METEOR-BERICHTE
94-6

# *CARBON CYCLE AND TRANSPORT OF WATER MASSES IN THE NORTH ATLANTIC - THE WINTER SITUATION*

Cruise No. 27

29 December 1993 - 26 March 1994

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**Abstract**

METEOR cruise no. 27 combined the activities of four programmes focussing on the interactions of climatic changes and the oceanic ecosystem:

- OMEX (Ocean Margin Experiment),
- BIO-C-FLUX (Biological Carbon Transport in the Benthic Boundary Zone of the Open Ocean,
- the working groups of the German JGOFS Programme (Joint Global Ocean Flux Study),
- WOCE (World Ocean Circulation Experiment).

The expedition M 27 started in Hamburg on December 29, 1993. Leg 1 (29.12.1993 - 17.01.1994) was designated to the activities of German and various European OMEX projects. OMEX, sponsored by the European Union represents a multinational, inter-disciplinary research programme which focusses on the exchange processes between the continental margin and the open ocean. The Celtic Sea's continental margin was chosen as a regional centre of activities for the OMEX studies which cover physical oceanography, marine biology, marine chemistry, geochemistry and geology. Research during leg 1 concentrated on the Celtic Sea's continental margins at the Goban Spur. M 27/1 is part of a multitude of OMEX expeditions with different European research vessels. Continental margin processes and exchange rates with the open ocean were studied under winter situation. Leg 1 ended in La Coruna on January 17, 1994.

Leg 2 (20.01.1994 - 08.02.1994) lead into the open Northeast Atlantic where the BIO-C-FLUX programme and the German JGOFS continued their studies from previous years. The reasearch activities concentrated to a time series station of the international JGOFS programme at 47°N / 20°W, the BIOTRANS-station. Objectives of leg 2 were to quantify the rates of chemical and biological carbon fixiation and to measure the fluxes of carbon and other compounds of biological importance under winter conditions. The investigations focussed on the upper ocean (JGOFS) and the benthic boundary layer (BIO-C-FLUX), where physical, chemical and biological processes are intensified. Another main subject was the measurements of the exchange rate of $CO_2$ between the atmosphere and the upper mixed layer. Leg 2 was designated to end on February 15, in Ponta Delgada but due to severe damages to the ship and the scientific gear by a hurricane force gale METEOR had to dock in a shipyard in Lisbon for a refit. Thus leg 2 already ended on February 8.

Leg 3 (18.02.1994 - 26.03.1994) lead METEOR to the tropical western Atlantic. Research focussed on the investigation of circulation and water mass exchange in the western tropical Atlantic, as well as on the investigation of the transport of deep water across the Vema Fracture Zone at 11°N within the context of the World Ocean Circulation Experiment (WOCE). This region plays an important role for the water exchange between the northern and southern hemispheres. The area was already studied in autumn of 1990 during M 14/2, in late spring of 1991 during M 16/3 and in fall of 1992 during M 22/2. The objective of the cruise was the advancement of our understanding of the seasonal and year-to-year variability

in the region, and further to study of the variability in the deep water, which was observed during the previous three cruises. M 27 ended on March 26, 1994 in Recife (Brazil).

**Zusammenfassung**

Die METEOR-Fahrt Nr. 27 faßte die Forschungsvorhaben von vier Programmen zusammen, die sich mit dem Themenkomplex der Wechselbeziehungen zwischen Klimaveränderungen und dem ozeanischen Ökosystem befassen:

- OMEX (Ocean Margin Experiment),
- BIO-C-FLUX (Biologischer Kohlenstofffluß in der bodennahen Wasserschicht des küstenfernen Ozeans),
- die Arbeitsgruppen des deutschen JGOFS (Joint Global Ocean Flux Study),
- WOCE (World Ocean Circulation Experiment).

Die METEOR-Fahrt Nr. 27 begann am 29. 12. 1993 in Hamburg. Auf dem ersten Fahrtabschnitt (29.12.1993 - 17.01.1994) wurden von deutschen und ausländischen Gruppen Arbeiten im Rahmen von OMEX durchgeführt. Das OMEX-Projekt (ein von der Europäischen Union gefördertes multinationales und interdisziplinäres Forschungsprogramm) befaßt sich mit den Austauschprozessen zwischen Kontinentalrändern und dem offenen Ozean. Als regionaler Schwerpunkt für die physikalisch-ozeanographischen, meeresbiologischen, meereschemischen, geologischen und geochemischen Untersuchungen wurde der keltische Schelfrand ausgewählt (Goban Spur), wo auch die Arbeiten des Abschnittes M 27/1 stattfanden. Der Fahrtabschnitt M 27/1 war eingebettet in eine Vielzahl von OMEX-Expeditionen europäischer Forschungsschiffe und sollte für Prozeß- und Raten-Untersuchungen eine typische Wintersituation erforschen. Der erste Fahrtabschnitt endete am 17.1.1994 in La Coruna (Spanien).

Der zweite Fahrtabschnitt (20.01.1994 - 08.02.1994) führte in den offenen Nordostatlantik. Er beinhaltete die Arbeiten von BIO-C-FLUX und der deutschen JGOFS-Gruppen, die als Prozeßstudien im Rahmen der Untersuchungen des internationalen JGOFS-Programms an der "Time series station" in 47°N / 20°W (BIOTRANS Station) geplant waren. Ziel der Untersuchungen war eine Quantifizierung der chemischen und biologischen Kohlenstoff-Fixierung und die Bestimmung der Flüsse kohlenstoffhaltiger Verbindungen und biologisch relevanter chemischer Elemente unter Winterbedingungen im Nordostatlantik. Dabei kam der Untersuchung der ozeanischen Deckschicht (JGOFS) und der Bodengrenzschicht (BIO-C-FLUX), in denen neben den physikalischen und chemischen auch eine Intensivierung biologischer Prozesse stattfindet, eine besondere Bedeutung zu. Weiterhin sollte die Wechselwirkung zwischen Ozean und Atmosphäre in bezug auf das $CO_2$-System gemessen werden. Der zweite Fahrtabschnitt endete eine Woche eher als geplant am 08.02.1994 in Lissabon, da das Schiff und ein großer Teil der wissenschaftlichen Ausrüstung bei den Arbeiten im BIOTRANS

Gebiet durch einen starken Orkan beschädigt wurde, so daß statt Ponta Delgada Lissabon angelaufen wurden mußte, um die Schäden in einer Werft auszubessern.

Der Abschnitt M 27/3 (18.02.1994 - 26.03.1994) diente der Untersuchung von Zirkulation und Wassermassenaustausch über den Äquator hinweg im westlichen tropischen Atlantik im Rahmen des deutschen Beitrags zum World Ocean Circulation Experiment (WOCE), sowie zur Bestimmung des Transportes von Tiefenwasser über die Vema-Bruchzone bei 11°N und der Untersuchung der Charakteristika der beteiligten Wassermassen. Die westliche Randstromregion spielt eine besondere Rolle im Wärme- und Massentransport über den Äquator hinweg. Dieses Gebiet wurde auf den Reisen M 14/2 bereits im Herbst 1990, auf M 16/3 im Spätfrühling 1991 und im Herbst 1992 auf M 22/2 untersucht. Ziel der Reise war es, den Kenntnisstand über die jährliche und zwischenjährliche Variabilität in der Region zu erweitern, sowie zuvor gefundene Variabilität im Tiefenwasser genauer zu untersuchen. Die METEOR-Reise Nr. 27 endete am 26.03.1994 in Recife (Brasilien).

## 1 Research Objectives

METEOR cruise no. 27 comprised 3 legs (Fig. 1; Tab. 1) and combined the activities of four programmes focussing on the interactions of climatic changes and the oceanic ecosystem:

- OMEX (Ocean Margin Experiment),
- BIO-C-FLUX (Biological Carbon Transport in the Benthic Boundary Zone of the Open Ocean,
- the working groups of the German JGOFS Programme (Joint Global Ocean Flux Study),
- WOCE (World Ocean Circulation Experiment).

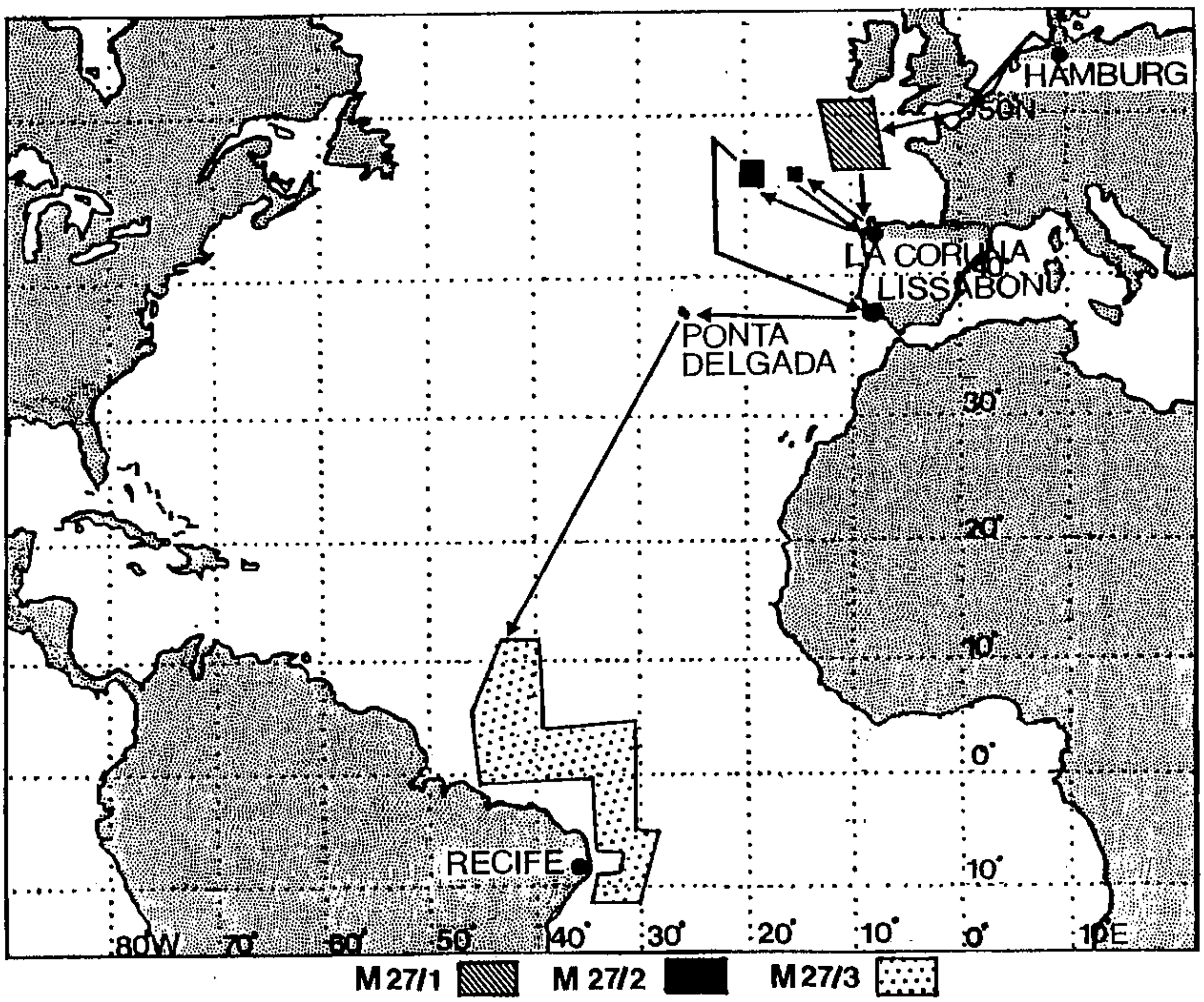



Fig. 1: Cruise tracks and working areas of METEOR cruise no. 27

**Tab. 1:** Legs and chief scientists of METEOR cruise no. 27

| | | |
|---|---|---|
| Leg 27/1 | | |
| | 29 December 1993 - 17 January 1994 | |
| | Hamburg/Germany - La Coruna/Spain | |
| | Chief scientist: | Prof. Dr. W. Balzer |
| Leg 27/2 | | |
| | 20 January 1994 - 08 February 1994 | |
| | La Coruna/Spain - Lisbon/Portugal | |
| | Chief scientist: | Dr. O. Pfannkuche |
| Leg 27/3 | | |
| | Lisbon/Portugal - Recife/Brazil | |
| | 18 February 1994 - 26 March 1994 | |
| | Chief scientist: | Prof. Dr. F. Schott |
| Coordination: | | |
| | Dr. O. Pfannkuche | |
| Masters (F.S. METEOR): | | |
| Leg 27/1-2 | | |
| | Captain H. Andresen | |
| Leg 27/3 | | |
| | Captain H. Papenhagen | |

## 1.1 OMEX

The OMEX project is funded by the European Union within the framework of MAST II. This multinational and interdisciplinary programme deals with exchange processes between European shelf areas including the adjacent continental margin and the open ocean. Emphasis is thereby paid on processes at the sediment/water interface and the atmosphere/ocean boundary. The Celtic margin where leg 27/1 took place was chosen as the regional focus of OMEX for studies of physical oceanographers, marine chemists, marine biologists, atmospheric chemists and geochemists. M 27/1 was part of a series of cruises of European research vessels. It was intended to investigate a typical winter situation for the different processes.

## 1.2 BIO-C-FLUX

BIO-C-FLUX (Biological Carbon Flux in the Benthic Boundary Zone of the Open Ocean) is funded by the German Federal Minister of Research and Technology. The project investigates the carbon flux through the benthic boundary zone in the temperate Northeast Atlantic. BIO-C-FLUX represents a seperate national programme on the biological carbon flux in the deep-sea, but is thematically and geographically closely coordinated with international and German JGOFS investigations.

BIO-C-FLUX consists of a joint working group of the Institut für Hydrobiologie und Fischereiwissenschaft, Universität Hamburg and the Institut für Meereskunde, Universität Kiel.

Benthic and abyssopelagic investigations are carried out in the BIOTRANS-area around 47°N / 20°W (Fig. 1) since 1985. Results from different months (period March - September) from the years 1985-1989 gave evidence for pronounced seasonality in the production of biomass within the smaller size classes of the benthos as well as for seasonally enhanced benthic remineralization rates which were coupled to the sedimentation of phytodetritus. Sediment pulses to the sea floor could be identified as early as March (M 21/1, 1992). Winter values to describe the seasonal amplitude of the benthic reactions were still missing and it was the main scientific goal of BIO-C-FLUX to measure these.

The BIO-C-FLUX studies include the near bottom water layer corresponding with the maximum extention of the nephloid layer up to 500 m above the sea floor, the sediment contact water (20 cm above the bottom) and the sediment down to 50 cm depth. This benthic boundary zone (BBZ) represents a specific ecosystem. To study the role of the organisms of the BBZ is of vital importance as the bulk of deep-sea carbon flux is generated by this ecosystem. The following BBZ organism groups were investigated: Bacteria, nano-, meio-, macro-, megabenthos, zooplankton, various size classes of the bentho- pelagic nekton. BIO-C-FLUX investigations are restricted to study the biological turnover of particulate organic matter (POM) in the BBZ. The main objectives are:

- What is the composition and quantity of POM on the sea floor?
- Which is the most important region for the decomposition of POM in the BBZ (e.g. nephloid layer, sediment contact water, certain sediment horizons)?
- Which gradients in quantity and species composition do exist in the benthopelagic nekton and BBZ plankton?
- Which food relationships do exist in the BBZ?
- What are the turnover rates of sedimented POM by the organisms of the benthic boundary layer (degradation of organic carbon, respiration, biomass production)?

## 1.3 JGOFS

National German JGOFS studies concentrate on the Northeast Atlantic along the 20°W meridian since 1989 with special reference to the BIOTRANS-station for time series studies.

### 1.3.1 Planktology

The planktological subproject of the JGOFS long-term study (IFM Kiel) on the variability of particle fluxes is concerned with the production, modification and sedimentation of biogenic particles in the North Atlantic. One main topic of this subproject is to carry out studies on upper ocean pelagic processes at the BIOTRANS-site (47°N / 20°W). In addition to earlier intensive studies during spring 1992 (M 21), summer 1993 (Poseidon 200/6 and Heincke JGOFS-93) and a pre-study during autumn 1993 (M 26/1) the planktological programme during M 27/2 was dedicated to study winter time conditions in the research area.

Winter time upper ocean properties like mixed layer depth, nutrient concentrations and relative abundance ($NO_3$:$PO_4$:$SIO_4$), phytoplankton seeding populations and standing stocks, vertical distribution and overwintering strategy of mesozooplankton are important determinants of the spring phytoplankton bloom. Since direct measurements of these properties in the North Atlantic open ocean are rare, the scientific goals of the planktological working group were as follows:

- To study the variability of mixing depths during winter;
- To study winter time concentrations of plant nutrients and suspended particles;
- To study biomass, composition and vertical distribution of phyto- and mesozooplankton.

The main working area of the JGOFS long-term study (BIOTRANS-site) is frequently influenced by stream-arms of the North Atlantic Current, introducing mesoscale hydrographical variability in the surface ocean. One goal of M 27/2 was to study mesoscale variability of winter time mixing depths in relation to the circulation patterns at depth. In addition diurnal changes in the mixed layer depth and their forcing functions (insulation, air temperature and wind stress) were monitored using CTD-profiles and shipborne sensors. Large-scale variability of mixed layer depths were studied during cruising from Spain to the BIOTRANS-site.

Winter time concentrations of nutrients and suspended particles of the boreal North Atlantic were measured with CTD-bottle cast water samples from the upper 500 m.

A third main goal of the planktological work during M 27/2 was to conduct studies on biomass, composition and vertical distribution of phyto- and mesozooplankton at the BIOTRANS-site. Samples for HPLC-pigment analysis, microscopy and flow cytometer were taken to study the composition of the phytoplankton seeding population.

### 1.3.2 Marine Chemistry

Since 1990 the Institute of Biogeochemistry and Marine Chemistry (Hamburg University) investigates the $CO_2$-system in the eastern North Atlantic. The extensive investigations gave us plenty information about the regional and seasonal development of the $CO_2$-system in the mixed layer. At the central JGOFS-station (47°N / 20°W) the total dissolved inorganic carbon decreases from 2100 µmol/kg in early April to 2030 µmol/kg in early August. This is due to biogene processes and is coupled with a consolidation and a reduction of the mixed layer depth. However, up to now little is known about the North Atlantic $CO_2$-system in winter time. The main goal of M 27-activities was to complete this lack by measuring total alkalinity (TA), $TCO_2$ and salinity. It was suggested that $TCO_2$ and $pCO_2$ reach a winter maximum with values higher than in April 1992. If that assumption is correct, a higher amount of $CO_2$ would have been removed from the mixed layer by the 'biological pump' during spring and summer.

A joint working group from the Institut für Ostseeforschung and the Woods Hole Oceanographic Institutions continued there studies of the seasonal development of dissolved organic carbon (DOC) and nitrogen (DON) concentrations in the whole water column.

### 1.3.3 Particle Flux

The JGOFS Project "Populations dynamics of planktonic foraminifers and pteropods and their influence on the export production and sedimentation (particle flux)" of the GPT Tübingen investigated the partikel flux mediated by the calcareous zooplankton.

Most calcareous zooplankton (e.g. planktic foraminifers) reproduce in dependence of the lunar phase (population dynamics). As a result, the particle flux (sedimentation) is also cyclic. Therefore, the cycles (e.g. $Ca^{2+}$ cycle) as well as the processes that mark or mask these cycles were investigated. The latter include primary production, the change of particle transport with water depth, the sediment production at the bottom before, during and after the spring bloom. At the JGOFS stations at 20°W / 47°as well as 33°, 40°, 52°, and 59°N these investigations are part of a long-time scale survey. Special emphasis was put on the upper 2500 m of the water column, especially on the photic zone. Sediment samples were taken to study the development in the sediment. Process studies and long time scale surveys are intended to investigate the carbon and calcium cycle in the water column and will finally increase our understanding of climatic change during the late Pleistocene and early Holocene (Historical Sedimentary Record).

## 1.4 WOCE

The main objective of the physical oceanography programme carried out during M 27/3 was the determination of the pathways of cross-equatorial exchange of the Atlantic conveyor belt circulation during the northern hemispheric winter season. In the near-surface layer this concerned especially the transport and final destination of the newly discovered North Brazil Undercurrent, which carries southern hemisperic waters toward a retroflection zone just north of the equator near 44°W from where it is disseminated into different zonal current branches. To better track these current branches from the 44°W to the 35°W section, an intermediate meridional section, along 40°W was added (Fig. 1). New aspects of the deep circulation to be studied during M 27/3 were the flow of North Atlantic Deep Water from the western to the eastern basin through the Vema Fracture Zone, which is located right along the cruise track from the Azores to the study area; and the deep circulation in the Guiana Basin, between the Ceara Rise and the Mid-Atlantic Ridge (Fig. 2). South of the equator the deep circulation objective was to determine the combination and recirculation of the cross-equatorial deep flow. Methods to be applied were Pegasus and ADCP current profiling systems for determination of currents and transports and CTD/tracer measurements for water mass identification. Finally, an important cruise objective was the retrieval of three current meter moorings which had been deployed in the western boundary current near 44°W in October 1992, during M 22/2.

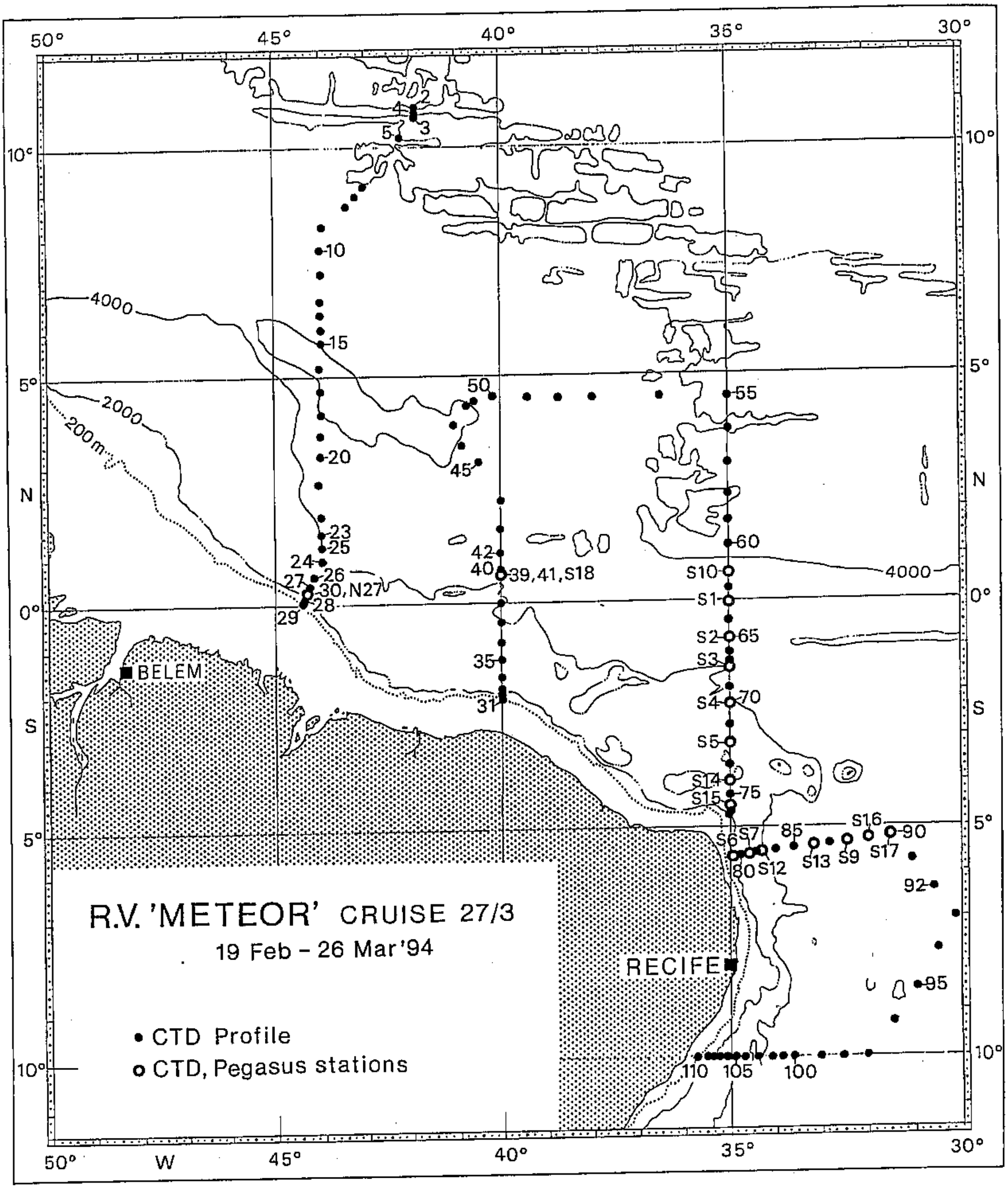



**Fig. 2:** CTD-stations (solid circles) and CTD and Pegasus stations (open circles) of M 27/3.

## 2 Participants

**Tab. 2:** Participants of METEOR cruise no. 27

**Leg M 27/1**

| Name | Speciality | Institute |
|---|---|---|
| Balzer, Wolfgang, Prof.Dr. (Chief Scientist) | Marine Chemistry | UBCh |
| Antia, Avan, Dr. | Marine Biology | IfMK |
| Behrens, Katrin, Technician | Benthic Biology | IHF |
| Brunn, Günter, Student | Marine Chemistry | UBCh |
| Büns, Ilse, Technician | Marine Biology | UHIBL |
| Deeken, Alois, Dipl.-Ing. | Marine Chemistry | UBCh |
| Flöck, Otmar, Student | Chemistry | MPICh |
| Grimm, Olaf, Student | Marine Chemistry | UBCh |
| Groß, Onno, Dipl.-Geol. | Paleontology | GPT |
| Jeskulke, Karen, Technician | Benthic Biology | IfMK |
| Keir, Robin, Prof. Dr. | Geochemistry | GEOMAR |
| Kenntner, Thomas, Technician | Chemistry | MPICh |
| Knaak, Christian, Meteorologist | Meteorology | DWD |
| Korves, Anette, Technician | Marine Biology | IfMK |
| Lehnert, Gerhard, Student | Marine Biology | IOW |
| Lendt, Ralf, Dipl.-Geol. | Marine Geology | IfBM |
| Nuppenau, Volker, Dipl.-Ing. | Benthic Biology | IHF |
| Ochsenhirt, Wolf-Thilo, Technician | Meteorology | DWD |
| Otto, Sabine, Dipl. Chem. | Marine Chemistry | UBCh |
| Peter, Sabine, Technician | Benthic Biology | IHF |
| Poremba, Knut, Dr. | Microbiology | IfMK |
| Rätzer, Harald, Student | Marine Geology | IfBM |
| Rawitz, Birgit, Technician | Marine Chemistry | UBCh |
| Rehder, Gregor, Dipl.-Chem. | Geochemistry | GEOMAR |
| Rogge, Katharina, Student | Oceanography | IfMH |
| Soltwedel, Thomas, Dr. | Benthic Biology | IHF |
| Schütt, Monica, Technician | Marine Biology | UHIBL |
| Thomsen, Laurenz, Dr. | Benthic Biology | GEOMAR |
| Ulshöfer, Veit, Dipl.-Phys. | Chemistry | MPICh |
| Waniek, Joanna, Dipl.-Oz. | Oceanography | IfMK |

**Leg M 27/2**

| Name | Speciality | Institute |
|---|---|---|
| Pfannkuche, Olaf, Dr. (Chief scientist) | Benthic Biology | IHF |
| Behrens, Katrin, Technician | Benthic Biology | IHF |
| Christiansen, Bernd, Dr. | Planktology | IHF |
| Götz, Sabine, Student | Benthic Biology | IHF |
| Heinrichs, Jörg, Student | Benthic Biology | IHF |
| Jensen, Stefan, Student | Benthic Biology | IHF |
| Jeskulke, Karen, Technician | Microbiology | IfMK |
| Kähler, Paul, Dr. | Planktology | IOW |
| Knaak, Christian, Meteorologist | Meteorology | DWD |
| Koeve, Wolfgang, Dr. | Planktology | IfMK |
| Koppelmann, Rolf, Dipl.-Biol. | Planktology | IHF |
| Lampe, Katrin, Technician | Planktology | IHF |
| Lendt, Ralf, Student | Marine Geology | IfBM |
| Martin, Bettina, Student | Planktology | IHF |
| Molis, Markus, Student | Planktology | IfMK |
| Nikov, Karina, Student | Benthic Biology | IHF |
| Nuppenau, Volker, Dipl.-Ing. | Electronic | IHF |
| Peltzer, Edward, Dr. | Planktology | WHOI |
| Poremba, Knut, Dr. | Microbiology | IfMK |
| Rätzer, Harald, Student | Marine Geology | IfBM |
| Reineke, Cornelia, Technician | Planktology | IfMK |
| Schartau, Markus, Student | Hydrography | IfMK |
| Scheibe, Stephan, Dipl.-Biol. | Benthic Biology | IOS |
| Scherbacher, Maria, Student | Palaeontology | GPT |
| Schiebel, Ralf, Dr. | Palaeontology | GPT |
| Twest, Anja, Student | Planktology | IHF |
| Uthicke, Sven, Dipl.-Biol. | Benthic Biology | IHF |
| Waniek, Joanna, Dipl.-Oz. | Hydrography | IfMK |

**Leg M 27/3**

| Name | Speciality | Institute |
|---|---|---|
| Schott, Friedrich, Prof. Dr. (Chief Scientist) | Marine Physics | IfMK |
| Assenbaum, Michel, Dipl.-Oz. | Marine Physics | IfMK |
| Badewien, Thomas, Student | Marine Physics | IfMK |
| Berger, Ralf, Technician | Marine Physics | IfMK |
| Campos, Ricardo, | Observer | IOUSP |
| Eisele, Alfred, Technician | Marine Physics | IfMK |
| Elbrächter, Martina, Technician | Marine Physics | IfMK |
| Fischer, Jürgen, Dr. | Marine Physics | IfMK |
| Fuchs, Patricia, Student | Marine Physics | IfMK |
| Garternicht, Ulf, Student | Marine Physics | IfMK |
| Jewson, Stephen, Student | Marine Physics | UOCL |
| Jochum, Markus, Student | Marine Physics | IfMK |
| Kindler, Detlef, Student | Marine Physics | IfMK |
| Krahmann, Gerd, Dipl.-Phys. | Marine Physics | IfMK |
| Lendt, Ralf, Student | Marine Geology | IfBM |
| Meinke, Claus, Dipl.-Ing. | Marine Physics | IfMK |
| Pinck, Andreas, Dipl.-Ing. | Marine Physics | IfMK |
| Plähn, Olaf, Student | Marine Physics | IfMK |
| Rätzer, Harald, Student | Marine Geology | IfBM |
| Rhein, Monika, Dr. | Marine Physics | IfMK |
| Stramma, Lothar, Dr. | Marine Physics | IfMK |
| Talaska, Arkadius, Technician | Marine Physics | USP |

**Tab. 3:** Participating Institutions

| | |
|---|---|
| DWD | Deutscher Wetterdienst, Seewetteramt<br>Bernhard-Nocht-Str.76<br>20359 Hamburg<br>Germany |
| GEOMAR | Forschungszentrum für marine Geowissenschaften<br>der Christian-Albrechts Universität zu Kiel<br>Wischhofstr. 1-3<br>24148 Kiel<br>Germany |
| GPT | Geologisch-Paläontologisches Institut<br>Universität Tübingen<br>Sigwartstr. 10<br>72076 Tübingen<br>Germany |
| IfBM | Institut für Biogeochemie<br>Biogeochemisches Labor<br>Bundesstr. 55<br>20146 Hamburg 13<br>Germany |
| IfMH | Institut für Meereskunde<br>Universität Hamburg<br>Troplowitzstr. 7<br>22529 Hamburg<br>Germany |
| IfMK | Institut für Meereskunde<br>an der Universität Kiel<br>Düsternbrooker Weg 20<br>24105 Kiel<br>Germany |
| IHF | Institut für Hydrobiologie<br>Universität Hamburg<br>Zeiseweg 9<br>22765 Hamburg<br>Germany |

**Tab. 3:** continued

| | |
|---|---|
| IOS | Institute of Oceanographic Sciences<br>Deacon Laboratory,<br>Wormley/Godalming,<br>Surrey GU8 5UB,<br>United Kingdom |
| IOUSP | Universidade de Sao Paulo<br>Instituto Oceanográfico, Cidade Universitária<br>CEP 055 08<br>P.O. Box 9075, Sao Paulo<br>Brazil |
| IOW | Institut für Ostseeforschung<br>Seestr. 15<br>18119 Rostock-Warnemünde<br>Germany |
| MPICh | Max-Planck-Institut für Chemie<br>Abt.: Biogeochemie<br>Postfach 3060<br>55020 Mainz<br>Germany |
| UBCh | Fachbereich 2<br>Universität Bremen<br>P.O. Box 330440<br>28334 Bremen<br>Germany |
| UHIBL | Institut für Biochemie<br>Universität Hamburg<br>Martin-Luther-King-Platz 6<br>20146 Hamburg<br>Germany |
| USP | Universidade de Sao Paulo<br>Institute Oceanografico<br>Sao Paulo<br>Brazil |

**Tab. 3:** continued

| | | |
|---|---|---|
| | UOCL | University of Oxford<br>Clarendon Laboratory<br>Parks Road OX1 3PJ<br>Great Britain |
| | WHOI | Woods Hole Oceanographic Institution,<br>Woods Hole,<br>MA 02543,<br>USA |

# 3 Research Programme

## 3.1 OMEX

Nine research groups representing different disciplines participated in M 27/1 (Fig. 3). Seven groups were related to the Ocean Margin EXchange programme (OMEX) while two groups dealt with JGOFS projects.

### 3.1.1 Organic Matter Degradation, Denitrification and Trace Metal Diagenesis
(W. Balzer)

For the understanding of the major controls over release fluxes from margin sediments a detailed investigation of early diagenetic processes acting within the sediments is necessary. Therefore, extensive work on pore water chemistry and on solid sediment phases at transects across the continental margin was conducted. The integrated rate of organic matter remineralization in near-surface sediments will quantified by modelling the pore water profiles obtained during M 27. In dependence on both the diagenetic redox milieu and the input terms, the benthic reactions and fluxes of selected trace metals were investigated to assess the significance of margin processes for the trace metal chemistry of the ocean. By analyzing the trace metal content in trapped particles, in suspended material, in sediments and in pore waters we will contribute to find relationships between vertical/lateral sedimentation fluxes, benthic release fluxes and burial rates of chemically differing elements. A special study dealt with sedimentary denitrification in continental margin sediments.

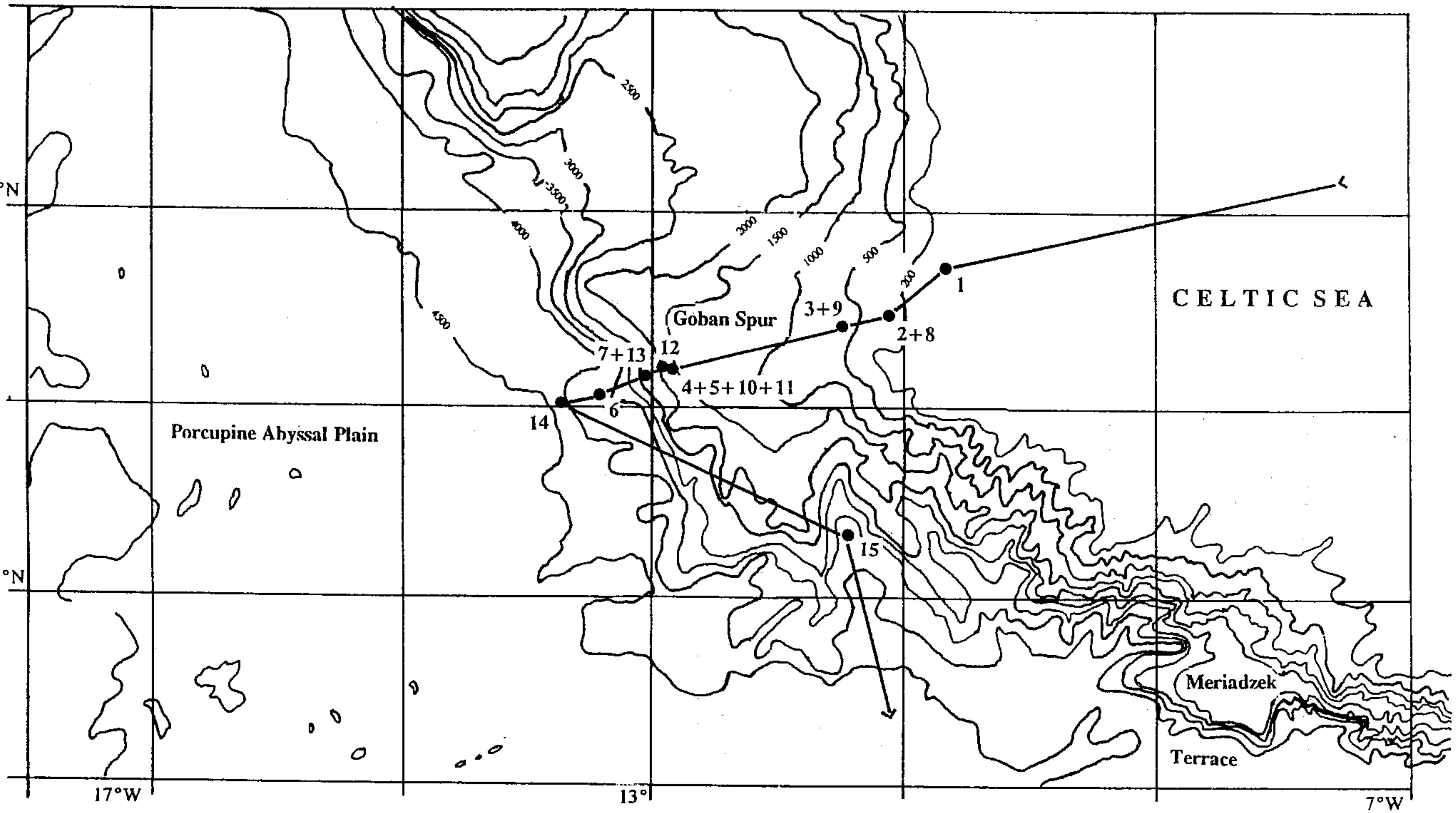



**Fig. 3:** Cruise track and sampling stations of M 27/1. Due to adverse weather conditions several stations had to be occupied several times.

### 3.1.2 Carbon Mineralization by the Benthic Community (O. Pfannkuche)

Rates of remineralization of organic carbon in the benthal are controlled by all transport processes acting in the water column. Parametrization of benthic processes is necessary to determine what portion of the sedimenting carbon is remineralized and what portion is accumulating in the sediments. The understanding of the biological, chemical and physical processes involved and their quantitative determination is vital for balancing carbon fluxes in the sediment. For the assessment of the role of benthic organisms for carbon cycling it is necessary to determine benthic community respiration, biomass production and benthic activity. Present knowledge obtained from deep-sea investigations of the temperate Atlantic ocean suggests that benthic respiration, activity and biomass production is subject to strong seasonal variations which correlate with carbon input by sedimentation. The largest part of benthic carbon removal is by organism respiration, its seasonal range being 80-90 %. The determination of in situ benthic oxygen respiration rates by use of "bottom landers" is therefore of central significance for balancing the carbon fluxes. Since most of the biotic oxygen consumption is generated by microorganisms, it is necessary to determine the part played by microorganisms in community respiration and biomass production.

### 3.1.3 Vertical Particle Flux at the Continental Margin (B. v. Bodungen)

The overall goal is the investigation of the seasonal pattern of particle sedimentation from the epipelagic zone to the sea floor and its dependence on the water depth at transects from the shelf edge to the Abyssal Plain. It is intended to identify the quality and relative significance of the different source materials. Therefore, the particle flux at different water depths were determined with high temporal resolution by using sediment traps. In the sedimenting material the following components and parameters were determined: Carrier phases, $^{15}N/^{14}N$ isotopic ratios, pigments, stable carbon isotopes, and trace elements. Light and electron microscopy was used to identify individual particles. In relation to the particulates fluxes of carbon and nitrogen as measured with traps, dissolved organic carbon (DOC)- and dissolved organic nitrogen (DON)-measurements of water samples were served to assess the significance of dissolved organic components for the cycling of carbon and nitrogen.

### 3.1.4 Phase Transfer of Organic Compounds during Self Edge Passage (U. Brockmann)

At the shelf edge nutrient rich water masses are injected into the euphotic zone due to upwelling processes. Here, inorganic components are rapidly transformed into particulate organic material, a part of which sediments to the sea floor where it is subject to remineralization. The spatial distribution of these processes depends to a large extent on advective processes at the shelf edge. Provided that currents are directed consistently to the shelf edge, the succession of individual processes can be traced by analyzing the distribution of nutrients as well as the distribution of the dissolved and particulate organic components.

Because the different nutrient elements are remineralized at different rates, gross inferences on the state of the biological development may be drawn from measured element ratios in both the dissolved nutrients and in the dissolved/particulate organic substances. These investigations are closely related to hydrographic studies and to an ecosystem analysis at the shelf edge of the selected region.

### 3.1.5 Distribution of Methane and $d^{13}C$ of $TCO_2$ in Continental Margin Waters (E. Suess)

In order to evaluate the role of biotic processes for the transfer of $CO_2$ through the upper ocean boundary, it was intended to determine the pattern of the vertical and horizontal distribution of methane and the $d^{13}C$ of total $CO_2$ in the water column of the continental margin at the Goban Spur transect. The $d^{13}C$ signal of total $CO_2$ in the water column reflects the interaction of the following processes whose relative significance was determined: Primary production, upwelling, gas exchange as well as lateral mixing and advection.

### 3.1.6 The benthic Resuspension Loop at the Shelf Break and on the Continental Slope (G. Graf)

The aim of this project is the investigation of the following processes occuring within the benthic boundary layer: Particle transport, sedimentation, accumulation and mass flux. By using the BIOPROBE bottom water sampler the following measurements were performed: Determination of current velocity and current direction at depths between 0 cm and 100 cm above the sea floor, determination of the quality and quantity of particles in the bottom water along with an evaluation of their size distribution and sinking speed, determination of quality and quantity of selected dissolved components in the bottom water, assessment of the influence of benthic organisms on the near-bottom particle transport.

### 3.1.7 Flux of Trace Gases at the Boundary between Ocean and Atmosphere (M. Andreae)

In collaboration with other European research groups the biogeochemical processes were investigated which are involved in the production and emission of trace gases being selected according to their relevance for climate and atmospheric chemistry. In continuation of measurements during the M 21/2 the photochemical production of carbonyl sulphide (COS) in the ocean and its exchange flux between ocean and atmosphere was determined. COS is produced from certain dissolved organic compounds and may be emitted to the atmosphere. Due to its long life time of more than one year, COS may reach the stratosphere where it forms the main source of the sulphate layer which influences both the ozone layer and the incoming solar radiation. The seasonal and spatial variability of the ocean as a source of COS is of particular significance in this context. During M 27/1 a photochemical/kinetic model was tested and improved that considers light dependent production of COS, hydrolysis of COS and its exchange at the ocean/atmosphere interface as well as vertical mixing in the ocean.

## 3.2 JGOFS

### 3.2.1 The $CO_2$-system in the Ocean (JGOFS 1991-1993) (S. Kempe)

None of the national or international programmes for the investigation of the marine ecosystem (e.g. GEOSECS, TTO, JGOFS, BOFS, etc.) has ever released data of a typical winter situation for the parameters: Total alkalinity (TA), total dissolved inorganic carbon (TC), pH and partial pressure of $CO_2$. These data are urgently needed for a proper description of the $CO_2$-system in the ocean mixed layer. Within the JGOFS programme the IfBM intended to fill this gap in the seasonal carbon cycle by measuring TA, TC and salinity during M 27/1.

### 3.2.2 Hydrographical Measurements during M 27/2

The BIOTRANS-site (47°N / 20°W), presently the main working area of the JGOFS "Long-term study on the variability of particle flux in the North Atlantic", is frequently influenced by stream-arms of the North Atlantic Current, introducing mesoscale hydrographical variability into the upper ocean. One goal of M 27/2 was to study mesoscale variability of winter time mixed layer depths in relation to the hydrographical structure in the investigation area. Lateral variability in the mixed layer and their forcing functions (solar insulation, air temperature and wind stress) were monitored by CTD-profiles and shipborne sensors. The hydrographic measurements were carried out to estimate the relevant depths for biological and chemical probing and for characterization of the winter time physical properties (depth of the mixed layer, distribution of temperature, salinity). Special emphasis was taken on the upper 500 m of the water column for characterization of the distribution of relevant physical, chemical and biological properties within the epipelagic zone.

During M 27/2 from La Coruna to Lisbon (20.01.1994 to 08.02.1994) hydrographic measurements were carried out in the vicinity of the BIOTRANS-station (47°N / 20°W) and during cruising from La Coruna to 47°N / 15°W. Underway sections (S16 to S45) and the XBT section taken during M 27/2 are shown in (Fig. 4a). During leg M 27/2 only 10 XBTs were dropped, mainly during the transit from 47°N / 15°W back to La Coruna (see Tab. 7.2.2). The distance between the XBT drops was about 30 miles. A map with CTD stations, carried out in the vicinity of the BIOTRANS-site is presented in (Fig. 4b), for more detailed informations see Tab. 7.2. The water column was probed by a Neil Brown CTD with a fluorometer and a 12 bottle water sampler with 12 l Niskin bottles. From the Niskin bottles water samples were taken for calibration of fluorescence- and salinity measurements and for determination of nutriens, oxygen, alkalinity, total dissolved anorganic carbon, dissolved

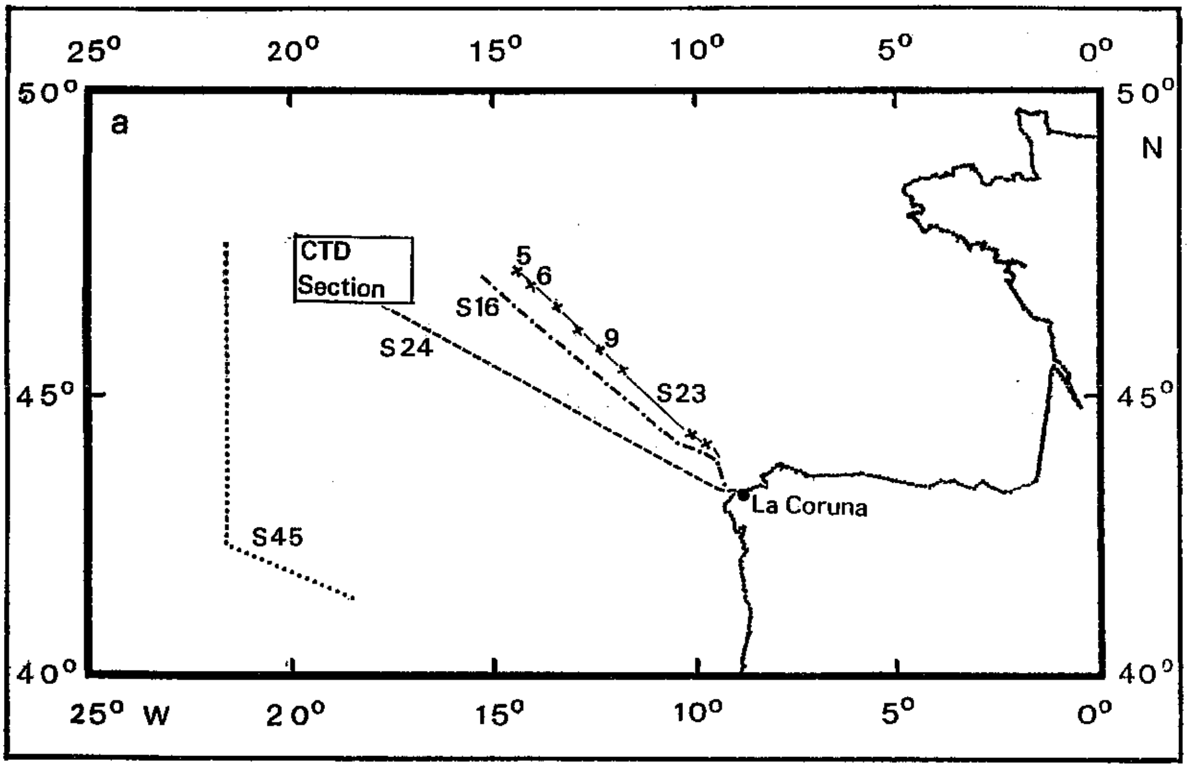



**Fig. 4a:** Cruise tracks and areas of investigations during M 27/2. S16, S23, S24, and S45 mark the underway stations, crosses mark the drops and the box the CTD.

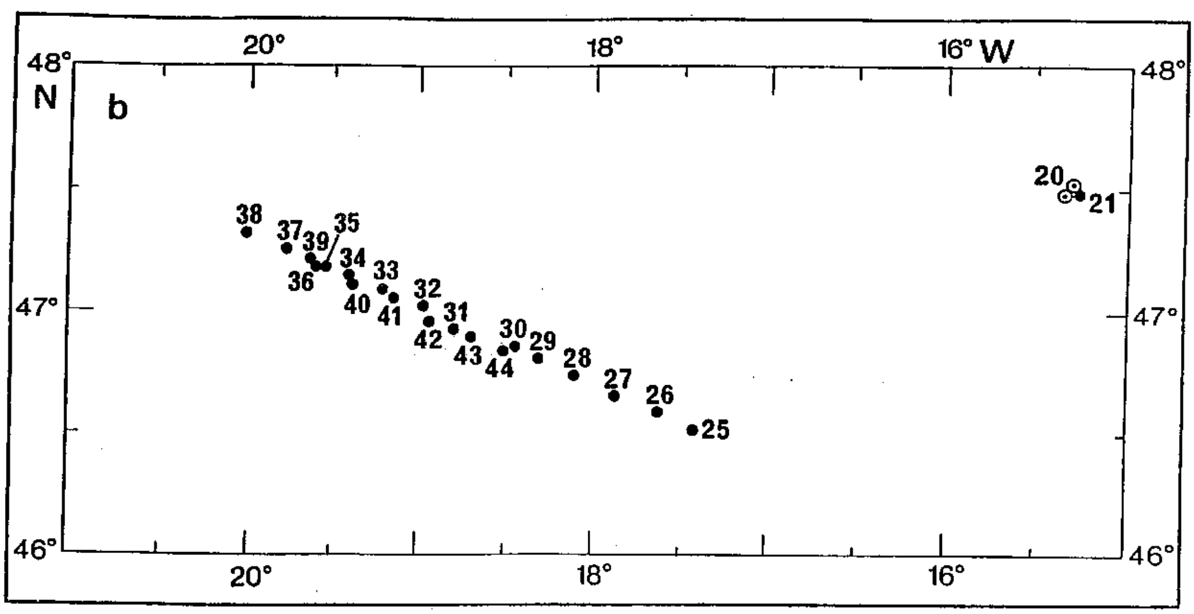



**Fig. 4b:** CTD section during M 27/2. Stations which have more than one profile are marked by a circle with point.

organic carbon and nitrogen and various biological stock parameters from distinct water depth. Due to heavy weather conditions we were not able to use electronic and mercury reversing thermometers for in situ-calibration of the temperature sensor of CTD.

## 3.3 WOCE

### 3.3.1 Physical Oceanography during M 27/3

The western tropical Atlantic is a region in which a net transfer of warm water and of Antarctic Bottom Water occurs from the southern to the northern hemisphere, compensated by southward return flow of North Atlantic Deep Water (NADW). Very little is known, however about the pathways along which the individual water masses are actually passing through the equatorial zone. Studies of the warm water routes in the past several years have shown that a continuous warm water inflow from the south exists in form of a subsurface intensified western boundary current, the North Brazil Undercurrent (NBUC), that together with the westward inflow of the South Equatorial Current (SEC), transports about 30 Sv (1 Sv=$10^6 m^3 s^{-1}$) towards the equator. In the context of WOCE, one objective of M 27/3 was to quantify the branching of this northward transport into the eastward Equatorial Undercurrent (EUC) and the two off-equatorial undercurrents during the winter season, while the previous three METEOR cruises had covered summer and fall situations. The key question, pursued in conjunction with the analysis of measurements carried out northwest of our study region by our partners from NOAA/AOML, Miami, is how much water of southern hemispheric origin is left to propagate toward the Caribbean along the western boundary, after these eastward branches have drawn their part of the flow. Shipboard and lowered ADCP profiling along the repeat sections between 10°S and 44°W, together with CTD measurements of the salinity and oxygen distribution are the key to understanding the complex interaction between southern hemispheric sources, transport routes and northern hemispheric destination of these water masses.

The present picture about the flow of deep water in the equatorial regime is similarly complex: Much more water, about 25 Sv, arrives near 5°N from the north than actually required from heat flux calculations, which is only about 15 Sv. Recent analyses of near-equatorial data hypothesized significant northward recirculation in the interior of the Guiana Basin. Therefore, an objective of M 27/3 was to achieve two sections with CTD/freon and current profiling measurements across the Guiana Basin, one along 44°W, upon arrival in the region, the second one along 4-5°N, from the eastern tip of the Ceara Rise to the Mid-Atlantic Ridge to investigate this potential recirculation regime (Fig. 2).

An important thorough fare of the deep circulation is the so-called Equatorial Channel, where we found the NADW rushing eastward along the Parnaiba Ridge, at 1.5°S, in our earlier METEOR cruises, with maximum speeds of 30 cm/s; and underneath, the Antarctic Bottom Water (AABW) is flowing westward. Transport measurements of both water masses were carried out. The 5°S and 10°S sections as well as their meridional connection line were investigated as to the transport of the different deep water branches further onward to the south, and for tracing the source waters of the warm water inflow back southward.

# 4 Narrative of the Cruise

## 4.1 Leg M 27/1 (W. Balzer)

After leaving Hamburg fine weather prevailed allowing maximal speed for METEOR. After half a day, however, the weather changed and as a consequence of permanent headwinds and opposing currents the effective speed was much less than expected all the way until the end of the English Channel. Since a hurricane with wave heights between 13 m and 17 m was approaching our research area according to meteorological forecast, METEOR seeked shelter provided by land at Lizard's Point, SW-England for 1.5 days. At still prevailing strong winds of about 8 Bft and considerable swell METEOR reached the first station near the shelf edge on January 3, at 5:30 pm (Fig. 2). The strong swell only permitted a reduced sampling programme of the water column to be conducted, while sediment sampling and the intended exchange of moorings deployed during previous cruises was impossible. At the third station even water sampling using a CTD-Rosette had to be given up.

