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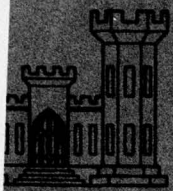
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## DREDGED MATERIAL RESEARCH PROGRAM



TECHNICAL REPORT D-77-30

### AQUATIC DISPOSAL FIELD INVESTIGATIONS COLUMBIA RIVER DISPOSAL SITE, OREGON APPENDIX B: WATER COLUMN, PRIMARY PRODUCTIVITY AND SEDIMENT STUDIES

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by  
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June 1978  
Final Report

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Monitored by Environmental Laboratory  
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Vicksburg, Mississippi

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**AQUATIC DISPOSAL FIELD INVESTIGATIONS  
COLUMBIA RIVER DISPOSAL SITE, OREGON**

**APPENDIX A: Investigation of the Hydraulic Regime and Physical Nature of Bottom Sedimentation**

**APPENDIX B: Water Column, Primary Productivity, and Sediment Studies**

**APPENDIX C: The Effects of Dredged Material Disposal on Benthic Assemblages**

**APPENDIX D: Zooplankton and Ichthyoplankton Studies**

**APPENDIX E: Demersal Fish and Decapod Shellfish Studies**

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IN REPLY REFER TO: WESYV

17 July 1978

SUBJECT: Transmittal of Technical Report D-77-30 (Appendix B)

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of several research efforts (Work Units) undertaken as part of Task 1A, Aquatic Disposal Field Investigations (ADFI), of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 1A is a part of the Environmental Impacts and Criteria Development Project (EICDP), which has as a general objective determination of the magnitude and extent of effects of disposal sites on organisms and the quality of surrounding water, and the rate, diversity, and extent such sites are recolonized by benthic flora and fauna. The study reported on herein was an integral part of a series of research contracts jointly developed to achieve the EICDP general objective at the mouth of the Columbia River, one of five sites located in several geographical regions of the United States. Consequently, this report presents results and interpretations of but one of several closely interrelated efforts and should be used only in conjunction with and consideration of the other related reports for this site.

2. This report, Appendix B: Water Column, Primary Productivity, and Sediment Studies, is one of five contractor-prepared appendices published relative to Waterways Experiment Station Technical Report D-77-30 entitled: Aquatic Disposal Field Investigations, Columbia River Disposal Site, Oregon. The titles of the appendices of this series are listed on the inside front cover of this report. The main report will provide additional results, interpretations, and conclusions not found in the individual contractor reports and will provide a comprehensive summary and synthesis overview of the entire project.

3. The purpose of this study, conducted as Work Unit 1A07B, was to determine background levels of various chemical properties in the water column and in the sediments in the nearshore area adjacent to the mouth of the Columbia River. In addition, the levels of various chemical properties within the sediments at historic disposal areas and in the sediments of an experimental disposal area were evaluated. Water-column perturbations caused during disposal of dredged material and changes in the levels of various chemical constituents in the sediments at the disposal area following disposal were studied.

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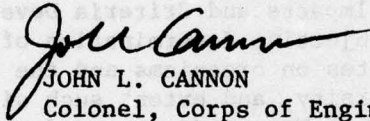
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4. It may be concluded from data collected during this study that disposal of riverine sand at the experimental disposal area had no measurable chemical effect on either the water column or the quality of sediments. Disposal of fine-grained, contaminated material was not tested during this study; however, isolated pockets of fine-grained sediments were encountered in the vicinity of the historical disposal area. These sediments typically indicated increased concentrations of nutrients and metals.

5. The results of this study are particularly important in assessing the local water-quality impacts of open-water dredged material disposal. However, before these results are applied to other dredging and open-water disposal operations, it will be necessary to obtain regional information on the type and quality of dredged material, the type of dredging equipment used, and the nature of the receiving waters. With this information, a more complete assessment of the significance of the dredging and disposal operations can be made.



JOHN L. CANNON  
Colonel, Corps of Engineers  
Commander and Director

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<p>This report presents the research conducted by Oregon State University at the mouth of the Columbia River entitled "Water Column, Primary Productivity, and Sediment Studies."</p> <p>The report describes the study plan and the sampling and analytical methods used. Few data are presented since the data are stored in the computer at the U. S. Army Engineer Waterways Experiment Station. However, some of the</p> <p>(Continued)</p>		

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20. ABSTRACT (Continued).

data are summarized in figures included in this report.

The study concludes that the disposal of clean sand in an open-water area has little effect on the levels of the various potential pollutants, either in the water column or in the sediments in the disposal area.

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## SUMMARY

This report presents the results of the water column, primary productivity, and sediment chemistry studies conducted in the vicinity of the mouth of the Columbia River. This study was one of a series of multidisciplinary projects conducted at the mouth of the Columbia River designed to provide information on the environmental impact of open-water disposal in the nearshore zone.

The project was initiated in late fall of 1974 and was terminated in March 1976, during which time sediment and water chemistry data were collected from nine sampling cruises in the study area.

Results of this study show that water column nutrients and metals in the disposal site can be highly variable, responding primarily to tides and river hydraulics. In general, however, nutrient and metal levels in the water column were well below what would be considered contaminated. This same general observation was found in the water column data for those samples taken in the vicinity of the hopper dredge as it released material at the experimental disposal area.

Sediment chemistry data from the experimental disposal area showed no increased levels of nutrients or metals following disposal. On occasion, however, elevated levels of contaminants were found in the vicinity of disposal area B. It is speculated that these increases were the result of previous disposal operations involving finer grained material from within the Columbia River estuary.

## PREFACE

This report presents the research conducted by the School of Oceanography, Oregon State University, under Contract Nos. DACW57-75-C-0126 and DACW57-76-C-0081 with the U. S. Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL), Vicksburg, Mississippi. This work forms part of a multidisciplinary study conducted between October 1974 and March 1976 as a part of the nationwide Dredged Material Research Program (DMRP).

This portion of the study, entitled "Water Column, Primary Productivity, and Sediment Studies," reports on chemical factors measured in this region.

This research was conducted under the supervision of Drs. Norman Cutshall, Louis Gordon, Robert Holton, and Lawrence Small of Oregon State University.

The report comprises Work Unit 1A07B of the WES Environmental Impacts and Criteria Development Project, Dr. Robert M. Engler, Manager, EL. The study was under the general supervision of Dr. John Harrison, Chief, EL.

Commanders of WES during the preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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## PART I: INTRODUCTION

1. This report presents the results of a study to investigate chemical parameters in the water column and bottom sediments in a study area at the mouth of the Columbia River. Also included in this report are data concerning the primary productivity in this same study region. In particular, emphasis was placed on conditions in a disposal site, termed the historic disposal site, that has been used for many years for the disposal of dredged material and a previously unused site first disposed on during the course of this study and referred to as the experimental disposal site in the following report. These sites have also been referred to as sites B and G, respectively, by the U. S. Army Engineer District, Portland.

2. This study is part of the Dredged Material Research Program (DMRP) initiated by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. This particular part of the study was funded for an 18-month period from October 1974 to March 1976. The total research program was largely concurrent with this study of chemical parameters. The total program also included physical, geological, and biological studies of the same region at the mouth of the Columbia River.

3. The field sampling associated with this research program consisted of nine cruises, conducted between September 1974 and October 1975. The station locations and a summary of the sampling conducted at each station is presented in Tables B1 - B10. The same data are used to prepare Figures B1 - B9 which map the stations occupied during each cruise and indicate the factors being measured at each station. In addition, Table B11 presents a chronology of the cruises with an indication of the samples taken on each cruise. This provides a reference framework for viewing the total sampling program.

4. Each cruise is designated by a cruise number in the text. For example, one of the cruises is labelled Y7506 B-1. The first letter indicates the vessel used. The letter Y indicates the R/V YAQUINA in

this case and C indicates the R/V CAYUSE. The first two numbers indicate the year, the next two the month. The example shows a cruise in June of 1975. The next letter indicates the number of cruises that vessel has made that month. In this case it is the second cruise made this month by the vessel. The final digit indicates the leg of that particular cruise being considered.

5. The particular parameters to be measured were specified in the contract with WES and the methods to be used in their measurement were likewise specified. Where the study methods varied from the WES-outlined procedures, they have been detailed in the text of this report.

6. Likewise, the methods used to obtain samples are described in the body of the report. Due to the sandy nature of the sediments, the researchers were unable to retain the interstitial water within the box corer. As soon as the corer came on deck, the overlying water on top of the corer drained through the sand, pushing the interstitial water out ahead of it. Therefore, no measurements on interstitial water are discussed.

7. The objectives of this study may be summarized as follows:

- a. Establish the baseline levels for the various chemical factors in the water column and in the sediments at the mouth of the Columbia River.
- b. Determine the levels of the various chemical parameters within the sediments at the historic disposal site.
- c. Measure the changes in the levels of the various factors that may occur during and after disposal operations at the experimental site.
- d. Report the levels of primary productivity that were measured at selected locations within the study area.

8. It can be concluded that the study established the chemical conditions within the sediments in a satisfactory fashion. However, the fact that the dredged material studied was in fact clean sand and was being disposed on clean sand left no opportunity to establish what

the impact of disposing contaminated materials would have been on the same area.

9. The chemical conditions in the water column have a much shorter response time than in the sediments, and the low level of metals and nutrients made it difficult to measure or establish the water-column conditions due to disposal in this highly variable region. The inability of the dredges to dispose of materials regularly during the periods that the research vessels were scheduled to be in the study area made it impossible to draw any firm conclusions concerning the impact of disposal on water-column chemistry.

## PART II: METHODS AND MATERIALS

### Field Methods

#### Water-column sampling

10. The parameters measured on all cruises in which water-column samples were taken included: water temperature, salinity, density, inorganic nutrients ( $\text{NO}_3 + \text{NO}_2$ ,  $\text{PO}_4$ ,  $\text{SiO}_4$ , and  $\text{NH}_3$ ), total available phosphorus, particulate carbon, particulate nitrogen, pH, dissolved oxygen, chlorophyll a, and primary production. On some cruises, values of percent light transmission were obtained. Daily solar radiation, though not specified in the contract, was monitored during most cruise days, and wind speeds and directions were monitored. Tidal velocities and heights were computed at the mouth of the Columbia River on all cruises involving water-column sampling.

11. Water samples were obtained with a STD (salinity, temperature, depth) pumping system which could be lowered to 200 m or within 1 m of the bottom at shallow stations. Upon completion of the STD descent cast, examination of the computer display plots allowed extreme flexibility in the choice of four to six discrete depths to be sampled by short-period pumping stops on the ascending cast. Emphasis was placed on sampling the upper waters subject to Columbia River effluent, the region of the pycnocline, and the water within 5 m of the bottom. Some CTD (conductivity, temperature, depth) casts were made on occasion with a separate instrument, for verifying the STD, and checks were also made from standard water-bottle casts.

12. From each discrete pumping depth, on-line instruments determined chlorophyll fluorescence by in vivo fluorometry and the four inorganic nutrients by Autoanalyzer. Discrete samples were drawn from the pump flow (or from water bottles) for chlorophyll a checks and for analyses for particulate carbon and nitrogen, dissolved oxygen, salinity, pH, total available nitrogen and phosphorus, additional nutrients, dissolved organic carbon, and  $^{14}\text{C}$  productivity studies. Many of the discrete samples were prepared for eventual analysis at the shore-based laboratory. The pH, oxygen, and salinity values were determined at sea.

13. Measurements of salinity, temperature, and depth were made with a Plessey Model 9040 STD which transmits FM multiplexed data to the deck unit via a 200-m hose cable, consisting of a signal coaxial cable, a 1.9-cm hose, a braided strength member, and power leads for the submerged pump. The STD deck unit converted the FM data to analog signals which were amplified and interfaced through a multiplex and A/D converter to a Digital Electronics Corporation PDP-8/L minicomputer in a shipboard laboratory.

14. During descent of the STD, a real-time display was produced on a Tectronics Model 611 display storage scope. Descent speed was continuously variable from 0 to 50 m/min, being altered to decrease velocity in areas of sharp gradient (because of the slower response of the temperature sensor and salinity compensation circuitry) and to increase when gradients were less severe. Information from the Tec scope was relayed to the winch operator on deck via closed circuit intercom, and the winch operator had a digital readout of the sensor depth at the winch control.

15. The shipboard data acquisition program on the PDP-8/L was designed to monitor the channel depth until depth had increased by 0.5 percent over the previous greatest depth. When a new depth was sensed, the program sampled the temperature, salinity, and depth channels 128 times each, outputted the average to a storage buffer, and updated the display scope. Full-scale depth was switch-selectable at 0 to 50, 0 to 100, or 0 to 200 m based on water-column depth, giving a maximum of 200 sample depths per cast.

16. At the completion of the descent cast, a hard-copy plot was made on a Calcomp model 565 incremental plotter and the raw digital data were punched onto paper tape for further processing ashore. Ashore, the raw data were processed on the Oregon State University (OSU) CDC 3300 computer to produce tabular listings to complement the Calcomp plots. Smoothed output from the computer program was used to produce the temperature and salinity plots.

17. After the descent cast was completed, the STD pumping system was brought back to the surface in a stepwise manner, with selected stops

at four to six depths (usually) so that the discrete water samples could be drawn on board from the effluent water stream being pumped through the hose. The outlet of the water stream of the OSU STD-pumping system was in an inside laboratory where it was sampled for the chemical and biological parameters listed earlier. The direct on-line measurements of chlorophyll a fluorescence were made with an Aminco fluorometer with flowthrough cell, and the dissolved nutrients were analyzed using a Technicon Autoanalyzer. Discrete samples were drawn from the pump hose for use in standard Winkler oxygen titration, spectrophotometric determination of chlorophyll a, particulate carbon and nitrogen determination, pH determination using an Orion pH meter, salinity determination using a laboratory salinometer, and later analysis of total available nitrogen and total available phosphorus.

18. Particulate carbon and nitrogen samples were collected on 1.1-cm-diam glass-fiber filters. The filters were frozen on board, oven-dried for several days after returning to the shore-based lab, and determined by combustion gas chromatography in a Carlo-Erba CHN elemental analyzer. The carbon and nitrogen peaks generated on chart paper were converted to concentrations by comparison to peak heights of weighted acetanilide standards.

#### Sediment sampling

19. Sediment samples were obtained with a Bouma Box Corer which consisted of a rectangular stainless steel core barrel ("box") 20.32 x 30.48 cm in cross section and 45.72 cm long. The core barrel was pushed into the sediment through the center of a pyramidal framework by approximately 453.6 kg of lead. The upward pull of the ship cable on a lever arm forced a steel plate down through the sediment and underneath the sampling box to seal the sediment inside. On deck, the box was removed and placed on an extruder stand. As the sediment was extruded, the desired sections were sliced off using a stainless steel cutter.

20. The desired section thickness (5 cm) was extruded into a sample frame positioned at the top of the box. One side of the sampling frame was covered with a Plexiglas sheet in which ports of various sizes

were cut and filled with plugs. The bottom of the sample frame consisted of the steel cutter. Air was excluded from the sample while the section was removed from the core and when the various subsamples were drawn for analyses.

21. Subsamples were taken by removing the plugs and inserting "minicorers" fitted with small valves to allow escape of air while the minicorer was filling. After insertion, the valve was closed, the minicorer withdrawn from the sample frame, and either transferred to appropriate containers for subsequent analysis or covered with a plastic lid to exclude air. The latter type of samples was stored at room temperature for short intervals between the time of collection and when they were placed in the squeezing chambers for extraction of interstitial water.

22. Due to special concern for isolating samples for sulfide analysis from atmospheric oxygen, the following procedure was developed. Disposable 10- and 12-ml polypropylene syringes were modified by cutting off the end of the syringe barrel with the needle fitting. The resulting cylinder and its plunger were used as a minicorer for collecting and storing sediment samples for sulfide determination. Samples were obtained from freshly sectioned box cores. The open end of the minicorer was covered with two layers of plastic wrap that were held in place with a tightly stretched rubber band. (Plastic wrap has low oxygen permeability.) After wrapping, the sample was promptly frozen and stored at  $-20^{\circ}\text{C}$ . Separate studies of sulfide sample storage stability showed that the sulfide content of the frozen samples changed  $< 10$  percent during a year of storage (see Appendix A'). Sulfide content of the sediments was determined titrimetrically (American Public Health Association Standard Method 228A).<sup>1</sup> The fluctuation of the blank analyses was about 0.05 mg of sulfide. Since the typical sample weighed about 15 g, the minimum detectable sulfide concentration was about 3 mg/kg.

#### Interstitial water

23. One hundred-cm<sup>3</sup> samples of the wet sediment collected in the minicorers, as described earlier, were stored at room temperature for the short time between collection and extraction. Lids were kept over

the exposed end of the sample plug during this time to prevent as much air contact as possible. The samples were placed in Teflon chambers designed after the Reeburgh apparatus.<sup>2</sup> Pressure was applied by bottled nitrogen. Nucleopore filters, 0.4  $\mu\text{m}$ , were used in the filter holder section of the apparatus. The extracts were stored in two types of containers depending on the type of analysis to be performed. Samples for interstitial trace metals were stored in standard 31-ml nutrient bottles (polyethylene). All samples were frozen immediately and kept frozen until analysis. Nutrient samples were analyzed using the Technicon Autoanalyzer system previously described.

#### Laboratory Methods, Instrumentation, and Analytical Techniques

##### Autoanalyzer methods

24. Inorganic nutrients were determined using a Technicon Instruments Corporation Autoanalyzer. Basically, nutrients are determined in much the same manner as with batch chemical and spectrophotometric methods, except that with the Autoanalyzer both filtered sample and reagents flow continuously through the system.

25. System composition. The total system is composed of (1) various input tubes from reagent bottles and the sample bottle for each nutrient being analyzed (a specialized dialysis filter is employed with the sample); (2) a specialized peristaltic pump to move the reagents and filtered sample through the input tubes and into the mixing coils, with one pump required for each nutrient analyzed; (3) mixing coils through which solutions pass and chemical reactions take place, with each set of coils specific for a nutrient; and, (4) a colorimeter set to analyze the color of the reaction mixture specific for a nutrient, with one colorimeter required for each nutrient analyzed. Since four nutrients were analyzed ( $\text{NO}_3 + \text{NO}_2$ ,  $\text{NH}_3$ ,  $\text{PO}_4$ , and  $\text{SiO}_4$ ), four pumps and four colorimeters, with their attendant mixing coils and reagent tubes, were required in the complete autoanalysis system. The readings from each colorimeter were outputted to a chart recorder, with a different colored pen used for each nutrient. Suitable standards and

blanks were analyzed with each nutrient run.

26. Differentiating features. The main features that make the Autoanalyzer different and more efficient than sequential batch chemical analyses are detailed more fully, as follows. The times necessary for the chemical reactions to be completed are obtained by passing solutions through various lengths of coiled glass tubing in the Autoanalyzer. As the total length of the small-bore glass tubing is very long (many meters), small air bubbles are injected into the system to prevent a bad "tailing" of the record. This can occur when a concentration gradient (e.g., a change from standard to blank solution) travels through such a length of tubing. The trouble arises from the viscous slowing of a solution near the tube wall compared with the liquid in the center of the tube. This injection of air to give discrete "slugs" in the tubing, plus the use of a peristaltic pump, both introduced into automatic analysis by Technicon, are responsible for the success of this approach, which is particularly suited to the analysis of a continuous stream of samples such as can be obtained from a ship at sea.

27. NO<sub>3</sub> + NO<sub>2</sub> analyses. The NO<sub>3</sub> + NO<sub>2</sub> chemical analyses were done as suggested in the Request for Proposals, except that the Autoanalyzer was used as discussed above. Basically, the method involves the reduction of nitrate to nitrite by running the filtered sample through a column of cadmium filings lightly coated with copper. The NO<sub>2</sub> is then made into a highly colored azo dye by adding sulfanilamide and N-naphthylethylene-diamine dihydrochloride, and the solution is "read" in the colorimeter at about 542 mμ. Analysis for NO<sub>2</sub> alone can be done by bypassing the cadmium-copper column in the Autoanalyzer setup. Nitrate alone is determined by subtraction of NO<sub>2</sub> from (NO<sub>3</sub> + NO<sub>2</sub>).

28. NH<sub>3</sub> analysis. The procedure for NH<sub>3</sub> was basically the same as given in the Request for Proposals, except that sodium phenate solution, sodium nitroprusside, and sodium hypochlorite solution are mixed in the proper order in the Autoanalyzer coils to form the strong oxidizing agent, phenylhypochlorite, which oxidizes ammonia to nitrite in the alkaline medium. The NO<sub>2</sub> is then measured. Total available nitrogen was measured after UV irradiation of a filtered water sample. All dissolved

organic compounds except probably some tertiary amines are catalyzed in the presence of  $O_2$  and UV (250-nm wavelength) to give an  $NO_3 + NO_2$  mixture which is analyzed by the  $(NO_3 + NO_2)$  method. Total available nitrogen is thus inorganic nitrogen plus dissolved organic nitrogen. Total nitrogen is total available nitrogen plus particulate nitrogen, with particulate nitrogen done chromatographically by CHN analyzer.

29. Silicate analysis. Silicate was determined via the Autoanalyzer by the reduction of a silico-molybdate complex to a blue color that is colorimetrically determined at 810 nm. The procedure is a standard one. Stannous chloride is used as the primary reductant, and tartaric acid acts to reduce, or decompose, any phospho- or arseno-molybdate formed along with the silico-molybdate complex.

30. Phosphate analysis. Phosphate was determined by autoanalysis by the method of the Request for Proposals, except that hydrazine rather than ascorbic acid was used as the reductant. The method involves reacting each sample in the mixing coils with molybdic acid (plus  $H_2SO_4$ ) and hydrazine sulfate. The resulting blue-colored complex is read in the colorimeter at 830 to 840 nm. Total available phosphorus was a filtered, UV-treated sample in which the phosphate was determined after the UV treatment.

Extraction and concentration  
of metals from seawater and  
interstitial water

31. Analysis is facilitated by concentration of the ions of interest. Separation and concentration may be effected by selective extraction of the heavy metals into an organic solvent with the aid of a suitable complexing agent. In the present work heavy metals were concentrated by extraction of ammonium pyrrolidine carbodithioate (APCD) complexes into chloroform.

32. The work was performed in a laboratory equipped with a laminar flow hood (LFH) that filtered out air-borne particulates. Extractions and transfers were done in the LFH as much as possible. Weighings were done outside the LFH. The LFH has no vacuum, water, or fume control facilities so the evaporations and digestions were done in a conventional

exhaust hood. Therefore, the additions of acids for digestion were done outside the LFH. House distilled water was deionized and then redistilled in an all glass still, therefore designated as glass distilled water. The nitric (16 M) and hydrochloric (6 M) acids were obtained from G. F. Smith Company. Both had been redistilled to assure a low metal content. The APCD was supplied by J. T. Baker Company, Phillipsburg, New Jersey.

33. All glassware was cleaned with hot nitric acid. Containers such as glass-stoppered test tubes were heated overnight in nitric acid. Distillation apparatus was cleaned by distilling nitric acid. The MIBK (4-Methyl-2 pentanone) was redistilled before use, and chloroform was twice distilled. Small Teflon vessels were heated overnight in nitric acid; large Teflon vessels were rinsed well with nitric acid.

34. Two percent APCD solution was prepared by mixing a weighed amount of APCD with 100 to 150 ml of water directly in a Teflon separatory funnel that had graduations marked on it. The APCD solution was cleaned by extracting twice with about 75 ml of MIBK. After shaking, the mixture was allowed to stand 4 hr or more or even overnight (until the lower, aqueous layer had become clear). The MIBK from the first extraction was discarded, but the MIBK from the second extraction was retained and used for the first extraction of the next batch of APCD solution. The APCD solutions have been reported as unstable with a slowly forming precipitate, and daily preparation of fresh solutions has been recommended; however, solutions used in this study showed little or no visible change within a week and were sometime 3 to 4 days old when used.

35. Samples of interstitial water (about 30 g) or seawater (about 500 g) were weighed into 125- or 1000-ml separatory funnels. Then 15 to 20 ml of 2 percent APCD solution was added to each sample. Using narrow range (3.0-5.5/6.0-8.0) pH paper, the pH of the mixtures was adjusted to pH 3.5 to 4.5 to ensure proper extractions. The pH was adjusted with hydrochloric acid and ammonia gas. Interstitial water mixtures were acidified until a persistent precipitate (pyrrolidine carbodithioic acid,  $pK_a \sim 3.2$ ) formed. Acid did not precipitate from the seawater sample

mixtures, probably because of the much greater dilution. The mixtures were extracted twice with 20-ml portions of chloroform, and the extra counts from each sample were combined in a Teflon beaker.

36. Colors sometimes developed after the APCD was added to the water samples. These colors, which ranged from pink to blue grey, were extracted into the chloroform phase and thereby considerably intensified. The removal of all the color from the aqueous phase by the first extraction indicates that the extraction of the color that caused pyrrolidine carbodithioate complexes is very efficient. In some early separations, when pH was not adjusted, even repeated extraction did not completely remove the color from the aqueous phase.

37. The beakers were placed in a glass evaporation vessel shaped somewhat as a small dessicator. The hemispherical cover was fitted with four vertical 10/30 standard taper inlet ports for adding reagents to the four Teflon beakers in the evaporator. A 29/42 outlet port in the center of the cover was fitted with a downward sloping glass exit tube that served as an air condenser. The bottom and the cover of the evaporation vessel were heated with electrical mantles. Heating tape was used to heat the vertical part of the exit tube.

38. Nitrogen was passed through a membrane filter (0.8- $\mu$ m pores, 13 mm diameter, Swinnex-Milipore holder) and introduced into the evaporator through one of the inlet ports. The other parts were closed with 9-mm glass stoppers except when materials were being added. The nitrogen flow was monitored by having the end of the exit tube submerged a few millimeters in an 800- or 1000-ml beaker of water.

39. The heater controls for the mantels for the cover and bottom of the evaporator were of the proportional on-off type. To shorten the warm-up time, the controls were initially set at a higher setting. After 20 to 30 min, the controls were set back to a moderate setting. After the chloroform had all been removed, the controls were moved back to a slightly higher setting. The residues left after evaporation of the chloroform were digested with a mixture of nitric and hydrochloric acids. Pipetors fitted with Teflon tubes as tips were used to transfer

1 ml of nitric acid and 0.1 ml of hydrochloric acid to each of the Teflon beakers. The entire evaporator was then moved or shaken to ensure that the liquid rinsed the entire bottom of the beakers. Digestions were completed when the residues were small and light colored. Frequently five or more treatments with the mixed acids were required to achieve this, and even then a light-colored residue was not always obtained.

40. After digestion, the evaporators were returned to the LFH. After the beakers were removed from the evaporator, 0.1 ml of nitric acid was added to each beaker. The acid was swirled around the beaker to dissolve as much as possible. Then 1 ml of water was added to each beaker, swirled around to mix with the acid, and the solution then transferred to a weighed 13- by 100-mm glass-stoppered test tube. The beaker was washed twice more with nitric acid and water, as before, and then once with 0.1 ml of hydrochloric acid and 1 ml of water. The solutions from each beaker were combined in the same test tube which was then weighed and used for atomic absorption analysis. If the extract residues had not been properly digested, the residues were difficult to dissolve, and brown precipitates sometimes formed in the solutions that had been made up for analysis.

#### Atomic absorption methods

41. Trace metals analyses were determined by atomic absorption spectrophotometry (AAS) using a Varian-Techtron model AA-5R (modified) system. The AAS operating parameters used for each metal were similar to those recommended by the manufacturer.<sup>3</sup> Output from the AAS was recorded on punched paper tape and typed simultaneously using a Teletype terminal (model ASR33). The punched paper tape record served as the data file for computer processing using a Digital Equipment Corporation model PDP 11/5 computer system. Both flame and nonflame (electroheated carbon rod) spectrophotometric techniques were employed. The instrument precision obtained during analysis typically varied from 1 to 10 percent from flame analyses and from 5 to 20 percent for the nonflame analyses, dependent upon the element being analyzed and its concentration.

#### Grease determination

42. Sediment samples were stored at 4°C in clean glass jars. About 25 g of wet sediment was transferred to a beaker or wide mouth jar and mixed with 10 to 15 g  $\text{MgSO}_4 \cdot \text{H}_2\text{O}$ . The mixture was stirred manually until it was uniform and dry. This change required 5 to 10 min and was accompanied by a mild exotherm. The dry material was transferred to soxhlet extraction thimble and extracted 4 hr with refluxing hexane. The hexane was then evaporated with a water bath at 90°C, and the flasks were left overnight at room temperature before weighing. The use of blank extractions and control flasks kept the weighing uncertainty to 1 mg or less. Since the dry sample weight was about 20 g, the minimum detectable grease concentration was about 50 mg/kg (procedure adapted from APHA Standard Methods 209C).

#### Mercury determination

43. In this procedure mercury in sediment was determined by flameless atomic absorption following digestion with nitric acid. A sample of about 10 ml was taken from the freshly sectioned sediment core with an acrylic and Teflon minicorer and transferred to a glass bottle that was previously cleaned with nitric acid. Samples were preserved by freezing until analyzed. At the time of analysis, the samples were weighed into a 250-ml flask, mixed with 15 ml of Baker nitric acid ("Suitable for Hg Determination"), and refluxed for 3 hr. The liquid and suspended particulate were then decanted to a cleaned ( $\text{HNO}_3$  washed), 100-ml polyethylene or polypropylene bottle. The sediment remaining in the digestion flask was washed three to four times with water which is also decanted into the polyolefin bottle. The combined solutions were refrigerated until analyzed.

44. The solutions were analyzed for mercury by flameless atomic absorption. Five to ten milliliters of solution was weighed into an aeration tube and treated with 1 to 3 ml of a hydroxylamine-stannous chloride reducing mixture. Air flow through a fritted bubbler tube then carried the liberated mercury into the beam of the atomic absorption unit. The short-lived absorption signal was plotted on a chart recorder. Standard solutions prepared from certified reference solutions provided

the points for a calibration curve. In control runs with known quantities of inorganic mercury, recovery of mercury was quantitative.

#### Analysis of particulate samples

45. Seawater samples were filtered at sea through Nucleopore membrane filters (47 mm diameter, 0.4- $\mu$ m pore diameter). The wet filter membranes were placed in polypropylene counting tubes and stored in a freezer.

46. The membrane filters containing the particles were transferred to 13- by 100-mm glass-stoppered test tubes with the aid of polypropylene forceps and a glass rod, both of which had been cleaned with nitric acid. The test tubes had been cleaned by heating overnight in nitric acid. The unstoppered digestion tubes with the filters were treated with 3 to 4 ml of G. S. Smith redistilled nitric acid and placed in 600- or 800-ml beakers. The digestion tubes were supported by a glass cylinder inside the beaker that held the lips of the digestion tubes away from the beaker wall. The beaker was covered with an evaporating dish and placed on a Corning hot plate set at 2 or less. At this setting, the nitric acid evaporated without boiling. The nitric acid condensed on the evaporating dish and dripped from the center of the dish to the bottom of the beaker without any danger of falling into the digestion tubes, which were leaning toward the outside of the beaker. As heating continued, nitric acid slowly escaped from the beaker through the gap between the beaker and the cover dish.

47. If the nitric acid had not all evaporated in 3 days, the evaporating dish would have been replaced with a watch glass that allowed faster escape of the nitric acid. After all the liquid had evaporated, the residue was dissolved and suspended in a mixture containing 0.3 ml of 16 M nitric acid, 0.1 ml of 6 M hydrochloric acid, and 4.0 ml of water (final solution was 1.1 M  $\text{HNO}_3$  and 0.13 M  $\text{HCl}$ ). The residues and solutions varied in color from bright yellow to colorless. The cause of the color is unknown. Digestion of five unused filters in one tube gave only a very small grey-brown residue. Addition of water gave a colorless, apparently clear, mixture, but in some other digestions brown residues were formed. Addition of water to these gave yellow mixtures.

### Cation exchange capacity

48. Cation exchange capacity was determined for sediment samples recovered after interstitial water was separated by squeezing. The sediments, which had been stored at room temperature, were dried to constant weight at 70°C. The following procedure for measuring the cation exchange capacity was adapted from Jackson:<sup>4</sup> a total of 5.1 g of dried sediment (unground) was placed in a 90-ml centrifuge tube and then treated successively with 30- to 40-ml quantities of the following reagents:

2x: 1 N sodium acetate, pH 5, 30 min, 90°C

4x: 1 N  $\text{gCl}_2$ , pH 7

5x-7x: 80 percent acetone-water. Washing was continued until no turbidity resulted when  $\text{AgNO}_3$  was added to the clear wash mixture.

4x: 1 N sodium acetate pH 7

49. In each washing step of the procedure, the sediment and reagent were thoroughly mixed in the centrifuge tube with a mechanical agitator. After centrifuging 5 min at 2000 rpm, the clear liquids were decanted or sucked from the centrifuge tube with a large pipette, without disturbing the sediment. The sodium acetate pH 7 washings were combined and diluted to 250 ml. These solutions were then diluted 50x (equiv. volume: 12.5 l) and analyzed for magnesium by atomic absorption. Results of analysis as mg/l were converted to meq/g as follows:

$$\frac{\text{mg}}{\text{l}} (12.5 \text{ l} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ eq}}{12 \text{ g}} \times \frac{1000 \text{ meq}}{1 \text{ eq}}) = \frac{\text{meq}}{\text{g}} \quad (1)$$

## PART III: RESULTS AND DISCUSSION

### Water Column

50. Chemical and primary productivity parameters of the water column in the general region of the historic and experimental dredged material disposal sites cannot be analyzed with any reasonable precision without first accounting for the effects of the predominant physical factors in the region. Unquestionably, the primary short-term effect on the water column of the disposal site is the tidal effect. Secondly, the day-night cycle and local winds and currents might affect short-scale distributions. Long-term distribution of chemical and biological parameters will be affected by seasonal shifts in winds and currents. Although sediment and interstitial water samples are affected primarily by the cumulative effect of disposal activities over long time periods, water-column features respond rapidly to perturbations in the same time scale as individual disposal events (hours to days). Thus, it is of paramount importance to examine the water-column features in the time scale of hours and days. When this is done, changes in the physical environment emerge as the predominant influence on chemical and biological distributions, and the effects of discrete dredged material disposal events in the upper waters are minimal and ephemeral.

#### Physical factors at anchor stations

51. Hydraulics. The tidal effects can be pulled out of distributional data only when sequential sampling has been done at a fixed location over at least one tidal cycle. Several anchor stations were occupied for at least 26 hr (usually longer) during this study. Also, effects of day-night cycles were observed over this time period. Examples are shown of the changes in tidal velocity, tidal height, and solar radiation at the mouth of the Columbia River (1) during a period of maximum Columbia River flow (mid-June) at two anchor stations (Figures B10 and B11), (2) during a period of minimum Columbia River

flow (late August) at one anchor station (Figure B12), and (3) during a period of seasonal transition from summer to winter conditions (mid-October) at two anchor stations (Figures B13 and B14). One of the two anchor stations in mid-June and one of the two in mid-October were over (or near) the historic disposal site, while the other anchor stations of each pair were over the experimental disposal site (see cruise track in Figures B4 and B9). The late August anchor station was over the experimental disposal site (Figure B7).

52. Sampling times are marked in the two tidal cycles and radiation cycle for each anchor station. It should be noted that the maximum tidal velocities at ebb always occur about 2 hr before minimum tidal heights, and maximum velocities at flood also precede maximum tidal heights by about 2 hr. As will be noted in more detail later, the tidal activities computed at the Columbia River mouth for two sequential anchor stations at slightly different locations (different disposal sites) give somewhat different distributions of water-column properties at the two locations. Note also in Figures B10 and B14 that radiation inputs vary on different days, and maximal radiation input (near noon) for the different anchor station sampling days are phased differently with tidal velocities and heights.

53. The local winds during summer were primarily from the north or northwest and averaged approximately 6.69 m/sec. During October, winds range from northward to southward and are quite variable in speed. The local currents have such a huge tidal component that their own directional influence in the upper waters of the sampling area is almost completely masked on a short-term basis. In fact, effects of both local winds and currents cannot be observed unequivocally in the disposal area water-column data at any time of the year.

54. Hydrography. Plots of temperature, salinity, and percent light transmission for the anchor stations of Cruise Y7506 B-1 (Figure B4) are given as Figures B15-B20. It is immediately apparent that tidal effects were different at the two anchor stations. The influence of the tides was large at anchor station 1 (historic disposal site), particularly in the temperature and salinity data. Generally, the strongest

tidal effect was in the top 20 m for temperature and in the top 15 m for salinity. The temperature excursions with time and depth seem exactly in phase with tidal velocity maxima at anchor station 1: that is, highest surface temperatures and deepest subsurface penetration of high-temperature surface water coincide with maximum ebb tide velocities, while lowest surface temperatures coincide with maximum flood tide velocities. The salinity excursions mirror those of temperature, with the exception, of course, that low-salinity water is representative of river water and high-salinity water equates to ocean water. No obvious phased heating effect (from radiation input) was observed in the temperature plots, indicating that tidal mixing was the predominant physical effect in this region.

55. The percent light transmission of the surface water at anchor station 1 was related most directly to tidal height extreme (or slack periods), not tidal velocity. The "dirtiest" water was always found at the surface, and the deepest subsurface penetration of that dirty water (transmission < 1 percent) coincided with minimum tidal height (maximum Columbia River contribution at the anchor station). The maximum penetration of relatively clean ocean water (10 percent transmission) from middepth into the surface layers seems to coincide best with the maximum tidal height, or flood slack, but could be due partly to river-induced upwelling of cleaner water at depth. Pockets of cleaner water embedded in dirty water at 5- to 10-m depths probably reflect cleaner flood-tide boluses that have been insufficiently mixed with ambient surface waters. Their appearance always corresponded to maximum flood-tide velocities. Instantaneous mixing of waters of greatly different densities was not expected. Surface-ward extensions of cleaner water from the bottom layers usually could be matched with the timing of flood slack periods, and the dirtiest bottom water generally coincided with ebb slack periods; however, the correlations were not very good and there was some indication in later nutrient data that the clean water may be river-induced upwelled water.

56. The tidal effect was much less at anchor station 2 (near experimental disposal site) (Figures B16, B18, and B20) than at anchor station 1, and the oceanic effect was greater. This situation is likely caused by the south jetty, which offers some protection from river effluent. Surface temperatures and percent transmission values were lower, and surface salinities were higher. Salinities below about 7 m were oceanic, with some upwelling influence. The surface responses of hydrographic features to tides generally did not appear to penetrate deeper than 5 m (even though anchor station 2 was located in only 30 to 35 m of water). The maximum ebb tide velocity was associated with intrusions of somewhat dirtier water from the bottom layers (Figure B20), a situation somewhat dissimilar to that at anchor station 1 (Figure B19). At anchor station 1, tidal action (and perhaps river-induced upwelling) apparently brought slightly cleaner water into a dirtier ambient background, while at anchor station 2 ebb tides appeared to release slightly dirtier water into a comparatively clean background. Dredged material disposal thus might affect the two sites differently at depth, depending on the timing of the disposal.

57. On Cruise Y7508 D-1 (Figure B7), an anchor station was sampled on 25-27 August 1975, at the location of the experimental disposal site. This time of year corresponds to minimum Columbia River flow, and the relationship between tides and hydrographic variables was somewhat different from maximum flow conditions in June (Figures B12, B21, and B22, compared to Figures B11, B16, and B18). Water temperatures were higher in August, as expected, while salinities were higher at the surface, but lower at depth than in June (i.e., there was less vertical gradient in August). The site still appeared to be dominated by oceanic water in August, however. The timing of higher temperature ( $14^{\circ}\text{C}$ ), lower salinity ( $29 \text{ }^{\circ}/\text{oo}$ ) water at the surface in August was not strongly related to either tidal velocity or tidal height. This is probably the result of low Columbia River flow, the position of the station with respect to the south jetty, and greater contributions of inertial motions and surface currents. The incursion of colder, saltier subsurface water

into surface waters was directly related to the timing of maximum ebb tide velocity, however, which apparently reflects compensatory shoreward movement of subsurface oceanic water at ebb, i.e., river-induced upwelling. Light transmission data were not available for this August cruise.

58. Anchor station 1 in October 1975 (Figure B9) was located at the experimental disposal site, in 25 to 30 m of water. Temperatures were quite uniform, surface to bottom (Figure B23), a result of seasonal decay of the thermocline (caused by surface cooling and increased convectional mixing and wind mixing). The extraordinarily low surface salinity (6 ‰) coincided with maximum ebb velocity (at 0500 hr), but the low-salinity feature did not repeat at the next maximum ebb velocity (at 1700 hr) (Figure B24). Interestingly, the region was predominately river influenced on 20-22 October, with few salinities above 32 ‰. Consideration of the time series of temperature and salinity data suggests patches of Columbia River water moving through a generally well-mixed region. The nutrient data, however, suggest more structure than this and are further discussed below.

59. Anchor station 2 in October 1975 (Figure B9) was over the historic disposal site in about 45 m of water. Basically, the region was not as well mixed as anchor station 1, with slightly warmer, fresher river water penetrating the surface in reasonable phase with minimum tidal height (not velocity) (Figures B25 and B26). The coincidence with tidal height is not perfect, although the association of salinity and nutrient distribution is very close. Near-surface temperature differences were slight in mid-October, but salinity differences were still large. Salinity was the most conservative hydrographic property through the seasons.

#### Chemical factors at anchor stations

60. Nutrients. Nutrients in surface waters at anchor station 1 in mid-June (Figure B4) reflected tidal height (or at least slack periods) more than extremes in tidal velocities (Figures B27-B30). Lowest values for  $\text{NO}_3$ , total N,  $\text{PO}_4$ , and total P at the surface always coincided with maximum tidal height (or with flood slack periods), indicating that

the surface ocean water adjacent to the Columbia River mouth (over anchor station 1) was relatively low in nutrients. The sharpest gradients with depth also occurred at maximum tidal height, indicating that deeper ocean waters (below about 15 m) remained enriched in nutrients at high tide. At the lowest tidal height (or during ebb slack), nutrient concentrations at anchor station 1 were high and nearly uniform surface to bottom. Later data will show that the water entering the sea from the estuary is low in  $\text{NO}_3 + \text{NO}_2$  and  $\text{PO}_4$  (but not  $\text{SiO}_4$ ). Entrainment of the deep, nutrient-rich water to the surface during ebb is responsible for the nutrient distribution at anchor station 1 during this time. It should be reiterated that maximum ebb velocities, which distribute low-salinity high-temperature water over anchor station 1, did not coincidentally distribute low nutrient levels over the station, as might be expected and might first appear from a casual examination of Figures B15, B17, and B27. There was an offset of about 4 hr between the salinity-temperature signature and the low nutrient signature over anchor station 1. This feature was seen most clearly in the nitrate data [particularly during the earliest anchor station times (Figure B27)], compared with the salinity data (Figure B17). Such patterns again suggested large contributions from deep waters entrained to the surface at ebb tide.

61. At anchor station 2 in mid-June, over the experimental disposal site, the pocket of low-nutrient surface water between midday and midnight on 18 June 1975 was the most obvious feature (Figures B31, B32, B33, and B34). This feature was due to biological uptake during and succeeding a day of relatively high radiation at this ocean-influenced station. Plots of pH,  $\text{O}_2$ , chlorophyll a, and particulate carbon tended to verify this interpretation, as they were all high during this time period. The fact that the core of the low-nutrient surface patch is rather broad and did not coincide with tidal fluctuations further implicates the radiation cycle and biological influence. As suggested earlier, the surface waters of the experimental disposal site in June did not appear to be greatly affected by river effluent since there was

no strong tidal signature. The appearance of relatively nutrient-poor water at the bottom was reasonably associated with lowest tidal height or ebb slack, supporting the idea of some ebb tide effect at this station; however, the correlations with all nutrients are not perfect.

62. In late August, at the experimental disposal site, there was a noticeable tidal effect in the nutrient data (Figures B35-B38), just as some tidal effect appeared in the temperature and salinity data. Highest nutrient levels in surface waters correlate well with maximum ebb velocities, and lowest surface nutrients fit well with maximal flood velocities. This fit actually is better in the nutrient data than in the hydrographic data. Again, oceanic water with a high vertical nutrient gradient (low in surface, high at depth) appeared to oscillate across the disposal site in phase with the flood tide, while the ebb tide brought higher surface nutrients by entraining deeper oceanic water into surface layers.

63. In October, the nutrients in the water columns at both anchor stations were lowest at middepths: that is, values near the surface and bottom were higher than values at intermediate depths (Figures B39-B46). These distributions prevailed even though temperatures and salinities continuously increased with depth (temperatures were actually quite uniform, with only slight increases with depth). Such nutrient distributions indicated that vertical structure was still evident, though perhaps ephemeral, during this transition season. Such structure, when present, was undoubtedly maintained by salinity gradients (Figures B24 and B26) not temperature (Figures B23 and B25). The slight vertical structure in the nutrient field apparently was tidally influenced. Nitrate-nitrite over the experimental disposal site, for example (Figure B39), showed two high concentrations at the surface (at about 0400 and 1800 hr), in reasonable agreement with high ebb velocities. Similarly, incursions of bottom nutrients into middepths cooccurred with high ebb velocities, lending further support to the idea of deeper water entrainment during ebb. The surface minimum and low water-column values at about 1200 hr and before coincides with flood tide features. Although

sample coverage was poor for the flood tide between about 2000 and 0100 hr, the water-column values tended to be lower than the ebb tide values at about 0400 hr. Similar surface features were noted over the historic disposal site in October (Figure B40), except that the higher nitrate surface pulses were more directly related to minimal tidal height (ebb slack).

64. pH. The pH values of natural waters have often been used as indicators of river-ocean mixing; in fact, Park<sup>5</sup> has used pH to trace the Columbia River plume in the ocean off Oregon. Generally, upwelled water and near-bottom water with much organic decomposition will have relatively low pH values (near 7.5), open-ocean surface water will be near pH 8.2, and surface water near the Columbia River mouth will be around 8.0. As suggested above, pH is a function of biochemical processes (production and decomposition) as well as the carbonate chemistry and general mixing of water types.

65. Generally, the pH time series mirrored the hydrographic picture at anchor station 1 in mid-June (Figure B47): that is, river-affected surface patches (pH 8.0) appeared in conjunction with maximum ebb tide velocities, while deeper waters with pH 8.0 appeared over the station in conjunction with maximum flood tide velocities. Interestingly, the pH time series over the experimental disposal site in June (Figure B48) showed more structure than the corresponding temperature and salinity series (Figures B16 and B18) and was more allied to the nutrient series (Figures B27 and B33, for example). The pocket of pH 8.0 water at the surface between 1600 and 2400 hr corresponded to a low-nutrient, high-oxygen patch (presumably biologically affected). Higher-than-ambient pH often reflects rapid removal of CO<sub>2</sub> from surface waters via photosynthesis. Without this patch in the series for pH, nutrients, and oxygen (see later), the upper waters would be quite uniform. Little or no surface tidal effects were observed, similar to the hydrographic series.

66. As expected, the pH data for the experimental disposal site in late August (Figure B49) reflected the same trends as the nutrient data. However, at this disposal site, lowest pH values at the surface were associated with maximal flood velocities. This was the reverse of the relationship at anchor station 1 in June. The pulsing of higher pH, oceanic surface water across the shallower disposal site in August probably reflected the higher biological productivity (and/or lower biological decomposition) in the oceanic surface waters relative to both the river-influenced water and the deeper water entrained to the surface during maximum ebb. The highest pH values thus appeared to represent different events at different stations at different times of year, and because of this the values may not be a very dependable diagnostic tool.

67. During October, the mixing of the water columns at both anchor stations was reflected in the rather uniform pH values (Figures B50 and B51). The appearance of slightly higher pH values at intermediate depths (relative to surface and bottom values) likely was related to the nutrient minima at intermediate depths. Unfortunately, no direct productivity or biomass estimates were made in October, but a slight enhancement of biological activity in the water found at mid-depths over both anchor stations was suspected.

68. Dissolved oxygen. Dissolved oxygen levels reflect biological activity as well as atmospheric exchange and mixing of water types. Well-oxygenated surface water ( $> 6$  mg/l) at first appeared to have its deepest penetration at maximal ebb velocity at anchor station 1 in June (Figure B52), although detailed study of the first 24 hr revealed that the most highly oxygenated water near the surface (10 mg/l) was likely a result of ocean-dominated flood tides (correlation of maximum oxygen values with flood slack times, or maximal tidal heights, was good over the initial 24 hr). Maximum surface-ward extension of poorly oxygenated bottom water at first appeared to match maximum flood tide velocity, but closer examination suggested that the relationship was best with minimum tidal height, or ebb slack. The oxygen data generally seem to

corroborate the nutrient and percent transmission data: ocean water with steep vertical gradients was moved over anchor station 1 in June at flood tide, while low oxygen water entrained from depth (with little gradient) was brought to the surface by ebb flow.

69. The higher surface oxygen values at anchor station 2 in June (Figure B53) appeared to be due to photosynthetic activity, although no explanation was found for the low surface values observed in one case at 1500 hr, other than a possible ebb slack feature. Generally, the high surface oxygen levels corresponded to the low nutrient levels during the same general time period.

70. Excursions of well-oxygenated surface waters to depth corresponded with maximum flood tide velocities in late August at the experimental disposal site (Figure B54). Similarly, incursions of low-oxygen water toward the surface corresponded with maximum ebb velocities. These data are entirely consistent with the nutrient and pH data for the same station.

71. The deep mixing of the water column in October at both anchor stations was exemplified by the uniform distribution of high oxygen values (Figures B55 and B56). No coherent tidal effects could be seen, with the possible exception of the movement of the 7 mg/l isoline at the historic disposal site on 22-23 October. Sampling frequency was low, however, and the effect was so diffuse as to be uninterpretable with respect to exact tidal phase.

#### Biological factors at anchor stations

72. Biomass indicators. Chlorophyll a concentrations are often used as estimates of living phytoplankton biomass, although it is suggested that such concentrations are really indicators of potential productivity rather than biomass. Chlorophyll a actually represents only a few percent of the organic fraction of living cells, by weight, and its concentration in the water column is strongly dependent upon the light field (being deeper during days of high light and shallower during nights and periods of low light). The phasing of chlorophyll a

and nutrients (nitrate + nitrite, for example, in Figure B27) at the historic disposal site was interesting. Maximum nutrients were available in surface waters during ebb slack periods and were lowest at flood slack. Maximum chlorophyll a was found at maximal flood velocities and was lowest at maximal ebb velocities. Thus, the ebb tide was most responsible for making nutrients available in upper waters at this disposal site in June, but the flood tide brought in the highest concentrations of phytoplankton pigment. The induction of deep-water nutrients in phytoplankton-rich waters of oceanic origin, via the ebb tide, must be the primary mechanism of maintaining the very high "oceanic" chlorophyll a levels in the region (Figure B57).

73. Particulate carbon is a measure of the total amount of carbon as particles, living or dead. At the surface of anchor station 1 in June (Figure B58), lowest concentrations ( $< 600 \mu\text{g}/\ell$ ) were reasonably well associated with maximum flood velocities. The very high concentrations at 10 m, and the values greater than  $600 \mu\text{g C}/\ell$  at the surface, were generally related to the ebb tide. Near-surface concentrations were highly variable, however, with patches of high and low carbon apparently entrained into nonorigin waters. The fact that high particulate carbon loads come from the river and the lower concentrations are oceanic becomes clearer when one examines the oscillations in the intermediate and deeper waters at the historic disposal site. The downward projection of the  $600\text{-}\mu\text{g C}/\ell$  isoline, for example, exactly matched maximum ebb velocities at about 2200, 0900, and 2300 hr, and suggested a generally "dirtier" water column at ebb. The higher carbon loads were likely due to direct river contribution rather than roiling of the ocean bottom sediments. Upward excursions of low-carbon bottom water tended to be related to maximum flood velocities, to yield a generally "cleaner" water column at flood. The opposite oscillations of particulate carbon and chlorophyll a in midwaters and bottom waters were noteworthy and indicated that particulate carbon generated by the ebb tide was largely non-chlorophyllous. In the near-surface waters, some of the high chlorophyll concentrations matched high carbon

concentrations, and some did not. The concentrations of chlorophyll a were thus not reliable indicators of heavy particulate loads in this region of high river runoff.

74. The surface chlorophyll a over the experimental disposal site in June (Figures B59) was also patchy. The distribution appeared on first look to be a function of the light field interrupted by maximum tidal velocities. Thus, the higher surface values ( $> 9 \mu\text{g}/\ell$ ) generally corresponded to the brightest daylight portions of 2 days (Figure B11), interrupted at 1200 hr by low-chlorophyll waters associated with maximum ebb velocity. Concentrations remained above  $6 \mu\text{g}/\ell$  through the night except where possibly interrupted at about 1800 hr and 0100 hr by maximum flood and ebb velocities, respectively. The lack of repetition of this pattern on 19 June made such speculation very tentative, however, and it was just as possible that the patchy conditions were not only functions of light, nutrients, and water motion, but also were caused by exact ship position relative to very small-scale patches. The fact that similar distributions did not show up in the percent light transmission data (Figure B20), the nutrient data (Figure B31, for example), or the particulate carbon data (see later) suggested that chlorophyll a was not a particularly good indicator of particle concentration in this region at this time of year.

75. The particulate carbon series at anchor station 2 in June (Figure B60) reflected the same surface distributional features as nutrients, with high carbon levels ( $> 700 \mu\text{g}/\ell$ ) overlapping low nutrient levels. There was some superficial similarity to surface chlorophyll and oxygen distributions. Bottom concentrations were hard to interpret, although the lowest values up to 2400 hr ( $< 150 \mu\text{g C}/\ell$ ) were somewhat related to the timing of flood slack. Particulate carbon and chlorophyll were both very patchy and were probably too sensitive to diel light periodicity and other time-space sampling problems to be very useful in assessing general particle distributions in some areas. Percent light transmission values likely give a more conservative, integrated picture of these distributions.

76. Certainly the most coherent picture of hydrographic, chemical, and biological features in surface waters occurred at the experimental disposal site in late August (Figures B61 and B62). Highest chlorophyll a and particulate carbon values were highly associated with the nutrient, oxygen, and pH data. There was little question that high primary production was associated with the more oceanic water flooded over the station, and low primary production was associated with the ebb tide.

77. The biomass data for the October stations (not pictured) reflected the uniformly mixed water columns which appeared in the other measurements. Both chlorophyll a and particulate carbon were randomly distributed, with somewhat higher concentrations in surface waters, but not nearly the gradients observed in the June and August data.

78. Biological "health" and rate indicators. Whereas chlorophyll a and particulate carbon might be reasonable, though different, estimators of biomass, they give no direct insights into the viability of phytoplankton stocks. At several of the anchor stations time series of carbon/nitrogen (C/N) ratios and potential primary productivity rates were determined. It must be kept in mind that C/N ratios of healthy cells will range between about 5 and 8, with ratios above 8 indicating either moribund or dead cells, or a substantial contribution of carbon-rich detritus in the sample. Ratios between 5 and 7 denote particularly clean, viable samples. Chlorophyll-specific potential productivity is an estimate of the rate of carbon incorporation per unit of chlorophyll at a standard light level. Nighttime values of this rate were obviously potentials, since no sunlight was available to actually stimulate photosynthesis in the field. Daylight values were estimates of the actual productivity rates at the field light levels simulated by the standard light. Carbon-specific potential productivity was identical to chlorophyll-specific productivity except the rates were normalized by particulate carbon concentrations in the water rather than by chlorophyll a concentrations. Carbon-specific rates should refer mainly to viable cells when comparable C/N ratios are below 8.

79. Interestingly, all particles in the lighted upper waters (above 20 m at anchor station 1 in mid-June (Figure B63) had C/N ratios below 8.

Nevertheless, some pattern was observed, with C/N ratios  $> 7$  at the surface being closely associated with the ebb tide, and C/N ratios  $< 7$  at the surface matching the flood tide. The boluses of very low C/N ratios ( $< 6$ ) at 10 to 15 m appeared to be an intermediate depth feature not expressly related to tidal heights or velocities. They possibly were related to flood slack periods, but the association was not very precise. These values also did not appear to be related to chlorophyll distribution. They were related to the presence of low-particulate-carbon water near the surface (Figure B58), which, as mentioned earlier, was probably a flood tide feature.

80. The most illuminating measurements of phytoplankton viability appeared to be the potential productivity series (Figures B64 and B65). Particularly, the carbon-specific rates (Figure B65) appear well related to tidal events. The cores of highest potential productivity at 10 m were all associated with the flood tide, while the lowest surface values were correlated with the ebb tide. The rate differences were large between the two alternating tidal regimes. Thus, particulate carbon of oceanic origin must be largely viable organisms, while particulate carbon associated with the ebb tide must be largely detritus. Intrusions of unproductive water from the bottom toward the surface also indicate phasing with the ebb tide, particularly ebb slack (Figure B65).

81. Chlorophyll-based potential productivity (Figure B64) does not present a picture quite as clear as the carbon-based rates. The surface patterns mainly subscribed to the ebb-flow cycle, but the core of the vertical patch of high values at about 0800 hr was displaced somewhat from the flood tide period from which it presumably was derived. The corresponding carbon-based data were also more diffuse at this flood period (Figure B65).

82. The C/N ratios for anchor station 2 on 18-19 June gave very little information, except that surface waters above 10 m generally had ratios around 7 and bottom waters had higher ratios (Figure B66). Unfortunately, specific productivity measurements were not made with enough regularity to construct plots for this station.

83. The C/N ratios in August indicated a water column with viable phytoplankton throughout (Figure B67). Ratios seldom exceeded 8, and then only near the bottom. Particles with ratios below 6.5 comprised a band with its lower threshold 10 to 15 m deep and its upper threshold 0 to 10 m deep.

84. Analysis of selected stations other than anchor stations. Since the tidal and river influences are very strong, particularly during periods of high river flow, analyses of cruise data (other than those data at anchor stations) were difficult. Maximum variability in data sets as a result of river flow should occur in June. Analysis of data from cruise Y7506 B-1 (Figure B4) indicates some consistently large differences in measurements; however, subtle changes are lost in the variability. Certain data sets along selected transects in June were examined irrespective of tidal or solar phase and irrespective of time order of station sampling, to determine the major differences between ocean surface water and river water. The first transect began in the Columbia River and proceeded into the ocean down the approximate axis of the river outfall at sea. Plots of salinity, temperature,  $\text{NO}_3 + \text{NO}_2$ ,  $\text{PO}_4$ ,  $\text{SiO}_4$ , and chlorophyll a against distance along the transect line are shown in Figures B68-B73. Only depth intervals to 20 m were used, as depths below 20 m have largely oceanic water. The stations used for the plots can mainly be seen in Figure B4, and are, in order: 31 (not shown), 30 (not shown), 29, 28, 27, 10, 35, 34, 33 (not shown), and 32 (not shown).

85. As expected, the salinity transects showed the most change (Figure B68). Stations 28-31 indicated maximum change due to tidal phase and are shown mostly at ebb tide. Surface water (0.5 m) never gained full oceanic salinity (> 32.5 percent) at the most offshore station (32), while waters below 5 m reached oceanic salinities by station 35. Note that the location of the historic disposal site (disposal site B) was near a surface salinity maximum, possibly due to a tongue of oceanic water which was deflected seaward off Cape Disappointment by the prevailing northerly winds, or due to river-induced upwelling, or both. The temperature data reflect this possible surface-water deflection,

also, with minimum surface temperatures near the location of disposal site B (Figure B69). The region of maximum temperature and salinity gradient appeared to be between stations 28 and 29: i.e., the main front between river and ocean waters. The nutrient data responded somewhat differently. Maximum fluctuations in nutrient values generally occurred from the river mouth to station 34 (Figures B70, B71, and B72). Seaward of station 34 nutrient values were low (lowest at 5 to 10 m due to production and usually highest at depth). In the estuary (stations 28, 29, 30, and 31)  $\text{NO}_3 + \text{NO}_2$  and  $\text{PO}_4$  concentrations tended to increase to maxima at the river mouth, but  $\text{SiO}_2$  concentrations were obviously of river origin and decreased rather systematically from the most up-river station to the river mouth. Chlorophyll a (Figure B73) was in extremely high concentration in the river, but dropped precipitously in the estuary and was relatively low at the river mouth. Note that surface chlorophyll a tended to be higher near disposal site B than at the river mouth or offshore, a fact which may lead to some faulty generalizations about the oceanic productivity in the general area (see discussion of chlorophyll a data at anchor station 1 in June).

86. Usually the same types of plots as above for other times of year show the same features at disposal site B, but with less difference between estuarine and oceanic water due to lower river contributions to the area and/or more wind mixing. At the experimental disposal site, data not normalized in any way showed discernible river effects only in the top 5 to 10 m in all seasons except possibly late summer (as indicated in the anchor station analyses).

87. Plots of various measurements against salinity gave definite signatures for totally oceanic regions, estuarine regions, and transition regions. This can be seen in plots for June (Figures B74-B77). Station 3 (Figure B4) is not river-influenced, as salinities at all depths vary only between 33 and 34 ‰. Temperature, nutrients, oxygen, pH, and chlorophyll a (and other measurements) vary along this narrow salinity range (Figure B74). Temperature varied by surface heating and cooling and through upwelling; nutrients varied through biological uptake and upwelling input, and so on. Station 28 (Figure B4) is in the

estuary, and the tidal influence is obvious. There was a wide salinity range, with  $\text{NO}_3 + \text{NO}_2$  and  $\text{PO}_4$  increasing with increasing salinity (at least to 32.5 ‰),  $\text{SiO}_4$  and temperature generally decreasing with increasing salinity (Figure B75). The  $\text{SiO}_4$  data generally reflected the river origin of  $\text{SiO}_4$ , but the  $\text{NO}_3$  and  $\text{PO}_4$  data indicated that the river was not the major source of these nutrients seaward of the river mouth. Rather, river-induced upwelling must have been the source of nutrient-rich water near the surface at the historic disposal site in June. Low oxygen levels and low pH values were found at all salinities at this station, perhaps reflecting the decomposition and respiration of bottom waters generally out of contact with the surface (Figure B75). The highest chlorophyll a concentration at 15 to 20 m (at about 32.7 ‰) was the seaward middepth chlorophyll maximum which was moved into the estuary on the flood tide. This again suggested that oceanic chlorophyll is in higher concentration than estuarine chlorophyll (although extraordinarily high pigment values have been noted in the river itself).

88. Station 10 was near the historic disposal site (Figure B4). Its temperature and nutrient signatures with salinity indicated transition between oceanic and estuarine waters (Figure B76). The most striking salinity increase occurred in the 0- to 5-m depth layer, on the average, and this strong salinity gradient was related to declines in the nutrients. There was little change in temperature. At depths below 10 m, salinities stabilized fairly well, nutrients increased with depth, and temperature decreased. The 5- to 10-m layer is a strong transitional layer basically separating surface estuarine input from deeper oceanic water. The oxygen and pH data also go through a transition (Figure B76), but the chlorophyll data showed an extraordinary concentration in the surface layer and much lower values at depth. Whether this chlorophyll value was an artifact or an intense, isolated patch is unknown. There was no hint of high chlorophyll at station 28 at 25 ‰ salinity (Figure B75). The high value, if real, was not estuarine input, but was the response of an oceanic population to the relatively warm, high-nutrient water mixed over the station at that time.

89. Finally, station 34 was chosen as a more seaward station than station 10, but one that still experienced river effects (Figure B4). The most obvious differences between stations 34 and 10 were in the nutrient and chlorophyll data in the 0- to 5-m layer. All nutrients were low near the surface at station 34, reflecting intense biological usage prior to the water reaching station 34 (Figure B77). The high chlorophyll value at station 10 thus might not have been an artifact. The low concentrations of chlorophyll in surface waters at station 34 undoubtedly reflected the nutrient insufficiency in these waters (Figure B77).

90. There are many possible plots that could be drawn, but a particularly useful series to contrast to the June stations above came from a transect across the axis of the Columbia River outfall during the low river flow (Figures B78-B86). Stations 9, 8, 7, 6, 5, 4, 3, 2, and 1 in September 1974 (Figure B1) are across the river effluent area. Stations 4, 5, and 6 are over historic disposal site B, with station 6 being very close to station 10 on the June cruise. Station 1 was somewhat "protected" by the south jetty and may be comparable to the experimental disposal site.

91. Temperature as a function of salinity along the arc of stations does not begin to change until station 6, whence slightly cooler, more mixed water was observed (Figures B78-B86). By stations 3 and 2, surface waters were about 3°C colder at the surface (less saline waters). Station 1 had a large temperature gradient, with high (19°C) temperature near the surface and low (9°C) temperature at depth. Station 1 was the "jetty-protected" station; stations 2 and 3 received maximum river water (colder than ambient seawater); lesser river contribution was present at stations 4, 5, and 6; and stations 7, 8, and 9 were probably affected by river flow only to a minor extent. The Columbia River outfall apparently had not begun to swing north along the coast by 27-30 September 1974.

92. Note that  $\text{NO}_3 + \text{NO}_2$  and  $\text{PO}_4$  levels generally were somewhat lower than in June, and  $\text{SiO}_4$  concentrations were about half those in

June, or less (Figures B78-B86). The characteristic pattern of  $\text{SiO}_4$  as a function of salinity changed with river influence. Stations 9, 8, and 7 displayed one general pattern, stations 5 and 4 another, stations 3 and 2 yet another, and perhaps station 1 a fourth pattern. Although concentrations of all nutrients were low (due to low river flow, biological production, and lessened river-induced upwelling), the levels in surface waters (particularly  $\text{NO}_3 + \text{NO}_2$ ) were excessively low (and probably severely limiting to phytoplankton growth) only in the "most oceanic" areas (stations 9, 8, 7) and in the surface waters of station 1. Plots for ammonia in the water column through the station series are shown in Figures B78-B86 (note scale change). Ammonia values were low at the surface at station 9 but in higher concentrations particularly at the edge of the river outfall axis. At station 9,  $\text{NH}_3$  levels were highest in the most saline water, while the reverse is generally true at the other stations. The high  $\text{NH}_3$  concentrations at the stations in and near the outfall axis could have been due to estuarine contribution, in situ zooplankton excretion or both.

93. Little new information was gained from pH, and little information was gained from chlorophyll a and oxygen except possibly at station 1 (Figure B86). At this station, note the high levels of oxygen and chlorophyll a at about 29 ‰. The relatively low oxygen and chlorophyll values at 25 ‰ reflected the higher  $\text{NH}_3$  values at that salinity. It should be noted that in the 25 to 32 ‰ salinity range chlorophyll a was, on the average, somewhat higher at station 9 and 8 than at stations in and near the outfall axis; however, the highest average chlorophyll concentrations were found at station 1. The somewhat protected position of station 1 undoubtedly helped provide a less turbulent environment for culture of phytoplankton. The increased concentrations of chlorophyll a at station 1, and to a lesser extent at stations 8 and 9, could be related to the lesser quantities of the total inorganic nitrogen ( $\text{NO}_3 + \text{NO}_2$  and  $\text{NH}_3$ ), but the dynamics of nutrient uptake by large phytoplankton stocks were really not interpretable from biomass and nutrient concentration data, particularly when the effect of zooplankton (grazing and  $\text{NH}_3$  excretion) has not been assessed and in

regions of rapid change and patchy distributions.

Summary of water-column results

94. During the period of major Columbia River runoff (June), the historic disposal site (disposal site B) was in the immediate path of the river effluent, whereas the experimental disposal site was somewhat sheltered by the south jetty. Hydrographic, chemical, and productivity features of the two sites were different during this time of year.

95. There was great tidal and river influence at disposal site B in June, and there was much less tidal effect and more oceanic influence at the experimental disposal site. Hydrographic features (temperature, salinity, and percent light transmission) at disposal site B were exactly in phase with tides down to the 15- to 20-m depth. Temperature was highest, salinity was lowest, and percent light transmission was lowest at ebb, while the reverse was true at flood tide. Lowest surface pH was associated with the intrusion of bottom water into near-surface water, and this seems to occur as a result of river-induced upwelling. The largest nutrient concentration gradients with depth (low values at the surface, high at depth) occurred in phase with the flood tide at disposal site B and it appeared that the dissolved oxygen data and the percent light transmission data also had their highest vertical gradients on the flood tide. With oxygen, however, the highest concentrations appeared at the surface and the lowest at depth, the reverse of the nutrient and percent light transmission profiles. River-induced upwelling, on the ebb tide, appeared to reduce the vertical gradients at disposal site B. Highest concentrations of chlorophyll a were associated with the flood tide, although the depths of the very highest concentrations seemed to have been mediated by the solar cycle (highest concentrations appeared deeper the more intense the surface radiation). Interestingly, the highest concentrations of particulate carbon were more reasonably associated with the ebb tide, which suggested that the river brings detrital, less chlorophyllous matter to the sea surface at ebb, and the ocean delivers chlorophyllous, lower detrital material over the station at flood. Generally, carbon/nitrogen ratios of surface-ocean-derived particulate matter were lower than those at ebb tide

(indicating the lower detrital component and/or better "health" of the surface oceanic phytoplankton). Unquestionably, the productivity per unit biomass at a single light level was highest in flood-tide waters and lowest in ebb-tide waters at disposal site B.

96. The more general oceanic influence at the shallower but jetty-protected experimental disposal site in mid-June was shown by the less severe river effects. Tidal effects penetrated the surface to only about the 5-m depth in the temperature and salinity data. The nutrient, pH, oxygen, and biological data all suggested patterns which were controlled primarily by the diel radiation cycle (biological uptake and release) rather than river effluent. Some effect of the ebb tide might have been observed in the percent light transmission data near the bottom at the experimental disposal site, with river discharge water tending to be moved into clearer ambient water at ebb. In contrast, at disposal site B, which was located in the axis of the river effluent, tidal action tended to bring cleaner water into an ambient field of river discharge water.

97. During the period of lowest effluent from the Columbia River (late August), the jetty-protected experimental disposal site was more affected by the river than during June. Undoubtedly this phenomenon was due to the fact that the river flow had less force and therefore less directional thrust into the sea in August. Flood and ebb tide effects were easily observed (though less dramatic than at disposal site B in June). Highest particulate carbon and chlorophyll concentrations at the surface fit well with low nutrient, high pH, high oxygen patches, and these patches were in phase with the flood tide. High primary production was thus associated with the surface oceanic water over the station, and low productivity was associated with the ebb tide (which induces deep ocean water to the surface and contributes river water directly).

98. October was a period of transition in the local winds and current fields and was a time of water-column mixing. These features were demonstrated in all the data. The mixing was not completely uniform surface to bottom, as it would be in winter, however. Low-nutrient, higher biomass values appeared at intermediate depths at

disposal site B, and some tidal effect was seen at the shallower experimental disposal site.

99. In conclusion, the water column was greatly influenced by the river during maximum flow at disposal site B, but was less affected at the experimental disposal site that was "protected" somewhat by the jetty. The situation appeared to reverse during minimum river flow, with more river effect apparent at the experimental site than at the historic site (although river effect in general was lower). In seasons of wind mixing and rapid atmospheric cooling or warming (early spring, fall), both sites appeared to be about equally affected by the river (with such river effect rather minimal).

#### Sediment Samples

##### Grease

100. The data presented for grease in Figures B87-B91 showed a low level of grease present with higher amounts seen only in occasional samples on an irregular basis. During the Y7409 F cruise (Figure B2) station 6 showed over 700 ppm grease in the surface sample and about 500 ppm in the 10- to 15-m-deep section (Figure B87). This value is difficult to explain since the sample was not taken within the historic disposal site, where the probability of such high values would be greater. During the Y7501 B cruise (Figure B3) elevated levels of grease were observed but only a maximum of about 300 ppm at depth at stations 4 and 6 (Figure B88). Both of these stations were at the historic disposal site, and such levels could easily be the result of past disposal activities of contaminated sediments. The samples taken during the Y7506 B-2 cruise (Figure B5) showed one elevated value, but below 200 ppm, at one station (Figure B89). This was at an area in the ship channel and was the location of the dredging. The single elevated sample probably represented a past random event associated with the ship traffic passing this site.

101. The samples from the Y7508 D-2 cruise (Figure B7) showed no elevated levels of grease (Figure B90). This included samples taken at

the experimental site at the conclusion of dumping. The final samples taken 2 months after disposal again showed no grease within the experimental site and only one random elevated measurement at one station outside the disposal site (Figure B91).

#### Ammonia

102. The measurement of ammonia (also shown in Figures B89-B91) showed no significant levels of ammonia present at the site of dredging during the Y7506 B-2 cruise (Figure B5). On the Y7506 D-2 cruise (Figure B7), no significant ammonia values at the experimental site were found, while greatly elevated levels were found at station 6, which was located outside the historic site. This can most likely be explained as the result of the random sampling of a local event, such as the decay of an organism, which might produce these elevated ammonia levels. The final sampling on cruise Y7510 C-1 (Figure B8) again confirmed the low levels of ammonia at the experimental site and in adjacent areas.

#### Particulate carbon and nitrogen

103. Particulate carbon and nitrogen (shown in Figures B92-B96) will be considered together. During the initial Y7409 F cruise (Figure B2), three stations, 4, 5, 6, all in or just outside of the historic site showed considerably higher levels of carbon and nitrogen than the other stations (Figure B92). These stations were in an area the benthic program had identified as being very productive and the values that were found may very well be a reflection of this productivity. This trend was confirmed again at station 6, on the Y7501 B cruise (Figure B3); the sampling for station 7 on this cruise, which was also in the historic area, was lost (Figure B93). All samples taken at the dredge site on cruise Y7506 B-2 (Figure B5) showed very low levels of particulate carbon and nitrogen (Figure B94). This, of course, was expected since this was a high energy region yielding samples of basically clean sand. The system was unstable enough that high benthic productivity at the dredge site would not be expected. The samples collected on cruise Y7508 D-2 (Figure B7) showed very low levels of carbon and nitrogen at the experimental disposal site and high levels only at station 6, which was located near the productive historic disposal site (Figure B95).

The final sampling on cruise Y7510 C-1 (Figure B8) again showed low levels of carbon and nitrogen at all stations, including three stations within the experimental disposal site (Figure B96).

#### pH and Eh

104. Figures B97-B101 show the values obtained for measurements of pH and Eh in the sediments. Although there was some variability of values noted on the various figures, a clear pattern or trend was difficult to establish. For example, the Y7501 B cruise (Figure B3) taken in January showed values of pH and Eh tending to decrease with depth, except the pH values at stations 3 and 4 which ran counter to this trend (Figure B98). All of these values are considered within a normal range and, as a result, a special emphasis should not be placed on the values that have been obtained.

#### Cation exchange capacity and sulfide

105. Figures B102-B106 show the values for cation exchange capacity and levels of sulfide. The levels of sulfide appeared high at three stations (4, 5, and 6) on the Y7409 F cruise (Figure B2) while the levels were lower for the remainder of the sampling period with only one sample in August 1975 and one sample in October 1975, showing elevated sulfide levels at the surface (Figure B102). All three of the stations that showed some elevated sulfide level in September of 1974 were in or adjacent to the historic disposal site. Stations in the historic disposal site did not show elevated sulfide in the January 1975 series, however (Figure B103). Likewise, the dredge site sampled in June 1975 did not show elevated levels (Figure B104), while the two stations showing increased levels in August 1975 and October 1975 were near the historic disposal site (Figures B105 and B106). The pattern suggests that conditions were correct for some increase in sulfide levels in and adjacent to the historic disposal site, but the increased mixing and turbulence associated with winter storms tended to reduce this seasonal phenomena to levels that were low and similar to that found in other areas. The variability that was noted in the cation exchange capacity in the figures does not follow any particular pattern. As the case with several other parameters, station 6 on the Y7409 F cruise (Figure B2) showed

higher values than any of the other stations. With this one exception, all of the other values were within a normal or expected range.

#### Nickel and iron

106. Figures B107-B111 depict the levels of nickel and iron detected in the sediments. The two elements can be discussed together, since common characteristics appear to be noted for both elements. On the Y7409 F cruise (Figure B2) increased levels for both elements at station 5 and 6 were observed (Figure B107). The increased levels were noted at the surface only at station 5, but both at surface and in the 10- to 15-cm section at station 6. Station 5, of course, was within the historic disposal site while station 6 was just outside of this area. A slightly elevated level of nickel and iron at depth at station 6 of the Y7501 B cruise (Figure B3) was observed (Figure B108). This station was within the historic disposal site. The samples of cruise Y7506 B-2 (Figure B5) taken at the site of dredging showed no unusually high values, but for some reason that cannot be explained, a more than usual variability in the values for nickel was noted (Figure B109). In both the Y7508 D-2 and Y7510 C-1 cruises (Figures B7 and B8) no numbers for either nickel or iron were above a background level, hence there is no evidence of any contamination at the experimental disposal site by either of these elements.

#### Manganese and copper

107. Figures B112-B116 show the values obtained for manganese and copper in the sediments. Figure B112 again shows elevated levels of manganese and copper at stations 5 and 6. These are the same two stations that also showed increased levels of nickel and iron as noted above and again station 6 of cruise Y7501 B (Figure B3) also showed some increase at depth for these two metals. The data shown on Figure B114 show no high values at the dredge site, just as Figures B115 and B116 show no evidence of any contamination at the experimental disposal site.

#### Zinc and cadmium

108. The values for zinc and cadmium in the sediments are shown on Figures B117-B121. Again on the Y7409 F cruise (Figure B2) increased

levels of metals, both zinc and cadmium, at stations 5 and 6 were found. Again station 5 was within the historic disposal site and station 6 was just outside of that site. It became clear that these two stations were showing a general contamination above the levels seen at other stations. On the Y7501 B cruise (Figure B3), no elevated levels of zinc were found and only at station 7 was an increased level of cadmium observed. This increased level of cadmium was only in the 10- to 15-cm-deep section and may represent some point of past contamination with cadmium at this location within the historic disposal site. The samples taken on the Y7506 B-2 cruise (Figure B5) showed that the material being dredged showed no elevated levels of zinc or cadmium whatever. Data from the Y7508 D-2 cruise (Figure B7) showed no zinc or cadmium contamination at the historic disposal site (Figure B120) and only a very slight increase in cadmium at the surface at stations 5 and 6, some distance away from the experimental disposal site. This same situation was confirmed by the data (Figure B121) obtained on cruise Y7510 (Figure B8). Again no contamination was noted within the experimental disposal site.

#### Mercury and lead

109. Figures B122-B126 depict the levels of mercury and lead that were found in the sediments. Results from the Y7409 F cruise showed high levels of mercury at the surface at station 5, but station 6, which had shown increased levels of other metals, did not show high levels of mercury (Figure B122). In the case of lead, station 6 again showed high levels at the surface and at depth with station 5 showing some increased lead at the surface. No ready explanation can be found for the high mercury value at station 5, although it was from within the historic disposal site. During the Y7501 B cruise a slightly increased level of mercury was found at depth at station 6, which was within the historic disposal site (Figure B123). This could represent a record of the past disposal of sediments with high levels of mercury. No increased values of lead were noted on this cruise (Figure B123). During the Y7506 B-2 cruise at the site of dredging, no increased levels of either mercury or lead in the materials being dredged were found, once again confirming the clean nature of these sediments (Figure B124). The samples obtained

on the Y7508 D-2 cruise indicated a very slight elevated level of both mercury and lead at station 3 within the experimental disposal site. It is difficult to explain this level, but it very likely represents the sampling of a single random event and very likely does not represent general conditions within the experimental site (Figure B125). Increased levels of mercury at the surface at station 5 and of lead at station 6 were found. These stations were away from the experimental disposal site. During the Y7510 C-1 cruise samples were taken in the experimental disposal site which showed no contamination with mercury or lead (Figure B126). However, a slightly increased level of mercury was noted at station 5 which was located in a control area.

110. In summary, probably the most important samples taken during this study were the samples taken on the Y7506 B-2 cruise (Figure B5) at the site of the dredging. These samples confirm that the dredge was working with clean material as far as the parameters being measured in this study were concerned. Coupling this information with the results shown at stations 1 and 2 on the Y7501 B cruise suggests that only background levels of these potential pollutants were present in the experimental disposal area before disposal. Then the results seen on the Y7508 D-2 and Y7510 C-1 cruises are obvious: clean sand deposited on top of clean sand results in a mixture of clean sand.

111. Station 6 of the Y7409 F cruise showed elevated levels of most of these potential contaminants when compared with the other stations. As noted before, this station was located near but outside of the historic disposal site. It can be assumed that the higher levels of contaminants noted at this station were either the result of past disposal activities or were the result of some other unknown event that produced some contamination within a local area. It appears that the second hypothesis is the more likely, since other stations in the historic disposal site did not show the same elevated contaminant levels.

### Interstitial Water

112. Although interstitial water samples were collected and the analyses on the samples were conducted, it was concluded that the plotting and interpretation of the resulting data would have no meaning. The samples were collected with the box corer and the material being sampled was a porous sand. It was clear that not only did the interstitial water that was present between the sand grains drain out of the corer, but the water collected above the core quickly drained through the sample and hence tended to flush the true interstitial out of the corer ahead of it. As a result, it is clear that whatever was being measured had little or no relationship to the true interstitial water that was originally present in situ. To try to interpret such data would at best be misleading.

