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Triennial Report:

TRANSPORT AND TRANSFER RATES IN THE WATERS OF THE CONTINENTAL SHELF AND SLOPE: SEEP

submitted to

DIVISION OF ECOLOGICAL RESEARCH
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TRIENNIAL REPORT

For Grant Years: 1 May 1987 - 30 April 1990

1.0 INTRODUCTION

1.1 Background: the SEEP Program and SEEP-II Plan

The SEEP Program was conceived in about 1980/1981 when most of the DOE-funded investigators in the Northeast decided to collaborate on a common experiment which was, for most, the next logical extension of their current research, but which was too large for any one or small subset to attempt on their own. Through a SEEP Executive Committee (consisting then of Walsh, Chairman; Biscaye, Csanady and Spencer), we proposed an experiment that had as its objective the quantitative determination of the fate of the fine-grained particulate material -- both biogenic and abiogenic -- observed in the waters of the continental shelf, but notably lacking in shelf sediments. Because most of the energy-related pollutants with which DOE is concerned become rapidly associated with fine-grained particles in the marine environment, a study of those particles and some pollutant proxies associated with them is, in effect, a study of the fate of pollutants. Specifically, it was posited that this fine material is transferred from the shelf to the slope waters by any of a number of mechanisms, and is accumulated as part of the sediment on the continental slope.

The SEEP Program was originally proposed in three successive phases in which experiments would be mounted first off New England and ending just north of Hatteras, with an intermediate experiment about mid-way between. The first experiment -- SEEP-I, off New England -- was carried out from 1983 to 1984, most of the papers from which were published in a special issue of Continental Shelf Research (1988, v. 8, Nos. 5-7).

The form of the SEEP-II experiment was conceived at a meeting of the SEEP Executive Committee (consisting then of Biscaye, Chairman; Csanady, Rowe, Spencer and Walsh) at a meeting in Savannah in October 1985. Due to fiscal constraints, the experiment was designed to encompass a reduced-scale version of what was to have been SEEP-II as well as SEEP-III in the original Program. That is, it was decided to design the experiment in two transects perpendicular to the isobaths, sufficiently distant from each other to constitute two separate realizations of the cross-shelf flux experiment. That plan was approved and a group of researchers, somewhat reduced from the list that participated in SEEP-I was funded to proceed on SEEP-II. The participating institutions in SEEP-II have been: Brookhaven National Laboratory, Lamont-Doherty, North Carolina State University, Old Dominion University, University of South Florida, Woods Hole Oceanographic Institution.

Two meetings at Lamont in June 1986 and June 1987 -- were the forum for apportioning responsibilities, putting together all available hardware into a practical, doable experimental plan and fine tuning that plan. Those meetings and the plan that emerged were the basis for a distinct improvement over the experiment that was carried out in SEEP-I. In that experiment, although there was a much ship sharing, data exchange and collaboration, there was still a great deal of division of effort along institutional and disciplinary lines. For example, there were "Geochemistry" and "Biology" cruises, and there were two different transects of moorings deployed for different periods. By contrast, in SEEP-II, except for two Biology cruises during spring-bloom periods during which there were no mooring deployments or recoveries, all cruises involved researchers from all participating institutions, and all disciplines had ship time during all cruises. Although all of the moorings were the responsibility of the Lamont Geochemistry group, all available equipment from all institutions was dispersed throughout all the moorings, insuring an added increment of cooperation and collaboration over what had been the case in SEEP-I (and that wasn't bad).

In addition some aspects of the experiment, considered by us to be important scientifically, were not funded by DOE due to fiscal constraints. A concerted effort was made to obtain funding from other agencies in support of those aspects, and in two of these we were successful.

1.2 The SEEP-II Experiment Rationale and Objectives

In SEEP-I we had found that, although there was evidence of the transfer of fine-grained particulate material from the shelf across the shelf/slope front and break (by "diffusive" processes) to the waters and ultimately to the sediments of the adjacent slope, this accounted for only on the order of ~10% of the shelf material. The remaining biogenic and abiogenic particles created on or introduced to the shelf were either consumed and recycled on the shelf, or were advected along the shelf to be exported advectively at Hatteras. The original SEEP plan had posited that this "diffusive" export of shelf material (and its pollutant load) to the slope would increase as we progressed from New England southwest towards Hatteras. In a piggy-back sediment trap-testing experiment on the MASAR "B" mooring, about 250 km southwest of SEEP-I (Fig. 1.2/1), we collected trap samples and data from 1985-1986 that, in fact the "diffusive" flux to the shelf at MASAR-B might be higher by a factor to 2 to 3 than that at SEEP-I.

The objective of the SEEP-II experiment was to attempt to measure that "diffusive" flux at two more southerly locations along the shelf break, to determine if what left the shelf was sedimented onto the slope, and to try to further understand the processes involved. That field experiment was undertaken from February 1988 to May 1989, and the planning and execution of it is the major focus of this Report.

1.3 Organization of this Report

As reviewed above, the preparations for that experiment began well before the initial cruise, and the analysis of samples and reduction of data will last well after the final cruise, so the entire three year period covered by this report (1 May 1987 to 30 April 1990) was almost entirely occupied with the SEEP-II experiment.

When the current grant period began, a Lamont Physical Oceanographic component, under the direction of Bob Houghton and Dick Ou, was part of this grant, as it had been for a long time previously. During the second grant year Houghton and Ou submitted a separate proposal to DOE for support of their work and, when that was approved, worked under separate grant support for the third grant year. We retain the same interactive communication and relationship with regard to the science as previously, the change being primarily an administrative/fiscal one that was to their benefit. Their work for the first year or so was, in effect, reported in their proposal, and their work subsequently will be reported in their renewal Report and Proposal. This Report, and the renewal Proposal accompanying it, will not therefore deal with any of the Physical Oceanography done by the Lamont group except as it relates to the science being done by us on the SEEP-II experiment.

The report that follows is organized into three primary sections which summarize our accomplishments in the past three years. The first section, 2.0 THE SEEP-II EXPERIMENT, is the largest as that has been our primary focus. The second, 3.0 THE SEEP-I EXPERIMENT: CONTINUING RESULTS, briefly summarizes some science from SEEP-I that was not ready for publication at the time the SEEP-I volume in Continental Shelf Research was prepared, and some which is

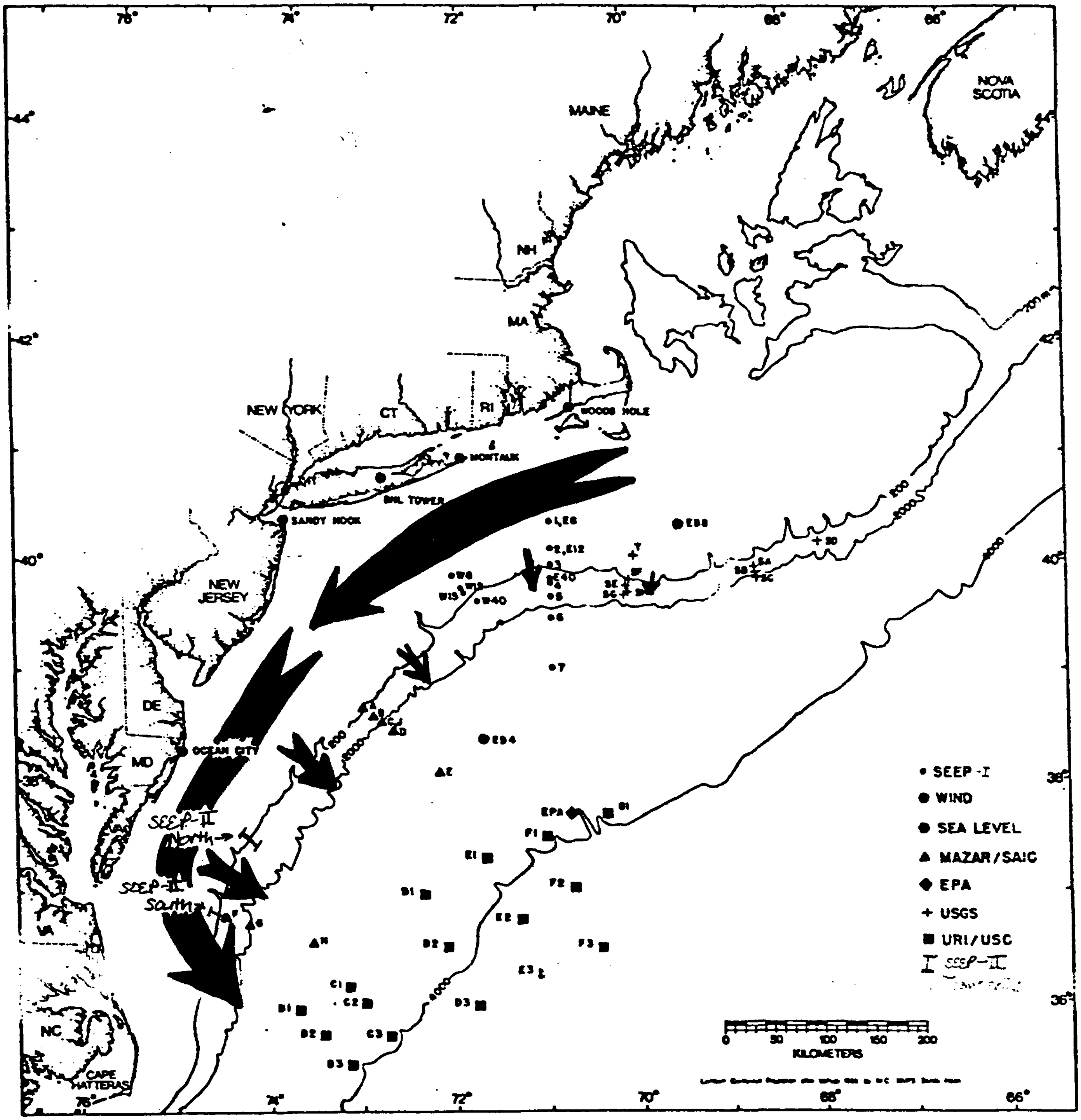


Fig.1.2/1 Map of Middle Atlantic Bight showing SEEP-I and -II in relation to other recent mooring projects in the area. Arrows at the shelf break suggest the anticipated increase to the southwest ir "diffusive" net offshore flux of particles and their pollutant loads. The large arrow on the shelf indicates thesouthwesterly "advective" flux of the rest of the fine particulate load which must be carried offshore where the shelf pinches off at Hatteras.

continuing. The third section, 4.0 COMPLEMENTARY PROJECTS, reports work on projects that are a logical extension of the SEEP Program. Finally section 5.0 is a listing the abstracts, talks and papers that have been presented or written during this grant period. An Appendix consisting of copies of the abstracts and papers listed in 5.0 is part of this report.

2.0 THE SEEP-II EXPERIMENT

This section is divided into a resume of the field experiment and of the analytical work and results so far on the samples and data obtained.

2.1 The Field Experiment

2.1.1 LDGO Responsibility and Participation.

Originally as Chair of the SEEP Executive Committee, but subsequently as the PI responsible for the SEEP-II moorings, Biscaye has had the major responsibility for the planning, integration of the various institutional resources and execution of the SEEP-II field experiment. This overall responsibility derived from the responsibility for the moorings and the decision of the Executive Committee in 1985 that observations, measurements and sampling that could be done as long-term time series over the course of the experiment would have the primary demand on the relatively limited resources available for the experiment. Thus the focus of the experiment was to be on the moorings and other long-term instruments. That is not to say that there was not a significant amount of ship time and effort devoted to "snapshot" observations, such as hydrography, fluorometry, transmissometry, primary productivity, phyto- and zooplankton tows, etc. But the schedule of cruises and the time during cruises were built around the deployment and recovery of the moored instruments.

Besides overall mooring responsibility, Biscaye and Anderson were responsible for the sediment traps, some of the moored transmissometers and the profiling transmissometer used with the CTFD. Lamont current meters (RCM-5s, VMCMs) from the PO group were also part of the overall instrumental effort, and these were prepped, deployed and recovered under the aegis of the LDGO Mooring Group.

2.1.2 SEEP-II Cruises.

The cruise schedule was built around a three-deployment schedule of the moorings over the course of15 months -- three deployment and three recovery cruises. In addition, there were two related

NSF-sponsored cruises devoted to sampling and studying the sediments and fluxes of dissolved species across the sediment-water interface (under a grant to Anderson and Biscaye; see 2.1.6 and 2.2.3 below). These two cruises -- one immediately after a spring bloom, and the other at a distinctly non-bloom time -- were scheduled between the two recovery and redeployment cruises while the mooring instruments and equipment were being turned around. Finally, DOE sponsored two SEEP-II cruises devoted primarily to biological sampling. We participated, to varying degrees, in each of the ten cruises. These are summarized in Table 2.1.2/1.

2.1.3 Moorings.

The available mooring and instrumental resources were unevenly divided into two transects perpendicular to the isobaths in what were called the North and South transects (Figs. 1.2/1 and 2.1.3/1). The distribution was uneven so as to be able to instrument one transect more thoroughly and extending from slope into the shelf, while still having a second transect, primarily for sediment trap flux measurements. Within all the SEEP-II institutions and PIs, we just did not have sufficient equipment to adequately instrument both transects. Distribution of the instruments on the ten moorings was done collectively by the SEEP-II PIs at the June1986 meeting at Lamont, and finalized at the Lamont meeting one year later.

All aspects of the design, construction, deployments, recoveries and turn-around of the moorings were under the supervision of Larry Sullivan, Head of the LDGO Mooring Group, working directly with Biscaye. The moorings were designed using the dynamics model generously lent us by Randy Watts of URI (Mo and Watts, 1987). Summary schematics of the instrumentation on all moorings for the three deployments are shown in Figs. 2.1.3/2A, -B, -C. Besides some changes in Moorings 1 & 2 because of losses (discussed below), the major changes between deployments were that two large sediment traps were added to Mooring 7 (discussed under 2.1.4) during the Summer and Winter deployments (Fig. 2.1.3/3) and the Thermistor chain at Mooring 3 during the Spring and Winter deployments was replaced by four RCM-5 current meters equipped with conductivity cells during the season when the shelf/slope front is defined by salinity rather than temperature (Fig. 2.1.3/4).

Because the mooring depths in some cases varied slightly from the original target depths, and from each other at the same site on successive deployments, we refer throughout this report to moorings and to

Table 2.1.2/1

SEEP-II CRUISES

R/V Endeavor
(unless otherwise noted)

CRUISE EN#/SEEP#	DEPART Date	PORT	ARRIVE Date	PORT
172/SII-01	5 Feb 88	Narraganssett	10 Feb 88	Norfolk
	10 Feb 88	Norfolk	15 Feb 88	Norfolk
	15 Feb 88	Norfolk	20 Feb 88	Narragansett
CH*/SII-02	10 Mar 88	Beaufort	20 Mar 88	Beaufort
178/SII-03	6 Jun 88	Narragansett	11 Jun 88	Norfolk
	11 Jun 88	Norfolk	14 Jun 88	Norfolk
179/SII-04 (#)	15 Jun 88	Norfolk	22 Jun 88	Norfolk
180/SII-05	23 Jun 88	Norfolk	27 Jun 88	Norfolk
	27 Jun 88	Norfolk	2 Jul 88	Narragansett
186/SII-06	16 Oct 88	Narragansett	19 Oct 88	Norfolk
	20 Oct 88	Norfolk	23 Oct 88	Norfolk
187/SII-07 (#)	25 Oct 88	Norfolk	31 Oct 88	Narragansett
188/SII-08	9 Nov 88	Narragansett	16 Nov 88	Norfolk
	16 Nov 88	Norfolk	21 Nov 88	Narragansett
192/SII-09	16 Mar 89	Narragansett	25 Mar 89	Narragansett
195/SII-10	1 May 89	Narragansett	4 May 89	Norfolk
	4 May 89	Norfolk	12 May 89	Narragansett

* CH= Cape Hatteras
# = NSF-sponsored cruise under Anderson/Biscaye Continental Slope Carbon Budget grant

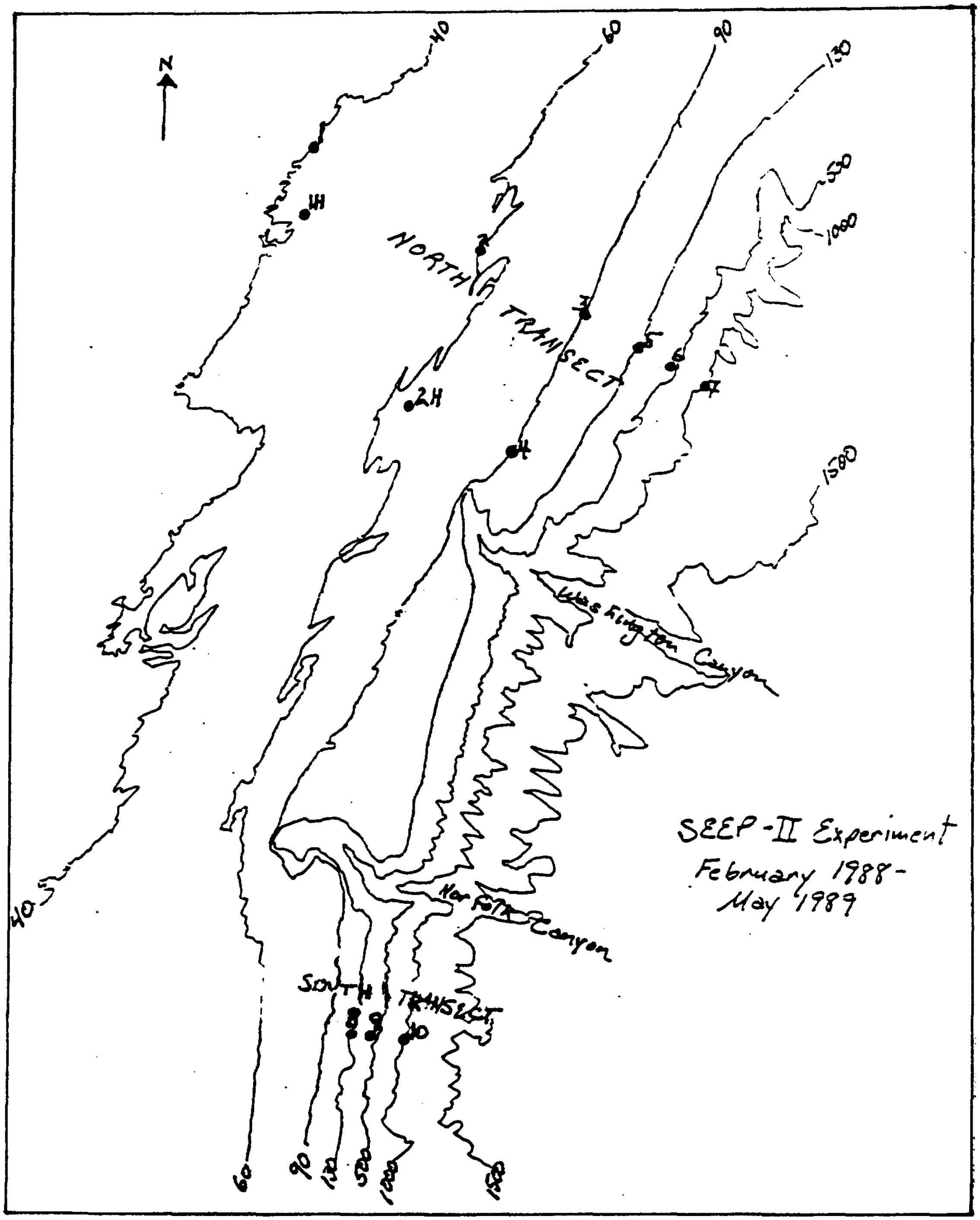


Fig. 2.1.3/1 Map showing SEEP-II mooring sites in more detail. Moorings 1-3 and 5-7 constituted the North Transect along with 4 at the same depth as 3 but offset to measure alongshore coherence. The South Transect consisted of Moorings 8, 9 and 10 at the same depths as 5, 6 and 7.

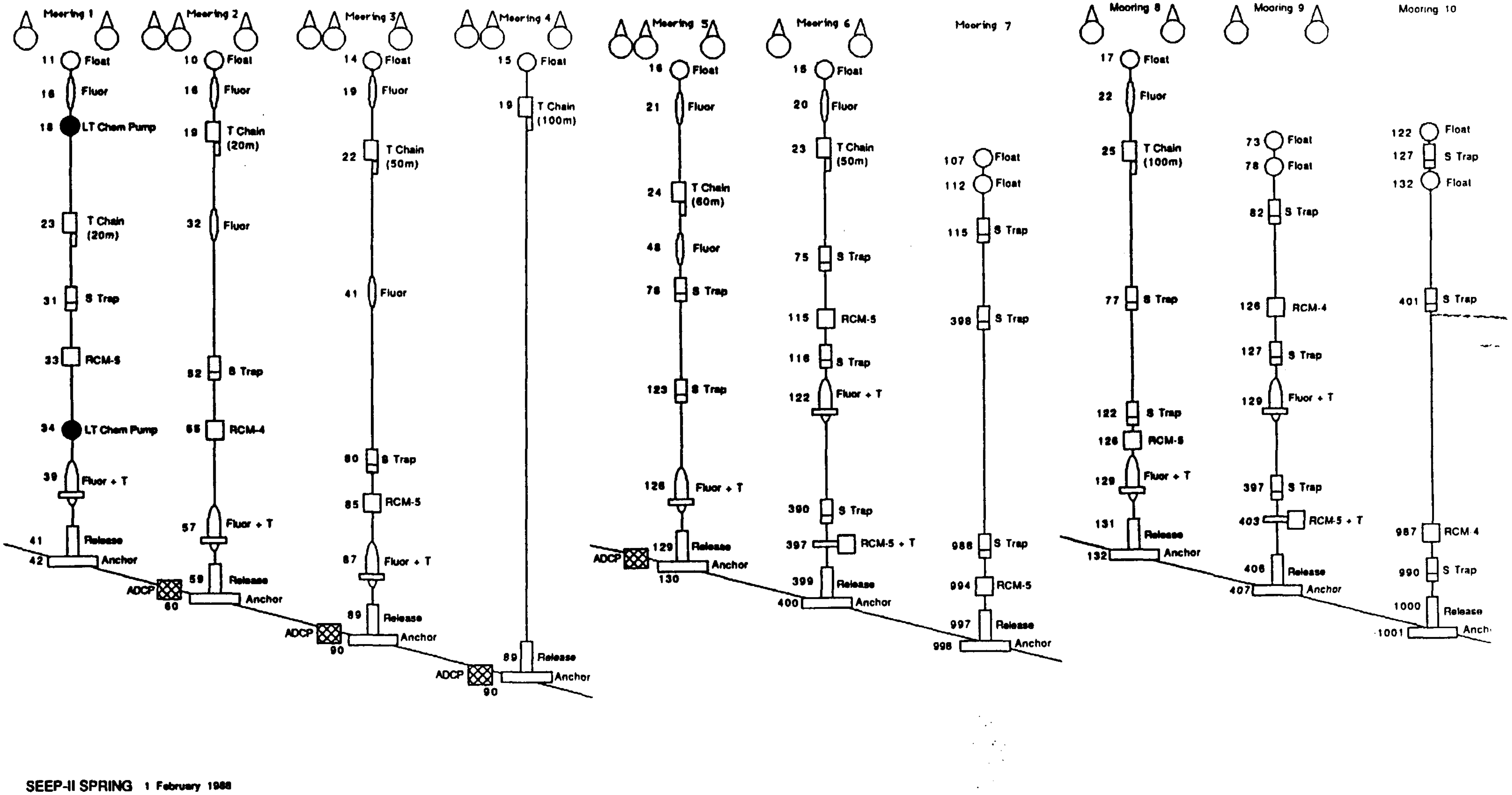


Fig. 2.1.3/2 Schematic of instrumentation on the 10 SEEP-II moorings for the:
A - Spring Deployment (Feb-June 1988)

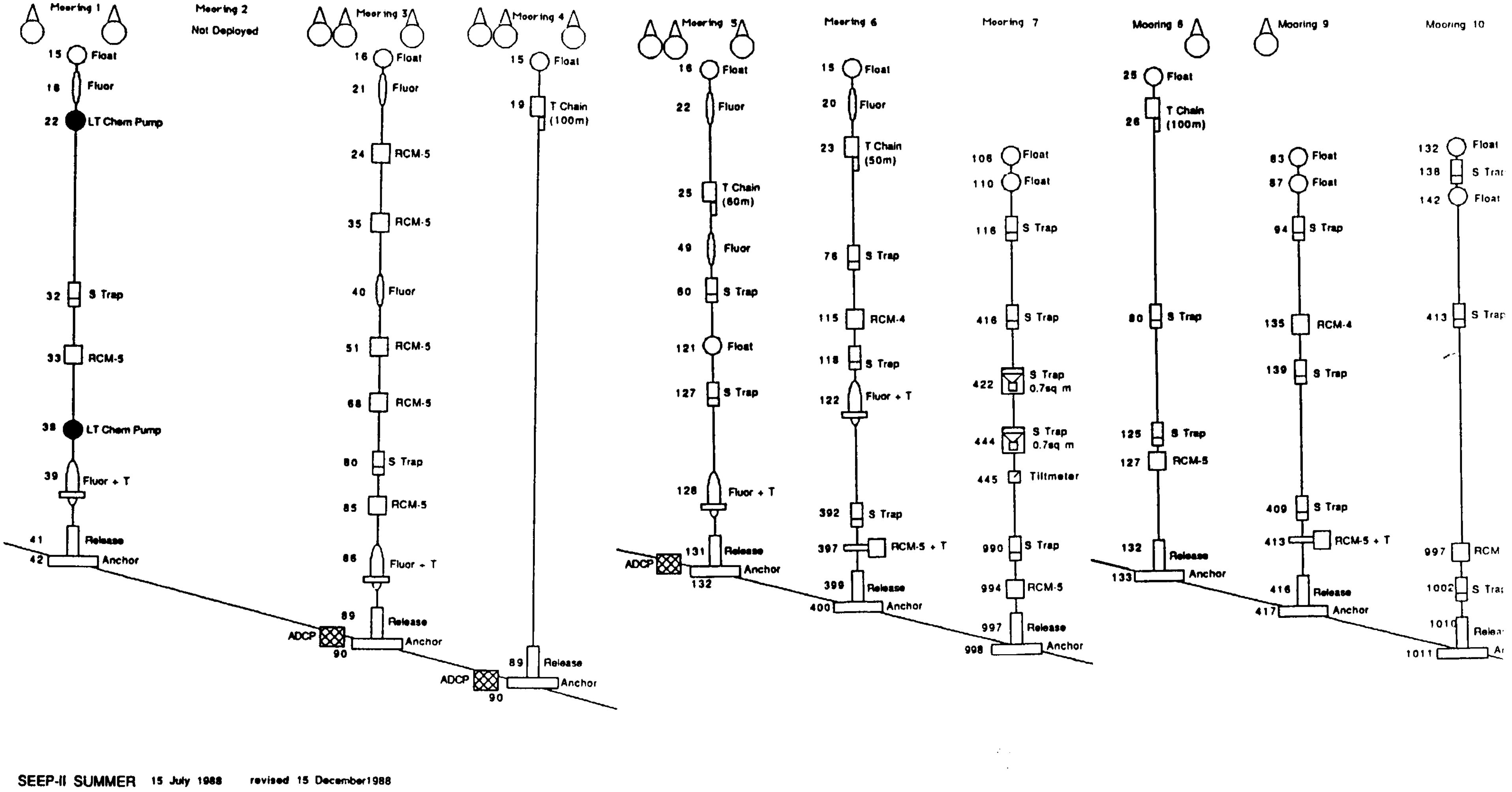
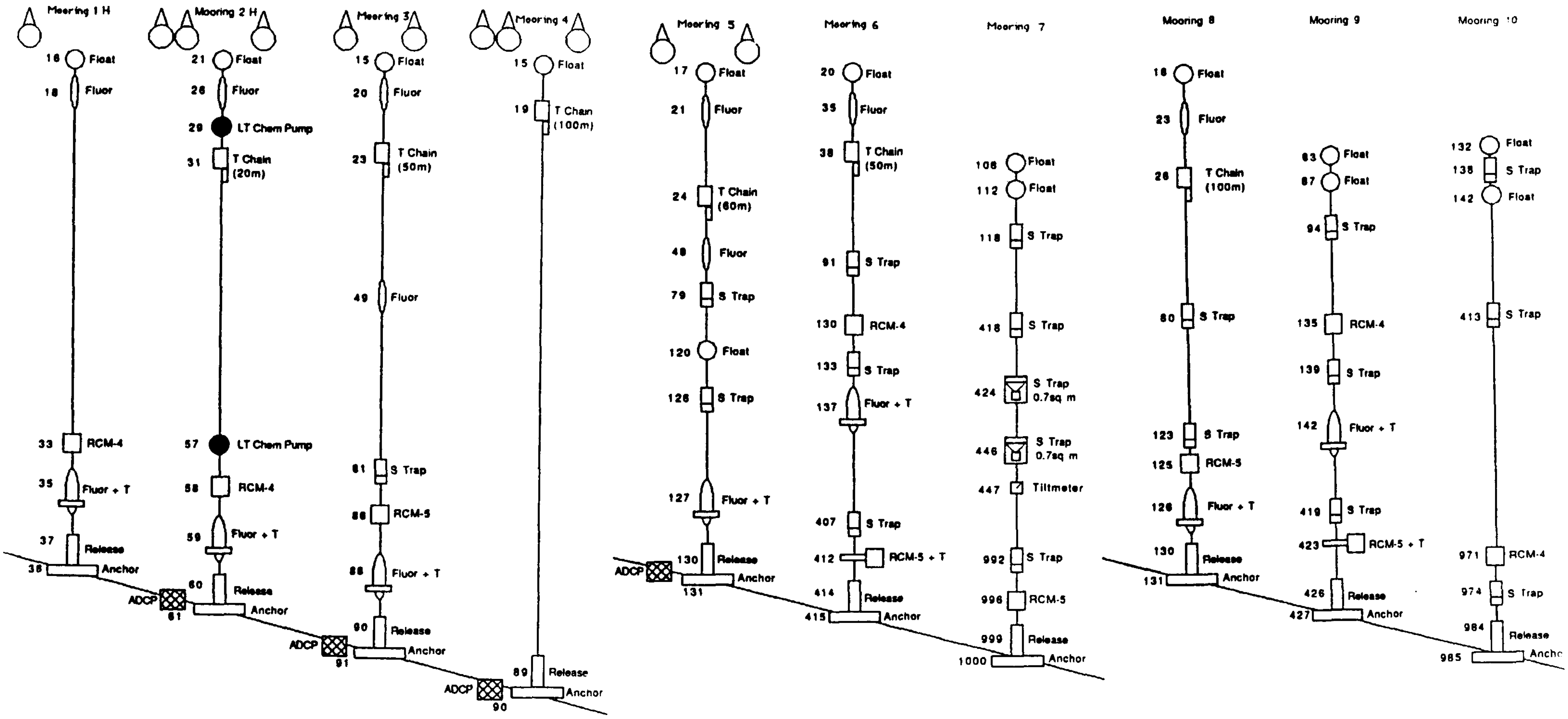


Fig. 2.1.3/2 Schematic of instrumentation on the 10 SEEP-II moorings for the:
B - Summer Deployment (June-October 1988)



SEEP-II WINTER 15 December 1988

Fig. 2.1.3/2 Schematic of instrumentation on the 10 SEEP-II moorings for the:
C - Winter Deployment (November 1988-May 1989)

Fig. 2.1.3/2C

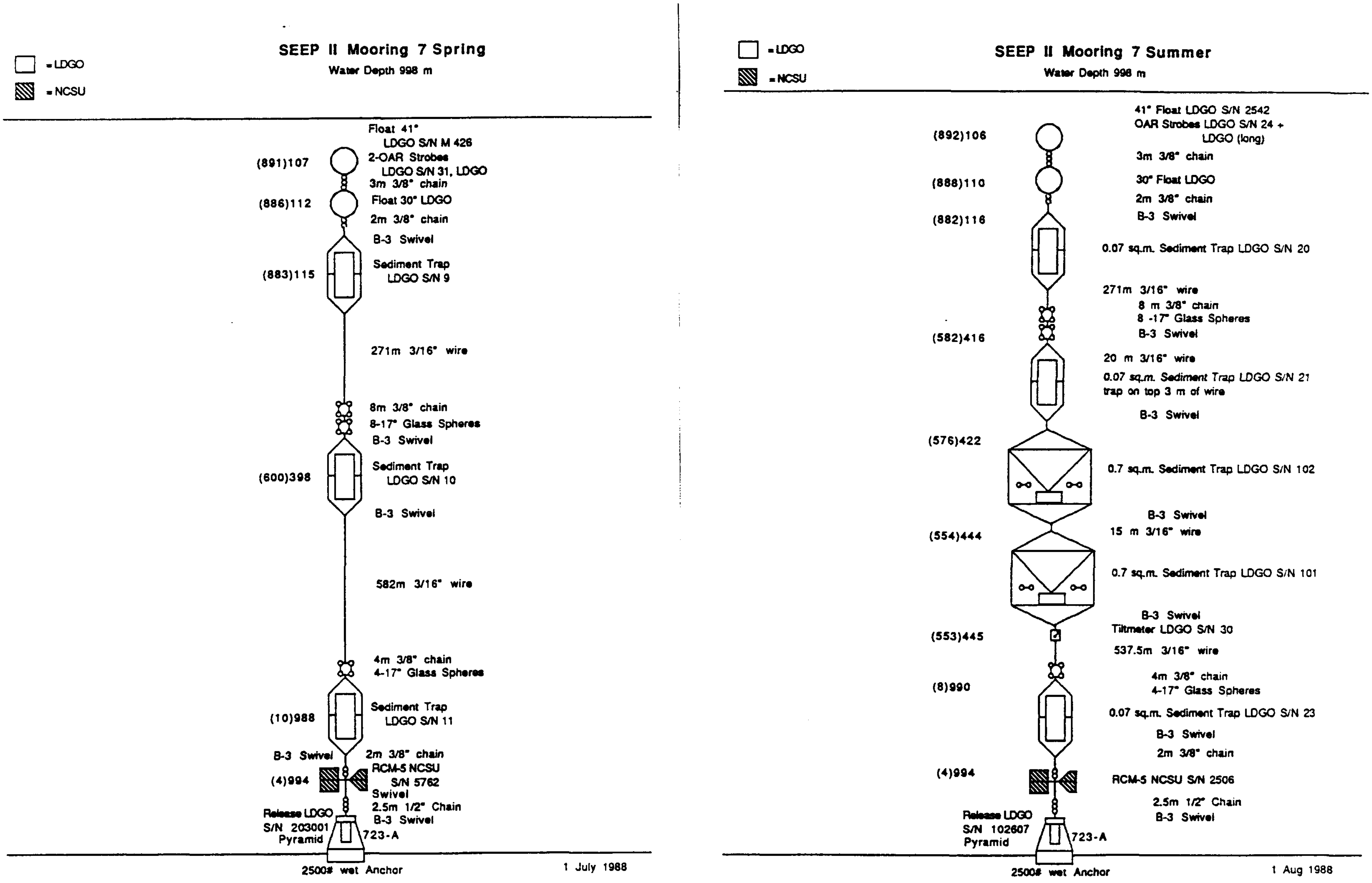


Fig. 2.1.3/3 A - Detailed mooring diagram of Mooring 7 - Spring.
B - Same mooring showing Summer addition of two large ($0.65m^2$) traps.

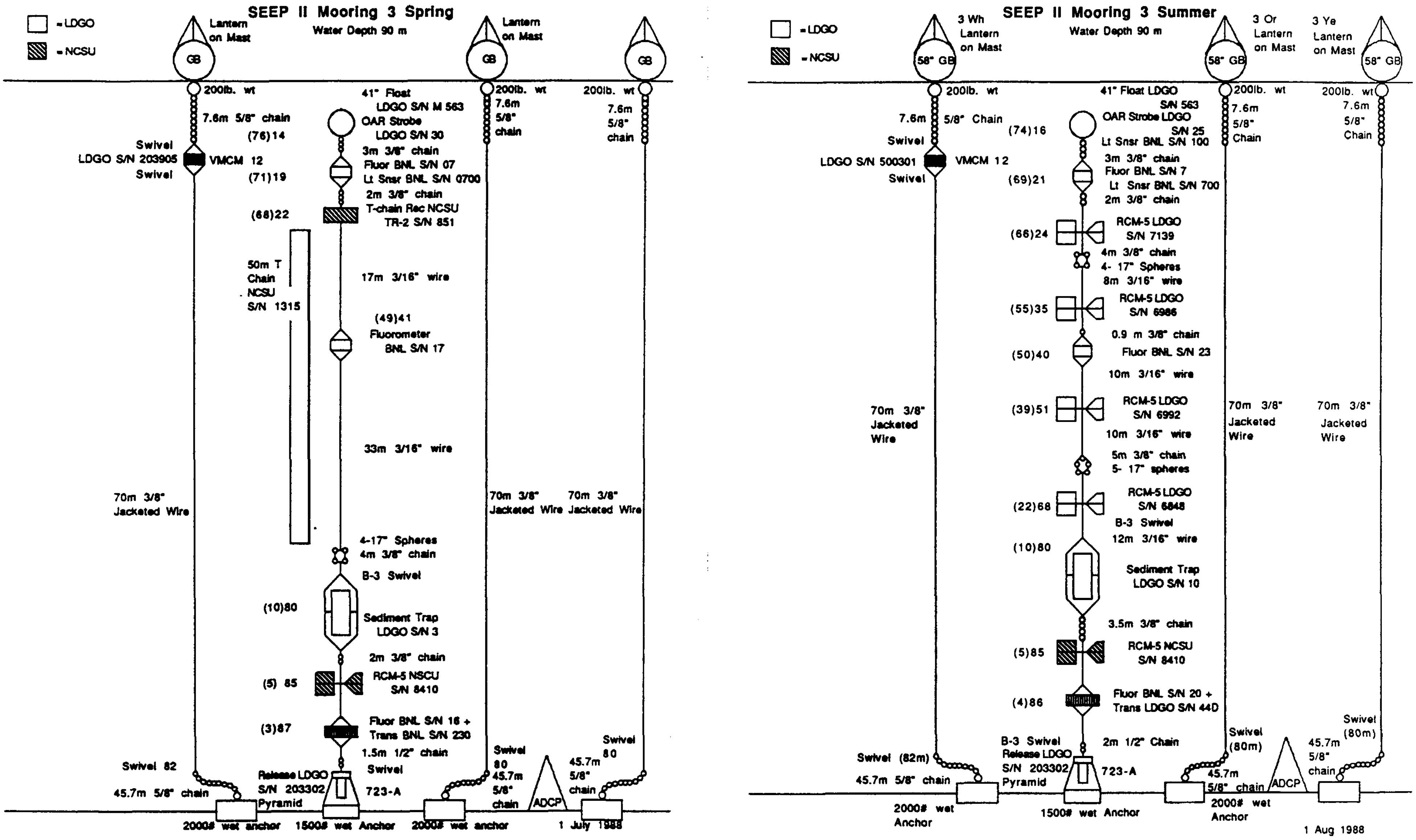


Fig. 2.1.3/4 A - Detailed mooring diagram of Mooring 3 - Spring (which is essentially the same as for the Winter deployment).
B - Same mooring showing Summer substitution of four RCM-5 current meters for the thermistor chain used in Spring and Winter.

the depths of instrumentation thereon by their nominal depths. Thus, the water depths of the 10 moorings were: 1 - 40 m; 2 - 60 m; 3 & 4 - 90 m; 5 & 8 - 130 m; 6 & 8 - 400 m; and 7 & 10 - 1000 m. The mooring position/depth variability is shown in Fig. 2.3.1/5 A through L which is the detailed bathymetric chart made at each mooring site and improved at each successive deployment. The particulars concerning each mooring -- position, depth, deployment and recovery dates are listed in Table 2.1.3/1. The three mooring deployment intervals were given the names Spring, Summer and Winter, both for the sake of uniform useage throughout the SEEP PIs, and for the principal season they covered, even though the "Winter" deployment also included a second Spring Bloom.

