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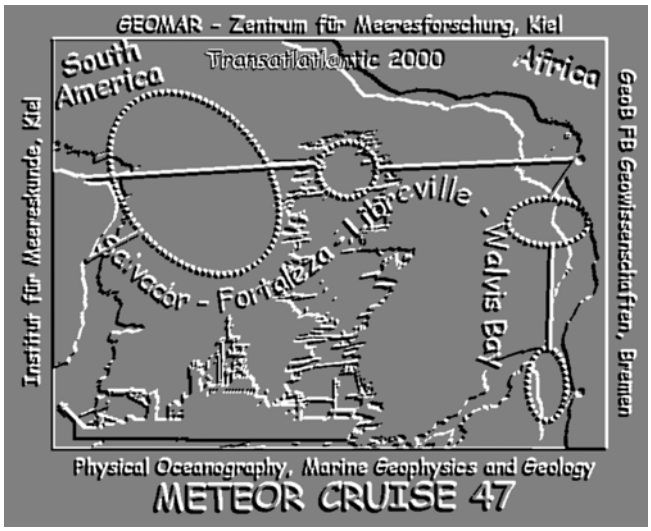
Trans Atlantic 2000

Cruise No. 47

16 March – 3 July 2000



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Abstract

R/V METEOR Cruise M47 was organized to bring together research focused on the Equatorial Atlantic Ocean from very different disciplines as oceanography, geophysics of the ocean crust and reflection seismics combined with marine geology and geochemistry. Three legs were scheduled from March, 16th, 2000 through July, 3rd, 2000, visiting the ports of Salvador and Fortaleza in Brazil, Libreville in Gabon and Walvis Bay in Namibia. The cruise started for leg 1 in Salvador for an oceanographic research program of the *Institut für Meereskunde, Kiel*, to follow the warm water pathways in the western tropical Atlantic. The subsequent leg 2, operated by the *Geomar Institute of Marine Research, Kiel* on the way from Fortaleza to Libreville, applies diverse geophysical methods in the vicinity of the Mid-Atlantic Ridge to investigate the structure of the oceanic crust. The final leg 3 from Libreville to Walvis Bay, combining seismic surveys, geologic sampling and geochemicals analyses of water column and sediment from different working groups of the *Department of Earth Science, University of Bremen*, lead to the southwest African continental margin off the Congo river and off the coast of Namibia to study regional stratigraphy, sediment distribution, fluid migration and early diagenesis. This report summarizes the main research objectives and provides detailed information about the sampling and surveying programs, complimented by preliminary results. The cruise was funded by the *Deutsche Forschungsgemeinschaft* and the *Bundesministerium für Bildung und Forschung*.

Zusammenfassung

Die METEOR Reise M47 wurde organisiert, um verschiedene Forschungsprojekte im äquatorialen Atlantik aus den Disziplinen Ozeanographhie, Geophysik der Ozeankruste und eine Kombination von Reflexionsseismik und mariner Geologie und Geochemie zusammenzuführen. Zwischen dem 16. März 2000 und dem 3. Juli 2000 wurden drei Fahrtabschnitte zwischen den Häfen Salvador und Fortaleza in Brasilien, Libreville in Gabun und Walfisch Bucht in Namibia durchgeführt. Auf dem ersten Fahrtabschnitt, ausgehend von Salvador, wurde ein ozeanographisches Forschungsprogramm des *Instituts für Meereskunde, Kiel*, mit dem Schwerpunkt auf die Warmwassertransporte im westlichen tropischen Atlantik durchgeführt. Auf dem zweiten Fahrtabschnitt wurden vom *GEOMAR Institut für Meeresforschung, Kiel*, auf dem Wege von Fortalzea nach Libreville verschiedene geophysikalische Verfahren eingesetzt, um die Struktur der ozeanischen Kruste an einem Abschnitt des mittelatlantischen Rückens zu untersuchen. Der dritte Fahrtabschnitt des *Fachbereichs Geowissenschaften der Universität Bremen* kombinierte reflexionsseismische Vermessungsarbeiten mit geologischer und geochemischer Beprobung am südwestafrikanischen Kontinentalrand vor der Kongo Mündung und vor Namibia, um Arbeiten zu den Themenkreisen Seismostratigraphie, Sedimentverteilung, Fluidmigration und Frühdiagenese durchzuführen. Dieser Bericht fasst die wichtigsten Arbeitsziele der verschiedenen Arbeitsgruppen zusammen. Er enthält vollständige Listen der Vermessungsprofile, der Stationen und eingesetzten Geräte und fasst erste, an Bord erzielte Ergebnisse zusammen. Die Reise wurde durch die *Deutsche Forschungsgemeinschaft* und das *Bundesministerium für Bildung und Forschung* finanziert.