### Water-Column Metals

#### Nickel

113. The data for measurement of metals in the water column are summarized in a series of graphs (Figures B127-B141). The measurements of nickel presented in Figure B127 for the Y7507 A cruise show low and rather uniform levels of nickel at all depths in the water column. These levels were not only uniform but were lower than the values cited for nickel by Brewer as a mean value for seawater.<sup>6</sup> This study found no explanation for this very low value. Figure B128 of cruise Y7508 D-2 shows low values for nickel in most particulate samples, but higher values than observed previously for the dissolved phase. However, the higher levels were noticeable in the near-surface samples. This undoubtedly reflects the input of nickel from the Columbia River. This tendency for higher nickel values in the river water may be noted in some of the other metals. It seems reasonable in all cases to expect that this increase at the surface may be due to input from the river and that it is not associated with the disposal of dredged material.

114. Samples collected near the surface during the Y7506 cruise showed similarly low levels of nickel while samples collected near the bottom during the Y7510 cruise showed low levels of nickel in most samples, but increased levels in two cases in measurements of particulate samples. This most likely represents two samples in which natural weather conditions caused an increased amount of sediment to be in suspension and therefore appear as increased nickel in the particulate phase.

#### Iron

115. The values for iron are shown in Figure B129 for the Y7507 A cruise and in Figure B130 and B131 for the Y7508 D-2 cruise. The values for the Y7507 A cruise show relatively higher values at the surface decreasing at middepth and increasing slightly near the bottom for both dissolved and particulate iron. The Y7508 cruise, however, shows low values for both the dissolved and particulate phases at all depths. This is a reversal of the patterns seen on the two cruises with nickel. This study found no explanation for the different patterns that appeared for these elements.

#### Manganese

116. The values for manganese are shown in Figures B132 and B133 for the Y7507 A and Y7508 D-2 cruises, respectively. The values follow the same pattern that was observed above for iron. However, the surface values observed on the Y7507 A cruise are very high values (as high as 75  $\mu\text{g}/\ell$ ) and not easily explained by input from the river. Goldberg et al.<sup>7</sup> indicated average values in river waters of only 7  $\mu\text{g}/\ell$  while data of Cutshall and Johnson<sup>8</sup> at Miller Sands in the fresh section of the Columbia River have shown soluble Mn values from 2 to 28  $\mu\text{g}/\ell$  and particulate Mn values from 16 to 69  $\mu\text{g}/\ell$  with a single value at 120  $\mu\text{g}/\ell$ . Therefore, the source of the high Mn at the surface is not fully explained.

#### Copper

117. The values for copper are shown in Figures B134 and B135 for the Y7507 A and Y7508 D-2 cruises, respectively, and show no apparent pattern with some rather random variation, however. The values are about what should be expected in seawater according to Brewer.<sup>6</sup>

### Zinc

118. The zinc values shown in Figures B136 and B137 also show low values according to Brewer again with some rather random variability with no particular trends in evidence.<sup>6</sup> For both copper and zinc there is clearly no evidence of any increases due to any kind of disposal activity.

### Cadmium

119. The cadmium values plotted in Figures B138 and B139 again show no consistent trends with depth. However, during the Y7508 D-2 cruise, cadmium in the dissolved phase appeared to be significantly higher than in the particulate phase. However, this pattern did not appear to be present in the data from the Y7507 A cruise. However, all of the values were low and no evidence of increased cadmium from the disposal of dredged material was evident.

### Lead

120. The values for lead are shown in Figures B140 and B141 for the Y7507 A and Y7508 D-2 cruises, respectively. During the Y7507 A cruise some increase in Pb in the surface was noted in the particulate matter, but this was not seen in the Y7508 D-2 cruise. However, again all of the values for lead were low with no indication of pollution present.

121. In conclusion, for all the metals measured no increases in metals in the water column were detected that can in any way be attributed to the disposal of dredged material. Most of the variability noted appeared to be some random variability in low measurements at or in some cases below expected levels in seawater. Only the indication of some metal input from the Columbia River, as noted above, appeared as a possible systematic trend for certain metals.

## PART IV: CONCLUSIONS

### Water-Column Nutrients

122. Properties measured in the water column during periods of high river flow at the historic disposal site were influenced to a great extent by both tides and river hydraulics. However, similar properties measured at the experimental disposal site showed a lesser tidal effect and more oceanic influence. Tidal effects at the experimental disposal site penetrated the surface to only about 5 m in the temperature and salinity data. The nutrient and biological data suggest distribution patterns which were controlled primarily by the diel radiation cycle (biological uptake and release) rather than river effluent.

123. During periods of low flow the experimental disposal site appeared to be more affected by the river. Flood and ebb tidal effects were observed in the data during low flow periods. High primary production and low nutrient values were associated with the flooding of surface oceanic water over the site and low productivity; high nutrient values were associated with the ebb tidal periods.

124. In transition seasons of wind mixing and rapid atmospheric cooling or warming, water-column properties at both disposal sites were well mixed. The mixing, however, was not completely uniform surface to bottom and both sites appeared to be nearly equally affected by the river.

### Sediment Characteristics

125. Examination of nutrient and metal data taken from sampling sites in the vicinity of the historic disposal site during the study suggests elevated levels of these properties when compared with levels determined at other sites, including the river dredging site and the experimental disposal site. At sites other than the historic disposal site, there was close agreement between levels of nutrients and metals

(little variation). The values observed were near or below background levels for each property. In addition, there was little change in concentration with depth in the sediment core at these sites which suggests homogeneous sediment type from surface to the bottom of the core.

126. Sediment samples taken in the historic disposal site consistently demonstrated higher levels of nutrients and metals in each season sampled. The vertical distributions of these properties generally were higher in the surface sediments and decreased to near background levels with depth in the cores. These distributions can best be explained on the basis of sediment texture at this site. The percentages of silt and clay-sized particles in the sediments near the historic disposal site was greater than at other sample sites. These finer grained materials, which characteristically demonstrated elevated levels of nutrients and metals, ultimately have their origin in the Columbia River and are transported onto the disposal site both by natural transport and sedimentation processes and previous disposal activities.

127. River sediments sampled in the dredging site prior to dredging and shelf sediments sampled in the experimental disposal site prior to disposal both showed only background levels of nutrients, metals, and other contaminant parameters. Examination of sediment samples taken from the experimental disposal site immediately following disposal and 2 months thereafter again showed only background levels of nutrients or metals, as would be expected since the dredged material could best be characterized as clean, fine to medium sand.

#### Water-Column Metals

128. For the dissolved and particulate metals measured in the water column, no increases which could be attributed to disposal activities could be detected. The random variability which was observed was explained by analyses which were at or below the analytical detection limits for the metals in seawater. There was some indication in the data of metal input from the Columbia River; however, this input was minor and did not represent a source of significant contamination.

#### REFERENCES

1. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 14th ed., 1975, American Water Works Association, Water Pollution Control Federation, Washington, D. C.
2. Reeburgh, W. S., "An Improved Interstitial Water Sampler," Limnol. Oceanogr., Vol 12, 1967, pp 163-165.
3. Varian, Instruction Manual for Varian-Techtron Model AA-5, Varian Techtron Pty; Limited, Melbourne, Australia, 1971.
4. Jackson, M. L., Soil Chemical Analysis, Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1958, 498 pp.
5. Park, K., "Alkalinity and pH Off the Coast of Oregon," Deep-Sea Research, Vol 15, 1968, pp 171-183.
6. Brewer, P., Chemical Oceanography, Chap. 7, Vol 1, 2nd ed., Academic Press, London.
7. Goldberg, E. D., Broecker, W. S., Gross, M. G., and K. K. Turekian, Radioactivity in the Marine Environment, Chap. 5, National Academy of Sciences, Washington, D. C., 272 pp.
8. Cutshall, N. H., and Johnson, V. G., "Habitat Development Field Investigations, Miller Sands Marsh and Upland Habitat Development Site, Columbia River, Oregon; Appendix A: Inventory and Assessment of Predisposal Physical and Chemical Conditions," Technical Report D-77-38, Nov 1977, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
9. Johnson, V. G., and Cutshall, N. H., "Final Report Geochemical Baseline Data, Youngs Bay, Oregon, 1974," School of Oceanography, Oregon State University, April 1975.

Table B1  
Station Locations and Collection Data, for Cruise C7409 C-1

Station No. #	Sample Type	Gear Type	Date 1974	Time PST	High-Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Sample Depths m
1A	Water Column	STD pump sys.	9/27	1250	2 past	46 $^{\circ}$ 12'00"	124 $^{\circ}$ 07'00"	30	0, 5, 10, 15, 20
2A				1445	4 past	46 $^{\circ}$ 12'30"	124 $^{\circ}$ 08'00"	30	0, 5, 10, 15, 25
3A				1715	5.5 before	46 $^{\circ}$ 13'00"	124 $^{\circ}$ 08'48"	30	0, 5, 10, 15, 25
4A				1900	4 before	46 $^{\circ}$ 13'24"	124 $^{\circ}$ 09'30"	31	0, 5, 10, 15, 25
5A				2045	2 before	46 $^{\circ}$ 14'00"	124 $^{\circ}$ 10'30"	29	0, 5, 10, 15, 25
6A				2227	0.5 before	46 $^{\circ}$ 14'30"	124 $^{\circ}$ 09'48"	21	0, 5, 10, 15, 25
7A			9/28	0030	1.5 past	46 $^{\circ}$ 15'24"	124 $^{\circ}$ 10'24"	30	0, 5, 10, 15, 25
8A				0140	3 past	46 $^{\circ}$ 16'24"	124 $^{\circ}$ 10'12"	30	0, 5, 10, 15, 25
9A				0415	5.5 past	46 $^{\circ}$ 17'24"	124 $^{\circ}$ 10'00"	30	0, 5, 10, 15, 25
ØB				0520	6 before	46 $^{\circ}$ 11'12"	124 $^{\circ}$ 06'24"	30	0, 5, 10, 15, 25
-1B				0640	5 before	46 $^{\circ}$ 10'18"	124 $^{\circ}$ 05'30"	31	0, 5, 10, 15, 25
1B				0843	3 before	46 $^{\circ}$ 12'00"	124 $^{\circ}$ 07'18"	29	0, 5, 10, 15, 25
2B				1013	1.5 before	46 $^{\circ}$ 12'30"	124 $^{\circ}$ 08'06"	31	0, 5, 10, 15, 25
3B				1225	1 past	46 $^{\circ}$ 12'54"	124 $^{\circ}$ 08'42"	30	0, 5, 10, 15, 25
4B				1345	2 past	46 $^{\circ}$ 13'24"	124 $^{\circ}$ 09'24"	28	0, 5, 10, 15, 25
5B				1520	4 past	46 $^{\circ}$ 14'00"	124 $^{\circ}$ 10'24"	30	0, 5, 10, 15, 20
6B				1729	6 past	46 $^{\circ}$ 14'24"	124 $^{\circ}$ 09'48"	30	5, 10, 15, 25

(Continued)

\* A, B, and C indicate separate legs.

Table B1 (Concluded)  
 Station Locations and Collection Data, for Cruise C7409 C-1

Station No.*	Sample Type	Gear Type	Date 1974	Time PST	High-Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Sample Depths m
$\alpha$	Water Column	STD pump sys.	9/28	2003	3.5 before	46 $^{\circ}$ 13'30"	124 $^{\circ}$ 12'06"	60	0,5,10,15,50
$\beta$				2130	2 before	46 $^{\circ}$ 13'30"	124 $^{\circ}$ 15'00"	70	0,5,10,20,60
$\gamma$			9/29	2405	0.5 past	46 $^{\circ}$ 13'42"	124 $^{\circ}$ 17'54"	110	0,5,10,25,95
$\delta$				0035	2 past	46 $^{\circ}$ 13'42"	124 $^{\circ}$ 20'48"	120	0,5,10,20,100
$\epsilon$				0200	3.5 past	46 $^{\circ}$ 13'42"	124 $^{\circ}$ 23'42"	146	0,5,15,25,130
4 Anchor	Water Column & Phyto-plankton	STD pump sys. with phyto-plankton sieve		0732	5.4 before	46 $^{\circ}$ 13'24"	124 $^{\circ}$ 09'36"	30	0,5,10,15,25
1C				2104	4.5 before	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 07'12"	29	0,5,10,15,25
2C				2425	1 before	46 $^{\circ}$ 12'24"	124 $^{\circ}$ 08'06"	30	0,5,10,15,25
3C			9/30	0200	1.5 past	46 $^{\circ}$ 12'54"	124 $^{\circ}$ 08'48"	30	0,5,10,15,25 phyto = 5,25
5C				0400	3.5 past	46 $^{\circ}$ 13'54"	124 $^{\circ}$ 10'18"	30	0,5,10,15,25 phyto = 1,10 P = 0,10
6C				0640	6.5 past	46 $^{\circ}$ 14'24"	124 $^{\circ}$ 10'00"	30	0,5,10,15,25 phyto = 0,5,10,15

Table B2

## Station Locations and Collection Data for Cruise Y7409 F

Station No.	Sample Type*	Gear Type**	Date 1974	Time PST	High-Tide Reference hr	Latitude $\phi_N$	Longitude $\lambda_W$	Water-Column Depth, m	Core Sections cm	Sample Depths m
1	S	B	9/29	2230		46° 11' 48"	124° 07' 42"	35	0-5 10-15	0, 5, 10, 15, 30
2	WC	NIO	9/29	2150	2.5 b <sup>+</sup>	46° 12' 00"	124° 07' 30"	34		
	S	B	9/30	0037		46° 12' 30"	124° 08' 00"	30	0-5 10-15 15-18	
3	S	B	9/30	0132		46° 13' 12"	124° 08' 48"	30	0-5 10-15 15-18	
4	WC	NIO	9/30	0108	0.5 p <sup>++</sup>	46° 13' 00"	124° 08' 36"	28		
	S	B	9/29	1312		46° 13' 21"	124° 10' 12"	26	0-5 10-15 15-20	0, 5, 10, 15, 25
5	S	B	9/29	1155		46° 13' 48"	124° 10' 30"	32	0-5 10-15 20-25	
6	WC	NIO	9/29	1116	1 b	46° 14' 00"	124° 09' 54"	25		
	S	B	9/29	1014		46° 14' 30"	124° 09' 48"	22	0-5 10-15 20-25	0, 5, 10, 15, 20
7	S	B	9/29	0725		46° 14' 48"	124° 05' 30"	16	0-5 10-15 20-25 30-35	
	WC	NIO	9/29	0934	2.5 b	46° 15' 24"	124° 04' 48"	15		0, 5, 10

\* S = sediment; WC = water column (selected parameters).

\*\* B = box corer; NIO = National Institute of Oceanography water sampler.

+ b = before.

++ p = past.

Table B3  
Station Locations and Collection Data for Cruise Y7501 B

Station No.	Sample Type*	Gear Type**	Date 1975	Time PST	High-Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Core Sections cm	Sample Depths m
1	S	B	1/25	0953		46 $^{\circ}$ 11'00"	124 $^{\circ}$ 04'52"	27	0-5, 10-15, 15-19	0, 5, 10, 15
2	WC	Nis		0942	high	46 $^{\circ}$ 11'00"	124 $^{\circ}$ 04'52"	27		
	S	B		0826		46 $^{\circ}$ 11'26"	124 $^{\circ}$ 06'31"	32	0-5, 10-14	0, 5, 10, 15, 20
3	WC	Nis		0807	1.5 b <sup>+</sup>	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 06'32"	31		
	S	B		0243		46 $^{\circ}$ 12'26"	124 $^{\circ}$ 06'29"	20	0-5, 10-15, 20-24	0, 5, 10, 15, 20
4	WC	Nis		0205	4 <sup>++</sup>	46 $^{\circ}$ 12'27"	124 $^{\circ}$ 06'30"	22		
	S	B		0103	p	46 $^{\circ}$ 11'58"	124 $^{\circ}$ 09'11"	40	0-5, 10-15, 15-20	0, 5, 10, 15
5	WC	Nis		0031	2.5 p	46 $^{\circ}$ 11'47"	124 $^{\circ}$ 09'02"	45		
	S	B	1/24	1814		46 $^{\circ}$ 13'36"	124 $^{\circ}$ 08'00"	17	0-5, 10-15, 20-25	0, 5, 10, 15, 25, 34
6	WC	Nis		1700	6 b	46 $^{\circ}$ 13'35"	124 $^{\circ}$ 07'59"	17		
	S	B		0826		46 $^{\circ}$ 13'29"	124 $^{\circ}$ 10'00"	37	0-5, 10-15, 15-20, 20-25	0, 5, 10
7	WC	Nis		0937	0.5 p	46 $^{\circ}$ 13'32"	124 $^{\circ}$ 10'05"	37		
	S	B		0124		46 $^{\circ}$ 14'02"	124 $^{\circ}$ 10'27"	36	0-5, 5-10, 10-15, 15-20	0, 5, 10, 15, 20
8	WC	Nis		0043	3.5 p	46 $^{\circ}$ 14'07"	124 $^{\circ}$ 10'28"	32		
	S	B	1/23	2022		46 $^{\circ}$ 15'21"	124 $^{\circ}$ 09'39"	17	0-5, 11-16	0, 5, 10, 15, 20, 25
	WC	Nis		1851	2 b	46 $^{\circ}$ 15'20"	124 $^{\circ}$ 09'34"	14		0, 5, 10

\*S = sediment.

\*\*B = box corer.

+b = before.

++p = past.

WC = water column (selected parameters).

Nis = 5-l Niskin bottle.

Table B4  
Station Locations and Collection Data for Cruise Y7506 B-1

Station No.	Sample Type	Gear Type	Date 1975	Time PST	High-Tide Reference hr	Latitude ON	Longitude OW	Water-Column Depth, m	Sample Depths m
3	WC*	CTD & 5-2 Niskin bottles	6/14	1430	2 b <sup>+</sup>	46°24'12"	124°15'00"	62	2, 7, 12, 16, 21, 60
4				1740	1.5 p <sup>++</sup>	46°19'36"	124°12'54"	46	2, 7, 11, 16, 26, 43
5				2105	4.5 p	46°15'12"	124°12'48"	54	2, 7, 11, 16, 26, 33
6			6/15	0015	3.5 b	46°11'00"	124°10'30"	63	2, 7, 12, 17, 26, 35, 55
7				0400	high	46°07'30"	124°07'09"	52	2, 7, 12, 17, 20, 21
8				0710	3.5 p	46°12'06"	124°04'54"	19	2, 7, 12, 16
9				0920	5.5 p	46°13'12"	124°07'18"	18	2, 5, 12, 16
10				1140	5.5 b	46°14'18"	124°09'48"	20	1, 6, 12, 17
11				1350	3.5 b	46°16'24"	124°09'42"	23	1, 8, 13, 18, 20, 21
12	WC/A**			1555	1.5 b	46°13'18"	124°10'18"	44	1, 5, 10, 20, 34
13				1750	0.5 p	46°13'30"	124°10'18"	44	2, 6, 10, 15, 26, 36
14				2000	3 p	46°13'39"	124°10'42"	42	2, 6, 10, 16, 25, 37
15				2150	4.5 p	46°13'42"	124°11'06"	44	12, 17, 26, 37
16			6/16	0010	5 b	46°13'42"	124°10'42"	43	5, 6, 9, 12, 21, 35
17				0230	2.5 b	46°13'42"	124°10'36"	44	2, 6, 12, 17, 25, 32
18				0430	0.5 b	46°13'36"	124°10'18"	40	2, 8, 14, 18, 29, 37
19	P*** WC/A P			0630	1.5 p	46°13'27"	124°10'54"	44	1, 5, 10, 15, 25
20	WC/A			0920	4.5 p	46°13'12"	124°12'00"	54	0, 8, 11, 17, 27, 40
21	P WC/A			1220	5.5 b	46°13'42"	124°10'36"	43	3, 7, 10, 13, 16, 21
22	WC/A P			1600	2 b	46°13'35"	124°10'13"	40	1, 5, 10, 15, 25 1, 7, 11, 16, 26, 36 1, 5, 10, 15, 25

(Continued)

\*WC = water column.  
 \*\*WC/A = anchor station.  
 \*\*\*P = primary production and potential productivity measurements were also used.  
 +b = before.  
 ++ p = past.

Table B4 (Concluded)  
 Station Locations and Collection Data for Cruise Y7506 B-1

Station No.	Sample Type	Gear Type	Date 1975	Time PST	High-Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Sample Depths m
23	WC	CTD & 5-l Niskin bottles	6/16	1900	1	46 $^{\circ}$ 13'12"	124 $^{\circ}$ 10'36"	44	2, 7, 11, 16, 26, 40
24				2250	5	46 $^{\circ}$ 13'36"	124 $^{\circ}$ 10'54"	44	CTD only
25			6/17	0025	6.5	46 $^{\circ}$ 13'42"	124 $^{\circ}$ 10'36"	45	1, 6, 10, 14, 27, 42
26				0200	4.5	46 $^{\circ}$ 13'36"	124 $^{\circ}$ 11'06"	48	CTD only
27				0500	1.5	46 $^{\circ}$ 15'18"	124 $^{\circ}$ 06'54"	16	2, 6, 9
28				0620	high	46 $^{\circ}$ 15'21"	124 $^{\circ}$ 00'18"	20	3, 6, 11, 16
29				0805	1.5	46 $^{\circ}$ 11'42"	123 $^{\circ}$ 55'30"	18	2, 7, 11
34			6/18	0135	6.5	46 $^{\circ}$ 10'18"	124 $^{\circ}$ 16'00"	92	2, 7, 11, 16, 25, 48, 84
35				0435	3	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 12'09"	61	2, 6, 11, 15, 26, 55
36	WC/A			0830	0.5	46 $^{\circ}$ 12'09"	124 $^{\circ}$ 08'06"	34	2, 8, 12, 16, 27
37	WC			1155	4	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 08'00"	32	2, 7, 11, 17, 26
38	WC/A			1400		46 $^{\circ}$ 13'42"	124 $^{\circ}$ 10'24"	50	CTD only
39	WC			1445	5	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 07'48"	30	2, 6, 10, 16, 24
40	WC/A			1810	1.5	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 07'54"	32	2, 5, 11, 17, 26
41				2055	1	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 08'12"	34	2, 7, 12, 18, 27
42			6/19	0040	5	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 07'54"	31	2, 7, 11, 16, 26
43	P			0408	5	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 08'00"	30	2, 6, 10, 14, 24
44	WC/A			0950	0.5	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 07'54"	32	1, 5, 10, 15, 25
45	P			1310	4	46 $^{\circ}$ 12'06"	124 $^{\circ}$ 07'06"	31	2, 6, 9, 14, 24
46	WC/A			1630	4	46 $^{\circ}$ 12'00"	124 $^{\circ}$ 08'18"	30	1, 5
47	P			1930	1	46 $^{\circ}$ 11'54"	124 $^{\circ}$ 04'48"	30	0, 7, 12, 17, 27
48	WC			2230	2	46 $^{\circ}$ 11'00"	124 $^{\circ}$ 10'24"	20	1, 5, 10, 15, 25
49			6/20	0215	5.5	46 $^{\circ}$ 14'00"	124 $^{\circ}$ 10'27"	54	2, 8, 13, 17, 27
50				0600	4	46 $^{\circ}$ 16'25"	124 $^{\circ}$ 09'48"	50	3, 7, 11, 17, 26, 50
51				0830	1.5	46 $^{\circ}$ 18'30"	124 $^{\circ}$ 07'54"	20	2, 8, 13, 17, 23, 39
								18	2, 8, 12, 16

Table B5  
Station Locations and Collection Data for Cruise Y7506 B-2 and Y7506 B-3

Station No.	Sample Type*	Gear Type	Date 1975	Time PST	High-Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Core Sections m
4	Sediment	Box Corer	6/22	0515	-	46 $^{\circ}$ 15'12"	124 $^{\circ}$ 04'24"	10	0-5 10-15
5				0701	-	46 $^{\circ}$ 15'04"	124 $^{\circ}$ 04'36"	11	0-5 10-15
6				0823	-	46 $^{\circ}$ 15'02"	124 $^{\circ}$ 04'45"	13	0-5 10-15 15-20 20-25
7				0940	-	46 $^{\circ}$ 14'59"	124 $^{\circ}$ 04'50"	12	0-5 10-15 20-25 25-30
8				1117	-	46 $^{\circ}$ 14'54"	124 $^{\circ}$ 04'57"	13	0-5 10-15 20-25 25-30
1	M/WC	Teflon bottle	6/25	1418	high	46 $^{\circ}$ 11'43"	124 $^{\circ}$ 06'30"	27	0.3
2				1423	0.5 p	46 $^{\circ}$ 11'40"	124 $^{\circ}$ 06'45"	30	0.3

\* M/WC = metals in water column.

Table B6  
Station Locations and Collection Data for Cruise Y7507 A

Station No.*	Sample Type**	Gear Type	Date 1975	Time PST	High-Tide Reference hr	Latitude <sup>0</sup> N	Longitude <sup>0</sup> W	Water-Column Depth, m	Sample Depths m
1a	MC/A	NIO	7/07	2305	0.5 p+	46° 11' 24"	124° 05' 54"	28	1, 15, 27
1a		Sampler	7/08	0023	high	46° 11' 21"	124° 06' 06"	29	1, 15, 27
1b			7/09	1112	high	46° 11' 34"	124° 06' 03"	26	1, 13, 25
1b			7/09	1133	high	46° 11' 34"	124° 06' 03"	27	1, 13, 25
1b			7/10	0849	5 b++	46° 11' 36"	124° 06' 06"	24	1, 11, 22
1b			7/10	0910	4.5 b	46° 11' 36"	124° 06' 06"	24	1, 11, 22

\* a = before dumping; b = during dumping as close behind the dredge as possible.

\*\* MC/A = metals in water column.

+ p = past.

++ b = before.

Table B7

## Station Locations and Collection Data for Cruise Y7508 D-1

Station No.	Sample Type*	Gear Type	Date 1975	Time PST	High Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Sample Depths m
1	WC	STD pump sys.	8/25	1445	0.5 p+	46 $^{\circ}$ 13'27"	124 $^{\circ}$ 10'36"	42	0, 5, 10, 15, 25, 42
2	WC			2015	6h P	46 $^{\circ}$ 12'12"	124 $^{\circ}$ 07'00"	30	0, 5, 10, 15, 24
3	WC/A			2315	2.5h b++	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 06'06"	25.2	0, 5, 10, 15, 22
4			8/26	0155	0.5h b	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 05'42"	24	STD only
5				0320	0.5h p	46 $^{\circ}$ 11'36"	124 $^{\circ}$ 05'36"	24	0, 5, 10, 15, 21
6				0530	3h p	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 05'43"	24	STD only
7				0720	4.5h p	46 $^{\circ}$ 11'24"	124 $^{\circ}$ 06'18"	23	0, 5, 10, 15, 20
8				1000	4.5h b	46 $^{\circ}$ 11'42"	124 $^{\circ}$ 06'06"		STD only
9				1200	2.5h b	46 $^{\circ}$ 11'36"	124 $^{\circ}$ 05'48"	24	0, 5, 10, 15, 22
10				1605	1.5h p	46 $^{\circ}$ 11'37"	124 $^{\circ}$ 05'52"	24	0, 5, 10, 15, 21
11				1845	4h p	46 $^{\circ}$ 11'33"	124 $^{\circ}$ 05'51"	24	STD only
12				2030	6h p	46 $^{\circ}$ 11'48"	124 $^{\circ}$ 06'06"	24	0, 5, 10, 15, 20
13				2235	4.5h b	46 $^{\circ}$ 12'00"	124 $^{\circ}$ 06'00"	24	STD only
14				0050	2.5h b	46 $^{\circ}$ 11'48"	124 $^{\circ}$ 05'48"	24	0, 5, 10, 15, 21
15			8/27	0900	6.5h b	46 $^{\circ}$ 15'18"	124 $^{\circ}$ 00'24"	22	
16	WC			1115	4.5h b	46 $^{\circ}$ 11'42"	123 $^{\circ}$ 00'24"	16	

\* WC = water column; A = anchor station

+ p = past

++ b = before

Table B8  
Station Locations and Collection Data for Cruise Y7508 D-2

Station No.	Sample Type*	Gear Type**	Date 1975	Time PST	High Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Core Sections cm	Sample Depths m
1	S	B	8/29	0919	-	46 $^{\circ}$ 11'42"	124 $^{\circ}$ 05'54"	24	0-5 10-15 20-25	
2	S	B		0952	-	45 $^{\circ}$ 11'42"	124 $^{\circ}$ 05'54"	24	0-5 10-15	
	S	B		1134	-	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 06'06"	26	0-5 10-15 20-25	
	S	B		1210	-	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 06'06"	26	0-5 10-15	1,14,26
3	M/WC	NIO		2138	5 past	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 06'18"	27		
	S	B		1328	-	46 $^{\circ}$ 11'18"	124 $^{\circ}$ 06'15"	30	0-5 10-15	
	S	B		1427	-	46 $^{\circ}$ 11'18"	124 $^{\circ}$ 06'15"	31	0-5 10-15	1,16,30
5	M/WC	NIO		2051	4 past	46 $^{\circ}$ 11'21"	124 $^{\circ}$ 06'36"	31		
	S	B		1545	-	46 $^{\circ}$ 12'42"	124 $^{\circ}$ 08'12"	30	0-5 10-15	
	S	B		1657	-	46 $^{\circ}$ 12'42"	124 $^{\circ}$ 08'12"	30	0-5 10-15	1,16,30
6	M/WC	NIO		2005	3.5 past	46 $^{\circ}$ 12'36"	124 $^{\circ}$ 08'24"	31		
	S	B		1730	-	46 $^{\circ}$ 13'09"	124 $^{\circ}$ 08'48"	26	0-5 5-10	
	S	B		1809	-	46 $^{\circ}$ 13'09"	124 $^{\circ}$ 08'48"	28	0-5 10-15 20-25	
	M/WC	NIO		1918	2.5 past	46 $^{\circ}$ 13'18"	124 $^{\circ}$ 09'06"	27		1,15,26

\* S = sediment; M/WC = metals in water column

\*\* B = box core; NIO = 1.4-l National Institute of Oceanography water sampler

Table B9  
Station Locations and Data Collection on Cruise Y7510 C-1

Station No.	Sample Type*	Gear Type**	Date 1975	Time PST	High Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Core Sections cm	Sample Depths m
1	M/WC	NIO	10/18	1825	6 before	46 $^{\circ}$ 11'42"	124 $^{\circ}$ 05'48"	25	0-5	24
	S	B		1846		46 $^{\circ}$ 11'42"	124 $^{\circ}$ 05'48"	25	10-15	
	S	B		2001		46 $^{\circ}$ 11'42"	124 $^{\circ}$ 05'48"	22	0-5 10-15	
2	M/WC	NIO	10/19	2038	4 before	46 $^{\circ}$ 11'30"	124 $^{\circ}$ 06'06"	24	0-5	23
	S	B		2047		46 $^{\circ}$ 11'33"	124 $^{\circ}$ 06'03"	24	10-15	
	S	B		2110		46 $^{\circ}$ 11'33"	124 $^{\circ}$ 06'03"	24	0-5 10-15	
3	M/WC	NIO	10/19	2140	3 before	46 $^{\circ}$ 11'24"	124 $^{\circ}$ 06'30"	28	0-5	27
	S	B		2148		46 $^{\circ}$ 11'21"	124 $^{\circ}$ 06'23"	28	10-15	
	S	B		2211		46 $^{\circ}$ 11'21"	124 $^{\circ}$ 06'23"	28	0-5 10-15	
5	M/WC	NIO	10/19	0711	5.5 before	46 $^{\circ}$ 12'48"	124 $^{\circ}$ 08'24"	26	0-5	25
	S	B		0725		46 $^{\circ}$ 12'42"	124 $^{\circ}$ 08'13"	28	10-15 20-24	
	S	B		0749		46 $^{\circ}$ 12'42"	124 $^{\circ}$ 08'13"	28	0-5 10-15	
6	M/WC	NIO	10/19	0825	4 before	46 $^{\circ}$ 13'30"	124 $^{\circ}$ 08'54"	21	0-5	20
	S	B		0834		46 $^{\circ}$ 13'29"	124 $^{\circ}$ 08'54"	21	10-13	
	S	B		0905		46 $^{\circ}$ 13'29"	124 $^{\circ}$ 08'54"	21	0-5 10-15	

\* M/WC = metals in water column; S = sediment

\*\* NIO = 1.4-l National Institute of Oceanography water sampler; B = box core

Table B10

## Station Locations and Collection Data for Cruise Y7510 C-2

Station No.	Sample Type*	Gear Type	Date 1975	Time PST	High Tide Reference hr	Latitude $^{\circ}$ N	Longitude $^{\circ}$ W	Water-Column Depth, m	Sample Depths m
1	WC	STD	10/20	0815	3.5 b**	46°15'24"	124°00'30"	22	
2		pump		1015	1.5 b	46°11'36"	123°55'12"	15	
5	WC/A	sys.		2035	5.5 b	46°11'36"	124°06'12"	26	25
6			10/21	0045	high +	46°11'30"	124°06'00"	25	STD only
7				0245	2 p	46°11'39"	124°06'06"	27	25
8				0600	5 p	46°11'30"	124°06'06"	25	STD only
9				0735	5 b	46°11'03"	124°04'48"	23	20
10				1100	1.5 b	46°11'26"	124°05'42"	26	STD only
11				1245	0.5 p	46°11'24"	124°05'12"	30	29
12				1530	3 p	46°11'00"	124°06'16"	30	STD only
13				1800	5.5 p	46°11'24"	124°06'06"	27.5	27
14				2000	5.5 b	46°11'33"	124°06'24"	24	STD only
15				2200	3.5 b	46°11'24"	124°05'27"	26	25
16			10/22	0035	1 b	46°11'00"	124°06'12"	28	STD only
17	WC/S			0245	1 p	46°10'18"	124°04'36"	29.5	29
18	WC/A			0900	4 b	46°13'30"	124°10'36"	44	43
19				1300	high	46°13'30"	124°10'42"	46	STD only
20				1530	2.5 p	46°13'30"	124°10'42"	31	31
21				1930	6.5 b	46°13'30"	124°10'36"	38	STD only
22				2055	5.5 b	46°13'12"	124°10'18"	38	STD only
23				2300	3 b	46°13'36"	124°10'36"	42	STD only
24			10/23	0100	1 b	46°13'24"	124°10'36"	40	STD only
25				0300	1 p	46°13'24"	124°10'54"	50	STD only
26				0500	3 p	46°13'12"	124°10'30"	47	STD only
27				0730	5.5 p	46°13'36"	124°11'00"	42	STD only
28				0910	4 b	46°13'24"	124°10'36"	43	STD only
29				1100	2.5 b	46°13'30"	124°10'42"	44	STD only
30	WC			1220	1 b	46°10'12"	124°16'12"	98	

\* WC = water column; A = anchor station; S = sediment.

\*\* b = before.

\*\*\* p = past.

Table B11  
Chronology of Field Sampling

	<u>Sep 74</u>	<u>Jan 75</u>	<u>Jun 75</u>	<u>Jul 75</u>	<u>Aug 75</u>	<u>Oct 75</u>
Water-Column Nutrients	X	X	X		X	X
Anchor Stations for Water-Column Nutrients	X		X		X	X
Sediment Samples	X	X	X		X	X
Water-Column Metals			X	X	X	X

NOTE: 10 Jul to 29 Aug 75 disposal at experimental disposal site.



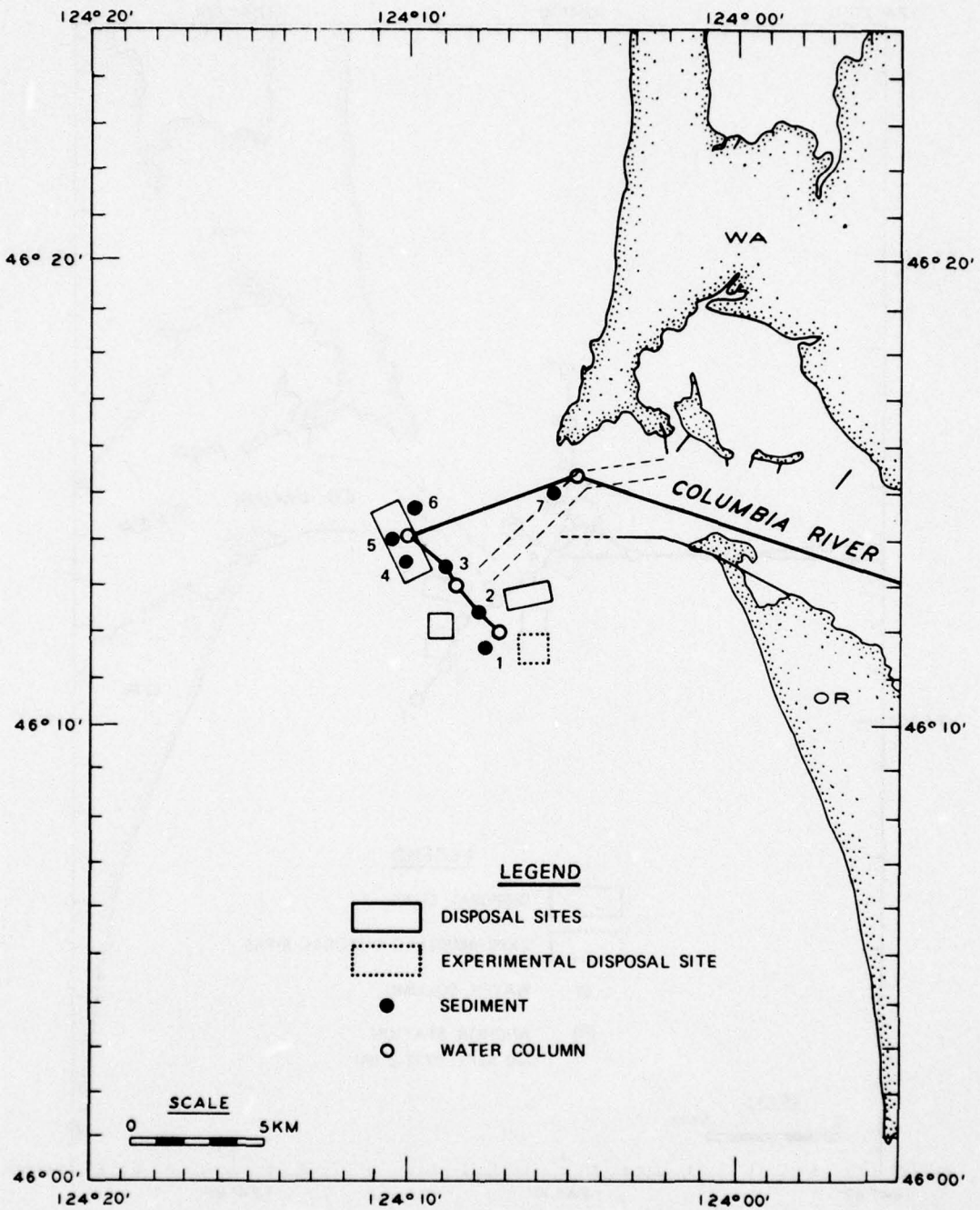


Figure B2. Station locations for samples collected on cruise Y7409 F

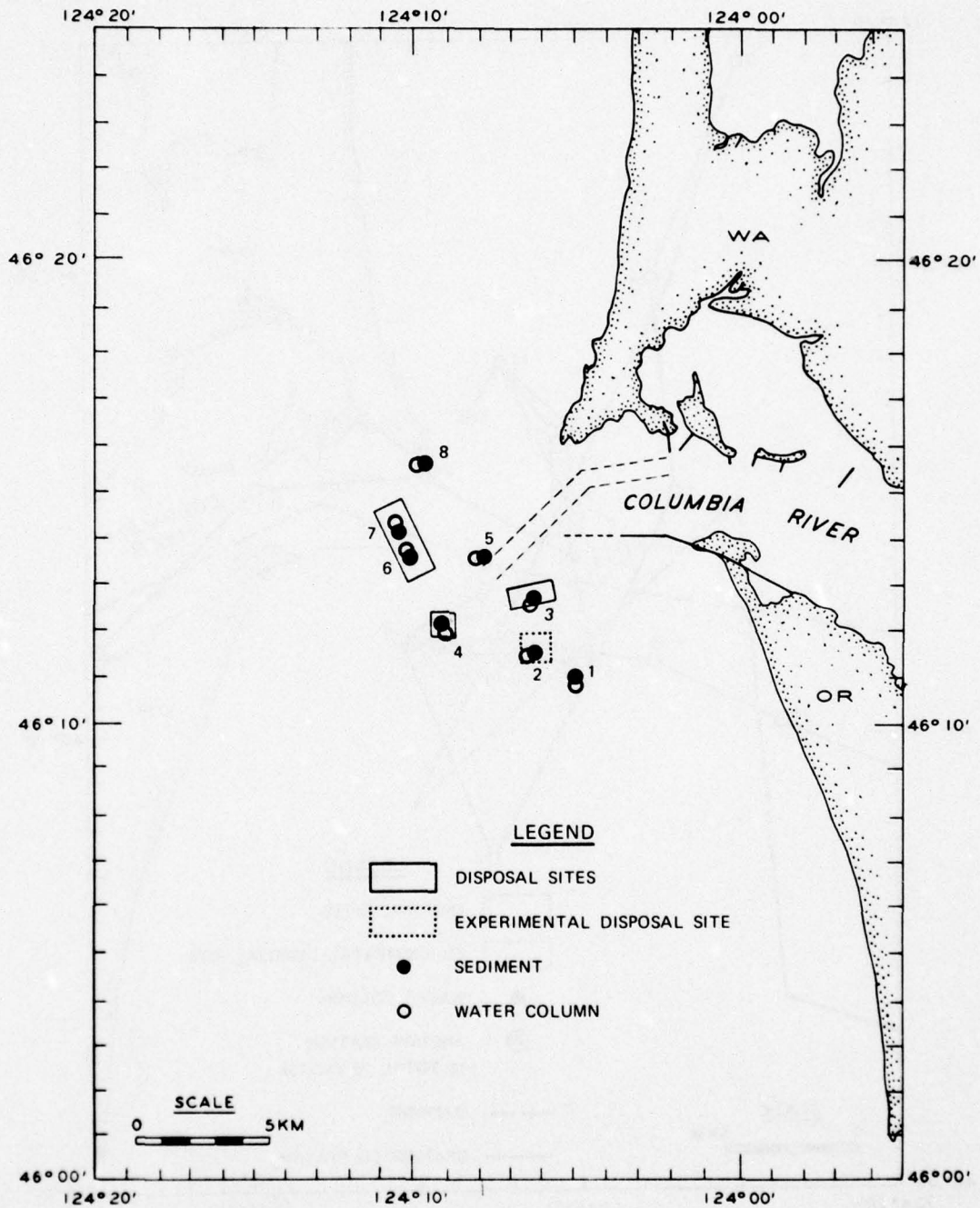


Figure B3. Station locations for samples collected on cruise Y7501 B

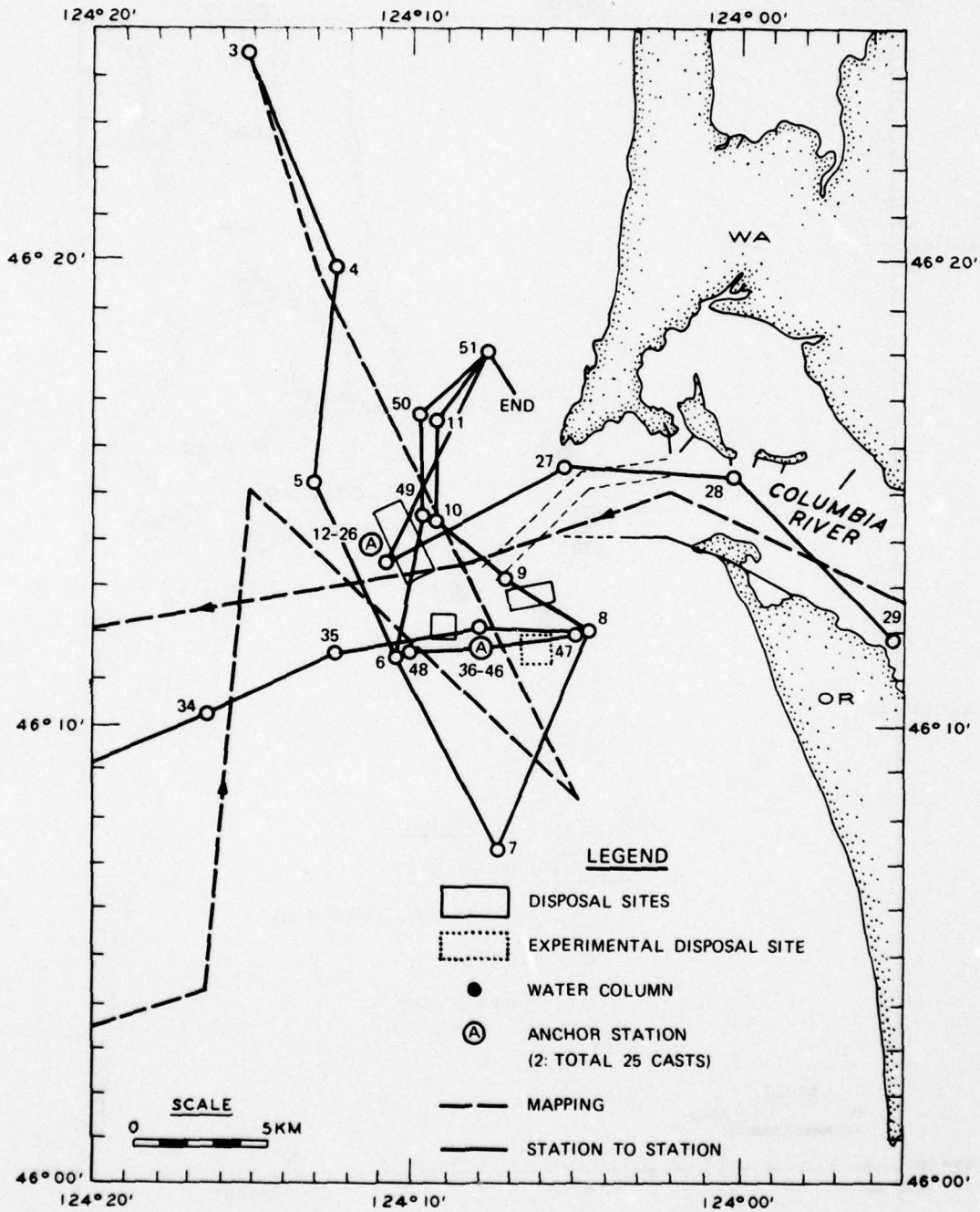


Figure B4. Station locations for samples collected on cruise Y7506 B-1

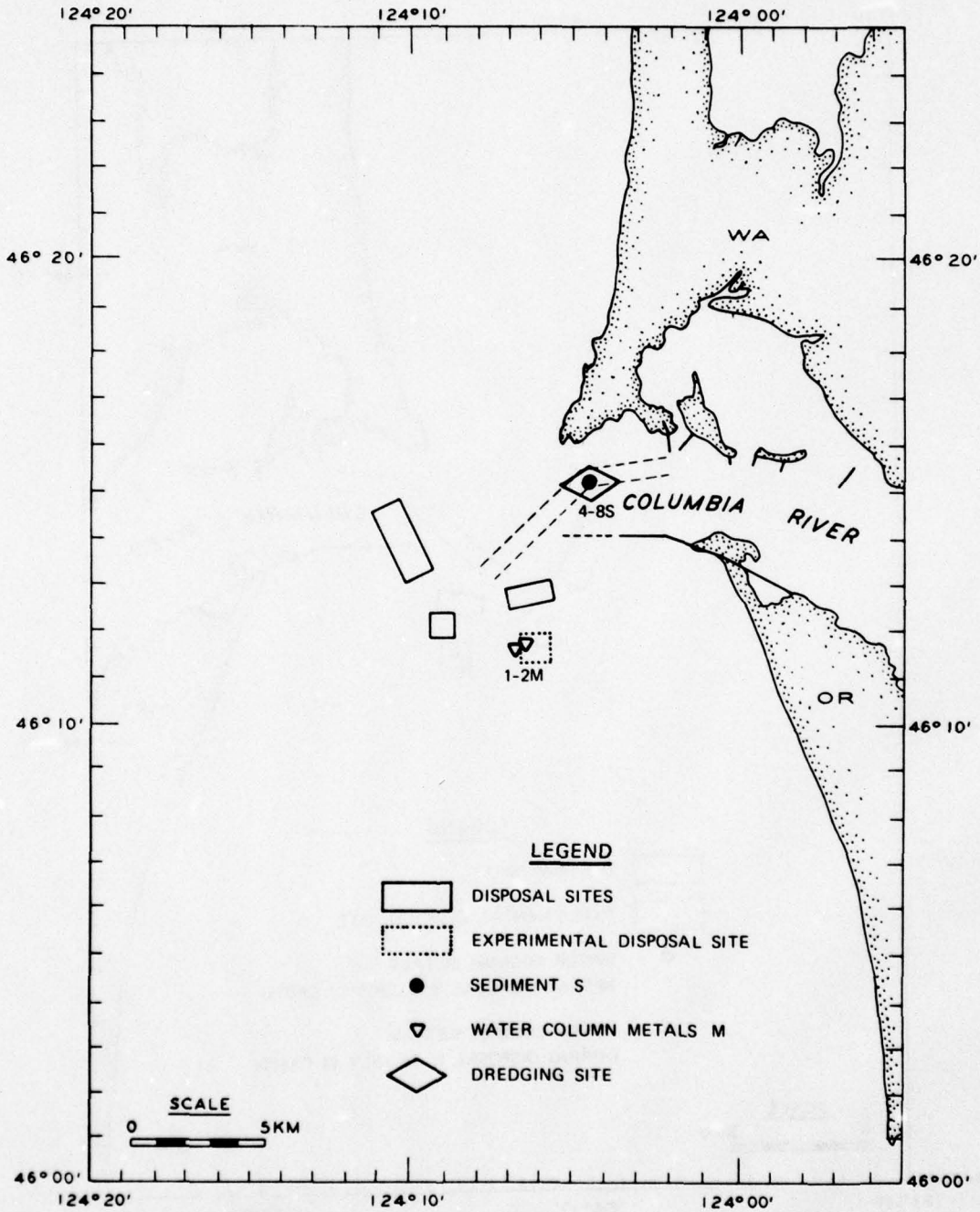


Figure B5. Station locations for samples collected on cruises Y7506 B-2 and Y7506 B-3

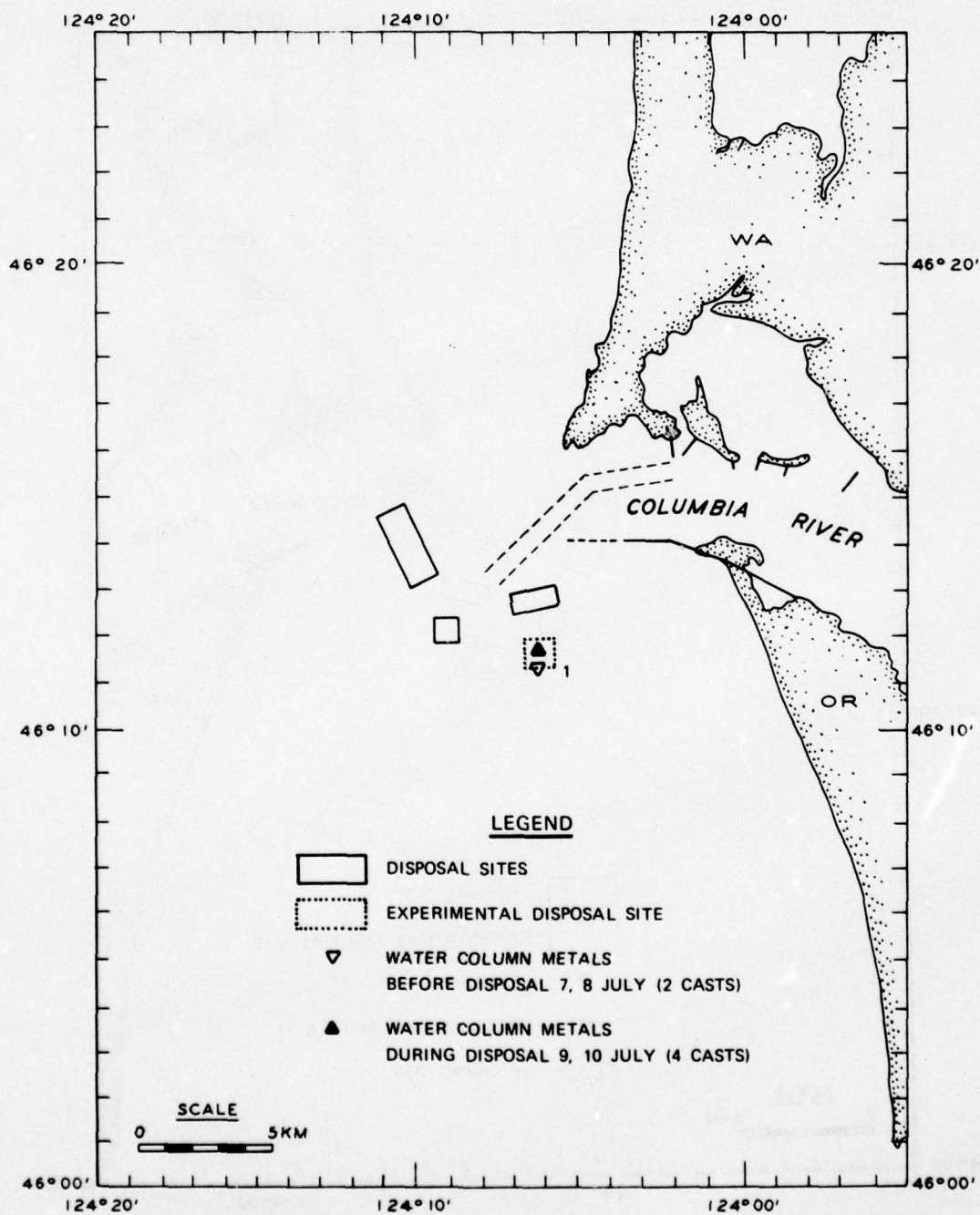


Figure B6. Station locations for samples collected on cruise Y7507 A

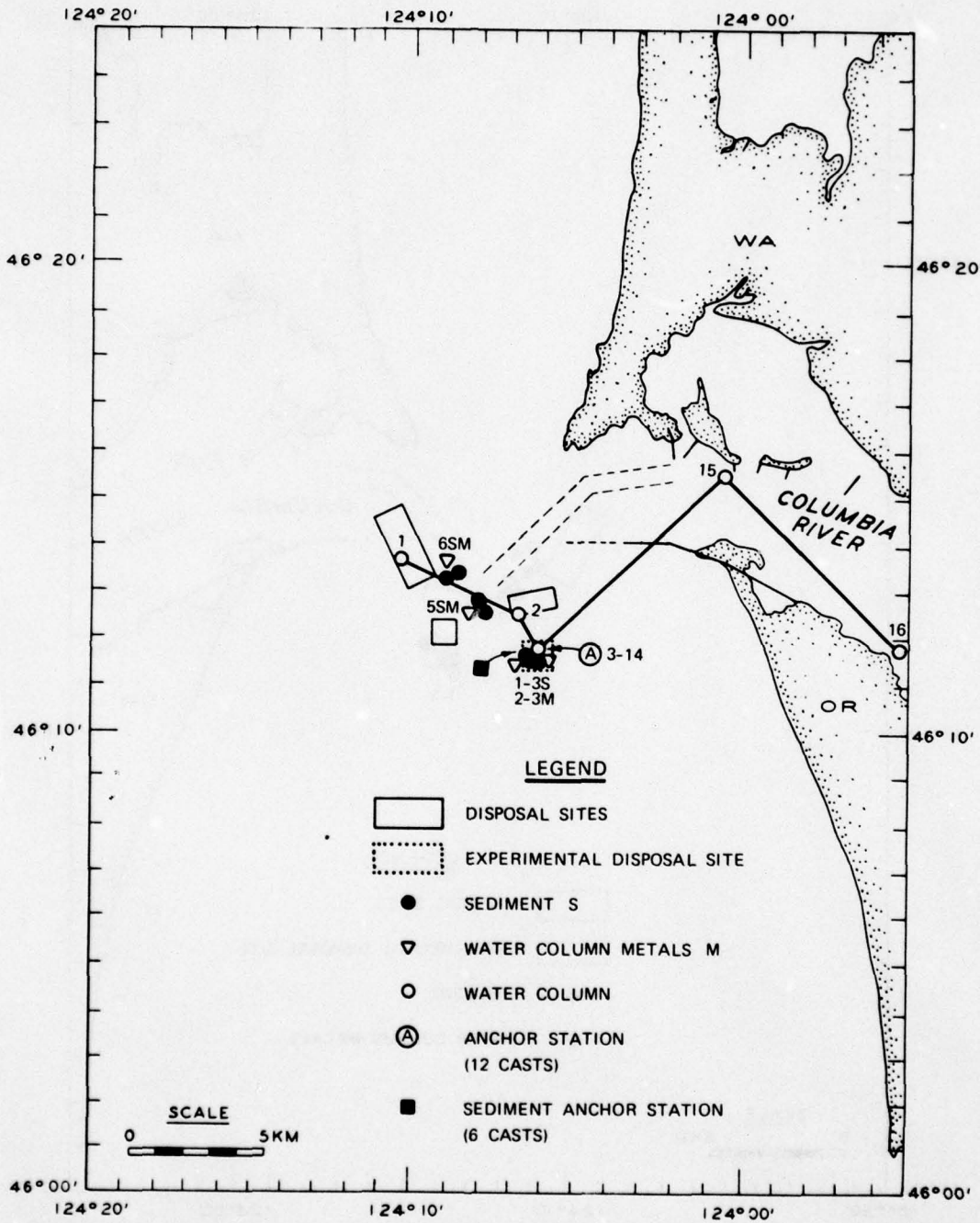


Figure B7. Station locations for samples collected on cruises Y7508 D-1 and Y7508 D-2

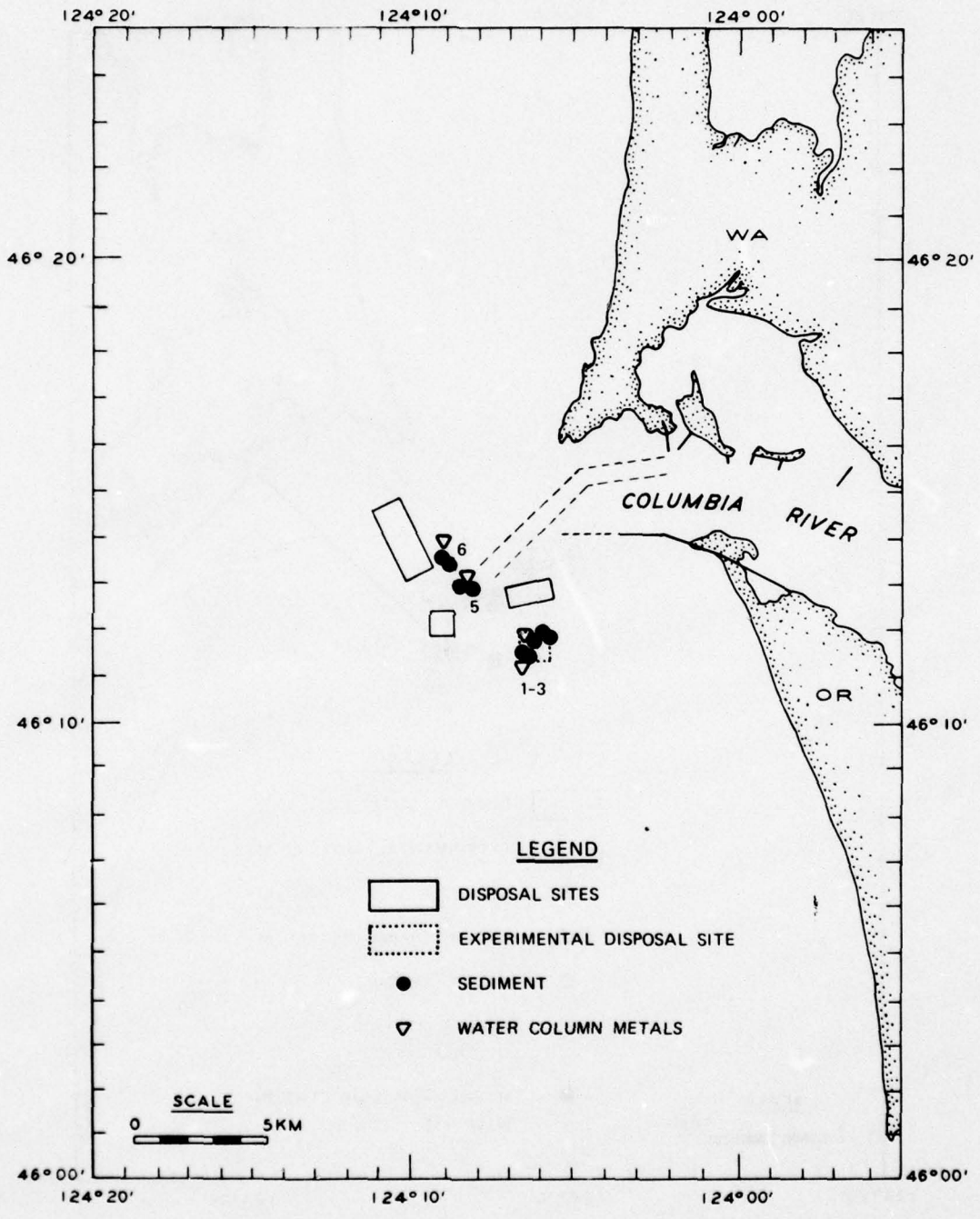


Figure B8. Station locations for samples collected on cruise Y7510 C-1

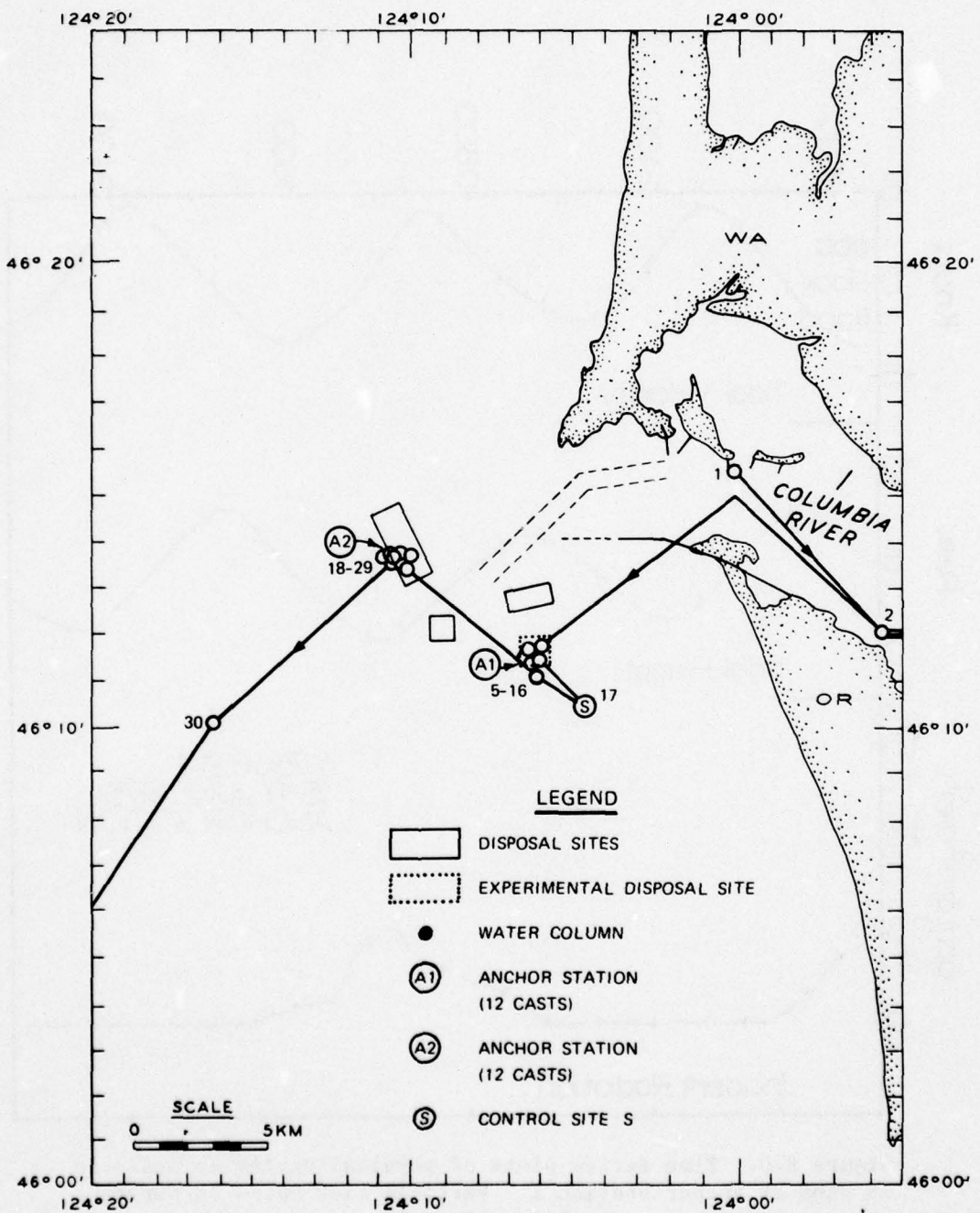


Figure B9. Station locations for samples collected on cruise Y7510 C-2

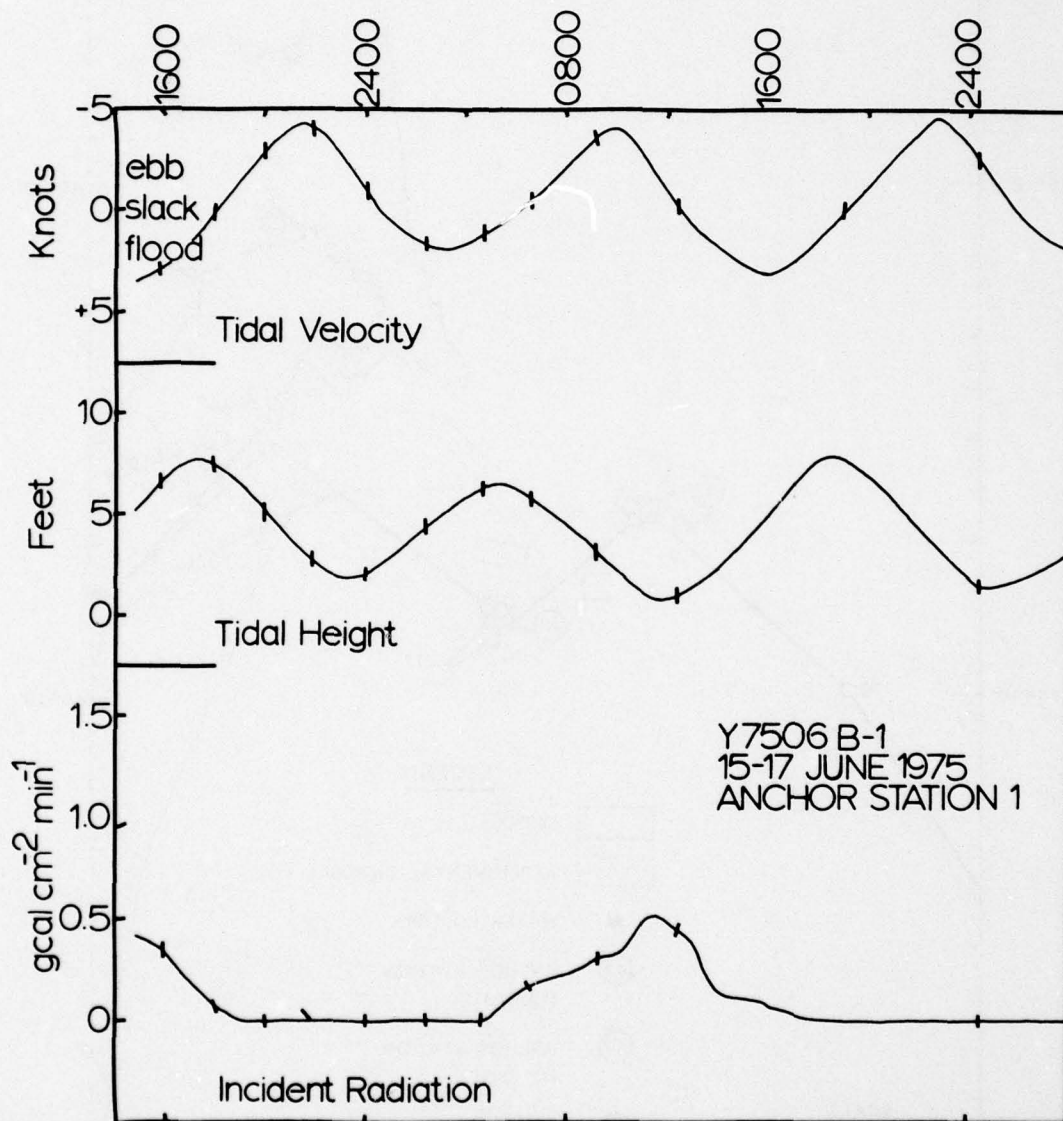


Figure B10. Time series plots of physical variables measured in June at anchor station 1. Vertical tick marks on curves equal sampling times

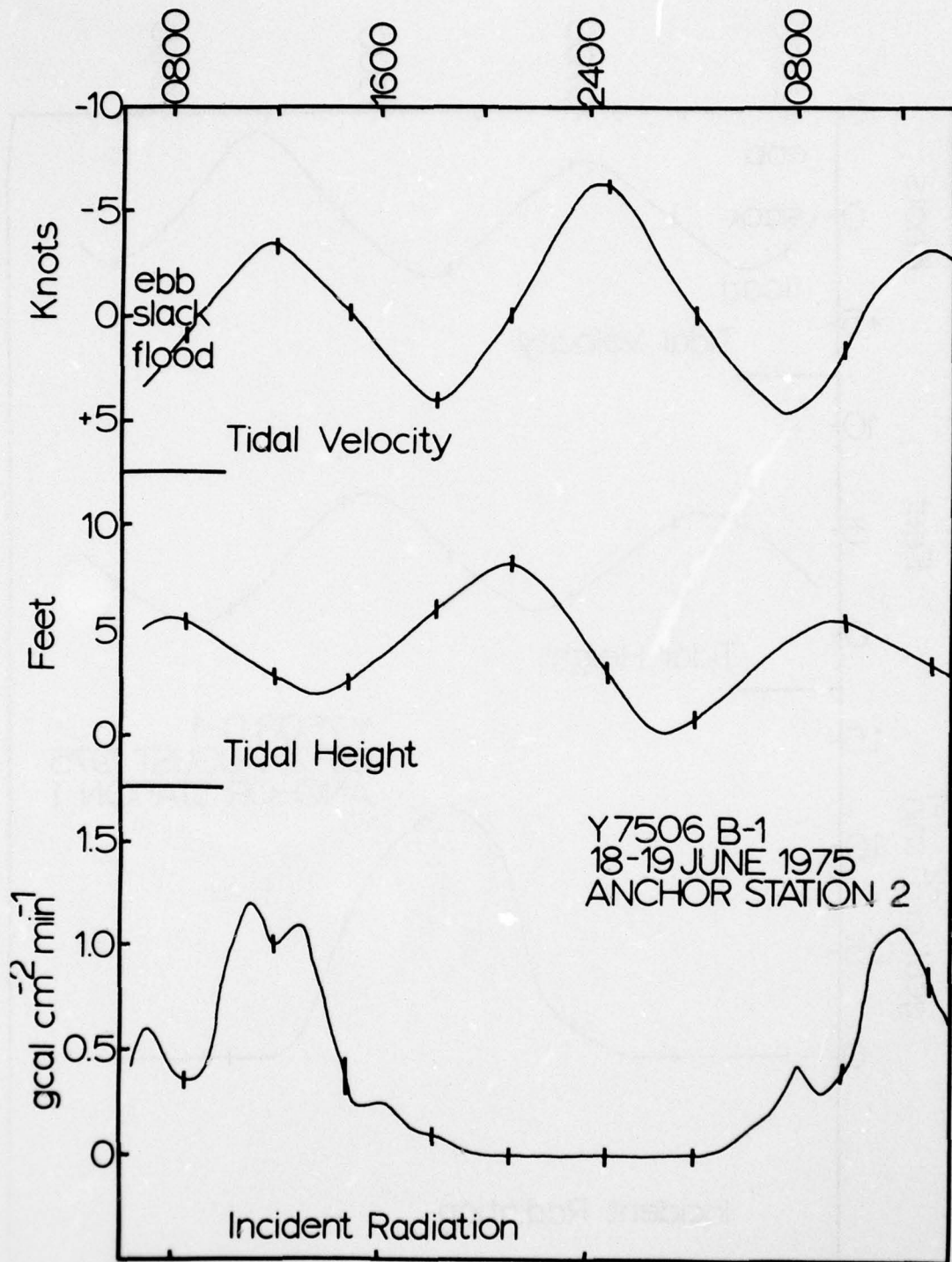


Figure B11. Time series plots of physical variables measured in June at anchor station 2. Vertical tick marks on curves equal sampling times

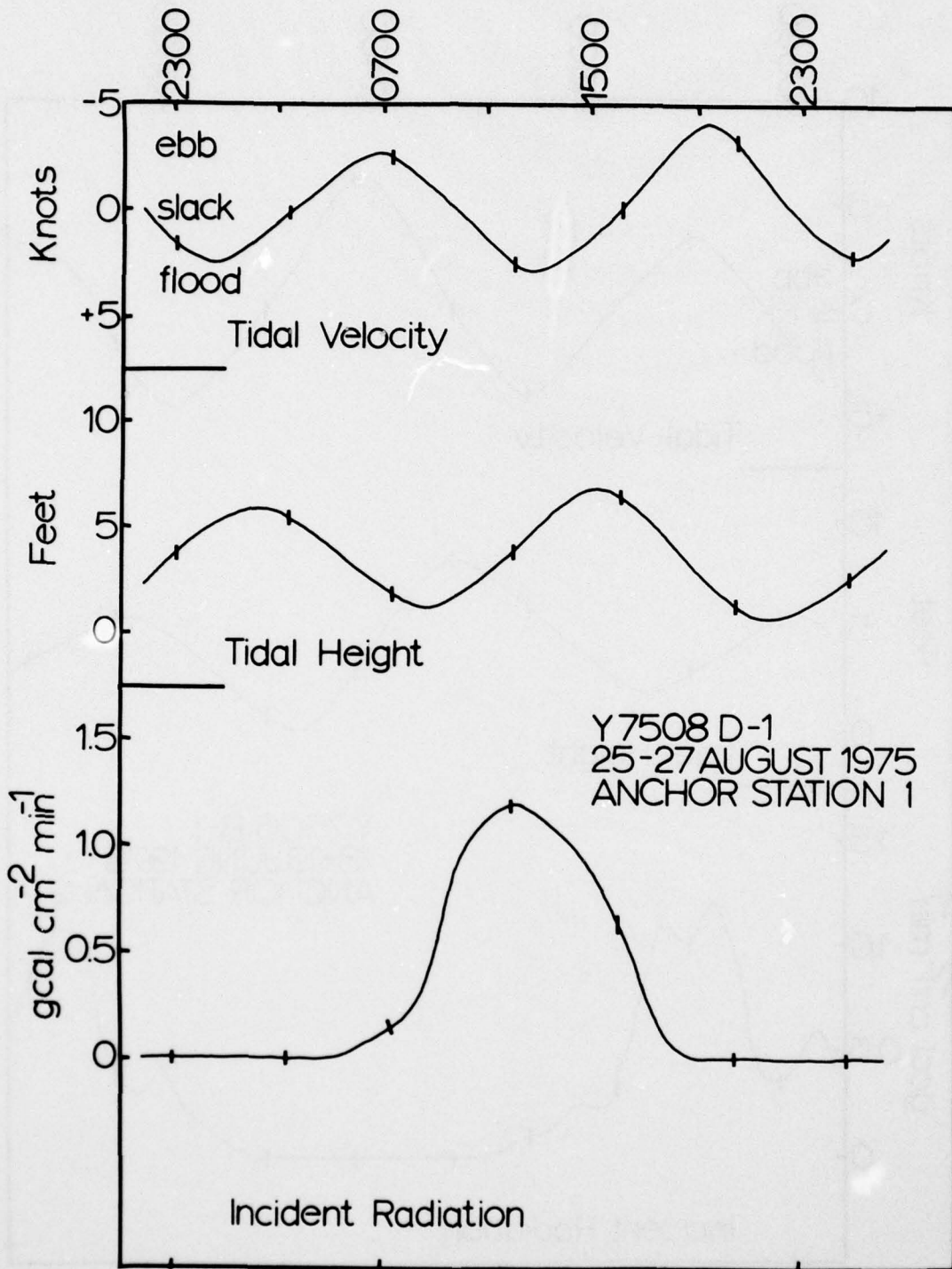


Figure B12. Time series plots of physical variables measured in August at anchor station 1. Vertical tick marks on curves equal sampling times

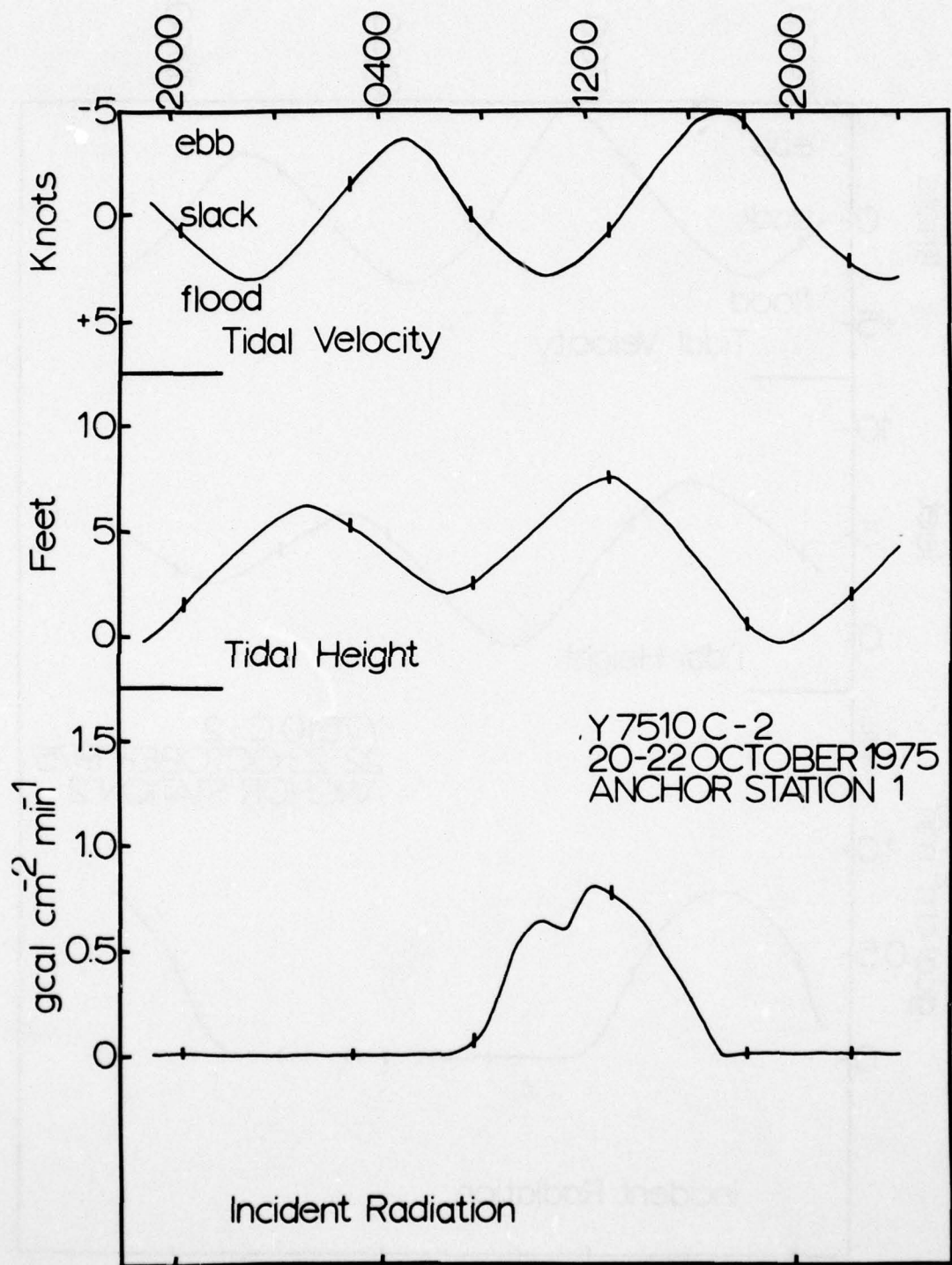


Figure B13. Time series plots of physical variables measured in October at anchor station 1. Vertical tick marks on curves equal sampling times

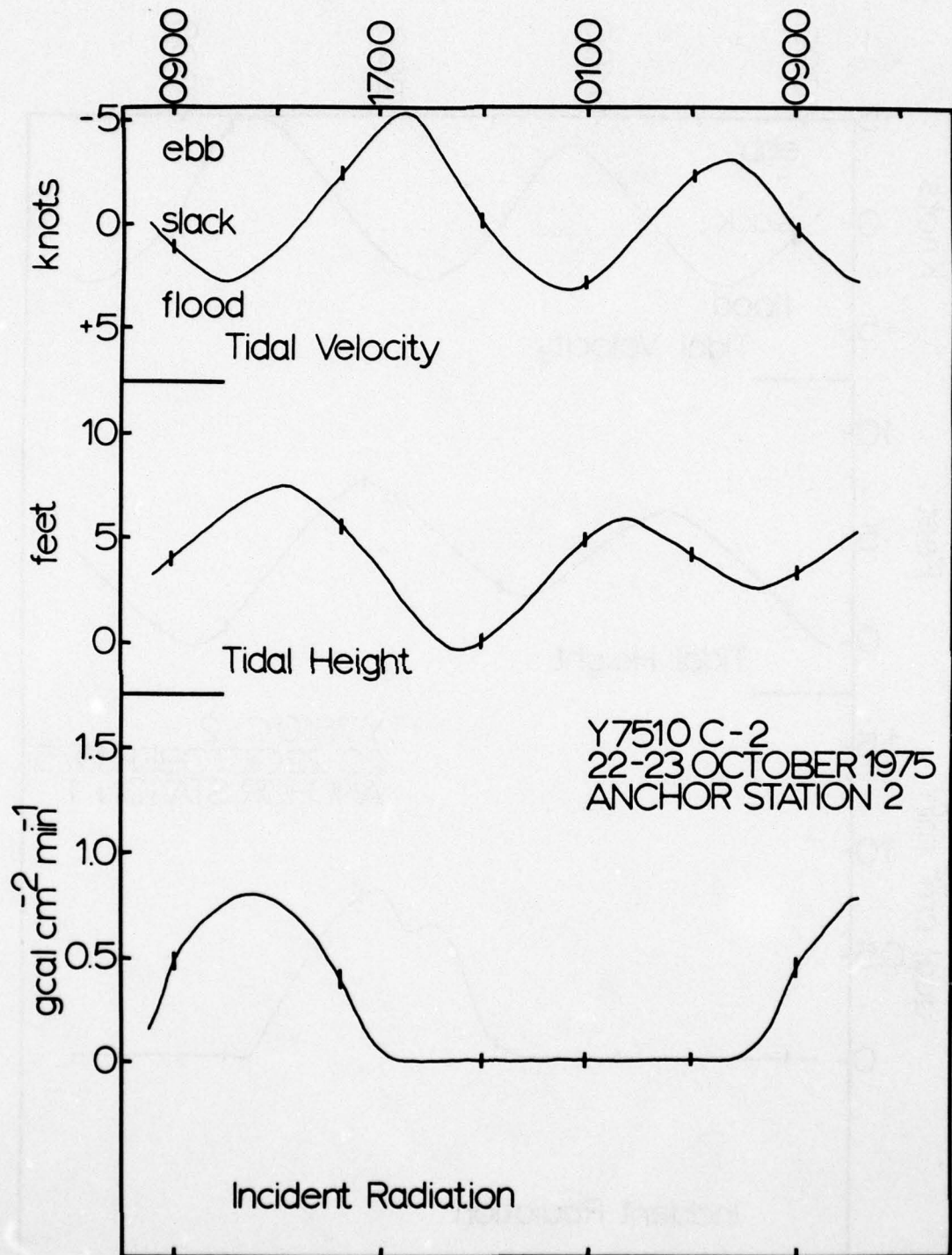


Figure B14. Time series plots of physical variables measured in October at anchor station 2. Vertical tick marks on curves equal sampling times.

