1 Research Objectives

1.1 Introduction

METEOR-cruise 39 took place in the North Atlantic Ocean with measurements mainly north of 40°N (Figure 1) except for some work off Portugal and near the entrance to the Mediterranean Sea during the first leg. The cruise began on 18 April 1997 in Las Palmas and ended on 14 September 1997 in Hamburg. METEOR-cruise 39 combined during five legs (Table 1) activities of paleo-oceanographic, physical oceanography, marine chemistry, meteorological, geological and tracer physics working groups.

After cruise M39 started in Las Palmas, METEOR headed towards the entrance of the Mediterranean. The work during the first leg off the southwest European shelf combined different working groups and measurement techniques to investigate paleo-oceanographic problems with regard to the thermohaline circulation during the last glacial period.

The aims during the second and forth leg were regional investigations of the thermohaline circulation in the western and eastern basins within the context of the new ”Sonderforschungs-bereich” at the University of Kiel SFB-460 ”Dynamics of thermohaline circulation variability”. The main objectives during the SFB-460 related cruise legs were hydrographic measurements as well as intense mooring work.

Besides the hydrographic and mooring work during the two SFB-460 related cruise legs distributions of total dissolved inorganic carbon and total alkalinity were measured at the hydrocast locations. Nutrients and dissolved oxygen were determined in parallel. This combined analysis will allow the calculation of the penetration of anthropogenic CO_2 into the water column. Additionally, a system to continuously monitor the CO_2 partial pressure in surface waters and air operated during the two legs. This will allow calculating the CO_2 flux between atmosphere and ocean.

During the third and fifth leg measurements of the thermohaline overturning circulation of the North Atlantic along two trans-Atlantic sections were carried out as final contributions of the Hamburg groups to the World Ocean Circulation Experiment (WOCE). Both sections were repeated several times since 1991 to investigate the transport rates of the meridional overturning circulation and its variability. Besides hydrography, marine chemistry and tracer measurements were carried out. During the fifth leg, measurements were made also for the ”Variability of Exchanges in the Northern Seas (VEINS)” Project as part of the EC-MAST II program.

As part of the joint operation between WOCE and JGOFS (Joint Global Ocean Flux Study), on the leg M39/3, the components of the CO_2-system, such as dissolved and particular carbon CO_2, were measured along the WHP-section A2 throughout the water column to describe the ocean's role as a buffer of atmospheric CO_2. Its input into these highly to moderately convective regions covered by section A2 is strongly variable and therefore calls for more frequent sampling than elsewhere in the ocean.

everal other groups not imbedded in the large projects summarized about participated in some of the cruise legs and their work is detailed under sections 3 and 5.

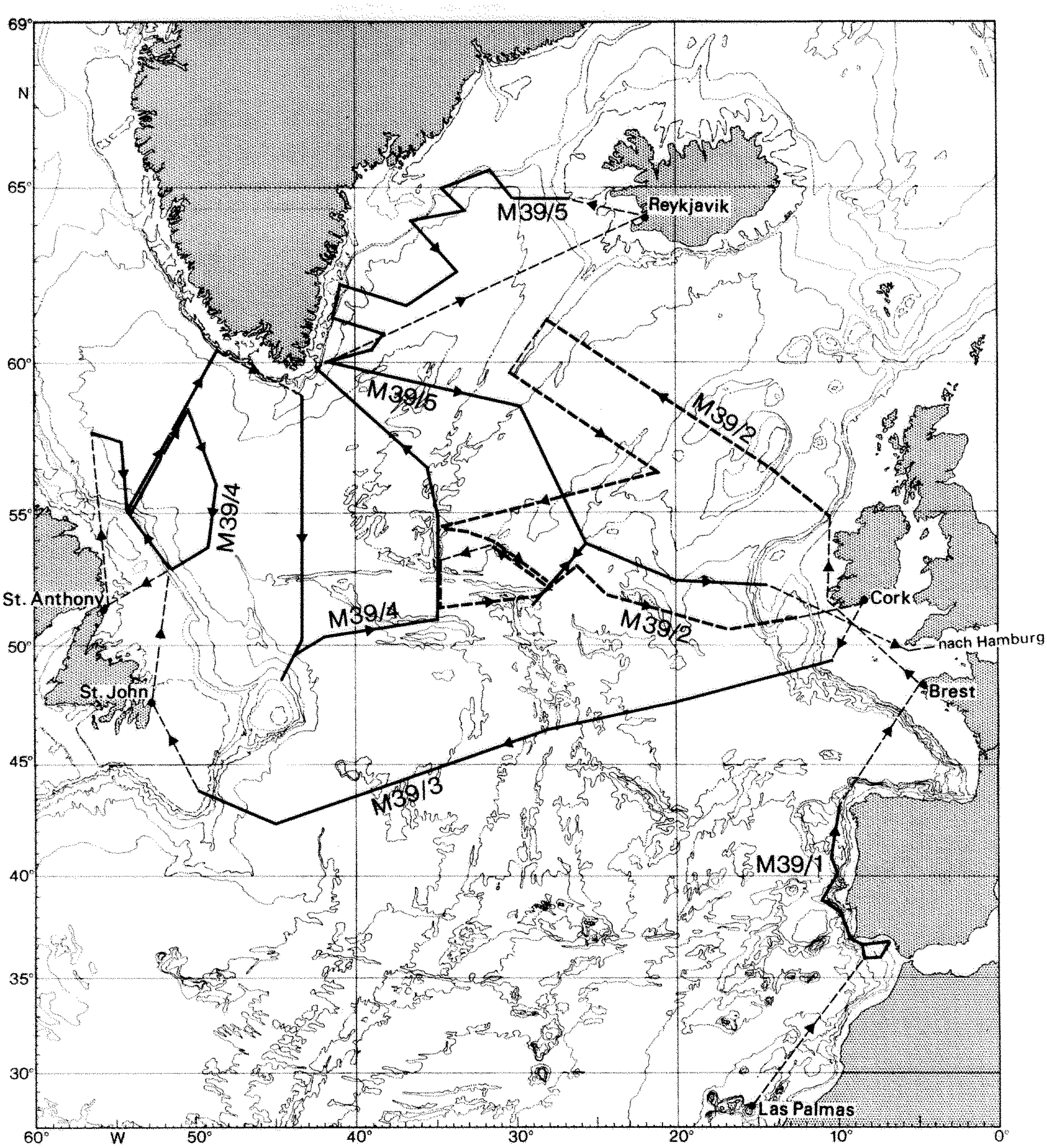

Fig. 1: Cruise track of the 5 legs of METEOR cruise no. 39. To separate the different cruise legs M39/2 is shown as dashed line. Transit sections are shown as thin dashed lines.

Tab.1: Legs and chief scientist of METEOR cruise No. 39

Leg M39/1
18.04.-12.05.1997, Las Palmas, Canary Islands, Spain - Brest, France
Chief scientist : Dr. R. Zahn

Leg M39/2
15.05.-08.06.1997, Brest, France - Cork, Ireland
Chief scientist : Dr. W. Zenk

Leg M39/3
11.06.-03.07.1997, Cork, Ireland - St. John's, Canada
Chief scientist : Dr. K. P. Koltermann

Leg M39/4
06.07.-11.08.1997, St. John's, Canada - Reykjavik, Iceland
Chief scientist : Prof. Dr. F. Schott

Leg M39/5
14.08.-14.09.1997, Reykjavik, Iceland - Hamburg, Germany
Chief scientist : Dr. A. Sy

Coordination: Prof. Dr. F. Schott

Masters: Captain D. Kalthoff
Captain M. Kull

1.2 Projects

A large fraction of the work carried out on cruise M39 is imbedded in the international WOCE program and the SFB-460, which both are shortly introduced here:

The goal of the World Ocean Circulation Experiement (WOCE) is to develop models for improved descriptions of the ocean circulation and prediction of climate changes and to collect the appropriate data in the World Ocean. The North Atlantic Ocean is characterized through an intensive meridional circulation cell, carrying near surface waters of tropical and subtropical origin northwards and deep waters of arctic and subarctic origin southwards. The transformation and sinking of watermasses at high latitudes are the important processes for the "overturning" of the ocean. The overturning rates and the intensity of the meridional transports of mass, heat, and salt are control parameters for the modelling of the ocean's role in climate.

The two legs M39/3 and M39/5 provided two complete full-depth transoceanic hydrographic sections in the North Atlantic as a prominent contribution to the WOCE Hydrographic Programme (WHP), completing the German WOCE field work that started with METEOR cruise M18 in 1991. Both legs, M39/3 and M39/5 were also part of the seven-year observational programme WOCE-NORD (World Ocean Circulation Experiment - Northatlantic Overturning Rate Determination), a German contribution to WOCE and funded by the Ministry of Education and Research. Using repeated hydrographic sections between the southern tip of Greenland and Ireland in combination with current measurements the overturning rates of the North Atlantic will be estimated. Quantifiying both input and output in the meridional overturning cell (MOC) will help to improve modelling the role of the ocean in the climate system.

The Sonderforschungsbereich SFB 460 "Dynamics of thermohaline circulation variability" began in 1996 at Kiel University. Main objective of the SFB 460 is to investigate the variability of the watermass formation and transport processes in the subpolar North Atlantic and to gain an understanding of its role in the dynamics of the thermohaline circulation and the ocean uptake of anthropogenic CO_2. The variability of circulation and water mass distribution appears to be related through the North Atlantic Oscillation (NAO) with climate changes in northern Europe. These connections shall be investigated.

Legs M39/2 and M39/4 were carried out within the context of the SFB 460 with a wide range of hydrographic, tracer and current measurement techniques to investigate the variability of the circulation in the North Atlantic. The cruises were part of the opening phase of the SFB although the leg to the Labrador Sea was already the second cruise to this area of annually planned cruises within the SFB. During these two legs the focus was on the pathways of the deep circulation and the associated signals in the water mass distributions. Besides the shipboard measurements, a large part of the work was mooring work and the deployment of floats.

2 Participants

Tab.2: Participants of METEOR cruise no. 39

Leg M39/1

Name	Speciality	Institute
Zahn, Rainer, Dr.	Chief Scientist	GEO
Bader, Beate	Sedimentology	GIK
Bassek, Dieter	Meteorol. radio operator	DWD
Bozzano, Graziella	Sedimentology	ICM
Didie, Claudia	Sedimentology	GEO
Flechsenhar, Kurt	Meteorologist	DWD
Harder, Angela	Inorganic chemistry	GEO
Heidemann, Kristina	Geophysics	GEO
Hollender, Franz-Josef	Geophysics	GEO
Hüls, Matthias	Paleocenaography	GEO
Jung, Simon	Paleocenaography	GEO
Karp, Tobias	Geophysics	GEO
Kohly, Alexander	Sedimentology	GIK
Lembke, Lester	Paleocenaography	GEO
Loncaric, Neven	Sedimentology	IGM
Müller, Anja	Sedimentology	GEO
Neufeld, Sergeij	Technician	GTG
Schäfer, Prisca, Prof. Dr.	Sedimentology, Paleontol.	GIK
Schönfeld, Joachim	Micropaleontology	GEO
Stüber, Arndt	Inorganic chemistry	GEO
Willamowski, Claudia	Inorganic chemistry	GEO

Leg **M39/2**

Name	**Speciality**	**Institute**
Zenk, Walter, Dr.	Chief scientist	IfMK
Amman, Lars	Marine Chemistry	IfMK
Bahrenfuß, Kristin	Tracer Oceanography	IfMK
Becker, Sylvia	Marine Physics	IfMK
Brandt, Benno	Meteorology	DWD
Carlsen, Dieter	Marine Physics	IfMK
Csernok, Tiberiu	Marine Physics	IfMK
Friedrich, Olaf	Marine Physics	IfMK
Johannsen, Hergen	Marine Chemistry	IfMK
Keir, Robin, Dr.	Geochemistry	GEO
Körtzinger, Arne, Dr.	Marine Chemistry	IfMK
Lenz, Bernd	Marine Physics	IfMK
Link, Rudolf	Marine Physics	IfMK
Meyer, Peter	Marine Physics	IfMK
Müller, Thomas J., Dr.	Marine Physics	IfMK
Nielsen, Martina	Marine Physics	IfMK
Heygen, Ronald	Logistic	RF
Ochsenhirt, Wolf-Thilo	Meteorology	DWD
Pinck, Andreas	Marine Physics	IfMK
Plähn, Olaf	Tracer Oceanography	IfMK
Rehder, Gregor, Dr.	Geochemistry	GEO
Schweinsberg, Susanne	Marine Chemistry	IfMK
Trieschmann, Babette	Tracer Oceanography	IfMK
Wehrend, Dirk	Marine Physics	IfMK

Leg M39/3

Name	**Speciality**	**Institute**
Koltermann, Klaus Peter, Dr.	Chief Scientist	BSH
Wöckel, Peter	CTD engineer	BSH
Stelter, Gerd	data scout and manager	BSH
Weichert, Hans-Jürgen	CTD data processing	BSH
Frohse, Alexander	Salinometer	BSH
Lohrbacher, Katja	Hydrowatch captain	BSH
Esselborn, Saskia	Hydrowatch	IfMH
Gouretski, Victor, Dr.	Hydrowatch captain	BSH/MPI
Stransky, Christoph	Hydrowatch captain, XBT	BSH
Morsdorf, Felix	Hydrowatch, L-ADCP	IfMK
Gottschalk, Ilse	Hydrowatch	BSH
Fick, Michael	Hydrowatch	IfMH
Giese, Holger	Moorings	BSH
Tacke, Helga	Nutrient Analyst	BSH
Gottschalk, Anke	Oxygen Analyst	BSH
Schmiel, Franziska	Oxygen Analyst	BSH
Kramer, Rita	Nutrient Analyst	BSH
Bulsiewicz, Klaus	Tracer/CFC	UB
Plep, Wilfried	Tracer/CFC	UB
Fleischmann, Ulrich	Tracer/CFC	UB
Sommer, Volker	Tracer/CFC	UB
Gleiss, Ralf	Tracer/CFC	UB
Neill, Craig	CO_2 Analysis, DIC	BNL
Lewis, Ernie	CO_2 Analysis, Alkalinity	BNL
Brandt, Benno	Meteorology	DWD
Ochsenhirt, Wolf-Thilo	Meteorology	DWD

