Technical cruise report

Midpac 4 (SO 66)

Geoscientific investigations and economic evaluation of Co-rich and Pt-bearing crust deposits in the seamount areas of the Central Pacific south of the equator (Kiribati and Tuvalu) and of massive sulfide occurrences in the North Fiji Basin (Fiji)

FS Sonne 1989/90

Supported by the
German Ministry for Research and Technology

Project management by the
Technical University of Clausthal,
Center for Raw Material Related Marine Research
in cooperation with
RWTH Aachen
University of Hawaii - Institute of Geophysics
East West Center, Hawaii
Preussag AG, Hannover

P. Halbach, A. Koschinsky, C.-D. Sattler, F. Teichmann, M. Wahsner,
D. Schöps, J. Post, D. Hansen, P. Dreßen, S. Bubilek

Technical University of Clausthal
Center for Raw Material Related Marine Research
Clausthal-Zellerfeld, Fed. Rep. of Germany
July 1990

Technical cruise report Midpac 4 (SO 66)

page

1. Introduction

The Midpac 4 project is an economy-related, geoscientific project to research and explore mineral raw material occurences on the ocean floor and to study their particular genesis. The research cruise SO 66 was focused on sampling and scientific investigations of areas south of the equator (fig. 1.1). The areas investigated so far within the Midpac program are mostly situated north of the equator. The research sites of SO 66 within the area of the Phoenix Islands (Kiribati) and of Tuvalu fulfill the criteria determined by the Midpac program which can be considered as prerequisites for the formation of Co-rich manganese crust deposits. The investigation of the hydrothermal field in the North Fiji Basin (area X) was carried out in order to sample massive sulfides.

The aim of the Midpac 4 project is to determine the local site factors as well as the ore potential of Co, Ni, Mn, and Pt in the areas P, R, S, T, U, and V, and to map these sites. According to preliminary information from American research cruises (De Carlo et al., Marine Mining 6, 1987), relatively thick (dm range) phosphorite deposits associated with the oxidic manganese crusts occur in the area of Kiribati. Therefore, a first assessment of quantitaty and quality of the phosphorites is a further aim of the project. Both above mentioned raw material minerals can be an economic potential for these Pacific Island States; the respective mining technique is yet to be developed, however. Depending on the morphological and oceanographic conditions, the variability of the metal composition and of the thickness of the mangenese crusts is the most important basis for the development of a technical recovery system.

The manganese crusts are an oxidic precipitate from the water column, their genesis is consequently controlled by paleooceanographic and geological parameters. The genetic model developed by our research group within the scope of the Midpac program is based on the facts that certain geochemical gradients exist in the oceanic water column and precipitation of colloidal manganese oxi-hydrate and other finely dispersed components (iron hydroxide, silicate) finally takes place after a mixing process of different water masses. The seamount ranges play an important role in the mixing of the water masses from the O_2-depleted oxygen minimum zone with the O_2-rich deep water, and the resulting oxidation of manganese connected with the precipitation of oxihydrate phases. Under normal circumstances the layering of the different water masses is fairly stable; seamount ranges reaching below the oxygen minimum zone, however, form obstacles for tidal currents which may cause turbulences and mixing of the water layers (Halbach et al., Marine Mining 1989). Thus, these seamounts are the preferred sites of the formation of hydrogenetic oxidic precipitates.

This long-term mixing process coincides with the relative motion of the Pacific plate towards the equatorial zone of high bioproductivity (fig. 1.2). The manganese crusts studied so far in the areas North of the equator were moved towards the north-west and thus out of the influence of the equatorial high bioproductivity during their time of growth (around the past 18 my). The areas studied during SO 66, however, were moved from the southwest into the zone of high bioproductivity (fig. 1.2). Therefore, our hypothesis is that different metal fluxes with differing gradients exist during the time of crust growth.

First indications of a shift of the metal gradients within the younger crust generation (Halbach et al, Marine Mining 1989) were observed in samples from the Titov seamount (close to the equator, 176° W); they showed a decrease in Co concentrations in the younger micro layers. The samples from areas now situated north of the equator had an increase in Co-concentration towards the outer layers. Since the chemical changes in the microlayers of the manganese crust reflect the genetical variations of the local geochemical and paleooceanographic environment, a comparative geochemical study and its interpretation are the most important geoscientific aims of the research project.

Area X is situated in the central part of the North Fiji Basin which is a marginal basin located at the convergent boundary of the Pacific and Indo-Australian plates. It has a triangular shape and is limited to the north by the fossil Vityaz subduction zone, to the west by the New Hebrides arc (Vanuatu), and to the south by the Matthew-Hunter frac-

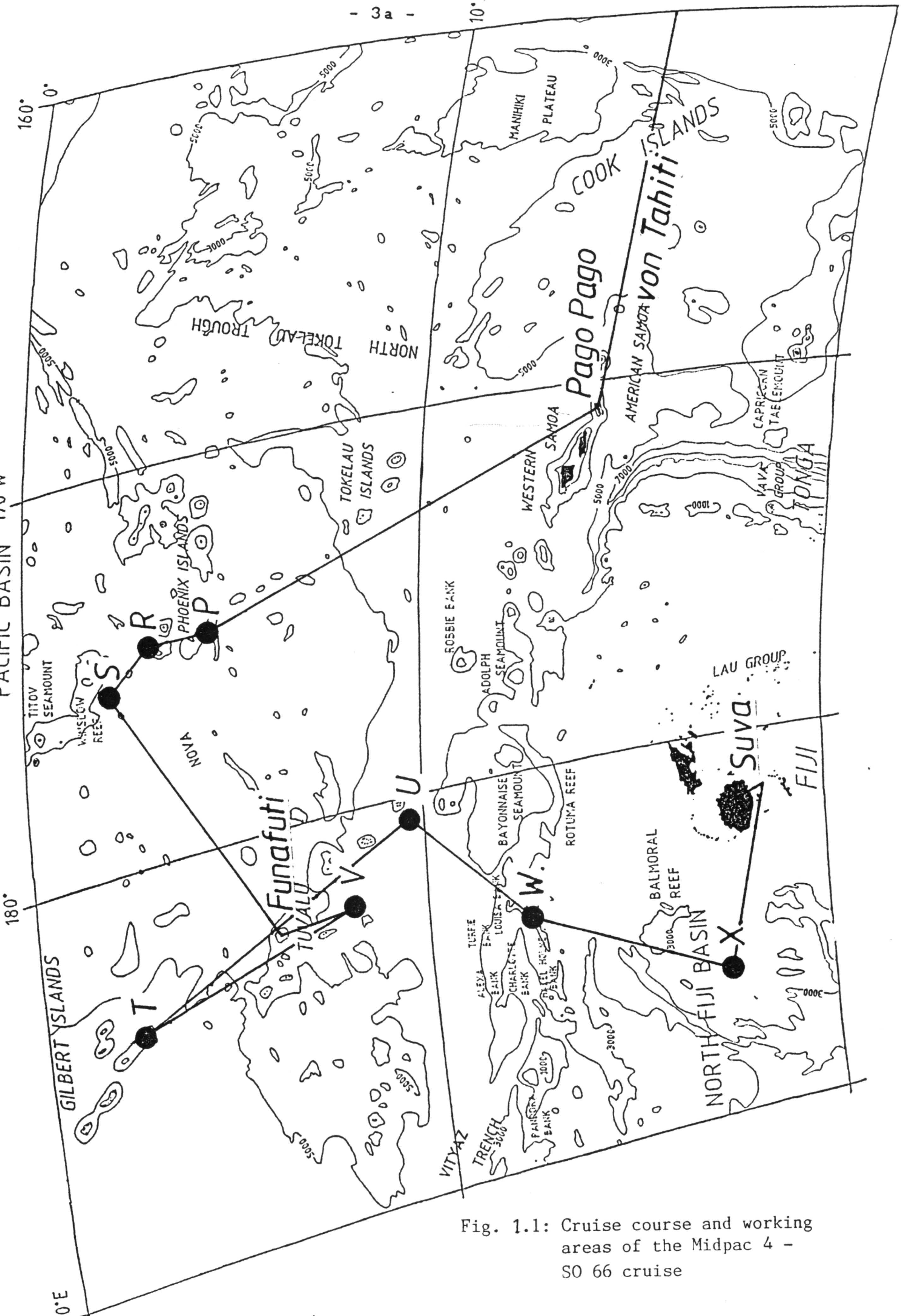


Fig. 1.1: Cruise course and working areas of the Midpac 4 - SO 66 cruise

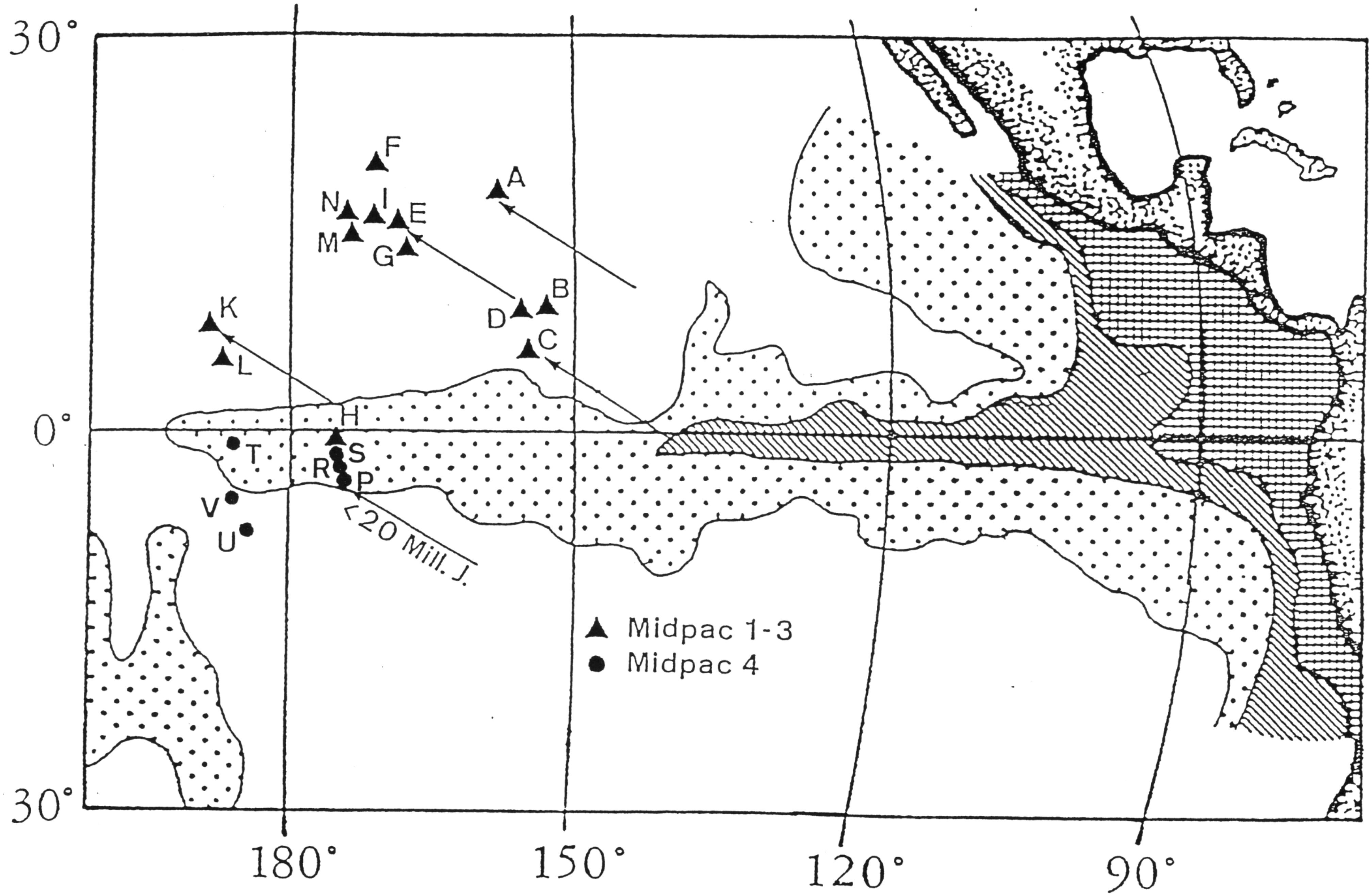


Fig. 1.2: Site of Midpac areas in the Pacific Ocean; arrows represent the plate movements in the past 20 million years.

bioproductivity in the East Pacific 100-150 150-250 250-650 mg C m^{-2} d^{-1}

ture zone and Fiji Islands. The southern part of the North Fiji Basin has been cut by a north-south spreading ridge for the past few million years (Auzende et al., Geology 16, 1988). The sea floor spreading at this north-south ridge may be related to the beginning of the opening of the Lau Basin which is located further east on the other side of the Fiji Islands. The present north-south trending spreading axis consists of a 10 km wide dome rising about 200-300 m above the ocean floor. On both sides of the axis the ocean floor shows ridges and troughs parallel to the axis. At about 16° 40' S the seafloor spreading ridge meets the western end of the North Fiji fracture zone constituting a ridge-ridge-fracture zone triple junction (Auzende et al., 1988).

Extinct hydrothermal sites occur all along the graben immidiately south of the triple junction. They consist of fossil chimneys, oxide stainings and dead shells. In the center of a hydrothermal site at 16° 59' S an active chimney ("White Lady") has been discovered which consists of a 3 m high accumulation of anhydrite (Auzende et al., Geologie Marine, 1988); The discharging hydrothermal solution has a temperature of 285° C. The observations made in this area by French and Japanese scientists (Auzende et al., 1989) suggest that the volcanic activity is scattled over several paralled ridges; the tectonic activity seems to prevail on the whole system. We have concentrated our station work of sampling and seafloor observation on the area between the "White Lady" and the triple junction in order to obtain more information on the massive sulfide deposit of the site with fossil chimneys.

Literature:

1. J.-M. Auzende et al. (1989): Le cadre geologique d'un site hydrothermal actif: la campagne STAMER 1 du submersible Nautile dans le Bassin Nord-Fidjien. Geologie marine 1989
2. J.-M. Auzende et al. (1988): Recent geodynamic evolution of the north Fiji basin (southwest Pacific). Geology 16, 925-929
3. P. Halbach et al. (1989): Cobalt- rich and platinum-bearing manganese crust deposits on seamounts: nature, formation, and metal potential. Marine Mining 8, 23-39
4. E. H. De Carlo et al. (1987): Geochemistry of ferromanganese deposits from the Kiribati and Tuvalu region of the west Central Pacific Ocean. Marine Mining 6, 301-321

2. Cruise course, working areas and utilisation of ship time (App. 2)

The charter of the ship began on 3. Jan. 1990 in Papeete, Tahiti, where four scientists boarded RV SONNE. After the container and the air freight had been taken onboard RV SONNE left Papeete on 4. Jan. 1990 at 3:00 p.m. In the transit time to Pago Pago (American Samoa) the scientists and the crew installed and tested the equipment in order to have it ready until the beginning of Leg 2 / SO 66.

The vessel reached Pago Pago on 8. Jan. 1990 at 6:00 p.m. Five scientists from Clausthal, three scientists from Preussag AG and one guest scientist from the University of Hawaii boarded RV SONNE. Leaving Pago Pago on 10. Jan. 1990 at 2:00 p.m., Leg 2 / SO 66 started.

The ship reached Area P (174° 51' W/4 10'S) northwest of Gardner Island (fig. 1.1) on 11. Jan. The seabeam map (app. 3) shows it as an isolated seamount with the typical shape of an earlier volcano. The small summit region lies at 1040 m water depth from where three flank rift zones (45°,180° and 275°) extend to water depths of around 2300 m. The mapped area of the seamount amounts to 16.6 km * 20.4 km . The slopes are characterized by flank rift zones, smaller volcanic cones as well as cliff and terrace structures. The foot regions deeper than 3800 m were not mapped.

In order to use the full GPS-time for mapping the seamounts the team left area P on Jan. 14 at 7:30 a.m. towards area R, where the seabeam mapping (app. 3) was finished till midnight of 15. Jan. While the processing of the seabeam map was being executed, the station work was continued.

On 16. Jan. at 8:40 p.m. the group left area P for area R. This seamount (174° 43' W/3° 25' S) west of McKean Island (Phoenix Islands) (fig. 1.1) shows a NW-SE elongated plateau (6.5 km * 4.6 km) at an approximate depth of 1300 m with numerous volcanic cones which arise up to 1040 m. The slopes are characterized by flank rift zones, volcanic cones as well as cliff and terrace structures. The mapped area (app. 3) amounts to 20.4 km * 16.6 km, whereby the foot region was not covered.

On 18. Jan. 1990 at 2:25 a.m. the crew left area R towards area S, which was reached on the same day at 6:00 a.m. After three dredge hauls with no crust recovery the team returned to area P, where further station work was carried out from 19. Jan. 6:00 a.m. till 23. Jan. 00:05 a.m. During the transit to Funafuti, the slope of Gardner Island atoll was sampled.

Funafuti/Tuvalu was reached on 26. Jan. 1990 at 10:20 a.m. The American guest scientist left the vessel, whereas on 27. Jan. Prof. Dr. Halbach from Clausthal and two other guest scientists from the East-West-Center, Hawaii, and the Hawaii Institute of Geophysics as well as an observer from the Republic of Tuvalu boarded RV SONNE.

Guests of honour from the Republic of Tuvalu were invited to a reception dinner on board of the vessel. The captain and the chief scientist welcomed the guests, showed the facilities of the ship and gave informations concerning the objectives of the cruise.

Leg 3 / SO 66 started on 28. Jan. 1990 at 8:40 a.m. leaving Funafuti for area V, which was reached at 9:20 p.m. Area V (177° 18' E/8° 28' S) west of Funafuti is situated on a north/south extending ridge structure, which is dotted by numerous volcanic cones. The least water depth is 1900 m. The mapped area (app. 3) amounts to 37 km * 11 km. The foot region was not covered. Due to the developing of the tropical cyclone "OFA" near Funafuti atoll station work had to be stopped on 30. Jan 1990 at 4.10 p.m. in order to leave northward in the direction of area U. Because of bad weather conditions it was not possible to carry out station work there, so the vessel had to be moved farther north to area T, where the station work started on 1. Feb. 1990 at 8.40 a.m. Area T (176° 11' E/ 2° 03' S) southeast of Onotoa atoll (southern Gilbert Islands) is a part of a NW-SE striking structure with two volcanic summits which arise to a minimum water depth of 1350 m (app. 3). The intervening valley has a water depth of around 1900 m. The mapped area amounts to 16.7 km * 6.5 km. After the end of the station work the group left area T on 4. Feb. 4 at 9.35 a.m. towards Funafuti atoll where the observer from the Republic of Tuvalu left RV Sonne with a pilot boat on 5. Feb at midnight. On 6. Feb. at 11.00 a.m. the ship reached area U and seabeam mapping (app. 3) was started. Area U (179° 56' E/ 9° 56' S). Due to sudden upcoming rough weather conditions station work had to be stopped on 7. Feb. at 4.00 a.m. and the ship moved to area W, which was reached on 8. Feb. at 8.20 a.m. Area W (175° 59' E/ 13° 34' S; figure 1.1) west of Rotuma Island is situated on the Melanesian Border Plateau and shows a non uniform structure which is characterized by numerous volcanic cones and steep slopes (app. 3). The maximum water depth is reached in the NE at 2340 m, whereas the shallowest parts on the western side are met at 220 m depth. On 9. Feb. 1990 at 8:35 a.m. the crew left area W and reached area X on 10. Feb. at 8:45 a.m. Area X (173° 55' E/ 17° 00' S; fig. 1.1) comprises an NNE-SSW striking around 500 m wide axial graben at a depth of around 2200 m and the two crests which have A minimum water depth of 1850 m. The distance between the two crests is around 3 km. The mapped area (app. 3) has a size of 12.9 km * 11.1 km. The hydrothermally active area had been discovered by French scientists on an earlier research cruise and had been named "La Dame Blanche" (White Lady). Station work in area X was finished on 14. Feb. 1990 at 6:00 a.m. The vessel reached the pier in Suva/ Fiji on 15. Feb. 1990 at 9:55 a.m. From 15.Feb. to 18. Feb. 1990, RV Sonne was unloaded.

The cruise Midpac 4/ SO 66 ended on 18. Feb. 1990. The whole cruise Midpac 4/ SO 66 lasted 47 days including harbour time and time for transits. The utilisation of the ship time is subdivided as follows:

Leg 1:	Harbour time	87.8 hrs = 3.66 days
	Transit time	100.8 hrs = 4.20 days
Leg 2:	Harbour time	46.3 hrs = 1.93 days
	Station time	228.0 hrs = 9.50 days
	Transit time	129.3 hrs = 5.39 days
Leg 3:	Harbour time	71.0 hrs = 3.18 days
	Station time	257.5 hrs = 11.48 days
	Transit time	183.8 hrs = 7.66 days

3. Navigation and bathymetry

The positioning of the survey vessel was based on the combined use of the integrated TRANSIT satellite navigation system (delivered by Magnavox) and the global positioning system GPS (delivered by Texas Instruments). The orientation on certain topographic singularities was often an additional help.

The bathymetric measurements were carried out by use of the multibeam echosounder SEABEAM and the single beam ELAC deep sea echosounder.

3.1 Use of the TRANSIT system

Two separate receiving systems were available. The more comfortable two-frequency-sytem MX 200 was in continuous use while the simpler one-frequency-unit was used as a backup system. Both units have been described in detail in former cruise reports.
The MX 200 is computer controlled. Via screens it serves all laboratories with the actual ship's position and some other useful data, such as date, time, speed, heading etc.

Ship's speed and heading were used to calculate the position continuously between satellite updates, which came up at an average of 100 minutes. All relevant navigation data was stored on the hard disk of the central computer in a 30 seconds cyclus. Every two hours a new data file has been created for the purposes of further processing. The navigation computer itself is linked to a navigation planning system (Nautomat), which steers the trackplotter in the wheelhouse besides other functions.

3.2 Use of the GPS system

For a detailed description refer to former SONNE reports or the handbook of the Texas Instruments TI 4100 receiver.

A number of 8 NAVSTAR space vehicles were available for navigation for about 12 hours a day. Within the GPS navigation windows the receiving and the resulting position accuracy varied considerably. However, compared with the TRANSIT system the GPS system delivered more accurate position data. The system is not fully automatized and demands a continuous watch of an experienced operator. All relevant navigational data were stored at the disk of the central computer, again at a 30 seconds cyclus. Also every two hours a new data file has been created. In addition, the data of the actual position every 30 seconds was linked to the navigation computer of the TRANSIT system in order to update this system, which serves the screens in the laboratories with navigation data online and which serves the trackplotter in the wheelhouse.

3.3 Processing of navigation data

All work was done on the central computer VAX 750. As already mentioned every two hours data files with GPS data (if any) and data files with TRANSIT data have been created. Each record within these files contains date, time, geographic position, speed and heading and some other information, which is essential for the operator. GPS positions are more precise than those of TRANSIT. However, some quality checks are always necessary. These reliability checks include inquiries about the number of satellites in use, the satellite configuration, the computed mean accuracy and the computed ship's speed. Uncertain data have been rejected. After this quality control GPS and TRANSIT data have been mixed giving priority to GPS data. TRANSIT data fill the gaps of missing or rejected GPS data. In further processing steps significant jumps and peaks within the position data file have been smoothed or eliminated. This processing procedure has been performed every day. The result was a daily position file containing 2880 records at 30 seconds intervals.

3.4 Bathymetry

It was good practice to use both existing echosounder systems, which are the narrow beam ELAC deep sea system and the GENERAL INSTRUMENTS' multibeam system called SEABEAM. Both systems have often been described in earlier cruise reports.

As SEABEAM is sidelooking, the waypaths of the soundwaves are not straight lines within an area of varying sound velocity. The acoustic properties of seawater vary considerably with depth resulting in a refraction of sound waves on the way to the seafloor and back to the surface. This physical reality has to be taken into account calculating the points of reflections of the various acoustic beams of the SEABEAM system. SEABEAM determines 16 of such points of reflections perpendicular to the ship's axis by using the so called 'Ray bending routine'. This routine calculates the effect of refraction due to layers of different sound velocity using Snell's law. The true horizontal distance from the vertical center line to the point of reflection will be determined. Additionally the true depth will be calculated by using the measured traveltimes and the known sound velocity profile. However, the true depth will not be displayed or recorded. All true depths will be recalculated on a basis of a fixed sound velocity of 1500 m/sec. The reason for this recalculation is the fact, that all standard sea chart depths are based on a sound velocity of 1500 m/sec and standard echosounders use the same value as input.

The sound velocity profile has been determined with the CTD probe 'ME Multisonde' at working station 1MS. For input into the SEABEAM system the profile has been simplified as follows:

Surface	1543 m/sec
200 m	1531 m/sec
400 m	1495 m/sec
800 m	1485 m/sec
1600 m	1487 m/sec
2400 m	1497 m/sec
3600 m	1515 m/sec
4200 m	1524 m/sec

During the cruise no remarkable changes of the a.m. profile could be observed within the CTD recordings resulting in the permanent use of the simplified profile shown above. A good test of a correct sound velocity input is always possible, when the ship sails in an area with a very flat sea bottom. There, the connecting line of the 16 bottom reflections, which are displayed by SEABEAM, must be a straight line. This condition could be verified during the cruise from time to time in deep sea areas between the surveyed seamounts.

3.5 SEABEAM data processing and presentation

Raw SEABEAM data are always stored on magnetic tape. Each record contains - besides some other information - the 16 depth values and the related 16 horizontal distances. The first processing step is a mixing of SEABEAM and navigational data. Connecting element is the time, which is recorded in both units. For each record the locations of the 16 bottom reflections will be computed within the geographic coordinate system.

After that the operator can choose a plotting of single profiles showing only the bathymetric information of certain tracks in a width of 2/3 of the waterdepth or he can choose a plotting of a complete bathymetric chart which contains all information sampled in a certain area. A large selection of scales and isobath distances are available. The final product is a bathymetric chart within the Mercator system and based on an averaged sound velocity of 1500 m/sec.

During the cruise 21 of those charts have been prepared in various scales and sizes.

A complete list of charts is enclosed to this report (app. 12).

4. Equipment use and stations

112 stations were carried out during Midpac 4 (SO 66) (appendix 2, table 4.1). These stations comprise 9 different areas and are subdivided in 67 dredge stations, 8 CTD-profiles, 7 sediment stations, 9 OFOS-KT and 2 OFOS-ST profiles, 9 TV-grab stations, 10 current meter stations as well as 14 seabeam mapping stations.

Table 4.1: Overview of stations during the Midpac 4 - SO 66 cruise

Equipment	Area									Σ
	P	R	S	G.I.	T	U	V	W	X	
MS	3	1	—	—	1	—	—	1	2	**8**
GK	3	—	1	—	1	—	—	—	—	**5**
CG	2	—	—	—	—	—	—	—	—	**2**
DSR	17	2	3	1	10	—	7	—	—	**40**
DSO	3	1	—	—	2	—	1	—	—	**7**
DSK	—	1	—	—	—	2	—	4	13	**20**
OFOS KT	5	1	—	—	1	—	—	—	2	**9**
OFOS ST	2	—	—	—	—	—	—	—	—	**2**
SM	6	—	—	—	4	—	—	—	—	**10**
GTV A	4	—	—	—	—	—	—	—	4	**8**
GTV D	1	—	—	—	—	—	—	—	—	**1**
Σ Stations	**46**	**6**	**4**	**1**	**19**	**2**	**8**	**4**	**19**	**112**
Seabeam (h)	*13,3*	*14,0*	*5,0*	*0,5*	*16,2*	*10,2*	*14,2*	*8,0*	*11,0*	***92,4***

MS = multi sonde
GK = spade corer
CG = gravity corer
DSR = round chain-bag-dredge
DSO = oval chain-bag-dredge
DSK = angular chain-bag-dredge

OFOS KT = compact Ocean floor observation system
OFOS ST = stereo Ocean floor observation system
SM = current meter
GTV A = TV-grab, twin shell type
GTV D = TV-grab, polygon type

4.1. Dredges

In respect to the sampling of ferromanganese crusts and substrate rocks as well as hydrothermal precipitates the dredge is a cheap but effective equipment. For that reason 67 of the 112 stations were dredge hauls, using a rectangular dredge (20 hauls), a round one (40 hauls) as well as an oval one (7 hauls). The latter one which had been manufactured for the cruise showed constructive defects since it lost half of its metal teeth during the first use and the chain bag got some holes.

In order to prevent the chain bag from turning upside down it was filled with some iron weights.

In the manganese crust fields the recovery was often not very high because of the hard substrate rocks or plain crust surfaces, whereas it was very high up to more than 600 kg per haul in the hydrothermal fields mostly because of the fresh glassy basalt.

4.2 OFOS-KT and -ST

The visual exploration of the seamount slopes and their crust coverage was carried out nine times by OFOS-KT tracks and two times by the OFOS-ST, which is a Hydro-Products sled equipped with a stereo camera system.

The OFOS was always pulled downslope after having investigated the seabeam maps whereby the following parameters determined about the track direction: wind direction, local ocean currents, and wave height. Furthermore the OFOS was used only within GPS-time in connection with a 12 kHz pinger 30 m above the system in order to ensure an exact localisation and thus to guarantee a greatest possible security. The OFOS-system, which was connected to the vessel by a coax cable, was dragged with a ships velocity of 0.5 to 1.0 knots, whereby it was kept at a distance of around 5 m from the ocean floor by means of an on line TV-control and an exact wind handling adequate to the changing morphology. Installed black and white TV-cameras, photo cameras, flashes and spot lights which are supplied by battery power packs enable an on line video-and photo-documentation (color slides).

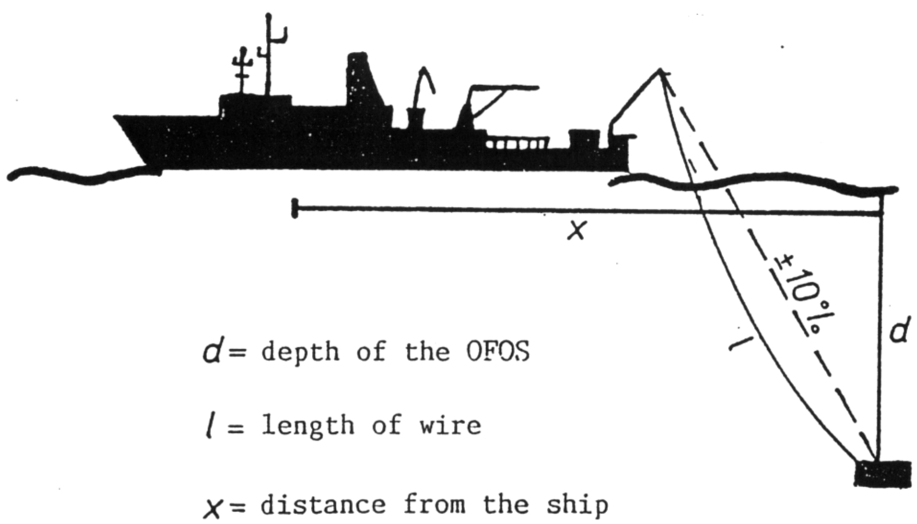
The cameras were set to an exposure time of 1/125 sec. at a stop opening of f 8 in order to ensure a focussing within a range of 3 to 8 m. The used film material was a Kodak Ektachrome 200 ASA, 24 mm * 36 mm. The films could be processed on board with the "Emeraude developing system". The evaluation of the slides and the video films was supported by a 25 cm * 50 cm sized compass, which was hanging approximately 5 m under the OFOS and shows the N-direction. One compass got lost during station 40 OFOS-KT.
Furthermore the system was equipped with a CTD-probe which continuously transmits data about pressure, water depth, temperature, salinity, conductivity, and sound velocity to the onboard computer systems. Eight water samplers fixed to the system enable a sampling of the water column during the heaving by releasing each of them in a certain water depth. For a more detailed report see chapter 4.5 as well as 5.3.
All in all the OFOS-KT worked without problems and yielded high quality slides and video-films.

The OFOS-ST system was equipped with two calibrated stereo cameras (Photosea 5000). The distance to the ocean floor was kept at approximately 4 m. We used the same film material as in the OFOS-KT. Initial problems could be solved till the station 47 OFOS-ST.

Until then it has always been impossible or rather difficult to determine the OFOS position in reference to the ship position. Only the use of transponder navigation could guarantee a good sub-positioning. The ultrashort baseline navigation system RS is only helpful at steep slopes close to the vertical. Due to technical problems the data sonic transponder RS 904 could not be used, thus the exact track lines were recalculated as follows:

During the Midpac 4 cruise a new developed OFOS was used to carry out a survey of the ocean floor. This new system could be controlled by a personal computer and the OFOS data could be plotted on line. The OFOS-KT utilizes an accurate pressure sensor to calculate the exact depth of the sledge. The data were continuously arriving on board and were stored on a disk. During the first half of the cruise the OFOS position at a certain time was calculated from a graphic print at intervals of 5 minutes where the water depth of the OFOS was plotted against the time. On Leg 2 of the Midpac 4 the OFOS software was improved and could give a print out of the OFOS depth and the corresponding time for every minute. To reconstruct the exact OFOS position it was necessary to have a detailed bathymetric map and also to know the length of the wire at a certain time, which could automatically be registered in the OFOS protocol, written on a VAX terminal. With both values, wire length and OFOS depth it was possible to calculate the OFOS distance from the ship with the Pythagorean theorem (fig. 4.2.1).

Fig. 4.2.1: Sketch for calculation of the OFOS tracks



During the SO 61 cruise some trials had lead to the conclusion that the wire length is 5-10 % longer than the actual distance between the ship and the OFOS because the wire forms a curve in the water column. To the calculated OFOS distance from the ship, 50 m were added, this represents the length from the ship's stern to the echosound receiver.

The sledge does not run on a straight line behind the vessel. There is always an offset between the ship's track and the sub-track depending on wind, surface current and deeper currents.

Main criterion for the determination of an OFOS position is the recorded depth. Therefore the position (on the chart) is fixed at a certain contour line. The second determining element is the horizontal distance (on a circle with a definite radius). Ideally the OFOS position is the intersection of the contour line and the a.m. circle. Besides the main criterions, some other recordings are helpful and often necessary to determine the most probable position. These are the ship's speed and heading, changes in cable length and significant observations of the seafloor topography.

The above described procedure is time consuming and cannot be automized. The possibility to reconstruct an exact OFOS track with this method is only given in areas with sufficient differences in the morphology, because in nearly flat areas with few depth lines it is not possible to find an exact crosspoint between depth and constructed arc of circle. This situation was met in area X (White Lady) and therefore it was not possible to reconstruct the OFOS track for the stations 97 OFOS and 106 OFOS.
All results have been plotted on charts in a scale of 1:10.000 (app. 5).

4.3 GTV-A + D

The TV-controlled grabs (type A with two shovels, type D with 5 shovels (polygon)) were constructed in order to have a visually controlled sampling of the ocean floor. The GTV-A is equipped with an osprey valve camera, the GTV-D with an IBAC CCD-camera respectively. The advantage of the TV-controlled grabs is that the success or failure of the sampling could be seen on the on-board TV screens. The battery power allows to close and open the shovels 3 times per station. The grabs are dragged above the ocean floor with a velocity of 1/2 to 1 knots at a distance of 3 to 4 m. To keep the distance, a weight (20 cm in size) is hanged 3 m under the grabs. Furthermore the distance bottom-grab is controlled by a 16 khz pinger, fixed 50 m above the instrument.
The GTV-A was used four times in each each of the areas P and X, whereas only one GTV-D station was carried out in area P. The recovery was very low in the crust fields due to lack exposed rock features, thus the shovels could not break off ferromanganese crusts or substrate rocks. Greater success was achieved by the stations in the hydrothermal fields, where loosened glassy basalt and some stacks of sulfide smokers could be recovered.

4.4 Sediment stations

During the SO 66 cruise, only 7 sediment stations were carried out in three different areas (tab. 4.4.1). A spade corer and a gravity corer of 3 m length were used for the sediment sampling. Some surface sediments were also sampled with a TV-grab in area X. To carry out a sediment station it is necessary to have some information about the thickness and the location of the sediment occurences. The 3.5 kHz-echosound recorder is a useful tool to identify the distribution of sediments on the ocean floor and to estimate their thickness. Before lowering the sampling equipment the subbottom profiles are observed, until a distinct sediment signal is visible on the record. About 20 m above the seafloor the lowering must be stopped and the record of the bottom profile must be checked again, as because of surface currents it is often difficult to hold the ship position above a sediment field.

Table 4.4.1: Sediment stations of the SO 66 cruise

station no.	area	latitude	longitude	water depth (m)	recovery
2 GK	P	4° 09'40 S	174° 58'68 W	4250	27 cm
3 CG	P	4° 08'68 S	174° 51'27 W	1080	--
27 GK	S	2° 41'37 S	175° 06'15 W	1160	23 cm
44 GK	P	4° 09'60 S	175° 05'34 W	1510	--
45 GK	P	4° 09'20 S	174° 51'72 W	1360	--
55 GK	P	4° 08'49 S	174° 48'14 W	2400	--
82 GK	T	2° 03'03 S	176° 09'77 W	1980	--
98 GTV	X	16° 57'90 S	173° 55'04 W	1970	25 kg
99 GTV	X	16° 57'84 S	173° 55'28 W	1970	30 kg

The gravity corer consists of an outer metal pipe with a 3 m long plastic lining. During the SO66 no gravity score station was successful because the core overturned after hitting a hard rock. The spade corer enables sampling of a 50 cm thick sediment package. Only in two cases a successful station was carried out (tab. 4.4.1).

4.5 Water stations

During the SO 66 cruise 17, water stations (hydrocasts) were carried out at defined locations to obtain information on several physico-chemical parameters of the water column. On bord of the "FS Sonne" two instruments were providing water samples and CTD-data: the multisonde and the OFOS-KT.

The KMS-multiparameterprobe (the so-called multisonde) made by Meerestechnik-Elektronik (FRG) is equipped with a rosette water sampler with 12 independent electronically releasable Niskin bottles and instruments for the simultaneous measurements of the six parameters conductivity, temperature, hydrostatic pressure, sound velocity, light attenuation, and dissolved oxygen content. From these data the salinity is calculated on-line. The measurements were simultaneously monitored and later stored on a VAX computer system.
The measurements of the parameters were monitored during the lowering and the lifting phase of the multisonde. The sampling was carried out during the lifting phase. To prevent contamination and the adverse effects of warming, the procedure of filling and storing the water samples was carried out immediately after the return of the sonde to the deck.
All sensors delivered reliable data exept for the oxygen sensor which did not provide any correct information during the whole cruise despite several technical checks. Occasionally, a defect of the electromagnetic triggering of the sampler bottles led to the loss of a water sample.

The multisonde could be used to water depths down to 5000 m and was therefore mainly used for profiles in deep working areas. The main objective was to find indications of the Antarctic Bottom Water (AABW), which is supposed to intersect the lower parts of the seamounts.
While the multisonde was mainly used for profiles between 5000 and 1000 m water depth, the OFOS-KT, which is equipped with 8 independent electronically releasable bottles and sensors for the measurement of temperature, conductivity, and pressure, was applied to get more detailed profiles of the oxygen minimum zone. While the OFOS was lifted from the bottom after the camera mapping of the seafloor,

the water samples were taken between 2000 and 100 m depth. The temperature, conductivity and pressure data were recorded on-line during the whole OFOS-track. The CTD-sonde in the OFOS (from the German company SIS) also delivers on-line calculated data for salinity, density, potential temperature, depth in meters and sound velocity.

In the working areas P to W the water samples were only used for the oxygen determination by Winkler titration (see chapter 6.3). Further analytical investigations on the water samples were omitted because the danger of contamination was very high. Storing water samples for investigations in the home laboratory was also found to be very difficult because of the extremly low element concentrations in seawater.
However, in the North Fiji Basin (area X) where the concentrations of several elements are expected to be distinctly higher than in normal ocean water because of hydrothermal activity, about 40 water samples were taken with OFOS and multisonde. The samples were filled in acid-cleaned polyethylene bottles (0.25 - 1.0 l), the pH was adjusted to 2 with nitric acid, and the samples were stored in a cold room. Analytical chemistry on these samples will be carried out by the Department of Oceanography / University of Hawaii for the following elements: iron, manganese, silica, and perhaps copper, nickel, and zinc.

4.6 Current meters

During the MIDPAC 4 cruise a number of six rotor-type current meters (Aanderaa RCMS) were available. With these instruments the current velocity is measured by counting the rotor's revolution per time interval and the current direction is determined by using a vane, which is mounted at the recording unit, and an interval compass. After each measurement the data sets are recorded on an magnetic tape. The storage capacity of such a tape is about 10.000 cycles.
Five current meter moorings were launched during the MIDPAC 4 cruise (tab. 4.6.1). All moorings were equipped with two current meters, which were mounted 5 and 225 meters above seafloor. For savety reasons each mooring was equipped with two release-transponders (see fig. 4.6.1).

All moorings suspended during the cruise were retrieved successfully. Except for the upper current meter on Station No. 17 SM all instruments worked without any down-time. Therefore a number of 9 complete data sets were available.

Fig. 4.6.1: Sketch of a current meter chain

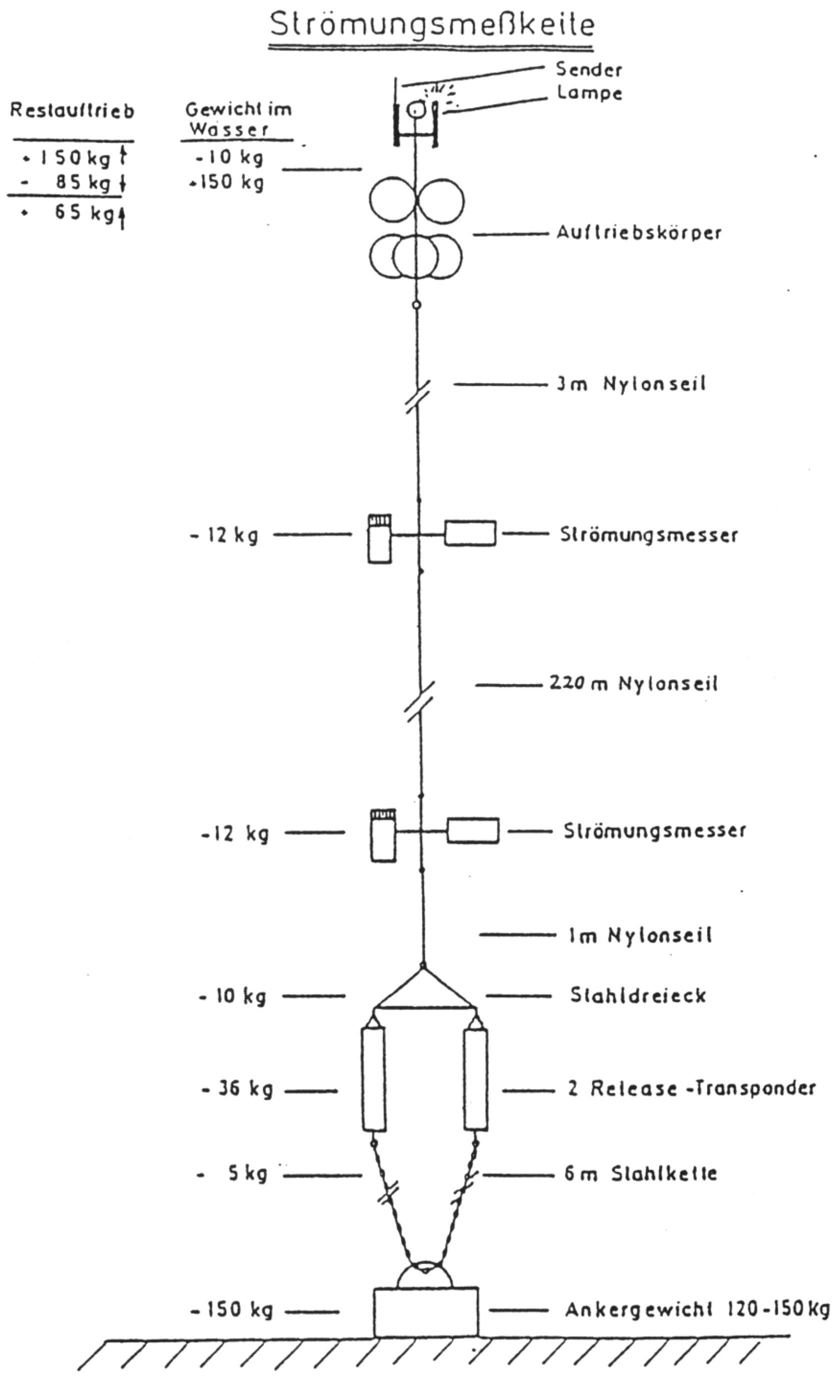


Table 4.6.1: Statistics of current meter stations

stat. no.	area	position		meas. time		meas. time (h)	water depth (m)	meas. depth (m)
		lat.	long.	start	end			
16 SM	P	4° 07.40' S	174° 54.74' W	17/01/90 7.05 h	20/01/90 23.45 h	88.5	3033	2808, 3028
17 SM	P	4° 08.78' S	174° 51.34' W	17/01/90 7.40 h	23/01/90 1.30 h	137.8	1268	1263
38 SM	P	4° 08.52' S	174° 48.05' W	21/01/90 3.20 h	22/01/90 7.15 h	27.9	2412	2187, 2407
70 SM	T	2° 01.79' S	176° 09.47' E	02/02/90 4.40 h	03/02/90 19.15 h	38.6	1395	1170, 1390
71 SM	T	2° 01.42' S	176° 14.45' E	02/02/90 6.00 h	03/02/90 20.00 h	38.0	3255	3030, 3250

5. Onbord investigations (methods)

5.1 Treatment of crust and substrate samples

After emptying the dredges the whole recovered material was photographed and the weight of the crusts and the substrate rocks was estimated. Samples of high interest were selected and cut With a diamond saw, followed by description and characterization of the samples; thickness, color, texture, size, and morphology were recorded in a protocoll book. Every described sample was marked, photographed and packed. From each dredge recovery at least one sample was selected for analysis with XRF. For this purpose about 100 g of the crust were separated from the substrate rock with hammer and chisel. Old and young generation and interlayer were investigated separately. Sometimes also substrate material (mostly carbonate rocks) was prepared for XRF-analysis. The small sample pieces were dried for 12 hours in an oven at 110° C and the dry material was grained in an agate ball mill. The fine crust powder was pressed to tablets which were analyzed by XRF.

From each dredge station with a high crust recovery crust material was collected and packed for analytical investigations in the home laboratory and for processing and leaching experiments.

5.2 X-ray fluorescence (XRF)

On board of the ship 54 samples have been analyzed quantitatively for 13 elements with a PHILIPS PW 1410 X-ray spectrometer. The samples were dried at around 105°C, milled, and pressed to pellets with 40 mm in diameter under a pressure of 10 tons.
The theoretical basis of the X-ray spectroscopy is well known and is discussed in the respective literature.
The measuring time amounts to 100 seconds each for the elements silicium, aluminium, titanium, copper, cobalt, nickel, zink, strontium,

and lead; calcium is counted for 40 seconds, and for iron and manganese the time is stopped when 4×10^6 counts are reached. For all elements and samples the measuring conditions are as follows:

Tube voltage: 50 kV
Tube current: 40 mA
Voltage of scintillation counter: 1084 V
Voltage of gasflow counter: 1854 V
LL/W: 20%/50%
Time constant: 1 second

Three programs in BASIC computer language are written to achieve largely automatically handling. Computing the concentration runs with a **HEWLETT PACKARD** table calculator that contains all values of the calibration lines. To eliminate fluctuations of the equipment every sample is analyzed four times and the mean is taken as the correct value. Ten standards with similar composition as the actual samples are used as reference material. These standards have been analyzed prior to the cruise by several laboratories. Table 5.2.1 shows the element concentration for these standards.

Technical report

The X-ray fluorescence system worked quite well during the whole cruise, though it was not possible to load data from the table calculator into the program unit of the XRF (only the other way round succeeds). Therefore all E-, M-, and P-sets for the three programs had to be stored by hand into the program unit after restarting the system. A loss on argon/methan gas to flush the gasflow counter was stopped by replacing a gasket at the manometer of the gas cylinder. After switching off the instrument the water circulation system was cleaned, the vacuum and gasflow system checked, and the oil changed.

Table 5.2.1: Composition of reference material analyzed by several laboratories.

	Mn	Fe	Ni	Co	Cu	Zn	Si	Ti	Ca	Al	Pb	P	Sr
1	28.11	7.49	1.45	1.13	0.115	0.127	0.81	0.60	7.25	0.68	0.148	2.41	0.115
2	29.70	6.93	1.01	1.04	0.054	0.110	0.52	0.66	7.50	0.17	0.197	2.26	0.143
3	30.14	10.96	0.76	1.81	0.044	0.069	1.64	0.85	2.60	0.49	0.189	0.34	0.137
4	16.67	17.93	0.26	0.40	0.112	0.063	7.37	1.17	3.36	1.95	0.141	0.70	0.143
5	21.99	12.79	0.65	0.59	0.186	0.082	4.17	1.07	5.15	1.37	0.131	1.47	0.154
6	23.20	14.61	0.51	0.77	0.123	0.219	3.57	1.24	4.69	1.04	0.252	0.82	0.151
7	23.63	9.31	0.65	0.56	0.063	0.082	1.02	0.75	11.77	0.23	0.150	3.89	0.167
8	42.53	1.60	0.62	0.016	0.300	0.114	2.89	0.08	1.25	0.95	0.004	0.08	0.043
9	14.60	9.44	0.39	0.49	0.053	0.071	2.25	0.75	16.54	0.69	0.105	6.14	0.179
10	20.89	18.39	0.29	0.81	0.110	0.074	3.70	1.34	4.44	0.72	0.171	1.22	0.176

Data are given in wt.-%.

