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OBSERVATIONS OF CURRENTS AND WATER PROPERTIES IN COMMENCEMENT BAY

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ABSTRACT

Observations of currents and water properties have been made in Commencement Bay, Washington, to provide background information which would be useful in describing physical transport processes in the Bay, and hence, the fate and effect of any dissolved and suspended contaminants. Observations were made during low river runoff commencing in September 1980 and during a higher runoff period commencing in March 1981 using moored subsurface current meter arrays and CTD surveys. Each survey entailed shipboard water property measurements for about three days during deployment of the current meter arrays. The arrays provided additional water property and current measurements continuously for approximately sixty days. This data report includes a description of the experiments and representative data presentations. It is intended to provide relatively quick dissemination of the observations for those with special needs. Additional analyses and interpretations will be made at a later time. A complementary study of suspended particulate matter will be described in a separate report. Both were sponsored primarily by NOAA's MESA Puget Sound Project.

1. INTRODUCTION

Commencement Bay is one of the major deep-water commercial seaports in Puget Sound (Figure 1). It is located at Tacoma, Washington, between Point Defiance and Brown's Point at the southern end of the Main Basin of Puget Sound about 25 km south of Seattle. The embayment is bounded on the northwest by Dalco Passage which connects to The Narrows and then to the southern basin of Puget Sound. It connects with East Passage and the major shipping lanes to the northeast around Brown's Point. There are eight commercial waterways along the southeastern shore, two of which are on natural features, Hylebos Creek and the Puyallup River, which are the sources of freshwater. The bay measures approximately 7.5 km along the southwest shore to Point Defiance, by 4.3 km across the inner bay, by 4.7 km along its northerly shore. Depths of the bay proper range from 42 m to 185 m with free connection with the deepest water in the main basin. Tidal currents in Commencement Bay are characterized in the yearly published Tidal Current Tables as "too weak and variable to be predicted," and studies in the Puget Sound hydraulic model at the University of Washington have shown no discernible surface movements throughout the tidal cycle (McGary and Lincoln, 1977). The mean tide in the bay is about 2.1 m, which is the same as most of the Main Basin of Puget Sound.

Commencement Bay has been a focus of recent investigations sponsored by NOAA's Marine Ecosystem Analysis (MESA) Puget Sound Project Office to provide environmental information regarding various Puget Sound embayments. Other previous work has focussed on Elliott Bay (Sillcox et al., 1981; and Baker and Cannon, 1982). Because human activities have also introduced contaminants into Commencement Bay and because there existed little information concerning circulation to use in determining the fate of these contaminants, MESA initiated a multidisciplinary transport process study in 1980. The purpose of the study was to obtain background information that would be useful in describing the fate and effects of critical contaminants introduced into the bay. This report describes the current meter and hydrographic (CTD) observations that were made, and it presents representative results in various graphical forms to give the broadest possible view of the range of existing conditions that may be of use in determining transport of dissolved and suspended matter in the bay. Further analysis of these data will be incorporated into a MESA-sponsored synthesis with the suspended particulate observations and with available historic data. They are presented here with minimal interpretation to make them readily available to others, particularly to environmental managers who may have to make assessments concerning pollutants in the bay.

Previous physical oceanography field observations in Commencement Bay have been very limited. However, Winter (1977) carried out an hydraulic model dye study that showed circulation patterns concerning two dredge disposal sites within the bay. The sites, located in about 110 m off the Puyallup (near station TS in Figure 2) and in 165 m southwest of Brown's Point (about midway across the mouth of the bay), showed larger tidal excursions and mixing than were observed in Elliott Bay. Dye at the outer site was frequently removed from the bay in one tidal excursion. Also, during the early part of large ebbs, turbulence from The Narrows was diverted around Point Defiance and appeared to be carried into Commencement Bay resulting in strong mixing throughout the water column. As the ebb progressed, this process decreased, and water from The Narrows presumably was directed more through Colvos

Passage. At the inner site during spring tides, excursions of about one mile were observed. However, on neap tides, water appeared to remain at the site with much less movement. Water appeared not to leave the bay until the tides became more nearly equal. One purpose of the field studies was to provide information that could be used in assessing the degree of agreement between the hydraulic model and the real environment.

Oceanographic observations were made in Commencement Bay during low runoff in September-November 1980 and during higher runoff in March-June 1981. The observations included subsurface current meter arrays, conductivity-temperature-depth (CTD) transects, and shipboard time-series stations. In addition, simultaneous samplings for suspended particulate matter and water chemistry studies were made. Observations were also made in the contiguous water systems of The Narrows and East Passage to assess influence on flow in Commencement Bay. The circulation in the Main Basin of Puget Sound, which interacts with waters from oceanic origin, forms the outer boundary of Commencement Bay. Representative current meter and CTD data are presented.

2. OBSERVATIONAL PROGRAM

2.1 September-November 1980

Current Meter Moorings. Two current meter moorings, CB-3 and CB-4, were deployed in Commencement Bay (Figure 1). These were taut-wire, subsurface arrays with EG&G (AMF) acoustic releases attached to railroad-wheel anchors. ORE 28-inch floats were the primary flotation. They were attached at the top of the mooring just above the shallowest current meter, and one was just above the bottom meter near the release. Secondary flotation of vinyl floats were intermittantly spaced along the line usually near an instrument for ease in hand deployment/recovery. Three Aandaara RCM-4 current meters were used on each mooring. Each had temperature and conductivity sensors, and the bottom meter of each mooring also had a transmissometer recording on the Aanderaa pressure channel. In addition to the current meters and transmissometers, each mooring had a sediment trap located between the middle (~75 m) and bottom (~175 m) current meters. These traps are multi-sampling, multi-filtered devices with adjustable time rate, used to collect sized sediment particles at specified depths. They are used in conjunction with the transmissometers for suspended particulate studies and will be reported elsewhere.

Mooring CB-2 in The Narrows had four Aanderaa RCM-4 current meters on a taut-wire array. The shallowest meter was at 15 m and the deepest at 65 m. Because of expected high current speeds (~200 cm/sec), the primary flotation for this array was a torpedo shaped, fiber-glass hull containing three 28-inch ORE subsurface floats. CB-2 had the most mechanical difficulties, including entanglement with fishing nets and lines and being dragged by boats, which resulted in broken current meter vanes, bent spindle rods, rotor malfunction, etc.

Mooring CB-5 was deployed in the traffic separation zone of East Passage approximately 100 meters northeast of traffic buoy "TC." Five Aanderaa current meters were on the array from 15 m below the surface to 170 m, approximately 5 m off the bottom. An Aanderaa TG-3A pressure gauge was attached to the acoustic release 1 m above the anchor. (See array listing for meter depths.)

A wind station (including wind speed, direction, and temperature sensors) was installed on traffic buoy "TC" in an attempt to obtain local surface wind data to correlate with the current meter data. This effort, however, was unsuccessful due to equipment failure, sensor theft, and removal of the buoy for servicing without notice by the Coast Guard. Some local weather data are available from the Point Robinson light station through the National Weather Service.

All current meters had 15-minute sampling intervals, but due to the anticipated range of current speeds at the deployment sites, rotor revolution/speed counts had to be varied. The moorings were deployed and recovered using the University of Washington R.V. ONAR.

CTD Surveys. Eleven CTD stations were occupied within Commencement Bay during mooring recovery in November 1980 (Figure 2). The grid included the deployment sites of the two current meter arrays, CB-3 and CB-4. A Plessey model 9400 CTD system with a model 8400 data logger was used to sample temperature, conductivity, depth, and transmissivity twice a second. Traces for transmissivity were taken both on down- and up-casts, and a lowering (and raising) rate of 30 m per minute was used. Calibration samples for salinity and temperature were taken every other cast. Corrections from these calibrations were applied to the CTD data when reduced to 1-m averages from which sigma-t and dynamic heights were computed.

2.2 March-June 1981

Current Meter Moorings. Five subsurface current meter and transmissometer moorings were deployed on 23-24 March 1981 by the NOAA ship McARTHUR in Commencement Bay and nearby Puget Sound to attempt to investigate the effects of higher river discharge on the circulation. River runoff in this area is dominated more by rainfall than by snowmelt. Three of the arrays (CB-5, CB-4, and CB-3) were located where they had been in fall 1980. The remaining two were located in Dalco Passage (CB-6) and Colvos Passage (CB-7).

The moorings were all taut wire with subsurface floats as described for the 1980 moorings. However, at CB-5, in the East Passage, a SPAR buoy was utilized to measure surface currents and water properties. This buoy had damping plates to minimize vertical motion and was moored to the subsurface buoy. Moorings CB-5, CB-4, and CB-3 had several sediment traps in addition to the current meters and transmissometers. The current meter was at a depth of approximately 3 m between the damping plates.

The moorings were recovered after about two months, during the week of 2 June 1981, using the University of Washington research vessel HOH. Mooring CB-3 was not recovered due to unknown causes, but since it was in an area of high shipping traffic within Commencement Bay, it is possible that it was damaged by tug and tow or by other ship traffic. Subsequent efforts have been successful in recovering all but the bottom part of this mooring. The upper-most current meters on the recovered moorings and the SPAR buoy were heavily fouled with red algae. In addition, weather observations were made on Point Robinson on Maury Island. Earlier work had shown this location to be representative of the southern Main Basin.

CTD Surveys. Conductivity, temperature, depth, and transmissivity observations were made following the current meter mooring deployments. The station grid within Commencement Bay was identical to the fall survey. One 25-hour time-series station was made at the mouth of the Puyallup River at the same location as in the fall, and 8-hour time series stations covering the flood phases of tidal cycles were made at three other locations. A total of 22 stations were made in the Commencement Bay-Narrows-Colvos Passage area, and 106 stations were made in the area from The Narrows to Admiralty Inlet off Whidbey Island.

3. DATA REDUCTION

Current meter and CTD data are converted to scientific units and edited using techniques developed at PMEL (Krancus et al., 1979). The resulting currents are resolved into north and east components, and individual data points exceeding the mean by three standard deviations have been replaced by the mean of neighboring points. CTD data are averaged at 1-m intervals. The data are then entered into a data storage system utilizing disk and tapes. These data can then be accessed by a set of FORTRAN programs, linked by procedure file, for rapid retrieval and data display (called R_2D_2; Pearson, 1981). Data are stored as random access disk files for rapid access and sorting. Programs are interactive and have graphics capability. A wide range of display and analysis outputs are available, including time series plots, data listing, statistics, spectral and tide analysis, empirical orthogonal function analysis, and maps of properties.

4. OBSERVATIONS

Sample presentations at the end of the report have been selected to give the reader an feeling for the overall magnitude and variations of currents and water properties in Commencement Bay and in the nearby Main Basin of Puget Sound. A summary of the data recovered from the current meter moorings is given in Table 1.

4.1 Water properties

Shipboard CTD observations are shown in three presentations. Charts of the near-surface (3 m) distributions of salinity and temperature are shown for the two seasons in Figures 3 and 4. Figures 5-7 show vertical sections of salinity in the upper 40 m across the inner bay near the commercial waterfront and across the middle bay at the current meter moorings. Time series profiles of salinity and temperature just off the mouth of the Puyallup River are shown in Figures 18 and 19.

4.2 Currents

The current meter data are presented in several different summaries to emphasize various aspects of the flow. First, there are the actual current meter observations (Figures 12-17) presented as time series which have been 2.8-hour filtered to remove only the highest frequency oscillations and still retain the tidal signal. These time series include pressure, from which the depth of the meter can be determined more accurately; currents in the east-west (+ is east) and north-south (+ is north) directions; and observed current speed regardless of direction, temperature, and salinity. Pressure is omitted

Table 1. Current meter mooring and record statistcs summary

Station	Location	Depth (m)	Interval	Length (days)	Mean Speed (cm/s)	Variance $(cm/s)^2$	Net Flow Speed (cm/s)	Net Flow Dir. (°T)
1. 1980								
CB-2	47.31N 122.56W	65	9/10-11/13	64	61.4	1633	34.6	155
CB-3	47.28N	24	9/9-11/12	64	4.7	16	1.7	126
	122.46W	74		64	3.9	11	1.0	128
CB-4	47.29N	25	9/9-11/12	64	4.9	10	0.8	231
	122.44W	75		64	3.8	8	0.8	332
		125		64	5.3	20	5.2	126
CB-5	47.33N	15	9/9-11/12	64	13.9	88	11.7	1
2. 1981								
CB-4	47.29N	27	3/24-6/3	71	5.2	34	0.5	349
	122.44W	127		71	8.8	106	0.7	95
CB-5	47.33N	4(SPAR	3/24-6/3	71	33.8	1679	6.9	211
	125.45W	125 buoy)		29	13.9	215	10.9	222
		170		71	13.8	169	9.0	40
CB-6	47.33N	15	3/24-6/2	70	39.6	2058	7.4	184
	122.52W	90		26	31.0	1227	7.2	136
CB-7	47.44N	15	3/24-6/3	38	29.8	404	29.8	11
	122.52W	92		71	27.5	670	22.7	356

when transmissivity (not presented here) is recorded. The temperature and salinity sensors have been calibrated from the shipboard CTD data. Nearest surface and near bottom (except mooring 5) time series are given for moorings CB-3, 4, 5, and 2 in 1980 and for CB-4 and 5 in 1981. The deeper time series at CB-5 is at the same depth as the deeper observations within Commencement Bay.

Charts of the maximum tidal currents in Commencement Bay at various depths are presented in Figure 8. The vectors were constructed from an hourly average of the currents at all meters near maximum flood and ebb in the Main Basin. The approximate stage of the tide is shown in an inset. The currents at mooring 5 in East Passage show the flow along the Main Basin at three depths and the flow within Commencement Bay can be referenced to these. Also, these charts can be compared to the figures in McGary and Lincoln (1977) which showed weak flow in Commencement Bay using the Puget Sound model.

In order to visualize the longer term average flow and its variations, the tidal signal was removed from the records using a 35-hour filter. The filtered data are shown as vector stick plots at 6-hour intervals (Figure 9) for the 1980 time series shown in Figures 12-15. The scales are the same for all records to make intercomparisons visually easier. Note specifically the relatively weaker flow in Commencement Bay compared to either East Passage or The Narrows.

Progressive vector diagrams were constructed by vector addition of the low-pass-filtered currents (Figures 10 and 11). The diagrams do not represent real particle trajectors, but they do give an indication of the longer period fluctuations at a single point and the direction and magnitude of the average flow. Because of the varying magnitudes as shown in Figure 9, various horizontal scales are used here. Figure 10 compares the shallowest and deepest observations at CB-3 and 4 in Commencement Bay in 1980. Figure 11 compares observations within Commencement Bay to those in East Passage.

5. DISCUSSION

A detailed analysis and interpretation is beyond the scope of this report. However, the following major observations are noted from the figures:

1) Tidal flow in Commencement Bay is relatively weak compared to that the Main Basin (Figures 8, 12-17). However, maximum currents at some locations are larger than are predicted in the Tide Prints book (McGary and Lincoln, 1977). Near-surface currents were relatively large at CB-4 (north side) during maximum ebb (~40 cm/sec), and both near-surface and near-bottom currents were relatively large at CB-3 (south side) during maximum flood (~20 cm/sec). Thus, it is possible that the near-bottom currents might be large enough to resuspend bottom sediments.

