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ABSTRACT

The present contract year has been one of transition from an emphasis on field work and sample gathering to the predominance of sample and data analysis and the formulation of testable hypotheses concerning specific processes in the New York Bight.

We have begun to understand the seasonal transition in the role of phytoplankton vs. grazing zooplankton in forming the particles on which some reactive pollutants are removed. This allows a plan for differential sampling of biomass constituents in the coming year.

Using natural radioactive tracers we have estimated the removal rates of reactive metals from the surface waters and these range over an order of magnitude from most rapid nearshore to least rapid over the upper continental slope. Once removed nearshore, however, these tracers, and the pollutants for which they proxy, do not remain permanently in the sediments but appear to be remobilized (probably by oxidation) during the winter and are reintroduced into the water column. We have also used man-made radioactive tracers from the Oyster Creek nuclear reactor to measure the transport of those radionuclides within and out of Barnegat Bay. Slightly under half of the radiocobalt introduced into Oyster Creek from the reactor has been deposited in the sediments of the Bay while the remainder has been exported from the Bay and probably been generally dispersed on the continental shelf.

Work on transport and mixing processes of pollutants which are or behave like those in solution has continued along several fronts. Hydrographic data on the structure of the water column continues to give a

description of the system that is crucial to understanding geochemical and biological processes which affect pollutants. Hydrographic characterization of water masses from the data sets of cruises has resulted in hypotheses concerning the renewal of shelf water by direct exchange between shelf and upper slope water. This is seen as interleaving tongues of both water types. A paper on double diffusion as the mechanism of mixing of these two water types has been written.

Progress on the use of oxygen isotope ratios to identify water mass origins awaits construction of the sample equilibration system. Work on the use of excess radon-222 as a natural tracer of small scale water motions and mixing has focused on improving the analysis of dissolved radium-226 parent, on the variability of the sediments as the source of excess radon and on both vertical and horizontal modelling of existing radon data sets. Partly as a result of an informal conference on the zone of low near-bottom excess radon and low suspended particulate matter, we propose to test an hypothesis on its origin in a field program in the coming year.

We began work on the suitability of tritium as another conservative tracer for distinguishing water masses and mixing processes on the scale of the New York Bight. Preliminary results are very promising and we plan to expand this work in the coming year.

The only field work supported under this contract year will take place on a one week cruise next month (August 1978) the principal objectives of which are to test short term (scale of hours to days) variability of a number of the measurements we have made under this program (excess radon, suspended particulate matter, chlorophyl a, nutrients, T, S, O_2, etc.), and to obtain box cores for radionuclide measurements while testing the suitability of two different box coring devices.

1.0 INTRODUCTION

The present contract year has been one of transition in progress toward our long-term goal: to understand and to quantify the processes that govern the transport and dispersal of energy-related pollutants introduced to the continental shelf by man's activities. The transition has been both scientific and administrative. Scientifically we have to a great degree shifted from the descriptive emphasis of the first several years of gathering seasonal data sets, to one of using those data for quantitative modelling, understanding processes and formulation of hypotheses for testing. Administratively at Lamont we changed from five Principal Investigators to one in order to improve both intra- and extra-mural communication, and in Washington the funding agency became a new Department. From our point of view the practical effect of this change, along with outside triennial review, was to delay consideration of our proposal for this year's work until early 1978. In response to that review and to consideration of available time, we submitted a Revised Proposal in February 1978 which was subsequently approved. The Revised Proposal to some degree summarized progress to that date and we rely in part on that recent summary in reporting progress to this date.

That progress is summarized most briefly in the ABSTRACT. The next most succinct summary is in Section 1.1 Accomplishments of D.O.E. Goals which simply lists specific major achievements in our program.

The remainder of the Report is organized exactly as was the Revised Proposal (February 1978) and as is the Renewal Proposal which accompanies this Report. The discussion in each case is organized conceptually into three parts: first, because of the importance of fine-grained particulate matter in processes affecting the transport of reactive pollutants, PROCESSES ASSOCIATED WITH SUSPENDED SOLIDS, (Section 2.0); second, is Section 3.0, MIXING RATES OF CONTINENTAL SHELF SEDIMENTS, which deals with understanding the problem of removal of pollutants from the system by mixing them downward in the sediment column once deposited; and third, (Section 4.0) SPREADING OF WATER CHARACTERISTICS AND SPECIES IN SOLUTION) which involves the identification of the many sources of water on the continental shelf processes which mix, exchange and transport water, and tracer and pollutant species which move with water masses.

The many processes which are involved in the behaviour of pollutants within these conceptual divisions are chemical, physical and biological in nature. Data from the three disciplines into which the project is administratively organized (Geochemistry, Physical Oceanography and Marine Biology) are required in all conceptual divisions and emphasize the fact that our project is increasingly one in which the division of labor is along goal-oriented, and not along classical disciplinary lines. The complexity of the problem and the futility of classical disciplinary division is illustrated by Fig. and Table 1 (p.2-4) in the Revised Proposal (February 1978), and which is repeated as Fig. 1.0 - 1 in our Renewal Proposal. Seventeen different processes are enumerated, the elucidation of most of which are specific goals of this project and for which we have utilized some analytical technique, whether geochemical, biological or physical oceanographic. In the present contract year we have added one geochemical tracer - tritium - to our arsenal. Tritium, despite its origin largely in global fallout, appears to have great potential in helping to unravel water mass origins and mixing processes on the reduced scale of the New York Bight.

In the three major sections of the Report which follows, we summarize progress made this year toward understanding and quantifying those processes. The most measurable progress toward these ends is the publication of scientific papers and the status of these is listed in the final section. Reprints of these papers either not included or included in preprint form in last year's Report are collected in an Appendix of which only a single copy is being sent to D.O.E. (Dr. Arnold Joseph).

1.1 Accomplishments of D.O.E. Goals

The following statements and conclusions represent significant accomplishments toward our long term goal of understanding how and at what rates pollutants are dispersed, transported and removed from the New York Bight.

-Using natural radionuclides we have measured the actual removal rates of reactive species and find that they generally increase shoreward. That is, the time for the system to remove half of a reactive pollutant decreases from the upper continental slope (where it ranges from 2 to 6 months,) to the inner shelf (where it is on the order of tens of days). Pollutants removed in oxidizeable form, however, appear to be remobilized during the winter and reintroduced into the water column.

-From the distribution of $^{239,240}Pu$ in the waters and particulate matter of the Bight it appears that this very important and dangerous energy-related pollutant moves in dissolved or extremely fine colloidal form, rather than associated with larger suspended particulate matter.

-In conjunction with work under other support we have learned that there are two major pathways by which plankton influence the vertical flux of radioactive nuclides in the Bight: early in the season the flux is primarily via diatom detritus directly whereas later in the summer (after the water becomes stratified) the flux is provided by fecal material from zooplankters grazing on nanoplankton.

--Primary productivity, rather than biomass or total particulate concentration, probably controls the residence time of reactive pollutant species. During the course of thermocline formation this productivity moves from the center of the continental shelf both shoreward toward the Apex and seaward toward the shelf break, both sources of nutrients.

- We have measured radioactive isotopes from the Oyster Creek nuclear reactor on Barnegat Bay and have measured the relative rates at which radiocesium, manganese and cobalt are removed from the water onto particulate matter. We have done a complete budget of radiocobalt and found that only 40% of that nuclide produced by the Oyster Creek reactor resides in the sediments of Barnegat Bay. The other 60% has escaped to the continental shelf on either suspended or dissolved form where it is probably only temporarily stored in local pockets of fine-grained sediments which are subsequently generally dispersed.

- Seasonal and short term (yo-yo) CTD data sets indicate that the interleaving of shelf and upper slope water may be an important mechanism of exchange. Dissipation of these parcels of water into the adjacent regime may be by double diffusion of both heat and salt.

2.0 PROCESSES ASSOCIATED WITH SUSPENDED SOLIDS

2.1 Introduction

Our approach to the role of suspended solids as both tracers and carriers of pollutants in the Bight has been several fold. First, for every 30ℓ Niskin sample taken we have filtered an aliquot of the water for gravimetric analysis of total suspended matter concentration. This has resulted in three-dimensional distribution maps as a function of season most of which have been published and discussed in previous reports. During the present contract year we have begun analysis of these data in the context of their relationship to other parameters measured on the same water samples, e.g., relationship to chlorophyl-a (Sec. 2.2), to the distribution of radionuclides (Sec. 2.3). As mentioned in our Revised Proposal (Feb. 1978) we also want to try to exploit the apparently analogous behaviour of resuspended particles and excess radon. Both are bottom-source tracers, the source strength of which is, to a first approximation, a function of grain size, both reflect vertical distributions related to vertical mixing characteristics and both exhibit similar scales of horizontal dispersion from sources. We have not actually begun a quantitative evaluation of these relationships, as this requires more progress in modelling the radon data than we have made to date (Sec. 4.3.3).

The next approach is aimed at understanding the nature and sources of particulate matter, i.e., breaking it into its numerous constituent parts. The upgrading of the XRF facility at Lamont (with other funds) has recently been completed and we will start thin film XRF analyses on particulate matter shortly. Mineralogical analysis of particulate matter on filters has been delayed by problems in interfacing the sample changer with the diffractometer, but these too should be underway before the end of the present contract year.

Section 2.2 deals with our attempt to understand the role of biogenic particles in the total particulate milieu. This section reports a statistical analysis of the biological data on primary productivity, the total suspended particulate concentrations, and some of the radioisotope tracer data.

Section 2.3 (below) deals with a third approach to understanding the role of particulate matter - the use of natural and man-made radioisotopes which are or become associated with marine particulate matter. These isotopes provide very sensitive tracers for particle-related processes and, in several cases where we know tracer source functions, provide internal radioactive clocks for estimating the rates at which these processes occur.

2.2 The Production and Fate of Phytoplankton Biomass

Introduction

Suspended particles play a major role in the transport of heavy metals, radionuclides and chlorinated hydrocarbons within and through waters of the continental shelf. Since phytoplankton production is the major source of organic particles in the NY Bight, an understanding of the origin and fate of phytoplankton and phytodetritus is critical to an evaluation of the influence of particles on the distributions of these pollutants.

We participated in four cruises in 1977. The results of the first three were presented in the 1977 annual report. The results of the fourth cruise in September 1977 and of a statistical analysis of the relationships between distributions of total suspended solids, phytoplankton biomass (as indicated by chlorophyll *a*) and a variety of radionuclides are presented in this report. We have completed a manuscript (to be submitted to *Limnology and Oceanography*) on the production and fate of phytoplankton biomass based in part on information from these cruises (Appendix).

Phytoplankton Biomass during September 1977

Stations were occupied in a mid-shelf area north and south of the Hudson Channel 19-24 September 1977 (Fig. 5.0-1) Methods of sampling and measurement were presented in the 1977 annual report. Phytoplankton biomass was generally low (<1 µg Chl l^{-1}) and similar to concentrations found in the same area above the pycnocline during April and May 1977. Vertical distributions of chlorophyll a were characterized by subsurface maximum (1 to 4 µg Chl l^{-1}) associated with the pycnocline and an oxygen maximum. This is a common feature of the mid-shelf region when the water column is thermally stratified and probably reflects a tendency for centers of maximum biomass to move closer to the nutrient reservoirs that supply the euphotic zone as solar insolation increases (cf. Malone, 1976; Walsh et al., 1978). The presence of chlorophyll a and oxygen maxima together in the pycnocline (usually near the base of the euphotic zone) suggest that the subsurface maximum consists of actively growing cells.

Estimates of photosynthetic rates from 2-hr (artificial light) and 24-hr (sunlight) incubations of surface water were also similar to rates observed in April and May. Light saturated doubling times (C:Chl = 50) ranged from 0.4 to 2.4 days compared to rates of 4 to 50 days at the 2% light level (roughly the percent light level at the chlorophyll a maximum).

These observations are consistent with our earlier conclusion that distributions of phytoplankton biomass are strongly influenced by horizontal and vertical density gradients. As the water column stratifies across the shelf, the centers of maximum biomass move closer to the nutrient reservoirs that supply the euphotic zone. Horizontally, this is expressed as the development of narrow zones of high production along the coastline and the shelf-break. Vertically, this is reflected in the development of a chlorophyll maximum in the pycnocline near the base of the euphotic zone as the vertical flux of nutrients from below becomes the major input of nutrients over most of the mid-shelf area.

Relationships between Total Suspended Solids, Chlorophyll *a* and Radionuclides

Correlation and factor analyses were run on data from the March (28 March-1 April), May (29 April-11 May) and September (19-24 September) cruises. Concentrations of suspended solids and chlorophyll *a* were generally highest nearshore and early in the year and lowest in mid-shelf and late in the year. Total suspended particulates (TSP) and chlorophyll *a* were usually significantly correlated (Table 1). These best correlations were found in the surface layer in zones of most active production (nearshore and along the shelf-break). Variations in chlorophyll *a* accounted for 64% of the variation in TSP nearshore and for 88% along the shelf-break. Correlations were poor in bottom waters and during September because of relatively low chlorophyll *a* concentrations and sediment resuspension and (nearshore) terrestrial runoff.

Data from the May cruise were used to evaluate relationships between temperature, salinity, TSP, chlorophyll *a*, radionuclides and radionuclide activity ratios (Tables 2 and 3). Significant correlations were found between chlorophyll a and all radionuclides and activity ratios except for ^{228}Th and ^{228}Ra. TSP was significantly correlated only with ^{210}Po, ^{239}Pu and $^{228}Th/^{228}Ra$.

The correlation matrix was subjected to a factor analysis in which 5 factors were found to account for 94.3% of the variation (Tables 4 and 5). Salinity, ^{234}Th, ^{228}Ra, $^{234}Th/^{238}U$ and $^{228}Th/^{228}Ra$ were associated primarily with factor 1, ^{239}Pu with factors 1 and 2, TSP with factor 2, chlorophyll a with factors 2 and 3, temperature with factor 3, ^{228}Th with factor 4, and ^{210}Po with factor 5. Thus, both TSP and chlorophyll a were not associated with the same factors that most of the radionuclides were. Except ^{228}Th and ^{210}Po, all radionuclides identified with factor 1, suggesting that the factor(s) controlling their distributions are similar.

Residence time of ^{228}Th in the water column was estimated to be about 10 days during summer and fall (Li et al., in press). Such a short residence time indicates that ^{228}Th is removed from the water column by sinking particles (phytodetritus) or by food-chain processes that move ^{228}Th into large organisms (macrozooplankton, micronekton, nekton that are not sampled with Niskin bottles) or fecal pellets with high sinking rates (Higgo et al., 1978).

The poor correlations between TSP and ^{228}Th and between chlorophyll a and ^{228}Th suggest that the residence time of particles in the water column may be more important than concentration per se in determining the distribution of radionuclides such as ^{228}Th in the NY Bight, at least during the period when the water column is thermally stratified (May-September). Malone and Chervin (Appendix) have shown that the plume of the Hudson River progresses from a phytoplankton dominated system prior to thermal stratification when phytoplankton biomass is high, to a detritus dominated system during the summer and fall when phytoplankton biomass is low (but productivity high). Residence times of phytoplankton in the water column were longer (mean = 8 days) prior to stratification because sinking was the major mechanism of removal. Residence times were short (mean= 2 days) during the summer because grazing was the major mechanism of removal. Sinking fecal material may be an important mechanism by which organic matter of phytoplankton origin is transported to the benthos during periods of strong stratification. Fecal pellets have been shown to be rich in radionuclides (Higgo _et al._, in press; Beasley _et al._, 1978; Kharkar _et al._, 1976) and to have high sinking rates (Smayda, 1969, 1971). Thus, the production and sinking of fecal material could also be an important mechanism by which radionuclides are removed from the water column.

Summary

Our work has led to the following conclusions:

(1) Phytoplankton biomass is an important component of total suspended solids, particularly during phytoplankton blooms prior to thermal stratification and in zones of high production along the coastline and the shelf-break.

(2) TSP and chlorophyll a concentrations are not related to distributions of radionuclides when the water column is thermally stratified and the system is characterized by low biomass and high turnover rates.

Based on these results and results from other programs (Appendix), there appears to be two major pathways by which plankton influence the vertical flux of radionuclides in the NY Bight. Netplankton biomass (dominated by diatoms) peaks prior to thermal stratification and appears to sink out of the water column within a week or two of its production. Nanoplankton productivity peaks during the summer, and biomass is kept low by grazing. Thus, a major mechanism of removal appears to be sinking of phytoplankton prior to thermal stratification and sinking of fecal material during thermal stratification.

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Table 1. Descriptive statistics and correlations between Chl *a* and total suspended particles (TSP) for values obtained in N. Y. Bight during 1977: 28 Mar-1 Apr, 29 Apr-11 May, and 19-24 Sept. $\bar{X}$ = mean, S = Standard Deviation, r = correlation coefficient, r^2 = coefficient of determination, n = number of cases.

	Chl *a* ($\mu g\ l^{-1}$)				TSP ($\mu g\ l^{-1}$)					
	$\bar{X}$	S	Range	n	$\bar{X}$	S	Range	n	r	r^2
ALL	1.19	1.92		469	266	293		459	0.60***	0.36
Surface	1.65	2.79	0.20 -19.81	83	284	367	32-2971	79	0.79***	0.62
Nearbottom	1.40	2.64	0.006-18.00	73	296	247	15-1000	72	0.52***	0.27
NEARSHORE	1.63	2.33	0.09 -19.81	277	349	352	42-2971	269	0.55***	0.30
Surface	2.28	3.57		44	403	470		41	0.79***	0.62
Nearbottom	1.99	3.10		48	367	265		47	0.47***	0.22
SHELF	0.49	0.53	0.06 - 4.00	172	146	82	10- 645	170	0.43***	0.18
Surface	0.48	0.29		27	115	55		26	0.35*	0.12
Nearbottom	0.30	0.28		20	187	130		20	0.36ns	
SLOPE	1.20	1.61	0.006- 5.90	20	164	151	15- 603	20	0.95***	0.90
Surface	1.99	1.67		12	240	148		12	0.94***	0.88
Nearbottom	0.018	0.009		5	61	59		5	0.77ns	
MAR-APR	3.83	3.94	0.50 -19.81	60	613	590	42-2971	58	0.44***	0.19
Surface	4.11	5.72	0.77 -19.81	14	620	727	59-2971	13	0.80***	0.64
Nearbottom	4.30	4.48	0.50 -18.00	16	497	320	42-1000	15	0.45ns	
APR-MAY	0.82	0.99	0.006- 5.90	264	239	194	10-1450	259	0.57***	0.32
Surface	1.48	1.45	0.20 - 5.90	45	263	216	58-1167	44	0.71***	0.50
Nearbottom	0.48	0.59	0.006- 2.28	40	244	218	15- 918	40	0.61***	0.37
SEPT	0.78	0.71	0.14 - 4.22	145	172	97	19- 645	142	0.33***	0.11
Surface	0.55	0.35	0.21 - 1.51	24	126	68	32- 292	22	0.20ns	
Nearbottom	0.81	0.95	0.26 - 4.22	17	240	130	50- 645	17	0.11ns	

Table 1. (Continued)

	Chl a (µg l^{-1})				TSP (µg l^{-1})					
	$\bar{X}$	S	Range	n	$\bar{X}$	S	Range	n	r	r^2
NEARSHORE										
MAR-APR	3.83	3.94	0.50 -19.81	60	613	590	42-2971	58	0.44***	0.19
Surface	4.11	5.72		14	620	727		13	0.80***	0.64
Nearbottom	4.30	4.48		16	497	320		15	0.45ns	
APR-MAY	0.96	1.00	0.09 - 5.26	159	308	213	61-1450	156	0.53***	0.28
Surface	1.68	1.54		21	355	257		21	0.66***	0.44
Nearbottom	0.70	0.64		24	332	241		24	0.51**	0.26
SEPT	1.18	0.87	0.22 - 4.22	58	186	100	56- 505	55	0.31**	0.10
Surface	0.83	0.37		9	148	83		7	-0.07ns	
Nearbottom	1.27	1.27		8	227	66		8	0.39ns	
SHELF										
APR-MAY	0.47	0.64	0.06 - 4.00	85	128	62	10- 327	83	0.56***	0.31
Surface	0.62	0.33		12	115	49		11	0.59*	0.35
Nearbottom	0.22	0.34		11	135	41		11	0.44ns	
SEPT	0.51	0.39	0.14 - 3.10	87	163	94	19- 645	87	0.37***	0.14
Surface	0.37	0.21		15	116	61		15	0 0.25ns	
Nearbottom	0.40	0.10		9	251	172		9	0.53ns	
SLOPE										
MAY	1.20	1.61	0.006- 5.90	20	164	151	15- 603	20	0.95***	0.90
Surface	1.99	1.68		12	240	148		12	0.94***	0.88
Nearbottom	0.018	0.009		5	61	59		5	0.77ns	

* Significant at 0.05 level ** Significant at 0.01 level *** Significant at 0.001 level
ns = not significant

Table 2. Means ($\bar{X}$) and standard deviations (S) of temperature (°C), salinity ($^o/oo$), Chl a ($\mu g\ l^{-1}$), total suspended particles (TSP, $\mu g\ l^{-1}$), and radionuclide concentrations (dpm 100 l^{-1} except ^{234}Th as dpm l^{-1}) for 29 Apr-11 May 1977 in nearshore (NS, water depth < 50 m), mid-shelf (SH, water depth 50 to 300 m), and slope (SL, water depth > 300 m) areas.

	Total		NS		SH		SL	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Temperature	10.14	1.46	9.24	0.32	9.69	0.71	11.79	1.81
Salinity	32.93	1.08	31.45	0.70	32.95	0.92	34.45	1.07
Chl a	1.08	1.30	0.73	0.41	0.67	0.33	1.95	2.13
TSP	231	149	304	153	151	75	305	199
^{228}Th	0.45	0.07	0.43	0.04	0.46	0.09	0.44	0.06
^{234}Th	1.16	0.37	0.79	0.20	1.14	0.20	1.66	0.22
^{210}Po	3.60	1.63	3.57	0.84	2.80	0.71	5.61	2.30
^{239}Pu	0.098	0.028	0.089	0.026	0.088	0.022	0.124	0.026
^{228}Ra	13.17	5.42	18.13	3.41	13.71	3.41	6.47	2.32
$^{228}Th/^{228}Ra$	0.042	0.024	0.024	0.003	0.035	0.013	0.073	0.022
$^{234}Th/^{238}U$	0.505	0.140	0.361	0.078	0.500	0.081	0.685	0.083

Table 3. Correlation matrix for temperature, salinity, Chl *a*, total suspended particles (TSP) and radionuclide concentrations and their activity ratios for values obtained in N. Y. Bight 29 Apr-11 May 1977.

	Temp	Sal	Chl *a*	TSP	^{228}Th	^{234}Th	^{210}Po	^{239}Pu	^{228}Ra	$^{228}Th/^{228}Ra$	$^{234}Th/^{238}U$
Temp		0.66***	0.73***	0.34ns	-0.14ns	0.67***	0.48**	0.64***	-0.64***	0.66***	0.66***
Sal			0.50**	0.04ns	0.19ns	0.82***	0.37*	0.56***	-0.74***	0.76***	0.81***
Chl *a*				0.68***	-0.07ns	0.49**	0.53**	0.67***	-0.52**	0.57**	0.48**
TSP					-0.04ns	0.13ns	0.58**	0.46*	-0.33ns	0.42*	0.12ns
^{228}Th						0.16ns	0.18ns	-0.27ns	-0.01ns	0.31ns	0.17ns
^{234}Th							0.40*	0.62***	-0.88***	0.89***	0.99***
^{210}Po								0.36*	-0.39*	0.70***	0.36*
^{239}Pu									-0.76***	0.65***	0.61***
^{228}Ra										-0.89***	-0.87***
$^{228}Th/^{228}Ra$											0.87***

* Significant at 0.05 level ** Significant at 0.01 level *** Significant at 0.001 level ns = not significant

Table 4. Factor analysis: variance accounted for by each factor (based on correlation matrix in Table 3).

Factor	Eigenvalue	Percent of Variance	Cumulative Percent
1	6.4	58.4	58.4
2	1.9	15.3	73.8
3	1.3	11.6	85.4
4	0.5	4.8	90.2
5	0.4	4.1	94.3

Table 5. Factor analysis: rotated factor matrix (based on correlation matrix in Table 3).

Variable	FACTOR 1	2	3	4	5
Temp	0.516	0.183	0.715	-0.193	0.249
Sal	0.784	-0.066	0.465	0.138	0.102
Chl a	0.308	0.654	0.646	-0.037	0.126
TSP	0.034	0.926	0.073	-0.017	0.302
^{228}Th	0.112	-0.036	-0.061	0.977	0.082
^{234}Th	0.940	0.032	0.225	0.078	0.144
^{210}Po	0.237	0.337	0.179	0.100	0.879
^{239}Pu	0.660	0.505	0.208	-0.363	0.003
^{228}Ra	-0.925	-0.271	-0.070	0.085	-0.098
$^{228}Th/^{228}Ra$	0.828	0.285	0.144	0.203	0.411
$^{234}Th/^{238}U$	0.936	0.030	0.230	0.090	0.093

2.3 Natural and Man-Made Radionuclides in the Water Column

We have completed the radionuclide analysis of water samples from R/V VEMA 32-01, (Oct. 1974), R/V CONRAD 19-01 (July - Aug. 1975), R/V CONRAD 19-05 (Jan. 1976) and R/V CAPE HENLOPEN 77-01 (May, 1977) cruises. We have obtained from these data the removal rates of ^{228}Th, which is a proxy for highly reactive pollutants, from New York Bight waters at four different seasons. The data from the summer (CONRAD 19-01) and the fall (VEMA 32-01) will be published in a paper entitled "^{228}Th-^{228}Ra radioactive disequilibrium in the New York Bight and its implication for coastal pollution" in the Earth and Planetary Science Letter (in press). A preprint of this paper is included in the Appendix.

The complete data from the winter (CONRAD 19-05) and the spring (CH77-01) cruises are displayed in Figures 2.3-1 to -19. We hope to publish all these data in two papers (now in preparation) before the end of this year.

The highlights of the winter results (CONRAD 19-05, 1976) are:

1) The surface ^{228}Ra concentration versus salinity plot is linear in the shelf water (Figure 2.3-2), i.e., ^{228}Ra behaves almost like a conservative tracer. Therefore, as one would expect, the aerial distribution of ^{228}Ra and salinity are very similar (Fig. 2.3-1 and -3).

2) The surface ^{228}Th concentration and $^{228}Th/^{228}Ra$ activity ratio as well as ^{210}Po and ^{210}Pb concentrations decrease from the slope to the mid-shelf, then increase toward the shore (Figures 2.3-4, -5, -6), indicating the regeneration of ^{228}Th, ^{210}Po and ^{210}Pb from the inner shelf sediments. (For comparison, in the summer and the fall, both ^{228}Th and $^{228}Th/^{228}Ra$ ratio decrease monotonously from the slope to the

shore with no indication of a regeneration of ^{228}Th). The $^{210}Po/^{210}Pb$ ratio of more than one (Fig. 2.3-6) indicates that ^{210}Po is more mobile than ^{210}Pb in the coastal environment. We are thus beginning to discriminate seasonal variations in the behavior of these tracers.

3) The half removal time of ^{228}Th by particles t_c, i.e., the time span required for an initial ^{228}Th concentration to be reduced to half by settling particles alone, is ∿ 120 to ∿ 190 days in the slope water and ∿ 22 to ∿ 40 days in the mid-shelf water (Figure 2.3-5). The t_c in the inner shelf is not estimated because of the regeneration of ^{228}Th from sediments. For comparison, the t_c in the slope water is ∿ 70±10 days and in the shelf waters, ∿ 10 to 30 days during the three non-winter seasons.

The highlights of the spring results (CH 77-01, 1977) are:

1) The half removal time of ^{228}Th and ^{234}Th by particles as obtained from $^{228}Th/^{228}Ra$ and $^{234}Th/^{238}U$ ratios are the same within our analytical uncertainty (Figure 2.3-7, -9, -13) indicating the validity of our assumption, i.e., the production rate of thorium isotopes in a water parcel is balanced by their radioactive decay rate and their removal rate by particles, neglecting the water mixing effect. Also, it will be easier to obtain the removal rate of thorium in the shelf environment by measuring ^{234}Th in future work.

2) The ^{228}Ra concentration in the inner shelf water is the highest during spring maximum runoff season (∿ 23 dpm/100 kg, Figures 2.3-10, -11) as compared to other season (15 ± 1 dpm/100 kg). This indicates maximum input of ^{228}Ra from the estuarine runoff and/or from the inner shelf sediments both by resuspension and by desorption during the spring season.

3) The ^{234}Th concentration decreases from the slope toward the shore (Fig. 2.3-8). On the other hand, ^{228}Th increases slightly in concentration near shore (Fig. 2.3-12) indicating regeneration from sediments as is the case in the winter data.

4) The ^{226}Ra concentration in the New York Bight area (S < 35°/₀₀) is about 10.5 ± 0.5 dpm/100ℓ in the spring (Fig. 2.3 - 14) which is higher than in the surface open ocean (∿ 8 dpm/100ℓ), again suggesting estuarine runoff and shelf sediments as the sources of Ra isotopes. Whether or not this is true for other seasons awaits completion of other sets of high-quality ^{226}Ra data (see Sec. 4.3.1).

5) Both ^{210}Pb and ^{210}Po concentrations decrease from the slope to the outer shelf, but increased inner shelf concentrations, especially near the southeast shore of Long Island (Fig. 2.3 - 15, 16) suggest the regeneration of both nuclides possibly from the "mud hole" area south of Rhode Island.

6) $^{210}Pb/^{226}Ra$ and $^{210}Po/^{210}Pb$ activity ratios of surface waters are always less than one, indicating preferential removal of ^{210}Po over ^{210}Pb, and ^{210}Pb over ^{226}Ra, but the locations of the ratio maximum is consistent with the high input of ^{210}Pb and ^{210}Po along the shore of Long Island (Fig. 2.3-17).

7) The $^{239,240}Pu$ concentration decreases from the slope to the mid-shelf, then increases again toward the shore wherever the suspended particle concentration is also high (compare figures 2.3-18 and -19). But $^{239,240}Pu$ content in the collected suspended particles is too low to explain the increase of Pu in the near-shore water. Apparently, Pu is mainly in either dissolved and/or in extremely fine colloidal forms.