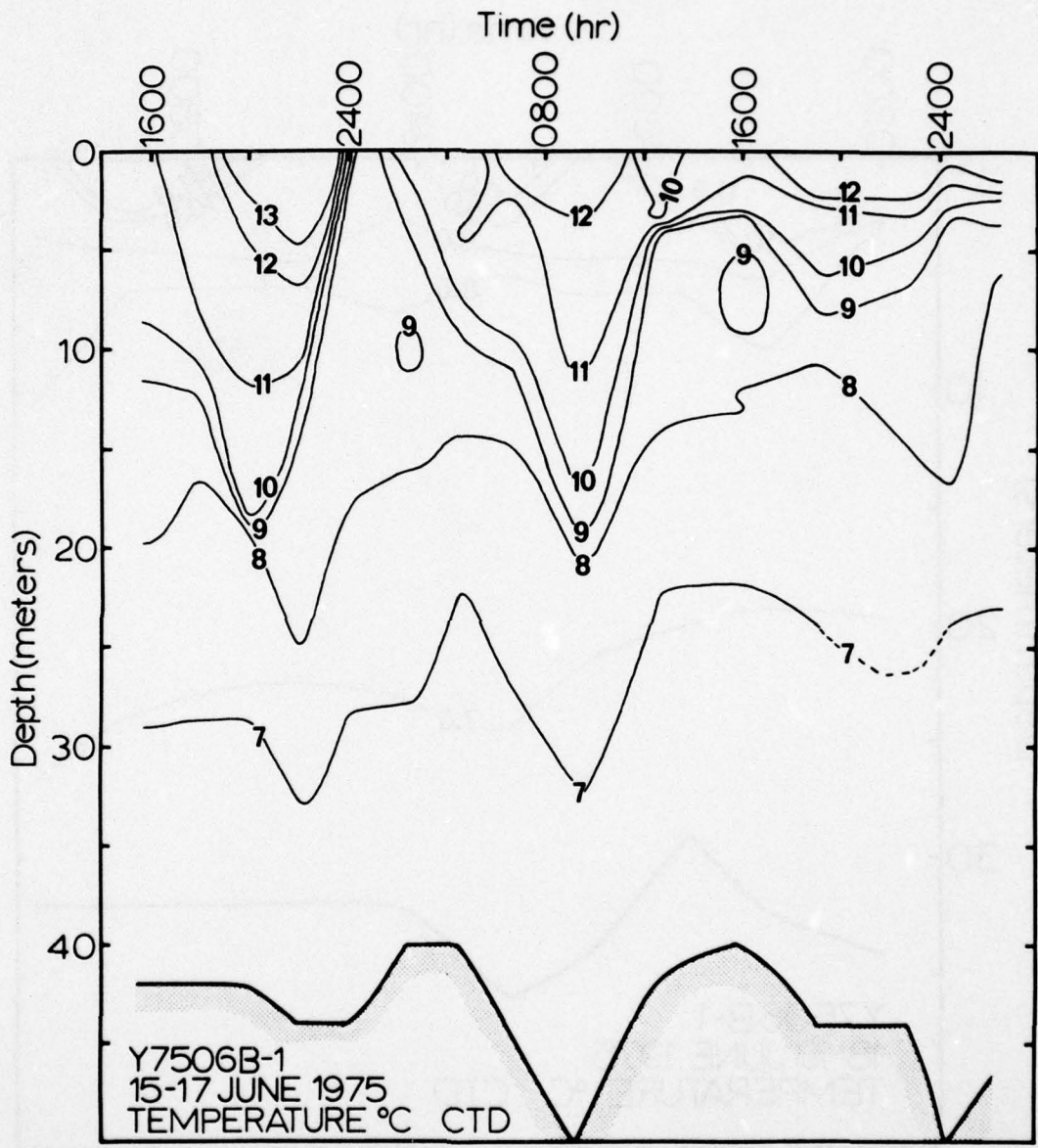


Figure B15. Temperature distribution plot for June anchor station 1

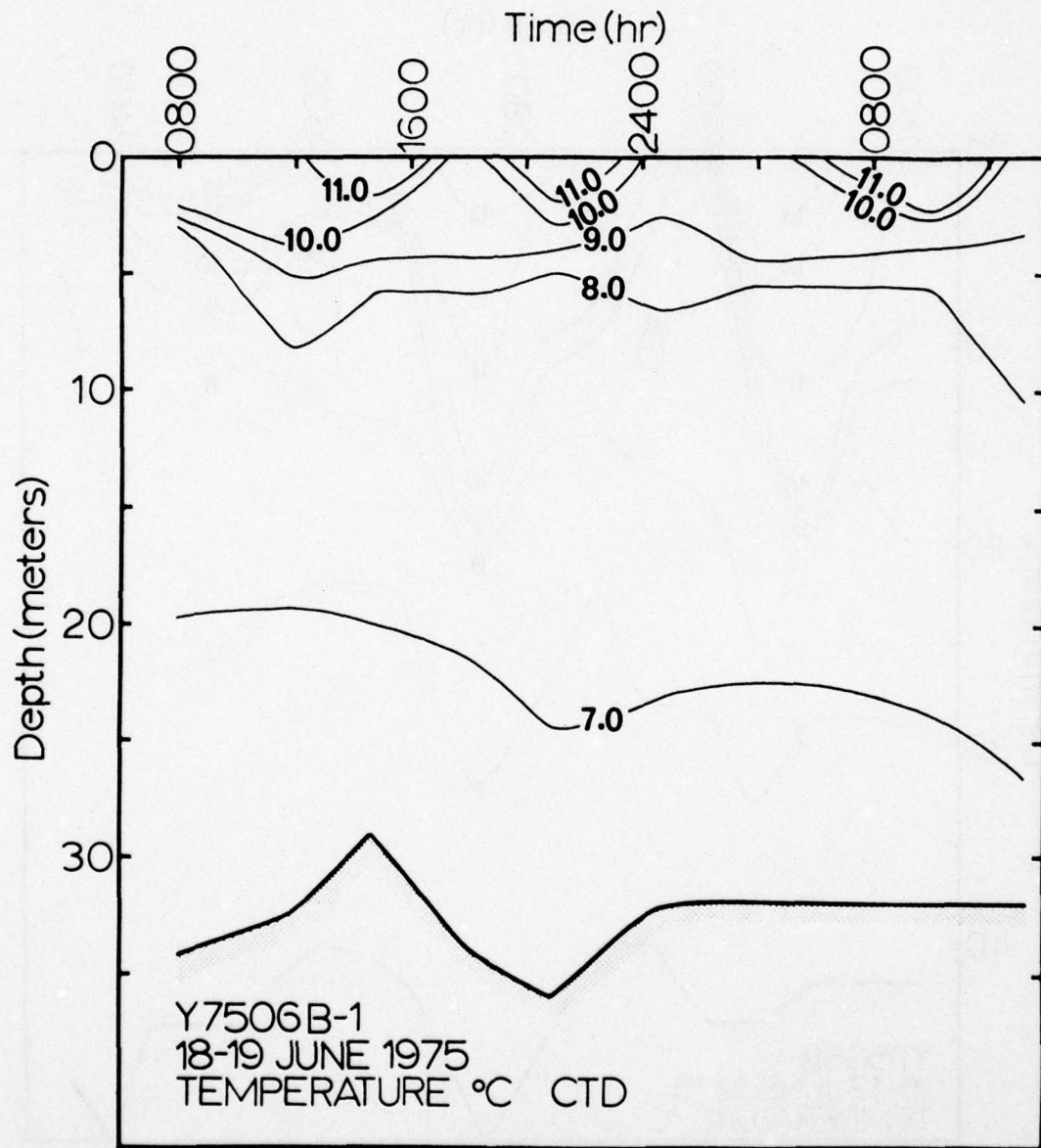


Figure B16. Temperature distribution plot for June anchor station 2

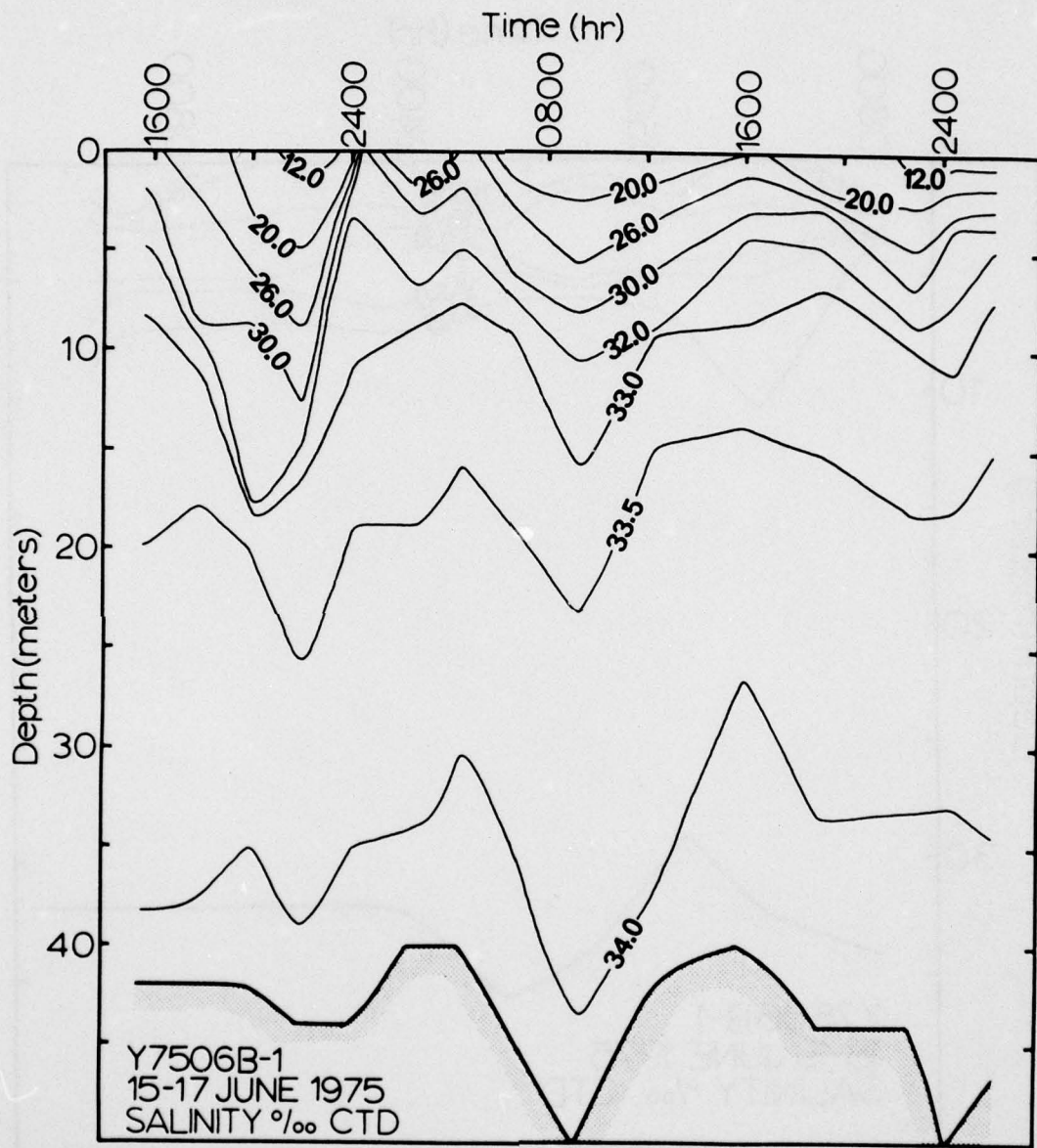


Figure B17. Salinity distribution plot for June anchor station 1

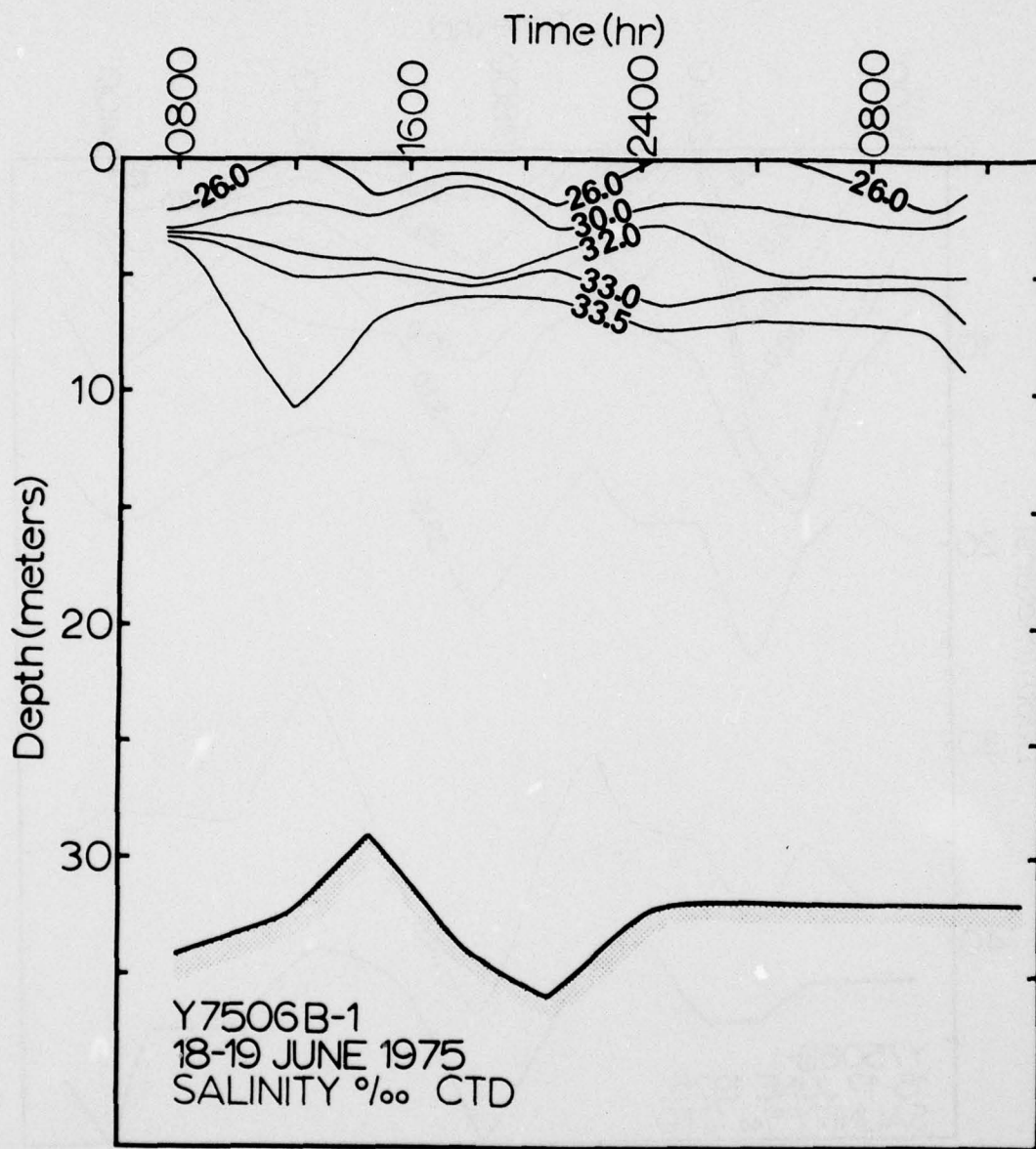


Figure B18. Salinity distribution plot for June anchor station 2

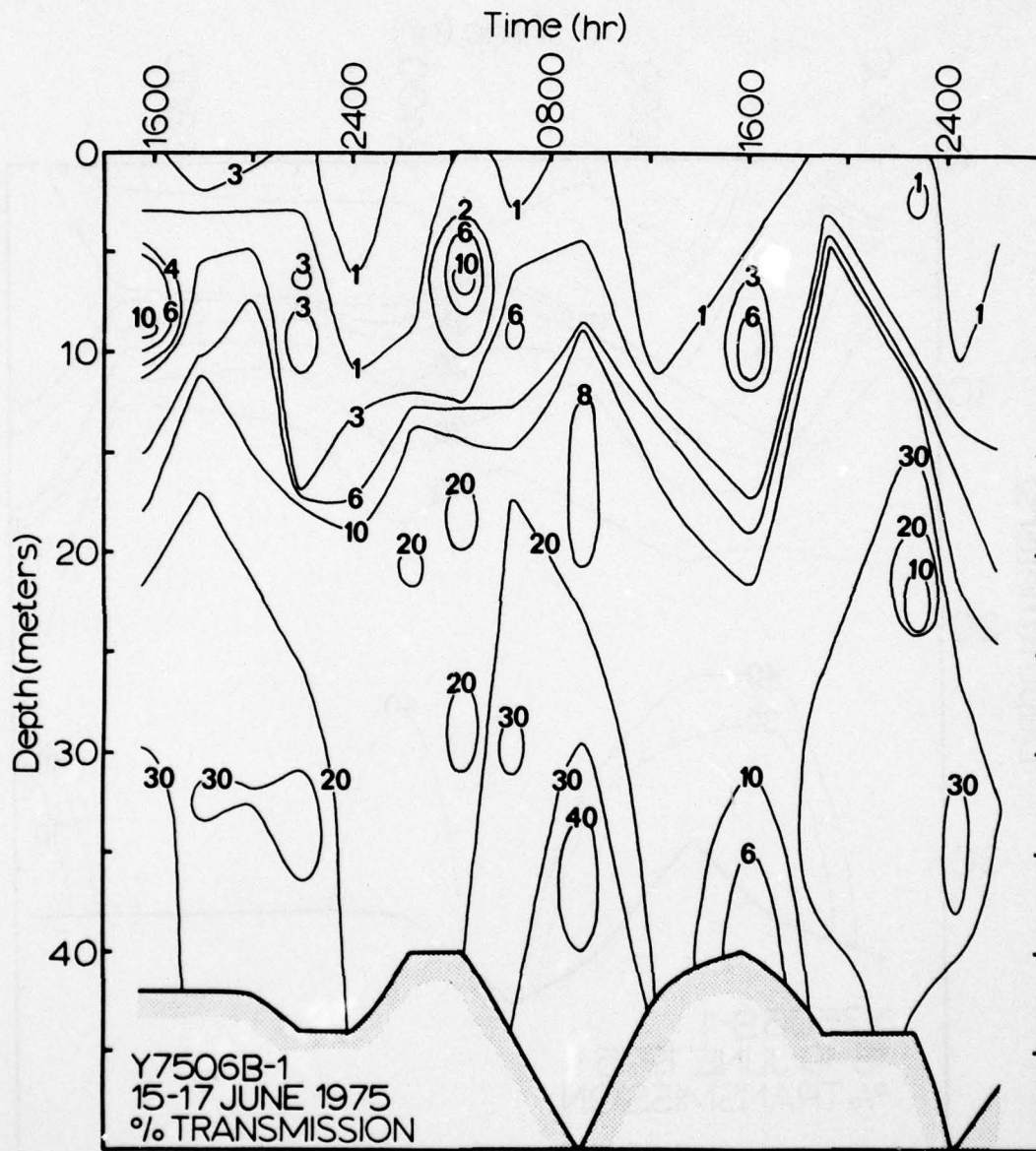


Figure B19. Percent light transmission plot for June anchor station 1

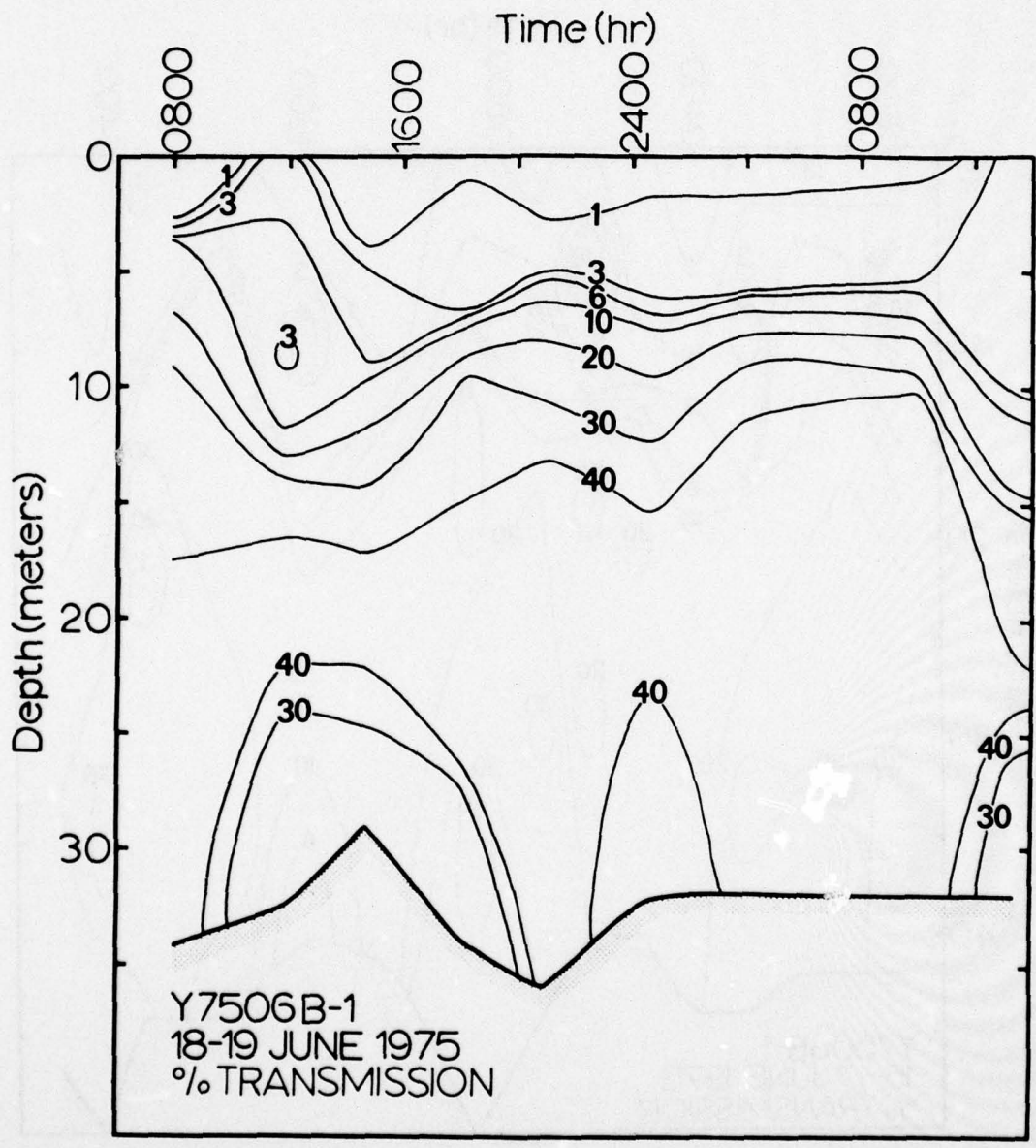


Figure B20. Percent light transmission plot for June anchor station 2

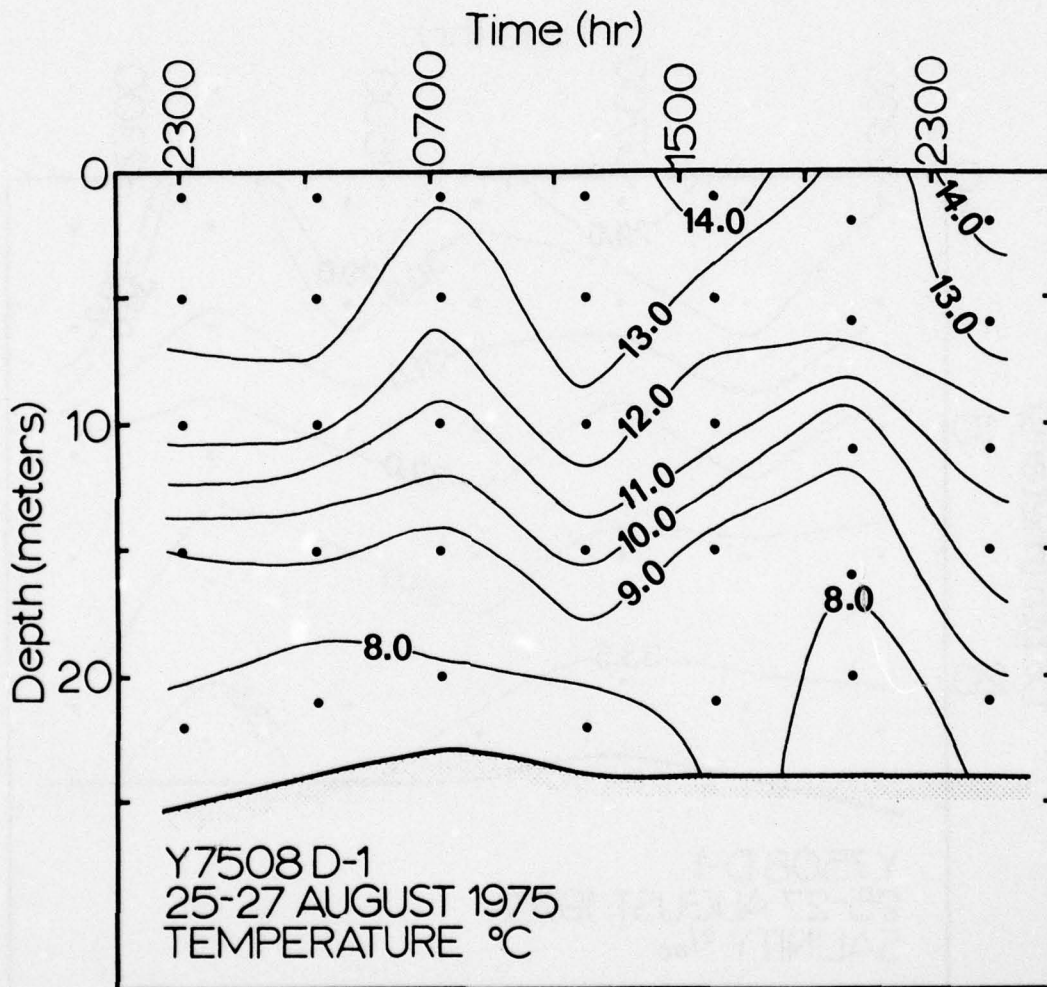


Figure B21. Temperature distribution plot for August anchor station

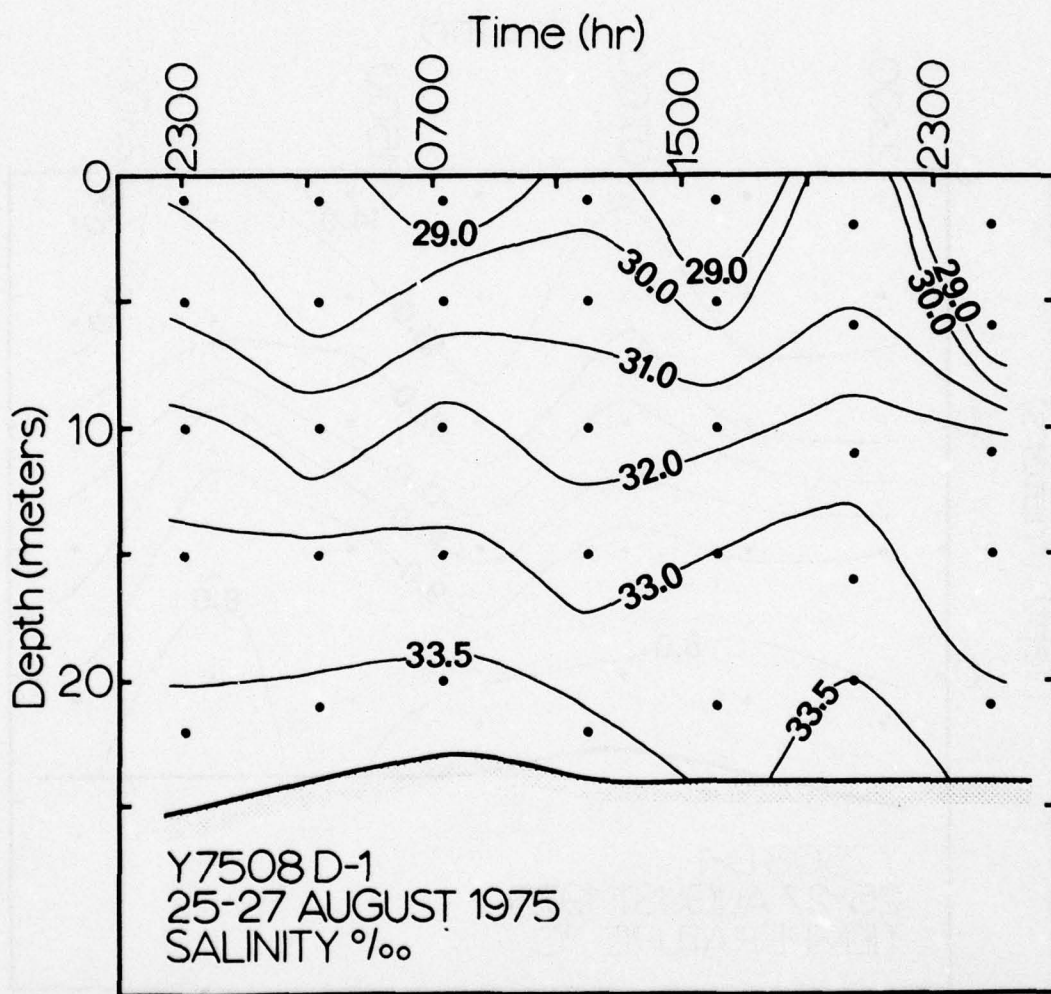


Figure B22. Salinity distribution plot for August anchor station

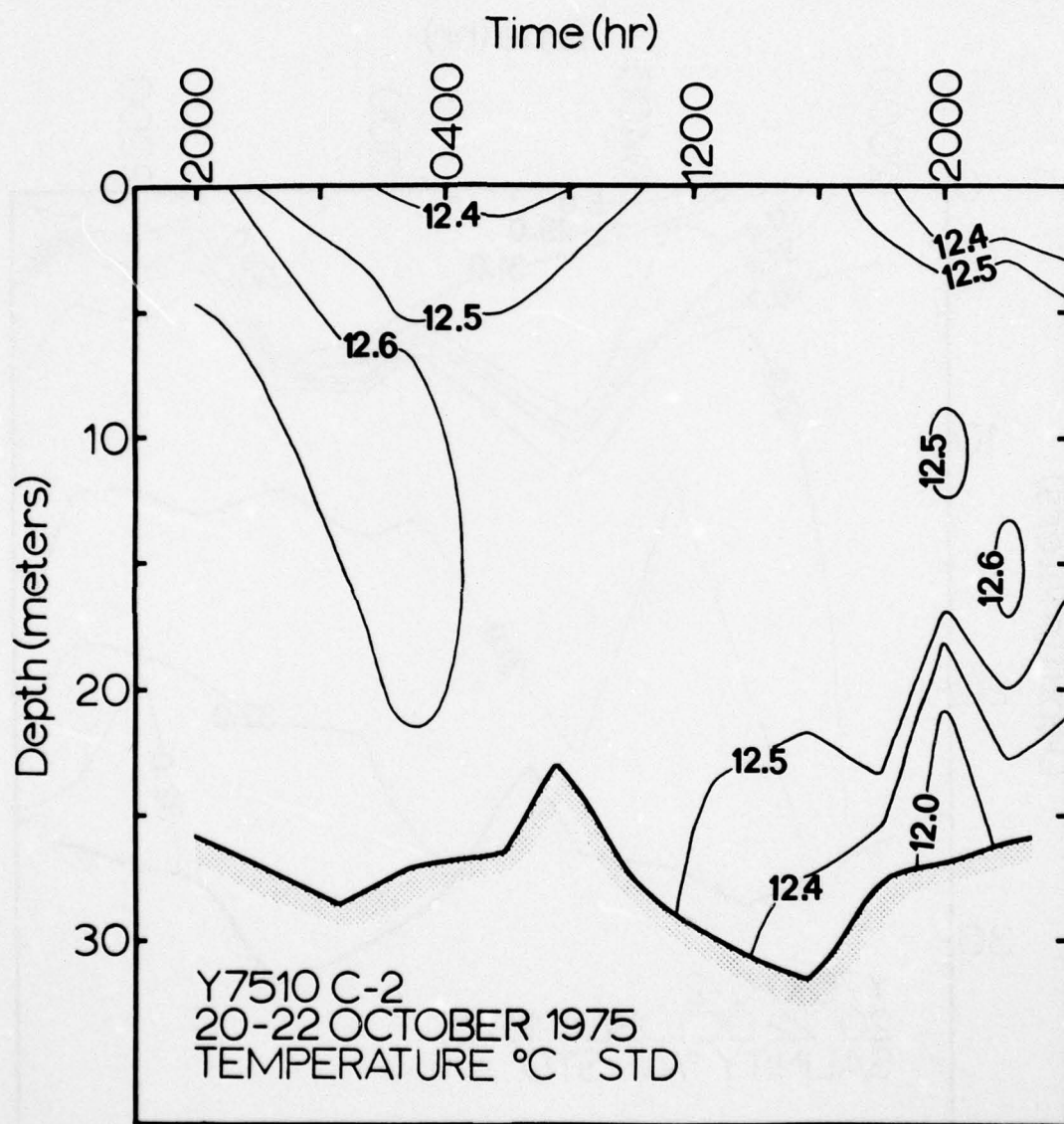


Figure B23. Temperature distribution plot for October anchor station 1

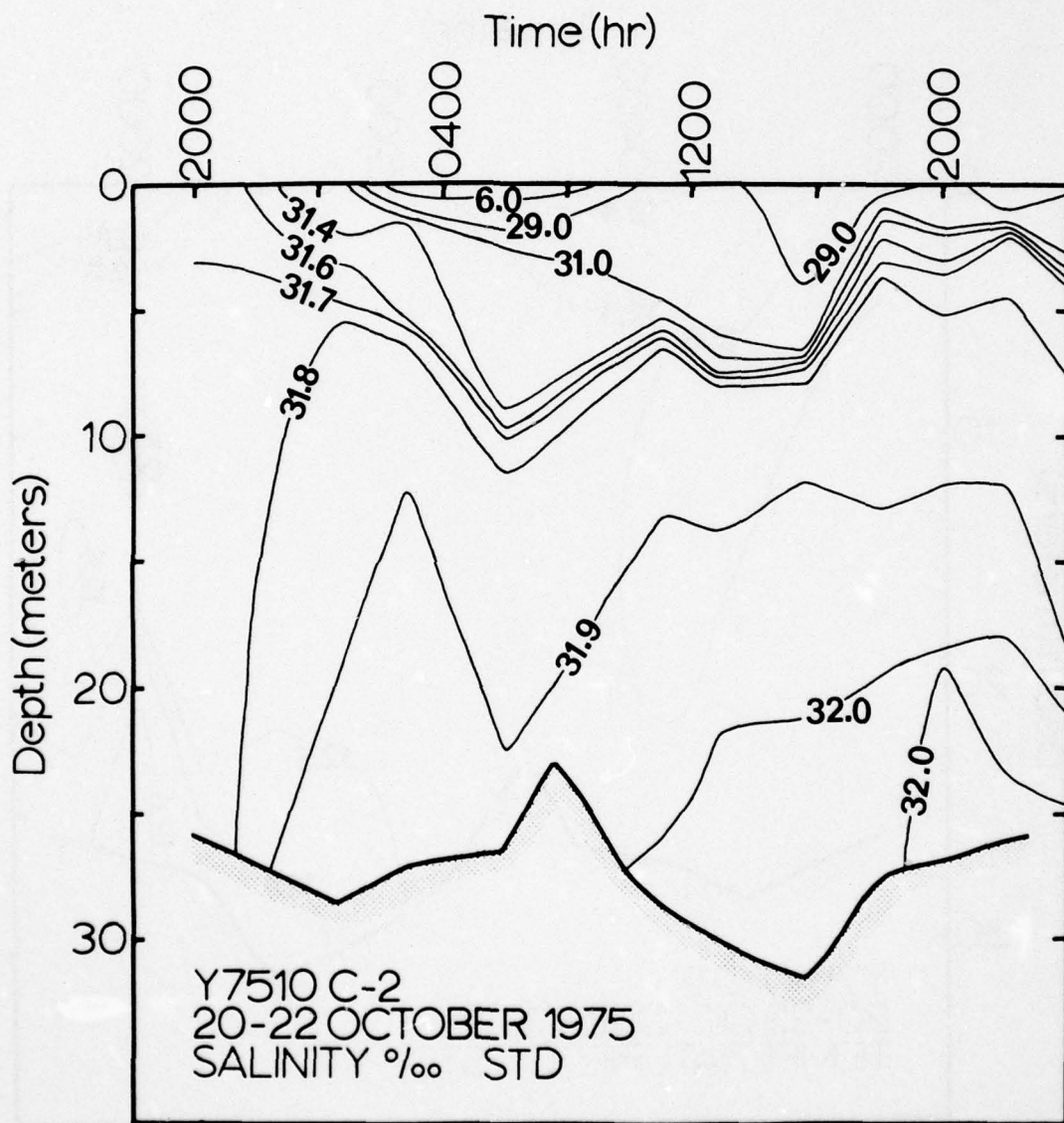


Figure B24. Salinity distribution plot for October anchor station 1

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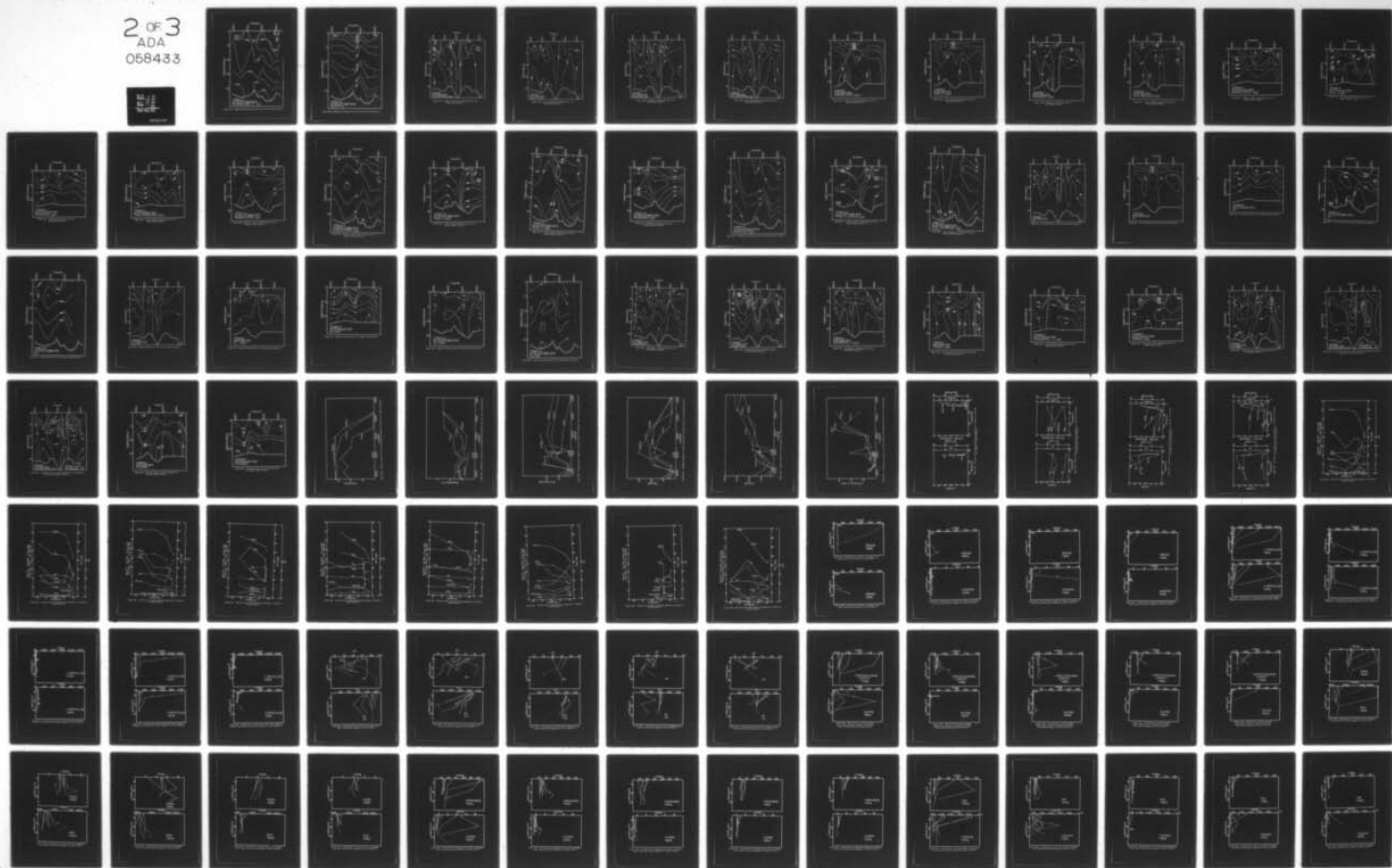
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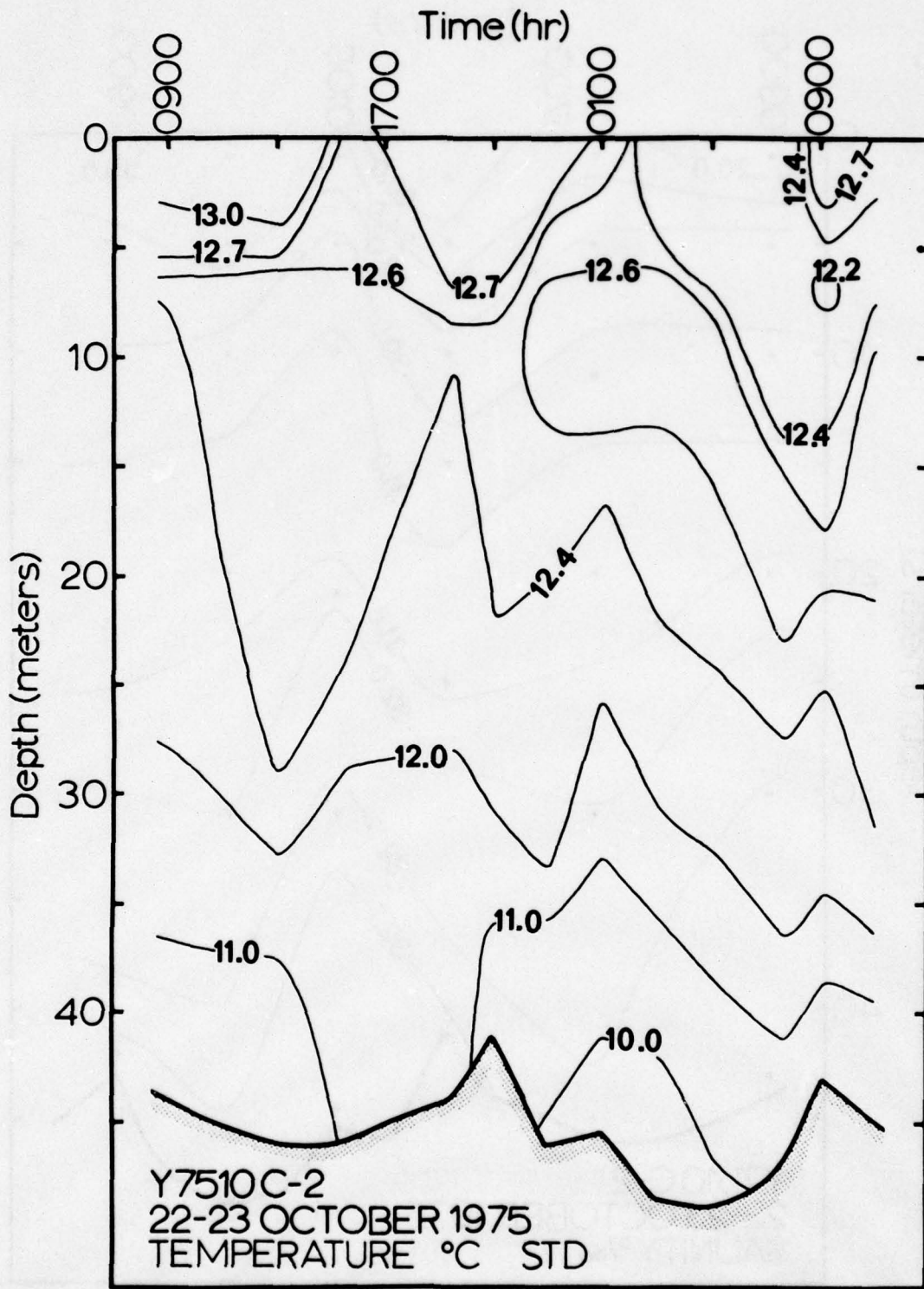