Leg M39/4

a) 06.07. - 16.07.1997 St. John’s, Canada - St. Anthony, Canada
b) 16.07. - 11.08.1997 St. Anthony, Canada - Reykjavik, Iceland

Name	Speciality	Institute
Schott, Friedrich, Prof., Dr.	Chief Scientist (a,b)	IFMK
Adam, Dorothee	Tracer (b)	IFMK
Arnold Matthias	Helium/Tritium (a)	IUP
Bahrenfuß, Kristin	Tracer (a, b)	IfMK
Begler, Christian	Oceanography (a, b)	IfMK
Dombrowsky, Uwe	Oceanography (a, b)	IfMK
Eisele, Alfred	Oceanography (a, b)	IfMK
Fischer, Jürgen, Dr.	Oceanography, (a, b)	IfMK
Friis, Karsten	CO_2 (b)	IfMK
Fürhaupter, Karin	Foraminifera	GEO
Gäng, Holger, Dr.	Meteorology (a, b)	IfMK
Kahl, Gerhard	Meteorology, (a, b)	DWD
Karger, Uwe	Meteorology (a, b)	IfMK
Keir, Robin, Dr.	Methan (b)	GEO
Kindler, Detlef	Oceanography (a, b)	IfMK
König, Holger	Oceanography (a, b)	IfMK
Malien, Frank	Oxygen, Nutrients (a, b)	IfMK
Mauuary, Didier, Dr.	Tomography (a)	CEP
Meinke, Claus	Oceanography (a, b)	IfMK
Mertens, Christian	Oceanography (a, b)	IfMK
Mintrop, Ludger, Dr.	CO_2 (a, b)	GeoB
Ochsenhirt, Wolf-Thilo	Meteorology (a, b)	DWD
Papenburg, Uwe	Oceanography (a, b)	IfMK
Plähn, Olaf	Tracer (a)	IfMK
Rehder, Gregor, Dr.	Methan (b)	GEO
Rhein, Monika, Dr.	Tracer (b)	IfMK
Schweinsberg, Susanne	CO_2 (a, b)	IfMK
Send, Uwe, Dr.	Tomography (b)	IfMK
Stramma, Lothar, Dr.	Oceanography (a, b)	IfMK
Walter, Maren	Oceanography (a, b)	IfMK
Winckler, Gisela	Helium/Tritium (b)	IUP

Leg M39/5

Name	Speciality	Institute
Sy, Alexander, Dr.	Chief Scientist	BSH
Stolley, Martin	Hydro Watch, XBT	BSH
Mohn, Christian	Hydro Watch, VM-ADCP	IfMH
Berger, Ralf	Hydro Watch, CTD, L-ADCP	IfMK
Gottschalk, Ilse	Hydro Watch	BSH
Weigle, Rainer	Hydro Watch	IfMH
Struck, Petra	Hydro Watch	BSH
Verch, Norbert	Salinity	IfMH
Stelter, Gerd	Bottle Datamanagement	BSH
Mauritz, Heiko	CTD DATA Processing	BSH
Schulze, Klaus	TSG, Ship's Datamanagement	IfMH
Bakker, Karel	Nutrients	NIOZ
Kramer, Rita	Nutrients, Oxygen	BSH
Schmiel, Franziska	Oxygen	BSH
Machoczek, Detlev	Oxygen	BSH
Read, John	Moorings	CEFAS
Hargreaves, Geoff	IES, Moorings	POL
Ashley, John	IES, Moorings	POL
Hildebrandt, Hauke	Tritium/He, 0-18, SF-6	IUP
Rhein, Monika, Dr.	CFC, L-ADCP	IfMK
Elbrächter, Martina	CFC	IfMK
Czeschel, Lars	CFC	IfMK
Reich, Michael	CFC	IfMK
Thomas, Helmuth, Dr.	CO_2	IOW
Trost, Erika	CO_2	IOW
Gronau, Nicole	CO_2	IOW
Kahl, Gerhard	Meteorology	DWD
Bassek, Dieter	Meteorology	DWD
Henning, Arndt	Film Team	AmPuls
Schäfer, Werner	Film Team	AmPuls

Tab. 3: Participating Institutions

AmPuls	AmPuls Film Film und TV Produktion Curschmannstr. 13 20251 Hamburg — Germany
BNL	Oceanographic and Atmospheric Sciences Division Department of Applied Sciences Brookhaven National Laboratory Upton, NY 11973 — USA
BSH	Bundesamt für Seeschiffahrt und Hydrographie Bernhard-Nocht-Str. 78 20597 Hamburg — Germany
CEFAS	Centre for Environment Fisheries & Aquaculture Science Lowestoft Laboratory Lowestoft, Suffolk NR33 0HT — England
CEP	Centre d'Etude des Phénomènes Aléatoires et Géophysiques EINSIEG-CAMPUS Universitaire BP 46, 38402 Saint Martin d'hères Cedex-France
DWD	Deutscher Wetterdienst Geschäftsfeld Seeschiffahrt Bernhard-Nocht-Str. 76 20359 Hamburg — Germany
GEO	Geomar Forschungszentrum für Marine Geowissenschaften Universität Kiel Wischhofstr. 1-3 24148 Kiel — Germany
GeoB	Universität Bremen Fachbereich 5, Geowissenschaften Klagenfurter Str. 28359 Bremen — Germany

GIK	Geologisch-Paläontologisches Institut Universität Kiel Olshausenstr. 40 24118 Kiel — Germany
GTG	Geomar Technologie GmbH Wischofstr. 1-3 24148 Kiel — Germany
ICM	Institut de Ciencies del Mar Consejo Superior de Investigaciones Científicas Passeig Joan de Borbó, s/n 08039 Barcelona-Spain
IfMH	Institut für Meereskunde der Universität Hamburg Troplowitzstr. 7 22529 Hamburg — Germany
IfMK	Institut für Meereskunde an der Universität Kiel Düsternbrooker Weg 20 24105 Kiel — Germany
IGM	Instituto Geológico e Mineiro Rua Academia das Ciências, 19-2° 1200 Lisboa-Portugal
IOW	Institut für Ostseeforschung Warnemünde Seestraße 15 18119 Rostock-Warnemünde — Germany
IUP	Institut für Umweltphysik der Universität Heidelberg Im Neuenheimer Feld 366 69120 Heidelberg — Germany
MPI	Max-Planck-Institut für Meteorologie Bundesstr. 55 20146 Hamburg — Germany
NIOZ	Nederlands Instituut voor Onderzoek der Zee Postbus 59 1790 AB Den Burg, Texel —Netherlands

POL	Proudman Oceanographic Laboratory Bidston Observatory Birkenhead, Merseyside L43 7RA — England
RF	R/F Reedereigemeinschaft Forschungsschifffahrt GmbH Haferwende 3 28357 Bremen — Germany
UB	Universität Bremen Institut für Umweltphysik, Abt. Tracer-Oceanographie Bibliotheksstraße 28359 Bremen — Germany

3 Research Programs

3.1 WOCE program

Two hydrographic sections were carried out within the WOCE program. The northern section from Greenland to Ireland (WHP A1-East) cuts across the convective regime of the Subpolar Gyre, whereas the southern of the two sections, running from the English Channel to the Grand Banks off Newfoundland (WHP A2), spans the non or weakly-convective regime of the transition zone between the subpolar and subtropical gyres. The data are used to estimate the transports of heat and matter of the meridional circulation and contribute towards estimating the so-called “overturning” of the oceanic meridional circulation regarded as the main driving mechanism for the global thermohaline circulation and its temporal changes. Special emphasis is put on the intensive propagation of newly formed Labrador Sea Water (LSW) into the North Atlantic, first seen in the 1993 coverage of A2. These coverages of sections A1 and A2 repeat some earlier measurements that have shown a high temporal and spatial variability of both the water mass characteristics and the meridional transports of heat, salt and freshwater.

3.1.1 Physical Oceanography during WOCE cruises

3.1.1.1 Hydrographic measurements at 48°N in the North Atlantic along the WHP section A2

The meridional transports of heat, freshwater and salt in the Atlantic Ocean and their seasonal and internannual changes have been determined for the 90s across the latitude of the global maximum freshwater transport at ca. 50°N in the Atlantic Ocean. Results are compared with previous measurements in the 50s and 80s. They show surprisingly variable transports, suggesting time scales of 10 years for changes originating in the subpolar and some 30 years for those originating in the subtropical gyre.

Working the section A2/AR19 at about 48°N in the summer of 1993 with FS Gauss (G226) has shown the Labrador Sea Water temperatures some 0.4°C below its historical characteristic temperature, and deeper in the water column by some 700 m. This fits with the observations for the early 90s along 60°N and 24°30’N and indicates a rapid reaction of the intermediate circulation of the northern North Atlantic to changes in the buoyancy forcing in the Labrador Sea. This situation seems to have ended in 1995/96 when the NAO-Index, characterizing the prevailing atmospheric forcing over the region, changed from an all-time high to moderate values. First reactions of the ocean to these changes can be seen in the coverage of the sections A2 with FS Gauss (G276/1) and A1 with FS Meteor in the fall of 1994. The cruise M39/3 served also to document this tendency.

Following the WOCE Hydrographic Programme requirements, the section WHP-A2 along nominally 48°N was worked again as under “One-Time Survey” conditions. In addition to the classical hydrographic parameters, nutrients and small volume tracer concentrations were determined. Continuous ADCP (Acoustic Doppler Current Profiler) data provided the absolute vertical current shear of the top 500 m to calculate, from geostrophic transports, the absolute transport through this section. Additionally, velocity profiles have been acquired using a LADCP to support calculations of the absolute velocities. With a horizontal station spacing between 5 and 35 nm, a 24x10 l - rosette system was deployed to collect at up to 36 discreet depth levels water samples together with the quasi-continuous profiles of T, P, S and O_2 with a $CTDO_2$-probe. The track and station spacing essentially follows the Gauss section from 1993, covering 66 stations with 86 casts. Some additional casts for performance tests of the CTD/rosette system, calibrations and for the instruments for the chemical analyses have been worked.

Since the summer 1996 a mooring array again covers over the full water depth the deep eastern boundary current on the west side of the Mid-Atlantic Ridge on A2. The velocity, temperature and salinity data will describe the long-term changes of this current system that seems to play an important role in the exchange of newly formed water masses such as the LSW within the ocean basin or across the ridge. The moorings were turned around for another deployment of one year to be recovered in the summer of 1998. There were no problems in locating, retrieving or setting the moorings.

3.1.1.2 WOCE-NORD

The second part of leg M39/5 was part of the WOCE-NORD project funded by BMBF and was the sixth repeat of the WHP section A1E/AR7E. Meridional transports of heat and matter in the North Atlantic will be quantified through a section connecting Ireland and South Greenland. This section runs south of the region where the atmospheric forcing transforms the water advected to high latitudes such that it will sink to greater depths and spreads further south, forming the source water masses of the North Atlantic Deep Water. For several years we have been observing a cooling trend in the LSW caused by the spreading of newly formed LSW in the Labrador Sea. Estimates of circulation times derived by linking single LSW vintages, using hydrographic and tracer data independently, lead to trans-Atlantic propagation times of 4 to 5.5 years from the source region to the West European Basin. During the second part of leg M39/5 the A1E/AR7E section was sampled successfully.

3.1.2 Nutrients and tracer measurements during WOCE cruises

a) Nutrients along the WHP section A2

Along the WHP section A2 the nutrients PO_4, NO_3, NO_2, NH_4, $Si(OH)_4$ and the content of dissolved oxygen O_2 from all water samples were determined to differentiate water masses and their origin.

From 1591 water samples nutrients and dissolved oxygen were determined on board according to the WHP Standards. For quality assurance purposes additional samples were taken as duplicates or replicates. All data will be processed on board, subjected to detailed consistency and quality checks and compared to existing data sets from this region. An annotated data file was produced at the end of the cruise, containing all relevant information and documentation on methodology and the quality of the data.

b) CFC's and helium/tritium on WHP section A2 and A1E

In addition to the classical hydrographic data the measurements of anthropogenic tracers provide additional parameters for water mass analysis. They are particularly important for the determination of water mass transports and mixing processes making use of their well-known time-dependent input history at the ocean surface.

As on the A2-survey in 1994 (M30/2) measurements were carried out for the determination of the CFCs F-11, F-12, F-113, and CCl_4 and samples for the laboratory measurements of helium isotopes and tritium have been taken.

Since most of these tracers provide transient signals, the main objective will be to measure their time dependence. The hydrographic parameters for the mainly stationary flowing water masses like NADW or the deep waters of the eastern basin will not show much changes. But the tracer concentrations (except possibly for tritium) of these waters are expected to increase. The differences in tracer concentrations from these two cruises and the knowledge of the different input histories will allow us to determine the age structure of these water masses. The age structure is caused by mixing of waters of different age within a water mass, a process hardly detectable by hydrographic parameters. The "width" of the age structure gives an indication of the turbulent exchange coefficient, a parameter of general interest.

We expect further information on the intrusion of younger water from the north close to the bottom in the eastern basin which has been seen on the previous cruises M30/2 and further north during M18. This water is in contrast to older waters coming from the south as an eastern boundary current.

The highest tracer concentrations for NADW are expected in the western boundary current. The extension in zonal direction to and across the Mid Atlantic Ridge (recirculation) is easily detectable by the tracers. The LSW has changed its characteristic properties during the last years. To determine the development of these changes will be an objective of the cruise. The tracer concentrations will help to identify and to date the changes in the LSW.

