incubation chambers of the lander.

Unfortunately there were problems with the syringe system during the first experiment at WAST-Plain (station 15, Free-Falling Respirometer (FFR) 1, 16°15.02'N, 60°15.95'E) not allowing the syringe to inject the fluid. Thus the experiment failed.

At SAST (station 28, FFR 3, 10°00.96'N, 65°00.19'E) the second experiment failed as well because the lander could not be retrieved.

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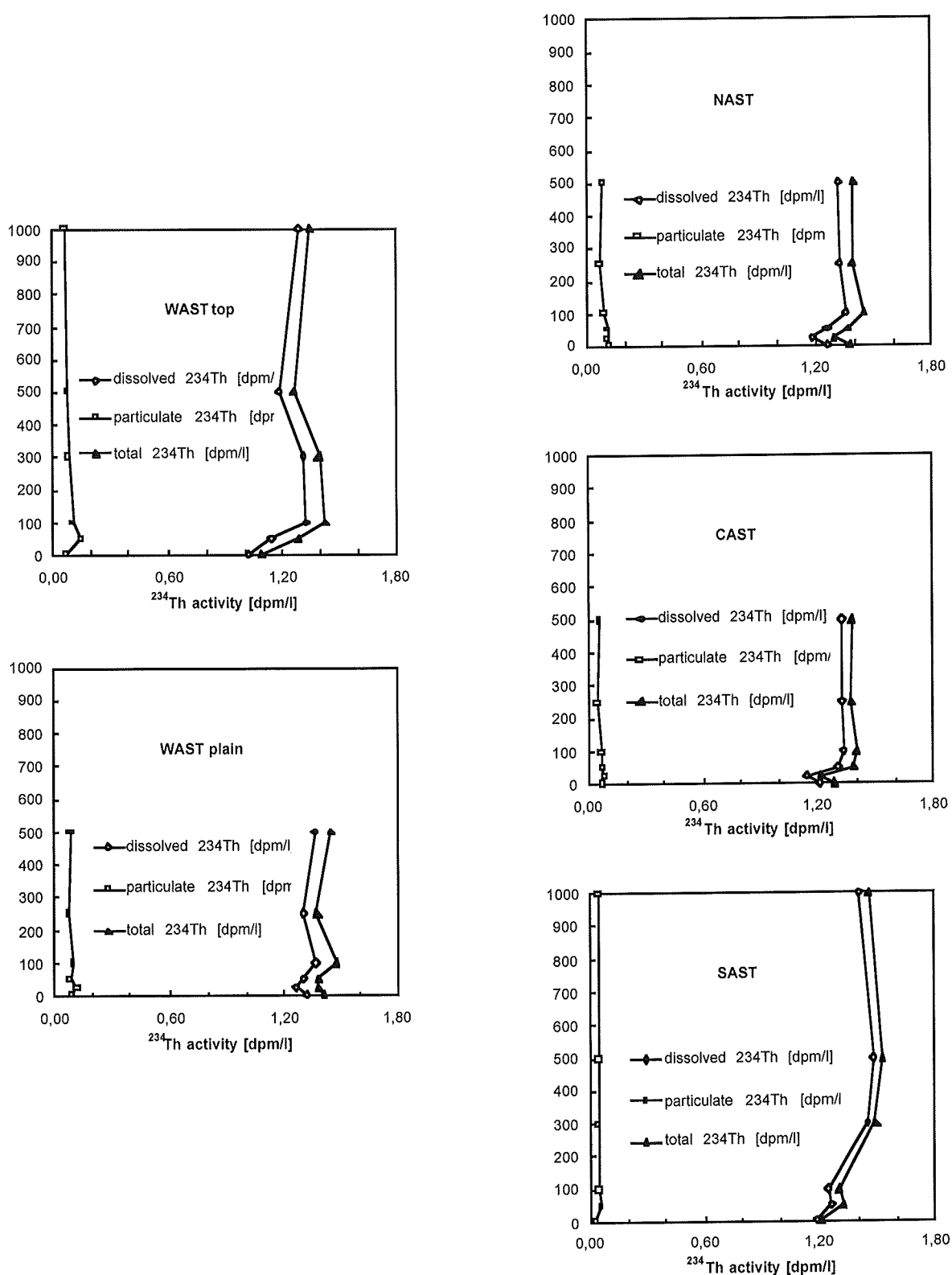


Fig. 1: Profiles of particulate, dissolved and total ^{234}Th at the BIGSET main stations and WAST-Top. The data are not corrected for selfabsorption of the filters.

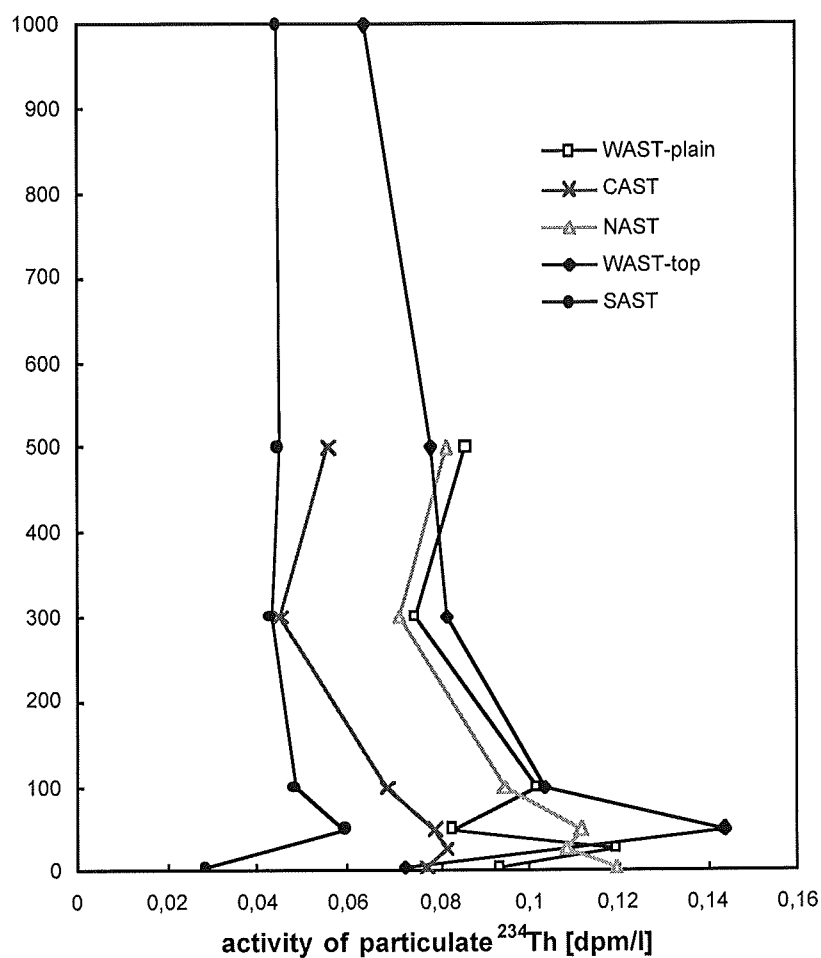


Fig. 2: Activity of particulate ^{234}Th at the BIGSET main stations and WAST-Top.
The activities are not corrected for selfabsorption of the filters.

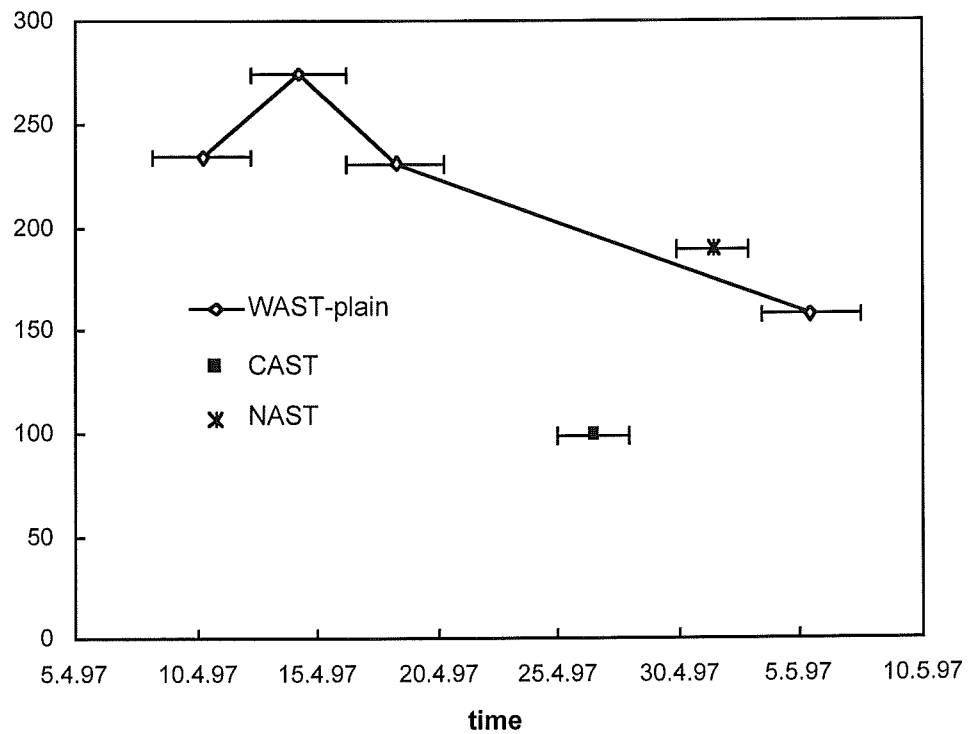


Fig. 3: Fluxes of ^{234}Th in short time sediment trap moorings on the BIGSET main stations WAST-Plain, CAST and NAST. The sampling intervals at WAST have been 4 days, at CAST and NAST 3 days (indicated by the horizontal bars). The activities are not corrected for selfabsorption of the filters.

5.9 Oxygen consumption of the sediment community

Ursula Witte, Frank Appel & Olaf Pfannkuche

Measurements of sediment oxygen demand (SOD) during METEOR Cruise M 33/1 have confirmed the ranking of the stations according to the sedimentation regime: SOD in October 1995 following the SW-monsoon was highest at WAST, somewhat lower at EAST and CAST and considerably lower at SAST. To our surprise, it was even higher at WAST in April 1997 than in October 1995. This confirms the high sediment content of CPE, ATP (see 5.12) and is probably due to a strong, prolonged NE-monsoon (T. RIXEN, pers. comm.). Due to loss of the Landersystem during the deployment at SAST no data for the other stations exist.

5.10 Macrofauna and megafauna abundance

Ursula Witte, Nicole Aberle & Wolfgang Queisser

Small size class biota can respond rapidly to pulsed input of POM, and this rapid response is mirrored e. g. by increased exoenzymatic activities and enhanced SOD. Larger organisms with longer life spans integrate environmental conditions over longer time periods. As expected, macrofauna samples taken during M33/1 revealed very high macrofauna standing stock at WAST, but contrary to SOD, CPE and exoenzymatic activities, there was no gradual decrease of macrofaunal abundance following the ranking of stations established above (WAST > NAST > CAST > SAST). Rather, there was a contrast between WAST with very high standing stock opposite to the other basin stations CAST, NAST, EAST and SAST with extremely low macrofaunal abundances. In addition, macrofauna below 1 cm sediment depth at WAST was dominated by ostracods, which were almost absent from all other stations.

During SO 118, bottom photographs were taken and video surveys conducted using the EXPLOS system in order to investigate the abundance patterns of megafauna organisms and their traces („Lebensspuren“ Tab. 1 and 2).

Tab. 1: Abundance of **Megafauna** determined from sea floor photographs (data base appr. 300/3500/m²)

no. of ind. / 1000 m ⁻²	WAST	NAST	CAST	SAST
Poriferans	_*	16	32	14
Pennatulids	_*	_*	_*	4
Ophiuroids	100	_*	29	_*
Asteroids	_*	6	_*	_*
Holothurians	_*	70	_*	_*
Natant decapods	_*	6	_*	6

*: not present

Tab. 2: Abundance of **Lebensspuren** determined from sea floor photographs (data base appr. 300/3500 m⁻²)

no. of lebensspuren / 1000 m ²	WAST	NAST	CAST	SAST
spoke-burows	_*	140	96	340
tracks:				
'caterpillar'	_*	_*	++	_*
'littorina-type'	_*	+	+	_*
spiral faeces	_*	930	+	_*
other faeces	+	+++	_*	_*

*: not present

Opposite to the macrofaunal abundance, patterns of megafauna occurrence show a different picture between WAST and the other stations. WAST is very poor of megafauna. Only brittle stars were found and traces of larger mobile epifaunal organisms are almost absent. At all other stations, despite the great differences in vertical flux, megafauna and/or traces from several taxonomical groups and feeding types were found. THURSTON et al. (1994) found sharp contrasts between megafaunal colonisation patterns on the Madeira (MAP) and Porcupine Abyssal Plain and related these to the rapid build up and downward transport of large macroscopic aggregates that occurred at PAP but not at MAP. However, none of our stations in the Arabian Sea is distinguished from the others by the absence of aggregates or fluff. Nevertheless, it can be speculated that the striking difference in

colonisation patterns of larger organisms might be related to the quality of the settling material. WAST is situated beneath an area of strong upwelling, resulting in a stronger silicate flux. The presence of diatoms in sediment samples at WAST but not at the other basin stations confirming this finding (YOUNG & KINDLE 1994). DINGLE (1995) described the occurrence of very high ostracods abundances beneath upwelling areas off West Africa.

However, further investigations need to confirm that the colonisation patterns observed are not caused by unusual seasonal variations in megafauna abundance, and detailed analysis of vertical particulate flux have to identify possible controlling factors.

5.11 Scavenging communities in the deep Arabian Sea: observations by baited camera

Ursula Witte, Nicole Aberle, Frank Appel & Wolfgang Queisser

Introduction

It has long been speculated that large food falls might add substantially to deep-sea benthos nutrition (e. g. ISAACS 1969; DAYTON & HESSLER 1972; STOCKTON & deLACA 1982). Evidence for their existence came from direct observation (e. g. HEEZEN & HOLLISTER 1971; JANNASCH 1978) as well as captures of fish that contained beaks from squids larger than the fish (PEARCY & AMBLER 1974). Baited-camera deployments demonstrated a variety of benthopelagic organisms like ophiuroids, shrimp, amphipods, gastropods and several groups of demersal fish to be attracted to bait placed on the sea floor (SMITH 1985). A specialised, highly mobile scavenging fauna dominated by macrourid fish and lysianassid amphipods was described for the North Atlantic and Pacific Ocean. (CHRISTIANSEN 1996; HARGRAVE 1985; HARGRAVE et al 1994, 1995; PRIEDE et al. 1994.) In the Northern hemisphere the macrourid *Coryphaenoides armatus* dominates the abyssal demersal scavenging niche and is invariably the first to arrive at bait very shortly after exposure (PRIEDE et al. 1991) in such quantities that even large food falls such as dolphins are consumed within days (JONES, pers. comm.)

Our experiments carried out during SO 118, however, indicate the existence of a completely different scavenging community.

Material and methods

Two large food fall experiments were carried out at stations, WAST-Plain (4040 m) and WAST-Top (1900m). Both are situated in the western Arabian Sea where annual maxima of primary productivity in the Arabian Sea occur during SW-monsoon and benthic activity is several times higher than found for other deep-sea regions.

The Lander frame used for benthic chamber deployments was equipped with a BENTHOS deep-sea camera 372 and a BENTHOS 382 deep-sea flash. The camera was oriented vertically above the bottom and photographed an area of 1.15 m² of seafloor. As bait, two sharks that had been caught in the area a few days prior to the experiments were used. Both were stored at 6°C until deployment. At WAST-Plain, a white-fin shark of 1.6 m length and 29 kg weight was deployed for 11 days, while the camera took color photographs at intervals of 20 min.

At WAST-Top, a smaller shark of 1 m length was deployed for 4 days and photographed at intervals of 10 min. The skin of both sharks was shed at the back to facilitate odour dispersal and access for scavenging organisms and the carcasses were covered by a net to ensure that remains of the carcass could be recovered completely and that large scavengers could not tear the carcass or parts of it out of view of the camera. Upon retrieval of the gear, the sharks were weighed, photographed and then carefully dissected. All organisms found were collected and stored in 5% buffered formalin for taxonomic identification.

Results

Scavenger community

Both carcasses were retrieved fairly intact and had lost only a few kg of weight. At WAST-Plain (Fig.1, Tab.1), three groups of megafaunal organisms were observed in the vicinity of the carrion: benthic fish of the family Zoarcidae, decapod shrimp and lysianassid amphipods. Shrimp and amphipods were present after less than 1 h, reaching peak densities after 21 h. Afterwards they occurred rarely, probably discouraged by the increasing number of fish. First zoarcids were present after 5 h, the peak density of 69 Ind. was reached after 57 h.

At WAST-Top, stone crabs and rattails were the major scavenging organisms, three individually identifiable stone crabs sitting alternatingly on or near the carcass for most of the observation period. The first rattail appeared after 50 min and single

macrourids occurred steadily on appr. 1/3 of all photographs until the end of the observation period. Additionally, a zoarcid, a member of the family Chimaeridae, and a specimen of an as yet unidentified fish species appeared once.

Tab.1: Occurrence of scavengers as observed on photographs of 2 shark carcasses placed on the seafloor in the deep Arabian Sea

	WAST Plain 4040m				WAST Top 1900m			
	time of			maximum density / photograph	time of			maximum density / photograph
	first occurrence	last occurrence	peak density		first occurrence	last occurrence	peak density	
Lysianassidae	40 min	5 d	21 h	9				
Zoarcidae	5 h	5d 9h	2d 9h	68	3 h	21 h	-	1
shrimp (Aristeidae)	20 min	5d 9h	21 h	8				
Macrouridae					50 min	3d 8h	2d 1h	4
stone crab					2 h	3d 8h		2

Background megafauna community

Comparison with data on background megafauna community composition clearly indicate that none of the dominant megafauna organisms (shrimp and brittle stars at WAST-Top, brittle stars at WAST-Plain) was attracted by the bait (Tab.2).

Tab.2: Abundance of Megafauna in the background community at 1900 and 4040 m wd determined by photographic and video surveys

no. of Ind. per 1000m ²	WAST Top still camera (340 m ² covered)	WAST Top Video (1800 m ² covered)	WAST Plain still camera (280 m ² covered)	WAST Plain Video (3500 m ² covered)
shrimp (Aristeidae)	114	110	0	1
brittle stars	21	22	100	100
Macrourids	6	21	0	0
Zoarcidae	0	0	0	1

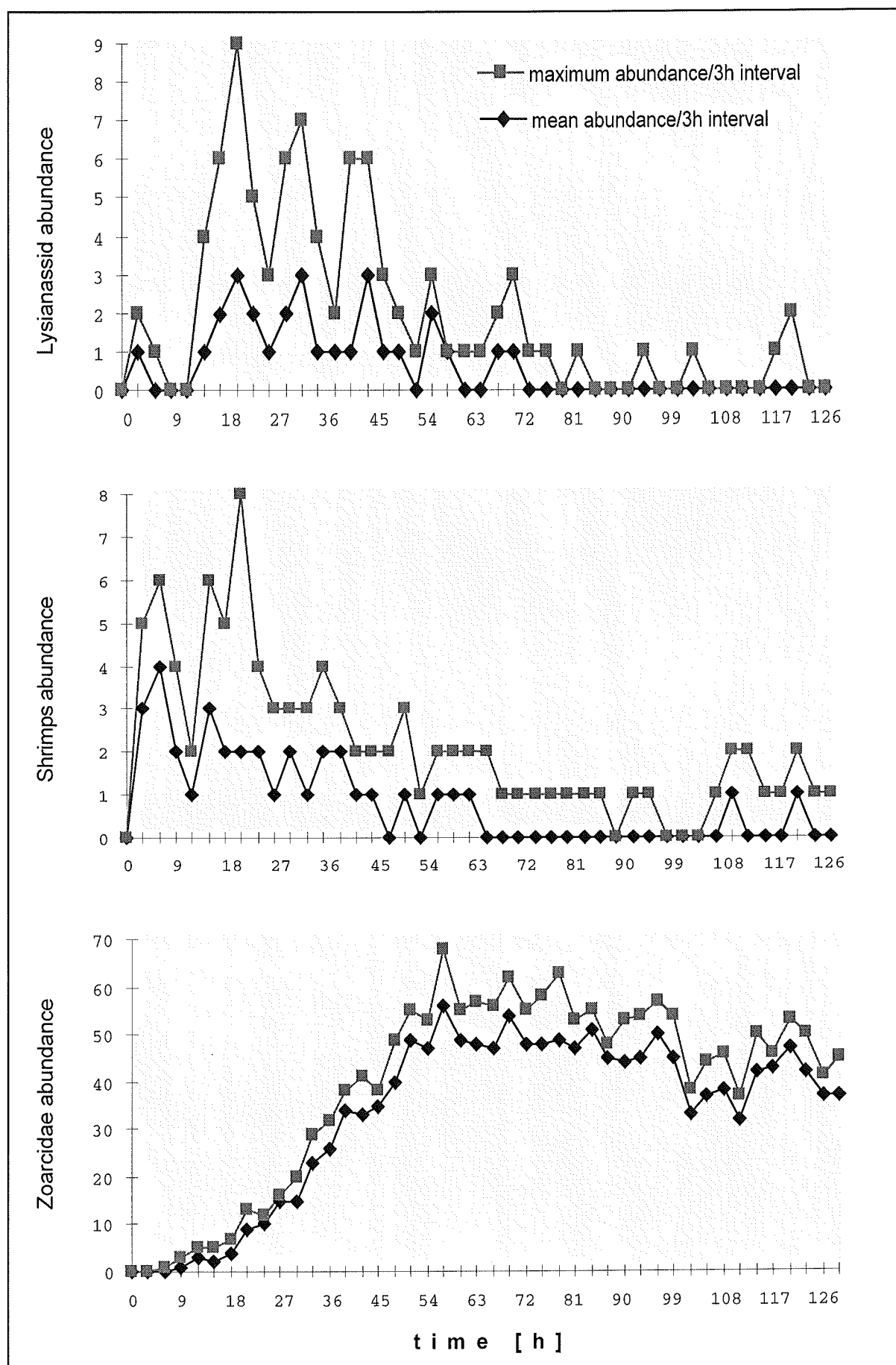


Fig.1: Abundances of scavengers at shark carcass at WAST Plain

Conclusions

- In the northern Indian Ocean, typical deep-sea scavengers that quickly assemble at bait (Macrouridae and Lysianassidae) are rare. Instead, the bait-attending scavenging community is dominated by zoarcid fish and decapods that reach peak densities at bait only after 1-2 days.
- The food uptake rate of the large number of scavengers assembled was surprisingly low: whereas a dolphin carcass at abyssal depth in the North Atlantic was consumed within days (JONES pers. comm.), only a small proportion of the carrion was consumed within 11 days at WAST-Plain.
- What is the reason? Large food falls seem to be rare to support a specialised fauna even under the situation of a high productivity in surface. A major characteristic of deep-sea scavenging amphipods is the capability to store disproportionately large meals (DAHL 1979; HARGRAVE 1994, 1995). STOCKTON & deLACA (1982) propose that deep-sea scavenging communities may be subdivided regionally according to the inter-food-fall distance, species with larger traveling and food storage capacities maintaining themselves at lower food-fall densities than species with lower capacities. The eelpouts and decapods attracted to bait in this study are probably generalist feeders that took the chance but do not depend on such large food falls.
- However, further investigations need to clarify why macrourids are common at WAST-Top but absent at WAST-Plain whereas eelpouts dominate the deep station and are of minor importance at WAST-Top.

