Cruise Report

PROcesses on the Continental Slope (PROCS)

cruise PROCS99-1

Pelagia cruise 64PE137

R.V. Pelagia 14 April - 05 May, 1999

21 june 1999

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(with contributions from participants)

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0. Contents

1. Summary of R.V. Pelagia PROCS cruise PROCS99-1

Within the project PROcesses on the Continental Slope (PROCS), the R.V. Pelagia (NIOZ, the Netherlands) cruise PROCS99-1 (64PE137) was in the Faroe-Shetland Channel between 16 April and 02 May, 1999. PROCS is partially funded by the Netherlands Organization for the advancement of Scientific Research. It is a multidisciplinary oceanographic study (involving marine physicists, chemists and biologists) on the interaction between sloping topography and internal oceanic motions and the associated effects for mixing of suspended material and the resulting zonation of sedimentation and benthic fauna. Specifically, the effects of internal wave reflection and focusing above a continental slope are investigated.

The working area of this first PROCS cruise (of two) is in the centre of the Faroe-Shetland Channel, between 60°45’ and 61°50’ N, and -005°10’ and -002°40’ W. Following the 1997 pilot study, all sampling focused on a single cross-section of the channel, thereby assuming most relevant processes and variability occurring two-dimensionally. The investigations reflect the multidisciplinary approach of this project, with a great variety of oceanographic sampling within the two weeks on site. Seven moorings covering one slope between 500-1000 m have been deployed. These moorings held fast-sampling instruments, acoustic Doppler current profilers (ADCP’s), current meters, thermistor strings, sediment traps and turbidity sensors. Focus was on sampling between 2 and 50 m above the bottom. Two long-range ADCP’s covered about 400 m of the water column. After the successful recovery of these moorings, five of them have been redeployed for the duration of 4 months with less instruments, sampling at slower rates. Whilst the fast sampling instrumentation was moored, shipborne sampling included extensive hydrographic, acoustic (current and reflection) and turbulence surveys across the channel, alternated with benthic sedimentological and biological sampling with different corers and fishing tools focusing on the slope near the moorings.

In general, the cruise has been successful, with 80-90% of the intended programme and data acquired. This success is achieved because of the experienced crew and participants on board, so that also in adverse weather conditions the sampling continued and repairs of busted instrumentation causing little or no delay. Most instruments worked flawlessly, with some problems occurring in acoustic (current) measurements attributable to the clearness of the water at some depths in terms of (the lack of) appropriate scatterers. One mooring is lost upon deployment due to a broken line. Currently, a mooring is drifting due to unknown causes. It is tracked by satellite.

Preliminary results show strong zonation of benthos and sedimentation along the slope. The benthos sampling and the novel fykes mounted on the sediment trap frames moored at the bottom gave high quality information on the variations in the benthic community. The sedimentation is found to vary in amplitude and in time across the slope. In addition, the timing of maximum sedimentation varies across the slope. Like during the 1997 pilot study, strong fronts are encountered, occurring more vigorously than before. These fronts are associated with strong near-bottom flow accelerations, temperature variations and bursts of (re)suspended material, occurring on time scales of minutes. The strong zonation and sedimentation variations above the slope are reflected in the enhanced turbulence dissipation rates found above the central part of the slope and the strong variations (with time) of the density stratification. This variability seems associated with (internal) tidal wave. Internal wave motions seem less important in the interior of the channel, but this requires further data analysis.

2. PROCS' general research summary and objectives.

Definition and aim.

PROCS (PROcesses at the Continental Slope) is a NIOZ oceanographic research project funded by the Netherlands Organization for scientific reseach (NWO-ALW). The project aims, by multidisciplinary approach, to significantly improve our knowledge on the mechanisms which are responsible for enhanced, spatially varying mixing near continental slopes with special emphasis on the possible role of geometric focusing of internal waves in a confined geometry. This spatially varying enhanced mixing might explain zonation in benthic fauna and the generation of intermediate nepheloid layers. In turn, the positioning of both phenomea on the continental slope will be used to localize the areas where this enhanced mixing can be expected to be dominantly present.

Research summary and objectives.

It is proposed to execute detailed field work at a transect perpendicular to the continental slope at the border between the northern North Sea and the Faroe-Shetland Channel. This area has been chosen because the Faroe-Shetland Channel is a well-confined, stratified basin with smoothly sloping sides, so that internal waves are abundant and geometric focusing may occur, while it is still coverable by moored and shipborne sampling during a modest duration of a cruise. Some disadvantages of the area are the relatively rough average weather conditions and the relatively strong residual along-slope currents. The project has been divided into three components which can be summarized as follows,

- detailed studies on the physical mixing processes which are responsible for enhanced mixing with emphasis on the importance of internal waves and their breaking,
- the mechanisms of transport and settling of (biogenic) material to the seafloor and the hydrographic implications of observed variations in concentrations of suspended matter,
- the biological response of the benthic system to (variations in) hydrodynamical conditions and vertical fluxes of organic matter and the hydrographic implications of observed variations in benthic fauna.

Field study summary.

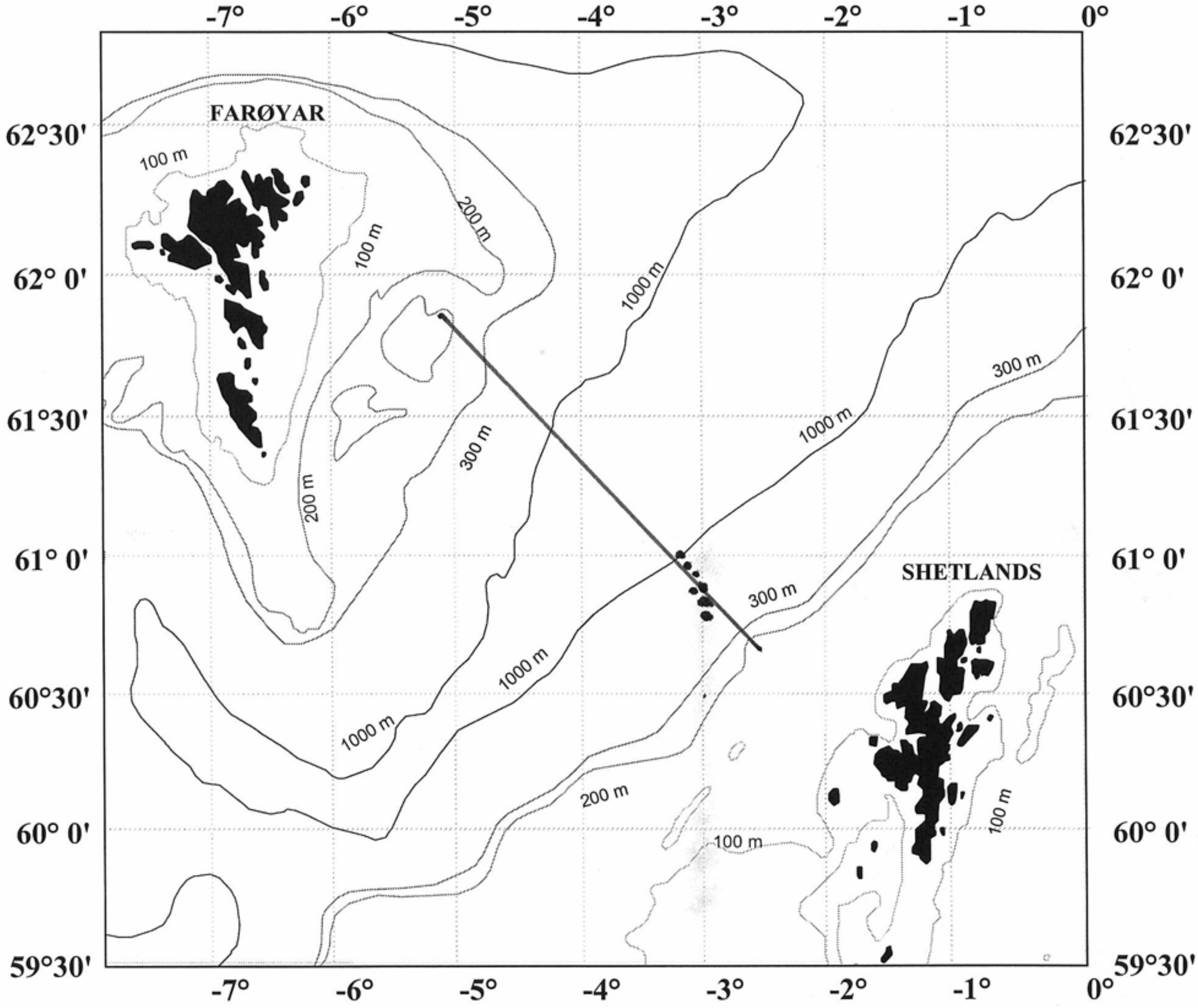
Following a pilot study in 1997 (*cf.* Appendix A), processes relevant to the PROCS research question are zoned within a rather narrow depth interval between 400 - 800 m. Internal waves of tidal frequency are present and impinge on the bottom at angles close to critical between 450-500 m depth. Geometric focusing of these waves would be possible with reflection points on the slope between ~ 400-600 m. Nepheloid layers were observed near the bottom at ~500 m and once at ~ 700 m. Sediment texture, benthic fauna densities, pigment ratios and ^{210}Pb inventories evidenced the dominance of erosion at depths shallower than 550 m and deposition deeper than 600 m, particularly between ~700-800 m on the slope.

Detailed measurements at short distances will be necessary to fully identify mixing processes, wave focusing, nepheloid layer formation and the response in the benthos to the hydrodynamic conditions in the bottom boundary layer. The oceanographic observations are planned for a period of about 6 months, between April and October 1999. At the beginning and end of this period research cruises are scheduled, each lasting 24 days. During the cruises 8 moorings will be deployed and recovered, whereby the instruments will be sampling fast and extensive shipborne sampling is scheduled on hydrography, turbulence dissipation, geochemical parameters and benthic fauna. In between the two cruises 5 moorings will remain on-site to monitor the long-term variability of currents and sedimentation above the continental slope.

a. PROCS99 cruises, experiment and site.

With reference to the results obtained from the pilot study, the main emphasis of the PROCS99 observations is concentrated along the main principle transect (Fig. 1) for the following reasons. This transect is located about halfway the Channel, so that possibly complicating influences due to the Whyville-Thompson Ridge to the south-west and the open boundary into the Norwegian Sea to the north-east are minimized. Here, the isobaths are amongst the smoothest found in the Channel. No indications could be inferred from the pilot study data that the location is inadequate for the aims of the study, so that it is thought to be useful to occupy the same site, so that the pilot study data can be used for further analysis in combination with the new data sets to be acquired.

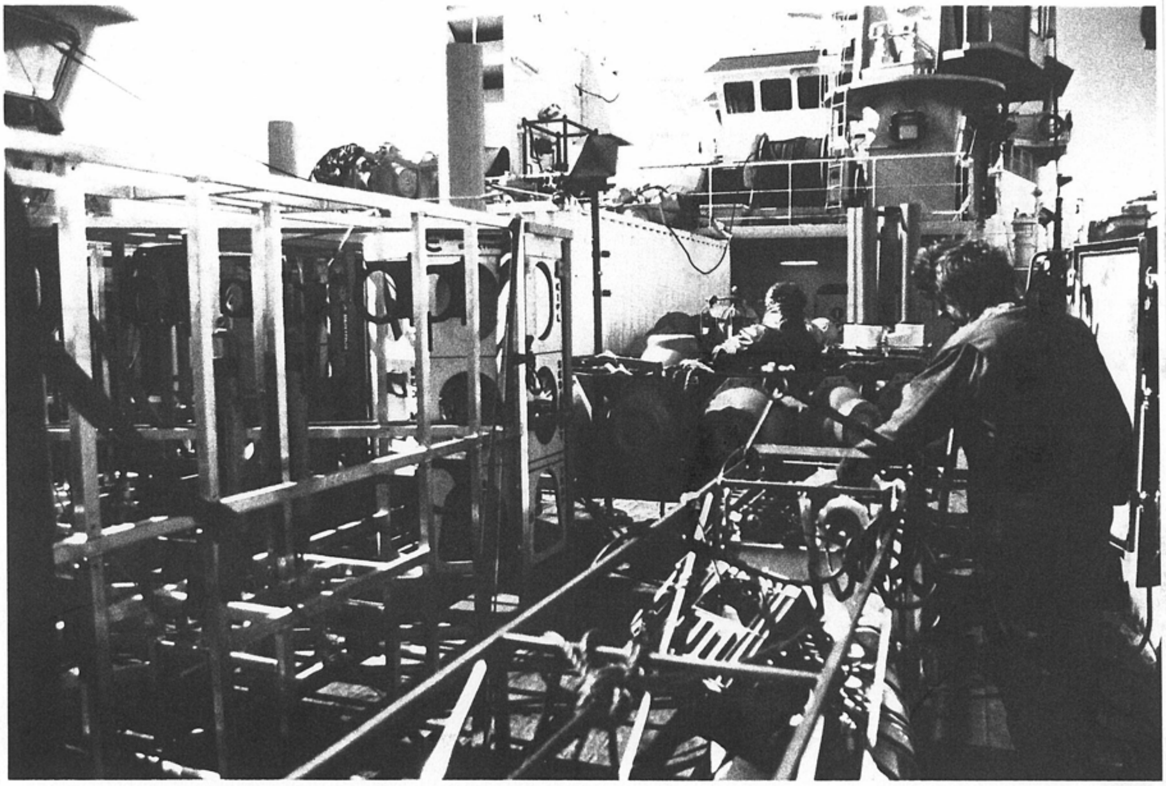
Fig. 1. Detailed map of the area and the main hydrographic survey line and location of moorings. (•)



Following the pilot study results,

- the number of moorings has been expanded from 3 (PROCS97) to 8 (PROCS99), and all are concentrated along a single transect perpendicular to the local isobaths, between 400 and 1000 m depth, where the largest variations were found, so that the vigorous small-scale variations will be more adequately sampled. Each of the different instruments will be set to sample as fast as possible to cover the scheduled deployment period of about 2 weeks, which implies sampling at rates varying between once per 30 s (ADCP) to once per day (sediment traps).
- Longer term variability will be monitored using 5 moorings that will be deployed at the end of the first cruise and which remain on-site for a period of 4 months in between the cruises. These moorings are deployed along the same transect perpendicular to the slope as above.
- All moorings are guarded using recently acquired ARGOS SMM satellite watch.
- Close to this transect repetitive CTD and microstructure profiling will be performed covering the entire width of the channel. Station distances vary from 1.5 (above the slope) to 5 nautical miles (centre channel).
- During all the surveying along the transects the autonomously recording SIMRAD echo sounder, underway sampling, and the novelly installed VMADCP will be recording data.
- The bottom sampling will be intensified between 300 and 1000 m, albeit this will put more strain on the equipment due to the relatively hard bottom texture.
- Similarly, the benthic video trawling will be intensified to fill the gaps that have remained after the pilot study. Further, megafauna samples will be collected between 400 and 900 m with a triangular dredge.
- Multinet sampling between 400-1000 m depth for the identification of scattering layers (SIMRAD and ADCP) and the source of faecal pellets entering the sediment traps.
- No sampling is foreseen for the along-isobath direction.

Impression of the instrumentation on the aft deck prior to deployment of the moorings.



3. Cruise PROCS99-1.

a. Participants.

Institute	*Name*
NIOZ-FO	Hans van Haren (PI)
NIOZ-MCG	Wim van Raaphorst
NIOZ-FO	Kees Veth
NIOZ-FO	Theo Hillebrand
NIOZ-FO/DMG	Ronald de Koster
NIOZ-MCG	Geert-Jan Brummer
NIOZ-MCG	Mark Grutters
NIOZ-MEE	Rogier Daan
NIOZ-MEE	Anke Weber
NIOZ-DE	Martin Laan
NIOZ-MCG	Karel Bakker
NIOZ-MCG	Laurens Pijl
NIOZ-DZT	Marcel Bakker
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NIOZ departments

FO	physical oceanography
MCG	marine chemistry and geology
MEE	marine ecology
DE	electronics
DZT	sea technology
DMG	data management group

b. Instrumentation and sampling strategies.

1. Shipborne equipment

During the entire cruise the following information has been continuously sampled and stored through the ship's ***ABC system***: time, ship's position lat/lon, depth (FURUNO and 3.5 kc), meteorological data, aquaflow (temperature, salinity and fluorescence from 4 m below surface). A few water samples have been taken for salinity calibration purposes.

During each transect across the Faroe-Shetland Channel the ***SIMRAD scientific echosounder*** has been operated, using the lowest frequency (38 kHz). The data have been stored on paper only. During these transects, also a newly installed hull-mounted 75 kHz acoustic Doppler current profiler (***VMADCP***) has been operated. When sufficient scatterers are available, this instrument samples the current velocities and acoustic scattering down to 600 m below the ship in 5 m bins, each 2 s. Thus a cross-section of vertically varying currents is obtained.

On board the R.V. Pelagia the ***CTD/Rosette*** system contains a Seabird 911 CTD, with additional electronic sensors on fluorescence (Wetlabs AC3, Chelsea Instruments Aquatracka MKIII), K-meter (PAR light attenuation), a Seapoint STM optical backscatter sensor (OBS) and transmissometers (Wetlabs AC3, Seatech). The CTD samples at a 24 Hz rate. The Rosette holds 22 12 l water bottles.

Water sampling has been done for analysis of the suspended matter:

1. Total Particulate Matter concentration (TPM) to calibrate the turbidity sensors; with emphasis on the near-bottom layers,
2. POC, PON, δ^{13}Corg, PTC, PTN, δ^{15}Ntot to determine the organic matter content, Corg/N ratio as well as the Corg and Ntot isotopic composition of the TPM in order to link the data from the water column with the sediment traps and the sediment,
3. 43 elemental composition: e.g. Ca, Al, Ti, Si, Fe, Mn, P, S, K, Mg, Sr, Ba, ... (ICP-analysis) to identify the source of the TPM (e.g. pelagic versus sediment-derived),
4. pigments and particulate hydrolysable amino acids.to calibrate the fluorometer on the CTD and to assess the degradation state of the particulate organic matter,
5. dissolved nutrients to better characterise the hydrography.

One ***FLY-II*** microstructure profiler has been used. This system is operated immediately after a CTD-cast to measure the turbulence dissipation rate in the water column and its temporal variations in relation to the variations in external and internal forcing. The CTD data are necessary for calibrating some of the additional (slow) sensors on the the FLY.

Sediment samples have been collected using the ***Multicorer*** to determine high-resolution pore-water and solid phase profiles of the upper 20cm as well as for measuring sediment-water exchange fluxes. In addition to the parameters measured in the TPM, we will analyse the reactive silica content as well as the ^{210}Pb and ^{234}Th activities to identify zones dominated by erosion and deposition, respectively. Pore-water and flux-data will be used to identify early diagenetic activity. Further, multicore samples will be used for measuring vertical profiles of phytopigment concentrations in the sediment and the overlying water.

Multinet samples will be analysed for plankton species composition in co-operation with the BIO-department at NIOZ. Where appropriate and possible, specific particles such as faecal pellets will be analysed for elemental and isotopic composition (see above).

Boxcore samples will be used for a detailed description of the macrofauna distribution along the slope and to collect shell material (Astarte) for growth band analyses.

