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BRISTOL BAY OCEANOGRAPHIC PROCESSES (B-BOP)

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I. SUMMARY

Beginning in autumn 1975, investigations were begun in Bristol Bay to address environmental questions brought forward by the potential petroleum development of the Outer Continental Shelf. This work has been sponsored by the Outer Continental Shelf Environmental Assessment Program (OCSEAP). Hydrographic data have resolved a picture of the bay, characterizing the bay with three zones: Bering Shelf breakwater, Central Shelf water, and Coastal water. The Bering Shelf is oceanic in nature, and the Central Shelf water is highly stratified and bounded on the shoreward perimeter by a structure front separating it from a well-mixed coastal water. Current meter records can be characterized as dominantly tidal with low net flow. The net flows, however, confirm the counterclockwise flow around the shoreward perimeter of the Bay and the northwest flow along the slope. Winter circulation is poorly resolved; however, current reversals and phase differences in low-frequency periodicity are suggested. Heat budget analyses have been preliminarily examined and bottom-mounted pressure gage and atmospheric data have been collected.

II. INTRODUCTION

A. Objective

The objective of this work unit is to relate oceanic advective and diffusive processes to potential pollution problems due to OCS petroleum development. The two specific goals are:

1. To describe the general water circulation in the study area for both summer and winter regimes; and

2. To determine the spatial and temporal variability of the velocity field and obtain indications of spatial coherence.

B. Tasks

1. Hydrographic data acquisition. This task reflects the response to better define the density field in the light of previous efforts. Higher density sampling in the area of the structure front separating the regions of coastal water and Central Shelf water was undertaken to better delineate the magnitude and structure of the front. This task was undertaken to further delineate the now identifiable water mass distributions with associated differences in dynamics.

2. Current meter data. This task is required to describe the spatial and temporal variability at specific sites within the identified water masses of Bristol Bay. In particular, this task will attempt to obtain an estimate of spatial coherence in the velocity field on the scale of the bay.

3. Pressure gage data. This task is required to interpret sea-level perturbation time and length scales in relation to current dynamics. The effort is directed toward understanding meteorological effects on the circulation as a response to storm surge or as a potential driving mechanism for longer termed pulses observed.

4. Meteorological data. This task is required for correction of pressure gage information to determine the true oceanic response to storms. This requires the correlation of barometric pressures around the bay to determine the scale of meteorological events and their relation to the low-frequency currents.

Data from these activities will allow a description of the seasonal circulation throughout Bristol Bay in the light of its water mass structure. Also, in shorter time scales these activities will yield information on the variation in tidal current energies due to interference with locally generated internal tides. Such occurrences may lead to periods of locally low kinetic energy, thus reducing mixing. A better understanding of driving mechanisms for circulation will likewise follow from the combined density field, current meter, and pressure gage information.

c. Application to Petroleum Development Hazard Assessment

You are referred to the 1975 Annual Report for a description of the evolution of spilled oil in seawater. Present work relates to the location and duration of events discussed in that review. Each water mass as identified in last year's annual report will have its own effect on the history of petroleum contamination. The quiescent, highly stratified shelf region might allow more time for volatiles to escape and cause a concentration of higher density particles to form at the interface between the two layers. This may allow a longer term effect on neritic and planktonic life forms with a long elapsed time before reaching the benthic zone at the bottom. If a source of contamination was located in the lower layer of the shelf area, a very long residence time could be expected, with the corresponding effect on benthic organisms. The stability of the area would also restrict the surfacing of contaminants to the very low density components which would tend to volatilize upon reaching the surface. The well-mixed coastal region would allow a uniform contamination of the water column with a shorter elapsed time before reaching the bottom environment. Also, the residence time in the coastal water areas would be long, due to low mean flow. The Bering Sea Slope Current area along the shelf break is more oceanic in nature and the advection of contaminants there would be greater, though the advective flow pattern for the shelf break is still ill-defined.

III. STUDY AREA

This research unit addresses the physical oceanography of Bristol Bay (fig. 1). This area is defined as the area south of a line drawn between Nunivak Island and the Pribilof Islands and east of a line drawn between the Pribilof Islands and Unimak Pass. This region encompasses approximately 150,000 km^2. The average depth is approximately 55 m, with 50% of the area less than 50 m in depth. The area can be characterized as an equilateral diamond with the points oriented north-south and east-west. The 50-m contour bisects the area along a northwest-southeast line from the midpoint of the Pribilof-Nunivak line to Port Moller, with a departure from that line at the Alaskan Peninsula in the form of a shallow valley projecting three-quarters of the distance toward the easternmost point.

Freshwater input is primarily from the Kuskokwim River watershed which enters at the midpoint of the northeast line. The Kuskokwim accounts for about 50% of the freshwater runoff, and the balance enters from the watersheds of many smaller rivers in the eastern portion of the area'. The total freshwater input amounts to approximately 1% of the volume of Bristol Bay.

For 5 months (November-March), about 60% of the area is ice-covered. The ice is l-year winter ice, generally less than 1 m thick. Ice formation begins in sheltered areas in mid-October and builds to the most severe conditions in February and March. A general northward retreat of the ice begins in ' April. A representative contribution of freshened water due to sea-ice melt is about 0.6% of the volume of Bristol Bay.

The combined effect of ice melt and freshwater runoff is to charge the bay with fresher water, first in the early spring and again in midsummer, such that an equivalent of 1.5% of the volume is replaced in the space of 7 months. The character of the bay should show distinctly different regimes

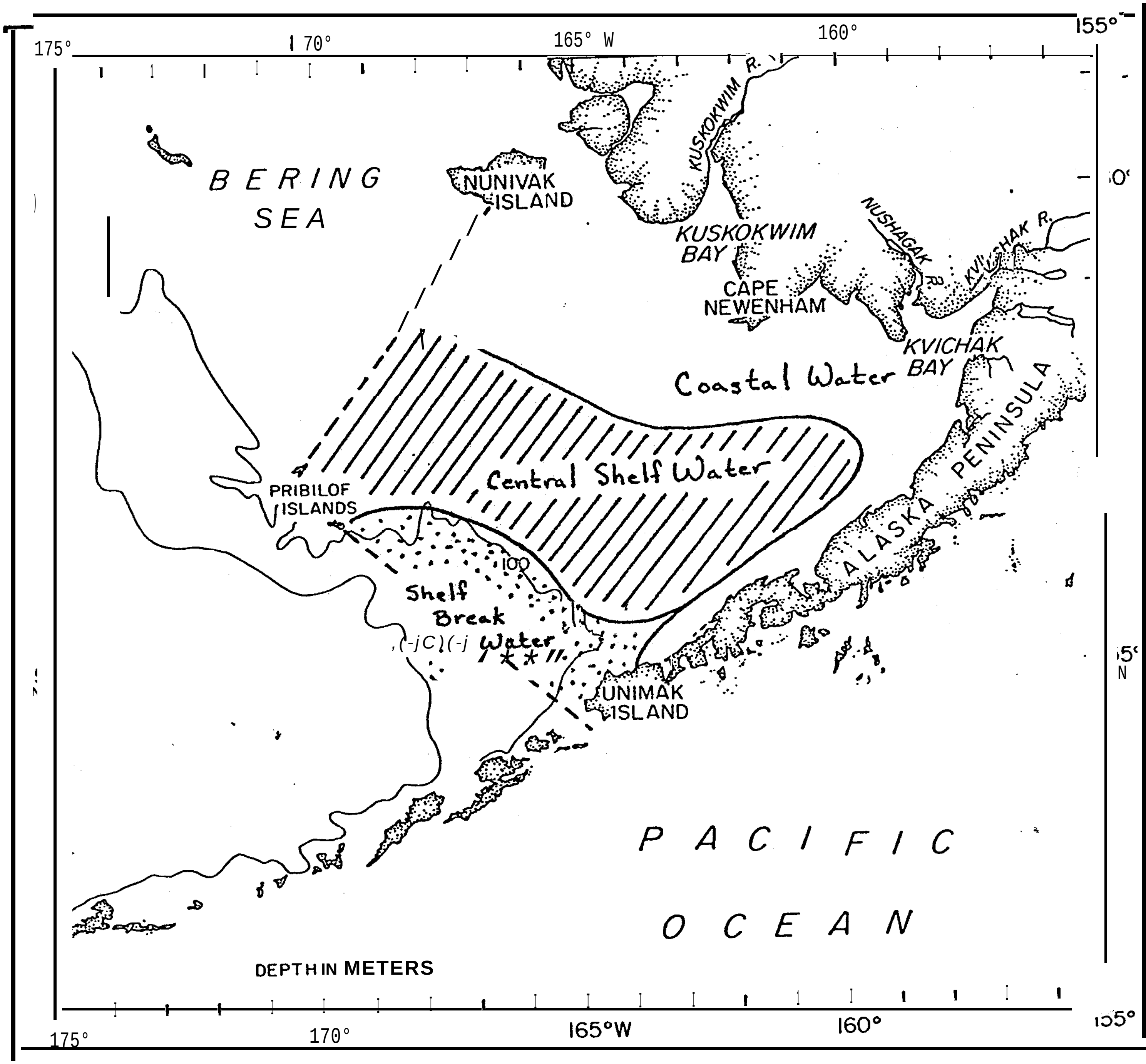

175°
170°
165° W
160°
155°
BERING SEA
NUNIVAK ISLAND
KUSKOKWIM R.
KUSKOKWIM BAY
CAPE NEWENHAM
NUSHAGAK R.
KVICHAK R.
KVICHAK BAY
Coastal Water
Central Shelf Water
PRIBILOF ISLANDS
100
Shelf Break Water
ALASKA PENINSULA
UNIMAK ISLAND
PACIFIC OCEAN
DEPTH IN METERS
165°W
N

Figure 1

in summer and winter due to the very different conditions in those two seasons. It is reasonable to expect some marked differences between the information gathered in the two years of the program in that the 1975-76 season was very heavy in ice and the 1976-77 season is quite light in ice. The difference in the 1975-76 and 1976-77 seasons indicates that year-to-year differences could be substantial. At present there is insufficient information available to determine the range of year-to-year differences in a normal, or average, sense.

The connection with the western Gulf of Alaska waters is through Unimak Pass at the southern point of the area. Exchange with the Bering Sea waters can take place along the entire southwestern line of the area. Exchange along the northwestern line would be with the adjacent shelf of similar character. It would seem reasonable that the nature of all the exchanges will vary significantly with the varying environmental conditions on a year-to-year basis.

IV. PRESENT STATUS

A summary of oceanographic data collected prior to the initiation of the OCSEAP effort has been presented in the first annual report. The additions to the data base due to the OCSEAP effort have been considerable.

The hydrographic data summary (Appendix 1) reveals 12 cruises collecting CTD data under summertime conditions. It is evident from the cruise distribution that wintertime data is difficult to obtain, though it is sorely needed to complete the hydrographic picture. The figures in Appendix 1 describe the track lines during CTD cruises and show the broad scope of hydrographic data acquisition.

The summary of instrumented moorings (Appendix 2) outlines the density of current and bottom pressure data being collected. To date, 30 moorings have been deployed over 17 sites (fig. 2).

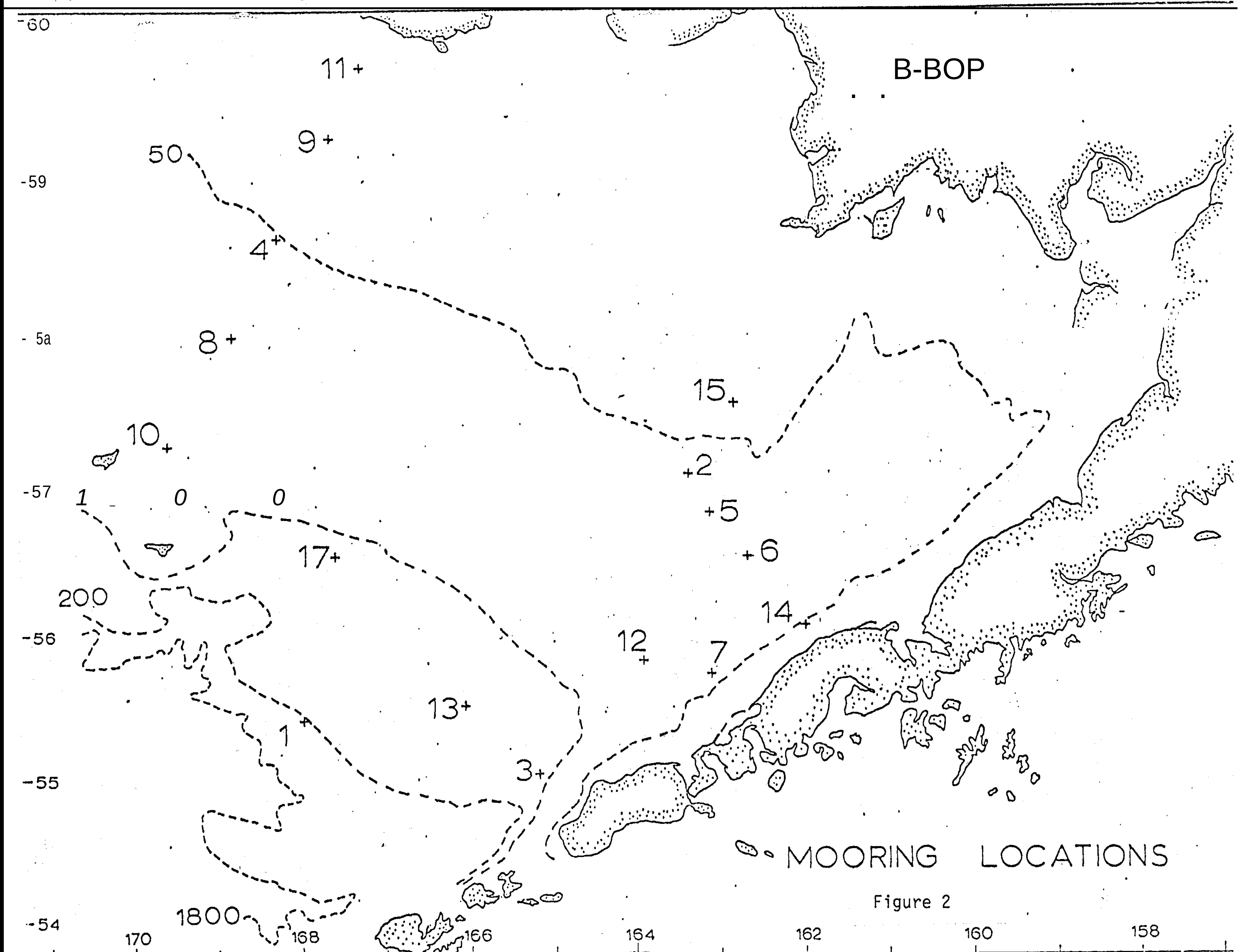

B-BOP
MOORING LOCATIONS
11+
9+
4+
8+
10+
15+
+2
+5
+6
17+
14+
12+
7+
13+
1+
3+
50
1 0 0
200
1800
-60
-59
- 5a
-57
-56
-55
-54
170
168
166
164
162
160
158

Figure 2

V. PROGRAM RATIONALE

To address the goals of this work unit, three long-term moored arrays, BC-2, -3, and -4, were maintained over the winter to assess flow under the ice and obtain information on the winter circulation.

Short-term arrays, BC-5, -6, -7, -8, -9, -10, -12, -13, -14, and -15, were deployed to better define the summer circulation by measuring currents flowing into and out of the bay. In addition, the arrays at BC-5, -6, and -4 were spaced to address cross-bay spatial coherence length scales.

VI. HYDROGRAPHY

Hydrographic data from June 1976 has been analyzed (Kinder, 1977, attached), and the major results are summarized.

1. The waters of the shelf are more clearly characterized by differences in vertical structure than by traditional temperature-salinity (water mass) categories. We propose three regions of stratification (during summer): coastal, shelf, and shelf break. The depth of water is the major factor influencing the distribution of vertical structure. The distribution of temperature and salinity is similar to those reported by Dodimead, et al. (1963), which was based on Redwing data from 1938-1941. Our data, however, reveal smaller scale features not shown by the earlier data. “

2. Temperature fine structure was found throughout the shelf break region; this is probably related to the density instabilities reported by Coachman and Charnell (1977, attached).

3. The front, near the 50-m isobath, first noted by Muench (1976), has been confirmed. We believe that the balance between the rate of buoyancy input and the rate of tidally induced mixing determines the frontal location.

4. Salinity distributions and dynamic topographies show that the most intense flow is in the shelf break region and that the flow is to the north-west, paralleling the isobaths. Salinity distributions also suggest some flow into the bay along the Alaska Peninsula.

5. A high-salinity anomaly was found west of Cape Newenham.

We consider Kinder (1977) a preliminary report, and we continue to analyze this data and to investigate the seasonal changes over the shelf.

Coachman and Charnell (1977, attached) have reported on fine structure found in the shelf break region during March 1976. The widespread distribution of temperature fine structure suggests that the situation they found in March is not rare.

VII. CIRCULATION

As a first step in displaying the circulation within Bristol Bay, the vector mean flow for each mooring was calculated and plotted on figures 3 and 4. The records were loosely characterized as "winter" or "summer" (table 1). Caution must be exercised in interpreting this form of display because varying record lengths, overlapping seasons, and different depths are all displayed on the same figure. Nonetheless, displaying the net vectors yields a qualitative description of the general circulation.

Examining the summer net vectors, a number of general statements are indicated. The central shelf area is quiet when compared to the shelf break or coastal water shoal. The strongest flows are indicated at the shelf break, BC-3, with significant components along the shelf break and into the Bay. Flow has been postulated along the Aleutian Islands flowing to the northeast and joining with flow entering the Bering Sea through Unimak Pass. In the vicinity of station 3, the flow bifurcates and flows both along the shelf break and into Bristol Bay along the Alaskan Peninsula. The area of inflow to the bay is generally ice-free during winter, and the hydrographic data indicate tongue-like features projecting into the bay; these facts lend support to the existence of the inflow along the peninsula. The shelf break flow is well confirmed by the northwest flow at station 13. The highest percentage of transport must be along the shelf break due to the consistency of flow from the upper to the lower levels. The small fraction which enters Bristol Bay would seem to manifest itself as a narrow flow counterclockwise around the bay near the 50-m isobath, as indicated by the records at stations 14 and 15. The breadth of the current would be considerably less than 100 km, particularly along the peninsula where it would be constrained by the coast to a width of 50 km. The location of the current may be associated with the location of the structure front separating the coastal waters and the shelf area.

