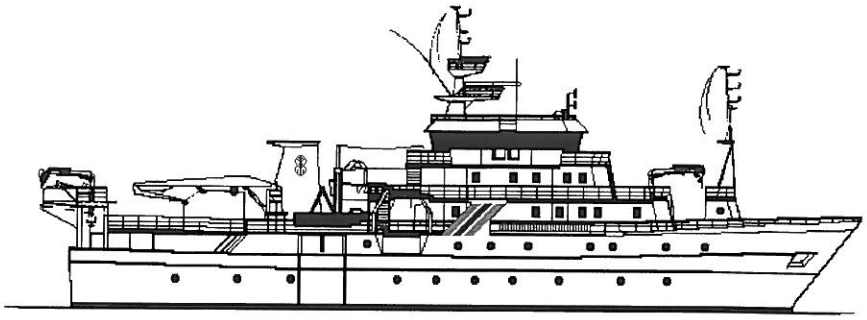

BENEFIT SURVEYS

Cruise Report No 1/97

Survey of the Angola Benguela front and the Angola Dome

4 April - 23 April 1997

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Ministry of Fisheries & Marine Resources
Swakopmund
Namibia

Sea Fisheries Research Institute
Cape Town
South Africa

CRUISE REPORTS "DR. FRIDTJOF NANSEN"

BENEFIT SURVEYS

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4 April - 23 April 1997

by

Tor Gammelsrød, Chris Duncombe Rae, Vianda Filipe, Janet Botha, Bjørnar Ellertsen, Petter Fossum, Rob Cooper, Heidrun Plarre, Anja Risser, Maria de Lourdes Sardhinha, Svein Floen, Tommy Bornman, Margarita Fernandez- Tejedor.

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CHAPTER 1 INTRODUCTION

1.1 Objectives

Scientific aims

An overall goal of BENEFIT is to improve knowledge and understanding of the important commercial stocks, their environments and linkages between the environmental processes and variability in their distribution and abundance. Relating environmental processes and plankton biomass and composition to the commercial fish stocks in the region, like pilchard, sardinella and horse mackerel is of particular interest. For a complete description of the BENEFIT scientific objectives, see the BENEFIT Science Plan (in press).

For this particular cruise the objective was to investigate the physical - biological processes in the Angola - Benguela front and the 'parent' water-masses, and their relations to the fish resources in this region. Of particular interest is the mapping of the fish and plankton distribution to investigate if the front may serve as a nursery area for some species. Also it is of interest to determine if there are differences in the fish stocks structure across the front compared with the northern and southern areas, particularly for horse mackerel, pilchard and sardinella.

On the job training

This took place continuously during the cruise. The use of the various instruments was explained. The observations were explained and discussed, and preliminary scientific interpretations were suggested.

Projects for training

Honours research projects

I) Tommy Bornman

Tommy Bornman, an honours student from the University of Port Elizabeth, is planning on doing a study on the phytoplankton assemblages found in the Angola Benguela front. The following are extracts from his project proposal.

Title

Composition of marine phytoplankton in the Angola Benguela front.

Introduction:

Very few studies have been done on the phytoplankton of the northern Benguela ecosystem. The cruise provides an opportunity to:

1) Sample the northern Benguela
2) Gain experience of marine collection
3) Observe the equipment utilized
4) Assist in the collection of data, i.e. chlorophyll *a* and phytoplankton fluorometry

Methods:

1) On board the ship I will observe, photograph and describe in detail how all the equipment work.
2) I will obtain surface (5 m) water samples using Niskin bottles connected to the CTD. From each station in or near the front I will collect 100 ml of the surface water and preserve the sample in 3% Glutaraldehyde. During the cruise I will collect 15 (100 ml) samples which I will take back to the University of Port Elizabeth for further study. These samples will then be settled and analysed under the Light- and Scanning Electron Microscopes. From the images I will do a species count and determine dominance for the following dinoflagellate; diatoms and flagellates. I will then identify and key out the dinoflagellates and diatoms to genus and species level (if possible) using microscopy.

The results will include the following:

1) Chart of the ship's cruise from 3-23 April, including full details of the voyage and the ship herself.
2) Data on phytoplankton not collected by myself, i.e. vertical profiles of temperature, salinity, oxygen and phytoplankton fluorescence.
3) Lists of species.
   Counts of species.
   Composition of species.

Products:

From the above study I plan to produce the following :

1) A report on the results.
2) Species names and a complete library of the Light- and Scanning Electron micrographs of the dinoflagellates and the diatoms, classified as far as possible.

ii) Ms A van der Westhuizen

A subset of the ichthyoplankton samples were taken on behalf of Ms A van der Westhuizen, who is employed by the Namibian Ministry of Fisheries and is at present completing an Honours degree at the University of Port Elizabeth. This sample set will be used for her Zoology Honours project. Budgetary provision has been made for her to receive training and assistance in the identification of ichthyoplankton in June 1997 (by staff normally involved in southern Benguela work), as study commitments prevented her participation in the cruise. The Plankton Section of the Namibian Ministry of Fisheries is grateful for the opportunity to collect the samples on the RV "Dr. Fridtjof Nansen", and to Dr Fossum for sharing advice and half of the Bongo net samples.

Master degree projects

Vianda Filipe

Vianda Filipe, at IIP, Angola, is planning to do a MSc research project on the Angola Dome. He has already obtained one data set (Dr. Fridtjof Nansen 1/96, 1996), and he wants also to use these data for his thesis. This will mean that only a subset of the Angola Dome data will be made available for general use in the BENEFIT project until he has finished his degree (end of 1999).

Fish and Mammals for South African Museum and Sea Fisheries collection

Separate specimens of fish and possibly mammals (if captured) will be made available. These will be preserved and stored onboard, either by freezing or storing in jars of formalin or alcohol.

1.2 Participation

The scientific staff consisted of:

Name	Field	Institution
Vianda Filipe	Environment	IIP, Angola
Fernando Gombo	Environment	IIP, Angola
Maria de Lourdes Sardinha	Fish	IIP, Angola
Henriette Lutuba	Biology	IIP, Angola
Chris Duncombe Rae	Environment	SFRI, South Africa
Rob Cooper	Fish	SFRI, South Africa
Tommy Bornman	Phytoplankton	Univ. of Port Elizabeth, South Africa
Janet Botha	Phytoplankton	NatMIRC, Namibia
Margarita Fernandez-Tejedor	Zooplankton	NatMIRC, Namibia
Heidrun Plarre	Fish	NatMIRC, Namibia
Tor Gammelsrød	Environment	IMR, Norway
Svein Floen	Technician	IMR, Norway
Terje Haugland	Acoustics	IMR, Norway
Reidar Johannesen	Acoustics	IMR, Norway
Petter Fossum	Ichthyoplankton	IMR, Norway
Bjørnar Ellertsen	Zooplankton	IMR, Norway

1.3 Narrative

The ship left Walvis Bay in the morning on April 4, and steamed northwards along the coast to about Rocky Point where the first leg started at 50 m depth and oriented westwards to investigate the upwelling area and the upwelling front. On this leg at 150 m depth a current meter mooring was deployed. For station positions, see the survey map shown in Fig 1.1 a.

The second leg headed northwards at 350 m depth with the aim of studying the actual Angola Benguela front. At the northern end of this leg the second current meter mooring was deployed.

The third main leg was oriented south-west parallel to the coast at a distance about 80 NM from the coast. A few sections perpendicular to the coast were also obtained. By April 15th the southern current meter mooring was recovered. A main leg in the central part of the investigation area was occupied before retrieving the northern mooring on April 18th.

The ship then continued northwards to survey the Angola Dome area (Fig 1.1 b). Three days was spent in this area before the ship left off for Luanda, arriving there on April 22nd in the afternoon.

1.4 Survey effort

Figures 1 show the cruise tracks with fishing stations and the hydrographic profiles and Table 1 the number of hydrographic, WP-2 hauls, oblique bongo trawls, pelagic and bottom trawl stations.

Table 1 Number of hydrographic (CTD), plankton hauls (Bongo, WP-2), bottom trawl (BT) and pelagic trawl (PT) stations by area.

Area	CTD	Bongo	WP-2	BT	PT
North of the front	24	13	16		1
Across the front	35	21	27	3	2
South of the front	26	7	9	2	3
Angola Dome	36	15	19		
Total	121	56	71	5	6

1.5 About this report

Much emphasize was put on training on this cruise, including how to write scientific reports. In Chapter 2 the various methods utilized are described. Chapter 3 constitutes the bulk part of the report where the results of the measurements are described. In writing up Chapter 3 the various participants started to make interpretations, looking into each other results and comparing existing litterature. We found it convenient not to stop, but rather to stimulate such activities. Therefore we descided to include Chapter 4: Discussion (preliminary), where we moved the parts better suited for a discussion chapter than in the result chapter. Needless to say, the discussion is not complete: the present data set will probably be the base for many publications, ranging from Honour degree work to publications in scientific journals.

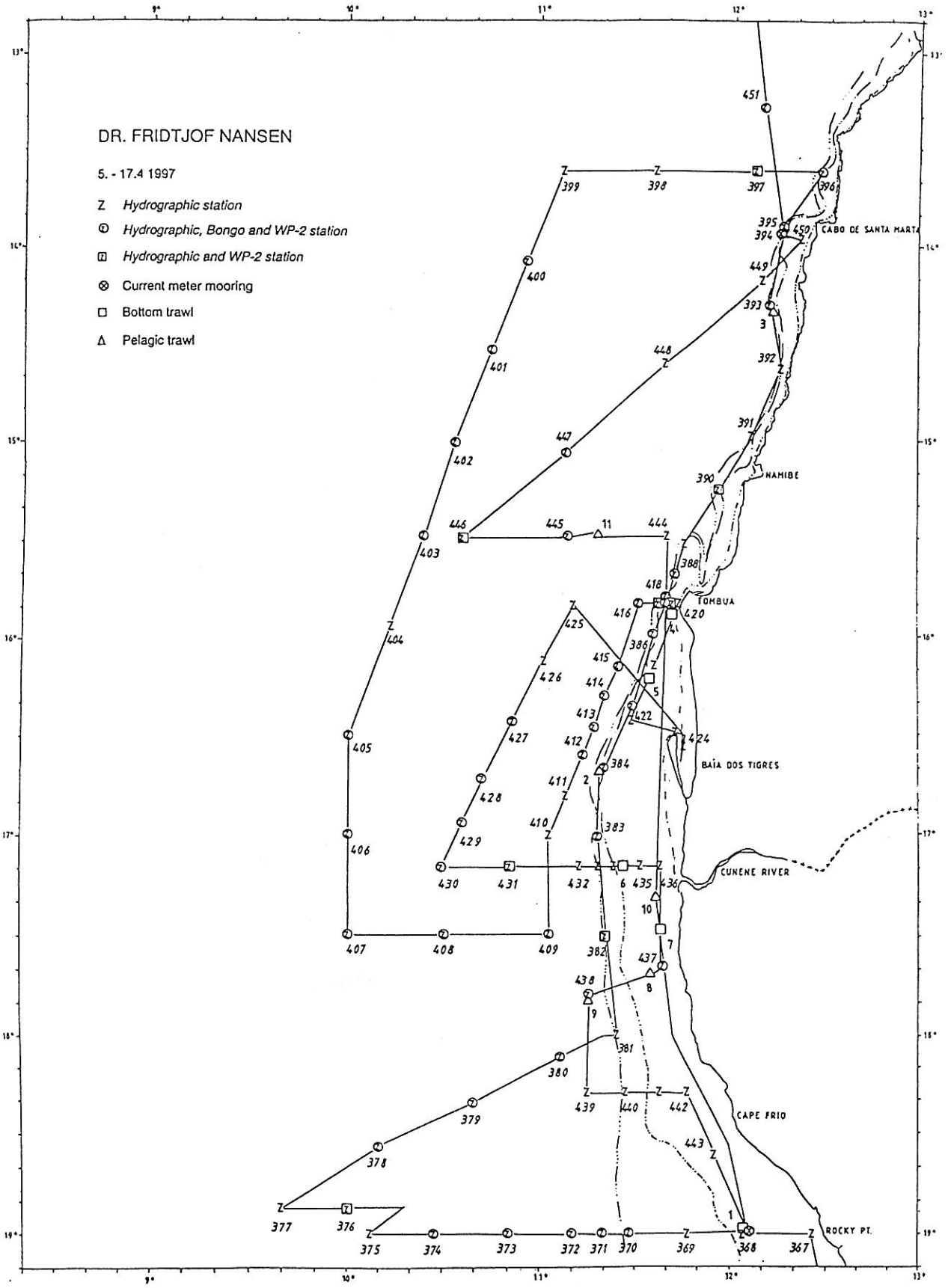

Figure 1.1 a Course track with hydrographic stations, vertical net (WP-2) hauls, Bongo and trawl stations, Angola-Benguela front area.

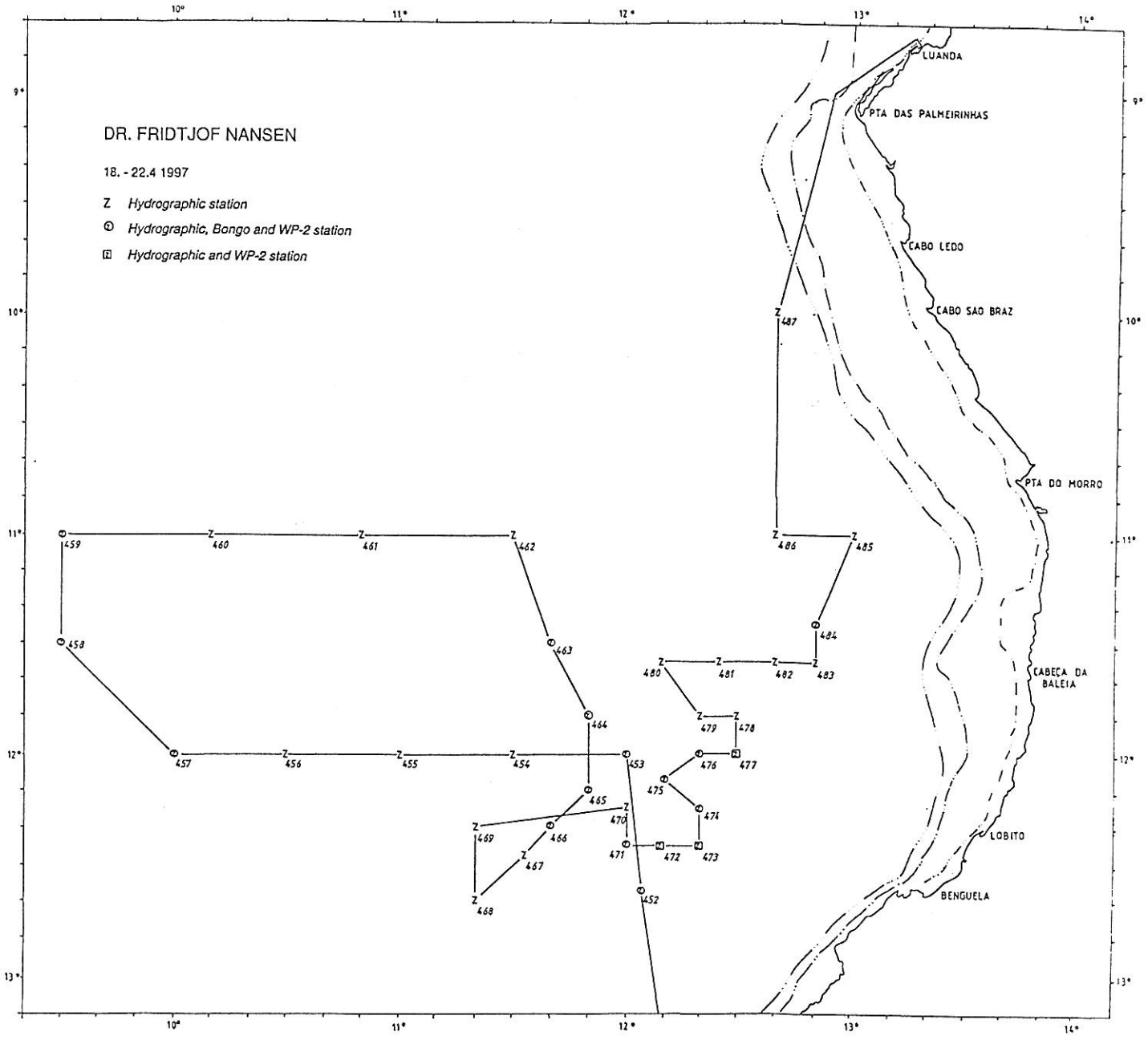

Figure 1.1 b Course track with hydrographic stations, vertical net (WP-2) hauls and Bongo hauls, Angola Dome.

1.6 Scientific background

Physical settings

The seasonal distribution charts of SST between the equator and 30°S given by Shannon and Agenbag (1987) show the existence of a well-developed front intersecting the African coast between 14 °S and 17°S (Lutjeharms and Stockton 1987, Meeuvis and Lutjeharms 1990). The front extends to a depth of at least 200 m, and it is particularly marked in the upper 50 m. The horizontal extent of the front is about 150 to 200 km from the coast (Shannon *et al.* 1987).

Most studies of this front are based on SST obtained by satellites (Meeuvis and Lutjeharms, 1990, Kostianoy 1996). Some investigations on the vertical structure have been performed using historical data bases, but synoptic surveys of the front seem to be sparse. Large scale features were studied by Moroshkin *et al.* (1970) and Bubnov (1972). Dias (1983 a, b) made some near synoptic studies of the vertical structure in the 60's and 70's in Angolan waters. Unfortunately, these studies only covered the northern part of the frontal zone near the mouth of the Cunene River.

The dynamics of the front are poorly understood. It is discussed which parameters are the most important to maintain the front. Meeuvis and Lutjeharms (1990) argue that the opposing flows of the Angola and Benguela Currents is the dominating factor, while Shannon and Nelson (1996) believe that the wind-system must play an important role.

There is also a hypothesis that the dynamics of the front may be determined by the Angola Dome (Shannon *et al.* 1987). The Angola Dome is a cyclonic eddy first documented by Mazeika (1967). On a recent survey it was found in a position near 12°S and 11°E (Filipe, 1996). It is also believed that the high productivity in the Angola Dome contributes to the oxygen minimum layer found along the Namibian coast (Chapman and Shannon, 1985).

Links to biology

To what extent this region acts as physical barrier for zoo- and ichthyoplankton is of special interest in the investigations. Kostianoy (1996) found that the Angola Benguela Frontal Zone (ABFZ) is a classic example of a multifrontal system, as it consists of a number of high gradient regions divided by waters with slowly changing characteristics (temperature). Zooplankton recordings in the parent water masses and in the frontal region is therefore of particular interest.

Ignyatev (1996) found that the macroplankton showed large horizontal spatial variability with regard to abundance and biomass in the frontal zone of the Benguela current, different water masses also gave rise to a varying vertical distribution. This phenomenon will also be a subject for the present investigation. However, in this pilot study large sampling devices like pelagic trawls a.o. will not be used, which will reduce the efficiency of sampling larger zooplankton organisms like adult euphausiids, etc.

One of the most important copepods, *Calanoides carinatus*, is found both south and north of the A-B front. This copepod population consists of two counterparts, surface and deep, the deep part being a diapauseal stock. Due to the loss of releasing mechanisms for the WP-2 net the vertical distribution of *Calanoides carinatus* and the other zooplankton organisms could not be investigated. The vertical distribution will be subject for later investigations.

Preliminary genetic investigations indicate that the Cunene and Cape horse mackerels should be considered as separated species, not subspecies (Sardinha, 1996). There seems to be two different populations of the Cunene species. One is probably related with the Benguela ecosystem and the other one with the Angola system.

The species distribution and dynamics of phytoplankton in the Benguela system has been studied by several investigators over the years, and from the literature it would appear that the Benguela is generally a diatom-dominated system (Shannon and Pillar, 1986). The apparent dominance of diatoms might possibly be due to the methods of sample collection and examination used in the past. In some studies net tows were used and in others, were bottle samples were examined, high magnifications were not employed, with the result that the nanoplankton were totally overlooked (Shannon and Pillar, 1986). Recent studies have indicated that high populations of coccolithophorids and microflagelates are found in the northern Benguela (Shannon and Pillar, 1986).

CHAPTER 2 METHODS

2.1 Physical oceanography

CTD measurements

A Seabird 911 CTD was used to obtain vertical profiles of temperature, salinity, oxygen and fluorescence. The fluorometer was made by Chelsea, and equipped with a housing which tolerates 6000 m. Real time and logging was done using the Seabird Seasave software installed on a PC. The profiles was taken down to a few meters above the bottom, but not deeper than 1500 m due to the capacity of the CTD cable.

Up to 12 Niskin bottles were triggered for water samples on each station, one near the bottom, one near the surface, and the other bottles for nutrient and phytoplankton samples taken at different levels.

The samples were analysed for salinity using a Guildline Portasal salinometer, and the oxygen content was determined using the Winkler method. These results were used to calibrate the CTD values.

For oxygen 137 samples were accepted for the calibration. A linear regression gave the following formula for correcting the oxygen values:

$$O_2 = O_{2CTD} * 1.018 + 0.327$$

The standard deviation of the calibration was 0.13.

For salinity 173 calibration samples were used. The average difference between laboratory and CTD values was 0.03 with a standard deviation of 0.007. Therefore the salinity values from the CTD were corrected according to the formula

$$S = S_{CTD} - 0.030$$

It should be noticed that these calibrations only were obtained at the end of the cruise, and the results presented in this preliminary report have to be adjusted accordingly in the final version. The vertical sections were plotted using the PC program package CTD-SECTION developed by Andersen *et al.* (1997a). The horizontal distribution maps were constructed using the Underway Mapping System (UMS) supported by Sea Fisheries Research Institute, Cape Town, South Africa (Zauner, 1993).

Current meter mooring

Two current meter rigs consisting of 2 Aanderaa RCM7 current meters and a WLR8 pressure gauge on one of the moorings was deployed. One mooring was anchored at about 150 m depth near Rocky Point, 18° 59.5'S, 1205.9E, on April 5 and recovered on April 15. This depth is chosen to reduce the risk of the rig being captured by a trawler, as trawling is prohibited inside the 200 m isobath in Namibian waters. The second mooring was anchored near Cabo de Santa Maria at 13° 56.8S, 12°16.5E also at 150 m depth . The registration period for this mooring was April 10 to April 18.

At each mooring the upper current meter was positioned at 25 m depth and the second at 125 m depth. Each current meter is equipped with pressure, temperature and conductivity sensors, thus allowing to compute the salinity. The data was recorded every 10 minutes. The data were analysed using a PC program package developed by Andersen *et al.*(1997b).

ADCP current measurements

A ship borne Acoustic Doppler Current Profiler (ADCP) from RD Instruments was activated while underway and on every CTD station. In situations where the ship was changing heading frequently (e.g. trawling) or using the thrusters excessively to maintain station (occasional bongo or net stations) the ADCP was stopped. The ADCP was set to ping every 8 seconds, the depth cell was chosen to 8 m and the number of cells to 50. As a routine the data was stored on files. The data was analysed by the PC software UMS (Zauner, 1993).

Calibration of the ADCP compass setting

The procedure for setting up the compass heading offset as outlined in Alan Boyd's notes was followed, adjusting the setting to read the same as the heading from the ship's gyro. It will be noted, however, that when the vessel is in shallow water (ie, when bottom can be logged by the ADCP), the same current when measured relative to bottom has a different direction when plotted

relative to navigation. This difference is often negligible but can be as much as two or three degrees. This error is due to lag times in the display of ADCP and gyro data when setting up the heading offset and the short-term variations in the ships heading relative to ground induced by pitch and roll. In an attempt to eliminate this error the following procedure was followed.

While the ship was steaming along a relatively constant isobath, shallow enough to be tracked by the ADCP (in this case ±80 m), on a relatively constant heading (332T), at a constant speed (10 knots), ensembles were collected by the ADCP over the period of more than an hour.

At the beginning and end of the transect, the position was noted from the GPS. These points were laid off and the heading over ground for the sample period was determined.

For each ensemble collected (14) during the sample period, the speed and heading determined by the ADCP from the bottom tracking were recorded, and averaged.

The two headings obtained were compared and found to differ by 2.36°. The compass heading offset was adjusted accordingly, and the new calibration checked by observing the difference between ship's heading relative to navigation and bottom for a further three ensembles. The difference was now negligible (<0.2°).

Table of calibration results:
Start position: 21°25.103' S; 13°28.857' E
End position: 21°15.067' S; 13°34.992' E

Course laid out: 330.34°

Readings over section: 333, 332, 332, 332, 333, 333, 333, 333, 333, 333, 333, 333, 333, 332

Average course over section: 332.7°

Adjustment to course = -2.36°

Meteorological observations

Wind (direction and speed), air temperature, global radiation and sea surface temperature (SST) (5 m depth) was logged automatically every nautical mile using an Aanderaa meteorological station.

A computer program was developed during the cruise (SF) to transfer the meteorological data to UMS format. The data were presented using the UMS program package (Zauner 1993).

Remote sensing data

The University of Cape Town (Scarla Weeks) provided real-time NOAA AVHRR high resolution images for the period of 1 April to 12 May. The area coverage was 12-23°S, 5-15°E. Via INMARSAT B the SST images were retrieved from Institut Für Ostseeforschung Warnemünde, Germany (IOW) (Bernd Schlichting) and transmitted to a PC onboard where colour prints of the images were made. For safe transmission the GIF format images were sent uuencoded and later uudecoded on the PC after transmission. The transmission speed was 9600 baud and the typical transmission time was 2 minutes for a 90K image.

2.2 Phytoplankton

Phytoplankton composition/ID

Samples of near-surface sea water were taken (36 x 100 ml samples) together with the chlorophyll samples discussed below. They were preserved (3% gluteraldehyde) for the identification of phytoplankton. The work will be done using the Light- and Electron microscopes of the University of Port Elizabeth, Botany Department. Fifteen of the samples will be analysed for an Honours project (by TB), the rest of the samples will be identified on a contract basis for the Namibian Ministry of Fisheries.

Phytoplankton biomass

Pigment extraction

Algal biomass is commonly estimated by the chemical extraction of chlorophyll$_a$ from harvested cells. It is not feasible to monitor algal biomass of large areas effectively by such time-consuming extracts, so remote methods (such as *in situ* and satellite biomass estimations) are usually combined with chlorophyll$_a$ analyses.

Water samples were collected from Niskin bottles into sample-rinsed, blackened polyethylene bottles. Most of these samples were taken at night and filtered soon after collection (some of the samples collected during off-shifts were filtered after a few hours delay). The cells were harvested using 0.45 µm pore size Sartorius cellulose nitrate filters, coated with a buffered pre-filter of magnesium carbonate (see Smith *et al.*, 1981). During filtration low vacuum was maintained to prevent the breakage of the algal cells.

Although it is known that some other solvents (e.g. methanol) are more efficient in the extraction of pigments (see e.g. Sartory, 1982), 90% acetone was used as solvent because of its efficiency for most types of algae (Environmental Protection Agency, 1992) and the wide spread publication of acetone-extracted chlorophyll values. Because of the known sensitivity of chlorophyll extracts to light degradation, it was strived to maintain subdued light when exposing the extracts. As we have found that sonication improves extraction in our waters, the filters in the solvent were given 10 minutes ultrasonic treatment. The extracts were allowed to steep for 24 hours in a freezer and thereafter clarified by centrifugation.

The chlorophyll concentration of such extracts can be determined by several methods (such as spectrophotometry, HPLC). A Turner Designs Model 10-AU Fluorometer calibrated for discrete sampling was used for this cruise. Fluorescence is measured after excitation of the chlorophyll molecules with blue light. (The methodology is discussed in e.g. Findenegg, 1974; JGOFS Protocols,1994; Riemann, 1976; Smith et al., 1981 and UNESCO, 1980.) The fluorometric method is sensitive and purported to be an improvement on the old spectrophotometric method, but in our rich waters we have found that quenching at higher concentrations necessitates many dilutions (for this reason only 50 ml sea water is filtered).

Chlorophyll$_a$ standard solutions made up from Sigma Chemicals' C-5753 were used to calibrate the fluorometer up to the upper limit of the linear dynamic range for the instrumentation (250 µg

chl_a per litre extract - Environmental Protection Agency, 1992). The instrument was zeroed using 90% acetone. After reading the fluorescence, the significant fluorescence caused by phaeopigments was corrected for by acidifying the sample with 0.1N HCl (which converts all of the $chlorophyll_a$ to phaeopigments). By applying a measured conversion for the relative strength of chlorophyll and phaeopigment fluorescence, the two fluorescence values (before and after acidification) are used to calculate $chlorophyll_a$ and phaeopigment concentrations.

Because of the sensitivity of the chlorophyll procedure to acidity, the labware has to be kept acid-free. This was done by soaking the labware in laboratory grade acid-free detergent (Contrad) and final rinsing in distilled water and acetone.

In situ fluorescence depth profiles

During this cruise *in situ* fluorescence depth profiles were obtained by lowering a Chelsea Aquatracka III *in situ* fluorosensor attached to the Sea-Bird SBE 9 11 CTD. Concomitant use of *in vivo* P.A.R. light sensors with fluorometer sensors increases the value of fluorescence data considerably, because of the relationship between irradiance and primary productivity. However, the use of a P.A.R. light sensor is limited by its depth (pressure) sensitivity and its requirement for daylight sampling. During this cruise, it was therefore decided not to employ a light sensor.

Continuous near-surface *In vivo* fluorescence measurements

Additional to the depth profiles of fluorescence, the scientific sea water system was used to pump sea water on a continuous basis through a Turner Designs Model 10-AU Fluorometer rigged in flow-through mode. This instrument has to be dissembled and cleaned of deposits sporadically. The external PC data logging capacity was not employed, because of complications in concomitant position logging.

In situ / In vivo fluorescence shows severe limitations in replacing chlorophyll analyses, this will be discussed later. Pigment analyses have to be done to calibrate the *In situ / In vivo* readings.

Particle size analysis (with Cell counts)

100 ml samples (collected with the chlorophyll samples) were preserved with Borax-buffered 5 % formaldehyde for biomass estimation by particle counts, and for particle size analysis. If the

Namibian Coulter Counter can not be repaired for this work, application will be made for the work to be done on a contract basis.

Southern Benguela researchers are testing the hypothesis that the plankton community size structure is influencing the success of the different clupeoid spp. Whereas anchovy show markedly higher clearance rates on particles larger than 580 μm (max. dimension), pilchard are more efficient at removing smaller particles (see e.g. van der Lingen, 1994 and Verheye *et al.*, 1993). The zooplankton community structure, too, is affected by the phytoplankton size spectrum. Small copepods are favoured when small algal cells dominate, this in turn would affect the pelagic fish (see Huggett, 1993 and Verheye *et al.*, 1993).

2.3 Zooplankton

Sampling

Vertical hauls were performed with a WP-2 net from 200 m depth to surface, or 10 m above bottom to surface at shallower stations. The net was equipped with 200 µm mesh. A 15 kg lead below the cod end provided the weight needed when the net was lowered. The speed during lowering the net was 1 m per second, when hauling 0.5 m per s.

A meter block was used to ensure that the similar length of wire was put during all stations, and deviations of the wire >30° from the vertical line was not accepted. The net was not equipped with flow-meters. With few exceptions the WP-2 sampling was performed between sunset and sunrise.

Handling of sample

Most samples were divided into two equal parts by means of a Folsom plankton splitter. One part was preserved in 4 % formaldehyde for later species identification.

The other half was prepared for biomass (DW) analyses.

The sample was filtered through 2000, 1000, and 200 µm gauze by careful rinsing with sea water. The organisms retained at each filter were thereafter rinsed with fresh water in order not to add the weight of salt to the dry weight obtained, and transferred to pre-weighed aluminium trays. Euphausiids and fish retained at the 2000 µm filter were further transferred to two separate trays,

and most euphausiids were identified to species. All trays were transferred to a drying oven, and the samples let to dry at 65°C for 24 hours, until a constant weight is obtained.

In a few cases when the sample was voluminous due to large amounts of diatoms, another subsampling procedure had to be followed. The volume of the total sample was measured, and after homogenizing the sample by thorough stirring, a known volume usually 1 liter, was put aside for further subsampling for preservation and biomass analyses, respectively.

Special organisms observed during the subsampling or filtering process was further analysed under the microscope as part of the job training, and their characteristics were commented, f.i. the surface dwelling blue copepod *Labidocera* sp., the pelagic amphipod *Phronima* sp. living in dead salps, various pteropods, the pleustonic insect *Halobates* sp. etc.

Zooplankton organisms from the Bongo net will also be used for identification, especially large specimens as euphausiids which are not sampled quantitatively or qualitatively in the slow moving WP-2 net.

2.4 Ichthyoplankton

Oblique Bongo (60; 0.28 m^2) hauls were performed from the surface to 20 m above the bottom or to 200 m if the depth was above 220 m. This sampling took place on each night station (18:00 hours to 06:00 hours) during the whole cruise to reduce avoidance of larger ichthyoplankton organisms. Additional sampling took occasionally place during day time. A depressor was placed below the Bongo to provide the weight needed when the net was lowered. The speed of the winch during lowering and hauling was 0.5 m s^{-1}, the speed of the ship was 1.25 m s^{-1} during this operation.

The Bongo (60) were equipped with one net with 375 µm mesh size and another with 180 µm mesh size. The sample from the 180 µm net were preserved in formalin and will later be worked up as a part of the Honours Research Project earlier mentioned. The sample from the 375 µm was investigated for ichthyoplankton. These were preserved in ethanol for later morphological and otolith microstructure investigations in Bergen. Growth characteristics and birth date frequencies of the ichthyoplankton will be related to the physical and biological properties of the different watermasses. The larvae will be identified in cooperation with the Honours Research Project. The micro-structure investigation will be performed according to the method described

in Andersen and Mokness (1988) where the hatch check, number of rings and increment widths are logged directly on a Mac-computer.

2.5 Fish sampling

Abundance estimation

The catches were sampled for species composition, by weight and numbers. Biological samples, i.e. length, weight compositions and otholits were taken for the target species. Records of fishing stations are presented in Annex I. Pooled length frequency distributions of selected species by area, are shown in Annex II.

A description of the acoustic instruments and their standard settings is given in Annex III. This also includes a description of the fishing gear used.

The following target strength (TS) function was applied to convert s_A-values (mean integrator value for a given area) to number of fish (pilchard, sardinella and Cunene horse mackerel):

$$TS = 20 \log L - 72 \; dB \qquad (1)$$

or in the form

$$C_F = 1.26 \cdot 10^6 \cdot L^{-2} \qquad (2)$$

where L is total length and C_F is the fish conversion factor. The following formula was used to calculate the number of fish in length groups (cm) for each fish concentration:

$$N_i = A \cdot S_A \cdot \frac{p_i}{\sum_{i=1}^{n} \frac{p_i}{C_{Fi}}} \qquad (3)$$

where:
N_i = number of fish in length group i
A = area (naut.miles^2) of fish concentration
S_A = mean integrator value in area (A)

p_i = proportion of fish in length group I in samples from the area

C_{fi} = fish conversion factor for length group i

The number per length group (N_i) was then summed and the total number of fish obtained:

$$N=\sum_{i=1}^{n} N_i \qquad (4)$$

The length distribution of a given species within an area was computed by weighing the length frequencies obtained in each trawl sample within the area by the average s_A value attributed to that species in the 5 mile where the sample was taken.

In the case of co-occurrence of *Sardinella aurita* and *S. maderensis* (these species cannot be separated in the echo traces), the respective contribution to the S_A value attributed to the 'sardinella' category was split in accordance with their presence in weight in the trawl catches. The biomass of fish per length group (B_i) was calculated by applying their condition factor observed mean weights per length group (W_i) multiplied by number of fish in the same length groups (N_i). The total biomass in each area was obtained by summing the biomass of each length group:

$$B=\sum_{i=1}^{n} N_i \bar{W}_i \qquad (5)$$

The number and biomass per length group in each concentration were at last summed to obtain the totals for each region. The mean integrator values in each sampling unit (s_A-values) were divided between the following categories of fish on the basis of trawl catches and characteristics of the echo traces:

- sardinella (*S. aurita* and *S. maderensis*)
- horse mackerel (*T. trecae and T. capensis*)
- pilchard
- round herring
- anchovy
- big-eye grunt (*Brachydeuterus auritus*)
- P2 (carangids, scombrids, barracudas and hairtails)
- other demersal fish
- plankton

Biological sampling

Total length and body weight were recorded for horse mackerel (*Trachurus trecae* and *T. capensis*) to the nearest 1 cm or 1 g below, respectively. Sex and reproductive stages were described by macroscopic examination, scoring each individually sampled fish according to the following categories:

1	Juvenile
2	Inactive
3	Active
4	Ripe
5	Running/ Spent

Pairs of otoliths were taken in ten individuals of horse mackerel per length group of 1 cm in each station were the species occurred. To extract the otoliths, a frontal head cut was made at the level of the top of the eye.