Video (Agassiz) trawling is concentrated on depth transects that were not covered during the pilot expedition in 1997. Additionally, epibenthic megafauna will be collected with a ***triangular dredge*** to identify the species that can be observed on the video records and to collect test animals for measuring metabolic activity (RNA;DNA ratio) and/or growth parameters.

2. Moorings (cf. Appendix B for the diagrams)

Since the pilot study, the number of moorings has been augmented. However, it was decided to cover almost the same cross-slope area as during the pilot study, with the aim of enhancing particularly the (unprecedented) spatial resolution. Thus, all moorings are located on a single cross-slope transect, on the Shetland side and between 400-1000 m depth. All moorings consist of a a buoyancy package at the top, which also holds an ARGOS beacon, and a weight coupled to two acoustic releases at the bottom. Four types of non-shipborne equipment will be launched.

Firstly, a bottom lander containing upward-looking 1200 kHz convential and 600 kHz 5-beam broadband (***BB-)ADCP***'s and two ***thermistor strings*** has been moored during the cruise. The purpose of the equipment is to sample at a fairly high temporal (30 s) and spatial (0.5- 1 m) resolution the water temperature as well as all three components of velocity and estimates on the variability of suspended matter in the water column through its back-scattered amplitudes. Its purpose is to attempt to estimate directly internal wave band eddy fluxes, besides the overall flow and temperature field within a range of about 50 m above the bottom. In order to couple the temperature variations to density variations a proper estimate of the temperature-density relationship is required through sufficient CTD sampling **(mooring type PROxay)**.

Secondly, two moorings have been deployed that contain a single ***75 kHz ADCP***, which covers the lowest 300-400 m of the water column, from 25 m above the bottom onwards, and sampling at resolution of 150 and 300 s (temporal) and 4 m (vertical). Two types are used, an old narrowband (NB-)ADCP and a novel 'Long Ranger' BB-ADCP. The purpose of these instruments is to monitor the larger scale internal wave (shear) variability with depth and time. These moorings have been redeployed at the end of the cruise, albeit sampling at a slower rate of about once per 10 min to endure the 4 month period until the next cruise. **(type PROxby)**

Thirdly, five moorings have been deployed, each holding 4 ***traps (fykes)***, 2 ***sediment traps***, 4 ***current meters*** and 2 Optical Back Scattering sensor (***OBS***) plus ***thermistors*** and ***tiltmeters***. The sediment traps are located at the bottom (in a bottom frame also holding the acoustic releases, Fig. 2) and at a distance of 30 m above the bottom. The current meters are positioned at 8, 21, 34 and 47 m above the bottom. In each mooring, 3 current meters are of the mechanical type (Aanderaa RCM8) and one is an acoustic Aanderaa RCM9 which also holds an additional OBS. The current meters have been sampling at once per 60 s, the sediment traps rotated one cup per day. The sediment traps will be used to determine the daily particulate mass flux to the sea floor through the water column, and to assess the pelagic and sediment-derived contribution to this flux, e.g due to intermittent resuspension events. Basically the same parameters will be measured as given for TPM and sediments. Amphipod fykes are mounted on the frame of each sediment trap to collect Amphipods and other hyperbenthic species for measurement of metabolic rates. One of these moorings held a recently developed Valeport NO_3 nutrient analyzer **(type PROxcy)**.

Fig. 2. Impression of a multidisciplinary mooring frame holding a sediment trap to the left and amphipod fykes to the right. Not visible are the OBS and the current meter.

4. Daily summary of cruise PROCS99-1.

Monday 12 April – Tuesday 13 April

Loading of the R.V. Pelagia starts at 8.00 local time in the NIOZ harbour, Texel NL. It continues on Tuesday until about 17 MET-DST, and includes 7 containers and a deck full of equipment. Due to bad weather conditions (NW winds Bf8) it is decided not to sail before the next morning.

Wednesday 14 April

NW 4. Departure for the Faroe-Shetland Channel at 8.30 MET-DST. The first day of sailing is smooth, with relatively calm seas. Clocks on board are switched to UTC.

Thursday 15 April

NW3 – N7. Increasing winds slow us down to speeds of 5-6 knots.

Friday 16 April

NNW 5-6, 3-4 m swell. In the early morning we are sailing in the Fair Isle Channel, with good visibility, and beautiful views of the Fair Isle, the Shetlands and Foula. As soon as we reach the Faroe-Shetland Channel, wind speeds and especially the swell are increasing. On deck the ARGOS beacons are exposed to the satellite for a test. All 8 platforms respond properly, but not after 3 of the receivers have been repaired. We reach our first deployment site by about 19.30 UTC, and we learn from a CTD cast that further work is impossible, the seas are too high.

Saturday 17 April

W 6-7, 3 m swell. Carefully we start clearing the full deck space, i.e. we start deploying moorings. Despite the large swell, the first three deployments are completed within 4 hours, by 12.10 UTC. From 13.30 UTC we start the deployment of the first sediment traps-current meters-OBS and a nutrient in-situ auto-analyzer mooring. Just before the final moment before launch, the cable breaks half-way the mooring line. A few moments later, it appears that a line has released from its socket, in principle an ‘impossibility’. Two acoustic releases, two current meters, a sediment trap, an OBS and the auto-analyzer are at the bottom, and two current meters and a sediment trap are heavily damaged due to the backlash of the line. The probable cause is sudden heavy tension in the line due to the 3 m swell with a slow response of the sediment traps through the water, in combination with a weak spot in the mooring line, being the insufficient molding of the line socket. Although we do not have possibilities to test the other mooring lines, it is decided to continue the deployments the next day, albeit using a completely different method of deployment from the stern rather than from the side, and after modifying the sediment trap mooring frames by removing some of the ground plates.

Sunday 18 April

NW3-5, 2-3 m swell. The relatively moderate winds and the slowly decreasing swell allow us to continue the deployment of the moorings. The first deployment of the day takes the entire morning, because the new method of deployment from the stern has to be set-up. The deployments are finished by 20 UTC, are do not cause any further troubles. Curiously, they attract large numbers of gannad’s each time, as well as fishermen. We inform them as we can, because they are bottomtrawling near us and down to depths of 700 m (!). Between 20-23.30 UTC a test track is sailed with SIMRAD echosounder and vessel mounted (VM-) ADCP on. The SIMRAD provides the usual beautiful picture, the VMADCP shows problems. One of the beams is not working, the pitch and roll sensors are not logged and the navigational software has not been set-up.

Monday 19 April

NNW6-4, 2-3 m swell. The VMADCP is submitted to a thorough check to find out the cause of the problems. Contact with the manufacturer, RDI in San Diego USA. 08 UTC start of the shipborne sampling programme, around the 400 m depth contour, with a CTD followed by two boxcores. From about 11 UTC onward triangular dredging, with two succesful catches at 400 and 500 m depth, respectively. At 15 UTC the sampling is stopped and dredging is started for the lost mooring PRO1c1. Without success, this activity is stopped at 21.30 UTC. From 23 UTC the channel is crossed for the first time, with SIMRAD echosounder and (bad) VMADCP on. RDI suggests to cut the wire of the bad beam, but data are not terrific yet.

Tuesday 20 April

ENE7-4, 2 m swell. 10.30 UTC start of the pelagic (CTD/FLY turbulence) sampling programme on the same cross-channel section, strewn with sampling stations. The FLY works good with little, and only high-frequent, noise. At all stations water samples are taken for nutrient determinations, and at every 3-4 stations water samples are taken for extensive biological and sedimentological sampling. Concerning the VMADCP, there are no tilt sensors on board, so that we are facing errors of typically 30-50 cm/s when sailing at full speed due to lack of such sensors.

Wednesday 21 April

E9, nice waves. 06.30 UTC suspension of the measurements. In the evening the problem with beam 2 of the VMADCP is solved. One of the 41 pins in the connector was bent and leaning against a beam 2 signal pin. The signals, now formally good, turn out to be difficult to interpret, with some problems remaining.

Thursday 22 April

E7. 06.29 UTC resume the measurements of the CTD/FLY section, under sometimes reasonably rough conditions. Apart from a few problems with the CTD (Rosette rotor power supply) and one bad FLY station (loose IC) most operations and activities proceed smoothly.

Friday 23 April

SE3-5. At 17 UTC the CTD/FLY section I is ended. The bottom sampling starts at 700 m depth with box- and multicores and triangular dredge. The next three days, fishing and bottom sampling are continued successfully.

Saturday 24 April

SE4-5. Focus on 550 m depth, with CTD (still with occasional Rosette rotor problems), boxcores, triangular trawl and multinet.

Sunday 25 April

SSE3-4. Focus on 850 m depth, except for benthic video camera system on the Agassiz trawl (550 m depth) until late night.

Monday 26 April

Var. A beautifully calm and later sunny day. A long day, with bottom sampling and fishing from 8 UTC until 1 UTC the following morning. Focus on 300 m depth, 600 m depth (with enormous problems in obtainig some boxcore samples due to a stony bottom) and 900 m depth (Agassiz-trawl only).

Tuesday 27 April

Var2-W5. The triangular trawl ends at 1.15 UTC. From 2 UTC onward CTD/FLY section II is started, from the Shetland side in the direction of the Faroe. During the day several problems occur with the CTD/Rossette rotor (again), and, once, a front end part of the FLY cable has to be cut. This should have occurred earlier, because after the repair and a much better way of folding and taping the cable, the FLY operates better than ever before, with only very limited noise levels. One shear sensor breaks after a bottom hit (the breaking is due to the sturdy but small protection rack). The last spare sensor is installed.

Wednesday 28 April
NW5-2. Continuation of the CTD/FLY section II. No problems, other than a loss of data on the VMADCP in clear, mid-channel waters (being too clear for acoustic reflections).

Thursday 29 April
SW2-W8. At 9 UTC CTD/FLY section II ends with a last test of the FLY protection racks. Indeed the larger, less sturdy one magnifies the noise levels by a factor of about 1000. Less than an hour after the completion of the section the wind starts picking up, and 3 hours later we have Bf8. Close to the Faroe, we salute a goodbye and sail back to the Shetlands with SIMRAD and VMADCP on. Initially, the increasing wind causes difficulties in steering the main section coarse, but the officers manage to push on track.

Friday 30 April
NW7-2. 08 UTC start with a CTD during pretty large swell. Lateron, a boxcore and a multicore follow, all at 900 m depth. Between 13-17 UTC a final triangular dredge is fishing the 300 m line. Before sunset the first 2 moorings are recovered.

Saturday 01 May
NE2-0. A fine day. Between 06 and 17 UTC 4 moorings are recovered and 3 deployed. With a unique system of recovering moorings at the side of the ship, refreshing instruments in the lab, and (re)deploying from the stern, moorings stay on deck for a couple of hours only. Most instruments have worked fine. All OBS deliver good data, and all sediment traps have done their job. All 4 ADCP's provide good data, 13 out of 16 current meters as well. Both thermistor strings show good data, although one logger leaked and the power supply of the other ended 8 hours before recovery. All traps mounted on the bottom frames carried (a variety of) animals.

Sunday 02 May
SW4-2. Between 09 and 14 UTC the last mooring is recovered and 2 moorings are deployed. The very last task of the cruise is a final dredging for the lost mooring PRO1c1. The attempts are given up around 20 UTC. We set sail for Texel.

Monday 03 May
SW2. Transit into the Northern North Sea.

Tuesday 04 May
NE2-6. Dolphins and pilot wales, finally.

Wednesday 05 May
SW4-2. 12 MET-DST arrival at Texel, NIOZ harbour.

5. Scientific summary

a. Mooring deployments (Appendix B for the diagrams)

The mooring work experienced a tough start, with large swell making the deployments rather difficult. Due to insufficient molding of a line socket in combination with some large strain induced by the waves and a slow response of the sediment traps through the water, the line of the fourth mooring to be deployed (PRO1c1) 'broke'. Two acoustic releases, two current meters, a sediment trap, an OBS and the in-situ nutrient auto-analyzer are lost while the remainder of the mooring is damaged. The remaining four deployments have been completed using a method of deployment from the stern rather than from the side, and after modifying the sediment trap mooring frames by removing some of the ground plates. This mooring method takes longer but has the additional advantage of a more precise positioning of the mooring in strong (surface) currents.

The positions of the moorings are in Table 1, and schematically in Fig. 3. As a compromise (the lost mooring was originally scheduled at 400 m depth), the second sediment trap mooring (scheduled at 550 m) has been moored at 475 m depth. All seven 'short-term'

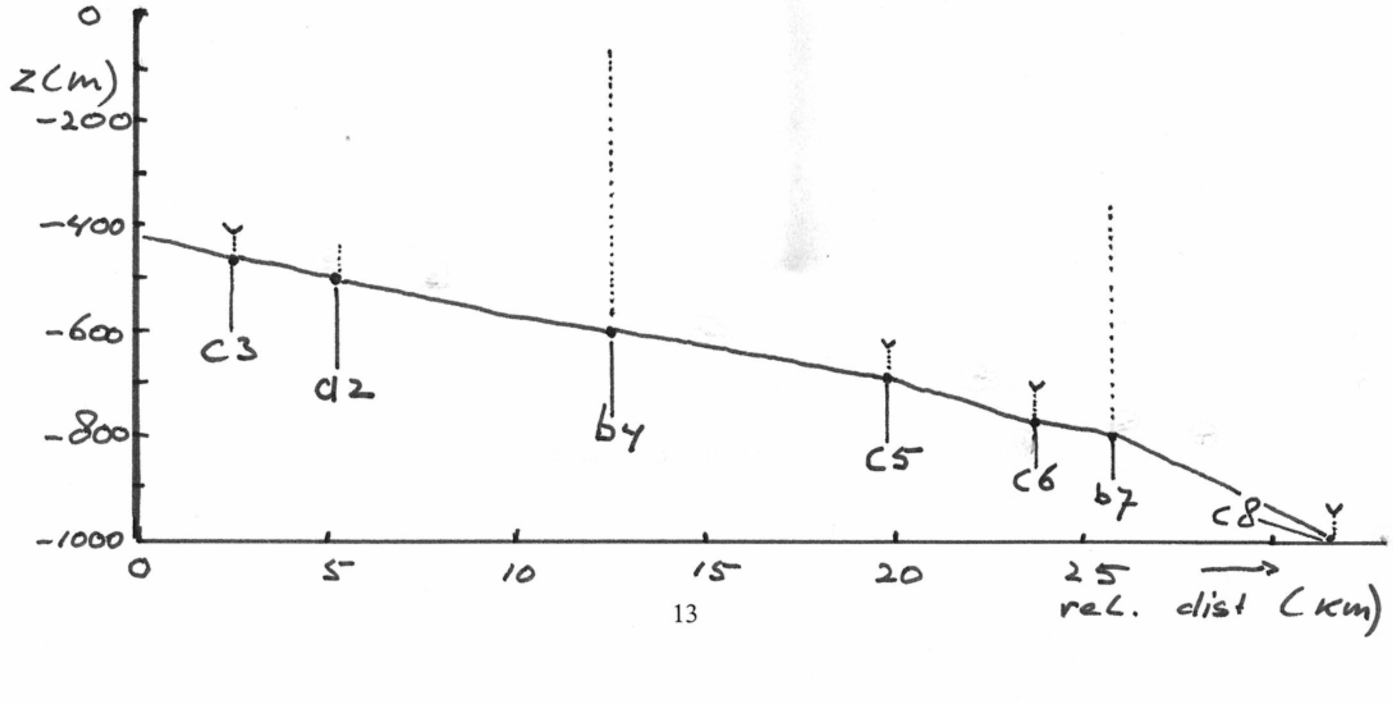
Table 1. Mooring positions

The lower case lettering **a-d** identifies the mooring type (**a** ADCP bottom lander, **b** 75 kHz ADCP, **c** 2 sediment traps/ 4 current meters, **d** sediment traps/current meter). The number **x = 1-3** identifies the deployment (1=April-May, 2=May-September, 3=September-October) and the number **y=1-8** identifies each mooring.

short-term moorings (990418-990501)			*long-term moorings (990502-99september)*		
PRO1c1	400 m	*lost*	PRO2d1*	552 m	*60°51.06'N -03°03.63'W*
PRO1a2	494 m	60°49.54'N -03°00.02'W	PRO2b2	593 m	60°52.42'N -03°05.63'W
PRO1c3	471 m	60°48.48'N -02°59.34'W	PRO2d3	803 m	60°57.41'N -03°14.25'W
PRO1b4	605 m	60°52.57'N -03°05.88'W	PRO2b4	850 m	60°58.20'N -03°15.30'W
PRO1c5	704 m	60°55.36'N -03°10.62'W	PRO2d5	1043 m	61°00.83'N -03°19.47'W
PRO1c6	777 m	60°56.91'N -03°13.22'W			
PRO1b7	807 m	60°57.63'N -03°14.12'W			
PRO1c8	997 m	61°00.09'N -03°18.39'W			

* Mooring PRO2d1 is drifting since day 154 (990603). Still (day 168) in the Faroe-Shetland Channel, it is scheduled to be recovered by the R.V. Pelagia soon.

Fig. 3. Schematic of relative positions of moorings across the Shetland slope.



moorings have been recovered successfully after two weeks of deployment, and the results are good as most instruments delivered data (see below). Perhaps the most remarkable 'catch' are the contents of the traps mounted on the bottom frames, carrying fish and even some snails. Without problems, five moorings have been (partially re-) deployed to remain on-site for another four months. Unfortunately, the ARGOS satellite mooring monitoring service has signalled a drifting mooring, about a month after its deployment. At the time of writing, this mooring (or what is left of it) has not been recovered.

1. Current and temperature measurements

All four ADCP's provided good data, 13 out of 16 current meters as well. Both thermistor strings show good data, although one logger leaked and the power supply of the other ended 8 hours before recovery. Detailed inspection of the raw data has to be done still, but the first analyses show some familiar, some new aspects.

The water column was very clear in terms of acoustic scatterers. As a result, the signal-to-noise ratio of the ADCP's was low and comparable with Antarctic waters, albeit varying strongly with time (Fig. 4) and space. On a diurnal time scale the range of good data varied between 300-500 m. Spatially, distinct layers with and without acoustic data are detected. As found during the pilot study, the strongest scattering layer coincides with the major pycnocline, which coincides with the layer of strongest shear. This layer varies in depth between about 350-500 m showing some diurnal variability with time, surprisingly. On the shorter vertical scales, closer to the bottom, the extreme frontal zones are again recognized, with currents accelerating from 0-40 cm/s within a minute (Fig. 5a), accompanied by strong bursts of acoustic reflection upon suspended particles (Fig. 5b) and strong temperature drops (see below). After such frontal passage, a group of velocity and acoustic reflection waves having typical periods of 10-15 min emerge, resembling internal solitary waves.

Fig. 4. Mooring PRO1b4 (600 m; Longranger BB-ADCP) vertical current shear for the entire period of measurements.The black band varying daily with time and 150 m vertically reflect 'bad' current measurements due to lack of scatterers.

