Dredged Material Research Program

TECHNICAL REPORT D-77-30

AQUATIC DISPOSAL FIELD INVESTIGATIONS COLUMBIA RIVER DISPOSAL SITE, OREGON

APPENDIX A: INVESTIGATION OF THE HYDRAULIC REGIME AND PHYSICAL NATURE OF BOTTOM SEDIMENTATION

by

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Final Report

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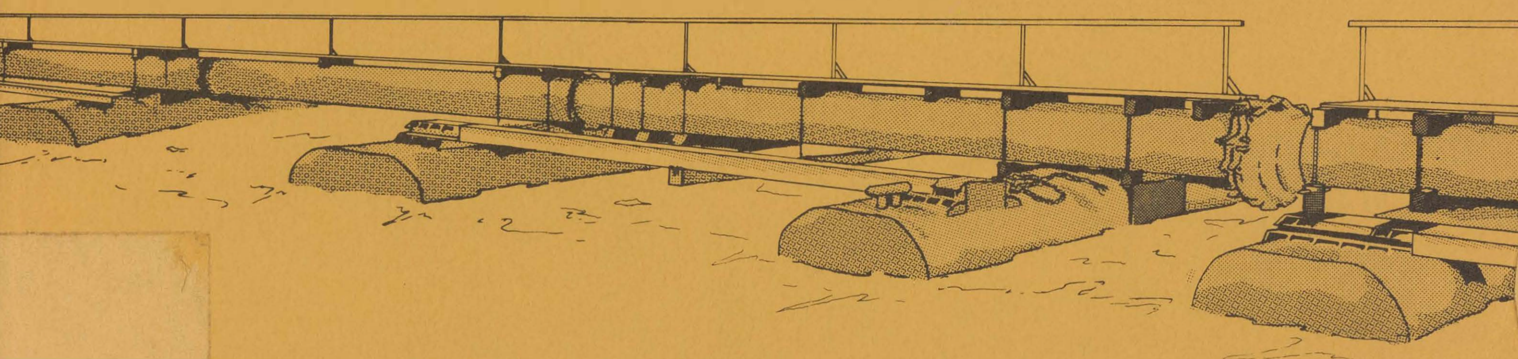

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P. O. Box 631, Vicksburg, Miss. 39180

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

DEPARTMENT OF THE ARMY
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31 January 1978

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

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, of the Corps of Engineers' Dredged Material Research Program. 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 activities on organisms and the quality of surrounding water, and the rate, diversity, and extent disposal 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 Disposal Site, 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 A: Investigation of the Hydraulic Regime and Physical Nature of Bottom Sedimentation, is one of five contractor-prepared appendices published relative to the Waterways Experiment Station Technical Report D-77-30 entitled: Aquatic Disposal Field Investigations, Columbia River Disposal Site, Oregon. The titles of all 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 appendices and provide a comprehensive summary and synthesis overview of the entire project.

3. The purpose of this study, conducted as Work Unit 1A07A, was to identify the hydraulic regime and the physical nature of bottom sedimentation in the vicinity of the mouth of the Columbia River. The report includes the results of a 19-month study of the bottom sediment characteristics, flow conditions, mineralogical relationships, and

bottom sedimentation in this region. Seasonal variations in these conditions are discussed and emphasis is placed on the interpretation of the sedimentary response to the flow conditions, including frequency and cause of sediment movement, mode and direction of transport, and quantities of materials being transported.

4. It can be concluded from this study that based on sedimentological data, dredged material deposits can be identified relative to ambient sediments. Combined sedimentologic and hydraulic results suggest that the dredged material deposit will remain in place with a slight tendency to migrate northward at a rate of approximately 0.5 km per year.

5. The results of this study are particularly important in determining placement of dredged material for open-water disposal. Referenced studies, as well as the ones summarized in this report, will aid in determining the optimum disposal conditions and site selection for either the dispersion of the material from the dump site or for its retention within the confines of the site, whichever is preferred for maximum environmental protection at a given site.

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

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16. DISTRIBUTION STATEMENT (*of this Report*)

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17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

Appendix A11 was reproduced on microfiche and is enclosed in an envelope attached inside the back cover of this report. Plates A1 and A2 are also in an envelope at the end of the report.

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Bottom sediment	Field investigations
Columbia River	Hydraulic regimen
Disposal areas	Sedimentation
Dredged material disposal	

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A two-part study was conducted in a region seaward of the Columbia River where disposal of large quantities of dredged material has occurred over the last several decades. The first part included repeated bathymetric surveys and sampling for distribution and seasonal variations of sediment texture and mineralogy throughout the study area, and especially at designated disposal sites. Near-bottom hydraulic conditions (waves, tides, currents, turbidity) were also measured at several sites and during all seasons. The (Continued)

20. ABSTRACT (Continued).

second part was related to an experiment in which 600,000 cu yd of material dredged from the Columbia River estuary were dumped at a specially designated site, which was monitored before, during, and after disposal. The objectives of the sedimentological aspects of the study were to identify and map all deposits of dredged material and to recognize seasonal and long-term changes. The objectives of the hydraulic aspects were to document the ambient near-bottom conditions, and their effect on the deposit at the experimental site.

Sedimentological data show that deposits of dredged material can be identified relative to the surrounding sediments. They tend to maintain their identity for many years, and disperse northward at approximately 0.3 nmi per year. At the experimental disposal site the volume of the bottom deposit was 61% of the total material dumped. Calculations of bedload transport rates, based on seasonal measurements of bottom currents, suggest that 830 cu yd of material (0.2% of the total) spread northward from the site about 0.25 nmi per year. This is similar to the rates determined by the sedimentological techniques. The coherent and complementary nature of the results emphasizes the value of combining both descriptive sedimentological techniques and measurements of oceanic processes for monitoring and predicting the fate of dredged material.

SUMMARY

This report represents the results of a study to investigate the hydraulic regime and physical nature of bottom sedimentation in the vicinity of the mouth of the Columbia River. The emphasis of this study was placed on the fate of dredged material that is deposited on an annual basis in any of several designated disposal sites off the Columbia River. The overall objective was to increase understanding of the fate of dredged material deposited in the ocean environment seaward of the Columbia River mouth and to improve the ability to make decisions regarding disposal practices.

The research program consisted of two funding periods with slightly different objectives for each part. Phase I began 15 August 1974 and continued until 31 August 1975. The emphasis during Phase I was directed toward the major disposal site in the area, designated Disposal Site B, where the largest volume of sediment dredged from the Columbia River mouth has been deposited. The program objectives were: (a) to describe the bathymetry and sediments in the area; (b) to make measurements of waves, currents, and suspended sediment concentrations in the bottom boundary layer during the range of environmental conditions; and (c) to interpret these findings with respect to expected levels of sediment movement.

During the latter part of Phase I, a decision was made by the Corps of Engineers (CE) to conduct a disposal experiment at a new site (G) chosen south of the river mouth, and between 9 July and 26 August 1975 599,868 cu yd* of dredged material was dumped on the site. Phase 2 of

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*A table of factors for converting U.S. customary units to metric (SI) can be found on page 21.

this study consisted of carrying out predisposal surveys of bottom sediment and bathymetric characteristics and monitoring the changes that occurred during and after the disposal experiment. Hydraulic measurements of waves, currents, and suspended sediment were also conducted in the vicinity of Site G. These data were used to interpret the impact of the disposal experiment on the existing environment and the fate of the dredged material following the experiment.

Field methods consisted of bathymetric surveys conducted during Phase I to provide a baseline bathymetric chart for the complete study area as well as surveys at Disposal Site G immediately before, during, and after the disposal experiment. An additional bathymetric survey was made in January 1976; however, data analysis could not be completed before the end of the contract period. Numerous sediment sampling surveys were conducted throughout the study area and were designed to characterize the complete area as well as document seasonal variations and the effects of the disposal experiment at Site G.

Bottom boundary layer measurements were made with two instrumented tripods designed to remain submerged for periods of 30 days and (a) measure current speed and direction 3.3 ft off the seabed, (b) measure bottom pressure fluctuations associated with waves and tides, (c) monitor water turbidity due to suspended sediment 4.3 ft above the seabed (three suspended sediment samples were also collected when turbidity levels reached predetermined values); and (d) take a bottom photograph every 30 min. Instrumented tripods were deployed at seven stations in and around Sites B and G and measurements were made during all seasons as well as during and immediately after the disposal experiment.

The data collected under this study were used to describe the physical nature of the marine environment in this area. These data also indicate the variations in bathymetry and bottom sediment over the historical past including existing disposal sites and suggest the future changes at the experimental Disposal Site G. A synopsis of the major conclusions is given below.

Bathymetry

A distinct bathymetric feature is observed at Disposal Site B that represents the deposition of dredged material discharged at this site. The volume of this deposit is estimated at 9.5×10^6 cu yd, which is approximately 33 percent of the total volume of dredged material discharged at this site since 1957.

The result of the disposal of approximately 600,000 cu yd of sediment at Site G is a circular sedimentary deposit about 2500 ft in diameter and 5 ft high. The volume of this deposit is estimated at 425,000 cu yd, which is 71 percent of the total quantity.discharged.

Boundary Layer Conditions

Bottom currents in the area are the result of tides, river effluent systems, winds, and waves. Currents respond mostly to surface wind stress from winter storms sweeping the coastal region. Wind-generated bottom currents may exceed 60 cm/sec (3.3 ft off the seabed); however, bottom currents at any instant may exceed 80 cm/sec. The strong bottom flows are primarily north-northwest in response to southerly storm winds.

Frequency of sediment movement as a result of bottom currents generated by winds and waves varied significantly on a seasonal basis.

Estimates of the percentage of time that sediment threshold conditions were exceeded during the sampling periods are summarized below.

Station*	Month	Percent of Time that Threshold of Grain Motion was Exceeded: Mean Bottom Currents ($\bar{U}_{100}$)	Percent of Time that Threshold of Grain Motion was Exceeded: Waves
1,2	Apr/May	11	21
3	June	0	21
4,5	Aug/Sept	3	6
6	Dec/Jan	66	93

From modern hydraulic studies, estimated annual bedload transport of bottom sediment northward across Disposal Site G in response to wind-generated currents resulting from major storms in 1975 is 830 cu yd, and the migration distance is estimated at 0.25 n mi. This suggests that the dredged material discharged at Site G will be relatively stable and will not show significant change resulting from sediment transport over the next few years.

Concentrations of suspended sediment (4.3 ft above the bed) in the study area range from background levels of 1.5 mg/ℓ to greater than 100 mg/ℓ. Extreme variations result primarily from river input near the river mouth and resuspension by wave activity. Background levels of suspended sediment at Site G were not observed to change significantly as a result of the disposal experiment; however, both the dredged material and the ambient bottom sediment contained low concentrations of silt- and clay-size fractions (<3 percent by weight).

*Station locations are shown in Figure A26 of the main text.

Sediments

The bottom sediments in the study are characterized by a wide variety of sizes ranging from 1.75 to 12ϕ (medium sand to clay). In general the sediments at the disposal sites are distinctly different than the ambient shelf sediment and hence are recognized as sediment dredged from a different sedimentary environment. The fact that the dredged material at Disposal Sites B and G has maintained its identity and location for a number of years corroborates the conclusion regarding the relative stability of these deposits.

The dredged material deposit at Disposal Site G is also identifiable by its size characteristics; however, through the winter season, the sediment characteristics of the deposit have been reverting to those of the ambient sediment predating the disposal experiment. This occurrence is thought to result from the subsequent migration of surrounding sediment to cover the Site G deposit rather than the removal of the disposal deposit. Subsequent analysis of bathymetry and bottom sediment samples collected after the winter season would be necessary to understand the full nature of the changes at Site G after the disposal experiment.

Mineralogical investigations corroborate the findings of the sediment size-distribution studies. Additionally, lobes of mineralogically distinct sediment are seen to extend north and west from Site B suggesting the slow but continued bedload transport of bottom sediment from the disposal site. The direction of transport is similar to the trend of the wind-generated coastal flow and the rate of migration (assuming a 20-yr time span) is approximately 0.3 nmi/yr, which is similar to estimates based on modern hydraulic studies mentioned above.

PREFACE

A contract for studies of bathymetry, sediment characteristics, and bottom boundary layer conditions (current speed, direction, wave and tidal motions, and suspended sediment concentration) was approved through the Portland District U. S. Army Corps of Engineers on 15 September 1974. The study was supported by the U. S. Army Engineer Waterways Experiment Station (WES), Environmental Effects Laboratory (EEL), Vicksburg, Mississippi, under Contracts No. DACW57-75-C-0063 and DACW57-76-C-0088 to the Department of Oceanography, University of Washington, Seattle. The report forms part of the EEL Dredged Material Research Program (DMRP).

The field work was carried out between 3 September 1974 and 6 January 1976 in an area seaward of the Columbia River Mouth and primarily at the designated sites used by the Corps of Engineers for disposal of dredged material.

During the course of the investigation, liaison was maintained between the University of Washington and the Portland District and WES by means of conferences, telephone and written communications, and quarterly progress reports. The work at the University of Washington during the first study year was coordinated by Dr. J. S. Creager. The Phase 2 portion of the study and this final report were coordinated by Dr. R. W. Sternberg. Other senior investigators involved with this study were Drs. W. Glassley, L. Larsen, and J. D. Smith.

The authors wish to acknowledge the help of numerous persons and other scientific programs in carrying out this study and preparing the final report. The Portland District was extremely helpful throughout the contract period. Dr. Mark Holmes and Mr. Richard Roberts assisted with the field program, data interpretations, and sediment analyses. The authors wish to acknowledge the agencies that originally funded the development of the equipment that was used in this study, specifically the Energy Research and Development Administration for its initial support of the instrumented tripods and the Maritime Administration for support of the wave recorder.

Special thanks are also due D. Morrison, G. Peterson, S. Woods, C. Nittrouer, and T. McManus for their help in accomplishing this research and producing the final report.

The study was conducted under the direction of the following EEL personnel: Dr. R. M. Engler, Environmental Impacts and Criteria Development Project Manager, and Glenn Boone, Site Manager. The study was under the general supervision of Dr. John Harrison, Chief, EEL.

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

CONTENTS

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** Plates A1 and A2 are also in an envelope at the end of the report.

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CONVERSION FACTORS, CUSTOMARY TO SI
UNITS OF MEASUREMENT

Customary units of measurement can be converted to SI as follows:

Multiply	By	To Obtain
microns	0.000001	meters
feet	0.3048	meters
miles (U.S. statute)	1.609344	kilometers
miles (international nautical)	1852	meters
fathoms	1.8288	meters
square yards	0.8361274	square meters
square miles	2.589988	square kilometers
cubic yards	0.7645549	cubic meters
tons (short)	907.1847	kilograms
pounds (force) per square inch	6894.757	pascals
knots (international)	0.5144444	meters per second

Aquatic Disposal Field Investigations

Columbia River Disposal Site, Oregon

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

PART I: INTRODUCTION

1. This report presents the results of a study to investigate the hydraulic regime and physical nature of bottom sedimentation in the vicinity of the mouth of the Columbia River. Specific emphasis was placed on the conditions existing in and around the dredged material disposal sites designated B and G by the Portland District of the U. S. Army Corps of Engineers in order to better understand the fate of materials dredged from the Columbia River and discharged at those sites.

2. This study is part of a larger coordinated effort that was initiated by the Chief of Engineers, Washington; implemented by the U. S. Army Corps of Engineers, Waterways Experiment Station (WES), Vicksburg; and administered through the U. S. Army Corps of Engineers (CE), Portland District. The program of study off the mouth of the Columbia River began in August 1974. The total effort encompassed the observation and documentation of the physical, chemical, geological and biological characteristics of the region adjacent to the Columbia River mouth. This particular report includes the results of a 19-month study of the bottom sediment characteristics, flow conditions, and bottom sedimentation in this region. These data were used to describe the general nature of the bottom sediments in the area, including dredged material deposits, and the overall hydraulic conditions including the various causes of bottom currents and associated sediment movements.

Seasonal variations are also discussed and considerable effort is spent in interpreting the sedimentary response to the flow conditions including frequency and cause of sediment movement, mode of transport, and quantities of materials being transported.

3. It is generally concluded that these studies were not of sufficient duration to document the full impact of seasonal fluctuations in the hydraulic system or the longer term changes in dredged material deposits. Significant data have been collected, however, and it is hoped that these results will increase the understanding of the physical and sedimentological characteristics of this region in particular and will aid in future planning and management discussions regarding open-ocean disposal of dredged material.

PART II: OBJECTIVES

4. This program consisted of two funding periods with slightly different objectives for each part. Phase 1 began 15 August 1974 and continued until 31 August 1975. The objectives during Phase 1 were:

- a. Evaluate available bathymetric charts and establish in situ stations to describe and delineate hydraulic regime and the bottom sedimentation characteristics of disposal Site B and surrounding area.
- b. Document current speed and direction, wave activity, and meteorological and tidal fluctuations, and characterize the site and surrounding area according to expected levels of sediment movement.
- c. Sample the sediment during a wide range of environmental conditions to evaluate the sedimentary response to specific energy sources.

5. During the latter part of Phase 1, a shift in the emphasis of the program was requested. The Corps of Engineers proposed to establish an experimental disposal site (designated Site G) in order to investigate the fate of dredged material discharged there. The area chosen had not received dredged material in the past and hence would represent a unique experiment to investigate the fate of a dredged material deposit in an open-water disposal environment. The disposal experiment began on 9 July 1975 and continued until 26 August 1975, during which time 599,868 cu yd of dredged material was discharged.

6. Phase 2 of this study began on 1 September 1975 and continued until 31 March 1976. The emphasis during this phase was on

experimental Disposal Site G where the objectives were:

a. Monitor and evaluate the hydraulic processes active near the seabed at the study site insofar as necessary to determine the effect of the processes on the materials placed at Site G during the disposal experiment.

b. Continue regional mineralogic sampling and mapping of various sediment types with particular emphasis on Site G.

c. Attempt to document temporal and spatial change in the morphology of the disposal mound following termination of the disposal experiment.

7. This report presents the composite results of the complete study. No attempt has been made to clearly separate Phase 1 from Phase 2 but rather to integrate all aspects of the study into a coherent statement of results.

PART III: BACKGROUND

Regional Studies

8. In 1944 the Hanford Site, adjacent to the Columbia River near Richland, Washington, became the location of the first nuclear reactor for producing plutonium. Between the years 1944 and 1964, nine reactors were built at the Hanford Site and plutonium production continued until 1971. While these reactors were in operation, a variety of low-level radioactive wastes were introduced into the Columbia River by way of reactor cooling effluent. These radioactive products were carried by the Columbia River to sea and have been identified throughout the marine environment along the Washington-Oregon coast and adjacent oceanic areas.

9. In carrying out its responsibilities for monitoring the effects of these radioactive wastes, the Atomic Energy Commission (AEC) sponsored and coordinated numerous environmental studies by State, Federal, and private agencies. These studies were begun in 1961 and continue to this day even though the reactor and effluent conditions have changed significantly in the past 5 yr. As a result of these investigations, a wealth of information exists to provide a scientific background for this particular study. In general, these previous studies extended over a large geographical scale and did not include detailed studies near the mouth of the Columbia River; however, the results are important in providing insights into the nature of the oceanic system and boundary conditions so that this particular study can be tied in with the regional oceanography. A comprehensive summary of the AEC sponsored research is given in Pruter and Alverson (1972).

Winds

10. Wind effects are very important in the study area and show significant seasonal variations. The summer season in the northeast Pacific Ocean is dominated by the North Pacific High, which is best developed in July and is located near 30°N latitude, 150°W longitude. Winds during this period are characteristically from the north and northwest with dominant monthly speeds approximately 5 to 15 knots (Barnes et al. 1972).

11. Toward the end of the summer season, the North Pacific High weakens and wind patterns are dominated by a continuing series of low pressure systems migrating from west to east across the Washington-Oregon coast. Winds associated with these disturbances are quite strong and blow from the south and southeasterly directions. They occur as individual storms spanning 3- to 7-day intervals during which time the average wind speeds are approximately 10 to 20 knots with maximums of 50 to 55 knots (Barnes et al. 1972). The annual wind cycle over the northeast Pacific Ocean coastal area (42° to 48°N) and the north-south distribution of winds observed during 1961-1963 are summarized in Figures A1 and A2. The 1975 mean winds observed at the Columbia River Lightship are presented in Appendix A.

Tides

12. Tides along the Pacific coast of North America are of the mixed semi-diurnal type. At the mouth of the Columbia River, the mean tidal range is 6.5 ft. Extreme low water is estimated at -3.0 ft below mean lower low water (mllw) and extreme high water is +11.6 ft above mllw (Neal 1972).

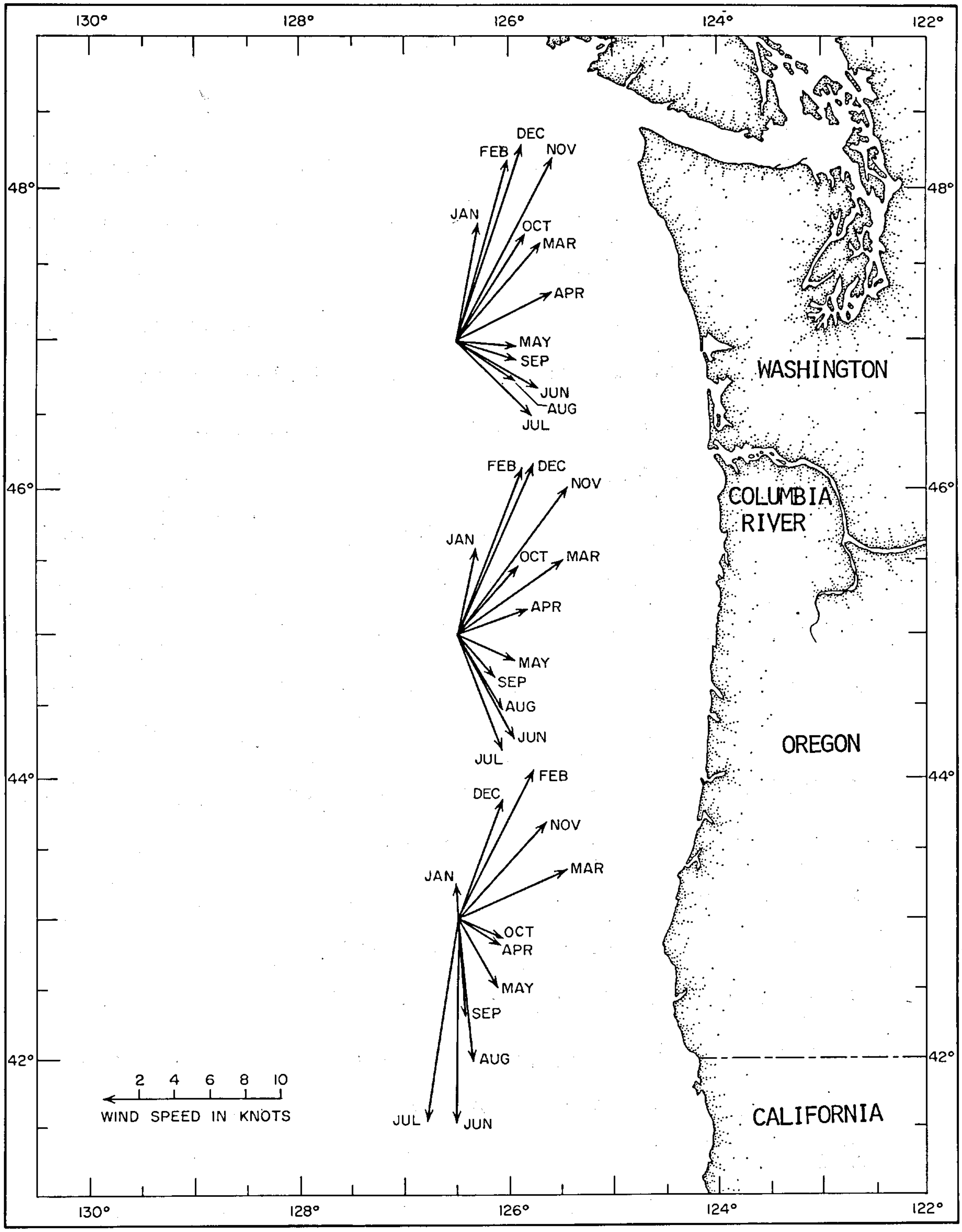

Figure A1. Average speed and direction of monthly winds at three ocean sites for the period 1961 to 1963 (Duxbury, Morse, and McGary 1966)

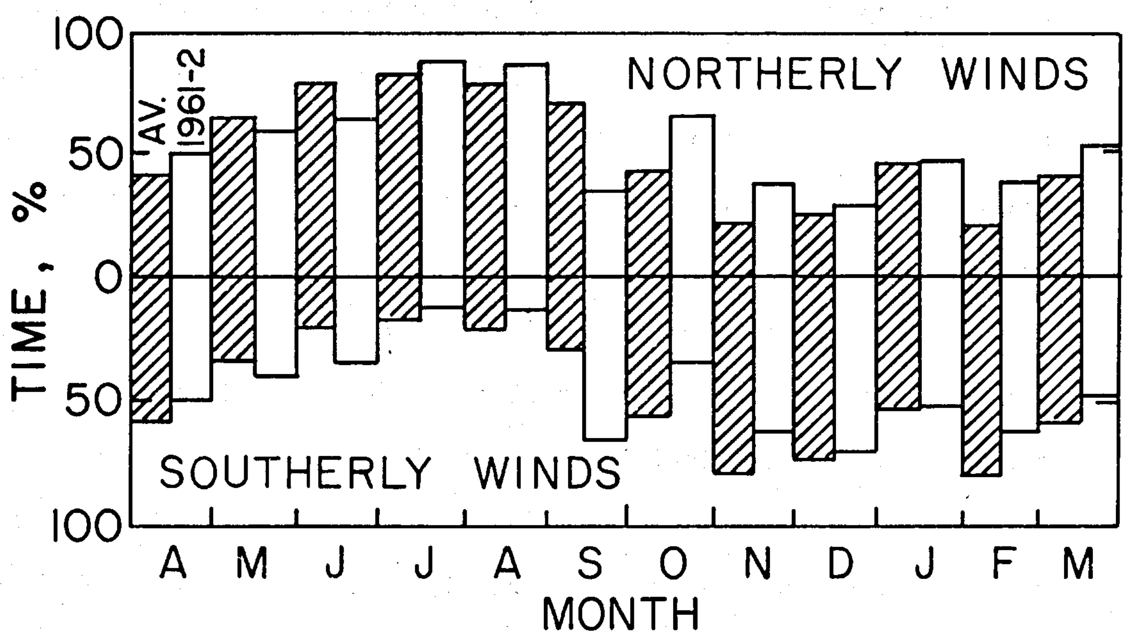

Figure A2. Annual wind cycle over the Northeast Pacific Ocean coastal area (42° to 48°N), (after Pruter and Alverson 1972)

Waves

13. Statistical wave studies for the mouth of the Columbia River have been carried out using hindcast methods in order to investigate several problems associated with harbor design at the mouth of the Columbia River (National Marine Consultants 1961). First, wave statistics were developed for three deep-water locations off the Washington-Oregon coast for the years 1956, 1957, and 1958. Second, wave statistics were developed at the three stations for the 12 most severe storms that occurred during the period 1950-1960. Third, the physical conditions near the Columbia River mouth were applied to the hindcast wave conditions in order to predict actual wave conditions at the channel entrance.

14. The results of this study revealed that waves associated with major storms can vary from 23 to 30 ft in significant height H_s and 11 to 14 sec in significant period T_s and generally approach from the southerly quadrants. The refraction study suggested that the maximum wave conditions expected at the river mouth are: $H_s = 33.5$ ft; $T_s = 13$ sec; direction from 234°. A storm that produces significant waves of 33.5 ft at the river mouth would statistically produce a maximum wave of 1.27 x 33.5 ft or 42.6 ft. Indeed, waves in excess of 40 ft have been reported by the U. S. Coast Guard at the mouth of the Columbia River (Lockett 1959).

General circulation

15. The coastal region of Washington and Oregon is characterized by relatively weak and poorly defined surface currents (5 to 30 cm/sec) which exhibit significant seasonal variations (Barnes and

Paquette 1957, Barnes et al. 1972). Offshore, the West Wind Drift moving eastward across the north Pacific Ocean separates into two streams, one moving northward feeding the Gulf of Alaska Gyre and one moving southward parallel to the west coast of North America approximately 300 nmi offshore. This south setting current is called the California Current (Figure A3).

16. Inshore of the main stream of the California Current is a poleward flowing surface flow called the Davidson Current. This current varies in its seasonal characteristics in response to the wind patterns of the northeast Pacific. The Davidson Current flows northward in the winter (average speed 10 to 20 cm/sec) and reverses in the summer (average speed 5 to 20 cm/sec) to become incorporated into the permanent California Current (Barnes et al. 1972).

17. Circulation on the Washington Continental Shelf is controlled predominantly by large-scale regional weather systems originating in the Gulf of Alaska (Hopkins 1971, Smith and Hopkins 1972). In the winter, southerly winds cause Ekman transport toward the coast and the formation of coastal downwelling and a seaward sloping sea surface. As a result of the balance between the Coriolis force and the offshore pressure gradient caused by the sloping sea surface, a northerly barotropic current develops and eventually downwelling destroys stratification, allowing these currents to extend to the bottom. In the summer, northerly winds cause offshore Ekman transport, the formation of coastal upwelling, a landward sloping sea surface, and a seaward sloping pycnocline and southerly barotropic surface currents. At depth, the pressure gradient force, resulting from the inclined surfaces of constant

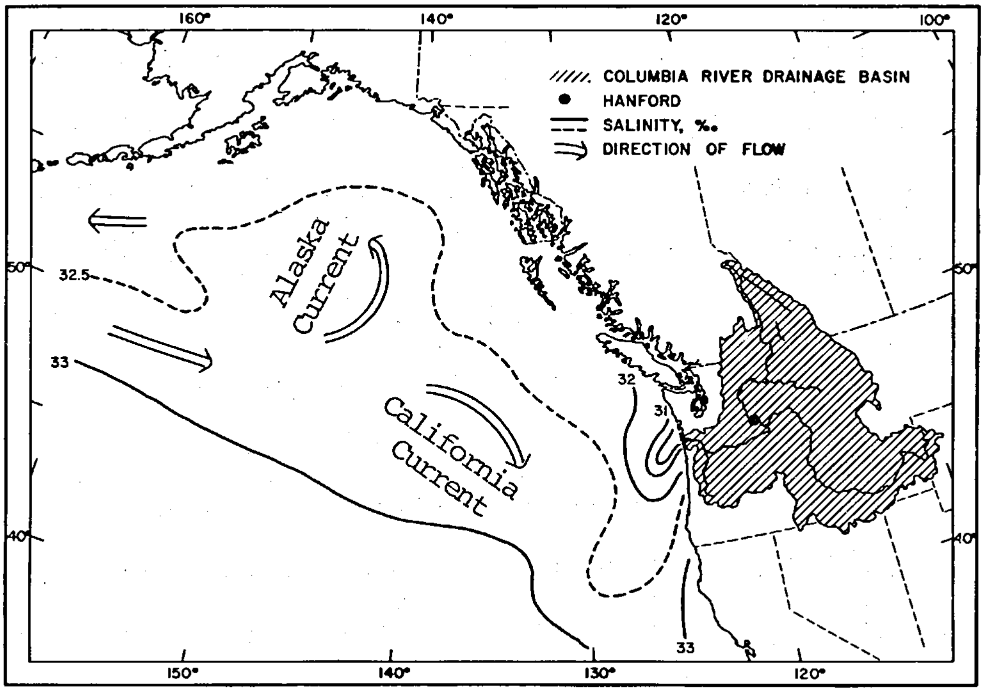

Figure A3. Map of Columbia River drainage basin and Northeast Pacific Ocean showing generalized summer salinity distribution and permanent circulation (after Barnes et al. 1972)

Table A1

Summary of Current Speed and Direction Measurements

Along the Oregon-Washington Coast (after Pruter and Alverson 1972)*

(a) Surface and Near-surface Currents

Speed, cm/sec	Direction	Season	Measurement Method	Reference
5-20	South	Summer	Dynamic heights	Budinger et al. (1964)
10-20	North	Winter	Dynamic heights	
5-10	Southerly	Summer	Drogue	Stevenson and Pattullo (1967)
4-8	Southerly	Summer	Drift bottles	Thompson and Van Cleve (1936)
16-22	Northerly	Winter	Drift bottles	Burt and Wyatt (1964)
21.0	215°T	July-Aug	Current meters	Collins and Pattullo (1970)
13.8	025°T	September	Current meters	
19.3	205°T	Sept-Oct	Current meters	

(b) Near-bottom Currents and Movement of Sediment Components

Type of Observation	Position or Area	Depth or depth range, m	Height off bottom, m	Speed, cm/sec	Direction, $^{\circ}$True	Reference
Direct Measurement	$46^{\circ}24'$N $124^{\circ}20'$W (310° 20 km from Columbia R. mouth)	79-88		4.5	330°	Hopkins (1972)
Bottom Drifters	Columbia R. mouth to Strait of Juan de Fuca	>40<180?	0.1-0.5	1.2	345°	Gross, Morse and Barnes (1969); Morse, Gross and Barnes (1968).
Radionuclides from Hanford	Off Columbia R. mouth to 60 km north	~40 100	Bottom sediments	0.07	343°	Gross and Nelson (1966)

*See References at end of main text.

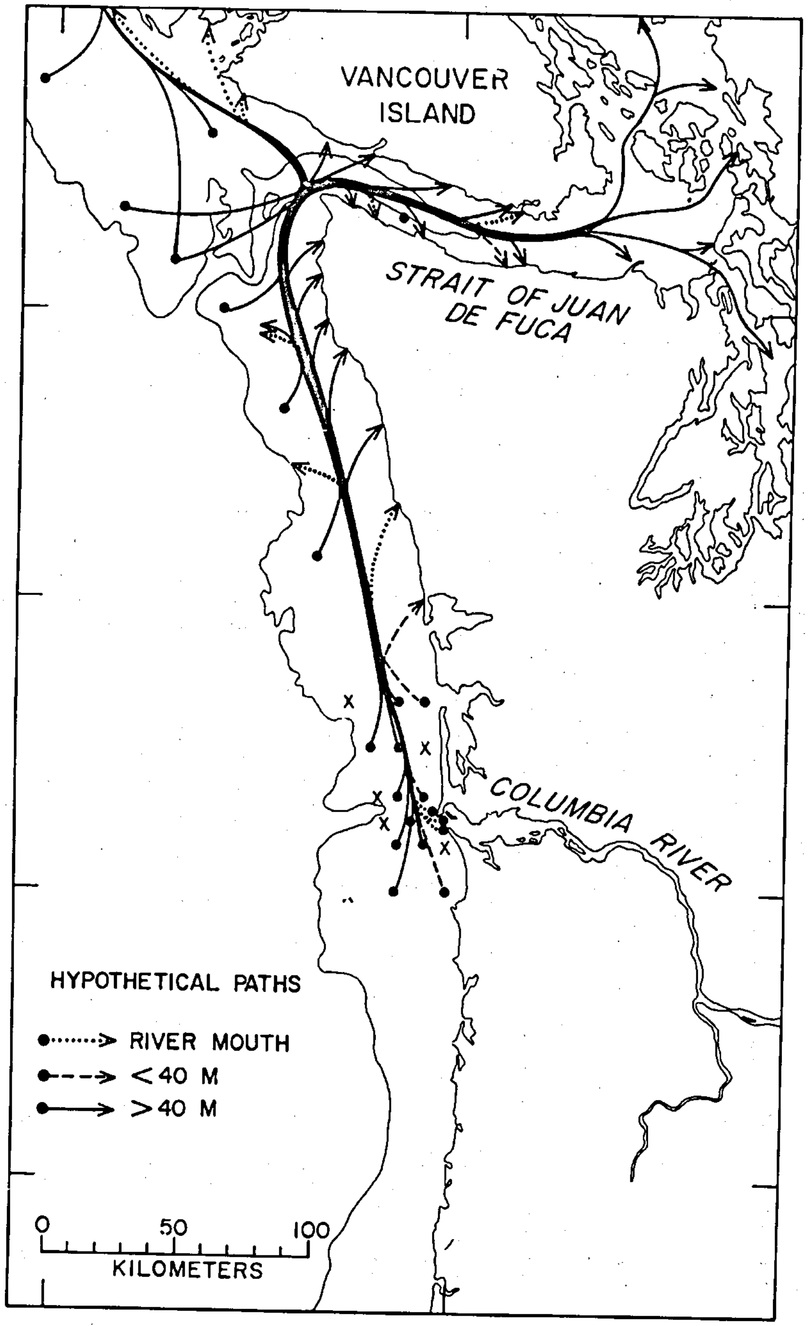

Figure A4. Hypothetical paths, and approximate recovery positions of seabed drifters found between the Columbia River and Vancouver Island, more than 100 km from the release point (modified from Barnes, Duxbury, and Morse 1972)

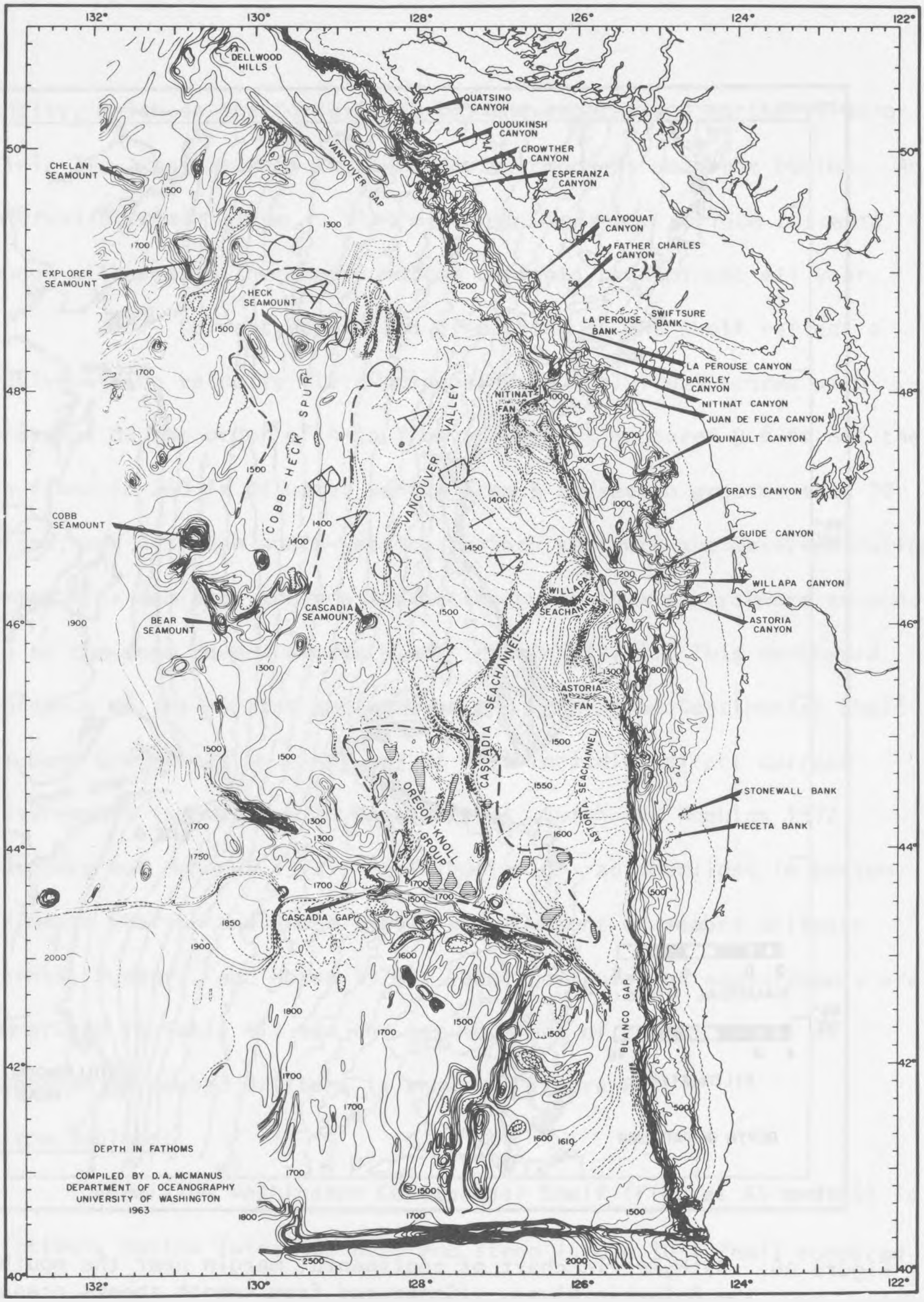

Figure A5. Bathymetric chart of continental margin and deep-sea floor off the Pacific Northwest (after McManus 1972 Contour interval, 10 fathoms)

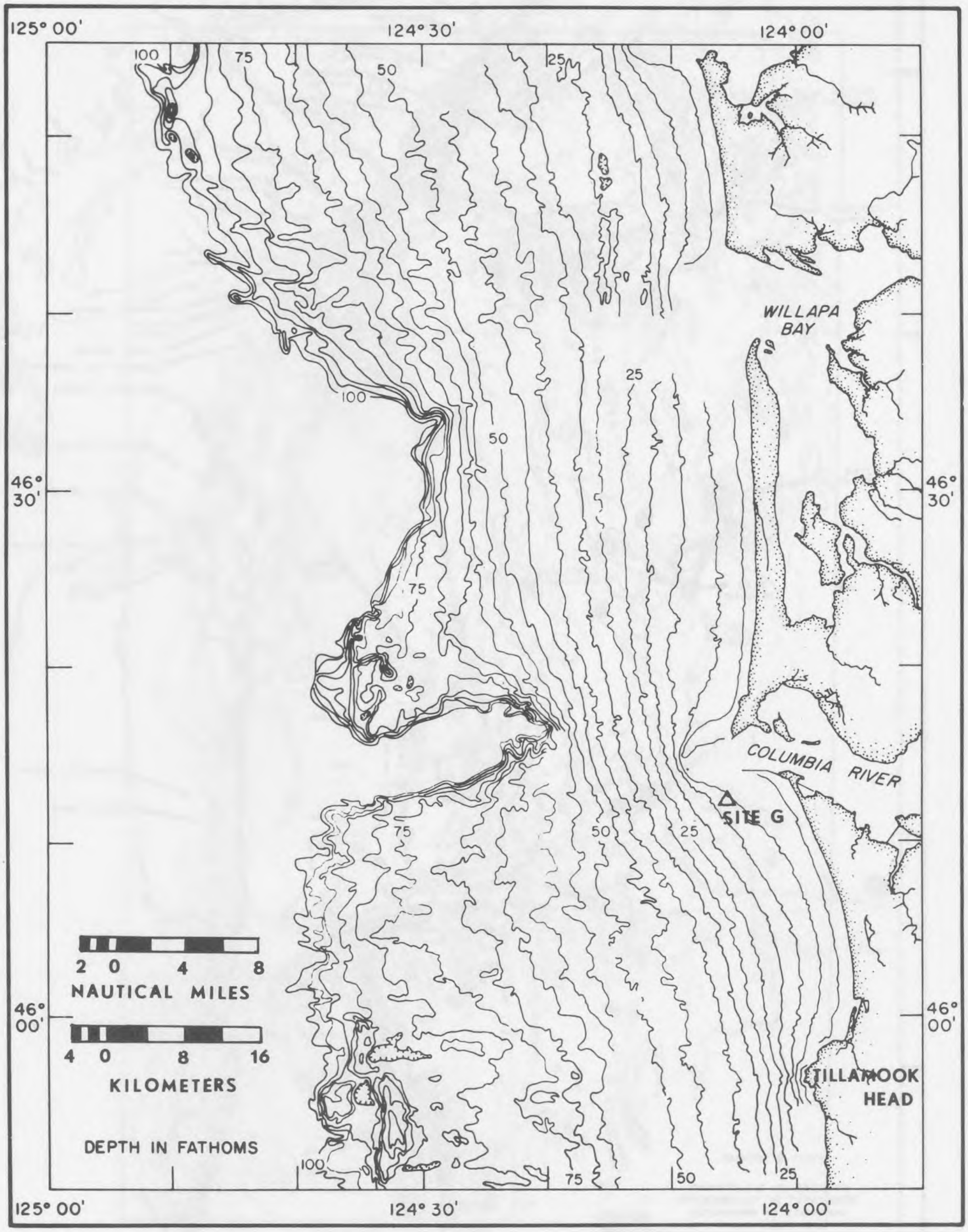

Figure A6. Bathymetric chart of continental margin near the mouth of the Columbia River. (Contoured from smooth sheets prepared by the U.S. Coast and Geodetic Survey. Depths are in fathoms; contour interval, 5 fathoms) density, balances the Coriolis force, and generates a northerly baroclinic flow that exceeds the barotropic component near the bottom. An interesting observation is that although winds and surface currents change with season, northerly bottom currents predominate all year.

18. Current speeds and directions on the shelf reflect a highly varying velocity field responding to individual storms with durations on the order of 4 to 7 days. Speeds measured 9.8 ft off the sea floor in 260 ft of water varied from 5 cm/sec to greater than 70 cm/sec, and although south-setting surface currents are observed during summer, the dominant surface and bottom currents are northward responding to the more severe winter winds (Hopkins 1971). This northward dominance of the current patterns on the Washington Continental Shelf has been documented in a variety of ways including direct current measurements (summarized in Hopkins 1971, Smith and Hopkins 1972, Sternberg and McManus 1972); distribution of radionuclides in bottom sediments (Barnes and Gross 1966); and movement of seabed drifters (Barnes, Duxbury, and Morse 1972). Shelf circulation measurements are summarized in Table A1, and the net movement of bottom waters as suggested by seabed drifters is shown in Figure A4.

Bottom sediment

19. The Washington Continental Shelf (Figures A5 and A6) is relatively narrow (width 27 nmi) and steep (slope 30 ft/nmi) compared to the average shelf characteristics described by Curray (1965): width, 41 nmi and slope, 10 ft/nmi. A number of submarine canyons incise the shelf, but the shelf gradient is extremely uniform, with the shelf break occurring at about 660 ft.

20. Studies of the distribution of sediment texture (McManus 1972, Kulm et al 1975), mineralogy, (White 1970), composition, (Gross et al. 1967), and micropaleontology (Harman 1972) all suggest three separate sedimentational regimes parallel to the coast (Figure A7) and very similar to those predicted by the Curray (1965) and Swift (1970) models. At depths less than 200 ft, modern sands from the Columbia River accumulate, a midshelf modern silt deposit extends between the 200- to 500-ft depth contours, and seaward of the 500-ft depth contour, relict sands remain uncovered (McManus 1972, Smith and Hopkins 1972). A unique series of radionuclide studies has confirmed the accumulation of modern silts and clays from the Columbia River as the midshelf deposit, predominantly north of the river mouth (Gross and Nelson 1966). As shown by McManus (1972) and Smith and Hopkins (1972), this silt derives from the Columbia River and is transported seaward diagonally across the shelf toward N25-30^{o}W (Figures 11.6 and 11.7 in McManus 1972). Numerous authors note the importance of three grain-size classes over the northern Oregon and southern Washington Continental Shelf (e.g., Smith and Hopkins 1972 and Kulm et al. 1975): the coarse silt fraction just discussed is one; the other two are a very fine sand (3.5ø mode according to Smith and Hopkins (1972) and 3.25ø mode according to Kulm et al. (1975) and a fine sand (3.0ø mode and 2.75ø mode respectively by the same authors). The differences (as shown below) are probably the result of different analytical techniques rather than real differences. All authors agree that the 3.25 to 3.0ø sediments originate in the Columbia River, are modern and quite mobile under the influence of present day processes, and are distributed both north and

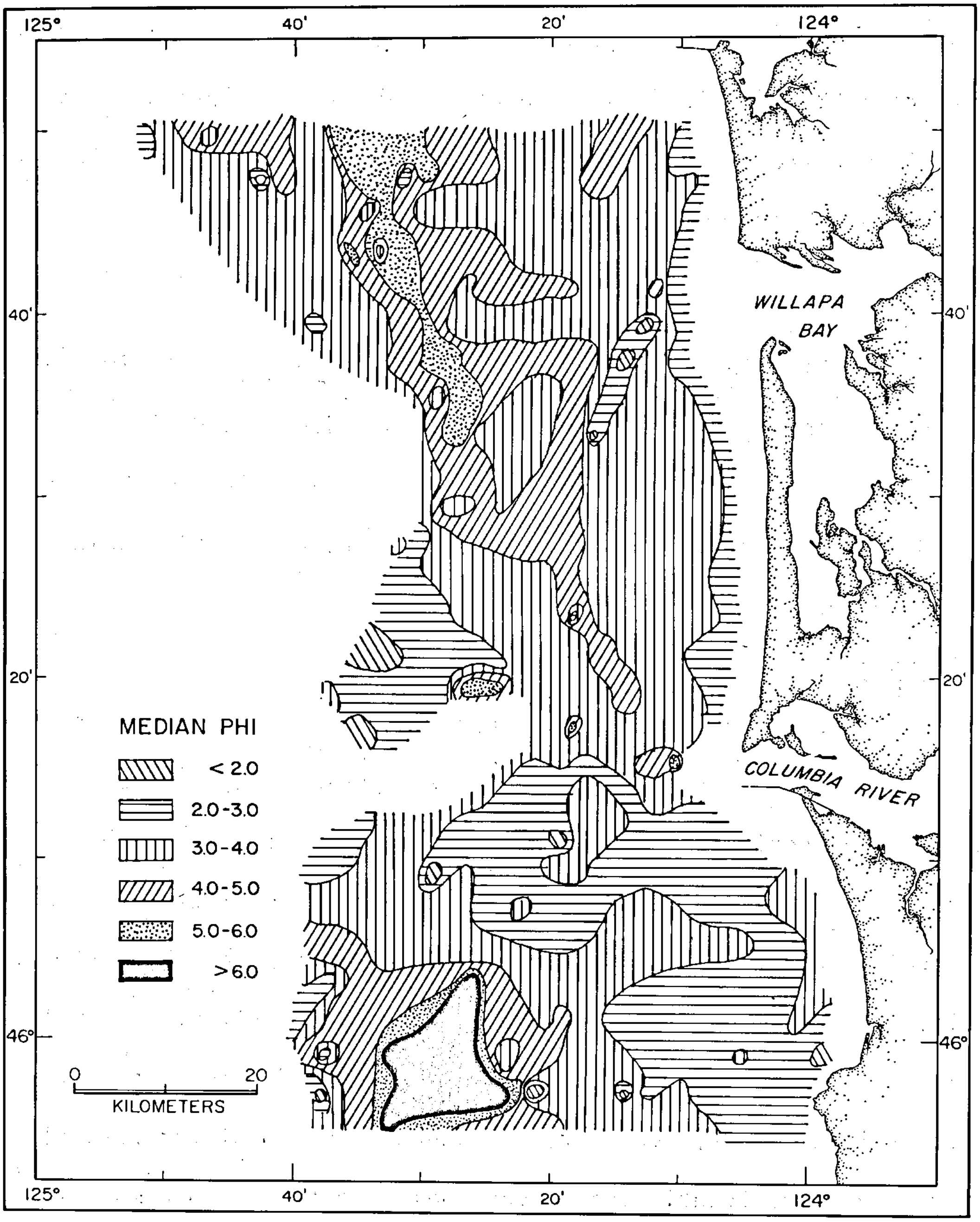

Figure A7. Distribution of sediment types based upon three end member classification of Shepard (1954) (after MacManus 1972) south of the river entrance. Kulm et al. (1975) and McManus (1972) consider the 2.75 to 3.0ø modes inshore as modern and offshore on the outer shelf as relict. Smith and Hopkins (1972) argue that this fraction occurring ubiquitously is probably relict everywhere.

River System

21. The Columbia River, which is the largest river along the Pacific coast of North America, is approximately 1210 miles in length and drains approximately 259,000 square miles of land within Oregon, Washington, Nevada, Wyoming, Idaho, Montana, and British Columbia (Figure A8).

Discharge

22. The Columbia River discharge varies significantly throughout the year reflecting the peak periods in local precipitation as well as spring snow melt from the higher altitudes of the catchment basin. A 15-yr mean discharge curve is shown in Figure A9. The average annual discharge is approximately 250,000 cu ft/sec. The primary discharge maxima occurs in May and June as a result of snow melt and flows of 1.2×10^6 cu ft/sec have been recorded. The secondary maxima occurs in November, December, and January due to winter rainfall and may vary significantly due to seasonal conditions. Minimum river flow occurs in August-September with an average discharge of 70,000 cu ft/sec and a maximum low of 65,000 cu ft/sec (Neal 1972). The Columbia River accounts for 60 percent of the total contribution of winter runoff along the coast between San Francisco Bay and the Strait of Juan de Fuca. During the spring, summer, and autumn, the contribution of the Columbia

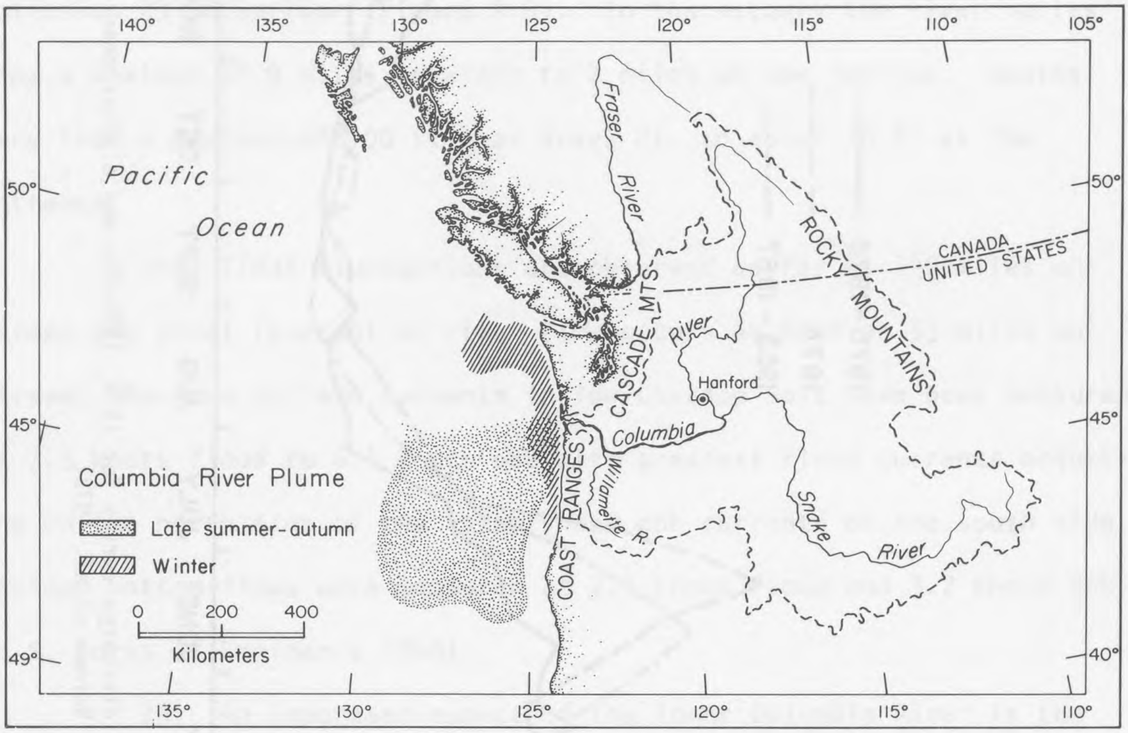

Figure A8. Map of the Columbia River drainage basin and the Northeast Pacific Ocean showing generalized seasonal distribution of the Columbia River plume. The limits of the plume are defined as the 31.5% surface isohaline (after Conomos et al. 1972)

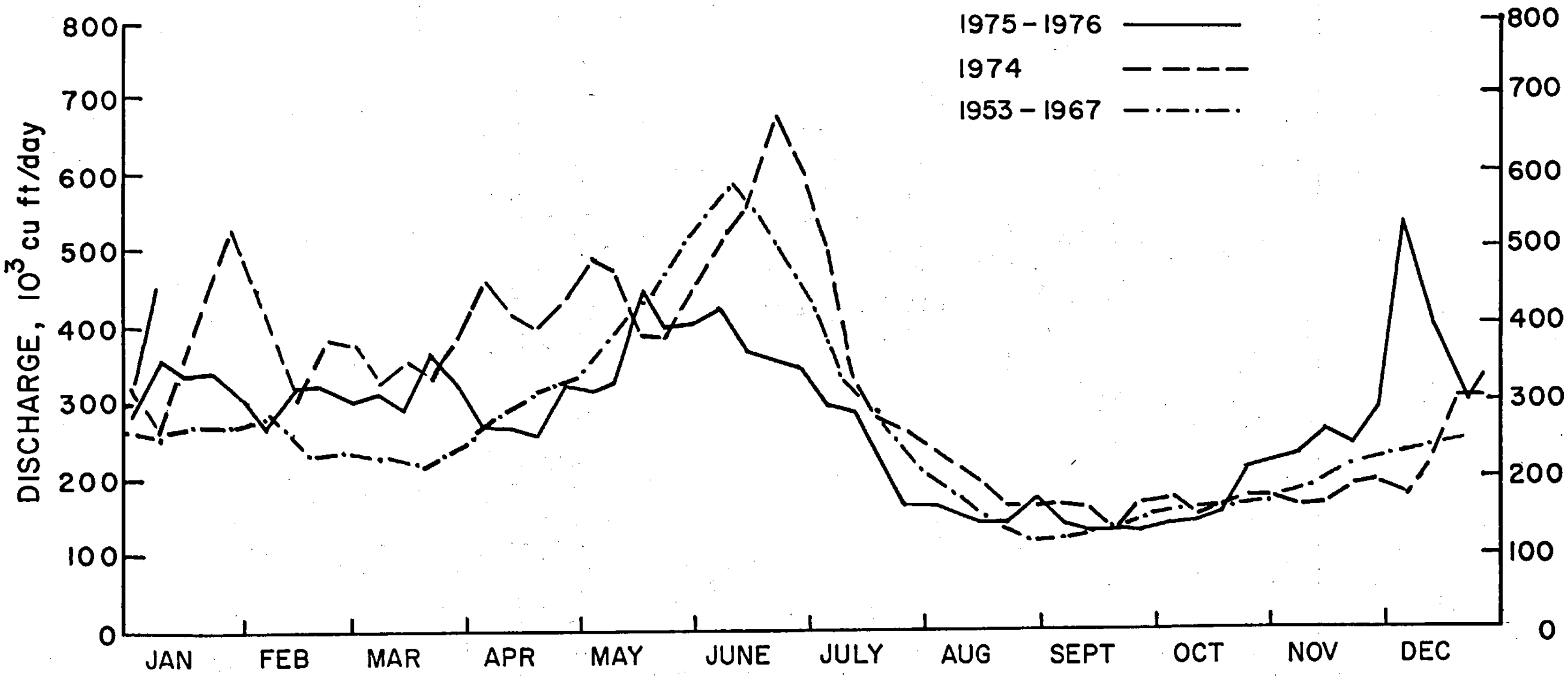

Figure A9. Columbia River discharge curves for 1974, 1975-76, and a 15-yr mean for 1953-1967 (after Barnes et al. 1972)

River is 90 to 95 percent of the total river runoff.