Figure B25. Temperature distribution plot for October anchor station 2

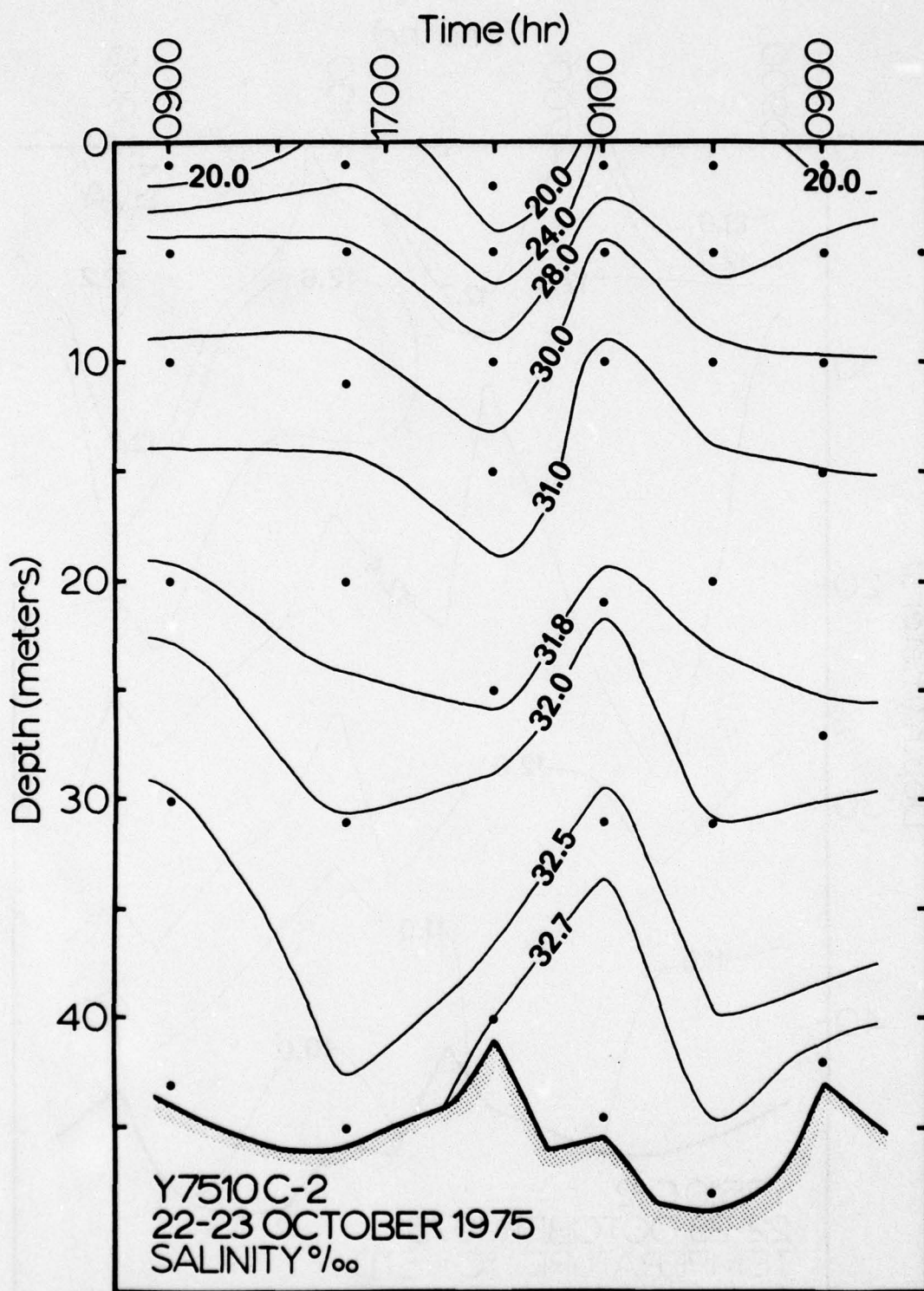


Figure B26. Salinity distribution plot for October anchor station 2

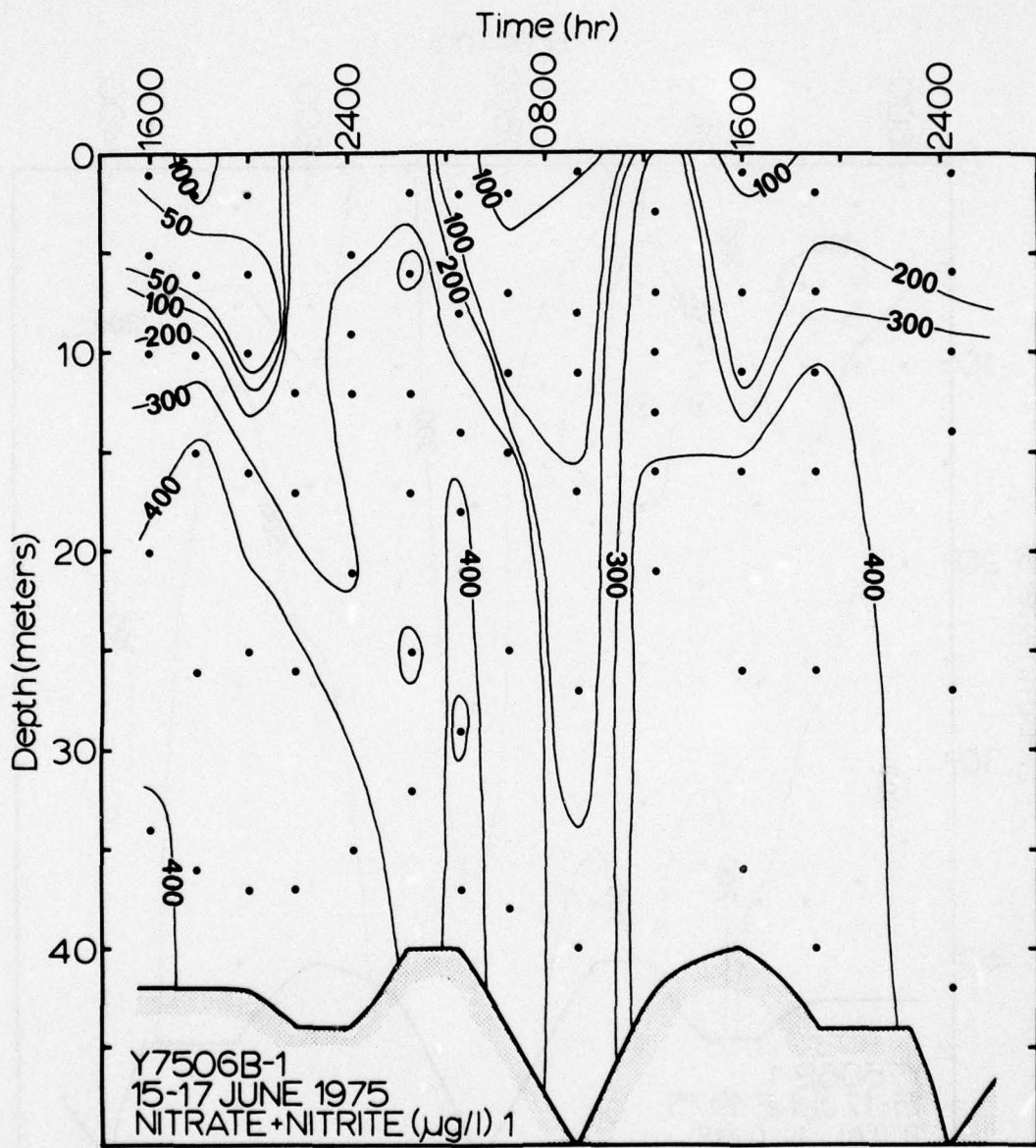


Figure B27. Nitrate + nitrite distribution plot for June anchor station 1

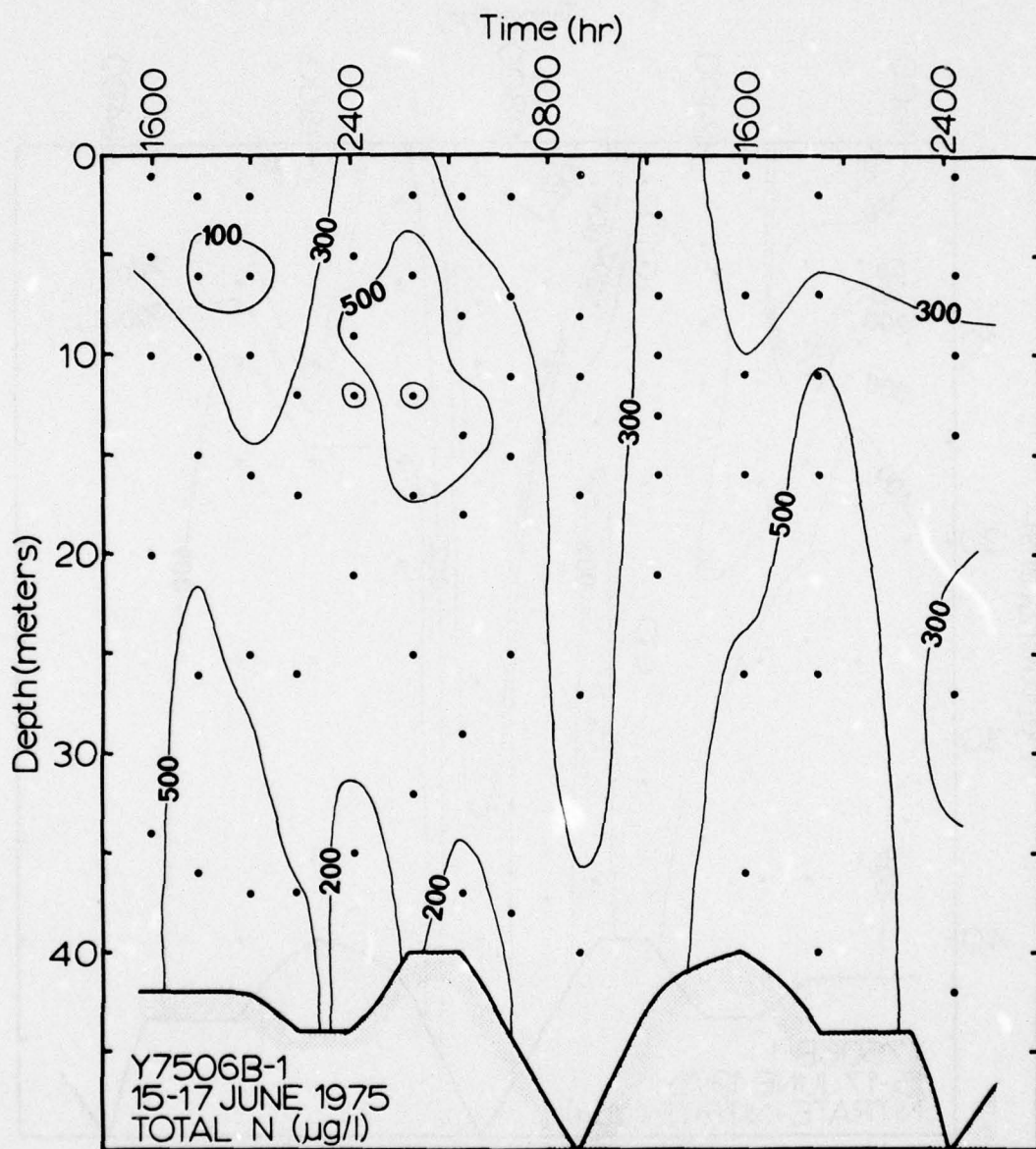


Figure B28. Total nitrogen distribution plot for June anchor station 1

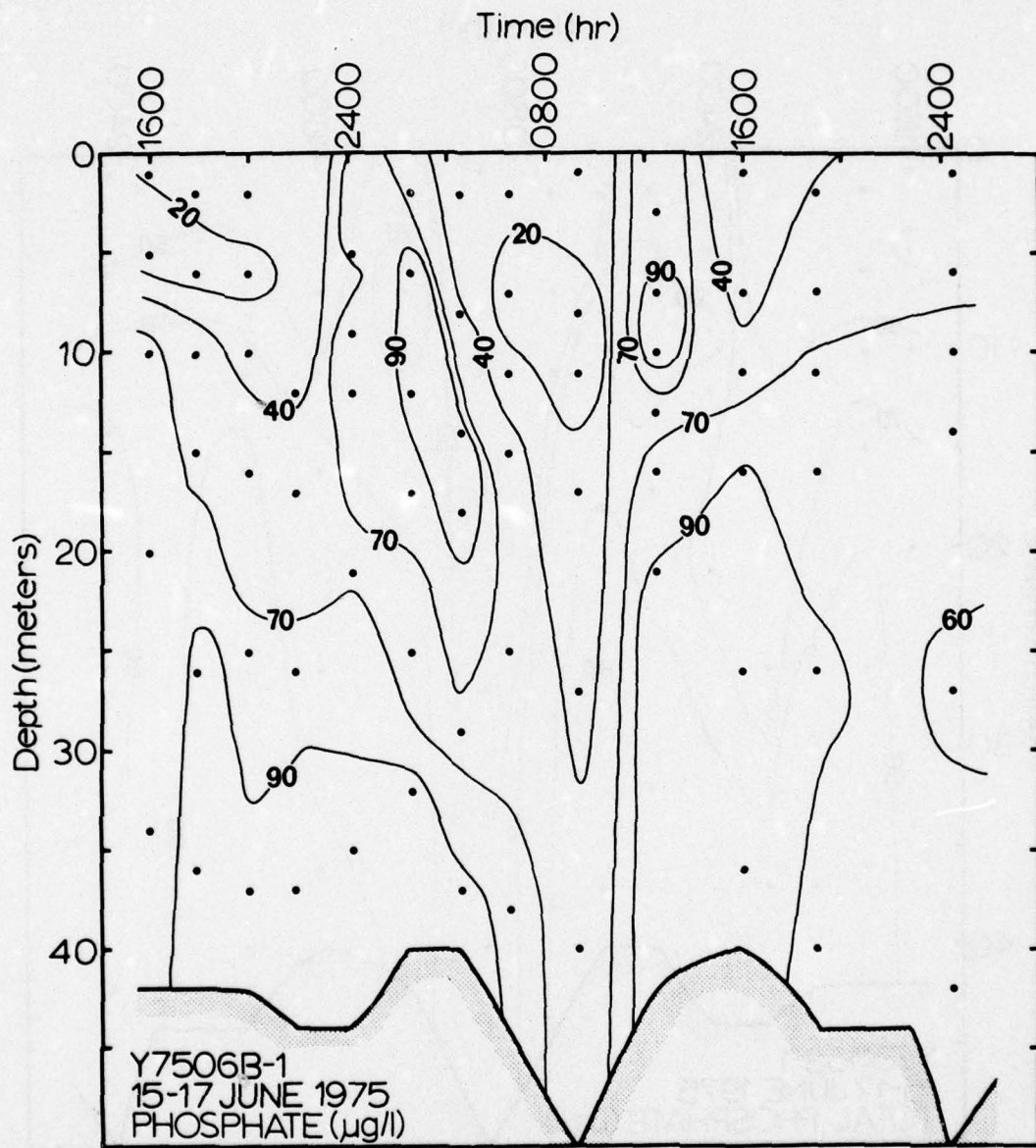


Figure B29. Phosphate distribution plot for June anchor station 1

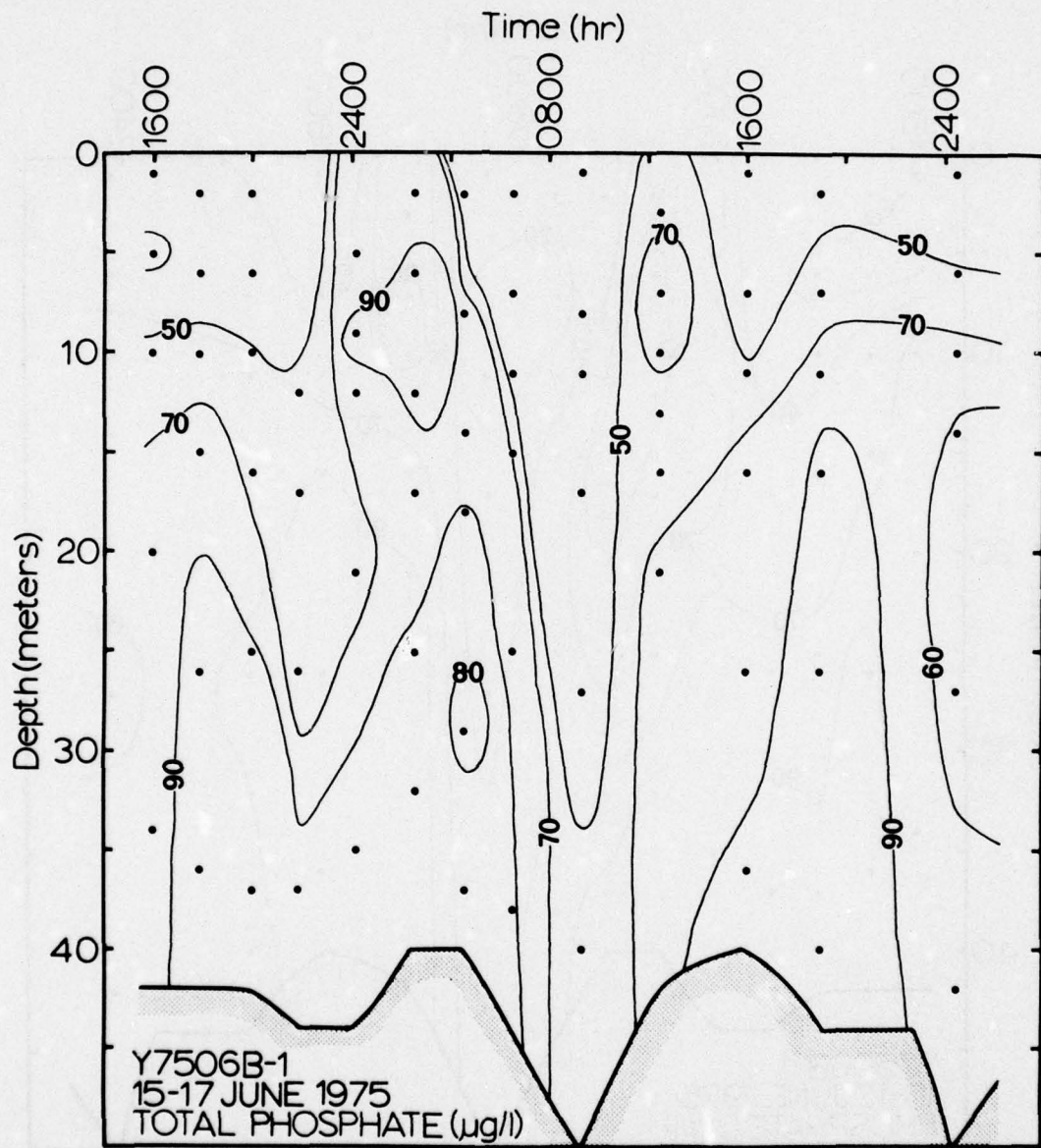


Figure B30. Total phosphate distribution plot for June anchor station 1

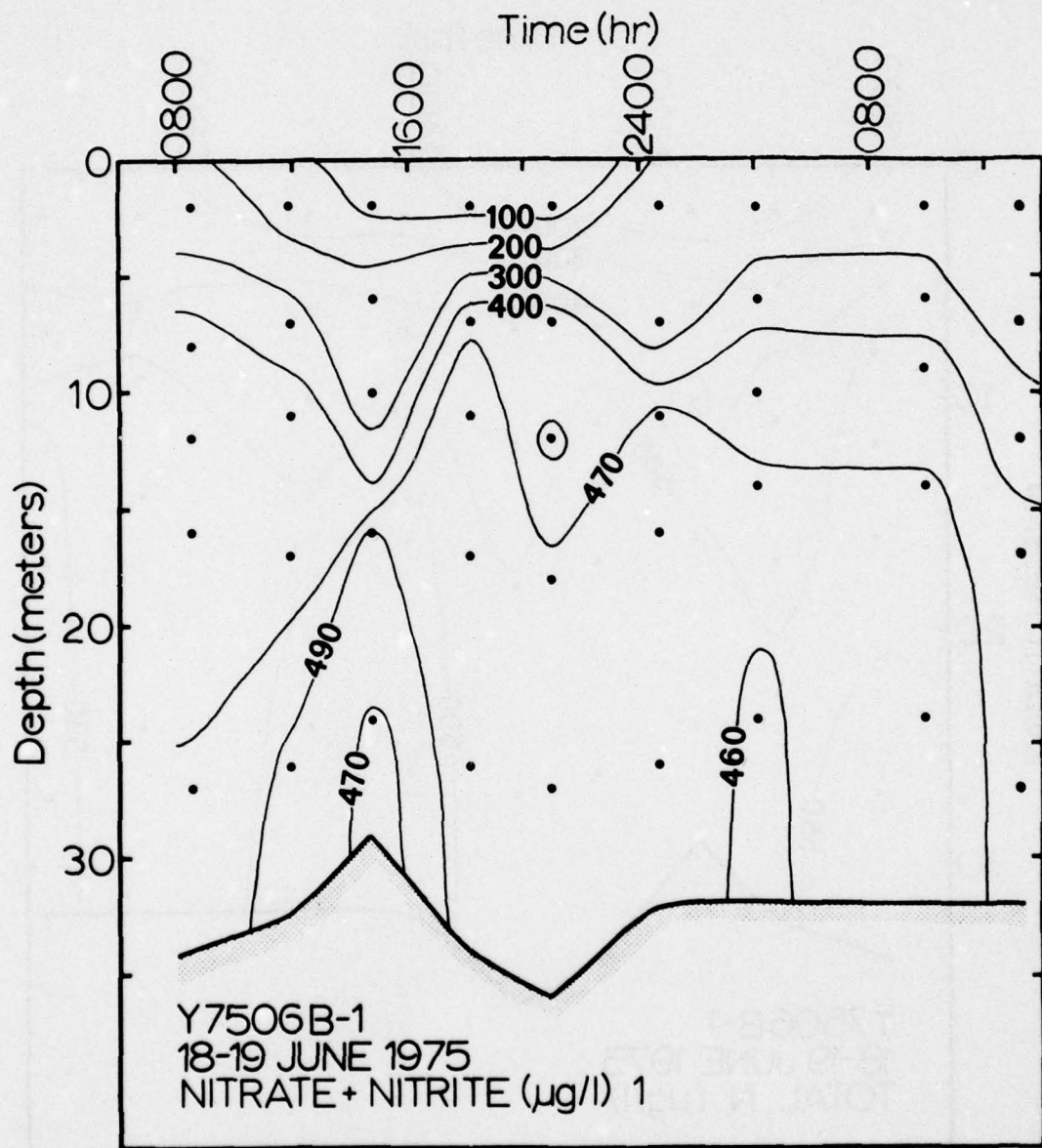


Figure B31. Nitrate + nitrite distribution plot for June anchor station 2

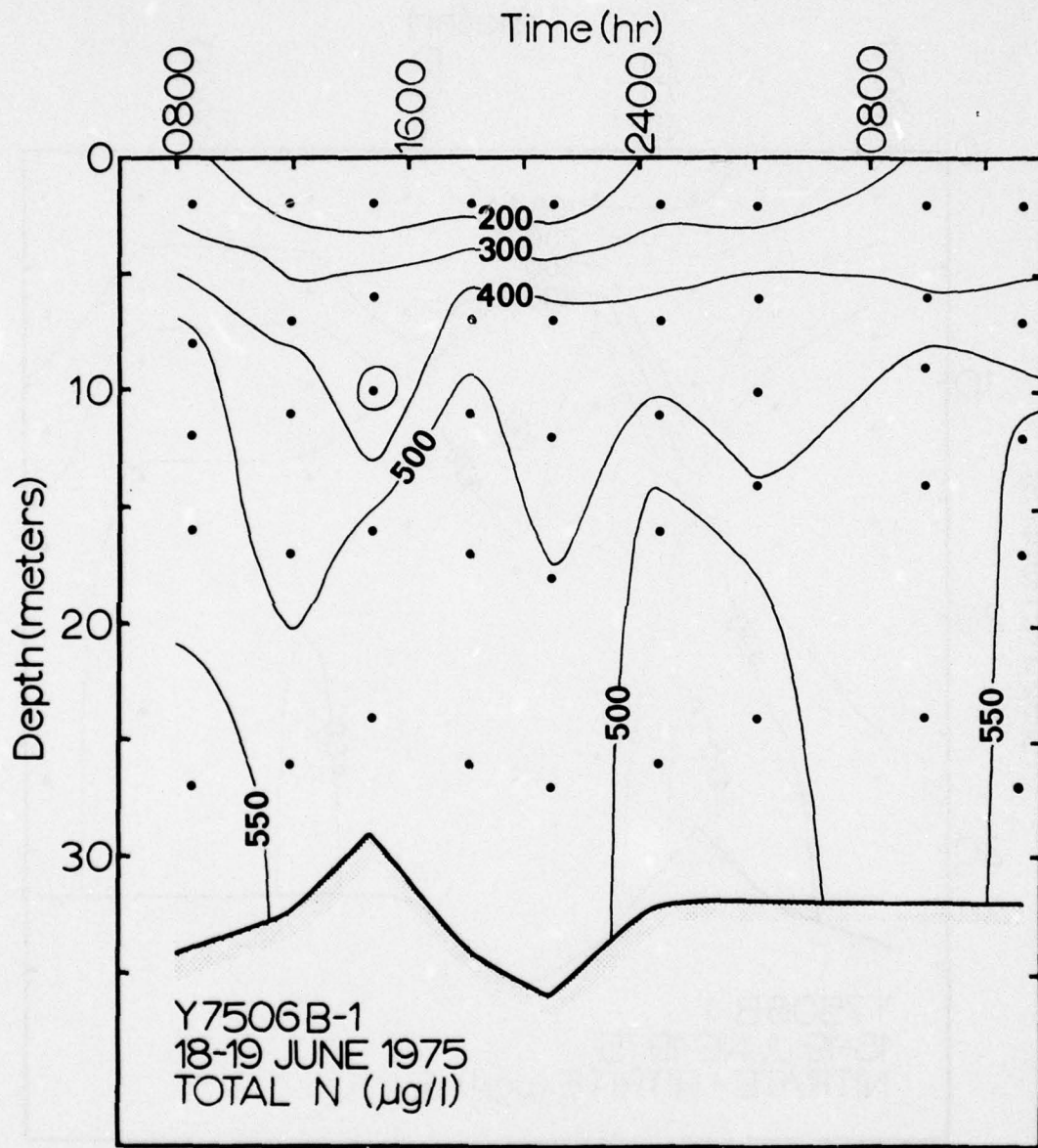


Figure B32. Total nitrogen distribution plot for June anchor station 2

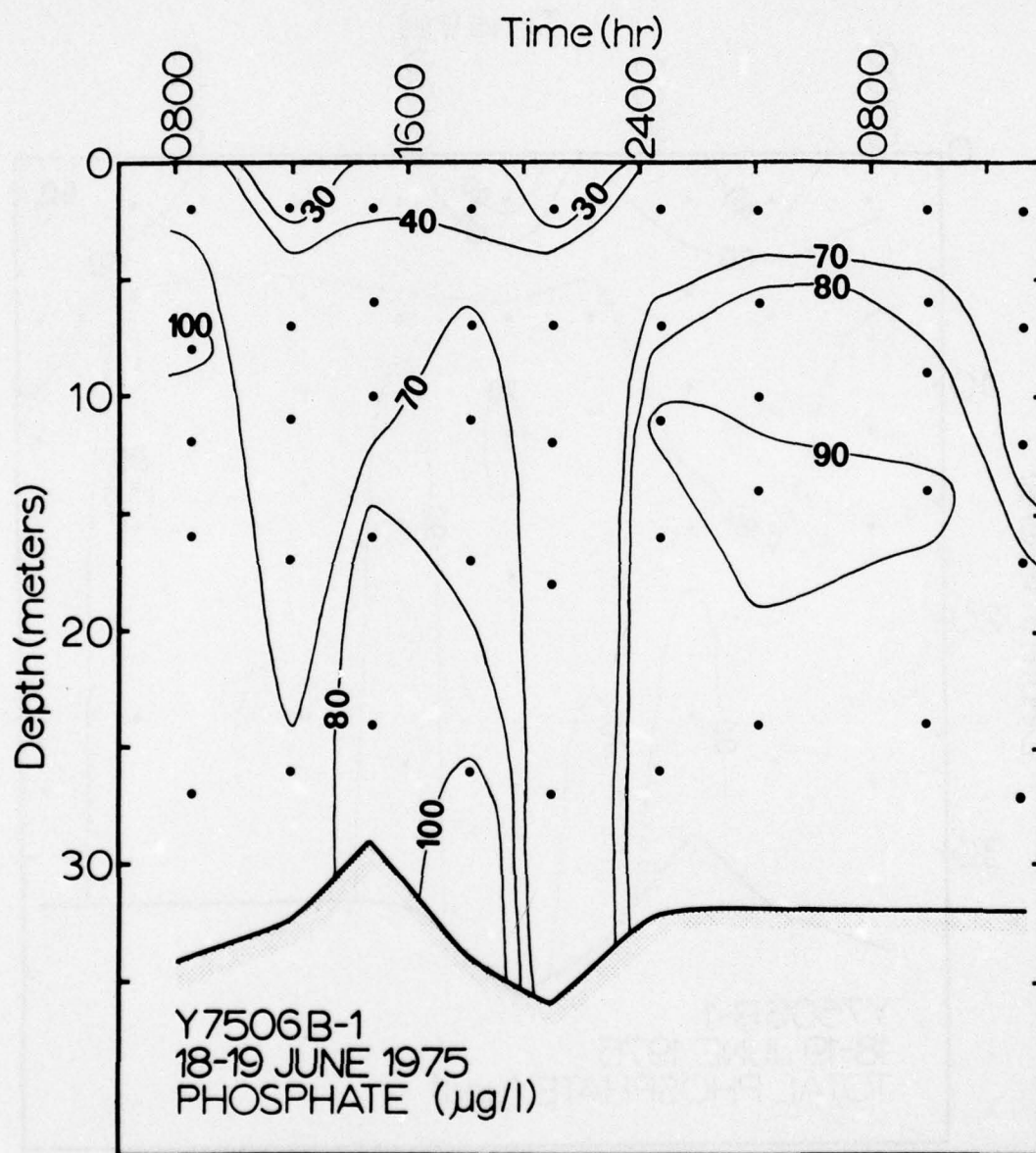


Figure B33. Phosphate distribution plot for June anchor station 2

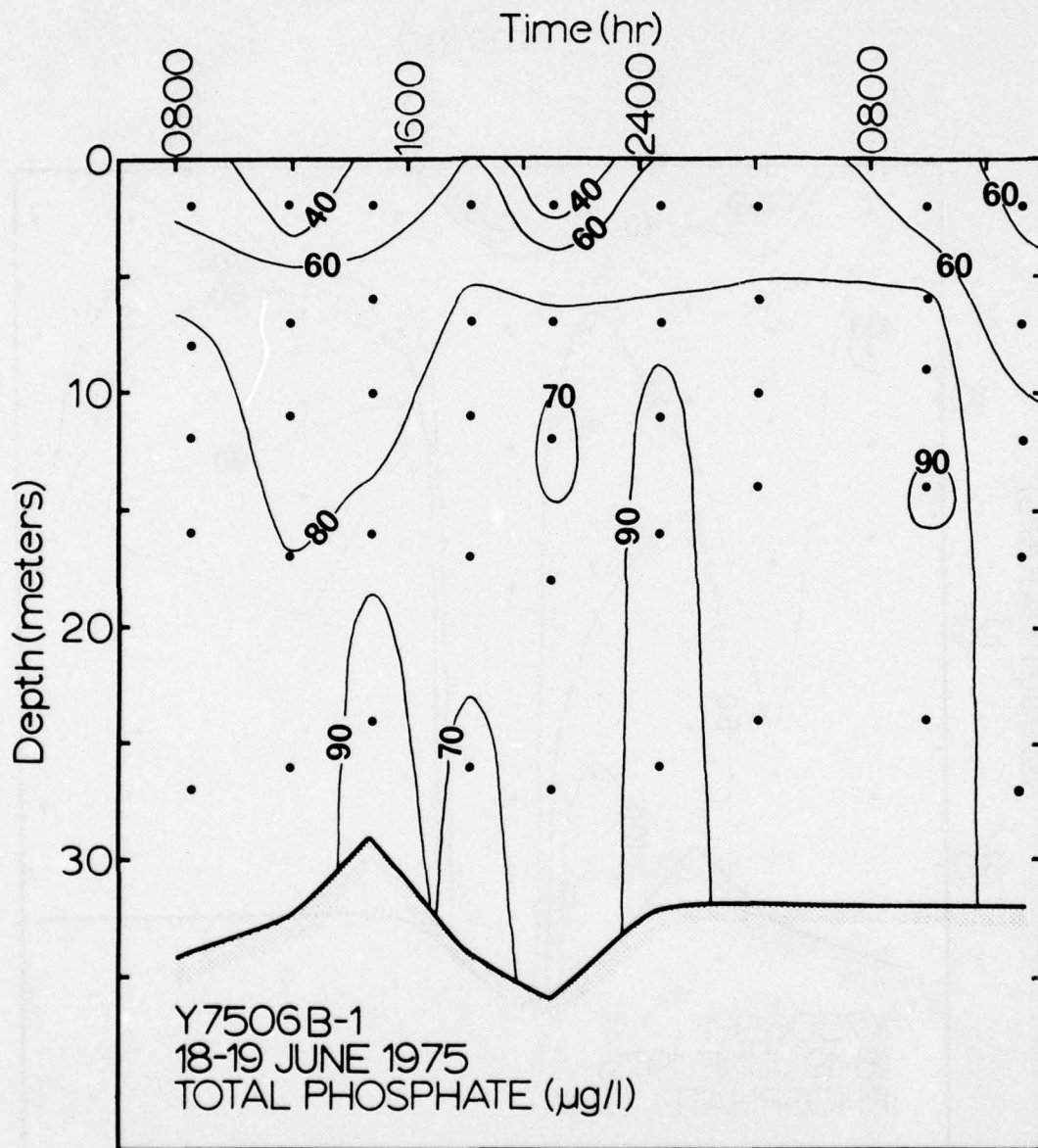


Figure B34. Total phosphate distribution plot for June anchor station 2

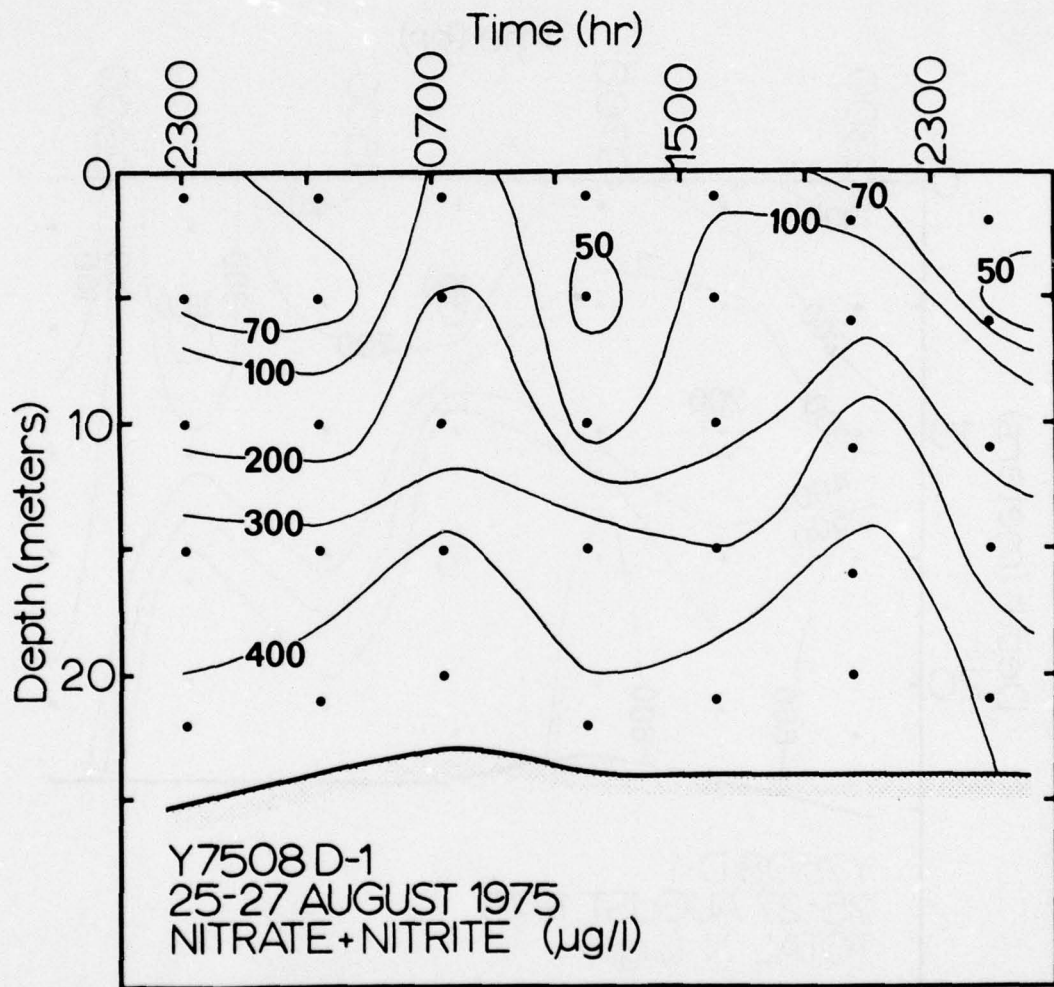


Figure B35. Nitrate + nitrite distribution plot for August anchor station

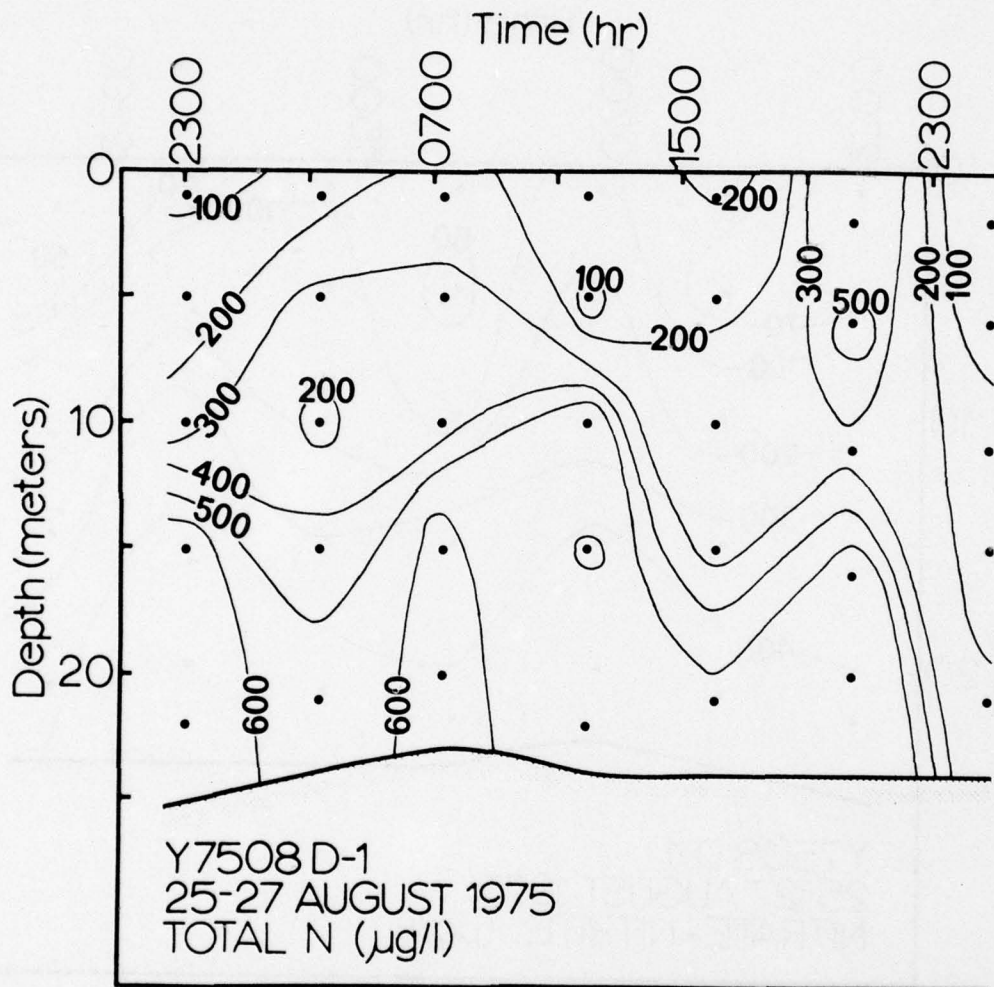


Figure B36. Total nitrogen distribution plot for August anchor station

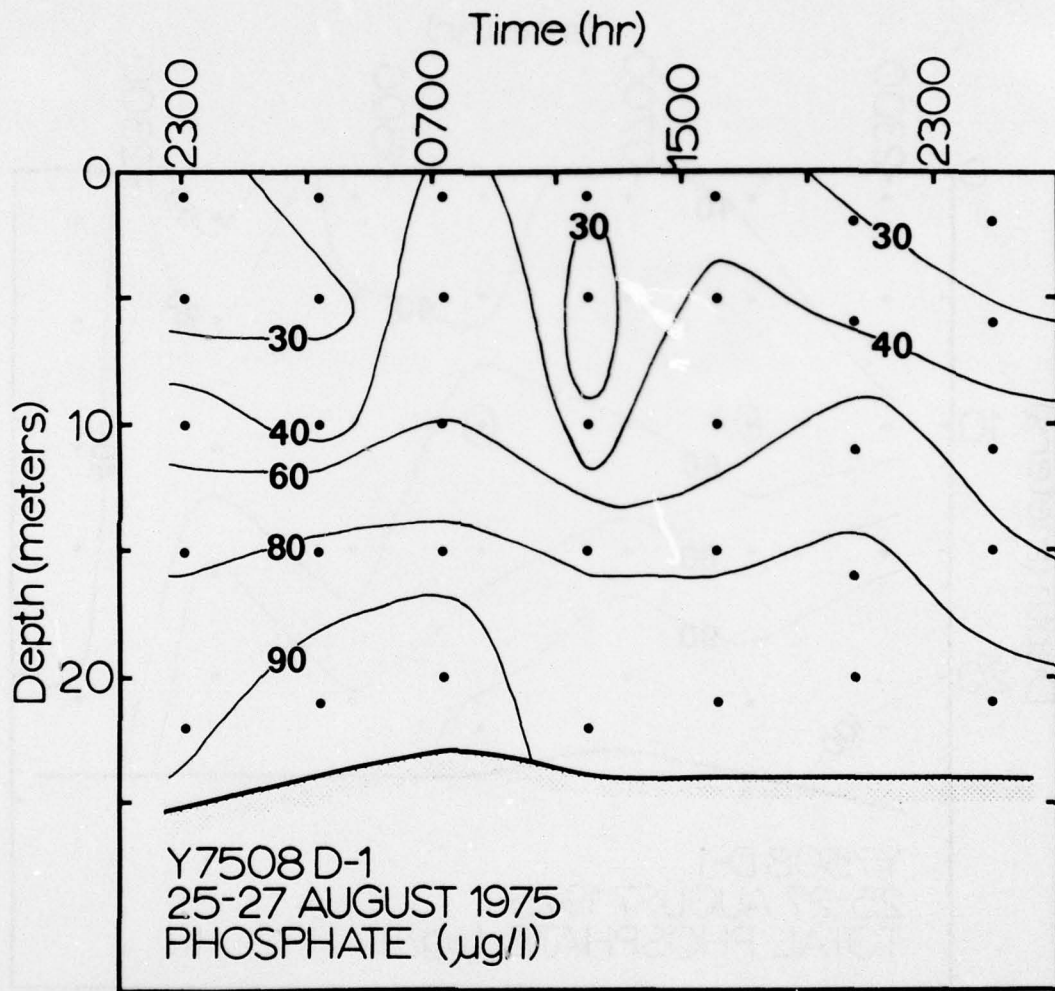


Figure B37. Phosphate distribution plot for August anchor station

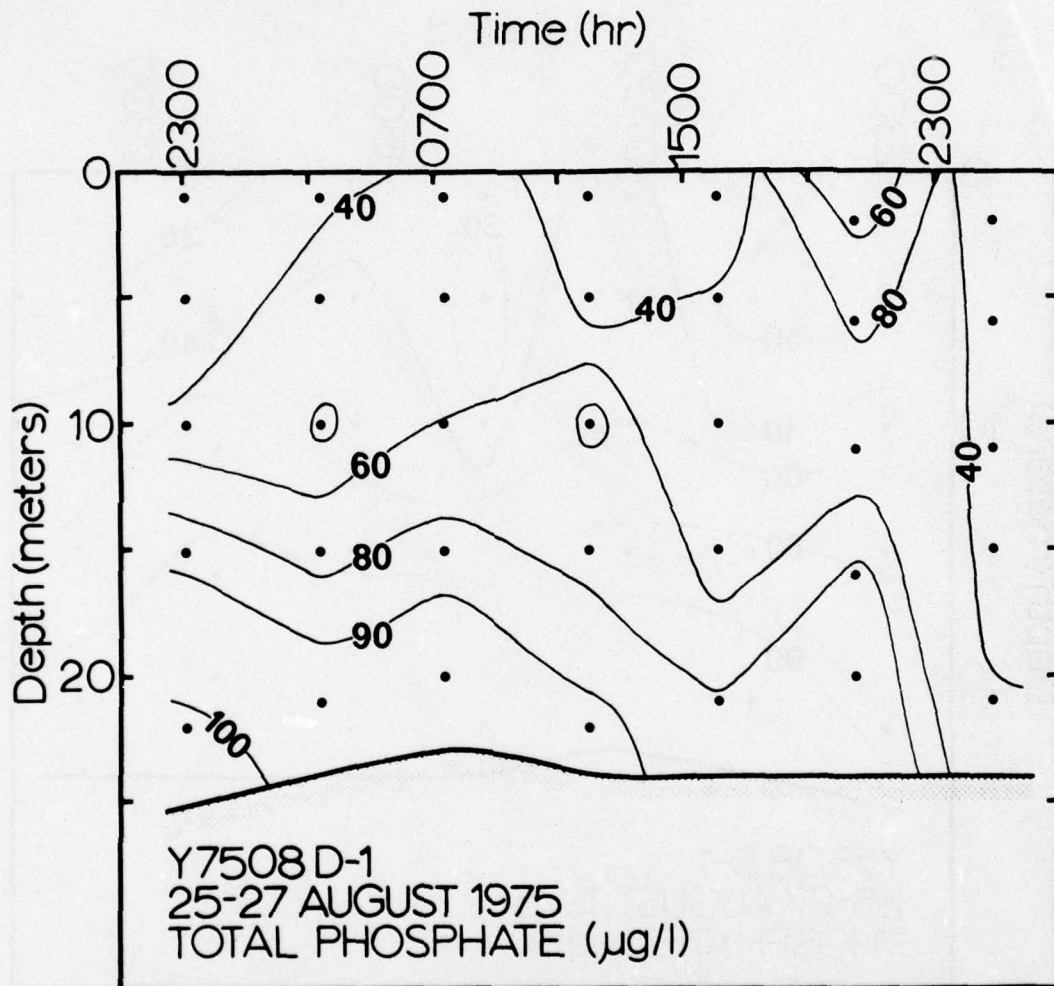


Figure B38. Total phosphate distribution plot for August anchor station

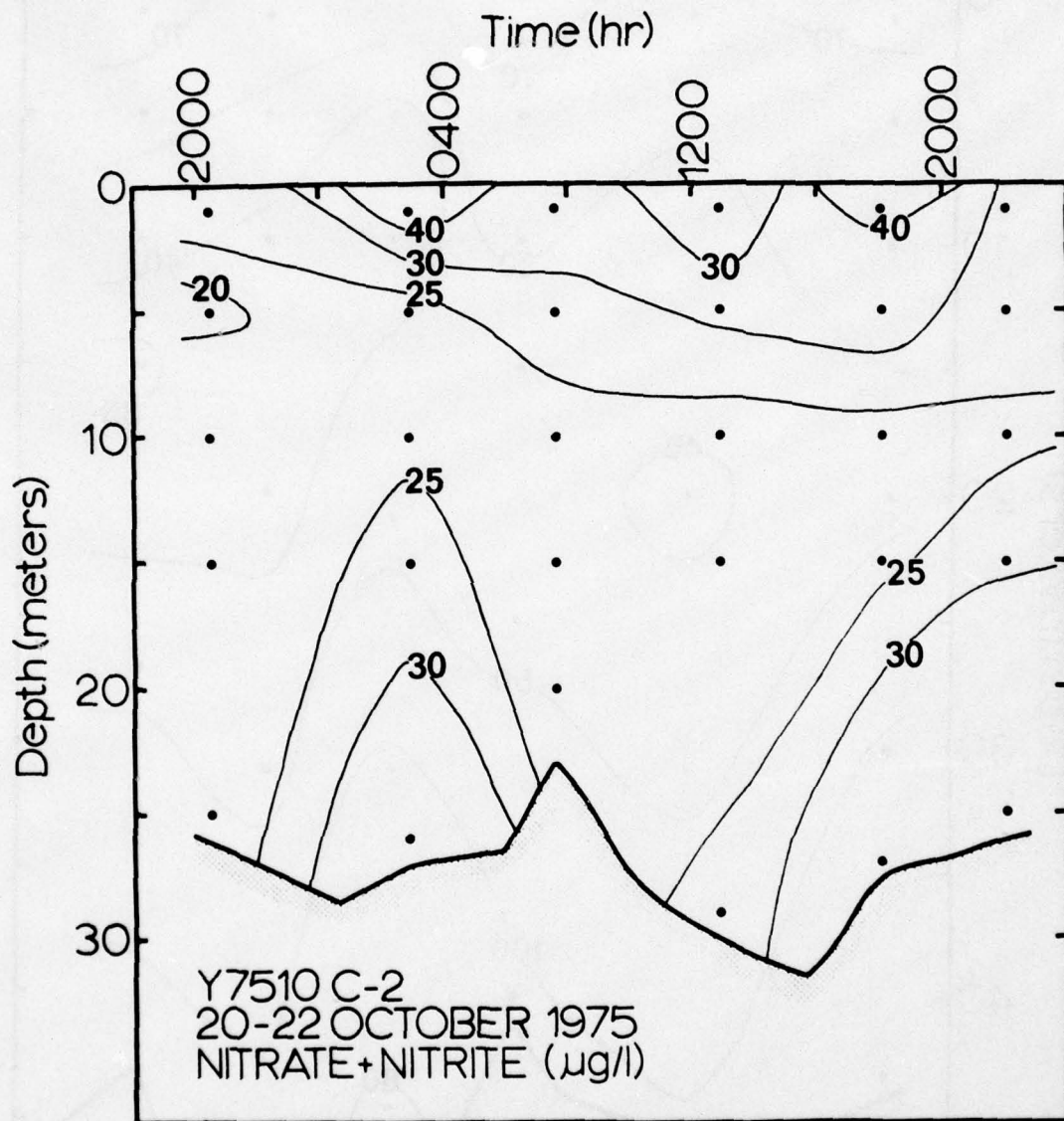


Figure B39. Nitrate + nitrite distribution plot for October anchor station 1

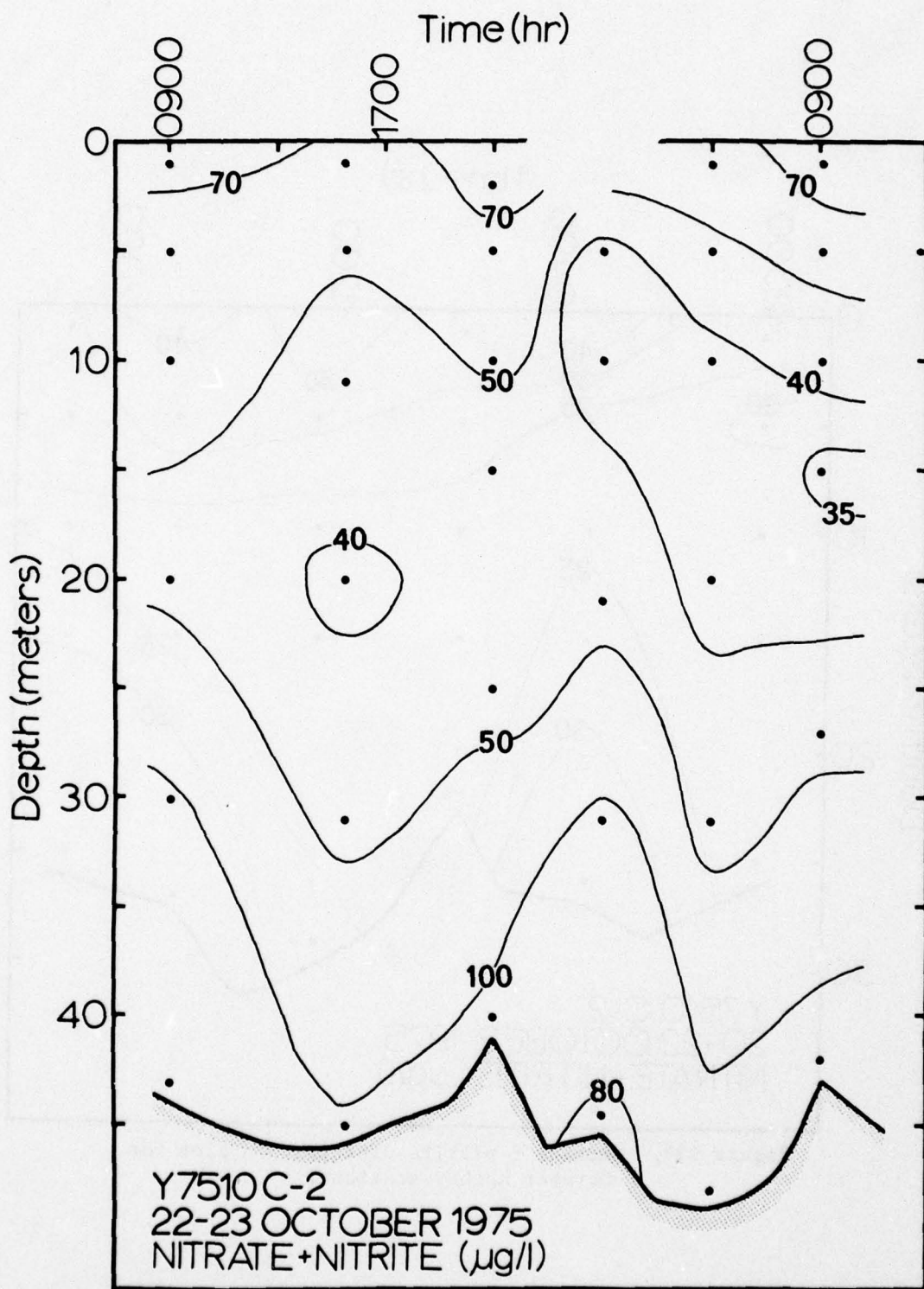


Figure B40. Nitrate + nitrite distribution plot for October anchor station 2

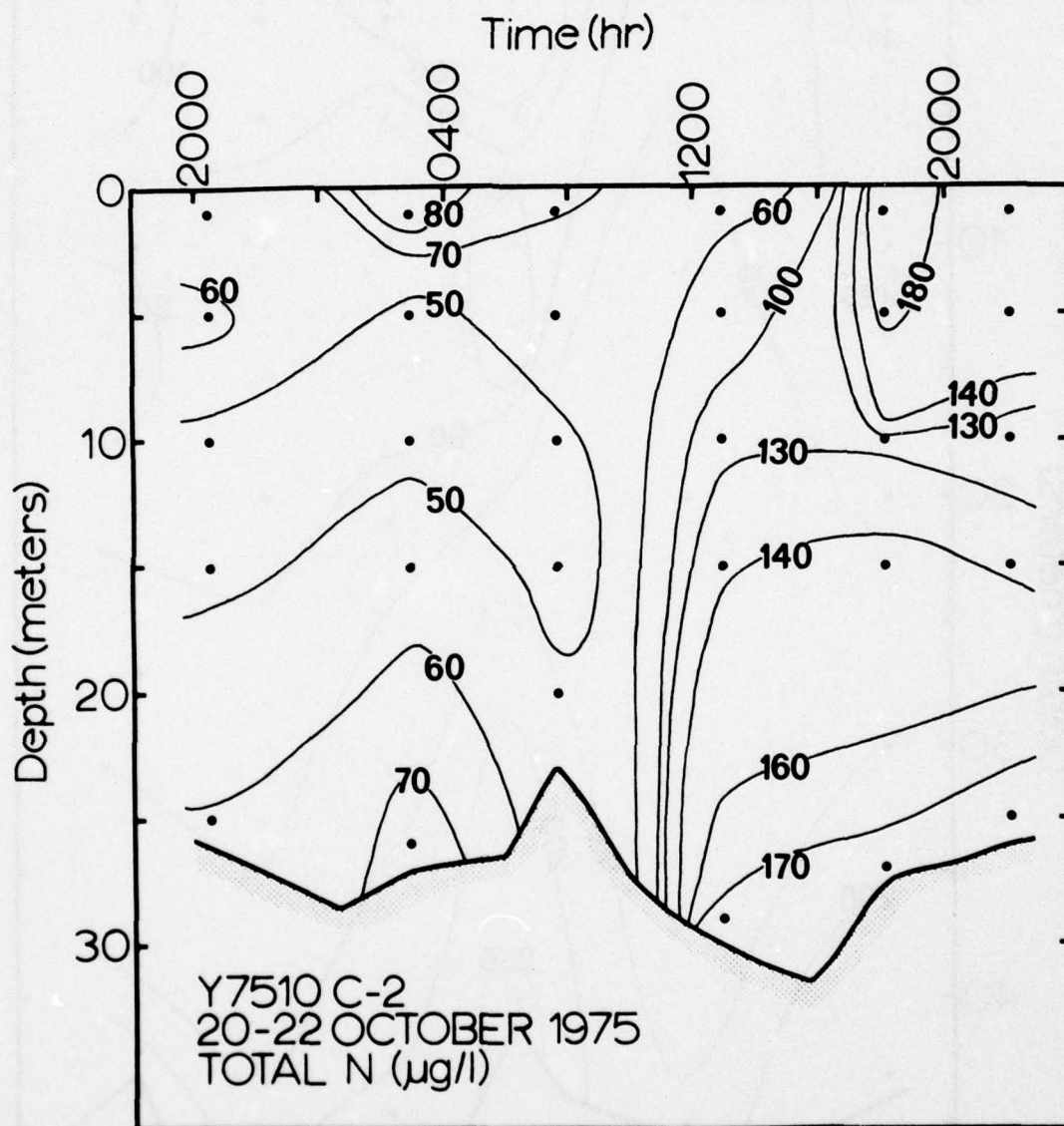


Figure B41. Total nitrogen distribution plot for October anchor station 1

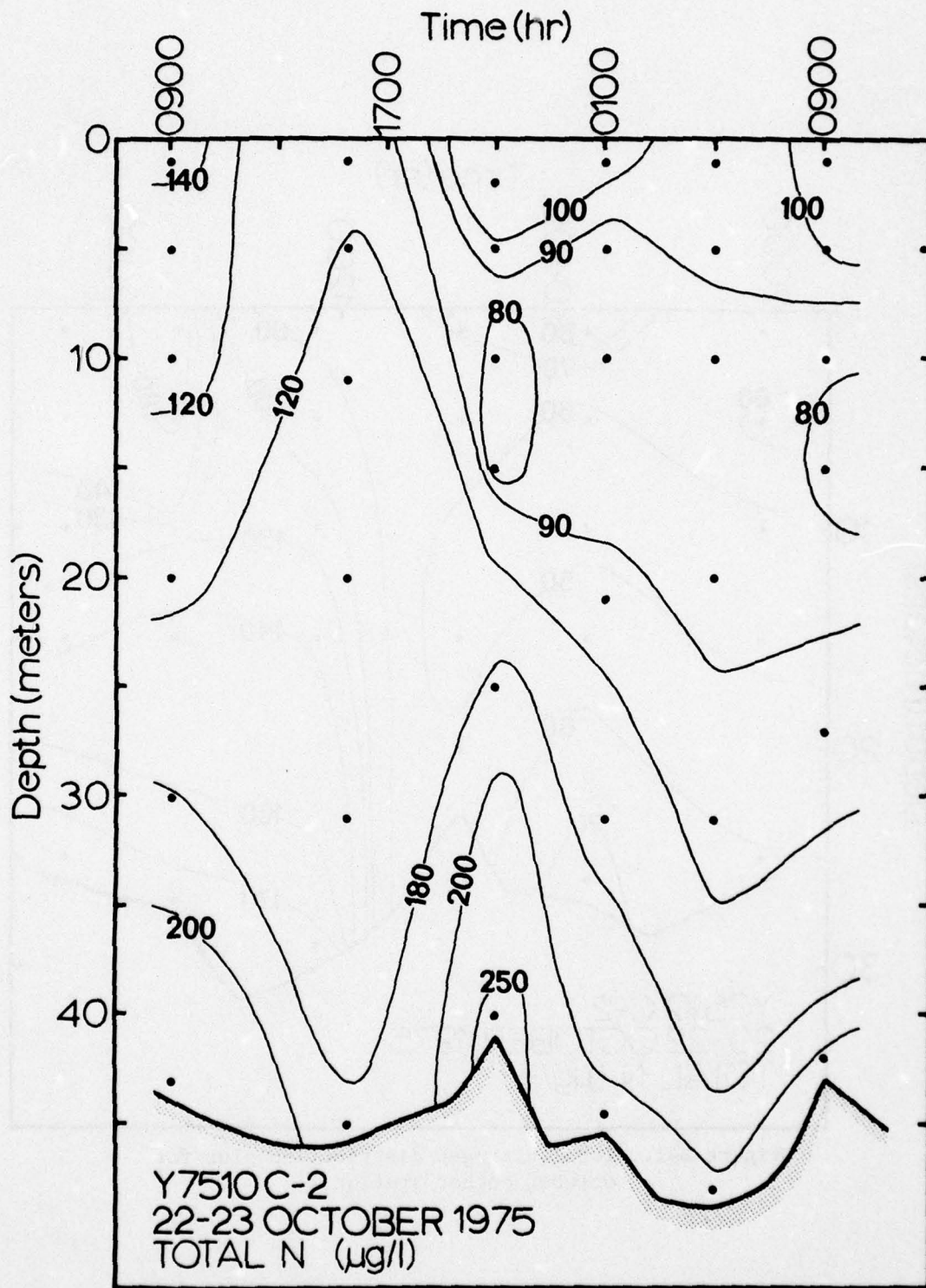


Figure B42. Total nitrogen distribution plot for October anchor station 2

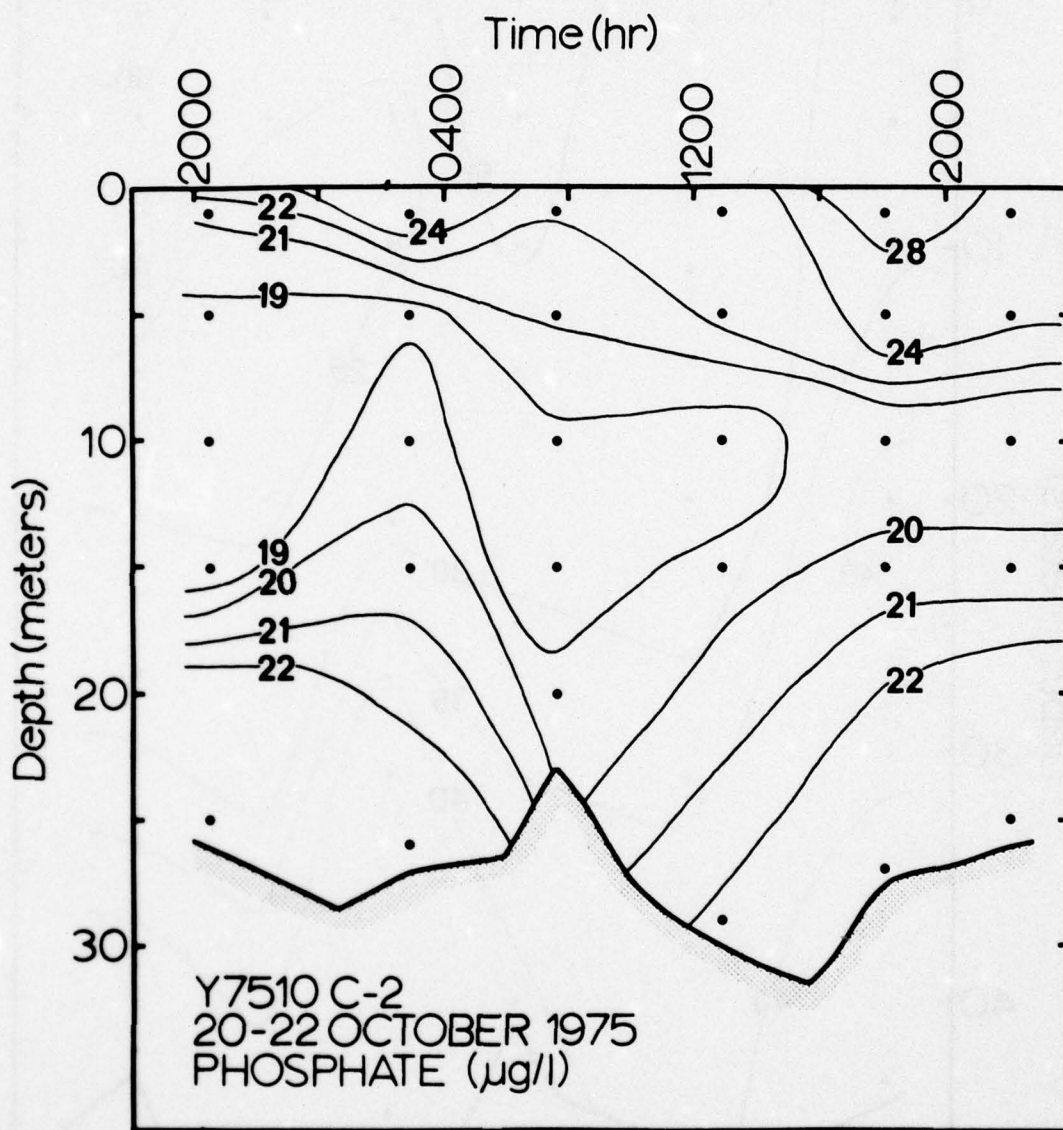


Figure B43. Phosphate distribution plot for October anchor station 1

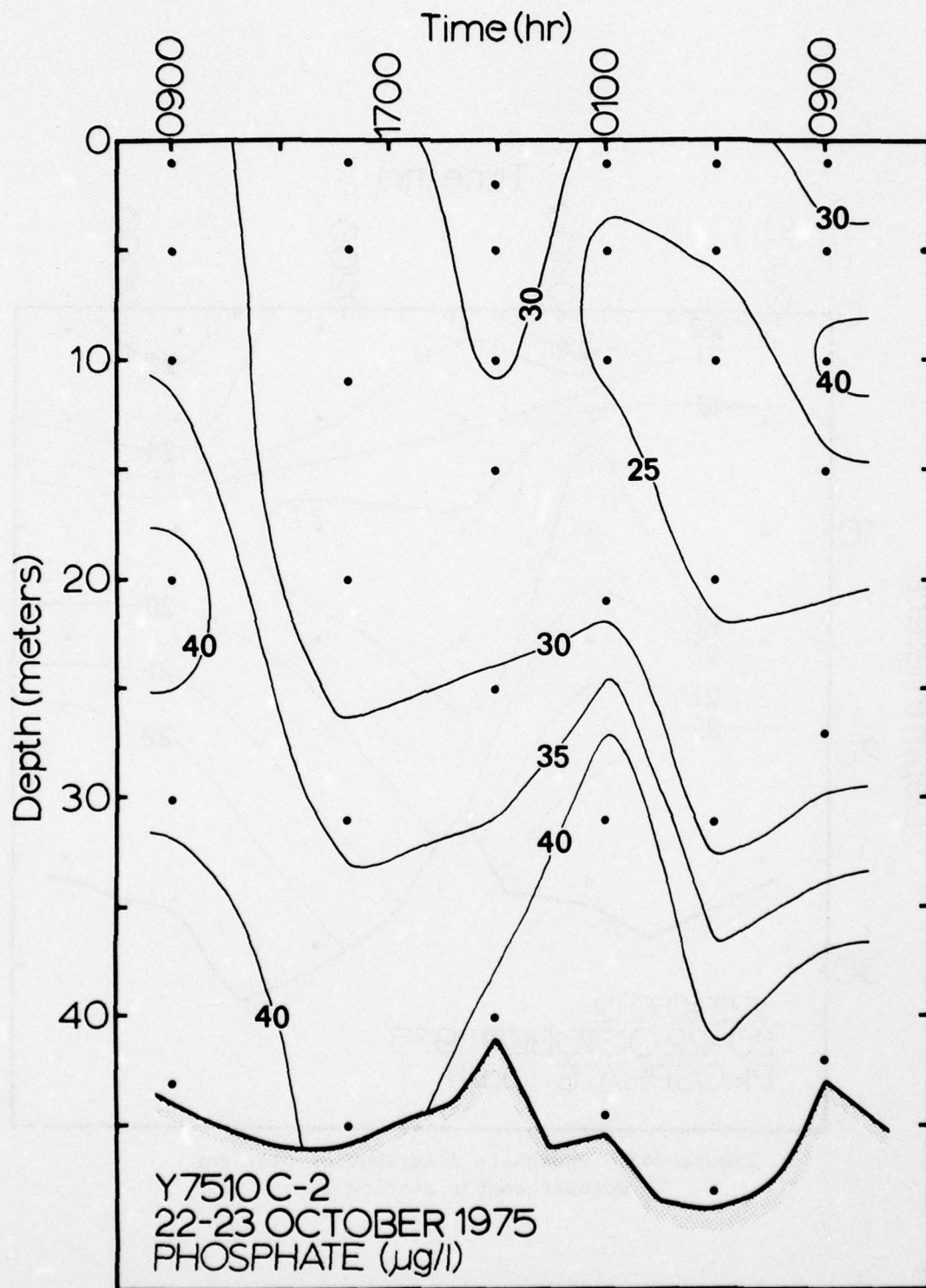


Figure B44. Phosphate distribution plot for October anchor station 2

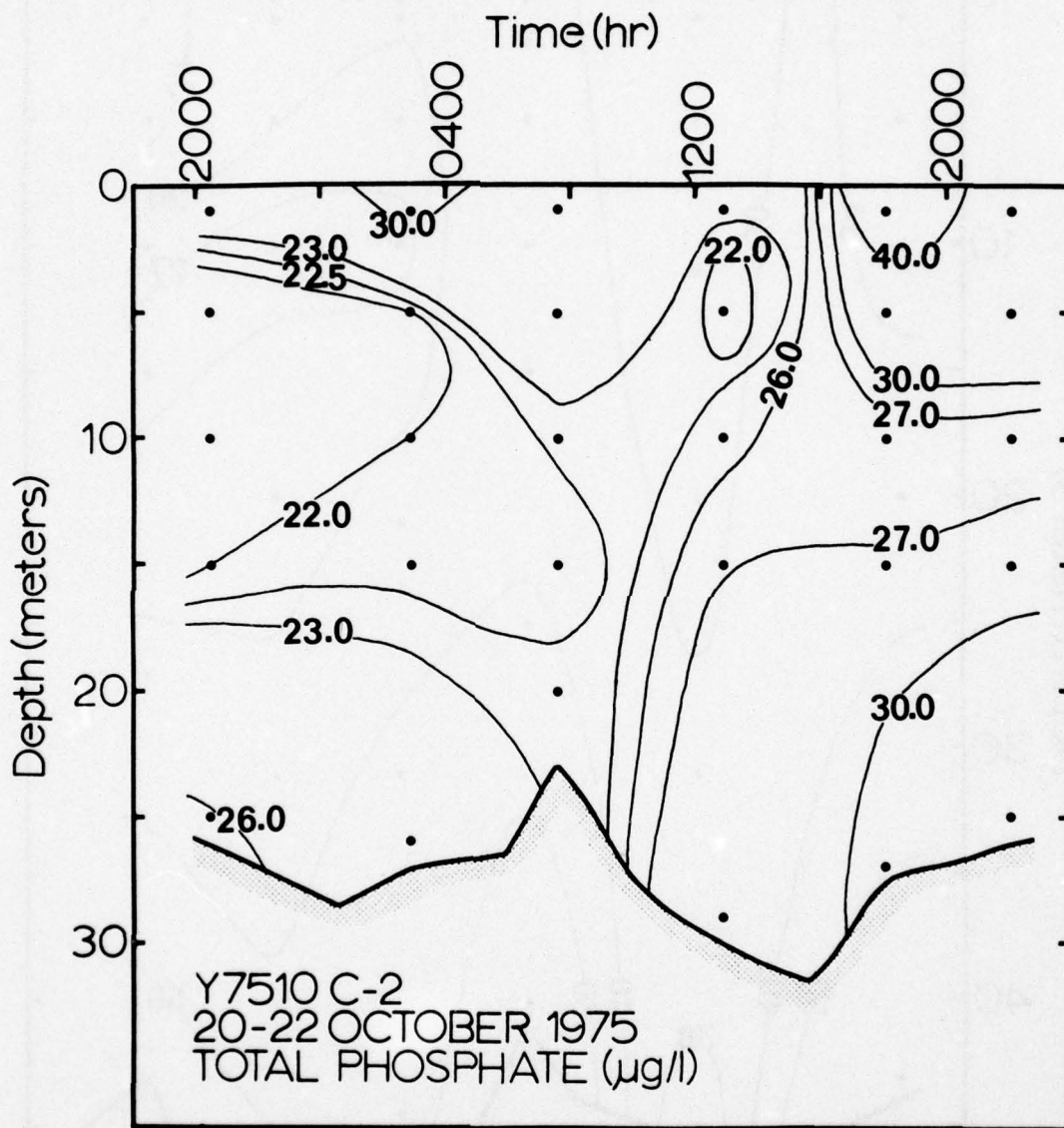


Figure B45. Total phosphate distribution plot for October anchor station 1

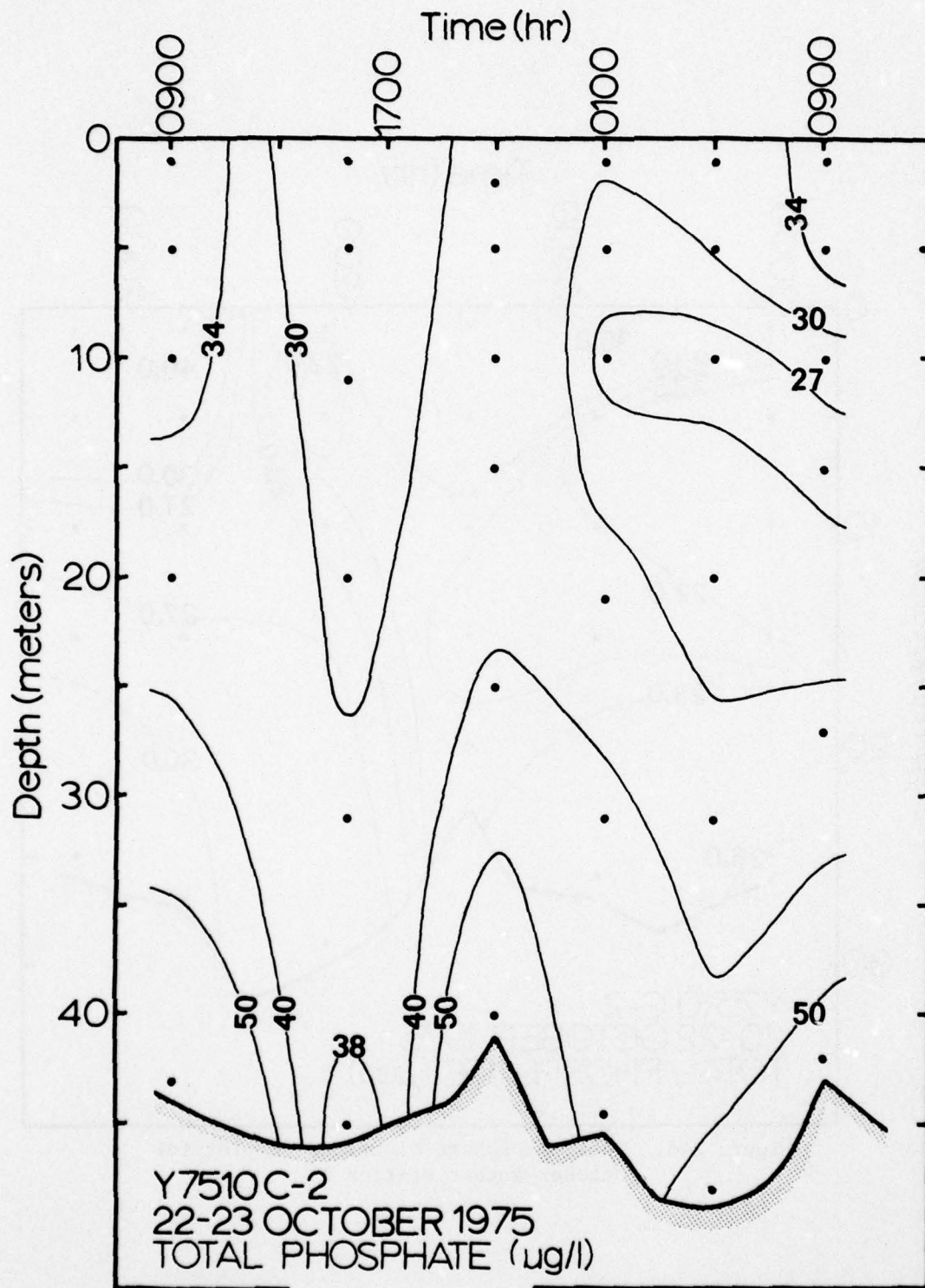


Figure B46. Total phosphate distribution plot for October anchor station 2

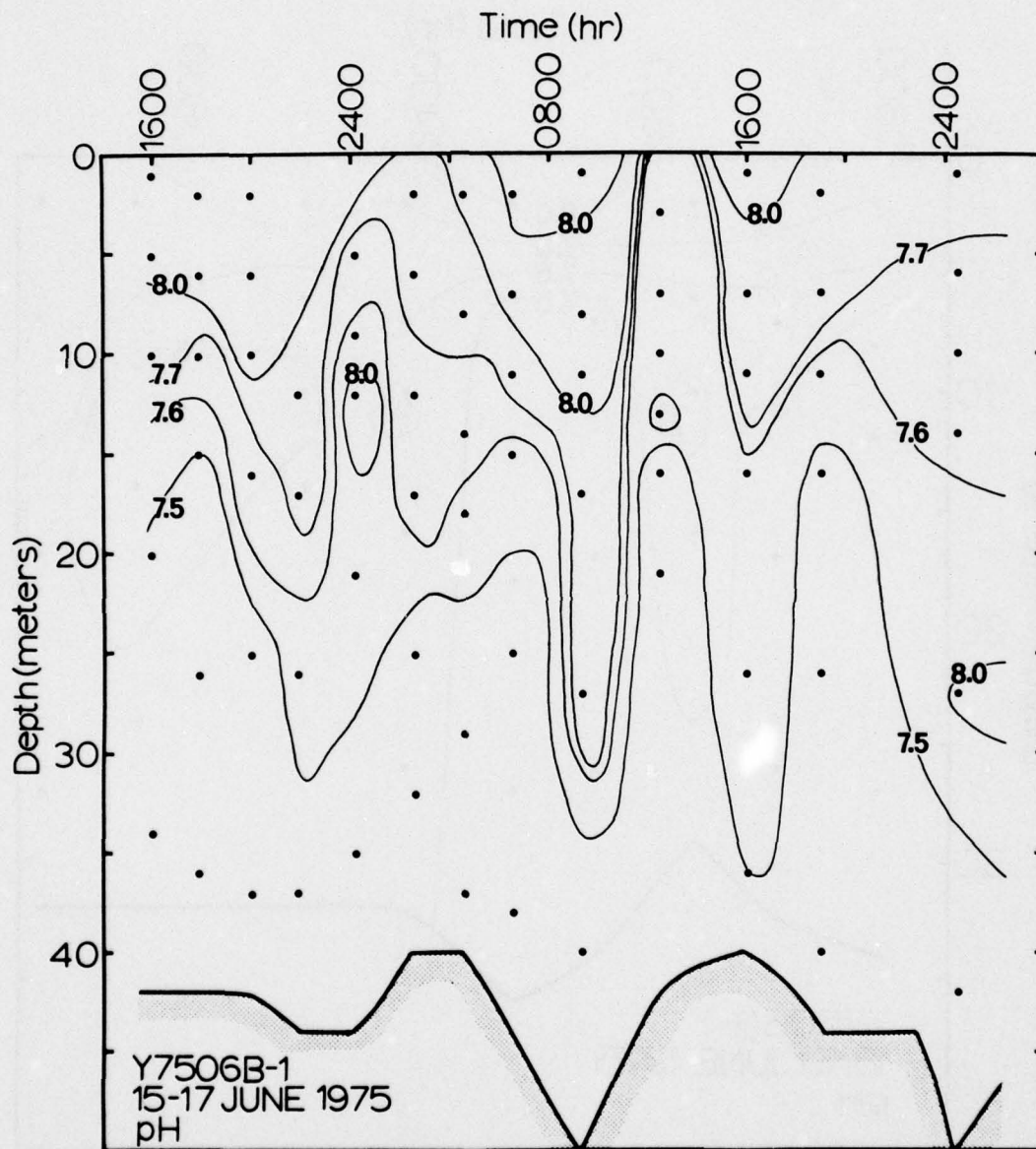


Figure B47. pH distribution plot for June anchor station 1

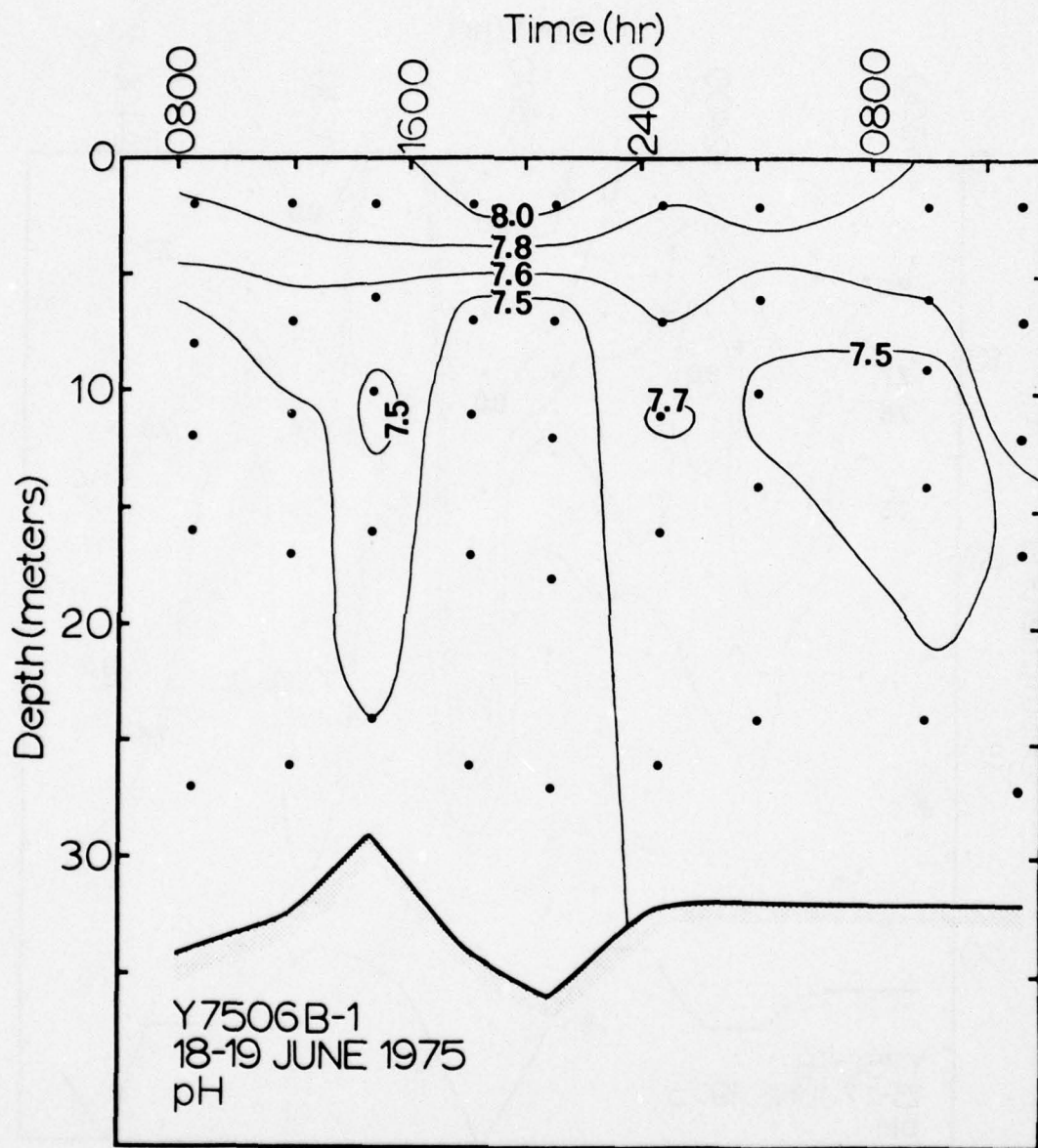


Figure B48. pH distribution plot for June anchor station 2

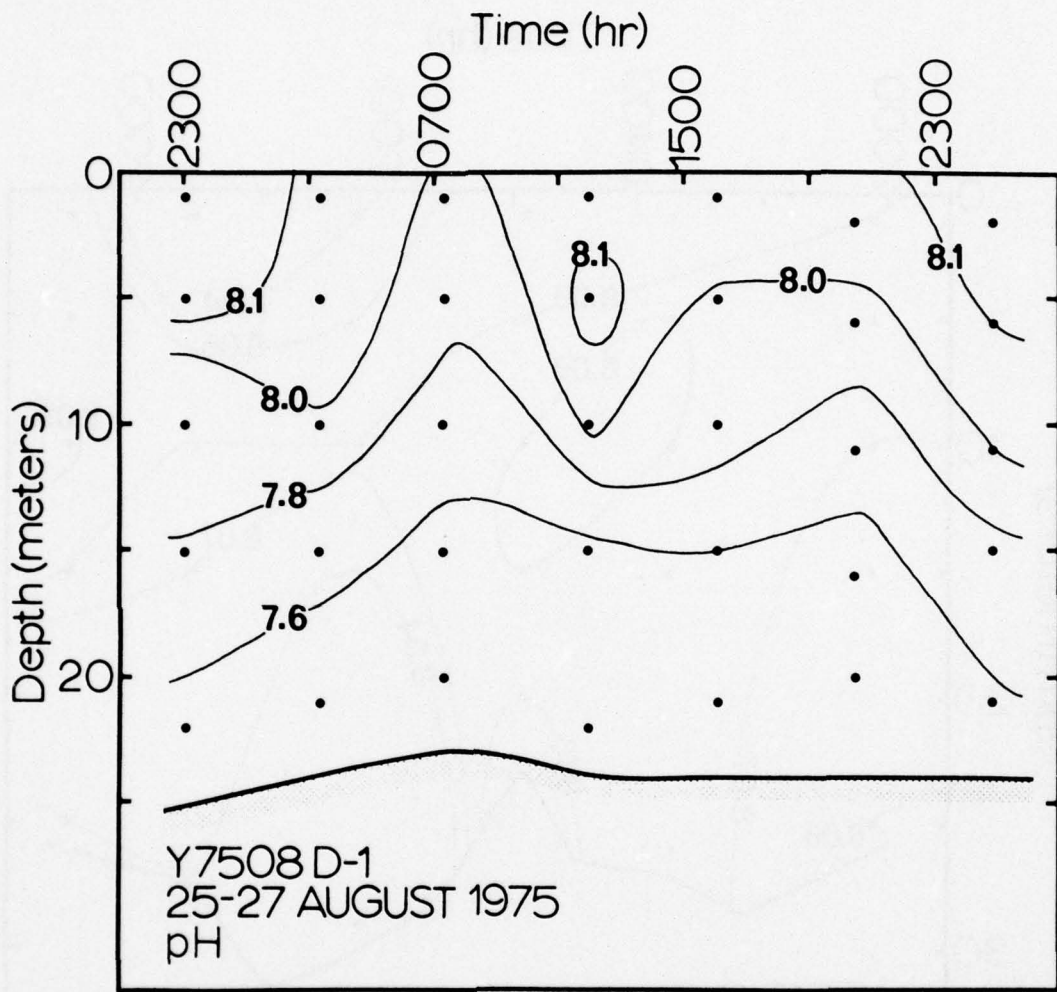


Figure B49. pH distribution plot for August anchor station

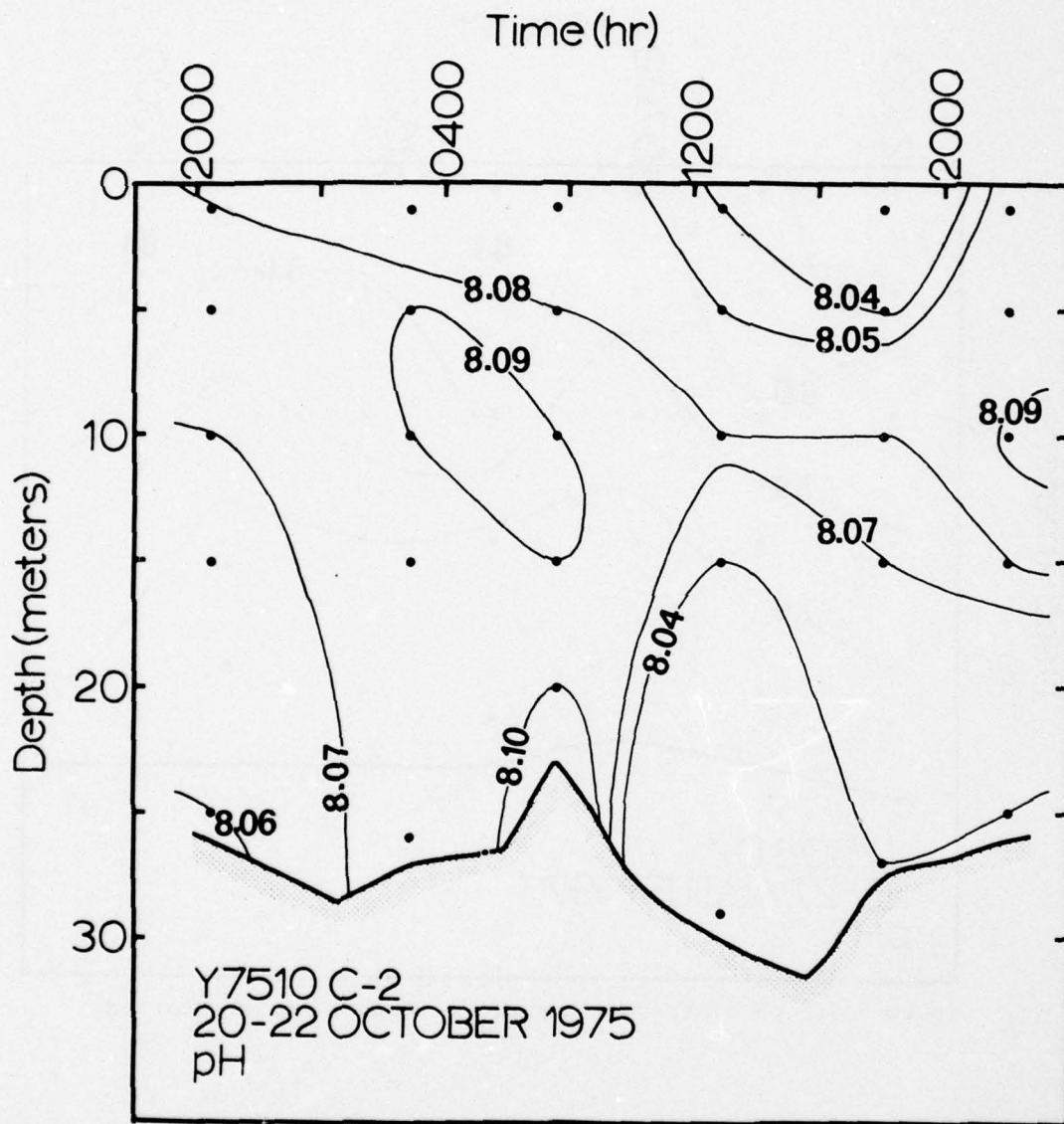


Figure B50. pH distribution plot for October anchor station 1

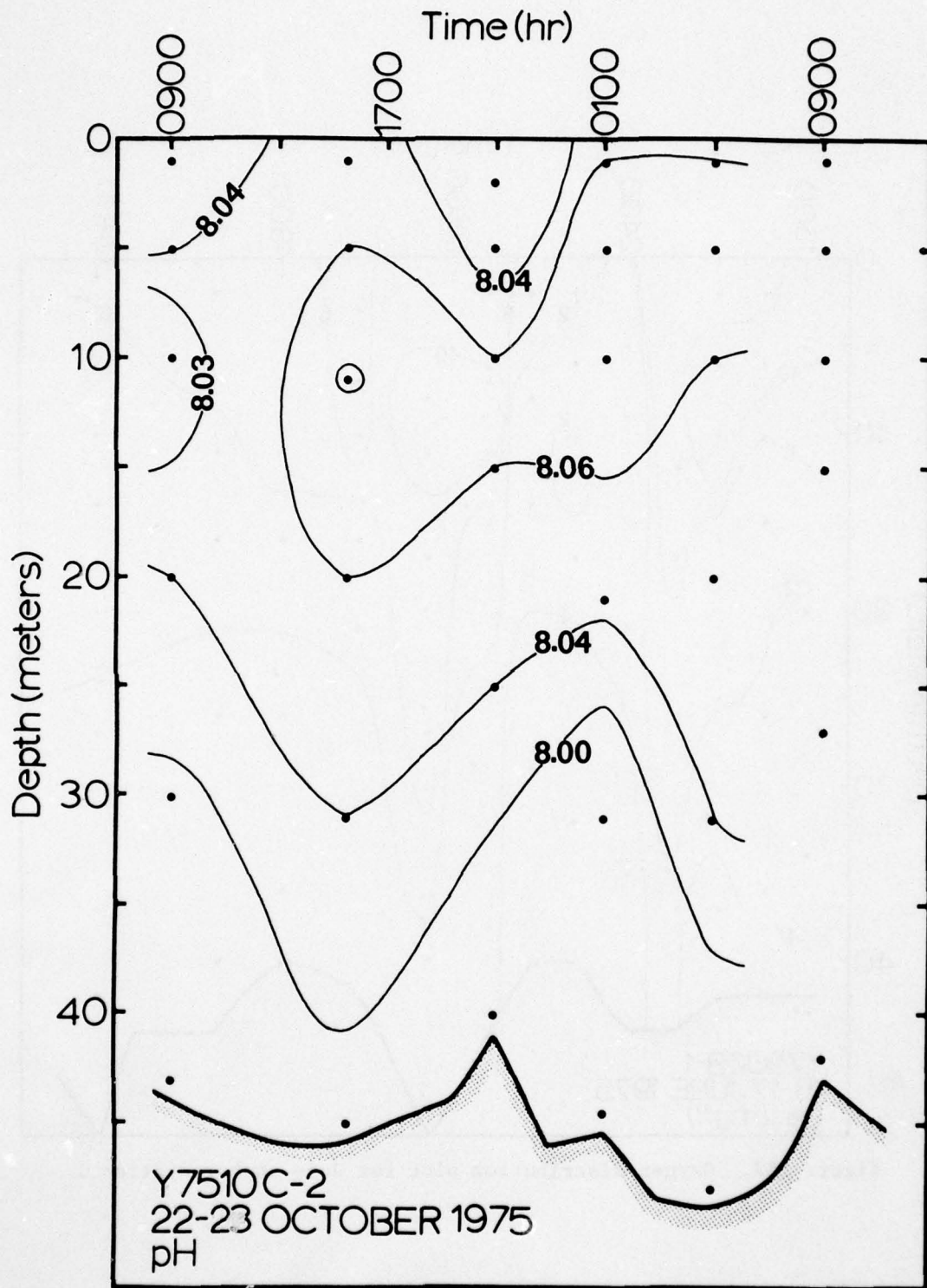


Figure B51. pH distribution plot for October anchor station 2

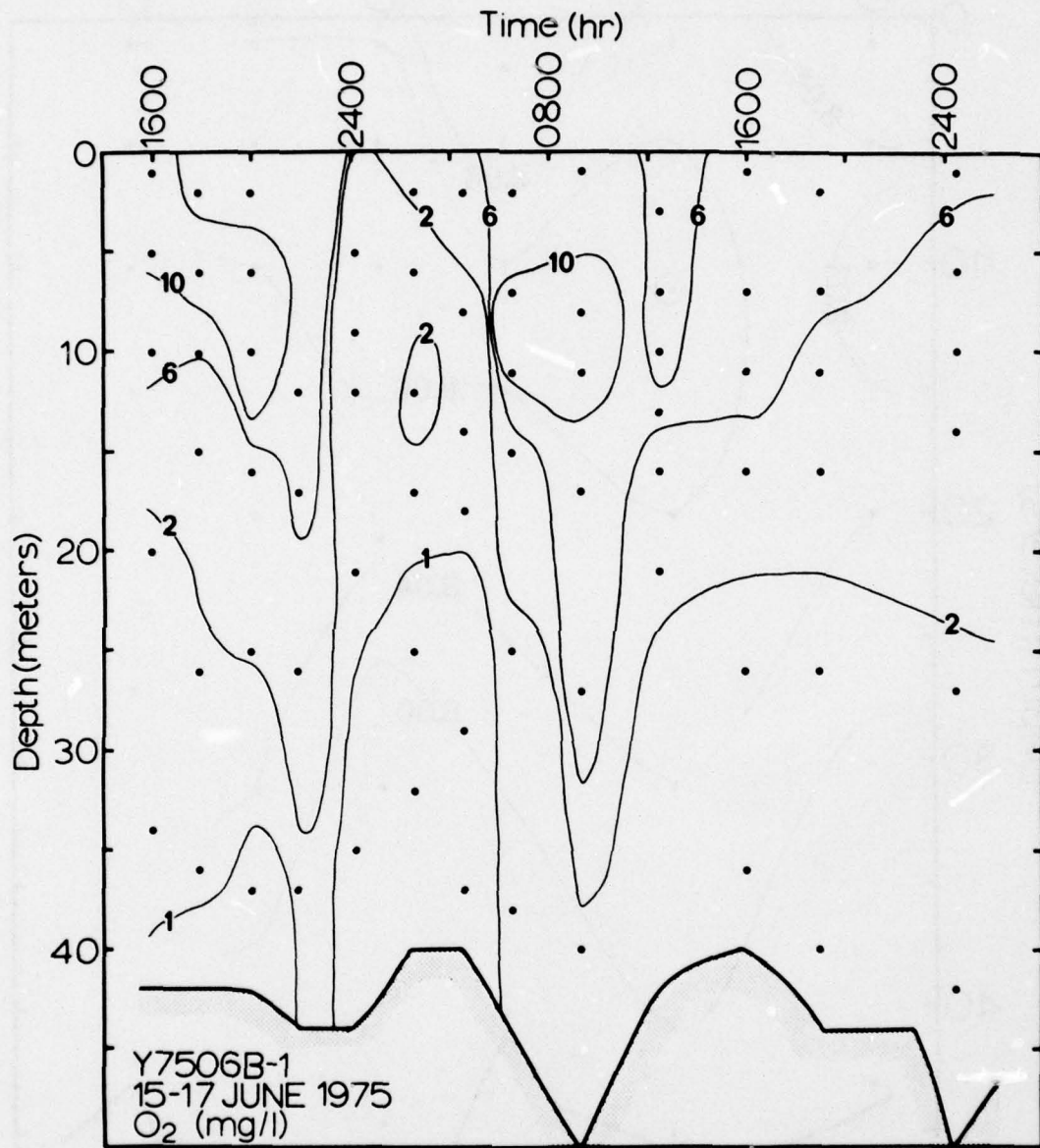


Figure B52. Oxygen distribution plot for June anchor station 1

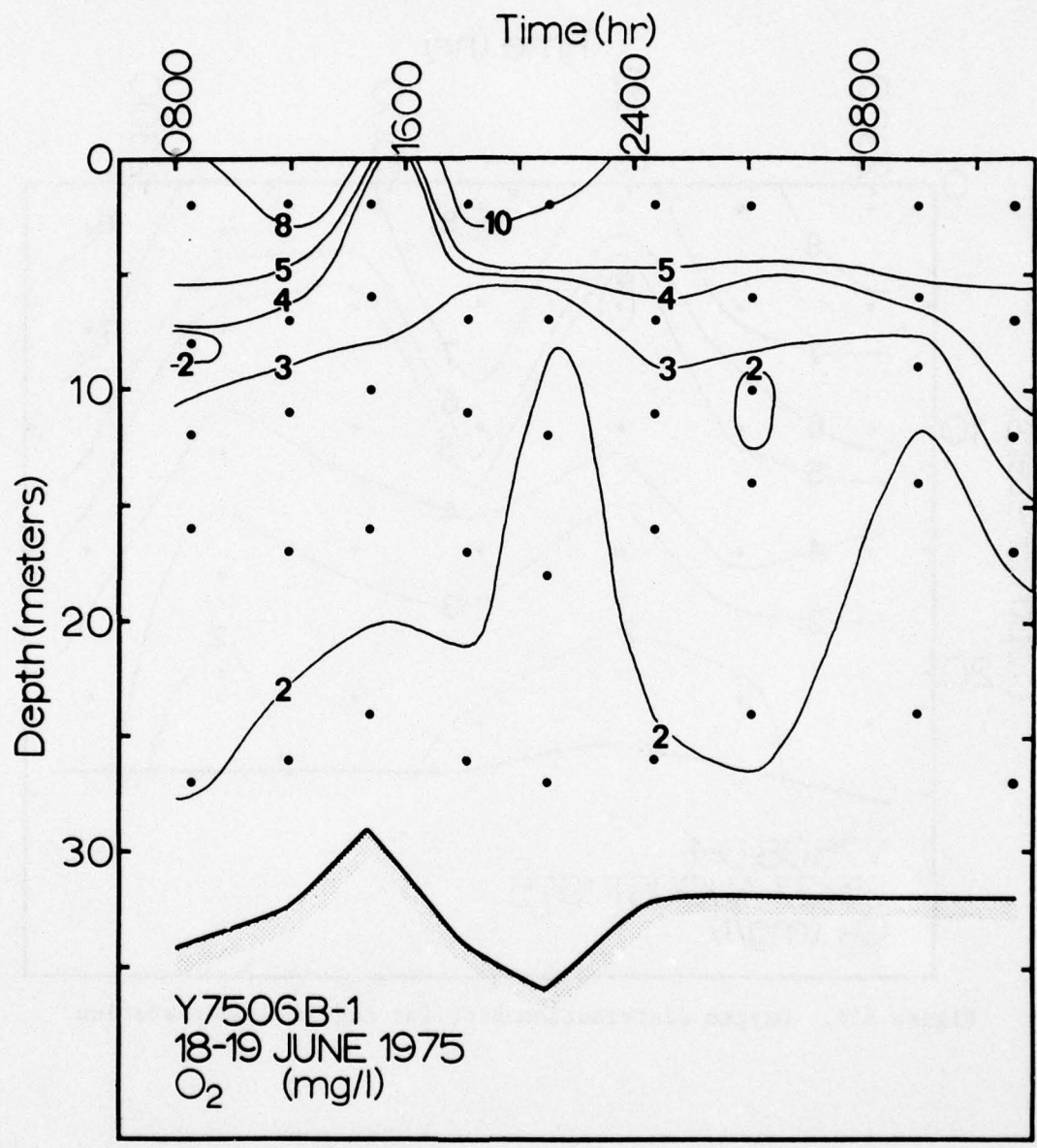


Figure B53. Oxygen distribution plot for June anchor station 2