2) Water property distributions give the impression that the dominant flow in the bay is along the shores (Figures 3 and 4). Highest salinities and warmest waters were observed in the middle of the bay. In the November 1980 data, the lowest salinities were observed on the north side, indicating that the Puyallup River plume leaves the bay along the northern shore.

3) Tidal currents also support near-surface outflow along the north side during ebb currents in the Main Basin (Figure 8). Near-surface inflow is indicated on the south side during flood currents and is accompanied by deeper outflow at that same location.

4) Tidally averaged currents indicate a net southward flow in the Main Basin at depths deeper than 15 m, as well as southward flow near bottom in The Narrows (Figure 9). This is consistent with earlier observations in this area.

5) The largest tidally averaged flow is directed into Commencement Bay near bottom at CB-4 and shows little variability (Figure 9). Near-surface flow at CB-4 and flow at both depths at CB-3 show more variability, particularly in direction. Progressive vector diagrams, however, indicate a net inflow at both depths at CB-3 and at near-bottom at CB-4 (Figure 10). Net outflow is indicated only at near-surface at CB-4. The latter is most likely the effect of the Puyallup effluent.

6) If the Puyallup discharge leaves Commencement Bay along the north shore, then it most likely continues northward in East Passage. This is consistent with historic CTD observations of the plume in East Passage, but inconsistent with implications from current meters. The latter have been used to infer mostly southward flow in East Passage. However, recent re-examination of historic data seem to indicate that there may be a thin (1-10 m) northward-flowing surface layer in East Passage.

7) Water properties indicate that Commencement Bay is uniform both horizontally and vertically from about 25-40 m to the bottom (Figures 5-7). The only gradients are in the upper 10 m. The freshest water on the inner section appears just off the mouth of the Puyallup or slightly north during higher runoff (Figures 6 and 7). The freshest water at the middle section is on the north side, also indicating that the plume exists there.

8) It is not possible to calculate residence or flushing times for Commencement Bay from these data. Also, net outward flow is only indicated at CB-4 at 25 m. The current speeds there, however, indicate an outward flux of about 0.8 km/day. Thus, only a couple of days would be required for Puyallup water to transit the Bay. Larger inflows, however, are observed at the bottom of CB-4. The drift there is about 4 km/day. Thus, the deep water could transit the Bay in about a day.

Further analysis and synthesis with observations on suspended particulate matter will be presented in a later paper.

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7. FIGURES

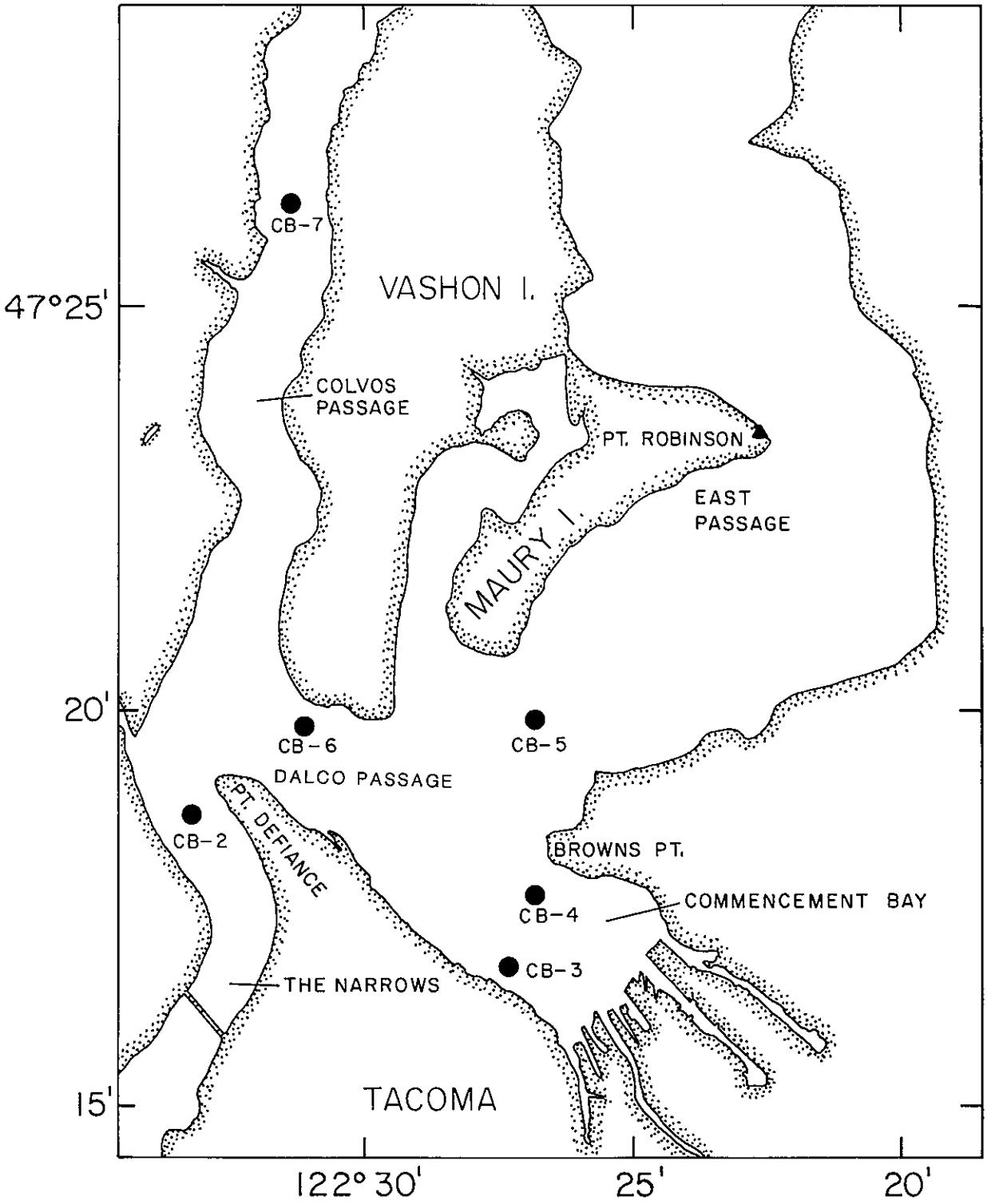

Figure 1. Southern part of the Main Basin of Puget Sound showing Commencement Bay and all current meter mooring locations.

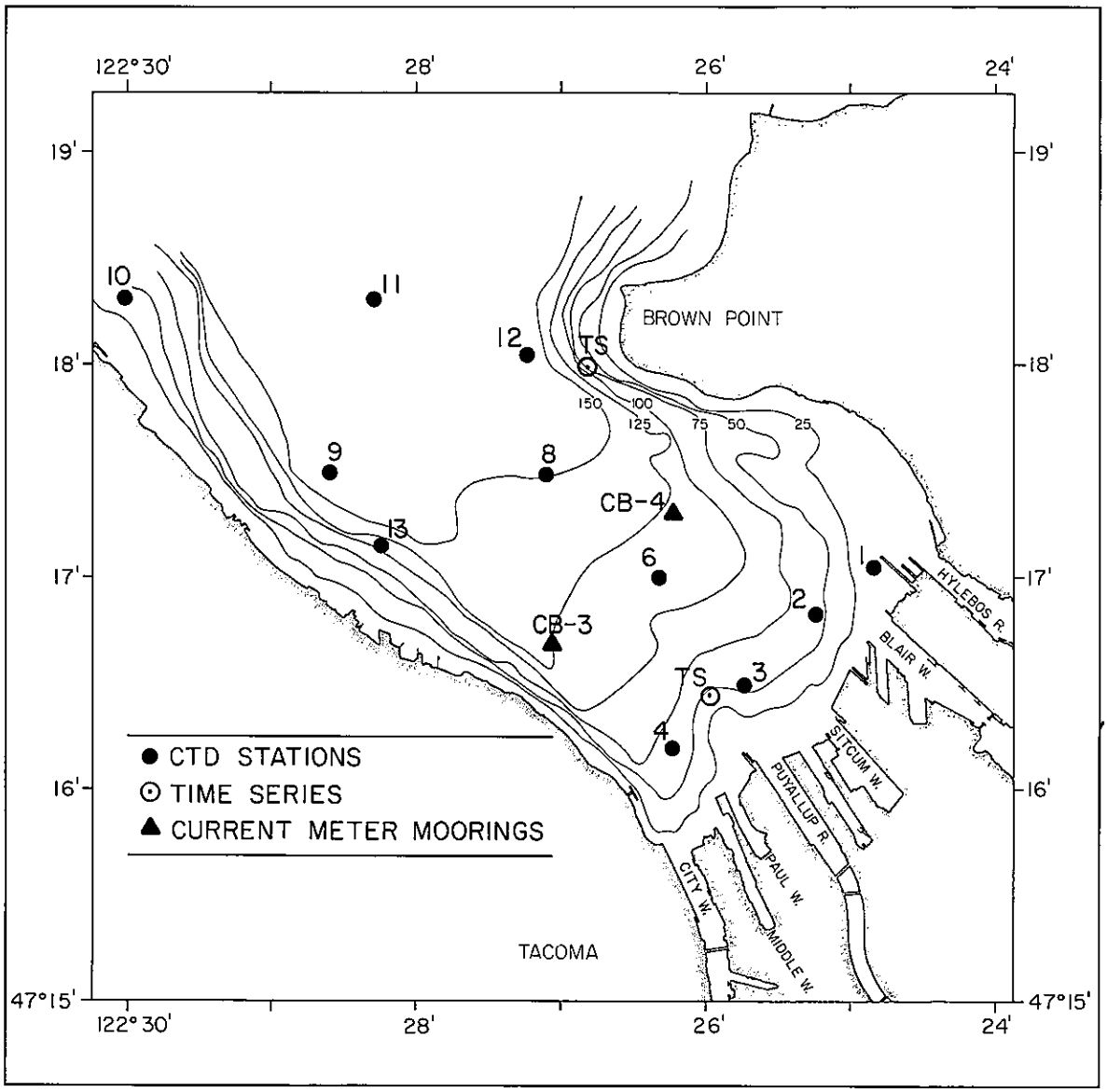

Figure 2. Bathymetry of Commencement Bay showing moorings and CTD stations.

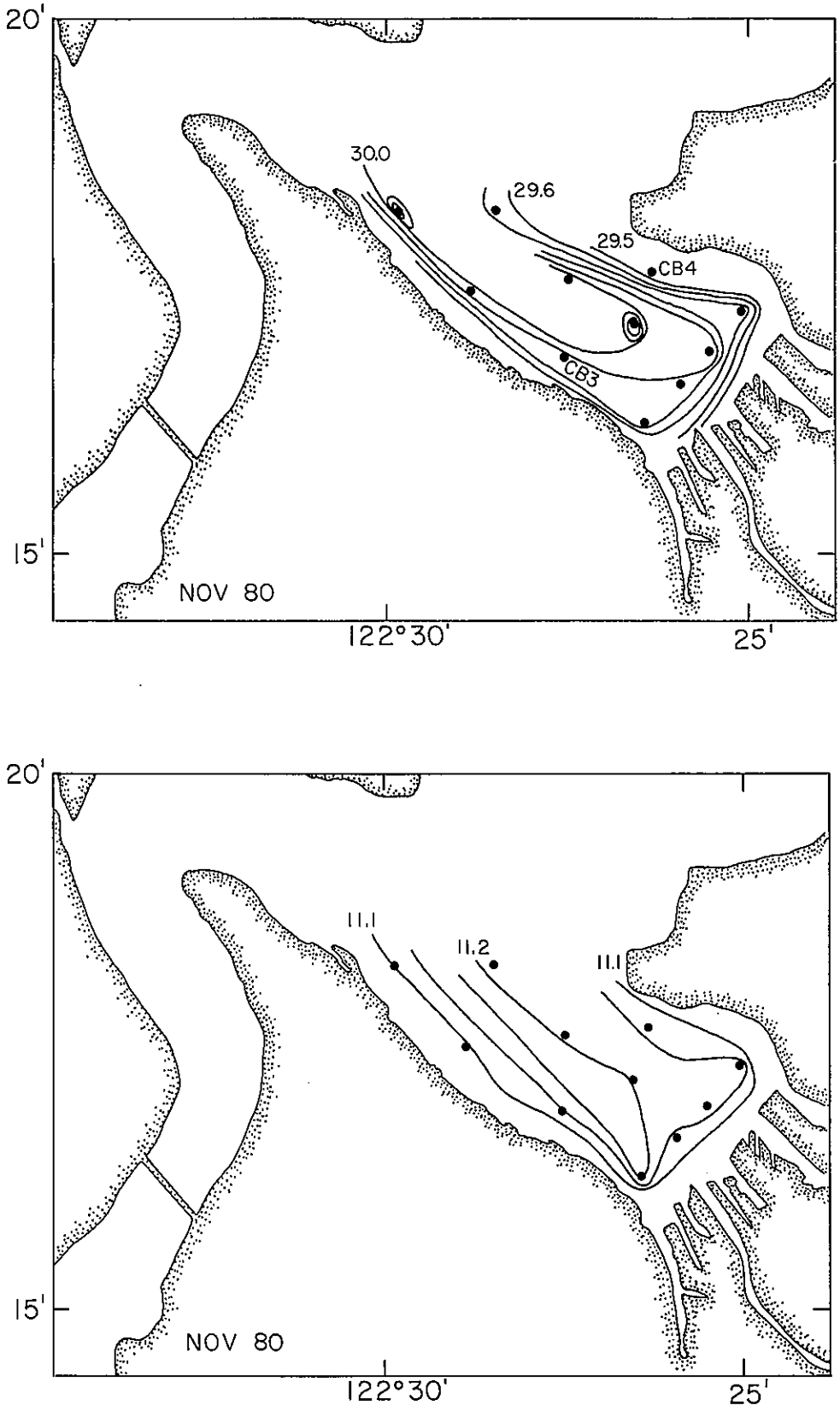

Figure 3. Distributions of near-surface (3 m) salinity (top, °/oo) and temperature (bottom, °C) in Commencement Bay, November 1980.