Specimen collection for SAM and SFRI

Specimens of fishes and cephalopods captured in both the trawling and zooplankton operations were kept. Most specimens were photographed and all were preserved by freezing. Each sample was appropriately labelled and placed in individual plastic bags.

No marine mammals were captured during trawling operations.

2.6 Nutrients

It was decided that nutrient samples would be collected at each CTD station and a full set analysed by the Namibian Ministry of Fisheries. In order to promote comparability of samples collected regionally, two other subsets of nutrients would be collected at selected stations, for analysis in Norway and Angola. These subsets would be processed by the methodology usually employed by the Angolan Instituto de Investigação Pesqueira and by the Norwegian Institute of Marine Research. (The choice whether or not to filter the nutrient samples after collection seems to present the main difference in analysis regionally.)

The procedure involving filtration which was followed for the Namibian analyses, is outlined in Annex II. The Angolan and Norwegian samples were not filtered. The Angolan samples were placed into a freezer immediately after collection, and the Norwegian samples were preserved with chloroform and refrigerated. A total of 149 nutrient samples were collected for the methodology comparison, this included samples from areas rich in particulates, where filtration could be expected to have the greatest effect.

CTD nutrient samples were taken at the following depths (in m): near surface (5), 30, 100, 200, 300, 500, near bottom. A total of 641 samples were obtained.

CHAPTER 3 RESULTS

3.1 Oceanography

THE ANGOLA - BENGUELA FRONT

Horizontal distribution

The horizontal distribution of SST at the surface (5 m depth) shown in Fig.3.1 clearly reveals the ABF. It is seen as maximum temperature gradient forming a tongue like shape. It leaves the coast near Tombua, where it is replaced by cold, upwelling water. The warm Angola water penetrates further south to the latitude of River Cunene (~17°S) where it meets colder water from the Benguela Current. This cold, newly upwelled water was penetrating further west, making a mushroom shaped signature of cold water embedded by warmer water as it was leaving the coast. This structure is confirmed by a satellite picture obtained April 11th, i.e in the middle of the survey (Fig.3.2).

The Sea Surface Salinity (SSS) showed the same structure (Fig.3.3) as the SST, the warm Angolan current water is associated with higher (S>36psu) salinity.

Even at greater depth the front may be identified as shown in the temperature (Fig. 3.4) and salinity (Fig. 3.5) distributions at 50 m depth.

An oxygen minimum is usually found in these waters at 300 - 400 m depth . The distribution of O_2 at 350 m is shown in Fig. 3.6. Two separate oxygen minima (<0.5ml/l) are observed. One associated with the front region on the shelf outside Baía dos Tigres and northwards to Namibe, and another in connection with the Benguela Current water. The oxygen content remained low (~1 ml/l) at this level in the whole investigation area, except outside the upwelling front in the SW corner.

Acoustic Doppler Current Profiler (ADCP)

The unfiltered raw ADCP data are shown in the figures. Data are shown from four depth bins: 18 m bin (Fig 3.7a), 34 m bin (Fig 3.7b), 50 m bin (Fig3.7c) and 74 m bin (Fig 3.7d). The 18 m depth bin is above the thermocline in the surface mixed layer at about 50% of the stations in the

survey area, while the 34 m bin lies generally within the upper intense thermocline. The 50 m and 74 m are below the thermocline at most stations.

The ADCP currents seem to be rather barotropic. Fig. 3.7 indicates strong southerly flow (40 to 60 cm/s) along the shelf edge to the north of the surface temperature front, indicating the presence of the Angolan Current. Along the front, off Cunene mouth, the flow turns westward, decreasing in intensity as it moves away from the shelf. Away from the shelf edge and the front, flow tends to be more variable tending northward. South of Cunene the flow is northward to westward at this level, showing the northern circulation of the Benguela Current.

Similar current patterns are seen in the deeper levels with the magnitude decreasing with increasing depth.

Wind observations

Results from the wind registrations are shown in Fig. 3.8. The wind was usually between 10 and 20 knots, and seldom above 30 knots. The wind direction was remarkably constant during the survey from SSW.

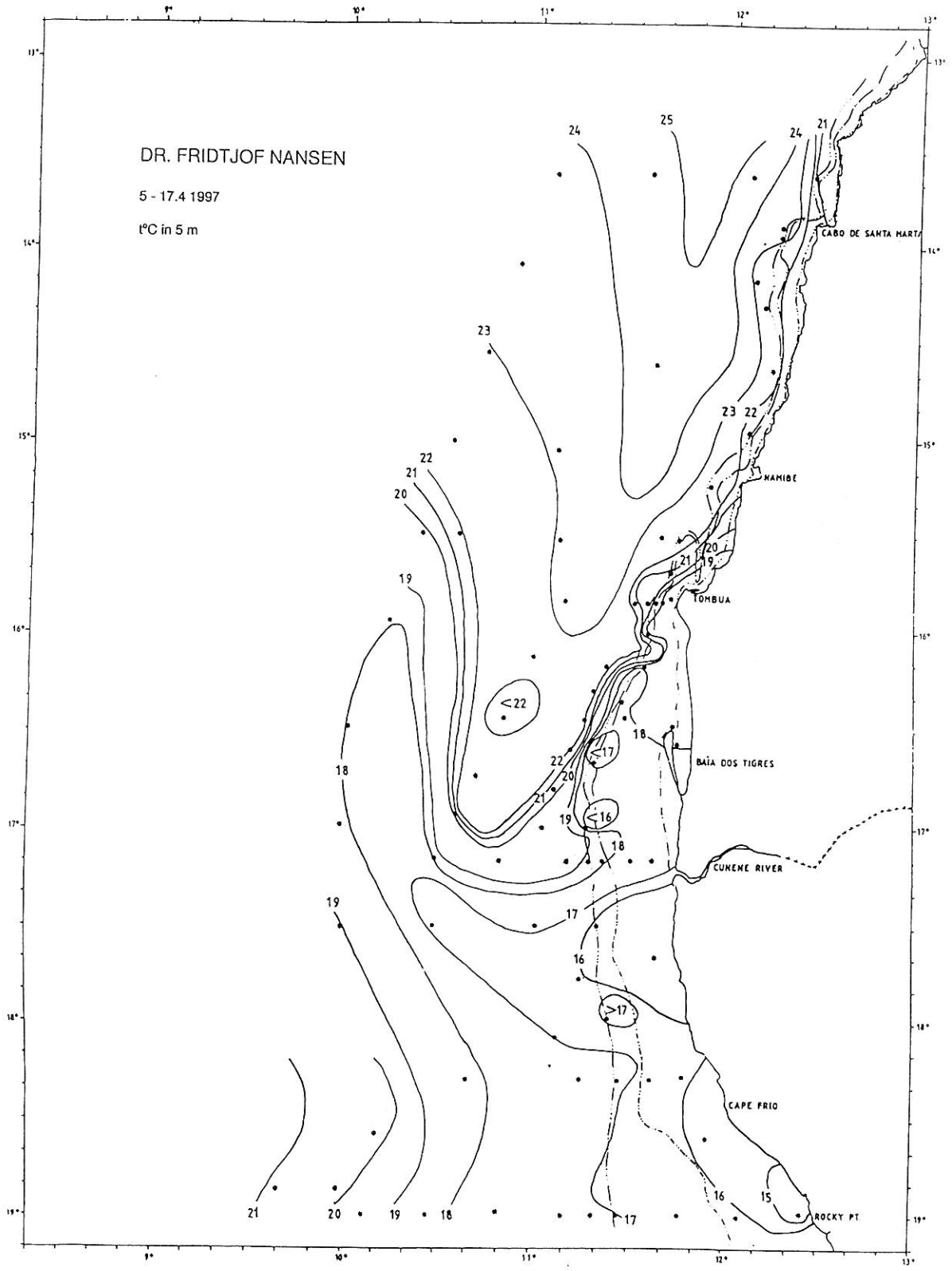

Figure 3.1. Horizontal distribution of temperature(°C) at 5m depth.

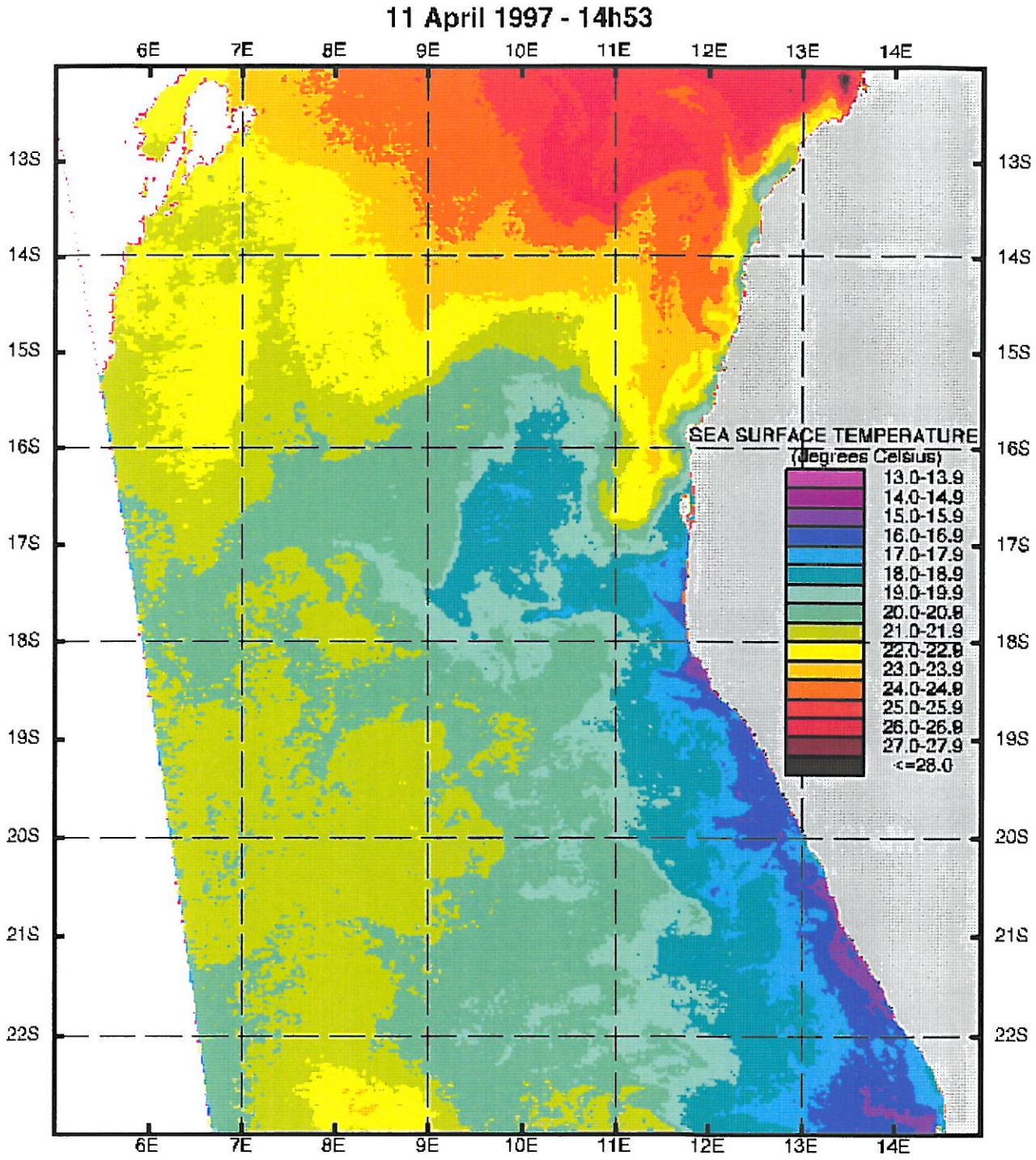

Figure 3.2 Temperature VHRR imagery obtained from a NOAA satellite on April 11, 1997

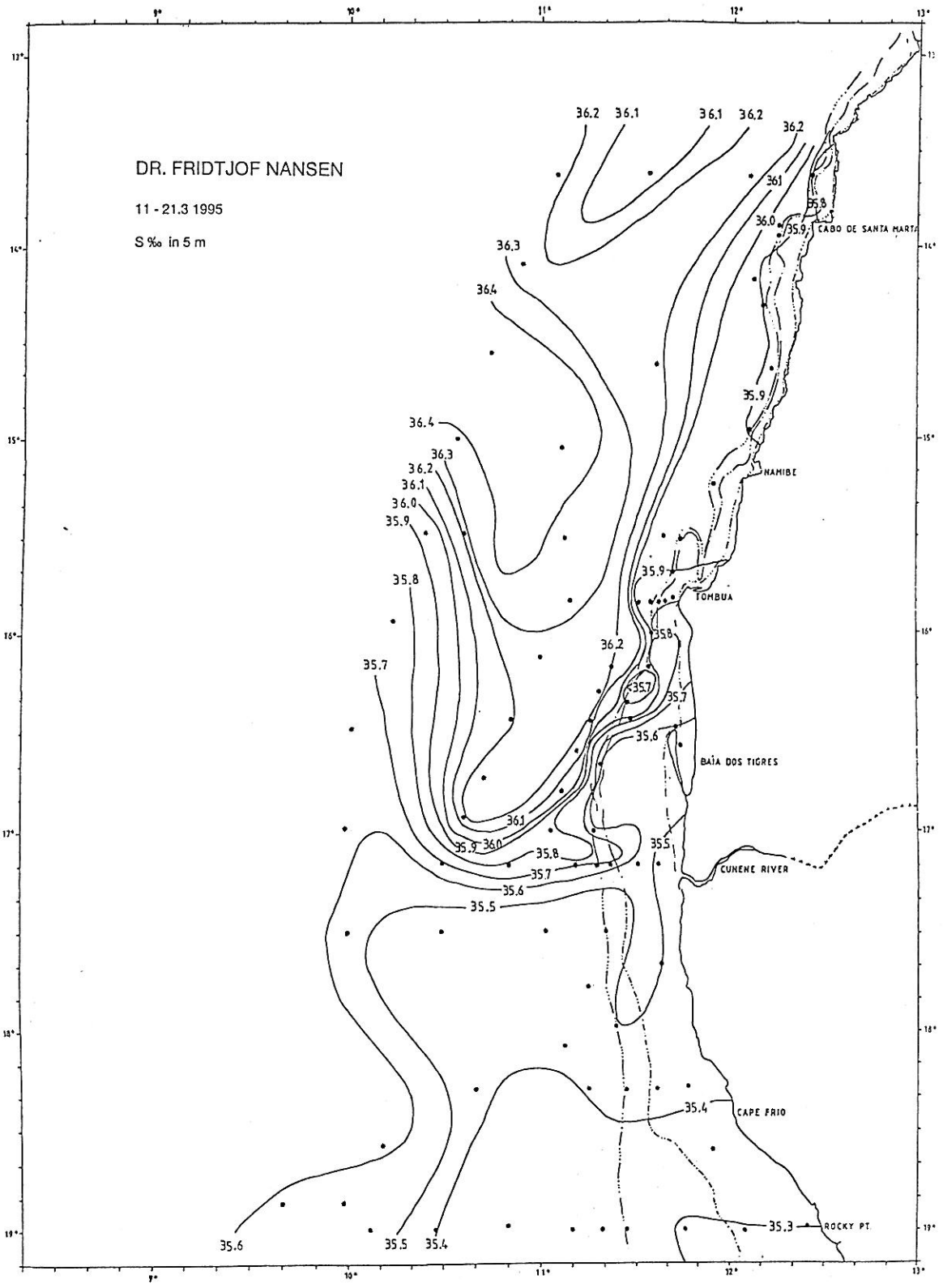

Figure 3.3. Horizontal distribution of salinity at 5m depth.

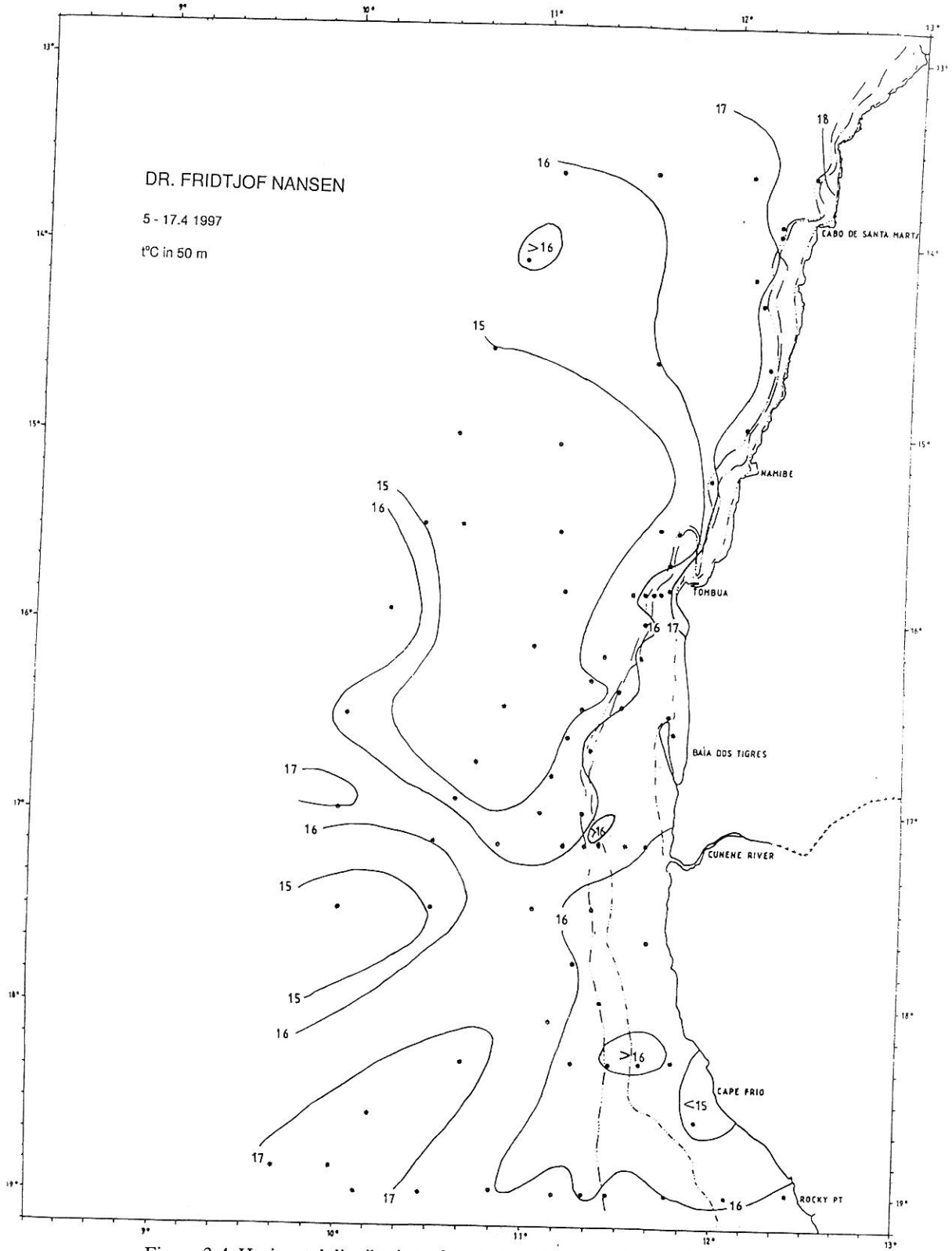

Figure 3.4. Horizontal distribution of temperature(°C) at 50m depth.

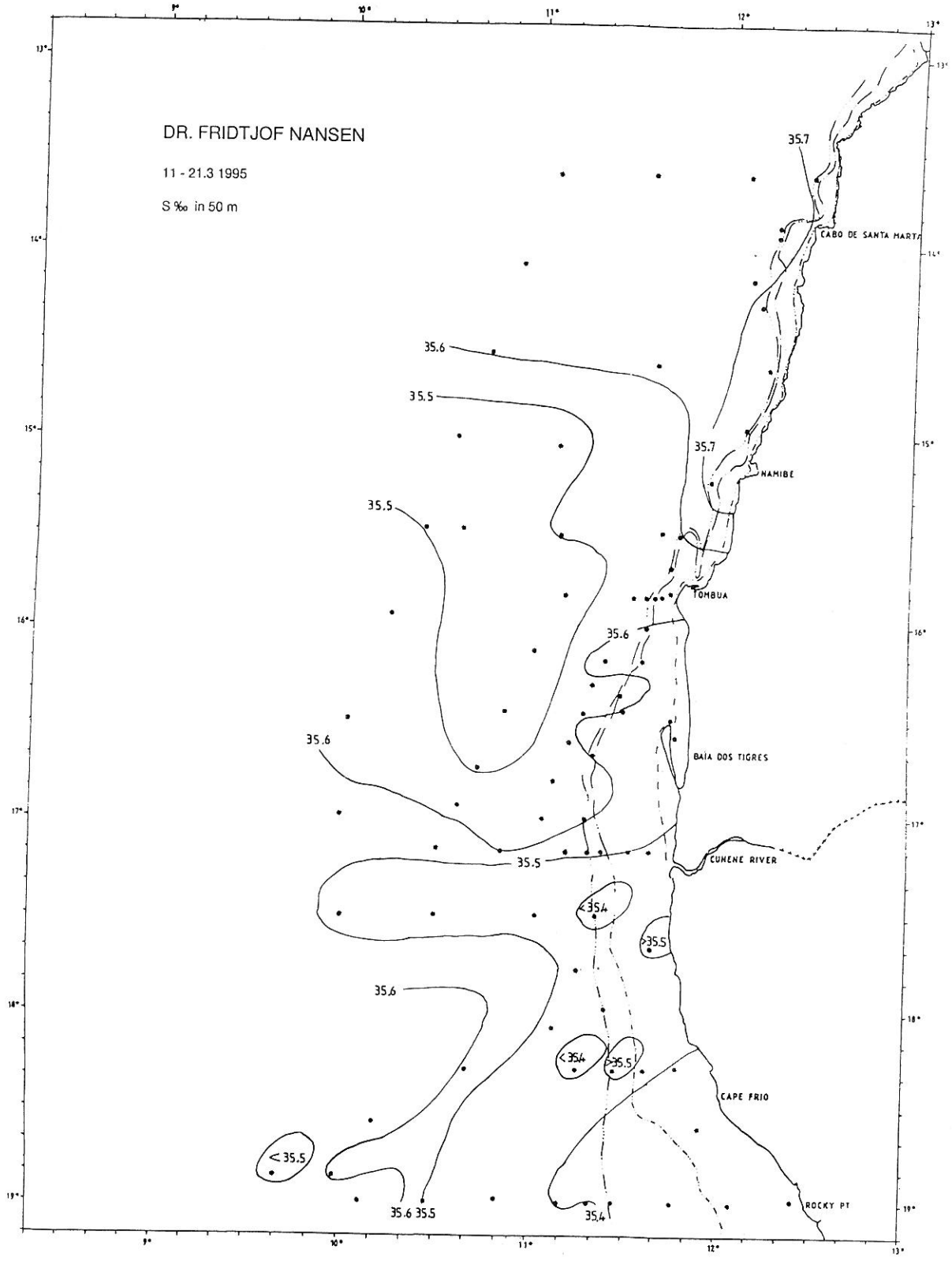

Figure 3.5 Horizontal distribution of salinity at 50m depth

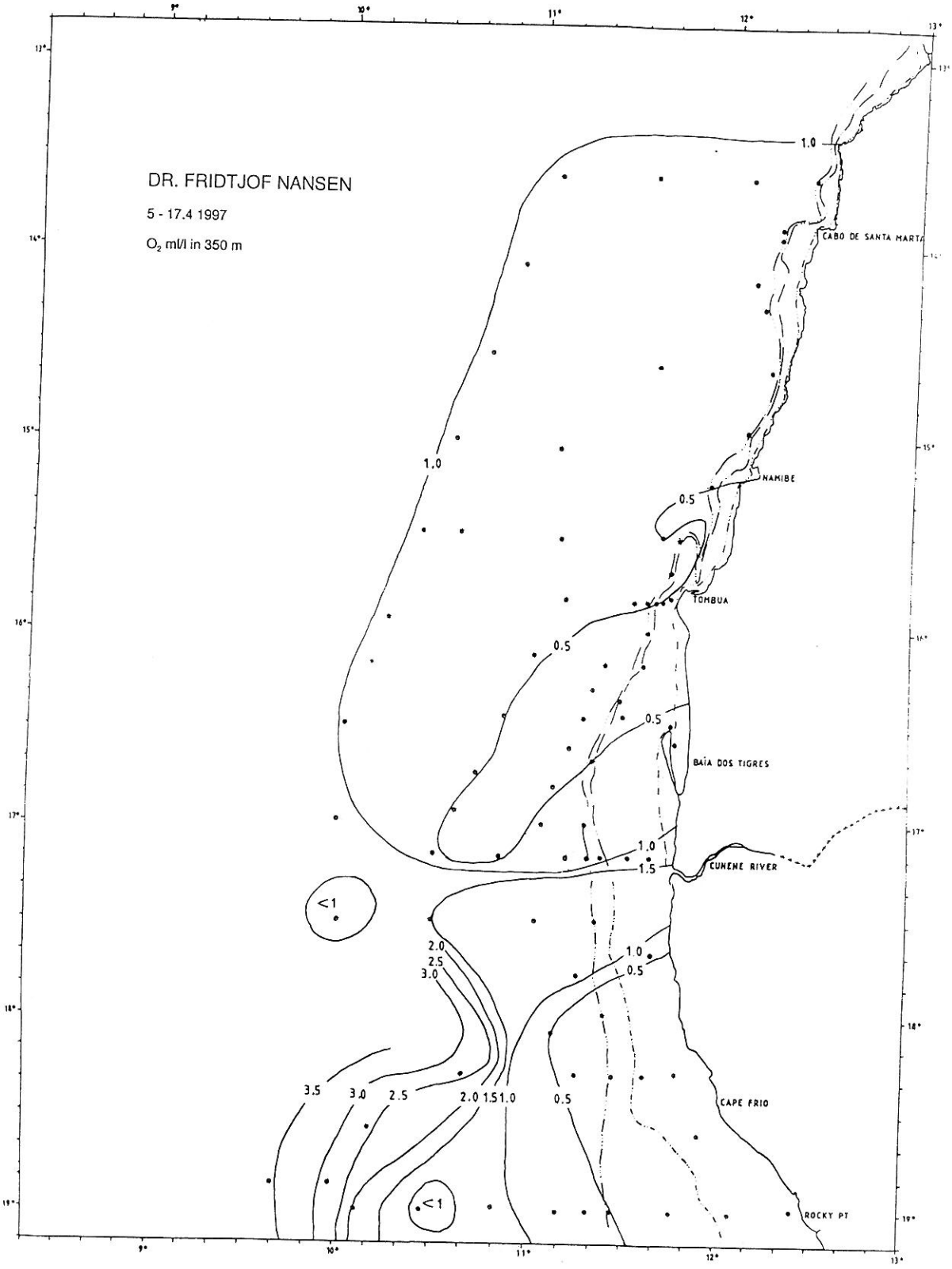

Figure 3.6. Horizontal distribution of oxygen at 350m depth.

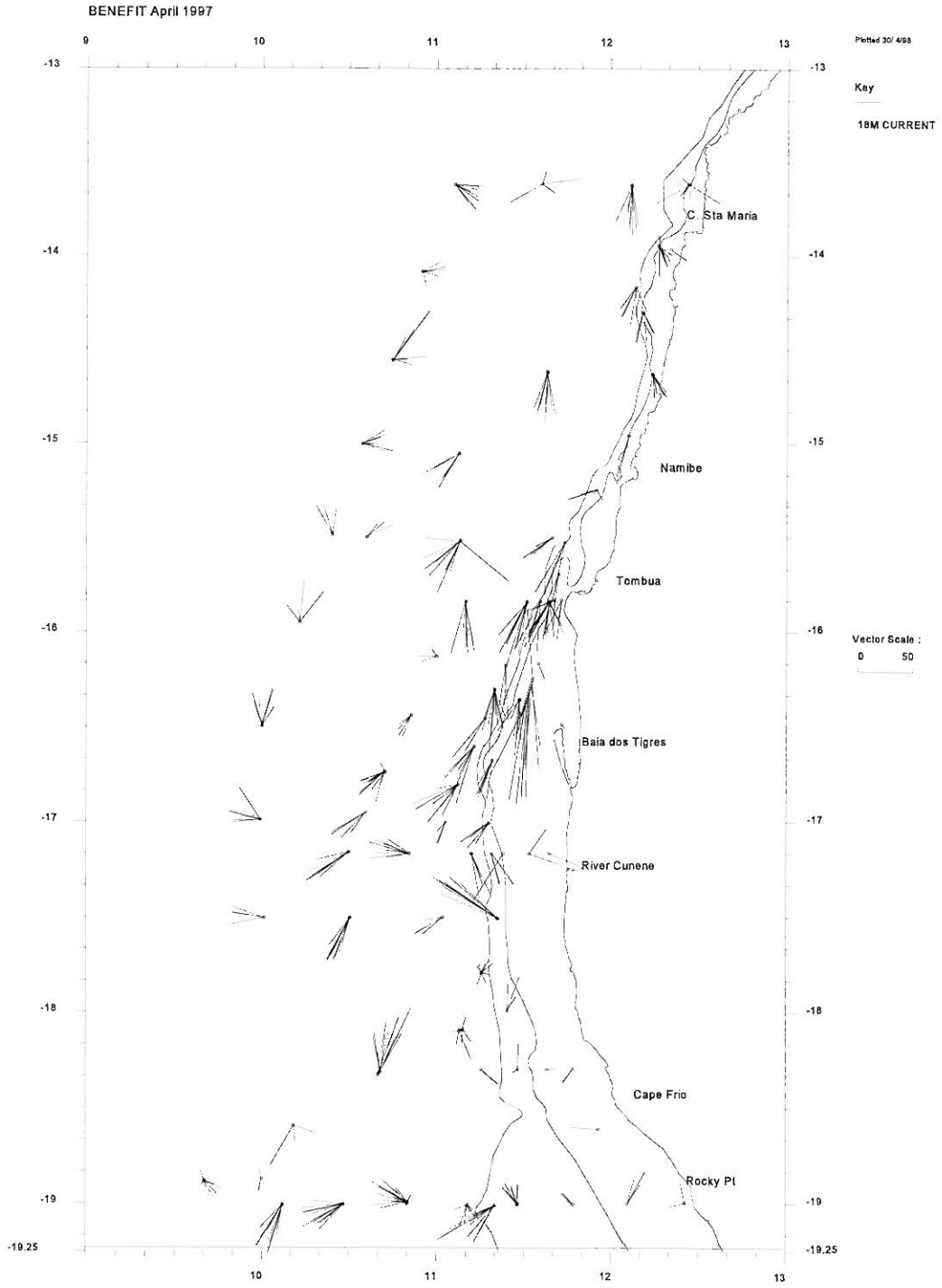

Fig. 3.7 a. ADCP current at 18 m depth

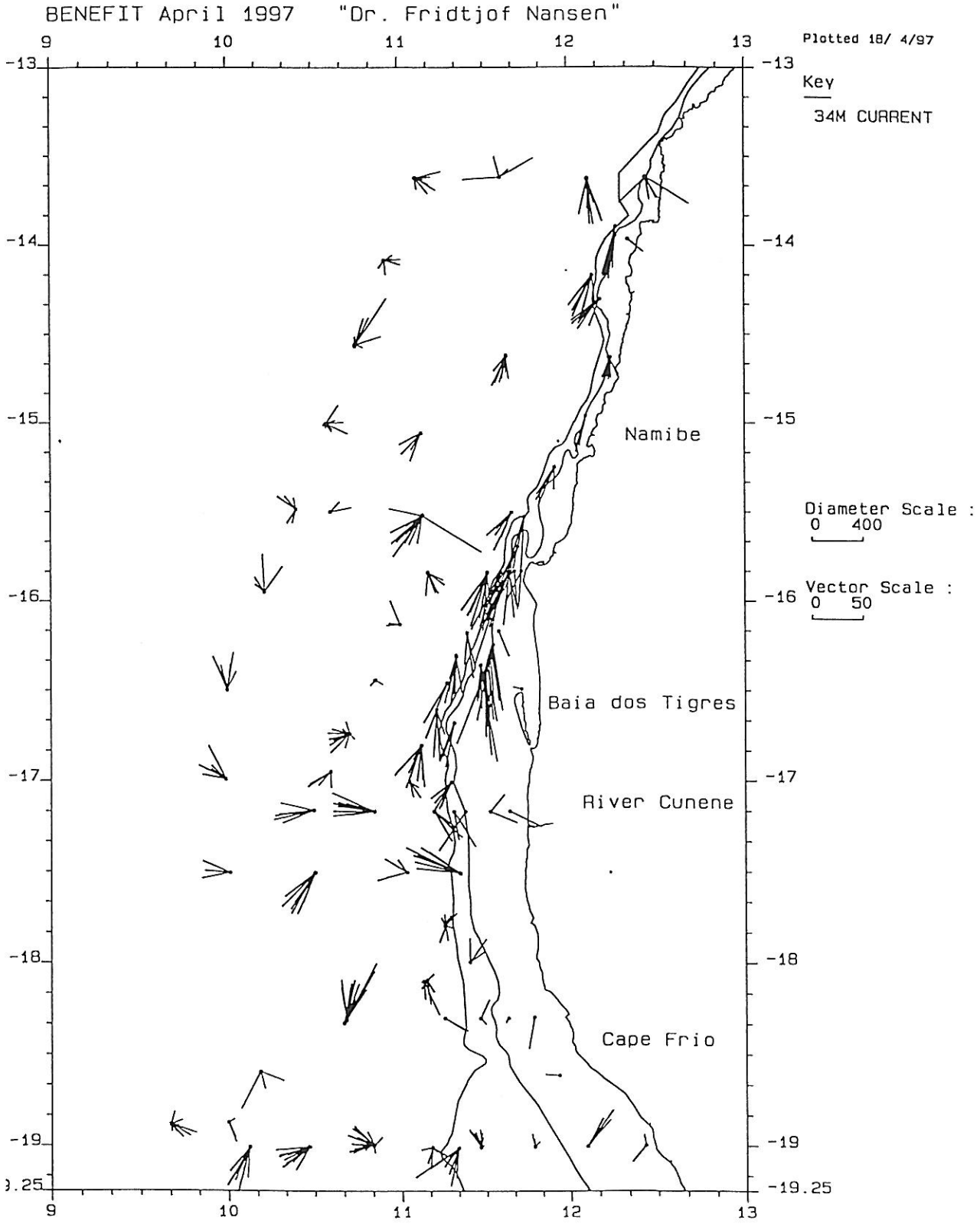

Figure 3.7 b ADCP current measurements at 34 m depth

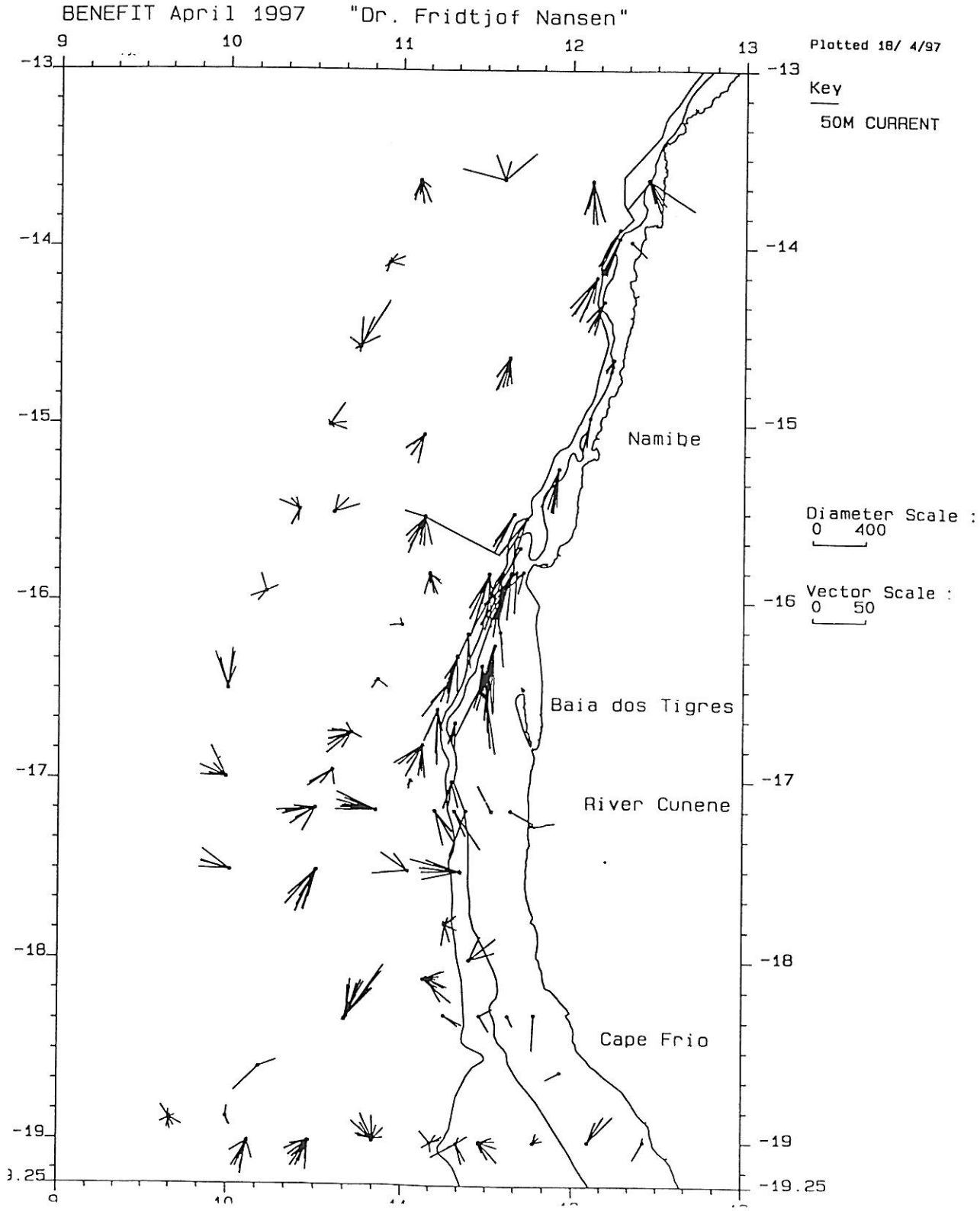

Figure 3.7c. ADCP current measurements at 50m depth.