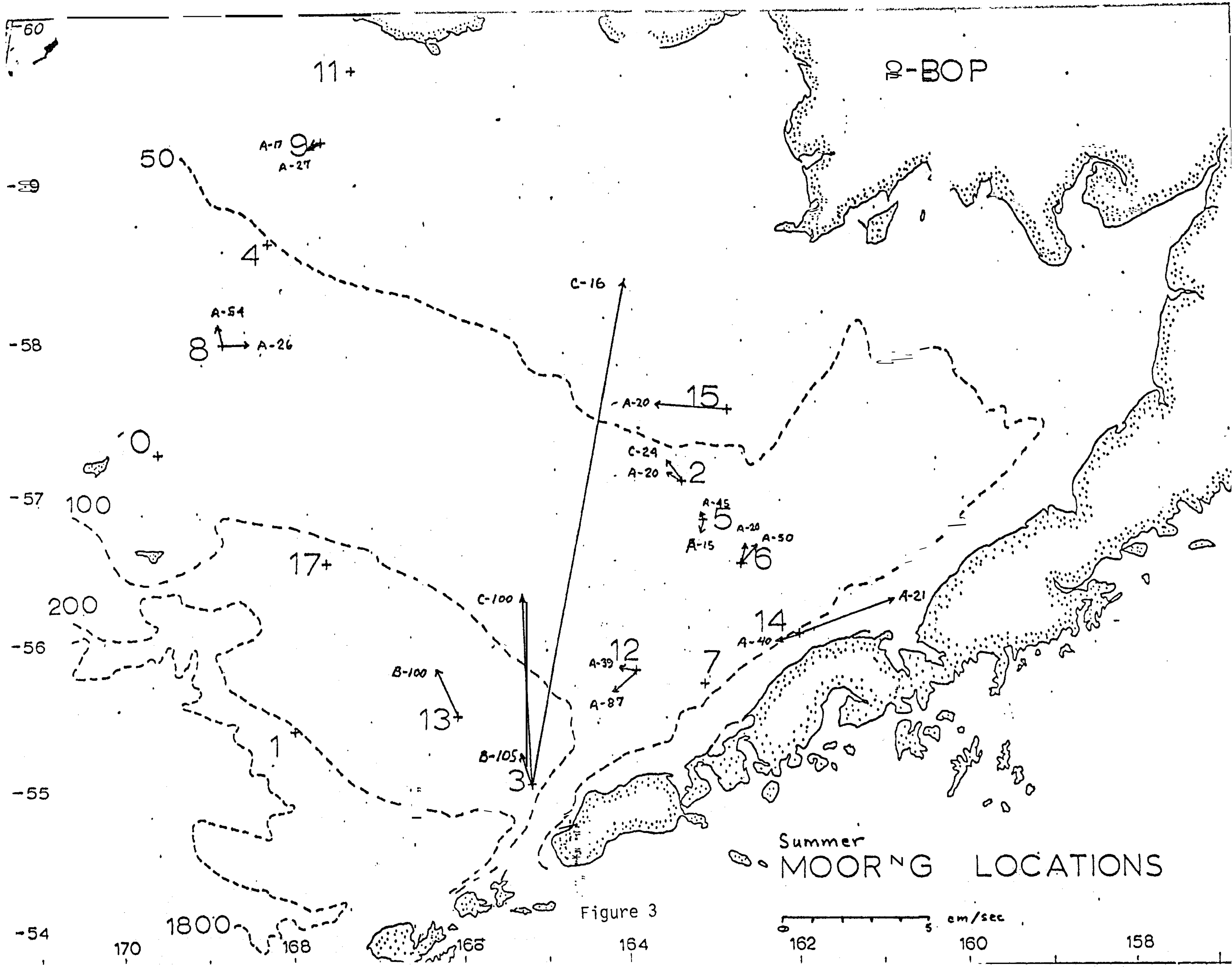
Table 1

0

Mooring	Observation Period	Instrument Depth (m)	Record Length (days)	Mean Speed (ems-l)	Total Vari ante (cm^2 S^{-2})		Net Fl ow (cm s^{-1})
BC-2A Winter	8 Sept. 75- 5 Nov. 75	20	58		u 323.4 v 112.9	436.3	0//5 @ 3050T
		50	58				0.9 @ 306°T
BC-2B Hinter	5 Nov. 75- 30 May 76	50	207	17.6	u 330.6 v 76.8	407.4	1.2 @ 089°T
BC-2C Summer	31 May 76- 26 Sept. 76	24	118	14.8	u 281.8 v 66.9	348.7	0.8 @ 324°T
BC-3A Winter	6 Nov. 75- 16 Mar. 76	20	130	29.1	u 435.3 v 595.1	1030.4	3.3 @ 01 0°T
BC-3B Summer	16 Mar. 76- 29 May 76	105	73	17.4	u 251.7 v 185.3	437,0	1//2 @ 342* T
BC-3C Summer	29 May 76- 28 Sept. 76	16	122	31.8	u 441 .3 v 581 .8	1022.1	17.2 @ 011°T
		100	122	20.5	u 265.6 v 270.4	536.0	6.7 @ 358*T
BC-4A Winter	7 Sept. 75- 4 Nov. 75	30	58	29.5	u 470.2 v 468.9	939.1	2//7 @ 297°T
		47	58	22.1	u 269.9 v 267.1	537.0	0//6 @ 315°T
BC-4B Winter	4 Nov. 75- 14 June 76	20					
BC-4C Summer	1 June 76- 25 Sept. 76	25	56	27.6	u 415.0 v 423.0	838.0	2//6 @ 312°T
		52	59	19.6	u 244.0 v 198.0	442.0	1.3 @ 301°T
BC-5A Summer	30 May 76- 27 Sept. 76	15	119	12.5	u 212.3 v 59.1	271.4	0.5 @ 192°T
		45	119	30.6	u 1182.1 v 202.6	1384.7	0-/ /3450T

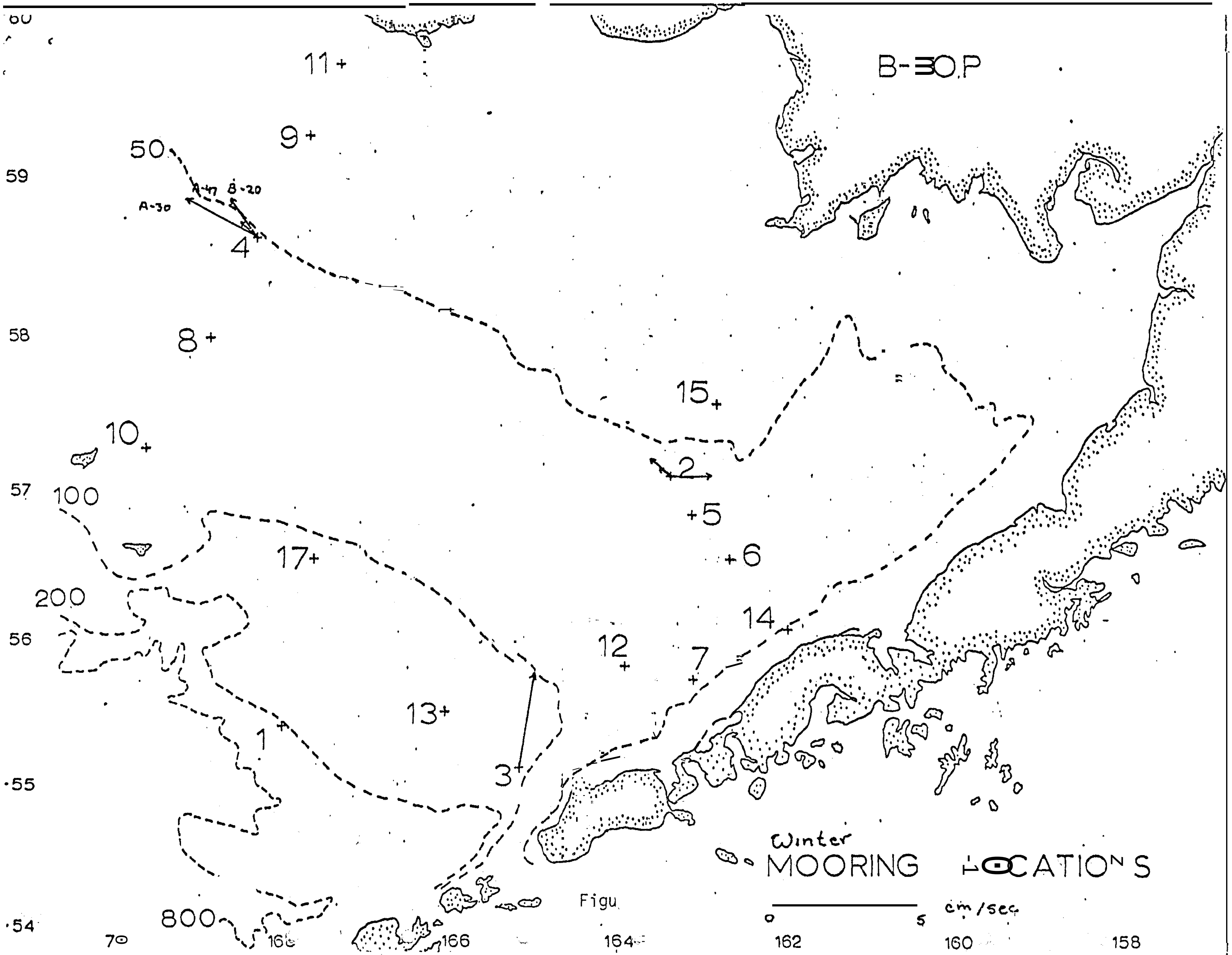
Table 1 (Continued)

Mooring	Observation Period	Instrument Depth (m)	Record Length (days)	Mean Speed (cm s^{-1})	Total Variance (cm^2 s^{-2})		Net Flow (cm s^{-1})
BC-6A Summer	30 May 76 27 Sept. 76	20	120	11.3	u 219.3 v 43.3	262.6	0.6 @ 012°T
		50	120	16.6	u 392.7 v 59.0	451.7	1.0 @ 038°T
BC-8A Summer	1 June 76- 31 July 76	26	59	21.8	u 277.0 v 269.0	546.0	0.9 @ 088°T
		54	59	22.0	u 296.0 v 253.0	549.0	0.6 @ 342°T
BC-9A Summer	2 June 76- 31 July 76	17	59	27.8	u 424.0 v 417.0	841.0	0.1 @ 160°T
		27	59	24.7	u 352.0 v 355.0	707.0	0.3 @ 255°T
BC-12A Summer	19 Mar. 76- 12 June 76	39	84	9.1	u 155.0 v 44.0	199.0	0.6 @ 277°T
		87	14	14.3	u 262.0 v 87.0	349.0	1.3 @ 232°T
BC-13B Summer	6 June 76- 29 Sept. 76	100	35	17.3	u 231.8 v 143.7	375.5	1.6 @ 366°T
BC-14A Summer	30 May 76- 27 Sept. 76	21	124	21.4	u 721.0 v 123.7	844.7	3.5 @ 070°T
		40	124	11.9	u 299.9 v 57.4	357.3	0,8 @ 233°T
BC-15A Summer	31 May 76- 26 Sept. 76	20	118	28.8	u 695.5 v 259.0	954.5	2.4 @ 274°T



Summer
MOOR NG LOCATIONS
0
5
cm/sec
8-BOP
11
9
A-17
A-27
50
4
8
A-54
A-26
0
100
200
1800
17
1
13
B-100
C-100
B-105
3
C-16
15
A-20
2
C-24
A-20
5
A-45
A-15
6
A-20
A-50
12
A-39
A-87
7
14
A-40
A-21
-60
-59
-58
-57
-56
-55
-54
170
168
166
164
162
160
158

Figure 3


B-3O.P
Winter
MOORING LOCATIONS
0
5
cm/sec
11
9
50
A-47
B-20
A-30
4
8
10
100
200
800
17
1
13
3
15
2
5
6
14
12
7
60
59
58
57
56
55
54
70
168
166
164
162
160
158
Figu

The front is generally found in the vicinity of the 50-m isobath. Current meter records from stations near the front show generally stronger flow than those distant from either side of the front. Currents away from the frontal area have net flows a third or less of the frontal stations. These low net velocities are a manifestation of generally high mean speeds with no consistent direction (figs. 5a and b). The net velocities do, however, represent the general drift, transport, of water in the area. This fact leads to the possibility that there exists a return flow, or displacement of bottom water out of the bay along the Alaskan Peninsula.

Winter records indicate inflow near Unimak Pass as in the summer records, lending support that this is the consistent picture. Outflow from the bay is indicated between Nunivak Island and the Pribilofs in the same vicinity and the front location in summertime. The interior records, however, do little to define the flow in the central reaches of the bay. Due to the lack of hydrographic data from under the ice, little speculation can be made concerning the details of the winter flow.

A. Low-Frequency Flow

The next logical step in understanding the flows within the bay is to examine the motions on a weekly time scale. This time scale allows the better resolution of seasonal changes and system responses. An attempt to interpret the low-frequency events will consist of examining the weekly averages to allow the history of each station to be characterized with regard to the hydrography.

Temperature provides the longest and most voluminous data set (fig. 6). A full year of records has been obtained from station 2. This station reveals a bit of the history of the shelf area. During the fall of 1975, the area was stratified with upper layer temperatures consistent with summer heating