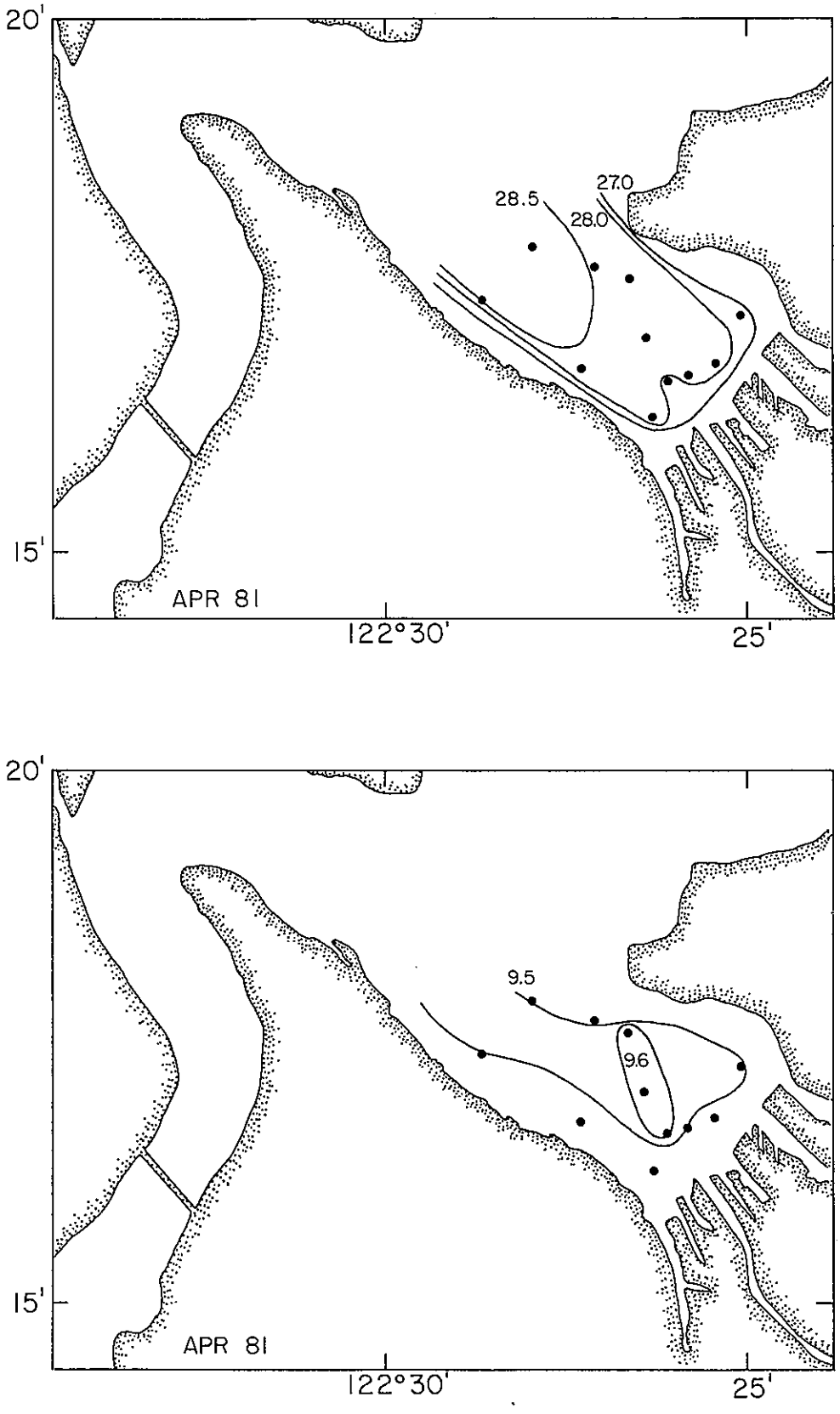

Figure 4. Distributions of near-surface (3 m) salinity (top, °/oo) and temperature (bottom, °C) in Commencement Bay, April 1981.

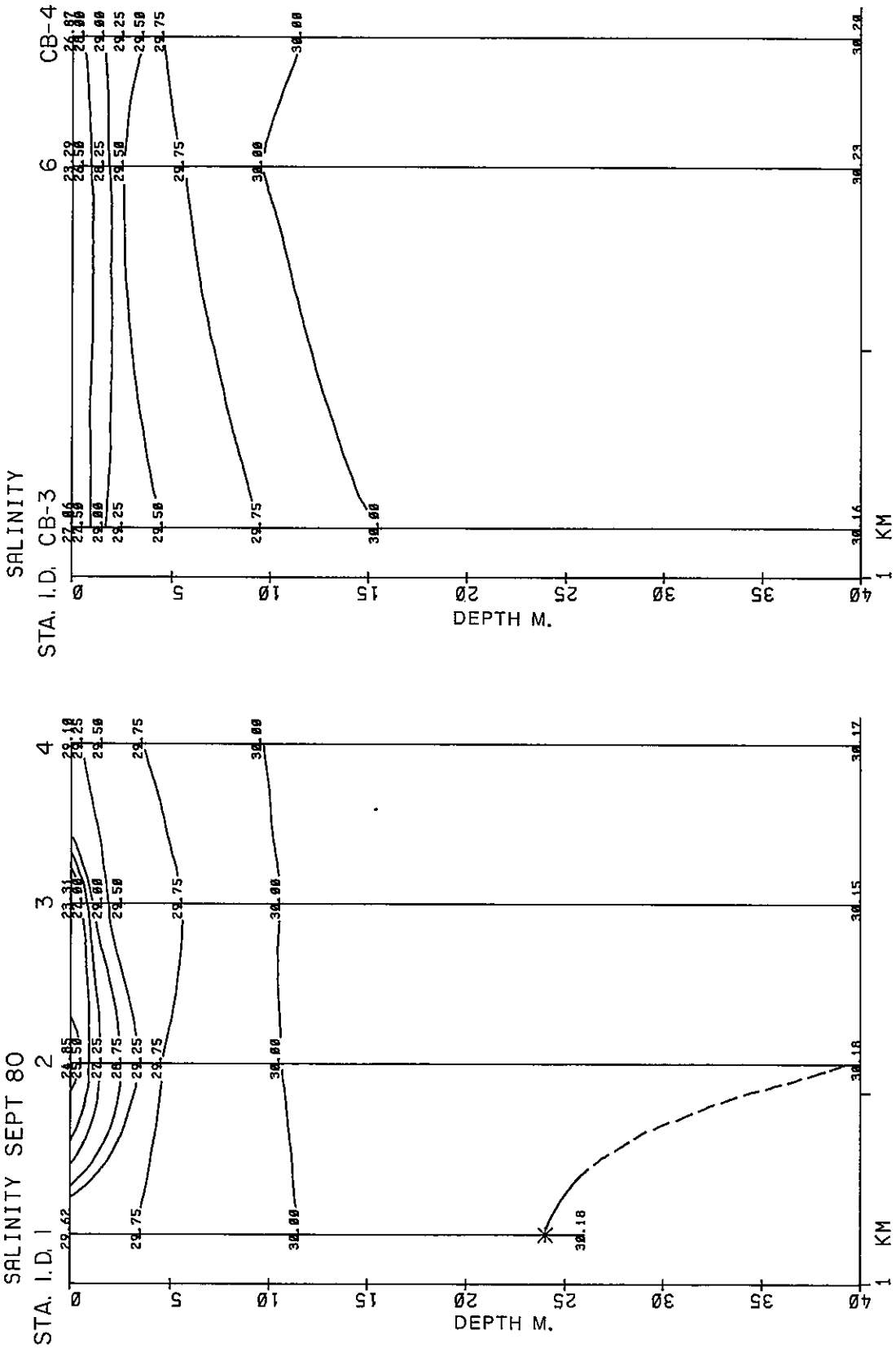

Figure 5. Salinity ($^{o}/oo$) sections across inner (left) and outer (right) Commencement Bay, September 1980.

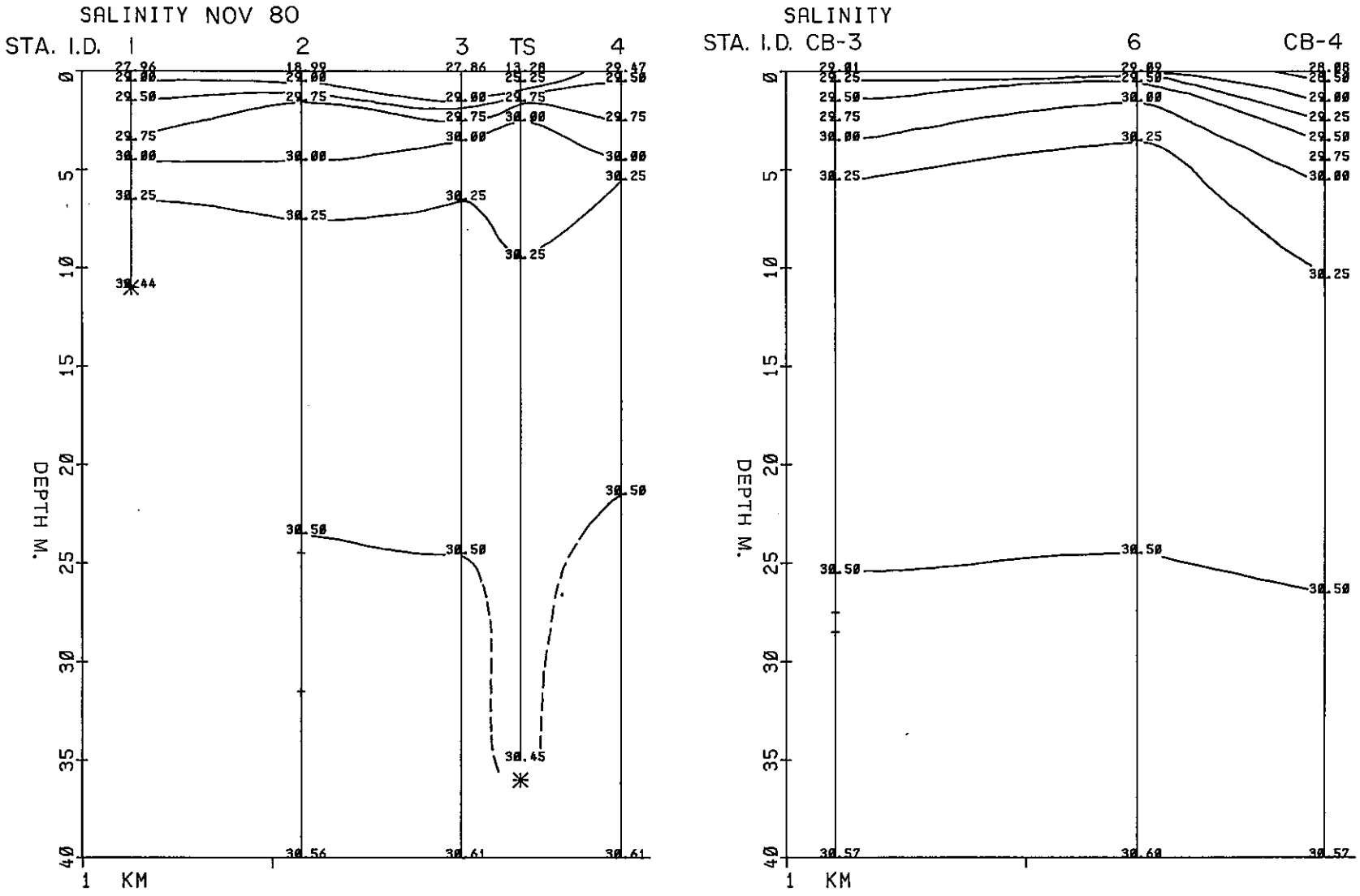

Figure 6. Salinity ($^{0}/oo$) sections across inner (left) and outer (right) Commencement Bay, November 1980.

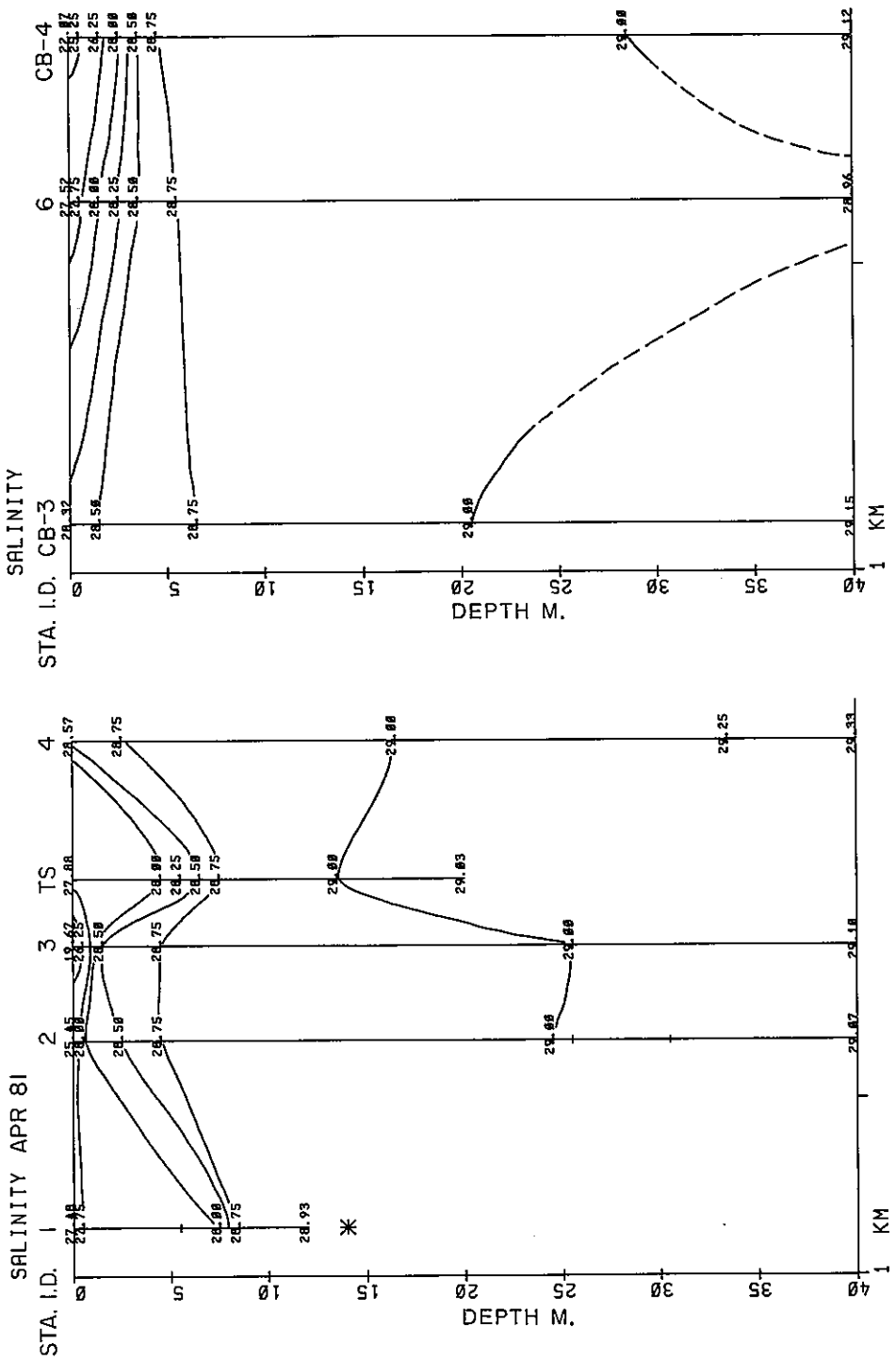

Figure 7. Salinity (^{o}/oo) sections across inner (left) and outer (right) Commencement Bay, April 1981.