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5.12 Biochemistry of Biogenic sediment compounds

Olaf Pfannkuche, Anja Kähler & Tina Treude

Introduction

Biogenic sediment compounds are applied as proxies for a variety of biological parameters such as input of phytodetritus into the sediment, benthic biomass and benthic activity. As the analyses are based on relatively small volumes of sediment (1cm³ respectively 3.4cm³ sediment volume per analysis) the measurements mainly provide information on the small size classes of the benthic size spectrum which include meiobenthos (size class 500-30µm), nanobenthos (size class 30-2µm) and bacteria (size class ≥2µm). In comparison to macrofauna biomass the biomass of the small benthic size classes clearly dominates total benthic biomass in the deep sea (PFANNKUCHE 1993, PFANNKUCHE & SOLTWEDEL in press). The predominance of small organisms in various deep-sea habitats was also stressed by GOODAY *et al.* (1992), who reported that 50% or more of the eukariotic biomass belonged to the foraminiferans, whereas LOCHTE (1992) found that about 80-90% of total benthic biomass in the outer Western European Basin was formed by bacteria. From their modes of reproduction bacteria and protozoans represent the most reactive potential of benthic communities. Bacteria and protozoans can multiply in hours and can also activate resting spores. Thus it is the small size spectrum of benthic organisms which can respond very quickly to any perturbations e.g. sedimentation pulses of particulate organic matter (POM). BOETIUS & LOCHTE (1994, 1996) could demonstrate the short times of response by deep-sea bacteria to POM input. Deep-sea bacteria increased the production of specific exoenzymes, which is the primary step of breakdown of polymeric compounds, within several days. This process necessitates a step-up of metabolic activity. Such a metabolic reaction could be shown by rising ATP levels in deep-sea benthic foraminifera following food supply (LINKE 1992) and by the increase in ATP concentrations in sediment samples less than 9 days after deposition of faecal pellets at a bathyal site (GRAF 1989). If a POM pulse is strong enough it can also result in an increase of small size scale biomass (PFANNKUCHE *et al.* in press). Any short term changes of benthic activity and biomass will therefore be mirrored by the small biota which can be demonstrated by the measurement of specific biogenic compounds.

5.12 Biochemistry of Biogenic sediment compounds

Olaf Pfannkuche, Anja Kähler & Tina Treude

Introduction

Biogenic sediment compounds are applied as proxies for a variety of biological parameters such as input of phytodetritus into the sediment, benthic biomass and benthic activity. As the analyses are based on relatively small volumes of sediment (1cm^3 respectively 3.4cm^3 sediment volume per analysis) the measurements mainly provide information on the small size classes of the benthic size spectrum which include meiobenthos (size class $500\text{-}30\mu\text{m}$), nanobenthos (size class $30\text{-}2\mu\text{m}$) and bacteria (size class $\geq 2\mu\text{m}$). In comparison to macrofauna biomass the biomass of the small benthic size classes clearly dominates total benthic biomass in the deep sea (PFANNKUCHE 1993, PFANNKUCHE & SOLTWEDEL in press). The predominance of small organisms in various deep-sea habitats was also stressed by GOODAY *et al.* (1992), who reported that 50% or more of the eukariotic biomass belonged to the foraminiferans, whereas LOCHTE (1992) found that about 80-90% of total benthic biomass in the outer Western European Basin was formed by bacteria. From their modes of reproduction bacteria and protozoans represent the most reactive potential of benthic communities. Bacteria and protozoans can multiply in hours and can also activate resting spores. Thus it is the small size spectrum of benthic organisms which can respond very quickly to any perturbations e.g. sedimentation pulses of particulate organic matter (POM). BOETIUS & LOCHTE (1994, 1996) could demonstrate the short times of response by deep-sea bacteria to POM input. Deep-sea bacteria increased the production of specific exoenzymes, which is the primary step of breakdown of polymeric compounds, within several days. This process necessitates a step-up of metabolic activity. Such a metabolic reaction could be shown by rising ATP levels in deep-sea benthic foraminifera following food supply (LINKE 1992) and by the increase in ATP concentrations in sediment samples less than 9 days after deposition of faecal pellets at a bathyal site (GRAF 1989). If a POM pulse is strong enough it can also result in an increase of small size scale biomass (PFANNKUCHE *et al.* in press). Any short term changes of benthic activity and biomass will therefore be mirrored by the small biota which can be demonstrated by the measurement of specific biogenic compounds.

Sediment sampling and analysis

Sediment samples with a multiple corer (BARNETT et al. 1984) were taken at all five main stations (WAST-Top, WAST-Plain, SAST, CAST, NAST) and at the intermediate stations. At each station a minimum of three individual multiple corer hauls were subsampled and analysed. Randomly selected multiple corer tubes were subsampled with small piston corers of 1.1cm or 3.46cm cross diameter. Three replicates for each parameter were taken from one multiple corer cast. Sediment samples were analysed in 0.5cm intervals for the sediment layer 0-2cm and in 1cm intervals down to 10cm depth followed by 2cm intervals to a maximum of 30cm depth. Samples for the following sediment analyses were taken (measurements marked with an asterisk were carried out in the ships laboratory) all other determination will be carried out GEOMAR:

Measurements of biomass

- adenylates (ATP+ADP+AMP)
- DNA

Measurements of metabolic activity

- electron transport system activity (ETS, respirative potential)*
- ATP
- hydrolysis rates of fluorescein diacetate (activity of bacterial exoenzymes)*

Measurements of plant pigments

- chlorophyll-a and pheopigments (fluorimetric)*
- pigments (HPLC)

other measurements

- proteins*
- C_{org}, N_{org}
- water content
- grain size

Preliminary results

Concentrations of sediment-bound pigments were measured to obtain general information of the sedimentation patterns and distribution of plankton-derived phytodetritus from the euphotic zone. Chloroplastic pigments are operationally

defined as chloroplastic pigment equivalents, CPE representing the sum of chlorophyll *a* and pheopigments.

Our working hypothesis for cruise SO118 was based on the existence of a sedimentation minimum to the sea floor due to a reduced surface production during the intermonsoon period. This assumption was based on the sedimentation long term trends of trap data from WAST, CAST and EAST by HAAKE et al (1993). However, an optical inspection of the first multiple corer haul at WAST showed a substantial detritus layer of brownish colour on top of the sediment. A clear sign of a recent or ongoing sedimentation of detrital material. Our CPE measurements confirmed the occurrence of a recent sedimentation pulse. Figure 1 shows the CPE content at all stations of cruise SO118 in comparison to results obtained in October 1995 (METEOR 33). A period when the sea floor was assumed to receive the annual maximum of POM deposition. For WAST, data from March 1995 (METEOR 31) are also presented in Figure 1. At all SO118 stations investigated CPE contents integrated for 0-5cm sediment depth were higher than in October 1995. The difference was significantly pronounced in the top centimetre of the sediment which clearly indicates a recent sedimentation pulse of POM. At WAST values from March 1995 were even higher than in April 1997 with October 1995 values being the lowest. The data from WAST and NAST give evidence that, in contrast to the period 1986-1992 reported by HAAKE et al. (1993) with maximum sediment trap fluxes during the SW-monsoon (Aug./Sept.), during our BIGSET investigations since 1995 the flux generated by the NE-monsoon produces similar or even higher POM pulses to the sea floor.

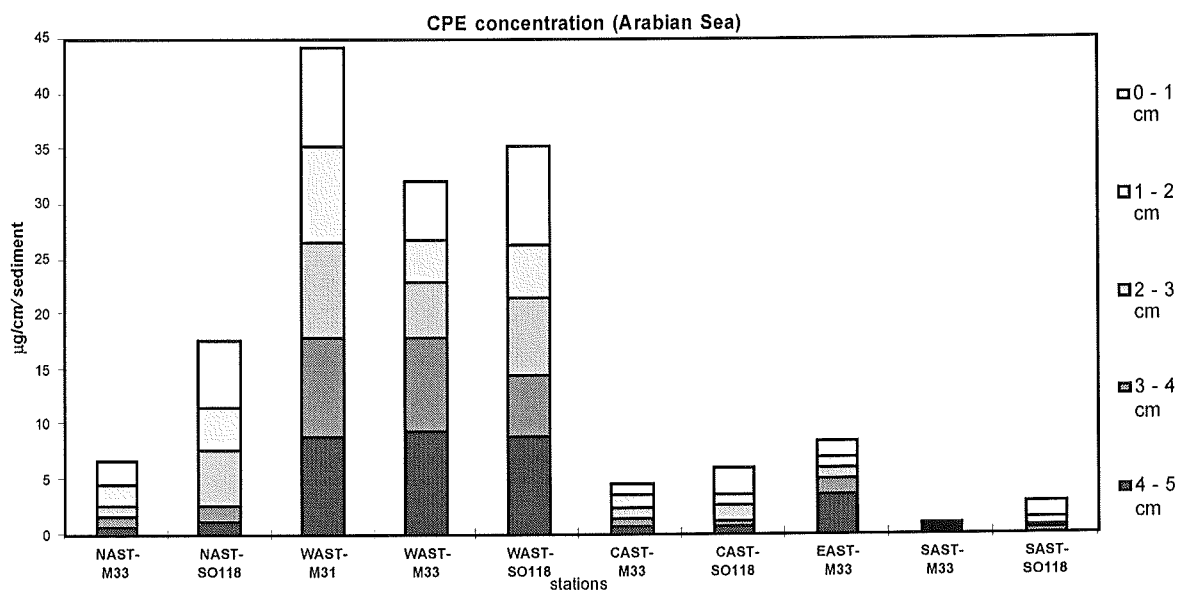


Fig 1: CPE contents for centimetres 0-5 of the sediment column. Data from SO118 in comparison to data from October 1995 (M33) and March 1995 (WAST only, M31).

At WAST we had the opportunity to follow the sedimentation pulse with a time series sampling over a period of four weeks (Fig 2). Significant changes could only be observed in the first 25mm of the sediment. Between April 5 and April 7 CPE values increased from $3.4\mu\text{g}/\text{cm}^3$ to $5.8\mu\text{g}/\text{cm}^3$. Two days later (April 9) the values still increased to $7.1\mu\text{g}/\text{cm}^3$ indicating that the sedimentation pulse still maintained. Eleven days later (April 20) CPE contents decreased to $5.4\mu\text{g}/\text{cm}^3$ but were again at $6.9\mu\text{g}/\text{cm}^3$ after 14 days (May 4). Below 25mm values decreased until 1.75cm depth. This part of the sediment is still supplied with oxygen and nitrate. Below 2 cm CPE values increased again due to accumulation in combination with small degradation rates under anoxic conditions

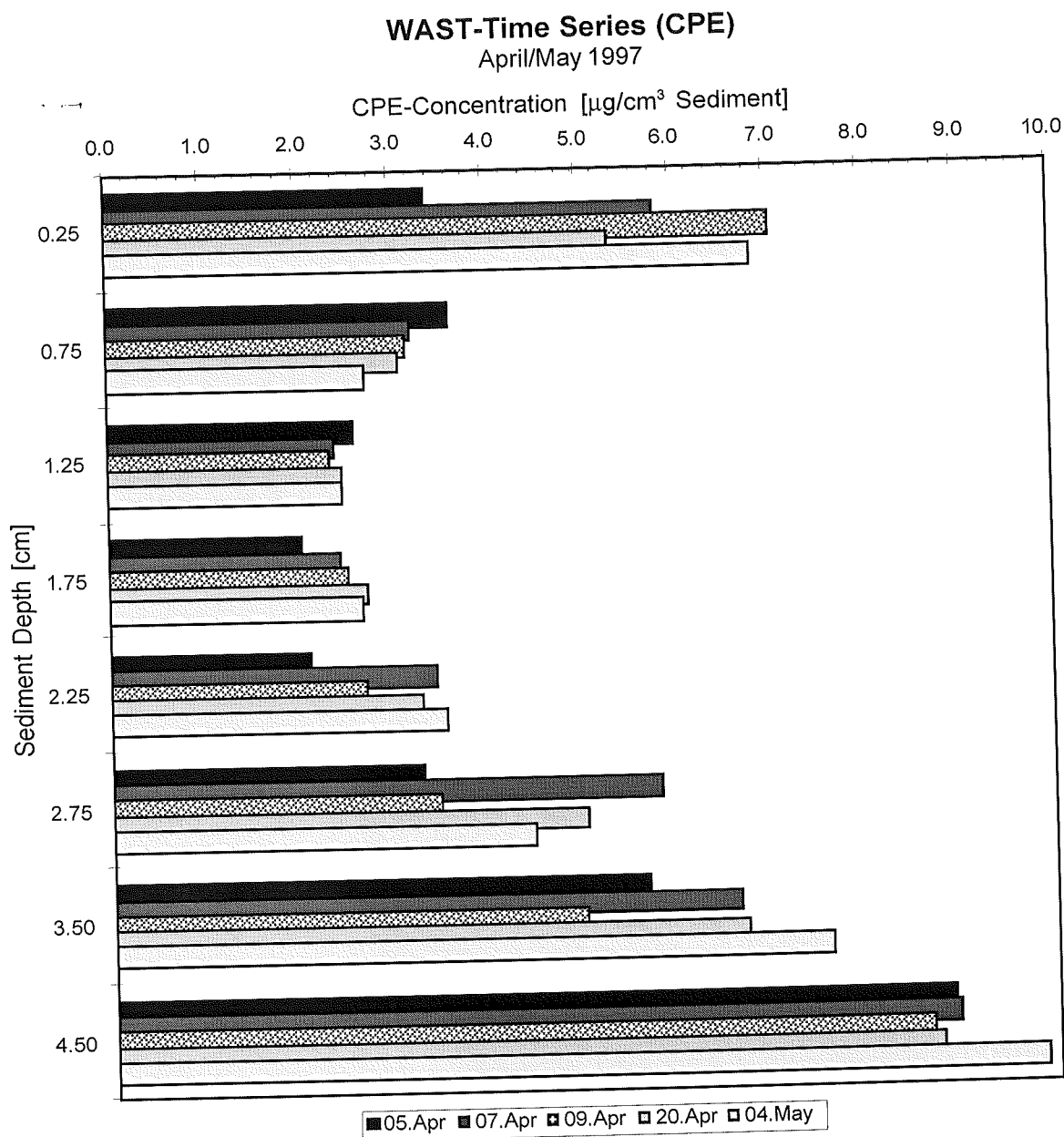


Fig 2: CPE contents for centimetres 0-5 of the sediment column at the time series station WAST. (Data from SO118, 5.4. - 4.5. 1997)

Bacterial exoenzymatic activity was measured as hydrolytic activity with the fluorogenic substrate (Fluorescein-diacetate, FDA). FDA is cleaved unspecifically by several different hydrolytic enzymes, particularly esterases. Therefore this parameter is used as a general indicator of changes of general hydrolytic activity. As the substrate is added to the sediment slurry in saturating concentrations,

previously determined by concentration experiments, the maximal hydrolytic potential is determined by this measurement. Figure 3 shows the hydrolytic activity at all stations of cruise SO118 in comparison to results obtained in October 1995 (M33). At all SO118 stations hydrolytic activity was clearly increased in comparison to the values determined in October 1995. Major changes could be attributed to centimetres 0-3 of the sediment column. In contrast to CPE differences in hydrolytic activity were smaller between the stations. Activity at SAST was found on a very high level.

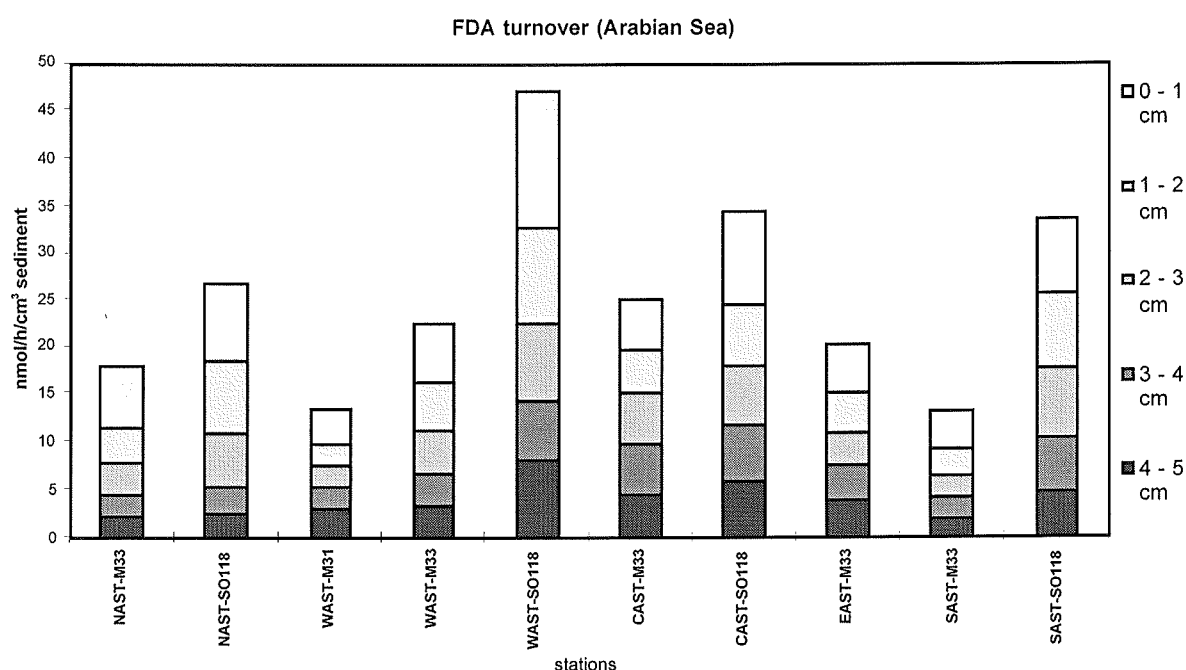


Fig 3: FDA turnover for centimetres 0-5 of the sediment column. Data from SO118 in comparison to data from October 1995 (M33) and March 1995 (WAST only, M31).

Hydrolytic activity at the WAST time series station (Fig. 4) was largest in the top 25mm of the sediment. Activity increased in the first week and showed quite inhomogenous values after 4 weeks respectively 4.4 weeks, when the lowest respectively highest activity was measured. However, a closer look on the different replicate samples showed a much larger variability between the replicates after 4 weeks than for the period April 5-20. This can be referred to a more inhomogenous

distribution of the detrital material which can be caused by the repacking and a more patchy distribution of the aggregates. Below 25mm hydrolytic activity decreased but still remained on high level down to 5cm depth. Activity in the deeper sediment horizons dropped proportionally to the surface values of the individual sampling dates.