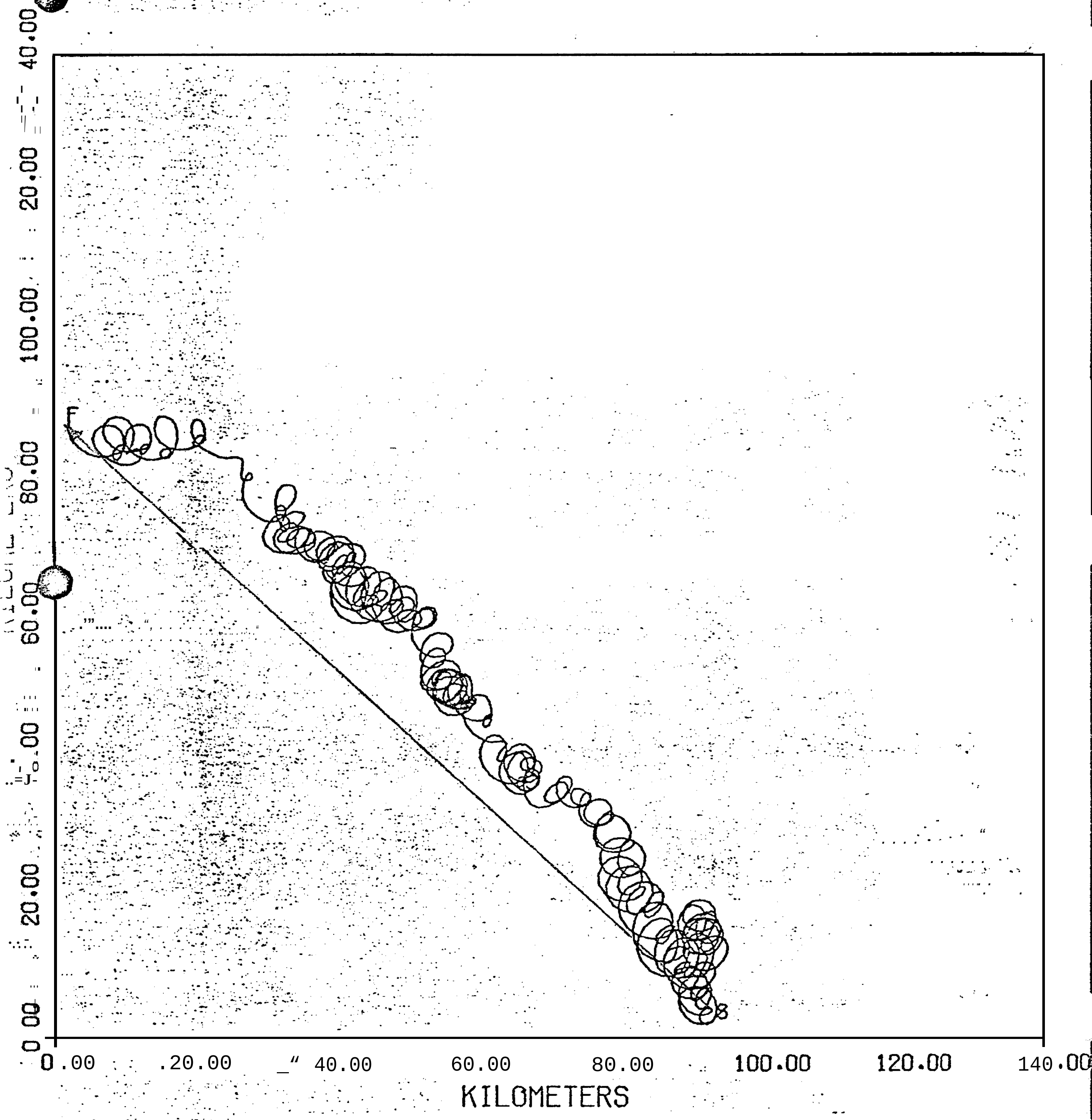


Figure 5b
PVD Station 4C depth 25 **meters**

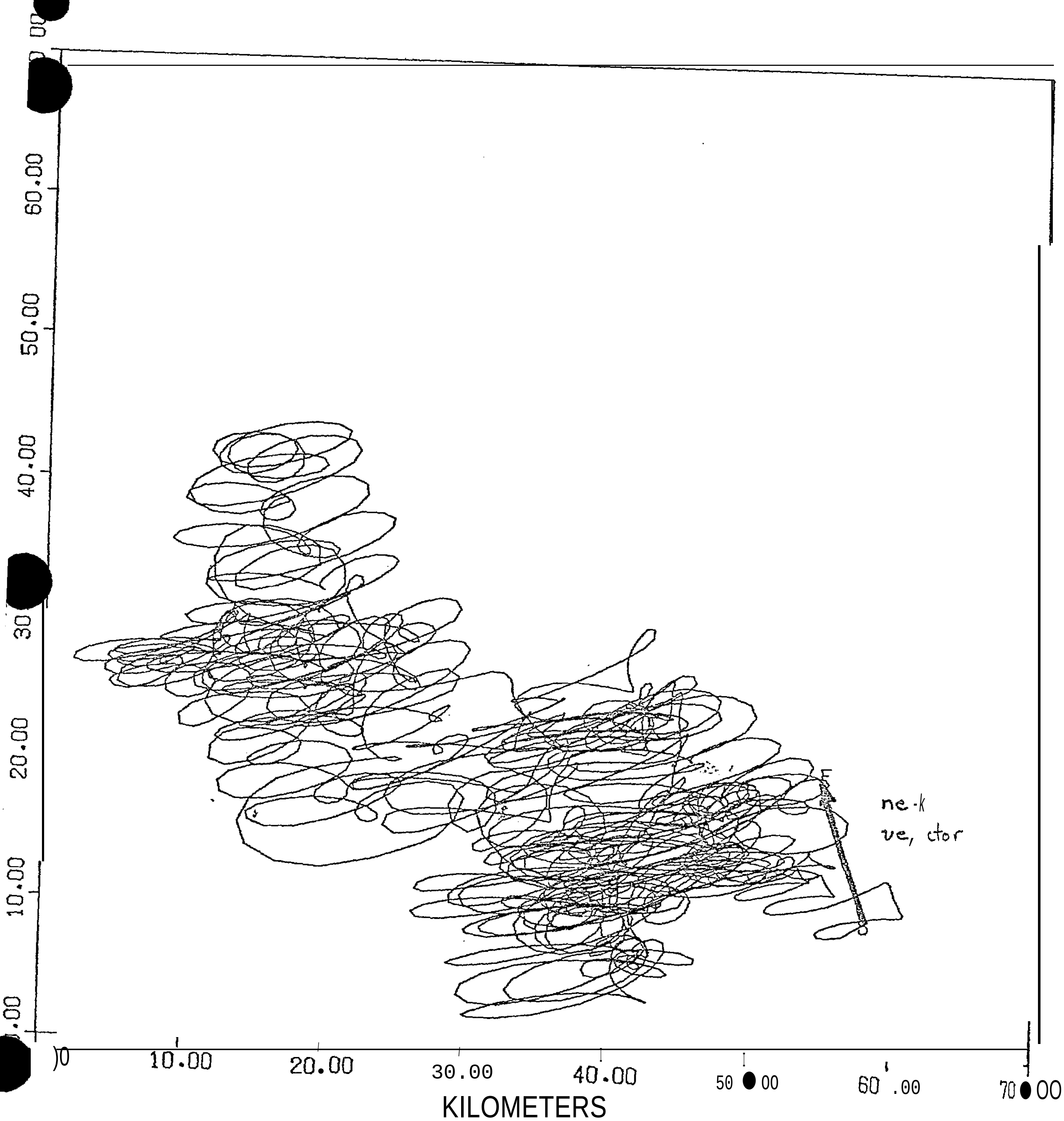


Figure 5a
PVD Station 5A depth 50 meters

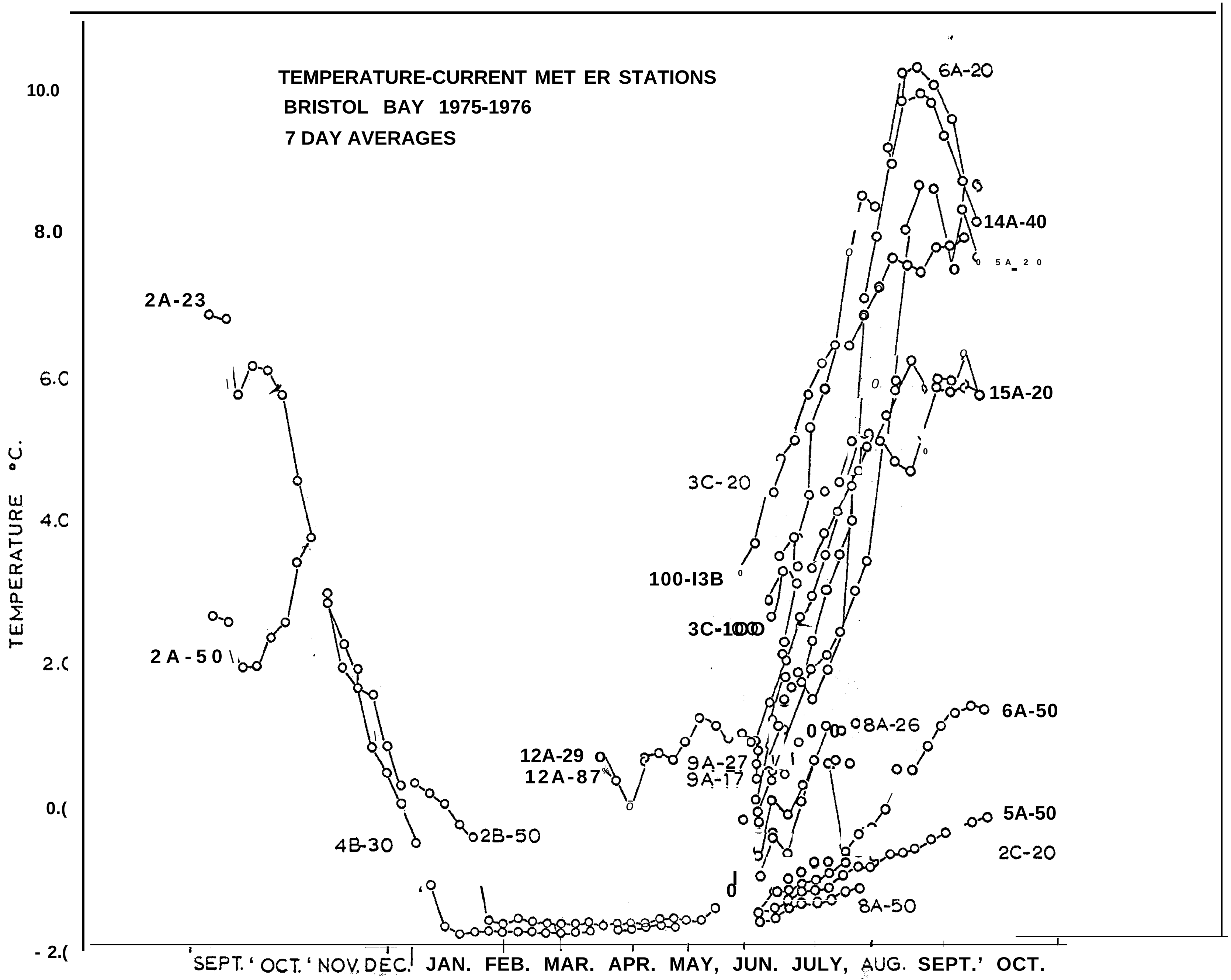

TEMPERATURE-CURRENT METER STATIONS
BRISTOL BAY 1975-1976
7 DAY AVERAGES
TEMPERATURE °C.
10.0
8.0
6.0
4.0
2.0
0.0
- 2.0
2A-23
2A-50
4B-30
2B-50
12A-29
12A-87
3C-20
100-I3B
3C-100
9A-27
9A-17
6A-20
14A-40
5A-20
15A-20
8A-26
6A-50
5A-50
2C-20
8A-50
SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY, JUN. JULY, AUG. SEPT. OCT.

FIGURE 6

and lower layer temperatures slightly warmer than those of the summer of 1975, which would indicate a mild winter the season before, 1974. The surface waters cooled with the onset of winter and the lower waters warmed slightly, possibly due to the reduced stability, until early November when the water became isothermal. The point at which the water became isothermal has two possible explanations: either the stability was reduced to the point where the general region could be fully mixed by the winds and tide, or the front passed laterally across the station. Through the winter, stations 2 and 4 were in place and continued monitoring events. The waters over the majority of the bay continued cooling at nearly the same rate. A satellite photo from 10 December 1975 shows the formation of loose ice with many leads. The temperature record indicates the ice was fully formed and stabilized about the first of January. The ice remained over the central area until late May 1976, as characterized by water temperatures of -1.8, which is the freezing point of 32 ‰ seawater. At the end of May, the seasonal heating began again over the entire bay. The summer heating at all stations along the shelf break and in the shallow mixed areas progressed at nearly the same rate regardless of depth.

In the shelf area the upper layers warmed as at the other stations, but the lower layers were effectively isolated from the seasonal heating. In the lower layer the increase in temperature over the summer was only 3°, while the upper layer warmed by 12°. The fact that waters offshore were considerably warmer and waters in the coastal region were likewise warmer substantiates the concept of very little lateral exchange with the shelf area lower layer. The hydrographic data from the summer of 1976 shows a very strong thermocline at 23 m, and this is reflected in the records of those current meter stations which had current meters just below the thermocline, such as station 4 at 25 m and station 2 at 24 m, which had records similar to those from stations with records from 50 m in the convective area.

Salinity (fig. 7) has a much smaller seasonal range in Bristol Bay than might be expected considering the freshwater input from ice melt and runoff in the summer. Salinities computed from the current meter's conductivity sensors are not highly accurate, but the changes measured indicate events passing the meter. Over the entire array of current meter measurements the total salinity difference was two parts per thousand. Generally the variation at any one site was less than half a part per thousand. Further, the largest changes occurred at those stations on the shelf break or vicinity, such as stations 3 and 14. Within the shelf area, the upper layers showed more variation than the lower layers, as expected. The largest change in salinity at any one station occurred at station 15 toward the end of the summer of 1976, indicating the transport of the low-salinity water from the Kivichak River westward. Near the end of July there was a general decrease in salinity at the shelf break stations and in the upper layers of the shelf area of 0.1 to 0.3 parts per thousand, which could have been the response to a major storm. The meters at station 3 and 14 indicated an increase of 0.2 parts per thousand in August, with the increase occurring at station 3 a few days before station 14. This again supports the view of inflow along the Alaskan Peninsula. Thus salinity reveals no major seasonal effects, but does give some insight into individual events.

The existence of periodic events in the current field are best illustrated by the current records themselves. The weekly averaged "speeds," the averages of the observed current magnitudes, are illustrated in figure 8. The predominant feature of the plot of mean speeds is the strong monthly periodicity and the apparent separation into two levels of activity. The overall range in mean speed is 40 cm/s with a dominant periodic variation of 10 cm/s.

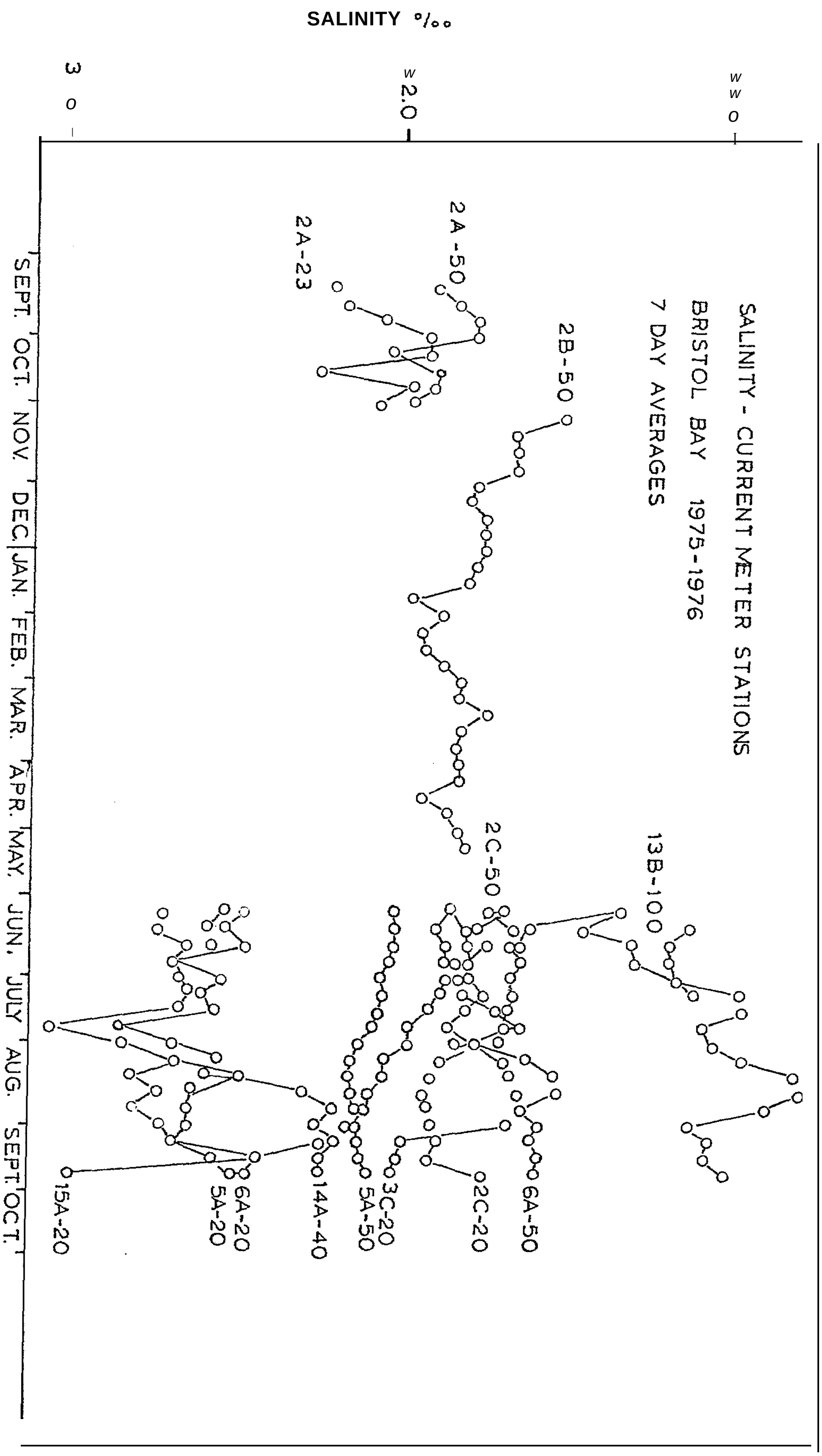

SALINITY ‰
SALINITY - CURRENT METER STATIONS
BRISTOL BAY 1975-1976
7 DAY AVERAGES
2.0
2A-50
2A-23
2B-50
2C-50
13B-100
15A-20
5A-20
6A-20
14A-40
5A-50
3C-20
2C-20
6A-50
SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY. JUN. JULY AUG. SEPT. OCT.
1976

FIGURE 7

'EAN SPEEDS - CURRENT METER STATIONS

ISTOL BAY

7 DAY AVERAGES

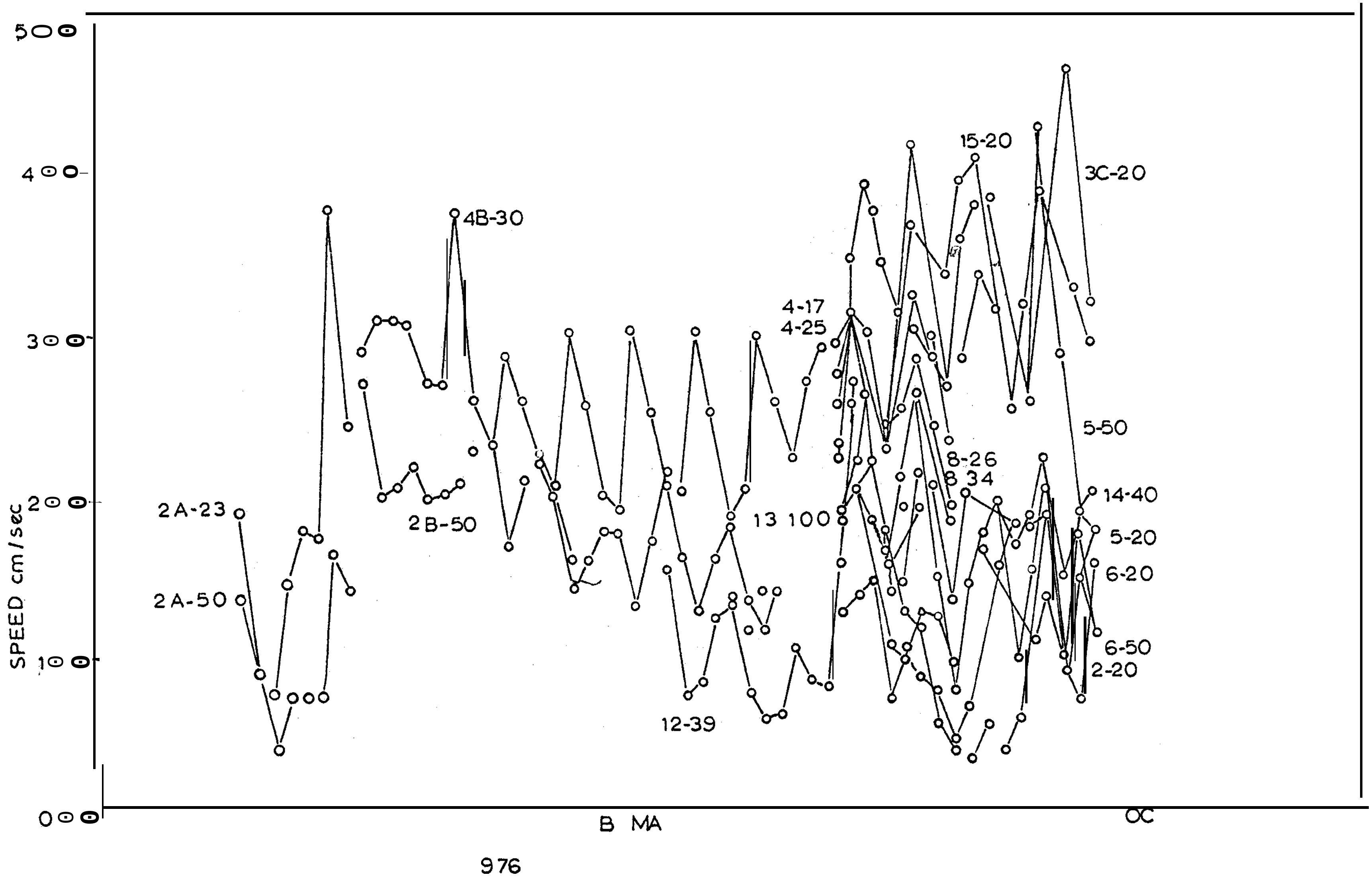


FIGURE 8

During the winter under the ice, the fluctuations in mean speed are very clean, with the striking feature that the phase of the fluctuation at northwestern end of the bay is 180 degrees out of phase with the fluctuations at the southeastern end of the bay. These fluctuations are particularly interesting, since they occur while the system is ice-covered and therefore not subject to wind stress directly. The winter record from station 4 is not out of phase with measurements in the rest of the bay during the summer months, this phase change relationship may be due to the ice lid on the system. The separation into two levels of energy is due to a tidal inference effect noted in the current meter records in the region of the shelf area. This effect is presently being investigated.

Interpretating 7-day averages of current vectors requires caution in that 7 days is not an integral number of semidiurnal periods. The effect can amount to approximately a l-cm/s contribution to each weekly average, the component reversing sign every 2 weeks.

The north-south and east-west components for the longest station record, station 2, and example records for winter from station and summer records from station 6 are displayed in figure 9. These records show monthly periodicity and also allow a better examination of the seasonal differences. All the stations represented in the figure show little net flow in a north-south direction seasonally. The net transport over the year is then best examined in the east-west plot. At station 2, the highest activity occurs at the transition from winter to spring. The flow at station 2 is eastward through autumn and westward through the rest of the year, which could represent the formation and destruction of the shelf regime. Station 4 again shows periods where the sign of the fluctuation is 180 degrees out of phase with the fluctuations at station 2, but not as consistently as in the mean speed plot. Also,

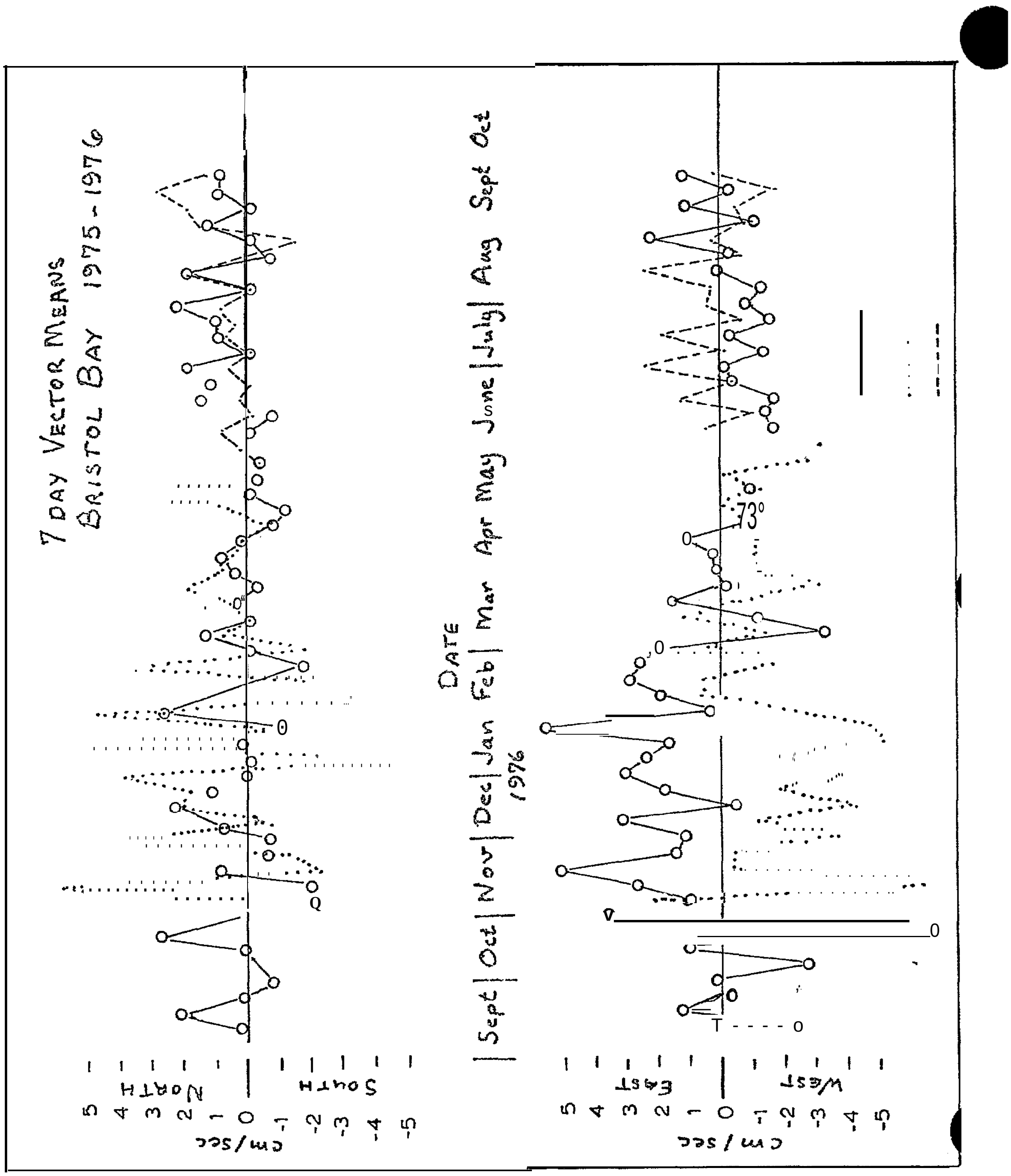

7 Day Vector Means
Bristol Bay 1975 - 1976
Date
Sept | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct
1976
North
South
East
West
cm/sec
5 4 3 2 1 0 -1 -2 -3 -4 -5
73°

Figure 9

the seasonal trend during winter is opposite of that at station 2. Both station 2 and station 4 changed character in February in the sense that the variability has reduced, perhaps representing the spin down of the system after the wind stress has been removed by ice cover. Stations 2 and 6 were approximately 20 km apart during the summer and show rather good agreement in the current fluctuations. Neither station was particularly active; both had a net northward flow, but station 2 was predominantly westward and station 6 was eastward, indicating a more complicated flow regime than was resolved with the current meter spacing.