Estuary

23. The estuary of the Columbia River extends from the mouth to approximately Harrington Point, the maximum distance of seawater intrusion 23 mi upriver (Figure A10). In the estuary the river varies from a maximum of 9 miles in width to 2 miles at the jetties. Depths vary from a maximum of 100 ft near Grays Pt. to about 70 ft at the entrance.

24. Tidal fluctuations are observed as far as 140 miles upstream and tidal reversal of river flow occurs as much as 53 miles upstream. Maximum surface currents inside Clatsop Spit have been measured at 3.5 knots flood to 6.4 knots ebb with greatest flood currents occurring on the north side of the estuary and ebb currents on the south side. Maximum bottom flows were measured at 2.4 knots flood and 3.2 knots ebb (U.S. Corps of Engineers 1960).

25. An important aspect of the lower Columbia River is the estuarine circulation associated with mixing processes and the intrusion of seawater into the lower regions of the river. Maximum seawater intrusion reaches approximately 23 miles upstream. This varies according to river flow and tidal cycle. During the spring discharge maxima and the lower-low period of the tidal cycle, the salt-wedge intrusion is less than 5 miles. In the late summer, with low river discharge, seawater intrudes from 17 to 23 miles upstream depending on the tidal cycle. The Columbia River estuary is generally considered to be a partially mixed estuary as defined by Pritchard (1955). This classification changes, however; during low river discharge and maximum tides,

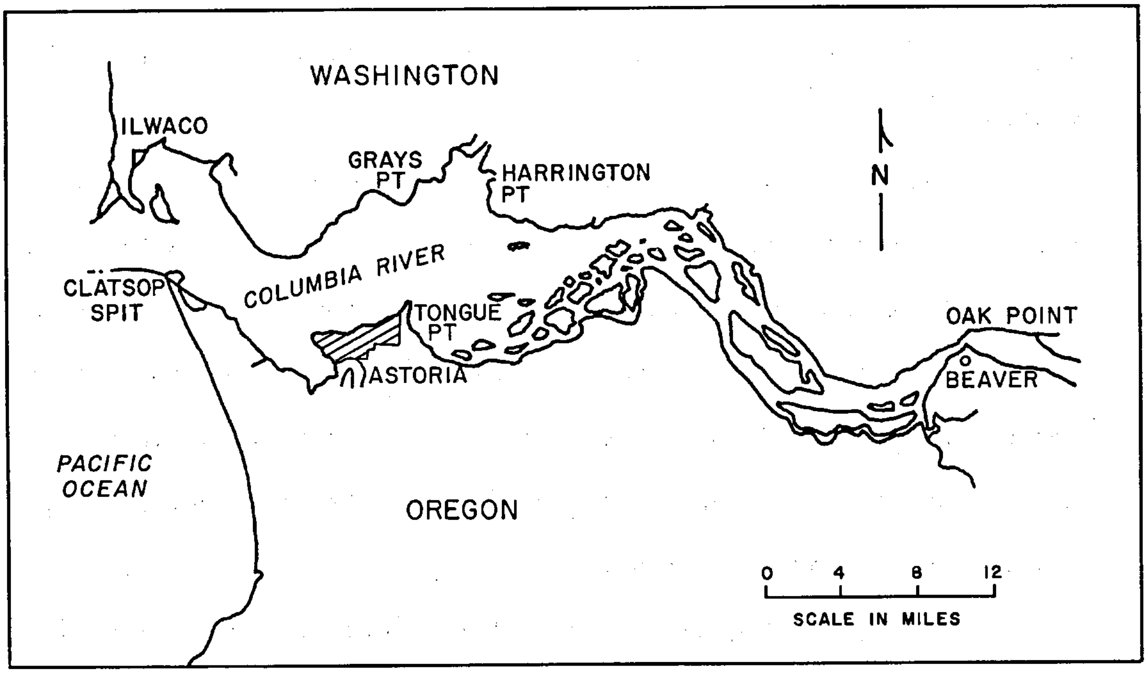

Figure A10. The Columbia River Estuary

the estuary tends toward vertical homogeneity while at high river discharge and low tide the classification shifts towards a horizontally stratified estuary (Neal 1972).

Sediment load

26. Estimates of suspended sediment load of the Columbia River and major tributaries have been summarized by Whetten et al. (1969) and Judson and Ritter (1964) and the results are given below:

Investigator	Year	River Position	Annual Suspended Load tons/yr
Van Winkle (1914a,b)	1910-1911	Cascade Locks (Bonneville)	7×10^6
Judson and Ritter (1964)	1950-1952	Denudation Rate Calculation	3.3×10^7
Haushild et al. (1966)	1962-1963	Vancouver, Wa.	8.4×10^6

The above values are for suspended load discharge. Bedload discharge, although not measured, is assumed to be approximately 10 percent of the suspended load (Judson and Ritter 1964; Whetten et al. 1969), hence bedload discharge is estimated at somewhat less than 10^6 tons/yr.

27. Textural characteristics of suspended load have been investigated by Conomos (1968) and Hubbell et al. (1971). Conomos found that, typically, 70 to 95 percent of suspended material in the Columbia River estuary was lithogenous with modal diameters of 8 to 4ø (0.004 to 0.063 mm) and a maximum of about 2.5ø (0.18 mm). Hubbell et al. compared suspended particulates during periods of minimum and maximum river flow (14 September 1968 and 23 May 1970, respectively), and the results are summarized in Table A2. In general, the major size class in suspension is silt-sized (56 to 88 percent by weight) with sand sizes

Table A2

Textural Composition of Suspended Sediment 5 ft Above the Bed at Various Times in the Tidal Cycle and at Various Longitudinal Positions in the Estuary (after Hubbell et al. 1971)

Date	Relative Time in Tidal Cycle	Location (Columbia River Mile)	Suspended Sediment Concentration mg/ℓ	Texture: Percentage in Class			Texture: Concentration in Class mg/ℓ		
				Sand	Silt	Clay	Sand	Silt	Clay
14 September 1969	1-1/2 hr after peak ebb velocity	14.0	17	0	63	37	0	11	6
	Low slack	14.0	24	1	71	28	0	17	7
	Low slack	18.2	11	0	56	44	0	6	5
	1/2 hr before peak flood velocity	14.0	59	9	81	10	5	48	6
	1/2 hr before peak flood velocity	18.2	87	3	83	14	3	72	12
	1-3/4 hr after peak flood velocity	14.0	85	3	85	12	3	72	10
	1/2 hr before high slack	18.2	60	0	70	30	0	42	18
	3/4 hr before peak ebb velocity	14.0	67	0	83	17	0	56	11
	3/4 hr before peak ebb velocity	18.2	34	0	88	12	0	30	4
23 May 1970	1/2 hr before peak flood velocity	5.6	310	7	46	47	22	142	146
	Peak flood velocity	10.7	344	8	71	21	28	244	72
	3/4 hr after peak flood velocity	8.5	638	1	65	34	6	415	217

varying from 0 to 9 percent depending on tidal cycle and river discharge. Suspended clays vary from 10 to 47 percent of the total sample.

28. Temporal and spatial variations in suspended particulate matter are so great that the extraction of average values as discussed above are relatively meaningless. Examples of variations of suspended sediment are discussed by Hubbell et al. (1971). During high river discharge, the concentration of suspended particulates is very large near the seabed with the maximum (>700 mg/ℓ) occurring somewhat after the peak in the ebb velocity and during the salinity transition associated with the advance and retreat of the salt wedge. On the successive flood tide, suspended sediment concentrations near the bed exceeded 600 mg/ℓ, lagged the peak flood velocity, and generally occurred in association with the salinity transition. During low river flow the concentration maxima are lower (~300 mg/ℓ), occur during the salinity transition, and more closely follow the times of maximum current. The pattern illustrated above is characteristic for partially mixed estuaries in that concentrations can vary significantly from tide to tide and for various flow conditions; the turbidity maxima corresponds approximately to the position of the leading edge of the salt wedge in the estuary.

River entrance improvements

29. The history of improvements at the Columbia River entrance including dredging operations through 1962 has been reported by Lockett (1959, 1962). Only a pertinent summary of this information is presented here. Prior to any permanent structures that were built at the entrance to the Columbia River, the main river channel passed

through the northern side of the entrance. This route was probably the result of the northward growth of Clatsop Spit, which forced the river along the northern side of the estuary (Figure A11. Lockett, Fig. 1 1959). It then turned sharply south to pass between the very prominent outer tidal delta and Clatsop Spit. In 1895 a permanent south jetty was completed to a length of 4.5 miles. Clatsop Spit continued to accrete northward over the jetty and force the main channel northward. By 1913 the south jetty had been extended an additional 2.1 miles with a more westerly alignment and by 1917 the north jetty had been completed to a length of 2.4 miles. In spite of the construction of southward pointing groins in 1939, northward migration of the main entrance channel continued to undermine the north jetty. Lockett (1962) reported that between 1939 and 1955 almost 15×10^6 cu yd of sediment was dredged from the entrance. This sediment was removed mainly from the north end of Clatsop Spit to retard its growth. In 1956 the Corps of Engineers began dredging the entrance seasonally to a channel depth of 48 ft. The modern entrance as shown in Figure A12 (Lockett, Fig.9 1962) is maintained by annual dredging seaward of the south jetty and between the jetties.

30. The effects on the bottom morphology produced by jetty construction are significant. Off the north jetty 30-ft depths have been displaced 7,000 ft seaward and the outer tidal delta appears to have been displaced seaward 10,000 ft or more between 1880 and 1962. Modification of the river entrance also appears to have caused a change in sediment texture. Grain-size analyses of bin samples collected from

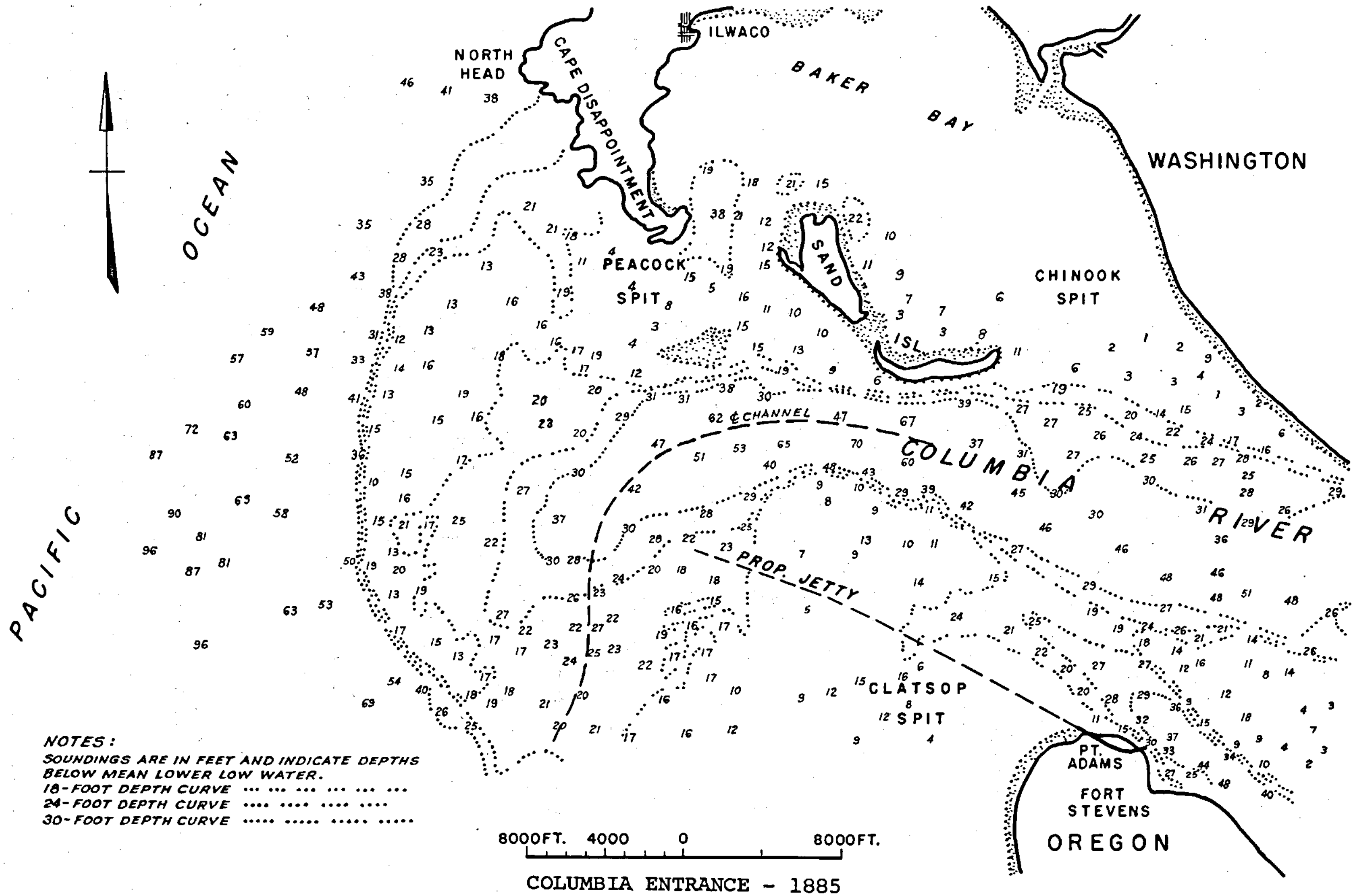

Figure A11. Columbia River entrance bathymetry before dredging 1885 (after Lockett 1959)

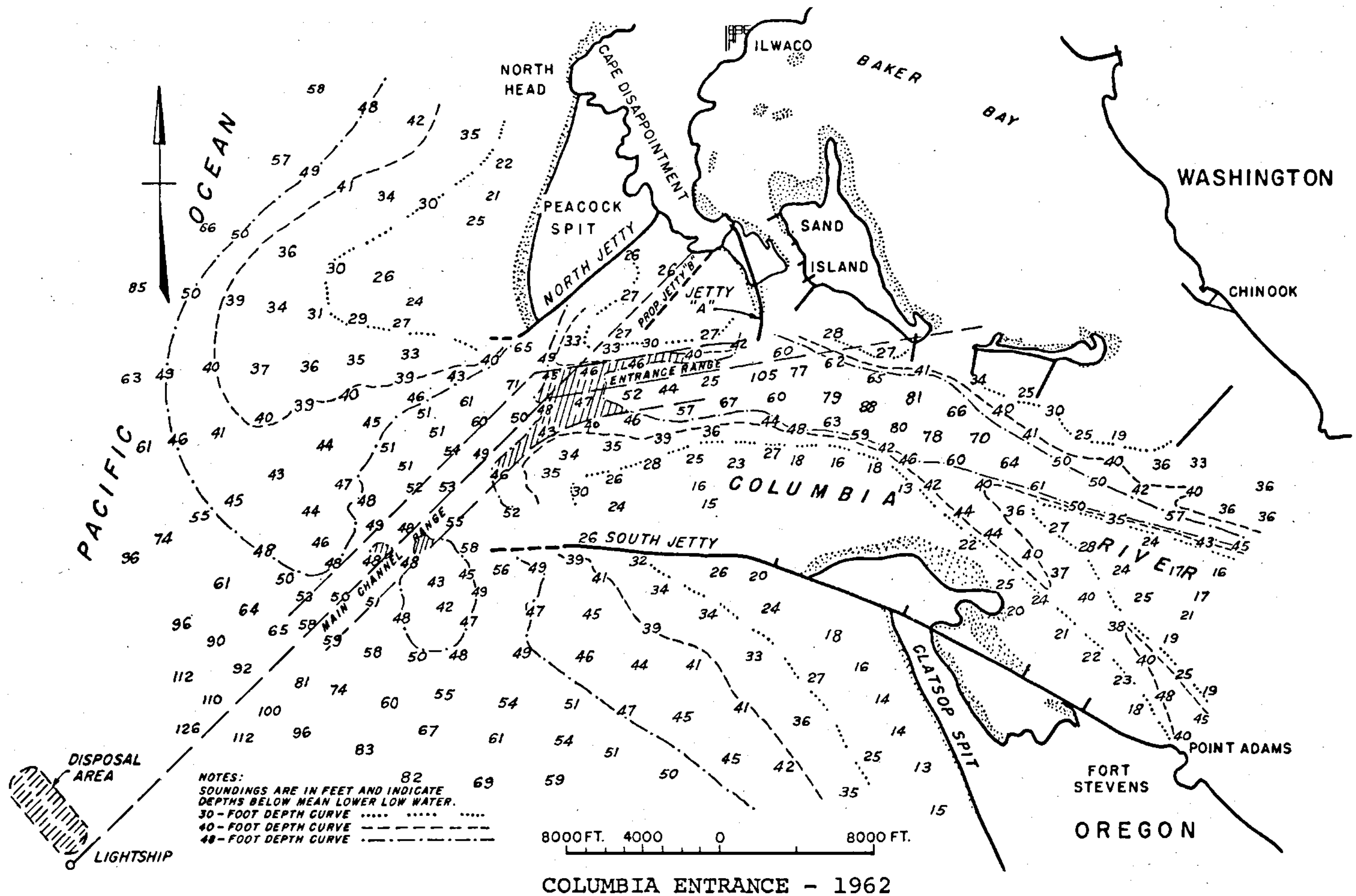

Figure A12. Columbia River entrance bathymetry 1962 (after Lockett 1962) the dredges before and after 1956 when the 48-ft channel dredging was started, indicate a distinct decrease in grain size after channel deepening (Table A3). Evidently the deeper water depths produced by the dredging resulted in weaker currents through the entrance and hence finer grained deposits or finer grained sediments were exposed and not removed by prevailing currents.

31. Precise location of the areas used for disposing of the dredged material is difficult. As can be seen in Figure A13, there are five open-water sites (A, B, E, F, and G) designated as disposal areas. Records of dredging operations supplied by the Portland District for the period 1957-1975 indicate the following distribution of dredged material:

Site	Total Volume Disposed cu yd
A	1,675,882
B	28,197,900
E	8,481,727
F	713,150
G	599,868

Additionally some 8,735,215 cu yd may have been placed near Site A and 935,915 cu yd at Site B during the 1956 dredging season when the channel depths were increased from 40 to 48 ft. It is difficult to determine accurately positions of disposal because the locations of disposal sites have apparently changed with time as displayed on various maps produced through the years by the Portland District (Lockett 1962). Evidently in 1956 Disposal Site B extended south and east along its general present alignment to include the area of Disposal Site F, and Disposal Site A was much nearer the end of the south jetty and had a more north-south alignment.

Effluent Plume

Geographical distribution

32. As a result of seasonal variations in river discharge, winds, and surface currents in the coastal and offshore regions of Washington-Oregon, it is expected that the Columbia River effluent would show various distribution patterns at sea. The extreme differences in the oceanic distribution of the river effluent occur in the late spring-early summer when river flow is at a maximum and in the winter when storm conditions with associated strong current movements and vertical mixing of the low salinity effluent waters prevail. The geographic distribution of the low salinity effluent waters is quite different during these seasons. During the summer (when the effluent discharge is just past its maximum), winds are from the north, and surface currents flow south to southwesterly. Under these conditions the effluent plume, as identified by the 32.5 ^{o}/oo surface isohaline, is at its yearly maximum and extends southward and offshore (Figure A14a). The plume is observed as much as 250 nmi southward and 150 nmi seaward of the coast.

33. During the winter, the river flow is variable depending on the coastal precipitation. Also, strong southerly winds prevail and coastal surface water is forced northward and toward the coast as a result of the Ekman transport. Under these conditions, the effluent

Table A3

Summary of Bin Samples Collected From Dredges Before and After Dredging the Channel Depth to 48 ft in 1956 (after Lockett (1959)

Date of Sampling	D_{10}* ø	D_{10}* mm	D_{60}* ø	D_{60}* mm	Uniformity Coefficient D_{60}/D_{10}
(a) Clatsop Spit Bin Samples					
23 July 1952	2.32	0.20	1.88	0.28	1.40
15 May 1953	2.32	0.20	1.94	0.26	1.30
8 June 1953	2.56	0.17	2.18	0.22	1.29
10 June 1954	2.82	0.23	1.74	0.30	1.30
26 July 1955	2.25	0.21	1.74	0.30	1.43
31 May 1956	2.42	0.18	1.88	0.28	1.55
22 August 1956	2.56	0.17	2.32	0.20	1.18
22 August 1956	2.94	0.13	1.94	0.26	2.00
16 September 1957	3.06	0.12	2.56	0.17	1.42
(b) Outer Bar Bin Samples					
26 July 1955	3.06	0.12	2.42	0.18	1.50
26 July 1955	2.84	0.14	2.12	0.25	1.64
31 May 1956	3.06	0.12	2.18	0.22	1.83
22 August 1956	3.06	0.12	2.00	0.25	2.08
22 August 1956	2.74	0.15	2.06	0.24	1.60
16 September 1957	2.94	0.13	2.32	0.20	1.53

*D_{10} = grain size of 10th percentile of size distribution plotted cumulatively by weight; D_{60} = 60th percentile.

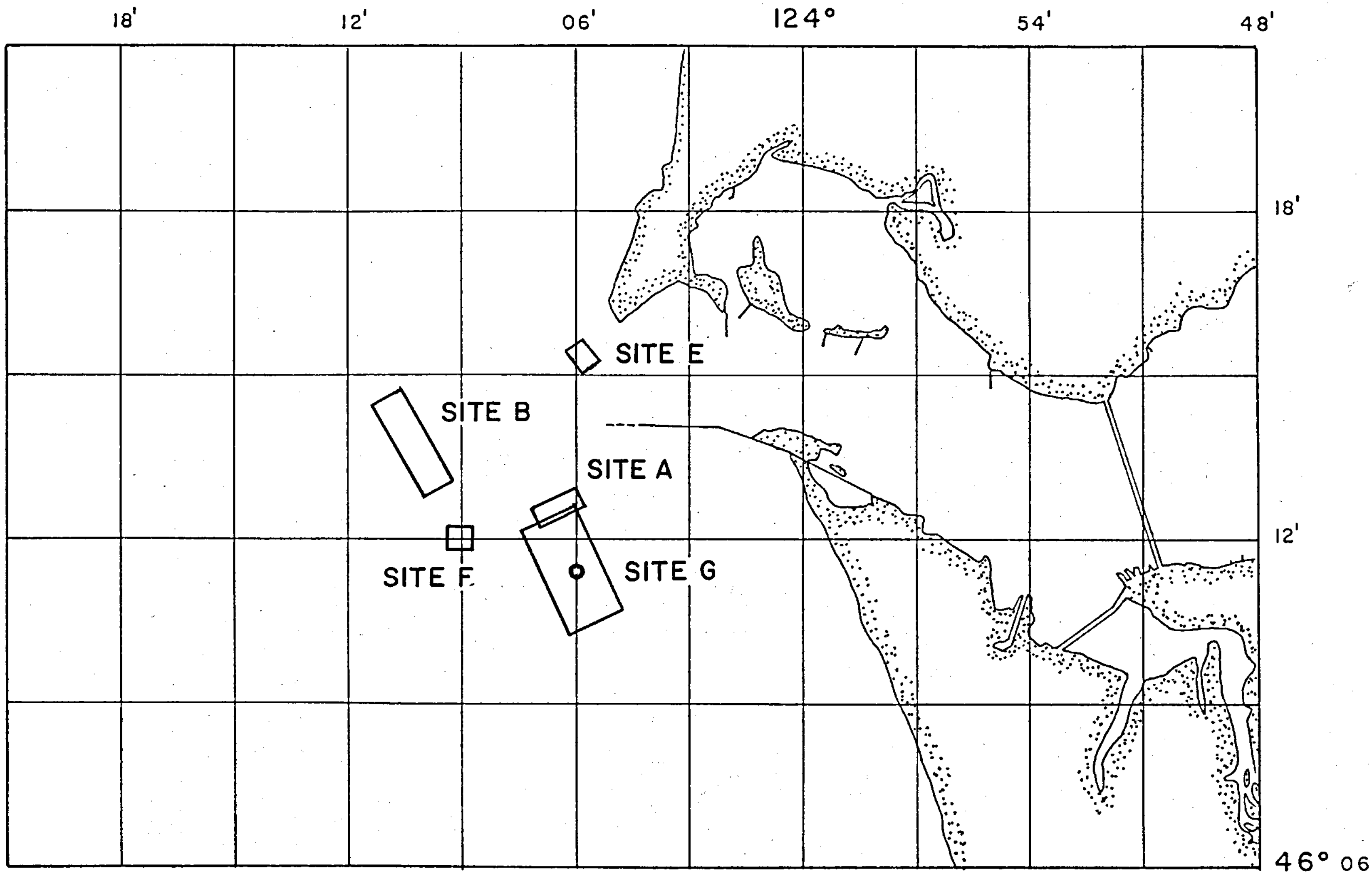

Figure A13. General area map showing designated Disposal Sites A, B, E, F, and G. The dot within Site G represents the buoy marking the experimental disposal site

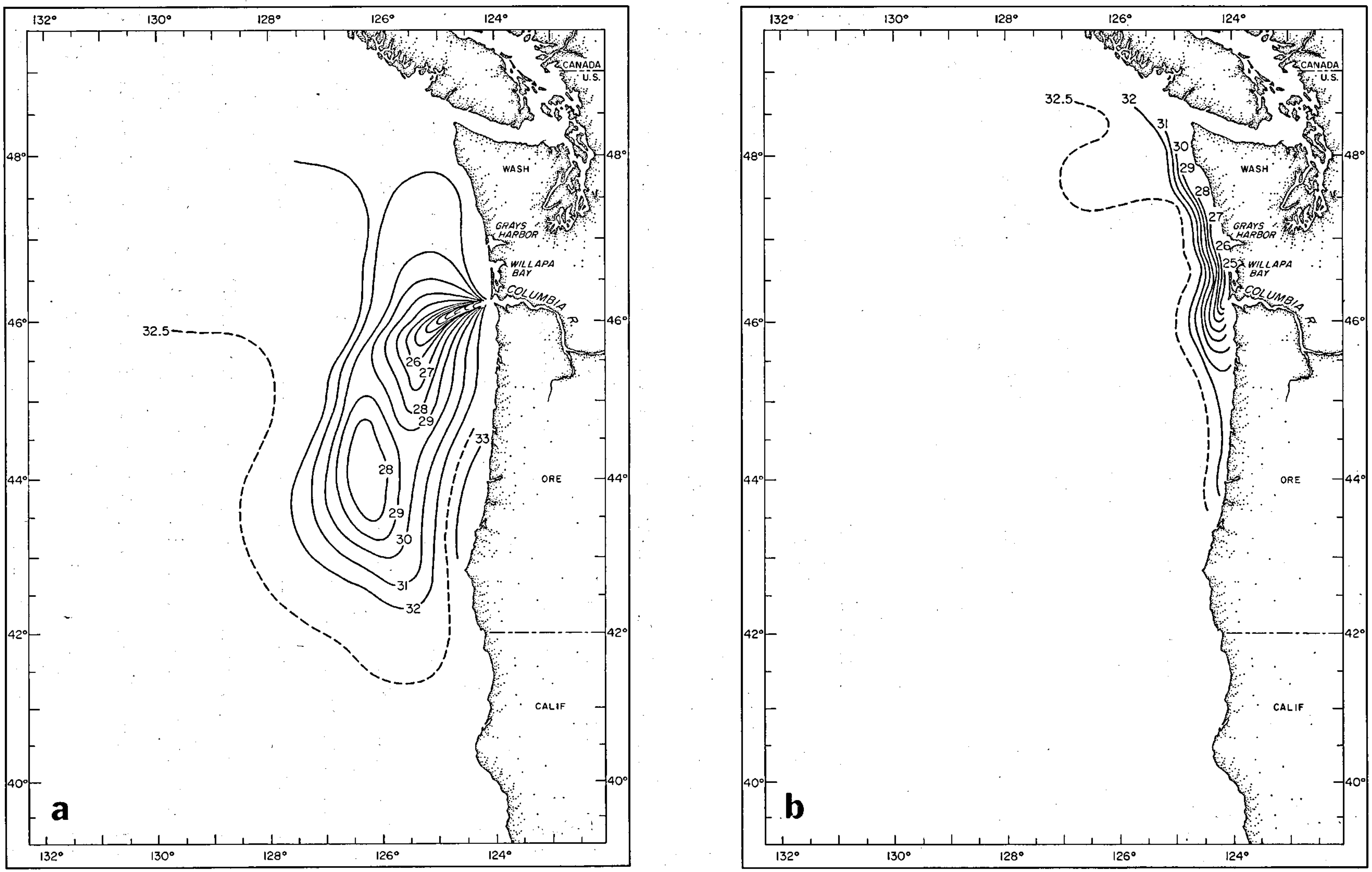

Figure A14. General surface salinity (°/oo) distribution during summer (a) and winter (b) seasons (from Duxbury, Morse and McGary 1966) plume is forced against the coast and migrates northward from the river mouth (Figure A14b). The seaward extent of the plume is more restricted and vertical mixing with underlying water is at a maximum.

34. Figures A14a and A14b represent the extreme conditions of the effluent plume during a summer and winter condition. The observed geographical distribution varies significantly from year to year and also during the transition seasons (spring and autumn) when a mixture of conditions prevails.

Currents near the river mouth

35. Currents just seaward of the river mouth are very complex in both space and time. Investigations by Conomos (1968) 6 nmi seaward of the river mouth show very rapidly changing water characteristics. The river injects low salinity water that moves in response to tidal and hydraulic forces and surface wind stress. Also, river-induced upwelling occurs which not only brings deeper waters into the estuary, but is also associated with some vertical mixing just seaward of the river mouth.

36. Bottom-drifting devices have been deployed over a 2-yr period in the region of the river mouth in an effort to understand the net bottom currents (Morse et al. 1968). Results of these studies suggest that for drifters released within 5.4 nmi of the river mouth, the dominant movement was toward the river mouth being grounded along Clatsop Spit on the south side of the river (Figure A15). Typical speeds were on the order of 0.3 knots. Drifters released within the river estuary tended to migrate seaward presumably along the north side of the channel being grounded in a 2-nmi section at Benson Beach just

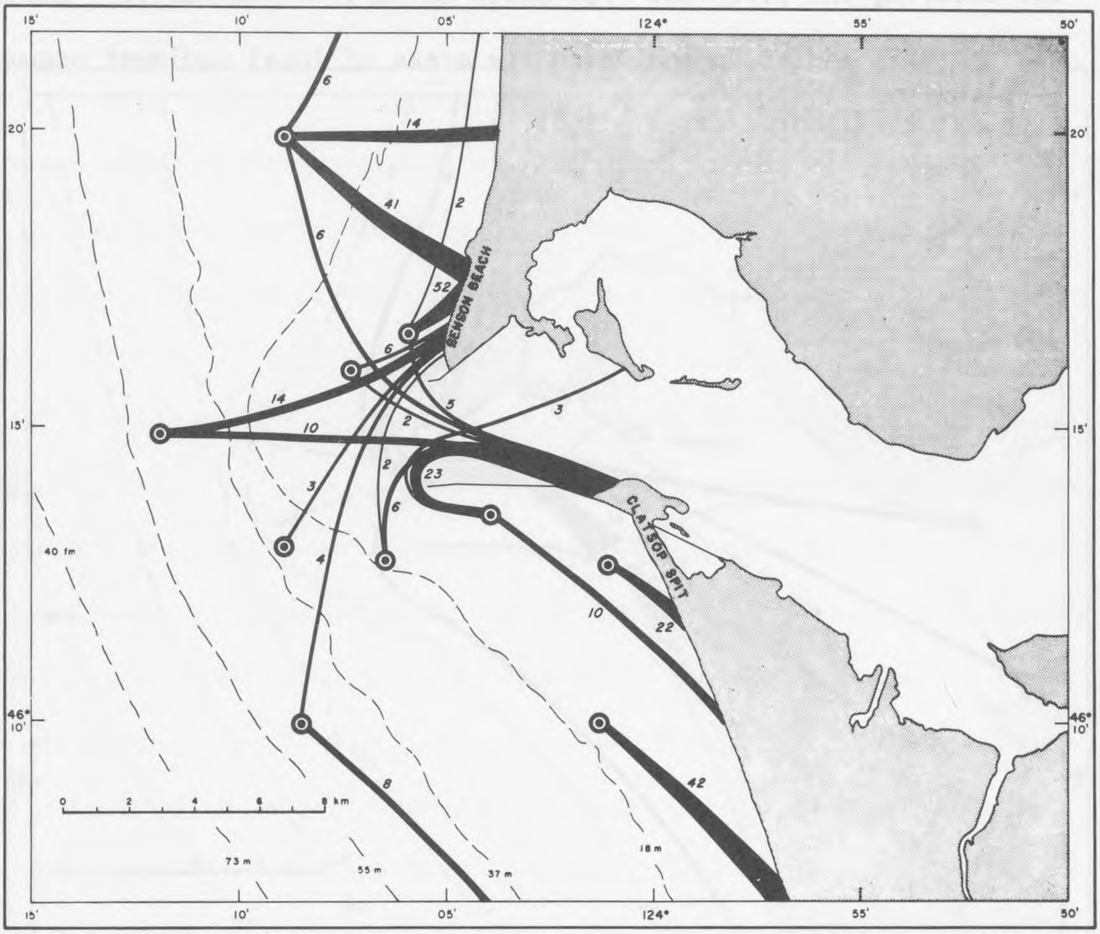

Figure A15. Schematic paths of drifters from release positions outside the river mouth and less than 10 km distant (after Morse et al. 1968) north of the river mouth (Figure A16). A small percentage of drifters also were recovered from Clatsop Spit. The dominant movement of drifters not entering the river was from south to north. The recovery points at Clatsop Spit and at Benson Beach are areas of local sediment accumulation (Lockett 1962, Morse et al. 1968).

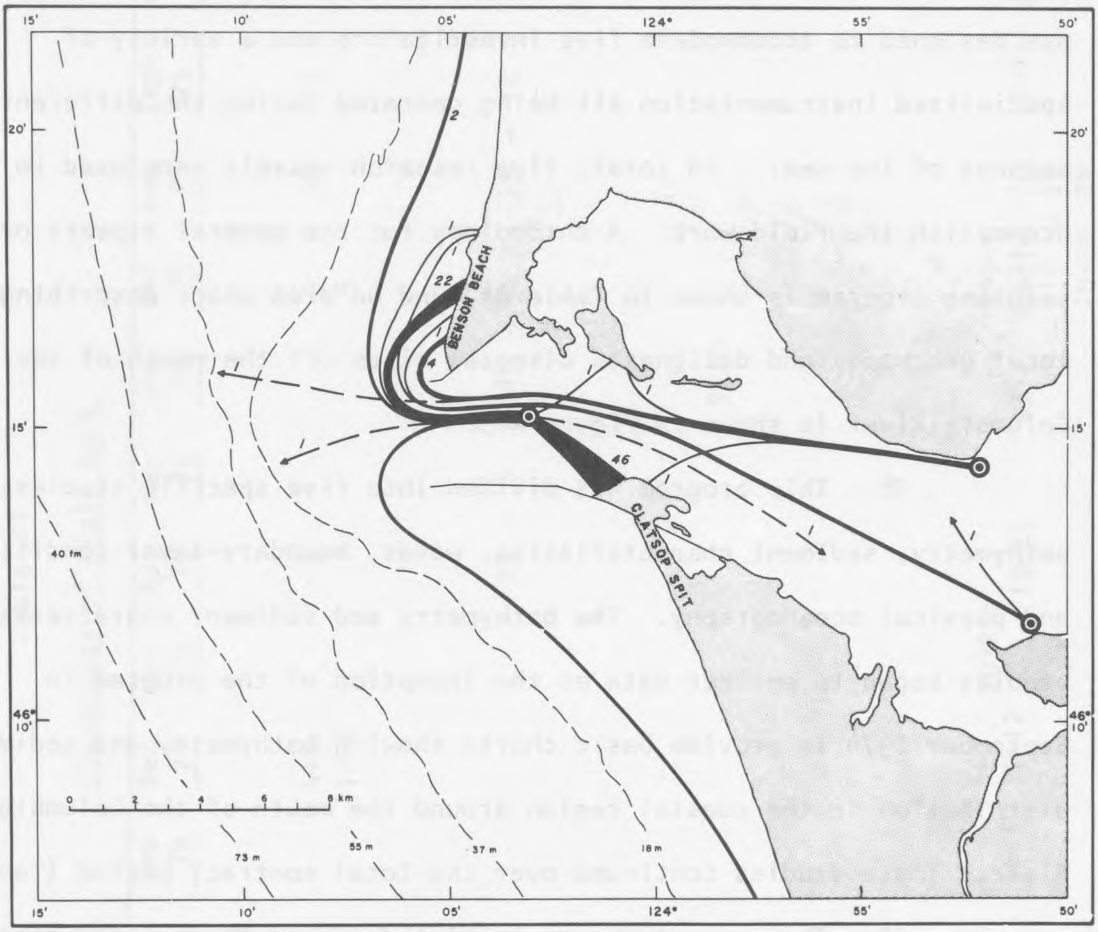

Figure A16. Schematic paths of drifters from release positions in the river estuary (after Morse et al. 1968)

PART IV: METHODS

Chronology of the Field Program

37. The sampling program for this study was quite varied and was designed to accommodate five investigators and a variety of specialized instrumentation all being operated during the different seasons of the year. In total, five research vessels were used to accomplish the field work. A chronology for the general aspects of the sampling program is shown in Table A4, and an area chart describing the local geography and designated disposal sites off the mouth of the Columbia River is shown in Figure A13.

38. This program was divided into five specific studies: bathymetry, sediment characteristics, waves, boundary-layer conditions, and physical oceanography. The bathymetry and sediment characteristics studies began to collect data at the inception of the program in September 1974 to provide basic charts showing bathymetry and sediment distribution in the coastal region around the mouth of the Columbia River. These studies continued over the total contract period (Table A4).

39. The wave study was initiated during Phase 1 and consisted of the deployment of a digital wave recorder on the Columbia River outer tidal delta*. This recorder was programmed to operate over a 6-month period encompassing the winter season. Deployment was carried out on schedule; however, the instrument was not recovered and salvage attempts were unsuccessful.

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*The term "tidal delta" is used throughout this report and is equivalent to the term "outer bar" used in CE reports.

Table A4

Chronology of Field Work

Study	Sept 74	Oct 74	Nov 74	Dec 74	Jan 75	Apr 75	May 75	Jun 75	Jul 75	Aug 75	Sept 75	Oct 75	Dec 75	Jan 76
Bathymetric and seismic profile	3→6			4→8 11→12					2 8	26	2			
Tripod measurements of bottom boundary layer						12 →	6	15 →	8	19 →	12		12 →	6
Hydraulic conditions*								9→20						
Sediment spatial and textural survey	28→30 30 →	3 17	16→17	4→8 11→12	20→25	19→21		23→27	8→9 10→18 9 → 10→30	20 24 26	12→14	21→22	11→12	

*This study was conducted by Dr. J. D. Smith as part of the first years work under this contract.

40. Investigations of the boundary-layer conditions in the study area were made with two large instrumented tripods that were designed to measure current speed and direction, pressure fluctuations due to waves and tides, light attenuation, and suspended sediment samples within 6.6 ft of the seabed. Six successful deployments of the instrumented tripods were accomplished with data collected in spring, summer, and late summer 1975, and in the winter season 1976 (Table A4). The physical oceanography study consisted of a 2-week investigation of the currents and water characteristics immediately seaward of the river mouth during June 1975, the period of maximum discharge. This part of the program was not continued beyond Phase 1.

Bathymetry and Subbottom Profiling

Field methods

41. Joint survey. A bathymetric, subbottom profile, and side-scan sonar survey was performed aboard the CE survey boat HICKSON during the first week of September 1974. The purpose was to produce a baseline bathymetric chart and determine whether subbottom reflection profiles and side-scan sonar would be useful in monitoring bathymetry and sediment distribution-accumulation due to dredged material disposal.

42. The joint University of Washington-CE bathymetric survey of 3-7 September 1974 used an automated hydrographic survey system based on an Atlas precision echo-sounder and Del Norte Trisponder navigation. The cruise tracks, shown in Figure A17, were chosen to provide coverage of the largest area possible, with high density sampling at Site B. Additional information was provided by offshore bathymetric

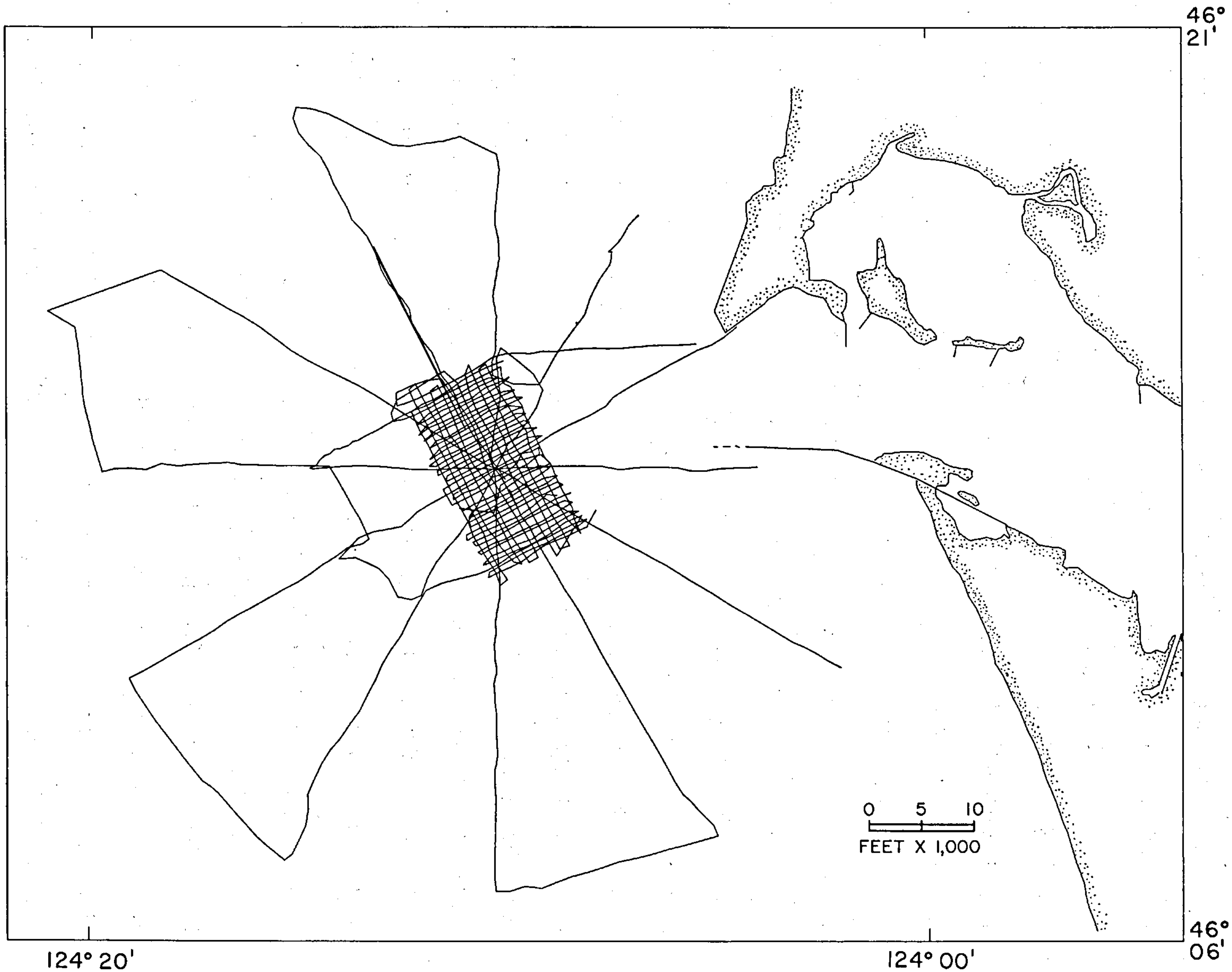

Figure A17. Cruise tracks for 3-7 September 1974 survey surveys conducted by the Portland District in 1964, 1965, 1966, 1971, and 1975. These surveys do not extend as far offshore as the joint survey of 1974, but cruise tracks are more closely spaced trending normal to the tidal delta contours.

43. During the joint survey, an Ocean Sonics 3.5 kHz subbottom profiling system was operated, at a power level of 1000 W and a pulse length of 0.4 msec, simultaneously with an Edgerton, Germeshausen, and Grier Side-Scan Sonar.

44. Disposal Site G. Four surveys were conducted at Site G during July, August, and September 1975. In all of these, the equipment was the same as in the September 1974 survey and operated at the same levels. Navigation was always by the Del Norte Trisponder distance measuring system.

45. On 7-8 July 1975, prior to initiation of the experimental disposal, the University of Washington and the Corps of Engineers conducted bathymetric, subbottom reflection, and side-scan sonar profiles at Site G. Cruise tracks were oriented east-west and spaced 500 ft apart. An additional bathymetric survey, for 2-3 July 1975, was also provided by the Portland District. These cruise tracks, spaced 250 ft apart, were oriented north-south.

46. On 25-26 August 1975, during the final 2 days of the disposal experiment, another joint survey (bathymetric, subbottom reflection, and side-scan sonar) was carried out. Cruise tracks were oriented east-west, occupying the same general positions as in the 7-8 July 1975 survey. The second day, additional profiles were obtained

in the vicinity of the test disposal. These were located approximately halfway between the previous day's tracks, decreasing the spacing to 250 ft between cruise tracks in that area. The Portland District provided information from an additional bathymetric survey conducted 2-3 September 1975. The north-south cruise tracks were spaced 250 ft apart in the eastern portion of the study area and about 200 ft apart in the western portion, where the experimental disposal was concentrated.

Laboratory analysis

47. Joint surveys. The offshore bathymetric surveys conducted by the Portland District in 1964, 1965, 1966, and 1971 were contoured at 1-m intervals, as was the joint University of Washington-CE survey of 1974. Charts provided by the Portland District had been corrected to mean lower low water using data from the CE tide gauge at Tongue Point, Astoria. Comparison of chart depths between surveys was used to estimate net gain or loss of sediment due to erosion or deposition. Chart comparisons were constructed for the time periods: 1964-1965, 1965-1966, 1966-1971, 1964-1971, and 1971-1974.

48. The survey conducted by the Portland District in 1975 was contoured at a 3-ft interval to a depth of 60 ft, and at 6-ft intervals at greater depths. A survey of 6 March 1975, conducted by the Portland District prior to the beginning of dredging in spring, was contoured at the same intervals for the area within the mouth of the Columbia River. The only bathymetric survey in waters deeper than 180 ft that had measurements detailed enough for this study was conducted in 1926 by the U.S. Coast and Geodetic Survey. This map was contoured at a 12-ft interval and was combined with the 1975 offshore and the 6 March 1975

inshore surveys to provide a baseline bathymetric chart.

49. Subbottom reflection records were examined, and the thickness of the uppermost layer was measured in feet. An isopach map of this layer was constructed for Site B and the area surrounding it where sufficient record was available.

50. Disposal Site G. Bathymetric maps were constructed for each of the four available cruises at Site G using a 1-ft contour interval. (Chart depths had been corrected to mllw using a 50-min time difference from the tide gauge at Tongue Point.) Side-scan sonar and subbottom reflection profiles indicated a field of sand waves in the upper northeastern corner of the study area. The sand waves were 2 to 3 ft in height and appeared to be migrating eastward. Significant perturbations in the bottom contours occurred in this region, especially for cruise tracks oriented north-south, and were probably related to passage of the ship over successive crests and troughs in the wave train. The field of sand waves was located well outside the area affected by the experimental disposal (as seen by comparison of pre- and post-disposal surveys), and therefore, apparent erosion and deposition associated with migration of the sand waves did not affect this experiment. To facilitate interpretation of the regional bathymetry, sand wave-related perturbations were smoothed in the contour maps by linear interpolations of depths between adjacent areas that were unaffected by sand waves. Systematic perturbations in the contours, extending for more than 1500 ft and occurring along the cruise tracks, were attributed to incorrect ship positioning. When sections of a cruise track were in

question, the entire track was shifted until contours approximately fit a linear interpolation between the cruise tracks on either side.

51. Subbottom reflection profiles were examined to determine the thickness of the uppermost layer. Side-scan sonar records were used as aids in interpretation of features occurring in the bathymetric and subbottom reflection data.

Bottom Boundary-Layer Conditions

Instrumentation

52. Measurements in the bottom boundary layer were made with an instrumented tripod that freely descends from the sea surface (Figure A18). It can remain on the seafloor for periods of up to 30 days and (a) continuously measure speed and direction 3.3 ft off the bed with a Savonius rotor current meter and direction vane (fabricated locally); (b) continuously measure differential pressure 6.6 ft off the bed to estimate tides and pressure fluctuations from surface-wave motion; (c) activate a beam transmissometer located 4.3 ft off the seabed each 30 min in order to estimate the concentration of suspended particulate matter (three suspended sediment sampling bags are attached which are activated by the transmissometer at different levels of light attenuation); and (d) take a photograph of the seafloor each 30 min. All data were recorded internally on a Rustrak Recorder and the tripod was retrieved by acoustic command or after a predetermined elapsed time. A complete description of the instrumented tripod is given by Sternberg et al. (1973) and Sternberg (unpublished manuscript).

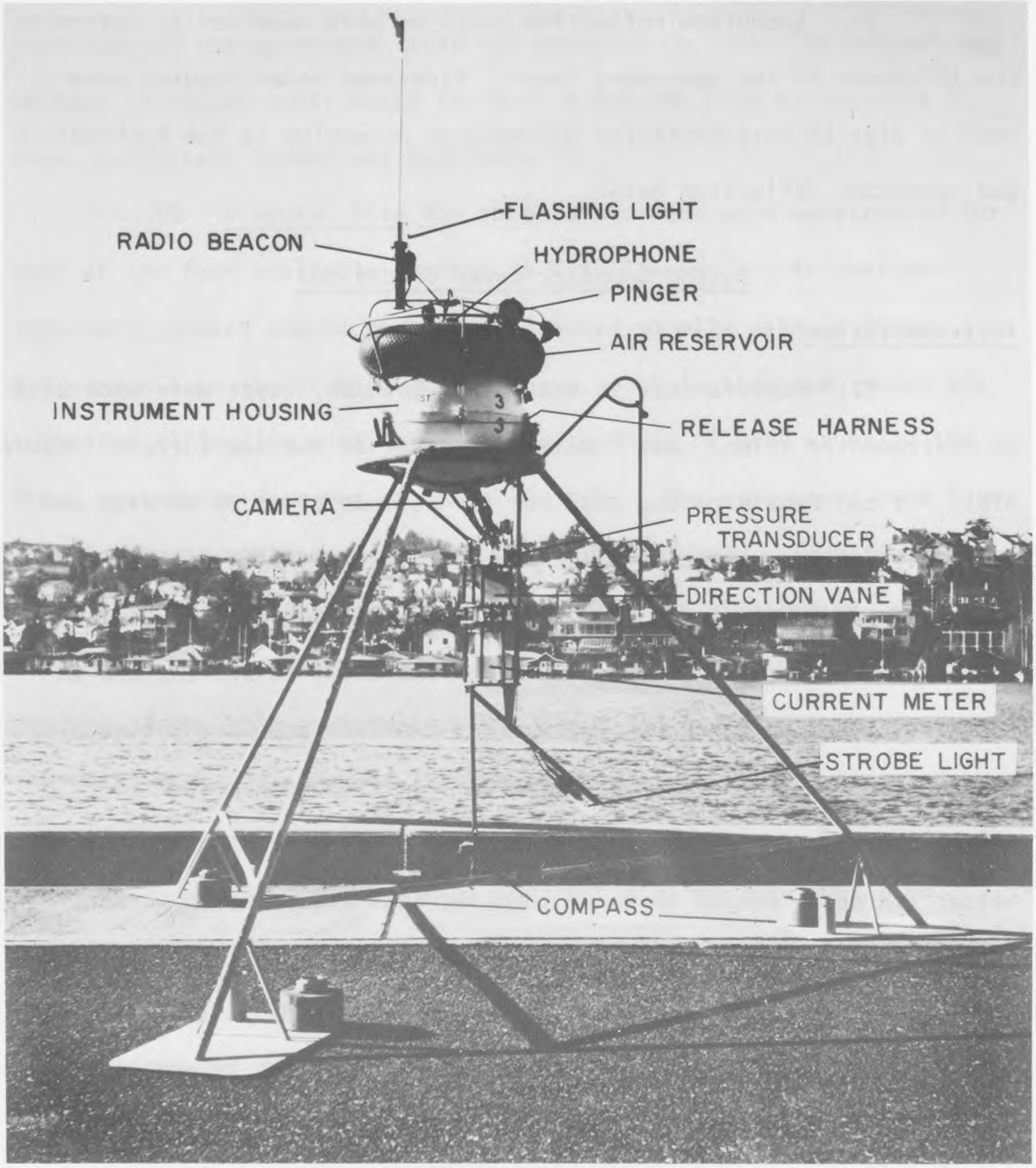

Figure A18. The instrumented tripod with major components identified. Transmissometer and water samples (not shown) mount between two of the legs.

Field methods

53. Instrument deployment was relatively simple and determined primarily by weather and sea conditions. Measurement sites were predetermined according to the objectives of the study. The instrumented tripods were shipped to Astoria, Oregon; assembled at the staging area; and activated before being loaded on the research vessel. The elapsed-time counters were normally set for 30 days of operation. The instruments were then taken to the measurement site and deployed by being lowered into the water and then released to make a free descent to the bottom. After approximately 20 days of operation, the instruments were retrieved during suitable weather conditions. During a relatively calm period, retrieval floats and connecting ropes were acoustically recalled to the surface and the tripods brought on board. The elapsed time counters were only used as a back-up release system in case of failure of an acoustic release.

Analytical techniques

54. Bottom currents. Bottom currents were analyzed to determine mean speed and direction 3.3 ft off the bed ($\bar{U}_{100}$). Current speed was measured with a standard 8-in.-high Savonius rotor using an optical means of detecting rotation rate. The physical and electronic configuration of the speed sensor was similar to that developed by Schick et al. (1968). All bottom currents were averaged over half-hour periods and are characterized as $\bar{U}_{100}$ referring to a mean velocity 3.3 ft off the bed.

55. A current direction vane was located directly above the Savonius rotor. The vane output was read each second by the recording system and was visually averaged over half-hour periods that coincide with the averaging period of the current speed determination. Current direction was analyzed in several steps. Calibrations had been obtained that related the recorder output to some reference position on the tripod (relative direction). Observation of a magnetic compass in view of the bottom photograph was used to determine the orientation of the tripod reference position to magnetic north. A level-bubble is also visible through the compass face to determine if the tripod is resting vertically on the bottom. Finally, the magnetic variation was taken into account in order for the computer to convert recorder output to true bearing.