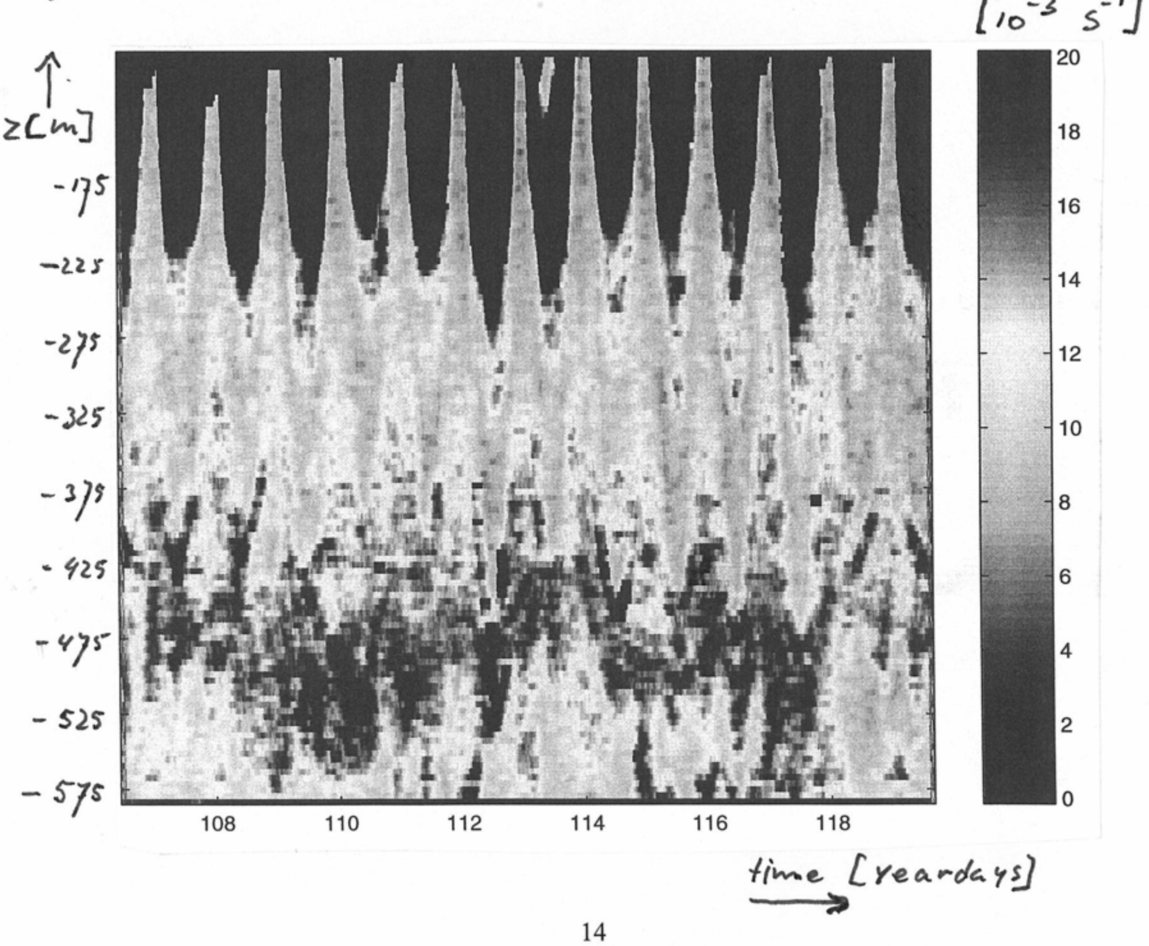
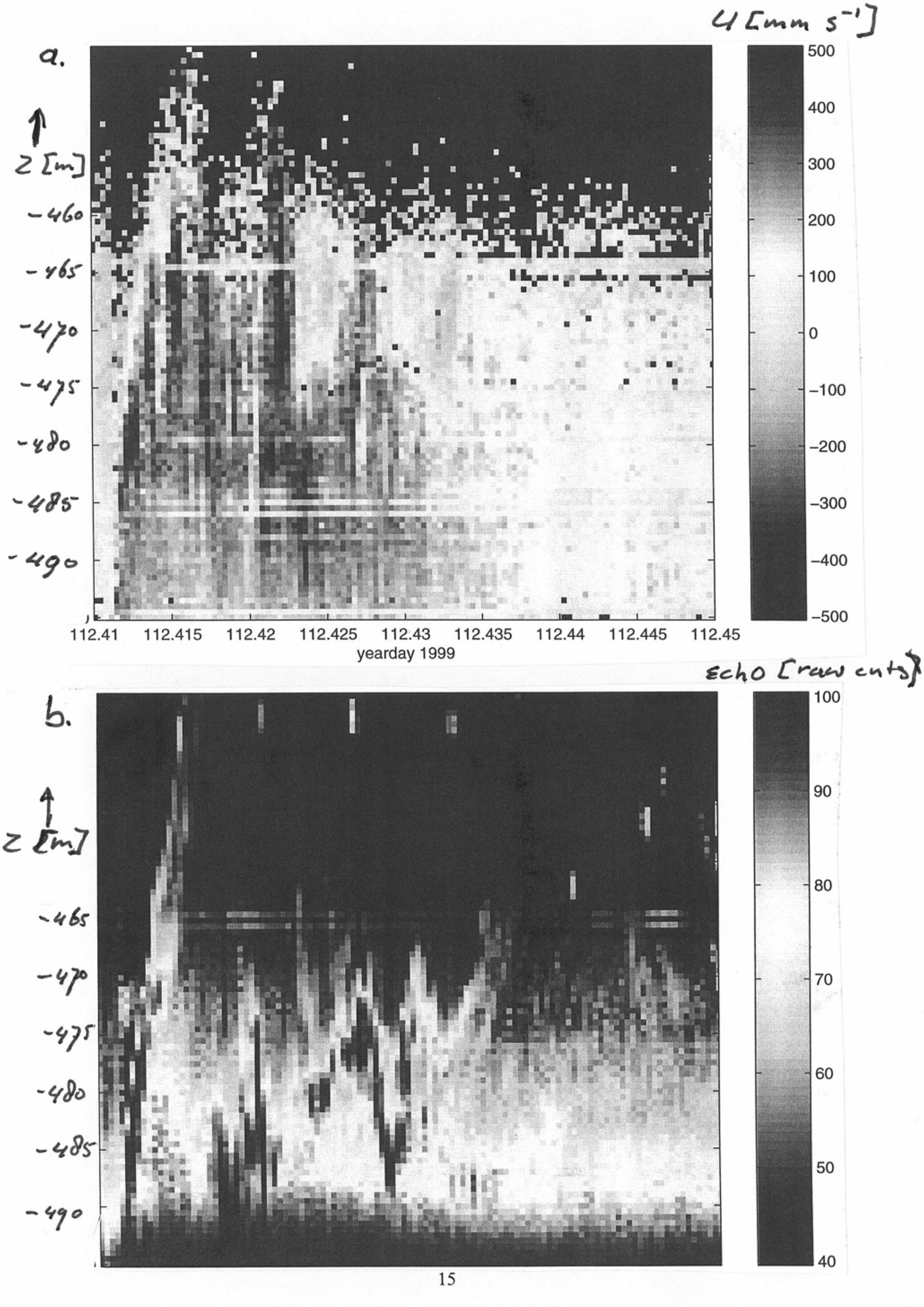


Fig. 5. a.One hour of near-bottom current data at mooring PRO1a2 (494 m; 600 kHz BB-ADCP). Like in Fig. 4, the black band above 465 m indicates bad data due to lack of scatterers. b. The corresponding back-scattered echo intensity.



2. Near-bottom turbidity

Timeseries of near-bottom turbidity were measured with Seapoint Optical Back-scattering Sensors (OBS) mounted on the sediment traps (2 mab and 30 mab). In total we collected 8 time series of 12 days each at 475, 700, 790 and 1000 m water depth with data intervals of 4 minutes. Together with the OBS data, time series of the tilt angle (x, y) of the traps, temperature and pressure measured. The sensors worked excellently with a sufficiently high signal-noise ratio. Even in the sometimes very clear water the OBS sensors produced reliable results, as evidenced by the almost identical series obtained with the 2 sensors 28 m above each other on the traps moored at 475 m water depth (Fig. 6c). Results show considerable differences in near-bottom turbidity across the slope. Highest turbidity was observed at 2 mab at 1000 m after day 112-113 (Fig. 6a), which may point at sediment focusing in a relatively thin benthic nepheloid layer towards the axis of the channel. Surprisingly, the increase in turbidity was not observed at 30 mab at the deepest station, but it did show up in the 790 m (not shown) and 700 m station, both at 2 and 30 mab, and to a much lesser extent at 475 m, also. Particularly at this latter station the increase in turbidity coincides with a dramatic change in bottom water temperature, a drop of almost 6 degrees within a very short time at 2 mab first and at 30 mab shortly after (Fig. 6f). A second but smaller drop in temperature occurred on day 116, but this was less clearly accompanied by an increase in turbidity. The temperature series at 700 m shows that the bottom water moves up and down the slope from day 108 to 112. The last peak on day 112 coincides with the drop in temperature higher up the slope and is directly followed by the steep increase in turbidity. Although the data have to be evaluated more properly and firm conclusions can not be drawn here, the data suggest the occurrence of benthic storms associated with rapid changes in the bottom water, most likely at mid depth (400-800 m). Down-slope transport and sediment focusing would thus explain the increasing turbidity with depth and the apparent delay in maximum turbidity at 1000 m.

3. Particle fluxes (by G.J. Brummer)

All traps were programmed to collect in 12 synchronised intervals of 24 hours, starting on April 18 at 24:00 hours UTC and ending on April 30 at 24:00 hours. Array PRO1C8 contained a HDW-type trap in the bottom frame with 20 collecting cups so that the initial 8 collecting intervals of 24 hours could be covered by 16 intervals of 12 hours. The other 7 traps were of the Technicap PPS 4/3-type with 12 collecting cups. In order to allow sampling in the high current velocity regimes, all standard traps were converted from funnel-shaped with a low aspect ratio to cylindrical with an aspect ratio of 8 and a baffled (10mm hexagons) collecting area of 0.175m^2. Prior to deployment all collecting cups were filled with seawater from near the deployment site and depth, to which a biocide ($HgCl_2$; 0.50g.l^{-1}) and a pH-buffer ($Na_2B_4O_7.10H_2O$; 2.00g.l^{-1}) was added to minimise further degradation of the organic matter and carbonate dissolution, respectively. In addition, CsCl and NaBr were added as tracers for assessing the exchange between cup solution and the ambient seawater (end concentrations 0.050 and 1.0g.l^{-1}, respectively) and NaCl was used to arrive at the ambient salinity. After recovery of the arrays, all traps appeared to have carried out their programmed sampling schedule flawlessly. The cylinder mounted on the topmost trap of PRO1C3 was lost at some unknown time during deployment, thus compromising comparison with the fluxes intercepted by the other traps.

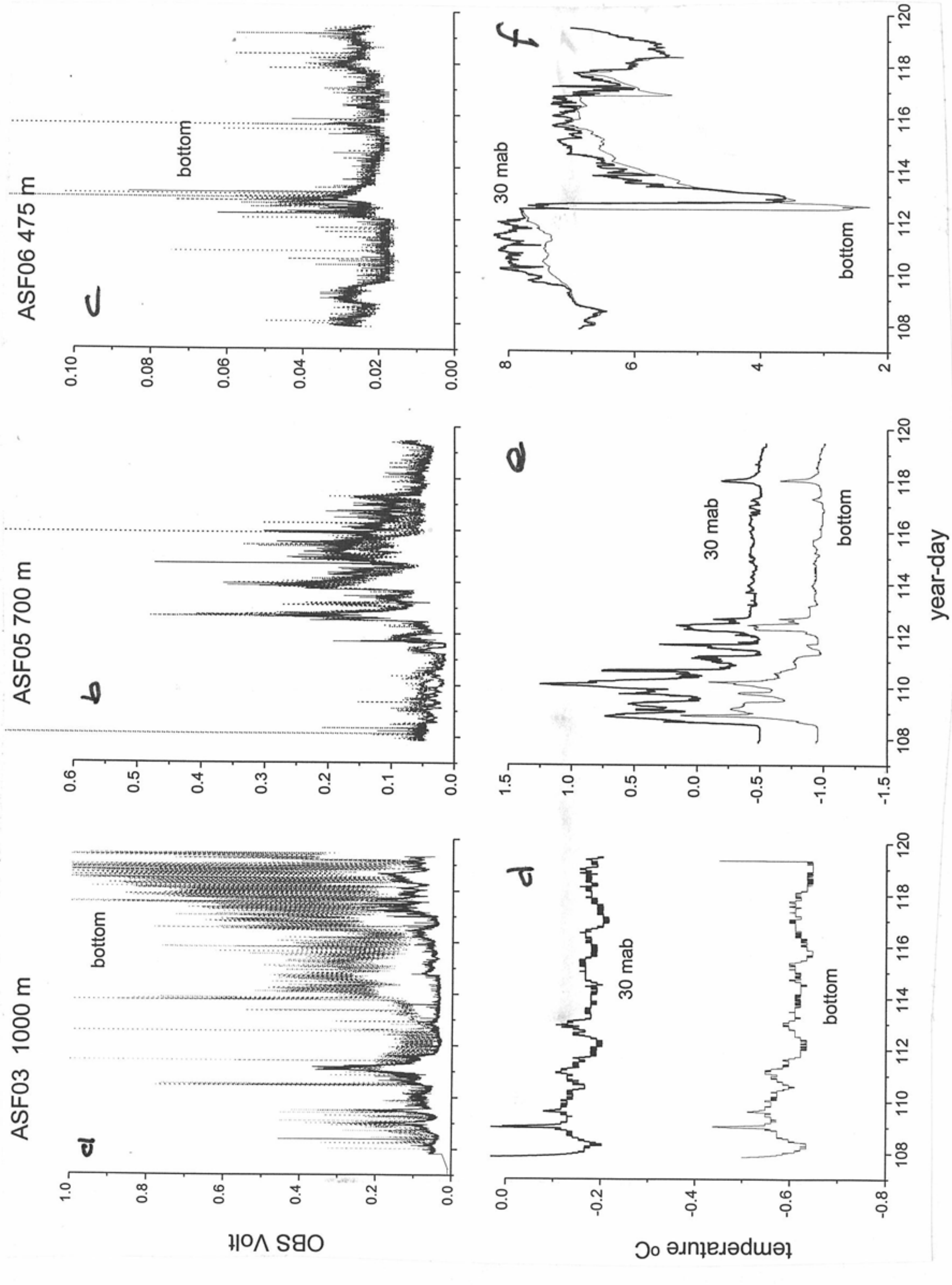
Although proper quantification of the particulate matter fluxes requires laborious shore-based analysis, some qualitative conclusions can be drawn at this stage:

1. fluxes are very low at the 470m mooring station (PRO1C3), both near the bottom and at 30mab, and seems to consist exclusively of fecal strings produced by pelagic copepods.
2. Highest fluxes are observed at the 780m mooring station (PRO1C6), particularly near the bottom with a pronounced maximum in April 23-25 (year-days 113-115). At about the same time the 700m mooring station (PRO1C5) shows a maximum albeit that fluxes are significantly lower. In both cases the timing coincides with marked pulses in optical back-scattering following rapid changes in bottom water movement across the slope (see above). The particulate matter concerned seems to originate from re-sedimented material

derived from the bottom rather than fecal strings as observed at 470m. Furthermore, fluxes are about 2 times higher in the near bottom traps than at 30mab, suggesting that material transport occurs predominantly along the seafloor.

3. Fluxes are relatively low at the 1000m mooring station (PRO1C8) with maxima during April 22 and 29-30 which again coincide with periods of enhanced turbidity as measured by optical back-scattering. Interestingly, both the near-bottom trap and the one at 30mab show about the same flux.

Fig. 6. OBS turbidity data (a-c) and temperature (d-f) measured at 2 and 30 m above the bottom.



In order to assess particulate fluxes on longer time scales and across the spring bloom, 3 moorings with a single sediment trap each as well as an OBS, temperature and tilt sensors were re-deployed at 550m (PRO2d1), at 800m (PRO2d3) and at 1000m (PRO2d5). These will be recovered in late September after completing a sampling schedule with a temporal resolution of 11 days.

4. Traps (by R. Daan & A. Weber)

On each of the frames of the four sediment traps that were lowered to the sea bed for the geochemical component of the project, we had mounted four traps (fykes) to collect hyperbenthic crustaceans such as amphipods and shrimps. The fykes consisted of persplex tubes (diameter: 20 cm; length: 60 cm) equipped with two conical metal grid inlets (mesh size: 5 mm). In 50% of the fykes the metal grid was overlayed with plankton net (mesh size: 0.5 mm) to improve the capturing of smaller specimens. The plankton gauze also narrowed the 4 cm opening of the metal grid cones. As a consequence the animals could still get in easily but were prevented to escape again. The traps were stocked with bait (dead sprat).

Generally, the bait in the traps seemed to have attracted in particular large amounts of amphipods and, to a lesser extent, shrimps. The highest number of specimens were consistently found in the fykes that were provided with plankton gauze. There are two plausible explanations for the smaller catches in the fykes without plankton gauze: 1) It is presumablly much easier for the animals to escape through the big inlets than through the inlets covered with plankton gauze, and 2) In several of the big-inlet fykes one or more fish had intruded. These fish were presumably attracted by the large amounts of crustaceans already present in the fykes. Once in the fykes they might have consumed the bulk of the present crustaceans. This hypothesis was supported by the result of an analysis of their stomach contents which clearly consisted of these crustaceans.

There seemed to be a clear depth-related gradient in the species composition of amphipods in the traps. The amphipods in the traps were preliminarily classified as five groups: black - , orange - , red - or brownish eyes, or a bright red body (Fig. 7). ‘Orange eyes’ dominated the shallow depths and disappeared below 800 m. ‘Red bodies’ were most frequent in the deeper parts and ‘black eyes’ predominantly occurred in the intermediate parts. All catches were stored at -80°C for later biochemical analysis. The fykes proved to be a promising method to collect undamaged living material for further study.

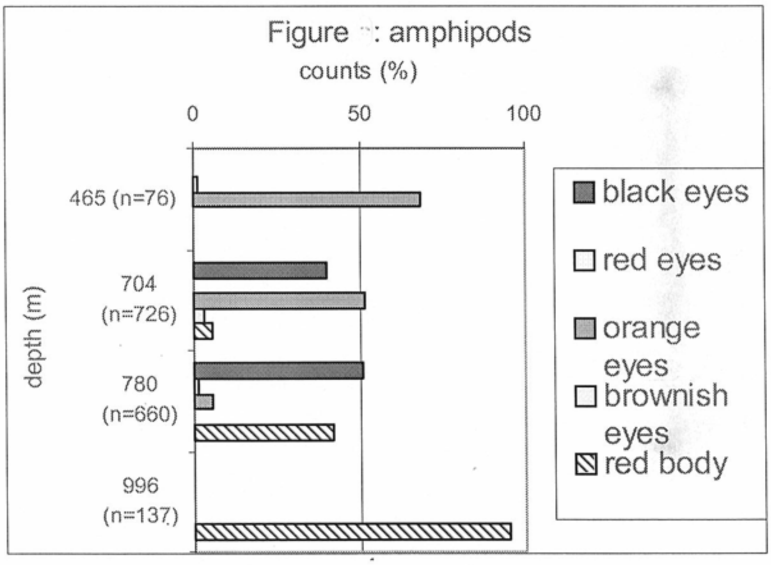


Fig. 7. Amphipods catches in near-bottom fykes.