To provide some indication for driving forces, the weekly averaged vectors of current from station 2 during summer and weekly averaged wind vectors for the station 2 region were compared. The wind information was obtained from the Fleet Numerical Weather Facility projections, utilizing a numerical model with 3-degree grid spacing centered over station 2. The scale of the model grid results in wind projections which would cover most of Bristol Bay and thus affect records from all of the moorings. Figure 10 displays the vectors in a progressive vector diagram format. The striking feature is the similarity in long-term direction. This similarity is coincidental, and would not be so evident if compared with the other current meter stations. The similarity is probably due to absence of other forcing. Though the directions are quite similar, the variations do not seem to be strongly correlated. The reversal of wind between June 7 and June 28 had no apparent effect, with the exception of a slight reduction in current speed between June 20 and June 27. Likewise the high winds at the beginning and end of the record show no acceleration of the water mass.

Figure 11 is a visually smoothed trajectory of one Numbus-6 Lagrangian drifter deployed at the same time the summer moorings were placed in the bay.

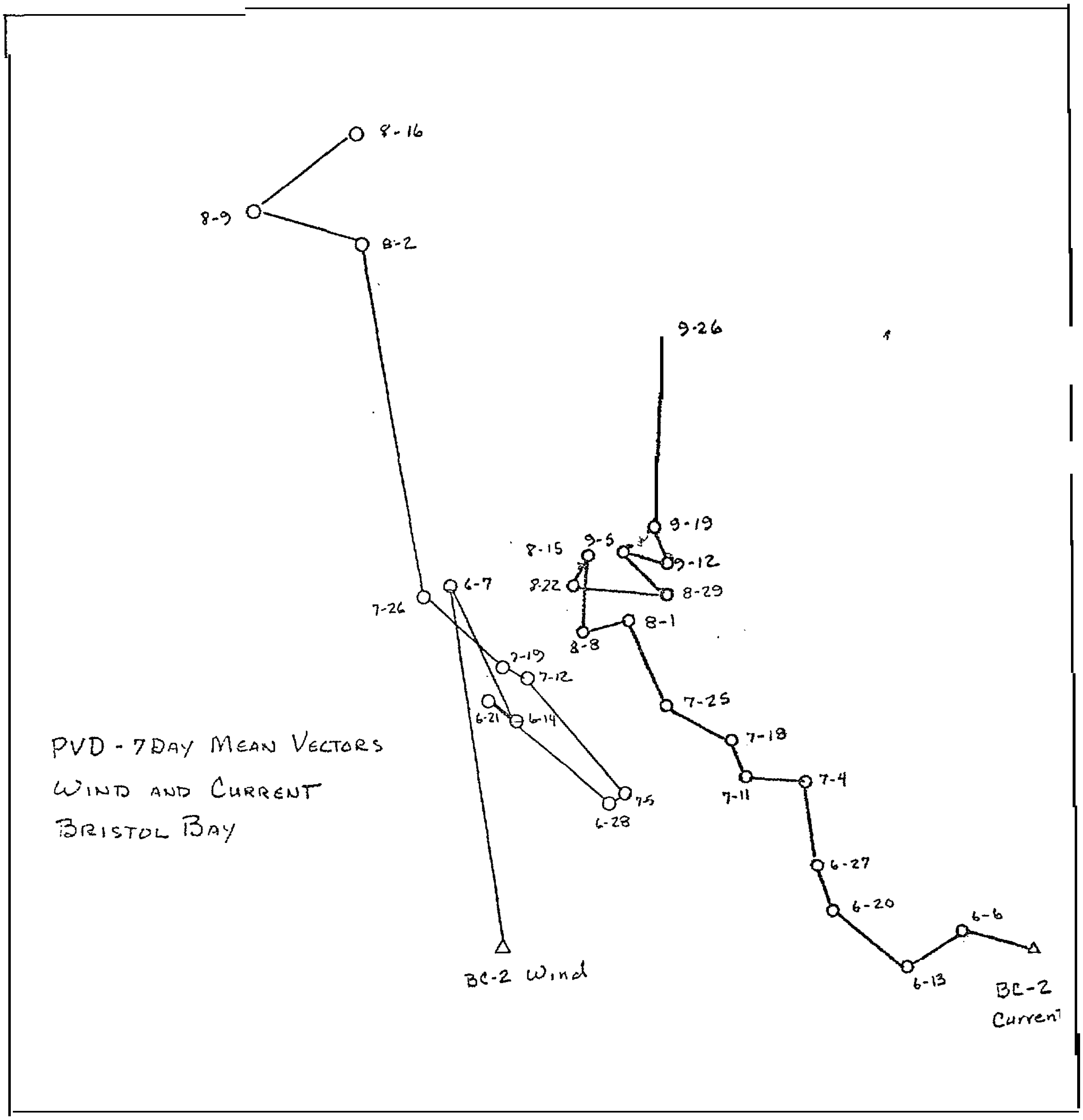

8-16
8-9
8-2
9-26
9-19
9-5
8-15
9-12
8-22
8-29
6-7
7-26
8-1
8-8
7-19
7-12
7-25
6-21
6-14
7-18
PVD - 7 DAY MEAN VECTORS
WIND AND CURRENT
BRISTOL BAY
7-5
6-28
7-11
7-4
6-27
6-20
6-6
BC-2 Wind
6-13
BC-2
Current

Figure 10

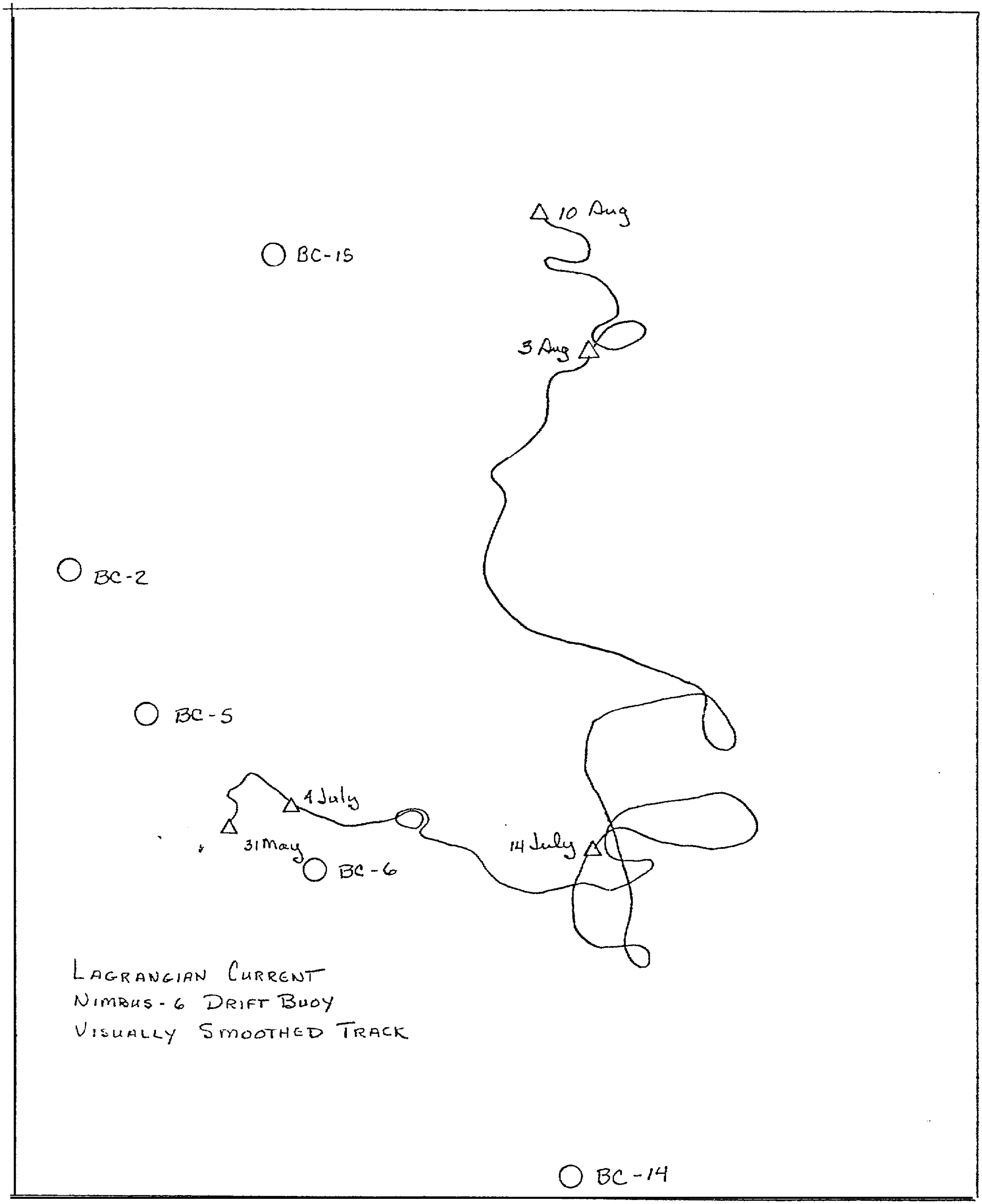

10 Aug
BC-15
3 Aug
BC-2
BC-5
4 July
31 May
BC-6
14 July
LAGRANGIAN CURRENT
NIMBUS-6 DRIFT BUOY
VISUALLY SMOOTHED TRACK
BC-14

Figure 11

Throughout June there was very little motion in agreement with the current meter records from station 6. The first 2 weeks of July, however, the drifter made substantial excursions to the east and south with little corresponding motion in the record from station 6. Over the next month the drift was to the north with some small amount of east-west displacement. At this time there was a northward flow at station 6, though not large as the easterly flow. The similarity between the drifter trajectory and the wind PVD is quite striking after July 14. All of the drifters deployed at this time were recovered, but none were found with the drogue sheets attached. From the record presented, it can be estimated that the drogue was lost from this drifter around July 9.

Thus in the low-frequency flow there are periodicities of 1 month with some interesting phase variations over the space of the bay. The low-frequency data indicate seasonal changes in flow patterns and in particular will provide flow reversal from summer to winter at station 2. The lower frequency fluctuations in currents do not seem strongly coupled to low frequency in the wind field, though seasonal variations may show a stronger coupling. The drifter data show that while the drogues were attached the flow was very quiescent and in agreement to the current meter records.

B. High-Frequency Flow

For the purpose of the report, high-frequency flow will be considered only as flow fluctuations with periods of 24 hours and 12,5 hours, the dominant tidal bands. Table 2 lists the velocity components for each of these periods for the available data. The fact that stands out is that the motion is dominantly east-west. Nearly 75% of the diurnal flow is in the east-west direction and 63% of the semidiurnal flow is in the east-west direction averaged over all the data. It is impossible at this stage of processing to determine phase relations of the tidal currents across the bay to determine whether or not the bay is sloshing back and forth as a solid body or as a wave propagating in one or the other directions across the bay. Efforts are currently underway to investigate this problem, however. There is a great deal of variation in the magnitude of the tidal energy throughout the bay; the standard deviations approximately equal the means. There are substantial variations in tidal energy temporally, horizontally, and vertically. From the table it is seen that the strongest tidal flows are in the lower layers of the shelf area; the reason for this result is not yet understood. Periods have been observed when the tidal current signal has virtually disappeared (fig. 12). It is hypothesized that this is due to interfering internal waves in the tidal frequencies. Perhaps this leads to amplification of the tidal motions in the lower layers. The thorough investigation of tides within Bristol Bay is underway.

Table 2. Tidal Component Energies $(cm/s)^2$

Station	Depth	24-hr - u	24-hr - v	12.5-hr - u	12.5-hr - v
BC-2C	20	73.0	0.5	147.2	46.1
BC-3B	50	93.5	3.5	171.3	53.1
BC-3C	20	46.4	30.0	181.0	268.6
BC-3C	100	34.4	30.0	148.9	161.8
BC-4C	25	46.2	57.0	312.8	302.6
BC-5A	20	51.1	3.0	101.6	30.1
BC-5A	50	322.7	22.1	659.8	122.3
BC-6A	20	50.0	4.6	101.3	18.0
BC-6A	50	106.6	15.5	213.3	24.8
BC-8A	26	37.4	35.7	205.0	201.4
BC-8A	54	52.4	37.4	211.6	188.9
BC-9A	17	69.5	92.4	306.6	296.3
BC-9A	27	74.8	81.4	233.9	208.0
BC-12A	39	27.3	5.4	52.1	16.5
BC-13B	100	39.1	10.7	132.2	92.1
BC-14A	37	72.2	18.3	152.0	19.6
BC-15A	20	148.4	3.8	449.7	213.2
	Mean:	79.2	26.6	222.1	133.0
	Standard deviation:	69.7	27.6	147.1	103.7

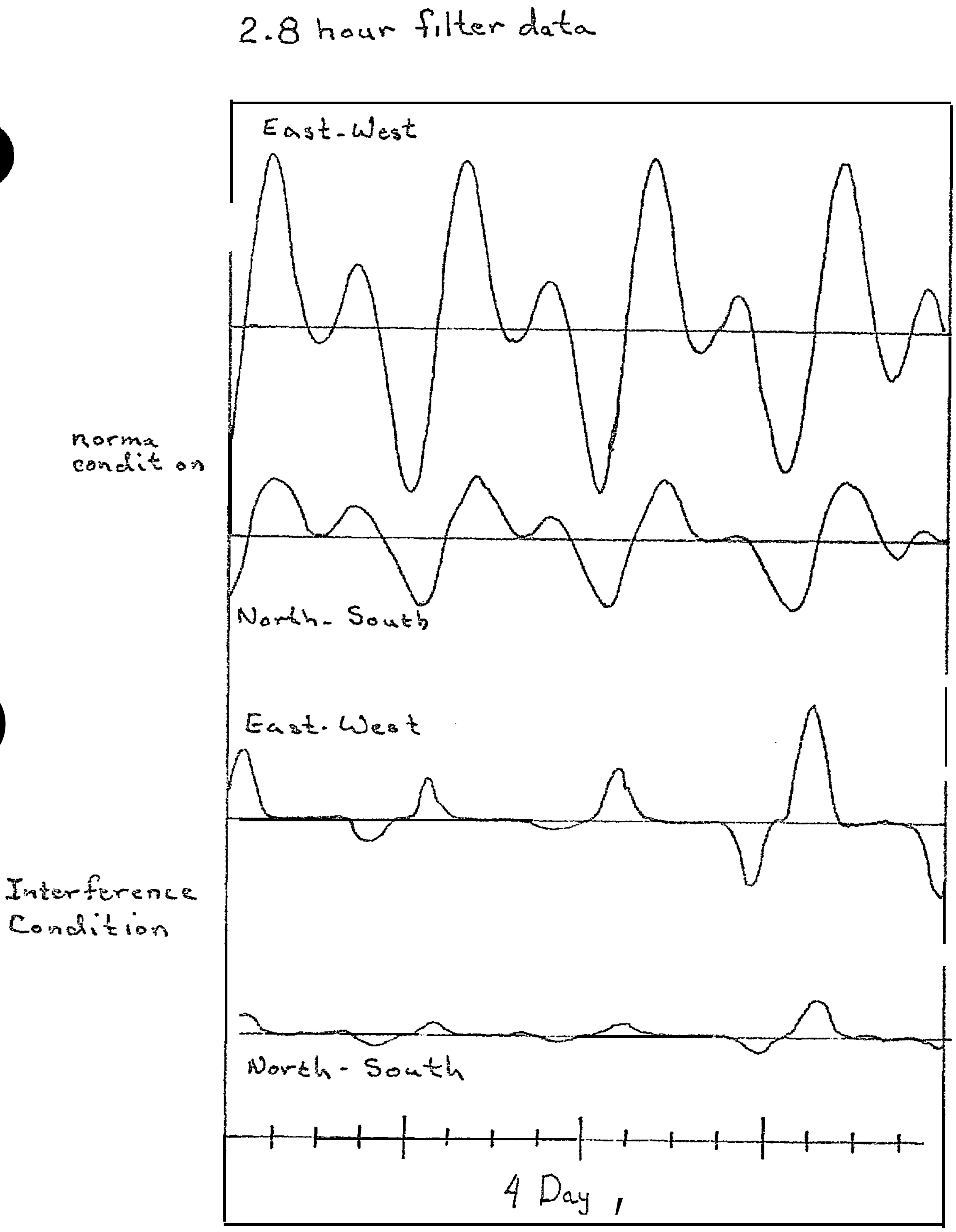

2.8 hour filter data
East-West
norma
condit on
North- South
East. West
Interference
Condition
North - South
4 Day ,

Figure 12

VIII. HEAT BUDGET OF THE EASTERN BERING SEA

This investigation it was felt, should be documented and the preliminary results made known because of their possible interest to OCSEAP investigators. The study is not complete, and some of the conclusions are tentative.

A. Results

Some very comprehensive oceanographic surveys of the eastern Bering Sea were completed as part of OCSEAP in summer 1976. The data are quite valuable for examining many oceanographic aspects of the region, but they are especially suitable for evaluating the heat content of this region and its changes during the seasonal heating.