56. Current speed and direction data were analyzed and plotted in four ways:

a. Individual plots of speed and direction versus time.

b. As eastward (U) and northward (V) components (unless otherwise indicated) versus time. This calculation was made by resolving each 30-min current vector ($\bar{U}_{100}$) into its northward (V) and eastward (U) components and plotting these versus time.

c. As progressive vector diagrams to reveal net movements of bottom water over the total sampling period. The term net in the context of this report refers to water movement occurring over time scales of 2 weeks or more. This plot is made by converting each velocity vector ($\bar{U}_{100}$) to its equivalent displacement vector ($\bar{U}_{100}$ x 1800 sec) and summing all vectors measured during the sampling period. This plot suggests the progressive path of a water parcel passing the station, assuming that the velocity field is locally uniform. The final position of the water parcel relative to the station represents the net bottom flow over the total sampling period.

d. As 25-hr time averages. All current velocity records were subjected to a running 25-hr time average which removes the tidal component and higher frequency variations from the record. This allows the investigation of other types of currents (e.g. wind-generated currents) during the sampling period. Current residuals resulting from the 25-hr averaging procedure are considered to be caused primarily by other than tide-producing forces and are termed the "nontidal" component of flow. It should be understood that net transport of water arising from dissimilarities in flood and ebb tidal transports at a station would appear also as a nontidal component. Nevertheless, the term nontidal is used to refer to velocity records which have been averaged over 25-hr periods.

57. Pressure. Pressure measurements were made with a Giannini type #47152 differential-pressure transducer and an air reservoir. The potentiometer-type transducer sensed up to ± 5 psi pressure changes while on the bottom. Static calibration tests indicated that the system

responded to maximum pressure excursions equivalent to ± 11.2 ft of water with a resolution of 0.1 psi. The frequency response of the pressure measuring system is not known.

58. The output from the pressure transducer was recorded (without filtering) on a Rustrak recorder and appeared as a composite of the tidal and higher frequency pressure fluctuations. The recorder paper speed was set at 1 in./hr. With no high frequency signal, the pressure record appeared as a thin line representing the tidal oscillations; but as pressure fluctuations from surface waves increased, the signal appeared as a scatter of points superimposed on the tidal curve (Sternberg et al. 1973).

59. The pressure record was visually averaged on half-hourly intervals to give the mean pressure due to tides. The half-hourly pressure reading was plotted relative to the tide level when the instrument was deployed and then the datum was shifted to mean sea level by averaging the pressure output over several 25-hr periods at times when the mean sea level appeared relatively stable.

60. The high frequency fluctuations are directly related to surface wave activity. These fluctuations (Delta-P) are obtained by measuring the width (in chart units) of the envelope containing the scatter of pressure data points about the tidal signal (hence, the tidal signal is removed from the Delta-P measurement). Because the recording system was not suitable to determine wave period, it was not possible to relate the bottom pressure fluctuation directly to a characteristic wave height and period. Observations of the response characteristics of the instrumented tripods showed that significant signal loss occurred

as signal frequency increased. In an effort to calibrate the tripod pressure system to high frequency signals, a comparison was made between the instrumented tripod output and a bottom-mounted wave recorder measuring the surface waves with significant periods of 9 to 17 sec (which is in the range expected to occur in the study area; Sternberg and Larsen 1975). This comparison is shown in Figure A19 and is used later in this report to estimate significant wave heights occurring over the Columbia River tidal delta. The standard deviation of data points in Figure A19 is ± 30 mb, which is equivalent to a ± 1.0-ft variation in sea level.

61. Turbidity. The general term "turbidity" is used in this report because observations of water transparency were made in two ways in order to estimate the concentrations of suspended particulate matter. The primary mechanism was a Montedoro-Whitney Inc. beam transmissometer using a 1.1-ft folded-light path that was positioned 4.3 ft above the seabed. This device was activated each half hour for a period of 6 sec. The output of the transmissometer is recorded on the Rustrak recorder with an arbitrary scale of 0-10 which represents a variation from low to high turbidity. The arbitrary unit scale was used for plotting all data because the calibration curve shown in Figure A20 was not completed until the end of the study period.

62. For calibration purposes, three suspended sediment sampling bags were mounted on the instrumented tripod and were activated by the output of the beam transmissometer. One sampling bag was activated respectively when specific values of light attenuation

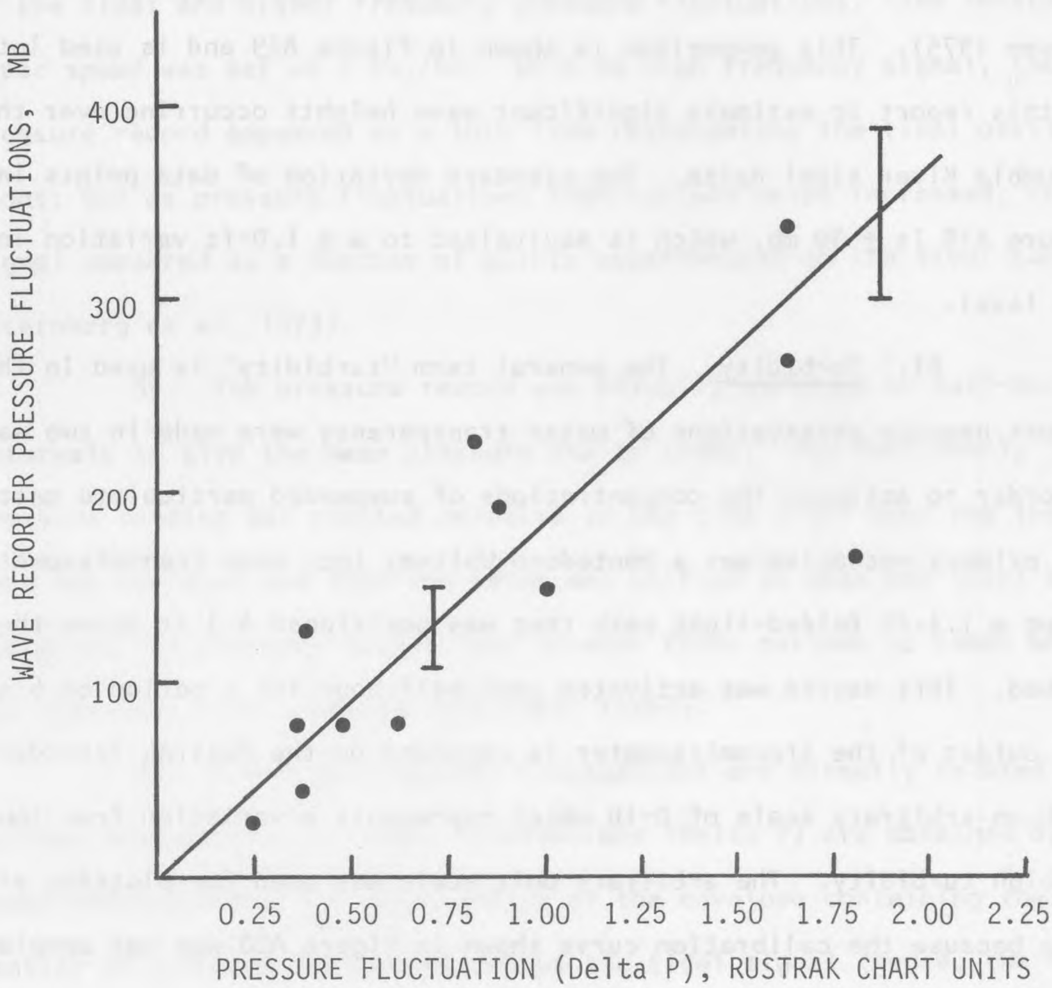

Figure A19. Comparison of bottom pressure fluctuations from surface waves measured by the instrumented tripod and a precision wave recorder (data from Sternberg and Larsen 1975). Error bars indicate the 75-percent confidence interval for estimates of wave recorder pressure fluctuations

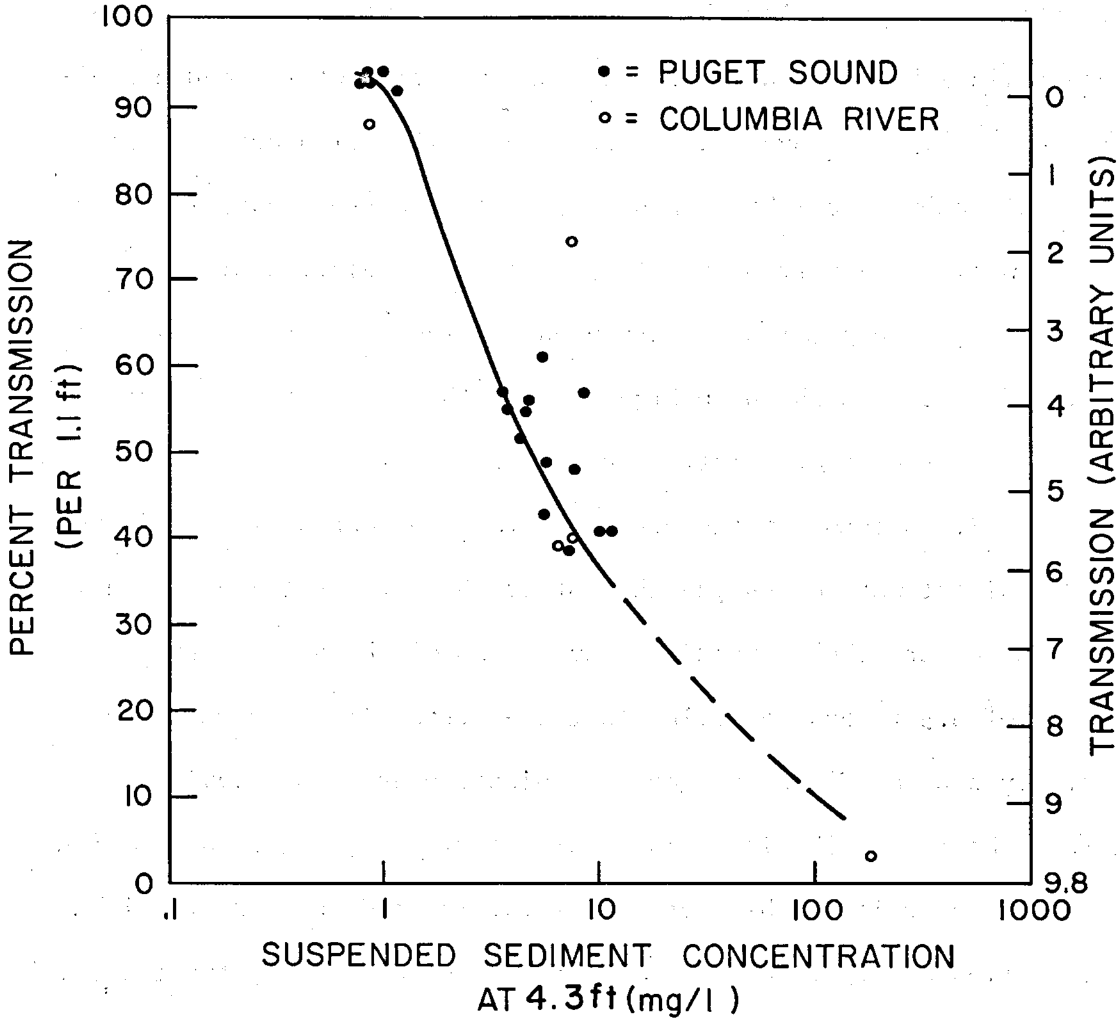

Figure A20. Transmissometer calibration as determined by analysis of in situ water samples. The scale on the left represents percent transmission for 1.1 ft; the scale on the right is in arbitrary recorder units equivalent to low, medium, and high concentrations of suspended sediment occurred. The bags collected approximately 1.7 ℓ of seawater over a sampling interval of about 100 sec. The water samples were filtered, dried, and weighed and the results used to construct an empirical calibration curve relating the transmissometer output on the Rustrak recorder (in arbitrary units) to the concentration of suspended sediment (mg/ℓ) 4.3 ft above the seabed. The calibration curve shown in Figure A20 includes calibration points collected from tests in Puget Sound as well as data from the study area. The relationship between transmissometer output (in arbitrary units) and percent transmission (per 1.1-ft) is also shown in Figure A20. Throughout this report all transmissometer data are plotted in arbitrary units.

63. A second means of estimating the concentration of suspended sediment was to analyze the bottom photographs taken each half-hour. The camera took a vertical photograph of the seabed from a distance of 5.5 ft and, assuming that the strobe light represented a relatively constant light source, a subjective scale was devised to interpret bottom visibility. The scale is given in Figure A21, which also shows the relationship between visibility and suspended sediment concentration at 4.3 ft above the seabed as determined by the transmissometer and sampling bags. The exposure of the bottom photographs does vary in relation to periods of daylight and darkness; however, exposure differences do not significantly influence the photo-visibility scale. Since the bottom photographs become completely obscured at concentrations of 50 mg/ℓ at 4.3 ft, then this is the upper limit that the

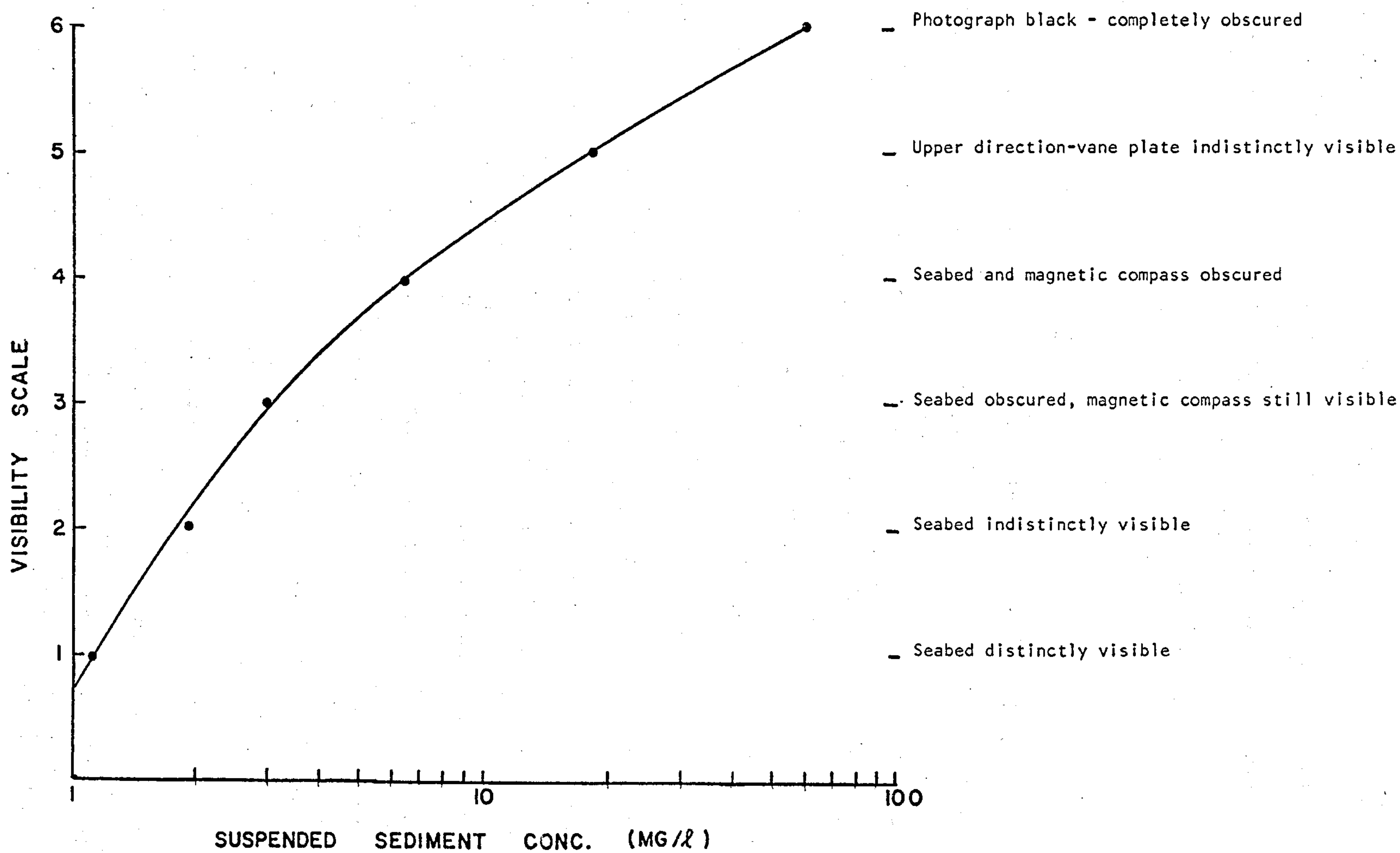

Figure A21. Photo visibility scale defined and compared with transmissometer concentration values as determined by the transmissometer calibration curve (Figure A20) visibility range can resolve. This procedure is very useful, however, because the beam transmissometers were not available throughout the study period and also it served as an aid in interpreting results.

Hydraulic Characteristics Near the River Mouth

Instrumentation and field methods

64. A study was conducted of the hydraulic conditions near the river mouth during the period of high river runoff (9-20 June 1975) with the use of (1) internally recording current meters anchored in the surface and bottom flows around the river entrance and (2) a concurrent series of 25-hr anchor stations with continual profiling of the temperature and salinity characteristics of the water column. Current measurements were made with Aanderaa (Type 4) current meters that were set to record mean speed and direction at 2-1/2-min intervals during the sampling period (NOAA 1972). A current meter array consisted of a taut-wire mooring anchored to the seabed through an acoustic release. Current meters were mounted on the wire at various levels above the seafloor. Three current meter arrays were used for this study. One contained four current meters equally spaced along the wire, while the other two contained two current meters mounted to measure currents near the bottom and surface, respectively.

65. During the period that the current meter arrays were deployed, anchor stations were maintained at several positions around the river mouth. The vessel was anchored for periods of 25 hr from which continuous profiles of conductivity, temperature, and depth (CTD) were made throughout the water column. Usually, profiles were made

every 1/2 hr over the total time the anchor station was maintained. The instrument used for these measurements is a Interocean Inc. CTD. The sensing element can be lowered through the water column and profiles of conductivity and temperature versus depth are plotted on an x-y recorder located on board the vessel. Station information (dates, locations, current meter positions, etc.) and data summaries for the current meter arrays and anchor stations are given in the Data Section of this report.

Sediment Characteristics

Field methods

66. Sediment samples analyzed during this investigation were collected by the University of Washington (UW) contractor aboard the Oregon State University (OSU) vessel YAQUINA in September 1974; the OSU vessel CAYUSE in September, November, and December 1974; and aboard the fishing vessel WASHINGTON in June and December 1975. Samples were also supplied by the OSU contractor from cruises made in December 1974 and January, April, June, August, September, and October 1975. A summary of all samples collected for this study is given in Table A5. Geographic locations of all sediment samples are shown in Plate A1 while sample locations within Disposal Site B are shown in Plate A2. Sample locations within Disposal Site G will be shown in the Data Section.

67. Samples collected by the UW contractor were obtained using a Shipek grab sampler. All grab samples were placed in vinyl bags, sealed, and cold stored (~4°C) until analysis. In cases where

Table A5

Bottom Sediment Sample Summary

Designations*	OSU	Dates	Number of Stations	Grab Samples Shipek UW	Grab Samples Smith-McIntyre OSU	Other Samples**	Granulometric analyses†	Core Samples Piston	Core Samples Gravity	Navigational Control††
Y7409	Y7409F	28-30 Sept 74		15			14	2	6	RB
C7409	C7409C	30 Sept-30 Oct 74		153			165			RB
C7411	C7411E	16-17 Nov 74	88	85			109			DN
C412B	C7412B	4-8 Dec 74			58		59			RL
C7412	C7412BB	11-12 Dec 74	86	84			84			DN
C7501	C7501D	20-25 Jan 75			49		51			DN,RL
C7504	C7504B	19-21 Apr 75			26		28			DN
C7506	C7506C	23-27 Jul 75			37		39			DN
C7508	C7508E	20 Aug 75			27		27			DN
C7509	C7509E	12-15 Sept 75			72		72			DN
C7510	C7510E	21-22 Oct 75			29		29			DN
WN001		8-9 Jul 75	51	51			51			DN
WN002		11-12 Dec 75	97	95			100			DN
B1074		17 Oct 75				13	12			
B0775		10-18 Jul 75				5	5			
H7875		9 Jul-24 Aug 75				38	38			
TOTALS			322	483	298	56	883	2	6	

*The cruise designation is a letter and numeral combination indicating the vessel and cruise number. The vessels are: Y - Yaquina, C - Cayuse, WN - Washington (chartered vessel out of Astoria, Ore), B - Biddle and H - Harding (The Biddle and Harding are CE vessels).

**Samples taken of dredged material being deposited into dredge hopper.

†Multiple analyses were done on selected grab samples from various cruises.

††RB - Range and Bearing; DN - Del Norte Trisponder system; RL - Range and Loran A.

stratification was evident in the sample, an effort was made to collect material from each layer and to treat each as a discrete sample. Material supplied by the OSU contractor was collected using a Smith-McIntyre bottom sampler. A number of separate grabs were made at each station, one of the grabs being reserved for the UW group.

68. Del Norte Trisponder navigation equipment was used during the cruises in November and December 1974, June and December 1975, and on all OSU cruises except December 1974 and January 1975. All other cruises used radar and sextant fixes for station locations. (For the latter cruises, station locations are believed accurate to 0.5 nmi.) The Del Norte Trisponder system, although capable of providing high precision and high accuracy locations, did not provide reproducible results at the precision level expected (± 50 ft). Bathymetric survey lines conducted on different days, as well as some conducted on the same day, suggested that sample and survey locations were accurate to a radius of uncertainty of ± 250 ft.

69. It should be noted that seasonal samples collected by the OSU contractor have an additional location uncertainty attached to them resulting from the fact that one navigational fix was taken for a station that was occupied for up to 1 hr, during which time multiple samples were collected. Although attempts were made to compensate for vessel drift during this time, a small but unknown amount of drift can be expected.

Sediment texture

70. Laboratory techniques. Textural analyses consisted of homogenizing and then successively quartering the bottom sample until about 20 to 40 g of sediment remained. This subsample was wet-sieved through a 4-ø (.0625 mm) screen into a 1000-ml cylinder. The sediment remaining on the 4-ø screen was dried and sieved (10 min) to 0.25-ø fractions. The pan fraction was added to the cylinder and a pipette analysis was used to determine the size distribution of the silts (at 0.5-ø intervals) and clays (at 1.0-ø intervals) (Krumbein and Pettijohn 1938). The 12-ø class size reported consists of all sediment finer than 11-ø. Sodium hexametaphosphate (approximately 0.2 g/ℓ) was used as the dispersing agent. The settling velocities of the various size fractions were computed using Waddel's correction to Stokes' Law (Krumbein and Pettijohn 1938). Because drying makes it very difficult to disperse the fine fraction, the total sample weight was determined by adding the weight of an initial aliquot collected from the settling tube to the weights of the sieved fractions.

71. Statistical parameters for the size analyses, such as median grain size, sorting coefficients, etc., were generated with a computer program. Additionally, this program converted the weights of individual size fractions to a percentage of the total subsample weight. The volume of information produced prohibits inclusion in this report, but all results are on file at WES and with the Environmental Data Service, National Oceanic and Atmospheric Administration (NOAA).

72. Data reduction. In order to work with the vast quantity of information produced, it was necessary to use some statistical techniques to assist in interpreting sediment characteristics in the study area. Classically this could have been done by individually considering the distributions of each of the 29 size classes (0 to 12ϕ) for every sample, but this would have been quite unwieldy and would not have readily produced information relating samples to each other. It is also impractical to consider producing areal plots using simple frequency graphs. Therefore, the data were subjected to a Q-mode factor analysis (Imbrie and Van Andel 1964) to assist in determining the relationships among samples. From this, the important size classes become quite obvious. The relationships among variables (size classes) could have been determined using R-mode factor analysis, but because the general nature of the important size classes was already known from previous work, (McManus 1972, Smith and Hopkins 1972, Kulm et al. 1975) and because of a limited budget, this technique was not applied.

73. The Q-mode factor analysis with final oblique rotation was run using the 29 grain-size classes (variables) in ϕ units. Because of memory limitations of the computer, only 100 samples could be analyzed at a time. Samples from the first three cruises, C7409, C7411, and C7412, were arbitrarily split into five groups on which to run factor analysis. Based upon eigenvalues generated by calculating cosin-theta coefficients (Table A6 displays an example of one run), it was noted that seven extracted factors accounted for 99 percent of the variability among all samples. Group one samples were run with

Table A6

Example of Eigenvalues for One Run of 65 Samples

Eigenvalues	Cumulative Percent of Communality
44.7975	68.92
7.8824	81.05
6.9776	91.78
2.5483	95.70
1.0956	97.39
0.7335	98.52
0.4489	99.21

the limitation that seven factors be extracted. The seven samples (extremals) from this group most closely associated with each extracted factor were then added to the second group which was then factorer. This process was repeated through all of the groups and again to the first group, if the seven characteristic extremal samples identified at the end of the fifth run were not the same as produced by the first run. The entire analysis was repeated imposing six- and nine-factor extraction to observe any effect. Seven or more extracted factors were required to produce stability in this iterative analysis. More than seven factors provided no additional information. Normally so many factors would not be retained, but were done so for this study in order to differentiate the apparently important relationships among the fine to very fine sand fractions and because the seldom occurring 3.75 ∅ fraction completely disrupted the analysis if it was not allowed separate factor occupancy.

74. The extremal samples for seven factors determined in these initial trial runs are shown in Table A7. From coarse to fine the factors and their associated extremal samples represent distinct grain-size distributions. For simplicity, throughout the remainder of this report, the grain-size distribution of these extremal samples and other associated samples (loadings greater than 0.40) will be characterized and referred to by their modal size class(es). Sediment samples associated with factor 1 have either a 2.0 or 2.5 ∅ mode, samples associated with factor 2 have a 2.5 ∅ mode, factor 3 sediments have either a 2.75 or 3.00 ∅ mode, factor 4 sediments have a 3.25 ∅ mode,

Table A7

Textural Data for Extremal Samples of Each Factor*

Factor	Sample	1.00**	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
1	C7409-154	1	1	6	17	32	19	11	6	2	1															1
2	C7411-32			1	4	13	16	47	9	3	2	1	1													1
3	C7409-19					1	5	15	32	24	11	2	1		1	1										3
4	C7409-149					1	1	2	8	15	32	18	10	4	5	1							1		1	1
5	C7411-60			1	3	8	8	7	6	5	8	5	28	14	3											1
6	C7411-86								1	1	3	5	5	4	42	13	7	3	2	2	1	1	1	2	1	4
7	C7409-43			1	1	1	1	1	2	2	3	2	1	1	2	9	8	5	8	8	5	6	7	7	6	12

*Rounded to whole percent for each class.

**Size in phi units.

factor 5 sediments have a 3.75φ mode, factor 6 sediments are characterized by a coarse silt mode (usually 4.5φ), and factor 7 sediments are the finest distributions with fine silt- or clay-size modes. It should be noted that sediment samples are often associated with more than one factor, having different loading values of each.

75. Factor analysis was performed on samples from each cruise as a group after cruise C7412. The seven extremal samples previously identified were also included in each analysis and treated as ordinary samples. Infrequently one or more of the initial seven extremal samples were replaced by new extremal samples. In all such cases the old extremal sample had a loading greater than 0.92 of that factor relative to the new extremal. In four of the seven cases, the loadings exceeded 0.99. This effect produces no differences in the contours of factor loadings used in this report, thus refactoring was not done. This lack of significant rejection of the initial extremal samples as characteristic of all later factor extractions is remarkable. This stability without regard to geographic area or season led to the acceptance of this analysis as a valid technique. Values of factor loadings on an oblique projection for all samples are available at WES and are not included in this report because of the volume of data.

Sediment mineralogy

76. _Point count analysis_. A split of the <4φ (>0.0625 mm) material recovered during size analysis was placed in a vinyl collar on a Teflon-coated sheet and impregnated with Fiberlay-epoxy base resin. After hardening (about 24 hr), the resulting disc was faced on a 600-

grit lap and mounted on a frosted glass slide with epoxy. The disc was then cut and ground to a thickness of 30 μ and faced using a 1000-grit lap. This finished surface was then stained for potassium feldspar using sodium cobaltinitrate solution and hydrofluoric acid. A glass cover slip was mounted to the slide using Canada balsam as the mounting medium.

77. A minimum of 300 points per slide were counted using a 14 register electronic point counter. Distance between points was fixed at 0.5 mm. A mineral index (MI) for each sample was calculated using the formula:

MI = (% Fresh Plagioclase + % Potassium Feldspar)/
(% Altered Lithic Fragments + % Altered Plagioclase
+ % Opaques)

78. Magnetic mineral analysis. A split of the same <4 ϕ (>0.0625 mm) material that was used in the point count analysis was also used in the magnetic separations. A Frantz magnetic separator was used at a back tilt angle of 25° and a current of 1.7 A. The front face of the magnet was covered with paper on which the magnetic fraction was retained. A 10- to 20-g sample was used in this analysis. The magnetic fraction and the nonmagnetic fraction were weighed, and the ratio of the weights was used to obtain the magnetic ratio (MR) defined as:

MR = (weight of nonmagnetic fraction)/
(weight of magnetic fraction)

79. Miscellaneous procedures. Electron microscopy, x-ray fluorescence analysis, and x-ray diffraction analysis were analytical

techniques applied to a few samples during the early reconnaissance studies of mineralogical properties of the sediments. The methods used are standard techniques treated in elementary texts and will therefore not be detailed here.

PART V: DATA

Bathymetry

Regional survey

80. A contour map of the regional bathymetry, based on the 1974 survey, is presented in Figure A22. Dashed lines indicate regions where contours are inferred from the 1971 bathymetry. Close spacing of survey lines at Site B enabled accurate determination of the bathymetry in that region which shows the existence of a positive bathymetric feature superimposed on the regional trend.

81. An estimate of the volume of material represented by the positive bathymetric feature was obtained by extrapolating the regional contours through Site B, using the average slope calculated from adjacent areas. The bathymetric difference between the actual contours and hypothetical contours yields an estimated volume of 9,479,000 cu yd of sediment. The composite baseline map is shown in Figure A23.

Site G

82. Difficulty in resolution of bathymetric data from Site G arose because of apparent navigation errors. A 1-ft difference in water depth, over the entire area, occurred between the two July surveys. This could not be accounted for by changes in sea level associated with storm activity. Shifting the positions of the 2-3 July 1975 cruise tracks 200 ft to the east brought the contours for that cruise into coincidence with those of 7-8 July 1975. Bathymetric data for the 25 and 26 August 1975 cruise were not coincident and could only be contoured after shifting the 26 August cruise tracks approximately 250 ft east.

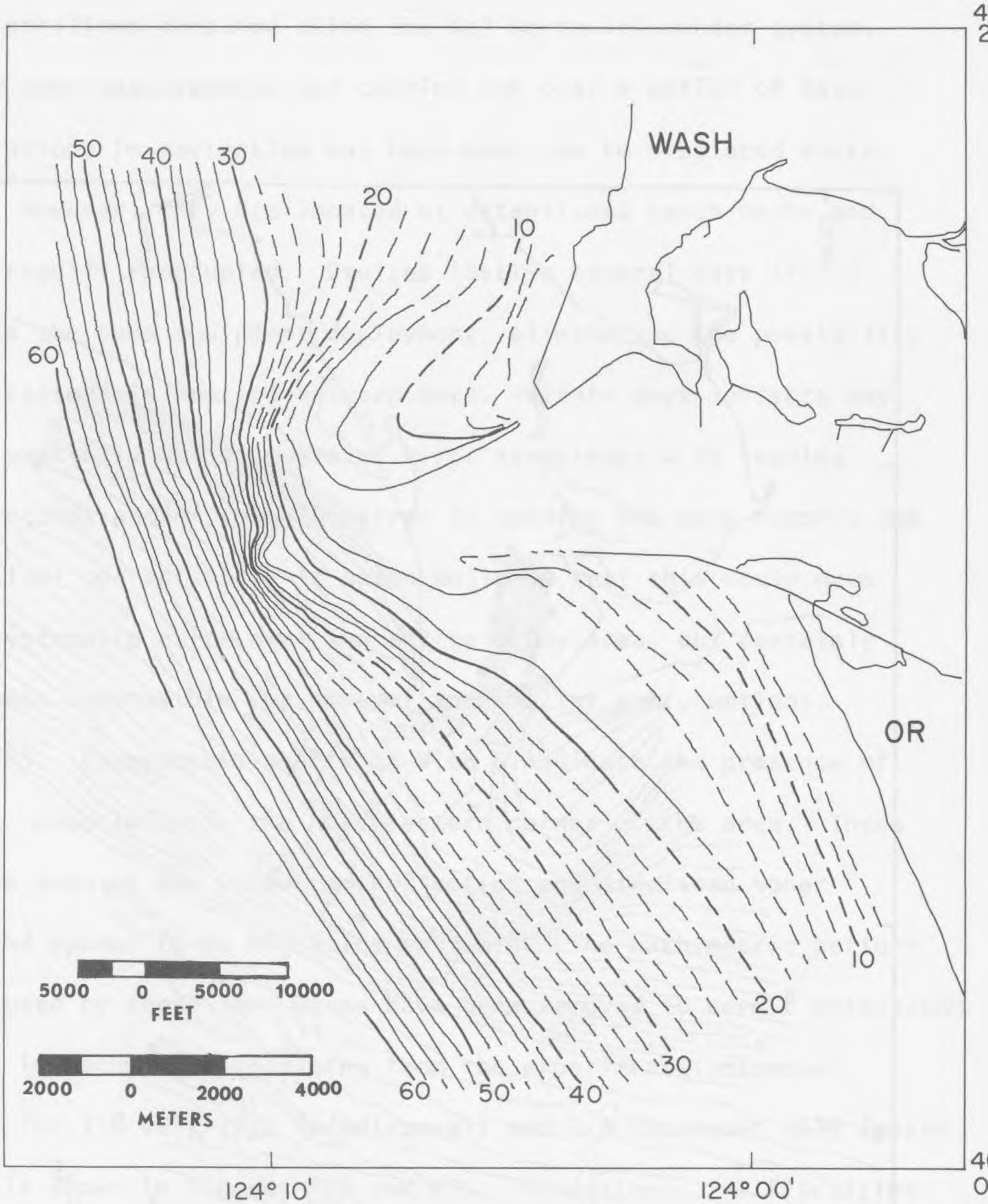

Figure A22. Bathymetry at the study area based on September 1974 survey. The contour interval is 2 m

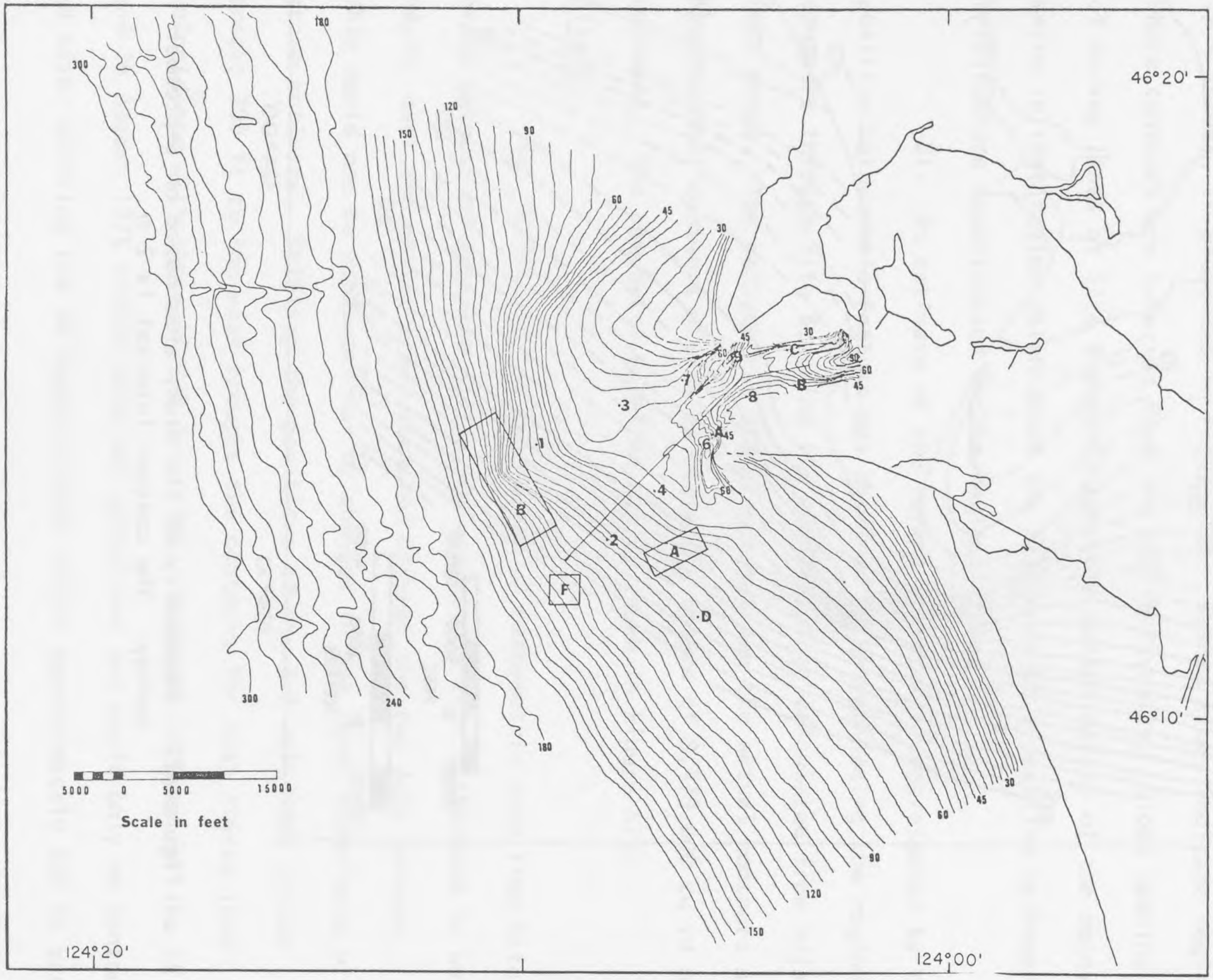

Figure A23. 1975 baseline bathymetry at the study area. Contours are in feet. Navigational buoys are also indicated

Some offsets in positioning occurred along sections of individual cruise tracks (see Part IV). This suggests that an accuracy of ± 250 ft be placed on positions obtained using the Del Norte Trisponder system, especially when measurements are carried out over a period of days. These variations in navigation may have been due to misplaced shore stations. However, they are located at established bench marks and should be readily reoccupied. Cruises lasting several days (25-26 August) use the same equipment deployment, eliminating the possibility of shore station mislocation between days. Within days, offsets may have been partially due to operator error associated with reading original records and/or rounding error in reading the same records and applying tidal corrections. It seems unlikely that this could have caused a systematic error over the entire study area, but certainly may have been responsible for some of the smaller perturbations.

83. Bathymetric charts of Site G indicate the presence of sand waves, especially in the northeastern corner of the area. These can also be seen on the subbottom reflection and side-scan sonar records, and appear to be migrating eastward. The bathymetric perturbations caused by these sand waves have been removed to permit detection of changes in bathymetry resulting from the experimental disposal. Bathymetry for 7-8 July 1975 (predisposal) and 2-3 September 1975 (postdisposal) is shown in Figures A24 and A25, respectively. Difficulties in navigation did not significantly hamper comparison of bathymetric surveys. Alignment of consecutive charts was made by matching contours away from the disposal site, rather than by matching latitudes and longitudes. This was possible because of the short time span between

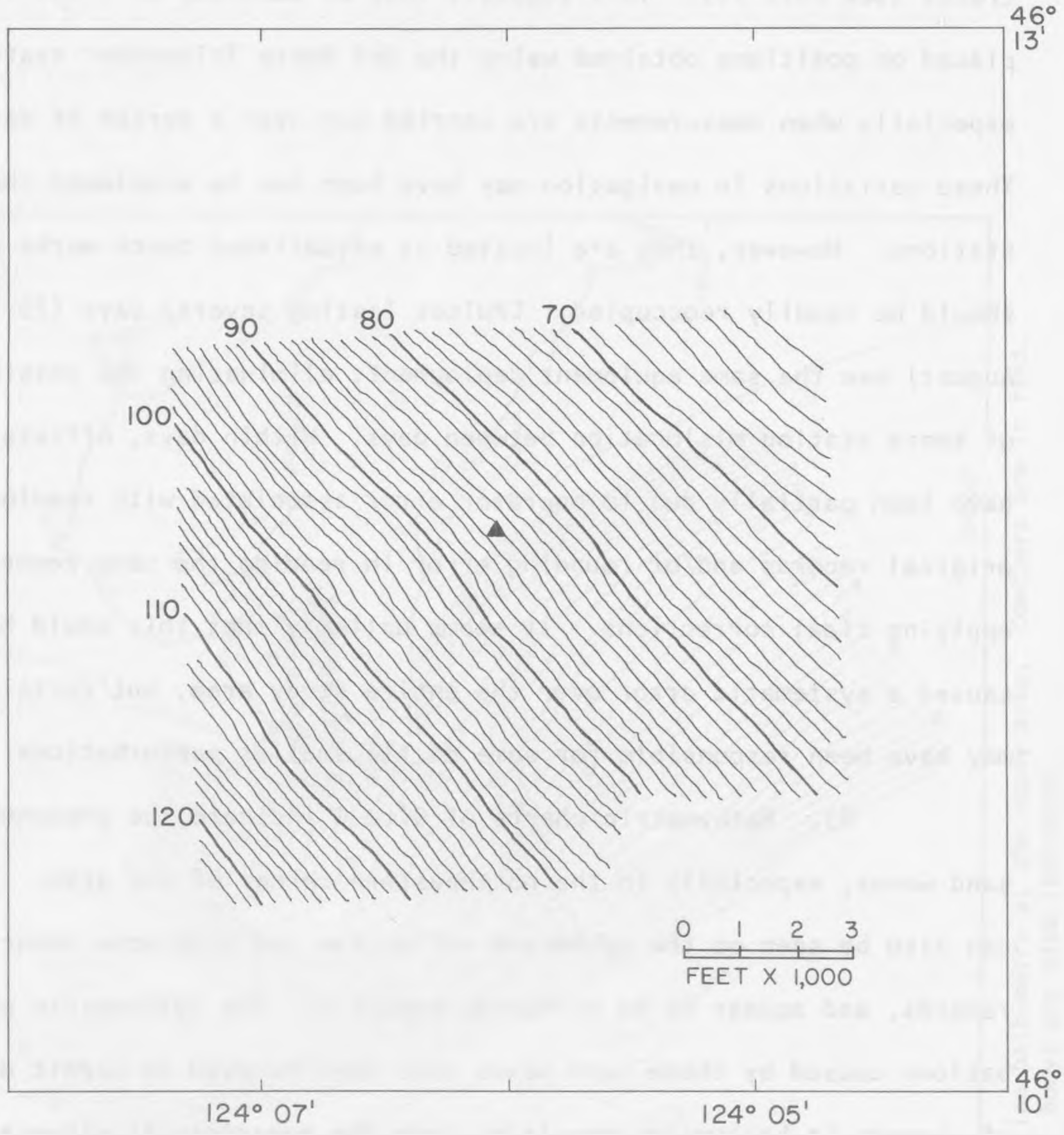

Figure A24. Predisposal bathymetry at Site G as of 7-8 July 1975. The contour interval is 1 ft. Solid triangle marks position of Special Purpose Buoy D surveys and calm sea surface conditions during the summer season. Close agreement of contours throughout the entire area supports the use of this method of superimposing charts. (This is not recommended for time periods during which significant sediment transport can occur). Based on an approximate horizontal distance between contours of 250 ft and navigation accuracy of ± 250 ft, water depths are estimated accurate to ± 1 ft. However, close agreement of contours from successive cruises implies that depths are accurate to at least ± 0.5 ft with respect to each other, and also probably from cruise to cruise.

84. The postdisposal bathymetry shows that most of the dredged material was released from the dredge on the south side of the buoy with the greatest accumulation to the south and southwest of the buoy. The relatively flat top of the deposit (Figure A25) lies within a radius of about 750 ft of the buoy with the base of the steeper depositional slope occurring at a distance of up to 1500 ft from the buoy. According to Charles Galloway,* the dredges circled the marker buoy at a distance averaging about 700 ft releasing the dredged material on the southern side. Sea and weather conditions resulted in disposal to the north of the buoy about 20 percent of the time.*

Hydraulic Conditions

85. Seven deployments of instrumented tripods were made in the study area during the contract period. As a result of physical

*Personal communication, Charles Galloway, Portland District, 1975

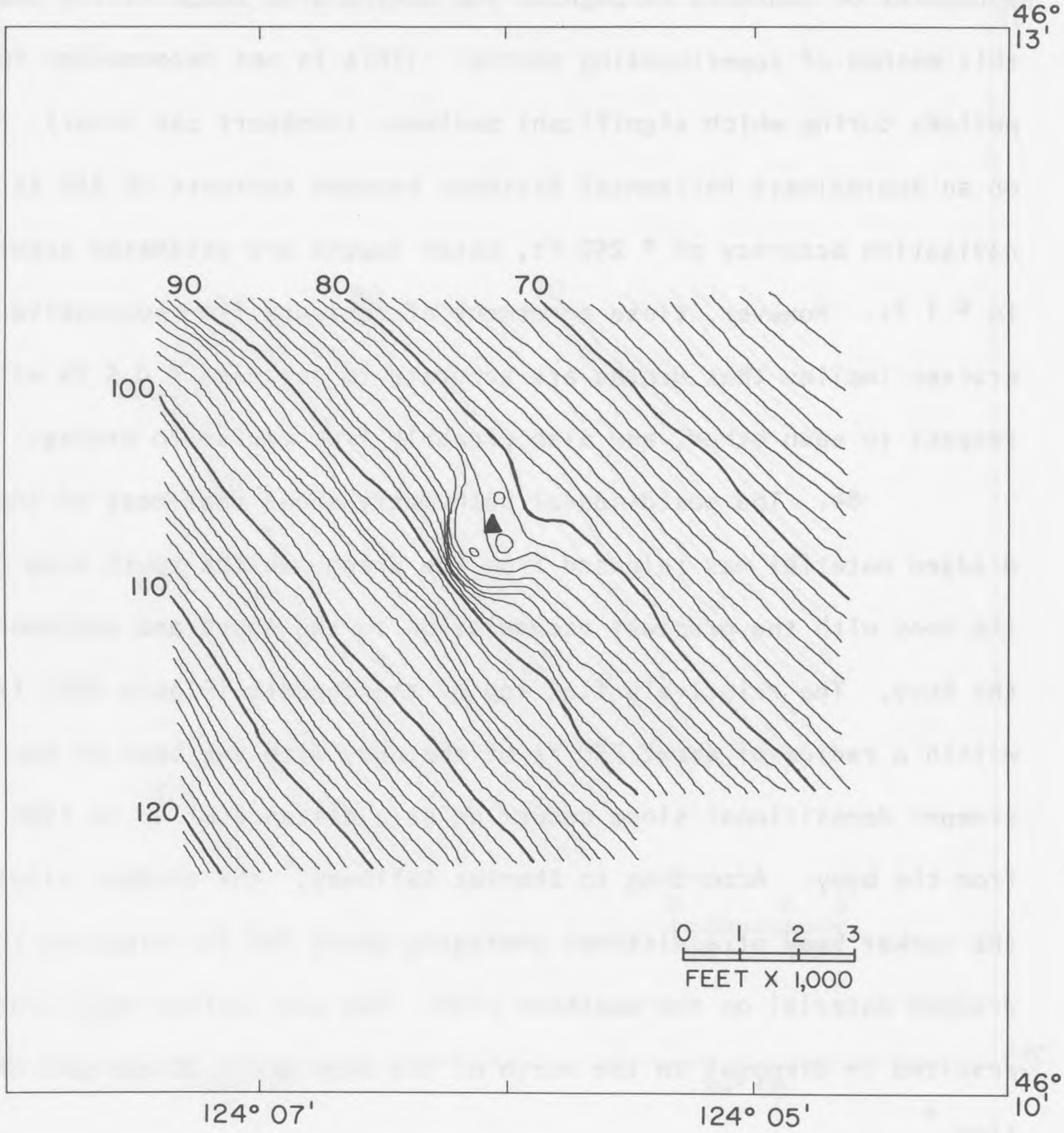

Figure A25. Postdisposal bathymetry at Site G as of 2-3 September 1975. The contour interval is 1 ft. Solid triangle marks position of Special Purpose Buoy D and/or program constraints, it was not possible to maintain geographically fixed measurement sites; however, stations were occupied during most seasons. A station location chart is shown in Figure A26 and a summary of pertinent station information is given in Table A8. The first instrument deployments began on 12 April 1975 with two instruments: one placed on the outer tidal delta at Site B and the second located on the tidal delta 1 nmi to the north (Figure A26). Data collection continued for 24 days.

86. The summer deployment at Site A (Station 3) consisted of one instrument placed 2 miles south-southwest of Clatsop Spit during the period 15 June to 8 July 1975. Concurrent measurements of the water movements and density field in the vicinity of the river mouth were also made during this time. The autumn deployments (Stations 4 and 5) were made during August-September to coincide with the conclusion of the disposal experiment carried out at Site G. Instruments were deployed on the north and south side of the experimental disposal site on 19 August 1975. The disposal experiment concluded on 26 August after 599,868 cu yd of dredged material had been discharged at the site. Bottom boundary layer measurements continued until 12 September 1975.

87. The winter deployment consisted of two instruments, one placed on Site B (Station 6) and the second on Site G (Station 7). Measurements began 12 December 1975. The instrumented tripod on Site B was recovered on 6 January 1976; the instrument at Site G was not recovered due to the extreme environmental conditions.

88. The data collected from all stations are discussed below. The order of discussion is in seasonal sequence; when two instruments

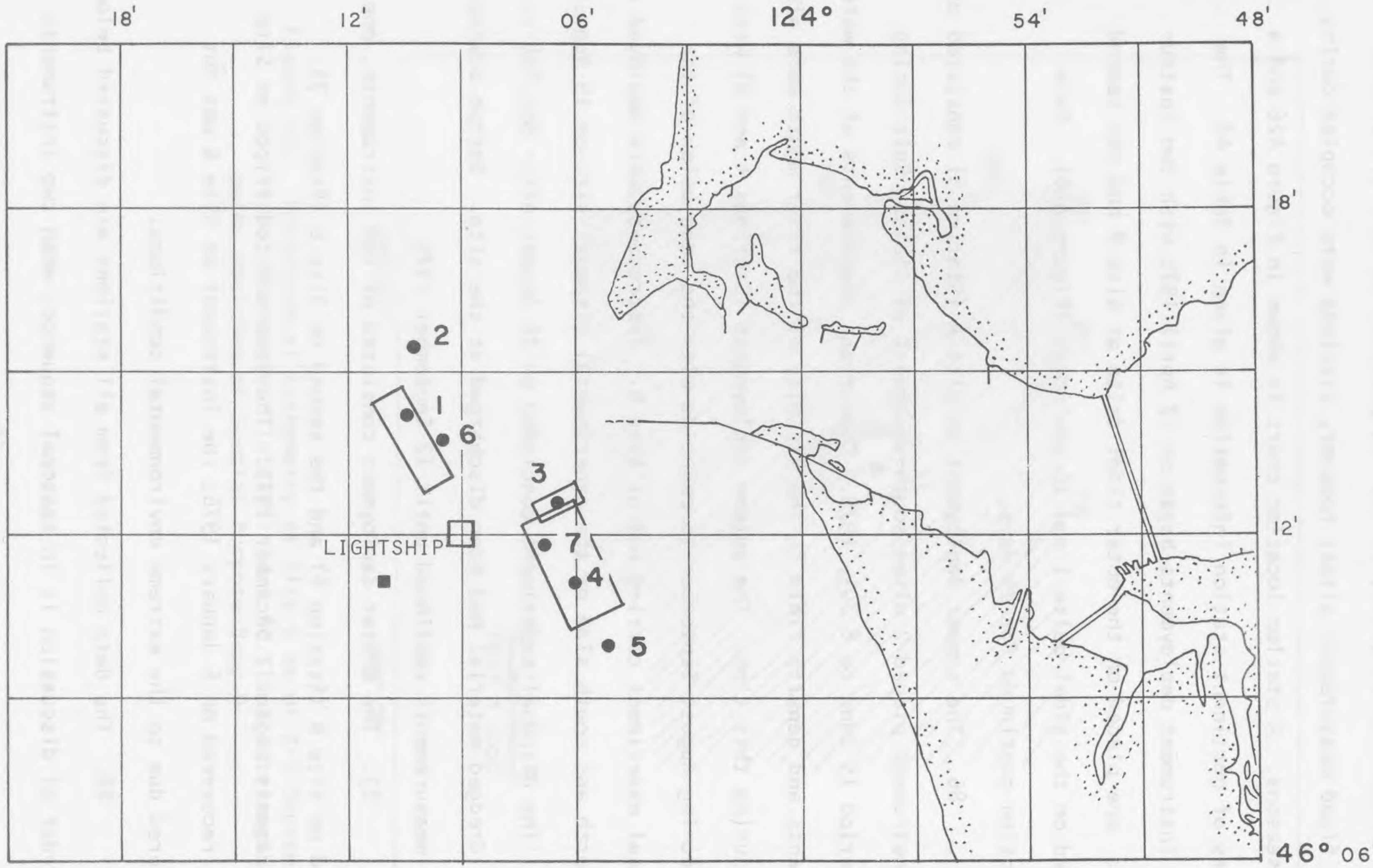

Figure A26. Instrumented tripod station locations

Table A8

Instrumented Tripod Deployment Summary

Station	Deployment Times	Deployment Dates	Latitude/ Longitude	Site	Depth m	Total Operating Hours	Data Recovery (Hours) Speed	Direction	Photo	Press	Trans.
1	1858 0810	4-12-75 to 5-6-75	46°12.28' 124°10.3'	B	30.0	565	565	565	565	565	420
2	2020 0910	4-12-75 to 5-6-75	46°15.25' 124°10.56'	Site B Control	31.1	565	565	565	565	565	No Instrument
3	1918 1015	6-15-75 to 7-8-75	46°12.5' 124°06.5'	A	24.0	543	543	543	543	543	543
4	1241 0815	8-19-75 to 9-12-75	46°11.25' 124°06.5'	G	28.5	570	570	570	570	570	570
5	1213 0902	8-19-75 to 9-12-75	46°10.0' 124°05.00'	Site G Control	31.3	572	572	572	50	572	572
6	0837 1405	12-12-75 to 1-6-76	46°13.96' 124°09.97'	B	24.0	605	351	605	351	605	333
7	0900	12-12-75	46°11.53' 124°06.1'	G	Instrument Not Recovered						
				Total Hours			3166	3420	2644	3420	2438
				Total Days			131.9	142.5	110.2	142.5	101.6

were deployed simultaneously, they are discussed together.

April-May 1975: Stations 1 and 2

89. Winds. Wind data from the Columbia River Lightship (Figure A26) during the sampling period are shown in Figure A27. The spring period is characterized by a series of low pressure cells that move eastward across the coast of Washington-Oregon. These produce southerly winds as the storm passes alternating with northerly winds during the intervening period of high atmospheric pressure. Three distinct storms occurred in the study area each having a duration of approximately 3 days and each more severe than the previous. The first storm (16-19 April, record days 5-8) was mild and was associated with mean winds of 6.5 m/sec (12.5 knots). The second storm occurred between 21-25 April (record days 10-14) and produced mean southerly winds in excess of 11.0 m/sec (21 knots). The third, and most severe storm (1-5 May, record days 20-24) produced mean winds of 16.5 m/sec (31.7 knots). It should be noted that wind speeds in Figure A27 represent mean speed averaged over 25-hr periods, hence the plotted maximum speeds are much lower than actual maximums. For example, the maximum wind measured at the Columbia River Lightship on 2 May 1975 was 23.15 m/sec (44.5 knots) as compared to the 25-hr mean of 16.5 m/sec (31.7 knots).

90. Waves. Although data from the precision wave recorder deployed for this study were not recovered, bottom pressure fluctuations from surface wave activity were recorded in the instrumented tripods and these data are shown in Figure A28.