The CFCs on section A2 were measured on the majority of the water samples. Helium and tritium sampling was restricted to about every second station, but with a high vertical resolution. The CFC data were available in preliminary form within about 24 h after sampling, so that they served to assist selecting sampling depths further on.

The CFC distributions in 1991 and 1994 along WHP section A1 led to estimates of the spreading times of LSW into the Irminger Sea and into the Northeast Atlantic, which were significantly shorter than previously thought. They correspond, however, with estimates derived independently from the cooling signal of LSW.

The CFC analysis at M39/5 did continue the CFC time series of the deep water masses. In combination with the analysis at M39/2 and M39/4 the spreading and mixing of the deep water masses in the subpolar North Atlantic will be studied.

c) TCO_2 and total alkalinity measurements on WHP section A2

Measurements were made of total dissolved inorganic carbon (TCO_2) and total alkalinity from full water column profiles collected along 48°N. At least one full profile (36 samples) was analyzed each day. TCO_2 was analyzed using a SOMMA-coulometer system that belongs to IfM Kiel; total alkalinity was measured by potentiometric titration (open cell titration) again using equipment which belongs to IfM Kiel. Certified Reference Materials for these parameters was analyzed daily.

With accurate preliminary hydrographic data provided to the analysts at the completion of the cruise, a final TCO_2 and alkalinity data set was made available for incorporation into the cruise data file.

The CO_2 measurements will be used for the following purposes:
(1) The zonal section of TCO_2 measurements will be combined with estimates of baroclinic, barotropic and Ekman water transport across the section to estimate the meridional transport of inorganic carbon at this latitude. These estimates should assist with the delineation of large scale patterns of divergence or convergence of the inorganic carbon transport in the North Atlantic ocean. These patterns in turn can be used as important constraints for large scale ocean carbon cycle models. Previous work during METEOR cruise M30/2 in 1994 has shown strong contrasts between waters from the source regions further to the North and particularly the deep Eastern Basin which was CO_2 free. We expect, because of the observed large changes in the intermediate waters in the 1990s, considerable changes of the CO_2 budget during this 1997 cruise.

(2) The observed TCO_2 can be separated into anthropogenic and preindustrial components. Such a separation has been attempted for an earlier CO_2 data set collected along this section and showed a large anthropogenic component penetrating to the ocean floor in the western basin and to approx. 4000 m in the eastern basin. However the influence of upper ocean seasonal changes can potentially obscure this anthropogenic signal: comparison of anthropogenic CO_2 components estimated from data collected during November 1994 and summer, 1997 should allow the magnitude of this possible seasonal contamination of the anthropogenic CO_2 signal to be addressed.

(3) TCO_2 is remineralized at depth in the ocean together with nutrients and in association with the removal of dissolved oxygen: as a result there are very robust inter-relationships between dissolved oxygen, TCO_2 and dissolved nutrient concentrations in the deep ocean. Whereas

Certified Reference Materials are available for quality control of measurements of the TCO_2 content of seawater, there are unfortunately no such standards for nutrients or oxygen. The observed empirical relationships between TCO_2 and the other parameters should, however, remain constant in the deep ocean for periods of at least several years to decades. Hence comparison of the quality controlled TCO_2 data with measured nutrients and oxygen concentrations provides one means by which the internal consistency of nutrient and oxygen measurements made on different cruises can be assessed. Simply put, any inaccuracies in the measurement of nutrients (for example) would show up as offsets or slope changes in the TCO_2-nutrient plots derived from various cruises. Hence measurement of TCO_2, because it is a parameter that can be traced to a Certified Standard, provides a means by which the quality of other closely related chemical parameter measurements can be assessed.

3.2 Sonderforschungsbereich (SFB) 460

The research program of the SFB is based on a combination of physical-oceanographic, marine chemistry and meteorological observation programs, which are carried out in close interaction with a series of numerical models with moderate (50 km), high (15 km) and very high resolution (5 km), which will allow a simulation of current structures and variability over a wide range of space and time scales. The main interests during the first SFB phase are, first of all, the water mass formation processes and the circulation of deep waters in the subpolar North Atlantic, their interaction and integral effects, especially with regard to the uptake of anthropogenic CO_2. Second, the variability of the ocean - atmosphere interaction is investigated, and modeling investigations of large-scale aspects and causes of this variability are supplemented by the analysis of fluxes from different meteorological standard models in comparison with observations, with emphasis on the fresh water exchange.

3.2.1 Physical Oceanography during SFB cruises

The western subpolar North Atlantic is a critical region for the climate of the North Atlantic region. Here, strong water mass transformations take place, with far-reaching consequences. This region is formation as well as transformation region of cold water masses, which are exported and as a consequence require northward compensating flow of warm water masses. The deep western boundary current, fed by the Denmark-Strait-Overflow at the lowest level and by the Deep Water from the Gibbs-Fracture-Zone above, flows along the topography in the Labrador Sea and continues past the Grand Banks. Indications exist for a deep cyclonic recirculation cell located between the Grand Banks and the Mid-Atlantic Ridge, its physical explanation is still unclear.

The work on leg M39/2 was related to subproject A3 of the SFB 460. The project focus deals with the variability of watermasses of the subpolar gyre during their passage through the Iceland Basin. Some critical data gaps in observations east of the Reykjanes Ridge and at the depth level of the eastward spreading Labrador Sea Water could be closed. Data collection was concentrated on seven hydrographic sections cutting through the Iceland Basin and the western European

Basin. With one exception all were oriented near-zonally between 60° and 52°N, i.e. between WOCE sections A1 and A2. The latter was occupied again during legs 3 and 5 of METEOR cruise 39. Detailed CTD surveys and the deployment of current meters and RAFOS floats were conducted for long-term observations of Overflow and Labrador Sea Water. The distribution of temperature, salinity, nutrients and CFC tracers were mapped by four sections across the subpolar gyre in the central eastern basin. Properties of Labrador Sea Deep and Overflow Water from the Iceland Faroer Ridge were of importance for the survey. In addition to the section work, two low-energy signal generators and the first RAFOS floats were deployed.

Further work was concentrated at the Middle Atlantic Ridge, where detailed investigation of the spreading paths and transports of overflow water approaching the Gibbs Fracture Zone was conducted. In addition to a number of short hydrographic sections, a group of three current meter moorings, which also include a third signal generator, were deployed. Traditional RAFOS floats and, for the first time, a float park was deployed. The latter array contains a number of independent floats temporarily moored at the sea floor. They will leave their fixed position in a delayed mode after the METEOR has left the site. After release from their moorings these floats ascend to their mission level (appr. 1500 m) of the Labrador Sea Water. The purpose of the float park is to provide a Lagrangian time series of the inflow of Labrador Sea Water into the Iceland Basin. Float missions amount between one and two years.

The SFB program in the northwestern Atlantic began with a "Valdivia"-cruise in summer 1996 and was continued with cruise M39/4. A main water mass of the investigation during M39/4 was the Labrador Sea Water. After its formation in late winter in the central Labrador Sea it seems to circulate along complicated paths in the western basin and crosses the Mid-Atlantic Ridge far into the eastern basin. Only much later the LSW export to the south within the deep western boundary current takes place. The LSW seems to participate also in the recirculation east of the Grand Banks.

Large differences might exist between different years. Further, the flow paths of the LSW are not continuous, but its spreading paths are actually made up by a complicated interaction of eddy transport and mean advection. Until recently it was believed that the exchange of LSW with the water masses of the Irminger Sea takes place on time scales of several years, but recent measurements within WOCE indicated that the LSW can progress within less than a year far into the Irminger Sea.

Recent investigations indicate that convection takes place not only in the central Labrador Sea, but also at its southern margin. The water mass formed there seems to make up the upper part of the deep water export south of New Foundland, and as tracer data show, it moves there faster and more directly than the LSW. In addition, the possibility of convection in the Irminger Sea cannot be excluded. In late winter surface-mixed layers of more than 600 m appear regularly in the Irminger Sea, which forms the Subpolar Mode Water of the North Atlantic. So far, deep convection in this region could not be proved.

The main objective of leg M39/4 was the investigation of the different paths of the deep water circulation in the western subpolar basin of the North Atlantic and its water mass distribution.

Especially the focus was on the outflow of Labrador Sea Water into the western basin and its recirculation. To investigate the water mass transports, profiling current measurements from the ship by the ADCP lowered with the CTD (LADCP) were made. To characterize the water masses, CTD-hydrography and tracer measurements (Freon) and tritium/helium and ^{18}O as well as nutrients and CO_2 measurements were carried out.

To investigate small scale convection processes (“plumes”), ADCP moorings were deployed in the convection regions of the central and southern Labrador Sea. To measure the integral effects of convection, acoustic tomography was used.

The deployment of the Deep Labrador Current (DLC) array was one of the major objectives of project A4 of the SFB 460. The array is designed to determine the transports of the DLC south of Hamilton Bank. The array is oriented perpendicular to the continental slope near 52°51’N, 51°36’W and then northeastward. There the topography is very steep and the measurements from summer 1996 (Valdivia 161) showed a well defined DLC. In addition to the current meters and ADCPs the array also contains several conductivity/temperature probes (SEACATs) to monitor the water mass characteristics in key layers.

3.2.2 Air-sea fluxes

The meteorological aim in the SFB 460 is the investigation of air-sea interaction parameters in the Labrador Sea. Especially the focus is on the variability of surface fluxes and their feedback with ocean deep convection events in this region. The comparison of model results, field experiments and satellite remote sensing data should lead to a better understanding of variability of air-sea fluxes on different time scales.

The METEOR cruise M39/4 was the second field experiment in the context of the SFB 460 in the Labrador Sea region. Data under meteorological winter conditions were sampled on a cruise on the RV Knorr during February and March 1997. The meteorological program on cruise M39 was devided up in two parts. The first part was the collection of data for the eddy correlation calculation of air-sea fluxes. For this purpose high resolution time series of three dimensional wind components, air temperature and humidity are neccesary. The second part of the program was to get atmospheric data for the improvement and development of air-sea flux algorithms for satellite remote sensing applications.

3.2.3 Carbon dioxide system, oxygen, nutrients during SFB-cruises

The determination of the carbon dioxide system parameters total dissolved inorganic carbon and alkalinity and their depth distribution is a prerequisite to understand the carbon cycle. While the nutrient concentrations determined in parallel are mainly used as indicators for water mass properties, the carbon parameters and dissolved oxygen values allow also for the calculation of uptake of anthropogenic carbon into the water column. A significant anthropogenic signal even at greater depth is expected for the study area where the transport of anthropogenic carbon into the Deep Water is achieved mainly through the thermohaline circulation. Another aspect of air-sea carbon exchange is the CO_2 partial pressure difference between surface seawater and the atmosphere. This difference indicates the degree of saturation of the surface waters and allows for the calculation of momentary air-sea exchange fluxes.

On the second and fourth leg of the METEOR cruise 39, the depth distribution of the parameters total dissolved inorganic carbon, alkalinity, nutrient- and dissolved oxygen concentrations were measured at the hydrocast locations. One aspect also was the determination of a baseline to detect variations in later studies within the SFB. In parallel, an automated system to measure CO_2 partial pressure in atmosphere and surface seawater was run during the whole length of both legs.

3.3 Other programs

3.3.1 VEINS programs

VEINS (Variability of Exchanges in the Northern Seas) is an EU-MAST III programme to measure and model the variability of fluxes of water, heat and dissolved matters between the Arctic Ocean and the North Atlantic over a period of three years. It is aimed at developing an efficient observation design to measure time series resolving up to decadal time scales which are considered crucial for advancing our predictive capabilities for shorter term climate changes.

For this purpose VEINS covers four key regions with recording current meters and repeat hydrography. One of these regions is the Denmark Strait (including the Greenland continental slope to the southwest) which was the working area for cruise METEOR 39/5. Here Atlantic input (Irminger Current) and output of polar surface waters (East-Greenland Current) as well as Arctic deep water (overflow) are the components of the exchange between the North Atlantic and the Seas of high latitudes. The measurements east of Greenland during the first part of leg M39/5 were carried out in the context of VEINS. Fourty-three hydrographic stations were taken, six current meter moorings and two Inverted Echo Sounders (IES) were deployed and four moorings and one IES were recovered.

3.3.2 Tracer sampling

a) Helium/Tritium

An extended sample set for on-shore analysis of helium isotopes, tritium concentrations and oxygen isotopes was collected along the cruise tracks of M39/4 and M39/5. In addition to the classical hydrographic parameters these tracer data will provide additional information for water mass analysis: making use of their well known time-dependent input history at the ocean surface the helium/tritium distribution will be used to estimate apparent $^3H/^3He$ ages of the prominent water masses and to determine spreading times and mixing rates. In particular, the interpretation of different tracer distributions characterized by different input histories (such as $^3H/^3He$ and

CFCs) allows to describe mixing processes and to determine the age structure of the water masses. Interpretation of the tritium/helium data obtained will be done in context to the tracer information accomplished during former occupations of the area and will especially refer to the investigations performed during the WOCE cruises M18 (1991) and M30/3 (1994).

Use of $^{18}O/^{16}O$ ratios as oceanographic tracer is based on the fact that isotopic fractionation processes during evaporation and condensation lead to a typical $\delta^{18}O$ signature of different oceanic reservoirs. The $\delta^{18}O$ analysis allows to separate fresh water components e.g. arctic run-off transported by polar water or contributions of melted ice derived from the Greenland ice-shield.

A total of 400 samples for helium isotope and tritium analyses was taken along the cruise track M39/4. The vertical and horizontal resolution of the sampling grid was determined by the topography and the dynamic structures of the water column. Special focus was on the distribution of the Labrador Sea Water as well as on the deep boundary currents resulting in a dense station coverage at the shelf sections of the track (off Labrador, off SW Greenland, off Cape Farewell and off Flemish Cap). Another focus was on the Gibbs Fracture Zone outflow. The helium isotope and tritium analyses will be performed using a sectorfield mass spectrometer at the IUP in Heidelberg. In addition, a total of 145 samples for $^{18}O/^{16}O$ analyses was collected along the cruise track of M39/4. Samples were taken in the upper 600 m of the water column focusing on sections marked by surface boundary currents. The analytical work will be done on shore at the IUP (Heidelberg) after the cruise.

b) delta ^{18}O

As supplement to the tritium, helium and $^{18}O/^{16}O$ samples taken by the Institut für Umweltphysik Heidelberg oxygen-18 (^{18}O) samples were taken during leg M39/4 for two other groups.