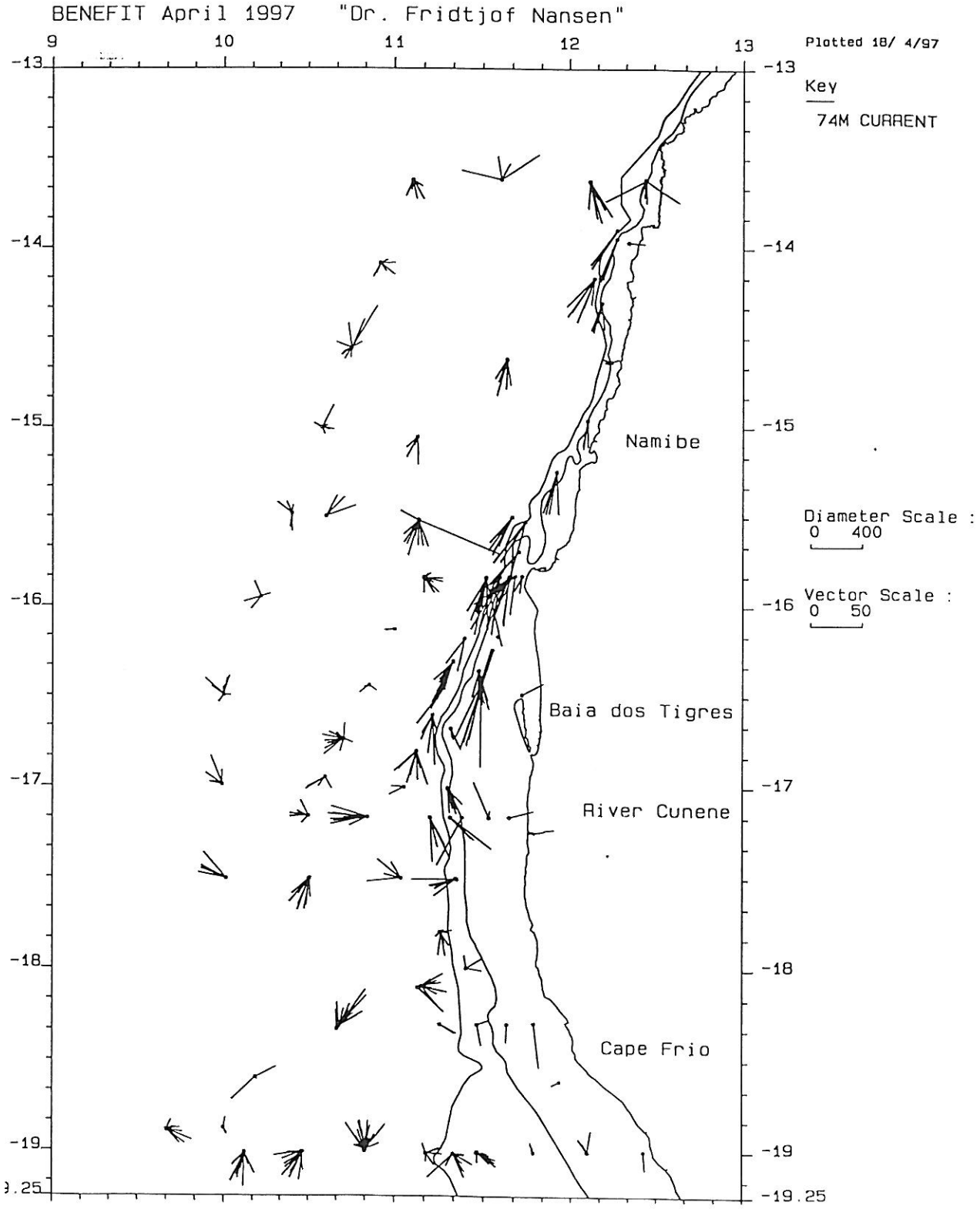

Figure 3.7d ADCP current measurements at 74m depth

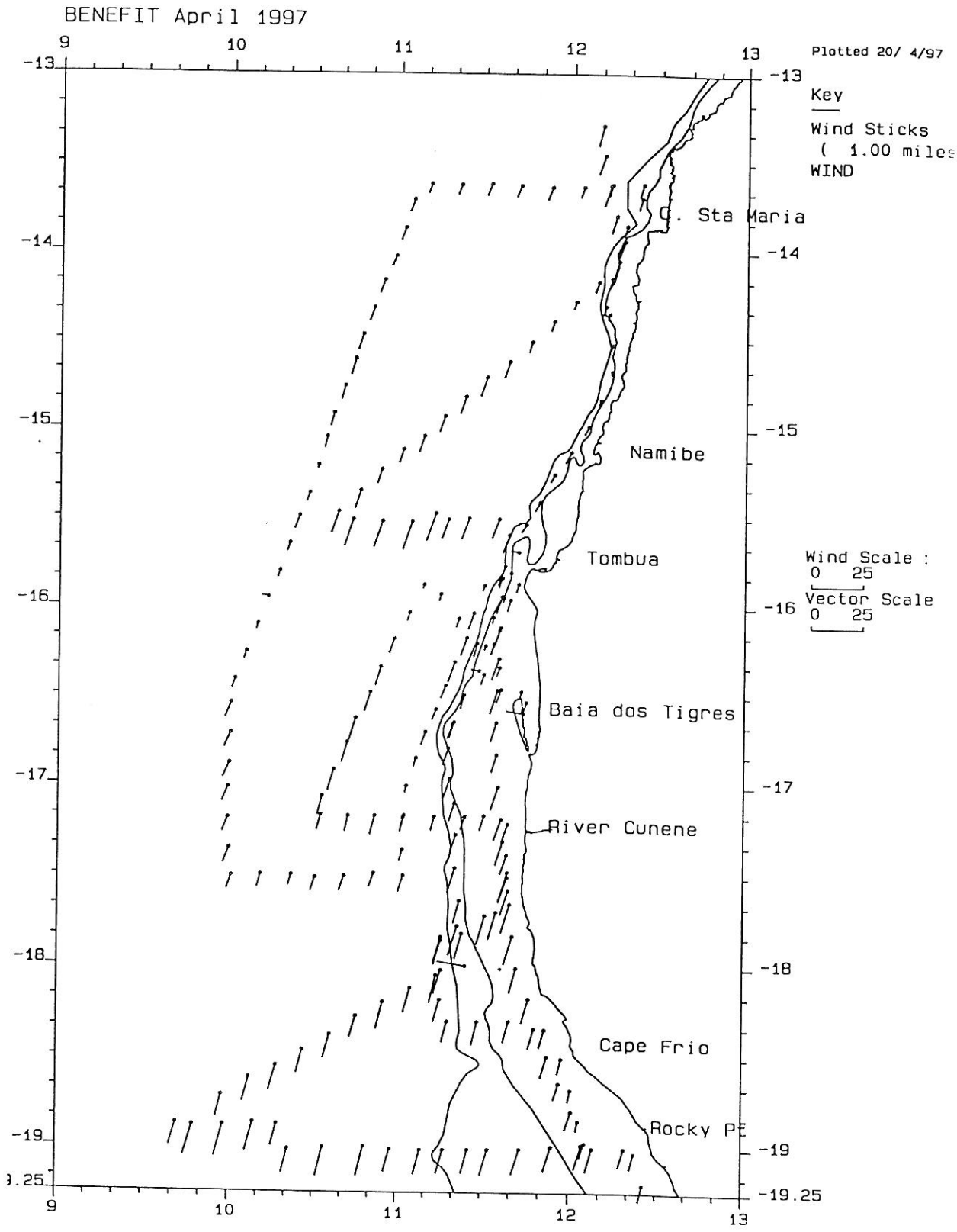

Figure 3.8. Wind measurements (knots) obtained with the shipboard weather station during the cruise.

Current meter moorings

The filtered speed, velocity components, temperature, salinity and pressure measured by the mooring outside Rocky Point (BENEFIT-S) are shown in Fig. 3.9 a for 25 m depth and Fig.3.9 b for 125 m depth. Fig. 3.9 a shows that the maximum current speed at the upper meter was about 50 cm/s. A mixed tidal signal seems to emerge. The northerly speed component was positive almost during the whole observation period, but it was strongest in the period from April 8 to 13. In this period also the temperature and salinity were higher. The pressure signal was strongest in the first few days of the registration, consonant with the new moon which occurred on April 7.

At the lower meter (Fig. 3.9 b) the current was weaker (max 25 cm/s), and the N-S component was negative most of the time. Only small temperature and salinity variations occurred. In contrast to the current meter at the upper meter, a semi-diurnal signal seems to emerge in the pressure at the lower meter. The sudden drop in salinity at the very end of the time series was due to a squid falling in love with our current meter. As may be noticed, the rotor also stopped during that period, while the temperature and pressure measurements remained undisturbed.

At the northern mooring site (BENEFIT-N) outside Cabo de Santa Maria the maximum current speed at the upper meter (25 m depth, see Fig. 3.10 a) was also about 50 cm/s. Here the N - S component was mainly negative (i.e poleward current) during the whole observation period. During the relative quiescent period from April 12 to 15, the temperature was decreasing, while the salinity was relative constant throughout the whole observation period. The pressure at this current meter is low during the periods with a weak current, reflecting that the mooring is tilted when the speed picks up.

The results from the lower meter (Fig. 3.10 b) show remarkably small variations during the registration period. The current was almost steady towards south - west at about 30 cm/s. The tidal signal was here much smaller than at the southern mooring site.

The fact that the currents measured at the upper meters at the two sites are opposite and thus creating a convergence, is more easily seen in the stick diagrams, see Figs. 3.11 and 3.12.

At the southern site (Fig.3.12) the current is rather baroclinic, with an equatorward current in the surface layer, and a poleward current in the bottom layer. At the northern site (Fig. 3.11) the current is near barotropic, with a poleward component at both observation depths.

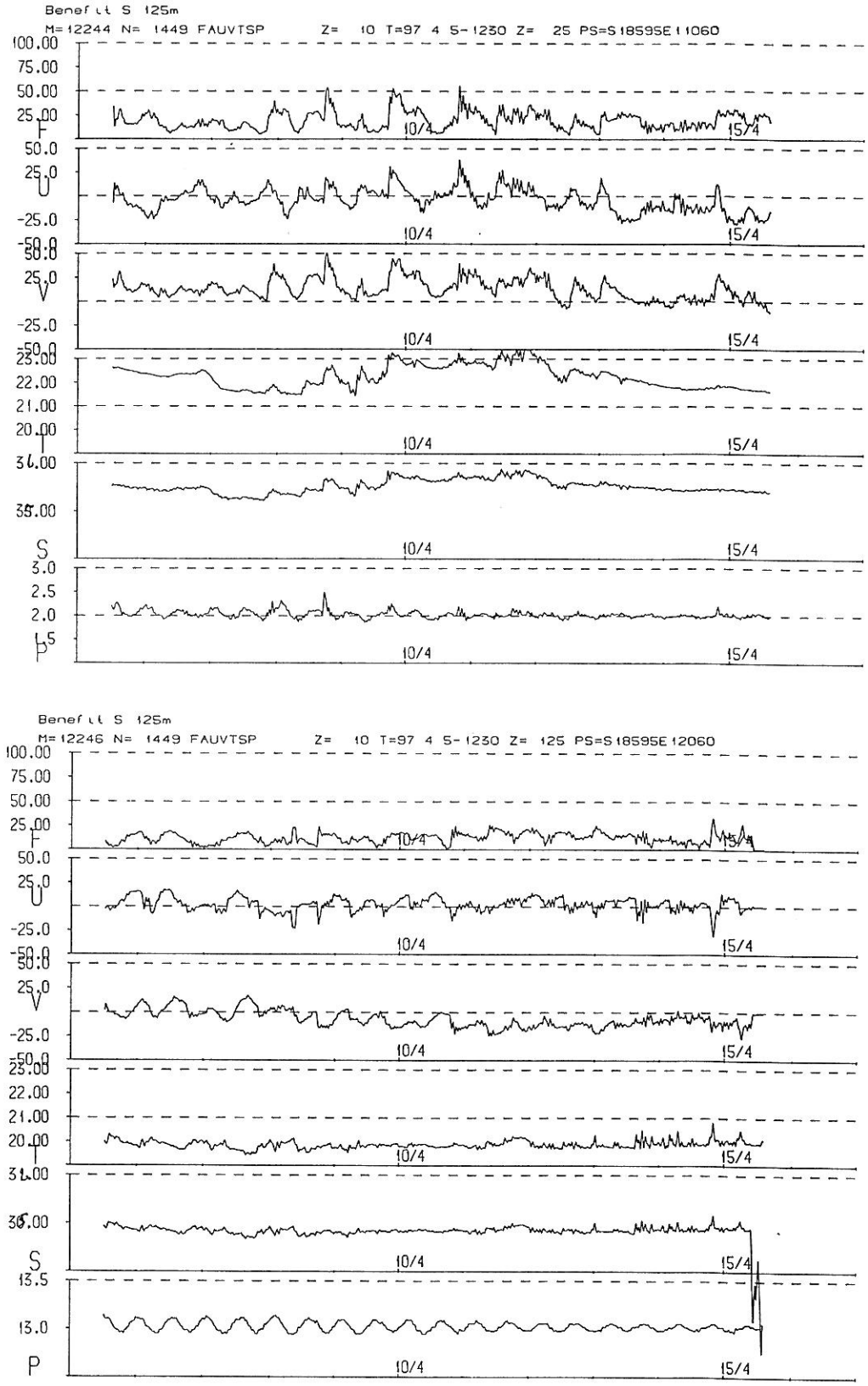

Figure 3.9 Time series obtained at the southern mooring, F: speed, U: velocity east, V: velocity north, T: temperature, S: salinity and P: pressure a) 25 m depth, b) 125 m depth .

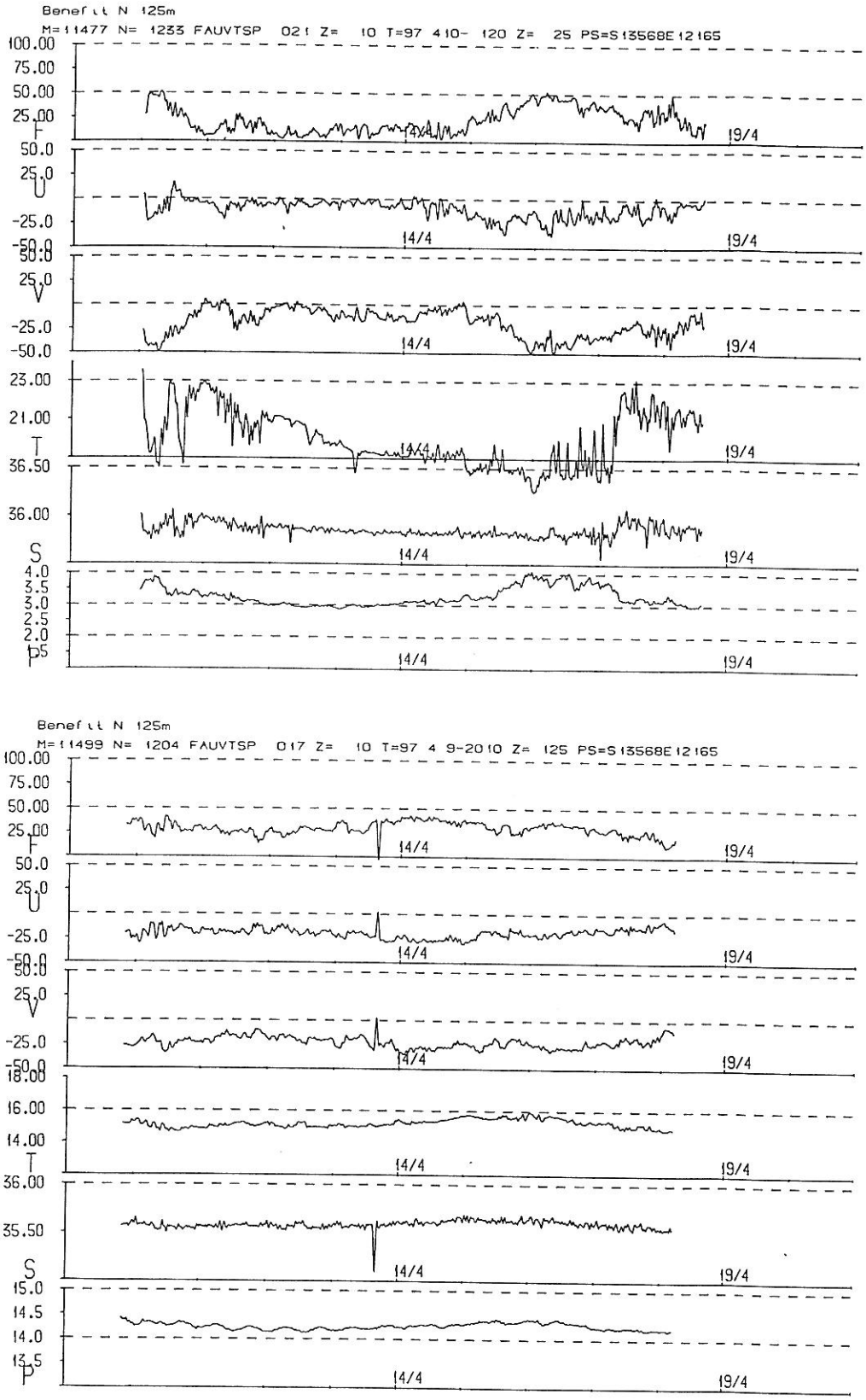

Figure 3.10 Time series obtained at the northern mooring, F: speed, U: velocity east, V: velocity north, T: temperature, S: salinity and P: pressure a) 25 m depth, b) 125 m depth .

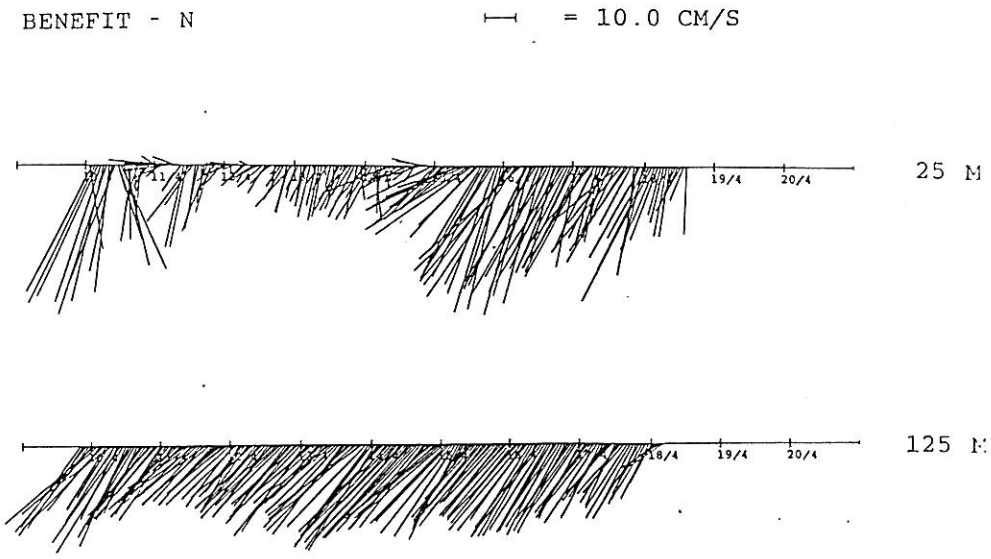

Figure 3.11 Stick plots at the Northern (BENEFIT-N) mooring site a) 25 m depth, b) 125 m depth.

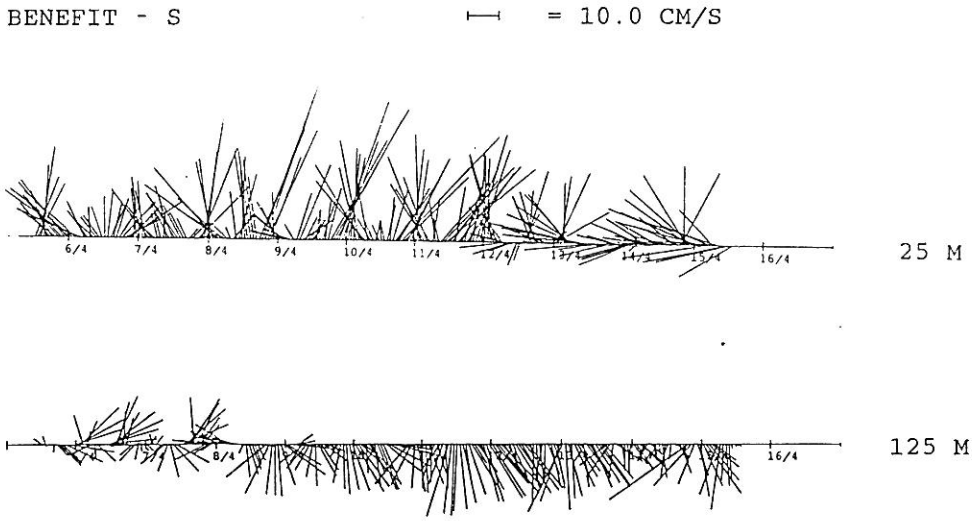

Figure 3.12 Stick plots at the Southern (BENEFIT-S) mooring site a) 25 m depth, b) 125 m depth.

Vertical distribution

The vertical structure of the temperature, salinity and oxygen distribution along a section outside the shelf brake is shown in Fig. 3.13. This section starts at 19°S and ends up north of Tombua at approximately 15°30'S, for positions see station map in Fig 1.1. The temperature signature of the ABF (Fig. 3.13 a) was centred between station 412 and 410 at 16°S to 16°30'S, the same is true for the salinity (Fig. 3.13 b). A surface oxygen front was located south of the ABF (Fig. 3.13 c), the waters south of the front were characterized by higher oxygen content. Also note the oxygen minimum centred around 350 m in the northern part of the section.

Fig 3.14 shows a longitudinal section cutting through the central part of our survey area. The ABF is very distinct around station 430 at about 17°S, compare Figs 3.1 and 3.2. South of 17°S we recognise the cold newly upwelled water from the Benguela current, and even further south we observe warmer water outside the upwelling front. The same structure is revealed in the salinity section (Fig. 3.14 b), where the warm Angola current water has higher salinity.

Notice also that the water column below the Angola Current water is dominated by a low oxygen content (< 1 ml/l) down to about 500 m, with a minimum below 0.5 ml/l centred around 300 m at about 16°30'S.

The western leg is shown in Fig. 3.15. Again we recognise the front in the temperature and salinity structure, but here the front is located further north around station 403 at 15°30'S. Also in this section the water is dominated by low oxygen content (<1 ml/l) between 100 m and 500 m depth, but here it never was below 0.5 ml/l as in the two sections further east.

To study the cross structure of the warm surface tongue (Figs. 3.1 and 3.2) we made a section running east-west at 15°30'S, just north of Tombua, see Fig. 3.16. (Note that the horizontal scale of the zonal section plots is half of the longitudinal plots). The structure of the front is clearly seen as a warm, saline water mass embedded by colder and fresher water on each side. The oxygen minimum layer is also recognised, with the absolute minimum (<0.5 ml/l) situated on the shelf break.

The cross section at the southern end of our investigation area is shown in Fig. 3.17. The temperature distribution (Fig. 3.17 a) reveals a strong near shore upwelling, accompanied by a secondary upwelling at the shelf break. At the outer end of this section we observe the upwelling front. In the salinity distribution (Fig. 3.17 b) the shelf edge upwelling is clearly seen, and the

upwelling front was also well defined. In the oxygen distribution (Fig. 3.17 c) the coastal upwelling is clearly defined, as well as the shelf break upwelling. Note also the anoxic layer (< 0.5 ml/l) at the bottom on the shelf. Even in the open ocean some 125 km from the coast there is an isolated oxygen minimum at 140 m depth.

Since the southern current meter mooring (see Figs. 3.9 and 3.11) was situated near station 368 in this section, we have calculated the geostrophic velocity using the thermocline depth at the upwelling front (40 m) as the zero velocity reference level, see Fig. 3.17 d. With this choice of reference level the surface layer velocity remains weak, except at the site of the mooring where an equatorward surface current of 10 cm/s, and a poleward current of 5 cm/s at the bottom are indicated, compare Figs. 3.9 and 3.11.

An east-west section at the northern end of our investigation area is showed in Fig. 3.18. Except near the shelf edge where an upwelling structure is apparent, bringing colder water to the surface, the surface layer was dominated by warm, saline Angola Current water. The oxygen content was low between 100 m and 500 m depth, but never as low as <0.5 ml/l found further south.

The geostrophic velocities here were calculated with bottom as the reference level, indicating a poleward current both at 25 m and 125 m depth, but somewhat stronger near the surface, compare the current measurements taken a little longer south and further in on the shelf, Figs. 3.10 and 3.12.

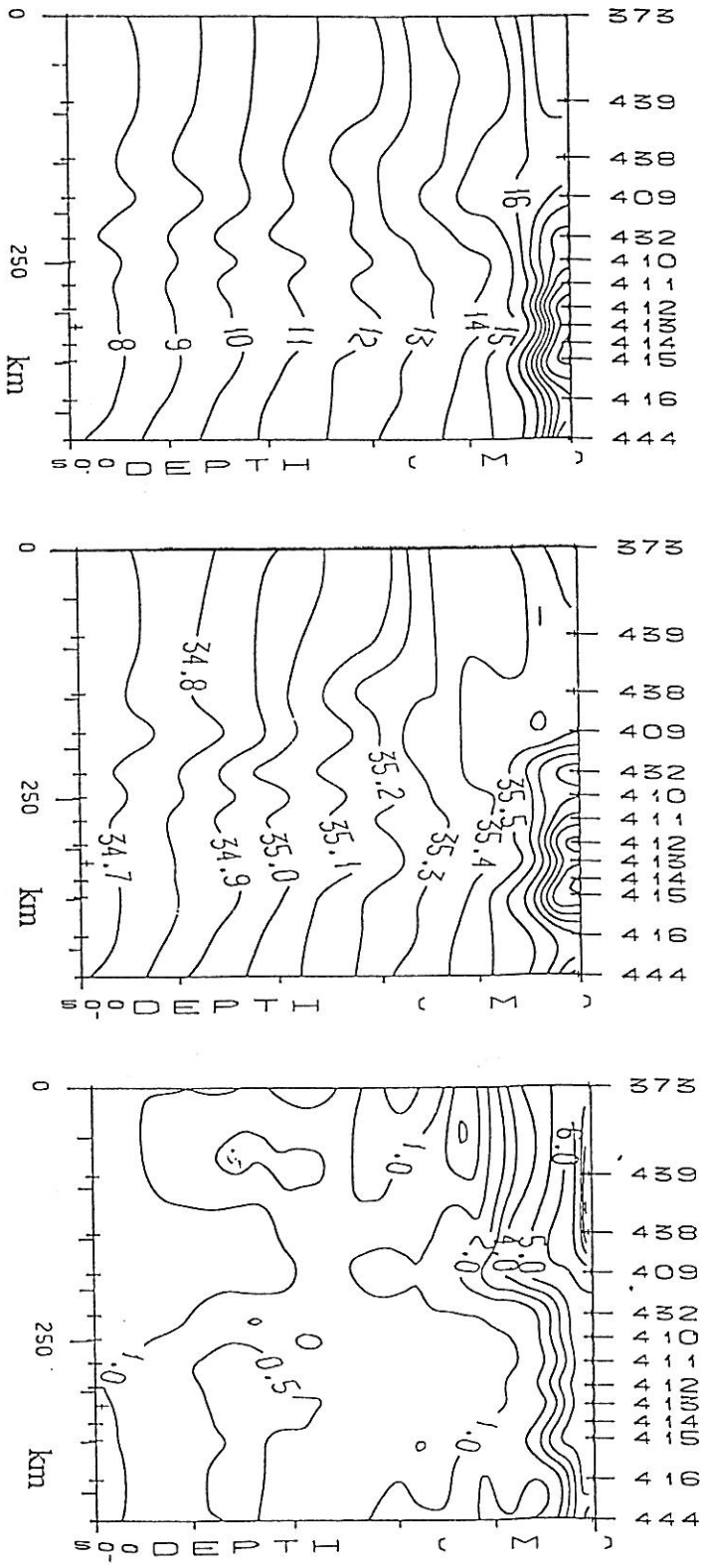

Figure 3.13 Vertical distribution of a) Temperature (°C), b) Salinity (psu) and c) Oxygen concentration (ml/l) for the section off the shelf break (for positions, see Fig. 1).

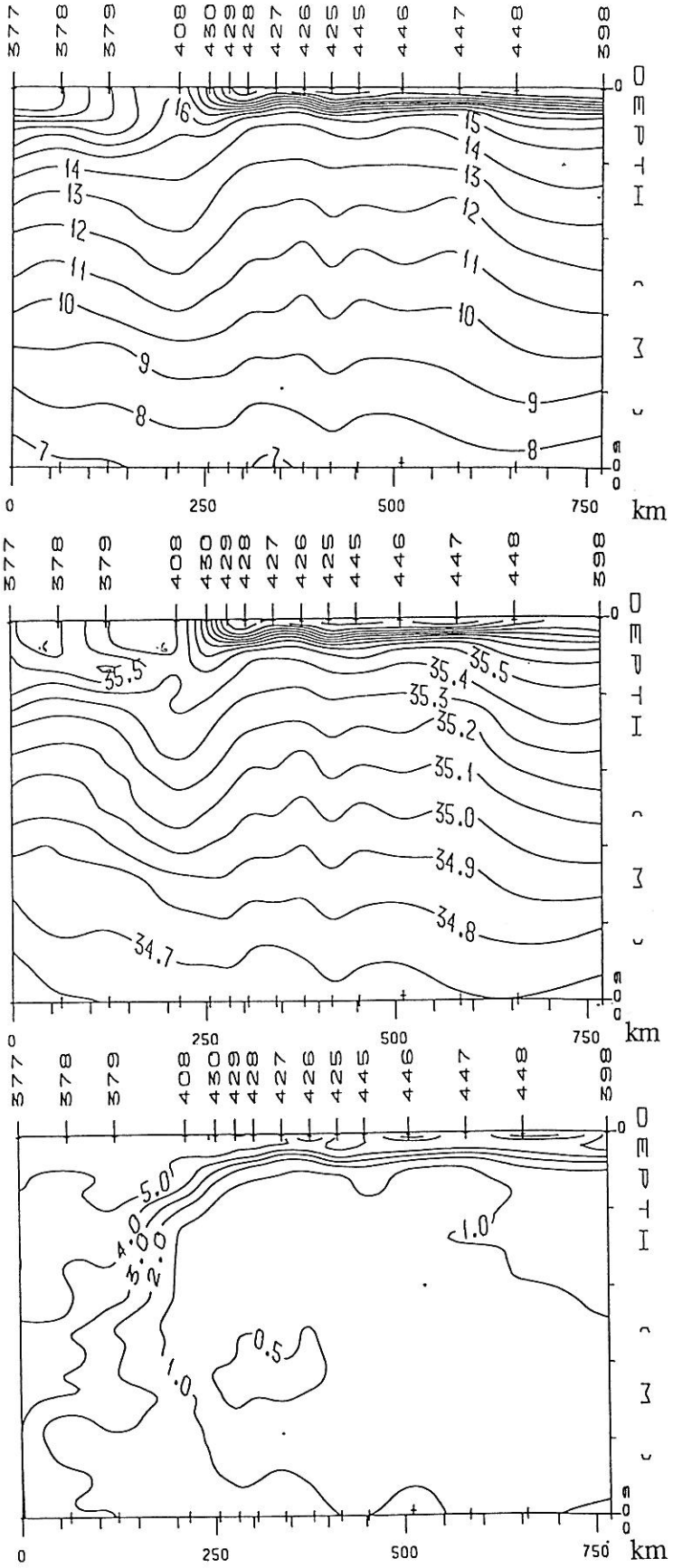

Figure 3.14. Same as Fig. 3.13 for longitudinal section in the central investigation area (for positions, see Fig. 1)

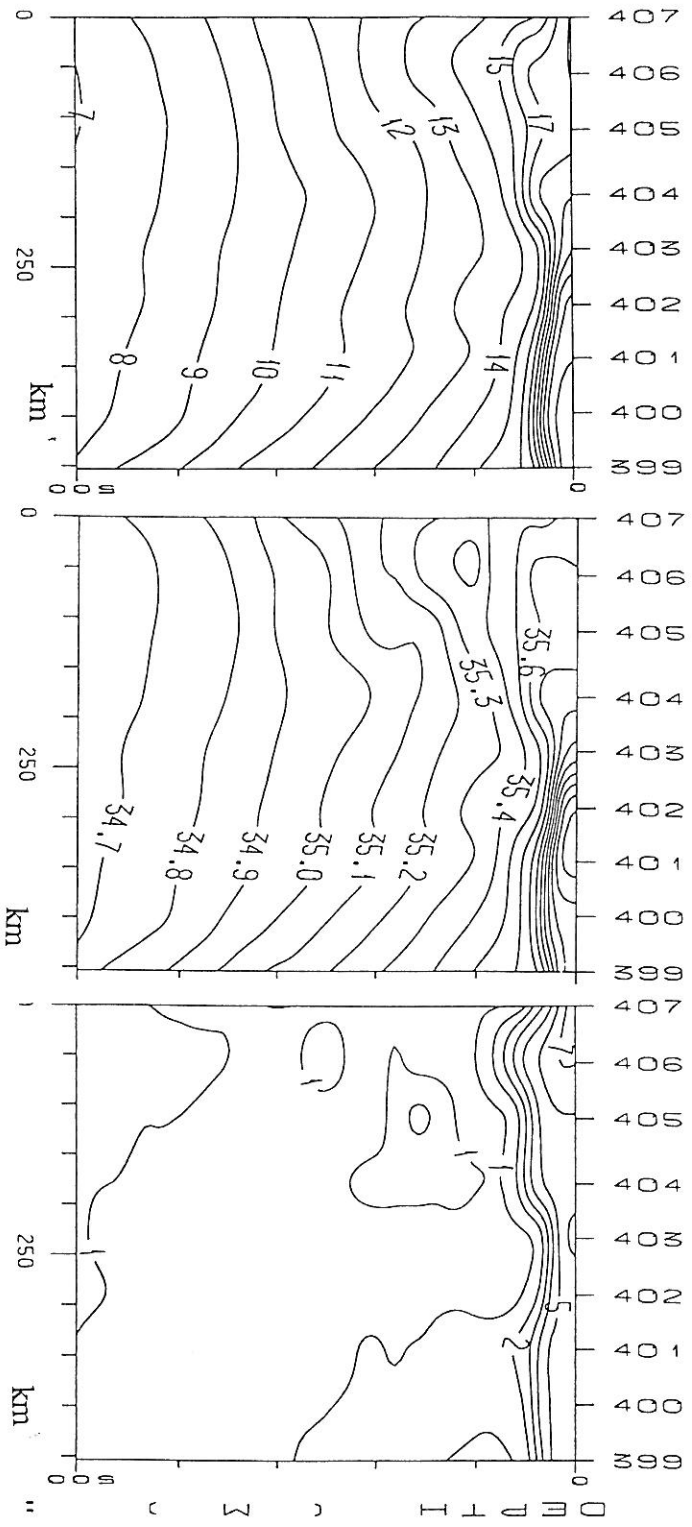

Figure 3.15. Same as Fig. 3.13 for section at the western margin of the survey area, (for positions, see Fig. 1)