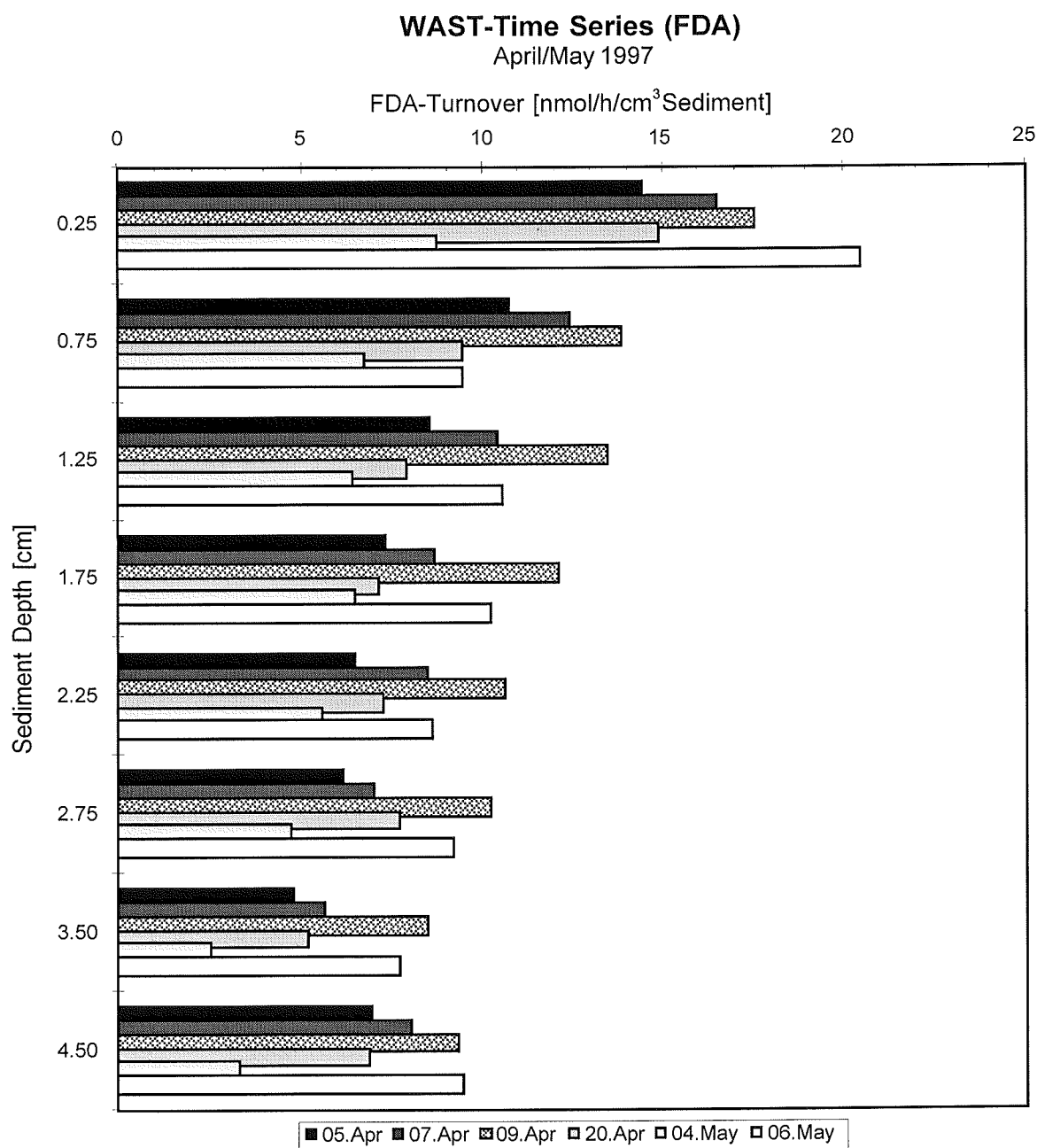


Fig. 4: Hydrolytic activity at the WAST time series station. Data are presented for the top 5cm of the sediment column.

The process of enhance of exoenzyme productions necessitates a step up in metabolic activity such as ATP production or electron-transport-system activity (ETSA). In consequence, corresponding to the enhanced hydrolytic activity we found an increase in ETSA at all stations investigated (Fig. 5)

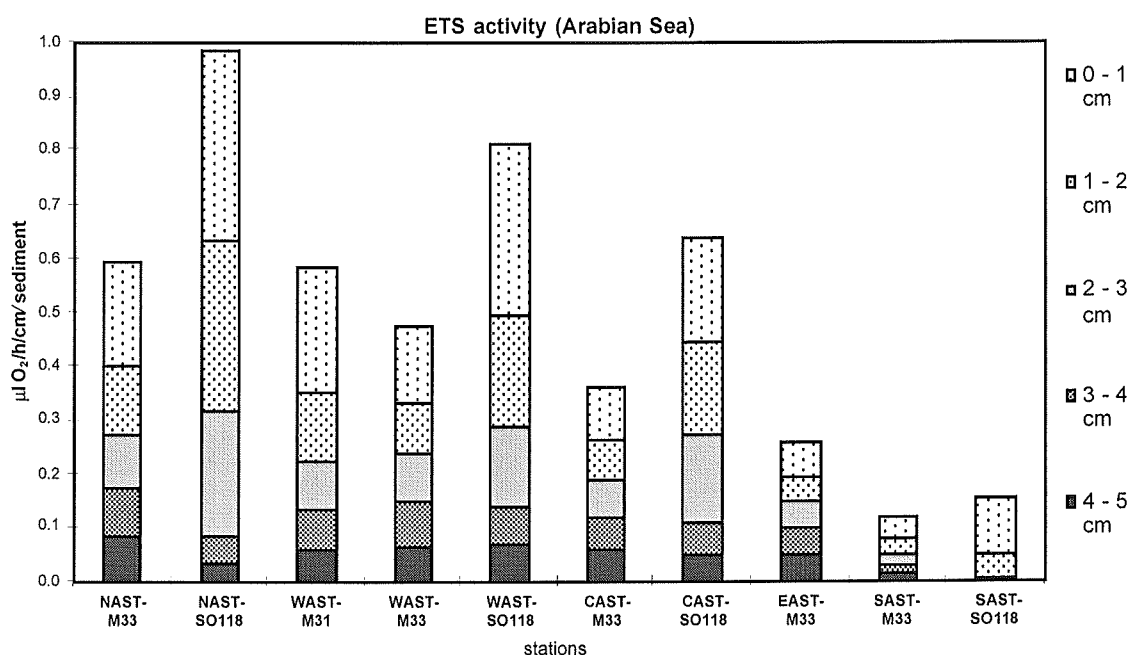


Fig 5: Electron-transport-system activity for centimetres 0-5 of the sediment column. Data from SO118 in comparison to data from October 1995 (M33) and March 1995 (WAST only, M31).

The ETSA data from the WAST time series station showed an increase of activity in early May which supports the view of an enhancement of metabolites shortly after the increase in hydrolytic enzyme production. Largest variations of ETSA occurred in the in top 25mm of the sediment column. ETSA remained on a relatively high level down to 3cm sediment depth. Below 3cm ETSA was markedly reduced.

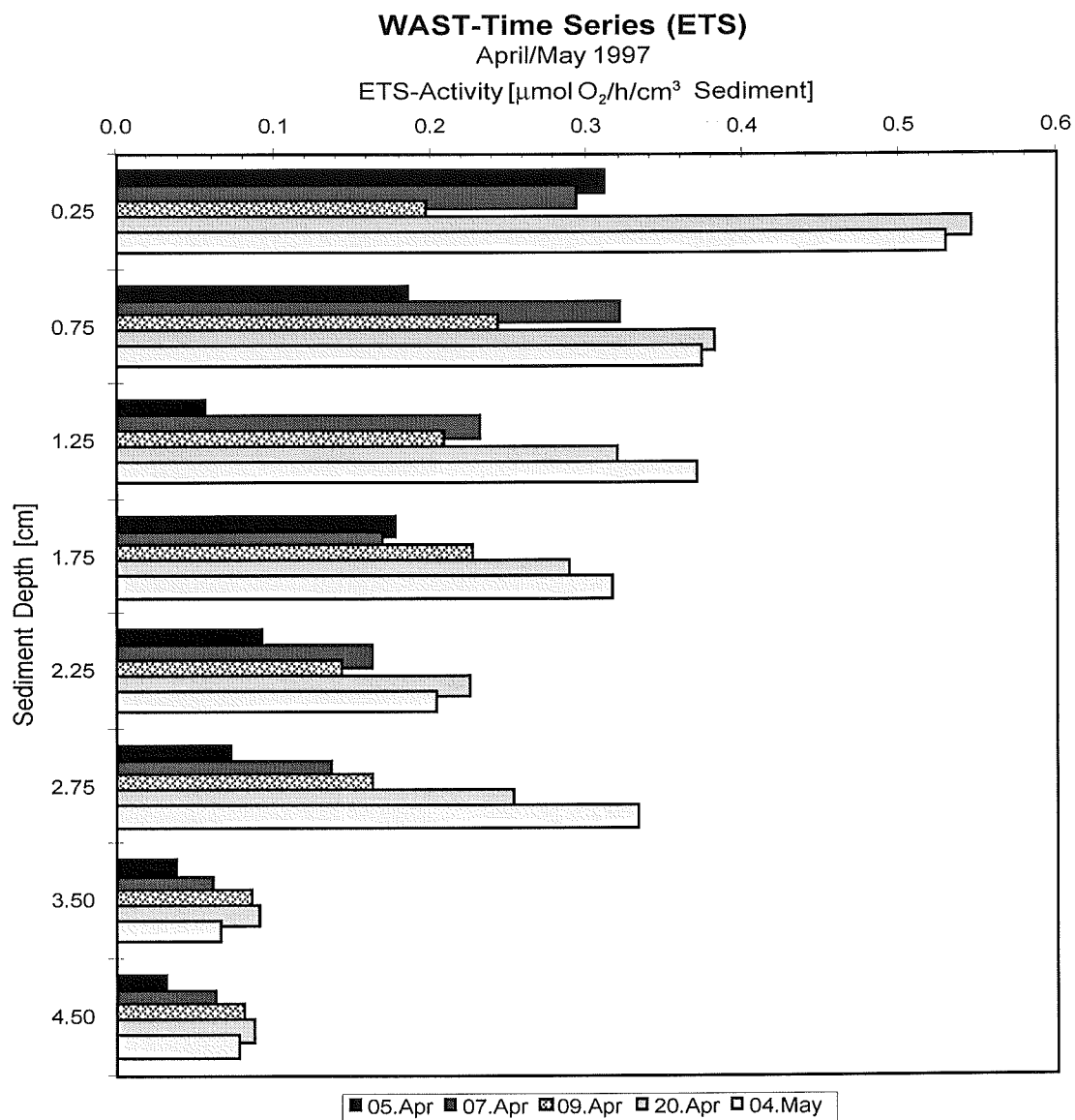


Fig. 6: Electron-transport-system activity at the WAST time series station. Data are presented for the top 5cm of the sediment column

Conclusions

The measurements of biogenic sediment compounds clearly pointed to a strong sedimentation pulse of labile particulate organic matter at all stations investigated. CPE values could prove an increase of phytodetrital matter on the seafloor. The small biota of the benthic community responded to the increase of labile organic matter by an overall enhancement of exoenzymatic activity which lead to an increase of other metabolic activities such as ETSA. The time series measurements at WAST could demonstrate the length and intensity of the POM-pulse (CPE-data) and of the benthic reaction. During the four weeks of sampling no significant change in metabolic activity was observed. The results of SO118 raise the question about the time and length of any decrease in benthic activity in relation to the intermonsoonal reduction of surface productivity.

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5.13 Pore-water geochemistry

Klaus Wallmann, Sybille Grandel, Roger Luff & Katja Heeschen

Research programme

One of the main interests of the geochemical research programme is to study the turnover processes of organic matter, biogenic opal and calcium carbonate in surface sediments of the Arabian Sea.

Sediment and water samples were analyzed to get information of the amount and vertical distribution of inorganic nutrients, pH, oxygen and iron.

Temporal changes in the sedimentation of biogenic matter are ubiquitous in the deep-sea environment and particularly well documented for the study area. Thus, the response of the benthic system to sedimentation events and seasonally controlled fluctuations will be a main research item.

Transport-reaction models need the measured data as initial and boundary parameters to determine the turnover rates of biogenic substances in the surface sediments. Other parameters such as water depth, sediment depth, rain rate of biogenic matter to the seafloor, concentration of dissolved and solid phase compounds are collected to describe the whole system and to study the triggered benthic processes.

Experiments accomplish the field data to obtain more information on the degradation of organic matter and dissolution of biogenic opal. In the dissolution experiments, the relation between dissolved silica and the opal dissolution rates is investigated. Degradation experiments are designed to study the impact of anoxic conditions on the preservation of organic matter in surface sediments of the Arabian Sea.

The laboratory and field data will be used to establish new kinetic equations that relate the degradation and dissolution rates to the rain rates of biogenic substances to the seafloor and to the sediment and bottom water composition. These equations will be combined with other equations that describe the physical and biogenic transport processes. The resulting transport-reaction model will be used to predict and quantify the benthic turnover of organic matter, biogenic opal and carbonate in surface sediments of the Arabian Sea.

In-situ measurements will determine the oxygen- and pH-profiles across the sediment-water interface because the values obtained by laboratory

measurements of the studied parameters may be affected by the sampling procedures. These technically demanding measurements will be applied in future expeditions (SO129).

Station works and preliminary results

Introduction

Main purpose for geochemical investigations of this cruise was the deciphering of temporal changes in the benthic activities. We expected low benthic turnover rates because the pelagic productivity and, thus, the rain rates of organic substances to the seafloor were expected to be at the lowest point in their seasonal cycle. Surprisingly, we found the highest benthic activities ever recorded in the Arabian Sea. In response to the extremely high and unusual degradation rates observed during our first visit to the WAST station, the cruise track was changed so that the decline of the rates could be followed over a period of one month at that station.

Methodology and description of the work carried out

Surface sediments taken with a multicorer, were segmented into the following depth intervals: 0-0.5 cm, 0.5-1 cm, 1-2 cm, 2-3 cm, 3-4 cm, 4-5 cm, 5-6 cm, 6-7 cm, 7-8 cm, 8-9 cm, 9-10 cm, 10-13 cm, 13-16 cm, 16-19 cm, 19-22 cm, 22-25 cm, 25-28 cm, and 28-31 cm. Pore-waters were separated from the wet segments in the cold room at 2-8 °C using a squeezer pressurized with argon at 2-3 atm, while filtering the samples on-line through 0,4 µm cellulose acetate filters. A complete list of analyzed multicorer sediments is given in Tab. 1.

The pore-waters and the overlying bottom water were analyzed on board for dissolved nitrite, nitrate, ammonia, and phosphate using an auto-analyzer. Within this instrument, samples are mixed with photometric reagents and the absorption of the resulting colored solutions is determined in photometric cells. The concentration of the examined substances is proportional to the measured extension and can be calculated using an external calibration. Replicate measurements result in relative standard deviations of 1 %, 2 %, 5 % and 10 % for nitrate, nitrite, ammonia and phosphate, respectively. Dissolved silica was determined on a separate photometer using a standard procedure after (GRASSHOFF ET AL., 1983).

The glass-electrode (GAT ionotrode IJ42) used for pH-measurements was calibrated with standards made up in seawater matrix (DICKSON, 1993). The calibrated pH-electrode and a thermometer were stuck into the wet sediment segments. The temperature and the electrode potential were registered and used to calculate the pH values. The resulting pH-values give the total concentration of protons present as H^+ and HSO_4^- (MILLERO, 1995).

Total alkalinity (TA) was determined by measuring the potential of a pH probe after a one-step addition of HCl. A volume of 0,3 to 0,5 ml of 0,01 M HCl was added to 1 ml pore water sample until a pH value of 3,0-3,52 was reached. The electrode was calibrated with two pH-buffers (3,00 and 3,52) prepared in seawater. The alkalinity of the artificial seawater was determined by GRAN titration and considered in the buffer preparation (STUMM & MORGAN, 1996). To control the quality and reproducibility of the method IAPSO seawater standard was titrated during every measurement. A mean TA of 2,34 mmol/kg with a standard deviation of 0,4 mmol/kg resulted from parallel measurements ($n=10$) of one-step titrations of the IAPSO seawater standard.

The measurement of oxygen-profiles were carried out in the cold room within one hour after the sampling of the multicores. Self-made glass microelectrodes of the Clark-type (REVSBECH, 1989) or a needle-oxygen electrode with internal reference (Diamond General) were assembled on a motor-driven micromanipulator, which was descended into the sediment in 0,1 mm steps. The measured currents of the electrodes varied between 10 to several hundreds of pA, the oxygen content is calculated via an external calibration.

Parallel to the segmentation, 1-2 g of wet surface sediments were mixed with 30 ml of 1N HCl solution to measure the amount of iron. The resulting sediment suspensions were shaken over a period of 24 h at a temperature between 2 and 8°C. Subsequently, the solids were separated by centrifugation and the dissolved phase was analyzed for ferrous iron and total iron using the ferrozine procedure (GRASSHOFF ET AL., 1983). With this procedure the reactive iron that takes part in rapid redox reactions is extracted and determined (WALLMANN ET AL., 1993).

Degradation experiments with sediment/seawater suspensions (with a ratio of 1:20) were made to study the impact of inorganic degradation processes and to evaluate the degradation capacity of the system. The amount of inorganic nutrients and several enzymatic activities was measured during an incubation time of about

2 weeks while the samples were shaken and stored dark at a temperature of 8-10°C. Subsamples were taken in an interval of 2-4 days, therefore the suspensions were centrifuged and 4 ml water were taken out for the measurements. The samples were refilled with the same amount of filtered seawater to keep the sample volume constant.

Tab. 1. Multicorer sediments (MUC) analyzed by the pore-water group.

MUC #	Station	Auto-analyzer	silica	alkalinity	pH	oxygen	Fe(II)/Fe(III)
2	WAST-Top	+	+	-	+	-	-
4	WAST-Plain	+	+	-	-	+	-
7	WAST-Plain	+	+	-	+	-	-
8	WAST-Top	+	+	-	+	+	+
9	WAST-Top	+	+	+	+	-	-
10	WAST-Plain	+	+	+	+	-	+
12	WAST-Top	+	+	+	+	-	-
13	WAST-Top	+	+	+	-	+	+
14	WAST-Plain	+	+	+	-	+	-
15	WAST-Top	+	+	+	+	+	-
16	WAST-Plain	+	+	+	+	+	+
18	SAST	+	+	+	+	+	-
23	SAST	+	+	-	+	-	+
24	SA-WA	+	+	-	+	-	-
25	WAST-Top	+	+	+	+	+	+
26	WAST-Top	+	+	+	+	-	-
28	WAST-Top	+	+	+	+	+	-
29	WAST-Plain	+	+	+	-	+	-
31	WAST-Plain	+	+	+	+	-	+
32	WAST-Plain	+	+	+	+	+	-
33	WA-CA	+	+	+	+	+	-
35	CAST	+	+	+	+	-	-
40	CAST	+	+	+	+	+	+
41	NAST	+	+	+	+	+	+
45	NAST	+	+	+	+	-	-
46	NAST	+	+	+	+	-	-
47	NA-WA	+	+	+	+	-	-
48	WAST-Top	+	+	+	+	-	+
49	WAST-Top	+	+	+	+	-	+
50	WAST-Plain	+	+	+	+	-	+
52	WAST-Top	+	+	+	+	-	+
53	WAST-Plain	+	+	+	+	-	+
54	WAST-Plain	+	+	+	+	-	+

Results

In Fig. 1, the sum of dissolved nitrite and nitrate concentrations measured in the pore-waters and the overlying bottom waters of station WAST-Plain is plotted as a function of sediment depth and sampling time. The concentrations in the top centimeter of the surface sediment were extremely high at the beginning of the cruise and decreased rapidly within the following two weeks. The benthic fluxes were calculated from the concentration difference between the overlying bottom water and the pore-water separated from the top sediment segment at 0-0.5 cm depth. Considering the dissolved species nitrite, nitrate, ammonia, and phosphate, the benthic N- and P-fluxes were calculated and evaluated as a function of time.

Fig. 2 shows that the N-fluxes at station WAST-Plain decrease in time whereas the P-fluxes follow the opposite trend. The resulting N/P flux ratios were anomalously high at the beginning of the expedition and approached the common Redfield ratio of 16 at the end of the cruise.

The high initial N-fluxes indicate very high organic matter degradation rates that were probably caused by a sedimentation event that transported easily degradable particulate organic matter to the seafloor. The anomalous N/P-flux ratios may indicate that phosphate released during organic matter mineralization was initially re-adsorbed on sediment surfaces. Only after saturation of these adsorption sites, phosphate is accumulating in the pore-water and the benthic fluxes are enhanced.

Fig. 3 shows that the benthic fluxes were even higher at the WAST-Top station. The sediments at this station were covered with a thick fluff layer. Nitrate concentration of up to 100 μM were registered in the surface layer. To our knowledge, these are the highest concentrations ever found in the deep-sea environment. The thickness of the fluff layer and the concentrations of nutrients varied between individual cores. The patchiness in the lateral fluff distribution was also observed during the EXPLOS deployments. Due to the extreme lateral variability, the time-dependence of the degradation processes was not resolved in the presented field data.

The values of the oxygen penetration depths of the ex-situ measured profiles correspond to the laboratory-data determined during M33/1 (Tab. 2). The comparison of measurements with the two different types of electrodes gave similar results.