In summary, the half removal time of ^{228}Th (as well as other highly reactive pollutants) by particles in the inner shelf surface waters varies only slightly with seasons (10 ∿ 30 days), therefore, any highly reactive pollutant will be removed from the water column fairly rapid into sediments. But once highly reactive pollutants have deposited in the coastal sediment, will they stay in the sediment permanently? Our data show that the answer is no. ^{210}Po, ^{210}Pb and, to a lesser degree, ^{228}Th can be regenerated from the sediments back to the water columns probably by oxidation of organic materials with which they are removed to the sediments.

Even $^{239,240}Pu$, too, can diffuse back to the inner shelf water column by yet unknown mechanisms (organic complex as Bowen suggested?).

The mechanisms and rates of regeneration processes of those natural reactive nuclides need further studies.

On the other extreme, Ra isotopes as well as minor alkaline and alkaline-earth elements (e.g., Rb, Cs, Sr, Ba) are desorbed from the river-borne suspended sediments as soon as the river sediments hit the salt wedge in an estuary. Therefore, coastal sediments very often become the sources of trace alkaline and alkaline earth elements for the coastal waters and open oceans.

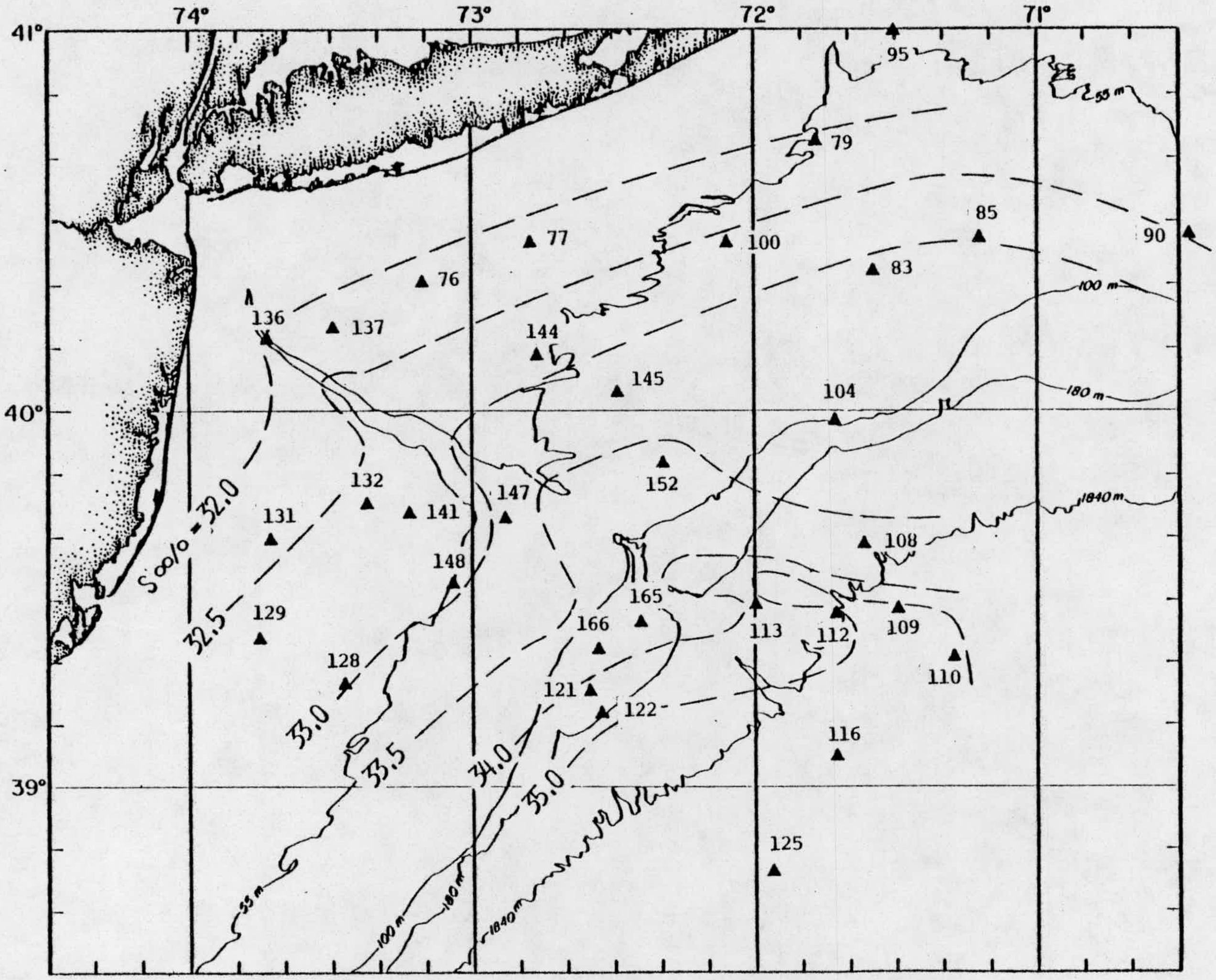


Fig. 2.3-1. Ship station numbers and surface iso-salinity contours (CONRAD 19-05, Jan. 1976).

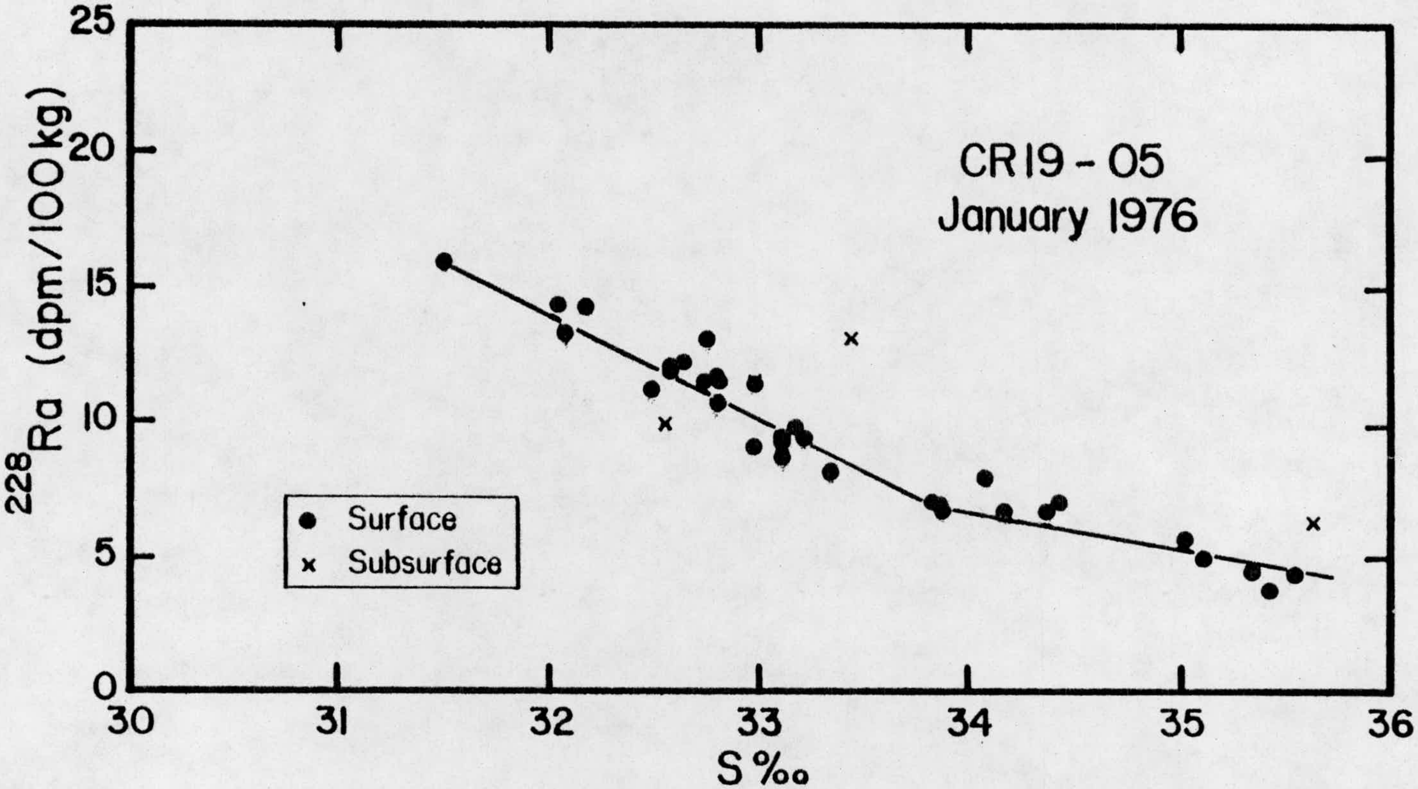


Fig. 2.3-2. The plot of ^{228}Ra concentration vs. salinity.

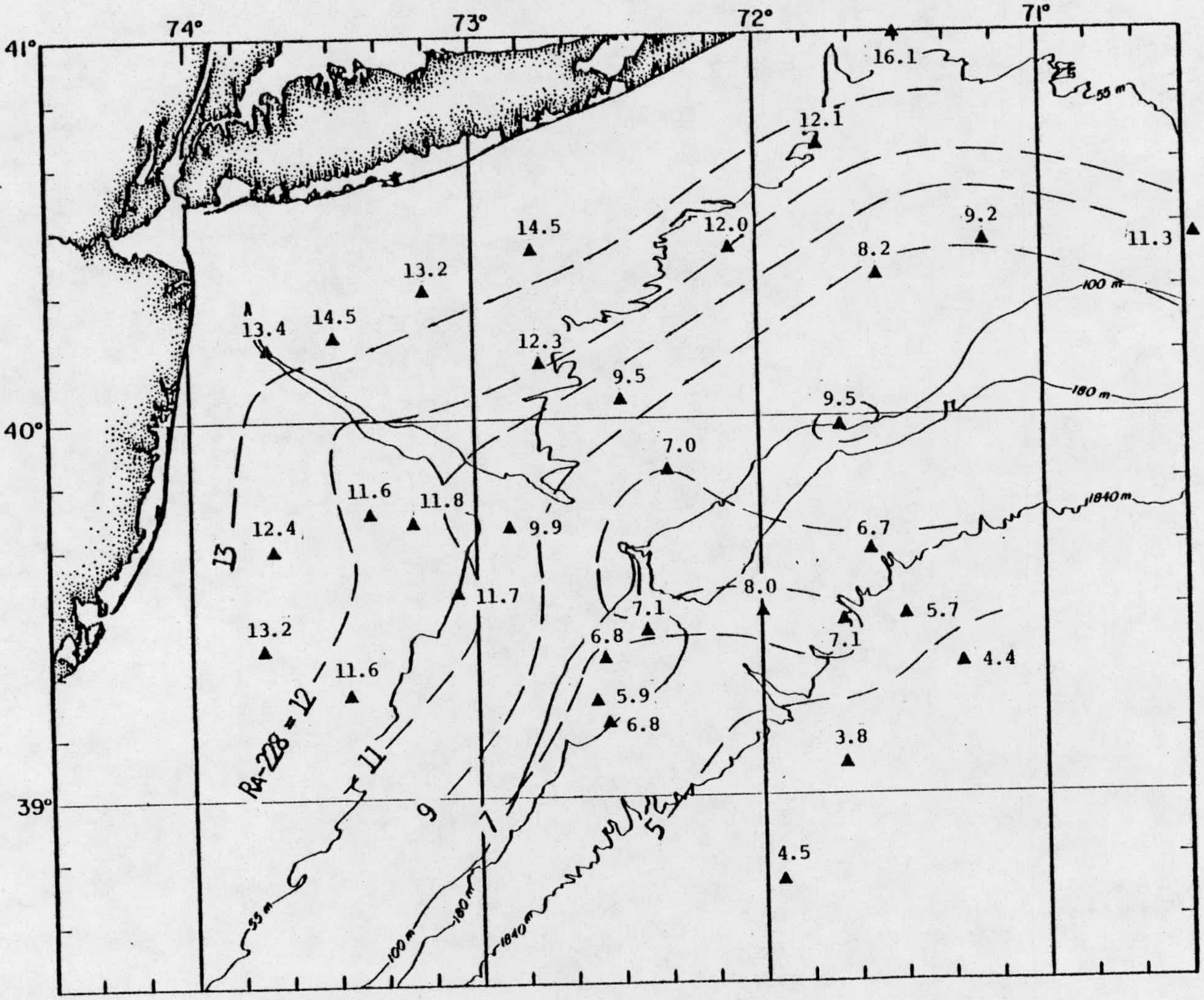


Fig. 2.3-3. The ^{228}Ra concentration at each station and its contour lines (CONRAD 19-05, Jan. 1976). The concentration increases toward shore.

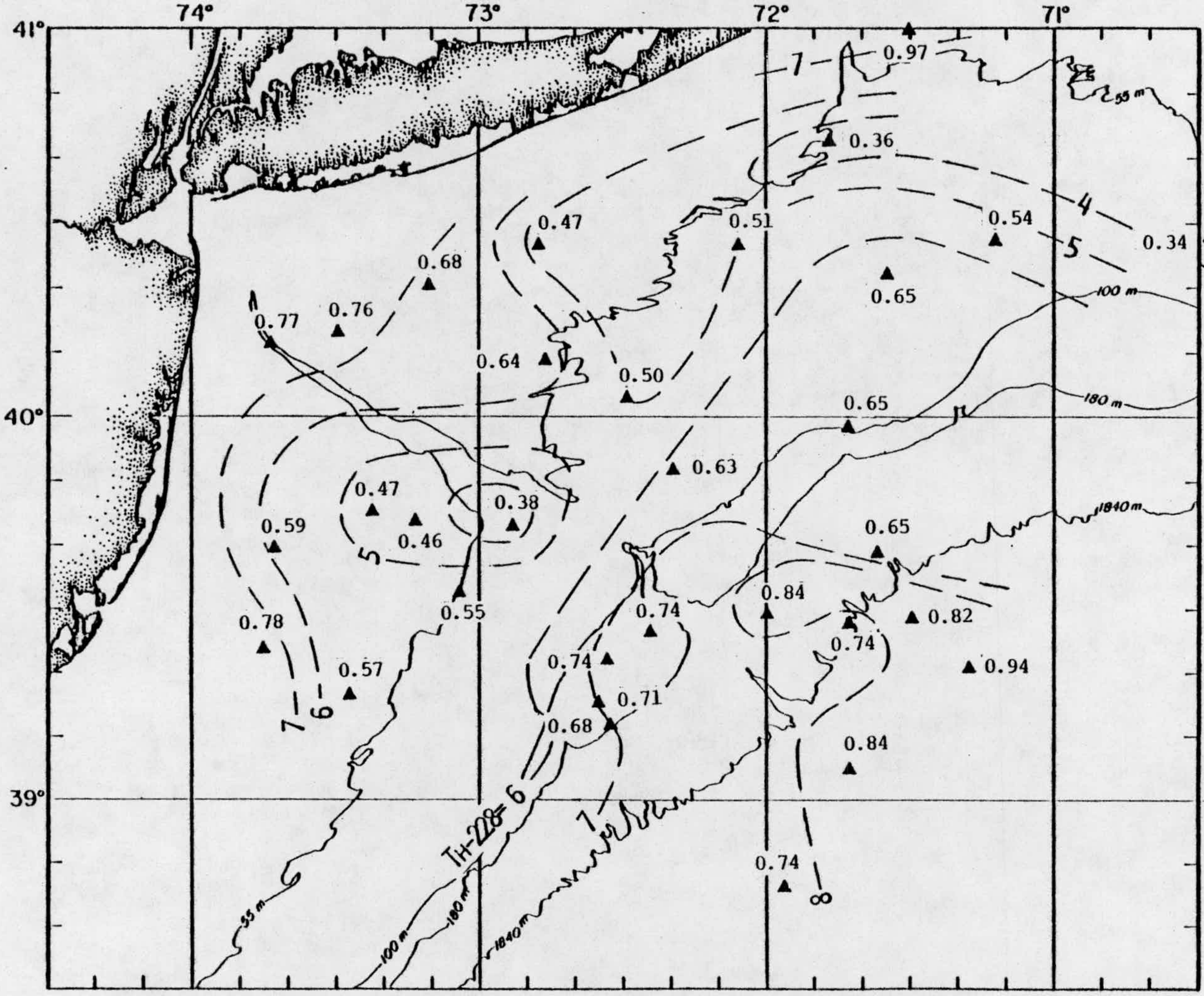


Fig. 2.3-4. The surface ^{228}Th concentration at each station and its contour lines. (CONRAD 19-05, Jan. 1976). Notice the minimum in the mid-shelf.

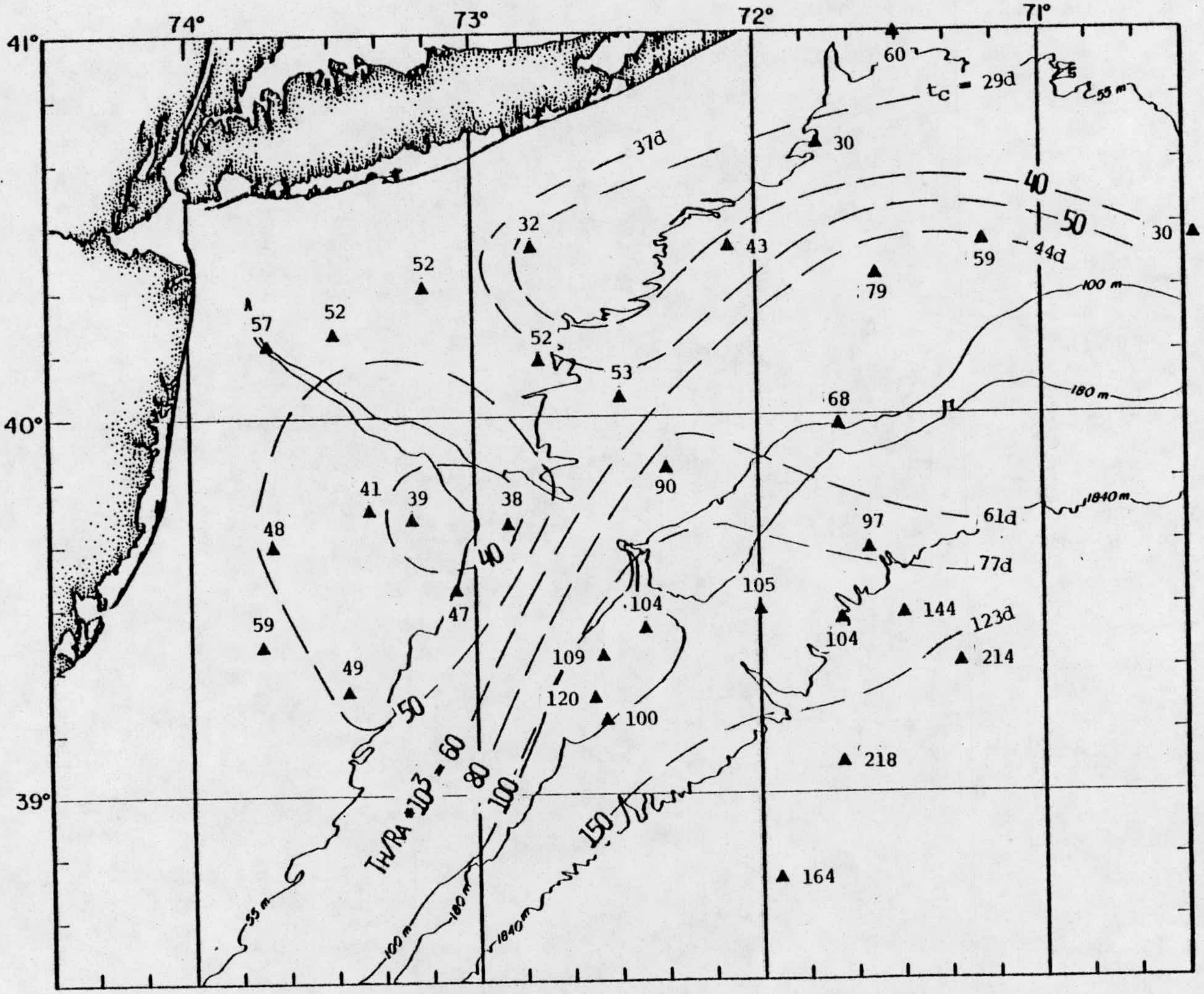


Fig. 2.3-5. The surface $^{228}Th/^{228}Ra$ activity ratio at each station (CONRAD 19-05, Jan. 1976). Notice the minimum in the mid-shelf.

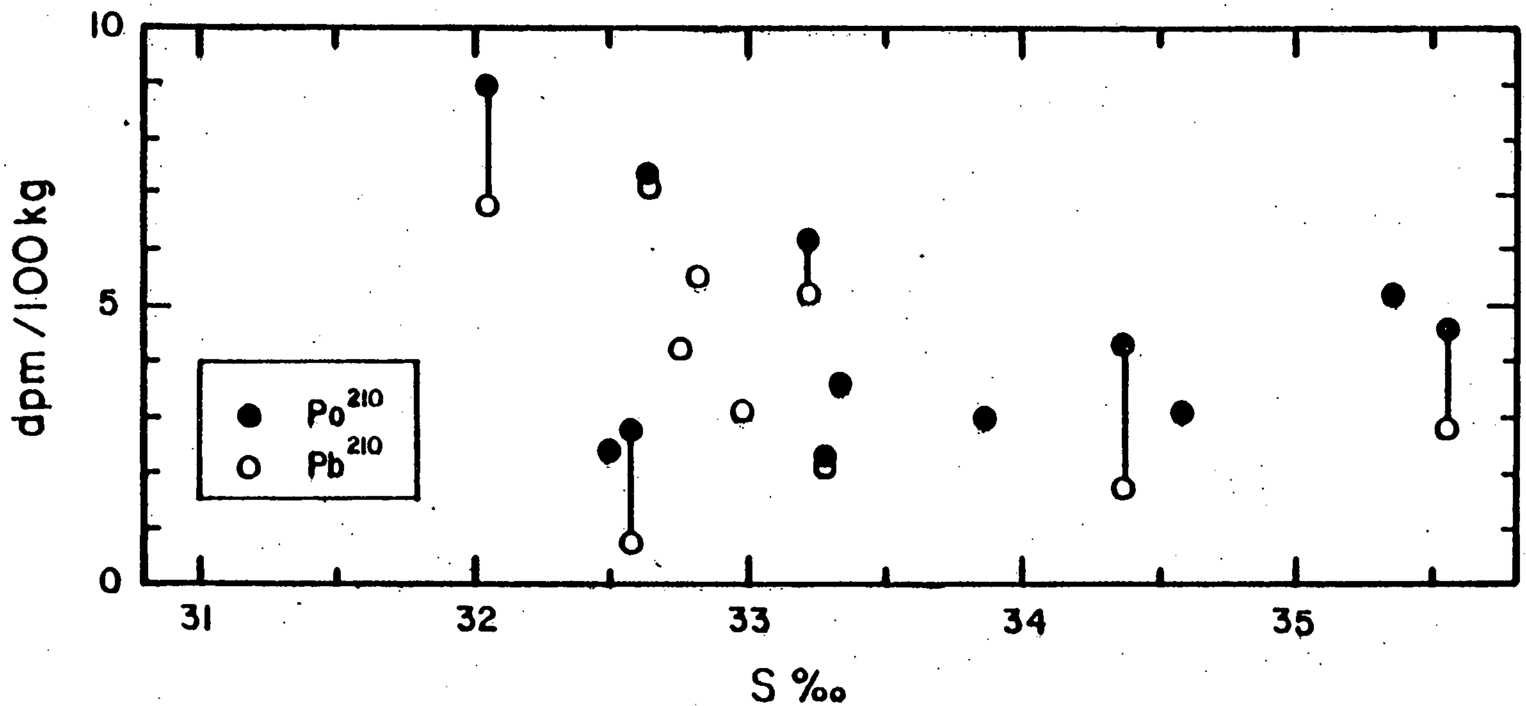


Fig. 2.3-6. The concentration of ^{210}Po and ^{210}Pb vs. salinity (CONRAD 19-05, Jan. 1976). ^{210}Po activity is always higher than ^{210}Pb activity in same water samples (connected by vertical lines).

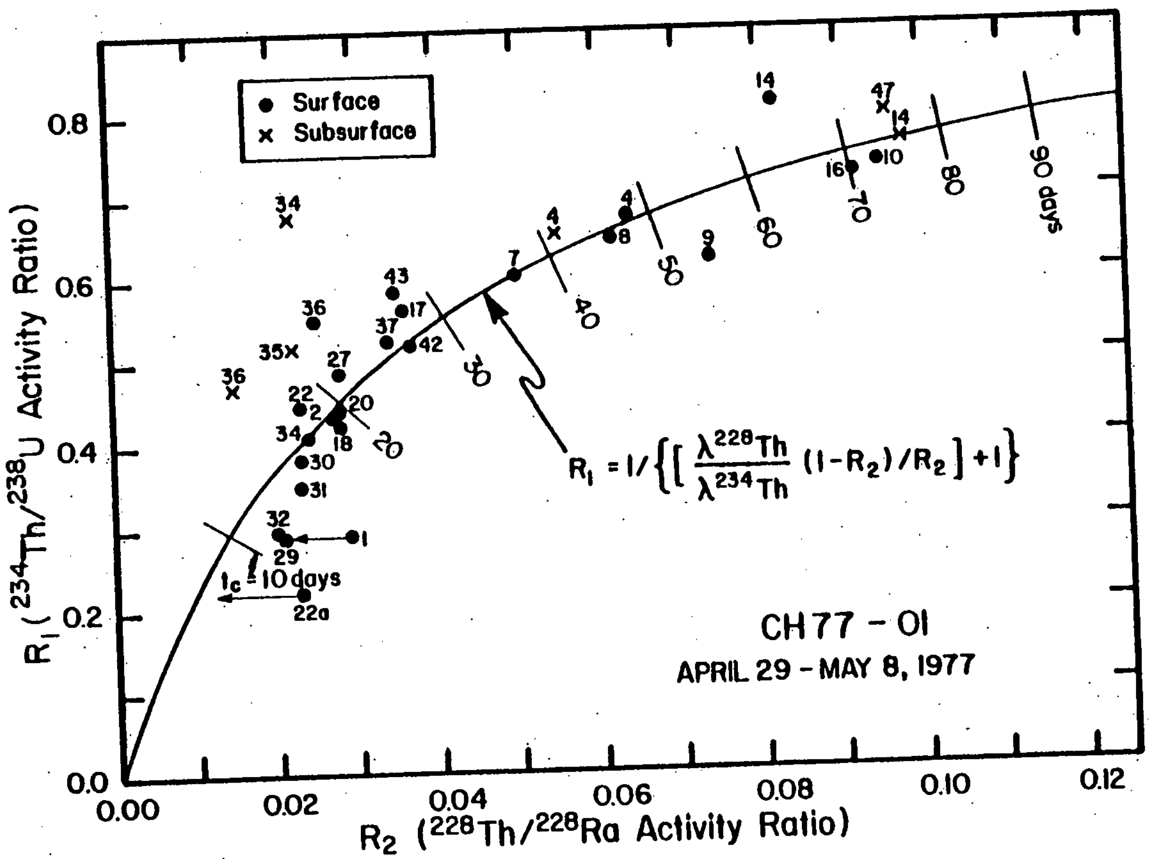


Fig. 2.3-7. The plot of $^{234}Th/^{238}U$ vs. $^{228}Th/^{228}Ra$ (R/V CAPE HENLOPEN 77-01). The most data points fall on the Concordia curve, which is obtained by assuming that the removal rate constants for ^{234}Th and ^{228}Th are the same.

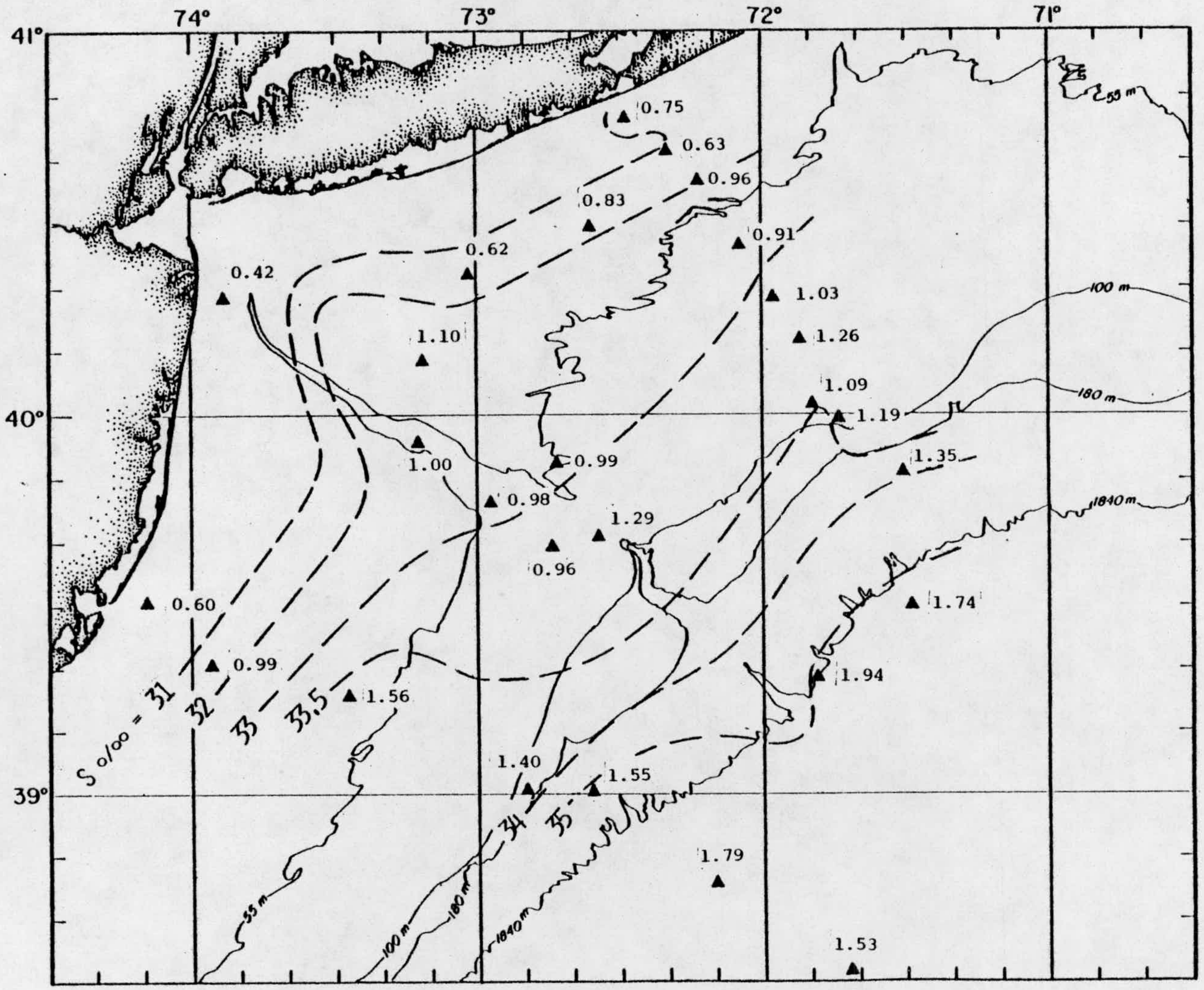


Fig. 2.3-8. The surface ^{234}Th concentration at each station and the iso-salinity contour lines (CH 77-01, 1977).