The aspect of the moorings that proved to be one of the most costly in terms of concern, ship time and money was that of guard buoys. In SEEP-I all LDGO subsurface moorings in water shallower than 500 m were guarded by large (5 ft diameter) surface buoys with radar reflectors and strobe lights on either side of the instrument mooring; about 30% of the guard moorings and one of the instrument moorings were lost. We began SEEP-II with the same philosophy, that subsurface moorings in water shallower than 500 m had to be guarded. But at three of the mooring sites there was an Acoustic Doppler Current Profiler (ADCP) as well as a subsurface vertical instrument mooring, requiring a triangle of 3 guard moorings, rather than the flanking pair used at the other four shallow moorings, or a total complement of 20 guard moorings. These proved to be extremely vulnerable to loss by several means -- hardward failure due to corrosion and strain; wire cutting by fishing trawler wires; and even sinking by rifle shots (Fig. 2.1.3/6). Of the original 20 deployed plus 4 replacements, a total of 14 were lost and not recovered (including another one sunk by rifle fire and dredged up by a scalloper who refused to return it without the payment of an absurd ransom).

Despite the guard buoys, 3 instrument moorings and one ADCP were lost or damaged by fishermen, almost certainly trawlers, and various percentages of their instrumentation was recovered -- by dragging, and by fishermen who either dredged up from the bottom or picked up floating components and either returned them graciously or demanded something as ransom. Table 2.1.3/2 contains a summary of instruments lost, recovered, and damaged by all participants during SEEP-II.

Because of heavy losses shortly after deployment at mooring site 2 (60 m), and because these losses were obviously malicious, apparently because we had inadvertently chosen the site in a working

SEEP-II MOORING 1

(DEPTHS IN UNCORRECTED METERS)

1988-1989

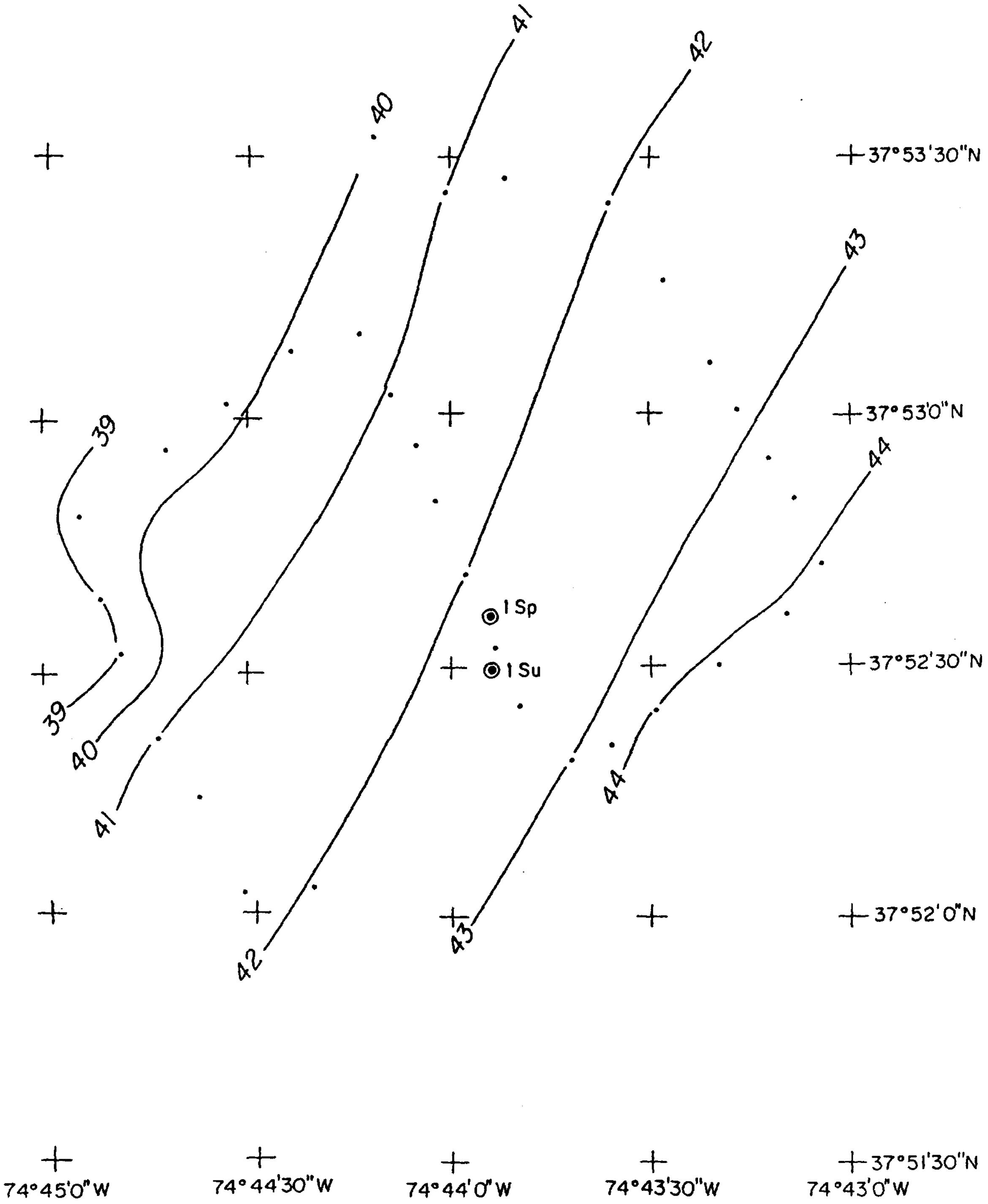


Fig. 2.1.3/5B

SEEP-II MOORING 1H

(DEPTHS IN UNCORRECTED METERS)

1988-1989

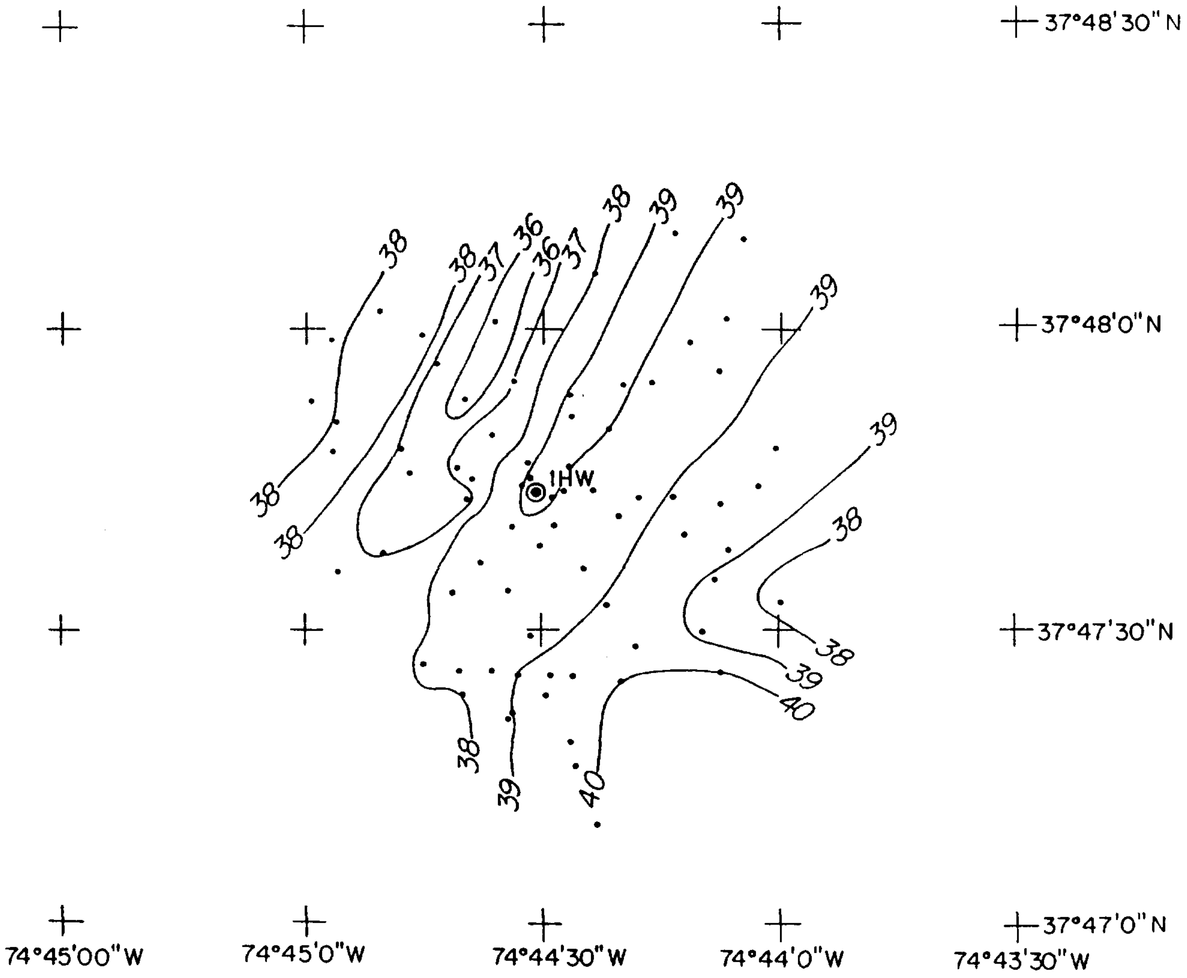
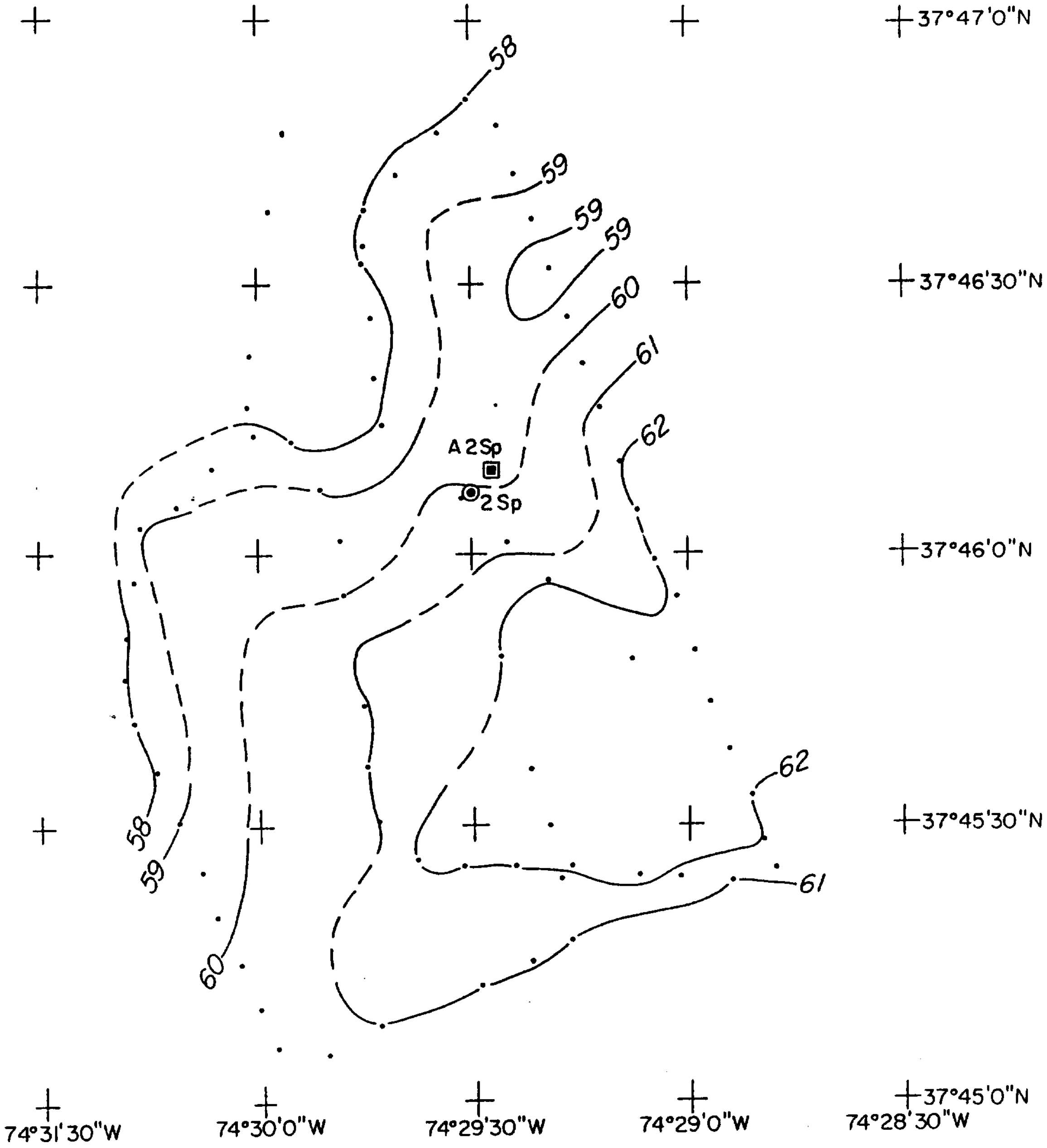


Fig. 2.1.3/5C

SEEP-II MOORING 2

(DEPTHS IN UNCORRECTED METERS)

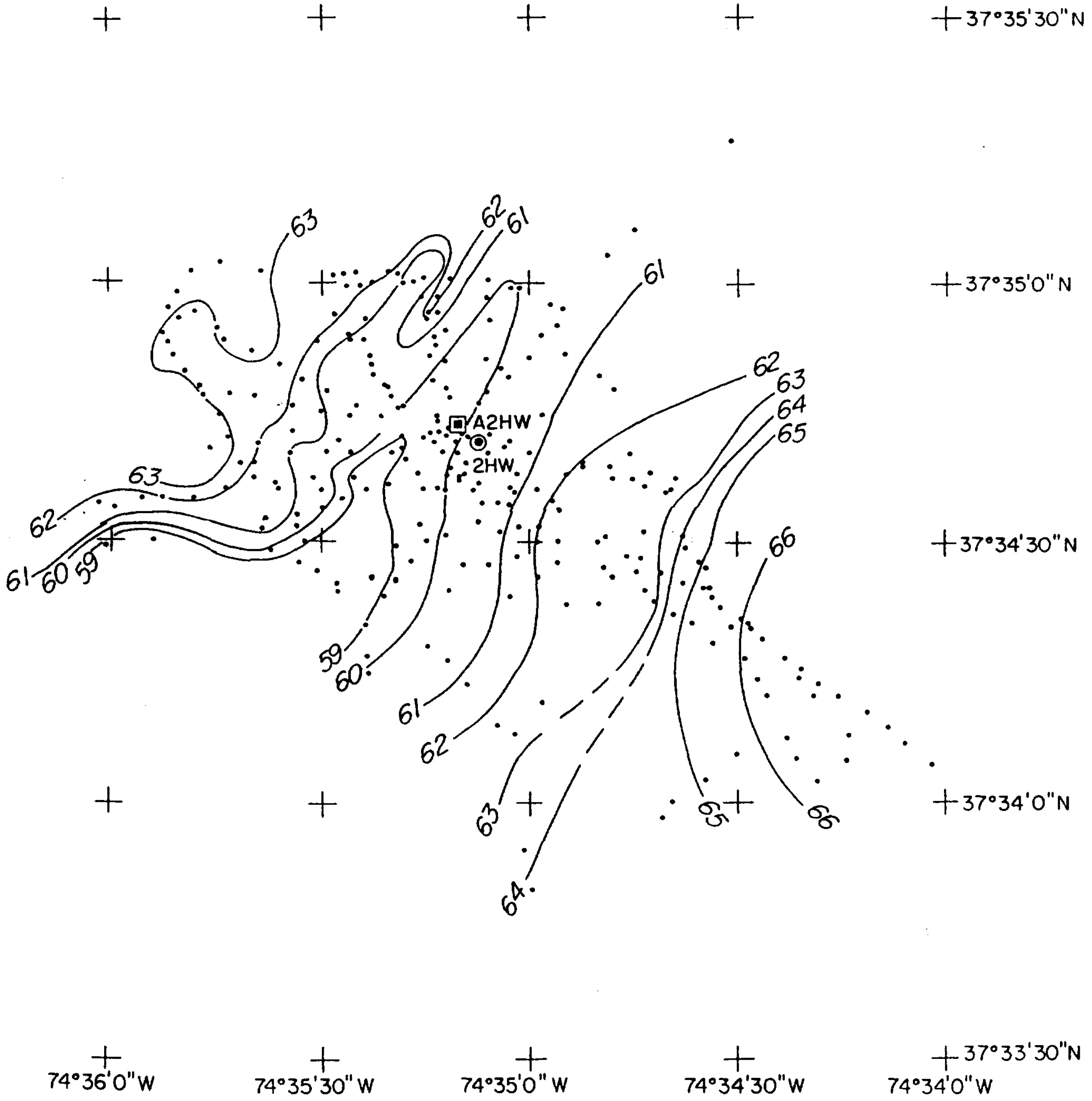
1988-1989



SEEP-II MOORING 2H

(DEPTHS IN UNCORRECTED METERS)

1988-1989



SEEP-II MOORING 3

(DEPTHS IN UNCORRECTED METERS)

1988-1989

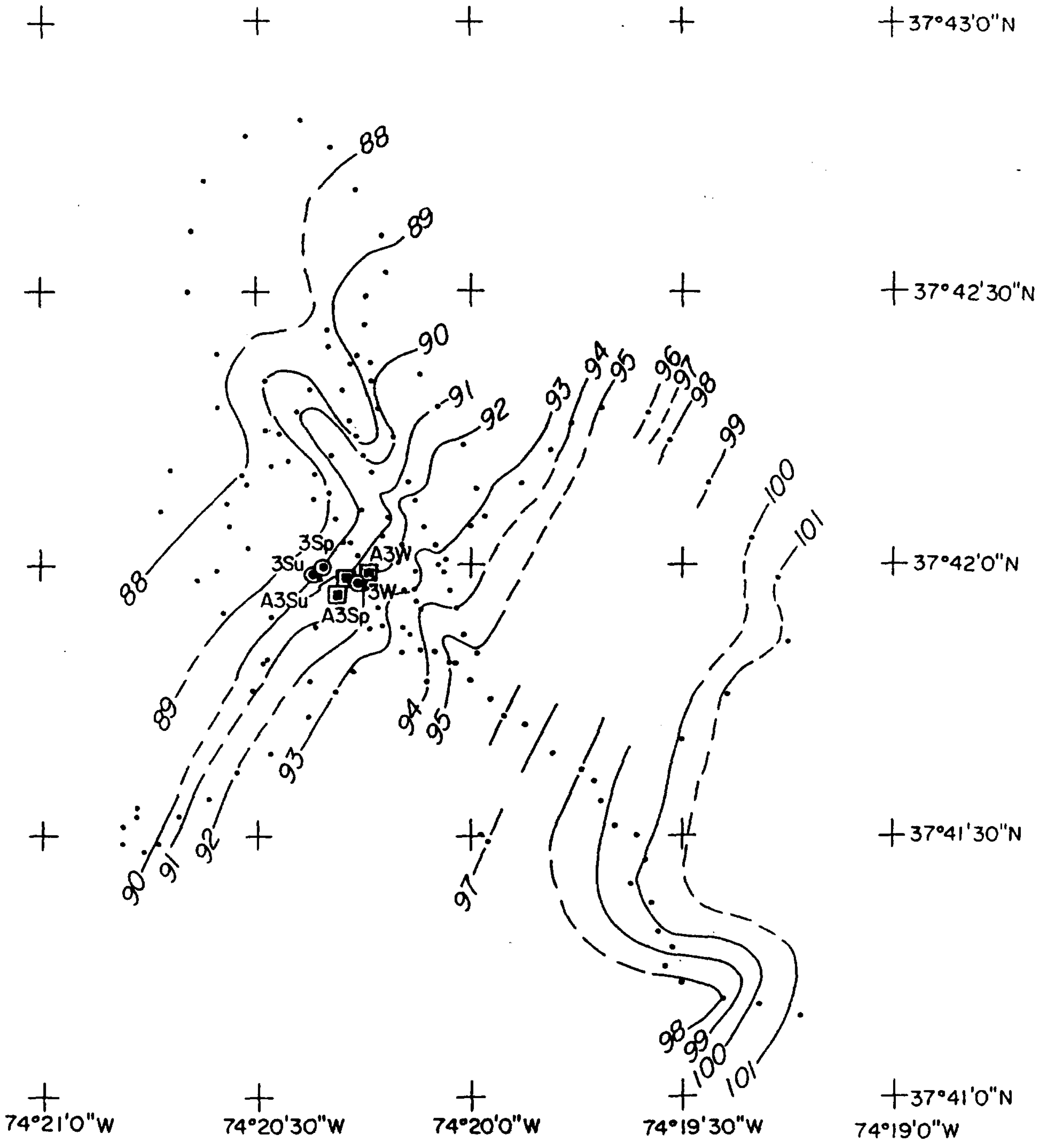


Fig. 2.1.3/5F

SEEP-II MOORING 4

(DEPTHS IN UNCORRECTED METERS)

1988-1989

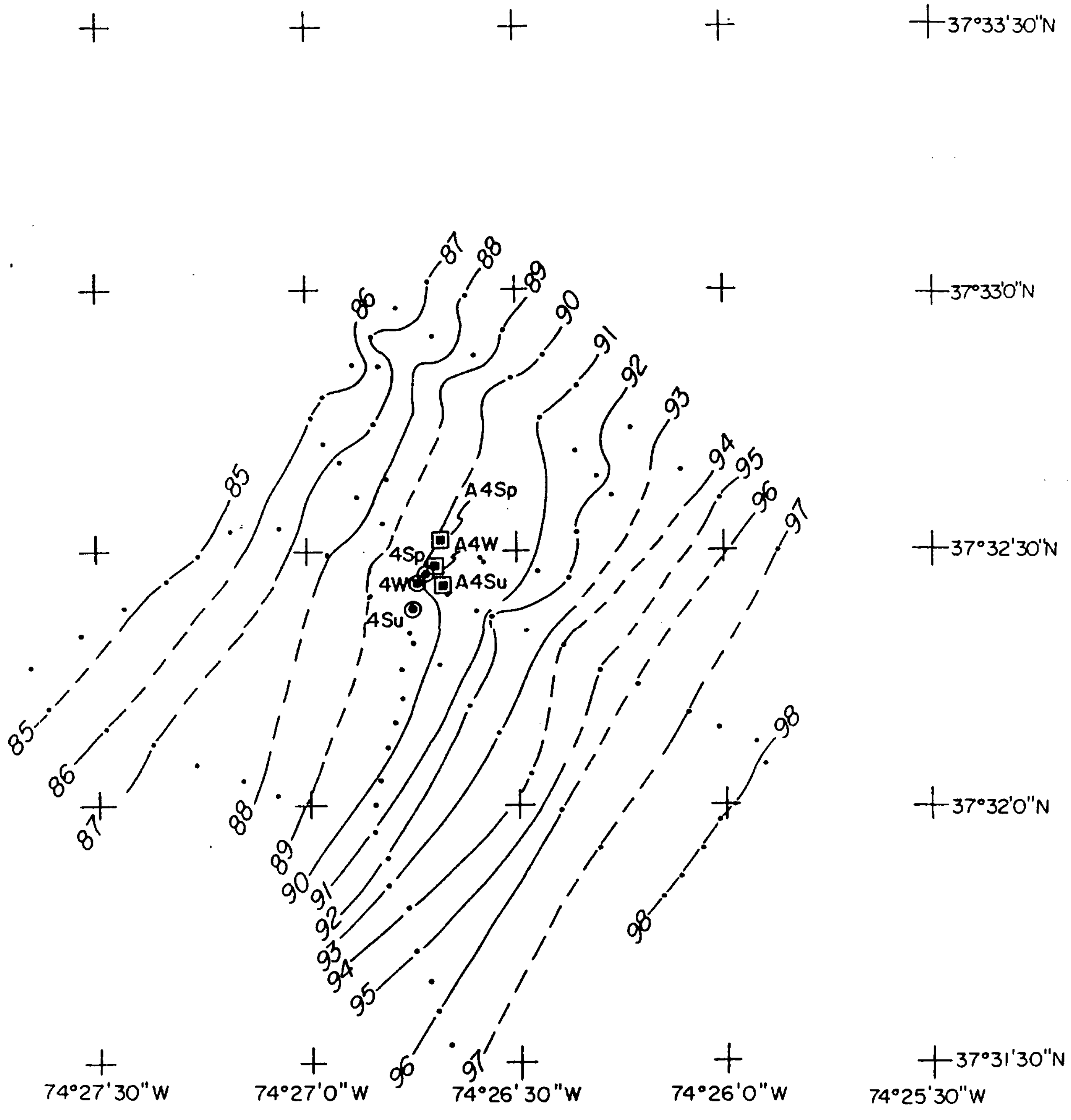


Fig. 2.1.3/5G

SEEP-II MOORING 5

(DEPTHS IN UNCORRECTED METERS)

1988-1989

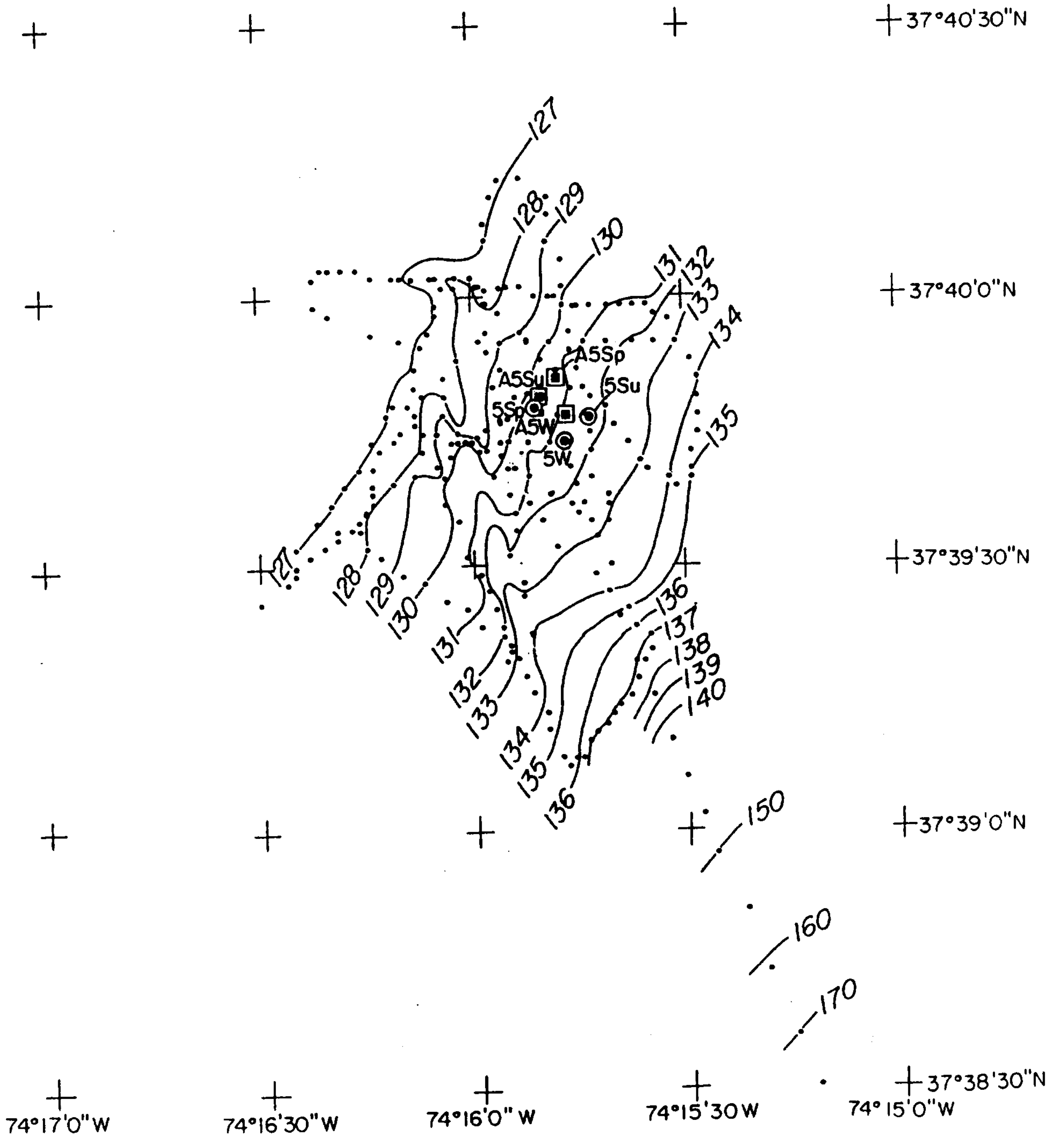
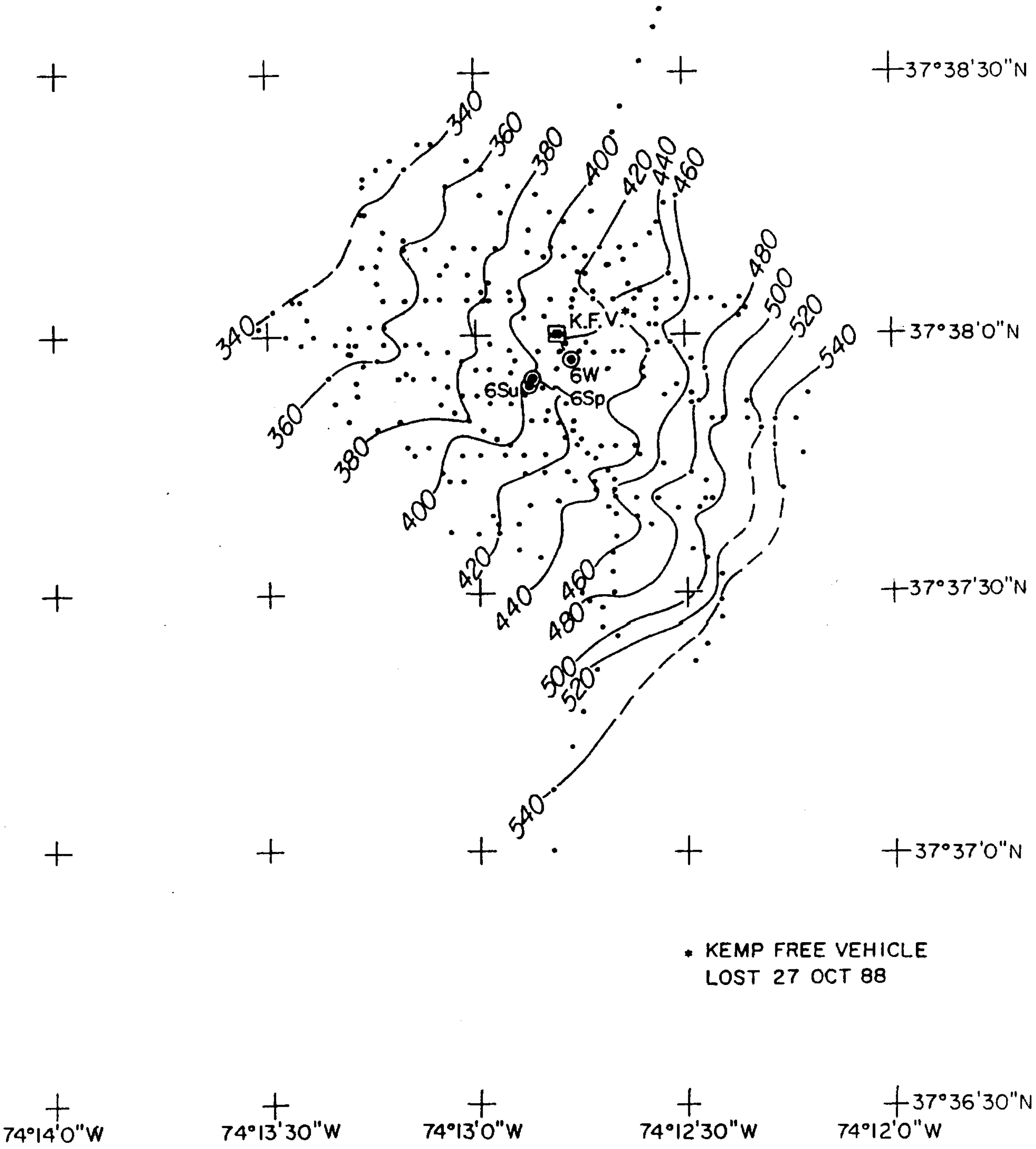


Fig. 2.1.3/5H

SEEP-II MOORING 6

(DEPTHS IN UNCORRECTED METERS)

1988-1989



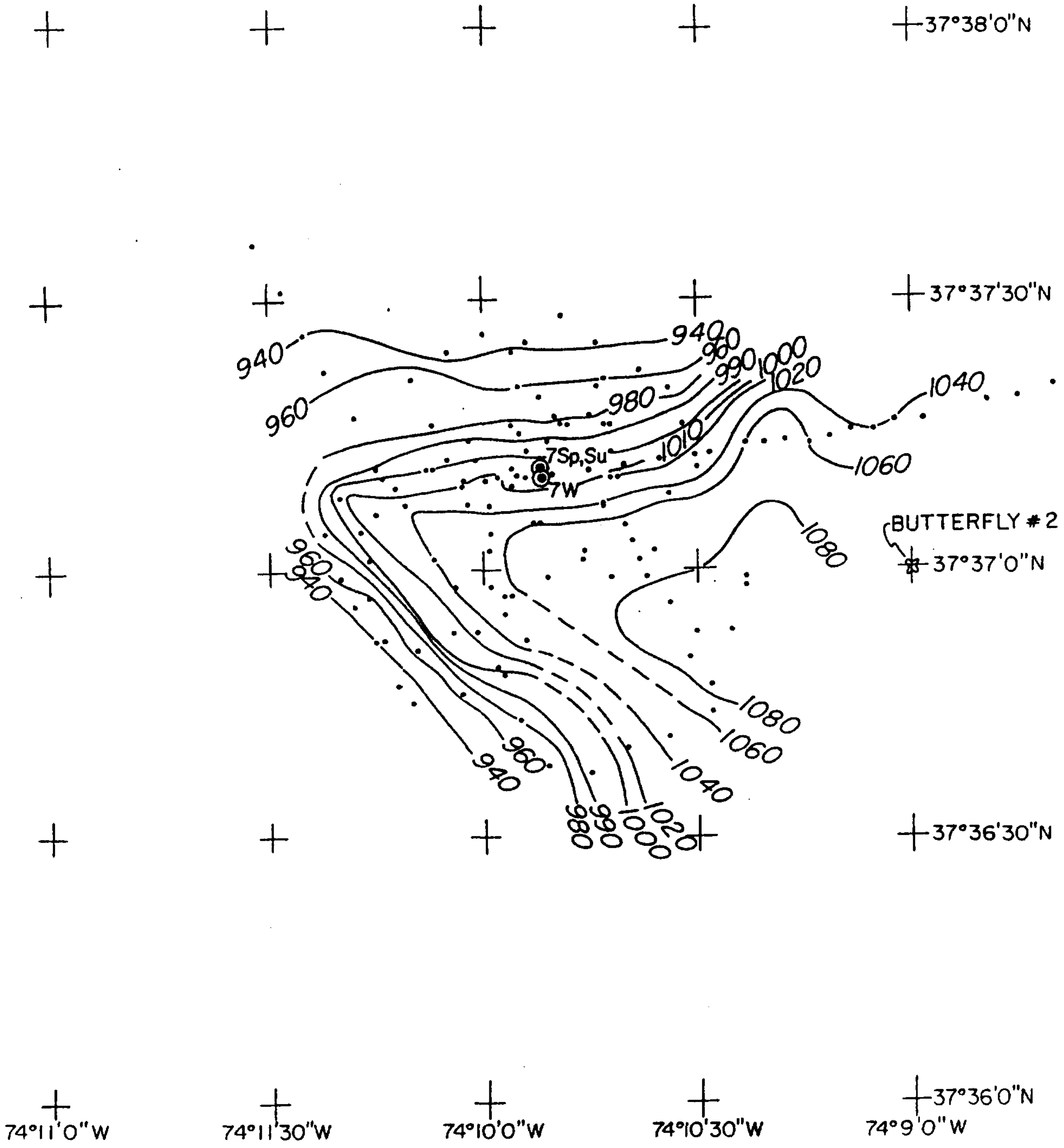
* KEMP FREE VEHICLE
LOST 27 OCT 88

Fig. 2.1.3/5I

SEEP-II MOORING 7

(DEPTHS IN UNCORRECTED METERS)

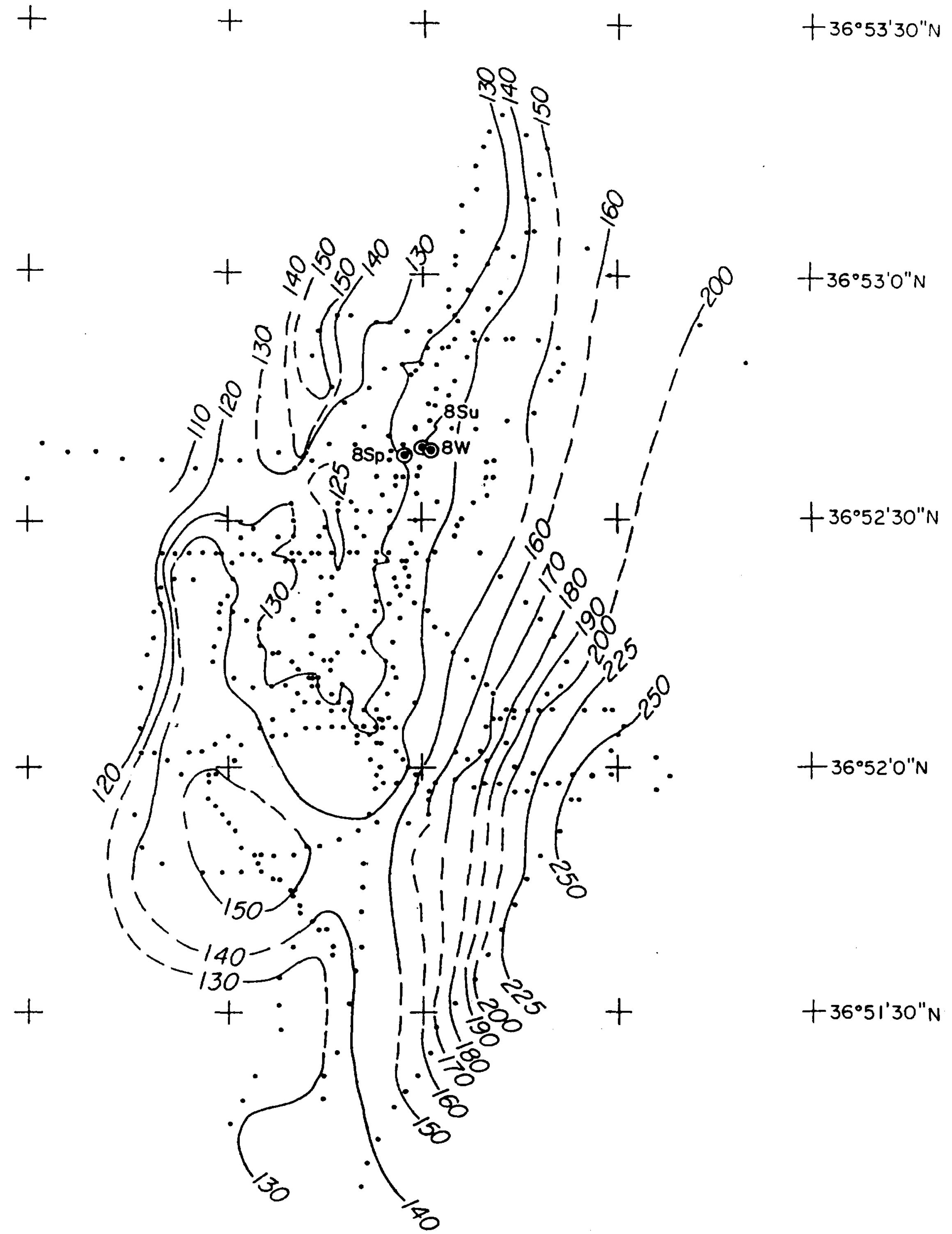
1988-1989



SEEP-II MOORING 8

(DEPTHS IN UNCORRECTED METERS)