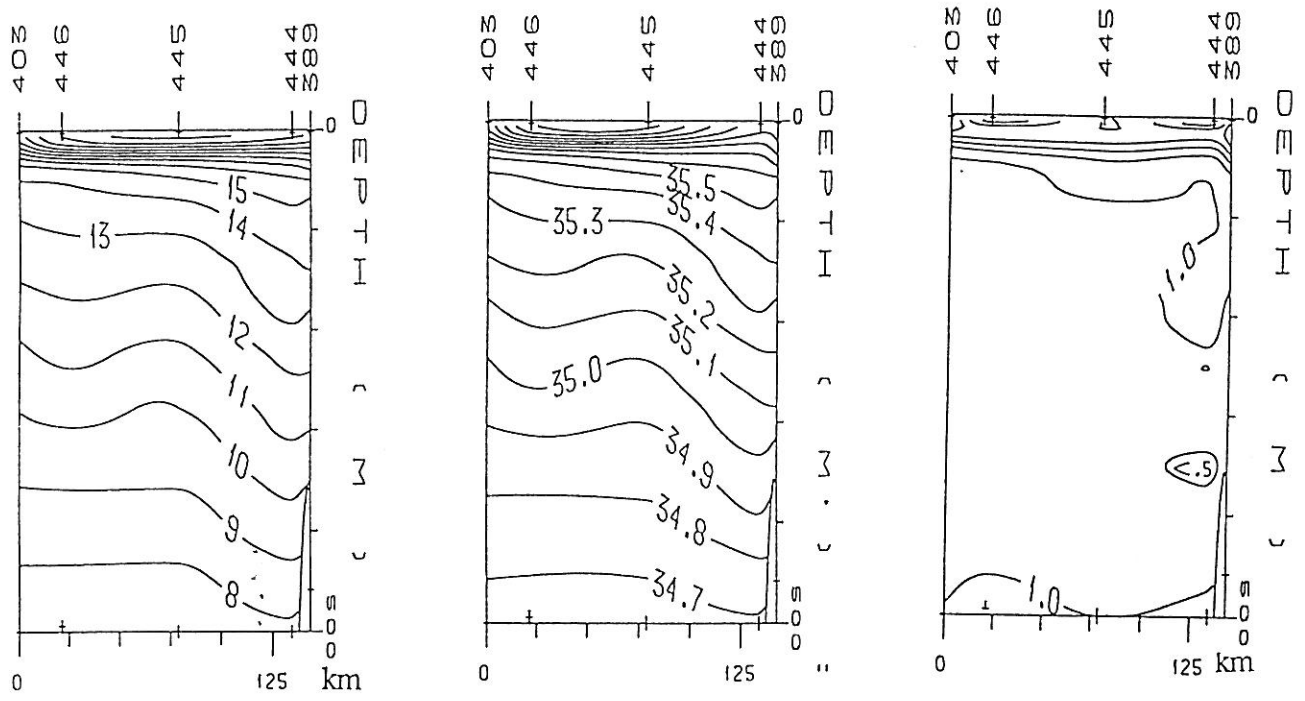

Figure 3.16. Same as Fig. 3.13 for cross-section through the front area ,(for positions, see Fig. 1)

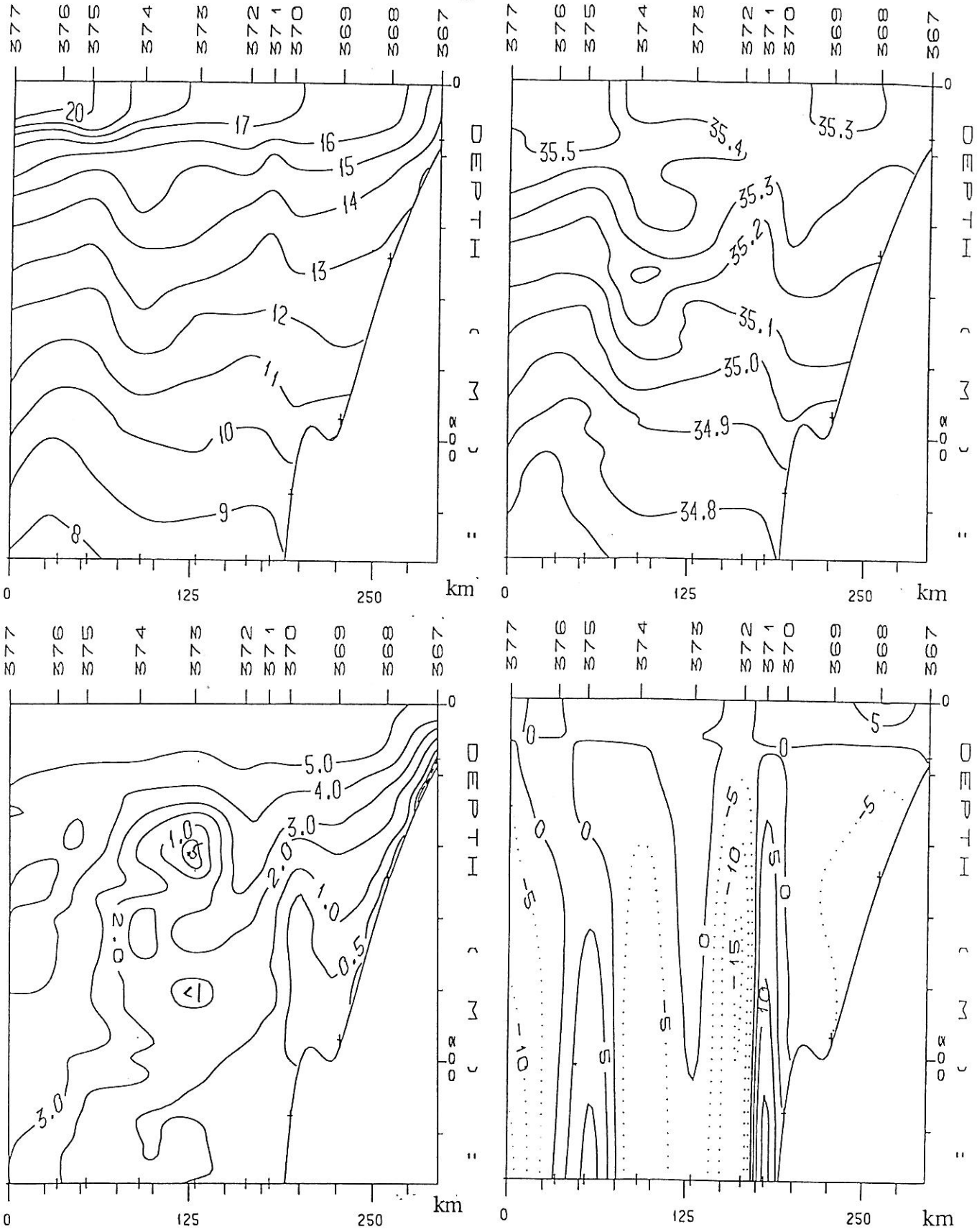

Figure 3.17 Vertical distribution of a) Temperature (°C), b)Salinity (psu), c)Oxygen concentration (ml/l) and d) geostrophic velocity (reference level 40 m) for the section defining the southern limit of the survey area (for positions, see Fig. 1).

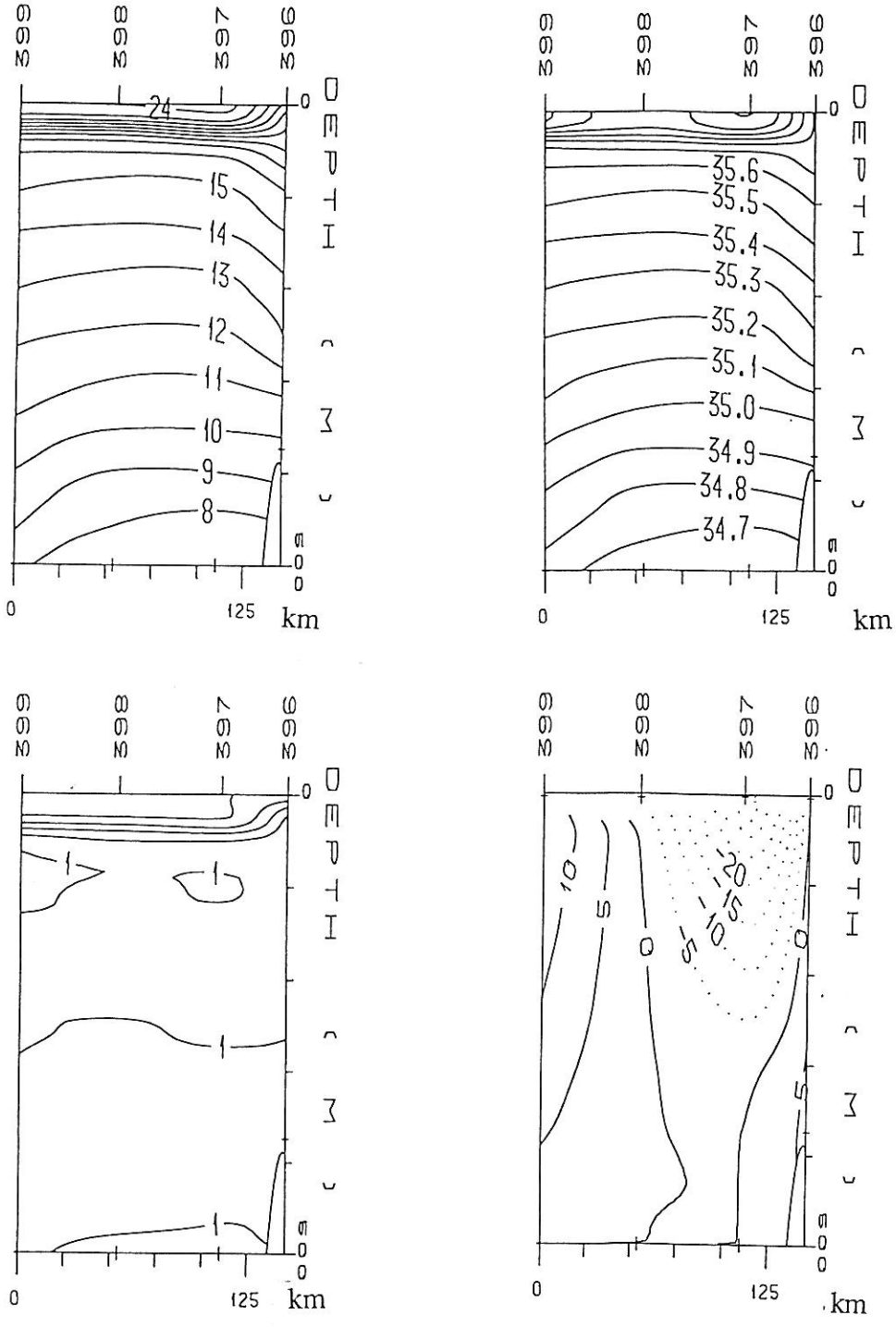

Figure 3.18 Vertical distribution of a) Temperature (°C), b)Salinity (psu), c)Oxygen concentration (ml/l) and d) geostrophic velocity (reference level 40m) for the section defining the northern limit of the frontal area (for positions, see Fig. 1).

THE ANGOLA DOME AREA.

Horizontal distribution

The station map for the Angola Dome survey is shown in Fig. 1.1b. For the results presented here we have also used a few stations obtained near the coast about one month earlier. The interpretation of the combined results should therefore be used with caution, because of the non-synoptic nature of the data.

The horizontal temperature distribution at 5 m and 20 m is shown in Fig. 3.19. It may be observed that no structure of the Dome is seen at 5 m depth, but at 20 m a clear minimum in temperature centered around 12°S, 12°E appeared. The temperature difference between the center and the surroundings is about 4°C. The Dome seems to have a stretched structure oriented SW - NE.

In the salinity distribution (Fig. 3.20) there seems to be a signal of the Dome, appearing as a surface minimum, even at the surface. The difference between the center of the Dome and the surroundings was about 0.7 psu at both levels.

The oxygen distribution at 20 m did not show any marked structure, see Fig. 3.21.

Vertical distribution

The vertical distribution of temperature, salinity and oxygen at 12°S are shown in Fig. 3.22. The isotherm doming was centered around station 476. In this position there was also an upwelling structure in salinity and oxygen creating a local minimum in oxygen below 20 m depth.

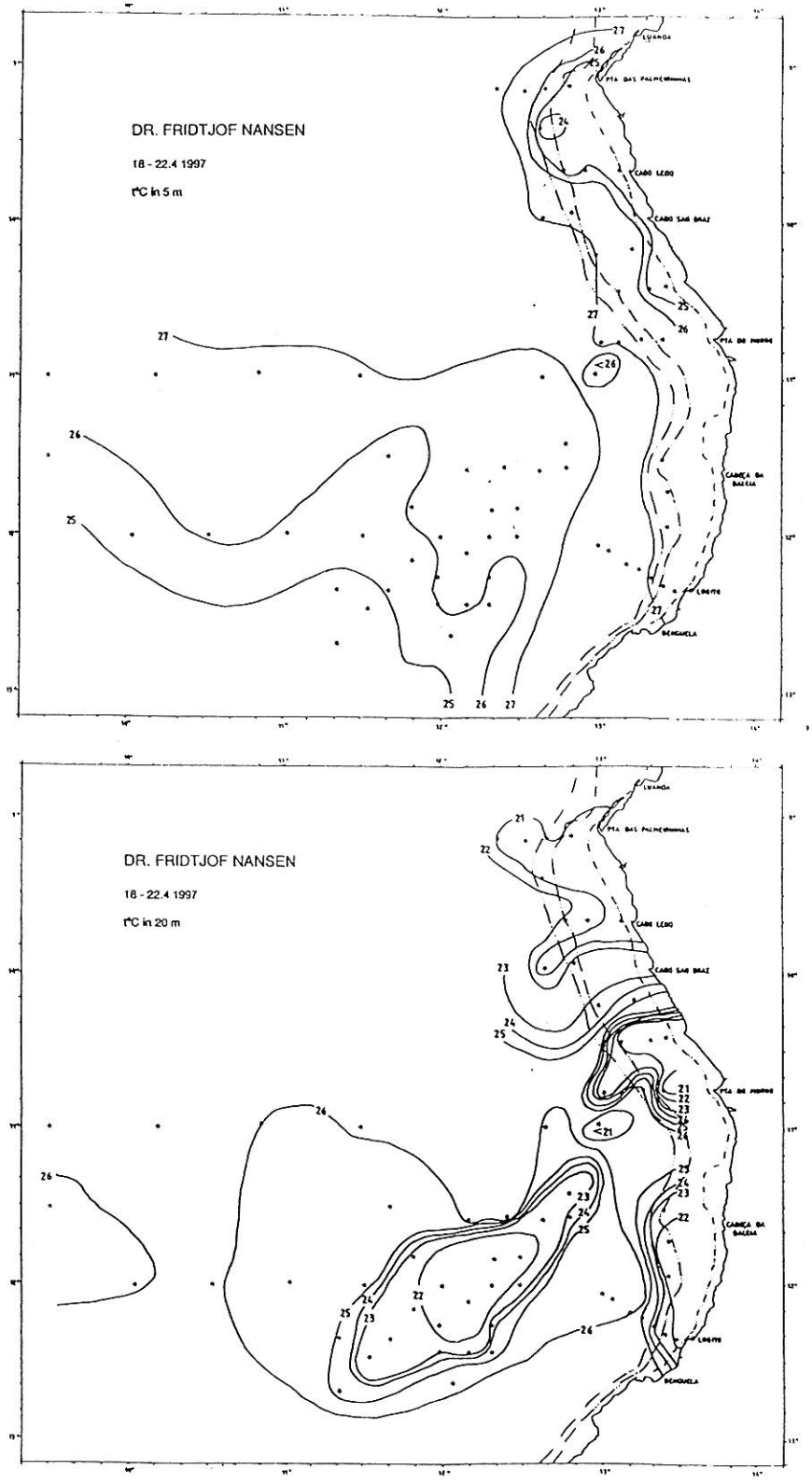

Figure 3.19. Horizontal distribution of temperature in the Angola Dome area, (for positions, see Fig.1.1b). a) 5m depth, b)20m depth

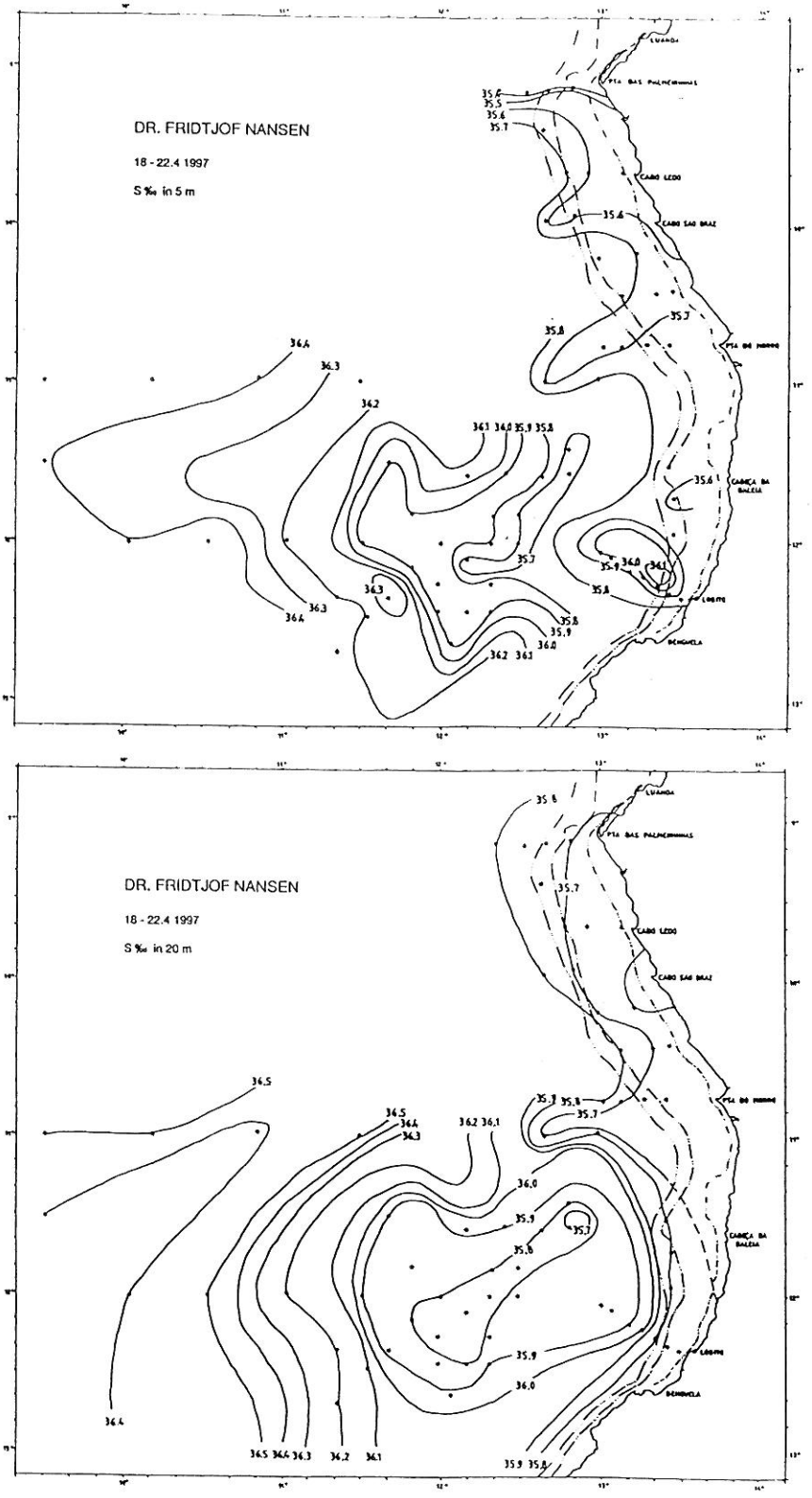

Figure 3.20. Horizontal distribution of salinity in the Angola Dome area, (for positions, see Fig.1.1b). a) 5m depth, b)20m depth

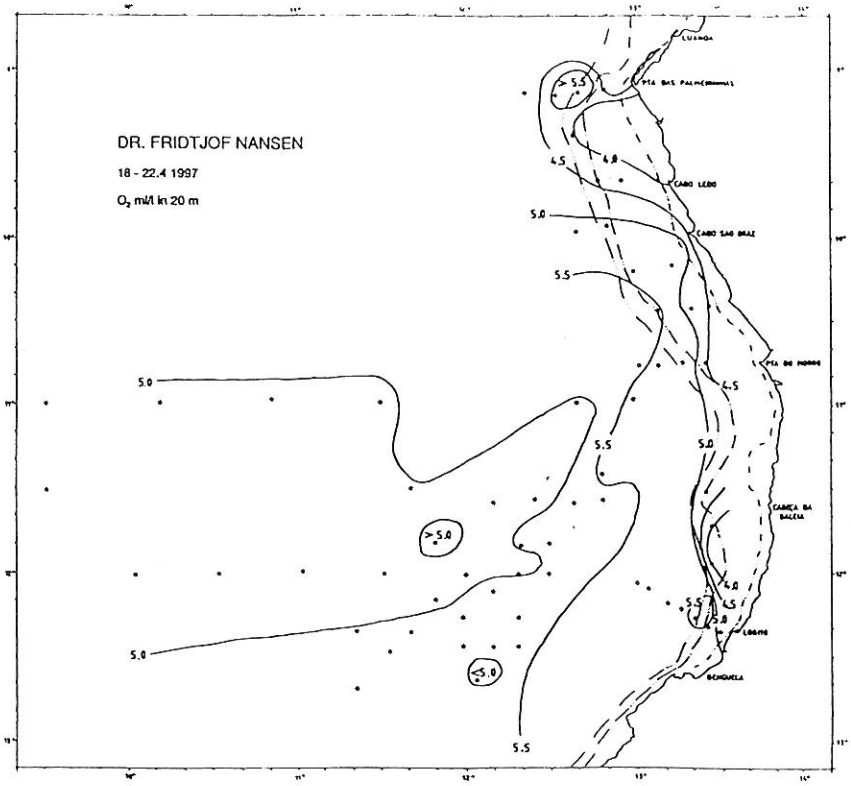

Figure 3.21. Horizontal distribution of oxygen at 20m depth in the Angola Dome area, (for positions, see Fig.1.1b).

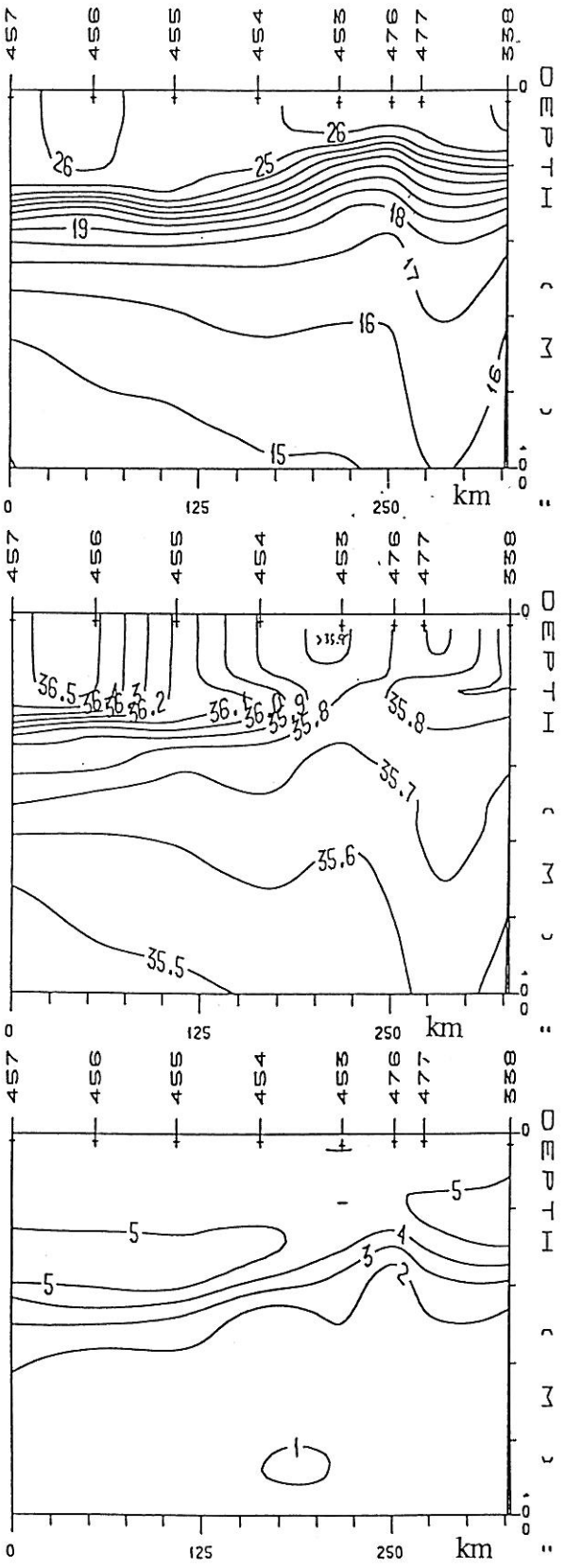

Figure 3.22. Vertical sections of a)Temperature, b) Salinity and c) Oxygen at 12°S crossing the Angola Dome.

3.2 Phytoplankton

Pigment extractions and fluorescence.

This discussion will firstly look at the factors which were taken into consideration in the estimation of the phytoplankton biomass, followed by a description of the biomass levels found.

Processing of the data: For the calculation of the chlorophyll estimates, the following results were considered in this priority order: a) Pigment extractions, b) *In situ* fluorescence depth profiles, and c) *In vivo* fluorescence of pumped sea water. The most of the phytoplankton biomass estimations collected on this cruise, were in the form of CTD fluorescence values. Whilst dozens such fluorescence readings were produced per station, manpower limitations allow only a few pigment extractions per station.

The ease with which fluorescence profiles are collected, has led to their proliferation in the literature, however, fluorescence is limited as an indicator of chlorophyll: Unfortunately the amount of *in vivo / in situ* fluorescence measured per unit of chlorophyll isn't fixed - the factors affecting the ratio are discussed by Holm-Hansen *et al.* (1965); Nusch (1980) and UNESCO (1980): The species composition of a site will effect the ratio of Fluorescence: Biomass (e.g. accessory pigments may fluoresce less than chlorophyll a). The stage of life cycle, past light history, diurnal cycles, physiological/ nutrient status of cells, presence of chlorophyll b, amount of suspensoids at the site, etc. also affect the ratio. At higher chlorophyll concentrations self-absorption causes an underestimation of biomass.

The UNESCO Working Group for the Intercalibration Tests for the Determination of Chlorophyll concluded : "Our recommendation is that *in vivo* fluorometry is invaluable as a "search" method for phytoplankton populations at sea. It should be used as a guide to the appropriate location for the field experiment. It should not be substituted for an accurate measurement of chlorophyll$_a$".

In order to carry out this recommendation, pigment extractions of water sampled together with the *in vivo/ in situ* readings, were used for the calculation of calibration ratios: The ratios measured at a site (of the amount of chlorophyll$_a$ present, per unit of fluorescence produced) were plotted as a depth profile using a contouring program Surfer 6.04. "Slices" were then made to obtain calibration factors to apply (on a meter depth basis) to the CTD fluorescence values.

The resultant chlorophyll$_a$ estimations were then plotted as the depth profiles given in Figs. 3.23 to 3.27.

The ratio of the amount of chlorophyll$_a$ present per unit of fluorescence, generally was lower in the deeper parts of the water column during the study. (The ratio near the surface, several times was observed to decrease with an order of magnitude within the first 30 m of the water column.) This is not surprising, considering the dependence of photosynthesis on light: (The algae in the upper level of the water column would be actively growing, with the cells in the deeper water often representing decaying cells drifting to the bottom, with their fluorescence mostly being caused by phaeophytin.) There were deviations, e.g. in the area sampled by stations #382 and 383, waters deeper than 30 m had high chlorophyll$_a$: fluorescence ratios (and relatively high chlorophyll$_a$ concentrations, considering how little light would penetrate there) - see Fig. 3.24.

Biomass levels: In the trans-shelf transect done off Rocky point (Fig. 3.23a), it was found that the algal biomass was high near the coast but decreased rapidly from about 25 μg per liter in the upper waters inshore (station 367), to less than 5 μg per liter, within the first 20 or 30 NM. In the deep waters (stations 370 to 377), there were low levels of chlorophyll$_a$. This will be discussed when the nutrient results are available.

In the transect done obliquely, returning from the deep sea station 377 to the coast north of Cape Frio (station 381, see Fig. 1.1 it was again found that the levels were lower offshore, increasing towards the coast (Fig.3.23 b).

If Figs. 3.24 and 3.25a are considered as a near-coast progression from the relatively cold waters south of the Angola Benguela front (station 381 at 18°S), to the relatively warm waters north (station 396 near 13°30S), it can be seen that the chlorophyll$_a$ levels dropped markedly towards the north. In this near-shore transect, the area ca. 17°30S to 15°30S (i.e. stations 381 to 389, Fig. 3.24) showed high chlorophyll levels relative to the stations north of 15°30S (i.e. stations 390 to 396, Fig.3.25 a).

The trans-shelf transect done in the north, from near the coast to about 90 NM offshore (Fig. 3.25 b, stations 396 to 399) shows the following: The biomass was relatively high at the coast, then decreased offshore. There was a patch about 80 NM offshore where higher levels were found deeper in the water column (about 25 m deep).

The long, offshore transect (Stations 399 to 407, see Fig. 1.1 a): Roughly the same trend was seen as in the near-shore transect, namely that chlorophyll$_a$ levels increased as the ship travelled from north (station 399, Fig. 3.26) to south. As in the case of the near shore transect, relatively higher chlorophyll$_a$ levels were once again observed in the area 15°30S to 17°30S on this far-offshore transect. This pattern was not as clear in the transect done of the area between the above-mentioned transects: In the transect from stations 410 to 416 the chlorophyll levels were lower (see Fig. 3.27).

Depth distribution of the phytoplankton: The profiles show the occurrence of sub-surface maxima, some as deep as 50 m (see Figures 3.24, 3.26 and 3.30). In Fig. 3.30 the effect of thermal stratification on the algal distribution in the water column is clearly visible, where the algal maxima occurs near the depth of the thermocline. Sub-surface maxima at depths of 20m have also been recorded by Shannon *et al.* (1984) in the region. The importance of these subsurface maxima will be discussed later.

With regard to the depth profiles which were obtained with the fluorescence sensor: It was found that the fluorescence data was less reliable in certain stations, where large centric diatoms occurred (see Fig. 3.30). On previous cruises it has also been noted that fluorescence readings fluctuate markedly like this when large phytoplankton cells like *Noctiluca* are present. This tendency in the instrument response obviously effects the data, and it therefore seems wiser to obtain an average value over a few meters when the chlorophyll: fluorescence ratio is being calculated and applied. As these fluctuations have been observed with both Aquatracka and Biospherical fluorometers, the phenomena seems worth being considered by other researchers.

Angola Dome: By the time this area was surveyed, it was necessary to drastically downsize the sampling effort to allow analysis of previous samples, and for packaging of the numerous equipment. However, preliminary results show that the phytoplankton biomass levels in the Angola dome area were very much lower than those encountered in the north of Namibia and the south of Angola (see Fig. 3.29).

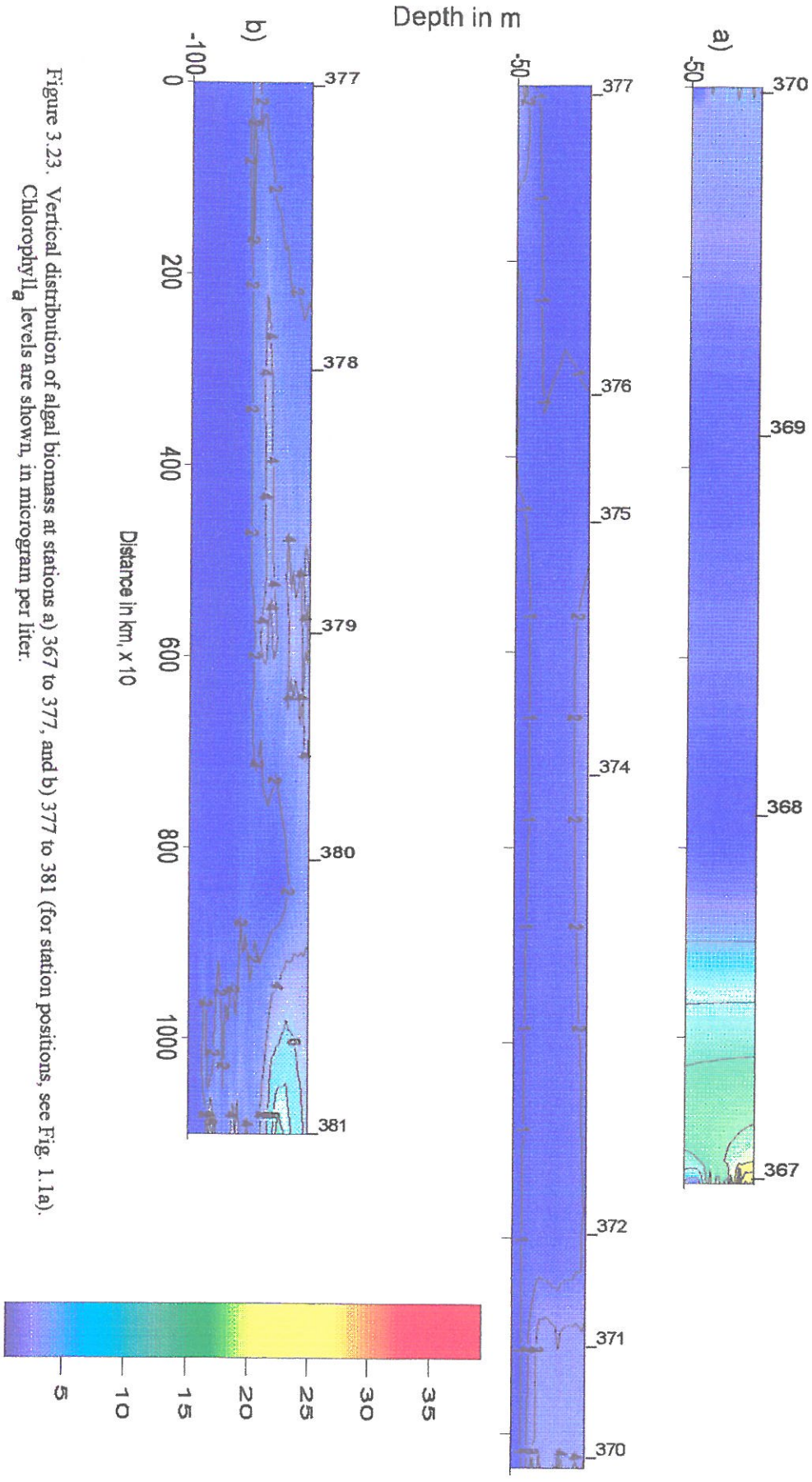

Figure 3.23. Vertical distribution of algal biomass at stations a) 367 to 377, and b) 377 to 381 (for station positions, see Fig. 1.1a). Chlorophyll$_a$ levels are shown, in microgram per liter.