5.3 Oxygen determination of the water samples

As the multisonde did not provide any correct oxygen measurements, the oxygen determination of the water samples from the multisonde as well as from the OFOS-KT has been made by Winkler titration.

Procedure:

Immediately after the sonde or OFOS is back on deck two water samples are taken from each sampler and filled without bubbles into volume-calibrated glass bottles (about 300 ml). 2 ml of 80 % $MnCl_2$ solution and finally 3 ml of strongly alkaline KI solution are added carefully with long injection needles. The bottles are closed without trapping air bubbles and shaken for 20 seconds. By this procedure the dissolved oxygen is fixed by a redox reaction with Mn^{2+}:

$$1/2\ O_2 + 2\ Mn^{2+} + H_2O + 4\ OH \xrightarrow{pH > 7} 2\ Mn(OH)_3$$

The bottles are stored in a refrigerator for at least 2 hours. The sample solution is acidified with 12 ml of 50 % H_2SO_4, and another redox reaction takes place:

$$2\ Mn(OH)_3 + 2\ KI + 3\ H^+ \xrightarrow{pH < 1} 2\ Mn^{2+} + I_2^0 + 6\ H_2O + 2\ K^+$$

The precipitate is dissolved and the formation of yellow iodine can be observed. I_2 is immediately titrated with $Na_2S_2O_6$ (0.01 n, Titrisol) to prevent any loss of iodine. (The factor of the titrant solution is determined with KBr (0.01 n, Titrisol)). Shortly before the solution becomes colourless, 1 ml of a 0.5 % starch indicator solution is added which forms a deep blue inclusion formular with iodine. The titration is continued until the solution is colourless. The oxygen content of the water samples can be calculated from the volume of the titrant solution needed for the titration.

Each water sample was investigated by double determination. The standard deviation was always lower than 5 %. For the construction of the oxygen-depth profiles (app. 10) the mean values of the double determinations were used.

6. Sample material and preliminary results

6.1 Crusts and substrate rocks (App. 6)

Description of crust samples

The ferromanganese ores cover the substrate either as a mm to cm thick crust layer or encrust a small piece of substrate and thus form a ferromanganese nodule. The ore is intergrown with substrate and can only with difficulty be removed from it. This is especially true for crusts on reef limestone. In general two growth generations are developed: the older generation and the younger crust generation. The typical old generation typically is compact-layered and shows phosphate inclusions. The color is graphite-like and gleamy. The fracture is conchoidal. The young generation is less hard, often fine porous and shows clay fillings (see fig. 6.1.2). It can also be layer-structured.
The boundary between the two generations is not always easy to determine. Often it is a finely porous zone or a phosphate layer, or a zone with phosphate fillings. In some samples the interlayer can be subdivided into subinterlayers.
The thickness of the crusts varies from a few mm to up to 9 cm (see fig. 6.1.1, fig. 6.1.2). The young generation is generally much thicker than the old one. The surface of the crusts can be finely to coarsely knotty. Some crust surfaces have abrasion features caused by intense bottom currents.

Description of substrates

The substrate samples from all areas can be classified into three groups:

1. volcanoclastites
2. pillow-basalts
3. reef limestone

1. Volcanoclastites are breccious with basalt clasts (mostly fine vesicles) and partly with fragments of carbonatic phosphatic rocks. Some clasts of both kinds are encrustrated. The matrix is calciferous and phosphatic. Some of the volcanoclastites can be classified as hyalo-

clastites. These are highly weathered and rich in clay minerals.

2. Pillow basalts have fine to coarse vesicles or are amygdaloidal (cavities filled with zeolithe, calcite or phosphate), microcristalline or compactly porphyric with feldspar phenocrystals . The pillow fragments show contraction fractures and chill margin and usually a glassy surface. Sometimes the surface has a sheet flow lava texture.

3. Reef limestones are generally phosphatized porous to cavernous, dendritic and fossilioferous (mostly coral bearing). The cavernous structure is often covered with Mn-crust or thin Fe-hydroxide coatings.

We found the following distribution of substrates in the working areas of SO 66:
In the areas P, R, S, T, U, and V we recovered volcanoclastites and reef limestone (see fig. 6.1.1 and fig. 6.1.2) but no basalts. In area W we found pillow basalt and in area X again vulcanoclastites, but these differ from those found in area P to V. These basalt clasts have a glassy surface and an elongated angular shape. Sheet flow lava structure was only found in area X.

The quantity of crusts recovered in the different areas varies over a wide range (see app. 6). The bulk of samples was recovered in area P. 20 dredge stations in 1050-3000 m water depth yielded about 400 kg of crusts. The most interesting samples (e.g. 43 DSO with a marked old generation) were found in this area. In area R we sampled only thin Mn-coatings on substrate rock. In area S two successful dredges brought only 2 kg of 1-3 cm thick crusts on limestone and thin coatings on chalk from a depth range of 1250-2600 m. In area T we recovered about 70 kg of crusts from 12 dredge stations (1300-3100 m). Some of these samples showed an interesting crust-substrate relation (e.g. 69 DSO 2). In area U we recovered about 45 kg of crust samples in a depth range of 1500-2500 m. These crusts are about 5 cm thick and show clay fillings. The thickest crust (9 cm) was found in one of the 7 dredge stations in area V (2200-3000 m). The total yield was 45 kg. Area W, however, produced only thin coatings in a depth range of 1200-2200 m.

Appendix 6 shows an overview of the crust and substrate samples that were recovered by dredges during the SO 66 cruise.

Fig. 6.1.1: Photo of crust sample 6 DSR 1 from a water depth of 2300 m in area P. The about 7 cm thick crust grew on phosphatized reef limestone.

Fig. 6.1 .2: Photo of crust sample 85 DSK 1 from area U, water depth 2600 m. This 7 cm thick crust consists only of the younger growth generation and is highly contaminated with alumosilicates from the weathering of neighbouring seamounts. The substrate is reef limestone.

Chemical composition

The chemical composition of the manganese crusts was analyzed on board ship by X-ray fluorescence (XRF; see chapter 5.2 ; app. 7). The crusts mainly consist of a crystalline δ-MnO_2 phase (vernadite) and an amorphous iron-oxyhydroxide ($FeOOH * x H_2O$). Additional mineral phases within the crusts include phosphorite and minor amounts of smectite. Mostly vesicular basalt as well as nearly pure phosphorite form the substrate.

Generally, the manganese crusts recovered consist of two generations: a younger and an older one. Between these two generations distinct differences in the chemical composition occur. Table 6.1.1 gives minimum, maximum, and mean values of thirteen elements of the young and the old crust generation which were analyzed directly on board.

Table 6.1.1: Minimum, maximum, and mean values for the young and the old crust generation, respectively.

	young			old		
	min.	max.	mean	min.	max.	mean
Mn	17.59	32.85	**27.33**	11.82	31.91	**23.74**
Fe	11.78	22.61	**17.20**	7.43	14.98	**10.65**
Ni	0.26	0.86	**0.55**	0.27	0.96	**0.73**
Co	0.30	1.46	**0.81**	0.20	1.14	**0.55**
Cu	0.03	0.16	**0.07**	0.06	0.15	**0.10**
Zn	0.057	0.084	**0.066**	0.064	0.103	**0.086**
Si	0.93	6.37	**2.54**	0.54	5.58	**1.45**
Ti	0.79	1.85	**1.03**	0.62	1.04	**0.84**
Ca	0.39	6.70	**2.95**	5.54	12.46	**9.03**
Al	0.22	1.98	**0.61**	0.15	1.84	**0.47**
Pb	0.102	0.200	**0.155**	0.095	0.207	**0.145**
P	0.39	2.02	**0.56**	1.31	4.38	**2.84**
Sr	0.147	0.174	**0.160**	0.148	0.191	**0.166**

All data given in wt.-%. n=26 for the young generation, n=13 for the old generation.

Generally, the iron content of the old crust generation is much less than in the younger one (10.65 vs. 17.20 wt.-%). The same pattern is visible for cobalt (0.55 vs. 0.81 wt.-%). Nickel shows a contrary behaviour: it is enriched in the old generation, depleted in the younger one (0.73 vs. 0.55 wt.-%). A phosphatization took place during formation of the old crust generation resulting in high phosphorus (2.84 wt.-%) and calcium (9.03 wt.-%) values.

Besides the manganese crusts, analyses have been carried out on calcite- and phosphorite-rich substrates, respectively, showing that nearly pure carbonate as well as pure phosphorite can occur. The results of all samples are given in detail in appendix 7.

6.2 Hydrothermal precipitates

Area X (White Lady) is localized in a recent active hydrothermal zone. Several dredge and TV-grab stations were carried out in this area and about 3 t of sample material could be recovered. It consists mainly of basalt and fresh lava, but also thin coatings of Mn-oxides on basalt and about 100 kg of sulfides were sampled.

Area X is located at the axial graben of the spreading-ridge in the North Fiji Basin, close to the triple junction with the North Fiji Fracture Zone at 16°40' S. Two hydrothermal fields with different hydrothermal mineralizations can be distinguished in this area. The southernmost hydrothermal field consists of the active chimneys of the "White Lady" which are composed of anhydrite precipitated from a high-temperature hydrothermal activity. The northern hydrothermal field shows old chimney structures of massive sulfides. The surfaces of the chimneys have distinct oxidation features.

Three different types of mineralizations can be distinguished. The first is a sulfide bearing basalt-breccia. Angular basalt and lava pieces of mm to cm size are cemented by a massive sulfide matrix. The color of these samples is light grey to greyish gold. The second type consists of siliceous substrate rock impregnated with sulfides (amorphous SiO_2 and chalcedony with fine-grained pyrite crystals). The surfaces of the samples are coated with black to brownish Fe-Mn-hydroxides. The third type is massive sulfide (fig. 6.2.1 and fig. 6.2.2) consisting mainly of pyrite, marcasite, sphalerite, and subordinately of chalcopyrite. Many samples have a fine and porous texture, the cavities for the transport of the hydrothermal solution are visible (fig. 6.2.2). The walls of the cavities often show mineralizations of idiomorphic pyrite crystals; in some cases also sphalerite cystals occur. Other massive sulfide samples show a collomorphic texture (fig. 6.2.1). The colour of the massive sulfide samples varies between black-grey and green-grey.

Fig. 6.2.1: Sample of a massive sulfide from about 1900 m water depth in area X. Distinct collomorphic textures are visible. Size of sample: 12 cm

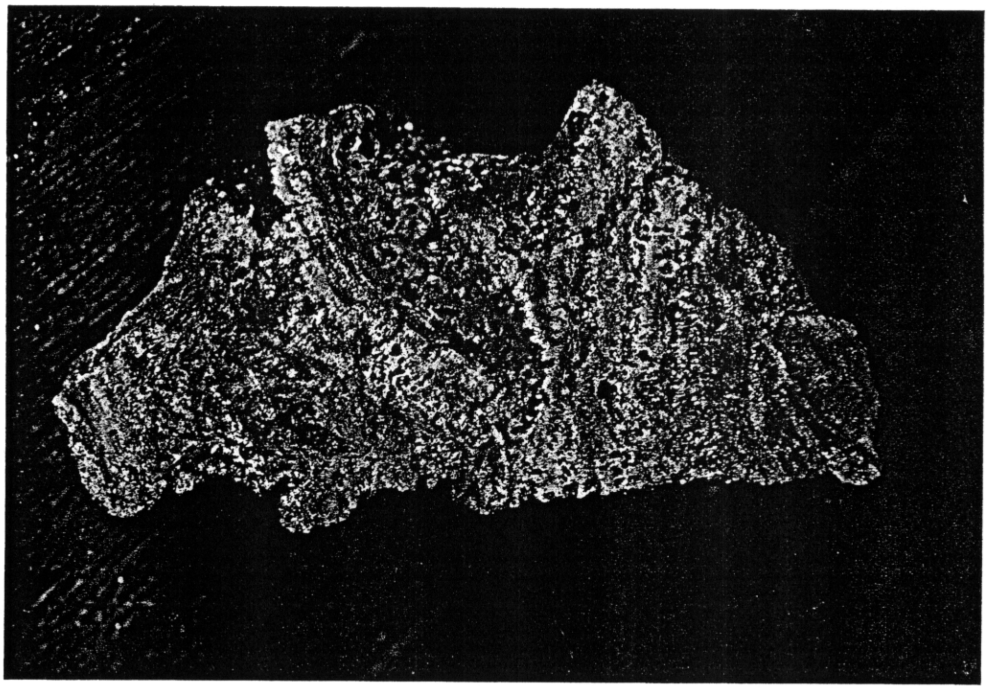
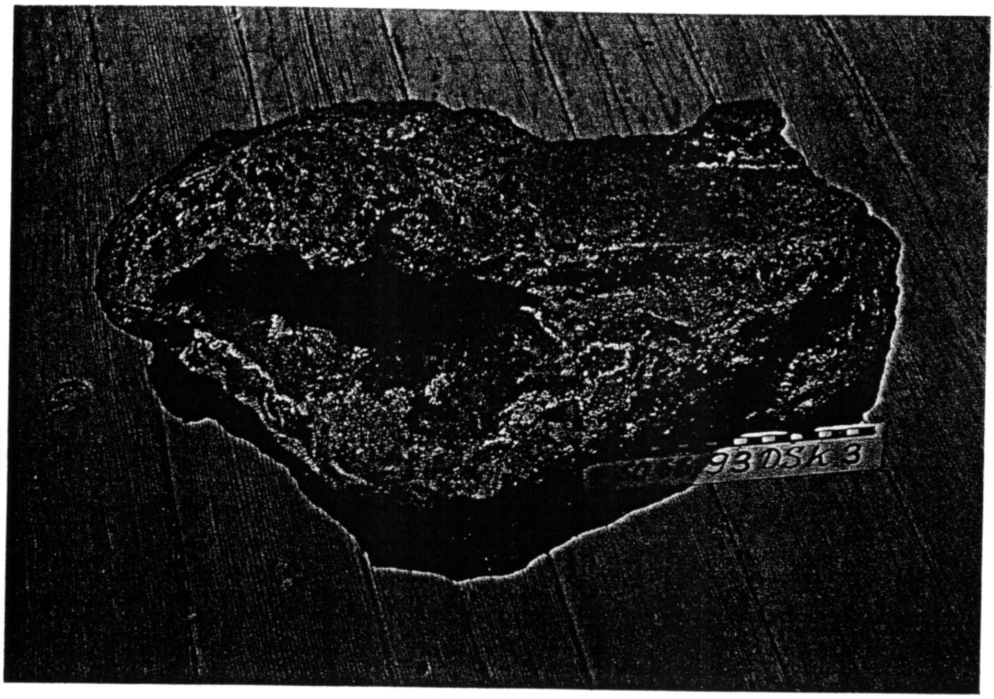


Fig. 6.2.2: Massive sulfide sample from area X (1900 m water depth). The sample shows cavities for the transport of hydrothermal solution. Size of sample: 60 cm



6.3 Description of the OFOS stations

AREA P

7 OFOS - KT:

Date: Jan. 15/16, 1990

Start: 20.01 (GMT), 4°08,45'S / 174°51,28'W

End : 02.52 (GMT), 4° 10,75'S / 174°49,41'W

Bottom - contact: 22.36 - 01.32 ^ 176 min recording

Water depth: 1009 - 2740 m

Track: SE - slope; from the top around 150° to SE

Documentation: 275 slides

1009 - 1035 m: Top of the seamount. Mainly debris fields composed of slab fragments (10 cm - 1 m).
Sediment coverage around 50 %.

1035 - 1090 m: Lava flow fields with smooth surfaces and sharp edges (lava fow fronts); intermediate debris aprons. The biota of the top region is numerous (mainly fishes, starfishes)

1090 - 1300 m: Increasing sediment coverage.

1300 - 1500 m: Very rough morphology with steep slopes and walls.

1500 - 1550 m: Large sediment fields or terraces with a few debris fields or outcrops of crust covered substrate rocks. The crust coverage increases with increasing water depth.

1550 - 2300 m: All outcropping rocks are totally covered by manganese crust. The morphology is characterized by alternating steep cliffs and highly bioturbated sediment fields.

2300 - 2600 m: Decreasing crust coverage, increasing sediment as well as debris coverage.

ca.2600 m : Last occurrance of crust covered rocks.

2600 - 2740 m: Mainly sediment and debris aprons.

8 OFOS - ST:

Date: Jan. 16, 1990

Start: 03.52 (GMT), 4°08,90'S / 174°51.10'W

End : 03.57 (GMT), " / "

Due to a malfunction of the cameras breaking off of the station after around 5 minutes. The electronic system needed to be checked.

9 OFOS - KT:

Date: Jan. 16, 1990

Start: 05.23 (GMT), 4°08,82'S / 174°51,19'W

End : 10.15 (GMT), 4°27,54'S / 174°40,11'W

Bottom contact: 05.54 - 09.00 (GMT) ^ 186 min recording

Water depth: 1076 - 2708 m

Track: NE slope; from the top around 65° to NE

Documentation: 314 slides

1080 - 1280 m: The sediment coverage at the top region amounts to more than 50%. Characteristic are m^2 sized rock plates, whichseem to be partly covered by manganese crusts. Sometimes these rock plates are covered by a thin sediment layer. The outcropping rocks are reef limestones with carved surface and a thin manganese coating. The topography is characterized by an alternation of sediment and debris terraces with steep cliffs and slopes.

1280 - 1400 m: The topography starts to be more plain with increasing sediment coverage.

1400 - 1570 m: First clear indications of ferromanganese crusts on a rounded microtopography. The crusts show a knobby surface texture. The sediment fields are still dominant. They show ripple marks and a high grade of bioturbation.

1570 - 2100 m: Clear indications of ferromanganese crusts on a reef microtopography, whereby the thin younger crust generation sometimes is ripped off. The sediment coverage is decreasing to 20 - 30%; mostly the crusts are covered by "white snow". The morphology is characterized by steep cliffs and slopes.

2100 - 2400 m: First predominantly crust covered debris. Later areas with a high crust coverage. The ferromanganese crusts show a knobby surface texture.

2400 - 2700 m: Sediment fields with tracks and trails.

15 OFOS - KT:

Date: Jan. 15/16, 1990

Start: 23.45 (GMT) 4°08,84'S / 174°51,58'W

End : 04.34 (GMT) 4°07,58'S / 174°55,44'W

Bottom contact: 00.01 - 03.00 (GMT) ^ 170 min. recording

Water depth: 1037 - 2969 m

Track: WNW slope; from the top around 285° to W

Documentation: 238 slides

1040 - 1280 m: The top region is dominated by slab fragments, which show no or just a thin manganese coating. Sediment fields alternate with debris fields (around 50% each). Further downslope the ocean floor is rather plain with an increasing amount of slab debris. Then follows an alternation of sediment free reef outcrops with steep cliffs and debris terraces. The biota of the top region is characterized by a high number of fishes.

1280 - 1430 m: At around 1280 m the ocean floor markably flattens and is covered by thin sediments, which show ripple marks and other marks of current activity.

1430 - 1540 m: The morphology starts to be rough again (steep cliffs and walls alternate with intermediate terraces). The outcropping reef limestones show a porous to cavernous surface. A distinct coral cementary is located at around 1500 m.

1540 - 1660 m: First occurrence of ferromanganese crusts.

1660 - 2000 m: Steep cliffs and walls with intermediate small terraces which are covered by encrustated rocks. Sediment is found only in pocket structures.

2000 - 2700 m: Markably increasing sediment coverage with distinct ripple marks and a few outcropping rocks (size > 1 m).

32 OFOS - KT:

Date: Jan. 20, 1990

Start: 06.53 (GMT), 4°08,94'S / 174°51,36'W

End : 11.13 (GMT), 4° 11,39'S / 174°51,53'W

Bottom contact: 07.26 - 10.10 (GMT) ^ 164 min. recording

Water depth: 1260 - 2530 m

Track: S - slope; from the top around 190° to S

Documentation: 304 slides

1260 - 1630 m: At the top the sediment coverage amounts to 50 - 100% .
Outcropping reef limestones are rare and show a rough to angular surface. At places there are m^2 sized slabs, which are coated by manganese crust. The sediments show no current marks but a distinct bioturbation.

1630 - 1850 m: At around 1630 the topography is dominated by steep cliffs and sediment free steep slopes. They are followed by sediment fields with ripple marks and bigger as well as smaller outcrops of reef rocks with a rough surface.

1850 - 2140 m: First indications of ferromanganese crusts. At around 2000 m all boulders, blocks, etc. are covered by crusts. Sediments are reduced to white snow.

2140 - 2200 m: Increasing sediment coverage with weak ripple marks. The amount of debris is low.

2200 - 2460 m: Low grade encrustation of boulders and pebbles. Increasing grade of current marks on the sediments.

2460 - 2480 m: Extended manganese nodule field on sediments (nodule size around 10 cm).

2480 - 2510 m: 30 m high steep wall.

2510 - 2530 m: At the foot of the wall are well coated rocks. They are followed by debris covered sediment fields.

40 OFOS - KT:

Date: Jan. 21, 1990

Start: 03.34 (GMT) 4°08,91'S / 174°51,17'W

End : 07.46 (GMT) 4°07,66'S / 174°54,22'W

Bottom contact: 04.10 - 06.42 (GMT)^ 157 min. recording

Water depth: 1100 - ??? m

Track: NW - slope; from the top around 295° to NW

Documentation: 323 slides

Remark: Compass lost

1100 - 1250 m: Sediment coverage around 50% with ripple marks. At the top angular to flat rock fragments occur. They are followed by an area with outcropping reef limestones. The rims of the steep cliffs are rounded. The sediment coverage decreases and sometimes debris of flat rocks can be observed.

1250 - 1650 m: Some sediment fields with high grade of bioturbation but no ripple marks. Later the amount of outcropping limestones increases. They show rough to angular surfaces.

1650 - 1700 m: Sediment fields with ripple marks.

1700 - 1770 m: Steep and rough topography with steep cliffs (several meters high). It is followed by an extended sediment field with no ripple marks but bioturbation and a few outcrops of angular rocks.

1770 - 1800 m: Clear indications of ferromanganese crusts on boulders and blocks. The steep walls are not covered by crusts.

1800 - 1960 m: Extended sediment terrace with a few outcropping rocks, which are thinly coated by manganese.

1960 - 2300 m: At 1960 m water depth again clear indications of ferromanganese crusts. They are followed by a rough topography with steep cliffs and walls .

2300 - 2470 m: More plain area with sediment fields which show ripple marks and crust covered debris.

2470 - ??? m : Extended sediment terrace with weak ripple marks but high grade bioturbation.

47 OFOS - ST:

Date: Jan. 22, 1990

Start: 06.03 (GMT), 4°08,87'S / 174°51,22'W

End : 10.30 (GMT), 4°06,75'S / 174°50,24'W

Bottom contact: 06.03 - 10.36 (GMT) ^ 189 min. recording

Water depth: 1095 - 2738 m

Track: NNE - slope; from the top around 20° to N

Documentation: 2 * 358 slides

1095 - 1250 m: Angular, dm to m sized fragments of reef rocks. The sediment coverage amounts to 40% and shows no ripple marks. From plact to place big boulders of reef limestone occur. Downslope the sediment coverage increases distinctly to around 90% with big ripple marks, scattered debris aprons or outcropping reef limestones with scallop structures.

1250 - 1400 m: Outcropping massive reef limestone with a rough surface covered by white snow. It is followed by a zone of reef debris aprons consisting mainly of flat fragments.

1400 - 1680 m: Again outcrop of massive reef limestone with a very rough surface (sharp rims, scallop structures). If sediment occurs it shows only low grade ripple marks but distinct tracks and trails.

1680 - 1900 m: First occurrence of ferromanganese crusts. Some smaller sediment fields.

1900 - 2180 m: High coverage of ferromanganese crusts on outcropping reef limestones as well as on debris. Sediment coverage is still high (50 - 100%). Till there the morphology is smooth and uniform.

2180 - 2310 m: Very high flat crust coverage (80 - 100%). The crusts show rounded forms with a knobby surface texture.

2310 - 2450 m: Distinct increase of the sediment amount (partly > 50%) with parallel decrease of crust coverage (crust thickness seems to be less because the crust's surface follows rather the microtopography).

2450 - 2680 m: At first again better crust coverage. Then the sediment coverage increases steadily.

from 2680 m : Extended sediment fields with scattered big boulders of reef rocks.

Fig. 6.3.1: Deep-sea still photo from area P (water depth about 1700 m). The picture shows a gentle slope with a rough and angular morphology, an indication that the manganese crust coverage of the substrate rocks cannot be very high.
Length of the trigger weight with compass: 75 cm

Fig. 6.3.2: Deep-sea still photo of a relatively smooth and plain region in area P in about 1840 m water depth. The substrate rocks show a manganese crust coverage with the typical nippled and knobby surface. The amount of deep-sea organisms (like sea-urchins or sea lilies) must be very high because of the high grade of bioturbation.
Length of trigger weight with compass: 75 cm

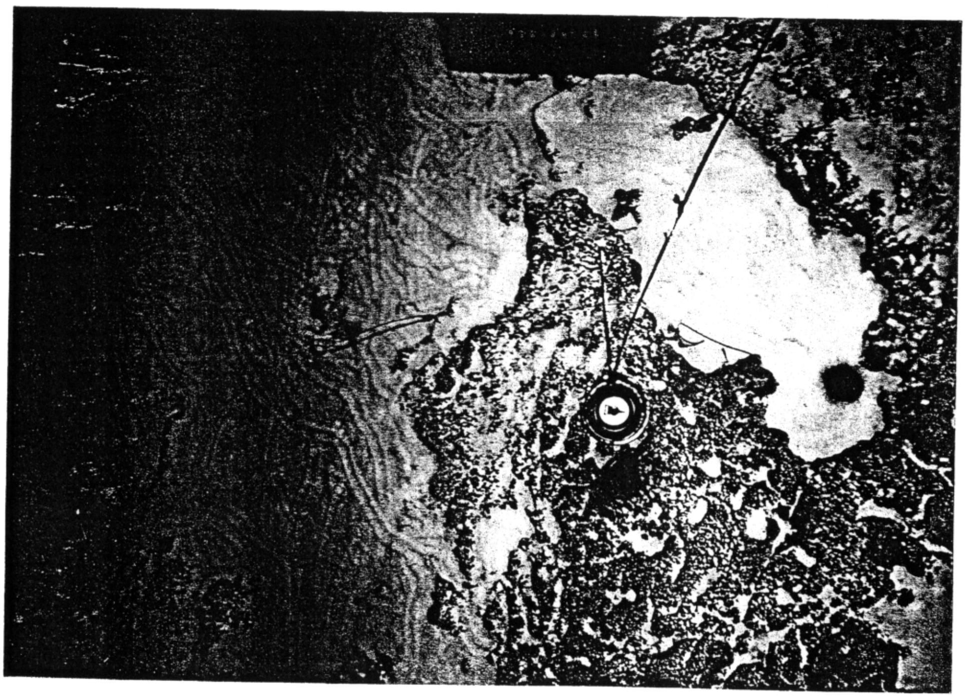
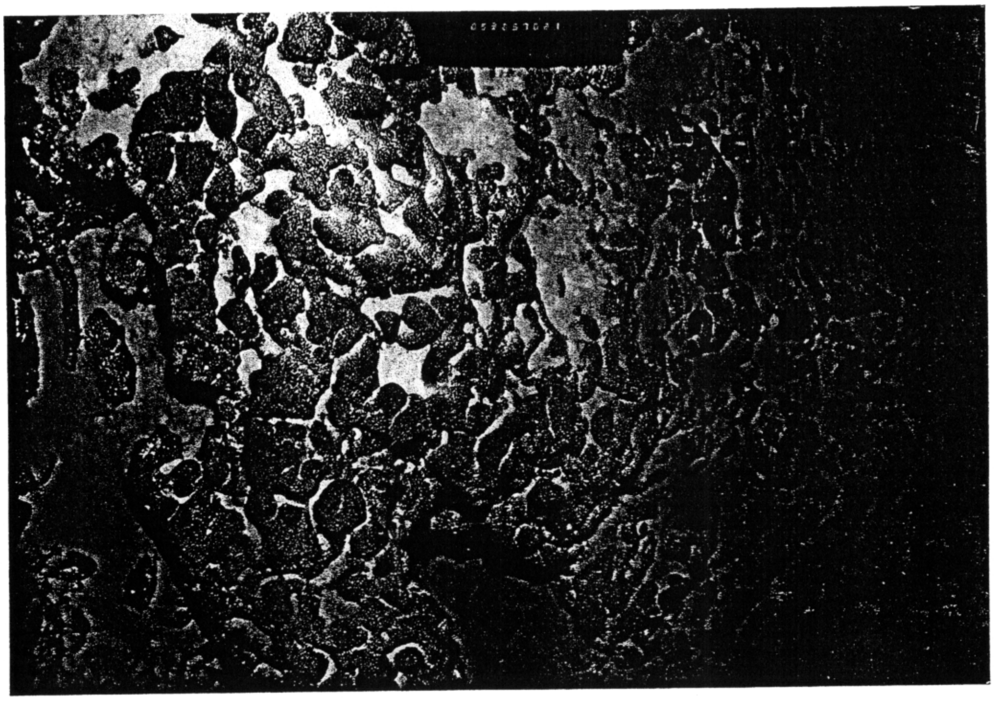


Fig. 6.3.3: This deep-sea still photo shows a gentle slope with high crust coverage (abound 90 %) in area P (water depth 1970 m). Possibly the thickness of the crusts is very high because of the knobby and rounded surface of the outcropping rocks. Even the edges are rounded. Length of the trigger weight with compass: 75 cm



AREA R

22 OFOS - KT:

Date: Jan. 18, 1990

Start: 03.11 (GMT), 3°24,41'S / 174°42,91'W

End : 08.03 (GMT), 3°24,06'S / 174°40,65'W

Bottom contact: 03.36 - 06.41 (GMT) ^ 180 min. recording

Water depth: 1030 - 2300 m

Track: E - slope, from the top around 85° to E

Documentation: 257 slides

1030 - 1140 m: The top region is covered by reef limestones with a rough to angular surface. Besides white snow there is almost no sediment. At around 1040 m a sediment terrace follows, which is covered by dm to m sized fragments of reef limestones. The sediment itself shows no current marks. It is followed by outcropping angular reef limestones partly with scallop structures. Sediment is found only in pockets. At around 1050 m follows a further sediment terrace with some outcropping reef limestones. The sediment shows no ripple marks but a high grade of bioturbation.

1140 - 1180 m: Topography with some steep cliffs. The surface of the reef limestones is rounded with some porous features. Sediment only in pockets.

1180 - 1260 m: Extended sediment terrace with no debris and ripple marks but a high grade of bioturbation.

1260 - 1320 m: Again outcropping reef limestones alternating with smaller sediment fields.

1320 - 1600 m: Extended compact reef area (middle reef?), with smooth rims and some striped features. Also some scallop structures occur. The area is characterized by steep cliffs and walls.

1600 - 1770 m: Again sediment terraces with dm sized debris. Then plain without ripple marks but bioturbation.
Massive reef limestones follow with scallop structures which are covered to around 50% by sediment.

1770 - 1050 m: Steepening topography with outcropping reef limestone. Some steep cliffs with rounded rims. Sediment coverage amounts to around 50%.

2050 - 2070 m: Steep cliff.

2070 - 2300 m: Sediment field without ripple marks. Outcropping reef limestones show scallop structures.

AREA T

72 OFOS - KT:

Date: Feb. 2, 1990

Start: 06.25 (GMT), 2°03,95'S / 176°11,41'E

End : 12.05 (GMT), 2°03,10'S / 176°08,20'E

Bottom contact: 07.15 - 10.44 (GMT) ^ 209 min. recording

Water depth: 1360 - 2638 m

Track: NW - slope of the southern summit; from the top around 285 to NW.

Documentation: 476 slides

The OFOS - track started already before reaching the top of the seamount at a water depth of around 1370 m.

1370 - 1330 m: Massive reef limestone with a rough surface and a high relief. Remarkable are two fracture systems which strike perpendicular to each other. No debris and only sediment in form of white snow. A little bit upslope debris aprons and small sediment fields with ripple marks occur.

1330 - 1440 m: At the top outcropping reef limestone with steep cliffs and rounded rims. No debris. Downslope the amount of debris and boulders increases.

1440 - 1700 m: Again outcropping reef limestone with a high relief and scallop structures. Decreasing sediment coverage.

1700 - 1900 m: First occurrence of manganese crusts on outcropping reef limestones and debris. The reef limestone shows a very rough surface. At around 1850 m the outcropping rocks are partly free of crusts.

1900 - 2050 m: At around 1900 m outcropping rocks and debris are only coated by manganese. Then good crust coverage occurs again. The sediment amount is low and shows ripple marks.

2050 - 2260 m: Increasing sediment amount with no ripple marks but distinct tracks and trails; remarkable is an unusual dirty color of the sediment.

2260 - 2640 m: Extended sediment fields with ripple marks.

2400 - 2640 m: Some outcropping encrustated reef limestones and debris.

AREA X

97 OFOS - KT:

Date: Feb. 10/11, 1990

Start: 23.08 (GMT), 16°58,81'S / 173°54,90'E

End : 02.50 (GMT), 16°57,86'S / 173°55,46'E

Bottom contact: 23.52 - 01.09 (GMT) ^ 77 min. recording

Water depth: 1966 - 1977 m

Track: NNE-track along the graben structure

Documentation: 298 slides

In contrast to the seamount slopes the track is described using the time marks.

At first there are fresh lava structures with a high amount of rock debris, debris aprons, small fracture zones and steep walls. The sediment amount is low.

From 23:57 : Distinct increase of the sediment amount and occurrence of Pahoehoe-lava.

From 00.15 : First indication of pillow lava.

From 00.20 : Distinct occurrence of pillow lava

From 00.27 : Greyish sediments indicate the first occurrence of hydrothermal activity.

From 00.32 : Hydrothermal field with dark sediments, sulphur-mineralization and black smokers.

From 00.40 : Pahoehoe - lava and pillow lava, small fracture zone and debris aprons.

At 00.59 : Structures with a brownish coverage may indicate old stacks of smokers.

At 01.04 : End of the profile.

106 OFOS - KT:

Date: Feb. 2, 1990

Start: 03.39 (GMT), 16°58,79'S / 173°54,86'E

End : 08.38 (GMT), 16°59,30'S / 173°54,90'E

Bottom contact: 04.29 - 06.37 (GMT) ^ 128 min. recording

Water depth: 1935 - 1987 m

Track: ???

Documentation: 489 slides

In contrast to the seamount slopes the track is described using the time marks.

From 04.29 : 90 - 100% sediment coverage with scattered lava frag-
to 04.42 ments or outcrops.

From 04.42 : Lava debris aprons and steep cliffs.

From 05.47 : First hydrothermal indications in form of hydrothermally mineralized f ragments lying on the sediment.

From 06.05 : Active hydrothermal field with brownish precipitates,
to 06.14 sulphur precipitates and white mineralizations on the sediments as well as on the substrate rocks.

From 06.14 : Non active area.

From 06.25 : Again hydrothermal indications.

From 06.33 : Active hydrothermal field: white crabs, dead and li-
to 06.37 ving clams (partly in bigger colonies), fishes and other organisms at or directly near white vents.

Due to a malfunction of the coax-cable the station had to be broken off.

Fig. 6.3.4: Deep-sea still photo from the hydrothermal site in area X ("White Lady"). It shows hydrothermal precipitates covered by hydrothermally altered yellowish sediments. Length of the trigger weight with compass: 27 cm.

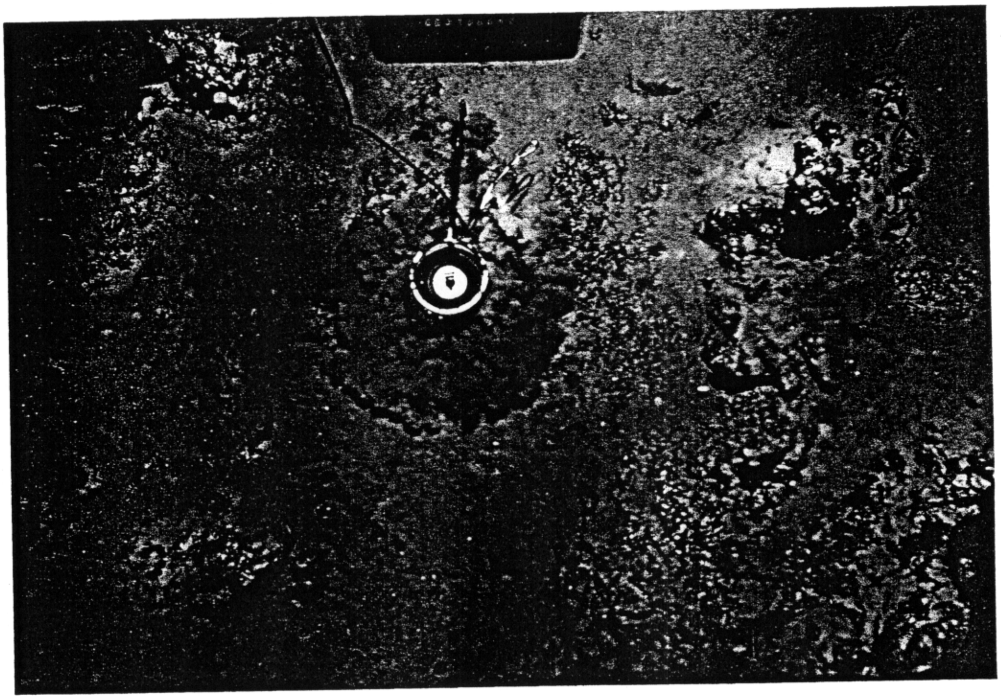
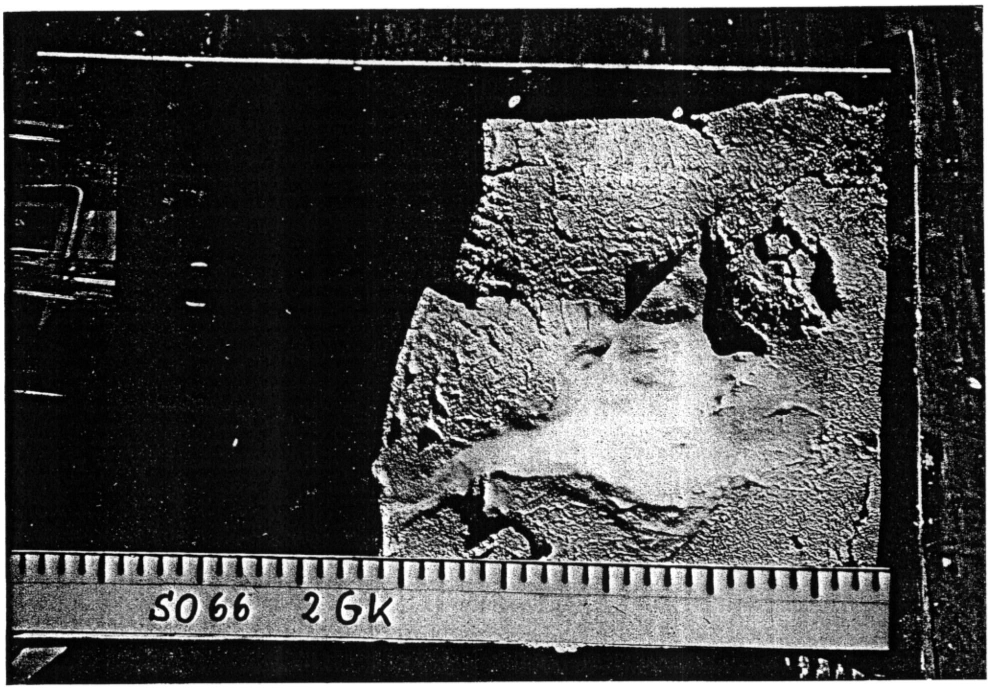


Fig. 6.3.5: This deep-sea still photo from area X shows talus of basaltic material, with probably impregnated hydrothermal ore. The white crabs and clams represent the typical benthic fauna of hydrothermally active sites.
The lower edge of the picture has a lenght of about 6 m.

6.4 Sediments

The sediment sample of station 2 GK (fig. 6.4.1) can be devided into two types of foraminiferal sand; the upper 25 cm have a white color (10YR 8/2, Munsell Color Chart), whereas the 2 cm at the base are dark yellowish brown (10YR 4/4). The upper part mainly consists of tests of planctonic foraminifera , but only few species could be identified; besides Globigerina and Globoquadrina, Pulleniatina -about 90 %- and Globorotalia are most frequent. Shark teeth, spins of sea-urchins and radiolarians can be observed, too. The tests are very well preserved and only a few pieces of substrate rocks occur in the sediment. In contrast to this, the 2 cm at the base contain many substrate rocks and mangenese crust pieces, some of them are several cm in size. Altered basalt with distinct cavaties filled with calcite and zeolite crystalls occur. The tests of the planktonic foraminifera are badly preserved.

Fig. 6.4.1: Sediment sample of station 2 GK in area P (water depth 4250 m). The 27 cm thick core consists of 2 different types of foraminiferal sand; the upper 25 cm have a light color, whereas the 2 cm at the bottom have a more brownish color. (Scale bar in cm).



The sediment in station 27 GK has a very pale brown color (10YR 8/3) and consists mainly of tests of planktonic foraminifera , which are very well preserved und show only few Fe-hydroxide coatings. The $CaCO_3$-content reaches 97 %. Main genera are Orbulina, Pulleniatina, Globigerinoides, Globorotalia and Sphaeroidinella. The small species of Globingerinoides ruber can alo be observed.
The sediment samples from area X (98 GTVA and 99 GTVA) have a brownish color (7.5YR 3/4) and they are very fine grained - about 75 % is smaller than 63 µm. They have a muddy character because of the high water content. Early geochemical analyses show that the main difference between these two samples is the SiO_2 content. Sample 98 GTVA has a low SiO_2 content of about 31 % whereas the SiO_2 in sample 99 GTVA reaches 57 %. The manganese and iron contents (Mn 1,3 %; Fe 12,8 %) are also very high in both samples.

6.5 Physico-chemical parameters of the water column

Besides the measurement of the main physical parameters of the water body within the target areas one of the major tasks of the hydrographic subprogram was the measurement of dissolved oxygen in the water column. Because of a grave malfunction in the Multisonde's oxygen probe the determination of oxygen was done by titration applying Winkler's method (see chapter 5.3).

CTD-Measurements

During the MIDPAC 4 cruise a number of seven CTD-stations were carried out with the multisonde (app. 8). Three of these stations are located within area P, one station within area R, one station within area W and two stations within area X. As already mentioned above the continuous profiling of dissolved oxygen with the Multisonde was not possible. Additionally it has to be mentioned that the light transmission profiles showed a bad hysteresis between lowering and hoisting data, that these data have to be handled with reservation. For this reason the oxygen and light transmission data are neglected within the following short data evaluation.

Regarding the vertical profiles of the remaining four parameters as there are temperature, conductivity, salinity, and sound velocity, it can be seen at the first glance that corresponding to the two main working areas - one west of 180° and the other east of 180°-, the profiles can be roughly devided into two groups with similar characteristics (Fig. 6.5.1 a-d).

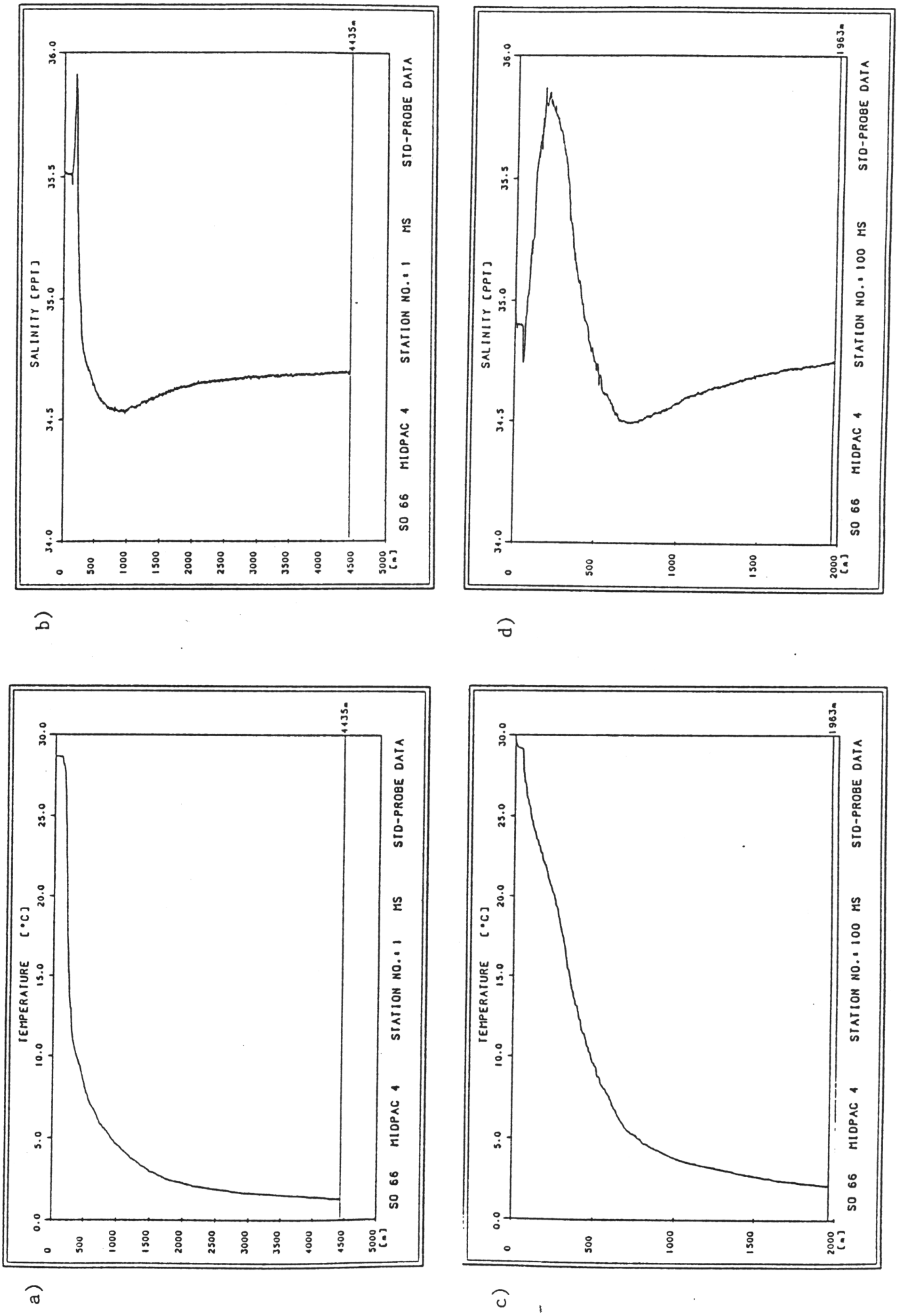
Whereas all profiles in these areas exhibit a pronounced surface layer which reaches down to a water depth of about 100 to 150 meters, a more detailed view of this layer shows the remarkable differences between the two areas. Regarding the temperature curves in Fig. 6.5.1 it can be seen that the eastern area (Station No. 1 MS) exhibits a well mixed surface layer with a constant temperature of 28.7°C down to the thermocline within about 150 m water depth, whereas the western area reveals within the uppermost meters of the survace layer a micro-structure where the temperature decreases rapidly wi thin some 20 meters from 29.8° to 29.2°C. From here the well mixed surface layer remains stable down to a water depth of about 100 meters. Below the thermocline the temperature profiles of all stations show a very similar course down to the abyssal depth.

A comparison of the salinity profiles presented in Fig. 6.5.1 also reveals the pronounced surface layer. The eastern profile starts with a high salinity of 35.54 ‰ down to a water depth of about 120 meters, where a local minimum of 35.45 ‰ is directly followed by a maximum peak of 35.86 ‰. From here the salinity values decrease and follow the normal deep water course.

The western profile starts in the surface with a much lower salinity (34.88 ‰). It shows similar to the temperature profile of this station a small decrease within the uppermost 20 meters and remains stable down to a water depth of about 100 meters. Within this depth a local minimum (34.76 ‰) is followed by a rapid increase up to a maximum of about 35.85 ‰ which is similar to the maximum value of the eastern areas. Below this maximum the salinity decreases and reveals a very similar behaviour like the deep pant of the eastern profiles.

Regarding the conductivity and sound velocity, it can finally be stated that the CTD-profiles exhibit variations within sthe uppermost 100 to 200 meters from one area to the other, but that the deep water within all target areas which were focussed on the crust studies is very similar and uniform.

Fig. 6.5.1 a-d: Comparison of temperature and salinity profiles east and west of the day-line



Besides the CTD-measurements with the multisonde we also recorded and plotted the data of the CTD-sonde which is installed in the OFOS-KT (app. 9).

Oxygen profiles (app. 9)

As already mentioned above the determination of the dissolved oxygen was done by a titration method. Therefore the resolution of the vertical profiles was strongly restricted by the number of samples which could be obtained with the different devices. This was 12 samples for the rosette sampler and 8 with the Compact-OFOS.

The oxygen determination was carried out mainly to get information about the oxygen supply within the deeper portions of the water body with the aim to detect the oxygen-rich "Antarctic Bottom Water". Because of the long way from the source to the target areas and therefore also a long time of mixing with the overlaying water masses, it seems to be hopeless to find a real layering. Nevertheless we believe that we found at least indications of the "Antarctic Bottom Water" within the lowermost 300 to 400 meters of Station No. 56 Ms (Fig. 6.5.2).