^{18}O samples were taken for Robert Houghton at the Lamont Earth Observatory U.S.A. at the legs M39/4 and also M39/5 and for Tim Winters at the University of East Anglia, U.K. during M39/4. ^{18}O samples for Robert Houghton were taken during M39/4 at 6 short near coastal stations of the upper 200 m at the Labrador and Greenland coasts and of the Flemish Cap. In collaboration with Rick Fairbanks, Houghton studies the freshwater balance along the northeast continental margin from Labrador to Georges Bank using oxygen isotope analysis to trace freshwater sources. In the Labrador Sea they are attempting to resolve conflicting estimates of the relative importance of freshwater input via the Baffin Basin and the West Greenland Current.

The ^{18}O samples for Tim Winters were taken at the AR7 section from Labrador to West Greenland and for a short section at the southeastern shelf of Greenland over the full depth range. The samples are for measuring the ^{18}O content of the water in the Labrador Sea. Winters will use an unmixing model to quantify the amounts of the various components of NADW as it flows south in the Deep Western Boundary Current through 50°N. It is intended to utilize ^{18}O content of the water as an extra conservative parameter to identify the relative amounts of source waters in the NADW.

3.3.3 Methane

The overall goal of the methane program is to understand the nature of various processes that influence the distribution of this dissolved gas in the ocean. Methane appears to be slowly consumed in deep waters by oxidation and its concentration in old deep waters is very low. Sources include exchange with the atmosphere, production in the upper few hundred meters of the ocean by a biological process that is not fully understood, and bottom sources where hydrothermal and cold vents occur. In connection with the first of these, the concentration of methane in the atmosphere has varied over time. Proxy measurements made in ice cores indicate that over the last 200 years, the atmospheric methane has risen from about 700 to 1800 ppb volume, and, on a percentage basis, the rise has accelerated during the last decades at a rate faster than the rise of atmospheric CO_2. As has already been observed in other transient tracers such as tritium and chlorofluorocarbons, the changing atmospheric concentration should result in a time dependent net input of methane to the ocean, the signature of which should be observable in recently formed deep waters.

Since the majority of the ocean's deep water is produced in the northern Atlantic, it is an area where the changing atmospheric exchange should influence the distribution of methane most strongly. Research objectives include determination of the concentrations of the dissolved CH_4 in the various water masses of the northwestern Atlantic, particularly in the various sources of North Atlantic Deep Water, and determination of the $^{13}C/^{12}C$ isotope ratio of the dissolved methane. The isotope measurements should provide an indication of the extent of the methane decrease in the water column that is due to oxidation, because this process consumes the lighter isotope preferentially. In contrast, the carbon isotope ratio of methane in the atmosphere has remained nearly constant over time, and changes in the distribution due to varying atmospheric concentration should not strongly affect the isotope ratio in the ocean.

Discrete CH_4 Measurements

Measurements of the dissolved methane concentration in the water column were made from the hydrocast collections during M39/2 and M39/4. In order to conduct these measurements, a new procedure for separating the gas phase from the water was employed. Water from the Niskin bottles is drawn into a 200 ml glass syringe without contact to the air. The syringe is then connected to an evacuated 500 ml bottle. As the water is drawn into this bottle from the syringe, most of the dissolved gas separates from the liquid phase. Altogether, 400 ml of water from 2 syringes is added to each bottle. The gas is now led into an evaculated burette by injecting a degassed brine into the bottom of the sample through a sidearm at atmospheric pressure. At this point, 1 ml of gas is extracted and injected into a gas chromatograph equipped with a flame ionization detector.

The gas remaining in the burette is collected in an evacuated vial for carbon isotopic analysis by mass spectrometry ashore. In addition to the gas samples, on a few stations separate water samples were collected in air free bottles, and these will be returned to the shore-based laboratory for carbon isotope analysis. The dissolved gas in these samples will be stripped using helium, and the trapped methane injected directly into the mass spectrometer. These isotope measurements will be compared to those on the already separated gas samples.

Surface Water pCH_4

Since deep waters are formed from surface waters, one needs to observe whether the atmosphere does indeed tightly control the methane concentration in the open ocean where this formation occurs. The partial pressure of methane in the surface layer of the ocean as well as in the atmosphere was surveyed continuously underway with a gas equilibrator connected to a pump 5 meters below the water line. A sample of the air recirculated in the equilibrator is periodically shunted into a gas chromatograph equipped with a flame-ionization detector. Both the methane and the CO_2 partial pressure were measured, the latter by catalytic convertion to methane. These measurements were also carried out continuously on air pumped from overtop the bridge into the wet lab. The apparatus provides a semi-continuous measurement of the partial pressures in the water every twenty minutes and atmospheric measurements every 40 minutes.

3.3.4 Foraminifera ($\delta^{13}C$ and $\delta^{18}O$ data in foraminifera)

The isotopic signal of carbonate shells of planktonic foraminifera is used to deduce water mass temperatures or climatic changes in the past. However, without knowledge of the influence of biological factors on the isotopic composition of these shells, there is considerable latitude for false interpretation of the data.

Therefore plankton samples at different sites of leg M39/4 should give more information about horizontal and vertical distribution patterns, calcification depth and population dynamics of the foraminifera, *Neogloboquadrina pachyderma* (sin.) (Ehrenberg), an important species in palaeo-oceanography. The values of $\delta^{13}C$ and $\delta^{18}O$ of the foraminifera shells can then be compared with values of the water.

Some specimens of *N. pachyderma (sin.)* will be used for culture experiments under controlled temperature and food conditions in order to gain a palaeo-temperature-equation for low temperature ranges.

On 18 different stations in polar and subpolar water masses plankton samples were taken with a multinet at specific depth intervals (500-300 m, 300-200 m, 200-100 m, 100-50 m, 50-0m). These samples were preserved in ethanol for later inspection.

4 samples were taken for culture experiments. The foraminifera of the species *N. pachyderma* (sin.) were sorted out and held in cell wells containing filtered sea water at a temperature of 4°C (similar to natural environment) Culture medium was changed every week and food (fresh algae cells about 20-64 µm in diameter) was added once a week. The culture experiments themselves will start immediately following this expedition.

3.4 Paleoceanography

The scientific program of R/V METEOR cruise M39/1 concentrated on the history of the North Atlantic's thermohaline circulation during the last glacial period. A primary cruise objective was to monitor the evolution of Mediterranean Outflow Water that today constitutes an important hydrographic component for North Atlantic mid-depth waters. Of special interest were short-term climatic anomalies that occurred sporadically during the last ice age and their effects on the regional circulation. Temperatures in the North Atlantic region rose between 2° and 7°C during these abrupt climatic shifts, and remained high for several 100 to 1000 years. Then they dropped back abruptly - within few 10-100 years - to 'normal' ice age values. These anomalies caused distinctive changes in the North Atlantic's thermohaline circulation: melt water surges flooded the North Atlantic and resulted in an almost complete shut-down of surface water convection and deep water formation. The oceanographic signals that were caused by these anomalies reached the Portuguese margin. Further interest concentrated on benthic growth habitats and carbonate production at the Iberian shelf and Gulf of Cadiz which may serve as an example of extra-tropical carbonate production.

R/V METEOR cruise M39/1 consisted of acoustic surveys of sediment drifts in the Gulf of Cadiz, and a sampling program including sediment sampling along depth transects immediately west of the Gibraltar Strait and at the western Iberian margin as well as plankton hauls and hydrocasts. Shorebased sedimentological and geochemical analyses that will be carried out post-cruise will provide data that are needed to decipher the history of climate change and ocean variability in the northeastern Atlantic in association with changes of climate and ocean circulation in the northern North Atlantic and the Mediterranean Sea.

The intended paleoceanographic and paleoclimatic research depends critically on the quality of the sediment samples. Acoustic surveys that map the sea floor topography and the internal structure of the upper sediment layers are essential to locate coring positions that are suitable for this research and provide continuous and undisturbed sediment records. The combination of R/V METEOR's Hydrosweep and Parasound systems allows integrative mapping of topography and sediment structure which is an important prerequisite to reconstruct current-induced sediment redeposition and erosion, and to detect current patterns - e.g., of Mediterranean Outflow Water in the Gulf of Cadiz. Paleoceanographic proxy-records to be established by using M39/1 sediment samples will include a wide range of biological-micropaleontological and organic and inorganic geochemical parameters. The most viable paleoceanographic proxies are benthic and planktonic foraminiferal community structures, stable oxygen and carbon isotope composition of benthic and planktonic foraminiferal shells and foraminiferal trace element composition that all trace various physical and chemical oceanographic parameters.

Interpretation of paleo-oceanographic time series requires knowledge about how tightly individual proxies are linked to environmental parameters such as water temperature and salinity, and nutrient concentration. To gain better control on the sediment data, continuous water column temperature and salinity profiles as well as profiles of trace element and nutrient concentration provide ground-truth data bases that are essential for calibrating the paleoceanographic proxy-records. Hydrographic surveys using CTD-probes in conjunction with water sampling bottles and separate sets of clean GoFlo bottles for trace-metal water sampling were thus a central research program of R/V METEOR cruise M39/1.

3.4.1 Water Column Profiling: Ground-Truth Data Base for Calibration of Paleoceanographic Proxies

The hydrography of deeper water masses at the Portuguese margin is defined by the advection of North Atlantic Central Water (NACW), Mediterranean Outflow Water (MOW), upper and lower North Atlantic Deep Water (NADW), and Antarctic Bottom Water (AABW) (HARVEY and THEODOROU, 1986; MCCARTNEY, 1992; SCHMITZ and MCCARTNEY, 1993). MOW is the most outstanding hydrographic component in that it comprises a prominent salinity maximum. MOW today enters the North Atlantic with temperature-salinity (T-S) values of 13°C/ 38.4 (HOWE, 1982; , 1975; AMBAR et al., 1976). Potential density of this water is around 37.4 (σ_2=density on 2000 dbar surface), i.e. considerably higher than that of 36.7 for North Atlantic Deep Water (NADW). Rapid mixing with less saline North Atlantic Central Water (T-S=13°/ 35.6; ZENK (1975)) and Labrador Sea Water (LSW, a component of upper NADW; T-S=3°/ 34.85; TALLEY and MCCARTNEY (1982)) that both flow at the depth level of MOW reduces the density of MOW so that it flows northward along the upper Portuguese Margin in an upper (750 m) and lower (1250 m) core layer (ZENK and ARMI, 1990). Immediately west of the Gulf of Cadiz, T-S values for upper and lower MOW are around 12.5°/36.2 and 11.5°/36.4, respectively; northward advection (compared to the 2000 dbar surface) in the upper layer is highest, around 2.73 Sv (1 Sverdrup = 10^6 m^3 s^{-1}), compared to 1.24 Sv in the lower layer (ZENK and ARMI, 1990).

The paleoceanographic evolution of deeper water masses in the Northeast Atlantic has been reconstructed by mapping benthic foraminiferal stable carbon isotope ratios from sediment cores at the Northeast Atlantic continental margin, the open North Atlantic, and the Norwegian-Greenland Seas (BOYLE and KEIGWIN, 1987; ZAHN et al., 1987; DUPLESSY et al., 1988; VEUM et al., 1992; OPPO and LEHMANN, 1993; SARNTHEIN et al., 1994; JUNG, 1996). These studies infer enhanced ventilation of the mid-depth North Atlantic, in response to the formation of a Glacial North Atlantic Intermediate Water (GNAIW, *sensu* DUPLESSY et al. (1988)) or enhanced formation of Upper North Atlantic Deep Water at the expense of Lower North Atlantic Deep Water (BOYLE and KEIGWIN, 1987; SARNTHEIN et al., 1994). Northward advance of AABW far into the northern North Atlantic caused significantly decreased ventilation there at depths below 3500. The net result of the reorganization of vertical water mass architecture in the North Atlantic was a steeper vertical gradient of biologically cycled nutrients between nutrient depleted mid-depth and nutrient-enriched deep and bottom waters.

From this pattern it is concluded that during the last glacial the upper Portuguese margin, at water depth above 1500 m, was influenced by the presence of a well ventilated water mass. Enhanced glacial benthic carbon isotope levels at the upper Moroccan continental margin have been inferred to document a stronger influence of MOW on the North Atlantic mid-depth hydrography (ZAHN et al., 1987). This hypothesis has also been used to explain enhanced benthic carbon isotope values further north, at the Portuguese margin and the Rockall Plateau area in the open northern North Atlantic (SARNTHEIN et al., 1994; JUNG, 1996). Evaluating benthic oxygen isotope in view of equilibrium δ_c fractionation as a function of ambient water temperature and salinity, however, implies that MOW contribution must have been reduced during the last glacial, and that enhanced mid-depth ventilation at the Portuguese margin must have come from a North Atlantic source, similar to today's North Atlantic Central Water (ZAHN et al., 1997).

An important aspect of the M39/1 paleoceanographic work was to collect water column data that will serve as an oceanographic ground-truth data base to better define the paleoceanographic proxy-signals of MOW close to the Strait of Gibraltar i.e., prior to large-scale mixing of MOW with Atlantic waters. T-S profiles in conjunction with water column oxygen, phosphorus and stable oxygen and carbon isotope analyses (as well as water column trace element analysis; see below) will serve as a modern control for the interpretation of paleoceanographic proxy records and their interpretation in terms of glacial-interglacial changes in physical circulation and regional nutrient inventories. To obtain high-quality water samples from paleoceanographically important depth intervals, CTD-derived T-S profiles in conjunction with Rosette and GoFlo water sampling were a central scientific objective of M39/1.