The heat budget of a water column is altered by: (1} net surface exchange, which consists of net insolation, net long-wave radiation, evaporative heat flux, and conductive heat exchange between the ocean and atmosphere; (2) horizontal advection and diffusion of heat; and (3) vertical advection and diffusion of heat. Earlier heat budget studies were often hampered by little knowledge of horizontal temperature gradients or currents (horizontal heat advection), and the empirical formulas for estimating net insolation and net long-wave radiation varied so greatly that it was difficult to choose among them with confidence. A recent research effort in our laboratory has been to review and evaluate the formulas for estimating the radiative fluxes, and it is believed that these can now be specified to an accuracy of 5-10% over a period of about a month. In addition, the OCSEAP data provided direct current measurements, adequate spatial coverage to allow determination of the first and second derivative of heat content and oceanographic conditions such that a layer could be chosen deep enough to neglect vertical fluxes.

The following data sets were used: Moana Wave and Miller Freeman, 6-17 June 1976; Acona and Moana Wave, 7-10 August 1976; and Acona, 28-30 September 1976. The CTD data (l-m averages) were used to derive the heat content of the upper 50 m by vertical integration, and the individual station values were plotted. For each cruise, the heat content values were meaned by 1° x 1° areas; the values, however, were spatially weighted to the center of each 1° area after determination of the east-west and north-south gradients from the original plots. Values for the June and August cruises are shown in figures 13 and 14.

(At present the September data have not been treated in the detail accorded the June and August data. A number of the CTD casts have not been read off the tape due equipment problems; consequently the number of casts is quite small, and the weighting of the data results in rather uncertain values. If the remainder of the data can be retrieved, this data set can perhaps also be used.)

It should be noted that data exist outside of the area shown on the maps; in August, however, there were no data east of this area and very few to the north. It was decided not to use the data farther west because it is difficult to find a consistent level where the vertical advective and diffusive terms can be neglected. The data shown on the maps have been used in light of a model of heat conservation stated as follows:

$$\frac{\partial H}{\partial t} = Q - u\frac{\partial H}{\partial x} - v\frac{\partial H}{\partial y} + Ah\left(\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2}\right)$$

where $\partial H/\partial t$ is the local change of heat content, Q is the net surface heat exchange, $u\frac{\partial H}{\partial x}$ and $v\frac{\partial H}{\partial y}$ are the horizontal advective terms where u is the east (x) component of velocity and v is the north (y) component of velocity, and remaining term is the horizontal diffusion of heat with Ah the eddy thermal conductivity. Upon examination of the data base, it was decided to evaluate the various terms for the two 1° areas between 56°-570 N. and 164°-166° W.

The various terms in the equation, except Q, were determined by finite difference methods for space and time. The spatially dependent terms were computed from both June and August data, and a mean was used. The value of Ah used was 10^7 $cm^2 s^{-1}$. Although this value cannot be stated with the confidence of a physical constant, numerous studies would suggest that it is unlikely to be in error by more than a factor of 2. The advective term is, of course, dependent on flow of the water. Current meters were not placed in either 1° area of interest, but there are data from two arrays to the southwest and three arrays to the northeast. The two arrays to the southwest were presumably in the Bering Slope Current; northwest flow of 2-19 cm/s was indicated. The three arrays between 56.5°-57.00 N., near 163° W., all showed net flow of 1 cm s^{-1} or less with no consistent direction. In addition, maps of the geopotential anomaly (0/50 db) revealed the Bering Slope Current, but suggested very weak flow in the region of the two 1° areas of interest. Thus the advective terms are considered to be very small and have been neglected.

The net surface exchange consists of four components: Qs, the net insolation; Q_b, the net long-wave radiation; Q_e, the evaporative flux; and Q_h, the conductive flux. Q_s and Q_b were determined by the empirical formulas ‘ and methods derived in our recent studies. The most critical factor for their determination is cloud cover, which was estimated from daily NOAA-4 satellite images (visual channel), corrected by +0.20 to agree with observer’s - a estimates that were used to derive the cloud factors. Computations of Q_e and Q_h were made with bulk aerodynamic formulas using the transfer coefficients from a recent review paper with meteorological data from the National Climatic

Center. The computations are summarized in the following table, where single estimates of Qs, Q_b, Q_e, and Q_h were made for the combined 1° areas rather than separately. Units are cal cm^{-2} rei^{n}-'.

Area (56°-570 N.)	∂H/∂t	‘s	‘b	‘e	‘h	$A_h\left(\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2}\right)$	Residual
164°-1650 W.	0.23	0.23	-0.02	-0.01	0	0.04	0.01
165°-1660 W.	0.16	0.23	-0.02	-0.01	0	0.02	0.06

The residuals reveal the lack of an exact balance; if both areas are meaned, the value is 0.03 cal cm^{-2} min^{-1}, which is quite small considering the various approximations and uncertainties. The principal conclusion that emerges is that during this period the changes in heat content in this area were primarily controlled by surface exchange, with net radiation being by far the major factor.

Discussion. Do the results of this heat budget investigation, namely, that changes in summertime heat content are dominated by net radiation, generally apply to the shallow eastern Bering Sea as a whole? It seems likely that they do. First, there is considerable historical evidence that the flow is weak and variable, and all of the OCSEAP measurements on the continental shelf, except a few nearshore, have shown very weak net flow. Second, winds in summer are usually weak; hence the evaporative flux would be small. Finally, there is generally very little temperature gradient in the lower part of the water column. Vertical fluxes should usually be negligible, although in late summer or early fall (as suggested by the late September 1976 data) vertical diffusion of heat downward might assume some importance. It should be stressed that the above discussion applies only to summer. In winter, winds are strong, the air is cold, and latent and sensible heat fluxes are likely to be quite large. In areas subject to ice formation, the surface heat exchanges may be drastically altered.

The implication that net radiation almost wholly controls changes in heat content during the summer is of interest for a number of reasons. First, this simple (and rare) oceanic situation makes it quite straightforward to apply a heat budget model. Thus the changes in heat content could have been forecast using the formulas for estimating net insolation and net long-wave radiation, with the only data input being cloud cover from satellite photographs. The fact that insolation acts on an almost motionless column of water may have important implications to the primary productivity in this area. Finally, this behavior of the environment is important to the ecosystem as a whole.

Heat content (kcal cm⁻²)

7-10 August 1976

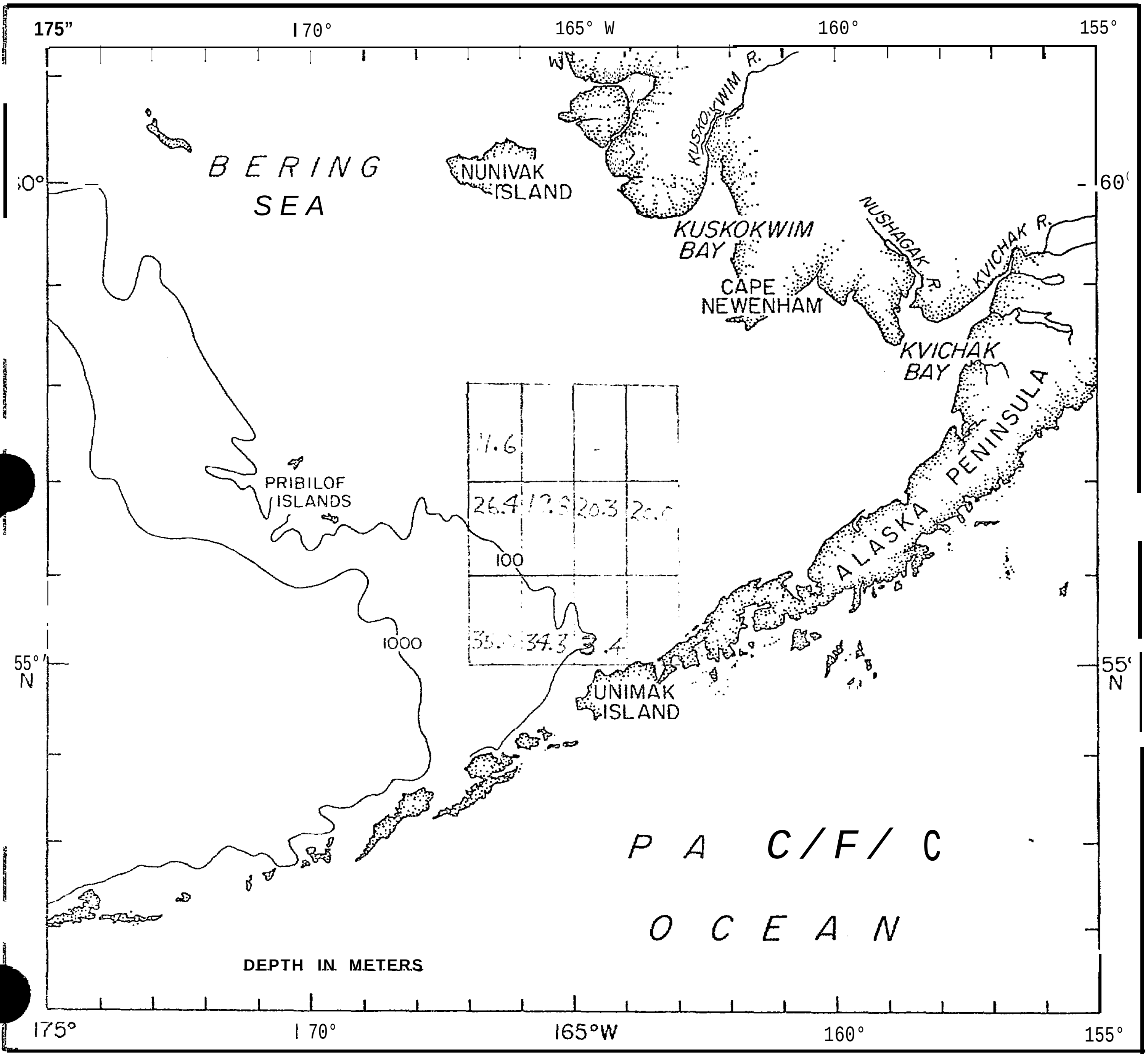


Figure 13

Heat Content (kcal cm^{-2})

6-17 June 1976

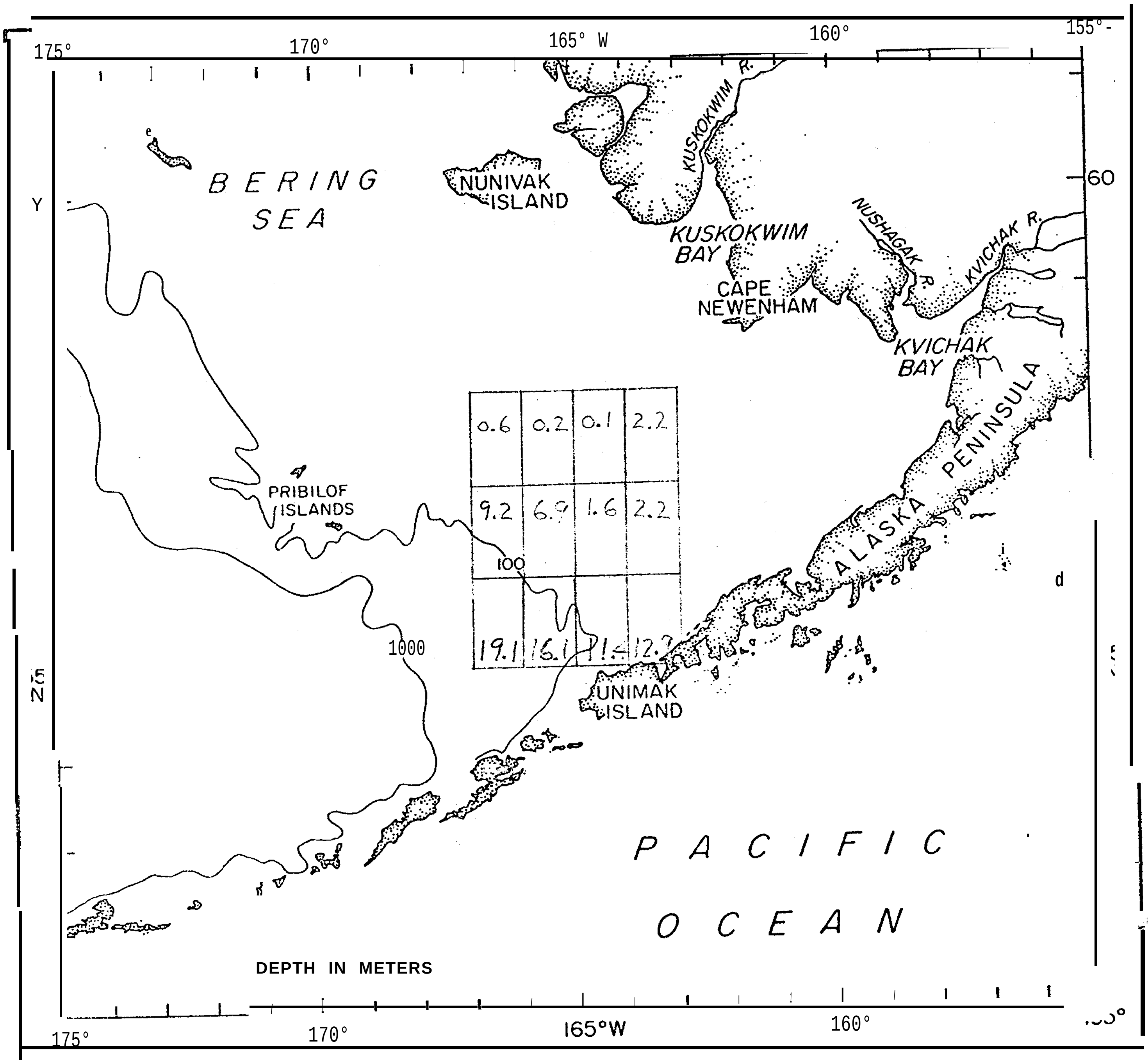


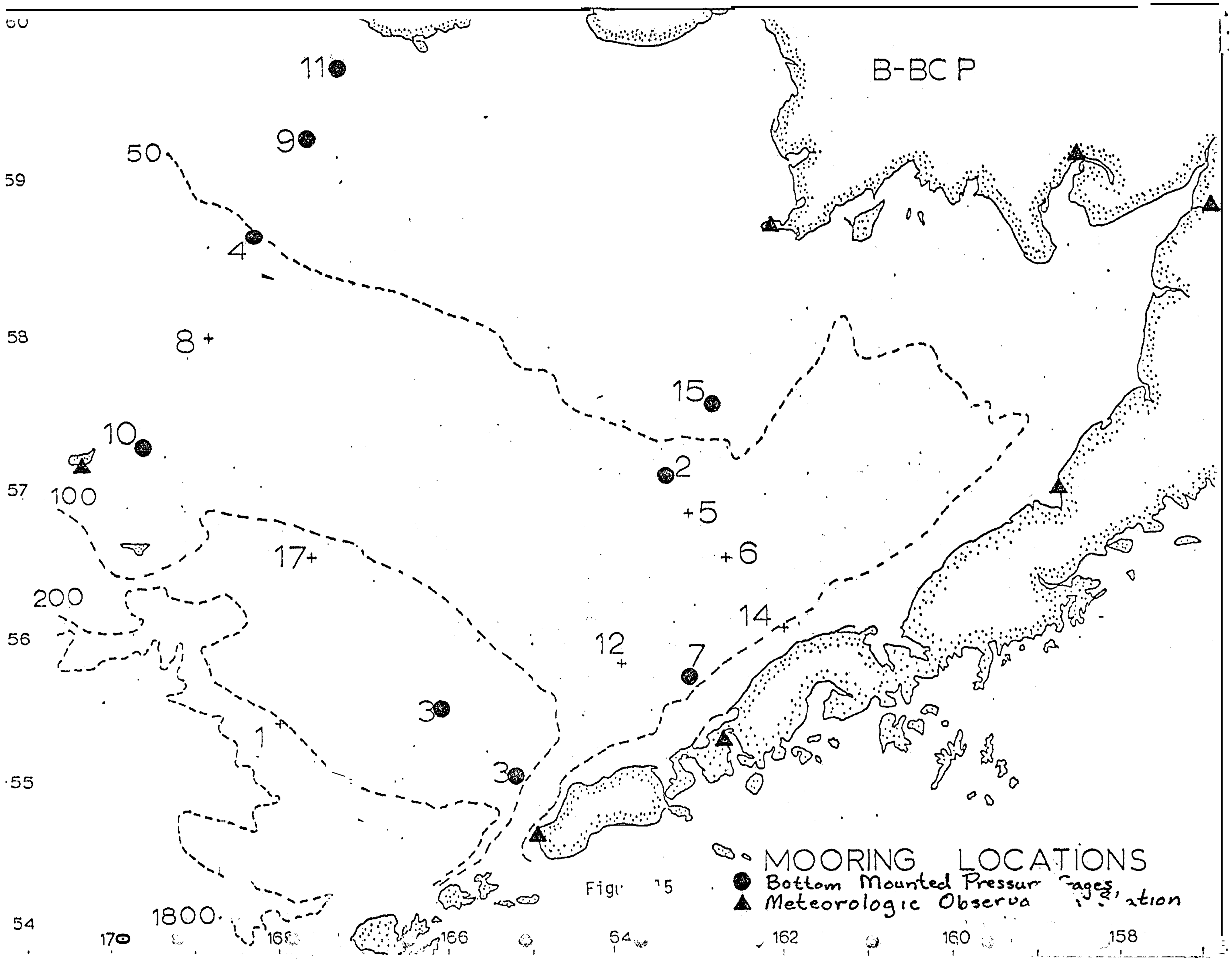
Figure 14

Bottom Mounted Pressure Gages and Meteorological Observations

The distribution of actual bottom pressure is central to the problem of circulation within Bristol Bay in that horizontal pressure gradient is one of the principle terms in the balance of forces. Combined with the atmospheric pressure field it is possible to separate baroclinic and barotropic components of the pressure field and thereby examine the contributions to the circulation of the various components of forcing such as geostrophy, slope current, and hydrostatic adjustment. The task of obtaining the required information is well underway.

Bottom mounted pressure gates have been deployed with a number of current meter arrays throughout Bristol Bay, Figure 15. These have been of the Aanderaa TG-2&3 type. Data from the pressure gages is now in processing and has yet to be fully examined. As noted in the last annual report events in the pressure record occurred concurrently with pulses in the current. As these records become available for analysis a complete picture of the pressure field can be formed.

The task of adjusting the records to account for atmospheric pressure requires (1) a study of the sea-level atmospheric pressure from around the bay, and (2) algorithm determined to allow for correction of the pressure gage records offshore. To date, atmospheric pressure records for the year 1975 are being analyzed for the purpose of program design and debugging and to provide information towards the design of the correct algorithm. If the correlation between shore station pressure records is linear the correction algorithm will be straight forward, however, if the spatial scale of atmospheric events is smaller than the horizontal scale of the bay, a more complex problem must be solved in order to provide the proper correction information. When the 1976 data are available from the National Climatic Center the results of the 1975 effort will be applied so that the effort of understanding the bottom pressure field can get underway.



B-BC P
MOORING LOCATIONS
Bottom Mounted Pressur Gages,
Meteorologic Observa
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1800
Figi 15
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166
164
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158

X. Papers resulting from the Bristol Bay Investigations to date:

1. FINESTRUCTURE IN OUTER BRISTOL BAY, L. K. Coachman and R. L. Charnell, Accepted in Deep sea Research for publication summer 1977.

2. THE HYDROGRAPHIC STRUCTURE OVER THE CONTINENTAL SHELF NEAR BRISTOL BAY, ALASKA, JUNE 1976, T. H. Kinder, University of Washington Technical Report M77-3, January 1977.