Fig. 6.5.2: Indications of the Antarctic Bottom Water in an oxygen profile

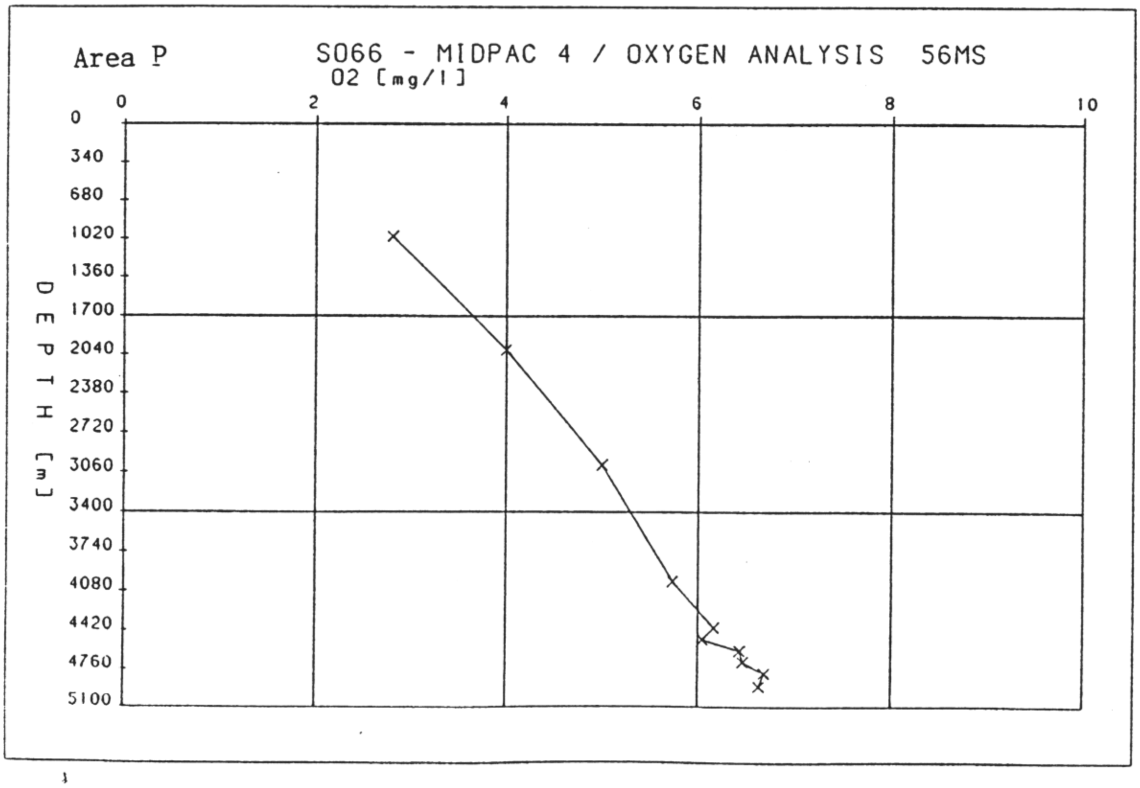
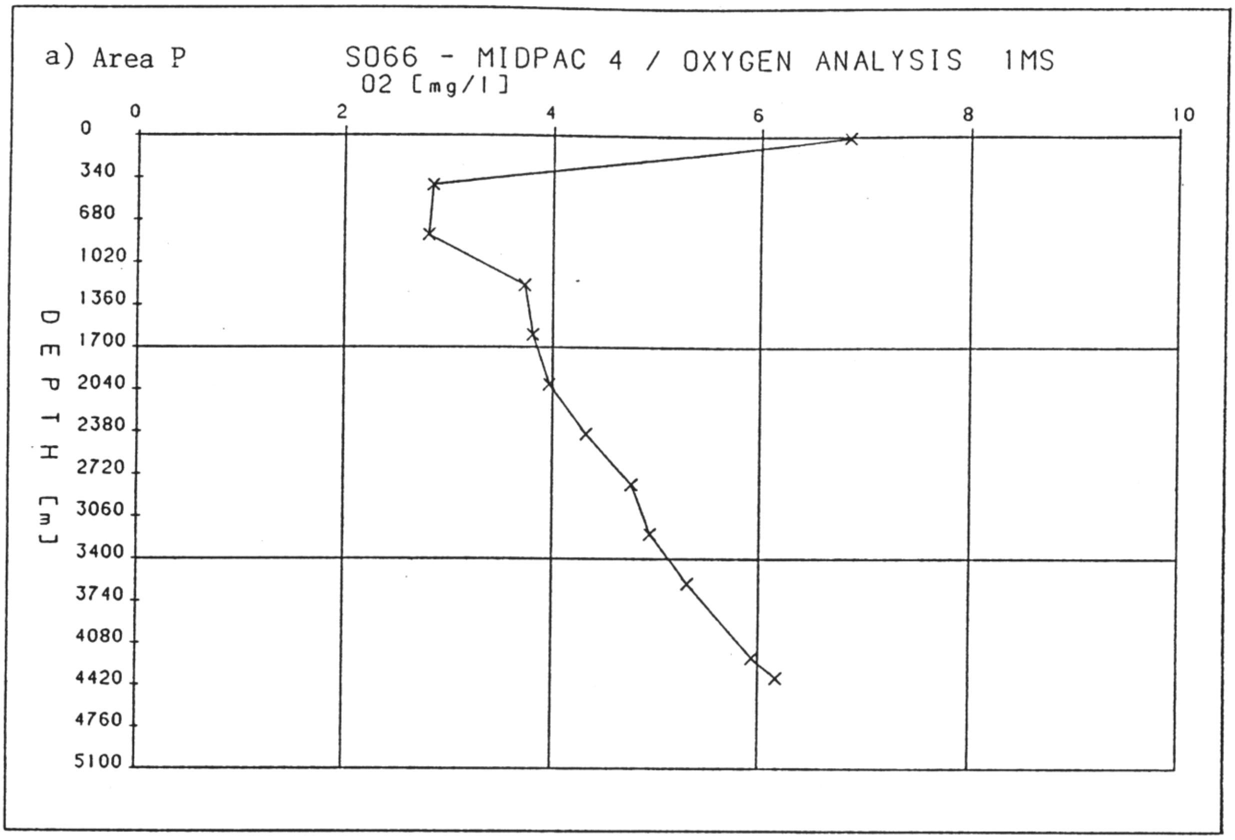
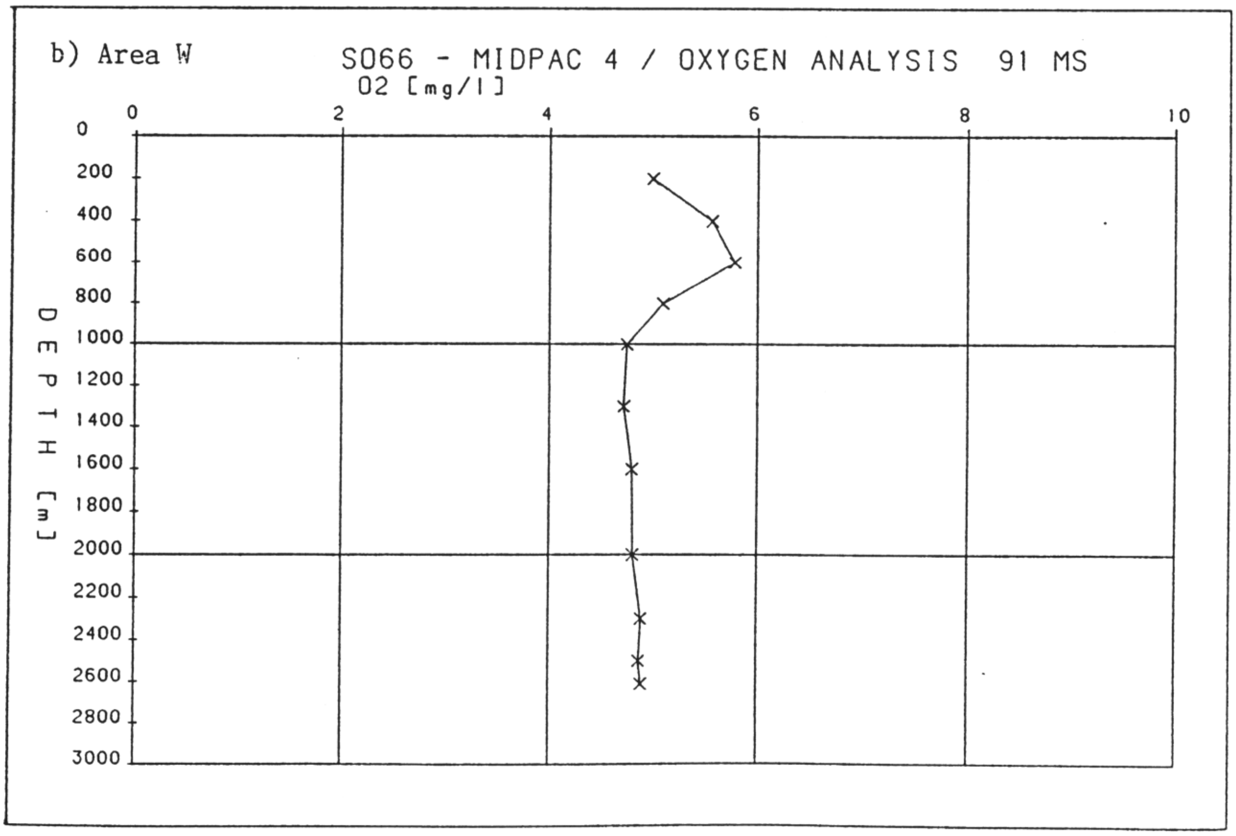


Fig. 6.5.3: a) normal oxygen profile
b) unusual oxygen profile





Another interesting finding could be gained within the areas T, W, and X. On the way south from area T (2° south) to area X (17° south) the oxygen minimum zone got less and less pronounced and at least changed to a maximum zone (Fig. 6.5.3). The shape of the southern oxygen profiles from the areas W and X is very unusual. One preliminary explanation for this phenomenon might be that oxygen-rich antarctic water masses not only propagate northwards within the deep ocean but also within surface-near layers. This question will be investigated thoroughly in the next months.

6.6 Current meter measurements

Taking into account that the oxygen-rich antarctic deep water might provide an important contribution to the growth of crusts within the target area, one of the sub-programs of the MIDPAC 4 cruise was focussed on current measurements within the deep portion of the water body. It was the aim to get information on the transport velocity and direction of the oxygen-rich antarctic bottom water to get some quantitative analyses about the geochemical processes involved in the genesis of crusts.

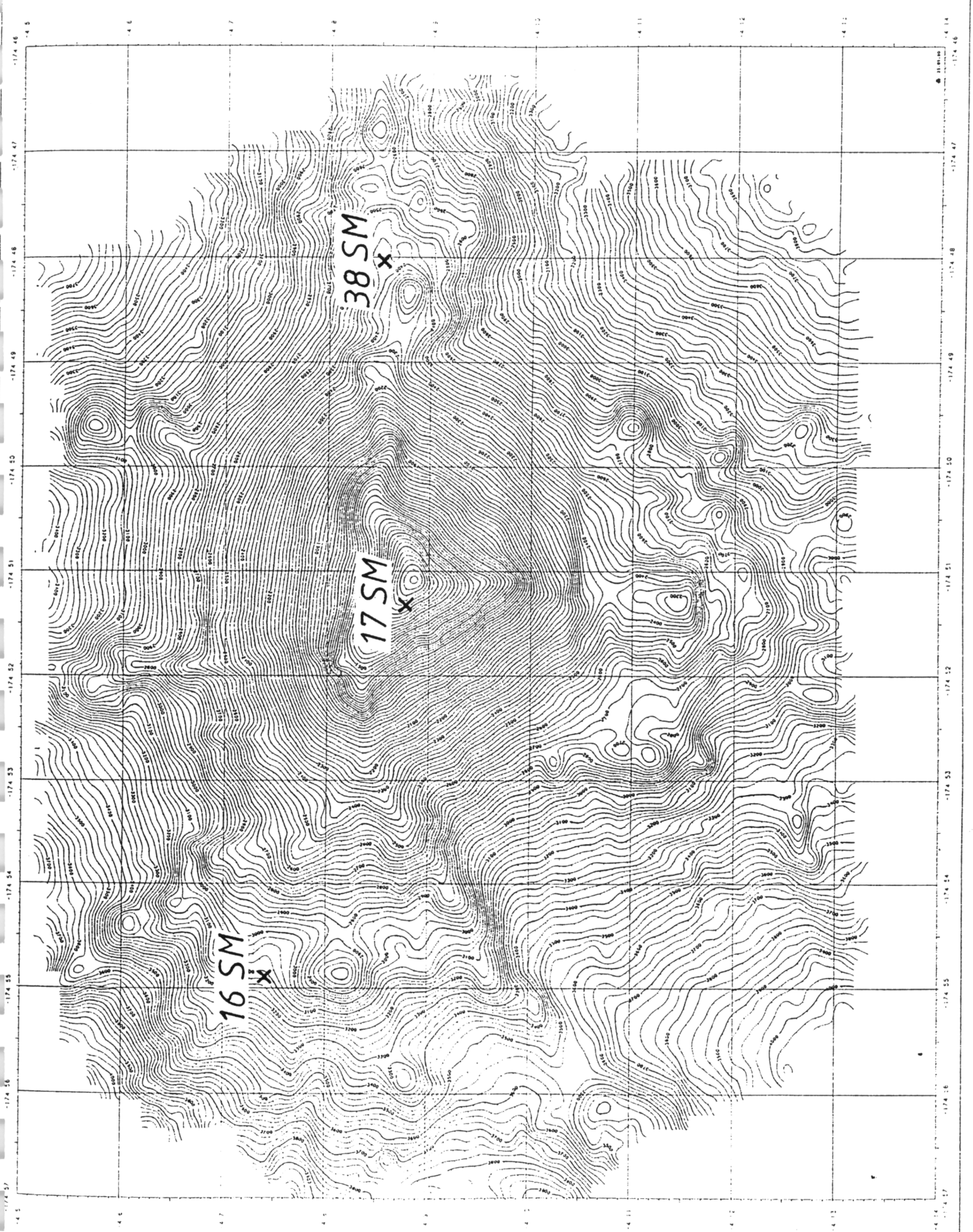
Due to the fact that the current data were already pre-processed during the cruise a first data evaluation could be done on board.

Area P

The current mooring lines 16, 17, and 38 SM were located within area P. Station No. 16 SM and 38 SM were moored within the deep water close to the seamount, whereas Station No. 17 SM was placed directly on the top (Fig. 6.6.1).

Regarding the current velocities measured at these locations, it can be stated that the current velocities close to the bottom are higher than the velocities within the water body 200 m above the seafloor. At the other hand the mean current velocity on top of the seamount is considerably higher (16.7 cm/sec) than that measured within the deep waters (8.4 cm/sec). Highest values were gained on top of the sea-

Fig. 6.6.1: Area P current meter station map



mount. The high current velocities which are measured within the bottom layer of the deep ocean are obviously caused by the very rough topography of the area. Close to the bottom, the water masses are forced to pass narrow gaps and valleys so that the so-called nozzle-effect induces localy high current velocities.

The current directions measured at the different locations within area P reveal two main axes. At the top and also at the deep water moorings the bottom-near currents are oscillating mainly in NW-SE direction whereas the currents some 200 m above the seafloor tend towards a NE-SW alternation.

All data sets from area P reveal a pronounced semi-diurnal lunar tide (M2-tide). Within the deeper locations the tide is superposed by a weak current tending towards northern directions (Fig. 6.6.2). One reason for this trend might be the influence of the antarctic deep water moving towards north.

On top of the seamount the tides are superposed by a pronounced current, which tends towards SW. This strong superposition seems to be caused by the "South Equatorial Current", which is dominating within these latitudes of the Central Pacific (Fig. 6.6.3).

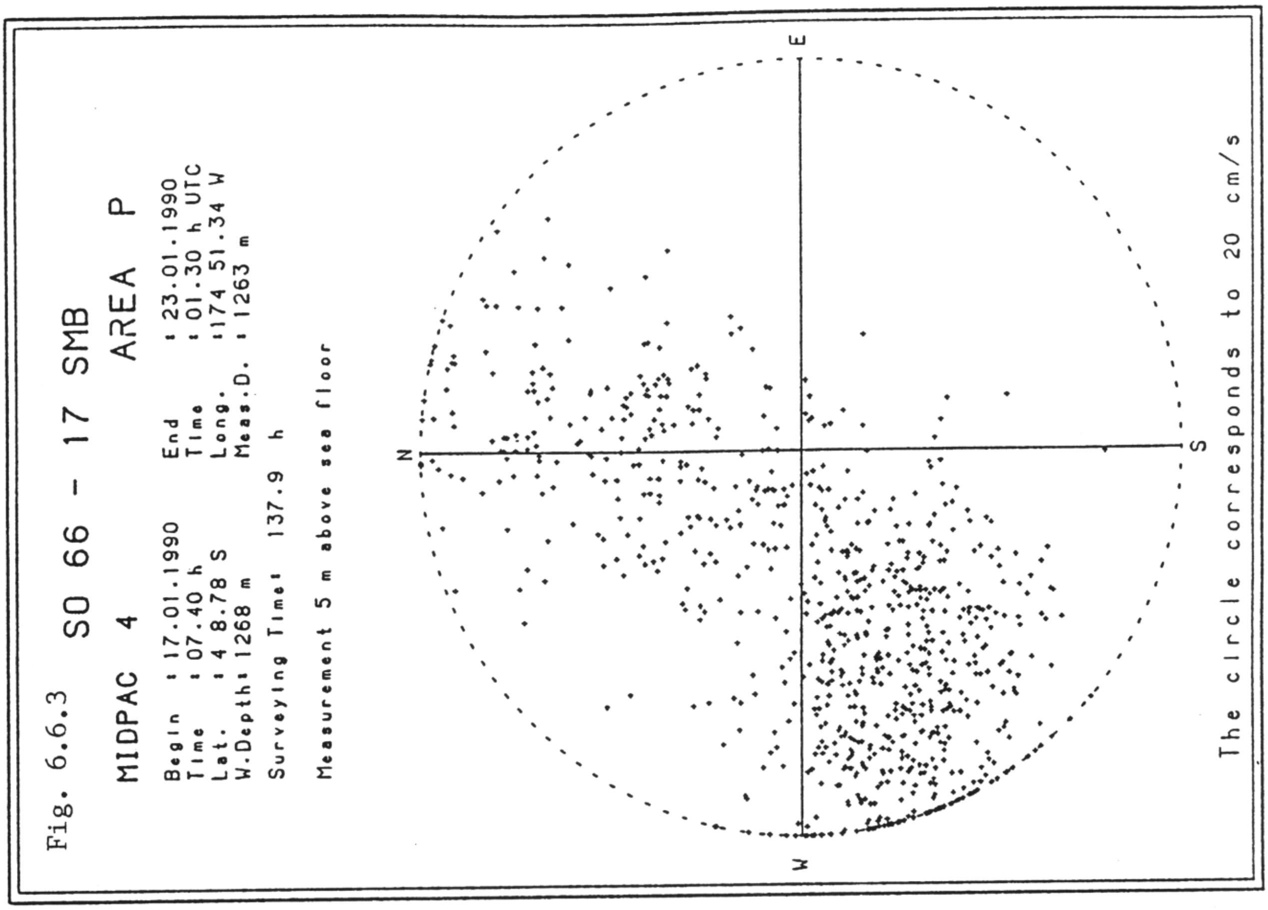
Area T

The current mooring lines of Station No. 70 SM and 71 SM were located within the target area T. Station No. 70 SM was moored on top of the seamount and 71 SM was moored in the deep water within the close vicinity of the seamount.

Regarding again the current velocities within the target area, it can be stated that also in area T the velocities are influenced by the rough topography so that the bottom-near current velocities are again higher than that measured about 200 m above the seafloor. Within area T the maximum currents were measured within the deep water (19.3 cm/sec). This phenomenon might be explained on the one side with the rough bottom structure and on the other side with a less pronounced influence of the "South Equatorial Current" within the upper portion of the water body.

A comparison of the current directions measured at the different locations and water depths reveals a pronounced difference between the bottom-near currents and the layer within about 200 m above the sea-

Fig. 6.6.2 and 6.6.3: Scatter plots of 16 SMB and 17 SMB



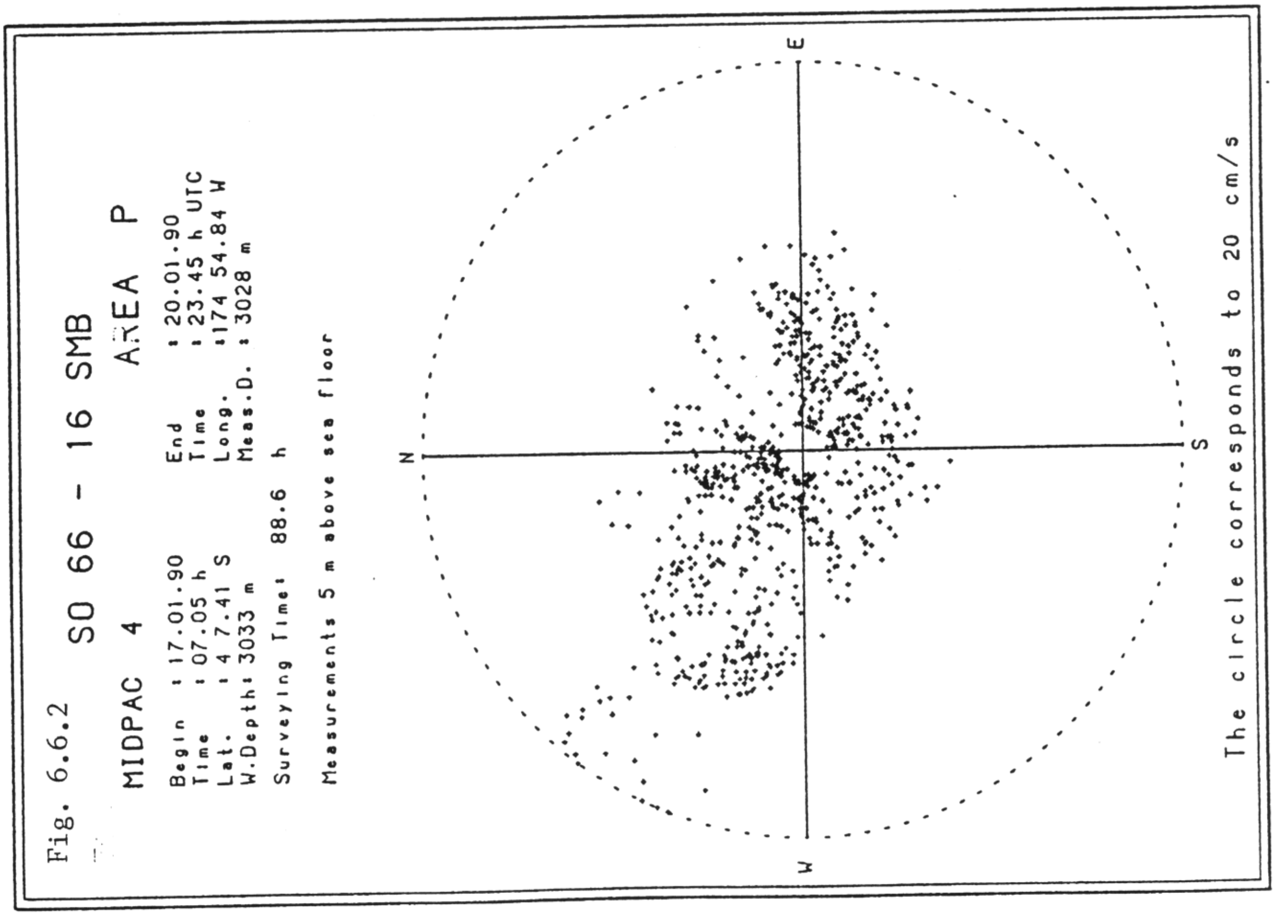


Fig. 6.6.4 a and b: Time series of 71 SMA and 71 SMB
(Current meter measurements)

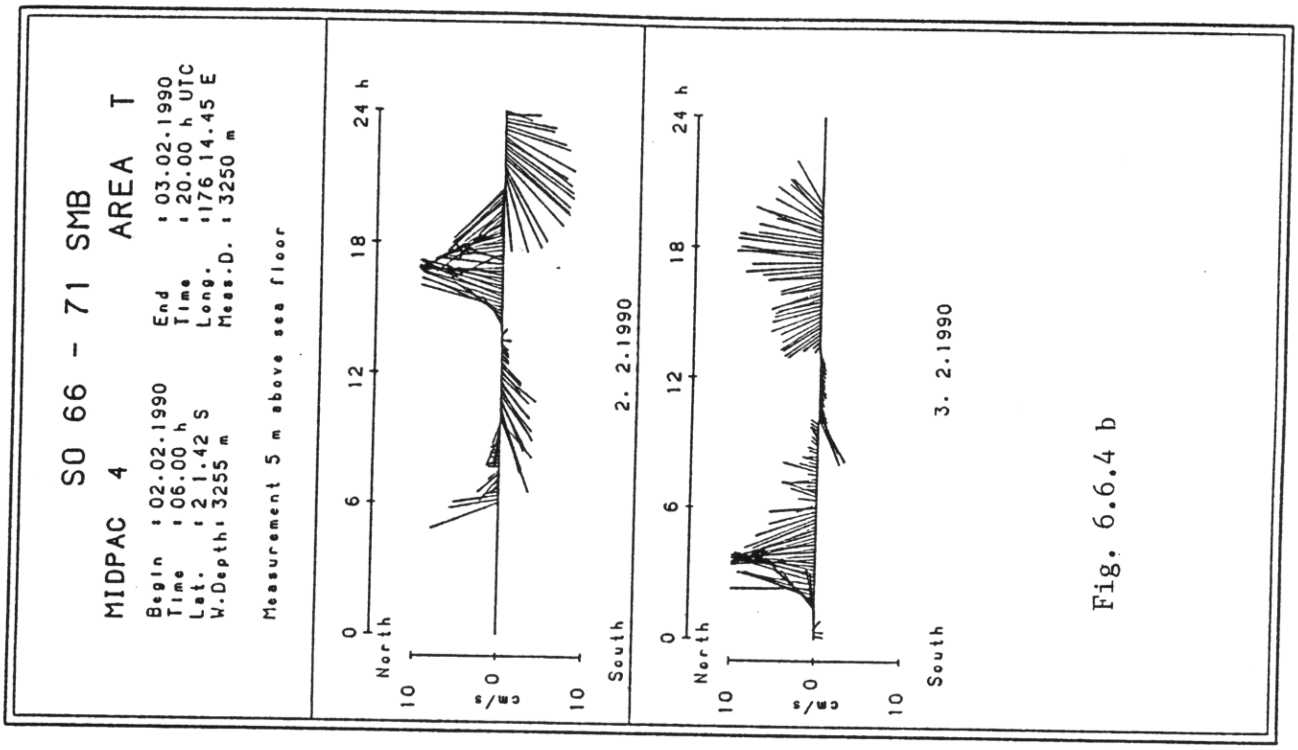


Fig. 6.6.4 b

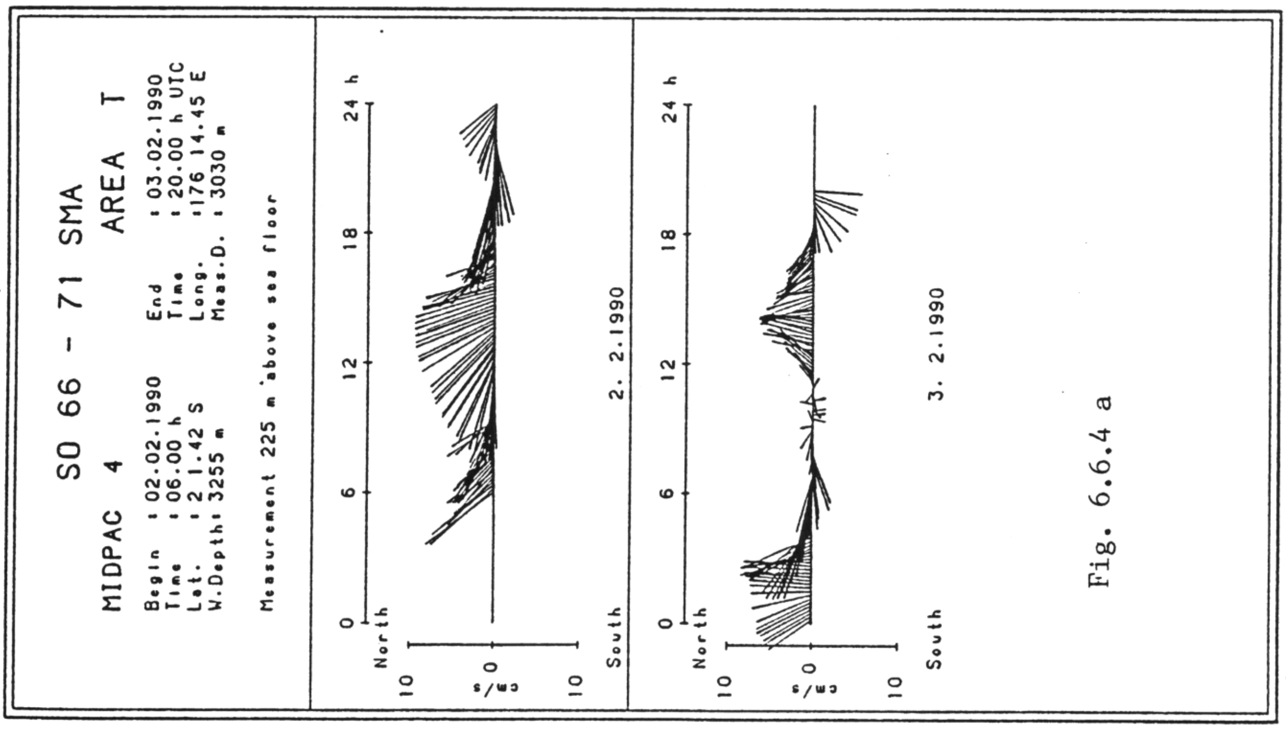


Fig. 6.6.4 a

floor (Fig. 6.6.4 a and b). Whereas the currents which were measured close to the seafloor show a pronounced semi-diurnal tidal signal with only a weak northern trend (Station No. 71 SMB), the upper layer shows only a weak tidal signal which is superposed by a strong northern current (Station No. 71 SMA). This phenomenon can be observed on top as well as at the foot of the seamount. Due to the fact that only a data set of 38 hours is available from area T, it seems to be impossible for the moment to give an interpretation for this strange effect and it can not be excluded that the measured period represents only a short event.

7. Outlook

All together about 600 kg of manganese ore crust material and more than 1000 kg of substrate rock were sampled in areas P to V (200-nm zone of the states of Kiribati and Tuvalu); this amount is enough in order to carry out further detailed research. The following investigations are to be done in our home laboratory:

- analysis of main and minor elements including the noble metal platinum, separately for the respective samples and areas, as well as for the younger and older growth generations

- microchemical stratigraphy of crust profiles in order to determine geochemical changes with time growth

- fractionated leaching experiments in order to determine the chemical bonding of the metals and/or metal compounds

- X-ray phase analyses of ore samples and rocks

- detailed analyses of the OFOS deep-sea pictures (2545 pictures from areas P to V; 787 pictures of area X) in order to assess quantitatively the manganese ore crust coverage and the total amount of crust with consideration of the crust thickness, and in order to estimate the micromorphology

- microscopical studies of thin and polished sections in order to investigate phase distributions and micro-structures of mineral and rock samples

In the investigated areas most of the manganese crusts were found on phosphatized reef carbonates. Only in deeper locations (1800 m) basaltic and hyaloclastic substrates were found. The calcareous reef rocks mostly are strongly phosphatized; maximum values are up to 19 % P (corresponding to 43.5 % P_2O_5). Values of about 12 % P (corresponding to 27.5 % P_2O_5) are of mining quality in land-based phosphorite deposits. Thus, an important aim in our research of the manganese crust deposits south of the equator is to estimate the phosphate content of the substrate rocks and to consider its raw material potential. The contents of Co and Ni (tab. 6.1.1) are somewhat lower than those of the deposits north of the equator; the crust thickness (up to 9 cm), however, is in the same order of magnitude. Such high P_2O_5 contents in substrate rocks were not observed north of the equator. The samples from the North Fiji Basin will be studied mostly regarding their contents and intergrowth relationships of pyrite (FeS_2), markasite (FeS_2), sphalerite (ZnS), and chalcopyrite ($CuFeS_2$); a geochemical comparison with massive sulfide samples from other mid-oceanic ridges is planned.

List of Appendices 1-12:

Appendix 1: Participants of the Midpac 4 - SO 66 cruise

Institutions:

- TU Clausthal - Zentrum für Rohstofforientierte Meeresforschung
- RWTH Aachen - Abteilung für angewandte Lagerstättenkunde
- Preussag AG, Hannover
- University of Hawaii - Hawaiian Institute of Geophysics
- East West Center, Hawaii

Leg 1:

name	institution	responsibility
F. Teichmann	TUC	co-chief scientist
D. Schöps	TUC	XRF
G. Faulborn	TUC	electro-technician
H. Schüttenhelm	Preussag	technician
U. Eicher-Heidbüchl	TUC	physician

Leg 2:

name	institution	responsibility
C.-D. Sattler	TUC	co-chief scientist, station management
F. Teichmann	TUC	station management
A. Koschinsky	TUC	analytical chemistry
M. Wahsner	TUC	sediments, station work
D. Schöps	TUC	XRF
P. Dreßen	TUC	station work
S. Bubilek	TUC	sample preparation
G. Faulborn	TUC	electro-technician
R. Arvidson	Hawaii	station work
J. Post	Preussag	station management
D. Hansen	Preussag	seabeam, VAX
D. Keipke	Preussag	electronics, OFOS
H. Schüttenhelm	Preussag	technician
U. Eicher-Heidbüchl	TUC	physician, photolab work

Leg 3:

name	institution	responsibility
P. Halbach	TUC	chief scientist
C.-D. Sattler	TUC	station management, co-chief scientist
F. Teichmann	TUC	station management
A. Koschinsky	TUC	analytical chemistry
M. Wahsner	TUC	sediments, station work
D. Schöps	TUC	XRF
P. Dreßen	TUC	station work
S. Bubilek	TUC	sample preparation
G. McMurtry	Hawaii	station work, geochemistry
A. Clark	Hawaii	station work, deposits
T. Malaki	Tuvalu	observer
J. Post	Preussag	station management
D. Hansen	Preussag	seabeam, VAX
D. Keipke	Preussag	electronics, OFOS
H. Schüttenhelm	Preussag	technician
U. Eicher-Heidbüchl	TUC	physician, photolab work

Appendix 2:

Short time schedule of the SO 66 research cruise (MIDPAC 4)

Date	Time	Remarks
Leg 1 / SO 66 :		
3.1.90	9:00 Uhr	Charter begin, boarding of 4 scientists
4.1.90	8:30 Uhr	RV Sonne moving to the bunker pier
4.1.90	15:00 Uhr	Leave port of Papeete, transit to Pago Pago on transit crossing one timecount (-1h)
8.1.90	18:00 Uhr	arrival at the pier in Pago Pago harbour
9.1.90	8:30 Uhr	moving to roadstead
9.1.90	23:00 Uhr	boarding of scientific crew and guest scientists
Leg 2 / SO 66 :		
10.1.90	14:00 Uhr	transit to area P
12.1.90	22:00 Uhr	arrival area P, begin of station work (seabeam, multi sonde with water sampler, spade corer, gravity corer, dredge) station numbers from 1 MS to 4 DSR
14.1.90	7:30 Uhr	leaving area P, transit to area R
14.1.90	14:00 Uhr	arrival area R, begin of station work (seabeam)
15.1.90	0:00 Uhr	leaving area R, transit to area P
15.1.90	3:45 Uhr	arrival area P, begin of station work (dredge, OFOS KT with water sampler, current meter) station numbers from 5 DSR to 17 SM
16.1.90	20:40 Uhr	leaving area P, transit to area R
17.1.90	1:00 Uhr	arrival area R, begin of station work (seabeam,dredge, OFOS KT with water sampler, multi sonde with water sampler) station numbers from 18 DSR to 23 MS
18.1.90	2:25 Uhr	leaving area R, transit to area S
18.1.90	6:00 Uhr	arrival area S, begin of station work (seabeam,dredge, spade corer) station numbers from 24 DSR to 27 GK

App. 2

18.1.90	21:30 Uhr	leaving area S, transit to area P
19.1.90	6:00 Uhr	arrival area P, begin of station work (dredge, TV-grab, OFOS KT with water sampler, current meter, gravity corer, spade corer, multi sonde with water sampler) station numbers from 28 DSR to 56 MS
23.1.90	0:05 Uhr	leaving area P, transit to Gardner Island
23.1.90	3:55 Uhr	arrival Gardner Island, begin of station work (sea beam, dredge, recent reef research)
23.1.90	16:30 Uhr	leaving Gardner Island, transit to Funafuti on transit crossing one timecount (-1 h) and date line (+24 h)
26.1.90	10:20 Uhr	arrival at the pier in Funafuti harbour exchange of scientists, boarding of scientific observer of Tuvalu; reception onboard for honourable guests of Tuvalu

Leg 3 / SO 66 :

28.1.90	8:40 Uhr	leaving Funafuti, transit to area V
28.1.90	22:10 Uhr	arrival area V, begin of station work (sea beam, dredge) station numbers from 58 DSR to 65 DSO
30.1.90	16:10 Uhr	breaking off of station work due to bad weather conditions leaving area V, transit to area U
31.1.90	16:00 Uhr	arrival area U, because of bad weather conditions no station work possible, leaving area U, transit to area T
1.2.90	8:40 Uhr	arrival area T, begin of station work (sea beam, dredge, current meter, OFOS KT with water sampler, multi sonde with water sampler) station numbers from 66 DSR to 84 SM
4.2.90	9:35 Uhr	leaving area T, transit to Funafuti-Atoll
5.2.90	24:00 Uhr	arrival Funafuti-Atoll, drop scientific observer from Tuvalu
6.2.90	0:24 Uhr	transit to area U
6.2.90	11:00 Uhr	arrival area U, begin of station work (sea beam, dredge) station numbers from 85 DSR to 86 DSK
7.2.90	4:00 Uhr	leaving area U, transit to area W

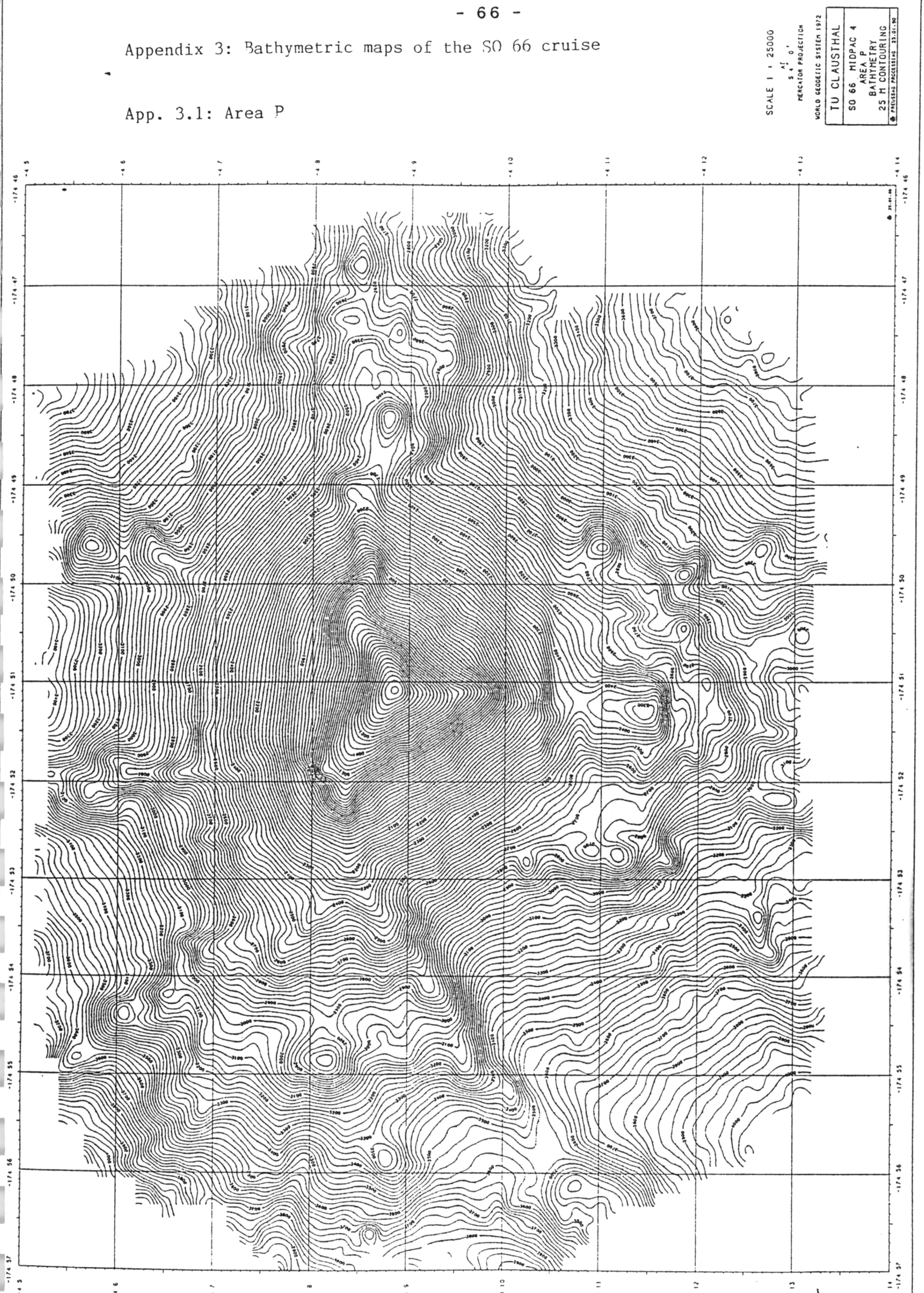
App. 2

8.2.90	8:20 Uhr	arrival area W, begin of station work (sea beam, dredge, multi sonde with water sampler) station numbers from 87 DSK to 91 MS
9.2.90	8:35 Uhr	leaving area W, transit to area X
10.2.90	8:45 Uhr	arrival area X, begin of station work (sea beam, dredge, OFOS KT with water sampler, TV-grab, multi sonde with water sampler) station numbers from 92 DSR to 112 MS
14.2.90	6:00 Uhr	leaving area X, transit to Suva
15.2.90	9:55 Uhr	arrival at the pier in Suva harbour
18.2.90	afternoon	all scientists of the SO 66 left RV Sonne

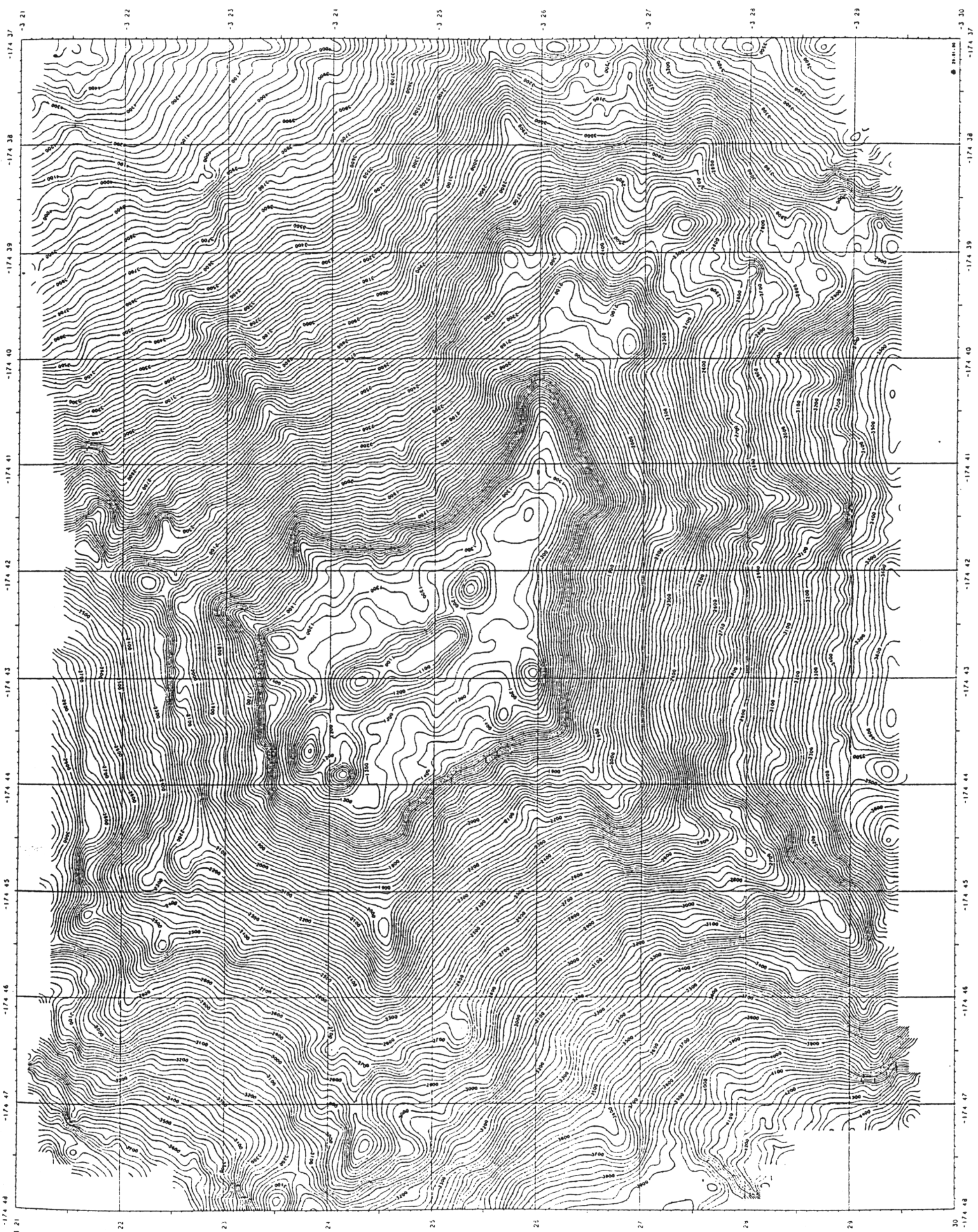
end of charter of SO 66 (Midpac 4)