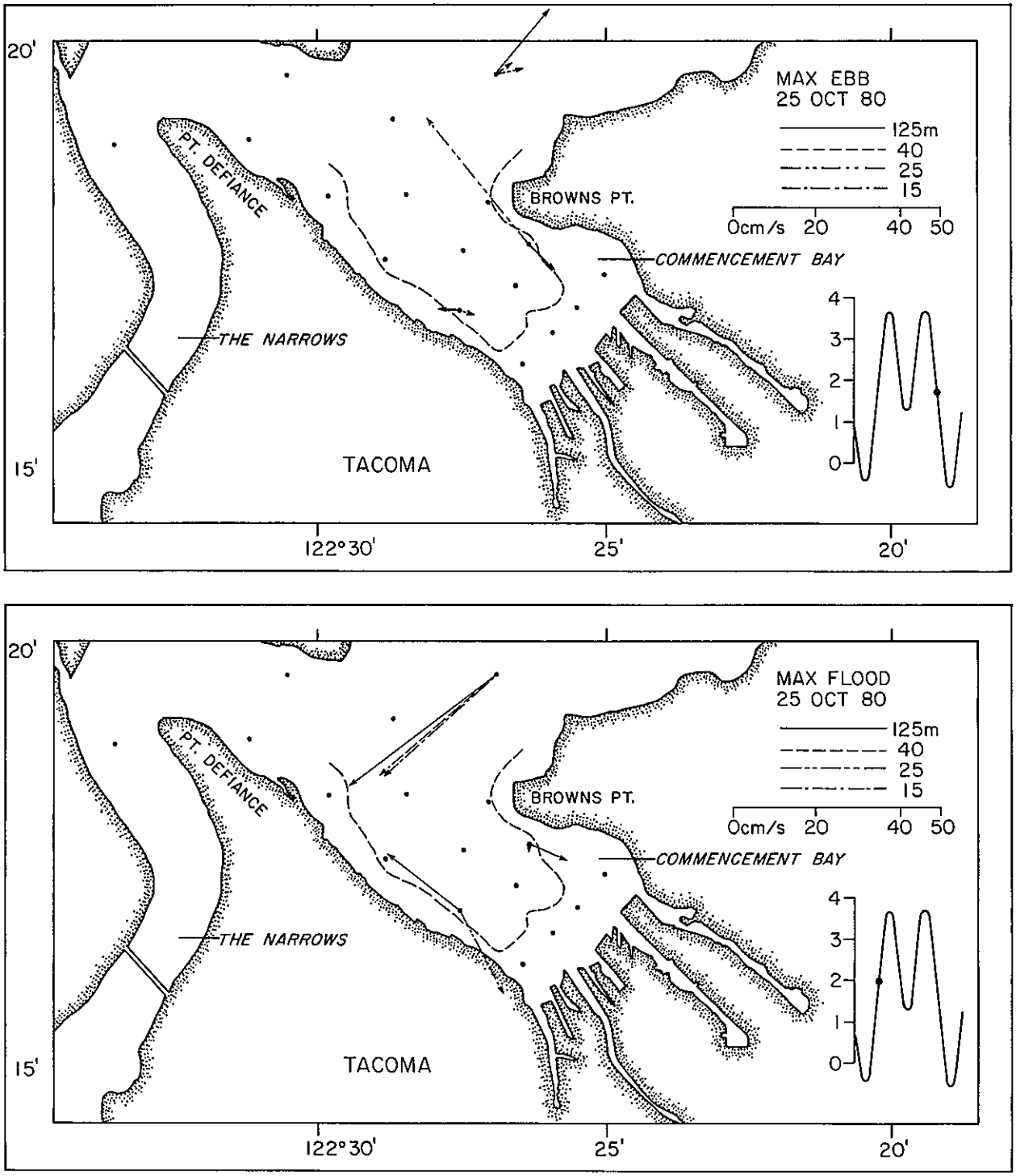

Figure 8. Tidal current chart at selected depths for representative maximum ebb (top) and flood (bottom).

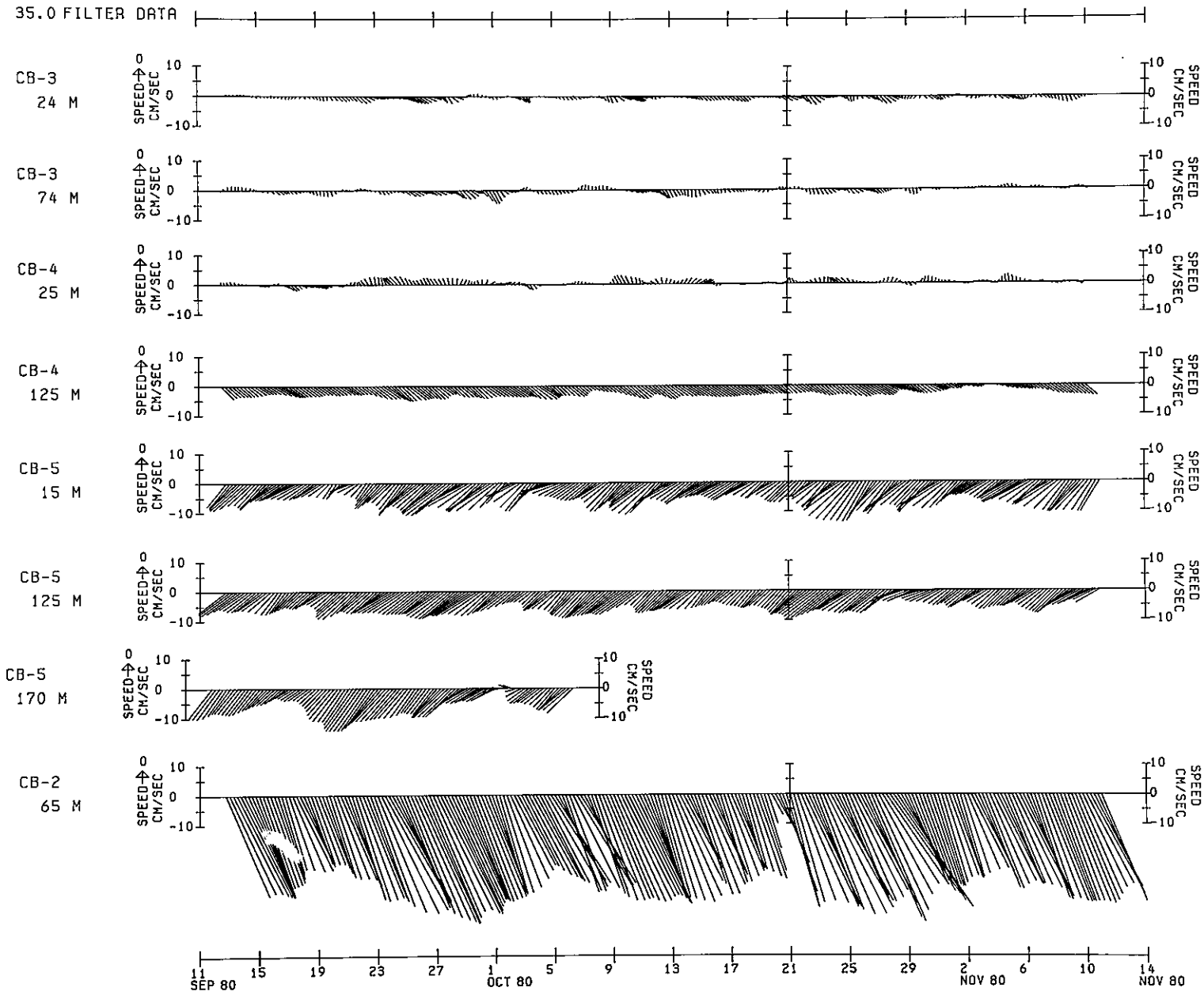

Figure 9. Low frequency currents (35-hour filtered) for indicated moorings and depth, September-November 1980.

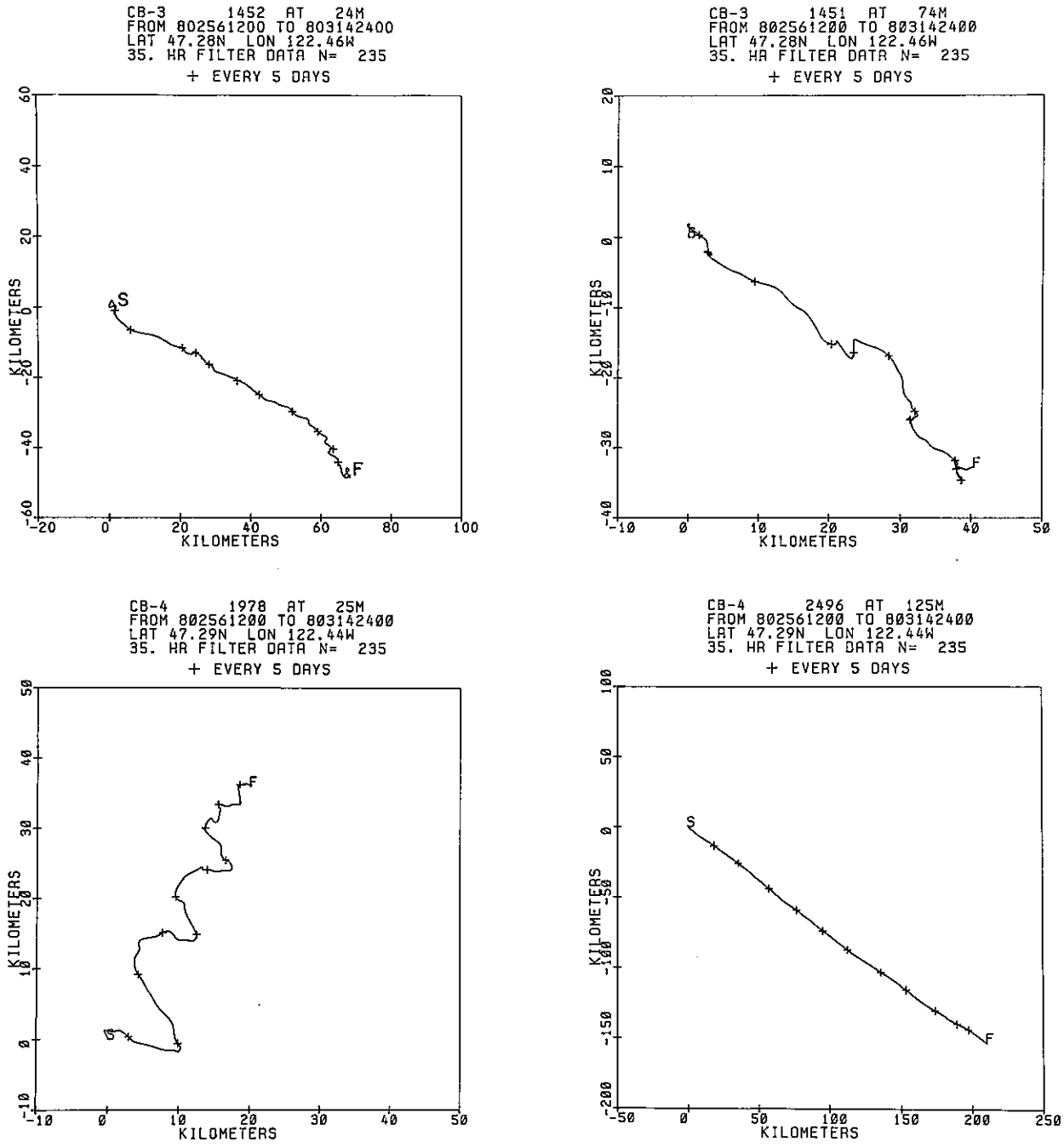

Figure 10. Progressive vector diagrams for nearest surface and near bottom at moorings 3 and 4 in Commencement Bay, September-November 1980. (S is start, F is finish, and symbol (+) indicates 5-day interval.)

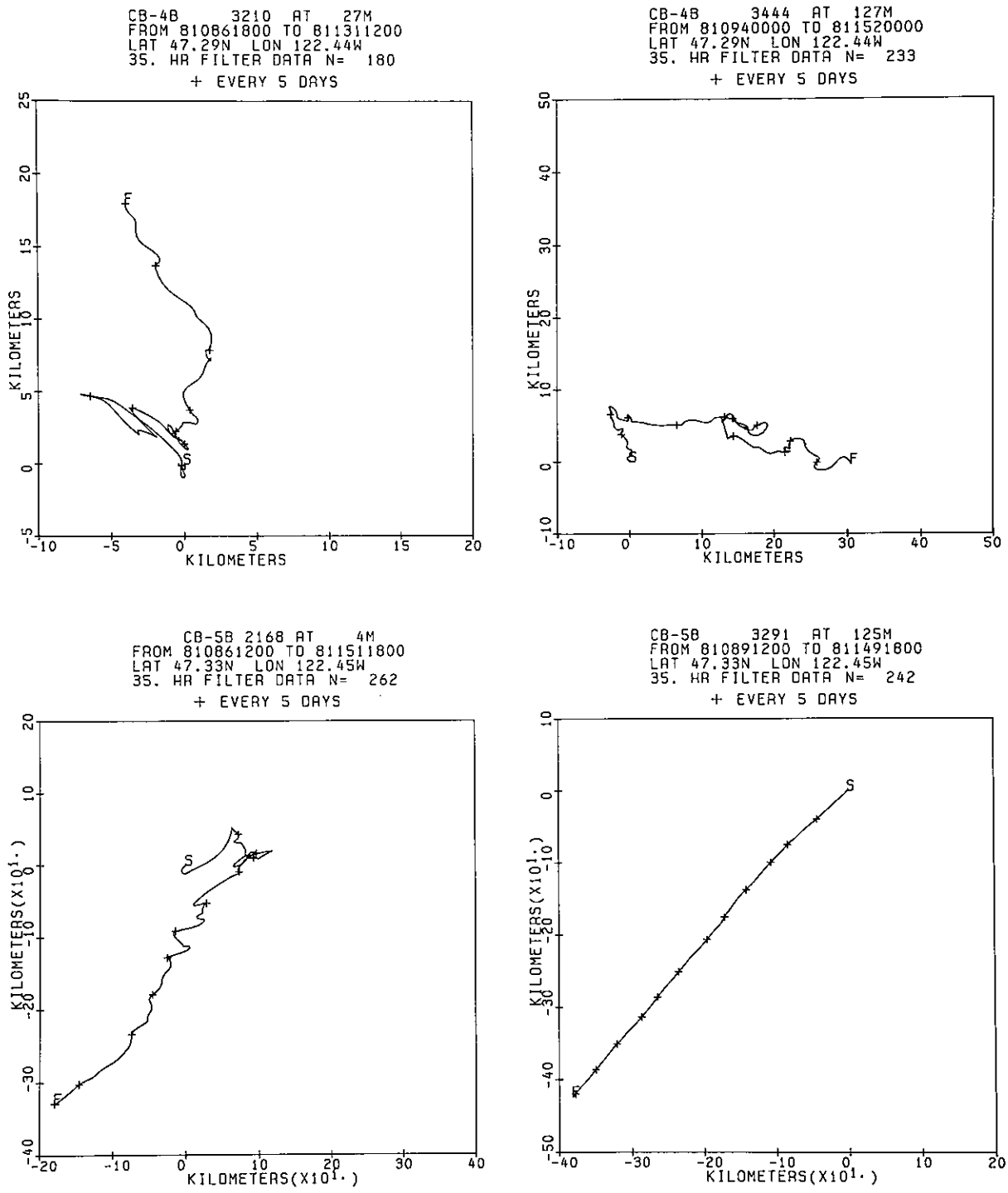

Figure 11. Progressive vector diagrams for nearest surface and near bottom at mooring 4 in Commencement Bay and at comparable depths at mooring 5 in nearby East Passage, April-June 1981.