At still prevailing strong winds the mooring OMEX-2 (1445 m) equipped with 2 sediment traps and current meters was recovered successfully. Having a major improvement of the weather conditions on January 7, the mooring OMEX-3 (3650 m) with the same equipment as above was recovered successfully and redeployed during the following day. The attempt to recover the mooring OMEX-1, however, was not successful: Although the bottom release unit responded to our hydrophone calls, it could not be released and finally we had to quit our efforts due to the nearing of a heavy storm; this mooring will not be recovered before April 1994 when another OMEX cruise is directed to this area. The end of our mooring activities was marked by the successful redeployment of mooring OMEX-2 during extremely bad weather conditions. Despite the problems with mooring OMEX-1 the exchange of the other two moorings during bad weather and the fact that all sampling cups had rotated as predetermined may be considered a major success.

At all stations, where moored sediment traps had to be recovered and re-deployed for long-term studies of the seasonality of particle sedimentation, several other devices were deployed regularly: One or more CTD-Rosette casts were taken for studies of hydrographical parameters, nutrients, lipids, the carbonate system, carbon isotope ratios, methane, and DOC; for the sampling of carbonyl sulfide GoFlo-bottles especially designed to reduce contamination and gas exchange were deployed. For investigations of trace element cycling, in situ-pumps were used at different water depths to collect suspended particles from 400 - 900 l seawater, and GoFlo-bottles were taken for contamination-free sampling of dissolved trace elements.

Contrary to water sampling and mooring work, the sampling of sediments being one focal point during this cruise was a complete desaster. Due to strong winds between 7 and 9 Bft there were generally only a few "weather windows" for the deployment of the box corer or the multi-corer. Even worse was the fact that the wire contained weak parts prone to rupture and that the heavy winch did not work properly. Thus, several groups with the intent to investigate the sediment, return back home with only one sediment sample.

Due to failure of the deep-sea winch the rest of the cruise was dedicated to water sampling. Closest to the sea floor was the bottom water sampler which takes several water samples a few decimeters above the bottom and which in addition is equipped with a current meter and a camera to obtain photographs of the bottom texture. Always searching for appropriate weather conditions for sampling, METEOR moved up and down the slope at Goban Spur twice and finally reached a good set of samples from CTD-casts, water bottles, and in situ-pumps all along the Goban Spur transect between 49°28' N / 11°12' W and 49°01' N / 13°45' W. Facing bad weather almost all the time it was finally decided to skip the intended sampling of a second margin transect at Meriadzek Terrace in favour of getting a complete set of samples from the priority transect at Goban Spur.

Summing up the work during M 27/1 it can be stated that the groups working with samples from the water column obtained a good set of data and samples along the Goban Spur transect. With respect to the weather conditions during this season in the Celtic Sea also the mooring work has to be considered a success. Only the scientific groups who intended to sample sediments or to study benthic processes completed an overall disappointing cruise.

Right in time at the morning of January 17, METEOR reached at the quays of La Coruna having fine weather for the first day.

## 4.2 **Leg M 27/2** (O. Pfannkuche)

METEOR sailed from La Coruna on Saturday January 21, heading for the first sampling site at 47°30' N / 15°20' W at the Porcupine Abyssal Plain. Due to repairs on the friction winch and the exchange of the deep-sea wire, which proofed to be damaged in the course of leg 1, our departure was delayed for two days. During the exchange of the deep-sea wire a foreroll of the winch broke. A repair of the roll seemed to be too time consuming as the broken part was completely inaccessible and could only be reached by welding through the wall of a ballast tank. In consequence it was decided to do all deep-sea sampling with the 18 mm cable. During the passage to sampling site 1, which was reached on the evening of January 23, water samples for $CO_2$-measurements and nutrients were taken with a pumping system.

Station work at 47°30' N / 15°20' W started with the deployment of two free-vehicle-longline system for catching deep-sea fishes. After the sussessful deployments a series of multiple corer samples were planned. Weather conditions deteriorated with wind forces of 6-7 Bft and a swell of 4-5 m height. When lowering the multiple corer the deep-sea cable looked quite corroded so that the speed of lowering was reduced to less than 1 m/sec. About 30 m above the sea bed (water depth 4850 m) the winch was stopped as some single strands of the cable broke and we tried to tape them. A few minutes later the cable broke about 30 m below the sea surface which lead to the loss of the muliple corer, a pinger and 4800 m of the cable. The tension on the cable was about 5 to which was less than 1/3 of the guaranteed capacity of 18 to. Benthic sampling was stopped and CTD/rosette samples were carried out during the rest of the night. During the next morning we tried to retrieve the two free-vehicle-longline systems. In both cases the releases commanding the ballast weights were successfully activated, as we got a positive confirmation for the activation of the releases on the control board as well as by acoustical signal on a headphone. However, in both cases the gear did not float up as the range meter indicated, that the mooring remained in 4850 m water depth. Although release of the ballast weight was repeated several times with positive confirmations, the moorings gave no sign of floating to the surface. In the afternoon we decided to stop any further attempts. It can only be speculated about the malfunctioning of the mooring. An implosion of the glass spheres seems to be a possible explanation.

As the deep-sea wire on winch no. 11 could not be used and the deep- sea cable proofed to be a safe risk for any further benthic sampling the ship had to turn back to La Coruna, which was reached in the morning of January 26. A new cable was put on winch no. 12 and the broken roll on winch no. 11 could also be exchanged as spare parts had been flewn in. A spare multiple corer could also be delivered by lorry from Hamburg. Repair work was finished in the late evening of January 27 and METEOR left La Coruna at midnight, heading to the second station (BIOTRANS) of leg 2 in 47°11' N / 19°34' W. During the passage to the BIOTRANS-station water samples for $CO_2$-measurements and nutrients were taken again with a pumping system. In the afternoon of January 29, at 46°30' N / 17°25' W a transect of CTD/rosette samples in 10 nm intervals and multinet samples in 50 nm intervalls was started which was finished at 47°11' N / 19°34' W in the early morning of January 31. A series of four successful multiple corer hauls was taken during the day. For the evening a prolongation of the CTD/rosette transect was planned. Weather conditions deteriorated during the day reaching force 9 Bft in the evening. In consequence station station work had to be canceled after the first CTD-cast at 20:30 until 14:00 the next day, when the CTD/rosette transect as continued with course 115°. The transect was finished at 2:30 February 2. METEOR steamed back to the central Benthos-station at 47°11' N / 19°34' W, where after a test of glass floats and transponders on the deep- sea wire a series of multiple corer samples was taken. During the course of the station weather conditions deteriorated rapidly. The barometer dropped 20 hPa/3h between 14:00-17:00. Wind force was already 10 Bft when the gear was retrieved reaching force 12 Bft an hour later with maximum gusts of more than 230 km/h and wave heights of 18-20 m. The vessel held against the wind with about 2 kn course 320°. At 01:52 the laboratory container was smashed out of the twist locks and was washed over the back part of the working deck damaging an escape hole and thus creating a leakage. Water invaded the hole but could be controlled by pumping. During the course of the night the leakage could be sealed provisionally. At 02:39 the container knocked a winch from its stand. The container and the winch were now washed around on the working deck damaging other gear and smashing about 30 gas bottles out of their containers. Train wheels for moorings and other ballast weights and a box grab became loose creating havoc on the working deck. The container and the winch could be provisionally fixed two times during the night but were again knocked free. At 9:10 the crew managed to fix them finally. During the course of the night the life boats were loosened by wave action and the central crane was knocked from its lock. The crane swung around from port side to starboard side threatening the ship's chimney. The lifeboats and the crane could also be fixed by the crew in lifethreating battle. The hurricane force gale kept on for the next 36 hours. On February 4, wind speed went down to 7 Bft in the morning. We were able to turn round and take a course of 180° in order to head for calmer waters as another low with violant gale winds was coming up.

An inspection of all damages to the ship and to the scientific gear revealed, that no further scientific work was possible without repair in a ship yard. It was therefore decided to head for Lisbon. METEOR reached Lisbon in the morning of February 8, at 8:15 where leg M 27/2 ended.

## 4.3 Leg M 27/3 (F. Schott)

Due to the repairs in Lisbon the ship departed one day behind schedule from Ponta Delgada, on February 19, 16:00 local time. The scientific party of 17 participants from IfM Kiel, two from the University Hamburg, one from the University of Oxford, and one from the University of Sao Paulo embarked in the morning of the departure day. The Brazilian observer, Cpt. Ten. R. Campos from the Naval Hydrographic Institute already had boarded in Lisbon. Two containers and air freight were loaded in the morning, but due to anticipated heavy weather only immediately needed materials and equipment were unpacked while still in port.

On February 19 and 20, a zone of severe weather was passed, but then the weather turned nicely subtropical and on February 21, the equipment was installed and tested. Data registration with the shipboard ADCP began and it was noted that the range was increased by about 50 m since the protective cover under the hull was removed. To pass the 7 day transit time to the measurement region, a seminar series was held, where scientists and students presented oceanographic topics of the study region.

In the morning of February 24, a test station was operated where CTD and the lowered ADCP (LADCP in the following) were found to operate satisfactorily, and where it also was tested to interrogate transponders with a hydrophone installed on the telescope mast under the ship's hull.

During crossing the Vema Fracture Zone, three deep stations with CTD/LADCP were run across the channel. A freon maximum was found in 4300 - 4600 m depth, indicating the passage of lower NADW from the western to the eastern basin, but unfortunately the deep LADCP measurements did not yield satisfactory measurements for transport determination.

During February 27-28, a deep section from the Mid-Atlantic Ridge (MAR) to the Ceara Rise across the Guiana Basin was carried out to measure the deep boundary current there and possibly recirculation west of the MAR.

An essential objective was to retrieve three moorings along the western boundary near 44°W. Two moorings could be retrieved intact on March 4, and the third one on March 5. It was a big relief that the acoustic release worked without problems since the trawl whinch needed to tow a wire in case of acoustic release malfunction had been damaged during the storm of the previous cruise leg and been removed in Lisbon. In between mooring work, CTD/LADCP stations were continued and on Saturday, March 5, the 44°W section was completed.

The work on the 40°W section began on March 7. Dense station spacing was planned north of the Belem Rise near 0°30' S, where throughflow of a lower NADW current core was presumed to take place. Because of LADCP malfuntion during several stations of this section, a Pegasus transponder pair was deployed there and measured in, however, although a high freon core was found, currents recorded were much weaker than further east, suggesting other topographic control of the flow.

At the northern end of that section, a northwesterly leg was attached to connect with the southeastern flank of the Ceara Rise and cut across the deep bounadry flow there. Unfortunately, both LADCPs were out of commission during that part and the eastward leg to the MAR at 35°W, so that only geostrophy is available for current determination across the southern Guiana Basin. On March 13, we begun the section 35°W at 4°30' N with shallow (to 2200 m) stations over the MAR, southward to 1°N. The flow through the Equatorial Channel was investigated on March 14-15, and the lower NADW core along the Parnaiba Ridge, at 1°30' S, was found in 3600 - 2400 m depth with core velocities near 30 cm/s. Underneath, Antarctic Bottom Water (AABW) was flowing westward.

In the near-surface layers, the Equatorial Undercurrent and the two off-equatorial undercurrents, at 3-4° latitude, were well within the range of the shipboard ADCP so that CTD and XBT sampling could be guided. All 8 Pegasus transponder pairs along 35°W, deployed in fall 1990 and spring 1991, were still operational, and good profiles were obtained at those stations. Good proflies were also obtained along the entire 35°W section on the CTD casts by the LADCP.

On March 18, measurements in the boundary currents off Natal near 5°40' S, were begun. At the first deep Pegasus station, one transponder had ceased operation and a new pair was deployed so that this station can be used for a few more years. The North Brazil Undercurrent was found much weaker than in previous sections but a very high southward deep boundary flow was recorded by several inshore deep stations.

The connection from the 5°S to the 10°S sections was occupied by 6 deep stations which would later allow box budget calculations. The southward leg was terminated in the morning of March 23, and the work at the last section, along 10°S, began. The last CTD station was made on March 25, and the ship arrived in Recife in the morning of March 26, 1994, where the cruise M 27/3 ended.

# 5 Preliminary Results

## 5.1 Physical Oceanography

### 5.1.1 OMEX-studies during M 27/1 (J. Waniek, K. Rogge)

Due to heavy weather during the first leg of M 27 from Hamburg to La Coruna only a few CTD-profiles have been obtained. The list of stations is shown in Tab. 7.1.2; at several stations more than one profile was recorded. The hydrographic measurements were carried out to study the water column structure and to estimate the relevant depths for biological and chemical sampling. The water column was sampled from the shelf area of the Celtic Sea to the Abyssal Plain along the Goban Spur by a Neil Brown CTD with oxygen sensor, transmissometer and a rosette sampler equipped with 12 Niskin bottels (12 l). From the rosette water samples were taken for the calibration of the CTD-sensors of oxygen and salinity as well as for the determination of nutrients, dissolved gases and lipids. Unfortunately due to heavy weather we were not able to use electronic and mercury reversing thermometers for in-situ calibration of the CTD-temperature sensor. The data of the oxygen sensor and the transmissiometer can not be used, because these devices were not working properly. Special emphasis was put to characterise the upper 1000 m of the water column.

First results must only be regarded as qualitative information, since the post-cruise calibration of the CTD-measurements are still lacking. On the basis of existing experience with the hydrography of the North Atlantic and especially of the Celtic Sea and because of the high primary quality of the CTD-measurements the following statements can be made: Fig. 5a, b shows a selection of potential temperature and sigma theta profiles for the upper 1000 m calculated from CTD data measured during the first leg of M 27. The curves show a uniform distribution near the surface, which indicates the winter mixed layer (for the position of the profiles see Tab. 7.1.2). To estimate the depth of the mixed layer we used the criteria suggested by TALLEY and McCARTNEY (1982). Due to the definition, the maximum depth of the mixed layer was 300 m, the variability in the depth of the mixed layer ranged from 100 m at the shelf to 300 m in the open ocean. The same structure can be seen in Fig. 6a, b which shows sections of potential temperature and sigma theta for the upper 1000 m from the first station at the shelf of the Celtic Sea (49°42.0 N, 9°40.0 W) until the last station of the adjacent Abyssal Plain (48° 20.0 N, 11°30.6 W).

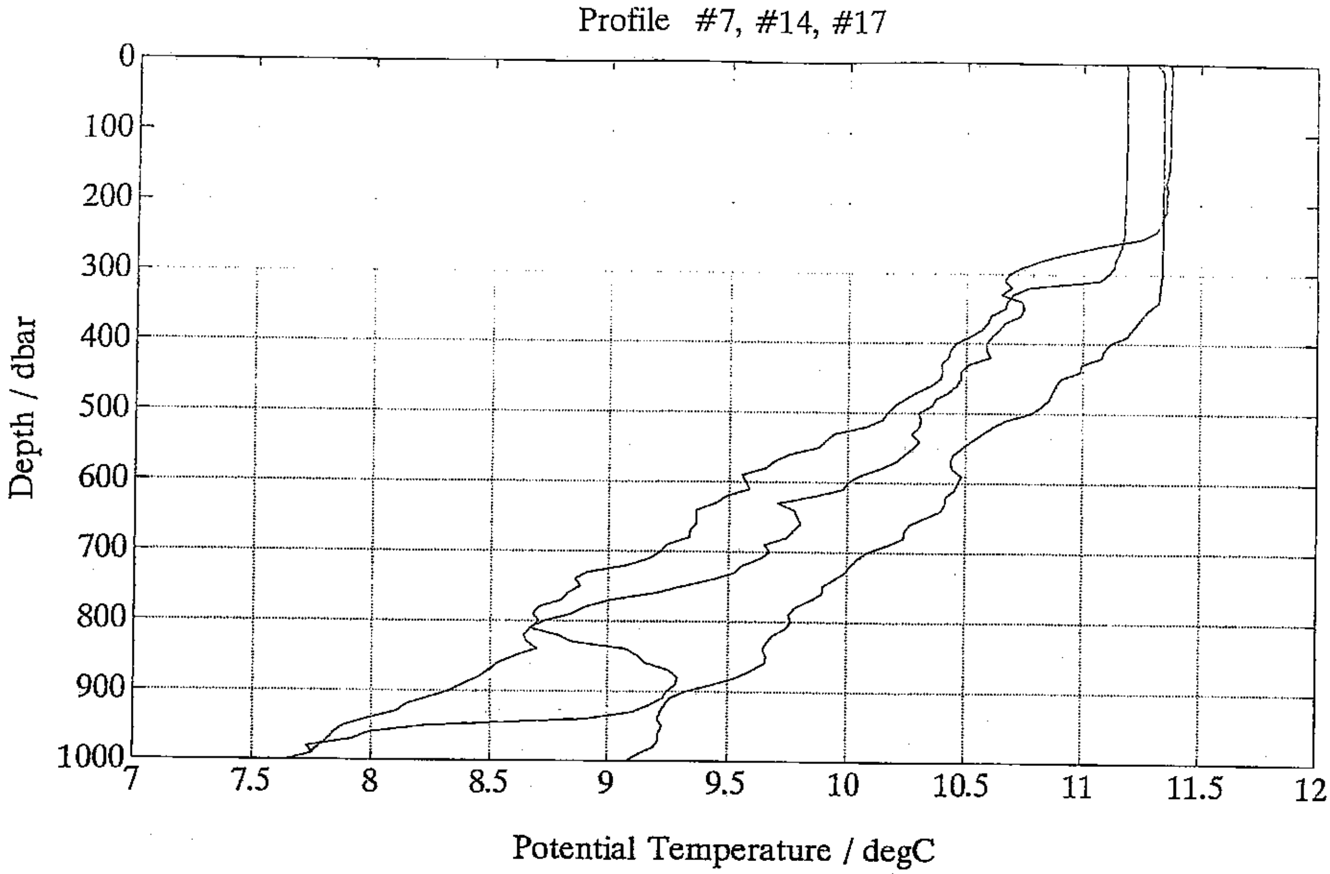



**Fig. 5a:** Sections of potential temperature of profiles (see Tab. 7.1.2) along Goban Spur during M 27/1

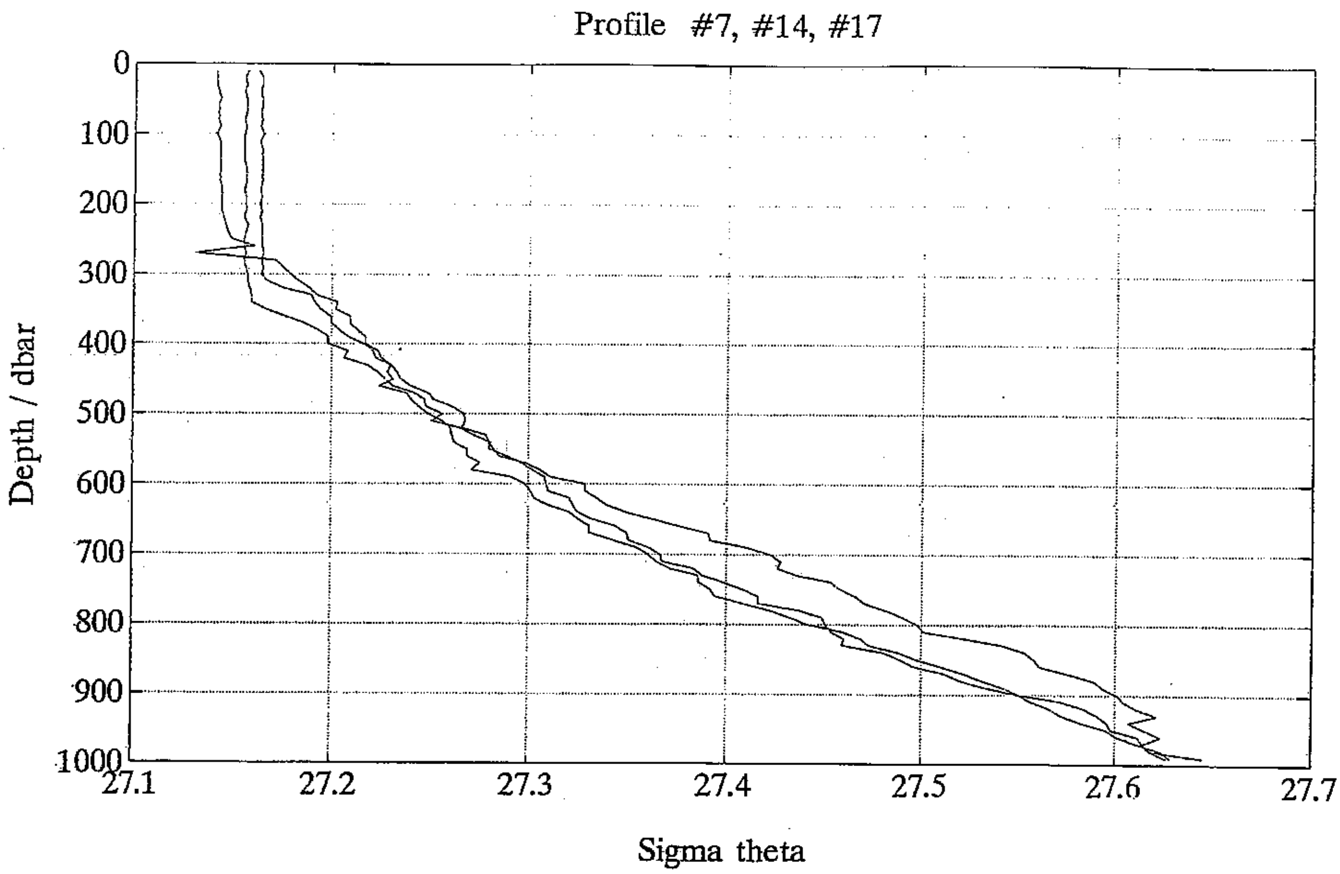



**Fig. 5b:** Sections of sigma theta of profiles (see Tab. 7.1.2) along Goban Spur during M 27/1

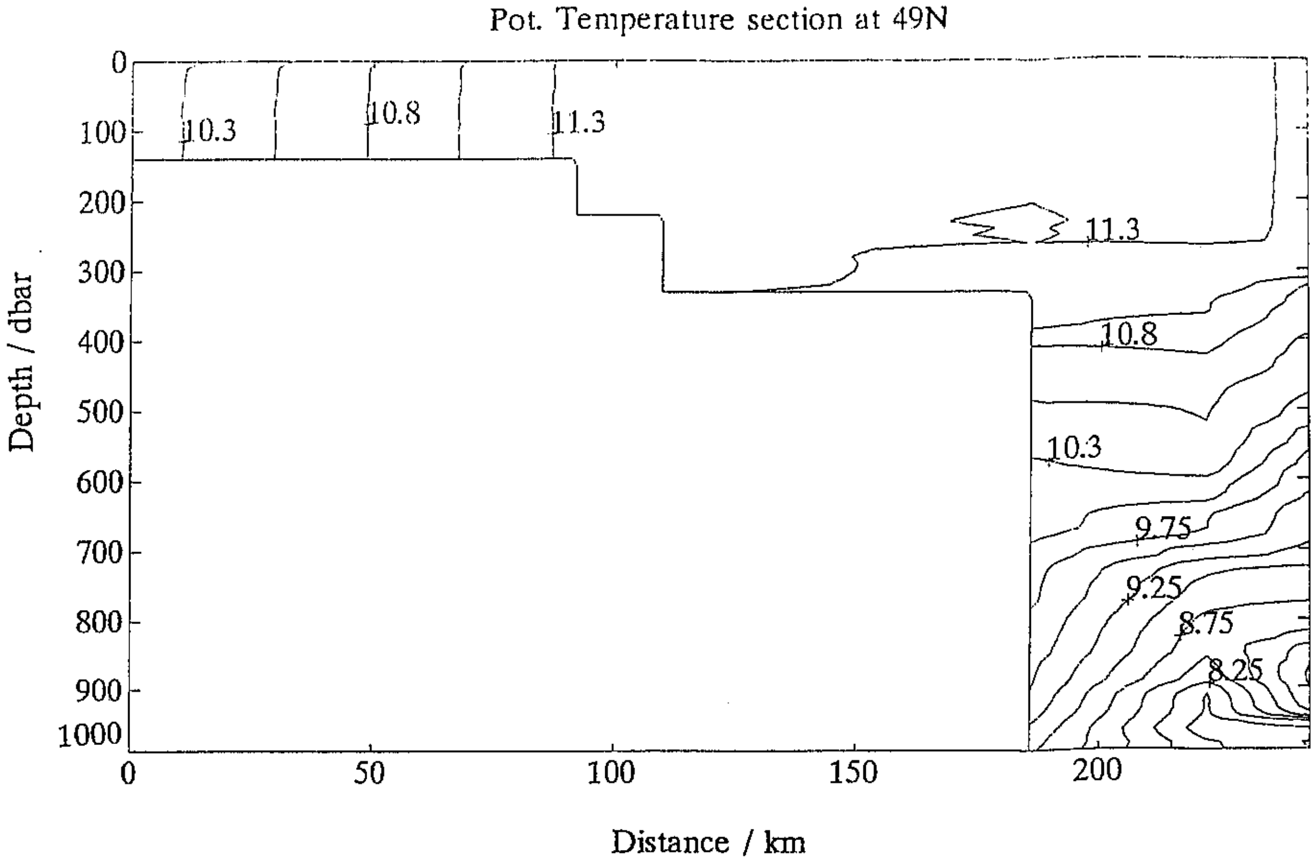



**Fig. 6a:** Selected potential temperature profiles calculated from CTD data measured during M 27/1

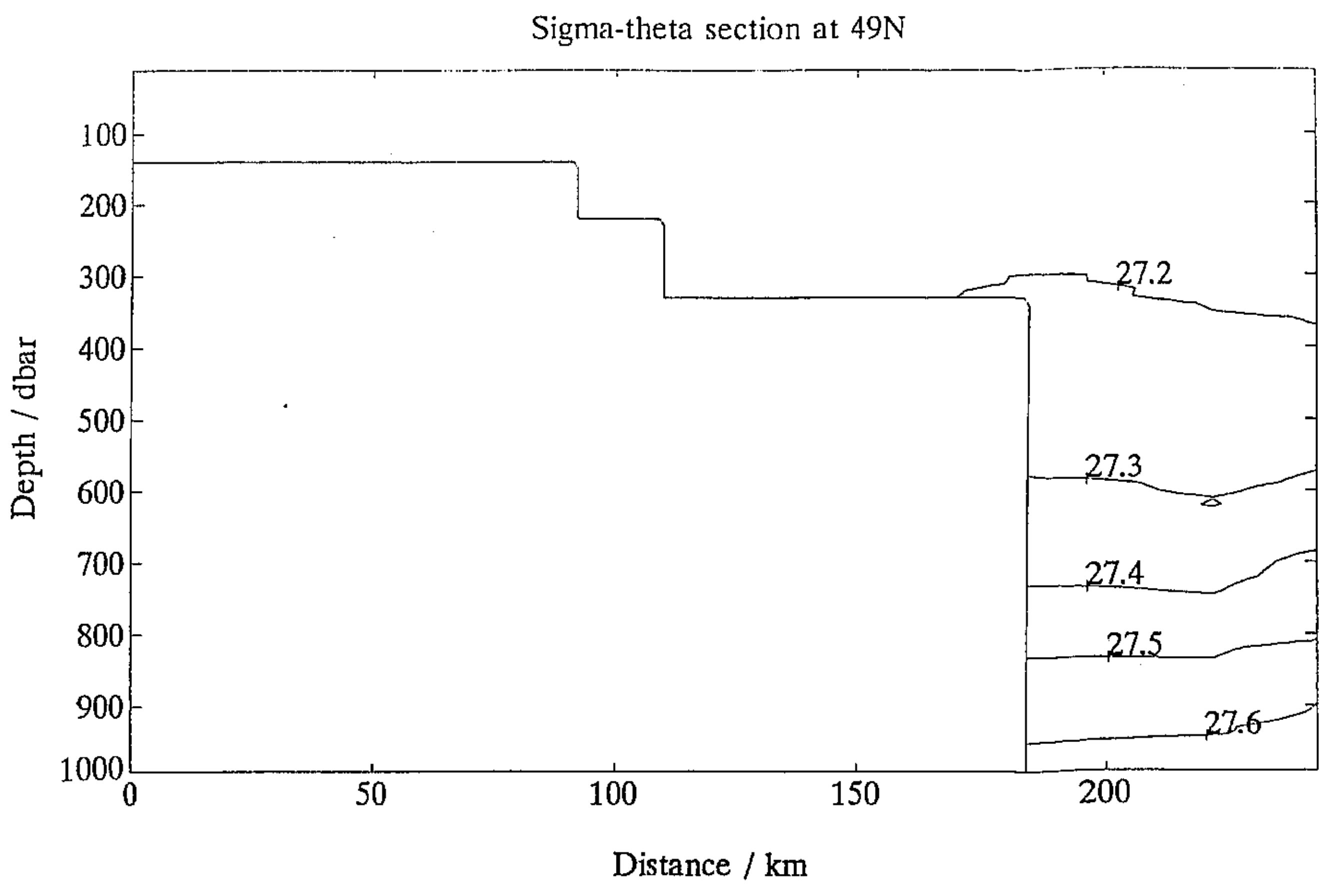



**Fig. 6b:** Sigma theta profiles calculated from CTD data measured during M 27/1

### 5.1.2 JGOFS: The Variability of Mixed Layer Depth along a CTD section during M 27/2 (J. Waniek, M. Schartau, W. Koeve)

The mixed layer depth depends on the past history of the wind in the locality, the stability of the underlying water and the heat balance through the surface, determining convective effects. Derived from historical CTD data sets and applying different methods the depth of the winter mixed layer for the area of investigation has been estimated to range from 200 to 500 meters (LEVITUS ,1982; GLOVER and BREWER, 1988).

LEVITUS (1982) suggested two criteria to estimate the winter mixed layer depth: In the first case he computed the mixed layer depths as the depths corresponding to a temperature change of 0.5°C (delta T=0.5°C) relative to the surface temperature. This criterion, however, was found to be not adequate for determining mixed layer depths over the entire world ocean. In subarctic regions e.g., one observes isothermal conditions or temperature profiles with inversions combined with salinity profile that stabilizes the water column and controls the depth of mixing. Therefore LEVITUS (1982) developed a second criterium defined by sigma-t change of 0.125 $g*m^{-3}$. Since the stability of the water column is a function of temperature and salinity and makes comparison of the mixed layer depths based solely on a temperature criterion with mixed layer depths based solely on a sigma-t criterion ambiguous. Therefore GLOVER and BREWER (1988) have suggested to calculate the depth of winter mixed layer from the Levitus winter data set applying a variable sigma-t criterion. In this procedure the surface values of temperature and salinity are taken as starting values, and a sigma-t due to lowering of the surface temperature by 0.5°C is calculated. Subsequently subsurface sigma-t values are checked against this sigma-t until they become greater. A linear interpolation between the last depth interrogated and the depth directly above is performed to find the precise depth at which the density profile reaches its target value. Mixed layer depths, calculated with the three methods gives values between 285 and 481 m (see Tab. 4). The variability of these results depends on the quality and quantity of the available data sets and on the mixed layer criterion chosen. The accepted criteria, described above, are all "very strong" and therefore the resulting mixed layer depths will be called in following "potential" winter mixed layer depths.

We calculated "potential" winter mixed layer depths derived from our winter CTD data set with the three methods described above. Fig. 7 shows the calculated depths of mixed layer from transect I (stat. 25 to 35), that had been carried out under moderate wind conditions (< 8 Bft). The mixed layer depths estimated with delta T=0.5 °C is ranging between 280 m and 350 m (see Fig. 7). The computed winter mixed layer depths with a criterion defined by delta sigma-t 0.125 have a thickness of 550 m along this CTD section. The calculated mixed layer depths for the variable density criterion show intermediate values ranging from 380 m to 480 m.

During winter time the mixed layer dynamic is a dominating process for the development of the phytoplankton (SVERDRUP, 1953). Phytoplankton growth conditions, however are not related to any "potential" mixed layer depth, but to the "actual" state of mixing at a given

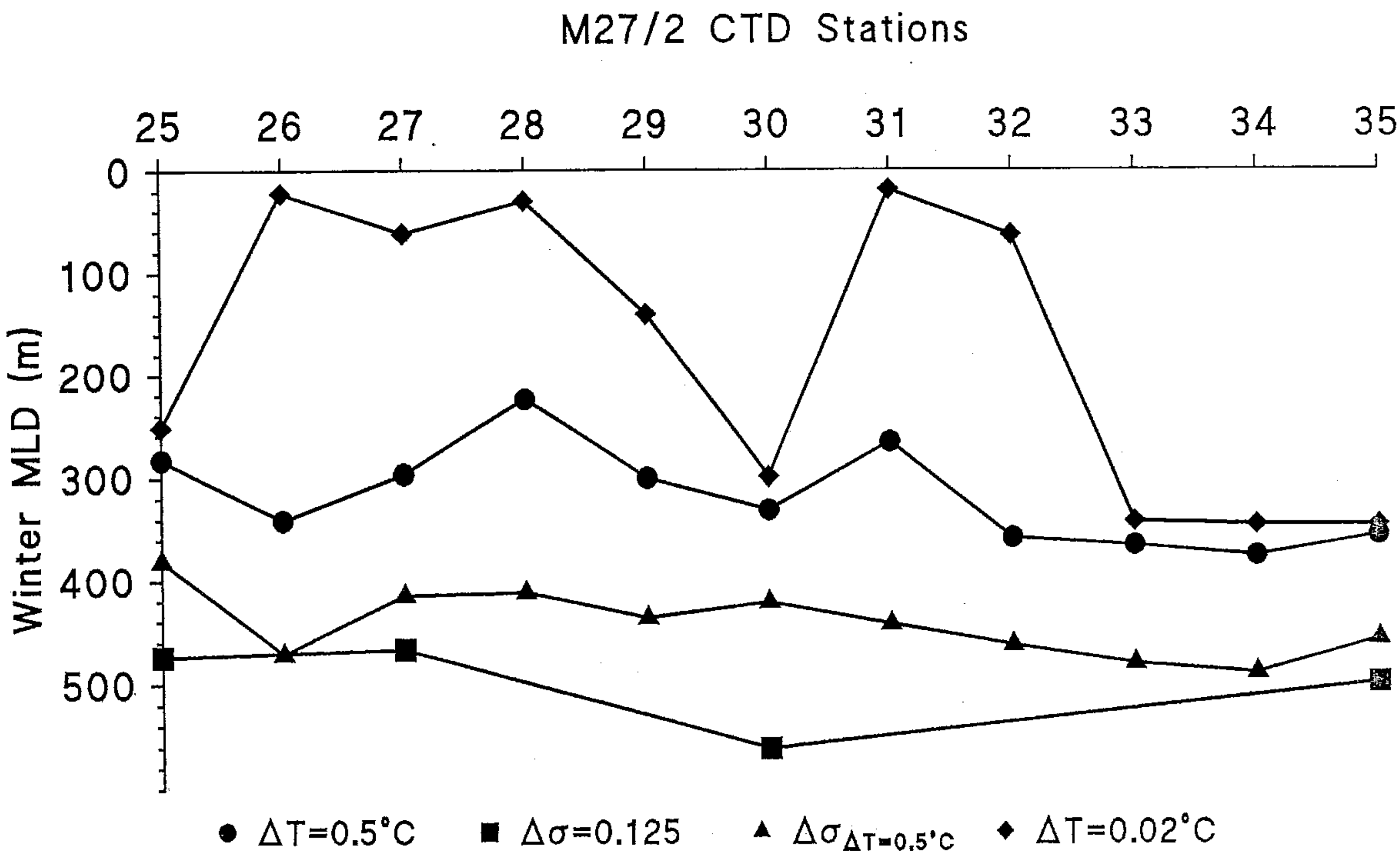



**Fig. 7:** Depths of the winter mixed layer calculated by different methods for stations 25 to 35 taken before storm event. The circles mark delta temperature 0.5°C, the squares the delta sigma-t 0.125, the triangles the delta sigma dependend from delta temperature 0.5°C, and the rhombus the delta temperature 0.02°C criterion.

location and a given time. To describe the actual mixed layer depth we depicted a criterium (delta T=0.02°C) suggested by LOCHTE et al., (1993). Computed "actual" mixed layer depths were highly variable, ranging from 20 to 350 m during transect I (Fig. 7).

**Tab. 4:** Mixed layer depth derived from the Levitus winter hydrographical data set (February - April) applying different methods (for details see text). Calculations were performed for a 3°x 3° grid around 47°N / 20° W (n=9). Calculated values adopted from KOEVE (subm.).

| | mean (m) | standard deviation (m) |
|---|---|---|
| delta T=0.5 (°C) | 285 | 7 |
| delta sigma-t=0.125 (g $m^{-3}$) | 481 | 70 |
| delta sigma-$t_{(delta\ T=0.5°C)}$ | 368 | 50 |

During winter and especially within the area of investigation temporally observed stratification of the upper water column is interrupted by stormy periods, which due to atmospheric cooling and wind induced turbulence deepens the mixed layer. Fig. 8 shows a comparision of calculated winter mixed layer depths along two CTD-sections being separeted by a storm event (9-10 Bft, 01.02.1994). While the "potential" mixed layer depth (eg. calculated according to a delta T=0.5°C) did not change, the actual mixed laxer depth (MLD) deepend particulary on stations with a shallow pre-storm actual MLD.

The horizontal distribution of potential temperature calculated from CTD data within the upper 450 m is given in Fig. 9. The prominent feature during transect I (Fig. 9a) was a band of warm water observed in the northern part of the section near the surface (in the upper 250 m) showing potential temperatures higher than 12°C. During transect II (carried out after the first storm event) waters in the north show an almost uniform temperature distribution down to about 350 m, however, a warm water band, extending down to 200 m, can be seen between station 40 and 44. The warm water is now about 0.2 °C colder as before the storm. Below 350 m on the north and 200 m on the south end of the section the water column is well stratificated and homogenization effects are not evident (Fig. 9b).

The big variability in potential temperature profiles measured during this cruise leg is illustrated in Fig. 10. At station 25 a well developed winter mixed layer up to 250 m is

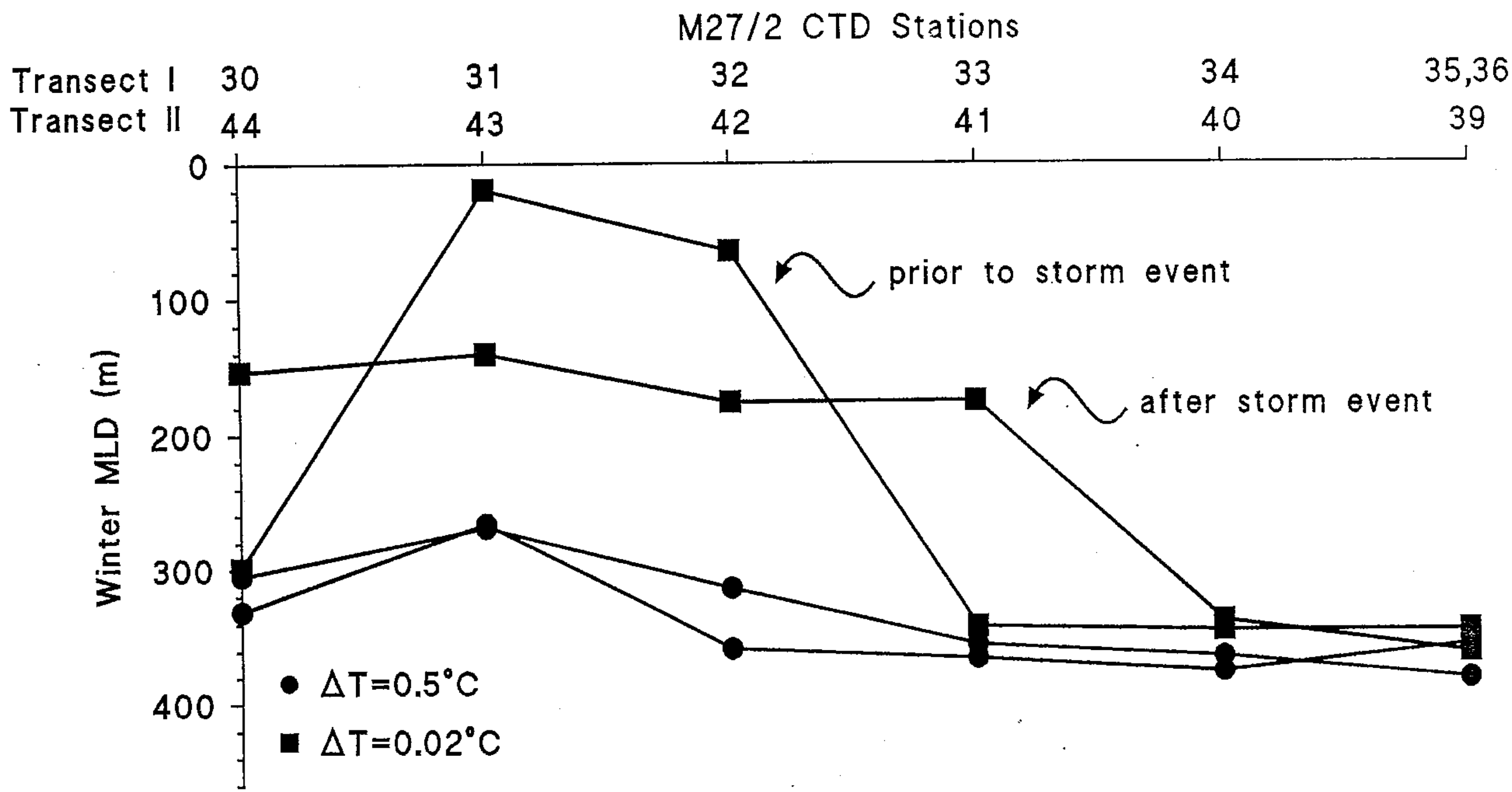



**Fig. 8:** Depths of the winter mixed layer calculated by two different methods. Comparison between stations taken before and after the storm event on February 1, 1994. The circles mark delta temperature 0.5°C and the squares the delta temperature 0.02°C criterion.

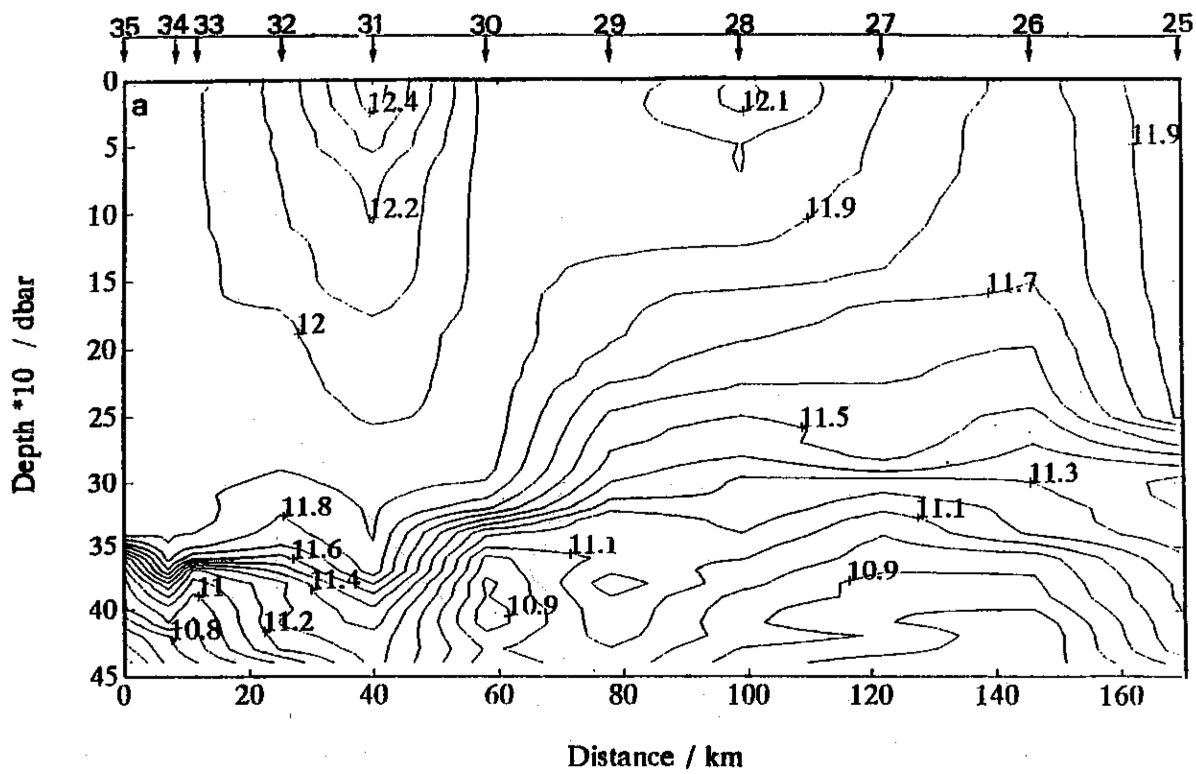



**Fig. 9a:** Section of potential temperature, stations 25 to 35 taken before storm event, distance calculated to station 35.

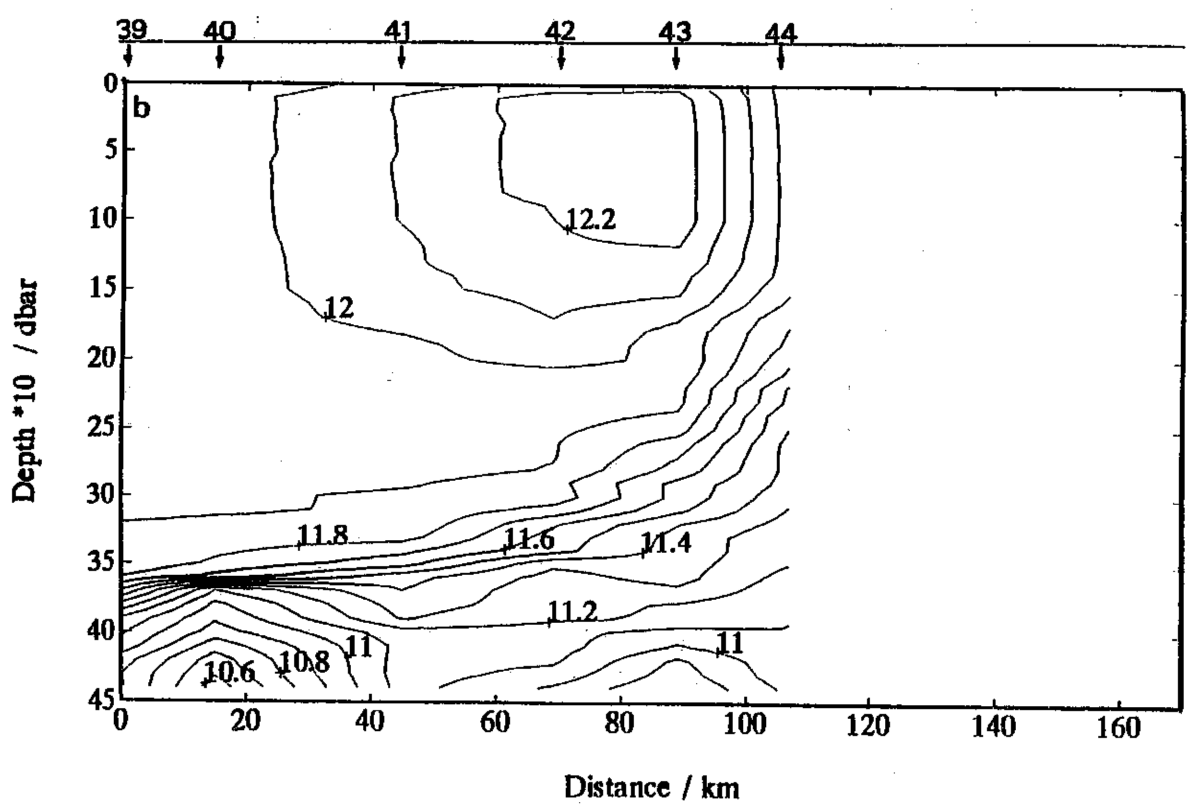



**Fig. 9b:** Section of potential temperature stations 39 to 44 taken after storm event, distance calculated to station 39.

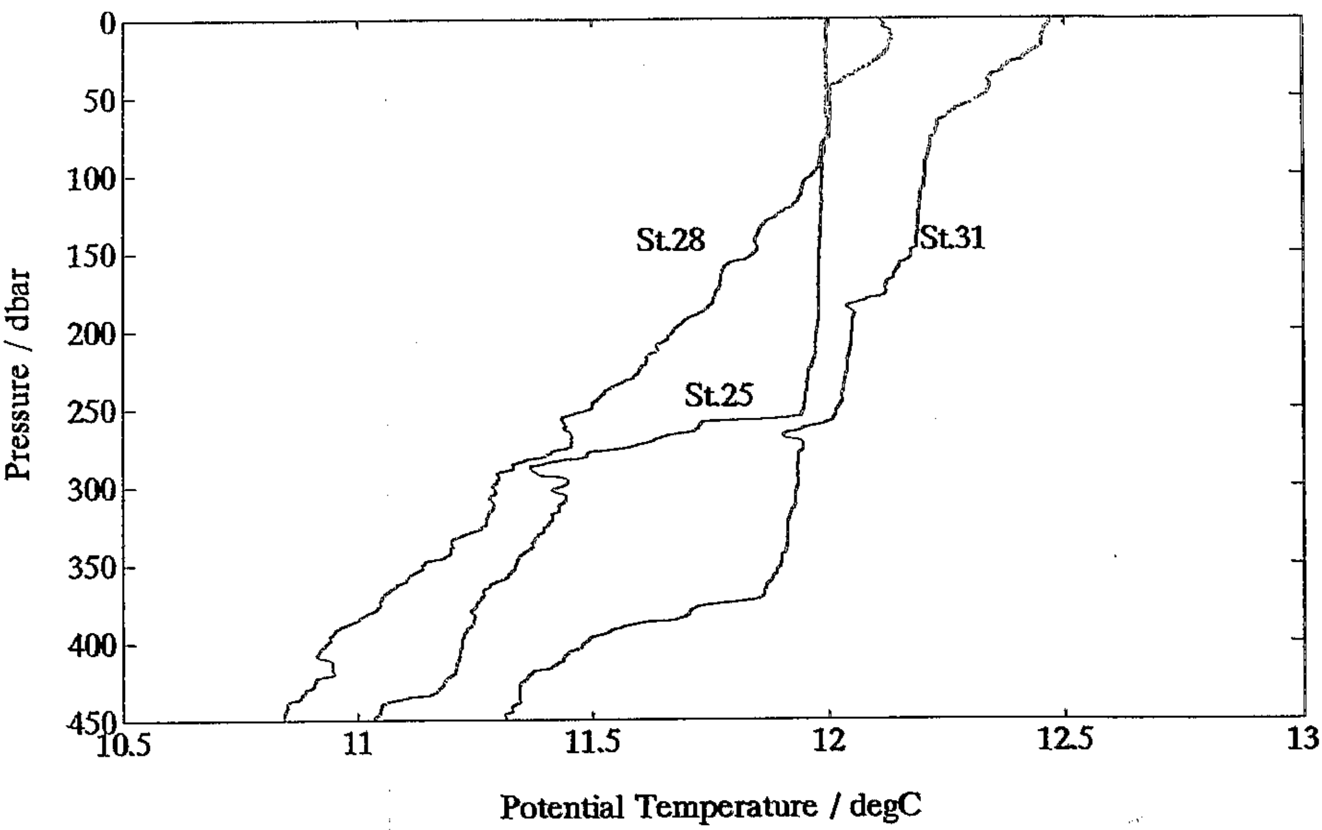



**Fig. 10:** The upper 450 m of selected potential temperature profiles versus depth measured by CTD during M 27/2 (Stations 25, 28, and 31).

evident. A different vertical distribution is observed at station 28. The potential temperature in upper 50 m is higher and show the influence of heating due to solar insulation. The potential temperature profile at station 31 shows step-like structures, caused by interaction between recent mixing and stabilization of the upper water column.

The same variability in vertical temperature distribution is evident in the temperature profiles measured by XBT drops. Fig. 11 shows the upper 600 m of selected temperature versus depth profiles (XBT no. 5, 9, and 10) below the actual mixed layer, that is only a fiew meters thick, reached a recent mixed layer by XBT no. 5 to 300 m, by XBT no. 9 to 220 m and by XBT no. 10 only to 120 m. In the subplot is the XBT no. 6 is shown, where the mixed layer depth nearly reached 400 m.

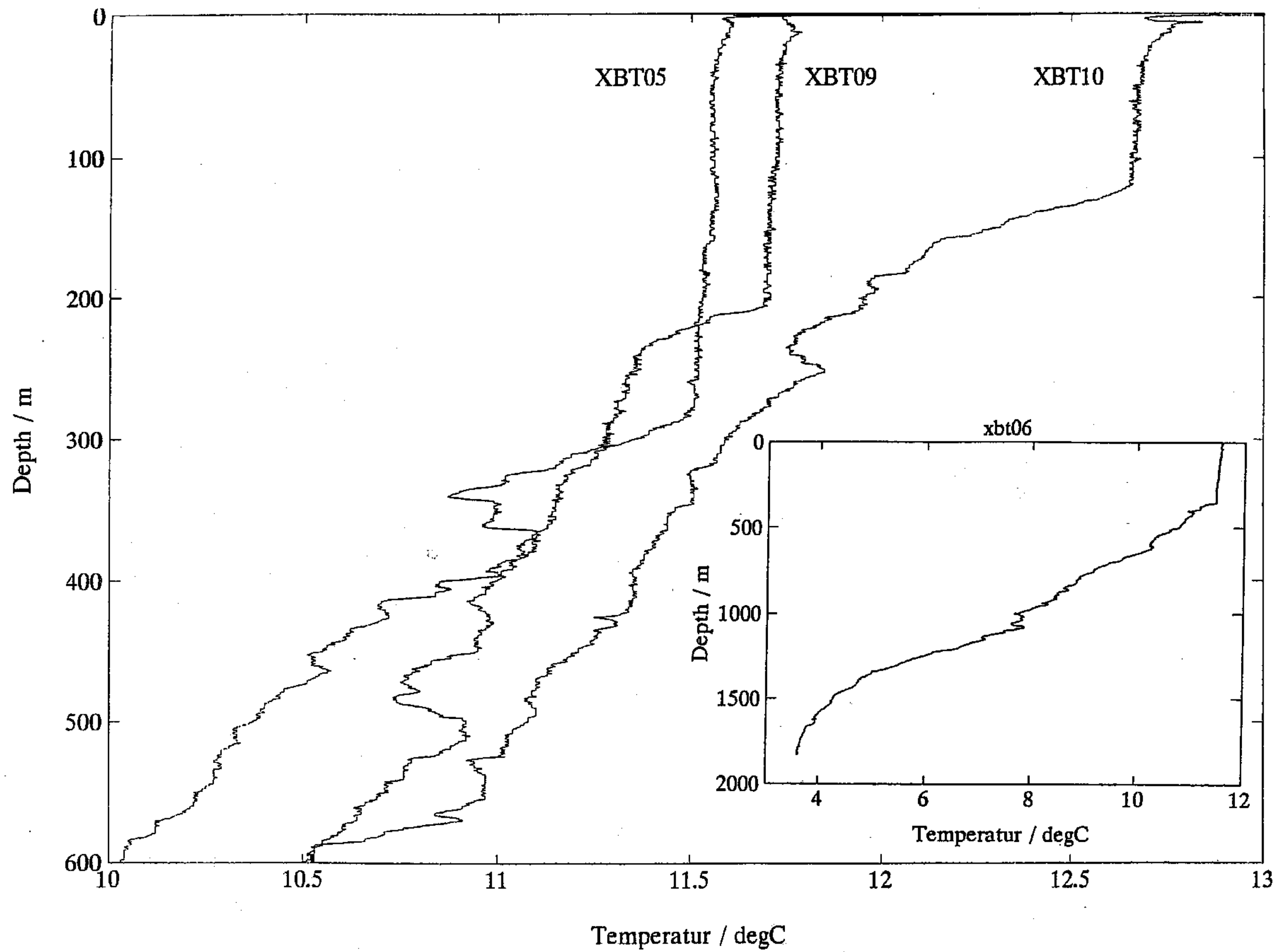



**Fig. 11:** The upper 600 m of selected temperature profiles versus depth measured by XBT drops during M 27/2. (XBT drops no. 5,9, and 10). Subplot of XBT no. 6.