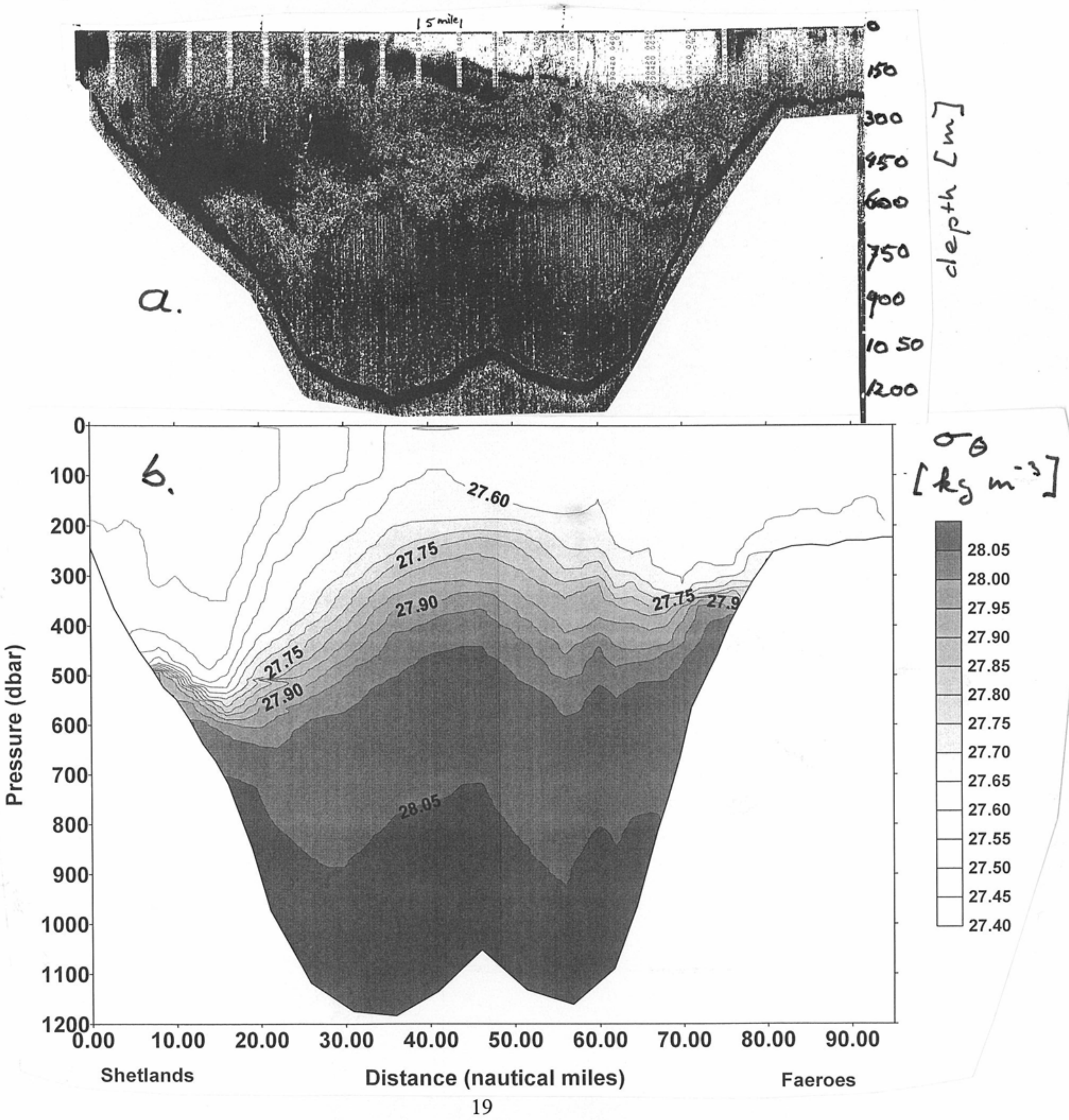
b. Continuous shipborne recording

All continuos sampling has been focused on two transects, both more or less perpendicular to the bottom slope. One is along the moorings on the eastern slope on the Shetland side. The other is rotated to the east by about 10 degrees, crossing the entire channel, and being perpendicular to the average of the two slopes on the Shetland and Faroe sides.

1. Aquaflow

These data show the surface outcropping of fronts as observed in all parameters monitored (temperature, salinity, fluorescence and oxygen). Although not conclusive, these fronts cannot directly be associated with canonical 'shelf-break' fronts, because they are found too far off-slope from the shelf break. This may point at some other, internal wave related?, frontal mechanism.

Fig. 8.a. SIMRAD 38 kHz reflection pattern across the Channel. b. Corresponding sigma-theta (density anomaly) from CTD-observations obtained during the three after the SIMRAD survey.



2. SIMRAD scientific echosounder

The 38 kHz echosounder has been operated at the maximum sensivity. The different crossings showed differing acoustic reflection patterns in the positioning of fronts and the near-bottom 'upslope creeping' of strong density fronts, and a general pattern in the main thermocline depth (Fig. 8). Note the areas of little of no scatterers in the upper 50-200 m on the Faroe side, and two regions around 750 m, on both sides of the central 'ridge'.

3. Vessel-mounted 75 kHz ADCP

This instrument has been recently installed on the R.V. Pelagia. After repair of the main connector and installation of the navigational data-file reasonable data were obtained. As tiltsensors are not available, errors occurred upto tens of cm/s in rough seas, which are not uncommon in the Faroe-Shetland Channel. Like the other ADCP's, this instrument also suffered from lack of acoustic scatterers, especially in the centre of the channel, and between about 100-400 m depth. Despite the unfavourable circumstances, some reasonable dataflow has been created during the last two transects (out of four). They show strong along slope currents upto 1.3 m/s and occurring above the centre of the slope (500 m depth), predominantly on the Shetland side. Deeper into the watercolumn, strong vertical current differences (shear) are noticed, but no coherent pattern of internal wave propogation could yet be detected from the raw data. These data require considerable effort to become a coherent set. The post-processing includes calibration with data from the moored ADCP's, due to the variable reference velocities (to subtract the ship speed).

c. CTD and water sampling

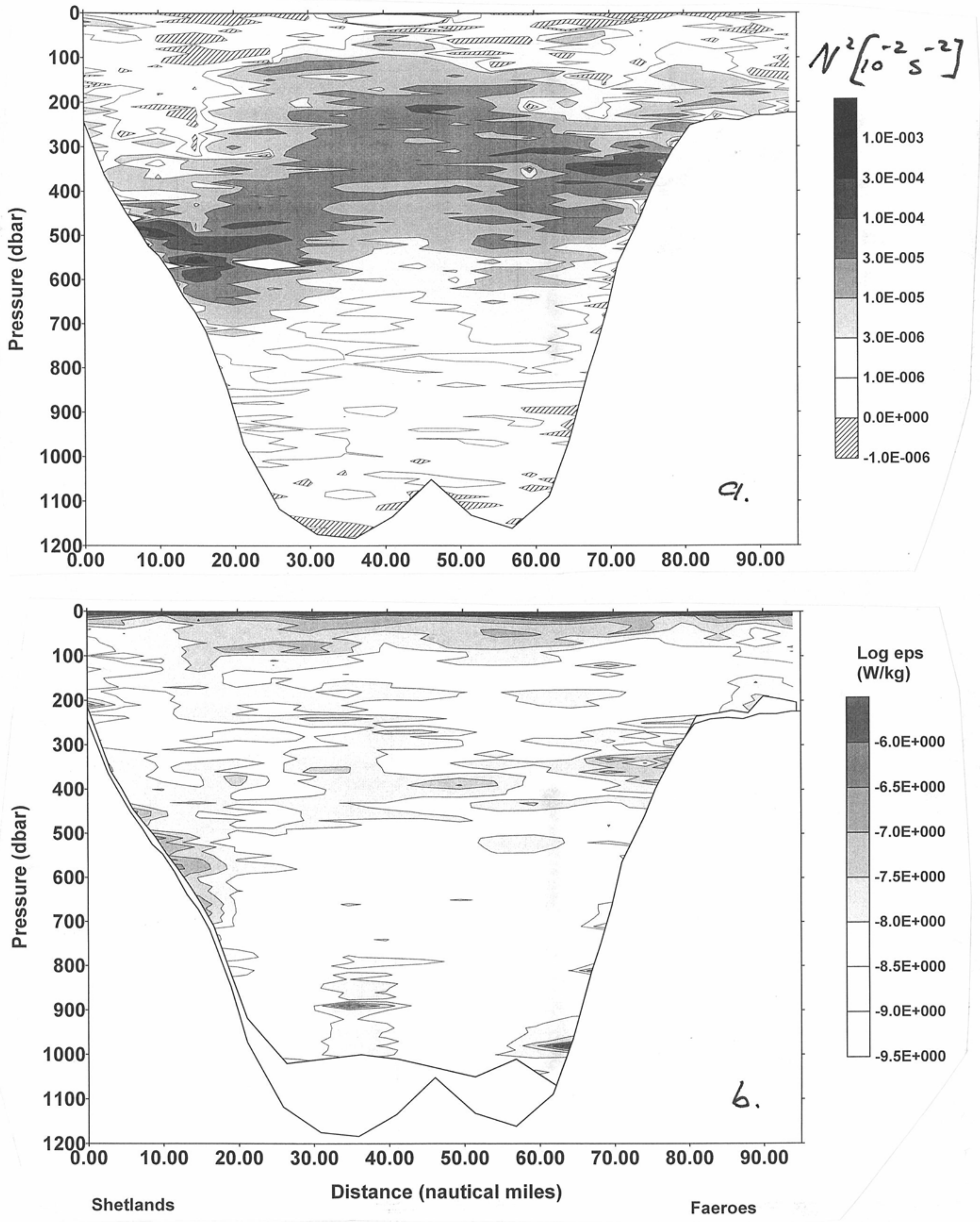
The CTD operations were 'normal', requiring a modest amount of repair-work on the Rosette 'multi-valve' system, only. This multi-valve system consumed too much power, causing several bottles not closed at the required depths, but no CTD stations has to be cancelled. The problems signalled with this system have raised new ideas about how to close bottles in the Rosette in the future.

Twice, a large hydrographic section has been extensively sampled. This section covers the cross-section of the channel with 38 stations at 1.5 nautical miles mutual distances above the sloping sides upto 5 nautical miles in the centre of the channel (Fig. 1). Water sampling from 5-6 depths has been performed every station. As each CTD cast was followed by a FLY cast, each section took about 55 hours to complete. The hydrographic surveys confirmed by-and-large earlier (1997) surveys, but also showed distinct differences (like in the SIMRAD data). The main pycnocline tends to cap the channel around 400 m depth more a-symmetrically than has been observed before (Fig. 8b, 9a). Also, above both slopes, a distinct bottom boundary layer is found, moving upslope. The sloshing back-and-forth of such bottom fronts cause the dramatic near-bottom current and turbidity patterns. Roughly, but not exactly, the main pycnocline pattern is associated with the main distribution of turbulent dissipation (Fig. 9b; see below).

d. FLY microstructure profling (by C. Veth)

This cruise was the first when 'workable' data have obtained with the FLYII microstructure profiler, acquired some 15 months before. The launching of this instrument with the line-puller system worked fine from the stern, upto wind force Bf7. The instrument measures turbulence down the finest dissipation scales, and did so down to 1000 m depth. As the system is extremely sensitive to any disturbing motions (e.g. of its frame), a new protective has been installed prior to the cruise. This cage reduced the noise levels considerably, so that turbulence signals were detectable now. However, it has the disadvantage that the instrument can not be dropped to sea floor, as the sensors are too exposed. Thus, the line-throwing of this free-falling instrument was halted some 20 m above the bottom, resulting in profiles down to 18 m above the bottom and, exceptionally, the bottom proper. A line rupture further improved the noise levels as the following cable repair

Fig. 9. a.Density stratification (buoyancy frequency squared) from CTD transect I. b. 'Raw' turbulent dissipation data from the same transect.



resulted in a more thorough packing of the loose end. Nonetheless, some instrumental problems remain, and further elaborate data analysis is needed to improve the data to a consistent set.

The first data analysis (resulting in dissipation data accurate to within a factor of four, roughly) shows a correspondence between the distribution of enhanced turbulent dissipation rates and density stratification. Close to the bottom slopes turbulent dissipation rates are enhanced (just below) where the stratification creeps upslope. The effects of this enhanced sloping boundary turbulence on mixing has to be established, yet.

e. Sedimentological sampling

1. Total particulate matter in bottle samples

Bottle samples were collected every 100 m, 10 m below the surface and near the bottom on all CTD stations and analyzed for dissolved nitrate, nitrite, ammonium, phosphate, silicate and inorganic carbon (DIC). On 33 stations we filtrated samples of 3-6 different depths to determine chlorophyll and other pigments (47 mm cellulose acetate, 0.45 μm), total particulate matter and its elemental composition (pre-weighted polycarbonate filters, 0.4 μm), total nitrogen and carbon content and $\delta^{15}N$ ratio (25 mm glass fiber, 0.9 μm), as well as organic carbon and nitrogen content and $\delta^{13}C$ ratio (13 mm glass fiber, 0.9 μm). In total 168 samples were filtrated corresponding to about 2.5 m^3. Aim of these measurements was twofold: 1) to collect calibration data for the turbidity sensors on the CTD and trap-moorings as well as for the fluorometer on the CTD, 2) to characterize the particles and possibly differentiate between their sources.

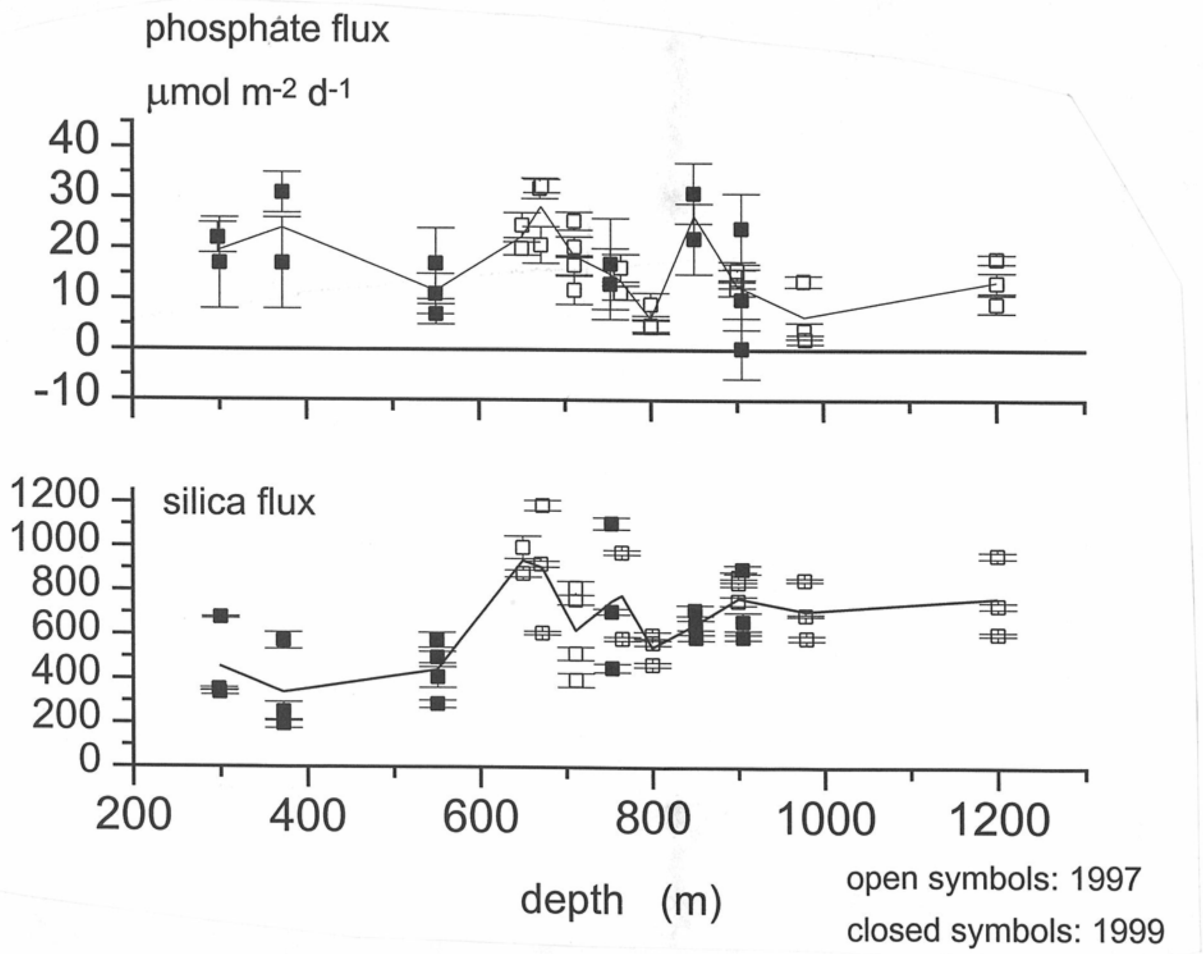
The amount and composition of organic matter (OM) that is delivered to the sediments strongly depends on the duration of vertical and lateral transport through the water column and nepheloid layers near the sediment surface. The preferential utilization of amino acids, the building blocks of proteins, causes the relative amount of amino acid nitrogen in total nitrogen to decline from 75-90% in plankton to 40-50% in sinking particulate nitrogen and 10-30% in sedimentary particulate nitrogen. In addition, relative contributions of amino acids in OM changes during transport through the water column and early diagenesis in the sediments, which make amino acids good indicators of OM degradation state. An amount of 40 liters from surface layer water, nepheloid layers at 230-280m and bottom water at station 59-1 (550m), 66-1 (850m), 73-1 (303m) and 126-1 (909m) were filtrated through pre-combusted Whatman GFF filters (0.7 μm, in total 480 liter) to collect suspended organic matter. All filters were stored at –20°C until analysis at the NIOZ.

2. Sediment samples

Multi-corer or box-corer samples were collected at 7 stations between 300 and 900 m water depth at the West Shetland Slope. The multi-corer could be used at the deeper stations, only. For the shallower stations, which were either covered by gravel and stones or consisted of hard sands, we used the 0.5 m diameter box-corer and sub-sampled the core with the multi corer liners. Sediment cores were sliced in intervals of 2.5 mm (0-1 cm), 4 x 5 mm (1-3 cm), 4 x 10 mm (3-7 cm) and 4 x 20 mm (7-15 cm). Sediment slices will be analyzed for the same parameters as particulate matter (including amino acids), as well as for porosity, particle size composition and biogenic silica. By combining similar data from the sediment, sediment traps and particulate matter we hope to get insight in the sources and transport routes of particles from the shelf and the productive surface layer, through the water column to the sediment.

Pore water profiles of phosphate, ammonium, nitrate, nitrite, silicate and dissolved inorganic carbon were determined after combined centrifugation/filtration of sediment slices at 3.5-4.5 °C. These data will be merged with the data of the 1997 pilot cruise and will be used in conjunction with the flux measurements to identify zones with enhanced or lowered diagenetic activity on the slope. Preliminary results of the flux measurements show that the sediment-water exchange rates of the PROCS99 are of the same magnitude as measured during the 1997 cruise. In 1997 we collected cores at stations deeper than 650 m, only. The data of PROCS99 extend this initial dataset to 300 m. Two examples of flux data are given in Fig. 10. Phosphate fluxes are low without a clear trend with station depth, probably because at such low flux rates any trend is obscured by the relatively large “error-bars”. For silica fluxes could be estimated with more confidence. Apart from considerable core-to-core variability pointing at heterogeneity within 0.5 m length scales, the data show a clear increase in the fluxes between 550 and 650 m depth. This finding confirms our earlier ideas that most of the reactive particles are delivered to the bottom deeper than about 600 m, and much less to shallower sediments.