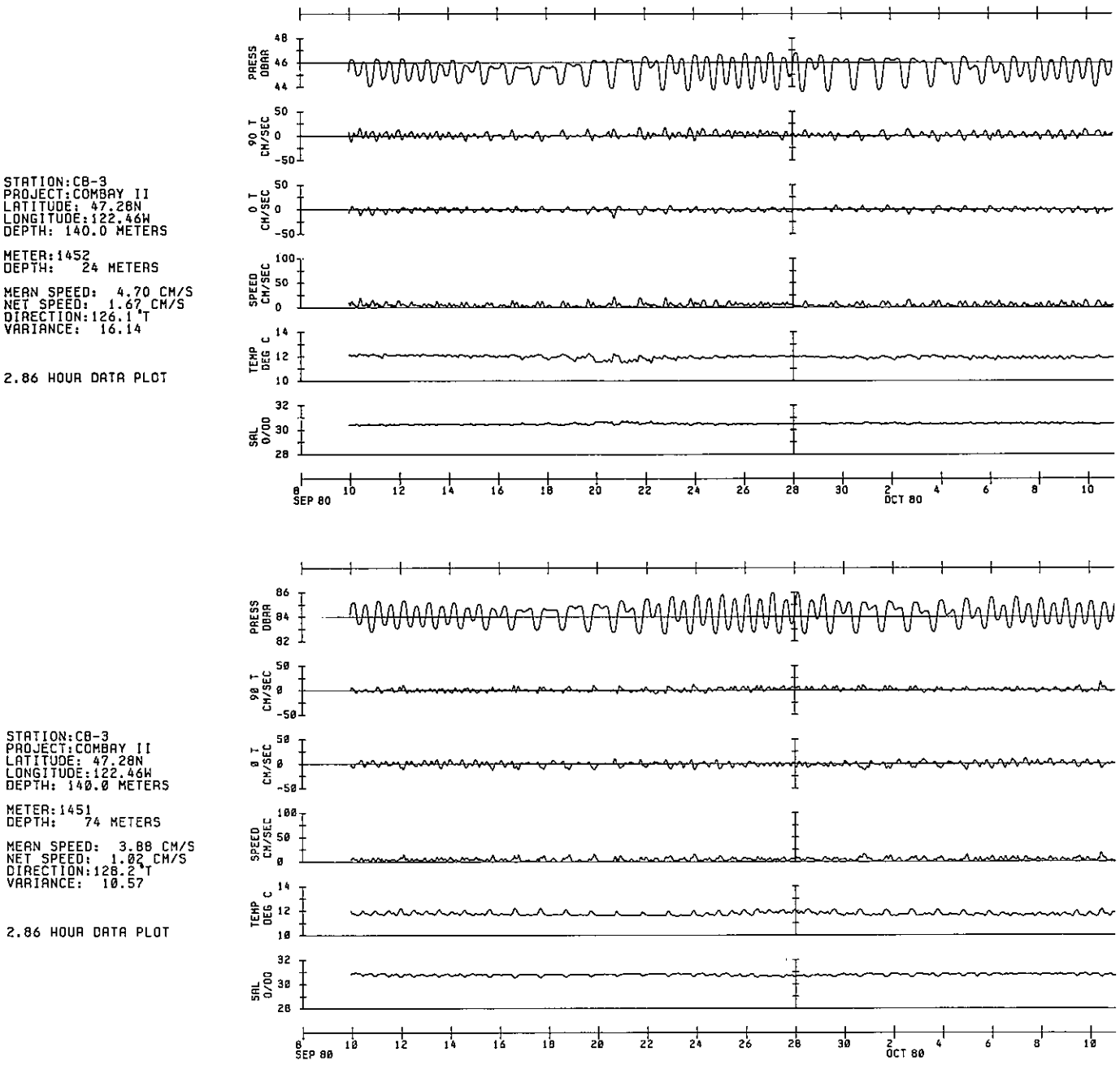

Figure 12. Time series of currents, temperature, and salinity at the indicated depths for mooring 3, September-November 1980.

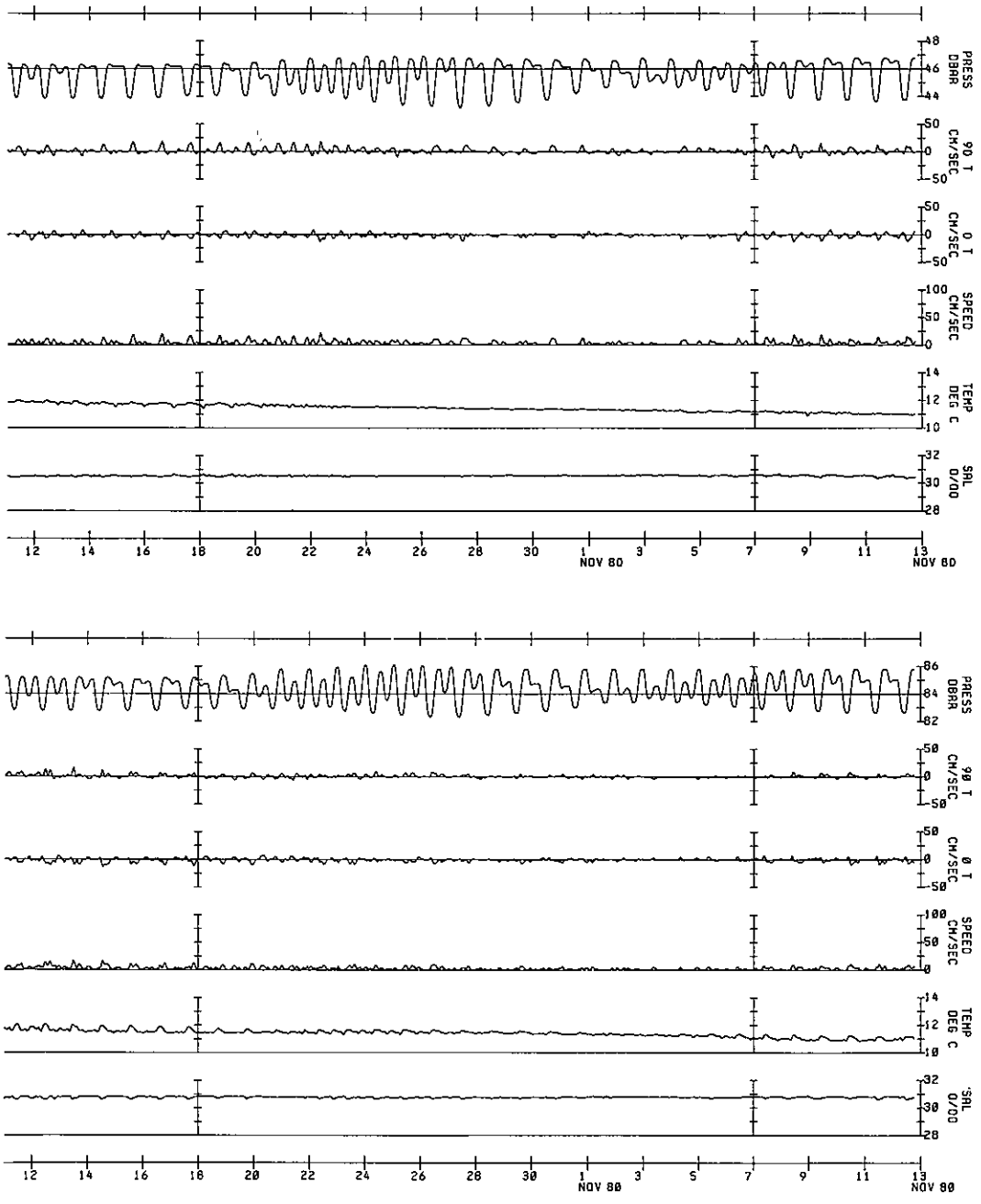

Figure 12. (continued)

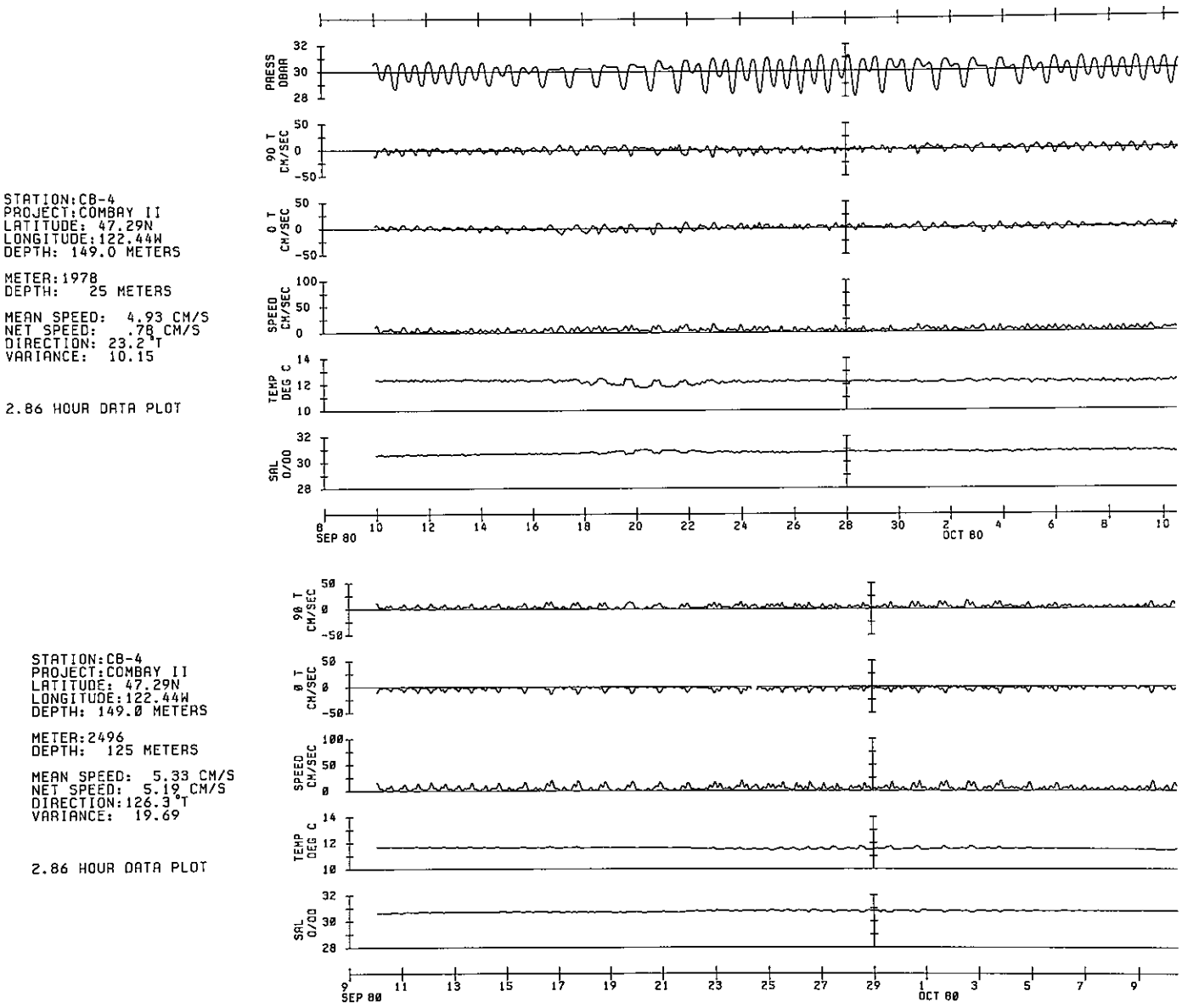

Figure 13. Time series of currents, temperature, and salinity at the indicated depths for mooring 4, September-November 1980.

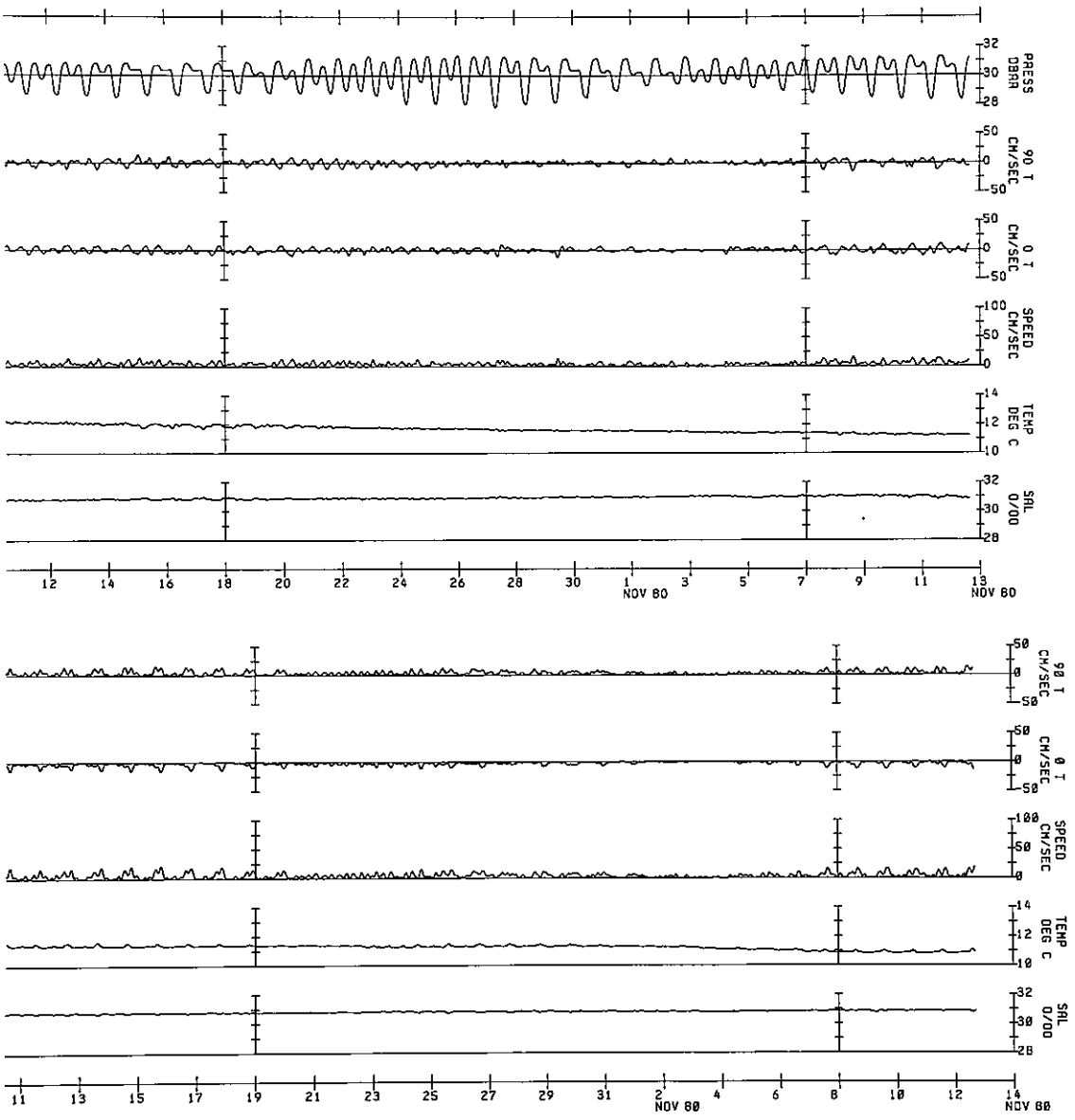

Figure 13. (continued)