3. INTERNAL TIDES OF BRISTOL BAY, ALASKA, R. L. Charnell, H. O. Mofjeld, and J. D. Schumacher, in preparation.

4. OBSERVATIONS OF MEDIUM SCALE FEATURES ALONG THE SEASONAL ICE EDGE IN THE BERING SEA, R. D. Muench and R. L. Charnell, Journal of Physical Oceanography, Vol. 7, #4, 1977.

XI. NEEDS FOR FURTHER STUDY

Hydrographic properties during winter conditions need examination. This would require running several CTD lines (off Cape Newenham, midway between this line and one run seaward from Nunivak Island) using helicopter ice techniques already developed. Additionally, it is recommended that three current meter arrays be deployed in the Kuskakwin Bay region; one at a site where historical data base exists and the other two separated by approximately 25 km on either side of the 50 m isobath. It should be noted that the three arrays recommended for the NCOP study (all south of the Bering Strait) will be located "downstream" of the B-BOP arrays and thus will provide a more coherent description and understanding of eastern Bering Sea shelf flow.

To further study flow on the St. George Basin area, Lagragian drifter studies are required since the high density of fishing operations inhibits its success of moored arrays. As is always required for understanding of forcing, meteorological data must be provided from a moored buoy.

In the context of these needs for further study the specific subjects for study can be classified into three categories:

A. Nearshore

1. A front is known to exist in certain areas of the bay; however, a detailed delineation of the front is lacking. A thorough survey of the front is required to delineate the zones of coastal water and shelf water.

2. The structure of the front is not presently known. A detailed examination of the currents and physics" parameters of the front is required to define the generation mechanism of the front and current dynamics associated with the front.

3. To date, the investigations have not fully disclosed the disposition of freshwater inputs to the bay from river discharge and its relation to high-salinity anomalies located in the coastal waters.

4. Two high-salinity anomalies have been sampled within the coastal waters. The sourve anomalies and the distribution of the anomalies has to be addressed.

B. <u>Central Shelf</u>

The temporal and spatial distribution of the tidal current reductions noted in the summer season of 1976 is not known. Also, the cause of the current reduction is only speculated at the present time, and additional information is required before a firm mechanism can be developed.

C. <u>Bering Sea Slope</u>

1. Fine structure has been noted in the slope region. The extent of the fine structure and the lifetime of the structures are unknown. A better resolution of these questions will assist in understanding the source of the fine structure.

2. The success of current meter data acquisition on the slope has been marginal due to high equipment losses resulting from heavy fishing activity. Information on the circulation on the slope could be improved by the use of Lagrangian methods in the heavily fished region near Unimak Pass and current meter moorings farther "downstream" near St. George Basin..

D. <u>General</u>

1. The glaring need reflected in this report is the lack of winter data, either current or CTD. The spatial distribution of current meters wintering over has not been sufficient to resolve the winter current regime. Winter current meter stations are required to fill in the gaps in our knowledge. Also the collection of winter CTD data is critical to the understanding

of winter circulation. This problem may be best addressed by collection through the winter ice cover.

2. Present meteorological information is on a scale too large to resolve events which have a dimension less than that of the bay. To allow a better resolution of these smaller events a meteorological buoy in the center of the bay is necessary. This would permit a distribution of small events to be drawn and the influence of small meteorological events on the water to be investigated.

XII. CONCLUSIONS

Investigations into the environment of Bristol Bay have been in operation for 2 years. A basic description of the physical oceanography of the bay has been drawn and questions concerning specific processes formulated.

Bristol Bay can be characterized as having three distinct zones: (1) the coastal waters where all the properties are uniform from the surface to the bottom; (2) the central shelf where the water column is highly stratified, forming a distinct two-layer system; and (3) the Bering Sea Slope where the characteristics are similar to that of the Bering Sea proper but reflect the effects of interaction with the shelf. The coastal water is well-mixed vertically and has modest horizontal gradients of salinity reflecting the influence of the freshwater discharge from rivers, though definite river effluent has yet to be identified. Currents measured in the coastal water thus far have been predominantly tidal with virtually no net flow when away from the zone of transition to central shelf waters. High salinity anomalies have been noted in the coastal waters, but their source and lifetime are not determined. The-coastal waters are separated from the central shelf waters by a strong horizontal change in character from well-mixed to highly stratified. Thus structure front has yet to be well understood in terms of its effect on the circulation in the bay. . Currents appear to be stronger near the front and in a direction which suggests a counterclockwise flow around the' perimeter of the bay at the frontal zone, which needs further spatial delineation. Within the central shelf area, the currents are dominantly tidal with very low net flows. No consistent pattern of flow can be defined, and the tidal flow also contains periods of sustained reduced value. These two facts combine to make the central shelf area very sluggish in terms of advection through the area. At the shelf break where the central shelf water and the Bering Sea meet, the currents are the strongest, though poorly sampled due to fishing pressure. Fine structure has been noted in the area, which is a rare phenomenon at best, the cause and extent of which is uncertain. The interaction at the shelf break is important in determining any exchange with the central shelf. Conclusions to this point are based primarily on summer data.

Winter influences on the circulation have yet to be fully determined. The general picture of circulation appears to be similar to the summer; however, details are poorly resolved. Current reversals have been noted, the extent and significance of which are yet to be ascertained. The winter hydrography is virtually unknown.

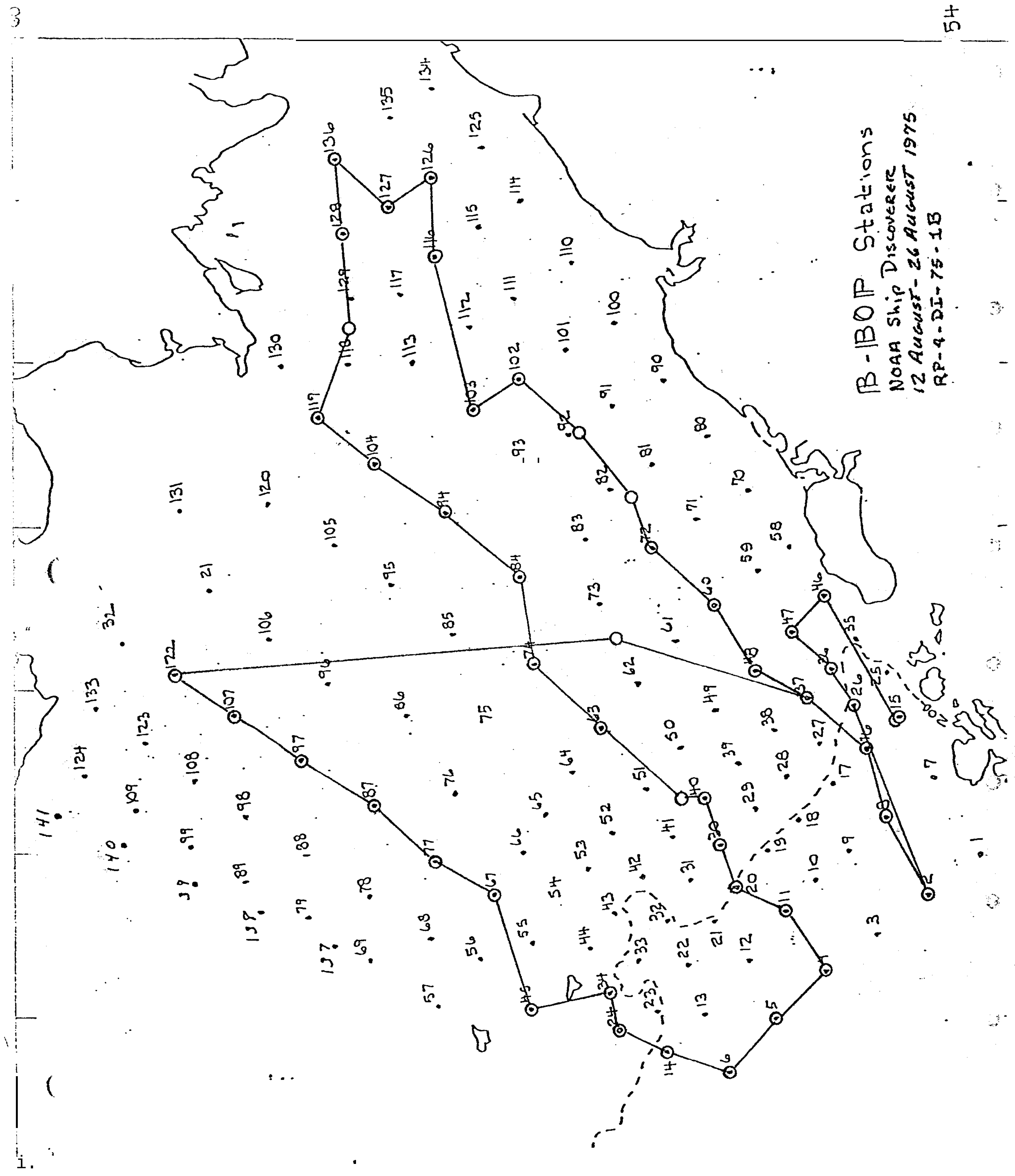
When the detailed processes have been addressed, a good description of Bristol Bay will have been formed.

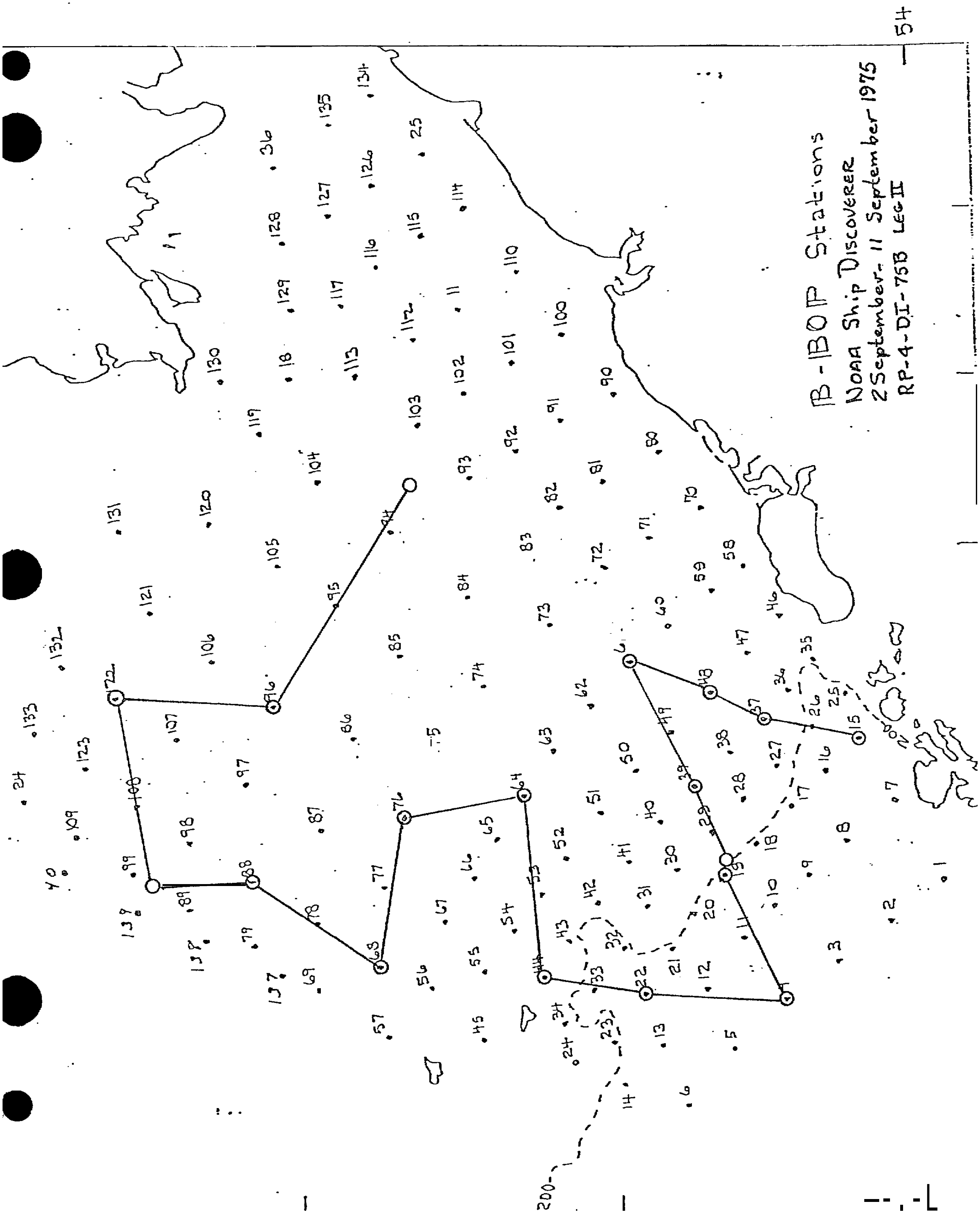
APPENDIX 1

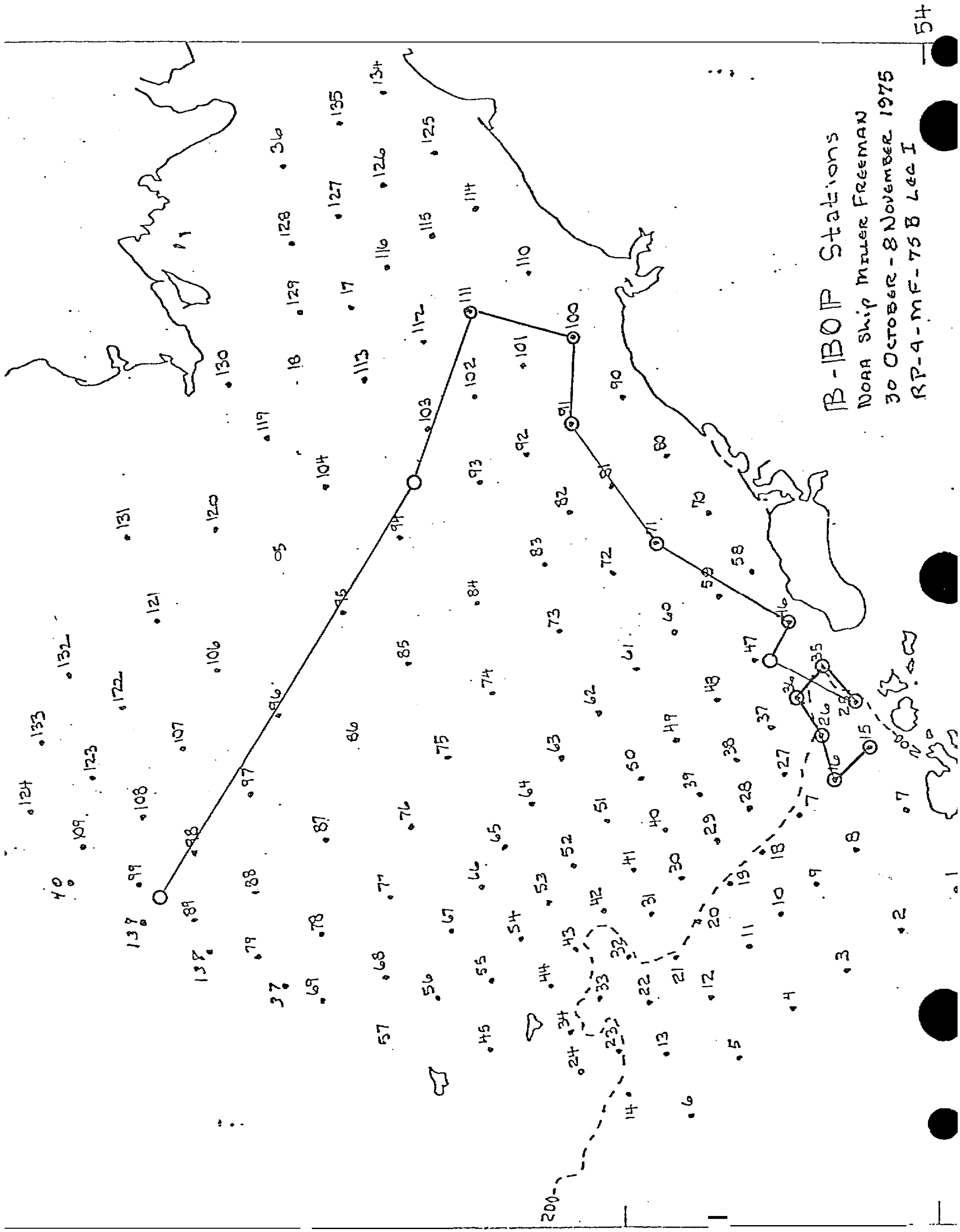
B-B(IP HYDROGRAPHIC DATA SUMMARY

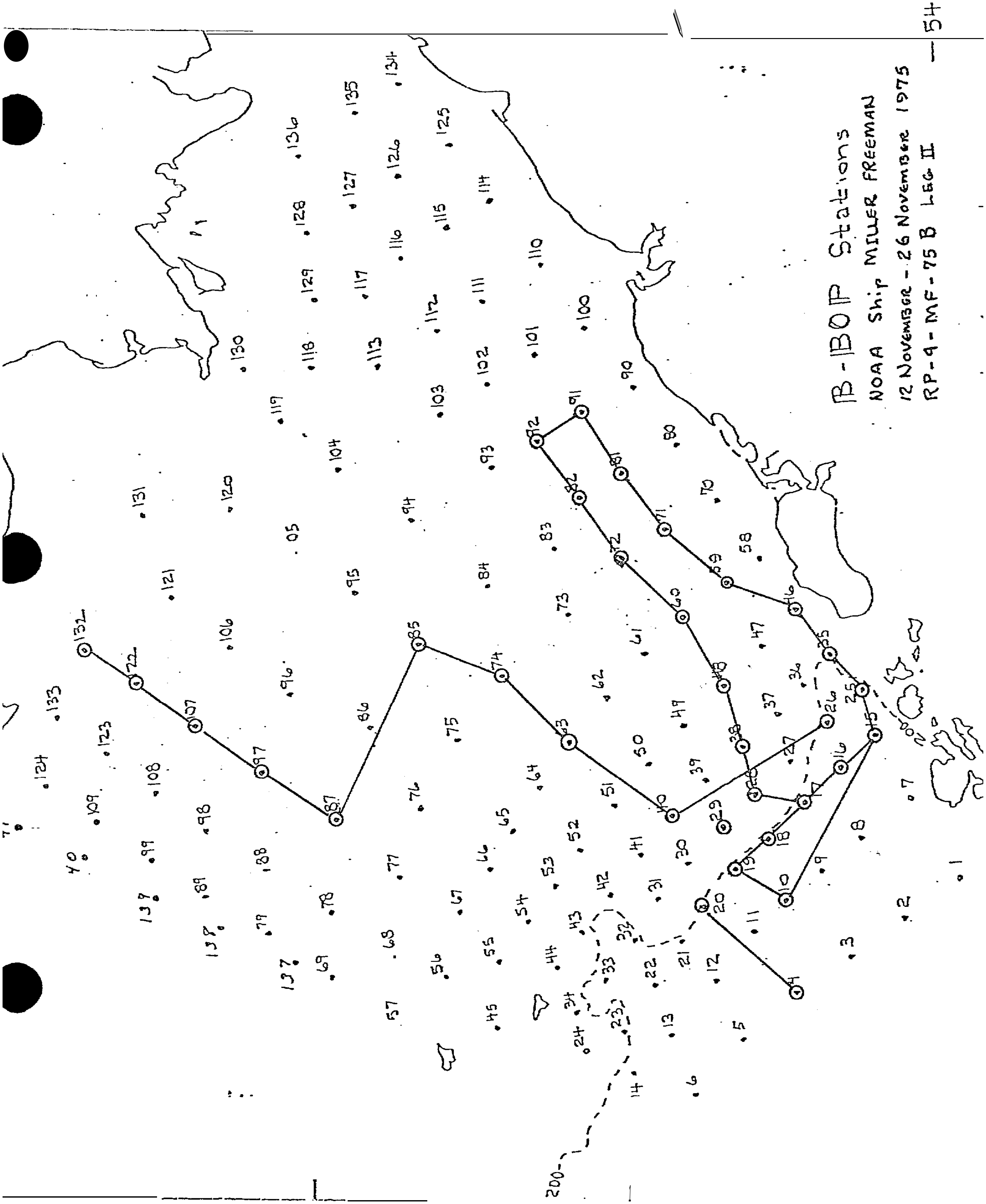
Dates	Stations[1]	Cruise	Region	Remarks
.2-26 Aug. 75	48	Discoverer RP-4-DI-75B Leg I	Outer & inner Bristol Bay	Ship of opportunity
2-11 Sept. 75	41	Discoverer RP-4-DI-75B Leg II	Outer Bristol Bay	
4-8 Nov. 75	14	Miller Freeman RP-4-MF-75B Leg I	Outer Bristol Ban	Analog data only
16-23 Mar. 76	27	Moana Wave RP-4-MW-76A	Unimak Pass	Stations near ice edge
16-18 June 76	19	Miller Freeman RP-4-MF-76A Leg IV	Nearly entire B-BOP grid less deep slope	3 lines of closely spaced (- 5 nm) stations; 2 are across 50 m front
7-18 June 76	152	Moana Wave RP-4-MW-76A Leg VII		
30 June-8 July 76	59	Moana Wave RP-4-MW-76B Leg VIII	Outer Bristol Bay	Ship of opportunity
3-10 Aug. 76	85	Acona 233	AS/CA interaction zone	Moana Wave aborted after massive electronic failure
5-9 Aug. 76	30	Moana Wave RP-4-MW-76C Leg II		
21-30 Sept. 76	66	Moana Wave RP-4-MW-76C Leg II	AS/CA interaction zone	Digitizer failure on Moana Wave
29 Sept.-2 Oct. 76	42	Acona		
12-26 Nov. 75	32	Miller Freeman RP-4-MF-75B Leg II	Outer Bristol Bay	