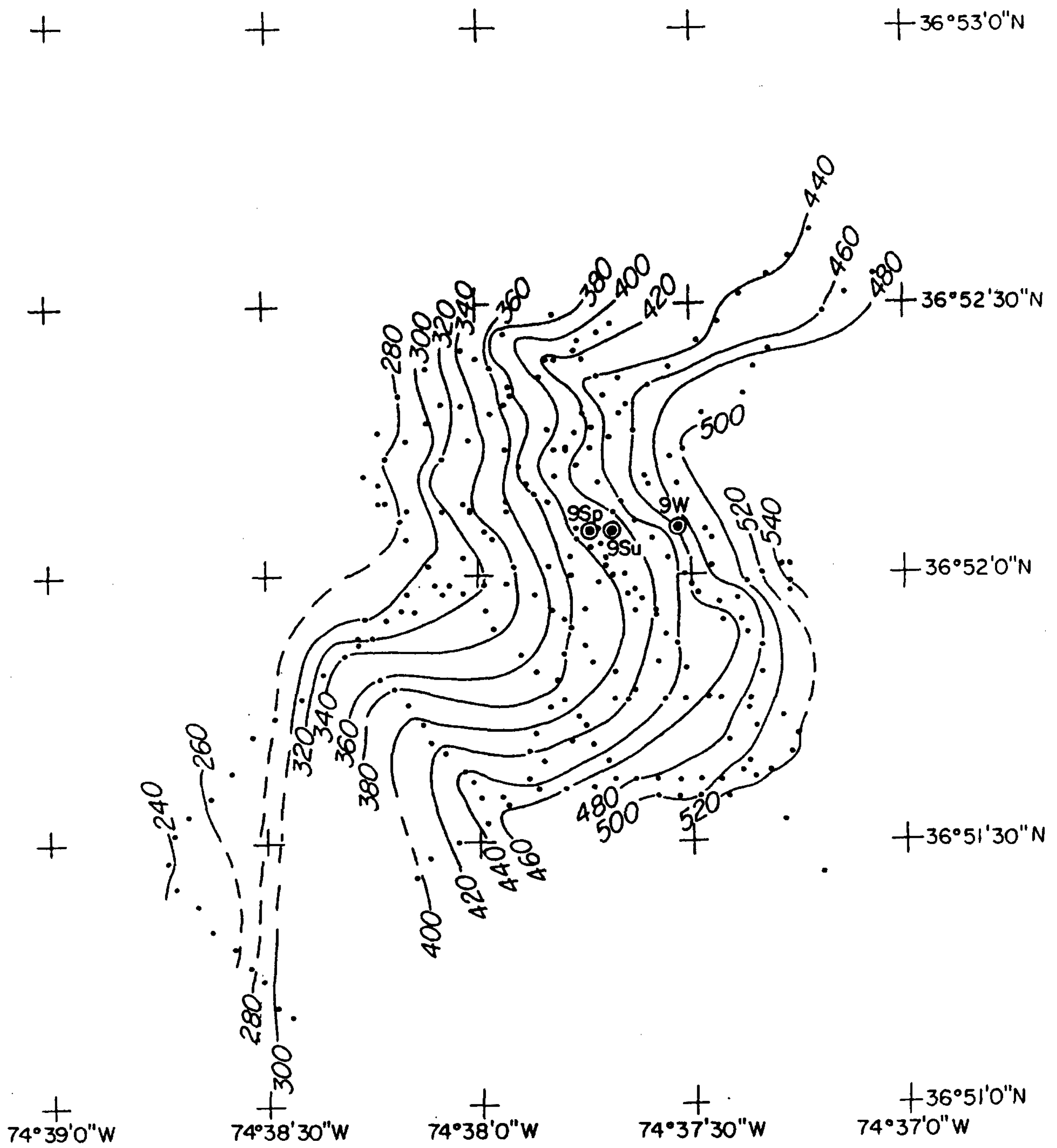
1988-1989



SEEP-II MOORING 9

(DEPTHS IN UNCORRECTED METERS)

1988-1989



SEEP-II MOORING 10

(DEPTHS IN UNCORRECTED METERS)

1988-1989

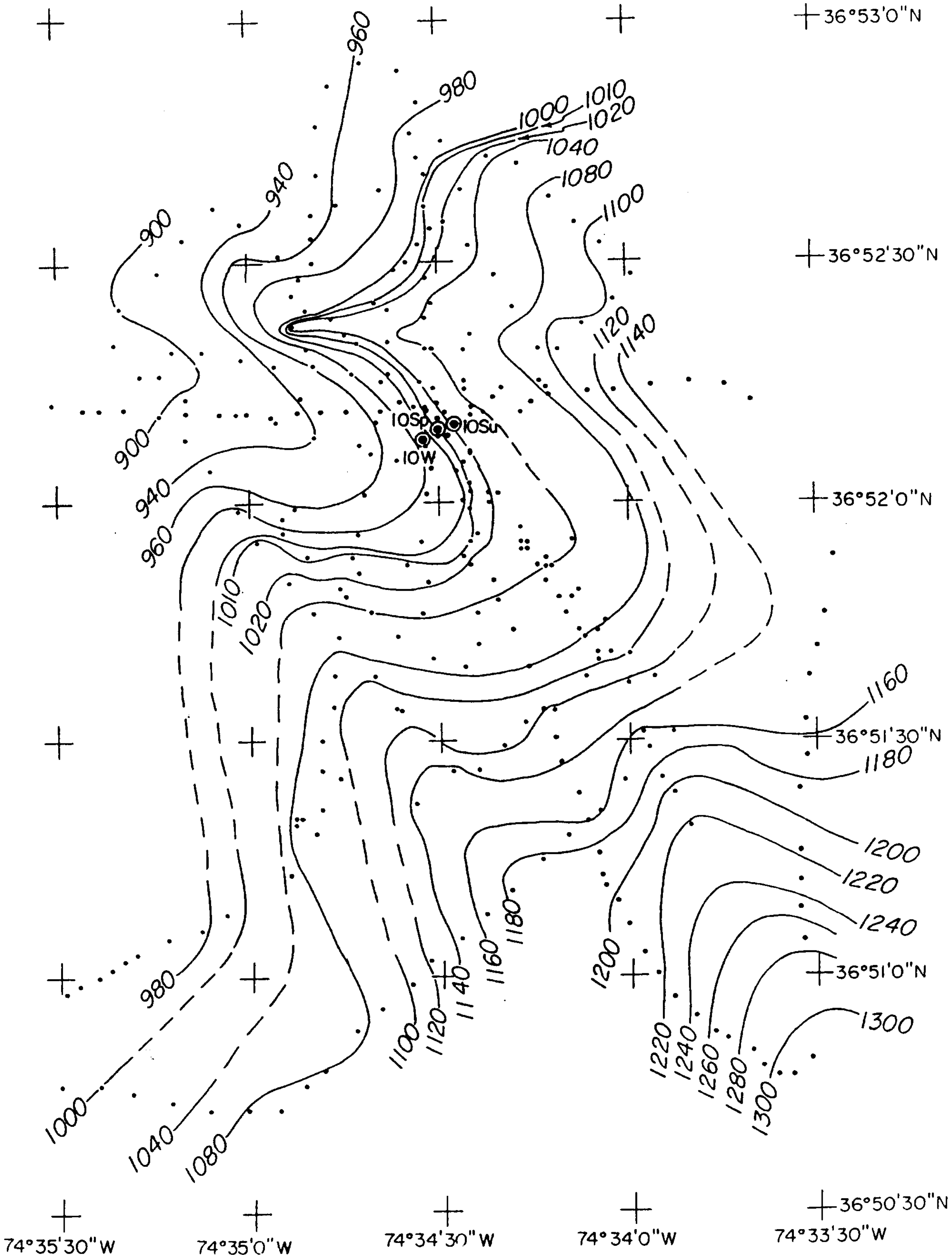


Table 2.1.3/1 - A

SEEP-II-SPRING -- MOORING LOCATIONS AND DEPTHS

Mrg #	Depth (cor m)	Latitude North Minutes & Secs/ Decimal Minutes	Longitude West Minutes & Secs/ Decimal Minutes
1	42	37° 52' 36.0"	074° 43' 53.8"
		37° 52.60'	074° 43.90'
2	60	37° 46' 06.7"	074° 29' 30.0"
		37° 46.11'	074° 29.50'
ADCP-2	60	37° 46' 09.1"	074° 29' 26.9"
		37° 46.15	074° 29.45
3	90	37° 41' 59.2"	074° 20' 21.2"
		37° 41.99'	074° 20.35'
ADCP-3	91	37° 41' 56.5"	074° 20' 19.1"
		37° 41.94'	074° 20.32'
4	90	37° 32' 27.3"	074° 26' 43.0"
		37° 32.46'	074° 26.72'
ADCP-4	90	37° 32' 31.2"	074° 26' 41.0"
		37° 32.52'	074° 26.68'
5	130	37° 39' 47.7"	074° 15' 50.9"
		37° 39.80'	074° 15.85'
ADCP-5	131	37° 39' 51.0"	074° 15' 48.0"
		37° 39.85'	074° 15.80'
6	400	37° 37' 54.6"	074° 12' 51.6"
		37° 37.91'	074° 12.86'
7	998	37° 37' 11.1"	074° 09' 51.8"
		37° 37.18	074° 09.86'
8	132	36° 52' 37.7"	074° 39' 02.5"
		36° 52.63'	074° 39.04'
9	407	36° 52' 04.4"	074° 37' 44.0"
		36° 52.07'	074° 37.73'
10	1001	36° 52' 08.8"	074° 34' 30.0"
		36° 52.15'	074° 34.50'

Table 2.1.3/1 B
SEEP-II-SUMMER -- MOORING POSITIONS AND DEPTHS

Mrg #	Depth (cor m)	Depth (uncor m)	Latitude North Minutes & Secs/ Decimal Minutes	Longitude West Minutes & Secs/ Decimal Minutes	Guard Moorings In Place
1	42	42	37° 52' 29.5"	074° 43' 54.2"	1Wh, 1Ye
			37° 52.49'	074° 43.90'	
2	-------------Abandoned to Scallop Fishermen-------------------				
ADCP-2	----------- Abandoned to Scallop Fishermen-------------------				
3	90	90	37° 41' 58.5"	074° 20' 21.7"	3Wh, 3Ye, 3Or
			37° 41.98'	074° 20.37'	
ADCP-3	91	91	37° 41' 58.1"	074° 20' 17.7"	
			37° 41.97'	074° 20.30'	
4	90	90	37° 32' 23.0"	074° 26' 44.5"	4Wh, 4Ye, 4Or
			37° 32.38'	074° 26.74'	
ADCP-4	90	90	37° 32' 25.8"	074° 26' 40.8"	
			37° 32.43'	074° 26.68'	
5	132	132	37° 39' 47.0"	074° 15' 43.3"	5Wh, 5Ye, 5Or
			37° 39.78'	074° 15.72'	
ADCP-5	131	131	37° 39' 48.6"	074° 15' 50.1"	
			37° 39.81'	074° 15.84'	
6	400	403	37° 37' 54.2"	074° 12' 52.4"	None (Lost)
			37° 37.90'	074° 12.87'	
7	998	1007	37° 37' 10.7"	074° 09' 51.6"	None
			37° 37.18'	074° 09.86'	
8	133	133	36° 52' 38.5"	074° 39' 00.0"	8Wh
			36° 52.64'	074° 39.00'	
9	417	420	36° 52' 05.0"	074° 37' 40.7"	9 Or
			36° 52.08'	074° 37.68'	
10	1011	1020	36° 52' 09.4"	074° 34' 28.2"	None
			36° 52.16'	074° 34.46'	

Table 2.1.3/1 - C

SEEP-II-WINTER -- MOORING POSITIONS AND DEPTHS

Mrg# (H = hang)	Depth (cor m)	Latitude North Minutes & Secs/ Decimal Minutes	Longitude West Minutes & Secs/ Decimal Minutes	Guard Moorings (*= VMCM)
1H	38	37° 47' 37.2"	074° 44' 36.0"	1Wh
		37° 47.62'	074° 44.60'	
2H	61	37° 34' 41.4 "	074° 35' 07.8"	2Wh*, 2Ye, 2Or
		37° 34.69'	074° 35.13'	
ADCP-2H	60	37° 34' 43.2"	074° 35' 10.2"	
		37° 34.72'	074° 35.17	
3	91	37° 41' 57.6"	074° 20' 16.2"	3Wh, 3Or*
		37° 41.96'	074° 20.27'	
ADCP-3	91	37° 41' 58.8"	074° 20' 14.4"	
		37° 41.98'	074° 20.24'	
4	90	37° 32' 25.8"	074° 26' 44.4"	4Wh*, 4Ye, 4Or
		37° 32.43'	074° 26.74'	
ADCP-4	90	37° 32' 28.2"	074° 26' 42.0"	
		37° 32.47'	074° 26.70'	
5	131	37° 39' 43.8"	074° 15' 46.8"	5Wh, 5Ye*
		37° 39.73'	074° 15.78'	
ADCP-5	131	37° 39' 46.8"	074° 15' 46.2"	
		37° 39.78'	074° 15.77'	
6	415	37° 37' 57.0"	074° 12' 46.2"	-
		37° 37.95'	074° 12.77'	
7	1000	37° 37' 10.2"	074° 09' 51.6"	-
		37° 37.17'	074° 09.86'	
8	135	36° 52' 38.4"	074° 38' 58.8"	-
		36° 52.64'	074° 38.98'	
9	427	36° 52' 08.4"	074° 37' 38.4"	-
		36° 52.14'	074° 37.64'	
10	985	36° 52' 07.8"	074° 34' 32.4"	-
		36° 52.13'	074° 34.54'	

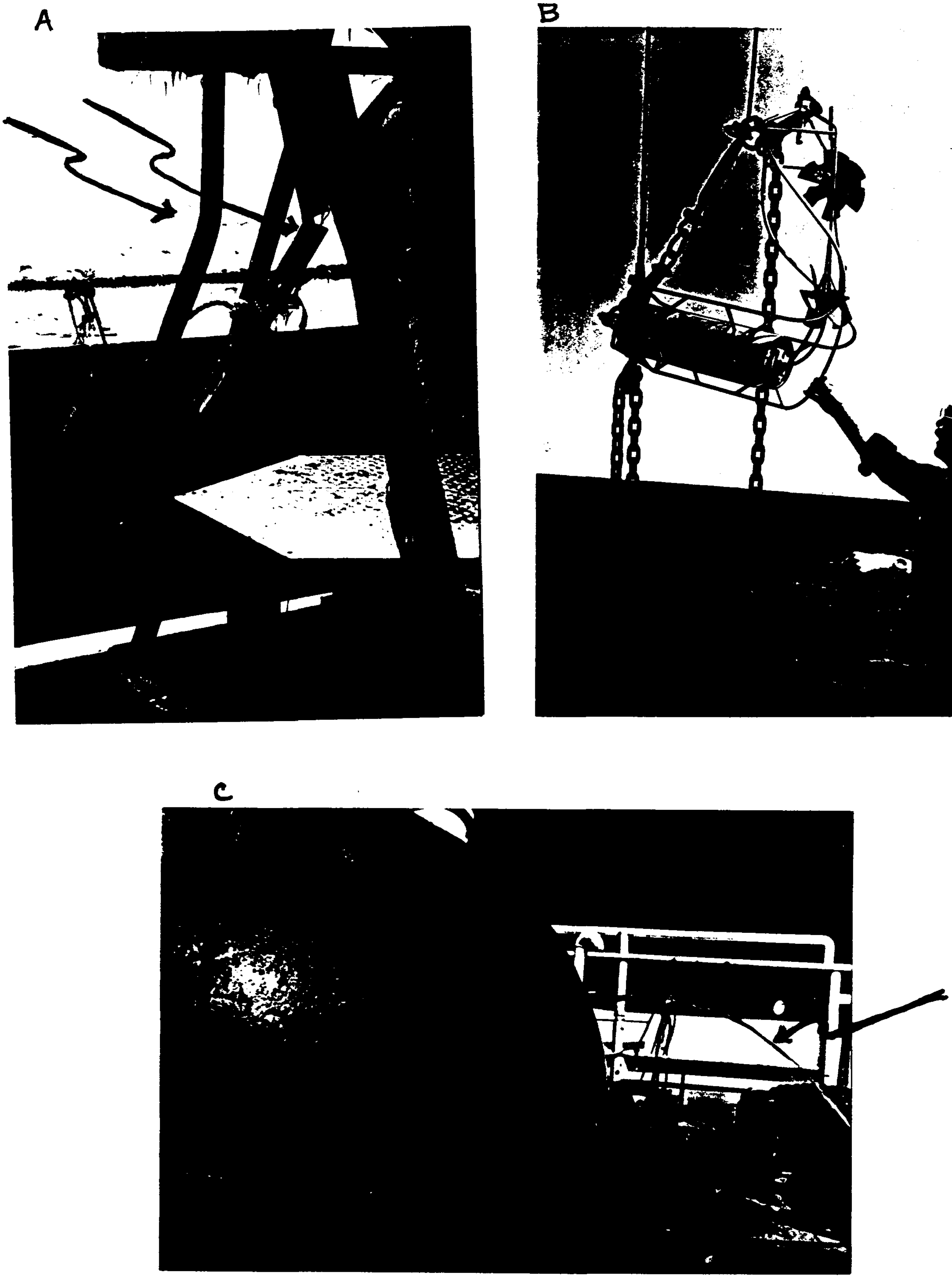


Fig. 2.1.3/6 Photographs of equipment damaged by fishermen and recovered by dragging:
A. Broken and bent legs (Aluminium L-bar) on ADCP frame
B. Bent VMCM frame and want
C. Seawater spurting from bullet hole in just-dragged-up guard buoy

Table 2.1.3/2
Instruments, Equipment Lost, Recovered and Damaged during SEEP-II

Equipment/Instrument	# Lost	# Recovered	Net # Lost
Guard Moorings	16	2	14
Glass Flotation Spheres	14	2	12
Acoustic Releases	3	3	0
Current Meters			
ADCPs	1	0	1
VMCM	5	2@	3
RCM-4, -5	2	1	1
Thermistor Chains	2	1	1
Flurometers	3*	1	2
Transmissometers	1*	0	1
Sediment Traps (0.074 m^2)	4	0	4
Long-Term Chemical Pumps	3	2#	1
Kemp Free Vehicle	1	0	1

@ One badly damaged
* Plus one each damaged/destroyed by explosion
# Both badly damaged by fishing gear

scallop bed, we abandoned that site for both the Summer and Winter deployments. And because of losses during both the Spring and Summer deployments at mooring site 1 (40 m) that site too was abandoned for the Winter deployment. (During the Spring deployment both guard moorings and the instrument mooring at 1 were cut, and during the Summer deployment, the instrument mooring was picked up from between the two guard moorings and moved 1/2 mile away, with damage to and loss of some, but not all, instruments).

The partial data set that had been acquired at sites 1 & 2 by some instruments before the moorings were cut, were considered of sufficient value to warrant redeployment at a different site of the same depth for the Winter deployment. For these two deployments we used the sites of known "hangs" to help protect the moorings from further damage. A "hang" is the location of a wrecked ship, plane or other obstacle on which some bottom fishermen has previously gotten his gear "hung up" and has reported the location to some agency. There are both informal and "official" compendia of these hangs, and we used one published by NOAA through the Sea Grant program at North Carolina (McGee and Tillett, 1983). Based on the Hang Guide and conversations with some fisherman and NMFS personnel, we selected a number of potential "hang" sites not too far from the North Transect and at approximately 40 and 60 m depth. During the bathymetric site surveys of these sites, and even during a commercial side-scan sonar survey for which we paid, we never saw an indication of the actual obstacle on the bottom. On the theory, however, that it is better to have the mooring where some (hopefully many, or all) of the fishermen think there is a hang and therefore avoid it, we chose alternate sites and these are referred to in Figs. 2.1.3/1, 2.1.3/4 B & D and in Table 2.1.3/1 as 1H and 2H.

Despite these losses and perturbations, the SEEP-II moorings overall were deployed for a total of 15 months, from February 1988 to May 1989 and recovered an impressive array of samples and data.

2.1.4. LDGO Sediment Traps.

The sediment traps used in SEEP-II were basically the same design (and the same actual traps) as had been used in SEEP-I. These had been based on a design by Ed Baker and Hugh Milburn of PMEL (Baker and Milburn, 1983) which we had scaled up by 225% to yield a small trap (0.071 m^2), capable of being hung anywhere on a mooring wire, with a time series capability in which a carousel containing 10 sample tubes rotated under an offset funnel. In this section we describe improvements that were made to these traps between the SEEP-I and -II experiments, and a larger trap that was built and tested during SEEP-II.

Reference is made in this section to baffles used in our traps. These are used both for the purpose of excluding "swimmer/feeders" (zooplankton and fish that might enter the trap and feed on some of the collected sample), and for the purpose of breaking up turbulent eddies that might enter the traps and also remove material already collected therein. A more thorough discussion of the "swimmer" problem and our response to it is given below under *2.2.1.2 Sample treatment -- laboratory; and the poison/preservative and swimmer problems*. The problem of poison and preservative is tied up with the swimmer problem.

2.1.4.1. Trap modifications. Subsequent to the SEEP-I experiment we began a program to improve the sediment traps we had used. The electronics of our SEEP-I traps were identical to those of Baker and Milburn (1983) and could be set to change samples over a wide range of intervals, but the sampling interval of each trap sample had to be identical. Thus, in SEEP-I the first (Winter) deployment had trap samples of 19 d duration each, and the second (Summer) deployment had a 17.5 d interval. We regarded this as a restrictive limitation and, because the microchip technology had advanced considerably over its status at the time the Baker and Milburn design was fixed, we decided to implement a new design with sampling intervals variable from sample to sample. This was done and implemented first in a prototype by Bob Luption, the LDGO Geochemistry Electronics Engineer, and was tested first as a piggyback experiment on the MASAR "B" (MMS) mooring (Fig. 1.2/1). Additional traps with the new electronics were piggybacked and tested on a subsequent MASAR "B" deployment, on two moorings under the Gulf Stream in the ONR-sponsored SYNOP experiment, and on a mooring in conjunction with Ed Baker on the axis of the Juan da Fuca Ridge. Most of these experiments returned good samples which, aside from showing that the traps worked properly (their chief function), have been useful in confirming the trend of increasing fluxes in proceeding southwesterly from SEEP-I to SEEP-II toward Hatteras (MASAR), and, for the SYNOP samples, providing data to help in thinking about an experimental plan for COMFS (the tentative name for the successor program to SEEP; see Proposal).

A second modification of the traps was relatively minor, but served to preclude a problem that had cost us a number of samples in the first SEEP-I experiment. Evidently because of material getting between the fixed and the rotating plates of the sample carousel, the carousel had jammed after variously different numbers of successful samples. Subsequent efforts of the stepping motors to rotate the carousel resulted in the torquing of the stainless steel drive shaft, almost, in some cases, to the point of breaking. To overcome this, new shafts were made from a different stainless alloy and were case hardened, and, rather than a flat washer under the locking nut (which determines the pressure between the fixed and rotating plates), a waffle washer was used to provide some give in case of potential binding. These too were tested in the MASAR and subsequent piggyback tests.

The third improvement of the traps was born of the same problem that led to the case-hardened drive shafts -- the jamming of the SEEP-I Winter series samples. When a time series sediment trap is recovered with other than a complete set of apparently valid samples (or, for the ultra cautious, even with a complete set of apparently valid samples), how can one be sure that the sample in each sample tube was actually collected during the programmed interval? How does one know for sure that the trap worked properly, and the samples represent the fluxes caught during the intervals they were supposed to? In SEEP-I when, on the recovery of the first (Winter) deployment, we only had 43% of the possible samples, we had nagging doubts, but, because of the nature and consistency of the failure, eventually became convinced that the traps had operated in the proper sequence until they became jammed. But since then we have had, for instance, a trap recovered with samples in the first several tubes, nothing in the next few, and then apparently good samples for the remaining tubes. What intervals do those samples and non-samples represent?

In view of the amount of time and money invested in each sediment trap and in each long-term trap deployment, we have devised a system to independently verify the functioning (or non functioning) of our traps. Four criteria that the design was to meet were that the system should: 1) be completely separate from the electronic control system so that there would be an independent record of what had happened in case of subsequent failure of the electronics system; 2) be based on a sensing of the actual rotation of the sample carousel, rather than on some electronic record that all the proper rotation signals had been sent and received; 3) be relatively simple; and 4) be inexpensive relative to the overall cost of the sediment trap and its use. This system was begun and tested during the later piggyback experiments between SEEP-I and -II

(MASAR, SYNOP, Juan da Fuca), and, by the SEEP-II Summer deployment, we had most of the bugs out of it and working properly.

The system is described in a paper in preparation for submission to Deep-Sea Research: "A System for Function Verification in Oceanographic Instruments" by Biscaye, but its operation is, briefly, as follows. Small magnets have been set into the rotating plate of the carousel between each sample tube, and a reed switch mounted adjacent to the edge of the rotating plate. When the carousel rotates, the reed switch senses the passing by of the magnet and sends a signal to an inexpensive camera inside a separate pressure case. The camera has a motorized film advance and a Data Back. The Data Back has a clock and can record on the film the LED image of the hour and minute or the year-month-day. Each rotation of the carousel thus yields a record on each successive film exposure of the date on which the rotation event actually occurred.

The first and second design criteria -- separate record and detection of actual sample changing -- were met. The third design criterion -- simplicity -- is certainly true in principle, and was certainly true on the bench top, but turned out to be more difficult to achieve in actual practice in the field. After a number of field tests, however, each of which revealed a minor glitch which was overcome in the next test, the system does turn out to work smoothly and, in fact, rather simply. The fourth criterion -- inexpensive -- may also be a matter of interpretation, but our system costs between 5 and 10% of the cost of the traps, and we think that that added expense is well worth the guarantee of really knowing when the samples were taken.

2.1.4.2 Large sediment traps. The biologists at BNL were responsible for the two "biology" cruises during SEEP-II which occurred during March 1988 (SEEP-II-02) and March 1989 (SEEP-II-09). Both were aimed at taking place during the spring bloom, and in 1988 they planned to do a lot of work -- primary productivity, phyto- and zooplankton work, nutrients, dissolved oxygen, etc. -- around mooring site 1 at which they were especially desirous of having vertical particle flux measurements. The SEEP-II mooring at site 1 had been in place for a month (and had not yet been destroyed by fishermen), but they wanted time series flux measurements on a much shorter time scale, i.e. daily or even diel sampling. They asked us to provide traps (and eventually asked us to provide the mooring) for a short term (<1 week) flux experiment. We had on hand a couple of back-up traps that had not been required for the Spring deployment, but, for such a short sampling duration, were concerned that our traps were too small.

We had previously contemplated building larger traps for short-term or low-flux deployments, but had not actually built any. We decided that it was important to try to get a large trap built and ready in time for the cruise, and to also use two of our small, back-up traps as a check. The large trap (36 in diameter or 0.65 m^2, compared to our standard 12 in diameter or 0.071 m^2) used a funnel cone identical to the one used by Peter Betzer (Betzer et al., 1984) which feeds into the same carousel as we use in the small traps (Fig. 2.1.4.2/1). The trap was completed in time for the cruise except that there was insufficient time to obtain the 36 in diameter piece of Hexcel baffle for the large trap. The trap did have the ~4 in diameter "flow spoilers" that Betzer uses, but we wanted to also use beneath it the same Hexcel baffle (cell size ~0.8 cm^2) as we use at the top of the 0.071 m^2 traps. So lacking the Hexcel we substituted the only thing we could obtain in time: we put a stainless steel mesh of grid size ~0.8 cm^2 underneath the layer of flow spoilers. This mesh performed the function of precluding entry by large "swimmers" and fish, but did not serve, as does the Hexcel, to break up turbulent eddies that would otherwise enter the trap. The flow spoiler breaks up eddies of the scale of several inches, but we wanted the same smaller scale baffling effect that we have in the small traps.

The mooring was deployed for five days and each of the traps -- one small trap 6 m above and the other 7 m below the large trap -- sampled 10 twelve-hour samples. The samples changed at 0600 and 1800 hrs each day in order to provide alternate "daylight" and nightime samples. All three traps worked properly except that the large trap did not collect on the order of 9 times more material than the small ones. The ratio was ~1-4 compared to the upper trap, and <<1 compared to the lower trap. Even allowing for the fact that, in only 42 m of water, there was a large vertical gradient in particle flux due to resuspended sediment in the near-bottom trap, the large trap clearly undertrapped compared to the small ones. Our hypothesis for this undertrapping was the absence of the Hexcel in the large trap.

To test this hypothesis and to further test the large traps, we constructed a second large trap and deployed both -- one with the Hexcel baffle and the other with only the stainless anti-swimmer grid -- directly underneath a small trap during the Summer and Winter deployments. The three traps, each separated by 22 m, were put in the middle of Mooring 7 where vertical flux gradients were expected to be

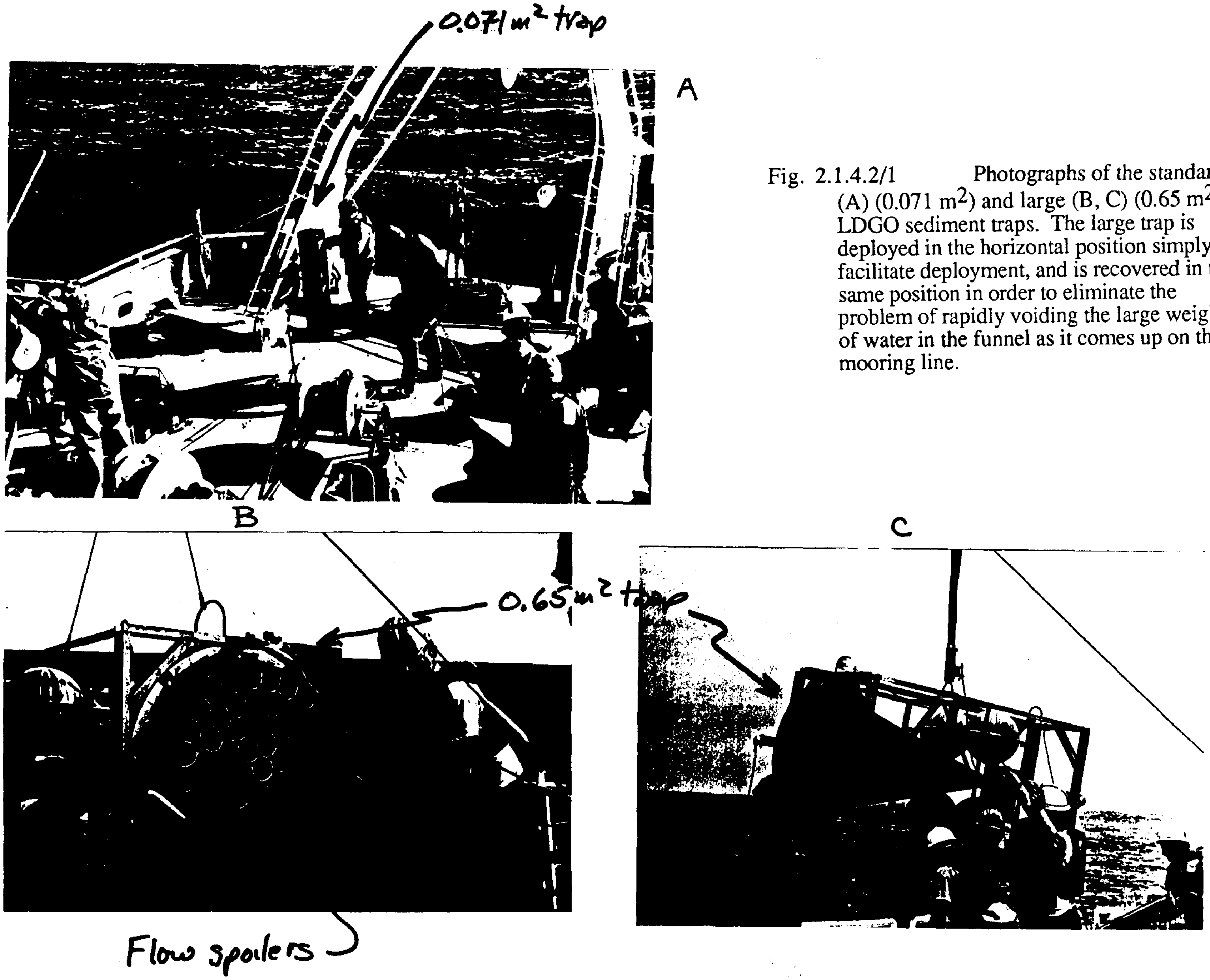


Fig. 2.1.4.2/1 Photographs of the standard (A) (0.071 m^2) and large (B, C) (0.65 m^2) LDGO sediment traps. The large trap is deployed in the horizontal position simply to facilitate deployment, and is recovered in the same position in order to eliminate the problem of rapidly voiding the large weight of water in the funnel as it comes up on the mooring line.

minimal. In both deployments the small, "standard" trap and the large trap with Hexcel operated perfectly, but the large trap without the Hexcel did not rotate properly (almost the only trap to have any problem). The samples from these traps have not yet been picked of swimmers and weighed to yield the true mass flux, but, comparing the height of the material in the sample tubes, the large trap with Hexcel did in fact collect approximately 9 times more material in each of the same sampling periods than did the small trap. Unfortunately we do not have the results from the trap lacking Hexcel to see if it (again) undertrapped with respect to the small (or the other large) trap. But at least it appears that the large and small traps collect proportionately comparable fluxes of vertically sinking material. Besides getting accurate mass fluxes on both the large and small traps, there are a number of other variables that will have to be tested for comparability between the two trap sizes, e.g., concentrations of radionuclides, carbon, nitrogen, opal, carbonate etc., but none of these data are available at this writing.

2.1.5. LDGO Transmissometers.

Transmissometers were used in SEEP-II to obtain a measure of fine-grained suspended particulate matter (SPM) in two modes: as moored, time-series instruments; and as a vertically profiling instrument from shipboard. As was the case for the current meters, the transmissometers used in the experiment were the property of two institutions, one of which was LDGO in each case. In all cases the instrument used was the 25 cm path length Sea Tech transmissometer. In the same spirit of an integrated, single experiment, the moored transmissometers were pooled and their distribution determined mutually by BNL (Dr. Creighton Wirick) and by us. Thus, our 4 transmissometers were dispersed throughout the moorings (see Fig. 2.1.3/2), in some cases used in tandem with the BNL fluorometers. (In fact one of the LDGO transmissometers, deployed in the cage transverse to a BNL fluorometer, was severely damaged by an explosion of the fluorometer batteries. The explosion stripped the end-cap bolts from their tapped holes in the fluorometer pressure case and drove the end-cap mechanism broadside into our transmissometer with sufficient force to bend and break the transmissometer frame.

With the exception of this damaged transmissometer, all four of the LDGO Sea Tech transmissometers were deployed and recovered intact three times.

Besides the moored, time-series mode, LDGO transmissometers were used throughout SEEP-I and -II in conjunction with the CTD/profiling fluorometer/profiling oxygen probe as an instantaneous indicator of the distribution of SPM. The transmissometer used in the shipboard, profiling mode in SEEP-I was the 100 cm-path length Sea Tech instrument. In preparation for SEEP-II, we needed to check out this instrument in the field, and used it, as in SEEP-I, on the BNL CTD/fluorometer rosette package on a test cruise on Endeavor in the spring of 1987. This was the cruise on which Charlie Flagg and Sharon Smith were working around a bottom-moored ADCP with CTD and plankton tows to calibrate the ADCP in terms of biomass, and on which the CTD package was to-blocked by an inexperienced seaman and the whole thing lost, including our 100 cm transmissometer. We spent several hours at the end of two different SEEP-II cruises dragging for the lost CTD, but with no success.

During SEEP-II we used a 25 cm path length Sea Tech as the profiling instrument, as Bob Bartz of Sea Tech insists that the new 25 is just as sensitive as the old 100, and, in any case, refused to build another 100 cm instrument (even after quoting us a usurious price, which we said we would pay.) The CTD/trans/fluor/ox system was used to define the hydrographic, SPM, chlorophyl and dissolved oxygen characteristics of the SEEP-II study area during all but two of the SEEP-II cruises; there were not sufficient trained personnel to run the system during the two NSF-sponsored sediment-interface/-coring cruises. There are thus data sets of vertical SPM profiles (in the context of CTD, fluorometry and dissolved oxygen) for eight cruises from which seasonal "snapshots" of the areal distribution of SPM can be constructed: February; two in March (1988 and 1989); May; two in June (1988); October; and November.

2.1.6 Sediment Cores

It is essential to include a study of the sediments in the SEEP-II region for two principal reasons. First it permits us to complete mass budgets for fine-grained particulate matter, organic carbon, radiotracers, and associated substances of interest to DOE in the study area. Second, we need some means of verifying that the mass fluxes of particulate matter and associated substances collected with sediment traps accurately measure the true delivery of these substances to the sea floor. Valid concerns about the reliability of the operation of sediment traps exist (Knauer and Asper, GOFS, 1989). Comparing the average annual flux of a naturally-occurring radiotracer, ^{210}Pb, with the mean flux required to support its standing inventory in the sediments is a straightforward approach to identify any biases in the trap fluxes that might occur, for example, through the collection of locally-resuspended sediments.

SEEP investigators are addressing several important questions regarding the ocean's role in the global carbon cycle. Some of these include: What percentage of the ocean's primary productivity occurs in coastal waters? How much of the organic matter fixed by this coastal productivity is physically transported offshore into deep waters, rather than being recycled (remineralized) within the coastal zone?, and finally, What is the fate of that portion of the organic matter carried offshore? The high organic carbon content of upper slope sediments at around the 1000-m isobath led to the hypothesis that much of the organic matter produced in shelf waters is buried on the upper slope. Alternatively, most of the organic matter delivered to the slope region could be remineralized there. Only through a quantitative examination of rates of carbon burial and remineralization in slope sediments could we address this question, and thereby complete a mass budget for organic matter in the shelf-slope system.

Due to financial limitations, sediment studies were not funded by DOE. Proposals were submitted to NSF to cover this portion of the work in the overall SEEP-II program. Both the reviewers and the program managers at NSF recognized the importance of the sediment component of the carbon budget, and the proposals (Anderson and Biscaye at LDGO; Rowe at TAMU) were funded. Dr. P. Kemp at BNL is the third major collaborator in the sediment component of the SEEP-II experiment. Although most of the sediment work is not directly supported by DOE, it is an integral and essential part of the overall SEEP-II program, and hence a discussion of it is included in this report and the accompanying proposal.

Two coring cruises were included in the SEEP-II program: Endeavor 179 in June, 1988 (SEEP-II-04) and Endeavor 187 in October, 1988 (SEEP-II-07). Cruises were scheduled to occur just after the spring bloom and then following the summer period of water column stratification, which was observed in the SEEP-I experiment to be a time of relatively low flux of organic matter and other forms of particulate matter. One objective was to see if there was a measurable seasonality in the rate of benthic respiration in response to the anticipated strong seasonality in supply of organic matter. Seasonality would be most evident in the oxygen flux measurements made by Rowe and in the microbial metabolism rate measurements made by Kemp, but the distribution of organic carbon in cores from both cruises is also being examined for evidence of a seasonal component to the organic carbon distribution in the upper sediment column.

Coring operations included collection of several types of samples. Grab samples were collected first, especially at the shallower sites, to give us an immediate indication at sea of the sediment composition. Box cores were collected along both SEEP-II transects, from which we measured/are measuring: 1) the distributions of biogenic metabolites in the pore waters, 2) detailed distributions of organic carbon and $CaCO_3$ in the upper sediment column, and 3) radionuclide tracers to provide mixing rates needed to calculate organic matter consumption rates within the upper sediment column (^{210}Pb, $^{239+240}Pu$) and to provide a means of validating sediment trap fluxes (^{210}Pb). Samples from gravity cores collected along both transects will be analyzed for ^{14}C, organic carbon, and $CaCO_3$ to provide long-term carbon accumulation rates for the study region. Lists of the sediment samples collected during these cruises are presented in Tables 2.1.6/1 an 2.1.6/2. Many additional grab samples were collected which are not listed in the tables.

2.2 Analytical Work and Data Reduction.

The first samples and data (from the Spring deployment) came back to Lamont beginning in June 1988; the second increment (Summer deployment) in October 1988; and the last samples (Winter deployment) in May 1989. As indicated below under *2.2.1.2 Sample treatment -- laboratory; and the poison/preservative and swimmer problems.*, an enormous amount of time and man hours have been, and are being expended in preparing the samples for all of the analyses that must be done. So most trap samples have not had much done to them in the line of analyses, but we did select three traps for immediate picking and analysis of the short-lived isotope ^{234}Th and many of the other major component analyses. In this section we summarize the status of our knowledge of SEEP-II from these early analyses and other preliminary indications.