Fig. 10. Two examples of flux data, including data from the 1997 pilot study.



f. Plankton species composition (by G.J. Brummer)

Twice, the Multinet was operated, sampling three nets between 900 – 200 m depth. The aim of the Multinet sampling is to determine, where appropriate and possible, specific particles such as fecal pellets that are also found in the sediment traps. Therefore the net contents will be analysed fo elemental and isotopic composition. The successful sampling will also be used for guidance of the interpretation of the acoustic (ADCP and SIMRAD) sampling. The Multinet worked well, albeit some problems were noticed with the lowering through relatively strong pycnoclines. The different layering visible in acoustic data were perfectly visible in the Multinet catches. Clearly, large amounts of copepods result in large acoustic reflection and low acoustic signal-to-noise ratios coincide with layers (almost) void of scatterers.

g. Benthos sampling (by R. Daan & A. Weber)

An inventory of the benthos on the west-Shetland slope of the Faroe Channel was carried out with a variety of methods along the main transect. Aside the fykes on the mooring frames we identify,

1. Box cores

Between 300 and 900 m box cores were collected. Material from the top 15 cm was washed over a sieve (mesh size: 1mm). Residual material consisting of macrobenthos and small gravel was preserved in buffered 5% formalin for later analysis. Visible fauna consisted mainly of small sponges, tube-building worms, small crustaceans and occasionally brittle stars and sea urchins.

2. Triangular dredges

Larger epibenthic fauna was collected with a small-sized triangular dredge (90*90*90 cm). Each dredging period lasted between 5-15 min between lower and heave. This type of net had been proved useful in areas with a rough bottom texture. In spite of slight damages of the net in almost each haul each catch contained a number of epibenthic species. The shallower areas were dominated by sponges and brachiopods (300-600 m) but in the deeper parts particularly the brachiopods disappeared. At the deeper stations the catches were generally smaller and consisted of small brittle stars, molluscs, tube-building polychaetes and sponges. Generally the material was preserved in buffered formalin (5%). A number of large sponges were frozen (-18 °C). Special attention was paid to the bivalve *Astarte* spec. Several different-sized specimens of this species were found at stations down to 600 depth. This material was frozen at -80 °C for later biochemical analysis and growth measurements based on shell increments.

3. Video recordings

Video records of the sea bed were collected with a camera mounted on a frame of an Agassiz trawl. Each two-hour recording covered part of the south-eastern slope (560-470 m and 900-770 m). These depth transects had not been covered during the pilot study in 1997. The record of the shallower transect showed a varied bottom structure with a great variety of sponge species, shrimps and anemones. On many sponges echinoderm species (urchins, starfish) had settled suggesting symbiotic relationships. In the deeper areas the sea bed was less rugged. Dominant sediment dwellers were tube-building polychaetes. Stones, though present, seemed to be generally covered with a thin layer of sediment which was not observed in the shallow section. In the deeper part of the transect the sea bed surface was relatively flat, but at around 800 m strong regular sand ripples could be observed suggesting a sudden change in hydrodynamic conditions. Together with the records collected during the pilot study in 1997 we now have an almost complete set of video records of the sea bed between 450 - 1000m depth.

6. Concluding remarks

Despite the adverse weather during the first week and, associated perhaps, some misheaps like the mooring loss occurring in the same period, this cruise has been very successful. The successrate of the moorings, the completion of two cross-channel hydrographic and micro-structure surveys, the sediment sampling and the unexpectedly successful benthic sampling have resulted in an unprecedented detailed sampling of a continental slope. First analyses show that we captured fast and vigorous eventlike bursting of near-bottom processes. It remains to be investigated what process determines such events, whether by internal waves or not, and whether they are characteristic for the Faroe-Shetland Channel or for continetal slopes in general. The overall influence of internal wave activity in the basin awaits further analysis and comparison with numerical modelling.

This success could only be achieved by the harmonious collaboration of the entire group of people onboard, who managed to handle the good number of completely different activities in a harmonious way. On behalf of the participants, I would like to thank captain John Ellen and his crew of R.V. Pelagia for the very pleasant cooperation. Funding by the Netherlands Organization for the advancement of Scientific Research is gratefully acknowledged.

This was a very good cruise,
thank you all who made it such a success.

Appendix A. Summary of the pilot study PROCS97.

The sampling program of PROCS'97 ran from 30 April (yearday 120) to 17 May 1997 (yearday 137). Six CTD sections were occupied perpendicular to the axis of the channel, five across the southeastern slope at mutual distances of 5-10 nautical miles, and one across the northwestern slope. The distances between the stations on the sections were 2.5, 5 and 10 nautical miles depending on depth gradients as revealed by the CTD casts.

The hydrographic data confirmed the water mass distribution known from other studies, most particularly the presence of warm surface water flowing to the north and cold bottom water draining southward. The major pycnocline between these water masses was at 400-600 m depth.

Near-bottom current velocities were up to about 0.6 m s^{-1} at stations shallower than 600 m and up to 0.4 m s^{-1} at about 700 m depth. The cross-slope component of the current was, on average, directed down-slope in the surface water and directed up-slope in the bottom layer. This implies an intrusion of water from the slope to the interior of the channel at the depth of separation between both water masses (400-600 m). The cross-slope current velocities contained significant signals of semi-diurnal (M_2) frequency above, in and below the major pycnocline, and the corresponding power density spectra followed the theoretical spectrum for internal waves. Noteworthy was the almost 180° phase difference between the M_2 signal below and above the major pycnocline. Time series of temperature in the bottom water were dominated by relatively large variations with periods of about 3-5 days, related to possible meandering of the along-slope current or other features causing that water is moved up and down the slope. The up-slope movement was very rapid (within less than 1 h) and associated with short-lasting peaks in current velocity, large enough to induce resuspension.

The current and, to a lesser extent, the temperature data analyzed so far are consistent with, albeit not a proof of, the occurrence of internal waves of tidal frequencies impinging on the slope. Classically, internal waves are thought to cause enhanced resuspension when they are reflected critically, i.e. when the wave angle matches the angle of the sloping bottom. For larger angles of the wave rays reflection is forward towards the shelf-break (super-critical reflection), for smaller angles backward towards the interior of the channel (sub-critical reflection). The angles of the wave rays are determined by the frequency of the wave and the stratification of the water column, the waves propagating more horizontally when stratification is stronger.

CTD data showed that stratification was generally strongest between 400-600 m depth over the entire width of the Channel, most particularly close to the bottom at 500-600 m. The data further suggest that critical and sub-critical reflection of M_2-waves may occur in a zone between 450-550 m depth, possibly extending down to 650 m. At the same depths we observed enhanced turbidity suggesting bottom erosion into nepheloid layers, most clearly at about 500 m, but also deeper at about 700 m, i.e. slightly below the depth where M_2 is critical. These findings indicate that resuspension and formation of nepheloid layers occur in well-defined depth zones related to the reflection of internal waves on the sloping bottom.

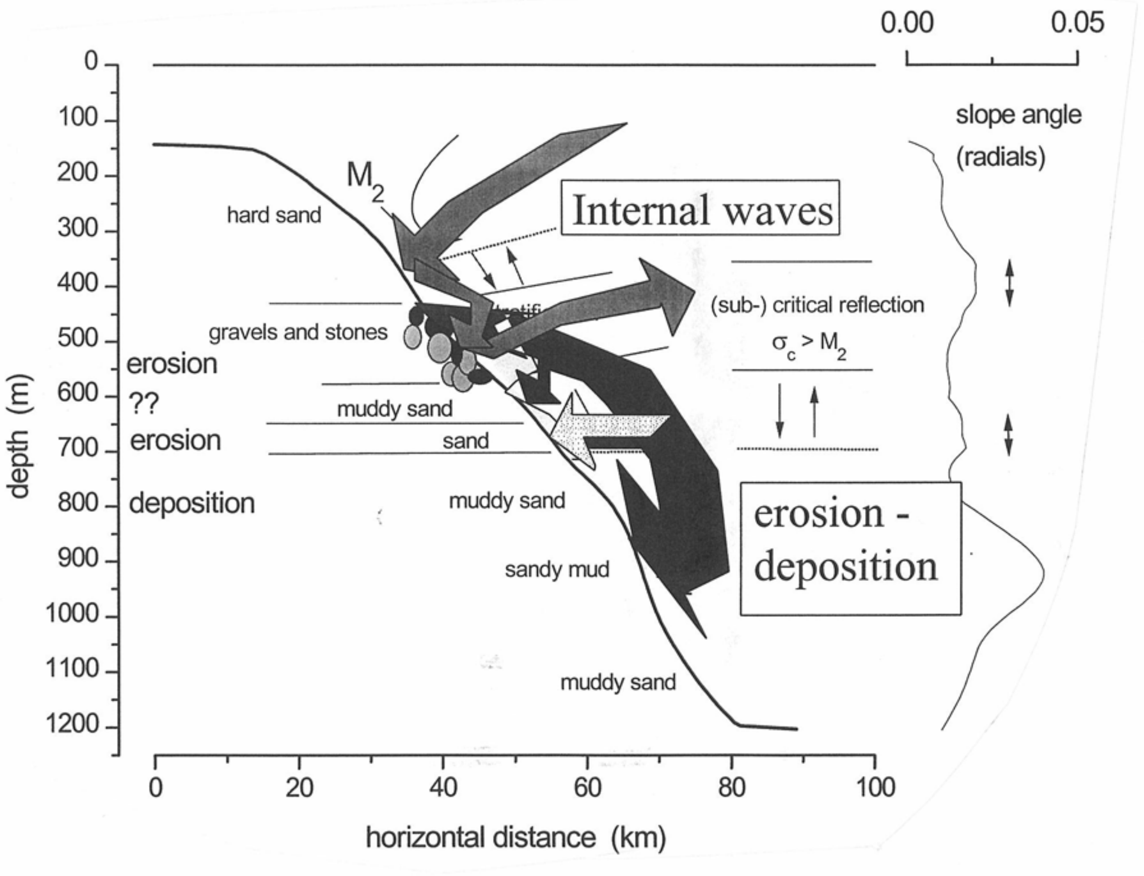
After some filtering, a basin-wide overview of the coarsely resolved buoyancy gradient appears to show indications of a two-cycle pattern that resembles a possible focusing of internal waves. Clearly this needs more work, both on the observational side through detailed basin-wide high-resolution CTD-surveying, and on the modelling side using the 'back-ground' in-situ observations.

Sediment samples could be taken with a multi-corer at stations deeper than about 600 m, only. Sediments between 300- 450 m consisted of hard sands in which our corer could not penetrate, and between 450-600 m the sea floor was densely covered with gravels and cobbles deposited during the last glacial ice retreat. Sediment organic carbon content shows little trend with station depth, but $\delta^{13}C$ and pigment ratios suggest that deposition may occur deeper than 700 m. For macrofauna boxcores could be taken at depths shallower than 600 m also. Numbers of living mollusks and polychaetes per boxcore confirmed the above zonation: low at stations shallower than about 500-550 m, maximum density at about 600 m and gradually decreasing densities when descending the slope. This pattern was most clear for deposit feeding species, giving evidence that a sharp gradient exists in depositional conditions at 550-600 m depth.

A suitable indicator for particle transport and deposition is provided by ^{210}Pb inventories. ^{210}Pb profiles were measured at 7 stations between 649-978 m depth. All profiles show excess ^{210}Pb concentrations in about the upper 6 cm relative to the background ^{226}Ra supported concentrations. We estimated bioturbation rates from the profiles, which yielded low rates at the two shallowest stations (649, 672 m) increasing sharply to a maximum rate at 711 m depth and subsequently decreasing again to low rates at stations deeper than 900 m. These findings compare favourably with the zonation of macrofauna density. ^{210}Pb input fluxes to the sediment (a measure for particle deposition), as calculated from the profiles, also showed a distinct minimum at 672 m depth and highest fluxes at 766-801 m. Comparing the calculated fluxes to the theoretical input flux based on solely vertical particle transport through the water column, indicated that at all stations, particularly those deeper than 750 m, additional deposition of ^{210}Pb activity derived from lateral inputs is necessary to explain the ^{210}Pb inventories in the sediment. At St. 78 at 672 m depth, however, the ^{210}Pb input flux is distinctly less than what is expected theoretically. This implies that at this particular station erosion dominates over deposition, while at the other stations, most clearly between 766-801 m, deposition dominates, including of particles eroded up-slope at stations shallower than 600 m.

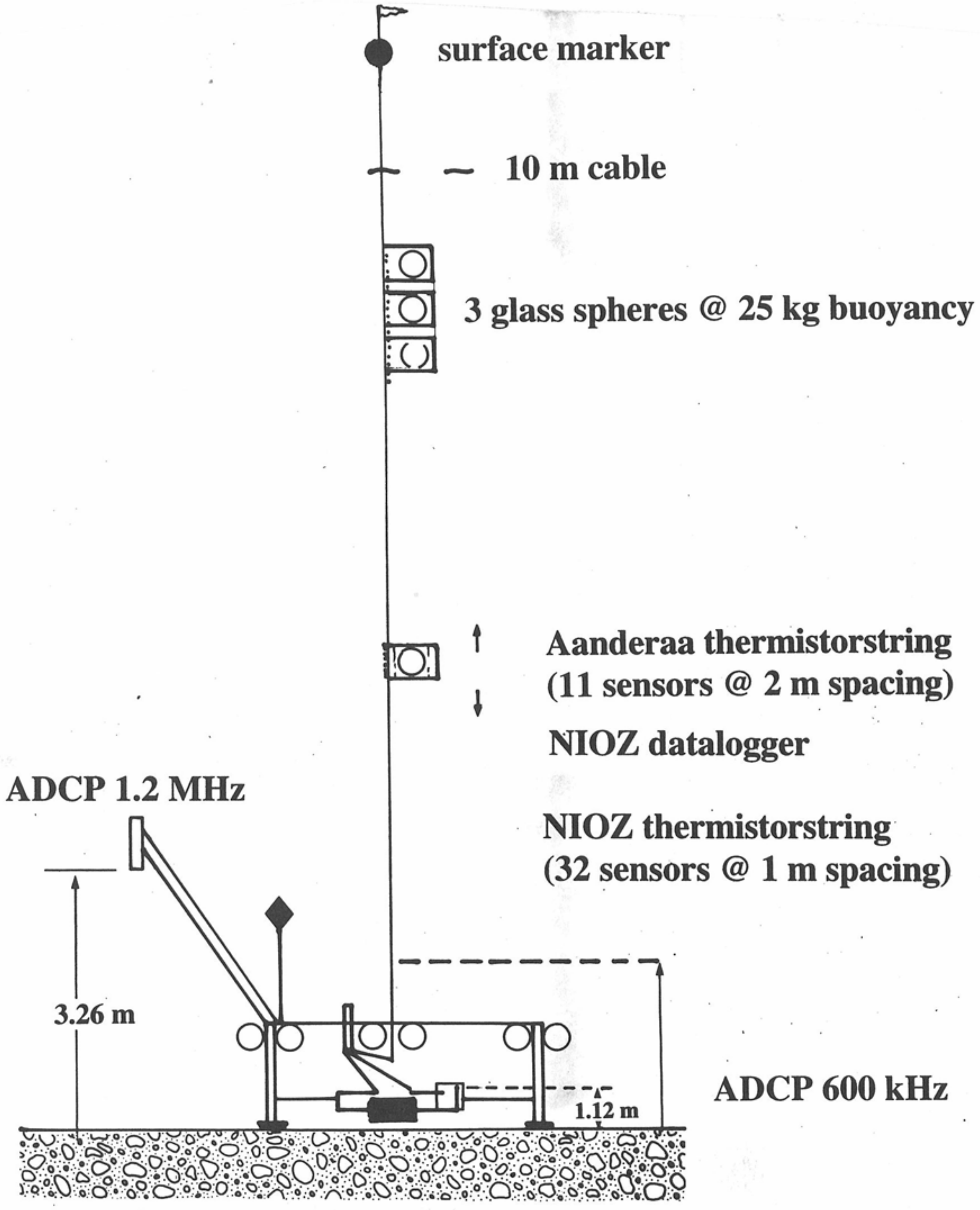
Thus, internal waves of tidal frequency are present and impinge on the bottom at angles close to critical between 450-500 m depth (Fig. 11). Geometric focusing of these waves would be possible with reflection points on the slope between ~ 400-600 m. Nepheloid layers were observed near the bottom at ~500 m and once at ~ 700 m. Sediment texture, benthic fauna densities, pigment ratios and ^{210}Pb inventories evidenced the dominance of erosion at depths shallower than 550 m and deposition deeper than 600 m, particularly between ~700-800 m on the slope.

Fig. 11. Impression of processes at the slope from observations of the 1997 pilot study.