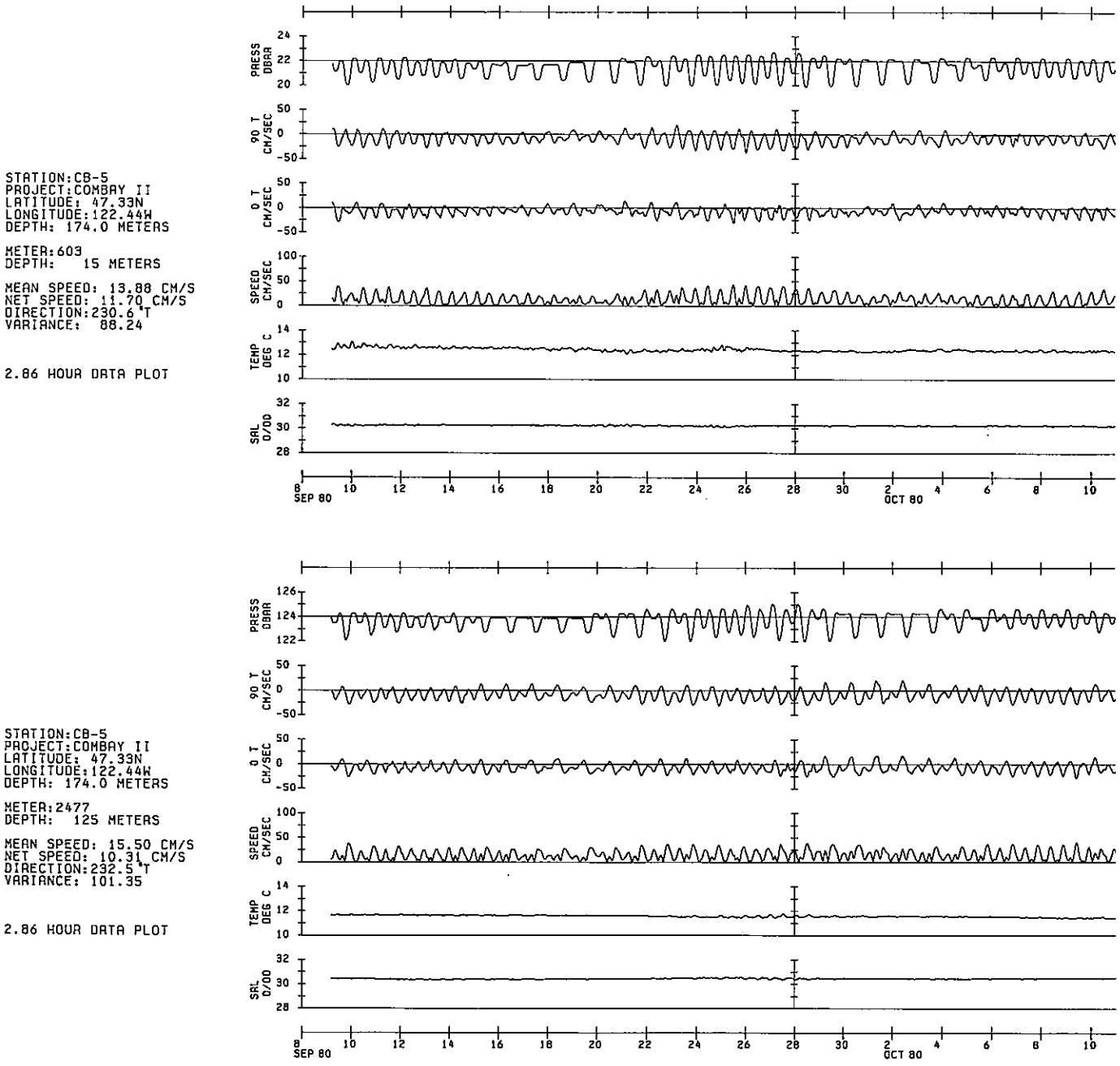

Figure 14. Time series of currents, temperature, and salinity at the indicated depths for mooring 5, September-November 1980.

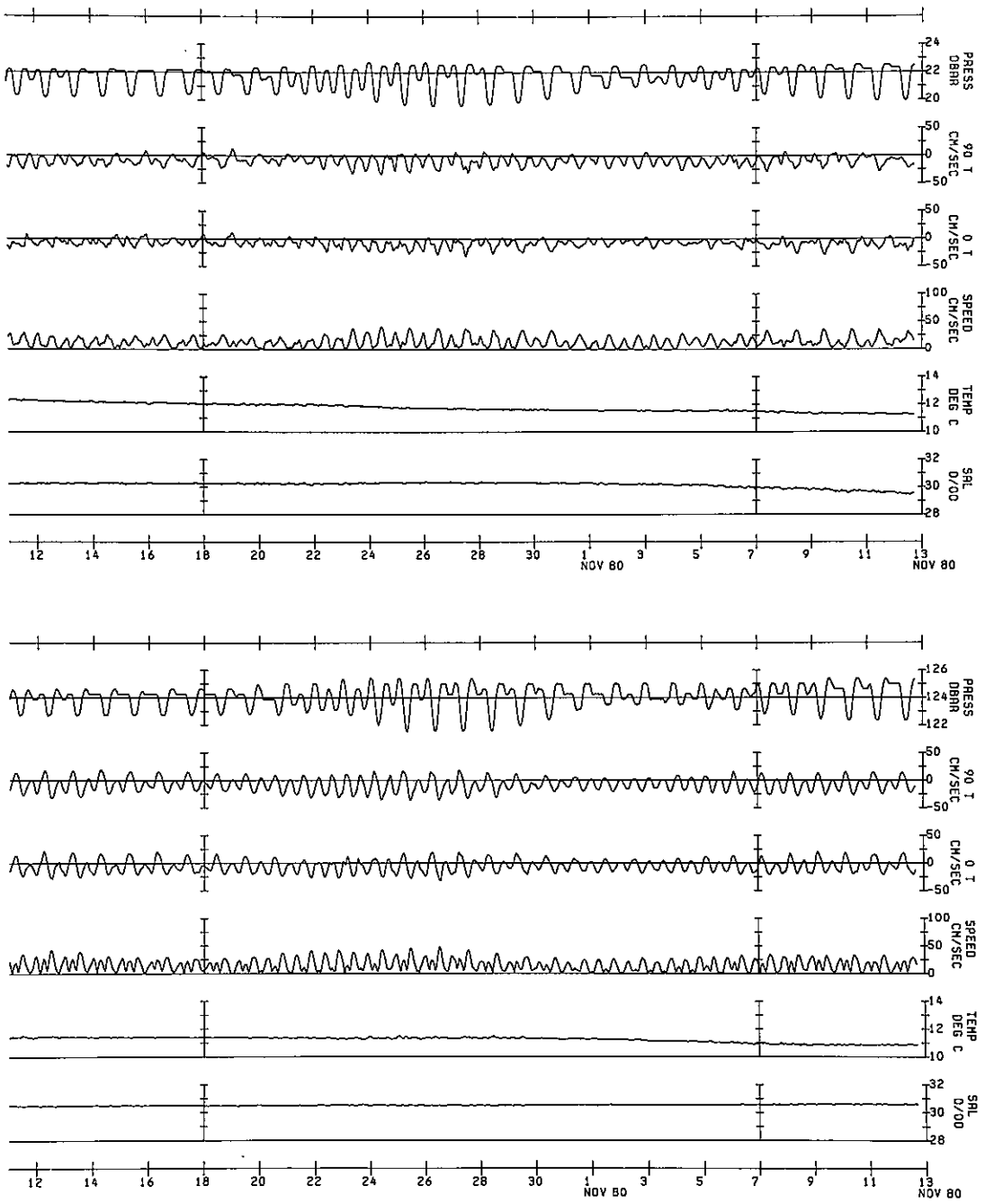

Figure 14. (continued)

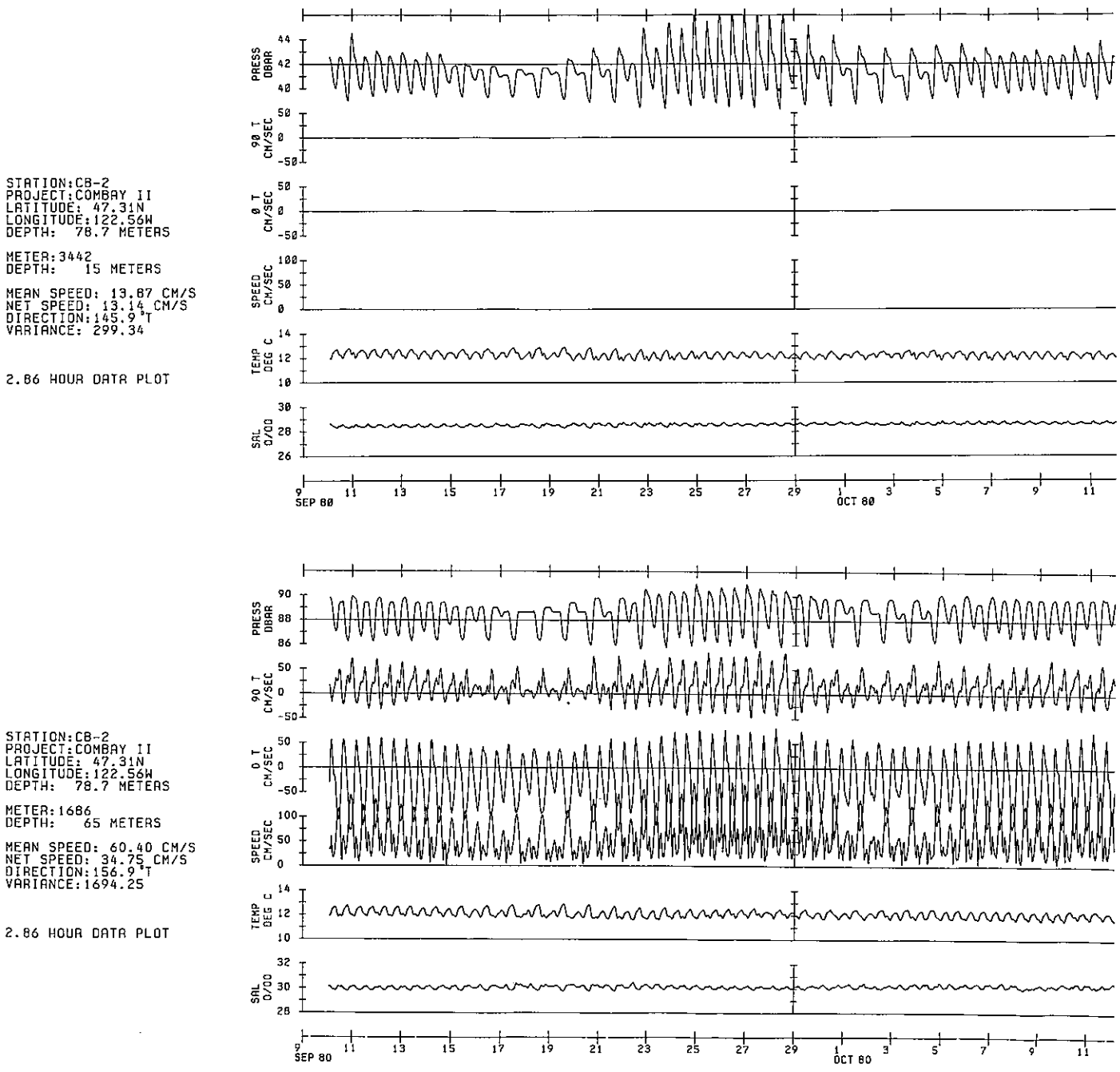

Figure 15. Time series of currents, temperature, and salinity at the indicated depths for mooring 2, September-November 1980.

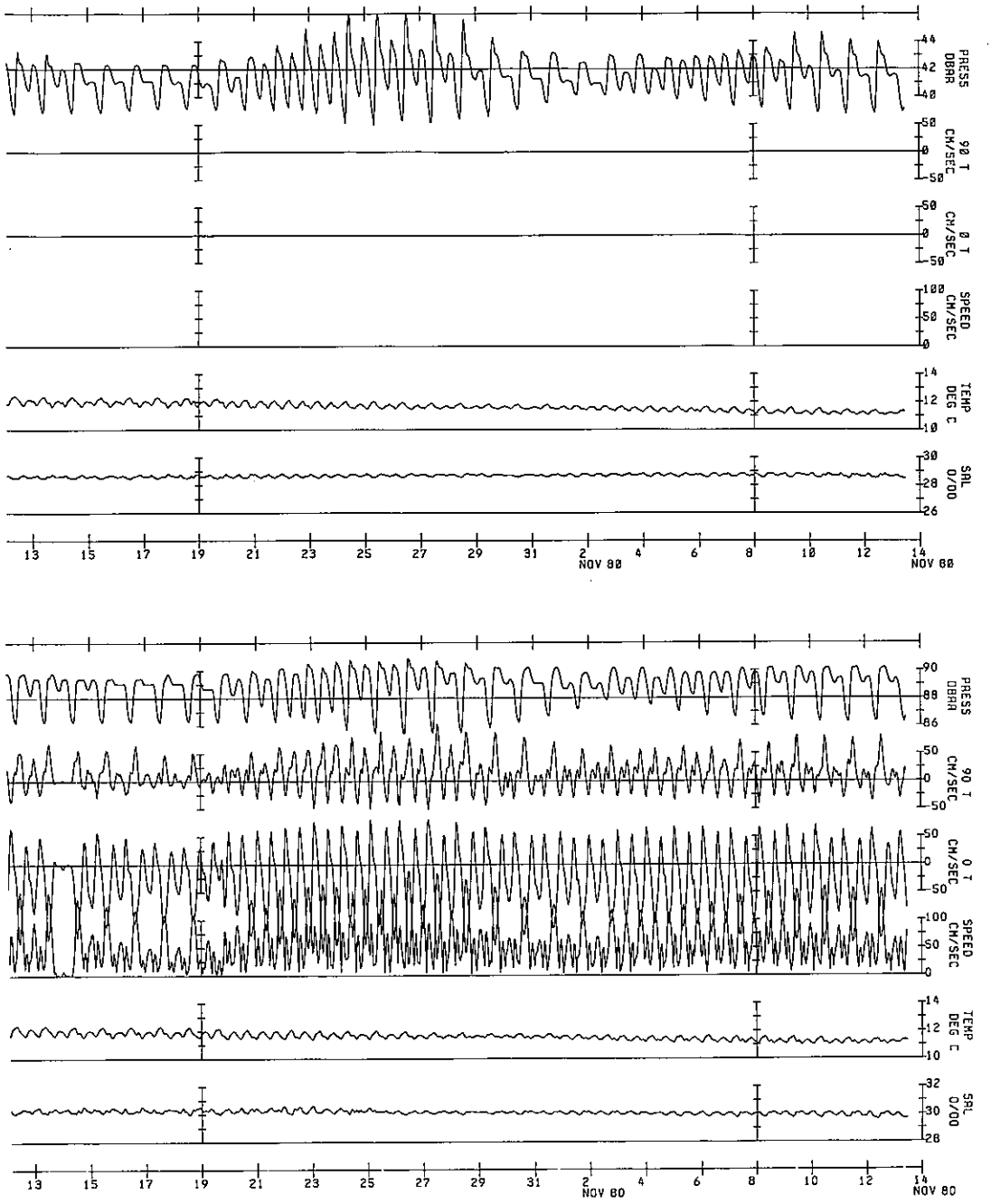

Figure 15. (continued)