Appendix 3: Bathymetric maps of the SO 66 cruise

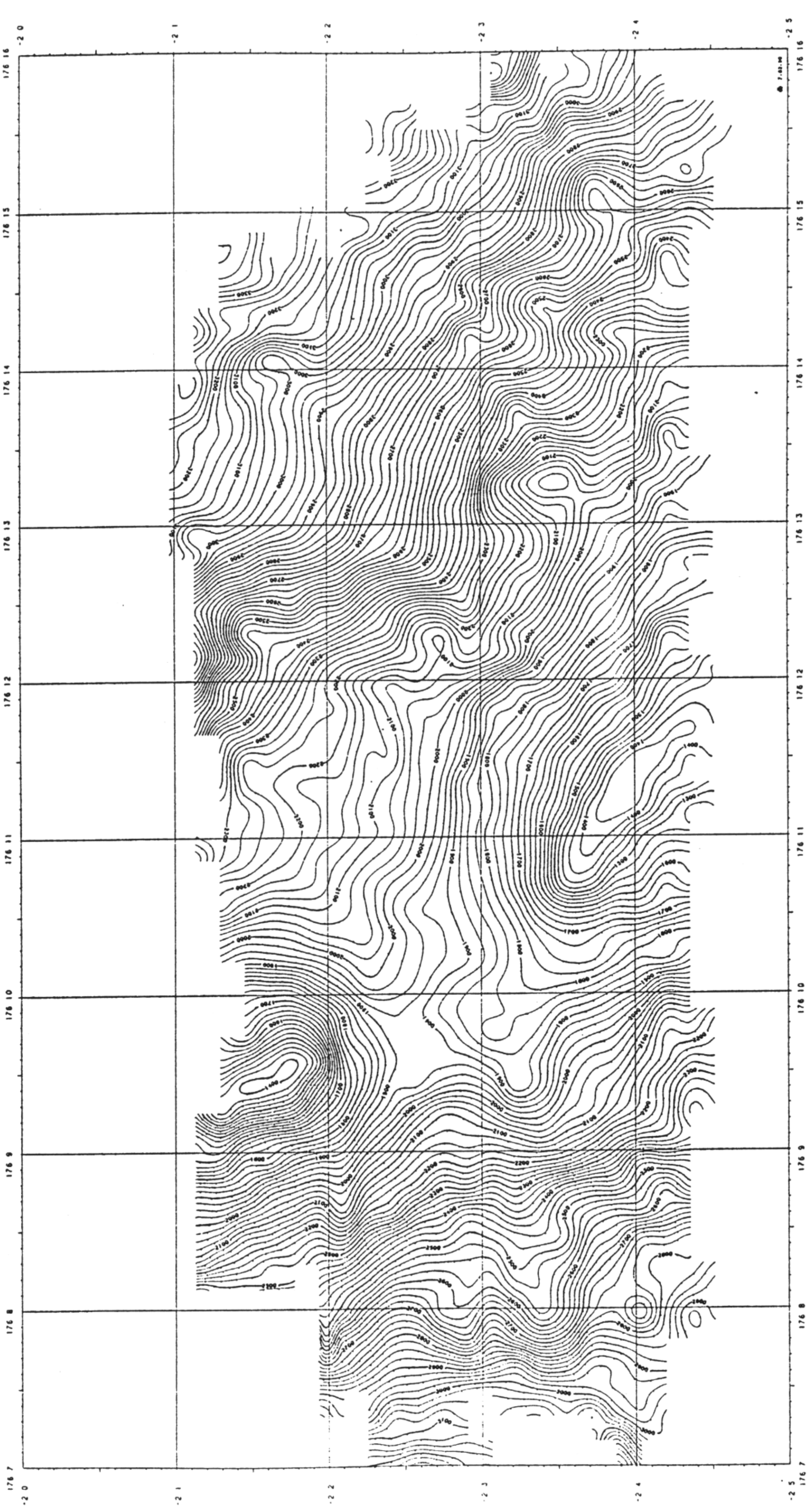
App. 3.1: Area P



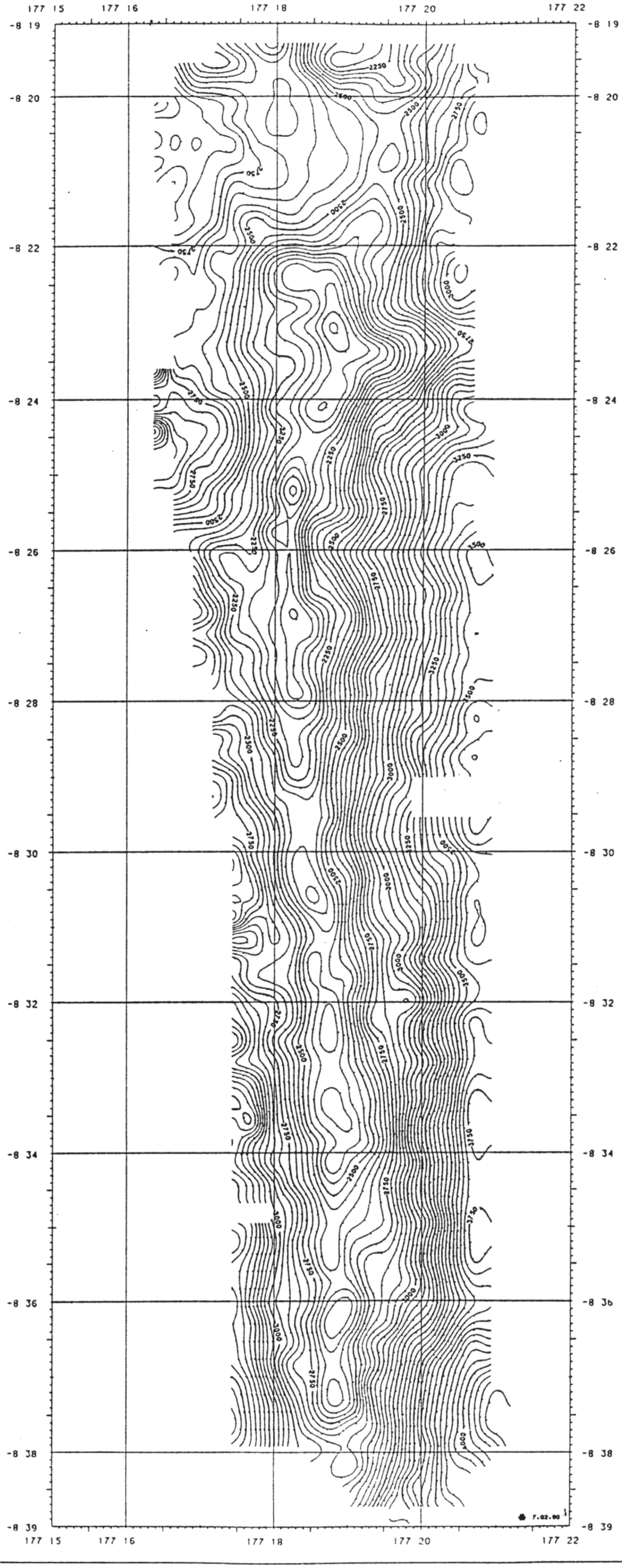
App. 3.2: Area R


TU CLAUSTHAL
SO 66 MIDPAC 4
AREA R
BATHYMETRY
25 M CONTOURING
SCALE 1 : 25000
MERCATOR PROJECTION
WORLD GEODETIC SYSTEM 1972

App. 3.3: Area T


TU CLAUSTHAL
SO 66 MIDPAC 4
AREA T NORTH
BATHYMETRY
25 M CONTOURING
WORLD GEODETIC SYSTEM 1972
MERCATOR PROJECTION
SCALE 1 : 20000

App. 3.4: Area V



SCALE 1 : 50000
AT
S 8° 0'
MERCATOR PROJECTION

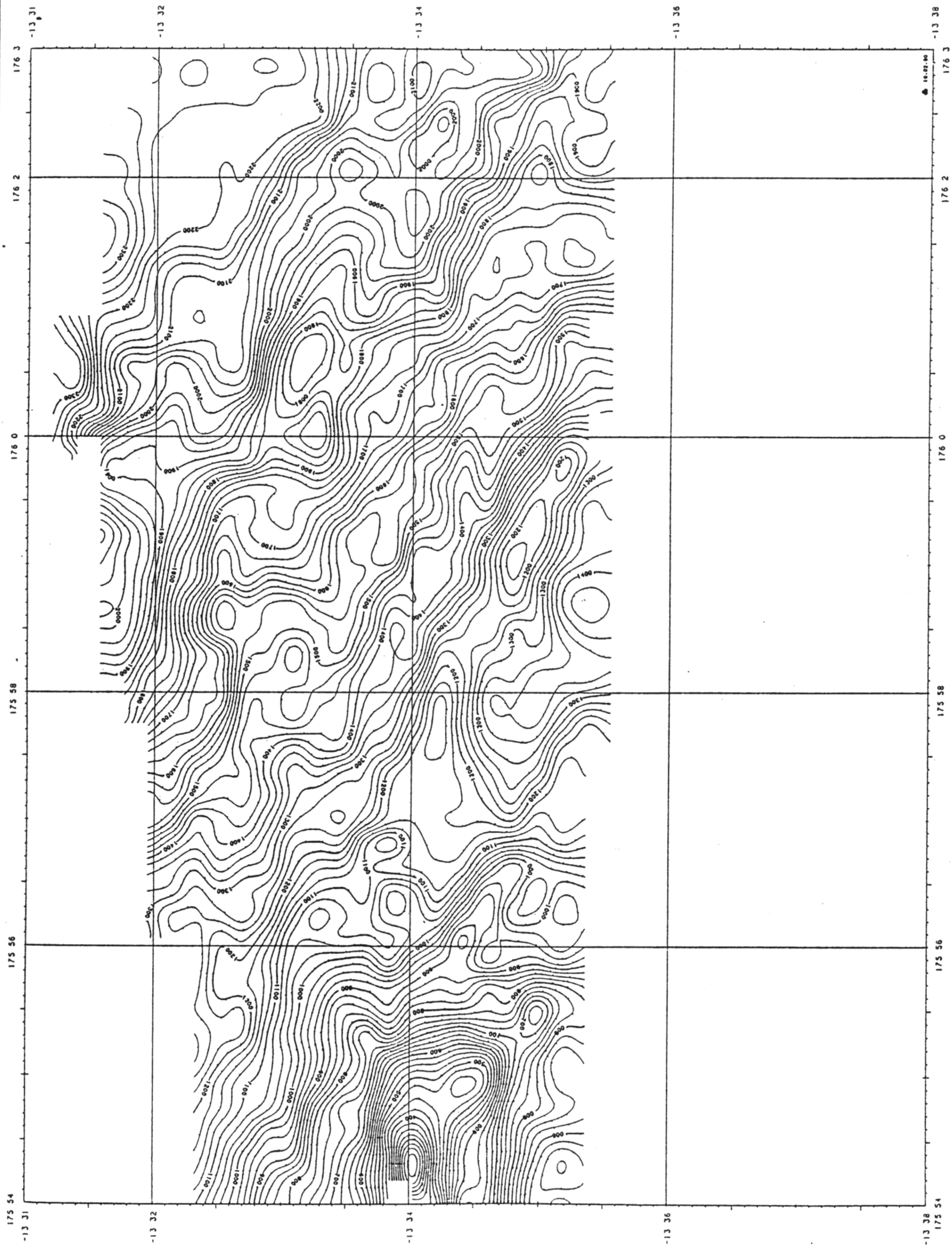
WORLD GEODETIC SYSTEM 1972

TU CLAUSTHAL

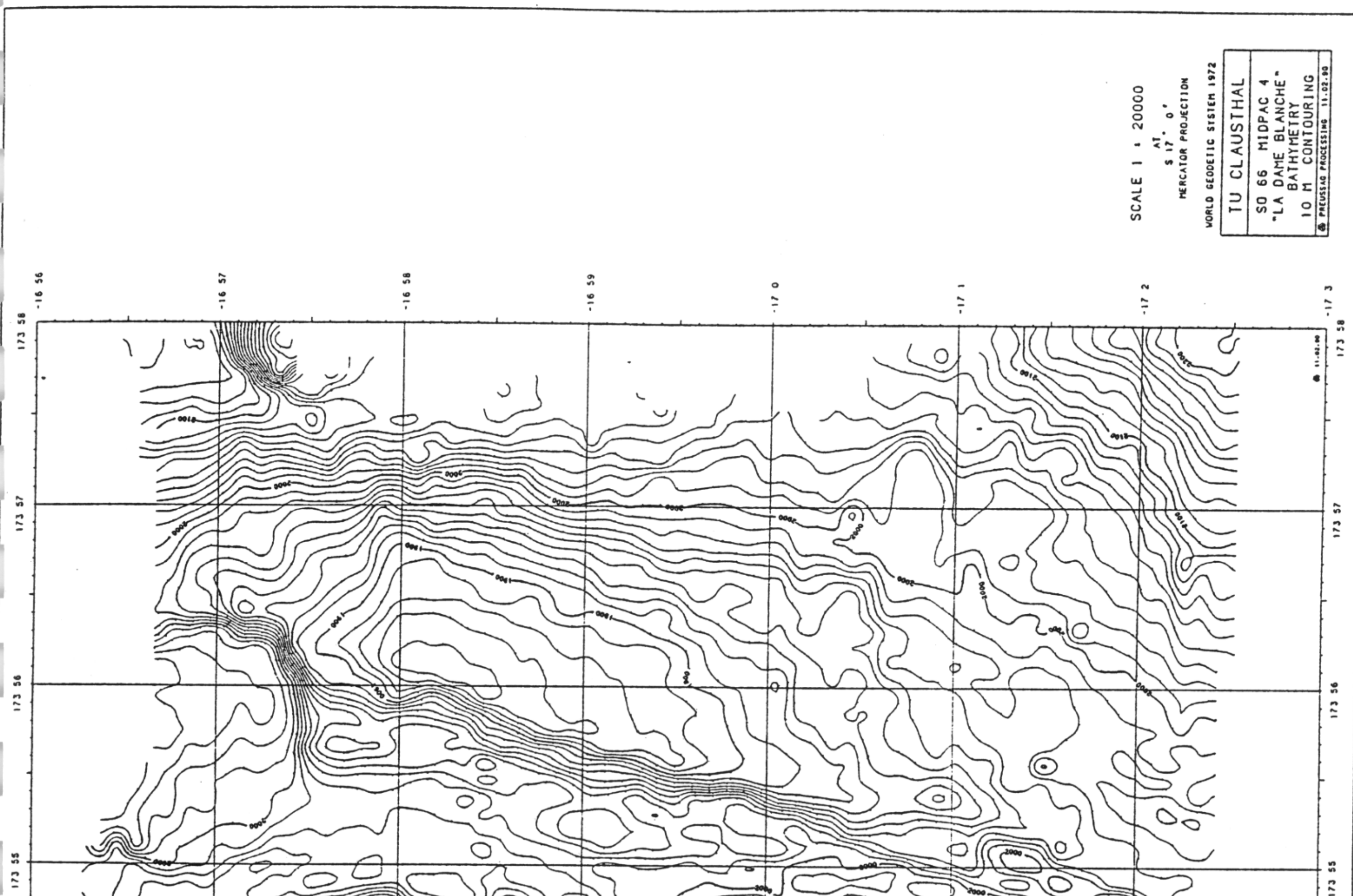
SO 66 MIDPAC 4
AREA V
BATHYMETRY
50 M CONTOURING

PREUSSAG PROCESSING 7.02.90

App. 3.5: Area W


SCALE 1 : 25000
AT S 14' 0'
MERCATOR PROJECTION
WORLD GEODETIC SYSTEM 1972
TU CLAUSTHAL
SO 66 MIDPAC 4
AREA W
BATHYMETRY
25 M CONTOURING
PREUSSAG PROCESSING 10.02.90
-13 31
-13 32
-13 34
-13 36
-13 38
176 3
176 2
176 0
175 58
175 56
175 54

App. 3.6: Area X


TU CLAUSTHAL
SO 66 MIDPAC 4
"LA DAME BLANCHE"
BATHYMETRY
10 M CONTOURING
SCALE 1 : 20000
MERCATOR PROJECTION
WORLD GEODETIC SYSTEM 1972

Appendix 4: Complete statistics of Midpac 4 - SO 66 stations

Station	Date	Area	Duration [h:min]	Location*	Water depth [m]	Remarks*
Seabeam	12.1.90	P	3:20			
1 MS	13.1.90	P	3:25	4° 09, 24 S 174° 58, 99 W	4366	O_2-sonde damaged
2 GK	13.1.90	P	5:20	4° 09, 40 S 174° 58, 68 W	4246	27 cm yield
3 CG	13.1.90	P	1:15	4° 08, 68 S 174° 51, 27 W	1075	no yield, breaking off of first attempt
Seabeam	13.1.90	P	10:00			
4 DSR	14.1.90	P	7:30	4° 08, 84 S 174° 54, 63 W	2986	110 kg yield
Seabeam	14.1.90	R	10:00			
5 DSR	15.1.90	P	3:25	4° 08, 85 S 174° 53, 60 W	2500	80 kg yield
6 DSR	15.1.90	P	2:55	4° 08, 42 S 174° 52, 63 W	2305	30 kg yield
7 OFOS KT	15.1.90	P	4:35	4° 08, 45 S 174° 51, 28 W	1122	with water samples
8 OFOS ST	15.1.90	P	0:10			breaking off of station because of malfunktion
9 OFOS KT	15.1.90	P	4:35	4° 08, 72 S 174° 51, 14 W	1076	with water samples
10 DSR	16.1.90	P	2:55	4° 10, 14 S 174° 51, 21 W	1984	100 kg yield
11 DSR	16.1.90	P	1:55	4° 09, 50 S 174° 51, 21 W	1415	no yield
12 DSR	16.1.90	P	1:30	4° 07, 80 S 174° 51, 20 W	1429	no yield, weak link broken
13 DSR	16.1.90	P	1:30	4° 08, 12 S 174° 51, 60 W	1664	40 kg yield
14 DSR	16.1.90	P	1:50	4° 08, 61 S 174° 51, 67 W	1385	60 kg yield
15 OFOS KT	16.1.90	P	4:55	4° 08, 84 S 174° 51, 48 W	1150	with water samples
16 SM	16.1.90	P	0:45	4° 07, 41 S 174° 54, 84 W	3045	current meter set out
17 SM	16.1.90	P	0:35	4° 08, 78 S 174° 51, 34 W	1282	current meter set out
18 DSR	17.1.90	R	3:00	3° 24, 50 S 174° 45, 02 W	2059	no yield, weak link broken

App. 4

19 DSR	17.1.90	R	2:50	3° 24, 12 S	174° 44, 57 W	1720	5 kg yield, dredge damaged
20 DSO	17.1.90	R	1:30	3° 24, 41 S	174° 43, 52 W	1255	10 kg yield, dredge damaged
21 DSK	17.1.90	R	1:50	3° 25, 62 S	174° 43, 52 W	1650	5 kg yield
Seabeam	17.1.90	R	4:00				
22 OFOS KT	17.1.90	R	5:00	3° 24, 41 S	174° 42, 91 W	1026	with water samples
23 MS	17.1.90	R	3:50	3° 14, 04 S	174° 46, 58 W	5088	O_2-sonde damaged
Seabeam	17.1.90	S	5:00				
24 DSR	18.1.90	S	3:10	2° 41, 37 S	175° 09, 75 W	3050	150 kg yield
25 DSR	18.1.90	S	3:05	2° 41, 34 S	175° 08, 99 W	2719	20 kg yield
26 DSR	18.1.90	S	1:35	2° 41, 60 S	175° 07, 22 W	1408	5 kg yield
27 GK	18.1.90	S	1:00	2° 41, 37 S	175° 06, 15 W	1164	23 cm yield
28 DSR	19.1.90	P	4:05	4° 09, 74 S	174° 53, 79 W	3033	200 kg yield
29 DSR	19.1.90	P	3:00	4° 09, 54 S	174° 52, 57 W	2550	100 kg yield
30 GTV A	19.1.90	P	1:55	4° 08, 80 S	174° 51, 09 W	1041	3 attempts, 15 kg yield
31 GTV A	19.1.90	P	2:05	4° 08, 73 S	174° 50, 84 W	1342	3 attempts, no yield
32 OFOS KT	19.1.90	P	5:30	4° 08, 94 S	174° 51, 36 W	1342	with water samples, OFOS ST because of malfunktion not usable
33 DSR	20.1.90	P	2:45	4° 08, 96 S	174° 52, 51 W	2179	25 kg yield
34 DSR	20.1.90	P	1:55	4° 09, 35 S	174° 51, 86 W	1900	20 kg yield
35 DSR	20.1.90	P	1:45	4° 09, 13 S	174° 51, 58 W	1670	15 kg yield
36 DSR	20.1.90	P	1:25	4° 09, 19 S	174° 51, 38 W	1370	no yield
37 DSR	20.1.90	P	1:55	4° 08, 76 S	174° 51, 30 W	1112	2 kg yield
38 SM	20.1.90	P	1:00				current meter 16 SM brought in
39 SM	20.1.90	P	0:15	4° 08, 47 S	174° 48, 07 W	2382	current meter set out
40 OFOS KT	20.1.90	P	4:55	4° 08, 91 S	174° 51, 17 W	1052	with water samples, OFOS ST because of malfunktion not usable, during station deep-sea compass lost

App. 4

41 GTV D	20.1.90	P	1:15	4° 08, 86 S	174° 51, 22 W	1051	no yield, hydraulic-system damaged
42 DSO	20.1.90	P	3:05	4° 06, 88 S	174° 50, 99 W	2502	25 kg yield
43 DSO	21.1.90	P	2:55	4° 08, 06 S	174° 52, 84 W	2260	25 kg yield
44 GK	21.1.90	P	1:15	4° 09, 40 S	174° 51, 51 W	1513	no yield, not closed
45 GK	21.1.90	P	1:05	4° 09, 20 S	174° 51, 72 W	1355	no yield, box damaged
46 MS	21.1.90	P	3:50	4° 19, 94 S	175° 02, 63 W	5084	O_2-sonde damaged, with XBT-test
47 OFOS ST	21.1.90	P	4:30	4° 08, 87 S	174° 51, 22 W	1095	
48 DSO	22.1.90	P	4:25	4° 07, 48 S	174° 51, 32 W	2050	10 kg yield
49 DSR	22.1.90	P	2:00	4° 07, 86 S	174° 50, 90 W	1836	4 kg yield
50 DSR	22.1.90	P	1:25	4° 08, 41 S	174° 50, 75 W	1406	60 kg yield
51 GTV A	22.1.90	P	3:40	4° 08, 91 S	174° 50, 95 W	1045	no yield
52 GTV A	22.1.90	P	1:30	4° 09, 00 S	174° 51, 39 W	1036	no yield
53 SM	22.1.90	P	0:40				current meter 17 SM brought in
54 SM	22.1.90	P	1:00				current meter 39 SM brought in
55 CG	22.1.90	P	2:05	4° 08, 49 S	174° 48, 14 W	2394	no yield
56 MS	22.1.90	P	4:10	4° 01, 51 S	174° 44, 51 W	4931	O_2-sonde damaged, with XBT-test
Seabeam	23.1.90	(G.I.)	0:30				sounding of dredge profile
57 DSR	23.1.90	(G.I.)	2:10	4° 40, 86 S	174° 34, 38 W	2006	70 kg yield
	23.1.90	(G.I.)	8:30				recent reef survey
Seabeam	28.1.90	V	2:50				total breakdown of seabeam-system
58 DSR	29.1.90	V	2:50	8° 23, 16 S	177° 19, 79 E	3017	20 kg yield
59 DSR	29.1.90	V	3:00	8° 23, 39 S	177° 19, 26 E	2545	50 kg yield
60 DSR	29.1.90	V	2:35	8° 22, 61 S	177° 19, 01 E	2450	1 kg yield
Seabeam	29.1.90	V	11:25				
61 DSR	29.1.90	V	3:00	8° 24, 56 S	177° 20, 01 E	2821	10 kg yield

App. 4

62 DSR	30.1.90	V	3:05	8° 25, 07 S 177° 19, 16 E	2700	100 kg yield
63 DSR	30.1.90	V	2:30	8° 25, 45 S 177° 19, 02 E	2352	no yield
64 DSR	30.1.90	V	2:40	8° 21, 65 S 177° 18, 06 E	2680	0,5 kg yield
65 DSO	31.1.90	V	4:25	8° 22, 65 S 177° 17, 74 E	2210	no yield
Seabeam	1.2.90	T	13:50			problems with seabeam-system due to rough sea
66 DSR	2.2.90	T	3:45	2° 01, 60 S 176° 13, 77 E	3140	0,8 kg yield
67 DSR	2.2.90	T	3:55	2° 02, 77 S 176° 13, 77 E	2627	no yield
68 DSR	2.2.90	T	3:10	2° 02, 74 S 176° 14, 10 E	2560	no yield
69 DSO	2.2.90	T	2:45	2° 03, 38 S 176° 13, 55 E	2000	100 kg yield
70 SM	2.2.90	T	0:35	2° 01, 79 S 176° 09, 47 E	1395	current meter set out
71 SM	2.2.90	T	0:30	2° 01, 42 S 176° 14, 45 E	3255	current meter set out
72 OFOS KT	2.2.90	T	6:05	2° 03, 85 S 176° 11, 34 E	1345	with water samples
73 DSO	3.2.90	T	2:55	2° 03, 87 S 176° 13, 98 E	2170	25 kg yield
74 DSR	3.2.90	T	2:00	2° 03, 66 S 176° 12, 11 E	1790	no yield
75 DSR	3.2.90	T	2:30	2° 03, 29 S 176° 11, 60 E	1810	0,5 kg yield
76 DSR	3.2.90	T	2:25	2° 03, 79 S 176° 11, 47 E	1850	5 kg yield
77 DSR	3.2.90	T	1:50	2° 04, 06 S 176° 11, 78 E	1462	30 kg yield
78 MS	3.2.90	T	1:15	2° 04, 01 S 176° 11, 59 E	1355	O_2-sonde damaged
Seabeam	3.2.90	T	1:10			total breakdown of seabeam-system
79 DSR	3.2.90	T	2:15	2° 01, 39 S 176° 10, 25 E	2080	3 kg yield
Seabeam	3.2.90	T	1:15			
80 DSR	4.2.90	T	2:10	2° 01, 30 S 176° 09, 59 E	1787	50 kg yield
81 DSR	4.2.90	T	1:10	2° 02, 62 S 176° 09, 84 E	1300	breaking off of station due to bad weather conditions and breakdown of radar-system
82 GK	4.2.90	T	1:40	2° 03, 02 S 176° 09, 77 E	1976	no yield, not closed

App. 4

83 SM	4.2.90	T	0:45			current meter 70 SM brought in
84 SM	4.2.90	T	1:00			current meter 71 SM brought in
Seabeam	6.2.90	U	10:10			
85 DSK	6.2.90	U	2:25	9° 56, 71 S 179° 55, 86 E	2600	100 kg yield
86 DSK	7.2.90	U	2:00	9° 56, 24 S 179° 56, 55 E	1865	80 kg yield
Seabeam	8.2.90	W	8:00			
87 DSK	8.2.90	W	3:50	13° 31, 43 S 176° 00, 37 E	2150	95 kg yield
88 DSK	8.2.90	W	2:40	13° 32, 20 S 175° 59, 53 E	1792	200 kg yield
89 DSK	9.2.90	W	2:10	13° 31, 71 S 175° 57, 16 E	1540	400 kg yield
90 DSK	9.2.90	W	1:20	13° 32, 90 S 175° 56, 03 E	1200	400 kg yield
91 MS	9.2.90	W	2:05	13° 39, 69 S 175° 53, 43 E	2615	O_2-sonde damaged
Seabeam	10.2.90	X	11:00			
92 DSK	10.2.90	X	2:20	16° 57, 87 S 173° 55, 35 E	1940	500 kg yield
93 DSK	11.2.90	X	2:15	16° 57, 79 S 173° 55, 04 E	1888	150 kg yield
94 DSK	11.2.90	X	2:00	16° 58, 18 S 173° 55, 30 E	1922	400 kg yield
95 DSK	11.2.90	X	1:50	16° 58, 39 S 173° 55, 39 E	1955	300 kg yield
96 DSK	11.2.90	X	2:05	16° 57, 00 S 173° 56, 10 E	2005	150 kg yield
97 OFOS KT	11.2.90	X	3:45	16° 58, 81 S 173° 54, 90 E	1966	with water samples, problems with the wire / winch
98 GTV A	11.2.90	X	5:30	16° 57, 90 S 173° 55, 04 E	1957	120 kg yield, technical problems with GTV D, equipment changed
99 GTV A	11.2.90	X	1:50	16° 57, 84 S 173° 55, 28 E	1973	60 kg yield
100 MS	12.2.90	X	1:50	16° 58, 03 S 173° 55, 24 E	1970	O_2-sonde damaged
101 DSK	12.2.90	X	1:50	16° 57, 57 S 173° 55, 13 E	2040	100 kg yield
102 DSK	12.2.90	X	1:50	16° 58, 06 S 173° 55, 05 E	1900	150 kg yield
103 DSK	12.2.90	X	2:35	16° 58, 86 S 173° 54, 69 E	1920	250 kg yield
104 DSK	12.2.90	X	2:30	16° 57, 96 S 173° 54, 94 E	1850	300 kg yield

App. 4

105 DSK	12.2.90	X	1:50	16° 58, 09 S	173° 55, 18 E	1900	350 kg yield
106 OFOS KT	12.2.90	X	5:00	16° 58, 79 S	173° 54, 86 E	1935	with water samples, problems with the wire / winch during station deep-sea compass lost
107 DSK	13.2.90	X	1:40	16° 59, 22 S	173° 54, 92 E	1915	100 kg yield
108 DSK	13.2.90	X	2:05	16° 59, 45 S	173° 54, 95 E	1950	130 kg yield
109 DSK	13.2.90	X	2:30	16° 59, 45 S	173° 54, 92 E	1952	no yield
110 GTV A	13.2.90	X	8:50	16° 59, 28 S	173° 54, 67 E	1960	no yield, grab not closed
111 GTV A	13.2.90	X	3:50	16° 58, 05 S	173° 55, 19 E	1973	no yield
112 MS	14.2.90	X	4:40	16° 59, 36 S	173° 54, 56 E	1977	O_2-sonde damaged, bathymetry-winch damaged

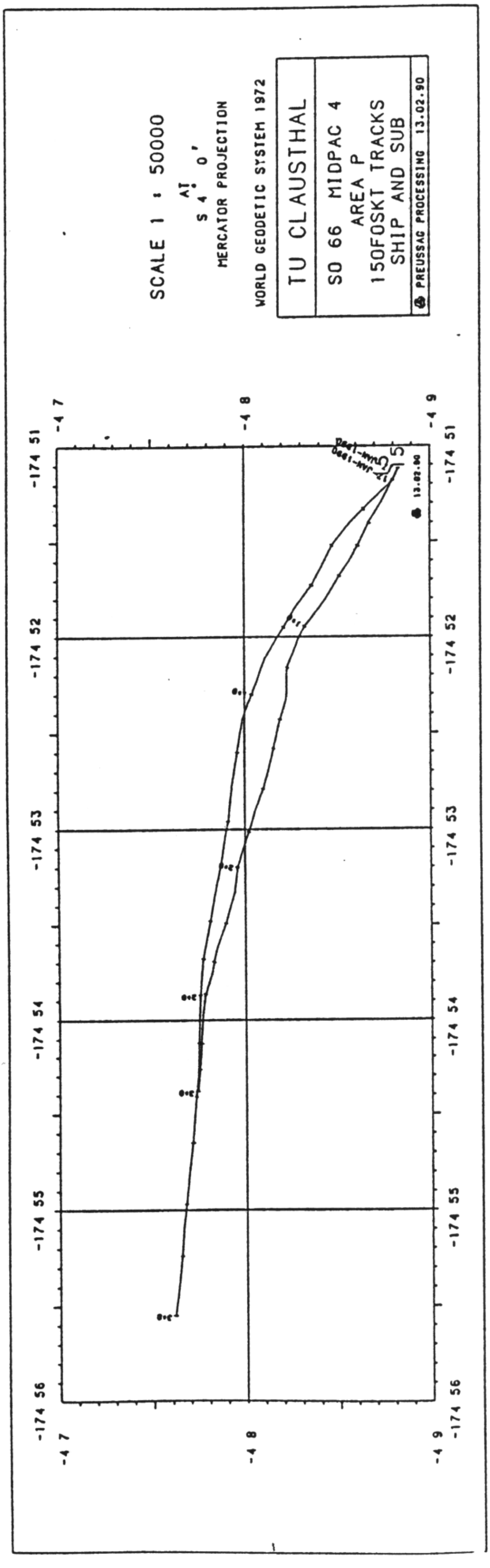
MS = multi sonde (CTD)
GK = spade corer
CG = gravity corer
DSR = round chain-bag-dredge
DSO = oval chain-bag-dredge
DSK = angular chain-bag-dredge

OFOS KT = compact Ocean Floor Observation System
OFOS ST = stereo Ocean Floor Observation System
SM = current meter
GTV A = TV-grab, twin shell type
GTV D = TV-grab, polygon type

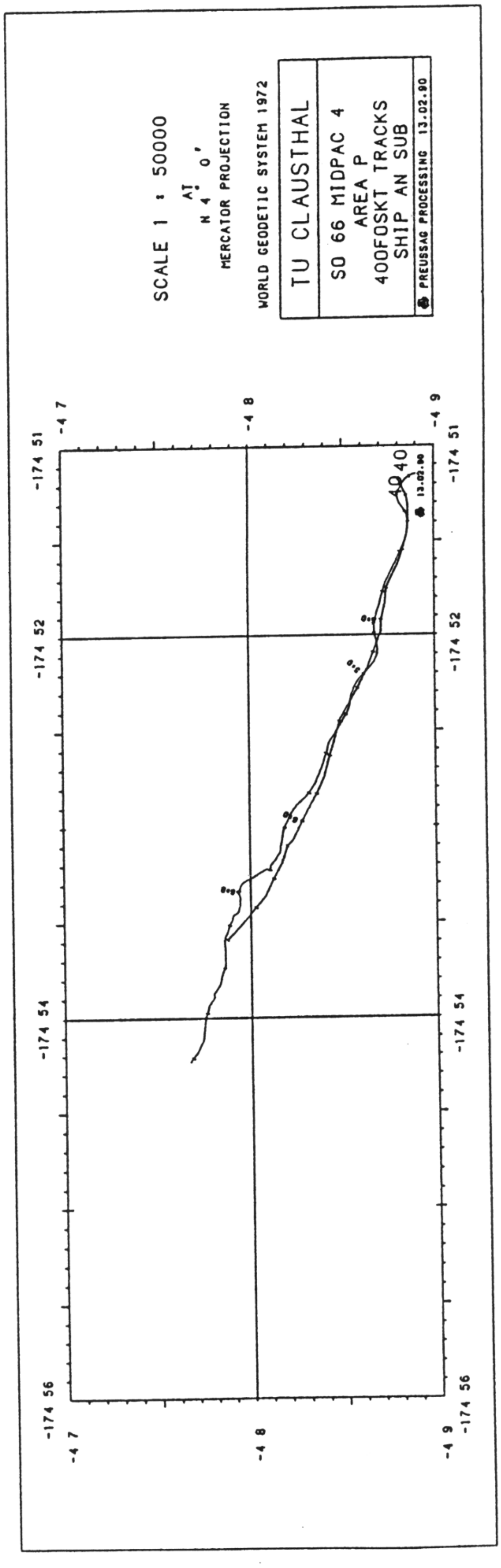
* = first bottomcontact or first bottomview