Because of the high temperature effects during the sampling of the multicores in this region it can be assumed that the in-situ oxygen profiles would show different

penetration depths and values (GLUD ET AL, 1994; SCHLÜTER, 1996). Therefore, as already mentioned above, the employment of an in situ oxygen-profiler is in preparation for the next cruise.

Tab. 2: Ex situ measured oxygen penetration depths in mm determined during the cruises M33/1 and SO118

	WAST-Plain	WAST-Top	CAST	EAST	SAST	NAST
M33/1*	8-9	nm	14-20	20	<40	11
SONNE 118	7-12	5-7	14-16	nm	> 25	18-20

* from WITTE & PFANNKUCHE, 1996

nm: no measurements

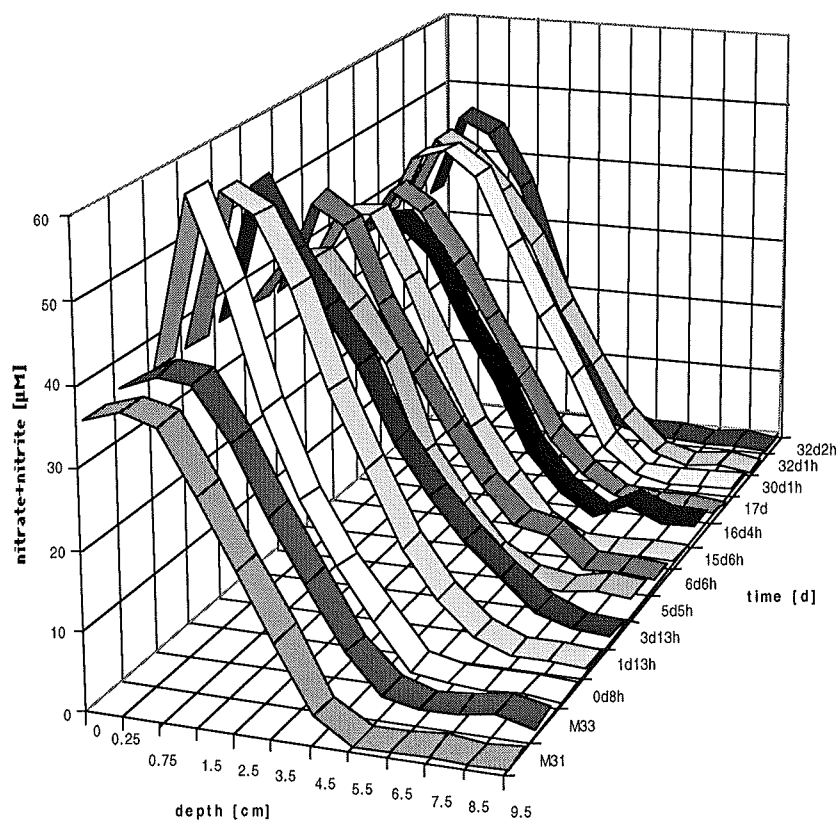


Fig. 1: Concentrations of dissolved nitrate and nitrite in pore-waters from the WAST-Plain station. Time zero corresponds to the 4th of April 1997, the time of the first multicorer deployment during the SO118. The profiles obtained at the same site during the previous M31 and M33 expeditions are plotted for comparison.

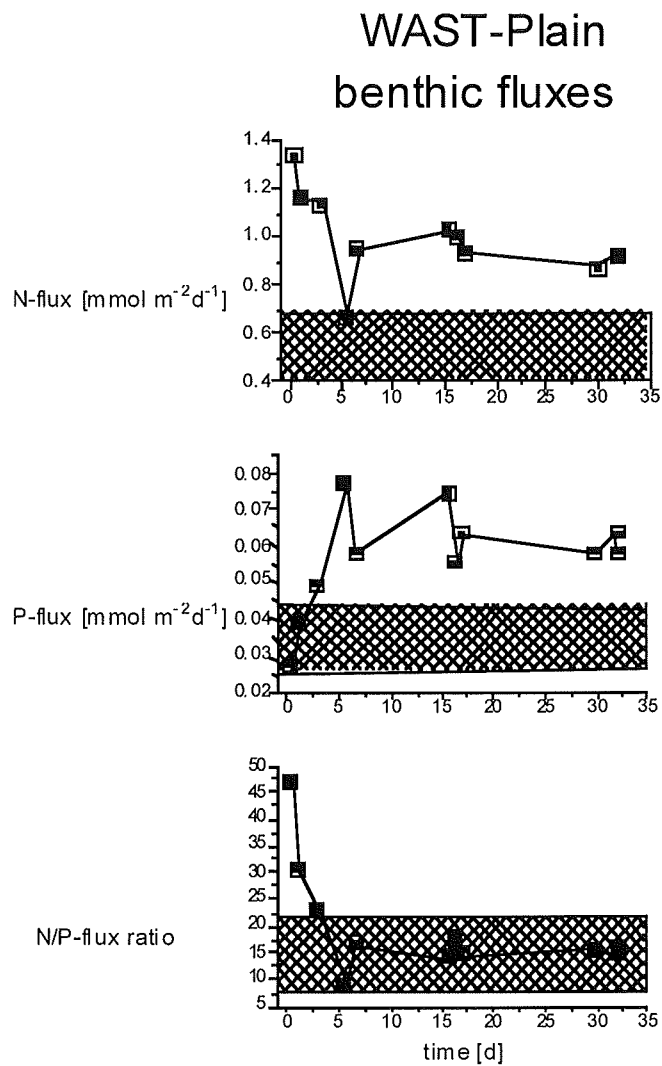


Fig. 2: Benthic fluxes at the WAST-Plain station as calculated from the pore-water and bottom water data. The hatched areas indicate the range of fluxes registered during the previous M31 and M33 expeditions.

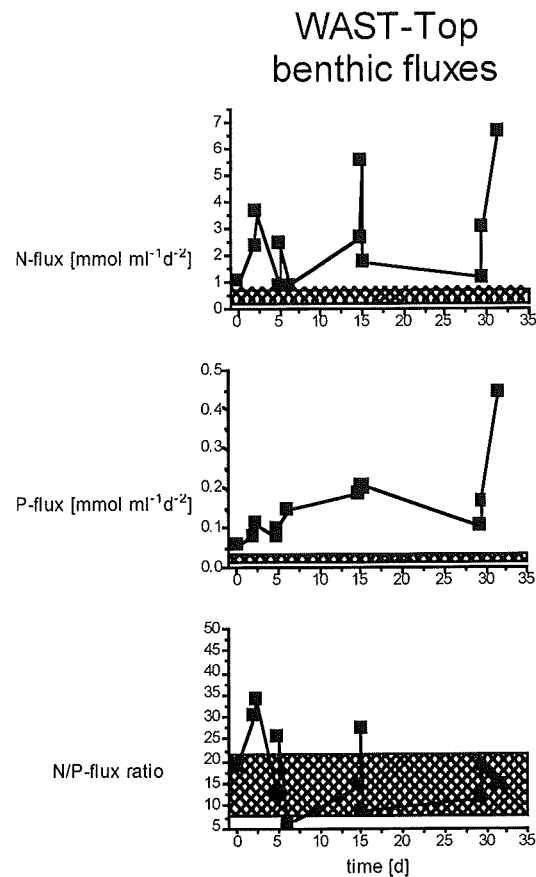


Fig. 3: Benthic fluxes at the WAST-Top station as calculated from the pore-water and bottom water data. The hatched areas indicate the range of fluxes registered during the previous M31 and M33 expeditions at the WAST-Plain station.

Conclusions

The WAST-Plain data clearly indicate that particulate organic matter with a half-life of only about 10 days was exported to the seafloor. The time scale of the degradation processes is much smaller than previously thought. The data suggest that the benthic-pelagic coupling is very effective and that the benthic degradation processes have to be studied at a very narrow timed resolution. A monthly sampling of sediments is obviously not appropriate. Instead, the strategy adopted

during the SONNE 118 cruise, where sediments were taken over a period of one month at intervals of only a few days, seems to be more promising.

The SONNE 118 expedition produced an unique data and sample set that will be intensely evaluated in the future. It could, for the first time, give a complete picture of the chemical and biological changes that occur in the benthic environment of the deep-sea after the settling of a detritus pulse on the seafloor.

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5.14 Interaction between seasonal benthic reaction rates, particle flux and trace element distribution in deep-sea sediments

Lars Dittert

Research programme

Aim of this subproject is to qualify and quantify the influence of seasonal processes on the geochemical environment of the sediment and thereby on the distribution of trace elements. SHANKAR ET AL. (1987) showed that in the Holocene four factors are very important for the distribution in the solid phase elements in the Arabian Sea: the hydrothermal activity of the Carlsberg Ridge, the distribution of terrigenous matter, authigenic precipitates and the distribution of biological matter. The recent regional distribution of organic material and the input of aeolian transported particles is strongly influenced by the monsoon system. Processes that control the elemental distribution occur in the ocean surface water (e.g. blooms of plankton, input of aeolian dust), in the water column (e.g. sinking of particles) and at the sediment surface (e.g. deposition, chemical and microbial decomposing of particles, bioturbation and bioirrigation). Especially the last processes can effect the pH- and Eh-conditions in the sediment in a seasonal and interannual rhythm. One of the consequences is precipitation or solution of trace elements.

If coherences between the short-term processes in the water and the precipitation or solution of elements in the sediment can be demonstrated, they can possibly be connected to the chemical parameters, meteorological, biological, and oceanographical effects. Depending on the preservation of such a proxy-parameter signal in the sediment, it can be used as a paleo-indicator.

Of special interest is the relationship of the trace element concentration between the sediment's pore water and its solid phase, to evaluate, if a certain trace element diffuses from above or from below into an enrichment layer and where the source depth is located.

Meteorological, biological and other effects vary not only in time, but also in space. Therefore another goal will be a coupling of the geochemical results of the investigated stations to the different geochemical provinces of the Arabian Sea.

Station works and preliminary results

Introduction

To quantify the relationship between content of sediment trace metals in the solved and solid phase, the pore water must be separated from the sediment. Of great importance are the nutrient profiles and their related fluxes out of or into the sediment which enable a calculation of organic material. Depending on the quantity of the organic matter and the speed of its degradation the geochemical conditions can change dramatically. In consequence trace metals that were incorporated into the organic material are released and (2) that these metals already in the sediment react according to the changing chemical conditions (e.g. precipitation or solution).

Methodology and description of the work carried out

13 cores of 10 multicorer deployments and 4 gravity cores were taken for porewater-squeezing and solid phase sampling. The locations of the cores were WAST-Top (MC01, MC12, MC25 and SL6), WAST-Plain (MC04, MC11, MC29, MC51 and SL2), SAST (MC19 and SL1), CAST- (MC37) and NAST stations (MC41 and SL4).

In order to prevent the sediments from warming up on board all cores were transferred into a cooling room immediately after recovery and maintained at a temperature of 2°C at the beginning of this cruise. Unfortunately the temperature in the laboratory gradually increased to 8°-10°C after one week.

The sediment cores were processed within a few hours. Samples of the associated bottom water were taken for further analysis. The remaining bottom water was carefully removed from the multicorer tube with a siphon to avoid destruction of the sediment surface. During subsequent cutting of the cores into slices for pressure filtration in a glovebox under argon atmosphere, pH and Eh measurements were performed with a minimum resolution of 0.5 cm depth intervals

The gravity cores were cut into 1 m segments on deck and stored in the cooling room. Within one (SL1 and SL2) or three (SL4 and SL6) days after recovery gravity cores were split into two halves and processed. On one halve core pH and Eh were determined and sediment samples were taken in 5 cm intervals from 5 to 20 cm

core depth and then every 10 cm for pressure filtration. Additionally solid phase samples were taken at 5 cm intervals and kept in gas-tight glass bottles under argon atmosphere. For determination of the water content samples were generally taken every 10 cm. They were placed into 12.5 ml PE-containers covered with parafilm and a cap. All sediment and pore water samples were stored at -20°C to avoid dissimilatory oxidation. Work on splitted gravity cores was carried out in a glove box under argon atmosphere.

For pressure filtration Teflon-squeezers were used. The squeezers were operated with argon under pressure which was gradually increased up to 5 bar. The pore water was sucked through 0.2 µm cellulose acetate membrane filters, which were treated in argon bubbled water before using. Depending on the porosity and compressibility of the sediments, the amount of pore water recovered, ranged between 5 and 35 ml. After squeezing the remaining sediment was stored in PE-foil for further analysis.

Eh and pH were determined with electrodes before the sediment structure was disturbed by sampling.

All pore water samples were acidified with HNO₃(s.p.) down to a pH value of <2 and frozen until further treatment in the home laboratory.

Results

Due to the complex and difficult methods for trace metal analysis (HF-HClO₄-HNO₃-digestion of solid phase samples and extraction of pore water) no results for trace metal distribution could be received on board. The samples were conserved for further treatment in the home laboratory. The pH and Eh data of WAST-Plain suggest that a temporal variation in the profiles of the porewater nutrients during the settling and the biologic degradation of a plankton bloom was demonstrated by the results of WALLMANN ET AL. (this volume, 5.13). However, inhomogeneous pH- and Eh-distributions in parallel cores from the same multicorer were found (Fig. 1).

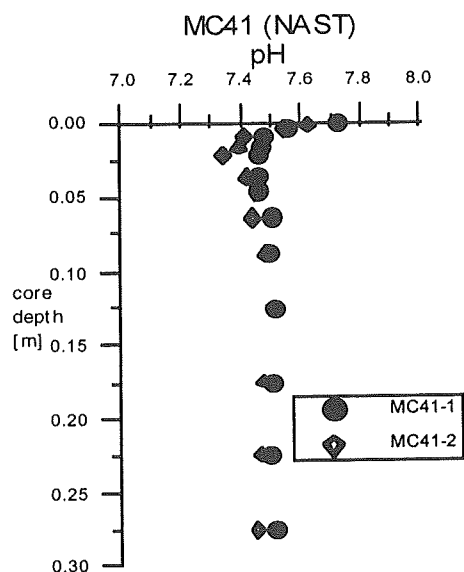


Fig 1: Distribution of pH in the sediment (MC41 at NAST). Parallel cores showed differences, especially in the upper part of the sediment. Variations occur not only in time, but also in small space.

First results of the distribution of copper in the solid phase of a multicorer (MC25) at WAST-Top and a multicorer (MC29) and a gravity core (SL2) at WAST-Plain could be gained in the home laboratory. The concentration at WAST-Plain is two to four times higher in the upper 20 cm than at WAST-Top (Fig. 2). In the gravity core SL2 a copper enriched layer was found between 45 cm and 75 cm of core depth. The concentration of copper reaches a maximum value of about 80 $\mu\text{g}/\text{kg}$ in the sample at 60-65 cm sediment depth (Fig. 3). This enrichment is located just below the described upper turbidite sequence (compare „Core description“, this volume).

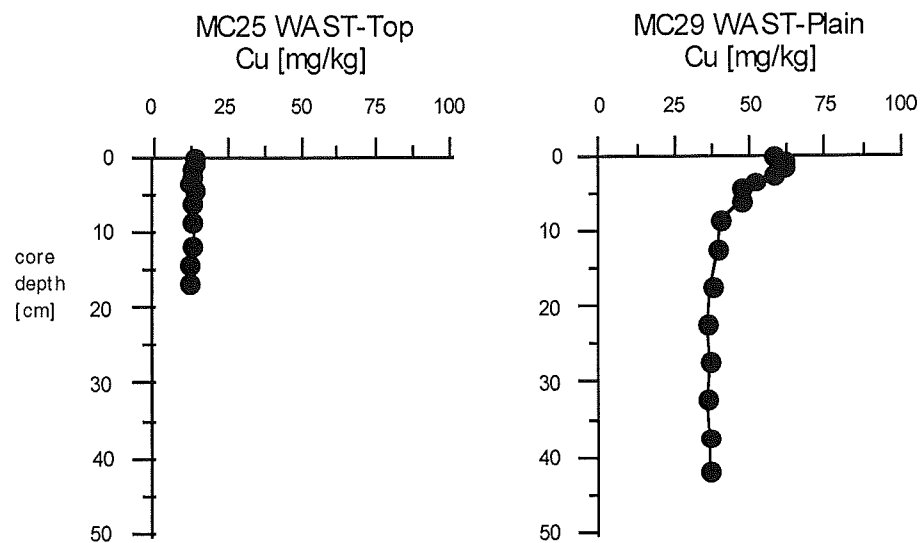


Fig 2: Concentration of copper in the solid phase (MC25 and MC29). The content of copper is significant lower at WAST-Top compared to WAST-Plain.

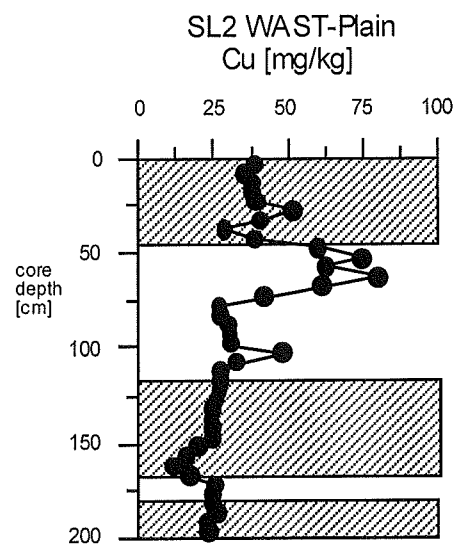


Fig.3: Distribution of copper in the solid phase of gravity core SL2 at WAST-Plain. The shaded areas indicate turbidites. Just below the youngest turbidite copper is enriched.

Conclusions

The change of chemical conditions during enhanced benthic degradation rates after the deposition of a plankton bloom results in the mobilization of trace metals that are bound to the solid phase or can immobilize others that are already solved in the pore water. This reaction is in sediment samples from the time series samples of WAST-Plain and WAST-Top. The first trace metals of interest are Cu, Cd and Pb.

To get a correlation with the nutrient profiles of the multicorer cores investigated by the GEOMAR group pore water samples will be analyzed additionally for other elements such as Fe, Mn and Si using the ICP-AES.

First results of the concentration of copper in the solid phase give an idea of different valence of processes at WAST-Top and WAST-Plain.

Literature

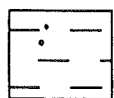
SHANKAR R., SUBBARAO K.V. and KOLLA V. (1987) Geochemistry of surface sediments from the Arabian Sea. *Marine Geology*, **76**, 253-279.