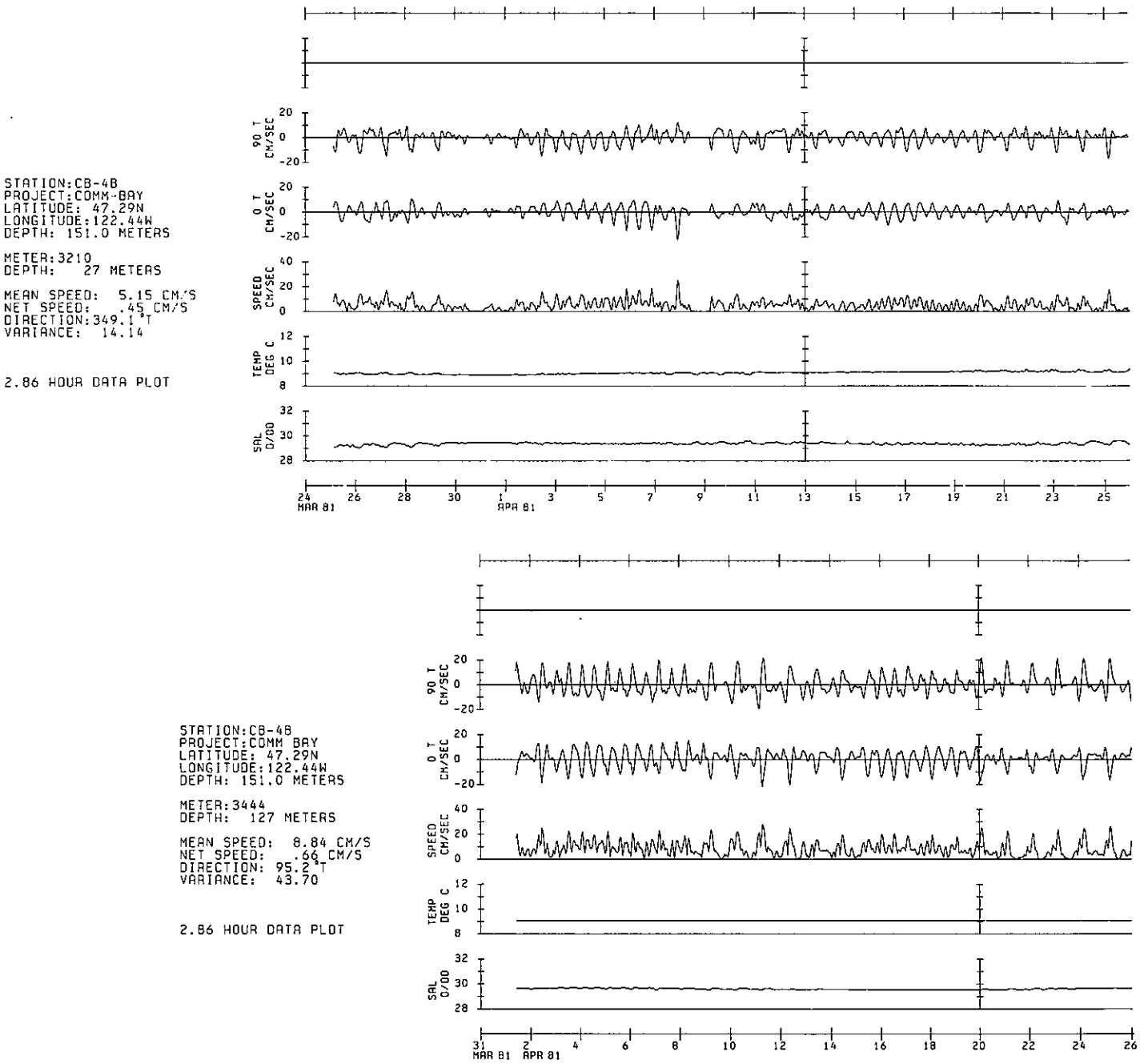

Figure 16. Time series of currents, temperature, and salinity at the indicated depths for mooring 4, April-June 1981.

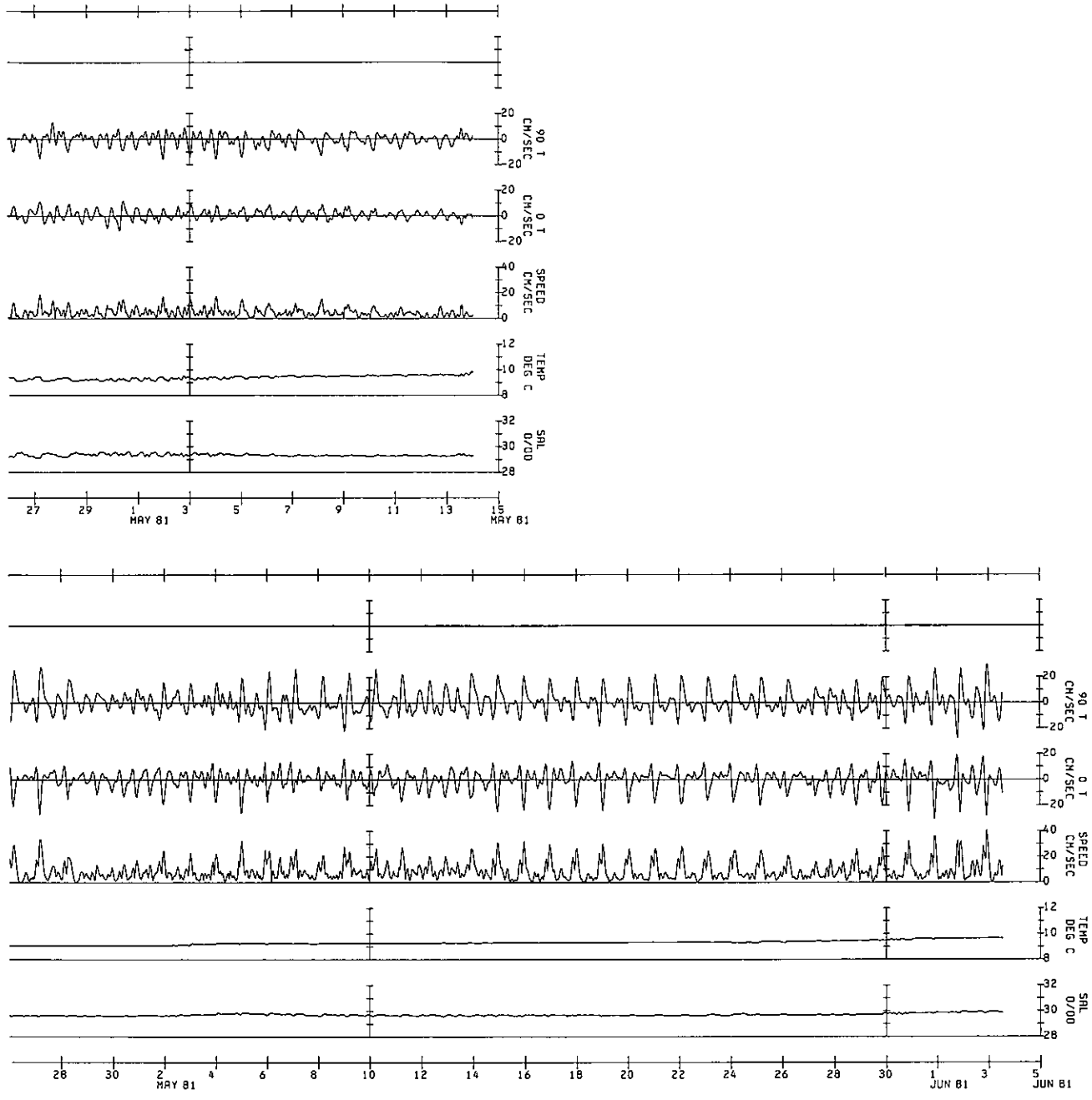

Figure 16. (continued)

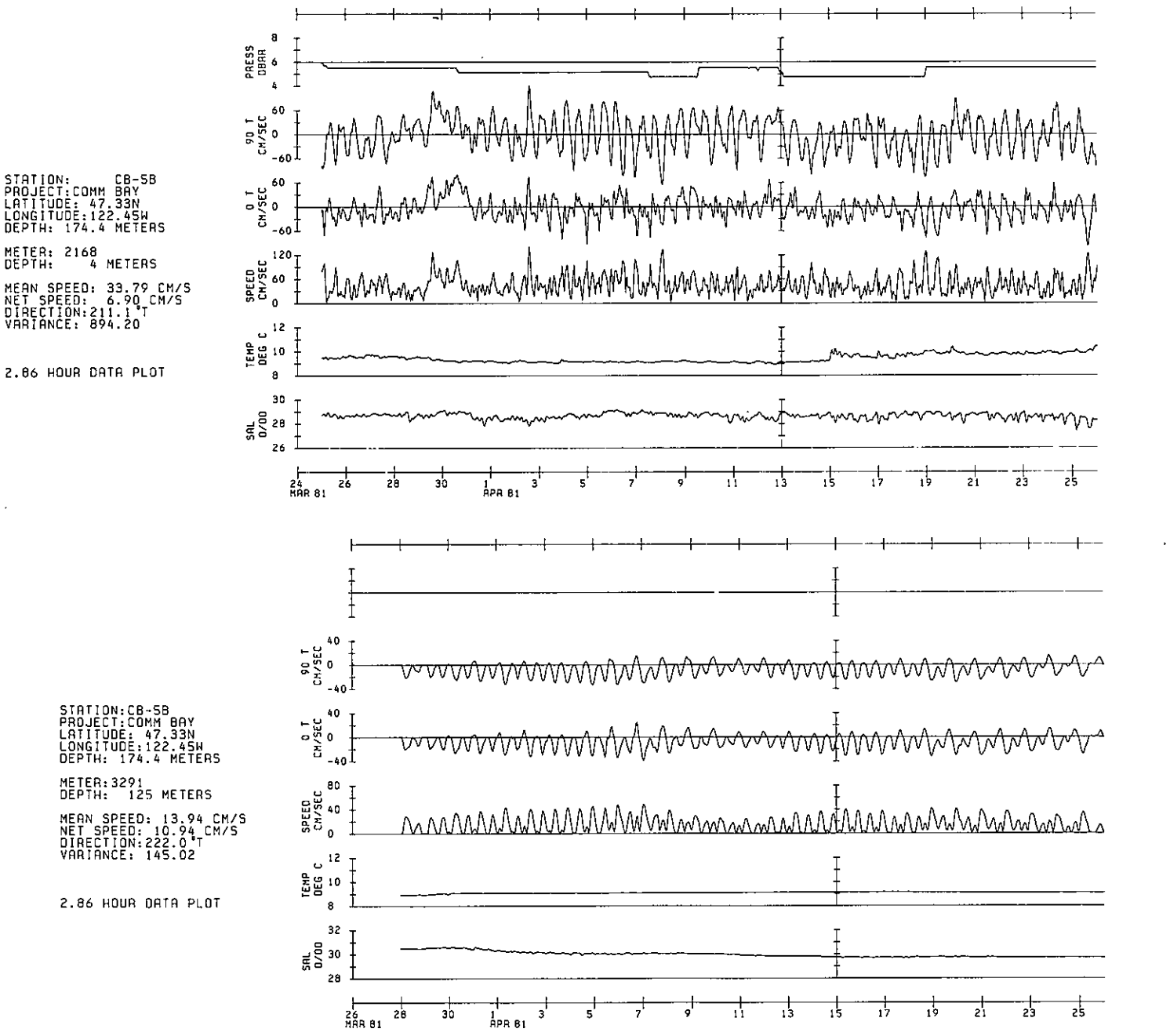

Figure 17. Time series of currents, temperature, and salinity at the indicated depths for mooring 5, April-June 1981.

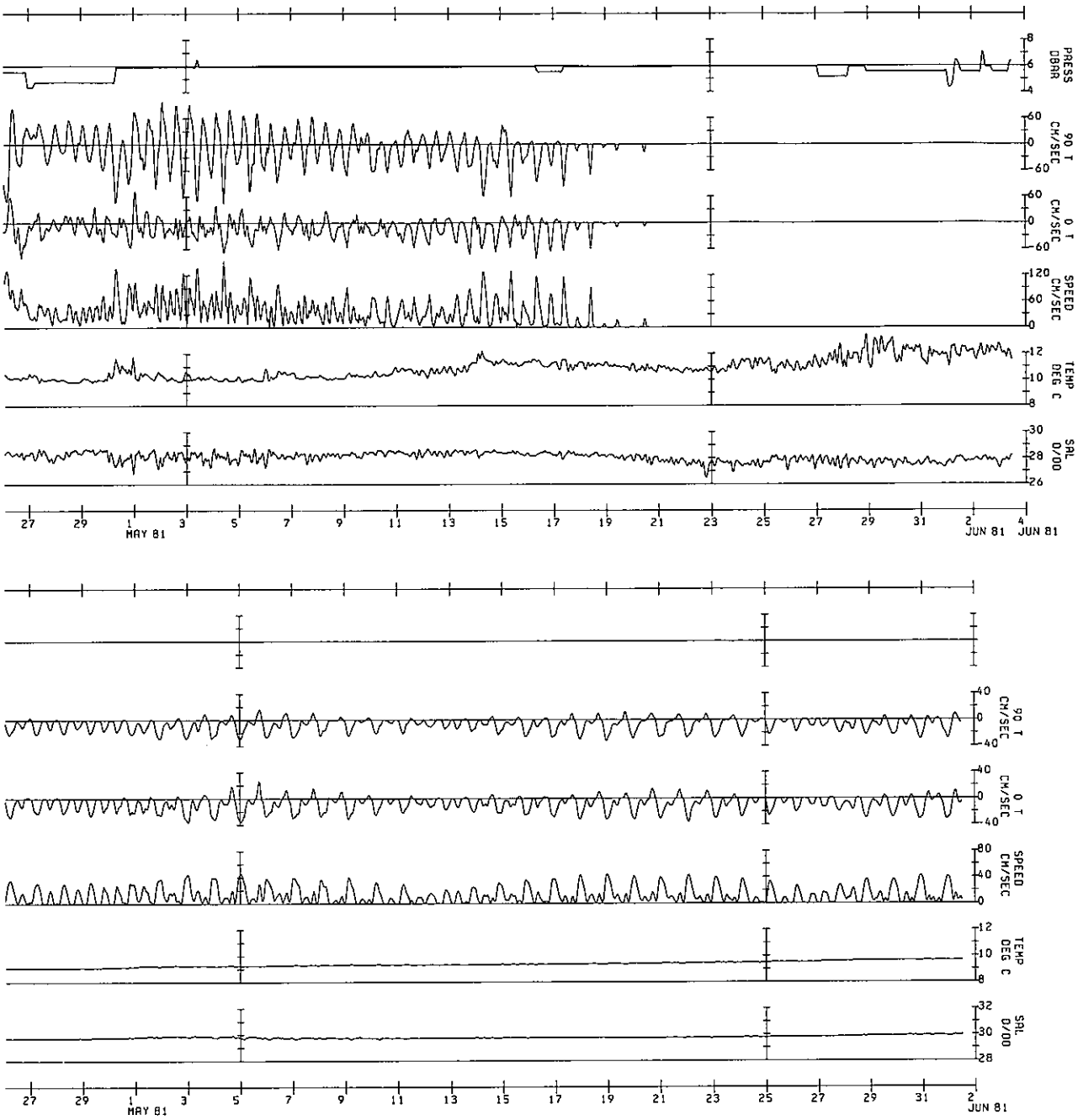

Figure 17. (continued)