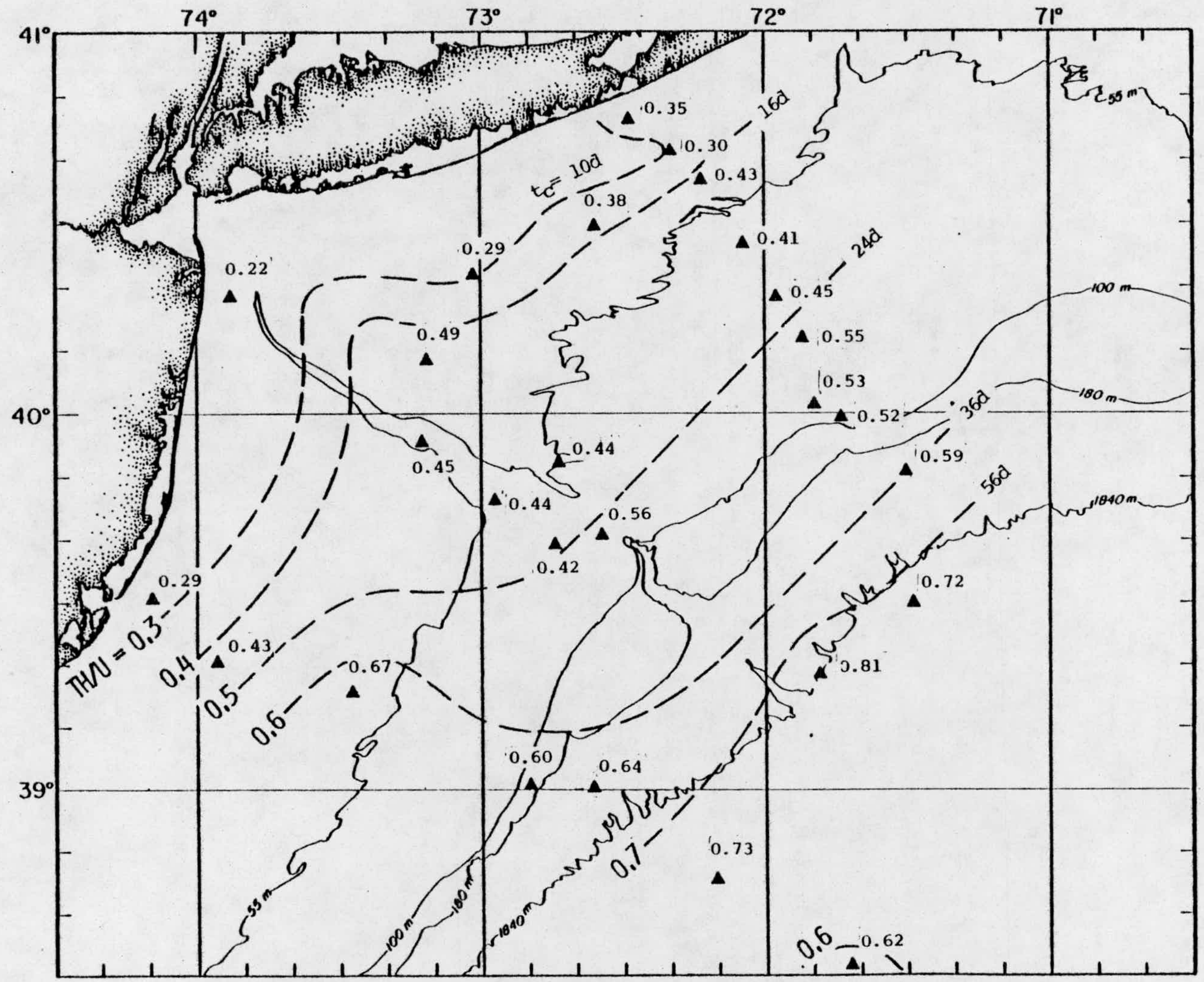


Fig. 2.3-9. The $^{234}Th/^{238}U$ activity ratio at each station and its contour lines with the corresponding half removal time of ^{234}Th by patricles, tc, (CH 77-01, 1977).

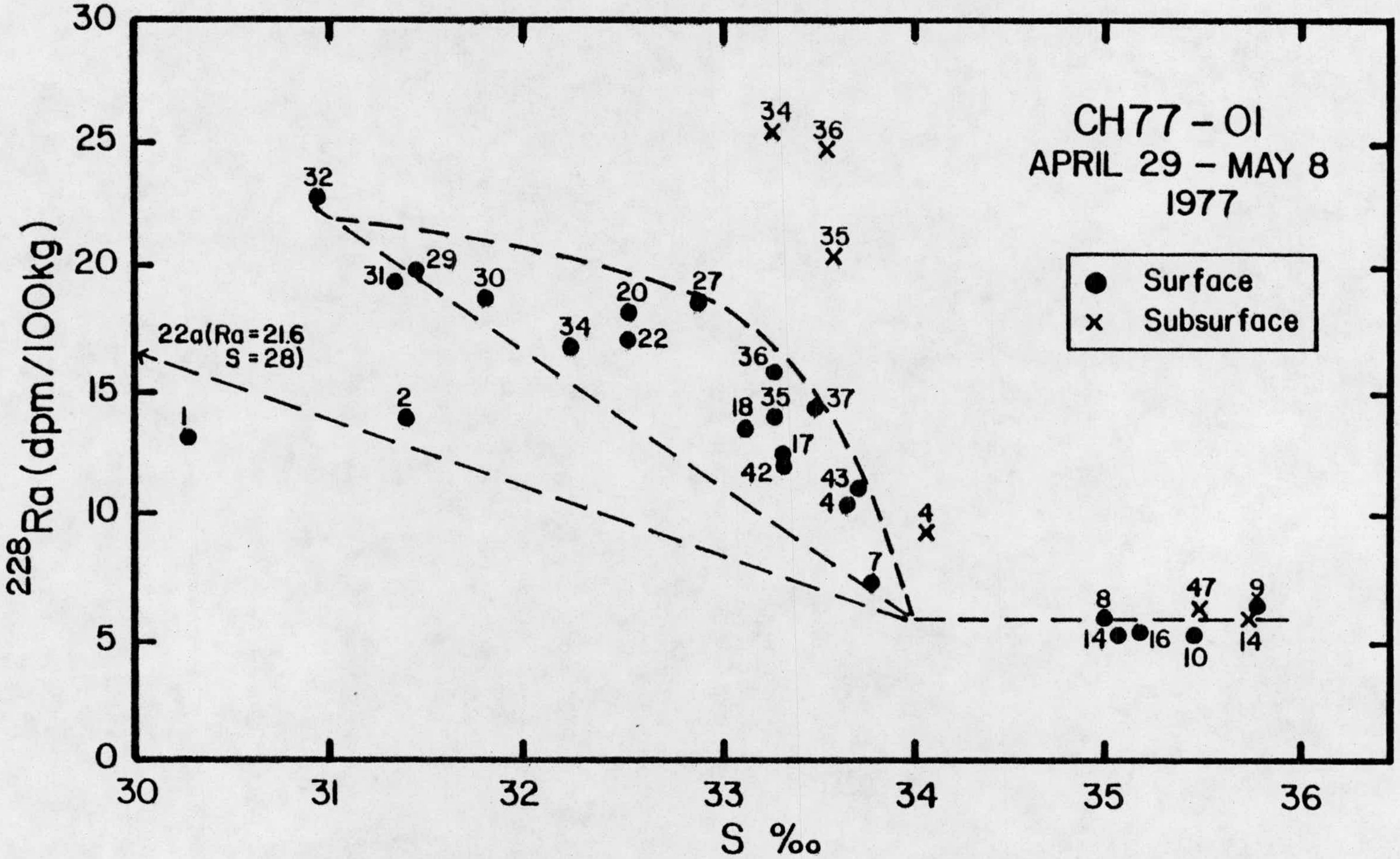


Fig. 2.3-10. The plot of ^{228}Ra concentration vs. salinity (CH 77-01, 1977). The boundary between the surface shelf and slope waters is at salinity ∿ 34°/∘∘. The numbers beside each data point are the station numbers.

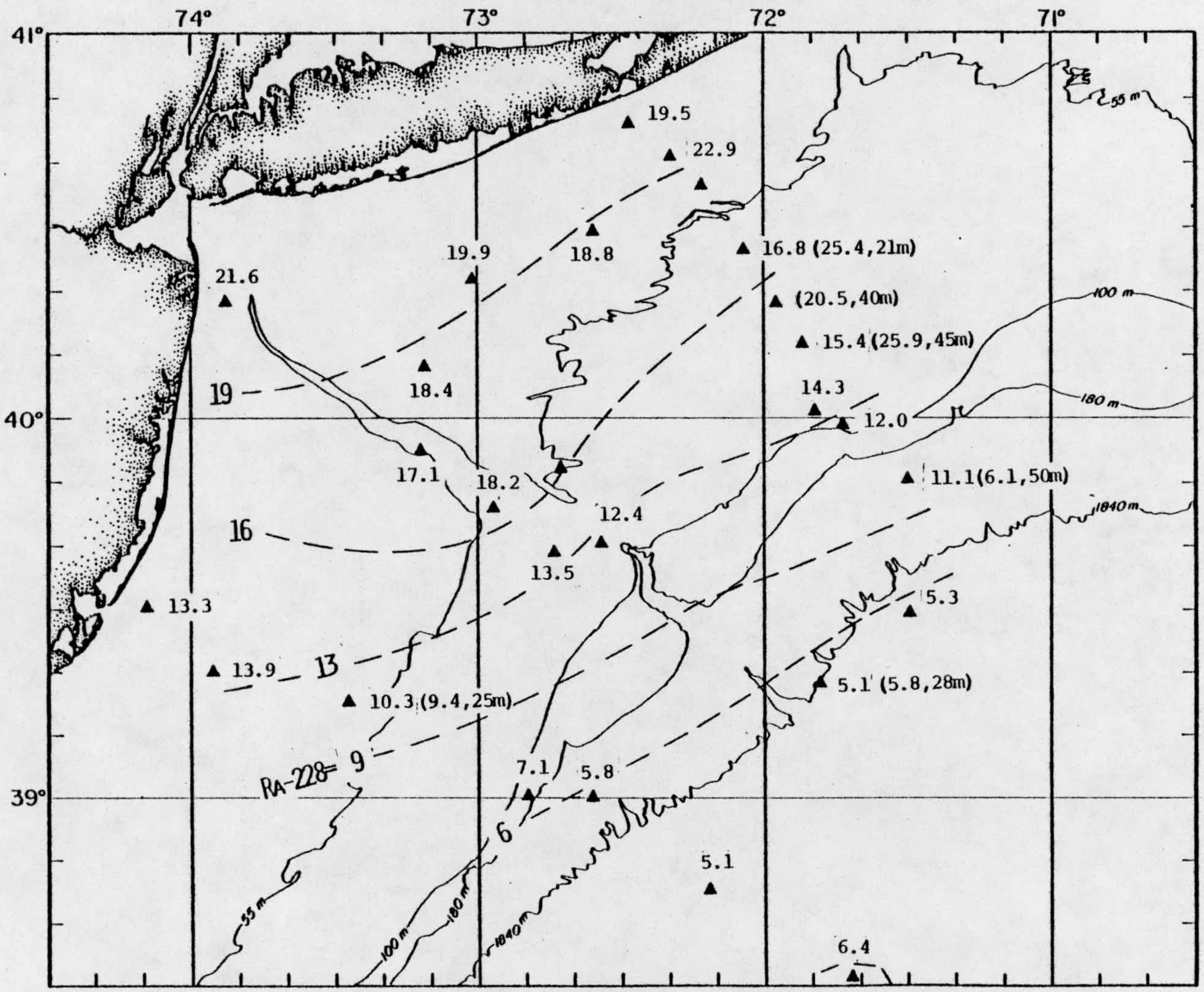


Fig. 2.3-11. The surface ^{228}Ra concentration at each station and its contour lines. The subsurface values are give in parentheses with sampling depth. (CH 77-01, 1977).

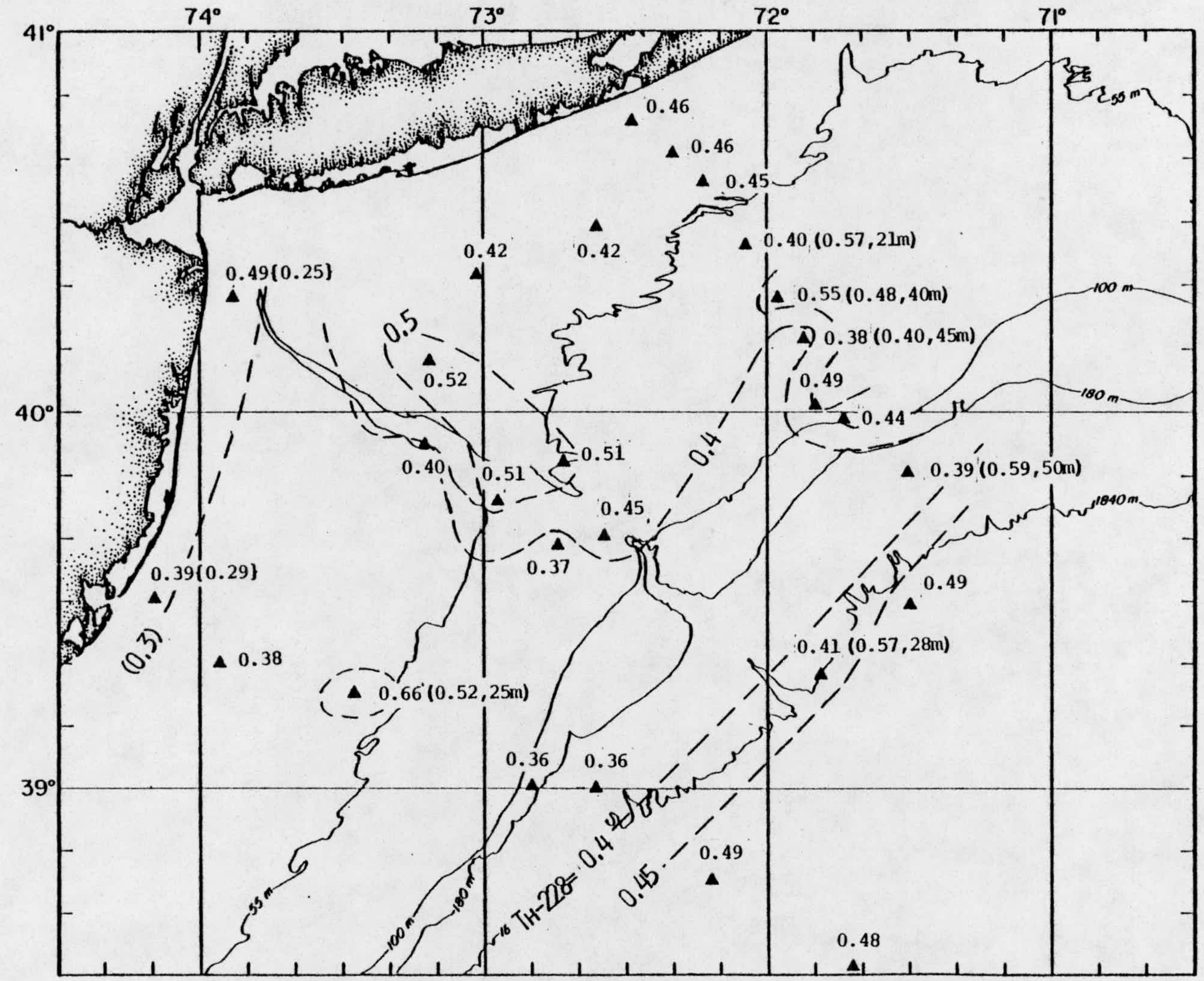


Fig. 2.3-12. The surface ^{228}Th concentration at each station and its contour lines (CH 77-01, 1977). The values in brackets are ^{228}Th concentration corrected for contribution from suspended particles. The subsurface values are given in parentheses.

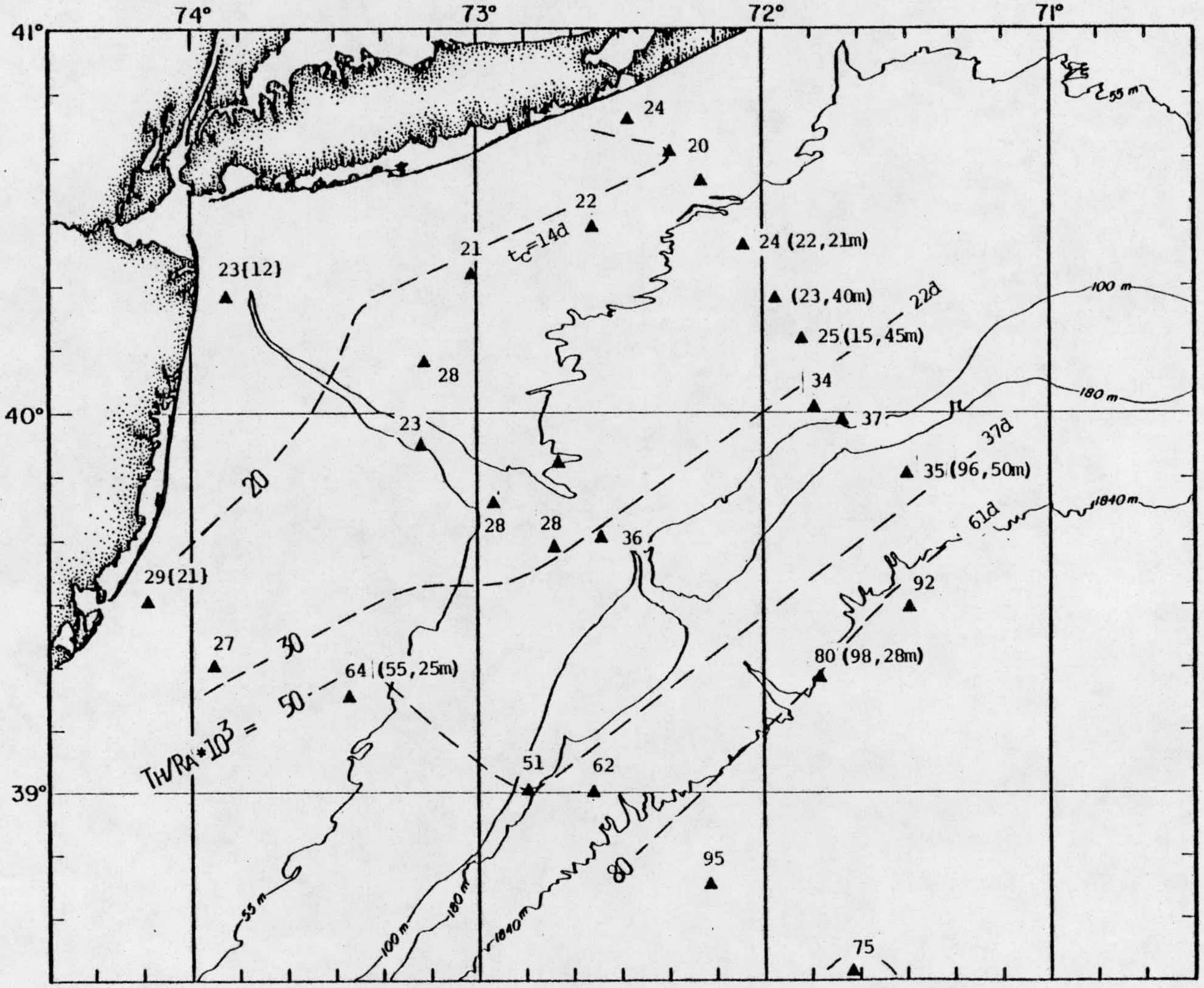


Fig. 2.3-13. The surface ^{228}Th/^{228}Ra activity ratio at each station and its contour lines with the corresponding half removal time of ^{228}Th by particles, tc, (CH 77-1, 1977). The subsurface values are given in parentheses.

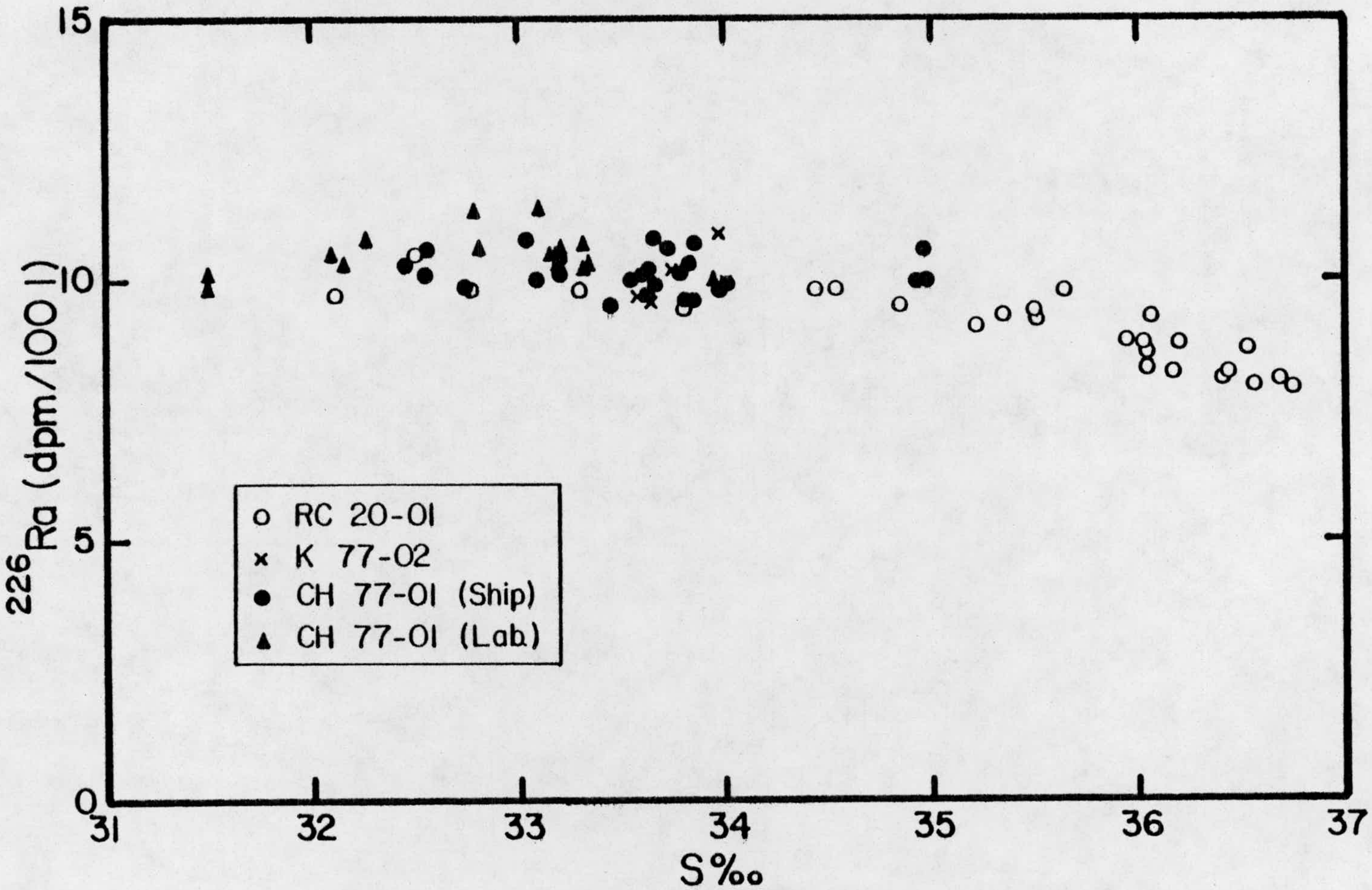


Fig. 2.3-14. The ^{226}Ra concentration vs. salinity from various cruises.

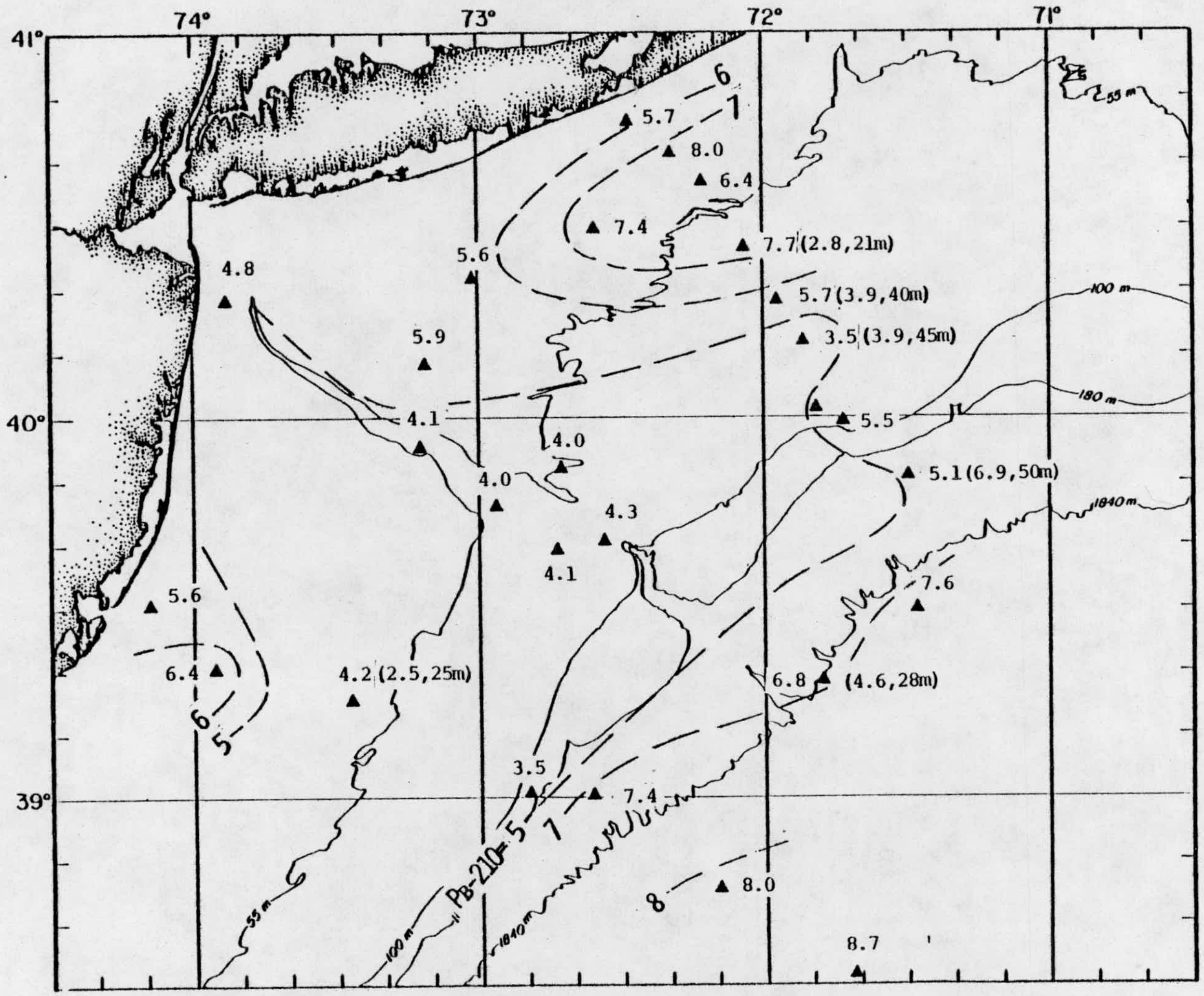


Fig. 2.3-15. The surface ^{210}Pb concentration at each station and its contour lines (CH 77-01, 1977). The subsurface values are given in the parentheses.

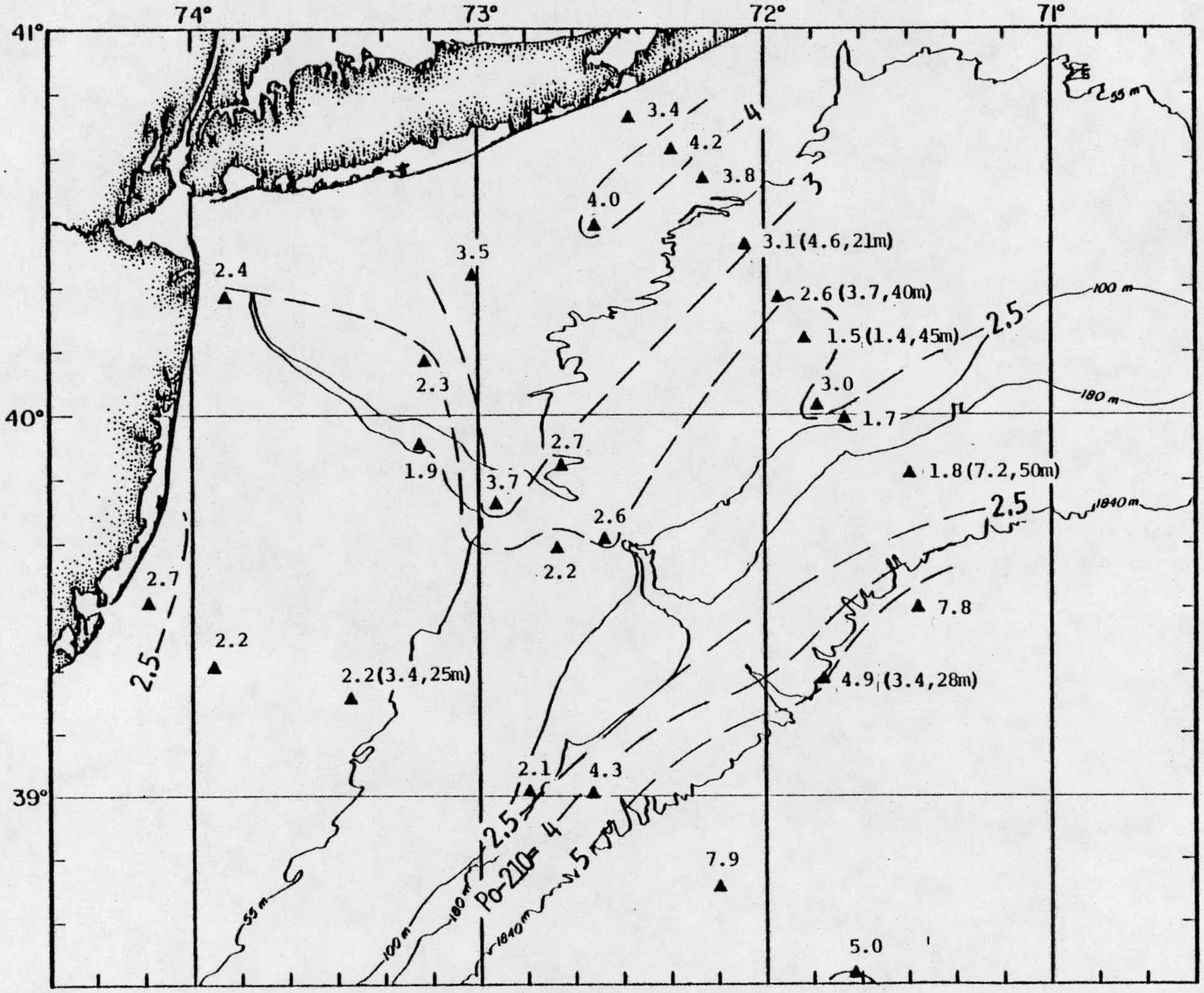


Fig. 2.3-16. The surface ^{210}Po concentration at each station and its contour lines (CH 77-01, 1977). The subsurface values are given in the parentheses.