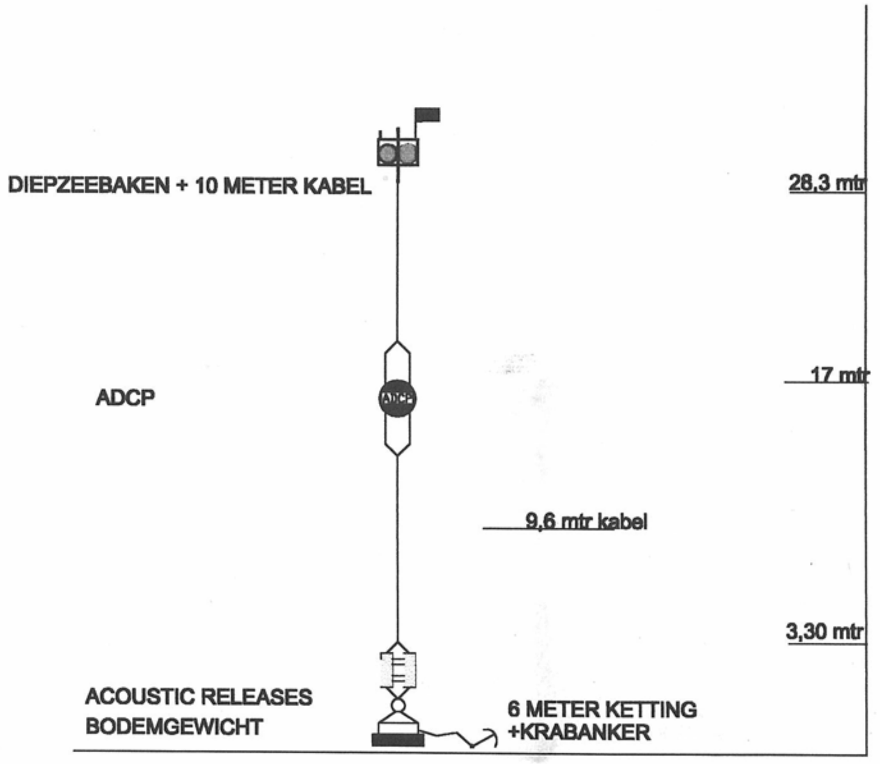


Appendix B Mooring schemes (*Dept. Sea Techn.*)

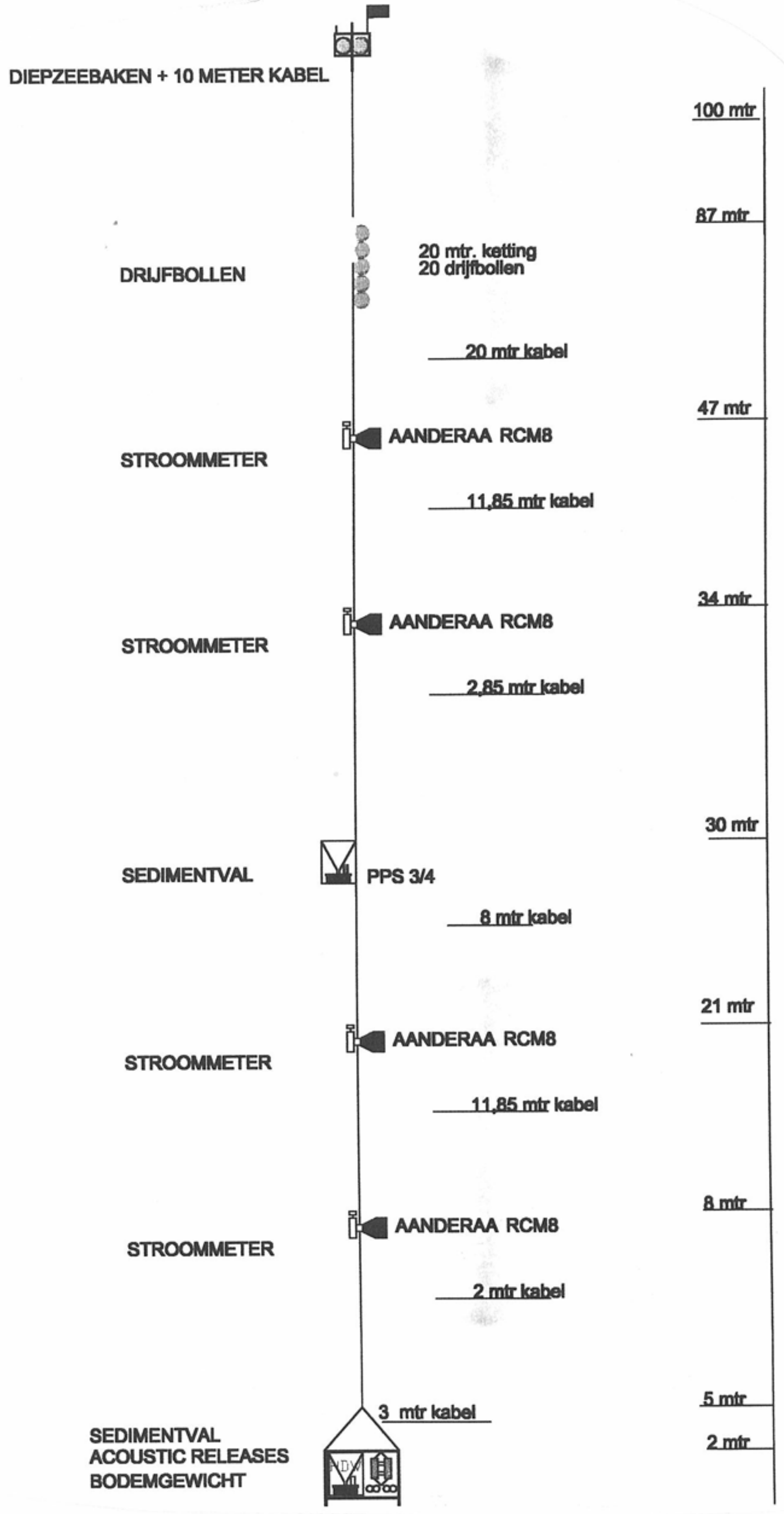
PROxay *Short-term Fast sampling ADCP-Thermistorstring mooring*



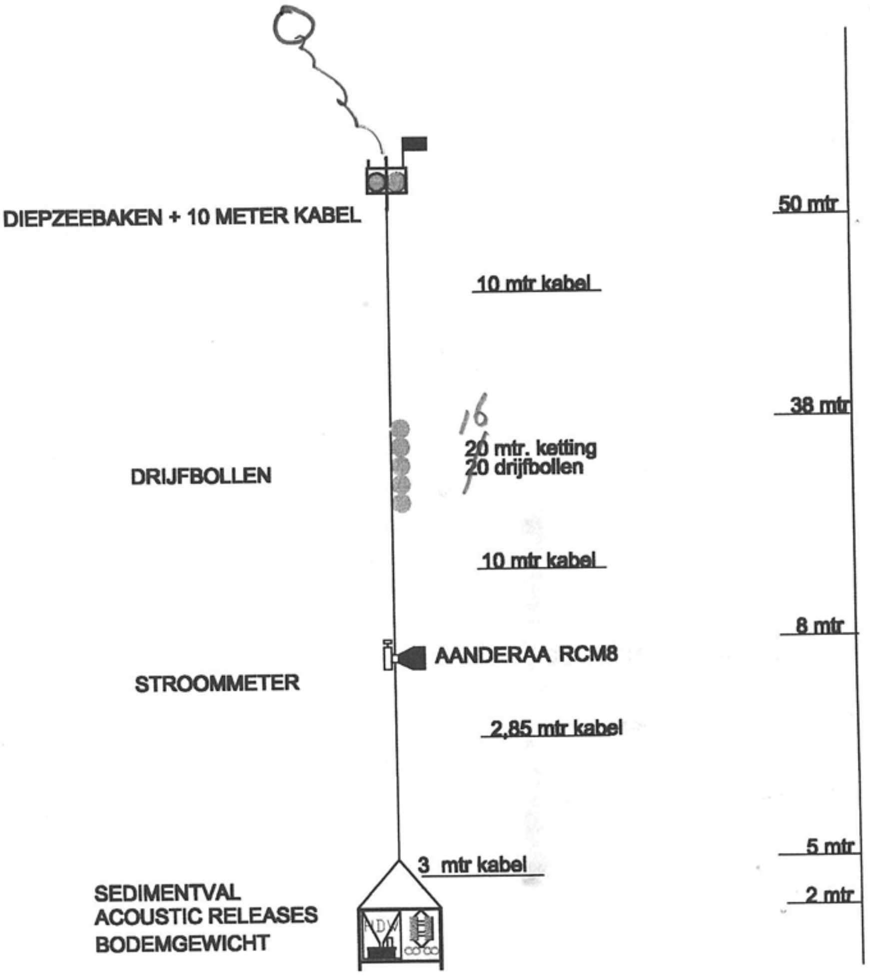
PROxby *Short- and Long-term 75 kHz ADCP mooring*



PROxcy *Short-term sediment trap/current meter mooring*



PROxdy *Long-term sediment trap/current meter mooring*



Appendix C Cruise summary of stations (activities)

Cruise Summary Pelagia cruise 64PE137 **PRO99-1**

Compass dev 7°52' W

NAV: GPS

Bottom slope Shetlands: 52° E

Main transect CTD/FLY: 313°

Cast types:

CTD	ctd
ROS	ctd-rosette
BOX	boxcore
MUL	multicore
TWD	triangle trawl
MOR	mooring
SIM	simrad track
ADC	ADCP/simrad track
ATV	Agassiz

Event codes:

BE	Begin
BO	Bottom
EN	End
DE	Deploy
RE	Recovery
F	Failed

1 salinity	8 SPM
2 oxygen	9 Chla
3-7 nutrients	

STN#	CAST#	CAST TYPE	mm/dd/yy hh:mm CAST DATE	EVENT CODE	LATITUDE Deg.	LONG Deg.	Uncorr. DEPTH	Measurements	COMMENTS
001	01	ROS	4/16/99 19:52	BE	60.9616	-3.2280	807	sediments	Sediment trap vullen
002	01	MOR	4/17/99 9:30	DE	60.9605	-3.2348	810	NBADCP	PRO1b7
003	01	MOR	4/17/99 10:50	DE	60.8667	-3.0834	605	LongRangerADCP	PRO1b4
004	01	MOR	4/17/99 12:10	DE	60.8248	-2.9990	494	Cur and temp	PRO1a2
005	01	MOR	4/17/99 16:00	DE/F	60.7643	-2.9349	400	Cur and sed	PRO1c1 + AA
006	01	MOR	4/18/99 10:29	DE	60.8080	-2.9889	471	Cur and sediment	PRO1c3
007	01	MOR	4/18/99 14:44	DE	60.9227	-3.1770	704	Cur and sediment	PRO1c5
008	01	MOR	4/18/99 17:06	DE	60.9485	-3.2203	778	Cur and sediment	PRO1c6
009	01	MOR	4/18/99 19:51	DE	61.0014	-3.3065	996	cur and sediment	PRO1c8
010	01	ADC	4/18/99 20:30	BE	61.0340	-3.3574	1094	ADCP + Simrad	VM-ADCP test track
010	01	ADC	4/18/99 22:52	F	60.7824	-2.9519	422	ADCP	Geen ADCP data
010	01	ADC	4/18/99 23:33	EN	60.6841	-2.8085	201	Simrad	
011	01	ROS	4/19/99 8:28	BE	60.7595	-2.9202	374	nuts + flux water	
011	01	ROS	4/19/99 8:49	EN	60.7613	-2.9189	374		2 bodem,1/100m,10m
011	02	BOX	4/19/99 9:39	BE	60.7626	-2.9133	374		Rogier
011	02	BOX	4/19/99 9:46	BO	60.7627	-2.9127	375		
011	03	BOX	4/19/99 11:04	BE	60.7645	-2.9010	371		Wim
011	03	BOX	4/19/99 11:11	BO	60.7647	-2.9001	372		
012	01	TWD	4/19/99 12:04	BE	60.7688	-2.8940	368		
012	01	TWD	4/19/99 12:26	EV	60.7798	-2.8683	372		
012	01	TWD	4/19/99 12:41	BH	60.7843	-2.8605	375		
012	01	TWD	4/19/99 13:06	EN	60.7894	-2.8488	375		
013	01	TWD	4/19/99 13:58	BE	60.8462	-2.9511	498		
013	01	TWD	4/19/99 14:15	EV	60.8525	-2.9310	501		
013	01	TWD	4/19/99 14:18	BH	60.9003	-2.9338	500		
013	01	TWD	4/19/99 14:43	EN	60.8605	-2.9001	492		
014	01	SIM	4/19/99 22:48	BE	60.6866	-2.6500	190		
014	01	SIM	4/20/99 9:30	EN	61.85	-5.2666	230		
015	01	ROS	4/20/99 9:51	BE	61.8292	-5.1757	224		
015	02	FLY	4/20/99 10:19	BE	61.8385	-5.1672	227		
015	03	FLY	4/20/99 10:29	EN	61.8337	-5.1660	230		
016	01	ROS	4/20/99 11:00	BE	50.8022	-5.1318	230		
016	01	ROS	4/20/99 11:15	EN	61.8075	-5.1288	227		
016	02	FLY	4/20/99 11:23	BE	61.8053	-5.1213	224		
016	03	FLY	4/20/99 11:32	EN	61.801	-5.1177	218		
017	01	ROS	4/20/99 11:53	BE	61.777	-5.0712	230		

017	01	ROS	4/20/99 12:10	EN	61.7797	-5.0705	227
017	02	FLY	4/20/99 12:15	BE	61.7793	-5.0680	227
017	03	FLY	4/20/99 12:21	EN	61.7782	-5.0663	230
018	01	ROS	4/20/99 12:46	BE	61.7503	-5.0143	241
018	01	ROS	4/20/99 13:01	EN	61.7545	-5.0152	244
018	02	FLY	4/20/99 13:11	BE	61.7537	-5.0178	244
018	03	FLY	4/20/99 13:24	EN	61.743	-5.0077	235
019	01	ROS	4/20/99 13:50	BE	61.7262	-5.6238	238
019	01	ROS	4/20/99 14:05	EN	61.7298	-4.9592	235
019	02	FLY	4/20/99 14:10	BE	61.7287	-4.9618	238
019	03	FLY	4/20/99 14:20	EN	61.722	-4.9588	250
020	01	FLY	4/20/99 14:39	BE	61.7043	-4.9208	238
020	02	FLY	4/20/99 14:46	EN	61.7012	-4.9255	235
020	03	ROS	4/20/99 15:21	BE	61.698	-4.9058	241
020	03	ROS	4/20/99 15:35	EN	61.7003	-4.9070	238
021	01	ROS	4/20/99 16:07	BE	61.669	-4.8563	252
021	01	ROS	4/20/99 16:22	EN	61.669	-4.8560	252
021	02	FLY	4/20/99 16:30	BE	61.6672	-4.8505	252
021	03	FLY	4/20/99 16:38	EN	61.665	-4.8443	252
022	01	ROS	4/20/99 17:00	BE	61.6398	-4.7935	310
022	01	ROS	4/20/99 17:17	EN	61.6398	-4.7923	312
022	02	FLY	4/20/99 17:26	BE	61.638	-4.7928	312
022	03	FLY	4/20/99 17:34	EN	61.6347	-4.7922	318
023	01	ROS	4/20/99 17:51	BE	61.6235	-4.7537	355
023	01	ROS	4/20/99 18:11	EN	61.623	-4.7522	355
023	02	FLY	4/20/99 18:15	BE	61.6217	-4.7503	358
023	03	FLY	4/20/99 18:26	EN	61.6178	-4.7475	364
024	01	ROS	4/20/99 18:40	BE	61.6082	-4.7182	398
024	01	ROS	4/20/99 18:53	BO	61.6075	-4.7170	398
024	01	ROS	4/20/99 19:03	EN	61.6072	-4.7153	401
024	02	FLY	4/20/99 19:09	BE	61.6067	-4.7142	401
024	02	FLY	4/20/99 19:22	EN	61.6005	-4.7110	415
025	01	ROS	4/20/99 19:35	BE	61.5917	-4.6820	458
025	01	ROS	4/20/99 19:47	BO	61.5908	-4.6795	458
025	01	ROS	4/20/99 19:58	EN	61.5913	-4.6800	458
025	02	FLY	4/20/99 20:02	BE	61.5922	-4.6812	458
025	02	FLY	4/20/99 20:18	EN	61.5845	-4.6730	472
026	01	ROS	4/20/99 20:35	BE	61.5743	-4.6390	512
026	01	ROS	4/20/99 20:50	BO	61.5740	-4.6400	512
026	01	ROS	4/20/99 21:08	EN	61.5715	-4.6415	512
026	02	FLY	4/20/99 21:12	BE	61.5720	-4.6413	515
026	03	FLY	4/20/99 21:32	EN	61.5610	-4.6282	521
027	01	ROS	4/20/99 21:52	BE	61.5563	-4.6017	564
027	01	ROS	4/20/99 22:04	BO	61.5575	-4.5997	564
027	01	ROS	4/20/99 22:18	EN	61.5585	-4.6012	564
027	02	FLY	4/20/99 22:23	BE	61.5588	-4.6018	561
027	03	FLY	4/20/99 22:43	EN	61.5500	-4.5930	590
028	01	ROS	4/20/99 22:56	BE	61.5410	-4.5643	664
028	01	ROS	4/20/99 23:11	BO	61.5423	-4.5615	667
028	01	ROS	4/20/99 23:31	EN	61.5453	-4.5538	667
028	02	FLY	4/20/99 23:34	BE	61.5452	-4.5522	670
028	03	FLY	4/21/99 0:05	EN	61.5290	-4.5378	727
029	01	ROS	4/21/99 0:21	BE	61.5257	-4.5240	747
029	01	ROS	4/21/99 0:36	BO	61.5300	-4.5210	744
029	01	ROS	4/21/99 0:56	EN	61.5352	-4.5243	734
029	02	FLY	4/21/99 1:03	BE	61.5348	-4.5267	730
029	03	FLY	4/21/99 1:30	EN	61.5237	-4.5238	750
030	01	ROS	4/21/99 1:52	BE	61.5108	-4.4922	812
030	01	ROS	4/21/99 2:02	BO	61.5117	-4.4900	812
030	01	ROS	4/21/99 2:36	EN	61.5128	-4.4837	815
030	02	FLY	4/21/99 2:42	BE	61.5113	-4.4848	818
030	03	FLY	4/21/99 3:18	EN	61.4950	-4.4938	835
031	01	ROS	4/21/99 4:02	BE	61.4813	-4.4283	964
031	01	ROS	4/21/99 4:19	BO	61.4788	-4.4235	972
031	01	ROS	4/21/99 4:43	EN	61.4767	-4.4215	975
031	02	FLY	4/21/99 4:53	BE	61.4750	-4.4122	987