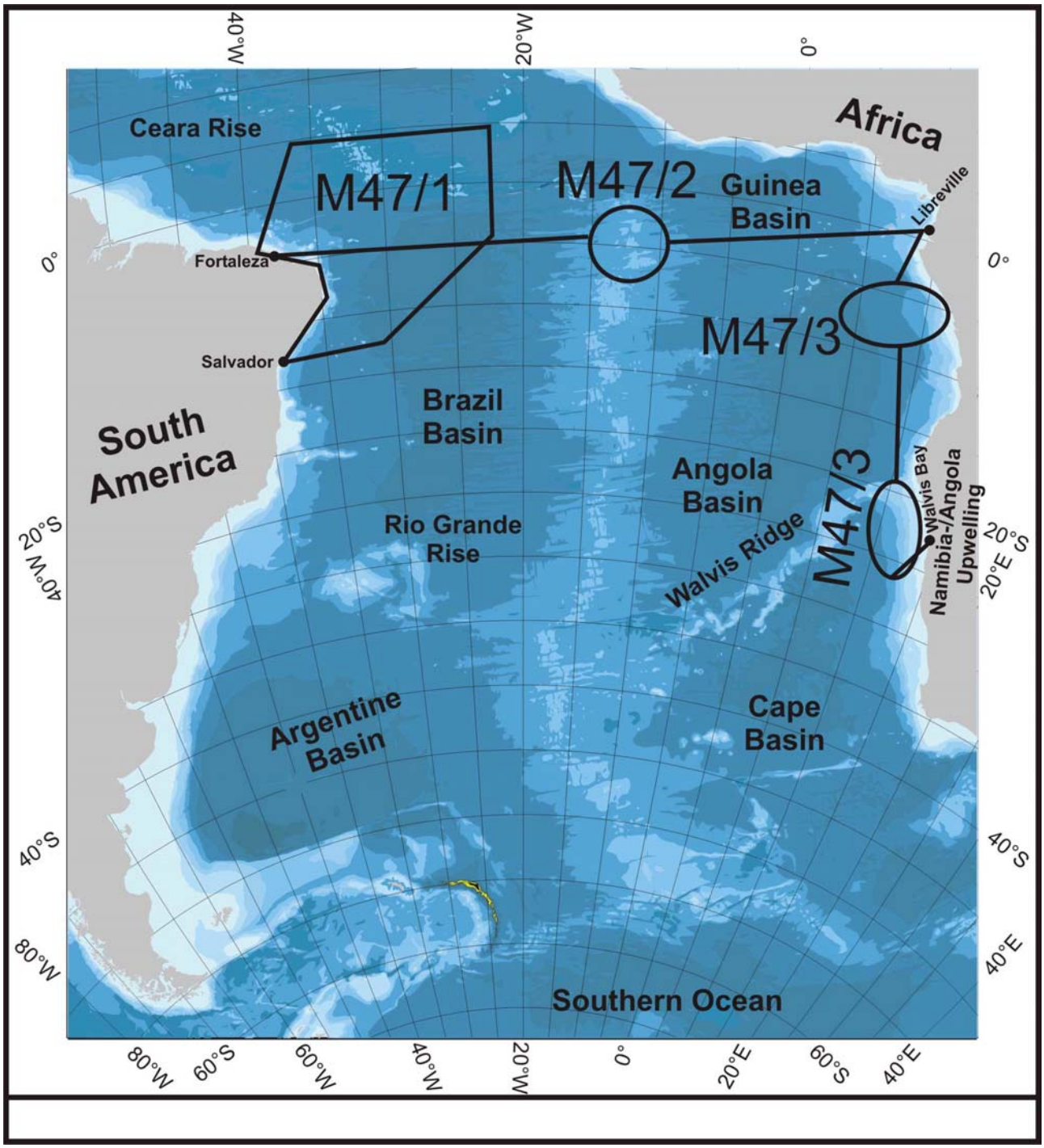

Fig. 1: Working Areas of METEOR Cruise M47 – TransAtlantic 2000 - in the Equatorial and Southwestern Atlantic Ocean.

Research Objectives

Leg 1

The research during **first leg of Cruise M47** was work carried out in the context of the project "tropical-subtropical interaction in the Atlantic Ocean" which is part of the German CLIVAR/marin program. The objectives of the international CLIVAR program are to describe and understand the physical processes responsible for climate variability and predictability at

seasonal, interannual, decadal, and centennial time-scales, through the collection and analysis of observations and the development and application of models of the coupled climate system, in co-operation with other relevant climate-research and observing programs. Within the German CLIVAR/marin program, funded by BMBF, presently 16 projects are funded to investigate climate variability.

The tropical Atlantic Ocean is a critical region for climate variability. Besides several modes of oceanic and atmospheric variability influencing the near-equatorial climate of the Americas and Africa, the tropical Atlantic Ocean is also thought to play an important role in the Thermohaline Circulation (THC) of the North Atlantic. Especially, the poleward transport of water mass anomalies generated in the tropics by ocean-atmosphere interaction under the influence of an increasing greenhouse effect may have an impact on the stability of the THC. Among the presumed modes of interannual and decadal climate variability of the tropical-subtropical Atlantic are the modes of the trade wind zones of both hemispheres and the mode of the equatorial region similar to the El Nino/Southern Oscillation of the Pacific Ocean. The aim of the measurements carried out during M47/1 was to investigate aspects of the variability of the equatorial climate system also in comparison with earlier measurements. As there is an interhemispheric exchange of water masses across the equator from the surface to the ocean bottom, the monitoring of water mass properties in the equatorial region should also allow to assess the variability in their formation region.