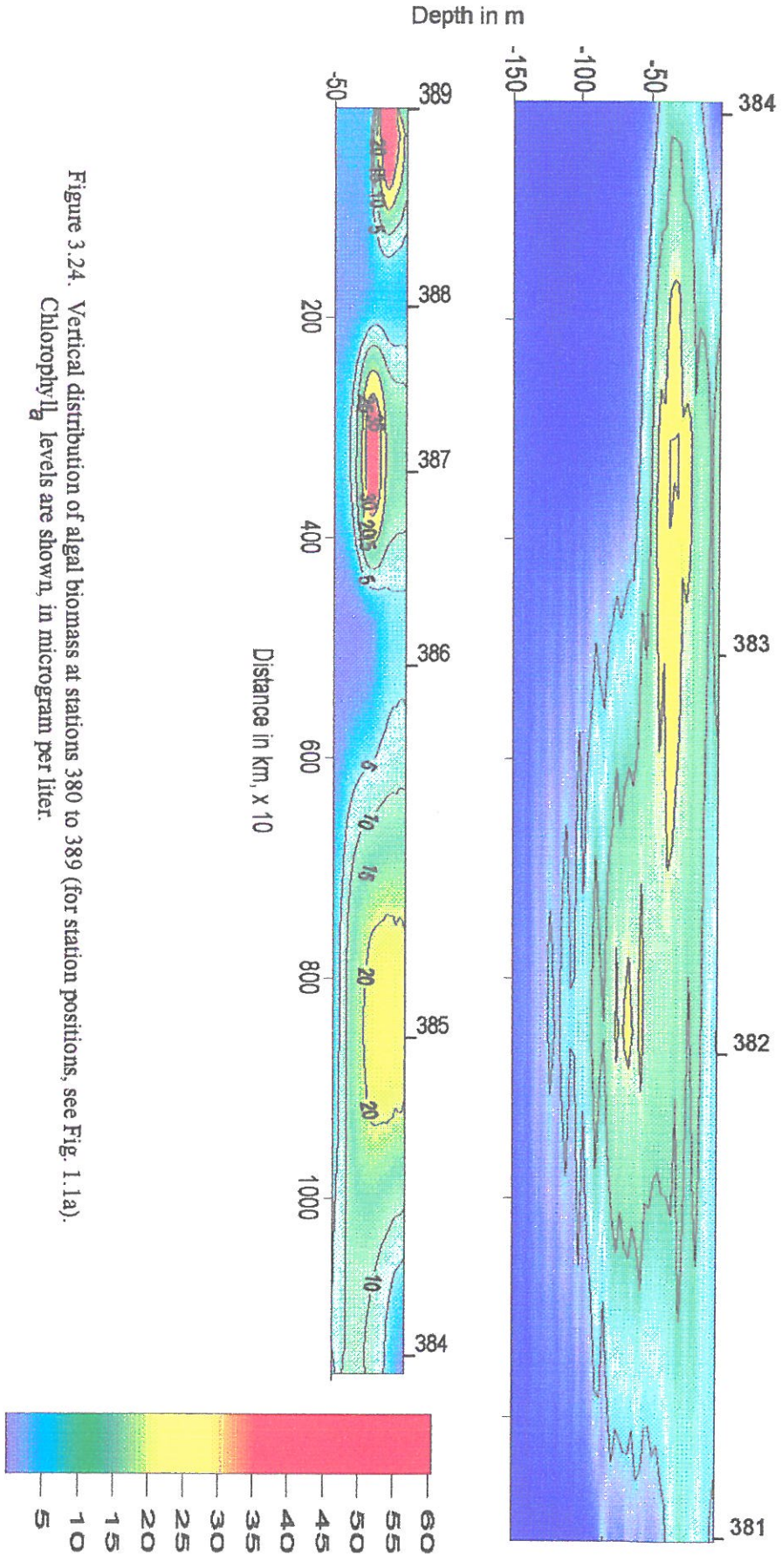

Figure 3.24. Vertical distribution of algal biomass at stations 380 to 389 (for station positions, see Fig. 1.1a). Chlorophyll$_a$ levels are shown, in microgram per liter.

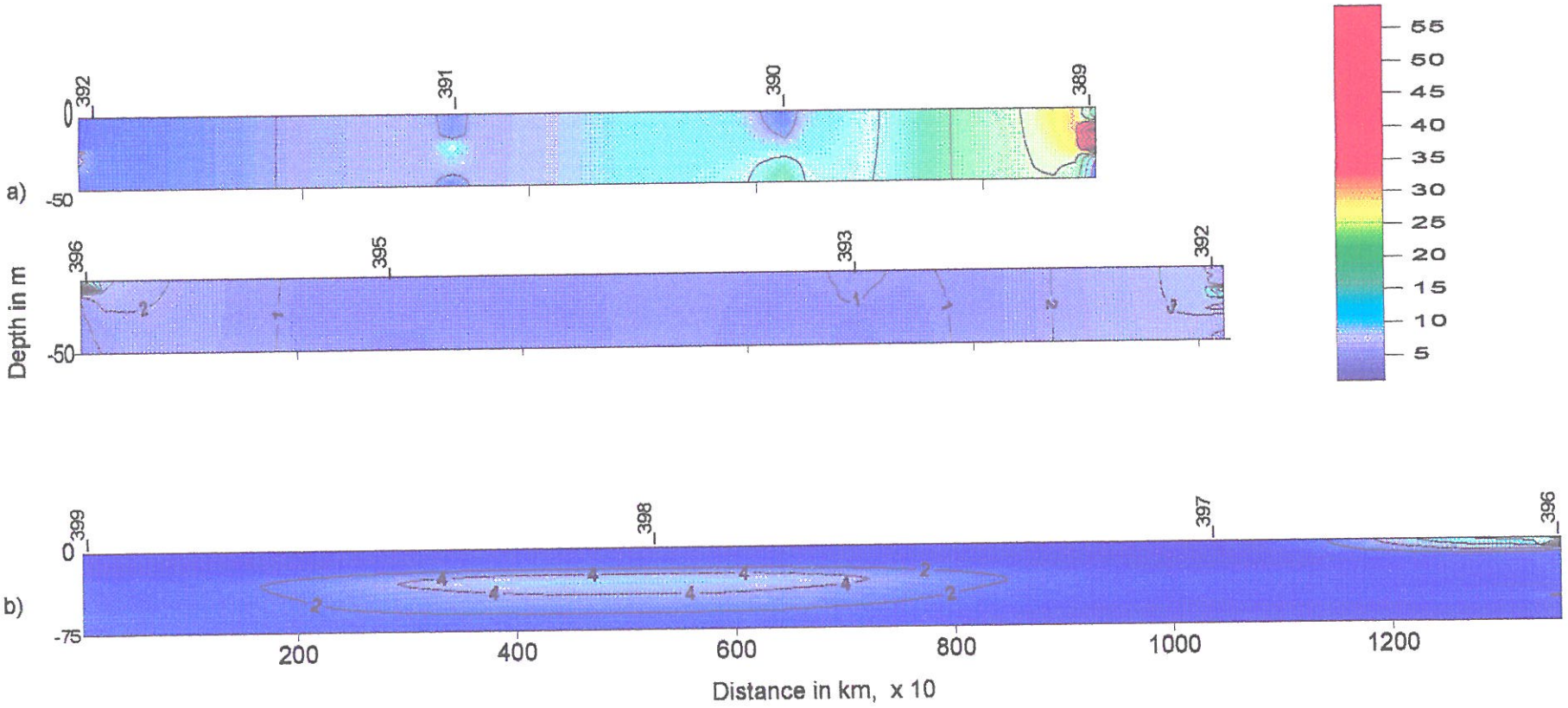

Figure 3.25. Vertical distribution of algal biomass at stations a) 389 to 396, and b) 396 to 399 (for station positions, see Fig. 1.1a). Chlorophyll$_a$ levels are shown, in microgram per liter.

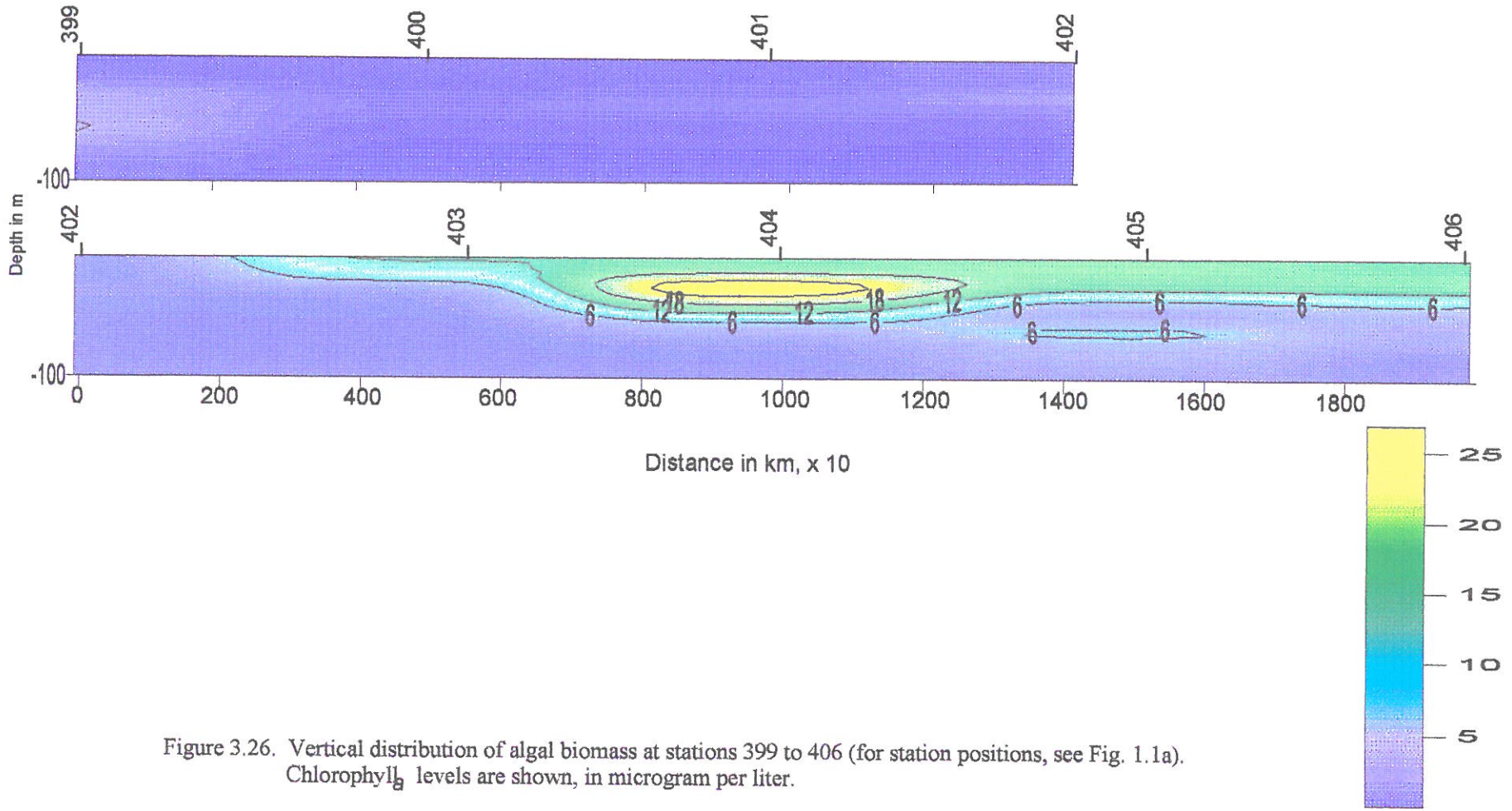

Figure 3.26. Vertical distribution of algal biomass at stations 399 to 406 (for station positions, see Fig. 1.1a). Chlorophyll$_a$ levels are shown, in microgram per liter.

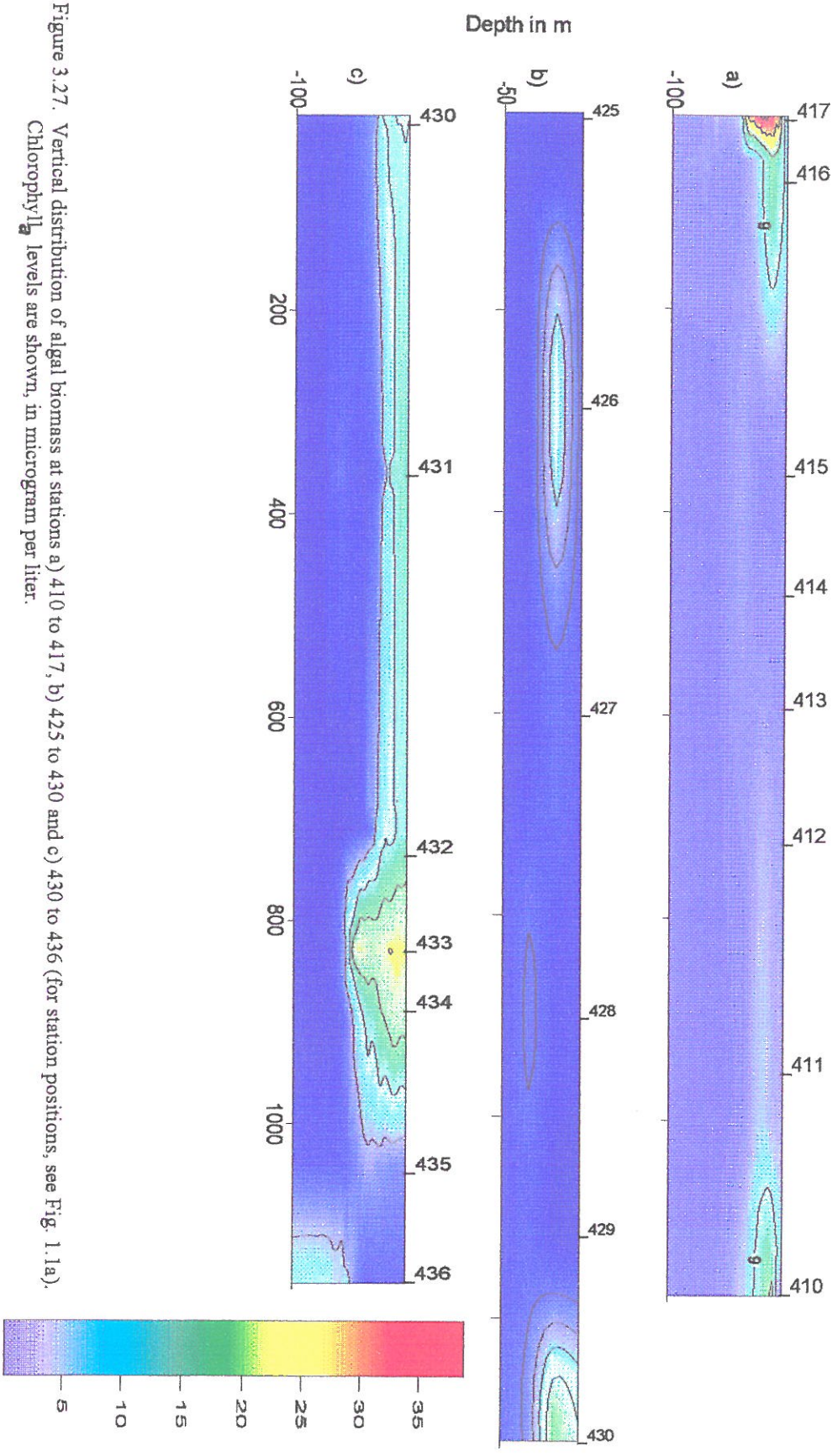

Figure 3.27. Vertical distribution of algal biomass at stations a) 410 to 417, b) 425 to 430 and c) 430 to 436 (for station positions, see Fig. 1.1a). Chlorophyll $_a$ levels are shown, in microgram per liter.

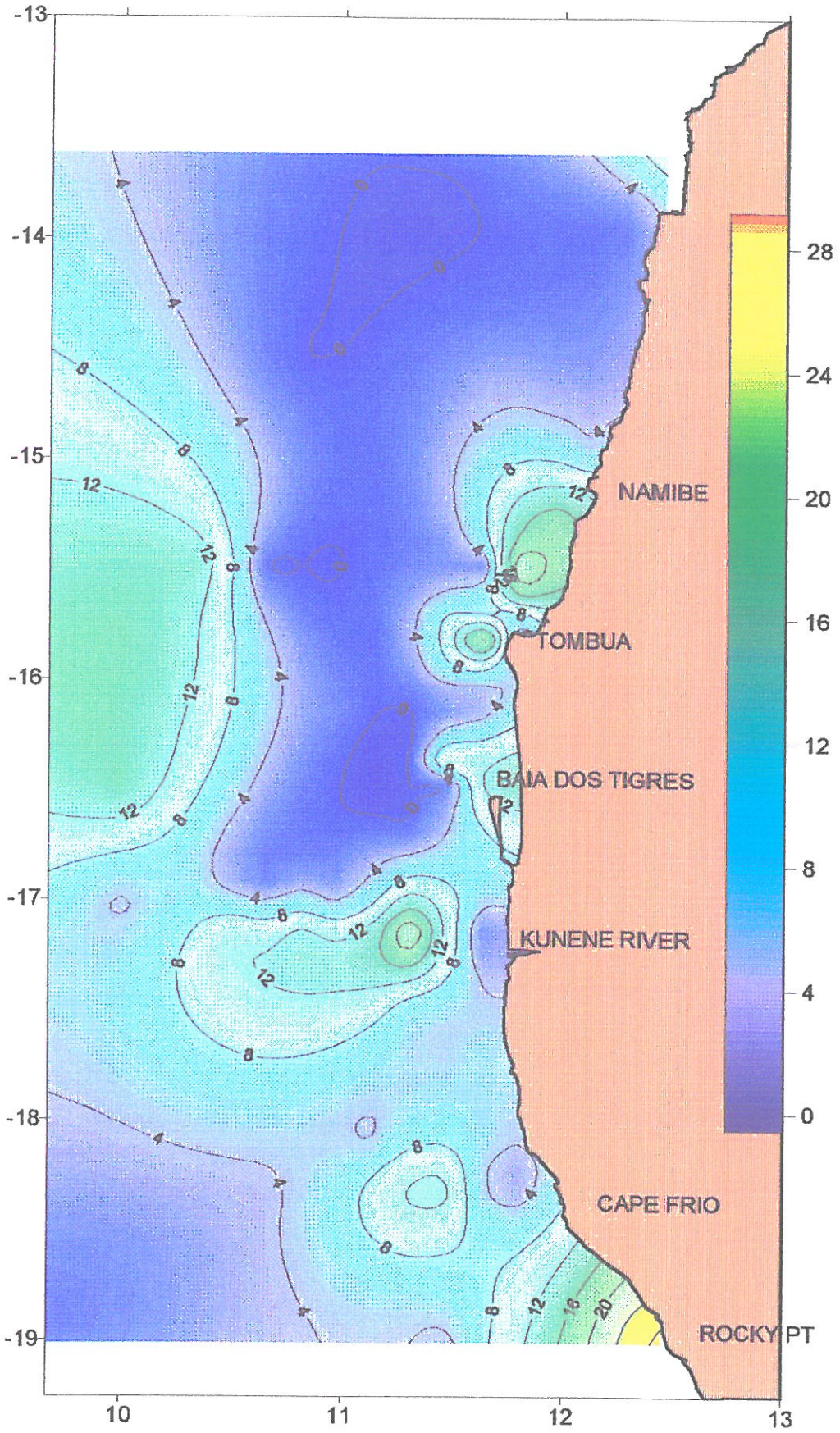

Figure 3.28. Subsurface (-5m) chlorophyll$_a$ levels (in microgram per liter) measured in the Angola Benguela Front Area.

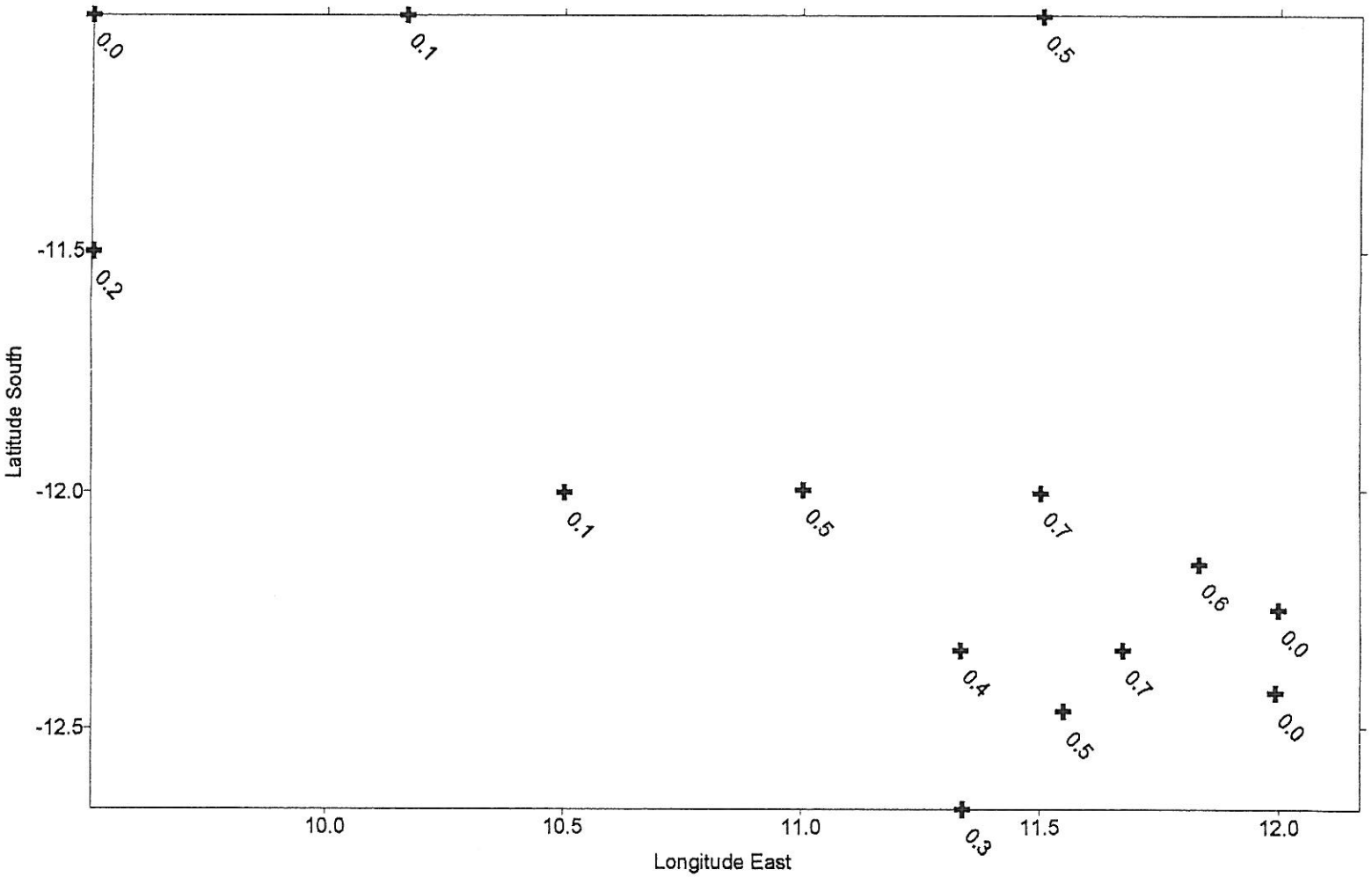

Figure 3.29. Subsurface (-5m) chlorophyll$_a$ levels (in microgram per liter) measured in the Angola Dome Area.

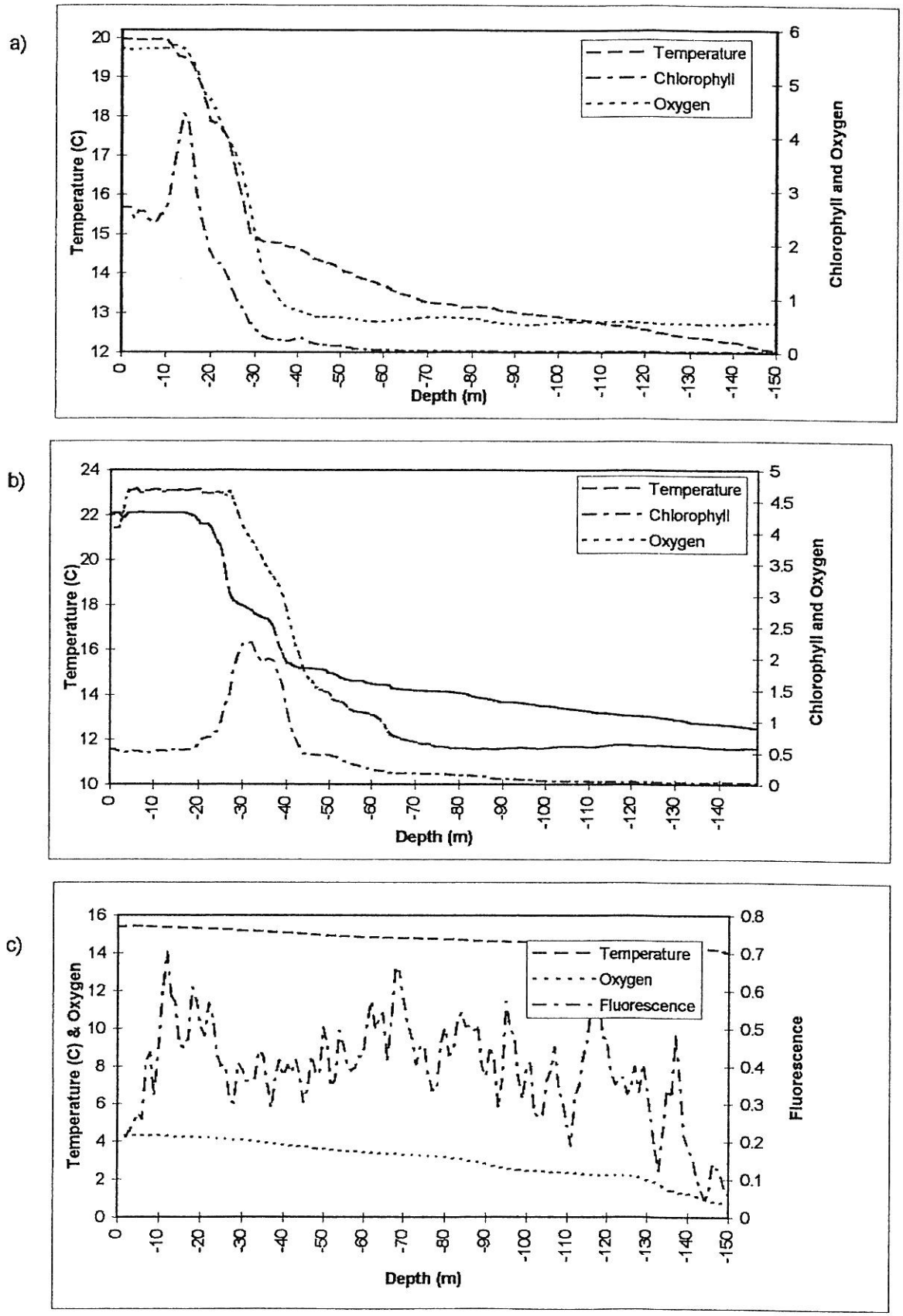

Figure 3.30. Depth profiles at stations a) 403, b) 429 and c) 382.

3.3 Zooplankton

The immediate impression is that the zooplankton assemblages varied both quantitatively and qualitatively with the various water masses investigated. In the southern part of the area, i.e. south of the temperature front, pseudothecosomate pteropods, doliolids, and salps were quite numerous, north of the front small copepods dominated the samples. At the westernmost stations (st.405-08) in the front area, the zooplankton, especially the smaller sized fraction, was masked by very high densities of diatoms.

From st. 452 on, i.e. in the Angola Dome, the zooplankton seemed richer, especially in small copepods. The ctenophore *Beröe* sp. was first observed at st. 453, thereafter it was regularly found in the dome area. However, medusae and other gelatinous organisms were quite scarce in the dome area, while large numbers of siphonophores and medusae again were observed in the WP-2 samples west of the Angola Dome.

All through the area the dominating euphausiids belong the the genera *Euphausia* and *Nematoscelis*.

Zooplankton biomass, dry weight (DW).

Figs. 3.31 and 3.32 show the the distribution of zooplankton biomass, the three size categories (>2000, 1000-2000, and 200-1000 μm) combined for the Angola-Benguela Front and the Angola Dome areas.

In the southwestermost area the biomasses are below 2000 mg/m^2. This is a region where relatively warm water masses, above 17°C, enters from southwest (Fig. 3.4) at 50 m depth.

The biomasses increases northwards. However, due to very high densities of diatoms in the area between 18 and 17°S, the dry weight biomass of zooplankton can not be estimated, since the animals are all masked by the huge numbers of diatoms. An example of the diatom dominance is st. 437, where the weight of the WP-2 sample equals 0.154 kg DW/m^2, almost all due to the diatoms.

At about 16°50´S a distinct gradient is observed. This biomass gradient represents the Angola-Benguela Front (ABF). North of the front the biomasses are low, especially off the coast in 15-16°C water masses (50 m depth); below 2000 mg/m^2 in a large area. In the eastern part of this

region another gradient was found. Over a distance of a few nautical miles, biomasses varied from above 4000mg/m2 east of the gradient, to below 2000 mg/m^2 to the west. This gradient followed the 200-500 m depth contours, i.e. high densities of zooplankton occurred at or just off the shelf break, low densities over deeper waters. Remarkable high densities, above 15000 mg/m^2, was observed at one station (st.417) just off the shelf break west of Tombua, neighbouring stations gave 7000-9000 mg/m^2.

The overall impression is that the zooplankton biomasses in the southern part of the investigated areas, i.e. between 19° and 15°S, was strongly related to the water masses, and the isolines for zooplankton biomass to a very high degree follows the isotherms at e.g. 50 m depth (Fig. 3.4).

North of 15°S the biomass with few exceptions varied between approx. 3000 to 4000 mg/m^2. Between 15° and 14°S this relatively high biomasses were partly due to the presence of salps, further north, especially in the Angola Dome region, the high biomasses were mainly due to copepods.

At a few stations in the very centre of the Angola Dome, i.e. within the 23°C isoterm at 20 m depth (Fig. 3.19 b), the biomasses were very high, from 5000 to 20000 mg/m^2. The zooplankton at these stations consisted mainly of copepods and siphonophores.

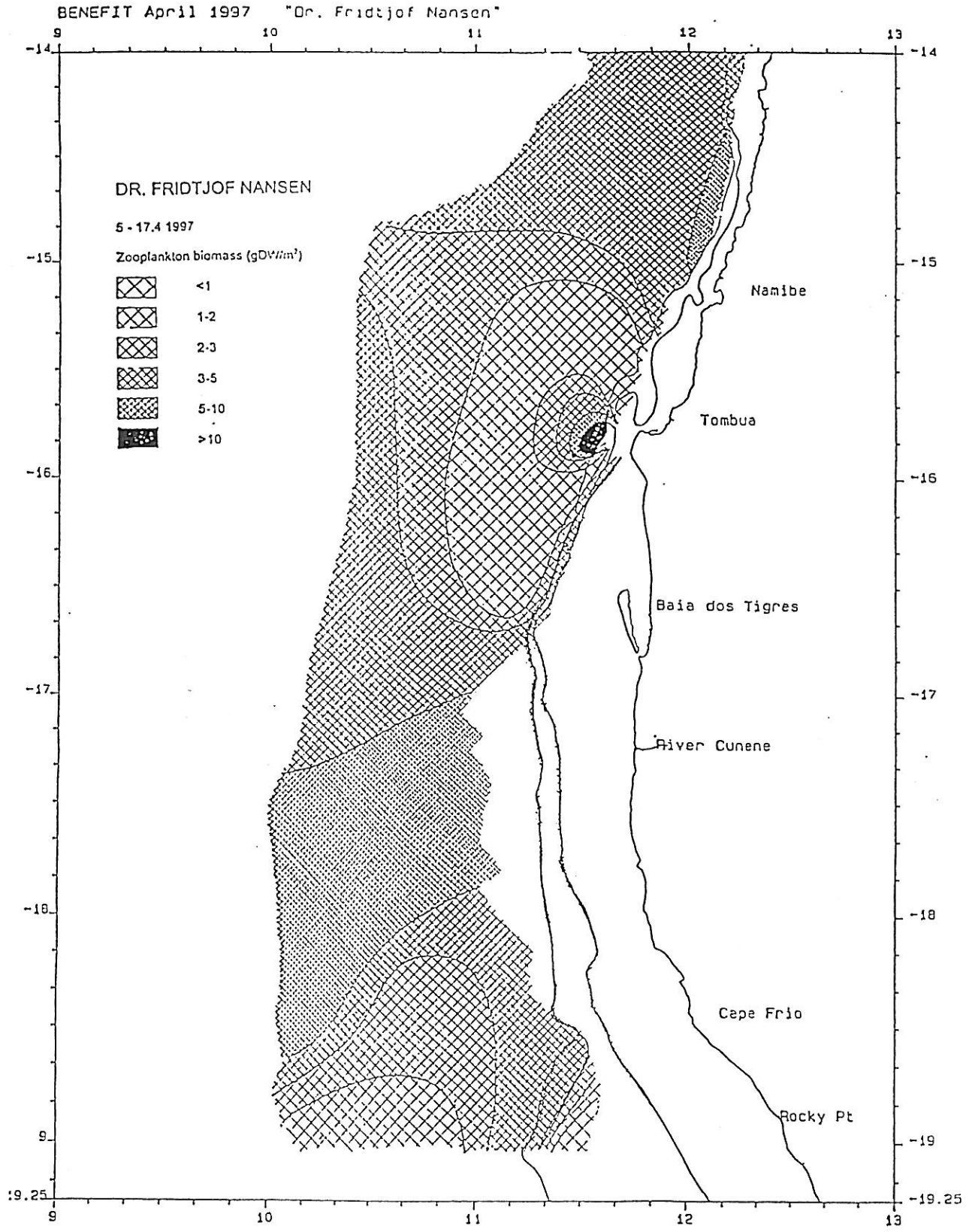

Fig. 3.31 Horizontal distribution of zooplankton biomass, the 3 size-categories (>2000, 1000-2000 and 200-1000 µm) combined in the Angola-Benguela Front.

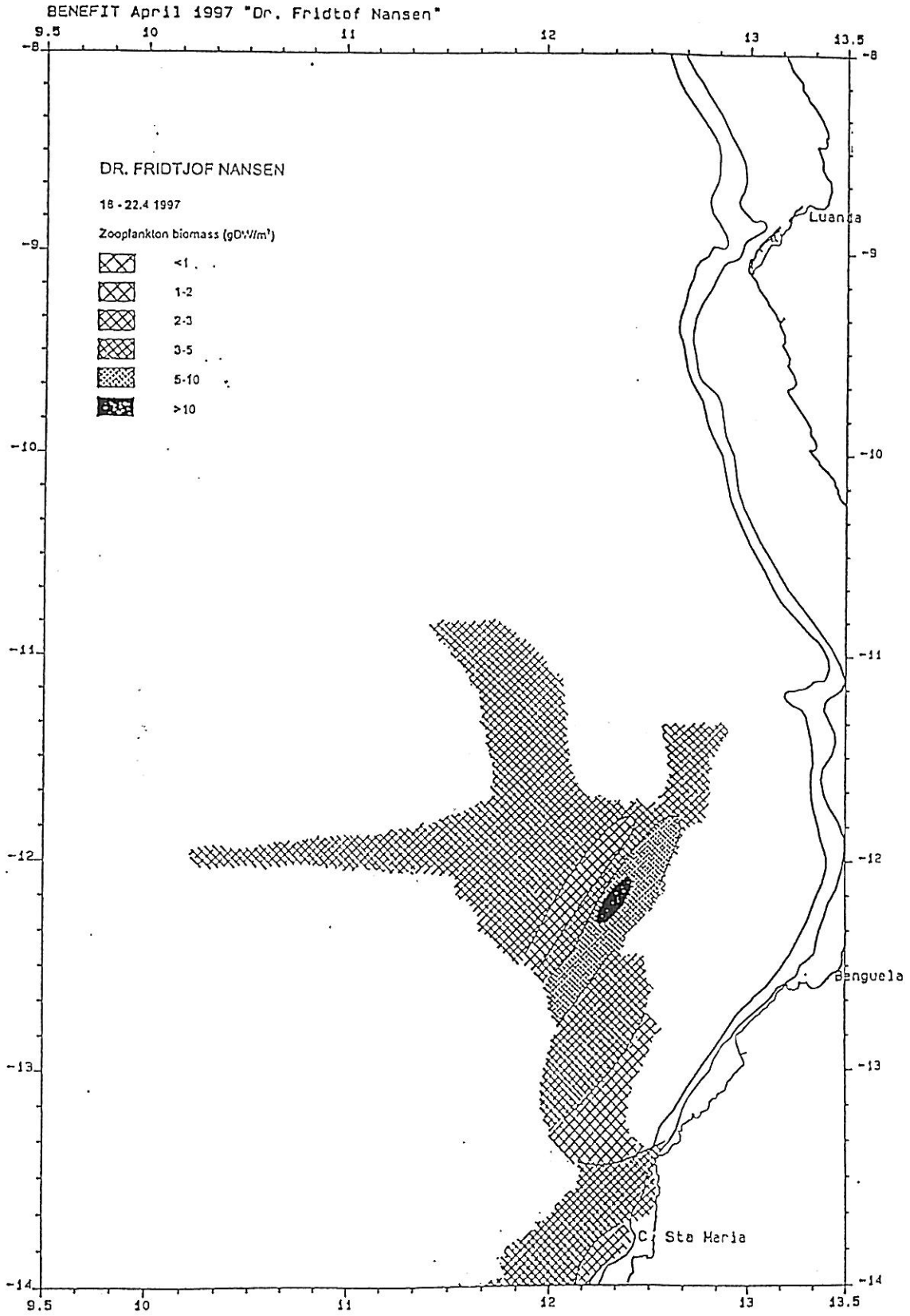

Fig. 3.32 Horizontal distribution of zooplankton biomass, the 3 size-categories (>2000, 1000-2000 and 200-1000 µm) combined in the Angola Dome area.