2.2.1 Sediment Trap Samples

As indicated above, not all of the standard (0.071 m^2) LDGO traps deployed were recovered, and, of those recovered, a few had sample tubes lacking samples, because of failure of the carousel to make the final rotation, or for whatever reason. Thus, although we recovered a total of 550 trap samples of all kinds, durations and sizes during SEEP-II, preliminary results from the "standard" array of 17 traps x 10 samples/trap x 3 deployments is what we are primarily reporting here (see Fig.

Table 2.1.6/1. Sediment Cores Collected from the Upper Slope of the Middle Atlantic Bight- Endeavor Cruise 179 (SEEP-II-04)

Core	Depth (m)	Latitude (°N)	Longitude (°W)	Comments
BC1	417	37°37.97'	74°12.81'	Hard clay at 33cm
BC2	892	37°37.48'	74°09.95'	Total recovery 56cm
BC3	1031	37°38.36'	74°08.57'	Total recovery 47cm
BC4	1318	37°31.74'	74°02.26'	Total recovery 38cm
BC5	384	37°37.81'	74°13.06'	Total recovery 34cm
BC7	1989	37°25.06'	73°49.41'	Total recovery 34cm
GC2	1034	37°37.86'	74°09.09'	Total recovery 255cm
GC7	402	37°38.07'	74°12.85'	Total recovery 140cm

Cores BC6, GC1, and GC3-GC6 were not successfully recovered.

Table 2.1.[illegible]2. Summary of Sediment Sampling on Endeavor Cruise 187 (SEEP-II-07).

Station	Water Depth (m)	Latitude (N)	Longitude (W)	Activity/ Comments
1	132	37°37.89'	74°15.59'	Shipek Grab #1
1	195	37°38.77'	74°14.40'	BC#1A/ No Trip
1	265	37°38.06'	74°12.25'	BC#1B/ 40cm, sandy
2	63	37°45.42'	74°29.28'	Shipek Grab #2
2	60	37°45.13'	74°28.86'	BC#2A/ No Trip
2	60	37°45.13'	74°28.86'	BC#2B/ 20cm, sand, high bio density
3	52	37°47.29'	74°36.41'	Shipek Grab #3/ high density of fauna
4	410	37°38.11'	74°12.92'	BC#3/ Good Core
4	402	37°37.89'	74°12.90'	GC#1/ Short; sand-clay unconformity
4	426	37°37.33'	74°13.30'	BC#4A/ No Trip
4	512	37°37.33'	74°13.85'	BC#4B/ Good Core, 50cm
5	770	37°37.33'	74°11.59'	GC#2/ Good Core, nearly 3m
6	1045	37°37.05'	74°10.03'	BC#5/ Good Core, 50cm
6	1015	37°37.15'	74°09.76'	GC#3/ Good Core, 2.5m
7	2000	37°24.01'	73°49.69'	BC#6/ Good Core, 45cm
7	2090	37°24.64'	73°50.34'	GC#4/ Good Core, 2.8m
8	980	36°52.03'	74°34.51'	BC#7/ Good Core but lost on deck
8	1020	36°52.00'	74°34.38'	BC#8/ Slight overpenetration Interface salvagable
8	990	36°52.19'	74°34.65'	GC#5/ Overpenetrated 10-foot barrel by 70cm
8	1165	36°52.20'	74°33.84'	BC#9/ Good Core, 47cm
10	580	36°52.45'	74°36.77'	BC#10/ Good Core, 52cm
11	1125	37°02.30'	74°34.26'	BC#11/ Good Core, Norfolk Canyon, High H_2S
11	1180	37°02.46'	74°34.18'	GC#6/ Good Core, 2.5m, H_2S, CH_4 outgassing (?)

2.2.1/1). This consists of 490 samples: 17 x 10 x 3 = 510 less 20 lost as entire traps and individual samples = 490.

2.2.1.1 Sample treatment -- shipboard. As soon as sediment traps were recovered aboard ship, the carousel with its sample tubes were removed, photographed, put in large plastic bags and stored in the walk-in refrigerator at 2° C until they could be described -- generally that same evening.

Processing consisted of recording several of the more obvious characteristics of each sample -- height in tube (which, until the samples are weighed, when normalized to sampling interval is the first approximation of particle flux), color, relative abundance of several visible kinds of fecal pellets, relative abundance of the various swimmers, etc. After gentle shaking to homogenize the sample, an aliquot -- generally 10 ml, which is about 6% of the total sample -- is taken, another aliquot of formalin is added, and the sample is stored under refrigeration. This aliquot constitutes the archive of the original sample, and it is on further aliquots of this sample that certain studies requiring original, wet sample are done, e.g., fecal pellets, phytoplankton, bacteria, etc.

The remaining sample is decanted into a plastic sample jar (using several ml of filtered sea water for the final rinse of the sample tube), marked, taped, and stored under refrigeration. During SEEP-I this major portion of the sample was frozen until processed in the laboratory, but, with the decision to pick out the swimmers rather than to filter them out, freezing had to give way to refrigeration so as to preserve the swimmer bodies as much as possible.

Samples were transported to the laboratory under refrigeration and kept cold until the initiation of laboratory processing.

2.2.1.2 Laboratory sample treatment and the

poison/preservative and swimmer problems. The great value of time-series sediment traps is that, as moored instruments, they are directly sampling the vertical particulate flux at pre-set intervals for long periods of time during which time they are not costing ship time or anything else (except perhaps some anxiety). The disadvantage of this remote, long-term capability is that the samples constitute a magnificent potential lunch for zooplankters and their superiors in the food web, and also for the bacteria that are so ubiquitous in the marine environment. These predators of our samples at both ends of the size spectrum require guarding against, and, to date no one in the trapping community has come up with a good way to

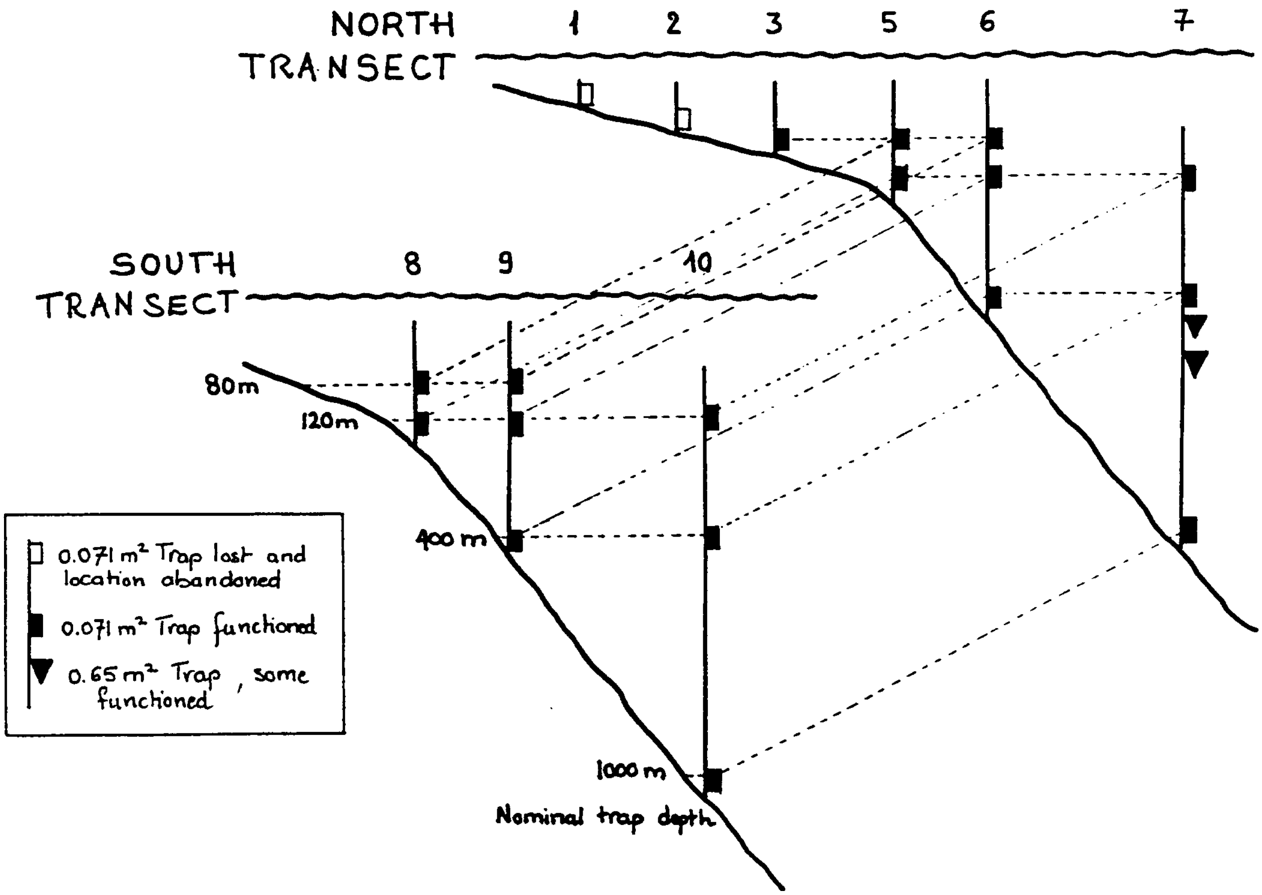


Fig. 2.2.1/1 Schematic distribution of LDGO sediment traps between the North and South transects, and their nominal water depths.

do either. An NSF-sponsored workshop was held last November in Mississippi under the aegis of GOFS and the status of the swimmer-poison-preservative problem was thoroughly bemoaned and discussed, and the report of that workshop (Knauer and Asper, GOFS,1989) has recently been published.

That workshop report goes into the problems and the varied responses to them in much greater detail than is necessary here, but the problem and our responses to it in SEEP-II is as follows. If unguarded, swimmers can enter a trap, consume part of the sample, and leave -- with or without leaving at least a fecal pellet or two to make up for what they have eaten. If guarded against by means of baffles, the lower limit of the mesh size required would quickly clog and prevent the trapping of anything. So we use "reasonable" mesh size baffles and poison the traps, killing any predators that enter, thereby preventing them from eating our sample, but yielding the horrendous job of physically separating these dead "swimmers" from the passive, true vertical flux. Our response to this in SEEP-I was perhaps a bit naive and driven by the enormity of the job of picking out swimmers. Faced with about 250 samples, we opted to sieve the samples at 1 mm and to operationally define as proper, "passive flux" anything that passed through the filter, and as "swimmers" anything that did not. Studies elsewhere throughout the oceanographic community, however, have demonstrated that this method, previously used as well as by other investigators operating sediment trapping programs, is inadequate. The only reliable, and hence acceptable, procedure for removing swimmers is through the extremely tedious and time-consuming process of picking them out by hand one at a time, even though we have more than twice as many samples as in SEEP-I.

This requires a dedicated and highly skilled technician who can not only recognize zooplankton, but also physically remove them from the jumbled mass of biogenic and lithogenic debris collected by sediment traps while viewing the whole operation under a microscope.

Our Senior Staff Associate, Adele Hanley, was trained in Sharon Smith's zooplankton laboratory and has undertaken the job of picking the swimmers from each of the samples. Because of the potential for subjectivity in the job, it is best for only one person to do the job since, at least all samples will be picked more identically than if more than one person undertakes it. At this writing Adele has picked about 300 samples in the 16 months since the first samples were returned, and there is still more than a man-year of picking left to do (if she were to do nothing else, which we won't allow since we don't want to drive her crazy). This picking process is absolutely essential to the success of the SEEP-II project. This is most important for our studies of carbon transport and deposition because, obviously, the zooplankton corpses would contribute significantly to the total mass of organic carbon collected by the sediment traps. We have no choice but to perform the tedious picking procedure, which therefore means that most of the other analytical work that could have been done during this time has to be postponed.

So, besides an approximate doubling of the samples in SEEP-II, more than two man-years of sample preparation time has been added by the problem of picking swimmers from the samples.

We recognize the possibility that picking, rather than sieving, swimmers may render some of our SEEP-II results less comparable to those from SEEP-I, but there are still other problems, plus we cannot continue an outmoded procedure simply for the sake of comparability.

The problem at the other end of the spectrum -- bacterial degradation -- has also been a source of concern. Based on the advice of Dr. Susumo Honjo of Woods Hole, who, prior to SEEP-I had probably recovered more sediment trap samples than anyone else, we used sodium azide as an anti-swimmer poison/anti-bacterial preservative. That poison/preservative had worked to some extent in SEEP-I and, based on that experience and the desire for intercomparability of the two sample sets, we began SEEP-II using sodium azide to poison the traps. During the first deployment, however, as a result of conversations with other sediment trappers and including the GOFS initiative, we made the decision to pick the swimmers, and became convinced that formalin was a sufficiently better preservative than azide, that we decided to switch to formalin for the second (Summer) and third (Winter) deployments. The negative factor of changing horses in mid stream was mitigated by the fact that the Winter deployment was designed to last through the 1989 spring phytoplankton bloom. So, if the first (Spring) deployment turned out to be seriously not-comparable to the subsequent ones, we would still have a sample record that covered 11 months and included a spring bloom. We chose the formalin recipe used by George Knauer and which seemed to be on the way to becoming the GOFS standard recipe. The SEEP-II traps were therefore deployed with a oversaline, filtered sea water in the sample cups in which was dissolved 10% sodium azide for the Spring deployment, and 2% buffered formalin for the Summer and Winter deployments.

Work done to date on both the swimmer picking and on the study of SEEP-II fecal pellets (see Section *2.2.1.6*) confirms the superiority of the formalin over the azide for both activities.

2.2.1.3 Summary of Planned Analyses. It was clear from the beginning of the SEEP-II experiment that we could not begin to complete all of the desired analyses of sediment trap samples during the 3-year funding period covered by the present grant. Most of our resources were committed to carrying out the field program, and now we have the added burden of picking the swimmers from the samples.

Having recognized that only limited numbers of samples could be processed during the present funding period, but also recognizing the need to begin our study of the transport and cycling of particulate organic matter and related substances, we selected three (out of ~20) traps for which we will try to complete the principal chemical and radiochemical analyses during the present funding period. Three traps, with 10 samples from each trap collected during each of three deployments, is a total of 90 samples. Analysis of these samples is itself not a small task, except in relationship to the herculean effort which will be required to process and analyze the entire set of 522 SEEP-II sediment trap samples.

The three trap positions selected for this preliminary study are located at Moorings 8 and 10 (Fig.2.1.3/1). These trap positions were selected to give us the maximum information about the transport and fluxes of particulate matter at critical locations with the minimum number of analyses. The critical locations, and the processes of interest associated with them, include the transport of particulate matter off the shelf to the slope region (Mooring 8, Trap 13), the flux of particulate matter out of the photic zone in the slope region (Mooring 10, Trap 17), and the deposition of particulate matter around the 1000-m isobath previously recognized to be a zone of high organic carbon accumulation (Mooring 10, Trap 19).

Results to be obtained for these 90 samples during the present funding period include: total mass fluxes, as well as concentrations and fluxes of organic carbon, $CaCO_3$, opal, $^{210}Pb/^{210}Po$, and ^{234}Th. The general procedure for processing the sediment trap samples is as follows. Once the zooplankton swimmers have been removed, the particulate matter is concentrated by centrifugation. Either the entire sample, or an aliquot of the sample, depending on sample size, is centrifuged into a small plastic tube which fits tightly into our well-type germainium detector. Samples are gamma counted for 1 - 3 days to measure the activities of ^{210}Pb and ^{234}Th. Following gamma counting, the particulate matter is removed from the tube and filtered onto a preweighed Nuclepore filter. The filter is dried and reweighed to obtain the dry weight of the particulate matter, from which fluxes collected by the sediment traps are later calculated. Gamma spectra are reduced after dry weights have been obtained. Nuclide activities (dpm/g) are calculated from the gamma spectra using the measured dry weights as well as appropriate geometry corrections for the size of the sample in the counting tube. After weighing, the dried particulate matter is ground and stored for later chemical analysis.

Five to 10 mg of sample are analyzed for ^{210}Po by isotope dilution with ^{208}Po and alpha spectrometry. One to 2 mg of sample are analyzed for total carbon and nitrogen using a Carlo Erba elemental analyzer. An additional 2-5mg are similarly analyzed following the addition of sulfurous acid to remove $CaCO_3$, which provides a measure of the organic carbon content. The $CaCO_3$ content is calculated from the difference between total carbon and organic carbon. Opal contents are measured by colorimetric determination of silica following an alkaline leach of 2-5 gm of sample.

Other analyses proposed for funding in future years include measurement of longer-lived radionuclide tracers by alpha spectrometry and/or mass spectrometry (see proposal) and analysis of selected major and minor elements by plasma spectrometry. Major element analysis will provide us with a measure of the aluminosilicate content of the samples (Al, Ti), an estimate of the oxyhydroxide coatings of the particulate matter thought to be an important factor in the scavenging of particle-reactive trace elements from the ocean (Fe, Mn), and an independent estimate of the $CaCO_3$ content of the samples (Ca). Determining the aluminosilicate content of the samples is of interest for two reasons. First, these inorganic phases are thought to play an important role in the chemical scavenging (removal) of certain particle-reactive elements from the ocean. Many of the radioactive tracers we are measuring are good chemical analogs of pollutant substances of concern to DOE. One of our objectives is to determine the relative importance of aluminosilicates, oxyhydroxide coatings of particles, and biogenic particle phases as scavenging agents for particle-reactive substances in ocean-margin regions. Second, it has been observed that the removal of aluminosilicate phases from open-ocean waters occurs largely through their incorporation into large, rapidly-settling biogenic aggregates of particulate matter. The extent to which this process also controls the removal of aluminosilicates from coastal waters is largely unknown. Our study of the associations among the various biogenic and inorganic particulate phases will address this question.

Evaluating the use of minor elements, such as Ba, Cu, Zn and I, as proxies for organic carbon is of widespread interest today. These minor elements are fixed from seawater in association with organic matter, although the exact mechanism by which these minor elements become associated with particulate phases remains unknown in most instances. The advantage provided by these proxies is that they may remain behind with refractory particulate phases long after the labile organic phases have been remineralized. There is widespread interest in determining how oceanic productivity has responded to changing climatic forcing factors. Past ocean responses to climate change are used to test and evaluate models being constructed by a number of national and international groups to predict future oceanic response to climate change, particularly in regard to the impending Greenhouse effect. The record of past oceanic responses to climate change is contained in marine sediments but, unfortunately, direct evidence for changes in ocean productivity in the form of particulate biogenic phases is often absent due to remineralization of these labile biogenic materials. Some of these proxy indicator elements are much more refractory than the organic phases and remain behind in the sediments. It is hoped that their distribution in sediments will provide a quantitative record of past ocean productivity that can be correlated with indicators of climate change that are also contained in the sediments (e.g., ^{18}O content of $CaCO_3$ tests). While it is clear that a relationship exists between organic matter and these minor elements, the exact nature of the relationship has not been established quantitatively. Further studies are needed to determine whether the proxies are most strongly related to total primary productivity, to new production, to the total particulate organic carbon content of settling particulate matter, or to some other aspect of the particulate organic carbon cycle. This relationship needs to be established before proxies can be used to evaluate past changes in ocean productivity.

A major program on the west coast called MULTITRACERS has been funded by NSF to examine the relationship between these minor element proxies and the production and flux of organic carbon. This program will examine the relationship between each proxy element and the particulate organic carbon flux in time series sediment trap samples collected along a transect off the coast of northern California. We intend to make a similar comparison between the fluxes of organic carbon and three of these proxies (Ba, Cu and Zn) in the SEEP sediment trap samples. Analysis of our samples for Al, Ti, Fe and Mn by plasma emission allows us to obtain the minor element results as well for only a little extra analytical effort. If useful relationships between the proxies and organic carbon are discovered, then it will be important to determine the extent to which they apply over large geographic regions. Comparing results from the

Pacific and Atlantic coasts of the U.S. will be an important first step in establishing this. This work will not only be of interest to DOE, but will be of value to other aspects of the Global Climate Change initiatives which address the response of the ocean to climate change as well as its role as an initiator or modifier of climate change.

2.2.1.4 Mass Fluxes. We have, to date, obtained dry weight mass fluxes and ^{210}Pb (^{210}Po) activities for the 90 priority sediment trap samples. ^{234}Th activities have been measured in as many samples as could be processed for this short-lived nuclide (half life = 24 days) before its activity decayed to unmeasurable levels. We have observed little disequilibrium between ^{210}Pb and ^{210}Po so, for this discussion, we will refer to the results as ^{210}Pb activities regardless of whether ^{210}Pb or ^{210}Po was actually measured. The major important features of the results will remain unchanged by interpreting preliminary ^{210}Po activities to be representative of ^{210}Pb activities. By the end of the project we will have both ^{210}Pb and ^{210}Po activities for each of the 90 samples. Analysis of the 90 sediment trap samples for total carbon and organic carbon began late in September, but no results are yet available to include in this report. Opal analyses will be completed during this funding period. These results will enable us to make some important preliminary conclusions about: 1) the organic carbon budget for the SEEP-II region, 2) the processes responsible for transporting particulate matter off the shelf into the slope region (in collaboration with SEEP physical oceanographic studies), and 3) the processes responsible for scavenging of particle-reactive pollutant-like elements fom ocean-margin regions. However, the complete benefits from this project will require that all of the time-series sediment trap samples be analyzed. This is the principal focus of the accompanying proposal.

Higher mass fluxes occurred at the shelf break (Mooring 8, Trap 13) during the spring than during the summer (Figure 2.2.1.4/1), but these seasonal changes were overwhelmed by the massive fluxes collected at this site during the winter deployment (Figure 2.2.1.4/2A). Radionuclide results suggest that the peak fluxes collected at this position during the winter of 1989 consisted largely of resuspended sediments (see below). Mass fluxes collected at a comparable water depth out at the 1000-m isobath (Mooring 10, Trap 17) were also higher during the spring than during the summer (Figure 2.2.1.4/2B). The winter deployment sampled one brief major flux event at this position which peaked approximately 2 weeks (one time-series sample interval) after the flux event at Mooring 8 (compare A and B panels of

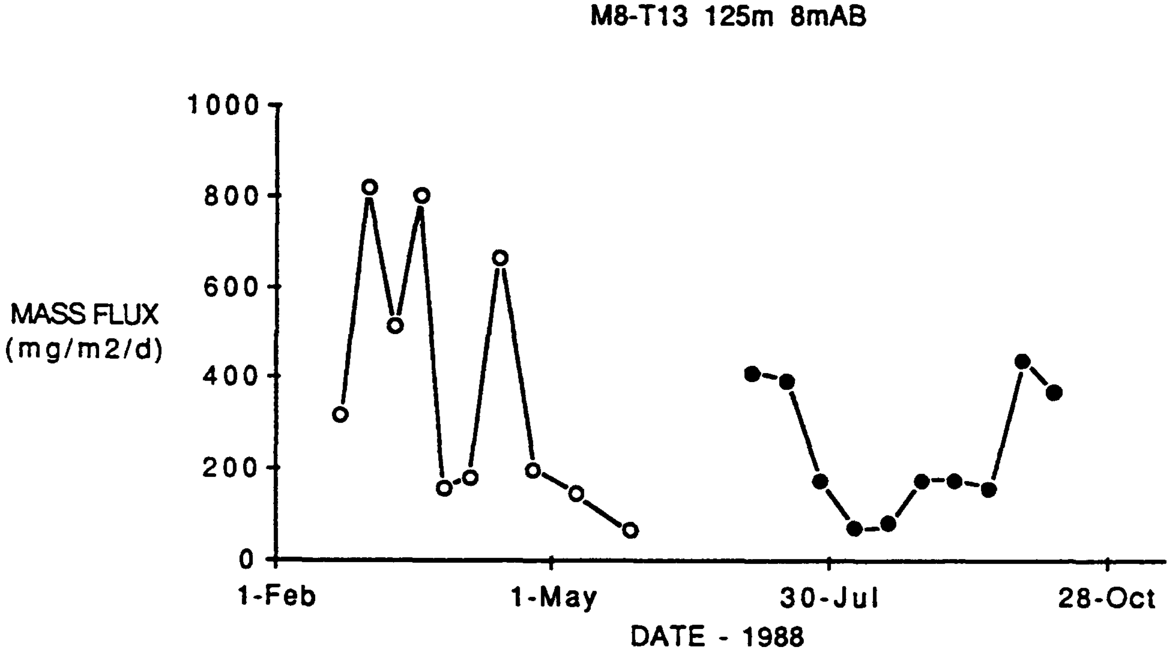


Fig. 2.2.1.4/1. Mass fluxes collected by a sediment trap positioned 8m above bottom at SEEP-II Mooring 8 near the shelf-slope break on the South transect. Results are shown here on an expanded scale compared to Figure 2.2.1.4/2 so to permit visualization of flux variability during the spring and summer deployments.

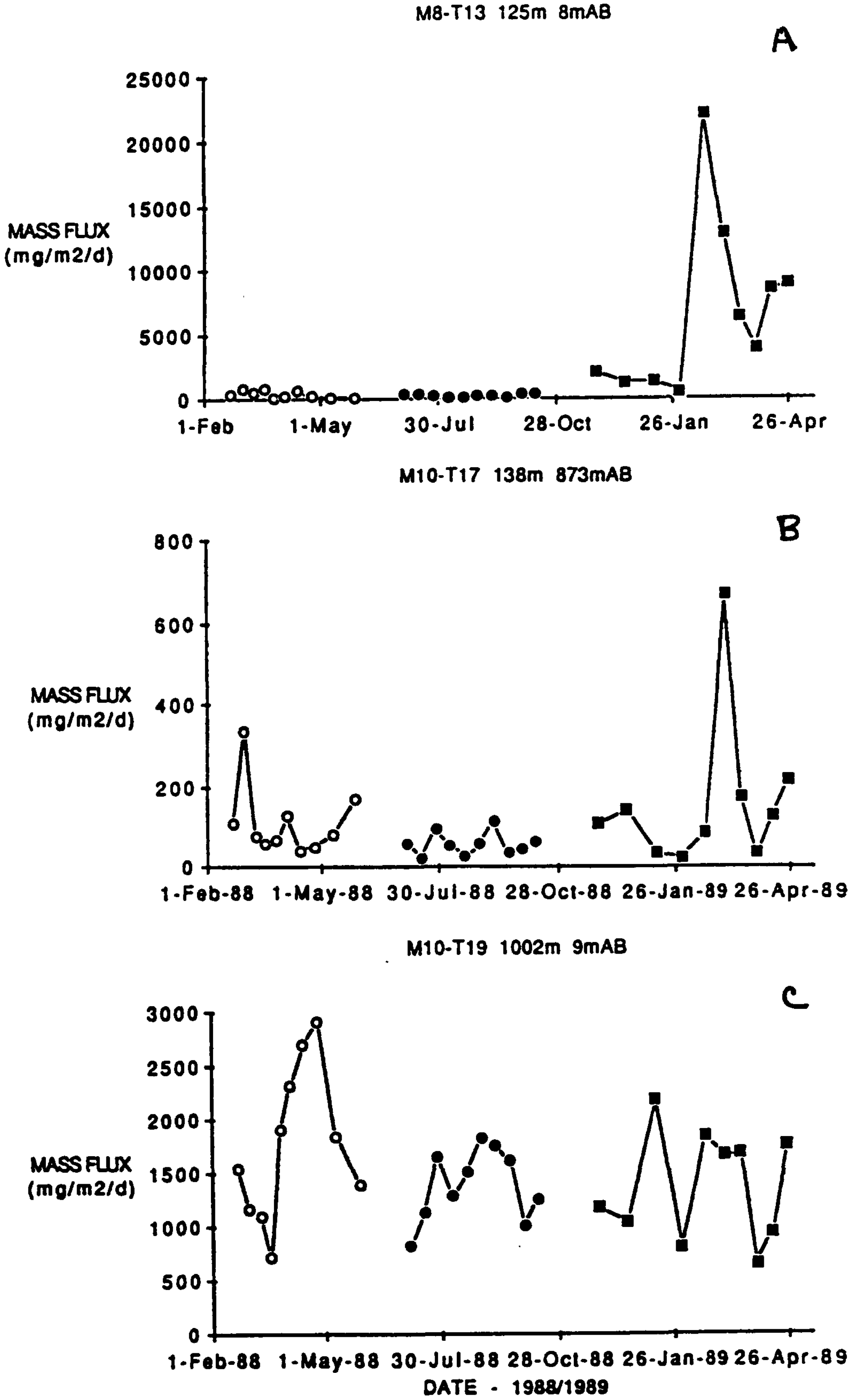


Fig. 2.2.1.4/2. Mass fluxes collected by three sediment traps located on the southern SEEP-II transect. Mooring 8 - Trap 13 is located 8m above bottom near the shelf-slope break. Mooring 10 is located in ~1000m of water in the region where sediments are enriched in organic carbon. Trap 17 is positioned at 138m to collect material settling out of the photic zone while Trap 19 is located ~9m above bottom to sample the material being deposited in the carbon-rich zone.

Figure 2.2.1.4/2). Planned chemical analyses of these samples will indicate whether the resuspension event transported particles as far as Mooring 10 or if this peak flux of particles reflected the fallout from the spring bloom in this region.

The flux record at the nominal 1000-m trap showed no evidence of the major flux events during February and March 1989 recorded at shallower depths (Figure 2.2.1.4/2). This record shows some indication of an increase in flux during April of 1988, but nothing corresponding to the spring bloom in 1989. At the site of Mooring 10 the average mass fluxes at 1000m are an order of magnitude greater than at 138m (Figure 2.2.1.4/2). Radionuclide activities suggest that the 1000-m trap was not collecting resuspended sediments (see below), indicating that this increase in flux with depth is somehow related to an offshore transport of particles from the shelf. The nature of this transport will become clearer when we have more data on the composition of the particles and when we can correlate the measured fluxes with physical oceanographic measurements.

In addition to the total mass flux data from the three South transect traps, we can say something about relative fluxes in both the North and South transects throughout the experiment based on the volumes of material caught in the various trap samples. If we normalize these volumes by sample collection duration, we have a "volume flux" in arbitrary units (actually, for the cross sectional area of the sample tube, in mm $6.6cm^{-2}$ d^{-1}). The distribution of this arbitrary flux unit for both transects for the first sampling period of SEEP-II (17 - 27 Feb 1988) is shown in Fig. 2.2.1.4/3 in which the indication of increasing mass flux with water depth and proximity to the slope boundary is indicated, particularly at mooring 9. That the flux increases with depth, as we found in SEEP-I, is shown in Fig. 2.2.1.4/4 which shows the distribution for the second sampling period, 27 Feb - 6 Mar 1988, along with the fact that the fluxes overall have increased. The maximum in flux that spring occurred in April 1988, and is shown for the period 18-30 April in Fig. 2.2.1.4/5. The rest of the distributions show variations, generally of this same theme, and, until we get the actual mass fluxes for all the samples, is not worth belaboring. There is indication, however, from these preliminary data, that the total mass flux will be shown to be higher for the South, than for the North transect. This is seen in these three figures (2.2.1.4/3,/4 and /5) as well as in a time series plot of this "volume flux" parameter. We have taken the average volume flux of the three near-bottom traps on the slope for each sampling period in Spring and Summer, and plotted them in Fig.

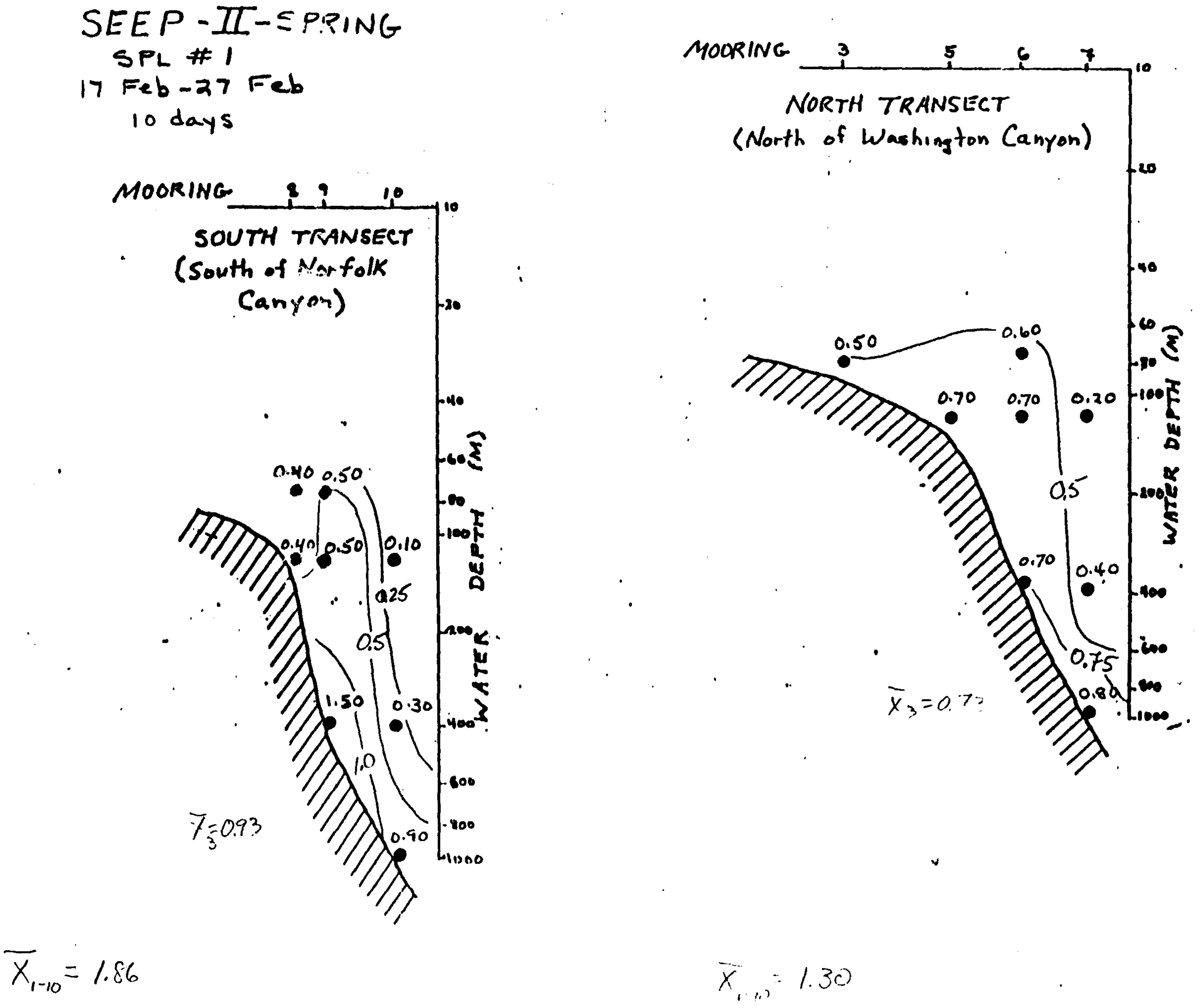


Fig. 2.2.1.4/3. Distribution of volume flux (in arbitrary units) collected throughout the SEEP-II sediment trap array during the first sampling period: 17 - 27 February 1988.

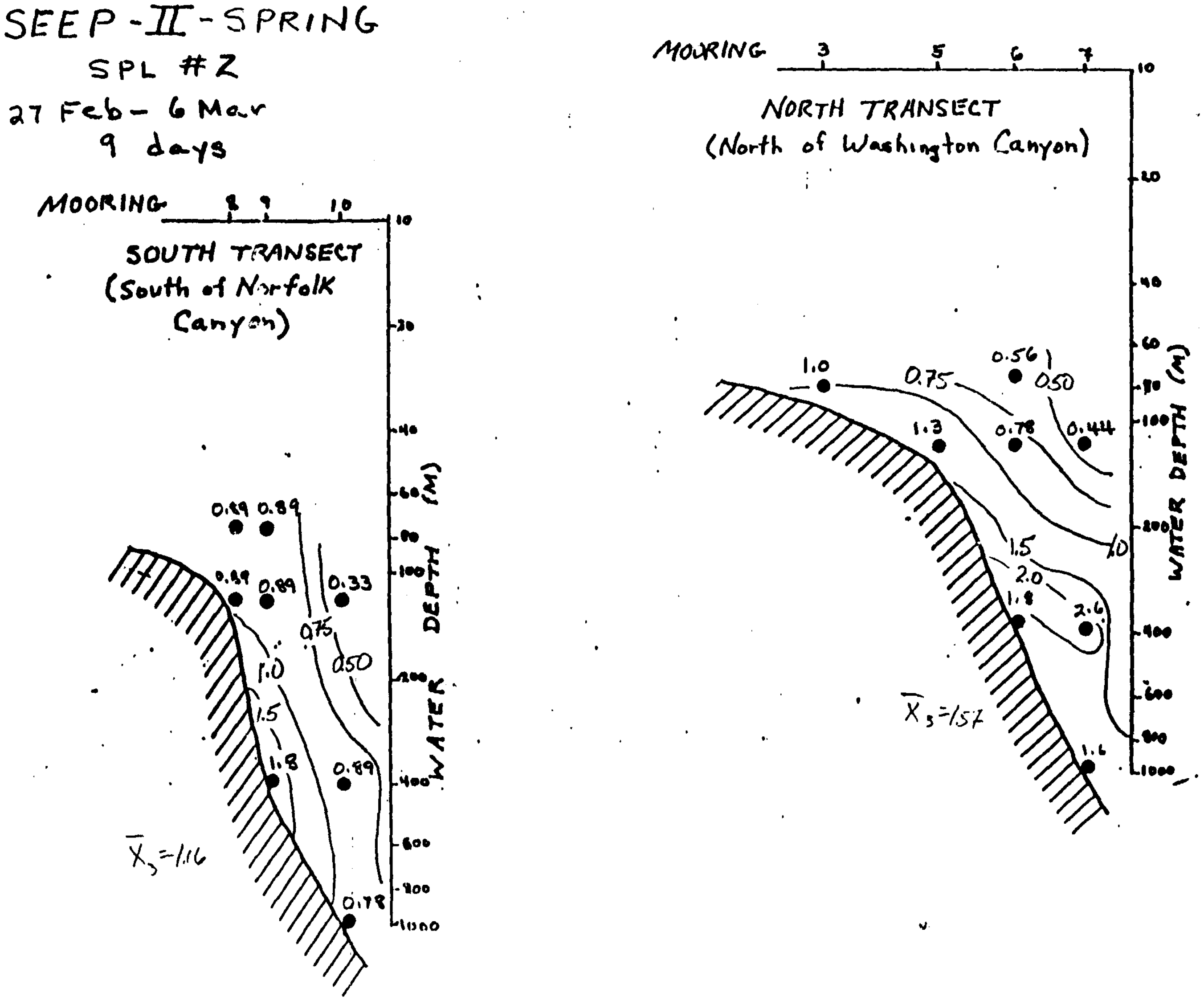


Fig. 2.2.1.4/4 Distribution of volume flux (in arbitrary units) collected throughout the SEEP-II sediment trap array during the second sampling period: 27 February - 6 March 1988.