### 5.1.2.1 The Weather Data Measuremed by Shipborn Sensors

During M 27/2 the shipborn sensors registrated weather parameters as wind speed, wind direction, air pressure and air temperature and sea surface temperature and salinity. Fig. 12a shows the time series of air pressure for the period from 30.01.1994 to 05.02..1994. On 01.02.1994 at 12:00 UTC the sensors registrated 1015 hPa. The barometer fell within a few hours to 965 hPa (02.02.1994, 17:00 UTC). The winds reached velocities up to 55 m/s (more as 12 Bft, Fig. 12b) during this time. The strong winds induced a cooling of air temperature from 10 to 3°C (Fig. 13a) and a cooling of sea surface temperature of 1°C, (Fig. 13b). Turbulence and cooling during storm events seemed to play a major role because of entrainment due to mixing with water masses below the mixed layer. A storm with wind force greater than 12 Bft, as occuring these two days can cause dramatic changes in the depth of mixed layer induced. We calculated the mixed layer depths with delta temperature 1°C, as observed during the second storm event, and obtained depths up to 420 m. Unfortunately due to heavy damage on the ship after the second storm, we had to stop our investigations, and no more CTD-station could be carried out, to evidence the deepening of the mixed layer.

### 5.1.3 WOCE Measurements during M 27/3 (F. Schott)

### 5.1.3.1 Methods

*CTD/oxygen measurements and calibration*

During the entire third leg of M 27 the IfM Kiel NB-3 CTD (Neil Brown Mark III) was well operating. This instrument showed good performance during earlier cruises and was operating well also on this cruise. On many stations reversing thermometers were used to check the lab calibration for temperature and pressure. Water samples were taken from the bottles to calibrate the salinity ond oxygen sensors of the CTD. As the CTD-measurements were terminated shortly before reaching Recife and the conductivity sensor suddenly showed an apparent time dependence during the last few casts, no final data set could be produced before the end of the cruise. The final calibration was done in Kiel shortly after the cruise and the coefficients agreed well to earlier calibrations and the preliminary coefficients used during the cruise.

*Freon analysis F11,F12*

During the cruise, the computer controlled freon system worked continuously from February 26, to March 25, without major technical or contamination problems. The performance of the system was excellent during the whole cruise.

Some minor problems occured: The valve, which connects the carrier gas flow through the water sample with the cooling trap had to be replaced four times due to cross-leaks, caused by salt crystals in the rotor. Each time the replacement could be carried out within an hour, so that only a few samples were lost during the cruise. The accuracy of the freon concentrations was ±0.003 pmol/kg for F11 and F12, and the overall blanks were in the range of

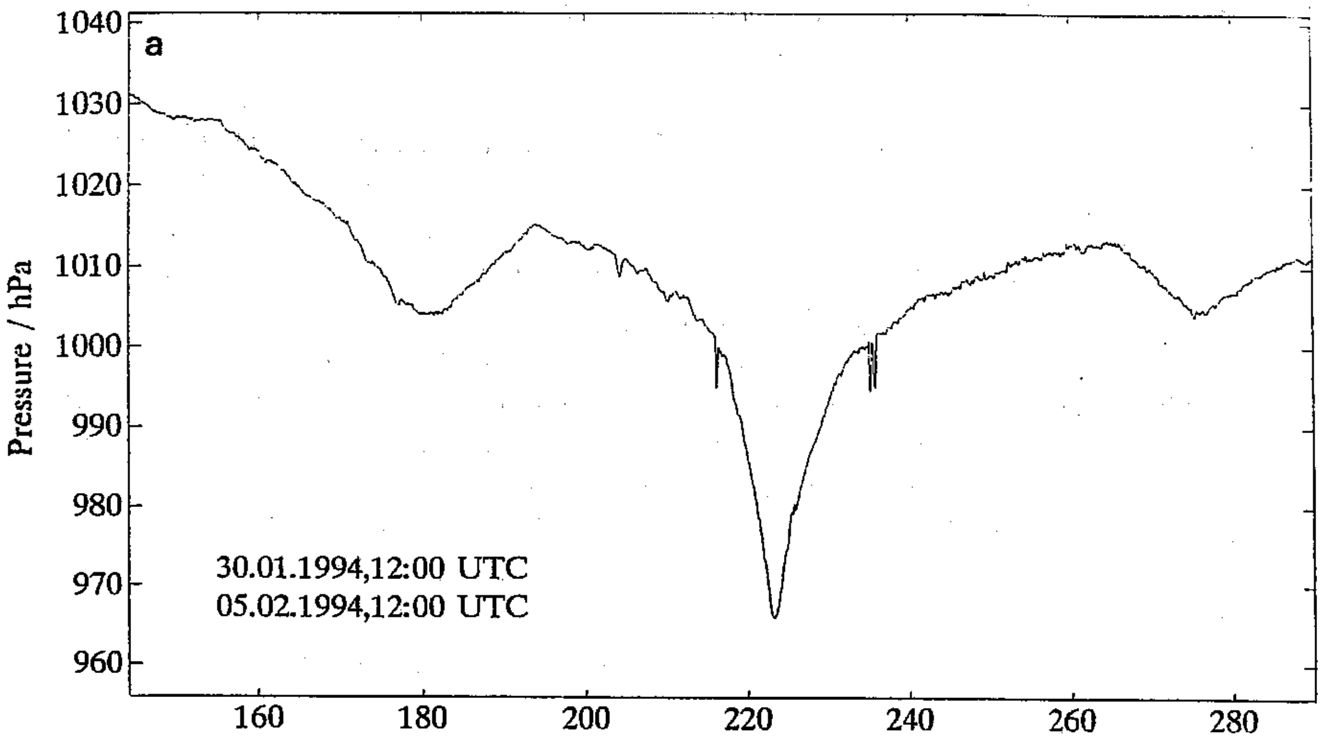



**Fig. 12a:** Time series of air pressure registrated by shipborn sensors. Time period from January 30, 1994, 12:00 UTC to February 05, 1994, 12:00 UTC.

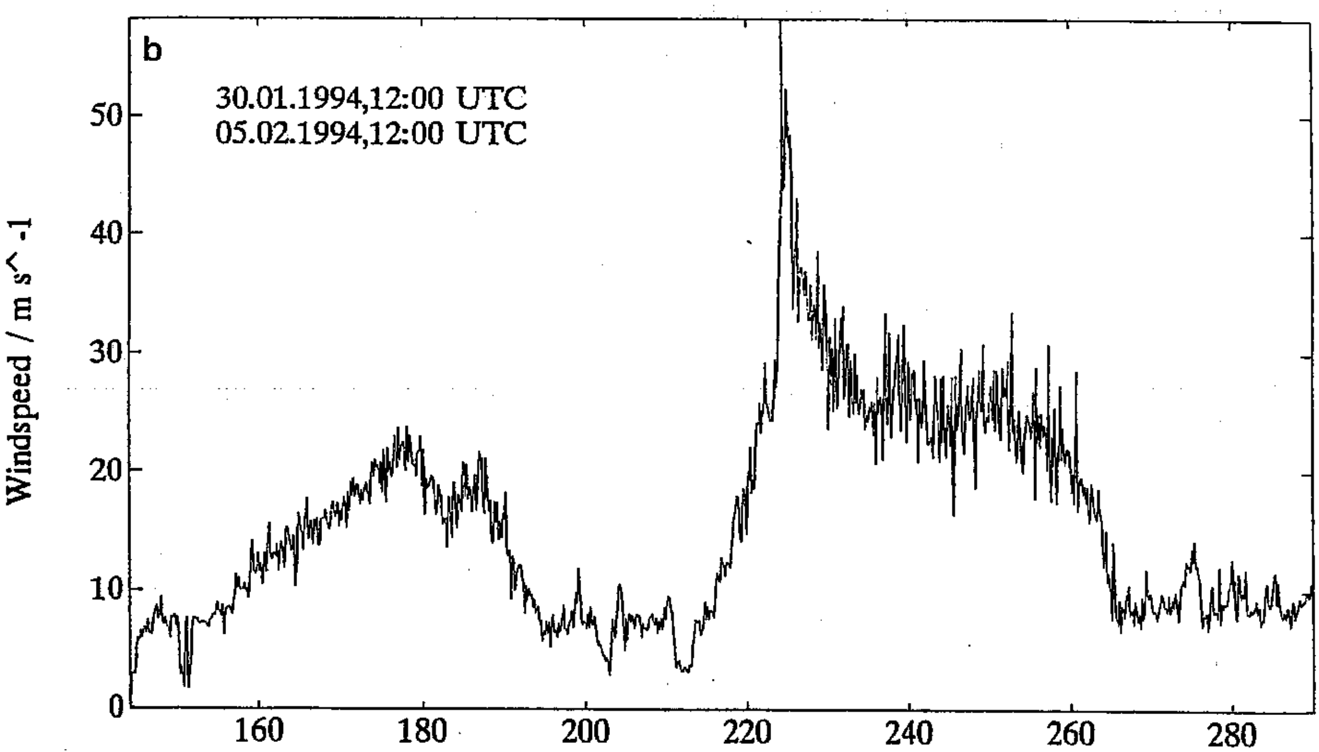



**Fig. 12b:** Time series of windspeed registrated by shipborn sensors. Time period from January 30, 1994, 12:00 UTC to February 05, 1994, 12:00 UTC.

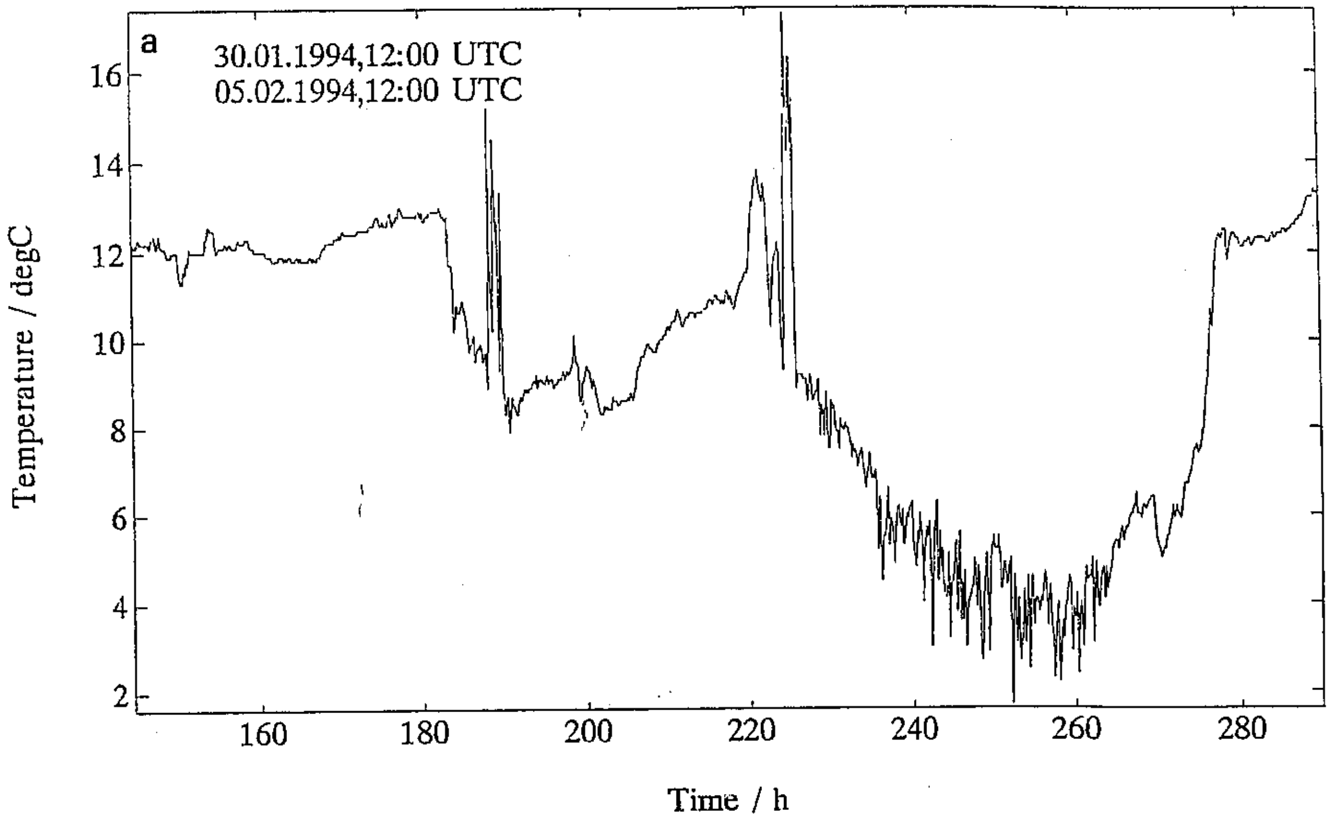



**Fig. 13a:** Time series of air temperature registrated by shipborn sensors from January 30, 12:00 UTC to February 05, 1994, 12:00 UTC.

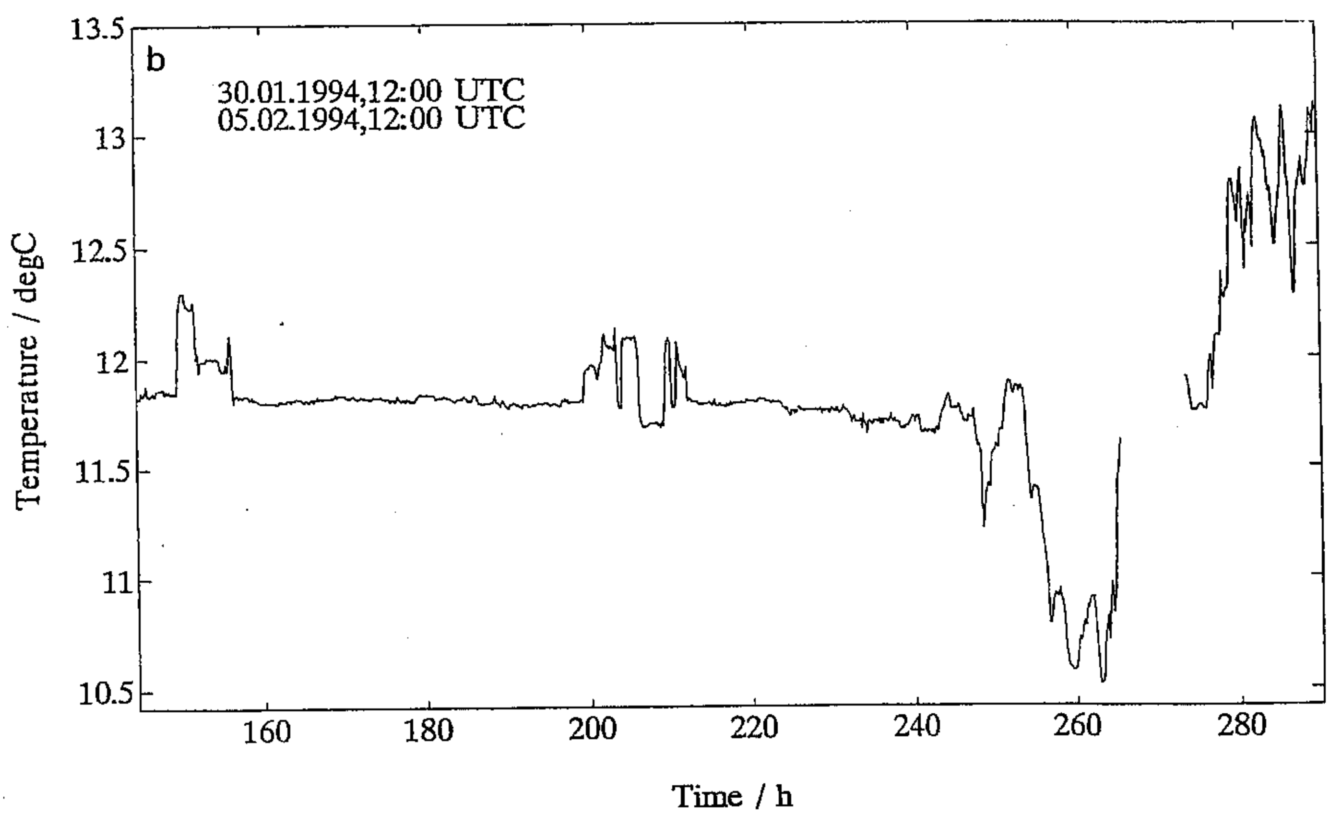



**Fig. 13a:** Time series of sea surface temperature registrated by thermosalinograph-sensor from January 30, 1994, 12:00 UTC to February 05, 1994, 12:00 UTC.

0.002 pmol/kg F11 and 0.003 pmol/kg F12. Air samples have been taken regularly and analyzed.

For each analysis about 100 ml water were transferred from the precleaned Niskin bottles to a purge and trap system with a gas tight ground glass syringe. The freons were separated from other gases in a Gaschromatograph equipped with a packed stainless steel column and detected by Electron Capture Detection. Analysis of a water sample took about 11 min. Calibration of the variable efficiency of the Electron Capture Detector (ECD) was done with a gas standard with known freon concentrations kindly provided by R.Weiss, Scripps Institution of Oceanography, San Diego.

The freon (F11, F12) measurements were restricted to depths below 700 m in order to get a sufficient vertical resolution in the deep water masses with the available bottle samples. Moreover, the time to calibrate the ECD was minimized, as in the concentration range of deep water in the tropical Atlantic, the response of the ECD behaved almost linear. In total, 3000 analyses were performed, including 1500 water samples.

The analysis of other halocarbons, e.g. Carbontetrachloride (CCl4), on our second analysis system equipped with a capillary column dedicated to these measurements, failed due to technical problems caused by accidental flooding of the whole system with seawater. Even replacements of the stainless steel connections, the cooling trap and the capillary column did not lead to a stable response of the ECD to CCl4 or F-113.

In addition to the freon analysis, 100 tritium and helium samples in deep water were taken at the 5°S section. They complement the samples taken in October 1990 and 1992. The analysis will be carried out at the Institut für Umweltphysik, University of Heidelberg.

*LADCP profiling*

On all CTD-stations a self-contained ADCP was lowered together with the CTD to obtain ocean deep velocity profiles. Unfortunately, both ADCPs showed severe problems during the first half of the cruise and most of the current profiles were of degraded quality for that part. One of the two ADCPs, the broad-band ADCP (BB-ADCP), showed the same problems as during M 22, i.e., large data gaps on the upward trace of the casts although the manufacturer had claimed to have the problem fixed. Some of the shallower casts (2200 m) along the 44°W section were complete and of sufficient quality. The older 'narrowband' ADCP (NB-ADCP) showed a compass problem resulting in a large heading deviation. The reason for this failure could not be identified, but it seemed to be a bias rather than higher order deviations. This was supported by comparing the LADCP data with simultaneously measured PEGASUS profiles.

At the 40°W section the electronic mainframe of the LADCP was exchanged with that of another ADCP just recovered. An undetected incompatibility of the electronic boards led to total data loss at the southern end of that section. For the northern part of that section we used the BB-ADCP.

With the NB-ADCP repaired at the beginning of the 35°W section we performed two compass tests which revealed large deviations but no singularities. During the section several PEGASUS profiles were used to estimate the heading bias. The mean deviation was 190° with a standard deviation of ± 3°. In some of the profiles the heading fluctuations seemed larger than during previous experiments, but it could not be excluded that this might be caused by unusually large ascent rates (up to 1.6 m/s).

Altogether the current measurements with this instrument were of sufficient quality along the southern part of the 44°W section, along 35°, 5°S, and 10°S. A preliminary comparison of the LADCP- and the shipboard-ADCP transports is given in Table 5. Below at about 4000 m depth, the standard deviation of the current shears increased due to the small measurement range, and the very deep currents should be accepted with caution.

**Tab. 5:** Transport comparison LADCP/VMADCP

| section | direction | depth | range | VMADCP | LADCP |
|---|---|---|---|---|---|
| 44°W | westward | 0-350 m | out to 1.5°N | 24.4 Sv | 17.0 Sv |
| 44°W | westward | 350-1000 m | out to 1.5°N | - | 14.0 Sv |
| 35°W | westward | 0-350 m | out to 3.6°S | 18.2 Sv | 12.7 Sv |
| 35°W | westward | 350-1000 m | out to 3.6°S | - | 6.2 Sv |
| 5°N | northward | 0-350 m | out to 33.2°W | 13.6 Sv | 12.7 Sv |
| 5°N | northward | 350-1000 m | out to 33.2°W | - | 5.3 Sv |
| 10°S | northward | 0-350 m | out to 33.2°W | 11.0 Sv | 11.3 Sv |
| 10°S | northward | 350-1000 m | out to 33.2°W | - | 10.7 Sv |

*PEGASUS Profiling*

During M 27/3 17 PEGASUS stations were occupied successfully. A hardware failure of one of our PEGASUS systems caused us to repeat one of the stations (PEGASUS 02), while all other profiles were accomplished without any problems.

Two of the sea floor mounted transponder arrays, which are necessary for the PEGASUS system, were newly deployed and surveyed in. The surveys were done with ship speeds of up to 8.5 knots, which in comparison with earlier METEOR cruises, when ship speeds of up to only 6 knots were used, decreased the necessary time by half an hour. At all other stations, transponder arrays deployed during earlier cruises (M 14, M 16, M 22) were used for the casts. Unexpectedly, most of the M 14 transponder arrays were still found operating after 3.5

years (nominal lifetime 2 years), while all of the arrays deployed 4 years ago by scientists from Miami along 44°W were found dead. Thus only one station, deployed by our group during M 14, was occupied along this section.

All surveys and profiles have been fully processed, and the final results of the current measurements are available. The results already were used in comparison with currents obtained by the LADCP, i.e., the PEGASUS results were used to calibrate the LADCP heading.

*Mooring retrieval and data return*

Three moorings, K359-K361, had been deployed during October 27-28, 1992. Each was equipped with an ADCP on top and Aanderaa Current Meters (ACMs) underneath; a total of 24 ACMs were distributed on the three moorings to cover both, the warm water flow below the ADCPs and above 1000 m and the deep water core, reasonably well.

Fortunately, all moorings were equipped with double releases, since a tow whinch for dragging operations was not available. All three moorings were retrieved intact during March 4-5, 1994. One of the two releases on K361 did not respond when triggered, but in a subsequent test on deck the release function worked. The transponding and release operations were executed from the hydrophone installed on the telescope mast, which made navigation by transponder ranging particularly easy. All mooring equipment came back aboard in good shape, with no effects of fouling or corrosion.

The data of ll instruments were read and calibrated on board. From the ADCPs, good time series were obtained over the entire deployment for stations K360, K361, while the recorder on K359 stopped after 3 months. The reason was a slow leakage and a short in the outside cable plug that emptied one battery. For the ACMs, the data return was not as high as hoped for. Complete records were obtained from 9 instruments; 11 records were shorter, mostly around one year long, where the reason was lack of battery power in the older models; two instruments were flooded (unfortunately, these were two of the four borrowed from ORSTOM/Cayenne); one ACM had a full battery and only a few cycles on the DSU, and one ACM contained no data on the DSU, but had an empty battery. However, by drawing on the whole storage content of these two instruments, we were able to extract 11 months and 10 months of data, respectively, from these two ACMs. Overall, out of the 27 instruments deployed, 21 had records of at least one year duration, and 2 had 10 to 11 month of data.

*Shipboard ADCP*

During M 27/3 we used the hull-mounted ADCP which had the protection shield removed in the ship yard prior to the cruise. For most of the time, the measurement range was about 400 m. This range was significantly larger than with the protection shield in place (e.g. M 22). The vertical resolution was 8 m from 20 m depth downwards. The raw data were ensemble- averaged over 5 minutes, yielding an average horizontal resolution of 1.5 km.

A short test with an ADCP mounted in the ship's well showed less range and this instrument was therefore kept as a standby system.

In addition to the Doppler measurements, the ship's heading as well as, a pitch and roll angles were used for the internal ADCP processing. External position data from our own GPS-system were continuously recorded at a resolution of one average position per minute, and were used to calculate a reference velocity.

For each of the sections we had to perform a separate heading calibration. Due to a failure in the ship's gyro system, course and speed dependent gyro deviations were not compensated for and led to significant differences in the calibration angles along the sections (Tab. 6). The largest deviations were observed during the north-south sections showing differences of about 5° between the sections with reverse heading. This was supported by heading deviations determined from astronomical fixes.

It is not clear what the heading biases were along the transect from 44°W to 40°W, where the course was first northeastward and then southeastward, and where cloud cover prevented astronomical fixes. Here we applied the calibration coefficients determined from the 40°W section for the first part (northeastward), and from the 44°W section for the second part (southeastward).

After the calibration, the data were averaged into 30 minute time intervals along the track. Reversing partitions in a section were removed because of the course dependent heading error. The final processing stage was smoothing and regridding the data to 0.1° latitude or longitude depending on the general orientation of the sections.

By the end of the cruise, all ADCP sections were calibrated. Velocity maps, section plots of current components and transports calculations were the first products.

**Tab. 6:** Calibration coefficients for VM-ADCP compass

| section | phase | phase dt | amplitude | time base |
|---|---|---|---|---|
| 8°-11°N | - 1.71 - | 0.0592 | 1.0229 | 60.4 |
| 44°W | - 1.71 | - 0.0592 | 1.0229 | 60.4 |
| 1°S-N | 2.86 | 0.0493 | 1.0229 | 67.1 |
| 1°S-S | - 1.71 | - 0.0592 | 1.0229 | 60.4 |
| 40°W | 2.86 | 0.0493 | 1.0229 | 67.1 |
| 4°N | 0.73 | 0.1014 | 1.0469 | 69.9 |
| 35°W | - 1.6385 | 0.0 | 1.0270 | - |
| 5°S | 0.98 | 0.4647 | 1.0354 | 77.6 |
| 30°W | - 1.91 | - 0.152 | 1.0321 | 80.4 |
| 10°S | - 0.27 | 0.0916 | 1.0406 | 82.8 |

*XBT casts*
During M 27/3 a total of 87 XBT's were dropped. The distribution of the XBT casts is given in the list in chapter 7. The XBT measurements were carried out in between the CTD's along the sections with larger station spacing as well as from 18°52' N / 37°23' W to the Vema Fracture Zone (Fig. 2), where the continuous CTD measurements of M 27/3 started, and on the transfer leg near the Brazilian shelf between the 44°W and the 40°W sections.

*DVS*
Temperature and salinity were continuously recorded by the ships data recording system (DVS). This data set also contains meteorological data (wind, air temperatures, radiation etc.), the ship's speed over ground as well as through the water, and depth from different echosounders (only outside Brazilian waters).

Hull depth temperature and salinity, wind and ship drift were plotted on a daily basis for comparison with other data sources such as the ships ADCP.

The thermosal data were calibrated using CTD station data from 10 m depth. The overall agreement of the two temperatures was good, and no calibration was needed (the bias between the two measurements was less than 0.01°C). Salinity was biased by 0.085 towards higher values. Time dependent trends in salinity were not obvious, and the remaining scatter after the calibration was 0.033 psu.

At the end of the cruise, calibrated sea surface salinities and temperatures were plotted along the sections.

### 5.1.3.2 Summary on Preliminary Scientific Results

#### 5.1.3.2.1 Upper-layer Circulation and Water Masses

*Water masses and current structure*
Salinity and oxygen are the important tracers to pursue upper-layer water masses through the western subtropical Atlantic. Fig. 14a shows the distinction of the water masses in a OOOS diagram: southern water masses are characterized by a large salinity maximum at the Tropical Underwater (TUW) core at $\sigma_\theta$ = 24.5-25.0. The northern maximum is at a similar density level, but is lower along the western boundary. Below the $\sigma_\theta$ = 25.8 level, along the near-linear TS relation of the Central Water, the southern water masses are fresher than those from the north. An even stronger distinction is possible through the oxygen distribution (Fig. 14b): Except for the surface-mixed layer, water masses in the salinity range 35.1-36.3 psu have much higher oxygens, above 4 ml/l, when stemming from the southern hemisphere than when originating in the north, where they show <3.2 ml/l. Distributions of salinity and oxygen on isopycnals therefore allow discrimination in the distribution of both water mass types along our sections.

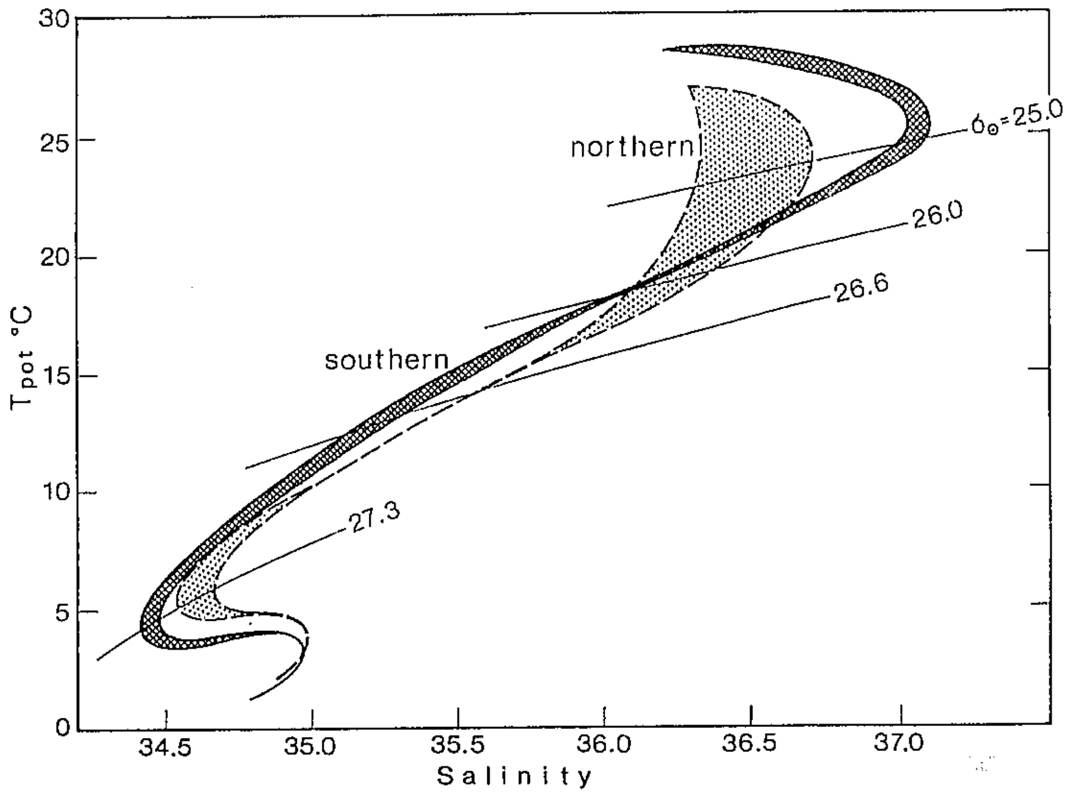



**Fig. 14a:** Northern and southern water mass contrast θS diagramm for stations 8-12, along 44°W, (Fig.2) and stations 79-82 along 5°S near the coast.

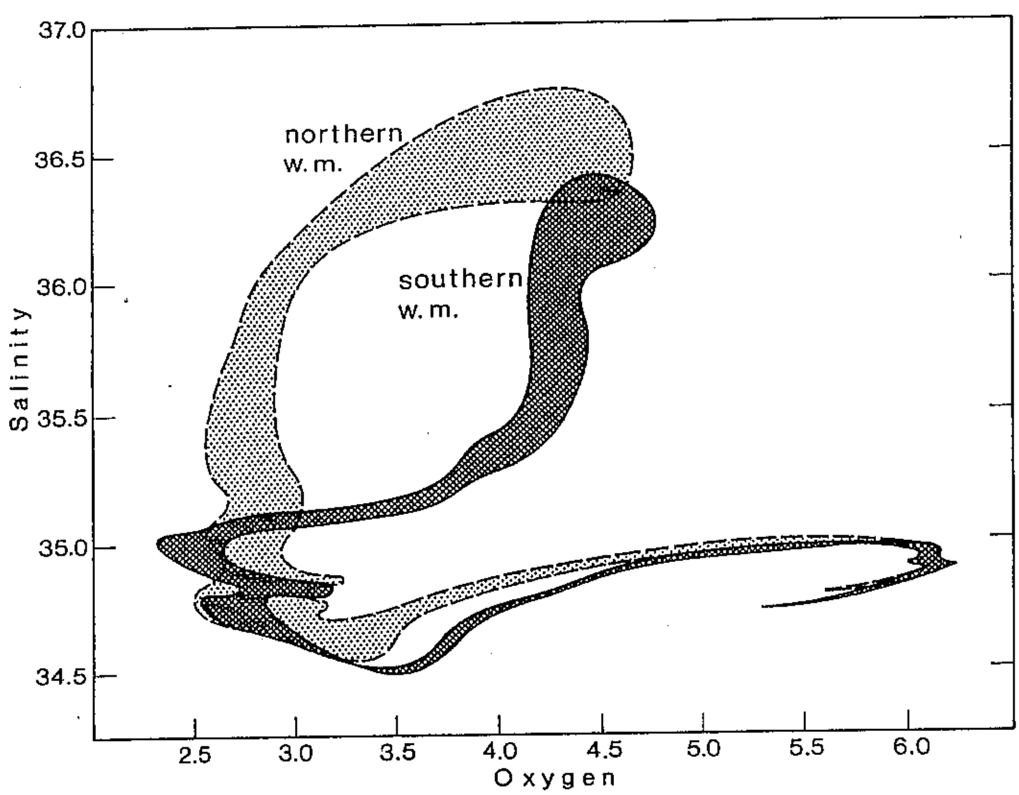



**Fig. 14a:** Northern and southern water mass contrast $S/O_2$ diagramm for stations 8-12, along 44°W, and stations 60-64 along 35°W near the equator.

A composite picture from M 27/3 CTD/ADCP results for the currents and water mass distributions along the 35°W section is shown in Fig. 15. The velocity contours mark three regiones of eastward flow (unshaded); the Equatorial Undercurrent (EUC) between 1.5°S and 2°N, reaching from 200 m up to the surface and with maximum speeds exceeding 80 cm/s; and the North and South Equatorial Undercurrents NEUC and SEUC, at 3°-4° N and S, respectively. These three eastward cores are embedded in the westward-flowing South Equatorial Current (SEC). Near the coast, the North Brazil Undercurrent (NBUC) turns around Cape San Roque with a subsurface maximum of 60 cm/s.

The salinity contours in Fig. 15 show the NBUC salinity maximum near the coast and again in the core of the EUC, where most of NBUC flow is returning eastward, as shown below. The oxygen contours (dotted) in Fig. 15 show the maximum associated with the NBUC near the coast, high values again in the EUC but low values in the SEUC and NEUC. These regional differences are apparent in the property distributions on isopycnals. As seen from Fig. 15, the isopycnal surface $\sigma_\theta$= 25.0 is well suited to show property distributions in the core of the EUC and the NBUC salinity maximum. Isopycnal $\sigma_\theta$ = 26.6 cuts through the lower part of the EUC and the upper parts of the NEUC and SEUC while $\sigma_\theta$= 26.8 can be used as a lower limit for ADCP transport integration.

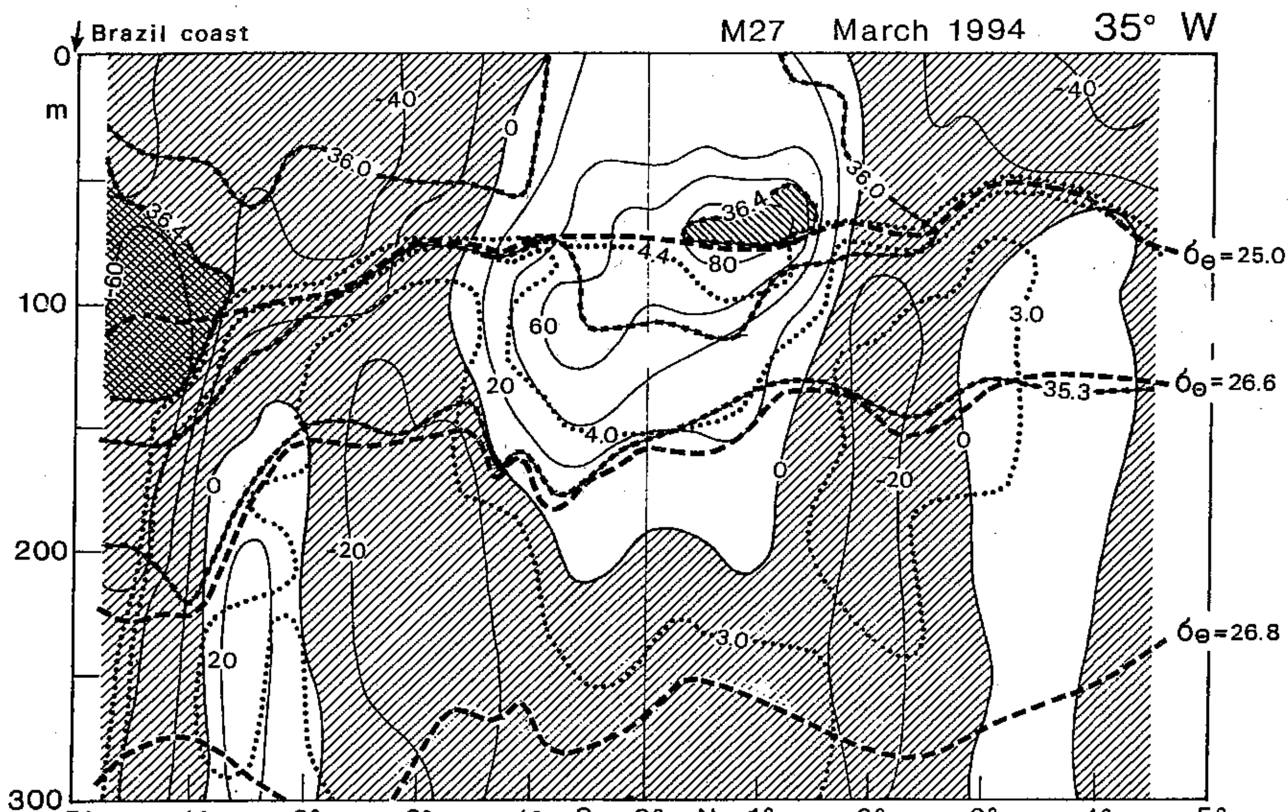



**Fig. 15:** Zonal velocity distribution (cm/s) along 35°W in the upper 300 m from shipboard ADCP. Shaded areas indicate westward velocities. Included are the isopycnals of $\sigma_\theta$ = 25.0, $\sigma_\theta$= 26.6, and $\sigma_\theta$= 26.8 by long dashed lines. Selected isohalines are given as short dashed lines and the oxygen distribution (ml/l) by dotted lines.

The property maps show very clearly that the NBUC and NBC flow along the coast can be traced from 10°S all the way northwestward to 44°W. High oxygens, of > 4.4 ml/l, mark the connection of the EUC at 40°W and 35°W with the NBC retroflection zone at 44°W/NBUC. The maps suggest that water of southern hemispheric origin mostly retroflects into eastward zonal currents, and that a clear distinction between northern and southern sources of the zonal flows exists at 3-4° N.

*Transports and budgets*

The upper-layer currents are mostly within the range of the shipboard ADCP, thus allowing transport calculations at good resolution. The ADCP currents as well as the salinity and oxygen distribution show that the retroflection at 44°W supplies both zonal currents, the EUC and the NEUC, out of the NBC inflow. At 44°W, the EUC and NEUC cores are not separated yet; at 40°W (Fig. 16) there are two distinct maxima: The EUC is still located north of the equator, at 1°N, the NEUC core is located at 2.5°N. At 35°W (Fig. 16), the EUC core has almost reached the equator.

Transports of the individual current branches balance each other quite satisfactorily: The NBUC at 5°S transports 14 Sv above 400 m which partially turns westward north of Cape San Roque where the SEC overrides it and both together transport 30 Sv westward in latitude range 1-5°S composed of 27 Sv from the zonal flow (Fig. 16) and 3 Sv from the meridional component as the section near the shelf is slightly titled. 2 Sv of this flow return eastward as SEUC at 3-4°S. Further along, at 40°W, the NBC transport is 29 Sv westward, and across 44°W the NBC transports 31 Sv composed of 25 Sv zonal flow and 6 Sv meridional flow. A very interesting result that a large part of the NBC transport, 20 Sv, return eastward in latitude range 1°40' N - 3°55' N, which comprises the joint transport of the EUC and NEUC at that longitude.

At 40°W, these two currents cross in the 0 - 3°20' N latitude range, with a joint transport of 22 Sv. Of these, the NEUC core splits off northward on the way east to 35°W and appears at 35°W near 4°N with a transport of 2 Sv . Across 35°W the EUC transports 22 Sv.

North of 4°N, we observed a totally separate flow regime. The water masses are northern, i.e., of low oxygen and high salinity below the thermocline. The NECC flows westward north of 4°N, and is not clearly distinct from the northern branch of the SEC. Both together transport 12 Sv westward across 35°W in the latitude band 0-4.5°N. At 44°W, where our section extended further northward, the westward transport in latitude range 4-8°N was 20 Sv. Further careful data analysis is needed to combine these transports to a general flow scheme of this region.

From the observations of M 14/2 in October 1990 and M 22/2 in November 1992 STRAMMA et al. (1994) determined a NBUC transport between the surface and 1000 m of about 20 Sv at 5°S from a combination of direct velocity measurements by shipbord-ADCP and lowered ADCP. One objective of M 27/3 was to investigate the NBUC in austral fall.
Computations with sparse historical hydrographic data (STRAMMA et al.,1994) resulted in a

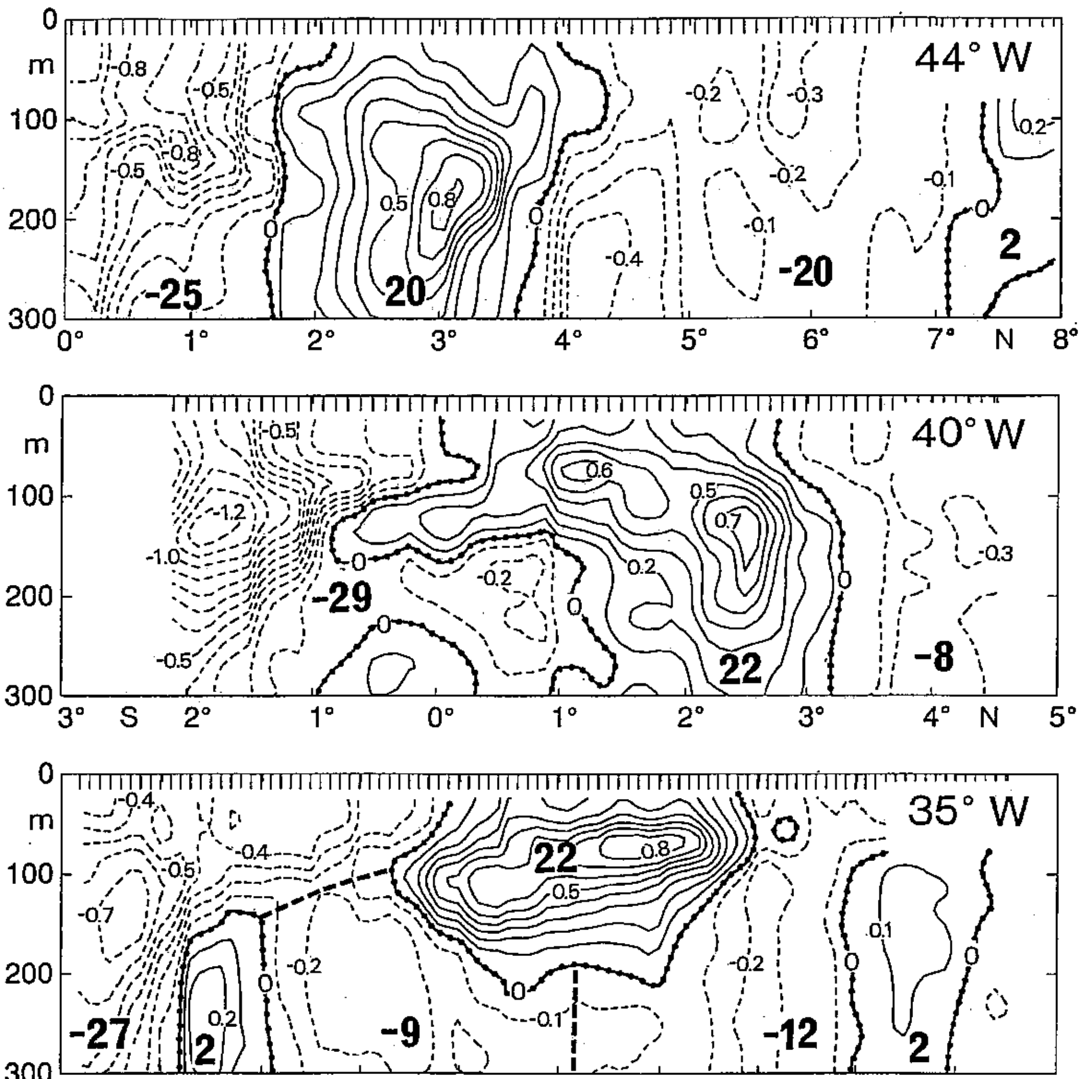



**Fig. 16:** Zonal velocity distributions (m/s) along 44°W, 40°W and 35°W in the upper 300 m from shipboard ADCP. Transports in Sv for indicated boxes are given in bold type numbers.

weaker NBC in austral fall. The first results of M 7/3 section along 5°S in March 1994 indicate from the LADCP a weaker flow and the geostrophic transport relative to $\sigma_1 = 32.15$ for the core of the NBUC amounted to 20.9 Sv in the upper 1000 m, i.e., about 3.5 Sv less than in November 1992. The velocity observed in the core of the NBUC ranged up to 120 cm/s. A careful combination of the different methods is needed for a final statement of the transport changes between the different cruises.

### 5.1.3.2.2 Deep Circulation and Water Masses

*Vema Fracture Zone*

The CTD programme started with three CTD-stations across the Vema Fracture Zone (VFZ). The Vema Fracture Zone crosses the Mid-Atlantic Ridge near 11°N from the Demerara Abyssal Plain in the western Atlantic to the Gambia Abyssal Plain in the eastern Atlantic. According to McCARTNEY et al. (1991), the VFZ is the primary passage for bottom water flow into the northeastern Atlantic basins. McCARTNEY et al. (1991) did geostrophic computations at the eastern end of the VFZ and computed a bottom water flow of 2.1 to 2.3 Sv for water colder than 2.0 potential temperature. As reference level the potential temperatures between 2.17 and 2.43°C were selected from water mass distribution constraints.

Our three CTD-profiles were made in the eastern part of the Fracture Zone at 41°56.5 W. The geostrophic velocity profile between the northern and southern stations is shown in Fig. 17. For a comparison to McCARTNEY et al. (1991) the reference was chosen to be 2.2°C. The mean eastward geostrophic velocity for the bottom water below 4000 m is more than 10 cm/s reaching up to 17 cm/s. The geostrophic transport below the 2°C isotherm at 3950 m is 1.95 Sv to the east. This transport value is only a little less than the transport of 2.1 to 2.3 Sv derived by McCARTNEY et al. (1991). As can be seen from Fig. 17 the velocity gradient is large below 3450 m, where the 2.2°C isotherm is located, and a deeper reference would reduce the eastern transport considerably, while a little shallower reference layer would slightly increase the eastward bottom water flow. Unfortunately no usable LADCP profiles at the three VFZ stations could be obtained for comparison with the geostrophic results.

*Circulation of the Guiana Basin*

Two deep circulation branches pass through the Guiana Basin: Antarctic Bottom Water (AABW) enters from the southeast out of the Equatorial Channel, and northward speeds of 7 cm/s were measured east of the Ceara Rise at 4°N by WHITEHEAD and WORTHINGTON (1982). The upper limit of the AABW is estimated to lie near the $\sigma_4$=45.90 surface, which is at 4000 - 4200 m depth in the northwestern Guiana Basin.

The bottom water found in the Vema Fracture Zone has to move to the northwest between the Ceara Rise and the Mid-Atlantic Ridge. The CTD potential temperature and salinity distribution (Fig. 18a, b) shows the signature of the low temperature and low salinity bottom water below about 4000 m. The T and S distribution clearly indicates, that the larger part of

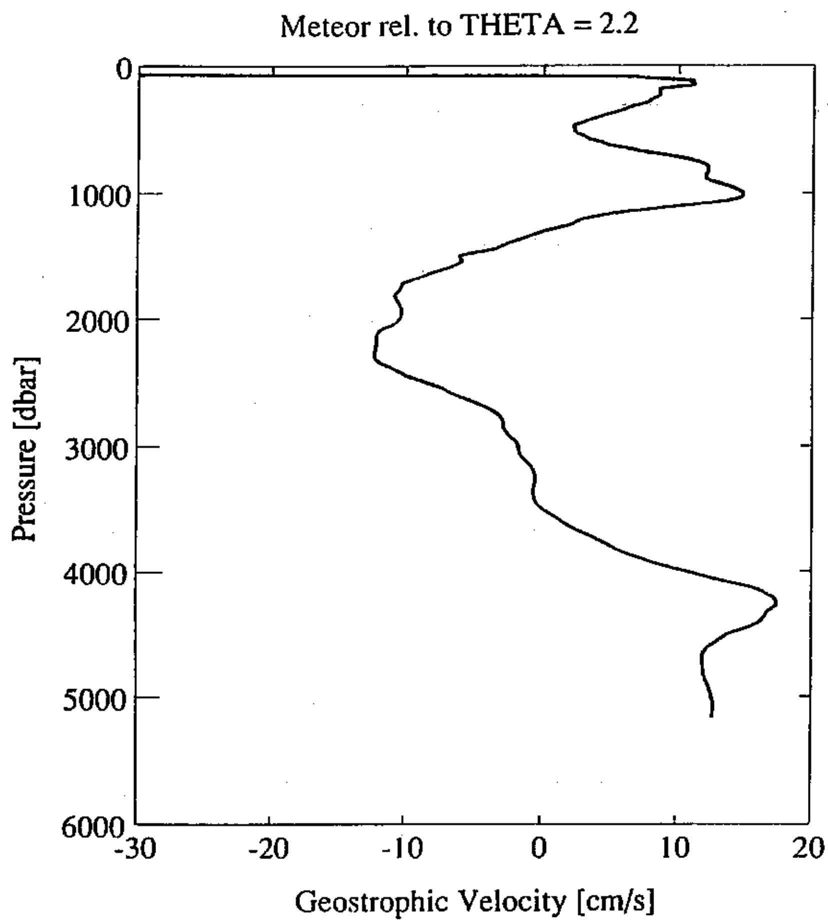



**Fig. 17:** Geostrophic velocity profile in cm/s from two CTD-stations at the northern (10°50.5 N) and southern (10°43.5 N) end of the Vema Fracture Zone at 41°56.5 W relative to the potential temperature of 2.2°C (positive velocity is to the east).

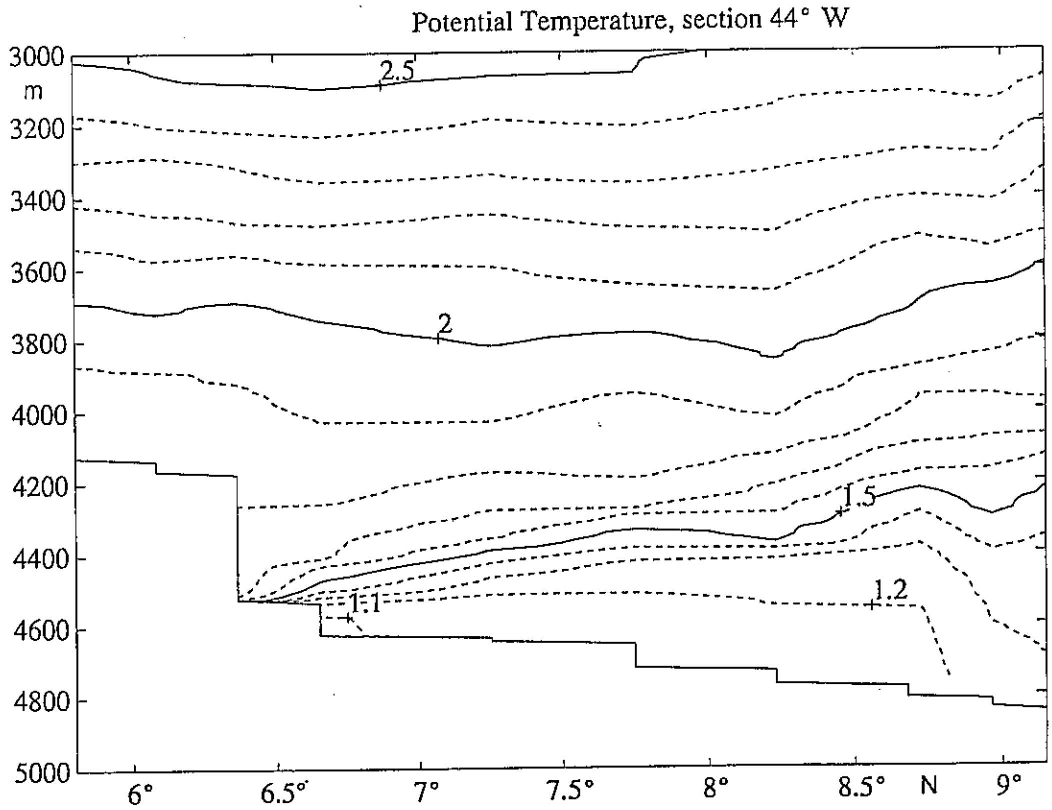



**Fig. 18a:** Potential temperature (°C) in the deep ocean below 3000 m between the Ceara Rise (left) and the Mid-Atlantic Ridge (right) at 44° W.