031	03	FLY	4/21/99 5:26	EN	61.4560	-4.3902	1055
032	01	ROS	4/21/99 5:42	BE	61.4493	-4.3630	1087
032	01	ROS	4/21/99 6:03	BO	61.4473	-4.3618	1087
032	01	ROS	4/21/99 6:29	EN	61.4403	-4.3513	1095
033	01	ROS	4/22/99 6:28	BE	61.4493	-4.3585	1090
033	01	ROS	4/22/99 6:52	BO	61.4507	-4.3635	1087
033	01	ROS	4/22/99 7:11	EN	61.4485	-4.3628	1087
033	02	FLY	4/22/99 7:17	BE	61.4477	-4.3635	1087
033	03	FLY	4/22/99 7:49	EN	61.4398	-4.3598	1090
034	01	ROS	4/22/99 8:37	BE	61.3918	-4.2367	1161
034	01	ROS	4/22/99 9:00	BO	61.3883	-4.2352	1158
034	01	ROS	4/22/99 9:34	EN	61.3857	-4.2272	1158
034	02	FLY	4/22/99 9:38	BE	61.3842	-4.2288	1158
034	03	FLY	4/22/99 10:23	EN	61.3673	-4.2572	1144
035	01	ROS	4/22/99 11:15	BE	61.3317	-4.0922	1132
035	01	ROS	4/22/99 11:37	BO	61.3297	-4.0843	1130
035	01	ROS	4/22/99 12:07	EN	61.3303	-4.0843	1127
035	02	FLY	4/22/99 12:12	BE	61.3300	-4.0738	1130
035	03	FLY	4/22/99 12:49	EN	61.3363	-4.0833	1132
036	01	ROS	4/22/99 13:46	BE	61.2698	-3.9577	1052
036	01	ROS	4/22/99 14:03	BO	61.2682	-3.9518	1052
036	01	ROS	4/22/99 14:33	EN	61.2700	-3.9450	1052
036	02	FLY	4/22/99 14:39	BE	61.2697	-3.9412	1050
036	03	FLY	4/22/99 15:10	EN	61.2583	-3.9258	
037	01	ROS	4/22/99 15:56	BE	61.2103	-3.8270	1135
037	01	ROS	4/22/99 16:15	BO	61.2100	-3.8208	1138
037	01	ROS	4/22/99 16:48	EN	61.2113	-3.8223	1135
037	02	FLY	4/22/99 16:56	BE	61.2108	-3.8152	1135
037	03	FLY	4/22/99 17:33	EN	61.1972	-3.7893	1155
038	01	ROS	4/22/99 18:10	BE	61.1548	-3.6970	1184
038	01	ROS	4/22/99 18:33	BO	61.1548	-3.6902	1184
038	01	ROS	4/22/99 19:03	EN	61.1542	-3.6920	1184
038	02	FLY	4/22/99 19:09	BE	61.1538	-3.6925	1184
038	03	FLY	4/22/99 19:52	EN	61.1428	-3.6575	1192
039	01	ROS	4/22/99 20:33	BE	61.0980	-3.5683	1175
039	01	ROS	4/22/99 20:56	BO	61.0988	-3.5612	1175
039	01	ROS	4/22/99 21:30	EN	61.1007	-3.5538	1175
039	02	FLY		BE	61.1003	-3.5508	1175
039	03	FLY	4/22/99 21:34	EN	61.0940	-3.5165	1170
040	01	ROS	4/22/99 22:52	BE	61.0388	-3.4433	1118
040	01	ROS	4/22/99 23:12	BO	61.0402	-3.4428	1118
040	01	ROS	4/22/99 23:38	EN	61.0398	-3.4418	1118
040	02	FLY	4/22/99 23:42	BE	61.0400	-3.4413	1118
040	03	FLY	4/23/99 0:20	EN	61.0258	-3.4128	1101
041	01	ROS	4/23/99 1:00	BE	60.9868	-3.3195	972
041	01	ROS	4/23/99 1:18	BO	60.9875	-3.3167	968
041	01	ROS		EN	60.9912	-3.3000	962
041	02	FLY	4/23/99 1:54	BE	60.9907	-3.2883	944
041	03	FLY	4/23/99 2:22	EN	60.9877	-3.2633	918
042	01	FLY	4/23/99 3:00	BE	60.9767	-3.2140	821
042	02	FLY	4/23/99 3:29	EN	60.9760	-3.1835	802
042	03	ROS	4/23/99 3:50	BE	60.9787	-3.2313	847
042	03	ROS	4/23/99 4:05	BO	60.9795	-3.2295	847
042	03	ROS	4/23/99 4:28	EN	60.9812	-3.2152	838
043	01	ROS	4/23/99 5:03	BE	60.9302	-3.1945	718
043	01	ROS	4/23/99 5:16	BO	60.9312	-3.1953	721
043	01	ROS	4/23/99 5:35	EN	60.9315	-3.1940	721
043	02	FLY	4/23/99 5:40	BE	60.9312	-3.1947	721
043	03	FLY	4/23/99 6:07	EN	60.9277	-3.1628	698
044	01	ROS	4/23/99 6:32	BE	60.9130	-3.1577	672
044	01	ROS	4/23/99 6:36	BO	60.9132	-3.1578	672
044	01	ROS	4/23/99 6:53	EN	60.9123	-3.1577	672
044	02	FLY	4/23/99 6:57	BE	60.9123	-3.1547	667
044	03	FLY	4/23/99 7:21	EN	60.9120	-3.1395	650
045	01	ROS	4/23/99 7:34	BE	60.8957	-3.1205	638
045	01	ROS	4/23/99 7:46	BO	60.8947	-3.1212	635

045	01	ROS	4/23/99 8:02	EN	60.8962	-3.1202	641	
045	02	FLY	4/23/99 8:05	BE	60.8968	-3.1220	641	
045	03	FLY	4/23/99 8:35	EN	60.8948	-3.0883	618	
046	01	ROS	4/23/99 8:49	BE	60.8778	-3.0783	587	
046	01	ROS	4/23/99 9:02	BO	60.8777	-3.0793	590	
046	01	ROS	4/23/99 9:16	EN	60.8772	-3.0778	587	
046	02	FLY	4/23/99 9:20	BE	60.8768	-3.0762	585	
046	03	FLY	4/23/99 9:46	EN	60.8675	-3.0548	567	
047	01	ROS	4/23/99 9:57	BE	60.8597	-3.0395	547	
047	01	ROS	4/23/99 10:08	BO	60.8595	-3.0387	547	
047	01	ROS	4/23/99 10:22	EN	60.8597	-3.0400	550	
047	02	FLY	4/23/99 10:26	BE	60.8595	-3.0403	550	
047	03	FLY	4/23/99 10:50	EN	60.8505	-3.0208	532	
048	01	ROS	4/23/99 11:01	BE	60.8437	-3.0033	524	
048	01	ROS	4/23/99 11:11	BO	60.8443	-3.0045	524	
048	01	ROS	4/23/99 11:26	EN	60.8438	-3.0037	524	
048	02	FLY	4/23/99 11:30	BE	60.8440	-3.0022	521	
048	03	FLY	4/23/99 11:49	EN	60.8382	-2.9897	510	
049	01	ROS	4/23/99 12:03	BE	60.8280	-2.9700	487	
049	01	ROS	4/23/99 12:14	BO	60.8272	-2.9678	484	
049	01	ROS	4/23/99 12:30	EN	60.8280	-2.9677	487	
049	02	FLY	4/23/99 12:33	BE	60.8288	-2.9663	486	
049	03	FLY	4/23/99 12:52	EN	60.8230	-2.9495	472	
050	01	ROS	4/23/99 13:09	BE	60.8115	-2.9295	450	
050	01	ROS	4/23/99 13:16	BO	60.8117	-2.9287	450	
050	01	ROS	4/23/99 13:45	EN	60.8133	-2.9285	451	
050	02	FLY	4/23/99 13:40	BE	60.8125	-2.9237	447	
050	03	FLY	4/23/99 13:53	EN	60.8085	-2.9152	435	
051	01	ROS	4/23/99 14:05	BE	60.7932	-2.8912	404	
051	01	ROS	4/23/99 14:14	BO	60.7932	-2.8885	404	
051	01	ROS	4/23/99 14:22	EN	60.7962	-2.8900	404	
051	02	FLY	4/23/99 14:30	BE	60.7947	-2.8860	404	
051	03	FLY	4/23/99 14:50	EN	60.7840	-2.8685	378	
052	01	ROS	4/23/99 15:03	BE	60.7780	-2.8572	364	
052	01	ROS	4/23/99 15:11	BO	60.7778	-2.8547	362	
052	01	ROS	4/23/99 15:24	EN	60.7782	-2.8532	364	
052	02	FLY	4/23/99 15:30	BE	60.7778	-2.8528	361	
052	03	FLY	4/23/99 15:42	EN	60.7720	-2.8433	344	
053	01	ROS	4/23/99 16:05	BE	60.7450	-2.7923	245	
053	01	ROS	4/23/99 16:11	BO	60.7460	-2.7860	238	
053	01	ROS	4/23/99 16:18	EN	60.7465	-2.7822	236	
053	02	FLY	4/23/99 16:28	BE	60.7445	-2.7710	218	
053	03	FLY	4/23/99 16:38	EN	60.7413	-2.7617	204	
054	0-1	BOX	4/23/99 18:12	BE	60.9220	-3.1580	693	
054	01	BOX	4/23/99 18:27	BO	60.9220	-3.1532	698	
054	02	MUL	4/23/99 19:29	BO	60.9183	-3.1448	690	
055	01	TWD	4/23/99 20:20	BE	60.9190	-3.1513	679	1100 m draad uit TRD3
055	01	TWD	4/23/99 20:20	EN	60.9180	-3.1465	676	start halen
056	01	TWD	4/23/99 21:15	BE	60.9203	-3.1165	662	1200 m draad uit TRD4
056	01	TWD	4/23/99 21:15	EN	60.9207	-3.1038	656	start halen
057	01	ROS	4/24/99 8:15	BE	60.8523	-3.0588	550	
057	01	ROS	4/24/99 8:28	BO	60.8530	-3.0538	550	
057	01	ROS	4/24/99 8:46	EN	60.8532	-3.0530	550	
058	01	BOX	4/24/99 9:30	BE	60.8532	-3.0563	551	
058	01	BOX	4/24/99 9:42	BO	60.8525	-3.0557	551	
059	01	BOX	4/24/99 10:12	BE	60.8530	-3.0567	551	
059	01	BOX	4/24/99 10:21	BO	60.8533	-3.0553	551	
060	01	BOX	4/24/99 10:56	BE	60.8530	-3.0558	550	
060	01	BOX	4/24/99 11:04	BO	60.8527	-3.0555	550	
061	01	BOX	4/24/99 11:20	BE	60.8530	-3.0558	550	
061	01	BOX	4/24/99 11:30	BO	60.8527	-3.0553	550	
062	01	TWD	4/24/99 13:27	BE	60.8530	-3.0470	545	950 m draad uit
062	01	TWD	4/24/99 13:52	EN	60.8527	-3.0278	534	start halen
063	01	TWD	4/24/99 14:51	BE	60.8535	-3.0522	550	

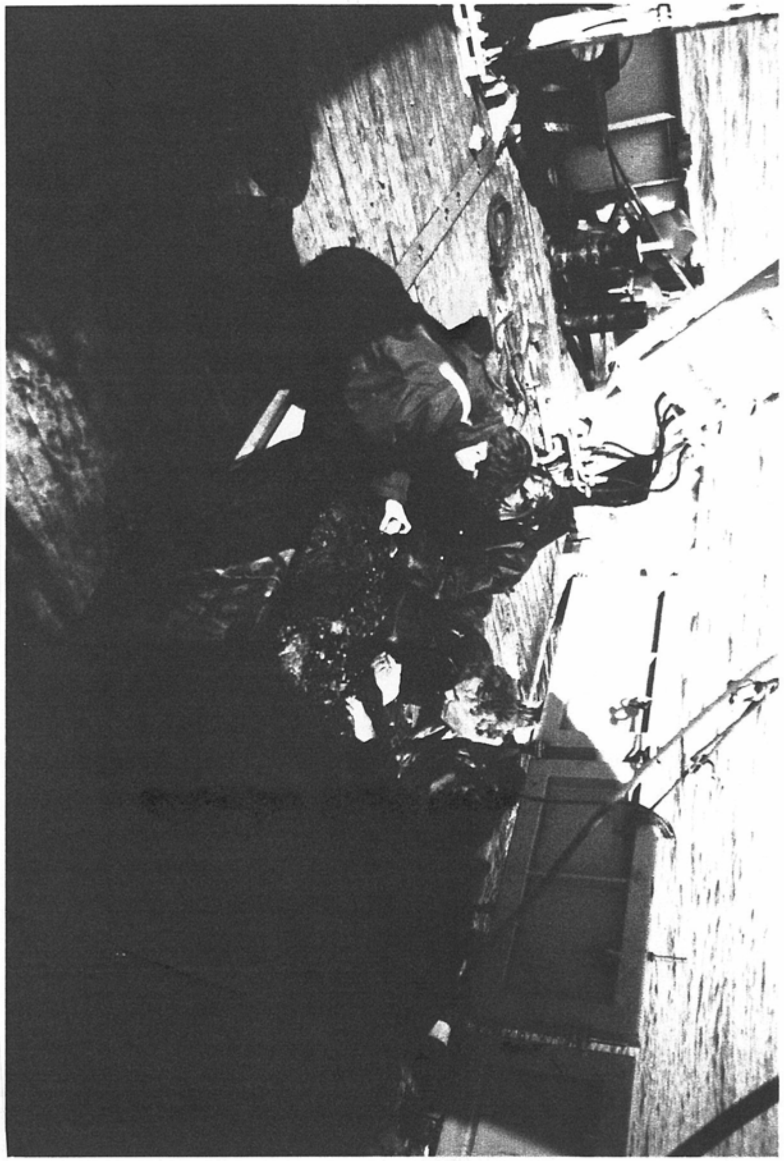
063	01	TWD	4/24/99 15:12	EN	60.8512	-3.0373	537	halen	
064	01	MNT	4/24/99 15:53	BE	60.8525	-3.0520	548		
064	01	MNT	4/24/99 16:16	BO	60.8480	-3.0323	534	stop vieren	
064	01	MNT	4/24/99 16:25	EN	60.8483	-3.0253	536	halen 446 m lijn uit	
064	01	MNT	4/24/99 17:01	EN	60.8462	-3.0000	523	halen 30 m/min	
064	01	MNT	4/24/99 17:10	EN	60.8442	-2.9917	517	oppervlakte	
065	01		4/24/99 18:49	BE	60.9497	-3.2515	800	test druk sensor	
066	01	ROS	4/25/99 8:20	BE	60.9703	-3.2533	850		
066	01	ROS	4/25/99 8:34	BO	60.9703	-3.2533	850		
066	01	ROS	4/25/99 8:59	EN	60.9707	-3.2540	850		
067	01	BOX	4/25/99 9:40	BE	60.9707	-3.2542	850		
067	01	BOX	4/25/99 9:55	BO	60.9705	-3.2537	850		
068	01	MUL	4/25/99 10:34	BE	60.9705	-3.2538	850		
068	01	MUL	4/25/99 10:51	BO	60.9707	-3.2548	851		
069	01	TWD	4/25/99 11:43	BE	60.9675	-3.2403	831	uit vieren	
069	01	TWD	4/25/99 12:11	EN	60.9620	-3.2150	796	halen (1300 m gevierd)	
070	01	MNT	4/25/99 13:27	BE	60.9695	-3.2425	838		
070	01	MNT	4/25/99 14:08	BO	60.9522	-3.2022	783	gestopt met vieren	
070	01	MNT	4/25/99 15:55	EN	60.9522	-3.1015	708		
071	01	MUL	4/25/99 16:23	BE	60.9428	-3.2053	750		
071	01	MUL	4/25/99 16:38	BO	60.9447	-3.2040	751		
071	01	MUL		EN	60.9465	-3.2008	753		
072	01	ATV	4/25/99 18:50	BE	60.8695	-3.0540	566		
072	01	ATV	4/25/99 19:02	BO	60.8662	-3.0507	562		
072	01	ATV	4/25/99 19:11	BO	60.8620	-3.0453	551	gestopt met vieren	
072	01	ATV	4/25/99 21:50	EN	60.8160	-2.9598	468	begin halen	
072	01	ATV	4/25/99 22:10	EN	60.8105	-2.9585	457	uit	
073	01	ROS	4/26/99 8:23	BE	60.7350	-2.8717	303		
073	01	ROS	4/26/99 8:29	BO	60.7345	-2.8697	299		
073	01	ROS	4/26/99 8:48	EN	60.7347	-2.8650	298		
074	01	BOX	4/26/99 9:26	BE	60.7342	-2.8662	299		
074	01	BOX	4/26/99 9:48	BO	60.7335	-2.8632	295		
075	01	BOX	4/26/99 9:59	BE	60.7342	-2.8712	300		
075	01	BOX	4/26/99 10:03	BO	60.7337	-2.8693	296		
076	01	BOX	4/26/99 10:43	BE	60.7338	-2.8715	300		
076	01	BOX	4/26/99 10:47	BO	60.7335	-2.8693	295		
077	01	BOX	4/26/99 11:14	BE	60.7345	-2.8708	299		
077	01	BOX	4/26/99 11:19	BO	60.7330	-2.8690	295		
078	01	BOX	4/26/99 11:53	BE	60.7342	-2.8713	299		
078	01	BOX	4/26/99 11:58	BO	60.7338	-2.8698	298		
079	01	TWD	4/26/99 13:34	BE	60.7352	-2.8652	290		
079	01	TWD	4/26/99 13:59	EN	60.7448	-2.8335	286	HALEN	
080	01	TWD	4/26/99 15:20	BE	60.8787	-3.0868	601		
080	01	TWD	4/26/99 15:45	EN	60.8728	-3.0582	575	HALEN	
081	01	BOX	4/26/99 16:39	F	60.8787	-3.0850	596		
082	01	BOX	4/26/99 17:22	F	60.8802	-3.0865	601		
083	01	MNT	4/26/99 18:45	BE	60.9730	-3.2288	831		
083	01	MNT	4/26/99 19:17	EN	60.9635	-3.1978	786	oppervlakte	
084	01	ATV	4/26/99 20:08	BE	60.9937	-3.2438	900		
084	01	ATV	4/26/99 20:39	EN	60.9882	-3.2038	850		1250
086	01	TWD	4/27/99 0:40	BE	60.7208	-2.8553	250		
086	01	TWD	4/27/99 1:11	EN	60.7092	-2.8300	211		
087	01	ROS	4/27/99 2:09	BE	60.6842	-2.6505	160		
087	01	ROS	4/27/99 2:15	BO	60.6833	-2.6502	160		
087	01	ROS	4/27/99 2:20	EN	60.6852	-2.6547	161		
087	02	FLY	4/27/99 2:29	BE	60.6895	-2.6660	163		
087	03	FLY	4/27/99 2:37	EN	60.7122	-2.7117	165		
088	01	ROS	4/27/99 3:07	BE	60.7132	-2.7113	178		
088	01	ROS	4/27/99 3:12	BO	60.7137	-2.7107	178		
088	01	ROS		EN	60.7162	-2.7143	177		
088	02	FLY	4/27/99 3:21	BE	60.7162	-2.7143	178		
088	03	FLY	4/27/99 3:29	EN	60.7190	-2.7257	181		
089	01	ROS	4/27/99 3:46	BE	60.7293	-2.7497	193		
089	01	ROS	4/27/99 3:52	BO	60.7292	-2.7502	193		
089	01	ROS	4/27/99 3:57	EN	60.7298	-2.7505	192		
089	02	FLY	4/27/99 4:00	BE	60.7298	-2.7480	189		