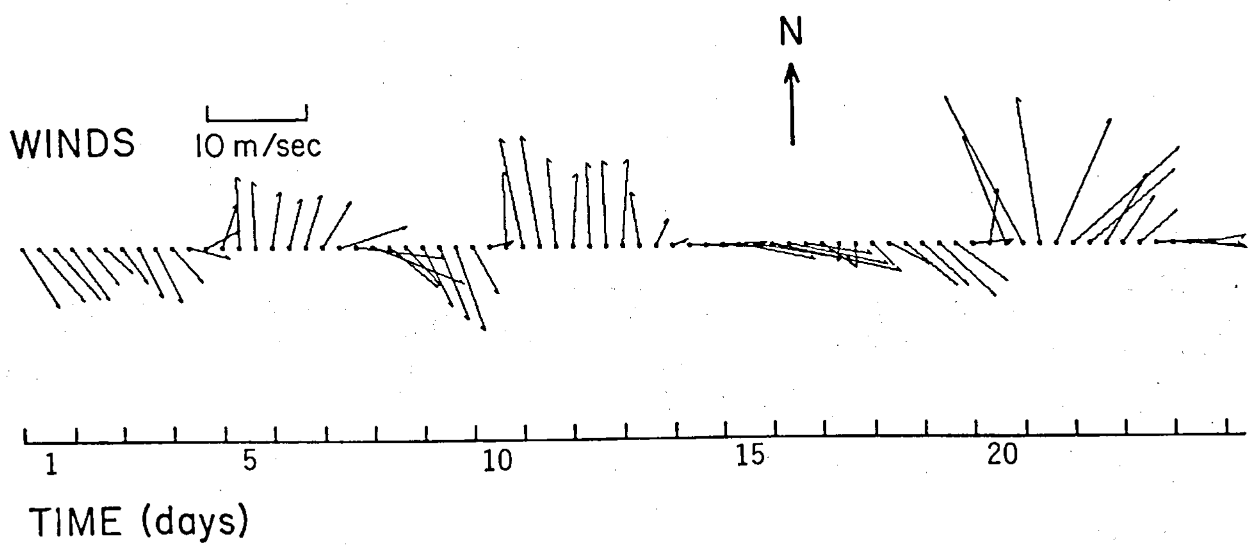

Figure A27. Columbia River Lightship winds during Stations 1 and 2, 12 April to 6 May 1975. The horizontal scale is in days, the vector is 10 m/sec/unit. Wind data represented 25-hr running averages with a vector scale plotted each 8 hr; vectors were plotted as direction toward which the wind was blowing

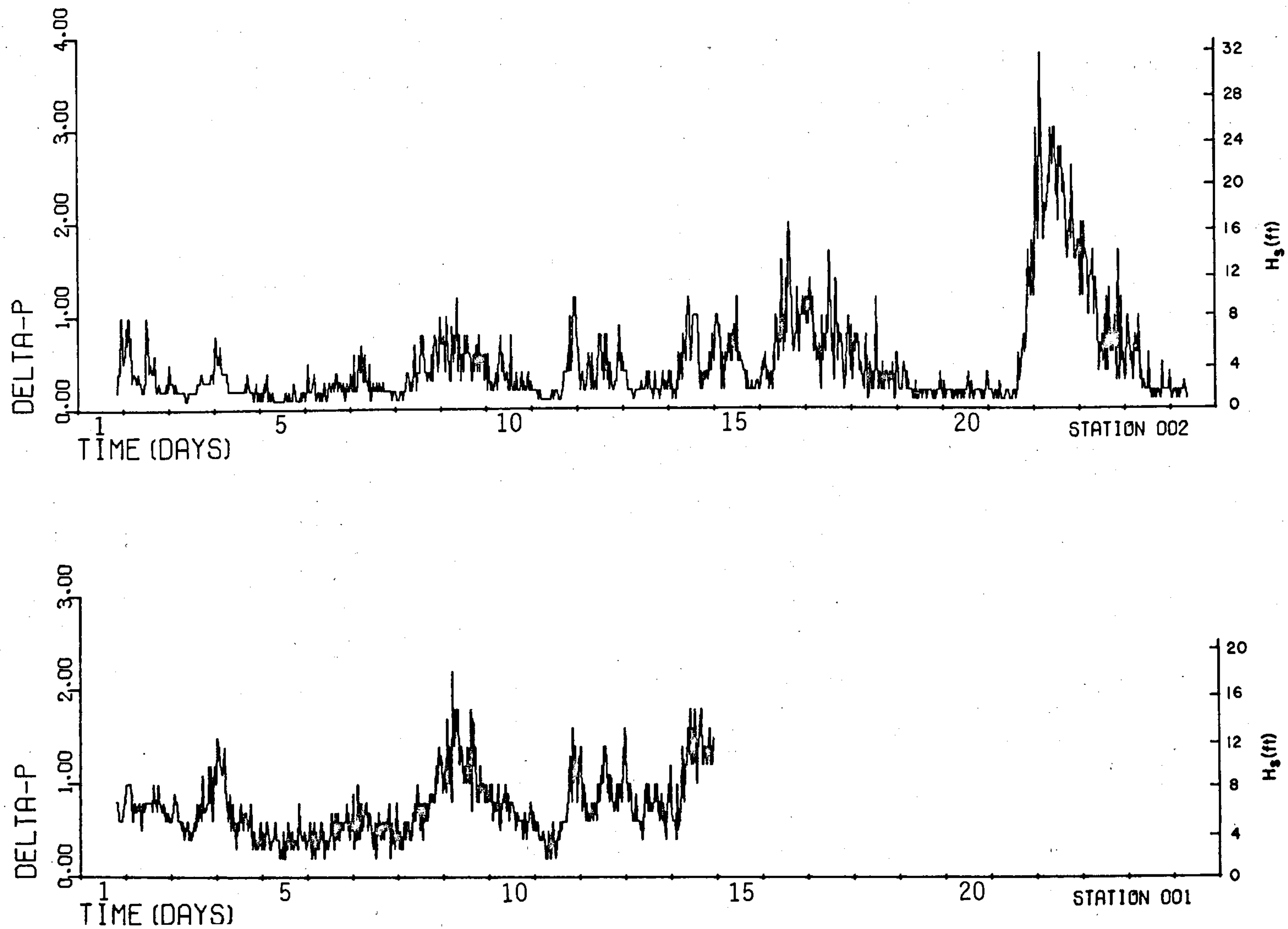

Figure A28. High frequency pressure fluctuations (DELTA-P) at Stations 1 and 2 during the period 1900 12 April 75 to 0800 6 May 75. The DELTA-P scale is in recorder units. The wave scale on the right was computed using the pressure calibration curve in Figure A19 for a wave with a T_s of 12 sec

91. In general, high frequency pressure fluctuations, hence wave activity, were low to moderate throughout the earlier part of the sampling period. Bottom pressure fluctuations (DELTA P) were less than 1 to 1.5 recorder units, which would correspond to surface waves having a significant height (H_s) of 8 to 13 ft* at Stations 1 and 2. Wave heights increased significantly on 2 and 3 May (21-22 record days) corresponding to the major storm passing over the study area. During the entire 24-hr period on 3 May (record day 22), H_s at Station 2 exceeded 20 ft and reached a maximum of approximately 32 ft. Due to a failure in an underwater connector, pressure fluctuation measurements at Station 1 were discontinued on 25 April 1975.

92. Tides. The tidal records at Stations 1 and 2 exhibit the mixed semidiurnal pattern typical of the eastern north Pacific (Figure A29). During this sampling period, tide height variations reached 13.9 ft.

93. Bottom currents. Current speed ($\bar{U}_{100}$) and current direction time series are plotted independently for Stations 1 and 2 (Figures A30 and A31) and also summarized as speed-direction frequency distributions (Figures A32 and A33). The time series of the eastward (U) and northward (V) components for each station are plotted in Figures A34 and A35, respectively.

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*Based on wave hindcast studies by National Marine Consultants (1961), a significant wave period of 12 sec is used in order to convert the tripod pressure fluctuation measurements to surface wave height estimates. This conversion of DELTA P to wave height for a 12-sec wave is used throughout the text.

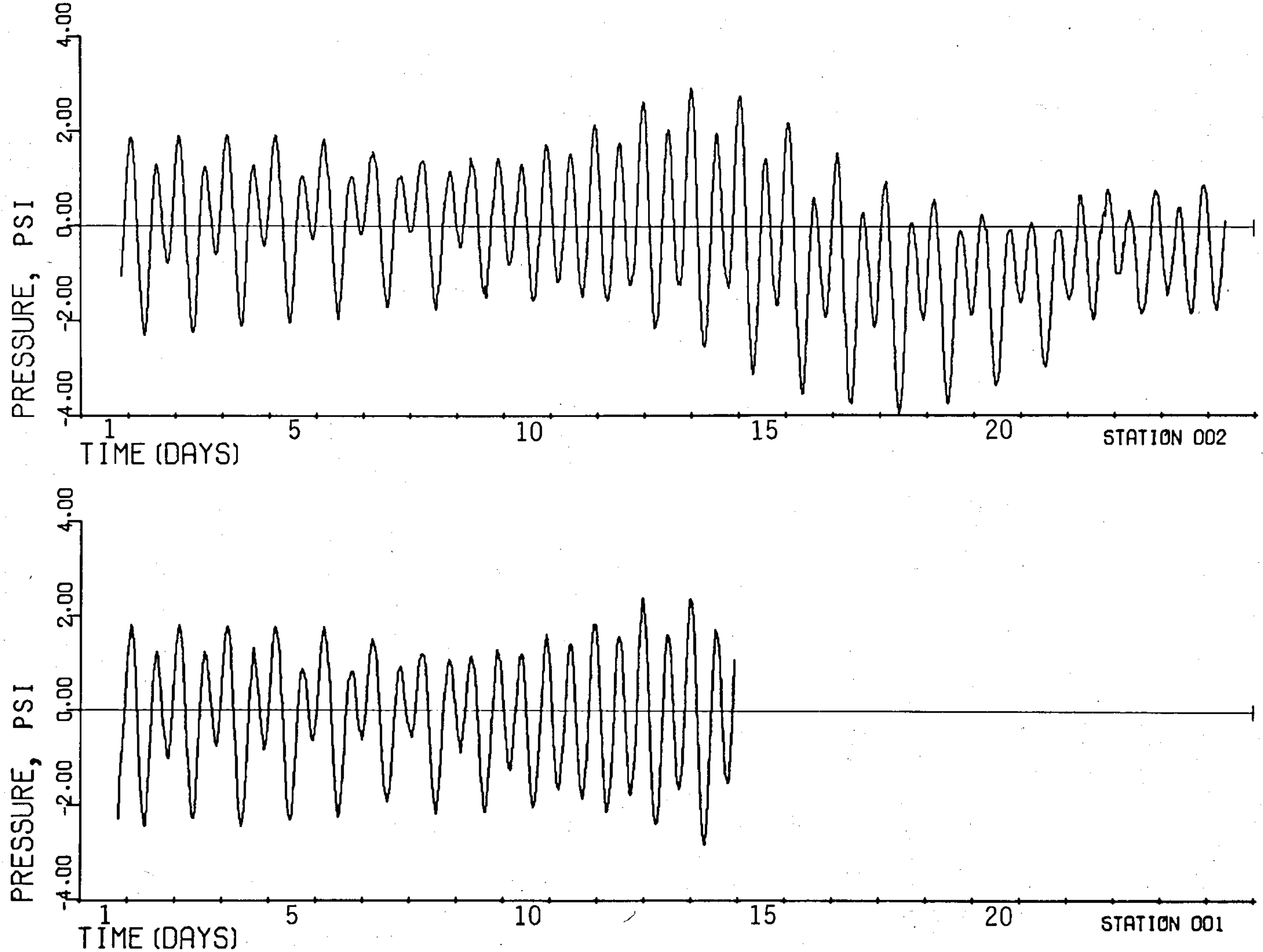

Figure A29. Tide height vs. time in days at Stations 1 and 2 during the period 1900 12 April 75 to 0800 12 May 75. The vertical scale is in psi referenced to mean sea level (1 psi ~ 2.2 ft)

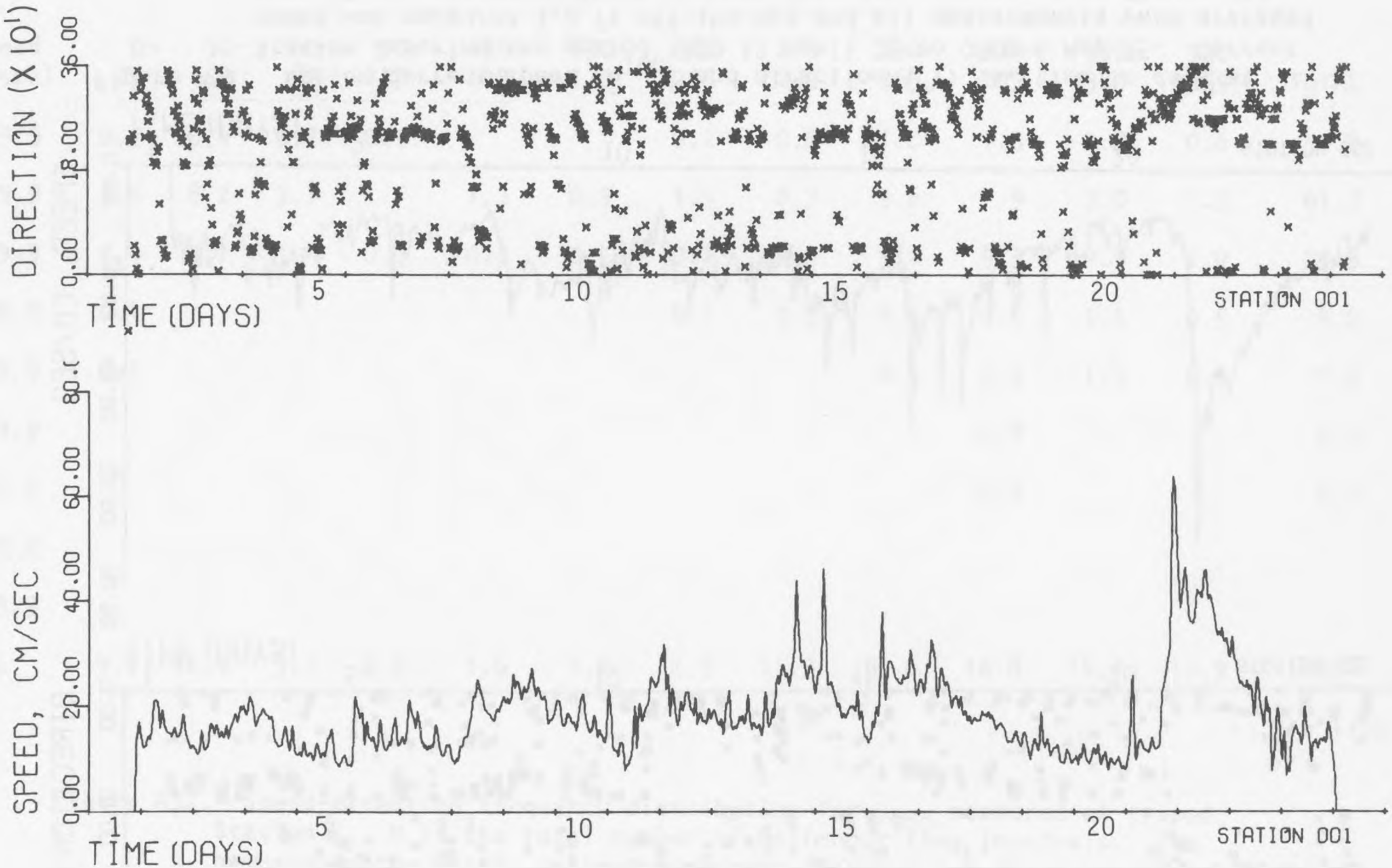

Figure A30. Bottom current speed ($\bar{U}_{100}$) and direction (^{o}T) vs. time in days at Station 1 during the period 1900 12 April 75 to 0800 6 May 75. Current speed was measured 3.3 ft off the bed and all measurements were averaged over 30-min periods. These current data are summarized in Figure A32

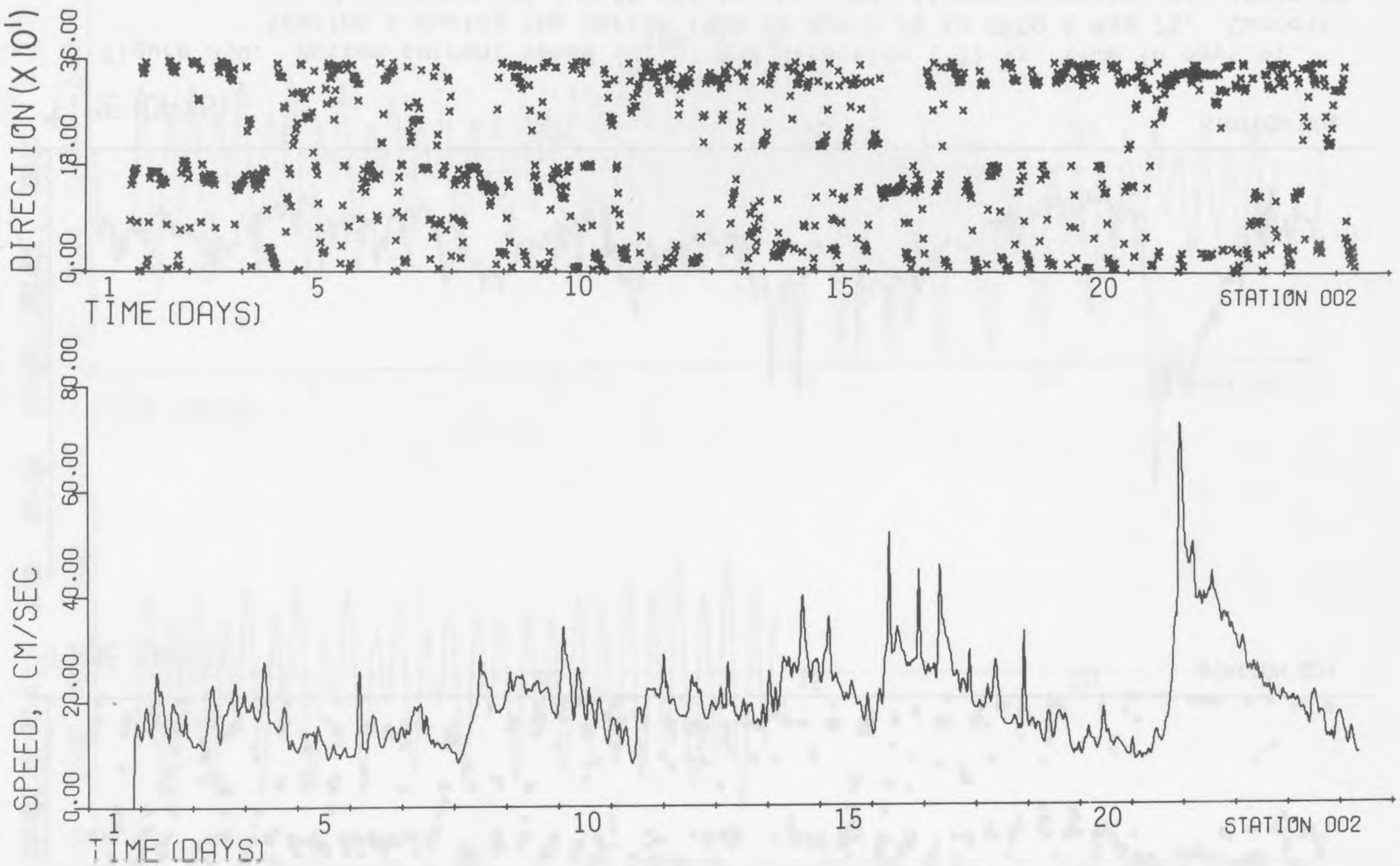

Figure A31. Bottom current speed ($\bar{U}_{100}$) and direction (°T) vs. time in days at Station 2 during the period 1900 12 April 75 to 0800 6 May 75. Current speed was measured 3.3 ft off the bed and all measurements were averaged over 30-min periods. These current data are summarized in Figure A33

TRIPOD STATION 1 (12 April - 5 May, 1975)

Direction (^{o}T)

Speed (cm/sec)	0-29	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	270-299	300-329	330-359	TOTAL
0-9.9	0.7	0.4	0.2	0.1			0.2	0.6	1.0	1.3	0.7	0.6	5.8
10-19.9	5.9	8.2	2.1	1.7	1.3	0.5	1.5	8.7	9.6	7.9	7.0	7.3	61.7
20-29.9	2.6	3.7	1.4	0.5	0.3	0.5	0.1	2.3	3.4	4.3	4.5	2.0	25.6
30-39.9	0.4						0.1	0.3	1.1	0.5	1.1	0.5	4.0
40-49.9	0.1								0.5	0.3	1.4	0.5	2.8
50-59.9										0.2			0.2
60-69.9										0.3			0.3
70-79.9													
80-89.9													
TOTAL	9.7	12.3	3.7	2.3	1.6	1.0	1.9	11.9	15.6	14.8	14.7	10.9	100.4

N = 1109

Figure A32. Speed-direction frequency distribution for $\bar{U}_{100}$ measured at tripod Station 1. N is the total number of half-hour time intervals. The numbers in the matrix represent percent of total sampling time

TRIPOD STATION 2 (12 April - 5 May, 1975)

Direction (^{o}T)

Speed (cm/sec)	0-29	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	270-299	300-329	330-359	TOTAL
0-9.9	0.5	0.4	0.4		0.5	0.4	0.1			0.4	0.5	1.3	4.5
10-19.9	7.5	4.1	3.5	1.8	3.6	6.9	2.2	2.4	2.8	2.3	7.0	12.1	56.2
20-29.9	3.6	2.2	1.2	0.5	4.1	3.7	0.7	1.2	0.5	0.6	4.9	7.5	30.7
30-39.9	0.4	0.5			1.1	0.4		0.4	0.1	0.5	0.7	1.8	5.9
40-49.9	0.3	0.3			0.3	0.1					0.1	1.2	2.3
50-59.9	0.1	0.1			0.1								0.3
60-69.9	0.1											0.1	0.2
70-79.9												0.2	0.2
80-89.9													
TOTAL	12.5	7.6	5.1	2.3	9.7	11.5	3.0	4.0	3.4	3.8	13.2	24.2	100.3

N = 1127

Figure A33. Speed-direction frequency distribution for $\bar{U}_{100}$ measured at tripod Station 2. N is the total number of half-hour time intervals. The numbers in the matrix represent percent of total sampling time

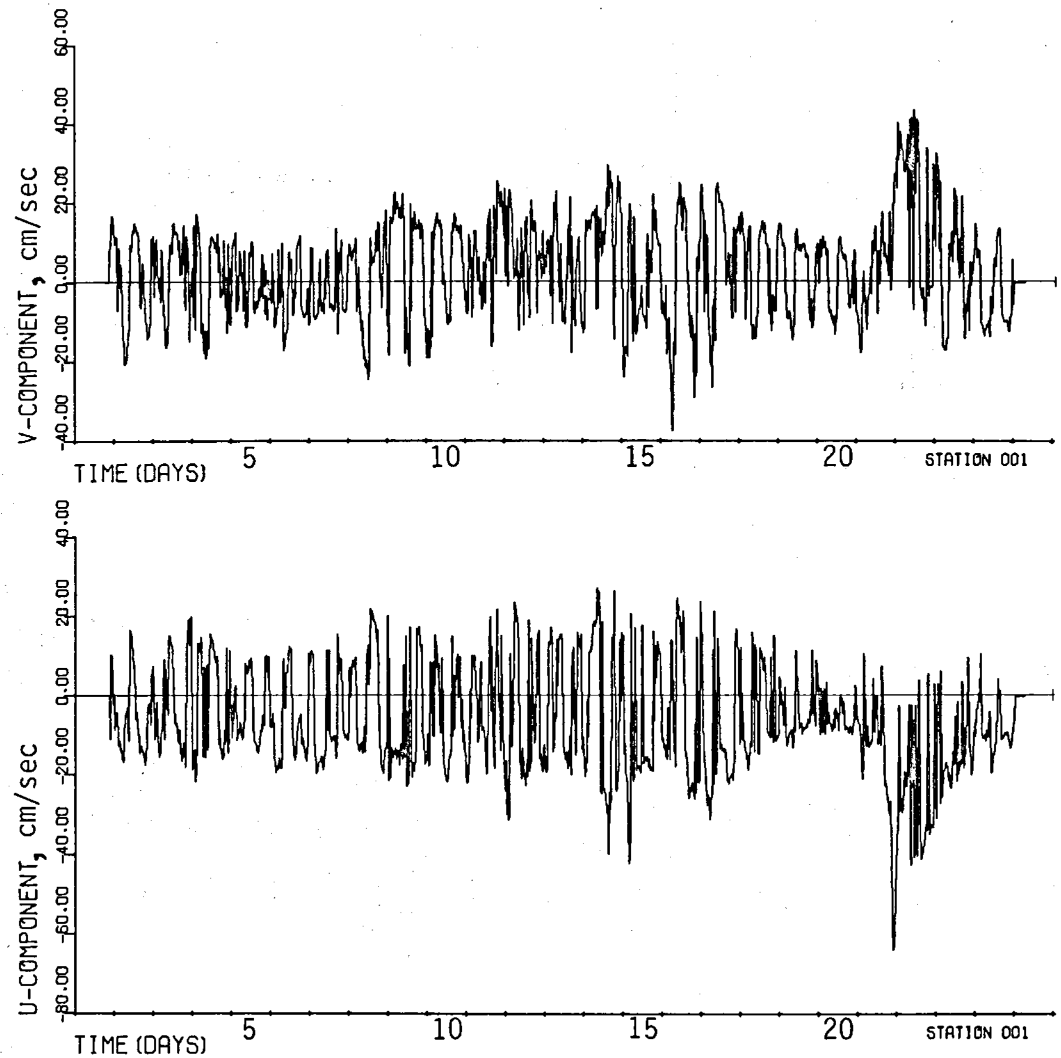

Figure A34. Northward (V) and eastward (U) components of current velocity 3.3 ft above the bed at Station 1 during the period 1900 12 April 75 to 0800 6 May 75

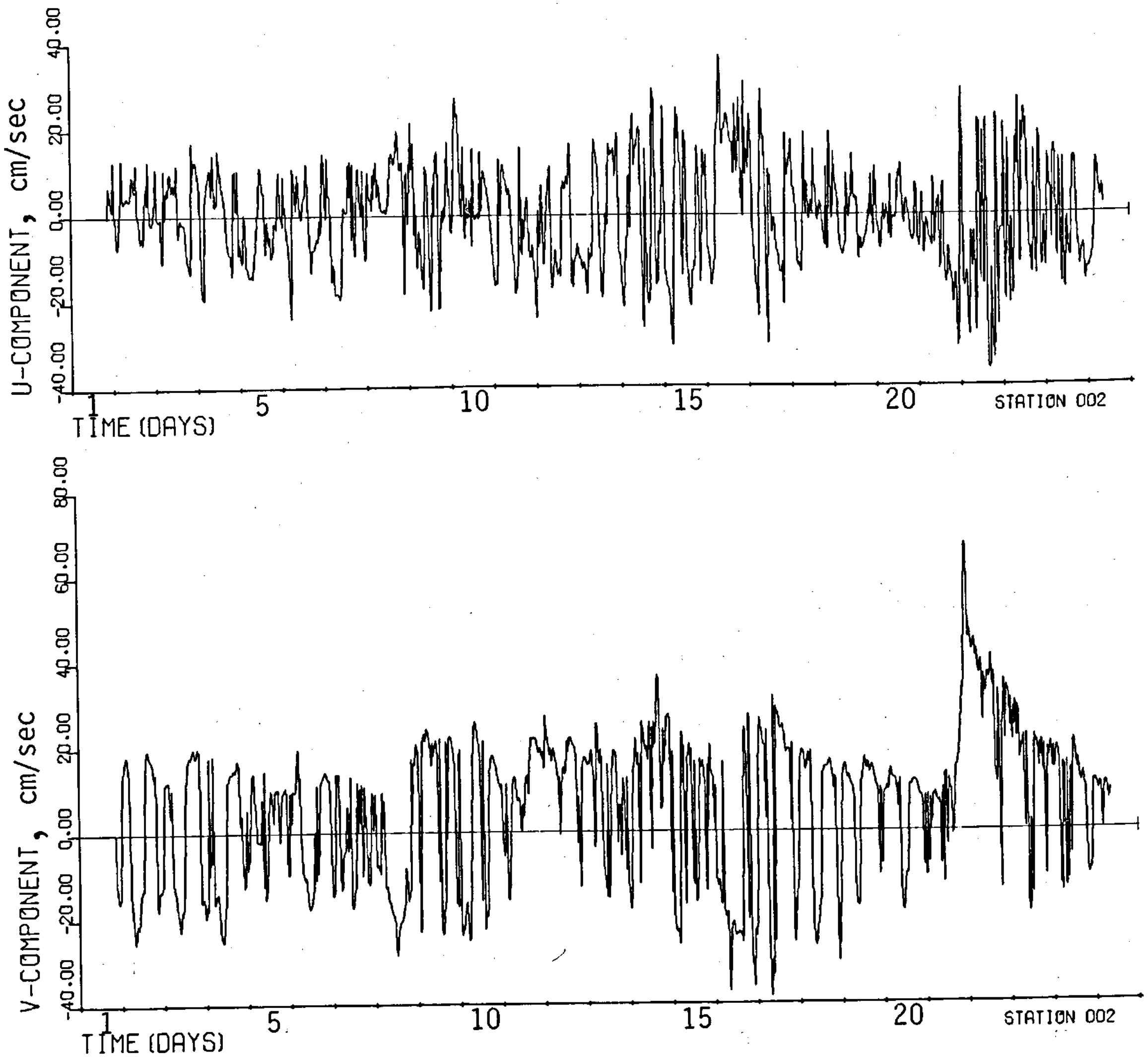

Figure A35. Northward (V) and eastward (U) components of current velocity 3.3 ft above the bed at Station 2 during the period 1900 12 April 75 to 0800 6 May 75

94. Currents during the sampling period were generally less than 20 cm/sec (67.5% and 60.7% of the duration of Stations 1 and 2, respectively) and exhibited a strong tidal component. Observed direction of flood and ebb flows are northwest and southeast, respectively. Significantly higher speeds were measured during the latter part of the measurement period. Between 25 and 28 April (record day 14 and 17, Figures A30 and A31), several short-period peaks in $\bar{U}_{100}$ occur with speeds in excess of 40 to 45 cm/sec. These speeds occurred during a spring tide ebb current and had a southeasterly direction. The major storm occurring on 2-4 May (record day 21-23) was associated with bottom current speeds in excess of 65 cm/sec flowing in a northwesterly direction. Current speed increased in a matter of hours in response to the strong southerly winds, then decreased more slowly over the next several days.

95. Progressive vector diagrams for Stations 1 and 2 are shown in Figures A36 and A37, respectively, and illustrate the net current residuals during the total sampling period. Net bottom flow at Station 1 exhibited a continued northwesterly trend which averaged 8.4 cm/sec at 200°T. The trend of the isobaths at Station 1 was 200°T. Net flows at Station 2 averaged 3.8 cm/sec at 354°T. The trend of the isobaths at Station 2 was 348°T.

96. Bottom turbidity. Two types of bottom turbidity estimates were obtained from the instrumented tripods. One technique used the beam transmissometer with a path length of 3.3 ft. This method was used at Station 1 and the output is shown in Figure A38. The second technique rated the clarity of the bed features as seen in

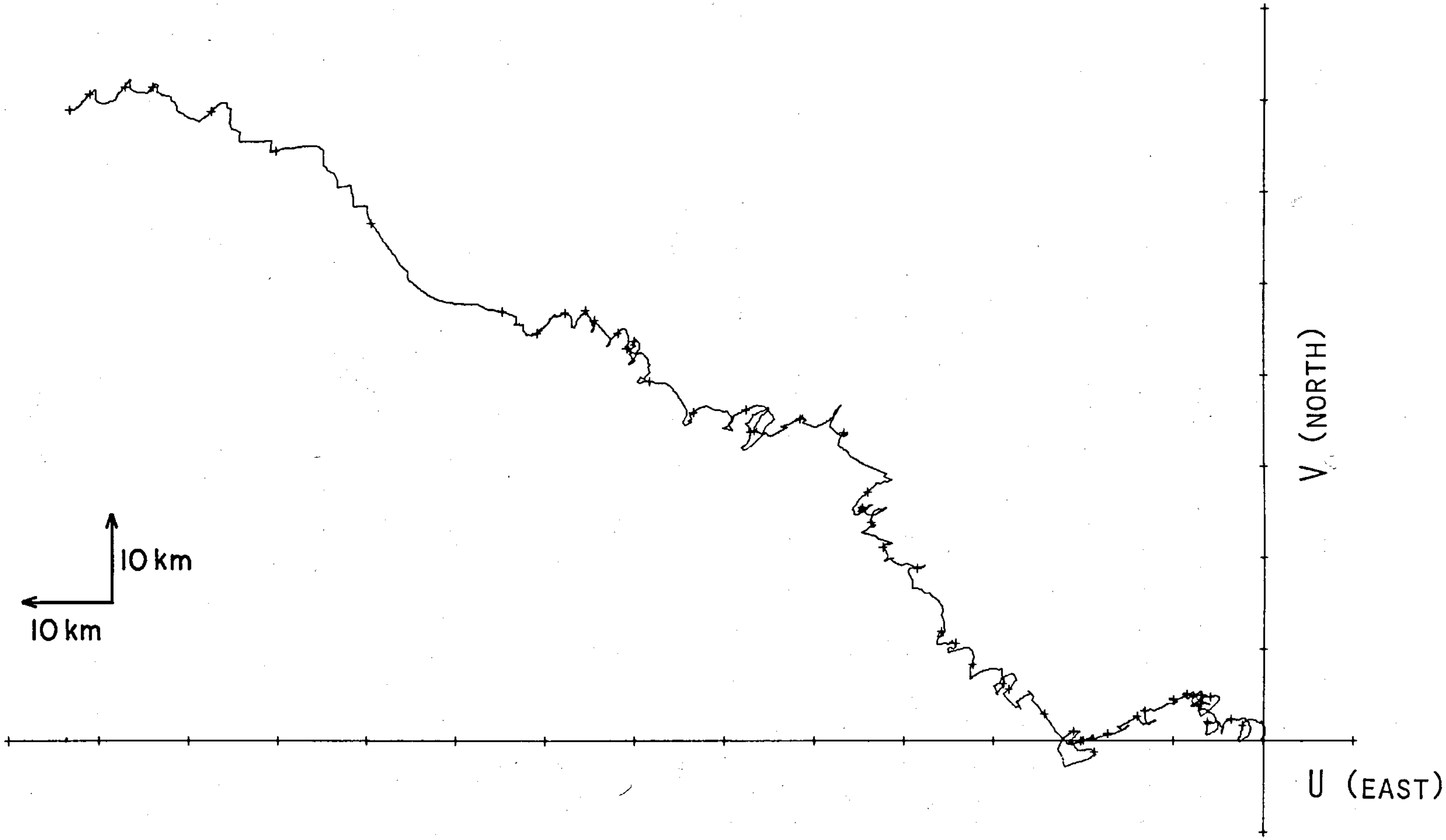

Figure A36. Progressive vector diagram (PVD) for Station 1 during the period 1900 12 April 75 to 0800 6 May 75. The positive vertical axis represents true north.

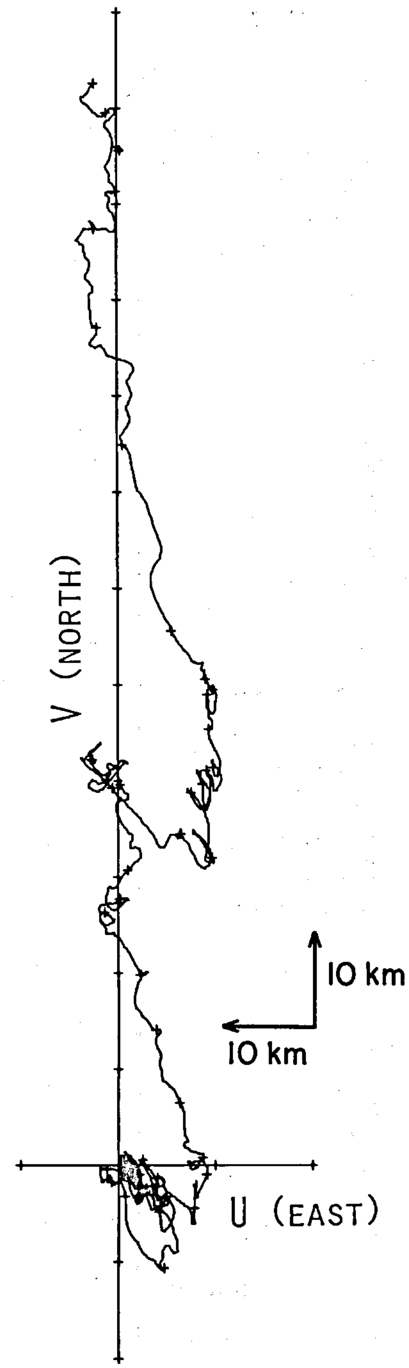

Figure A37. Progressive vector diagram (PVD) for Station 2 during the period 1900 12 April 75 to 0800 6 May 75. The vertical axis represents true north

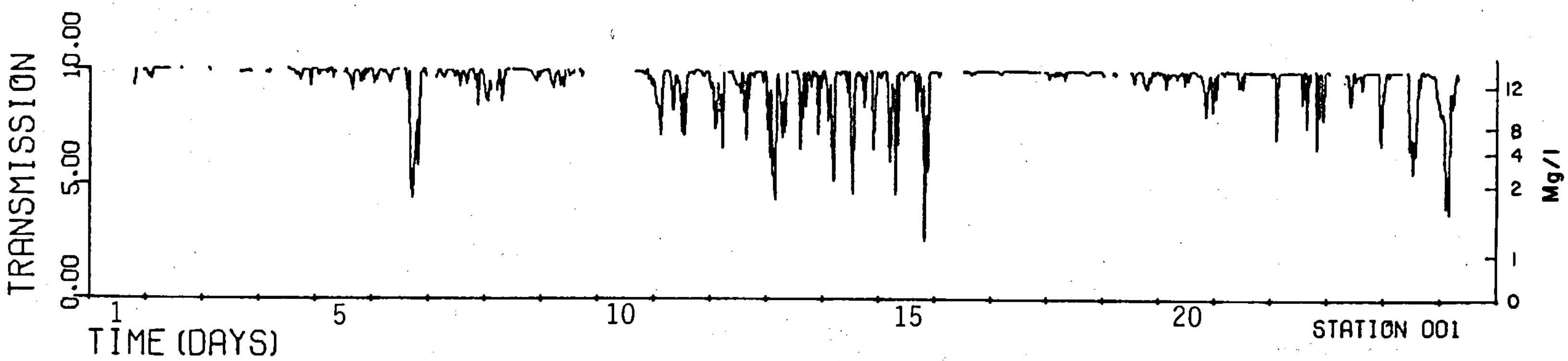

Figure A38. Transmission (in arbitrary recorder units) at Station 1 during the period 1900 12 April 75 to 0800 6 May 75. The scale at the right represents concentration of suspended sediment (mg/ℓ) 4.3 ft above the seabed (see Figure A21) the bottom photographs on a scale of 1 to 6 (see Figure A21 for a definition of the scale). These analyses are also plotted and the results for Stations 1 and 2 are shown in Figure A39.

97. Estimates of total suspended particulate matter from the beam transmissometer were not satisfactory. The deployment at Station 1 was the first transmissometer deployment. The 3.3-ft path length proved to be too great and caused the recorder to be off scale on the high end during most of the sampling period, thus losing the part of the record associated with high suspended sediment concentrations. The low attenuation part of the transmissometer record (Figure A38) was characterized by relatively low suspensoid concentrations (1 to 5 mg/ℓ). Individual periods of low concentration show a strong tidal variation which corresponded to periods of flood flow. This is the only part of the record that could be evaluated. The remainder of the record was lost.

98. Photo-interpretation results (Figure A39) for Stations 1 and 2 gave visibility values between 3 and 6. The periods of less turbid water correlated to the transmissometer record. According to this analysis, concentration of suspensoids during the sampling period varied from 3 mg/ℓ to greater than 60 mg/ℓ (the maximum that this technique will resolve).

<u>June-July 1975: Station 3</u>

99. <u>Winds</u>. The Columbia River Lightship was not on station during the latter part of June; as a result, wind records for this deployment were only available after 1 July (Figure A40). Mean winds

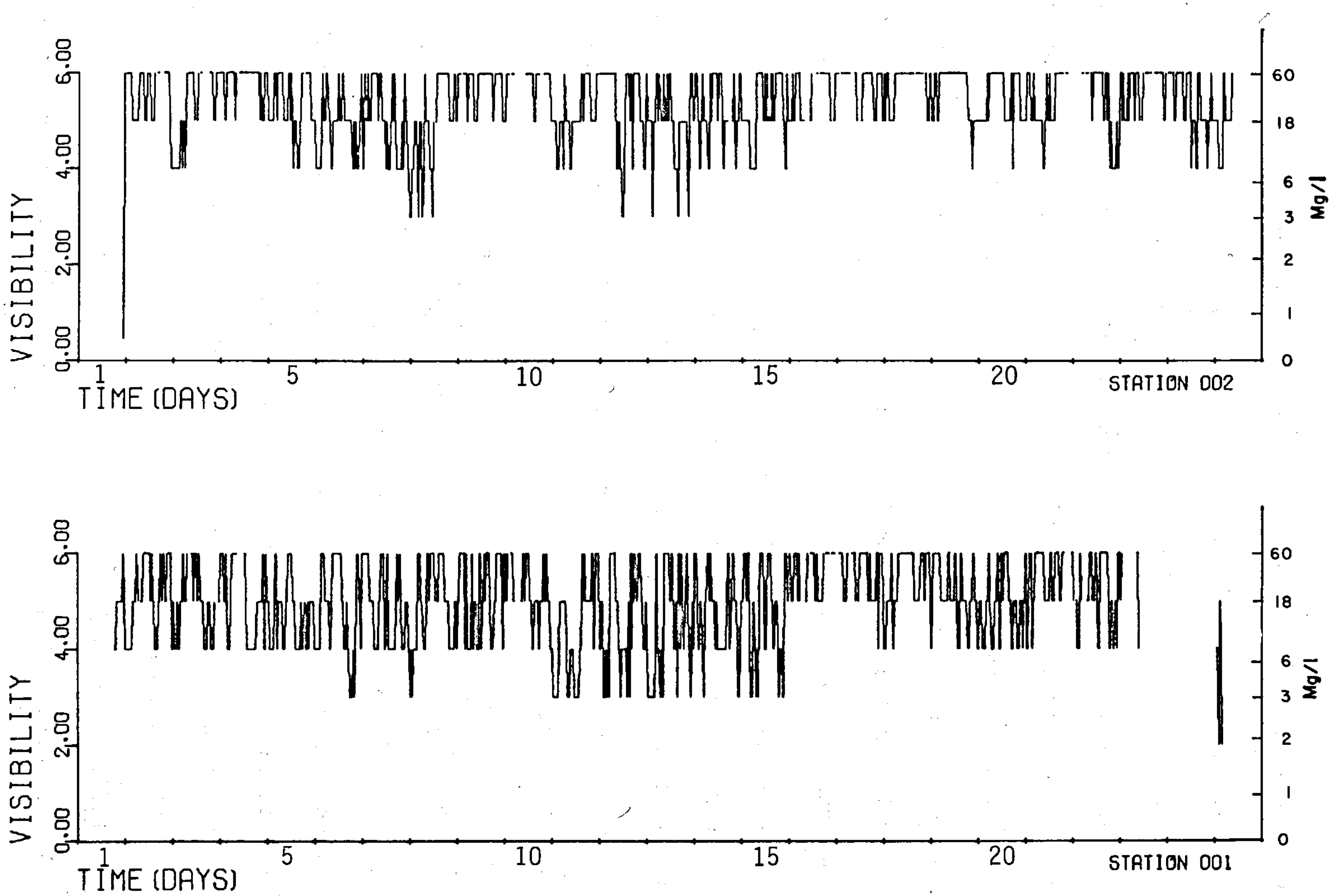

Figure A39. Photo visibility for Stations 1 and 2 during the period 1900 12 April 75 to 0800 6 May 75. The scale at the right represents concentration of suspended sediment (mg/ℓ) 4.3 ft above the seabed (see Figure A21)

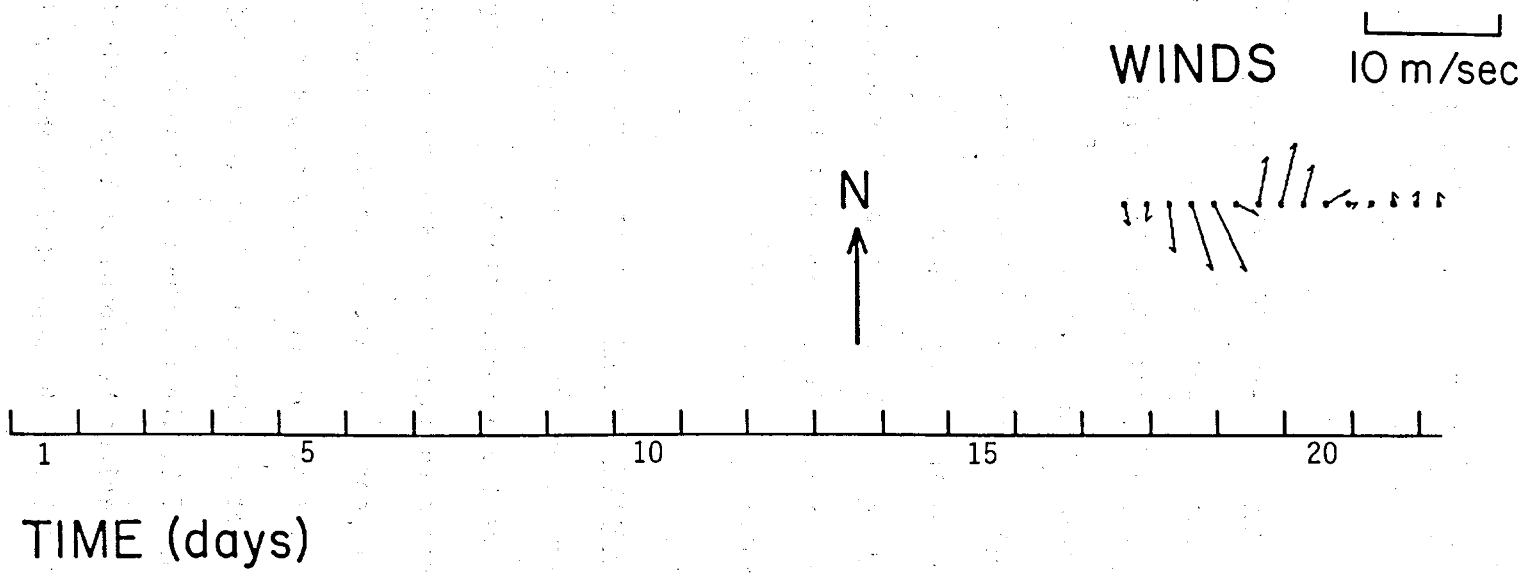

Figure A40. Columbia River Lightship winds during a portion of Station 3, 2 July 75 to 8 July 75 (ship off station in June and early July). The horizontal scale is days; the vector scale is 10 m/sec/unit. Wind data represented 25-hr averages. Vectors were plotted as direction toward which the wind was blowing during this period were light, varying between 5.6 m/sec (10.8 knots) from the north (1-3 July) and 4.7 m/sec (9 knots) from the south (3 and 4 July).

100. Waves. Bottom pressure fluctuations during June-July were very low, showing no evidence of major storms or large swells propagating into the area (Figure A41). Estimates of surface wave activity over Station 3 show that H_s was less than 7 ft throughout the first 20 record days. On 5 and 6 July (record day 21-22), H_s reached 10 ft, a maximum for the sampling period.

101. Tides. The tidal record for Station 3 is shown in Figure A42. The maximum tidal range varied between 5.6 ft during the neap tide to greater than 11 ft during the spring tide portion of the sampling period.

102. Bottom currents. Bottom current speed and direction at Station 3 (Figures A43 and A44) showed similar conditions to the fair weather portions of the previous stations. The magnitude of $\bar{U}_{100}$ did not exceed 25 cm/sec throughout the sampling period, and flood and ebb currents flowed in northerly and southerly directions, respectively.

103. Analysis of the U and V components of $\bar{U}_{100}$ revealed some interesting bottom flow conditions (Figure A45). For example, during record days 5-9, the U component (and V component to a lesser extent) was characterized by groups of 3 to 4 distinct fluctuations with a period of 3.5 to 4 hr separated by about a 16-hr period of very low current speed. Comparison of Figure A45 and the tidal record in Figure A42 shows that the higher frequency oscillations occurred only

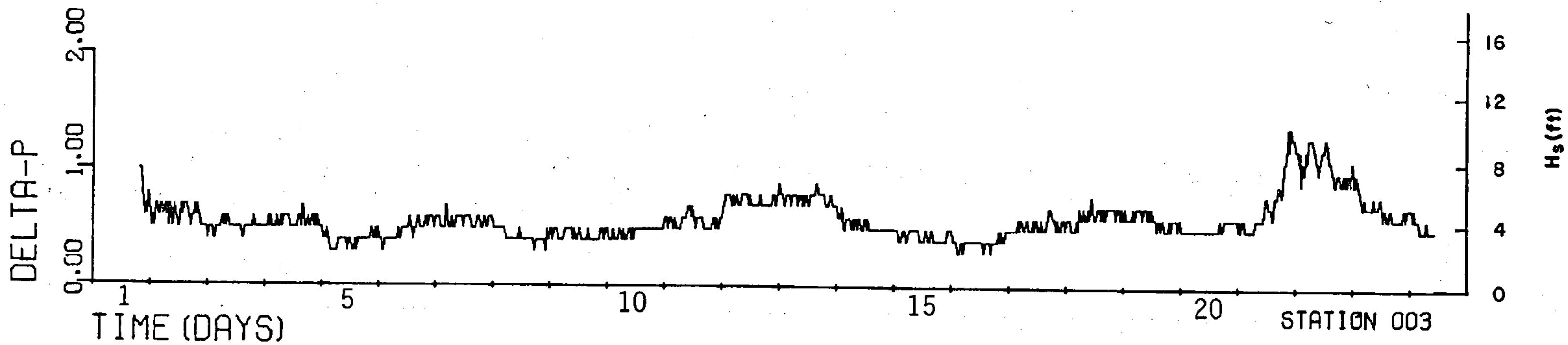

Figure A41. High frequency pressure fluctuations (DELTA-P) at Station 3 during the period 1930 15 June 75 to 1000 8 July 75. The DELTA-P scale is in recorder units. The wave scale on the right was computed using the pressure calibration curve in Figure A19 for a wave with a T_s of 12 sec

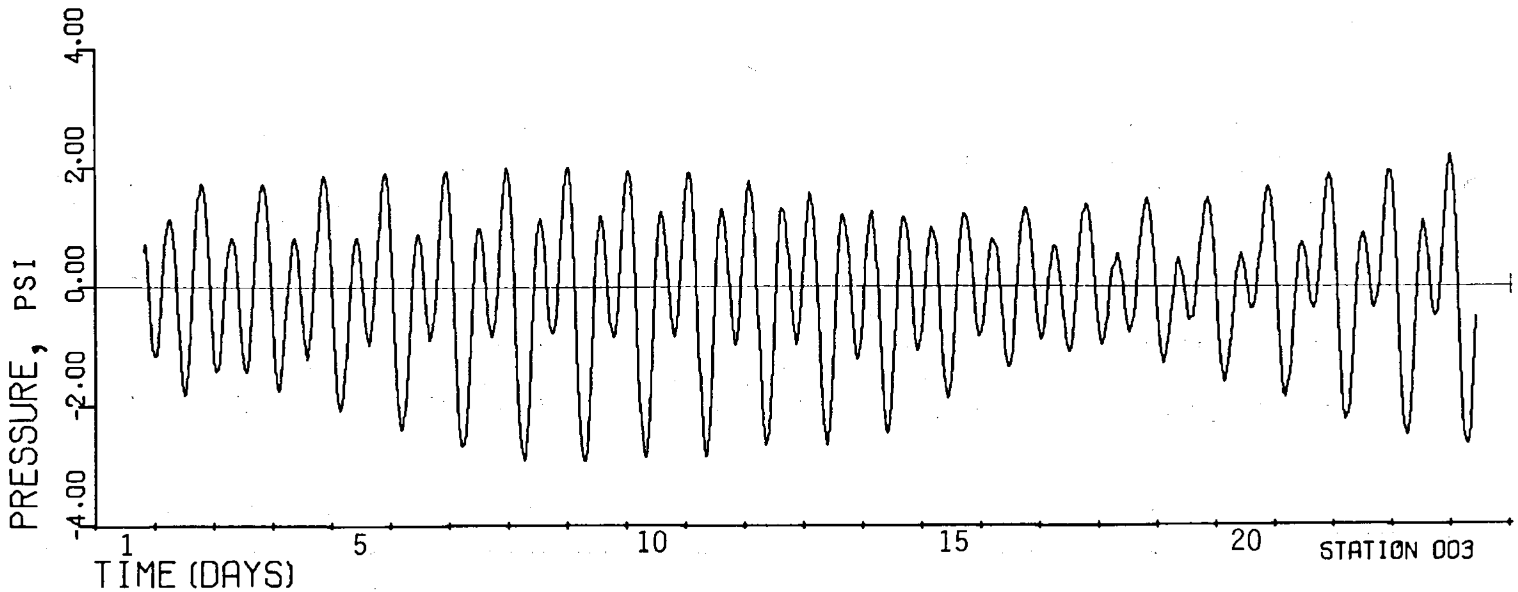

Figure A42. Tide height vs. time in days at Station 3 during the period 1930 15 June 75 to 1000 8 July 75. The vertical scale is in psi referenced to mean sea level (1 psi ~ 2.2 ft)

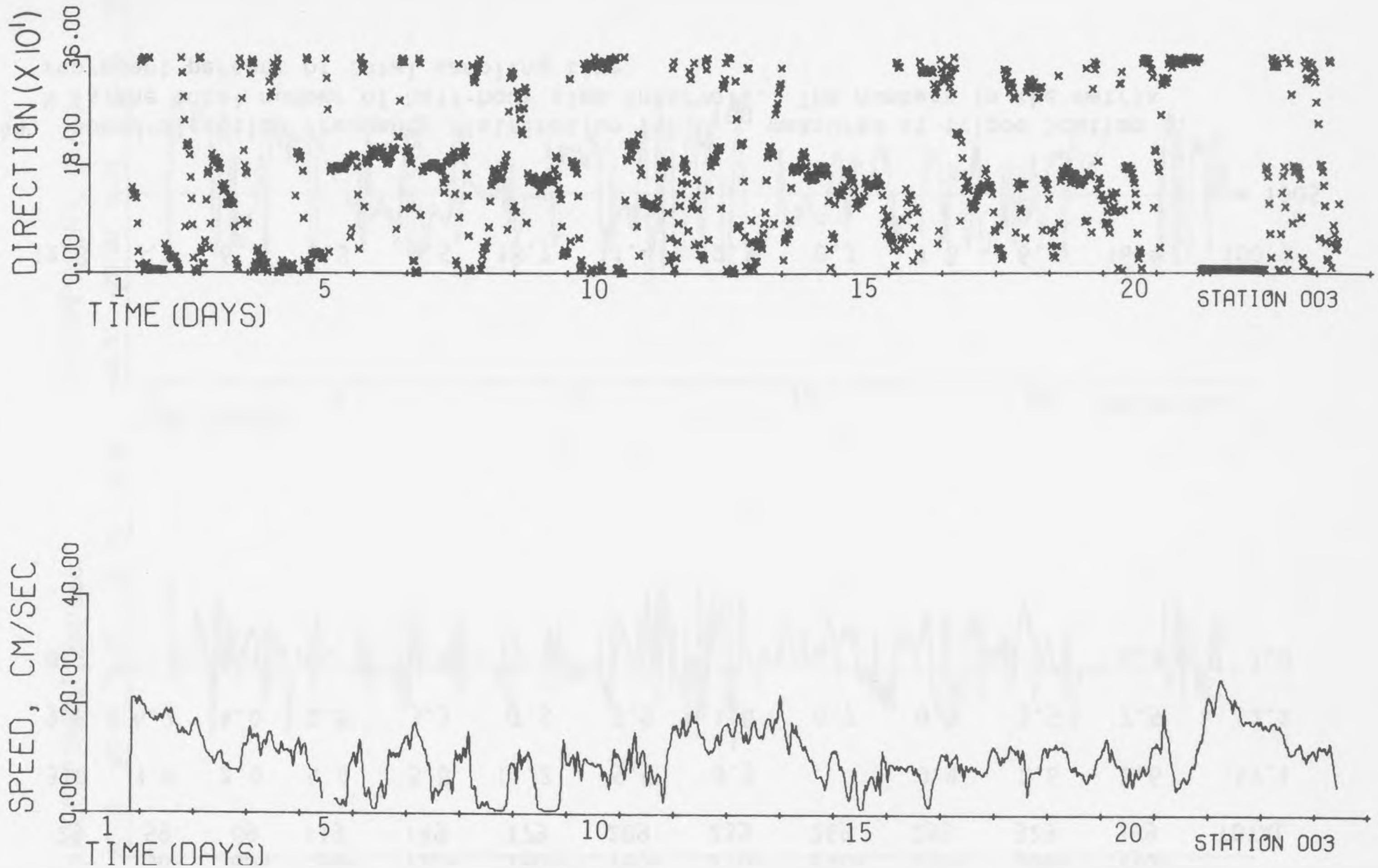

Figure A43. Bottom current speed ($\bar{U}_{100}$) and direction (^{O}T) vs. time in days at Station 3 during the period 1930 15 June 75 to 1000 8 July 75. Current speed was measured 3.3 ft off the bed and all measurements were averaged over 30-min periods. These current data are summarized in Figure A44

TRIPOD STATION 3 (15 June - 8 July, 1975)

Direction (^{o}T)

Speed (cm/sec)	0-29	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	270-299	300-329	330-359	TOTAL
0-9.9	3.0	3.0	2.0	4.0	5.8	11.2	5.5	0.5		0.9	2.6	8.6	47.1
10-19.9	9.6	4.7	4.0	2.8	3.3	7.5	5.9	1.8	0.7	0.9	3.5	7.5	52.2
20-29.9	0.2		0.1		0.4							0.3	1.0
30-39.9													
40-49.9													
50-59.9													
60-69.9													
70-79.9													
80-89.9													
TOTAL	12.8	7.7	6.1	6.8	9.5	18.7	11.4	2.3	0.7	1.8	6.1	16.4	100.3

N = 1005

Figure A44. Speed-direction frequency distribution for $\bar{U}_{100}$ measured at tripod Station 3. N is the total number of half-hour time intervals. The numbers in the matrix represent percent of total sampling time

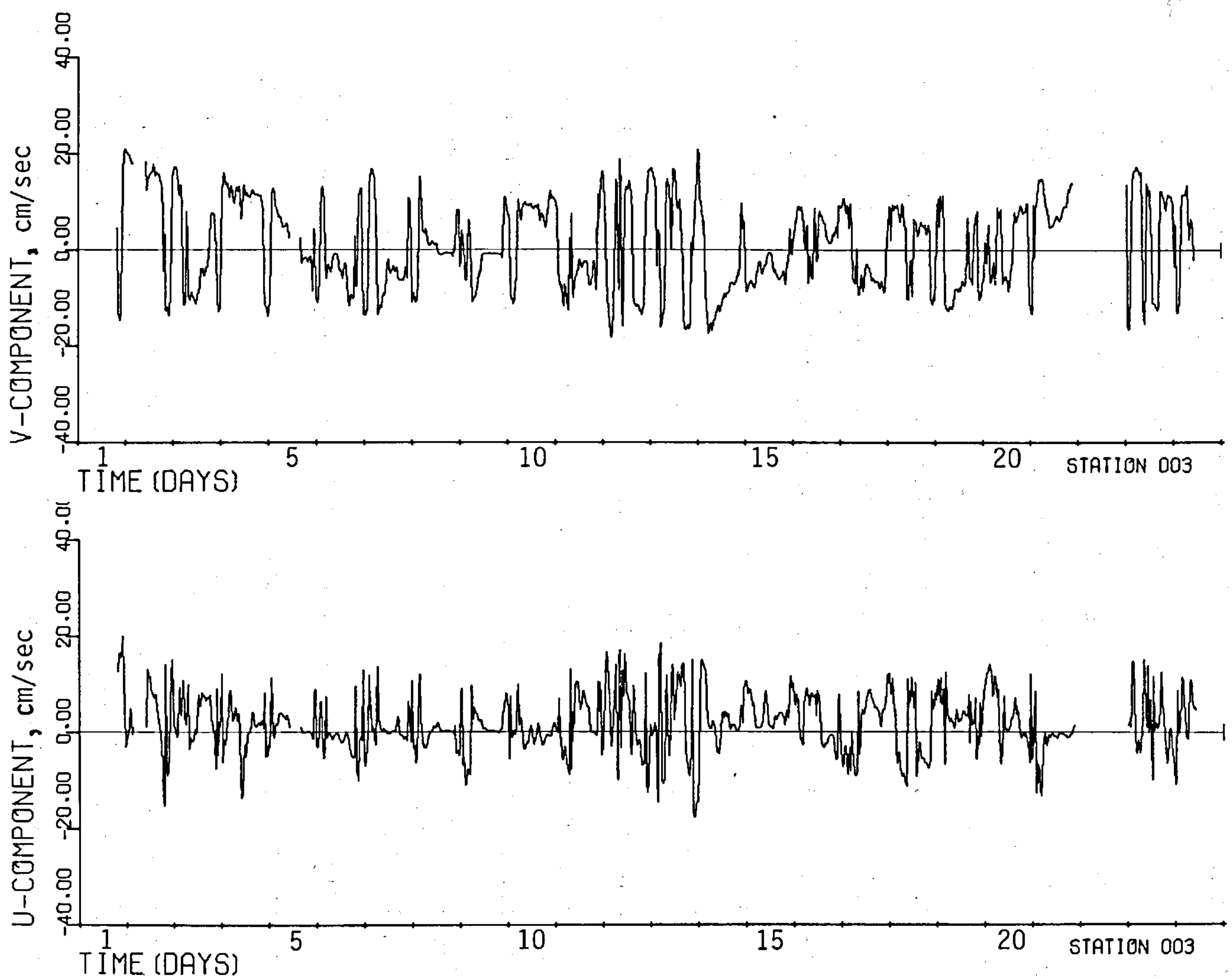

Figure A45. Northward (V) and eastward (U) components of current velocity 3.3 ft above the bed at Station 3 during the period 1930 15 June 75 to 1000 8 July 75 during flow associated with the maximum ebb range, i.e., between the higher high and lower low spring tides, whereas bottom currents associated with the lower high and higher low portions of the tides were very low. Bottom currents during the neap tide part of the data record (record days 17-18; Figure A45) exhibited the more expected semidiurnal tidal current pattern.