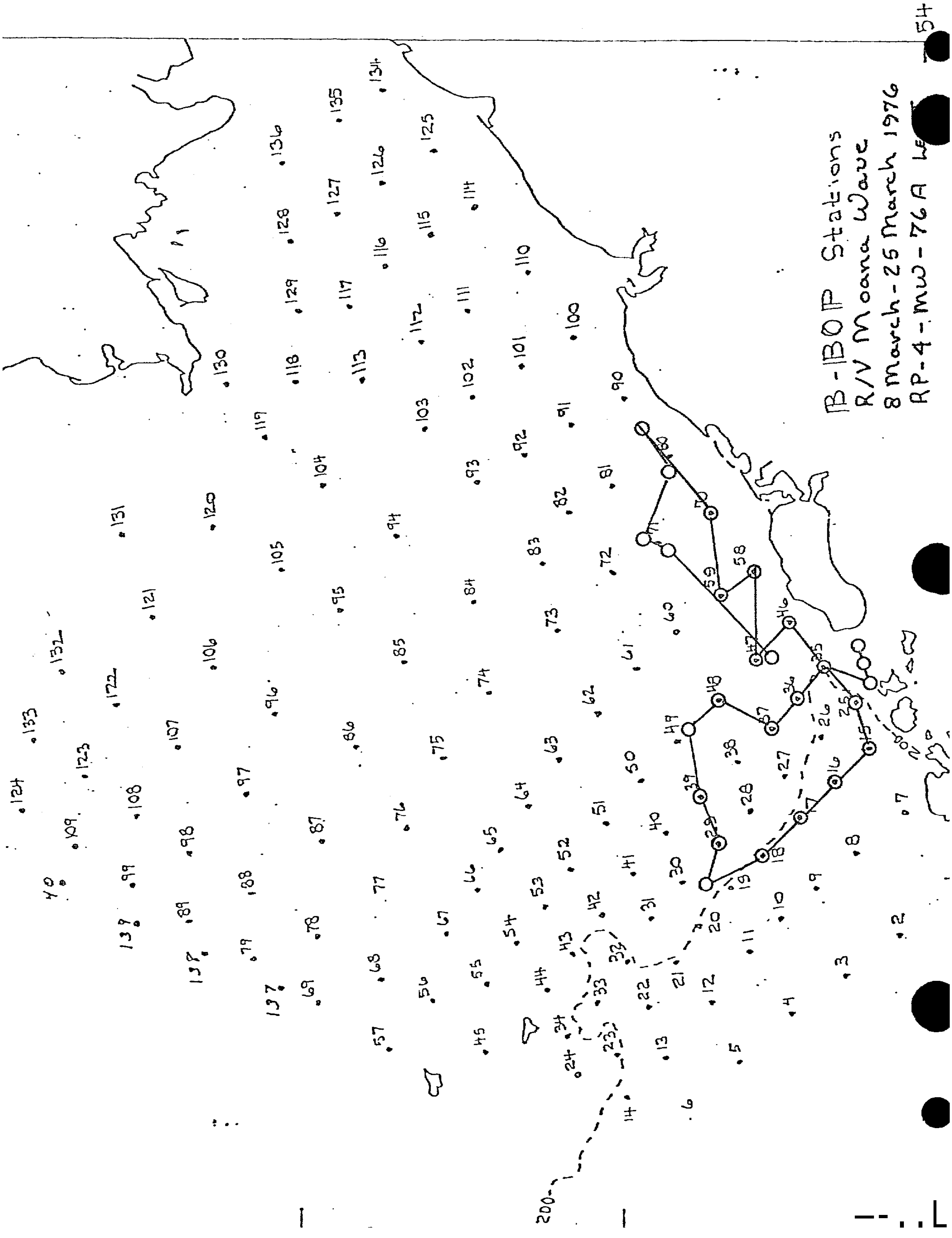
[1]Does not include stations occupied at mooring sites or outside B-BOP grid.

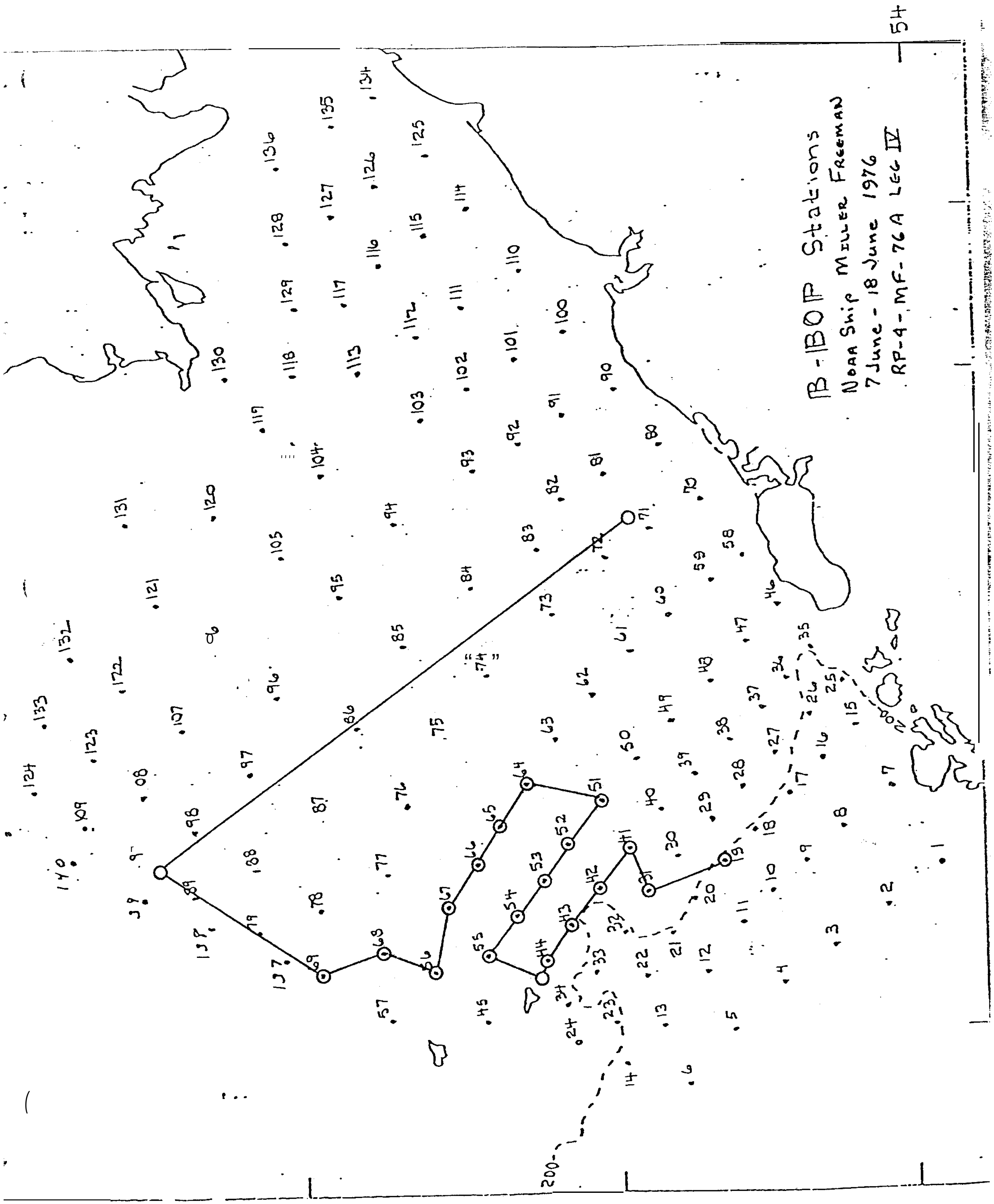

B-IBOP Stations
NOAA Ship Discoverer
12 August - 26 August 1975
RP-4-DI-75-1B

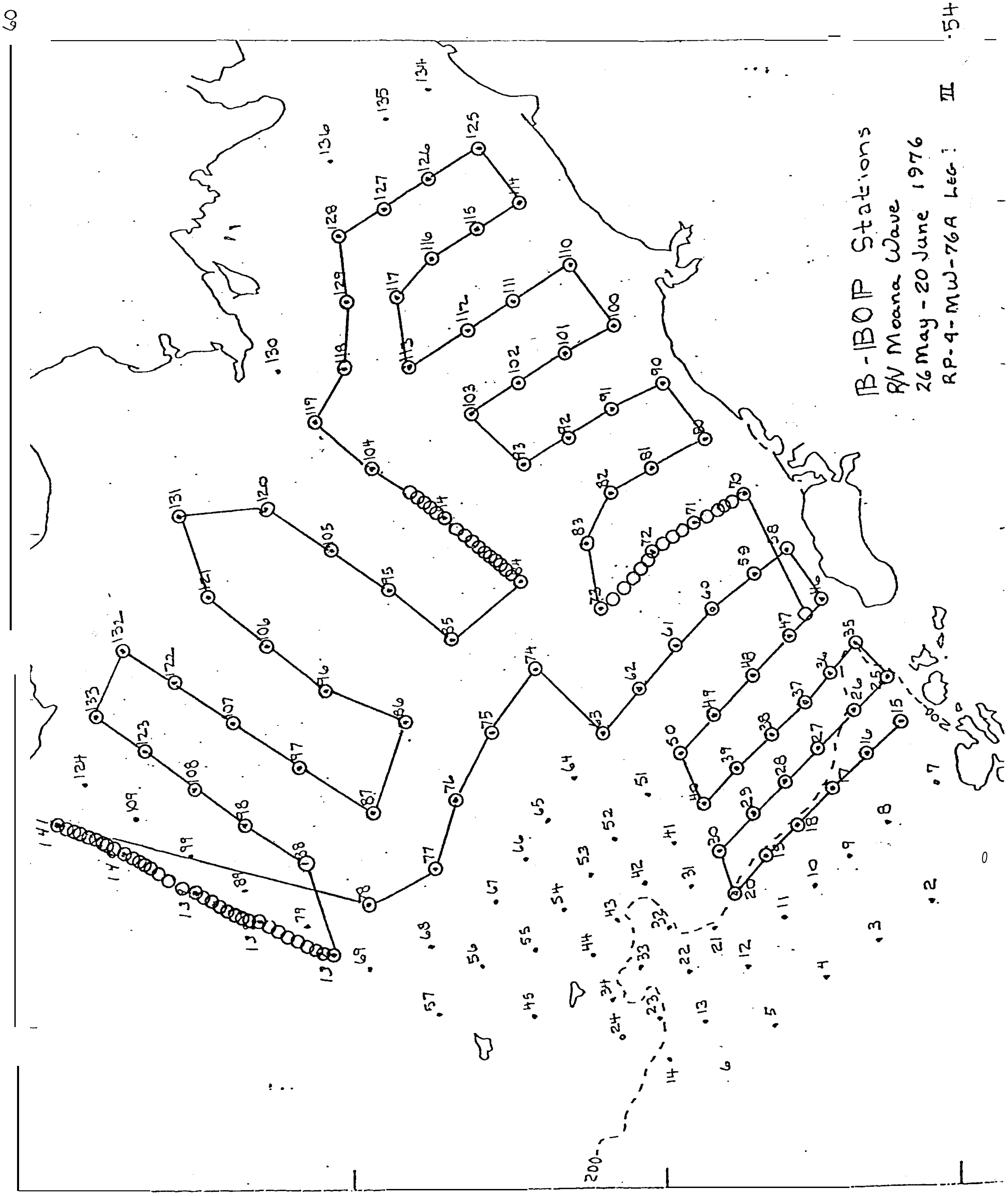

B-BOP Stations
NOAA Ship Discoverer
2 September - 11 September 1975
RP-4-DI-75B LEG II


B-BOP Stations
NOAA Ship Miller Freeman
30 October - 8 November 1975
RP-4-MF-75B Leg I
200


B-BOP Stations
NOAA Ship MILLER FREEMAN
12 November - 26 November 1975
RP-4-MF-75 B LEG II
54
200


B-IBOP Stations
R/V Moana Wave
8 March-25 March 1976
RP-4-MW-76A


B-IBOP Stations
Noaa Ship Miller Freeman
7 June - 18 June 1976
RP-4-MF-76A Leg IV