Legend for lithologic profiles

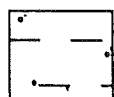
Grainsize:



clay



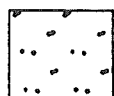
sandy clay (few grains with sandsize)



sandy clay (many grains with sandsize)



clayey sand



sand

Structure:



bioturbation



bioturbation (uncertain)



strong bioturbation



fining upwards



laminated

Figure 1: legend

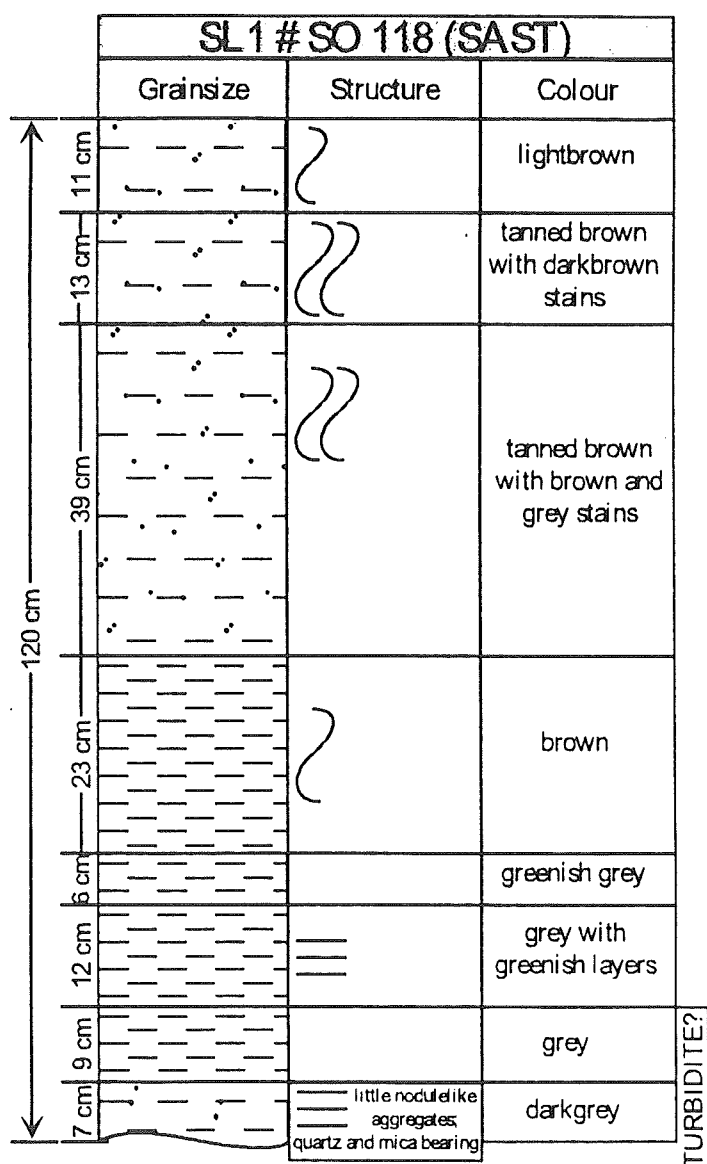


Figure 2: SL 1

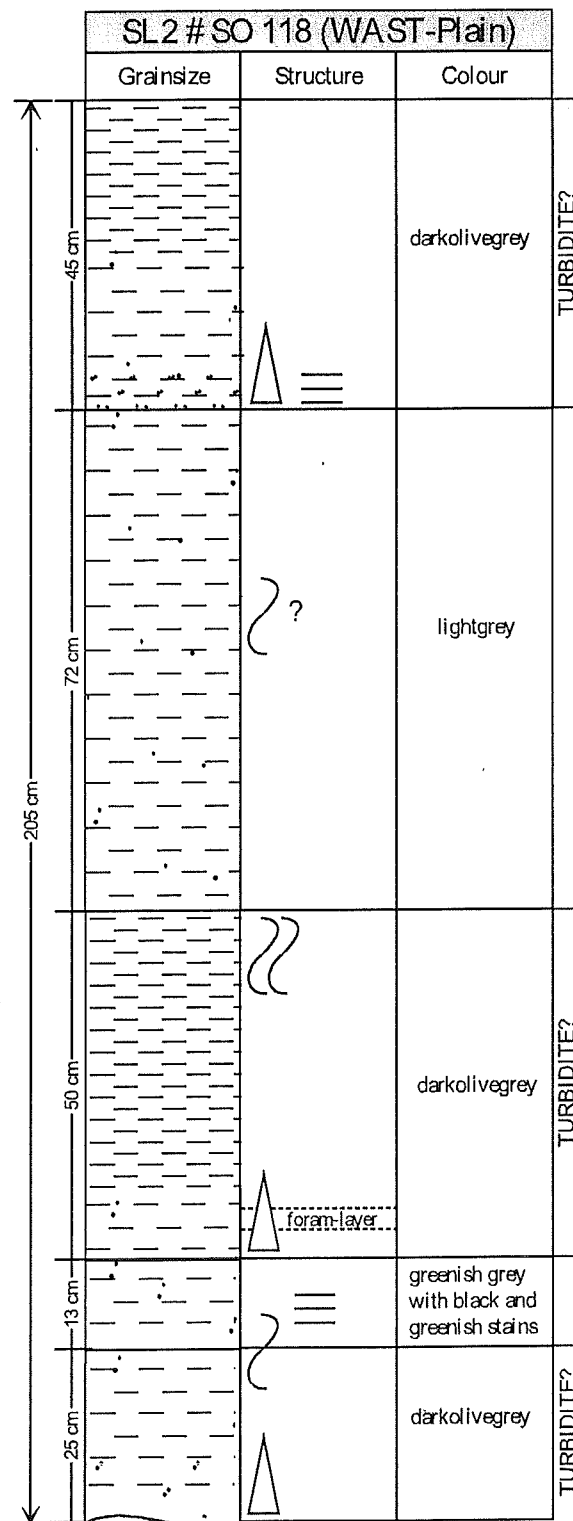


Figure 3: SL 2

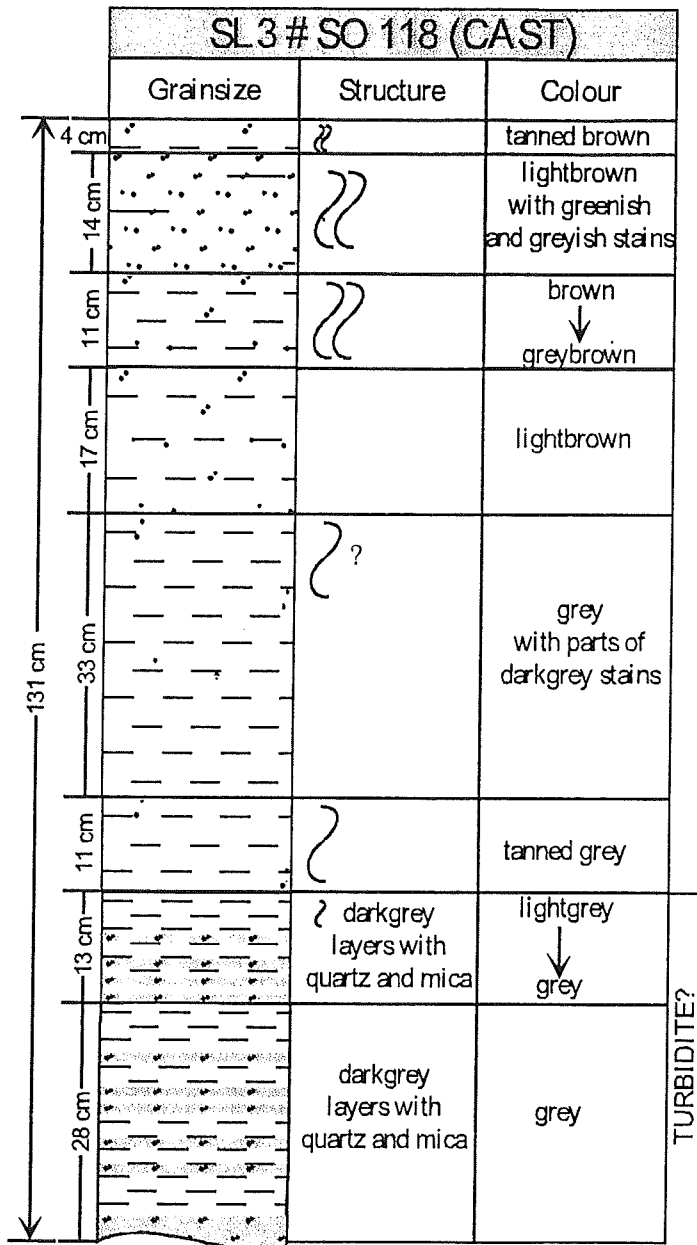


Figure 4: SL 3

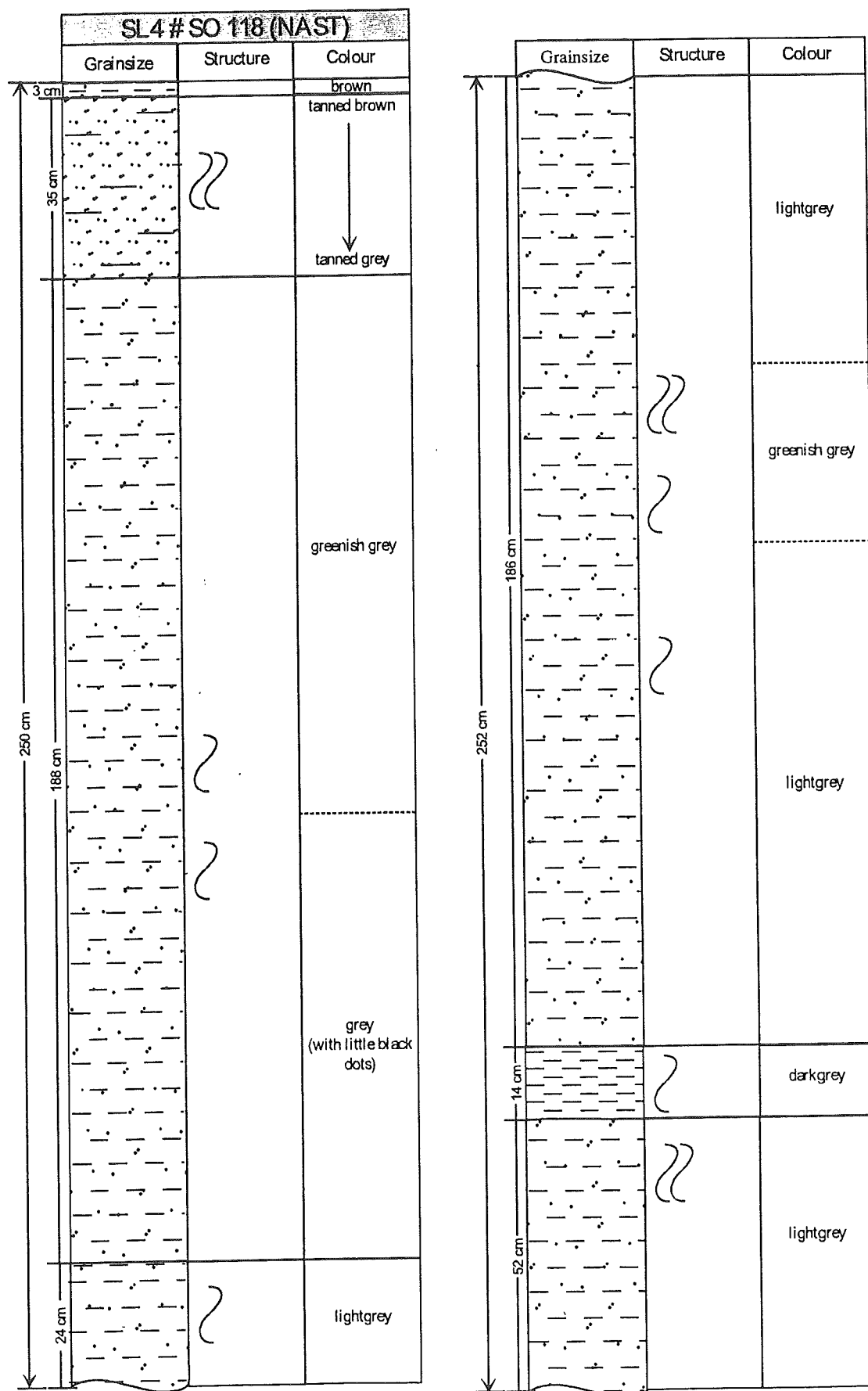


Figure 5: SL 4

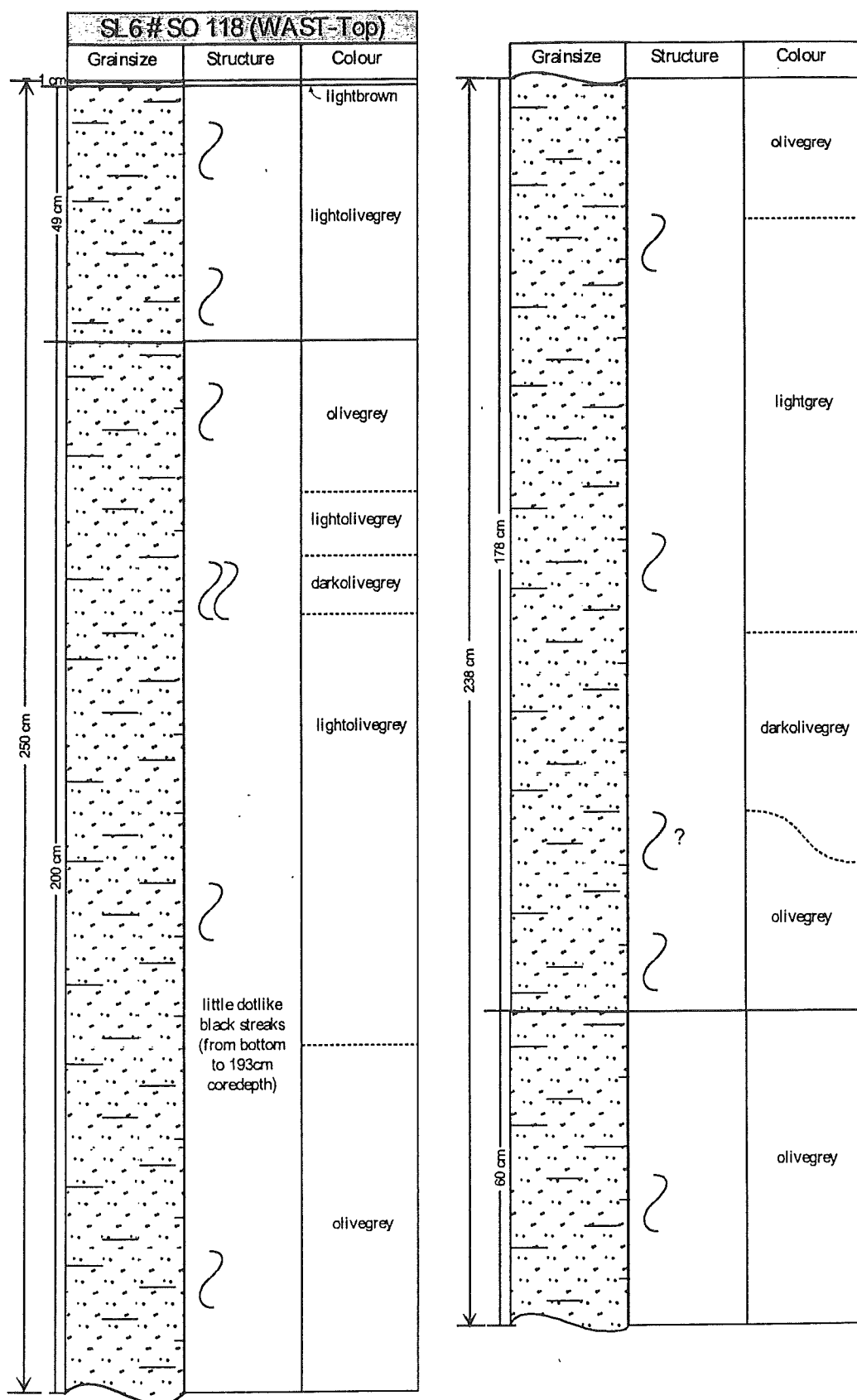


Figure 6: SL6

5.15 Biogenic, lithogenic, aeolic and hydrothermal signals of trace elements in the deep sea sediments of the Indian and Atlantic Ocean

Holger Schale

Research programme

In this subproject fluxrates of elements which are involved in biocycles or are bound to lithogenic components are quantitatively determined. The areas of investigation are the northern Atlantic (two stations: BENGAL and BIOTRANS; already visited during cruise METEOR 36/6) and the Arabian Sea (six stations: WAST-Plain, WAST-Top, NAST, CAST, SAST and EAST; except EAST visited during cruise SONNE 118).

Solid phase samples were taken from the upper sedimentary column (see Tables 1 and 2) and from sediment traps. Additionally water column samples were taken from two stations, besides the supernatant water from the recovered multicorers. The high-resolution chemical analysis of sediment cores should mirror the (cyclic?) changes of climatic parameters with time, which is often reflected in varying amounts of deposited biogenic and lithogenic components. To distinguish between primary signals from the ocean/atmosphere-system and early diagenetic signals, pore-water is analysed. The sulfur-isotopic composition of sulfate in the pore waters will evaluate if bacterial sulfate reduction is of importance in the investigated sediments.

Measurements of excess ^{230}Th by ICP-MS are carried out to use this new and time-saving method for dating purposes. Further tests will be carried out with ICP-MS measurements of stable Pb isotope ratios to distinguish source areas of the lithogenic component by specific patterns.

Station works and preliminary results

Sample handling and XRF-analyses

Introduction

The main target was to obtain samples from multicorer and gravity corer runs. These samples will be analyzed by XRF for major elements and some metals. The content of sulfur, total and inorganic carbon will be determined by coulometric methods. Depending on these results further element determinations will be carried out by spectrometric methods (AAS, ICP-AES, ICP-MS) after sample

digestion with mineral acids. International and in-house standard materials will be analyzed in parallel for checking precision and accuracy of the analytical methods.

Table 1: Subsampling of multicorer-cores

Multicorer	MC 1	MC 5	MC 11	MC 18
Station	WAST-Top	WAST-Plain	WAST-Plain	WAST-Top
Date	04.04.97	04.04.97	04.07.97	04.09.97
Position	16°10'7 N 55°45'7 E	16°13'0 N 60°16'0 E	16°13'0 N 60°16'0 E	16°10'5 N 55°46'0 E
Depth	1918 m	4047 m	4075 m	1916 m
Number of cores	1	3	1	2
Slices*0.5-2 cm/porewater	+ 0-18 cmbsf	+ 0-44 cmbsf	-	-
Slices in mm-scale	-	+ (1 mm:1- 6.5 cmbsf)	-	-
Complete core frozen	-	+	-	+

Table 1: *continued*

Multicorer	MC 18	MC 34	MC41	MC 49
Station	SAST	CAST	NAST	WAST-Top
Position	10°02'0 N 65°00'0 E	14°25'0 N 64°34'0 E	20°00'0 N 65°35'0 E	16°10'5 N 55°46'0 E
Date	04.12.97	04.23.97	04.28.97	05.03.97
Depth	4426 m	3957 m	3186 m	1917 m
Number of cores	3	3	3	2
Slices*0.5-2 cm/porewater	+ 0-34 cmbsf	+ 0-13 cmbsf	+ 0-32 cmbsf	+ 0-9
Slices in mm-scale	+ (2 mm 1-10 cmbsf)	+ (2 mm 1-10 cmbsf)	+ (2 mm 1-10 cmbsf)	+ (2 mm 1-10 cmbsf)
Complete core frozen	+	+	+	-

* sampling-intervals: 0-5 cm , 0.5 cm; 5-10 cm, 1 cm; remaining, 2 cm

Table 2: Subsampling of the gravity cores

Gravity-corer	SL 1	SL 2	SL 3	SL 4	SL 6
Station	SAST	WAST-Plain	CAST	NAST	WAST-Top
Date	04.15.97	04.21.97	04.25.97	04.29.97	05.05.97
Position	10°02' N 65°00' E	16°13' N 60°16' E	14°25' N 64°34' E	20°00' N 65°35' E	16°10' N 55°46' E
Depth	4425 m	4042 m	3954 m	3186 m	1916 m
Core-length	135 cm	214 cm	130 cm	500 cm	475 cm
Sampling intervals	1 cm	1, partly 0.5 cm	1 cm	1 cm	1 cm

Methodology and description of the work carried out

On board only sampling and sampling processing was carried out because all analyses have to be conducted in the home-laboratory. Information about the recovered cores can be drawn from tables 1 and 2. Pore waters, whole cores and some special samples were stored at -20°C. The supernatant water of the multicorer-cores was filtered through 0.45 µm Nalgene SFCA-filters and acidified with 2 % HNO₃. These samples were kept in the refrigerator, temperature (4°C). Every third sediment sample (3 cm intervals) of cores SL 1 (SAST), SL 2, and SL 6 (WAST-Plain and Top) is presently processed (freeze-dried, grinded and analyzed by XRF). Core MC 5 (WAST-Plain) is completely analyzed by XRF. For comparison a gravity core and a multicorer core sampled during cruise METEOR 33/1 (WAST-Plain) were included into the data set.

Results

Among all stations, the highest amounts of CaO (representing carbonate) were found at WAST-Top, followed by WAST-Plain and finally SAST reflecting different water depths since WAST-Top is the shallowest station sampled. Figure 1 demonstrates that almost all samples may be regarded as mixtures of an average shale component with CaO representing carbonate. The samples from WAST-Plain and WAST-Top have a slight tendency to relatively higher SiO₂-values, especially those from the assumed turbidites.

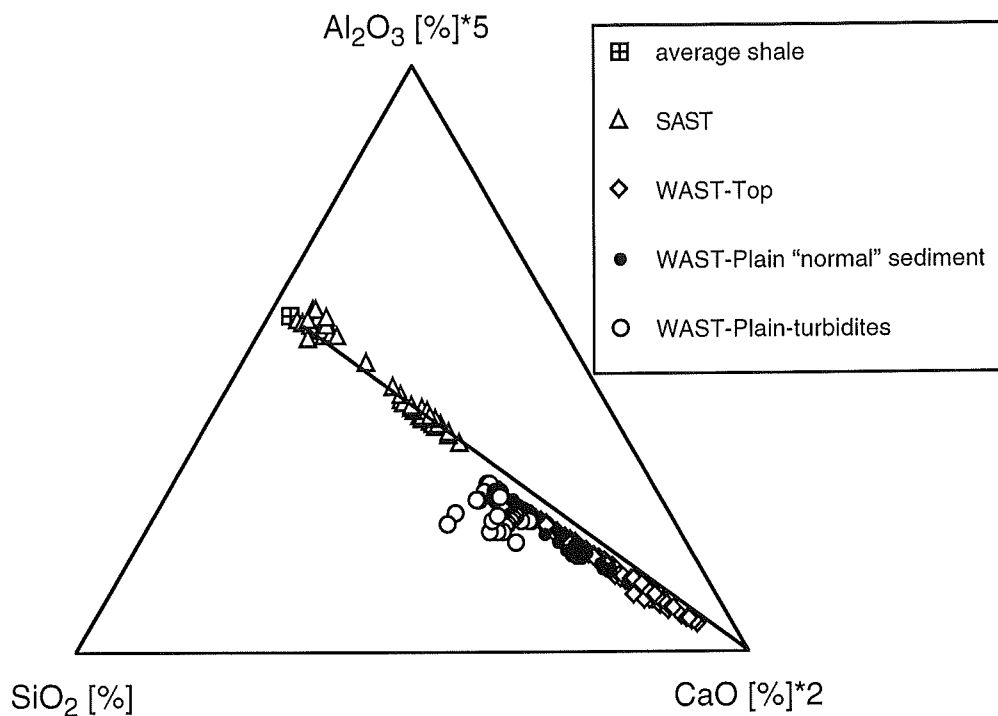


Fig. 1: Ternary diagram of major elements for the characterization of the Arabian Sea sediment material

WAST-Plain, gravity cores

Fig. 2 shows a comparison of two gravity cores sampled on WAST-Plain. Graphs of Si/Al as well as Zr/Al versus depth show similar profiles but the position of the individual downcore maxima differ between both cores. These differences between the two cores are likely depending on changed conditions during sampling when a gravity corer hits the sediment surface with a speed of 1.2 m s^{-1} the uppermost 10 to 50 cm of the sediment are compacted and partly pushed aside. The different shape of some element profiles result from differences in sampling resolution (5 cm versus 1 cm). Further discussion will focus on cores obtained from cruise SONNE 118.