More specific objectives to be pursued during cruise M47/1 and with the deployed instrumentation were the following:

Warm water circulation questions:

- coupling of the tropics and subtropics through the shallow tropical-subtropical thermohaline cell and role of anomalies of this coupling for tropical ocean-atmosphere interaction.
- mean pathways and water mass transformation of the warm water spreading of the Atlantic thermohaline circulation in the equatorial zone
- the potential influence of ENSO-effects on the inter-hemispheric exchanges.

The work on the warm water circulation is related in its scientific objectives to the Project Area B of the German CLIVAR/marin program as well as the Principle Research Areas (PRAs) D2 (Tropical Atlantic Variability) and D3 (Atlantic Thermohaline Circulation) of the international CLIVAR-Science Plan.

Deep Water circulation questions:

- Deep Western Boundary Current (DWBC) transports and recirculation
- propagation of anomalies in the upper Deep Water (Labrador Sea Water) which have already been observed further north along the western boundary, and
- circulation and recirculation east of the DWBC as well as the exchange across the Mid Atlantic Ridge with the eastern basin.

The Deep Water Circulation is investigated as a supplement within the context of the former national Deep Sea Research Program (TIEFBIT).

In addition, a Marine Chemistry project carried out bromoform and related chemical measurements during M47/1. The main objectives concerning bromoform degradation are:

- Is nucleophilic substitution by chloride ion the main sink for bromoform in the deep ocean?
- Is it possible to use the relative degree of chloride substitution into bromoform as an index of the isolation time of a water mass?

- Does this substitution process lead to a significant production of chloroform in the deep ocean, and how important is this process for the sea-to-air flux of chloroform and other volatile bromo-chloro compounds?