Appendix 5: OFOS and ship track charts of the OFOS stations

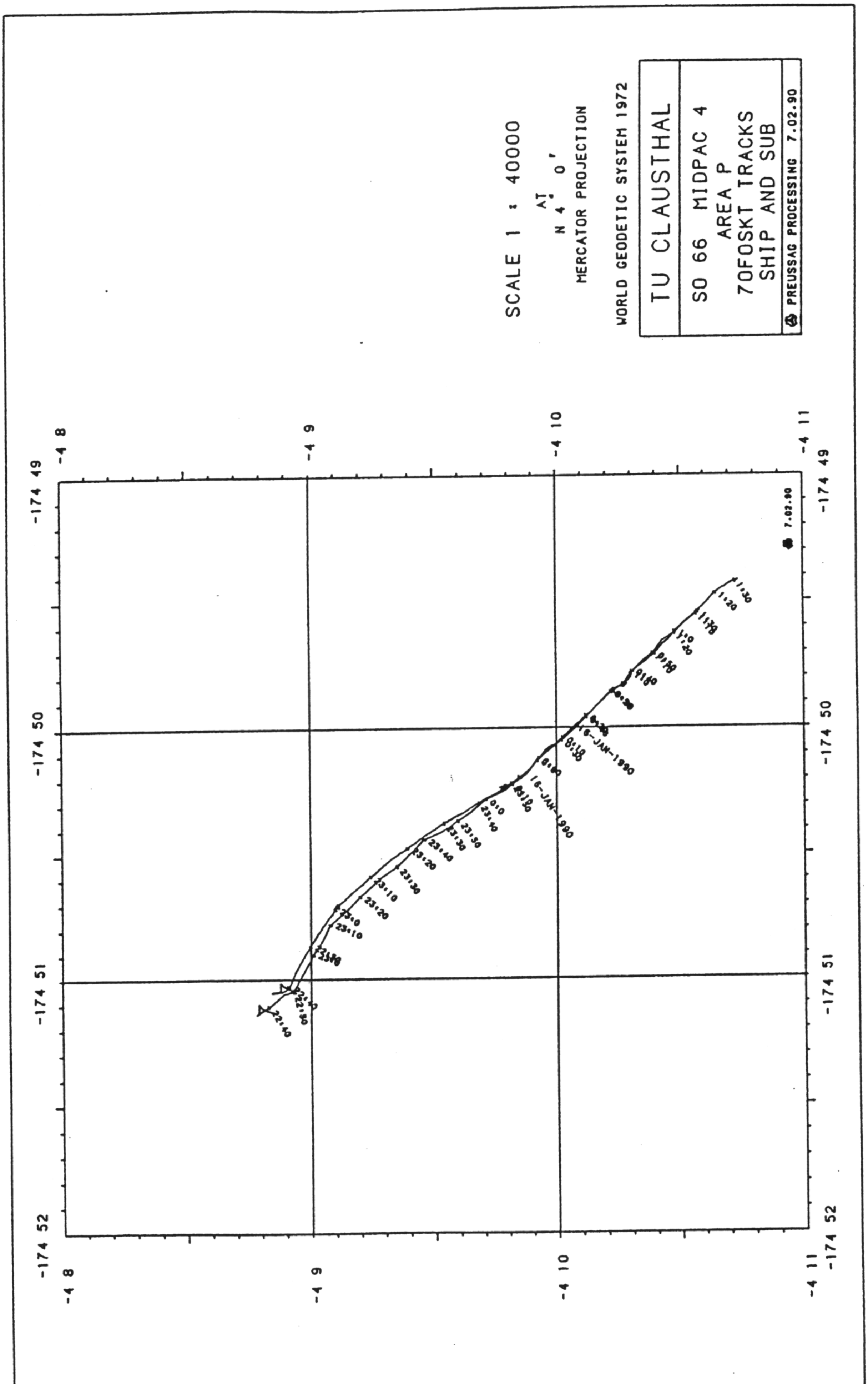
App. 5.1: 15 OFOS-KT



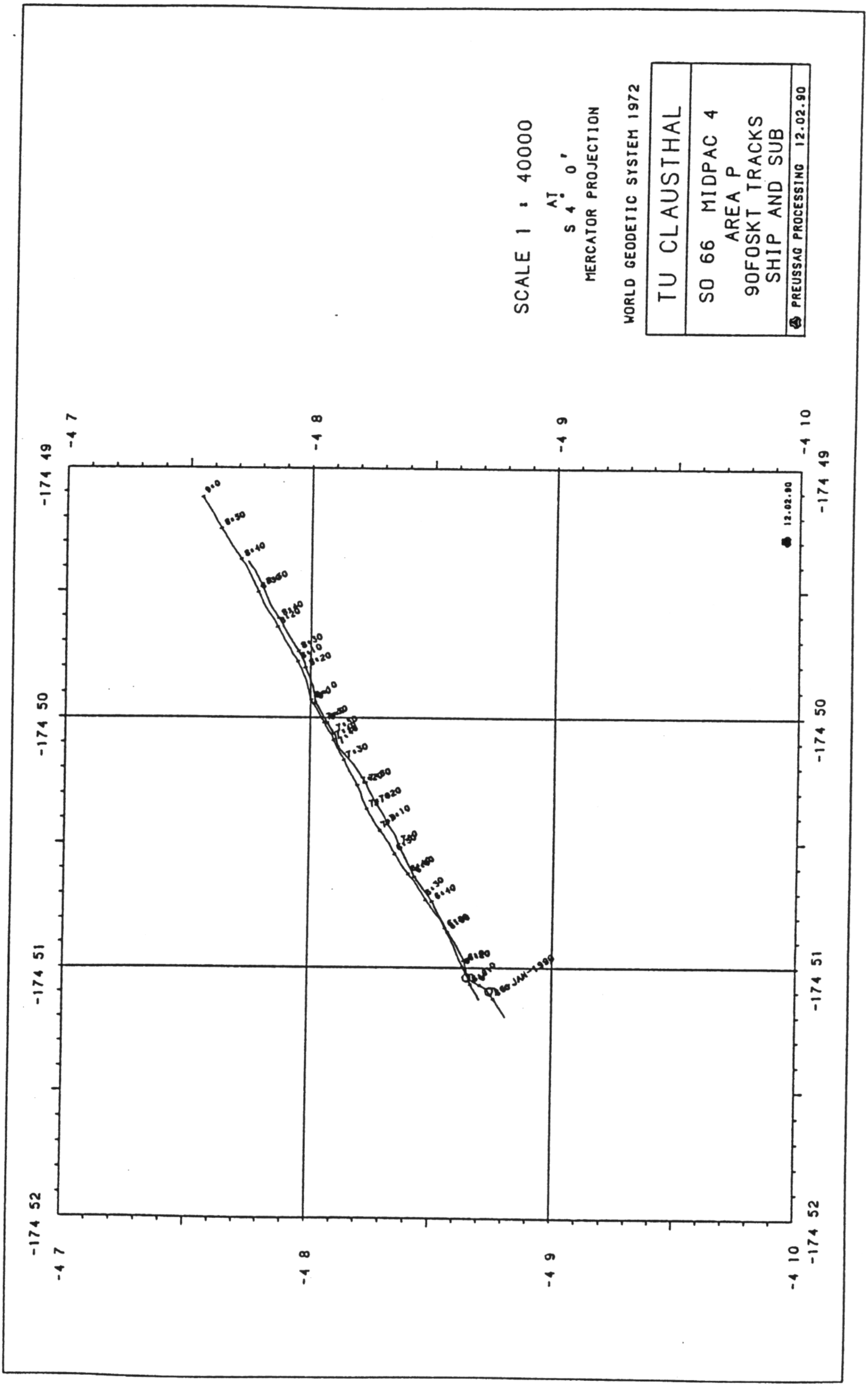
40 OFOS-KT



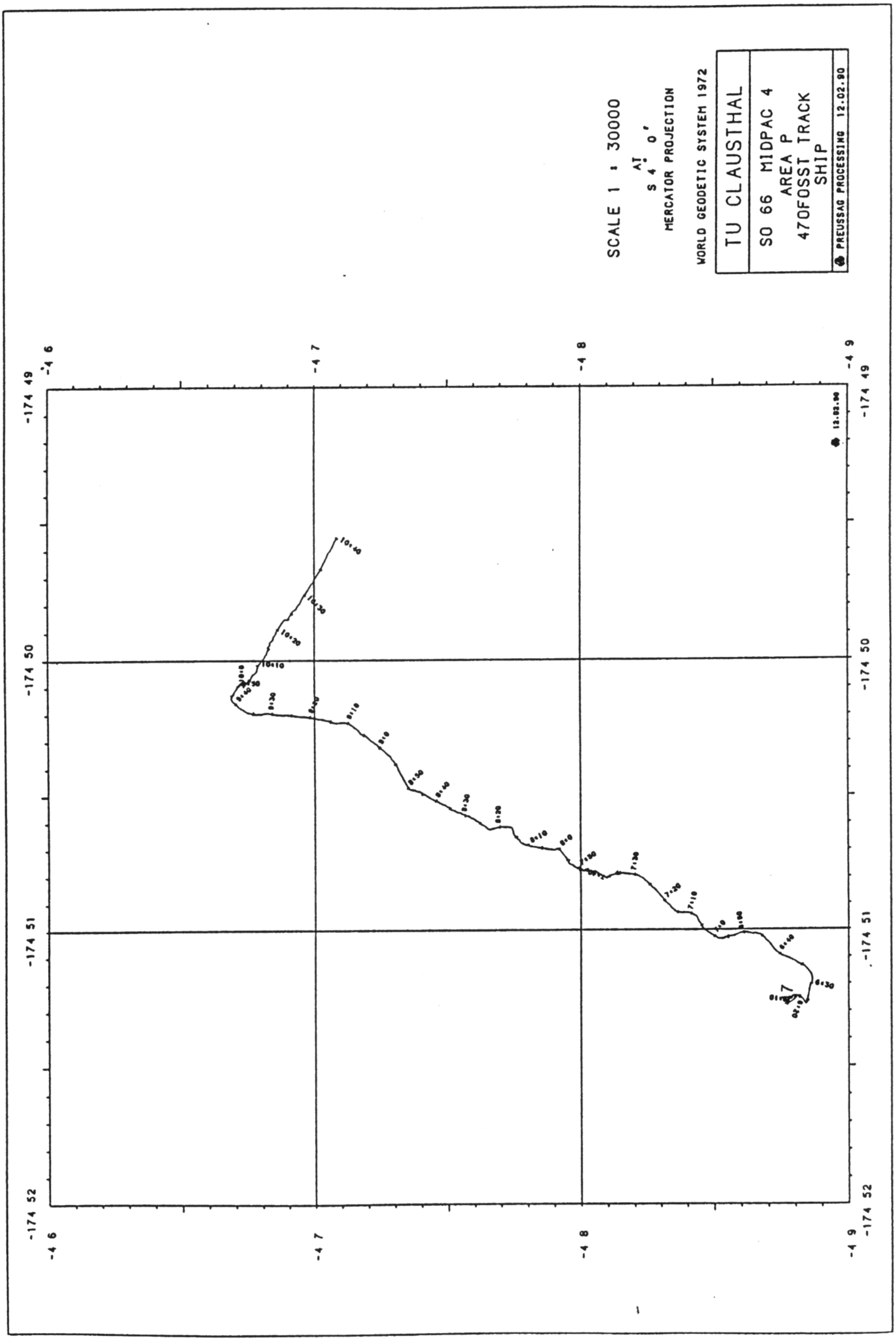
App. 5.2: 7 OFOS-KT



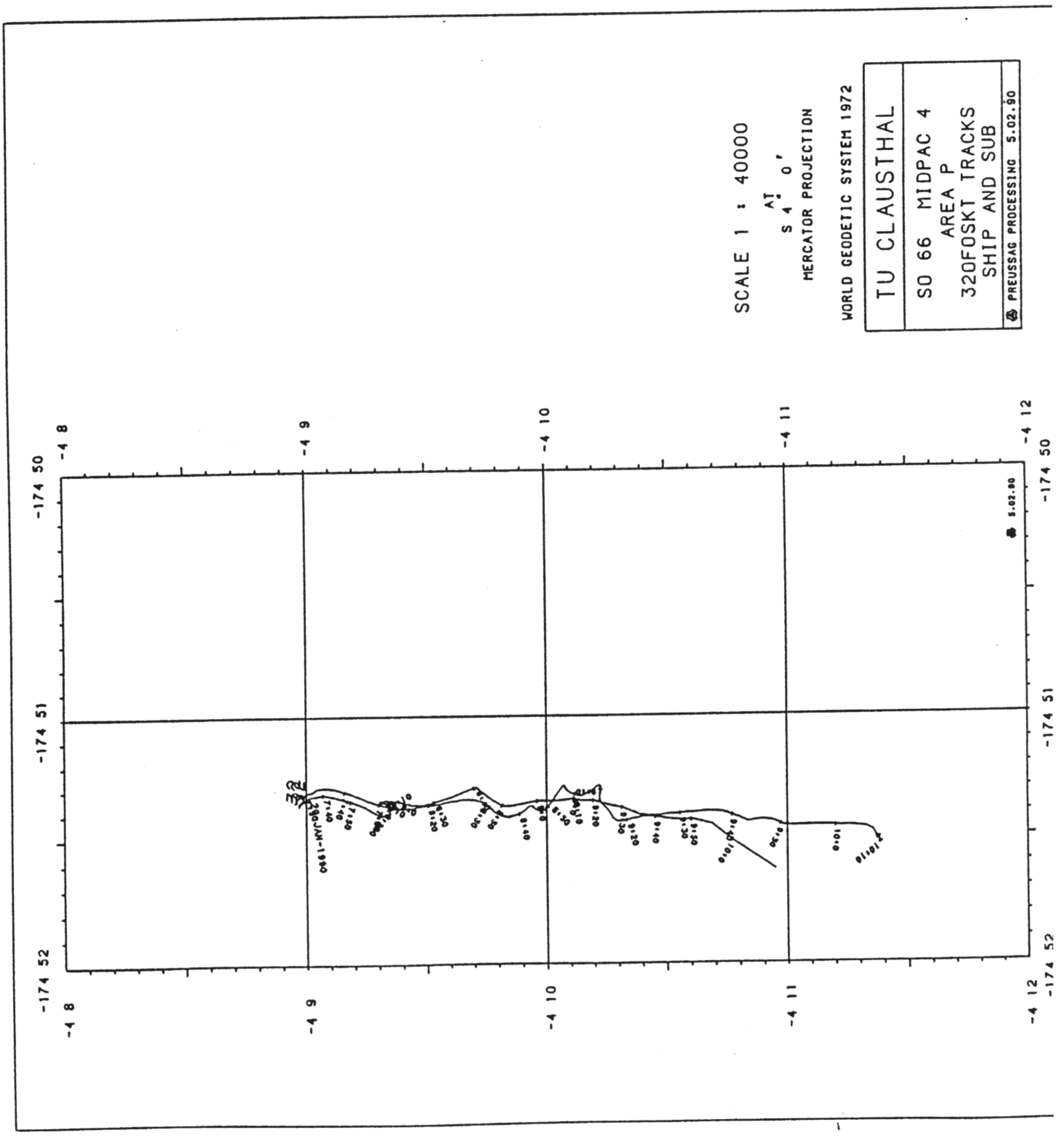
App. 5.3: 9 OFOS-KT



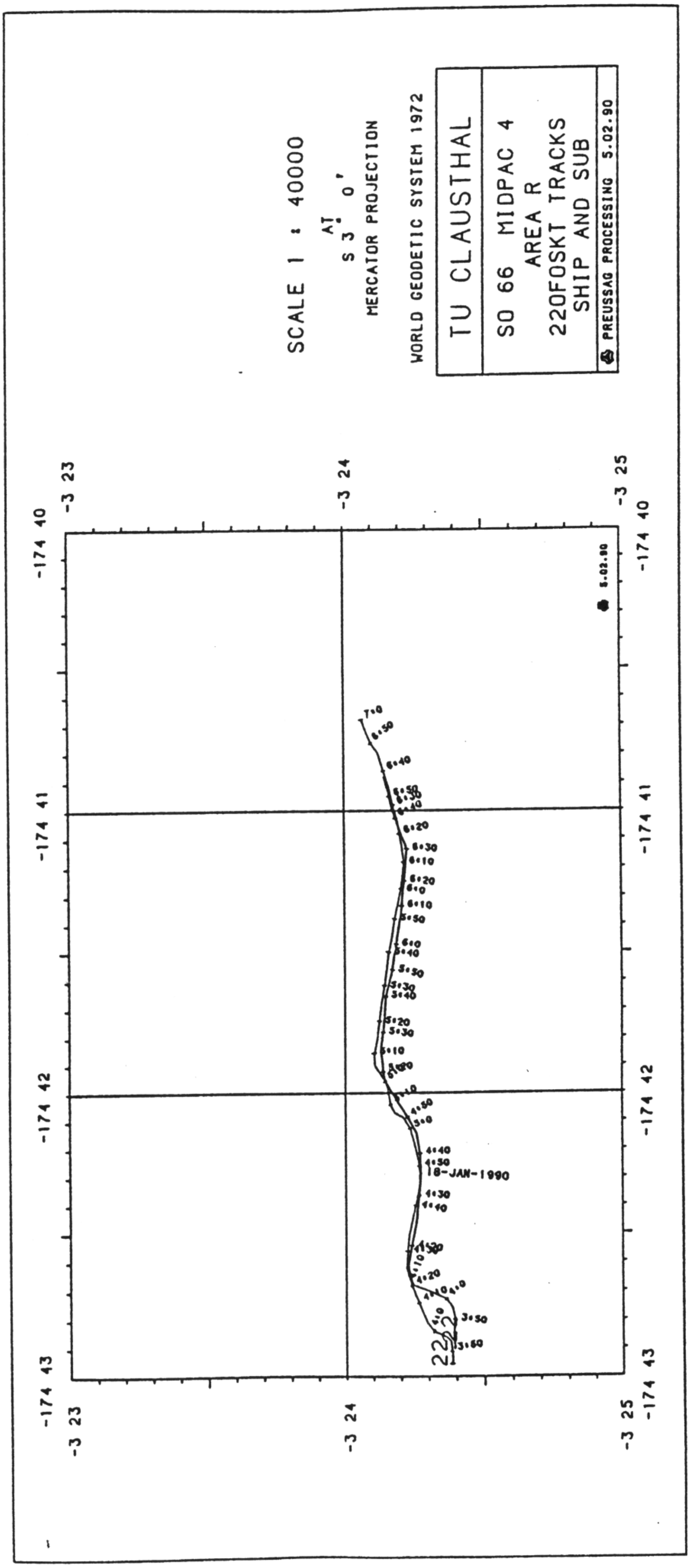
App. 5.4: 47 OFOS-KT



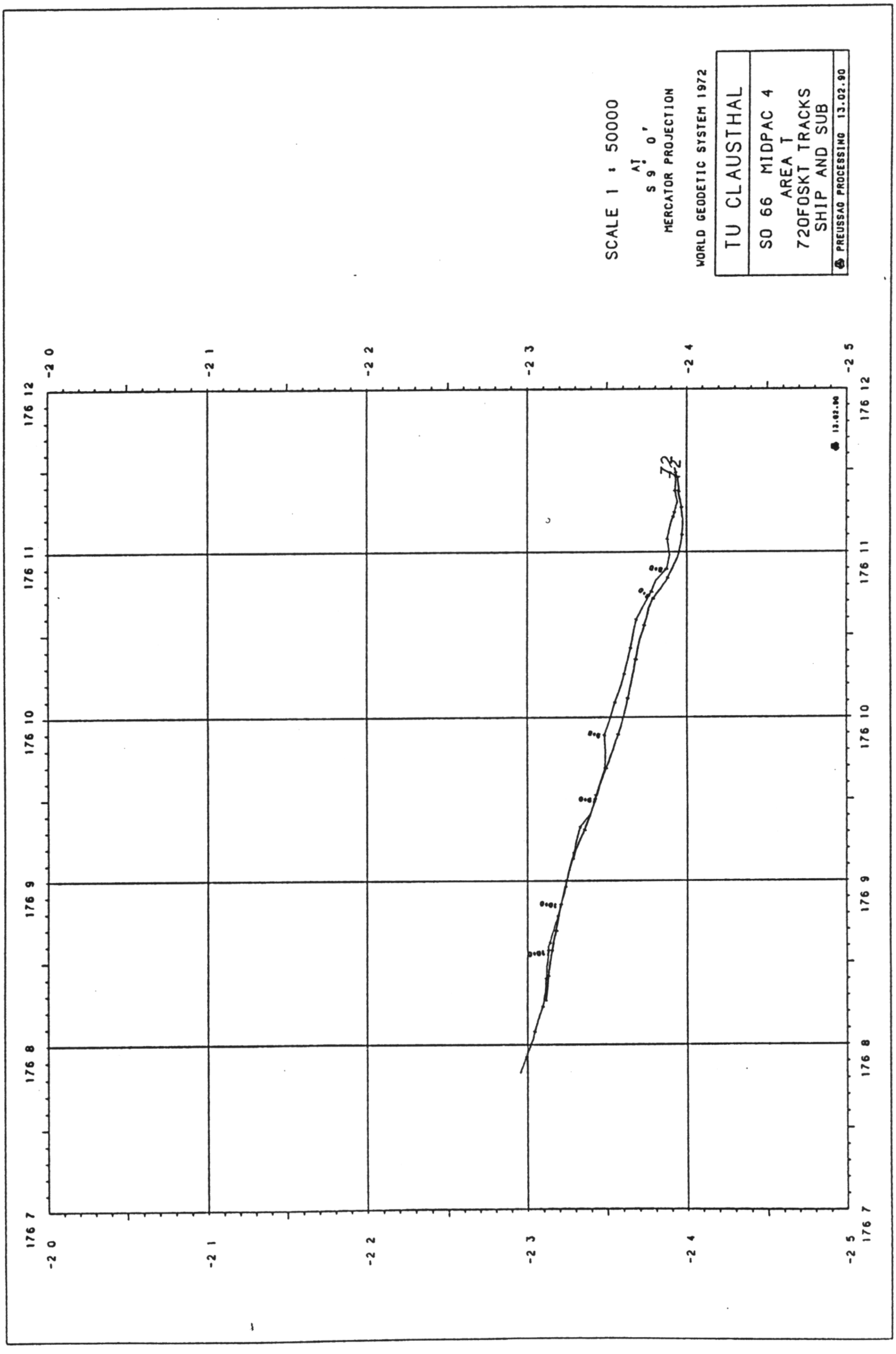
App. 5.5: 32 OFOS-KT

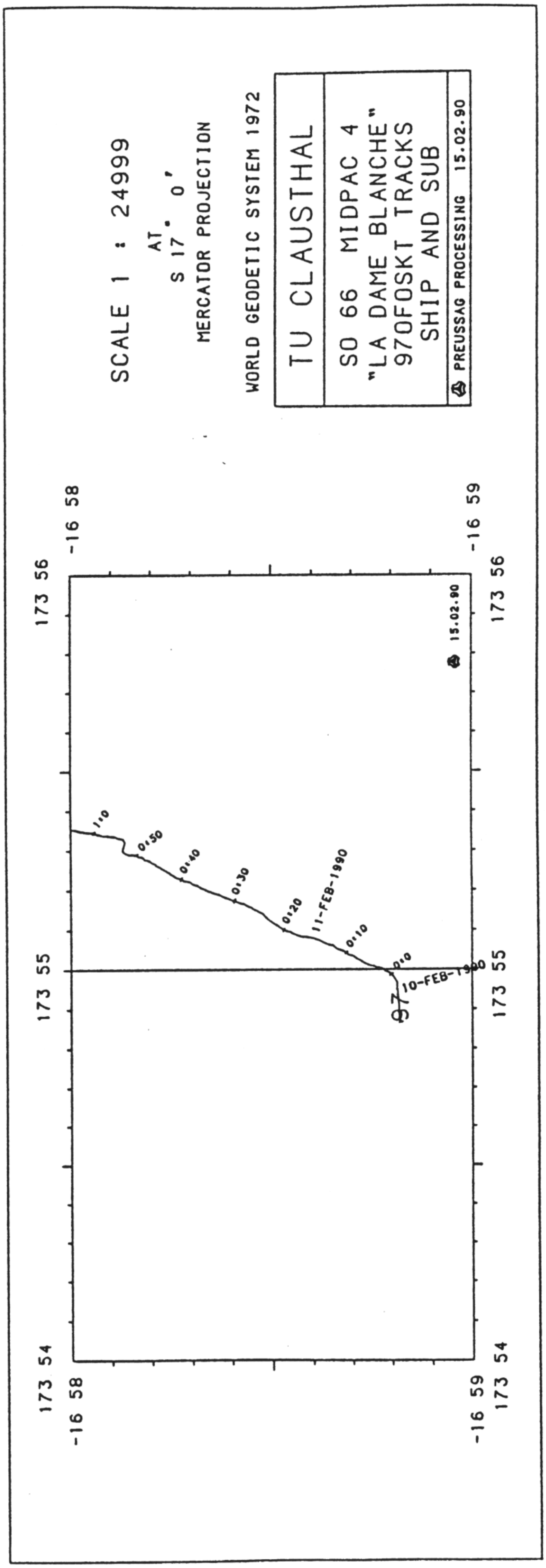


App. 5.6: 22 OFOS-KT



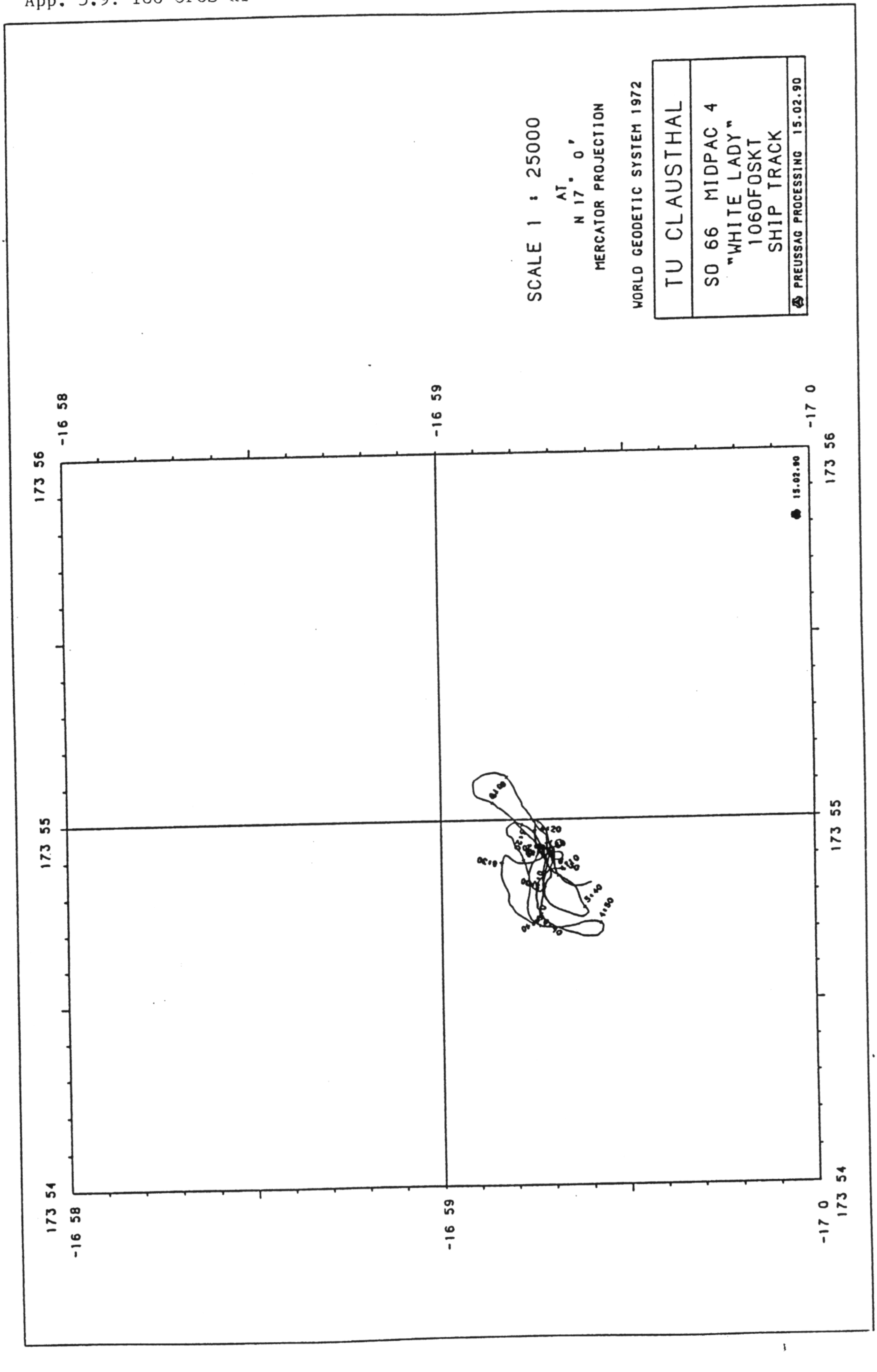
App. 5.7: 72 OFOS-KT





App. 5.8:

97 OFOS-KT


SCALE 1 : 25000
AT
N 17° 0'
MERCATOR PROJECTION
WORLD GEODETIC SYSTEM 1972
TU CLAUSTHAL
SO 66 MIDPAC 4
"WHITE LADY"
1060FOSKT
SHIP TRACK
PREUSSAG PROCESSING 15.02.90
15.02.90
-16 58
-16 59
-17 0
173 56
173 55
173 54

App. 6: Overview of crusts and substrates sampled during the SO 66 cruise

station no.	water depth (m)	substrate	crust layer	thickness (m)	Mn (%)	Fe (%)	Co (%)	Ni (%)
4 DSR P	2986 - 2663	volcanoclastite with pieces of blister basalt	G	5.5				
			A	0.5				
			Z	3	25.17	17.92	0.72	0.42
			J	2	25.44	19.35	0.54	0.42
5 DSR P	2550 - 2156	volcanoclastite with pieces of blister basalt, phosphatic matrix	G	5.5				
			A	4	21.23	10.34	0.40	0.63
			Z					
			J	3.5	28.54	15.99	0.76	0.65
10 DSR P	1984 - 1520	phosphatic lime-stone, cavernous, poor in fossils	G	5.5				
			A	2.5	25.11	7.43	0.62	0.91
			Z	0.5	33.33	12.07	0.91	0.90
			J	4	28.28	17.63	0.85	0.54
14 DSR P	1322 - 1045	phosphatic lime-stone	G	3				
			A	2				
			Z					
			J	1.5	30.98	14.26	1.28	0.73
28 DSR P	3004 - 2677	phosphatic lime-stone porous , cavernous	G	4.5	25.51	19.31	0.55	0.42
			A	3.5				
			Z					
			J	3.4	26.47	18.58	0.67	0.49
29 DSR P	2445 - 2357	phosphatic lime-stone	G	1.9				
			A	1				
			Z					
			J	3	26.37	19.16	0.66	0.44

App. 6

station no.	water depth (m)	substrate	crust layer	thickness (m)	Mn (%)	Fe (%)	Co (%)	Ni (%)
33 DSR P	2285 - 2190	limestone	G					
			A					
			Z					
			J		26.37	18.76	0.66	0.47
34 DSR P	1944 - 1592	limestone cavernous	G	4				
			A	1.6	27.62	11.95	0.84	0.95
			Z					
			J	2.4	29.86	15.71	0.92	0.68
35 DSR P	1398 - 1165	limestone	G	4	29.43	16.34	1.24	0.58
			A	1				
			Z					
			J	4	32.85	12.07	1.06	0.86
37 DSR P	1253 - 1112	reef limestone	G	0.8				
			A	0.6	30.12	11.02	1.14	0.83
			Z					
			J	0.5	31.24	14.67	1.44	0.63
43 DSO P	2369 - 2263	reef limestone	G	7.5				
			A	2.5	26.51	11.04	0.70	0.70
			Z					
			J	5	28.07	17.65	0.80	0.60
48 DSO P	2090 - 1800	reef limestone	G	3				
			A	1.5				
			Z					
			J	1.5	27.56	17.58	0.76	0.54

App. 6

station no.	water depth (m)	substrate	crust layer	thickness (m)	Mn (%)	Fe (%)	Co (%)	Ni (%)
49 DSR P	1888 - 1700	reef limestone	G	2,5				
			A	0.6				
			Z					
			J	1.9	27.89	16.48	0.83	0.65
50 DSR P	1507 - 1344	reef limestone	G	3				
			A	1.5	31.91	10.28	0.99	0.83
			Z					
			J	1				
26 DSR S	1332 - 1243	reef limestone	G	3.2				
			A	2.4	29.67	11.32	0.88	0.96
			Z					
			J	1.5	30.08	16.54	1.18	0.52
59 DSR V	2600 - 2400	volcanoclastite	G	7.5				
			A	3.5	11.82	14.98	0.20	0.27
			Z	4.9	19.12	20.33	0.58	0.34
			J	4	19.79	22.11	0.34	0.27
61 DSR V	2943 - 2625	volcanoclastite	G	2.1				
			A	1.7				
			Z					
			J	1	27.02	11.78	0.97	0.79
62 DSR V	2600 - 2200	volcanoclastite	G	0.9	16.46	17.86	0.57	0.36
			A					
			Z					
			J	0.9				

App. 6

station no.	water depth (m)	substrate	crust layer	thickness (m)	Mn (%)	Fe (%)	Co (%)	Ni (%)
65 DSO V	2320 - 2267	without substrate	G	2.3	24.90	19.08	0.89	0.42
			A					
			Z					
			J					
69 DSO T	2249 - 2026	volcanoclastite	G	3.5				
			A	1.7	19.14	11.78	0.38	0.49
			Z					
			J	2	27.13	17.68	0.80	0.46
75 DSR T	1818 - 1351	weathered volcanic rock	G	1.4	28.31	18.82	0.95	0.45
			A					
			Z					
			J	1.4				
79 DSK T	2008 - 1700	limestone with feedings tracks	G	2.2	28.65	16.32	0.81	0.59
			A	1.7				
			Z					
			J	0.5				
80 DSK T	1680 - 1599	carbonate clastite	G	3.1				
			A	1.4	25.73	7.62	0.87	0.90
			Z					
			J	2	30.68	15.58	0.91	0.64
85 DSK U	2555 - 1865	carbonate clastite	G	5				
			A	0.5	17.59	22.04	0.34	0.26
			Z					
			J	5	19.81	22.61	0.30	0.26

App. 6

station no.	water depth (m)	substrate	crust layer	thickness (m)	Mn (%)	Fe (%)	Co (%)	Ni (%)
		hyaloclastite	G	5				
86 DSK	1852 - 1490		A	2.8	16.20	11.73	0.36	0.37
U			Z	1				
			J	1.2	21.67	19.59	0.66	0.33
87-90 DSK W	2200 - 950	pillow basalt	coatings		13.56	19.30	0.24	0.21

Appendix 7: X-ray fluorescence analyses of the crust samples (onboard investigations)

MIDPAC 4 (SO 66) Dez. 89 - Feb. 90 Areal: P

RFA - Bordanalyse
Bearbeiter: Schöps

GKB	Station	Beschreibung	Mn %	Fe %	Ni %	Co %	Cu %	Zn ppm	Si %	Ti %	Ca %	Al %	Pb ppm	P %	Sr ppm
500	4 DSR	Zwischenerzschicht	25.17	17.92	0.42	0.72	0.19	723	3.59	1.54	2.63	0.86	1042	0.41	1537
501	4 DSR	junge Generation	25.44	19.35	0.42	0.54	0.11	600	3.55	1.11	2.62	0.74	1109	0.45	1524
502	5 DSR 1	alte Generation	21.23	10.34	0.63	0.40	0.11	831	1.47	0.87	11.12	0.37	1191	3.67	1716
503	5 DSR 1	junge Generation	28.54	15.99	0.65	0.76	0.11	768	2.61	1.19	2.93	0.63	1356	0.43	1502
504	5 DSR 3	junge Generation	28.89	16.33	0.68	0.77	0.11	805	2.65	1.17	2.66	0.65	1386	0.39	1468
505	5 DSR 3	alte Generation	22.71	9.55	0.81	0.48	0.14	1026	1.15	0.83	10.65	0.39	1280	3.47	1655
506	10 DSR	junge Generation	28.28	17.63	0.54	0.85	0.04	620	2.22	1.03	2.86	0.49	1535	0.49	1614
507	10 DSR	Zwischenerzschicht	33.33	12.07	0.90	0.91	0.07	842	0.84	1.06	3.30	0.17	1553	0.41	1546
508	10 DSR	alte Generation	25.11	7.43	0.91	0.62	0.07	1026	0.55	0.67	11.23	0.15	1390	3.58	1627
511	14 DSR 6	junge Generation	30.98	14.26	0.73	1.28	0.07	741	1.03	0.89	3.16	0.46	1893	0.63	1560

App. 7

MIDPAC 4 (SO 66) Dez. 89 - Feb. 90 Areal: P

RFA - Bordanalyse
Bearbeiter: Schöps

CKB	Station	Beschreibung	Mn %	Fe %	Ni %	Co %	Cu %	Zn ppm	Si %	Ti %	Ca %	Al %	Pb ppm	P %	Sr ppm
512	28 DSR	junge gener. (oberste mm)	25.51	19.31	0.42	0.55	0.16	619	3.04	0.89	2.60	0.54	1158	0.51	1557
513	28 DSR	junge generation	26.47	18.58	0.49	0.67	0.08	600	3.11	1.00	2.62	0.64	1191	0.47	1540
514	29 DSR	junge generation	26.37	19.16	0.44	0.66	0.05	584	2.90	0.92	2.74	0.52	1266	0.50	1587
515	33 DSR	junge generation	26.37	18.76	0.47	0.66	0.05	609	3.09	0.95	2.63	0.61	1354	0.48	1588
516	34 DSR	junge generation	29.86	15.71	0.68	0.92	0.07	716	1.77	1.00	2.77	0.41	1668	0.47	1557
517	34 DSR	alte generation	27.62	11.95	0.95	0.84	0.13	940	1.66	0.96	5.88	0.58	1505	1.57	1489
518	35 DSR	junge generation	29.43	16.34	0.58	1.24	0.04	620	1.54	1.03	2.83	0.30	1846	0.50	1629
519	35 DSR	junge ~~alte~~ generation	32.85	12.07	0.86	1.06	0.06	844	0.93	0.97	3.50	0.25	1878	0.57	1526
520	37 DSR	junge generation	31.24	14.67	0.63	1.44	0.04	622	1.01	0.92	2.91	0.26	1993	0.51	1646
521	37 DSR	alte(?) generation	30.12	11.02	0.83	1.14	0.06	874	0.72	0.79	5.86	0.25	2072	1.33	1638
522	43 DSO	junge generation	28.07	17.65	0.58	0.81	0.06	609	2.48	0.97	2.81	0.47	1334	0.46	1584
523	43 DSO	alte generation	26.51	11.04	0.68	0.70	0.10	816	1.42	1.02	7.59	0.26	1400	2.10	1727
524	48 DSO	junge generation	27.56	17.58	0.54	0.76	0.06	641	2.36	0.96	3.19	0.49	1494	0.66	1649
525	49 DSR	junge generation	27.89	16.48	0.65	0.83	0.06	698	2.71	1.03	2.60	0.67	1539	0.44	1502
526	50 DSR	junge generation	31.75	14.33	0.67	1.46	0.04	642	1.00	0.98	2.88	0.24	1947	0.49	1591
527	50 DSR	alte generation	31.91	10.28	0.83	0.99	0.06	817	0.54	0.79	5.54	0.16	1862	1.31	1622
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.45	0.04	576	0.97	0.93	3.08	0.23	1995	0.59	1696

App. 7
MIDPAC 4 (SO 66) Dez. 89 - Feb. 90 Areal: W

RFA - Bordanalyse
Bearbeiter: Schöps

CKB	Station	Beschreibung	Mn %	Fe %	Ni %	Co %	Cu %	Zn ppm	Si %	Ti %	Ca %	Al %	Pb ppm	P %	Sr ppm
553	87-90 DSK	Mn-coatings on basalt	13.56	19.30	0.21	0.24	0.07	647	7.44	0.98	4.67	2.72	672	0.52	1408

App. 7

MIDPAC 4 (SO 66) **Dez. 89 - Feb. 90**

Areal: U

RFA - Bordanalyse
Bearbeiter: Schöps

CKB	Station	Beschreibung	Mn %	Fe %	Ni %	Co %	Cu %	Zn ppm	Si %	Ti %	Ca %	Al %	Pb ppm	P %	Sr ppm
549	85DSK	junge Generation	19.81	22.61	0.26	0.30	0.11	587	5.21	0.86	2.43	1.30	1022	0.52	1572
550	85DSK	junge Generation	17.59	22.04	0.26	0.34	0.12	717	6.37	1.27	2.07	1.98	1099	0.44	1540
551	86DSK	junge Generation	21.67	19.59	0.33	0.66	0.05	739	3.64	1.85	2.80	1.06	1829	0.56	1739
552	86DSK	alte Generation	16.20	11.73	0.37	0.36	0.06	654	1.38	0.88	12.46	0.39	1453	4.38	1907

App. 7

MIDPAC 4 (SO 66) Dez. 89 - Feb. 90 Areal: T

RFA - Bordanalyse
Bearbeiter: Schöps

CKB	Station	Beschreibung	Mn %	Fe %	Ni %	Co %	Cu %	Zn ppm	Si %	Ti %	Ca %	Al %	Pb ppm	P %	Sr ppm
540	66 DSR1	Gesamtprobe	24.18	15.71	0.31	0.24	0.12	763	7.14	0.81	2.23	2.16	739	0.63	1331
541	69 DSO3	alte Generation	19.14	11.78	0.49	0.38	0.09	774	1.92	0.90	10.52	0.45	1420	3.56	1799
542	69 DSO3	junge Generation	27.13	17.68	0.46	0.80	0.09	718	2.62	1.39	2.61	0.50	1589	0.42	1722
543	75 DSR	Gesamtprobe	28.31	18.82	0.45	0.95	0.03	576	1.70	0.86	2.88	0.29	1989	0.65	1788
544	79 DSK	Gesamtprobe	28.65	16.32	0.59	0.81	0.13	812	2.41	1.21	2.70	0.63	1610	0.43	1682
545	80 DSK	junge Generation	30.68	15.58	0.64	0.91	0.04	664	1.30	0.86	3.02	0.24	1849	0.53	1703
546	80 DSK	alte Generation	25.73	7.62	0.90	0.87	0.08	959	0.58	0.71	10.44	0.27	1324	3.48	1657
547	80 DSK	Substrat	-	-	-	-	-	-	0.03	0.10	56.44	0.09	-	2.94	379
548	77 DSO1	Substrat	-	-	-	-	-	-	-	0.09	59.07	0.06	-	0.57	294

App. 7
MIDPAC 4 (SO 66) Dez. 89 - Feb. 90

Areal: R/V

RFA - Bordanalyse
Bearbeiter: Schöps

GKB	Station	Beschreibung	Mn %	Fe %	Ni %	Co %	Cu %	Zn ppm	Si %	Ti %	Ca %	Al %	Pb ppm	P %	Sr ppm
535	20 DSO	Phosphorit	–	–	–	–	0.01	341	–	0.09	36.70	0.05	–	18.92	1771
536	50 DSR	mit Kruste Phosphorit	–	–	–	–	0.01	278	0.11	0.14	38.87	0.09	24	16.18	2510
537	58 DSR	Kalk	–	–	–	–	0.01	–	1.51	0.12	54.61	0.48	–	1.46	852
538	62 DSR	phosphor. Kalk	–	–	–	–	0.01	–	0.32	0.10	45.15	0.17	–	12.12	1485

App. 7

MIDPAC 4 (SO 66) Dez. 89 - Feb. 90 Areal: V

RFA - Bordanalyse
Bearbeiter: Schöps

GKB	Station	Beschreibung	Mn %	Fe %	Ni %	Co %	Cu %	Zn ppm	Si %	Ti %	Ca %	Al %	Pb ppm	P %	Sr ppm
529	60 DSR	alte Generation	20.89	9.35	0.86	0.76	0.11	907	1.26	0.62	11.35	0.59	1342	3.86	1797
530	59 DSR	alte Generation	11.82	14.98	0.27	0.20	0.15	636	5.58	1.04	8.98	1.84	945	3.09	1477
531	59 DSR	Zwischenschicht	19.12	20.33	0.34	0.58	0.14	631	6.03	1.45	2.50	1.86	1090	0.42	1368
532	59 DSR	junge Generation	19.79	22.11	0.27	0.34	0.07	596	5.70	0.86	2.75	1.56	1053	0.49	1532
533	61 DSR	~~junge~~ alte Generation	27.02	11.78	0.79	0.97	0.07	762	1.04	0.79	6.70	0.37	1996	2.02	1689
534	62 DSR1	Gesamtprobe	16.46	17.86	0.36	0.57	0.26	786	8.80	1.59	2.95	2.55	974	0.69	1286
539	65 DSO	Gesamtprobe	24.90	19.08	0.42	0.89	0.08	626	2.74	1.70	2.43	0.60	1583	0.38	1582

App. 7

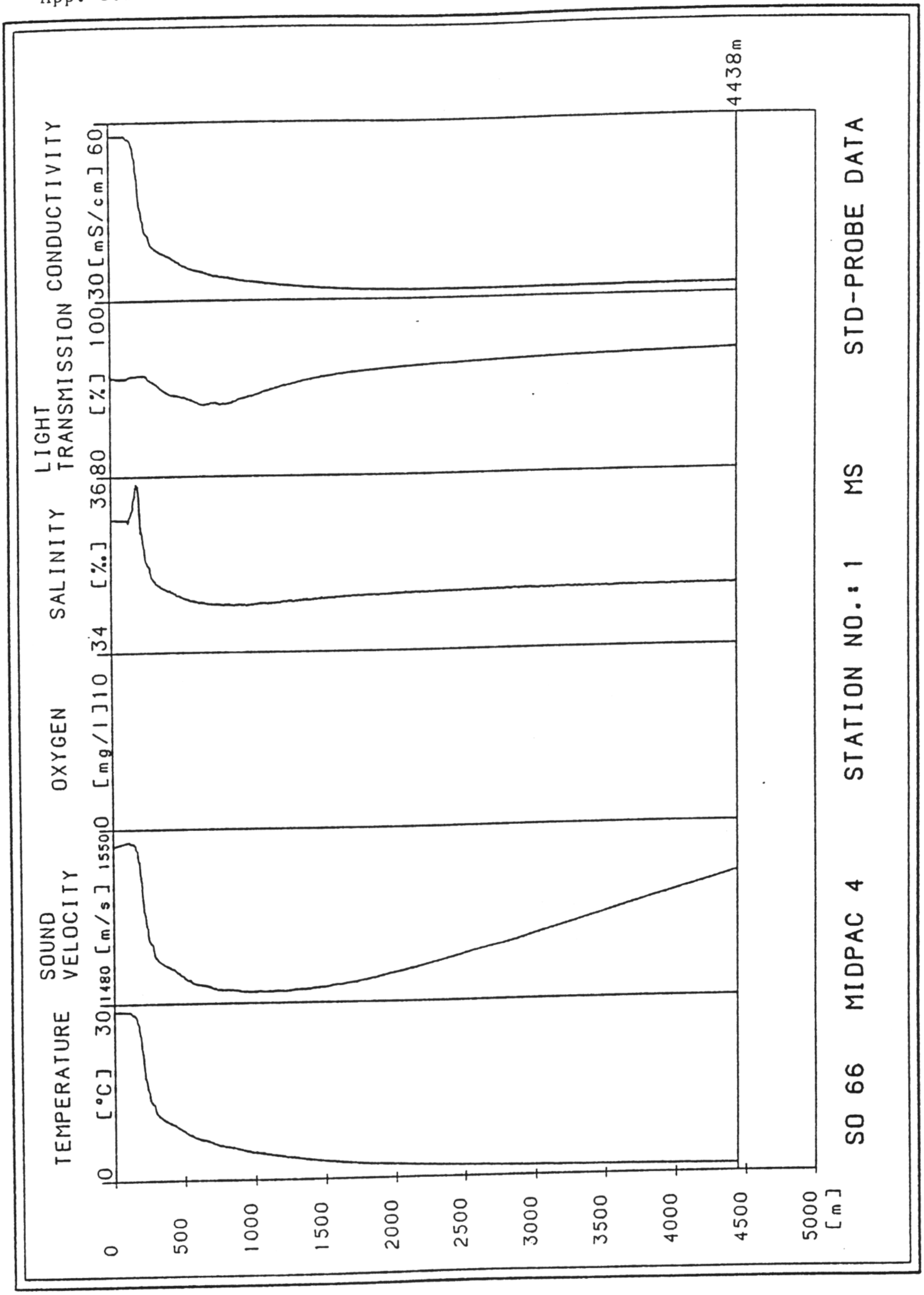
MIDPAC 4 (SO 66) **Dez. 89 - Feb. 90** Areal: S

RFA - Bordanalyse
Bearbeiter: Schöps

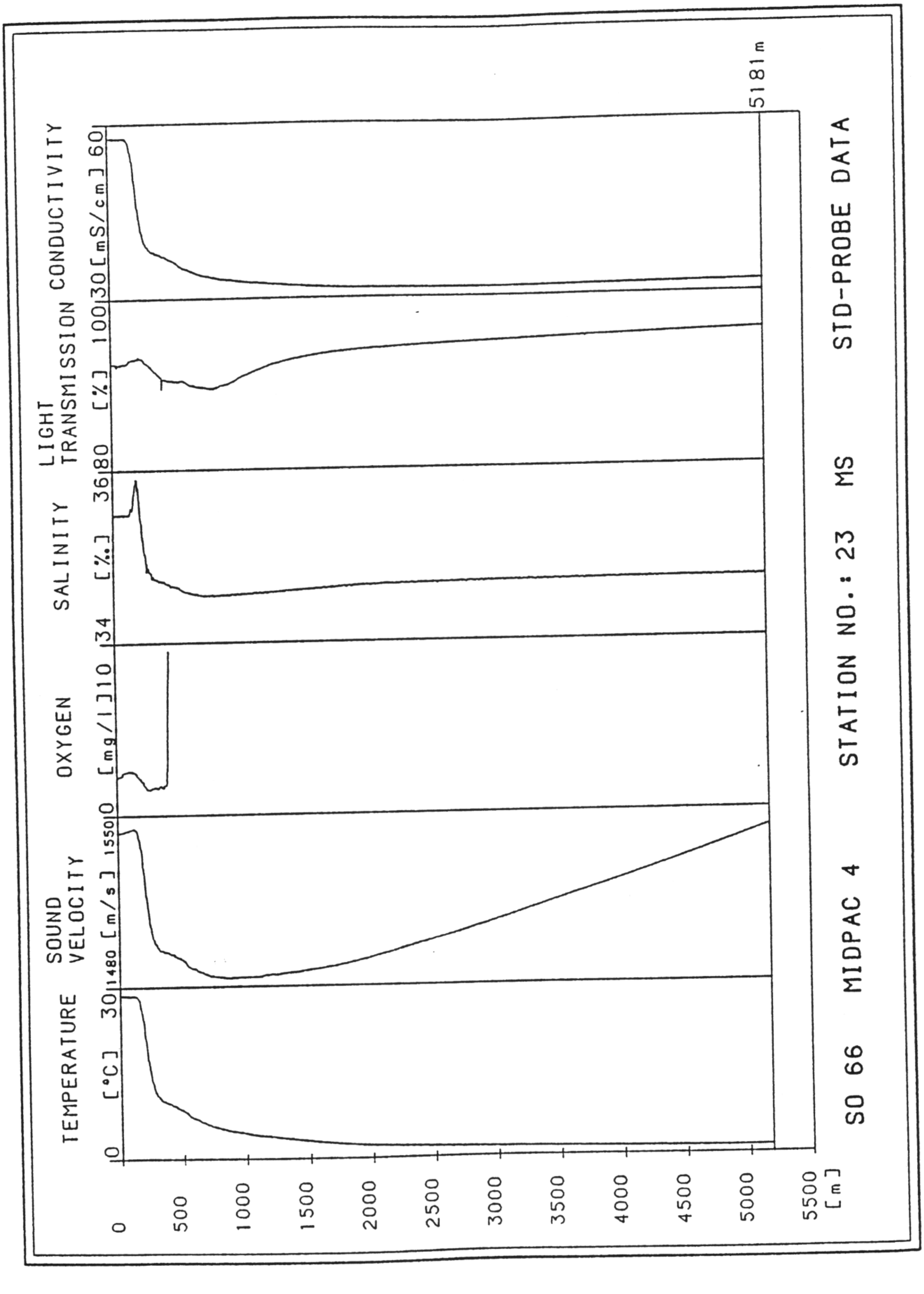
GKB	Station	Beschreibung	Mn %	Fe %	Ni %	Co %	Cu %	Zn ppm	Si %	Ti %	Ca %	Al %	Pb ppm	P %	Sr ppm
509	26DSR	alte Generation	29.67	11.32	0.96	0.88	0.08	972	0.89	0.79	5.72	0.43	1660	1.54	1521
510	26DSR	junge Generation	30.08	16.54	0.52	1.18	0.03	571	1.17	0.88	3.05	0.22	1946	0.58	1676

Appendix 8: multisonde data plots

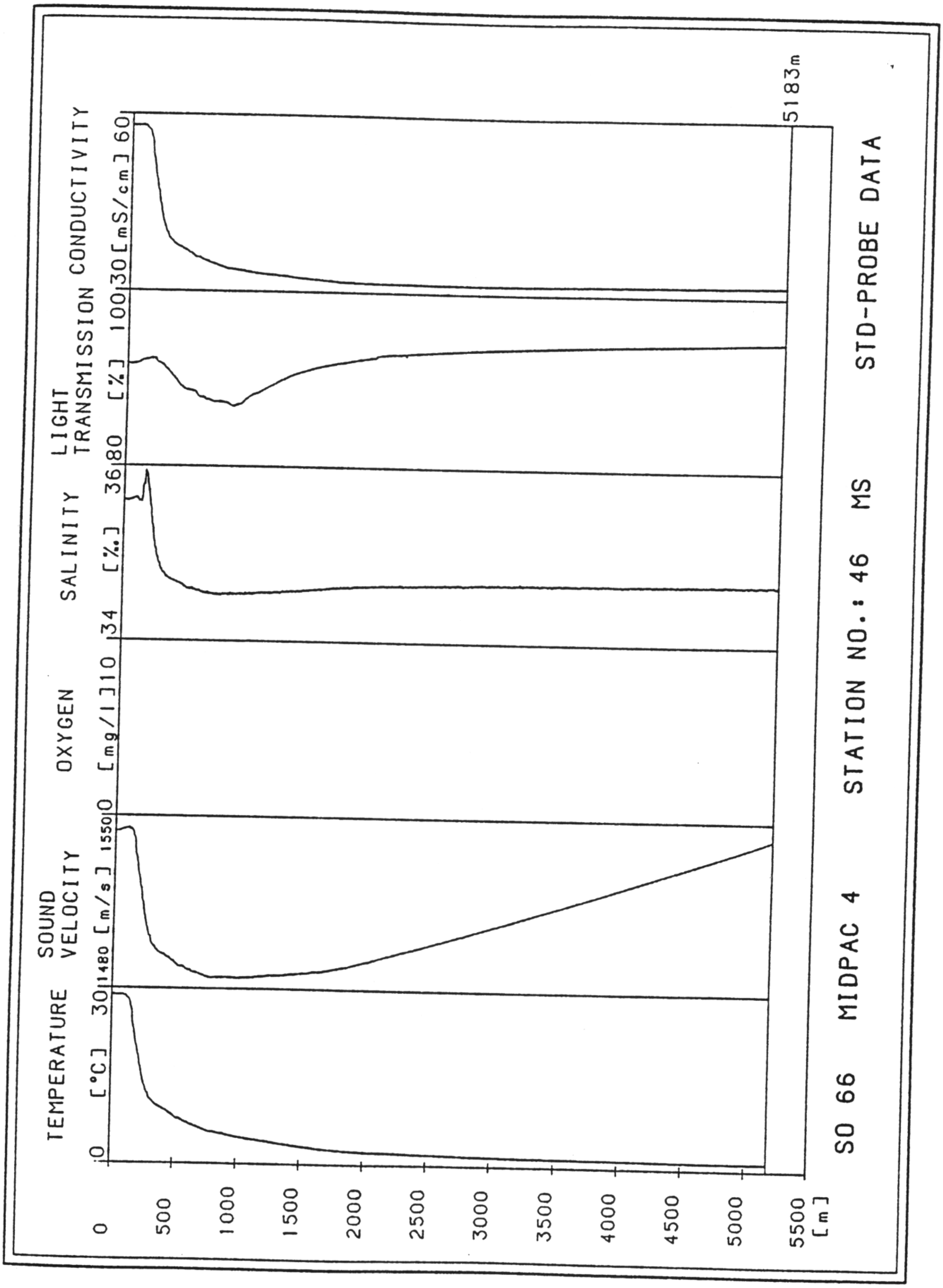
App. 8.1: 1 MS



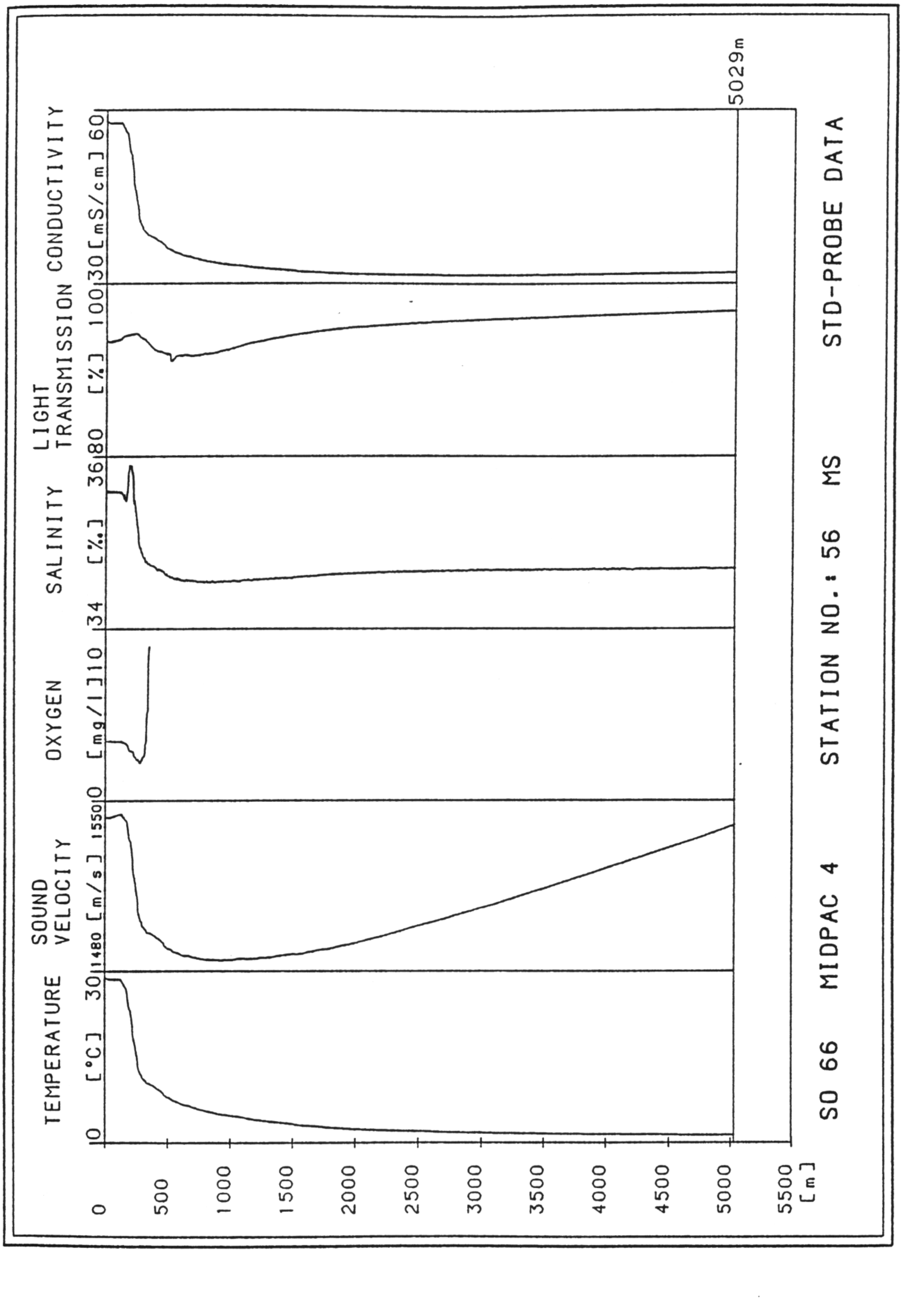
App. 8.2: 23 MS


TEMPERATURE [°C] 0 30
SOUND VELOCITY [m/s] 1480 1550
OXYGEN [mg/l] 0 10
SALINITY [‰] 34 36
LIGHT TRANSMISSION [%] 80 100
CONDUCTIVITY [mS/cm] 30 60
5181 m
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 [m]
SO 66 MIDPAC 4 STATION NO.: 23 MS STD-PROBE DATA

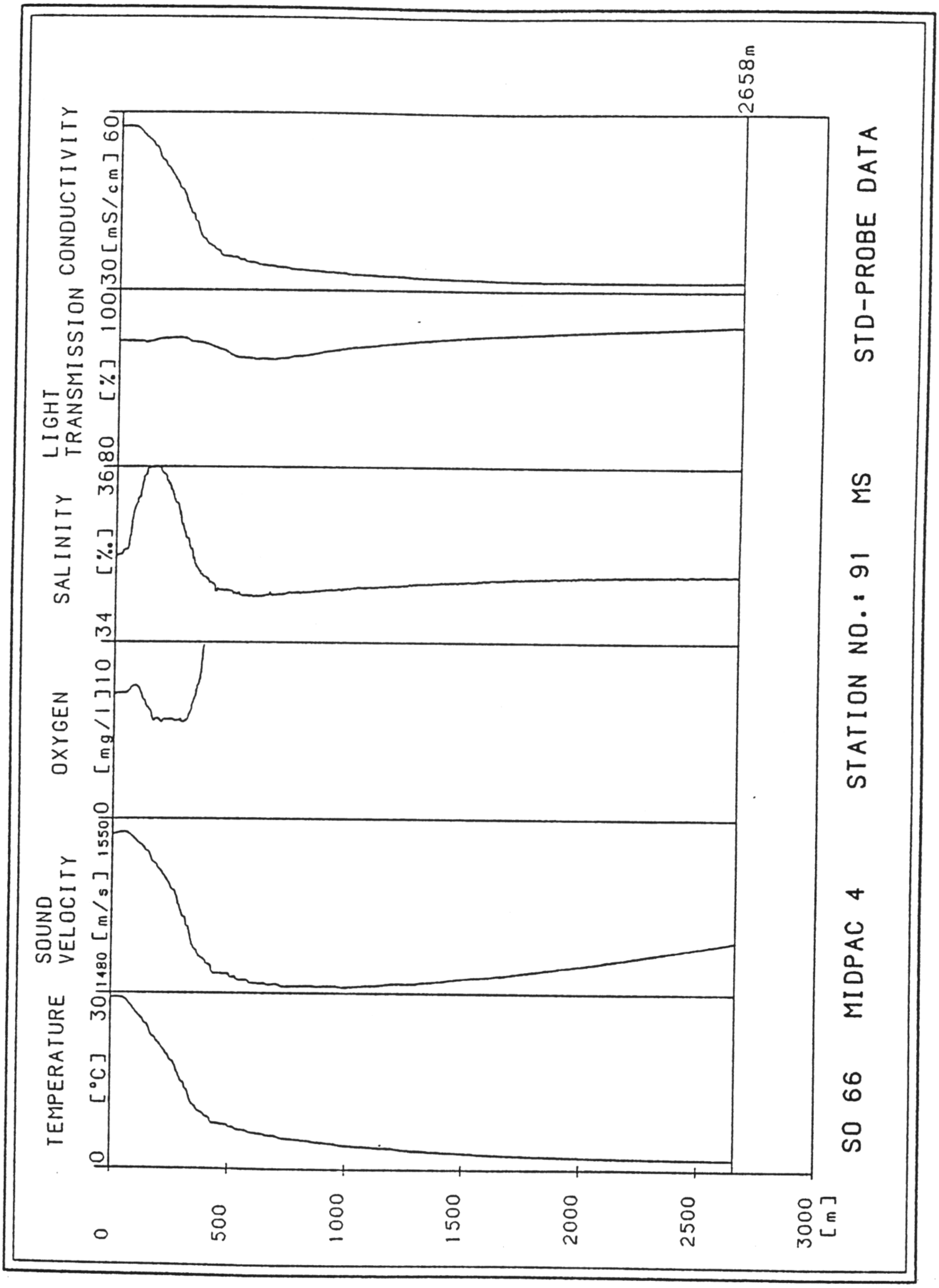
App. 8.3: 46 MS


TEMPERATURE [°C] 0 30
SOUND VELOCITY [m/s] 1480 1550
OXYGEN [mg/l] 0 10
SALINITY [‰] 34 36
LIGHT TRANSMISSION [%] 80 100
CONDUCTIVITY [mS/cm] 30 60
5183m
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 [m]
SO 66 MIDPAC 4 STATION NO.: 46 MS STD-PROBE DATA