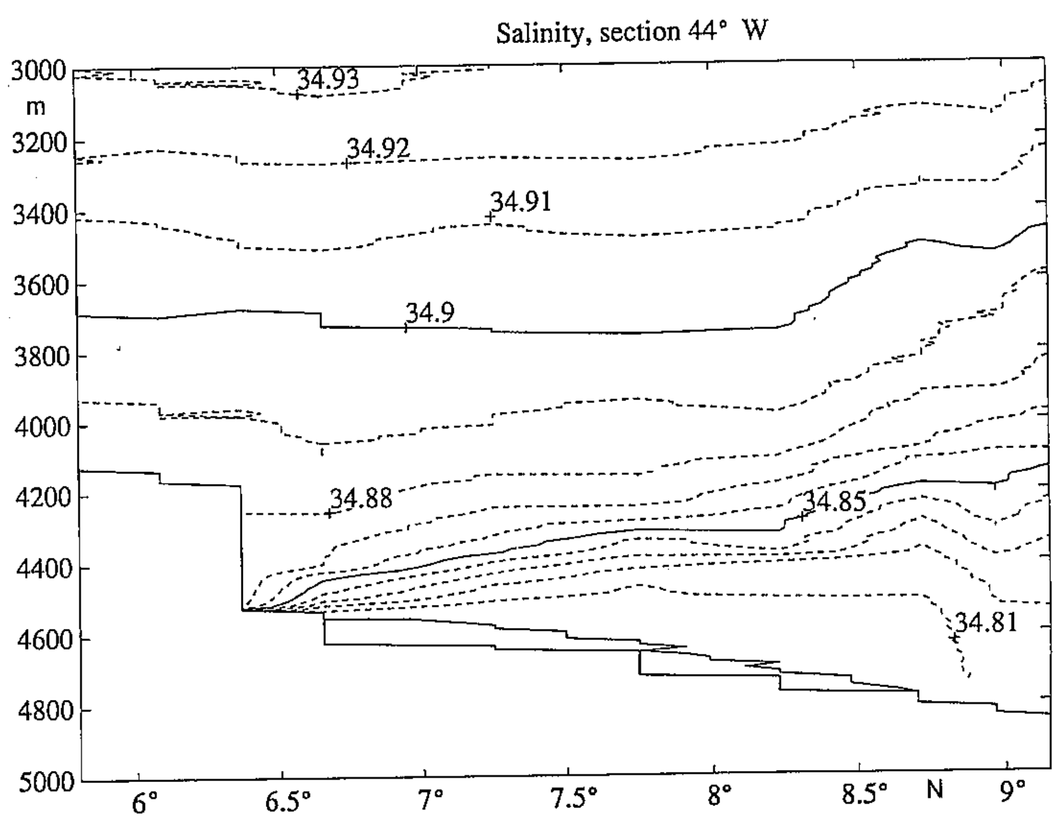



**Fig. 18b:** Salinity distribution in the deep ocean below 3000 m between the Ceara Rise (left) and the Mid-Atlantic Ridge (right) at 44° W.

the bottom water is found on the northern side, guided by the Mid-Atlantic Ridge, but also on the southern end of the section near the Ceara Rise bottom water is present.

Above the AABW, lower North Atlantic Deep Water (lNADW) flows southward as a western boundary current along the Ceara Rise. This is the lNADW branch that cannot pass over the 4000 - 4100 m deep sill west of the Ceara Rise. During M 22/2, an lNADW transport of 7 Sv was measured, compared to about 5 Sv that pass west of Ceara.

Recently, other investigators (REID, 1994; FRIEDRICHS et al., 1994) concluded, from water mass distributions and basin budgets, that considerable lNADW recirculation should take place in the Guiana Basin. Our own studies also indicate that the export of lNADW into the southern hemisphere through the Equatorial Channel is much lower than the 12 Sv crossing the 44°W meridian (see c). Therefore, the two sections, along 44°W and 4.5°N (Fig. 2) were run across the Guiana Basin to investigate this potential recirculation. Unfortunately, the deep profiles of the LADCPs were unreliable in the western boundary areas of both sections and therefore geostrophy needs to be applied for deep currents and transports. Freon measurements along both sections show cores with maxima near 4000 m depth at the western margin, and a continuous decrease of concentrations with increasing distance from the western boundary. For a recirculation as a separate northward branch within the Guiana Basin, where western boundary water would have to return before reaching the 35°W meridian one would expect to see a second freon maximum offshore. That it does not exist implies either that very strong horizontal mixing is active or that such recirculation branch does not exist. Our LADCP profiles were not reliable on both these sections but geostrophic calculations did not yield a northwestward return flow in the interior of the basin.

*Deep Western Boundary Current at 44°W and 40°W*

The structure of the deep western boundary current (DWBC), as measured along 44°W by LADCP, is shown in Fig. 19. From previous shipboard and moored measurements, the lNADW core was expected between 1°N and 2°N, and therefore deep profiling was begun at 1°50' N. This time, however, the deep core apparently was further removed from topography than usual; the largest freon value of the deep maximum was located at 1°50' N, although it is not resolved in Fig. 20.

The upper NADW flow, usually centered at 1400 - 2000 m, was also removed from the topography by a core of westward flow (Fig. 19). This is similar to what we found during M 16/3 and could also be documented by reversals in current meter records (SCHOTT et al., 1993) and was seen to occur as looping motion in deep float tracks (RICHARDSON and SCHMITZ, 1993). In contrast to the deep and bottom water, the tracer signature of shallow upper NADW showed a basin wide recirculation in the Guiana Basin with patches of high salinity and freon water (Fig. 20) distributed in the basin south of 9°N.

When the means of the ACMs are inserted into the section plot obtained from earlier deployments (SCHOTT et al., 1993), the NADW core between 1400 m and 2500 m appears

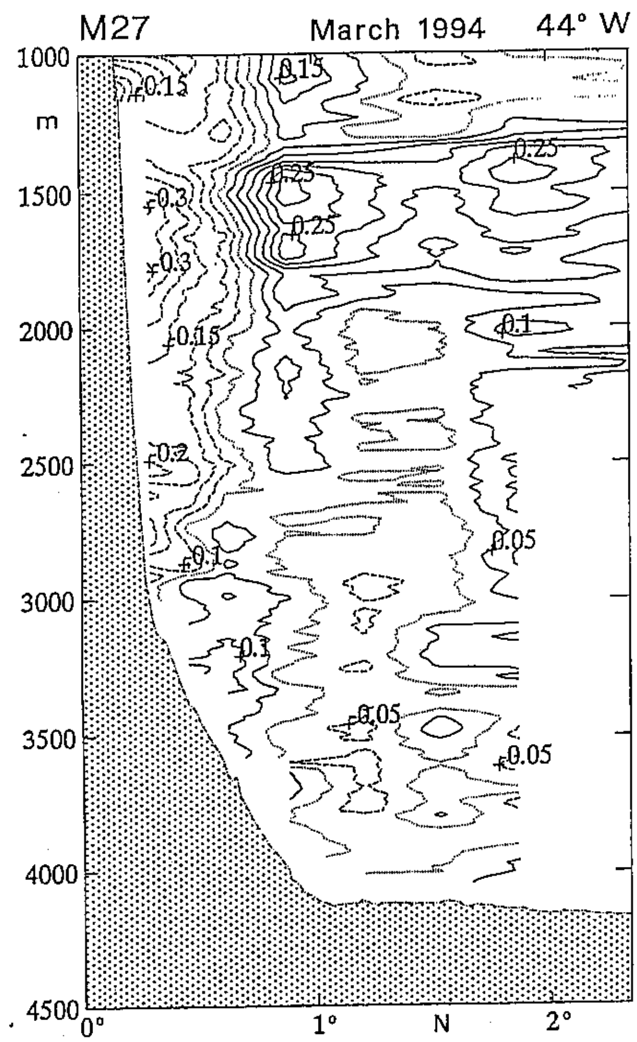



**Fig. 19:** Zonal velocity component (m/s) along 44°W from the LADCP

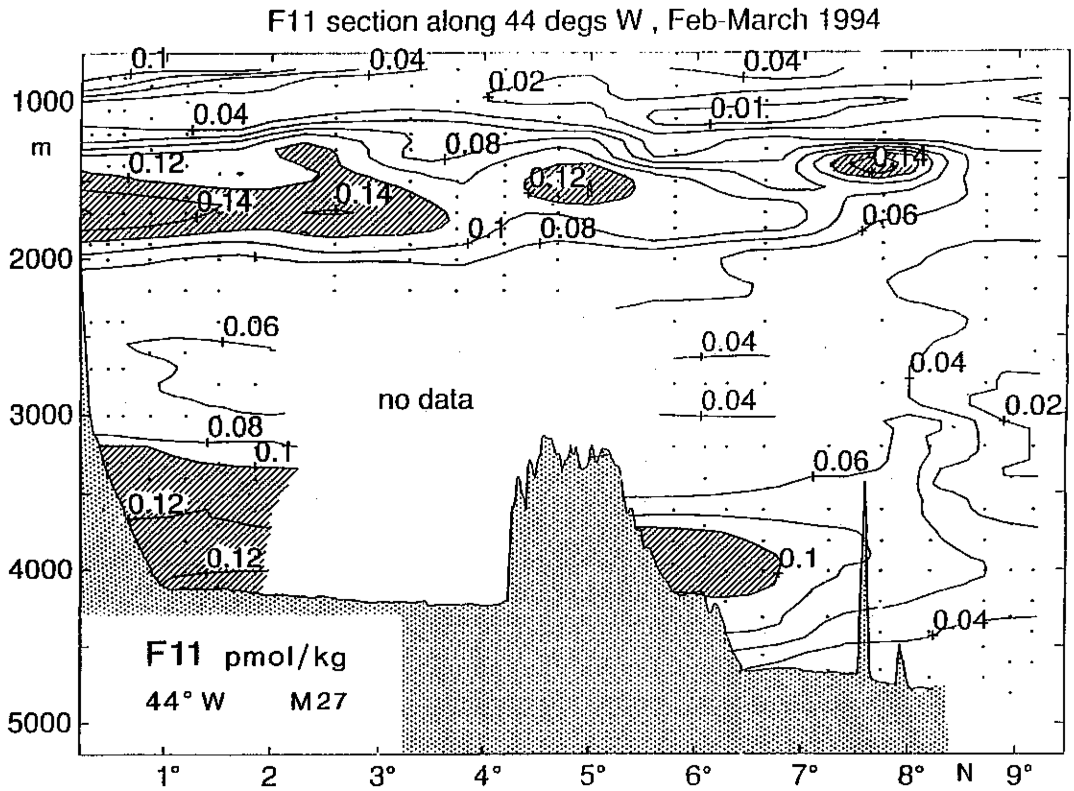



**Fig. 20:** F11 - distribution (pmol/kg) below 800 m along 44°W. The maxima characterizing shallow upper NADW (1700 m) and overflow lNADW (3800 m) are hatched.

to have a shape that differs from the earlier annual means, showing that interannual variablity is a factor and that individual annual means are not stable estimates of the deep circulation.

We had anticipated that the deep lNADW core would be guided along the 40°W section along 0°30' N by the Belem Ridge, and we spaced stations closely there. The freon concentrations showed similarly high values as those at 44°W. Since the LADCPs both were defunct at the time, a Pegasus transponder pair was deployed just north of Belem Ridge (Fig.2) for current profiling. However, the Pegasus current profile did not show the expected significant flow at the lNADW level, possibly suggesting other topographic guidence (the Belem Ridge is not a continuous feature in all maps).

*The deep flow through the Equatorial Channel*

This channel is 4300 - 4600 m deep (Fig. 21) and limited in the north by the MAR at 0°45' N, in the south by the Parnaiba Ridge at 1°33' S. Here the lNADW has to pass eastward when entering the southern hemisphere and the AABW has to flow westward underneath it. A deep LADCP section for the zonal current component is shown in Fig. 21, demonstrating the lNADW core between 3200 m and 4100 m south of 1°S, and westward AABW beneath it.

The AABW core again was concentrated at the southern slope of the channel. The transport during M 27/3 was approximately 2.4 Sv for the AABW in agreement with RHEIN et al. (1994), who estimated a transport of 2.6 Sv from earlier METEOR cruises. The freon core near 3800 m depth, at 0.11 pmol/kg, was higher than in November 1992, when it was at 0.07 and in October 1990, when it was only 0.05, indicating the increasing penetration southward. Similarly, the AABW underneath showed freon values of > 0.015 for the first time, indicating the arrival of the freon signal at the equator from the southern ocean ventilation region. In the 500 - 2000 m range, the near-equatorial current profiles show the "stacked jet" structure of reversing zonal currents which so far has not allowed detection of a mean eastward current branch of upper NADW, that is presumed to exist near the 1500 m depth level. (Current meters were deployed in cooperation with WHOI for two years on the equator 200 km west of our position at the upper NADW level to explore this further).

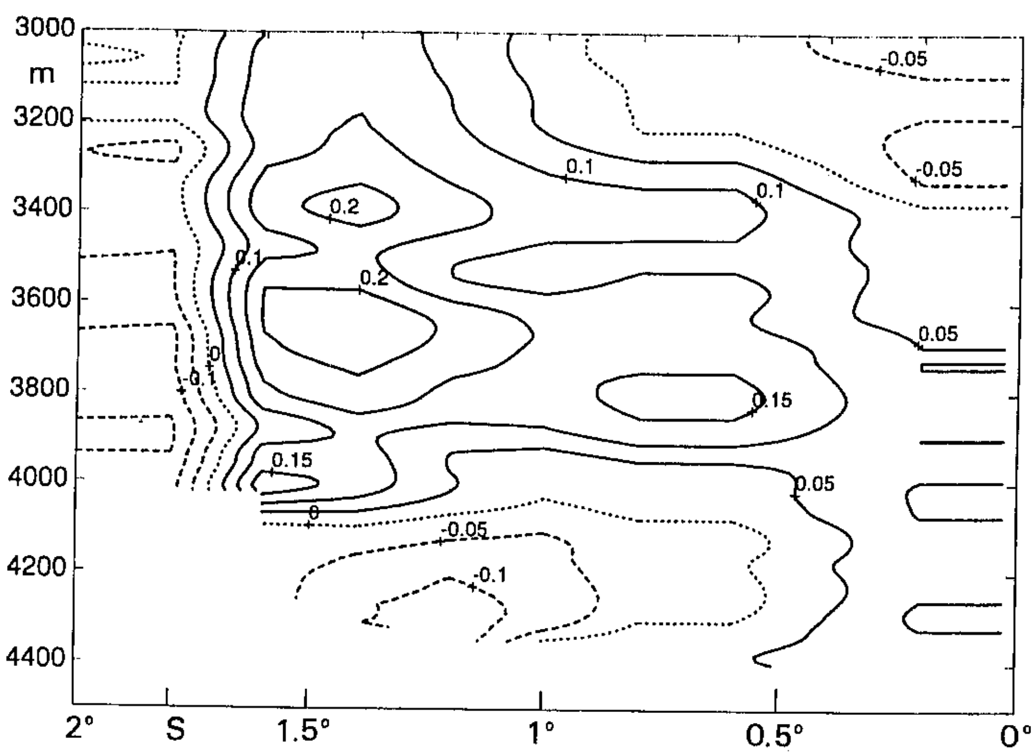



**Fig. 21:** Zonal velocity component (m/s) across the equatorial channel at 35°W below 3000 m from LADCP

*Deep circulation at 5 - 10°S*

From previous sections along 5°S it was known that beyond the southward NADW flow near the boundary an offshore deep recirculation regime may exist. During M 27/3 the southward flow was much larger than in the previous surveys. Between the continental slope and 33°W it showed a large cell in the depth range 1200 - 3700 m (Fig. 22) that carried a transport of about 45 Sv southward compared to about only one third that amount that was determined as a mean for the three previous cruises. In longitude range 33.0 - 31.5°W 29 Sv were recirculating northward, leaving a net southward transfer of 16 Sv. Hugging the bottom of the continental slope, the AABW flowed northward at a transport of 2.4 Sv (Fig. 22). As in previous surveys, the NADW does not show two separate velocity cores as it does north of the equator but rather an elongated vertical single cell. In the freon concentrations, however, upper and lower maxima can be clearly identified near 1800 m and 3500 m (Fig. 23), and secondary maxima, suggestive of reciculation, occur offshore in the region of the northward velocity cell.

## 5.2 Chemical Oceanography

### 5.2.1 JGOFS: The $CO_2$-System (R. Lendt)

During M 27 299 seawater samples were taken at 30 CTD-stations with a rosette seawater sampler (12 and 24 x 10 $dm^3$ Niskin bottles). 430 underway (uw) samples were taken in a water depth of ca. 7 m by a continual seawater pump system (IfBM Hamburg, compare: SCHÜSSLER and KREMLING, 1993) (Tab. 7).

**Tab. 7:** List of CTD-stations, CTD samples and underway samples during M 27

| cruise | CTD-stations | CTD samples | uw samples |
|---|---|---|---|
| M 27/1 | 11 | 113 | 59 |
| M 27/2 | 7 | 96 | 130 |
| M 27/3 | 12 | 90 | 241 |
| Total | 30 | 299 | 430 |

Total alkalinity (TA), total dissolved inorganic carbon (TC), salinity and pH were measured on board. These data will be used to calculate the partial pressure of carbon dioxide ($pCO_2$) and the carbon dioxide concentration ($CO_2$) of seawater. Some samples were analysed twice.

TA and TC (calculated from TA) were analyzed by a potentiometric precision titration method (DICKSON, 1981; DICKSON and GOYET, 1991; ALMGREN et al., 1983)

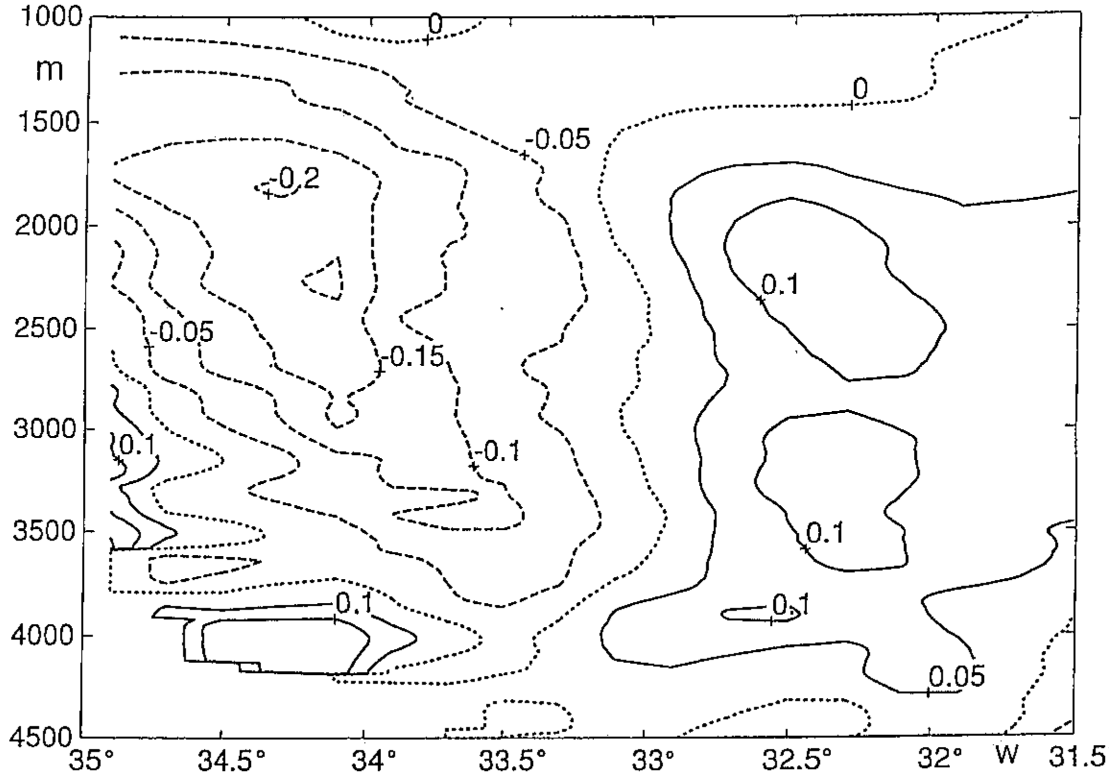



**Fig. 22:** Meridional velocity component (m/s) along 5°S below 1000 m depth from LADCP

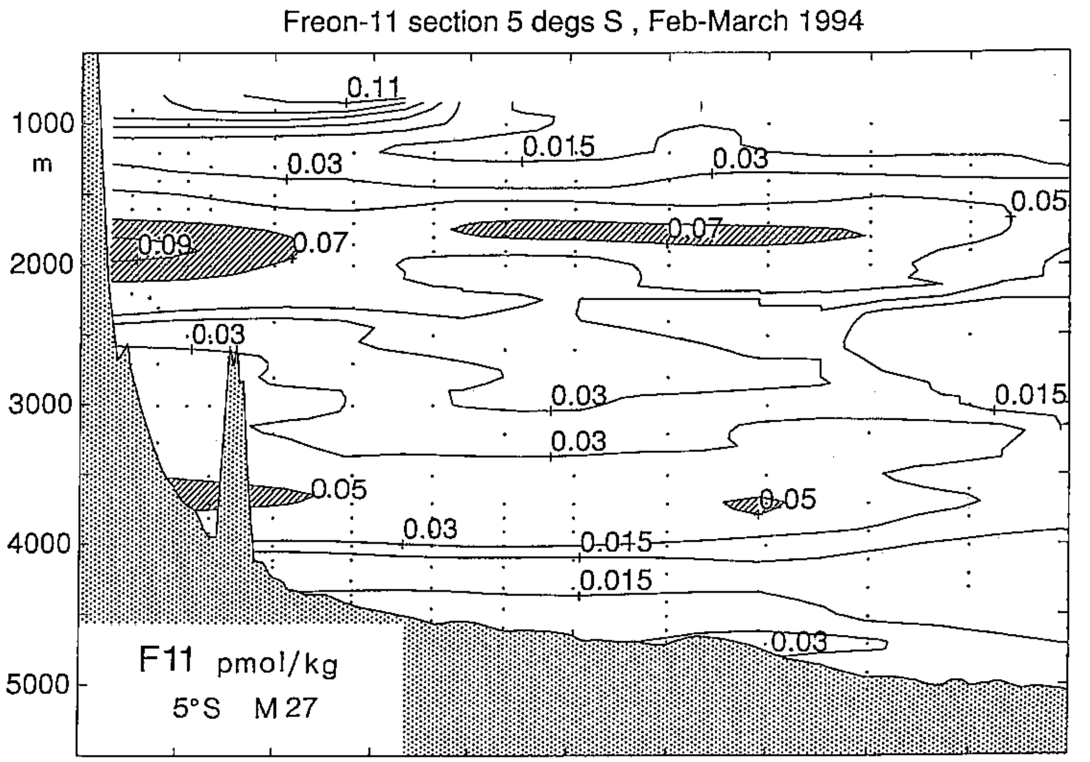



**Fig. 23:** F11 - distribution (pmol/kg) below 800 m along 5°S. The maxima characterizing shallow upper NADW and overflow-lNADW are hatched.

immediately after sampling. In addition to this method the TC concentrations should have been measured directly with a coulometric detector combined with a $CO_2$ extraction unit (ROBINSON and WILLIAMS, 1991; DICKSON and GOYET, 1991). Because of a defect in the extraction unit most of the TC samples had to be poisoned and stored and will be measured in Hamburg. PH was measured with a pH-meter, standardized twice a day by technical buffers. Salinity was detected triple with a Guildline Autosal salinometer.

TA and TC change proportionally to salinity (BROECKER and PENG, 1982). To exclude the salt effect on TA and TC, these parameters have been normalized to a salinity of 35 psu (TAn, TCn). The TC and TA data discussed in this report are preliminary results. They were calculated by a granplot programme without considering nutrient concentration and the electrode slope factor. PH was recalculated for in situ-temperatures according to GRASSHOFF et al. (1993).

#### 5.2.1.1 Surface Profiles

The M 27/1 N-S profile (all samples were taken with the pump system in 7 m depth) indicates a gradually decreasing salinity (Fig. 24) from the south (ca. 35.7 psu at 44°N) to the north (35.6 psu at 49.5°N). Accordingly the temperature at the surface sinks from 12.5°C at 44°N to 11.2°C at 49°N, reaching a minimum value of 10°C at 49.8°N. At this latitude there is also a sudden drop of the salinity down to 35.3 psu at 49.8°N. The pH at in situ-temperature is about 8.2 at 44°N, wich decreases to 8.15 between 48° and 49°N, before reaching its maximum value of 8.22 at 49.8°N. The variability of TC concentrations (Fig. 25) is low between 44°N (2085 µmol/kg) and 48.5°N (2088 µmol/kg), while TC distinctly rises between 48.5°N and 50°N, reaching a maximum value of 2124 µmol/kg. The TA data (Fig. 26) nearly follow this tendency: After low variability in TA concentrations between 44°N (2348 µeq/kg) and 48.5°N (2339 µeq/kg) TA increases to 2360 µeq/kg at 50°N. Because of high salinity the normalized TCn and Tan values are low by 30 - 40 µmol/kg compared to the original data (TC, TA).

Fig. 27 depicts a maximum water temperature of 13.8°C between 42° and 42.6°N during M 27/2, followed by a maximal salinity of 35.92 psu at the same location. A subsequent maximum of both parameters can be seen at 45.2°N (13°C and 35.85 psu). Temperature and salinity decrease northwards, reaching 12°C and 35.65 psu at 47.6°N. The pH slightly decreases from 8.3 at 41°N to an average value of 8.2 at 47.6°N.

In opposite to Fig. 25, where the results of coulometric analysis are shown in the TC curve, the following TC figures contain potentiometric TC values. The TC values (Fig. 28) increase from 2103 µm/kg at 41.2°N to 2120 µmol/kg at 47°N. TA (Fig. 29) increases from 2330 µeq/kg at 41°N to 2350 µeq/kg at 42.8°N. Another TA minimum with 2330 µeq/kg was detected at 46.2°N.

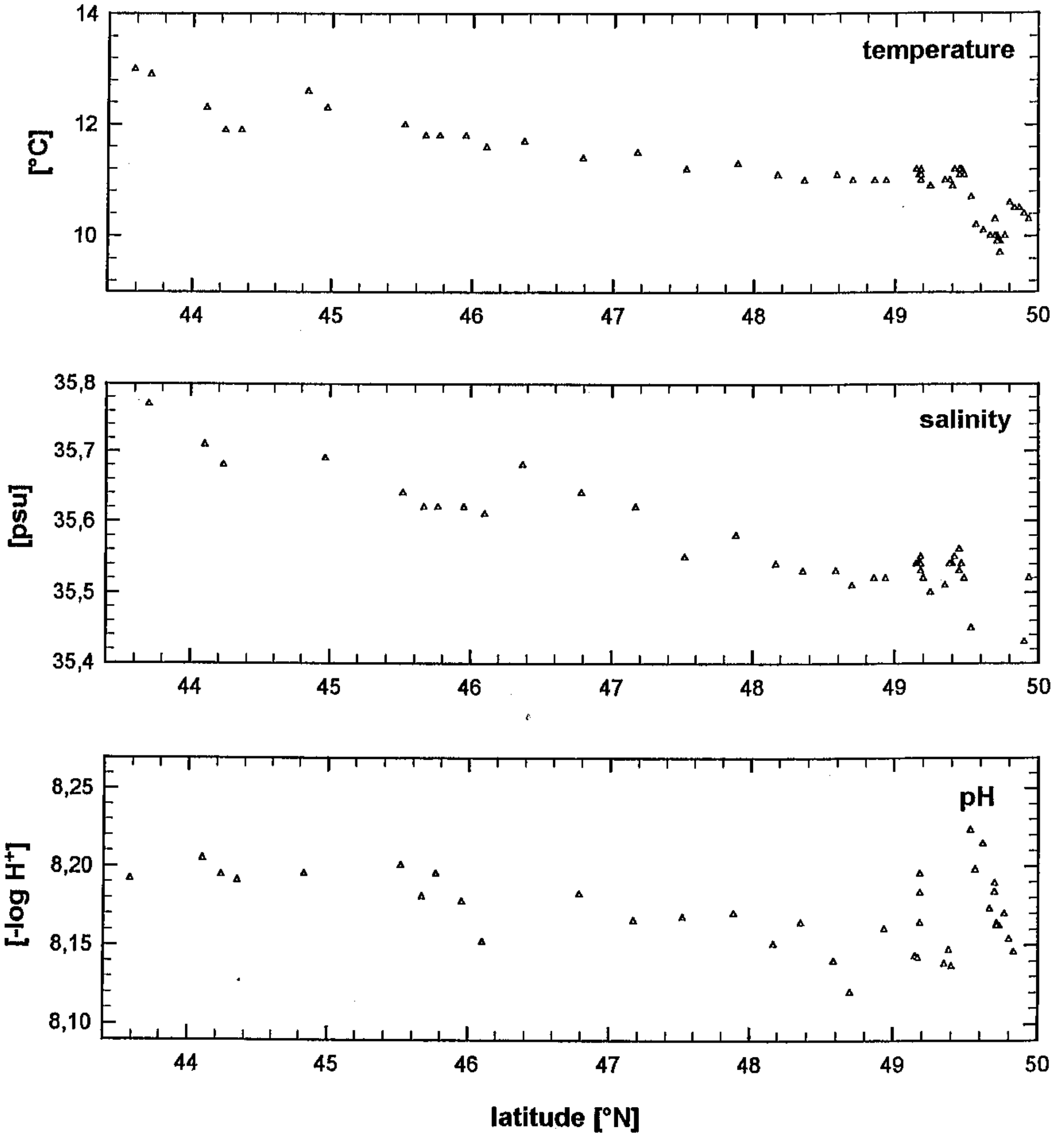



**Fig. 24:** M 27/1 N-S profile: Water temperature, salinity and pH at in situ-temperature at 7 m water depth (uw-samples).

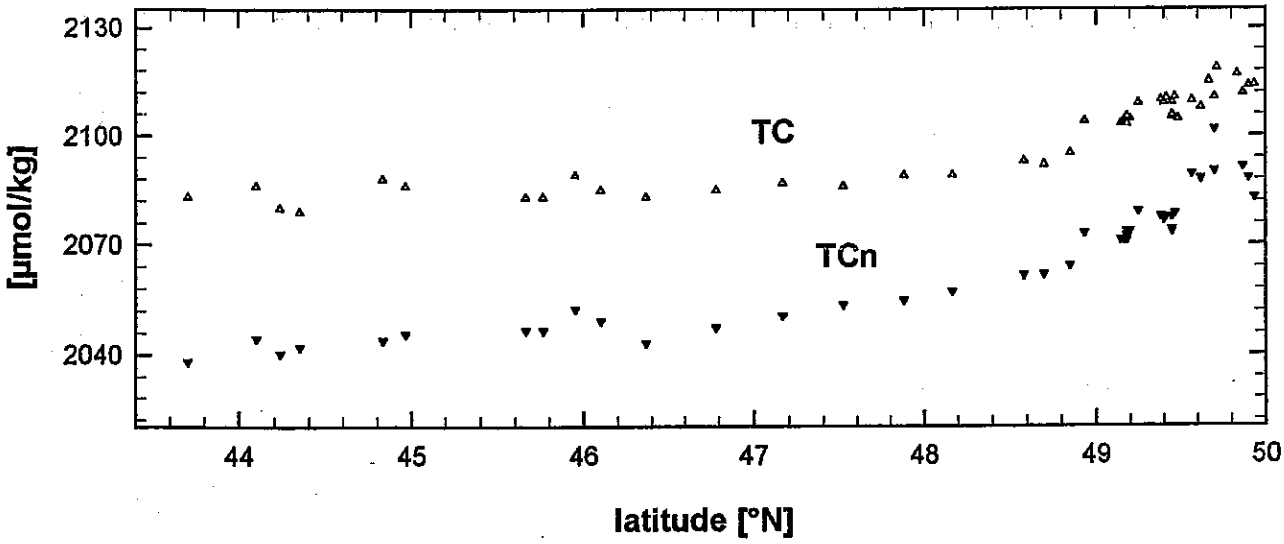



**Fig. 25:** M 27/1 N-S profile: Total inorganic carbon (TC) and total inorganic carbon normalized to 35 psu salinity (TCn) in 7 m

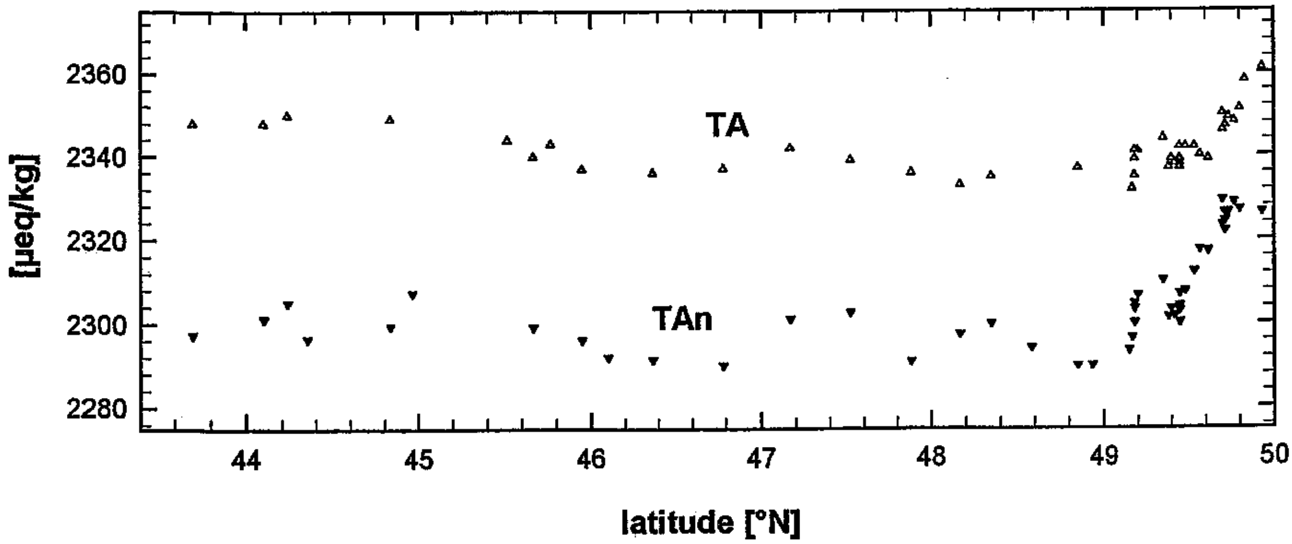



**Fig. 26:** M 27/1 N-S profile: Total alkalinity (TA) and total alkalinity normalized to 35 psu salinity (TAn) in 7 m

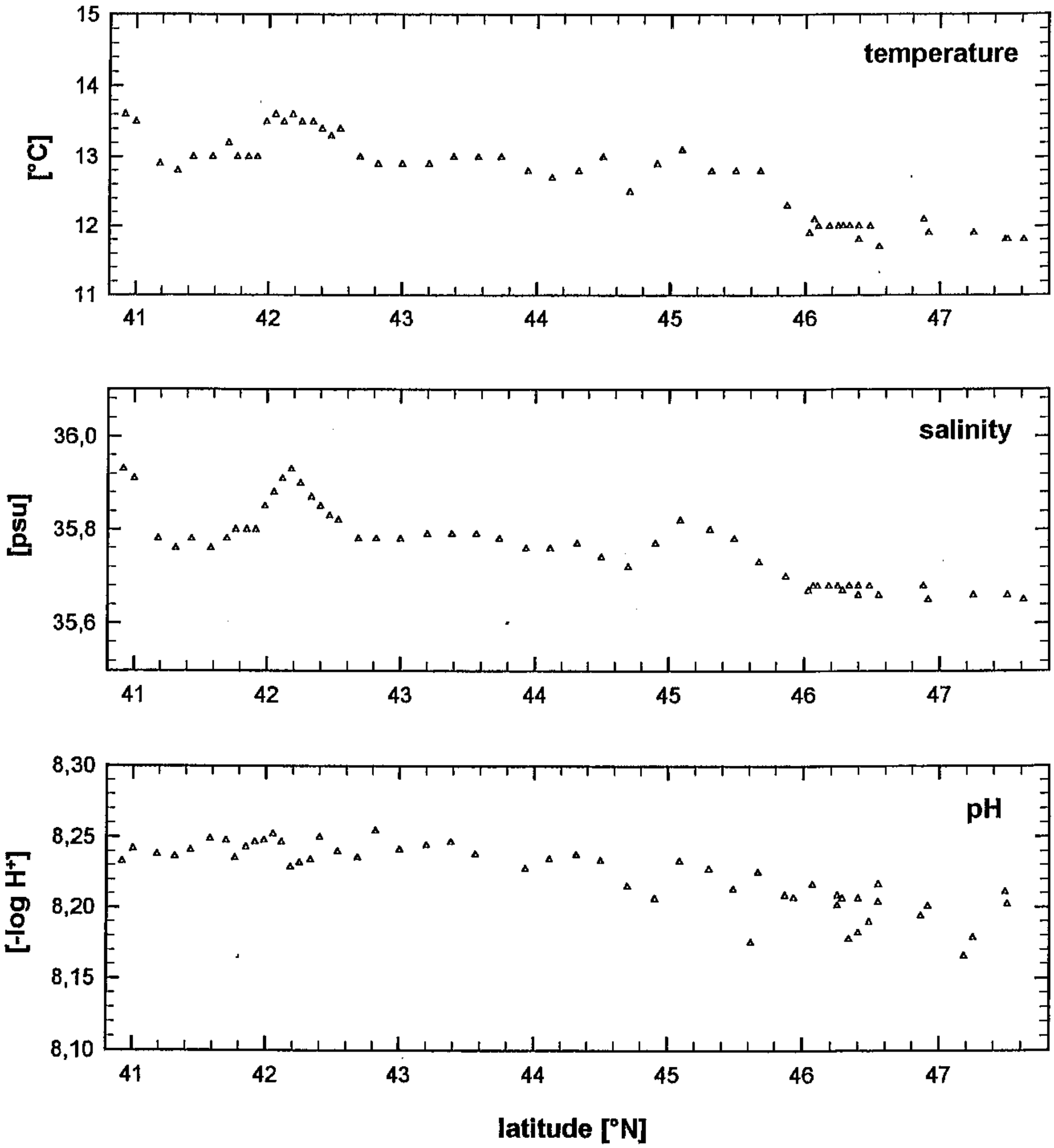



**Fig. 27:** M 27/2 N-S profile: Water temperature, salinity and pH at in situ-temperature at 7 m water depth (uw-samples).

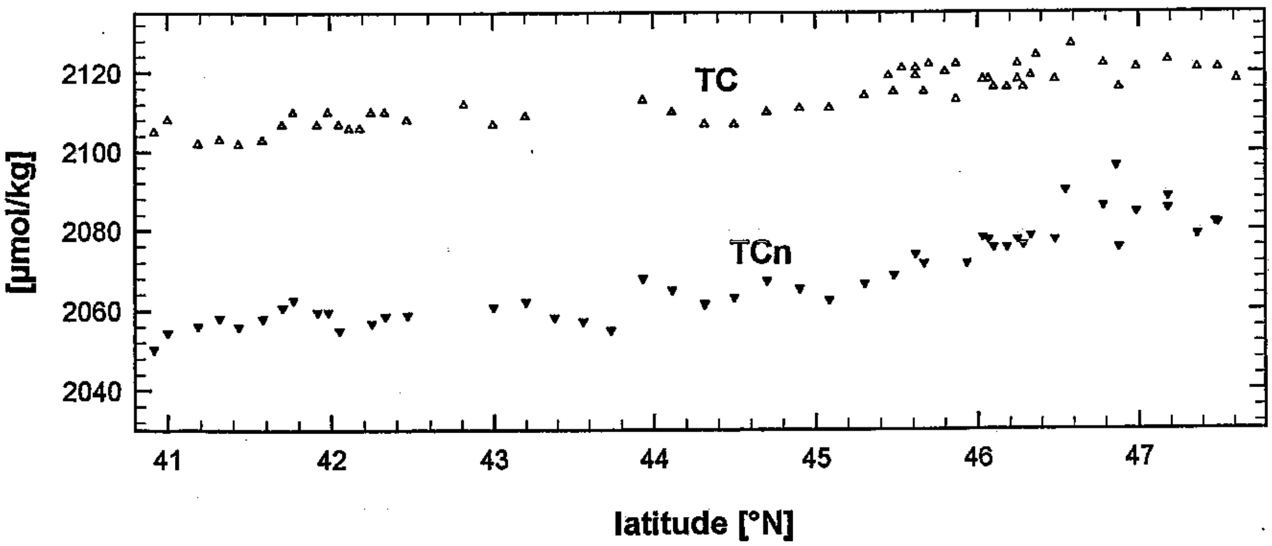



**Fig 28:** M 27/2 N-S profile: Total inorganic carbon (TC) and total inorganic carbon normalized to 35 psu salinity (TCn) in 7 m

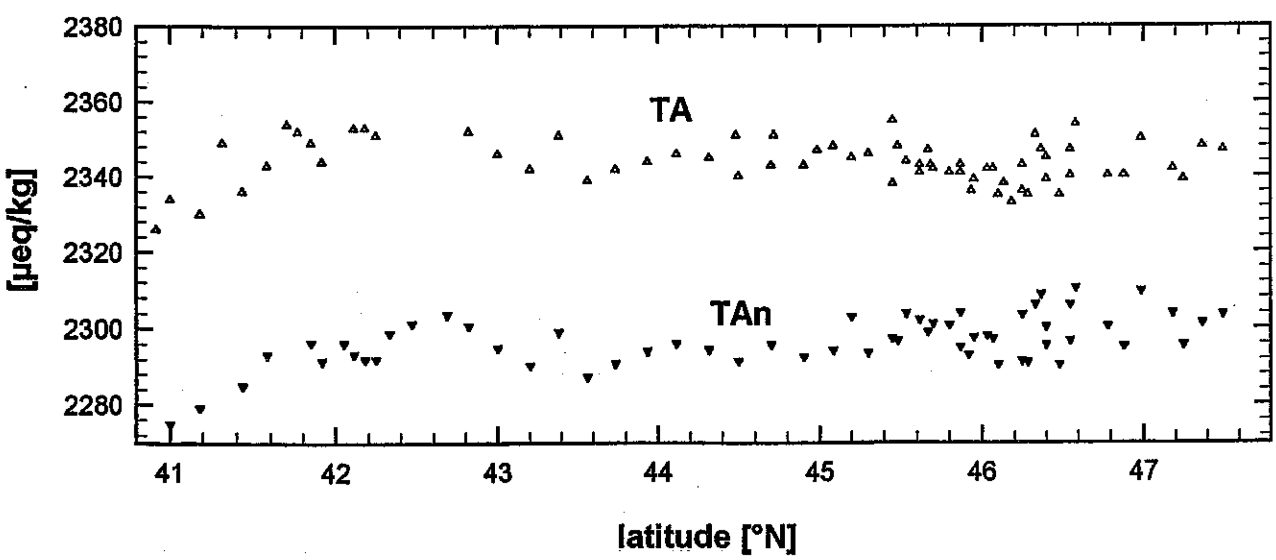



**Fig. 29:** M 27/2 N-S profile: Total alkalinity (TA) and total alkalinity normalized to 35 psu salinity (TAn) in 7 m

During M 27/3, surface seawater temperature constantly rises from 16°C at 37°N to 29°C at 06°S, (Fig. 30). Salinity does not follow this trend: At the beginning of the cruise salinity amounted to 36.2 psu, reaching its maximum value of 37.4 psu between 26° and 20°N. More south it is influenced by the northern Equatorial Current and drops down to 36.2 psu at 15°N, reaching a minimum of 36 psu at 07°S. PH slightly decreases from 8.3 at 37°N to 8.18 at 5°S. The TC data (Fig. 31) show a trend similar to that of salinity: In the northern part of the profile (37° to 22°N) TC varies about 2120 μmol/kg. Between 22° and 16°N TC decreases down to ca. 2040 μmol/kg. In the southern part two subsequent TC maxima were measured at 10°N and near the equator. Nearly the same tendency was determined for TA concentrations (Fig. 32): TA increases from 2355 μeq/kg at 37°N to a maximum of 2450 μeq/kg between 25°and 20°N. More south TA suddenly drops down to about 2350 μeq/kg at 13°N. TAn data slightly increase from 34°N to 19°N (2275 to 2300 μeq/kg).

Both TCn and TAn tendencies are smoothed by normalization because this parameters strongly depend on salinity. The remaining variabilities in their concentrations belong to water mass changes and/or biological activities like photosynthesis or respiration.

### 5.2.1.2 CTD-Stations

First results of M 27/2 CTD-stations are shown in Fig. 33 to 36: The TC and TA data used in this figures are not normalized to 35 psu salinity. Temperature and salinity data were taken from the CTD sonde.

The following four CTD-station profiles are examples for a winter time mixed layer system recorded under stormy weather conditions.

Fig. 33 (CTD station 021 at 47°30.06 N / 15°18.95 W): Temperature and pH constantly rise from 490 m (11°C, pH 8.09) to 250 m depth (11.7°C, pH 8.19). In the upper 250 meters these parameters hardly change. Salinity increases towards the surface from 35.5 psu at 490 m to 35.6 psu at 90 m. In the upper 90 meters salinity is almost constant. Below the suggested maximum depth of the mixed layer of ca. 300 m, the TC concentration shows a minimum value of ca. 2120 μmol/kg at 310 m. In the upper 250 m TC varies about 2120 to 2130 μmol/kg. A TA minimum was detected at 300 - 400 m (ca. 2330 μeq/kg). Above 300 m depth, TA significantly reveals higher concentrations of approximately 2345 μeq/kg.

TC, TA and pH clearly depict, that in the upper 250 - 300 m winter time conditions form a chemocline rather than a thermocline. The latter does not show a sharp separation between the mixed layer and the thermocline itself.

Fig. 34 (CTD-station 027 at 46°38.75 N / 17°52.49 W), Fig. 35 (CTD-station 031 at 46°55.63 N / 18°45.75 W) and Fig. 36 (CTD-station 033 at 47°03.95 N / 19°12.34 W) show a similar hydrographic situation as at station 021: Temperature and salinity data suggest, that the stormy weather deepens the mixed layer down to 300 - 350 m. This tendency can be

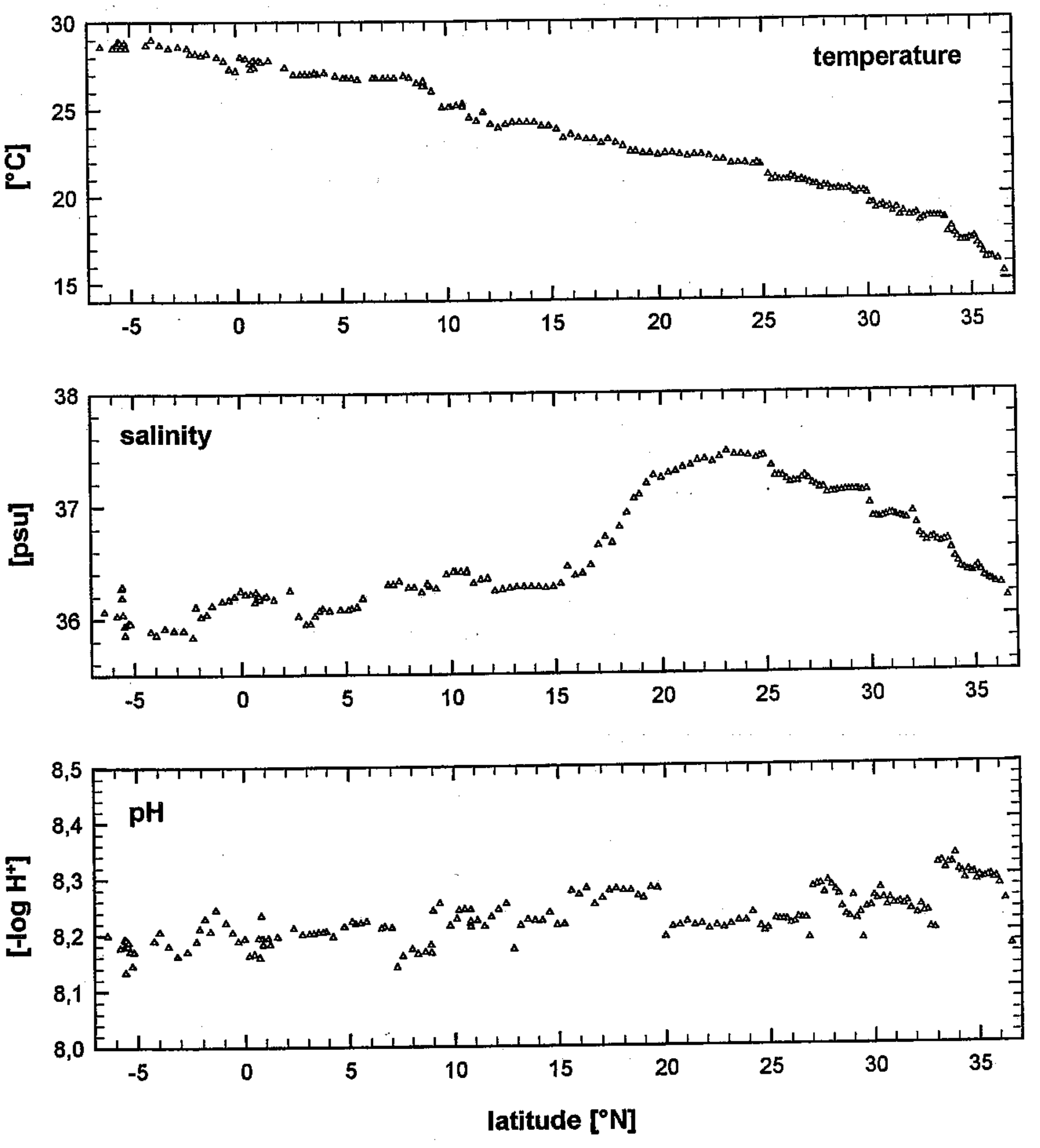



**Fig. 30:** M 27/3 N-S profile: Water temperature, salinity and pH at in situ-temperature at 7 m water depth (uw-samples)

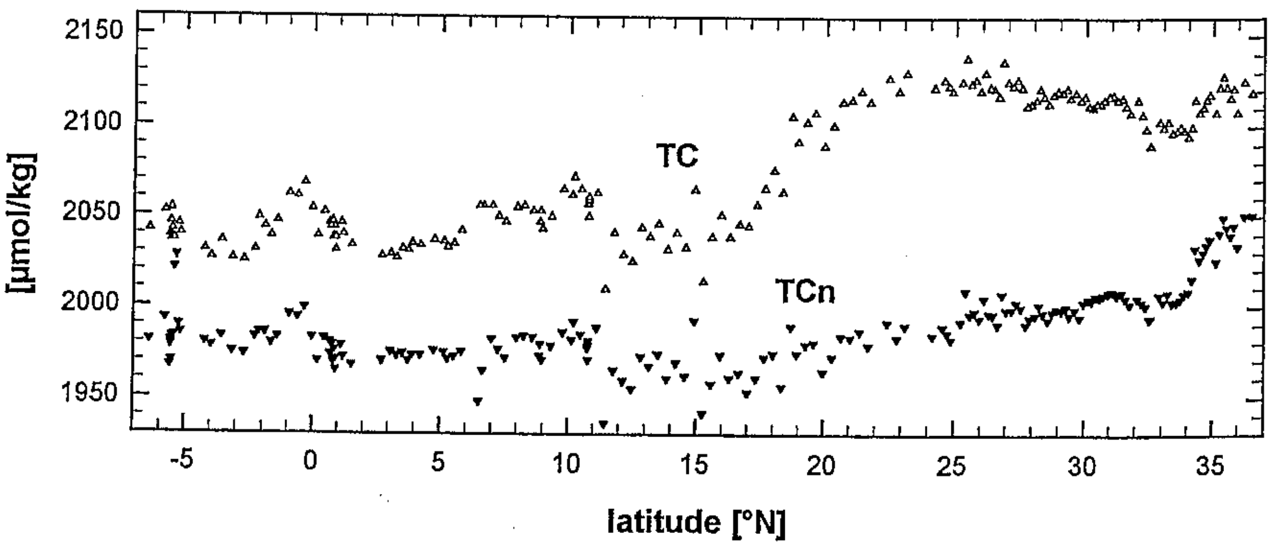



**Fig 31:** M 27/3 N-S profile: Total inorganic carbon (TC) and total inorganic carbon normalized to 35 psu salinity (TCn) in 7 m