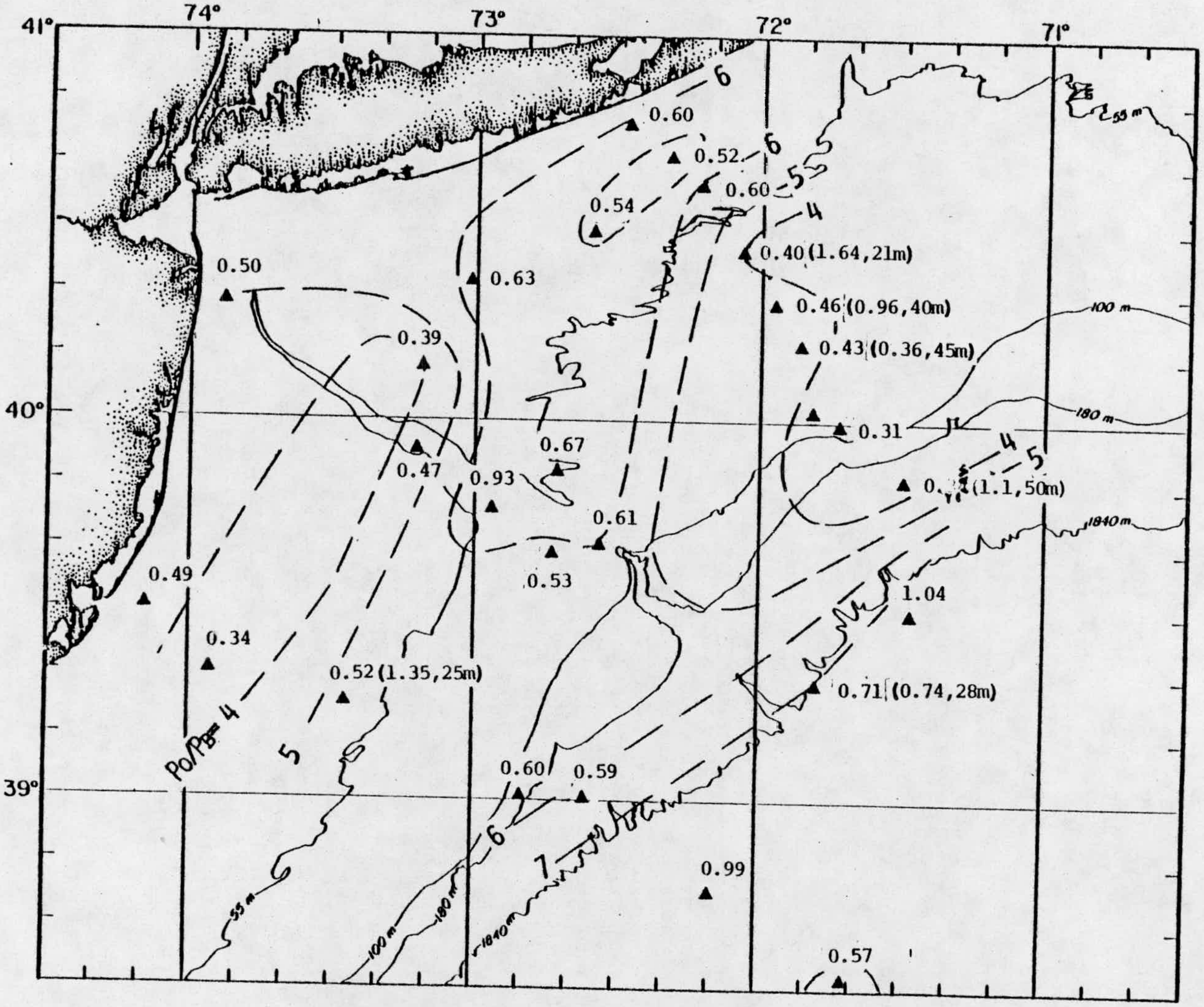


Fig. 2.3-17. The $^{210}Po/^{210}Pb$ activity ratio at each station and its contour lines (CH 77-01, 1977). The subsurface values are given in the parentheses.

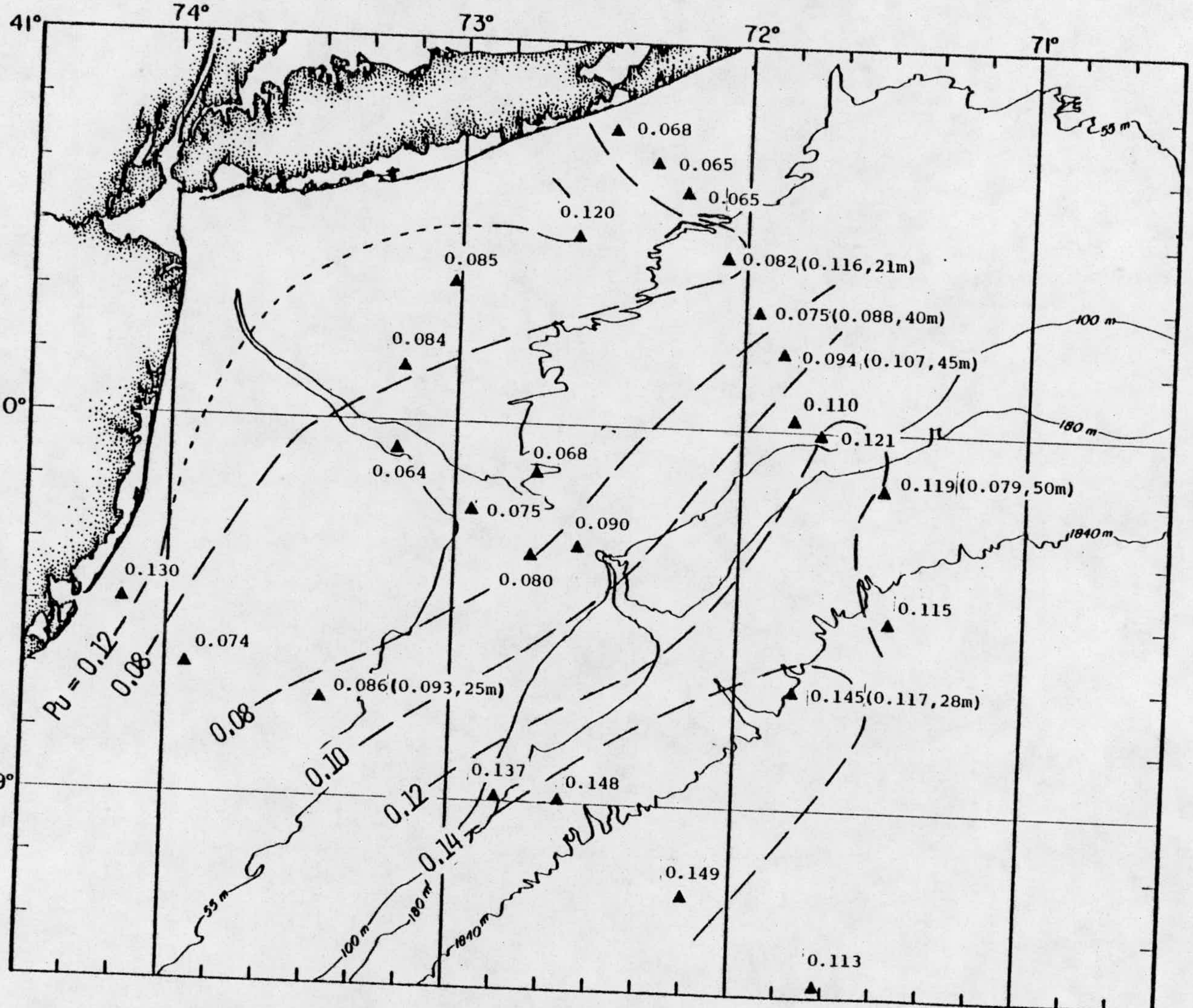


Fig. 2.3-18. The ^{239,240}Pu concentration at each station and its contour lines. Notice the minimum in the mid-shelf. (CH 77-01, 1977).

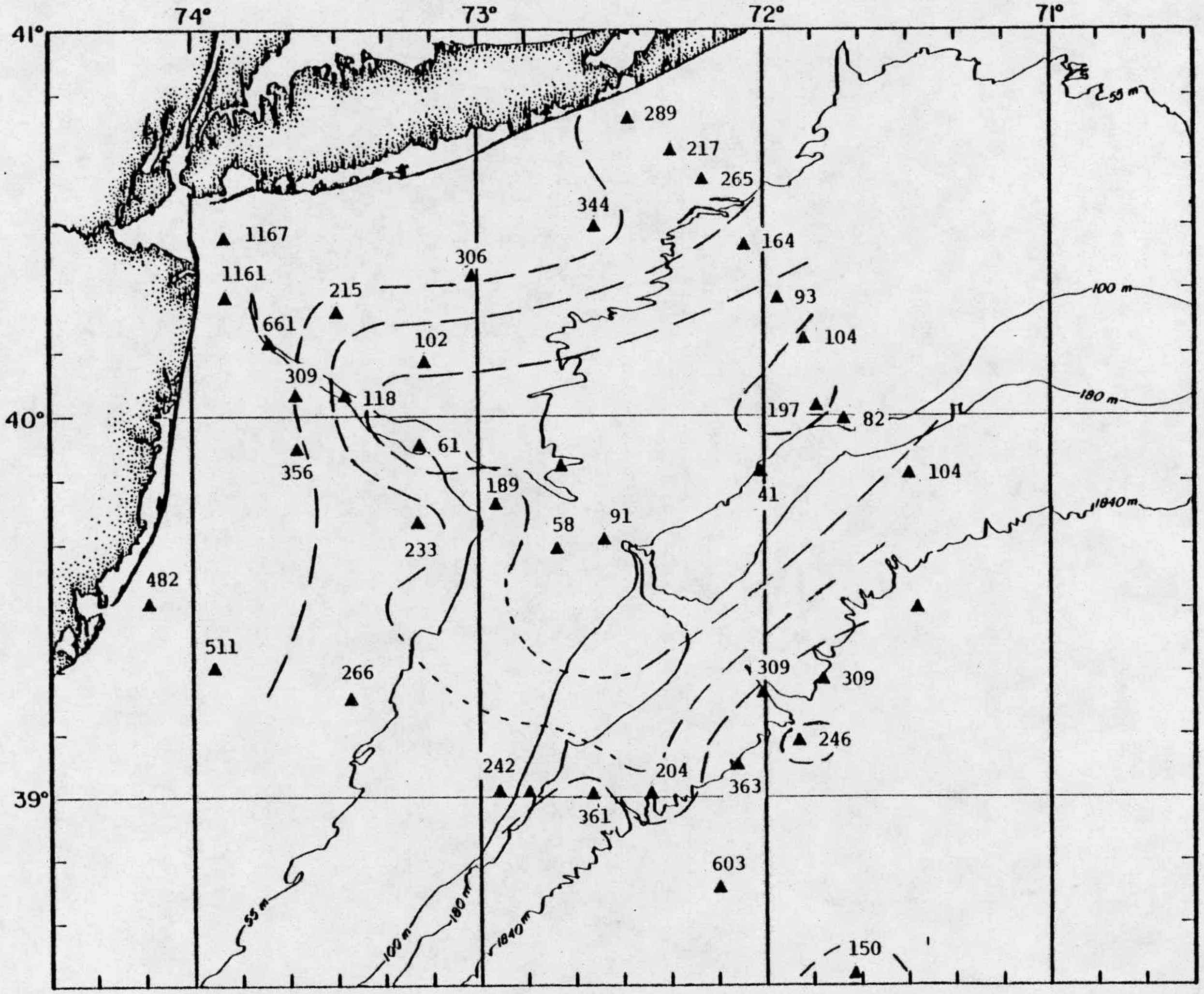


Fig. 2.3-19. The surface concentration of suspended particles (CH 77-01, 1977).

2.4 Man-Made Radionuclides in (and out of) Barnegat Bay

Included in last year's Annual Report were preliminary results on our work on anthropogenic radionuclides in Barnegat Bay. A draft of a paper on these results was included with the February 1978 revised proposal and a preprint of the paper as submitted is included in the Appendix ("Reactor-Released Radionuclides and Fine-Grained Sediment Transport and Accumulation Patterns in Barnegat Bay, New Jersey and Adjacent Shelf Waters", by Olsen, Biscaye, Simpson, Trier, Kostyk, Bopp, Li and Feely). Because of the significance of this study, the most important features are summarized below.

Anthropogenic radionuclides have been introduced into the Barnegat Bay environment via global fallout from nuclear weapons testing and by low-level discharges from the Oyster Creek Nuclear Generating Station into a small tributary of the Bay. A significant portion of these radionuclides have been adsorbed to fine-grained particles and consequently provide excellent tracers for fine-sediment transport and accumulation patterns in the Bay and adjacent shelf environment.

Fine-grained particles, tagged with reactor nuclides are presently accumulating along the landward shore of Barnegat Bay at rates between 1 and 7 cm/yr. There is some indication that reactor-tagged sediments are also being transported into the mouths of small tributaries which discharge into the Bay. Reactor-tagged particles that escape from the Bay, through Barnegat Inlet, onto the shelf, are accumulating during the summer with fine-grained material from other sources, in depressions along the shelf bottom. These near-shore mud deposits are apparently resuspended and dispersed by major storms probably on a seasonal basis.

By comparing radionuclide ratios in the reactor-releases with the ratios observed in the fine-grained sediments in the vicinity of the reactor, it appears that (1) 35% to 50% of the total ^{137}Cs activity in the top 30 cm of the sediments in Oyster Creek is attributable to reactor releases, (2) if transuranic releases have occurred from the Oyster Creek Reactor, the increments of $^{239,240}Pu$ and ^{238}Pu are not distinguishable from the fallout plutonium burden in the sediments and (3) radiomanganese is removed from the liquid effluent and stored in the sediments at least 2X more effectively than radiocobalt and ∿45X more effectively than radiocesium.

A budget of ^{60}Co, based on inputs from the reactor, storage in the Bay sediments, and outputs through Barnegat Inlet on particles and in the dissolved phase, indicates that 40% of the ^{60}Co released by the Oyster Creek reactor resides in the sediments of Barnegat Bay. The accumulation and dispersal patterns of reactive activation products such as ^{60}Co released during routine nuclear reactor operations provide important clues to the probable transport pathways of transuranic radionuclides if significant releases of such materials were to occur.

2.5 Sediment Traps

Because suspended particulate matter is so important in the transport and removal of reactive pollutants in the marine environment, what we would really like to measure are vertical and horizontal fluxes, not concentrations, of suspended particulate matter. The use of sediment traps, long used as flux-measuring, sample-collecting devices in lakes, has enjoyed a recent boom in the marine environment. Some questions exist, however, about the validity of true vertical flux estimates in the open ocean where advection may perturb the measurements. We therefore, have only faint hopes of making true vertical flux measurements with traps in the highly active shelf regime. But it is so difficult, expensive (of ship time) and important to obtain large enough samples of suspended particulate matter that traps are extremely valuable as simply a long-term sampling device. (In the deeper, more quiescent regime of the upper slope waters there are indications that we may both measure fluxes as well as collect samples with sediment traps.)

For these reasons we requested funds to begin equipping ourselves with sediment traps in the present contract year. Because the actual award of these funds has come relatively late in the contract year we have only begun ordering materials and parts at this writing. Some improvement in trap hardware has been realized in the interim, however, and our trap arrays will ultimately benefit therefrom.

3.0 MIXING RATES OF CONTINENTAL SHELF SEDIMENTS

Because many highly reactive pollutants are associated with suspended particulate matter which will eventually settle onto the sediment surface, we must gain an understanding of the processes of sediment mixing (mostly bioturbation) that will bring the pollutants deeper into the sediment column and out of direct contact with the overlying water.

We have been using the profiles of natural radionuclides ^{234}Th, ^{210}Pb and ^{14}C and bomb produced radionuclides ^{137}Cs and $^{239,240}Pu$ in sediment columns to quantify the depth and rate of sediment mixing.

We have already developed a two-layer, steady state analytical model for the natural radionuclides and a two layer, time-dependent computer numerical model for ^{137}Cs and $^{239,240}Pu$ in the upper sediment column. The former is given in a paper "A model for sediment mixing" which has been submitted to EPSL and is included in the Appendix. The latter is still waiting for real data to be tested on the computer.

We hope the scheduled summer cruise this year will bring back several box cores from the "mud hole" area. Those cores will be analyzed for ^{234}Th, ^{210}Pb, ^{137}Cs and $^{239,240}Pu$. Those data will be fitted to our models for their refinement.

As explained in last year's proposal a box corer is essential to obtaining sediment samples with an undisturbed surface layer. At the writing of this report we have not yet committed ourselves to a corer of a particular design for the reason that, during the short cruise in August 1978 supported under this contract year, we shall be testing two box corers of different design. These are the two with the best reputation in the community and we are borrowing them from Woods Hole and Yale for the cruise.

4.0 SPREADING OF WATER CHARACTERISTICS AND SPECIES IN SOLUTION

Whereas many anthropogenic pollutants are chemically very reactive and follow geochemical pathways associated with particulate matter, some occur in the dissolved state, e.g., tritium from a specific nuclear reactor source. Others may be associated with particles so fine that their behaviour follows essentially that of the water column. We adduce some evidence (Section 2.3) that this may be the case in part with plutonium. Even larger particulate matter is to some degree dispersed in the water column while sinking. In the final analysis it is very importantly the rate at which the water of the New York Bight is exchanged and renewed which determines levels of pollution.

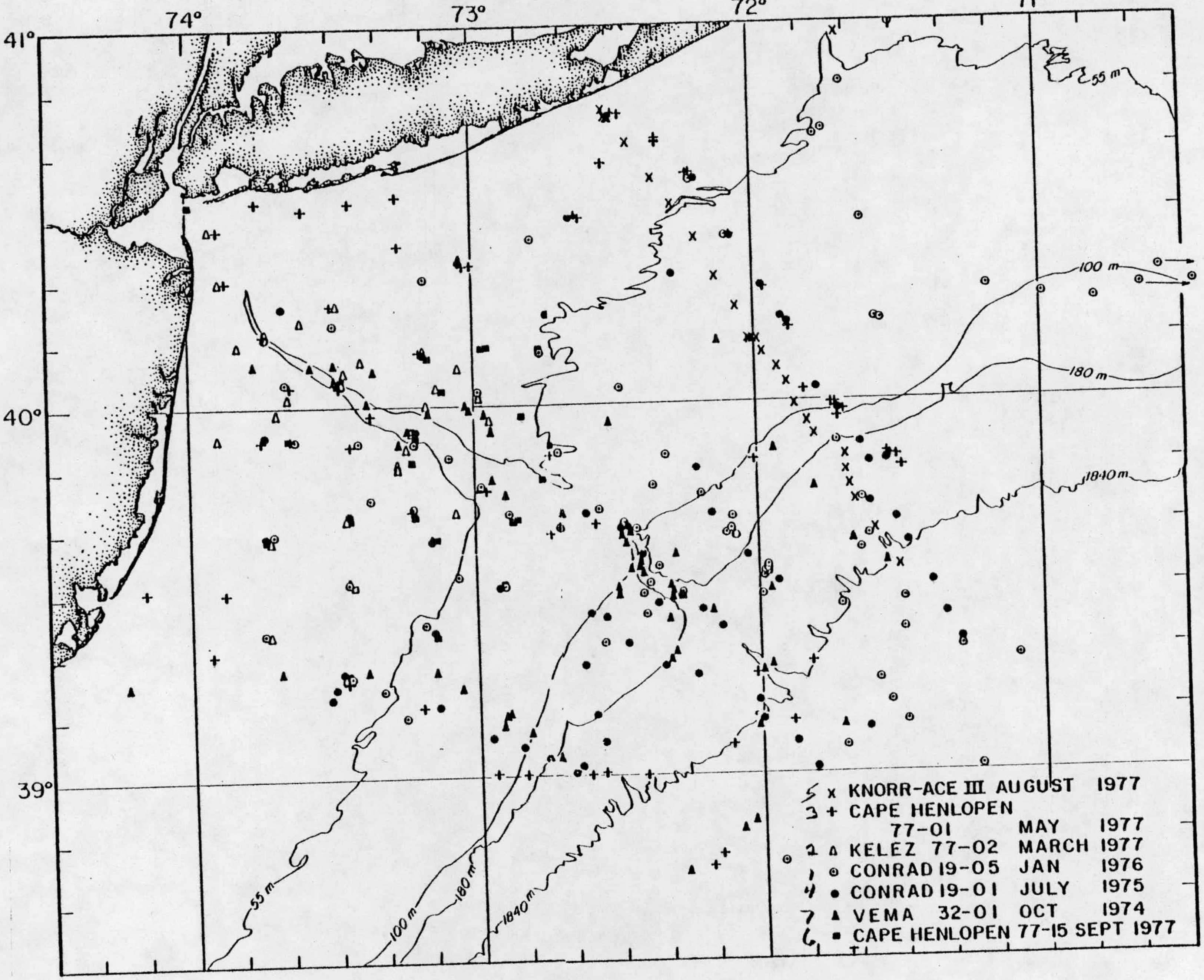
An important part of our program is therefore to try to understand the many different sources of Bight water, the processes which affect their transport in to and out of the Bight and the rates at which this occurs. Classical physical oceanography - the measurement of temperature and salinity, albeit by non-classical (CTD) techniques - forms the framework for this study and provides data on water column stability as well as water mass origins. To this we add several geochemical tracer techniques - oxygen isotopes, radon and, in the past year, tritium - progress on which is summarized in this section.

4.1. HYDROGRAPHIC AND PHYSICAL MIXING PROCESSES

4.1.1. Introduction

During the 1977-78 contract period significant progress was made in the two major areas of data processing and analysis. All the data sets (figure 4.1.1. - the station distribution for each cruise was given in last year's report) were processed to an advanced enough quality for analysis to begin. This includes the 1977 high resolution CTD-O_2 data and the balky STD data from CONRAD cruises 19-01 (July 1975) and 19-05 (January 1976). I hesitate to call these data final, since further refinement of matching the rosette bottle data to some STD stations still needs to be carried out, as well as the calibration of the oxygen sensor output from the CTD-O_2. For all the cruises the Lamont and Brookhaven oceanographers engaged in DOE studies of the New York Bight have received: rosette bottle listings, CTD or STD standard level listings with the density related parameters, CTD or STD and rosette temperature and salinity plotted against depth on three different scales, and temperature-salinity diagrams for each station. For each observation period, we have all sea surface temperature charts and IR image information supplied by the U.S. Naval Oceanographic Office and NOAA.

During the 1977-78 contract period data analysis progress was reported by Gordon and Houghton at: 1- the 1977 Annual Workshop on Physical Oceanography of the Middle Atlantic and New York Bights, hosted by Lamont on 15-16 November, 1977; 2- the spring AGU meeting in Miami, Fla, in mid-April 1978 (abstracts published in EOS); and 3- the DOE review held in March 1978 at Brookhaven Laboratories. In addition to these presentations, a manuscript was prepared in the 1977-78 period by



74°
73°
72°
71°
41°
40°
39°
55 m
100 m
180 m
1840 m
x KNORR-ACE III AUGUST 1977
+ CAPE HENLOPEN 77-01 MAY 1977
Δ KELEZ 77-02 MARCH 1977
⊙ CONRAD 19-05 JAN 1976
● CONRAD 19-01 JULY 1975
▲ VEMA 32-01 OCT 1974
■ CAPE HENLOPEN 77-15 SEPT 1977

Fig. 4.1-1

E. Posmentier and R. Houghton "Fine Structure Instabilities Induced by Double Diffusion in the Shelf/Slope Water Front", and is now "in press" in the Green JGR. A list of these presentations and papers is included in section 8 of this Report.

With our full New York Bight data sets processed, the data analysis effort is accelerating. The first level objective is a comprehensive descriptive evaluation of the total data set and its comparison to the historical data set. This work is needed to lay the foundation for a more quantitative study of advective-diffusion spreading of water properties and for establishment of exchange process hypotheses. Hypotheses provide the conceptual basis which form a framework for understanding the chemical and biological data sets, and provide a guide for planning of specific field work anticipated in the near future.

4.1.2. Data Processing

A full report of our data collection and processing methods was given in our last DOE Report (June 1977). Updating is necessary mainly in regard to processing of the CONRAD STD data sets, CONRAD 19-01 and 19-05.

Processing of the STD data from these two cruises had been hampered by a change in the computer system at Lamont in mid-1977 (the three IBM-1130 systems were replaced by a PDP-11/70 system). Additionally, leg 5 data was collected by a sea going data acquisition mini-computer, which was loaned to us by the physical oceanography department at the University of Rhode Island. The digital tapes written on that system proved very difficult to read on our new PDP-11/70 system, due to (1) the peculiar tape format used by the URI system, and (2) basic differences in the way the Lamont and URI systems store numbers internally. After much support from programmers at URI, the tapes were read.

Cruise 19-01 had particular problems with the STD salinity sensor, which experienced a very high drift rate. This complicated data processing by not permitting the stations to be grouped for calibration to the rosette derived data.

A 12-bottle rosette sampler was used with the STD on both CONRAD cruises. Temperature, salinity, dissolved oxygen and nutrient data were collected. Thermometric depths, temperatures and salinities were used to fit correction curves to each of the STD sensors needed for calibration. These curves were polynomials determined by least squares fit to the differences between STD and rosette values at depths where rosette samples were taken. Bottles tripped in regions of high gradients were excluded from curve fitting due to the difficulty in obtaining a valid comparison between STD and rosette in those regions.

Salinities were smoothed by a 7-point running mean to remove noise. Spikes and small offsets were individually removed wherever they occurred. On CO-19-01, July 1975, the lag correction applied to the salinities to correct for salinity spikes in regions of large temperature gradients was of particular importance in view of the strong temperature gradient associated with the thermocline. A lag correction has not been applied to the winter data, because of uncertainty in the sampling interval of the URI system. Fortunately temperature gradient induced salinity spikes were not an evident problem in the winter data when vertical thermal gradients were weak.

CTD-O_2 processing up-date:

The CTD-O_2 and rosette data from our 1977 cruises (Cape Henlopen cruises in May and September, and the Knorr cruise in August in conjunction with the Brookhaven group) has been distributed in preliminary form. The rosette data has been quality controlled and is considered final. The jobs yet remaining involve the final adjustment of the CTD temperature, salinity and pressure output to the rosette derived data (inspection of the differences of the rosette data and these CTD data indicate that adjustments are of insignificant magnitude for most uses to which the data can be applied) and bottle data; adjustment of the CTD-O_2 oxygen sensor output (this adjustment of the CTD-O_2 oxygen sensor output will significantly alter the present "raw" oxygen sensor data).

Kelez Cruise 77, Leg 2: 28 March - 1 April 1977:

The processing of the 33 InterOcean CSTD stations taken during this cruise was immensely simplified through the assistance of the Atlantic Oceanographic and Mateorological Laboratory (AOML) of NOAA in Miami. Their Physical Oceanography Laboratory generously agreed to reduce and calibrate our raw data tapes, using the system and programs already set up by them for the routine treatment of all CSTD data collected from the Kelez. Thermometer data and salinities from the bottle data were used for in-situ calibration of the CSTD temperature and conductivity sensors. The processing steps included various filters, fitting curves to the filtered data, hand editing of the filtered data, interpolation at one meter intervals, calibration and a final print-out of the processed data at one meter intervals, the form in which the final data was distributed.

4.1.3. Data Analysis

The stage of the work we are now in is what may be considered a first cut descriptive study, a necessary task to better define a more quantitative approach and aid in hypotheses development. It is anticipated that much of this work will be carried out in the summer of 1978 and into the early part of the 1978-79 DOE contract presently being proposed. Publication of a comprehensive descriptive account of our data set by Gordon, Houghton, Woodroffe and Aikman is a goal within our 1978-79 period (see proposal).

It is noted that the data sets represent the various seasons, but not all of the same year. Hence, yearly variations or short-term variability (the data sets represent for the most part a two-week interval within each season) do not allow all observed structures to be interpreted as seasonal variability. However, a significant re-occurring variability is associated with the seasons
for water lying at densities above σ-t 27.0, which marks the top of the seasonal (nearly) invariant slope water.

It is clear that developing hypotheses recognize the spatial and time variable factors, as well as the relation of the observation period to the historical mean for the same period. To deal with the latter problem we are acquiring the full NODC file New York Bight data set. This will allow comparison of our data with the historical mean and variations.

The specific study items in 1977-78 period involve (as stated in our revised proposal for 1977-78 period in February 1978, p. 29):

(1) vertical stratification within the shelf-slope front and the frontal exchange processes active at this front, particularly the role of isopycnal processes, which generate interleaving of shelf and slope

characteristics, and of the molecular based process of double diffusion which acts to destroy the interleaving (Joyce, 1977); and

(2) importance of isopycnal boundary layer processes to the spreading of characteristics across the continental shelf, shelf break and slope, across the seasonal pycnocline and frontal zones. In the more general sense, we can divide the analysis work into studies of exchange processes at the shelf-slope front, over the continental shelf and over the continental slope, though in some respects the divisions overlap.