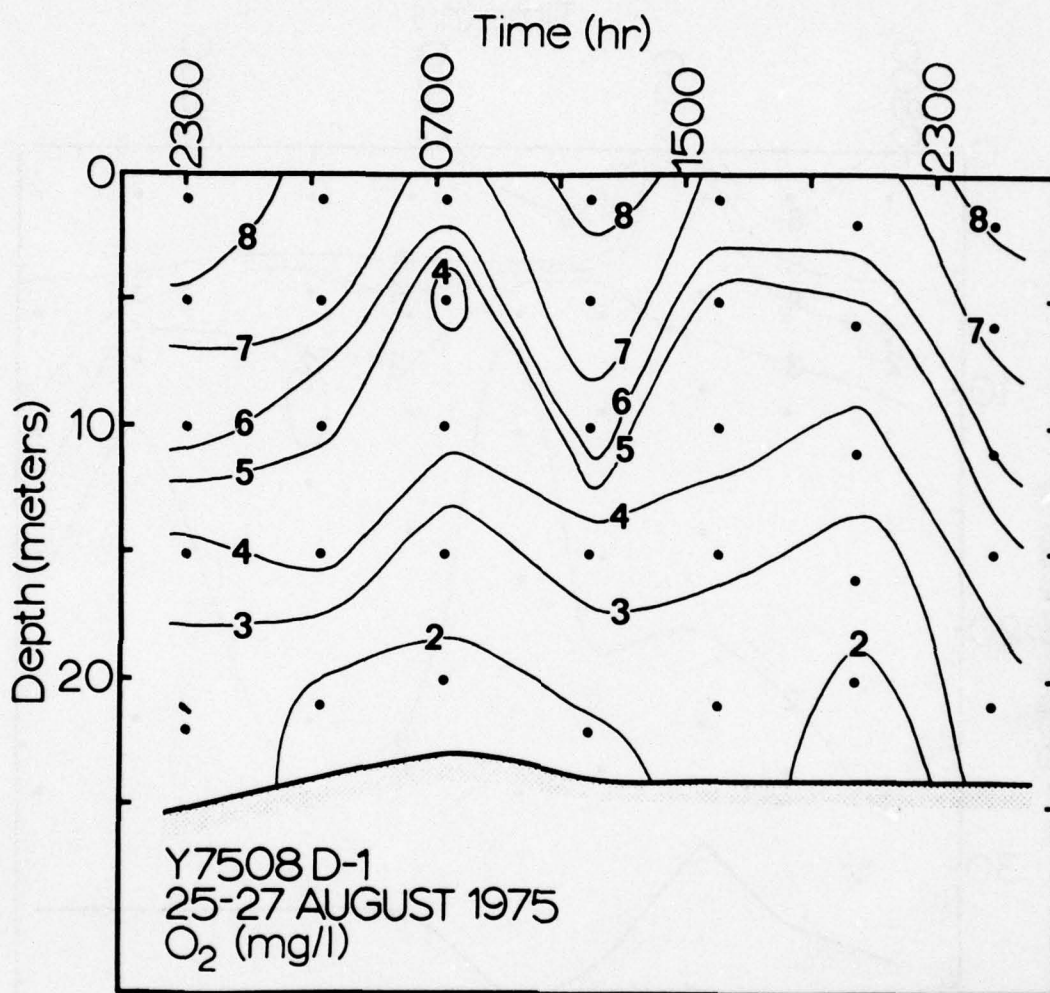


Figure B54. Oxygen distribution plot for August anchor station

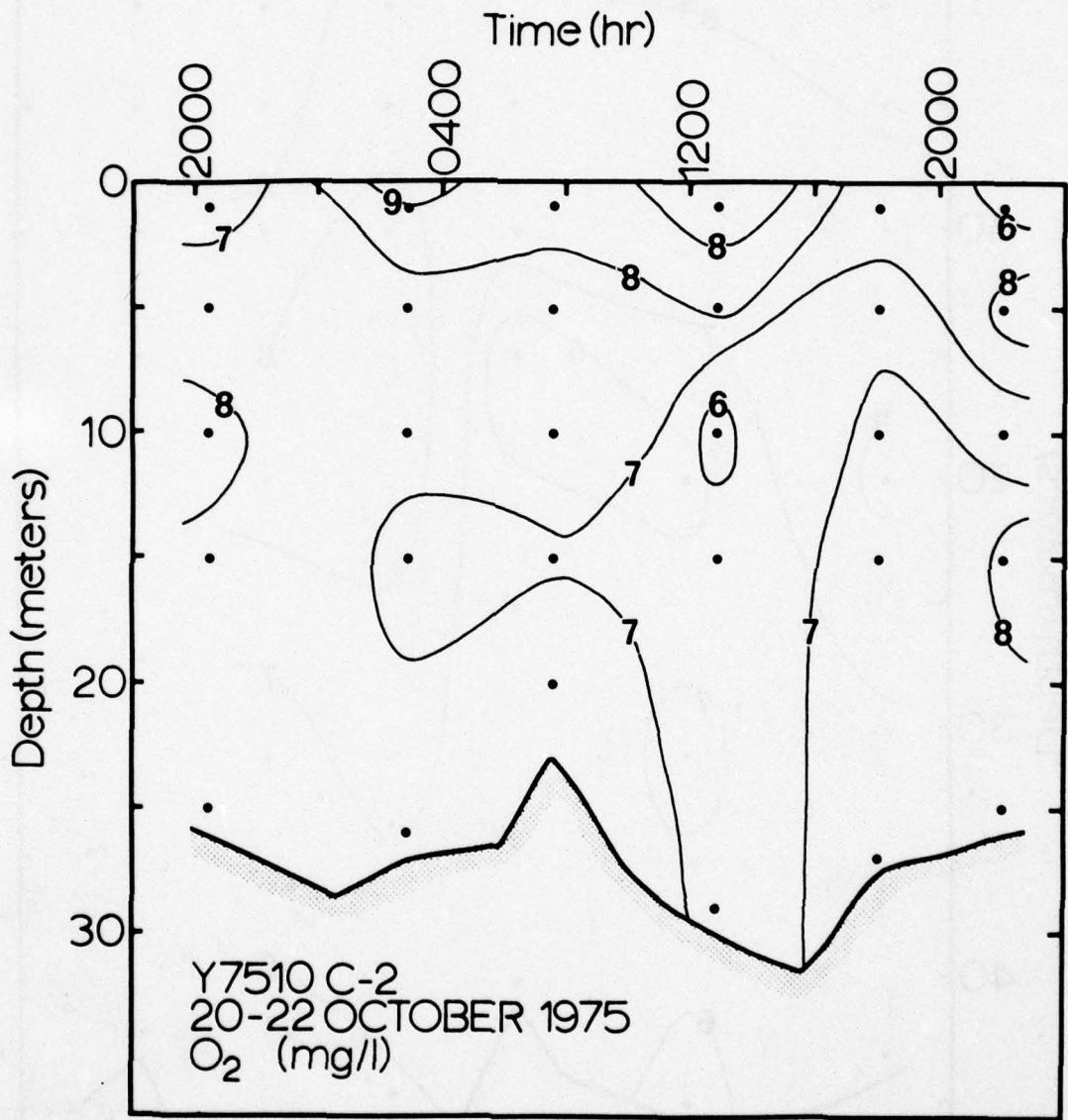


Figure B55. Oxygen distribution plot for October anchor station 1

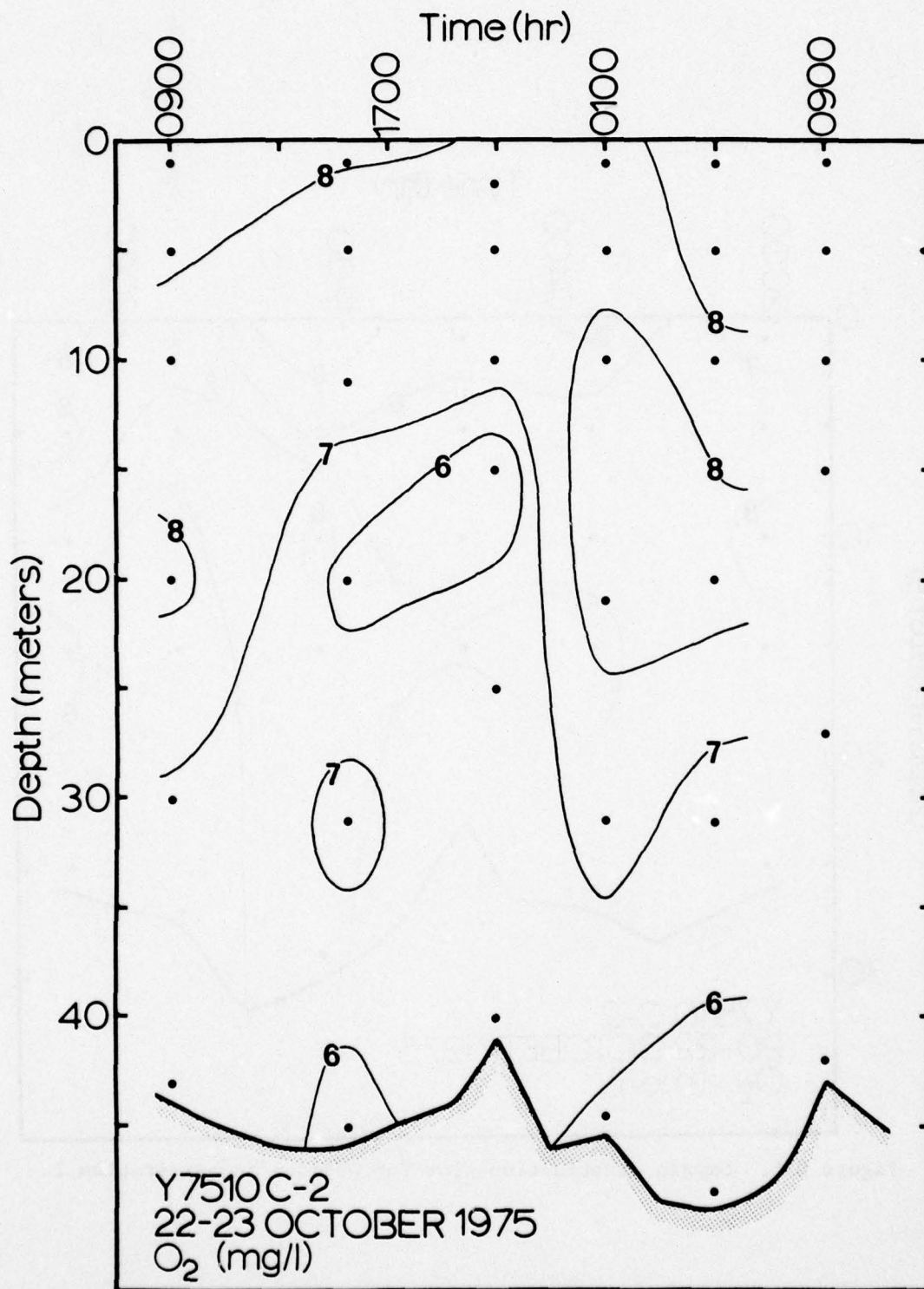


Figure B56. Oxygen distribution plot for October anchor station 2

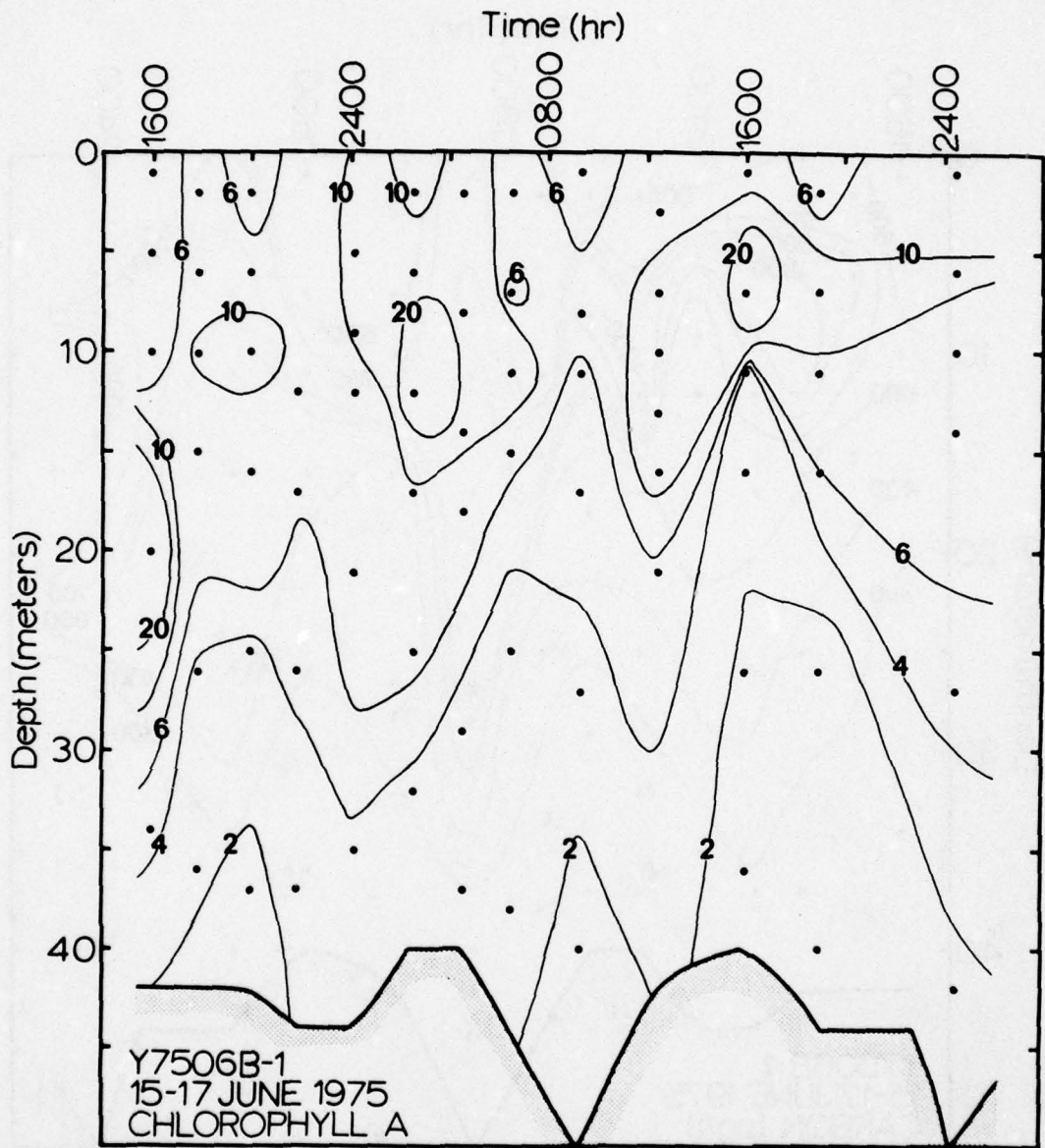


Figure B57. Chlorophyll a distribution plot for June anchor station 1

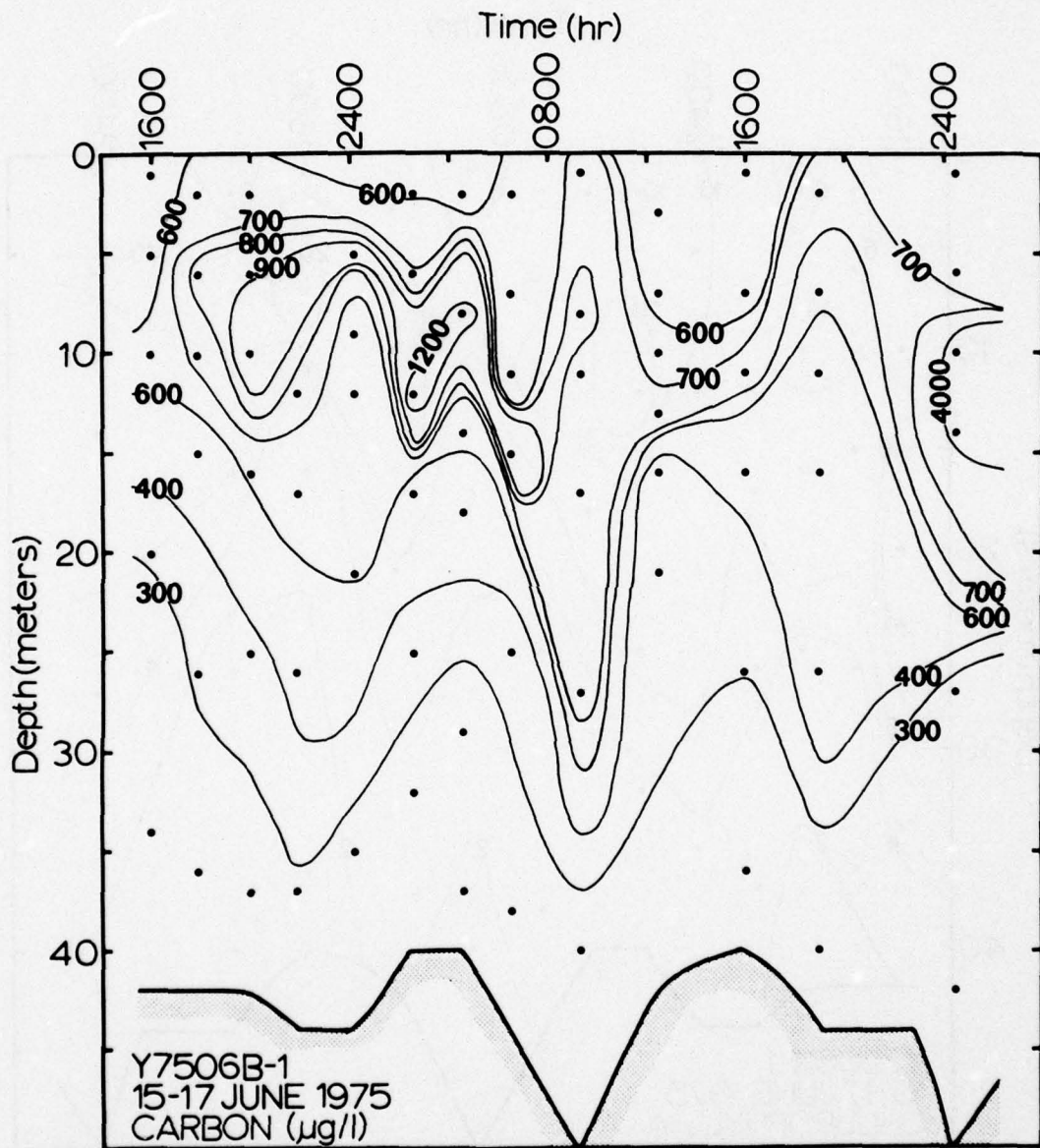


Figure B58. Particulate carbon distribution plot for June anchor station 1

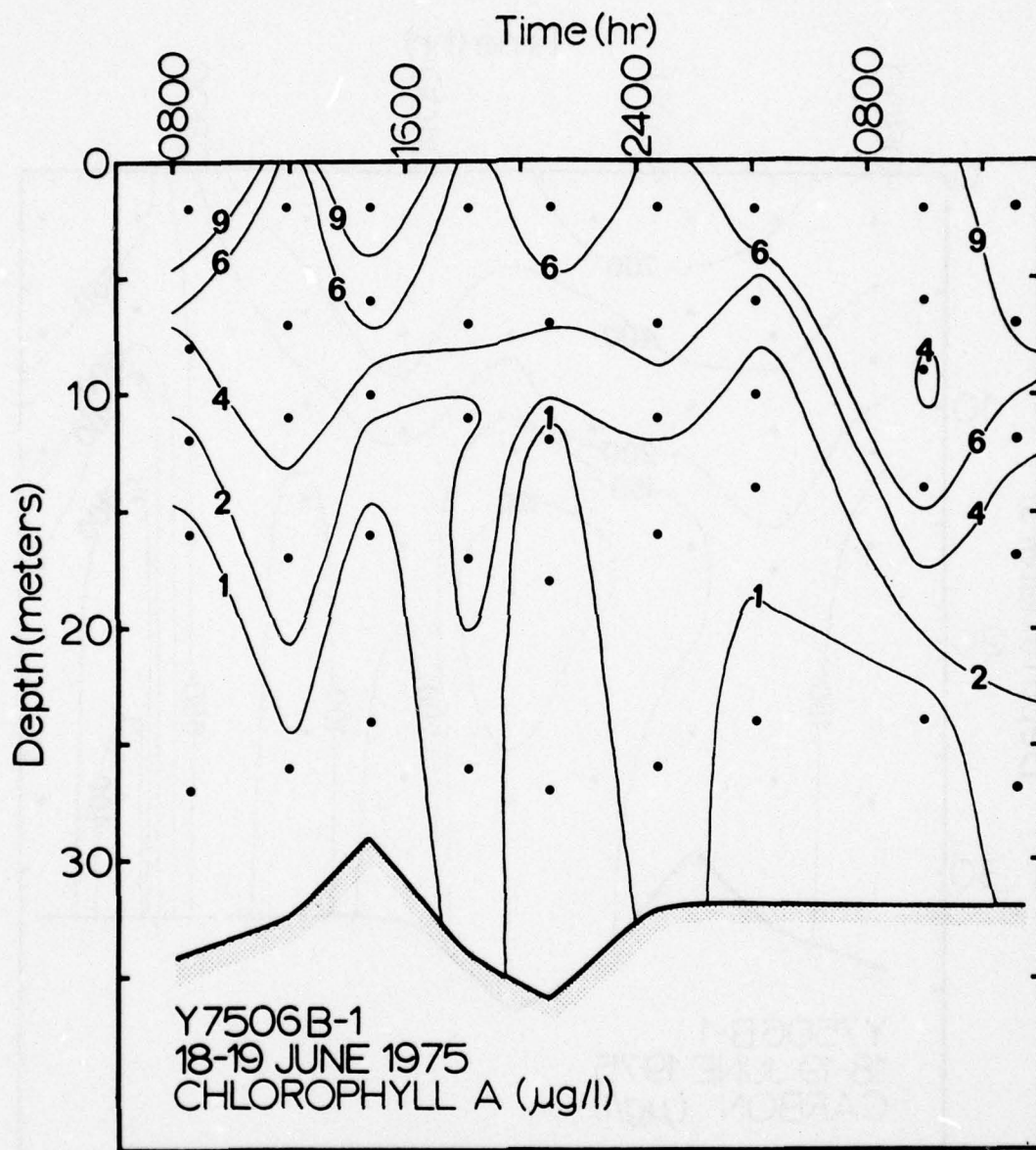


Figure B59. Chlorophyll a distribution plot for June anchor station 2

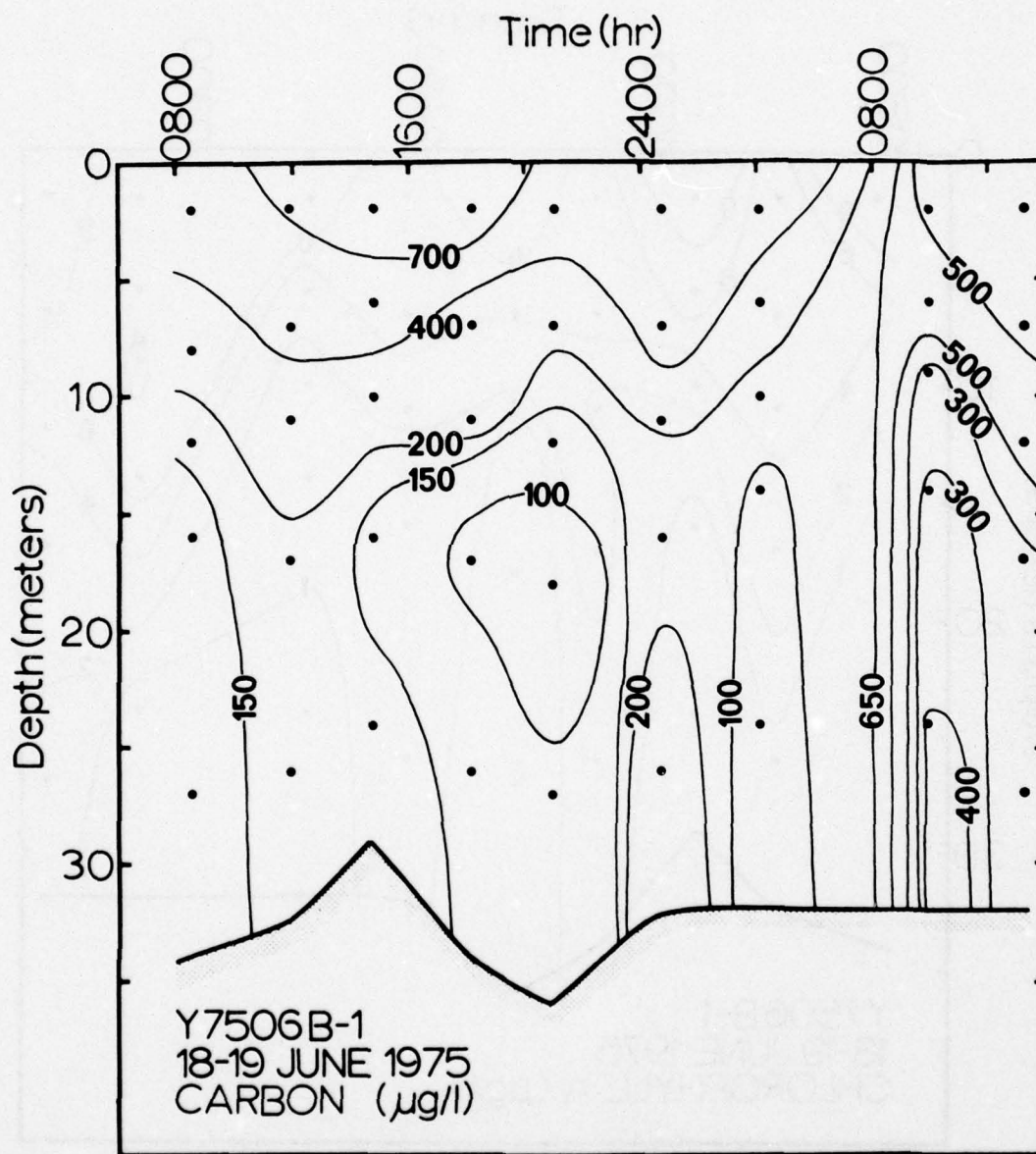


Figure B60. Particulate carbon distribution plot for June anchor station 2

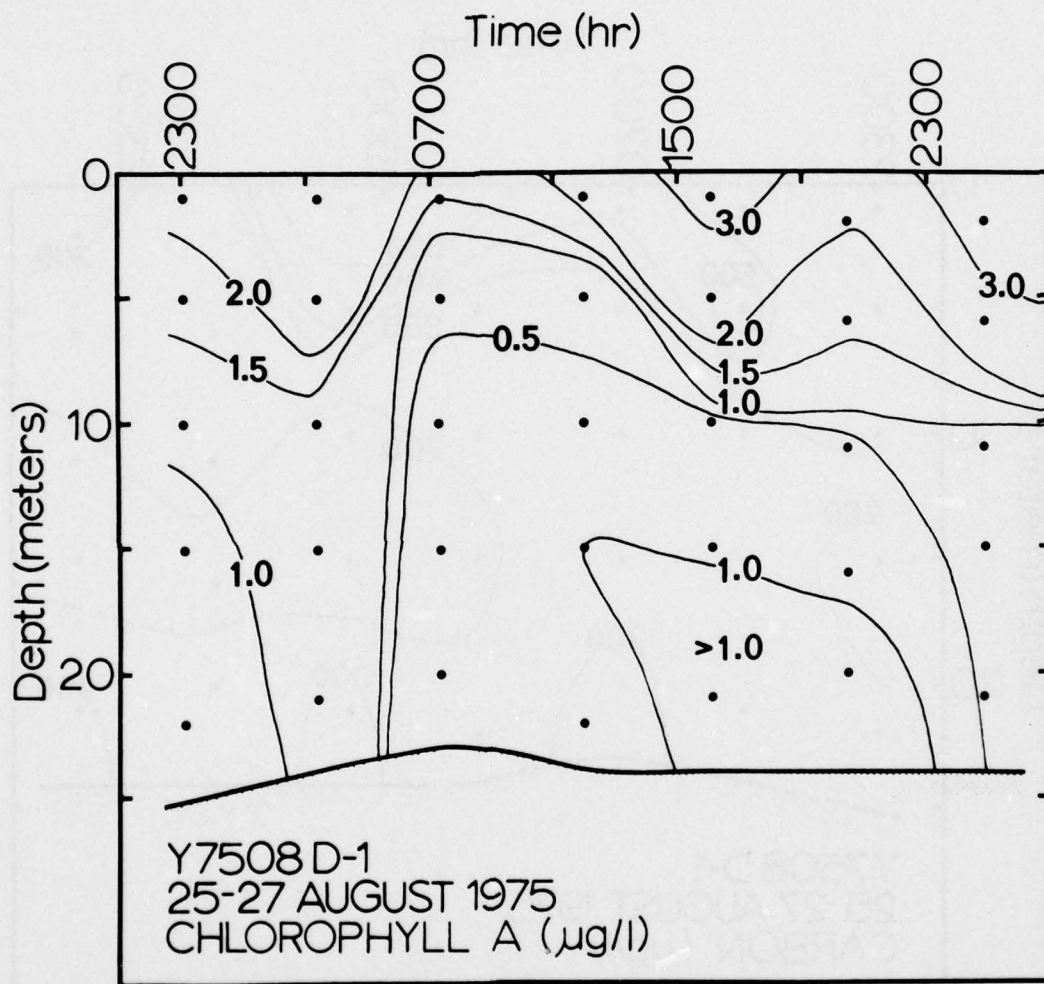


Figure B61. Chlorophyll a distribution plot for August anchor station

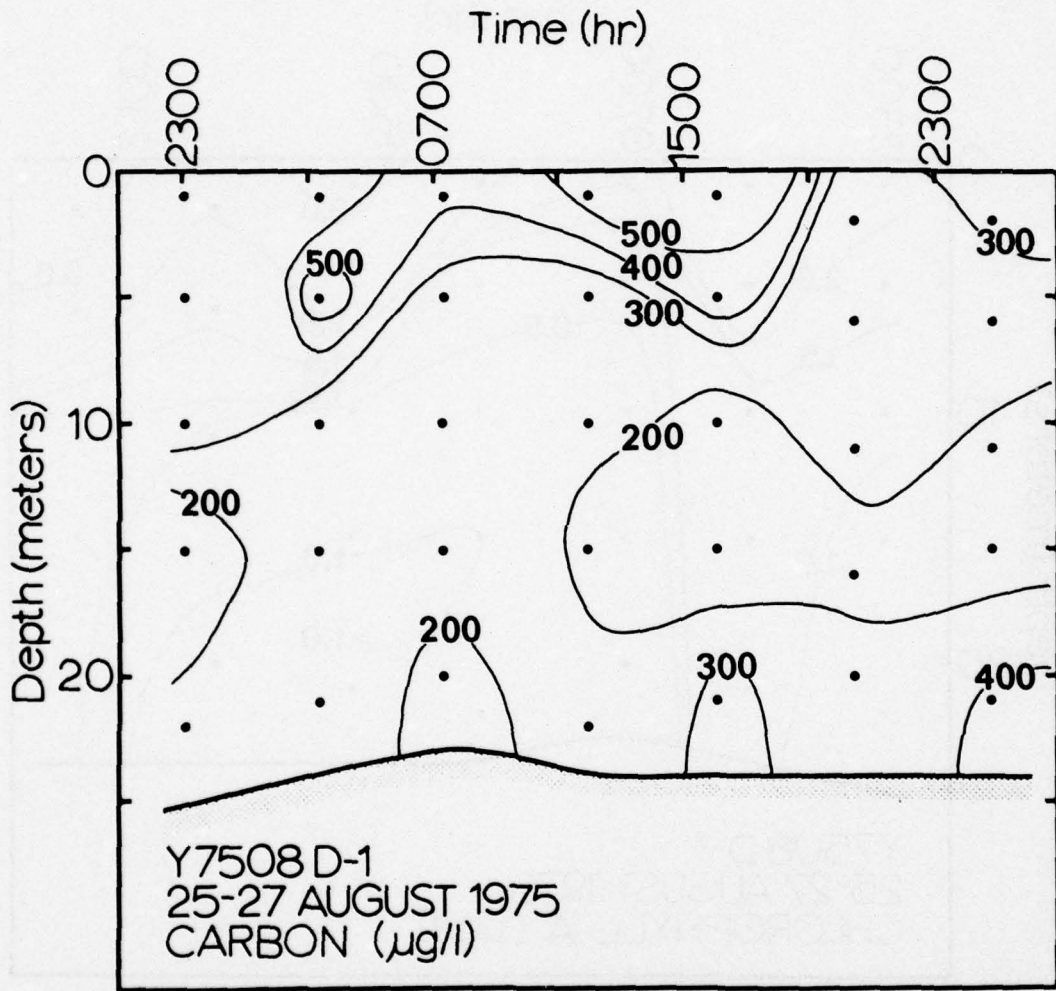


Figure B62. Particulate carbon distribution plot for August anchor station

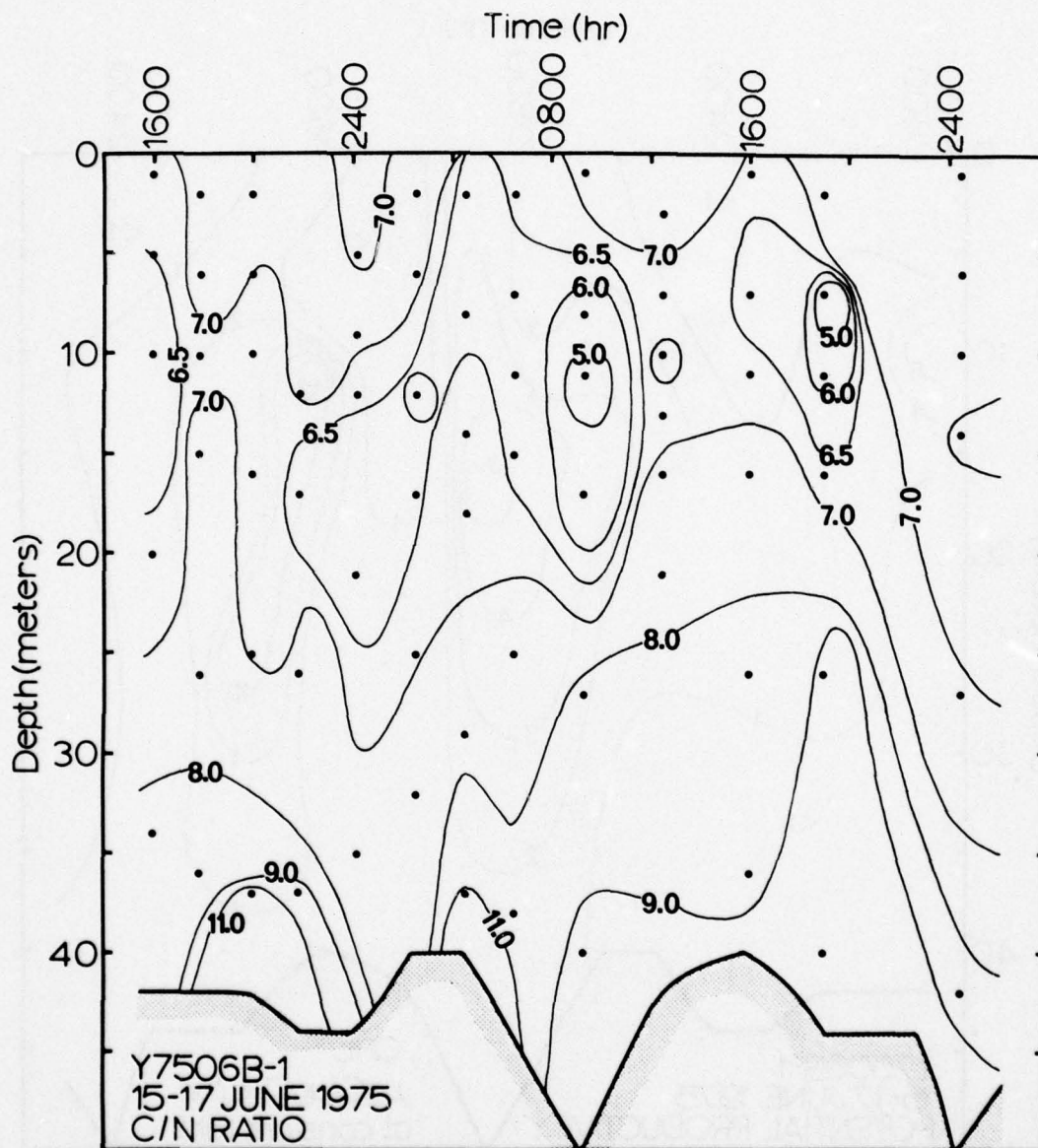


Figure B63. Carbon/nitrogen ratio distribution plot for June anchor station 1

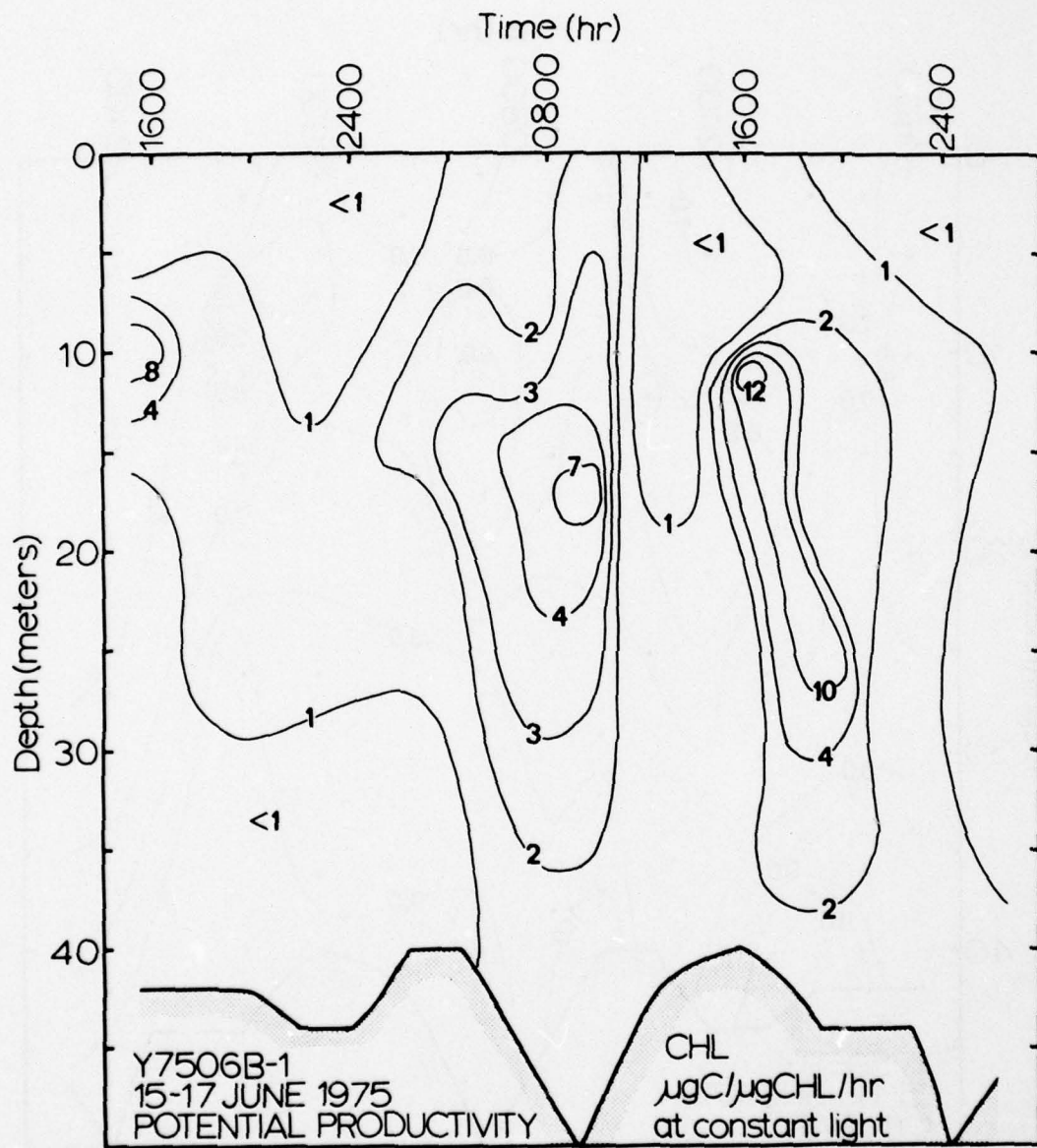


Figure B64. Chlorophyll-specific potential productivity distribution plot for June anchor station 1

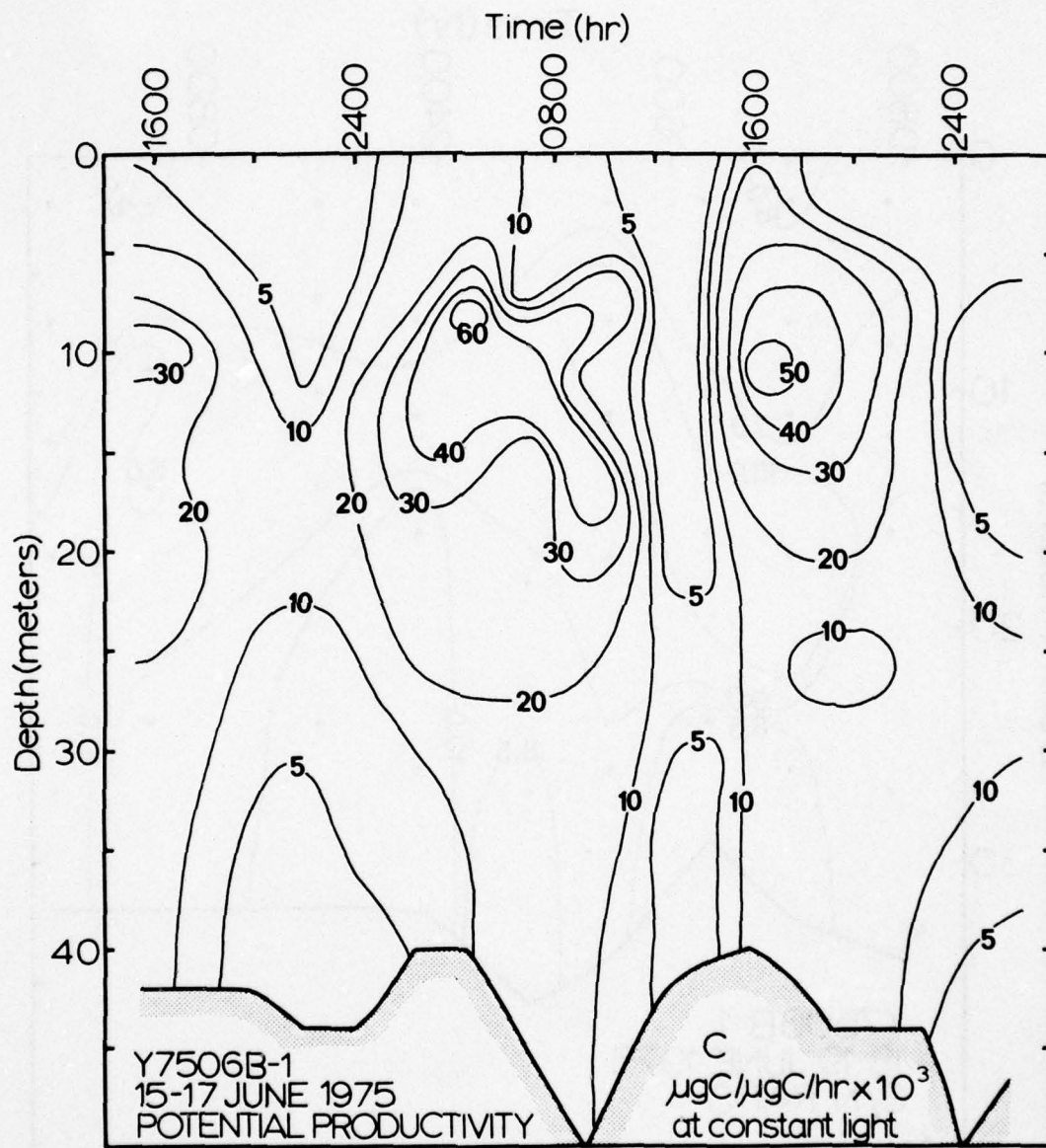


Figure B65. Carbon-specific potential productivity distribution plot for June anchor station 1

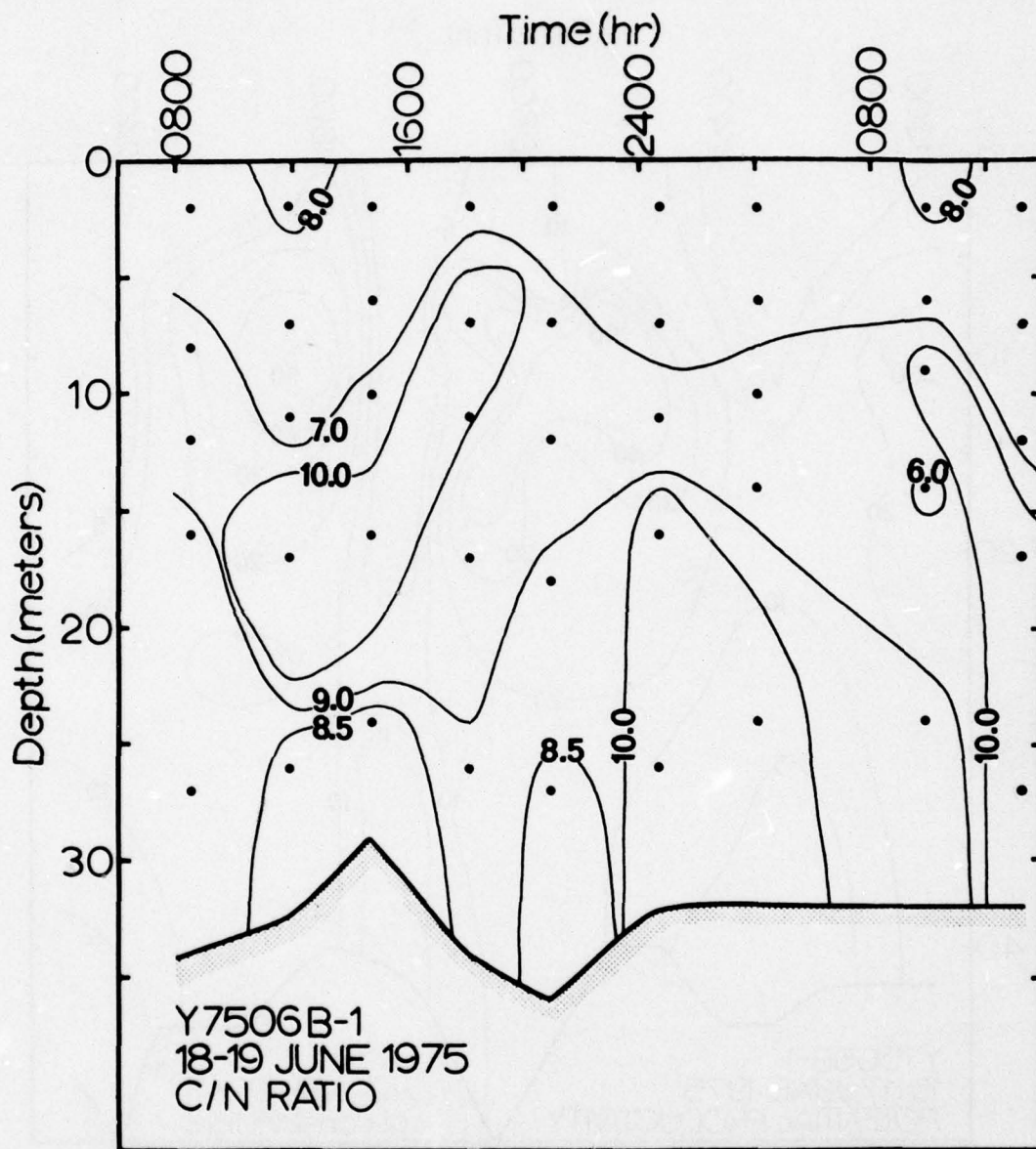


Figure B66. Carbon/nitrogen ratio distribution plot for June anchor station 2

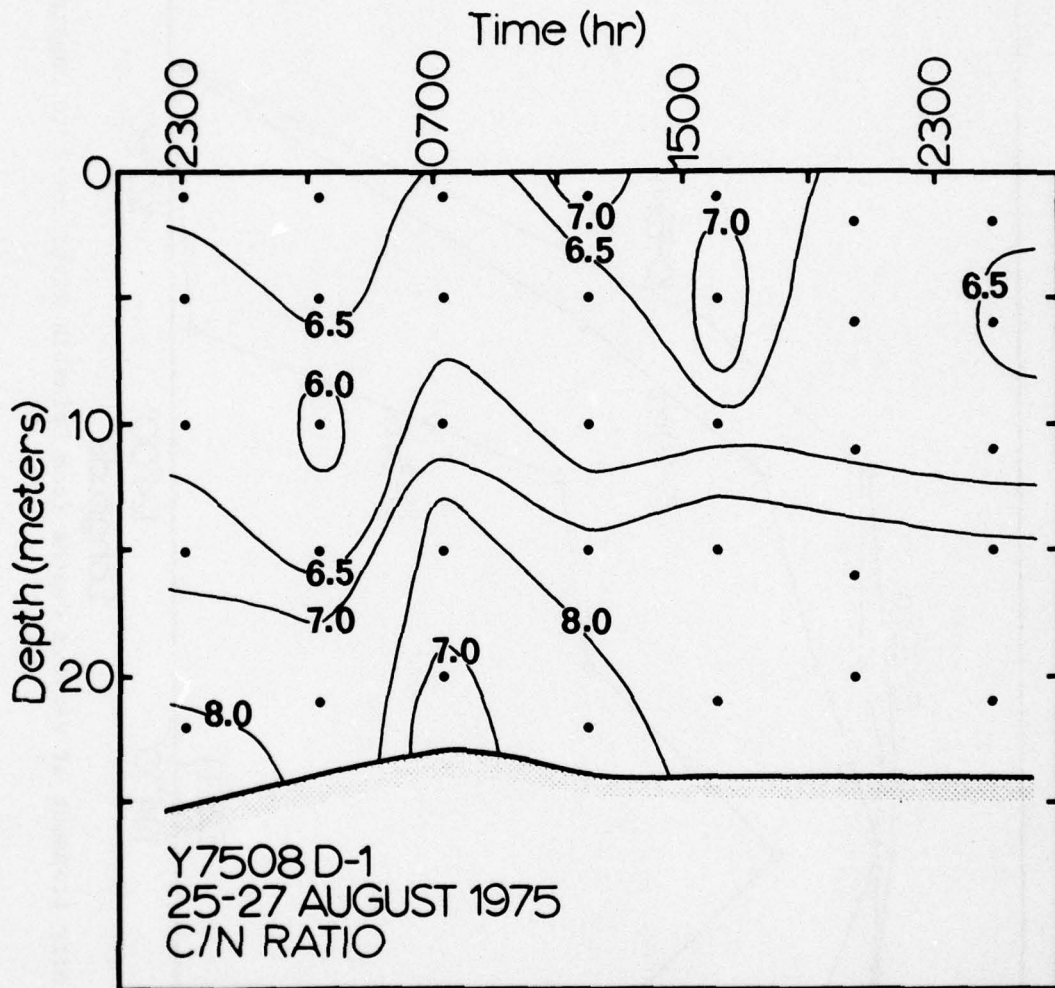


Figure B67. Carbon/nitrogen ratio distribution plot for August anchor station

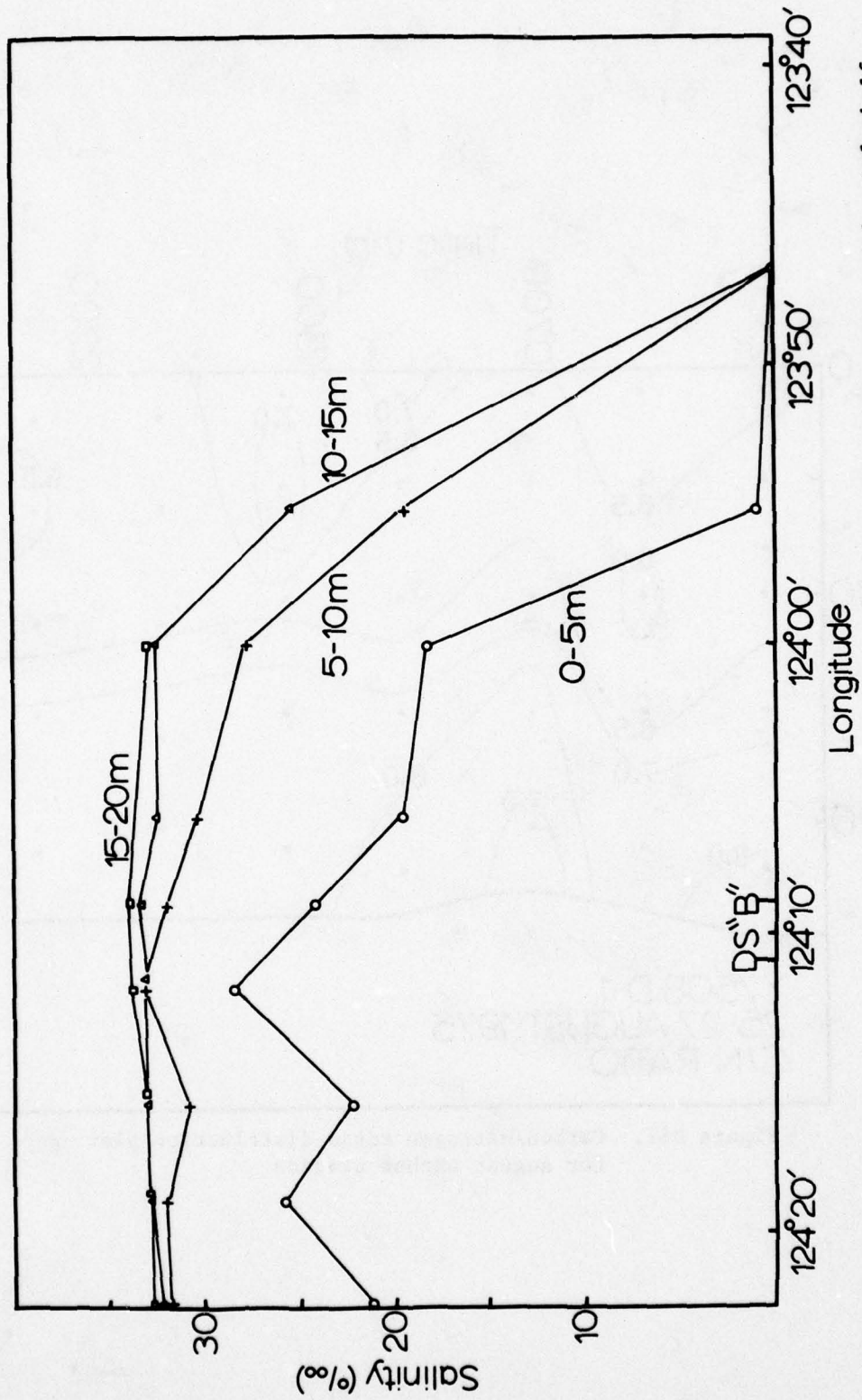


Figure B68. Salinity transect at various depths from Columbia River out onto continental shelf

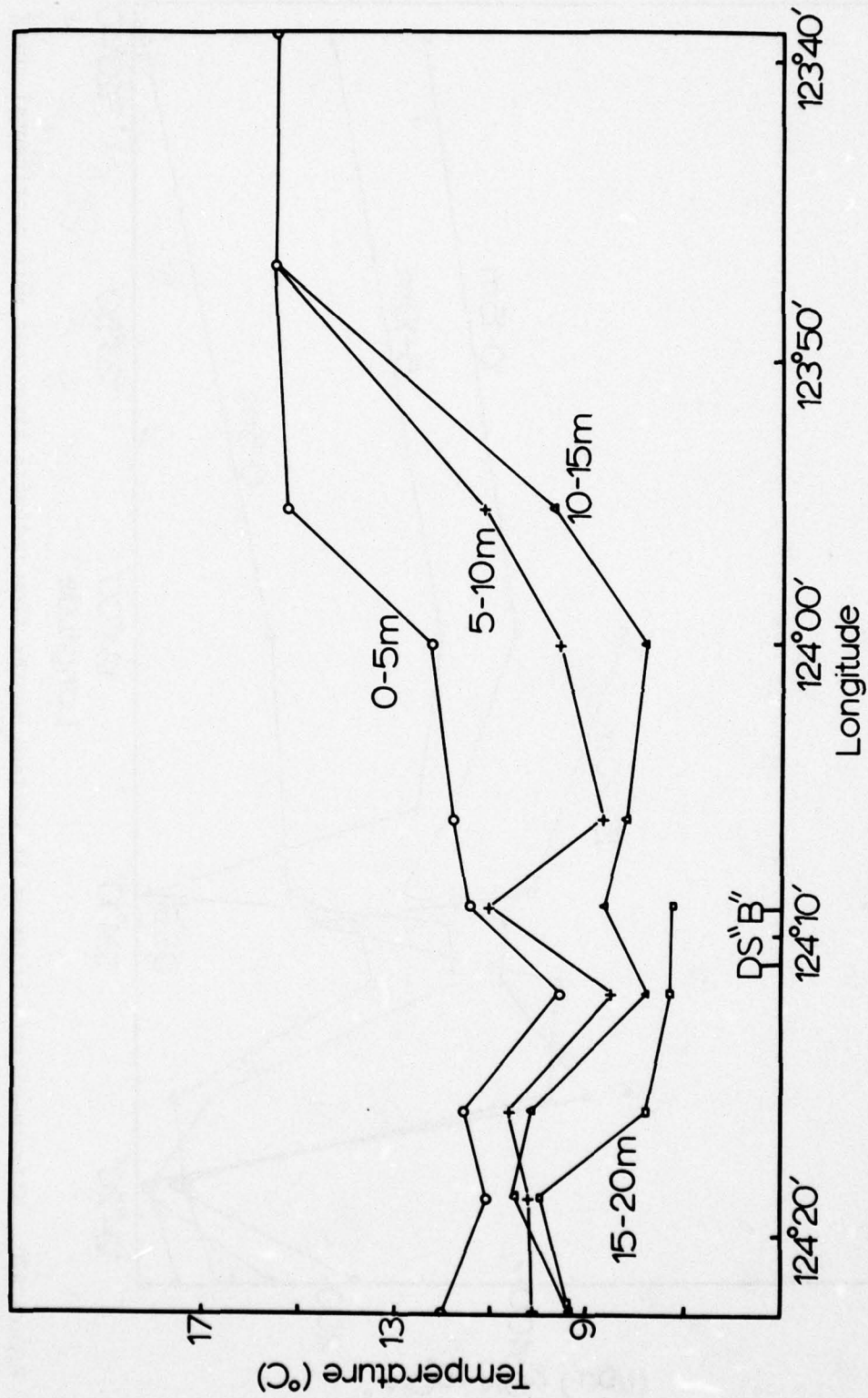


Figure B69. Temperature transect at various depths from Columbia River out onto continental shelf

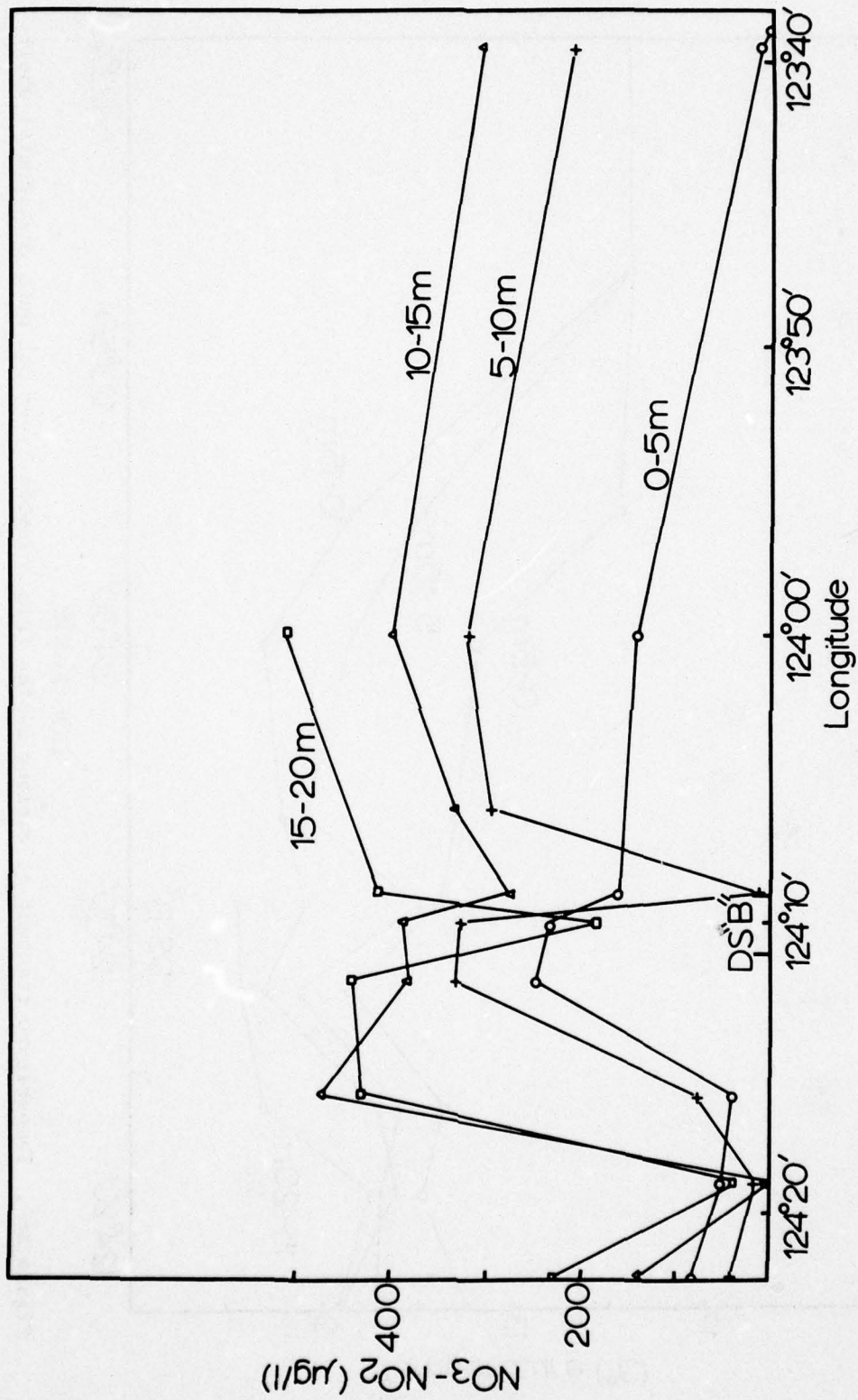


Figure B70. Nitrate-nitrite transect at various depths from Columbia River out onto continental shelf

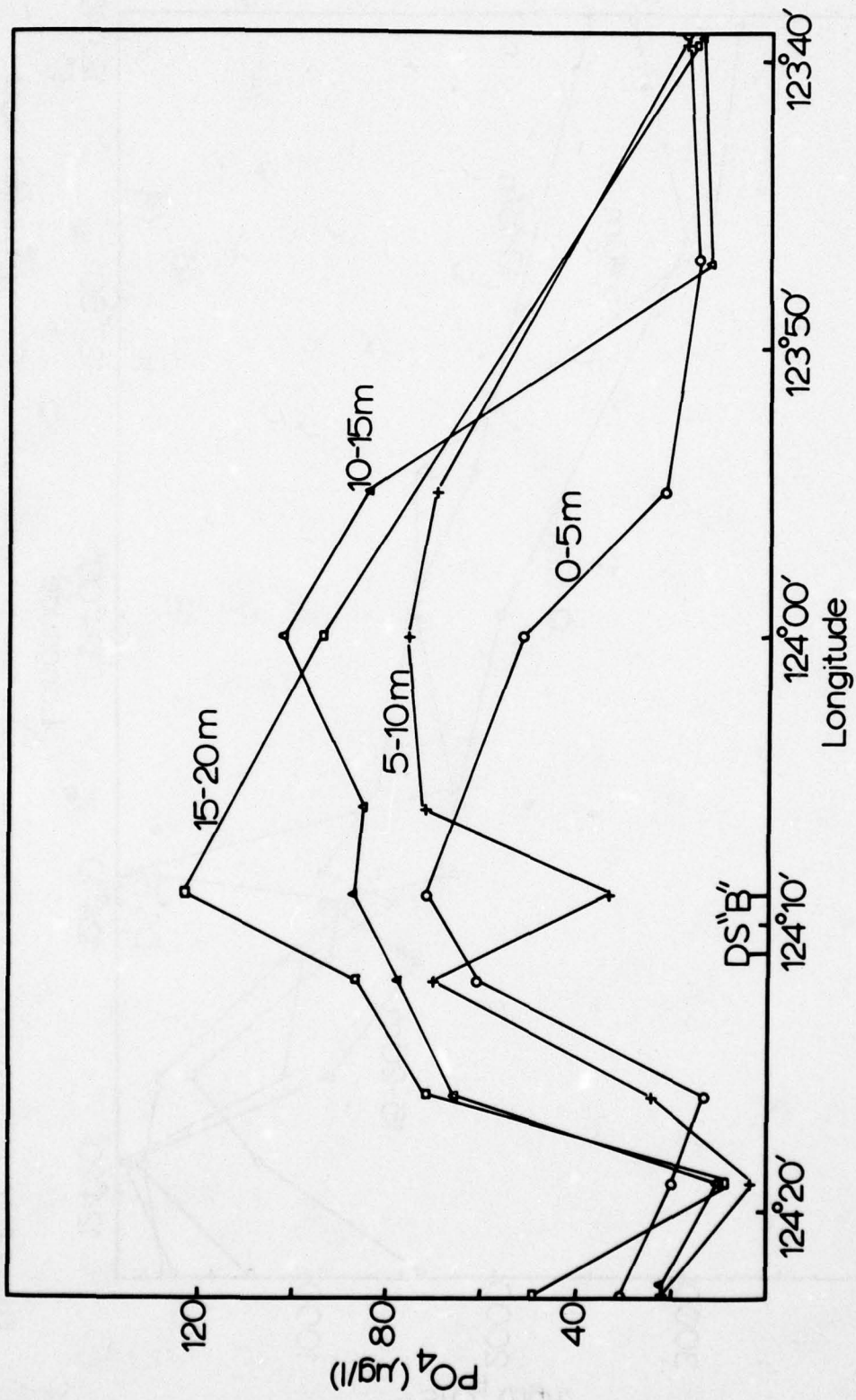


Figure B71. Phosphate transect at various depths from Columbia River out onto continental shelf

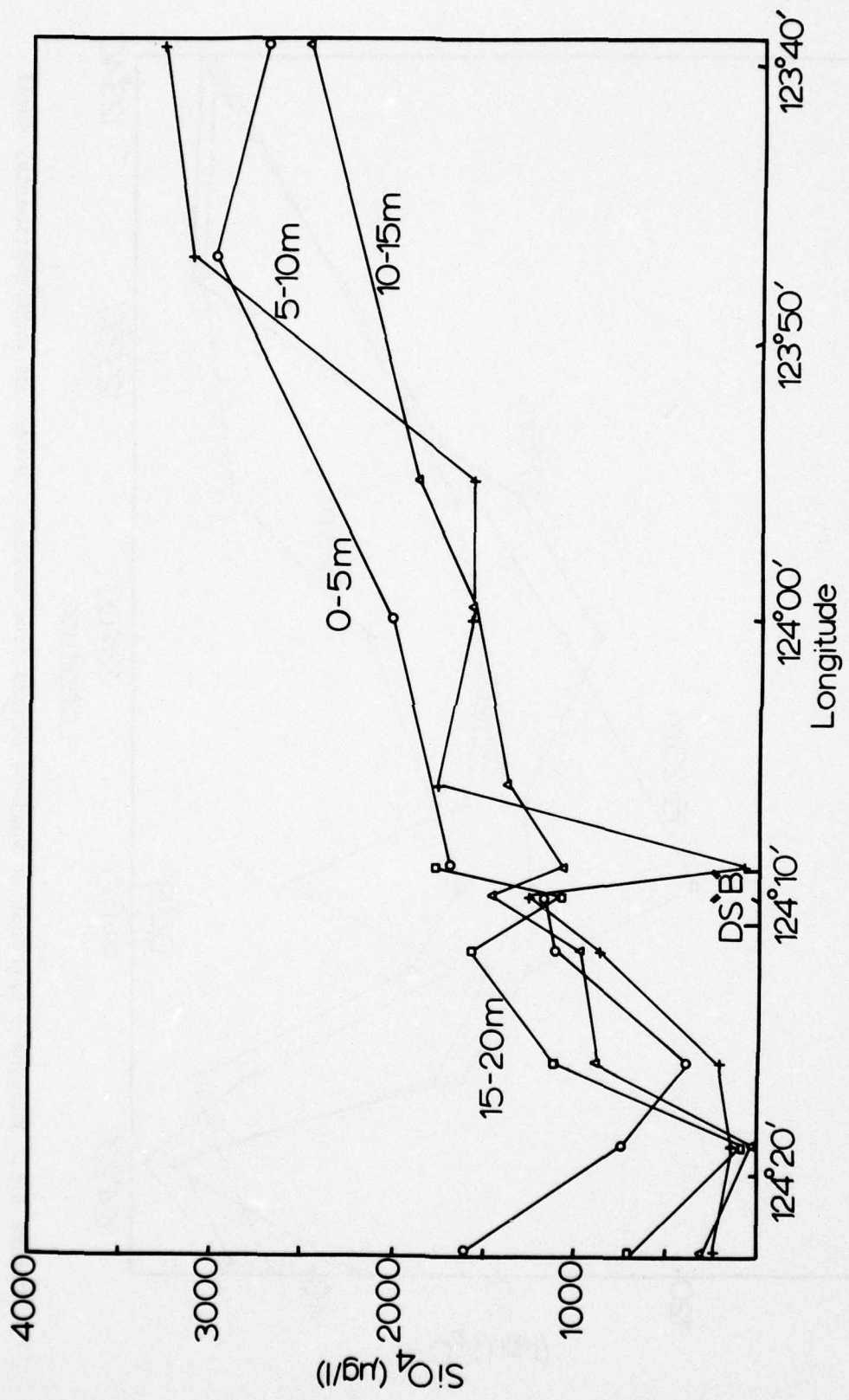


Figure B72. Silicate transect at various depths from Columbia River out onto continental shelf

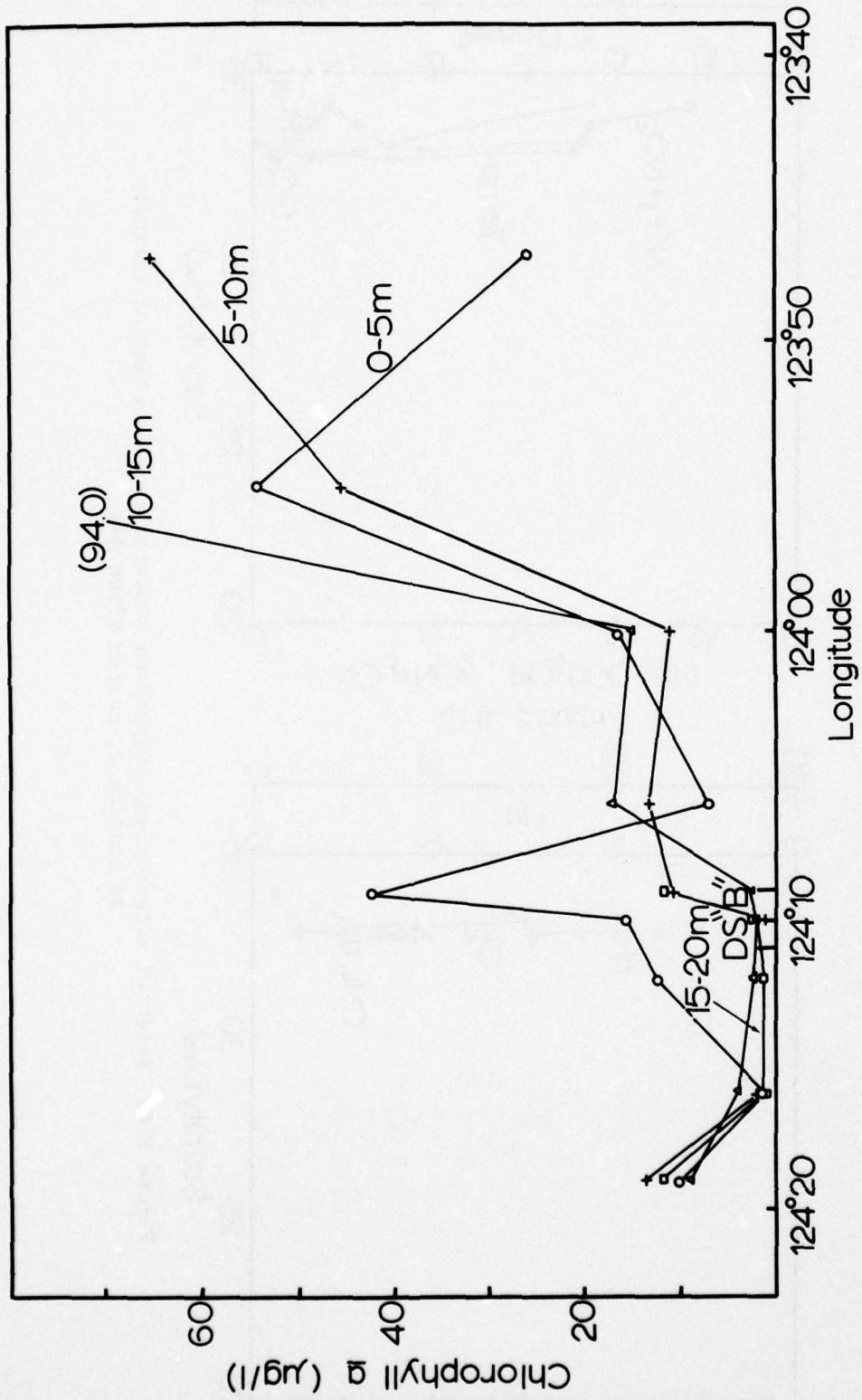


Figure B73. Chlorophyll a transect at various depths from Columbia River out onto continental shelf

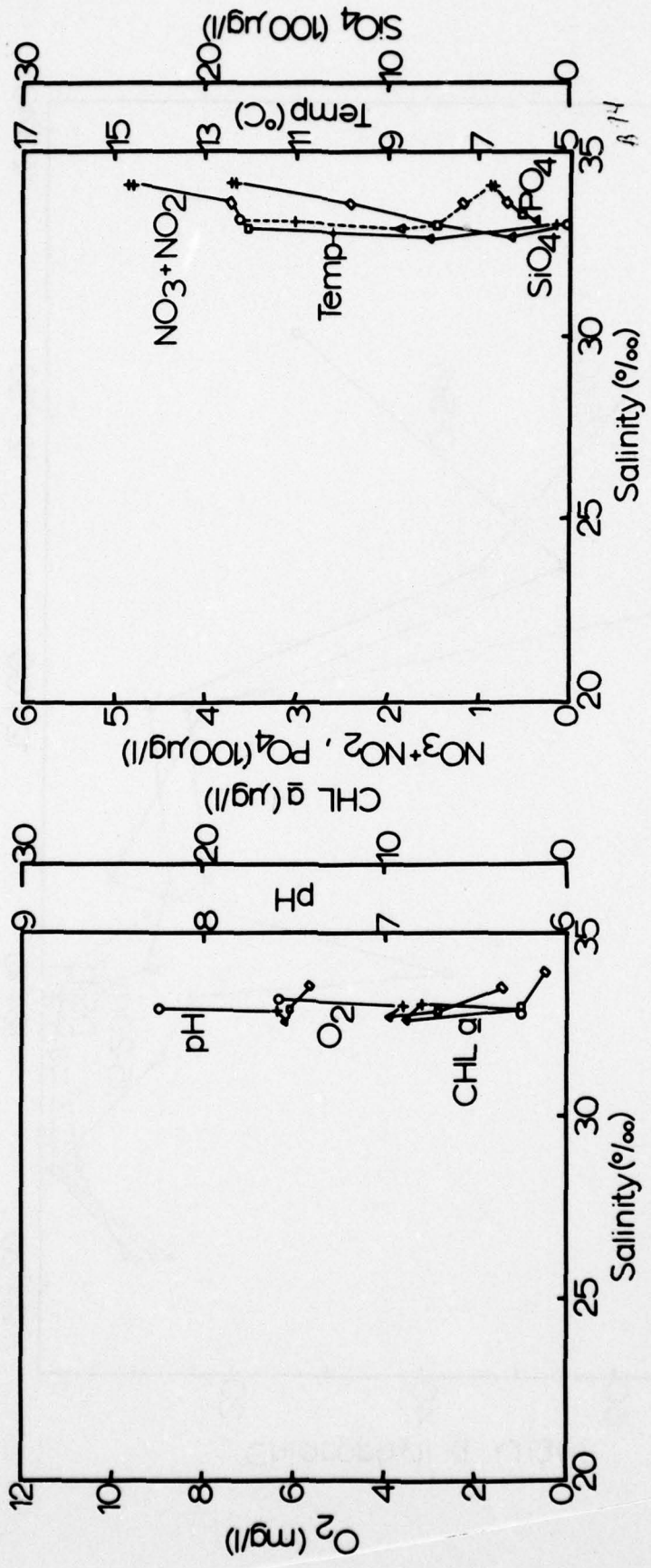


Figure B74. Selected water-column properties measured as a function of salinity at station 3, cruise Y7506 B-1

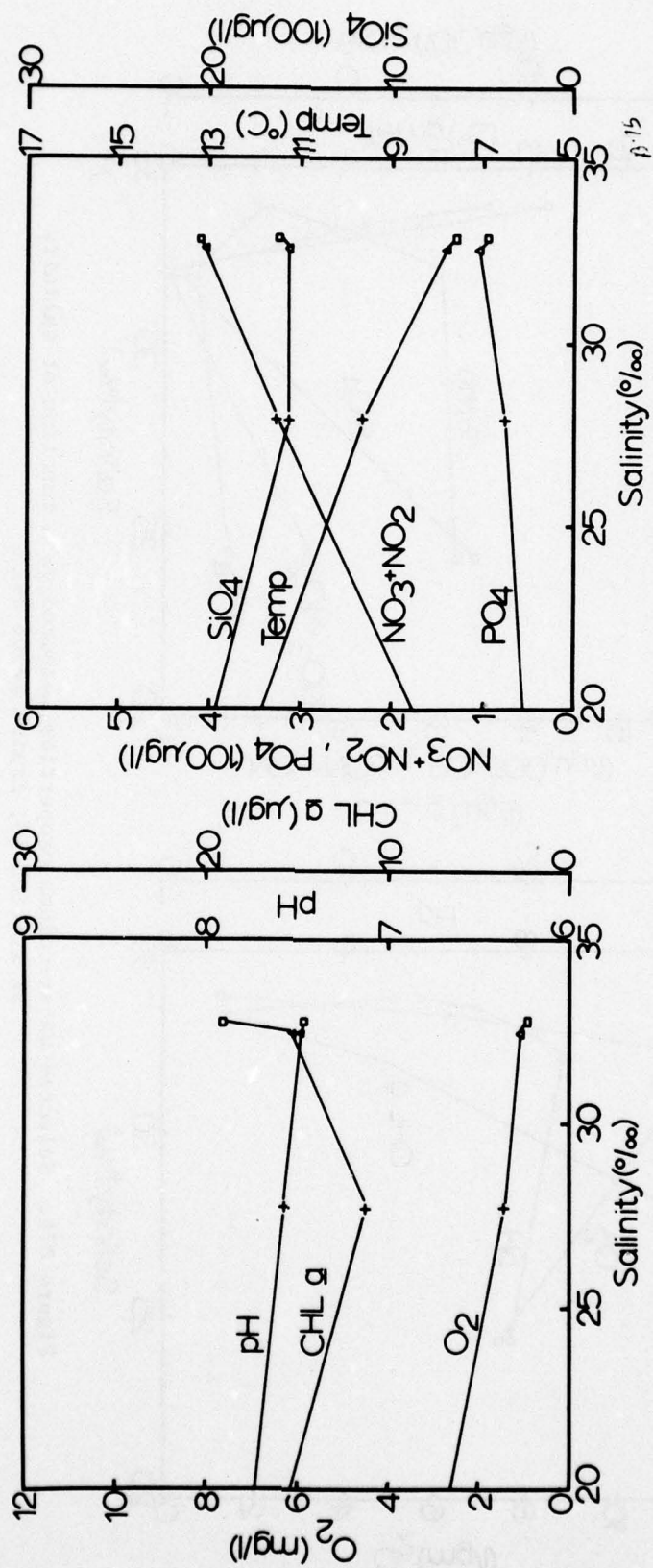


Figure B75. Selected water-column properties measured as a function of salinity at station B75, cruise Y7506 B-1

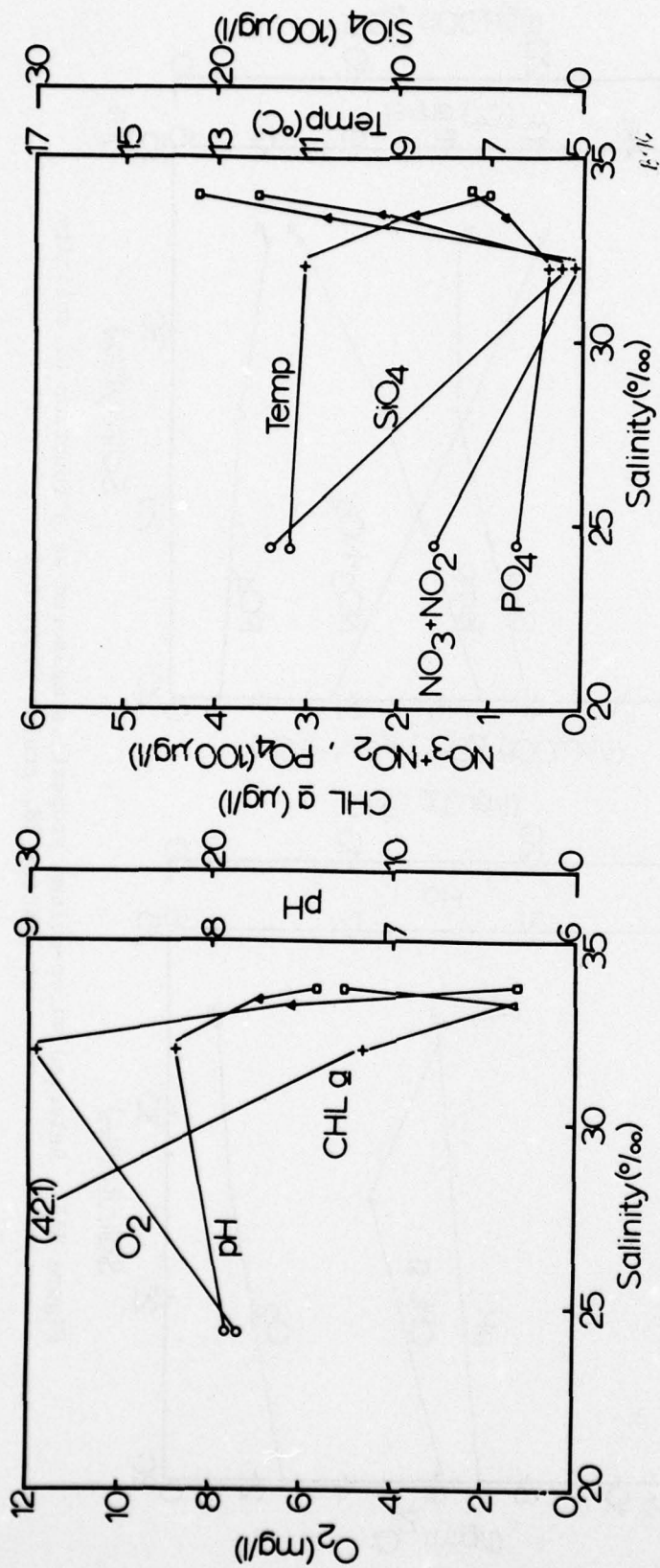


Figure B76. Selected water-column properties measured as a function of salinity at station 10, cruise Y7506 B-1

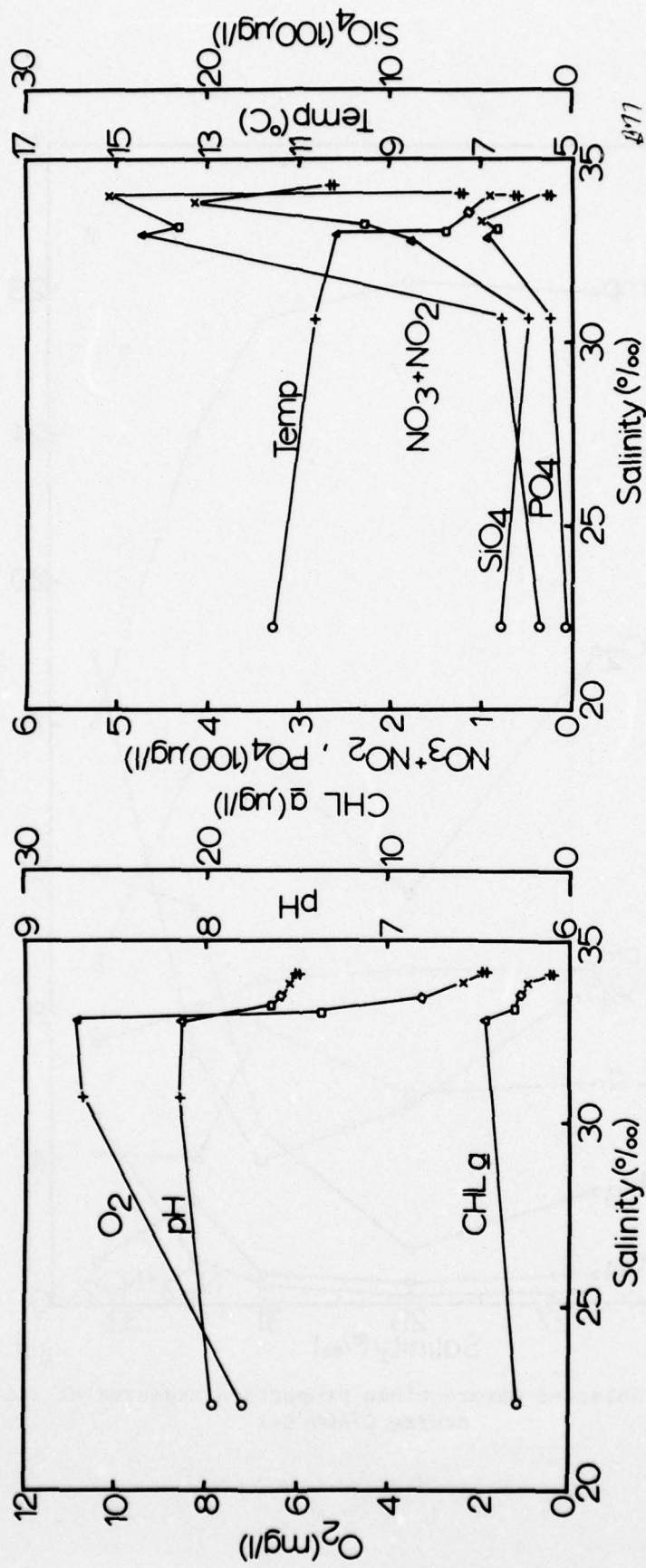


Figure B77. Selected water-column properties measured as a function of salinity at station 34, cruise Y7506 B-1

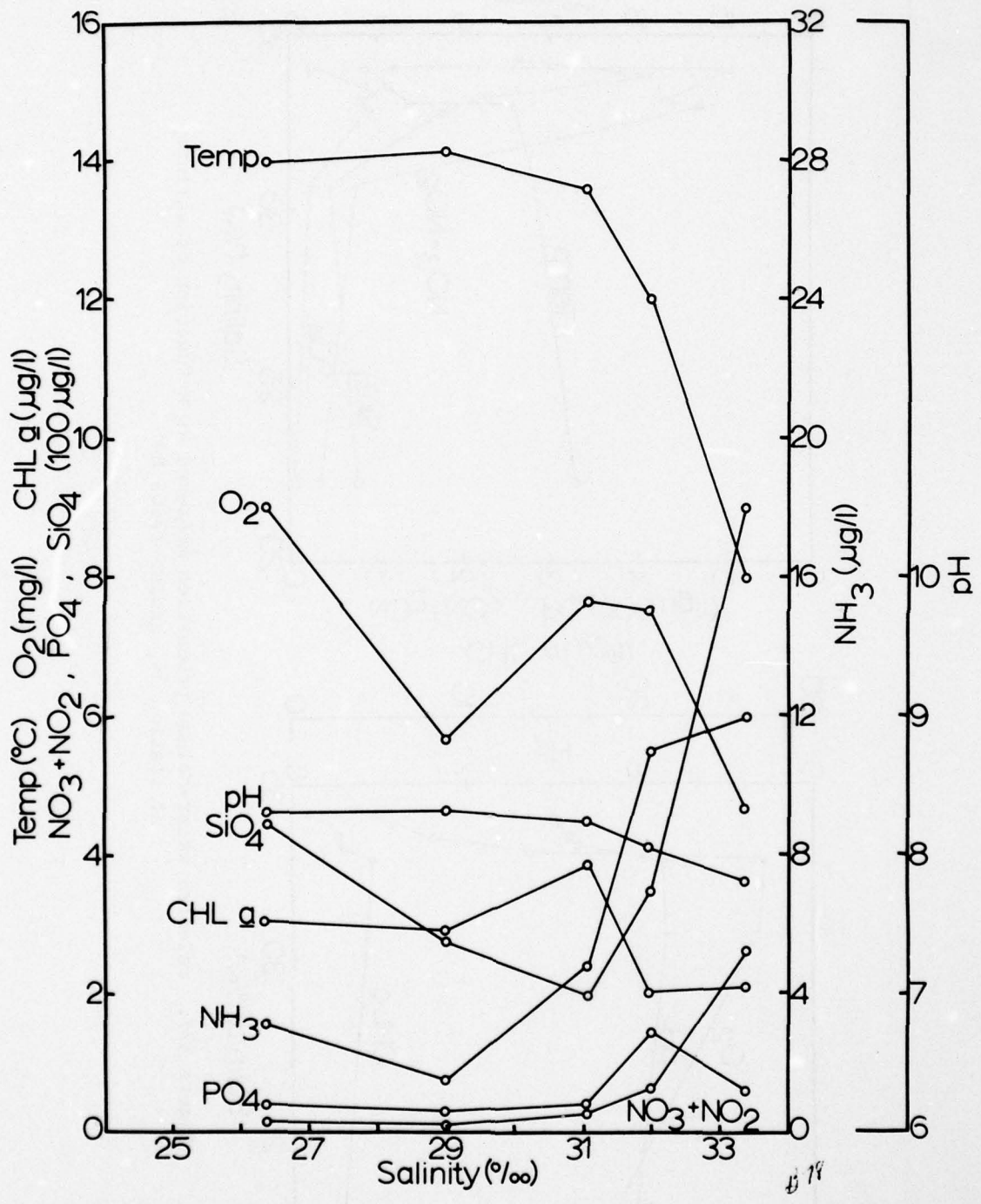


Figure B78. Selected water-column properties measured at station 9, cruise C7409 C-1