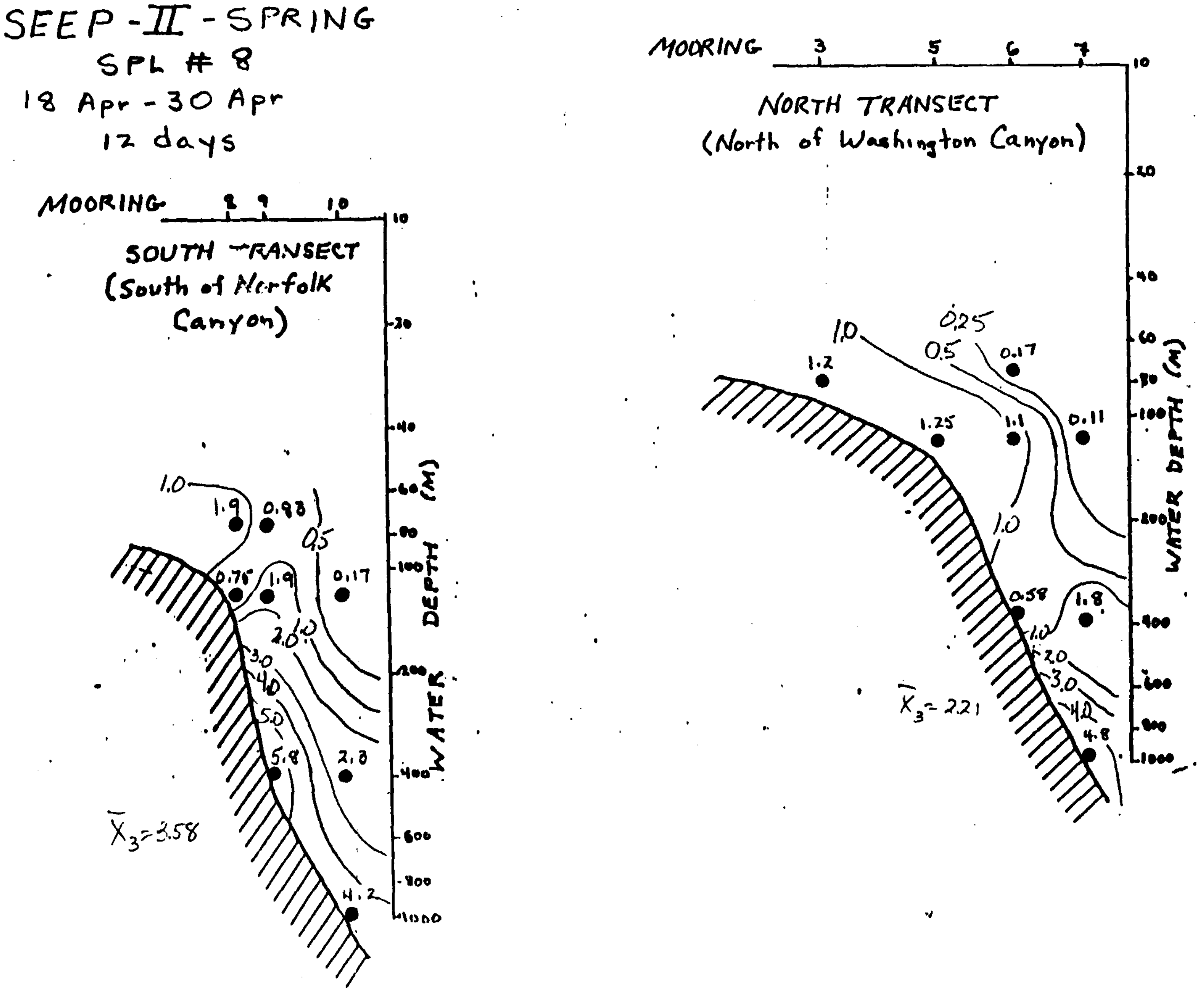


Fig. 2.2.1.4/5 Distribution of volume flux (in arbitrary units) collected throughout the SEEP-II sediment trap array during the eighth sampling period: 18 - 30 April 1988. This is the maximum flux period in the Spring 1988 period.

2.2.1.4/6, along with the ratio of South to North. That the ratio is >1.0 for all but a few samples confirms the higher flux at the South transect. Along with that general observation -- which is consistent with the original SEEP hypothisis that the flux should increase toward Hatteras -- there are major flux "events" which will be interesting to look at in the context of a completed current meter data set. For example, he April/May peak in volume flux at both transects reflects a major hydrographic event signalled for the Physical Oceanographers in their current meter (RCM-5, VMCM and ADCP) as well as the thermistor-chain data. The Winter data set will reveal more of these "events".

2.2.1.5. Radionuclide Activities and Fluxes. Already from our preliminary radionuclide data we can see evidence of interesting processes occurring in the SEEP-II region of the Middle Atlantic Bight. The most valuable radionuclide in our arsenal of tracers is ^{210}Pb. The principal source of ^{210}Pb is atmospheric deposition. Pb is quickly adsorbed onto fine-grained particulate matter after its deposition on the ocean, after which it can be used as a tracer to study the transport and deposition of particles. We know that it is delivered to the SEEP-II region at a rate of ~1 dpm cm^{-2} yr^{-1}. We can then compare the flux of ^{210}Pb collected in sediment traps to its known rate of supply to evaluate the net lateral focussing of particles to, or away from, the location of each trap. When the measured flux of ^{210}Pb approximately balances its rate of delivery from the atmosphere, we can conclude that there is no large net gain or loss of particulate matter and associated substances of interest (organic carbon, trace metals, etc.) by lateral transport.

During the spring and summer deployments the average flux of ^{210}Pb at the base of Mooring 8 near the shelf-slope break is close to, but a little lower than, the regional average rate of ^{210}Pb from the atmosphere (Figure 2.2.1.5/1). This suggests that there was little net lateral gain ot loss of particles at this site during this time period. Contrast this with the fluxes of ^{210}Pb measured during the winter deployment at this site which were as much as 15 times greater than the regional rate of supply (during the peak in Feb. 1989; Figure 2.2.1.5/2A). This peak flux could reflect one of two things- either there was intense local resuspension of sediment by storm activity, or, a very large amount of biodetritus was swept off the shelf following a late-winter bloom. Planned chemical analyses will answer this question, but for now we must address it with the information provided by the radionuclide activities. There is a minimum in ^{210}Pb activity of the particulate matter at the time of the peak in mass flux (compare Figures 2.2.1.4/2A &

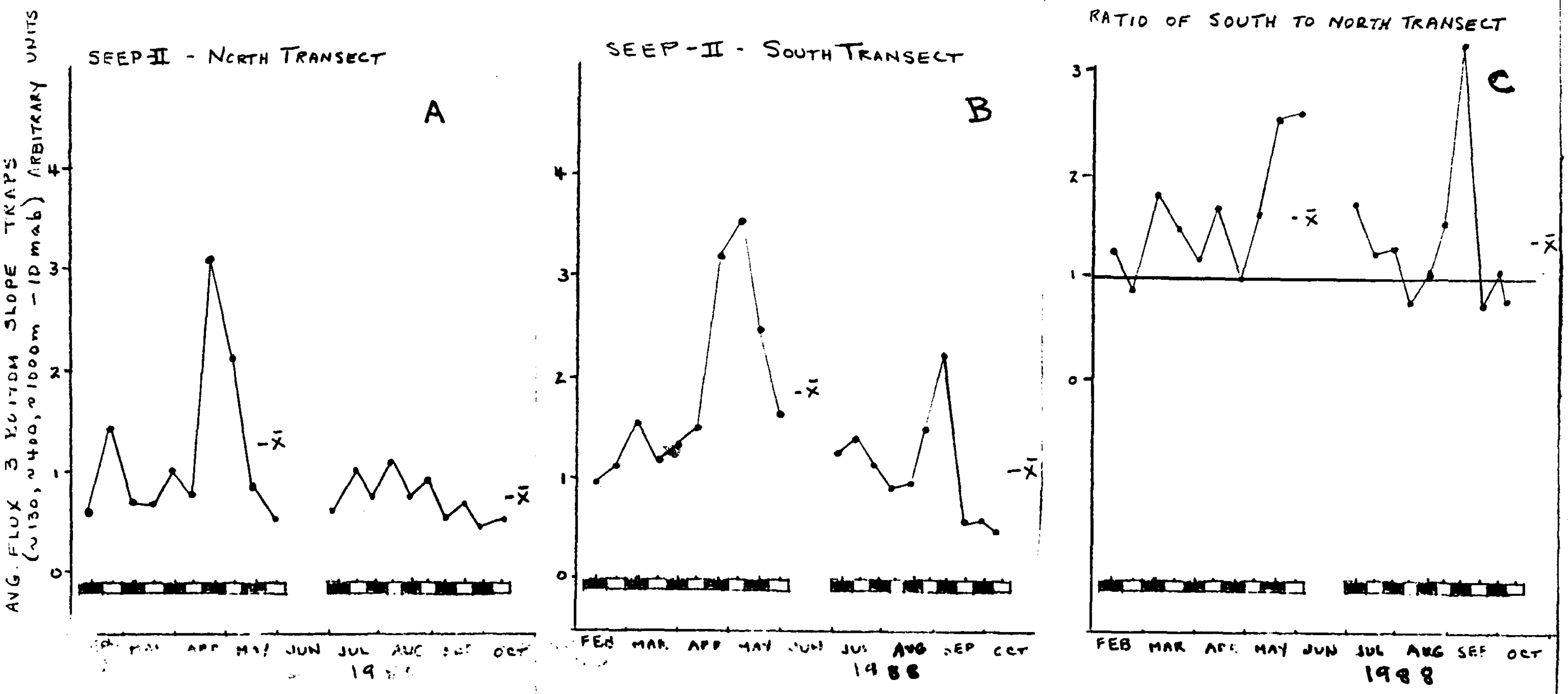


Fig. 2.2.1.4/6 Time series for the Spring and Summer periods of the average volume flux (same arbitrary units) for the three, near-bottom traps on the Slope:

A. North transect (Moorings 5, 6 &7)

B. South transect (Moorings 8, 9 & 10)

C. Ratio of B. to A. (South to North) During all but four of the sampling periods the ratio is >1, indicating a greater flux at the South transect.

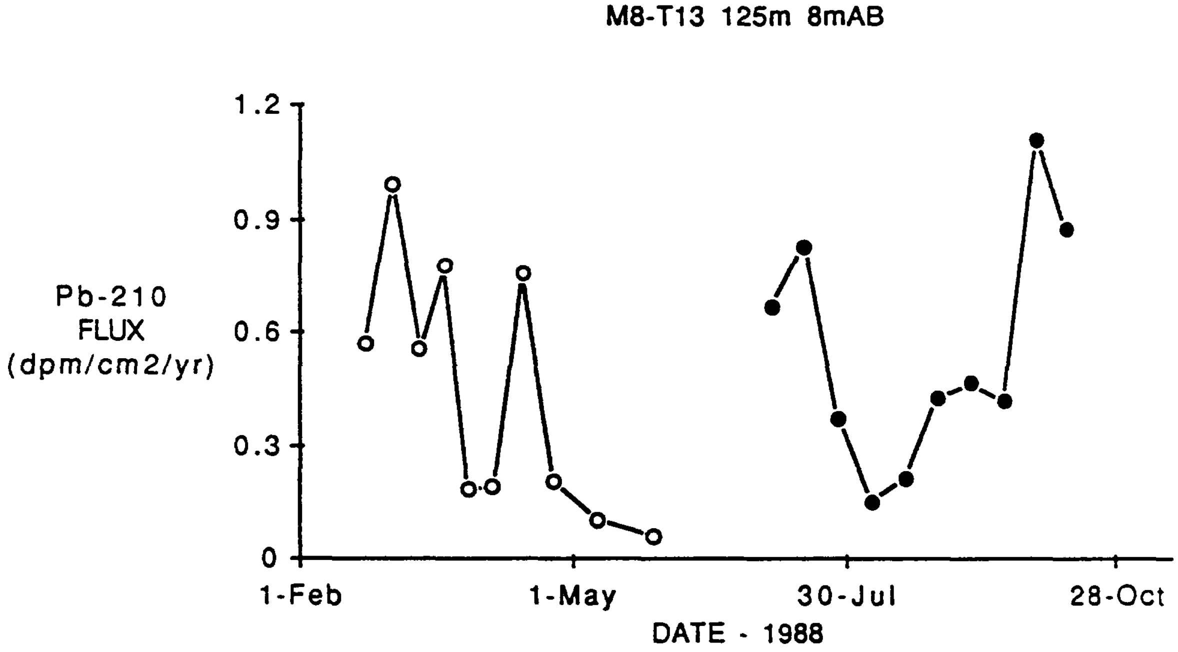


Fig. 2.2.1.5/1. ^{210}Pb fluxes collected by a sediment trap positioned 8m above bottom at SEEP-II Mooring 8 near the shelf-slope break on the South transect. Results are shown here on an expanded scale compared to Figure 2.2.1.5/2 so to permit visualization of flux variability during the spring and summer deployments.

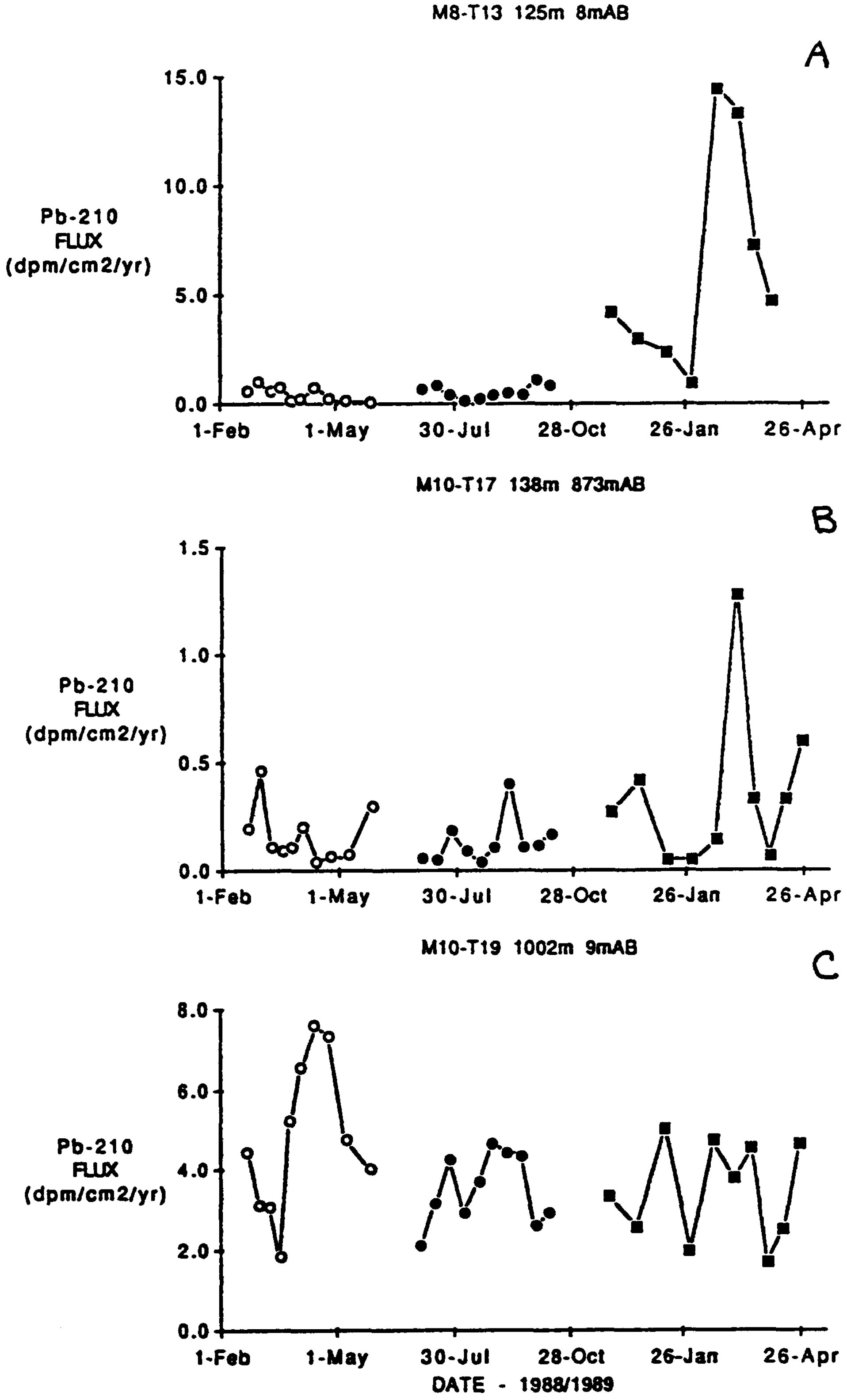


Fig. 2.2.1.5/2. ^{210}Pb fluxes collected by three sediment traps located on the southern SEEP-II transect. Trap locations are described in the caption with Figure 2.2.1.4/2.

2.2.1.5/3A). The ^{210}Pb content of sediments is only 20-30% of the ^{210}Pb content of "virgin" particles (those produced in the water column and existing in adsorption equilibrium with dissolved ^{210}Pb). This minimum in ^{210}Pb activity of the particles suggests, though does not prove, that the flux peak was associated with a resuspension event. ^{234}Th activities are also available from trap samples from this location during this flux event. The ^{234}Th activities during the winter period of high particle flux are much lower than during the summer period of stratification, and are even significaltly lower than during the spring of 1988 (Figure 2.2.1.5/4A). This too suggests that the material collected during this flux event consisted largely of resuspended sediments, which contain negligible ^{234}Th.

With the exception of the brief period of high particle flux in early March 1989, the ^{210}Pb flux at 138m at Mooring 10 (the seaward end of the`south transect) was less than the regional average rate of ^{210}Pb deposition (Figure 2.2.1.5/2B). Particulate ^{210}Pb fluxes out of the upper water column were similarly less than the regional atmospheric delivery rate in the SEEP-I region. We interpreted this to reflect the shoreward transport of dissolved ^{210}Pb in surface waters, followed by intense scavenging near the shelf-slope break and the seaward return of ^{210}Pb associated with particulate matter in a near-bottom nepheloid layer (Biscaye et al., 1988). A similar process may be occurring in the SEEP-II region where the ^{210}Pb flux at 1000 m (Mooring 10; Figure 2.2.1.5/2C) averages about an order of magnitude greater than the ^{210}Pb flux exiting the surface waters (Figure 2.2.1.5/2B). The ^{210}Pb flux at 1000m shows no evidence of an increase associated with the February 1989 resuspension event. The only significant deviation from the average ^{210}Pb flux at 1000m occurred in April 1988 and coincided with an increase in the total mass flux at that time (Compare Figures 2.2.1.4/2C & 2.2.1.5/2C). The close correlation between the ^{210}Pb flux and the flux of total particulate matter at 1000m arises from the fact that the ^{210}Pb activity of particles trapped at this depth is amazingly constant with time (Figure 2.2.1.5/3C).

The ^{210}Pb activity of particles trapped at 1000m (70-80 dpm/g) is about a factor of 3 greater than the activity of the underlying surface sediments, indicating that local resuspension of sediments probably contributed little to the high flux of ^{210}Pb at 1000m. Particles trapped at 1000m must therefore be supplied by lateral transport from some other region. One hypothesis being tested by the SEEP program is that fine-grained particulate matter originating on the shelf is swept across the shelf-slope break and deposited on the upper slope. The ^{210}Pb activity of particles trapped at 1000m is comparable to that of

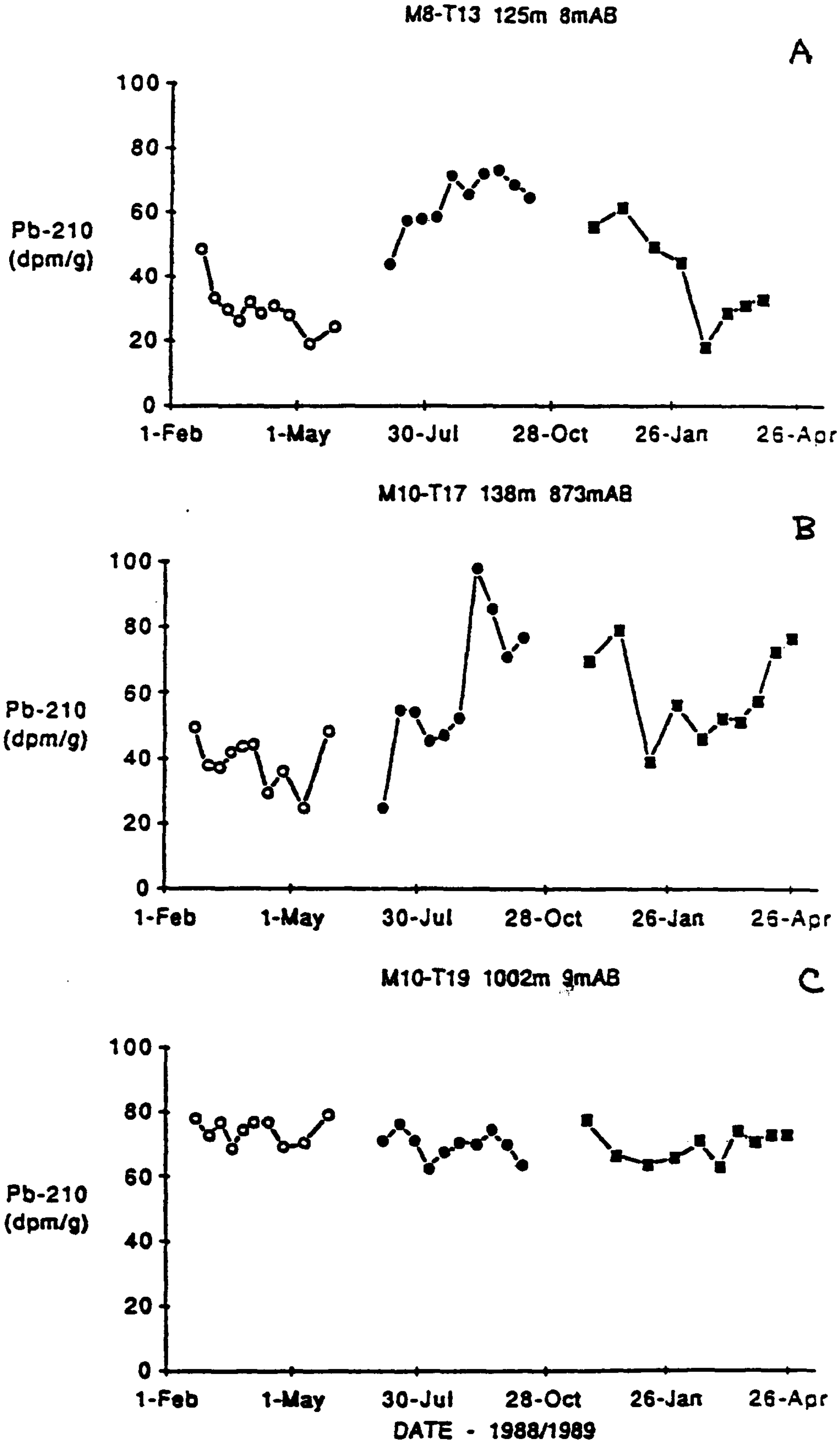


Fig. 2.2.1.5/3. ^{210}Pb activities of particles collected by three sediment traps located on the southern SEEP-II transect. Trap locations are described in the caption with Figure 2.2.1.4/2.

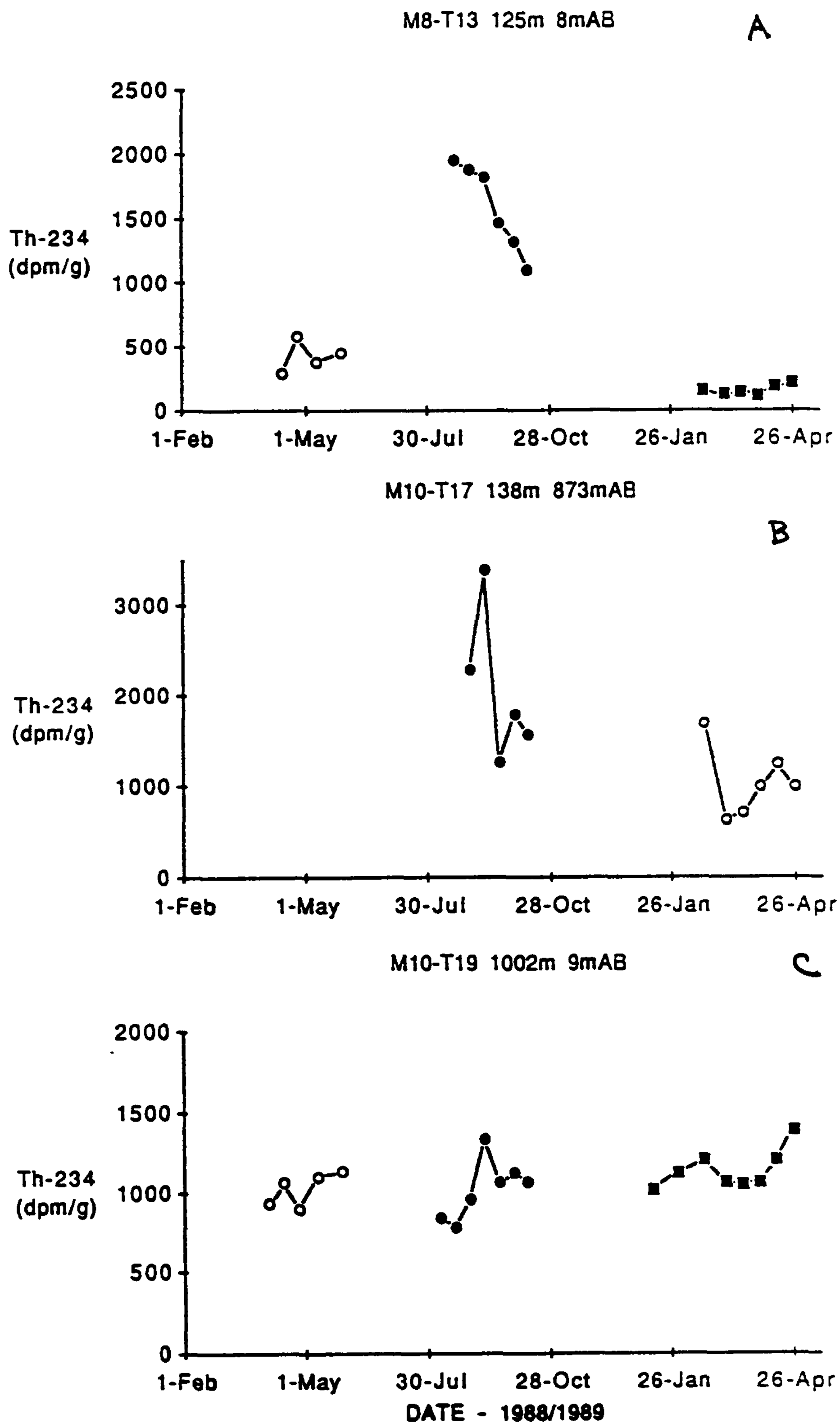


Fig. 2.2.1.5/4. ^{234}Th activities of particles collected by three sediment traps located on the southern SEEP-II transect. Trap locations are described in the caption with Figure 2.2.1.4/2.

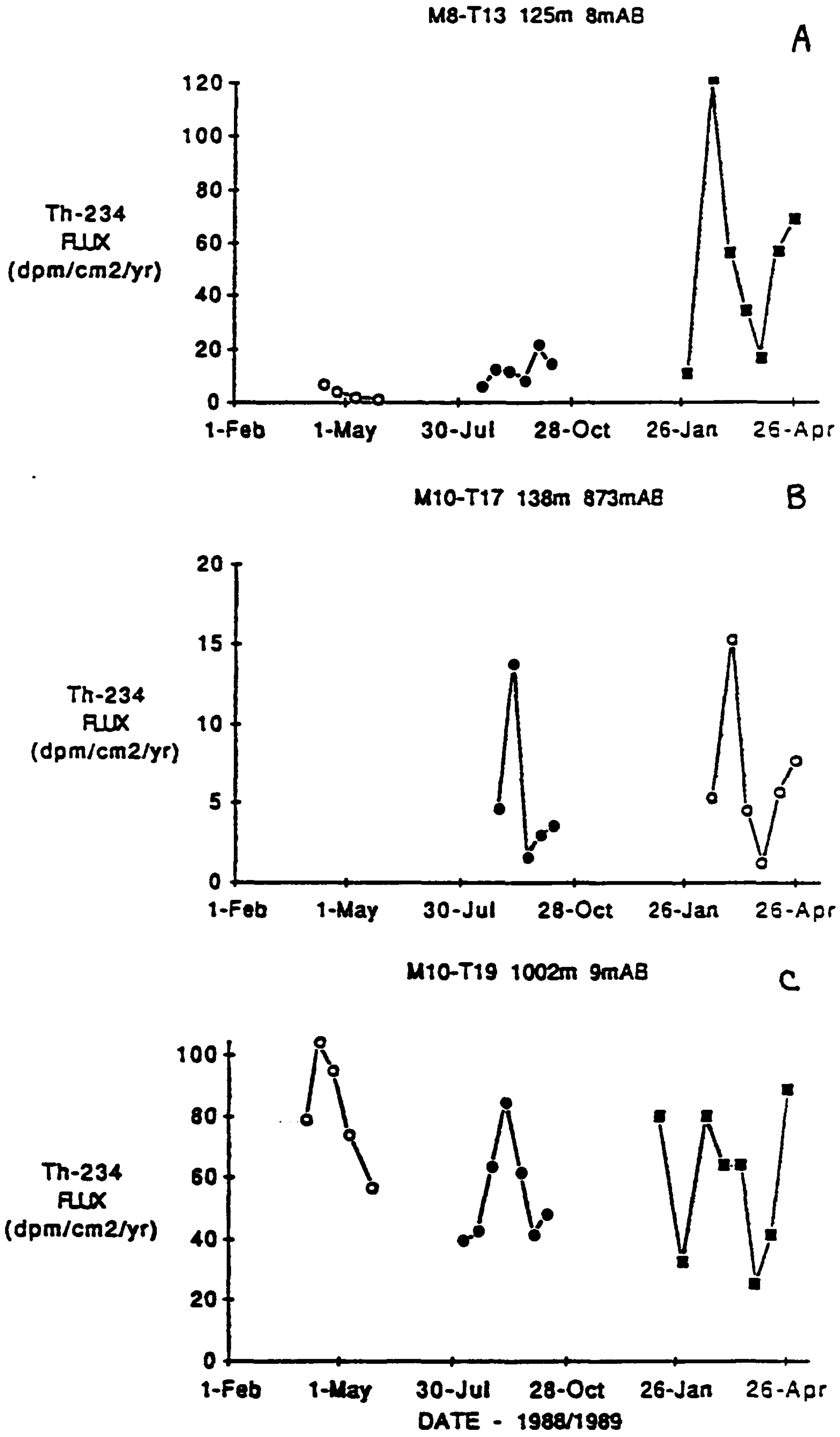


Fig. 2.2.1.5/5. ^{234}Th fluxes collected by three sediment traps located on the southern SEEP-II transect. Trap locations are described in the caption with Figure 2.2.1.4/2.

particles trapped near the shelf-slope break during late summer (Figure 2.2.1.5/3A) when stratification would prevent significant resuspension of bottom sediments. While this evidence alone is insufficient to prove that the particulate ^{210}Pb trapped at 1000m was derived by offshore transport of fine-grained organic-rich particles from the shelf, it is consistent with that hypothesis. Planned studies of the chemical composition of the trapped material (see above and the accompanying Proposal) as well as examination of fecal pellets and microfossil tests incorporated into the particles trapped at 1000m will help identify the source of this material. Regardless of the source, the ^{210}Pb fluxes help quantify the extent of lateral focussing of particulate matter to the upper slope region which acts as a depocenter for organic carbon. This knowledge will prove to be beneficial to our planned construction of an organic carbon budget for the shelf-slope system.

It is interesting to note that the activities of both ^{210}Pb and ^{234}Th in particles trapped at 1000m are surprisingly uniform with time (Figures 2.2.1.5/3C & 2.2.1.5/4C), especially compared to the large range of activities observed in samples from the other traps. We would expect the composition of particles to vary seasonally in accord with the time-varying sources of biogenic and lithogenic particles. We would further expect the different particulate phases to have very different scavenging efficiencies (adsorption affinities) for particle-reactive elements like Pb and Th. Consequently, we would expect the activities of Th and Pb to vary seasonally. Either the composition of particles at 1000m does not vary seasonally, or particle composition does not influence the efficiency with which particles scavenge reactive substances from the water column. Either explanation is contrary to conventional wisdom. It will prove very instructive to complete the analysis of the trap samples. These results will help us determine if the particles collected at 1000m, i.e., the source material for the ribbon of sediments containing high organic carbon content, are derived by lateral transport from some large pool of particulate matter having a uniform composition, or if particle composition is not an important factor influencing chemical scavenging.

2.2.1.6 Fecal Pellets. We have begun studies of the fecal pellets in the SEEP-II traps since the arrival in mid July at Lamont of Serge Heussner, a French Post Doctoral Fellow, from the University of Perpignan. We met Heussner in connection with Biscaye's review of the French ECOMARGE program at the ECOMARGE Colloquium in Perpignan in June 1987 (See 4.3.1 below). Heussner is trained as a biologist, has been in charge of the ECOMARGE sediment trap program and has worked on the radionuclide and fecal pellet (F-P) aspects of the ECOMARGE trap samples. The ECOMARGE program is very similar to the SEEP program in objectives, in its multidisciplinary and multi-institutional nature, and in the actual carrying out of the field program.

Because of his committments at Perpignan he could only spend three months at Lamont, but this has been sufficient to get a good start on the F-P studies, to train us in some of the methods, and to derive some interesting preliminary data (summarized below) which will be the basis of his returning to France with additional SEEP-II samples and continuing the study there. Because of his being between appointments in France, in order for him to be able to make this visit, although his travel expenses were paid by the French, we paid Heussner's salary for his three-month stay. But his continued work on the SEEP samples is a specific part of his program under CNRS appointment, so will cost us no salary. We intend the collaborative relationship to be a long term one, involving both SEEP-II, ECOMARGE and other samples, and will cost us only some travel expenses for exchange of visits to work on results and papers.

Fecal pellets are recognized as being a major contributor to the vertical transfer of particles and everything associated with them -- carbon as a source of energy, radionuclides, particle-reactive pollutants, etc -- for two possible reasons. First, fecal pellets have very high sinking rates so are able to contribute to a rapid transfer of material from the surface to the bottom. Second, and this is currently under discussion in the community, their abundance may mean that they contribute a large proportion of the vertical flux. Some of the preliminary data reported here bears on the question of their relative importance as flux carriers.

Our objectives in the F-P work on the SEEP-II samples are twofold. First, we want to determine the importance of the flux of material through the water column and across the slope carried specifically by fecal pellets. This provides insight into a specific kind of biogenic flux generation and permits relative evaluation of biogenic and physical forcing functions. Secondly, an objective that is much more speculative is the attempt to relate the several kinds of fecal pellets to the various kinds of swimmers found in the trap samples with the hope that, from this time-series sample of zooplankton organisms and fecal products can be derived information about the succession of zooplankton species in the water column during the experiment. While far from being a simple problem, we think this objective is worthwhile in that the trap samples constitute the only time-series sampling of the zooplankton (and, in fact, the phytoplankton) populations during the experiment. The addition to SEEP-II (by Charlie Flagg of BNL) of an ADCP (Acoustic Doppler Current Profiler), tweaked to yield a measure of zooplankton biomass in the water column, was the first step in getting any kind of time-series data about zooplankton. But if those data could be amplified by additional data on zooplankton populations, we would have made a great advance in providing biological data important to understanding particulate fluxes.

Thus the first objective takes us toward a better understanding of geochemical and sedimentological fluxes, while the second takes us in the direction of understanding the underlying biological processes that were going on during the experiment.

After studying the fecal pellets in several samples scattered in space and time through the mooring array over the course of the experiment, we decided that the most informative approach would be to select a minimal number of sample periods that represent seasonal (and possibly biological) extremes, and to analyze these samples (sample periods) throughout the entire array. It is necessary to be extremely selective in this choice because of the labor-intensive (and tedious) nature of the analysis.

To help in this selection, we used both the ADCP backscatter intensity ("zooplankton biomass") record supplied by Charlie Flagg of BNL, and a number of moored fluorometer records supplied by Creighton Wirick of BNL. The three samples we chose which are hopefully representative of seasonal extremes were:

Summer deployment sample #3: 22 July - 2 August 1988 ("Summer")
Winter deployment sample # 3: 1 Jan - 21 Jan 1989 ("Winter")
Winter deployment sample # 9: 7 Apr - 19 Apr1989 ("Spring bloom").

After examining several of the Spring deployment samples that had been poisoned with sodium azide rather than formalin, we determined that the state of preservation, while adequate, was not as good as that of samples poisoned/preserved with formalin, so we chose as our "Spring bloom" sample period, one from the 1989, rather than the 1988 spring bloom. During Heussner's stay at Lamont, we have completed analysis of the "Summer" (22 July - 2 August 1988) sample in all traps in the SEEP-II array. The results reviewed below are all from that one sample period. We have also picked a collection of the several main kinds of fecal pellets for subsequent bulk density, chemical and radiochemical analysis.

In analysis of a sediment trap sample, the raw data are the number, size and kind of fecal pellets in the sample. The samples used are the 10 ml subsamples taken aboard ship to which additional formalin is added, and kept under refrigeration. In practice, Heussner's technique is to pick out the swimmers by hand and then to split the 10 ml sample by from 1/2 to 1/10, using a continuously flowing, very high precision (<0.1 % by volume) peristaltic pump. His sample splitting procedure is described in one of the ECOMARGE papers (Heussner et al., 1990) to be published in a special volume of Continental Shelf Research (see section 4.3.2. below). This yields a sample which, after cleaning of most of the fine-grained, non-F-P material, yields a useable concentration of pellets in the Dolfuss cuvette in which the analysis is made under the microscope. The fecal pellets are counted and measured in microns (using a calibrated reticular ocular) in three principal, ubiquitous shape classes according to these dimensions: cylindrical (diameter and length); elliptical (major and minor axes); and spherical (diameter). Other types of fecal pellets occur only occasionally, e.g., very large fish and salp pellets, as well as unidentifiable fecal masses. The number of pellets counted is multiplied by the reduction factor for each sample.

Plots of the size frequency distribution of all pellets of each shape generally revealed a bimodal distribution, and each shape category was divided into "Large" and "Small" pellets based on the division between those two populations. The size cutoff for the two populations for each shape category are: cylindrical (> and < 136 um of the diameter -- not the length, which can be broken and is therefore not characteristic of anything); elliptical (> and < 148 um of the minor axis); and spherical (> and < 144 um of the diameter). These cutoff sizes are rather similar for the three shape categories, as are the range in sizes of each of the three categories: ~20-~140 um for the Small, and ~140-~250 um for the Large ones.

With respect to the first objective -- the importance of the fecal pellets in the total particulate flux -- the entire raw data set for each sample thus consists of the number and individual pellet dimensions of two size classes of three different shape classes of fecal pellets. We can plot the distribution of these parameters throughout the North and South mooring transects (for this one 11 day period in Summer 1988) for each of the six shape and size classes and the total as the relative number flux (#F-P/m^2/d). The most striking thing about the distribution is the much higher number flux in the South compared to the North transect, but also that this higher South transect flux consists of larger proportions of "Small" pellets.

To make the necessary step from numbers to mass fluxes one must introduce data on the bulk wet density of the pellets. For our calculations we have used data from the literature, but these will be corrected when we get our own wet density values from the sorted F-P collections that we have made. Almost all the literature values are based on measurements on fecal pellets obtained from fresh, cultured pellets, not from actual trapped, "aged" pellets, as ours will be. The range given in the literature is 1.1 to 1.5 g/cm^3 and we have used 1.22 g/cm^3 (Komar et al. 1981). This is obviously an approximation that introduces some error, as it is not reasonable to suppose that all pellets, no matter what size or shape, or which was produced by no matter what zooplankter, should be of equal density. In fact, the literature range quoted above is for different kinds of pellet producers. Assuming that this error is of the order of 20%, an even greater potential for error lies in the factor that must be applied to obtain dry pellet weight from wet. This can vary (although there are very few data), and we have used a factor of 4 (Fowler, 1977), but will use our own data on these SEEP-II pellets eventually.

These approximations notwithstanding, we can therefore derive mass fluxes (mg m^{-2} d^{-1}) for the total number of particles and for each F-P size/shape class. These data are shown altogether in Fig. 2.2.1.6/1. The relative contribution of the F-P to the total mass flux is of great importance, and these data are given in Table 2.2.1.6/1.

We have also calculated the settling velocities for each of the observed fecal pellets using the Komar et al. (1981) modification of the Stokes settling formula. Two examples, illustrative of the diversity in this parameter, reflecting the diversity in fecal pellet size, are shown in Fig. 2.2.1.6/2. These are samples from the uppermost (nominal 120 m) and near-bottom traps on the 1000 m mooring on the South transect. In the 120 m trap, 40% of the pellets by mass have sinking speeds greater than 0.45 cm/sec (almost 400 m/d), while in the near-bottom trap which especially on the South transect is characterized by small, spherical and elliptical pellets, 40% of the pellets by mass only exceed 0.04 cm/sec (or about 35 m/d) in sinking speed. The settling velocity cumulative frequency distribution for all of the pellets measured in the mid-Summer for the entire trap array (1742 actual measurements) is shown in Fig. 2.2.1.6/3. Overall, half of the particles by mass have sinking speeds in excess of 0.35 cm/sec or over 300 m/d. These F-P velocity distributions, once improved by more accurate pellet densities, are part of the data for eventual flux modelling calculations at SEEP-II.