3.4.2 Plankton in Surface Waters off Portugal

Plankton organisms represent the base of the marine trophic chain. Seasonally varying abundances indicate varying bio productivity at the sea surface. During settling to the sea floor, the plankton assemblage changes mainly due to grazing and shell dissolution. Moreover, lateral advection of plankton organisms by ocean currents might as well affect the sedimentary assemblage. A comparative study of plankton at the sea surface and in surface sediments was carried out to shed light on the loss of primary produced material and the loss of species during settling. Analysis of living and the dead (fossil) assemblages and documentation of the autochtonous plankton signal in surface waters and underlying sediments, as well as an evaluation of MOW-related advection/transport of allochtonous plankton was thus an important objective of the cruise.

3.4.3 Benthic Foraminifera: Faunal Composition and Stable Isotopes

Benthic foraminiferal studies are part of an ongoing research project on late Quaternary water mass patterns at the western Iberian margin. Main objectives are to document (i) the impact of sporadic North Atlantic meltwater events on water mass stratification and advection in the northeastern Atlantic during the late Quaternary and (ii) the dynamics of the Mediterranean Outflow Water (MOW) during the last glacial, deglacial, and Holocene. Benthic carbon isotope data from the western Iberian margin document distinct anomalies that are coeval with glacial meltwater events in the open North Atlantic (ZAHN et al., 1997). The data imply that the hydrographic response to sporadic collapses of thermohaline overturn in the northern North Atlantic was felt outside the immediate region of maximum meltwater fluxes i.e., at the Portuguese margin, and may have been of ocean-wide importance. Detailed evaluation of water mass patterns during these events is hindered by a lack of information on the advection history of MOW during the meltwater pulses. M39/1 was designed to retrieve sediment cores close enough to the

Strait of Gibraltar to allow for the documentation of MOW flow in that the proxy-records would trace the source signal of Mediterranean waters at their entrance into the North Atlantic.

The benthic foraminiferal community structure also shows distinct changes of faunistic constituents that are coeval with periods of sporadic thermohaline spin-down (Baas et al., submitted). The faunistic proxies closely complement the isotope data. They need to be refined and calibrated with oceanographic data to corroborate reconstructions of glacial and deglacial deep-water circulation from benthic isotopes (KAIHO, 1994; BAAS et al., submitted). An epibenthic foraminiferal association indicative of recent current MOW advection off southern Portugal is to be traced further towards the MOW source in the Gulf of Cadiz to monitor the response of the biota to higher current strength. The study also needs to be extended further to the north to document the correlation between epibenthic foraminiferal assemblages and the spreading of MOW (SCHÖNFELD, 1997). New surface samples and sediment cores from suitable locations are needed to fill in gaps in the present data sets which inhibit a conclusive interpretation and application of foraminiferal faunal and isotope proxies. Sediment sampling is complemented by water column measurements of oxygen concentration, nutrients, stable isotopes, temperature and salinity of near-bottom waters to provide environmental data for calibration.

An important aspect of this work is the potential influence of porewater chemistry on benthic foraminiferal assemblages. The faunal composition of benthic foraminiferal assemblages in surface sediments is closely linked to organic carbon fluxes to the seafloor (ALTENBACH, 1985; LUTZE and COULBORN, 1984; ALTENBACH et al., 1989). A relation to oxygen concentrations of ambient bottom waters is also indicated (KOUTSOUKOS et al., 1990; HERMELIN, 1992; ALVE, 1995). Species adapted to dysoxic conditions such as *Globobulimina affinis* and *Chilostomella ovoidea* commonly prefer a deep endobenthic microhabitat (CORLISS, 1985), but they appear close to the sediment surface in regions of low-oxic bottom waters and/or of high flux rates of organic matter (HARMAN, 1964; MULLINEAUX and LOHMANN, 1981). A detailed examination of the relation between dysoxic species and pore-water oxygen levels will help to discern the impacts of both environmental factors (LOUBERE, 1997). Only few studies report on depth habitats of *Globobulimina* and oxygen concentrations in ambient pore waters (REIMERS et al., 1992). This is mainly reflects the fact that micropaleontological studies and geochemical measurements are rarely carried on the same sets of sediment samples. Our strategy is to provide *in situ* oxygen data for the same samples that will be used later for analysis of the benthic foraminiferal fauna. For the porewater oxygen measurements we use an oxygen needle-probe and determine pore-water oxygen concentrations in subsurface sediments of that multicorer tube, which was later sampled for benthic foraminiferal depth-habitat studies.

3.4.4 Trace Fossils and Bioturbation as Indicators of Paleo-Environmental Conditions

Trace fossil assemblages are related to environmental conditions at the sediment/water interface e.g., temperature, salinity, oxygen and nutrient concentrations, sediment stability and grain size. Thus, a comparative study of trace fossil assemblages at different water depths is carried out to improve their paleoceanographic application. In particular, the relation of trace fossil changes to MOW-advection changes e.g., in the course of glacial-interglacial climatic cycles, will be studied.

The primary intention is to revise and improve the concept of trace fossils as monitors of environmental change.

3.4.5 Temperate Water Carbonates

Modern and late Quaternary changes of biogenic carbonate production and carbonate accumulation are investigated at the western Iberian continental shelf and margin, and in the Gulf of Cadiz. The response of benthic carbonate organisms to environmental factors such as productivity of surface waters, terrigenous sediment input and redeposition and their relation to the global state of climate are studied. Warm temperate carbonate shelf sediments that are formed under variable upwelling regimes are compared to carbonate sediments in temperate, high boreal, and subarctic shelf settings.

3.4.6 Trace Metals in Calcareous Microorganisms as Paleoceanographic Tracers

a) Cadmium

The distribution of dissolved cadmium is globally correlated with the distribution of biologically cycled nutrients (BOYLE, 1988; FREW and HUNTER, 1992) and is used in paleoceanographic studies in conjunction with benthic $\delta^{13}C$ data as an independent tool to reconstruct past ocean circulation patterns and nutrient inventories (BOYLE, 1994). The great potential of cadmium as a paleoceanographic proxy comes from the fact that - in contrast to $\delta^{13}C$ - Cd is cycled within the ocean only and no "external" pathways are know (except for leaching at some continental slope deposits; FREW, 1995). The ocean carbon cycle, on the other hand, also involves air-sea gas exchange which is associated with carbon isotope fractionation (BROECKER and MAIER-REIMER, 1992). In high latitudes, the isotope fractionation during outgassing or carbon uptake may exceed the biologically-driven "Redfield" $\delta^{13}C$ fractionation and severely hamper extraction of nutrient information from paleoceanographic $\delta^{13}C$ data sets. Cd is not involved in air-sea fluxes and thus, it is considered a faithful recorder of ocean nutrient cycling (ZAHN and KEIR, 1994). Apparent disparities between benthic foraminiferal Cd and $\delta^{13}C$ signals thus bear information on water mass source regions and can be used in paleo-ocean circulation studies as conservative tracers for water mass tracking (LYNCH-STIEGLITZ et al., 1996).

Basin-wide compilation of benthic foraminiferal $\delta^{13}C$ from glacial sections of North Atlantic sediment cores documents large-scale changes in the regional water mass pattern that went along with changes in northern North Atlantic surface ocean conditions (DUPLESSY et al., 1988; SARNTHEIN et al., 1994). The principal change was a shift in depth of the core layer from 3000 m to around 2000 m during the last glacial in response to enhanced buoyancy of convecting water masses. Only in the immediate vicinity of convection, i.e. north of 45°N, did the influence of newly-convected deep waters reach water depths similar to today (SARNTHEIN et al., 1994). At depths below 3000 m, depleted benthic $\delta^{13}C$ values signify an enhanced influx of a chemically aged water mass of presumably Southern Ocean origin (DUPLESSY et al., 1988; SARNTHEIN et al., 1994). Benthic $\delta^{13}C$ records from the upper Portuguese margin, at water depths of 1000-

1200 m, display distinct negative anomalies that were associated with sporadic meltwater events (ZAHN, 1997; ZAHN et al., 1997). The data imply a rapid slow-down of thermohaline circulation in the North Atlantic during these events. Benthic foraminiferal Cd records imply increased nutrient concentrations in ambient mid-depth waters during these periods and thus confirm convective slow-down. The data, however, are inconclusive as to whether these “old” waters originated from the southern hemisphere (e.g., a glacial Antarctic Intermediate Water) or whether limited convection still occurred in the northern North Atlantic.

Water column cadmium analysis in conjunction with the determination of oxygen and phosphorus concentrations was a primary scientific objective of M39/1. The data are intended to provide information on regional Cd distribution in the Gulf of Cadiz and at the western Iberian margin that would allow to calibrate the Cd-to-P relation in the northeastern Atlantic. Special emphasis is on MOW in terms of Cd and nutrients concentrations to better constrain the paleoceanographic patterns observed in sediment cores from the upper Portuguese and Moroccan margins.

b) Strontium, Magnesium

The general objective of this project is to test and improve the application of Sr/Ca and Mg/Ca records of calcareous planktonic and benthic microorganisms as proxies for paleoceanographic reconstructions. Aspects to be addressed are i) processes which determine the uptake of trace metals during biomineralisation in the water column; ii) the influence of diagenetic alteration on trace metal composition of fossil carbonate shells; iii) chemical variability during climatic changes. The western Iberian margin is well suited for these investigations, because: (i) distinct variations of surface water temperature during glacial-interglacial times are documented from the N-Atlantic (BOND et al., 1993), changes that should also be documented in the Mg/Ca signals of planktonic foraminifera off Iberia; (ii) sporadic glacial meltwater events documented by ice-rafted detritus and temperature anomalies (BOND et al., 1992, 1993; MASLIN et al., 1995) induced severe changes in the surface hydrography. Due to a insensivity of the Mg/Ca-ratio to minor salinity changes (NÜRNBERG et al., 1996a), Mg/Ca-time series should primarily reflect temperatures changes, and thus, should help to detect meltwater events when compared to $\delta^{18}O$-data. (iii) Fluctuation of the late Pleistocene Mediterranean outflow, that are documented in marked temperature and salinity anomalies (ZAHN et al., 1987), should have caused distinct chemical signals in the shells of benthic ostracods. The Western Iberian continental slope will therefore serve for a case study to test whether the temperature reconstruction from Mg/Ca-ratios can compete against conventional temperature reconstructions based on stable oxygen isotopes and/ or faunal analysis. Furthermore, the characteristic MOW water properties should be clearly depicted in the shell chemistry of benthic ostracods. A primary goal is to study the relationship between foraminiferal Sr/Ca ratios and Sr-depletion in surface waters to improve the potential of foraminiferal Sr record as paleoceanographic tools. Comparison of trace metal concentration in seawater and benthic ostracods will elucidate if MOW carries a characteristic Mg/Ca signal, and if the signal is picked up by benthic organisms.

3.4.7 Sediment Geochemistry and Mineralogy

The Gulf of Cadiz has been one of the most interesting research areas for the ICM Marine Geology group of Barcelona. In this area, geophysical, geochemical, sedimentological and stratigraphic studies have been carried out, which resulted in a dense grid of seismic profiles and a large number of sediment cores of the eastern part. Here, gas-charged sediments and seafloor pockmarks-like features were recoGnized on the slope area and described in BARAZA and ERCILLA (1996). Furthermore, this work will focus on the impact of the Mediterranean Outflow on the sea floor, e.g. formation of contourites and sea floor bed forms. These processes are either linked to changes of sea level or the strength of the undercurrent itself (NELSON et al., 1993). Moreover, geochemical studies will be carried out to improve our understanding of contamination of suspended particles and surface sediments by heavy metals from mining factories, and its relationship to modern sedimentary processes of the area (PALANQUES et al., 1995; VAN GEEN et al., 1997).

The overall intention is, to study the paleoclimatic record in Pleistocene-Holocene sediments, based on different mineralogical and geochemical parameters. Mineralogically, smectite apparently offers a great paleoceanographic potential. Today, smectite is discharged through the Guedalquiver River into the Gulf of Cadiz, partially even into the Alboran Sea (AUFFRET et al., 1974; GROUSSET et al., 1988; BOZZANO, 1996). Variations of this clay mineral, as recorded in the Alboran Sea cores possibly depend on changes of the Atlantic inflow during the past, a hypothesis, which we intend to verify with sediment cores from the Gulf of Cadiz. An important objective of this study is to follow the path of the smectite track from the Atlantic into the Mediterranean, and improve our understanding of the oceanographic constraints implied in this transfer process.

The main objectives of the geochemical study are to characterize the conditions of past sea surface waters in the Gulf of Cadiz. Based on a high-resolution biomarker studies, the paleoceanographic response in the Gulf of Cadiz to rapid climatic changes in the North Atlantic should be depicted. A second objective is to compare records from the Gulf of Cadiz and the Alboran Sea to elucidate the impact of the inflowing Atlantic water on water mass dynamics in the Alboran Sea. Finally, the Gulf of Cadiz, the Alboran Sea and the Agadir zone are ideally suited for a prospective study of slope-sediment instability. P-wave velocity, density and magnetic susceptibility of regional sediments will also be studied.

4 Narrative of the cruise

4.1 Leg M39/1 (R. Zahn)

The M39/1 scientific party arrived in Las Palmas on 16 April 1997. After the ISO 9002 certification of R/V METEOR was successfully completed, all scientists embarked R/V METEOR the next day. On April 18, 09:00, R/V METEOR left Las Palmas and headed north-north-east to the Gulf of Cadiz. After a transit of 53 hours in good weather and calm seas we reached our first working area in the outer Gulf of Cadiz (Figure 2). Functionality and handling trials were successfully run with the full suite of sediment sampling devices and the CTD/Rosette. During the following 10 days, extensive PARASOUND and HYDROSWEEP surveys were carried out that were followed by sediment and water sampling at 29 sites. The sampling sites were targeted to cover the depth ranges of North Atlantic Central Water, MOW, upper North Atlantic Deep Water (NADW) and uppermost lower NADW. Spectacular temperature and salinity profiles were collected across the MOW flow path at four hydrographic stations and water samples were collected to measure stable isotope, nutrient and trace element compositions of the key water masses.