For some further background one can see last year's report, in which: 1) the January 1976 property-property distributions (T-S, T-O_2, T-P, T-Si) were compared with the July 1975 distributions; 2) the shelf-slope front is discussed and attention is drawn to the significant interleaving observed in the Cape Henlopen May 1977 data at the shelf-slope front; and 3) the results of the 1974 Hudson Canyon current meter 53-day station, which was submitted to JGR by Amos, Baker and Daubin, and is presently in the process of being revised for publication.

Analysis of the New York Bight hydrographic data has concentrated to some degree on the spatial and temporal variability observed within the shelf-slope front, situated near the shelf break. This is a region of active interleaving resulting in mixing and exchange of shelf and slope water. The degree of variability that we observe on time scales of hours to days advises caution in attempting detailed interpretation of data derived from stations with large spacial and temporal separation. The material described below has been presented at the November 1977 Workshop and at the AGU spring meeting in Miami Beach (part of which is now "in press" in the Green J.G.R., see attached preprint by Posmentier and Houghton).

Data for this analysis was taken primarily from the Cape Henlopen 77-01, May 1977 cruise (Fig. 4.1-1), in which stations 36-46 form a time series of observations at approximately 6 hour interval, at sites on both sides of the shelf-slope front. Fig. 4.1-2 shows the large horizontal gradients in the front that extend to the surface. Over the shelf the seasonal thermocline is forming. Compensating salinity gradients produce nearly horizontal isopycnals across the front.

The temperature structure over the shelf is shown in Fig. 4.1-3, where the profile displacement is proportional to the station spacing and the date and time of the station are indicated. Slope water intrusions along the shelf floor extend into stations 37 and 41. Station 45, which is within the shelf-slope front, has an additional slope water intrusion at 50 m, which was not present 17 hours earlier at station 39.

These intrusions of warm, salty slope water into cooler, fresher shelf water create structures where double-diffusion is possible and this would enhance the exchange of shelf and slope water (Posmentier and Houghton, "in press"). Applying the same flux rates used by Voorhis et al. (1976) and Horne (1978), we infer lifetimes of an individual intrusion of 1-2 days.

However, the changes in the profile at station 45, between the downtrace and an uptrace taken 20 minutes later (Fig. 4.1-4), suggest significant variability on even shorter time scales. To account for the changes observed at 60 m by double-diffusion requires unrealistic flux rates, therefore such rapid change is more likely the result of advection, presumably along isopycnal surfaces of fairly small scale parcels of water.

Seaward of the frontal zone the temperature structure is also highly variable, as seen in the profiles shown in Fig. 4.1-5. Intrusion of the cooler shelf water is particularly evident at the surface, 30 m, 70 m, and 90 m.

Mixing and interleaving of shelf and slope water is seen more clearly in Fig. 4.1-6 , which is a composite of T-S curves for stations on the shelf and slope side of the frontal zone. The mixing of water along isopycnals is particularly evident at the surface and along the shelf floor. If we consider the two nearly vertical T-S lines to represent pure shelf water (left) and pure slope water (right), then the distance along the isopycnal joining these two lines is proportional to the percent of slope water mixed with shelf water.

The results of such an analysis are shown in Fig.4.1-7, where the percentage of slope water present at the surface and 30 m level of the slope stations and on the shelf floor at the shelf station is plotted as a function of time, with the time of the local high and low tides marked. A semi-diurnal fluctuation is seen at 30 m over the slope and is consistent with the advection of the frontal zone, 2-4 km, by the barotropic tide. At the other location the tidal component in the fluctuation is not as evident. It is not unexpected that in the vicinity of the frontal zone, where strong horizontal gradients are present, there exist fluctuations of water characteristics at tidal and inertial frequencies.

Fig. 4.1-8 shows the interleaving structure of shelf and slope water that is often encountered in the frontal zone. These two stations are separated by 18 km across the frontal zone; the double-diffusive fluxes produced by such structures is thought to produce a significant contribution to the exchange of water on the shelf. Interleaving structures have been observed on all of our New York Bight cruises and appear to be more prevalent in the vicinity of a topographic feature such as the Hudson Canyon, or along the perimeter of a warm core eddy incident on the slope. A schematic representation of the interleaving in the frontal zone, suggested by the profiles in Fig. 4.1-8 is shown in Fig. 4.1-9.

The T-S diagrams of stations 44 and 45 revealed curious patterns of loops associated with the interleaved intrusions (Posmentier and Houghton, in press). These suggest regions of neutral or negative stability, where vertical mixing would be greatly enhanced. These T-S patterns are not the result of instrumentation errors, ship's motion, or internal waves. We believe that they are direct evidence of double-diffusive processes, whereby parcels of water move off the T-S correlation curve due to the differential flux rates of salt and heat.

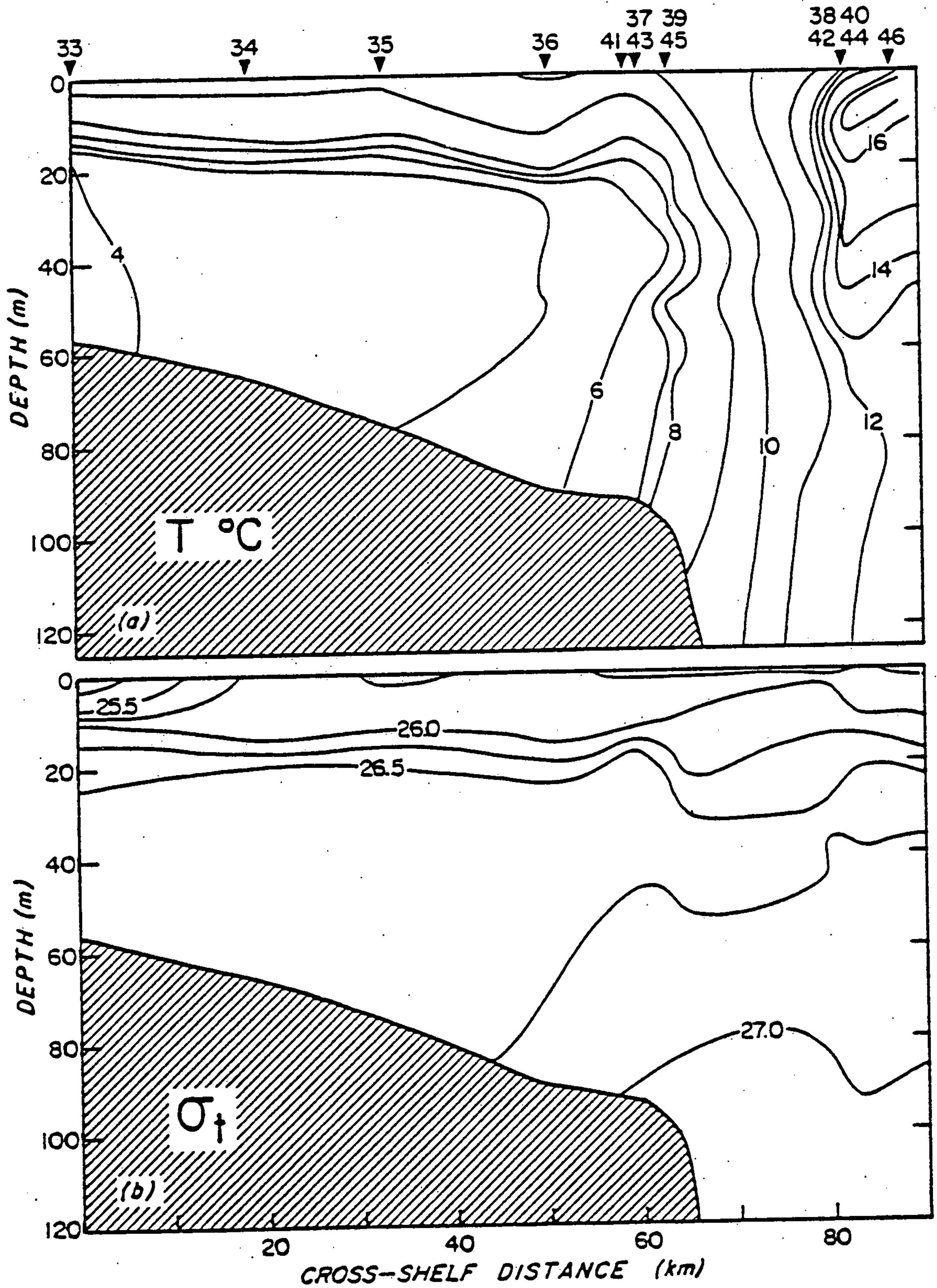

33
34
35
36
37 39
41 43 45
38 40
42 44
46
T °C
(a)
4
6
8
10
12
14
16
DEPTH (m)
0
20
40
60
80
100
120
σt
(b)
25.5
26.0
26.5
27.0
CROSS-SHELF DISTANCE (km)
20
40
60
80

Fig. 4.1-2

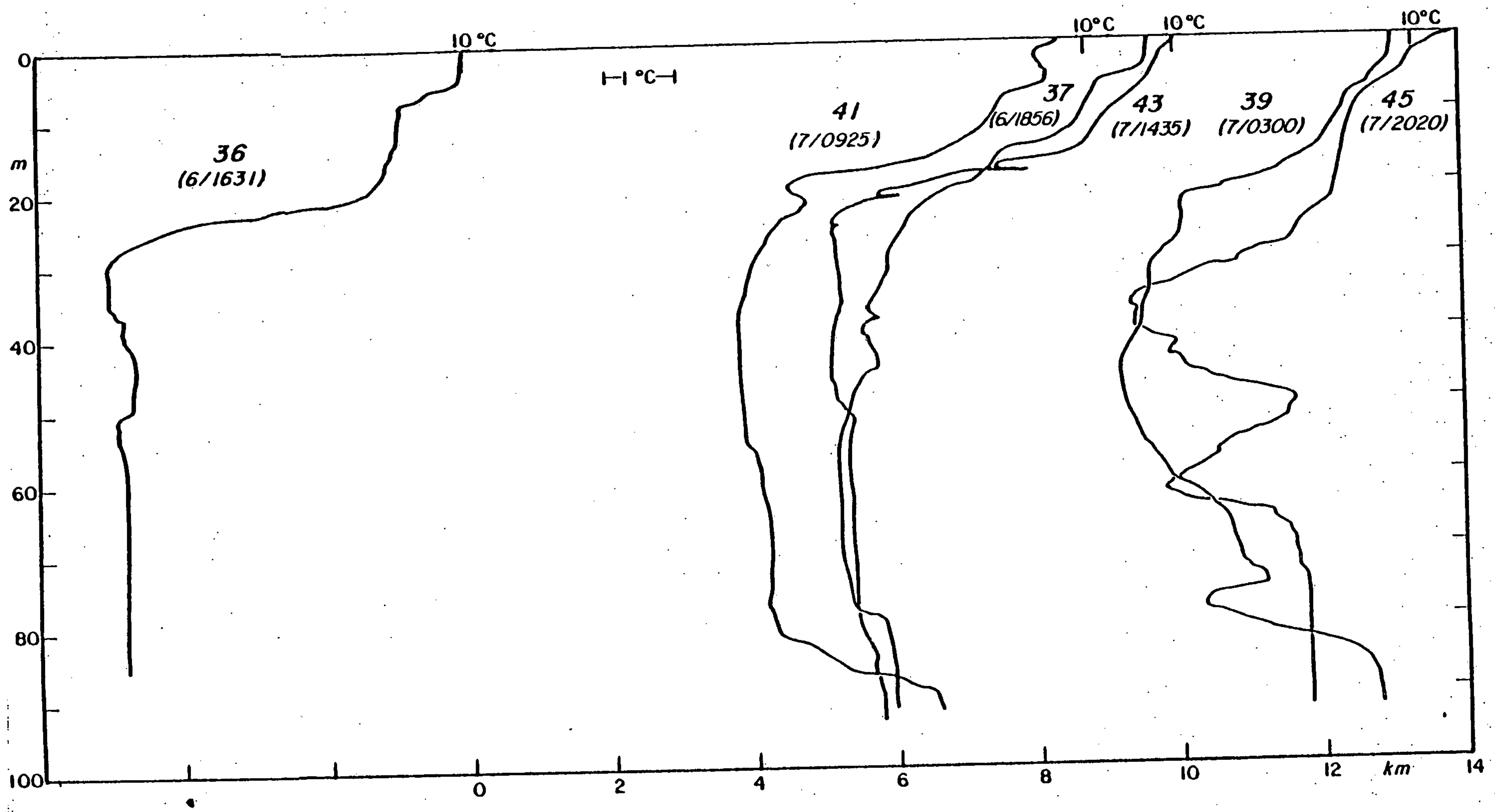

10 °C
10°C
10°C
10°C
|–| °C |–|
36
(6/1631)
41
(7/0925)
37
(6/1856)
43
(7/1435)
39
(7/0300)
45
(7/2020)
m
0
20
40
60
80
100
0
2
4
6
8
10
12
14
km

Fig. 4.1-3

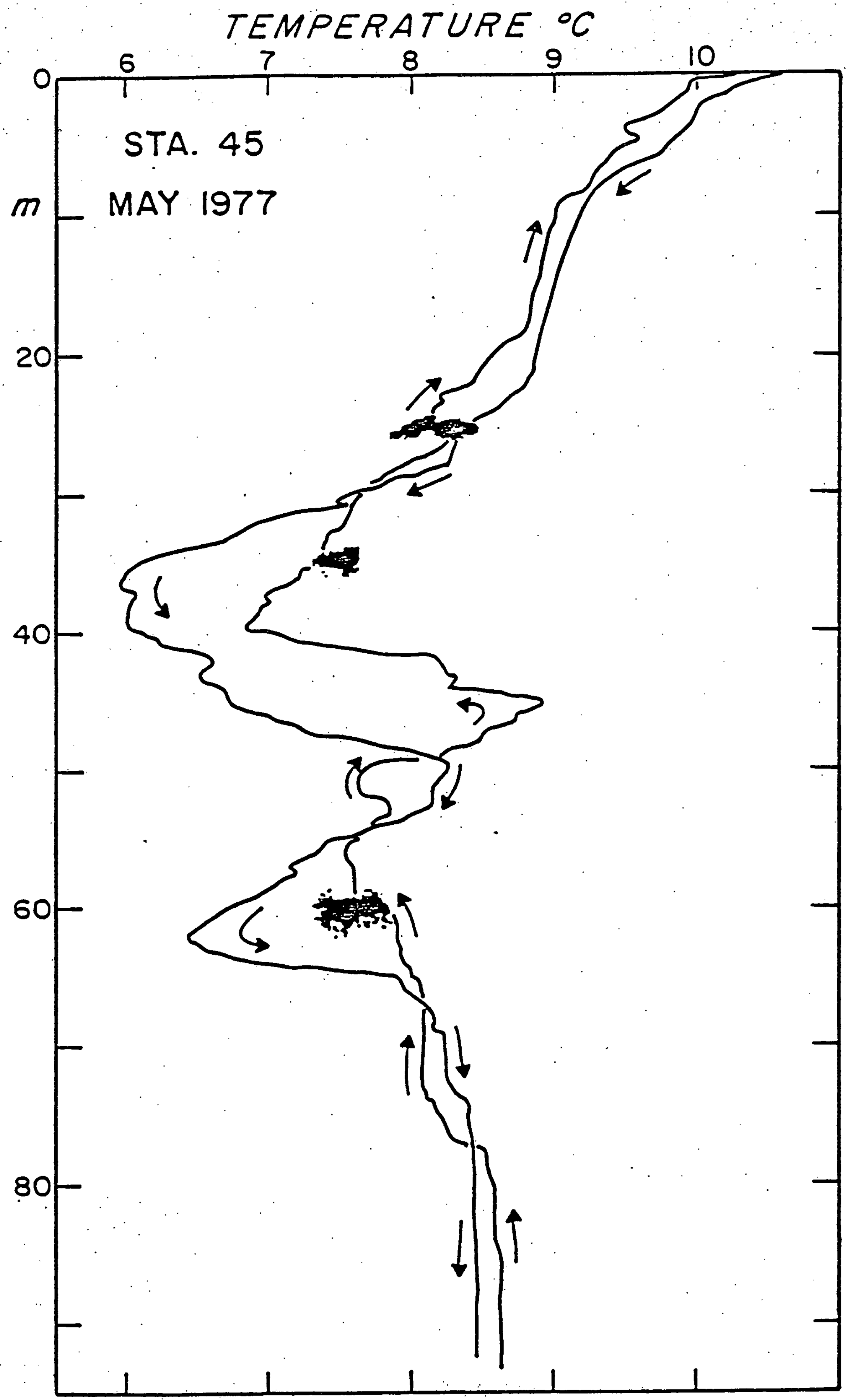


Fig. 4.1-4

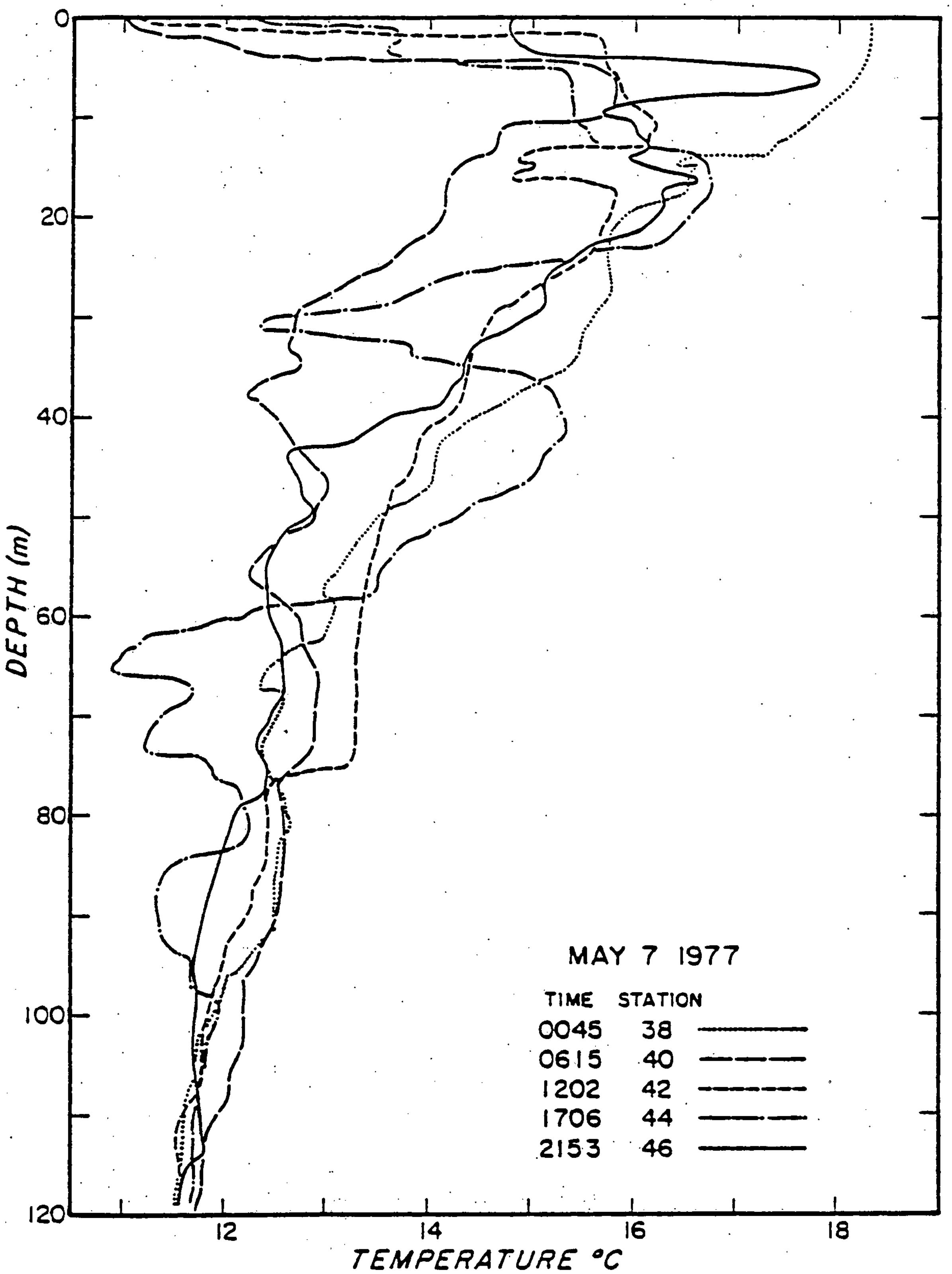
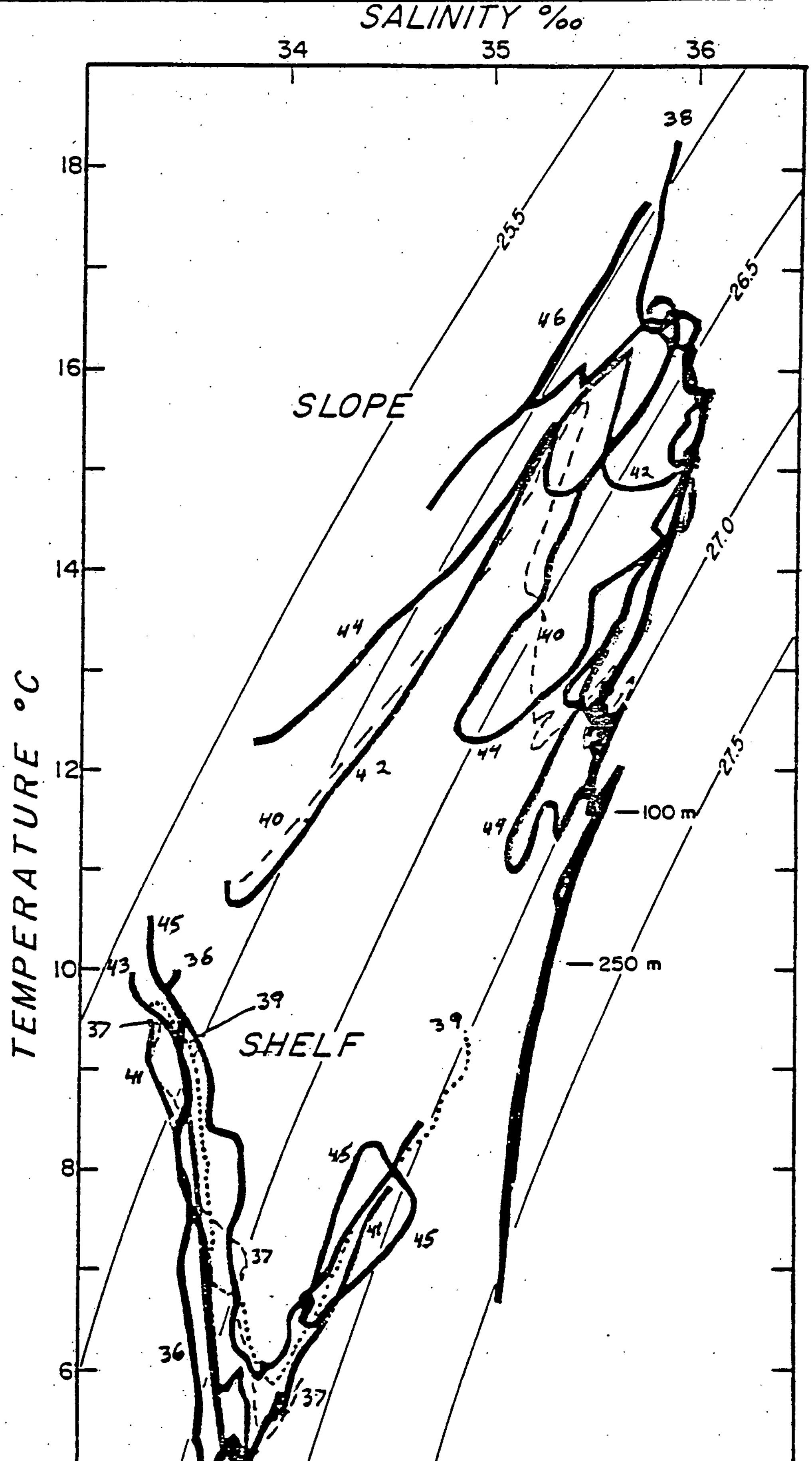

0
20
40
60
80
100
120
DEPTH (m)
12
14
16
18
TEMPERATURE °C
MAY 7 1977
TIME STATION
0045 38
0615 40
1202 42
1706 44
2153 46

Fig. 4.1-5



note: Stations marked on T-S diagram

Fig. 4.1-6

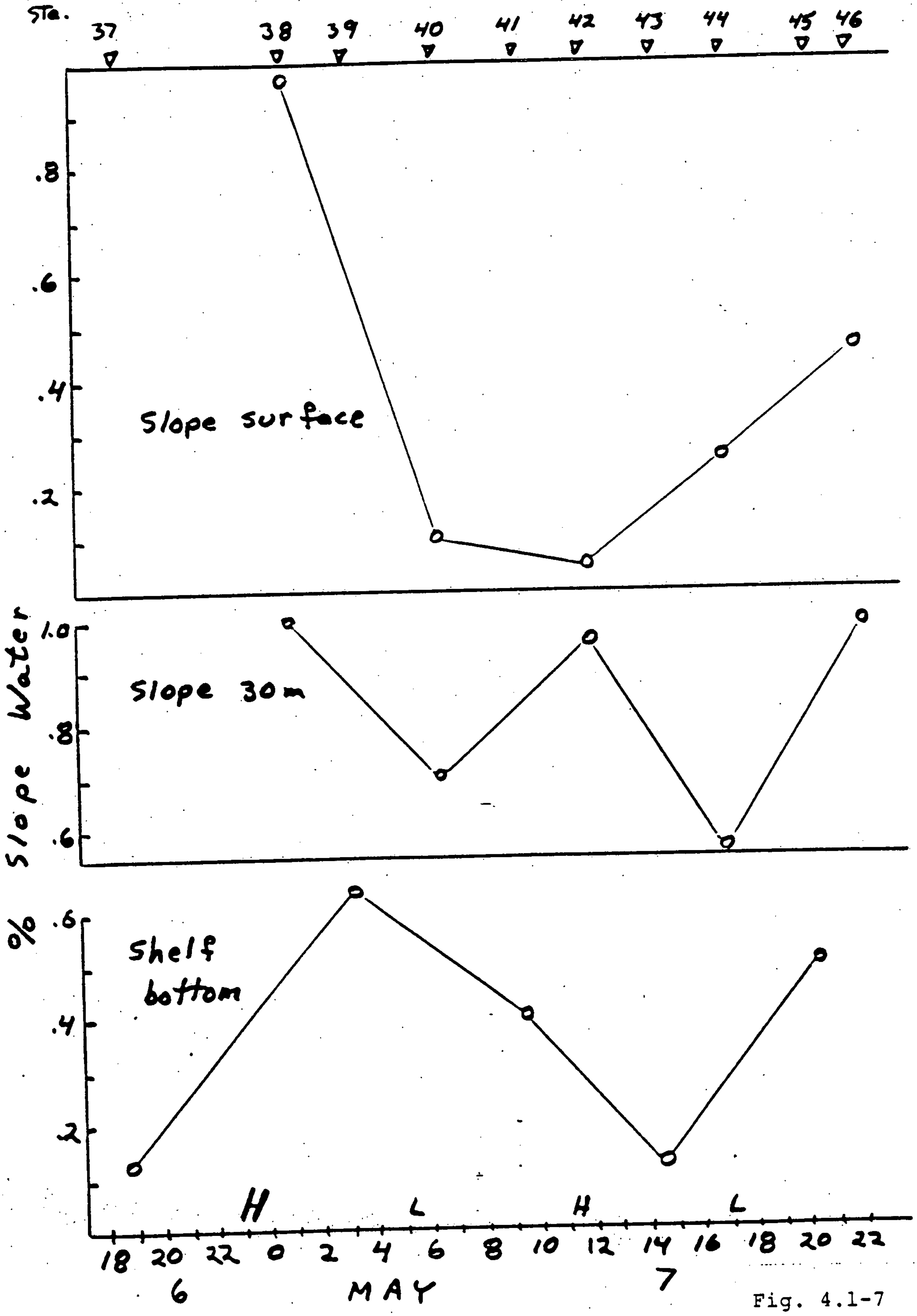

Sta.
37
38
39
40
41
42
43
44
45
46
.8
.6
.4
.2
Slope surface
1.0
.8
.6
Slope 30 m
Slope Water
% .6
.4
.2
Shelf bottom
H
L
H
L
18
20
22
0
2
4
6
8
10
12
14
16
18
20
22
6
MAY
7