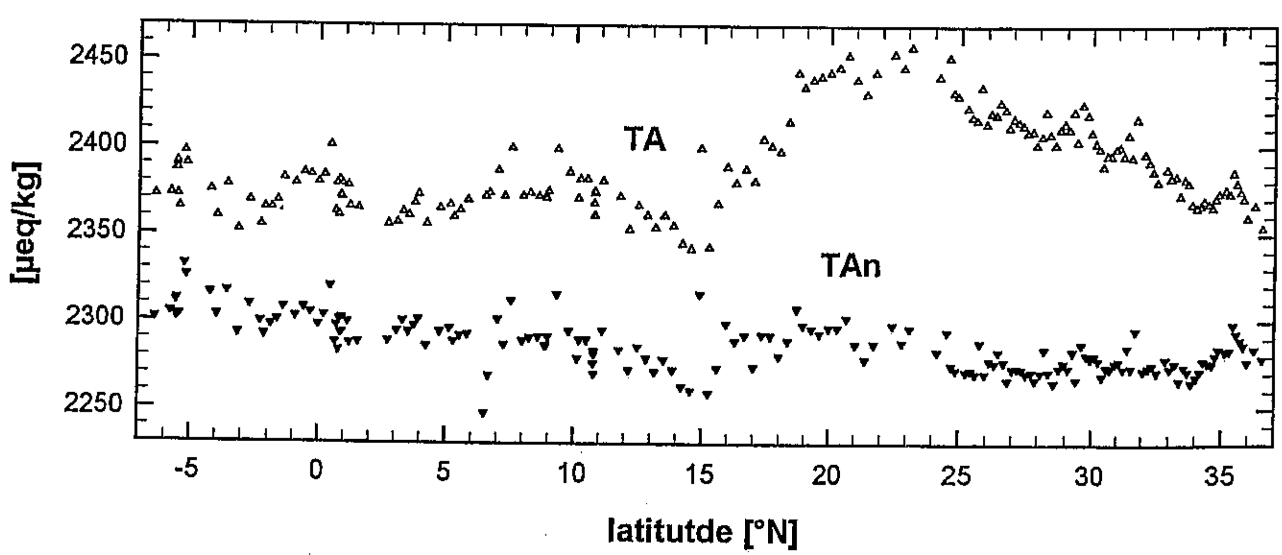



**Fig. 32:** M 27/3 N-S profile: Total alkalinity (TA) and total alkalinity normalized to 35 psu salinity (TAn) in 7 m

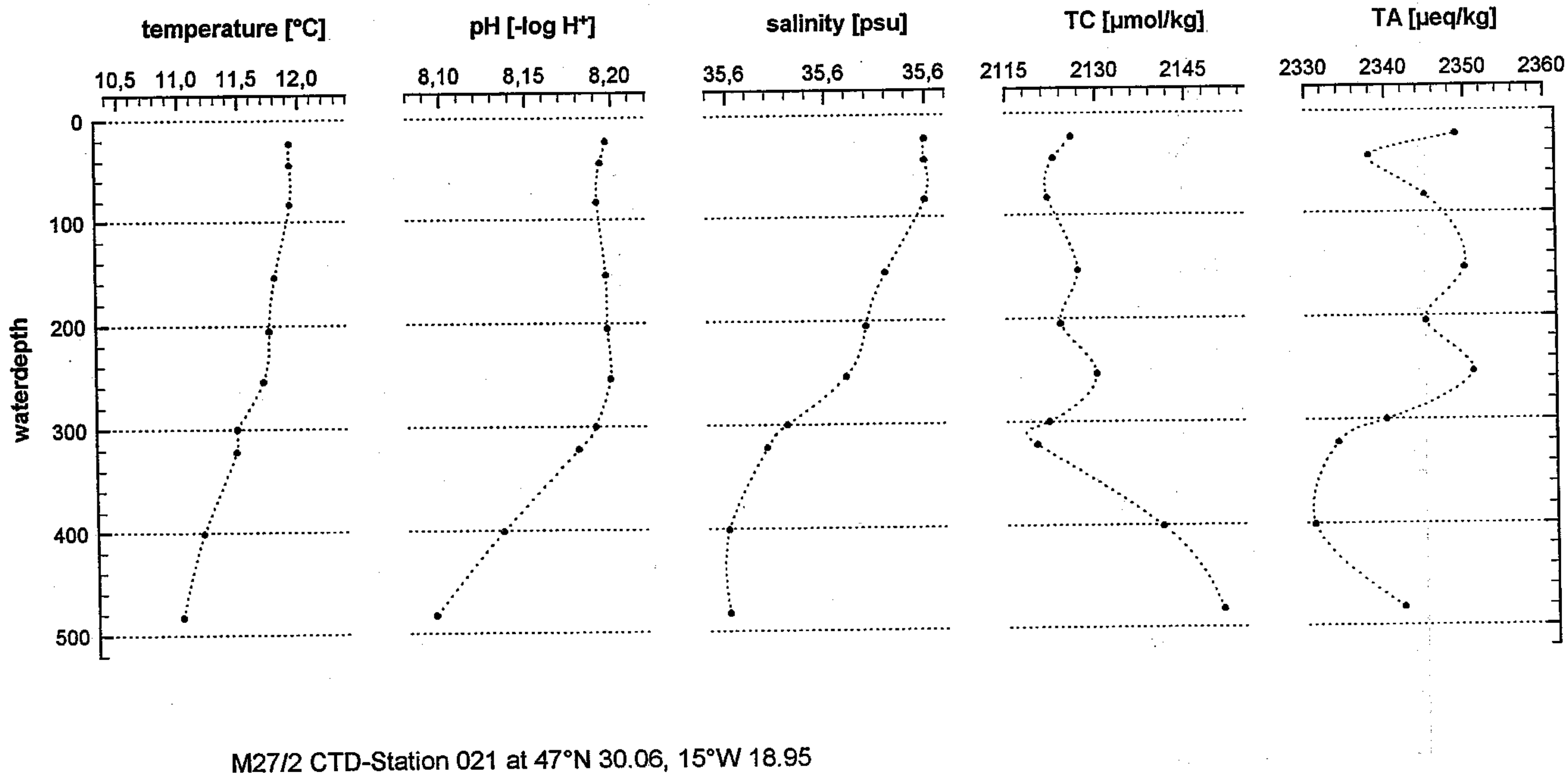
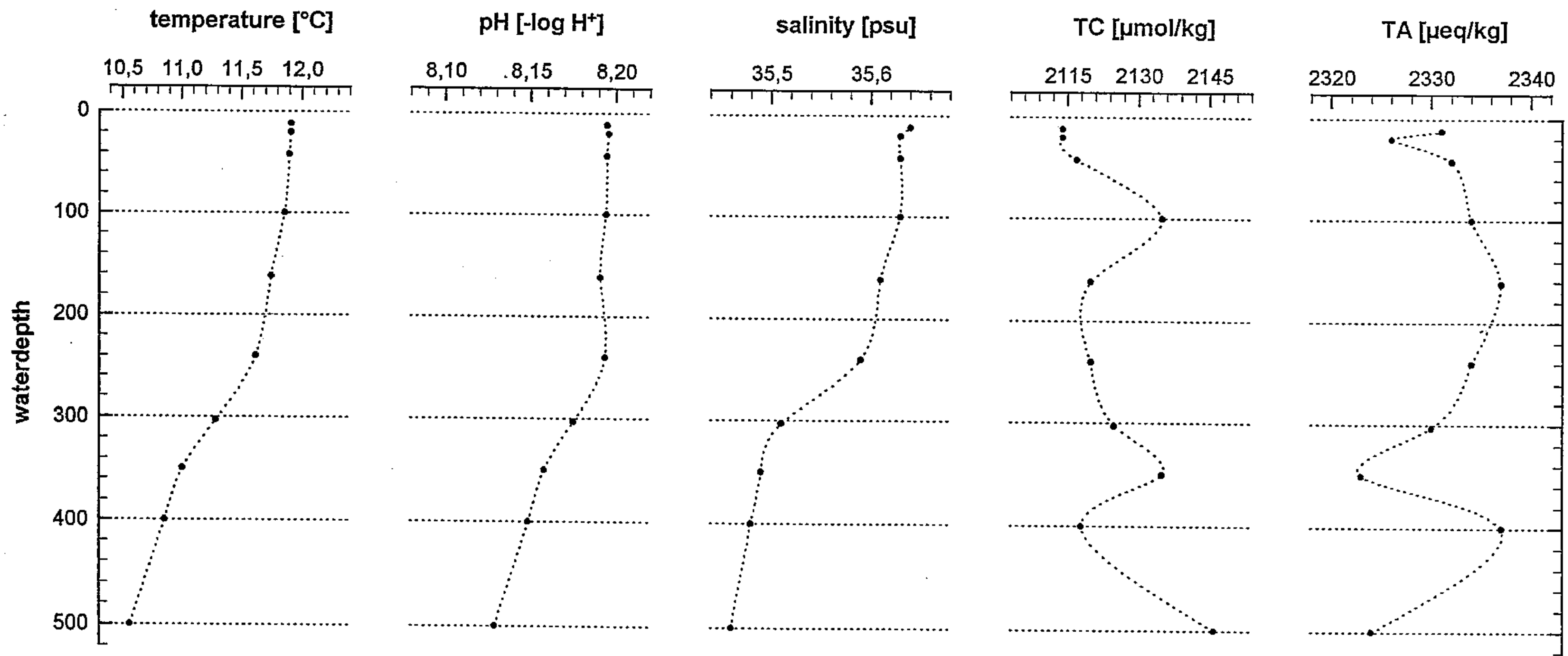



**Fig. 33:** M 27/2 CTD-station 021 at 47°30.06 N / 15°18.95 W.




M27/2 CTD-Station 027 at 46°N 38.75, 17°W 52.49

**Fig. 34:** M 27/2 CTD-station 027 at 46°38.75 N / 17°52.49 W.

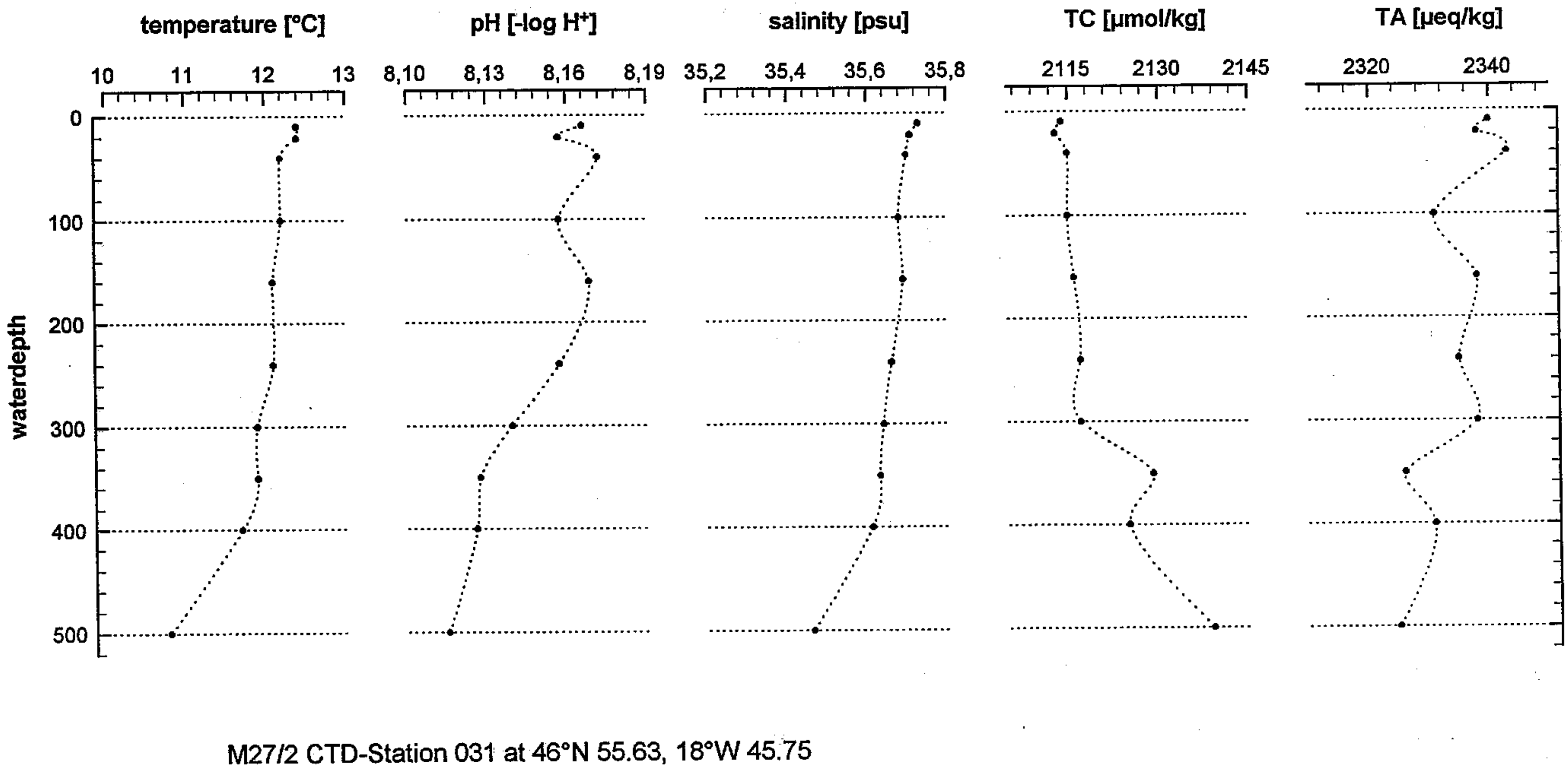



**Fig. 35:** M 27/2 CTD-Station 031 at 46°55.63 N / 18°45.75 W.

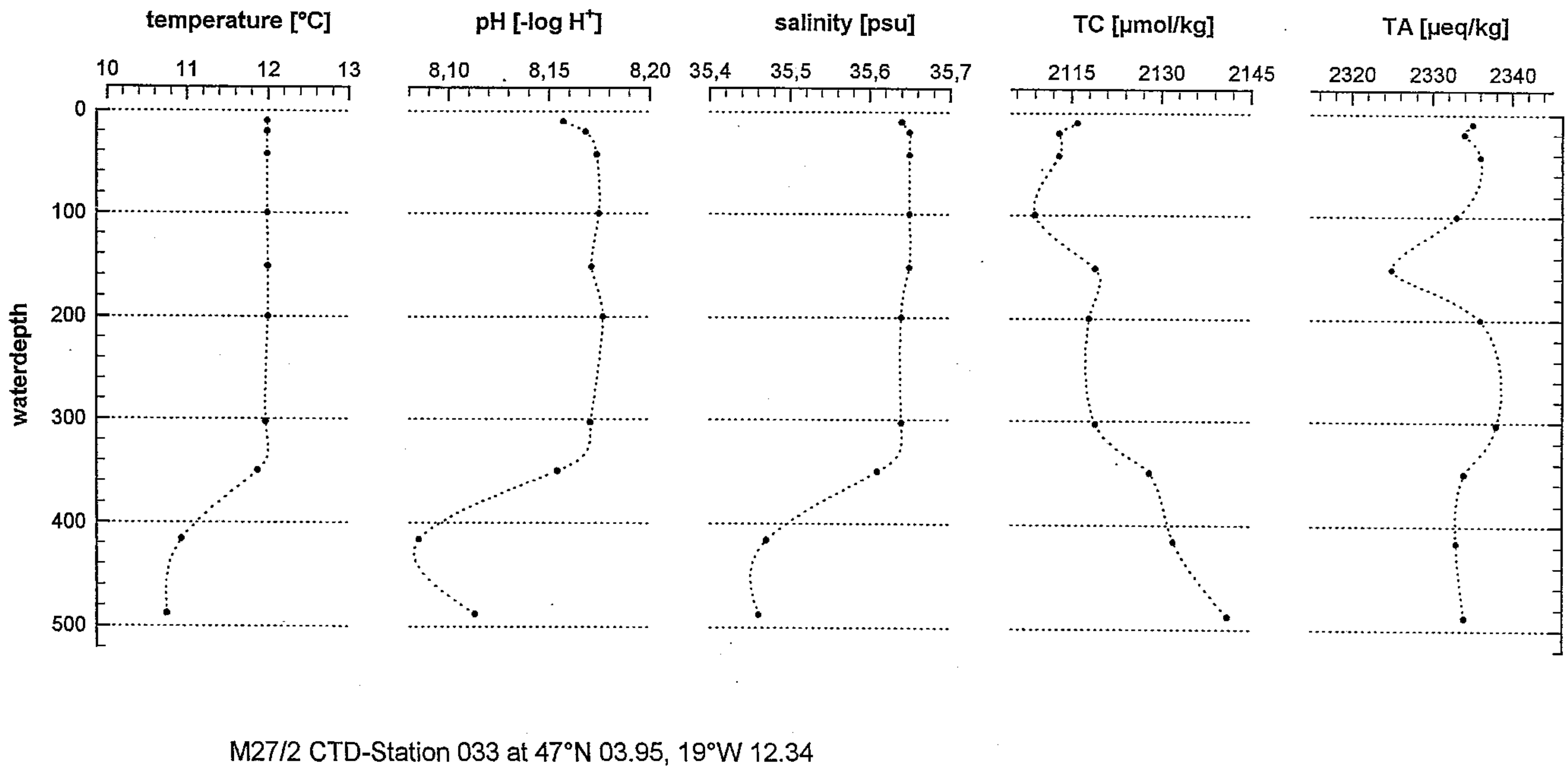



**Fig. 36:** M 27/2 CTD-Station 033 at 47°03.95 N / 19°12.34 W.

distinctly seen in Fig. 36, where temperature does not vary at all in the upper 300 m. An exception is station 31 (Fig. 35), where higher surface temperatures point out a subsequent surface layer in the upper 40 m. This might come about a short termed calming in weather conditions.
TC and TA values of all stations indicate a chemocline at 250 m depth on June 24, which seems to deepen to more than 350 m on June 30, 1994. These station profiles might also be influenced by water mass changes because sampling advanced from east to west. Below, strong gradients lead to higher TC and lower TA values. The variability of TC and TA above 400 m is probably the result of biological activity. A TC maximum and a TA minimum at 350 m (station 27, 31) is distinctly shown in Fig. 34 and 35.

*Conclusions*
In comparison to the spring and summer data of M 21 in 1992 near 47°N / 20°W, the concentrations of TC and TA during M 27/2 hardly differ. Although a hydrographic winter system was detected, biological processes in the mixed layer seemed to vary TC and TA thus suppressing high TC concentrations which should occur in a winter time mixed layer almost free of marine life.

### 5.2.2 JGOFS: DOC Measurement Programme (E.T. Peltzer, P. Kähler)

Dissolved Organic Carbon (DOC) has been measured during the "North Atlantic Bloom Experiment" in 1989 in the North Atlantic employing "2nd generation" high-temperature catalytic oxidation methods introduced by SUZUKI et al. (1985) for the first time. At that time, the method still suffered from problems mainly concerning varying blanks which were not checked for then, resulting in widely discrepant DOC concentrations reported by different workers. This became notorious in an intercalibration exercise conducted by J. Hedges (Seattle) in 1991 with 35 laboratories taking part, and by the fact that Suzuki retracted his paper on the measurement of DOC. Meanwhile, with due attention paid to the blank problem, it was shown that the results of different workers' DOC analyses can compare well.

With these improvements in the measurement technique, DOC has recently been shown to vary both spatially and temporally in the open ocean. As such it is thought to be important in the oceanic carbon cycle both as a resevoir for the end products of primary production and as a source or substrate for bacterial production. Precise measurements are required to see these changes, and substantial uncertainties remain regarding absolute concentrations and temporal variations. It was hoped that by directly comparing two instruments at sea using freshly collected samples, that some of these uncertainties could be resolved.

There were two major objectives of the DOC measurement programme during M 27/2. The first was to obtain a detailed winter time profile of the distribution of dissolved organic carbon (DOC) at the 47°N / 20°W BIOTRANS-site and an understanding of near surface variability of DOC on short time scales at this site, and to round off the survey of the seasonal development of DOC at this station established during 1992/93 (PK) with a season not yet covered. The second objective was to compare two independent analytical systems at sea; both are based on the new high-temperature combustion technique. PK's is a modified commercial system (Dimatec) and ETP's is a home-made analyzer based upon improvements in Suzuki's design.

*Results and Discussion*

- Comparison of the two analyzers produced several results. First, both analyzers yielded the same DOC concentrations for identical samples. However, significant differences were observed between various sample collection and pre-treatment procedures. Contamination during sample collection and filtration was found to occur and it was concluded that the best results were obtained whenever the samples were handled the least.

- Mixed-layer DOC concentrations were observed to be quite patchy based upon the underway snorkel samples. Results from these samples are shown in Figure 37. Generally, the concentrations are low. This is consistent with the winter time situation of low production and deep convection.

- Figure 38 shows a typical profile obtained during the small-scale survey conducted upon our arrival at the BIOTRANS-station at 47°N / 20°W. The subsurface maximum was typical of all the profiles obtained and surface concentrations from profile to profile were constant. The subsurface maximum was a bit of a surprise as it suggests a rather shallow mixing during this time of year. There were already sligtly elevated stocks of phytoplankton in the surface water and nutrient levels were already significantly depleted (cf. W. Koeve's contribution). Also the distribution of DOC showed what we believe to be spring features. The slightly elevated DOC content in the surface water is from freshly produced DOC, otherwise the concentration would be uniform down to the maximum mixing depth near 400 m.

- Several days later a much different profile was obtained in the same area (Figure 39). Overnight the wind had picked-up to 40 knots and the air temperature was 1-2 degrees cooler than the sea. This event was sufficient to cause the complete overturn of the upper water column down to a depth of almost 400 m. This mixing can be clearly seen in the DOC profile. It results in a net downward transport of carbon below the level of the summer mixed layer.

- DOC in sediment contact water was measured in three cores: There was no gradient with distance from the sediment surface (four 12 cm increments), and the concentration was the same as in the deep water. This indicates that the sediments of the BIOTRANS-site are not a source of DOC to the overlying water.

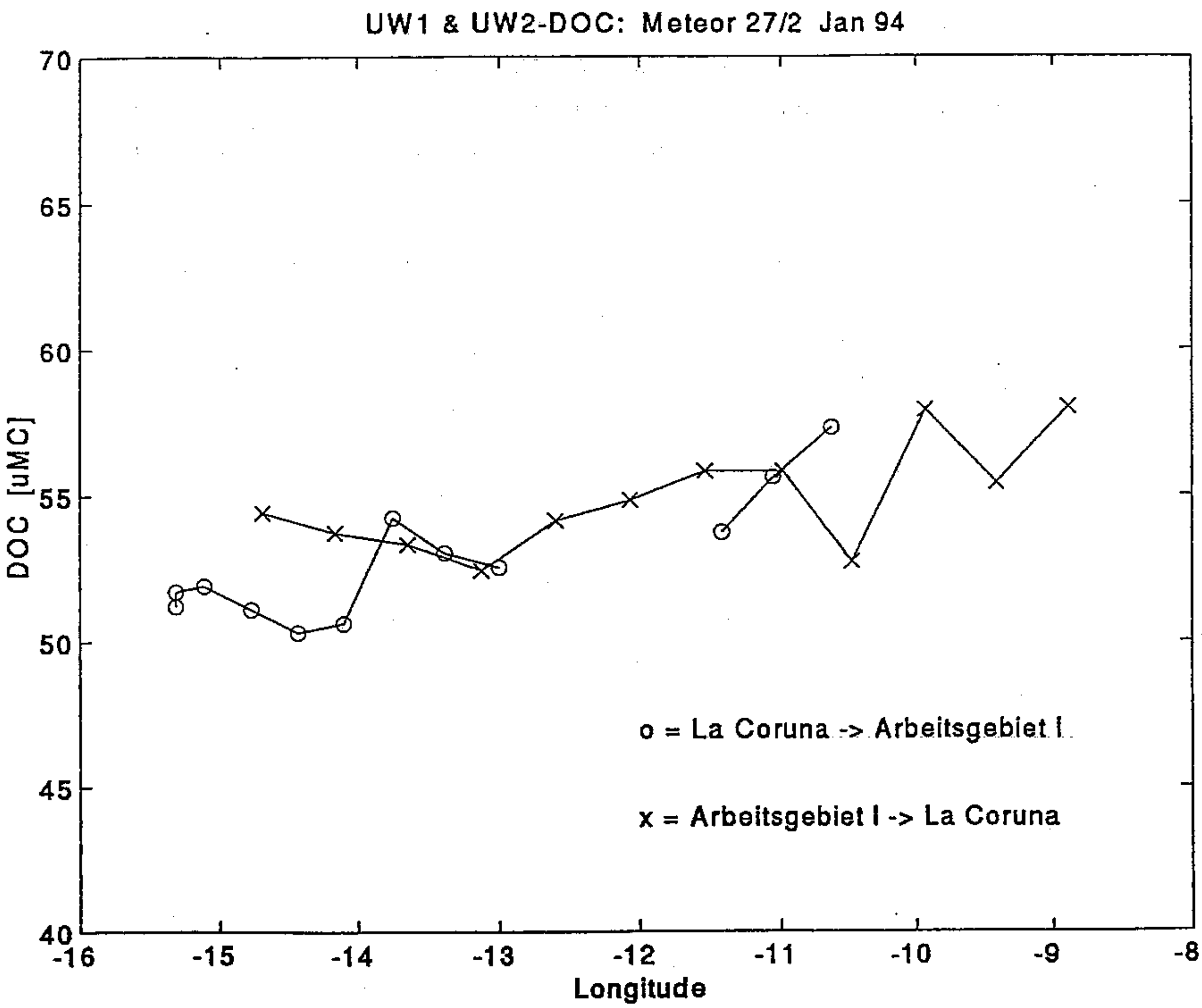



**Fig. 37:** DOC concentrations in surface water, transects between La Coruna and 47°N /15°W.

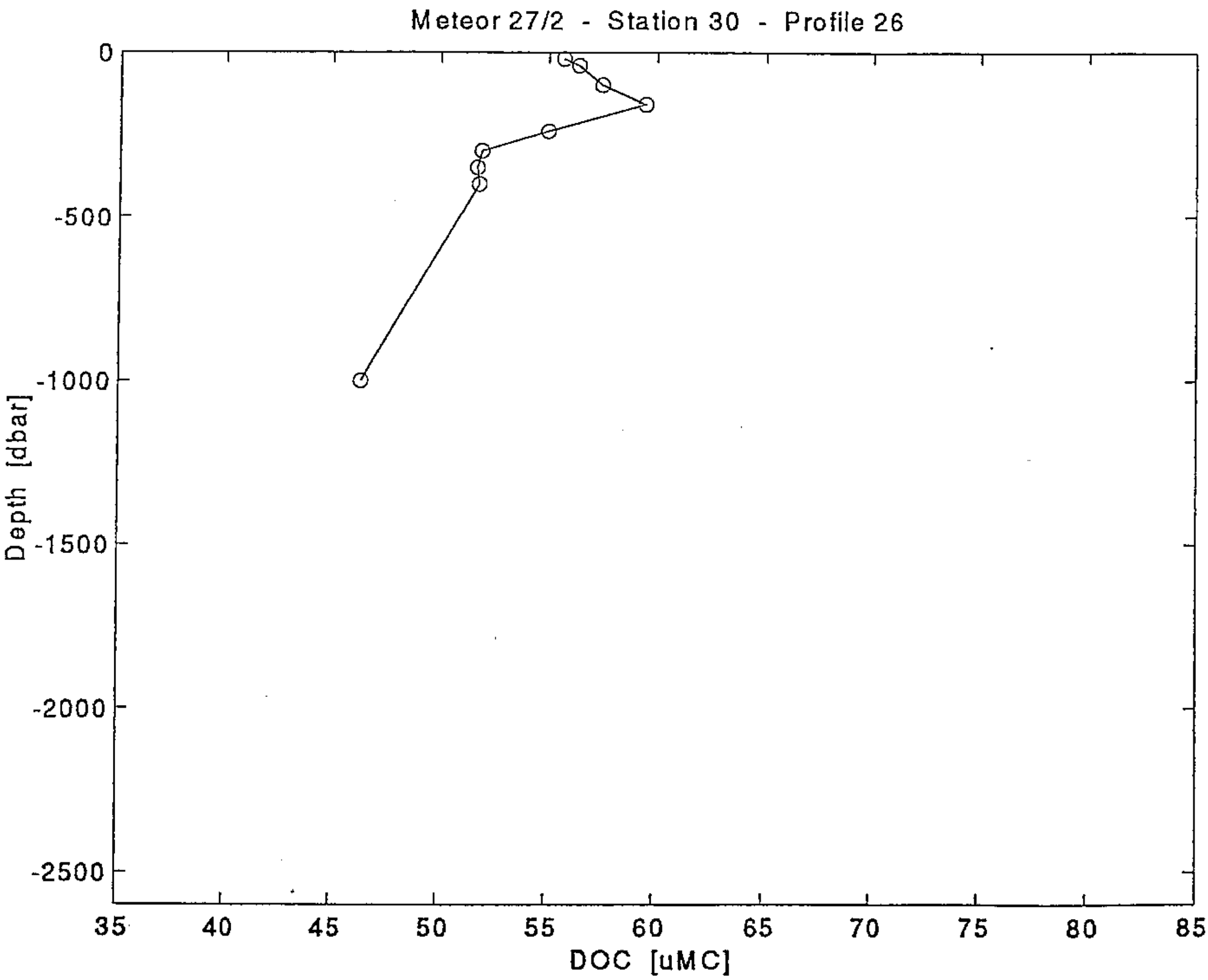



**Fig. 38:** Depth profile of DOC at the BIOTRANS-site (47°N / 20°W, January 30, 1994), shallow mixed layer.

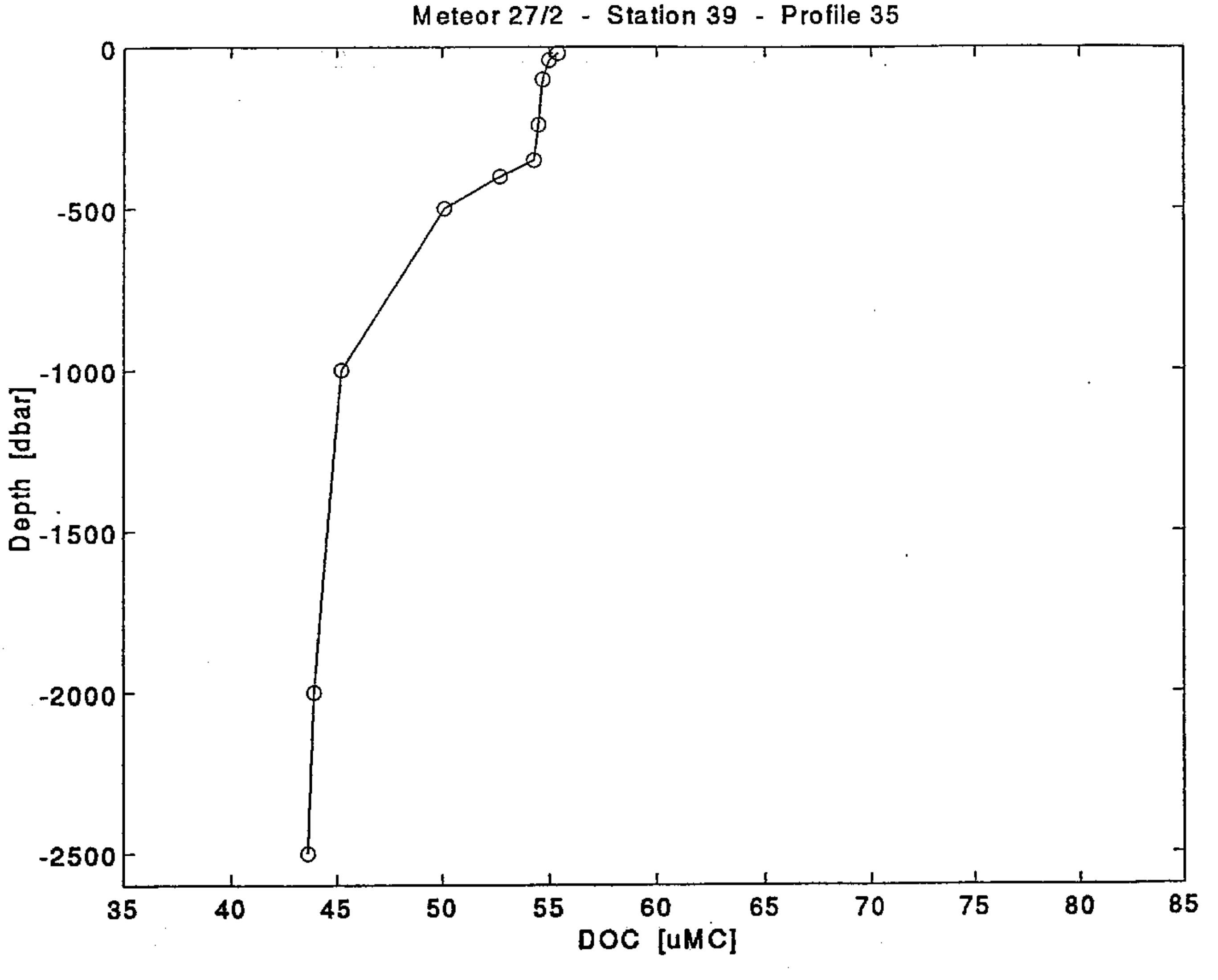



**Fig. 39:** Depth profile of DOC at the BIOTRANS-site (47°N /20°W, February 1, 1994), with deepened mixed layer after a gale.

### 5.2.3 Nutrients, Organic Compounds and Fatty Acids

(T. Raabe, I. Büns, M. Schütt, U. Brockmann)

The main objective during this cruise was the investigation of the transfer and transformation processes of nutrients and organic compounds in water masses passing the shelf break. For that purpose several collective parameters were analyzed as well as individual compounds in order to relate concentration changes to biogeochemical processes more precisely. At all CTD-stations water samples were taken from the rosette sampler and were passed through glass fibre filters (Whatman GFC) applying vacuum filtration (< 0.2 bar). The volumes to be filtered were chosen according to the expected content of particulate matter. The filtrate, partly preserved with mercury(II)chloride, was stored in glass and polyethylene bottles in a cooling chamber. The filtrate will be analyzed for dissolved organic nitrogen/ phosphorus/carbon and total carbohydrates. The filters were stored in a freezer at -17°C. From these filters dry weight, particulate carbon/nitrogen/phosphorus, carbohydrates and fatty acids will be determined. The nutrients nitrate, nitrite, phosphate, silicate and ammonium were determined directly in the samples by use of a Technicon AutoAnalyzer System, provided that the content of particulate matter was not too high. Total dissolved nitrogen and phosphorus were analyzed in filtered samples following a wet-chemical oxidation method. The parameters pH (WTW pH-meter), fluorescence (Turner fluorometer) and turbidity (Turner nephelometer) were analyzed immediately in every sample. Oxygen was determined in selected samples by Winkler titration with a Metrohm titration unit.

During the whole cruise 120 samples had been taken at 9 stations. Taking all stations together, the concentration of nitrate plus nitrite ranged from 7 to 24 µmol/l. The lowest concentrations of 7 to 8 µmol/l were always found within the upper 200 m layer of the water column that was very well mixed. From 200 m to 800 m nitrate plus nitrite concentrations steadily rose up to 16 to 18 µmol/l, then more slowly increasing up to maximum values of 22 µmol/l at depths below 3000 m (Fig. 40). Since the vertical profiles at the King Arthur Canyon were almost identical to those of the Goban Spur transect, they will not be mentioned here explicitly. For phosphate very similar distribution patterns were observed: a low concentration of less than 0.5 µmol/l was found within the upper 200 m of the water column, increasing to 1 µmol/l at 800 m depth and reaching maximum values of 1.5 µmol/l below 3000 m depth (Fig. 41). At all stations the concentration of silicate amounted to about 3 µmol/l in the upper 200 m layer. From 200 m to 2000 m the content of silicate slightly increased to 10 to 11 µmol/l. Below 2000 m a stronger increase was observed, reaching a maximum concentration of more than 40 µmol/l silicate in the bottom layers of the deeper stations (Fig. 42). Compared to the nutrients nitrate, phosphate and silicate, the vertical profiles of ammonium and nitrite were different. The concentrations of ammonium were about 0.5 µmol/l throughout the water column. At the deeper stations M0006-94 and M0014-94 slightly increased amounts were observed in the upper 100 m layer, ranging from 0.7 to 0.9 µmol/l. A maximum concentration of 1.27 µmol/l was found in 100 m depth at station M0006-94 (1st cast, see Fig. 43). Nitrite concentrations were far below 0.1 µmol/l, in most cases about 0.04 µmol/l in the surface mixed layer and 0.02 µmol/l at depths below 400 m. At station M0006-94 (first cast) the surface values exceeded 0.05 µmol/l (Fig. 44).

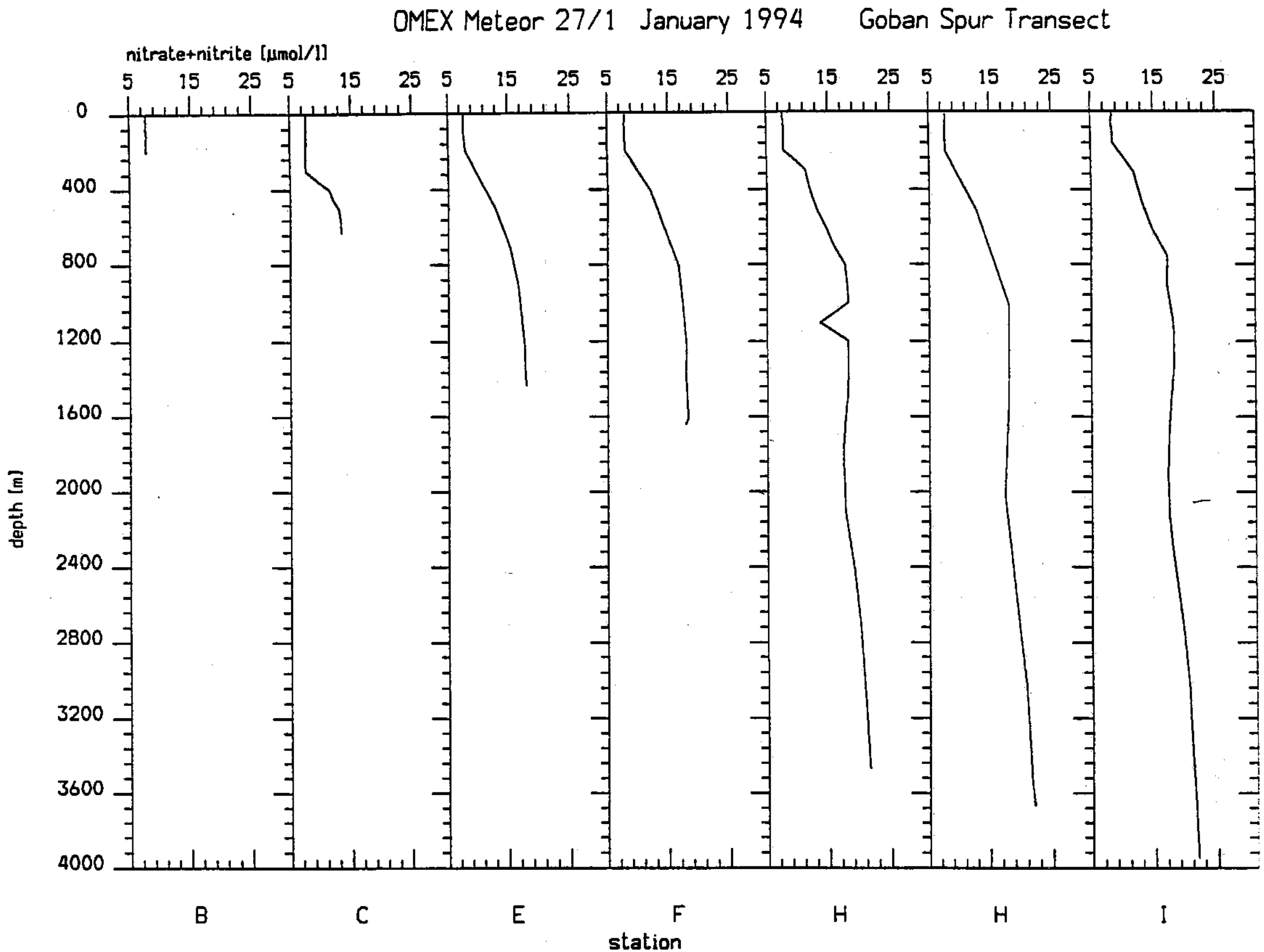



**Fig. 40:** Winter distribution of nitrate plus nitrite along the Goban Spur transect. The profiles using OMEX notation B-I correspond to the following stations during M 27/1: B=002-94, C=003-94, E=004-94, F=007-94, H=006-94, I=014-94.

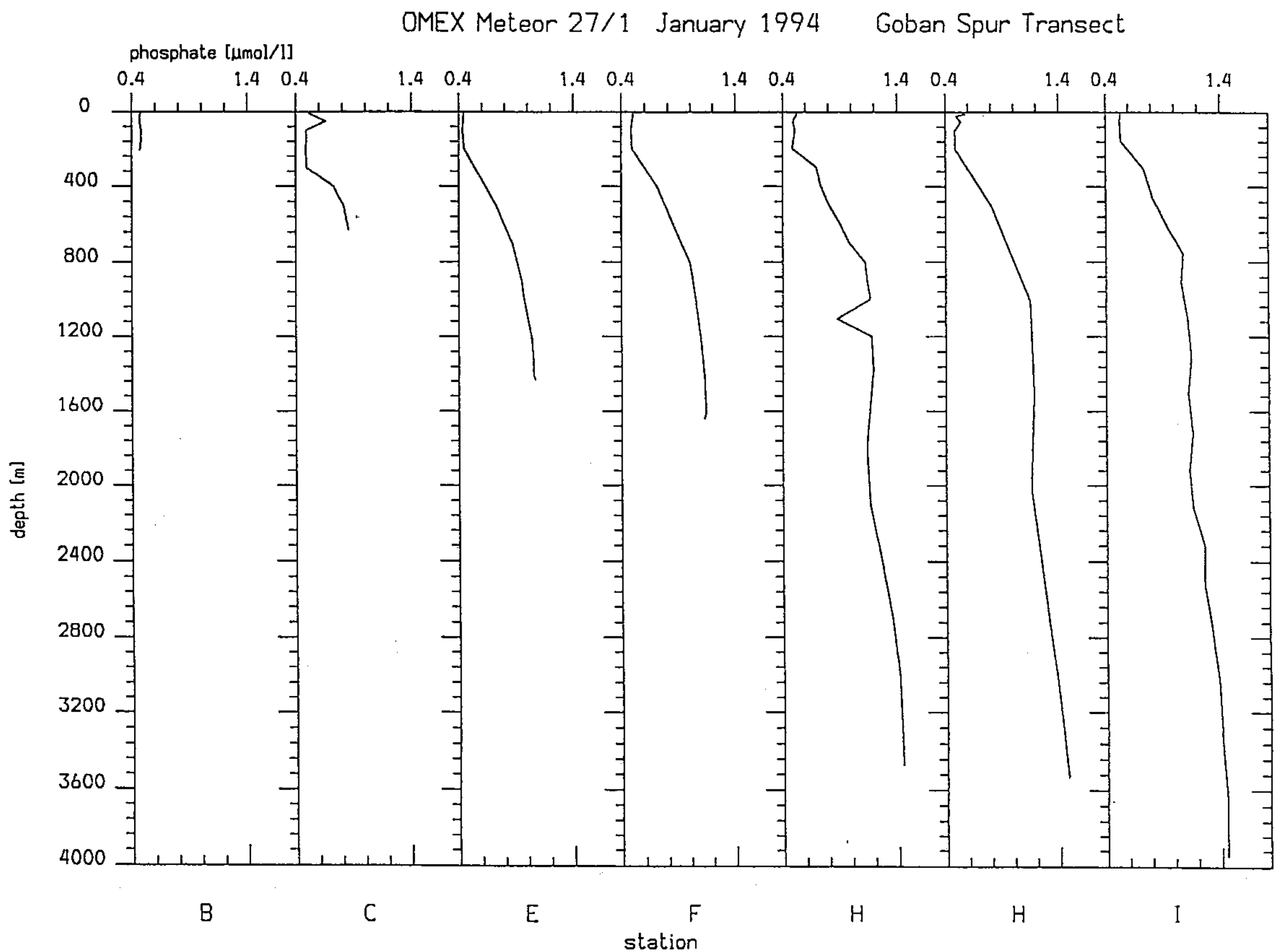



**Fig. 41:** Winter distribution of phosphate along the Goban Spur transect (for notation of stations see Fig. 40).

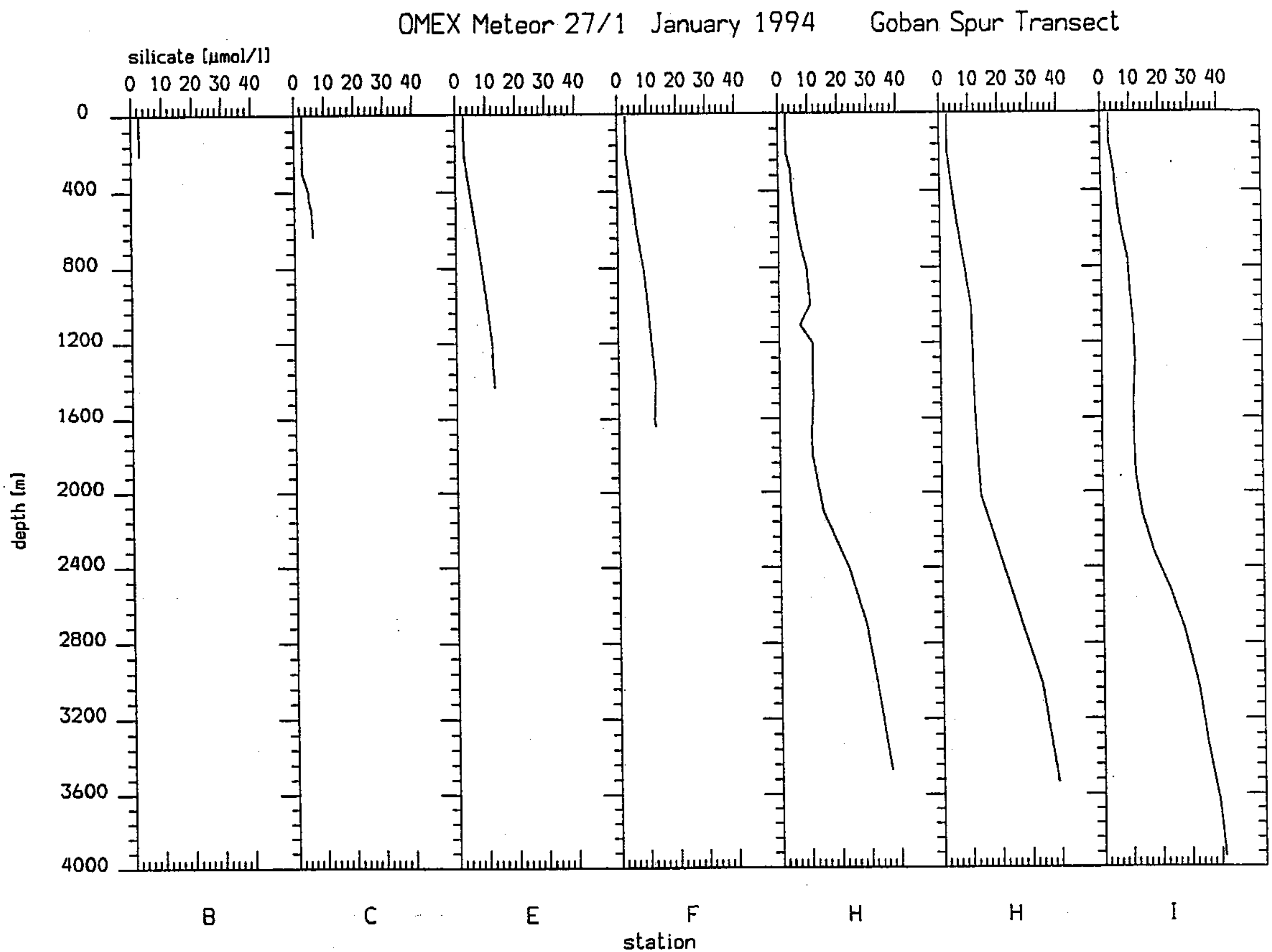



**Fig. 42** Winter distribution of silicate along the Goban Spur transect (for notation of stations see Fig. 40).

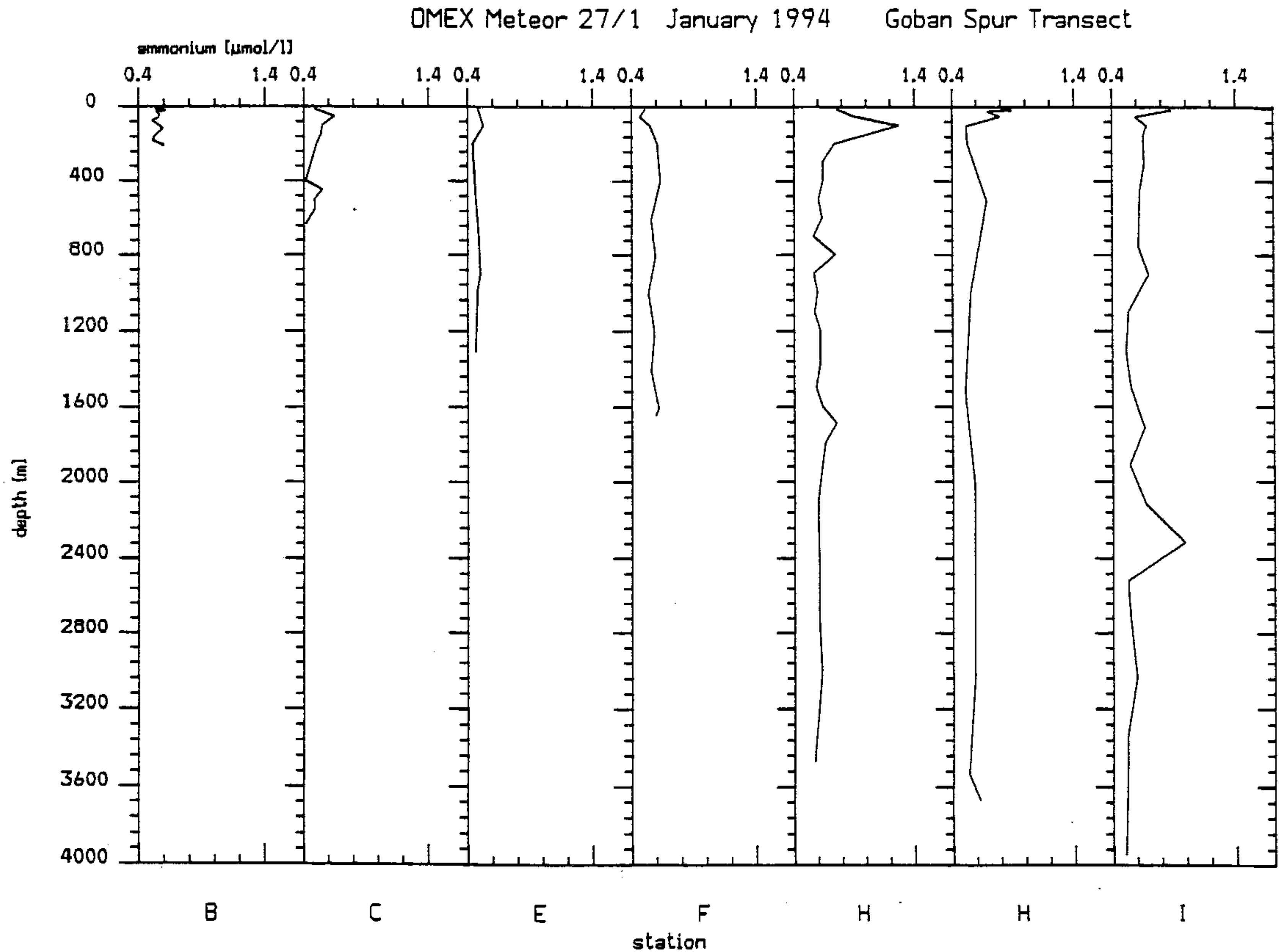



**Fig. 43:** Winter distribution of ammonium along the Goban Spur transect (for notation of stations see Fig. 40).

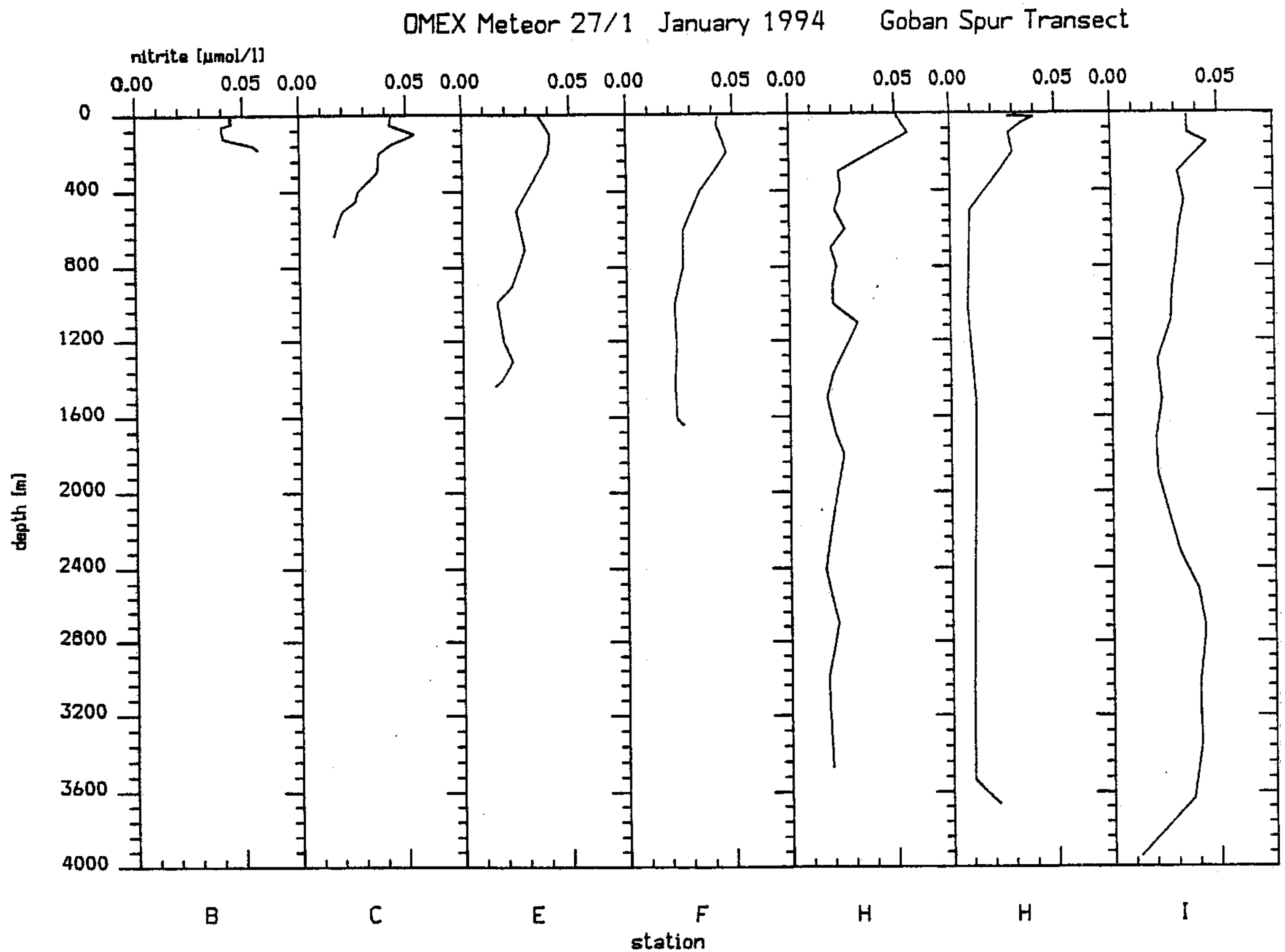



**Fig. 44:** Winter distribution of nitrite along the Goban Spur transect (for notation of stations see Fig. 40).

The observed distribution patterns of the nutrients reflect the winter situation along the Celtic Shelf: Lower amounts of nutrients were usually found in the upper layer of the water column being advected from the shelf. The 200 m layer was well mixed and the concentrations of all nutrients exceed the limiting values for phytoplankton growth. The slightly increased values for ammonium found in the upper layers at stations M0006-94 and M0014-94 correlated with higher values of fluorescence indicating some planktonic production on a low level. Compared to the summer cruise having maximum concentrations of the degradation products ammonium and nitrite in 50 to 80 m depth being related to distinct phytoplankton blooms, no other strong gradients or characteristic peaks of ammonium and nitrite were found within the euphotic zone. This was due to the missing planktonic production during the winter cruise. The nutrient concentrations determined at depths below 200 m indicated deep-seawater with the described high amounts of nitrate plus nitrite, phosphate and silicate. The concentrations and distribution patterns of the nutrients in the deeper layers were very similar to those found on the OMEX summer cruise in July 1993.

### 5.2.4 OMEX: Dissolved and Particulate Trace Elements

(W. Balzer, G. Brunn, A. Deeken, O. Grimm, B. Rawitz)

Within the OMEX project on trace element cycling at the Celtic margin, the distribution of dissolved trace elements has to be compared with their concentration in suspended particulate material (SPM), in particles caught with sediment traps and in sediments. The main objectives are:

- The deepening of our general knowledge about the control of trace element distribution by interaction with biogenic and abiotic particles, and
- to investigate whether dissolved trace elements and suspended particles (eventually resuspended from the sediments) are injected from the margin into the open ocean and whether they affect the trace element chemistry of the open ocean.