The second half of the cruise was devoted to sediment and water sampling along the western Iberian margin. 48 sampling stations between Cabo Sao Vincente in the south to Cabo Finisterre up north at water depths from 20 m to > 3000 m were occupied. The shallow stations on the shelf were designed to recover surface carbonate sediments which are to be used to estimated the carbonate production potential on the Portuguese shelf and its influence on the sedimentary regime of the upper continental slope. Core log profiles, namely magnetic susceptibility and color reflectance, along sediment cores from the upper and central slope revealed quasi-cyclic changes of sediment properties that could tentatively be correlated with high-frequency climatic oscillations known from Greenland ice cores. Distinctive positive anomalies in the susceptibility logs further indicated the sporadic incursion of ice rafted debris horizons which have already been documented in sediment cores that were collected during earlier cruises to the area.

The scientific program of M39/1 was completed on 10 May, 13:00. After a 41 hour transit, R/V METEOR arrived in Brest in the early morning hours of 12 May. In total, 78 stations were occupied during the cruise and a rich collection of water and sediment samples, and of hydroacoustic profiles were retrieved. As such, the cruise was successful in that all major scientific objectives were achieved. This success to no small extent was made possible by the ship's master, Kapitän Dirk Kalthoff, his officers and the crew who cooperatively collaborated with the scientists and made our work possible even under difficult conditions. To all of them we owe our sincere thanks.

We are also indebted to the Portuguese and Spanish governments for granting us clearance to carry out our scientific work in their national waters. In particular, we appreciate the good collaboration with the Portuguese naval command and the Spanish ship traffic control that made it possible for us to work in intricate terrain such as major ship traffic areas and at near-shore, shallow water sampling sites.

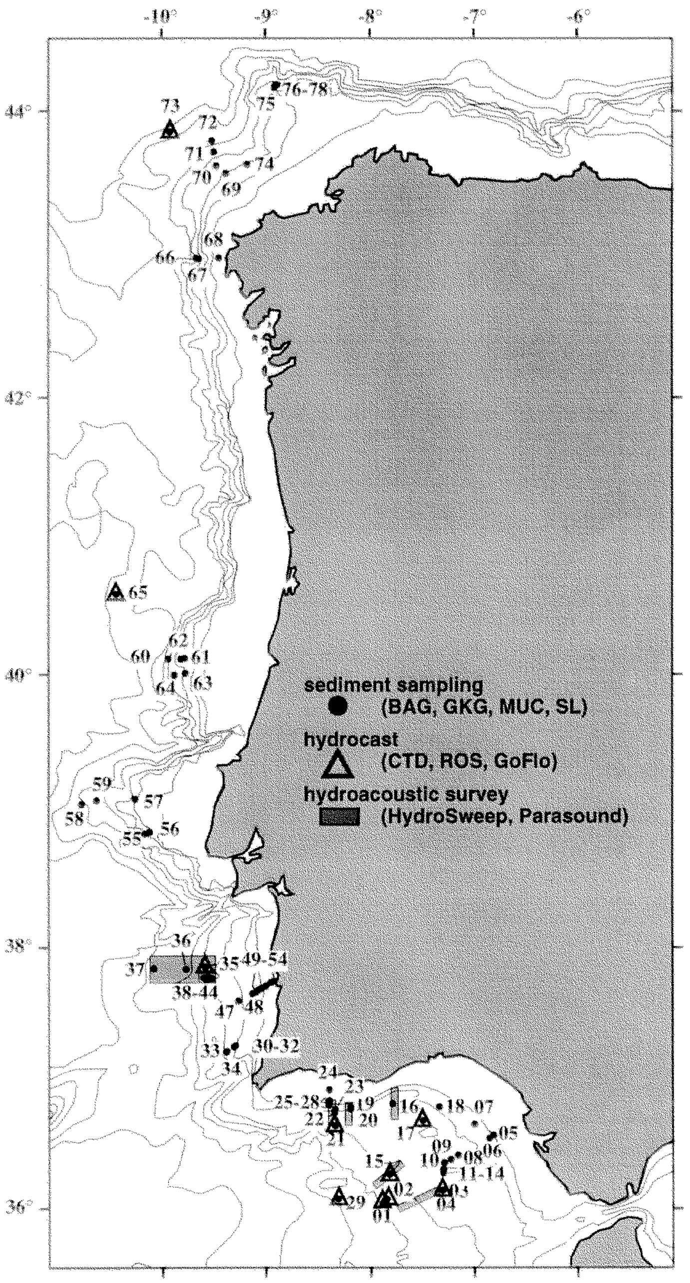

Fig. 2: Location map of M39/1 sediment and water sampling sites in the Gulf of Cadiz and at the western Iberian margin.

4.2 Leg M39/2 Brest - Cork (W. Zenk)

On the evening of the 13 May an informal reception was held for the participants of an Eurofloat meeting at IFREMER together with a number of local representatives from IFREMER and from the *Service Hydrographique et Oceanographique de la Marine* (SHOM).

On the afternoon of the 14th, the majority of cruise participants arrived in Brest and installation of equipment on board started immediately. After initial testing of the chemical instrumentation and of various computer systems was successfully concluded, the METEOR left Brest at 14:00. The next two days we sailed for the starting point of our scientific mission on the northwestern shelf edge of Ireland north of Porcupine Bank. This location was reached on the morning of May 17 on Sta. 200 (see chapter 7, list 7.2.1). An essential test station had been occupied the day before. Starting from the continental slope, METEOR cruised straight (306°) towards the Middle Atlantic Ridge, crossing Rockall Trough, Rockall Bank, and Maury Channel in the Central Iceland Basin (Fig. 3). This first hydrographic Sect. A (Sta. 200-224) was paralleled by a second (B) positioned 230 km southwestward between the Ridge and the southern flank of the Hutton Bank (Sta. 225-232). A third section (C) followed subsequently. It brought us back to the Middle Atlantic Ridge north of Charles Gibbs Fracture Zone (Sta. 240) where METEOR arrived on May 28.

On the initial Sections A-C, 40 full depth CTD stations were occupied, those at Maury Channel (215, 230, 234) being the deepest. With the exception of four stations during strong gale conditions on Sect. A the CTD system included a rosette sampler (RO) and an acoustic Doppler current profiler (LADCP). Two interruptions in the CTD work were necessary to launch moorings IM1 and IM2 (see list 7.2.2). They contain low-energy signal generators, an essential infrastructure for the application of the RAFOS technology (see Fig. 5). Nine RAFOS floats were launched up to May 26 (see list 7.2.3). Over the following 12-24 months they will monitor the spreading of Labrador Sea Water in the Iceland Basin at approximately 1500 m depth.

After reaching Sta.240 we set course on a fourth section (D) with CTD stations 243, 242, 244, 249, 245-248 (see Fig. 3). The non-monotonic station sequence over this section was the result of the difficult weather conditions in the northern West European Basin. It is positioned just north of Charlie Gibbs Fracture Zone where we expected the Overflow Water to still be confined to the eastern flanks of the Reykjanes Ridge before escaping westward through the fracture zone into the Irminger Sea. For this reason, we deployed three current meter moorings (V386, V 387, and V388 [IM3] see list 7.2.2) at this gateway. The array hosts 13 recording instruments and a further RAFOS generator at the depth of the Labrador Sea Water and at several levels below within the Overflow Water. From these long-term current observations we expect continuous records of transport fluctuations at intermediate and near-bottom depths at Gibbs Fracture Zone, the major conduit for watermass exchange in the central North Atlantic.

These efforts were be complemented by the installation of ‘Float Park North’ at Sta. 245, where four RAFOS floats were launched from the METEOR. While one of them descended to its mission depth, the rest have been temporarily moored at the bottom (3170 m) for 2, 4, and 6 months, respectively. The stepped delays of the three new dual-release floats will enable us to establish a modest Lagrangian time-series at the entrance of mid-depth watermasses into the eastern basin (Fig. 4). The latter is a major research topic of the initiative SFB 460 of the University of Kiel. It features the dynamics of the thermohaline circulation variability, thought to be relevant for climate variability.

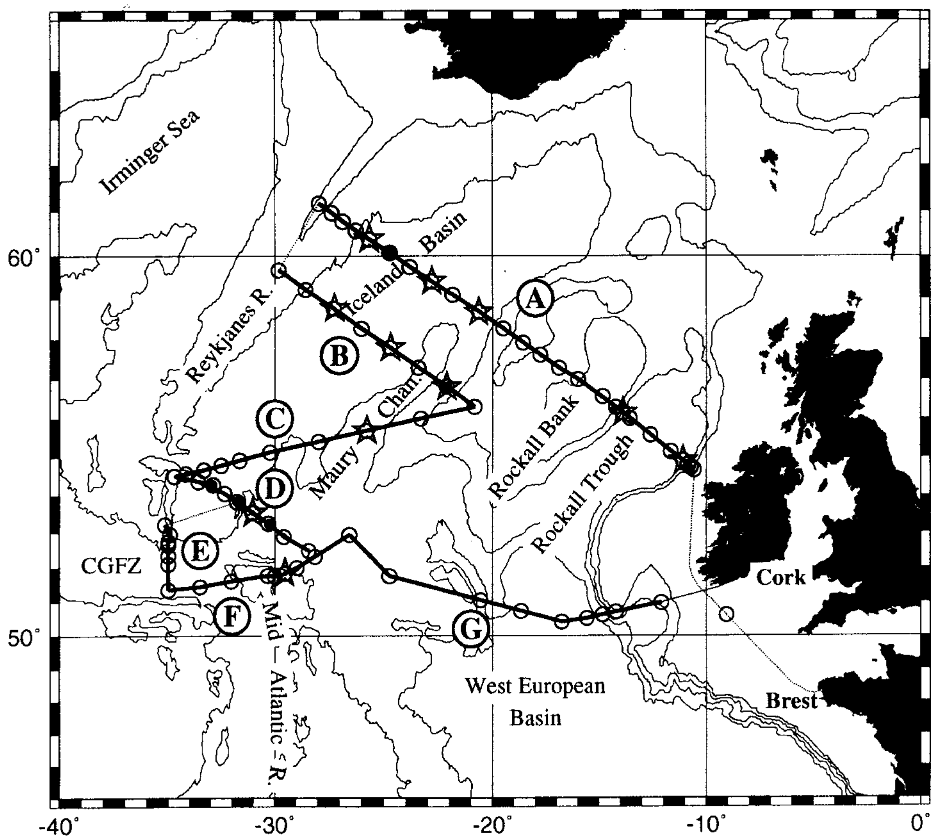

Fig. 3: Geographical setting of METEOR cruise 39/2. Capital letters denominate sections. Hydrographic stations (cf. list 7.2.1) are shown as circles. Stars represent RAFOS float launch positions (cf. list 7.2.3). Dots stand for mooring locations (cf. list 7.2.2).

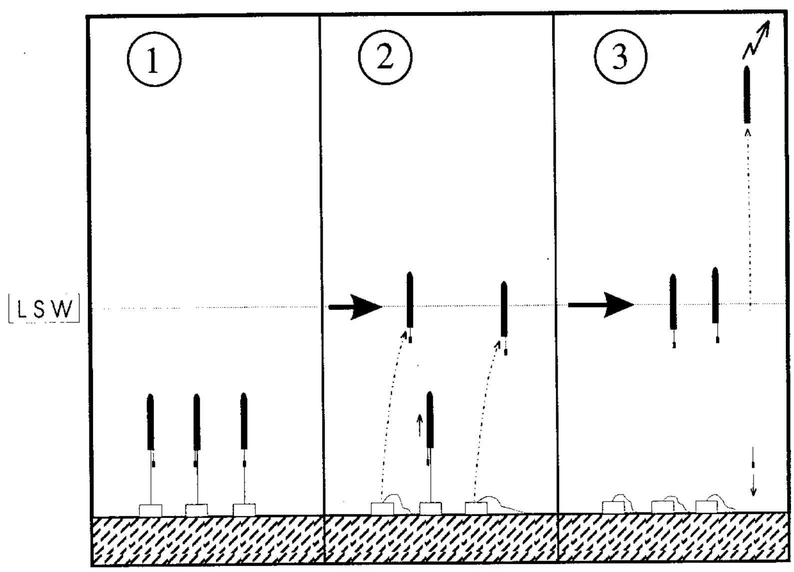

Fig. 4: Principle of the "Float Park" deployed during METEOR cruise 39/2. During phase 1 RAFOS floats with dual-releases are moored temporarily at the bottom. Phase 2 begins with the anchor release. It enables floats to reach their mission level at the Labrador Sea Water (LSW) plume. Finally they drop their balast weight (phase 3), return to the surface and transmit their recorded data. For mission lengths see Table 7.2.3.

After we had lost more than a day due to unfavorable weather conditions with three attempts to occupy Sta. 245 at mooring V387, METEOR cruised towards the Gibbs Fracture Zone on 31 May, where a meridional hydrographic section (E) on 35°W was occupied. It consisted of seven closely spaced deep CTD stations (250-256) and was finished early in the morning on 2 June. Then, METEOR proceeded eastward, initially cutting through the Middle Atlantic Ridge at a nominal latitude of 51°N. During the next two days until 4 June, Sect. F consisting of Sta. 256 to 264, was completed. On Sta. 261, 'Float Park South' was installed (see Fig. 5 and 6). Again, it contains four RAFOS floats of which only one drifts immediately at its mission depth while the rest of the group remains anchored for the next 3, 6, and 9 months. We expect the combination of Sections D, E and F to allow a synoptic budget of the transports of Overflow Waters at the 3-way junction 'Gibbs Fracture Zone'. Furthermore, it is worth noting that the chemists on board detected elevated methane concentrations in the rift valley at Sta. 260, which is situated at the extension of the Middle Atlantic Ridge south of Gibbs Fracture Zone.