B-IBOP Stations
R/V Moana Wave
26 May - 20 June 1976
RP-4-MW-76A Leg: III
60
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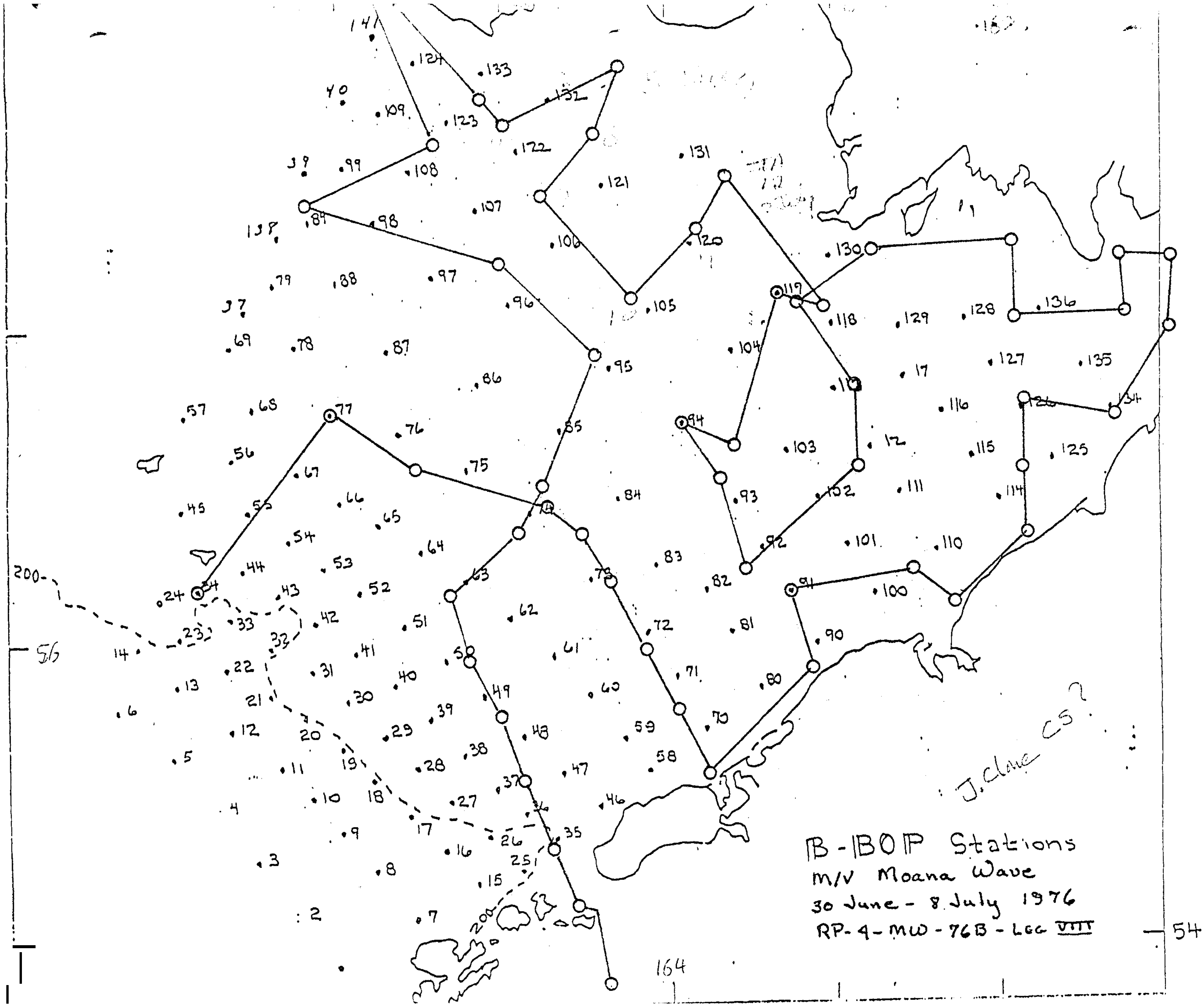
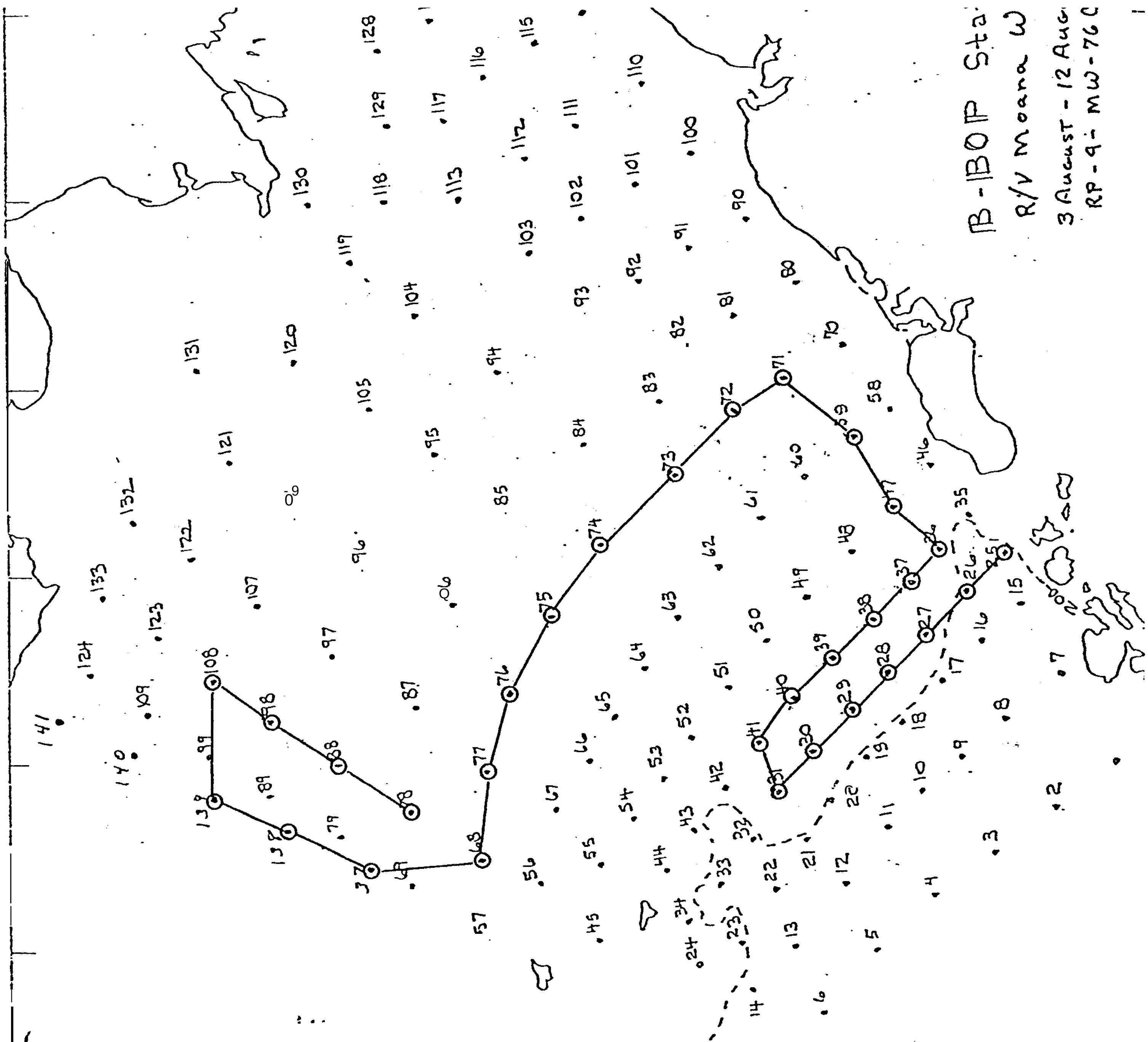
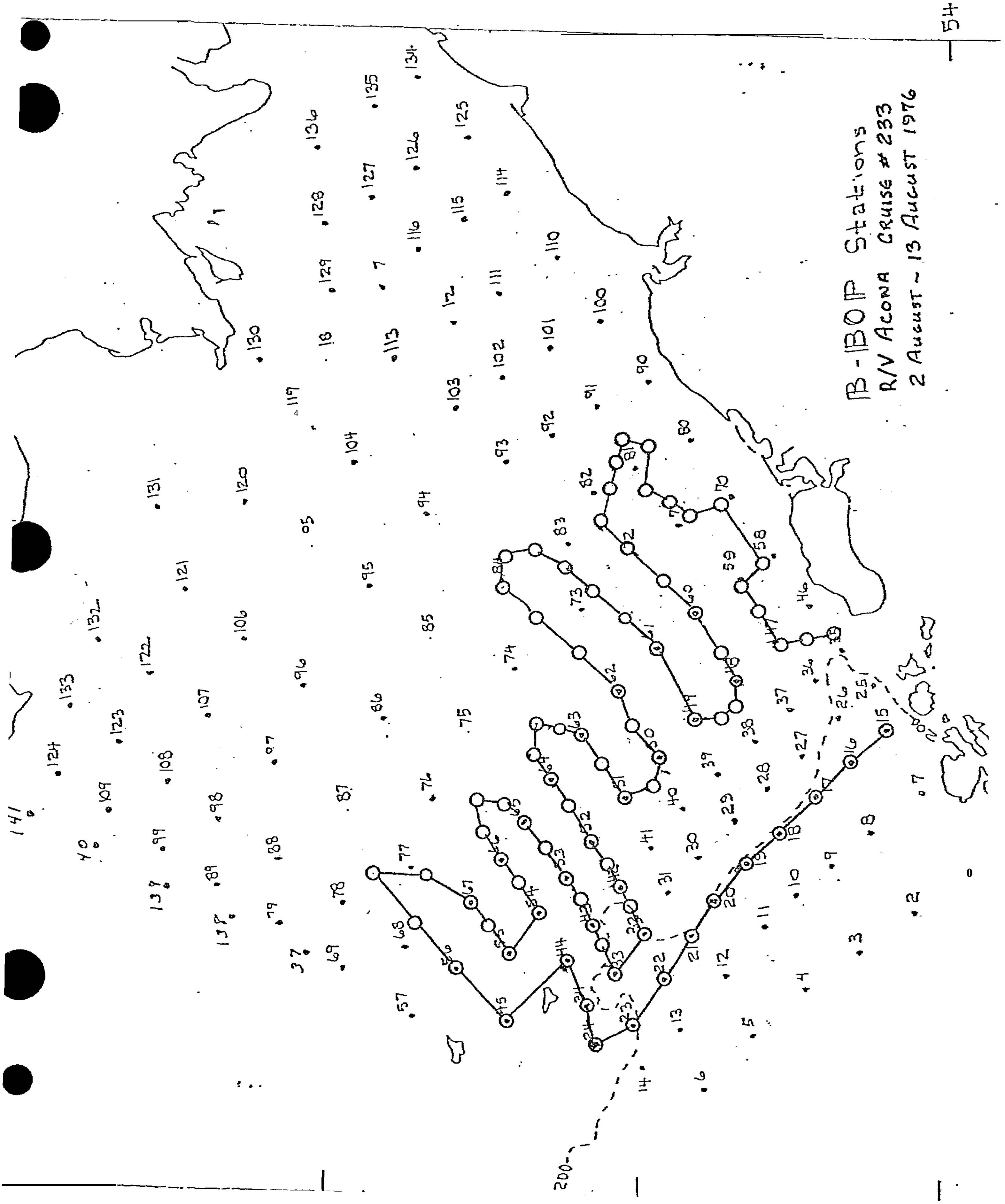
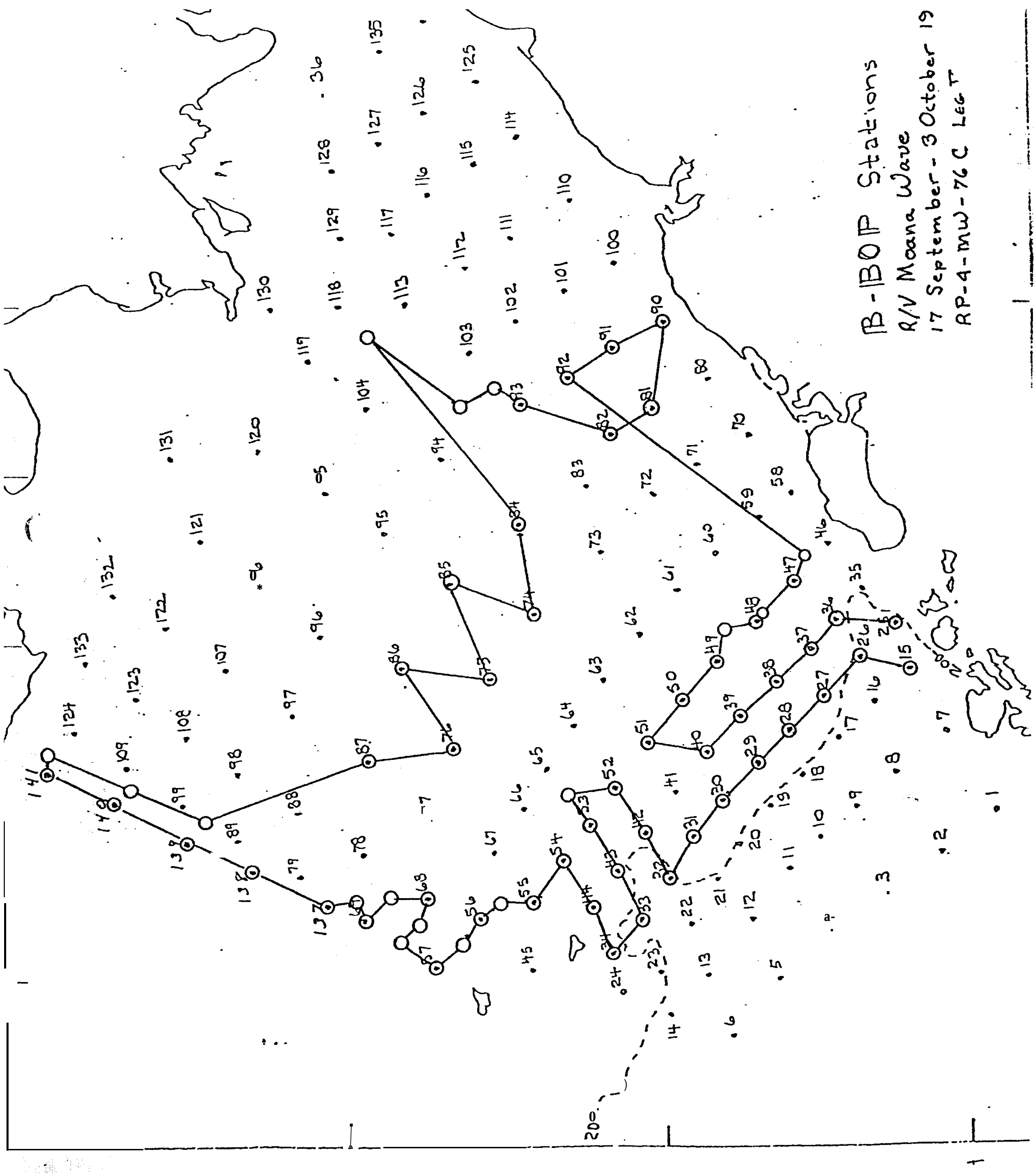
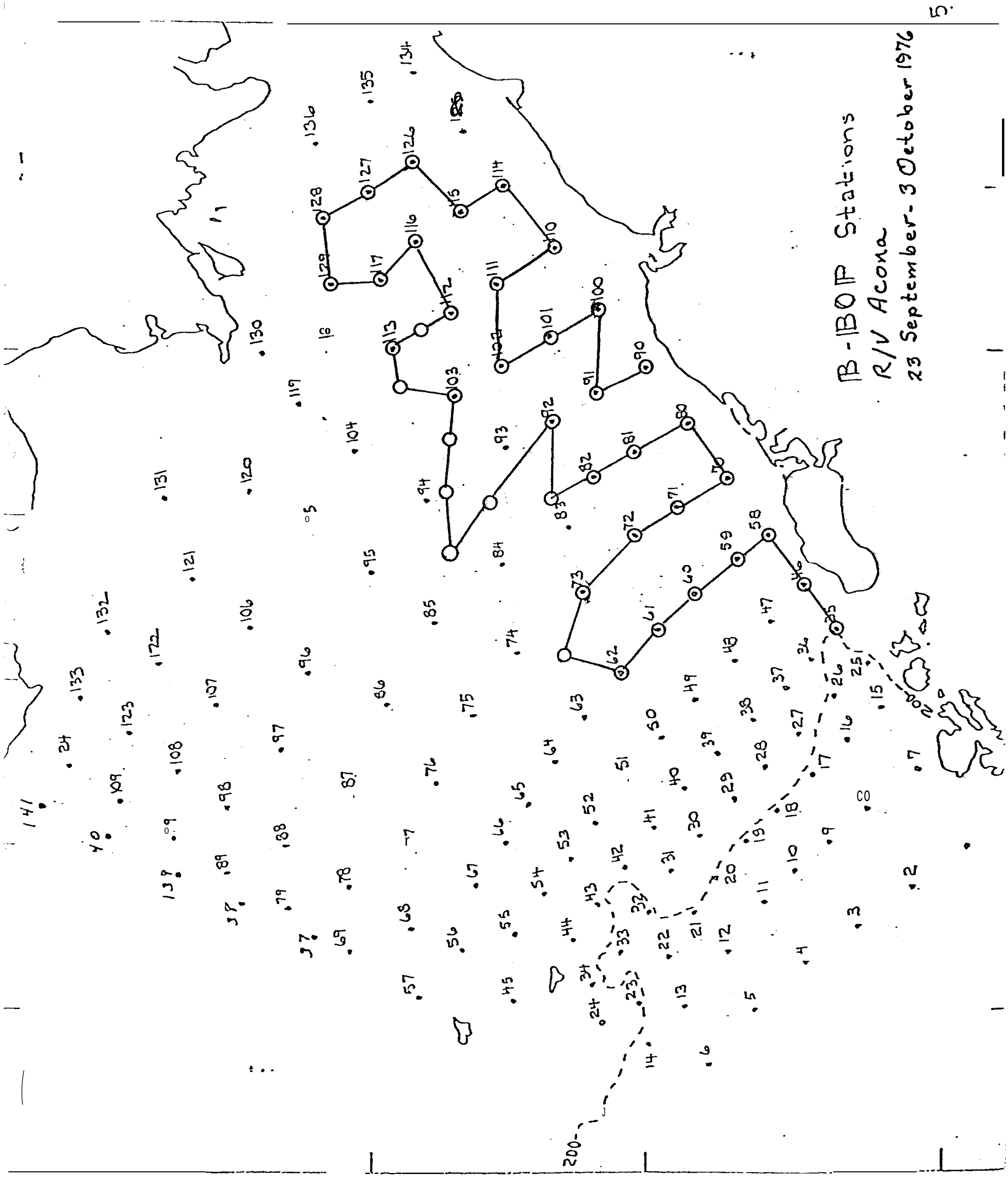

B-BOP Stations
M/V Moana Wave
30 June - 8 July 1976
RP-4-MW-76B - Leg VIII
J. Clue CS?


B-BOP Sta
R/V Moana W
3 August - 12 Aug
RP-9-MW-76
200


B-BOP Stations
R/V Acona Cruise # 233
2 August - 13 August 1976
54
200


B-BOP Stations
R/V Moana Wave
17 September - 3 October 19
RP-4-MW-76 C LEG


5.
B-BOP Stations
R/V Acona
23 September - 3 October 1976

APPENDIX 2

B-BOP INSTRUMENT SUMMARY

Date	Location	Instruments	Days[2]	Remarks
7 Sept.- 4 Nov. 75	BC-4A 58-37.0 168-14.0 55 m	2 RCM-4 1 TG-2	58	
6-21 Sept. 75	BC-1A 55-24.6 167-57.5 201 m	2 RCM-4 1 TG-2	3, 16	Trawl ed
8 Sept.- 5 Nov. 76	BC-2A 57-04.3 163-19.5 65 m	2 RCM-4 1 TG-2	58	
4 Nov. 75	BC-1B 55-24.0 167-58.0 205 m	2 RCM-4 1 TG-2	0	Trawl ed
4 Nov. 75- 14 June 76	BC-4B 58-37.0 168-14.1 55 m	2 RCM-4 1 TG-2	228	Partial recovery
5 Nov. 75- 30 May 76	BC-2B 57-03.7 168-21.8 65 m	2 RCM-4 1 TG-2	2-07	
6 Nov. 75- 16 Mar. 76	BC-3A 55-01.5 165-10.3 115 m	2 RCM-4	130	
16 Mar.- 29 May 76	BC-3B 55-01.3 165-04.8 116 m	2 RCM-4 1 TG-2	8, 73	
19 Mar.- 12 June 76	BC-12A 55-48,2 163-54.1 97 m	2 RCM-4	15, 85	

[1]RCM-4: Aanderaa recording current meter, model 4.
TG-2,3: Aanderaa pressure gages, models 2 and 3.

[2]Number of days of usable data.

Date	Location	Instrumental	Days[2]	Remarks
20 Mar.- 30 May 76	BC-7A 55-42.3 163-01.3 67 m	2 RCM-4 TG- 2	71 (TG-2)	
22 Mar.- 6 June 76	BC-13A 55-30.2 166-01.7 122 m	2 RCM-4 1 TG-2		
31 May- 26 Sept. 76	BC-2C 57-03.7 163-21.3 119 m	2 RCM-4 1 TG-2	23, 118	
29 May- 28 Sept. 76	BC-3C 55-01.8 165-09.8 114 m	2 RCM-4	122	
30 May- 27 Sept. 76	BC-6A 56-32.1 162-35.3 76 m	2 RCM-4	125	
6 June- 29 Sept. 76	BC-13B 55-30.1 165-49.4 122 m	2 RCM-4 1 TG-2	35	Trawled
30 May- 27 Sept. 76	BC-14A 56-02.3 161-50.0 51 m	2 RCM-4 1 TG-3	124	TG-3 not recovered
31 May- 26 Sept. 76	BC-15A 57-36.4 162-45.2 51 m	2 RCM-4 TG-2	118	one RCM-4 lost
1 June- 23 Sept. 76	BC-10A 57-16.6 169-32.8 66 m	1 RCM-4 1 TG-3	- 60	
1 June- 24 Sept. 76	BC-8A 57-58.5 168-49.5 73 m	2 RCM-4	--60	

[1] RCM-4 : Aanderaa recording current meter, model 4.
TG-2,3: Aanderaa pressure-gages, models 2 and 3.
[2] Number of days of usable data.

Date	Location	Instruments[1]	Days[2]	Remarks
30 May- 27 Sept. 76	BC-5A 56-49.2 163-06.6 70 m	2 RCM-4	119	
1 June- 25 Sept. 76	BC-4C 58-35.8 168-20.7 58 m	2 RCM-4 1 TG-3	- 60 Faded	
2 June- 24 Sept. 76	BC-9A 59-14.0 167-36.1 39 m	2 RCM-4	~ 60	
2 June- 24 Sept. 76	BC-11A 167-13.6 31 m	1 TG-3	~ 90	
27 Sept. 76	BC-2D 57-02.3 163-25.7 66 m	2 RCM-4 1 TG-2		
29 Sept. 76	BC-13C 55-47.2 165-13.8 108 m	2 RCM-4 1 TG-2		
26 Sept. 76	BC-15B 57-37.7 162-44.9 46 m	2 RCM-4 1 TG-2		
21 Sept. 76	BC-17A 56-34.0 167-33.0 108 m	2 RCM-4		
25 Sept. 76	BC-4D 58-36.6 168-21.7 55 m	2 RCM-4 1 TG-3		
24 Sept. 76	BC-9B 59-13.0 167-42.0 40 m	2 RCM-4 1 TG-3		

[1]RCM-4: Aanderaa recording current meter, model 4.
TG-2,3: Aanderaa pressure gages, models 2 and 3.

[2]Number of days of usable data.

APPENDIX 3

Estimate of Funds Expended by University of Washington to 28 February 1977

Total Allocation (5/16/75-9/30/77):			$330,400
A.	Salaries – faculty, staff & students	56,030	
B.	Benefits	6,112	
C.	Expendable Supplies & Equipment	18,210	
D.	Permanent Equipment	67,020	
E.	Travel	13,157	
F.	Computer	107	
	Consultation	4,000	
G.	Other Direct Costs	26,633	
H.	Indirect Costs	24,541	
Total Expenditures			215,810
Remaining Balance			$114,590