Within the 3 main classes of elements (according to their vertical distribution grooped into: "conservative", "nutrient-type", "scavenged") as many elements as possible at acceptable accuracy will be determined in different matrices. Three particulate phases were sampled using different techniques:

- the SPM filtered by using in situ-pumps is supposed to consist of slowly sinking biogenic and terrestrial detritus exhibiting a large surface area for sorptive processes,
- the material caught with intercepting sediment traps consisting of larger, faster sinking particles which incorporate trace elements during their formation in the ocean's top layer and by scavenging,
- the sediment representing the ultimate result of all water column processes and early diagenetic modifications near the sediment/water interface.

In addition to the determination of trace element concentrations, data from other groups working with sediment trap particles are needed for the analysis of carrier phases such as carbonate, organic carbon, opal and lithogenics. In addition to SPM sampled during M 27/1, aliquots of the trap material will be analyzed at home for trace and major components after digestion with nitric and hydrofluoric acid.

Due to the low concentration of SPM below the mixed layer, large volumes of seawater have to be filtered for trace element determinations in SPM. Between 250 l and 550 l seawater from depths down to 4400 m close to the Celtic margin were filtered through acid cleaned 293 mm Nuclepore filter using in situ-pumps (Tab. 7.1.3). To reduce contamination risks a non-metallic wire was used and all handling of the filters was performed under a clean bench within a clean room container. Because in situ-pumping is very time-consuming pumps were combined with bottle casts whenever possible. From pump deployments a total of 39 filters were obtained covering the whole Goban Spur transect and all relevant depths (Fig. 45).

At all stations where in situ-pumps were deployed and especially where sediment trap moorings were positioned, casts of GoFlo bottles were taken to analyze the vertical distribution of trace elements in the water column. For the trace metal studies precautions had to be taken against the risks of contamination: Before use the GoFlo bottles were acid cleaned thoroughly, at station the bottles were attached to a non-metallic wire, during handling on deck both opening ends were covered with plastic bags, all manipulations after subsampling were performed under a clean bench. When the filled bottles were brought to the lab, dissolved oxygen was subsampled first; then two plastic containers were filled for trace elements and acidified thereafter using subboiled $HNO_3$; finally subsamples for nutrient analysis were taken and deep-frozen.

When brought back to the home laboratories, selected trace elements (primarily: Ba, Cd, Co, Cr, Cu, Mn, Ni, Pb) will be analyzed, and the vertical and horizontal distribution will be compared with results from the particle analysis. The only component that was determined directly on board was oxygen (by conventional Winkler titration) serving to check the compatibility with the rosette-casts.

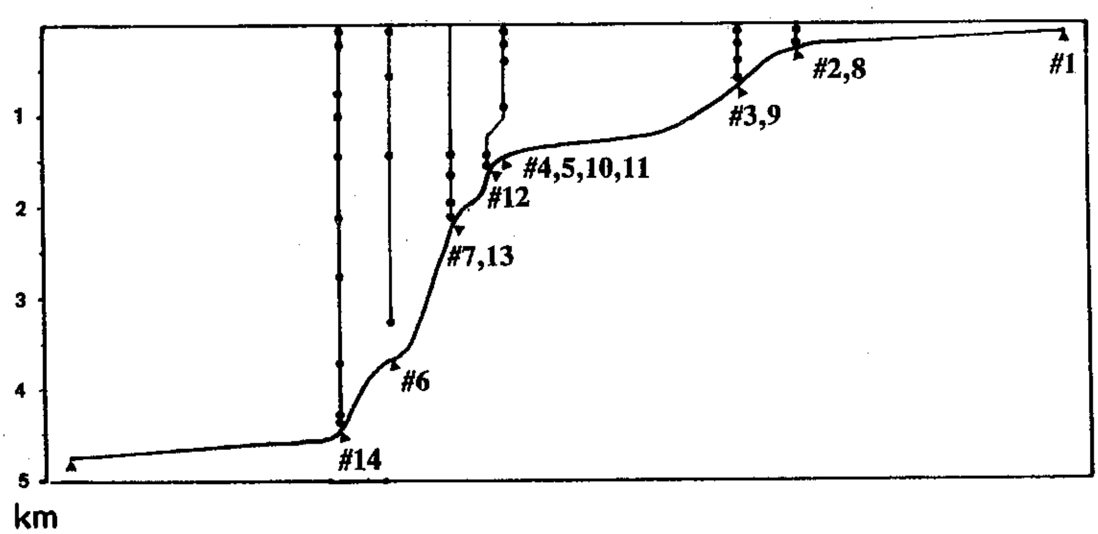



**Fig. 45:** Location of the stations on the Goban Spur transect and the depths where suspended particles were collected by in situ-pumping.

### 5.2.5 OMEX: Seawater Concentrations and Air-sea Exchange of Carbonyl Sulfide (COS) (V. Ulshöfer, O. Flöck, T. Kennter)

The focus of the biogeochemical investigations by our group during leg 1 was the determination of COS in surface waters and in the atmosphere, as well as the distribution of this climatically relevant trace gas in the water column. Some preliminary results are presented in the following. Air samples were analyzed for COS every 2 hours by cryogenic trapping, chromatographic separation and flame photometric detection. The air inlet was mounted on the mast of METEOR ca. 38 m above the sea surface. COS concentrations in the surface water were obtained every 2 hours by equilibrating a fixed volume of air with a continuous supply of seawater and analyzing the equilibrated air as above. Unfortunately, the clean seawater pumping system of the ship could not supply bubble free seawater, so it could not be used for the equilibrating system. Thanks to the group from IfBM, Hamburg, we could use their seawater pumping system ("Kiel Pumping System"), which supplied a continuous flow of bubble free water from ca. 7 m depth taken through a special inlet.

Furthermore, depth profiles of dissolved COS were taken at selected stations using GoFlo samplers and seawater incubation experiments were carried out to obtain COS photo-production rates. The GoFlo samplers were modified to allow pressurization with helium (no contact of the contents with ambient air) and all the rubber seals, which leak COS, were replaced by silicon seals. Incubation experiments were carried out in silanized duran glass flasks. In these discrete water samples COS was analyzed using a purge and cryogenic trap method. For the characterization of air masses, a radon monitor was used to continuously monitor the $^{222}$Rn content of the air. For the determination of chlorophyll-a, as well as seawater fluorescence and absorption, 25 surface water samples have been collected. Analysis of these samples is still taking place.

Air mixed ratios and surface water COS concentrations are shown in Fig. 46. The COS mixing ratio was determined on 124 samples with a mean of 428 pptv with a standard deviation of 100 pptv. This mixing ratio is somewhat below a global average of 510 pptv, but is consistent with an average of 480 pptv measured by our group (G. Uher) nearby during M 21/2 in April 1992. Air-to-sea fluxes of COS may be one possible explanation for the relatively low air mixing ratios. The average concentration of dissolved COS in surface waters was 5.4 pmol/l (n=120) with a standard deviation of 1.9 pmol/l. These values are extremly low and are mainly explained by the low photochemical production due to very low solar UV light intensities (see Fig. 47) and a "dilution effect" due to the deep mixed layer (> 200 m). For the estimation of the air-sea-exchange rate of COS, the saturation ratio of COS in surface waters with respect to the atmosphere was determined (SR=[COS]equilibrated air/[COS]ambient air). All samples exhibited undersaturation of the surface waters with a mean of 0.46 and a standard deviation of 0.13. Undersaturation means that the direction of the COS flux was from the atmosphere into the seawater. Using the gas-exchange model from LISS and MERLIVAT (1986), an average COS flux of 34 nmol $m^{-2}$/day is estimated. This data set is the first reliable set in which a persistent undersaturation of surface waters and a resulting net flux into the ocean could be shown.

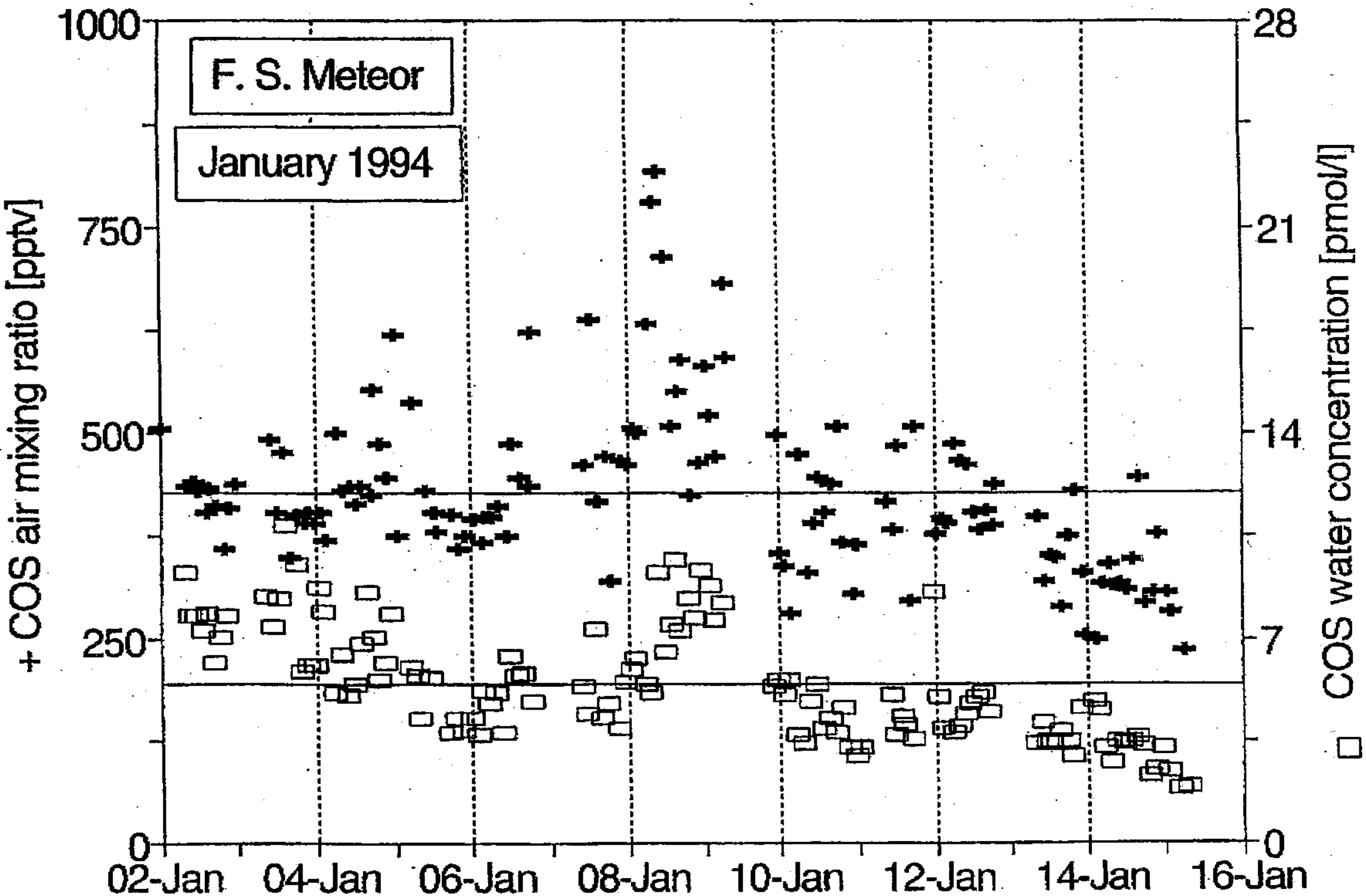



**Fig. 46:** COS air mixing ratios and water concentrations. The scales are selected in a way that the air mixing ratio corresponds approximately to its equilibrium value in surface water (e.g. 500 pptv = 14 poml/l). The surface seawater was under-saturated at all times with respect to the overlying air.

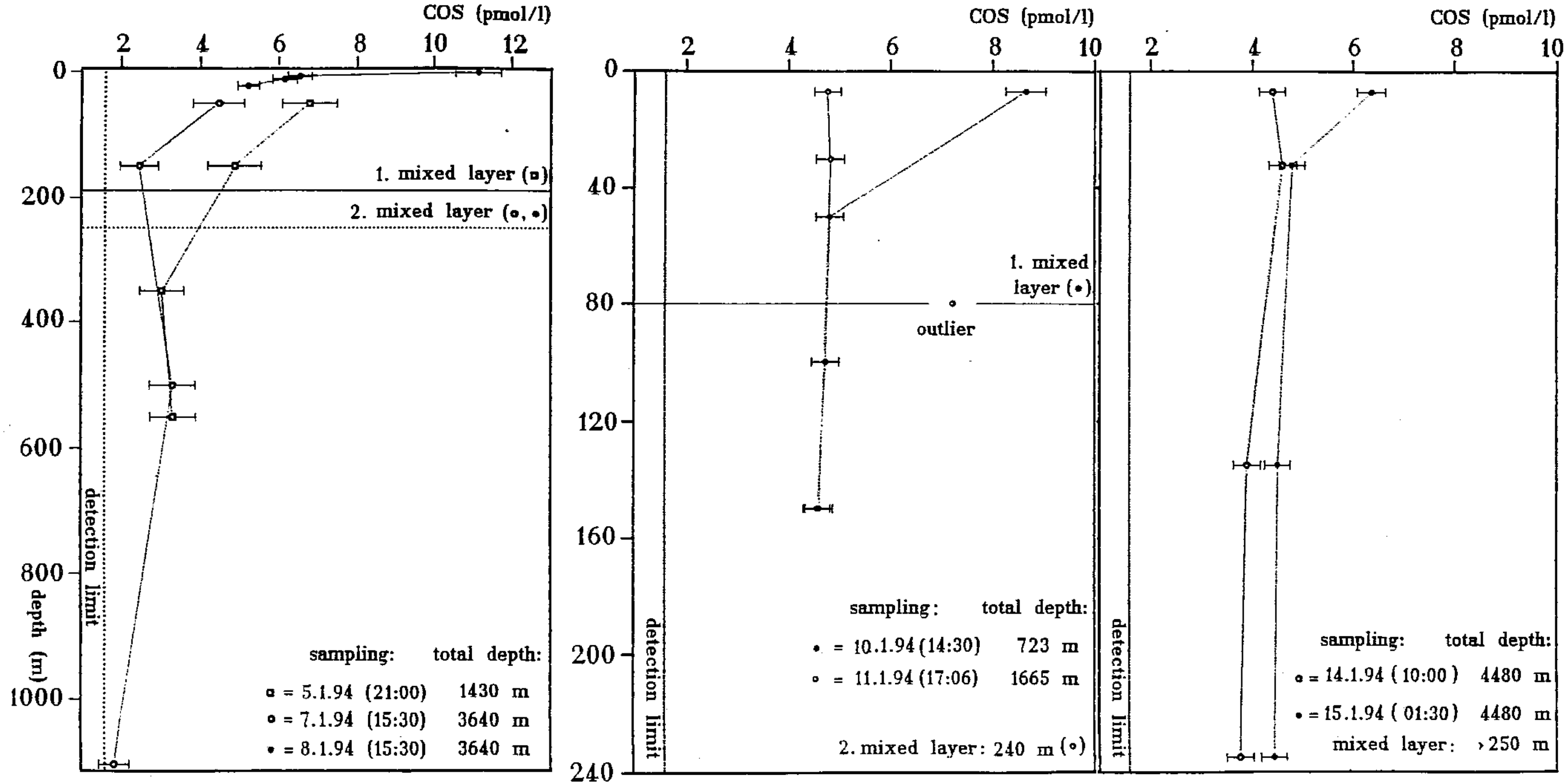



**Fig. 47:** Vertical profiles of dissolved COS. Concentration decreased with increasing depth within the mixed layer, reaching a fairly uinform level (3-4) pmol/l directly underneath the mixed layer and even smaler concentrations in greater depths.

Since there are missing sinks in the global budget of COS, this could partly be explained by an overestimation of the oceanic source of COS.

Depth profiles of COS are shown in Fig. 47. A general trend is the maximum at the sea surface with decreasing COS concentrations to ca. (3-4) pmol/l beneath the mixed layer. To compensate for losses of COS due to hydrolysis in this layer, transport and/or non-photochemical production mechanisms must provide ca. 3.6 pmol/l per day (if assuming steady state conditions). In even deeper waters very low concentrations (<1.8 pmol/l) of COS are found (here transport or production must provide ca. 1 pmol/l per day). An increase in the mixed layer depth caused a decrease in COS concentrations due to downward mixing out of the zone of photochemical production. Elevation of the COS concentrations in the surface waters appeared to be mostly due to photochemical production and only partly due to air-to-sea flux. Incubation experiments showed that even with such low UV light intensities photo-production of COS takes place (Fig. 48), as can be seen from the correlation of the COS concentrations with the energy flux. Dark controls show little or no increase in COS concentration.

### 5.2.6 OMEX: Methane and $d^{13}C$ of $TCO_2$ over the Goban Spur

(R. Keir, G. Rehder)

Methane is a trace gas in the atmosphere which has a variety of natural and anthropogenic sources. Its distribution in the ocean is still only poorly known, but in general it appears to be depleted at greater depths, except in areas where strong bottom sources such as cold vents occur. In surface waters methane will be controlled through gas exchange and solubility, as well as any in situ-generating processes as appear to occur in strong oxygen minimum zones. As part of the OMEX projekt, water samples from a transect of hydrocasts normal to the European margin were collected and analyzed on board for methane concentration using an ultrasound degassing unit and gas chromatography. Fig. 49 shows the station locations in the Goban Spur region.

Fig. 50 and Fig. 51 show preliminary results in terms of the methane concentration per unit of extracted gas on the right side and calculated gas concentration in the water on the left. The latter is calculated from the observed volume of extracted gas and the measured methane concentration in the gas. Two ultrasound baths were used in tandem for the extractions, and since gas volumes obtained by this method tended to vary, especially between the two baths, considerable noise is introduced into the calculated methane concentrations. However the depth profiles of methane concentration in the extracted gas are very consistent, and some features of the water column distribution of methane stand out. Surface waters have concentrations which appear to be in equilibrium with an observed atmospheric concentration of about 1.9 ppmv. This concentration extends to a depth of about 300 m, which appears to be the extent of the mixed layer in January, as seen from temperature and salinity. Below about 3000 m, methane concentrations in North Atlantic Deep Water were found to be quite low, on the order of about 10 nl $CH_4$ per liter of water. In the depth range of about 1000 m to 2000 m,

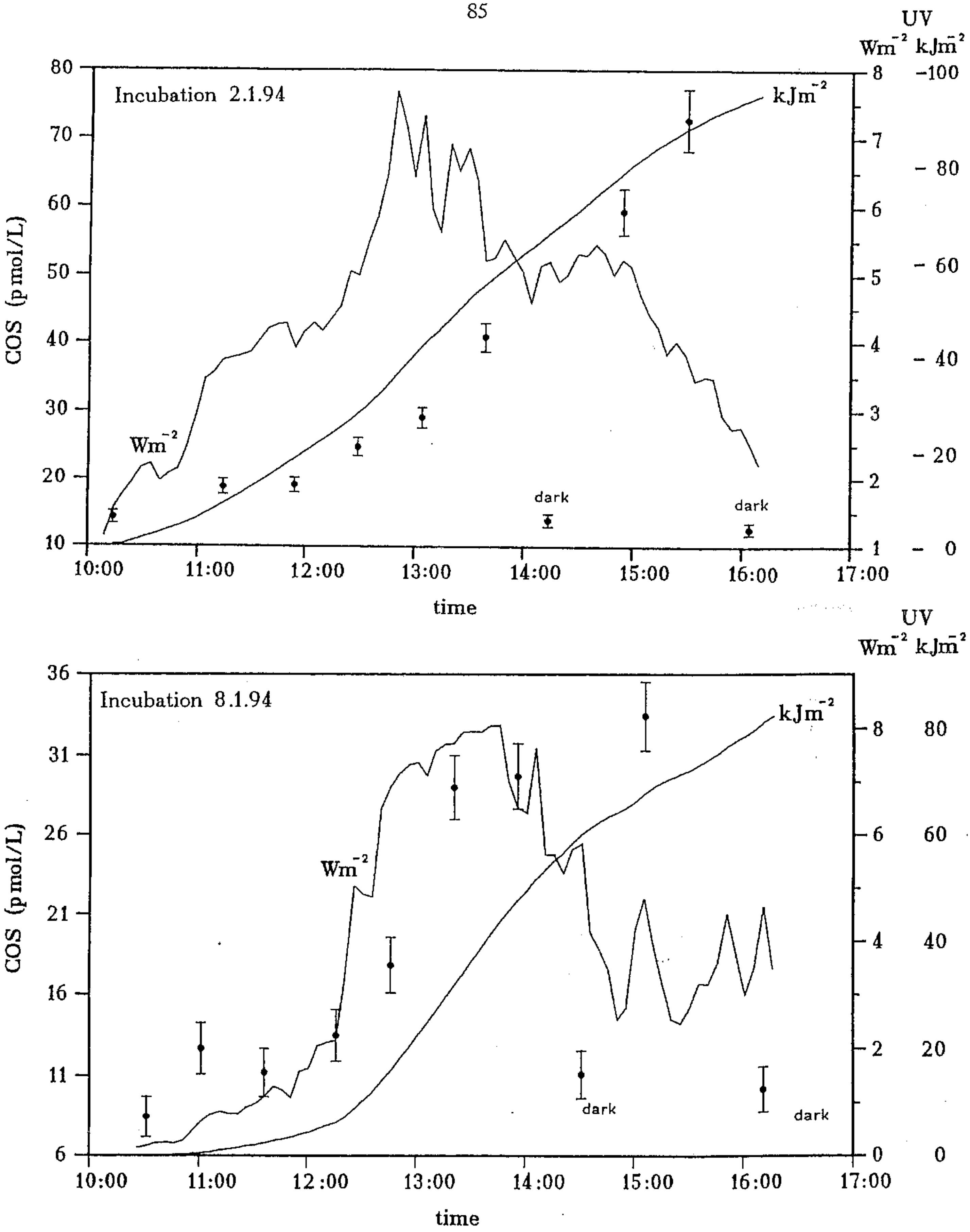



**Fig. 48:** COS photo-production correlated with the total incident UV sun light energy. Dark controls show little or no increase in COS concentration. Time scale is local time. Sun rise and sun set can be estimated from the UV light intensity curve.

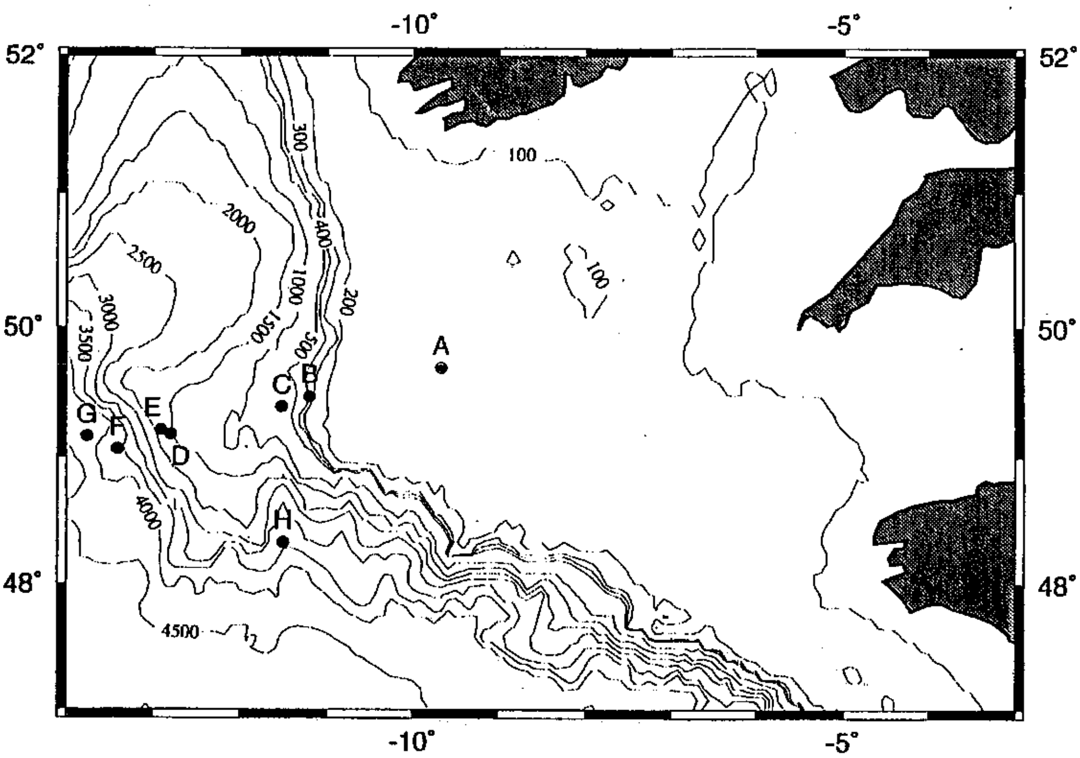



**Fig. 49:** Location of stations sampled for methane and stable carbon isotopes. The positions A-H correspond to the following stations during M 27/1: A=001-94, B=002-94, C=003-94, D=004-94, E=012-94, F=006-94, G=014-94, H=015-94.

a fairly uniform concentration was observed that is intermediate between surface and deep water values. At station M0003-94, just off the continental shelf in about 600 m depth, the methane concentration in the extracted gas increases between 300 m and the bottom, which is in contrast to the deeper stations further off the shelf.

The preliminary methane results are presently being examined with a series of shorebased laboratory experiments. In particular it appears that the gas extraction is not 100 % efficient, and it also appears that the methane gas concentration of the water can be appraised independently of the actual amount of gas extracted within certain limits. Final calculation of the methane results will follow reevaluation of this method.

Fractionation of the stable carbon isotopes of total dissolved $CO_2$ within the ocean results from a combination of the biological pump, which transfers $^{12}C$ preferentially from the surface to deeper waters as particulate carbon, and isotope fractionation of the $CO_2$ exchanging between the sea and air. In winter the continental margin may be of particular interest in regard to these dynamics because air-sea exchange should have its maximum development while the biological pump should be at its minimum stage. Samples for $\delta^{13}C$ analysis were collected at the stations shown in Fig. 49, poisoned and transferred to the radiocarbon laboratory at the University of Kiel. Under the direction of Dr. H. Erlenkeuser, shorebased analysis of these samples is presently carried out.

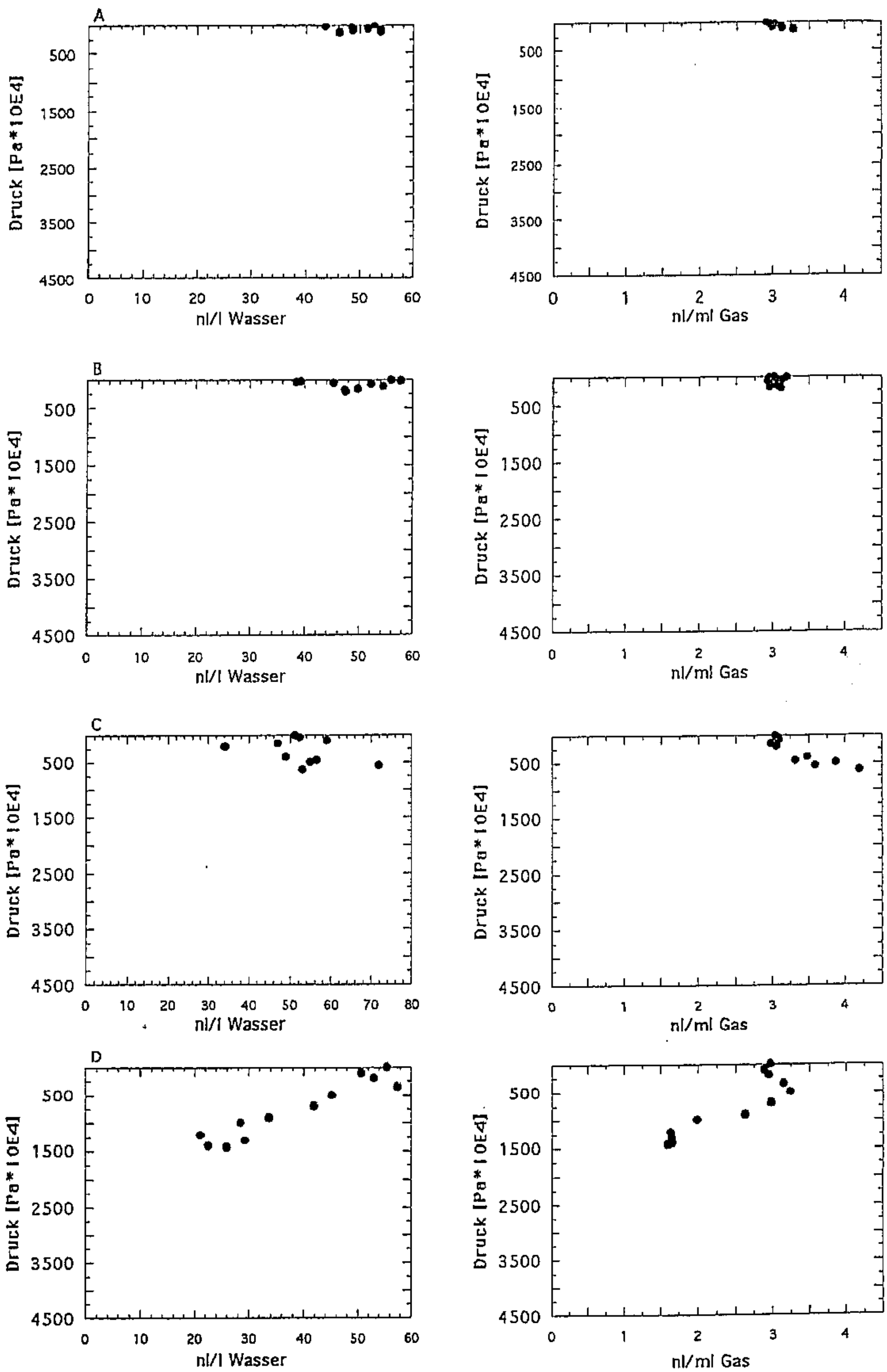



**Fig. 50:** Distribution of methane at stations A-D (see Fig. 49).
Left column: methane content per liter seawater.
Right column: methane content per ml extracted gas.

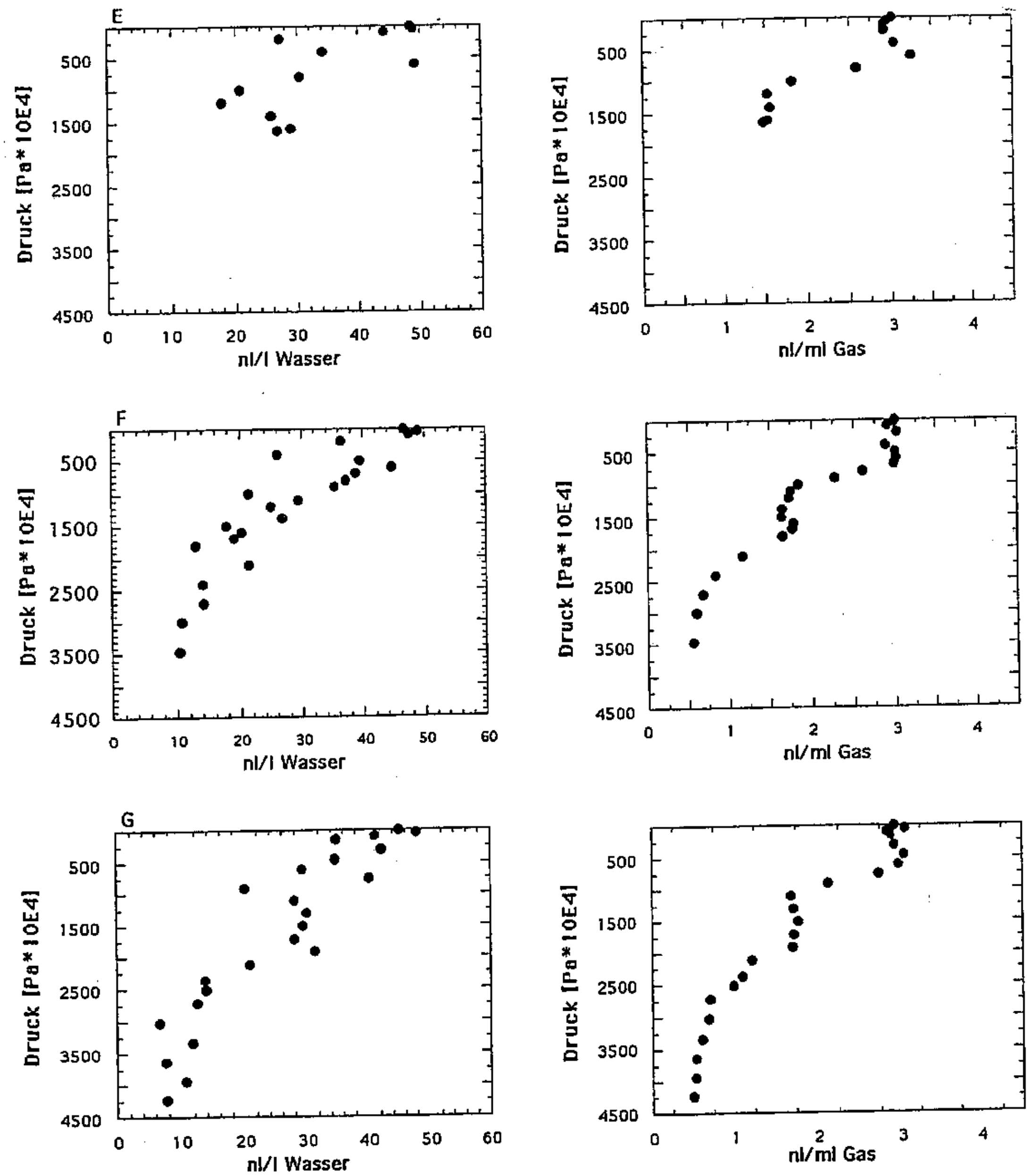



**Fig. 51:** Distribution of methane at stations E-G (see Fig. 49).
Left column: methane content per liter seawater.
Right column: methane content per ml extracted gas.

### 5.2.7 OMEX: Dissolved Organic Carbon (S. Otto, W. Balzer)

In order to investigate dissolved organic carbon (DOC) in the water column across the continental margin, samples from seven CTD-rosettes were taken at the Goban Spur transect and from one station in the King Arthur Canyon. At each position the whole water column was sampled. It is very critical in the determination of DOC to avoid contamination of the samples. Therefore, great care was taken from the first step of sampling throughout the whole work-up procedure: samples from the rosette were taken in specially cleaned glassbottles, immediately filtered through precombusted GF/F filters and finally acidified and sealed in brown glass ampoules. All samples were stored at +4°C until analysis.

The DOC determinations were performed by the High-Temperature-Catalytic-Oxidation (HTCO), which is the most common method for DOC determination in the marine community since several years. Additional ampoules were prepared from several water samples for a DOC intercomparison exercise to be conducted together with the Plymouth Marine Laboratory. In addition to the investigation of DOC in the water column, it was planned to determine DOC in pore waters. Because of the weather and problems with the winch we could get only one sediment sample. After squeezing the sediment in a cold room, the pore water was analyzed for DOC and for total inorganic carbon. The DOC showed low values in the entire water column at all stations of the Goban Spur transect as compared to other sea areas. Surface values were in the range from 50 to 65 µmol/l. Below the mixed layer DOC generally decreased to about 40-50 µmol/l in near-bottom waters.

## 5.3 Biological Oceanography

### 5.3.1 BIO-C-FLUX: Benthic Investigations at the BIOTRANS-station (O. Pfannkuche)

Benthic investigations at the BIOTRANS-site between 1985 and 1990 gave evidence for a close pelago-benthic coupling between processes in the epipelagic zone and processes at the deep-sea floor (4550 m depth). Maximum sedimentation rates of particulate organic matter in early summer (THIEL et al., 1988/89) induced an significant increase in benthic carbon consumption rates and activity (ATP-concentration) by a factor of 2-5 in comparison to March values (PFANNKUCHE, 1992; 1993). Benthic response to peak sedimentation rates of POM were mainly channeled through the small benthic size groups, mainly bacteria (LOCHTE, 1992), protozoa and small meiofauna. These results, which were obtained from the synthesis of a five years survey, probably describe the general pattern of pelago-benthic coupling for this part of the NE Atlantic, but they contain a range of interannual variability. This view was supported by results from M 21 in 1992 (results are included in Figs. 1 and 3). In contrast to previous cruises where a first noticeable sedimentation event on the sea floor was registered in late April and early May (PFANNKUCHE and LOCHTE, 1993) we could recognize a sedimentation event on the sea floor as early as March, when green-brown phytodetrital material was found on top of the sediment in the multiple corer tubes. In consequence, a phytoplankton bloom must have taken place some weeks earlier at the end of February, a phenomenon which has not been reported from this part of the Atlantic. No detectable sedimentation of detrital matter was found in April and May whereas in August some multiple corer samples contained some white already degraded phytodetritus. Sediment chlorophyll-a and pheopigments did not increase significantly between March and August. The activity of hydrolytic enzymes also exhibited no seasonal difference, correspondingly the values of total adenylates did not show a substantial increase in biomass. The data suggested that there was no discrete large sedimentation pulse in 1992 and no substantial effect on the benthic community as in 1986 was found (THIEL et al., 1988/89), when a significant increase in benthic standing stock and activity was measured.

The main objective of the BIO-C-FLUX benthos programme during M 27/2 was to measure benthic activity under presumed winter conditions in order to estimate the annual minimum of benthic rates in comparison to previous studies.

#### 5.3.1.1 Executed Work

Sediment samples were taken with a multiple corer (BARNETT et al., 1984). Individual cores were subsampled using small piston corers with a surface area of 3.5 $cm^2$ (5 replicates for each parameter from one multiple corer cast) down to a maximum depth of 10 cm. The piston corers were sectioned horizontally into one-centimetre layers of the following horizonts: 0-1 cm, 1-2 cm, 2-3 cm, 3-4 cm, 4-5 cm, 6-7 cm, 9-10 cm were analyzed separately.

Sampling at the BIOTRANS-station was performed in an area of 1 $sm^2$ on an Abyssal Plain in 4560 m depth, but due to the unfavorable weather conditions only 3 multiple corer hauls could be retrieved. The list of sampling stations is given in Tab. 7.2.1.

Subsamples for the following analyses were taken. Measurements marked with an asterix were carried out in the ship's laboratory:

- Measurement of the potential respiratory activity (ETS)*;
- Measurement of ATP-activity*;
- Measurement of enzymatic activity (hydrolysis of fluorescein-diacetate, FDA)*;
- Measurement of biomass parameters ;
  a) total proteins;
  b) phospholipids;
  c) total adenylates (ATP, ADP, AMP)*;
  d) DNA;
- Measurement of plant pigments in sediments;
  a) chlorophyll-a and pheopigments (TURNER Fluorometer)*;
  b) chlorophyll-a,b,c, and pheopigments (spectro-fluorometer);

### 5.3.1.2 Sediment Bound Chloroplastic Pigments

Sediment cloroplastic pigments at the BIOTRANS-site were much higher than expected. The values of CPE (sum of chorophyll a and pheopigments) were in the range of values measured in March 1992 (Fig 52). Integrated CPE-mass for the top 5 cm of the sediment was 675 ng/cm² in February 1994 in comparison to 759 ng/cm² in March 1992, indicating the presence of a substantial quantity of detrital matter on the sea floor. The results correspond to the results from the phytoplankton studies (KOEVE et al., this volume) which detected a substantial phytoplankton biomass in surface waters. Phytoplankton biomass was about twice the stock observed in late summer/autumn.

### 5.3.1.3 Potential Hydrolytic Activity

The microbial sediment community comprising bacteria and protozoa represents the dominant group of decomposers at the BIOTRANS-site. About 80-90 % of the total carbon flux is channeled through this group (LOCHTE, 1992; PFANNKUCHE, 1992). Organic material in deep-sea sediments is mainly deposited as particulate organic matter. These macromolecules have to be hydrolysed by extracellular enzymes into mono- or oligomeres before they can be taken up by bacteria. Metazoans correspondingly mobilize intrascellular enzymes. Enzymatic activity can be measured with model substrates, which release fluorescent dyes during hydrolytic clevage. Fluorescein-diacetate (FDA) represents a substrate which is hydrolysed by a variety of enzymes. As the substrate is added in saturation concentration, the measured enzymatic activity corresponds to the hydrolytic potential of the sediment community which is proportional to the amount of enzymes. FDA-measurements can be used as an indicator for benthic activity.

The FDA-hydrolysis rate of 10.6 nmol/cm² (February 1994, Fig. 53) is comparable to the values from March 1992 with 11.5 nmol/cm². The difference is in agreement with the difference in CPE values and indicates a substantial benthic activity as early as February.

### 5.3.1.4 Conclusions

The question of "When is the seasonal minimum (winter condition) in benthic activity and how do these minimum rates compare to the reaction of the benthic community to large sedimentation pulses after a spring phytoplankton bloom ?" is still open and needs further investigations. Previous data showed a noticable reduction in benthic rates in early autumn (end of September/early October 1985; PFANNKUCHE, 1993). The results of the winter investigations of M 27/2 failed to show a distinct minimum but rather point to continuing small sedimentation inputs even in winter. All results from the BIOTRANS-area point to a close pelago-benthic coupling, so that the processes in the plankton community will largely influence the behavior of the benthic organisms. The existence of an autumn phytoplankton bloom is hypothesized but still not verified for the open NE Atlantic. Although there seems to

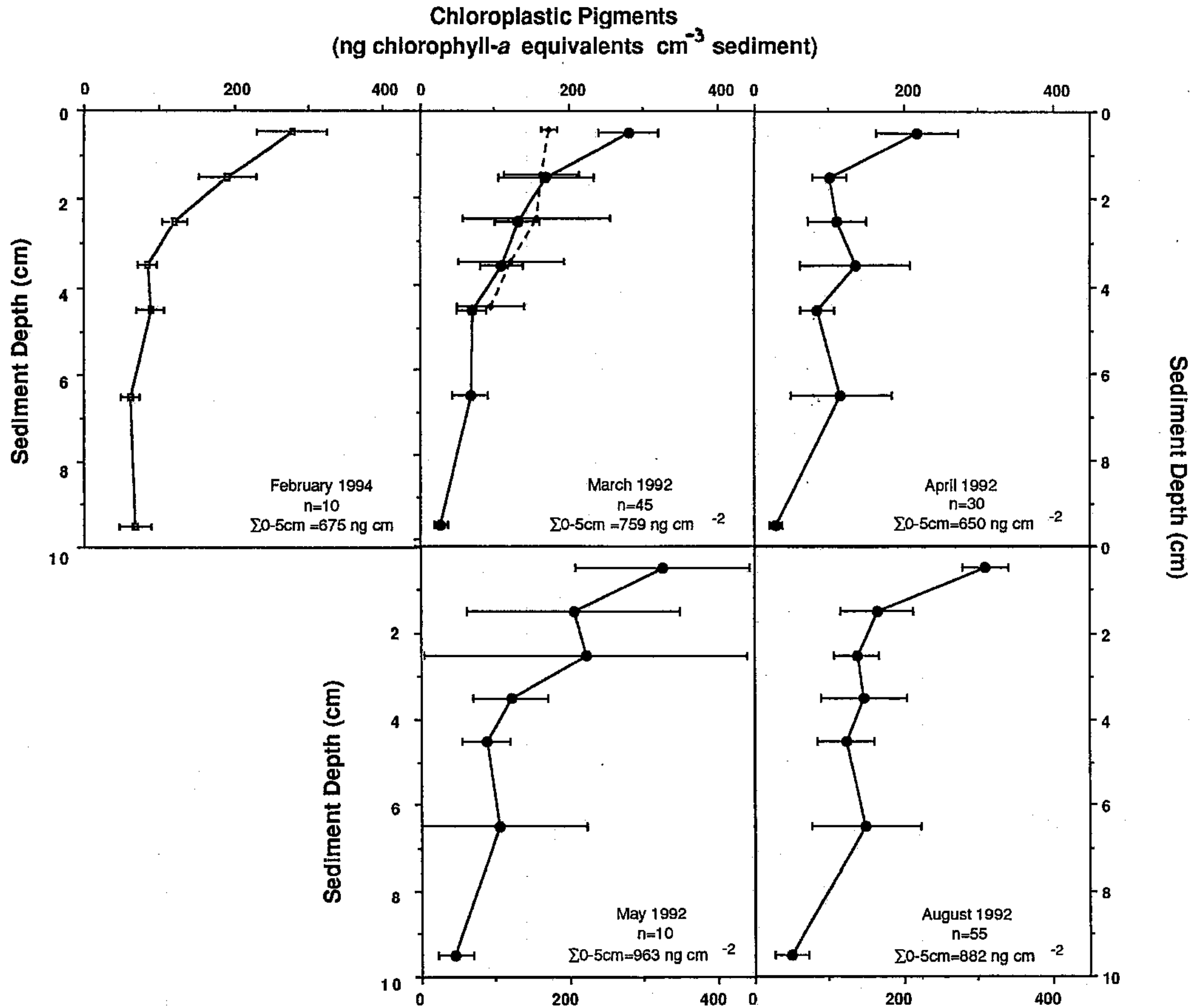



**Fig. 52:** Sediment bound chloroplastic pigments at the BIOTRANS-station.

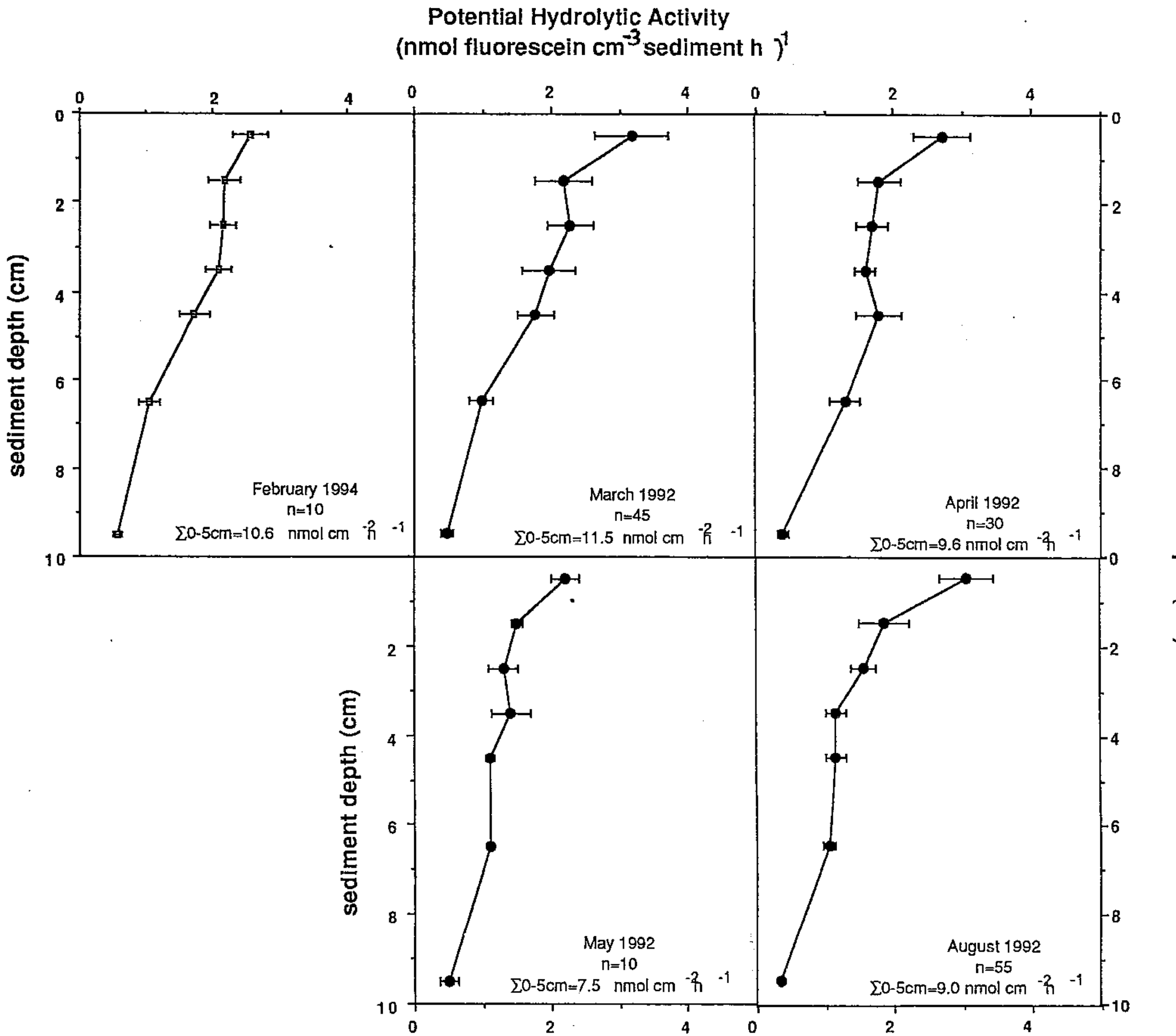



**Fig. 53:** Benthic activity (FDA reduction rates) at the BIOTRANS-station.

be an overall seasonal pattern of benthic activity, as described above, individual sedimentation pulses during any time of the year can stimulate benthic reactions. The limiting factor appears to be the quantity and quality of the sedimenting POM. Whenever material is deposited many deep-sea organisms can mobilize enzymes to cope with the material arriving at the sea bed in a short time span of less than a week. (BOETIUS and LOCHTE, 1994; PFANNKUCHE et al., manuscript.).

### 5.3.2 BIO-C-FLUX: Benthic Microbiology (K. Poremba, K. Jeskulke)

Microbiological investigations involved the determination of abundance and activity of bacteria in the sediment and partly also the whole water column between surface and sea floor. Sediment samples were taken with a multicorer and water samplings were performed using a hydrographic rosette sampler. The samples were immediately transferred into a cooled experimental container avoiding artefacts due to temperature shifts of the samples. The later incubations for activity measurements were performed under temperature conditions according to the in situ-temperature of the sample, and under simulated in situ-pressure conditions using pressure vessels.

The measurements included the fixation of subsamples with formol and later counting of bacterial cells (in the home laboratory), the measurement of extracellular hydrolytic activity using 5 different fluorogenic analog substrates for protease, esterase, lipidase, chitinase, and alpha/beta-glucosidase, and the biological utilisation of radioactive labeled food. The choosen labeled substrates were $^{3}H$-labeled thymidine, $^{3}H$-labeled leucine, and $^{14}C$-labeled cells of Anacystis spec. (cyanobacteria). Moreover, subsamples were freezed for the determination of the DNA-content in the sediment.

During leg M 27/1, several stations of a transect over the continental shelf margin were visited. Results of a former cruise with RV VALDIVA in July 1993 (VA 137) gave evidence that microbial abundance and activity decrease with increasing water depth and increasing depth along the transect, so the questions addressed in leg M 27/1 was, how the situation between microbial and environmental parameters had changed in winter.

Due to bad weater conditions the multicorer could be performed only 2 times at a single station in 2200 m depth. The rate of incorporation of labeled thymidine in that sediment sample was about 20 % lower than expected from our measurements in July, which indicated a limited seasonality of microbial growth intensity. Countings of bacterial abundance and DNA-content must be performed later in the home laboratory.

In contrast to this, measurements of microbial activity in the water column showed much greater seasonality than in the sediment. Hydrolytic enzyme activity was nearly not detecable, and also thymidine incorporation was much lower compared to July. Moreover, while in July 1993 the populations of all water depths showed preference of their natural pressure conditions, in Januar 1994 only the samples < 2000 m water depth showed barophilism and samples from 0 - 2000 m depth were not significantly influenced by different pressure conditions. The determination of cell concentration in that water samples will take place in the home laboratory, too.

Leg M 27/2 was mainly directed in the BIOTRANS-site in 47°N / 19°W. Here, several biological investigation had been performed between 1985 and 1992 giving evidence for a close pelago-benthic coupling between epipelagic processes and those on the sea floor in 4550 m depth. E.g., microbial abundance increased twice between March and August, and the comparision of microbial activity data showed also a strong increase in summer, so seasonality of microbial values at the sea floor are indicated. So far, no investigations had been performed in winter, which should be the baseline of seasonal abundance and activity of microorganisms. Thus, we wanted to fill this gap on leg M 27/2.

Faciliated by relatively good weather conditions at the beginning of the cruise, multicorer samples were taken 2 times and incubations for thymidine incorporation or utilization of labeled cells of cyanobacteria were performed. Unfortunately, most samples were lost during the storm on 2 to 4 Februar, because they were stored in the experimental container, which was completely destroyed. Moreover, the pump and the vessels needed for incubating samples under elevated pressure conditions were also destroyed, so that no further experiments with water samples were possible. Due to this circumstances, the only samples for microbiological investigations are those for the determination of bacterial biomass, which had not been performed yet.

### 5.3.3 BIO-C-FLUX: Biologically Available Labile Proteinaceous Material (S. Scheibe)

These studies were carried out in order to discriminate between that part of sedimentary organic material potentially recyclable by the benthic community, concerning mainly meiofauna and bacteria, and the non-degradable compounds supposedly becoming buried within the sediment and eventually ending up as the geological record. In particular it was planned to focus on the protein pool. The difference between chemically extractable total proteins and the remaining proteins after experiments simulating a biological digestion by enzymes (proteases) should lead to a rough estimation of both recyclable and rather conservative proteinaceous material. In order to find out if there are any correlations between these results and the present conditions of the meiofaunal and bacterial benthos additional determinations were planned concerning sedimentary organic input, biomass, activity and potential respiration.

Since seasonal variations do occur in the BIOTRANS-area these investigations were supposed to deliver base line data of a situation without a recent organic input. Therefore it was of particular interest if the amount of non-degradable proteinaceous material would vary seasonally with probably lower values in the winter. If so this would suggest that the proteinaceous material considered to be rather conservative within the summer would not be buried in the end but might be available for organisms during the winter when a lack of any noticeable organic input is very likely so that the only food resource could be exactly this less labile sedimentary material.

Samples were obtained out of a single multiple corer (MC 470) by slicing five sediment cores into five 1 cm thick layers down to 5 cm depth with an additional deeper layer from 9 - 10 cm. The five corresponding slices of each sediment layer were combined and mixed to form a homogenized sediment equivalent to an area of approximately 100 $cm^2$. Five to six replicates per analysis were taken out of each of the six 1 cm homogenates and shock-frozen (-80°C) immediately. The subsamples for the following parameters were later stored at -20°C and either analyzed on board (o.b.) or prepared for frozen transport and for later analyses at the home laboratories (h.l.):

- input of primary organic matter or its remains as a potential food resource by measurement of chlorophyll-a and pheopigment as chloroplastic pigment equivalents (o.b.),
- active biomass by determining adenylates (ATP, ADP, AMP) (h.l.),
- potential respiratory activity by measuring electron transport system activity (ETSA) (o.b.),
- total biomass as protein content expressed as $\gamma$-globuline equivalents (h.l.),
- labile proteinaceous material that is potenially available to organisms as an extracellularly digestable part of total proteins as well as the conservative part of proteinaceous material both expressed as $\gamma$-globuline equivalents (h.l.).