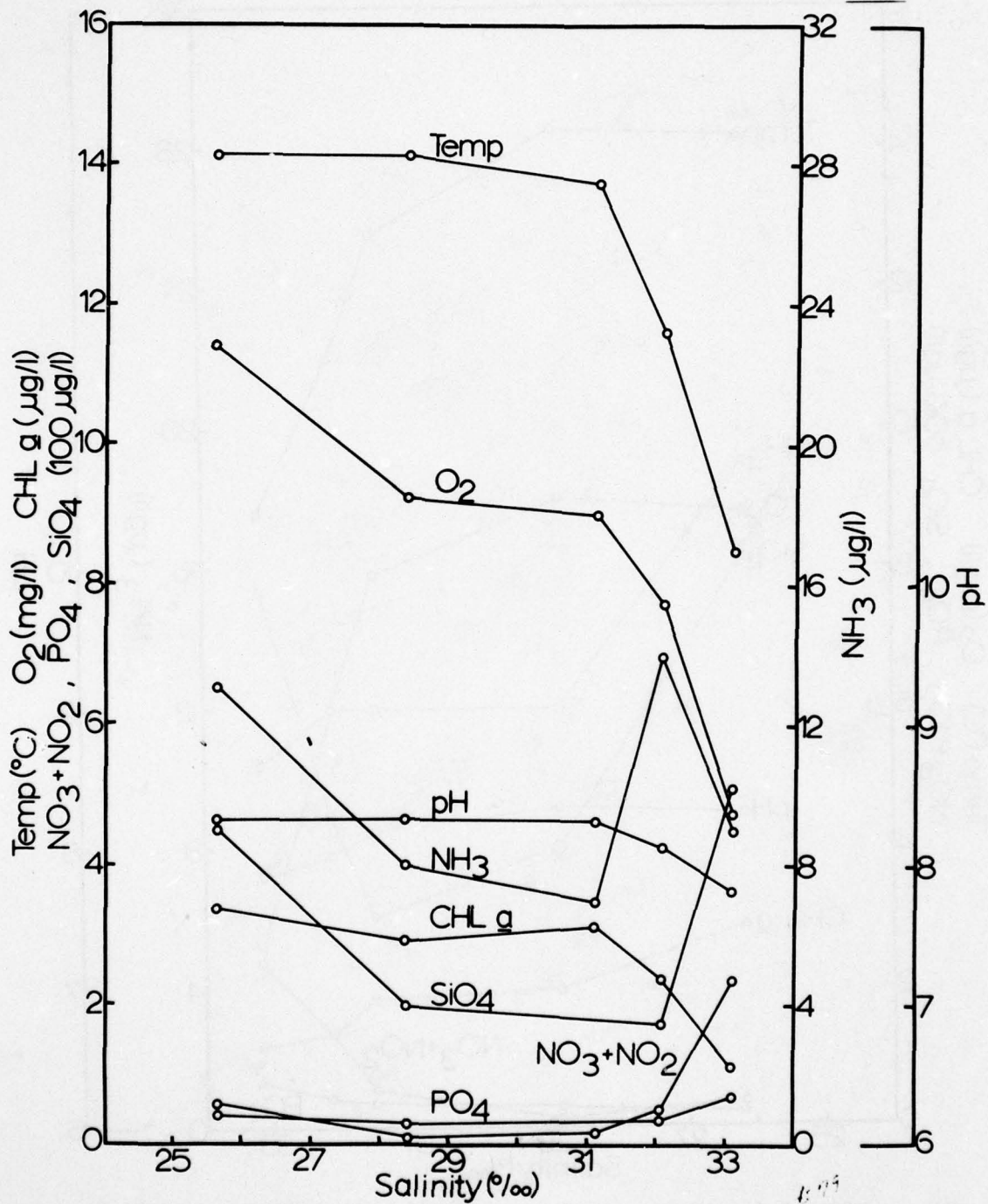


Figure B79. Selected water-column properties measured at station 8, cruise C7409 C-1

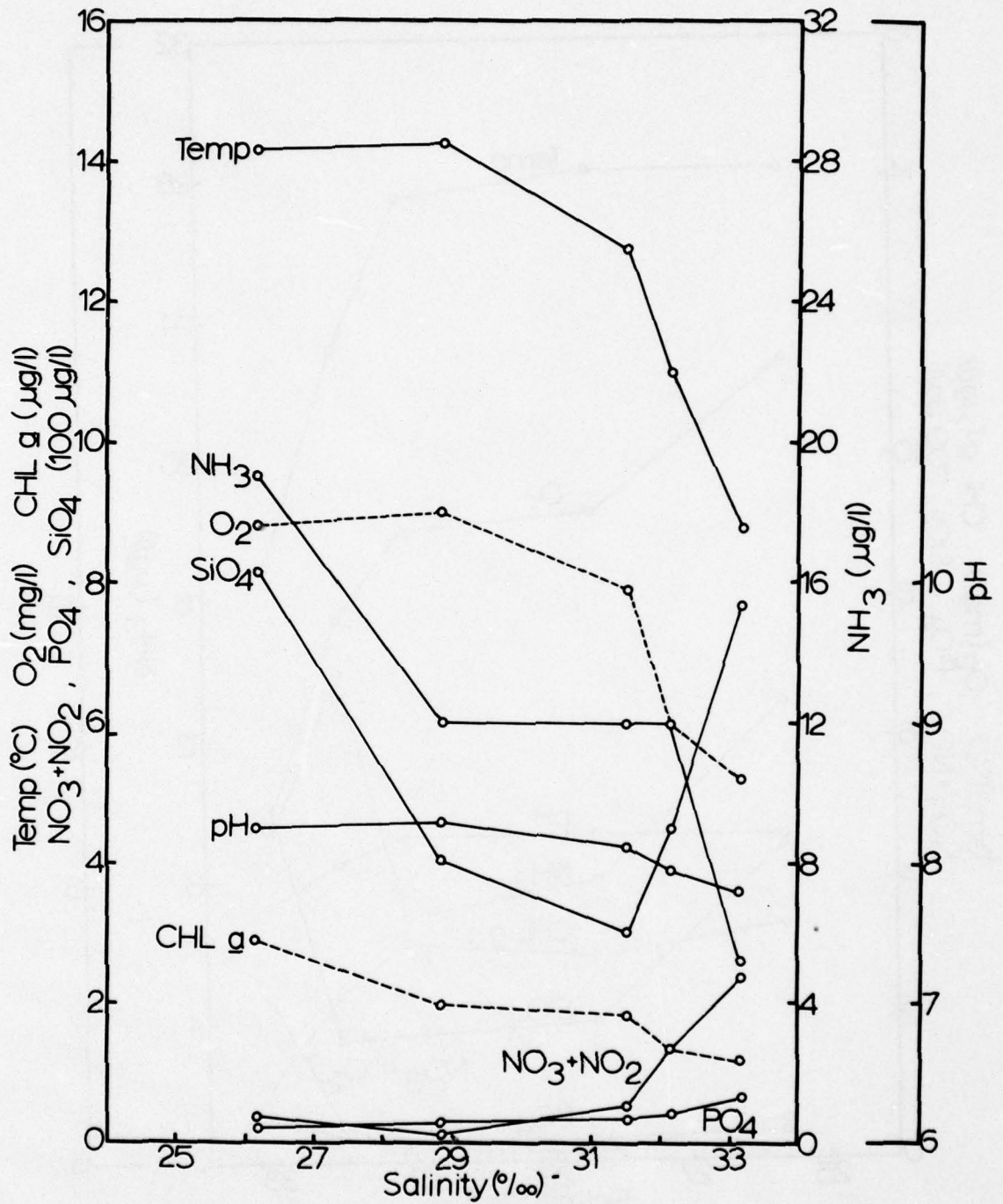


Figure B80. Selected water-column properties measured at station 7, cruise C7409 C-1

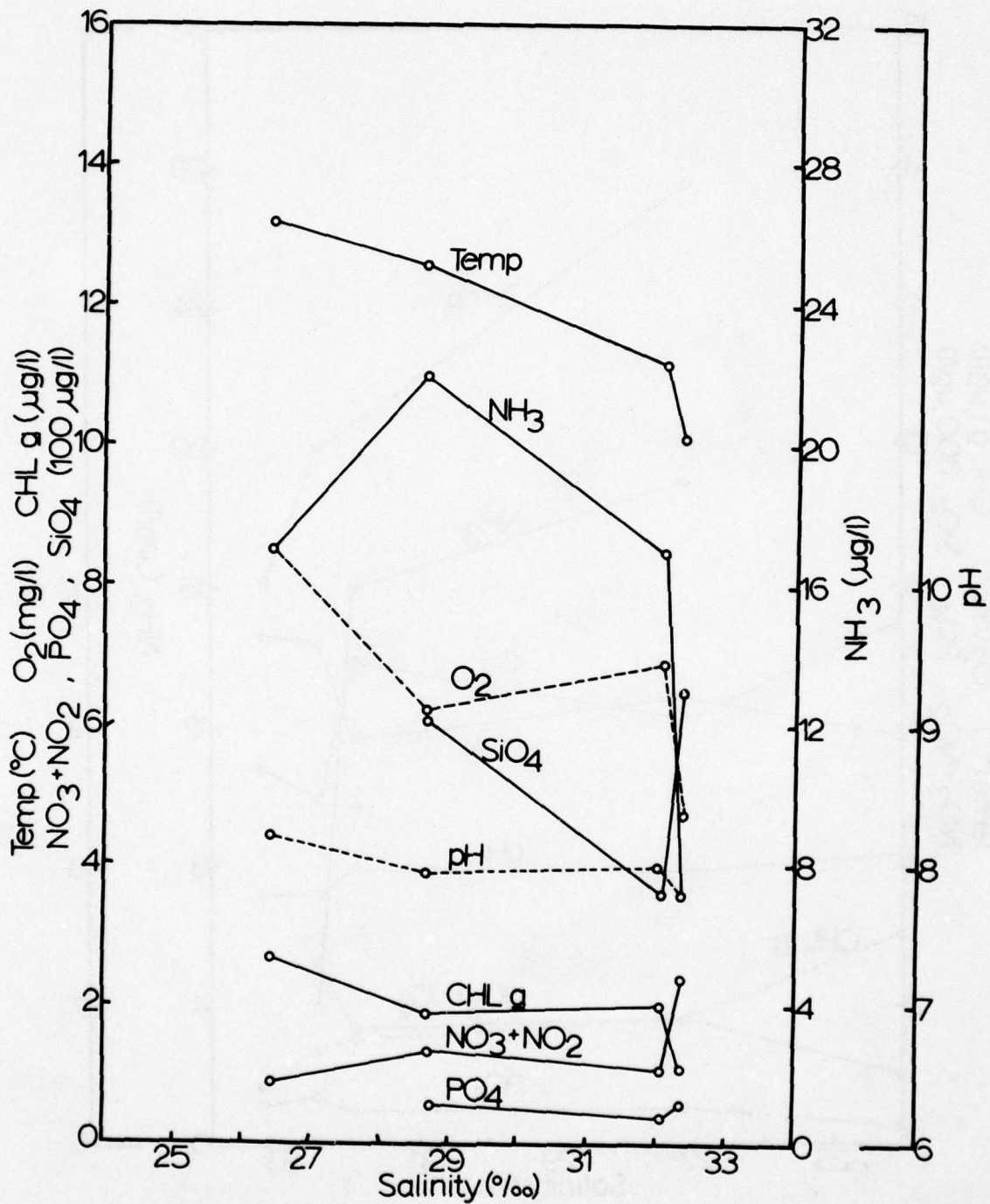


Figure B81. Selected water-column properties measured at station 6, cruise C7409 C-1

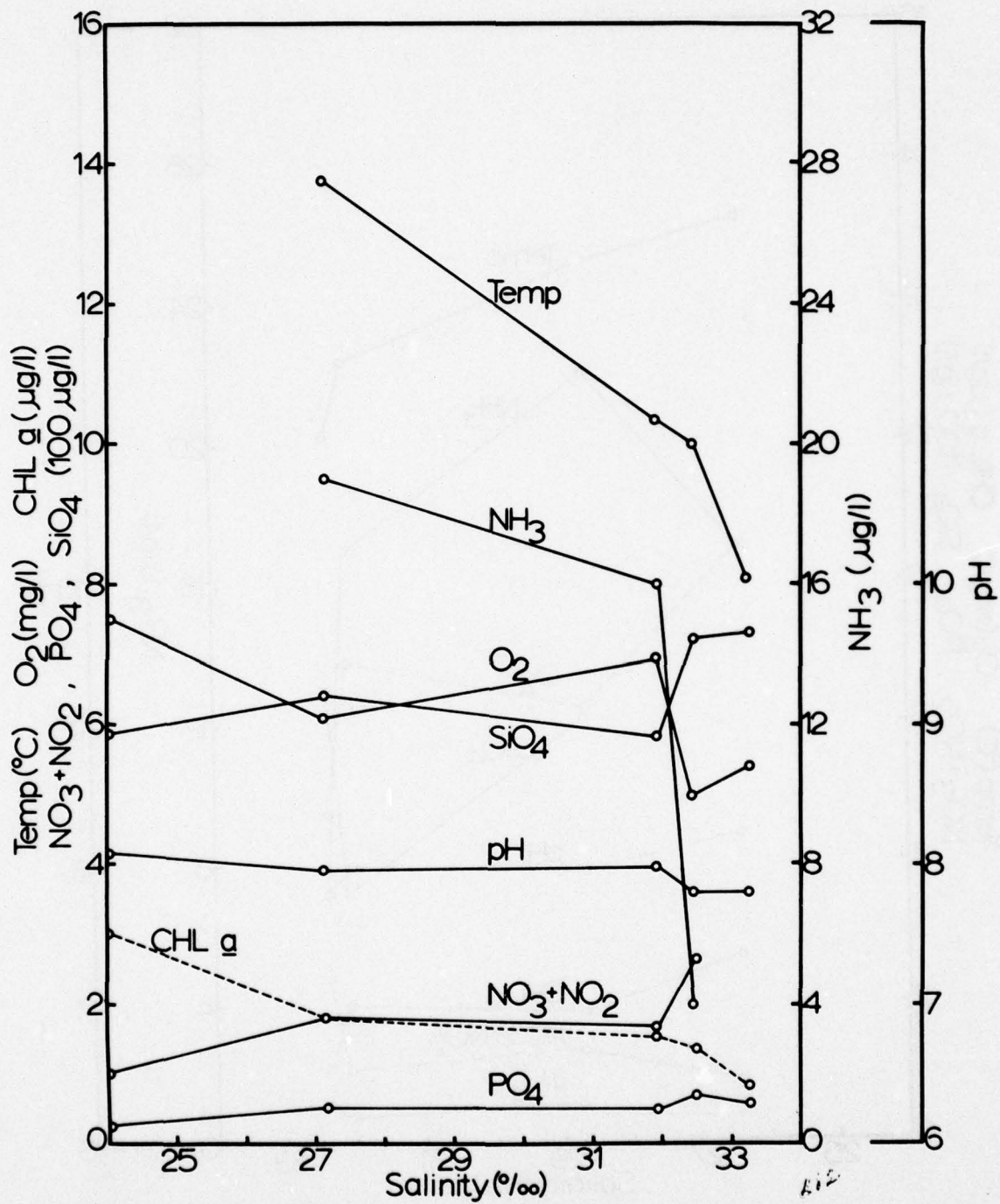


Figure B82. Selected water-column properties measured at station 5, cruise C7409 C-1

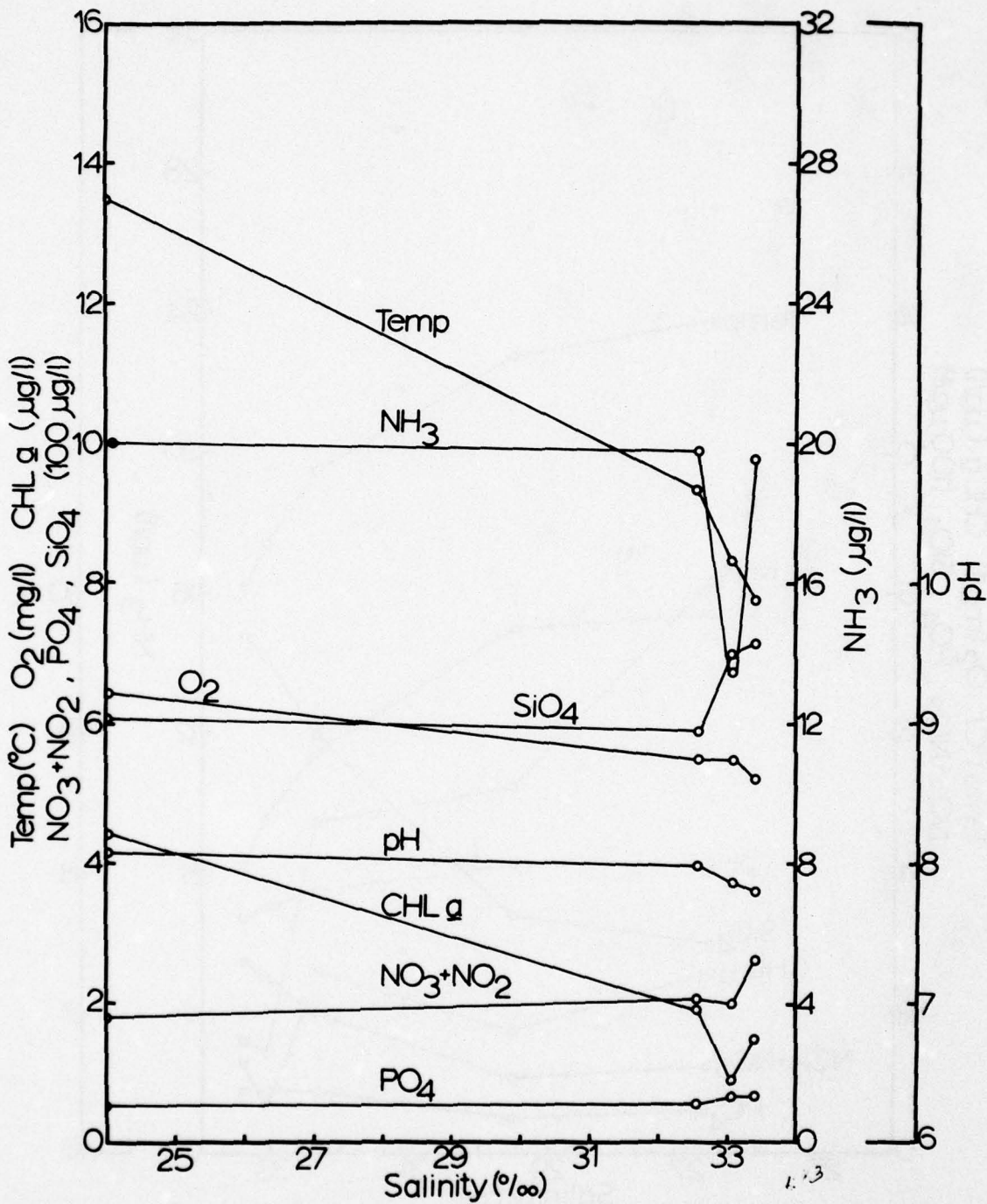


Figure B83. Selected water-column properties measured at station 4, cruise C7409 C-1

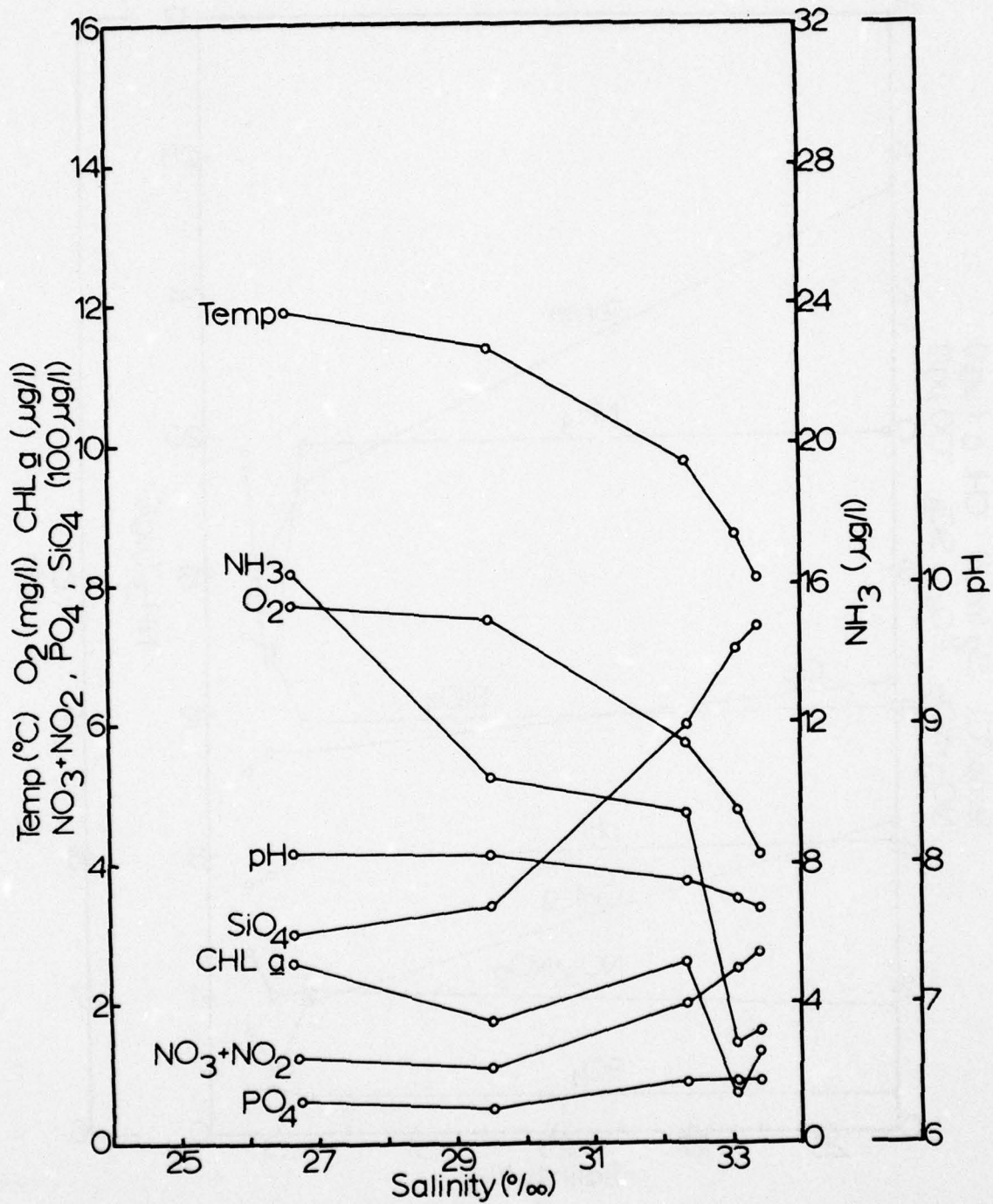


Figure B84. Selected water-column properties measured at station 3, cruise C7409 C-1

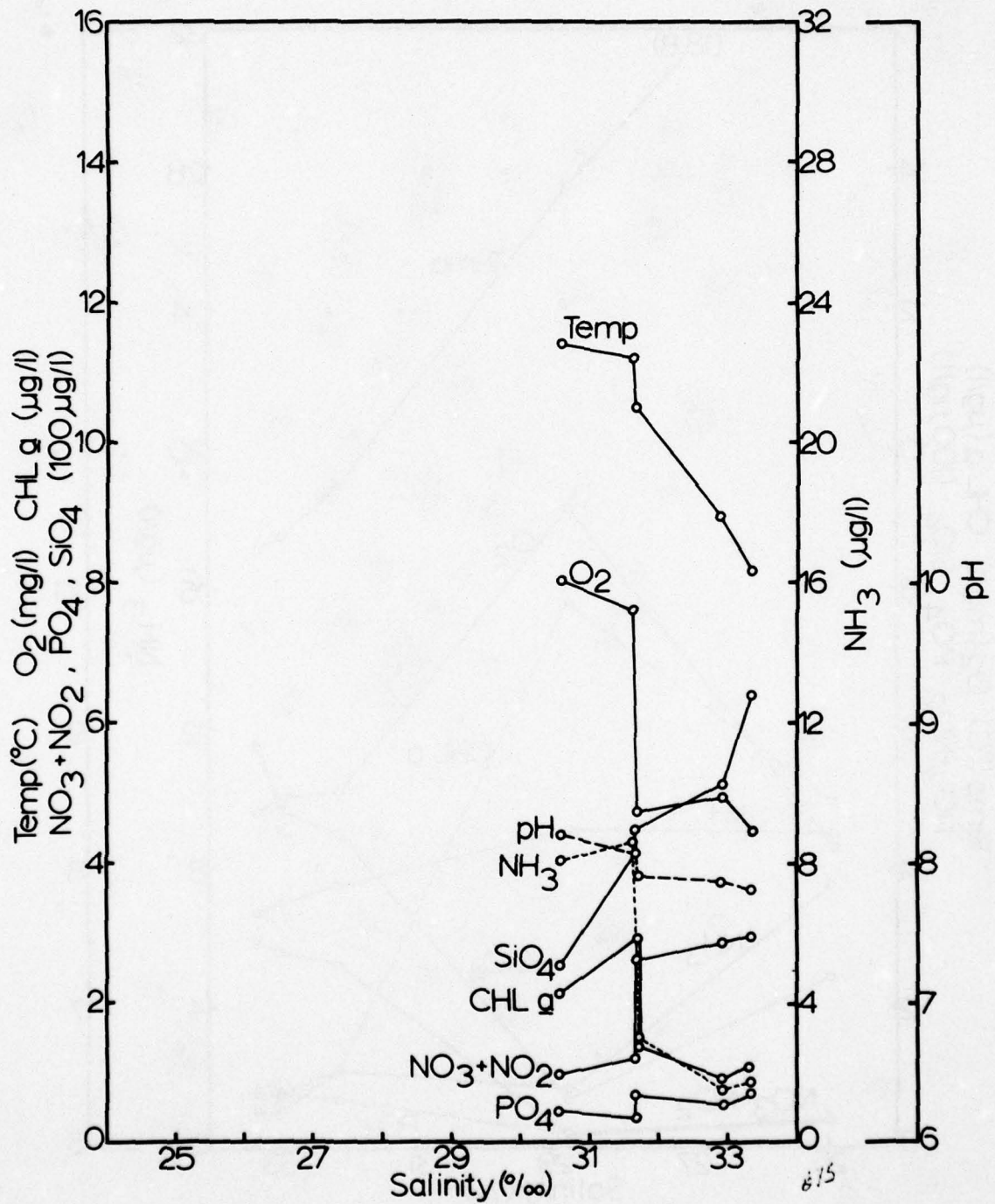


Figure B85. Selected water-column properties measured at station 2, cruise C7409 C-1

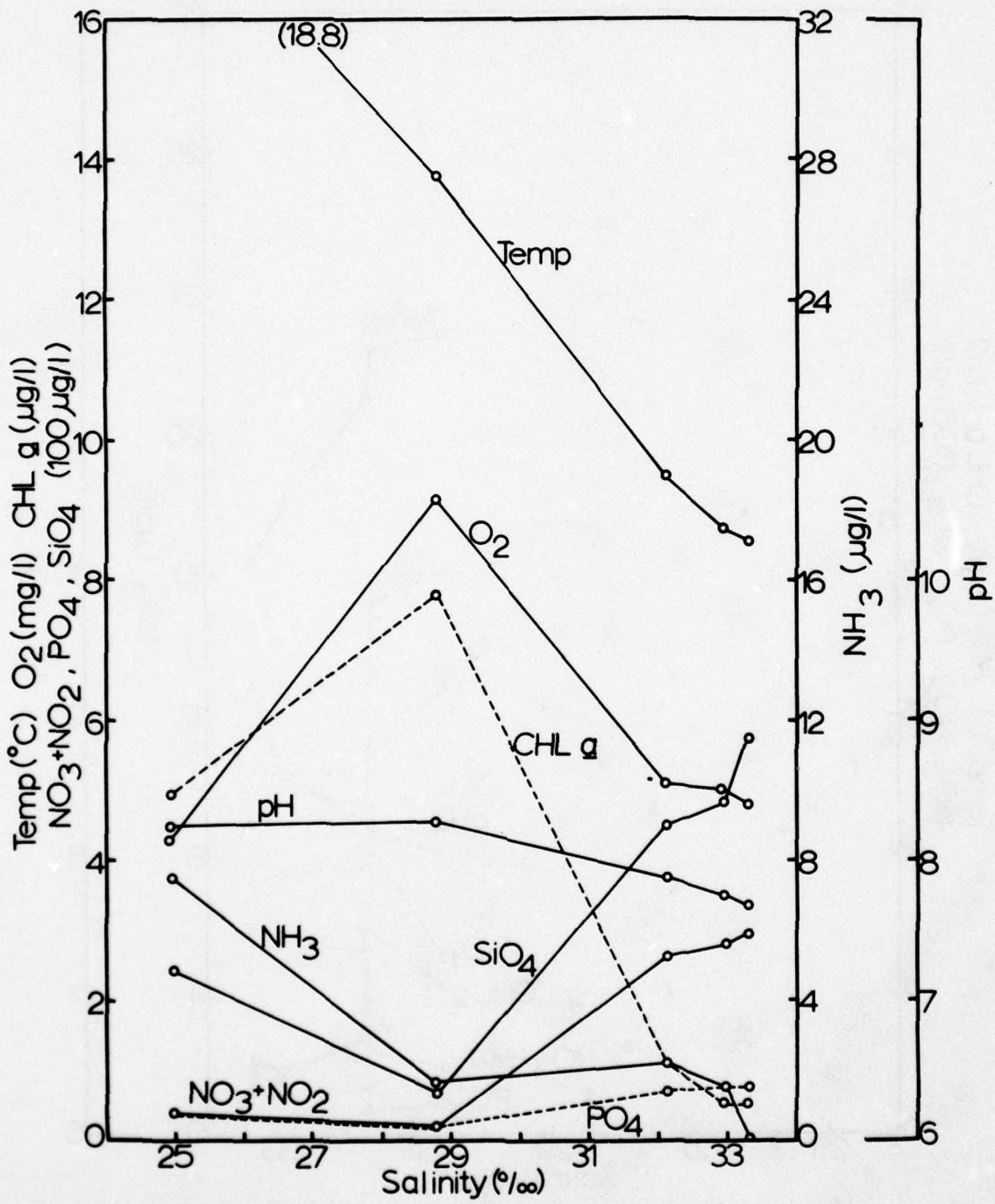


Figure B86. Selected water-column properties measured at station 1, cruise C7409 C-1

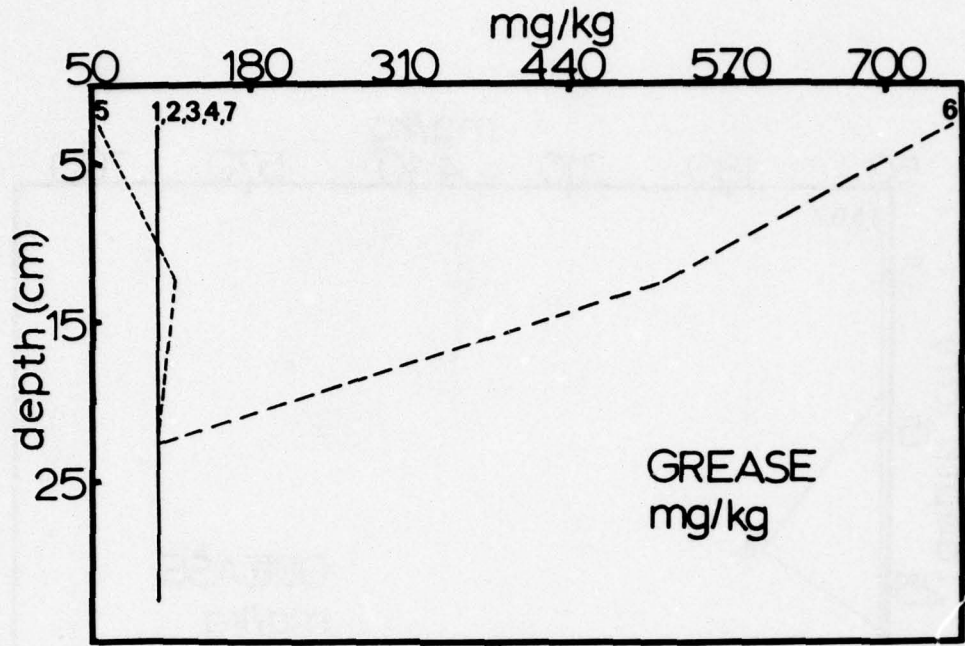


Figure B87. Distribution of grease in sediment cores taken from stations sampled on cruise Y7409 F

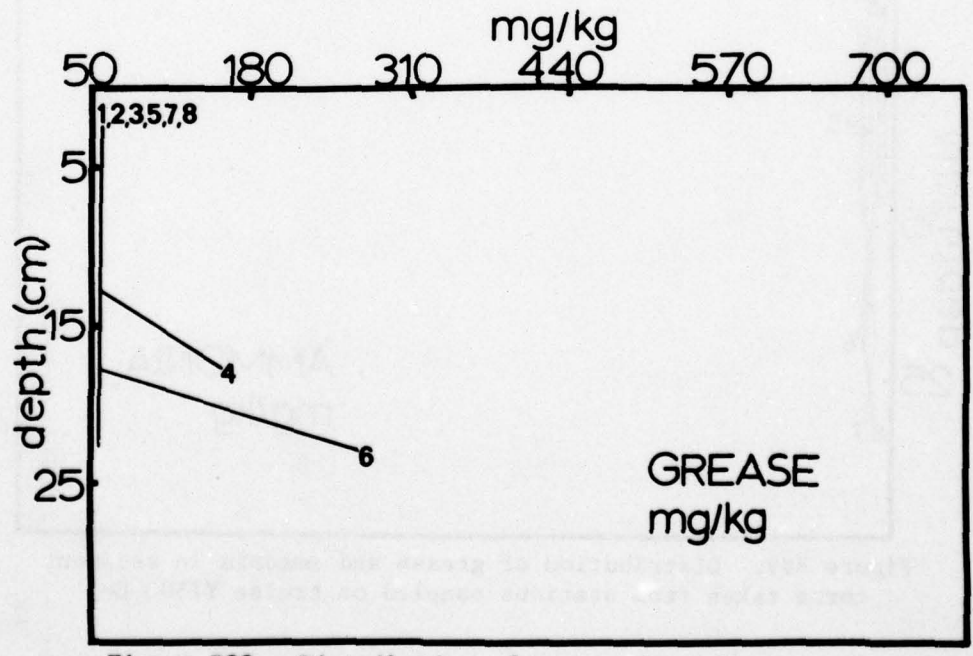


Figure B88. Distribution of grease in sediment cores taken from stations sampled on cruise Y7501 B

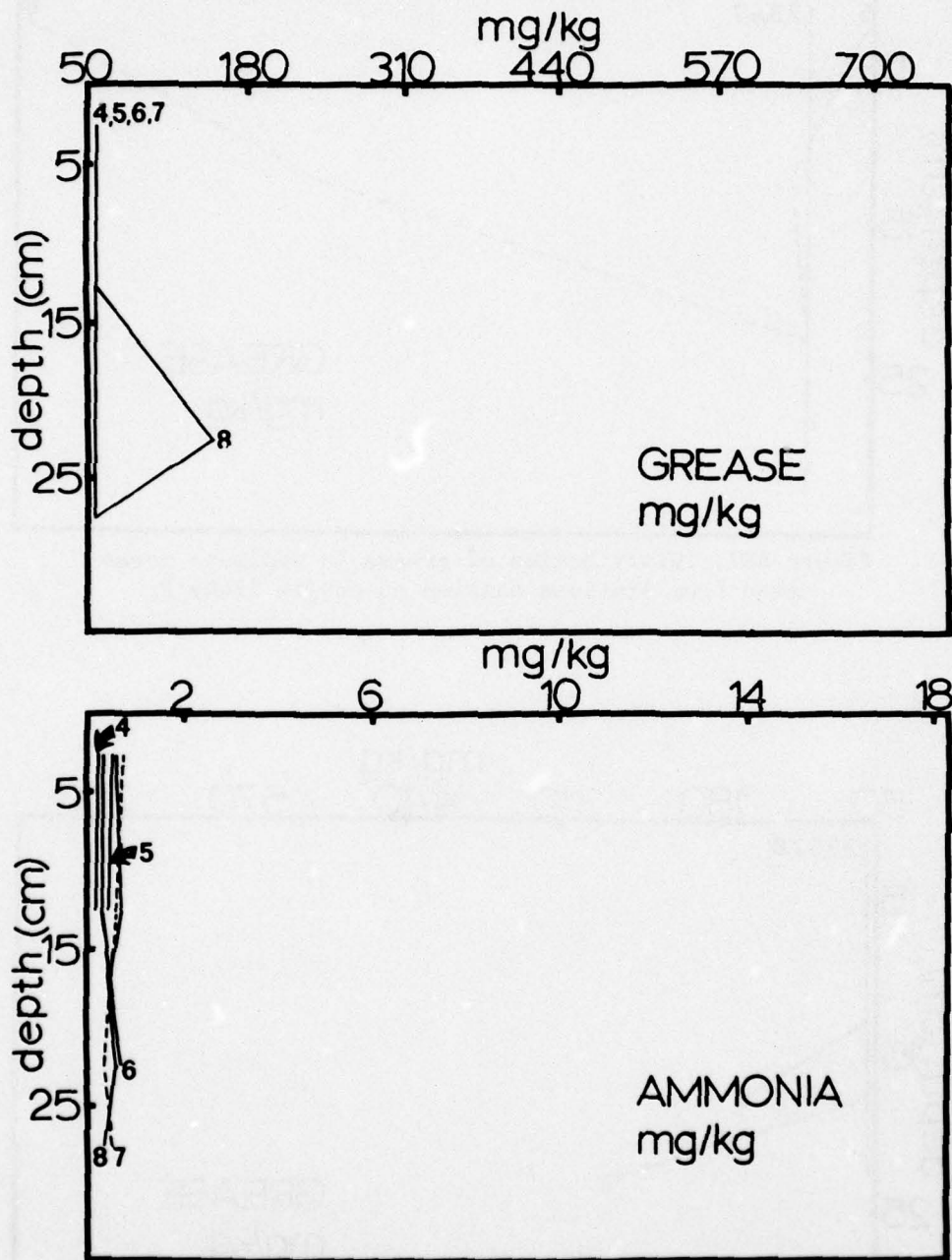


Figure B89. Distribution of grease and ammonia in sediment cores taken from stations sampled on cruise Y7506 B-2

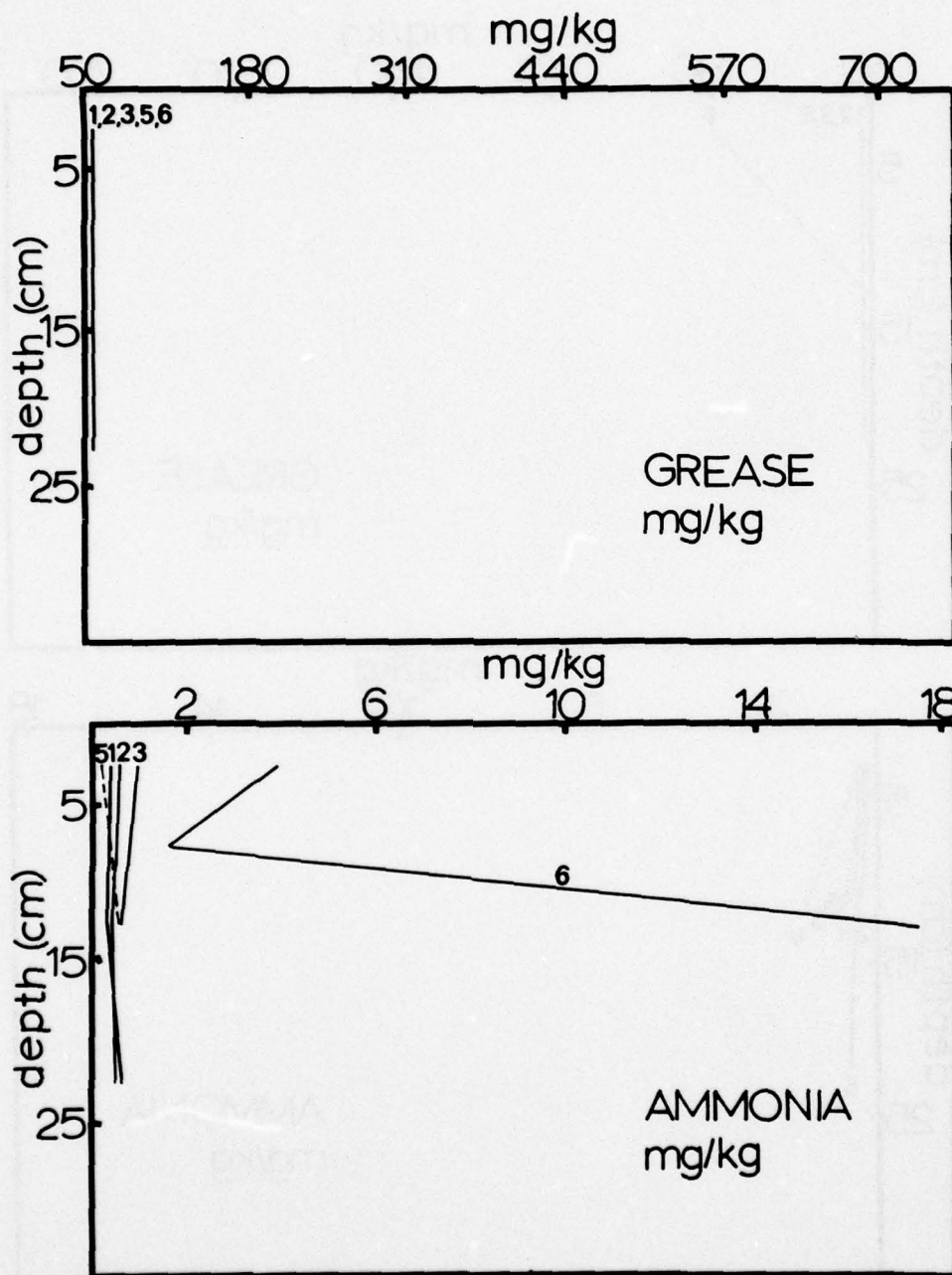


Figure B90. Distribution of grease and ammonia in sediment cores taken from stations sampled on cruise Y7508 D-2

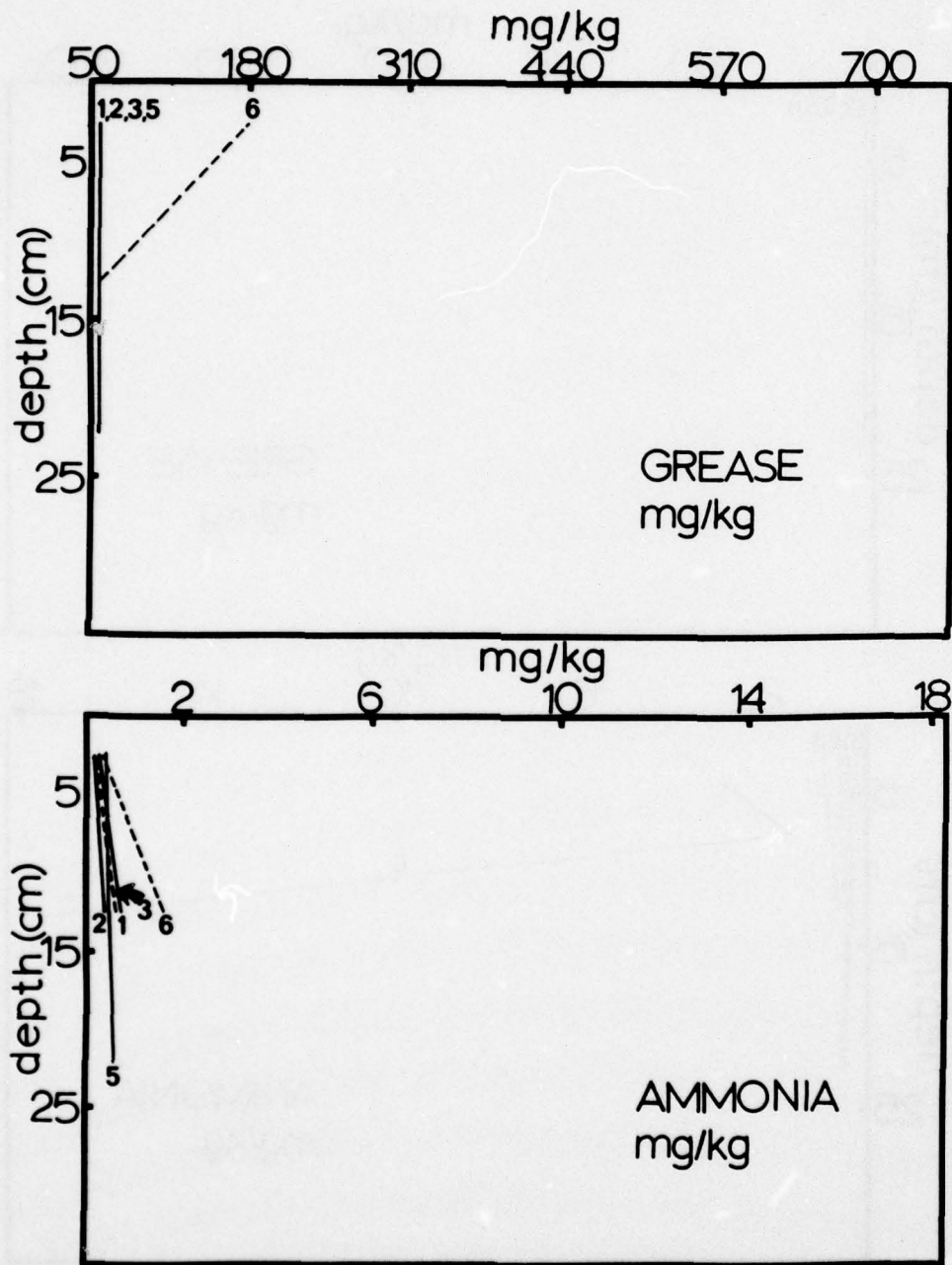


Figure B91. Distribution of grease and ammonia in sediment cores taken from stations sampled on cruise Y7510 C-1

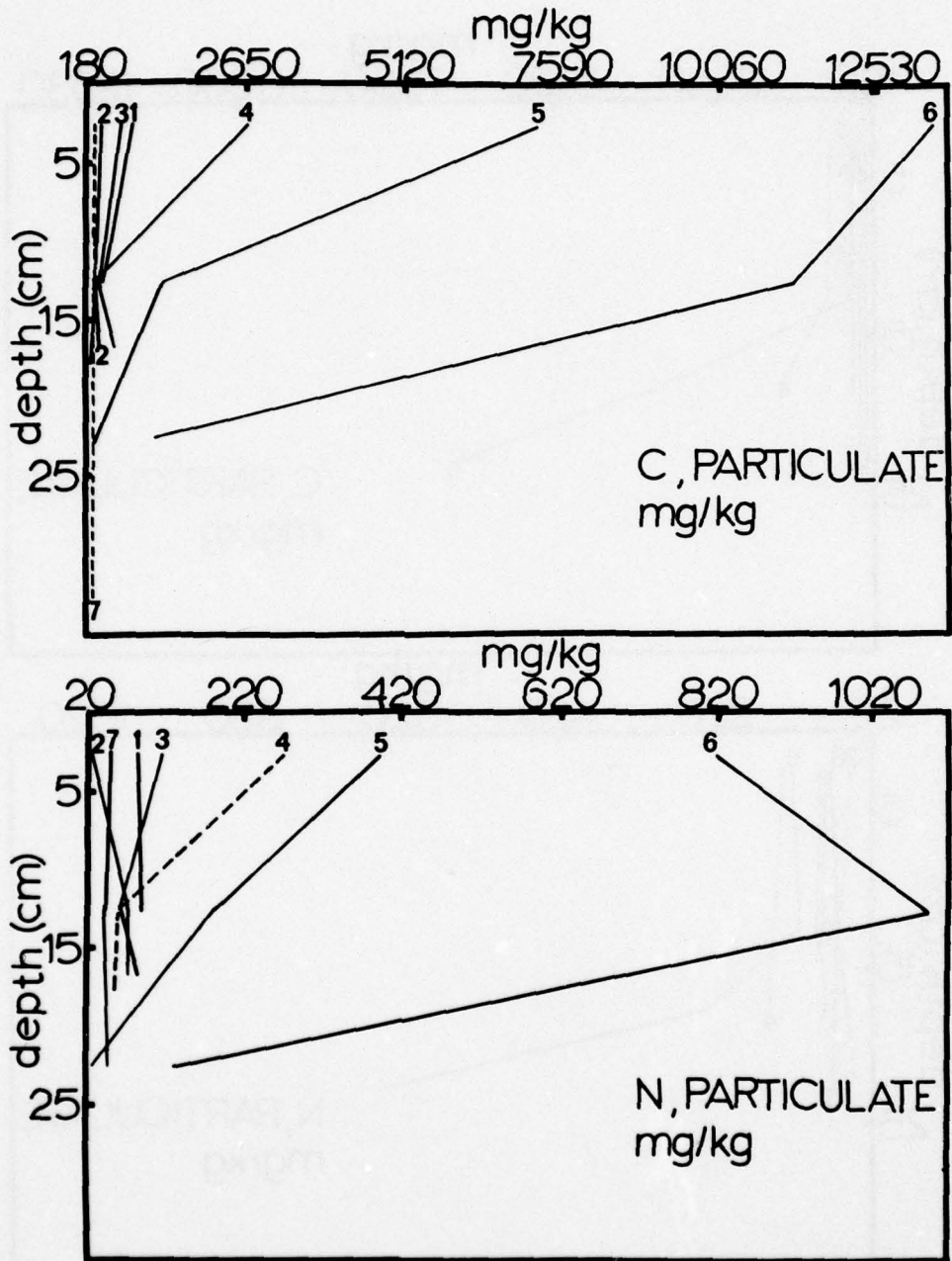


Figure B92. Distribution of particulate carbon and nitrogen in sediment cores taken from stations sampled on cruise Y7409 F

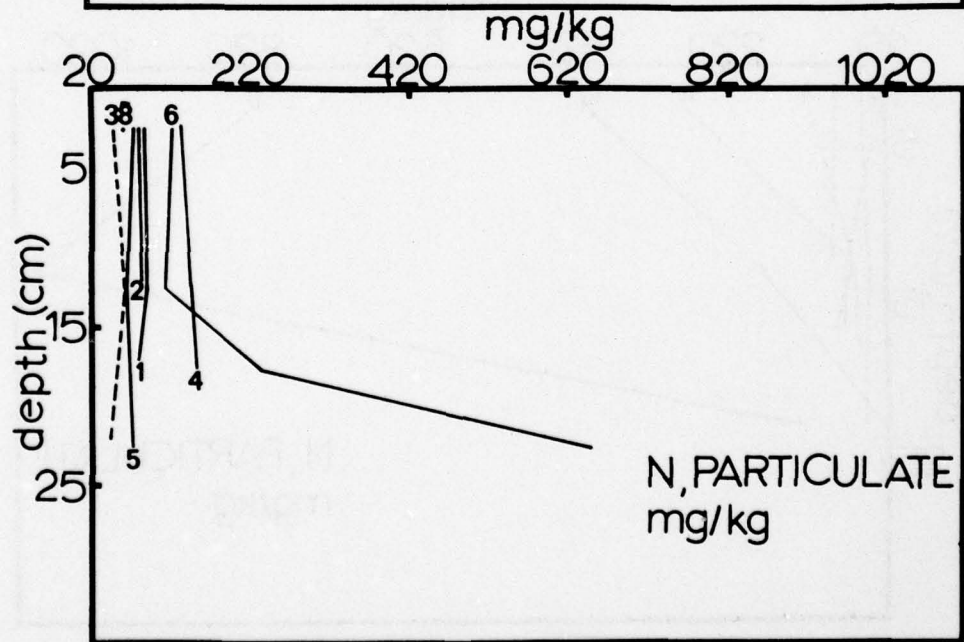
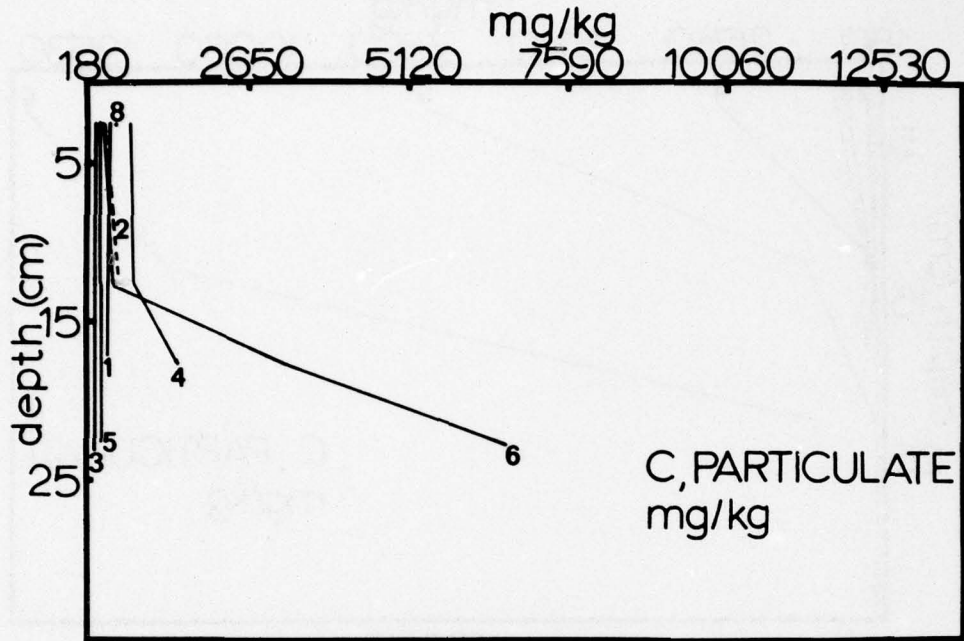


Figure B93. Distribution of particulate carbon and nitrogen in sediment cores taken from stations sampled on cruise Y7501 B

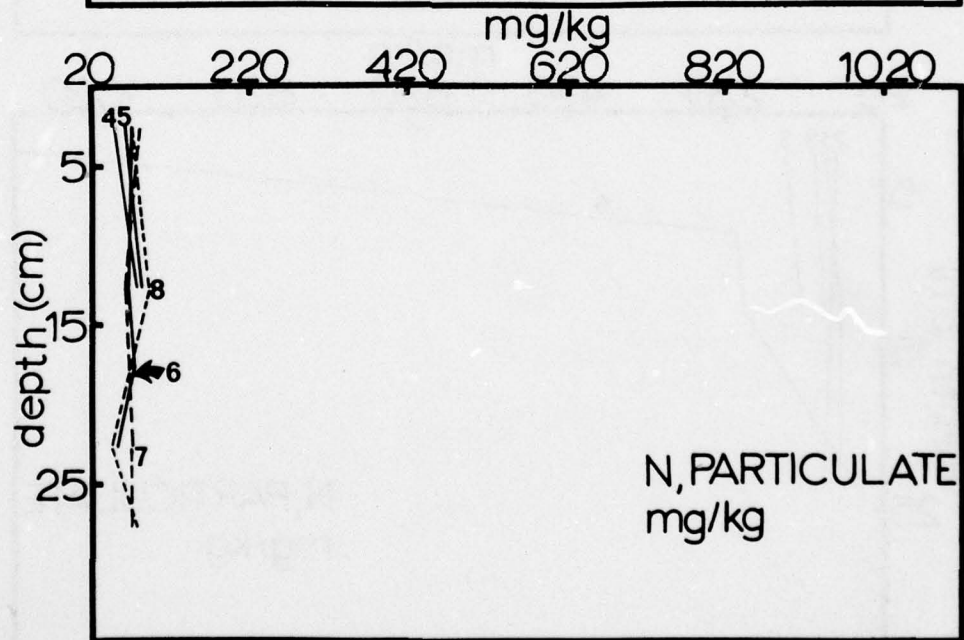
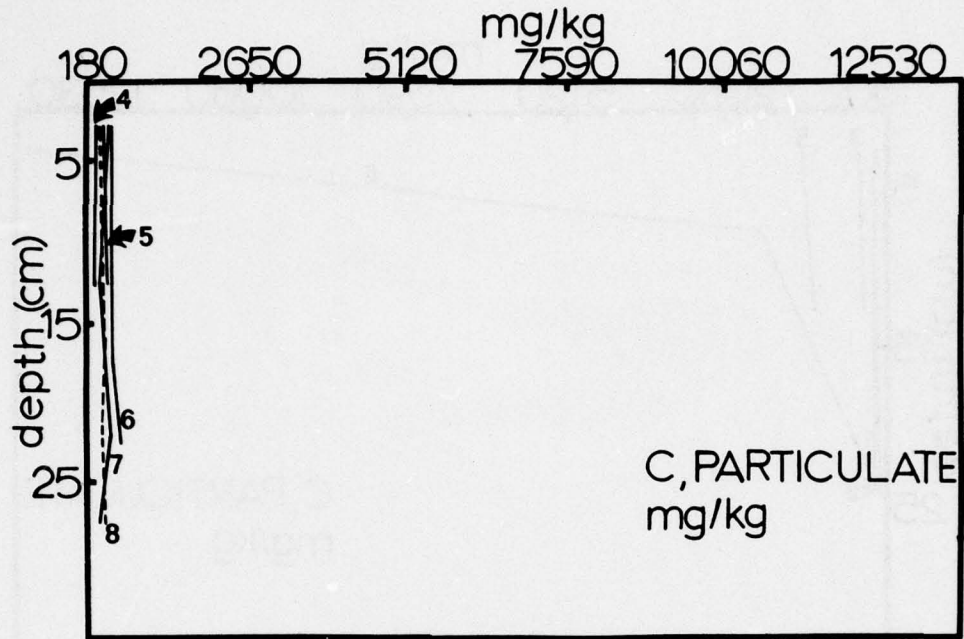


Figure B94. Distribution of particulate carbon and nitrogen in sediment cores taken from stations sampled on cruise Y7506 B-2

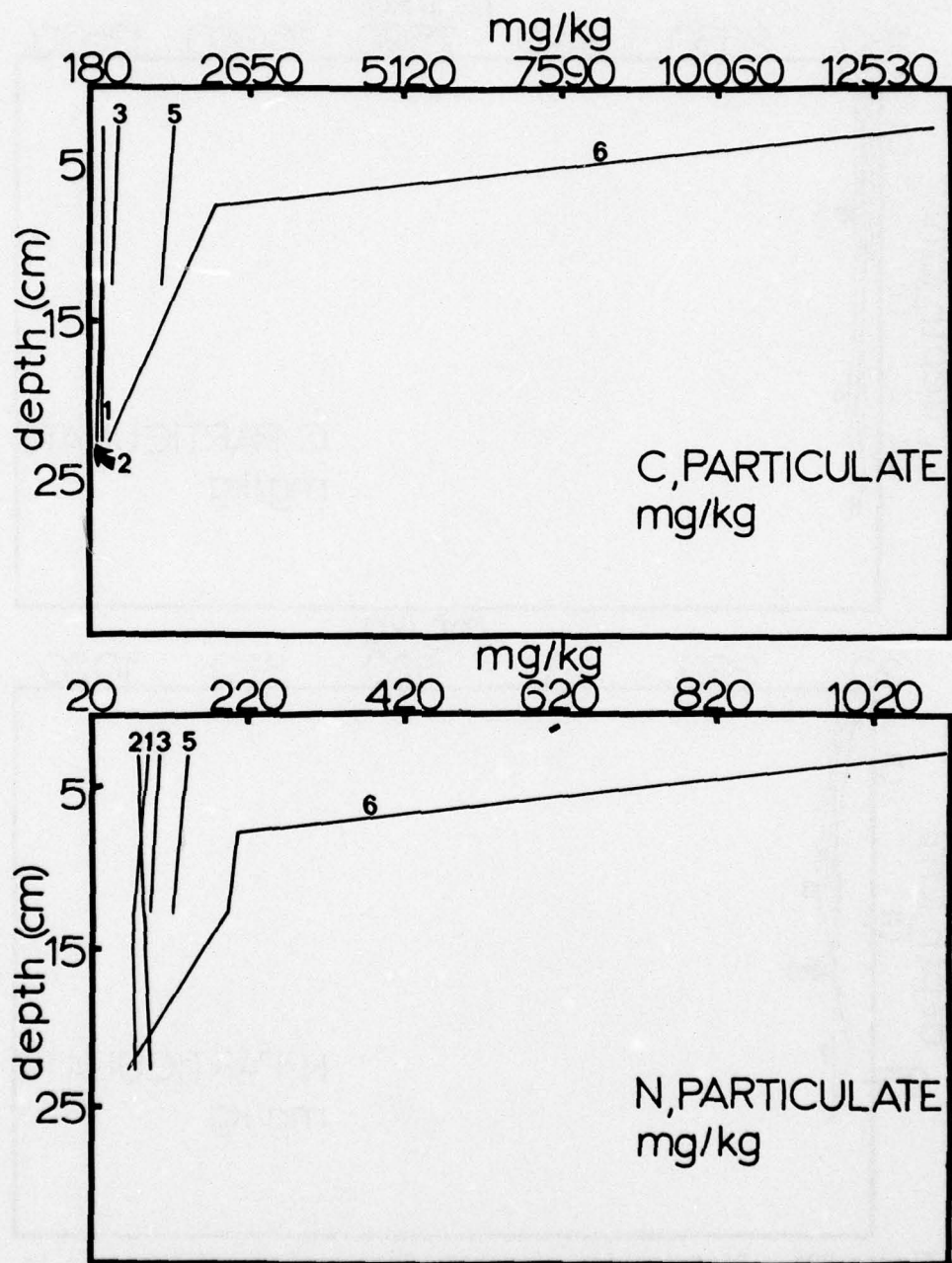


Figure B95. Distribution of particulate carbon and nitrogen in sediment cores taken from stations sampled on cruise Y7508 D-2

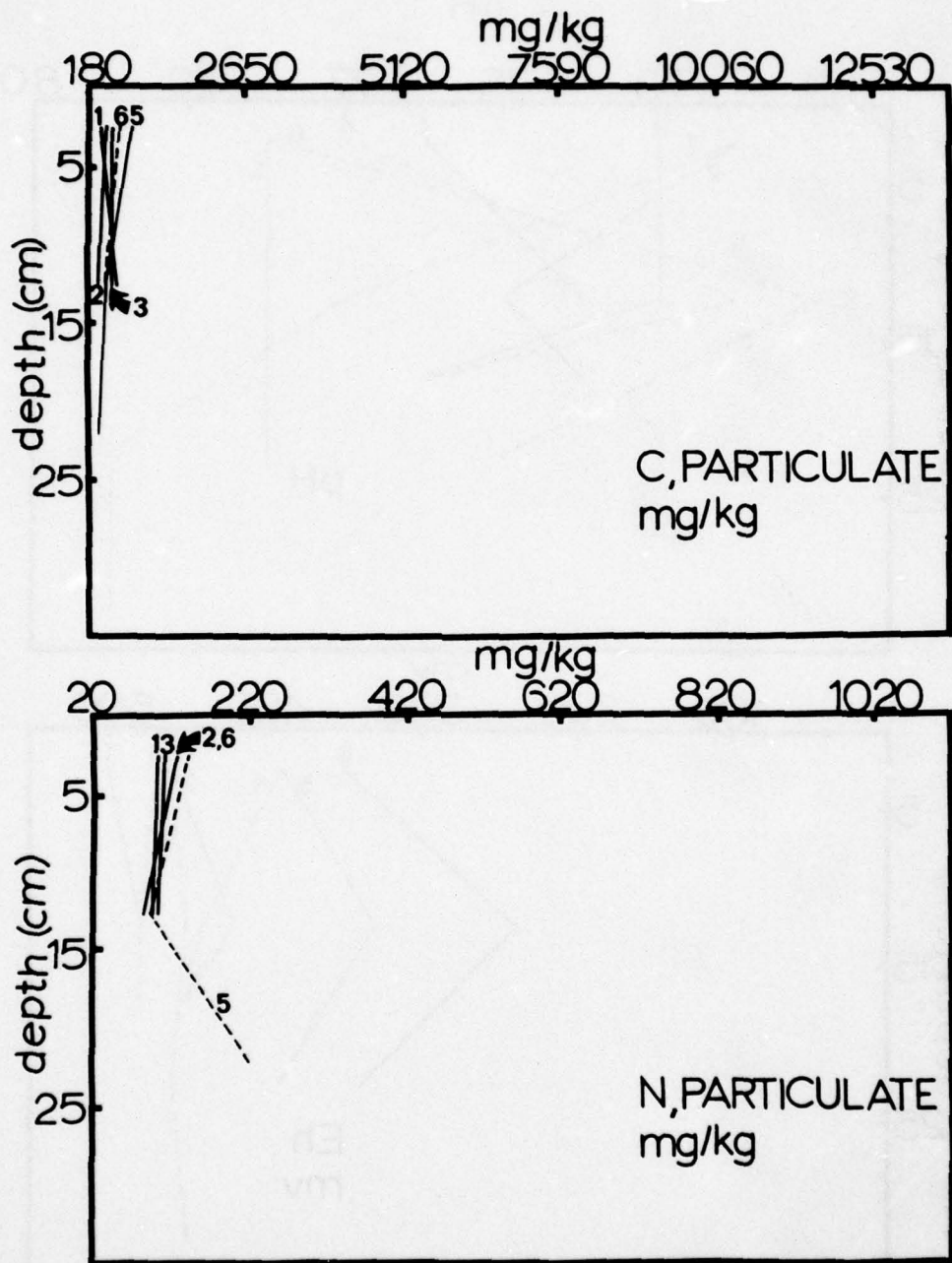


Figure B96. Distribution of particulate carbon and nitrogen in sediment cores taken from stations sampled on cruise Y7501 C-1

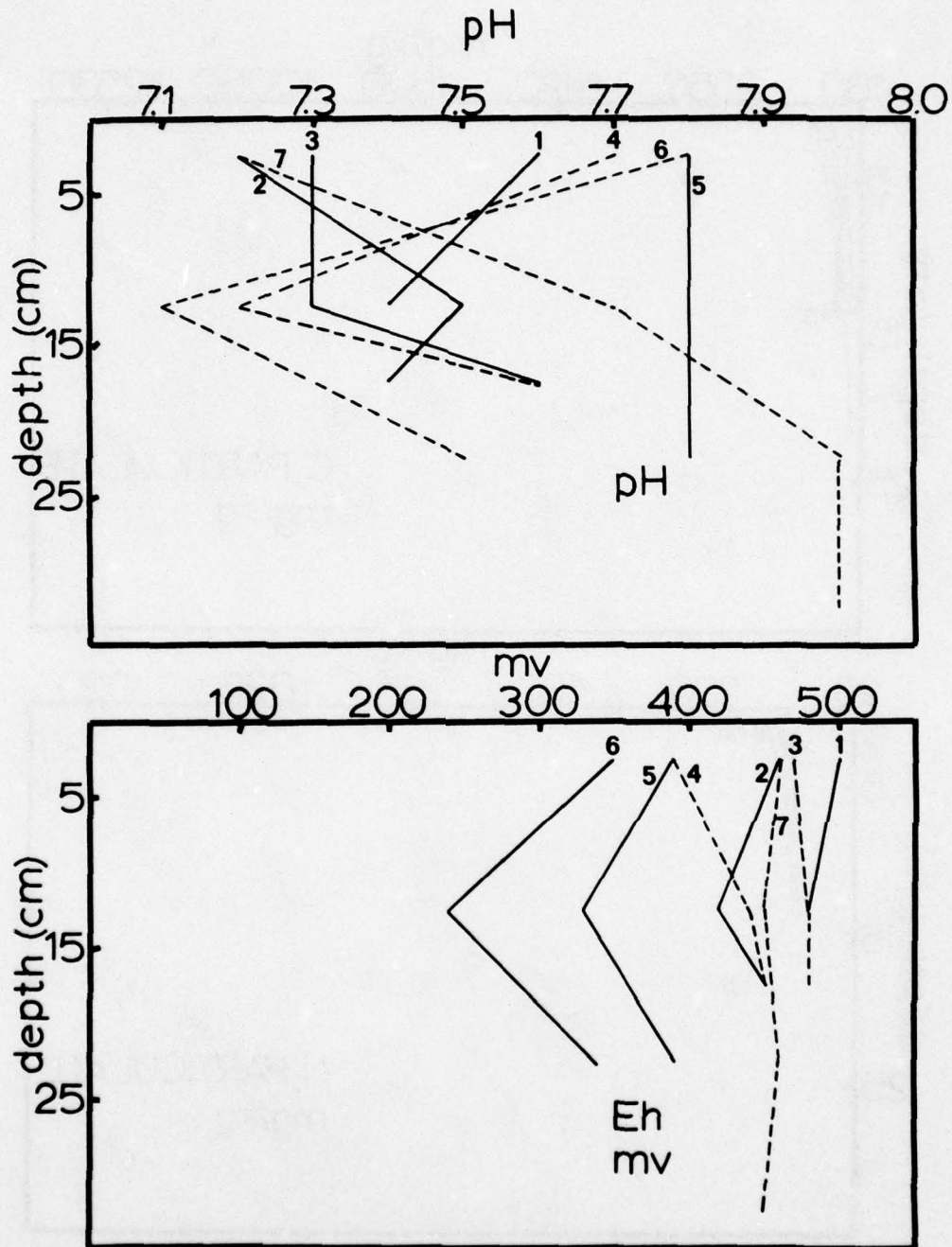


Figure B97. Distribution of pH and Eh in sediment cores taken from stations sampled on cruise Y7409 F

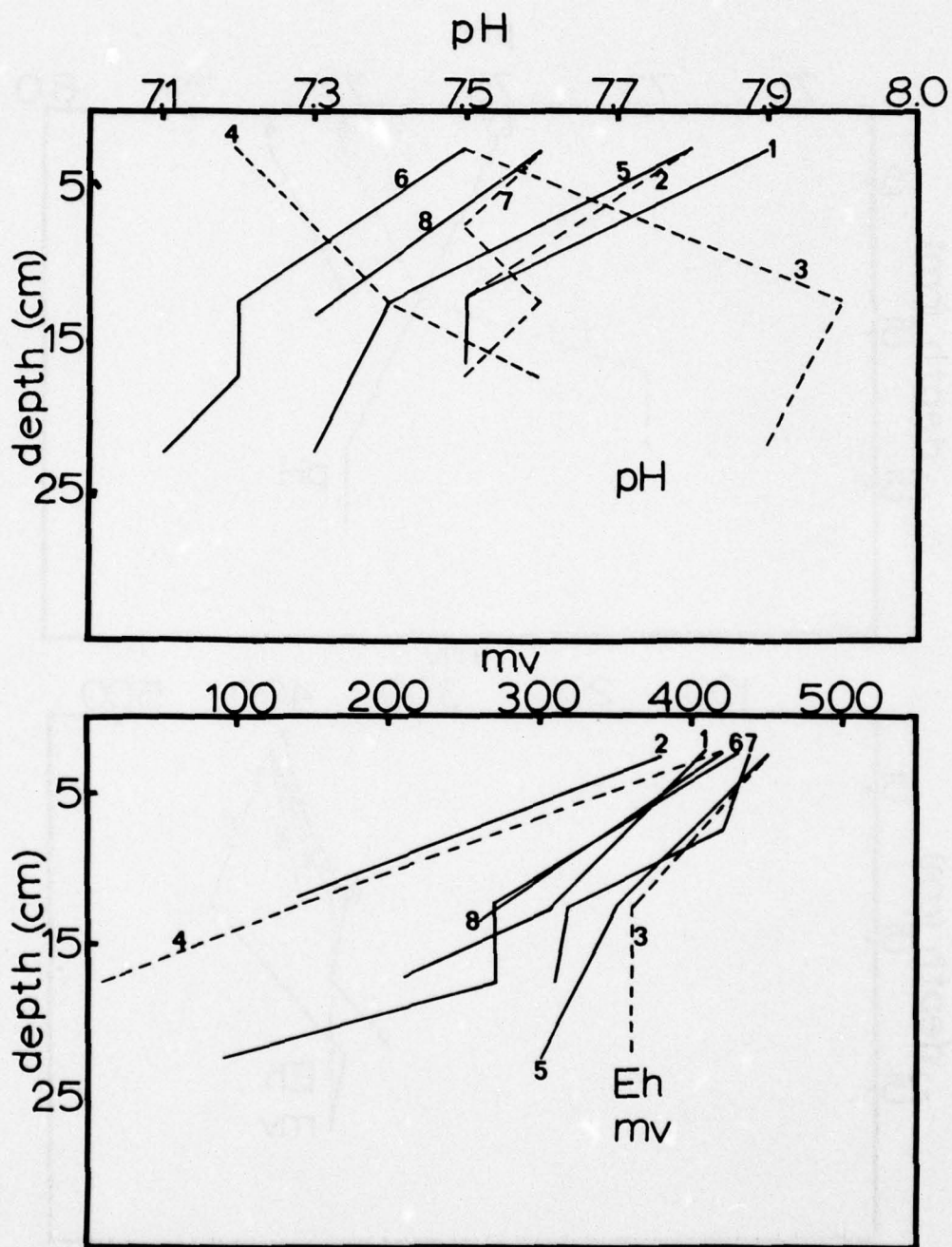


Figure B98. Distribution of pH and Eh in sediment cores taken from stations sampled on cruise Y7501 B

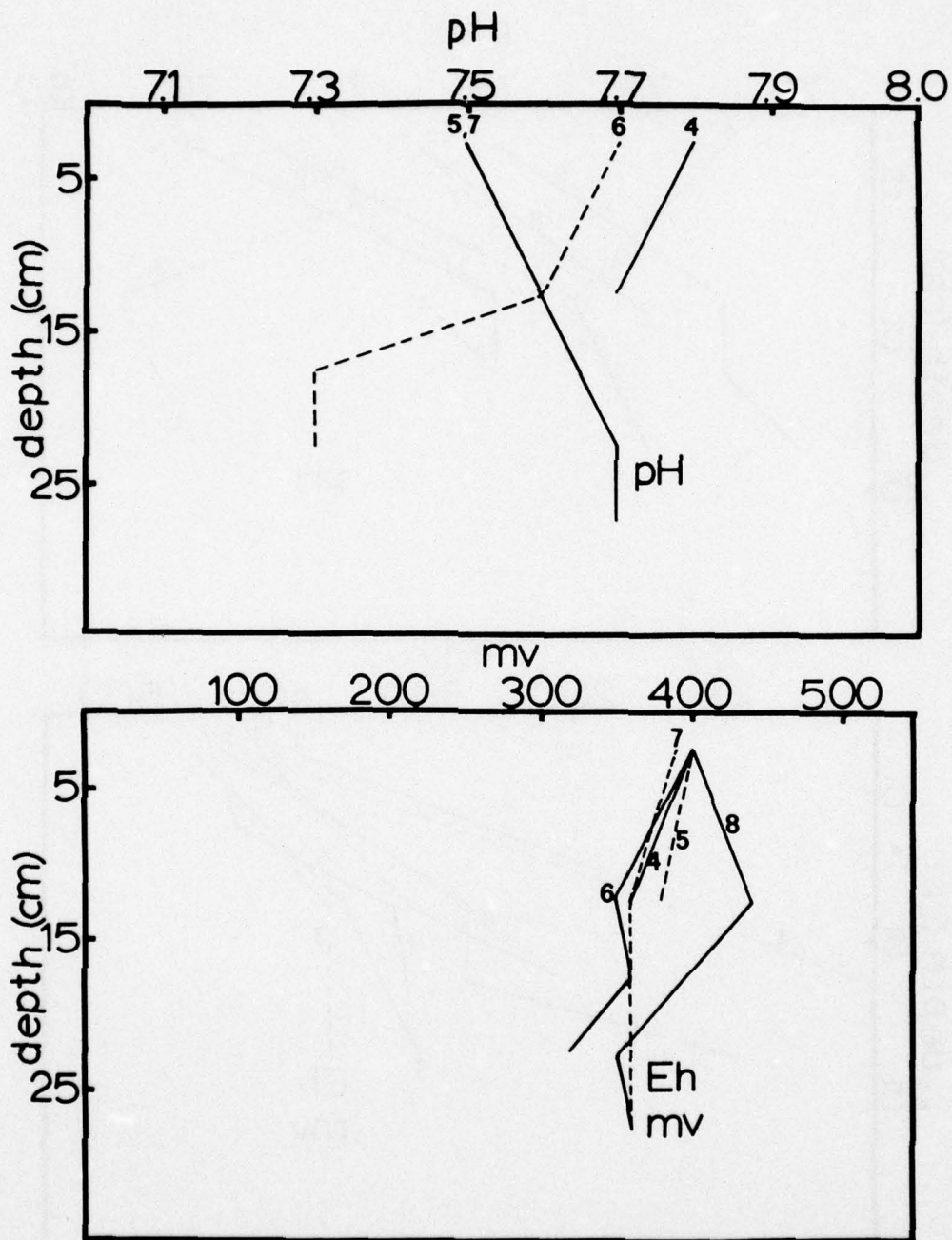


Figure B99. Distributuion of pH and Eh in sediment cores taken from stations sampled on cruise Y7506 B-2

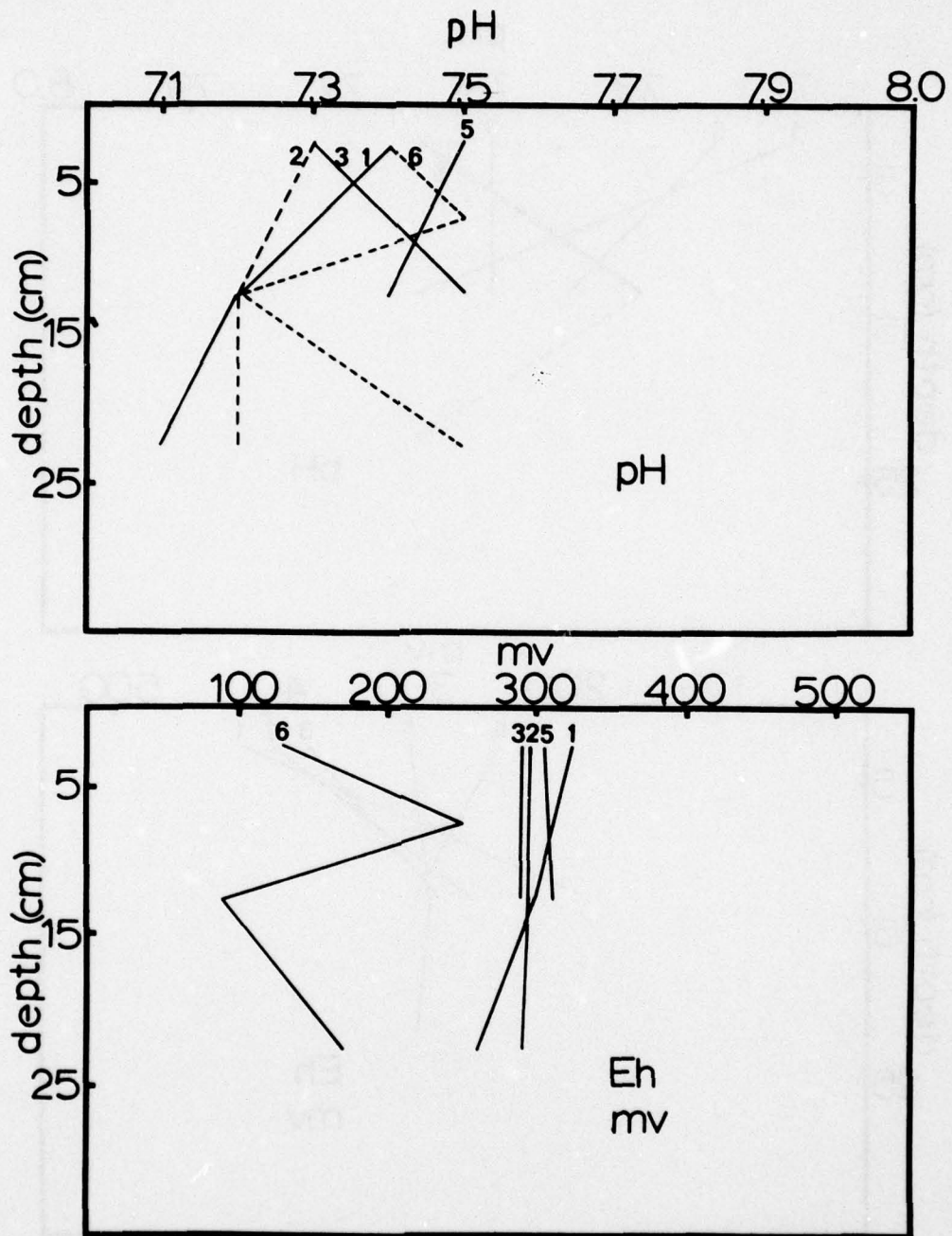


Figure B100. Distribution of pH and Eh in sediment cores taken from stations sampled on cruise Y7508 D-2