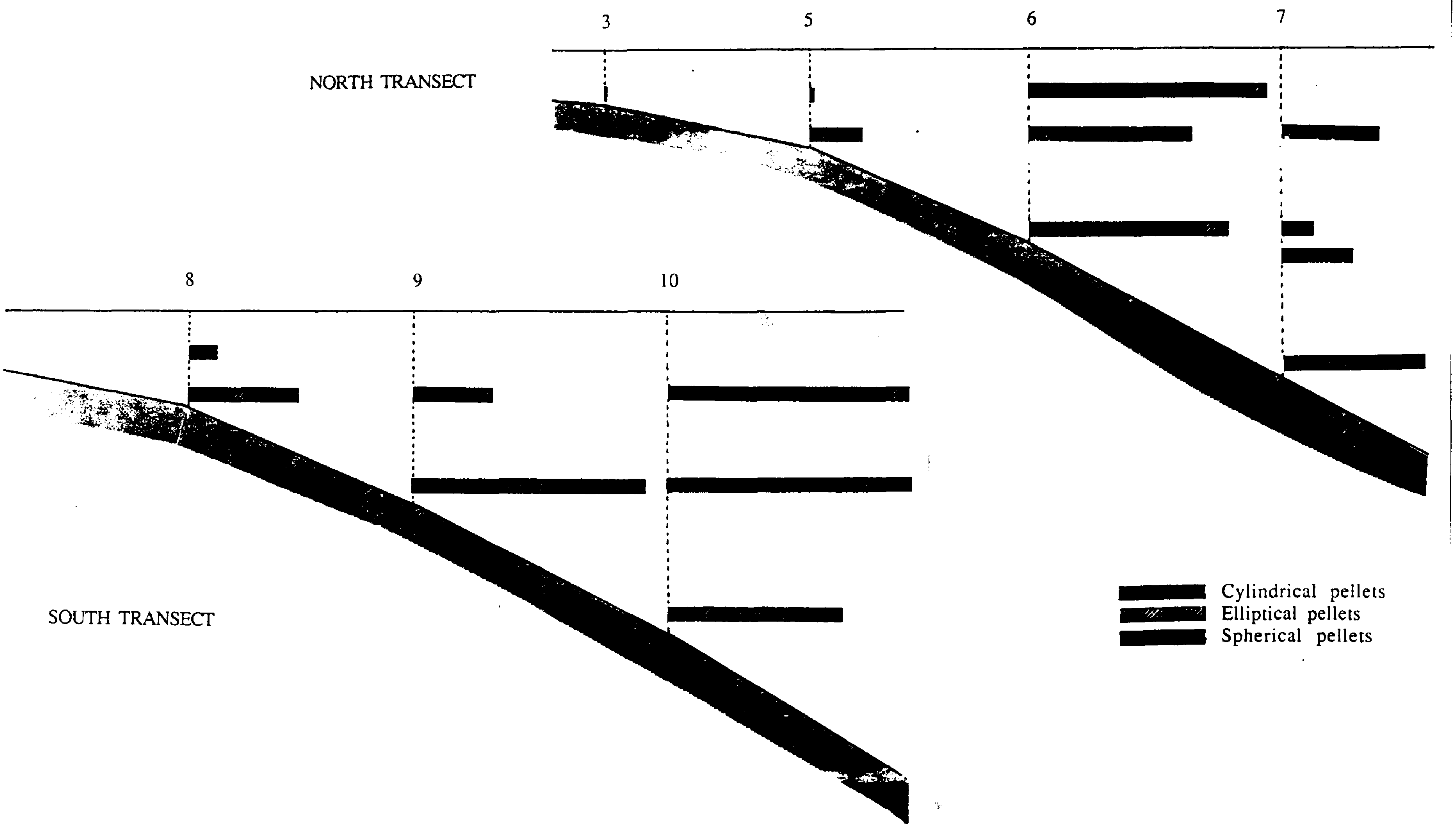


Fig. 2.2.1.6/1 **Distribution of fecal pellet fluxes (in mg m^{-2} d^{-1})** by pellet shape throughout the SEEP-II array for the "Summer" sample of 22 July - 2 August 1988. From left to right in each bar the shape classes -- cyllindrical, elliptical and spherical -- are cumulative so the bar length represents the total flux of the three shape classes. The values of the shape class- and total-fluxes are given in Table 2.2.1.6/1.

Table 2.2.16/1

Estimate of Fecal Pellet Contribution to Total Mass Flux
Summer Spl #3 -- 22 July - 2 August 1988

Water Depths of Moorings and Traps are nominal depths in meters
Fluxes are in mg m^{-2} d^{-1}

Mrg/ W.Dpth	Trap Dpth	Cylind. FP flux	Ellipt. FP flux	Spher. FP flux	Tot F-P Flux	Tot Mass Flux	% Contrib. of FP Flux
North Transect							
3/90	80	0.441	0.144	0.108	0.693	-	-
5/130	80	0.543	0.950	0.945	2.44	-	-
5/130	120	6.82	8.60	12.8	28.2	73.7	38
6/400	80	125.5	2.83	3.51	131.8	110.1	120
6/400	120	82.5	3.95	4.24	90.7	127.0	71
6/400	390	97.6	6.06	6.58	110.3	218.2	51
7/1000	120	50.9	1.03	1.14	53.1	-	-
7/1000	390	15.5	1.22	0.0	16.7	-	-
7/1000	990	22.6	22.9	32.0	77.5	848.0	9
South Transect							
8/130	80	13.6	1.17	1.30	16.1	-	-
8/130	120	25.7	6.00	30.0	61.6	121.3	51
9/400	120	40.0	1.81	2.38	44.2	83.7	53
9/400	390	28.8	46.5	53.3	128.6	1930.8	7
10/1000	120	123.4	3.22	5.97	132.6	81.1	164
10/1000	390	104.2	12.5	16.8	133.4	489.0	27
10/1000	990	18.7	47.1	30.5	96.3	1329.3	7

Table 2.2.16/2

Tentative Identification of SEEP-II Fecal Pellet Producers by Shape and Size Classes

	Small (~20 - ~140)	Large (~140 - ~250-300)
Cylindrical	Large copepods and other crustaceans	Euphausids, large amphipods and other shrimp-like crustaceans
Elliptical	Small copepods and, to a much lesser degree, appendicularians	Unknown benthic organisms (These almost always occur in near-bottom traps)
Spherical larger	Juvenile stage of copepods (nauplii) and possibly harpacticoid (benthic) copepods, and degradation stages of elliptical F-P.	Most of these are pieces of F-P, e.g., salps and herbivorou fish

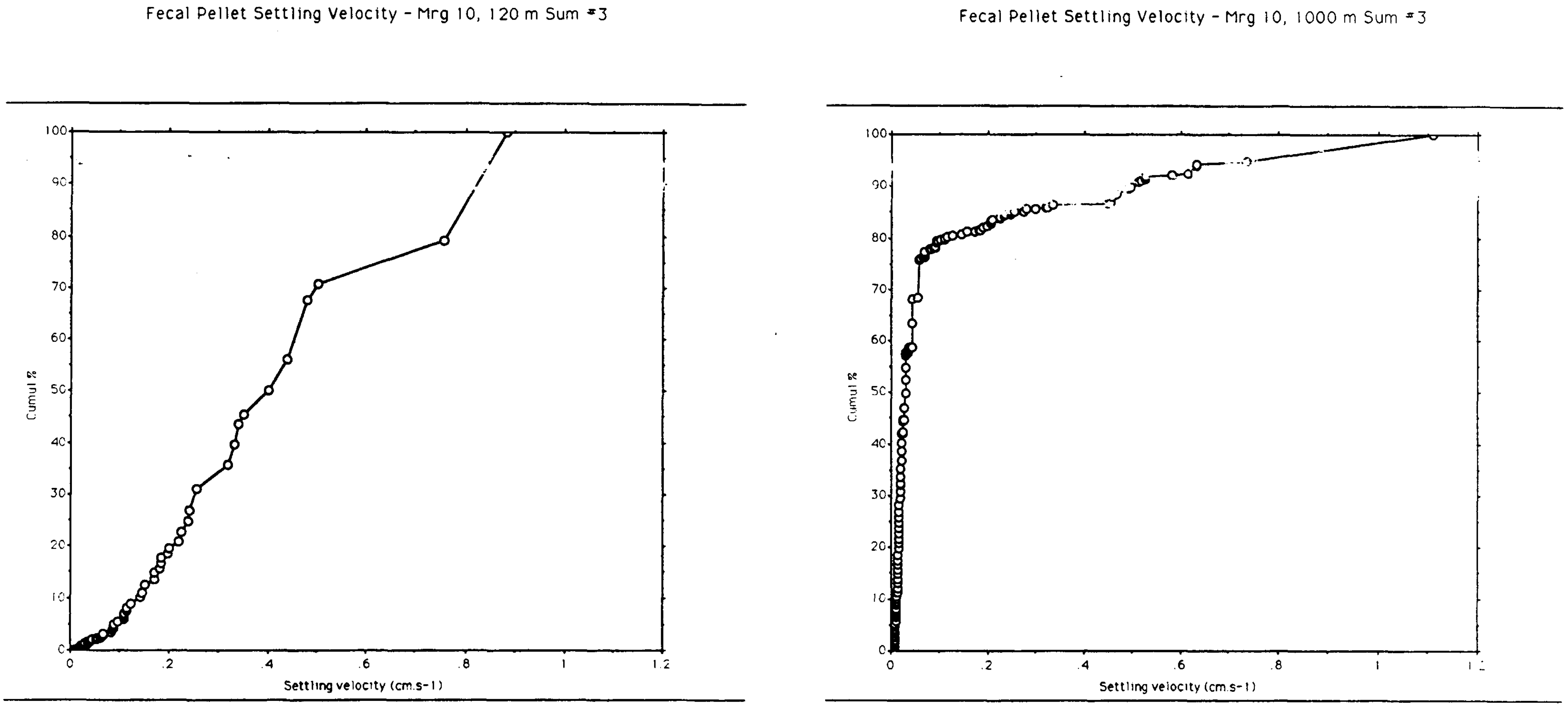


Fig. 2.2.1.6/2 Cumulative frequency distributions of fecal pellet settling rates (in cm/sec) for the "Summer" 22 July - 2 August 1988 sample from the uppermost (nominal 120 m) and near-bottom (nominal 1000 m) traps at Mooring 10.

Settling Velocity (cm.s-1) of all summer FP data

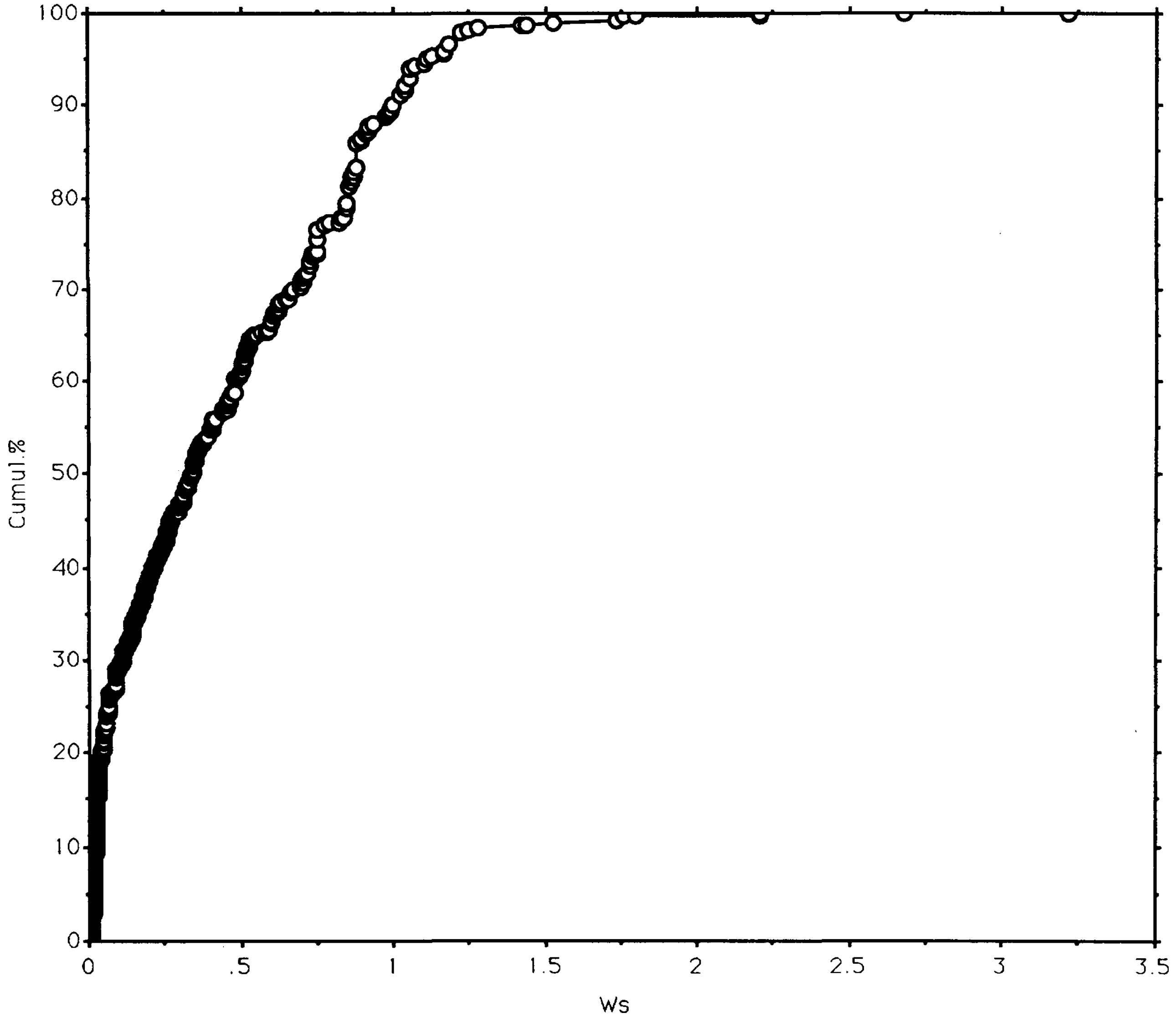


Fig. 2.2.1.6/3 Cumulative frequency distribution of fecal pellet settling speeds for all fecal pellets in the SEEP-II trap array for the "Summer" 22 July - 2 August 1988 sample.

At this writing we have just completed this data set just prior to Heussner's return to France and have not had much time to study it together, but there are a few observations we can make that, we think, indicate the potential of these studies for helping to understand the mechanisms of the removal of particles and their radionuclide and pollutant load from the shelf to the slope, and from the water column to the sediments.

1. Although in Table 2.2.1.6/1 some of the results indicate a percentage of F-P flux greater than 100 (emphasizing the potential for error in the assumptions of pellet density and wet-to-dry weight), the numbers do indicate quite a range of contributions to the flux by fecal pellets, and that, in some samples, the F-P flux is extremely important -- of the order of 100% of the flux. The F-P contribution to total flux is generally low (<10%) in the near-bottom traps compared with traps higher in the water column. As the F-P mass fluxes remain constant or even increase with depth, this result is due to dilution by resuspended sediment (from somewhere). This may be due to dilution by resuspended sediment near the bottom, but, when these data are integrated with a complete set of radionuclide data (section 2.2.1.5), we may find other explanations.

2. While the distribution of number flux shows the South transect to be very much higher than the North, the conversion of this to mass flux shows the two transects to be less disparate. There certainly are significant differences between the two transects, e.g., the greater contribution to mass flux of small elliptical and spherical pellets in near-bottom samples in the South transect, but a lot of those differences are much less obvious and more difficult to generalize. If, however, one compares the flux through a given water depth for the two transects (at either 120 m for the three traps at that level, or 400 m for the two traps), the F-P flux is of the order ~40% greater at the South transect.

3. The total F-P mass fluxes tend to be lower in near-surface traps than in those near the bottom, indicating inputs of pellets at depth. These inputs are particularly noticeable for the elliptical and spherical pellets produced by smaller organisms, and are due either to down-slope advection (as concluded in SEEP-I) and/or to F-P production in the deeper water column (or both). In contrast, the cylindrical pellets, particularly the large ones, despite their rapid settling velocities, tend to display a reduction in flux with depth, which might indicate rapid degradation and/or consumption.

4. Most of the F-P production takes place around mid-slope, with almost none taking place at our one, surviving "shelf" trap (at 80 m water in 90 m water at Mooring 3).

5. The fact that such a large proportion of the mass of the pellets have such a high settling velocity (our distribution in Fig. 2.2.1.6/3 gives >300 m/d for half the pellet mass flux) is rather surprising, and, if true, emphasizes the importance of this mechanism of vertical transport of particulate material. We will check the temperature and water density parameters we used for these estimates when we recalculate these velocities using our own measured pellet densities.

6. Based on his previous experience with the ECOMARGE traps in the Mediterranean, and on some of the observed distributions in SEEP-II, Heussner makes the tentative identifications of the producers of the various fecal pellets in SEEP-II in Table 2.2.1.6/2

Our immediate plan is to analyze the two other seasonal samples (Spring and Winter), and based on those first fifty-odd samples, select one or two traps for analysis of the entire time series -- from February 1988 to May 1989. Given the interesting results so far from a limited data set, we anticipate a great deal more insight from that completed data set. And the questions still unanswered or that have not yet arisen can still be addressed in almost four hundred remaining samples.

2.2.1.7. Supernatant seawater. Leaching of particulate substances from trapped particles and selective dissolution of certain particulate phases has been a subject of concern in some sediment trap experiments (Knauer and Asper, GOFS, 1989). Some investigators (e.g. G. Knauer) have suggested that reliable fluxes cannot be obtained without separately analyzing the supernatant solutions in which particulate matter is collected and stored. Phosphorus is the element which exhibits the most significant dissolution. We are not measuring particulate phosphorus, so we have no need to correct for its dissolution. Dissolution of $CaCO_3$ has been a problem when saturated salt brines were used as a collecting-solution/preservative in sediment traps. Our sediment trap collection cups were filled with a seawater solution that was enriched in salt by only 20% to 42 per mil. Furthermore, this solution with its preservative was buffered by adding sodium carbonate (to pH=8.2), which should further inhibit dissolution of $CaCO_3$. There is no evidence that significant amounts of $CaCO_3$ dissolve in collecting solutions of this composition.

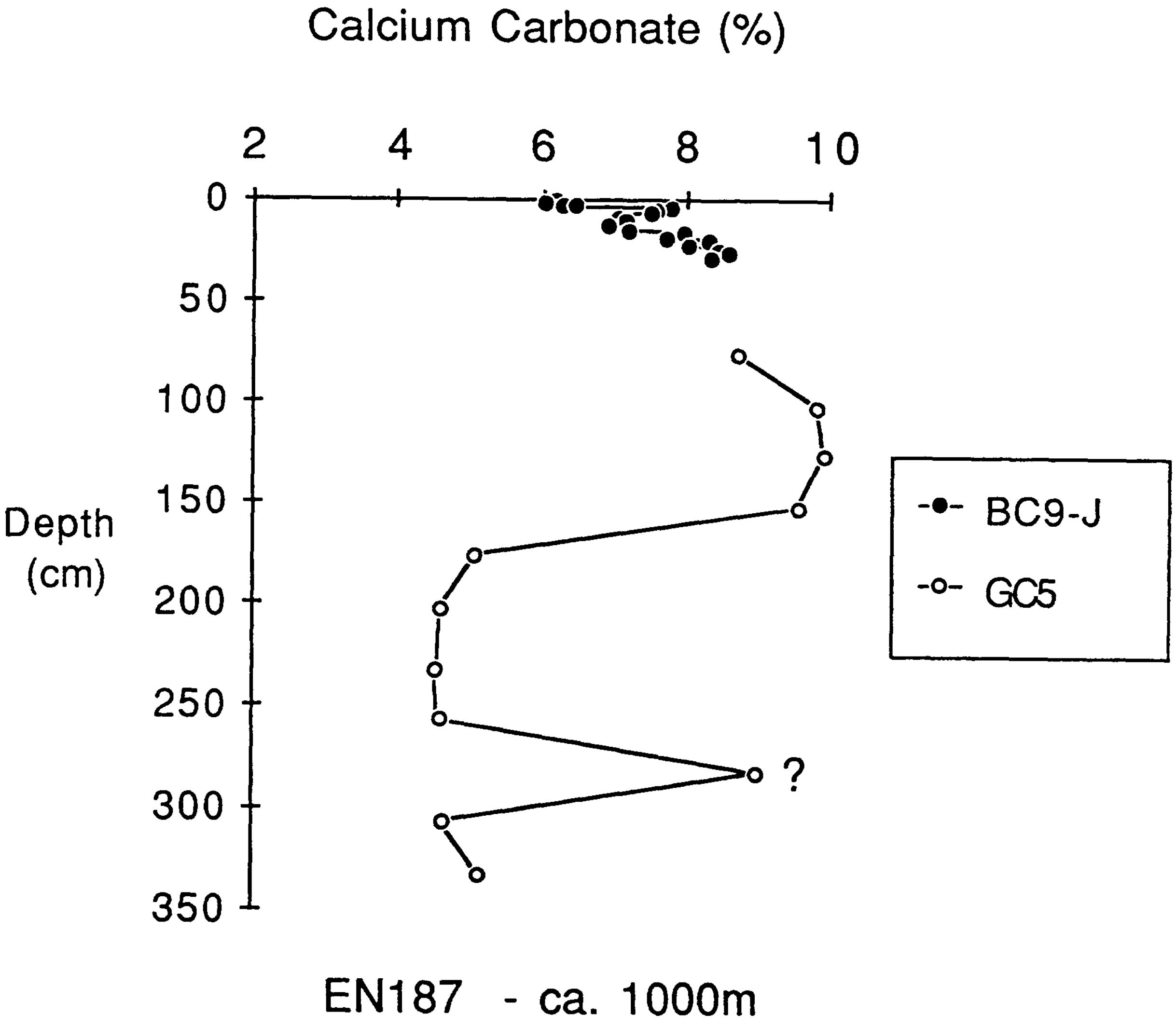


Fig. 2.2.3.1/1 Carbonate profile from EN187 GC5 collected at a depth of 990m on the southern SEEP-II transect. This gravity core overpenetrated, and the top 70cm were lost in the core head. The upper portion of the carbonate profile was therefore reconstructed using carbonate data from a nearby box core. If the increase in carbonate content at 170cm corresponds to the last deglaciation at ~12,000 years BP, then the sediment accumulation rate at this site is about 14 cm/1000years.

Leaching of organic carbon and nitrogen has been a problem during some of the VERTEX experiments and during other deployments of the Moss Landing PIT traps. However, the ratio of supernate volume to weight of trapped particulate matter collected ranges from 2 to 4 orders of magnitude greater for the PITs than for our traps. Whereas significant amounts of particulate organic carbon may be leached from particles collected by the PITs, we believe that the design of our traps and the nature of our experiments greatly reduces, if not entirely eliminates, this problem. Formalin was included in the supernate solution as a preservative. This greatly facilitates removal of swimmers, but it precludes analysis of the supernate solutions for dissolved organic carbon. For both of these reasons, our supernate solutions are not analyzed for DOC/DON.

Bacon has shown that particle-reactive radionuclides in which we are interested are not significantly leached from particulate matter while stored in collection solutions. We likewise examined several SEEP-I samples and found no significant leaching of ^{210}Pb into the supernates.

For the resons described above, we have no plans to analyze any of the supernate solutions from the SEEP-II sediment trap samples. However, all of the supernate solutions have been saved in case some new information arises which changes our plans.

2.2.2 Transmissometer Data

2.2.2.1 Moored transmissometer data. The data from all three deployments of our transmissometers have been reduced and is awaiting integration with the BNL transmissometer data. We have looked at some of it, the quality is good and we have recorded a number of what are apparently resuspension events. Once the entire data set is reduced and integrated, we will participate in the examination and interpretation of the data and the writing of papers based on it.

2.2.2.2 Profiling (shipboard) transmissometer data. A Spanish Post Doctoral Fellow -- Alberto Palanques -- spent part of the past year that he spent at Lamont working with Biscaye on the SEEP-I shipboard transmissometer data. His work on this data set is reviewed below under **3.0 SEEP-I** (3.2 Shipboard Transmissometer). We have also acquired the SEEP-II data set from Charley Flagg at BNL and, although Palanques has returned to Spain, we will work on those data also. The only thing that can be said of the SEEP-II data set at this early date is that, the SPM distribution with time at the South Transect appears to be very different from that at the North Transect, and that some of the regularities in the SPM distribution and its relation to hydrographic features observed in SEEP-I do not appear to be present in SEEP-II.

2.2.3 Sediment Core Results

The rationale for a sediment component of the SEEP-II program a well as the collection of sediment samples was described in Section 2.1.6. Although this part of the project is funded by NSF, we briefly summarize here some of the results to date from our study of sediments collected in the SEEP-II region.

2.2.3.1. Status of sample processing. Processing of the cores collected during the SEEP-II cruises began this year (1989). The status of sample analysis is as follows:

Box Cores: Subcores for ^{210}Pb inventory have all been sectioned, dried, ground, and canned for gamma counting to measure ^{226}Ra. About 20% of the samples have also been processed for ^{210}Pb. Larger subcores were sectioned at finer intervals to measure the distributions of $CaCO_3$, organic carbon, ^{210}Pb and plutonium. All of the subcores from both cruises have been sectioned, dried, and ground. Analysis of all cores for $CaCO_3$ has been completed. Analysis for ^{210}Pb and C_{org} are presently underway and will be completed by the end of this year. Preliminary results are shown below.

Gravity Cores: Gravity cores from both cruises are being curated by the Lamont core facility. As this involves a full core description and the core lab is backlogged with cores from other projects, this process has been slow, and the last of the SEEP-II gravity cores was opened only a few days ago. Consequently, there are few results to report from the gravity cores. Carbonate contents from one gravity core are shown in Figure 2.2.3.1/1. The C_{org} results from this core will be available before the end of this month. Carbonate and C_{org} analyses of remaining gravity cores may have to wait until next year because we are using as much time as we can get on the Lamont C/N/S elemental analyzer to process SEEP-II sediment trap samples.

2.2.3.2 Summary of results to date. A SEEP PI meeting was held last April to discuss preliminary results from the SEEP-II field program. Although we had few final results to present, we made a first attempt to construct a carbon budget for the upper slope (specifically at the 1000-m isobath where the highest organic carbon concentrations occur). Extrapolating the 2/3-year sediment trap record of mass fluxes available at that time to a full year and assuming that the organic carbon content of trapped particles, which has not been measured yet, is similar to the C_{org} contents of particles collected during SEEP-I farther to the north, it appears that the C_{org} flux to the sediments (~60 mg C m^{-2} d^{-1}) pretty well balances the oxygen fluxes measured with benthic flux chambers by G. Rowe. Bacterial metabolism in the upper 0-1cm of sediments measured by P. Kemp accounts for about 90% of the oxygen flux. This implies that relatively little of the particulate C_{org} flux to the sediments survives to long-term burial and furthermore that remineralization of C_{org} within the bioturbated mixed layer at depths >1cm is a relatively small component of the total carbon recycling.

Our preliminary sediment results are consistent with this interpretation. Assuming that the sediment accumulation rate in this region is similar to that measured elsewhere on the upper slope in the Middle Atlantic Bight at about 10 g cm^{-2} ka^{-1}, and using an average sediment C_{org} content of 2% (Figure 2.2.3.2/1), we estimated that burial accounted for about 5-10% of the POC flux to the sediments. While we do not yet have ^{14}C results to provide more accurate sediment accumulation rates, the carbonate record of EN187 GC5 (Figure 2.2.3.1/1) suggests that this average accumulation rate is a pretty good estimate for the SEEP-II region.

Pore waters were obtained from sediments collected on both coring cruises using a Jahnke-type whole-core squeezer (Jahnke, 1988). Profiles of nitrate, ammonia, phosphate and silica obtained during the October 1988 cruise are shown in Figure 2.2.3.2/2. These organic rich sediments are anoxic below a depth of 1-2cm. This is evident in the rapid depletion of nitrate (Figure 2.2.3.2/2-A) and the appearance of dissolved ferrous iron by 1 to 3 cm (data not shown). Average diffusive fluxes of ammonia and phosphate were calculated from these profiles (Figure 2.2.3.2/2-B&C). As all of the organic N remineralized under anoxic conditions is released as ammonia, we can estimate total C_{org} remineralization within the mixed layer from the ammonia flux if the C/N ratio of the remineralized organic matter is known. Assuming a C/N ratio of 7 (measured in the SEEP-I region), the rate of C_{org} remineralization estimated from the ammonia flux (3.6 mg C m^{-2} d^{-1}) is equivalent to a little more than 5 % of the POC flux to the sediments. A similar result (5.5 mg C m^{-2} d^{-1}), but with greater uncertainty, is estimated from the phosphate flux assuming Redfield stochiometry of the remineralized organic matter. The pore water data therefore indicate that C_{org} remineralization within the mixed layer accounts for only 5-10% of the POC flux to the sediments and is much smaller than the rate of C_{org} remineralization at the sediment-water

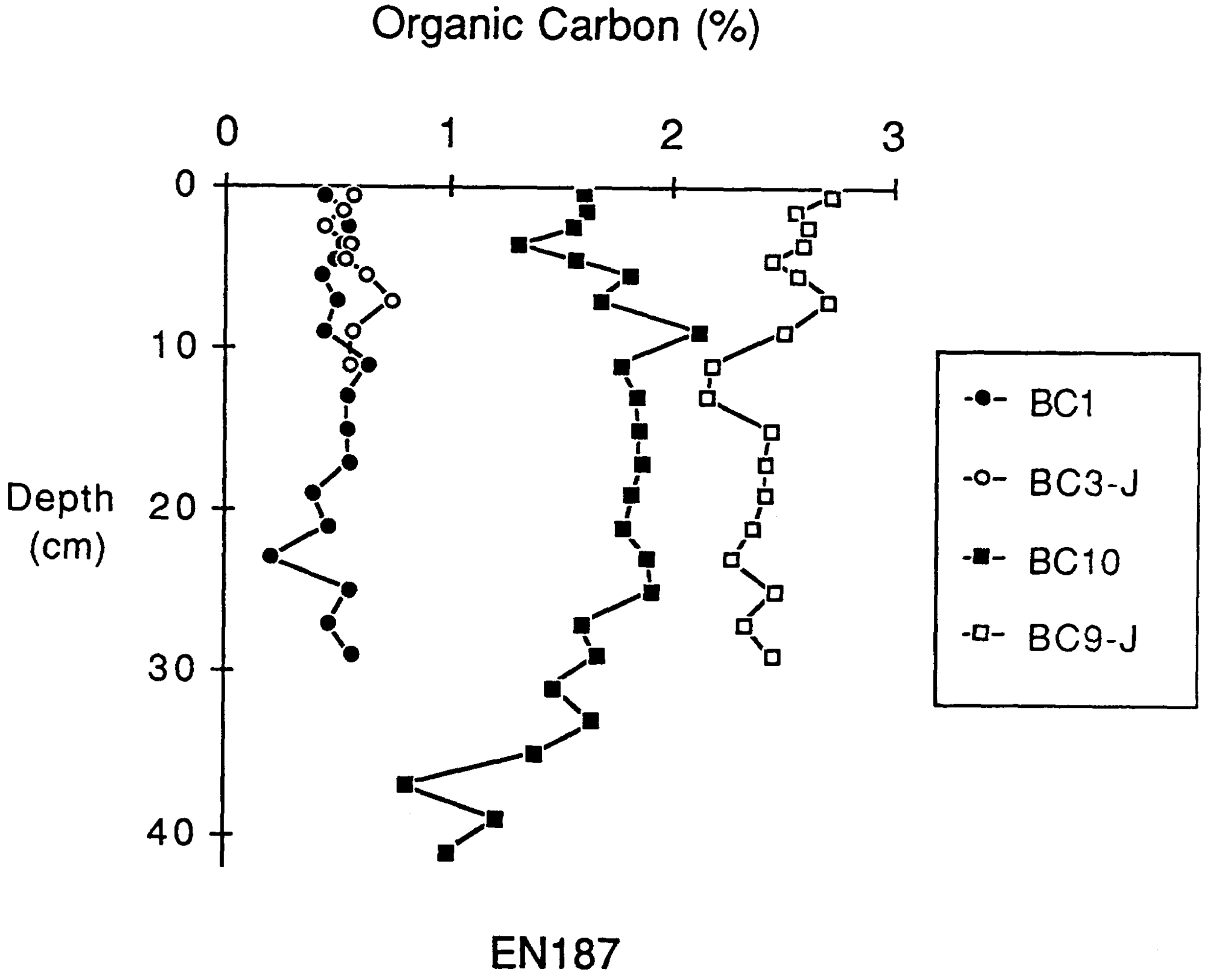


Fig. 2.2.3.2/1 Profiles of organic carbon in 4 box cores collected during EN187. C_{org} analysis for other box cores is in progress and should be completed by the end of October.

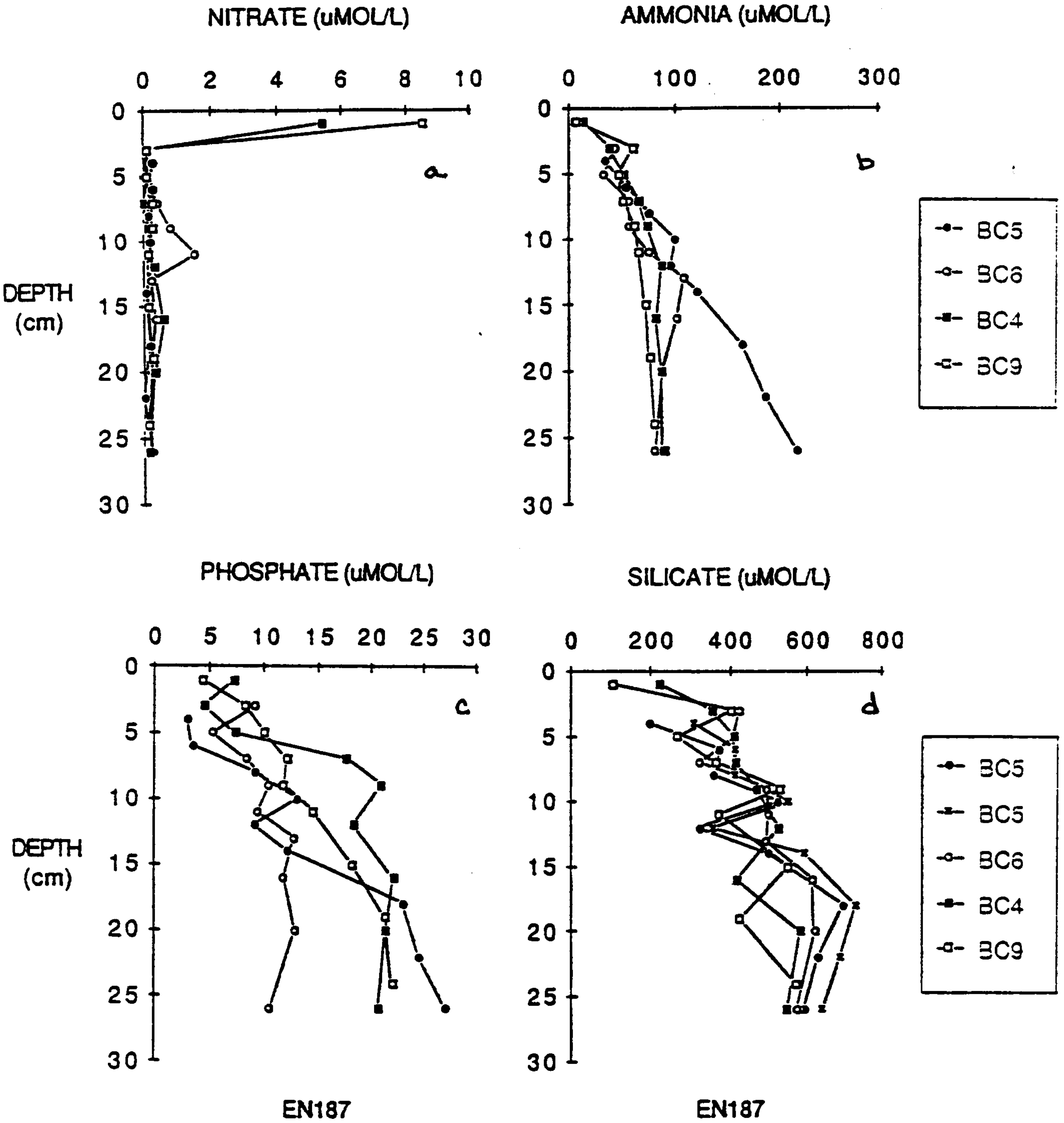
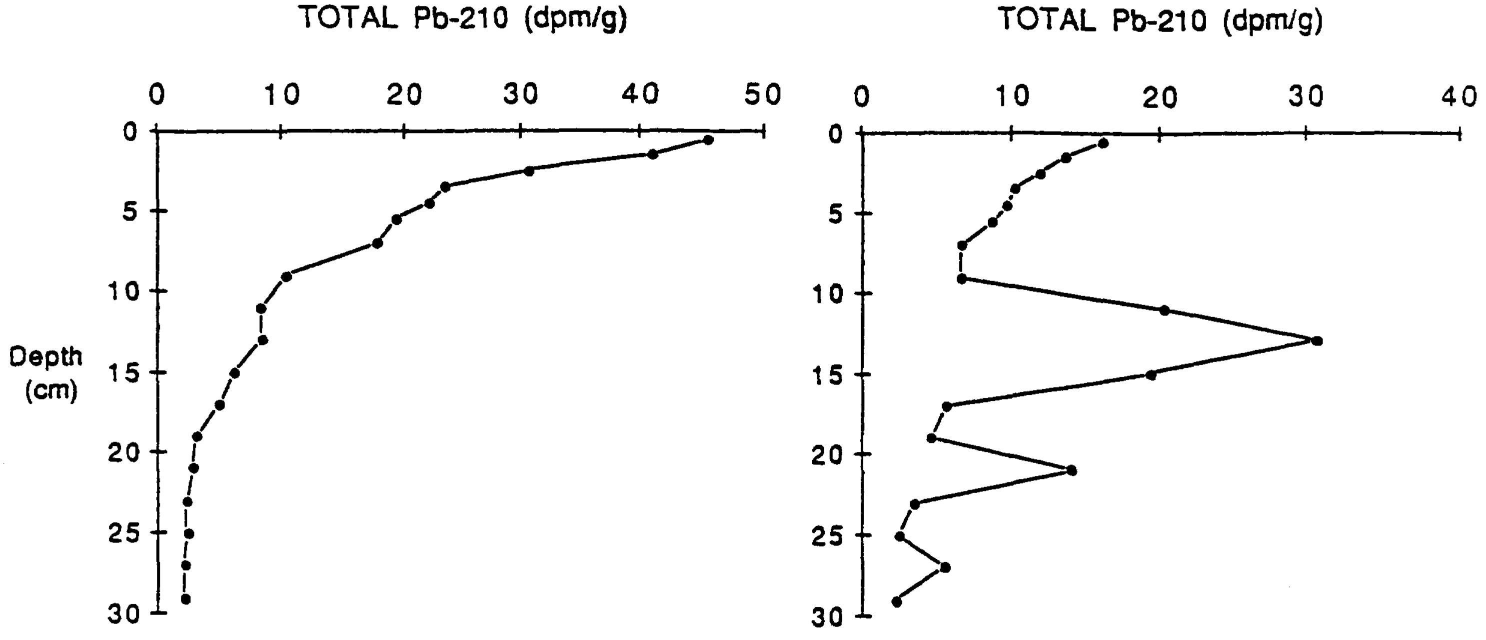


Fig. 2.2.3.2/2 Concentrations of nitrate (a), ammonia (b), phosphate (c) and silica (d) in pore waters collected from 4 box cores during the October 1988 coring cruise (EN187). Pore waters were squeezed from box core subcores using a Jahnke-type squeezer and analyzed by autoanalyzer in G. Rowe's lab.

interface (operationally-defined here as the upper 0-1cm of sediments) derived from Kemp's bacterial metabolism rate measurements.