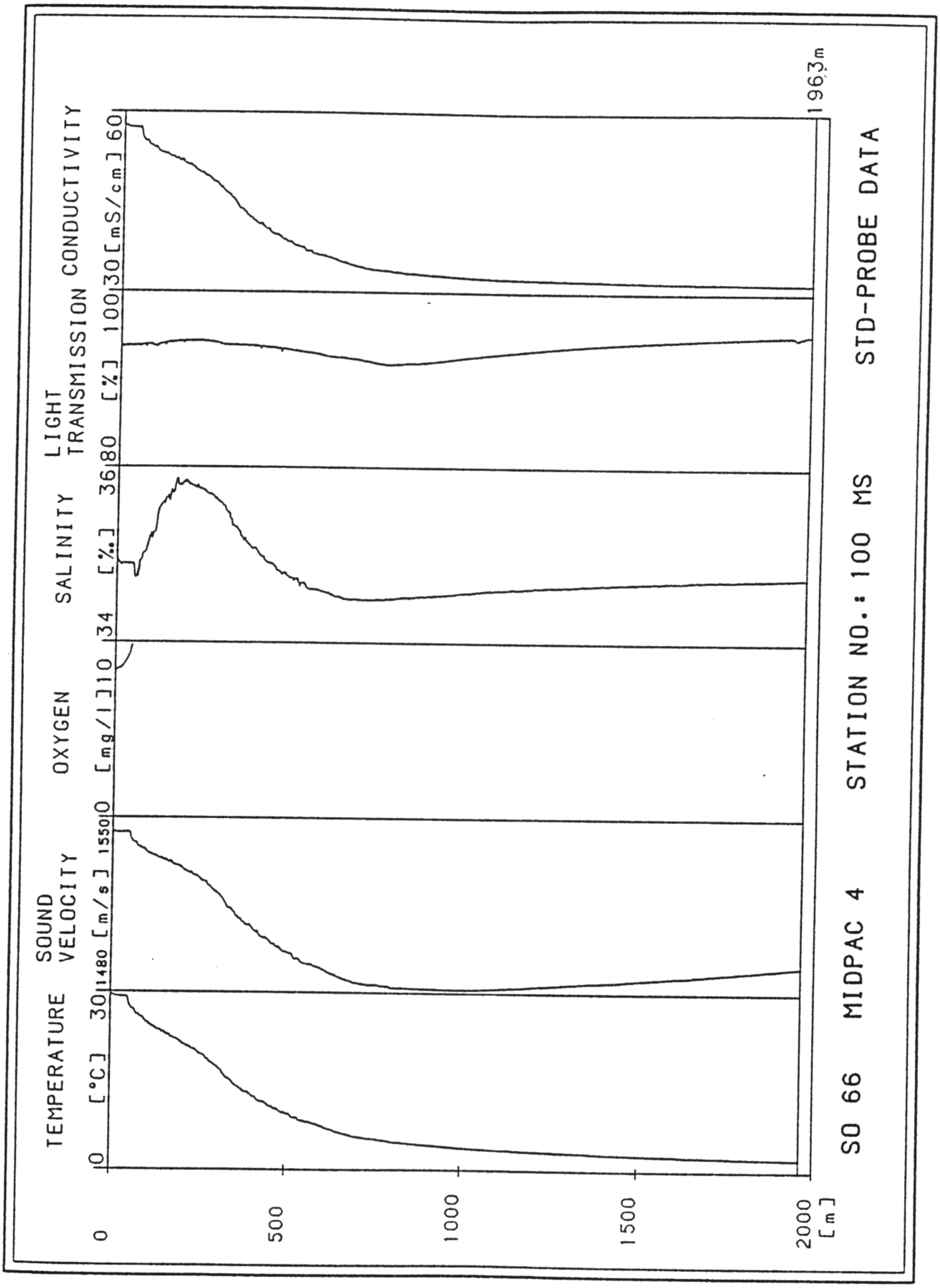
App. 8.4: 56 MS


STD-PROBE DATA
SO 66 MIDPAC 4 STATION NO.: 56 MS
TEMPERATURE [°C] 0 30
SOUND VELOCITY [m/s] 1480 1550
OXYGEN [mg/l] 0 10
SALINITY [‰] 34 36
LIGHT TRANSMISSION [%] 80 100
CONDUCTIVITY [mS/cm] 30 60
5029m
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 [m]

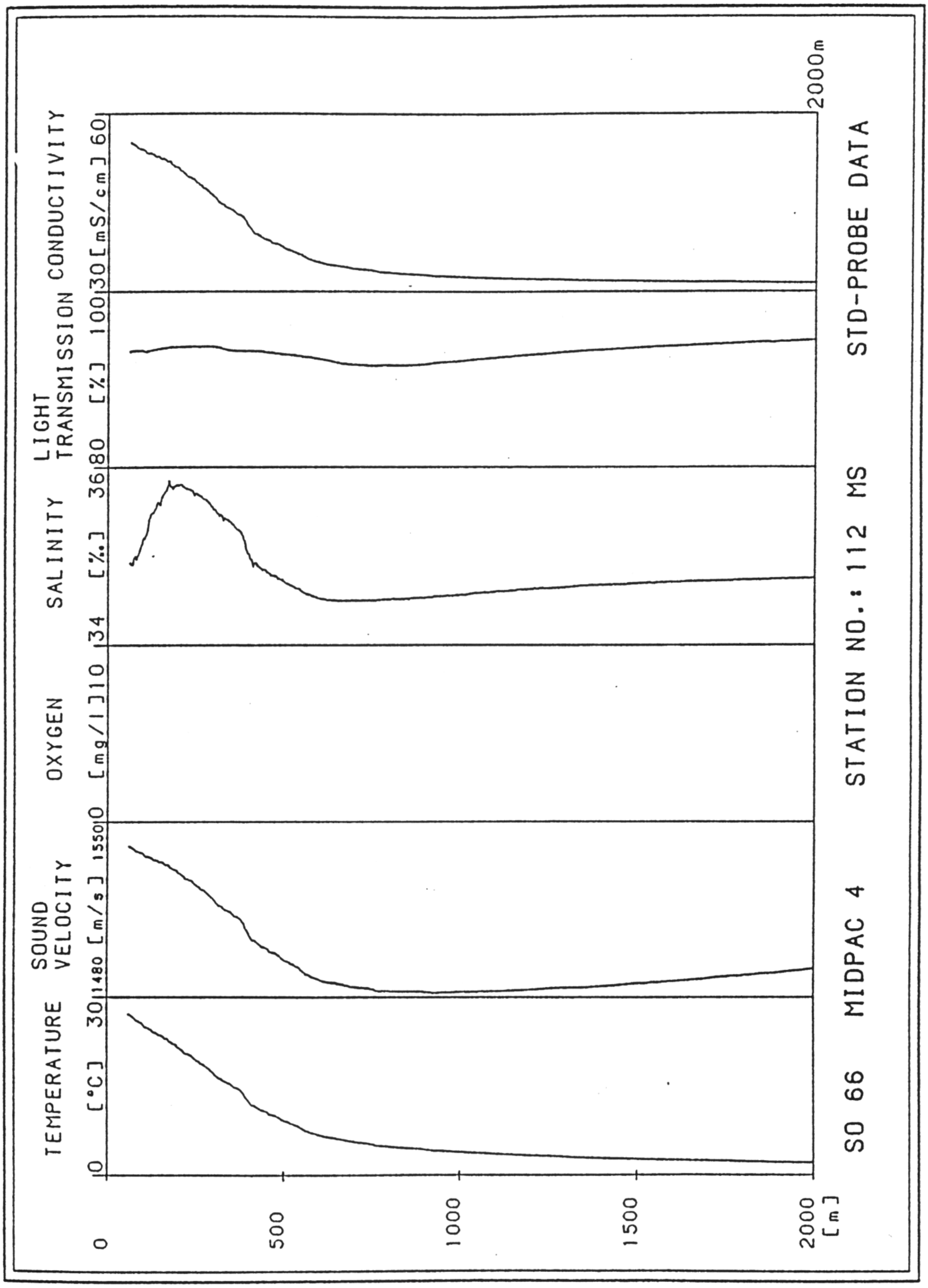
App. 8.5: 91 MS


TEMPERATURE [°C] 0 30
SOUND VELOCITY [m/s] 1480 1550
OXYGEN [mg/l] 0 10
SALINITY [‰] 34 36
LIGHT TRANSMISSION [%] 80 100
CONDUCTIVITY [mS/cm] 30 60
2658m
0
500
1000
1500
2000
2500
3000 [m]
SO 66 MIDPAC 4 STATION NO.: 91 MS STD-PROBE DATA

App. 8.6: 100 MS

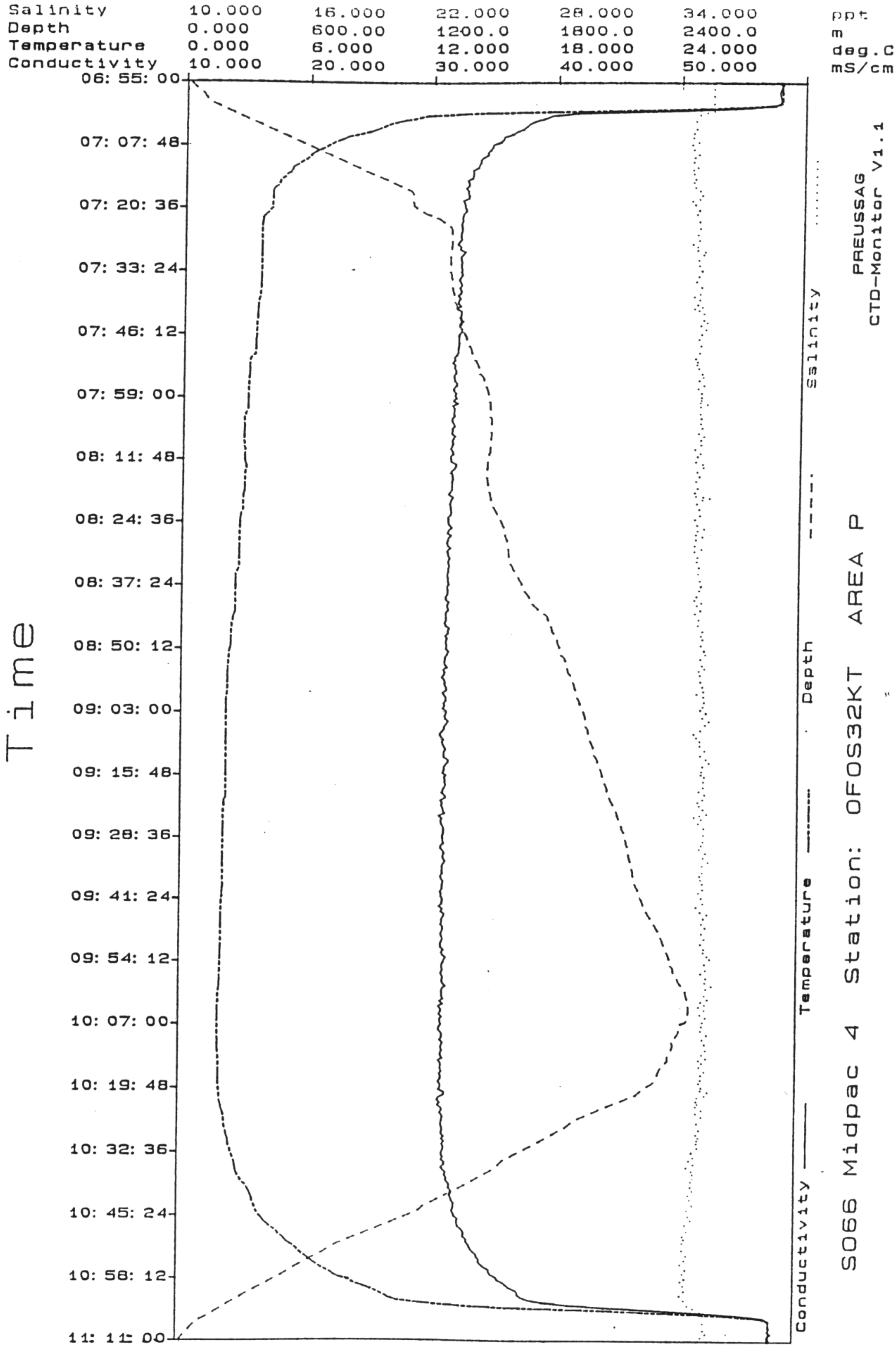

TEMPERATURE [°C] 0 30
SOUND VELOCITY [m/s] 1480 1550
OXYGEN [mg/l] 0 10
SALINITY [‰] 34 36
LIGHT TRANSMISSION [%] 80 100
CONDUCTIVITY [mS/cm] 30 60
1963m
0 500 1000 1500 2000 [m]
SO 66 MIDPAC 4 STATION NO.: 100 MS STD-PROBE DATA

App. 8.7: 112 MS

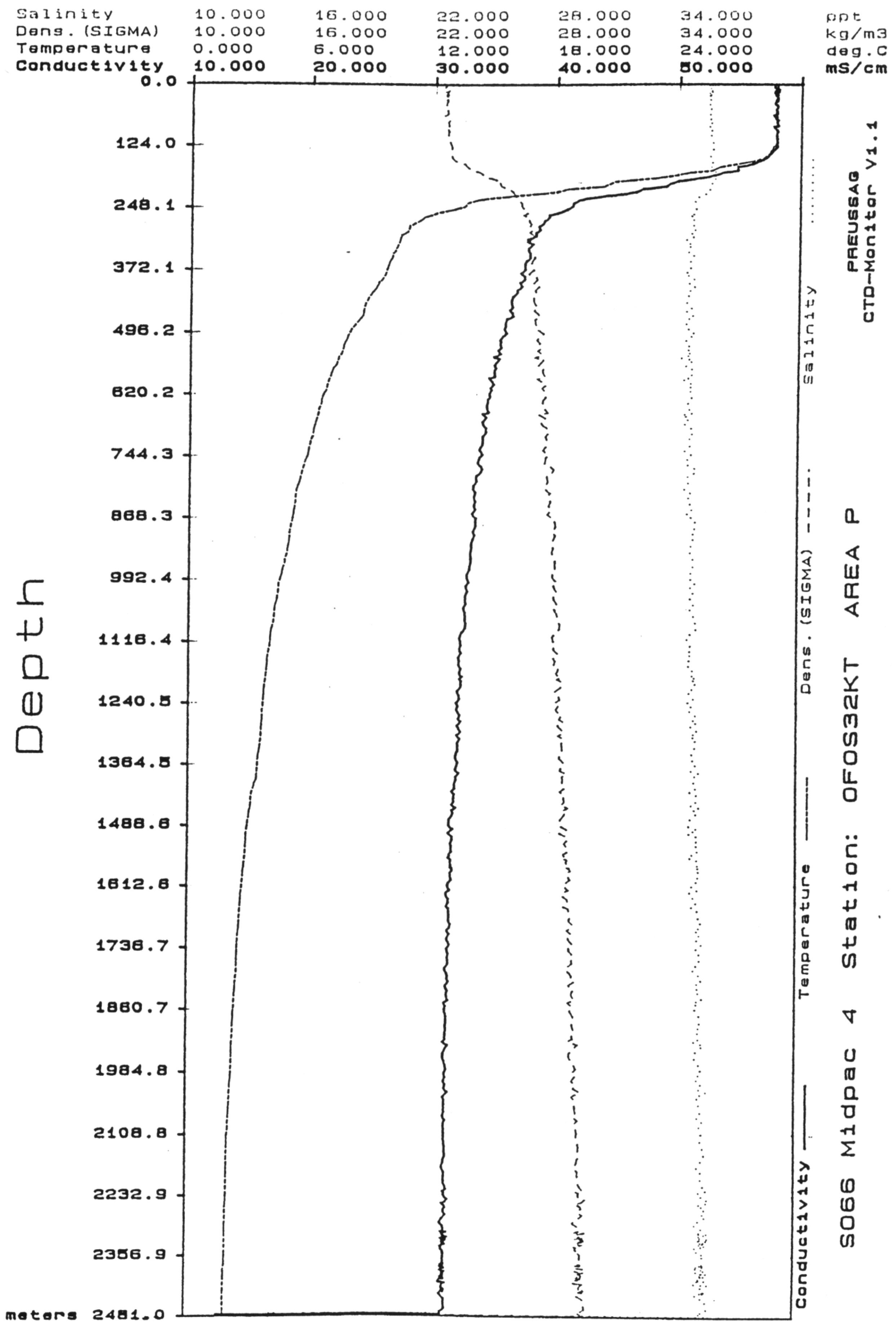

SO 66 MIDPAC 4 STATION NO.: 112 MS STD-PROBE DATA
TEMPERATURE [°C] 0 30
SOUND VELOCITY [m/s] 1480 1550
OXYGEN [mg/l] 0 10
SALINITY [‰] 34 36
LIGHT TRANSMISSION [%] 80 100
CONDUCTIVITY [mS/cm] 30 60
0 500 1000 1500 2000 [m]
2000m