3.4 Ichthyoplankton

Fish larvae were found on all stations except from one. The highest numbers were found in Angolan watermasses. Figure 3.33 shows the horizontal distribution of fish larvae during the first part of the cruise. The highest abundance of fish larvae was found in connection to the Angolan Dome (not shown in the figure) with a maximum of 175 larvae in a haul. The Dome may act as a retention area for eggs and larvae. On a station outside the front at River Cunene, 117 larvae were sampled.

Since the sampling volume of the Bongo nets was estimated to approx. 250 m^3, the highest density was 0.7 larvae m^{-3}. Large differences in size and species composition were seen throughout the investigation area, and microstructure investigations may show the eventual growth and birthdate differences between fish larvae connected to the different water masses.

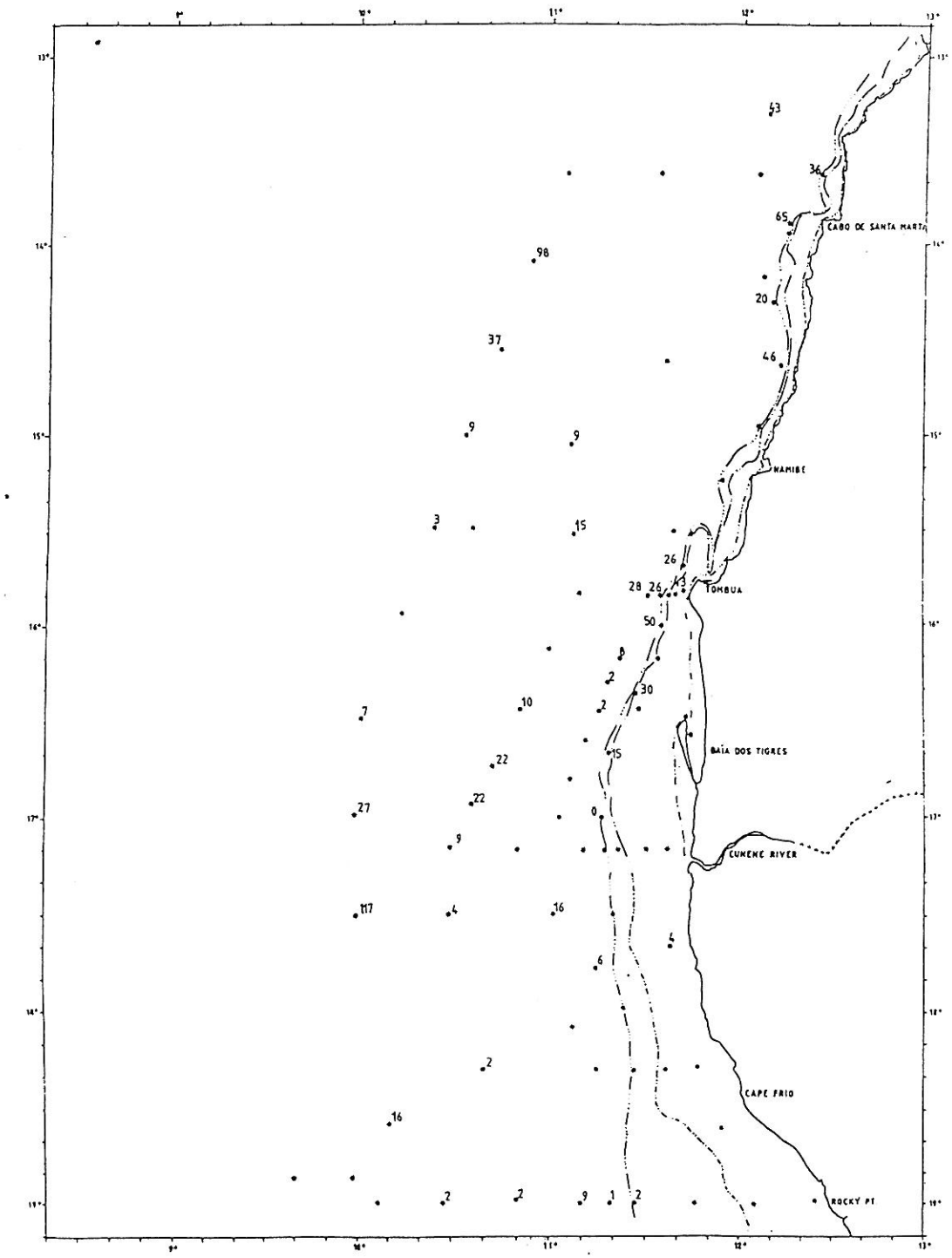

Figure 3.33 The horisontal distribution of fish larvae during the first part of the cruise.

3.5 Fish composition and distribution

3.5.1 Species composition

The main species encountered in the studied area were the two species of horse mackerel, the Cunene horse mackerel (*Trachurus trecae*) and the Cape horse mackerel (*Trachurus capensis*). The latter occurred in seven out of eleven stations and the Cunene species in two of the trawls. No sardinella echoes were registered and no fish were captured in the trawls. Round herring (*Etrumeus whiteheadi*) and the anchovy (*Engraulis capensis*) were the only other commercially important pelagic species recorded and captured. Annex I shows the percentage of occurrence of the main pelagic fish and three important demersal species.

The central objective of this investigation was to map the fish composition across the Benguela-Angola front and compare the results between the southern and northern areas. As can be seen in Annex I, across the front (Stations 2, 4, 5 and 6) the dominant species were the horse mackerels whereas in the south the round herring and the anchovy were also present. Due to the nature of the survey insufficient data were collected to do justice to the main objective. However the data collected confirms conclusions from previous investigations with regard to the area overlap of the two horse mackerel species.

3.5.2 Distribution

Horse mackerels

Figures 3.34 and 3.35 show the distribution of horse mackerels. The Cape species was distributed from Tombua southwards whereas the Cunene horse mackerel was found north of Baía dos Tigres confirming the overlapping area for these species reported in previous investigations (see cruise reports 'Dr Fridtjof Nansen' 2/95 and 1/97).

As shown in Fig. 3.34 high concentrations of Cape horse mackerel were found outside Baía dos Tigres and south of Cape Frio. The length frequency distribution of the species (Fig. 3.36) consist of fish with lengths ranging from 12 to 29 cm with a modal length of 16 cm in the south. In the area of the Benguela-Angola front the sizes ranged from 18 to 27 cm with the mode at 22 cm (Fig. 3.37).

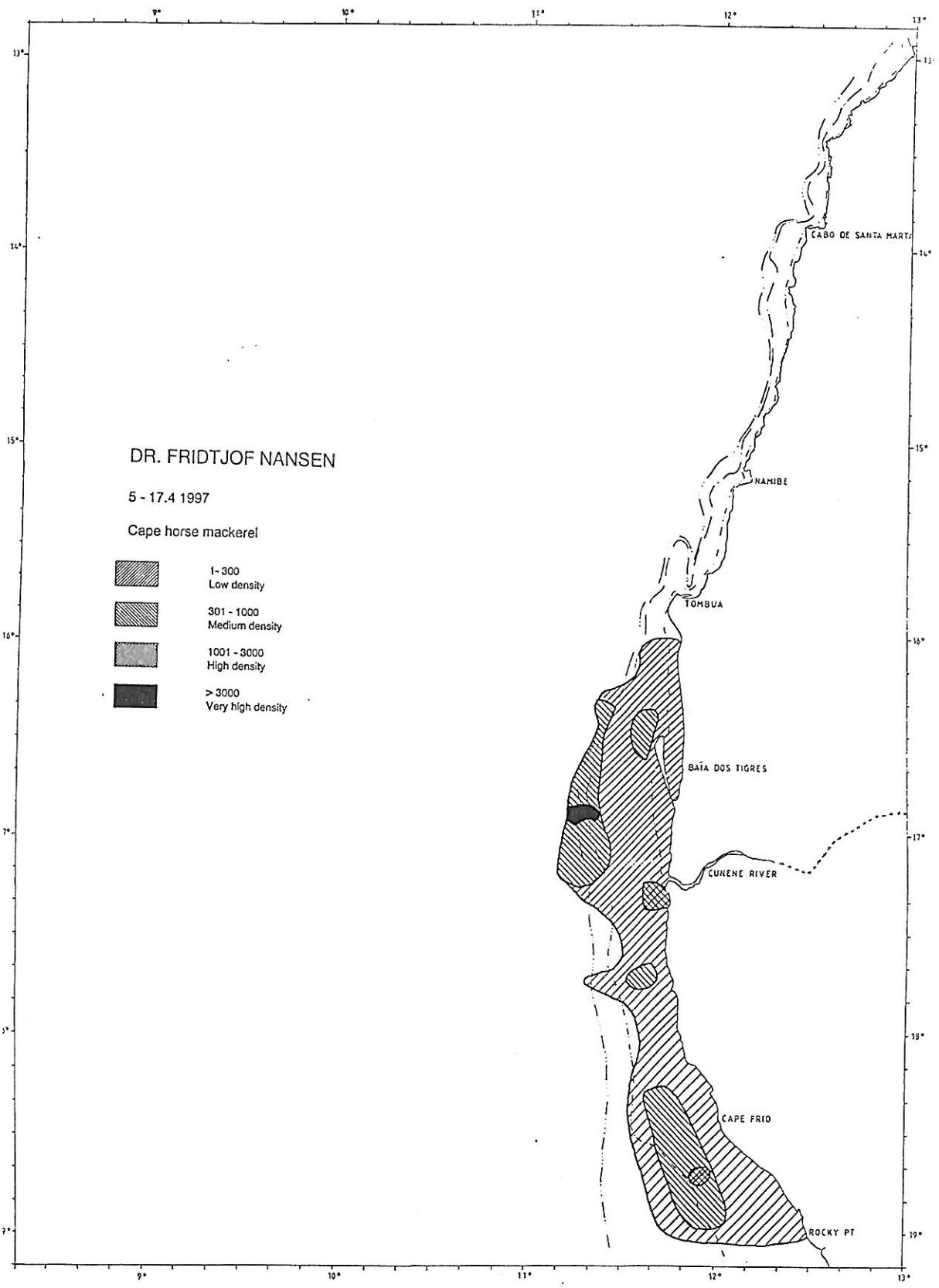

Fig. 3.34 Distribution of Cape horse mackerel.

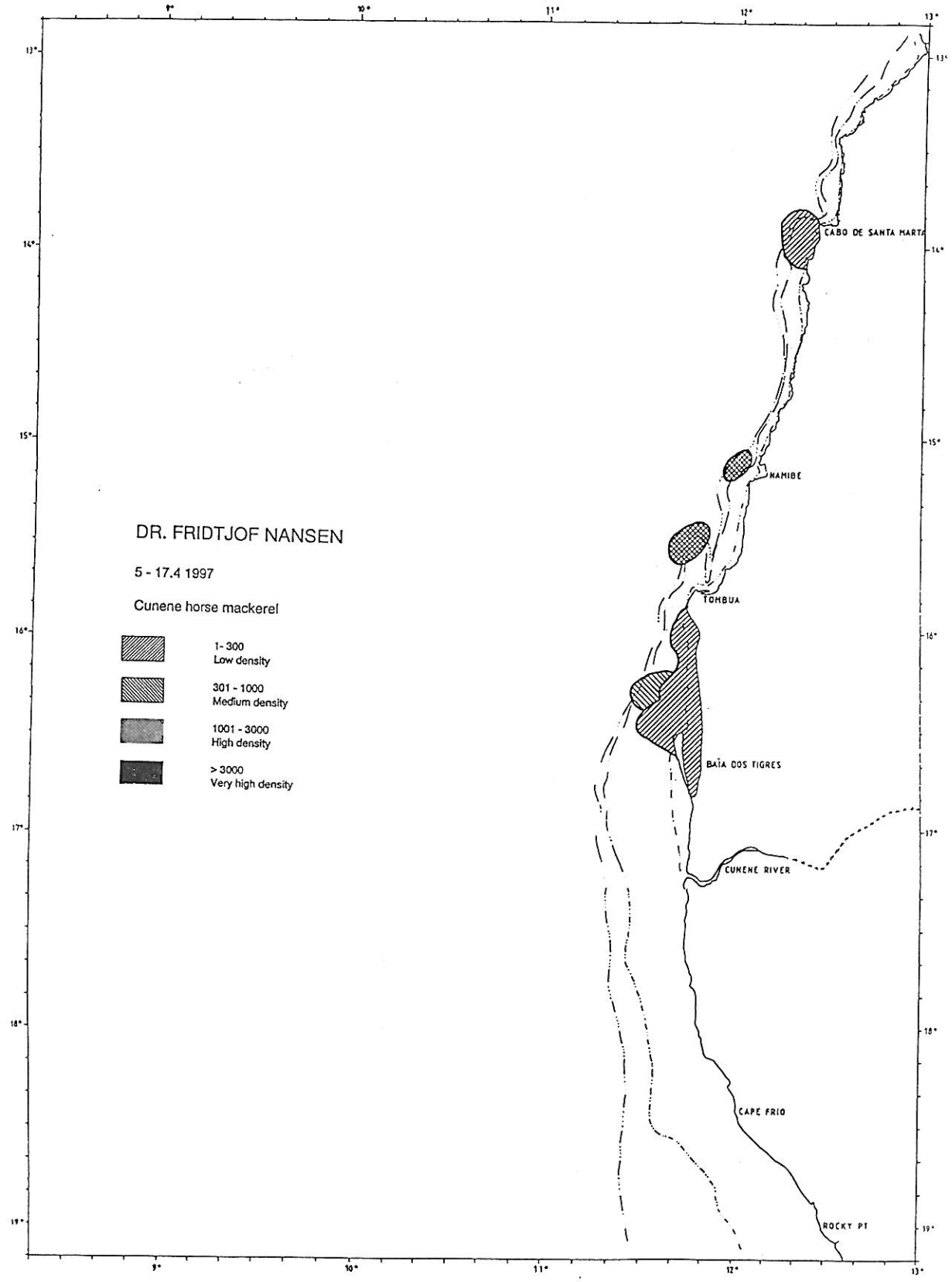

Fig. 3.35 Distribution of Cunene horse mackerel.

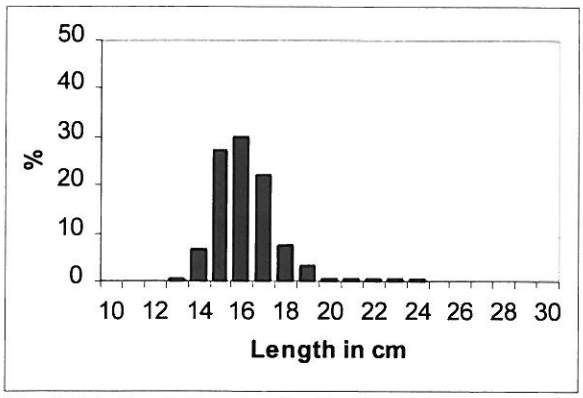

Fig. 3.36 Total length distribution of Cape horse mackerel (*T. capensis*) in the south.

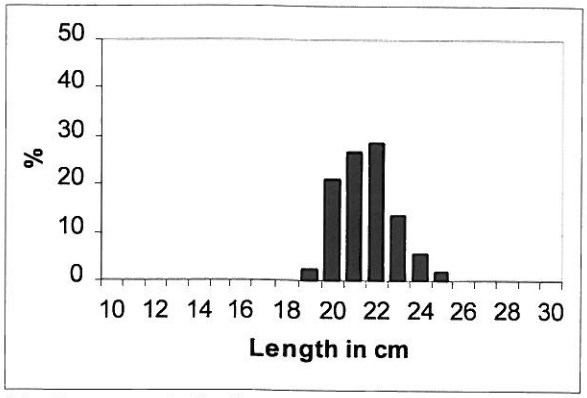

Fig. 3.37 Length distribution of Cape horse mackerel in the front.

Figure 3.35 shows the distribution of Cunene horse mackerel. Very few echo records were attributed to this species north of the front which can be due to the fact that the survey effort in this area was located rather far offshore. The main concentrations were located between Baía dos Tigres and Tombua but densities were generally low. The highest concentrations were registered off Namibe and north of Tombua. The length frequency distribution showed two main modes for the Cunene species in the frontal area at 14 and 20 cm, the length range was from 13 to 24 cm (Fig. 3.38).

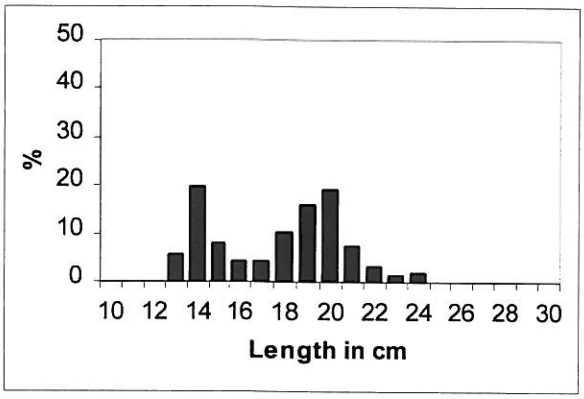

Figure 3.38 Total length distribution of Cunene horse mackerel (*T. trecae)* in the front.

Round herring

This species was found in the area south of the Front, from the Cunene river southwards (Fig.3.39). Two concentrations were observed with high densities off Rocky Point and around 17°40'S. Although three individuals were captured in trawl number 5, (16°14'S, north of the front), no acoustic targets were assigned to this species in the area due to the low density. The length frequency distribution is shown in Fig. 3.40.

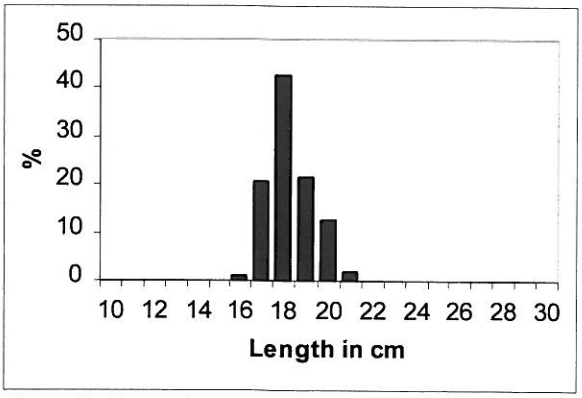

Figure 3.40 Total length of round herring (*E. whiteheadi)* in south.

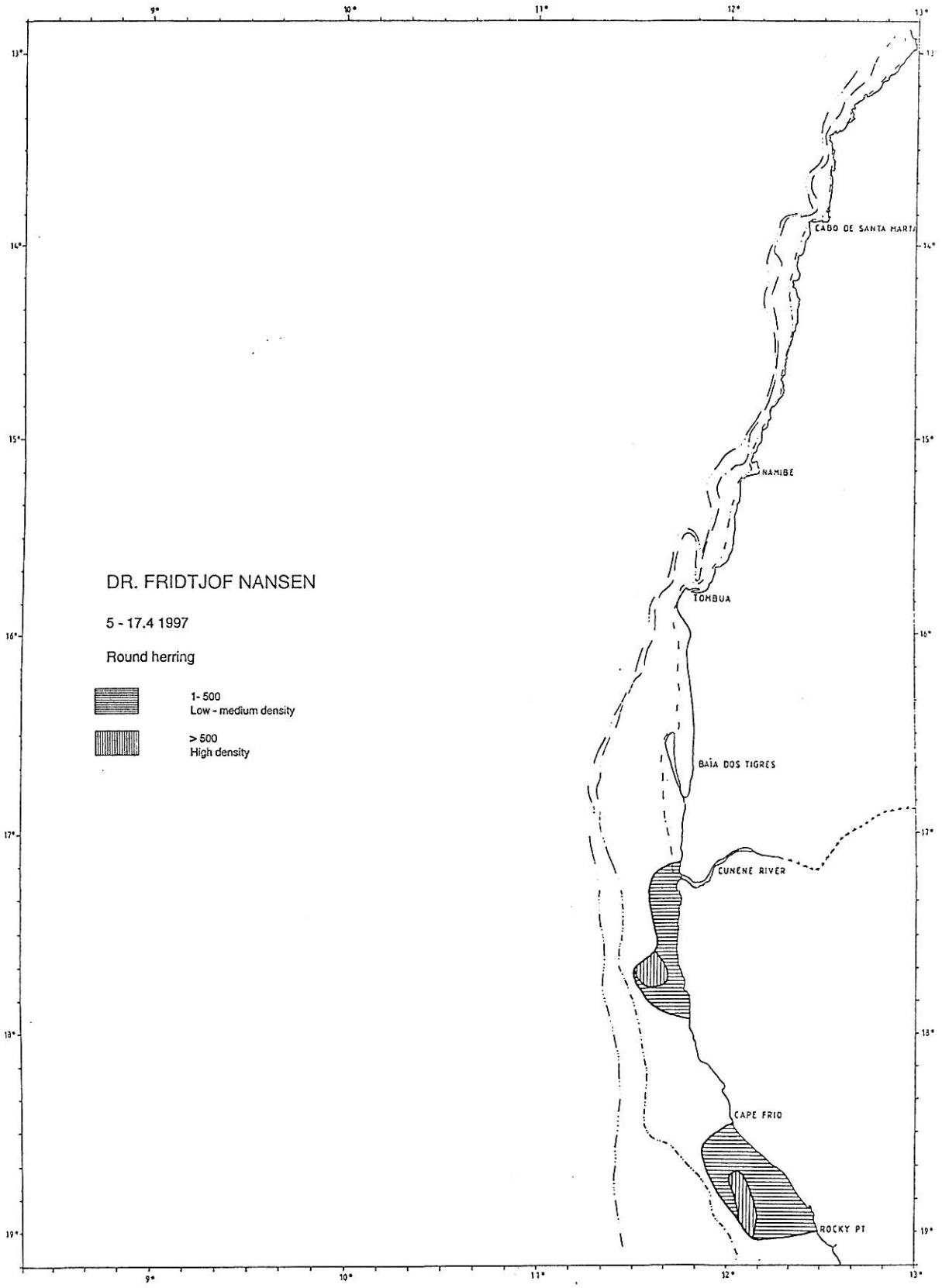

Figure 3.39 Distribution of round herring.

Specimen collection for SAM and SFRI

Specimens of the following species were collected, photographed and frozen for further study at the South African Museum and Sea Fisheries Research Institute:

Perulibatrachus rossignoli	Toadfish
Hoplostethus cadenti	Black slimehead
Gephyroberyx darwini	Darwin's slimehead
Trachipterus jacksonensis	Oar fish
Tetragonurus atlanticus	Bigeye Square tail
Carapidae	Pearl fish
Taaningichthys sp.	Mictophid
Bramidae	Pomfret
Histioteuthis sp.	Jewel squid
Vitreledonellidae	Transparent octopus
Myctophidae	Various species
Lepidotrigla carolae	Prickly gurnard
Trigla lyra	Piper gurnard
Zeus faber	John dory
Zenopsis conchifer	Silver john dory
Anguilliformes (eels)	3 species
Dentex gibbosus	
Dentex barnardi	Barnard's dentex
Dentex macrophthalmus	Large-eye dentex
Scorpaena stephanica	Scorpionfish
Synagrops microlepis	Thinlip splitfin
Sepia officinalis	Common cuttlefish
Macroparalepis macrogeneion	Barracudina sp

3.6 Nutrients

THE ANGOLA-BENGUELA FRONT

Horizontal Distribution

The nutrient distribution plots give a good indication of where the Angola-Benguela Front is situated. One can clearly distinguish the cold, nutrient-rich upwelled water from the warmer, nutrient-poor Angola current water.

The silicate distribution (at 5m depth) in Fig. 3.40 shows a maximum of >3.0μM along the Cunene River to Cape Frio region. This correlates with an upwelling area of 16°C seen in Fig. 3.1. The offshore front between 17°S to 19°S also appears in Fig. 3.40, with the silicate concentrations here reaching 24μM. Further upwelling is indicated north of Cabo de Santa Marta.

The phosphate distribution (Fig. 3.41) again suggests coastal upwelling south of the Cunene river and north of Cabo de Santa Marta, as well as the offshore front moving up to 17°S. In addition, a phosphate maximum of 2.0μM is found about 80 NM offshore at 17°S. From Fig 3.1 it is seen that this is the Angola-Benguela Front. The Angola Current just north of this frontal region is characterised by much lower surface phosphate concentrations (<0.1-0.5μM).

The surface nitrate plot (Fig. 3.42) clearly indicates the coastal upwelling between Rocky Point and Tombua with the cell situated south of the Cunene at 17°30S. A tongue of this upwelled nitrate-rich water moves offshore and northward, winding around the frontal zone. The coastal upwelling at Cabo de Santa Marta is marked by a 5m depth nitrate maximum of 25μM. The nitrite distribution in Fig 3.43 mirrors the nitrate plot, a nitrite maximum of 0.9μM is found at the upwelling cell at 17°30S.

The ammonia plot (Fig. 3.44) at 5m depth highlights the upwelling and frontal areas, with a maximum of 1.5μM noted. However, there is also an ammonia maximum at Namibe, an area with typically warm 22-24°C Angola current water. This ammonia probably originates from the decomposition of phytoplankton and would be indicated by a local phytoplankton maximum.

Vertical distribution

Cross sections of the nutrient data were plotted from stations 367 to 377, 389 to 403, and 396 to 399 (refer to Fig. 1.1 for the course track).
The vertical cross section at Rocky Point (Fig. 3.45): The upward sloping isolines in the silicate and, especially, the phosphate and nitrate plots suggest some upwelling. Nitrite and ammonia are typically concentrated on the shelf.

The 15°30S section (Fig. 3.46): The plots here (esp. nitrate) show some stratification. This would accord with conditions in the Angolan current waters. Both ammonia and nitrite surface to 30m depth maxima are exhibited. These higher ammonia and nitrite concentrations probably arise from the decomposition of a phytoplankton bloom.
The section just north of Cabo de Santa Marta (Fig. 3.47) indicates stratified stable conditions within the water column offshore. However, close to the coast there is strong upwelling, especially within the first fifty to hundred metres of the water column.

A longitudinal section along the shelf was plotted from station 369 at Rocky Point to station 396 near Cabo de Santa Marta. The phosphate and nitrate plots (Fig. 3.48) both register a frontal zone between 15°50S to 16°30S. The vertical isolines at 17°30S and 13°50S in the nitrate plot also point out two upwelling areas. Once again note the stratified conditions between 14°S and 16°S that mark the Angola current waters.

Fig. 3. 49 is a longitudinal section taken off the shelf. The nutrient profiles here only show a slight doming between 15°20S to 15°50S, where the frontal zone is situated. The nitrate plot also shows some downward mixing unto 200m at the front.

THE ANGOLA DOME AREA

Horizontal distribution

The horizontal nutrient distributions at 5m depth are characterised by very low nutrient concentrations. The only high concentrations are found in the south-eastern corner of the study area, near Lobito and Benguela. These maxima coincide with a part of the dome front that is signified by the closely spaced 23-25°C isotherms in Fig. 3.19. Refer to Figs 3.50, 3.51 and 3.52 for the silicate, phosphate and nitrate distributions respectively.

Vertical distribution

Vertical cross sections were plotted of station 477 to 457, and station 462 to 459. As can be seen from Fig. 3.54, the nutrients are generally stratified and stabile throughout the water column, except for a slight narrowing and doming at 12°20E (station 476). The northernmost cross section (Fig. 3.55) does not show any marked changes across the water column.

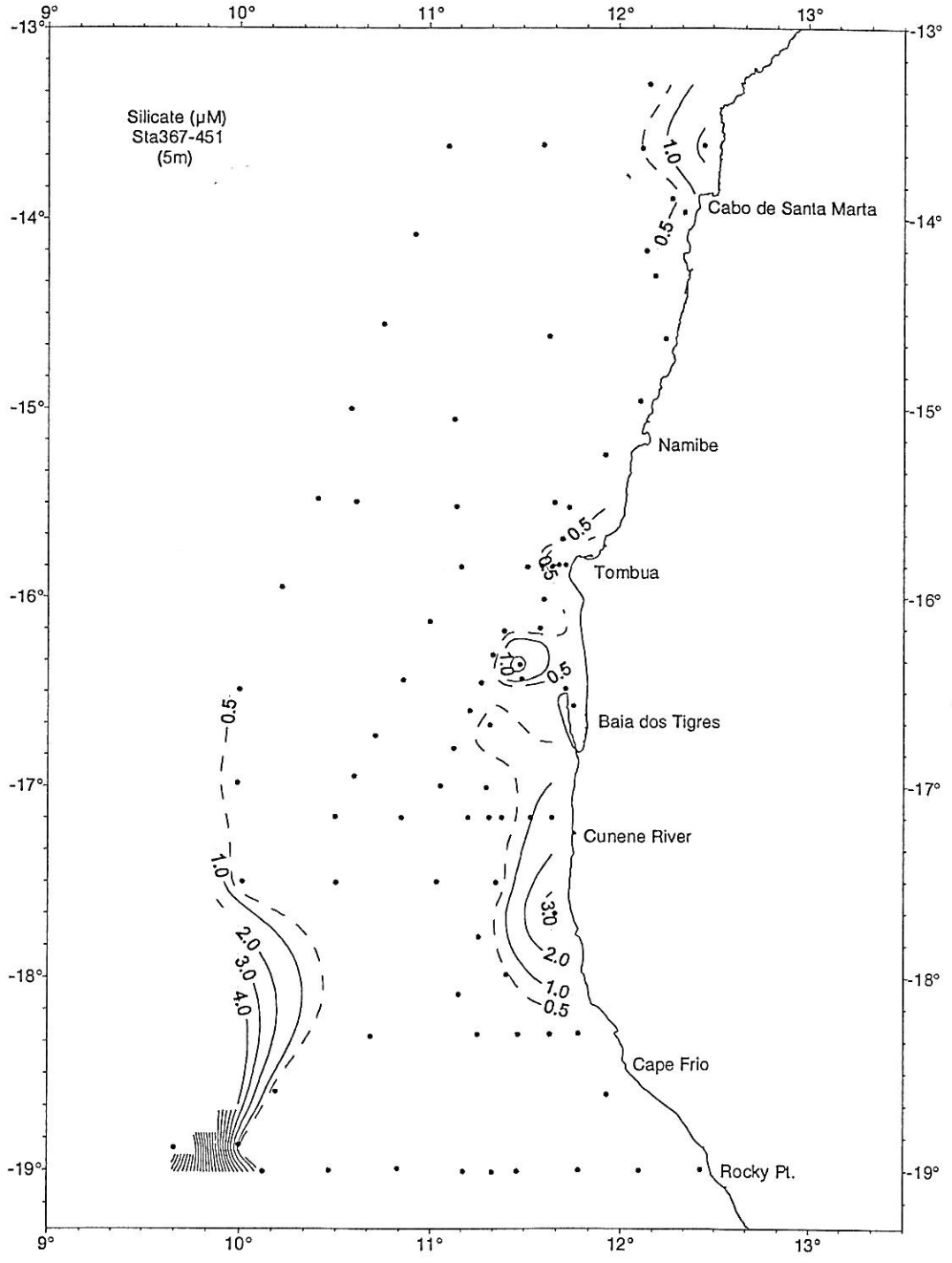

Fig. 3.40 Horizontal ditribution of Silicate (µM) at 5m depth in the Angola Benguela front region

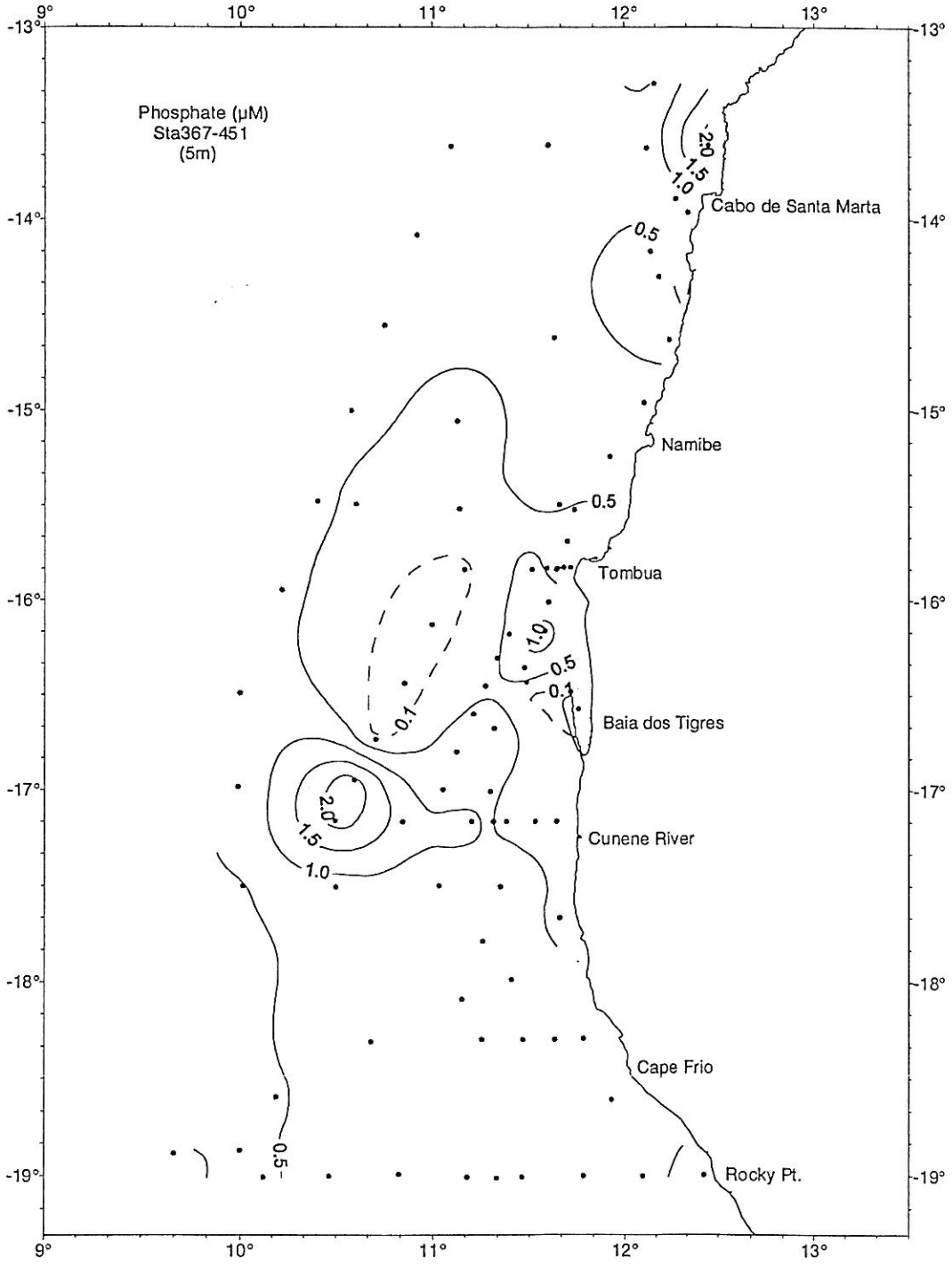

Fig. 3.41 Horizontal distribution of Phosphate (µM) at 5m depth in the Angola Benguela front