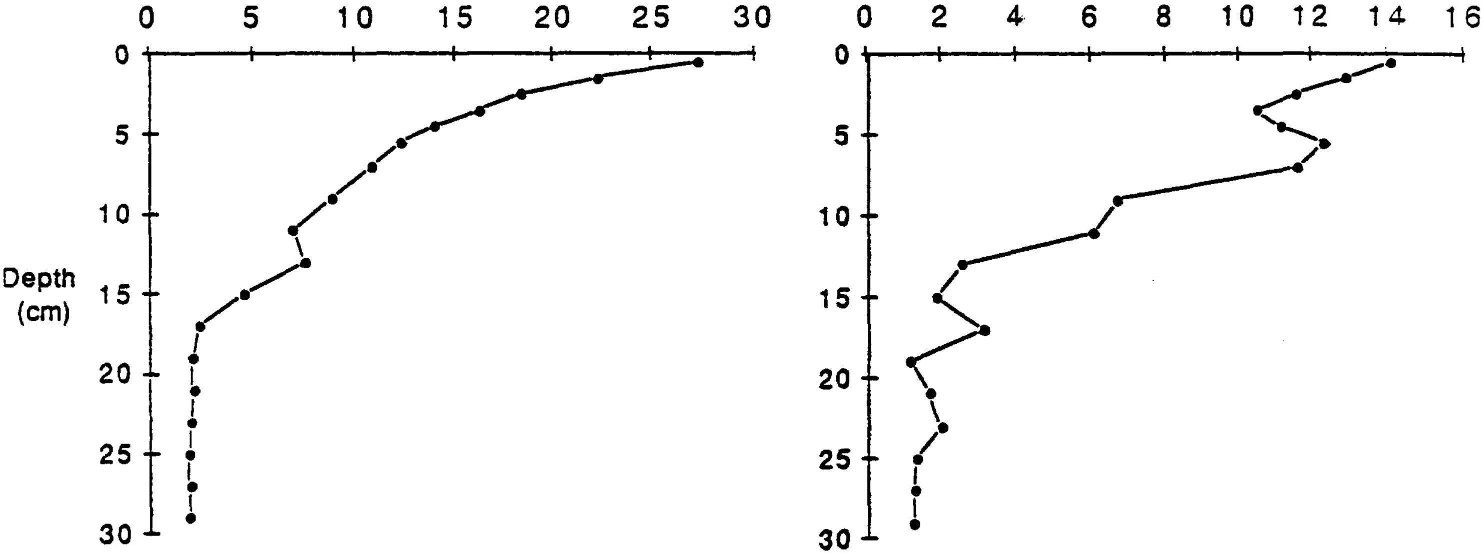
One of our objectives was to couple the C_{org} distribution in the bioturbated upper sediments with mixing rates derived from distributions of ^{210}Pb and plutonium isotopes to estimate C_{org} consumption rates within the mixed layer. This approach has been successfully applied to pelagic sediments (e.g. Emerson et al., 1985; Heggie et al., 1987) where strong C_{org} gradients have been found within the mixed layer. Emerson et al. concluded that C_{org} consumption within the mixed layer exceeded consumption at the sediment-water interface and nearly balanced the POC flux measured with sediments at the pelagic sites. Quite a different situation exists in the slope sediments where we find little, if any, decrease with depth in the C_{org} content of sediments over the upper 5 cm (Figure 2.2.3.2/1) where Emerson, Heggie, and others have observed the greatest C_{org} gradients. We have yet to calculate an upper limit for C_{org} consumption within the mixed layer using this approach, partly because we have both C_{org} (Figure 2.2.3.2/1) and ^{210}Pb results (Figure 2.2.3.2/3 &/4) for only 2 cores as of now. However, by analogy with consumption rates calculated from similar C_{org} and ^{210}Pb profiles in the SEEP-I region, we can state with reasonable assurance that C_{org} consumption within mixed layer sediments of the SEEP-II region derived from this approach will prove to be a small part of the C_{org} budget. This is consistent with the other results noted above which suggest that most of the C_{org} is recycled within the upper 0-1cm of sediments.

Another interesting difference between pelagic and margin sediments involves the rate of organic matter remineralization. Emerson et al. (1987) concluded that labile C_{org} has a residence time with respect to biological remineralization within the mixed layer of deep-sea sediments of 100-1000 years. During the SEEP-I project we concluded that organic matter in that slope region must degrade at the sediment-water interface on a time scale of a few years or less (Anderson et al., 1988). Preliminary SEEP-II results suggests that a similar situation exists in the SEEP-II region. The question of why C_{org} degrades much more rapidly in margin environments than in the deep sea may be related to the relative abundance of benthic biota. Photographic sled tows by Barbara Hecker of LDGO (personal communication) suggest, however, a minimum in the distribution of biomass of important kinds of megabenthos at just about that



EN187 BC5-J

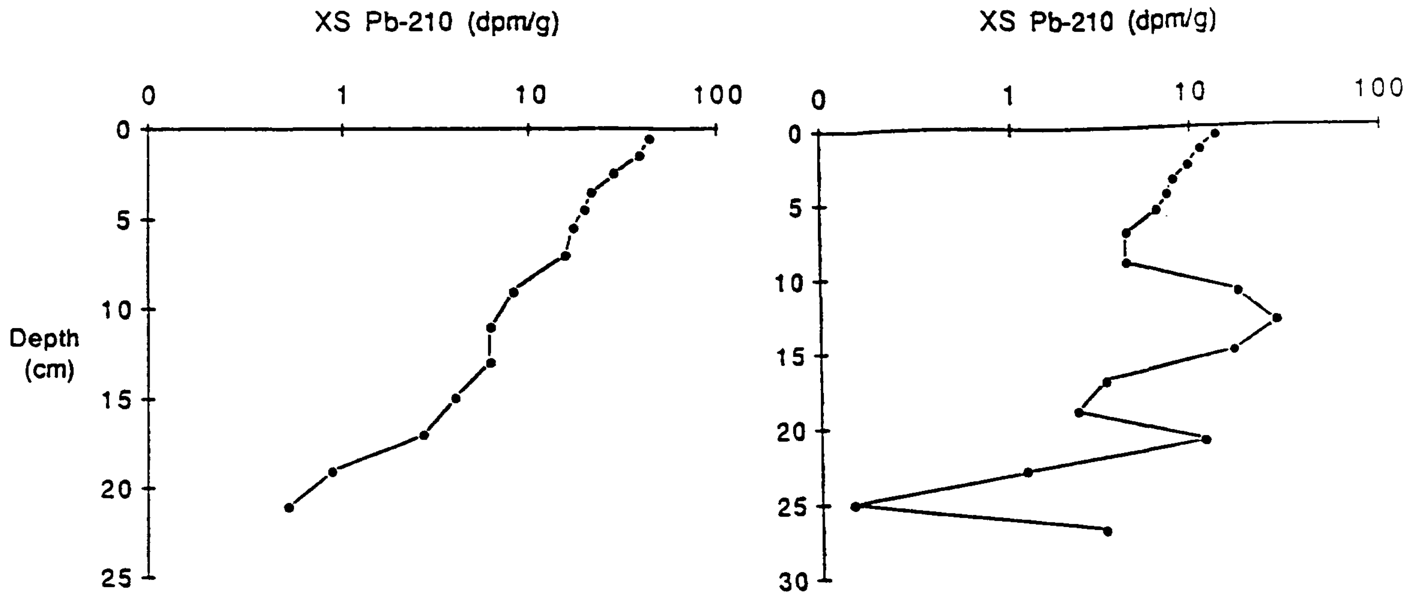
EN187 BC6-J



EN187 BC9-J

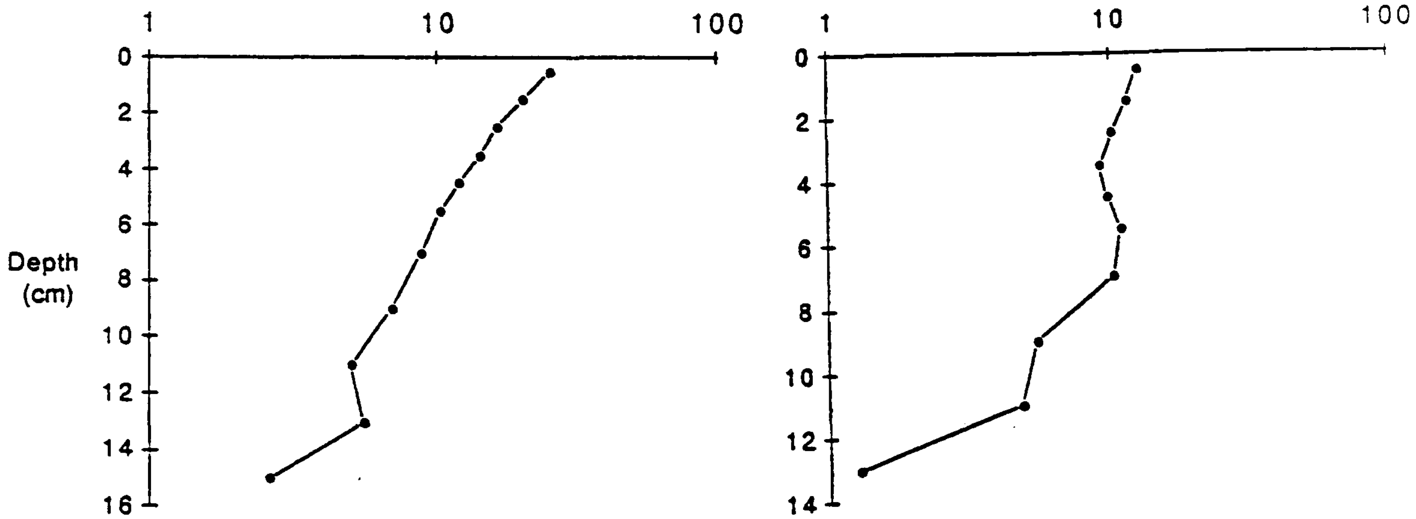
EN187 BC10

Fig. 2.2.3.2/3 Profiles of total ^{210}Pb activity in 4 box cores collected during EN187. Profiles from BC5-J and BC9-J exhibit the classical exponential decrease with depth in unsupported ^{210}Pb activity (Fig. 2.2.3.2/4) from which mixing (bioturbation) rates can be easily calculated. BC10 shows a small subsurface peak at 5-7cm while BC6-J shows two large peaks below 10cm. These subsurface peaks indicate that mixing does not occur in a "random walk" fashion at these sites, and may reflect "conveyor belt" feeding processes by benthic macrofauna. In each case the bioturbated region extends to a depth of about 15-20cm.



EN187 BC5-J

EN187 BC6-J



EN187 BC9-J

EN187 BC10

Fig. 2.2.3.2/4 Profiles of unsupported ^{210}Pb activity in the 4 box cores shown in Figure 2.2.2/4. Unsupported activities were calculated by subtracting the constant ^{210}Pb activity at depth in each core from the total activities at shallower depths. Mixing rates appear to be uniform throughout the entire mixed layer depth in BC5-J and BC9-J. The ^{210}Pb profiles in the upper 7cm of BC6-J and BC10 can be used to place limits on the mixing rates over these intervals.

part of the slope where we are finding rapid Corg degradation rates. There is obviously a lot more analytical, modelling and interpretive work to be done.

3.0 THE SEEP-I EXPERIMENT: CONTINUING RESULTS

By the time the SEEP-II experiment started, we were still analyzing SEEP-I samples and data, both in Geochemistry at Lamont, and in conjunction with other workers at Lamont and elsewhere. Some of these analyses have been completed and the data already published or in the process of being written up in papers. Other analyses are still in process. These residual projects, while a relatively minor part of our effort, included some very interesting data and ideas, and we review them here. Most are related to the SEEP-I sediment trap samples, but one represents additional insights from the SEEP-I shipboard transmissometer data.

3.1 Sediment Trap Samples

3.1.1 Long-Lived Radionuclides.

The SEEP-I experiment was designed to include the study of several long-lived radionuclides, including isotopes of Pu, Th, and U as well as ^{231}Pa. The potential release of Pu into the ocean, either from the operation of commercial power reactors or from weapons production, creates the need for a better understanding of the behavior of Pu in the ocean so that reliable predictions can be made of the consequences resulting from various release scenarios. Plutonium introduced into the atmosphere during testing of nuclear weapons in the 1950's and 1960's is now distributed throughout the oceans at measurable concentrations. Plutonium is being measured in time-series sediment trap samples from both the SEEP-I and SEEP-II experiments to address three principal questions: 1) How do particle flux events, such as those generated by storms, by the passage of fronts and eddies (e.g., Gulf Stream Rings), and by the spring bloom influence the removal, transport, and fate of plutonium in the oceanic environment?; 2) How does the chemical composition of particulate matter influence the scavenging of Pu from the oceans?; and 3) What has been the history of Pu delivery to ocean sediments? Did it occur mainly as a pulse coincident with, or shortly after, the peak in fallout during the late 1950's and early 1960's, or has deposition to the sediments been maintained at a relatively constant level by scavenging from the large reservoir of dissolved Pu in the water column? A full description of the issues related to the third question requires more space than is available here, but the answer to this question has important implications for our ability to use the distribution of Pu in marine sediments to derive rates of bioturbation (mixing) and accumulation. It, along with the answers to the first two questions, is critical to our goal of providing an understanding of the behavior of Pu in the oceans sufficiently completely and accurately so as to be able to predict the fate of future releases into the environment of this energy-related pollutant. Analysis of SEEP time series sediment trap samples will enable us to address each of these questions.

One of the original goals of the SEEP program was to gain a more complete understanding of the conditions and processes which lead to the preferential deposition of certain particle-reactive elements in ocean-margin sediments. Chemical scavenging from seawater is greatly enhanced in ocean-margin regions, where some elements are deposited in sediments at rates more than an order of magnitude greater than in open-ocean regions. Enhanced deposition of particle-reactive elements in ocean-margin sediments has been observed in all of the major oceans (except possibly the Arctic), and the general phenomenon has been termed boundary scavenging (Spencer et al., 1981). Boundary scavenging was deemed a process of considerable interest to DOE because it would also affect many elements and other chemical substances of pollutant origin. This, in turn, could lead to their concentration in nearshore sediments where fishing and other activities could provide a route back to mankind.

Most of our knowledge about the nature of boundary scavenging has been derived from studies of uranium-series radionuclides, specifically ^{210}Pb (e.g., Bacon et al., 1976; Spencer et al., 1981; Cochran et al., 1983) and the ^{230}Th/^{231}Pa pair (e.g., Anderson et al., 1983A&B; 1989). Therefore, the SEEP-I experiment was planned to include extensive studies of these nuclides. Their concentrations and distributions were measured in the water column and sediments while their fluxes were to be assessed with sediment traps. Most of the water column and sediment work has been completed and reported in the literature by ourselves and by our colleagues at WHOI and Yale (SEEP-I volume).

Analysis of sediment trap samples require large amounts of time both from our analysts and from our alpha counting equipment, so that this portion of the SEEP-I project is not yet completed. The current status is that individual SEEP-I sediment trap samples have been combined into larger composite samples to provide sufficient material to measure Pu and the long-lived U and Th-series radionuclides. Chemical processing of all of the composite samples has been completed. The composite samples from the winter

SEEP-I deployment have all been counted. Of the composite samples from the summer deployment, all of the uranium fractions have been counted, and about half of the Th and Pu fractions have been counted. None of the summer Pa fractions have been counted yet. There is no usable information to be derived from counting Pa fractions of shallow-water trap samples, so only the deeper samples are being counted.

A special session incorporating SEEP results is planned for the Spring AGU meeting in Baltimore. We will summarize the completed results for Pu and for the long-lived U and Th-series radionuclides at that time and shortly thereafter the results will be written up in papers for publication in peer-reviewed journals. Although some work remains to complete the study of the sediment trap samples, some interesting features about the nature of boundary scavenging in the Middle Atlantic Bight (MAB) are already evident. A brief summary follows, in chronological order of the findings.

Sediments in the SEEP-I region do not contain inventories of ^{210}Pb and Pu isotopes much greater than would be maintained by their respective regional average rates of supply by atmospheric deposition (Buesseler et al., 1985; Anderson et al., 1988). ^{210}Pb fluxes collected in SEEP-I sediment traps were also only a little greater than would be supplied by atmospheric deposition, and the excess ^{210}Pb was attributed to the downslope transport of particulate matter originating on the shelf or near the shelf-slope break (Biscaye et al., 1988). In contrast with this, sediments at sites along the west coast of the U.S., where active boundary scavenging occurs, have order of magnitude greater inventories of these nuclides. This was the first evidence that boundary scavenging is not operating to any great extent in the region of the MAB. Bacon et al. (1988 and unpublished) measured the distributions of dissolved ^{210}Pb and Th isotopes along the SEEP-I transect and beyond, into the Sargasso Sea. They did not find the expected lateral gradients of decreasing concentrations of these radionuclides approaching the continental margin. This was the second major finding suggesting that boundary scavenging processes are not operative in the MAB region.

An independent indicator of boundary scavenging is provided by ^{230}Th/^{231}Pa ratios of sediments and particulate matter. Without going into great detail, these nuclides are produced by radioactive decay of uranium dissolved in seawater at an initial ^{230}Th/^{231}Pa ratio of 10.8. Pa is an element that is extensively influenced by boundary scavenging whereas ^{230}Th is uniformly deposited over the sea floor with little net lateral redistribution between its production and burial. Consequently, ^{230}Th/^{231}Pa ratios of sediments and particulate matter in the open ocean are often as high as 30 while the corresponding ratios at ocean margin sites are as low as 3 (Anderson et al., 1983A&B; Yang et al., 1986). Ratios <10.8 are generally indicative of boundary scavenging, and the lower the ratio the more intense lateral import of Pa (i.e., boundary scavenging) is interpreted to be. We have analyzed core top samples from along the SEEP-I transect for ^{230}Th and ^{231}Pa, and we consistently find ratios ≥ 10.8. Analysis of SEEP-I sediment trap samples produced similar results (Figure 3.3.1/1). These ratios were interpreted to clearly indicate that there is not a significant net lateral import of particle-reactive elements like Pb and Pa to the sediments of the MAB. In fact, if anything, ^{230}Th/^{231}Pa ratios indicate that there is a net EXPORT of such elements from the slope waters of the MAB.

This is the only ocean margin region in the world where such behavior has been observed. SEEP investigators have hypothesized that perhaps this absence of boundary scavenging is somehow related to the close proximity of the Gulf Stream. The Gulf Stream is known to carry a large amount of particulate matter away from the margin to the open ocean, and it was hypothesized that this export may overwhelm the normal boundary scavenging process(es).

New evidence suggests that something more complicated than the simple offshore transport of particulate matter and associated substances by the Gulf Stream is taking place. By combining results from various sources, we can show that boundary scavenging influences the removal of ^{10}Be from the North Atlantic Ocean, and that the SEEP-I region is a site of greatly enhanced ^{10}Be deposition. ^{10}Be/^{230}Th ratios can be used in much the same way as ^{230}Th/^{231}Pa ratios to identify sites of boundary scavenging. ^{10}Be and ^{230}Th data are available from two open-ocean sites. Somayajulu et al. (1983) studied a core collected at 32°N on the Mid Atlantic Ridge. A Holocene ^{10}Be/^{230}Th ratio of 0.032 X 10^9 (atoms/dpm) can be calculated from their results. At another open-ocean site (40°36'N; 21°42'W; 3485m), Southon et al. (1987) reported a Holocene ^{10}Be/^{230}Th ratio of 0.070 X 10^9 (atoms/dpm). Results are also available for two ocean-margin sites. Holocene sediments off NW Africa contain a ^{10}Be/^{230}Th ratio of 0.15 X 10^9 (compare Th results from Mangini and Diester-Haass, 1983 with Be results from Mangini et al., 1984 for Core 12310: 23°30'N; 18°43'W; 3080m). We have analyzed surficial sediments from two cores collected on the SEEP-I transect (OCE-152 BC5: 38°09'N; 70°56'W; 2691m; OCE-152 BC9: 39°42'N; 70°55'W; 1981m) where we obtained an average ^{10}Be/^{230}Th ratio of 0.40 X 10^9 (atoms/dpm).

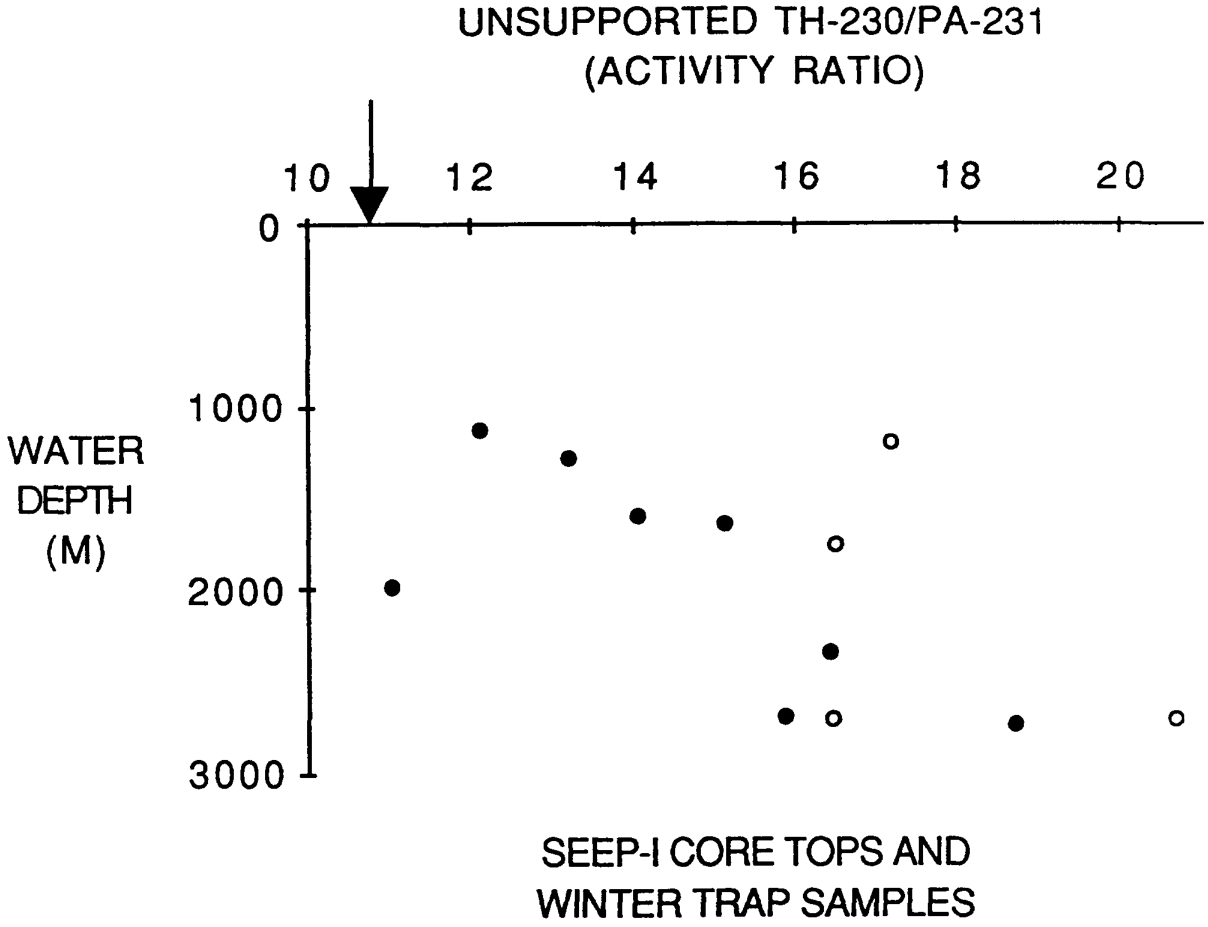


Figure 3.1.1/1 Unsupported $^{230}Th/^{231}Pa$ activity ratios in core top sediments (solid symbols) and composited sediment trap samples from the Winter SEEP-I deployment (open circles). The arrow at the value of 10.8 indicates the ratio at which ^{230}Th and ^{231}Pa are produced by radioactive decay of uranium in the water column. $^{230}Th/^{231}Pa$ ratios of sediments in most ocean margin regions are <10.8, and as low as 3, indicating net lateral import of Pa (i.e., boundary scavenging). The observed ratios in the SEEP-I region, as high as 20, indicate that there must be a net lateral export of Pa produced in the slope waters.

The ^{10}Be/^{230}Th ratio in margin sediments is as much as an order of magnitude greater than in open-ocean sediments, indicating that preferential removal of ^{10}Be at ocean margins occurs in the North Atlantic. More important, the ^{10}Be/^{230}Th ratio sediments from the SEEP-I transect are nearly a factor of 3 greater than the ratio in sediments from the margin off NW Africa where intense boundary scavenging with ^{230}Th/^{231}Pa ratios as low as 3 have been reported (Mangini and Diester-Haass, 1983).

^{10}Be/^{230}Th ratios suggest that intense boundary scavenging occurs in the SEEP-I region whereas ^{230}Th/^{231}Pa ratios and ^{210}Pb fluxes suggest that boundary scavenging is negligible. Boundary scavenging may not affect all elements to the same extent or in the same way. The MAB is clearly different from other margins, and if we can identify the important differences, then we can exploit these differences to gain a better understanding of the nature of the lateral exchange of particle-reactive elements and other substances between coastal regions and the ocean interior. The forthcoming DOE-sponsored COMFS Program will provide an excellent opportunity to address this question.

3.1.2 Major and Minor Elements

The rationale for measuring major and minor elements in the sediment trap samples by plasma spectrometry was given in Section 2.2.1.3. Major element results will provide us with a measure of the aluminosilicate content of the samples (Al, Ti), an estimate of the oxyhydroxide coatings of the particulate matter thought to be an important factor in the scavenging of particle-reactive trace elements from the ocean (Fe, Mn), and an independent estimate of the $CaCO_3$ content of the samples (Ca). Minor elements (Ba, Cu and Zn) will be measured to test their reliability as proxy indicators of ocean productivity. The status of analysis of our sediment trap samples was also discussed in Section 2.2.1.3 where it was noted (and explained thoroughly in 2.2.1.2) that our most senior analyst is fully committed to picking swimmers from the SEEP-II sediment trap samples. This task has taken up virtually all of her time since June 1988 when the first SEEP-II samples were returned to the lab. Since then, she has picked about 300 samples and has about 200 remaining to be picked. Our other skilled analyst, M. Fleisher, who developed the method for simultaneous measurement of major and minor elements by plasma emission, left Lamont for a university in a warmer climate. He has since been replaced by R. Schwartz, but she has been working on SEEP-II sediment samples since she started work at Lamont. We are trying to add another person to the project as soon as possible, and the principal task of that person will be the analysis of sediment trap samples for major and minor elements. The hiring of an additional person for the project is discussed further in the accompanying proposal.

3.1.3 Diatoms and opal.

At the time that our major paper on the SEEP-I sediment trap samples was accepted for publication, the analyses on opaline silica had not yet been finished. We have been looking subsequently for the best vehicle in which to publish this important, complementary data set, and a paper we are working on with Paul Falkowski at BNL appears to fill that need. The paper, tentatively titled, "Sedimentation of phytoplankton on the continental slope off New England" will be by Falkowski, Biscaye, Legendre and Sancetta, and we are still in the stage of exchanging drafts.

The paper is based on species composition counts of phytoplankton in the archive samples from each of the SEEP-I "Summer" traps and trap sampling intervals. Using the distribution in space and time of the species composition, and estimates of C and N associated with the almost-entirely diatom phytoplankton populations, we attempt to derive a C-N budget for just the phytoplankton and an independent estimate of the amount of phytoplankton C-N that was exported from the shelf to the slope. The opaline silica flux data have not yet been integrated into the paper, but the distribution of phytoplankton species confirm some of the major conclusions of our sediment trap paper (Biscaye et al., 1988), viz., that the greater diatom abundance (and, because of greater total mass flux, greater diatom flux) increases with depth in the water column and with proximity to the sediment boundary. This is consistent with the distribution of opal flux as shown in Fig. 3.1.3/1.

The time series of opal flux is shown in Fig. 3.1.3/2, both with all data on the same flux scale (A), and with data on different scales to see the detail in each mooring data set (B). These data show a number of the same flux features as does the total mass flux (Biscaye et al., 1988): the early December storm event was responsible for the export to the slope of a lot of resuspended opal (Churchill et al., 1988); the effects of the spring bloom are seen with decreasing intensity with distance offshore, and possibly with a seaward progression in time of the peak of the bloom. This paper will be finished and submitted to a refereed journal before the end of this calendar year.

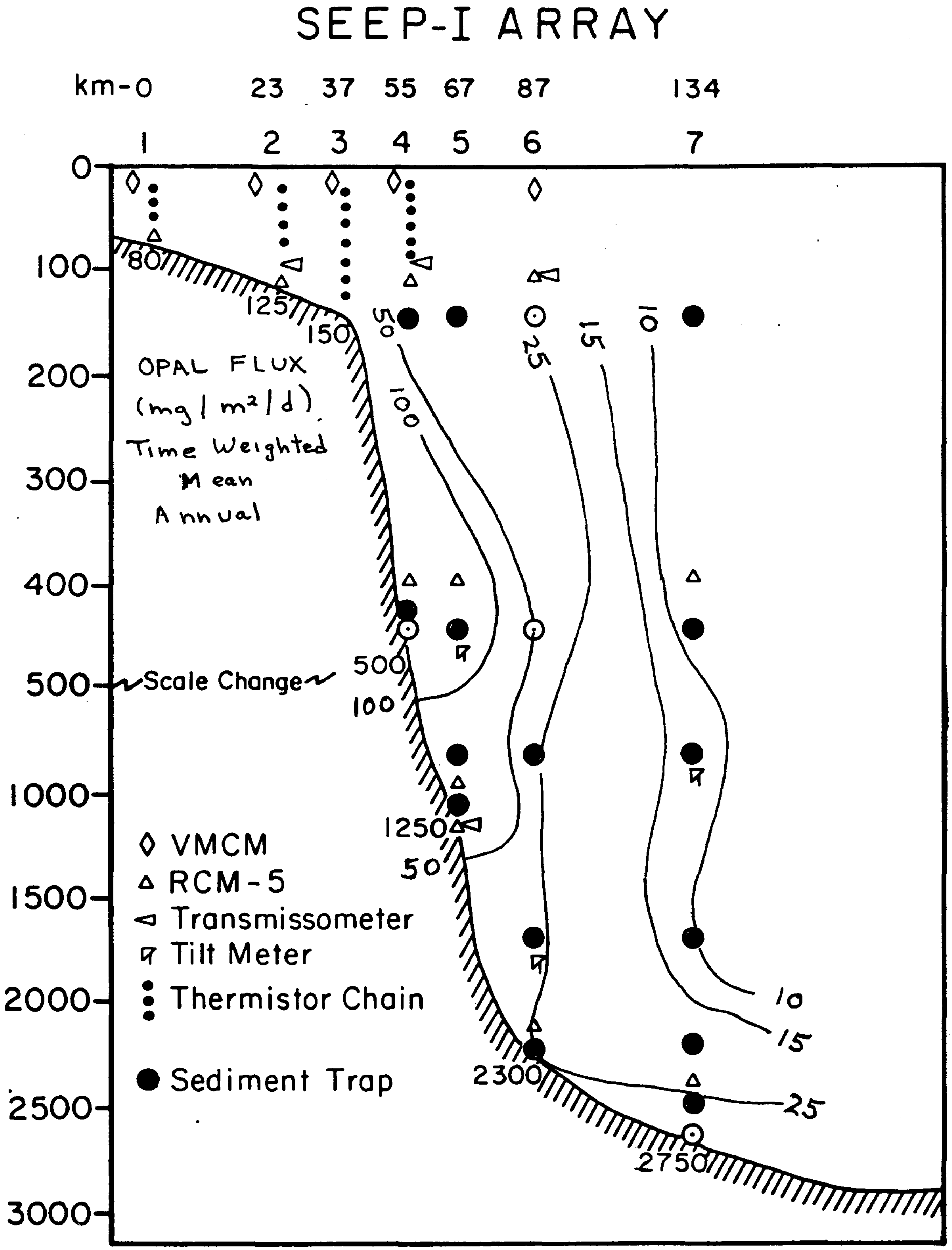


Fig. 3.1.3/1 Section along SEEP-I moorings of the time-weighted annual mean flux of opaline silica in mg m^{-2} d^{-1}. The flux of opal decreases offshore and with distance above and away from the sediment boundary.

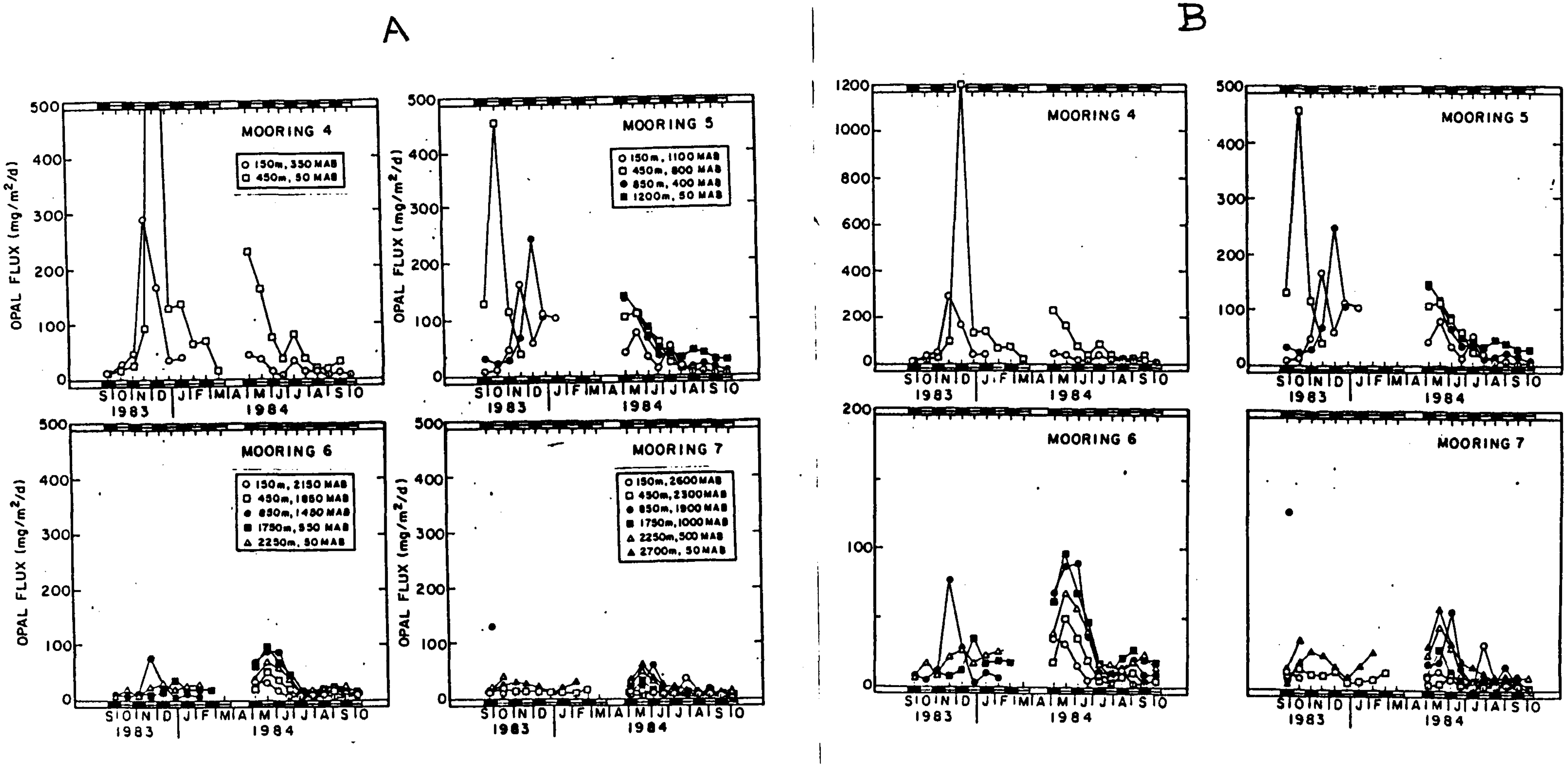


Fig. 3.1.3/2 Time series of opaline silica flux by mooring and trap.

A - Scale of flux intensity is 500 mg m^{-2} d^{-1} for all moorings.

B - Scales of flux intensity are different, decreasing offshore from 1200 mg m^{-2} d^{-1} for Mooring 4, to 500 mg m^{-2} d^{-1} for Mooring 5, and 200 mg m^{-2} d^{-1} for both Moorings 6 & 7.

3.1.4 Fecal Pellets

Prior to her taking a leave of absence from Lamont to have a baby and extending it to have another, Jeanne Stepien had completed most of the work on a study of fecal pellets from the SEEP-I sediment trap archive samples. The data, however, were not in a form to be readily put into a spread sheet for the kind of computative and statistical treatment necessary for such a study, i.e., similar to what we have reported above (section 2.2.1.6) on the SEEP-II fecal pellets with Serge Heussner. She had made some preliminary calculations of fecal pellet mass- (as opposed to pellet number-) fluxes, but the data were primarily in the form of numbers and sizes of pellets of the same size classes as used by Heussner. The data set is an excellent one, and we saw enough of it in talks Jeanne gave prior to her leave of absence, to know that it will still contribute significantly to our understanding of the processes that affected the fluxes of particulate matter into the SEEP-I traps. Over the past year we have worked with her in getting the data into a computer format, and she has had discussions with Heussner during his visit here on differences and similarities in their analytical methods, in their data sets and in the treatment of it. She will submit an abstract on the SEEP-I fecal pellet shape, size and mass flux distributions for the AGU-ASLO meeting in New Orleans in February 1990, and, based on those results, write a paper with Biscaye for publication in a refereed journal.

3.1.5 Nitrogen and Carbon Isotopes.

During a year's sabbatical at Lamont, K.K. Liu of the Institute of Earth Sciences (Academia Sinica) Taipei, Taiwan, R.O.C., set up extraction facilities for the preparation of samples for carbon and nitrogen isotopes. During that year (1987-1988) he became aware of the SEEP-I experiment and its results, and expressed interest in seeing whether or not our sediment trap samples might yield any interesting and useful data on nitrogen isotopes. Altabet (19__) has published interesting seasonal variations in $d^{15}N$ ratios on samples from Deuser's long-term sediment trap mooring near Bermuda, but explanations for the variations are complicated and convoluted to the point of conviction that there must be better. The SEEP-I sediment trap samples also exhibit very large seasonal variations in organic matter, but they differ from the Bermuda samples in comprising a strong gradient from coastal (continental shelf) towards open ocean (continental rise) conditions. On the premise that this gradient might contain variation that would provide insight into the published $d^{15}N$ values, we gave Liu aliquots of a few of the more abundant trap samples to try out. He did tests on the sodium azide with which the samples had been poisoned, did tests to reduce the amount of trap material needed for analysis, and obtained results which showed sufficient variability that we agreed to pursue the matter with additional samples. He has gone back to Taiwan to set up an extraction system and mass spectrometer there, and has taken eight more samples from a single trap representing a time series from April through December 1984. He has not contacted us with further results on these samples at this writing.

3.1.6 Bacteria

Before leaving Lamont for the Univ. of Maryland, Hugh Ducklow had been involved in the pre-SEEP and early SEEP activities. Based on the work he had done on pre-SEEP samples from the New York Bight, we took aliquots of the SEEP-I trap samples for bacterial analysis per his instructions. These samples, in fact, have become the "raw" archive samples that have proven so useful for the studies of fecal pellets (section 2.2.1.6 and 3.1.4) and phytoplankton (section 3.1.3) as well as bacteria. We sent both the Winter and Summer trap archive samples to Ducklow, and he completed analysis of the entire Winter series. At the point of possibly starting the Summer series, he got an image analysis system and wanted to get some sort of semi--automated analytical technique worked out using those samples rather than trying to proceed with the brute-force manual method used on the Winter samples. At just about that point, Ducklow also got involved up to his keester in GOFS and the North Atlantic Spring Bloom experiment, so I have had grave doubts about the Summer samples ever getting analyzed or the Winter analyses ever being published. My only hope, since Ducklow is an honest and dependable fellow, and since he agrees that the data set is excellent and contains obvious additional insights into SEEP-I particle flux processes, and since he writes extremely well and with a facility that is frustrating to those of us who sweat and groan in anguish and travail over writing, is that he will some day get to writing up those data. This effort having taken place under this grant period, we have mentioned it here, but this is the last we will bring it up until it sees the light of publication.

3.1.7 Chlorinated hydrocarbons

During SEEP-I Richard Bopp of Lamont received a modest amount of funding to make some analyses of chlorinated hydrocarbons in the SEEP-I sediment trap and sediment core samples. With some of those data, he was one of the authors in our (the only) sediments paper in the SEEP-I CSR volume (Anderson et al., 1988). Although he had made some analyses of sediment trap samples prior to the end of his SEEP funding, the number was insufficient to put together a complete story. The number of our trap samples he has been able to analyze since then has been restricted to a few samples related to other, funded projects, which we gladly provided. (We still think that, especially for the dollar, Bopp's work had and still has the potential to contribute something significant to the questions of across-shelf and off-shelf particulate transport being addressed in SEEP.) Along with the other reports of various completed and in-progress analyses of SEEP-I samples, we provide here a brief summary of what Bopp has found to date.