In the depth profiles of Si/Al, Ti/Al, Zr/Al and Cr/Al (Fig. 2 and 3) two events can be identified. The base of the first event is located at 167 cmbsf, the second one at 45 cmbsf. The enrichment of these elements most likely is related to higher quantities of heavy minerals and quartz. The data confirm the hypothesis that turbidites are present at WAST-Plain. The heavy mineral enrichments are due to grain size sorting effects and are most pronounced at the base of turbidites.

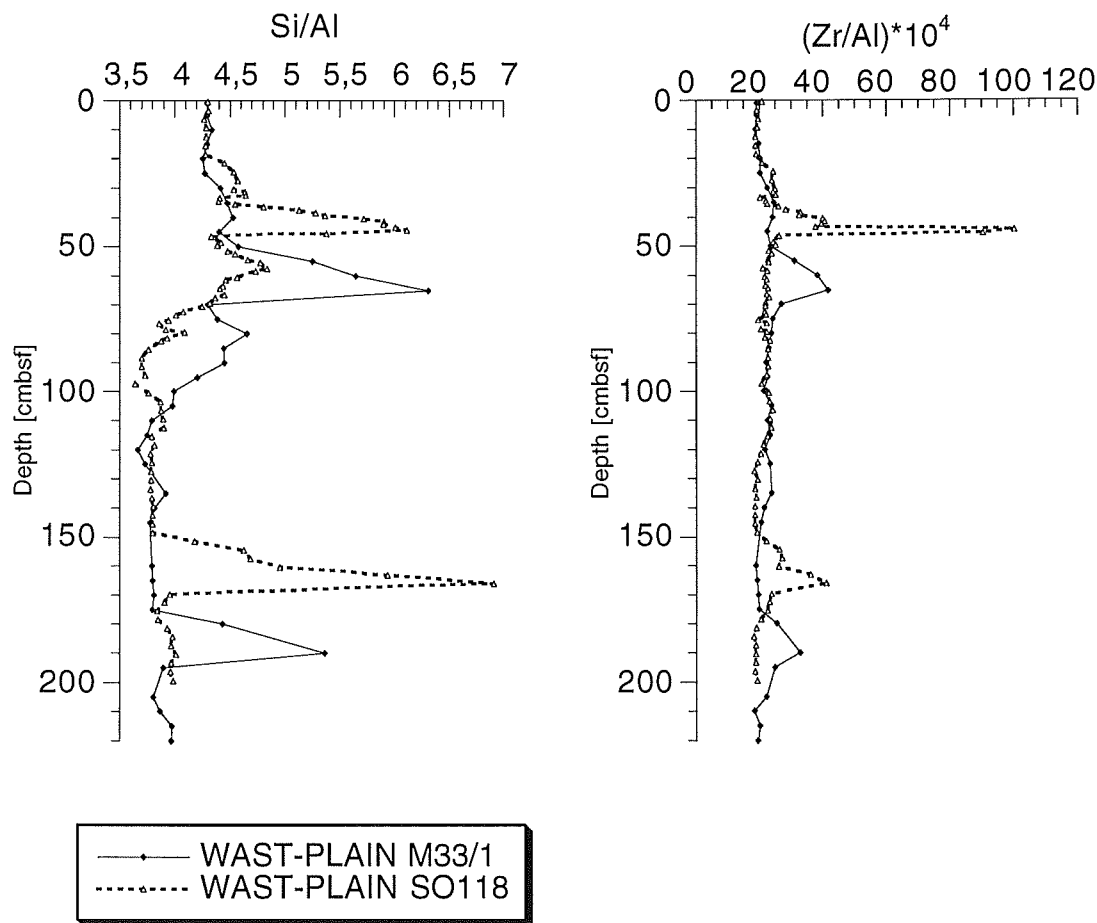


Fig. 2: Depth relationship between two gravity cores from WAST-Plain (Si and Zr normalized to Al)

Referring to this gravity core the first turbidite is located between 10 to 45 cmbsf, the second from approximate 120 to 167 cmbsf and the third begins at 180 cmbsf. At location WAST-Plain only the top cm, the interval between 45 and 120 cmbsf and 167 to 180 cmbsf are not dominated by turbidites. Redistribution of redox sensitive elements (Fe, Mn, Ni, Cu, Zn, and V) at the base of the turbidites are clearly visible.

WAST-Plain, multicorer samples

Fig. 4 shows XRF analyses of multicorer samples. Both cores have slightly differing major element ratios, but in particular the top 10 cm are almost identical. Below 10 cm (probably the top of a turbidite) only small variations are seen. The upper 10 cm are influenced by redox reactions. In this part of the core Mn as well as Ni, Co, Zn, V, and Fe are strongly enriched owing to remobilization processes in the turbidite, upward diffusion and precipitation at the sediment/seawater interface.

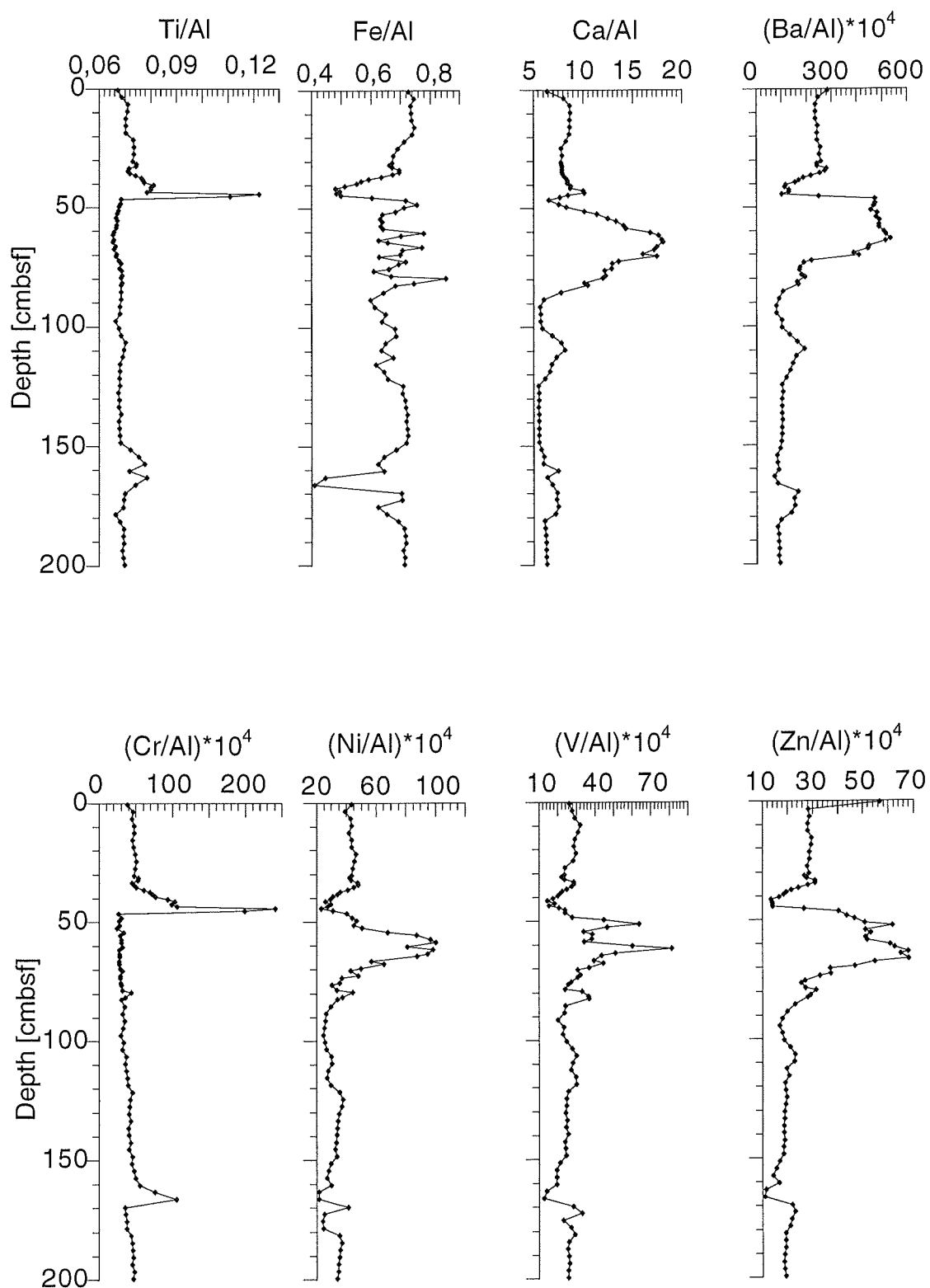


Figure 3: WAST-Plain gravity core, elements normalized to Al

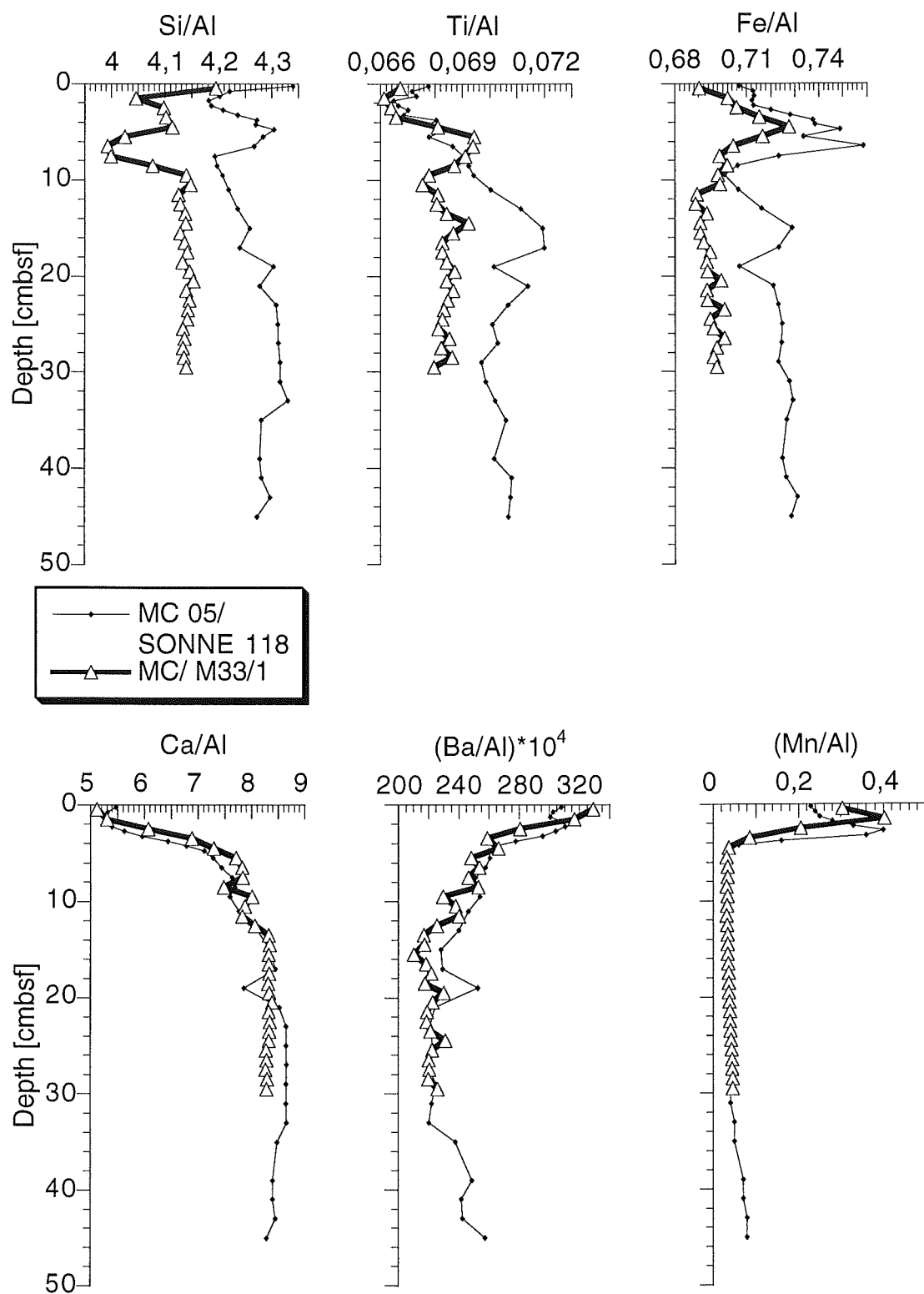


Figure 4: WAST-Plain, Multicorer samples

In the gravity core (Fig. 3) Ca/Al- and Ba/Al-ratios are showing similar trends, except for the core tops (Fig. 4). Ba/Al-ratios may reflect changes in bioproductivity and concomitant shoaling of the CCD.

SAST, gravity core

The top of the gravity core from SAST was disturbed, therefore the first centimeters could not be used for sampling. From the bottom of the core to 85 cmbsf at least one or more turbidites are present. Comparison of the turbidite-free sections of SAST (10-85 cm) and WAST-Plain (45-120 cm) gravity cores shows similar trends for Ca, Sr, Si and Ba (normalized to Al) (see Fig. 5). The similarity of these sections supports the assumption that turbidites are present. In future further XRF analyses will be performed to decide whether one or more turbidites are actually located at station SAST.

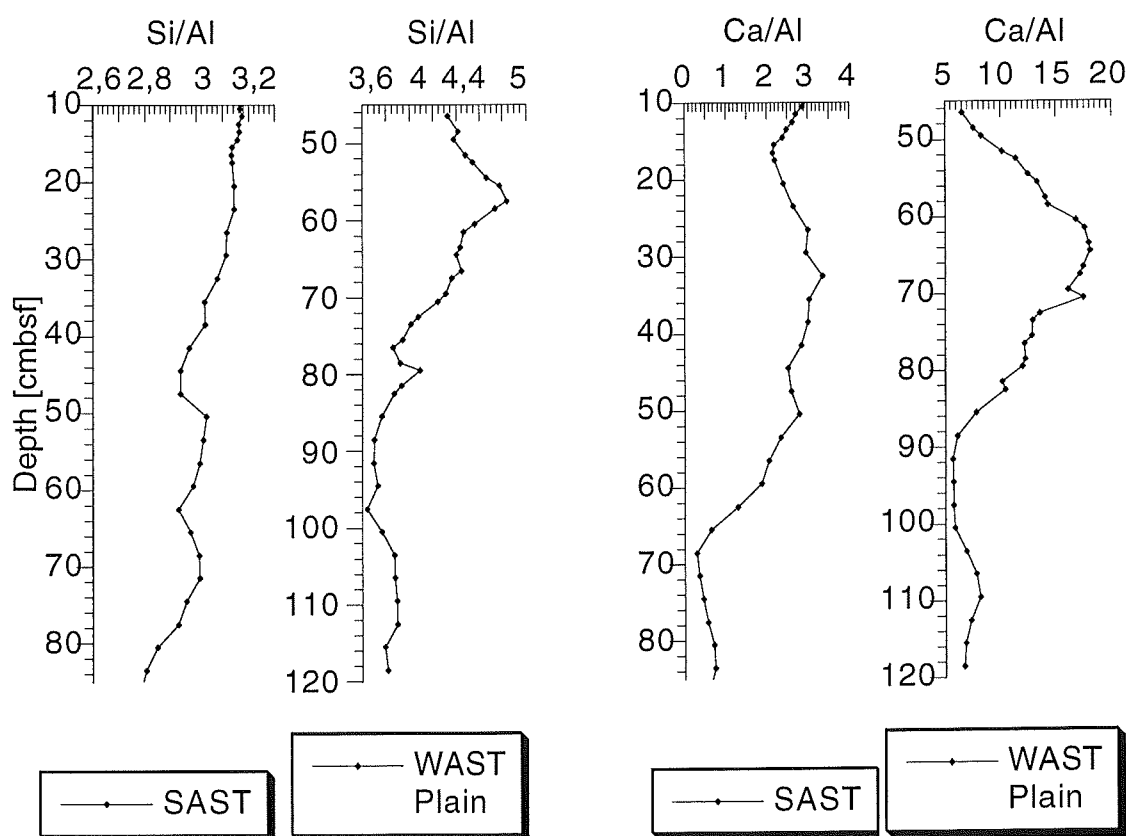


Figure 5a: Comparison between SAST and WAST-Plain samples

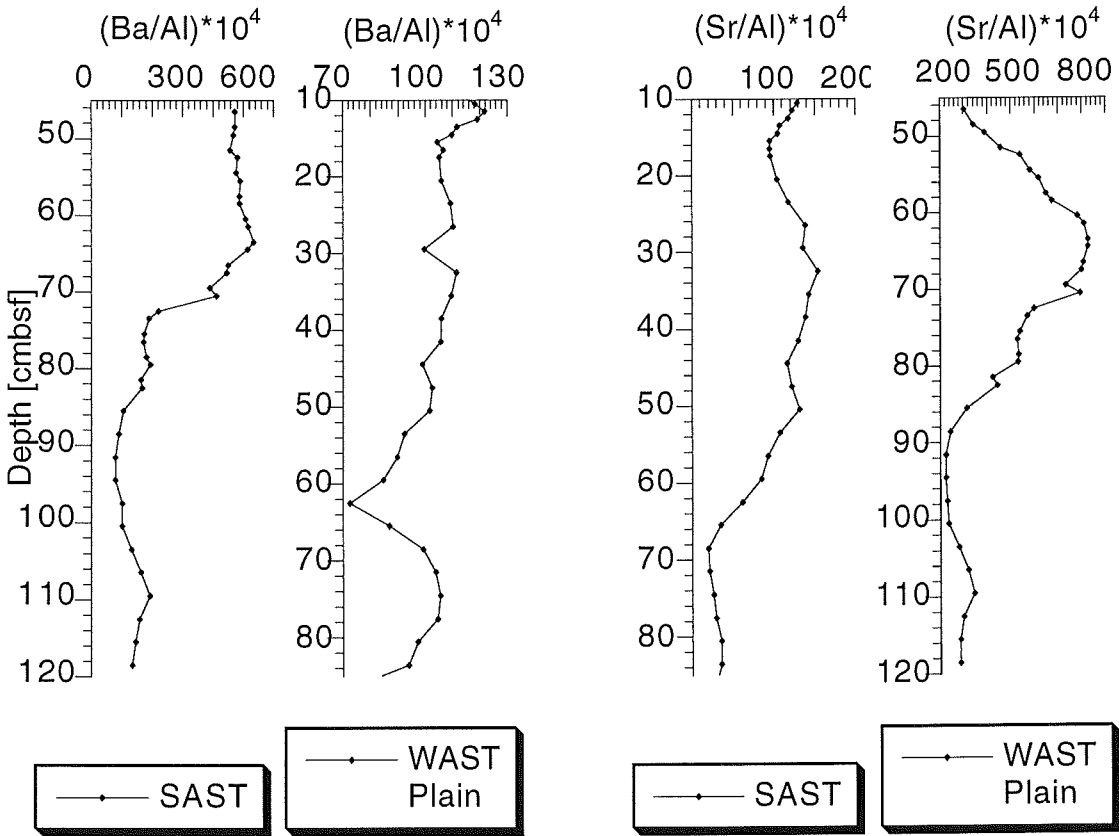


Figure 5b: Comparison between SAST and WAST-Plain samples

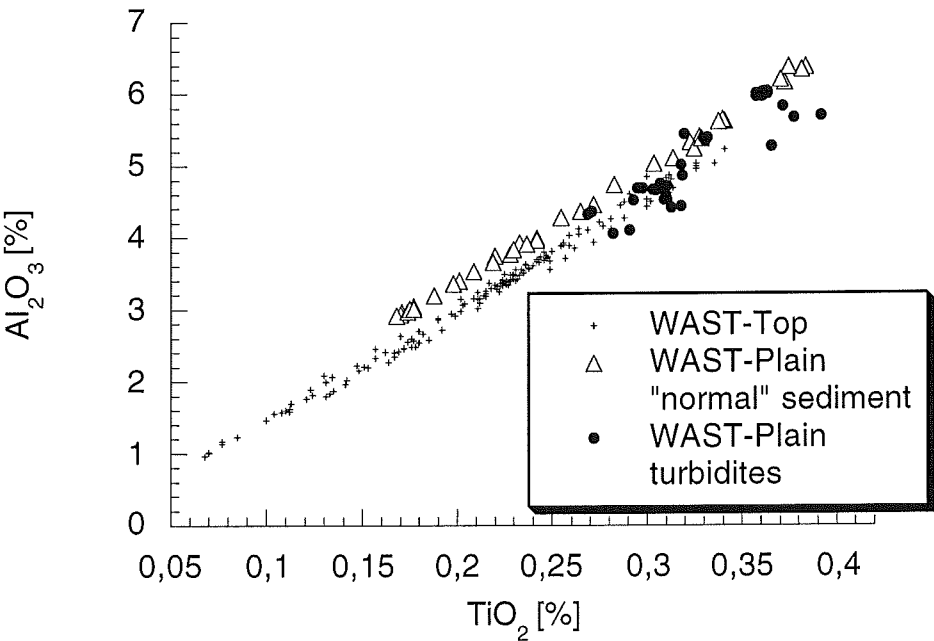


Figure 6: Comparison between WAST-Plain and Top

WAST-Top, gravity core

The core from WAST-Top was taken at significantly shallower water depth than those from SAST and WAST-Plain (Tab.1). For this reason the carbonate content is on average higher by a factor of two. This corresponds to the carbonate content of the WAST-Plain turbidites. In Fig. 6 a comparison is shown between WAST-Top, the "normal" sediment and the turbidite-material from WAST-Plain. Referring to this it seems likely that the turbidite-material is at least partly derived from WAST-Top.