Fig. 4.1-7

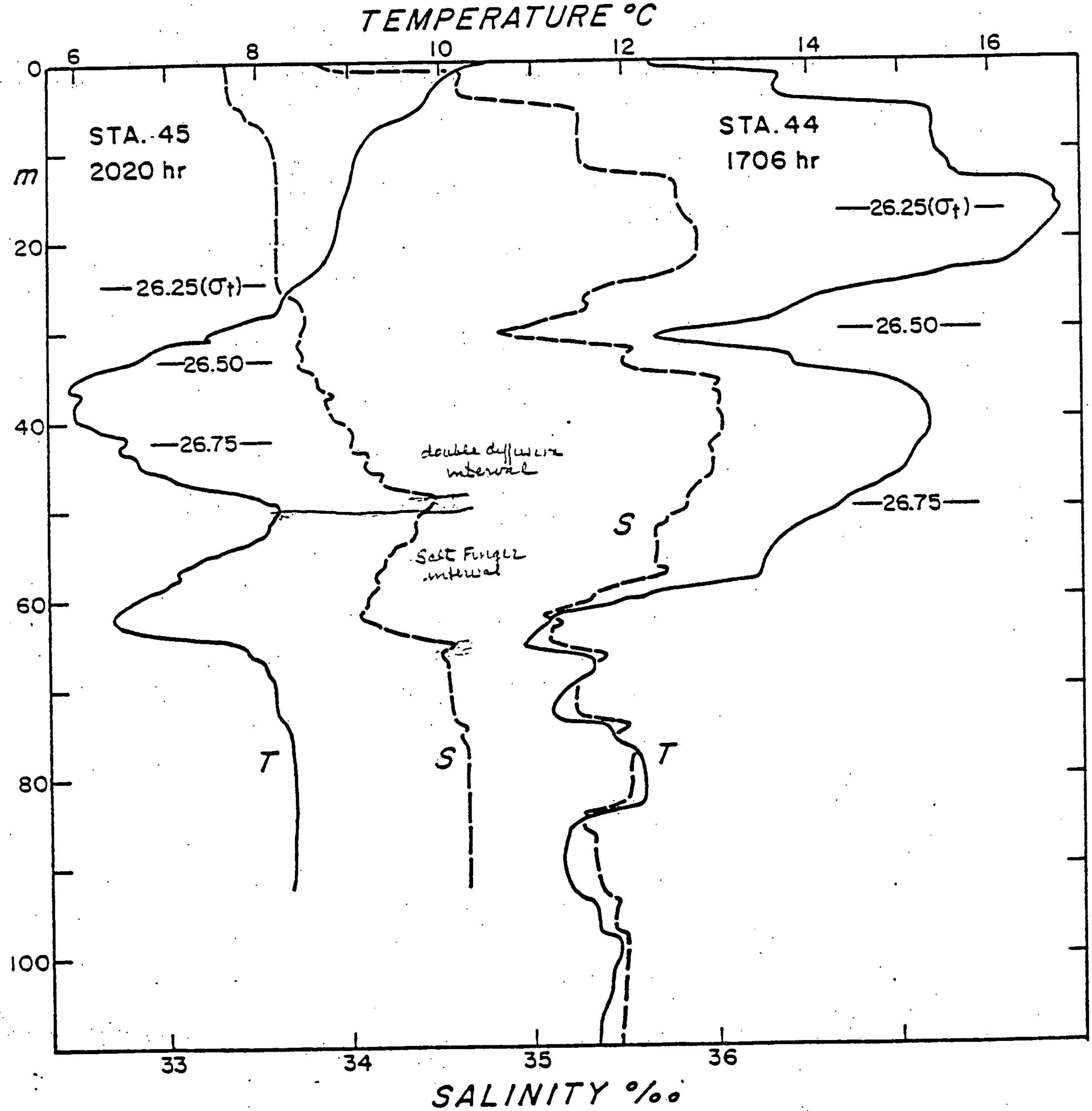

TEMPERATURE °C
6
8
10
12
14
16
0
m
20
40
60
80
100
STA. 45
2020 hr
STA. 44
1706 hr
26.25(σt)
26.50
26.75
26.25(σt)
26.50
26.75
double diffusive interval
Salt Finger interval
S
T
S
T
33
34
35
36
SALINITY ‰

Fig. 4.1-8

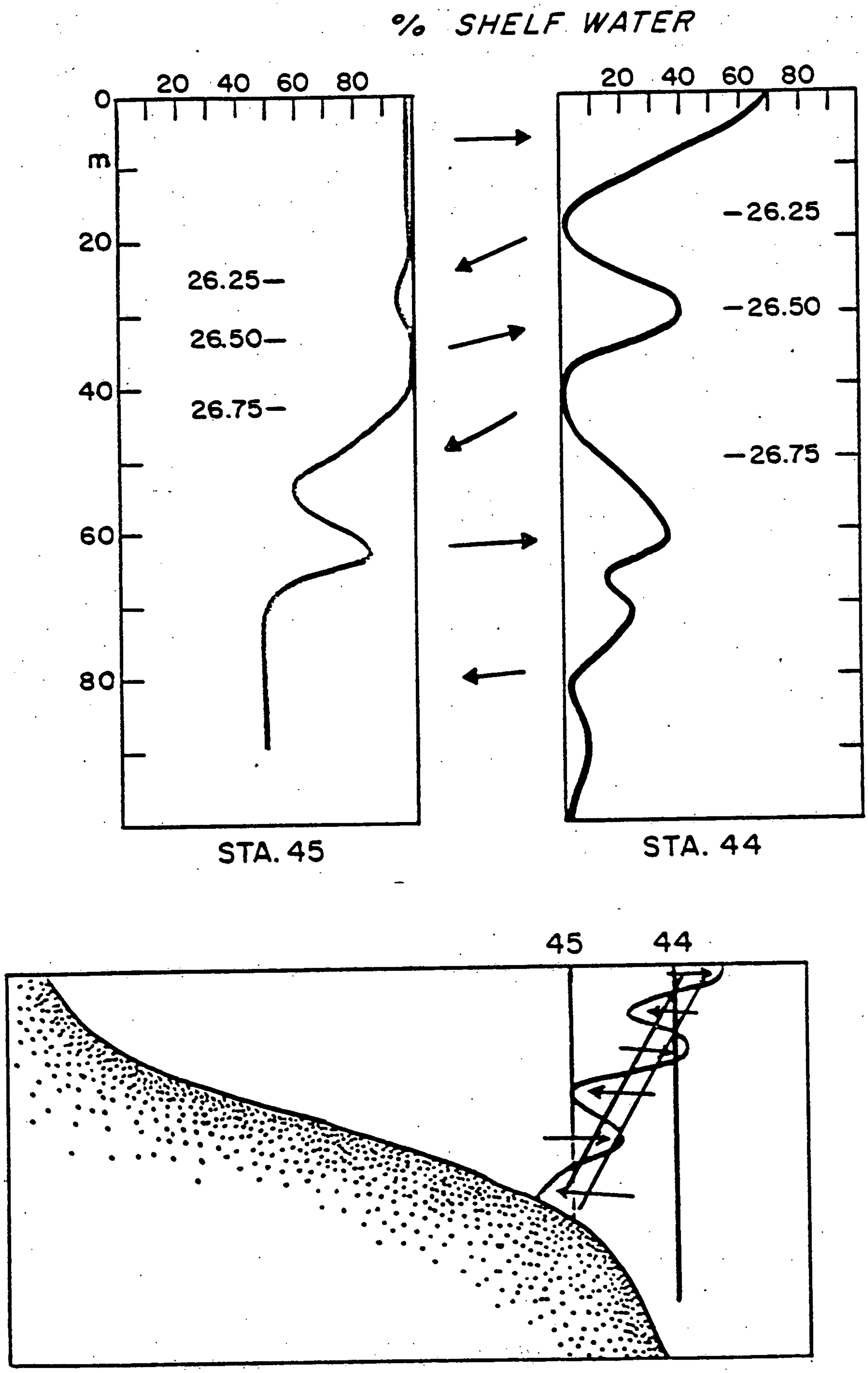

% SHELF WATER
20
40
60
80
0
m
20
40
60
80
26.25
26.50
26.75
STA. 45
STA. 44
45
44

Fig. 4.1-9

Continental Shelf Studies

Study of the full distribution of our data set on the continental shelf is just beginning, as the processed data sets become available. The approach is to first describe the thermohaline stratification, vertical stability and oxygen-nutrient distribution for the region north of the Hudson Shelf Channel, south of the Channel, and within the Channel, forfor each of the data sets. The objective of the shelf study is to define the water types (River, Shelf, Slope, Gulf of Maine influences) present, identify regimes of similar types of stratification, and locate the boundaries or fronts between these regimes. Evidence of regime-regime exchange process will be sought. Below are some considerations based on the preliminary stage of the continental shelf work.

Is there a Mid-Shelf Front?

Inspection of the Knorr, August 1977 data south of Long Island suggests the existence of a front over the continental shelf within the surface and pycnocline levels near the 33.0-34.0 °/₀₀ isohalines. This hypothetical mid-shelf front is most clearly seen in T/S space, Fig.4.1-10. The T-S boundaries of the inner-outer shelf and slope are determined by groups of all the Knorr stations; in Fig.4.1-10 only a sample of stations from each zone is shown.

Significant slope water intrusions are observed in the outer shelf zone in two layers marked by maximum in salinity: a pycnocline salinity maximum near 24.0 sigma-t, and a bottom layer salinity maximum near 26.5 sigma-t. The pycnocline S-max lies in the upper part or top of the thermocline. Its existence in other sections has been noted by Boicourt and Hacker (1976) and Gordon et al, (1976). Boicourt and Hacker suggest that it is due to an Ekman effect, as surface water is advected off-shore

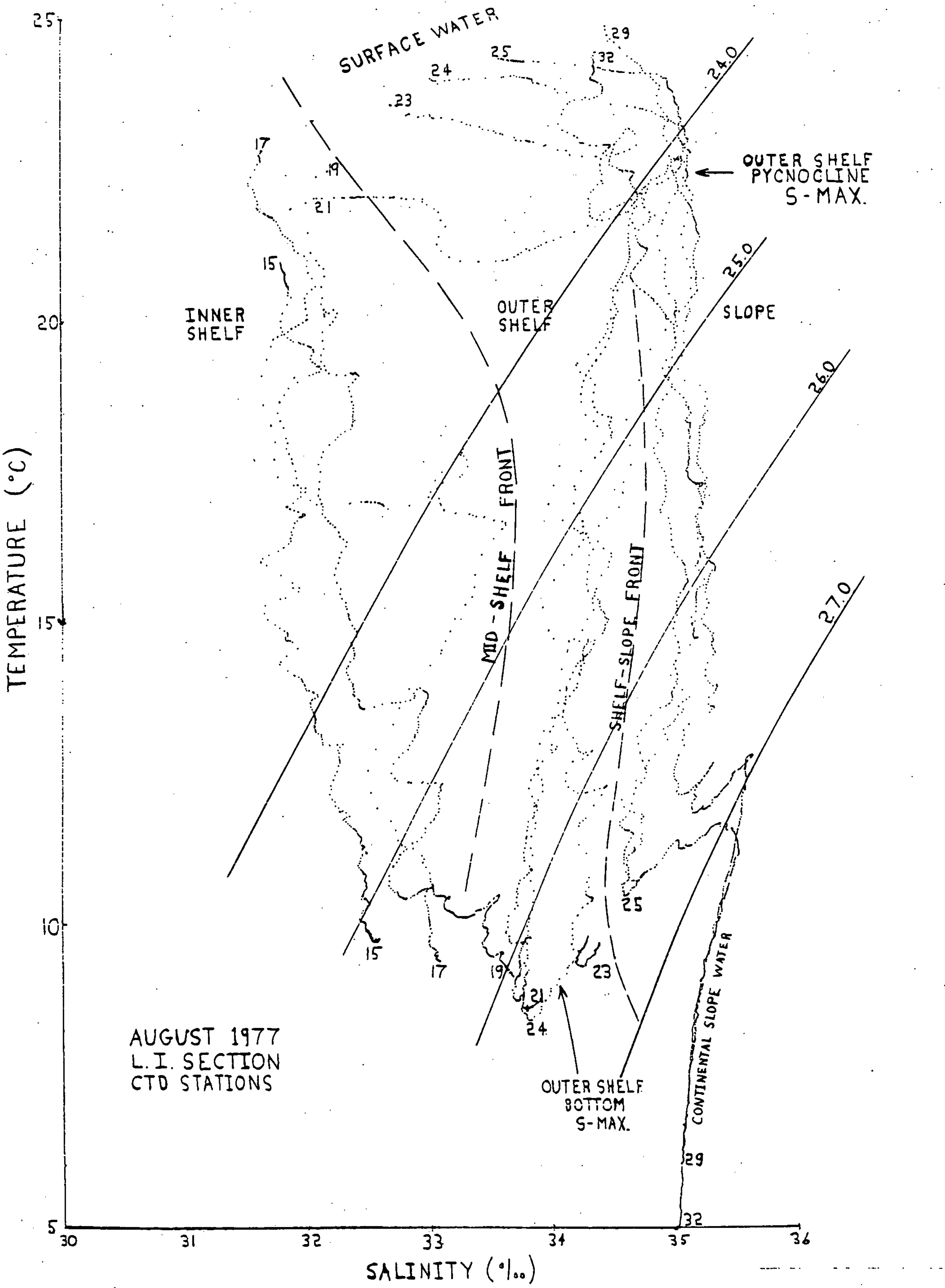

SURFACE WATER
OUTER SHELF PYCNOCLINE S-MAX.
INNER SHELF
OUTER SHELF
SLOPE
MID-SHELF FRONT
SHELF-SLOPE FRONT
24.0
25.0
26.0
27.0
TEMPERATURE (°C)
SALINITY (‰)
AUGUST 1977
L.I. SECTION
CTD STATIONS
OUTER SHELF BOTTOM S-MAX.
CONTINENTAL SLOPE WATER

Fig. 4.1-10

by the prevailing southwest summer wind a compensating landward flow is set up in the pycnocline. The depressed salinity of the surface water in the slope region is consistent with this picture.

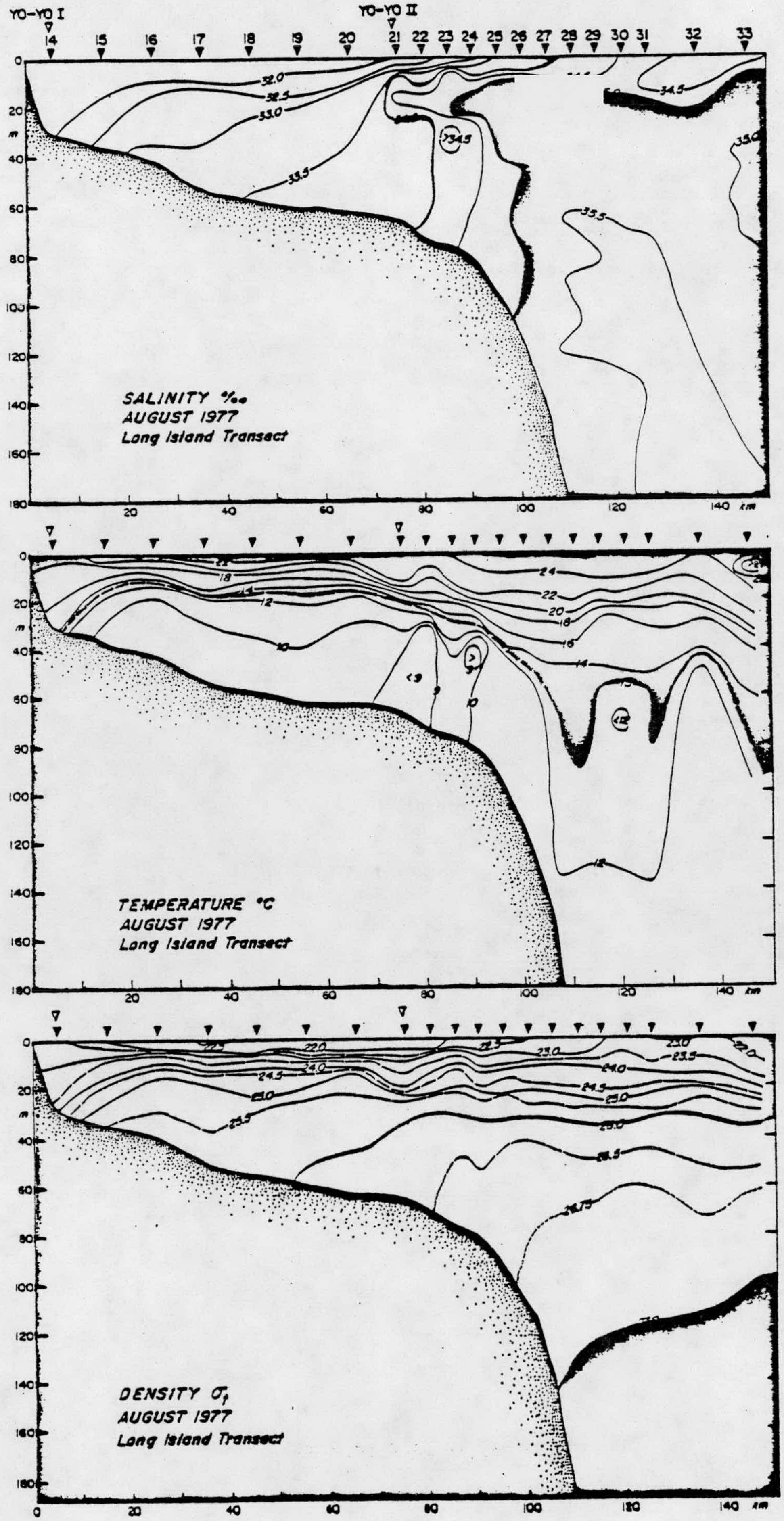
A mid-shelf front observed in August 1977, which divides the inner and outer shelf zones, may be taken as the landward position of the pycnocline and bottom slope water intrusion (near 65 m isobath) in the Knorr section. The pycnocline S-max is clearly seen in the vertical sections (figure 4.1-11).

The S-max is associated with a weaker pycnocline relative to the pycnocline observed shoreward of the mid-shelf front. The lowered stability within the S-max may be accompanied by a larger degree of vertical mixing across the pycnocline of the outer shelf.

A time series station (at yo-yo II, marked on Fig.4.1-11 taken over a 48-hour period (Fig. 4.1-12) indicates that the pycnocline S-max is persistent unlike the more transient slope water intrusions seen seaward at the shelf-slope front (discussed above). Greater spatial continuity of the pycnocline S-max of the outer shelf is suspected.

The sub-pycnocline S-minimum in the outer shelf zone (induced by the pycnocline and bottom slope water intrusion) is coupled to a temperature-minimum (Wright, 1976). It is believed to represent a remnant of the previous local winter water, which may be mixed to some extent (maybe totally?) with Gulf of Maine intermediate water, which is advected south of Georgia Bank (Hopkins and Garfield, 1977).

Within the inner shelf zone the thermohaline stratification is more estuarine in character, without persistent slope water intrusion to induce reversals in the vertical salinity gradient. An isolated pycnocline S-max is seen at CTD station 17, significantly inshore (40 km) of the



YO-YO I
YO-YO II
SALINITY ‰
AUGUST 1977
Long Island Transect
TEMPERATURE °C
AUGUST 1977
Long Island Transect
DENSITY σ_t
AUGUST 1977
Long Island Transect

Fig. 4.1-11

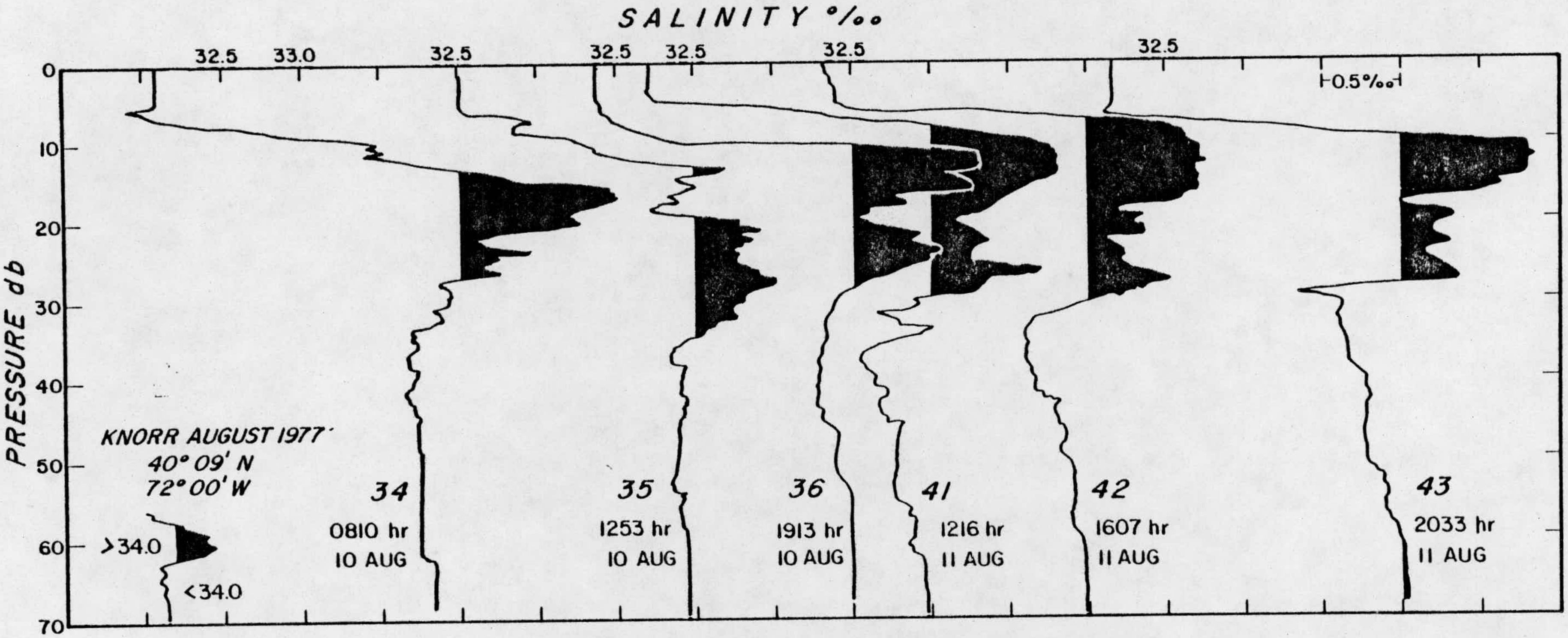

SALINITY ‰
32.5
33.0
32.5
32.5
32.5
32.5
32.5
⊢0.5‰⊣
PRESSURE db
0
10
20
30
40
50
60
70
KNORR AUGUST 1977
40° 09' N
72° 00' W
>34.0
<34.0
34
0810 hr
10 AUG
35
1253 hr
10 AUG
36
1913 hr
10 AUG
41
1216 hr
11 AUG
42
1607 hr
11 AUG
43
2033 hr
11 AUG

Fig. 4.1-12

mid shelf front marking the boundary of the pycnocline S-max, within sigma-t interval 24.0-24.6. This is the same density of the outer shelf pycnocline S-max. Landward isopycnal transfer of the S-max water is probable. The lower salinity and temperature of the intrusion at station 17, relative to that of the outer shelf "mother load", indicate some dilution by inner shelf water has occurred, but the transfer remains nearly isopycnal.

Landward spreading of slope water characteristics by isopycnal processes across the hypothetical mid shelf front would represent not only a cross-shelf exchange, but also a transfer from pycnocline to sub-pycnocline water layers, as hypothesized by Gordon et al. (1976), based on our first data set (Vema cruise 32-01, October 1974).

Do we see any evidence of a mid-shelf front in our other data sets? The October 1974 data (Gordon et al, 1976) show a strong S-max intrusion within the upper pycnocline layers in the Hudson Shelf Channel region, under which lies a bottom S-max and an intervening S-min to the 70-meter isobath. Landward of the co-existence of the pycnocline and bottom S-max, the pycnocline S-max is only found at some stations, with reduced temperature and salinity and at relatively lower positions within the pycnocline. This is similar to the Knorr situation: the hypothetical mid-shelf front would be placed at the landward boundary of the persistent pycnocline and bottom S-max intrusions, and the patch of S-max water found further inshore is isopycnally introduced from the pycnocline S-max.

The July 1975 data shows many similarities with the August 1977 data, though the mid-shelf front is a weaker feature than seen at the Knorr section.

The winter period (Conrad 19-05, January 1976), in which there is no pycnocline on which to form the pycnocline S-max slope water intrusion, yields a simpler picture: only a bottom slope water intrusion to the 70 meter level. It is interesting to note, however, that the upper layer of the outer shelf zone above the bottom S-max is surprisingly homogeneous, both in the vertical and cross-shelf directions. This contrasts with the shelf water inshore of the bottom intrusion which, while being nearly vertically homogeneous, displays significant cross-shelf salinity gradients (2.3°/₀₀ per 100 km). The reasons for this salinity structure and its relationship to the hypothetical summer-autumn mid-shelf front are not clear, though a number of ideas are being developed.

Slope Oceanography

The deep water stratification (defined as the water column below the seasonal invariant S-max layer near 100 m) of the New York Bight continental slope has been discussed by Gordon et al, (1976). The source of the slope water along the northeast U.S. coast is an admixture of Scotian shelf and slope water with North Atlantic central water, the latter component becoming increasingly dominant to the south. There are a number of inflections in the deep T-S curve marking water mass intrusions: at 8-9°C (300 m) an inflections marks the base of the thermocline waters, near 4°C (1000 m) is the low salinity Labrador Sea intermediate water, near 3.2°C is the more saline mediterranean overflow water, and below this is the middle and lower components of the North Atlantic Deep Water.

The geochemical measurements for bottom excess radon have found no excess radon over the floor of the continental slope near the 1000 m isobath. At a meeting at WHOI on May 1, 1978, to discuss this feature, it was the consensus that the lack of excess radon results from very rapid mixing of the radon away from the boundary layer. It is noted that the steep slope of the sea floor relative to the slope of the isopycnal surfaces would allow isopycnal spreading to be much more significant in carrying away bottom layer radon than in a case where density and sea floor surfaces are more parallel. The question of how the excess Radon is transferred away from the boundary layer where the larger scale isopycnal events can induce rapid spreading was discussed. One mechanism is the dissipation of an interval tide generated at the continental slope. Another is a pumping action due to differential variations in thickness of density layers, probably at tidal periods. In this model the spacing between isopycnals varies; in the contraction phase boundary water is transferred into the interior where large scale turbulent processes quickly disperse the radon.

Internal waves at tidal frequencies can be generated by the interaction of the surface tide with bottom topography. The theory of this internal tide generation for a two-dimensional model has been developed in detail by Baines (1973, 1974), who shows that internal wave energy emanates from the generation site along characteristics of the internal wave equation whose slope is given by

$$c = \left(\frac{\omega^2 - f^2}{N^2 - \omega^2}\right)^{1/2}$$

where f, N, and ω are the inertial Vaisälä-Brunt and tidal frequencies, respectively. The most efficient generation occurs where the topography is convex upward with s=c, where s is the local slope.

Fig.4.1-13(a) is an analysis by Baines (1973) of the New England shelf south of Rhode Island, showing the characteristic that is tangential to the slope at mid-depth. Fig.4.1-13(b) is a similar analysis by Petrie (1975) of the Nova Scotia slope south of Halifax. Moored current meters in locations that intersect the characteristics drawn from the generation zones record higher energy levels as expected. The internal waves propagate both shoreward and seaward of the generation site and presumably dissipate most of their energy within the slope region.

The generation of internal waves on the continental slope is of particular interest because of its effect on mixing of the water column and resuspension of sediments. Wunsch et al. (1978) have reported on recent experiments to document these effects in the Hudson Canyon, where internal wave motion is expected to be focused and intensified. Enhanced mixing due to internal waves generated all along the continental shelf could be responsible for the Radon minimum that has been found on the slope between 200 and 2000 m.

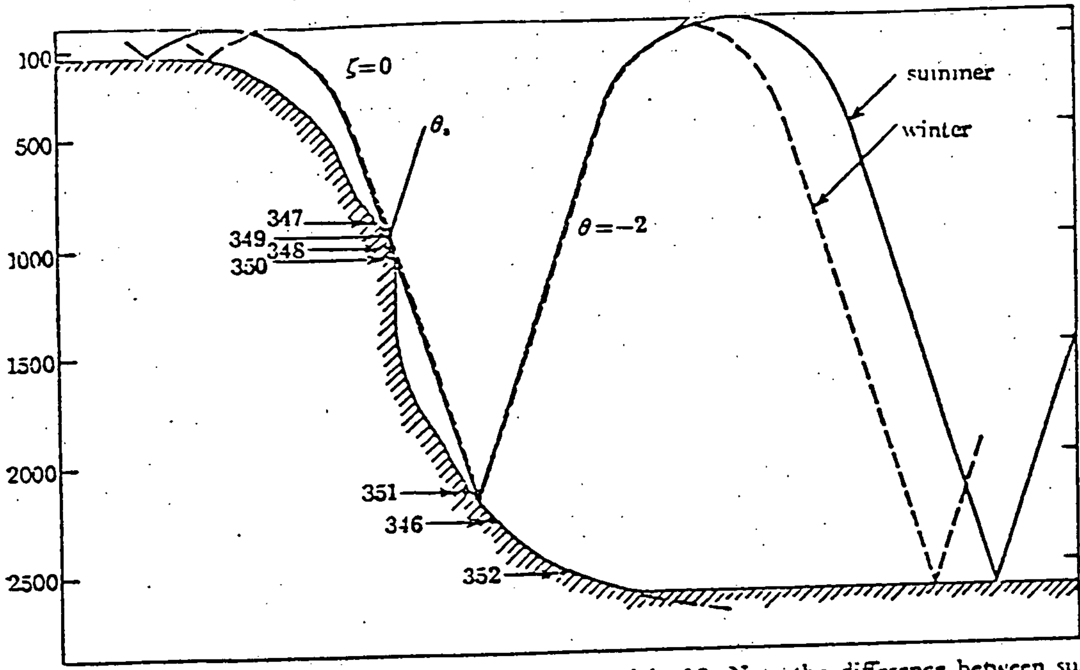
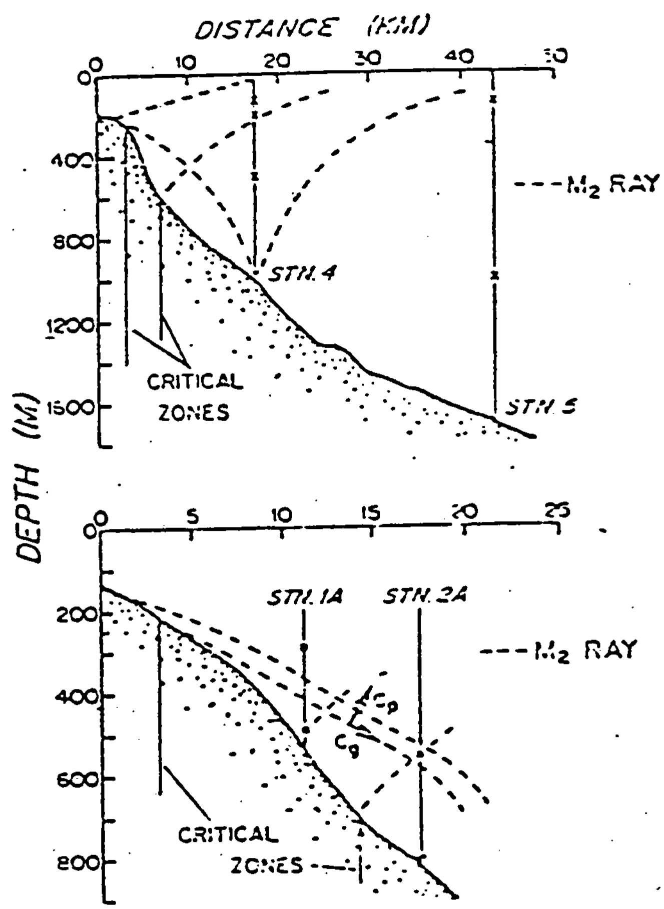


FIGURE 11. Topographic slopes and M_2 characteristics used in §8. Note the difference between summer and winter characteristics affected by stratification changes in the top 50 m. The numbers on the slope refer to the moorings of Wunsch & Hendry (1972).