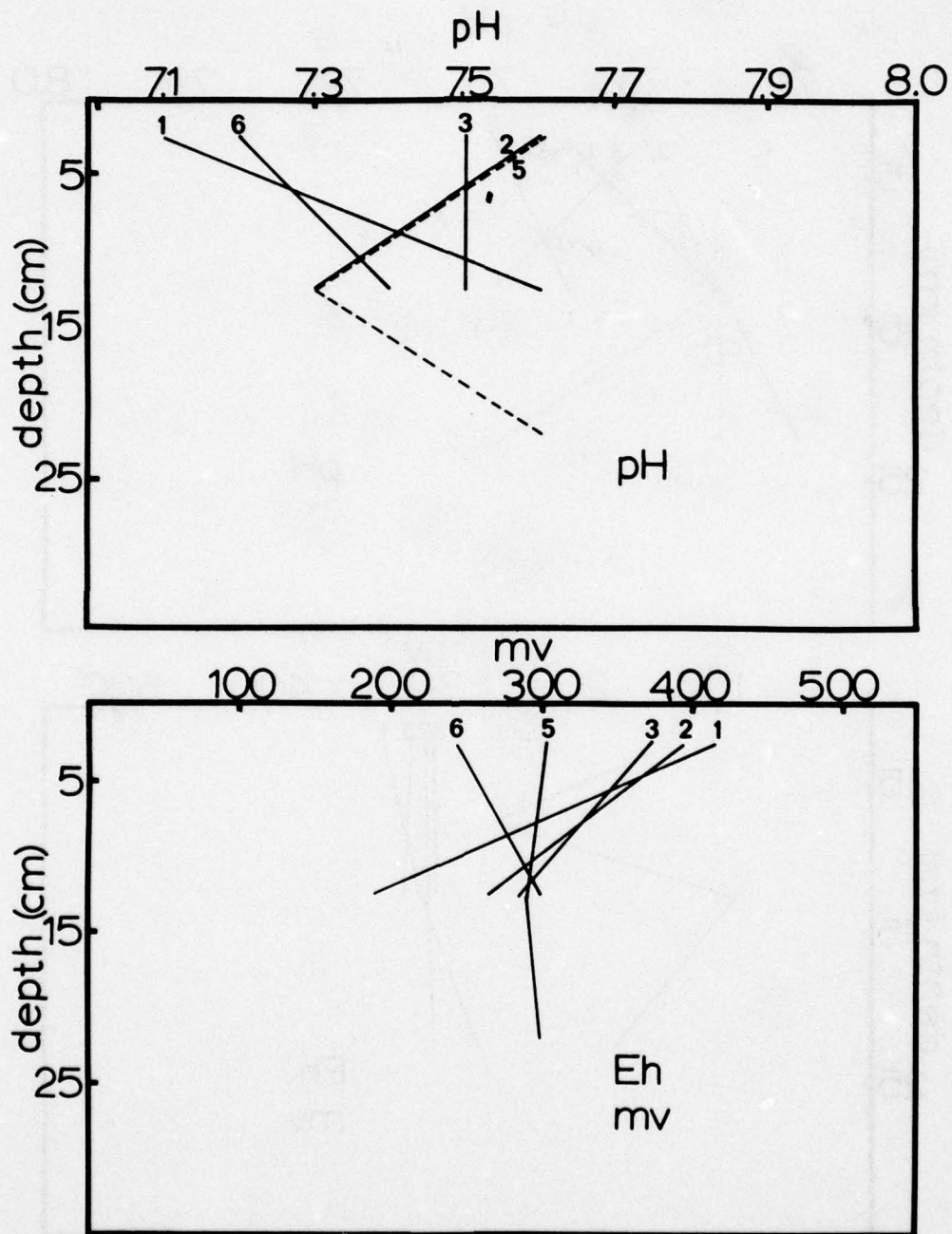


Figure B101. Distribution of pH and Eh in sediment cores taken from stations sampled on cruise Y7510 C-1

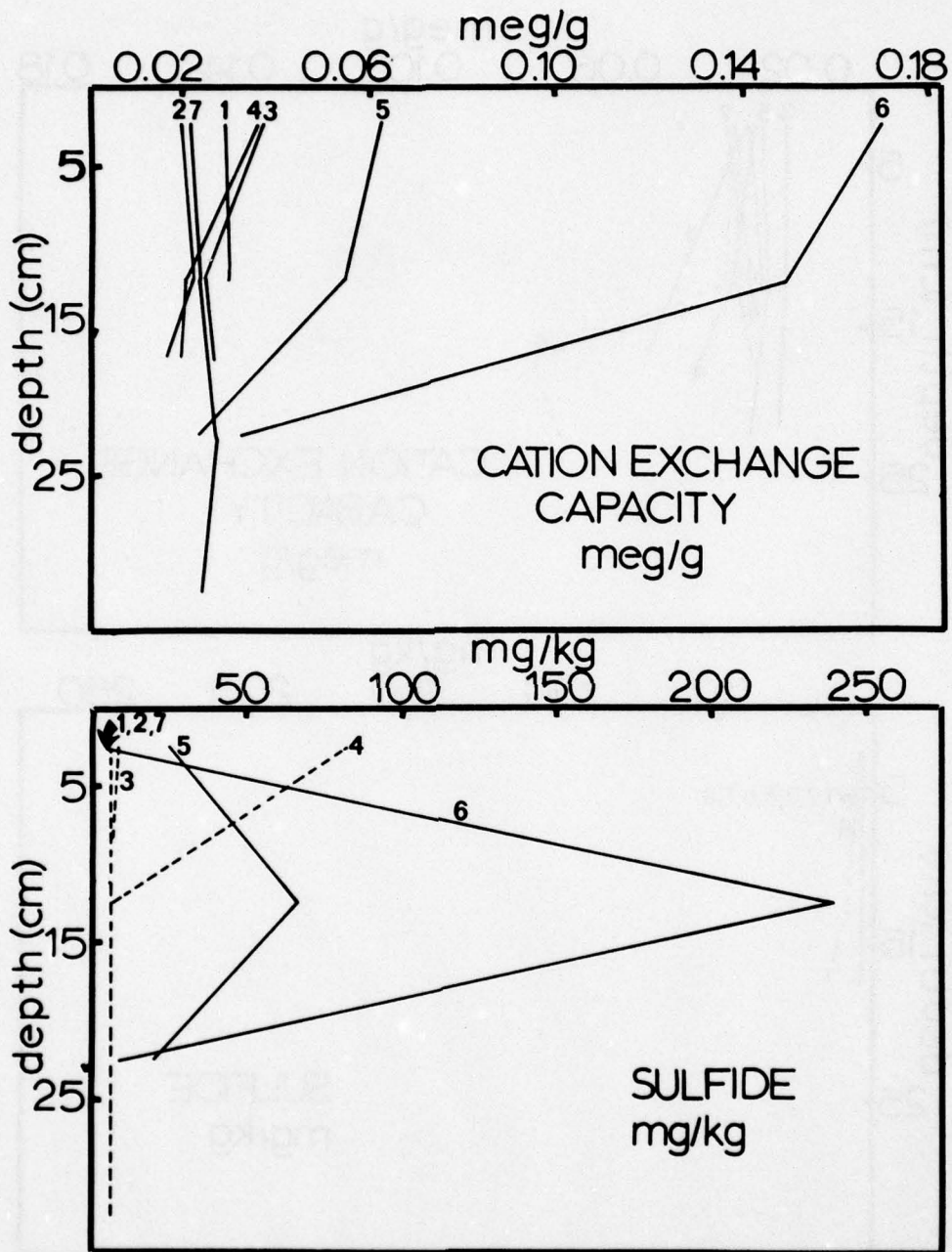


Figure B102. Distribution of cation exchange capacity and sulfide in sediment cores taken from stations sampled on cruise Y7409 F

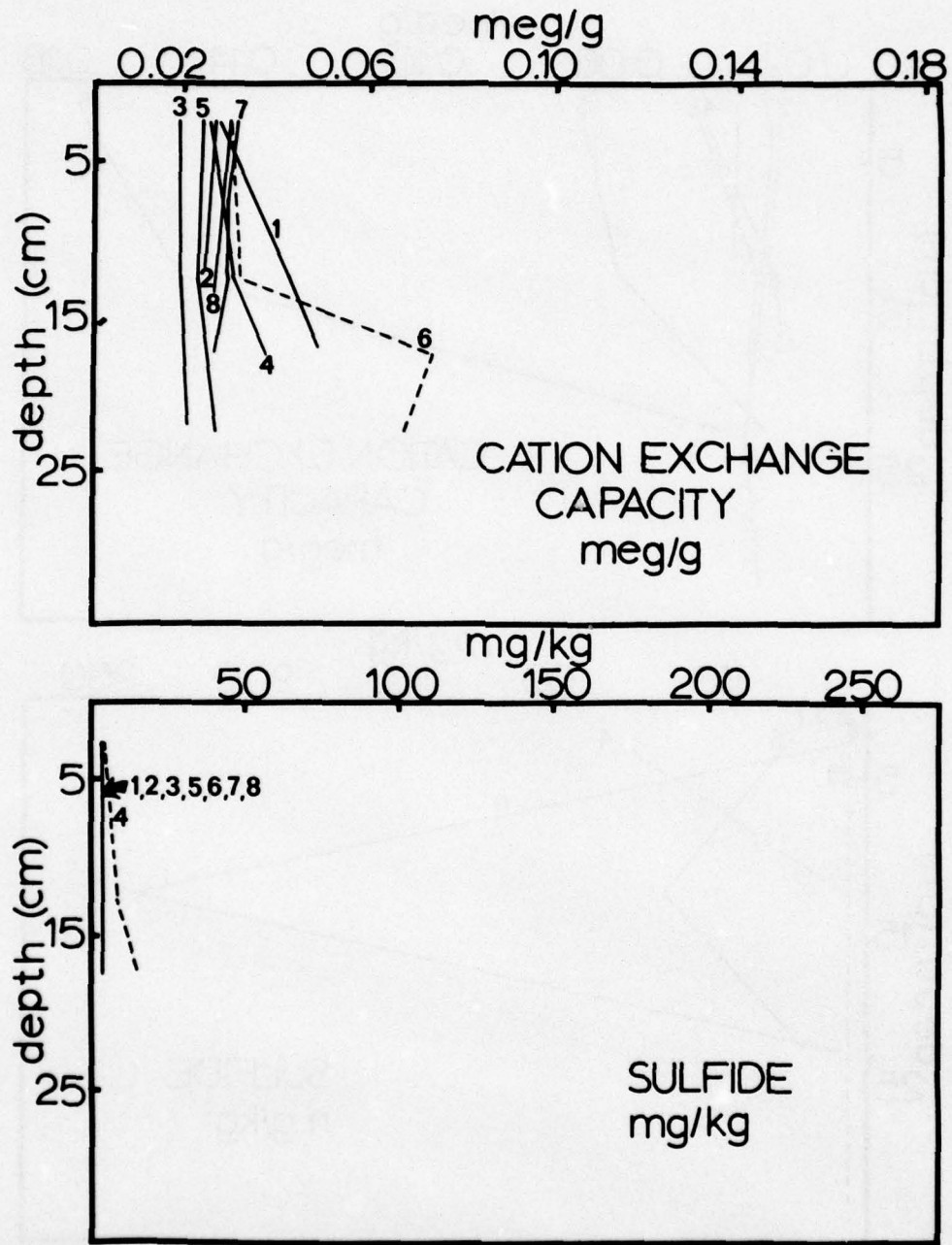


Figure B103. Distribution of cation exchange capacity and sulfide in sediment cores taken from stations sampled on cruise Y7501 B

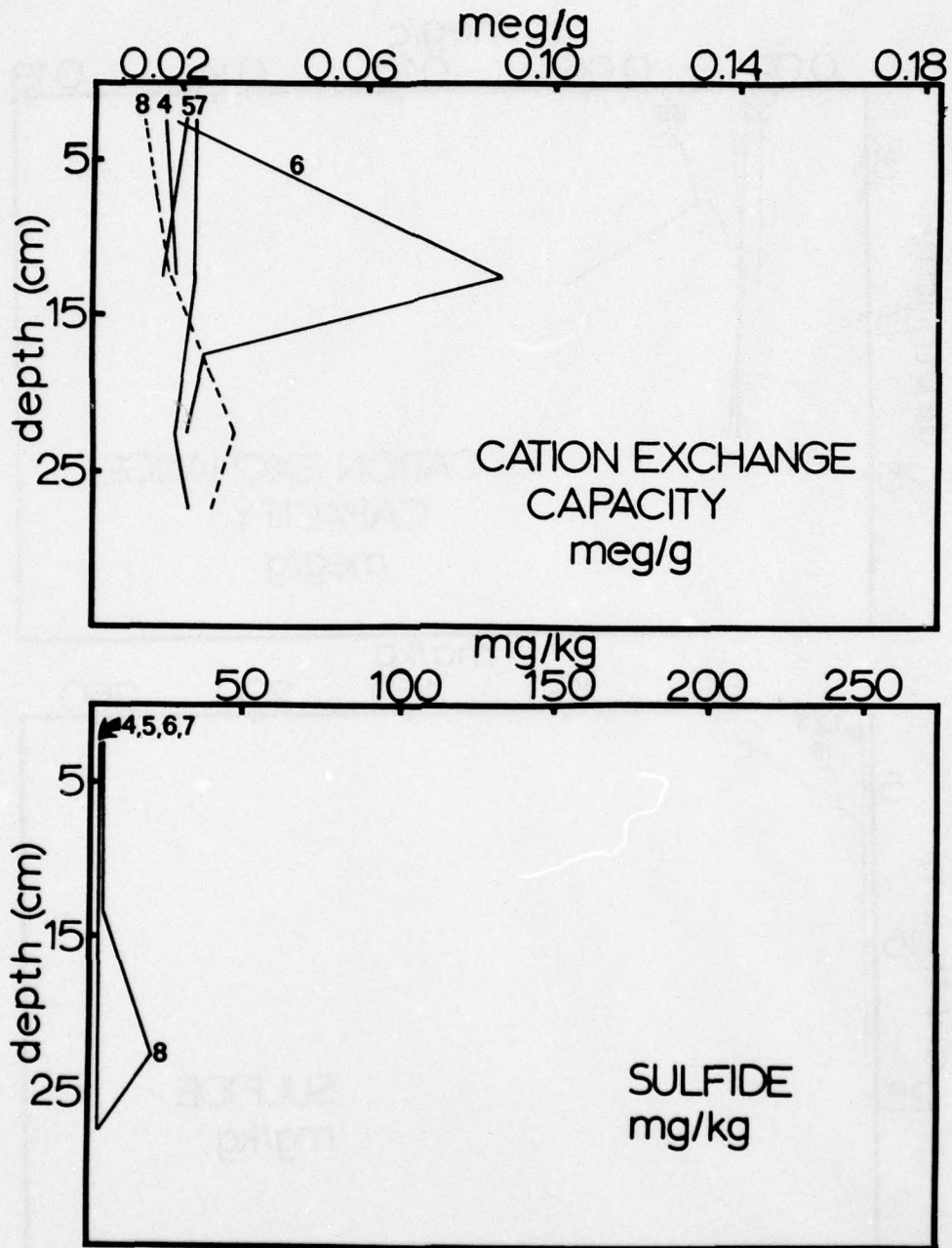


Figure B104. Distribution of cation exchange capacity and sulfide in sediment cores taken from stations sampled on cruise Y7506 B-2

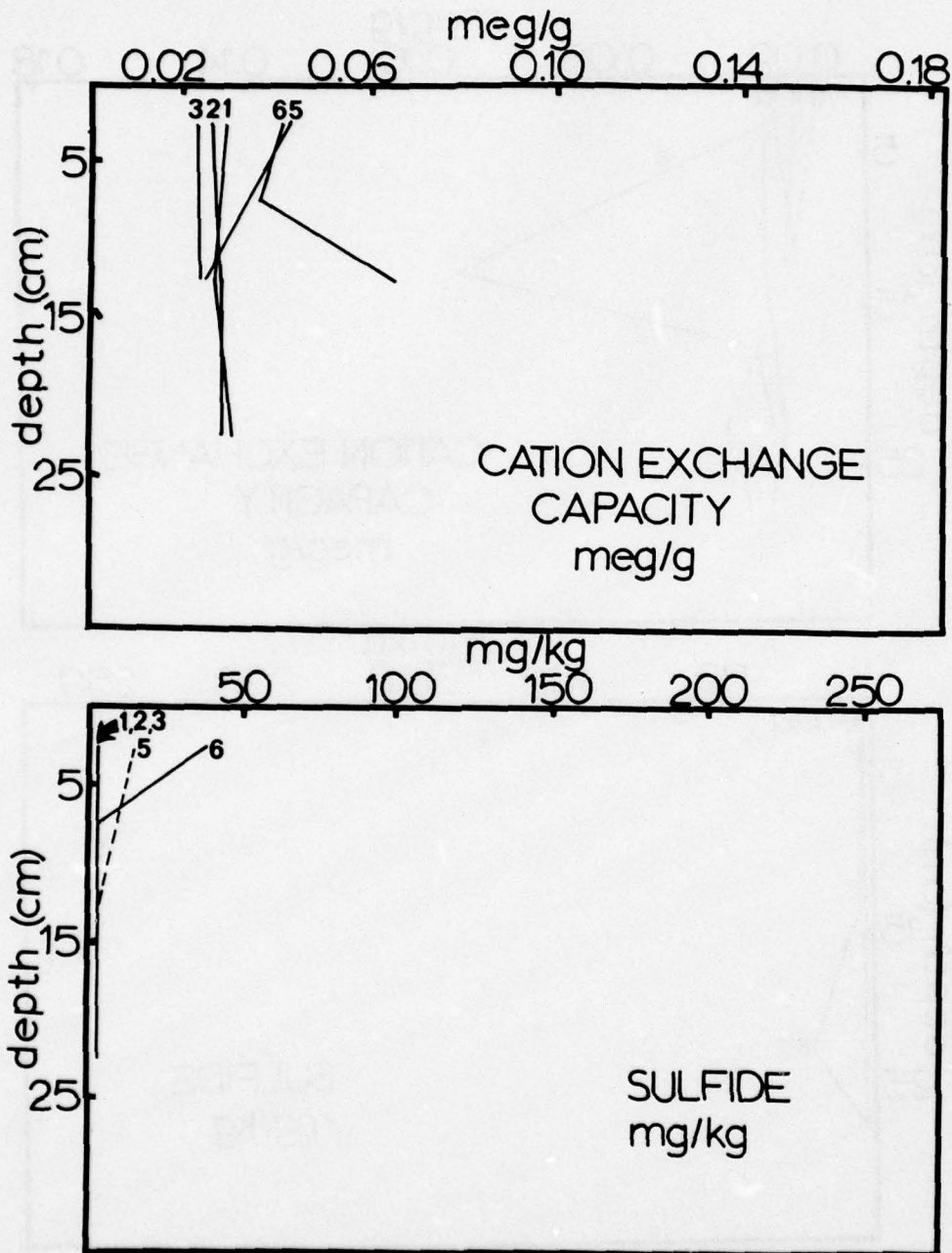


Figure B105. Distribution of cation exchange capacity and sulfide in sediment cores taken from stations sampled on cruise Y7508 D-2

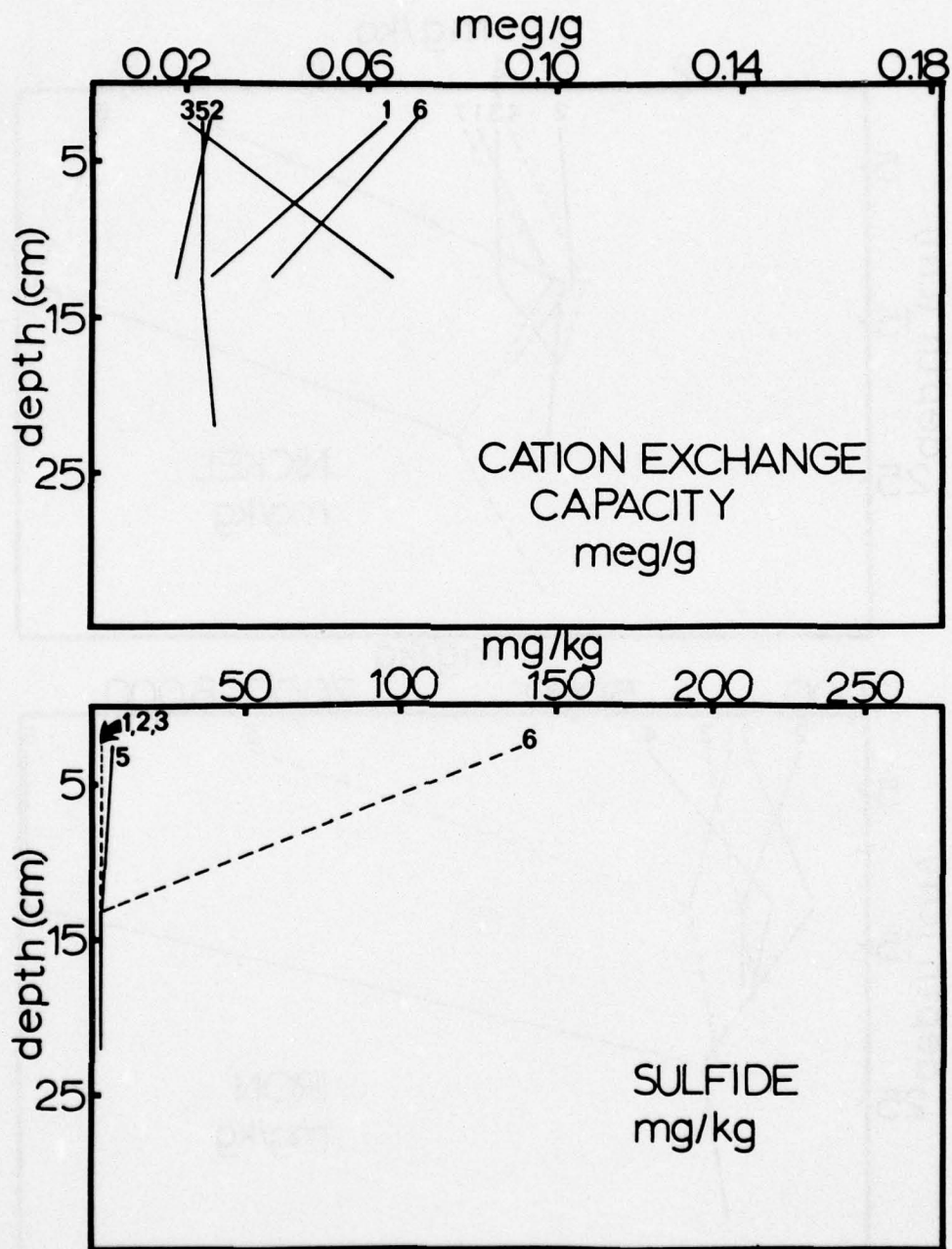


Figure B106. Distribution of cation exchange capacity and sulfide in sediment cores taken from stations sampled on cruise Y7510 C-1

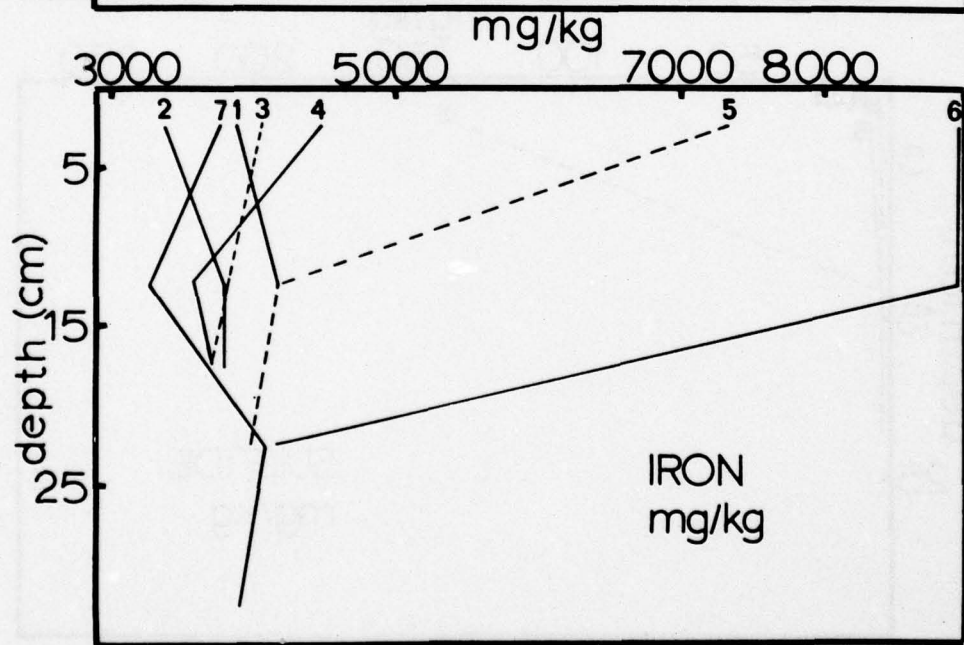
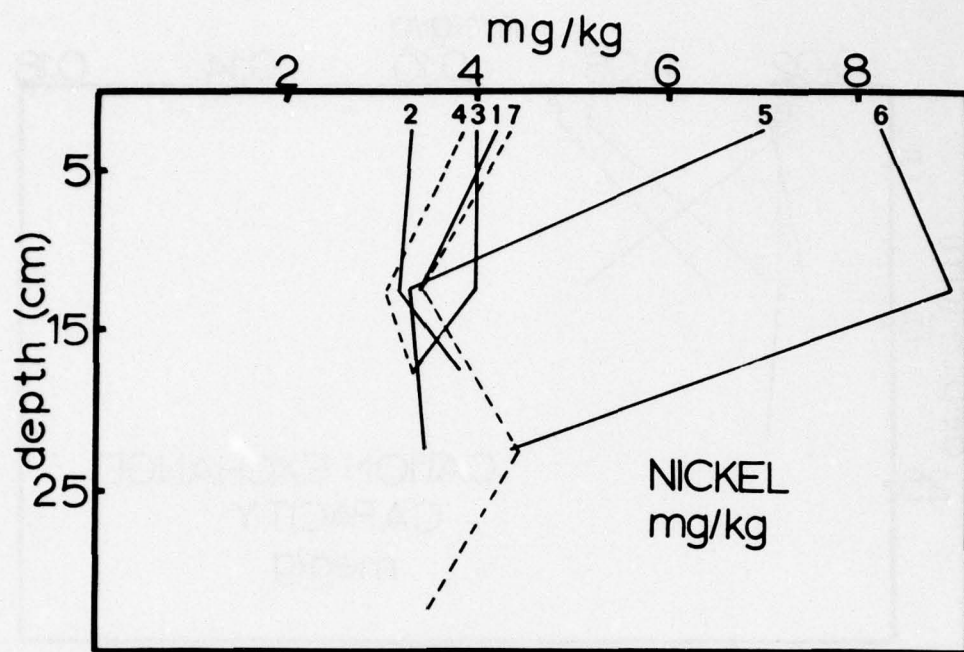


Figure B107. Distribution of nickel and iron in sediment cores taken from stations sampled on cruise Y7409 F

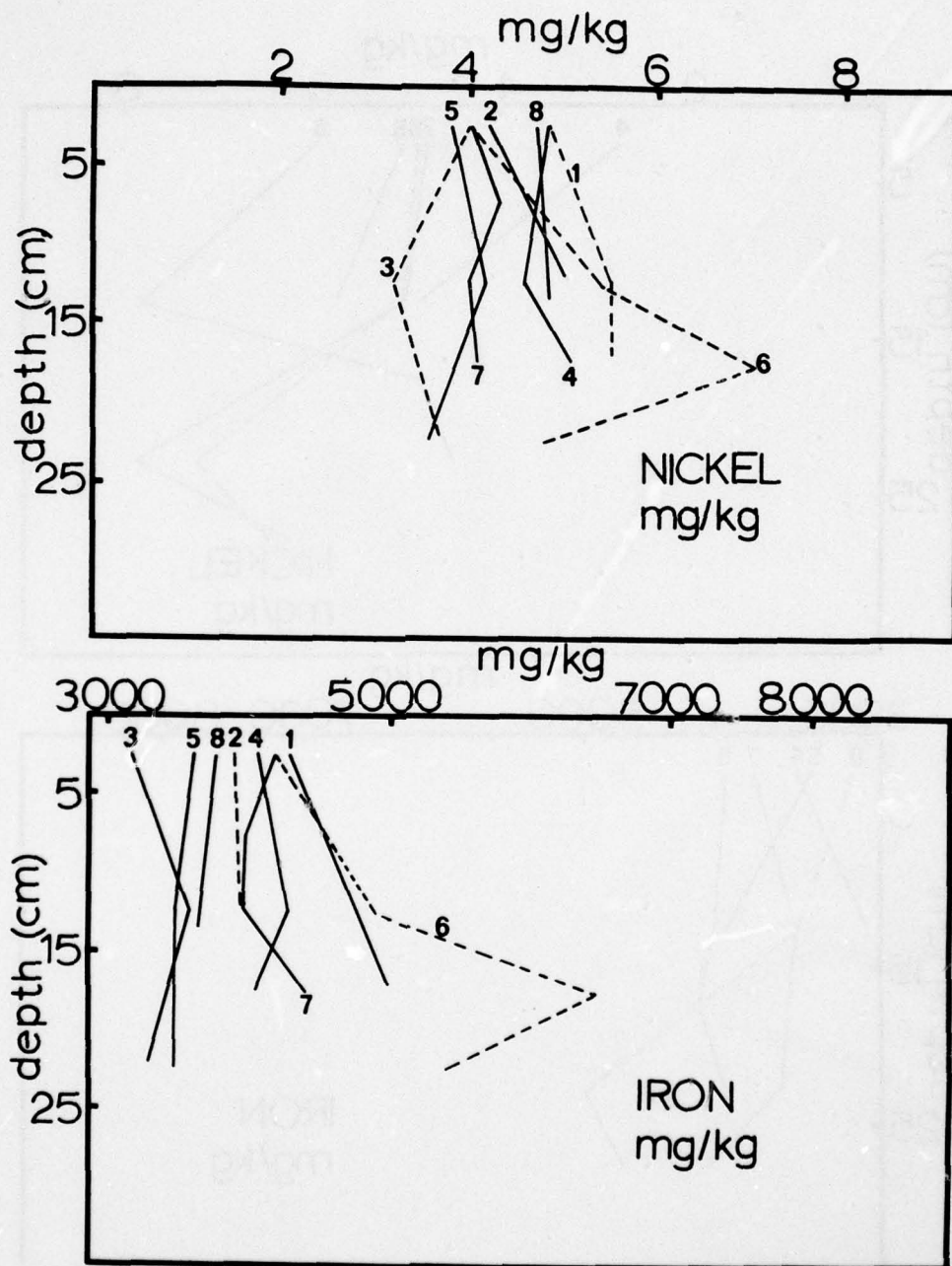


Figure B108. Distribution of nickel and iron in sediment cores taken from stations sampled on cruise Y7501 B

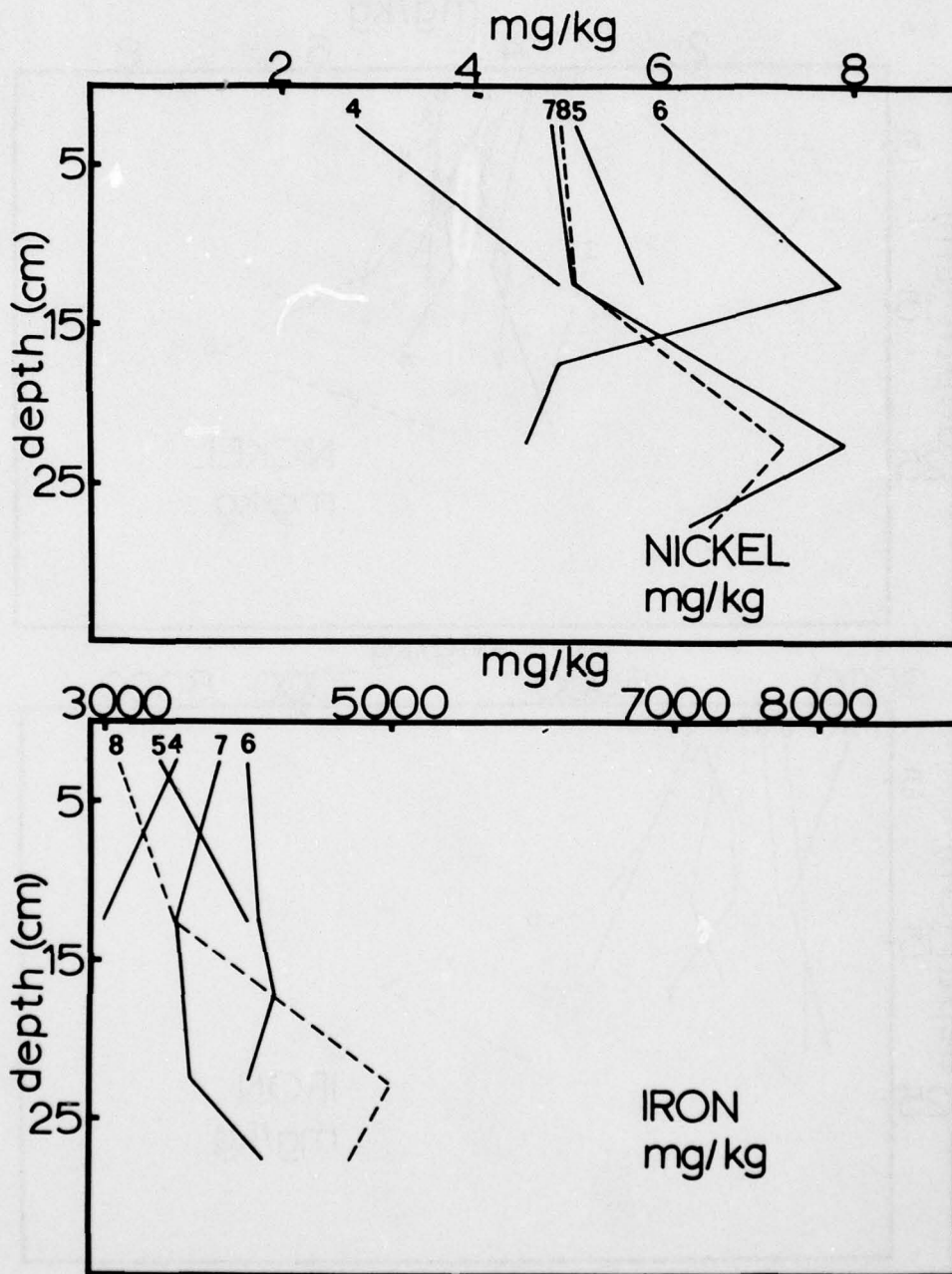


Figure B109. Distribution of nickel and iron in sediment cores taken from stations sampled on cruise Y7506 B-2

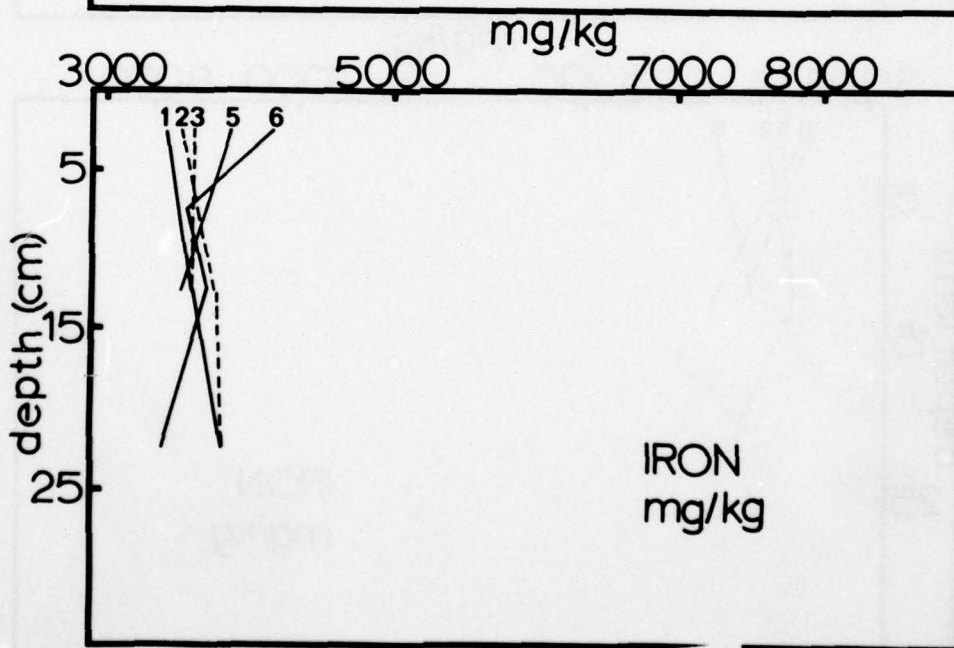
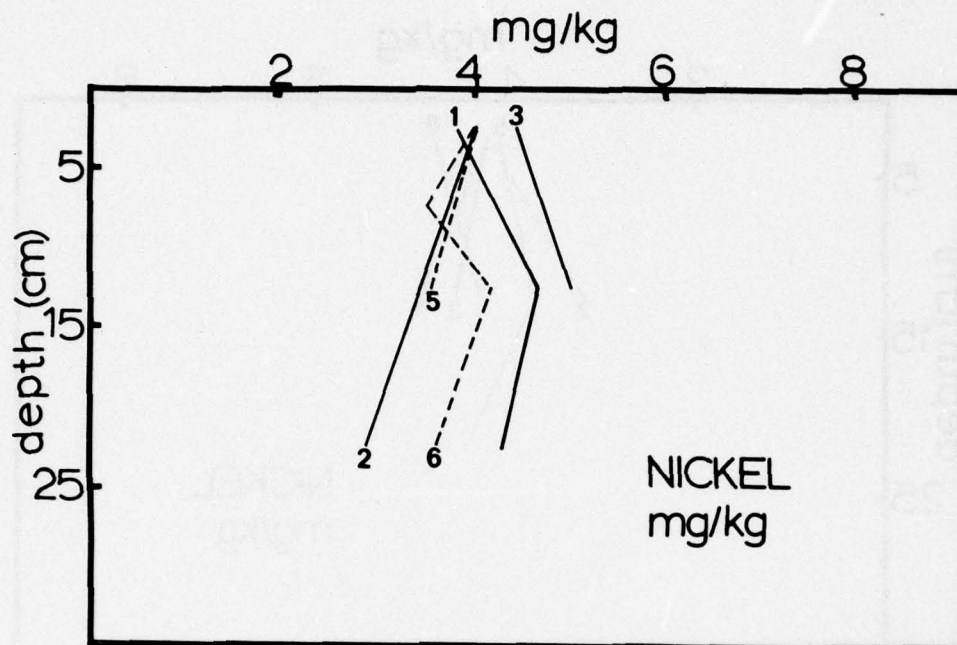


Figure B110. Distribution of nickel and iron in sediment cores taken from stations sampled on cruise Y7508 D-2

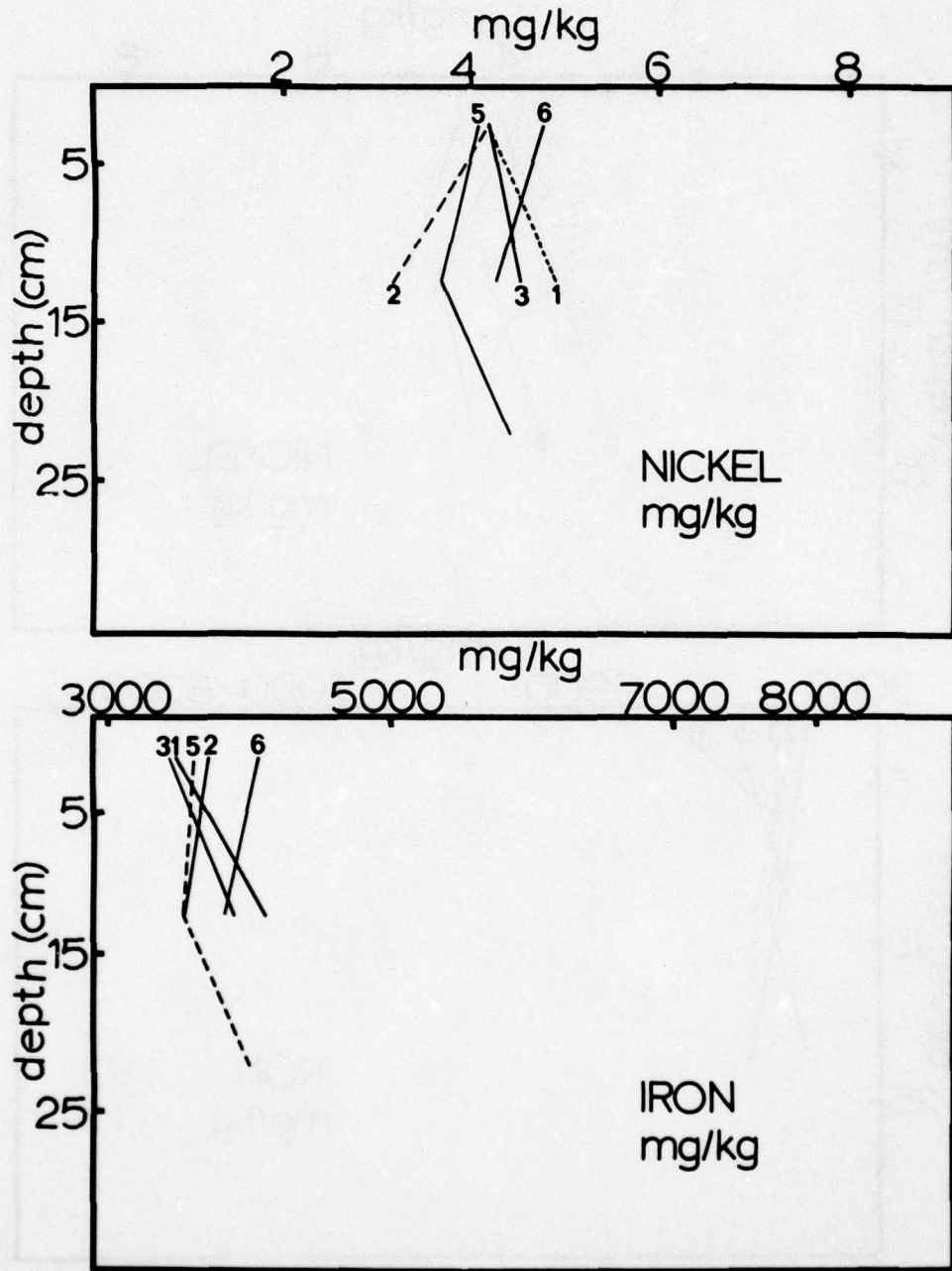


Figure B111. Distribution of nickel and iron in sediment cores taken from stations sampled on cruise Y7510 C-1

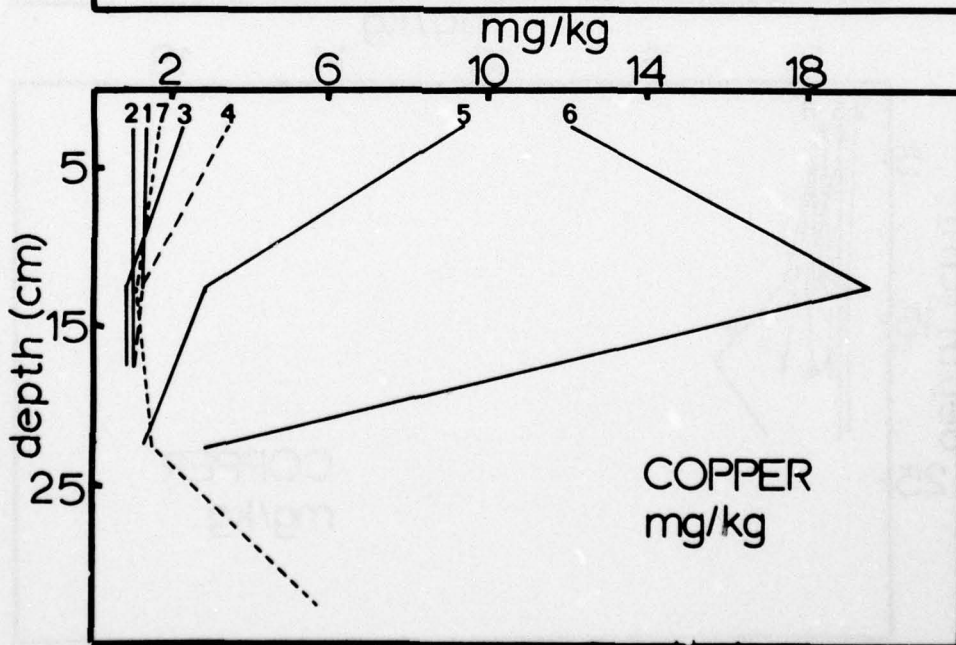
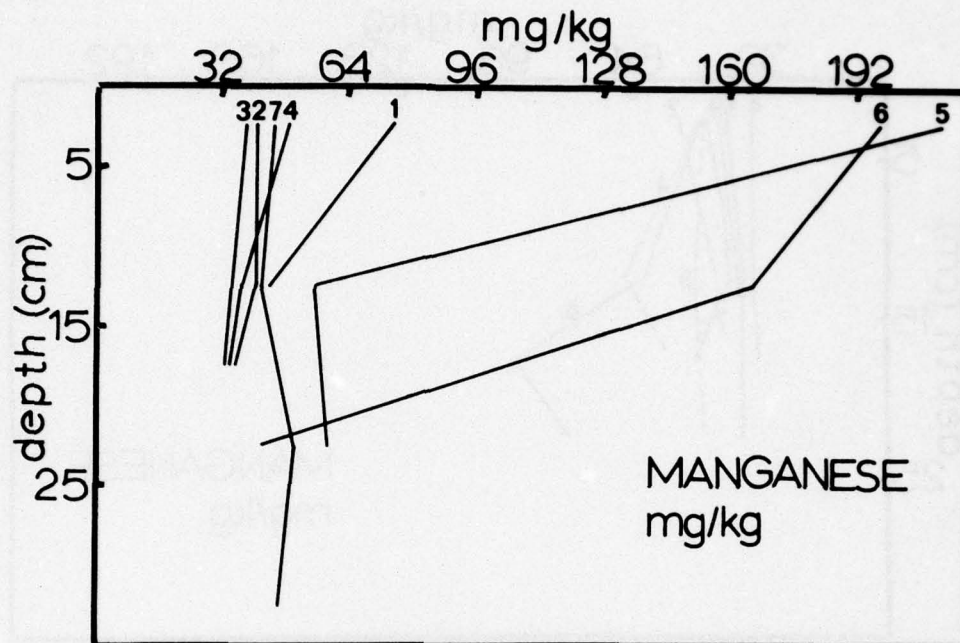


Figure B112. Distribution of manganese and copper in sediment cores taken from stations sampled on cruise Y7409 F

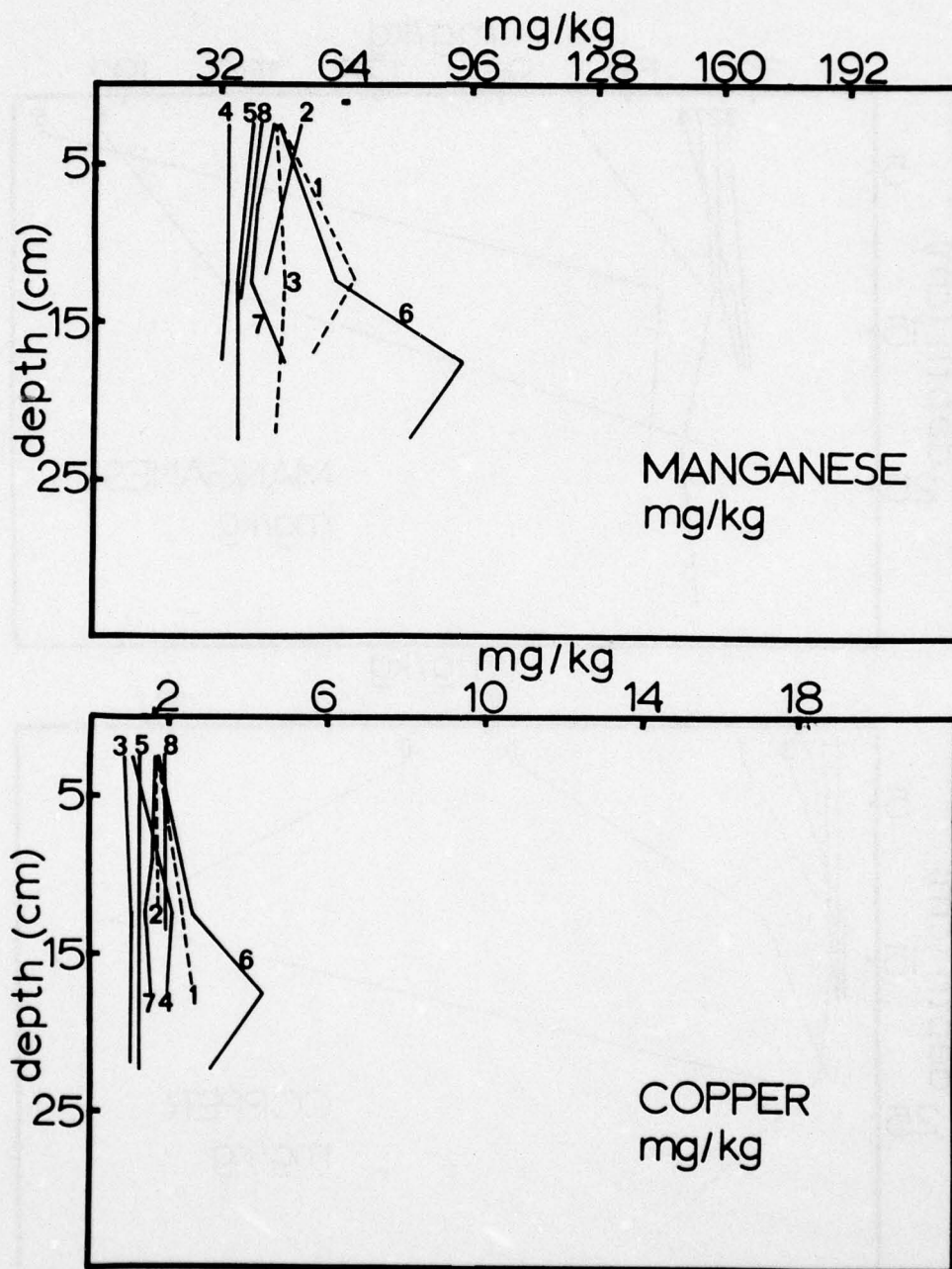


Figure B113. Distribution of manganese and copper in sediment cores taken from stations sampled on cruise Y7501 B

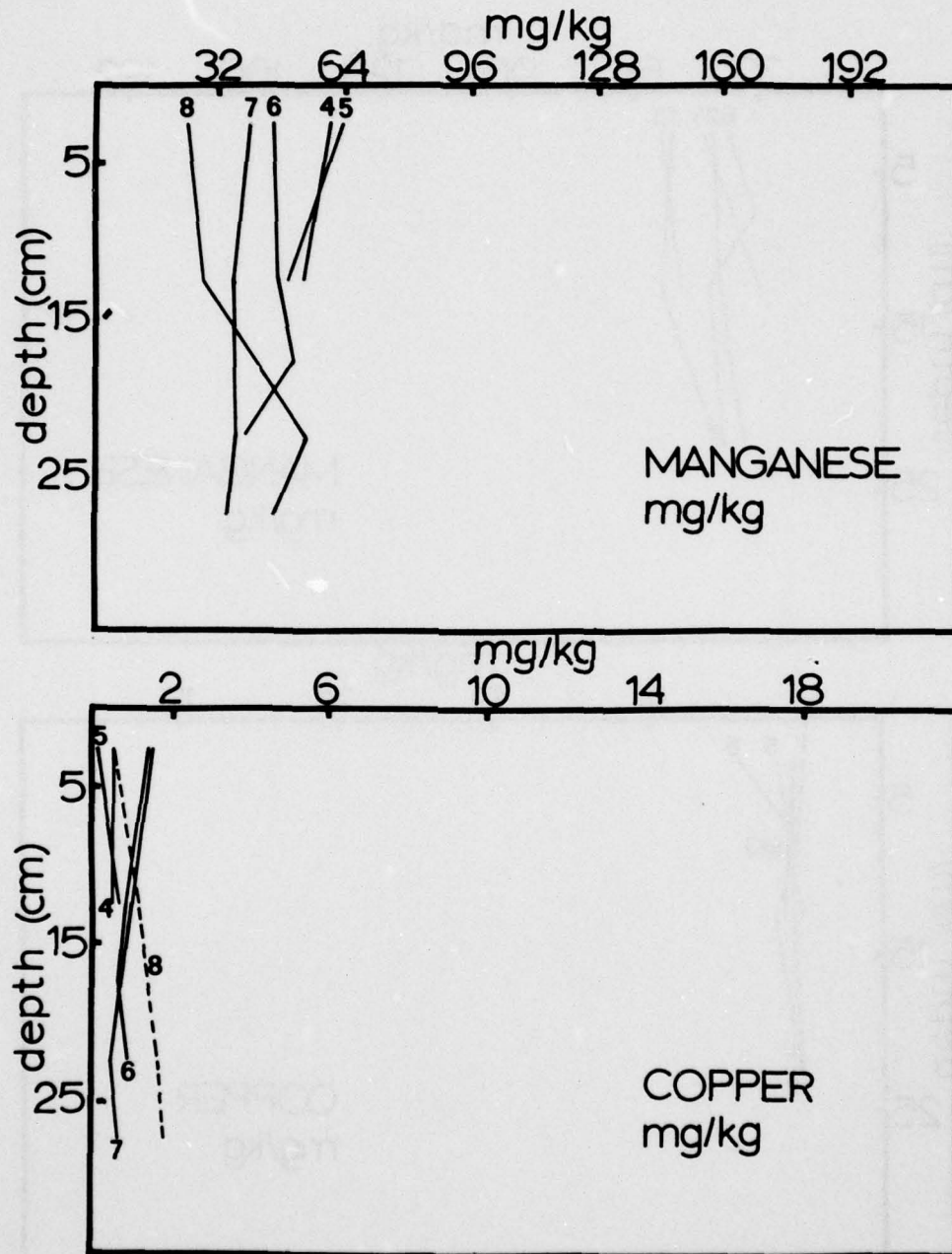


Figure B114. Distribution of manganese and copper in sediment cores taken from stations sampled on cruise Y7506 B-2

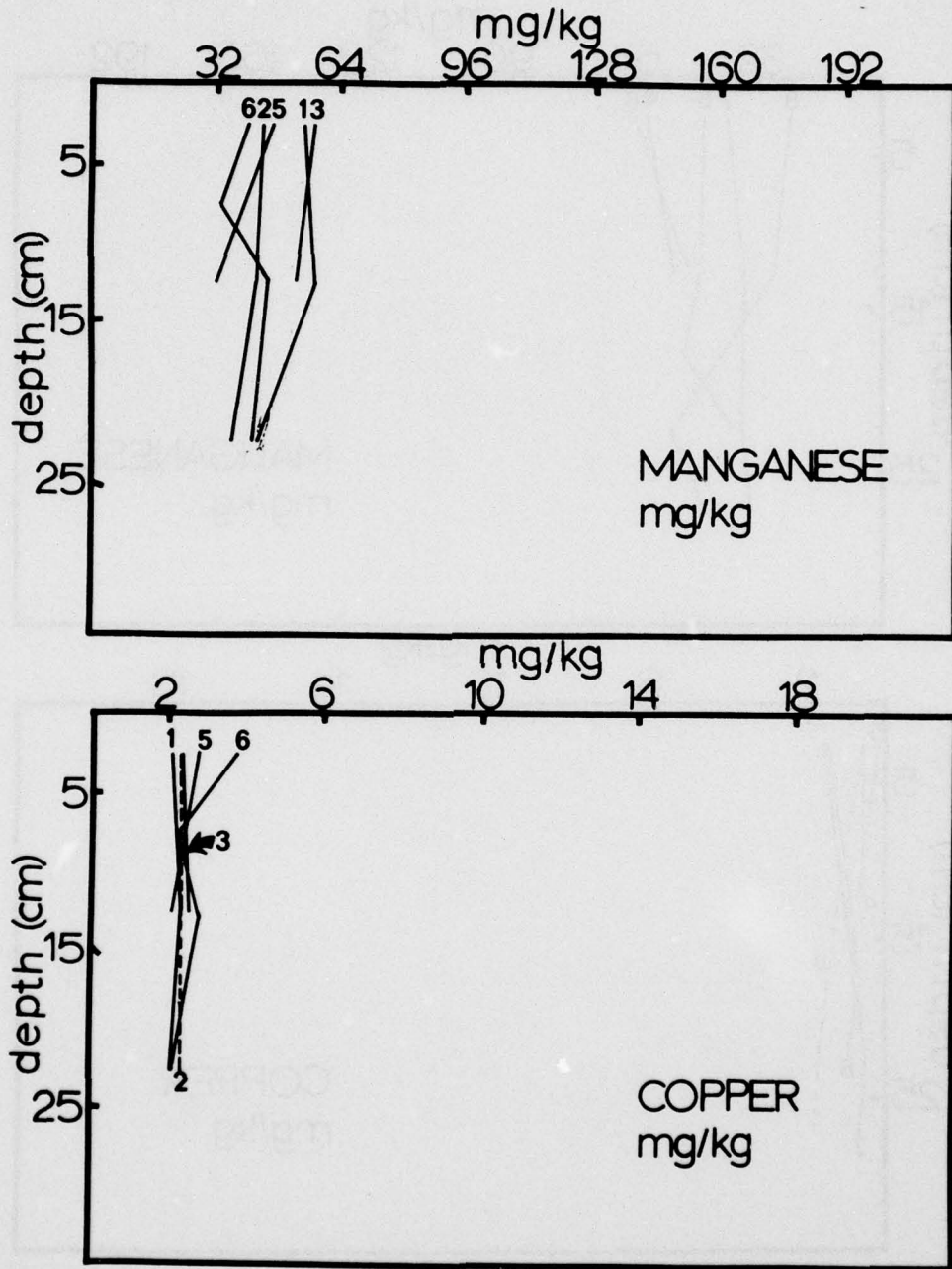


Figure B115. Distribution of manganese and copper in sediment cores taken from stations sampled on cruise Y7508 D-2

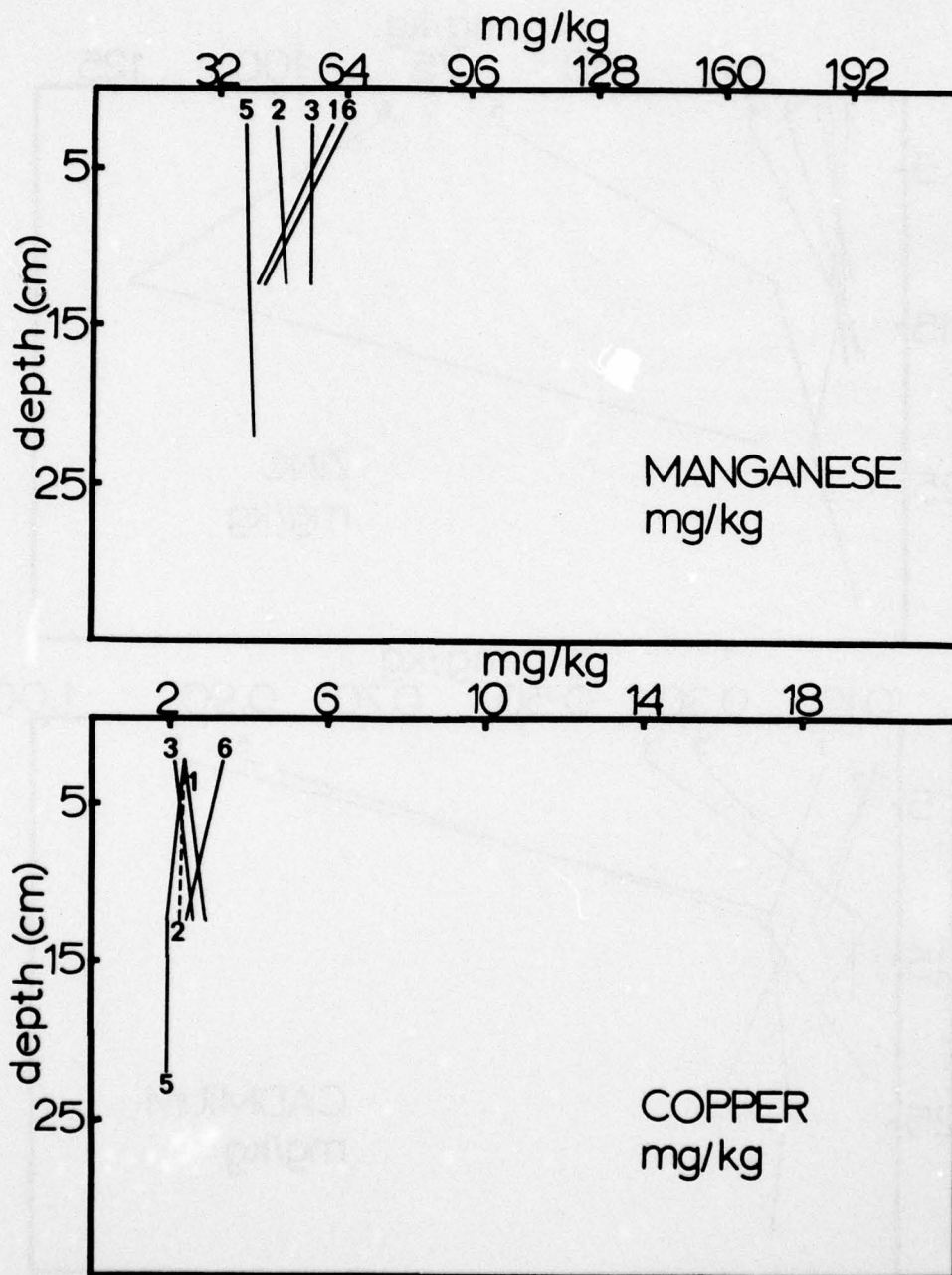


Figure B116. Distribution of manganese and copper in sediment cores taken from stations sampled on cruise Y7510 C-1

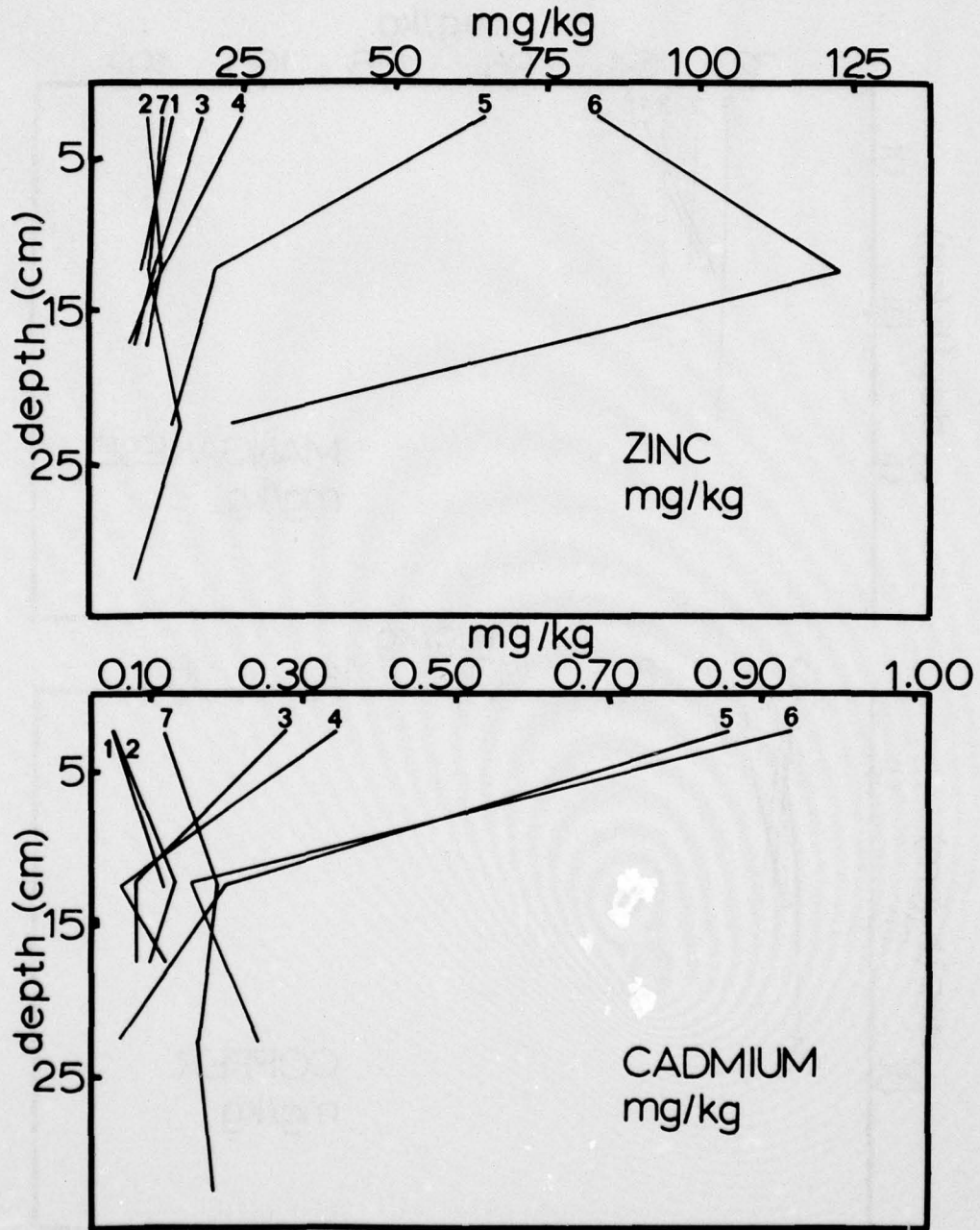


Figure B117. Distribution of zinc and cadmium in sediment cores taken from stations sampled on cruise Y7409 F

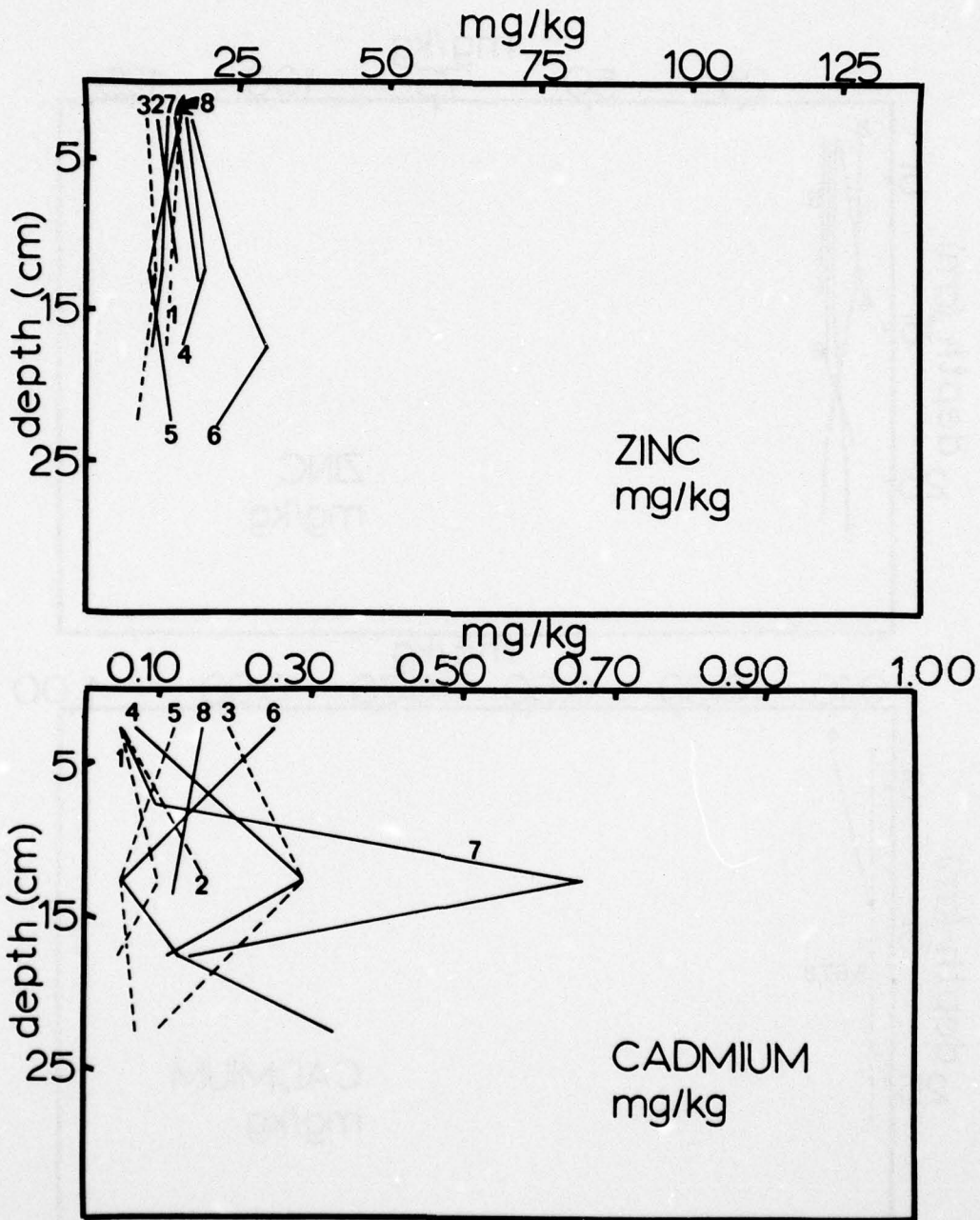


Figure B118. Distribution of zinc and cadmium in sediment cores taken from stations sampled on cruise Y7501 B

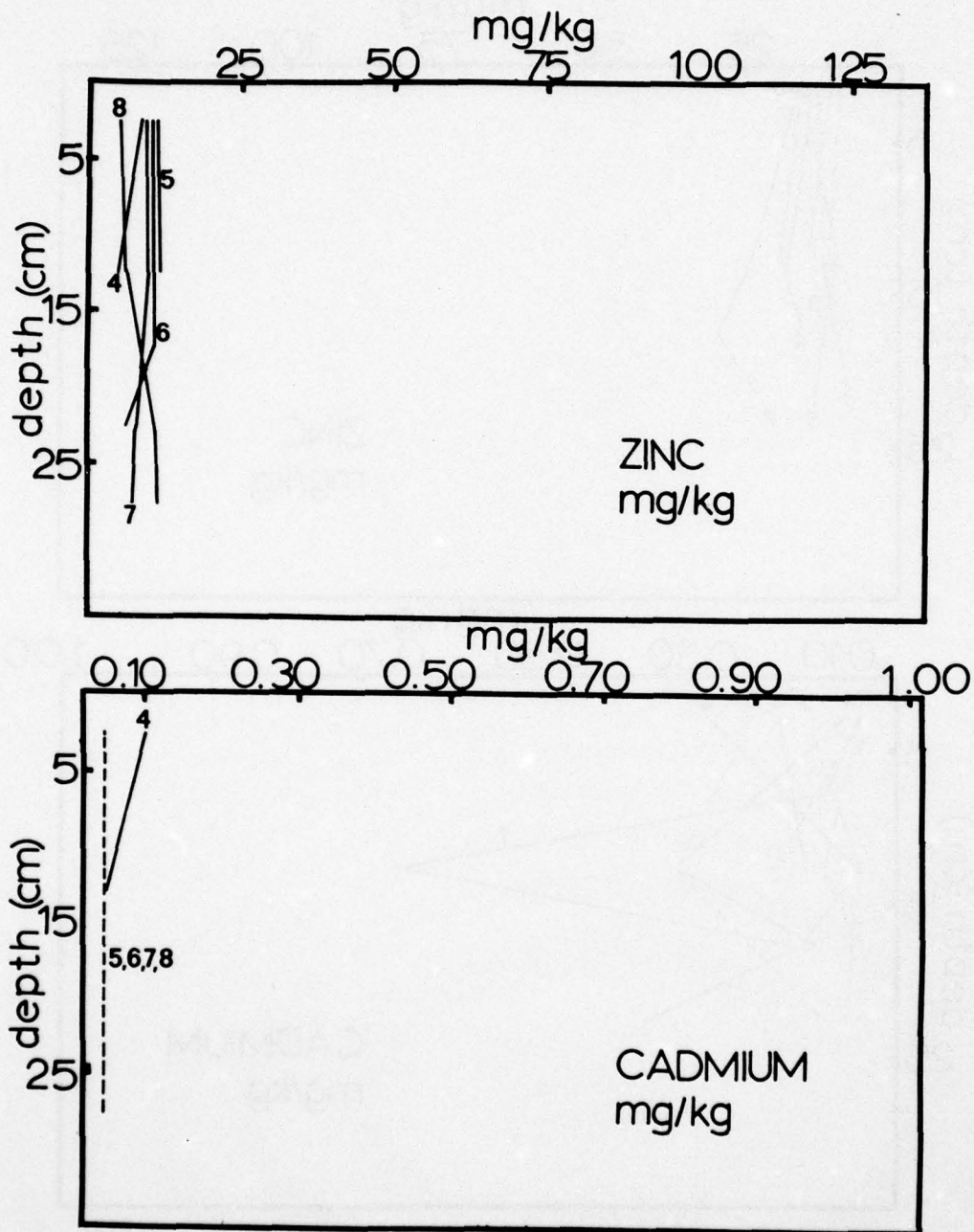


Figure B119. Distribution of zinc and cadmium in sediment cores taken from stations sampled on cruise Y7506 B-2

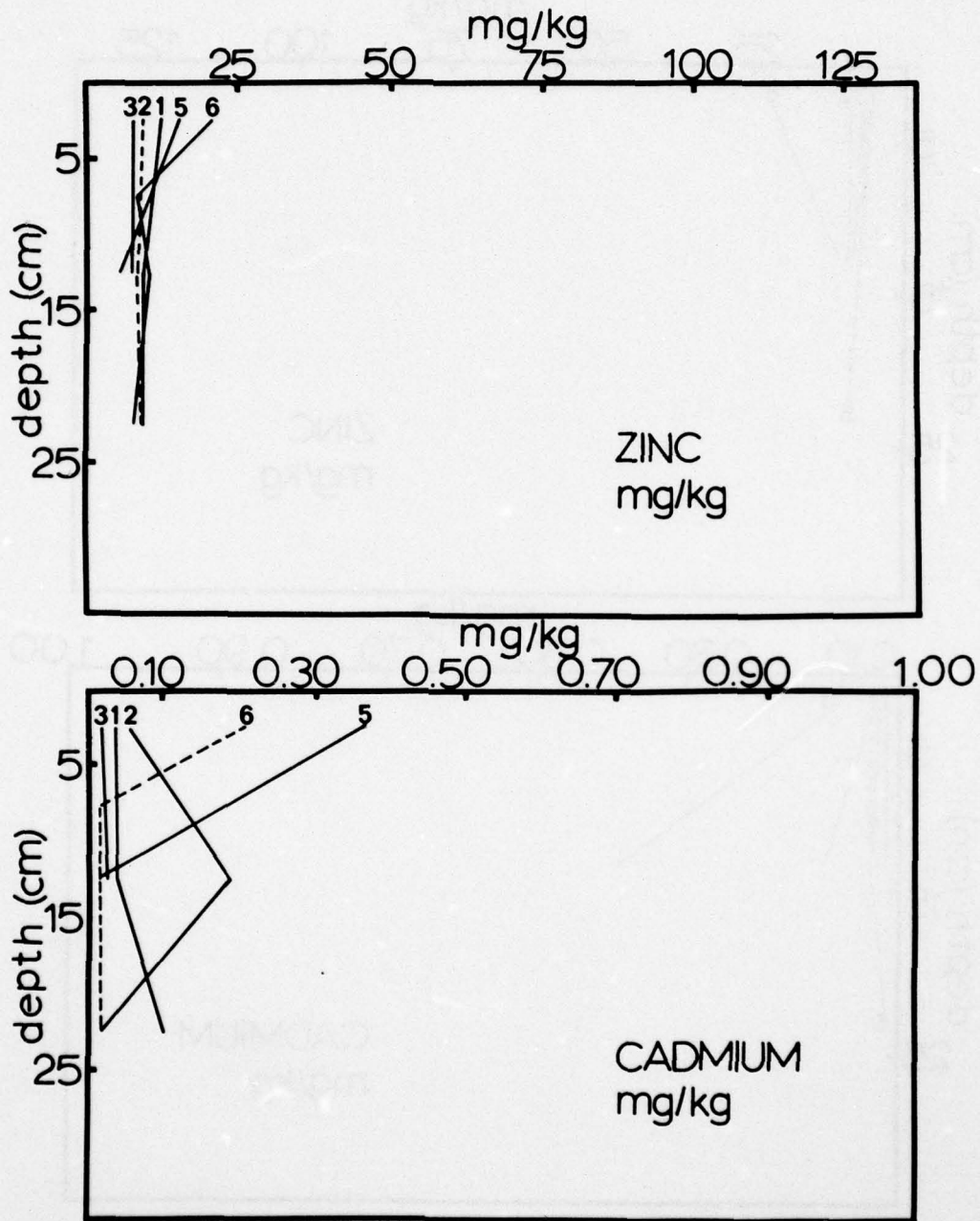


Figure B120. Distribution of zinc and cadmium in sediment cores taken from stations sampled on cruise Y7508 D-2

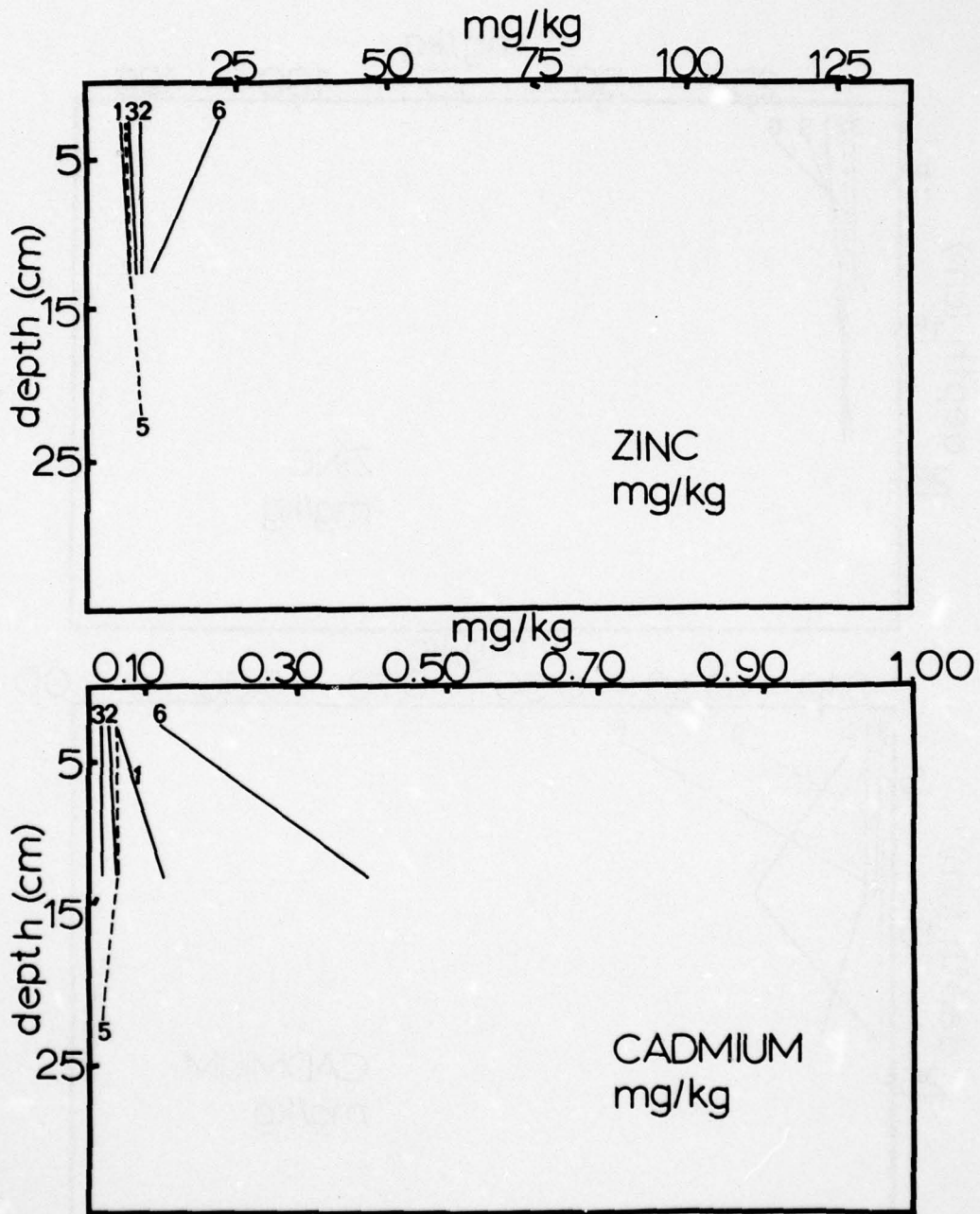


Figure B121. Distribution of zinc and cadmium in sediment cores taken from stations sampled on cruise Y7510 C-1