Appendix 9: Selected CTD-profiles from the OFOS-KT stations

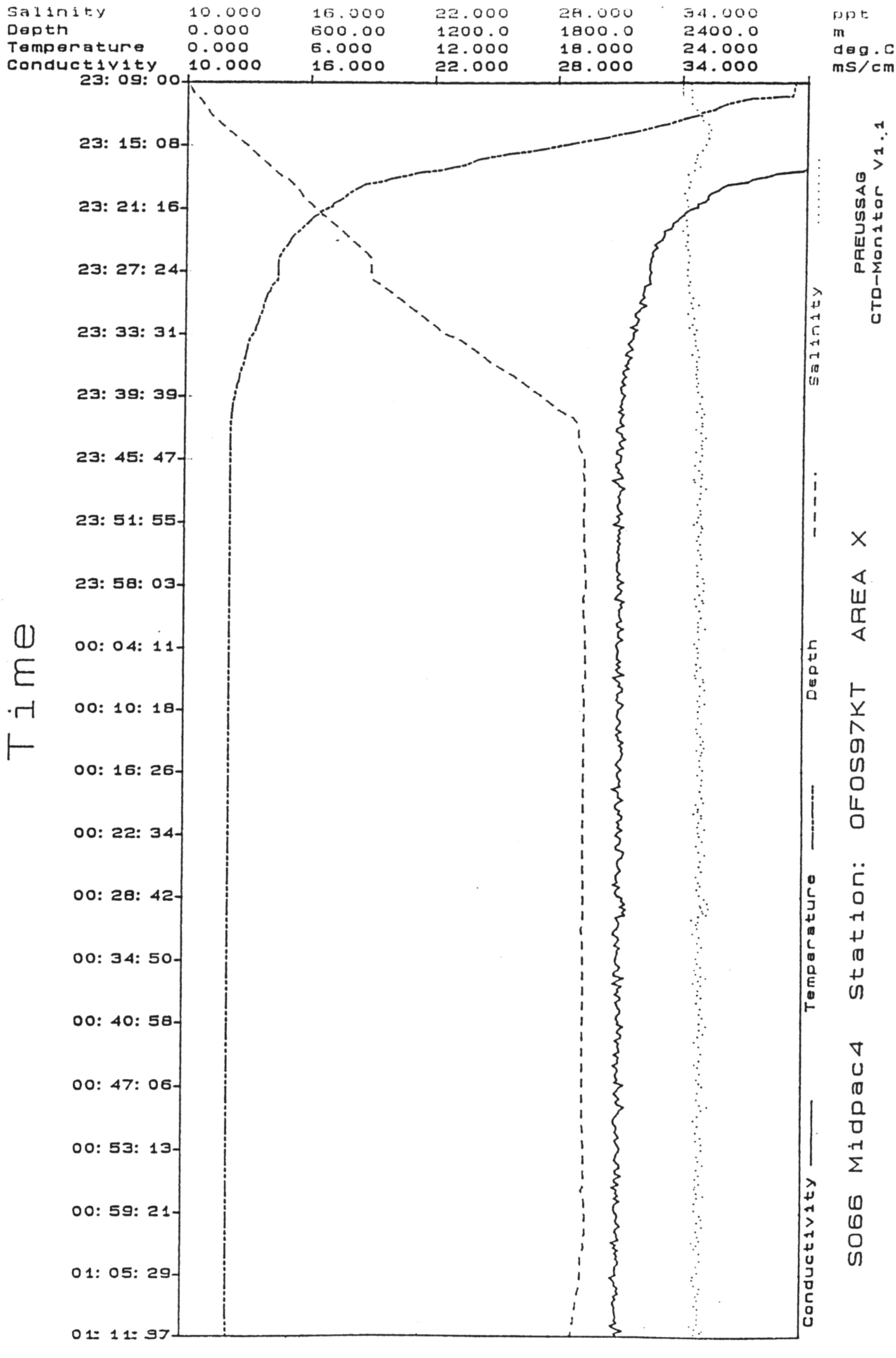
App. 9.1: 32 OFOS-KT, time profile



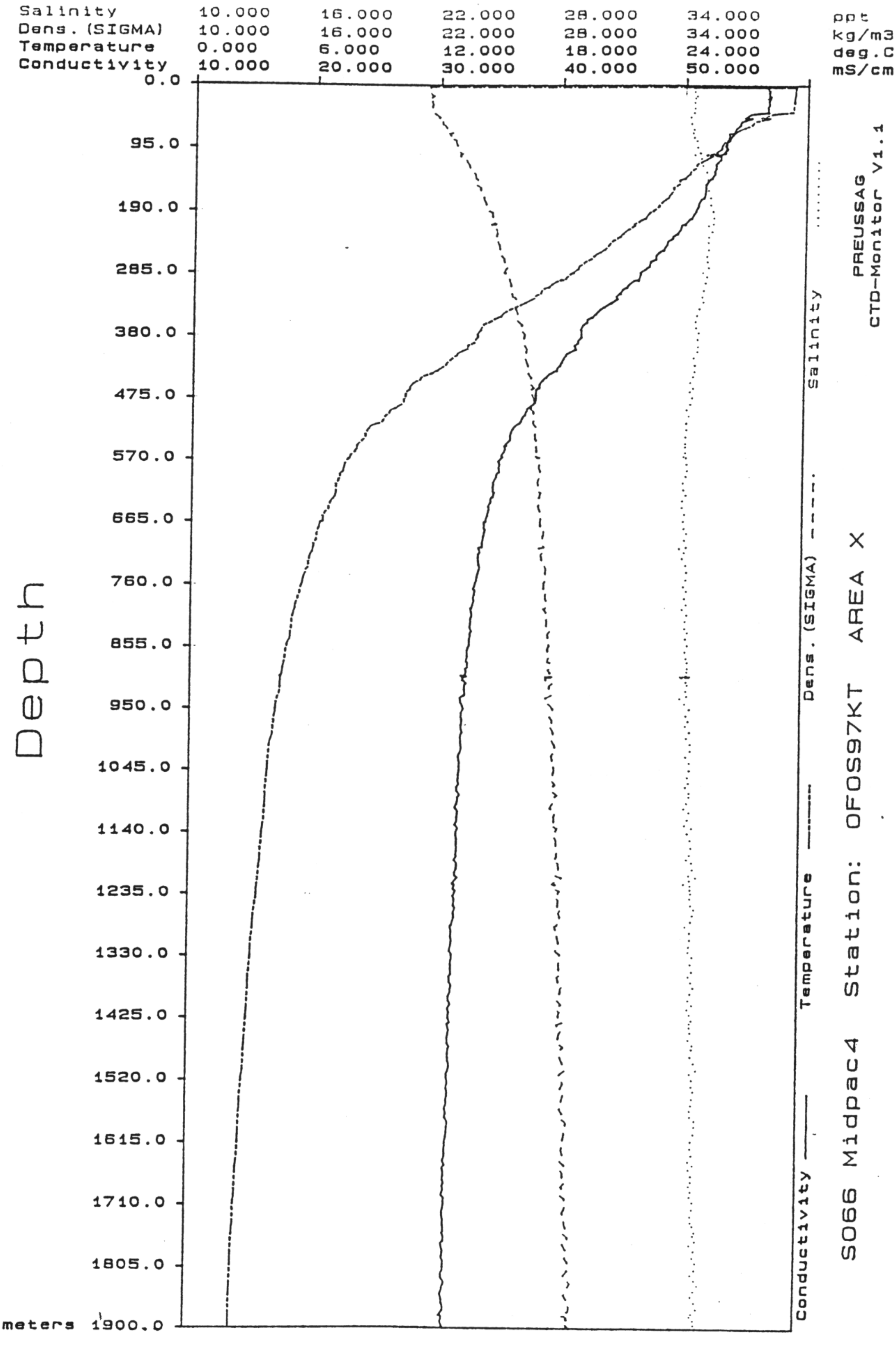
App. 9.2: 32 OFOS-KT, depth profile



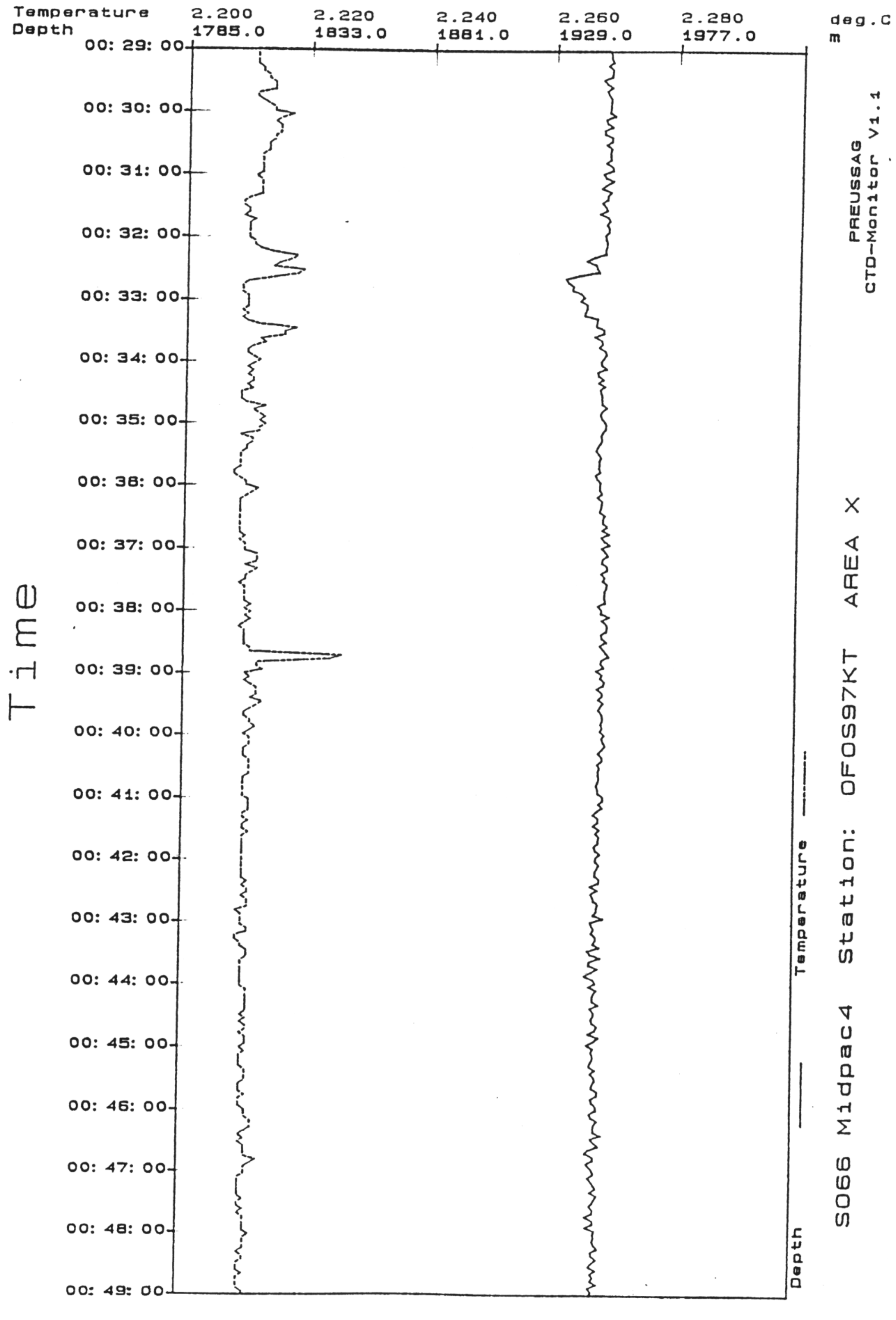
App. 9.3: 97 OFOS-KT, time profile



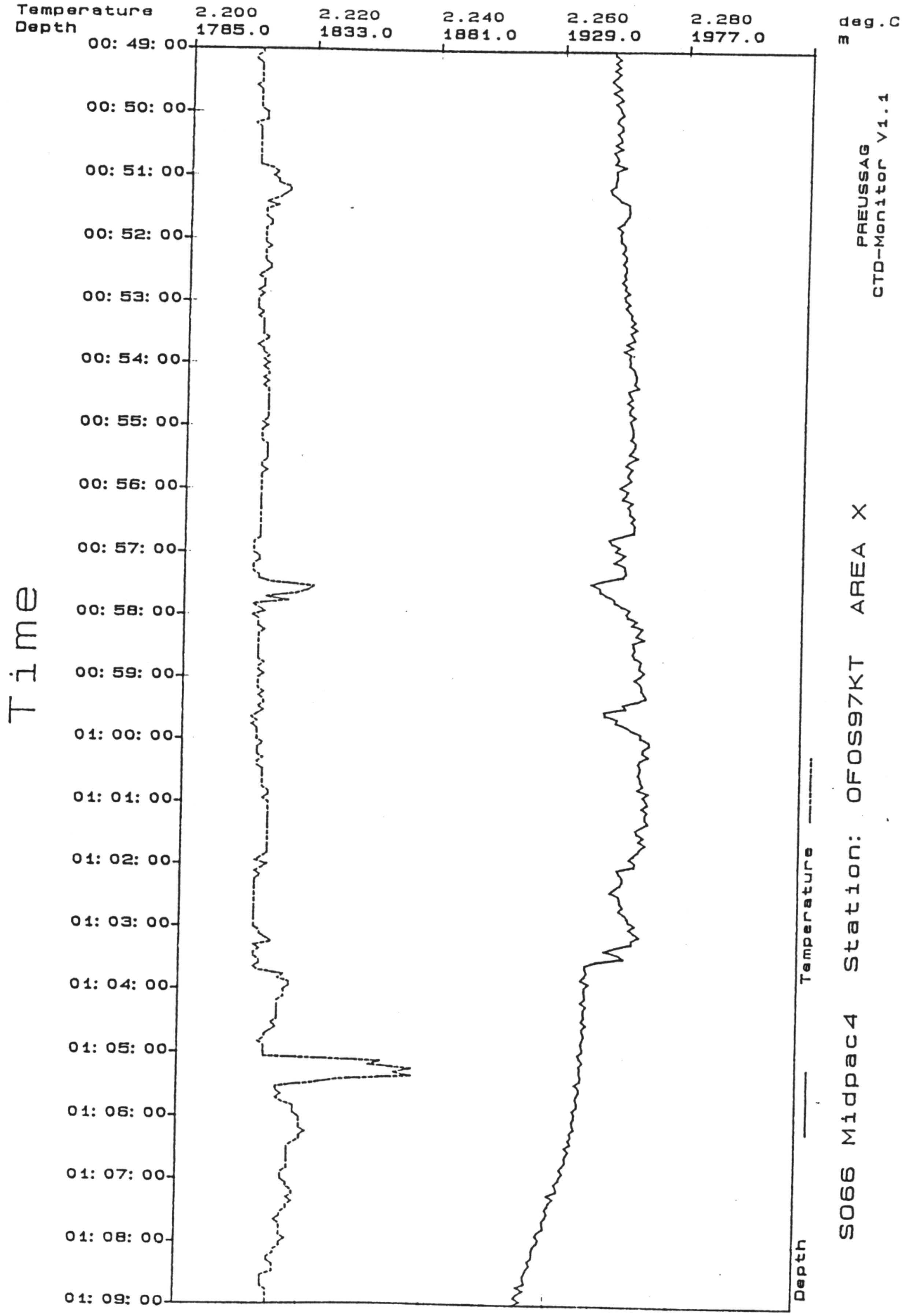
App. 9.4: 97 OFOS-KT, depth profile



App. 9.5: 97 OFOS-KT, highly resolved time-temperature profile

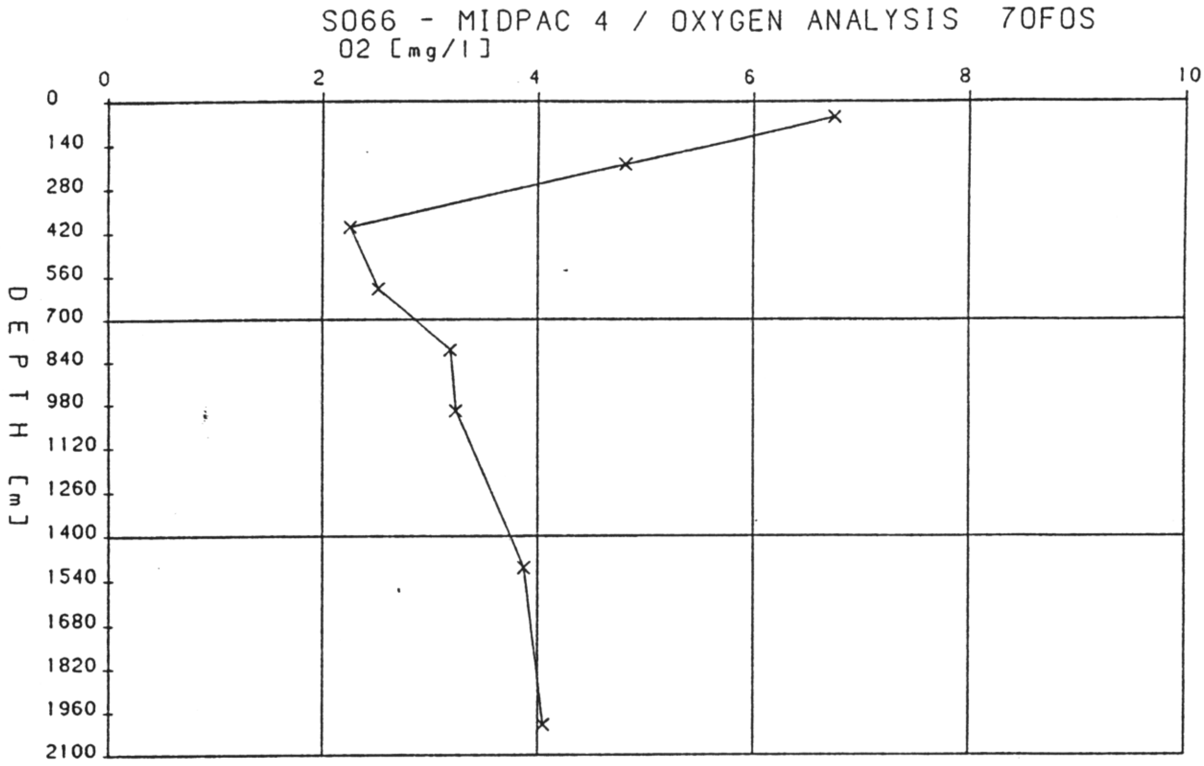


App. 9.6: 97 OFOS-KT, highly resolved time-temperature profile

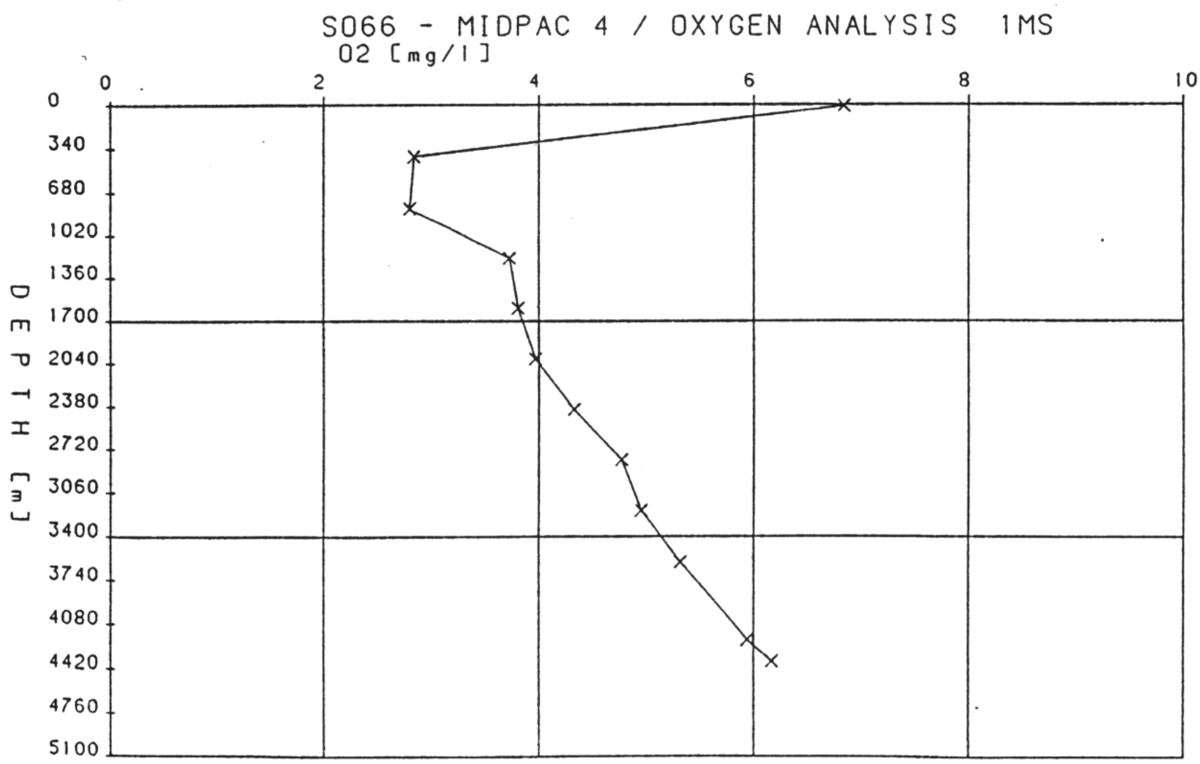


Appendix 10: Oxygen profiles of the multisonde and OFOS-KT water stations

App. 10.1: Stations 1 MS and 7 OFOS-KT

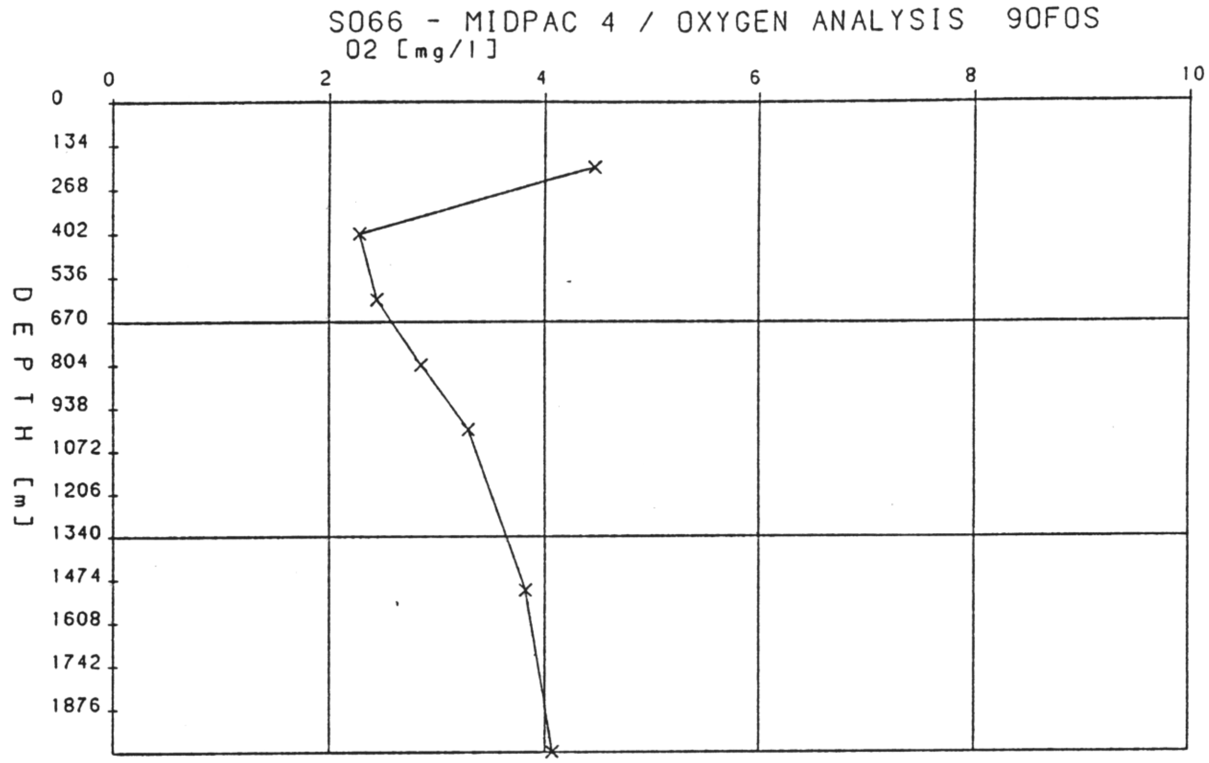


Area P 4°10.75' S 174°49.41' W

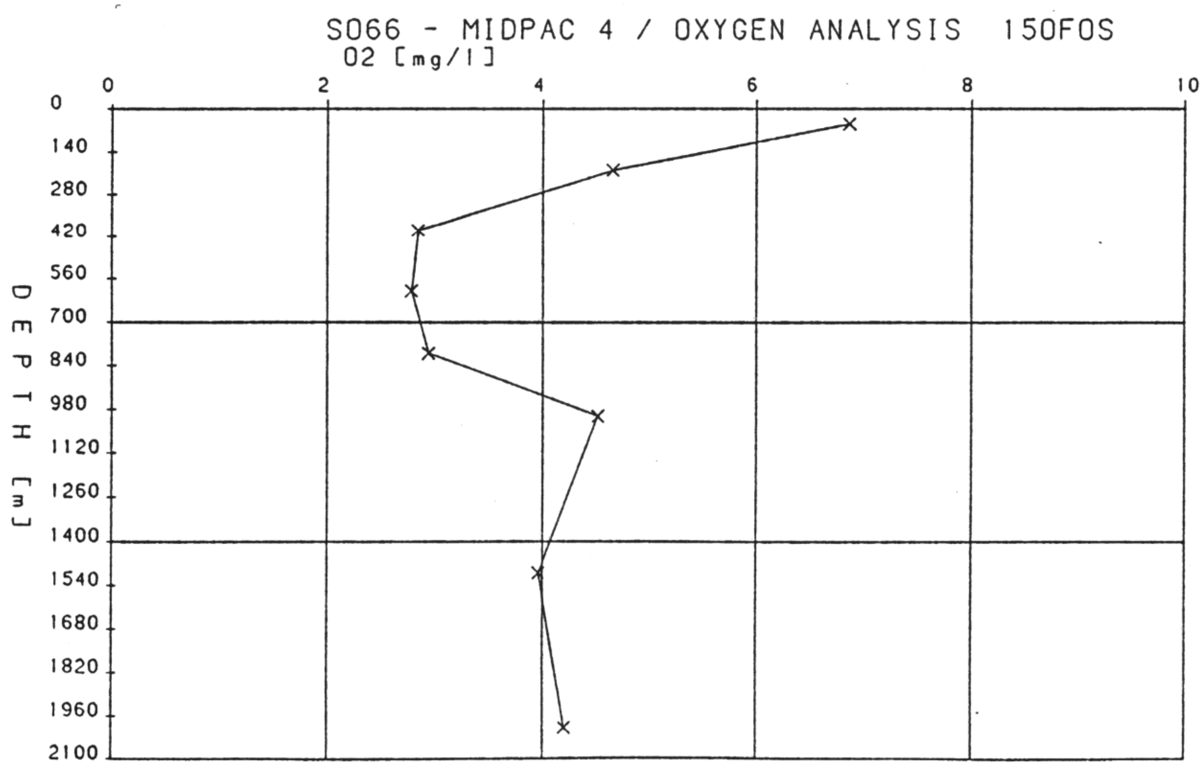


Area P 4°08.60' S 174°59.02' W

App. 10.2: Stations 9 OFOS-KT and 15 OFOS-KT

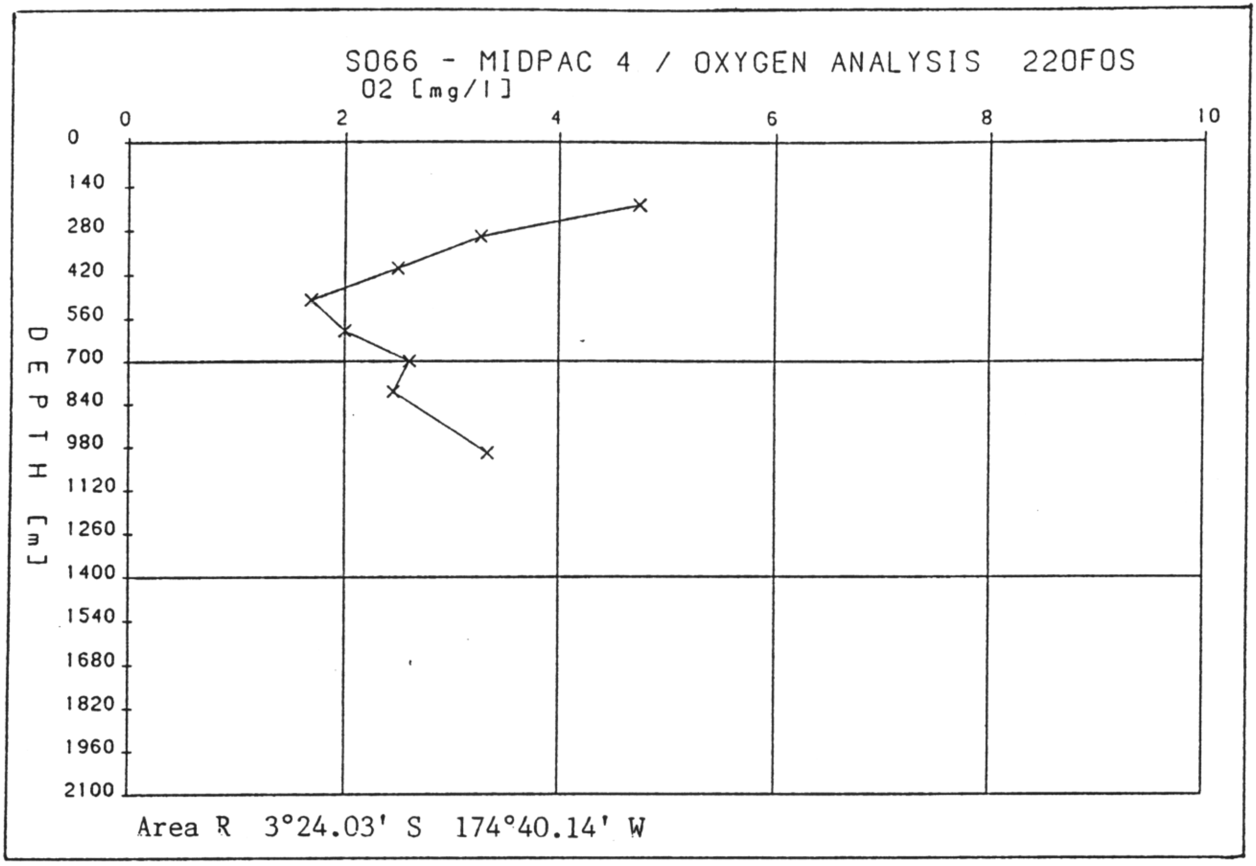


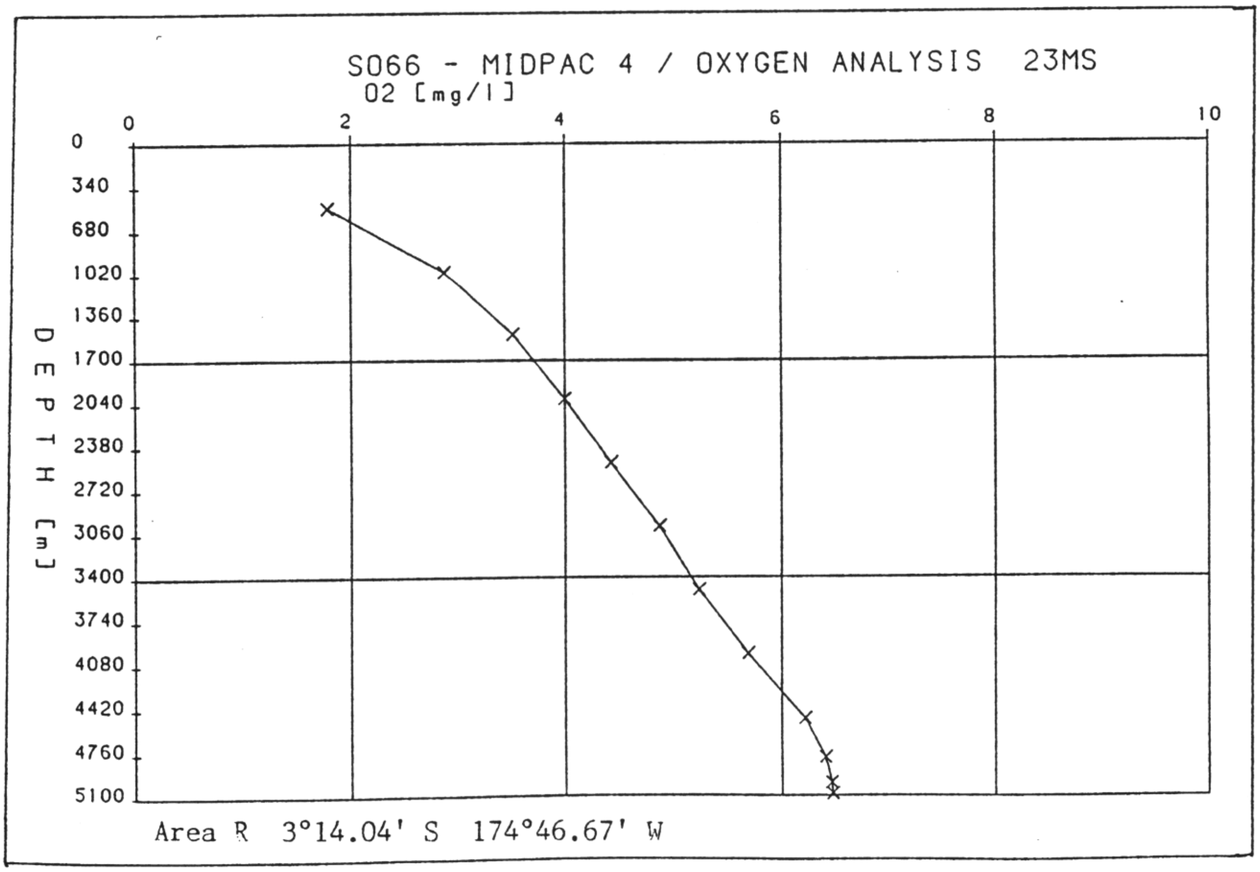
Area P 4°07.46' S 174°49.12' W



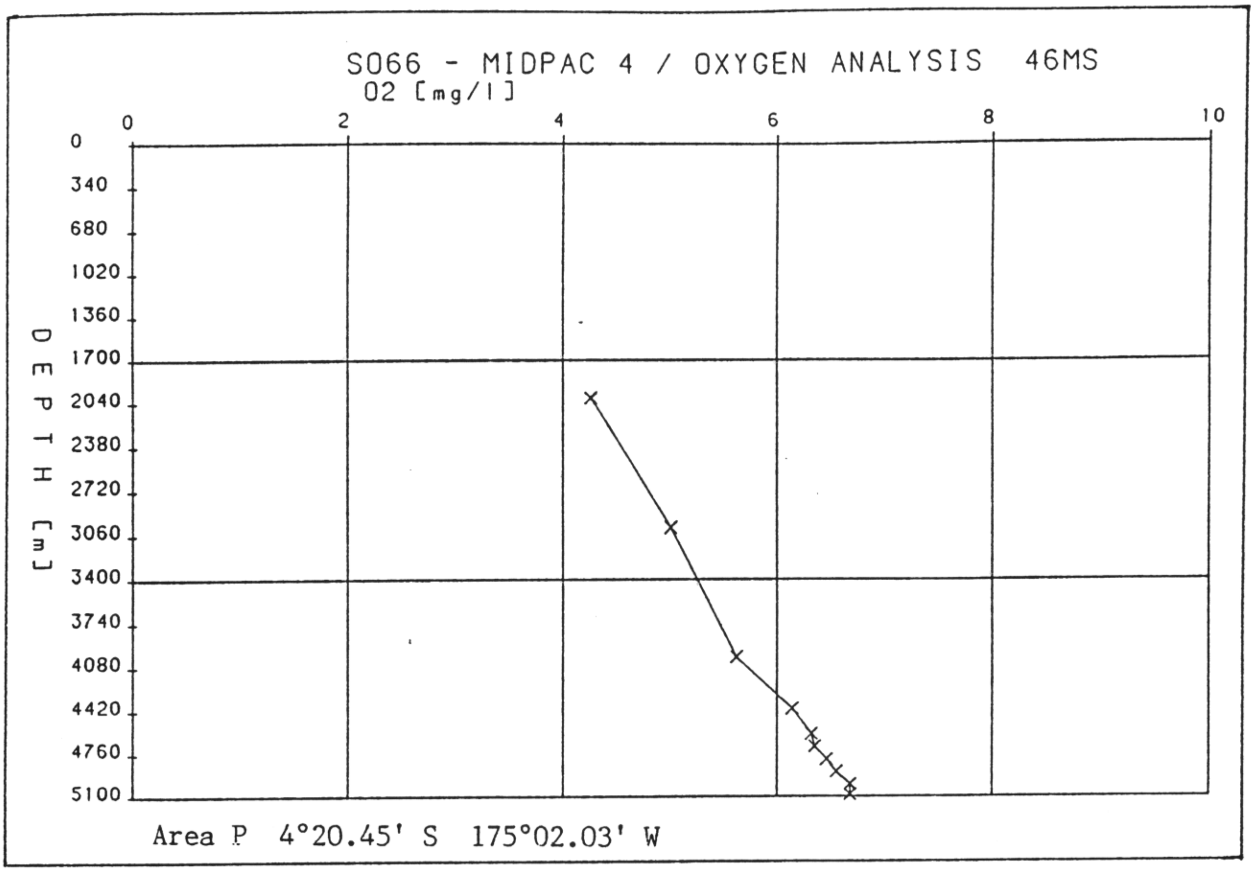
Area P 4°07.79' S 174°57.48' W

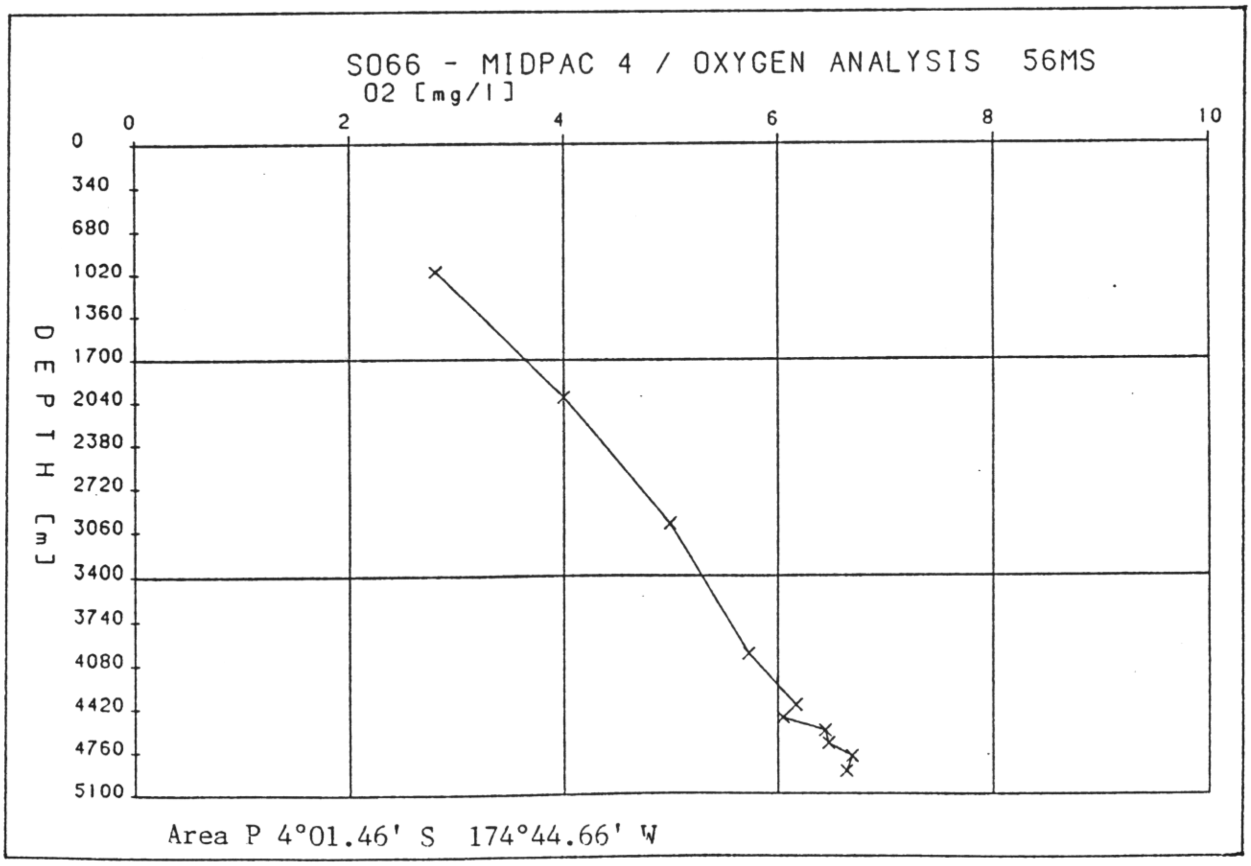
App. 10.3: Stations 22 OFOS-KT and 23 MS



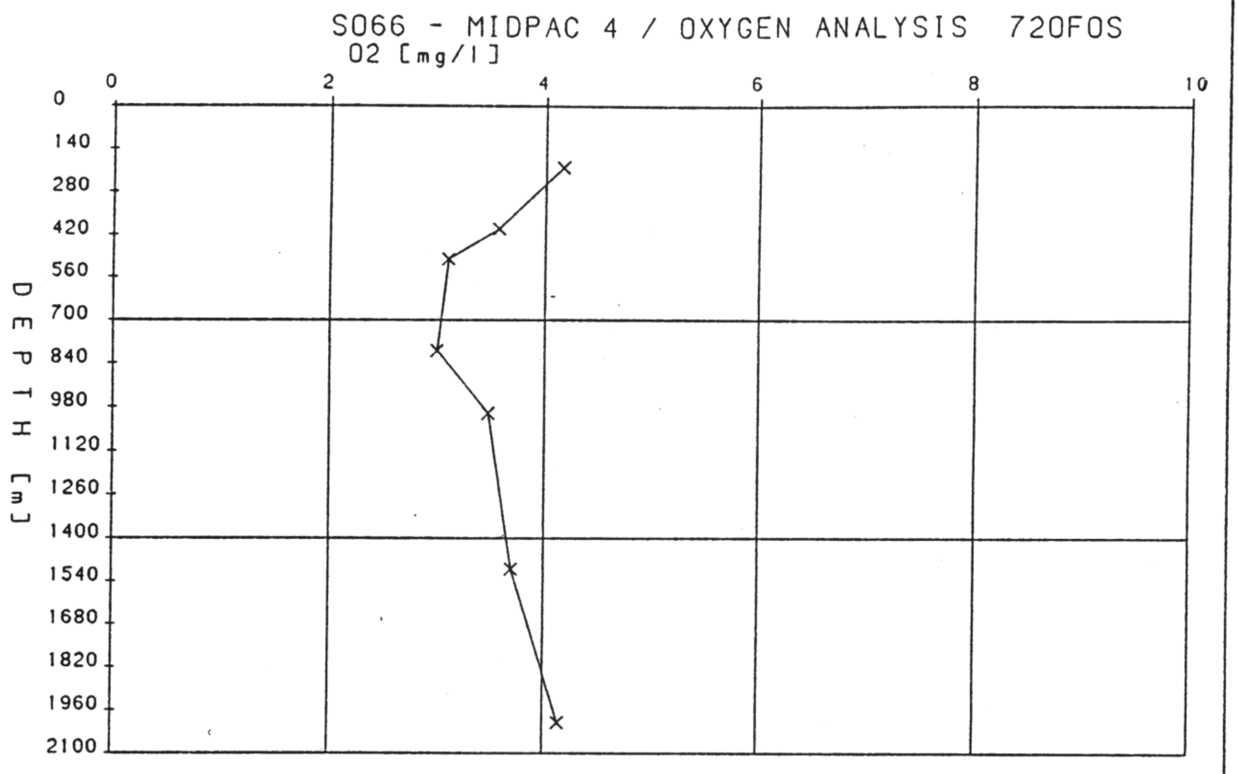


App. 10.4: Stations 46 MS and 56 MS

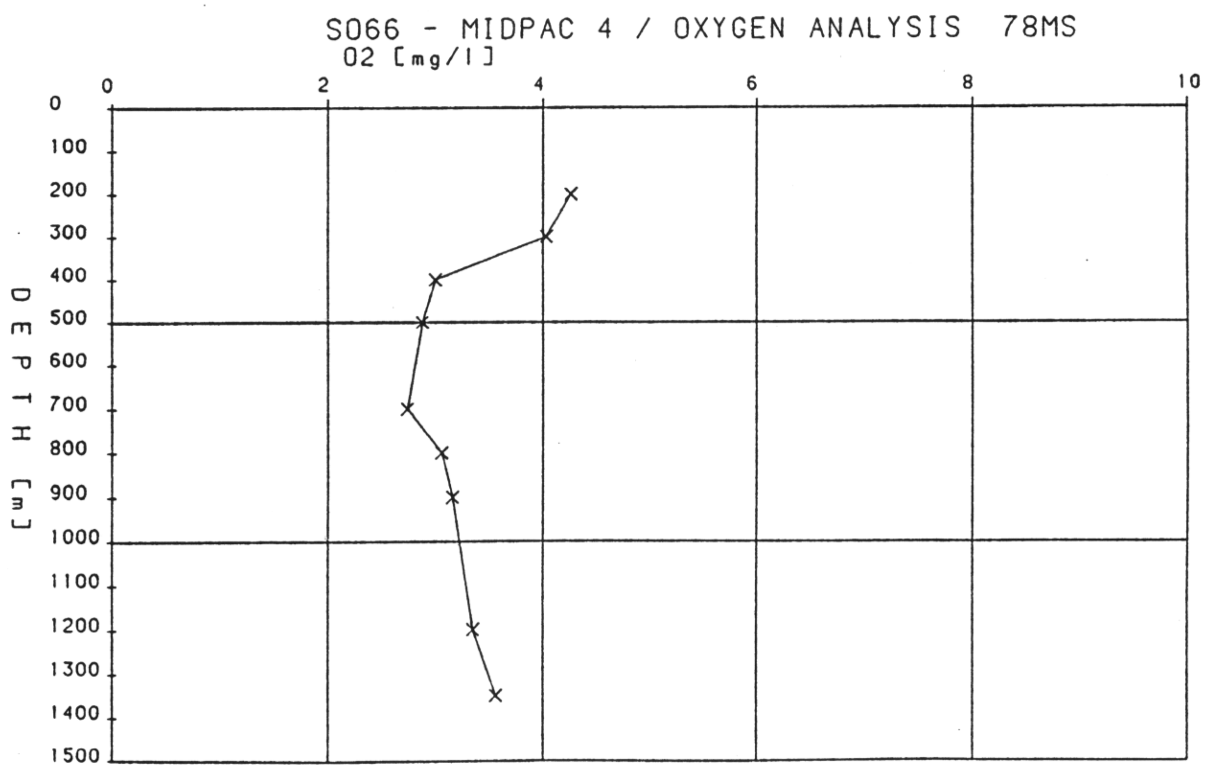




App. 10.5: Stations 72 OFOS-KT and 78 MS

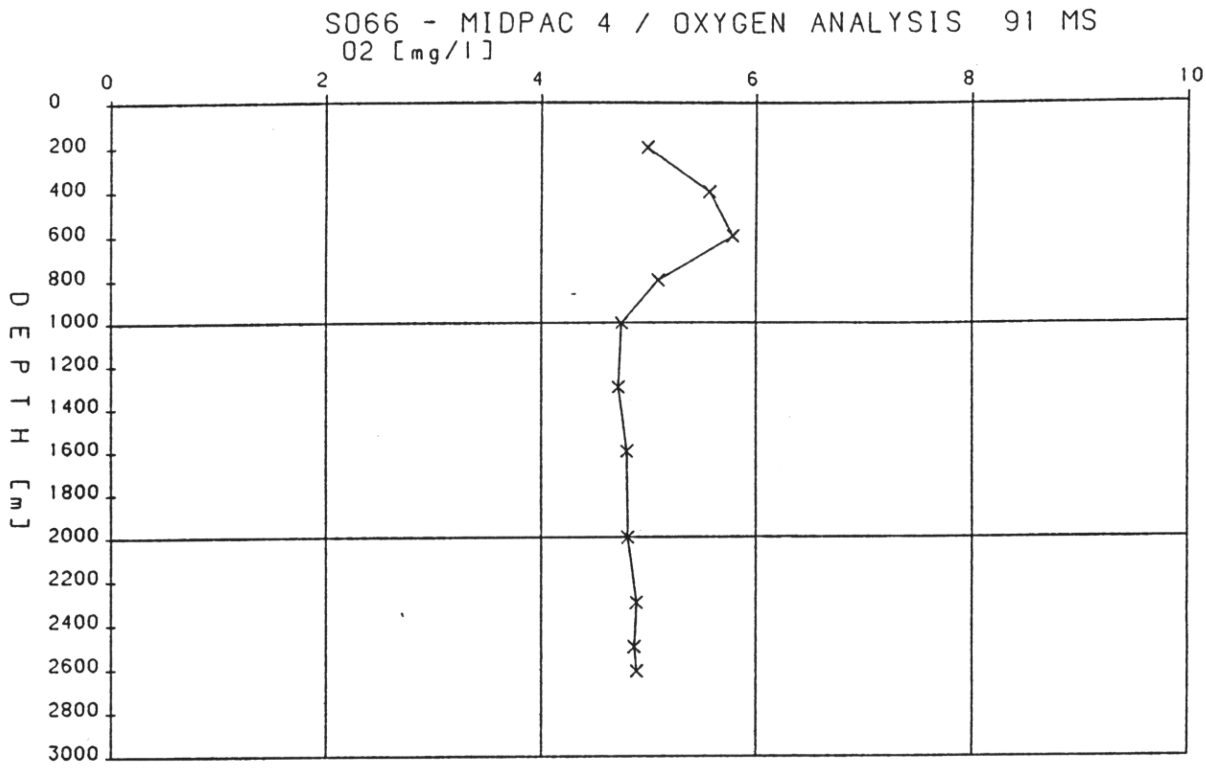


Area T 2°02.20' S 176°07.50 E

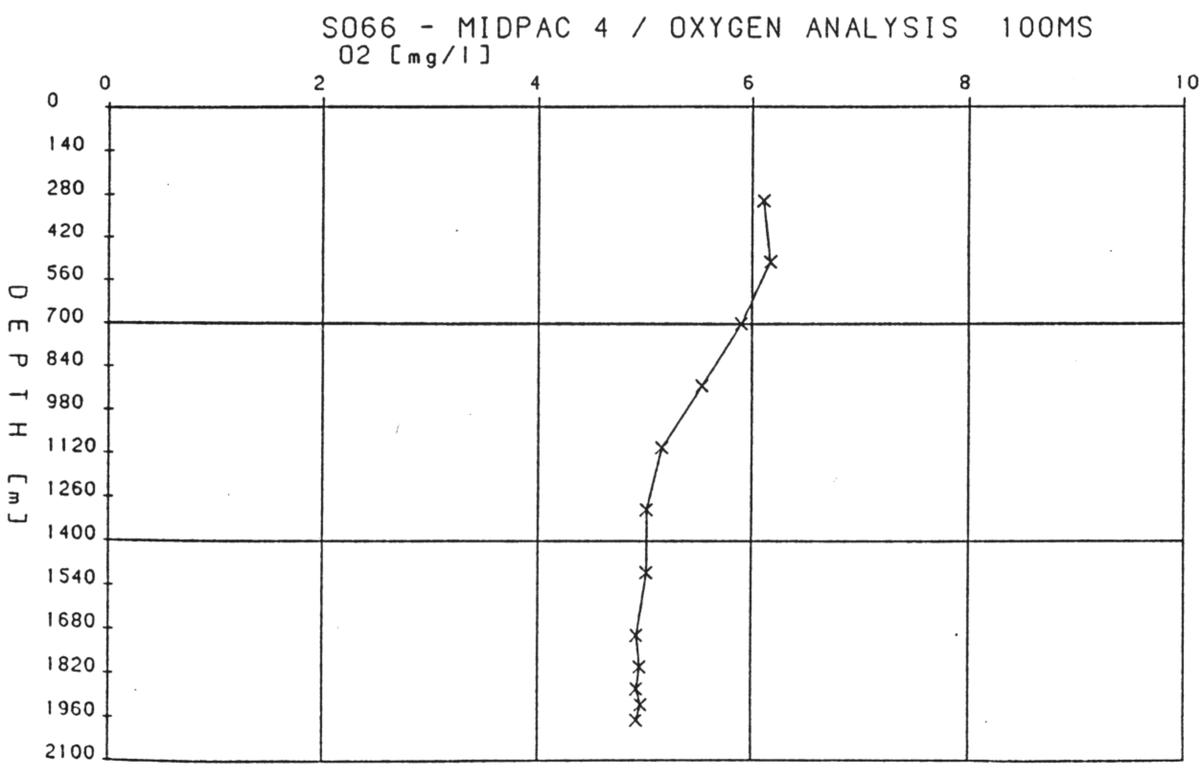


Area T 2°03.95' S 176°11.34' E

App. 10.6: Stations 91 MS and 100 MS

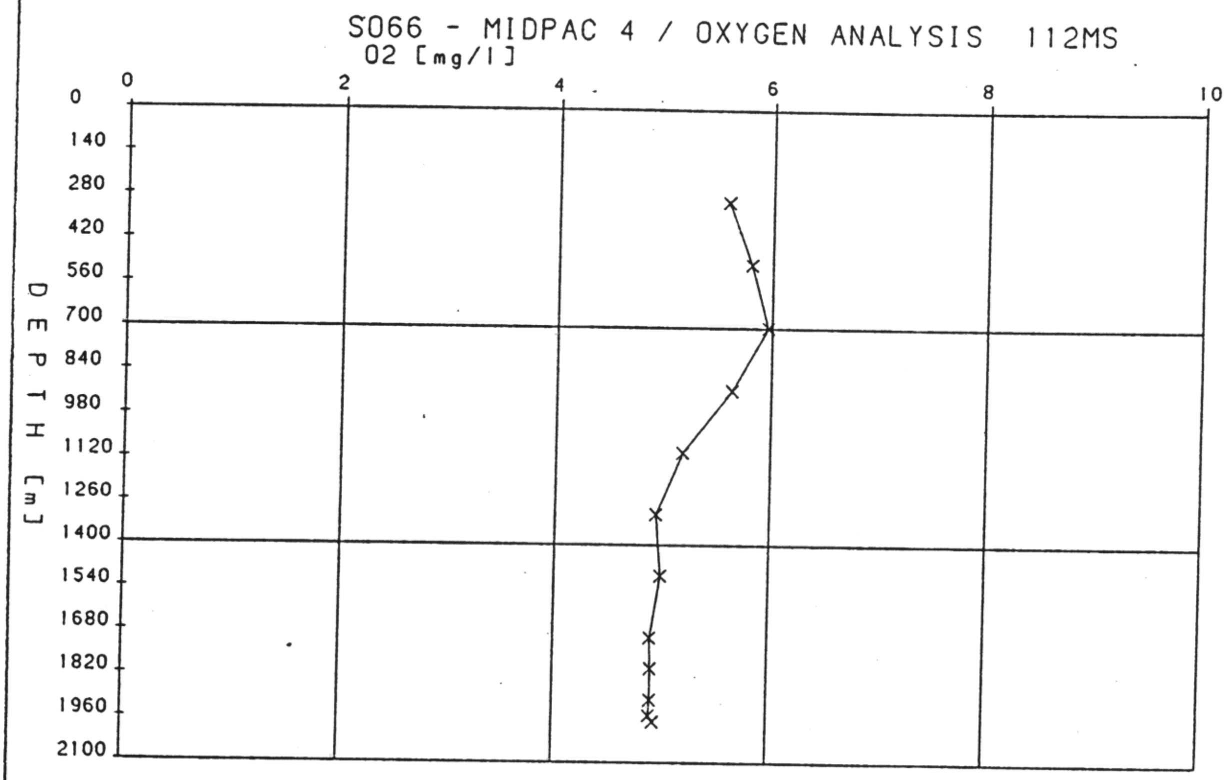


Area W 13°97.70' S 175°53.05' E



Area X 16°58.26' S 173°54.90' E

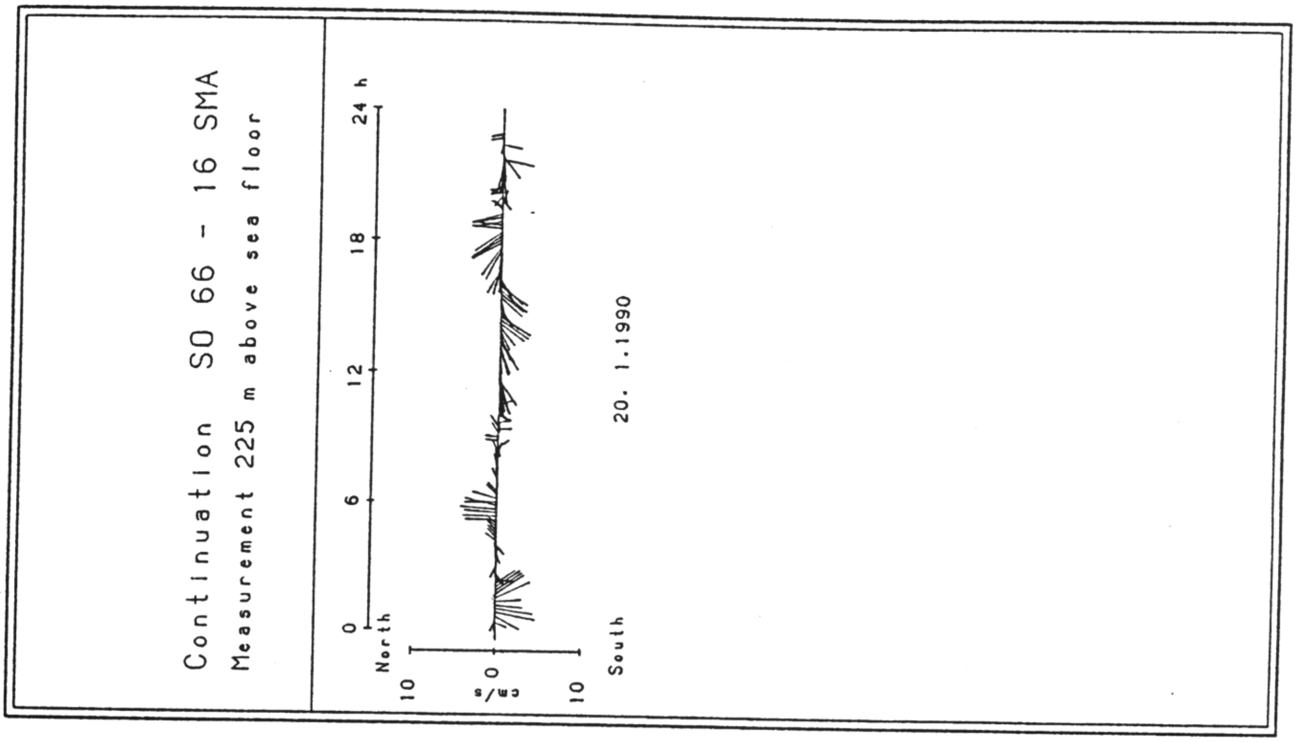
App. 10.7: Station 112 MS

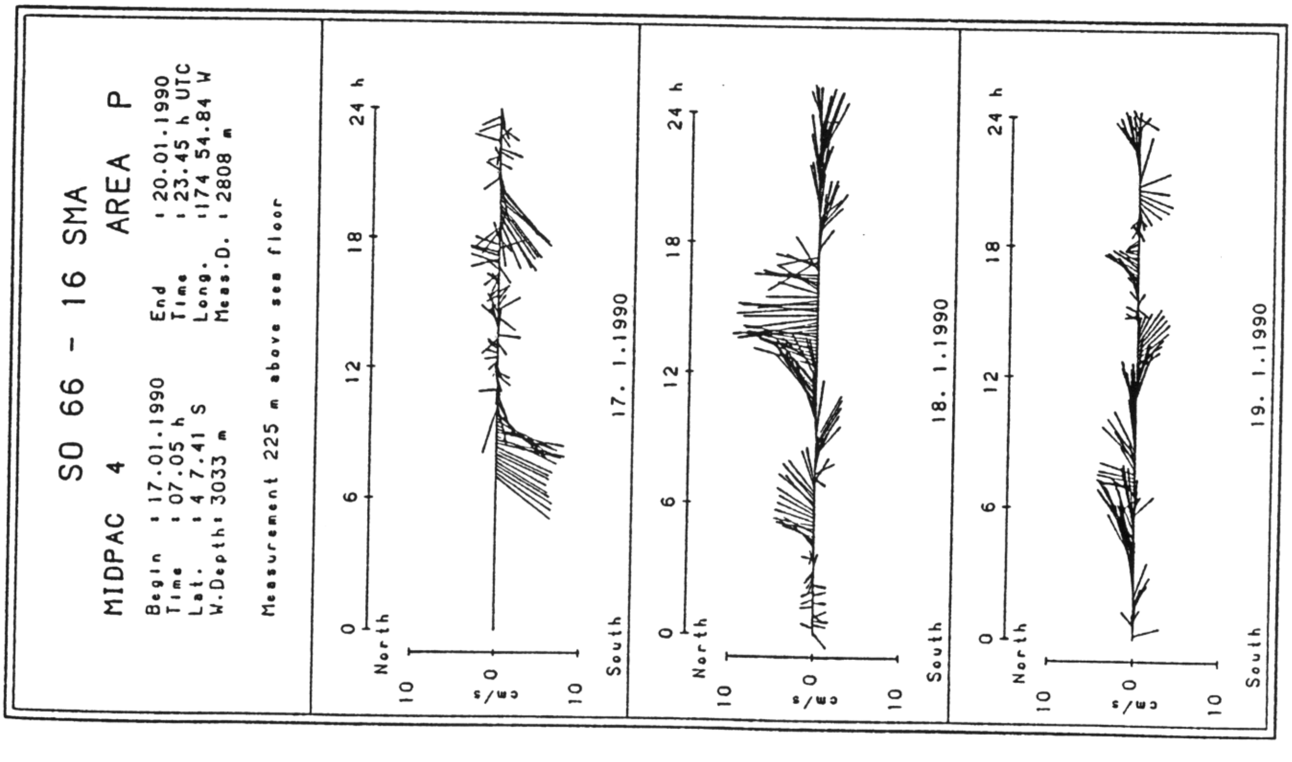


Area X 16°59.36' S 173°54.56' E

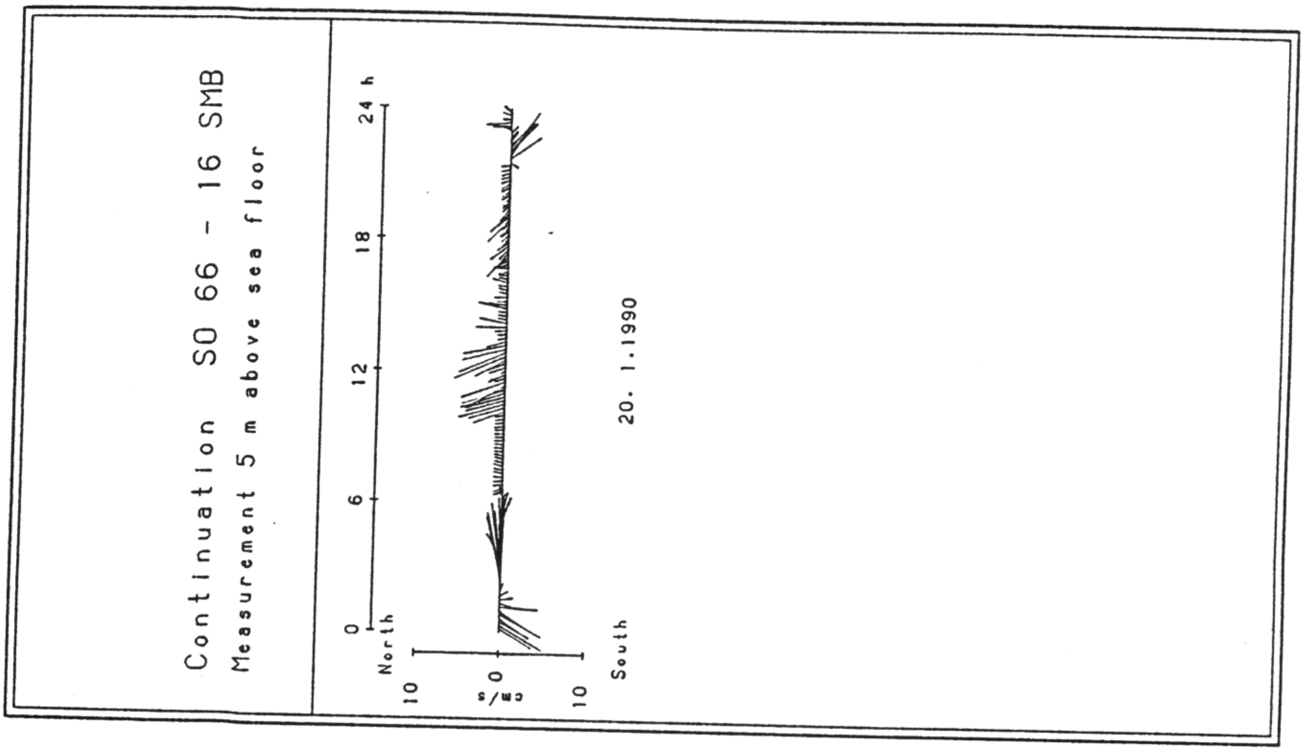
Appendix 11: Current meter measurements

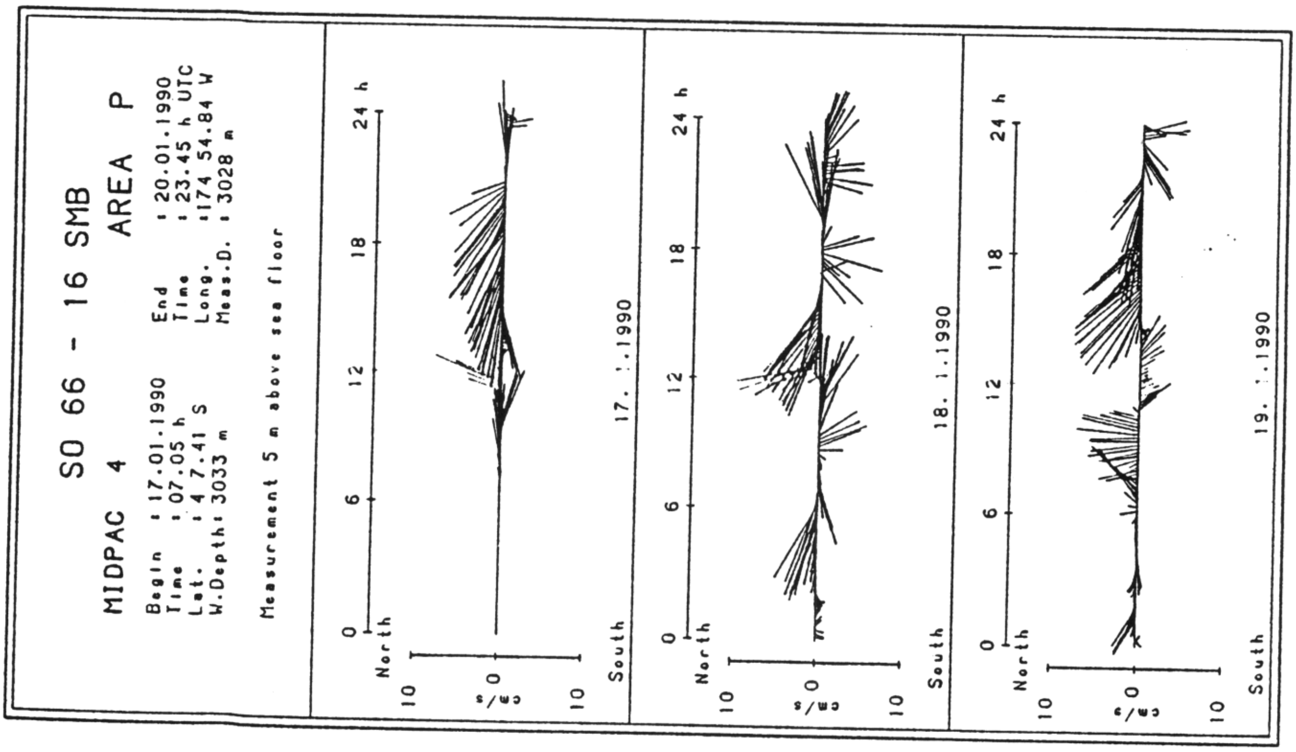
App. 11.1: Time series of 16 SMA



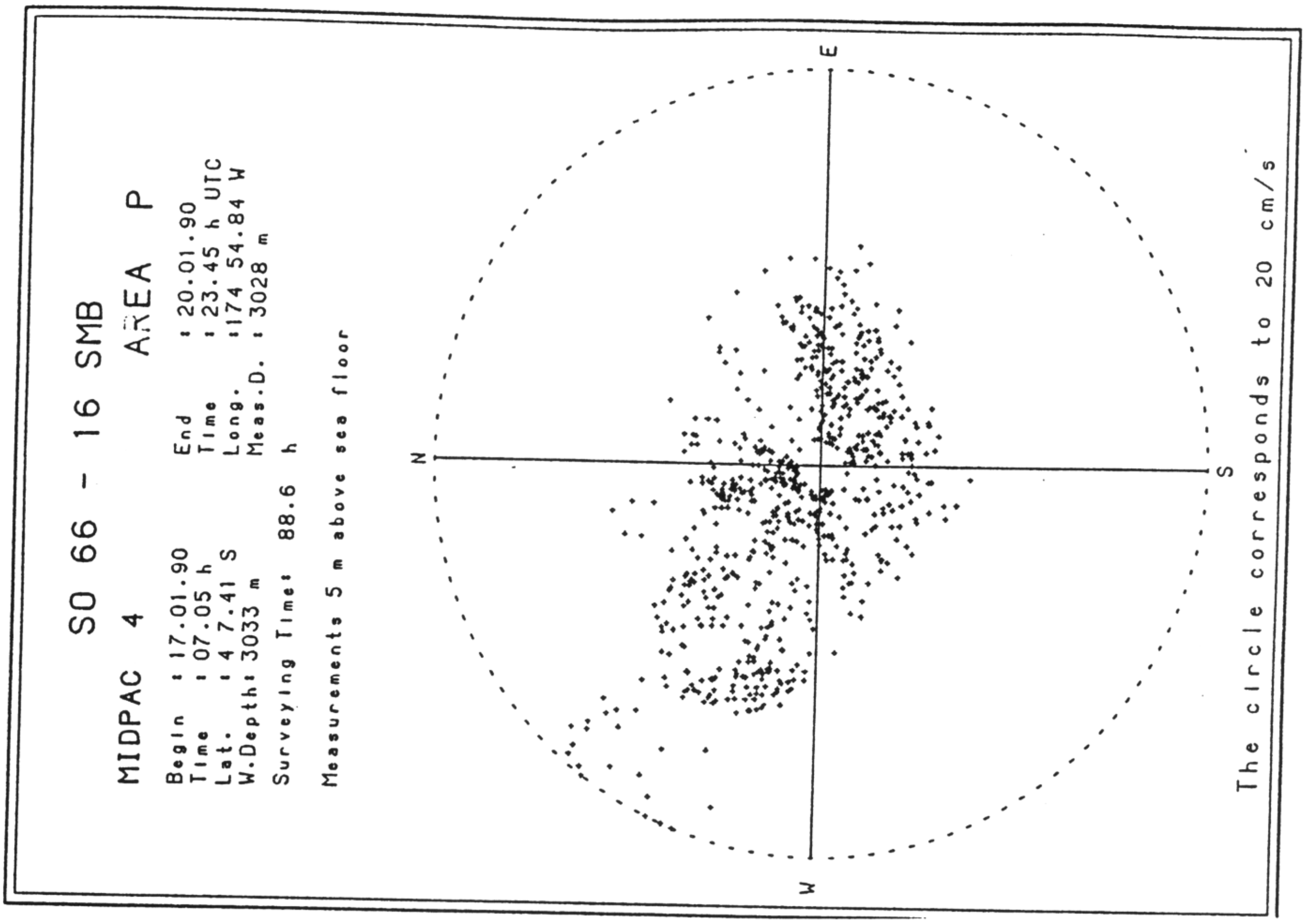


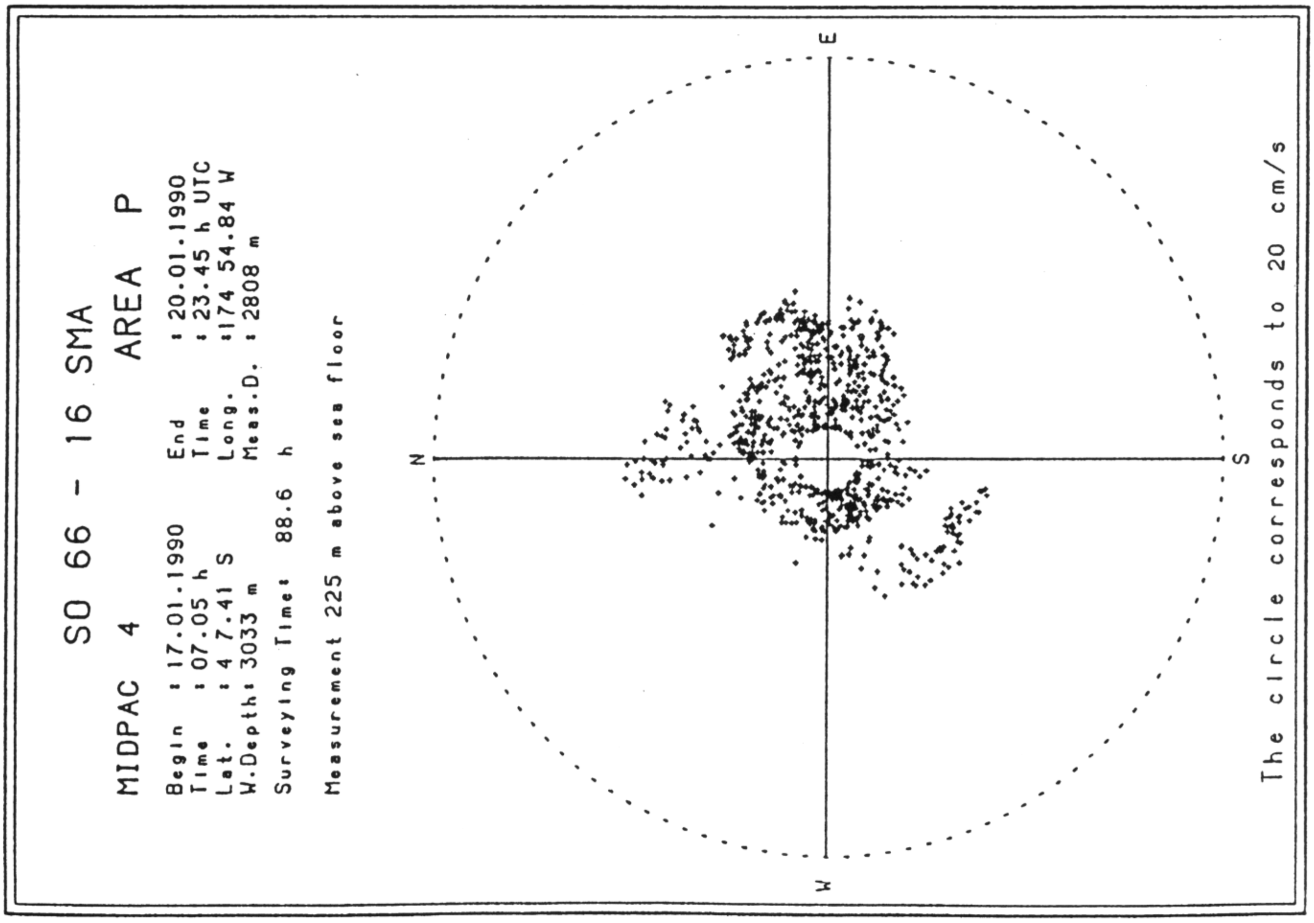
App. 11.2: Time series of 16 SMB



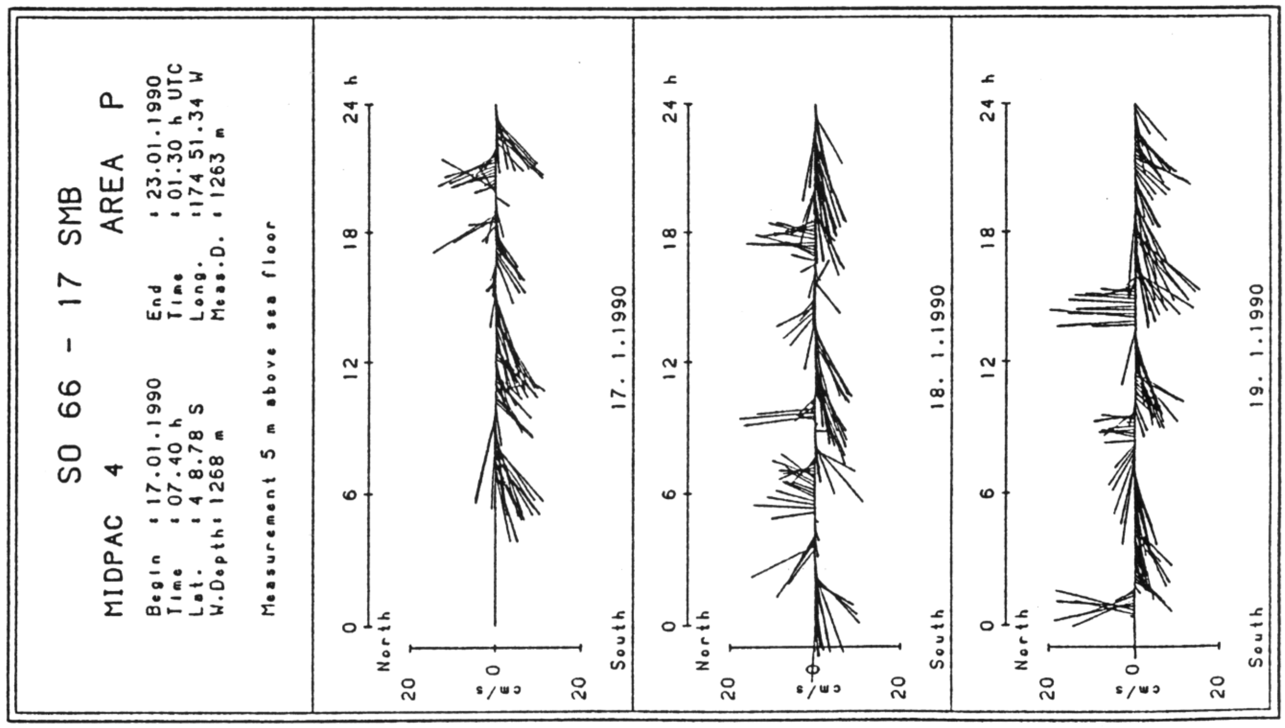


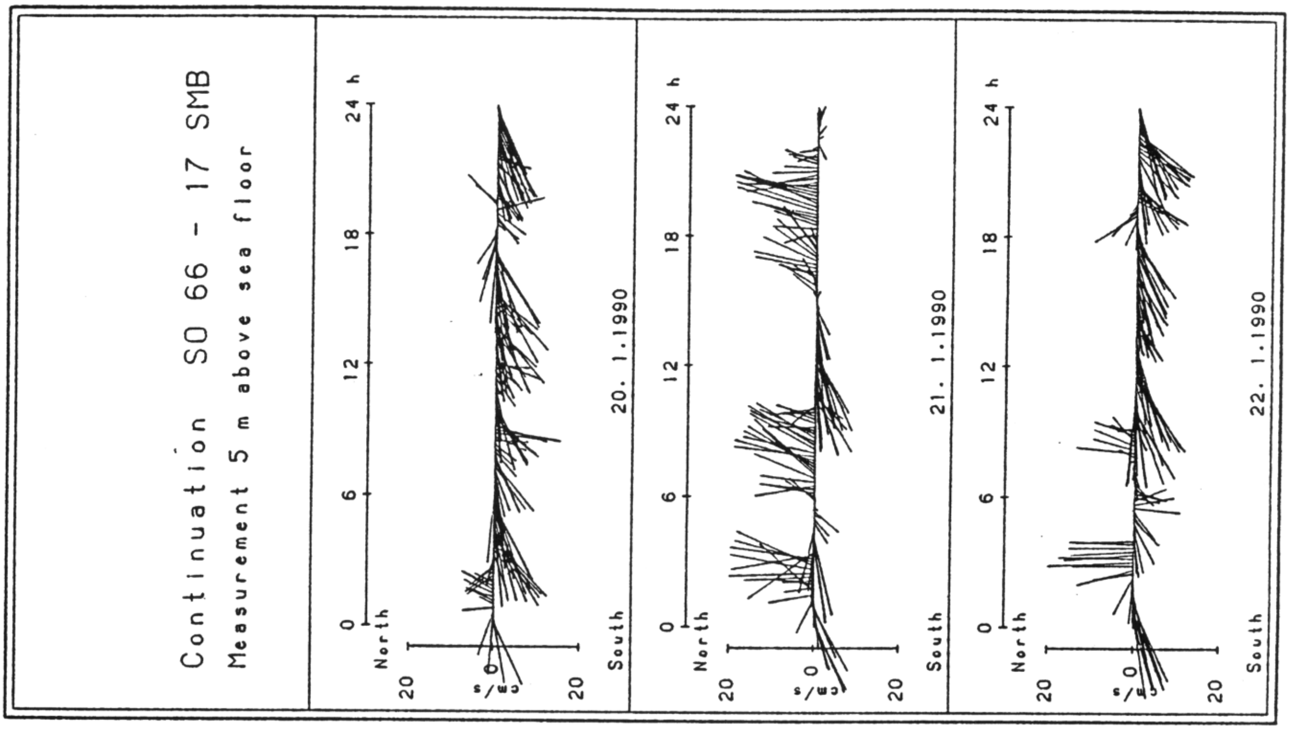
App. 11.3: Scatter plots of 16 SMA and 16 SMB