Conclusions

Comparing the stations WAST-Top, WAST-Plain and SAST, the highest amounts of CaO were found at WAST-Top, followed by WAST-Plain and SAST (CCD). Nearly all samples may be regarded as mixtures of an average shale component and CaO. The assumption, that turbidites are present at WAST-Plain seems to be likely, because of following reasons:

1. the depth profiles of Si/Al, Ti/Al, Zr/Al, and Cr/Al (WAST-Plain) show enrichments in the bases of the turbidites, related to higher quantities of heavy minerals and quartz due to grain size sorting effects.
2. the variations of element ratios within the turbidites (except the base) are only small.
3. depth profiles of Si/Al, Ca/Al, Ba/Al, and Sr/Al of the interval between the top two turbidites of WAST-Plain are showing parallels to the top of SAST.
4. In their relationship of Al_2O_3 to TiO_2 most samples of the turbidites have more similarities to those from WAST-Top than to the "normal" sediments of WAST-Plain.

6. Acknowledgements

Cruise SONNE 118 was financed by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF, Project No. 03 G 0118 A) and by BMBF grant No. 03 F 0177 A (BIGSET), which are part of its deep-sea initiative. Project review and administration was handled by the Forschungszentrum Jülich GmbH, Projektträger BEO. We thank these institutions and their staff for their support. Cruise SONNE 118 was a very successful expedition with nearly all of the projected research programmes fulfilled. This excellent result was made possible by the good cooperation and proficient technical assistance by captain Henning Papenhagen and his crew, which we gratefully acknowledge.

7. List of stations

Abbreviations of gears:

ADCP: Acoustic Doppler Current Profiler

SF: Sediment Trap

BWS: Bottom Water Sampler

SL: Gravity Corer

EXPLOS: TV-sled (Exploration System)

MC: Multicorer

FFB: Free Fall Observation System

FFR: Free Fall Respirometer

CTD: Multisonde/Rosette water sampler

HS: HYDROSWEEP

PS: PARASOUND

KG: Boxgrab

Station No.	Date	Time (UTC)	Gear	Area	Latitude N°	Longitude E°	Depth (m)	Wire Length (m)
1#1	03.04.1997		CTD-01	WAST	16°13.0'N	60°15.9'E	4047	800
1#2	03.04.1997	12.16	CTD-02	WAST	16°12.98'N	60°19.99'E	4042	4020
			ADCP-01	WAST				
2#1	03.04.1997	20.36	MC-01	WAST-Top	16°10.73'N	55°45.66'E	1918	1935
2#2	03.04.1997	22.25	MC-02	WAST-Top	16°10.44'N	59°45.90'E	1916	1933
2#3	04.04.1997	0.00	KG-01	WAST-Top	16°10.49'N	59°45.96'E	1915	1932
3	04.04.1997	10.25	FFB-Test	WAST	16°12.94'N	60°15.72'E	4043	3800
			ADCP-02					
4#1	04.04.1997	9.28	MC-03	WAST	16°13.00'N	60°16.02'E	4041	4061
4#2	04.04.1997	12.33	MC-04	WAST	16°12.99'N	60°16.00'E	4044	4067
4#3	04.04.1997	15.21	MC-05	WAST	16°12.97'N	60°15.97'E	4045	4070
4#4	04.04.1997	18.10	KG-02	WAST	16°13.00'N	60°16.00'E	4043	4037
5#1	04.04.1997	19.27	CTD-03	WAST	16°12.98'N	60°16.02'E	4044	2500
			ADCP-03					
5#2	05.04.1997	21.40	MSN-01	WAST	16°12.99'N	60°15.96'E	4045	2500
5#3	05.04.1997	1.40	MSN-02	WAST	16°13.05'N	60°16.06'E	4032	700

Station No.	Date	Time (UTC)	Gear	Area	Latitude N°	Longitude E°	Depth (m)	Wire Length (m)
5#4	05.04.1997	6.56	MSN-03	WAST	16°13.01'N	60°15.99'E	4040	100
6#1	05.04.1997	4.35	MC-06	WAST	16°12.98'N	60°15.98'E	4045	4040
6#2	05.04.1997	6.41	MC-07	WAST	16°12.99'N	60°15.96'E	4041	4052
7	05.04.1997	10.06	BWS-01	WAST	16°13.02'N	60°15.96'E	4041	4065
8	05.04.1997	12.23	CTD-04	WAST	16°13.21'N	60°15.96'E	4043	10
10	05.04.1997	23.16	HS/PS	WAST	16°15.00'N	60°13.00'E	4026	
11#1	06.04.1997	6.14	MC-08	WAST-Top	16°10.49'N	59°46.00'E	1916	1930
11#2	06.04.1997	7.32	MC-09	WAST-Top	16°10.48'N	59°45.97'E	1915	1927
11#3	06.04.1997	10.21	BWS-02	WAST-Top	16°10.53'N	59°45.90'E	1915	1926
11#4	06.04.1997	13.00	Explos-1	WAST-Top	16°10.38'N	59°46.37'E	1915	1917
12	06.04.1997	18.19	BWS-03	WAST-Top	16°10.52'N	59°45.99'E	1916	1921
13#1	06.04.1997	22.43	CTD-05	WAST	16°13.04'N	60°16.00'E	4042	4033
13#2	07.04.1997	2.30	WP2-1	WAST	16°12.98'N	60°15.98'E	4042	135
13#3	07.04.1997	6.46	MC-10	WAST	16°12.99'N	60°15.99'E	4046	4046
13#4	07.04.1997	9.24	MC-11	WAST	16°13.02'N	60°16.02'E	4042	4050
13#5	07.04.1997	10.36	MSN-04	WAST	16°13.04'N	60°15.95'E	4042	100
14	07.04.1997	11.15	SF-01	WAST	16°14.14'N	60°17.49'E	4039	
15	07.04.1997	13.14	FFR-01	WAST	16°15.02'N	60°15.95'E	4044	
16#1	07.04.1997	14.28	CTD-06	WAST	16°12.99'N	60°16.01'E	4045	4040
			ADCP-04					
16#2	07.04.1997	20.20	BWS-04	WAST	16°13.01'N	60°15.99'E	4043	4056
18#1	08.04.1997	8.20	WP2-2	WAST	16°12.99'N	60°15.96'E	4040	285
18#2	08.04.1997	13.45	KG-03	WAST	16°13.02'N	60°16.02'E	4045	4028
19	08.04.1997	15.14	FFB-01	WAST	16°10.99'N	60°15.92'E	4045	
21	08.04.1997	17.57	Explos-02	WAST	16°12.99'N	60°15.96'E	4043	4044

Station No.	Date	Time (UTC)	Gear	Area	Latitude N°	Longitude E°	Depth (m)	Wire Length (m)
22#1	09.04.1997	2.20	MC-12	WAST-Top	16°10.54'N	59°45.96'E	1914	1915
22#2	09.04.1997	3.35	MC-13	WAST-Top	16°10.52'N	59°46.02'E	1916	1925
22#3	09.04.1997	6.36	BWS-05	WAST-Top	16°10.52'N	59°46.01'E	1915	1924
24#1	09.04.1997	16.45	MC-14	WAST	16°13.00'N	60°15.99'E	4044	4044
24#2	09.04.1997	19.04	FFR-02	WAST	16°14.08'N	60°15.97'E	4043	
24#3	09.04.1997	20.00	KG-04	WAST	16°12.99'N	60°15.99'E	4045	4032
26#1	10.04.1997	4.05	CTD-07	WAST-Top	16°10.49'N	59°45.96'E	1916	1911
26#2	10.04.1997	6.09	CTD-08	WAST-Top	16°10.47'N	59°46.00'E	1916	1800
26#3	10.04.1997	8.20	MC-15	WAST-Top	16°10.45'N	59°46.02'E	1915	1923
26#4	10.04.1997	10.18	BWS-06	WAST	16°10.46'N	59°45.82'E	1917	1926
27#1	10.04.1997	14.00	WP2-3	WAST	16°14.12'N	60°15.95'E	4040	285
27#2	10.04.1997	17.02	MC-16	WAST	16°12.99'N	60°16.01'E	4045	4030
27#3	10.04.1997	19.25	KG-05	WAST	16°13.00'N	60°15.99'E	4042	4029
28	12.04.1997	9.56	FFR-03	SAST	10°06.96'N	65°00.19'E	4424	
29	12.04.1997	9.40	SF-02	SAST	10°02.99'N	65°02.02'E		
29	12.04.1997	9.40	WP2-4	SAST	10°02.99'N	65°02.02'E	4420	285
30#1	12.04.1997	14.56	MC-17	SAST	10°02.00'N	65°00.00'E	4424	4432
30#2	12.04.1997	17.30	KG-06	SAST	10°02.02'N	65°00.00'E	4425	4420
30#3	12.04.1997	20.00	MC-18	SAST	10°02.00'N	65°00.00'E	4426	4424
30#4	12.04.1997	22.54	MC-19	SAST	10°01.92'N	64°59.96'E	4425	4440
30#5	13.04.1997	2.46	BWS-07	SAST	10°02.00'N	65°00.00'E	4423	4431
31#1	13.04.1997	7.00	CTD-09	SAST	10°02.00'N	65°00.00'E	4423	4425
31#2	13.04.1997	8.56	CTD-10	SAST	10°01.94'N	64°59.92'E	4422	4125
31#3	13.04.1997	12.02	MSN-05	SAST	10°02.10'N	64°59.99'E	4425	700
31#4	13.04.1997	13.15	CTD-11	SAST	10°02.01'N	65°00.00'E	4426	2500
31#5	13.04.1997	15.23	MSN-06	SAST	10°02.06'N	65°00.00'E	4422	100

Station No.	Date	Time (UTC)	Gear	Area	Latitude N°	Longitude E°	Depth (m)	Wire Length (m)
31#6	13.04.1997	17.04	MSN-07	SAST	10°01.93'N	65°00.70'E	4424	2500
31#7	13.04.1997	19.46	Explos-03	SAST	10°02.20'N	65°00.00'E	4425	4424
31#8	14.04.1997	3.00	WP2-5	SAST	10°02.02'N	65°00.19'E	4425	285
31#8	14.04.1997	11.15	WP2-6	SAST	10°01.23'N	65°00.27'E	4425	285
31#9	14.04.1997	7.04	MC-20	SAST	10°02.03'N	64°59.99'E	4425	4433
33	14.04.1997	1.55	BWS-08	SAST	10°02.10'N	65°00.03'E	4424	4436
34#2	15.04.1997	5.53	SF-02	SAST	10°03.42'N	65°01.08'E		
35#1	15.04.1997	8.03	MC-21	SAST	10°01.98'N	65°00.00'E	4426	4426
35#2	15.04.1997	10.56	KG-07	SAST	10°02.00'N	65°00.00'E	4426	4416
35#3	15.04.1997	13.40	SL-01	SAST	10°01.99'N	65°00.01'E	4425	4420
35#4	15.04.1997	16.20	MC-22	SAST	10°02.01'N	64°59.98'E	4425	4439
35#5	15.04.1997	18.58	KG-08	SAST	10°01.99'N	64°59.99'E	4427	4421
36	15.04.1997	20.41	Explos-04	SAST	10°01.02'N	65°00.45'E	4423	4424
37	16.04.1997	2.31	SF-02	SAST	10°02.80'N	65°02.30'E		7500
38#1	16.04.1997	12.25	MSN-08	SAST	10°01.02'N	65°00.14'E	4430	100
38#2	16.04.1997	12.57	MSN-09	SAST	10°01.05'N	65°00.15'E	4426	500
39#1	16.04.1997	15.53	MC-23	SAST	10°01.99'N	65°00.00'E	4424	4435
39#2	16.04.1997	17.11	CTD-12	SAST	10°02.02'N	65°00.02'E	4424	4425
39#3	16.04.1997	21.52	HS/PS	SAST	10°03.82'N	64°54.99'E		
41	17.04.1997	22.52	MC-24	SAST/WAST	13°05.11'N	62°44.99'E	4168	4173
42	18.04.1997	18.20	HS/PS	WAST-Top	16°10.50'N	59°46.00'E		
43#1	19.04.1997	23.02	MC-25	WAST-Top	16°10.53'N	59°46.03'E	1914	1925
43#2	19.04.1997	0.34	MC-26	WAST-Top	16°10.55'N	59°46.05'E	1916	1927
43#3	19.04.1997	2.41	BWS-09	WAST-Top	16°10.52'N	59°46.00'E	1915	1928
43#4	19.04.1997	4.35	MC-27	WAST-Top	16°10.05'N	59°46.99'E	1915	1927
43#5	19.04.1997	5.20	CTD-13	WAST-Top	16°10.50'N	59°45.99'E		100

Station No.	Date	Time (UTC)	Gear	Area	Latitude N°	Longitude E°	Depth (m)	Wire Length (m)
43#6	19.04.1997	6.15	MC-28	WAST-Top	16°10.51'N	59°46.00'E	1916	1927
45#1	19.04.1997	7.15	HS/PS	WAST-Top	16°10.50'N	59°46.00'E		
45#2	19.04.1997	12.37	MSN-10	WAST	16°10.99'N	60°15.99'E	4049	100
46#1	19.04.1997	15.00	KG-09	WAST	16°12.99'N	60°16.08'E	4043	4036
46#2	19.04.1997	17.20	MC-29	WAST	16°13.00'N	60°16.00'E	4045	4057
46#3	19.04.1997	1.34	BWS-10	WAST	16°12.90'N	60°16.00'E	4044	4051
49	20.04.1997	4.08	SF-01	WAST	16°14.02'N	60°17.98'E	4045	
50#1	20.04.1997	7.25	MC-30	WAST	16°13.00'N	60°15.99'E	4045	4047
50#2	20.04.1997	8.50	CTD-14	WAST	16°12.97'N	60°15.94'E	4045	600
50#3	20.04.1997	10.45	KG-10	WAST	16°12.99'N	60°15.96'E	4043	4040
50#4	20.04.1997	13.25	MC-31	WAST	16°13.01'N	60°16.01'E	4040	4050
52	21.04.1997	2.22	FFB-02	WAST	16°11.97'N	60°16.00'E	4045	
53#1	21.04.1997	3.50	MC-32	WAST	16°12.99'N	60°15.99'E	4043	4044
53#2	21.04.1997	6.10	SL-02	WAST	16°13.01'N	60°15.99'E	4046	4034
53#3	21.04.1997	7.19	CTD-15	WAST	16°13.00'N	60°15.98'E	4043	4038
53#4	21.04.1997	13.55	CTD-16	WAST	16°12.99'N	60°15.98'E	4041	3990
53#5	21.04.1997	14.57	CTD-17	WAST	16°13.00'N	60°15.96'E	4044	600
54	22.04.1997	3.37	MC-33	WAST/CAST	15°19.99'N	62°19.99'E	3975	3982
55	22.04.1997	16.12	CTD-18	CAST	14°24.96'N	64°34.03'E	3955	600
57	23.04.1997	4.00	SF-03	CAST	14°22.95'N	64°33.74'E	3963	
58#1	23.04.1997	6.09	CTD-19	CAST	14°29.09'N	64°34.00'E	3955	3946
58#2	23.04.1997	10.30	MC-34	CAST	14°24.99'N	64°34.00'E	3953	3958
58#3	23.04.1997	12.55	MC-35	CAST	14°24.99'N	64°33.99'E	3954	3966
58#4	23.04.1997	15.19	KG-11	CAST	14°25.01'N	64°33.99'E	3956	3952
58#5	23.04.1997	17.40	Explos-05	CAST	14°25.01'N	64°33.99'E	3955	3959
59#1	24.04.1997	21.50	CTD-20	CAST	14°25.13'N	64°33.05'E	3954	2500

Station No.	Date	Time (UTC)	Gear	Area	Latitude N°	Longitude E°	Depth (m)	Wire Length (m)
59#2	24.04.1997	23.51	MSN-11	CAST	14°25.02'N	64°34.00'E	3956	100
59#3	24.04.1997	1.33	MSN-12	CAST	14°25.03'N	64°34.00'E	3954	2500
59#4	24.04.1997	4.05	MSN-13	CAST	14°24.99'N	64°34.00'E	3955	700
60#1	24.04.1997	7.24	BWS-11	CAST	14°24.99'N	64°34.00'E	3957	3969
60#2	24.04.1997	10.56	MC-36	CAST	14°24.96'N	64°33.90'E	3957	3987
60#3	24.04.1997	13.23	MC-37	CAST	14°24.99'N	64°34.00'E	3955	3966
60#4	24.04.1997	15.36	KG-12	CAST	14°25.02'N	64°33.99'E	3956	3955
62#1	25.04.1997	4.43	MSN-14	CAST	14°25.05'N	64°34.03'E	3955	2500
62#2	25.04.1997	7.27	CTD-21	CAST	14°24.98'N	64°33.97'E	3957	60
62#3	25.04.1997	9.00	SL-03	CAST	14°24.99'N	64°33.98'E	3955	3943
62#4	25.04.1997	11.29	MC-38	CAST	14°24.99'N	64°34.00'E	3952	3938
62#5	25.04.1997	13.39	KG-13	CAST	14°25.00'N	64°33.99'E	3956	3938
62#6	25.04.1997	17.16	BWS-12	CAST	14°24.99'N	64°34.02'E	3956	3969
66	26.04.1997	7.05	SF-03	CAST	14°23.07'N	64°33.81'E	3962	
67#1	26.04.1997	10.10	MC-39	CAST	14°25.00'N	64°33.98'E	3955	3962
67#2	26.04.1997	12.34	MC-40	CAST	14°25.00'N	64°33.99'E	3956	3962
67#3	26.04.1997	13.40	CTD-22	CAST	14°24.98'N	64°34.04'E	3955	3949
67#4	26.04.1997	17.48	CTD-23	CAST	14°25.03'N	64°34.06'E	3956	3904
68	26.04.1997	20.51	HS/PS	CAST/NAST	14°24.09'N	64°34.24'E		
69	28.04.1997	2.04	SF-04	NAST	19°56.71'N	65°35.08'E	3173	
70#1	28.04.1997	4.45	MC-41	NAST	20°00.01'N	65°34.99'E	3187	3193
70#2	28.04.1997	6.43	MC-42	NAST	19°59.99'N	65°35.00'E	3186	3197
70#3	28.04.1997	7.55	MC-43	NAST	19°59.99'N	65°35.00'E	3189	3187
70#4	28.04.1997	11.34	BWS-13	NAST	19°59.99'N	65°34.99'E	3189	3195
70#5	28.04.1997	14.09	KG-14	NAST	19°59.98'N	65°35.02'E	3188	3190
71#1	28.04.1997	15.07	CTD-24	NAST	19°59.99'N	65°34.97'E	3187	2500

Station No.	Date	Time (UTC)	Gear	Area	Latitude N°	Longitude E°	Depth (m)	Wire Length (m)
71#2	28.04.1997	17.21	MSN-15	NAST	19°59.95'N	65°34.99'E	3188	100
71#3	28.04.1997	17.46	MSN-16	NAST	19°59.99'N	64°35.00'E	3186	2500
71#4	29.04.1997	21.46	MSN-17	NAST	19°59.99'N	65°34.01'E	3188	700
72	29.04.1997	23.00	HS/PS	NAST	20°00.00'N	65°35.00'E		
73#1	29.04.1997	3.28	MC-44	NAST	19°59.99'N	65°35.01'E	3186	3195
73#2	29.04.1997	5.15	CTD-25	NAST	19°59.99'N	65°34.99'E	3186	60
73#3	29.04.1997	7.37	BWS-14	NAST	19°59.99'N	65°34.99'E	3187	3196
73#4	29.04.1997	10.15	SL-04	NAST	20°00.00'N	65°34.99'E	3188	3188
73#5	29.04.1997	12.10	KG-15	NAST	19°59.99'N	65°34.99'E	3189	3189
74	29.04.1997	13.16	Explos-06	NAST	20°00.28'N	65°35.07'E	3185	3204
76#1	30.04.1997	2.23	CTD-26	NAST	19°59.98'N	65°35.00'E	3186	3178
76#2	30.04.1997	5.26	MC-45	NAST	20°00.01'N	65°35.00'E	3188	3192
76#3	30.04.1997	7.24	MC-46	NAST	19°59.99'N	65°34.99'E	3188	3194
76#4	30.04.1997	9.18	KG-16	NAST	20°00.01'N	65°35.01'E	3188	3183
76#5	30.04.1997	10.16	MSN-18	NAST	20°00.01'N	65°34.99'E	3187	100
76#6	30.04.1997	10.39	CTD-27	NAST	20°00.00'N	65°34.98'E	3189	3183
76#7	30.04.1997	13.04	CTD-28	NAST	20°00.00'N	65°34.99'E	3188	3138
78	01.05.1997	3.11	Explos-07	NAST	20°00.16'N	65°35.06'E	3188	3185
79	01.05.1997	9.10	SF-04	NAST	19°56.77'N	65°35.01'E	3175	
80	02.05.1997	3.03	MC-47	NAST/WAST	18°00.80'N	62°48.81'E	3656	3647
82#1	02.05.1997	21.37	KG-17	WAST	16°13.02'N	60°16.02'E	4045	4028
82#2	03.05.1997	1.17	BWS-15	WAST	16°13.01'N	60°15.98'E	4045	4053
83	03.05.1997	3.40	SF-05	WAST	16°14.01'N	60°17.96'E	4041	
84	03.05.1997	5.00	HS/PS	WAST/Top	16°14.00'N	60°00.00'E	4040-1900	
85#1	03.05.1997	13.33	MC-48	WAST-Top	16°10.40'N	59°46.03'E	1916	1931
85#2	03.05.1997	15.29	MC-49	WAST-Top	16°10.49'N	59°46.01'E	1917	1931