The protein analyses are not finished yet, but preliminary results for chlorophyll-a, adenylates and potential respiratory activity indicate that organic input and benthic activities are indeed low, though not on the lowest level ever detected in this area, which was not expected. Therefore the results could lead to the preliminary assumption that either the winter data is not lower than that in early spring, which would mean that the early spring data could be regarded as base line data, or that the winter data varies between the years as known for the spring and summer data. This would mean that the winter data of this year could be higher than the spring and summer values of another year (as seems to be the case for the chlorophyll-a results of 1992). The remaining analyses of the proteins will hopefully give some more elucidation.

In comparison with data from the highly oligotrophic Eastern Mediterranean Sea (M 25/1, May 1993, 1900-3000 m depth), activities in the winterly BIOTRANS-area are considerably higher. This expected difference indicates that even in winter the northern Atlantic cannot be regarded as highly oligrotrophic.

As all these results show it is nessessary to investigate the deep-sea floor continously during the whole year but, as the obtainment of only one successful deployment (4 multiple corers during the whole leg) indicates, winter data is difficult to collect due to very tough weather conditions.

### 5.3.4 JGOFS: Plant Nutrients and Phytoplankton Stocks during Winter in the NE-Atlantic (W. Koeve, C. Reineke, M. Molis, M. Schartau, J. Waniek)

Surface concentrations of nutrients in the NE Atlantic during January/February 1994 showed a considerable range. Nitrate and silicate concentrations varied between 4.1 and 9 µmol and 1.5 and 3.3 µmol, respectively. Lowest concentrations usually where found near the coast and in more southern parts of the investigation area, while higher concentrations where observed in open ocean waters towards the north (Fig 54). Super imposed on these general trends were mesoscale variations with a smaller amplitude (about 1 µmol and 0.5 µmol for nitrate and silicate, respectively, Fig. 55). Vertical profiles of nutrients and oxygen concentration where usually almost homogeneous within the upper about 300 m (see Fig. 56a, b for examples). On some of the stations, characterized by a shallow actual mixed layer depth ($\Delta T$=0.02°C criterion, see chapter 5.1.2), however, slightly smaller near surface concentrations have been observed (eg. stat. 31, Fig. 57). Values of oxygen saturation within the upper 300 m usually were found to be slightly below 100 %.

Surface concentrations of chlorophyll-a in the investigation area were significantly higher than expected. During surface sampling chlorophyll-a concentrations between 0.1 and 0.8 mg $m^{-3}$ have been observed (Fig. 58). While the highest values were found in waters close to the Spanish coast, concentrations between 0.3 and 0.5 mg $m^{-3}$ were obvious in open ocean waters sampled during the transit from La Coruna to the BIOTRANS-site. Within the BIOTRANS-area typical surface concentrations close to 0.3 mg $m^{-3}$ were usually observed during transect I (stations 25-35), with a few exceptions with higher values up to 0.6 mg $m^{-3}$. During transect II (stations 39-44), being carried out to re-occupied the second half of transect I after a short storm event, surface concentrations where slightly lower (usually between 0.2 and 0.3 mg $m^{-3}$).

Shapes of vertical profiles, however, were highly variable (Fig. 59). Stronger vertical differentiation, as observed during transect I, was replaced by very similar concentrations within the upper. 300 m during transect II. Vertical structures like those from stat. 34 (Fig. 59c) appear to resemble earlier stages of different mixed layer depths. There is, however no simple relationship between either surface chlorophyll-a concentrations or integrated chlorophyll-a standing stock (eg. upper 100 m) and hydrographical properties like the depth of the actual mixed layer ($\Delta T$=0.02°C, see chapter 5.1.2).

Due to high concentrations below the euphotic zone (approx. upper 100 - 150 m), water column integrated chlorophyll-a stock (upper 300) was high (45 to 70 mg $m^{-2}$, mean 62 mg $m^{-2}$). This is about double the stock observe during late summer/autumn 1989 (about 30 mg $m^{-2}$; calculated from data reported in VELDHUIS et al., 1993). There are no vertical profiles from the period after the big storm (3-5.02.94) that forced METEOR to leave the BIOTRANS-area. Surface sampling, however, was continued as soon as possible. First stations occupied somewhat to the west of the BIOTRANS-site (south of 47°37.95 N, along 21°45 W) did show surface concentrations of about 1.4 mg $m^{-3}$, being significantly less than almost ever before during the cruise (Fig. 58).

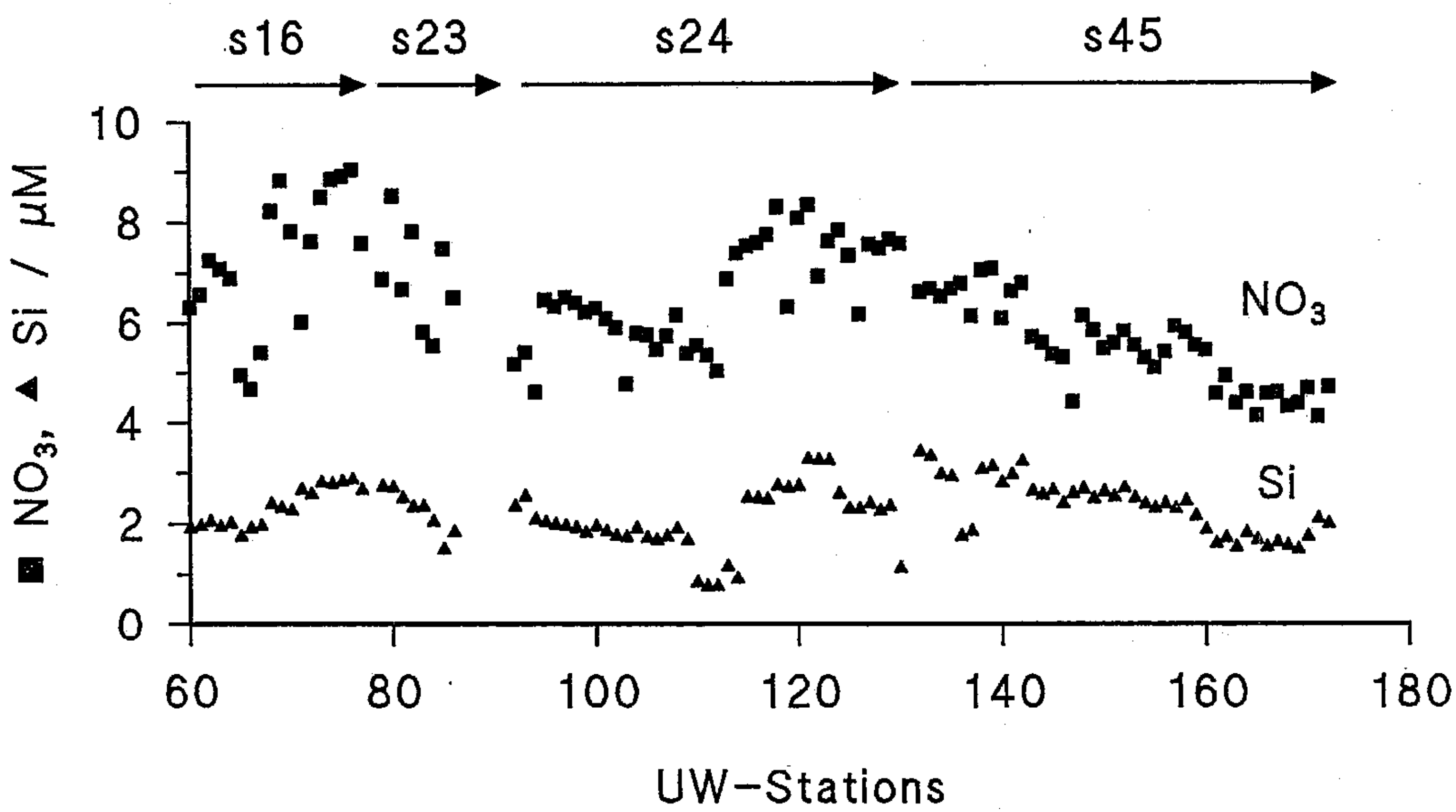



**Fig. 54:** Surface near concentrations of nitrate (squares) and silicate (triangles) in the NE Atlantic during January/February 1994. For locations of stations see Fig. 3a and Tab. 7.2.4.

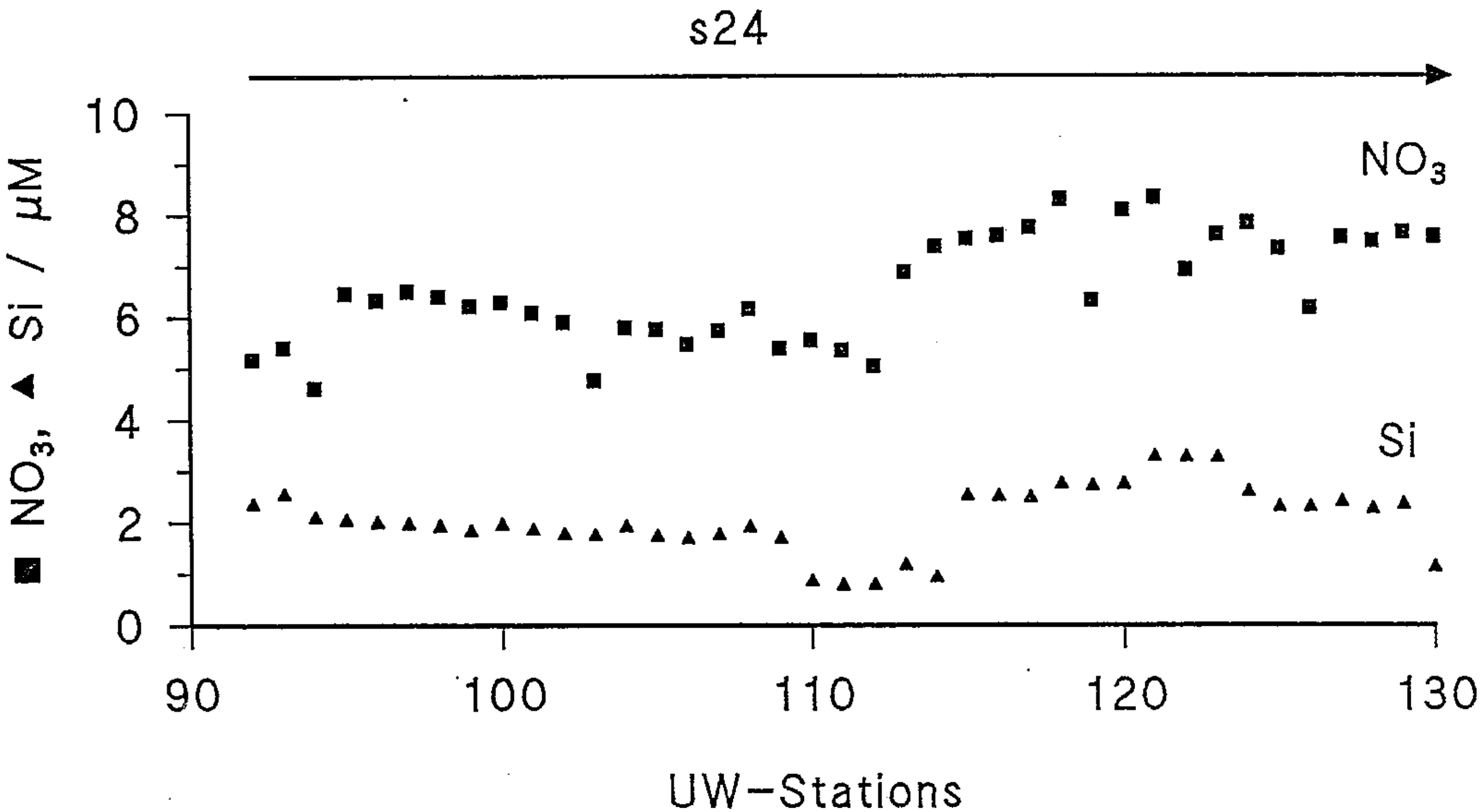



**Fig. 55:** Surface near concentrations of nitrate (squares) and silicate (triangles) during cruising from La Coruna to the BIOTRANS-site. For locations of stations see Tab. 7.2.4.

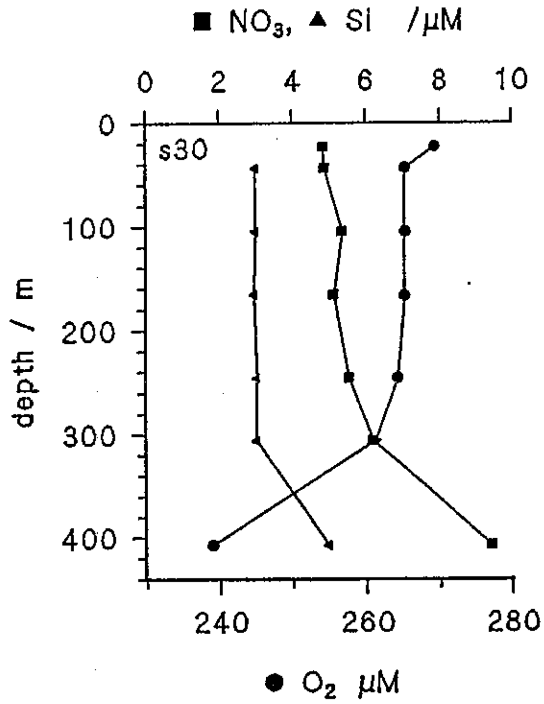



**Fig. 56a:** Vertical profiles of nitrate (squares), silicate (triangles) and oxygen (circles) concentrations at station 30 in the BIOTRANS area. For location of stations see Fig. 3a in chapter 3.2 and Tab. 7.2.3.

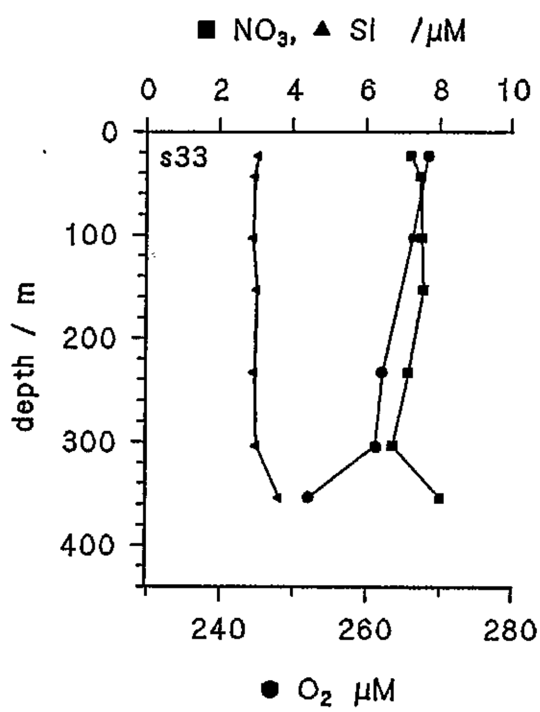



**Fig. 56b:** Vertical profiles of nitrate (squares), silicate (triangles) and oxygen (circles) concentrations at station 33 in the BIOTRANS area. For location of stations see Fig. 3a in chapter 3.2 and Tab. 7.2.3.

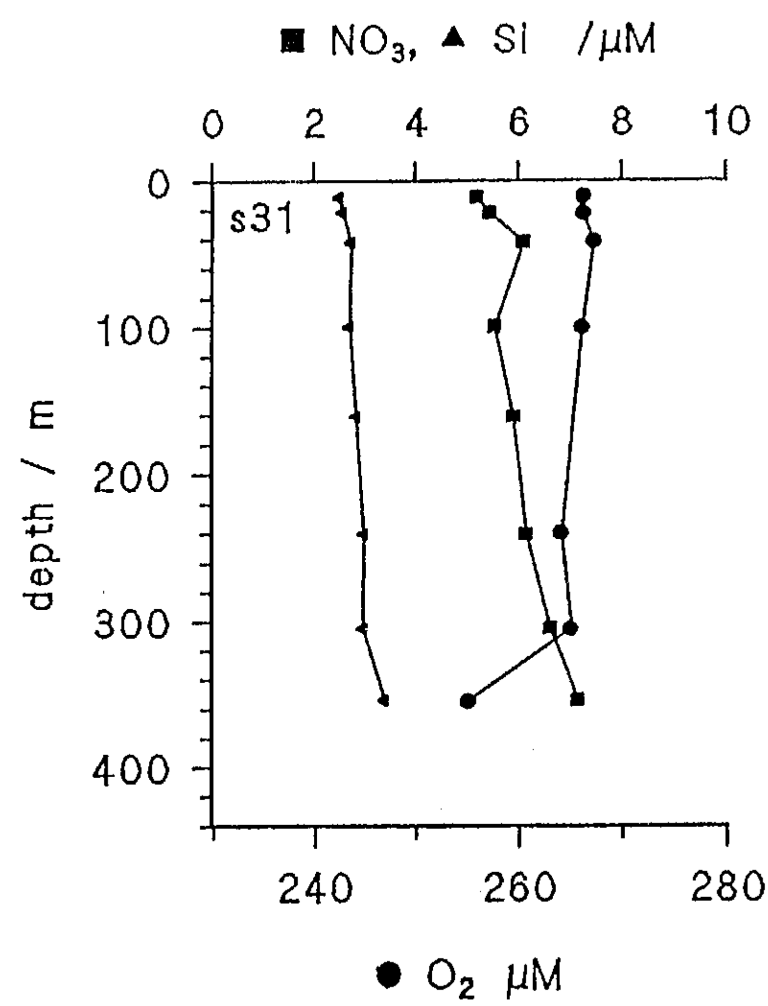



**Fig. 57:** Vertical profiles of nitrate (squares), silicate (triangles) and oxygen (circles) concentrations at station 31 in the BIOTRANS-area. Note the lower concentrations of nitrate and silicate in the upper 40 meters.

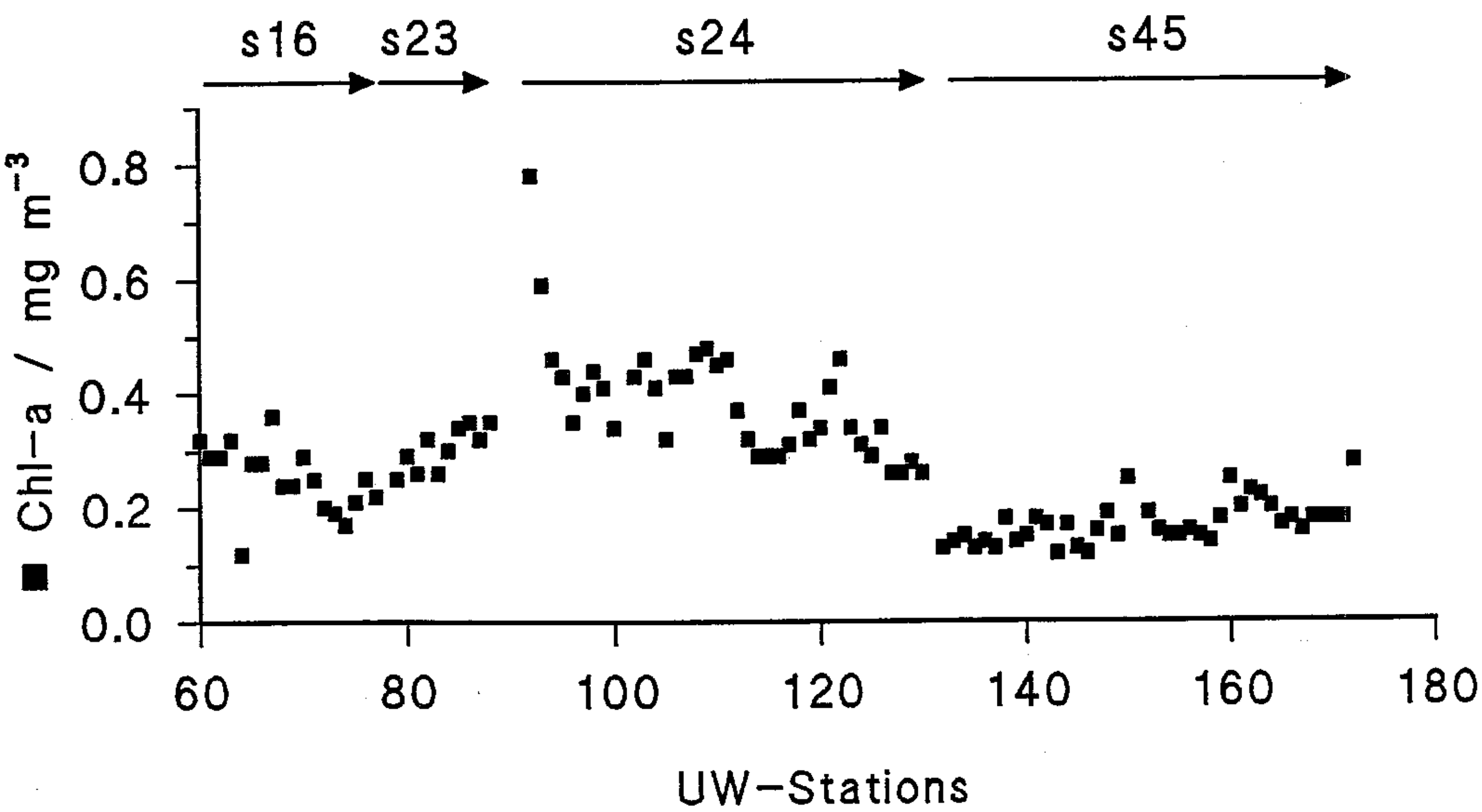



**Fig. 58:** Surface concentrations of chlorophyll-a in the NE Atlantic during January/February 1994. For locations of stations see Fig. 3a and Tab. 7.2.4.

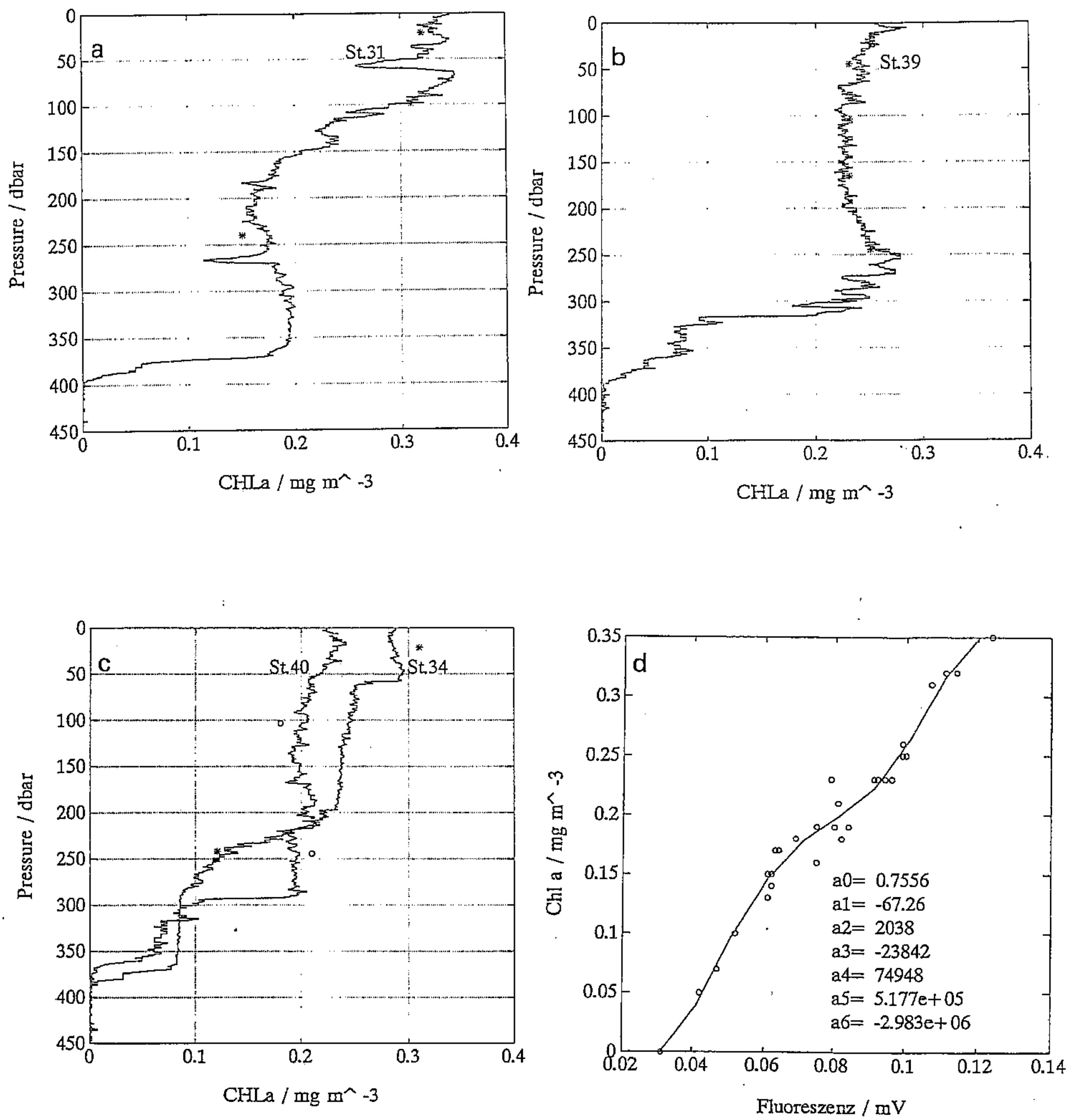



**Fig. 59:** Vertical distribution of chlorophyll-a in the BIOTRANS area. Continuous profiles where measured with an in situ fluorometer. The fluorescence signal of the in situ instrument was calibrated with chlorophyll-a concentrations derived from measurements of distinct water samples.

a-c: Calibrated Continuous profiles (lines) and concentrations of distinct water samples (symbols) plotted for four typical stations.

d: plot of the polynomial regression.

Assuming that the mean pre-storm chlorophyll-a concentration from the BIOTRANS-site (0.21 mg $m^{-3}$, upper 300 m) was valid also in this area, a maximum mixed layer depth of 450 m can be inferred from the chlorophyll-a observations. This is in agreement with similarly rough calculations based on the storm induced change in surface near temperature which suggested a post storm mixed layer depth of about 420 m (see chapter 5.1.2).

What is the winter about in the epipelagic zone of the NEA? The general belief of oceanographers and biogeochemists on typical properties of the winterly NE Atlantic and the zero hypothesis for this cruise was as follows: Due to permanent cooling and frequent storms the mixed layer is deep, giving rise for both high nutrient concentrations and worse growth conditions for phytoplankton (sensu the critical depth concept of SVERDRUP, 1953). Therefore we expected phytoplankton populations to be very small and at the detection limit (< 0.1 mg chlorophyll-a $m^{-3}$, eg. HONJO et al., 1989). Published estimates of winter nitrate concentrations for the BIOTRANS-site suggest rather high concentrations between 11 and 13 µmol (GLOWER and BREWER, 1988; GARSIDE and GARSIDE, 1993). Particularly these high pre-spring nutrient concentrations have been a problem for interpretation of observations of spring bloom dynamics at the BIOTRANS-site (see fe. the review on the results of the JGOFS North Atlantic Bloom Experiment (NABE), LOCHTE et al., 1993). Nitrate concentrations at the beginning of the NABE and during early spring 1992 (METEOR cruise no. 21/2; KOEVE et al., 1993; KOEVE et al., in prep.) where only about half of those concentrations GLOWER and BREWER (1988) had suggested to be the pre-bloom values. Either the mentioned publications of estimates of winter nutrient concentrations strongly overestimated these properties (KOEVE, subm.) or a significant proportion of spring phytoplankton production takes place very early in the year (GARSIDE and GARSIDE, 1993; TOWNSEND et al., 1994).

Observations during January/February 1994 (and March 1992; METEOR cruise no. 21/1; KOEVE et al., 1993; KOEVE et al., in prep) will help to constrain this much further. It is obvious that nutrient concentrations are much lower than previously suggested. Based on our observations and first calculations of advective transport during the strong storm observed during M 27/2 we suggest the winter nitrate and silicate concentrations not to be higher than about 8 and 3 µmol, respectively, these fitting quite well values calculated by KOEVE (subm.) with an independent method. The second striking feature is, that winter time phytoplankton standing stock is three to five times larger than expected, however, does not reach spring bloom values. While no direct estimates of primary production have been carried out, the structure of chlorophyll-a profiles and the fact that integrated chlorophyll-a standing stock during winter is significantly higher compared to autumn stocks suggests that this biomass is based on active in situ-growth during winter, although on a low level.

### 5.3.5 JGOFS: Population Dynamics of Planktic Foraminifera (R. Schiebel)

Multiple opening-closing net samples (MCN samples) were taken to investigate planktic foraminifers at the JGOFS stations complementing the stock of sample series from METEOR cruises no. M 6, M 10, M 11/1, M 12/3, M 17/2, M 21, M 26/1, and 3. These samples offer the possibility to compare spatial and seasonal distribution patterns of planktic foraminifers in the NE Atlantic, especially in the BIOTRANS-area. Additional samples descend from a short transect southeast of the BIOTRANS-area. CTD and fluorometer data collected as well as further plankton- and chemical investigations parallel to MCN sampling allow investigation of oceanographical settings influencing the planktic foraminiferal fauna. Multicorer (MC) sediment samples for comparisons of recent versus fossil coenoses reflect the paleoceanographic conditions and the climatic record of the sampled time interval.

At the sampled stations three vertical hauls (100 µm mesh size) from 100, 700, and 2500 m water depth were carried out. Each haul includes five consecutive water depth intervals sampled (0-20-40-60-80-100 m / 0-100-200-300-500-700 m / 0-700-1000-1500-2000-2500 m) which offers a practicable and detailed record of the planktic foraminiferal fauna. Due to unconvenient weather conditions on the last site in the BIOTRANS-area the deepest haul was not feasible. On the first site because of technical reasons only the shallowest haul was done. Multicorer (MC) samples were taken only in the BIOTRANS-area. The upper five sediment centimeters were sampled in 0.5 and 1 cm intervals. Sediment was stained with methanol/rose bengal solution. Sampling depth was 28 cm below sediment surface.

*First results*

The foraminiferal fauna at all stations sampled was similar in its quality. *Globorotalia scitula* was the most abundant species by far. *Globigerina bulloides* was frequent. Species diversity was low in the upper 700 m of the water column. At first site (47°35 N / 15°23 W, January, 24) *Globigerinella siphonifera* was present in the sampled waterdepth intervall from 0 to 100 m. Within the metazoan fauna copepods were most frequent, quantitatively followed by dinoflagellates (*Ceratium* spp.). Further, radiolaria, diatoms and crustacean naupliids were present mostly in the upper water column (0 to 300 m). From greater water depth pteropods, ostracods and amphipods were caught.

On the next sites the fauna resembled the fauna from the first site. *Neogloboquadrina incompta* and *Turborotalita quinqueloba* were present in some samples in minor quantities. Between 700 and 2500 m at the site 46°30N / 17°25 W (January, 24) the foraminiferal fauna in its quality reflects that of the overlying water column. At the next site (46°51 N / 18°32 W, January, 30) between 700 and 2500 m depth *Globorotalia inflata*, *Orbulina universa* and *Globigerinoides ruber* were present in small amounts.

In the BIOTRANS-area (January, 31) the foraminiferal fauna in the upper 700 m resembles the fauna of the other sites, but more empty tests (dead specimens) were found here.

*Globorotalia scitula* was the most abundant species *G. bulloides* was frequent. *Globorotalia hirsuta* was also present.

Total amount of planktic foraminifera at all sites was very low. Some of the samples only contained a few (less than 20) specimens. Planktic foraminiferal fauna from water depth down to 700 m can be regarded as living fauna as most of the tests are plasma bearing. Tests hauled from deeper waters are empty in large. Chlorophyll bearing phytoplankton was very rare.

As described by HEMLEBEN et al. (1989) in spring time *G. scitula* lives close to the water surface and later in the year prefers greater water depth. Maximal abundance of *G. scitula* in April and August, as shown by OTTENS (1991) for the NE Atlantic at 47°N, fall within 200 to 300 m water depth. In winter times, as shown here, the life habitat of *G. scitula* is expanded on a water depth intervall from 0 to 700 m, but as its maximum in the surface mixed layer.

### 5.3.6 OMEX: Particle Flux at the Ocean Margin

(A. Antia, A. Mintrop, G. Lehnert, B. v. Bodungen)

Determining the fate of shelf-derived biogenic production is one of the central aims of the OMEX project, and to ascertain to what extent this material is recycled in the slope and shelf environments, retained within its depo-centers or exported to the open ocean. Sediment traps and current meter moorings at the continental slope on the Goban Spur have been deployed since July 1993 and will provide information on the fluxes of essential elements in this region. The positions of these moorings and depths of instruments are given in Tab. 7.1.4. On M 27/1 it was planned to retrieve these moorings, and after servicing the instruments and changing the collector cups in the sediment traps, redeploy them at the same positions. Despite adverse weather conditions it was possible, due to the skilled support of the ships crew, to recover and redeploy two of the three (OMEX 2 and OMEX 3) moorings; the third could be recovered and is still in place.

Current meter data from the recovered moorings show the presence of a predominant along-slope current during the period of deployment. Current speeds ranged from 0-15 m/s with some periods of higher current speeds reaching 20-25 m/s. Also evident was the influence of tidal signals at all depths of deployment. During this 6-month period (July 1993 - January 1994) we could not see evidence of off-slope water transport in the depths of deployment, that have previously been reported by PINGREE (1989). Vector addition diagrams of current speed and direction for the mooring OMEX 3 on the Pedragon Escarpment (Fig. 60) show periods of varying current speed, and decreasing residual currents with depth. Also noticeable is the reversal of residual current direction to a southeasterly direction in 3280 m water depth. Data from these current meters will be used to ascertain the validity of particle interception by the sediment traps as well as to provide information as to the source of material collected. A preliminary look at the material in the trap sampling jars shows a slightly increased

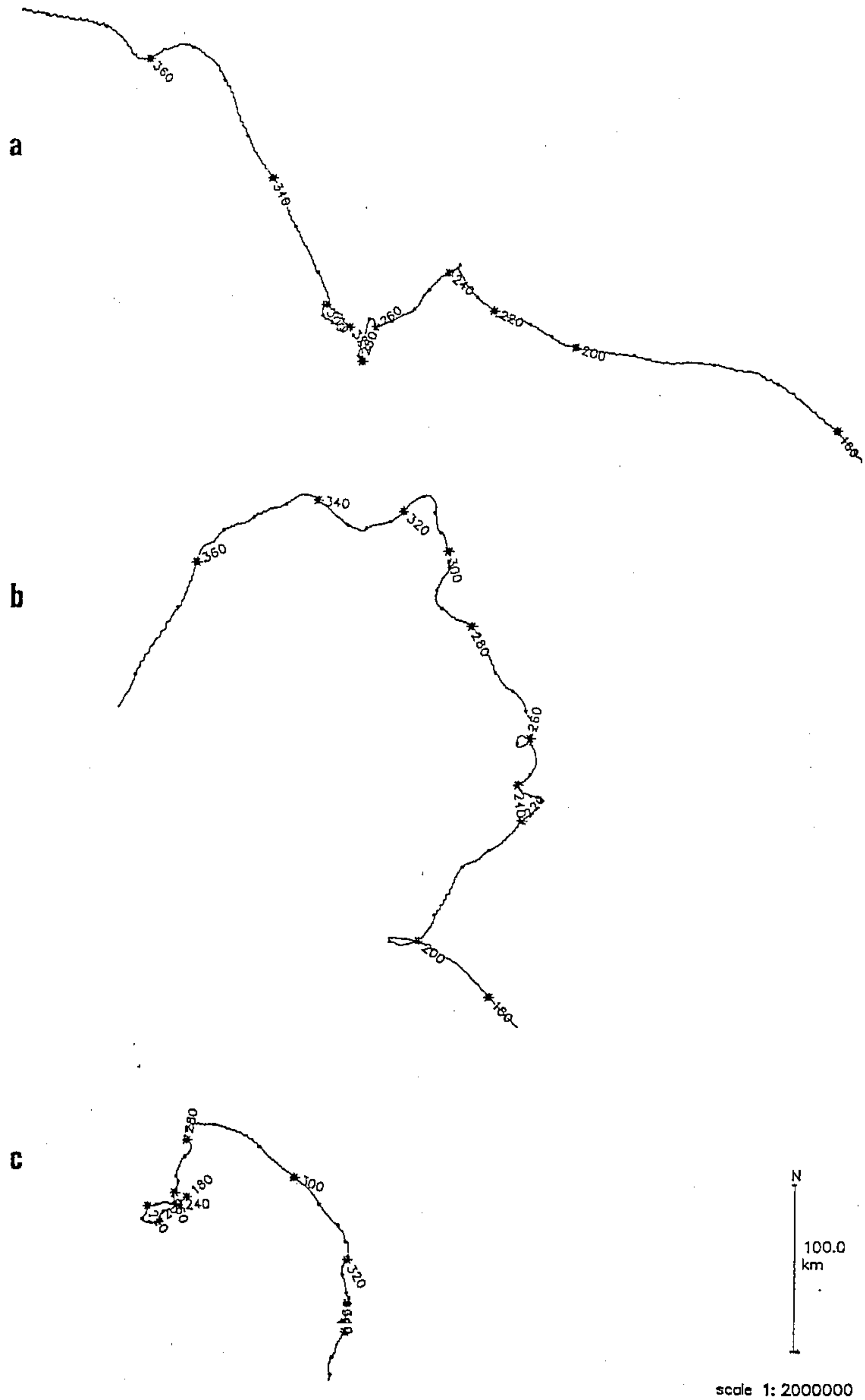



**Fig. 60:** Vector addition diagrams of current speed and direction in (a) 580 m, (b) 1490 m and (c) 3280 m from mooring OMEX 3 on the Pendragon Escarpment. Numbers indicate day number of the year 1993.

sedimentation during late autumn and the presence of numerous large (5 mm Ø) spiny radiolaria and zooplankton faecal pellets. The maximum bulk sedimentation was seen in the jars of the trap at 1490 m on the Pedragon Escarpment, although this impression awaits confirmation by the ongoing analyses. Analysis of trap material includes bulk parameters, microscopy and organic biomarkers to yield information as to its source and composition.

### 5.3.7 OMEX: Carbon Mineralization by the Benthic Community (T. Soltwedel)

Objectives of this OMEX subproject are to develop an understanding of biological, chemical and physical processes that are important in the benthic carbon cycling via the consumption and decomposition of organic matter as well as to assess the distribution and variability of carbon fluxes in the benthal. Benthic biomass is subject to spatial and seasonal variations in response to sedimentation of particulate organic matter. Input of phytodetritus will be assessed by measurements of sediment-bound chlorophyll-a concentrations, changes in activity and biomass of the benthic infauna by a series of biochemical assays:

- Esterases with fluoresceindiacetat, FDA (activity);
- Adenosintriphosphate, ATP (activity);
- Total adenylates, ATP + ADP + AMP (biomass);
- Desoxyribonucleinacid, DNA (biomass);
- Phospholipids (biomass),
- Particulate proteines (biomass).

Measurements of in situ-oxygen consumption rates were planned using a benthic lander system (new design). Additionally, samples were taken for grain-size analyses and to determine the sediment water content. Our investigations are restricted to the upper 10 cm of the sediments. To avoid a loss of activity, esterase measurements were done immediately after recovery of the bottom gear (multiple corer); adenylate measurements were taken to a certain step when deep-frozen extracts could be stored. Other subsamples for biochemical assays were shock-frozen (-80 %) and stored (-20 %) for later analyses at the home laboratory. Unfortunately, because of the bad weather conditions and technical problems with the ship's winches, only one benthic station on the OMEX Goban Spur transect (2200 m) could be sampled with success. Moreover, the rough sea also prevented the deployment of the benthic lander system for in situ-oxygen measurements, because its safe recovery could not be ensured.

### 5.3.8 OMEX: Pore Water Chemistry and Benthic Denitrification
(W. Balzer, A. Deeken, G. Brunn)

The project was established to contribute towards the understanding of the cycling of nitrogen, carbon and trace metals at continental margins where benthic processes are expected to play a significant role for the chemistry of the whole ocean. Necessary for the understanding of the major controls over release fluxes from boundary sediments is a detailed investigation of early diagenetic processes acting within the sediments. It was therefore planned to conduct extensive work on pore water chemistry and on solid sediment phases at the Goban Spur transect across the Celtic margin.

Due to the bad weather prevailing during the whole cruise and due to problems with the ships deep-sea winch we could only get one sediment sample (M007-94, 2250 m water depth). From this sediment taken by a Multicorer the pore water was squeezed under in situ-temperature conditions (cool room). Nitrate as the pore water constituent providing most information about the diagenetic milieu, rose rapidly from 17 µmol at the surface to 56 µmol at 2 cm sediment depth and decreased continuously thereafter to 22 µmol at 13 cm depth. There was a similar profile of ammonia exhibiting, however, lower concentrations than nitrate. Although the nitrate pore water profile suggests sub-oxic conditions typical for hemipelagic sediments of the North Atlantic ocean there must also be a significant contribution of sulfate reduction to organic matter degradation. The rates of carbon combustion by oxygen and nitrate, respectively, will be assessed in the near future by use of numerical models for steady-state diagenesis of organic matter.

### 5.3.9 **OMEX: Benthic Foramifera** (O. Gross)

Although the weather and technical problems prohibited a sufficient amount of sampling, two multicorer (sta. M007-94/1 and sta. M007-94/2) were deployed successfully and could be sub-sampled for the investigation of benthic foraminifera. Benthic foraminifera are known to be a common member of benthic communities and they especially gain importance with increasing water depth. The main purpose of this study was to evaluate the standing stock of benthic foraminifera along the Goban Spur transect and to collect living foraminifera for culture and experimental studies in the home laboratory. The Rose Bengal staining technique was used for quantitative investigations of the foraminiferal assemblages. One tube of the multicorer was sliced in centimeter layers down to 5 cm sediment depth and stained with Rose Bengal. The remaining sediment layers were sealed unpreserved in plastic bags. The isotopic composition of the foraminiferal tests will be analyzed in order to determine paleo-environmental conditions. Overlaying water was sampled and preserved with $HgCl_2$ to obtain the present isotopic signal.

Living foraminifera were taken from the sediment surfaces of 7 multicorer tubes. The work-up procedure took place in a 4°C coolroom. Sediment surface layers were filled into 100 ml glass bottles and covered with original seawater. The foraminifera in the culture bottles were observed for microhabitat preferences, migration rates and feeding strategies. Preliminary observations on the foraminiferal assemblages show *Trochammina sp.*, *Textularia sp.*, *Uvigerina sp.*, *Cassidulina sp.* and *Cibicidoides sp.* to be abundant. Migration speeds of *Cassidulina sp.* (2.27 µm/min) and *Trochammina sp.* (2.13 µm/min) were much lower than that of *Cibicidoides wuellerstorfi* (6.82 µm/min). The sediment layers were well bioturbated not only by foraminifera, but also by other living protozoa and nematoda. Future experimental investigations will obtain more data on the ecology and bioturbation potential of these benthic foraminifera.

### 5.3.10 **OMEX: Processes in the Benthic Boundary Layer** (L. Thomsen)

The aims of this study were:

- To characterize and to quantify the particulate matter in a spatial gradient very close to the sea floor,
- to see whether similar patterns of particle distributions are to be found at different sites on the continental margin, and
- to study the particle size distribution in the near bottom water.

For sampling a specially equipped Bottom Water Sampler (BWS) was used, which takes samples at 5, 10, 20, and 40 cm height above the sea floor. During deployment transmission and flowmeter data were transmitted online and recorded on board of the ship. Due to the bad weather conditions and malfunctions of the winches, the BWS was only deployed two times. At the station where the system was deployed flow velocity was measured at 30 cm height above the bottom. Velocities measured 3 month before at the same station were in the same order of magnitude (within the confidence limits, Fig. 61). Although the flow measurements were just spot measurements of 10 to 15 min each, there seems to be a correlation between flow velocity and sediment accumulation rates.

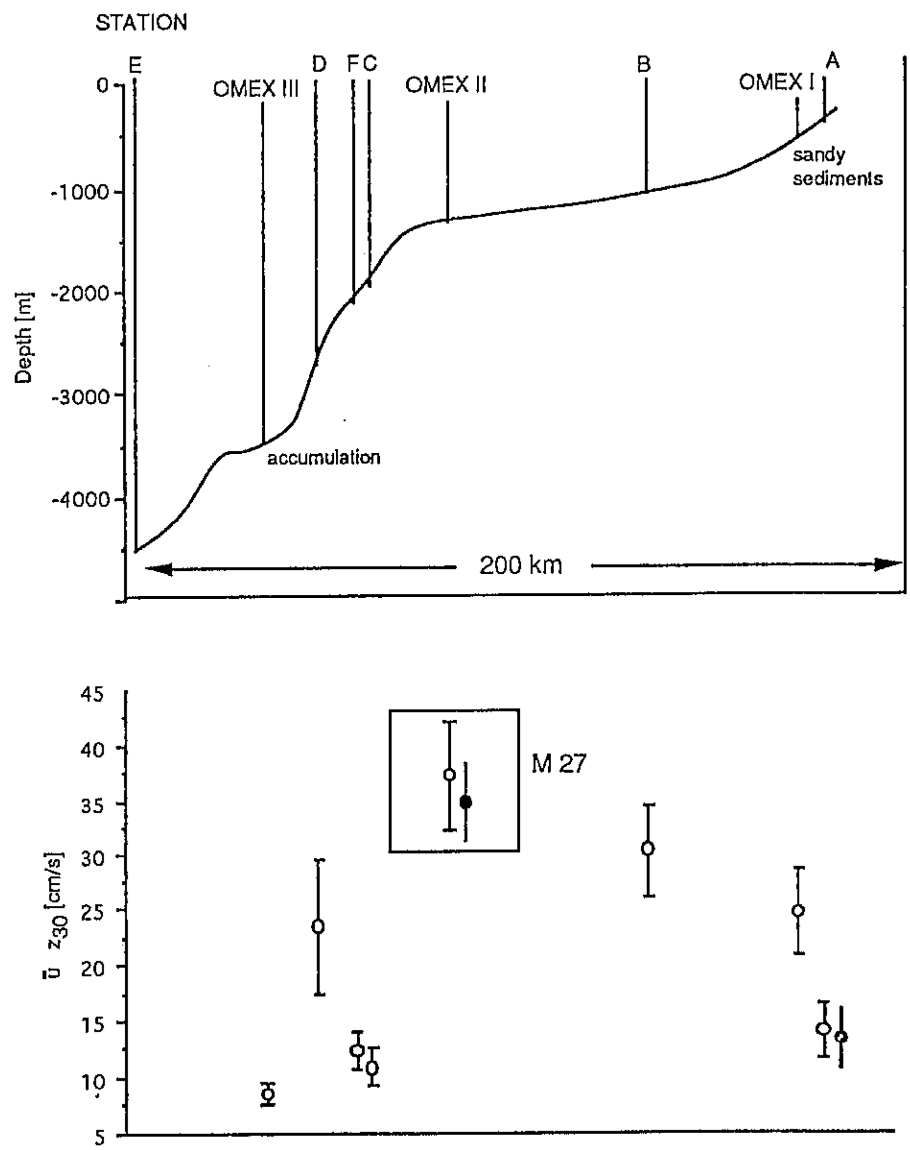



**Fig. 61:** Diagrammatic representation of the OMEX transect (upper panel) and measured flow velocities at OMEX-stations A-F (see Fig. 40) and the two moorings (OMEX II and OMEX III).

# 6 Ship's Meteorological Station (Chr. Knaak)

The weather situation during the first two sections and the beginning of the third section of M 27 was characterized by an severe cyclonic activity over the North Atlantic Ocean which disturbed essentially the scientific research activities.

## 6.1 Weather and Meteorological Conditions during Leg M 27/1

The isobaric pattern over the North Atlantic Ocean was governed by an extensive central low (ca. 960 hPa) south from Iceland almost during the whole first section (29.12.93 - 17.01.94, Hamburg - La Coruna). This caused a strong westerly flow in our reseach area (48°N / 13°W), in which secondary lows were guided continuously over the Atlantic. As a result medium wind forces of more than 6 Bft (up to 10 Bft) were observed during 3/4 of the time. Corresponding wave heights up to 7 m occurred.

## 6.2 Weather and Meteorological Conditions during Leg M 27/2

The report concernig the second leg confines to the description of the most remarkable meteorological event which took place on February 2, in the Biotrans-area near 47°N / 20°W causing severe damages.

This report confines to the description of the most remarkable meteorological event which took place on February 2, in the BIOTRANS-area near 47°N / 20°W causing severe damages:

At 00:00 UTC the waving cold front of an extensive low near Iceland was zonally directed at about 45°N. At this boundary of air masses a "family" of cyclones moved from west to east - steered by a very strong upper air motion in the 500 hPa level (about 5500 m height). The first of these cyclones did not deepen because there was no cold air available in the rear side. But the second member of the family developed to an extremely strong low with hurricane force winds. In this case several cyclogenetic features coincidated:

- A strong, slightly divergent upper air flow.
- A considerable amount of polar air masses from northwest.
- Together with this cold air in the rear side, subtropic air in the south, and moderate cold air northeast of the low formed a "Three Airmasses Situation", which is known for strong cyclonic developments.

As the result our barographic registration showed the enormous falling pressure tendency of almost 20 hPa/3h at 16 UTC. The wind augmented from SE Bft 7 at 14 UTC up to SW 10 at 16 UTC. It was veering to NW and increased rapidly up to Bft 12. Precipitation changed from rain to heavy showers, occasionally with soft hail. At 19 UTC the highest medium force was reached: 89 knots. Gusts up to 128 knots were observed. Hurricane windforce lasted several hours without interruption until midnight. During the following day (February 3rd) windforces of Bft 10 and 11 predominated almost continually. The medium height of the windsea was about 10 m, some singular waves were considerably higher.

The cyclone reached its climax with 950 hPa on February 3rd at 12 UTC not far from the southeast coast of Ireland.

The strong cold air advection in the rear side of the cylone caused a remarkable change of the air stream pattern in of the complete troposphere. For instance the almost zonal flow in the pressure level of 500 hPa changed to an intensive airstream from Northwest. A striking upper level trough developed with its axis over western Europe. Within 48 hours time the radio soundings of the weather station La Coruna registred a decline of temperature from minus 16 to minus 35°C (500 hPa level).

During the following days the cyclone moved to northeast, decreasing.

## 6.3 Weather and Meteorological Conditions during Leg M 27/3

At the beginning of the third leg a large central low at 60°N / 30°W dominated the northern Atlantic. A second low moved from the Newfoundland to soputheast deeping rapidly. Its coldfront passed METEOR during the second day or the cruise at 31°N / 30°W with gale of Bft 8 and gusts up to Bft 11 from west to northwest. The wave height reached 6 m. This was the last storm during M 27.

After crossing the horse latitudes the trade wind blew from northeast with 4 - 5 Bft, and occasionally 5 - 6. The wave height was about 2 m.

Not considering some strong showers near the ITCZ, the scientific work was not longer affected by meterorological events.