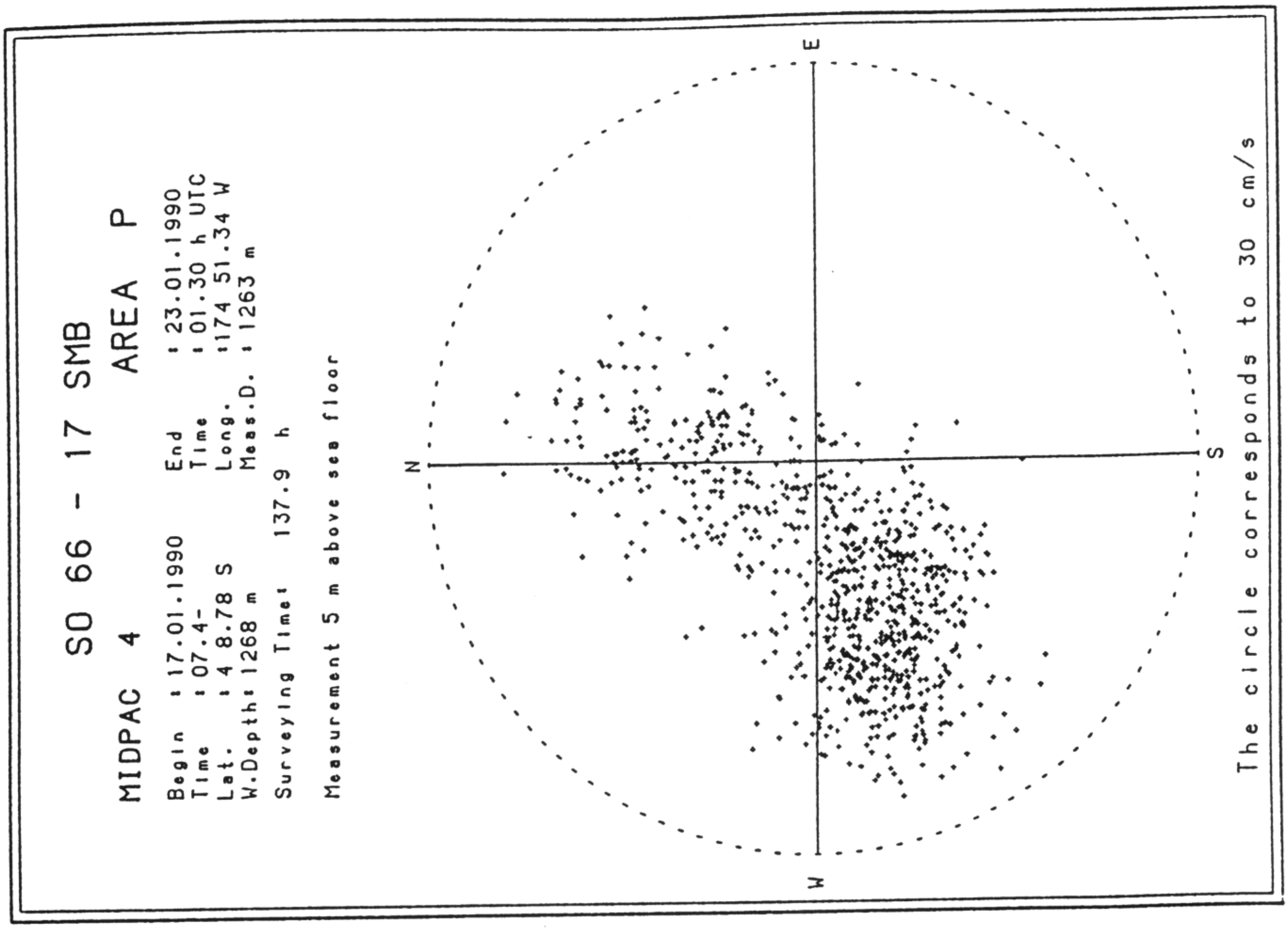


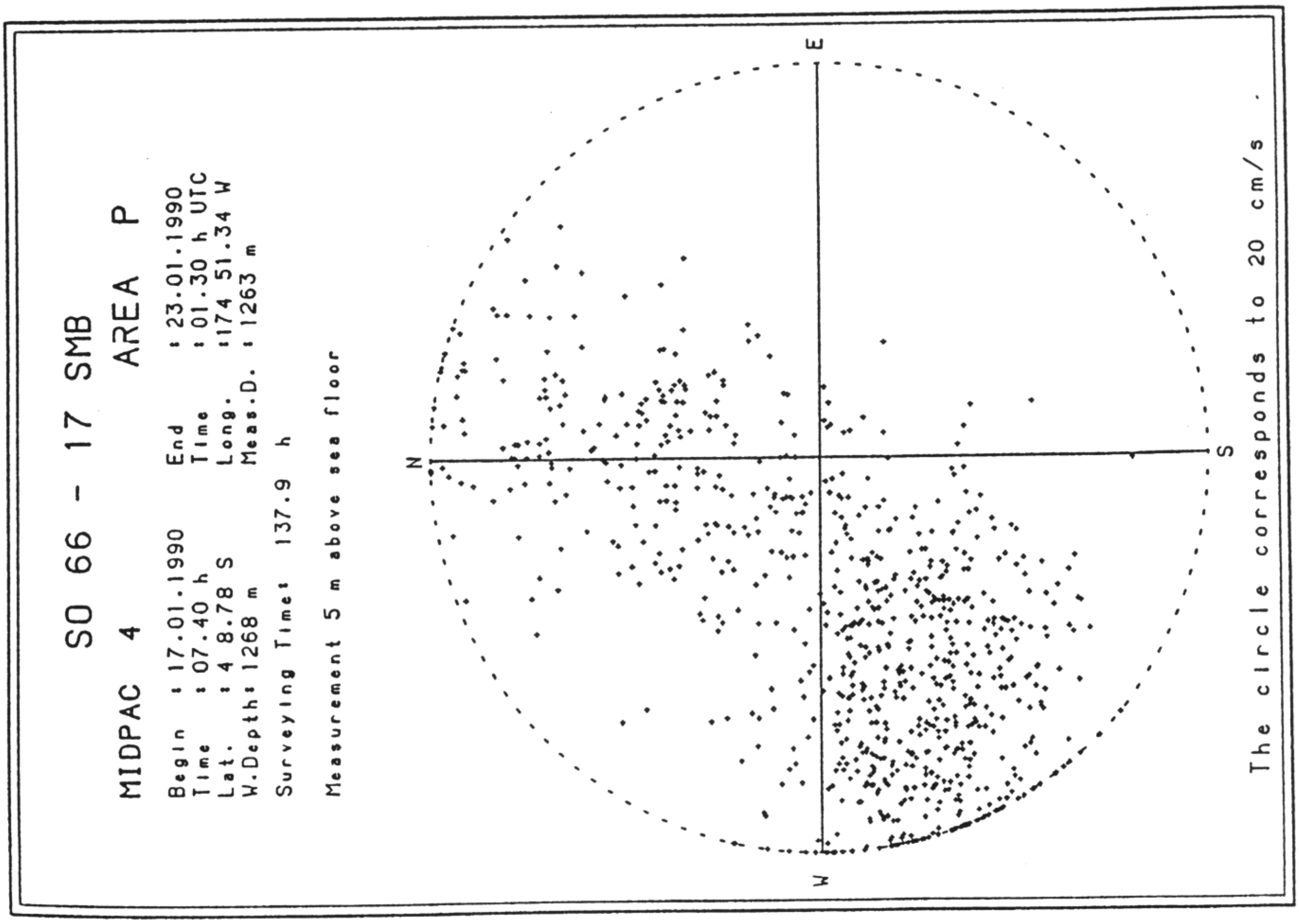
App. 11.4: Time series of 17 SMB



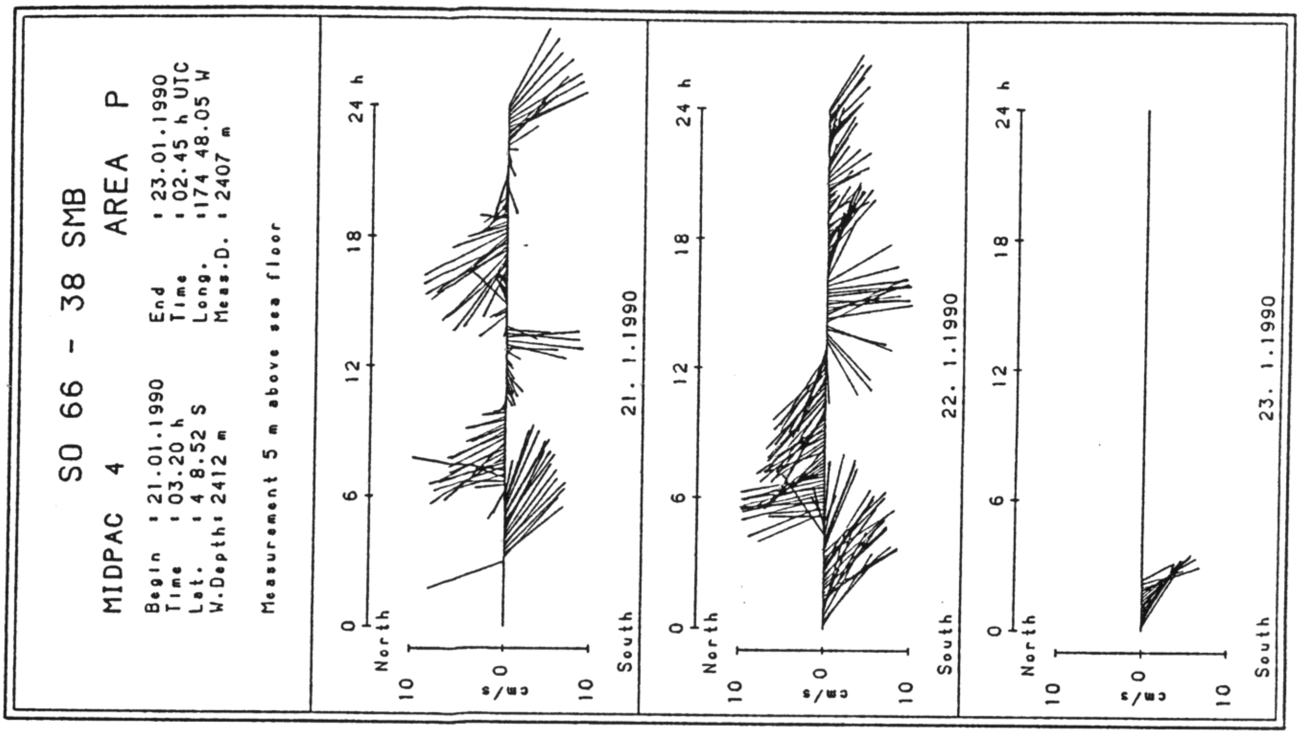


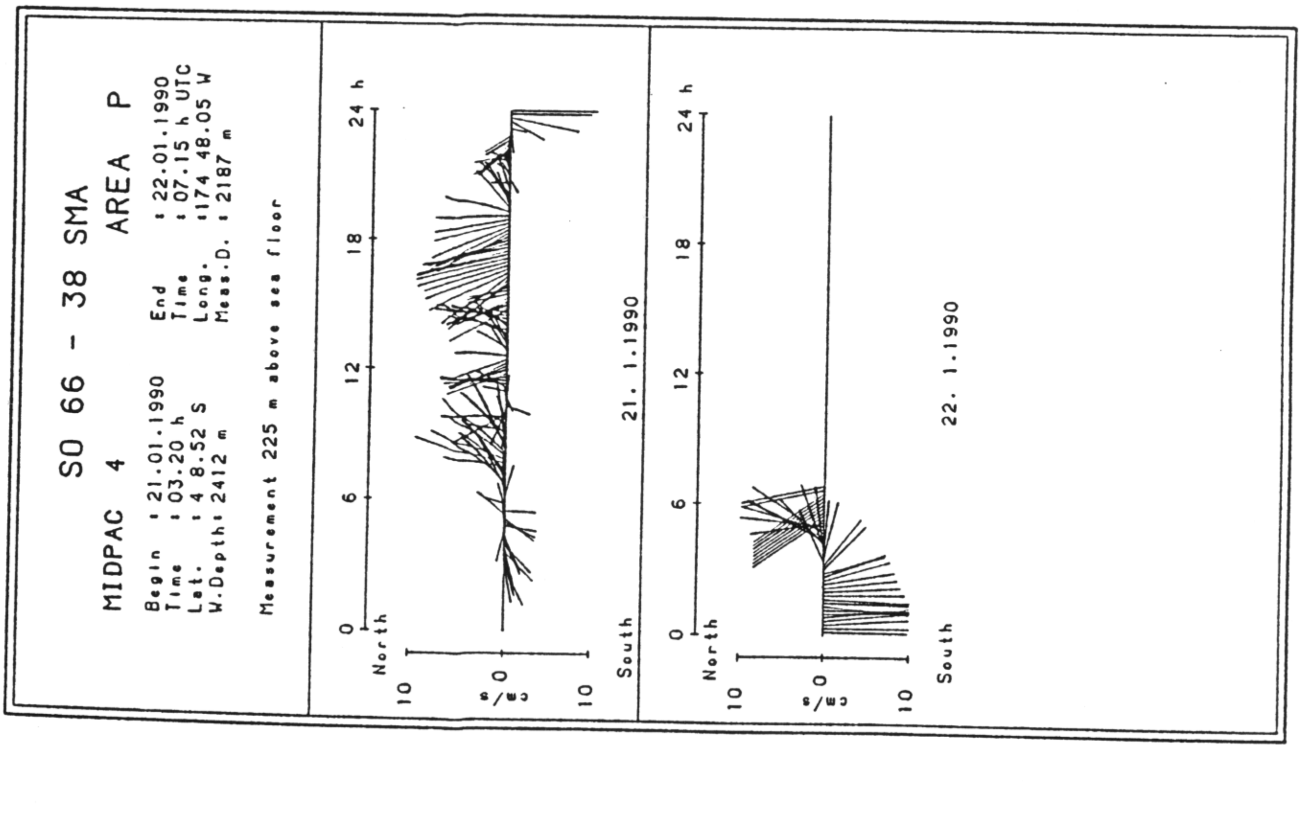
App. 11.5: Scatter plot of 17 SMB



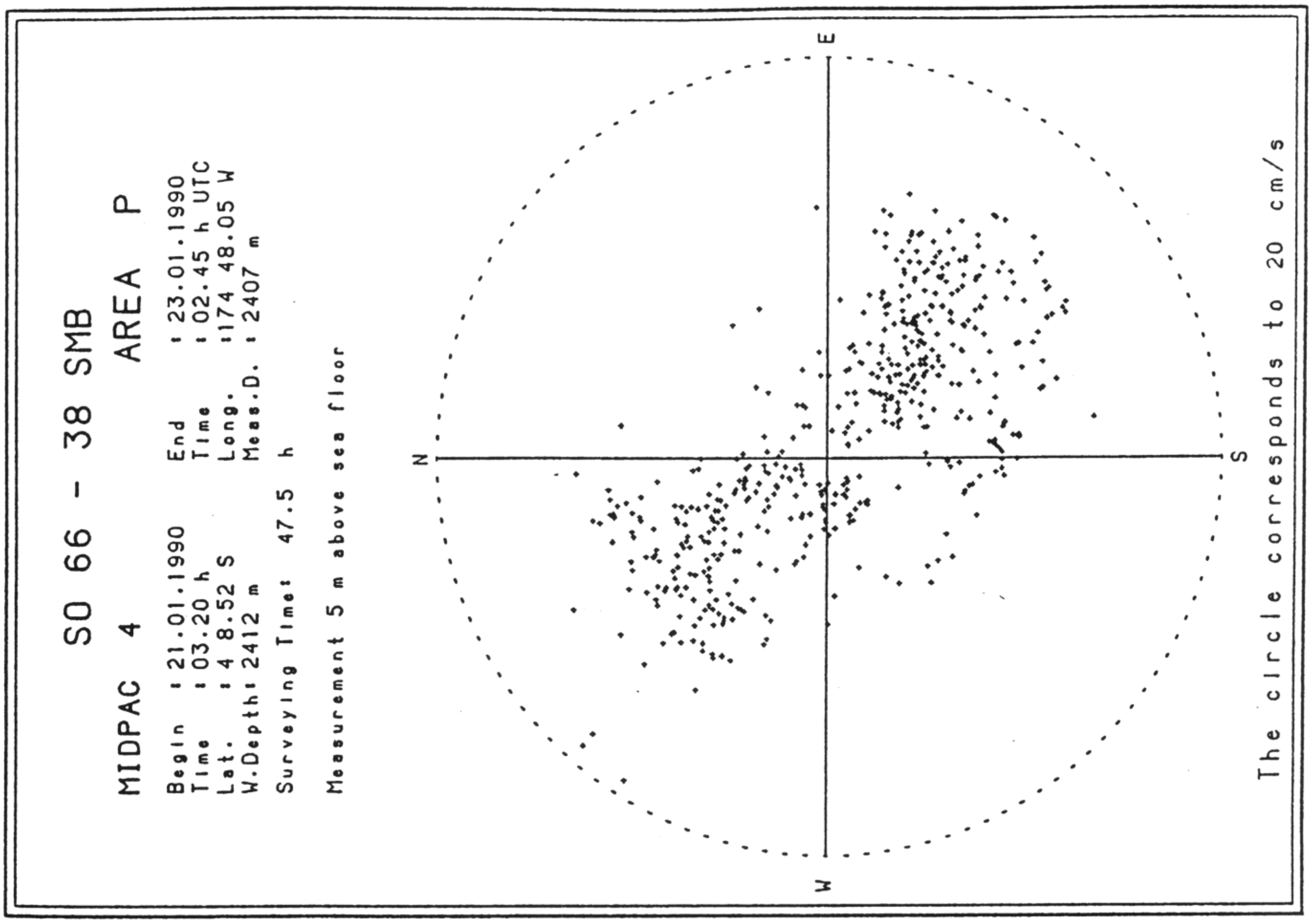


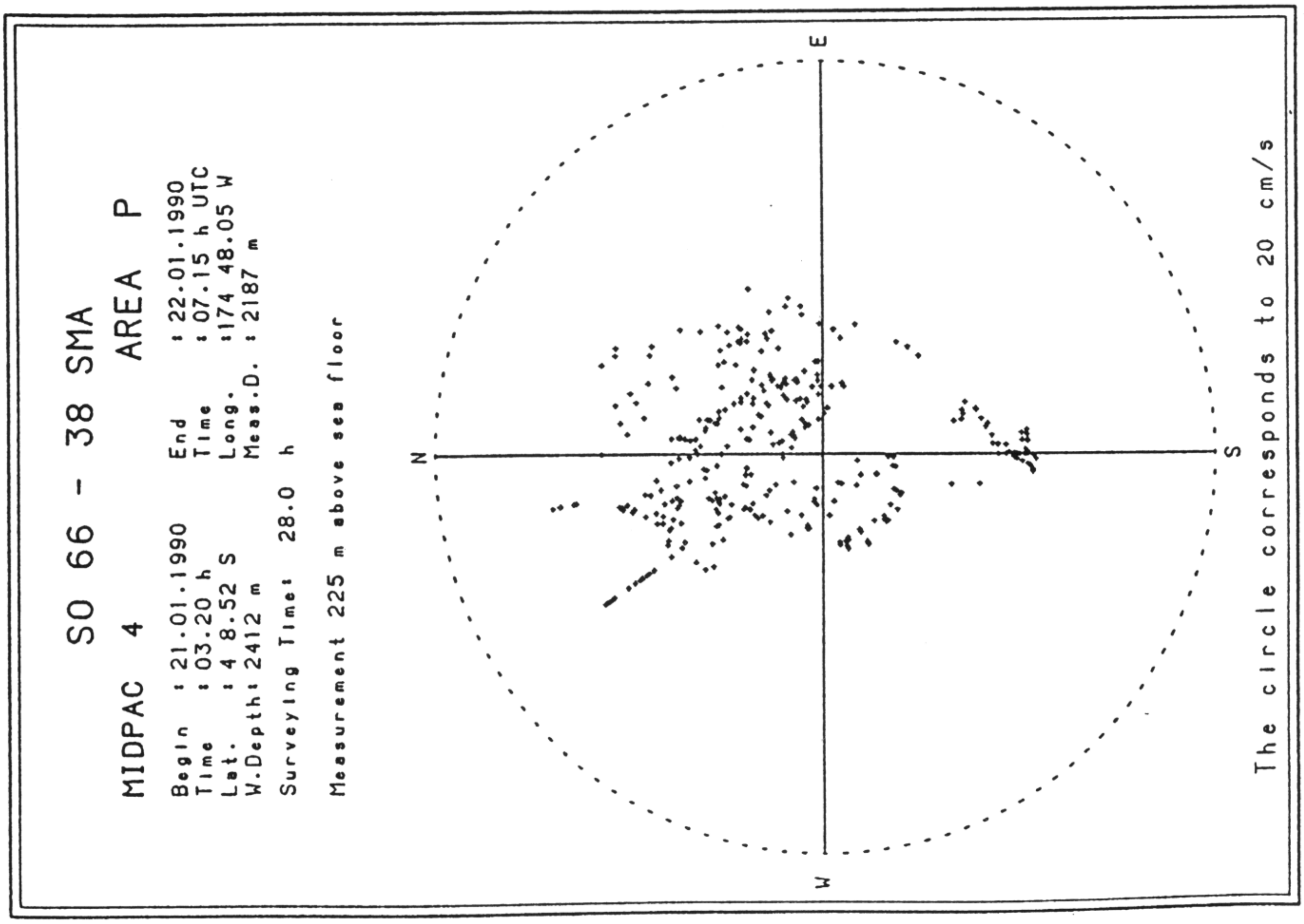
App. 11.6: Time series of 38 SMA and 38 SMB



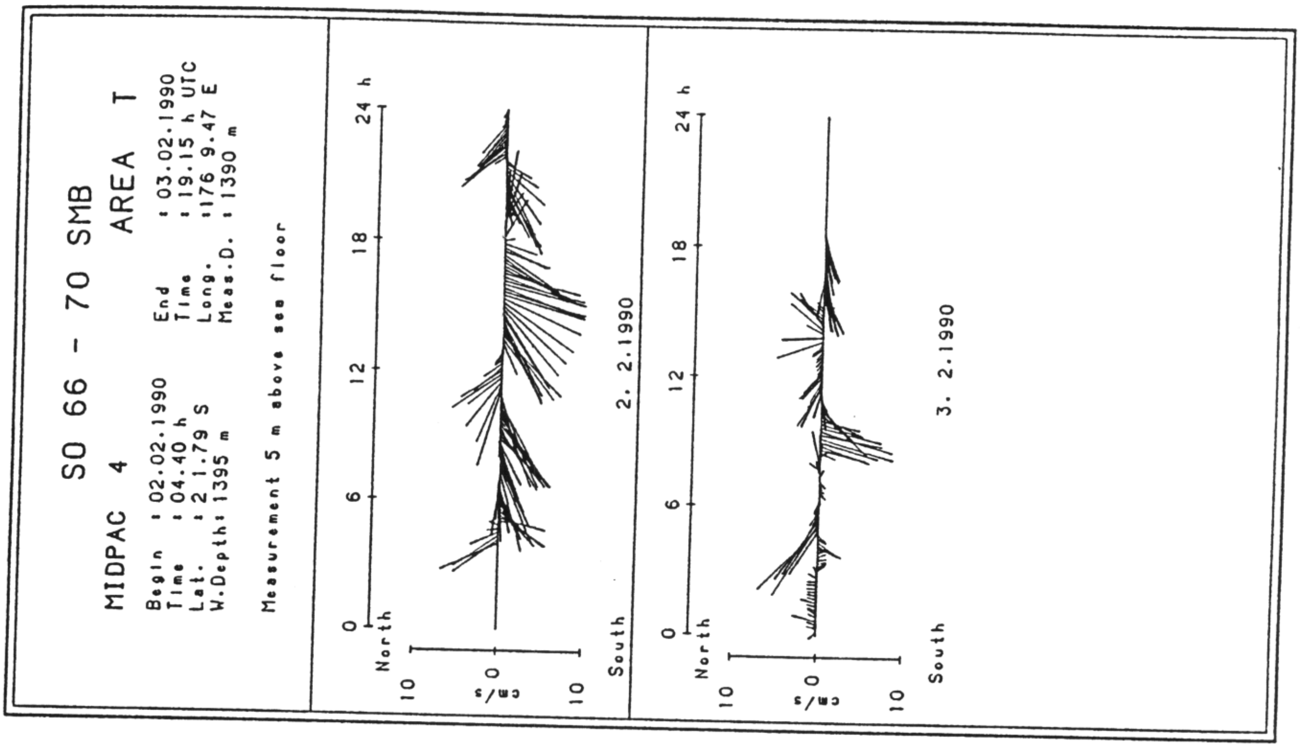


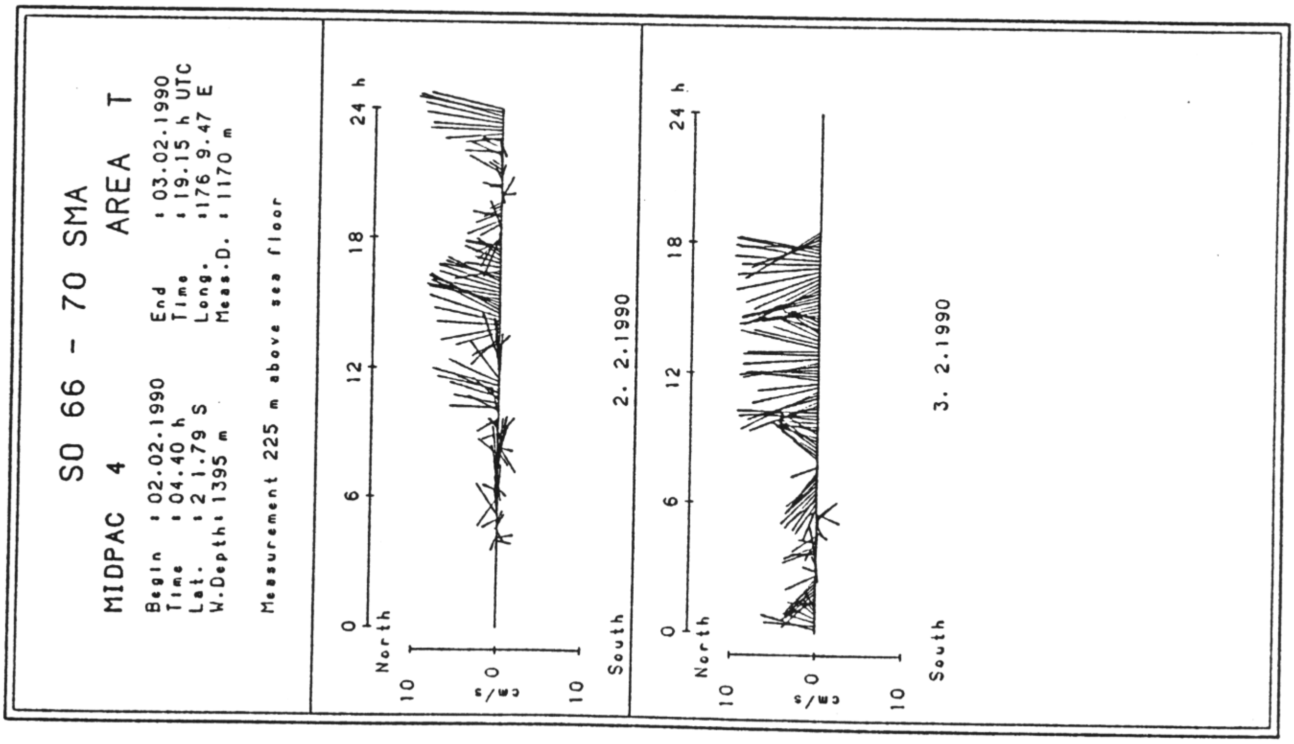
App. 11.7: Scatter plots of 38 SMA and 38 SMB



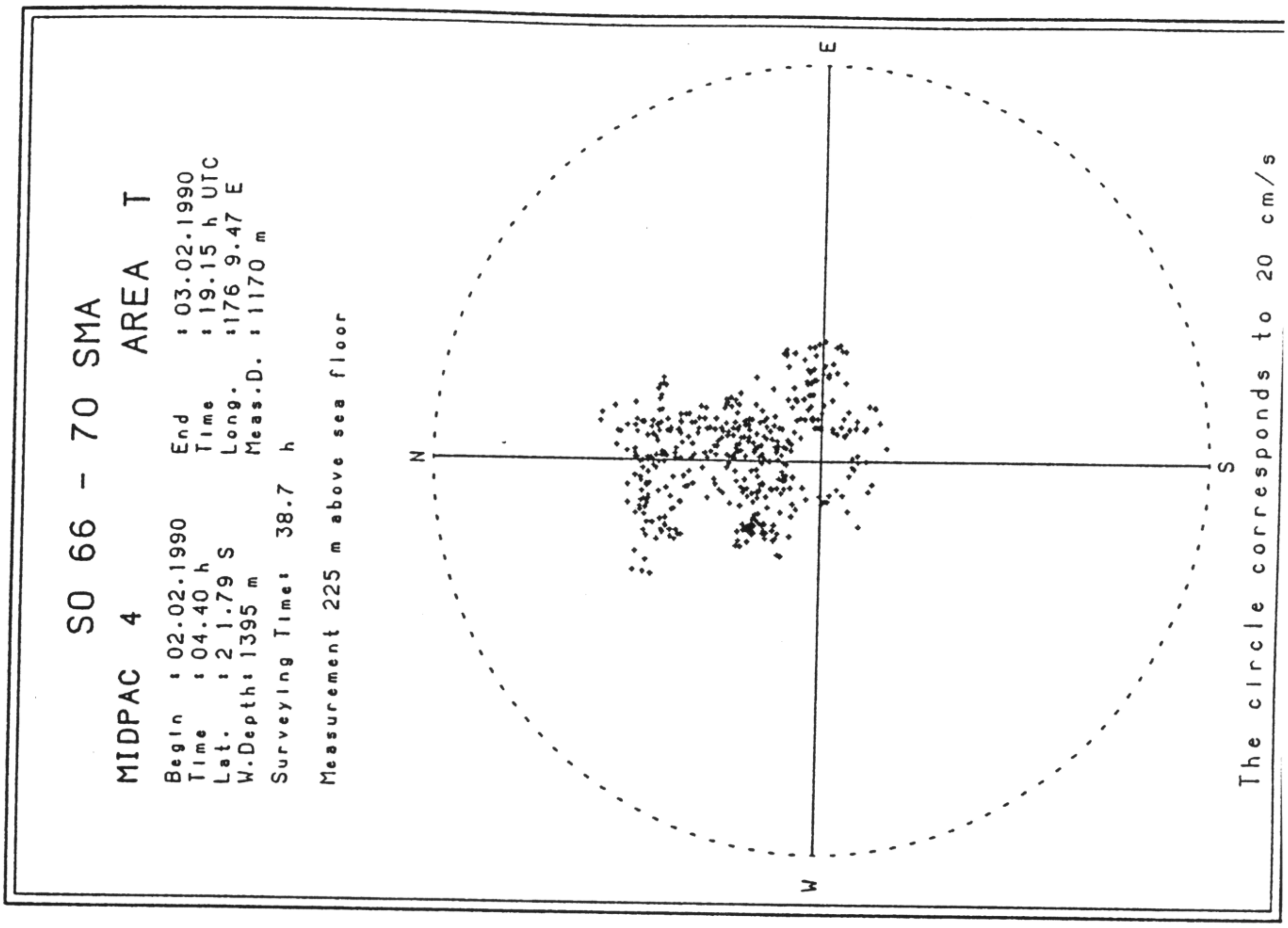


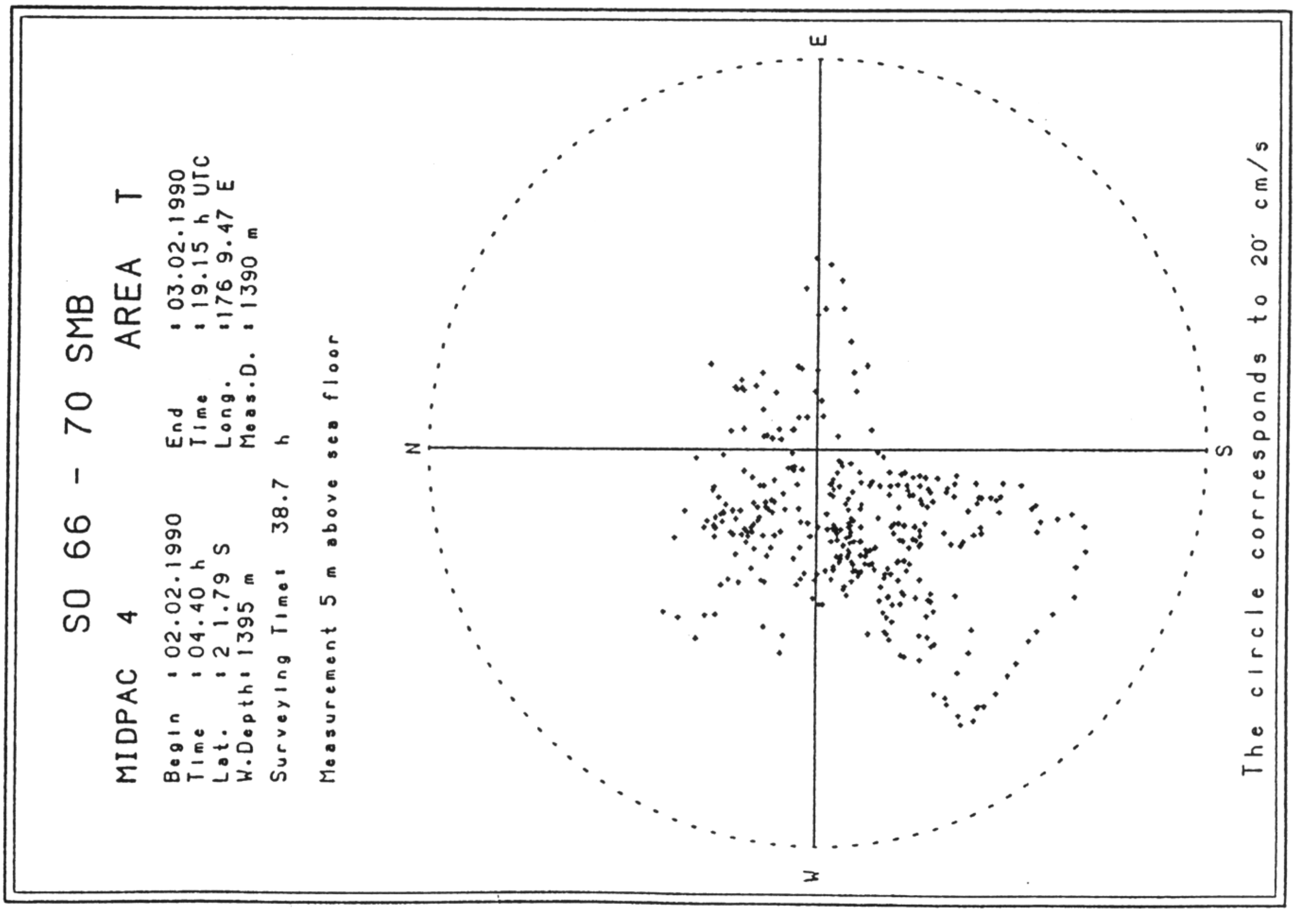
App. 11.8: Time series of 70 SMA and 70 SMB



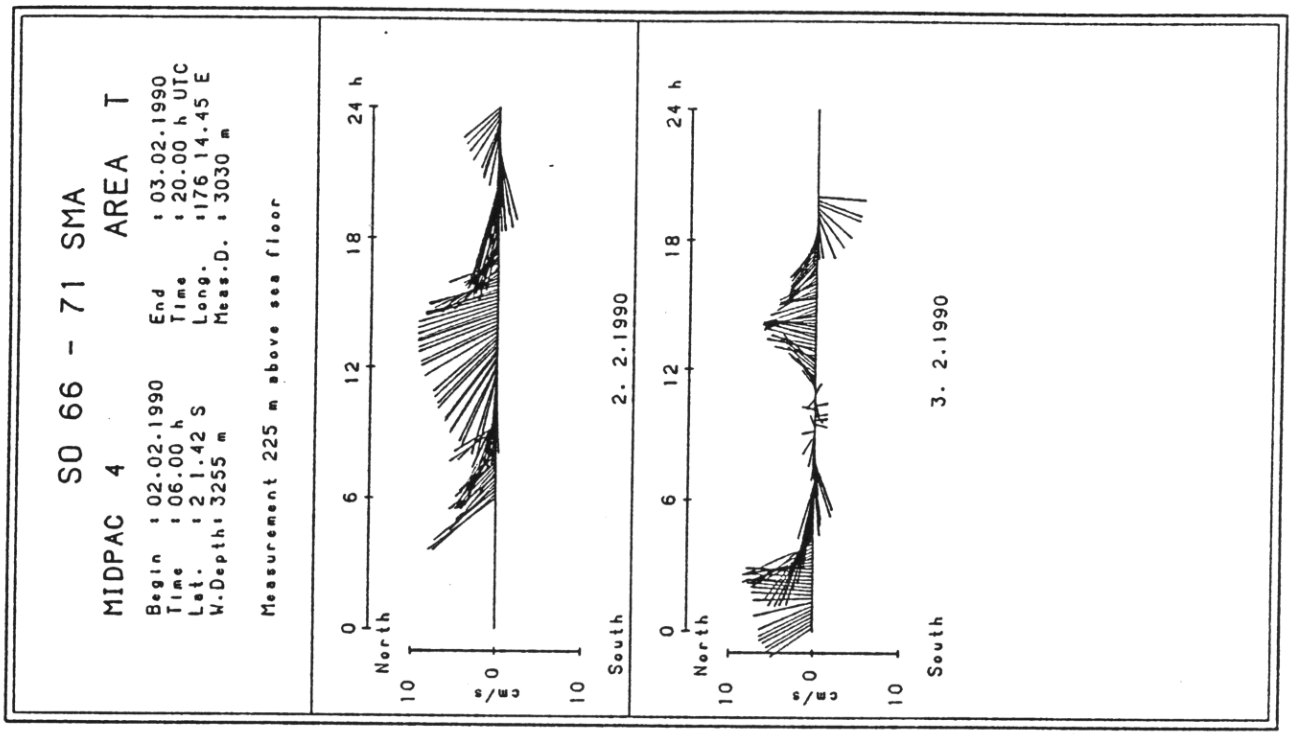


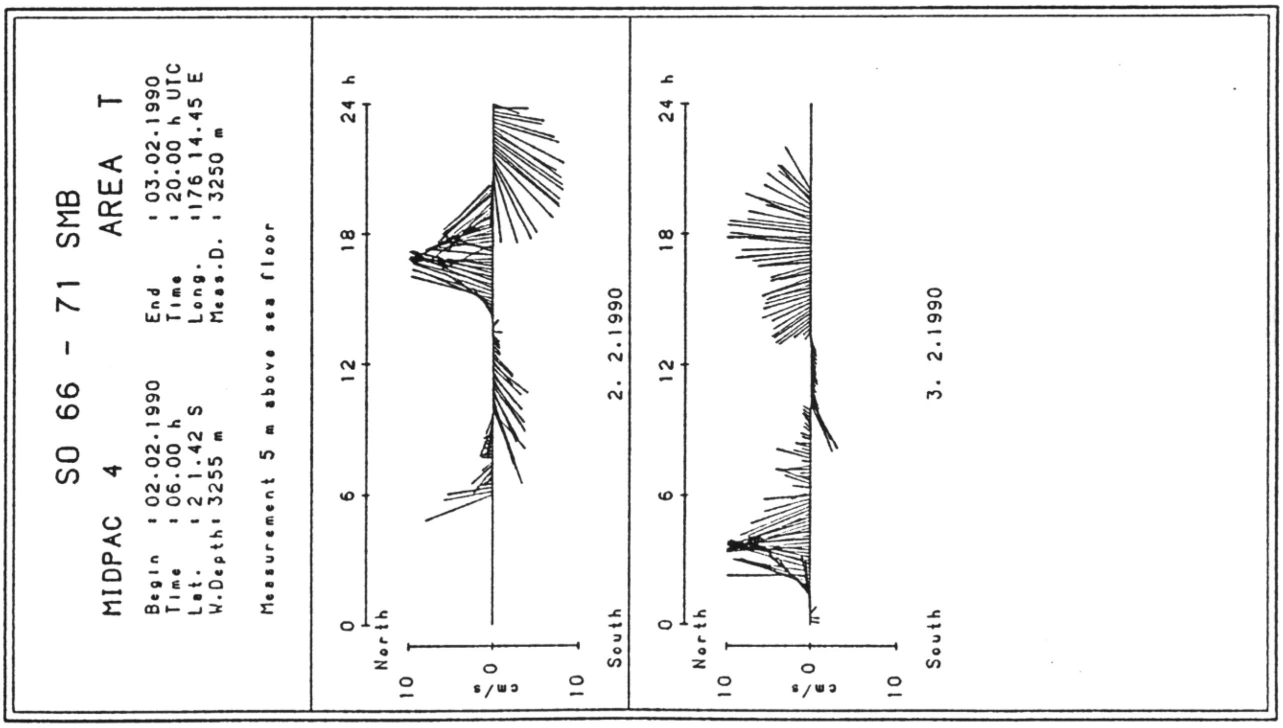
App. 11.9: Scatter plots of 70 SMA and 70 SMB



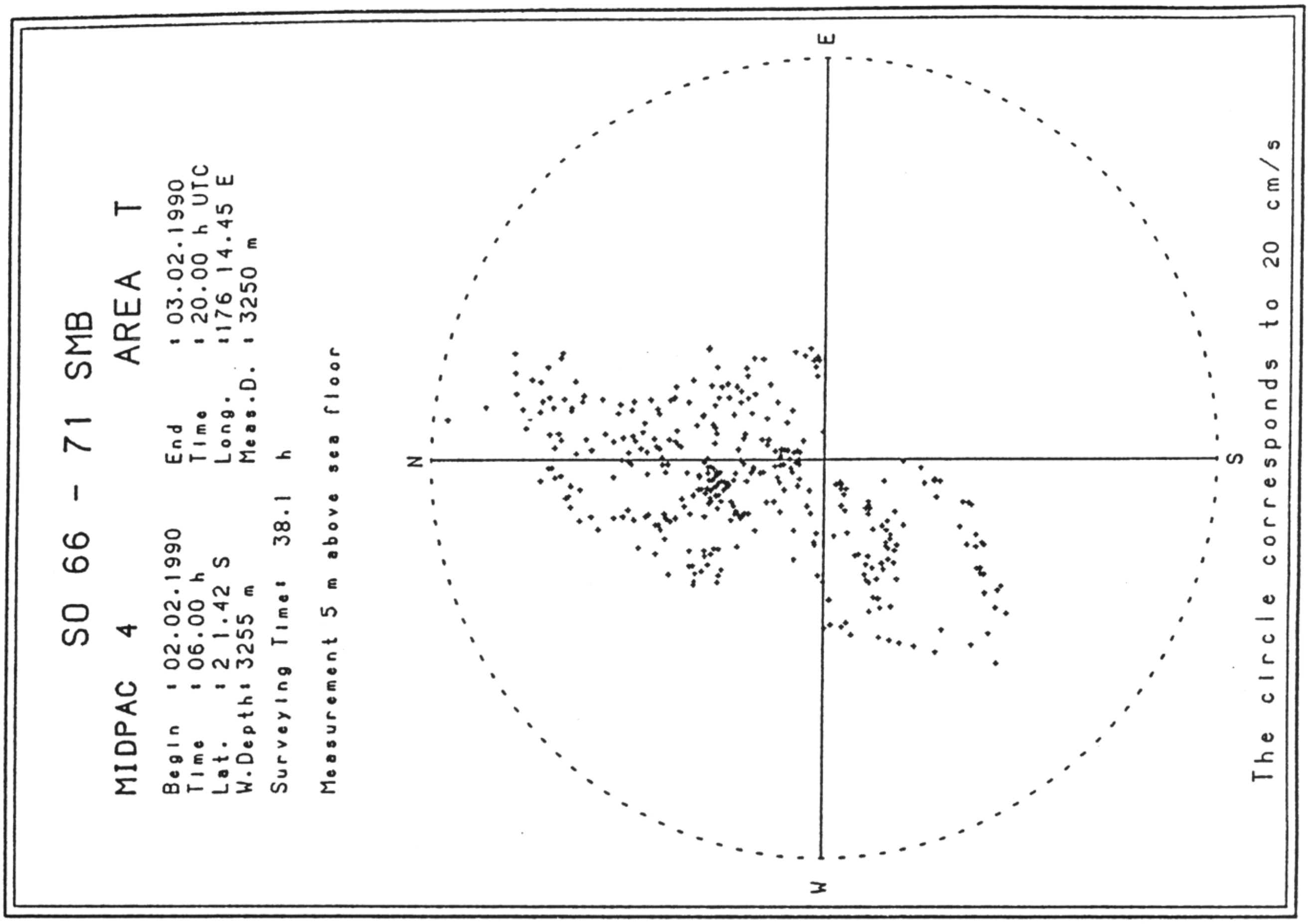


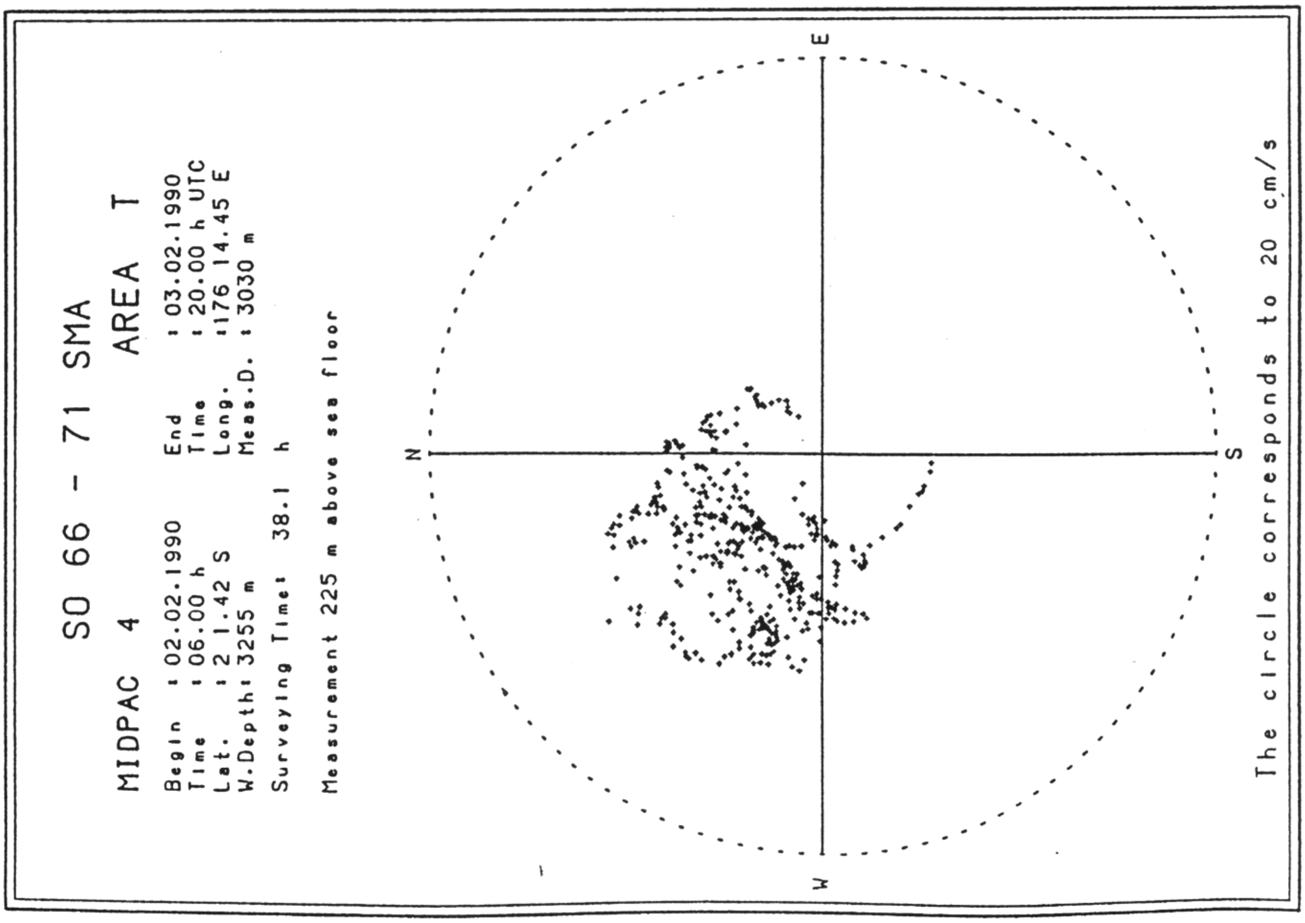
App. 11.10: Time series of 71 SMA and 71 SMB





App. 11.11: Scatter plots of 71 SMA and 71 SMB





Appendix 12: List of bathymetric charts on SO 66

area	name	scale
P	bathymetry, 25 m	25.000
P	bathymetry, 100 m	25.000
P	7 OFOS	10. 000
P	7 OFOS tracks	diverse
P	9 OFOS, 10 m	10.000
P	15 OFOS, 10 m	10.000
P	15 OFOS tracks	10.000
P	32 OFOS, 10 m	10.000
P	32 OFOS tracks	10.000
P	40 OFOS, 10 m	10.000
P	40 OFOS track	40.000, 10.000
P	47 OFOS, 25 m	25.000
P	sampling stations	10.000, 25.000
P + T	OFOS tracks	diverse
R	bathymetry, 25 m	25.000
R	22 OFOS, 10 m	10.000
R	22 OFOS tracks	10.000
R	sampling stations	25.000
S	sampling stations	25.000
T, north	bathymetry, 25 m	20.000
T	72 OFOS, 10 m	10.000
T	sampling stations	25.000
U	sampling stations	25.000
V	bathymetry, 25 m	25.000, 50.000
V	bathymetry, 50 m	50.000
V	sampling stations	50.000
W	bathymetry, 25 m	25.000
W	sampling stations	25.000
X	bathymetry, 10 m	10.000, 20.000
X	sampling stations	10.000, 20.000