Leg 2

The formation of oceanic crust at mid-ocean ridges is a three-dimensional time variant process controlled by the interplay of magmatism and tectonics. The ridge axis is divided into individual morphological segments (spreading cells), separated by ridge-axis discontinuities (e.g. transform faults). This global pattern is however not yet fully understood, especially for slow and intermediate spreading rates at which the relative importance of magmatic and tectonic processes are matters of some debate. Two models have been proposed: The *thermal model* and the *mechanical model*.

The thermal model explains the segmentation as a result of the focussing of mantle magma upwelling in the segment centre, and a consequent gradual change in the thermal and mechanical properties of the lithosphere moving towards the edge of the segment. In contrast, the mechanical model suggests that tectonic processes rather than mantle upwelling lead to the ridge-axis segmentation. These tectonic processes lead to the development of major detachment surfaces and intervening zones of crustal construction.

More recent *thermo-mechanical models* combine such detachments with mantle upwelling. In these models, the tectonic thinning of the crust occurs along low-angle, crustal-penetrating detachment faults at the segment ends and leads to the development at the ridge axis of a morphology characteristic of the Atlantic: where the ridge axis meets the active transform fault (or other ride-axis discontinuity) an elevated region is observed, whereas on the opposite side of the ridge axis, adjacent to the inactive fracture zone, the seafloor is much deeper. These are known as " inside corners and "outside corners", respectively.

The thermo-mechanical model explains these morphological effects through the preferential development of detachment faults at the inside corners, where the lithosphere is strongest. Moving towards the middle of a spreading segment, the crust becomes thicker, the lithosphere weaker and large faults disappear. Similarly, those processes cease to be important as the spreading rate increases.

The main objective of the **second leg of Cruise M47** was the investigation of a segment boundary at 5°S on the Mid-Atlantic Ridge to better distinguish between the different models. This region has been selected because satellite gravity data show that this region is relatively undisturbed: The 5°S Fracture Zone separates relatively wide spreading segments and is itself characterised by a single structure with an offset of appx. 50 km.

As a first step during the cruise, ocean bottom hydrophones (OBH) and ocean bottom seismometers (OBS) were deployed to record the microseismicity. Such microearthquakes constrain the location of hypocentres, the source mechanism and the stress field. They will be used to distinguish between tectonic and magmatic activity and hence constrain the existence and activity of detachment faults. Included in the grid of instruments were a few broad-band seismometers to record teleseismic arrivals and thus to constrain local variations in crustal structure.

During the microseismicity experiment, the Hydrosweep swath-bathymetric system installed on R/V Meteor was continuously operated to map the seafloor near the ridge-axis offset. The

detailed bathymetric map will constrain the tectonics of the spreading segment, and is the principal tool with which detachment surfaces and fault blocks have been identified elsewhere. Simultaneously recorded magnetic data shall constrain the spreading history (e.g. spreading rate) and the thickness of the magnetized layer. This is intended to help to distinguish between low velocity serpentinised mantle and oceanic basalts.

A grid of five wide-angle seismic profiles were shot using airguns and OBS or OBH across interesting structures. High resolution single channel reflection data, acquired using a small airgun, were collected in selected locations to image the crust beneath sediment pockets and trace faults into the basement.

Finally, dredge samples were collected from the ridge axis region, since so far only few samples have been collected from the region. Geochemical analyses will allow a comparison of the magmatic variability in this spreading segment with other parts of the Mid-Atlantic Ridge.

Leg 3

For the **third leg of Cruise M47** a variety of scientific objectives were defined to be investigated through the combination of multichannel seismic surveying and geological and geochemical sampling of sediments and water column. Among the major topics were: fluid migration, channel-levee and canyon systems, sediment tectonics, Neogene sedimentation history and seismic imaging of dolomitic layers.

The regions of investigation were located at the African continental slopes in the southern equatorial Atlantic north and south of the Congo Canyon near 5°S as well as the region between Walvis Ridge at 19°40'S and the African continental slope at 25°40'S off Lüderitz in the Namibian upwelling system.