104. The progressive vector diagram (Figure A46) shows a net flow of 1.1 cm/sec in an easterly direction. This net flow appears to be a combination of flow paths composed of a general northwest-southeast trend with an easterly drift superimposed.

105. Bottom turbidity. For Station 3, the beam transmissometer path length was adjusted to 1.1 ft, and the output is shown in Figure A47. During the sampling period the concentration of suspended particulate matter, as determined from the instrument calibration (Figure A20), varied significantly. Background concentration levels ranged from 1.5 to 3 mg/ℓ. However, superimposed on this, numerous short-period fluctuations occurred. Concentration levels associated with the fluctuations were quite variable but generally high, between 20 and 100 mg/ℓ.

106. Moored current meters and CTD profiles. The work carried out under the physical oceanography section of this contract culminated in a 2-week cruise during 9-20 June 1975 on the research vessel CAYUSE. The CAYUSE was responsible for deploying and retrieving three current-meter arrays as well as maintaining four CTD stations in the offshore river plume for periods of 25 hr. A chart showing the

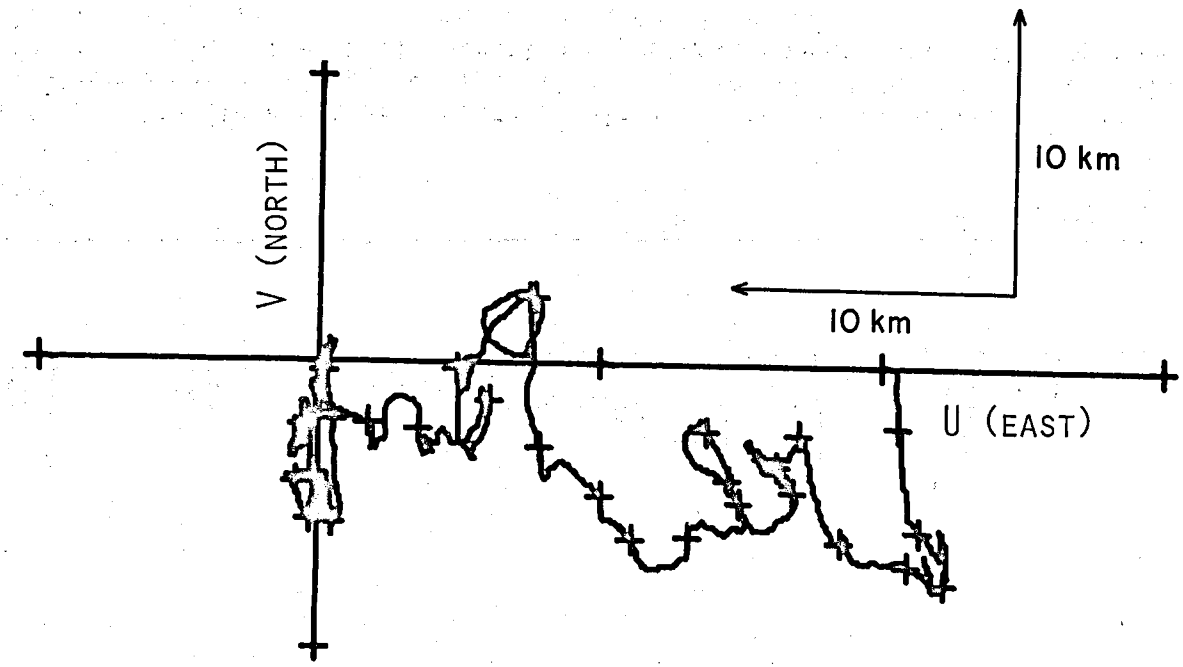

Figure A46. Progressive vector diagram (PVD) for Station 3 during the period 1930 15 June 75 to 1000 8 July 75. The positive vertical axis represents true north

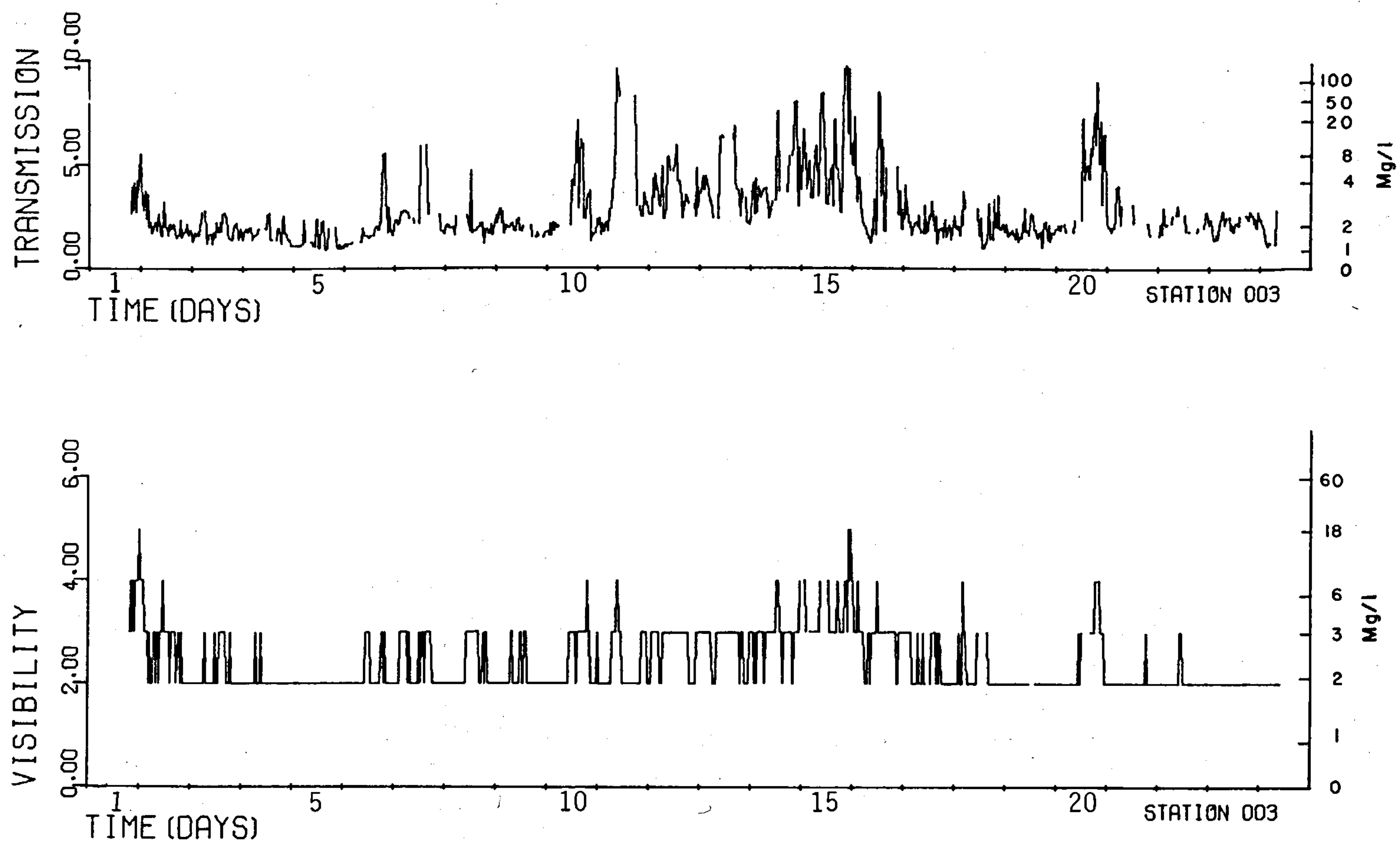

Figure A47. Transmission (in arbitrary recorder units) and photo visibility vs. time at Station 3 during the period 1930 15 June 75 to 1000 8 July 75. The scale at the right side of each illustration represents concentration of suspended sediment (mg/ℓ) 4.3 ft above the seabed (see Figure A21) position of the current-meter arrays and the CTD stations is given in Figure A48 and a description of the current meter array configuration is given below.

STATION	LOCATION	TOTAL DEPTH,m	CURRENT METER ELEVATION ABOVE BOTTOM, m Lower	Upper
A1	Buoy 1	29		11.4
A2	North Jetty	16.5	2.8	8.0
A3	South Jetty	15.5	4.6	9.4

107. Of the three current meter arrays deployed, moorings A3 at the south jetty and A2 at the north jetty, each with two current meters, were retrieved by the CAYUSE at the end of 2 weeks. Mooring A1 at Disposal Site B was not recovered at that time, because the mooring cable had been cut and three of the four current meters were lost. These meters were later picked up just offshore about 150 nmi south of the river mouth. The data show that the cable was cut during the first 2 days of the measurement period, thus only the results of the remaining current meter are reported.

108. The records from the current meters are plotted for the three stations. In general, maximum currents at all stations coincided with times of high or low tide. The current speed at Buoy 1 (mooring A1) and the U and V components for a meter located 38 ft above the seabed in a water depth of 96 ft are shown in Figure A49. These current speeds showed a dominant semidiurnal component with currents reaching 30 to 40 cm/sec on the flood and 90 cm/sec on the ebb. Vector representations of hourly averages of the flow at Buoy 1 (Figure A50)

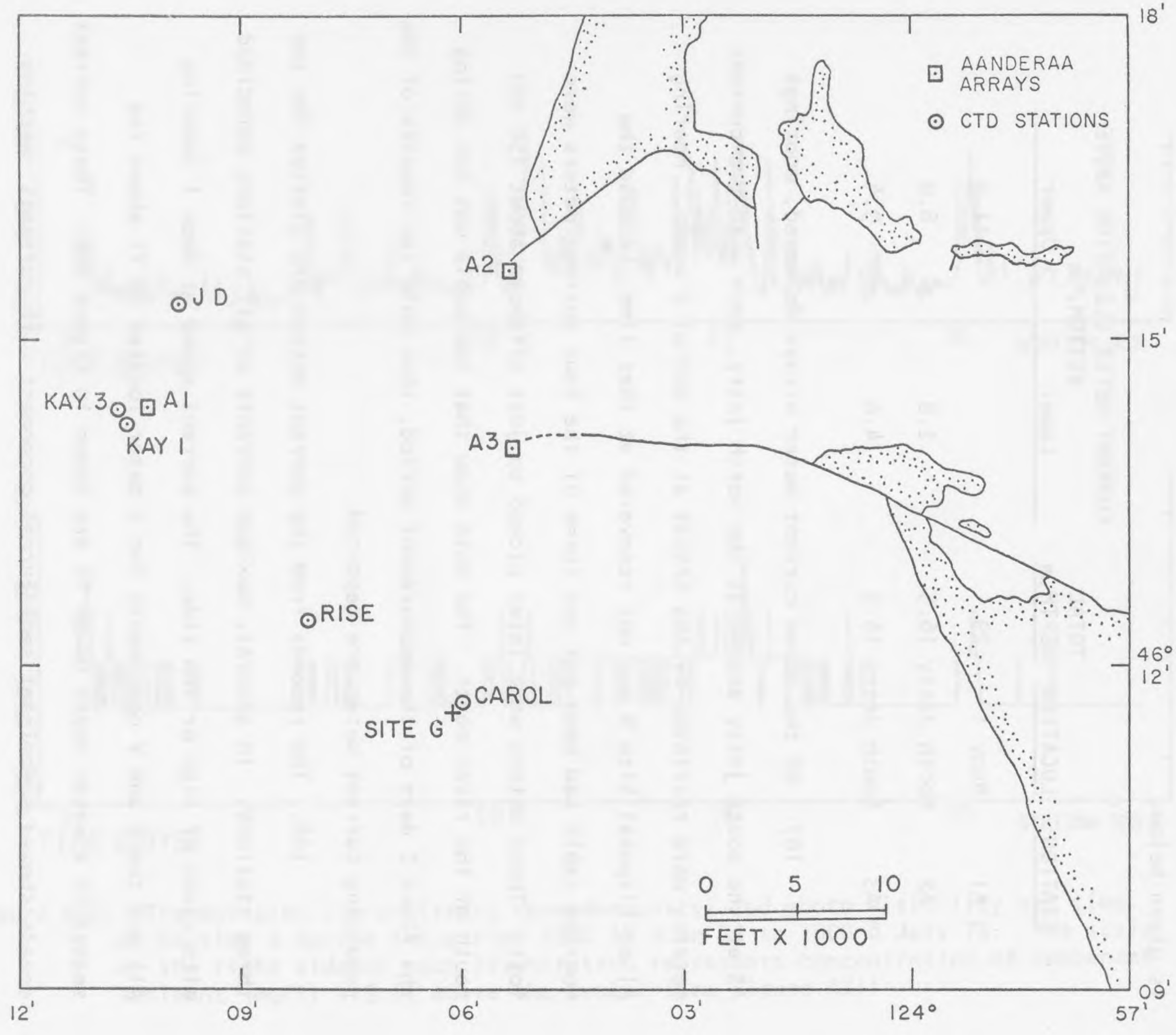

Figure A48. Location chart for moored current meters and CTD anchor stations during the period 9-20 June 75

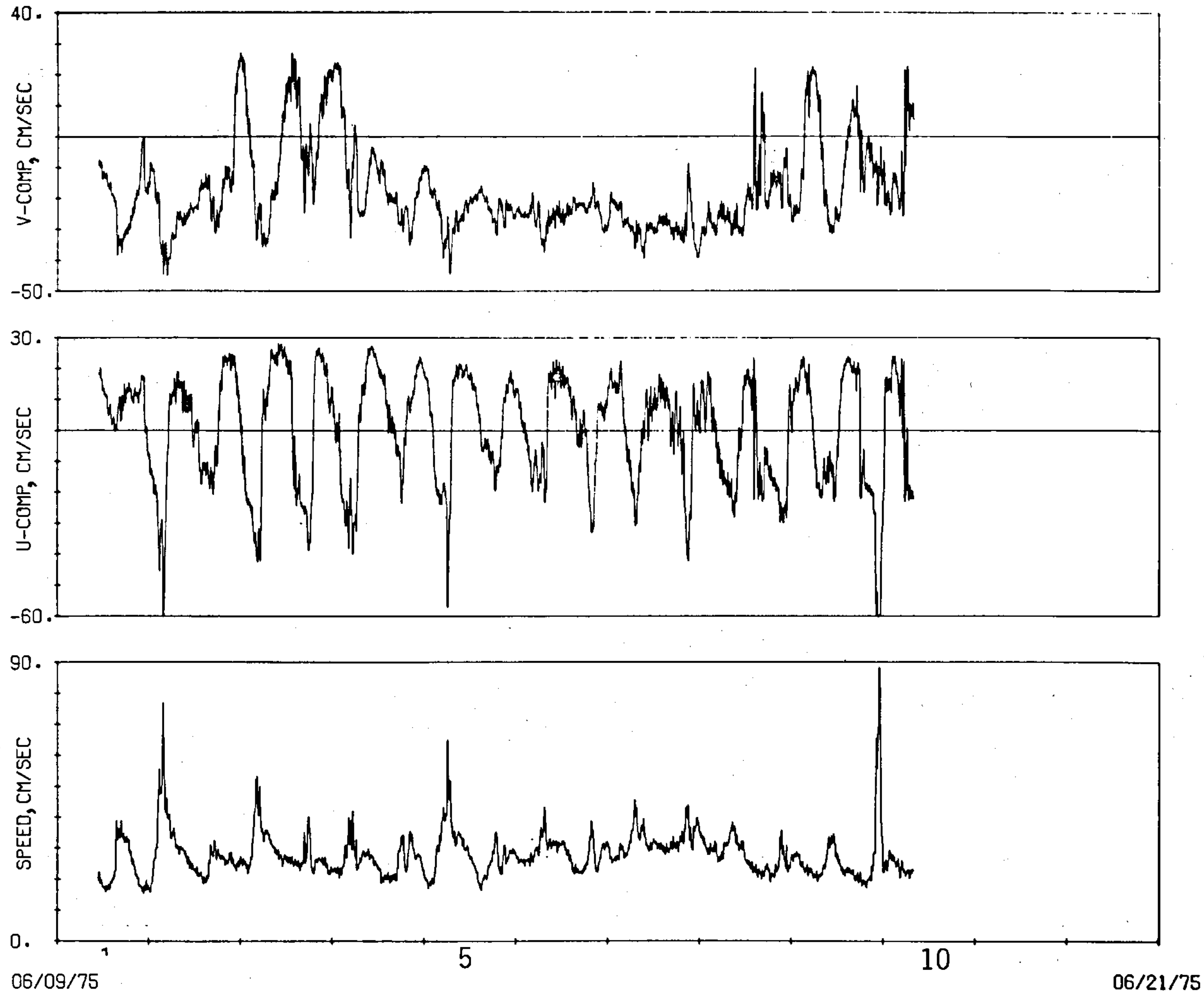

Figure A49. Current speed and U and V component vs. time in days for the moored current meter at Buoy 1, 11.4 m above the seabed. Total water depth was 29 m

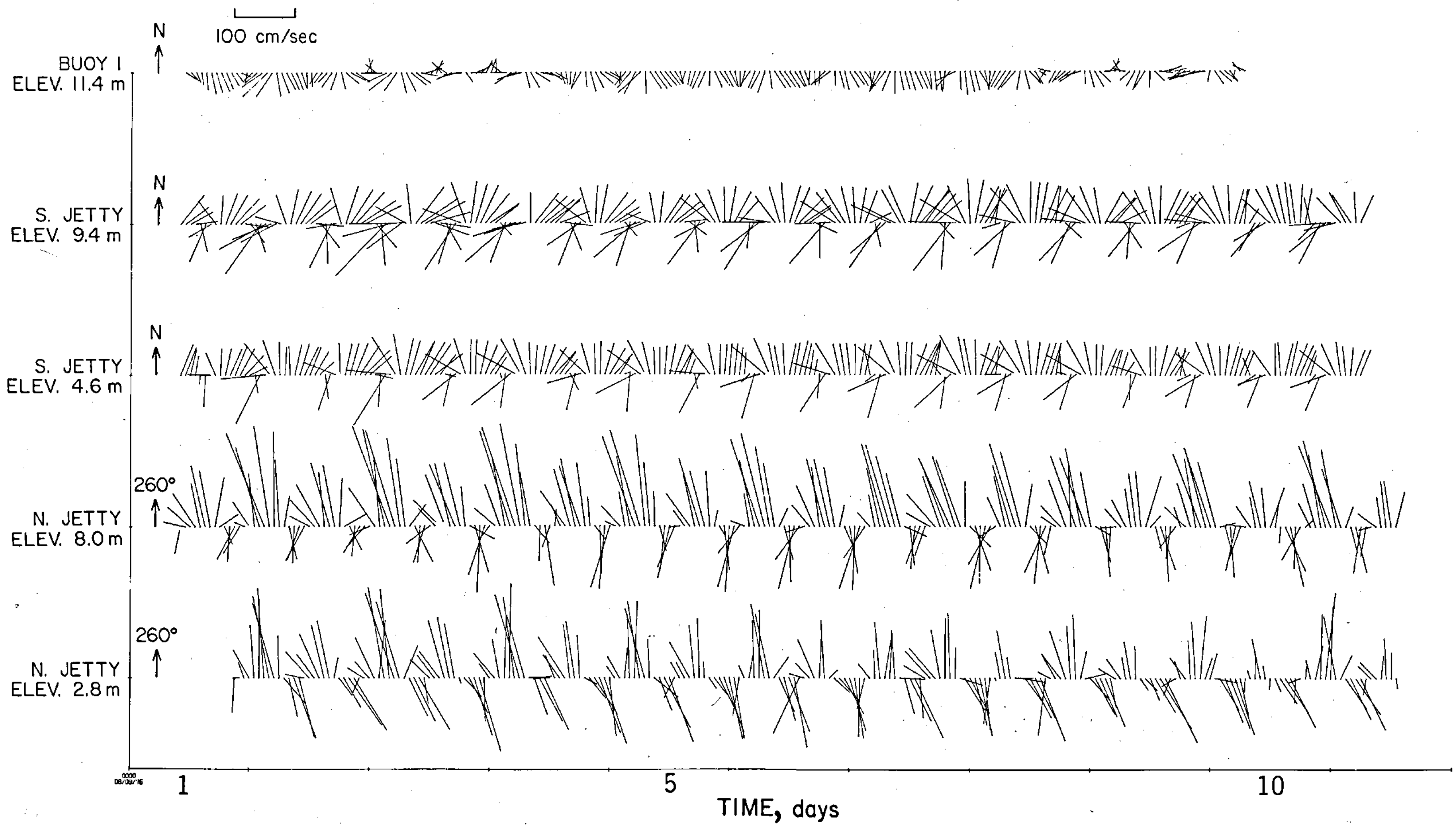

Figure A50. Vector representations of 1-hr time averages of current meter velocity measured at Buoy 1, north jetty, and south jetty. Note that the orientation of the vectors for the north jetty data were rotated - 100° counterclockwise to coincide with the river flow direction showed a net southerly flow during the sampling period.

109. Currents measured at the north jetty (mooring A2) are displayed in Figures A51, A52, and for the south jetty (mooring A3) in Figures A53 and A54. In general, tidal currents at these positions close to the river mouth were very strong (150 to 200 cm/sec). Vector representations of hourly averages (Figure A50) showed that the bottom flow near the south jetty was primarily northward, representing the zone of strong intrusion of the salt wedge. Surface flow at the south jetty was also dominantly northward. A stronger ebb or southward component was observed nearer the surface than at depth, but the currents at the south side of the channel tended to show an overall flood dominance and the zone of maximum salt-wedge intrusion appeared to be at the south side of the channel.

110. Currents at the north jetty are also represented in a vector form (Figure A50); however, they have been rotated 100° so that a vertical line on the illustration represents 260°T. These data show that at the north jetty, the flow both near the bed and in the surface layer varied on a tidal basis with the ebb currents flowing 260°T and flood currents flowing at 60°T. Net flows are seaward at surface and bottom; however, the surface water shows the strongest ebb dominance indicating that the river flows seaward along the north side of the channel.

111. The results of measurements made at the anchor stations Kay 1, Kay 3, Rise, Carol, and JD to determine vertical variations in temperature and salinity are not presented in tabular form because of

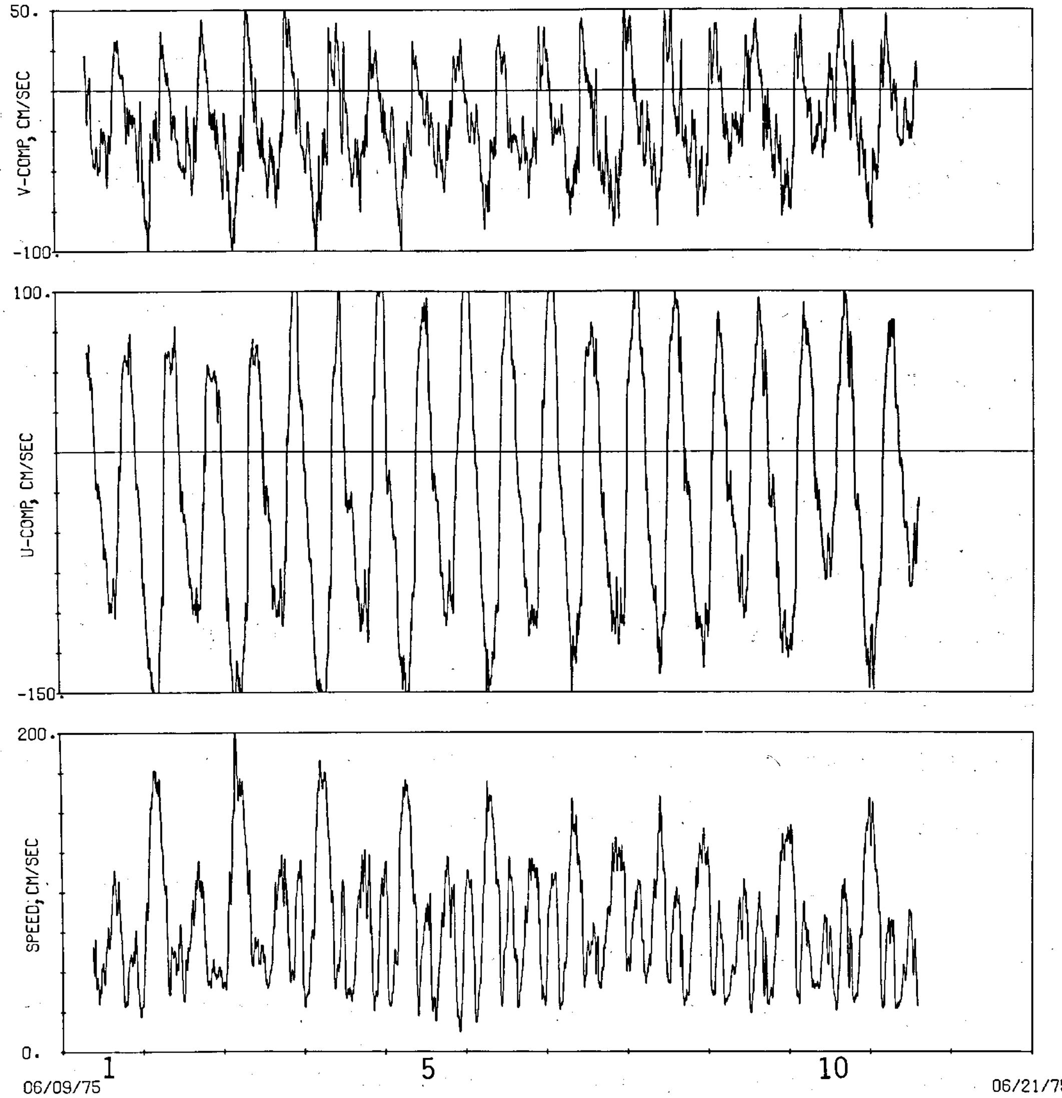

Figure A51. Current speed and U and V components vs. time in days for the moored current meter 8 m off the seabed at the north jetty (Station A2). Total depth was 16.5 m

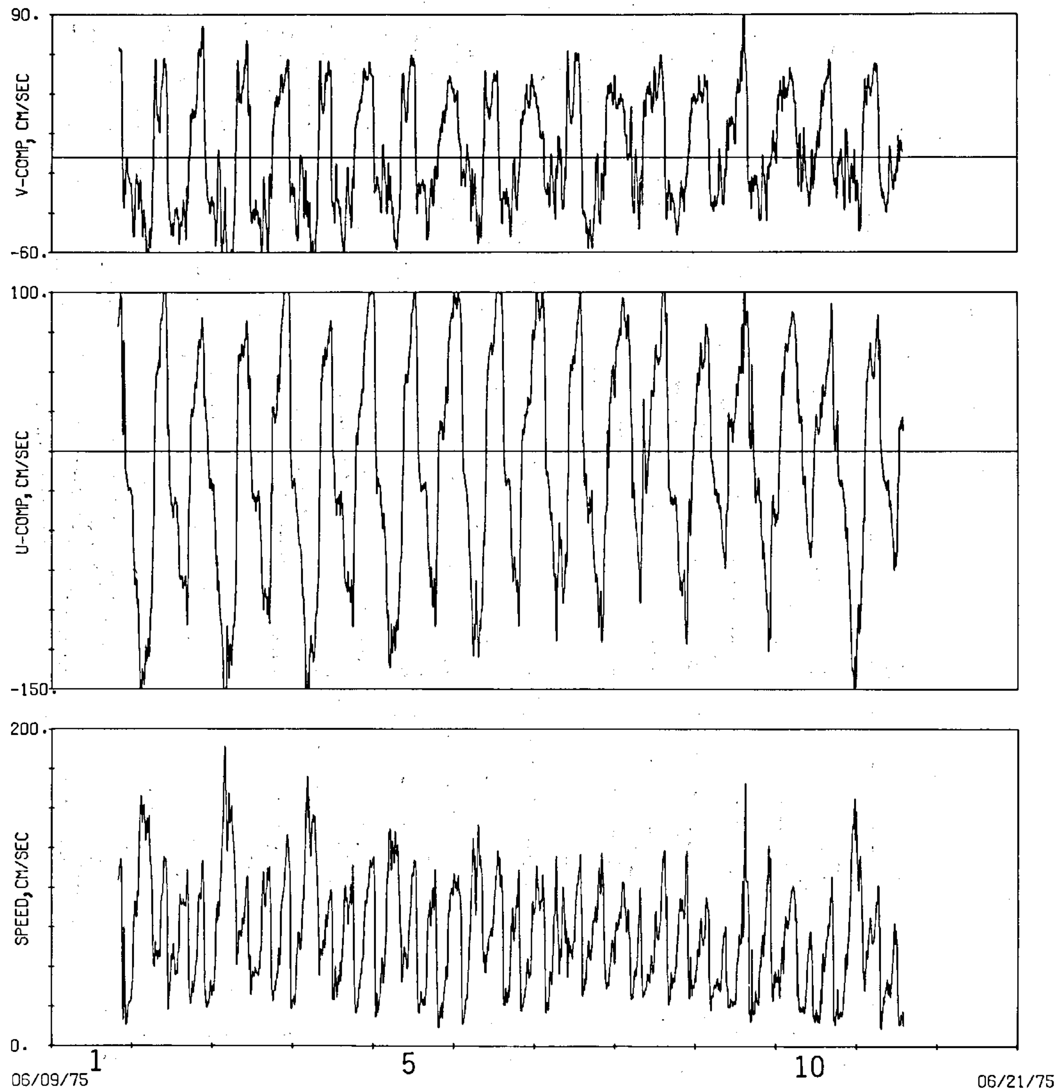

Figure A52. Current speed and U and V components vs. time in days for the moored current meter 2.8 m off the seabed at the north jetty (Station A2). Total depth was 16.5 m

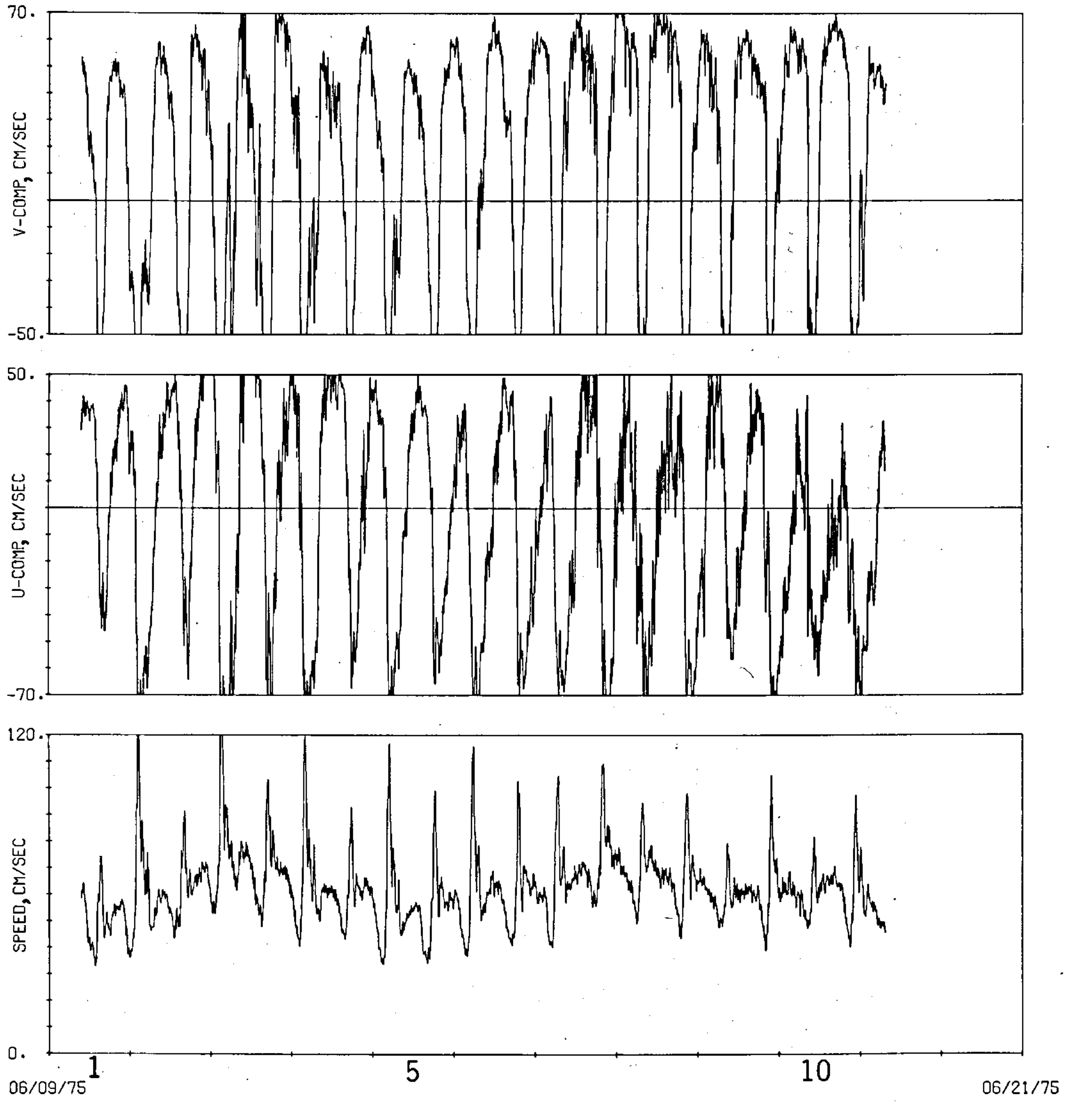

Figure A53. Current speed and U and V components vs. time in days for the moored current meter 9.4 m above the seabed at the south jetty (Station A3). Total depth was 15.5 m

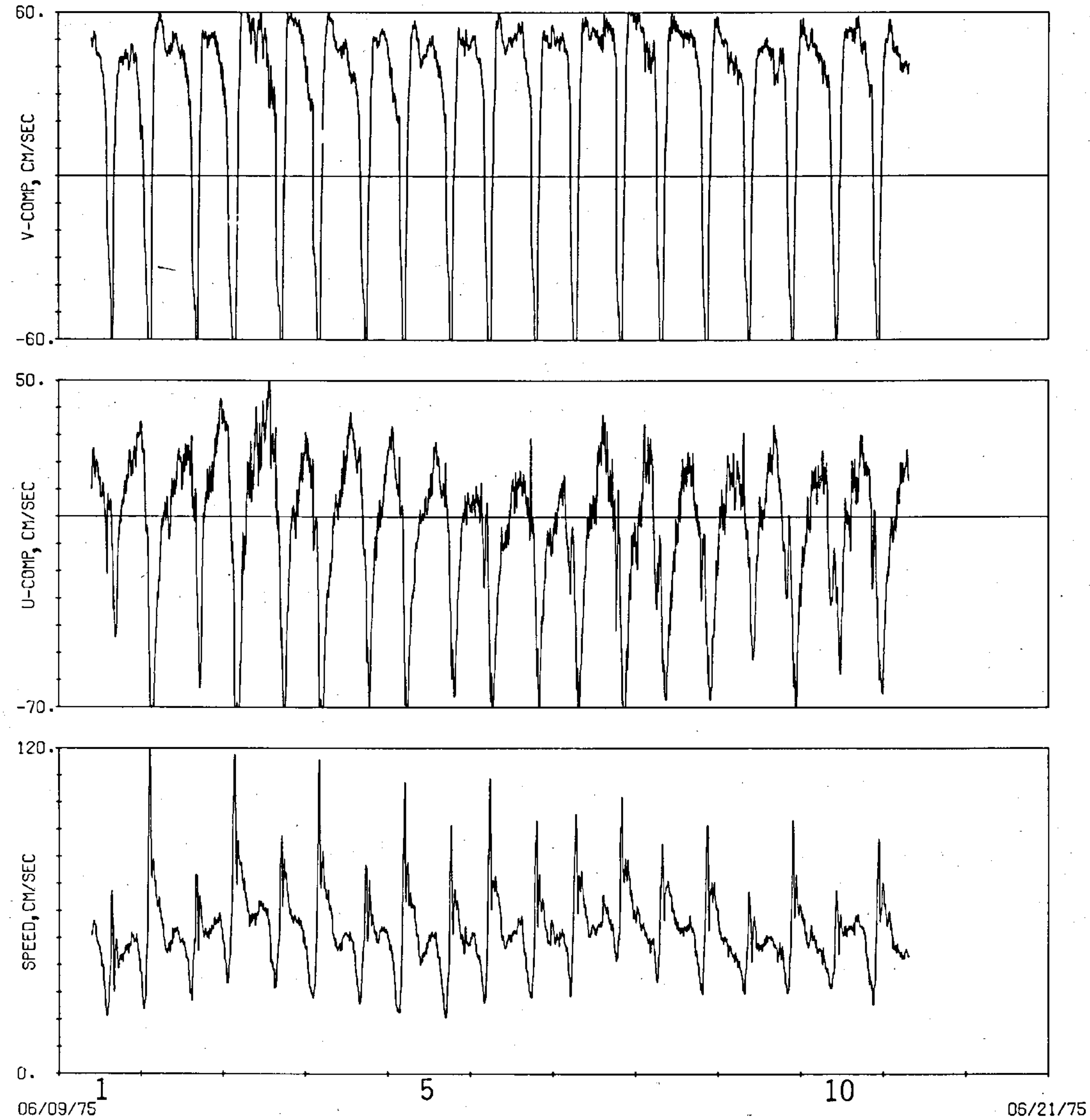

Figure A54. Current speed and U and V components vs. time in days for the moored current meter 4.6 m above the seabed at the south jetty (Station A3). Total depth was 15.5 m the quantity of data collected. These data have been analyzed and typical profiles of temperature and salinity are shown in Figures A55 and A56. General interpretation of data is given in Table A9.

August-September: Stations 4 and 5.

112. Winds. The mean wind recorded while tripods were deployed at Stations 4 and 5 was characterized by alternating periods of southerly and northerly winds of approximately 3-day durations (Figure A57). A major storm occurred on 26 August (record day 7) and lasted 5 days. Mean winds during this time were from the southeast reaching 13.5 m/sec (26.0 knots). Following this major storm, the winds were primarily from the northwest with maximum speeds of 11.7 m/sec (22.5 knots) observed.

113. Waves. The wave record was not obtained from Station 4 due to a malfunction of the galvanometer that records high frequency pressure fluctuations. The wave record obtained at Station 5 is shown in Figure A58. Wave heights were relatively low during the sampling period, never exceeding 8.5 ft except for a few hours on 30 August (record day 6) when 10.5 ft surface waves were recorded.

114. Tides. The tidal record for Stations 4 and 5 is shown in Figure A59. The maximum tidal range during the sampling period was 10.1 ft. A major oscillation in mean sea level occurred at Stations 4 and 5. Between 27 August and 2 September (record day 9-15), mean sea level was depressed equivalent to 1.1 psi or approximately 2.5 ft. This 6- to 7-day oscillation was observed at both stations and corresponded to the major storm that occurred in the area between 26-31 August.

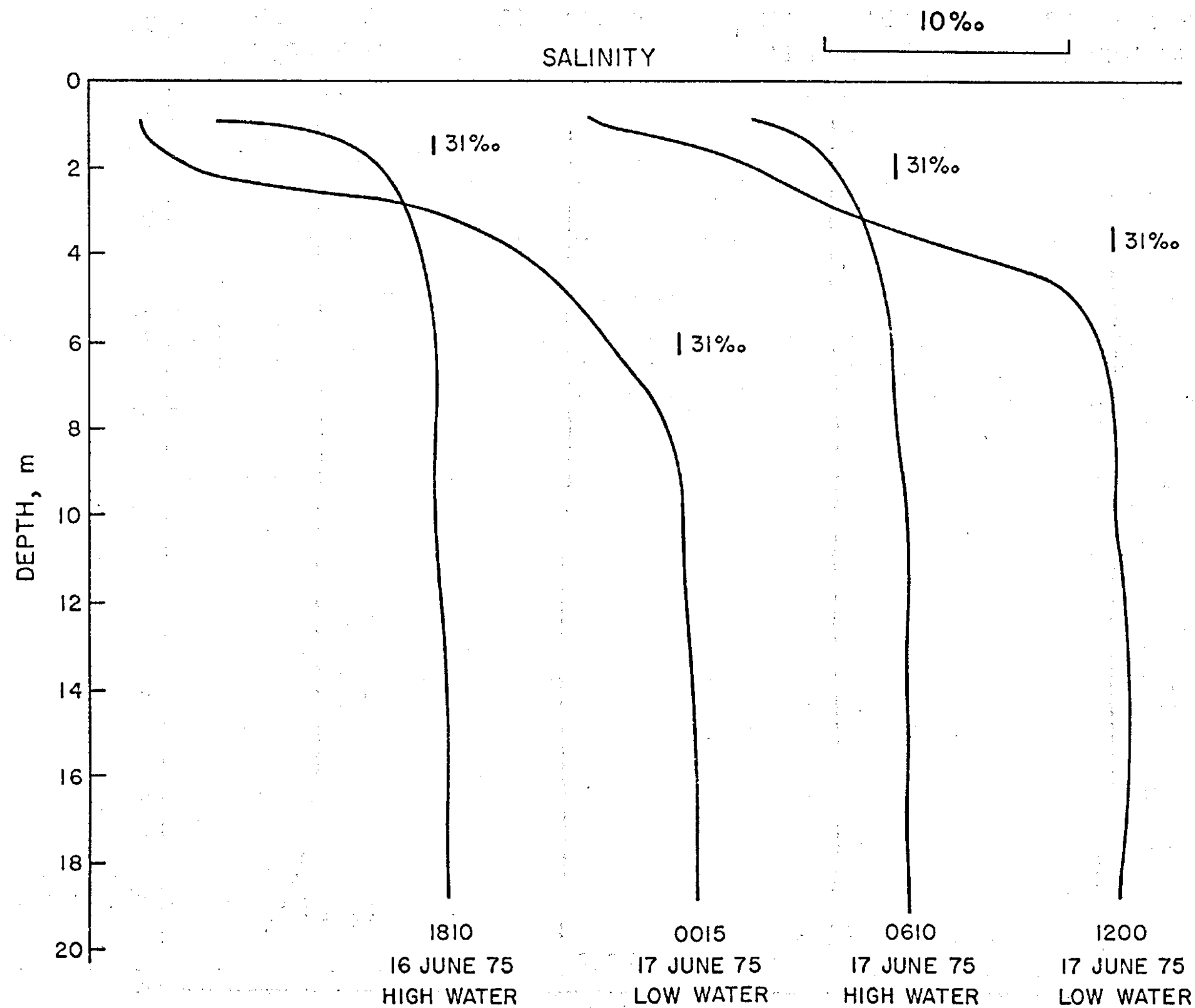

Figure A55. Salinity profiles at station Kay-3 (Site B) representing typical flood and ebb characteristics. Data were collected from 25-hr anchor stations

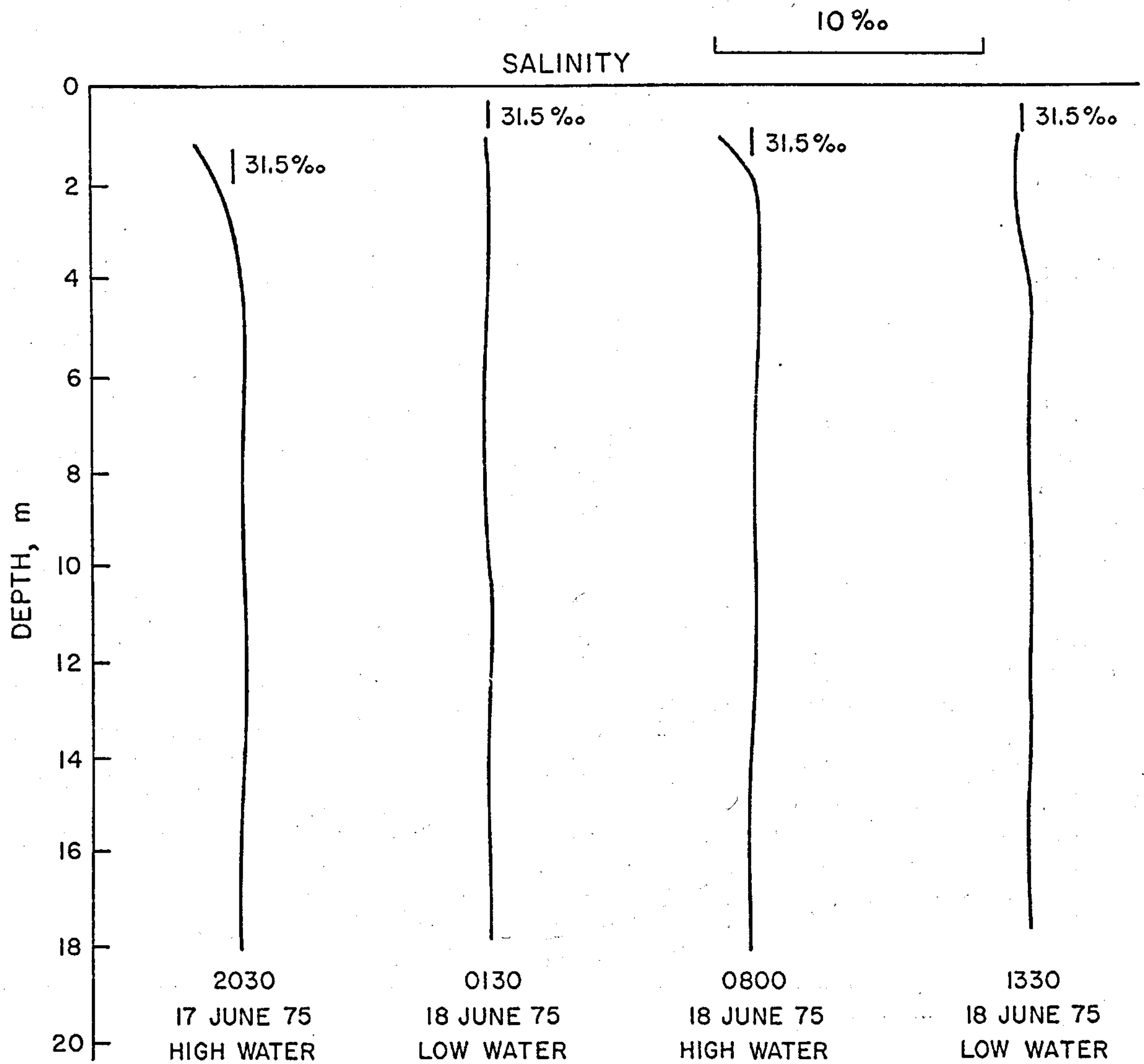

Figure A56. Typical salinity profiles at station Carol (Site G) representing typical flood and ebb characteristics. Data were collected from 25-hr anchor stations

Table A9

Characteristics of CTD Stations

J D and Kay	Rise	Carol
Depressed pycnocline (both halocline and thermocline)	In all aspects, Rise appears transitional between stations J D and Kay and station Carol	Halocline is nonexistent or faintly observed; a shallow thermocline is generally observed
Thickness of surface layer is tidally dependent		When a surface layer is observed, its thickness shows no relationship to tides
Both salinity and temperature fluctuations are in phase (temperature increases correlate with salinity decreases in the surface layer)		Salinity and temperature fluctuations are out of phase, and show no correlation with each other
Conclusion - the water column at stations J D and Kay shows a strong influence of the Columbia River, and is also very much tidally influenced		Conclusion - the water column at station Carol is out of the direct influence of the Columbia River, and is controlled by some other circulation pattern

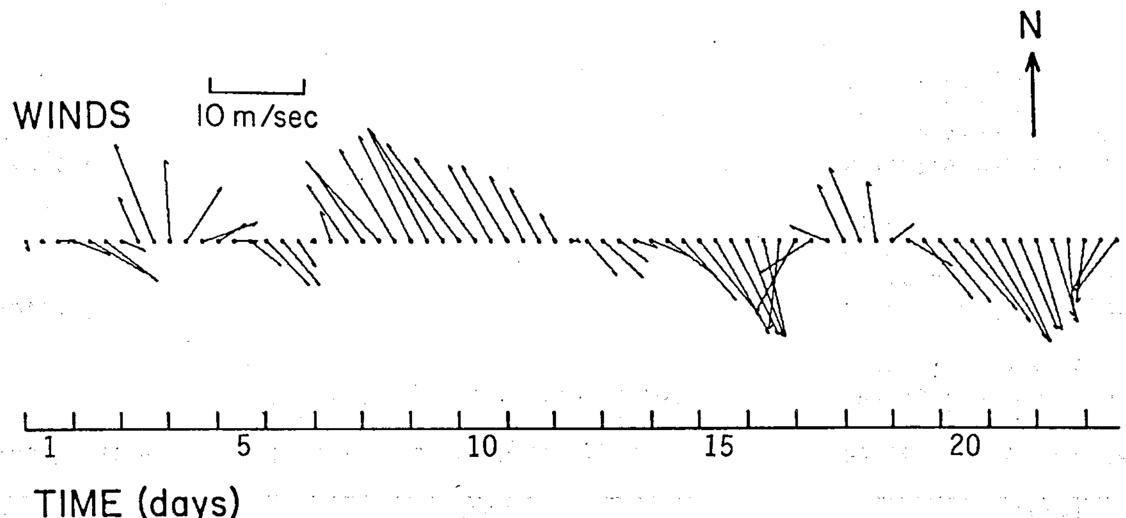

Figure A57. Columbia River Lightship winds during Stations 4 and 5, 19 August to 12 September 1975. The horizontal scale is days, the vector scale is 10 m/sec/unit. Wind data represented 25-hr averages. Vectors were plotted as direction toward which the wind was blowing

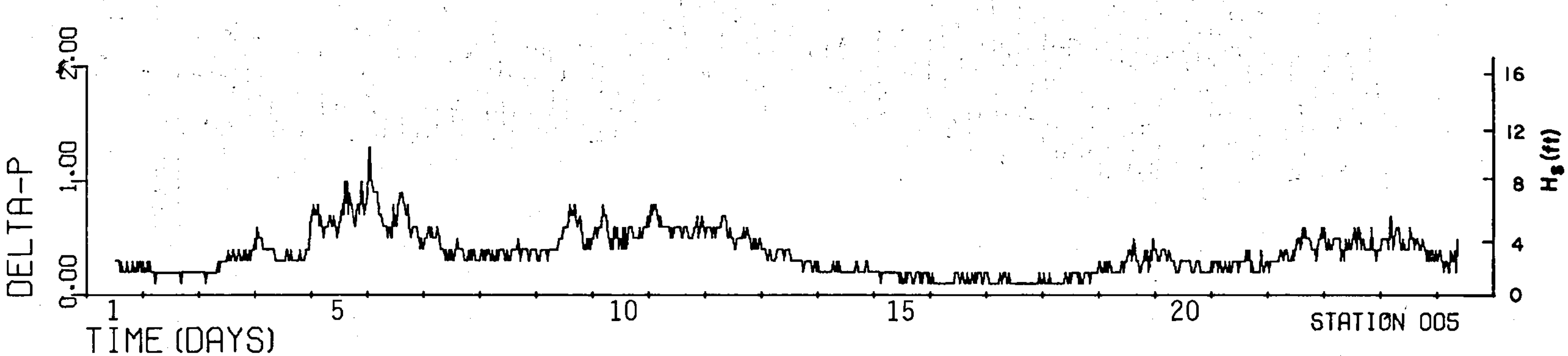

Figure A58. High frequency pressure fluctuations (DELTA-P) at Station 5 during the period 1300 19 August 75 to 0800 12 September 75. The DELTA-P scale is in recorder units. The wave scale to the right is computed using the pressure calibration curve in Figure A19 for a wave with a T_s of 12 sec

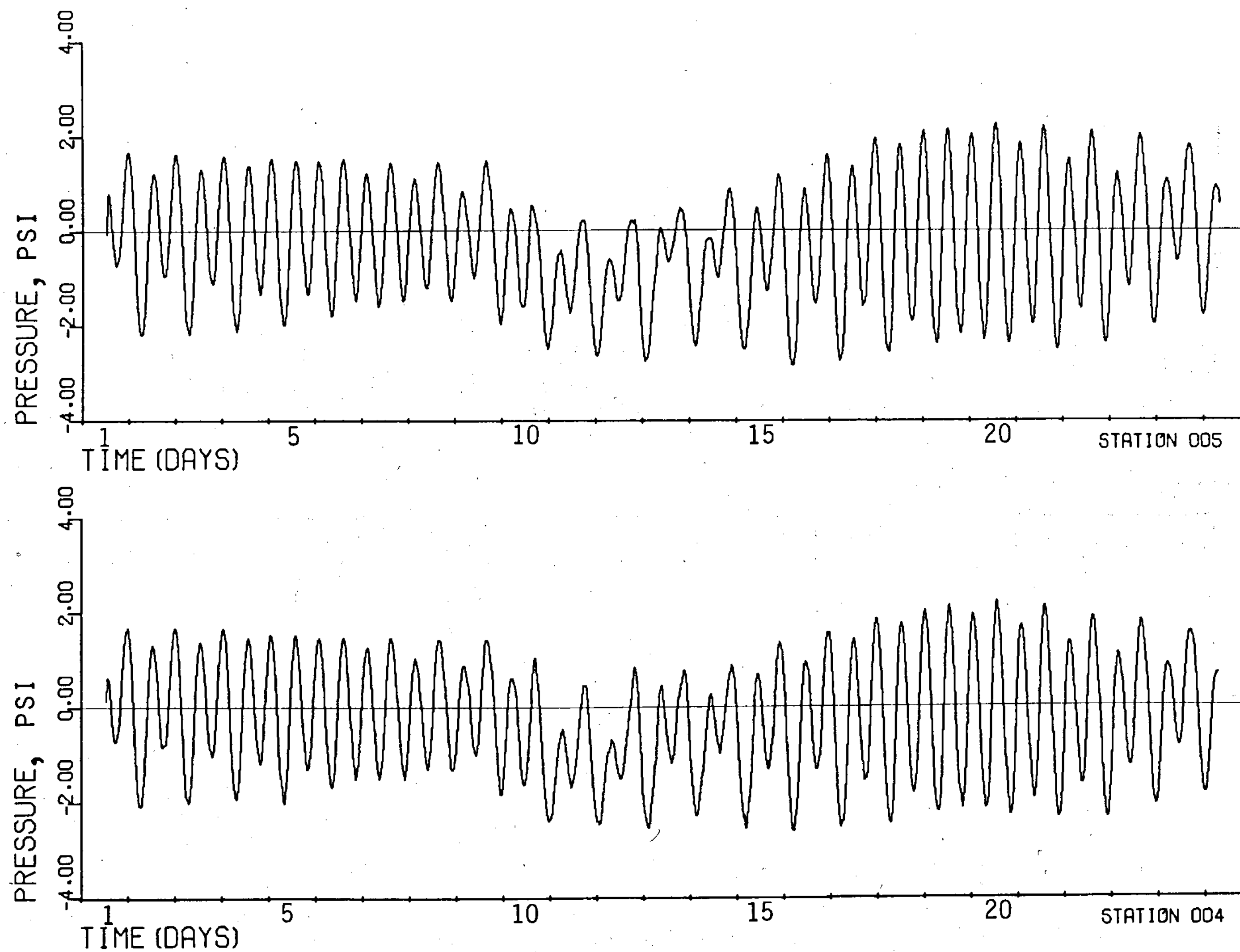

Figure A59. Tide height vs. time in days at Stations 4 and 5 during the period 1300 19 August 75 to 0800 12 September 75. The vertical scale is in psi referenced to mean sea level (1 psi ~ 2.2 ft)

115. Bottom currents. Current speed and direction time series are plotted independently for Stations 4 and 5 and also summarized as speed-direction frequency distributions (Figures A60-A63). In general, $\bar{U}_{100}$ values were less than 18 cm/sec, corresponding to the typical amplitude of tidal currents in the area. The dominance of the semidiurnal tide during most of the recording period is most clearly illustrated by the V component of bottom flow for the two stations (Figures A64 and A65).