Station No.	Date	Time (UTC)	Gear	Area	Latitude N°	Longitude E°	Depth (m)	Wire Length (m)
85#3	03.05.1997	16.25	KG-18	WAST-Top	16°10.49'N	59°46.01'E	1917	1910
86	03.05.1997	17.42	FFB-03	WAST-Top	16°09.96'N	59°44.92'E	1935	
88#1	04.05.1997	5.46	MC-50	WAST	16°13.00'N	60°15.99'E	4052	4029
88#2	04.05.1997	6.57	CTD-29	WAST	16°12.99'N	60°16.01'E	4046	
88#3	04.05.1997	8.40	MC-51	WAST	16°13.04'N	60°16.01'E	4045	4036
88#4	04.05.1997	10.57	KG-19	WAST	16°13.02'N	60°16.00'E	4047	4034
88#5	04.05.1997	14.31	BWS-16	WAST	16°13.00'N	60°16.01'E	4045	4055
88#6	04.05.1997	21.28	CTD-30	WAST	16°12.99'N	60°16.04'E	4042	2500
88#7	04.05.1997	23.34	MSN-19	WAST	16°12.99'N	60°15.99'E	4044	100
88#8	04.05.1997	23.56	MSN-20	WAST	16°13.07'N	60°16.20'E	4043	2500
88#9	05.05.1997	3.51	MSN-21	WAST	16°12.98'N	60°16.02'E	4044	700
89	05.05.1997	7.00	HS/PS	WAST	16°09.97'N	59°44.42'E	4000-1900	
90#1	05.05.1997	12.40	SL-05	WAST-Top	16°10.51'N	59°45.99'E	1919	1916
90#2	05.05.1997	14.41	MC-52	WAST-Top	16°10.49'N	59°45.99'E	1920	1909
90#3	05.05.1997	16.21	SL-06	WAST-Top	16°10.48'N	59°46.00'E	1920	1917
90#4	05.05.1997	19.00	BWS-17	WAST-Top	16°10.48'N	59°46.01'E	1913	1927
90#5	05.05.1997	20.59	KG-20	WAST-Top	16°10.51'N	59°45.98'E	1915	1907
91	05.05.1997	22.27	Explos-08	WAST-Top	16°10.49'N	59°46.01'E	1914	1913
92#1	06.05.1997	6.52	MC-53	WAST	16°13.00'N	60°16.00'E	4048	4034
92#3	06.05.1997	9.21	MC-54	WAST	16°13.01'N	60°15.99'E	4041	4035
92#4	06.05.1997	10.33	CTD-31	WAST	16°12.99'N	60°16.00'E	4043	4042
92#5	06.05.1997	13.39	CTD-32	WAST	16°13.00'N	60°16.00'E	4055	2880
94#1	07.05.1997	4.03	MSN-22	WAST	16°14.04'N	60°17.97'E	4048	100
94#2	07.05.1997	4.29	MSN-23	WAST	16°14.01'N	60°16.02'E	4043	700
96	07.05.1997	6.11	SF-04	WAST	16°13.92'N	60°18.28'E	4042	
99	07.05.1997	16.04	Explos-09	WAST	16°12.66'N	59°46.99'E	1883	1882
101	08.05.1997	6.00	HS/PS	WAST-Top	16°11.00'N	59°42.00'E		

8. Appendix

Tab. 1: Station numbers, sampling dates and sampling positions of BWS (lower part of the table) and CTD deployments (upper part of the table) for subproject 2.

WAST-Plain				WAST-Top				SAST				CAST				NAST			
Stat.-No.	Device	Date	Position	Stat.-No.	Device	Date	Position	Stat.-No.	Device	Date	Position	Stat.-No.	Device	Date	Position	Stat.-No.	Device	Date	Position
16#1	CTD-06	07. Apr	16°12.99' N 60°16.01' E	26#1	CTD-07	10. Apr	16°10.49' N 59°45.96' E	31#1	CTD-09	13. Apr	10°02.00' N 65°00.00' E	67#3	CTD-22	26. Apr	14°24.48' N 64°34.04' E	76#6	CTD-27	30. Apr	20°00.00' N 65°34.98' E
53#3	CTD-15	21. Apr	16°13.00' N 60°15.98' E	26#2	CTD-08	10. Apr	16°10.47' N 59°46.00' E	31#2	CTD-10	13. Apr	10°01.94' N 64°59.92' E	67#4	CTD-23	26. Apr	14°25.03' N 64°34.06' E	76#7	CTD-28	30. Apr	20°00.00' N 65°34.99' E
53#4	CTD-16	21. Apr	16°12.99' N 60°15.98' E																
6#3	BWS-01	05. Apr	16°13.00' N 60°15.00' E	11#2	BWS-02	06. Apr	16°10.55' N 59°46.02' E	30#5	BWS-07	13. Apr	10°02.00' N 65°00.00' E	60#1	BWS-11	24. Apr	14°25.00' N 64°34.01' E	70#4	BWS-13	28. Apr	19°59.99' N 65°34.98' E
16#2	BWS-04	07. Apr	16°13.00' N 60°16.00' E	11#4	BWS-03	06. Apr	16°10.51' N 59°46.01' E	33#2	BWS	08. Apr	10°02.02' N 65°00.05' E	62#5	BWS-12	25. Apr	14°25.00' N 64°34.02' E	73#3	BWS-14	29. Apr	19°59.99' N 65°34.99' E
43#3	BWS-09	18. Apr	10°10.54' N 59°45.86' E	22#2	BWS-05	09. Apr	16°10.00' N 59°46.00' E												
48	BWS-10	19. Apr	16°12.97' N 60°16.01' E	26#4	BWS-06	10. Apr	16°10.46' N 59°45.87' E												
82#2	BWS-15	2. May	16°13.02' N 60°15.98' E	90#4	BWS-17	5. May	16°10.48' N 59°46.00' E												
88#5	BWS-16	4. May	16°13.00' N 60°16.00' E																

Tab. 2: Information on the short time sediment trap moorings sampled for particulate ^{234}Th .

station	position	date	mooring	sampling intervall	depth of the trap [m]	height above seafloor [m]
WAST 14	16°14.17'N	07. Apr	WAST-ST-01	8 April 06:00 - 12 April 06:00	3478	563
WAST 49	60°17.50'E			12 April 06:00 - 16 April 06:00 16 April 06:00 - 20 April 06:00		
CAST 57 & 66	14°22.95'N	23. Apr	CAST-ST-01	23 April 10:30 - 26 April 10:30	3398	563
	64°33.74'E					
NAST 69 & 79	19°56.71'N	28. Apr	NAST-ST-01	28 April 09:00 - 1 May 09:00	2610	561
	65°35.09'E					
WAST 83 & 96	16°13.91'N	3. May	WAST-ST-02	3 May 10:00 - 7 May 10:00	3482	561
	60°18.08'E					

Table 3: Stations, depths and positions sampled for sedimentary ^{234}Th and ^{210}Pb .

parameter	station	station-no.	device	no. of cores	layers	sampled	depth [m]	position
^{210}Pb	WAST-Top	2	MC2	1		all *	1916	16°10.44'N 59°45.90'E
		11	MC9	1		all *	1916	16°10.5'N 59°46'E
	WAST-Plain	4#2	MC4	1		all *	4045	16°13'N 60°16'E
		4#3	MC5	1		all *	4047	16°12.97'N 60°15.97'E
	SAST	35#1	MC21	3		all *	4426	10°01.98'N 65°00.00'E
	SAST-WAST	41	MC24	3		all *	4168	13°05.11'N 62°45.00'E
	WAST-CAST	54	MC33	3		all *	3977	15°19.99'N 62°19.99'E
	CAST							
	CAST	60#2	MC36	2		all *	3955	14°24.96'N 64°33.90'E
		67#2	MC40	1		all *	3959	14°25.00'N 64°34.00'E
	NAST	70#2	MC42	3		all *	3188	19°59.99'N 65°35.00'E
	NAST-WAST	80	MC47	3		all *	3656	18°00.80'N 62°48.81'E
	WAST							
^{234}Th	WAST-Plain	4#2	MC4	1		+	4045	16°13'N 60°16'E
		4#3	MC5	1		+	4047	16°12.97'N 60°15.97'E
	SAST	35#1	MC21	2		flufflayer	4426	10°01.98'N 65°00.00'E
	WAST-Top	43#2	MC26	1		flufflayer	1916	16°10.55'N 59°46.05'E
	CAST	60#2	MC36	2		+	3955	14°24.96'N 64°33.90'E
	NAST	70#2	MC42	2		+	3188	19°59.99'N 65°35.00'E

* 0-3cm in 0.5cm steps, 3-10cm in 1cm steps, 10cm down to the deepest parts in 2cm steps

+ Flufflayer and/or 0-0.5cm, 0.5-1cm, 1-1.5cm, 1.5-2cm, 3-4cm

Table 4. Parameters measured in samples from CTD 06 (station 16#1) at WAST-Plain.

Sample bottle	depth[m]	height above seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part.234Th	diss.234Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	4040	5							+				
23	4040	5							+				
22	4040	5	+	+	+	+	+		+				+
21	4040	5	+	+	+	+	+						+
20	3990	50							+				
19	3990	50							+				
18	3990	50	+	+	+	+	+		+				+
17	3990	50	+	+	+	+	+						+
16	3940	100											
15	3940	100											
14	3940	100	+	+	+	+	+						+
13	3940	100	+	+	+	+	+						+
12	3740	300							+				
11	3740	300							+				
10	3740	300	+	+	+	+	+		+				+
9	3740	300	+	+	+	+	+						+
8	3540	500											
7	3540	500											
6	3540	500	+	+	+	+	+						+
5	3540	500	+	+	+	+	+						+
4	3040	1000											
3	3040	1000											
2	3040	1000	+	+	+	+	+						+
1	3040	1000	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7

Table 5. Parameters measured in samples from CTD 07 (station 26#1) at WAST-Top.

Samplebottle	depth[m]	heightabove seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part234Th	diss.234Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	1911	5						+	+				
23	1911	5						+	+				
22	1911	5						+	+				
21	1911	5	+	+	+	+	+						+
20	1911	5	+	+	+	+	+			+	+		+
19	1911	5								+	+		
18	1911	5								+	+		
17	1911	5								+	+		
16	1911	5								+	+		
15	1911	5								+	+		
14	1911	5								+	+		
13	1860	50						+	+				
12	1860	50						+	+				
11	1860	50						+	+				
10	1860	50						+	+		+	+	
9	1860	50								+	+	+	
8	1860	50								+	+	+	
7	1860	50								+	+	+	
6	1860	50								+	+	+	
5	1860	50								+	+	+	
4	1860	50	+	+	+	+	+						+
3	1860	50	+	+	+	+	+						+
2	1810	100	+	+	+	+	+						+
1	1810	100	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7

Table 6. Parameters measured in samples from CTD 08 (station 26#2) at WAST-Top.

Sample bottle	depth[m]	height above seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part234Th	diss.234Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	1810	100						+					
23	1810	100						+					
22	1810	100						+					
21	1600	300						+					
20	1600	300						+					
19	1600	300						+					
18	1600	300	+	+	+	+	+						+
17	1600	300	+	+	+	+	+						+
16	1400	500						+					
15	1400	500					+	+					
14	1400	500					+	+					
13	1400	500	+	+	+	+	+						+
12	1400	500	+	+	+	+	+						+
11	1400	500								+		+	
10	1400	500								+		+	
9	1400	500								+		+	
8	1400	500								+		+	
7	1400	500								+		+	
6	1400	500								+		+	
5	900	1000					+	+					
4	900	1000					+	+					
3	900	1000					+	+					
2	900	1000	+	+	+	+	+	+					+
1	900	1000	+	+	+	+	+	+					+

* measured by subproject 4

measured by subproject 7

Table 7. Parameters measured in samples from CTD 09 (station 31#1) at SAST.

Sample/bottle	depth[m]	height above seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part.234Th	diss.234Th	stable N&C isotopes*	carbohydrates*	amino acids*	nutrients#
24	4425	5								+	+	+	
23	4425	5								+	+	+	
22	4425	5								+	+	+	
21	4425	5								+	+	+	
20	4425	5								+	+	+	
19	4425	5								+	+	+	
18	4425	5						+	+	+	+	+	
17	4425	5						+	+				
16	4425	5						+	+				
15	4425	5	+	+	+		+						+
14	4375	50								+	+	+	
13	4375	50								+	+	+	
12	4375	50								+	+	+	
11	4375	50								+	+	+	
10	4375	50								+	+	+	
9	4375	50								+	+	+	
8	4375	50						+	+				
7	4375	50						+	+				
6	4375	50						+	+				
5	4375	50	+	+	+		+						+
4	4325	100						+	+				
3	4325	100						+	+				
2	4325	100						+	+				
1	4325	100	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7

Table 8. Parameters measured in samples from CTD 10 (station 31#2) at SAST.

Sample/bottle	depth[m]	height above seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part.234Th	diss.234Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	4125	300						+	+				
23	4125	300						+	+				
22	4125	300						+	+				
21	4125	300		+	+	+	+						+
20	3925	500						+	+				
19	3925	500						+	+				
18	3925	500						+	+				
17	3925	500	+	+	+	+	+			+	+		+
16	3925	500								+	+		
15	3925	500								+	+		
14	3925	500								+	+		
13	3925	500								+	+		
12	3925	500								+	+		
11	3925	500								+	+		
10	3925	500								+	+		
9	3925	500								+	+		
8	3925	500								+	+		
7	3925	500								+	+		
6	3925	500								+	+		
5	3925	500								+	+		
4	1000	3425						+	+				
3	1000	3425						+	+				
2	1000	3425						+	+				
1	1000	3425	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7

Table 9. Parameters measured in samples from CTD 15 (station 53#3) at WAST-Plain.

Samplebottle	depth[m]	heightabove seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part.234Th	diss.234Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	4038	5								+	+	+	
23	4038	5								+	+	+	
22	4038	5								+	+	+	
21	4038	5								+	+	+	
20	4038	5								+	+	+	
19	4038	5								+	+	+	
18	4038	5						+	+	+	+	+	
17	4038	5						+	+	+	+	+	
16	4038	5						+	+	+	+	+	
15	4038	5	+	+	+	+	+						+
14	4038	5	+	+	+	+	+						+
13	4018	25						+	+				
12	4018	25						+	+				
11	4018	25						+	+				
10	4018	25	+	+	+	+	+						+
9	4018	25	+	+	+	+	+						+
8	3990	50								+	+	+	
7	3990	50								+	+	+	
6	3990	50								+	+	+	
5	3990	50								+	+	+	
4	3990	50								+	+	+	
3	3990	50								+	+	+	
2	3990	50	+	+	+	+	+			+	+	+	
1	3990	50	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7

Table 10. Parameters measured in samples from CTD 16 (station 53#4) at WAST-Plain.

Sample bottle	depth[m]	height above seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part234Th	diss.234Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	3990	50						+	+				
23	3990	50						+	+				
22	3990	50						+	+				
21	3940	100						+	+				
20	3940	100						+	+				
19	3940	100						+	+				
18	3940	100	+	+	+	+	+						+
17	3940	100	+	+	+	+	+						+
16	3790	250						+	+				
15	3790	250						+	+				
14	3790	250						+	+				
13	3790	250	+	+	+	+	+						+
12	3790	250	+	+	+	+	+						+
11	3540	500								+	+	+	
10	3540	500								+	+	+	
9	3540	500								+	+	+	
8	3540	500								+	+	+	
7	3540	500								+	+	+	
6	3540	500								+	+	+	
5	3540	500							+				
4	3540	500						+	+				
3	3540	500						+	+				
2	3540	500	+	+	+	+	+						+
1	3540	500	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7

Table 11. Parameters measured in samples from CTD 22 (station 67#3) at CAST.

Sample/bottle	depth[m]	height above seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part ²³⁴ Th	diss. ²³⁴ Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	3952	5								+	+	+	
23	3952	5								+	+	+	
22	3952	5								+	+	+	
21	3952	5								+	+	+	
20	3952	5								+	+	+	
19	3952	5								+	+	+	
18	3952	5						+		+	+	+	
17	3952	5						+	+				
16	3952	5						+	+				
15	3952	5	+	+	+	+	+						+
14	3952	5	+	+	+	+	+						+
13	3932	25						+	+				
12	3932	25						+	+				
11	3932	25						+	+				
10	3932	25	+	+	+	+	+						+
9	3932	25	+	+	+	+	+						+
8	3904	50								+	+	+	
7	3904	50								+	+	+	
6	3904	50								+	+	+	
5	3904	50								+	+	+	
4	3904	50								+	+	+	
3	3904	50								+	+	+	
2	3904	50	+	+	+	+	+						+
1	3904	50	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7

Table 12. Parameters measured in samples from CTD 23 (station 67#4) at CAST.

Samplebottle	depth[m]	heightabove seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part234Th	diss.234Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	3904	50						+	+				
23	3904	50						+	+				
22	3904	50						+	+				
21	3850	100						+	+				
20	3850	100						+	+				
19	3850	100						+	+				
18	3850	100	+	+	+	+	+						+
17	3850	100	+	+	+	+	+						+
16	3700	250						+	+				
15	3700	250						+	+				
14	3700	250						+	+				
13	3700	250	+	+	+	+	+						+
12	3700	250	+	+	+	+	+						+
11	3450	500								+	+	+	
10	3450	500								+	+	+	
9	3450	500								+	+	+	
8	3450	500								+	+	+	
7	3450	500								+	+	+	
6	3450	500								+	+	+	
5	3450	500						+	+				
4	3450	500						+	+				
3	3450	500						+	+				
2	3450	500	+	+	+	+	+						+
1	3450	500	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7

Table 13. Parameters measured in samples from CTD 27 (station 76#6) at NAST.

Sample/bottle	depth[m]	height/above seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part ²³⁴ Th	diss. ²³⁴ Th	stable N&C isotopes*	carbohydrates*	amino acids*	nutrients#
24	3183	5								+	+	+	
23	3183	5								+	+	+	
22	3183	5								+	+	+	
21	3183	5								+	+	+	
20	3183	5								+	+	+	
19	3183	5								+	+	+	
18	3183	5					+	+					
17	3183	5					+	+					
16	3183	5					+	+					
15	3183	5	+	+	+	+							+
14	3183	5	+	+	+	+							+
13	3163	25						+	+				
12	3163	25						+	+				
11	3163	25						+	+				
10	3163	25	+	+	+	+	+						+
9	3163	25	+	+	+	+	+						+
8	3138	50								+	+	+	
7	3138	50								+	+	+	
6	3138	50								+	+	+	
5	3138	50								+	+	+	
4	3138	50								+	+	+	
3	3138	50								+	+	+	
2	3138	50	+	+	+	+	+						+
1	3138	50	+	+	+	+	+						+

* measured by subproject 4

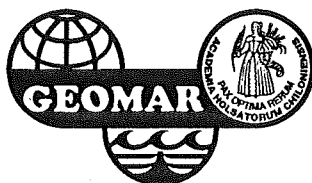
measured by subproject 7

Table 14. Parameters measured in samples from CTD 28 (station 76#7) at NAST.

Sample/bottle	depth[m]	height above seafloor[m]	TSM	POC	particulate nitrogen	particulate carbonate	bacteria	part234Th	diss.234Th	stable N & C isotopes*	carbohydrates*	amino acids*	nutrients#
24	3138	50						+	+				
23	3138	50						+	+				
22	3138	50						+	+				
21	3088	100						+	+				
20	3088	100						+	+				
19	3088	100						+	+				
18	3088	100	+	+	+	+	+						+
17	3088	100	+	+	+	+	+						+
16	2938	250						+	+				
15	2938	250						+	+				
14	2938	250						+	+				
13	2938	250	+	+	+	+	+						+
12	2938	250	+	+	+	+	+						+
11	2688	500								+	+	+	
10	2688	500								+	+	+	
9	2688	500								+	+	+	
8	2688	500								+	+	+	
7	2688	500								+	+	+	
6	2688	500								+	+	+	
5	2688	500						+	+				
4	2688	500						+	+				
3	2688	500						+	+				
2	2688	500	+	+	+	+	+						+
1	2688	500	+	+	+	+	+						+

* measured by subproject 4

measured by subproject 7



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