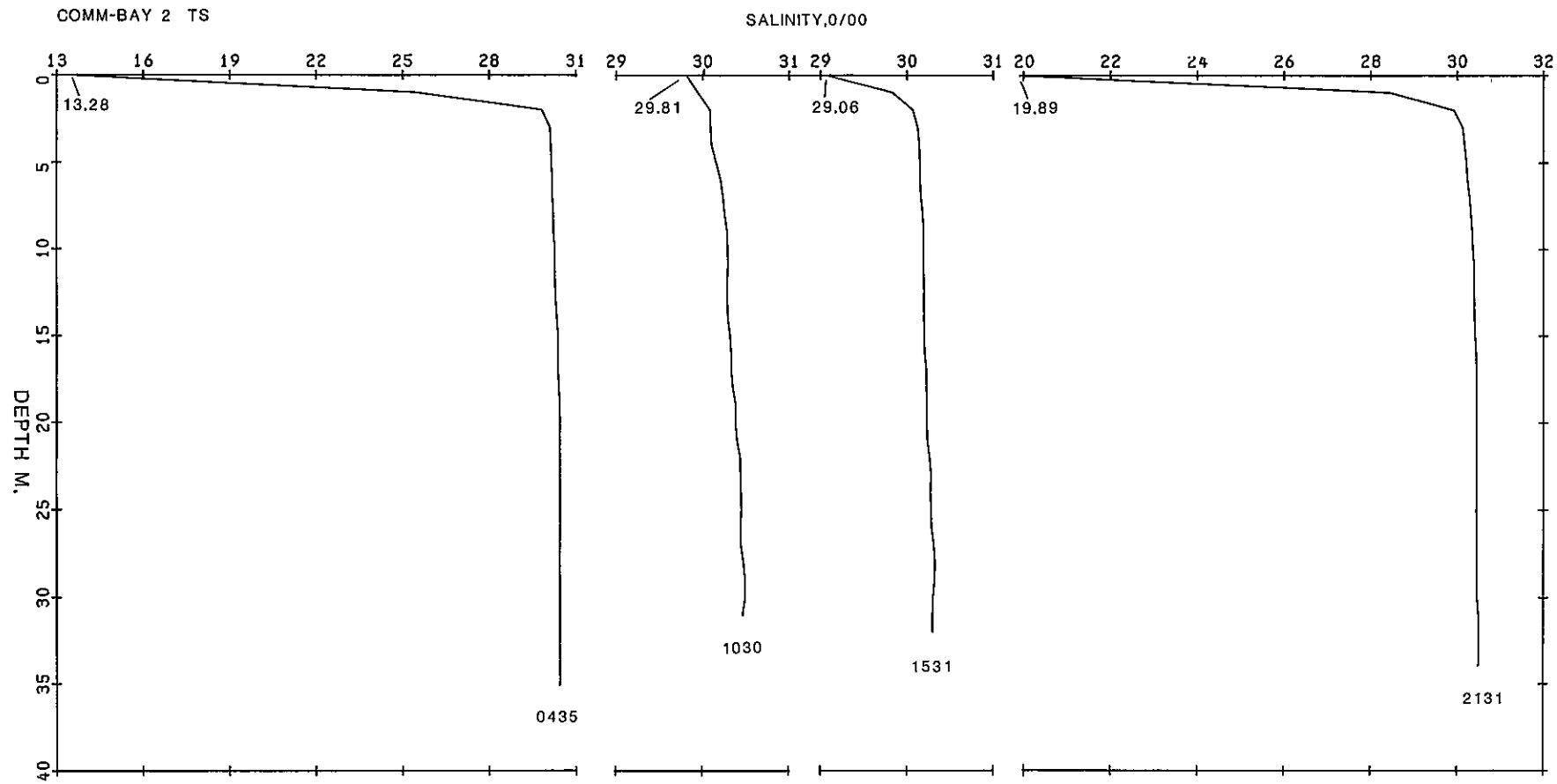

Figure 18. Time series profiles at about 6-hour intervals of salinity (left) and temperature (right) in Commencement Bay just off the mouth of the Puyallup River, November 1980. Salinity scales vary due to large river influence. Temperature profiles are offset with surface values at top and times at bottom.

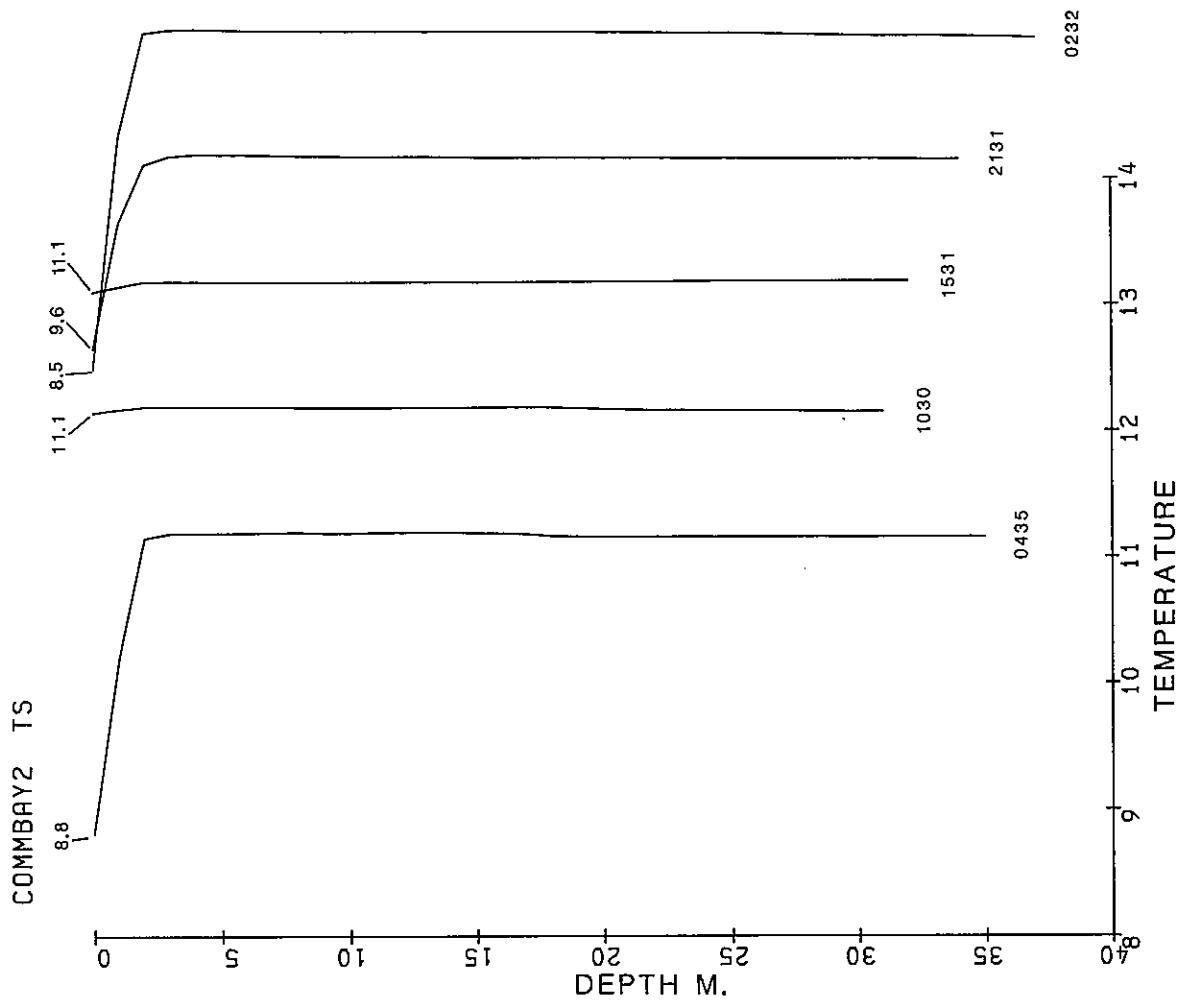

Figure 18. (continued)

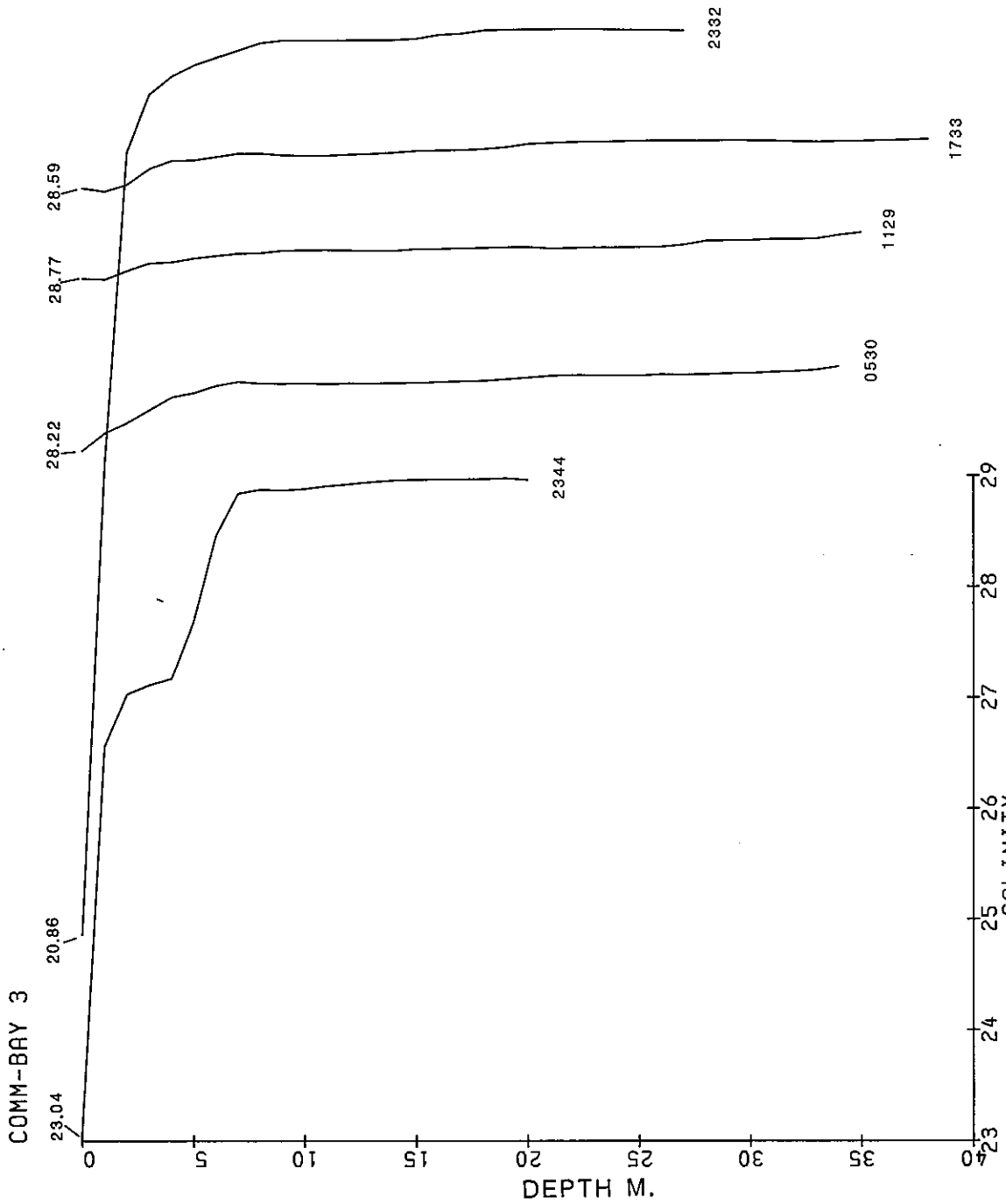

Figure 19. Time series profiles of salinity (left) and temperature (right) in Commencement Bay just off the mouth of the Puyallup River, March 1981. Profiles are offset with surface values at top and times at bottom.

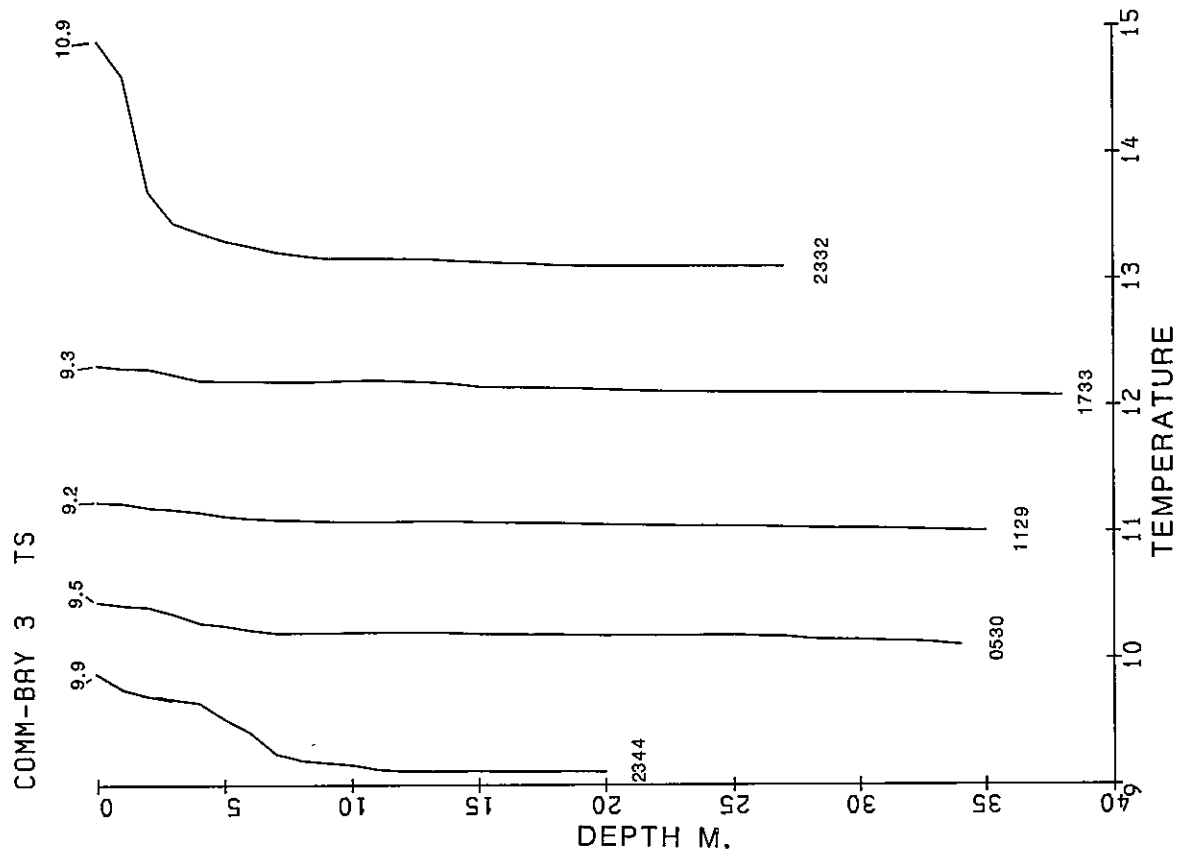

Figure 19. (continued)

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