(a)



(b)

To investigate generation zones along the mid-Atlantic Bight, we have considered shelf profiles from Hatteras to the Hudson Canyon (see Fig. 4.1-14). These slopes are compared with the characteristics which below 100 m have no seasonal variation. A critical zone where s=c occurs between 150-200 m at the shelf break for all of the profiles. At greater depths there is a qualitative difference north and south of profile #5 (near the Hudson Canyon). The northern profiles (see also Fig.4.1-13a) have a second convex slope region near 1000 m, where s∼c and hence a deep generation zone. It will be especially interesting to see if the proposed survey along the coast from Hatteras to the Hudson Canyon reveals alongshore differences in the width of the Radon minimum zone related to the changing topography. The lack of a deeper generation zone south of 39°N suggests that we might not expect the Radon minimum zone to extend as far down the slope as it does near and north of the Hudson Canyon.

We will continue to develop a hypothesis to explain the lack of an excess in radon on the slope. Our present slope data may be useful, but it is limited in that we do not have proper spatial coverage and time series observations. The data to be generated by the proposed field work for next year (see proposal) will allow for testing of an internal tide process.

Warm core eddies impinging on the continental slope contribute to exchange of waters across the shelf break. Estimates of this exchange have been made by Morgan and Bishop (1977), who show that it contributes a significant percentage of the total annual offshore shelf water transport. The presence of these warm core eddies introduce small scale structure over the slope such that any given section may deviate significantly from the norm.

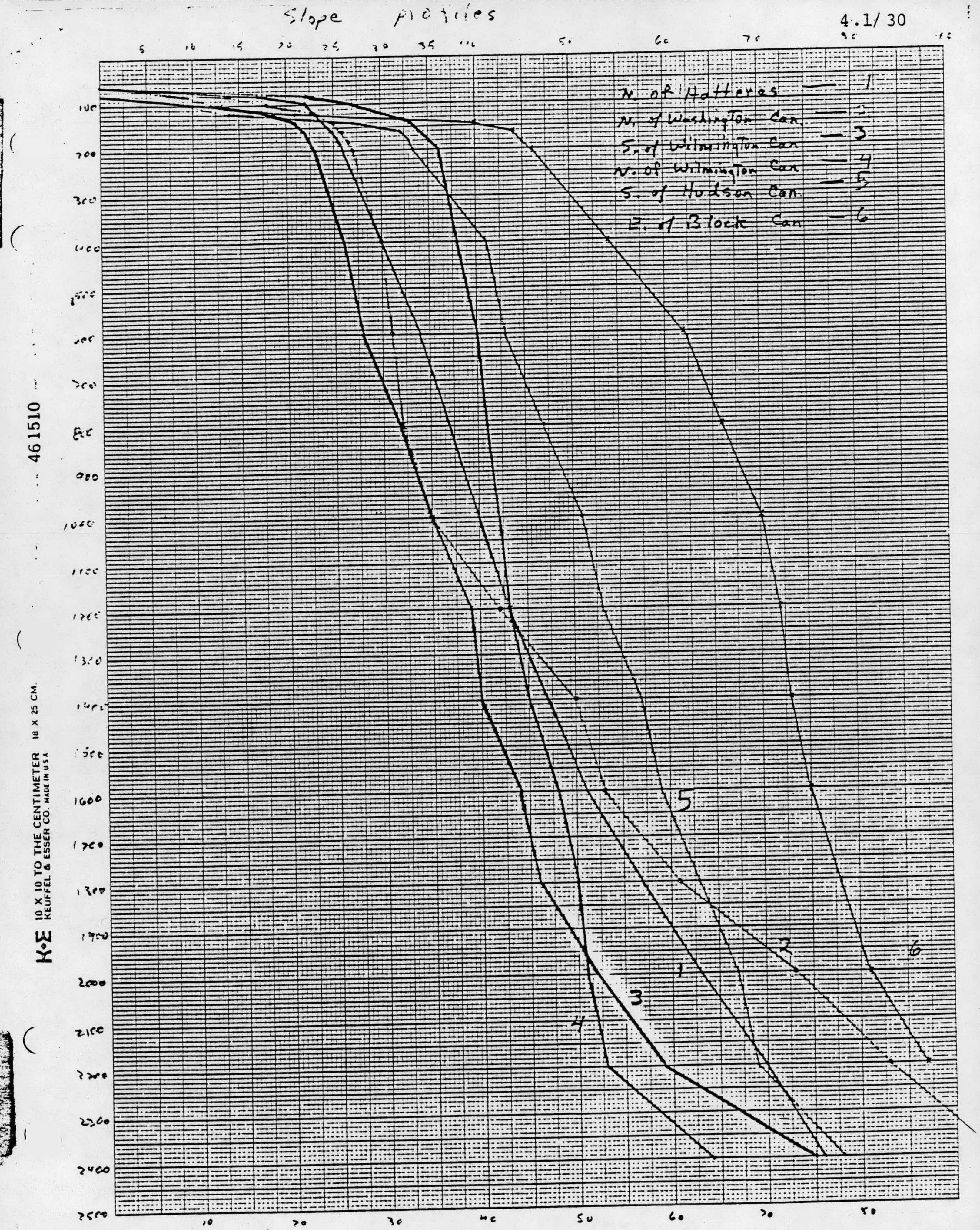

Slope profiles
N. of Hatteras — 1
N. of Washington Can — 2
S. of Wilmington Can — 3
N. of Wilmington Can — 4
S. of Hudson Can — 5
E. of Block Can — 6
46 1510
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

Fig. 4.1-14

A striking example of this was observed on the Conrad 19-01 cruise in July 1975. At station 384, south of the Hudson Canyon (see Fig.4.1-15) temperature and salinity profiles (Fig. 4.1-16) reveal a deep, well mixed layer between 100-400 m of 15°C and 36.15°/₀₀ water. At stations 387 and 388 the layer is thinner, extending only to 300 m. Stations 425 and 388 are on the perifery of this structure, while stations 424, 433, and 391 have normal slope water profiles. This structure is coincident with the core of the anticyclonic eddy shown in Fig. 4.1-17), and we believe it to be the remnant of winter cooled Sargasso Sea water trapped by the warm core eddy and now topped by the seasonal thermocline.

In his study of the formation of an anticyclonic eddy, Saunders (1971) presents temperature profiles (see Fig. 4.1-18), showing the winter cooling and deepening of this mixed layer. Notice that it cools to 15°C and mixes to 350 m, which is comparable to our observations. Since eddies have lifetimes in the range of 6 months to 1 year, it is quite possible for an eddy to form in the fall, cool in the winter, and then be observed on the slope the following summer. No other process can account for water with salinities greater than 36°/₀₀, yet cooled to 15°C. Our observation is significant in showing the longevity of this deep winter mixed water and the transport of Sargasso water from south of the Gulf Stream onto the continental slope, where it can be mixed onto the shelf.

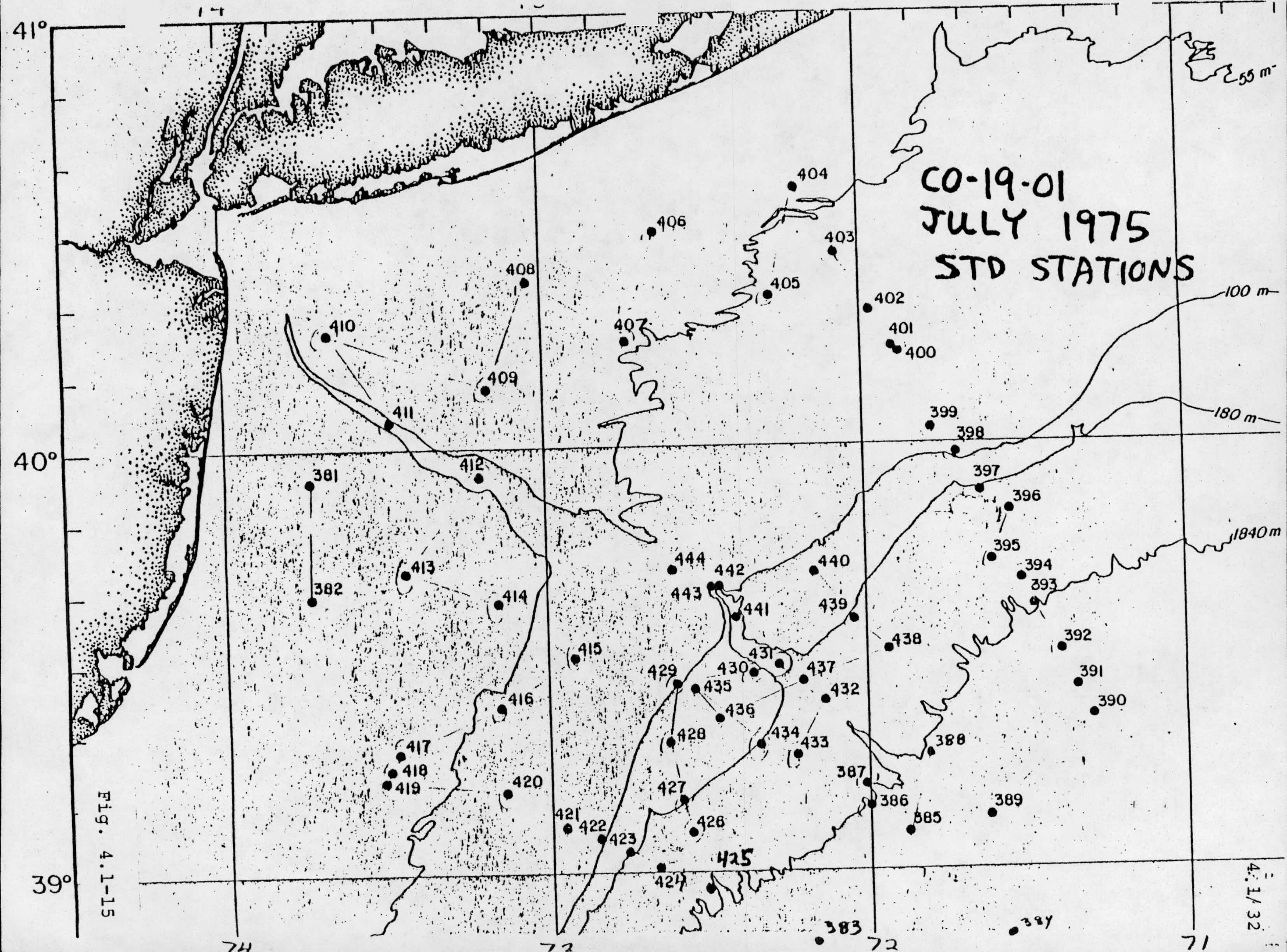


Fig. 4.1-15

4.1/32

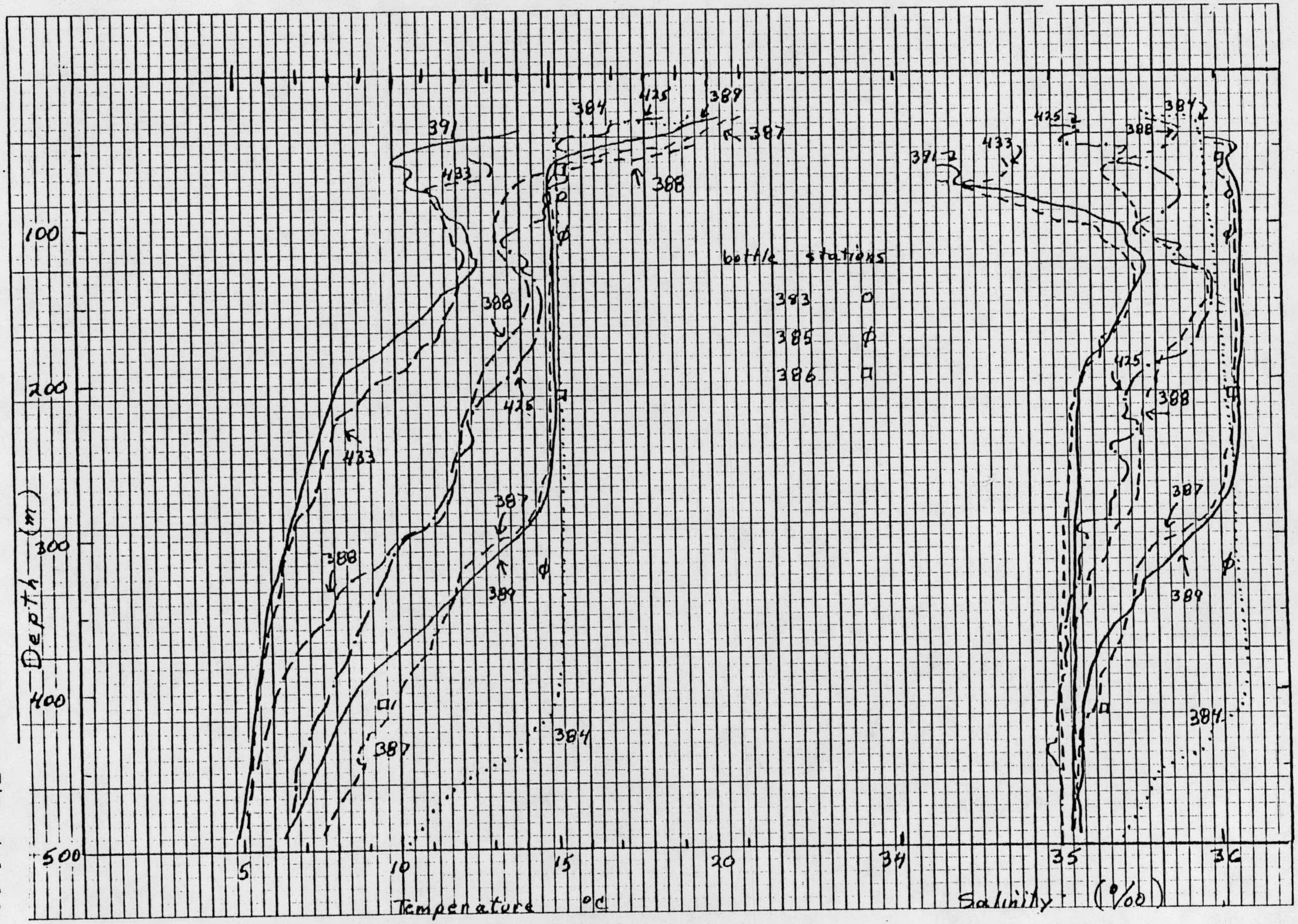

Depth (m)
100
200
300
400
500
5
10
15
20
34
35
36
Temperature °C
Salinity (‰)
bottle stations
383 o
385 ϕ
386 □
384
425
389
387
388
391
433

Fig. 4.1-16

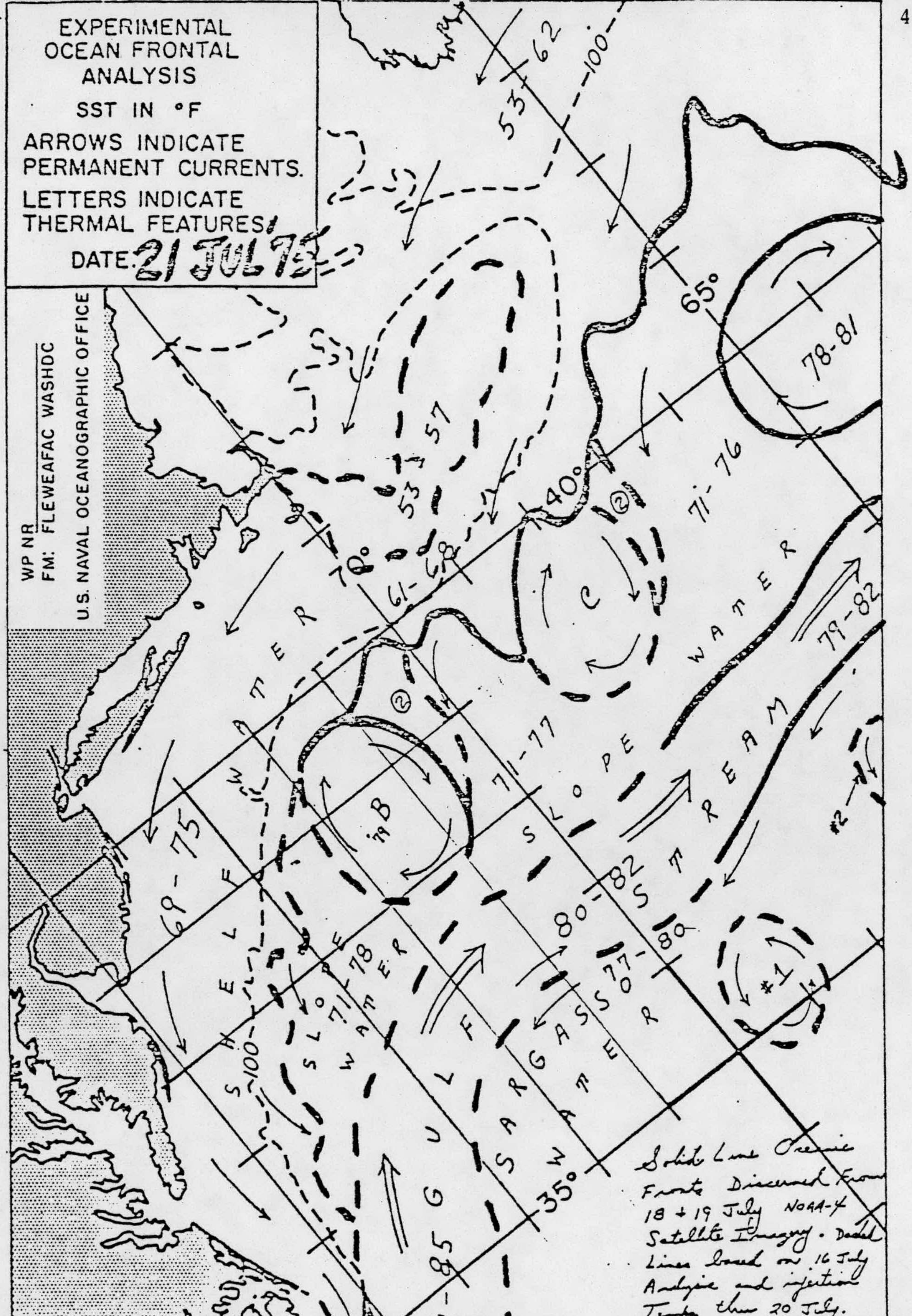

EXPERIMENTAL
OCEAN FRONTAL
ANALYSIS
SST IN °F
ARROWS INDICATE
PERMANENT CURRENTS.
LETTERS INDICATE
THERMAL FEATURES.
DATE: 21 JUL 75
WP NR
FM: FLEWEAFAC WASHDC
U.S. NAVAL OCEANOGRAPHIC OFFICE
SHELF WATER
SLOPE WATER
GULF STREAM
SARGASSO WATER
65°
70°
40°
35°
100
53
62
57
53
61-68
71-76
78-81
79-82
71-77
69-75
80-82
77-80
71-78
81-85
C
B
#1
#2
Solid Line Oceanic Fronts Discerned From 18 + 19 July NOAA-4 Satellite Imagery. Dashed Lines based on 16 July Analysis and injection Temps thru 20 July.
② Mixed Shelf + Slope Water.
Meander East of 65W still connected to Gulf Stream.

Fig. 4.1-1

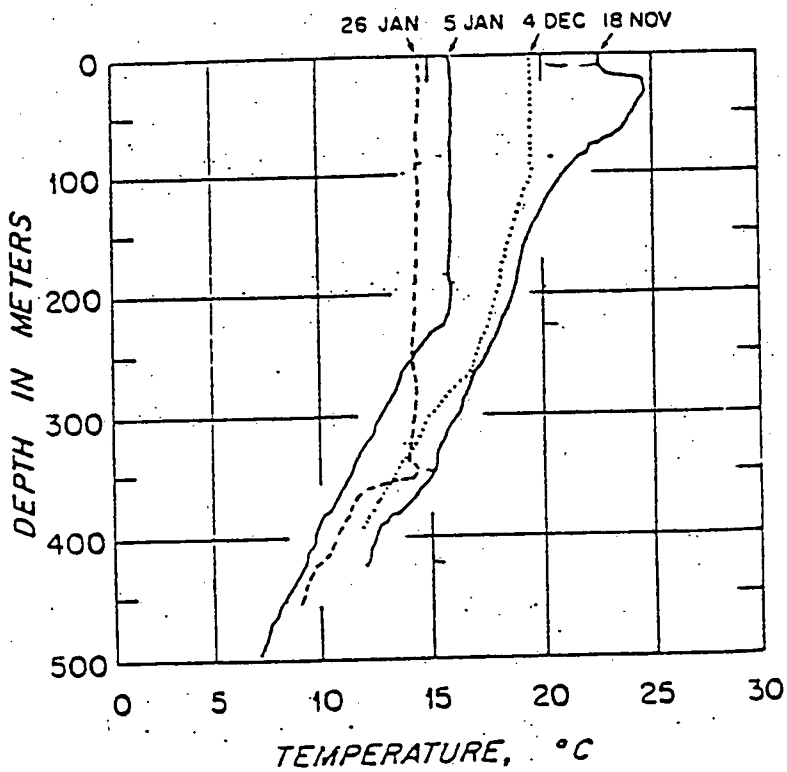


Fig. 11. Sequence of temperature–depth curves *near* the center of the eddy from about 10 days after its formation until last reported. Note the seasonal deepening and cooling of the mixed layer: seasonal effects do not generally penetrate below 100–150 m in the Slope Water.

from P. M. Saunders (1971),
Anticyclonic eddies formed from shoreward meanders of the Gulf Stream,
Deep-Sea Res., 18, 1207-1219

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4.2 Oxygen Isotopes as Tracers of Water Mass Origins on the Continental Shelf

There are latitudinal variation in the $^{18}O/^{16}O$ ratio in precipitation and resultant runoff, which results from the general increase in the percentage of the lighter isotope with higher latitude as the heavier isotope is more readily lost to precipitation. In mean sea water 1 out of every 500 water molecules contains an ^{18}O instead of the common isotope ^{16}O. Mixing of continental runoff from different latitudes with sea water results in varying proportions of these molecules which provides an oceanographic tracer like salinity, however, the isotopic composition is specific to the water component of the fluid.

As early as 1953, Epstein and Mayeda observed that the $^{18}O/^{16}O$ ratio could differ in ocean waters of the same salinity, because the sea waters received fresh water from different sources or latitudes. Further work by Craig and Gordon (1965) extended the descriptive study of Epstein and Mayeda and successfully applied oxygen isotopes as an ocean water mass tracer. Craig and Gordon were able to achieve a standard deviation of $\pm$ 0.020°/₀₀ (n = 21) for their laboratory standard water. Sample preparation in these studies followed the procedures outlined in Epstein-Mayeda and require CO_2 - water equilibration times on the order of several days. We currently use this method at L-DGO. Torgerson's isotopic data (which was appended to our revised proposal, Feb. 1978) on river water along the east coast of North America confirms and extends the results of Friedman (1953) and demonstrates the fact that

South Atlantic Bight, Mid-Atlantic Bight and Georges Bank waters can be isotopically distinguished over the salinity ranges which occur on the continental shelf provided a precision of 0.06°/₀₀ $\delta^{18}O$ is achieved.

With the advance in solid state electronics and subsequent development of a new generation of mass spectrometers such as our "state of the art" Micromass model 903, our precision and productivity is limited by the CO_2-water equilibration method. We have solved this problem by adopting a new method of CO_2-water equilibration which has been published by W. Roether (U. Heidelberg) and is now becoming the standard method for high precision (better than 0.04°/₀₀) oxygen isotope work. The more notable advantages over the Epstein-Mayeda method include: (1) CO_2-water equilibration time is reduced from 2 days to 2 hours (2) atmosphere evacuation is accomplished without repeated freezing and thawing procedures. (3) atmospheric evacuation and CO_2 introduction is done simultaneously on 10 samples under identical conditions; (4) the method is amenable to semi-automation. These improvements minimize time handling and processing samples and yield high precision data.

Approval of the budget containing funds to build the new equilibration system was given only this spring. We have acquired some of the components and are awaiting receipt of others. The system will be assembled, tested and calibrated this summer and water analysis will begin this fall.

4.3 Radon-222 As a Tracer of Water Motions and Mixing

To date we have measured the three-dimensional distribution of radon in the New York Bight on six different cruises; four of these covered a major section of the continental shelf-upper slope from mid Long Island to mid Jersey (V32-01, RC19-01, RC19-05, CH77-01) and the other two were focused on the Hudson Shelf Channel plume over a smaller area (K77-02 and CH77-07; see section 5.0 for the latter). The reduction and interpretation of these data constitutes a major portion of the PhD thesis of Steve Carson who is post-orals and actively working on this. Two papers summarizing the observational aspects and, some preliminary interpretation are in preparation ("Radon-222 as a radioactive tracer of water mixing processes on the New York Continental shelf; seasonal variability"; "Anomalous zone of low radon-222 and suspended particulate matter in near-bottom waters of the upper continental slope.

The rest of this section descrbies the status of several aspects of the problem of using these data to construct actual mixing models in the Bight. These involve 1) the problem of separating the excess radon signal from that from dissolved parent radium-226 in the water column; 2) the problem of quantifying the variable source function of excess radon from sediments; 3) the status of our preliminary modelling efforts; and 4) a brief synopsis of an informal meeting on 1 May 1978 to discuss the dynamics of the upper continental slope waters in general and the meaning of the 1°w-radon zone in particular.

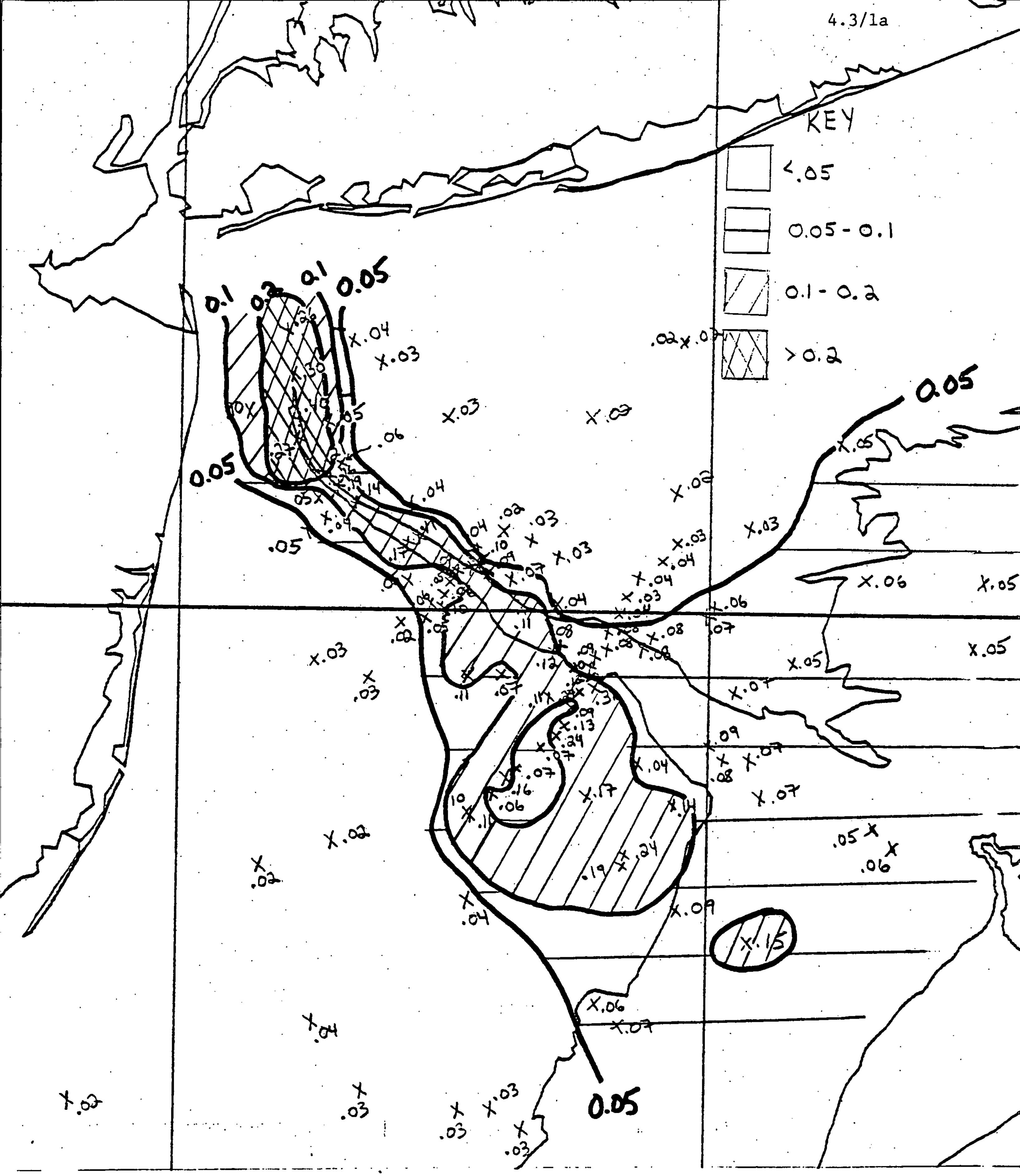

Figure 4.3/1 Radon-222 Production in the Sediments dpm/dry-gm.

4.3.1 Dissolved Radium-226 in the Water Column

Before rigorous modelling of the excess radon-222 distributions can be adequately performed, it is necessary to know the amount of radon-222 produced in the water column so that the number can be subtracted from the total radon measured on shipboard yielding the excess (or that released by the sediments). In the past, both in our open-ocean work and that in the Bight, this measurement has been plagued by analytical problems - particularly that of high bottle blanks. In the past contract year much effort has been devoted to reducing and carefully measuring these blanks and then beginning to analyze a new set of water samples. As discussed in section 2.3 of this report, these recent numbers along with some older analyses and some shipboard measurements of radon-222 within the thermocline (where there should be no excess or deficiency) have indicated that in the spring the radium-226 averages about 10.5 dpm/100ℓ in the Bight with a range of 10 to 11. (We have heretofore used 10 dpm/100ℓ as the radium-226 supported value.) We will continue this effort to more precisely define the Bight radium-226 value through the rest of this contract year and into the next, as we need to have a better idea of geographic and seasonal variability.