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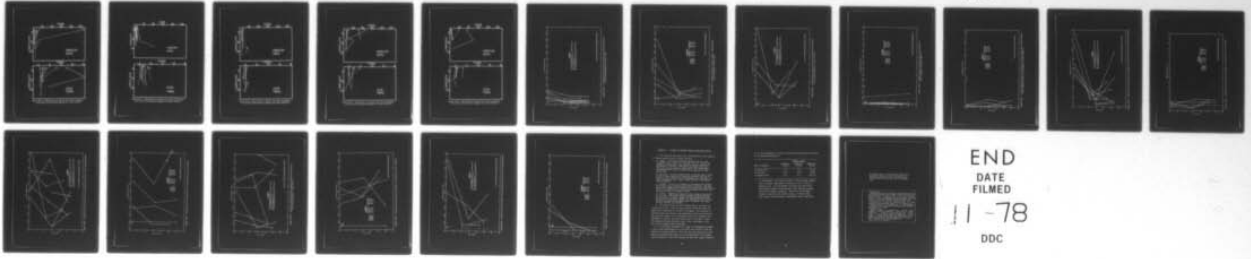
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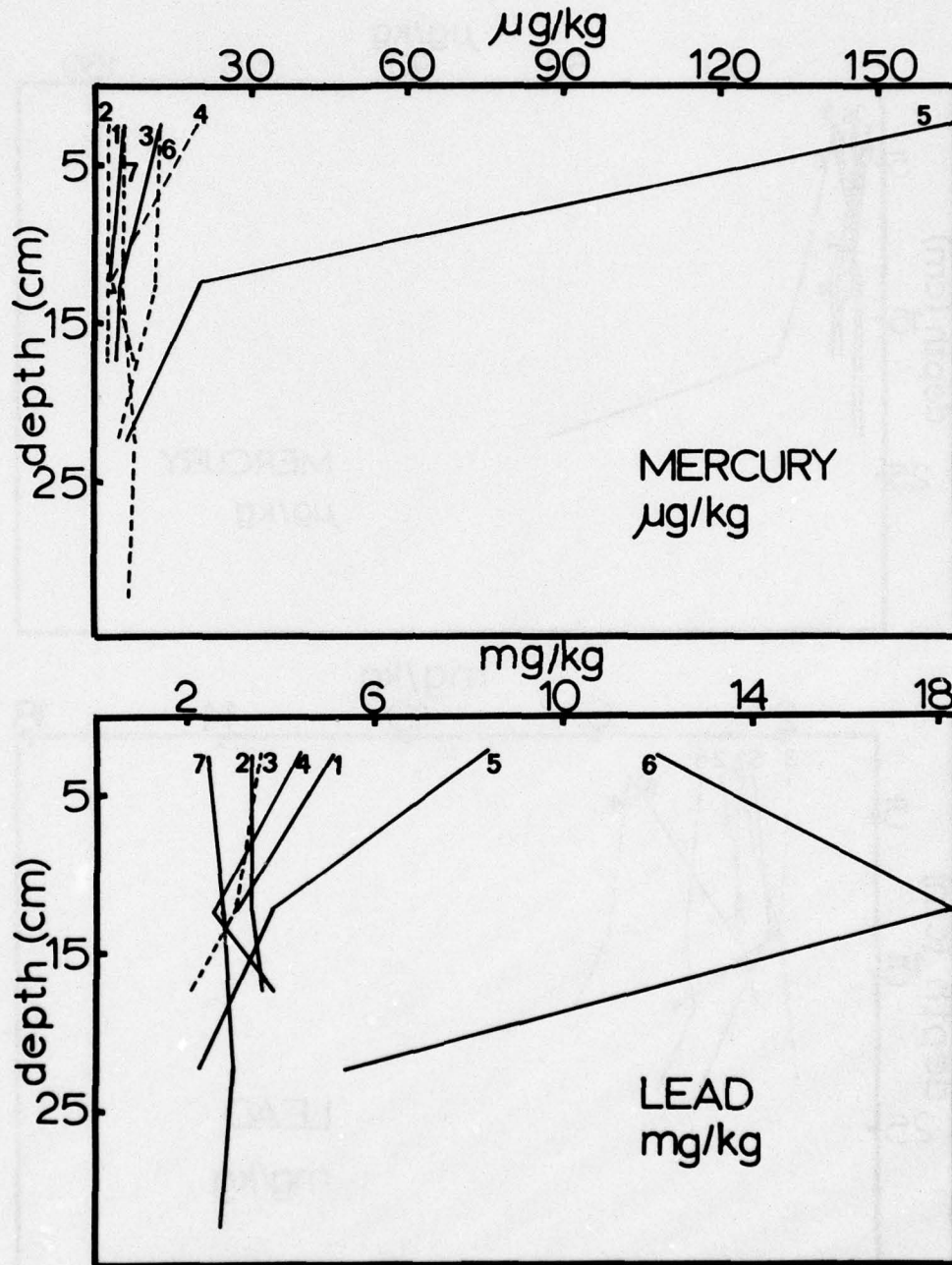


Figure B122. Distribution of mercury and lead in sediment cores taken from stations sampled on cruise Y7409 F

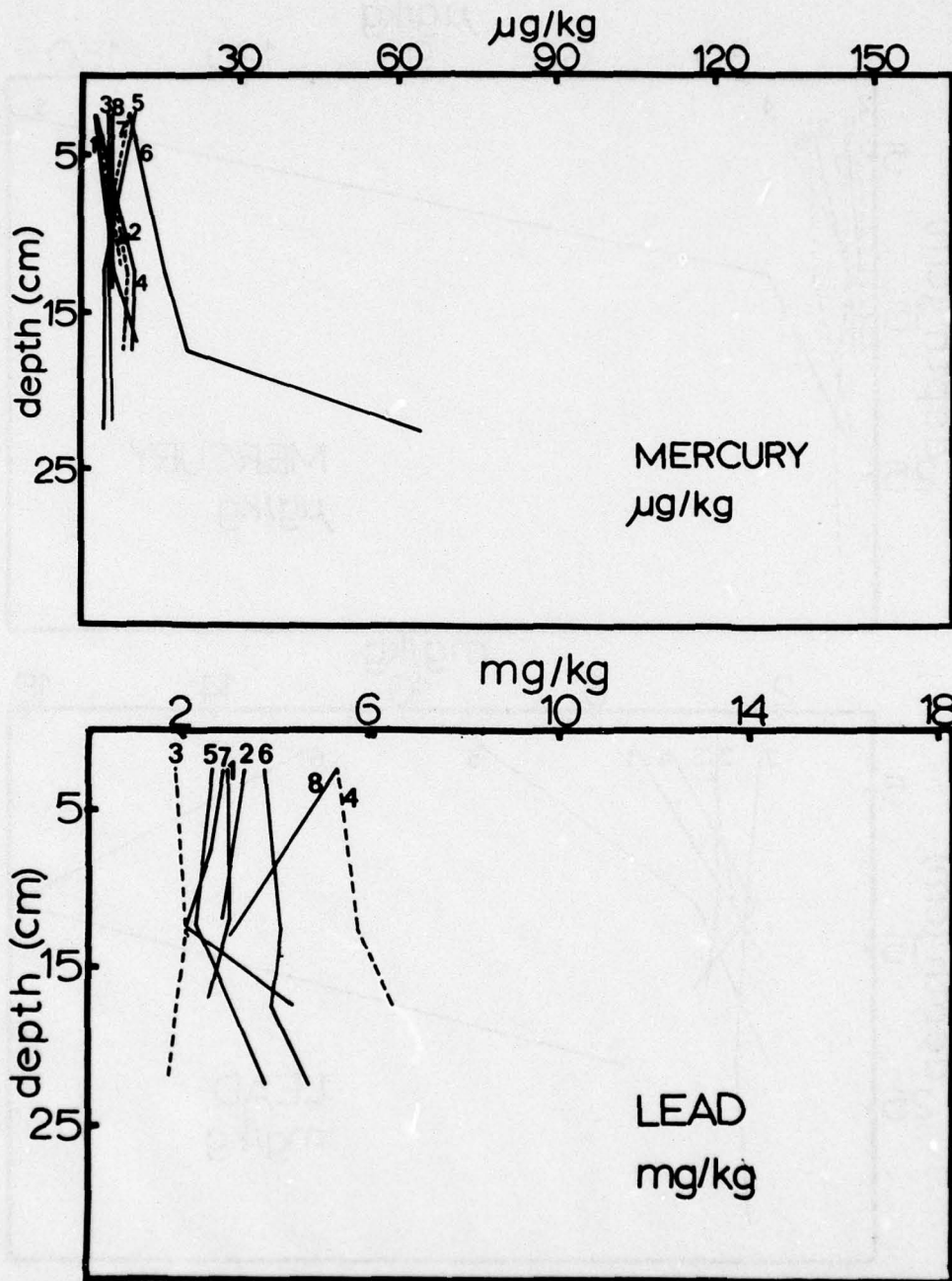


Figure B123. Distribution of mercury and lead in sediment cores taken from stations sampled on cruise Y7501 B

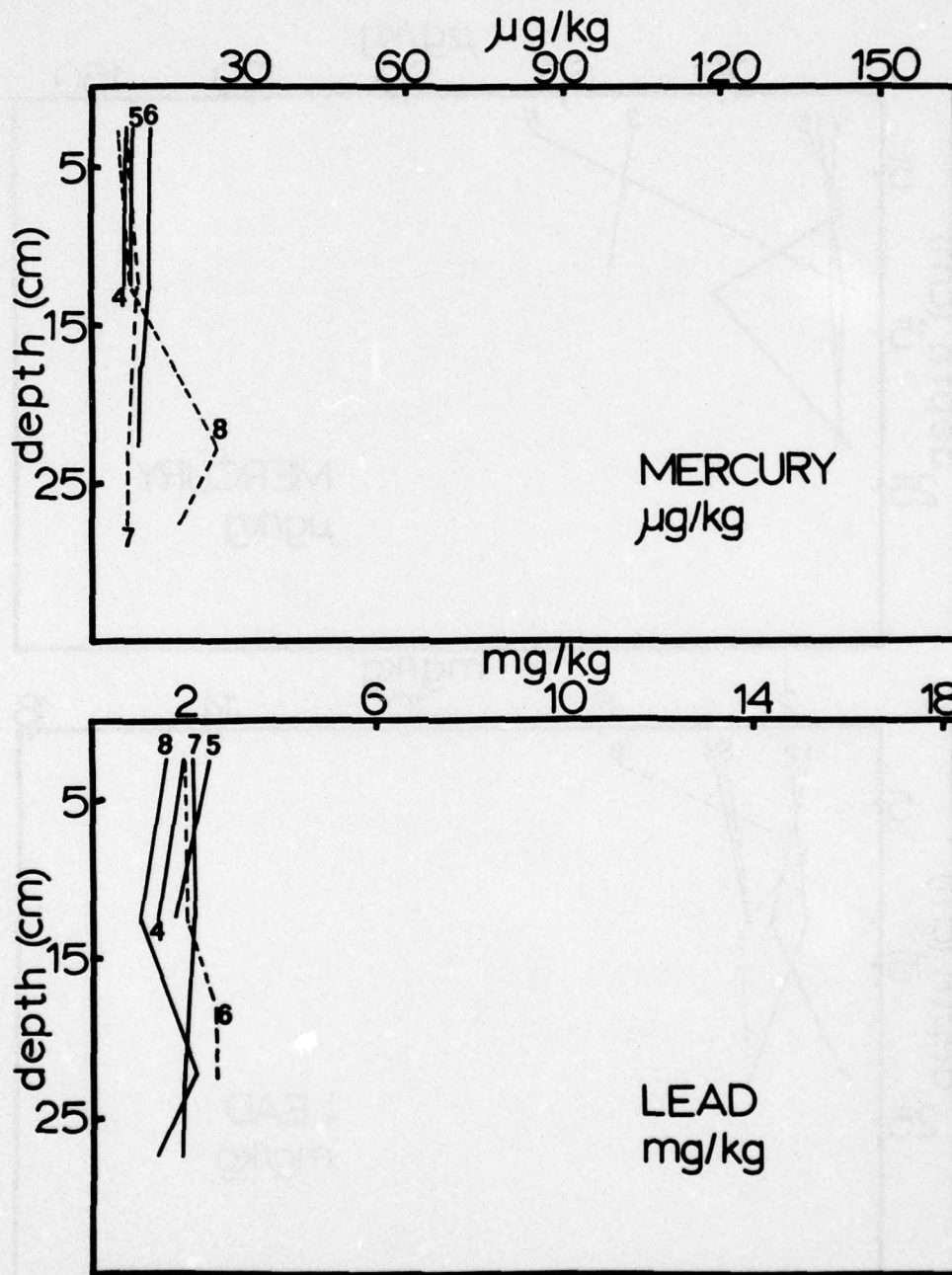


Figure B124. Distribution of mercury and lead in sediment cores taken from stations sampled on cruise Y7506 B-2

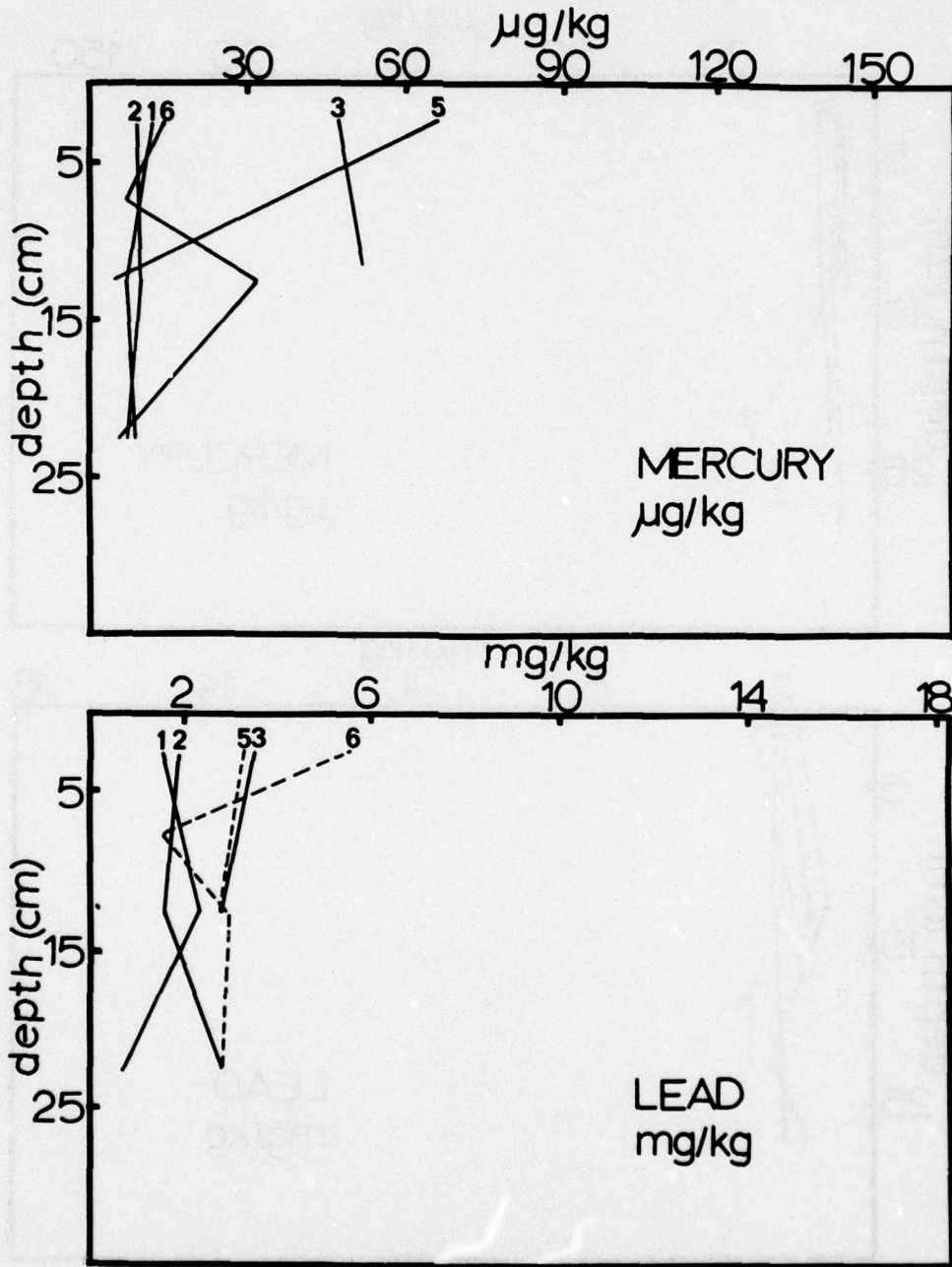


Figure B125. Distribution of mercury and lead in sediment cores taken from stations sampled on cruise Y7508 D-2

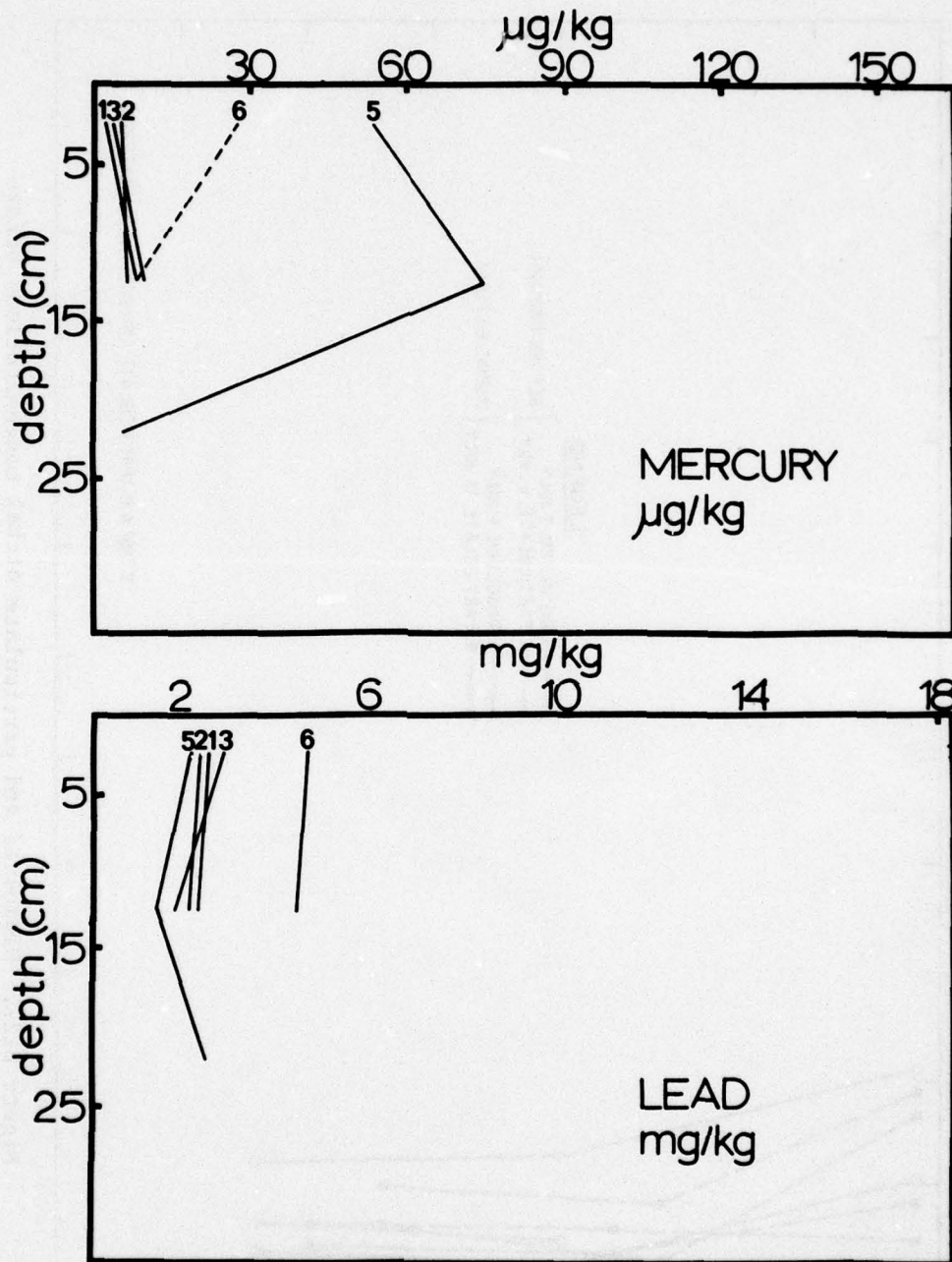


Figure B126. Distribution of mercury and lead in sediment cores taken from stations sampled on cruise Y7510 C-1

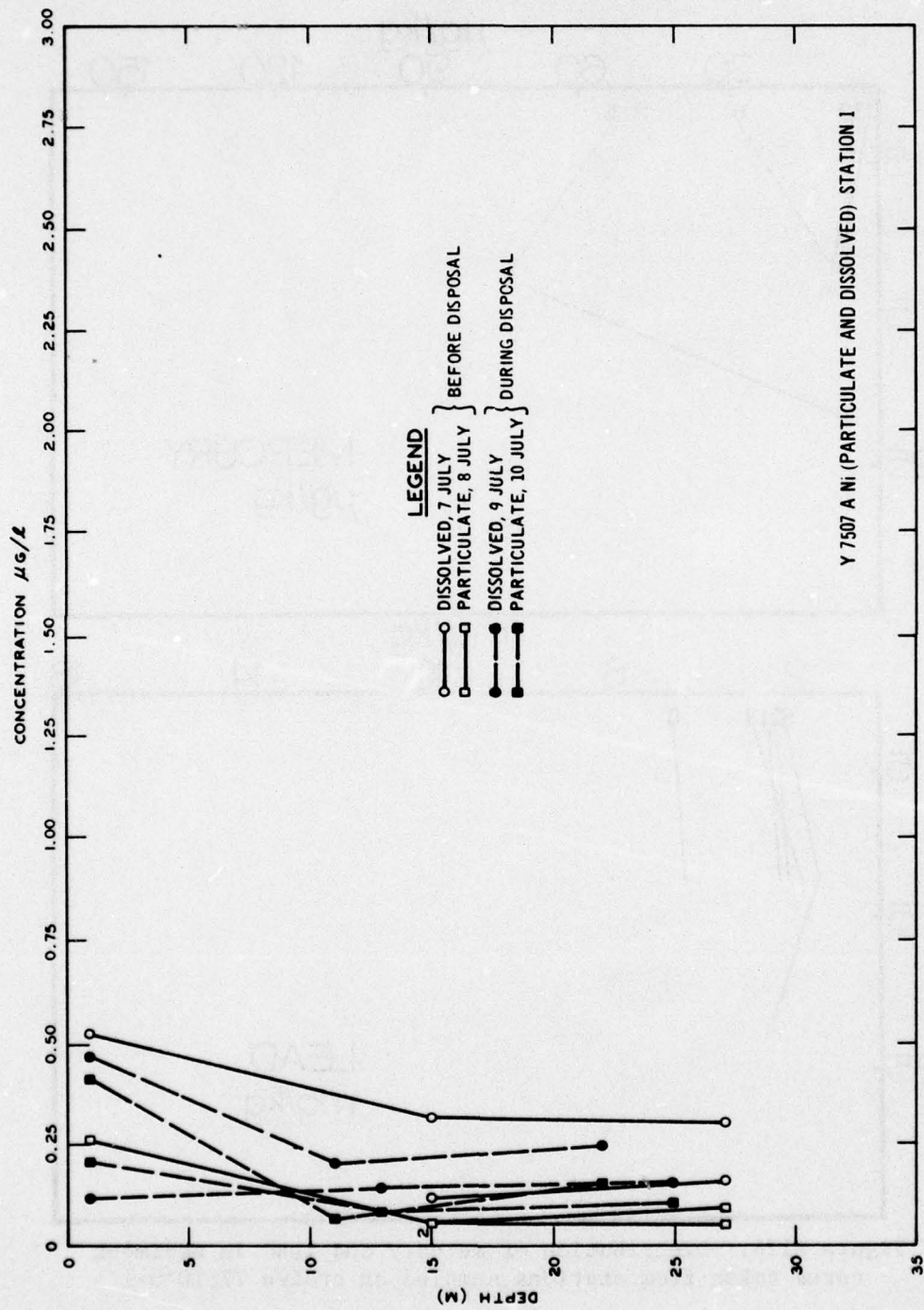
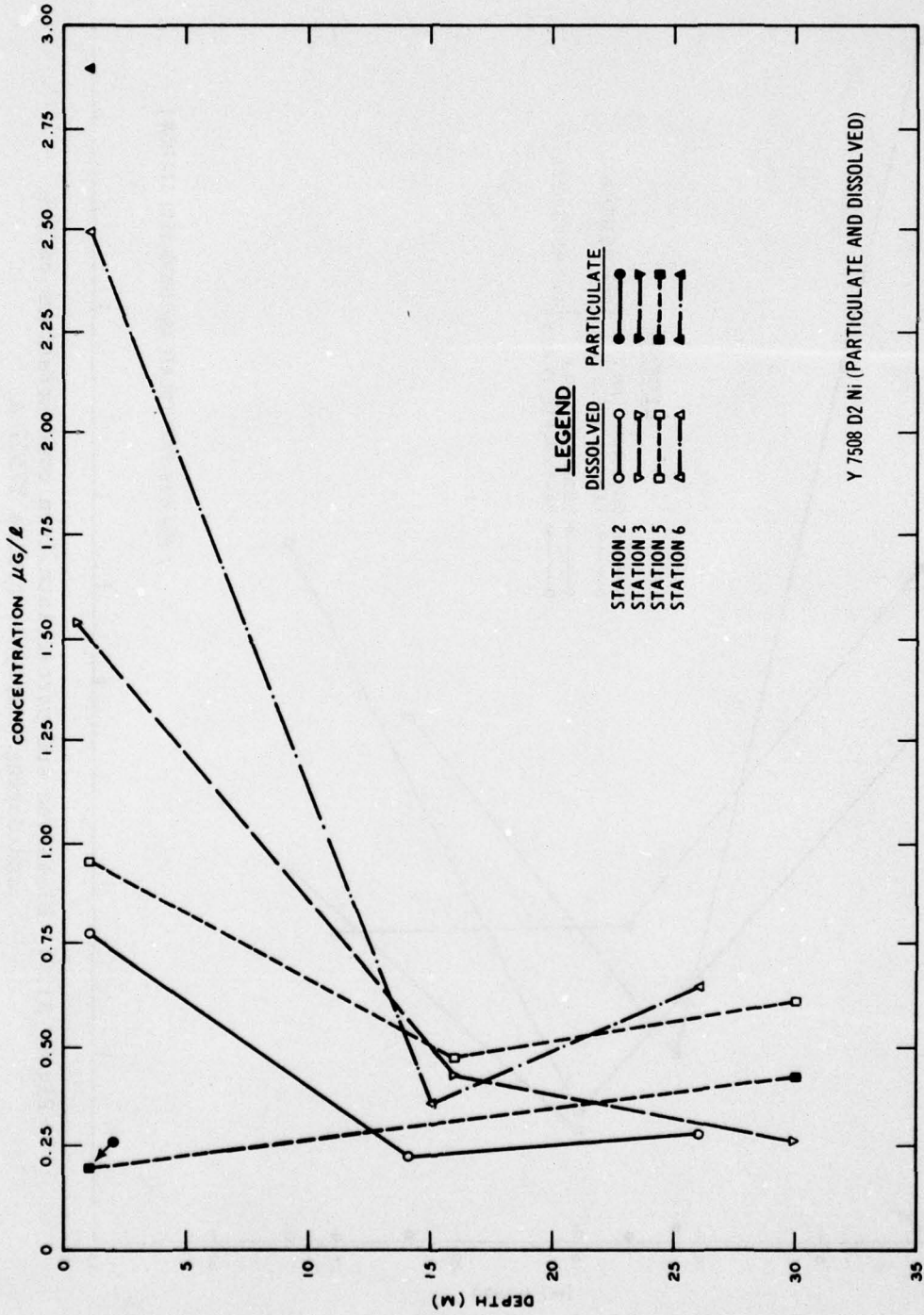


Figure B127. Dissolved and particulate nickel concentrations before and during disposal, cruise Y7507



Y 7508 D2 Ni (PARTICULATE AND DISSOLVED)

Figure B128. Dissolved and particulate nickel concentrations after disposal, cruise Y7508

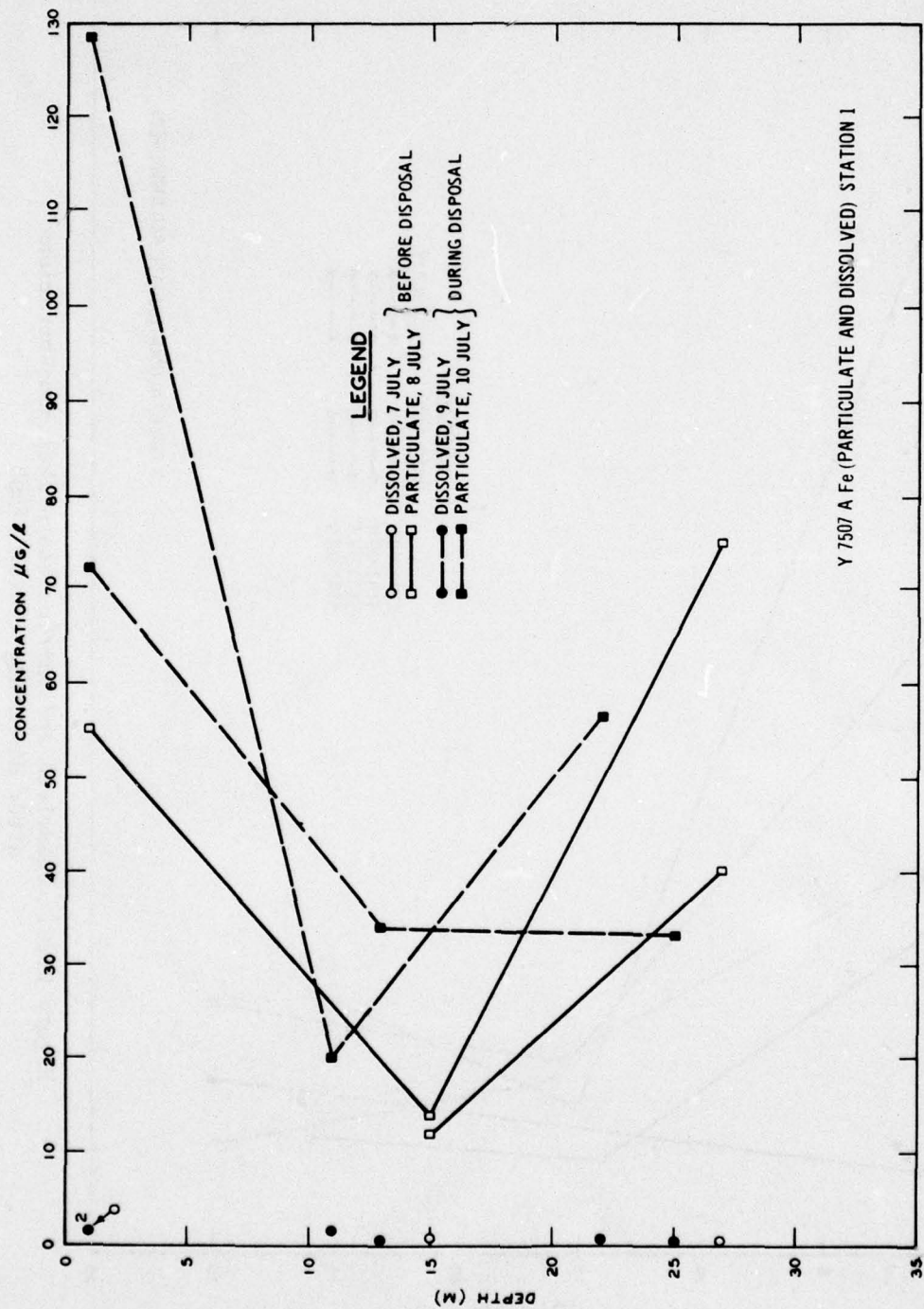


Figure B129. Dissolved and particulate iron concentrations before and during disposal, cruise Y7507 A

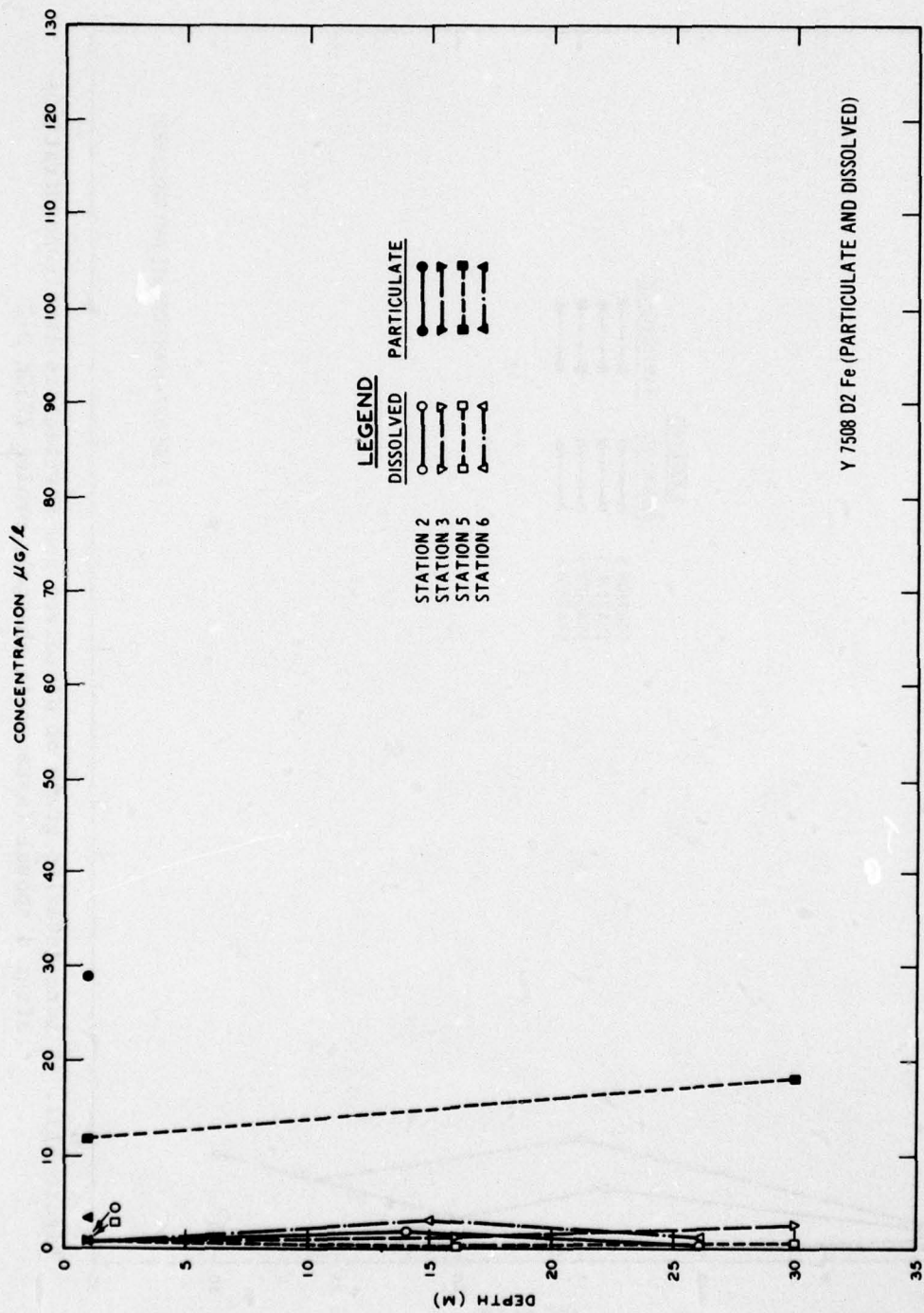


Figure B130. Dissolved and particulate iron concentrations after disposal, cruise Y7508 D-2

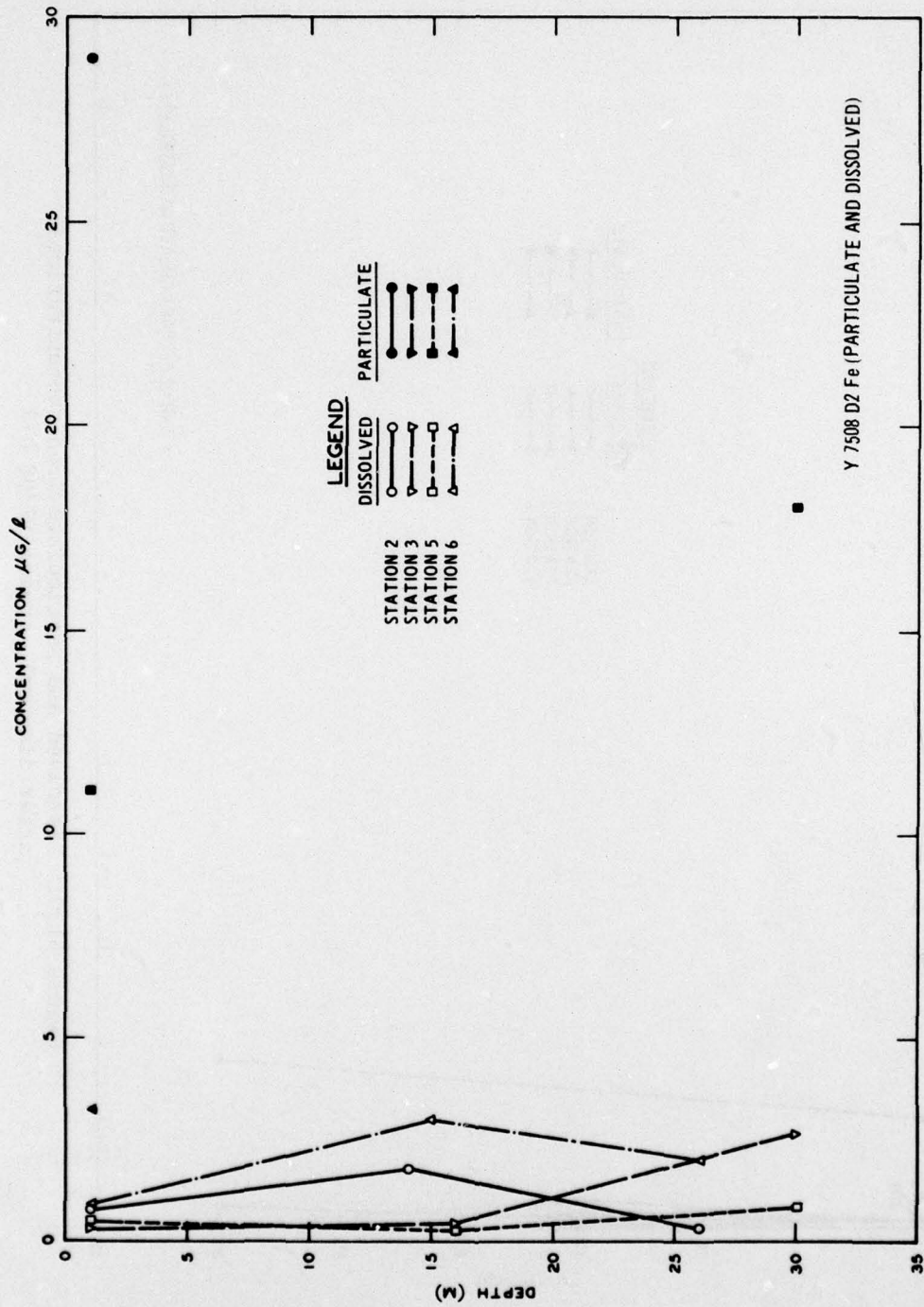


Figure B131. A more detailed graph of dissolved and particulate iron concentrations after disposal (note scale change), cruise Y7508 D-2

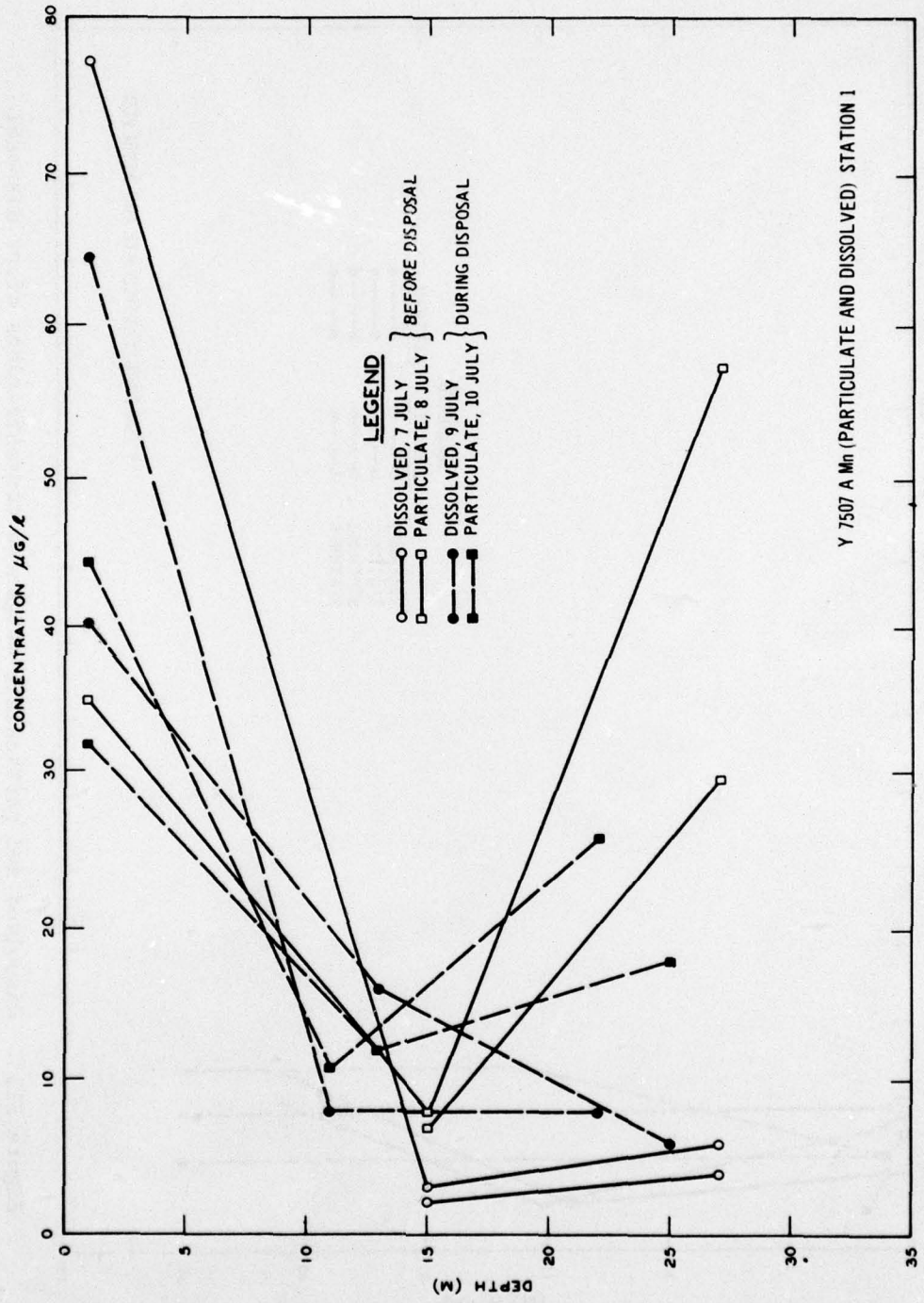


Figure B132. Dissolved and particulate manganese concentrations before and during disposal

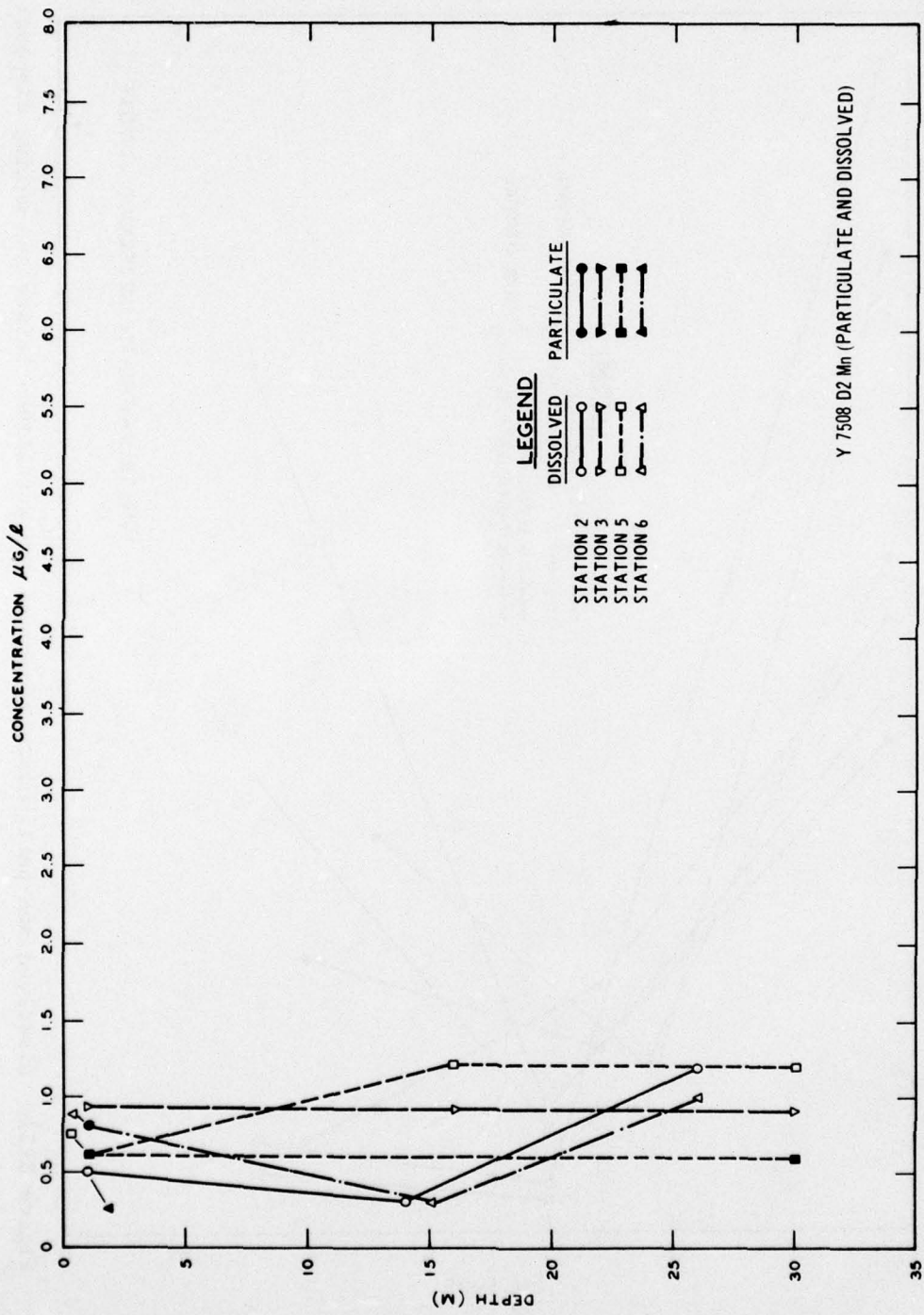


Figure B133. Dissolved and particulate manganese concentrations after disposal

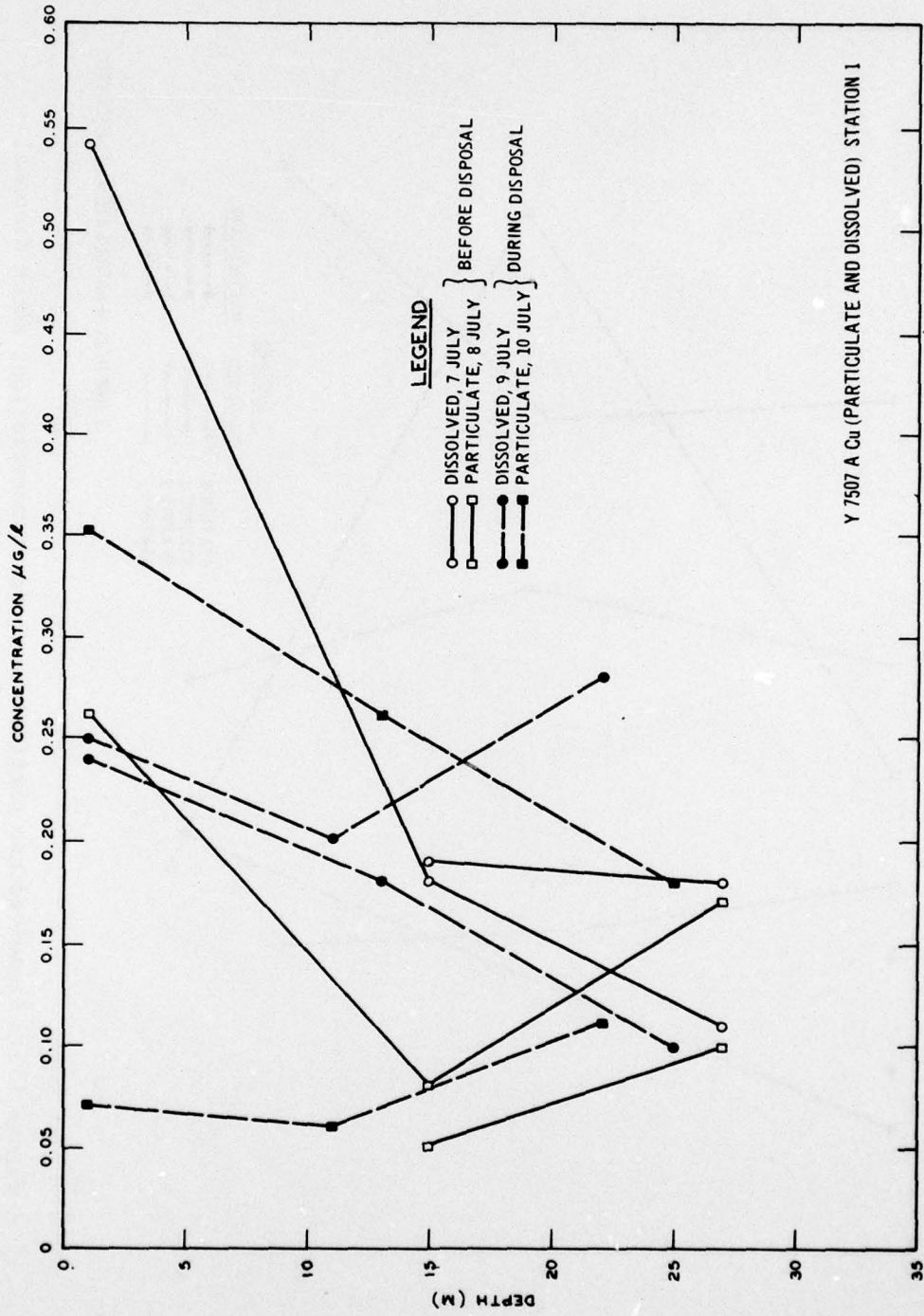


Figure B134. Dissolved and particulate copper concentrations before and during disposal

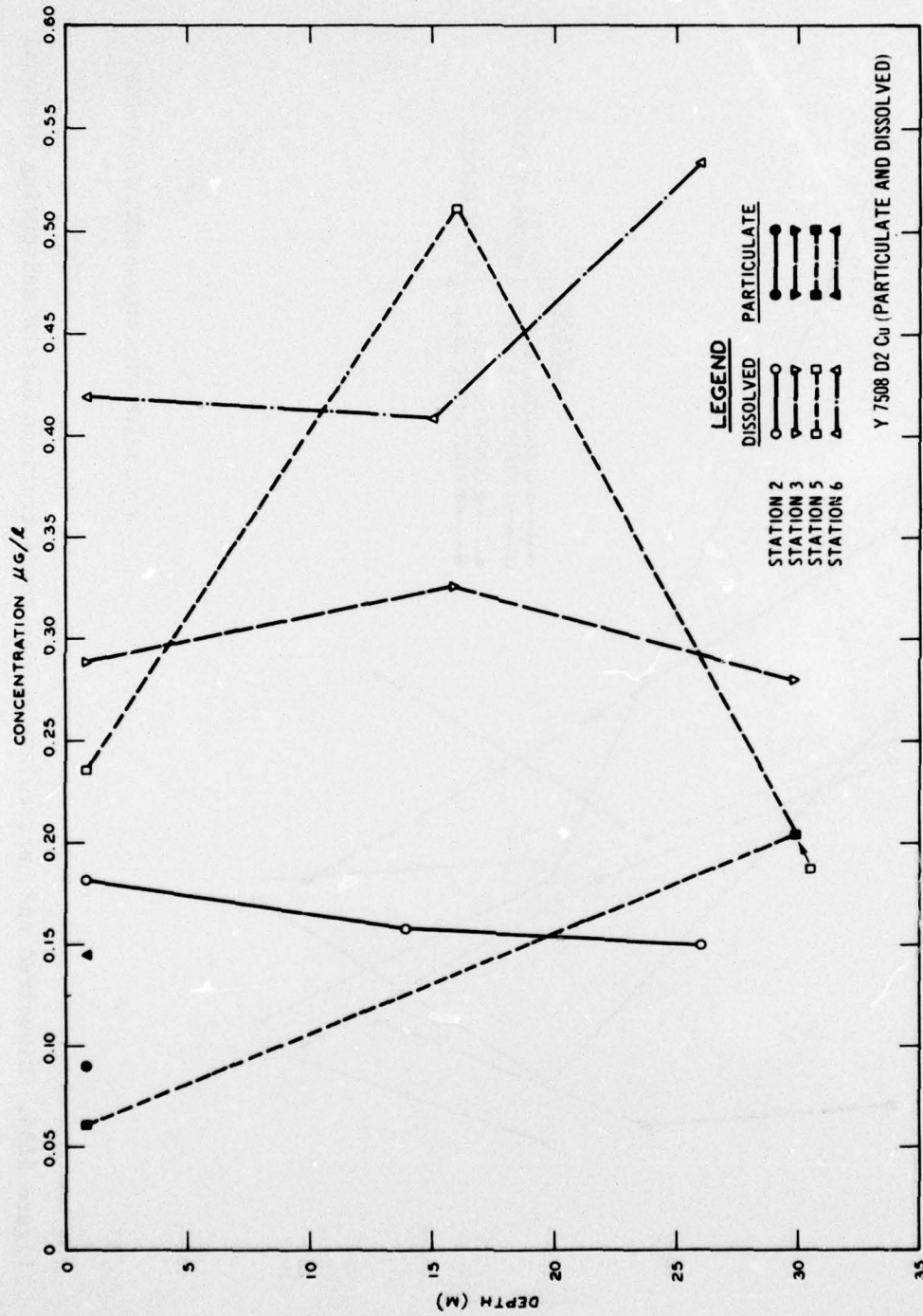
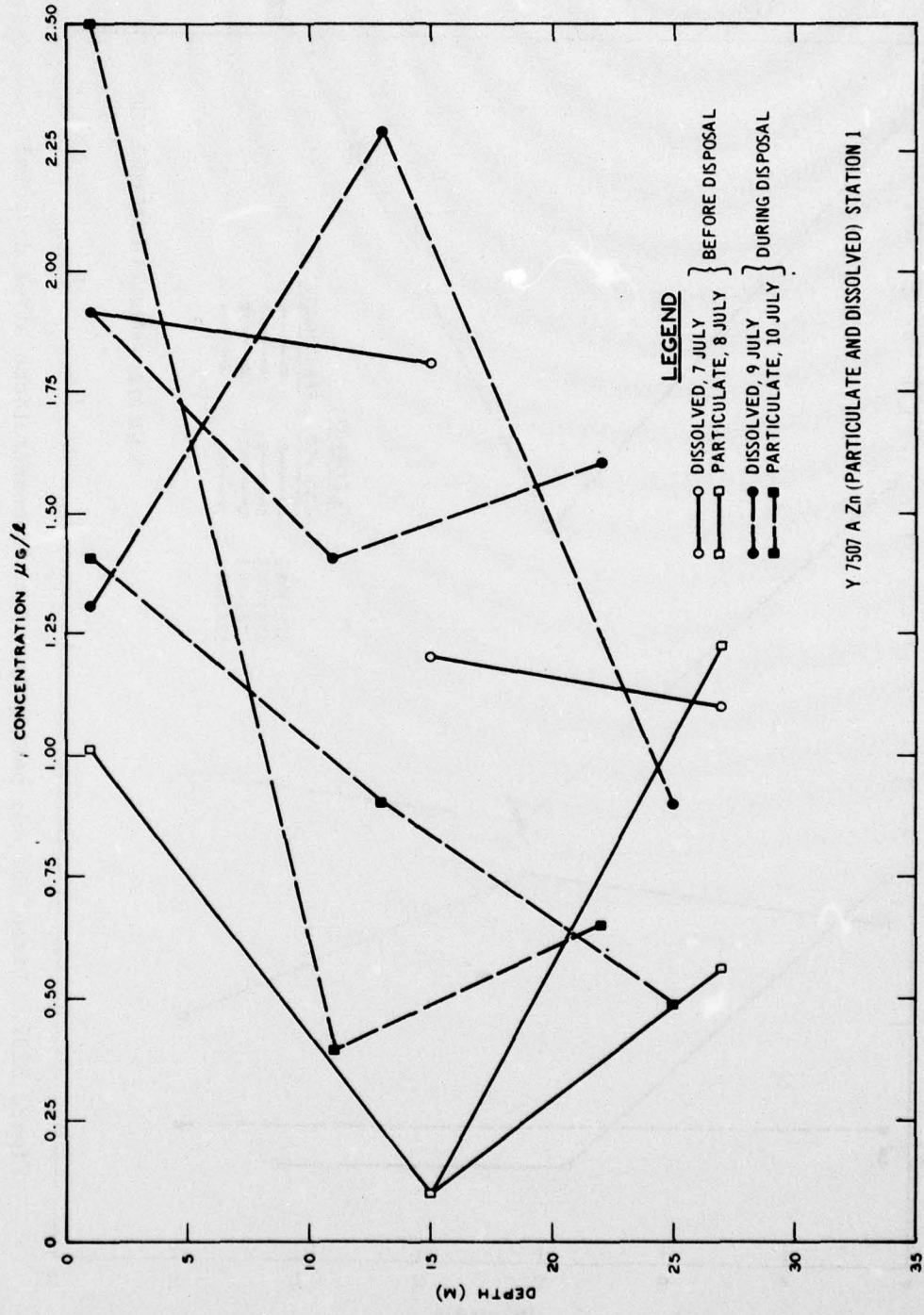


Figure 135. Dissolved and particulate copper concentrations after disposal



Y 7507 A Zn (PARTICULATE AND DISSOLVED) STATION 1

Figure B136. Dissolved and particulate zinc concentrations before and during disposal

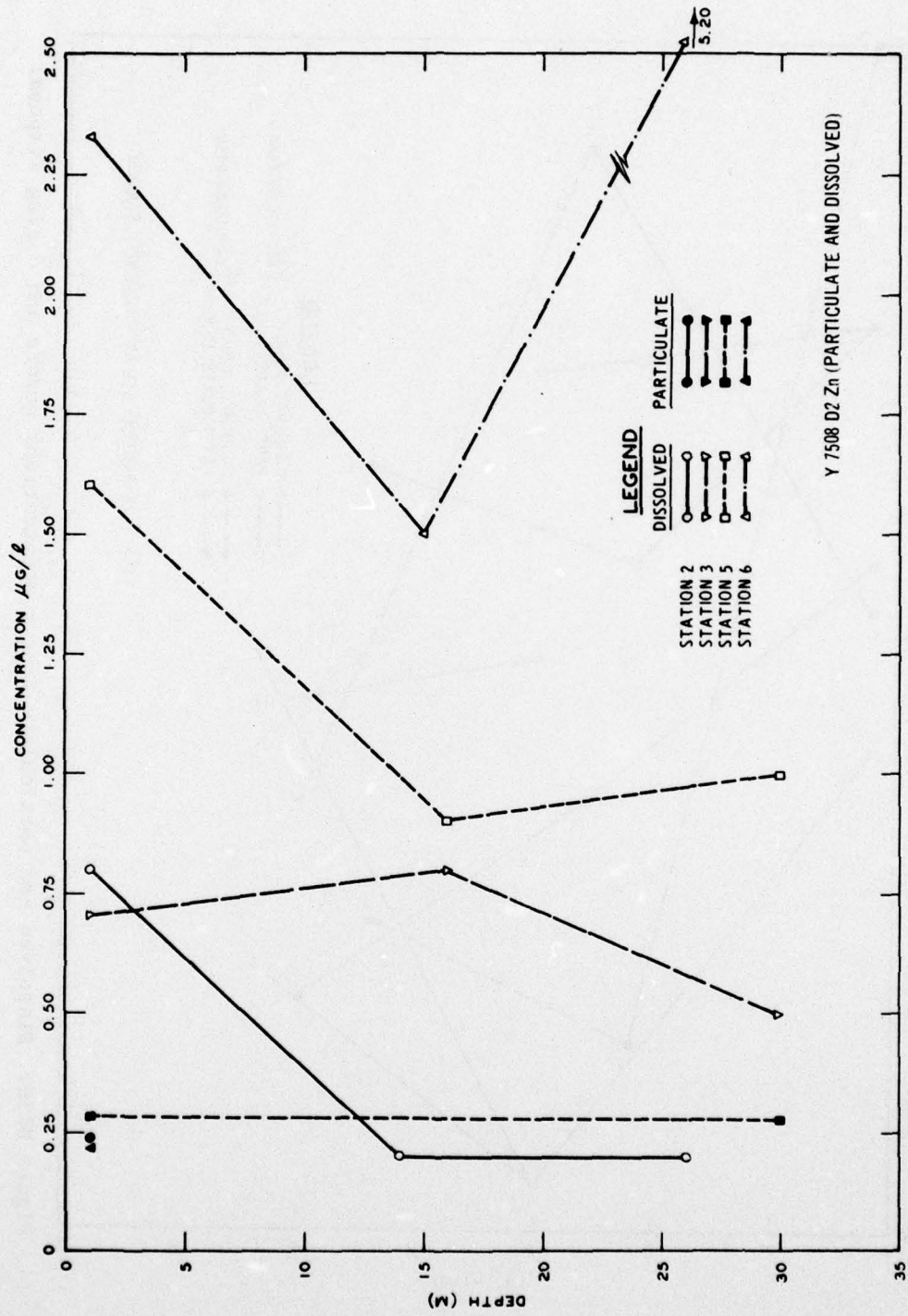


Figure B137. Dissolved and particulate zinc concentrations after disposal

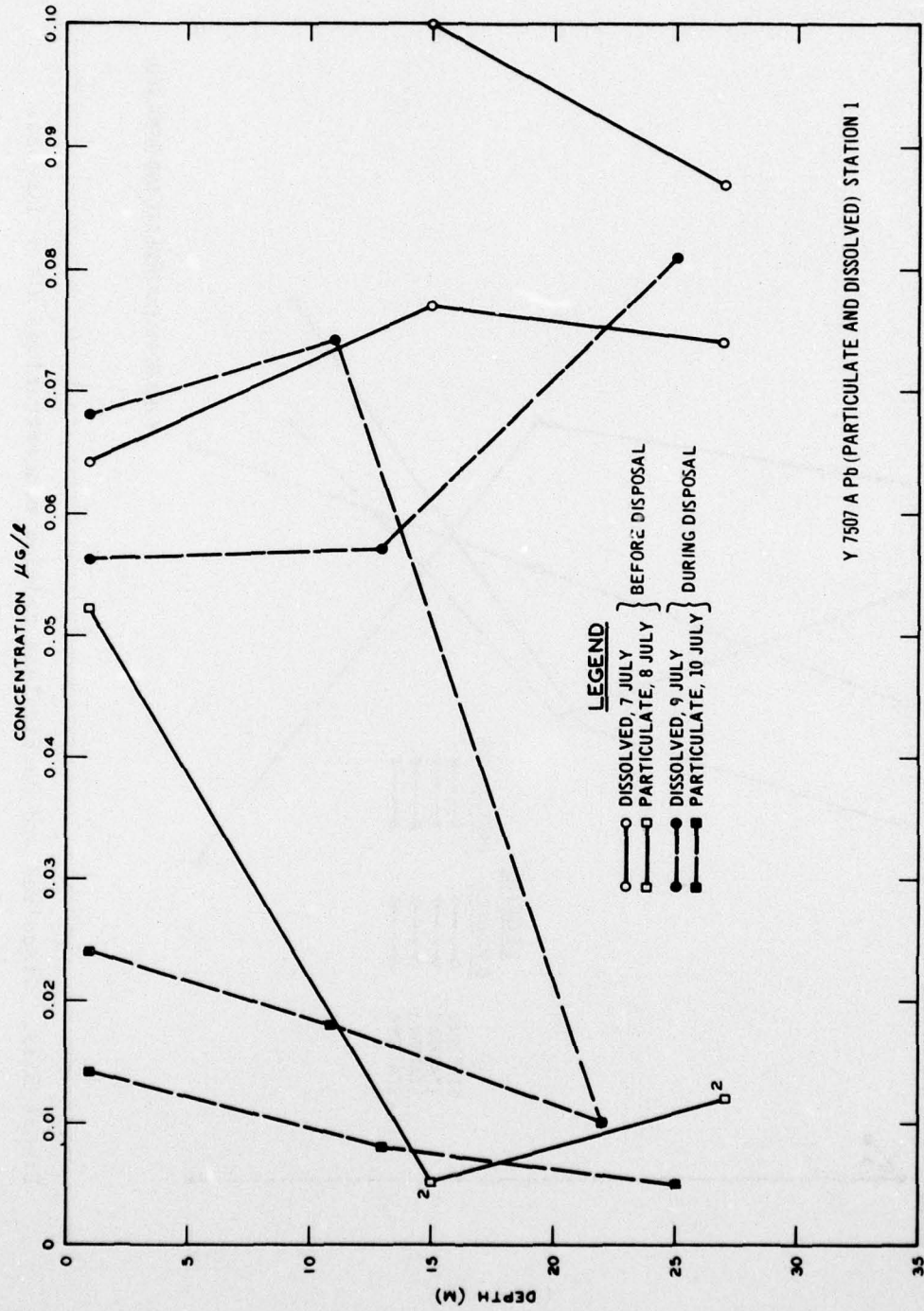


Figure B138. Dissolved and particulate cadmium concentrations before and during disposal, cruise Y7507 A

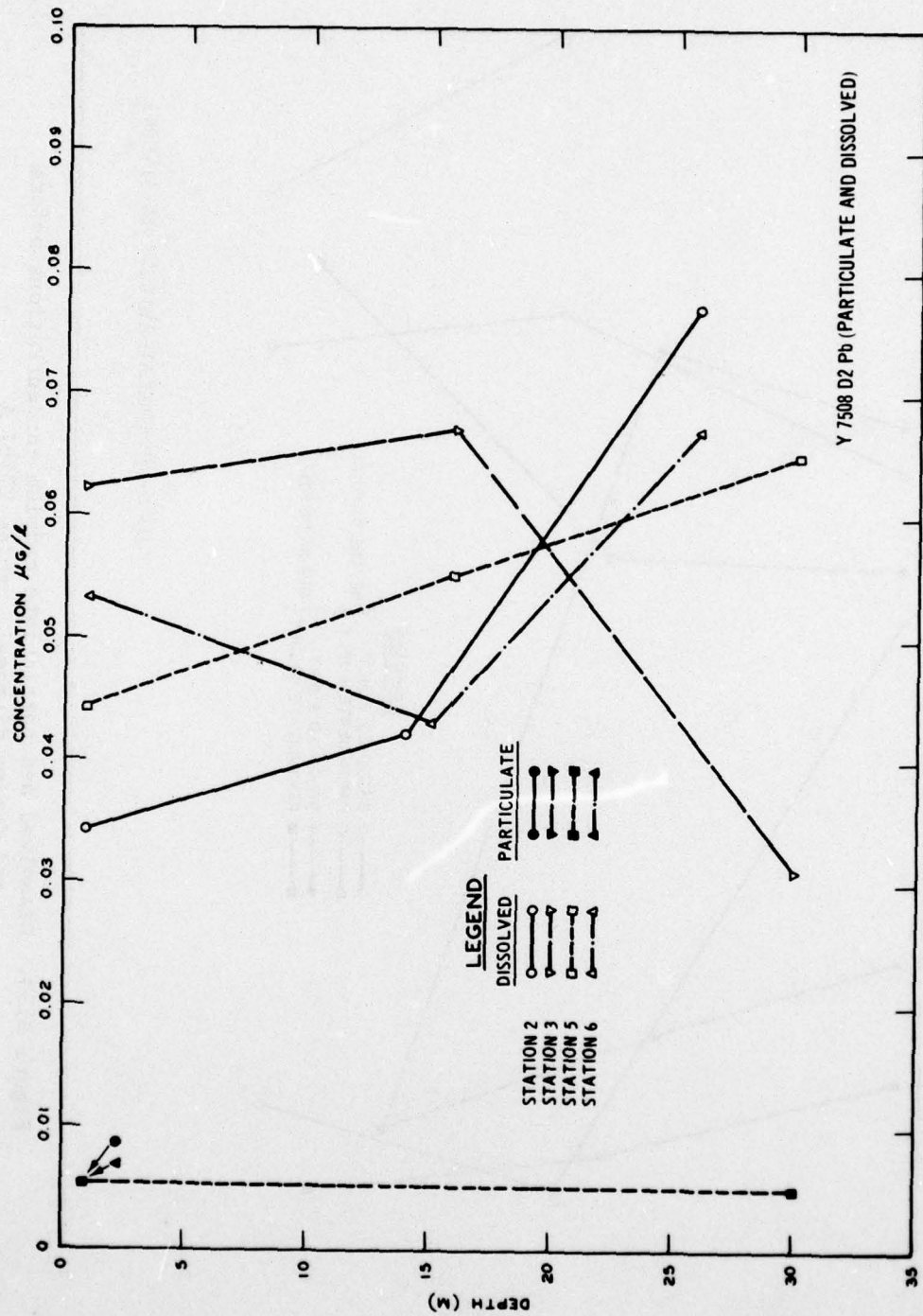
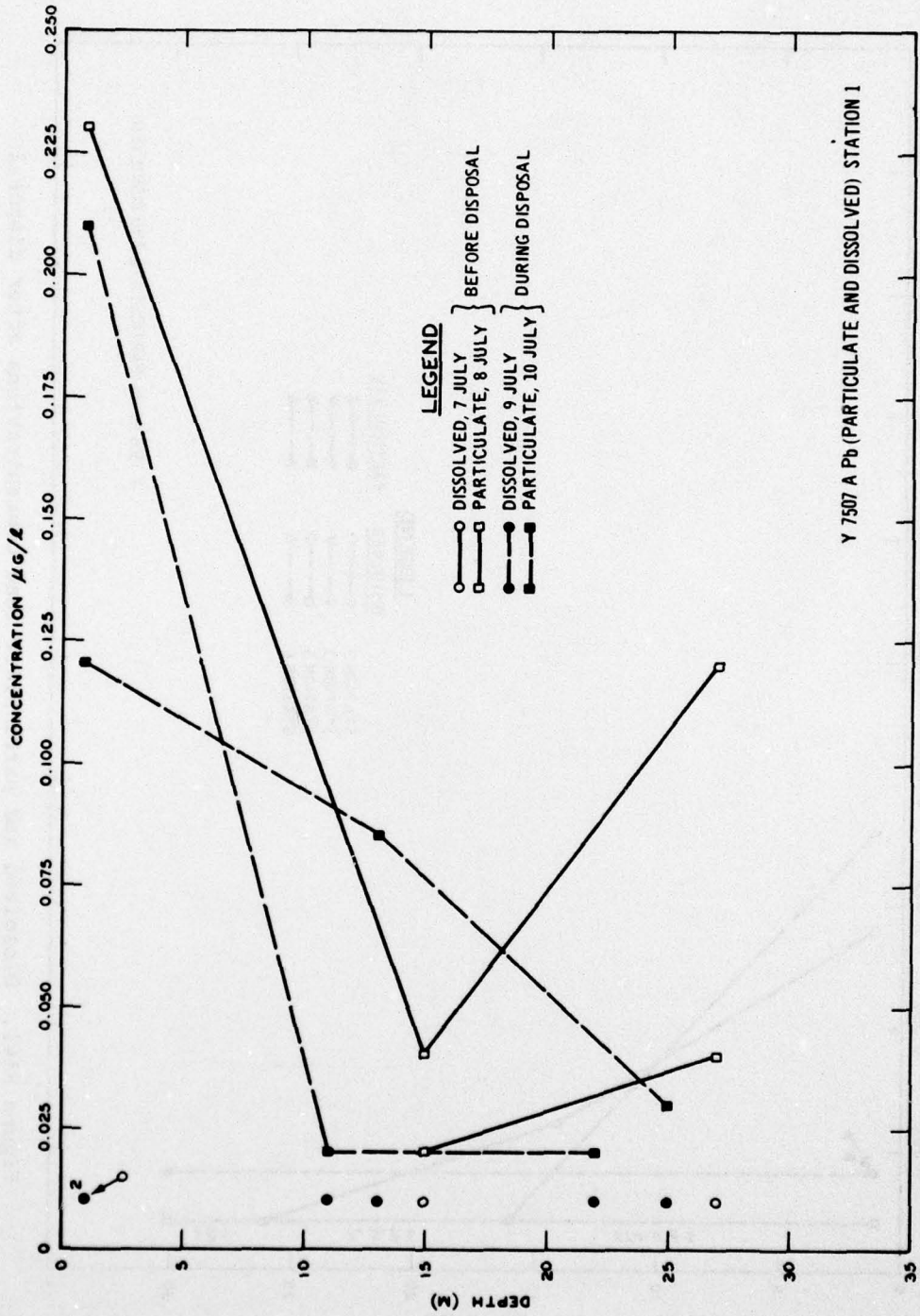


Figure B139. Dissolved and particulate cadmium concentrations after disposal



Y 7507 A Pb (PARTICULATE AND DISSOLVED) STATION 1

Figure B140. Dissolved and particulate lead concentrations before and during disposal

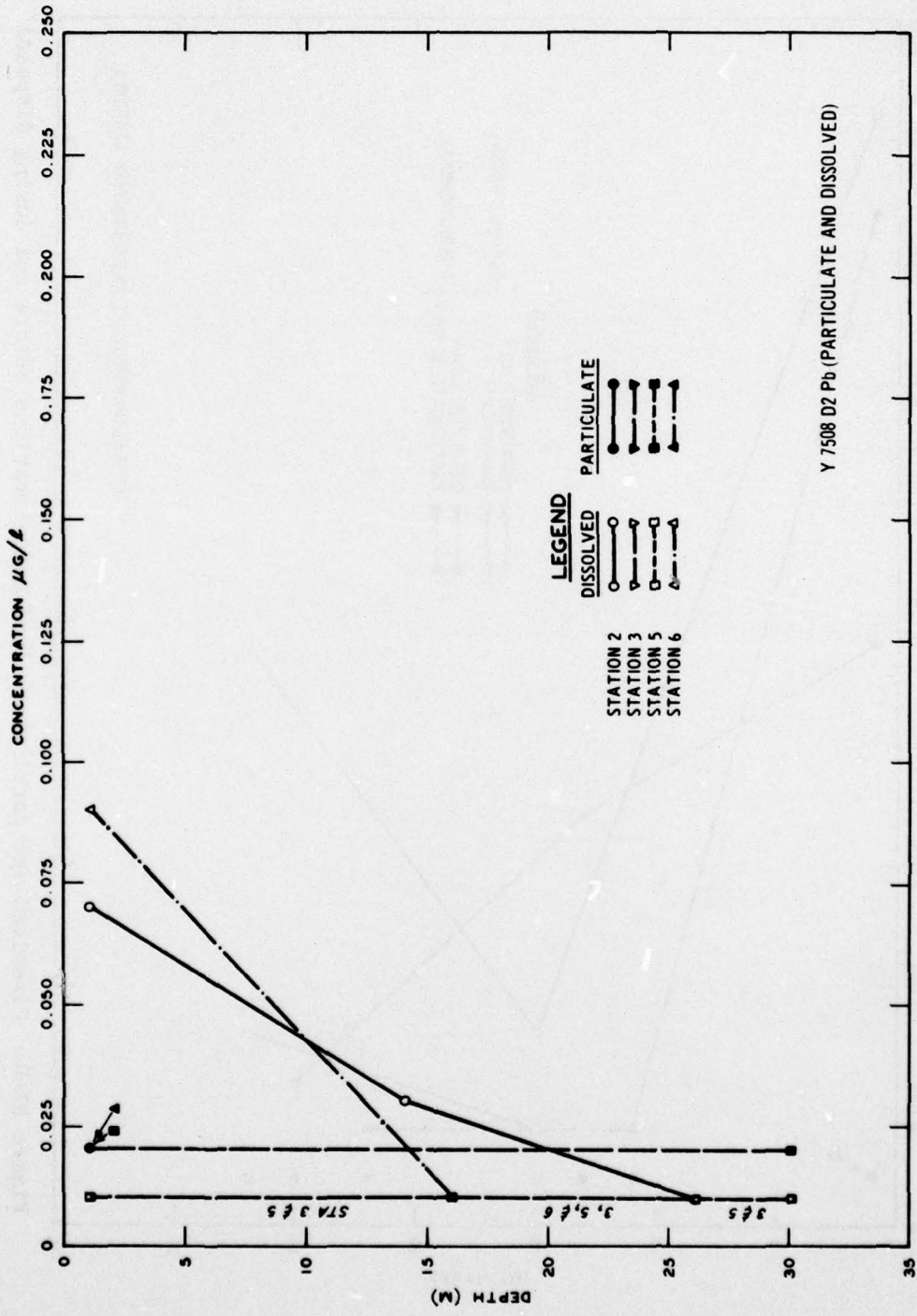


Figure B141. Dissolved and particulate lead concentrations after disposal

## APPENDIX A': STORAGE OF SEDIMENT SAMPLES CONTAINING SULFIDE

1. This appendix describes a brief investigation of the stability of sediment samples used for sulfide analysis:

a. Sample: Collected in Skipanon waterway with box corer, 10 October 1975. Station 75. Section 41-44 cm. About 1 kg sediment was placed in a sealed plastic bag and frozen until processing (15 October). The sample contained 57 percent water and was soft and gooey when thawed. The thawed sample was homogenized as well as possible by kneading the closed plastic bag.

b. Analysis: To check reproductivity of analyses and to check effect of minor variations in procedure (quantity and concentration of acid; sample size) eight samples were analyzed. Sulfide concentration (wet weight) ranged from 661 to 694 mg/kg (mean 678 mg/kg).

c. Storage: A total of 14 samples of the homogenized sediment was stored in 12-ml polypropylene disposal syringes. The open end of the syringe was well wrapped with plastic wrap (two layers). Seven of the samples were stored at room temperature (22°C) and seven were stored in a freezer (-10°C).

d. Results: Samples were analyzed after storage for periods of up to a year. The frozen samples averaged 735 mg/kg sulfide, and there was no dramatic change with increasing storage time. The sulfide of the frozen samples was somewhat greater than the sulfide concentration determined before freezing. The reason for this increase is not known.

2. The sulfide content of the unfrozen samples increased continuously with time. After 250 days, sulfide content was about 940 mg/kg, which represents an increase of 260 mg/kg. This increase is puzzling because the source of the additional sulfide is not obvious. The sulfate-S content of the interstitial water of a different core (Reference 9) taken at the same location was 0 to 230 mg/l. Since the sediment was about 60 percent water, there would appear to be less than 150 mg/kg sulfate-S available.

3. In a separate experiment three bags of unhomogenized sediment (1 kg or more) containing low sulfide levels were stored at 12°C and analyzed at various intervals. Each time they were analyzed the sediments were disturbed and exposed to air during removal of the sample used for analysis. After each analysis the bags were tightly closed so

as to retain minimum air. Results of duplicate determinations are given in the following tabulation:

Date of Analysis	<u>Sulfide, mg/kg</u>		
	Sample No. 4-1015	Sample No. 4-1520	Sample No. 6-2025
30 January 1975	5; 9	19;11	134;224
30 June 1975	8;29	<3;15	76;132
6 November 1975	<3;<3	17; 5	220; 55

a. Conclusions: The sulfide content of frozen sediment samples does not change significantly in storage of up to 1 year in absence of air. All the samples that were frozen and stored gave somewhat higher sulfide analysis after freezing (average difference 55 mg/kg; 8 percent). This study used sediment having a relatively high sulfide content. A similar study with a lower sulfide sediment (<100 mg/kg) would be desirable.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Holton, Robert L

Aquatic disposal field investigations, Columbia River disposal site, Oregon; Appendix B: Water column, primary productivity, and sediment studies / by Robert L. Holton ... [et al.], Oregon State University, School of Oceanography, Corvallis, Oregon. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

53, [153], 2 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-30, Appendix B)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract Nos. DACW57-75-C-0126 & DACW57-76-C-0081 (DMRP Work Unit No. 1A07B)

References: p.53.

1. Aquatic environment. 2. Columbia River. 3. Dredged material disposal. 4. Field investigations. 5. Pollutants. 6. Primary productivity. 7. Sediment. 8. Waste disposal sites. 9. Water column. I. Oregon. State University, Corvallis. Dept. of Oceanography. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-30, Appendix B.  
TA7.W34 no.D-77-30 Appendix B