116. During the interval of the major sea level fluctuation that occurred between 27 August and 2 September, $\bar{U}_{100}$ increased significantly. Bottom currents at Stations 4 and 5 reached 42 cm/sec, approximately twice the tidal current component for the area. Flow direction was relatively consistent in a north and offshore direction 330°T for Station 4 and 300°T for Station 5.

117. The progressive vector diagram for Station 4 (Figure A66) shows a very consistent trend toward 321°T at about 6.5 cm/sec. Net flow at Station 5 was more complex (Figure A67). During the early part of the record, the net $\bar{U}_{100}$ was toward the southeast. When the major storm occurred on 27 August, the flow reversed to about 300°T. Following the major storm, the net bottom flow varied considerably with distinct periods of southeasterly flow and northerly flow, presumably corresponding to the fluctuations in the wind. The net flow over the complete sampling period was approximately 1.1 cm/sec at 300°T.

118. Bottom turbidity. The transmissometer records for Stations 4 and 5 (Figure A68) show that concentrations of suspended sediment were relatively low throughout most of the sampling period.

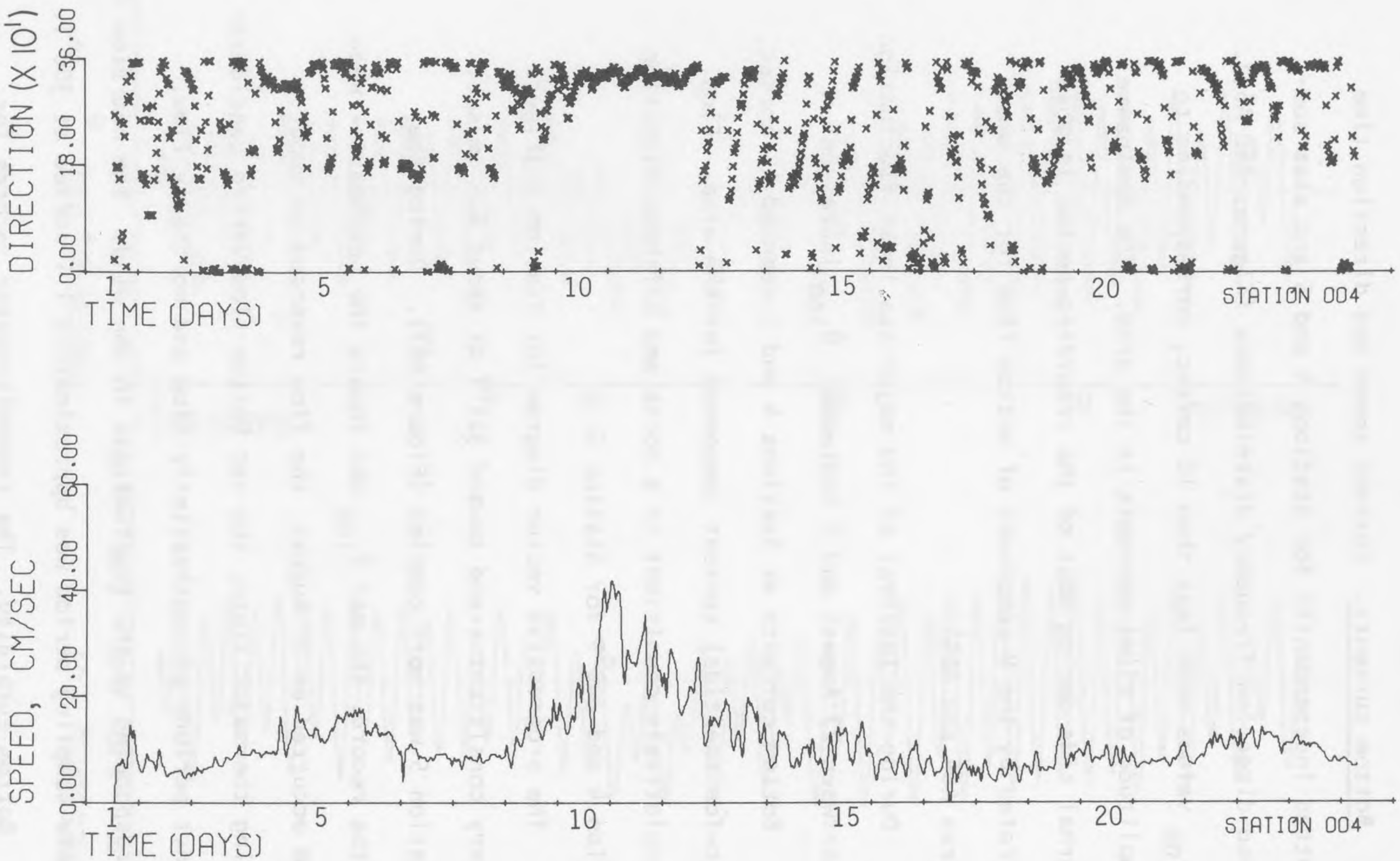

Figure A60. Bottom current speed ($\bar{U}_{100}$) and direction (^{o}T) vs. time in days at Station 4 during the period 1300 19 August 75 to 0800 2 September 75. The current speed was measured 3.3 ft off the bed and all measurements were averaged over 30-min periods. These current data are summarized in Figure A61

TRIPOD STATION 4 (19 August - 12 September, 1975)

Direction (^{o}T)

Speed (cm/sec)	0-29	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	270-299	300-329	330-359	TOTAL
0-9.9	8.1	1.9	0.3	1.1	2.1	7.0	4.8	2.3	4.0	2.0	5.7	12.7	52.0
10-19.9	2.0	0.8	0.1	0.1	0.6	1.8	3.3	2.9	2.4	3.6	9.1	12.4	39.1
20-29.9	0.2										2.8	3.3	6.3
30-39.9											0.4	1.7	2.1
40-49.9												0.5	0.5
50-59.9													
60-69.9													
70-79.9													
80-89.9													
TOTAL	10.3	2.7	0.4	1.2	2.7	8.8	8.1	5.2	6.4	5.6	18.0	30.6	100.0

N = 1138

Figure A61. Speed-direction frequency distribution for $\bar{U}_{100}$ measured at tripod Station 4. N is the total number of half-hour time intervals. The numbers in the matrix represent percent of total sampling time

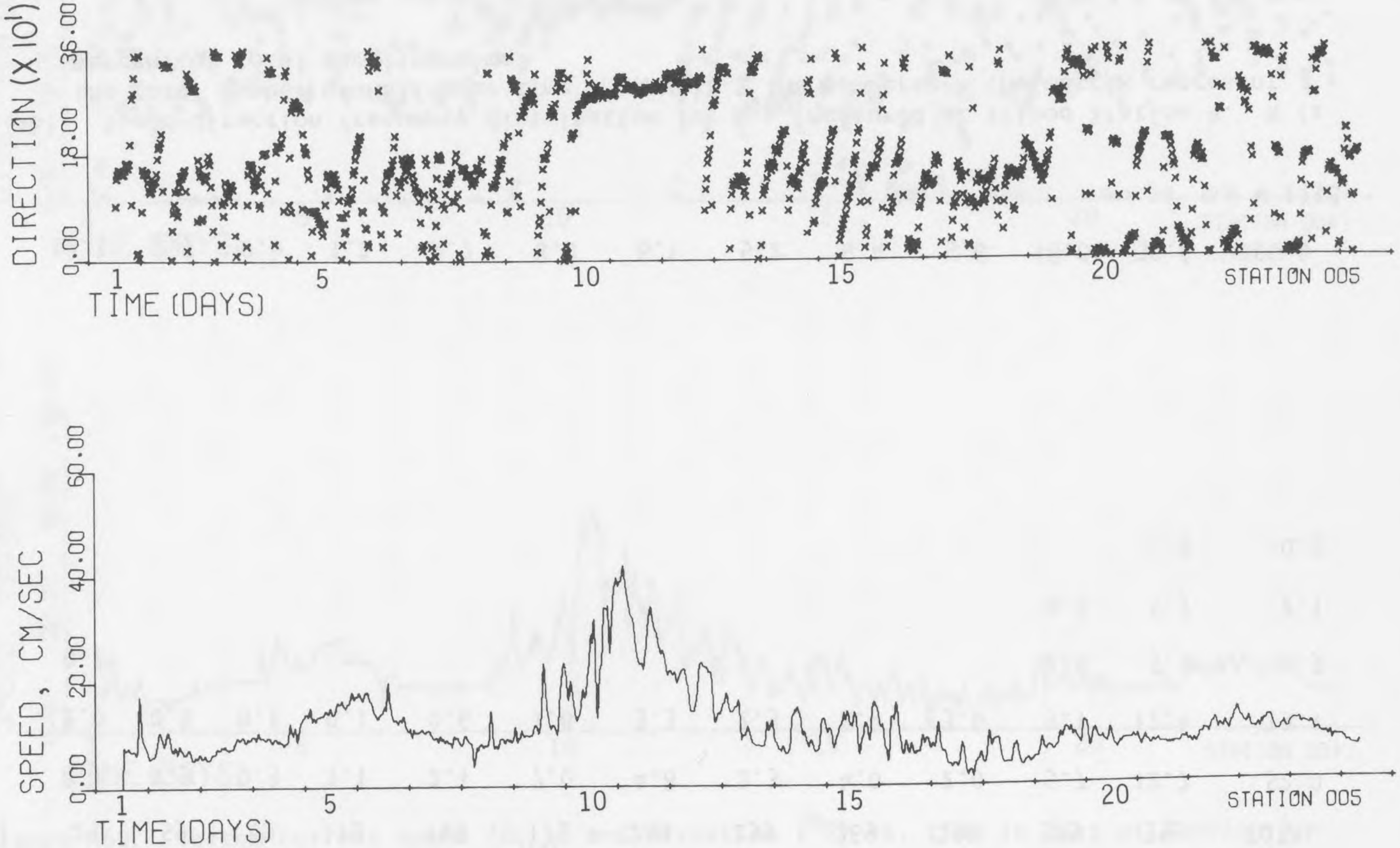

Figure A62. Bottom current speed ($\bar{U}_{100}$) and direction (^{O}T) vs. time in days at Station 5 during the period 1300 19 August 75 to 0800 12 September 75. The current speed was measured 3.3 ft off the bed and all measurements were averaged over 30-min periods. These current data are summarized in Figure A63

TRIPOD STATION 5 (19 August - 12 September, 1975)

Speed (cm/sec)	0-29	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	270-299	300-329	330-359	TOTAL
	Direction (°T)												
0-9.9	6.5	2.4	1.9	5.8	11.7	10.4	5.6	0.8	0.6	0.6	3.4	5.0	55.7
10-19.9	3.5	2.4	3.3	2.4	4.0	4.3	1.7	1.7	2.0	2.7	3.1	3.5	34.6
20-29.9	0.1	0.1							0.6	3.7	2.3		6.8
30-39.9										2.1	0.6		2.7
40-49.9											0.3		0.3
50-59.9													
60-69.9													
70-79.9													
80-89.9													
TOTAL	10.1	4.9	5.2	8.2	15.7	14.7	7.3	2.5	3.2	10.1	9.7	8.5	100.1

N = 1144

Figure A63. Speed-direction frequency distribution for $\bar{U}_{100}$ measured at tripod Station 5. N is the total number of half-hour time intervals. The numbers in the matrix represent percent of total sampling time

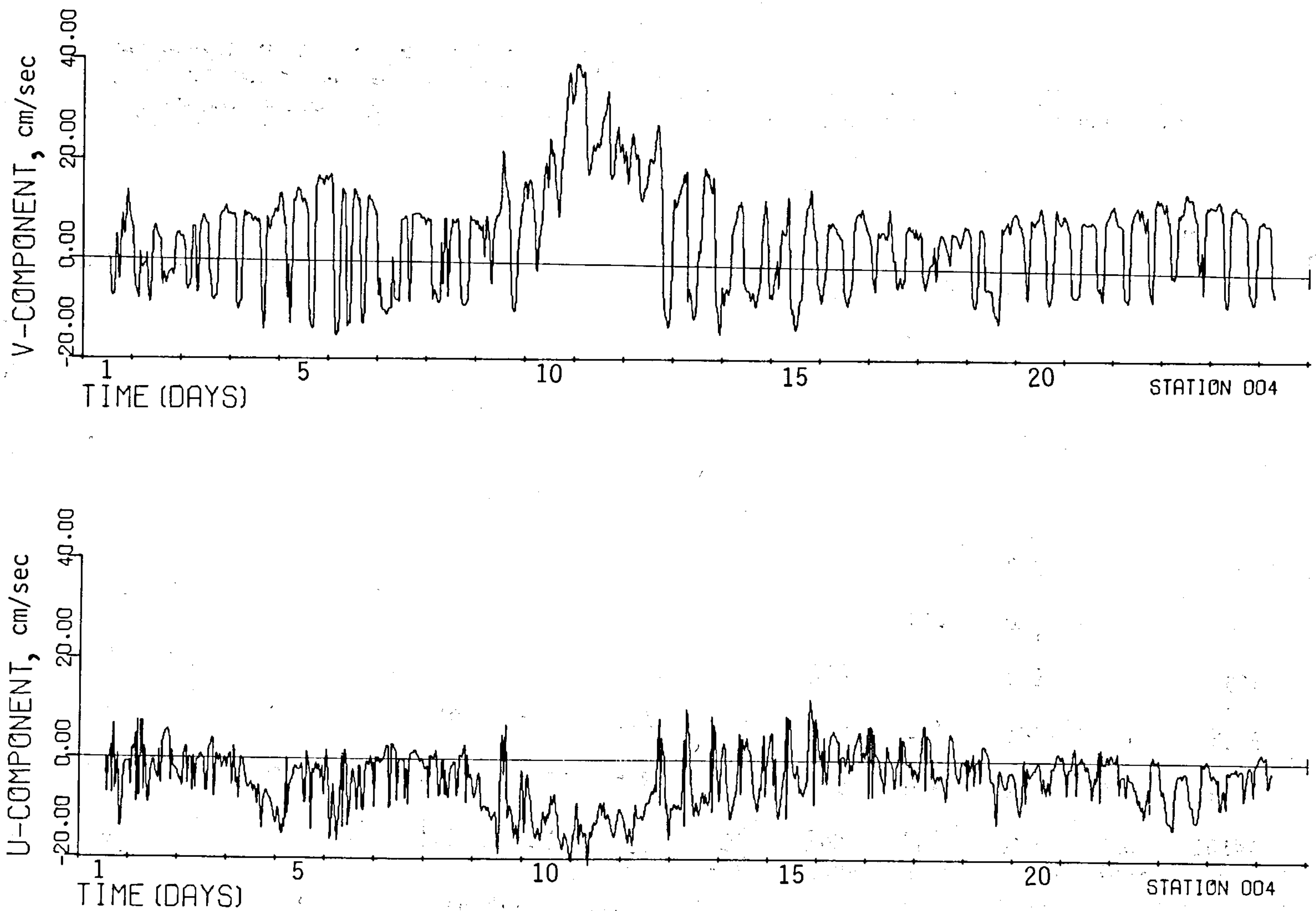

Figure A64. Northward (V) and eastward (U) components of current velocity 3.3 ft above the seabed at Station 4 during the period 1300 19 August 75 to 0800 12 September 75

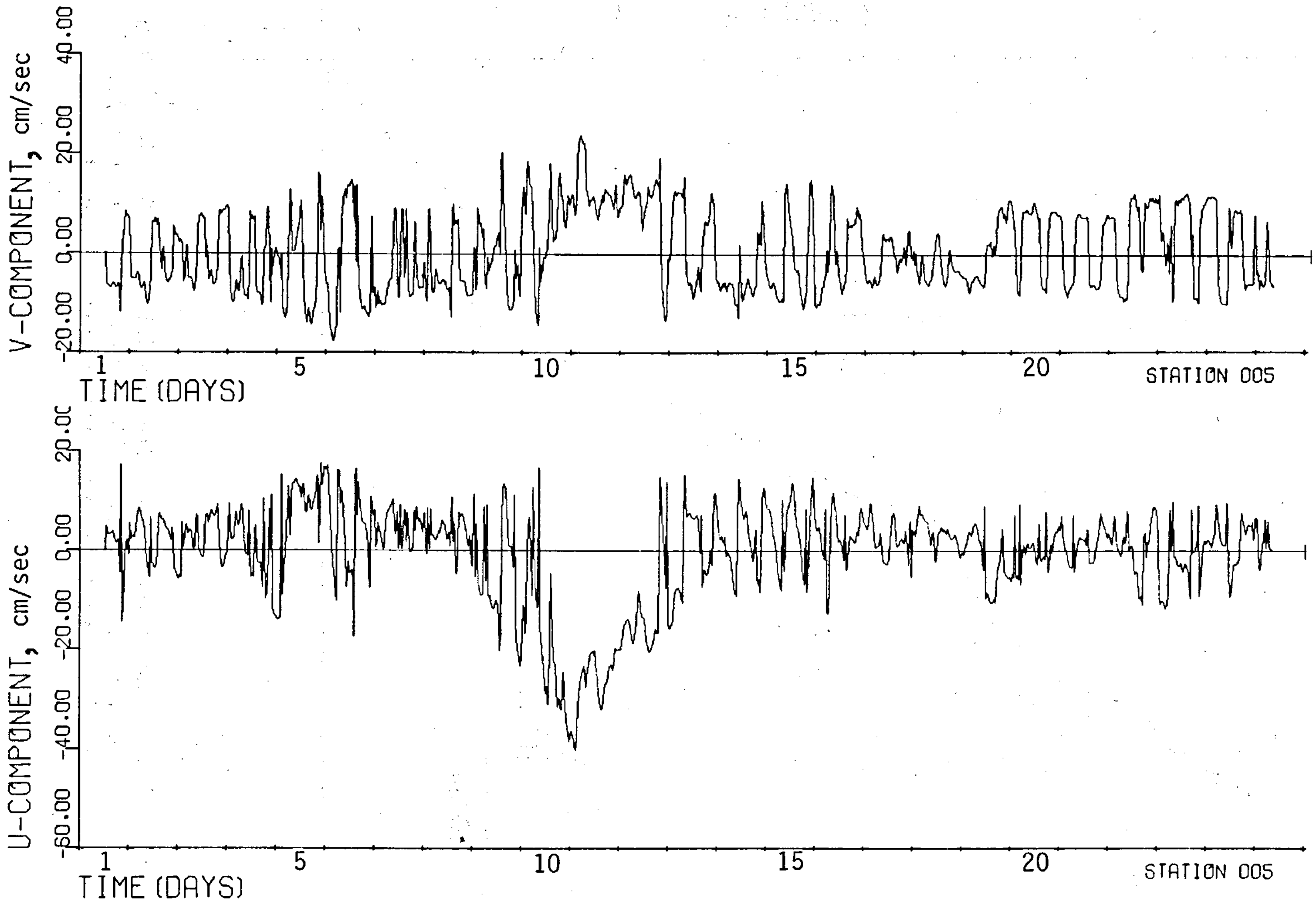

Figure A65. Northward (V) and eastward (U) components of current velocity 3.3 ft above the seabed at Station 5 during the period 1300 19 August 75 to 0800 12 September 75

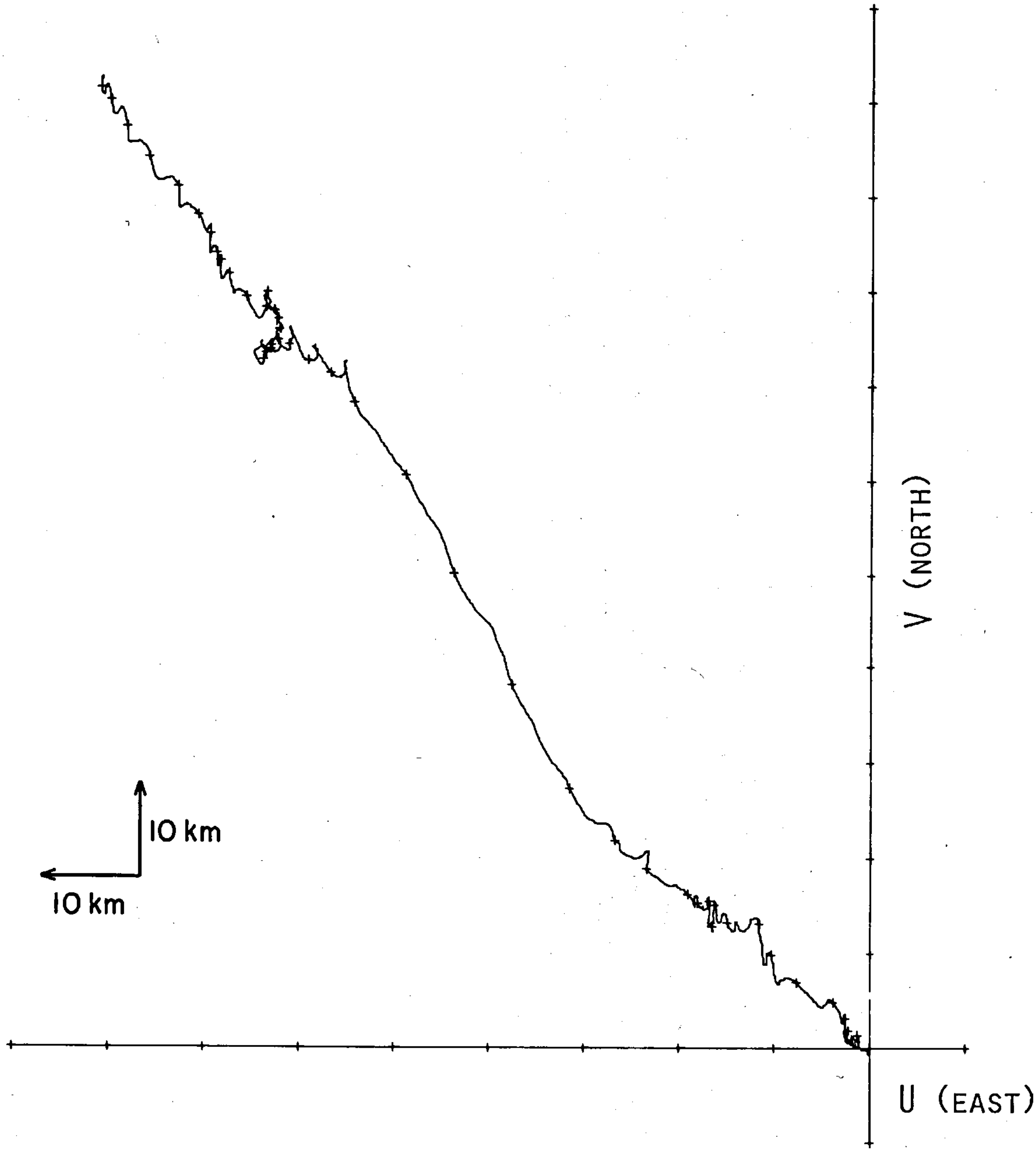

Figure A66. Progressive vector diagram (PVD) for Station 4 during the period 1300 19 August 75 to 0800 12 September 75. The positive vertical axis represents true north

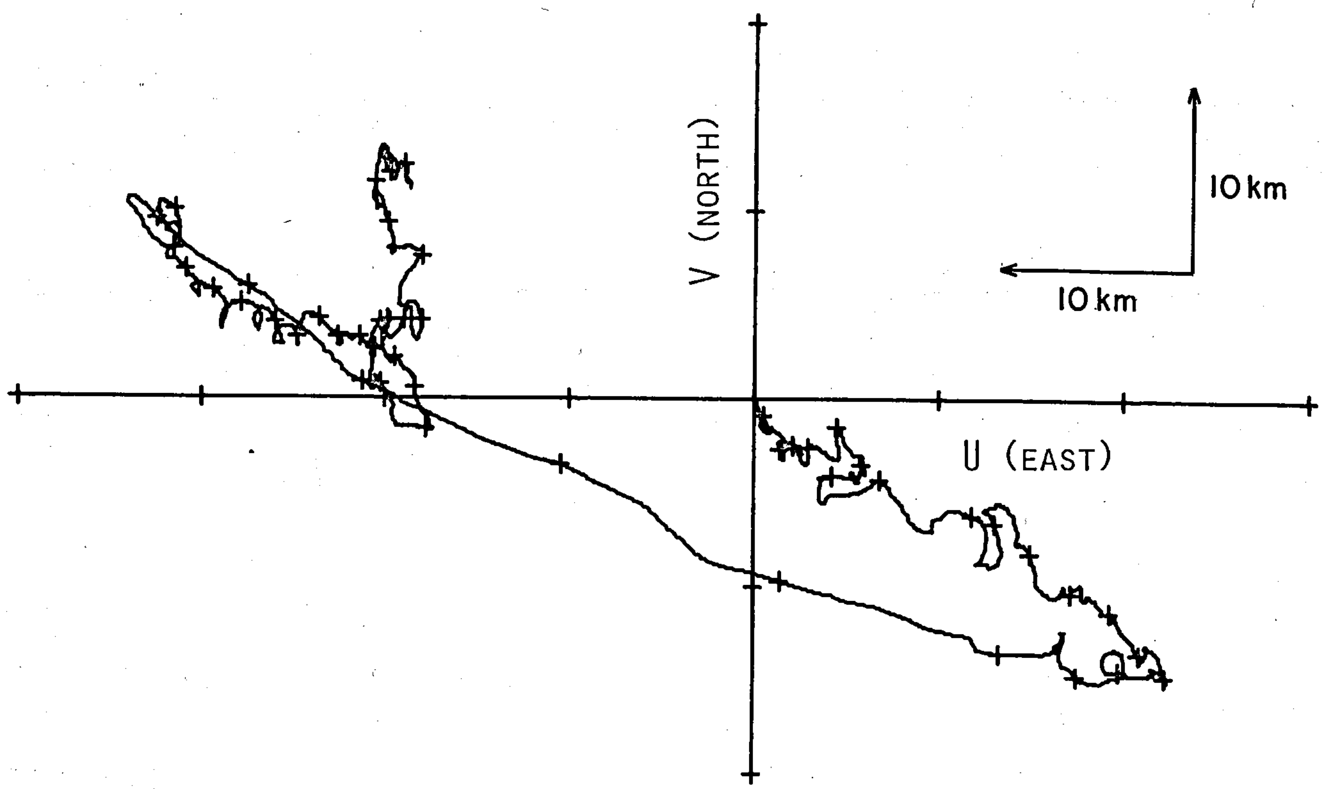

Figure A67. Progressive vector diagram (PVD) for Station 5 during the period 1300 19 August 75 to 0800 12 September 75. The positive vertical scale represents true north

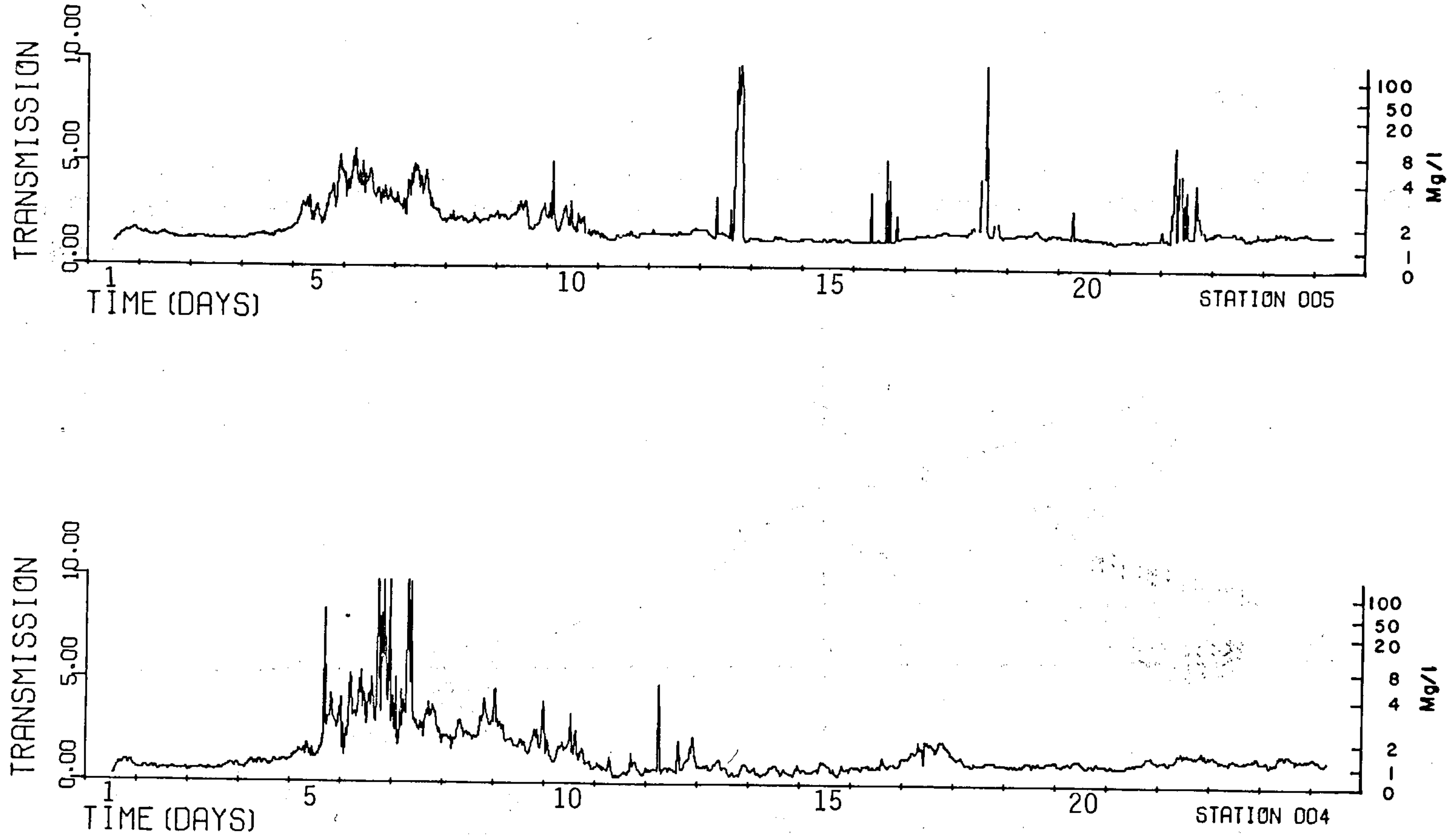

Figure A68. Transmission (in arbitrary recorder units) vs. time for Stations 4 and 5 during the period 1300 19 August 75 to 0800 12 September 75. The vertical scale at the right represents concentration of suspended sediment (mg/ℓ) 4.3 ft above the seabed (see Figure A21)

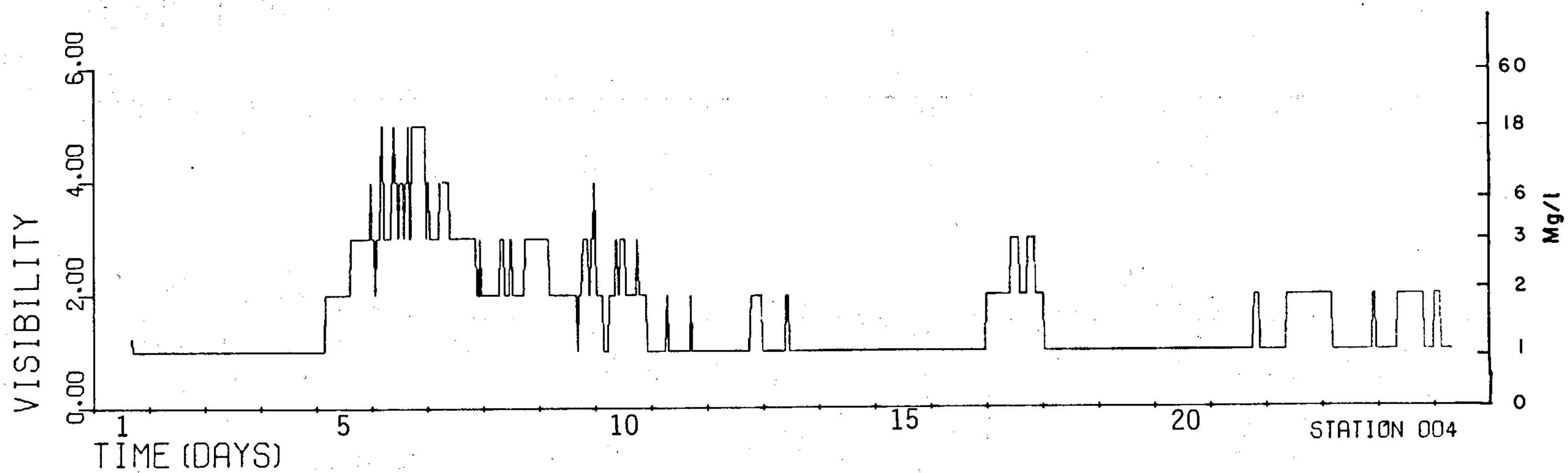

Figure A69. Photo visibility for Station 4 during the period 1300 19 August 75 to 0800 12 September 75. The scale at the right represents concentration of suspended sediment (mg/ℓ) 4.3 ft above the seabed (see Figure A21)

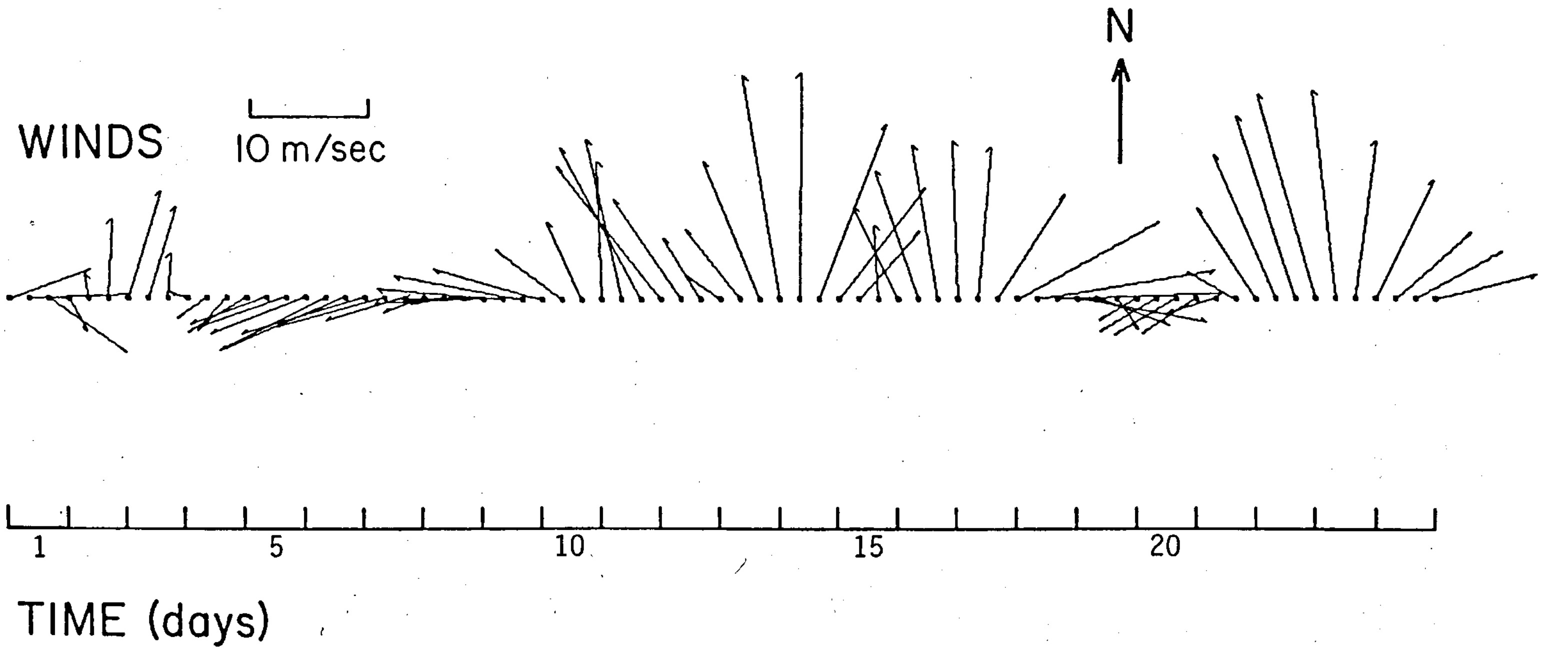

Figure A70. Columbia River Lightship winds for Station 6 12 December 75 to 6 January 76. The horizontal scale is days; the vector scale is 10 m/sec/unit. Wind data represented 25-hr averages; vectors were plotted as direction toward which the wind was blowing

During the first 5 days of the record (19-23 August), suspended sediment concentration was less than 2 mg/ℓ. Between 23-27 August (record day 5-9), the suspended sediment concentration increased to a level of 4 to 10 mg/ℓ. Superimposed on this general increase numerous short-period fluctuations were observed where concentrations increased to 20 to 100 mg/ℓ. These fluctuations were observed at Station 4 in both the transmissometer record and the visibility record (Figure A69), but were generally missing from Station 5, possibly because of its greater distance from the river mouth and hence from the influence of small-scale disturbances associated with the river entrance hydraulics.

119. The period after 27 August was again characterized by low concentrations of suspended sediment (<2 mg/ℓ). Station 5 did show numerous short-period fluctuations occurring on 31 August and 3, 5, and 9 September, but because of a camera malfunction, the visibility record from this station was not obtained; hence, it is not possible to compare the transmissometer and visibility records in order to interpret possible causes of these transient peaks in the transmissometer record.*

December 1975-January 1976: Station 6

120. Winds. Mean winds during the winter experiment were characterized by severe storms occurring frequently along the coast (Figure A70). Southerly winds with various degrees of intensity were observed between 12-14 December (record day 1-3), 20-30 December (record day 9-19), and 1-5 January (record day 21-25). Mean wind speeds were

*Many fish were observed in the bottom photographs during this sampling period, and some of these short-period fluctuations may result from fish interrupting the light path of the transmissometer.

very high during the passage of the storms reaching 14.4 m/sec (27.7 knots) on 23 December, 17.9 m/sec (34.4 knots) on 25 December, and 17.5 m/sec (33.7 knots) on 3 January 1976. A period of easterly winds occurred during 16-20 December (record day 2-8) with wind speeds reaching 10 m/sec (19.2 knots).

121. Waves. Surface waves over Station 6 were large as a result of local winds (Figure A71) with H_s varying between 10 and 15 ft. On 14 and 16 December (record days 4 and 6) and 1 and 2 January (record days 21 and 22), H_s was less than 5 ft. The maximum waves occurred on 13 December (record day 1) and on 26 and 27 December (record days 15 and 16) during the passage of the most severe storms when H_s reached 24 and 28 ft, respectively.

122. Tides. The mean pressure record for Station 6 is shown in Figure A72. Due to the large pressure fluctuations from surface wave activity, the pressure equilization system was actuated so frequently that it was impossible to rectify the tidal curve completely.* This problem was especially acute during the major storm period of 26-27 December (record days 15 and 16).

123. Bottom currents. Current measurements were obtained between 12-26 December, after which time damage to the Savonius rotor speed-sensor occurred. The current speed and direction record and

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*As discussed in Sternberg et al. (1971), the upper limit of the pressure transducer is ± 5 psi. If the pressure exceeds this value, then the reference and active side of the transducer are equalized, thus shifting the reference pressure by 5 psi (positive or negative). Normally, these shifts can be rectified.

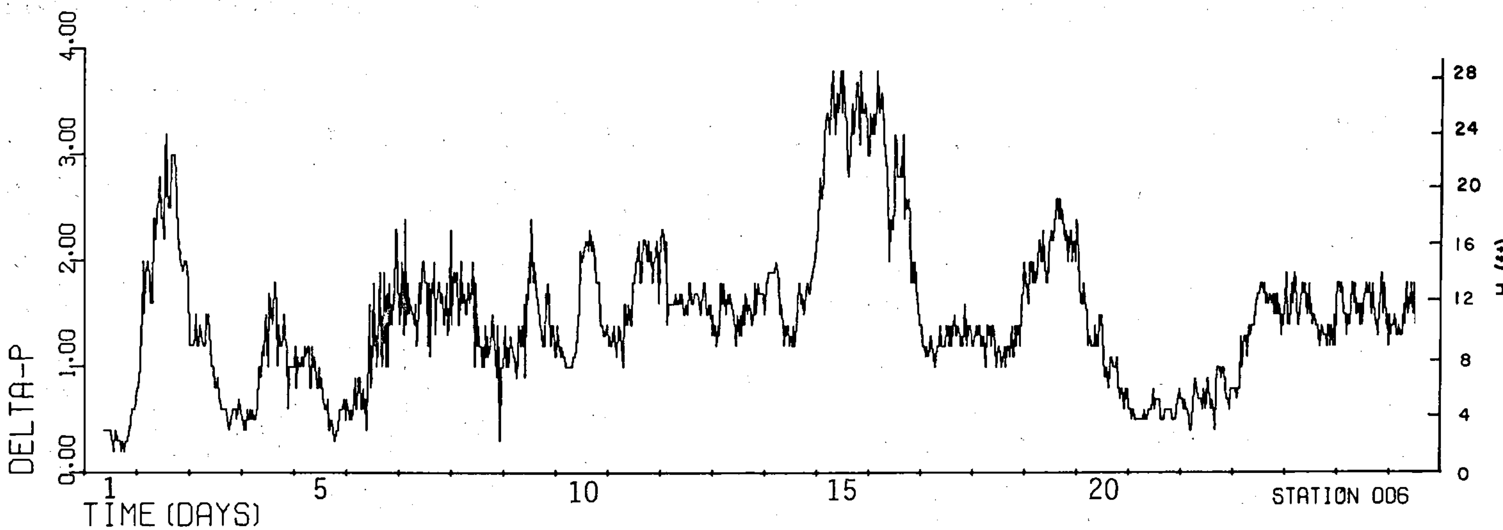

Figure A71. High frequency pressure fluctuations (DELTA-P) at Station 6 during the period 0900 12 December 75 to 1400 6 January 76. The DELTA-P scale is in recorder units. The wave scale to the right was computed using the pressure calibration curve in Figure A19 for a wave with a T_s of 12 sec

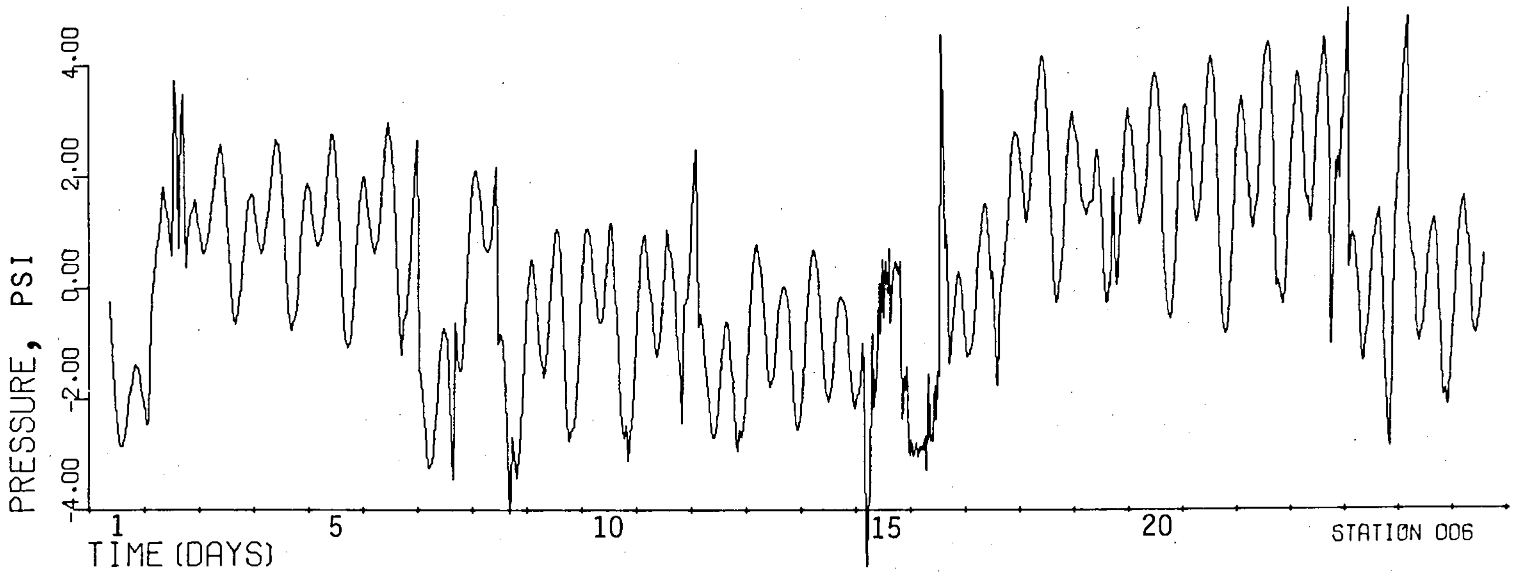

Figure A72. Tide height vs. time in days at Station 6 during the period 0900 12 December 75 to 1400 6 January 76. Mean sea level could not be established due to heavy wave activity during most of the station (see Figure A19) (1 psi ~ 2.2 ft) speed-direction frequency distributions (Figures A73 and A74) show average or background speed on the order of 30 cm/sec with significantly higher peaks occurring during severe storms. During the first 2 days of the sampling period (12-13 December), $\bar{U}_{100}$ reached 71 cm/sec, flowing in a southwesterly direction. The period 16-22 December (record day 5-11) was characterized by $\bar{U}_{100}$ of approximately 30 cm/sec, flowing in a westerly direction. A significant tidal component as observed in the current speed record (Figure A75) was superimposed on the mean westerly flow. On 22 December (record day 11), the bottom flow shifted to a northerly direction and began to increase. On 25-26 December during the period of maximum storm intensity, $\bar{U}_{100}$ reached 80 cm/sec (Figure A75).

124. The progressive vector diagram of the bottom flow (Figure A76) illustrated the trend of the current measurements. Bottom flows were westerly during the first 11 days of the record and then shifted northward in response to the strong southerly winds.

125. Bottom turbidity. Turbidity measurements were very limited during the sampling period due to mechanical difficulties in the beam transmissometer. The beam transmissometer became detached from its mounting bracket due to vibration, dropped to the seabed, and was swept into the Savonius rotor and camera strobe causing their destruction. Data return consisted of 6 days of transmissometer output and 16 days of bottom photographs for visibility measurements (Figure A77).

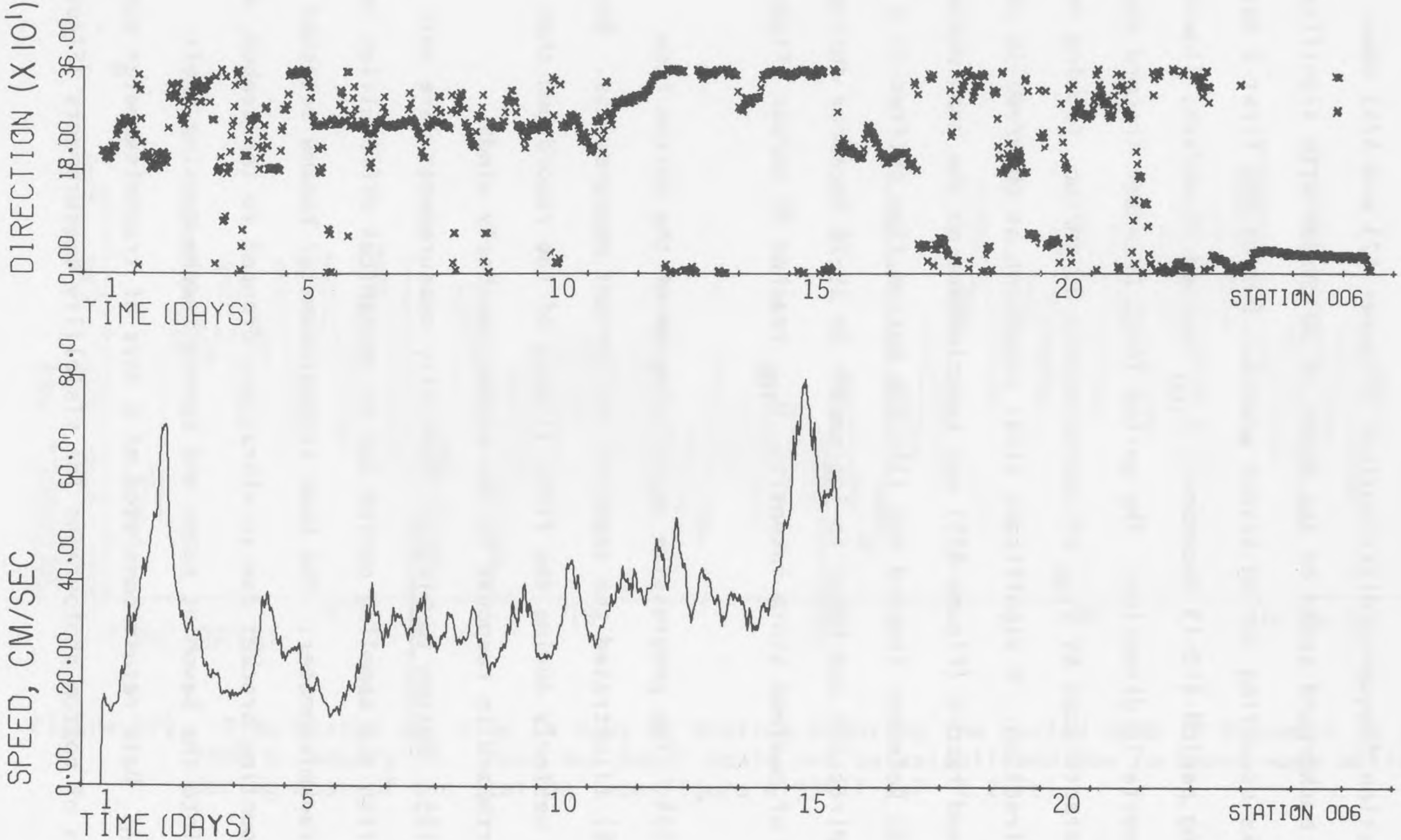

Figure A73. Bottom current speed ($\bar{U}_{100}$) and direction (^{o}T) vs. time in days at Station 6. The $\bar{U}_{100}$ record covers the period between 0900 12 December 75 and 2300 26 December 75. The direction period was between 0900 12 December 75 and 1400 6 January 76. Current speed was measured 3.3 ft off the bed and all measurements were averaged over 30-min periods. These current data are summarized in Figure A74

TRIPOD STATION 6 (12 December 1975 - 6 January 1976)

Speed (cm/sec)	Direction (^{o}T) 0-29	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	270-299	300-329	330-359	TOTAL
0-9.9													
10-19.9	0.4	0.1	0.7	0.4		0.3	1.4	1.4	3.6	1.0	1.0	1.6	11.9
20-29.9	0.9	0.1	0.4			0.3	1.4	0.9	11.1	4.0	3.2	3.9	26.2
30-39.9	3.0		0.3				2.0	3.0	12.3	4.5	8.3	6.7	40.1
40-49.9	0.9						1.2	0.4	0.9	0.6	2.0	5.9	11.9
50-59.9	1.4						0.7	0.1	0.1	0.1	0.1	2.0	4.5
60-69.9	0.1						0.6	0.1				1.9	2.7
70-79.9	0.4						0.6					1.3	2.3
80-89.9												0.1	0.1
TOTAL	7.1	0.2	1.4	0.4		0.6	7.9	5.9	28.0	10.2	14.6	23.4	99.7

N = 697

Figure A74. Speed-direction frequency distribution for $\bar{U}_{100}$ measured at tripod Station 6. N is the total number of half-hour time intervals. The numbers in the matrix represent percent of total sampling time

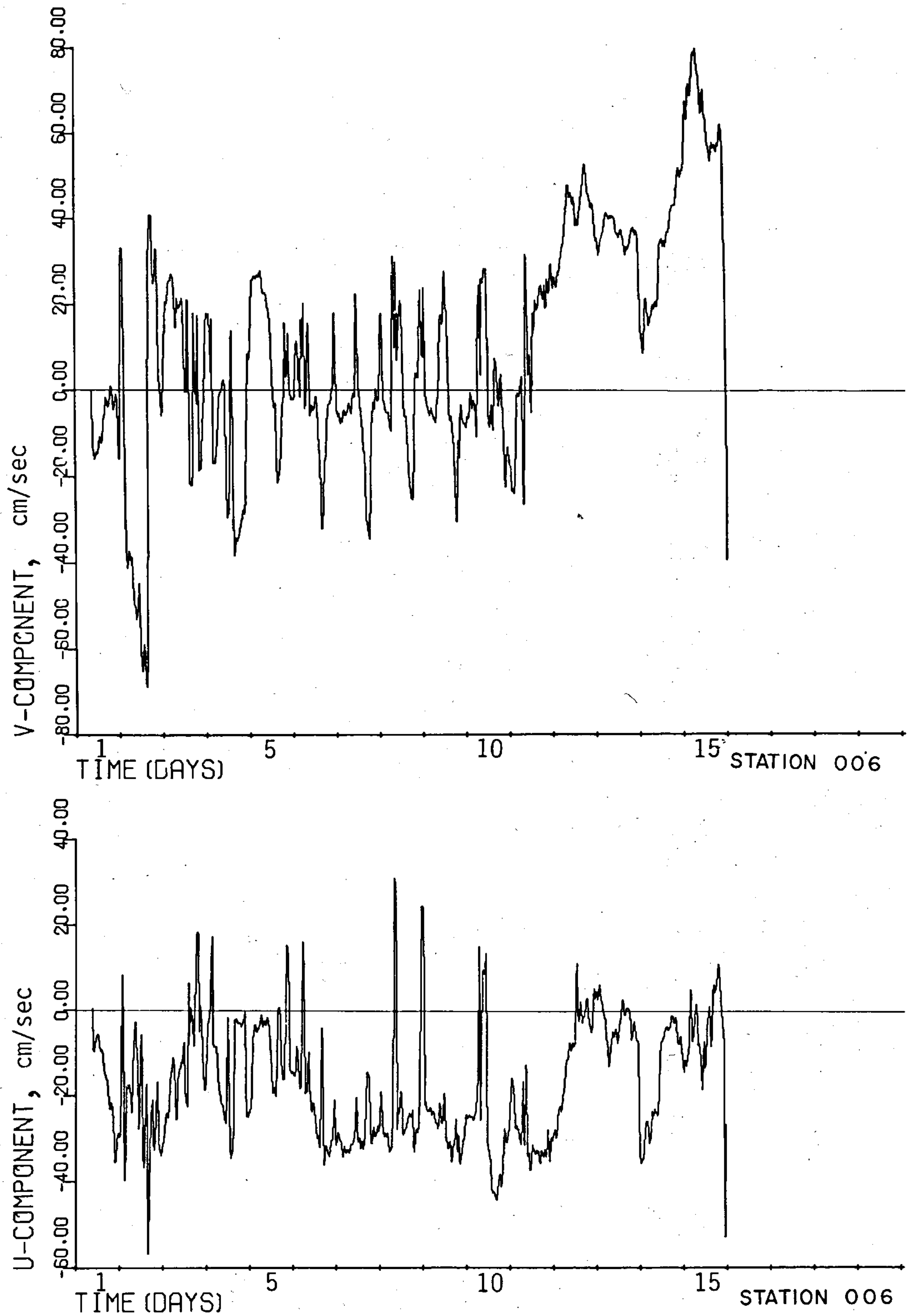

Figure A75. Northward (V) and eastward (U) components of velocity 3.3 ft above the seabed at Station 6 during the period 0900 12 December 75 to 2300 26 December 75

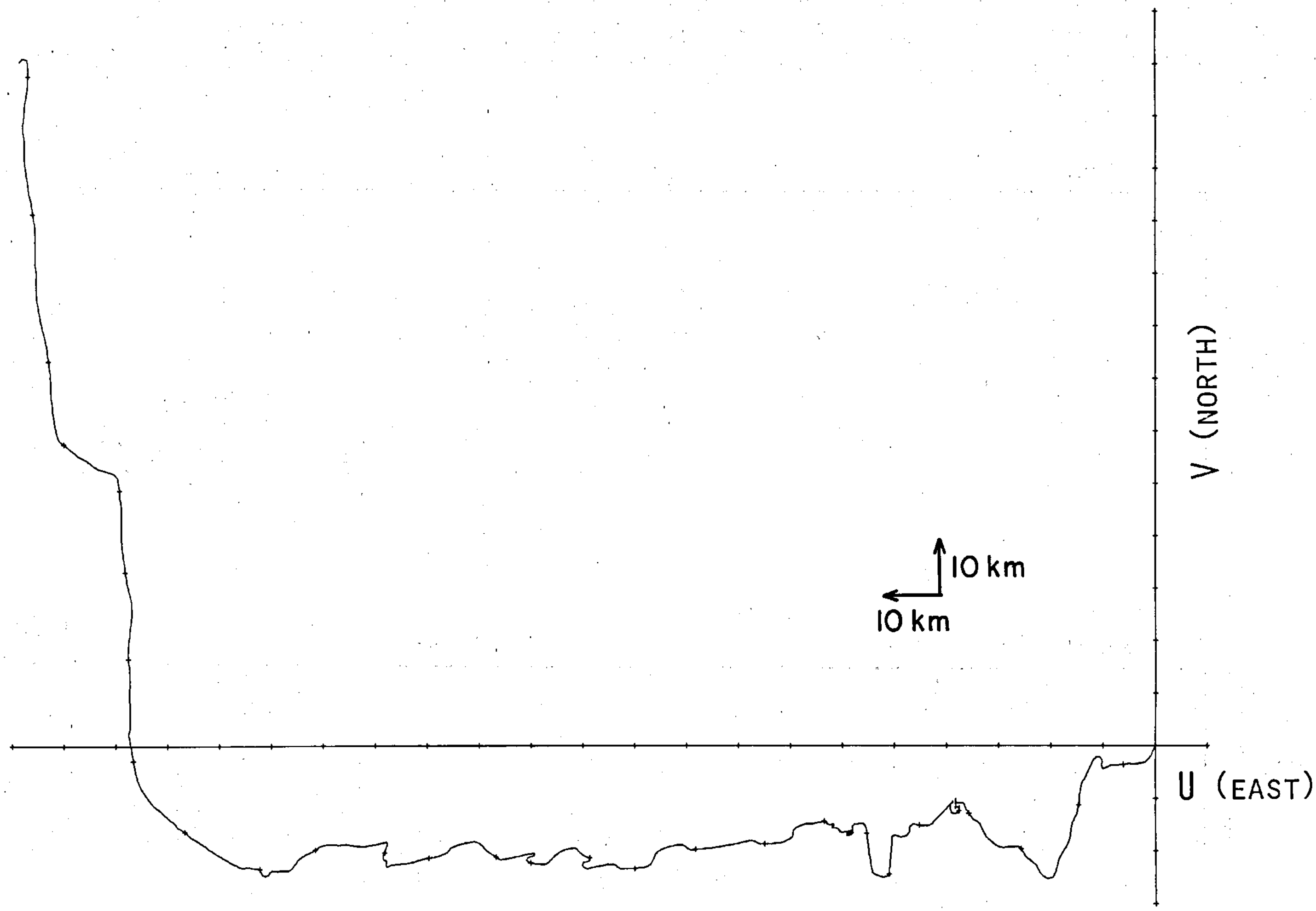

Figure A76. Progressive vector diagram (PVD) for Station 6 during the period 0900 12 December 75 to 2330 26 December 75. The positive vertical axis represents true north.