4.3.2 Radon-222 Source Function

In the past contract year the main effort in regard to the source function of radon-222 in the bottom sediments has been devoted to characterizing the region south of the Hudson Shelf channel that does not fit with the radon production versus grain size relationships found for the rest of the Bight. As discussed in last year's report the radon production in the sediments is correlated with the percentage of fine grained (<63μm) material in most areas, with one relationship applicable to the "mud hole" sediments and another to most of the rest of the Bight continental shelf. To the south of the Hudson Shelf Channel lies a relatively small region with very sandy sediments which exhibits anomalously high radon production. Since a detailed knowledge of the radon source function is necessary to the understanding of water column radon distribution, two approaches were taken to characterize this anomaly.

First, almost all of the grab samples collected in that region and in other areas near the Shelf Channel have been analyzed for radon production in order to define the extent of the anomalous zone and to map the actual production levels in the zone. The results of these analyses are shown in Fig. 4.3-1.

Second, more intensive size fractionation and analysis of sediments from the anomalous zone have been undertaken. It was originally hypothesized that a narrower size range within the <63μm fraction of the sediment may be the most important for radon production, since the

% <63μm fraction correlated so well with radon production in most areas. In order to test this hypothesis a sample from the anomalous region and one from a "normal" sandy region were compared by fractionating each of them into <63μm, 2-63μm and <2μ fractions and then analyzing each fraction for radon-222 production. Preliminary results indicate that it is really some phase(s) in the >63μm (greater than) fraction that accounts for the difference between the two regions. Further analysis of that fraction is still in progress.

While these studies are important to understanding the radon-222 source distribution, they may also provide insight into the capacity of the sediments of various regions of the Bight to adsorb dissolved metals. The radon production is a result of radium-226 decay and the distribution of sediment radon-222 production is thus indicative of the radium-226 distribution in the sediment. Understanding of that distribution may provide insight into removal and regeneration mechanisms of radium and metals which behave similarly geochemically.

4.3.3 Modelling of Radon Data

Prior to more rigorous modelling a simple graphical approach has been used to understand the vertical distribution of radon-222 during the spring of 1977 (data from Kelez 77-02 and Cape Henlopen 77-01). For this approach it was assumed that the water column could be divided up into layers each with a given coefficient of vertical eddy diffusion. Horizontal processes were discounted. The system was also assumed to be at steady state.

The data from each station was plotted as ln radon versus depth. Straight line segments were drawn through as many points as possible to define layers of constant eddy diffusivity. Thus breaks in slope represent boundaries between layers. This approach assumes that the radon concentration in each layer is exponentially decreasing with distance above the bottom of the layer. Boundary conditions between layers were ignored in calculating a first approximation to the eddy diffusion coefficient from the slope of the line in a given layer.

Using this approach rough eddy diffusion coefficients were estimated for layers at several stations from the two spring 1977 cruises. Stations were selected from the midshelf and those showing obvious horizontal influences, (e.g., mid-depth maxima), were not used. At 10 out of

19 stations analyzed from CH77-01 (May 1977) a bottom layer with an eddy diffusion coefficient of ∿ 100-300 cm^2/sec up to about 10-25 MAB. Immediately above this was a thin layer with slopes indicating eddy diffusion coefficients of about .01-.3 cm^2/sec. Comparison with the temperature, salinity and density vs. depth slots show that for those 10 stations the bottom layer showed well mixed T-S characteristics and the layer of lower eddy diffusion rates above it was associated with the base of the thermocline.

At the other 9 stations analyzed from the CH77-01 cruise a bottom, well-mixed layer with high eddy diffusion coefficients and a low diffusion coefficient layer associated with the base of the thermocline were also generally found. These layers were separated, however, by layers in which there were other slope changes in the ln radon versus depth plots. Although eddy diffusion coefficients were assigned to these intermediate layers, examination of the T, S and density slots indicated that these layers were generally associated with features that may represent intrusion of other water masses horizontally from surrounding areas. Thus it seems that eddy diffusion coefficients cannot be reasonably determined for the intermediate layers at those stations.

The results from the Kelez cruise (March 1977) were much more variable. A number of stations showed constant eddy diffusion coefficients throughout the water column. Others showed changes in slope indicating different layers. The relationship with the T, S and density slots are more complicated and have not been completely analyzed. This cruise was run during the period of thermocline formation, so assumptions of steady state are probably less valid than during the subsequent May Cape Henlopen cruise.

This work is preliminary to more rigorous modelling. These results can be used to define layers for a multilayer mathematical model. It can also be used for choosing stations that appear to be least affected by horizontal intrusions. A more rigorous model is being developed.

The horizontal diffusion model developed by Dr. Nevil Milford of the University of Queensland, Australia was rerun with an improved source function. The original model, discussed in last year's report, used a source function map based solely on grain size analysis and the two different empirical relationships between radon production and grain size. Thus the source function did not take account of the anomalous region south of the Hudson Shelf Channel discussed above. The most recent model calculations utilized a source function map that combined the radon production values calculated from the grain size analysis with those directly measured. This source function differed significantly from the previous one only in the anomalous region. The two models were compared by examining the ability of each to predict the standing crops of the July 1975 cruise. A normalization factor for converting sediment production measurements into flux was calculated in the original model (as discussed in last year's report) and used in the revised model. The major contrast occurs in the area of the sediment production anomaly and to the south. The original model predicted standing crops much lower than those observed. This was originally interpreted to indicate possible advection of high-radon water from the Shelf Channel southward. The new model, on the other hand, predicts values that are too high in the anomalous region. Thus, this region which was not well defined by the measurements at the time of the first model has proven to be very important to the horizontal distribution of radon in the Bight. Two possibilities exist for explaining the fact that the observed standing crops south of the channel are lower than those predicted. One is that advection from a low-radon source area is carrying the radon southward and out of the area. The second is the possibility that the normalization factor which was calculated from three Shelf Channel stations does not apply to the anomalous region due to differing sediment characteristics.

When the new model results are applied to the May 1977 cruise (CH7701) a very similar pattern of prediction capability can be seen. Again the anomalous region shows lower standing crops than those predicted. Other areas in which the measured values differ from the calculated values show similar distributions in both cruises. If the normalization factor for the model is multiplied by an empirically determined constant the number of stations in the May cruise at which standing crops can be predicted by the model to within 20% is increased. This indicates that there may be differences in fluxes between the two cruise periods. This possibility must be further explored.

The comparison of model predictions and measured standing crops from the September 1977 cruise (CH77-15) also shows a distribution similar to that of the other two cruises. Standing crops in the anomalous region are again predicted to be greater than observed. Evidence of advection is seen from the fact that to the southwest of that region the model predictions are much less than the observation. Thus high-radon water could be carried southwestward from the anomalous region. In this case, also, a different normalization factor from that calculated from the July data may be necessary, but the fact that the cruise was limited to a very complicated area of the Bight makes the calculation of such a factor more difficult than in the May cruise.

In summary, we have made significant progress in the interpretation of our sets of radon data both in terms of vertical and horizontal modelling. The continuation of this effort will comprise much of Steve Carson's efforts for his thesis.

4.3.4 Low-Radon Zone Meeting

Since our first cruise in the Bight on VEMA 32-01, we have consistently observed in the near bottom waters of the Upper Continental Slope, an anomaly with respect to excess radon, i.e. there is a broad zone in which, within analytical uncertainty, there is none. In view of what we know about the high potential of the underlying sediments to produce radon, this is extremely anomalous. In all the measurements of excess radon made by ourselves and others over the world oceans we know of no other incidence of such a phenomenon, yet we have observed it in every cruise that has extended that far offshore over the course of three years. The zone is also coincident with a minimum in the near-bottom standing crop of particulate matter.

Within the limitations of our data and sampling resolution, there appeared to be two opposite interpretations, either of which would be extremely important to an understanding of the removal of pollutants from the area of the New York Bight: 1) the zone represents one of extremely tranquil conditions in which the excess radon produced in the sediment interstitial waters moves only by molecular diffusion and is therefore not sampled by our lowermost bottle; 2) the opposite condition in which the zone represents conditions of rapid horizontal (isopycnal) mixing toward the interior ocean thus diluting the excess radon (and near-bottom particulate matter) with radon-free and low-particulate interior ocean water.

Presentation of the data and these opposite interpretations at the 1978 Annual DOE contractors meeting at Brookhaven resulted in discussions with Gabe Csanady who agreed to host an informal meeting on the subject.

The meeting was held at Woods Hole on 1-2 May and was attended by Woods Hole, Brookhaven and Lamont workers.

Results of the discussions are referred to in Section 4.1 of this report but they may be summarized as follows:

1) All dynamical evidence (principally from the Woods Hole Buoy Group) indicates that the Upper Slope is a highly active region and that the "tranquil zone" hypothesis is untenable.

2) From the few bottom grab samples we have of the underlying sediments the potential radon production (and therefore, likely the radon flux) is high. We really need, however, to confirm this with sediment cores which unequivocally sample the uppermost sediment in which most excess radon originates. This is another area where the box corer is necessary to the resolution of a problem involving upper-most surface sediments.

3) Since the evidence favors active horizontal mixing, what is the process by which this is accomplished so as to, a) dilute a high flux of excess radon, and b) do it in such a way as to exchange low-particulate for high-particulate water in such a way as to avoid stirring up the bottom and thereby resuspending more sediment?

After much discussion two processes were adduced (and which we propose testing in the coming year). The first involves the breaking of internal waves on critical slopes and the second involves pumping by differential variation in the thickness of isopycnal surfaces at tidal periods. These possibilites are discusses more fully in Section 4.1 and in the Renewal Proposal.

We found this kind of informal interdisciplinary meeting focused on a specific problem to be extremely useful and one of the major benefits of the annual DOE meetings. From this meeting came a hypothesis to explain our data which we specifically hope to test in the coming year.

4.4 Tritium as a Tracer of Water Mass Origins on the Continental Shelf

Since the higher the latitude in the northern hemisphere, the higher the tritium concentration in rivers and the surface ocean, we should be able to differentiate between shelf water originating from the north and south. During this contract year, we have investigated the variability of tritium concentration in coastal waters to test whether or not this is a useful tracer on the scale of our problems in the Bight.

Fig. 4.4-1 shows the magnitude of tritium concentration change across the shelf-slope - Gulf Stream - open ocean on samples taken under separate support. (Note: we still have minor calibration problems; the T.U. values given here are only relative.) The variation (16 to ∿ 2 T.U.) is big enough to be easily detected by our current detection limit of 0.5 T.U. and we anticipate further improvement in our detection limit.

Fig. 4.4-2 shows a nice mixing line between the Hudson River (∿ 50 T.U.) and the New York Bight (∿ 10 T.U.) indicating conservative behavior of tritium.

Fig. 4.4-3a, -3b show the tritium, salinity and temperature vs. salinity plots of data obtained during the Kelez 77-02 cruise, March 1977.

Both plots show nice three end member mixing (1. Hudson estuary, station #2 and 4; 2. south of Hudson Shelf Channel, station #6 and 20; 3. north of Hudson Shelf Channel, station #11). One big difference, however, is that in the temperature vs. salinity plot, all the surface data points (circles) tend to have higher temperature than would be expected from the tritium vs. salinity relationship (compare the top and bottom diagram in Fig. 4.4-3). A reasonable explanation is that the temperature of surface water is not conservative and has been warmed up, whereas tritium is behaving conservatively. Thus even in a small area of the New York Bight Apex, we can apparently distinguish three end members. For the calibration problem mentioned above we are currently checking our tritium standard against Ostlund's (U. of Miami) GEOSECS tritium standard.

We believe that tritium will serve as an excellent conservative tracer in the coastal environment in addition to salinity and O^{18}/O^{16} isotope ratios and hope to exploit its use in the coming year.

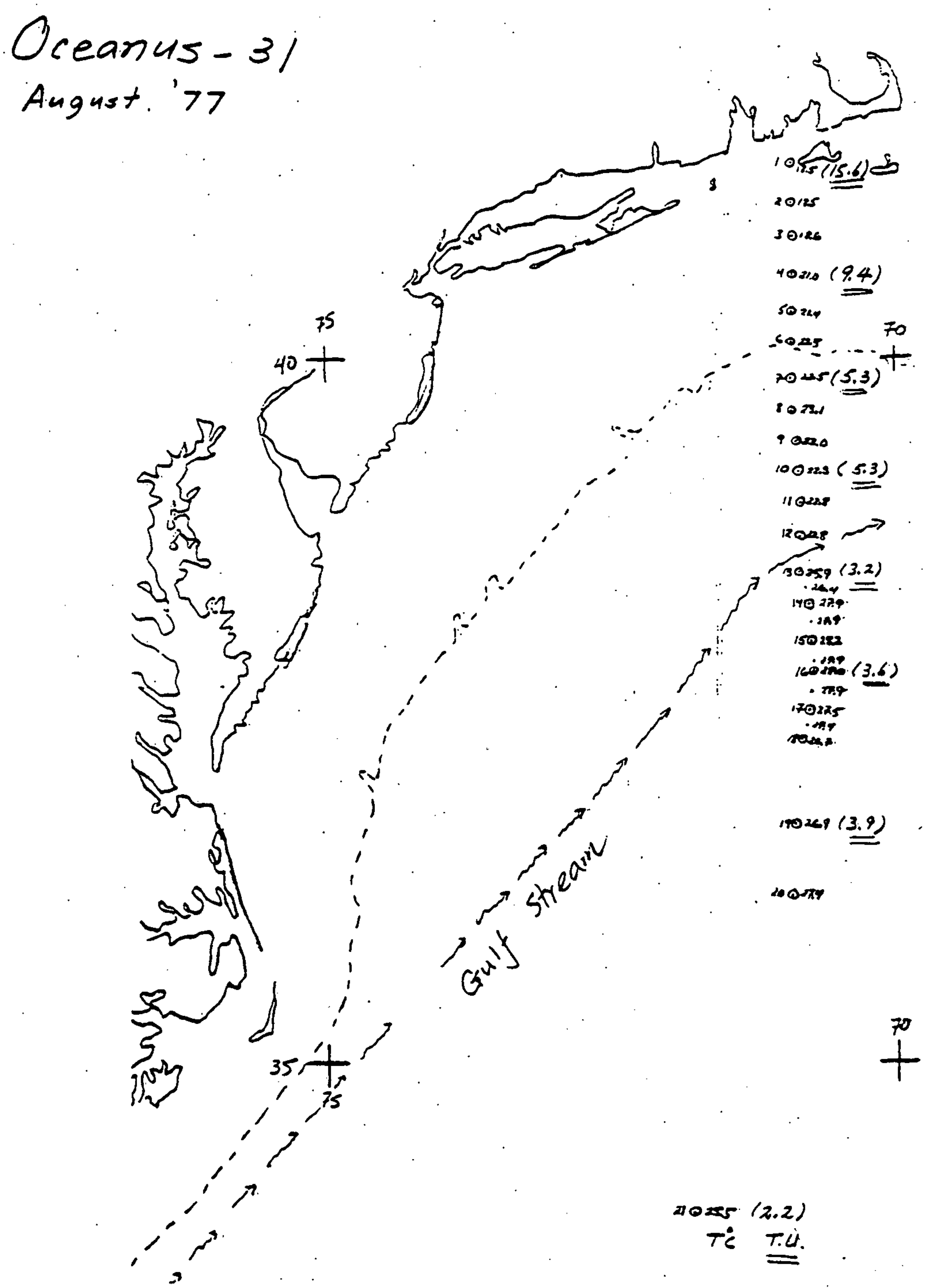

Fig. 4.4-1. The tritium concentration (T.U.) across the shelf-slope-Gulf stream-open ocean.

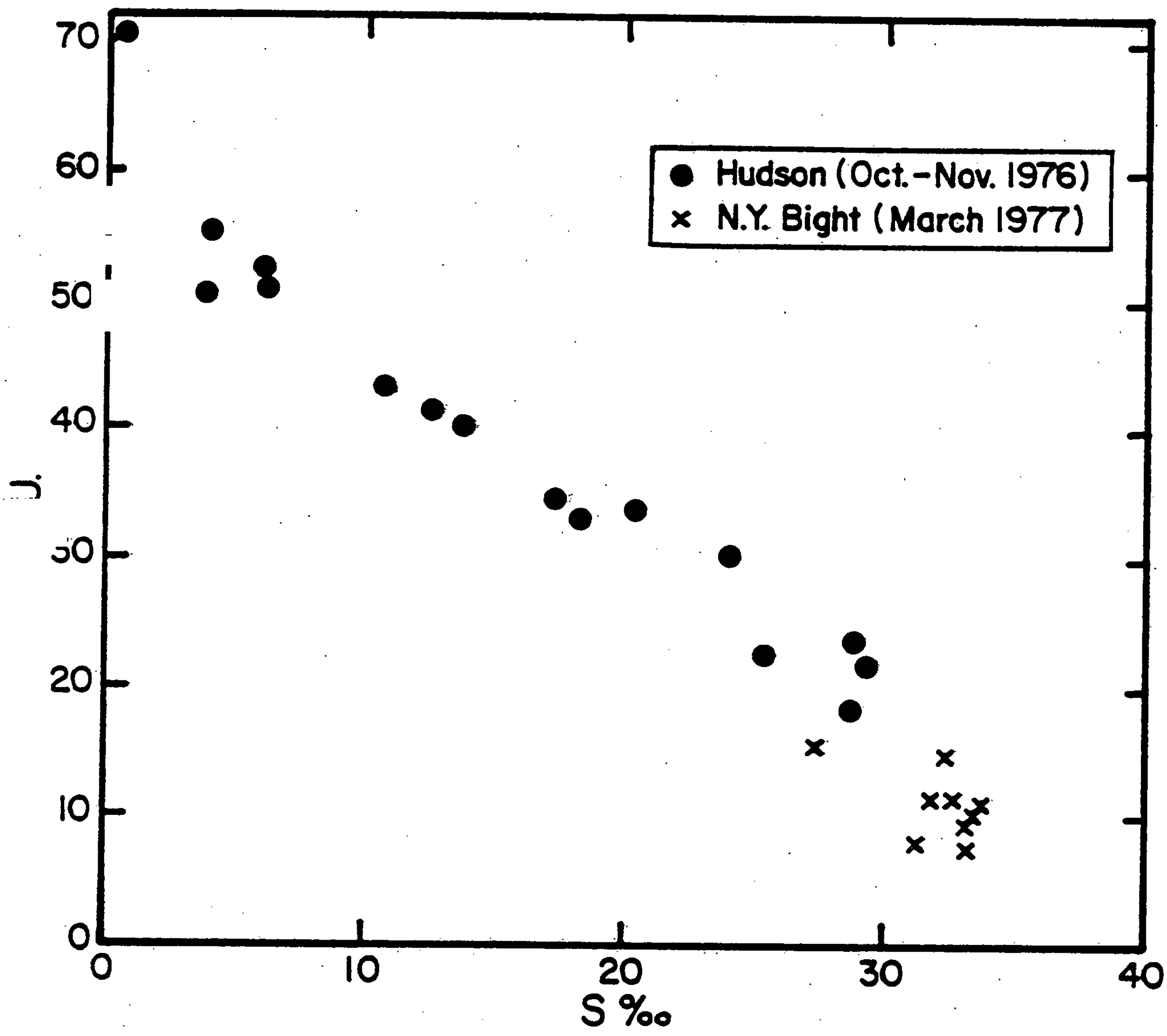

Fig. 4.4-2. The tritium concentration vs. salinity in the Hudson estuary and the New York Bight.

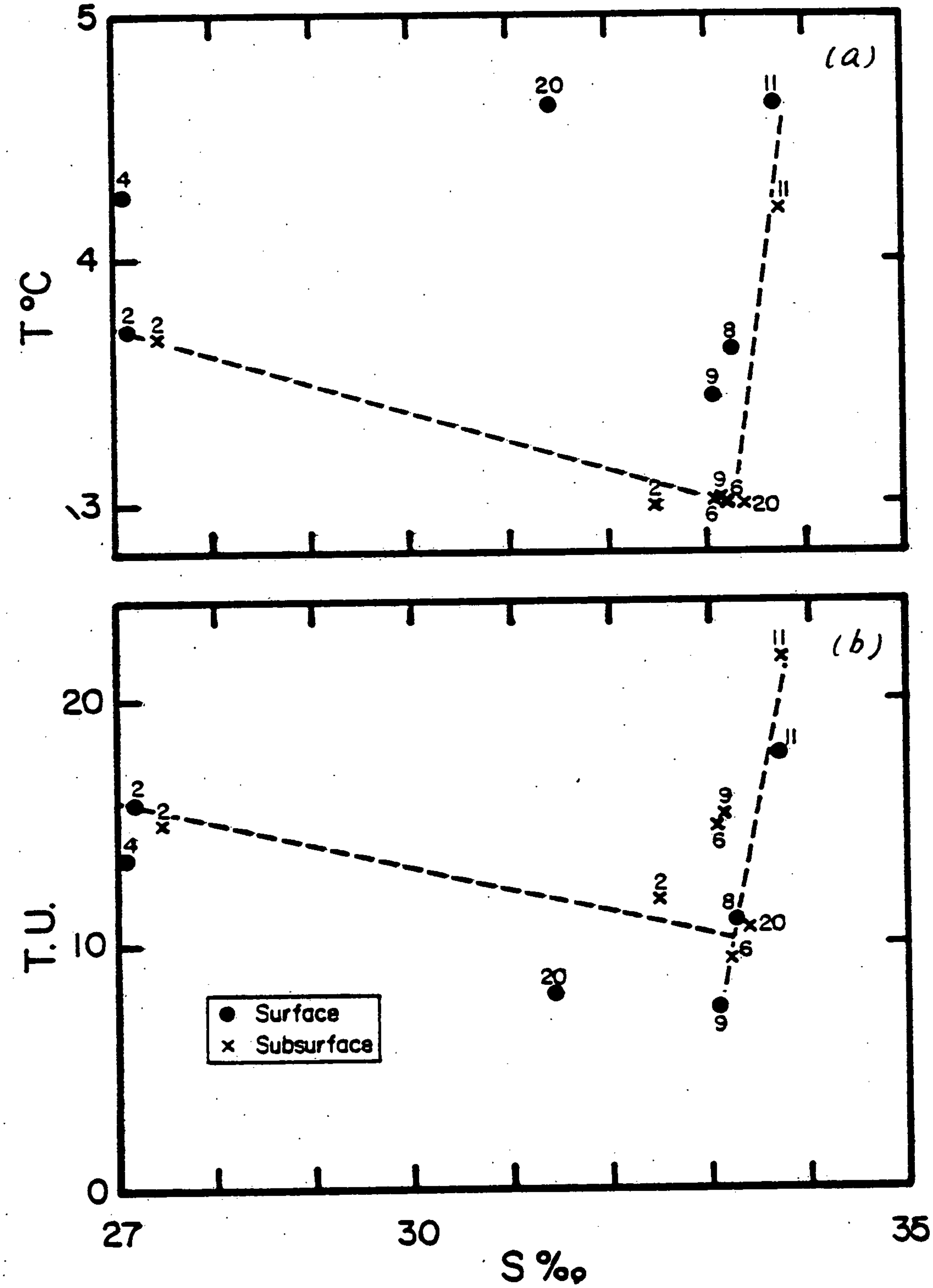

Fig. 414-3. The plots of tritium vs. salinity and temperature vs. salinity in the New York Bight Apex (KELEZ 77-02, 1977).

5.0 FIELD WORK

The only field work performed since the last annual report was a cruise in September 1978 designed to intensively measure the ^{222}Rn distribution in the area of the Hudson Chelf Channel in conjunction with the tracking of drogues in the area. This experiment was designed to try to separate the effects of advection and diffusion on the distribution of radon produced within and emmanating from the Shelf Channel sediment. Unfortunately, most of the drogues malfunctioned due to a design change performed by the manufacturer subsequent to our testing out one drogue before the cruise. The few that could be tracked for more than a day suggested that the southward moving current was very rapid. This is consistent with the ^{222}Rn distribution which showed a plume extending farther south than had been observed in previous cruises.

In general the radon distribution (Fig. 5.0-1) showed characteristics similar to those found in previous cruises and discussed in previous reports, i.e., a plume extending southward from the Channel and excess ^{222}Rn effectively "capped" by the thermocline. A feature observed at more stations in this cruise than during previous cruises was the presence of mid-depth ^{222}Rn maxima. The reasons for these are not clear at present, but may be related to the apparent rapid advective southwesterly flow. These data are being incorporated into a paper summarizing our work on radon in the Bight from the set of seasonal cruises to date.

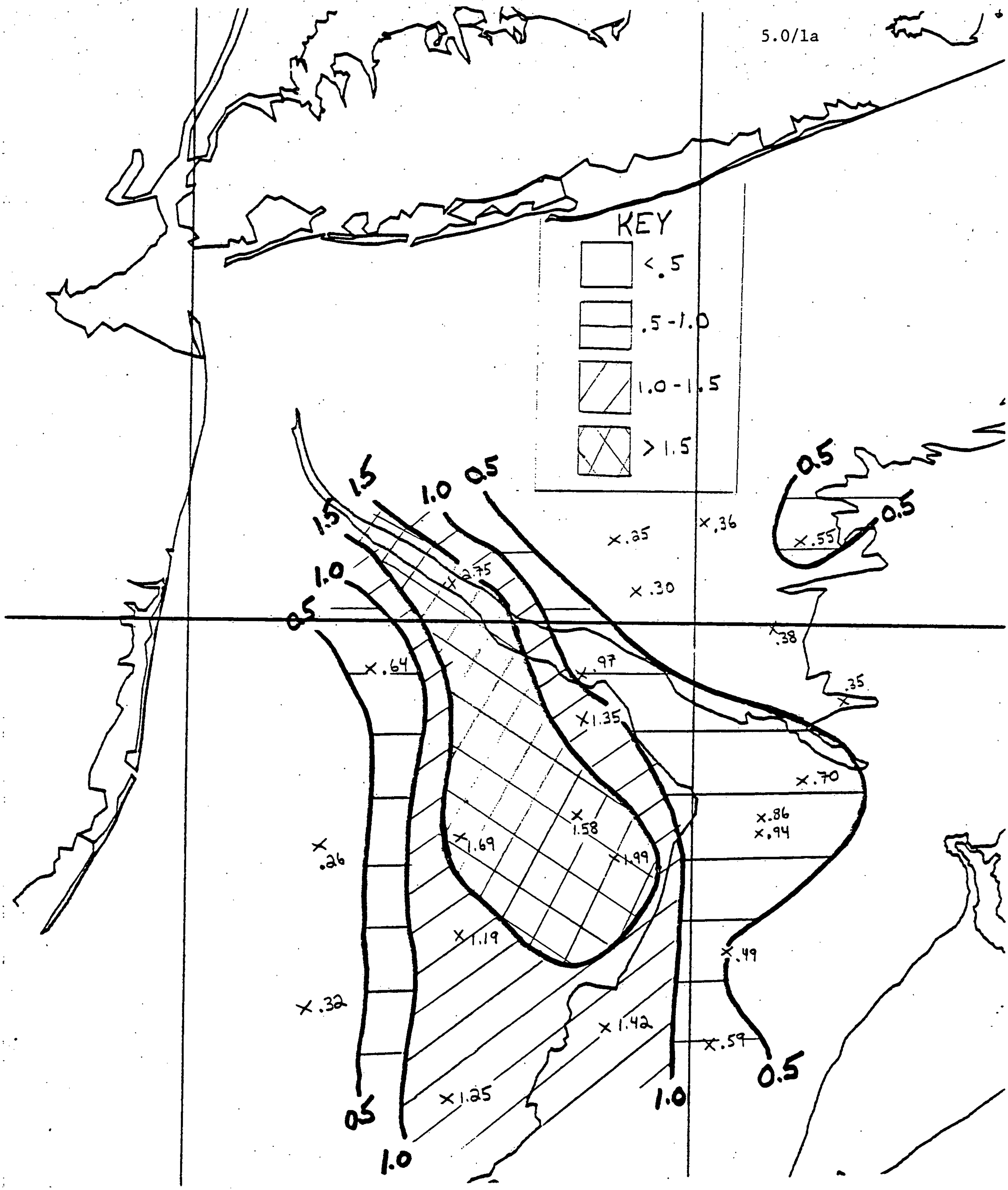

Figure 5.0/1 Radon-222 Standing Crops, September, 1978, Ch77-15, dpm/cm^2.

6.0 PAPERS, TALKS AND ABSTRACTS

What follows is an update of the list of talks, abstracts and papers produced and in preparation since the June 1977 Annual Report. This list therefore to some degree duplicates the list included as Section 8.0 of the Revised Proposal submitted in February 1978 but only includes titles from the June 1977 Report that have changed status, e.g., from "In Preparation" to "In Press" or "Published".

Papers Published, In Press or Submitted

Cook, R., and Li, Y.-H. A model for sediment mixing, submitted to EPSL.

Kadko, D., Thorium-230, radium-226 and radon-222 in abyssal sediments. Submitted to EPSL.

Li, Y.-H., Mathieu, G., Biscaye, P., and Simpson, H.J.,1977. The flux of ^{226}Ra from estuarine and continental shelf sediments. Earth Planet. Sci. Lett. v. 37, p. 237-241.

Li, Y.-H., Feely, H.W., and Santschi, P.H., ^{228}Th-^{228}Ra radioactive dis-equilibrium in the New York Bight and its implication for coastal pollution. In press, Earth Planet. Sci. Lett.

Malone, T.C. and M. Chervin. The production and fate of phytoplankton size fraction in the plume of the Hudson River, New York Bight. Submitted to Limnol. Oceanogr.

Olsen, C.R., P.E. Biscaye, H.J. Simpson, R.M. Trier, N. Kostyk, R.B. Bopp, Y.-H. Li and H.W. Feely, Reactor-Released Radionuclides and Fine Grained Sediment Transport and Accumulation Patterns in Barnegat Bay, New Jersey and Adjacent Shelf Waters. Submitted to Estuarine and Coastal Marine Science.

Posmentier, E.S, and R.W. Houghton. Fine structure instabilities induced by Double Diffusion. Journal of Geophysical Research. In Press.

Papers In Preparation

Biscaye, P.E., S. Carson and G. Mathieu. Radon-222 as a radioactive tracer of water mixing processes on the New York Continental Shelf; seasonal variability.

Biscaye, P.E., S. Carson and G. Mathieu. Anomalous zone of low radon-222 and suspended particulate matter in near-bottom waters of the upper continental slope, New York Bight.

Gordon, A.L., R.W. Houghton and F. Aikman. New York Bight Thermocline Stratification.

Li, Y.-H. and Chan, L.H. Desorption of Barium from river borne sediments in the Hudson estuary.

Li, Y.-H. and Trier, R. The geochemical behavior of $^{239,240}Pu$ in the New York Bight.

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