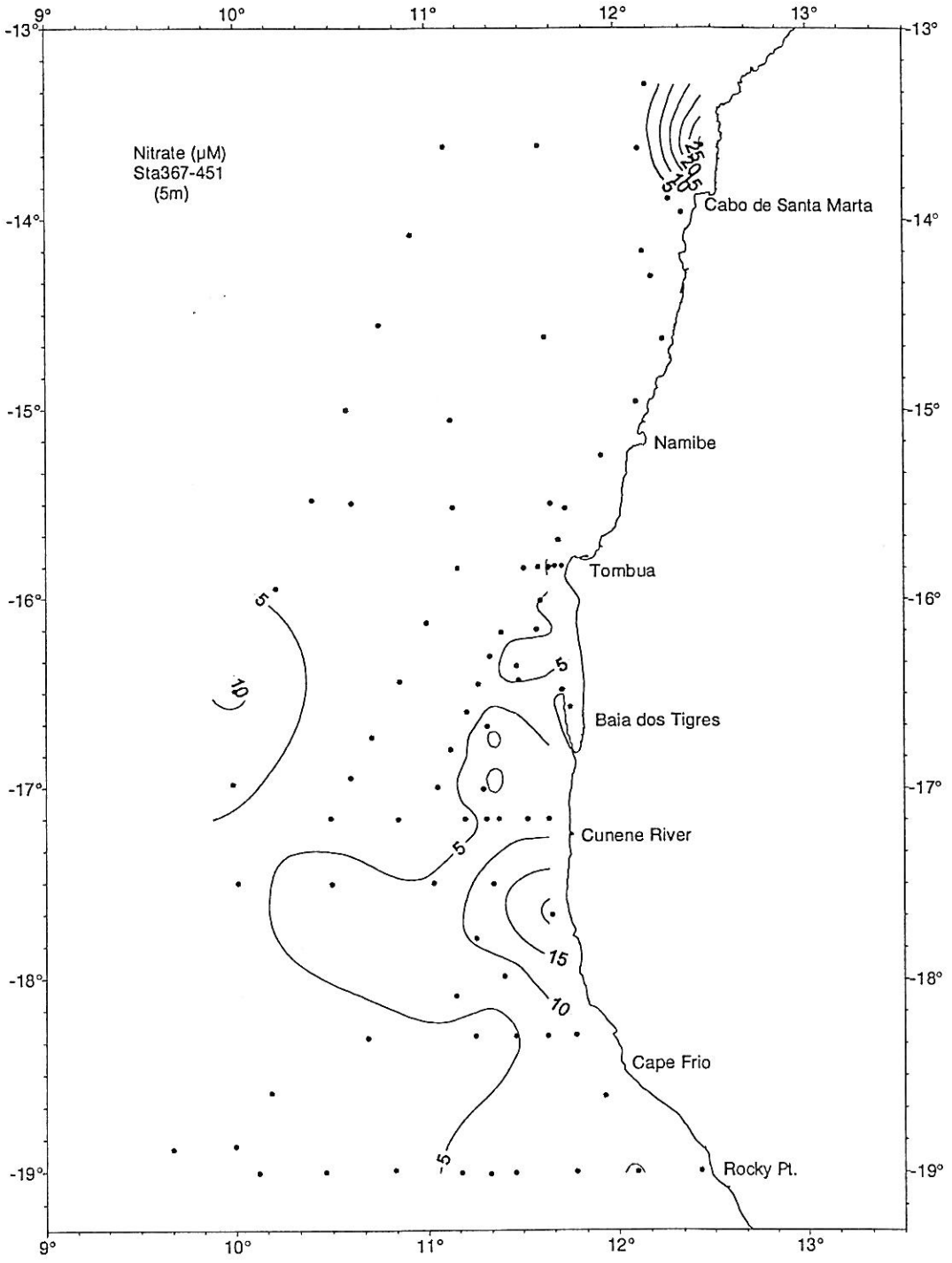

Fig. 3.42 Horizontal distribution of Nitrate (μM) at 5m depth in the Angola Benguela front

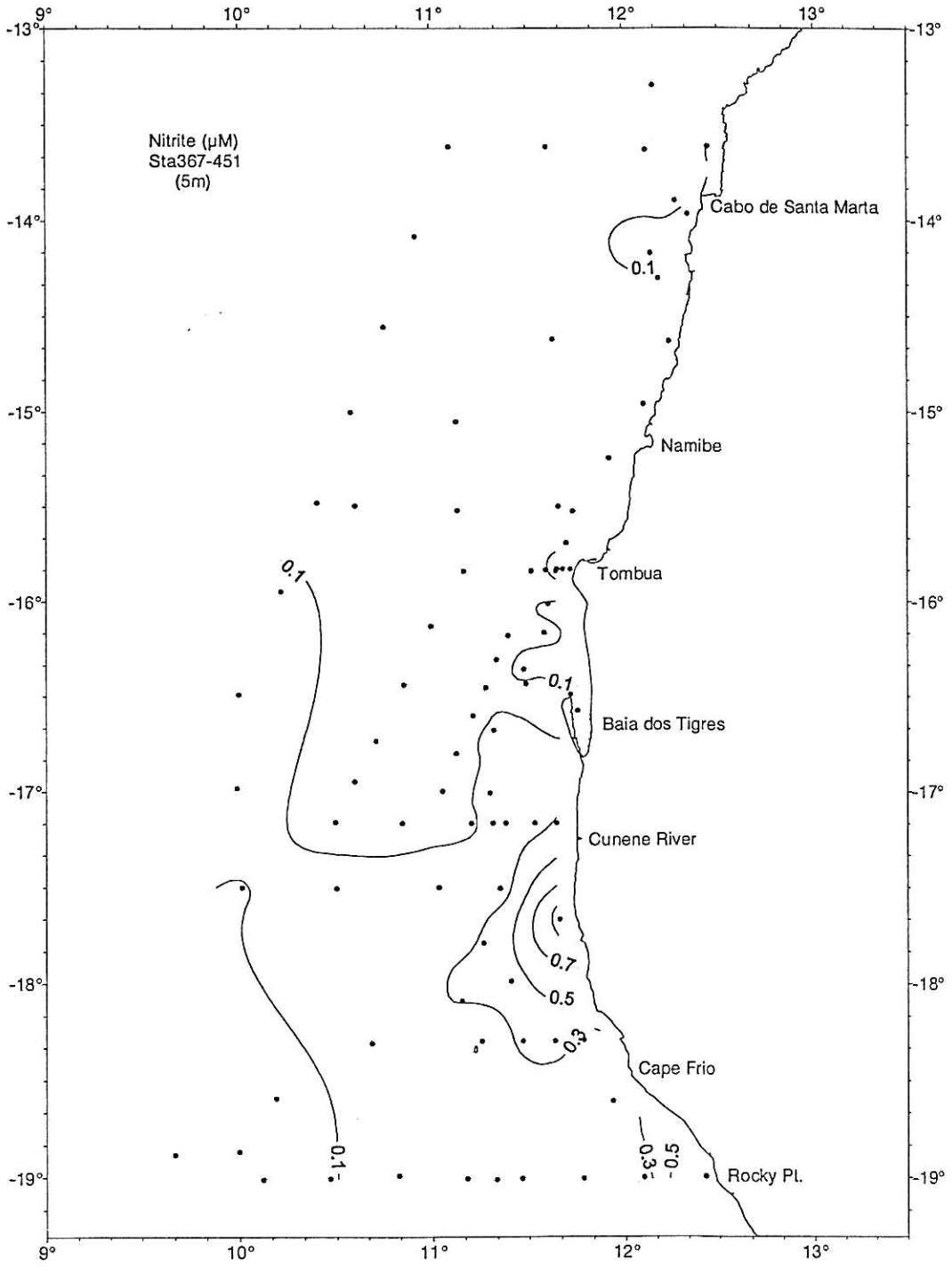

Fig. 3.43 Horizontal distribution of Nitrite (µM) at 5m depth in the Angola Benguela front

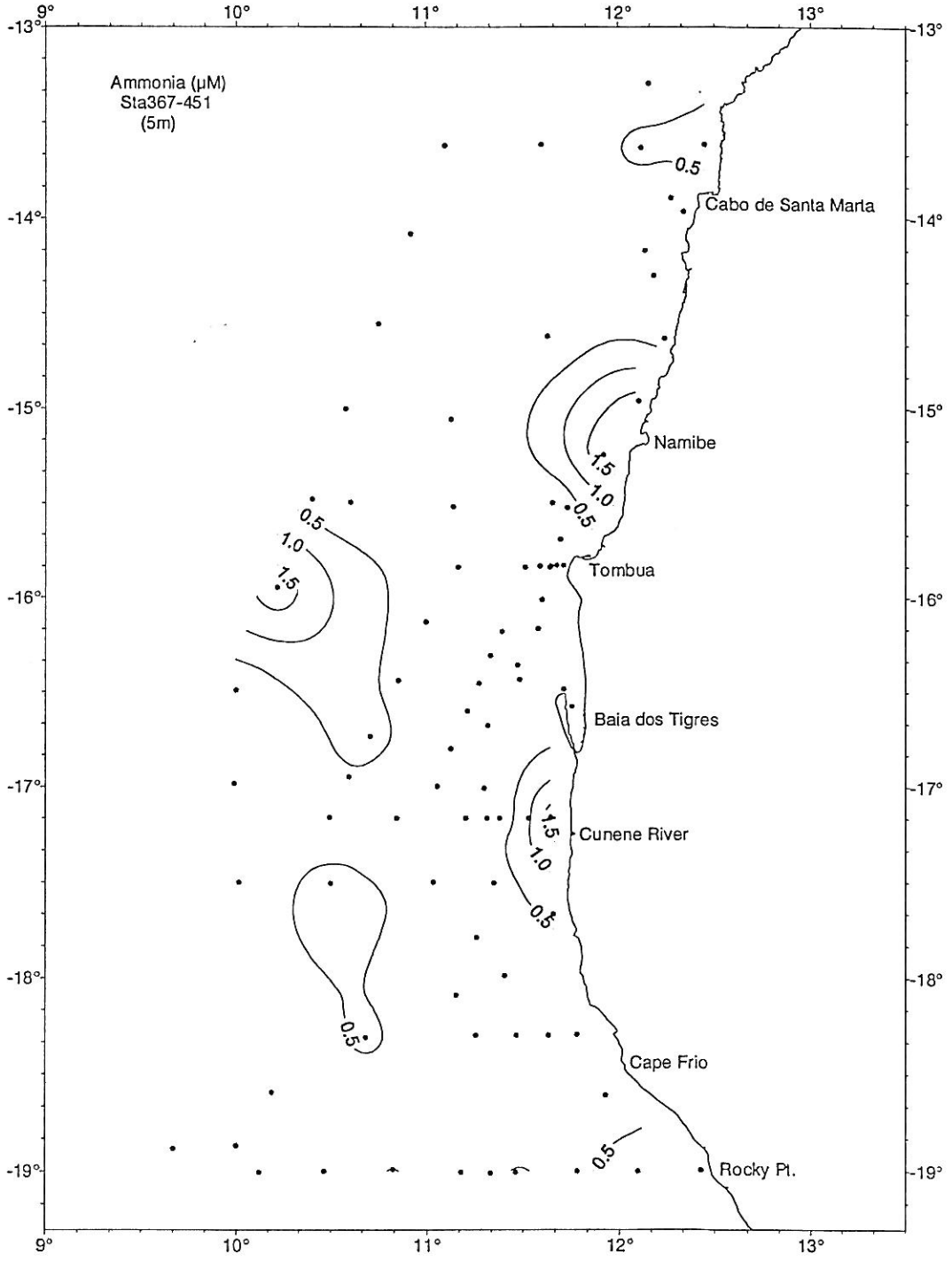

Fig. 3.44 Horizontal distribution of Ammonia (µM) at 5m depth in the Angola Benguela front

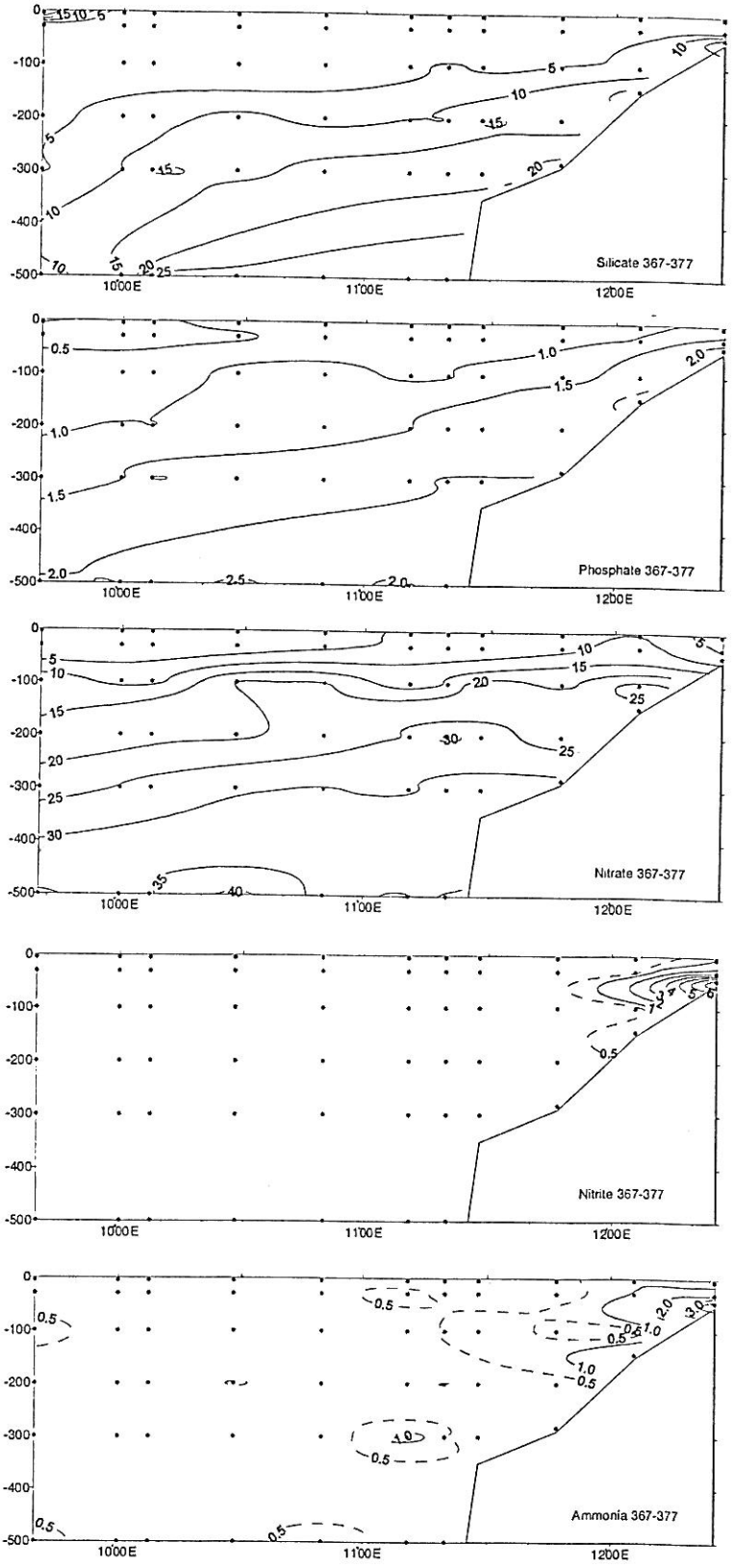

Fig. 3.45 Vertical distribution of a) Silicate, b)Phosphate, c) Nitrate d) Nitrite e) Ammonia, Rocky Point section

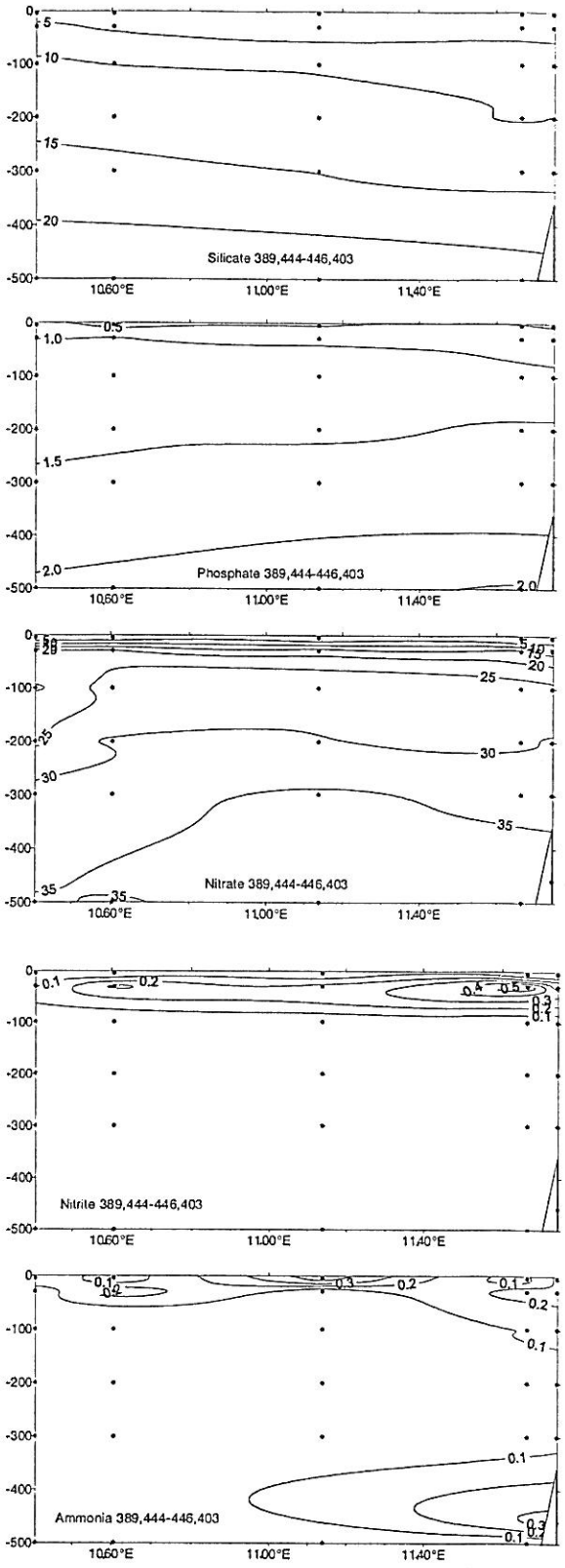

Fig. 3.46 Vertical distribution of a) Silicate, b)Phosphate, c) Nitrate d) Nitrite and e) Ammonia, Tombua section

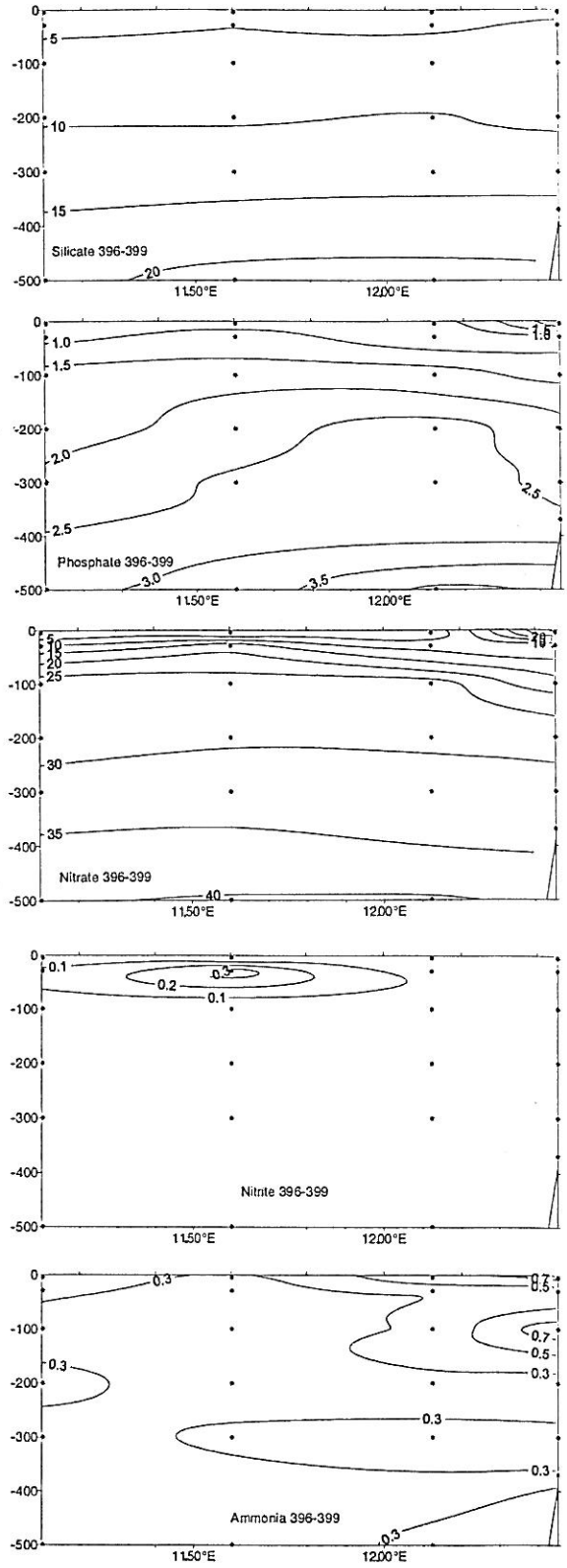

Fig 3.47 Vertical distribution of a) Silicate, b)Phosphate, c) Nitrate d) Nitrite and e) Ammonia, Cabo de Santa Maria section

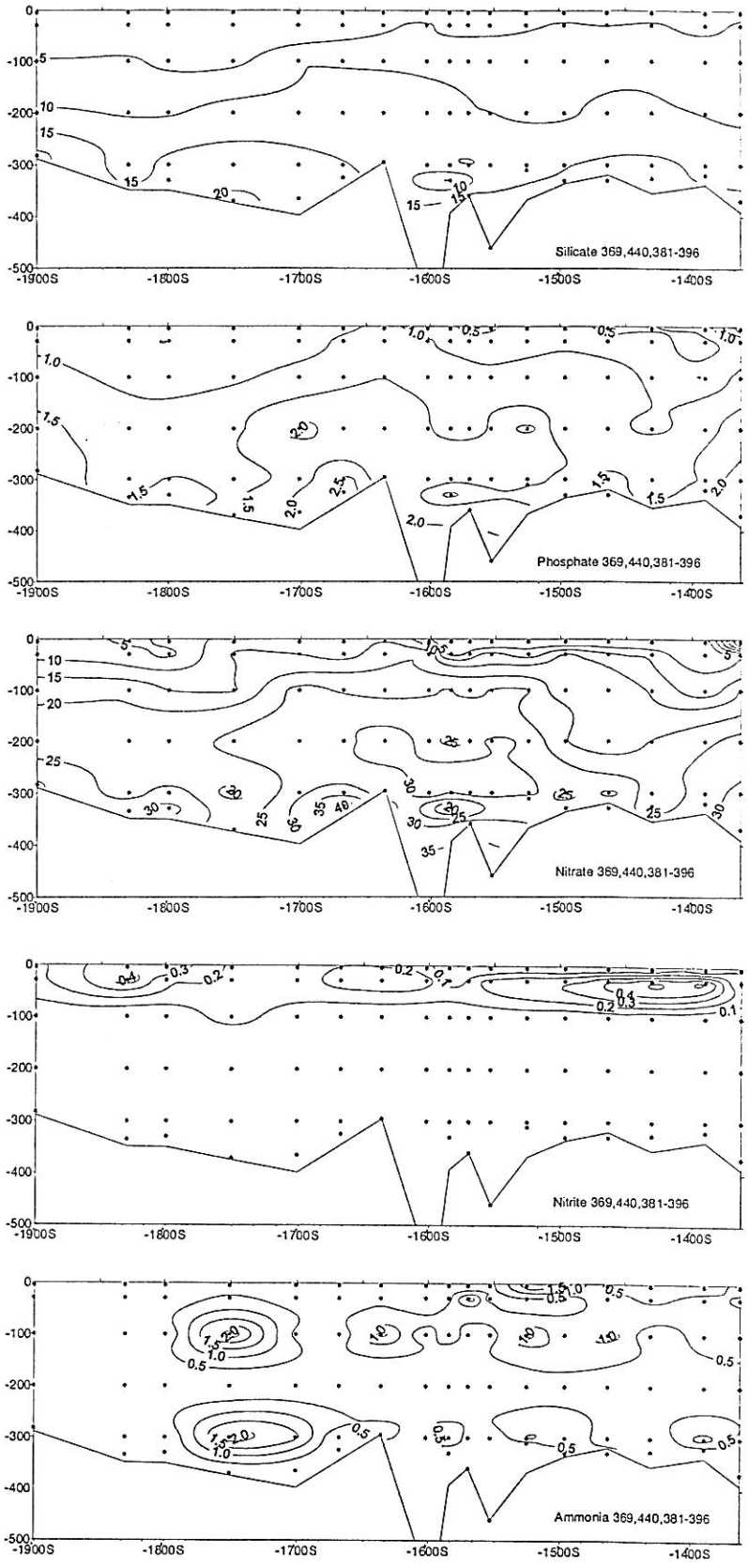

Fig 3.48 Vertical distribution of a) Silicate, b)Phosphate, c) Nitrate d) Nitrite and e) Ammonia, section at 300m depth

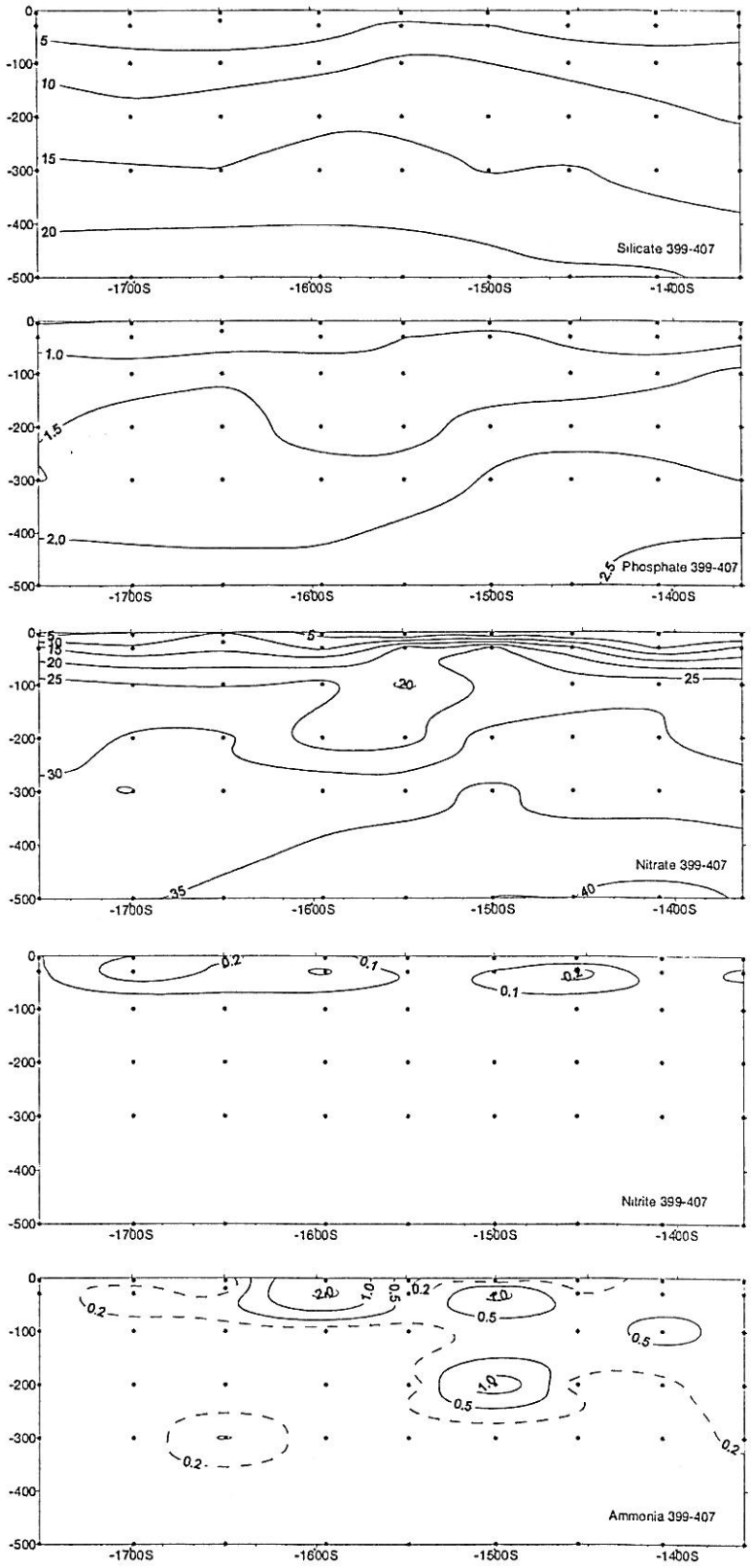

Fig 3.49 Vertical distribution of a) Silicate, b)Phosphate, c) Nitrate d) Nitrite and e) Ammonia, off shore section

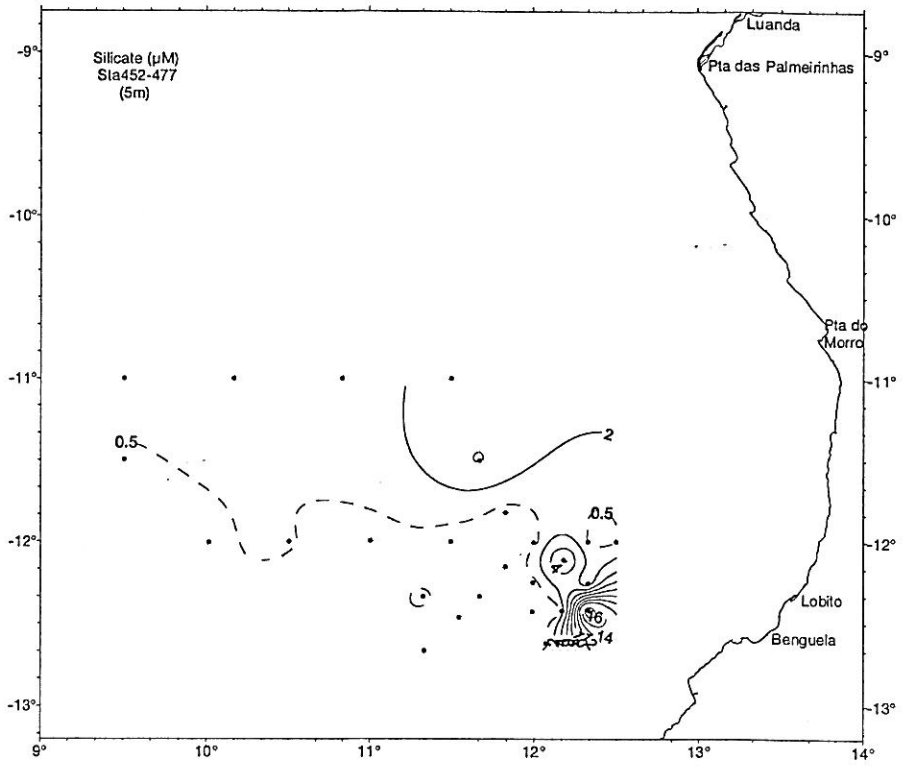

Fig. 3.50 Horizontal distribution of Silicate (µM) at 5m depth in the Angola Dome region

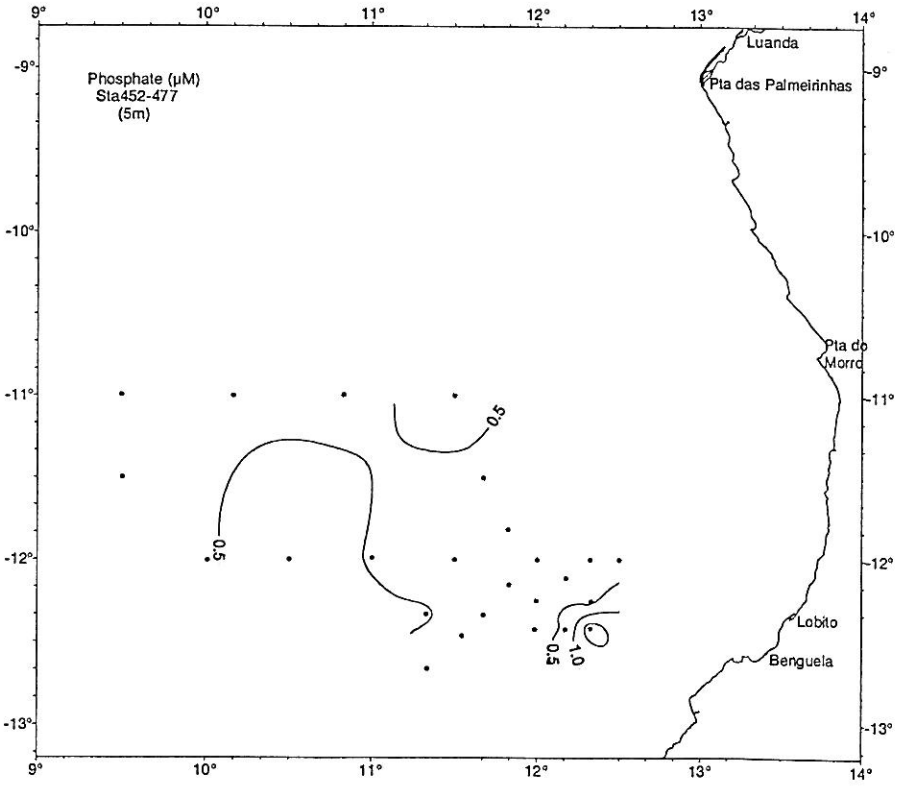

Fig. 3.51 Horizontal distribution of Phosphate (µM) at 5m depth in the Angola Dome region

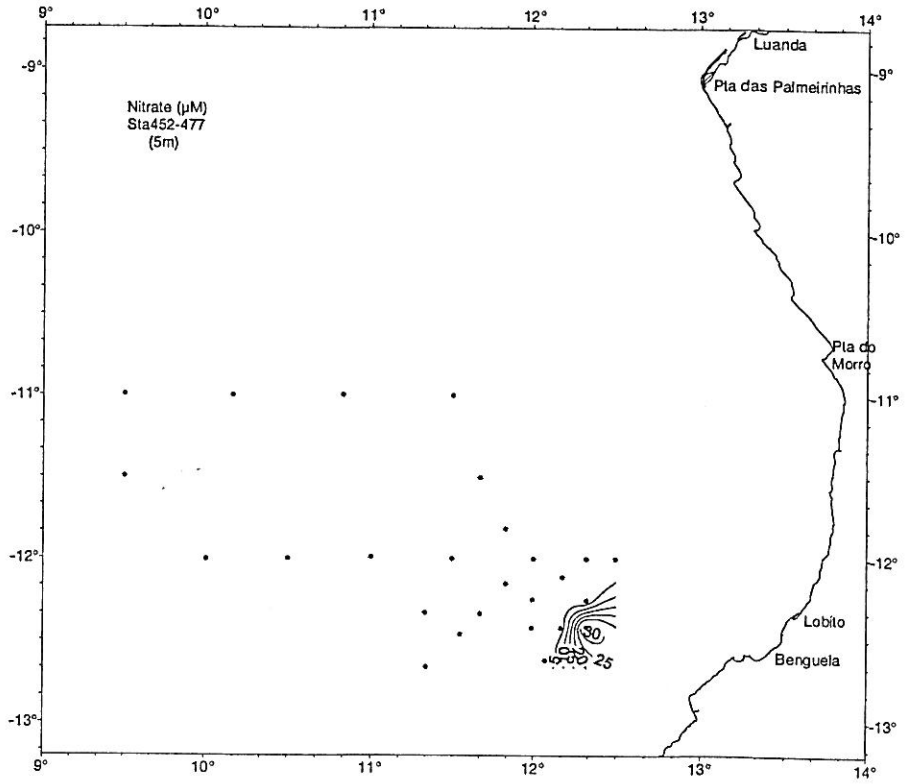

Fig. 3.52 Horizontal distribution of Nitrate (µM) at 5m depth in the Angola Dome region

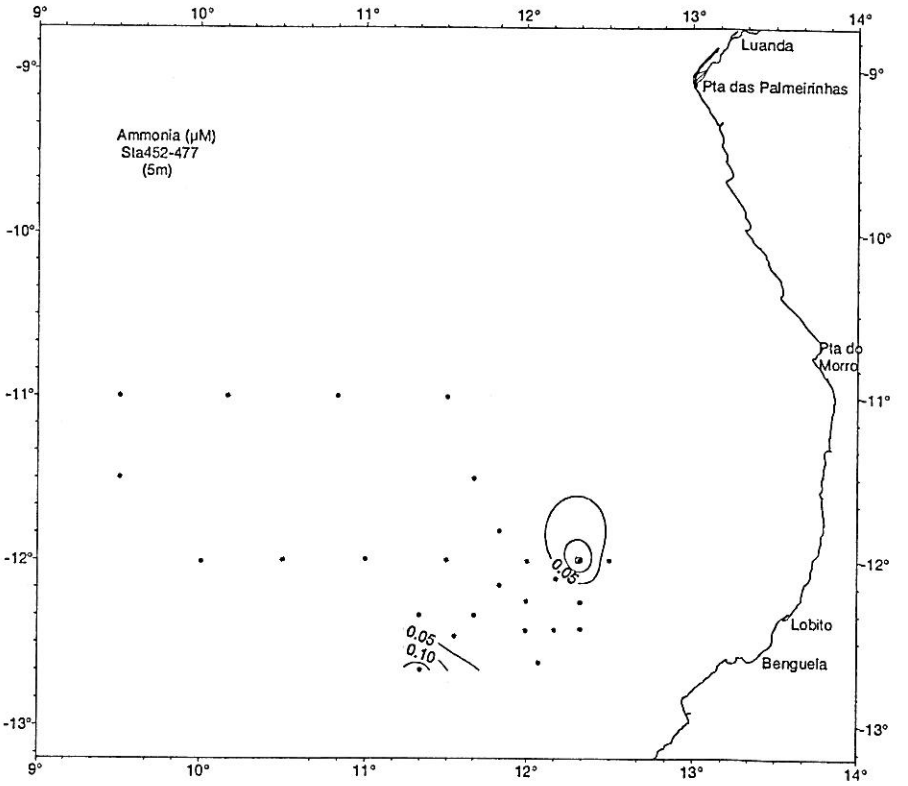

Fig. 3.53 Horizontal distribution of Ammonia (µM) at 5m depth in the Angola Dome region

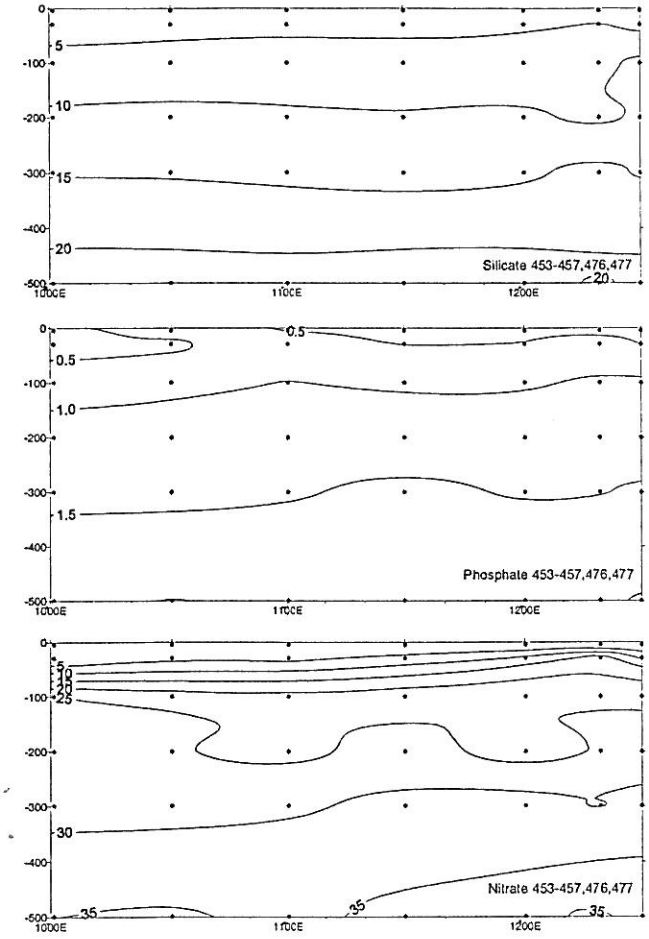

Fig. 3.54 Vertical distribution of a) Silicate b) Phosphate and c) Nitrate, northern section in the Angola Dome area.