Fig. 5: Deployment of RAFOS sound source (IfM Nr. V385) on Station 231.

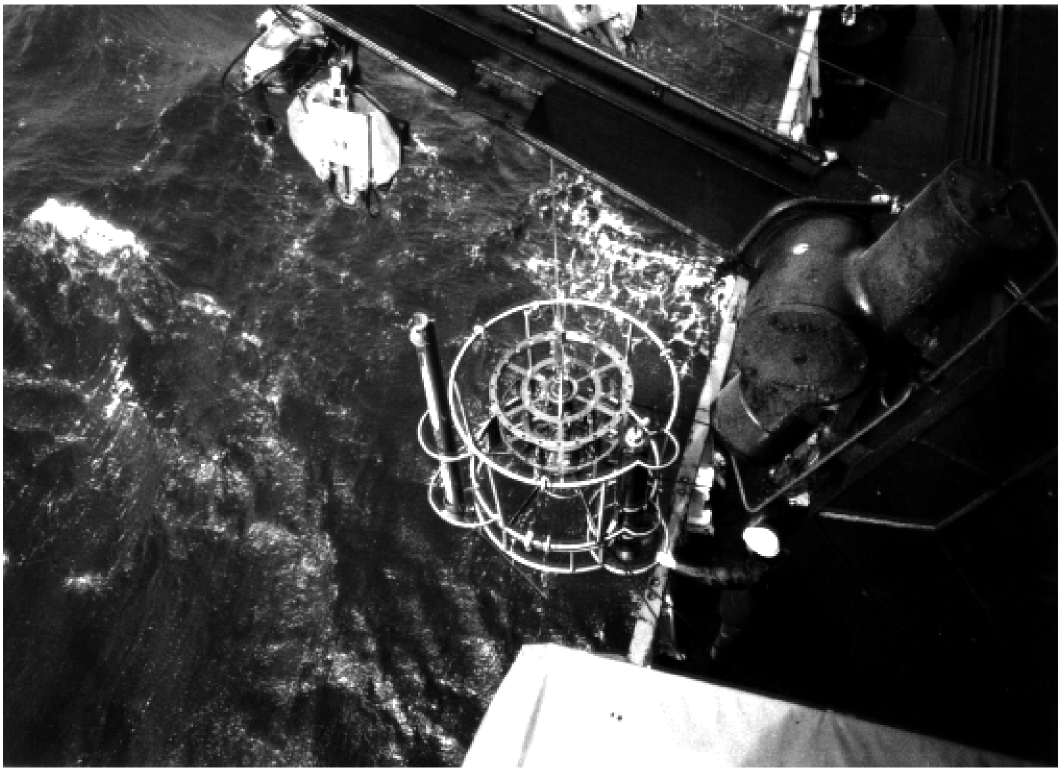

Fig. 6:
Deployment of the CTD probe on Station 261 carrying a RAFOS float to be moored temporaryly in a float park on the ground.

The final Sect. G, with much widerly spaced station intervals, was completed on 7 June. It consists of Sta. 263, 265-271, connecting the Middle Atlantic Ridge with the western approaches of the British Isles. In the afternoon of 7 June, the hydrographic observations were terminated and the METEOR sailed towards Cork. All CTD stations, mooring and float deployments are compiled in lists 7.2.1, 7.2.2 and 7.2.3.

While on passage to the western approaches of Ireland we contacted Prof. L. TALLEY from the Scripps Institution of Oceanography. She and her team had just started their hydrographic work aboard the research vessel KNORR. After the exchange of the latest informations about our observations on the METEOR the American group on the KNORR considered an adjustment of their cruise track in order to optimize the hydrographic coverage of the Iceland Basin on a quasi-synoptic scale in early summer 1997. On an unexpected stop-over of the KNORR we missed our colleagues in the port of Cork by only a few hours.

METEOR cruise 39, leg 2, was completed in Cork, Ireland, on 8 June 1997. Because of tunnel construction work under the *River Lee*, METEOR had to stay the same day at the new ferry terminal outside of Cork. In the afternoon of the next day she moved to *Tivoli* pier, right in the centre of the city. Disembarkation of the scientific party had taken place at the container pier before reaching *Tivoli* pier.

4.3 Leg M39/3 (K. P. Koltermann)

METEOR sailed from Cork, Ireland on 11 June 1997 the single day of Irish weather we encountered in Ireland, rain. A test station (273) was worked on 12 June 1997 in more than 4300 m depth at 49°30´W, 14°´W. Tests of the 36 x 10 l Rosette were not successful. After finally testing the established 24 x 10 l rosette package successfully, a further test station was worked on stat. 274 on 3722 m of water to get blank values for the CFC measurements (274 KAL). The ship worked then the A2 section (Figure 7) onto the European shelf towards East. At all station positions and halfway between stations XBT drop were added to the spatial resolution of the temperature field. In the mean time work on both the 36 x 10 l rosette and the DHI1 CTD was continued. On 14 June 1997 after working the easternmost station of the section (stat. 282) the ship sailed for the position of the second test station (274) to finally take up the section work westward. We used mainly the 24x10 l rosette equipped for the L-ADCP on loan from IfM Kiel. No difficulties were encountered with either rosette, L-ADCP or the CTD NB3. In the mean time the repair work of the other CTDs, planned to be the main stay of this work, left us with the NB3, a MkIIIB and the BSH2 without an oxygen sensor, MKIIIC.

On 20 June 1997 with stat 302 we crossed the Mid-Atlantic Ridge MAR and worked this station at the deepest part of the Rift Valley. There we also deployed the first of three C-PALACE floats, #719. On 21 June the mooring K1 was successfully recovered and another mooring deployed. No damage or losses were incurred. After another hydro station at the site, section work was continued. C-PALACE #720 was deployed on 20 June at stat 304 on the west side of the MAR. The last C-PALACE #718 was successfully launched on 22 June at station 307. The next day the mooring K3 was recovered at dawn and a new mooring deployed. After reaching depths in excess of 4100 m, on stations we deployed first the 24x10 l rosette B24 together with the CTD NB3 for a shallow cast to nominally 1200 m, followed by the deep cast with the 24 x 10 l rosette K24 and the BSH2 CTD, that included the LADCP. Two bottle positions had been sacrificed to incorporate the LADCP. The deep North American Basin was crossed until 29 June. Single cast stations were resumed up the slope towards the tail of the Grand Banks. On 30 June 1997 the last station was worked at 59 m depth.

Rosette work, after settling in on the work packages, was only effected by leakages, slipped O-rings and occasionally leaking spittoons. These leakage problems were the only but quite numerous handicaps in the water sampling. At some time a re-definition of the starting position of the rosette trigger had to be checked and confirmed with deliberate firings on deck. Throughout the cruise, as on all other previous ones, we used the BIO sample numbering scheme. Again, all who did not have previous experiences adopted it right away.

After passage on 1 July towards St John´s, Nfld, METEOR docked on 2 July, 1700 at pier 10. During the passage all wire work was concluded, the ship's measurement systems such as thermo-salinograph, ADCP and underway measurements were stopped when passing the 50 nm limit of Canada.

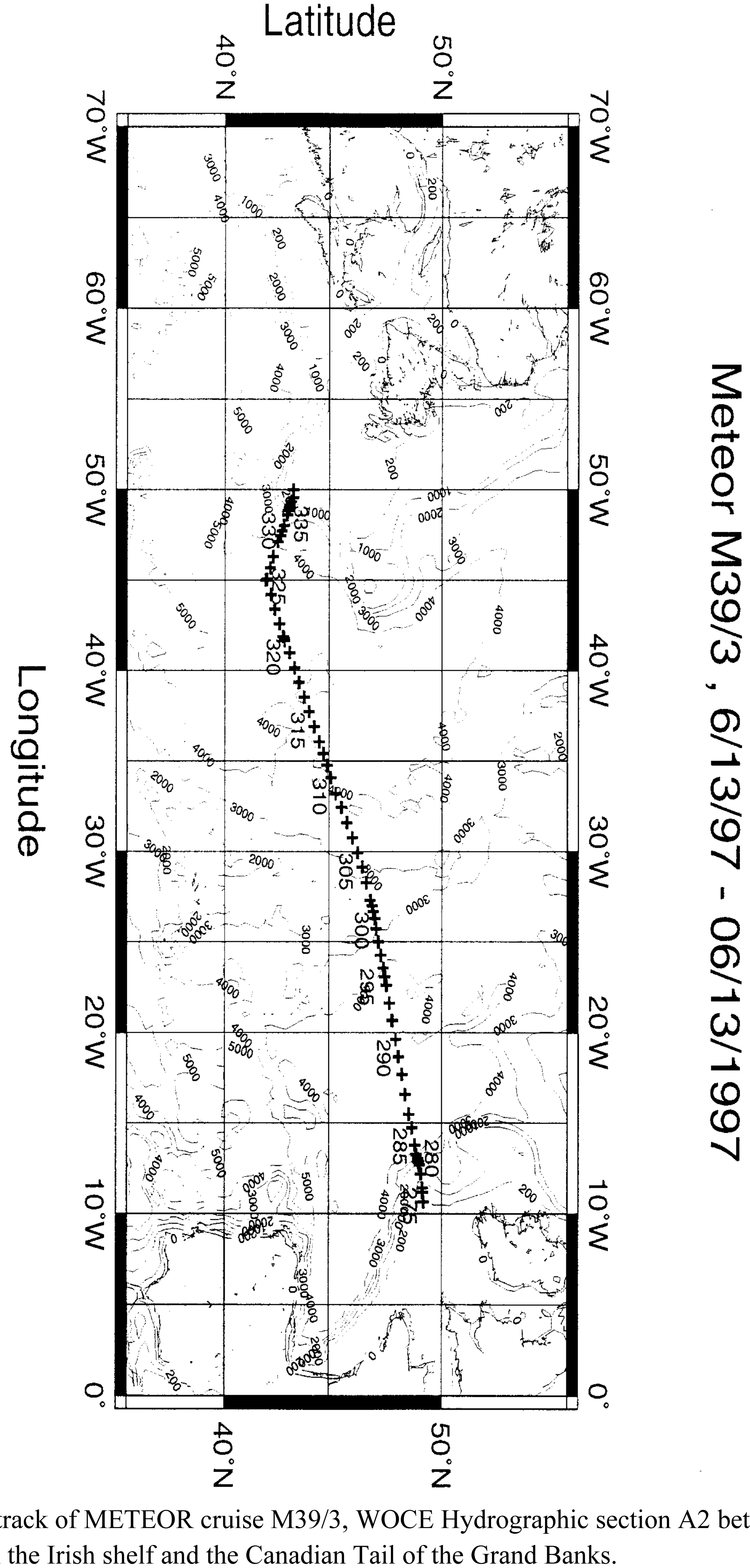

Fig. 7: Cruise track of METEOR cruise M39/3, WOCE Hydrographic section A2 between Goban Spur on the Irish shelf and the Canadian Tail of the Grand Banks.

4.4 Leg M39/4 (F. Schott)

Since cruise leg M39/4 had as an essential objective the retrieval and redeployment of a variety of moorings, it had to be subdivided into two segments with an interim stop on 16 July in St. Anthony, in case last-minute repairs needed to be made on tomography transceivers or convection observing instrumentation. The cruise began in St. John's amidst festivities to celebrate the 500th anniversary of Cabot's crossing with the "Matthews". A Japanese TV camera team escorted the ship out of the port, filming for an educational channel; they passed along a camera to the METEOR for underway filming.

The first part of the cruise repeated the "Valdivia" track of 1996, beginning north of Hamilton Bank along the WOCE line AR7 with retrieving moorings K2, K6 (Fig. 8) that had been deployed in August 1996 by "Valdivia". The moorings were both recovered on 8 July in good condition, thus alleviating fears that deep-reaching icebergs or shelf edge fishery might have jeopardized them. Across the boundary current 3 profiling ALACE floats (PALACE) were deployed to continue our Lagrangian observations across the boundary circulation that were started with deployment of 6 PALACEs in February 1997 by the "Knorr". On 10 July, an Inverted Echosounder (IES) of URI was recovered under unfavourable conditions (insufficient acoustic tracking signals and fog). Working our way northwestward along AR 7 to tomography station K4, this mooring was recovered intact in the evening of 10 July, but two of its transponders only sent weak signals and did not release. Then a southwesterly course was taken, back to the Labrador shelf. On 12 July, tomography mooring K3 and its three navigation transponders were recovered and during 14-20 July the boundary current meter array K7-K16 (Fig. 8) was deployed, while at nighttime CTD/LADCP stations across the Labrador Current were taken. This time period was particularly intense for those of the scientific party dealing with the equipment, since many of the instruments to be used for these deployments (tomotransceivers, acoustic releases, transponders, current meters, seacats) had to be turned around, after just having been retrieved. A special worrysome problem was that the data evaluation of the tomographic stations just recovered indicated that there had been phases of large mooring inclinations. These were larger than experienced anywhere else, although the mean currents in the interior Labrador Sea were small. The effect appeared to be dominantly due to small-scale but deep-reaching energetic eddies, that slowly drifted by a mooring position. One remedy was to increase net buoyancy of the moorings to the absolute limit of wire breaking strength.

On 16 July this first part of M39/4 was terminated according to plan. The quality of the shipboard and lowered ADCP profiles was much improved by the significantly increased navigation accuracy that was made possible by the newly introduced GPS/GLONASS receiver. It reduced the scatter on the GPS positions noticeably, and thus even more on their derivatives which should constitute the ship's motion vector. The new 75 kHz shipboard ADCP had been successfully put to work and routinely yielded depth ranges of more than 500 m except under very rough sea state conditions. A system that did not satisfactorily work when we got on board was the Ashtech direction determination unit. Two reasons were discovered: First, the antenna locations are less than adequate for the purpose and second, a new firmware had been developed by the manufacturer that was not yet installed on the vessel. When we received that by e-mail, the data return improved drastically.