The most interesting chlorinated hydrocarbon results on SEEP samples were obtained for pp'-DDT and its anaerobic derivative pp'-DDD. In box core EN123-BCE-6, these compounds were used to constrain sediment mixing and accumulation rates, the onset of anaerobic conditions in the sediment column, and DDT accumulation rates (Anderson et al., 1988). Recent work has focussed on the pp'-DDT to pp'-DDD ratio in sediment and large volume suspended particle samples as an indicator of cross-shelf pollutant transport. The two major, known, quantifiable sources of these compounds -- Hudson River discharge and Hudson River and environs dredge spoil disposal on the inner shelf -- are characterized by a pp'-DDT to pp'-DDD ratio of much less than 1. In contrast, surface sediments of the SEEP-I region have ratios much greater than 1, indicating minimal cross-shelf transport to this region (which is not improbable since the SEEP-I region is largely upstream in terms of the net, southwesterly, along-shelf drift direction). The SEEP-I trap samples also have ratios >>1, but consistently less than the uppermost portions of core EN123-BCE-6, which integrates the last several decades of input. This suggests that we are beginning to see some transport of nearshore pollutants to this region. Simple budget calculations indicate that this represents, at most, only a small fraction of the total dredge spoil and river discharge inputs to the shelf.

Results from the MASAR sediment trap samples (see location of the B trap in Fig. 1.2/1 and section 2.1.4.1) show the pp'-DDT to pp'-DDD ratios to be indistinguishable from those of the SEEP-I samples. We have hypothesized a "downstream-cross-shelf" scenario in SEEP to envision the transport of particles and pollutants from the nearshore to the shelf break. Thus, despite independent indication that the offshore flux of carbon and ^{210}Pb at the MASAR "B" trap might be a factor of ~2-3 higher than at SEEP-I (Biscaye et al., 1988), the pp'-DDT to pp'-DDD ratios suggest that the cross-shelf component of that transport is insufficient to bring polluted particles from the Hudson to the shelf break as far northeast as the region of MASAR mooring B.

The most likely source of the high pp'-DDT to pp'-DDD ratios is delivery of DDT from the atmosphere during aerial spraying in the Northeast in the 1950s and 1960s to control gypsy moths and mosquitos. The observation that this source continues to dominate the contamination of suspended particles indicates that DDT has a water column and surface sediment residence time of years to decades with respect to removal to and mixing into the sediments. Such a result is significant to our understanding of the fate of other particle-associated, energy-related pollutants (such as PAHs) in this environment.

Bopp has extended this work to the nearshore shelf environment through a grant from the NJDEP. He anticipates publishing all the results sometime in the coming year in a paper involving the geochemical behavior of DDT in the shelf/slope environment.

3.2 Shipboard Transmissometer Data

Alberto Palanques, a Post Doctoral Fellow from the University of Barcelona, spent a year at Lamont participating in SEEP-II, including 6 of the cruises. His thesis in Spain had been about particulate outflow from the Ebro estuary and its record in the adjacent continental shelf and slope and sediments, and a great deal of that dealt with the distribution of SPM in the shelf and slope waters. He participated in a number of the aspects of SEEP-II -- traps, radionuclide analyses, x-ray analyses, etc. -- but was particularly interested in the SPM distributions and the dynamic and biological processes affecting them. The SEEP-I shipboard profiling transmissometer data set had not been studied in any detail, and he took this on during his visit.

By the time he left in July 1989, we had completed the first draft of a paper entitled, "Patterns and controls of the suspended particle distribution over the shelf and upper slope south of New England" (Palanques and Biscaye). The principal results of that paper are that the SPM in the SEEP-I study area in the water column on the shelf and uppermost slope tends to display several regularities in its distribution that are related to certain hydrographic and dynamical features. These distributional features occurred with sufficient consistency throughout the year, irrespective of season, that we take them to be general characteristics of that portion of the Middle Atlantic Bight.

Proceeding from shallow water offshore, these features are as follows. 1) The shelf water column out to about 50-60 m water depth consistently displays very high beam attenution coefficients (BAC) (high SPM concentrations) which, like the water column, give evidence of being strongly mixed vertically from bottom to surface. This zone of high, well-mixed SPM coincides with the zone within which surface waves can reach to the bottom, resuspend and mix vertically bottom sediment. 2) Seaward of this zone, and partially defining it geographically, is a zone of relatively low BAC that coincides with that low-temperature residual feature called the cold pool. That low-SPM, low-temperature association must be related to reduced tendency toward vertical mixing because of isopycnal stability. We are not aware of any data on this count at the present, but it also seems possible that the "cold pool" does not participate in the general southwesterly advective drift as rapidly as the water around it, and therefore does not tend to resuspend sediment. 3) The next feature, generally seaward, is a zone of high-BAC near the bottom that coincides with the intersection of the shelf-slope front with the bottom. Whether the rapid back and forth seaward and shoreward movement of the foot of the front itself is capable of resuspending sediment, or whether there is a focussing of internal wave energy along the front at the foot, we are presently exploring. The coincidence of the two features, however, certainly means some dynamic relationship. 4) The most seaward feature is just at or beyond the shelf/slope break and is another zone of relatively high SPM adjacent to the bottom. We hypothesize that the energy responsible for this feature is the breaking of shoreward-propogating internal waves at this critical depth and change in bottom declevity.

Examples of the distributions in which we see these features are seen in Figs. 3.2/1 and 3.2/2. We anticipate being able to finish and submit this paper by the end of the current grant period.

4.0 COMPLEMENTARY PROJECTS

4.1 Sediments/Carbon Budget- Other Opportunities for Collaboration

SEEP PI's collaborating on sediment studies were identified in Section 2.1.6. Results from this work were described in Section 2.2.3. Here we note two exciting possibilities for collaborating with other investigators that were established during the present funding year. First, Chris Martens has been measuring rates of sulfate reduction and methanogenesis in the SEEP-II region for several years. He and his students presented their results at the Spring AGU meeting earlier this year. While we (including Kemp and Rowe) are measuring total carbon consumption rates in the sediments, we are not determining

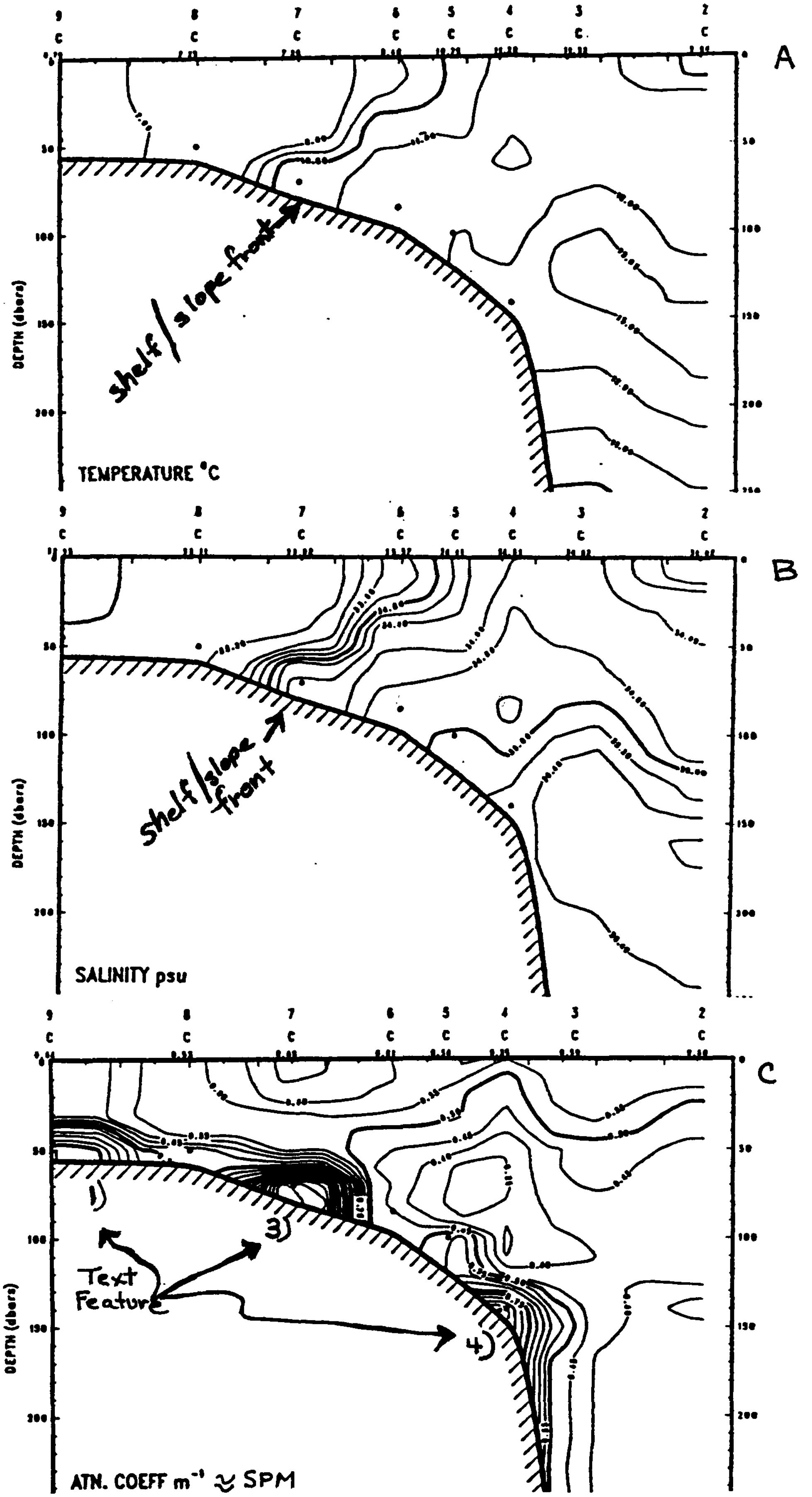


Fig. 3.2/1 Hydrographic/SPM transect during SEEP-I-04 cruise on 15 February 1984. A: Temperature distribution. B: Salinity distribution. C: Beam Attenuation Coefficient distribution, which is a measure of SPM. Features described in the text as 1), 3) and 4) are indicated.

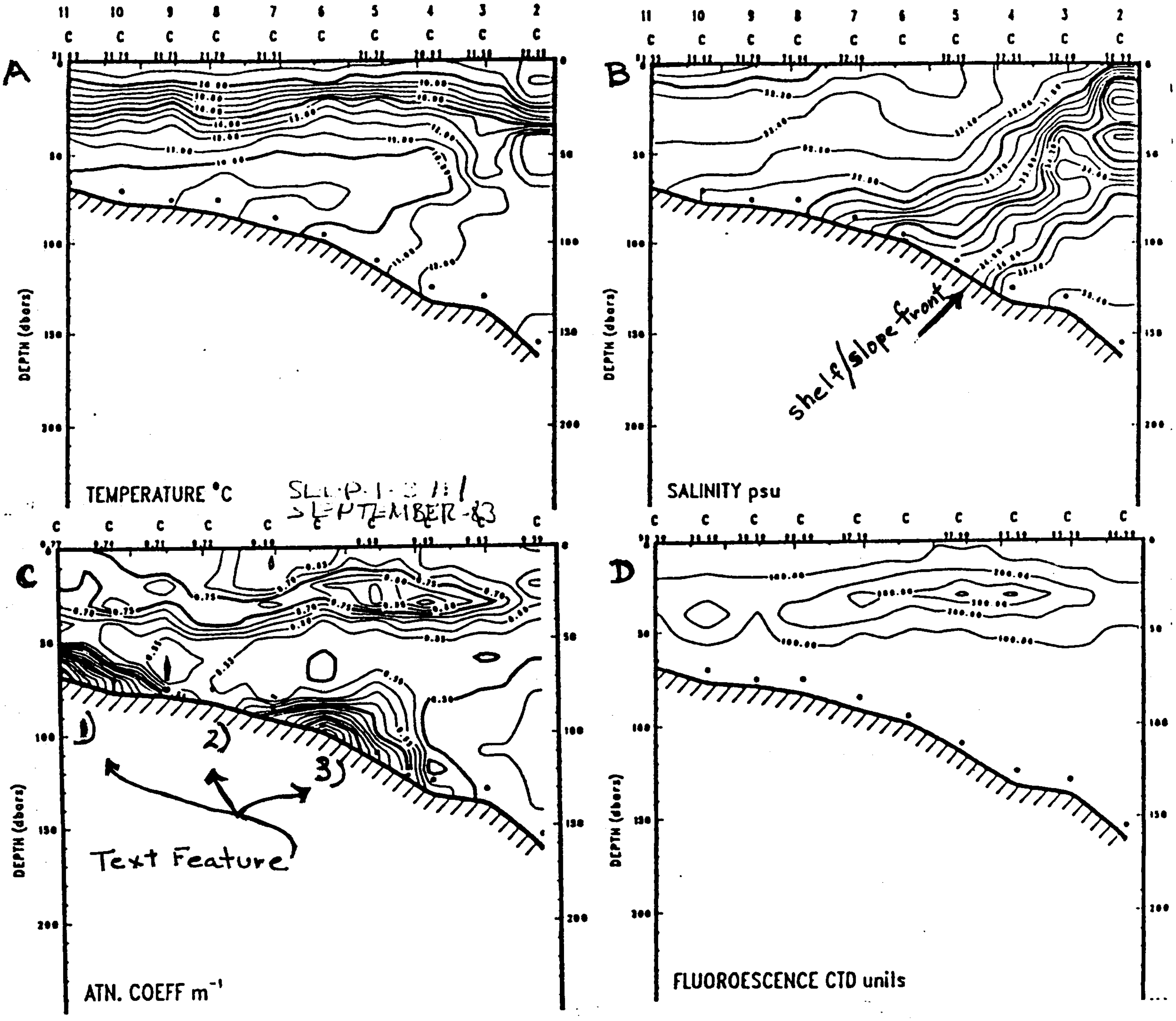


Fig. 3.2/2 Hydrographic/SPM transect during SEEP-I-03 cruise on 6-7 September 1983. A: Temperature distribution. B: Salinity distribution. C: Beam Attenuation Coefficient distribution, which is a measure of SPM. Features described in the text as 1), 2) and 3) are indicated. D: Fluorescence.

the individual contributions by sulfate-reducing and methane-producing bacteria. Collaboration with Martens will enable us to resolve total sediment respiration into individual major components.

Second, Dr. Susan Trumbore, a former graduate student at Lamont, is interested in examining the turnover rates of specific organic carbon compound classes in the organic-rich slope sediments. After completing her Ph.D. at Lamont, Trumbore spent a post doc year with W. Wolfli's group at the accelerator in Zurich. More recently, she spent a couple of months working with Chris Martens. Last month she took up a position with the new accelerator group at the Lawrence Livermore National Laboratory. Our samples from the SEEP-II region provide a unique opportunity to study carbon cycling. Radionuclide results suggest that our time-series sediment traps positioned ~10m above bottom on the upper slope caught material swept off the shelf. We believe that most of this material is relatively fresh biodetritus that represents the source of the high organic carbon contents of the upper slope sediments. These samples are large enough to provide Trumbore with sufficient material to analyze individual time-series (approx. 2-week interval) samples. Her fractionation scheme would include separation of total organic carbon into individual classes, the relative abundance, $^{13}C/^{12}C$ isotopic ratio, and ^{14}C age of which will help test our hypothesis that this indeed represents fresh biogenic material swept off the shelf and not much older slope sediments resuspended by bottom currents. Downcore changes in the abundance and apparent ^{14}C ages of individual compound classes will provide the relative turnover rates of each class. Comparing the trap samples with the underlying sediments will also help identify and quantify individual compound classes which are remineralized so rapidly at the sediment-water interface that they never become incorporated into the sediment record. Finally, our collaboration with Trumbore will address the question of how much of the refractory carbon which survives burial for thousands of years is of terrigenous origin. This is the first time, to our knowledge, that the relative turnover rates of various major organic carbon compound classes has been followed from fresh particulate phases in the water column to sediments that have been buried for thousands of years.

4.2 Atmospheric vs. Sediment Trap ^{210}Pb

In our work in SEEP-I on ^{210}Pb in sediment traps, sediments, and in attempts to budget that isotope and infer whether or not it is being focussed into slope sediments, we have relied extensively on the estimate of the flux of atmospheric ^{210}Pb by Turekian's group at Yale. Prior to the start of SEEP-II we had made contact with Tom Church of U. Delaware about his work on atmospheric ^{210}Pb, and, not only was he planning to take additional samples at Lewes DE, but he enthusiastically agreed to conform his sampling frequency to the same schedule as we were planning to use on the SEEP-II sediment traps. He has taken those samples, analyzed them, and, completed only preliminary data reduction on them. We have had one brief meeting just a few days prior to this writing, and his preliminary data indicate regular variation of about a factor of 3-4 in the flux of atmospheric ^{210}Pb during the course of about 9 months of the experiment. He does not have the absolute value of the flux yet, but we will be pursuing this valuable data set with Tom. It will certainly have a bearing on our SEEP-II ^{210}Pb sediment trap data, and we hope to eventually have something to publish with him on the atmospheric/ocean margin coupling of this isotope.

4.3 ECOMARGE

ECOMARGE is the name (ECOsystemes de MARGEs continentales) of a French program, sponsored by the CNRS, and which is part of the PFO (Particulate Fluxes in the Ocean), the name for the group of projects that is the French part of JGOFS. It is under the direction of Andre Monaco of the Universite de Perpignan, and includes investigators from several other countries -- Switzerland, Belgium, Spain, Italy, Greece, Yugoslavia, Canada and Algeria. Its objective -- to study the flux of particulate matter; its pollutants and energy from the continental margin out into the oceanic abyss -- is very similar to those of SEEP. And its experimental approach -- multi-disciplinary, -investigator and -institutional, time-series as well as "snapshot" data, etc. -- is also similar to that of SEEP. For that reason Biscaye was invited to attend as an external reviewer the first colloquium on ECOMARGE in Perpignan in June 1987. Through that first contact (4.3.1) he has continued a collaboration with this group which has included co-(guest)-editing a special ECOMARGE issue of Continental Shelf Research (4.3.2), and in the first pilot experiment of the extension of ECOMARGE from the Mediterranean onto the Atlantic side of France in the ECOFER-I experiment (4.3.3). This collaboration has flowed east to west, as well as west to east in the visit of Serge Heussner to Lamont to participate in analysis of the SEEP-II samples (2.2.1.6). This collaboration has been fruitful, we think in both directions, and we look forward to additional points of contact with these and other colleagues in Europe.

4.3.1 ECOMARGE Colloquium -- June 1987.

The Perpignan colloquium revealed a wide range of disciplinary interests participating in ECOMARGE, but, as is the case in SEEP, restrictions on the availablity of people and/or money mean that some of the scientific bases are not covered or covered poorly. About 60 papers were given at the colloquium, conveying a very good idea of the experiment and its results.

Besides differences in disciplinary emphases, kinds and quantities of equipment, etc., the major difference between the two programs is a philosophical one built into the hypotheses around which the experiments were designed. Based largely on the mid-slope ribbon of carbon-rich sediments in the Mid-Atlantic Bight, the SEEP hypothesis has been that the fine-grained particulate material formed on or introduced to the waters of the continental shelf (but not found in its sediments), is either consumed and recycled on the shelf, exits in the advective offshore flow at Hatteras, or is transferred across the shelf/slope break and deposited on the the slope. The question of the role of submarine canyons has been ignored, largely on the basis that we have insufficient resources to study both the transfer to the slope and the canyons at the same time. By contrast, based largely on the fact that about half of the continental slope in the Gulf of Lions is dissected by submarine canyons, the ECOMARGE hypothesis has been that the fine-grained material introduced to and formed on the continental shelf is largely transferred to the slope where it finds its way into canyons and thence down to the abyssal ocean. If it is sedimented onto the slope, this is a temporary deposition, and it is subsequently swept downstream into a canyon. Toward the end of the Mediterranean phase of ECOMARGE, they did some tests with moored sediment traps to test this hypothesis, but, we have not seen those results at this writing, but have heard that they confirm the ECOMARGE hypothesis on the role of canyons. We are participating in a further test of this in the ECOFER project (see 4.3.3). The proceedings of the colloquium have been published in book form as a collection of extended abstracts and the record of discussion sessions by the C.I.E.S.M. (Commission Internationale pour l'Exploration Scientifique de la mer Mediterrananee), Principality of Monaco (ECOMARGE Colloquium, 1987).

4.3.2 Continental Shelf Research special issue

As we did in SEEP-I, the French decided that Continental Shelf Research was the appropriate vehicle for a combined publication of the results from the Mediterranean ECOMARGE project.

They are putting together a special issue of that journal and asked Biscaye to share in the guest editorial duties. The general division of responsibilities is along the lines that Roger Pocklington, Bedford Inst. of Oceanography, Canada, is handling primarily the biological, organic geochemical papers; Biscaye the geochemical, sediment-trap, SPM papers; and Monaco the geological, physical and all the rest. The volume is approaching the final deadline for revised papers, and at present consists of about 20 papers distilled out of those presented at the colloquium. The CSR ECOMARGE issue should be out in early 1990.

4.3.3 ECOFER-I Experiment

The ECOMARGE group is presently committed to a similar experiment on the Atlantic side in that body of water the French, in their provincial chauvinism, call the Golfe de Gascogne, but which the Spanish, in a more outgoing recognition of an ancient heritage, call the Bay of Biscay, or, when they spell it correctly, the Bay of Biscaye. The new enterprise will include some new participants, notably a large contingent from the nearby Universite de Bordeaux, and in an effort to begin the practical matter of integrating a new team of scientists with a new mix of interests and talents, they have undertaken a pilot study in which they invited us to collaborate. It is called ECOFER which means something of the order, "ECOmarge experiment in the canyon de cap FERret". Their other objectives in the pilot study aside, we agreed on two objectives for our collaboration: first, that we intercalibrate, or, more modestly, we intercompare our SEEP sediment traps with the French traps that have been and will be used in ECOMARGE and in the upcoming French JGOFS experiment EUMELI; and second, that we attempt to address, in a very modest way, the philosophical difference between SEEP and ECOMARGE with respect to the flux of particles in submarine canyons versus those to the slope sediments between canyons, i.e., the interfleuves.

The intercomparison objective involves the simultaneous deployment of the several kinds of sediment traps in a part of the water column where one anticipates minimal flux gradients between the several traps. To accomplish this we sent four of our 0.071 m^2 traps (and two 25 cm Sea Tech transmissometers) to France to be deployed with six 0.125 m^2 PPS-3 (*Piege de Particule Sequentiel* ["time series sediment trap"] - model 3) traps, two 1.0 m^2 PPS-5 traps, and, at the last minute, one 0.85 m^2 trap from the French IFREMER lab at Brest which had been used a great deal previously by the Brest lab.

The scientific objective -- canyon vs. interfleuve for particle flux -- was addressed by dividing our resources between two moorings and deploying one in the Canyon and the other on an adjacent interfleuve. The moorings are identical, except for the single IFREMER trap on the interfleuve mooring. The moorings and their relative positions are presented schematically (and not to scale) in Fig. 4.3.3/1. We do not feel that the second scientific objective compromises the intercomparison objective, because the uppermost of the three groups of instruments (about 1000 meters above bottom = mab; ~1300 m deep) on both moorings is above the influence of the canyon walls, and is in a zone of minimum SPM concentration and vertical gradient, as determined by profiling nephelometer before the mooring deployments. It is the 1000 mab groups of instruments that contain two each of all varieties and sizes of traps (except one of the IFREMER). It is in the lower groups of instruments -- a LDGO and PPS-3 trap at ~250 mab on each mooring, and a single PPS-3 on each mooring at ~30 mab -- that we hope will provide some data on the difference between particle fluxes in the canyon vs. on the interfleuve. The ~250 mab pairs of LDGO and PPS-3 traps can also possibly be intercompared for total mass and constituent fluxes, since the two kinds of traps are only separated by 15 m, and the flux gradient <u>may</u> not be too great at that height above bottom, but we cannot be sure.

Biscaye participated in a French cruise on R/V Noroit to the region of the Canyon de Cap Ferret where the moorings were deployed in late June, and will be recovered in early November. The results from this experiment should be valuable in themselves, and will constitute an interesting complement to the SEEP project, on the other side of the Atlantic.

5.0 PAPERS PUBLISHED, SUBMITTED, PRESENTED AND IN PREPARATION

The following is a list of the various publications produced by Biscaye and Anderson under support of this grant since the last triennial report. Most of the work has been directly in connection with SEEP or with the complementary projects discussed in this Report. Some papers, however have been published during this triennial support period, for which there was no specific funding for either Biscaye or Anderson, resulting from techniques developed earlier under DOE support, and for which DOE support is acknowledged.

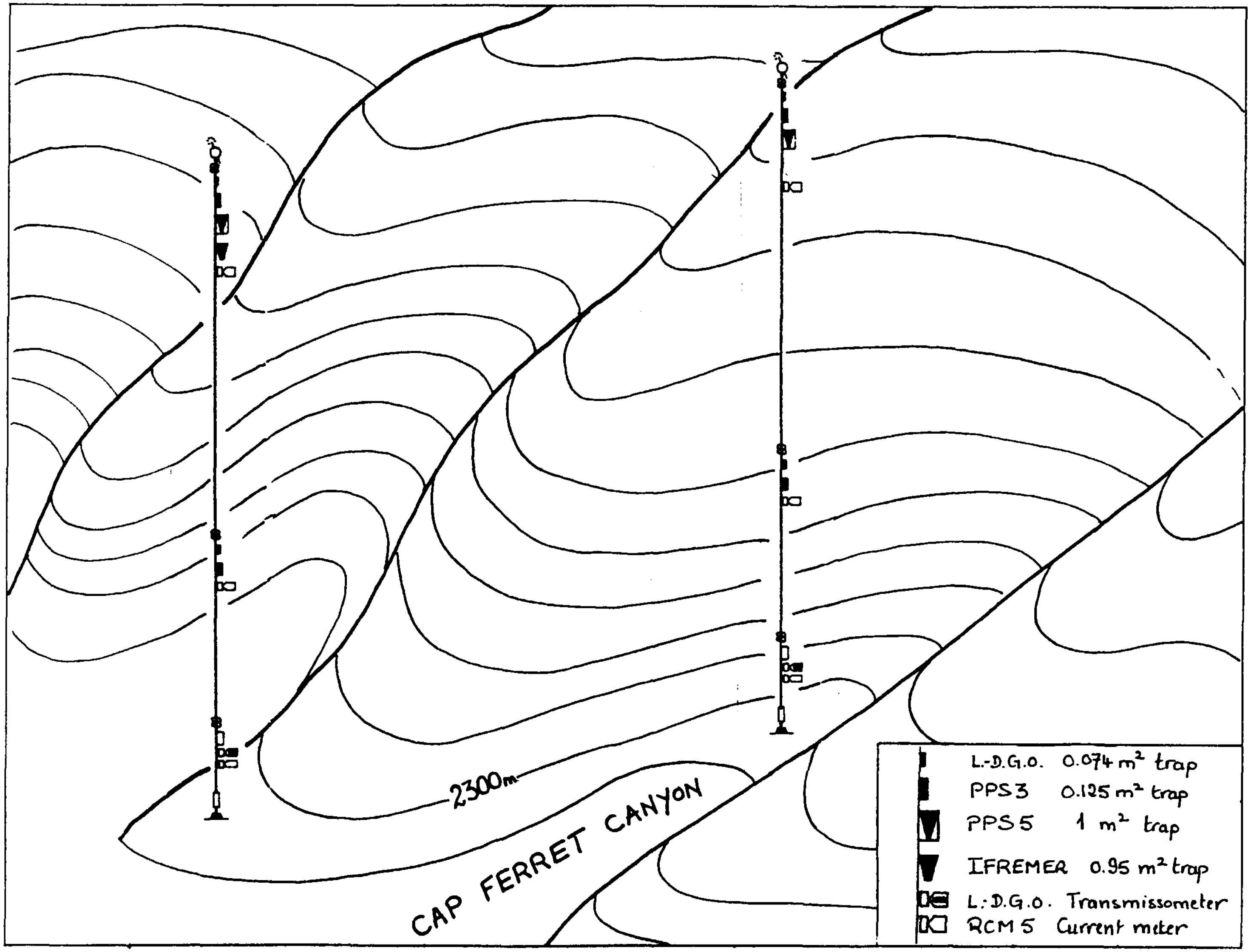


Fig. 4.3.3/1 Schematic representation of the two ECOFER-I moorings in the Bay of Biscay: one in the Canyon de Cap Ferret, and the other on an adjacent interfleuve at the same depth (~2300 m).

5.1 Papers Published and In Press

Anderson, R. F., R. F. Bopp, K. O. Buesseler and P. E. Biscaye (1988). Mixing of particles and organic constituents in sediments from the continental shelf and slope off Cape Cod: SEEP-I results. Cont. Shelf Res., 8: 925-946.

Anderson, R. F., Y. Lao, W. S. Broecker, S. E. Trumbore, H. J. Hofmann an W. Wolfli (1989). Boundary scavenging in the Pacific Ocean: A comparison of ^{10}Be and ^{231}Pa. Earth Planet. Sci. Lett., in press.

Biscaye, P. E., R. F. Anderson and B. L. Deck (1988). Fluxes of particles and constituents to the Eastern United States continental slope and rise: SEEP-I. Cont. Shelf Res., 8: 855-904.

Churchill, J.H., Biscaye, P.E. and Aikman, F. 1988. The character and motion of suspended particulate matter over the shelf edge and upper slope off Cape Cod. Cont. Shelf Res., 8, 789-809.

Grousset, F.E., Biscaye, P.E., Zindler, A., Prospero, J., and Chester, R. 1988. Neodymium isotopes as tracers in marine sediments and aerosols: North Atlantic. Earth and Planet. Sci., 87, 367-378.

Hamelin, B., F.E. Grousset, P.E. Biscaye, A. Zindler and J. Prospero, Anthropogenic lead in aerosols at Barbados and the isotopic contrast between lead pollution from U.S.A. and Europe over the North Atlantic. J. Geophys. Res. (in press).

Mathieu, G.G., Biscaye, P.E., Lupton, R.A. and Hammond, D.E. 1988. System for measurement of ^{222}Rn at low levels in natural waters. Health Physics, 55, 989-992.

Walsh, J.J., Biscaye, P.E. and Csanady, G.T. 1988. The 1983-1984 Shelf Edge Exchange Processes (SEEP) -I experiment: hypotheses and highlights. Cont. Shelf Res., 8, 435-456.

5.2 Ph D Thesis Completed

Carson, S.R. 1989, The use of Rn-222 as a tracer of mixing in the waters of the continental shelf and slope of the Middle Atlantic Bight. Columbia University, 478 pp.

5.3 Papers in Preparation

Biscaye, P.E. A System for Function Verification in Oceanographic Instruments (In preparation for submission to Deep-Sea Research).

Biscaye, P.E., and S. Carson, Anomalous zone of low concentrations of excess radon-222 in the near-bottom waters of the continental slope. (For submission to Jour. Geophys. Res.)

Biscaye, P.E., F.E. Grousset, and E.J. Dasch, Rubidium-strontium "model ages" in deep-sea sediments: Atlantic Ocean. (For submission to Earth and Planet. Sci. Let.)

Brun-Cottan, J.C., P.E. Biscaye, S. Carson, Intermittent sediment resuspension on the Eastern U.S. Continental Slope. (For submission to Jour. Geophys. Res.)

Falkowski, P.G., Biscaye, P.E., Legendre, P. and Sancetta, C. Sedimentation of phytoplankton on the continental slope off New England: SEEP-I. (Journal not yet decided)

Monaco, A., Soyer, J., Biscaye, P.E. and Pocklington, R. The 1985-1986 ECOMARGE (ECOsystemes de MARGEs continentales) experiment: Gulf of Lions (Western Mediterranean). (For submission to Continental Shelf Res.)

Palanques, A. and Biscaye, P.E. Patterns and controls of the suspended particle distribution over the shelf and upper slope south of New England: SEEP-I. (For submission to Continental Shelf Res.)

5.4 Abstracts Published

Bard, E.B., Hamelin, B., Lao, Y., Anderson, R.F. and Fairbanks, R.G., 1989. Dating the last interglacial period by U/Th mass spectrometry of Caribbean corals. ICP III, Cambridge, U.K.

Biscaye, P.E. 1987. SEEP (Shelf Edge Exchange Processes): Fluxes from the continental shelf to the slope and rise off the eastern United States. (abs.) Coll. Intern. Oceanol., Perpitnan, C.I.E.S.M.

Biscaye, P., F. Aikman III and J.H. Churchill, 1987. Motion of suspended particulate matter over the shelf-edge and upper slope off Cape Cod, (abs) EOS Trans. AGU, V. 68, p. 335.

Grousset, F., B. Hamelin, P. Biscaye and J. Prosporo, 1988, Trans-Atlantic transport of aerosols: evidence from anthropogenic Pb isotope signatures, (abs) Chemical Geology, v. 70, p. 196.

Grousset, F., P. Biscaye, B. Hamelin and A. Zindler, 1987, Pb isotopes as a tracer in aerosols and oceanic sediments North Atlantic Ocean): the geological signal (abs) EOS Trans. AGU, V. 68, p. 470.

Hamelin, B., F. Grousset, P. Biscaye, C. Lambert and A. Veron, 1987, Pb isotopes as a tracer in aerosols and oceanic sediments North Atlantic Ocean): the anthropogenic signal (abs) EOS Trans. AGU, V. 68, p. 470.

Lao, Y., Anderson, R.F., Broecker, W.S., Trumbore, S.E., Hofmann, H.J. and Wolfli, W., 1989. Boundary scavenging in the Pacific Ocean: A comparison of ^{10}Be and ^{231}Pa. (abs.), EOS, 70, 369.

6.0 REFERENCES

Anderson, R. F., M. P. Bacon and P. G. Brewer (1983A). Removal of ^{230}Th and ^{231}Pa from the open ocean. Earth Planet. Sci. Lett., 62: 7-23.

Anderson, R. F., M. P. Bacon and P. G. Brewer (1983B). Removal of ^{230}Th and ^{231}Pa at ocean margins. Earth Planet. Sci. Lett., 66: 73-90.

Anderson, R. F., R. F. Bopp, K. O. Buesseler and P. E. Biscaye (1988). Mixing of particles and organic constituents in sediments from the continental shelf and slope off Cape Cod: SEEP-I results. Cont. Shelf Res., 8: 925-946.

Anderson, R. F., Y. Lao, W. S. Broecker, S. E. Trumbore, H. J. Hofmann an W. Wolfli (1989). Boundary scavenging in the Pacific Ocean: A comparison of ^{10}Be and ^{231}Pa. Earth Planet. Sci. Lett., in press.

Bacon, M. P., D. W. Spencer and P. G. Brewer (1976). ^{210}Pb/^{226}Ra and ^{210}Po/^{210}Pb disequilibria in seawater and suspended particulate matter. Earth Planet. Sci. Lett., 32: 277-296.

Bacon, M. P., R. A. Belastock, M. Tecotzky, K. K. Turekian and D. W. Spencer (1988). Lead-210 and Polonium-210 in ocean water profiles of the continental shelf and slope south of New England. Continental Shelf Res., 8: 841-853.

Baker, E. T. and Milburn, H.B., 1983. An instrument system for the investigation of particle fluxes. Continental Shelf Res., 1, 425-435.

Betzer, P.R., Showers, W.J., Laws, E.B., Winn, C.D., DiTullio, G.R., and Kroopnick, P.M., 1984. Primary productivity and particle fluxes on a transect of the equator at 153 W in the Pacific Ocean. Deep-Sea Res., 31, 1-11.

Biscaye, P.E. A System for Function Verification in Oceanographic Instruments (In preparation for submission to Deep-Sea Research).

Biscaye, P. E., R. F. Anderson and B. L. Deck (1988). Fluxes of particles and constituents to the Eastern United States continental slope and rise: SEEP-I. Cont. Shelf Res., 8: 855-904.

Buesseler, K. O., H. D. Livingston and E. R. Sholkovitz (1985). ^{239,240}Pu and excess ^{210}Pb inventories along the shelf and slope of the northeast U.S.A. Earth Planet. Sci. Lett., 76: 10-22.

Churchill, J.H., Biscaye, P.E. and Aikman, F. 1988. The character and motion of suspended particulate matter over the shelf edge and upper slope off Cape Cod. Cont. Shelf Res., 8, 789-809.

Cochran, J. K., M. P. Bacon, S. Krishnaswami and K. K. Turekian (1983). ^{210}Pb and ^{210}Po distributions in the central and eastern Indian Ocean. Earth Planet. Sci. Lett., 65: 433-452.

ECOMARGE Colloquium, 1987. Colloque International d'Oceanologie: ECOsystemes de MARGEs continentales, Ed. A. Monaco, Perpignan, 23-26 juin 1987, Publ. C.I.E.S.M., Monaco, 96 pp

Emerson, S., K. Fischer, C. Reimers and D. Heggie (1985). Organic carbon dynamics and preservation in deep-sea sediments. Deep-Sea Res., 32: 1-21.

Emerson, S. C. Stump, P. M. Grootes and F. H. Schmidt (1987). Estimates of degradable organic carbon in deep-sea surface sediments from ^{14}C concentrations. Nature, 329: 51-53.

Fowler, S.W. 1977. Trace elements in zooplankton particulate products. Nature, 269, 51-53.

Heggie, D., C. Maris, A. Hudson, J. Dymond, R. Beach and J. Cullen (1987). Organic carbon oxidation and preservation in NW Atlantic continental margin sediments. In: Weaver, P. P. E. and J. Thomson, eds., Geology and Geochemistry of Abyssal Plains. Geol. Soc. Spec. Pub. No. 31, pp. 215-236.

Heussner, S., Ratti, C. and Carbonne, J., 1990. The PPS-3 time-series sediment trap and the trap sample processing techniques used during the ECOMARGE experiment. Cont. Shelf Res. (in press).

Jahnke, R. A. (1988). A simple, reliable, and inexpensive pore-water sampler. Limnol. Oceanogr., 33: 483-487.

Knauer, G. and Asper, V., 1989. Sediment trap technology and sampling. U.S. GOFS Planning Report No. 10.

Komar, P.D., Morse, A.P., Small, L.F. and Fowler, S.W., 1981. An analysis of sinking rates of natural copepod and euphausid fecal pellets. Limnol. Oceanogr., 26, 172-180.

Mangini, A. and L. Diester-Haass (1983). Excess Th-230 in sediments off NW Africa traces upwelling in the past. In: E. Suess and J. Thiede, eds., Coastal Upwelling: Its Sedimentary Record. Plenum Press, New York, pp. 455-470.

Mangini, A., M. Segl, G. Bonani, H. J. Hofmann, E. Morenzoni, M. Nessi, M. Suter, W. Wolfli and K. K. Turekian (1984). Mass spectrometric ^{10}Be dating of deep-sea sediments applying the Zurich tandem accelerator. Nucl. Instr. Meth. B5, 353-358.

McGee, J.A. and Tillett, R.H., 1983. Hangs and obstructions to trawl fishing: Atlantic Coast of the United States. Univ. North Carolina Sea Grant Publication UNC SG-83-01.

Mo, A. and Watts, R. 1987. A computer program for the design of taut subsurface moorings. GSO (Grad. School of Oceanog.) Technical Report No. 87-7, GSO, URI, Narragansett RI.

Somayajulu, B. L. K., P. Sharma and W. H. Berger (1983). ^{10}Be, ^{14}C and U-Th decay series nuclides and δ^{18}O in a box core from the central North Atlantic. Mar. Geol. 54, 169-180.

Southon, J. R., T.-L. Ku, D. E. Nelson, J. L. Reyss, J. C. Duplessy and J. S. Vogel (1987). ^{10}Be in a deep-sea core: implications regarding ^{10}Be production changes over the past 420 ka. Earth Planet. Sci. Lett. 85, 356-364.

Spencer, D. W., M. P. Bacon and P. G. Brewer (1981). Models of the distribution of ^{210}Pb in a section across the north equatorial Atlantic Ocean. J. Mar. Res., 39: 119-138.

Yang, H. S., Y. Nozaki, H. Sakai and A. Masuda (1986). The distribution of ^{230}Th and ^{231}Pa in the deep-sea surface sediments of the Pacific Ocean. Geochim. Cosmochim. Acta, 50: 81-89.

APPENDICES

Bound separately from this Report are Appendices consisting of copies of the papers and abstracts published and in press resulting from the support of this grant in the past three years.

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