# 7 Lists

## 7.1 Leg M 27/1

### 7.1.1 List of Stations

| Station No. | Date 1994 | Time (UTC) | Device | Latitude | Longitude | Water-depth (m) | Remarks |
|---|---|---|---|---|---|---|---|
| 001-94/1 | 01/03 | 18.00 | CTD/Ro | 49°42.2 N | 09°40.0 W | 155 | |
| 001-94/2 | | 18.40 | COS | 49°42.1 N | 09°40.3 W | 155 | |
| 001-94/3 | | 19.05 | GoFlo | 49°42.2 N | 09°40.3 W | 155 | |
| 001-94/4 | | 20.05 | CTD/Ro | 49°42.4 N | 09°39.8 W | 155 | Profile 1 |
| 002-94/1 | 01/04 | 07.20 | CTD/Ro | 49°28.4 N | 11°12.1 W | 232 | Profile 2 |
| 002-94/2 | | 08.05 | COS | 49°28.4 N | 11°12.0 W | 231 | |
| 002-94/3 | | 08.35 | GoFlo | 49°28.4 N | 11°11.9 W | 232 | |
| 003-94/1 | | 14.50 | CTD/Ro | 49°24.4 N | 11°30.8 W | 650 | Profile 3 |
| 003-94/2 | | 16.05 | COS | 49°24.4 N | 11°31.1 W | 655 | |
| 004-94/1 | 01/05 | 14.05 | CTD/Ro | 49°10.9 N | 12°48.2 W | 1434 | Profile 4 |
| 004-94/2 | | 15.45 | SFV | 49°11.2 N | 12°47.0 W | 1445 | OMEX 2 recovery |
| 004-94/3 | | 17.45 | CTD/Ro | 49°09.9 N | 12°47.3 W | 1428 | Profile 5 |
| 004-94/4 | | 19.25 | GoFlo | 49°09.6 N | 12°47.6 W | 1451 | |
| 004-94/5 | | 20.40 | COS | 49°09.6 N | 12°47.8 W | 1455 | |
| 004-94/6 | | 22.15 | ISP | 49°09.5 N | 12°48.7 W | 1479 | |
| 005-94/1 | 01/06 | 08.36 | MC | 49°11.2 N | 12°49.4 W | 1460 | not successful |
| 005-94/2 | | 09.27 | MC | 49°11.2 N | 12°49.1 W | 1450 | not successful |
| 005-94/3 | | 10.15 | MC | 49°11.1 N | 12°49.1 W | 1455 | not successful |
| 005-94/4 | | 12.27 | GKG | 49°11.0 N | 12°49.1 W | 1450 | not successful |
| 005-94/5 | | 13.16 | BWS | 49°11.1 N | 12°49.2 W | 1450 | low conduction |
| 006-94/1 | | 16.45 | GKG | 49°05.0 N | 13°24.4 W | 3630 | problems with wire |
| 006-94/1 | 01/07 | 07.45 | CTD/Ro | 49°04.6 N | 13°28.4 W | 3633 | Profile 6 |

| Station No. | Date 1994 | Time (UTC) | Device | Latitude | Longitude | Water-depth (m) | Remarks |
|---|---|---|---|---|---|---|---|
| 006-94/2 | | 10.00 | GoFlo | 49°04.6 N | 13°28.7 W | 3627 | |
| 006-94/3 | | 12.10 | SFV | 49°04.7 N | 13°26.1 W | 3650 | OMEX 3 recovery |
| 006-94/4 | | 14.55 | COS | 49°03.4 N | 13°25.2 W | 3650 | |
| 006-94/5 | | 16.45 | ISP | 49°03.3 N | 13°25.4 W | 3624 | |
| 006-94/6 | | 17.55 | COS | 49°03.3 N | 13°25.5 W | 3624 | |
| 006-94/7 | | 18.30 | BWS | 49°03.1 N | 13°25.6 W | 3623 | |
| 006-94/8 | | 20.20 | GoFlo | 49°03.4 N | 13°25.5 W | 3642 | |
| 006-94/9 | | 22.20 | CTD/Ro | 49°03.6 N | 13°24.3 W | 3632 | Profile 7 |
| 006-94/10 | 01/08 | 01.00 | ISP | 49°03.3 N | 13°23.4 W | 3643 | |
| 006-94/11 | | 05.15 | CTD/Ro | 49°04.8 N | 13°25.4 W | 3643 | Profile 8 |
| 006-94/12 | | 08.00 | CTD/Ro | 49°04.8 N | 13°26.0 W | 3637 | Profile 9 |
| 006-94/13 | | 13.50 | SFV | 49°05.5 N | 13°23.4 W | 3662 | OMEX 3 BT deployed |
| | | 14.26 | SFV | 49°05.5 N | 13°24.6 W | 3673 | OMEX 3 HB submerged |
| 006-94/14 | | 15.40 | COS | 49°05.1 N | 13°25.7 W | 3641 | |
| 006-94/15 | | 16.05 | MC | 49°04.9 N | 13°25.7 W | 3641 | not successful |
| 007-94/1 | | 20.08 | MC | 49°09.0 N | 13°05.2 W | 2256 | sediment obtained |
| 007-94/2 | | 21.32 | MC | 49°09.1 N | 13°05.1 W | 2249 | sediment obtained |
| 007-94/3 | | 23.18 | GKG | 49°09.1 N | 13°04.9 W | 2227 | not successful |
| 008-94/1 | 01/09 | 20.20 | ISP | 49°28.3 N | 11°12.0 W | 233 | |
| 008-94/2 | | 21.45 | GoFlo | 49°27.8 N | 11°12.0 W | 223 | |
| 009-94/1 | 01/10. | 01.25 | ISP | 49°25.0 N | 11°30.3 W | 630 | |
| 009-94/2 | | 04.50 | ISP | 49°25.1 N | 11°29.9 W | 630 | |
| 009-94/3 | | 08.40 | BWS | 49°23.9 N | 11°30.9 W | 646 | |
| 009-94/4 | | 11.30 | SFV | 49°24.7 N | 11°31.9 W | 670 | OMEX 1 recovery failed |
| 009-94/5 | | 13.55 | CTD/Ro | 49°24.9 N | 11°33.9 W | 725 | Profile 10 |
| 009-94/6 | | 14.35 | COS | 49°24.9 N | 11°33.9 W | 700 | |
| 009-94/7 | | 14.15 | GoFlo | 49°24.9 N | 11°33.9 W | 727 | |
| 010-94/1 | 01/11. | 02.05 | ISP | 49°11.2 N | 12°49.3 W | 1450 | |

| Station No. | Date 1994 | Time (UTC) | Device | Latitude | Longitude | Water-depth (m) | Remarks |
|---|---|---|---|---|---|---|---|
| 011-94/1 | | 12.00 | SFV | 49°11.5 N | 12°47.8 W | | OMEX 2 BT deployed |
| | | 12.22 | SFV | 49°11.3 N | 12°47.7 W | 1396 | OMEX 2 HB submerged |
| 012-94/1 | | 13.57 | MC | 49°12.5 N | 12°53.3 W | 1645 | |
| 012-94/2 | | 15.54 | BWS | 49°12.5 N | 12°53.6 W | 1647 | |
| 012-94/3 | | 17.00 | COS | 49°12.6 N | 12°53.6 W | 1635 | |
| 012-94/4 | | 18.00 | CTD/Ro | 49°12.8 N | 12°55.1 W | 1661 | Profile 11 |
| 012-94/5 | | 20.10 | ISP | 49°13.0 N | 12°55.1 W | 1706 | |
| 013-94/1 | 01/12 | 00.45 | ISP | 49°09.0 N | 13°04.8 W | 2195 | |
| 013-94/2 | | 14.05 | ISP | 49°09.3 N | 13°07.1 W | 2348 | |
| 014-94/1 | 01/14 | 00.05 | ISP | 49°01.7 N | 13°45.3 W | 4474 | |
| 014-94/2 | | 01.15 | CTD/Ro | 49°01.2 N | 13°45.3 W | 4479 | Profile 12 |
| 014-94/3 | | 04.00 | ISP | 49°00.8 N | 13°45.9 W | 4479 | |
| 014-94/4 | | 07.55 | CTD/Ro | 49°00.7 N | 13°46.7 W | 4468 | Profile 13 |
| 014-94/5 | | 09.55 | COS | 49°01.0 N | 13°46.7 W | 4463 | |
| 014-94/6 | | 13.20 | ISP/Goflo | 49°00.7 N | 13°45.4 W | 4470 | |
| 014-94/7 | | 17.50 | CTD/Ro | 48°59.5 N | 13°45.0 W | 4481 | Profile 14 |
| 014-94/8 | | 21.50 | ISP/GoFlo | 48°58.4 N | 13°44.6 W | 4477 | |
| 014-94/9 | 01/15 | 01.00 | CTD/Ro | 48°57.2 N | 13°45.4 W | 4479 | Profile 15 |
| 014-94/10 | | 01.55 | COS | 48°57.0 N | 13°46.0 W | 4479 | |
| 014-94/11 | | 03.25 | ISP/GoFlo | 48°57.0 N | 13°46.9 W | 4477 | |
| 015-94/1 | | 15.10 | CTD/Ro | 48°19.9 N | 11°30.1 W | 3736 | Profile 16 |
| 015-94/2 | | 18.35 | CTD/Ro | 48°20.4 N | 11°31.0 W | 3707 | Profile 17 |

Abbreviations

| | |
|---|---|
| CTD/Ro | Probe for Conductivity/Temperature/Depth plus Rosette with Niskin bottles |
| COS | Gastight GoFlo bottles (5 L) |
| GoFlo | GoFlo bottles (12 L) |
| MC | Multi-Corer |
| GKG | Giant box corer |
| ISP | In-situ-Pump |
| BWS | Bottom water sampler |
| SFV | Mooring with sediment traps |
| BT | Bottom weight of mooring |
| HB | Head buoy of mooring |

## 7.1.2 List of CTD-profiles during M 27/1

| Profile No. | Station No. | Date 1994 | Time UTC (m) | Latitude | Longitude | Water Depth (db) | Profile Depth |
|---|---|---|---|---|---|---|---|
| 01 | 001-94/4 | 01/03/ | 16:30 | 49°42.0 N | 09°40.0 W | 155 | 150 |
| 02 | 002-94/1 | 01/04/ | 06:00 | 49°28.4 N | 11°12.3 W | 230 | 230 |
| 03 | 003-94/1 | 01/04/ | 13:10 | 49°24.4 N | 11°30.9 W | 651 | 650 |
| 04 | 004-94/1 | 01/05/ | 12:20 | 49°11.0 N | 12°48.6 W | 1445 | 1430 |
| 05 | 004-94/3 | 01/05/ | 16:00 | 49°10.2 N | 12°47.5 W | 1411 | 1410 |
| 06 | 006-94/1 | 01/07/ | 05:15 | 49°04.4 N | 13°24.9 W | 3640 | 3640 |
| 07 | 006-94/9 | 01/07/ | 21:00 | 49°03.4 N | 13°24.5 W | 3648 | 1000 |
| 08 | 006-94/11 | 01/08/ | 03:20 | 49°04.9 N | 13°25.8 W | 3648 | 1800 |
| 09 | 006-94/12 | 01/08/ | 06:40 | 49°04.8 N | 13°26.1 W | 3643 | 3667 |
| 10 | 009-94/5 | 01/10/ | 12:10 | 49°24.8 N | 11°34.0 W | 725 | 720 |
| 11 | 012-94/4 | 01/11/ | 16:15 | 49°12.7 N | 12°53.0 W | 1643 | 1642 |
| 12 | 014-94/2 | 01/14/ | 00:00 | 49°01.4 N | 13°45.1 W | 4480 | 1500 |
| 13 | 014-94/4 | 01/14/ | 05:30 | 49°00.6 N | 13°46.4 W | 4468 | 4516 |
| 14 | 014-94/7 | 01/14/ | 15:15 | 49°00.1 N | 13°45.0 W | 4474 | 4497 |
| 15 | 014-94/9 | 01/14/ | 23:15 | 48°57.8 N | 13°44.4 W | 4480 | 1800 |
| 16 | 015-94/1 | 01/15/ | 12:35 | 48°19.8 N | 11°29.8 W | 3725 | 3757 |
| 17 | 015-94/2 | 01/15/ | 16:45 | 48°20.0 N | 11°30.6 W | 3713 | 1500 |

### 7.1.3 Particle Filtration using in situ-pumps

| Station No. | Date 1994 UTC | Time start (l) | Water Depth (m) | Volume pumped (l/h) | Pumping speed | Remarks |
|---|---|---|---|---|---|---|
| 004-94/6 | 01/05/ | 20:55 | 400 | 570 | 570 | |
| | | | 900 | 560 | 560 | |
| 006-94/5 | 01/08/ | 15:27 | 50 | 447 | 335 | |
| | | | 550 | 670 | 503 | |
| 006-94/10 | 01/08/ | 23:00 | 1450 | 730 | 548 | |
| | | | 3250 | 674 | 506 | |
| 008-94/1 | 01/09/ | 19:00 | 50 | 32 | 32 | torn |
| | | | 200 | 759 | 759 | slightly torn |
| 009-94/1 | 01/10/ | 00:00 | 390 | 474 | 356 | |
| | | | 600 | 580 | 435 | |
| 009-94/2 | 01/10/ | 03:42 | 50 | 526 | 395 | |
| | | | 200 | 475 | 356 | |
| 010-94/1 | 01/11/ | 01:06 | 50 | 400 | 400 | |
| | | | 200 | 315 | 315 | |
| 012-94/5 | 01/11/ | 18:38 | 1460 | 511 | 511 | |
| | | | 1680 | 520 | 520 | |
| 013-94/1 | 01/11/ | 23:06 | 1950 | 510 | 510 | wire angle |
| | | | 2250 | 242 | 242 | |
| 013-94/2 | 01/12/ | 12:30 | 1450 | 627 | 627 | wird angle |
| | | | 1650 | 533 | 533 | |
| 014-94/1 | 01/13/ | 23:05 | 50 | 440 | 440 | |
| | | | 200 | 454 | 454 | |
| 014-94/3 | 01/14/ | 02:40 | 1450 | 530 | 530 | |
| | | | 2250 | 597 | 597 | |
| 014-94/6 | 01/14/ | 10:10 | 4452 | 693 | 594 | |
| | | | 4455 | 670 | 574 | |
| 014-94/8 | 01/14/ | 19:20 | 2260 | 658 | 564 | |
| | | | 3700 | 475 | 407 | |
| 014-94/11 | 01/15/ | 02:22 | 770 | 846 | 725 | torn |
| | | | 1000 | 671 | 575 | |

For position of stations see Tab. 7.1.1

### 7.1.4 Positions of Moorings and Instrument Depth

| Mooring | Latitude | Longitude | Water Depth (m) | Depth (m) | Instrument |
|---|---|---|---|---|---|
| OMEX 1 | 49°24.72 N | 11°31.86 W | 670 | 383 | Sed. trap |
| | | | | 407 | RCM, Transm. |
| OMEX 2 | 49°11.20 N | 12°49.18 W | 1445 | 595 | Sed. trap |
| | | | | 618 | RCM |
| | | | | 1052 | Sed. trap |
| | | | | 1076 | RCM, Transm. |
| OMEX 3 | 49°05.0 N | 13°25.8 W | 3650 | 556 | Sed. trap |
| | | | | 580 | RCM |
| | | | | 1465 | Sed. trap |
| | | | | 1490 | RCM, Transm. |
| | | | | 3260 | Sed. trap |
| | | | | 3280 | RCM, Transm. |

## 7.2 Leg M 27/2

### 7.2.1 List of Benthic Sampling Stations

| Gear No. | Station No. | Date | Latitude | Longitude | Depth (m) |
|---|---|---|---|---|---|
| MC-468 | 19 | 01/23/ | 47°32.0 N | 15°20.0 W | 4807 (failed) |
| MC-469 | 36 | 01/31/ | 47°11.1 N | 19°34.0 W | 4569 |
| MC-470 | 36 | 01/31/ | 47°11.1 N | 19°33.9 W | 4568 |
| MC-471 | 36 | 01/31/ | 47°11.0 N | 19°34.0 W | 4568 |
| MC-472 | 36 | 01/31/ | 47°11.1 N | 19°33.9 W | 4569 |
| MC-473 | 45 | 02/02/ | 47°11.1 N | 19°33.8 W | 4568 (failed) |

(MC = multiple corer)

### 7.2.2 XBT-Protokoll (M27/2)

| XBT No. | Date 1994 | Time | Latitude | Longitude | Comments |
|---|---|---|---|---|---|
| 00 | 01/22/ | 16:50 | 44°05.6 N | 09°35.0 W | Test, defective |
| 01 | 01/22/ | 17:00 | 44°05.6 N | 09°35.0 W | Test, defective |
| 02 | 01/22/ | 17:05 | 44°05.6 N | 09°35.0 W | Test, defective |
| 03 | 01/22/ | 17:10 | 44°22.9 N | 10°03.9 W | only 1134 m |
| 04 | 01/24/ | 19:55 | 47°11.5 N | 14°42.8 W | defective |
| 05 | 01/24/ | 19:59 | 47°11.5 N | 14°42.8 W | |
| 06 | 01/24/ | 22:57 | 46°51.9 N | 14°09.4 W | |
| 07 | 01/25/ | 01:53 | 46°33.4 N | 13°38.8 W | |
| 08 | 01/25/ | 04:46 | 46°15.9 N | 13°08.9 W | |
| 09 | 01/25/ | 07:54 | 45°56.6 N | 12°36.5 W | only 1732 m |
| 10 | 01/25/ | 10:55 | 45°37.3 N | 12°04.0 W | |

### 7.2.3 List of CTD-stations (M 27/2)

| Station No. | Profile No. | Date 1994 | Time UTC | Latitude | Longitude | Water Depth (m) | Profile Depth (db) |
|---|---|---|---|---|---|---|---|
| 20 | 18 | 01/24/ | 01:30 | 47°31.08 N | 15°19.63 W | 4813 | 2969 |
| 20 | 19 | 01/24/ | 04:50 | 47°28.08 N | 15°21.04 W | 4797 | 2963 |
| 21 | 20 | 01/24/ | 10:20 | 47°30.06 N | 15°18.95 W | 4803 | 483 |
| 25 | 21 | 01/29/ | 20:45 | 46°30.03 N | 17°25.06 W | 4150 | 2511 |
| 26 | 22 | 01/30/ | 00:55 | 46°34.48 N | 17°38.79 W | 4226 | 506 |
| 27 | 23 | 01/30/ | 03:15 | 46°38.75 N | 17°52.49 W | 4414 | 503 |
| 28 | 24 | 01/30/ | 05:20 | 46°42.82 N | 18°06.13 W | 4464 | 496 |
| 29 | 25 | 01/30/ | 07:35 | 46°47.14 N | 18°19.29 W | 4592 | 505 |
| 30 | 26 | 01/30/ | 09:45 | 46°50.99 N | 18°31.99 W | 4172 | 2516 |
| 31 | 27 | 01/30/ | 17:40 | 46°55.63 N | 18°45.75 W | 5420 | 456 |
| 32 | 28 | 01/30/ | 19:55 | 46°59.27 N | 18°58.30 W | 4600 | 494 |
| 33 | 29 | 01/30/ | 22:30 | 47°03.95 N | 19°12.34 W | 4576 | 487 |
| 34 | 30 | 01/31/ | 00:45 | 47°08.05 N | 19°25.47 W | 4550 | 501 |
| 35 | 31 | 01/31/ | 02:30 | 47°10.70 N | 19°33.00 W | 4567 | 2520 |
| 36 | 32 | 01/31/ | 16:30 | 47°10.74 N | 19°33.72 W | 4568 | 502 |
| 37 | 33 | 02/01/ | 02:05 | 47°15.09 N | 19°46.66 W | 4513 | 502 |
| 38 | 34 | 02/01/ | 04:50 | 47°19.39 N | 20°00.49 W | 4511 | - |
| 39 | 35 | 02/01/ | 11:45 | 47°10.97 N | 19°34.39 W | 4568 | 2527 |
| 40 | 36 | 02/01/ | 15:10 | 47°07.33 N | 19°22.13 W | 4364 | 504 |
| 41 | 37 | 02/01/ | 17:20 | 47°03.08 N | 19°08.92 W | 4510 | 494 |
| 42 | 38 | 02/01/ | 19:40 | 46°58.47 N | 18°55.06 W | 4603 | 524 |
| 43 | 39 | 02/01/ | 21:58 | 46°54.42 N | 18°42.20 W | 4629 | 488 |
| 44 | 40 | 02/02/ | 00:30 | 46°50.70 N | 18°30.84 W | 4200 | 2487 |

### 7.2.4 List of Underway Stations during M 27/2

| List of underway stations during Meteor 27–2 | | | | | | |
|---|---|---|---|---|---|---|
| Stat No. | UW No. | Date 1994 | Time UTC | Latitude | Longitude | Comments |
| 16 | 60 | 22.01 | 11:00 | 43° N 45.26 | 9° W 02.31 | |
| 16 | 61 | 22.01 | 13:00 | 44° N 00.18 | 9° W 25.80 | |
| 16 | 62 | 22.01 | 15:00 | 44° N 14.24 | 9° W 49.64 | |
| 16 | 63 | 22.01 | 17:00 | 44° N 29.02 | 10° W 13.90 | |
| 16 | 64 | 22.01 | 19:00 | 44° N 43.09 | 10° W 37.11 | |
| 16 | 65 | 22.01 | 21:00 | 44° N 57.76 | 11° W 01.40 | |
| 16 | 66 | 22.01 | 23:00 | 45° N 11.98 | 11° W 25.09 | |
| 16 | 67 | 23.01 | 01:00 | 45° N 11.98 | 11° W 25.09 | |
| 16 | 68 | 23.01 | 03:00 | 45° N 26.64 | 11° W 49.55 | |
| 16 | 69 | 23.01 | 05:00 | 45° N 40.66 | 12° W 13.18 | |
| 16 | 70 | 23.01 | 07:00 | 45° N 55.01 | 12° W 37.38 | |
| 16 | 71 | 23.01 | 09:00 | 46° N 21.73 | 13° W 22.74 | |
| 16 | 72 | 23.01 | 11:00 | 46° N 34.86 | 13° W 45.04 | |
| 16 | 73 | 23.01 | 13:00 | 46° N 47.11 | 14° W 06.05 | |
| 16 | 74 | 23.01 | 15:00 | 46° N 58.68 | 14° W 25.85 | |
| 16 | 75 | 23.01 | 17:00 | 47° N 10.88 | 14° W 46.83 | |
| 16 | 76 | 23.01 | 19:00 | 47° N 22.36 | 15° W 06.81 | |
| 16 | 77 | 23.01 | 21:00 | 47° N 29.45 | 15° W 19.02 | |
| 16 | 78 | – | – | – | – | no data |
| 23 | 79 | 24.01 | 19:00 | 47° N 10.69 | 14° W 41.18 | |
| 23 | 80 | 24.01 | 22:00 | 46° N 51.82 | 14° W 09.22 | |
| 23 | 81 | 25.01 | 01:00 | 46° N 32.83 | 13° W 37.85 | |
| 23 | 82 | 25.01 | 04:00 | 46° N 15.38 | 13° W 08.03 | |
| 23 | 83 | 25.01 | 07:00 | 45° N 56.31 | 12° W 36.07 | |
| 23 | 84 | 25.01 | 10:00 | 45° N 37.33 | 12° W 04.07 | |
| 23 | 85 | 25.01 | 13:00 | 45° N 17.50 | 11° W 32.41 | |
| 23 | 86 | 25.01 | 16:00 | 44° N 57.53 | 10° W 59.30 | |
| 23 | 87 | 25.01 | 19:00 | 44° N 38.35 | 10° W 27.82 | |
| 23 | 88 | 25.01 | 22:00 | 44° N 18.62 | 9° W 55.85 | |
| 24 | 92 | 28.01 | 01:00 | 43° N 28.02 | 8° W 37.92 | |
| 24 | 93 | 28.01 | 02:00 | 43° N 32.76 | 8° W 51.56 | |
| 24 | 94 | 28.01 | 03:00 | 43° N 37.50 | 9° W 04.96 | |
| 24 | 95 | 28.01 | 04:00 | 43° N 42.35 | 9° W 18.82 | |
| 24 | 96 | 28.01 | 05:00 | 43° N 46.40 | 9° W 30.60 | |

| List of underway stations during Meteor 27–2 | | | | | | |
|---|---|---|---|---|---|---|
| Stat No. | UW No. | Date 1994 | Time UTC | Latitude | Longitude | Comments |
| 24 | 97 | 28.01 | 06:00 | 43° N 51.55 | 9° W 45.29 | |
| 24 | 98 | 28.01 | 07:00 | 43° N 56.51 | 9° W 59.61 | |
| 24 | 99 | 28.01 | 08:00 | 44° N 00.76 | 10° W 12.06 | |
| 24 | 100 | 28.01 | 09:00 | 44° N 05.29 | 10° W 25.33 | |
| 24 | 101 | 28.01 | 10:00 | 44° N 10.05 | 10° W 38.94 | |
| 24 | 102 | 28.01 | 11:00 | 44° N 14.82 | 10° W 52.61 | |
| 24 | 103 | 28.01 | 12:00 | 44° N 19.46 | 11° W 05.87 | |
| 24 | 104 | 28.01 | 13:00 | 44° N 24.11 | 11° W 19.16 | |
| 24 | 105 | 28.01 | 14:00 | 44° N 28.52 | 11° W 32.11 | |
| 24 | 106 | 28.01 | 15:00 | 44° N 33.31 | 11° W 45.92 | |
| 24 | 107 | 28.01 | 16:00 | 44° N 37.97 | 11° W 59.44 | |
| 24 | 108 | 28.01 | 17:00 | 44° N 42.60 | 12° W 12.90 | |
| 24 | 109 | 28.01 | 18:00 | 44° N 47.32 | 12° W 26.65 | |
| 24 | 110 | 28.01 | 19:00 | 44° N 52.73 | 12° W 40.30 | |
| 24 | 111 | 28.01 | 20:00 | 44° N 57.84 | 12° W 55.00 | |
| 24 | 112 | 28.01 | 21:00 | 45° N 02.52 | 13° W 08.65 | |
| 24 | 113 | 28.01 | 22:00 | 45° N 07.33 | 13° W 22.50 | |
| 24 | 114 | 28.01 | 23:00 | 45° N 12.13 | 13° W 36.39 | |
| 24 | 115 | 29.01 | 00:00 | 45° N 18.19 | 13° W 53.97 | |
| 24 | 116 | 29.01 | 01:00 | 45° N 21.58 | 14° W 03.71 | |
| 24 | 117 | 29.01 | 02:00 | 45° N 26.94 | 14° W 19.25 | |
| 24 | 118 | 29.01 | 03:00 | 45° N 31.93 | 14° W 33.91 | |
| 24 | 119 | 29.01 | 04:00 | 45° N 37.03 | 14° W 48.89 | |
| 24 | 120 | 29.01 | 05:00 | 45° N 42.13 | 15° W 03.80 | |
| 24 | 121 | 29.01 | 06:00 | 45° N 47.30 | 15° W 18.91 | |
| 24 | 122 | 29.01 | 07:00 | 45° N 47.38 | 15° W 19.48 | |
| 24 | 123 | 29.01 | 08:00 | 45° N 56.98 | 15° W 47.51 | |
| 24 | 124 | 29.01 | 09:00 | 46° N 01.82 | 16° W 01.70 | |
| 24 | 125 | 29.01 | 10:00 | 46° N 06.32 | 16° W 14.92 | |
| 24 | 126 | 29.01 | 11:00 | 46° N 10.50 | 16° W 27.89 | |
| 24 | 127 | 29.01 | 12:00 | 46° N 14.92 | 16° W 40.61 | |
| 24 | 128 | 29.01 | 13:00 | 46° N 19.65 | 16° W 53.72 | |
| 24 | 129 | 29.01 | 14:00 | 46° N 23.92 | 17° W 07.26 | |
| 24 | 130 | 29.01 | 15:00 | 46° N 28.81 | 17° W 21.32 | |

| List of underway stations during Meteor 27–2 | | | | | | |
|---|---|---|---|---|---|---|
| Stat No. | UW No. | Date 1994 | Time UTC | Latitude | Longitude | Comments |
| 24 | 131 | – | – | – | – | no data |
| 24 | 131 | – | – | – | – | no data |
| 45 | 132 | 04.02 | 15:00 | 47° N 37.95 | 21° W 44.79 | |
| 45 | 133 | 04.02 | 16:00 | 47° N 26.41 | 21° W 43.57 | |
| 45 | 134 | 04.02 | 17:00 | 47° N 16.81 | 21° W 42.98 | |
| 45 | 135 | 04.02 | 18:00 | 47° N 05.97 | 21° W 42.78 | |
| 45 | 136 | 04.02 | 19:00 | 46° N 54.90 | 21° W 42.98 | |
| 45 | 137 | 04.02 | 20:00 | 46° N 45.00 | 21° W 43.39 | |
| 45 | 138 | 04.02 | 21:00 | 46° N 34.73 | 21° W 44.03 | |
| 45 | 139 | 04.02 | 22:00 | 46° N 24.65 | 21° W 44.81 | |
| 45 | 140 | 04.02 | 23:00 | 46° N 14.46 | 21° W 45.76 | |
| 45 | 141 | 05.02 | 00:00 | 46° N 03.51 | 21° W 45.93 | |
| 45 | 142 | 05.02 | 01:00 | 45° N 52.17 | 21° W 46.26 | |
| 45 | 143 | 05.02 | 02:00 | 45° N 39.81 | 21° W 45.78 | |
| 45 | 144 | 05.02 | 03:00 | 45° N 28.88 | 21° W 46.09 | |
| 45 | 145 | 05.02 | 04:00 | 45° N 16.88 | 21° W 45.73 | |
| 45 | 146 | 05.02 | 05:00 | 45° N 5.40 | 21° W 45.58 | |
| 45 | 147 | 05.02 | 06:00 | 44° N 53.69 | 21° W 45.71 | |
| 45 | 148 | 05.02 | 07:00 | 44° N 41.77 | 21° W 45.92 | |
| 45 | 149 | 05.02 | 08:00 | 44° N 30.39 | 21° W 45.49 | |
| 45 | 150 | 05.02 | 09:00 | 44° N 19.06 | 21° W 45.77 | |
| 45 | 151 | 05.02 | 10:00 | 44° N 07.18 | 21° W 45.65 | |
| 45 | 152 | 05.02 | 11:00 | 43° N 56.26 | 21° W 45.20 | |
| 45 | 153 | 05.02 | 12:00 | 43° N 44.35 | 21° W 44.51 | |
| 45 | 154 | 05.02 | 13:00 | 43° N 34.16 | 21° W 44.19 | |
| 45 | 155 | 05.02 | 14:00 | 43° N 23.02 | 21° W 43.83 | |
| 45 | 156 | 05.02 | 15:00 | 43° N 11.89 | 21° W 43.75 | |
| 45 | 157 | 05.02 | 16:00 | 42° N 59.95 | 21° W 43.49 | |
| 45 | 158 | 05.02 | 17:00 | 42° N 48.76 | 21° W 43.31 | |
| 45 | 159 | 05.02 | 18:00 | 42° N 40.99 | 21° W 34.74 | |
| 45 | 160 | 05.02 | 19:00 | 42° N 36.54 | 21° W 19.72 | |
| 45 | 161 | 05.02 | 20:00 | 42° N 32.19 | 21° W 5.71 | |
| 45 | 162 | 05.02 | 21:00 | 42° N 28.13 | 20° W 52.67 | |
| 45 | 163 | 05.02 | 22:00 | 42° N 24.02 | 20° W 39.72 | |
| 45 | 164 | 05.02 | 23:00 | 42° N 19.58 | 20° W 25.65 | |

| List of underway stations during Meteor 27-2 | | | | | | |
|---|---|---|---|---|---|---|
| Stat No. | UW No. | Date 1994 | Time UTC | Latitude | Longitude | Comments |
| 45 | 165 | 06.02 | 00:00 | 42° N 15.37 | 20° W 12.27 | |
| 45 | 166 | 06.02 | 01:00 | 42° N 11.40 | 19° W 59.03 | |
| 45 | 167 | 06.02 | 02:00 | 42° N 07.28 | 19° W 45.80 | |
| 45 | 168 | 06.02 | 03:00 | 42° N 03.12 | 19° W 32.38 | |
| 45 | 169 | 06.02 | 04:00 | 41° N 59.01 | 19° W 19.20 | |
| 45 | 170 | 06.02 | 05:00 | 41° N 54.77 | 19° W 05.77 | |
| 45 | 171 | 06.02 | 06:00 | 41° N 50.67 | 18° W 52.55 | |
| 45 | 172 | 06.02 | 07:00 | 41° N 46.51 | 18° W 39.47 | |

## 7.3 List M 27/3

### 7.3.1 List of CTD with LADCP and Pegasus Stations

| Meteor M27/3 CTD Stations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Profile | Station | Latitude | Longitude | Depth | Date | UTC | SST | ADCP | Comment |
| 001 | 048 | 18°51.0' N | 37°21.7' W | 5626 | 24.02.1994 | 11:34 | 22.5 | BB | |
| 002 | 051 | 10°50.5' N | 41°56.5' W | 5165 | 26.02.1994 | 17:20 | 25.1 | NB | |
| 003 | 052 | 10°43.5' N | 41°56.5' W | 5152 | 26.02.1994 | 21:54 | 23.6 | BB | |
| 004 | 053 | 10°46.8' N | 41°56.1' W | 5137 | 27.02.1994 | 02:24 | 25.2 | NB | |
| 005 | 054 | 10°11.9' N | 42°17.9' W | 4284 | 27.02.1994 | 09:45 | 25.1 | | |
| 006 | 056 | 09°08.9' N | 43°00.8' W | 4841 | 27.02.1994 | 19:13 | 26.4 | NB | |
| 007 | 057 | 08°57.9' N | 43°11.8' W | 4836 | 28.02.1994 | 00:03 | 26.4 | NB | |
| 008 | 058 | 08°43.1' N | 43°28.0' W | 4819 | 28.02.1994 | 05:22 | 26.7 | NB | |
| 009 | 059 | 08°13.9' N | 43°59.8' W | 4766 | 28.02.1994 | 13:07 | 26.8 | NB | |
| 010 | 060 | 07°44.9' N | 44°00.0' W | 4733 | 28.02.1994 | 19:20 | 26.9 | NB | |
| 011 | 061 | 07°15.0' N | 44°00.0' W | 4669 | 01.03.1994 | 05:40 | 26.9 | NB | upward |
| 012 | 062 | 06°39.1' N | 44°02.2' W | 4628 | 01.03.1994 | 12:04 | 26.8 | NB | |
| 013 | 063 | 06°22.0' N | 44°00.0' W | 4530 | 01.03.1994 | 16:50 | 26.9 | NB | |
| 014 | 064 | 06°04.9' N | 44°00.1' W | 4221 | 01.03.1994 | 21:14 | 26.7 | BB | |
| 015 | 065 | 05°48.0' N | 44°00.1' W | 4132 | 02.03.1994 | 01:45 | 26.8 | BB | |
| 016 | 066 | 05°15.4' N | 44°01.3' W | 3332 | 02.03.1994 | 07:34 | 26.9 | BB | |
| 017 | 067 | 04°42.0' N | 44°00.1' W | 3243 | 02.03.1994 | 12:17 | 26.9 | BB | |
| 018 | 068 | 04°12.4' N | 44°02.3' W | 4185 | 02.03.1994 | 16:44 | 27.1 | BB | |
| 019 | 069 | 03°45.0' N | 43°59.9' W | 4216 | 02.03.1994 | 21:10 | 27.1 | BB | |
| 020 | 070 | 03°17.6' N | 44°00.7' W | 4202 | 03.03.1994 | 01:18 | 27.1 | BB | |
| 021 | 071 | 02°35.0' N | 44°03.0' W | 4172 | 03.03.1994 | 06:59 | 27.0 | BB | |
| 022 | 072 | 01°52.0' N | 44°00.1' W | 4130 | 03.03.1994 | 12:32 | 27.0 | NB | |
| 023 | 073 | 01°32.0' N | 44°00.0' W | 4106 | 03.03.1994 | 17:02 | 27.8 | NB | |
| 024 | 074 | 00°52.3' N | 44°02.3' W | 4024 | 03.03.1994 | 23.25 | 27.9 | NB | |
| 025 | 075 | 01°12.0' N | 43°59.9' W | 4110 | 04.03.1994 | 04:01 | 27.8 | NB | |
| 026 | 078 | 00°36.9' N | 44°09.8' W | 3675 | 04.03.1994 | 18:15 | 28.0 | NB | |
| 027 | 079 | 00°26.8' N | 44°16.3' W | 3378 | 04.03.1994 | 22:02 | 28.0 | NB | |
| 028 | 080 | 00°09.0' N | 44°23.1' W | 1123 | 05.03.1994 | 02:30 | 28.1 | NB | |
| 029 | 081 | 00°02.2' N | 44°23.1' W | 295 | 05.03.1994 | 04:33 | 28.0 | NB | |
| 030 | 082 | 00°16.9' N | 44°20.6' W | 2965 | 05.03.1994 | 06:58 | 28.0 | | Pegasus 01 |

| Meteor M27/3 CTD Stations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Profile | Station | Latitude | Longitude | Depth | Date | UTC | SST | ADCP | Comment |
| 031 | 085 | 02°07.2' S | 40°00.2' W | 1199 | 07.03.1994 | 04:13 | 28.2 | | + |
| 032 | 086 | 02°02.0' S | 39°59.9' W | 2596 | 07.03.1994 | 05:47 | 28.2 | | + |
| 033 | 087 | 01°52.0' S | 40°00.1' W | 3384 | 07.03.1994 | 08:42 | 28.2 | | + |
| 034 | 088 | 01°37.9' S | 40°00.0' W | 3675 | 07.03.1994 | 14:40 | 28.3 | | + |
| 035 | 089 | 01°16.0' S | 40°00.2' W | 3772 | 07.03.1994 | 19:15 | 28.4 | | + |
| 036 | 090 | 00°50.0' S | 39°59.9' W | 3875 | 07.03.1994 | 23:57 | 28.2 | | + |
| 037 | 091 | 00°24.9' S | 39°59.7' W | 3984 | 08.03.1994 | 04:05 | 27.9 | | + |
| 038 | 092 | 00°00.0' N | 39°59.9' W | 3449 | 08.03.1994 | 09:06 | 27.6 | | + |
| 039 | 093 | 00°38.9' N | 39°59.8' W | 4200 | 08.03.1994 | 17:15 | 27.3 | | + |
| 040 | 094 | 00°48.0' N | 40°00.0' W | 4377 | 08.03.1994 | 22:22 | 27.2 | BB | |
| 041 | 095 | 00°37.2' N | 40°00.9' W | 4228 | 09.03.1994 | 03:03 | 27.1 | BB | Pegasus 02 |
| 042 | 096 | 01°04.9' N | 39°59.3' W | 4395 | 09.03.1994 | 09:11 | 27.0 | BB | |
| 043 | 097 | 01°38.2' N | 39°59.9' W | 4425 | 09.03.1994 | 15:28 | 27.1 | BB | |
| 044 | 098 | 02°16.9' N | 40°00.1' W | 4422 | 09.03.1994 | 22:19 | 27.0 | BB | |
| 045 | 099 | 03°01.5' N | 40°30.4' W | 4211 | 10.03.1994 | 06:51 | 27.0 | BB | |
| 046 | 100 | 03°29.1' N | 40°51.0' W | 3962 | 10.03.1994 | 13:05 | 26.9 | BB | |
| 047 | 101 | 03°53.7' N | 41°03.8' W | 3897 | 10.03.1994 | 18:36 | 26.9 | BB | data gaps |
| 048 | 102 | 04°22.0' N | 40°48.0' W | 4513 | 11.03.1994 | 00:40 | 26.6 | BB | data gaps |
| 049 | 103 | 04°28.1' N | 40°38.0' W | 4607 | 11.03.1994 | 05:07 | 24.5 | BB | data gaps |
| 050 | 104 | 04°30.0' N | 40°12.1' W | 4653 | 11.03.1994 | 11:08 | 26.4 | BB | data gaps |
| 051 | 105 | 04°30.0' N | 39°25.1' W | 4420 | 11.03.1994 | 19:35 | 26.7 | BB | data gaps |
| 052 | 106 | 04°30.0' N | 38°45.0' W | 4407 | 12.03.1994 | 02:40 | 26.5 | BB | data gaps |
| 053 | 107 | 04°30.1' N | 38°00.0' W | 4469 | 12.03.1994 | 10:32 | 26.6 | BB | data gaps |
| 054 | 108 | 04°30.0' N | 36°30.0' W | 4022 | 12.03.1994 | 23:02 | 26.8 | NB | |
| 055 | 109 | 04°30.0' N | 35°00.2' W | 3876 | 12.03.1994 | 10:23 | 26.8 | NB | |
| 056 | 110 | 03°47.2' N | 35°00.0' W | 4259 | 13.03.1994 | 16:17 | 27.2 | NB | |
| 057 | 111 | 03°00.0' N | 35°00.0' W | 3812 | 13.03.1994 | 23:36 | 27.2 | NB | |
| 058 | 112 | 02°20.0' N | 34°59.9' W | 4133 | 14.03.1994 | 04:58 | 27.2 | NB | |
| 059 | 113 | 01°45.0' N | 35°00.0' W | 3696 | 14.03.1994 | 10:05 | 27.2 | NB | |
| 060 | 114 | 01°15.0' N | 35°00.0' W | 4000 | 14.03.1994 | 14:44 | 27.1 | NB | |

'+' : NB-ADCP with compass failure unrecoverable

| Meteor M27/3 CTD Stations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Profile | Station | Latitude | Longitude | Depth | Date | UTC | SST | ADCP | Comment |
| 061 | 115 | 00°38.5' N | 34°59.8' W | 4528 | 14.03.1994 | 20:09 | 27.2 | NB | Pegasus 03 |
| 062 | 116 | 00°17.9' N | 34°59.9' W | 4524 | 15.03.1994 | 02:20 | 27.2 | NB | |
| 063 | 117 | 00°01.8' S | 34°59.9' W | 4522 | 15.03.1994 | 05:50 | 27.4 | NB | Pegasus 04 |
| 064 | 118 | 00°24.0' S | 35°00.1' W | 4490 | 15.03.1994 | 12:15 | 27.4 | NB | |
| 065 | 119 | 00°46.6' S | 34°59.8' W | * | 15.03.1994 | 16:07 | 27.4 | NB | Pegasus 05 |
| 066 | 120 | 01°06.0' S | 35°00.0' W | * | 15.03.1994 | 22:10 | 28.0 | NB | |
| 067 | 121 | 01°16.9' S | 35°00.0' W | * | 16.03.1994 | 02.12 | 28.0 | NB | |
| 068 | 122 | 01°28.3' S | 35°00.2' W | * | 16.03.1994 | 06:04 | 28.1 | NB | Pegasus 06 |
| 069 | 123 | 01°52.0' S | 35°00.1' W | * | 16.03.1994 | 12:20 | 28.3 | NB | |
| 070 | 124 | 02°16.9' S | 34°59.9' W | * | 16.03.1994 | 17:36 | 29.1 | NB | Pegasus 07 |
| 071 | 125 | 02°43.0' S | 34°57.0' W | * | 16.03.1994 | 23:52 | 28.6 | NB | |
| 072 | 126 | 03°09.7' S | 34°53.0' W | * | 17.03.1994 | 05:04 | 28.6 | NB | Pegasus 08 |
| 073 | 127 | 03°35.0' S | 34°55.0' W | * | 17.03.1994 | 11:00 | 28.6 | NB | |
| 074 | 128 | 03°59.1' S | 34°57.2' W | * | 17.03.1994 | 15:31 | 28.9 | NB | Pegasus 09 |
| 075 | 129 | 04°15.1' S | 35°00.2' W | * | 17.03.1994 | 20:21 | 28.8 | NB | |
| 076 | 130 | 04°31.3' S | 35°03.8' W | * | 18.03.1994 | 00:32 | 28.5 | NB | Pegasus 10 |
| 077 | 131 | 04°40.0' S | 35°04.0' W | * | 18.03.1994 | 04:27 | 28.5 | NB | |
| 078 | 132 | 04°46.0' S | 35°06.0' W | * | 18.03.1994 | 06:40 | 28.6 | NB | |
| 079 | 133 | 05°38.7' S | 34°54.4' W | * | 18.03.1994 | 12:41 | 28.6 | NB | Pegasus 11 |
| 080 | 134 | 05°37.7' S | 34°44.9' W | * | 18.03.1994 | 16:04 | 28.8 | NB | |
| 081 | 135 | 05°35.9' S | 34°36.1' W | * | 18.03.1994 | 22:10 | 28.8 | NB | Pegasus 12 |
| 082 | 136 | 05°34.0' S | 34°28.0' W | * | 19.03.1994 | 02:09 | 28.8 | NB | |
| 083 | 137 | 05°33.2' S | 34°20.2' W | * | 19.03.1994 | 05:33 | 28.8 | NB | Pegasus 13 |
| 084 | 138 | 05°32.1' S | 34°01.8' W | * | 19.03.1994 | 11:11 | 28.8 | NB | |
| 085 | 139 | 05°31.1' S | 33°36.0' W | * | 19.03.1994 | 16:32 | 29.1 | NB | |
| 086 | 140 | 05°25.9' S | 33°11.0' W | * | 19.03.1994 | 22:24 | 28.9 | NB | Pegasus 14 |
| 087 | 141 | 05°25.0' S | 32°49.0' W | * | 20.03.1994 | 05:29 | 28.6 | NB | |
| 088 | 142 | 05°20.0' S | 32°28.0' W | * | 20.03.1994 | 10:38 | 28.5 | NB | Pegasus 15 |
| 089 | 143 | 05°15.1' S | 32°00.0' W | * | 20.03.1994 | 17:51 | 28.9 | NB | Pegasus 16 |
| 090 | 144 | 05°10.0' S | 31°30.5' W | * | 21.03.1994 | 01:54 | 28.4 | NB | Pegasus 17 |

'*' : depth soundings not permitted by Brazilian Hydrographic Office

| Meteor M27/3 CTD Stations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Profile | Station | Latitude | Longitude | Depth | Date | UTC | SST | ADCP | Comment |
| 091 | 145 | 05°46.9' S | 31°02.0' W | * | 21.03.1994 | 10:54 | 28.4 | NB | |
| 092 | 146 | 06°23.0' S | 30°32.9' W | * | 21.03.1994 | 18:42 | 28.6 | NB | |
| 093 | 147 | 07°00.0' S | 30°05.1' W | 5377 | 22.03.1994 | 02:09 | 28.6 | NB | |
| 094 | 148 | 07°45.0' S | 30°28.0' W | 5375 | 22.03.1994 | 09:57 | 28.7 | NB | |
| 095 | 149 | 08°30.0' S | 30°50.0' W | 5350 | 22.03.1994 | 17:19 | 28.6 | NB | |
| 096 | 150 | 09°15.0' S | 31°25.0' W | 5109 | 23.03.1994 | 01:18 | 28.5 | NB | |
| 097 | 151 | 10°00.1' S | 32°00.0' W | * | 23.03.1994 | 09:40 | 28.5 | NB | |
| 098 | 152 | 10°00.0' S | 32°29.9' W | * | 23.03.1994 | 15:21 | 28.5 | NB | |
| 099 | 153 | 10°00.0' S | 33°00.0' W | * | 23.03.1994 | 22:46 | 28.8 | NB | |
| 100 | 154 | 10°00.1' S | 33°24.9' W | * | 24.03.1994 | 04:04 | 28.9 | NB | |
| 101 | 155 | 10°00.0' S | 33°50.0' W | * | 24.03.1994 | 09:16 | 28.8 | NB | |
| 102 | 156 | 10°00.0' S | 34°07.0' W | * | 24.03.1994 | 13:59 | 28.8 | NB | |
| 103 | 157 | 10°00.0' S | 34°24.0' W | * | 24.03.1994 | 18:18 | 29.0 | NB | |
| 104 | 158 | 10°00.0' S | 34°40.1' W | * | 24.03.1994 | 22:12 | 28.9 | NB | |
| 105 | 159 | 10°00.0' S | 34°51.0' W | * | 25.03.1994 | 01:49 | 28.9 | NB | |
| 106 | 160 | 10°00.0' S | 35°02.1' W | * | 25.03.1994 | 05:06 | 29.0 | NB | |
| 107 | 161 | 09°59.9' S | 35°11.1' W | * | 25.03.1994 | 08:13 | 28.1 | NB | |
| 108 | 162 | 10°00.0' S | 35°20.0' W | * | 25.03.1994 | 10:50 | 28.2 | NB | |
| 109 | 163 | 10°00.0' S | 35°30.0' W | * | 25.03.1994 | 13:27 | 28.1 | NB | |
| 110 | 164 | 09°59.8' S | 35°41.2' W | * | 25.03.1994 | 15:36 | 28.4 | NB | |

'*' : depth soundings not permitted by Brazilian Hydrographic Office

### 7.3.2 List of XBT Drops

| Station | Latitude | Longitude | Date 1994 | UTC | SST | Comment |
|---|---|---|---|---|---|---|
| 001 | 18°52.1 N | 037°23.2 W | 02/24/ | 15:07:00 | 22.6 | |
| 002 | 18°26.1 N | 037°36.5 W | 02/24/ | 17:30:00 | 22.5 | |
| 003 | 17°59.5 N | 037°51.9 W | 02/24/ | 19:58:27 | 23.0 | |
| 004 | 17°34.5 N | 038°06.2 W | 02/24/ | 22:25:42 | 23.1 | |
| 005 | 17°09.0 N | 038°20.0 W | 02/25/ | 00:57:45 | 23.2 | |
| 006 | 16°44.6 N | 038°35.0 W | 02/25/ | 03:26:48 | 23.2 | |
| 007 | 16°17.7 N | 038°50.5 W | 02/25/ | 05:58:19 | 23.3 | |
| 008 | 15°52.0 N | 039°05.3 W | 02/25/ | 08:30:03 | 23.5 | |
| 009 | 15°26.2 N | 039°19.9 W | 02/25/ | 10:56:01 | 23.3 | |
| 010 | 15°04.7 N | 039°32.2 W | 02/25/ | 12:59:31 | 24.0 | |
| 011 | 14°33.8 N | 039°50.1 W | 02/25/ | 15:57:48 | 24.0 | |
| 012 | 14°08.0 N | 040°04.9 W | 02/25/ | 18:25:38 | 24.2 | |
| 013 | 13°41.8 N | 040°20.0 W | 02/25/ | 20:56:34 | 24.1 | |
| 014 | 13°26.1 N | 040°28.9 W | 02/25/ | 22:27:37 | 24.3 | |
| 015 | 12°55.1 N | 040°46.0 W | 02/26/ | 01:29:38 | 24.1 | |
| 016 | 12°25.2 N | 041°03.8 W | 02/26/ | 04:25:19 | 23.9 | |
| 017 | 11°58.1 N | 041°18.9 W | 02/26/ | 06:55:54 | 24.1 | 746 m |
| 018 | 11°32.6 N | 041°33.7 W | 02/26/ | 09:24:13 | 24.4 | |
| 019 | 11°06.2 N | 041°48.6 W | 02/26/ | 11:59:16 | 24.4 | |
| 020 | 10°27.0 N | 042°08.5 W | 02/27/ | 08:09:32 | 25.2 | |
| 021 | 09°56.0 N | 042°28.5 W | 02/27/ | 13:01:30 | 25.3 | |
| 022 | 09°41.1 N | 042°39.1 W | 02/27/ | 15:36:47 | 24.7 | |
| 023 | 09°25.0 N | 042°49.8 W | 02/27/ | 17:10:16 | 25.6 | |
| 024 | 08°29.0 N | 043°41.2 W | 02/28/ | 10:37:38 | 26.6 | |
| 025 | 08°02.0 N | 043°59.8 W | 02/28/ | 17:43:25 | 26.9 | |
| 026 | 07°30.0 N | 044°03.5 W | 03/01/ | 04:06:27 | 26.8 | |
| 027 | 06°57.0 N | 044°01.0 W | 03/01/ | 10:14:35 | 26.8 | |
| 028 | 06°30.0 N | 044°01.0 W | 03/01/ | 15:56:29 | 26.8 | |
| 029 | 05°32.0 N | 044°00.6 W | 03/02/ | 05:56:29 | 26.8 | |
| 030 | 04°59.0 N | 044°00.7 W | 03/02/ | 10:37:21 | 26.9 | |
| 031 | 04°27.0 N | 044°01.1 W | 03/02/ | 15:09:37 | 27.0 | |
| 032 | 03°59.5 N | 044°01.2 W | 03/02/ | 19:44:53 | 27.0 | |
| 033 | 03°31.0 N | 044°00.0 W | 03/03/ | 00:01:36 | 27.0 | |
| 034 | 02°57.0 N | 044°01.6 W | 03/03/ | 04:46:16 | 27.0 | |
| 035 | 02°13.5 N | 044°01.5 W | 03/03/ | 10:29:46 | 27.4 | |
| 036 | 01°11.0 N | 044°01.2 W | 03/03/ | 21:35:03 | 27.8 | |
| 037 | 00°52.0 N | 044°06.5 W | 03/04/ | 13:37:28 | 27.8 | |
| 038 | 00°18.0 N | 044°19.8 W | 03/05/ | 01:25:33 | 28.0 | |
| 039 | 00°34.6 N | 043°57.6 W | 03/05/ | 18:57:32 | 27.6 | |
| 040 | 00°41.7 N | 043°41.1 W | 03/05/ | 21:00:46 | 27.5 | |
| 041 | 00°49.1 N | 043°25.2 W | 03/05/ | 23:00:10 | 27.4 | |
| 042 | 00°55.2 N | 043°08.5 W | 03/06/ | 01:02:09 | 27.4 | |
| 043 | 00°47.2 N | 042°52.5 W | 03/06/ | 02:57:48 | 27.3 | |
| 044 | 00°37.0 N | 042°33.8 W | 03/06/ | 05:03:16 | 27.3 | |

| Station | Latitude | Longitude | Date 1994 | UTC | SST | Comment |
|---|---|---|---|---|---|---|
| 045 | 00°27.9 N | 042°16.8 W | 03/06/ | 07:00:51 | 27.3 | |
| 046 | 00°16.7 N | 042°00.2 W | 03/06/ | 08:55:53 | 27.2 | |
| 047 | 00°04.9 N | 041°42.5 W | 03/06/ | 10:59:23 | 27.1 | |
| 048 | 00°09.5 S | 041°27.4 W | 03/06/ | 12:57:29 | 27.2 | 753m |
| 049 | 00°26.9 S | 041°14.2 W | 03/06/ | 15:00:02 | 27.5 | |
| 050 | 00°54.7 S | 040°53.8 W | 03/06/ | 18:09:20 | 28.0 | |
| 051 | 01°01.7 S | 040°48.8 W | 03/06/ | 19:00:04 | 28.1 | |
| 052 | 01°15.6 S | 040°33.9 W | 03/06/ | 21:00:02 | 28.1 | |
| 053 | 01°30.5 S | 040°20.3 W | 03/06/ | 23:00:24 | 28.0 | |
| 054 | 01°45.4 S | 040°07.9 W | 03/07/ | 01:02:04 | 28.1 | |
| 055 | 01°27.0 S | 040°00.0 W | 03/07/ | 18:11:09 | 28.4 | |
| 056 | 00°34.6 N | 040°00.0 W | 03/08/ | 13:49:36 | 27.1 | |
| 057 | 02°33.0 N | 040°11.0 W | 03/10/ | 03:13:45 | 27.0 | |
| 058 | 02°49.0 N | 040°21.8 W | 03/10/ | 05:03:31 | 26.9 | |
| 059 | 04°08.0 N | 040°56.2 W | 03/10/ | 22:50:12 | 26.6 | |
| 060 | 04°30.0 N | 039°51.0 W | 03/11/ | 16:36:04 | 26.6 | |
| 061 | 04°29.9 N | 039°38.0 W | 03/11/ | 18:04:27 | 26.6 | |
| 062 | 04°29.9 N | 039°05.0 W | 03/12/ | 00:32:24 | 26.5 | |
| 063 | 04°30.0 N | 038°28.0 W | 03/12/ | 07:26:11 | 26.5 | |
| 064 | 04°30.1 N | 037°30.0 W | 03/12/ | 16:46:06 | 26.7 | |
| 065 | 04°30.0 N | 037°00.0 W | 03/12/ | 19:44:22 | 26.7 | |
| 066 | 04°30.0 N | 036°00.0 W | 03/13/ | 03:45:26 | 26.8 | |
| 067 | 04°30.0 N | 035°30.0 W | 03/13/ | 06:52:38 | 26.9 | |
| 068 | 04°08.0 N | 035°00.0 W | 03/13 | 14:18:42 | 27.0 | |
| 069 | 03°22.5 N | 035°00.2 W | 03/13/ | 21:18:56 | 27.1 | |
| 070 | 02°40.0 N | 034°59.9 W | 03/14/ | 03:00:58 | 27.2 | |
| 071 | 02°02.3 N | 035°00.0 W | 03/14/ | 08:29:14 | 27.2 | |
| 072 | 01°30.0 N | 035°00.0 W | 03/14/ | 13:00:28 | 27.1 | |
| 073 | 02°30.0 S | 034°58.5 W | 03/16/ | 22:34:28 | 28.6 | |
| 074 | 02°57.0 S | 034°55.1 W | 03/17/ | 03:42:35 | 28.6 | |
| 075 | 03°23.0 S | 034°54.0 W | 03/17/ | 09:49:00 | 28.5 | |
| 076 | 03°50.1 S | 034°56.4 W | 03/17/ | 14:32:26 | 28.8 | |
| 077 | 05°27.7 S | 031°16.5 W | 03/20/ | 08:25:50 | 28.5 | |
| 078 | 06°02.4 S | 030°48.0 W | 03/20/ | 15:53:19 | 28.6 | 693 m |
| 079 | 06°42.0 S | 030°19.0 W | 03/21/ | 23:45:45 | 28.6 | |
| 080 | 07°22.4 S | 030°16.5 W | 03/22/ | 07:32:19 | 28.7 | |
| 081 | 08°07.6 S | 030°39.1 W | 03/22/ | 15:12:11 | 28.8 | |
| 082 | 08°53.0 S | 031°08.5 W | 03/22/ | 22:54:28 | 28.5 | |
| 083 | 09°37.0 S | 031°41.9 W | 03/23/ | 06:53:50 | 28.5 | |
| 084 | 10°00.0 S | 032°15.0 W | 03/23/ | 13:54:45 | 28.5 | |
| 085 | 10°00.0 S | 032°48.5 W | 03/23/ | 20:02:24 | 28.8 | |
| 086 | 10°00.0 S | 033°12.0 W | 03/24/ | 02:44:29 | 28.9 | |
| 087 | 10°00.0 S | 033°37.1 W | 03/24/ | 08:00:50 | 28.8 | |

## 8 Concluding Remarks

Although violant storm and gales only allowed a restricted sampling during our reserach in the West European Basin (Legs 1 and 2). The few results gave most valuable information about biogeochemical processes under winter conditions, which will change our view about seasonality of processes and will stimulate further research activities. Our deepest thanks go to captain Andresen and his crew who under serious conditions battled against a hurrican and prevented worse by their initiative and courageous engagement. We also like to thank the members of the Leitstelle METEOR for the technical support of the expedition. The research programmes were funded by various grants from the EC, the Deutsche Forschungs-gemeinschaft and the Bundesminister für Forschung und Technologie.

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