The interim stop in St. Anthony allowed the exchange of a number of personnel (3 departing, 7 coming) and gave a welcome break for those aboard, which was used for an outing to a Viking settlement (“L’Anse aux Meadows”). From St. Anthony METEOR headed northward for deployment of tomography mooring K17 and of the moored cycling CTD (K15, Fig. 8). After deployment of tomography mooring K17 with the heavy HLF-5 sound source it turned out that the station did not operate properly. In the night the mooring was picked up again, a highly commendable effort by the crew who had by now been up and working for long hours. After installation of K15 and K17 this time with a Webb transceiver on 20 July the ship headed to the southeastern end of the WOCE line. Tomography / convection moorings K12 and K11 (Fig. 8) were deployed on 21/22 July and the last of the deployments was K14 on 23 July.

The northern boundary circulation was then investigated with 4 CTD/LADCP stations across the northern end of the WOCE-AR7 line whereupon the ship transited to Cape Farewell, past a beautiful scenery of icebergs and ice floes occupied by seals, to begin profiling the meridional section along 43.5°W. That meridional section away from the boundary was filled with energetic mesoscale eddies, but in order to have enough time for sampling the Gibbs Fracture Zone (GFZ) throughflow and the other deep boundary currents, fairly wide station spacing had to be used until reaching Flemish Cap. There the Labrador Sea Water was found to circulate southeastward offshore, separated by a front from the “Northeast Corner” of the North Atlantic Current.

After another connection section to 35°W, the investigation of the GFZ was begun on 1 August with increasingly closely spaced stations until reaching the main cross-connecting valley. On this approach, the Hydrosweep bottom observations taken on M39/2 could well be used for station planning, even more so since rough weather degraded the quality of our own soundings. The interesting result of that small-scale survey was that much throughflow also seems to originate in a valley a few km north of the main crossroads.

Following the axis of the Mid-Atlantic Ridge (MAR) northward it was found that it carries a deep valley along its crest that might play a role in the interbasin exchange through openings of other cross-ridge valleys in the north. On 6 August, the final transect was begun, running from the MAR to the Greenland coast just north of Cape Farewell (Fig. 8). Dense station spacing across the topographic slopes on both sides covered the deep boundary circulation. This last phase of the work was hampered by strong head wind. The station work was terminated in the night of 8/9 August and the transit to Iceland was commenced. After weeks and weeks of westward winds along this track the winds were now from the northeast, delaying our advance to port somewhat unexpectedly. Leg M39/4 had accomplished its objectives and ended around noon of 11 August in Reykjavik.

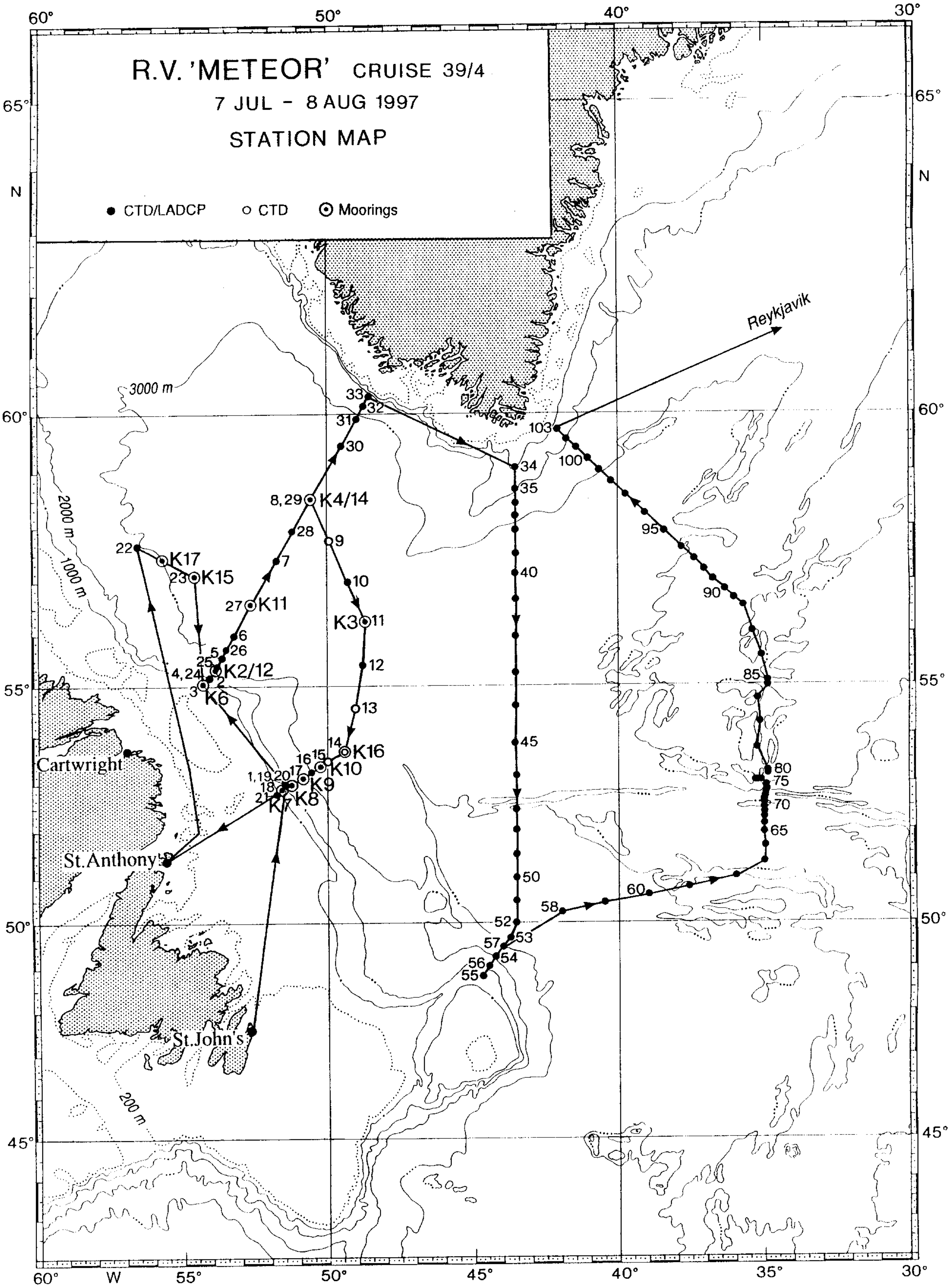

Fig. 8: Cruise track and station map of METEOR leg M39/4.

4.5 Leg M39/5 (A. Sy)

After three days in Reykjavik to exchange the scientific staff and set up the laboratory installations, R.V. METEOR sailed from Reykjavik (Iceland) on 14 August, 09:00 UTC heading for the startup position at 64°45'N, 26°40'W (stat. # 451; Fig. 9). Station work began the same day. The dense station spacing in conjunction with quiet weather facilitated the establishment of the necessary station work routine. We worked 5 short sections down the Greenland slope which covers the range from the cold and fresh East Greenland Current of polar origin to the warm and saline Atlantic water of the Irminger Sea (Fig. 10). During the VEINS part of our programme, which was finished on 24 August, 23:30 UTC (stat # 505), we worked 43 CTD/L-ADCP/Rosette stations, deployed 6 current meter moorings, 2 inverted echo sounders (IES) and recovered 4 moorings and one IES (see station listing 7.5.1, Fig. 9). Unfortunately, the recovery (dredging) of 5 moorings deployed in 1995 and 1996 failed. Stat. # 505 was also used as a test station for a performance check of all 3 CTD systems available.

CTD station work was resumed on 25 August at 07:00 UTC at the western end of the WOCE section A1/E on the eastern Greenland shelf at 60°N, 42.5°W. Because wind and sea conditions (see section 6.5) were moderate throughout, and we encountered no serious technical problems, station work proceeded fast and without any interruptions until 6 September. We were thus in the favourable position of having time to spare, which we used for two additional sections. These were orientated normal to the WOCE section from Eriador Seamount to Hecate Seamount (stat # 537 - 549) and from Lorien Bank to East Thulean Rise (stat # 558 - 563).

From 6 September, 17:00 UTC to 8 September, 04:30 UTC, station work had to be interrupted for the recovery of an ill crew member by an Irish rescue helicopter (MRCC Dublin). After that action and a detour of 360 nm, station work was resumed and the WOCE section was completed successfully on 9 September, 22:30 UTC. METEOR set course for the English Channel and reached Hamburg on 14 September 1997, at 10:00 LT.

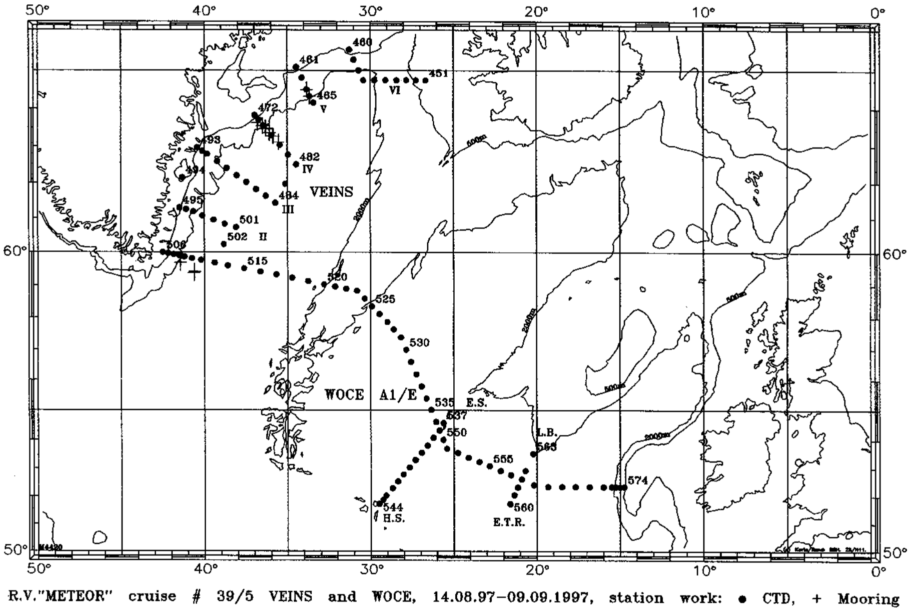

Fig. 9: positions of $CTDO_2$/rosette stations for R.V. METEOR cruise M39/5.

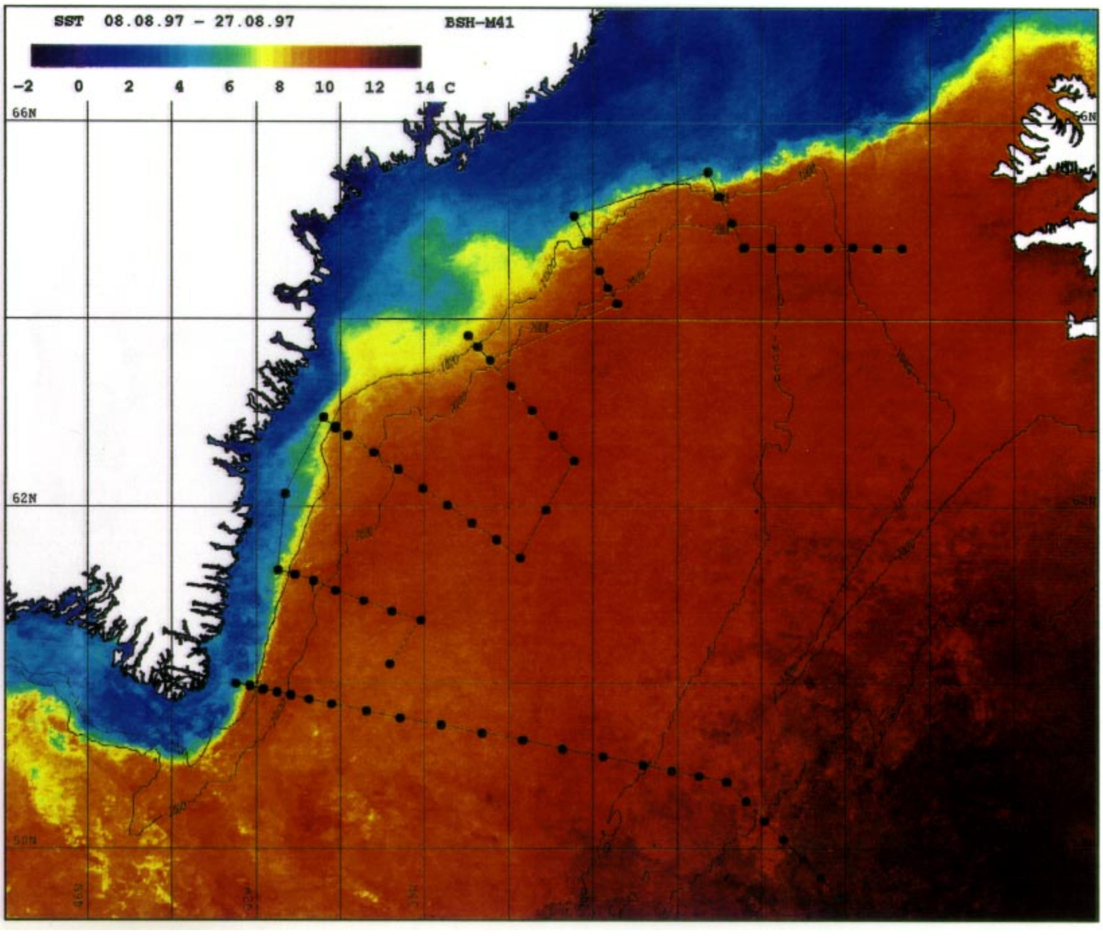

Fig. 10: Irminger Sea SST with M39/5 CTD stations (sea surface temperature composed from NOAA-12 and NOAA-14, 8.8.-27.8.97).