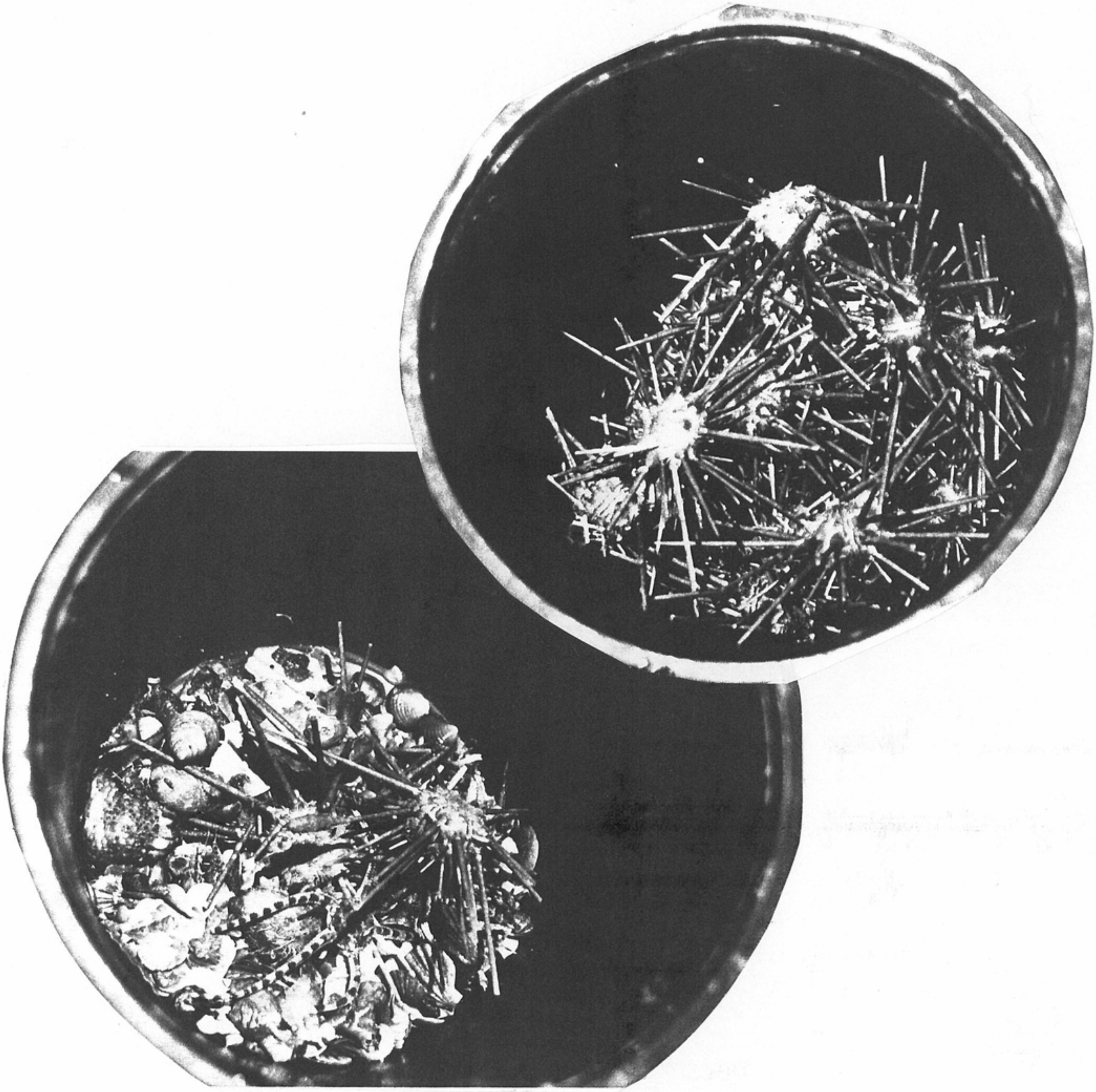
089	03	FLY	4/27/99 4:07	EN	60.7340	-2.7483	191
090	01	ROS	4/27/99 4:24	BE	60.7472	-2.7880	246
090	01	ROS	4/27/99 4:31	BO	60.7488	-2.7890	252
090	01	ROS	4/27/99 4:39	EN	60.7497	-2.7885	252
090	02	FLY	4/27/99 4:41	BE	60.7497	-2.7880	252
090	03	FLY	4/27/99 4:49	EN	60.7475	-2.7887	248
091	01	ROS	4/27/99 5:06	BE	60.7627	-2.8243	320
091	01	ROS	4/27/99 5:19	BO	60.7628	-2.8263	321
091	01	ROS	4/27/99 5:28	EN	60.7635	-2.8225	318
091	02	FLY	4/27/99 5:31	BE	60.7645	-2.8228	318
091	03	FLY	4/27/99 5:42	EN	60.7682	-2.8327	328
092	01	ROS	4/27/99 5:58	BE	60.7812	-2.8663	373
092	01	ROS	4/27/99 6:06	BO	60.7813	-2.8662	373
092	01	ROS	4/27/99 6:15	EN	60.7815	-2.8662	373
092	02	FLY	4/27/99 6:23	BE	60.7835	-2.8653	373
092	03	FLY	4/27/99 6:34	EN	60.7868	-2.8683	420
093	01	ROS	4/27/99 6:59	BE	60.7998	-2.9032	420
093	01	ROS	4/27/99 7:05	BO	60.8007	-2.8997	420
093	01	ROS	4/27/99 7:16	EN	60.8010	-2.8983	420
093	02	FLY	4/27/99 7:26	BE	60.8017	-2.8950	419
093	03	FLY	4/27/99 7:42	EN	60.8027	-2.8698	406
093	04	ROS	4/27/99 7:46	BE	60.8025	-2.8668	403
093	04	ROS	4/27/99 7:53	BO	60.8018	-2.8650	402
093	04	ROS	4/27/99 8:07	EN	60.8027	-2.8593	402
094	01	ROS	4/27/99 8:54	BE	60.8147	-2.9418	458
094	01	ROS	4/27/99 9:04	BO	60.8158	-2.9463	460
094	01	ROS	4/27/99 9:18	EN	60.8160	-2.9500	463
094	02	FLY	4/27/99 9:20	BE	60.8168	-2.9522	465
094	03	FLY	4/27/99 9:41	EN	60.8265	-2.9623	481
095	01	ROS	4/27/99 9:53	BE	60.8318	-2.9783	490
095	01	ROS	4/27/99 10:03	BO	60.8313	-2.9790	490
095	01	ROS	4/27/99 10:20	EN	60.8307	-2.9748	487
095	02	FLY	4/27/99 10:22	BE	60.8308	-2.9777	490
095	03	FLY	4/27/99 10:42	EN	60.8387	-2.9913	510
096	01	ROS	4/27/99 10:59	BE	60.8500	-3.0157	535
096	01	ROS	4/27/99 11:09	BO	60.8483	-3.0207	534
096	01	ROS	4/27/99 11:24	EN	60.8475	-3.0222	532
096	02	FLY	4/27/99 11:27	BE	60.8583	-3.0420	532
096	03	FLY	4/27/99 11:51	EN	60.8658	-3.0543	547
097	01	ROS	4/27/99 12:07	BE	60.8655	-3.0530	565
097	01	ROS	4/27/99 12:19	BO	60.8662	-3.0543	564
097	01	ROS	4/27/99 12:37	EN/F	60.8667	-3.0563	566
097	02	FLY	4/27/99 12:44	F	60.8665	-3.0558	568
097	03	ROS	4/27/99 14:08	BE	60.8665	-3.0558	568
097	03	ROS	4/27/99 14:19	BO	60.8647	-3.0533	560
097	03	ROS	4/27/99 14:36	EN	60.8657	-3.0552	564
097	04	FLY	4/27/99 16:17	BE	60.8698	-3.0522	567
097	05	FLY	4/27/99 16:34	EN	60.8703	-3.0620	573
098	01	ROS	4/27/99 16:49	BE	60.8822	-3.0868	604
098	01	ROS	4/27/99 17:03	BO	60.8822	-3.0895	607
098	01	ROS	4/27/99 17:20	EN	60.8818	-3.0870	603
098	02	FLY	4/27/99 17:23	BE	60.8823	-3.0873	606
098	03	FLY	4/27/99 17:41	EN	60.8892	-3.0953	615
099	01	ROS	4/27/99 18:05	BE	60.8987	-3.1257	651
099	01	ROS	4/27/99 18:18	BO	60.8988	-3.1260	651
099	01	ROS	4/27/99 18:32	EN	60.9005	-3.1235	651
099	02	FLY	4/27/99 18:35	BE	60.8995	-3.1232	651
099	03	FLY	4/27/99 18:55	EN	60.8997	-3.1357	654
100	01	ROS	4/27/99 19:16	BE	60.9142	-3.1625	679
100	01	ROS	4/27/99 19:29	BO	60.9152	-3.1612	681
100	01	ROS	4/27/99 19:45	EN	60.9987	-3.1600	679
100	02	FLY	4/27/99 19:52	BE	60.9155	-3.1593	679
100	03	FLY	4/27/99 20:13	EN	60.9222	-3.1700	698
101	01	ROS	4/27/99 20:29	BE	60.9323	-3.1962	724
101	01	ROS	4/27/99 20:43	BO	60.9320	-3.1943	724
101	01	ROS	4/27/99 21:01	EN	60.9318	-3.1952	724

101	02	FLY	4/27/99 21:05	BE	60.9323	-3.1955	724
101	03	FLY	4/27/99 21:27	EN	60.9407	-3.1937	
102	01	ROS	4/27/99 21:44	BE	60.9493	-3.2332	785
102	01	ROS	4/27/99 21:59	BO	60.9488	-3.2338	783
102	01	ROS	4/27/99 22:24	EN	60.9493	-3.2367	787
102	02	FLY	4/27/99 22:27	BE	60.9563	-3.2498	785
102	03	FLY	4/27/99 22:55	EN	60.9773	-3.3007	812
103	01	ROS	4/27/99 23:18	BE	60.9773	-3.2995	921
103	01	ROS	4/27/99 23:40	BO	60.9775	-3.3018	918
103	01	ROS	4/28/99 0:04	EN	60.9792	-3.2995	923
103	02	FLY	4/28/99 0:10	BE	60.9847	-3.3158	923
103	03	FLY	4/28/99 0:47	EN	60.9847	-3.3158	963
104	01	ROS	4/28/99 1:12	BE	61.0072	-3.3665	1057
104	01	ROS	4/28/99 1:30	BO	61.0070	-3.3682	1058
104	01	ROS	4/28/99 1:59	EN	61.0073	-3.3665	1059
104	02	FLY	4/28/99 2:06	BE	61.0065	-3.3657	1057
104	03	FLY	4/28/99 2:41	EN	61.0127	-3.3887	1081
105	01	ROS	4/28/99 3:20	BE	61.0608	-3.4913	1147
105	01	ROS	4/28/99 3:38	BO	61.0628	-3.4923	1150
105	01	ROS	4/28/99 4:05	EN	61.0637	-3.4932	1150
105	02	FLY	4/28/99 4:10	BE	61.0628	-3.4918	1150
105	03	FLY	4/28/99 4:47	EN	61.0762	-3.5137	1160
106	01	ROS	4/28/99 5:37	BE	61.1205	-3.6162	1192
106	01	ROS	4/28/99 5:55	BO	61.1202	-3.6158	
106	01	ROS	4/28/99 6:23	EN	61.1202	-3.6153	1189
106	02	FLY	4/28/99 6:28	BE	61.1207	-3.6162	1192
106	03	FLY	4/28/99 7:02	EN	61.1292	-3.6312	1202
107	01	ROS	4/28/99 7:36	BE	61.1773	-3.7393	1168
107	01	ROS	4/28/99 8:00	BO	61.1770	-3.7423	1165
107	01	ROS	4/28/99 8:31	EN	61.1762	-3.7440	1165
107	02	FLY	4/28/99 8:36	BE	61.1755	-3.7435	1165
107	03	FLY	4/28/99 9:03	EN	61.1817	-3.7495	1163
108	01	ROS	4/28/99 9:41	BE	61.2342	-3.8717	1081
108	01	ROS	4/28/99 10:00	BO	61.2343	-3.8695	1081
108	01	ROS	4/28/99 10:33	EN	61.2345	-3.8712	1081
108	02	FLY	4/28/99 10:36	BE	61.2347	-3.8732	1078
108	03	FLY	4/28/99 11:15	EN	61.2472	-3.8763	1073
109	01	ROS	4/28/99 11:48	BE	61.2918	-4.0012	1078
109	01	ROS	4/28/99 11:57	EN/F	61.2918	-4.0007	1078
109	02	ROS	4/28/99 12:15	BE	61.2913	-4.0012	1078
109	02	ROS	4/28/99 12:33	BO	61.2915	-4.0015	1078
109	02	ROS	4/28/99 12:59	EN	61.2922	-4.0035	1078
109	03	FLY	4/28/99 13:02	BE	61.3045	-4.0327	1081
109	04	FLY	4/28/99 13:46	EN	61.3490	-4.1297	1102
110	01	ROS	4/28/99 14:15	BE	61.3493	-4.1293	1144
110	01	ROS	4/28/99 14:35	BO	61.3483	-4.1300	1144
110	01	ROS	4/28/99 15:00	EN	61.3483	-4.1300	1144
110	02	FLY	4/28/99 15:03	BE	61.3492	-4.1320	1144
110	03	FLY	4/28/99 15:46	EN	61.3613	-4.1648	1150
111	01	ROS	4/28/99 16:12	BE	61.4052	-4.2592	1152
111	01	ROS	4/28/99 16:30	BO	61.4052	-4.2578	1152
111	01	ROS	4/28/99 16:58	EN	61.4053	-4.2585	1152
111	02	FLY	4/28/99 17:03	BE	61.4047	-4.2618	1152
111	03	FLY	4/28/99 17:40	EN	61.4165	-4.2933	1133
112	01	ROS	4/28/99 18:09	BE	61.4625	-4.3902	1052
112	01	ROS	4/28/99 18:29	BO	61.4625	-4.3912	1052
112	01	ROS	4/28/99 18:54	EN	61.4627	-4.3892	1052
112	02	FLY	4/28/99 18:59	BE	61.4637	-4.3907	1050
112	03	FLY	4/28/99 19:41	EN	61.4817	-4.4283	965
113	01	ROS	4/28/99 20:05	BE	61.4915	-4.4503	913
113	01	ROS	4/28/99 20:22	BO	61.4913	-4.4507	913
113	01	ROS	4/28/99 20:49	EN	61.4908	-4.4507	915
113	02	FLY	4/28/99 20:51	BE	61.4910	-4.4513	915
113	03	FLY	4/28/99 21:25	EN	61.5015	-4.4750	852
114	01	ROS	4/28/99 21:39	BE	61.5205	-4.5182	760
114	01	ROS	4/28/99 21:54	BO	61.5202	-4.5190	760

114	01	ROS	4/28/99 22:13	EN	61.5188	-4.5157	768
114	02	FLY	4/28/99 22:16	BE	61.5185	-4.5153	768
114	03	FLY	4/28/99 22:44	EN	61.5278	-4.5400	726
115	01	ROS	4/28/99 22:55	BE	61.5363	-4.5513	697
115	01	ROS	4/28/99 23:08	BO	61.5358	-4.5522	697
115	01	ROS	4/28/99 23:30	EN	61.5358	-4.5543	692
115	02	FLY	4/28/99 23:33	BE	61.5458	-4.5835	689
115	03	FLY	4/29/99 0:04	EN	61.5532	-4.5882	610
116	01	ROS	4/29/99 0:24	BE	61.5515	-4.5903	589
116	01	ROS	4/29/99 0:35	BO	61.5502	-4.5892	586
116	01	ROS	4/29/99 0:48	EN	61.5475	-4.5910	588
116	02	FLY	4/29/99 0:53	BE	61.5568	-4.6228	592
116	03	FLY	4/29/99 1:21	EN	61.5568	-4.6228	540
117	01	ROS	4/29/99 1:42	BE	61.5683	-4.6312	526
117	01	ROS	4/29/99 1:52	BO	61.5680	-4.6320	525
117	01	ROS	4/29/99 2:04	EN	61.5667	-4.6315	524
117	02	FLY	4/29/99 2:09	BE	61.5660	-4.6322	524
117	03	FLY		EN	61.5767	-4.6502	502
118	01	ROS	4/29/99 2:46	BE	61.5850	-4.6672	478
118	01	ROS	4/29/99 2:54	BO	61.5833	-4.6688	479
118	01	ROS	4/29/99 3:06	EN	61.5855	-4.6715	475
118	02	FLY	4/29/99 3:08	BE	61.5857	-4.6738	469
118	03	FLY	4/29/99 3:11	EN	61.5933	-4.6902	442
119	01	ROS	4/29/99 3:44	BE	61.6042	-4.7087	415
119	01	ROS	4/29/99 3:52	BO	61.6032	-4.7110	410
119	01	ROS	4/29/99 4:02	EN	61.6038	-4.7123	408
119	02	FLY	4/29/99 4:07	BE	61.6042	-4.7165	404
119	03	FLY	4/29/99 4:26	EN	61.6090	-4.7348	382
120	01	ROS	4/29/99 4:39	BE	61.6200	-4.7477	364
120	01	ROS	4/29/99 4:47	BO	61.6203	-4.7473	363
120	01	ROS	4/29/99 4:58	EN	61.6193	-4.7483	364
120	02	FLY	4/29/99 5:02	BE	61.6197	-4.7507	362
120	03	FLY	4/29/99 5:15	EN	61.6270	-4.7605	348
121	01	ROS	4/29/99 5:27	BE	61.6373	-4.7852	324
121	01	ROS	4/29/99 5:35	BO	61.6383	-4.7845	323
121	01	ROS	4/29/99 5:46	EN	61.6377	-4.7837	324
121	02	FLY	4/29/99 5:50	BE	61.6385	-4.7852	323
121	03	FLY	4/29/99 6:01	EN	61.6443	-4.7910	313
122	01	ROS	4/29/99 6:16	BE	61.6552	-4.8207	277
122	01	ROS	4/29/99 6:24	BO	61.6545	-4.8233	277
122	01	ROS	4/29/99 6:30	EN	61.6545	-4.8232	277
122	02	FLY	4/29/99 6:33	BE	61.6537	-4.8245	277
122	03	FLY	4/29/99 6:42	EN	61.6507	-4.8203	281
123	01	ROS	4/29/99 7:02	BE	61.6720	-4.8618	253
123	01	ROS	4/29/99 7:08	BO	61.6715	-4.8638	251
123	01	ROS	4/29/99 7:15	EN	61.6720	-4.8620	250
123	02	FLY	4/29/99 7:19	BE	61.6723	-4.8632	250
123	03	FLY	4/29/99 7:26	EN	61.6707	-4.8603	253
124	01	ROS	4/29/99 8:09	BE	61.7322	-4.9915	238
124	01	ROS	4/29/99 8:15	BO	61.7320	-4.9903	238
124	01	ROS	4/29/99 8:25	EN	61.7313	-4.9893	238
124	02	FLY	4/29/99 8:30	BE	61.7313	-4.9875	238
124	03	FLY	4/29/99 8:37	EN	61.7278	-4.9872	240
125	01	FLY	4/29/99 8:46	BE	61.7315	-4.9980	238
125	01	FLY	4/29/99 8:54	EN	61.7295	-4.5833	240
126	01	ROS	4/30/99 8:14	BE	60.9748	-3.2938	907
126	01	ROS	4/30/99 8:34	BO	60.9728	-3.2970	907
126	01	ROS	4/30/99 8:55	EN	60.9733	-3.2977	907
127	01	BOX	4/30/99 9:35	BE	60.9742	-3.2927	905
127	01	BOX	4/30/99 9:51	BO	60.9728	-3.2918	900
128	01	MUL	4/30/99 10:37	BE	60.9752	-3.2945	905
128	01	MUL	4/30/99 10:57	BO	60.7577	-3.8062	909
129	01	TWD	4/30/99 13:24	BE	60.7660	-2.7887	287
129	01	TWD	4/30/99 13:47	EN	60.7567	-2.8048	289
130	01	TWD	4/30/99 14:20	BE	60.7703	-2.7795	291
130	01	TWD	4/30/99 14:57	EN	60.6228	-2.6228	297

131	01	MOR	4/30/99 16:42	RE	60.8790	-3.0830		pro1b4
132	01	MOR	4/30/99 18:22	RE	60.9562	-3.2395		pro1b7
133	01	MOR	5/1/99 6:32	RE	60.8152	-2.9748		pro1c3
134	01	MOR	5/1/99 9:55	DE	60.9568	-3.2375	803	pro2d3
135	01	MOR	5/1/99 10:45	RE	60.9248	-3.1730		pro1c5
136	01	MOR	5/1/99 12:19	DE	60.9700	-3.2550	850	pro2b4
137	01	MOR	5/1/99 13:49	DE	61.0138	-3.3245	1043	pro2d5
138	01	MOR	5/1/99 14:35	RE	60.9978	-3.3192		pro1c8
139	01	MOR	5/1/99 17:00	RE	60.9365	-3.2275		pro1c6
140	01	MOR	5/2/99 9:58	DE	60.8510	-3.0605	552	pro2d1
141	01	MOR	5/2/99 12:12	RE	60.8417	-2.9440		pro1a2
142	01	MOR	5/2/99 13:58	DE	60.8737	-3.2945	593	pro2b2





The catch of the day