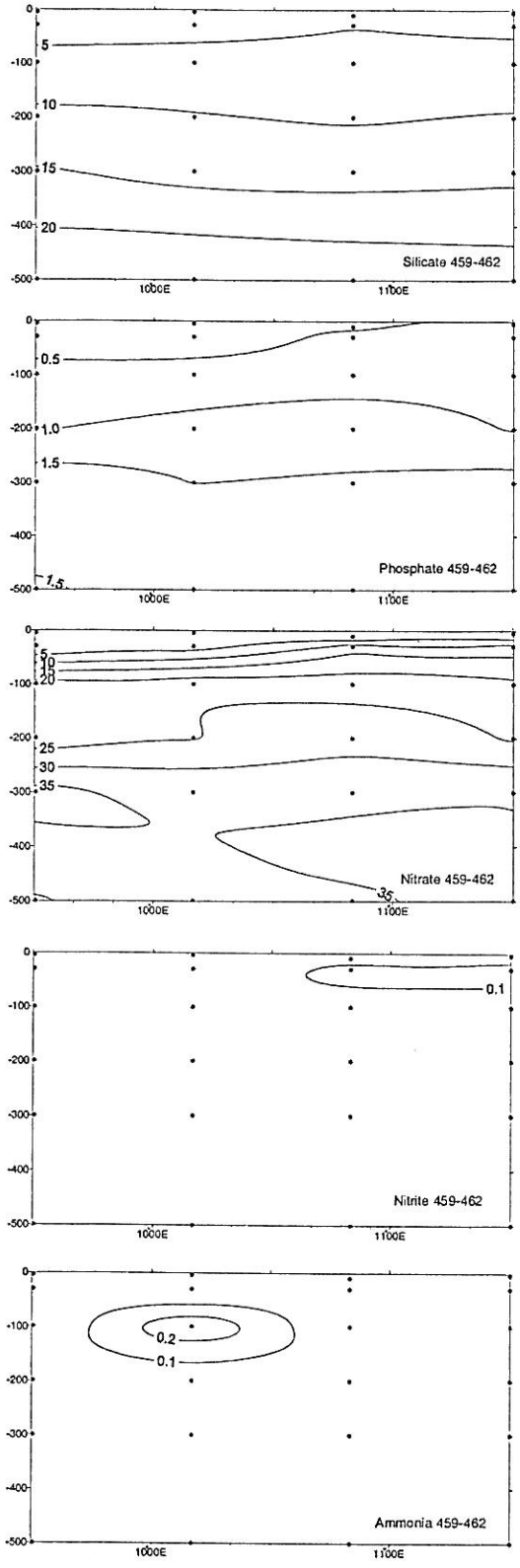

Fig. 3.55 Vertical distribution of a) Silicate b) Phosphate and c) Nitrate d)Nitrite and d) Ammonia central section in the Angola Dome area.

CHAPTER 4 DISCUSSION (Preliminary)

The Angola Benguela Front

The Angola Benguela Front (ABF) was clearly identified during this survey. The surface temperature and salinity distributions (Figs 3.1-3.3) show how the warm, saline southerly Angola Current meets the northward-bound cold and fresher water from the Benguela upwelling system in the center of our study area. The Angola Current is believed to be in near-geostrophic balance. Therefore it tends to stick to the coast because of the Coriolis force. In contrast, the Benguela current is mainly wind driven, and the Coriolis force will tend to deviate it away from the coast. Therefore the fact that the Angola Current was forced out from the coast where it meets the Benguela Current, is obviously due to the local upwelling favourable winds (see Fig.3.8).

The Benguela Current left the coast at about 17°S, and may be identified as a cold, relative fresh water layer as far west as 9°E (Figs. 3.1-3-3). The frontal structure is also noticeable at 50m depth (Figs 3.4 and 3.5). The westward penetrating Benguela water meets warmer water to the north and west, defining several fronts of various intensity: to the north-east with the warm, saline Angola Current core, to the north with warm, but somewhat less saline water from the Equatorial current complex, and to the west by the South Atlantic surface water. Together with the upwelling front, the region has a complicated structure, and a variety of habitat conditions are available. The Benguela current is known to be of high productivity, because of the upwelling. In the frontal structures additional upwelling may take place as waters of different densities meet. Therefore potential nursery areas for fish may be likely, as both the enrichment, the concentration and the retention conditions may be fulfilled in the area (Bakun, 1996).

Pigment extractions and fluorescence

It has been said that this survey recorded very high chlorophyll$_a$ levels in the frontal area from about 18 to about 16°S. In previous surveys we have done up to the south of Angola, we also encountered very high levels of chlorophyll in the South of Angola. Biomass levels above 20 microgram per litre (see Figures 3.23 to 3.25) are regarded as very high. However, the levels are not out of the range of high levels recorded at times in the southern Benguela (see e.g. Armstrong *et al.*, 1987; Mitchell-Innes and Walker, 1991 and Pitcher *et al.*, 1991).

The survey indicates a factor of importance to the upcoming SeaWiFS satellite ocean colour biomass estimations: Satellite imagery will only be able to give us estimations of phytoplankton pigments in the upper layer of surface water ("near-surface values"), the depth being sampled depends on algal concentration and variation in concentration occurring in the vicinity of the surface. It is therefore of importance for us to know how the surface values relate to the algal distribution in the rest of the water column. The subsurface maxima shown in this cruise will complicate the application of sea surface satellite estimations, and will have to be taken into consideration.

The low phytoplankton biomass levels in the Angola dome area will be discussed when other data (on nutrients, ichthyoplankton) will be available.

A comparison of the dynamics of the Angola and Benguela Currents.

The results from the southern current metre mooring (Figs 3.9 and 3.12) confirm that a poleward current is found below the equator-bound Benguela current. The Benguela current had a velocity of 10 to 20 cm/s, while the undercurrent was weaker. The results from the ADCP measurements compare well with the mooring results. The ADCP measurements at the site of mooring (see Fig.3.7) were obtained at the launching of the rig. At this site the ADCP show a northward current in the surface layers, getting weaker at greater depths. Thus it does not show a poleward current at this site. But comparing with the mooring results (Figs 3.9 and 3.12) it may be noticed that the current was northwards at both current metres in the beginning of the time series. The unidirectional behaviour may be due to the tides. The moon was new at April 7, giving near flood tides when the mooring was deployed.

An examination of the ADCP current measurements as we progress westwards on the shelf at about 19°S (Fig.3.7), realising that this is a mixture of time and space variations, confirm the two layer structure of the current regime in the area.

It was possible to reproduce the two layer structure of the current on the shelf by the geostrophic model by applying a zero velocity reference level at 40m depth (Fig.3.17d). The geostrophic currents are too weak compared with the current measurements, which confirm that the geostrophic model does not tell the whole story. It is well known that the Benguela current is wind driven, and friction must therefore be included in a model for this current.

On the other hand, the Angola Current is believed to be in geostrophic balance. The results of

the geostrophic calculations from the northern section, slightly north of the northern mooring, are shown in Fig. 3.18d. Applying a zero velocity reference level at the bottom yields a southward current on the shelf in the whole water column, varying from about 50 cm/s at the surface to around 10 cm/s at 125m depth. These theoretically calculated currents compare very well with the results from the mooring from the period when the section was taken (in the beginning of the time-series shown in Figs.3.10 and 3.11). The general impression from these time-series, though, is that the currents in this position are far less baroclinic than indicated by the theory.

The results from the ADCP measurements at the shelf in the northernmost section (Fig.3.7) also indicate a unidirectional southerly current at all levels, except at 18m depth. It is possible that the current at this level is influenced by the local winds (Fig.3.8).

The distribution of the oxygen minimum

The distribution of the oxygen minimum layer at 350m depth is shown in Fig3.6. This minimum is associated with the Central Water, and is transported southwards by the polar undercurrent. There is a discontinuity in the minimum layer in the frontal zone, see also Figs. 3.13 and 3.14. It is not clear what happens to the minimum layer in the frontal zone, but it may be deviated to the west due to the offshore motion created where the two opposing currents meet. It reappears again in the section at 19°S (Fig.3.17), close to the shelf break. At the shelf an anoxic bottom layer may be observed which probably is produced locally, and contributing to the oxygen minimum layer further south. Also in Fig 3.17 a separate oxygen minimum was observed further off-shore at a shallower depth (~125m depth), which may be associated with the uplifting of the water masses in the Angola current as it meets the more dense Benguela current water.

Note on the Antarctic Intermediate Water in the Angola Benguela Front

Antarctic Intermediate Water (AAIW) is identified in the oceanic water mass by the presence of a salinity minimum, introduced by excess precipitation over evaporation in its formation region in the Subantarctic Ocean. The AAIW characteristic salinity (33.87 psu at the source: Sverdrup *et al.* 1942, McCartney 1977) increases through mixing with Central Water above and Deep Water below as it travels away from its source regions through the mid-ocean gyres. Within the South Atlantic, AAIW enters the ocean through the Agulhas Current eddy shedding processes and direct leakage (Gordon 1986, Shannon 1966, Visser 1969), from the subantarctic region, and injected through the Drake Passage from the Pacific Ocean (McCartney 1977). The

signature shows the circulation through the Benguela Current, feeding into the equatorial current complex. Thus the AAIW in the Angola Benguela Front approaches the front from two directions: from the north through the cyclonic circulation in the Angola Basin and from the south in the Benguela Current. Shannon & Hunter (1988) discussed the distribution of the AAIW around southern Africa using data from the South African Data Centre for Oceanography (SADCO), and historical SFRI data.

During this first Benefit survey, observation of the AAIW was made from the CTD profiles where the cast extended below the depth of the AAIW layer. From these stations pressure, temperature, salinity and oxygen were extracted at the salinity minimum. Shannon & Hunter (1988) used the 27.28 sigma-t surface to characterise some properties of the AAIW in the ABF region, so parameters were extracted at this density level as well.

The pressure (indicating depth) of the two data strata are shown in Fig 3.29. The salinity minimum presents deeper within the water column to the north of the study region and shallower to the south, and along the continental shelf. The density level shows a similar depth distribution with less variation. The vertical difference between the levels of the two data strata at individual stations ranges between 0 and 100 metres through the study region.

Salinity distribution shows the same tendency on both strata: high values in the north, and along the continental shelf, low in the southwest (Fig 3.30), ranging from 34.46 to 34.51 psu. The temperature distribution on the salinity minimum surface shows no clear pattern, with high and low values scattered throughout the study region, while the temperature on the density surface presents high in the north and along the shelf edge, and low in the south west, ranging from 4.8 to 5.1 C (Fig 3.31).

The oxygen distribution shows the inverse of the other property distributions: high values in the south, low in the north and along the continental shelf.

Satellite imagery and the surface property distributions show the front to extend from Cunene Mouth northwestwards, with a plume or meander of the inshore part of the front extending southwards along the shelf edge. This is mirrored to some extent in the AAIW distribution.

The AAIW distribution encountered on this survey is also in general agreement with the distribution as discussed by Shannon & Hunter (1988), and in keeping with long term circulation patterns of the region.

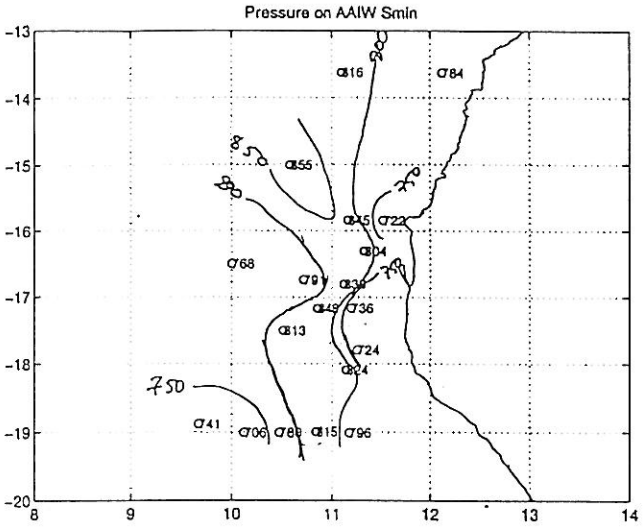

Fig 4.1a Pressure on AAIW salinity minimum

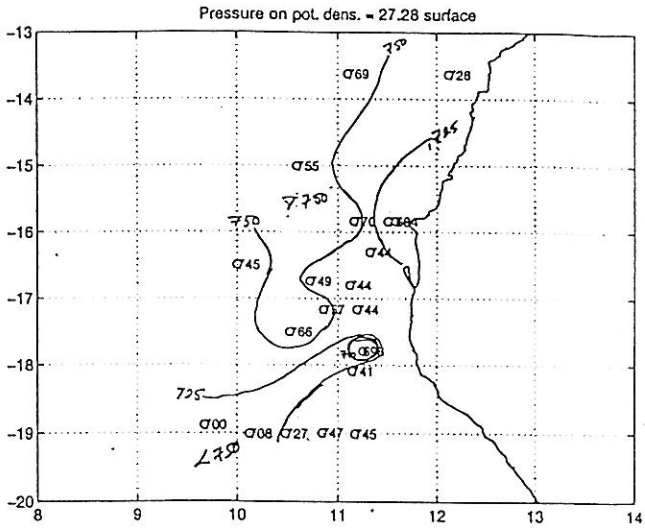

Fig. 4.1 b Pressure on potental density =27.28 surface

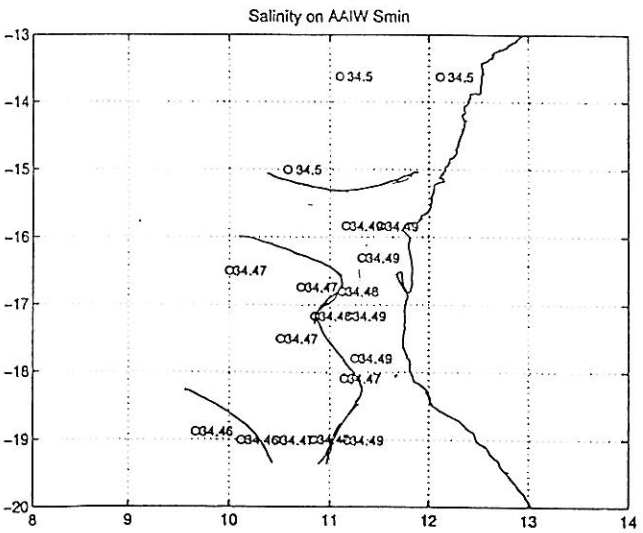

Fig. 4.2 a Salinity on AAIW salinity minimum

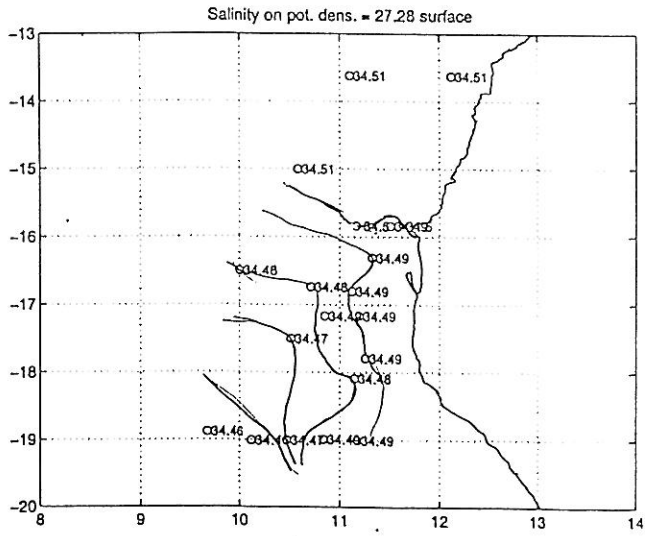

Fig 4.2b Salinity on potental density = 27.28 surface

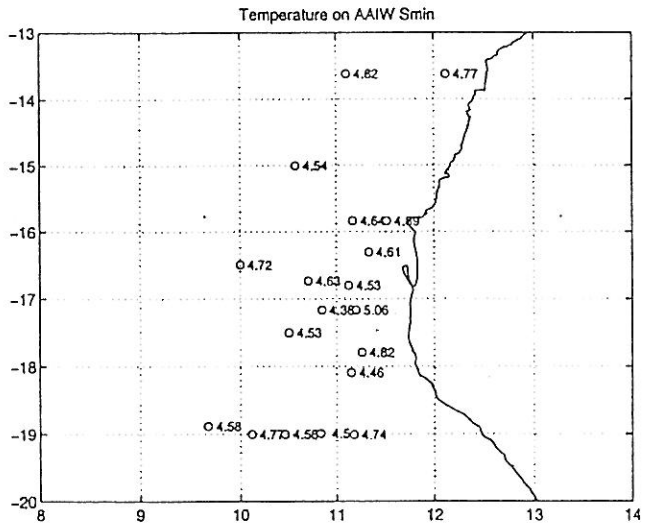

Fig. 4.3 a Temperature on AAIW salinity minimum

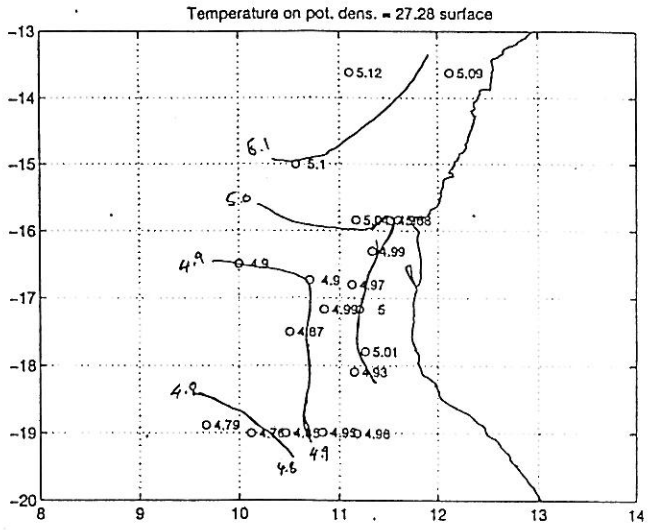

Fig.4.3b Temperature on potential density=27.28 surface

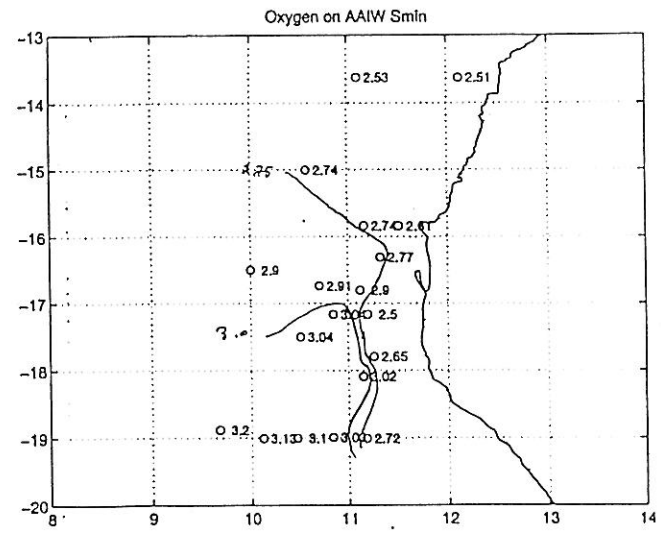

Fig. 4.4 a Oxygen on AAIW salinity minimum

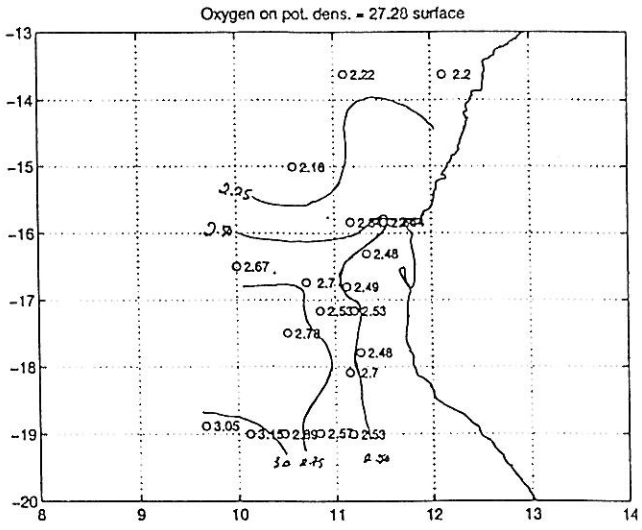

Fig 4.4b Oxygen on potential density=27.28 surface

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Annex I Records of fishing stations

PROJECT STATION: 1

DATE: 5/ 4/97 GEAR TYPE: BT No:1 POSITION:Lat S 1859
start stop duration Long E 1203
TIME :13:08:00 13:38:00 30 (min) Purpose code: 1
LOG :1280.30 1281.80 1.50 Area code : 1
FDEPTH: 178 161 GearCond.code: 1
BDEPTH: 178 161 Validity code: 3
Towing dir: 90° Wire out: 650 m Speed: 30 kn*10

Sorted: 63 Kg Total catch: 800.10 CATCH/HOUR: 1600.20

SPECIES	CATCH/HOUR weight	CATCH/HOUR numbers	% OF TOT. C	SAMP
Trachurus capensis	1064.40	11088	66.52	1
Merluccius capensis	298.40	6092	18.65	
J E L L Y F I S H	220.00		13.75	
Sufflogobius bibarbatus	8.60	1366	0.54	
Chelidonichthys capensis	6.80	26	0.42	
Perulibatrachus rossignoli	2.00	26	0.12	
Total	1600.20		100.00	

PROJECT STATION: 2

DATE: 7/ 4/97 GEAR TYPE: PT No:1 POSITION:Lat S 1640
start stop duration Long E 1119
TIME :18:23:12 18:51:46 29 (min) Purpose code: 1
LOG :1642.75 1644.18 1.80 Area code : 1
FDEPTH: 100 100 GearCond.code:
BDEPTH: 373 453 Validity code:
Towing dir: 210° Wire out: 350 m Speed: 30 kn*10

Sorted: 32 Kg Total catch: 2949.03 CATCH/HOUR: 6101.44

SPECIES	CATCH/HOUR weight	CATCH/HOUR numbers	% OF TOT. C	SAMP
Trachurus capensis	6051.42	68692	99.18	2
Merluccius polli	19.24	192	0.32	
MYCTOPHIDAE	15.39	7312	0.25	
Zenopsis conchifer	11.54	385	0.19	
Krill	1.92	770	0.03	
Hoplostethus cadenati	1.92	192	0.03	
Total	6101.43		100.00	

PROJECT STATION: 3

DATE: 8/ 4/97 GEAR TYPE: PT No:1 POSITION:Lat S 1420
start stop duration Long E 1212
TIME :19:07:11 19:26:55 20 (min) Purpose code: 1
LOG :1815.59 1816.63 1.15 Area code : 1
FDEPTH: 130 130 GearCond.code:
BDEPTH: 151 253 Validity code:
Towing dir: 180° Wire out: 400 m Speed: 30 kn*10

Sorted: 21 Kg Total catch: 55.96 CATCH/HOUR: 167.88

SPECIES	CATCH/HOUR weight	CATCH/HOUR numbers	% OF TOT. C	SAMP
Dentex macrophthalmus	88.29	501	52.59	
MYCTOPHIDAE	61.17	40824	36.44	
Synagrops microlepis	15.96	1305	9.51	
Parapenaeus longirostris	0.90	162	0.54	
Nematocarcinus africanus	0.57	333	0.34	
Sepia officinalis hierredda	0.42	33	0.25	
Parapandalus narval	0.33	105	0.20	
Macroparalepis macrogeneion	0.15	15	0.09	
Krill	0.09	81	0.05	
Total	167.88		100.01	

PROJECT STATION: 4

DATE:12/ 4/97 GEAR TYPE: BT No:1 POSITION:Lat S 1554
start stop duration Long E 1141
TIME 03:42:45 03:53:49 11 (min) Purpose code: 1
LOG :2396.11 2396.66 0.59 Area code : 1
FDEPTH: 90 89 GearCond.code:
BDEPTH: 90 89 Validity code:
Towing dir: 20° Wire out: 300 m Speed: 30 kn*10

Sorted: 177 Kg Total catch: 230.38 CATCH/HOUR: 1256.62

SPECIES	CATCH/HOUR weight	CATCH/HOUR numbers	% OF TOT. C	SAMP
Dentex macrophthalmus	335.07	3387	26.66	
Pagellus bellottii	210.98	1538	16.79	
Trachurus trecae	132.98	4724	10.58	3
Pterothrissus belloci	103.20	682	8.21	
Umbrina canariensis	90.44	644	7.20	
Spondyliosoma cantharus	79.42	147	6.32	
Atractoscion aequidens	70.36	98	5.60	
Lepidotrigla carolae	54.82	835	4.36	
Squalus megalops	45.87	120	3.65	
Pegusa lascaris	35.45	480	2.82	
Trigla lyra	26.29	207	2.09	
Mustelus mustelus	21.22	16	1.69	
Zeus faber	13.75	38	1.09	
Citharus linguatula	9.38	229	0.75	
Raja straeleni	7.53	5	0.60	
Sepia sp.	5.73	22	0.46	
Raja miraletus	4.20	5	0.33	
Mustelus palumbes	3.60	5	0.29	
OCTOPODIDAE	3.55	5	0.28	
Ophidion sp.	1.42	71	0.11	
OPHICHTHIDAE	1.36	16	0.11	
Total	1256.62		99.99	

PROJECT STATION: 5

DATE:12/ 4/97 GEAR TYPE: BT No:1 POSITION:Lat S 1614
start stop duration Long E 1134
TIME :06:38:34 07:08:18 30 (min) Purpose code: 1
LOG :2419.53 2420.97 1.43 Area code : 1
FDEPTH: 81 83 GearCond.code:
BDEPTH: 81 83 Validity code:
Towing dir: 20° Wire out: 300 m Speed: 30 kn*10

Sorted: 63 Kg Total catch: 1105.06 CATCH/HOUR: 2210.12

SPECIES	CATCH/HOUR weight	CATCH/HOUR numbers	% OF TOT. C	SAMP
Dentex macrophthalmus	1342.80	18864	60.76	
Trachurus trecae	610.20	8760	27.61	4
Scomber japonicus	97.92	900	4.43	
Atractoscion aequidens	60.20	82	2.72	
Trigla lyra	21.96	108	0.99	
Spondyliosoma cantharus	19.08	36	0.86	
Dentex gibbosus	15.12	144	0.68	
Trachurus capensis	12.60	72	0.57	
Squalus megalops	11.52	36	0.52	
Etrumeus whiteheadi	8.28	108	0.37	
Pagellus bellottii	4.68	36	0.21	
Todarodes sagittatus	2.16	36	0.10	
Scorpaena stephanica	2.16	36	0.10	
Lepidotrigla carolae	1.44	36	0.07	
Total	2210.12		99.99	

PROJECT STATION: 6

DATE:14/ 4/97 GEAR TYPE: BT No:1 POSITION:Lat S 1710
start stop duration Long E 1126
TIME :11:37:53 11:51:39 14 (min) Purpose code: 1
LOG :2666.19 2666.86 0.67 Area code : 1
FDEPTH: 149 148 GearCond.code:
BDEPTH: 149 148 Validity code:
Towing dir: 360° Wire out: 480 m Speed: 30 kn*10

Sorted: 58 Kg Total catch: 579.70 CATCH/HOUR: 2484.43

SPECIES	CATCH/HOUR weight	CATCH/HOUR numbers	% OF TOT. C	SAMP
Dentex macrophthalmus	1172.14	12686	47.18	
Synagrops microlepis	338.57	37714	13.63	
Trachurus capensis	334.29	4286	13.46	5
Pterothrissus belloci	231.00	2400	9.30	
Merluccius capensis	150.00	986	6.04	6
Trigla lyra	98.14	900	3.95	
Squalus megalops	69.00	86	2.78	
Raja miraletus	26.57	43	1.07	
Sepia orbignyana	16.29	129	0.66	
Zeus faber	13.71	43	0.55	
Zenopsis conchifer	10.29	129	0.41	
Pegusa lascaris	8.14	943	0.33	
Chlorophthalmus atlanticus	4.29	1071	0.17	
OPHICHTHIDAE	4.29	43	0.17	
OPHICHTHIDAE	4.29	43	0.17	
Todaropsis eblanae	2.14	43	0.09	
Lepidotrigla carolae	1.29	43	0.05	
Total	2484.44		100.01	

PROJECT STATION: 7

DATE:14/ 4/97 GEAR TYPE: BT No:1 POSITION:Lat S 1729
start stop duration Long E 1139
TIME :16:27:35 16:35:45 8 (min) Purpose code: 1
LOG :2703.58 2703.97 0.39 Area code : 1
FDEPTH: 98 97 GearCond.code: 4
BDEPTH: 98 97 Validity code:
Towing dir: 360° Wire out: 350 m Speed: 25 kn*10

Sorted: 16 Kg Total catch: 115.01 CATCH/HOUR: 862.58

SPECIES	CATCH/HOUR weight	CATCH/HOUR numbers	% OF TOT. C	SAMP
Trachurus capensis	543.38	17798	62.99	7
Dentex macrophthalmus	147.53	3518	17.10	
Solea senegalensis	77.18	3728	8.95	
Merluccius capensis	74.55	1365	8.64	8
Trigla lyra	10.50	53	1.22	
MURAENIDAE	9.45	263	1.10	
Total	862.59		100.00	

PROJECT STATION: 8

DATE:14/ 4/97 GEAR TYPE: PT No:1 POSITION:Lat S 1742
start stop duration Long E 1135
TIME :20:04:41 20:19:43 15 (min) Purpose code: 1
LOG :2724.42 2725.40 0.97 Area code : 1
FDEPTH: 300 230 GearCond.code:
BDEPTH: 136 126 Validity code:
Towing dir: 70° Wire out: 150 m Speed: 35 kn*10

Sorted: 55 Kg Total catch: 3006.80 CATCH/HOUR: 12027.20

SPECIES	CATCH/HOUR weight	CATCH/HOUR numbers	% OF TOT. C	SAMP
Etrumeus whiteheadi	11022.00	282700	91.64	9
Trachurus capensis	990.00	35200	8.23	10
Merluccius capensis	15.20	880	0.13	11
Total	12027.20		100.00	

PROJECT STATION: 9

DATE:15/ 4/97 GEAR TYPE: PT No:1 POSITION:Lat S 1749

	start	stop	duration			
					Long	E 1116
TIME	:01:35:54	01:46:14	10 (min)	Purpose code:	1	
LOG	:2757.65	2758.19	0.57	Area code :	1	
FDEPTH:	240	240		GearCond.code:	3	
BDEPTH:	106	106		Validity code:		

Towing dir: 360 Wire out: 880 m Speed: 35 kn*10

Sorted: 9 Kg Total catch: 53.73 CATCH/HOUR: 322.38

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
OPHIDIIDAE	95.70	1392	29.69	
MYCTOPHIDAE	66.12	20532	20.51	
CHAULIODONTIDAE	60.90	5568	18.89	
PANDALIDAE	46.98	142332	14.57	
VITRELEDONELLIDAE	16.44	12	5.10	
Tetragonurus cuvieri	14.70	72	4.56	
Trachipterus jacksonensis	11.28	12	3.50	
MYCTOPHIDAE	6.96	2088	2.16	
S H R I M P S	1.92	120	0.60	
BRAPT00	1.20	6	0.37	
SQUHI10	0.18	6	0.06	
Total	322.38		100.01	

PROJECT STATION: 10

DATE:16/ 4/97 GEAR TYPE: PT No:2 POSITION:Lat S 1719

	start	stop	duration			
					Long	E 1137
TIME	:00:35:00	00:49:00	14 (min)	Purpose code:	1	
LOG	:2963.67	2964.32	0.66	Area code :	1	
FDEPTH:	5	5		GearCond.code:		
BDEPTH:	100	100		Validity code:		

Towing dir: 175 Wire out: 150 m Speed: 35 kn*10

Sorted: 90 Kg Total catch: 3000.00 CATCH/HOUR: 12857.14

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	12354.43	252647	96.09	12
Etrumeus whiteheadi	480.86	9411	3.74	13
Merluccius capensis	11.57	146	0.09	
Engraulis capensis	10.29	587	0.08	14
Total	12857.15		100.00	

PROJECT STATION: 11

DATE:16/ 4/97 GEAR TYPE: PT No:1 POSITION:Lat S 1530

	start	stop	duration			
					Long	E 1118
TIME	:14:39:15	15:22:51	44 (min)	Purpose code:	1	
LOG	:3094.21	3096.48	2.21	Area code :	1	
FDEPTH:	270	250		GearCond.code:		
BDEPTH:	2090	2090		Validity code:		

Towing dir: 30 Wire out:1000 m Speed: 35 kn*10

Sorted: 2 Kg Total catch: 65.87 CATCH/HOUR: 89.82

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
MYCTOPHIDAE	88.50	14141	98.53	
STERNOPTYCHIDAE	1.32	1396	1.47	
Total	89.82		100.00	

Annex II Sampling procedures for Nutrient analysis

During a CTD drop water samples are usually taken at the surface (5m), near the bottom and at 3-5 depths inbetween, depending on the depth of the station.

- Collect ±200ml of the seawater sample from the CTD rosette in a water bottle (NB: Rinse water bottle twice with the seawater before keeping the sample)
- filter ± 50ml sample through a 0.45µm membrane filter (NB: Rinse filtering flask and then throw out the filtrate. Repeat.)
- After filtering ±50ml seawater sample for the third time, pour filtrate into two sampling tubes with a watertight seal (i.e. take a duplicate sample) (I use 15ml Falcon tubes)
- Freeze samples in a freezer that is not being used for fish samples (NB: Sample tube must not be totally filled because water expands on freezing)

It is crucial that the working area is clean. But the area must not be cleaned with detergents containing ammonia, phosphate, etc. as the samples may be contaminated. For the same reason, samples should not be frozen in a freezer containing fish or food. Do not smoke during sample collection or around sampling equipment as cigarette smoke is rich in nitrogen oxides (Smokers should wear gloves when sampling!).

It is essential that samples are properly marked for accurate identification and the supplied nutrient sampling logsheets correctly and completely filled out with respect to sample depth, station depth, position, etc.