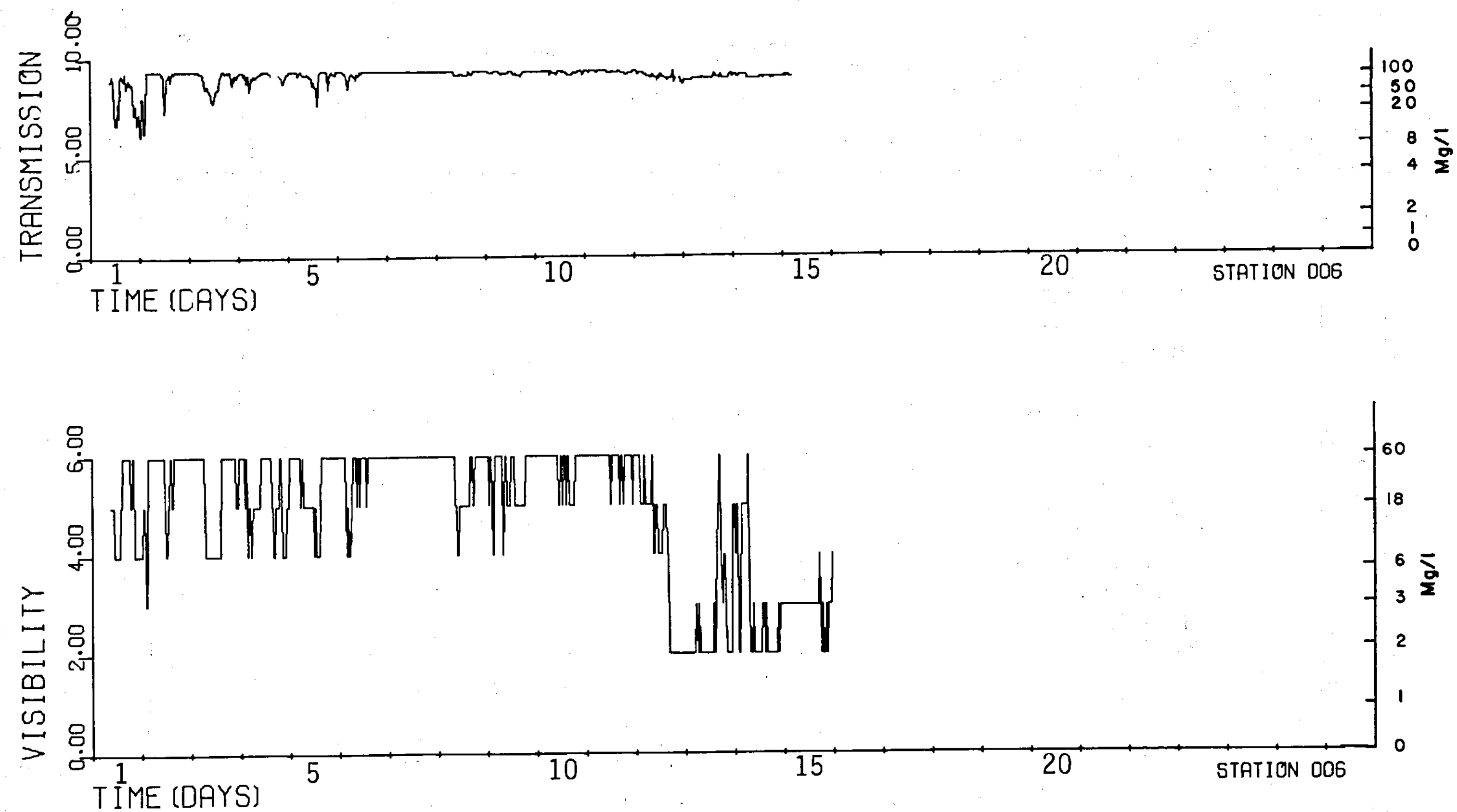

Figure A77. Transmission (in arbitrary recorder units) and photo visibility vs. time for Station 6 during the period 0900 12 December 75 to 1400 6 January 76. The scale at the right side of each illustration represents concentration of suspended sediment (mg/ℓ) 4.3 ft above the seabed (see Figure A21)

126. The first 11 days of the sampling period (12-23 December) were characterized as extremely turbid with suspended sediment concentrations in excess of 80 mg/ℓ. On 23 December (record day 12), the turbidity decreased suddenly, indicating a decrease in suspended sediment concentrations to approximately 2 to 5 mg/ℓ (Figure A77). This abrupt change coincided with the passage of a severe storm, strong southerly winds, and a shift in $\bar{U}_{100}$ from west to north (Figure A76).

Bottom Sediments

Textural properties

127. General areal distribution. The technique of factor analysis for identifying sample groupings by textural parameters proved to be of considerable value in identifying both the areal distribution of sediment textures and the general sediment dispersal system. Kulm et al. (1975) pointed out that "perhaps the best indication of the source and dispersal of modern sediment, particularly sand, on the Oregon shelf is sediment texture." They, following the suggestions of Curray (1960, 1961), used modal grain sizes to effectively trace sediment populations across the Oregon Continental Shelf.

128. The textural composition of the samples representing the extremals of the seven factors chosen for this study as shown by simple frequency graphs are displayed in Figure A78. Table A7 shows the textural data for each of these extremal samples. The findings of this study are in substantial agreement with those of McManus (1972) and Kulm et al. (1975). The differences that exist can be attributed

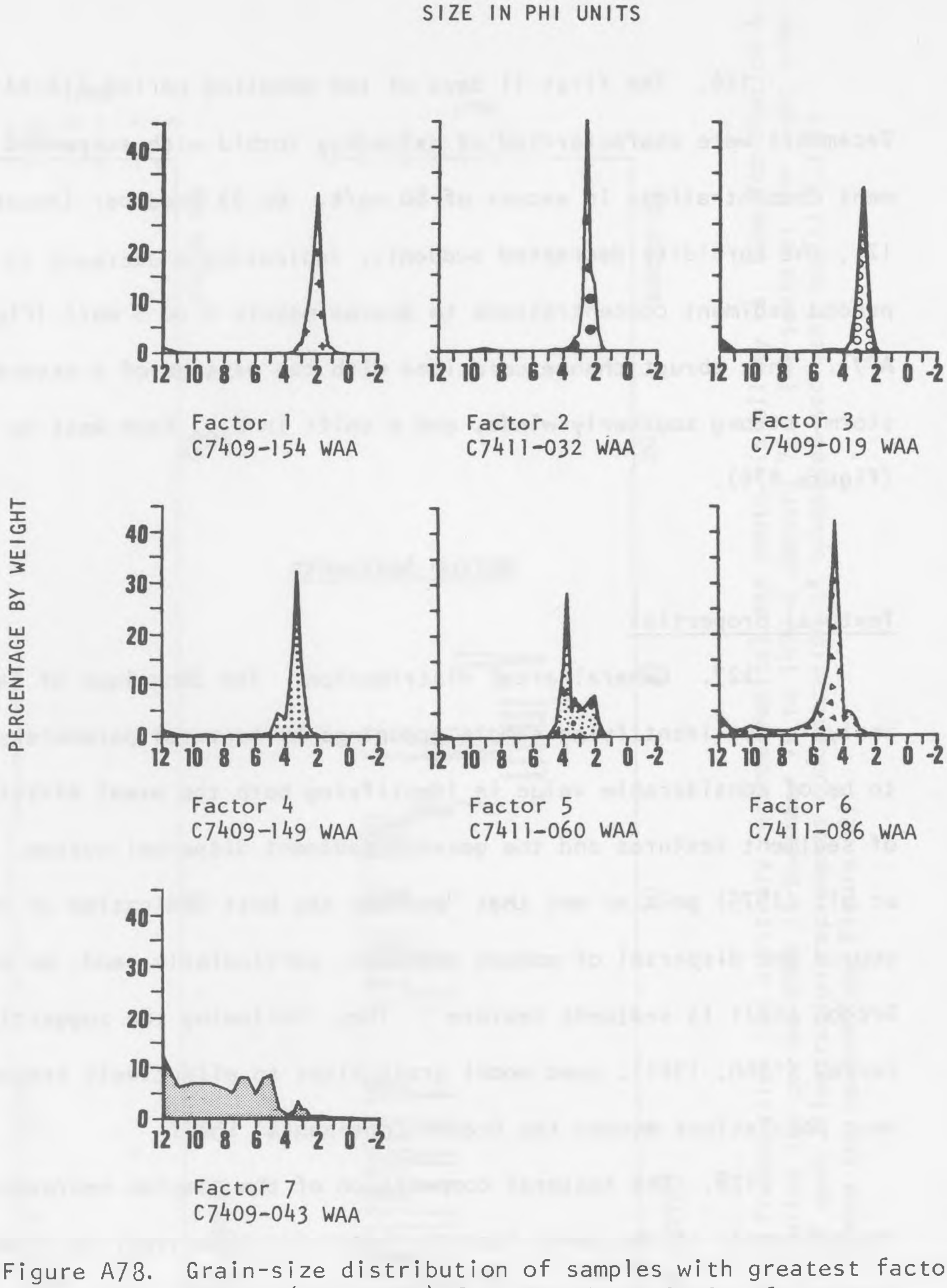

Figure A78. Grain-size distribution of samples with greatest factor loadings (extremals) from Q-mode analysis of texture. Identifying patterns will be used in later figures (for details of distributions see Table A7) to sampling density (55 samples shallower than 295 ft from McManus and 11 samples shallower than 330 ft from Kulm et al., as compared to approximately 800 samples used in this study); different analytical techniques (wet sieving of sands and Coulter-counter sizing of fines, McManus); and different field techniques (McManus statistically controlled sample location and collection, whereas the present study maintained a uniform areal distribution of sample sites). The modal classes chosen as significant by Kulm et al. (1975) are also recognized by this study's factor analysis. Factor 1 includes the 1.75, 2.00 and 2.25ϕ mode samples, whereas Kulm et al. (1975) combined the 2.25 and 2.50ϕ modes into one class.* Factor 5 includes those samples with 3.50, 3.75 and 4.00ϕ modes; whereas Kulm et al. (1975) recognized 3.5 to 3.75, and 4.0ϕ as two separate modal classes.

129. Factor 1 sediment. Factor 1 sediment was the coarsest grained (2.0 to 2.25ϕ modes)* sediment found in the study area and had only a limited distribution (Figure A79). Highest concentrations were found (a) in a triangular-shaped deposit with an apex at entrance Buoy 1 and a base approximately the 120-ft contour to the southwest (Figure A80); (b) in an irregular-shaped deposit northwest of the main entrance channel range line between depths of about 66 and 120 ft (Figure A80); (c) in a small area along the northern margin of Disposal Site A;

*Throughout the report a modal phi size will be listed jointly with a factor type sediment for the convenience of the reader. Although when considering all factor 1 type sediment, it is correct to note that the modal size may occur in one of two class intervals (2.0, or 2.25ϕ). When referring to a given factor 1 sediment sample at a specific time or location only the modal class or classes of that sample will be noted (Factors 3 and 5 will be treated similarly).

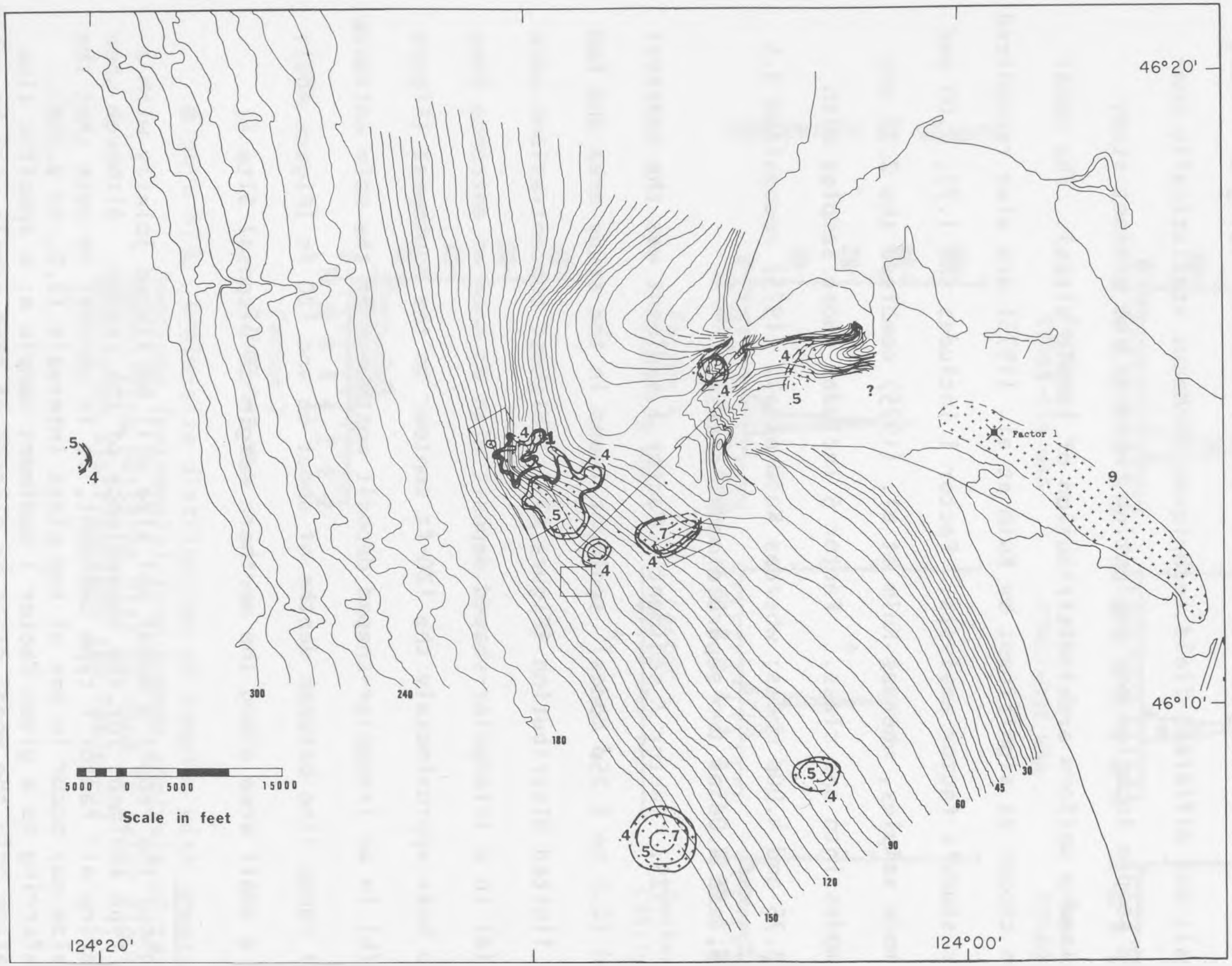

Figure A79. Areal distribution of Factor 1 (1.75, 2.0, or 2.25ϕ modes) sediment. Contours of loading values at 0.4, 0.5, 0.7, and 0.9 are shown where possible. Only the 0.9 loading is shown for the inner river channel. Disposal Sites A, B, and F, channel marker and dredging buoys (•) and the main channel entrance range line are shown (▣) for reference. Figures A80 and A94 should be consulted. Location of Factor 1 extremal sample is shown. Bathymetric contours are in feet and the interval is variable.

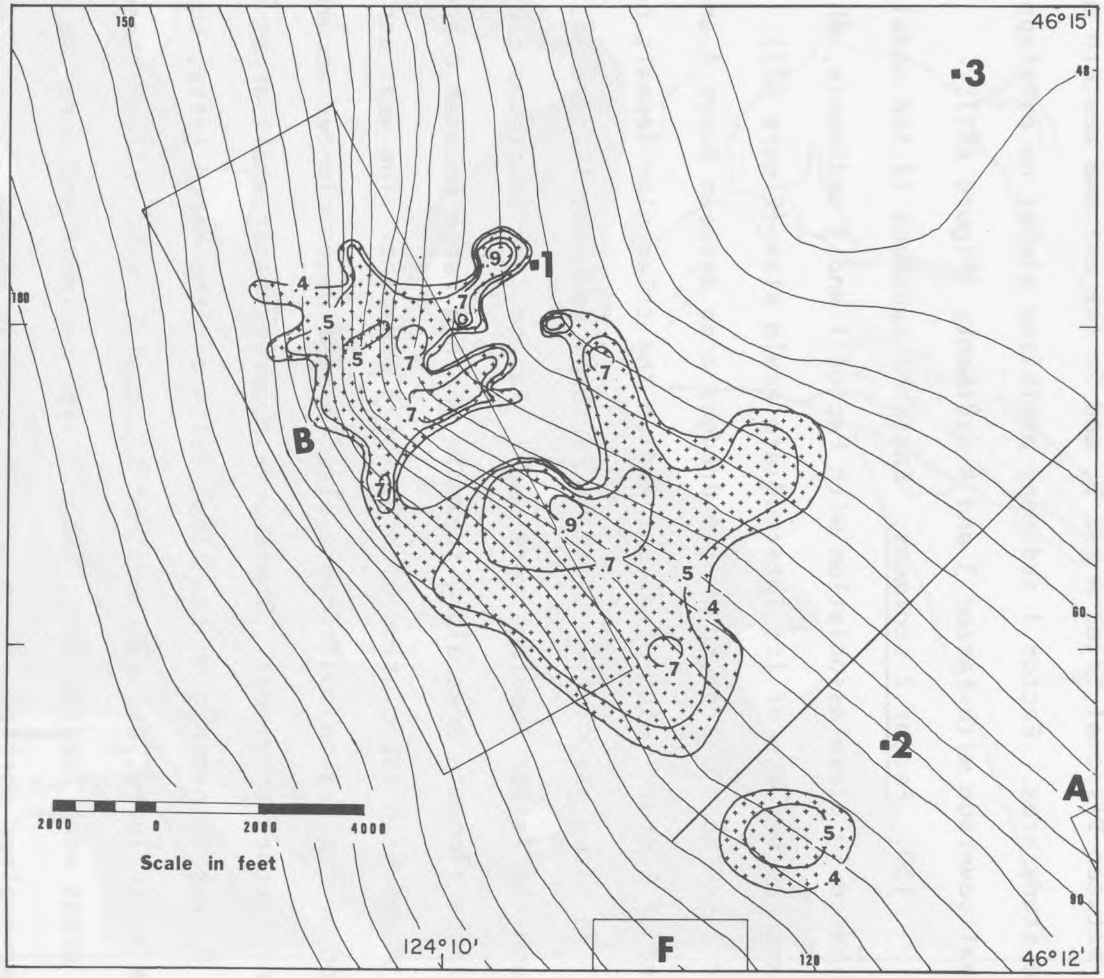

Figure A80. Areal distribution of Factor 1 (1.75, 2.0, or 2.25ϕ modes) sediment in the vicinity of Disposal Site B. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Disposal Sites B and F, channel marker buoys (•), and the main channel entrance range line are shown for reference. Bathymetric contours are in feet

(d) upstream from Buoy 8 (Figure A23) in the estuary as noted by bottom samples collected from the dredged areas and dredge bin samples; (e) in the natural main river channel just seaward of the north jetty; and (f) in four one-sample locations in the southeastern portion of the study area, between Disposal Sites A and B, and in the extreme western margin of the study area. Factor 1 sediment exhibited almost no overlapping in areal coverage with Factor 3 and 4 sediments (Figure A81).

130. Factor 2 sediment. Factor 2 sediment (2.50ø mode) was distributed in close association with Factor 1 and 3 sediments, which was expected because of its intermediate grain size (Figure A82). Factor 2 sediment was found in the dredged area between Buoys A and 8 seaward of Factor 1 concentrations and in the triangular deposit near Buoy 1 in close association with the Factor 1 sediment (Figure A83). Although the factor loadings were small, Factor 2 sediment was present in a large elongate area along the main channel range between Disposal Sites A and B in association with Factor 3 sediment. The west central portion of the region contained a sizable east-west oriented accumulation of Factor 2 sediment. There were numerous other small areas with minor Factor 2 loadings on the tidal delta off the north jetty, south of the south jetty, and southwest of Disposal Site B. All of these small areas were located with Factor 3 type sediment and were the coarser-grained portion of the samples in these areas.

131. Factor 3 and 4 sediment. Two sediment size distributions dominated the study area: 2.75 or 3.0ø mode (Factor 3) and 3.25ø mode (Factor 4). (These same modal sizes were dominant along the entire northern Oregon coast to depths of 330 ft; Kulm et al., 1975).

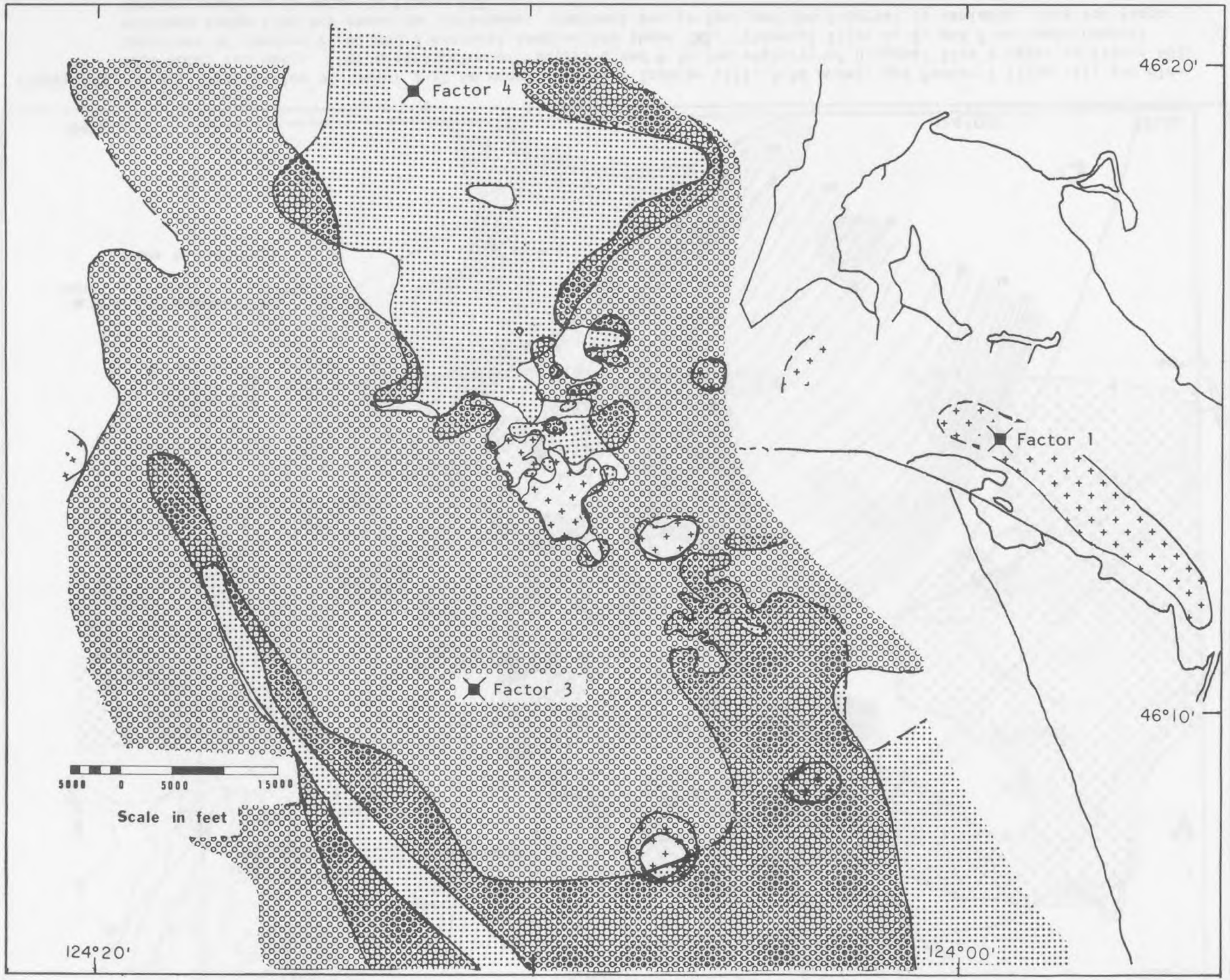

Figure A81. Areal distribution of Factor 1 (1.75, 2.0, or 2.25ϕ modes), Factor 3 (2.75 or 3.0ϕ mode), and Factor 4 (3.25ϕ mode) sediments defined by 0.4 loadings. Locations of Factor 1, 3, and 4 extremal samples are shown (▣). Key for factor loading shading is shown in Figure A78.

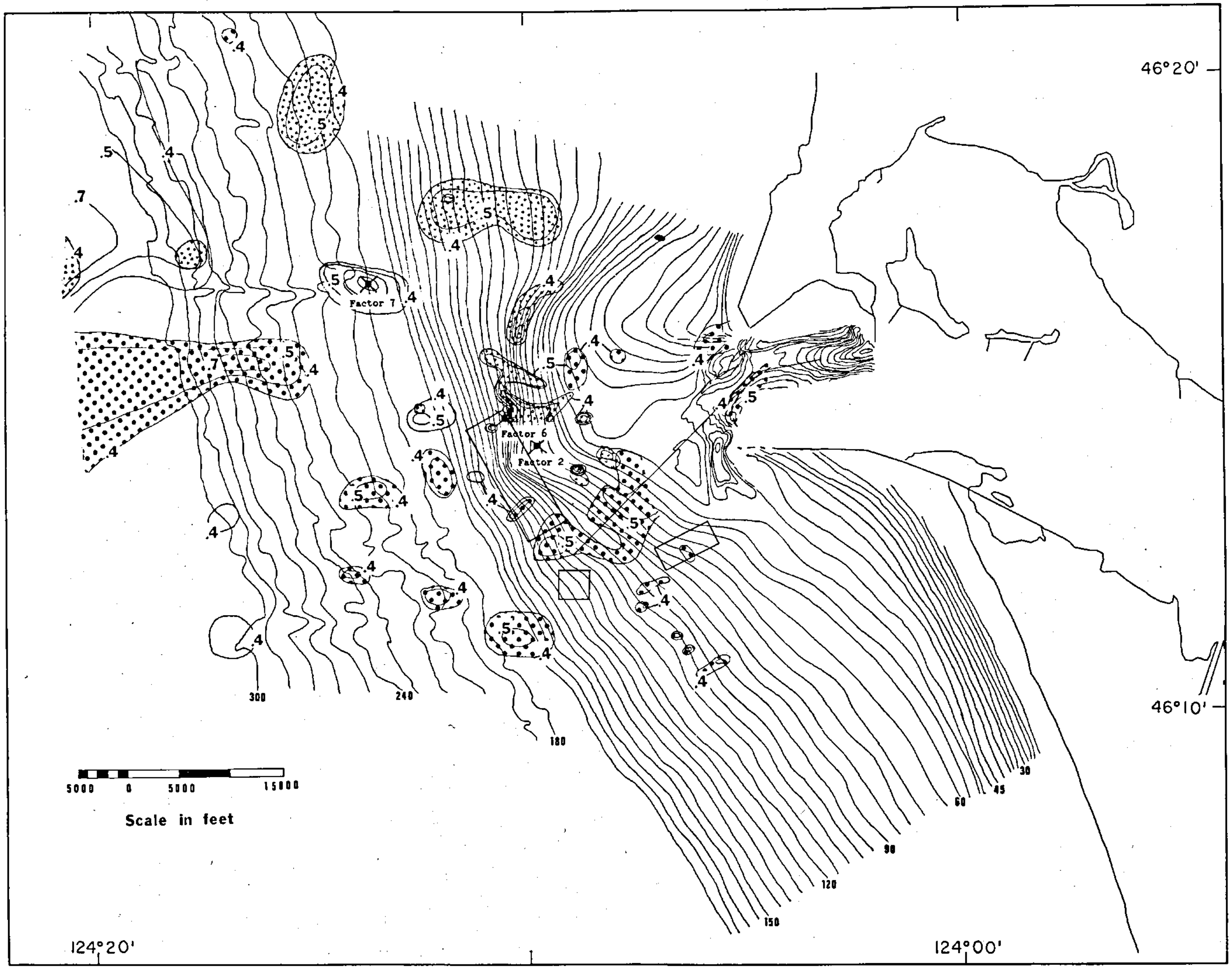

Figure A82. Areal distribution of Factor 2 (2.5ϕ mode), Factor 6 (coarse silt, 4.5ϕ mode), and Factor 7 (fine silt and clay, 12.0 mode) sediments. For distribution of Factors 2 and 6 in the vicinity of Disposal Site B refer to Figure A83. Locations of Factors 2, 6, and 7 extremal samples are shown (✖). Disposal Sites A, B, and F and main channel entrance range line are shown for reference. Contours are in feet and the interval is variable. Key for factor loading shadings is shown in Figure A78.

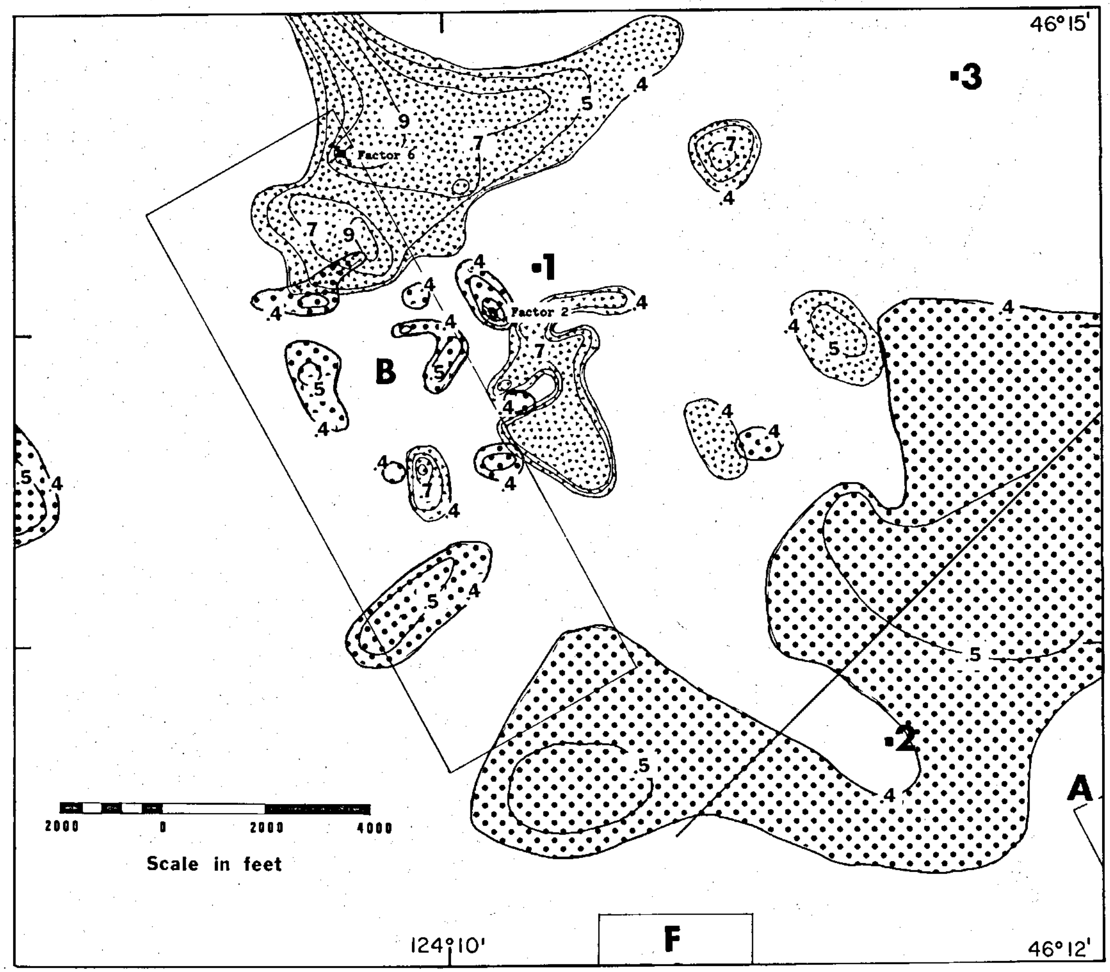

Figure A83. Areal distribution of Factor 2 (2.5ø mode) and Factor 6 (coarse silt, 4.5ø mode) sediments in the vicinity of Disposal Site B. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Locations of Factors 2 and 6 extremal samples are shown (⌧). Disposal Sites B and F, channel marker buoys (•), and the main channel entrance range line are shown for reference. Key to factor loading shadings is shown in Figure A78

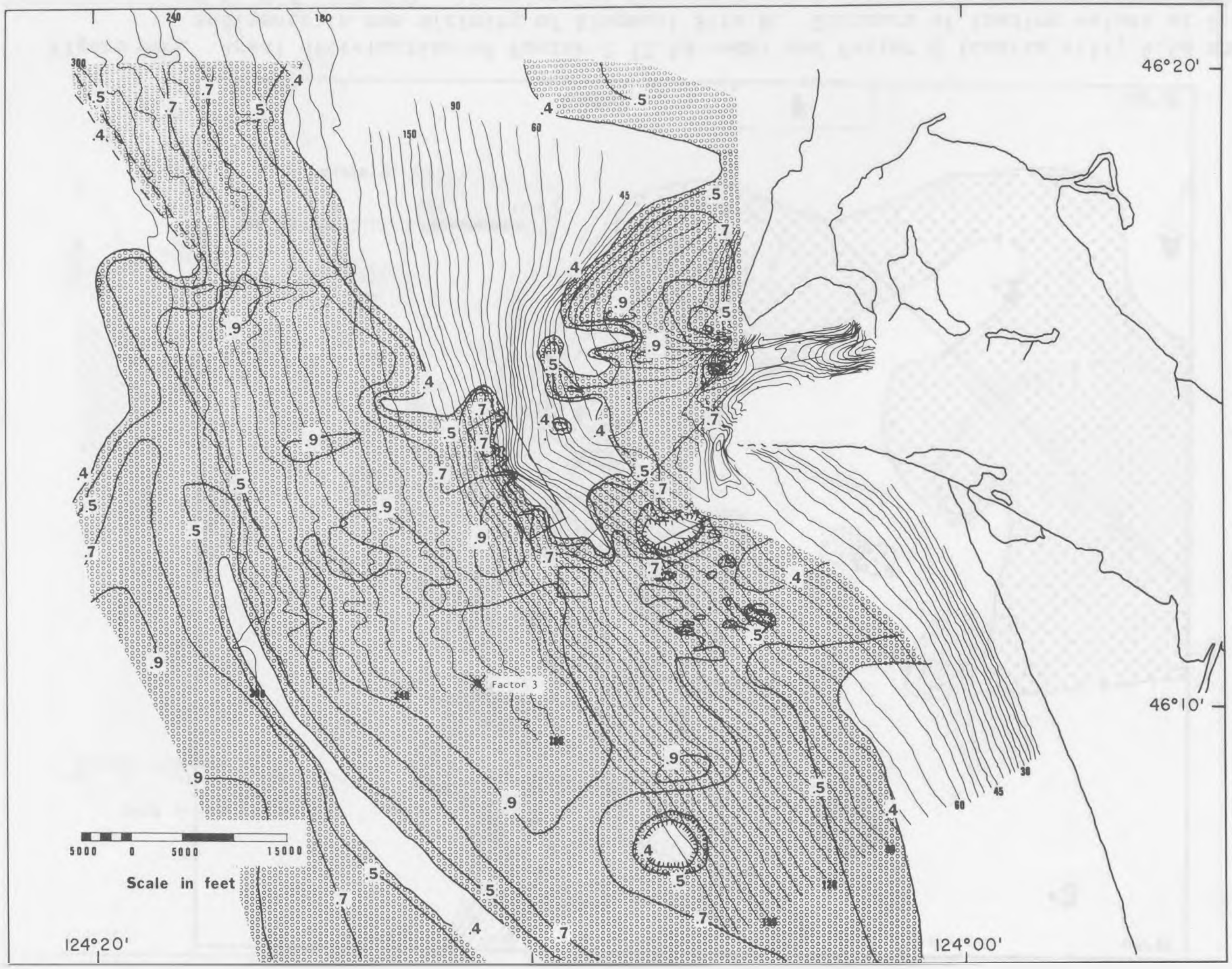

Figure A84. Areal distribution of Factor 3 (2.75 or 3.0ø mode) sediment. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Location of Factor 3 extremal samples is shown (⌘). Disposal Sites A, B, and F and the main channel entrance range line are shown for reference. Bathymetric contours are in feet and the interval is variable. Detail in the vicinity of Disposal Site B is shown in Figure A85.

132. Factor 3 sediment covered most of the area south of the river entrance and extended northward both east and west of Disposal Site B (Figure A84). It was generally absent in the southeast and northwest corners of the study area and was absent in a narrow northwest - southeast zone just seaward of the 300-ft contour in the southwest. North of the river entrance, Factor 3 sediment covered all except the western end of the tidal delta. An irregular lobe of Factor 3 sediment extended due west from the entrance toward Disposal Site B. Just south of the entrance at Disposal Site A, Factor 3 sediment was absent. Factor 3 sediment was present west of the 126-ft contour along the margin of Disposal Site B, but in detail it was seen that the factor loadings were much less west of the bathymetric nose produced through disposal at Site B (Figure A84 and A85). Toward the northwest, Factor 3 sediment was progressively restricted to greater depths of about 180 ft northwest of Site B, and to more than 200 ft in the northwest portion of the study area.

133. The finer-grained Factor 4 sediment, with the exception of Disposal Sites B and A, was generally dominant in the portions of the study area not dominated by Factor 3 sediments. South of the river entrance, Factor 4 sediment was present where Factor 3 sediment was of minor importance with the two sediment types broadly overlapping particularly in the southeastern area (Figure A81). Off the river entrance, Factor 4 sediment was prominent on the tidal delta north of the main river channel, dominant on the steeper seaward face of the tidal delta and along the north edge of Site B, and generally increased in dominance westward and northward seaward of the Factor 3

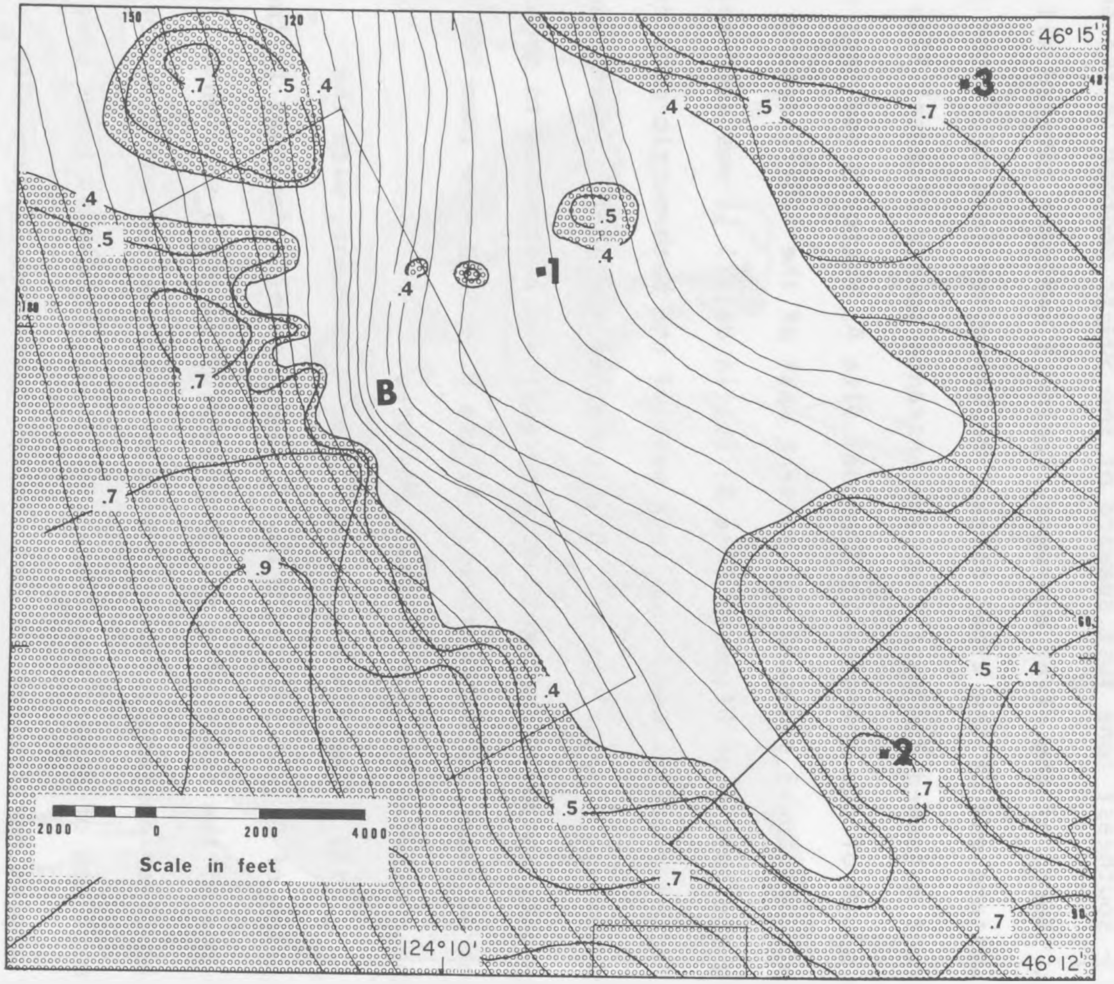

Figure A85. Areal distribution of Factor 3 (2.75 or 3.0ϕ mode) sediments in the vicinity of Disposal Site B. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Disposal Sites A, B, and F, channel marker buoys (•), and the main channel entrance range line are shown for reference. Bathymetric contours are in feet sediment. Factor 4 sediment followed the northern and eastern boundary of the dredged material at Site B (Figures A81, A86, and A87). Northward from Site B, Factor 4 sediment formed the bulk of a deposit that progressively widens in east-west width.

134. Factor 5, 6, and 7 sediment. These factors represented the fine-grained component of the sediment (Figure A82). Factor 5 sediment was represented by only three samples with loadings exceeding 0.4. Because no samples were ignored, these three had to be retained, but are not discussed or included in figures. They were all located with Factor 6 sediments.

135. Factor 6 sediment, with coarse silt modes, is representative of the coarse silts; while Factor 7 sediment, with fine silt- or clay-size modes, is representative of the finest fraction of the sediments of the Columbia River. It must be remembered that the analytical techniques which sized silts at 0.5-ø intervals and clays at 1.0-ø intervals biased the results in favor of the finer sizes. The progressively larger class interval increases the apparent importance of the finer sizes in the factor analysis and in the sample frequency distribution displays of the grain-size distribution of a sample. The reporting of total sediment finer than 11ø as 12ø also produces a bias.

136. Although there was a general increase in silt- and clay-sized particle concentration southwest of Disposal Site B, it was not significant enough to appear as large factor loadings except at two single-sample occurrences of Factor 7 sediment seen in the elongate zone of Factor 4 sediment in the southwestern portion of the study area (Figure A82).

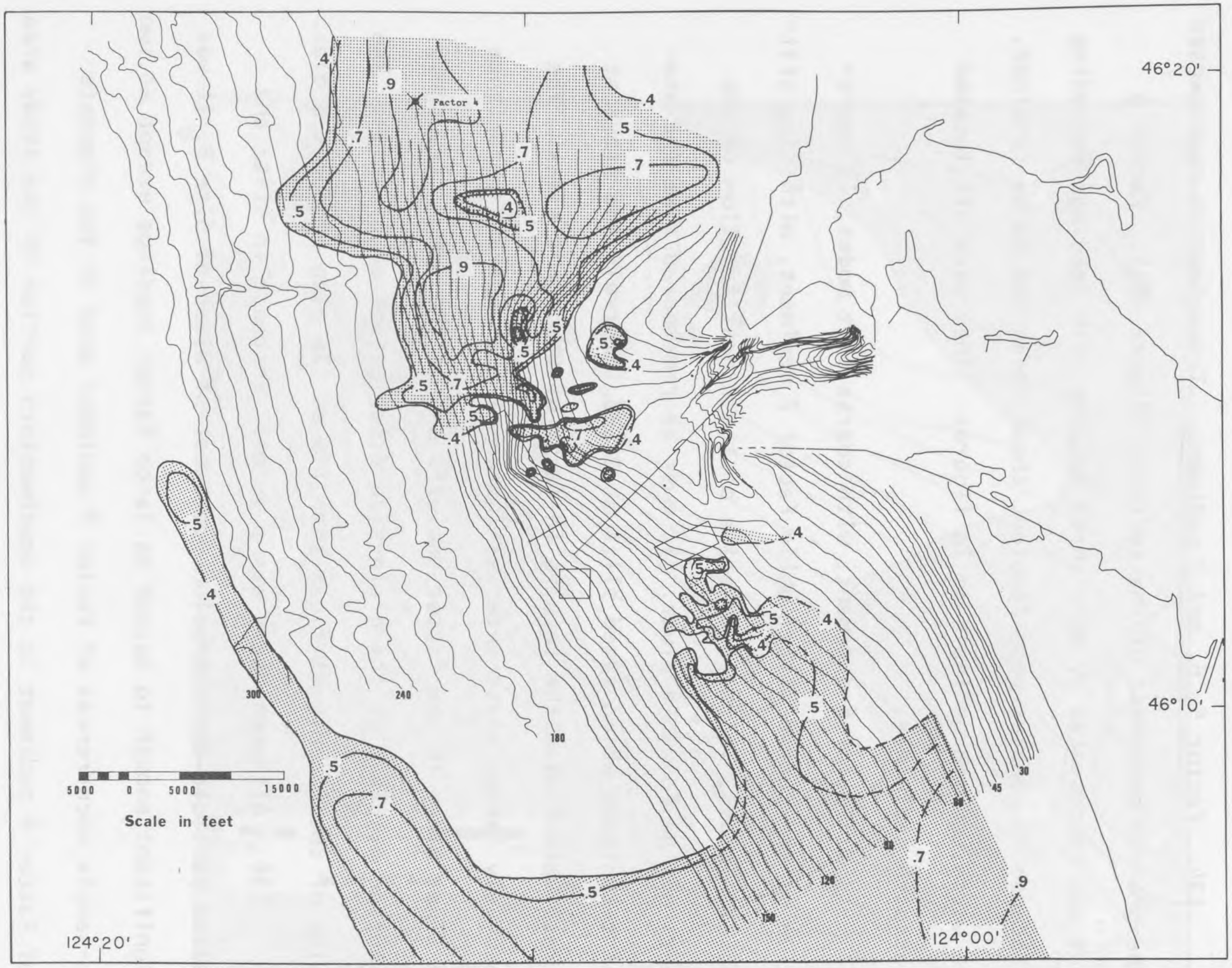

Figure A86. Areal distribution of Factor 4 (3.25ϕ mode) sediment. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Location of Factor 4 extremal sample is shown (⌘). Disposal Sites A, B, and F and the main channel entrance range line are shown for reference. Bathymetric contours are in feet and the interval is variable. Detail in the vicinity of Disposal Site B is shown in Figure A87.

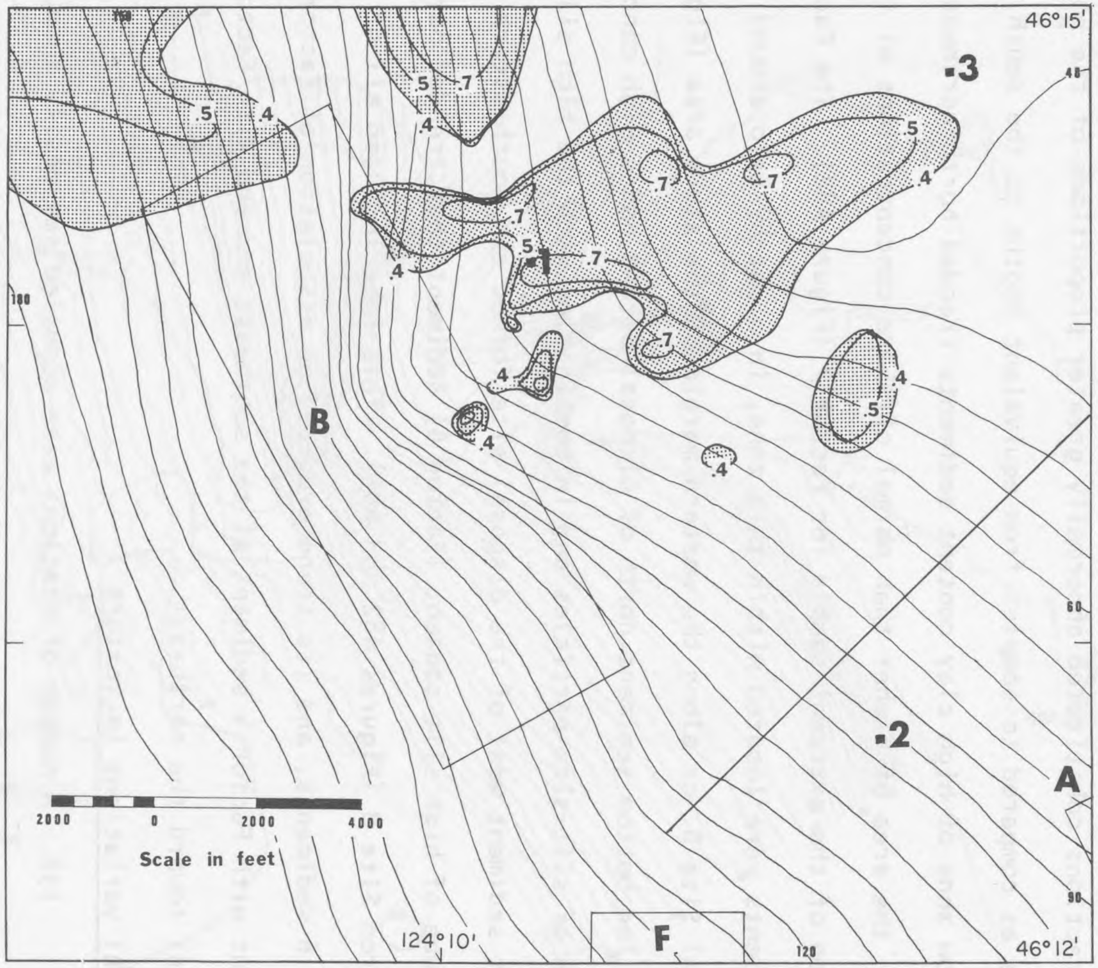

Figure A87. Areal distribution of Factor 4 (3.25ϕ mode) sediments in the vicinity of Disposal Site B. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Disposal Sites A, B, and F, channel marker buoys (•), and main channel entrance range line are shown for reference. Bathymetric contours are in feet

137. The areal distribution of silt and clay fractions (Figures A88 and A89*) showed that south of the river entrance both the silt and clay fractions increased in importance offshore in classical fashion. Immediately west of Disposal Site B both the clay- and silt-size fractions constituted abnormally greater proportions of the bottom samples as compared to samples from equivalent depths to the south. A narrow zone of high clay content sediments trended north-northwest to join the area of higher than normal offshore concentrations at the location of the extremal sample for Factor 7 (Figure A82). The Factor 7 sediments were located within this zone, in a patchy halo around Disposal Site B, or along the western margin of the study area (Figure A82). The bottom sediment north of Disposal Site B had a high concentration of silt-size particles and in combination with the high silt content sediment west of the disposal site formed the southeastern end of a lobe of high silt content (Factor 6) sediment that trended northwest from Site B (Figures A82 and A83). This lobe included all of the Factor 6 sediments, and its trend produced an association of Factor 6 sediment with Factor 4 sediment at the southeast end and with Factor 3 sediment toward the northeast.

<u>Seasonal variations in texture</u>

138. A number of stations were occupied seasonally throughout the study area both as part of this study and the benthic program at OSU. The locations of 70 of these samples are shown in Figures A90

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*The large seasonal variations in the quantity of silt and clay fractions in the sediments near Site B preclude a meaningful contouring of these parameters in this area.