The continental slope off the Congo River was subject to the first part of the ODP (Ocean Drilling Program) Drilling Campaign Leg 175, when 3 drill sites had been visited to study the Quaternary climatic and paleoceanographic history of the region. Due to the proximity of the continental slope north of the Congo Canyon to the mouth of the Congo River as a source of terrigenous sediment input, the sediments serve as a recorder of paleoclimatic signals from land as well as of marine signals. However, calibration of the riverine sediment flux versus the variability of marine productivity and current controlled sediment transport is required to decipher changes in sedimentation rates, provenance and composition as a function of land climate and regional oceanography. Selected seismic lines had been planned across the continental margin to both link the ODP Sites 1075 through 1077 with very high resolution seismic data, superior to the original pre-site survey data, and to reach an areal coverage, which should allow the reconstruction of spatial depositional patterns.

It has been speculated that regional tectonics has controlled the location of terrigenuous sediment sources as rivers and coastal mountain ranges, and the network of seismic lines in the study area was therefore designed to also image depositional patterns, stratigraphy and changes in sediment supply through Neogene times. Furthermore, the role of the Congo Canyon as an efficient trap for coarse sediment within the deep canyon flanks is not very well understood. Nowadays, most of the sand fraction is trapped and transported into the deep sea fan, and only fine-grained sediment in the suspension cloud is released from the Congo river into the region. Seismic lines across and near the canyon as well as selected coring should provide more information on the Holocene sedimentation and its climate control. Precise seismostratigraphic

control should be provided by several crossings of ODP Sites 1075 through 1077 through the subsequent calculation of synthetic seismograms from sediment core data.

It is well known that the continental margin from Gabon to Angola (13°S) is shaped by massive diapirism of salt, creating the steep Angola escarpment, a marginal plateau and local uplift and subsidence on lateral scales of 10's of kilometers. However, a structure as the Angola escarpment seems to be absent in the vicinity of the Congo Canyon, but may have still controlled sediment distribution on the continental margin through episodic uplift of barriers. The seismic survey in the Congo Region was designed to image variations on local and regional scales to develop an understanding of the role of salt tectonism from sediment distribution and fan development.

A major topic of the research carried out during R/V METEOR Cruise M47/3 is related to fluid migration and active venting. Based on few seismic and sediment echosounder data from the R/V SONNE Cruise SO 86 in 1997, areas of apparent focused fluid flow, pockmarks, anomalous amplitude distributions in surface sediments and intense small scale and large scale sediment tectonism was observed north of the Congo Canyon at the continental slope around 3000 m water depth.

A detailed survey and sampling program was designed to identify locations of assumed fluid flow and venting and to characterize both geochemical anomalies and sediments in the vicinity of such venting zones. The GeoB high resolution multichannel seismic systems should be used to gain detailed insights in near-surface structures and processes from digital echosounder and water gun seismic data as well as information from deeper levels through two different GI Guns, ranging in frequency between watergun and conventional seismic sources. Those data are acquired in an alternating trigger mode, which provides simultaneously 4 different seismic data sets on each seismic line, allowing studies on frequency dependent seismic properties and optimum structural imaging at different depth levels.

Another study area was chosen south of the Congo Canyon, where potential fluid migration was studied in an area of intense salt diapirism, which dominates sediment structures and deformation. A local survey was planned in conjunction with selected geologic and geochemical sampling.

As the last part of the research program, seismic surveying was planned along a latitudinal transect between Walvis Ridge at 19°S and the Namibia Upwelling Area off Lüderitz at 25°S. Target of the survey was the occurrence of dolomitic layers, which were drilled in ODP Leg 175 Sites 1081 through 1084. These layers had not been detected in the original seismic site survey data, since the layers were only a few decimeters thick, which was below the seismic resolution. New seismic data acquired with frequencies up to 1 kHz should be more suitable to detect these layers and in particular to map out their distribution as a function of burial depth, water depth and sediment supply as well as their relationship to an intermediate water bottom current, which is also responsible for erosion and the development of small scale mud waves.

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