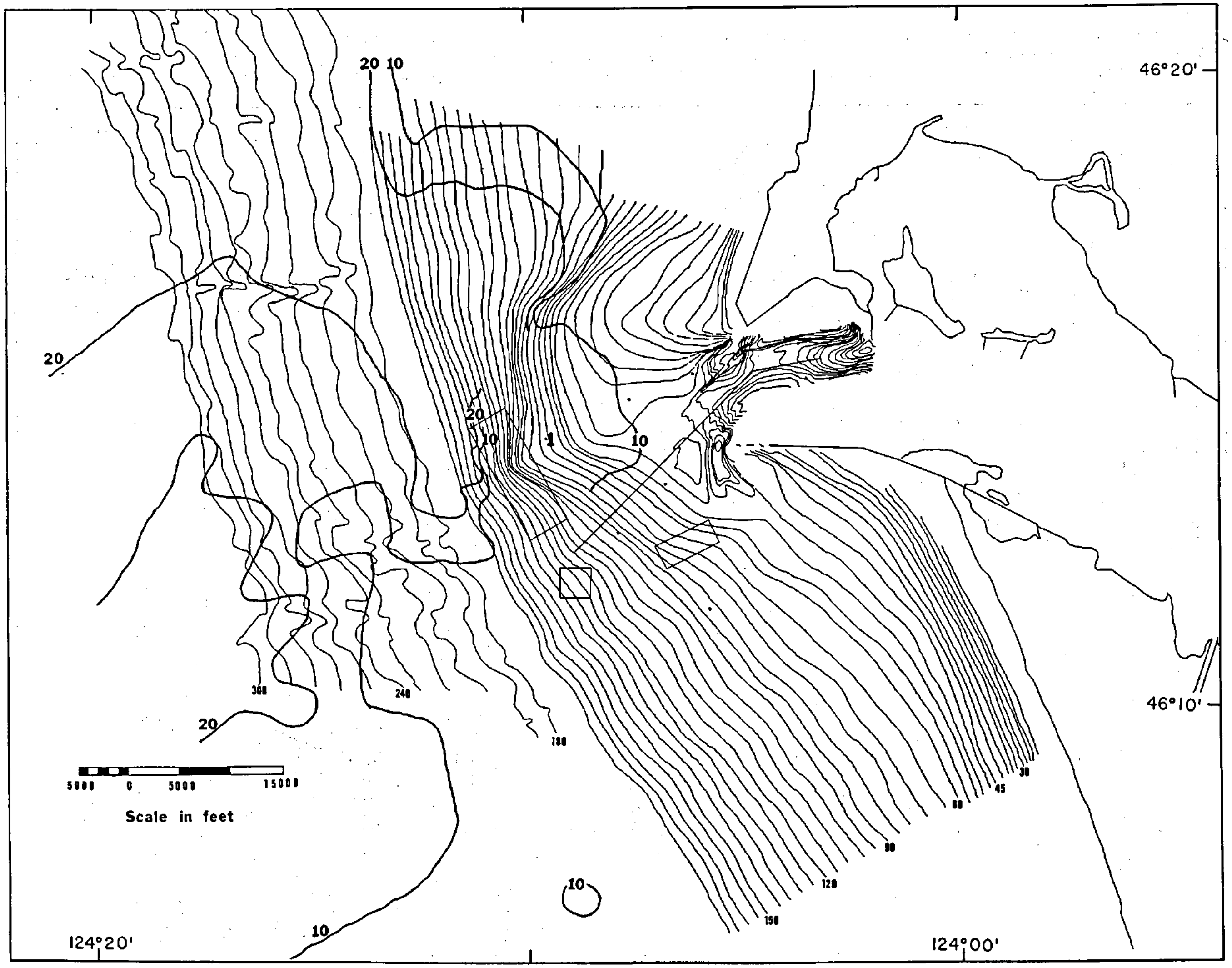

Figure A88. Areal distribution of the silt fraction of the bottom sediment. Contours of only 10 and 20 percent concentrations are shown and are omitted near Disposal Site B for reasons discussed in the text. Disposal Sites A, B, and F, channel marker and dredging buoys (•), and the main channel range line are shown for reference. Bathymetric contours are in feet and the interval is variable.

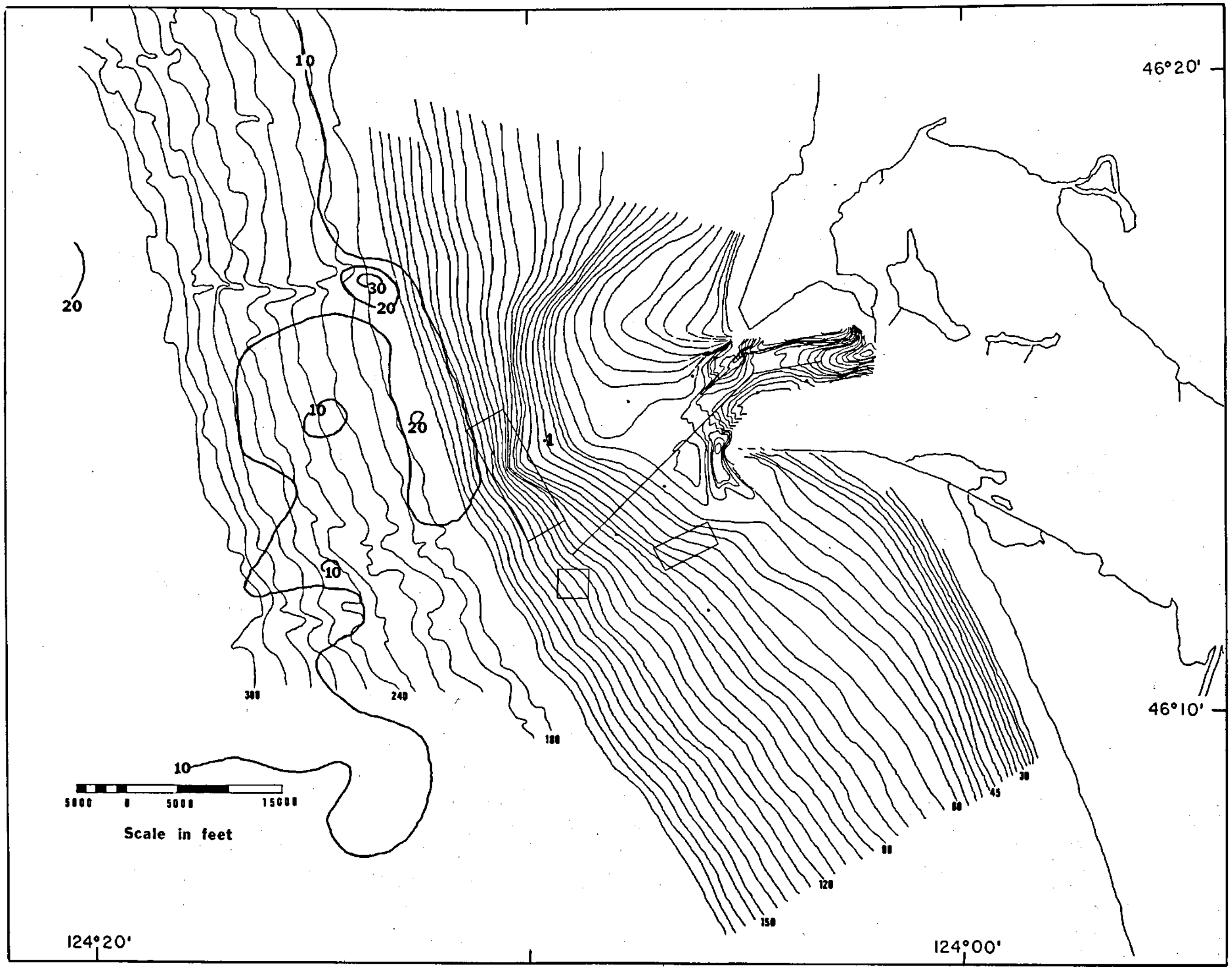

Figure A89. Areal distribution of clay fraction of the bottom sediments. Contours at 10 and 20 percent are shown and are omitted near Disposal Site B for reasons discussed in the text. Disposal Sites A, B, and F, channel marker and dredging buoys (•), and the main channel range line are shown for reference. Bathymetric contours are in feet and the interval is variable.

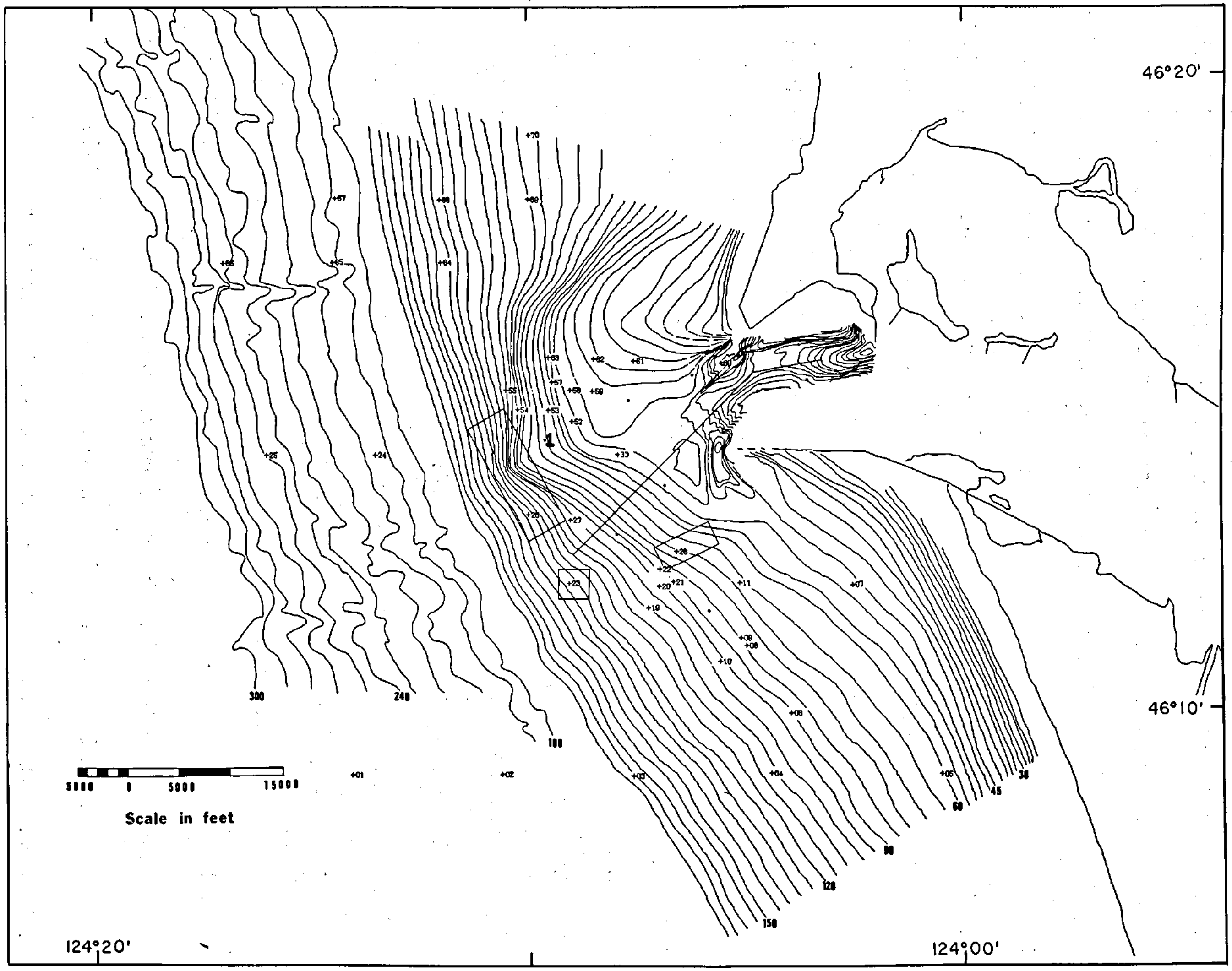

Figure A90. Location of groupings of samples collected within 0.1 minute of latitude or longitude (600 ft) of each other in different months. Each grouping is referred to as a station (see Table A10). Disposal Sites A, B, and F, channel marker and dredging buoys (•), and the main channel range line are shown for reference. Bathymetric contours are in feet and the interval is variable. See Figures A91 and A102 for locations of stations near Disposal Sites B and G.

and A91 (Site G stations will be shown later), and the grain-size distributions for samples from these stations are tabulated in Table A10.

139. Generally, excepting the experiment carried out at Site G, the texture of bottom sediments south of the Columbia River entrance changed little seasonally during the sampling period. Stations 1 to 25 included samples that were unimodal at 2.75 or 3.25ø (Factors 3 and 4), or were some bimodal combination with most seasonal changes producing only minor changes in the relation of these modes. Stations 5, 8, and 23 had the longest time series illustrating the lack of seasonal textural change. Station 23 was at the location of Disposal Site F and although this site had been used sparingly since 1966 and 1967 when about 500,000 cu yd were disposed there, the texture exhibited little seasonal variation and appeared quite similar to the textures present in samples from Stations 3 and 4 in similar depths of water to the south.

140. The remainder of the study area was much more dynamic. Seasonal textural changes near the river were expectably quite large varying from 2-ø modes (Factor 1) to silt modes (Factor 6) over a few months time. Northwest of the river mouth changes were still apparent, but were not as variable, changing seasonally from very fine sand (Factor 4) to silt (Factor 6) and back. Although sample locations within stations were generally no more than about 0.1 minute (~600 ft) apart, some samples collected the same month showed distinctly different textures. For example, Station 27 contained two samples (C7412B-196 and C7412B-208) collected the same day but at different times

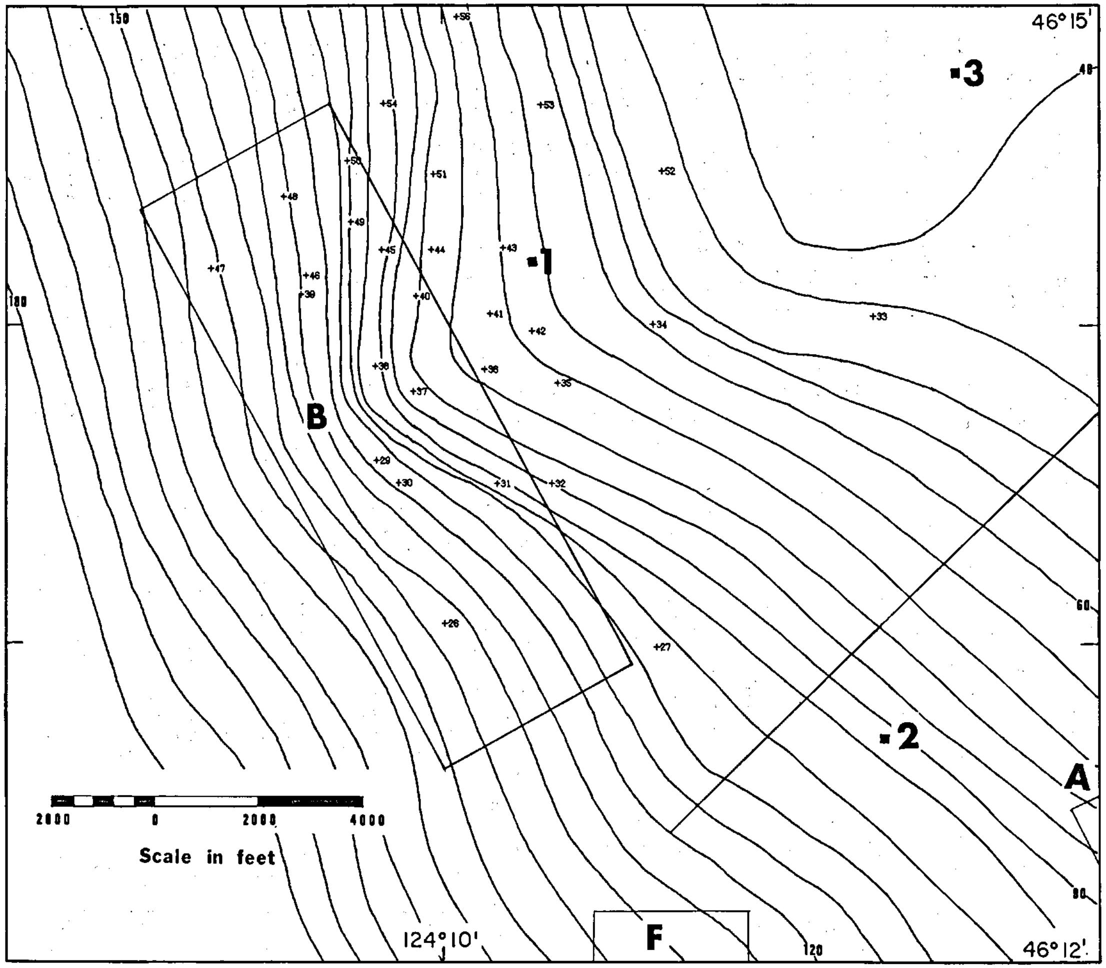

Figure A91. Locations of groupings of samples near Disposal Site B collected within 0.1 minute of latitude or longitude (600 ft) of each other in different months. Each grouping is referred to as a station (see Table A10). Disposal Sites A, B, and F, channel marker buoys (•), and the main channel range line are shown for reference. Contour interval is 6 ft

Table A10

Grain-Size Distributions (Percent by Weight) for Those Samples Collected Within 0.1 Minutes of Latitude or Longitude (600 ft) of Each Other in Different Months*

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
1	C4128 094 WAA	0	0	0	0	0	0	0	0	1	2	7	15	15	22	6	3	2	4	2	2	2	1	1	1	2	2	2	2	4
	C7504 005 WAA	0	0	0	0	0	0	0	0	1	3	9	19	14	20	5	3	1	4	2	2	1	2	1	1	1	2	2	2	4
	C7506 005 WAA	0	0	0	0	0	0	0	0	1	4	10	19	16	22	5	3	1	3	1	2	1	1	1	1	1	1	1	1	4
	C7509 R05 WAA	0	0	0	0	0	0	0	0	1	3	8	17	15	19	4	3	1	6	2	2	1	2	1	1	1	2	2	2	5
2	C4128 038 WAA	0	0	0	0	0	0	0	0	1	4	12	32	26	17	3	1	0	1	0	0	0	0	0	0	0	0	0	0	1
	C7504 004 WAA	0	0	0	0	0	0	0	0	1	4	13	31	25	15	3	1	0	1	0	0	0	0	0	0	0	0	0	0	2
	C7506 004 WAA	0	0	0	0	0	0	0	0	1	4	12	31	25	16	3	1	0	1	0	0	0	0	0	0	0	1	0	0	2
	C7509 R04 WAA	0	0	0	0	0	0	0	0	1	4	13	30	24	18	3	1	1	1	0	0	0	0	0	0	0	0	1	1	1
3	C4128 082 WAA	0	0	0	0	0	0	0	0	1	4	14	31	23	20	4	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7504 003 WAA	0	0	0	0	0	0	0	0	1	4	14	29	24	20	4	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 003 WAA	0	0	0	0	0	0	0	0	1	5	14	28	24	20	4	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 R03 WAA	0	0	0	0	0	0	0	0	1	4	13	30	24	19	4	1	0	0	0	0	0	0	0	0	0	0	0	0	1
4	C4128 076 WAA	0	0	0	0	0	0	0	0	1	4	10	22	17	24	12	7	2	0	0	0	0	0	0	0	0	0	0	0	1
	C7504 002 WAA	0	0	0	0	0	0	0	0	1	4	12	24	18	23	10	5	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 002 WAA	0	0	0	0	0	0	0	0	1	5	11	22	17	23	12	6	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 R02 WAA	0	0	0	0	0	0	0	0	1	4	11	22	19	23	11	5	3	1	0	0	0	0	0	0	0	0	0	0	1
	C7510 R02 WAA	0	0	0	0	0	0	0	0	1	4	11	22	19	24	11	6	1	0	0	0	0	0	0	0	0	0	0	0	1
5	C4128 130 WAA	0	0	0	0	0	0	0	0	1	4	8	17	15	25	14	9	3	1	0	0	0	0	0	0	0	1	0	0	0
	C7504 001 WAA	0	0	0	0	0	0	0	1	2	5	11	16	14	22	13	10	3	2	0	0	0	0	0	0	0	1	0	0	0
	C7506 001 WAA	0	0	0	0	0	0	0	0	2	5	10	18	16	23	13	8	3	1	0	0	0	0	0	0	0	0	0	0	1
	C7509 R01 WAA	0	0	0	0	0	0	0	1	2	5	10	18	15	24	13	9	3	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 R01 WAA	0	0	0	0	0	0	0	1	2	6	11	17	13	20	14	9	3	1	0	0	0	0	0	0	0	0	0	0	1
6	C7506 028 WAA	0	0	0	0	0	0	0	1	2	8	15	27	14	17	8	4	2	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 R28 WAA	0	0	0	0	0	0	0	0	2	5	12	21	14	21	13	8	2	1	0	0	0	0	0	0	0	0	0	0	1
	C7510 R28 WAA	0	0	0	0	0	0	0	1	2	6	14	21	15	20	11	6	2	1	0	0	0	0	0	0	0	0	0	0	1
7	C4128 124 WAA	0	0	0	0	0	0	1	3	8	12	17	23	13	13	5	2	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7506 010 WAA	0	0	0	0	0	0	1	4	9	12	16	20	10	13	6	4	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 R10 WAA	0	0	0	0	0	0	1	4	9	13	18	23	11	11	5	2	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 R10 WAA	0	0	0	0	0	0	1	3	7	10	15	21	12	16	8	4	1	0	0	0	0	0	0	0	0	0	0	0	0
8	C7412 005 WAA	0	0	0	0	0	0	0	0	1	5	12	23	16	21	12	6	2	0	0	0	0	0	0	0	0	0	0	0	1

*A few samples have greater separation but because they provide useful information, they are included and noted with an asterisk. Each group is identified as a station whose location can be found in Figures A90, A91, and/or A102 (see Table A11 for Stations 71-88). Samples labelled WAA are surface samples. Those labelled WBA and WCA are sub-stratum samples from the same grab sample. For dates of cruises see Table A5.

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
	C7501 509 WAA	0	0	0	0	0	0	0	0	1	5	12	23	17	21	10	6	2	1	0	0	0	0	0	0	0	1	0	0	0
	C7504 024 WAA	0	0	0	0	0	0	0	0	1	5	12	22	16	21	11	7	2	1	0	0	0	0	0	0	0	0	0	0	1
	C7506 024 WAA	0	0	0	0	0	0	0	0	1	5	12	21	17	22	12	7	2	1	0	0	0	0	0	0	0	0	0	0	0
	C7509 R24 WAA	0	0	0	0	0	0	0	0	1	5	12	21	15	21	13	7	3	1	0	0	0	0	0	0	0	0	0	0	1
	C7510 R24 WAA	0	0	0	0	0	0	0	0	1	5	12	22	15	22	12	7	2	1	0	0	0	0	0	0	0	0	0	0	1
9	C7412 063 WAA	0	0	0	0	0	0	0	0	1	5	11	22	17	21	11	7	2	1	0	0	0	0	0	0	0	1	0	0	0
	WN001 030 WAA	0	0	0	0	0	0	0	0	1	4	10	22	15	22	13	8	3	1	0	0	0	0	0	0	0	0	0	0	1
10	C7409 004 WAA	0	0	0	0	0	0	0	0	1	4	13	26	16	19	12	6	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7412 043 WAA	0	0	0	0	0	0	0	0	2	6	20	31	15	14	6	3	1	0	0	0	0	0	0	0	0	0	0	0	1
11	WN001 011 WAA	0	0	0	0	0	0	0	0	2	8	19	32	16	13	4	2	1	0	0	0	0	0	0	0	0	1	0	0	0
	WN002 012 WAA	0	0	0	0	0	0	0	0	2	6	14	24	14	18	10	8	2	1	0	0	0	0	0	0	0	0	0	0	1
12	C7412 036 WAA	0	0	0	0	0	0	0	0	1	4	13	24	16	20	10	7	2	1	0	0	0	0	0	0	0	1	0	0	0
	WN002 010 WAA	0	0	0	0	0	0	0	0	1	5	14	25	16	20	10	6	2	1	0	0	0	0	0	0	0	0	0	0	1
13	C7509 K20 WAA	0	0	0	0	0	0	0	0	2	6	15	27	16	19	7	4	1	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 015 WAA	0	0	0	0	0	0	0	1	2	5	13	24	16	20	9	6	2	0	0	0	0	0	0	0	0	0	0	0	1
14	C7509 R31 WAA	0	0	0	0	0	0	0	0	1	5	12	23	16	21	11	6	2	1	0	0	0	0	0	0	0	0	0	0	1
	C7510 R31 WAA	0	0	0	0	0	0	0	0	1	5	12	23	16	22	11	6	1	1	0	0	0	0	0	0	0	0	0	0	1
15	C7509 K27 WAA	0	0	0	0	0	0	0	0	1	4	10	20	16	23	12	9	3	1	0	0	0	0	0	0	0	0	0	0	0
	C7510 K27 WAA	0	0	0	0	0	0	0	0	1	5	12	24	16	23	11	5	2	1	0	0	0	0	0	0	0	0	0	0	1
	WN002 009 WAA	0	0	0	0	0	0	0	0	2	5	14	24	16	20	10	6	2	1	0	0	0	0	0	0	0	0	0	0	1
16	C7412 067 WAA	0	0	0	0	0	0	0	0	1	5	11	21	18	21	11	7	2	1	0	0	0	0	0	0	0	1	0	0	0
	C7509 K40 WAA	0	0	0	0	0	0	0	0	1	4	12	22	16	21	13	7	2	1	0	0	0	0	0	0	0	0	0	0	1
	C7510 K40 WAA	0	0	0	0	0	0	0	0	1	4	11	21	16	22	12	8	2	1	0	0	0	0	0	0	0	0	0	0	1
17	C7412 030 WAA	0	0	0	0	0	0	0	0	1	5	12	24	16	21	12	6	2	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 006 WAA	0	0	0	0	0	0	1	2	3	8	17	27	15	15	6	3	1	0	0	0	0	0	0	0	0	0	0	0	1
18	C7412 014 WAA	0	0	0	0	0	0	0	2	1	8	20	26	6	17	11	5	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7412 066 WAA	0	0	0	0	0	0	0	0	1	4	14	26	19	19	9	4	1	1	0	0	0	0	0	0	0	0	0	0	1

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
	WN001 016 WAA	0	0	0	0	0	0	0	0	1	4	11	24	16	22	12	6	2	1	0	0	0	0	0	0	0	0	0	0	1
	WN002 019 WAA	0	0	0	0	0	0	0	1	3	7	15	26	16	18	8	4	1	0	0	0	0	0	0	0	0	0	0	0	1
19	C7412 012 WAA	0	0	0	0	0	0	0	0	2	7	18	29	16	16	8	3	1	0	0	0	0	0	0	0	0	0	0	0	1
	WN001 039 WAA	0	0	0	0	0	0	0	1	2	6	17	29	16	17	7	3	0	1	0	0	0	0	0	0	0	0	0	0	1
20	WN001 040 WAA	0	0	0	0	0	0	0	1	3	7	17	30	16	15	5	3	0	1	0	0	0	0	0	0	0	0	0	0	1
	WN002 041 WAA	0	0	0	0	0	0	0	1	3	7	16	27	16	18	6	3	1	0	0	0	0	0	0	0	0	0	0	0	1
21	C7412 056 WAA	0	0	0	0	0	0	0	1	3	6	17	27	18	17	6	3	1	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 040 WAA	0	0	0	0	0	0	1	2	4	8	15	24	15	17	8	4	1	0	0	0	0	0	0	0	0	0	0	0	1
22	C7412 050 WAA	0	0	0	0	0	0	1	2	4	8	17	29	15	14	5	2	1	0	0	0	0	0	0	0	0	1	0	0	0
	WN001 042 WAA	0	0	0	0	0	0	1	2	7	12	21	27	12	11	4	2	0	0	0	0	0	0	0	0	0	1	0	0	0
	WN002 042 WAA	0	0	0	0	0	0	1	2	4	8	16	27	15	16	6	3	1	0	0	0	0	0	0	0	0	0	0	0	1
23	C7409 021 WAA	0	0	0	0	0	0	0	0	1	5	17	33	22	13	4	2	0	0	0	0	0	0	0	0	0	0	0	0	1
	C4128 112 WAA	0	0	0	0	0	0	0	0	2	6	16	31	18	17	6	2	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7501 491 WAA	0	0	0	0	0	0	0	1	4	9	17	29	16	14	5	2	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7504 018 WAA	0	0	0	0	0	0	0	1	4	10	18	24	13	12	4	2	1	4	2	1	1	0	0	0	0	0	0	0	1
	C7506 018 WAA	0	0	0	0	0	0	0	1	3	8	17	27	16	15	6	2	1	3	0	0	0	0	0	0	0	0	0	0	1
	C7509 R18 WAA	0	0	0	0	0	0	0	1	3	7	15	24	14	14	5	3	1	3	1	1	1	1	1	1	0	1	1	0	2
	C7510 R18 WAA	0	0	0	0	0	0	0	1	3	7	14	27	17	17	7	3	1	2	0	0	0	0	0	0	0	0	0	0	1
24	C7409 081 WAA	0	0	0	0	0	0	0	0	2	6	16	25	13	9	3	1	1	2	3	2	2	2	2	1	1	2	2	1	4
	*C7409 081 WBA	0	0	0	0	0	0	0	0	2	5	14	24	12	8	2	1	1	4	2	2	2	2	2	2	1	2	2	2	6
	C4128 166 WAA	0	0	0	0	0	0	0	1	2	7	16	27	13	9	2	1	1	1	2	2	2	2	1	1	1	2	2	2	4
25	C4128 172 WAA	0	0	0	0	0	0	0	0	1	6	17	29	12	8	2	2	1	4	2	1	2	1	1	1	1	2	2	2	4
	C7504 009 WAA	0	0	0	0	0	0	0	0	2	7	20	30	12	8	2	1	1	3	1	1	1	1	1	1	1	1	1	1	3
	C7506 009 WAA	0	0	0	0	0	0	0	0	1	7	18	28	12	8	2	2	1	3	1	1	2	1	1	1	1	2	1	2	4
	C7509 R09 WAA	0	0	0	0	0	0	0	0	1	7	19	30	12	7	2	1	1	2	1	2	1	1	1	1	1	2	2	2	3
26	C7409 100 WAA	0	0	0	0	0	0	1	3	9	14	19	25	11	9	3	1	0	1	0	0	0	0	0	0	0	0	0	0	1
	C4128 220 WAA	0	0	0	0	0	0	1	4	8	12	19	26	14	10	3	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7504 015 WAA	0	0	0	0	0	0	2	6	13	16	14	13	6	5	2	2	1	6	6	3	2	0	0	0	0	0	0	0	2
	C7506 015 WAA	0	0	0	0	0	1	2	2	3	5	5	6	3	4	3	2	2	23	12	7	4	3	2	2	1	2	1	1	5

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
	C7509 R15 WAA	0	0	0	0	0	0	1	3	9	14	15	14	7	7	3	2	1	8	4	2	1	1	1	1	1	1	1	1	3
27	C7409 026 WAA	0	0	0	0	0	0	2	7	21	23	21	14	5	2	1	1	0	1	1	0	0	0	0	0	0	0	0	0	1
	*C4128 196 WAA	0	0	0	0	0	0	2	9	25	28	20	10	3	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	C4128 208 WAA	0	0	0	0	0	0	2	6	17	23	23	17	6	4	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7504 014 WAA	0	0	0	0	0	0	1	3	7	11	12	16	12	17	8	5	2	4	1	0	0	0	0	0	0	0	0	0	1
	C7506 014 WAA	0	0	0	0	0	1	3	11	23	23	16	8	3	3	1	1	1	3	1	0	0	0	0	0	0	0	0	0	1
	C7509 R14 WAA	0	0	0	0	0	0	1	5	13	16	12	7	3	5	3	3	2	8	3	3	2	2	2	2	1	2	1	1	4
28	C7412 051 WAA	0	0	0	1	1	2	5	11	20	21	17	13	4	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7501 497 WAA	0	0	0	0	0	1	3	9	19	23	20	14	5	4	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7504 020 WAA	0	0	0	0	0	0	2	5	12	16	18	19	9	10	4	2	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 020 WAA	0	0	0	0	0	0	1	3	9	14	18	22	12	11	3	2	1	4	0	0	0	0	0	0	0	0	0	0	1
	WN001 043 WAA	0	0	0	0	0	0	2	6	14	17	18	19	10	9	3	1	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7509 R20 WAA	0	0	0	0	1	2	4	9	17	20	19	14	5	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 R20 WAA	0	0	0	0	0	0	1	2	7	12	18	24	13	14	5	2	1	0	0	0	0	0	0	0	0	0	0	0	1
29	C7411 040 WAA	0	0	0	0	0	0	2	7	20	21	20	11	4	3	1	1	1	3	1	1	0	0	0	0	0	0	0	0	2
	WN002 070 WAA	0	0	0	0	0	1	4	12	25	27	18	8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
30	C7411 058 WAA	0	0	0	0	1	1	1	2	3	2	2	4	5	11	11	9	7	22	4	3	2	1	1	1	1	1	1	1	3
	C4128 226 WAA	0	0	0	0	0	1	3	9	21	25	19	11	4	3	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
	WN001 059 WAA	0	0	0	0	0	0	1	3	7	9	7	6	2	3	2	2	1	6	12	6	5	4	4	3	2	2	2	1	7
31	C7411 062 WAA	0	0	0	0	0	0	2	9	26	23	15	8	3	4	2	1	1	2	0	0	0	0	0	0	0	0	0	0	1
	C4128 232 WAA	0	0	0	0	0	1	4	12	24	26	19	8	2	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
32	C7409 112 WAA	0	0	0	0	0	1	3	9	21	22	15	7	2	3	2	2	1	8	0	1	1	0	0	0	0	0	0	0	1
	C7409 112 WBA	0	0	0	0	1	1	5	13	22	19	11	5	1	2	1	1	1	7	2	2	1	1	0	1	0	1	0	0	1
	C7411 023 WAA	0	0	0	0	0	0	1	2	6	5	3	3	3	8	7	6	3	27	8	4	2	1	1	1	0	1	1	1	4
	C4128 238 WAA	0	0	0	0	0	0	2	9	24	28	19	10	3	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
33	C4128 148 WAA	0	0	0	0	0	0	0	2	6	14	19	20	13	15	5	3	1	1	0	0	0	0	0	0	0	1	0	0	0
	C4128 262 WAA	0	0	0	0	0	0	1	3	8	14	16	18	13	15	6	3	1	1	0	0	0	0	0	0	0	1	0	0	0
	C7504 025 WAA	0	0	0	0	0	0	2	11	25	25	14	7	3	4	2	2	1	2	0	0	0	0	0	0	0	0	0	0	1
	C7506 025 WAA	0	0	0	0	0	0	0	1	3	4	4	6	6	16	13	12	7	17	2	1	1	1	1	0	1	1	0	0	2
	C7509 R25 WAA	0	0	0	0	0	0	0	1	2	3	4	8	9	17	8	6	3	15	5	4	2	2	1	1	1	1	1	1	3

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
34	C7411 005 WAA	0	0	0	0	0	0	1	2	5	7	9	14	17	18	14	6	2	3	0	1	0	0	0	0	0	0	0	0	1
	C7504 013 WAA	0	0	0	0	0	0	1	4	9	10	8	10	8	16	9	7	4	11	1	0	0	0	0	0	0	0	0	0	1
	C7506 013 WAA	0	0	0	0	0	0	0	0	0	1	1	1	1	2	3	2	2	25	11	9	7	6	6	4	3	5	1	2	8
	C7506 013 WBA	0	0	0	0	0	0	1	2	4	5	5	8	6	11	6	5	3	23	6	3	3	2	1	1	1	1	1	1	3
	C7509 R13 WAA	0	0	0	0	0	0	0	0	0	1	1	5	8	21	12	9	4	15	5	3	2	2	1	2	1	2	2	1	4
	WN002 076 WAA	0	0	0	0	0	0	1	5	11	14	14	16	11	15	7	4	2	1	0	0	0	0	0	0	0	0	0	0	1
35	C7411 022 WAA	0	0	0	0	0	0	1	2	6	6	8	9	11	20	14	8	4	7	0	0	0	0	0	0	0	0	0	0	1
	WN001 051 WAA	0	0	1	0	0	0	0	0	0	0	0	1	1	2	2	2	2	27	14	7	6	6	5	4	3	3	3	2	9
36	C7411 069 WAA	0	0	0	0	0	1	4	11	24	19	12	7	4	5	3	2	1	4	0	0	0	0	0	0	0	0	0	0	1
	WN002 079 WAA	0	0	0	0	0	0	2	10	23	28	21	10	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
37	C7411 055 WAA	0	0	0	0	1	1	4	9	18	16	13	10	7	8	5	3	1	3	0	0	0	0	0	0	0	0	0	0	1
	WN002 080 WAA	0	0	0	0	0	1	3	11	24	28	20	8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
38	C7411 048 WAA	0	0	0	0	0	1	3	8	21	20	19	12	5	5	2	1	0	1	0	0	0	0	0	0	0	0	0	0	1
	WN002 081 WAA	0	0	0	0	0	1	4	13	24	28	19	8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
39	C7411 083 WAA	0	0	0	0	0	0	1	4	13	15	17	14	6	7	5	4	3	7	1	0	0	0	0	0	0	0	0	0	1
	WN001 048 WAA	0	0	0	0	0	0	1	4	11	16	16	12	4	4	2	2	1	7	4	2	2	1	1	1	1	1	1	1	3
40	C7409 135 WAA	0	0	0	0	0	0	2	5	10	13	13	10	4	5	3	3	3	9	3	2	2	2	1	1	1	2	2	1	3
	C7411 067 WAA	0	0	0	0	0	1	2	7	20	21	20	15	5	4	2	1	0	1	0	0	0	0	0	0	0	1	0	0	0
	WN002 065 WAA	0	0	0	0	0	0	1	6	16	27	27	15	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
41	C7411 032 WAA	0	0	0	0	0	0	1	4	13	16	47	9	3	2	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
	WN002 064 WAA	0	0	0	0	0	0	2	7	19	29	24	12	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
42	C7411 009 WAA	0	0	0	0	0	0	1	4	10	9	5	3	1	1	1	1	1	20	11	6	4	3	2	3	2	2	2	1	5
	C7411 009 W3A	0	0	0	0	0	1	2	7	14	13	13	12	10	13	7	3	1	2	0	0	0	0	0	0	0	0	0	0	1
	C4128 154 WAA	0	0	0	0	1	1	5	15	26	23	14	7	2	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	C4128 280 WAA	0	0	0	0	0	0	2	5	14	23	24	16	6	5	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7504 026 WAA	0	0	0	0	0	0	1	4	12	19	17	14	5	6	2	2	1	3	1	2	1	2	1	0	1	1	1	0	2
	C7506 026 WAA	0	0	0	0	0	0	1	5	9	11	7	4	2	4	3	3	2	15	6	4	3	3	3	2	2	2	1	2	4
	C7509 R26 WAA	0	0	0	0	0	0	0	0	0	1	1	3	5	14	10	9	5	25	6	4	2	2	1	2	2	2	1	1	5

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
43	C7411 018 WAA	0	0	0	0	1	2	7	14	27	19	12	6	3	3	2	1	0	1	0	0	0	0	0	0	0	0	0	0	1
	WN002 088 WAA	0	0	0	0	0	0	1	4	14	25	26	16	6	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
44	C7411 036 WAA	0	0	0	0	0	0	0	0	1	1	2	6	9	17	15	10	6	17	3	2	1	1	2	1	0	1	1	1	3
	C7411 036 WBA	0	0	0	0	0	0	1	1	2	3	5	12	15	23	14	8	4	9	1	0	0	0	0	0	0	0	0	0	2
	WN002 087 WAA	0	0	0	0	0	0	1	4	11	20	26	20	7	6	2	1	0	1	0	0	0	0	0	0	0	0	0	0	2
45	C7411 064 WAA	0	0	0	0	0	0	0	1	3	4	5	4	4	7	7	6	5	26	6	4	2	2	2	2	1	2	2	1	5
	C7411 073 WAA	0	0	0	0	0	0	1	2	4	4	3	4	4	9	8	6	5	22	5	3	2	2	2	2	1	2	2	2	4
	C7508 W64 WAA	0	0	0	0	0	0	0	1	3	4	4	3	2	4	4	5	5	32	11	6	2	2	1	0	1	2	2	1	4
	WN002 086 WAA	0	0	0	0	0	0	1	5	13	22	25	19	6	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
46	C7411 075 WAA	0	0	0	0	0	0	1	2	7	9	11	9	4	4	3	2	2	15	5	4	3	3	2	2	2	2	2	1	4
	C7508 W75 WAA	0	0	0	0	0	0	1	3	7	11	12	11	4	6	3	3	2	13	6	4	3	1	1	1	0	2	1	1	5
47	C7409 090 WAA	0	0	0	0	0	0	1	1	2	3	5	13	12	11	3	2	1	10	3	3	4	3	3	3	2	4	3	2	6
	C7411 087 WAA	0	0	0	0	0	0	1	3	8	9	11	15	11	10	4	3	2	11	3	1	1	1	0	0	0	0	1	1	2
48	C7411 076 WAA	0	0	0	0	0	0	0	1	1	2	2	3	3	5	5	5	6	20	12	9	6	3	2	2	2	3	1	1	5
	C7508 W76 WAA	0	0	1	0	0	0	0	0	0	1	1	1	1	3	2	2	2	17	9	7	6	6	5	4	4	6	5	4	11
49	C7411 037 WAA	0	0	0	0	0	0	0	0	1	1	1	2	3	6	5	4	4	31	10	6	4	3	2	3	2	2	2	1	6
	C7411 037 WBA	0	0	0	0	0	0	0	1	1	2	3	7	9	23	15	11	5	17	1	1	0	0	0	0	0	0	0	0	2
	C7508 W37 WAA	0	0	0	0	0	0	0	0	0	1	0	1	1	3	3	3	3	26	13	9	5	4	3	3	3	5	4	3	8
50	C7411 086 WAA	0	0	0	0	0	0	0	0	0	0	0	1	1	3	5	5	4	42	13	7	3	2	2	1	1	1	2	1	4
	C4128 310 WAA	0	0	0	0	0	0	1	2	4	6	6	10	8	11	6	6	4	18	7	3	2	1	0	1	1	1	1	0	3
	C7504 016 WAA	0	0	0	0	0	0	1	3	7	10	9	10	5	8	5	5	3	19	5	3	2	1	1	0	0	1	1	0	2
	C7506 016 WAA	0	0	0	0	0	0	0	1	1	1	1	2	1	3	2	3	2	11	11	11	7	8	7	5	4	5	5	1	9
	C7508 W86 WAA	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	2	28	12	7	5	4	4	3	2	5	4	3	8
	C7509 R16 WAA	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	1	8	11	16	15	10	8	1	1	3	3	6	6
	WN002 057 WAA	0	0	2	0	0	0	1	1	2	4	4	5	3	4	2	2	1	18	7	7	6	6	5	3	2	3	3	1	7
51	C7411 015 WAA	0	0	0	0	1	0	1	1	1	1	2	6	8	16	11	8	5	24	4	2	1	1	1	0	0	1	1	0	3
	*C7411 015 WBA	0	0	0	0	0	0	0	0	1	1	3	9	14	26	17	9	4	10	1	0	0	0	0	0	0	0	0	0	2
	C4128 316 WAA	0	0	0	0	0	0	1	2	6	10	12	16	11	15	8	6	4	8	1	0	0	0	0	0	0	0	0	0	1

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
	C4128 316 WBA	0	0	0	0	0	0	0	0	1	1	1	2	2	4	4	4	2	25	13	7	5	4	3	3	3	3	3	2	7
	C7504 022 WAA	0	0	0	0	0	0	1	3	6	10	11	14	10	16	7	5	3	9	1	0	0	0	0	0	0	0	0	0	1
	C7506 022 WAA	0	0	0	0	0	0	0	0	0	1	1	2	2	5	4	5	3	21	10	9	5	5	3	4	2	4	4	2	8
	C7506 022 WBA	0	0	0	0	0	0	0	1	3	6	7	10	8	16	11	10	6	12	2	1	1	1	0	0	0	1	0	0	2
	C7508 W15 WAA	0	0	0	0	0	0	0	0	1	1	1	2	3	9	9	11	7	28	7	4	2	2	1	1	1	2	1	2	4
	C7509 R22 WAA	0	0	1	0	0	0	0	0	0	1	1	2	3	10	8	42	4	15	3	2	1	1	1	0	0	1	1	0	2
	WN002 093 WAA	0	0	0	0	0	0	1	2	6	9	10	13	14	23	10	6	2	3	0	0	0	0	0	0	0	0	0	0	1
52	C4128 322 WAA	0	0	0	0	0	0	1	2	5	7	9	13	14	23	11	7	2	4	0	0	0	0	0	0	0	0	0	0	1
	WN002 060 WAA	0	0	0	0	0	1	3	9	20	24	18	11	5	5	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1
53	C7409 089 WAA	0	0	0	0	0	0	0	0	1	1	1	4	5	10	8	8	6	24	12	3	2	2	2	1	1	1	2	1	3
	C7409 089 WBA	0	0	0	0	0	0	0	0	0	1	1	6	7	16	11	10	6	22	4	2	2	1	1	1	0	1	1	1	3
	C7411 001 WAA	0	0	0	0	0	0	0	1	3	4	6	11	13	19	12	9	5	12	1	1	0	0	0	0	0	0	0	0	1
	WN002 097 WAA	0	0	0	0	0	0	1	2	5	8	9	14	16	24	10	6	2	2	0	0	0	0	0	0	0	0	0	0	1
54	C7409 085 WAA	0	0	0	0	0	0	0	1	2	3	4	7	6	8	4	3	2	12	8	5	6	4	3	2	2	3	3	3	7
	C7411 085 WAA	0	0	0	0	0	0	0	0	1	1	1	3	4	9	9	8	7	34	10	4	2	1	1	1	0	1	1	1	3
	C7508 W85 WAA	0	0	0	0	0	0	0	0	0	0	0	1	1	7	3	2	3	38	13	9	4	3	1	1	0	3	2	2	5
55	C7501 533 WAA	0	0	0	0	0	0	0	0	1	2	4	11	15	25	13	9	5	11	1	0	0	0	0	0	0	0	0	0	1
	C7504 017 WAA	0	0	0	0	0	0	0	0	1	1	3	8	11	22	12	10	5	19	3	2	0	0	0	0	0	0	0	0	2
	C7506 017 WAA	0	0	0	0	0	0	0	0	0	0	5	5	5	19	11	13	9	9	1	0	0	0	0	0	0	1	0	0	21
	C7509 R17 WAA	0	0	0	0	0	0	0	0	0	0	1	1	1	4	4	6	4	32	12	7	5	3	2	2	2	2	3	2	6
56	C4128 388 WAA	0	0	0	0	0	0	0	0	1	2	3	10	13	28	15	11	6	8	1	0	0	0	0	0	0	0	0	0	1
	C7501 539 WAA	0	0	0	0	0	0	0	1	3	4	7	15	13	25	14	10	4	3	0	0	0	0	0	0	0	1	0	0	0
	WN002 053 WAA	0	0	0	0	0	0	1	1	3	5	6	15	18	27	12	6	2	2	0	0	0	0	0	0	0	0	0	0	1
57	C7501 467 WAA	0	0	0	0	0	0	1	3	8	13	18	23	14	12	4	2	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7504 012 WAA	0	0	0	0	0	0	1	3	8	13	16	20	13	14	6	3	1	1	0	0	0	0	0	0	0	0	0	0	1
	C7509 R12 WAA	0	0	0	0	0	0	1	2	5	9	12	16	13	22	9	5	1	2	0	0	0	0	0	0	0	0	0	0	1
58	C7409 086 WAA	0	0	0	0	0	0	0	0	1	4	11	20	12	10	3	1	1	14	5	3	2	2	1	1	1	1	1	1	3
	C4128 334 WAA	0	0	0	0	0	0	0	1	2	5	8	17	17	25	12	7	2	1	0	0	0	0	0	0	0	1	0	0	0
	C7501 551 WAA	0	0	0	0	0	0	1	4	11	17	20	19	10	10	4	2	1	0	0	0	0	0	0	0	0	1	0	0	0
59	C7409 088 WAA	0	0	0	0	0	0	0	1	2	4	6	15	14	17	8	4	2	10	2	2	2	2	1	1	1	1	1	1	2

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
	C7501 557 WAA	0	0	0	0	0	0	1	2	7	11	15	19	14	17	7	3	1	1	0	0	0	0	0	0	0	0	0	0	1
60	C7501 443 WAA	0	0	0	0	0	0	0	1	3	8	18	35	17	11	2	1	0	1	0	0	0	0	0	0	0	0	0	0	1
	C7504 021 WAA	0	0	1	0	1	1	2	5	9	11	14	17	10	14	8	5	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7504 021 WBA	0	0	0	0	0	0	1	4	12	19	25	24	9	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 021 WAA	0	0	0	0	0	0	0	1	7	18	27	20	6	3	1	0	0	3	2	2	1	2	1	1	1	1	1	1	2
	C7509 R21 WAA	0	0	1	1	2	2	7	15	23	21	13	7	1	1	0	0	0	1	1	1	0	1	1	0	0	1	0	0	1
61	C7409 087 WAA	0	0	0	0	0	0	0	1	2	4	9	23	21	23	7	2	1	2	0	0	1	0	0	0	0	0	0	0	1
	* C7501 461 WAA	0	0	0	0	0	0	0	1	4	7	12	31	21	14	4	2	1	1	0	0	0	0	0	0	0	1	0	0	0
	C7504 011 WAA	0	0	0	0	0	0	0	1	5	10	15	25	18	17	4	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 011 WAA	0	0	0	0	0	0	1	2	4	8	13	24	20	17	4	2	1	3	0	0	0	0	0	0	0	0	0	0	1
	C7509 R11 WAA	0	0	0	0	0	0	0	1	4	8	15	30	20	15	3	1	0	0	0	0	0	0	0	0	0	0	0	0	1
62	C7409 067 WAA	0	0	0	0	0	0	0	1	2	4	4	5	4	7	6	5	5	20	8	7	2	2	2	2	2	3	2	2	4
	C7501 563 WAA	0	0	0	0	0	0	1	2	5	9	12	19	17	20	9	4	1	1	0	0	0	0	0	0	0	0	0	0	1
63	C7409 065 WAA	0	0	0	0	0	0	0	0	1	1	2	5	5	8	8	8	7	37	6	2	1	1	1	1	0	1	1	1	0
	C7501 575 WAA	0	0	0	0	0	0	1	2	5	10	17	22	12	14	7	5	2	1	0	0	0	0	0	0	0	1	0	0	0
64	C7501 623 WAA	0	0	0	0	0	0	0	0	0	0	1	4	7	25	20	13	6	16	3	1	0	0	0	0	0	0	0	0	1
	C7504 006 WAA	0	0	0	0	0	0	0	0	0	0	1	4	7	26	21	15	6	14	2	1	0	0	0	0	0	0	0	0	1
	C7506 006 WAA	0	0	0	0	0	0	0	0	0	0	1	4	7	25	20	13	6	15	2	1	0	1	0	0	0	1	0	0	2
	C7509 R06 WAA	0	0	0	0	0	0	0	0	0	0	1	4	8	24	19	15	5	14	2	1	0	1	0	0	0	0	1	1	1
65	C7501 629 WAA	0	0	0	0	0	0	0	0	1	3	6	12	7	7	4	3	2	9	6	6	4	5	3	3	3	4	4	3	7
	* C7501 629 WBA	0	0	0	0	0	0	0	0	2	5	12	22	13	13	5	3	2	6	3	2	2	1	1	1	1	1	1	1	3
	C7504 007 WAA	0	0	0	0	0	0	0	0	1	3	6	12	10	15	7	5	3	11	4	5	3	3	2	2	1	2	2	2	4
	C7506 007 WAA	0	0	0	0	0	0	0	0	1	2	5	12	11	17	7	5	2	8	3	3	3	3	2	2	2	2	1	2	5
	C7509 R07 WAA	0	0	0	0	0	0	0	0	1	2	5	11	10	14	7	5	3	11	5	4	3	3	2	2	2	2	2	2	5
66	C7501 635 WAA	0	0	0	0	1	0	1	1	1	5	15	26	9	7	3	2	1	5	3	2	2	2	1	2	1	2	2	1	3
	C7504 008 WAA	0	0	0	0	0	0	0	0	1	5	15	26	11	8	2	2	1	4	2	2	2	2	1	2	1	2	2	2	5
	C7506 008 WAA	0	0	0	0	0	0	0	0	1	5	14	24	11	8	3	2	1	8	1	2	2	2	2	2	1	3	2	2	5
	C7509 R08 WAA	0	0	0	0	0	0	0	0	1	5	16	25	10	8	2	2	1	4	3	2	2	2	2	2	2	3	2	2	5
67	C7501 653 WAA	0	0	0	0	0	0	0	1	1	3	7	12	9	14	8	6	4	11	4	3	2	2	1	1	1	2	2	1	4
	C7508 S20 WAA	0	0	0	0	0	0	0	0	0	1	1	3	5	19	16	12	6	12	3	3	2	2	1	1	1	2	2	1	4

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
68	C7501 647 WAA	0	0	0	0	0	0	0	0	0	0	0	3	4	10	8	7	6	52	4	1	1	0	0	0	0	0	0	0	2
	C7508 S18 WAA	0	0	0	0	0	0	0	0	0	0	1	4	7	17	14	14	8	24	2	1	1	1	0	0	0	1	1	0	2
69	C7409 144 WAA	0	0	0	0	0	0	0	0	0	1	2	9	11	22	17	13	8	12	1	0	0	0	0	0	0	0	0	0	1
	C7501 641 WAA	0	0	0	0	0	0	0	0	0	0	1	4	6	14	15	16	15	26	1	0	0	0	0	0	0	0	0	0	1
	C7504 023 WAA	0	0	0	0	0	0	0	0	0	1	2	8	9	21	16	15	8	16	1	0	0	0	0	0	0	0	0	0	1
	C7506 023 WAA	0	0	0	0	0	0	0	0	0	0	1	8	9	22	17	17	8	14	0	0	0	0	0	0	0	0	0	0	1
	C7509 R23 WAA	0	0	0	0	0	0	0	0	0	0	2	7	8	18	14	14	9	16	2	1	1	1	1	0	0	1	1	0	2
70	C7409 147 WAA	0	0	0	0	0	0	0	0	0	0	2	9	13	25	15	14	7	12	0	0	0	0	0	0	0	0	0	0	1
	C7501 683 WAA	0	0	0	0	0	0	0	0	0	0	2	14	15	26	14	10	7	10	0	0	0	0	0	0	0	0	0	0	1

supposedly at the same location which showed quite dissimilar textural distributions. There were a number of statistical tests that could have been made to determine the significance of the noted differences, but time constraints prevented such tests being made.

141. Stations 26, 27, and 28 lay along the southern boundary of the dynamic area. Station 28 was within the bounds of Disposal Site A, which has been used quite heavily in the past. The texture at this station became finer between winter and summer 1975. Seaward at Station 26 in 135 ft of water, the same general trend was noted, but the grain sizes involved were finer and included increased silt in the summer. Station 27 in about 100 ft of water was not texturally intermediate between Stations 26 and 28, but was more similar to stations to the north; the latter are located within, and discussed with, the historical Site B disposal area.

142. Northward the areal and temporal coverage was not complete enough to provide more than a general picture. The area off the Columbia River entrance encompassing Stations 27 and 29 to 63 had only Stations 33, 34, 42, 50, 51, 55, 60, and 61 with coverage from 4 or more different months.

143. During September 1974, the textural distribution through this region indicated the presence of various amounts of silt mixed with what was considered to be the ambient coarser grained modal sizes (Factors 1, 3, and 4). The silt was not present at Station 61, but seaward at Stations 62 and 63 the modal size was within the silt fraction. Along the line of Stations 59, 58, 53, 54, and 47, the silt and clay fractions increased offshore along the northern boundary of

Factor 1 (2.0ϕ mode), in the area of coarser sediment at Site B. In the northern portion of Disposal Site B, at Stations 36 and 32, the silt fraction was quite noticeable although the modal sizes were 2.0 to 2.5ϕ. The silt was not spread as far as at Station 27.

144. The November 1974 cruise provided the most complete picture for the area of Disposal Site B. The central area of Factor 1 sediment concentration at Site B (Stations 43, 40, 41, 36, 37, 38, and 31) was significantly coarser than in September as seen at Station 40. The surrounding stations showed finer textures through the addition of silt, and silt and clay in an offshore direction. This change in size was evident at Stations 32, 47, 54, and 53. At nearby Stations 44, 49, and 51, where the grab sampler recovered a stratified sample, the lower sample verified a deposition of silty Factor 6 sediment over very fine sandy Factor 4 sediment.

145. By December and January there was a general coarsening of sediment texture throughout the area between the river mouth and Site B comparing the available combinations of December 1974 and January 1975 samples with those of November and September 1974. This was seen at Stations 27, 30 to 33, 42, 50 to 61, and 63. In every case the coarsening was accompanied by a significant reduction of the silt and clay content (e.g., Stations 50 and 51) or almost complete removal of the fine fraction (e.g., Stations 30, 32, 42, and 56). Nearer the river entrance (e.g., Station 58), the sediment coarsened from Factor 4 to Factor 3 or 2 sediment (3.25 to 2.75 or 2.50ϕ). At Station 51 the lower stratum sampled by the grab sampler in December had more silt and clay than the surface sediment in conformity with

the above observation.

146. The April 1975 coverage was sparse, and, excepting Stations 27 and 42, did not include samples from stations within the Factor 1 coarse Site B zone. All stations (27, 33, 34, 42, 50, 51, 55, 57, 60, and 61) sampled exhibited similar textural changes becoming more poorly sorted by the addition of coarser sediment at Station 50; finer sediment at Stations 27, 34, 42, and 57; and at the other stations by the addition of coarser and finer sediment fractions to that prevalent during December and January. At the farthest offshore stations (50 and 55), silt remained a major component or became an important component on a seasonal basis.

147. Near the river entrance in June 1975 (Station 60), the texture of the bottom sediment changed from bimodal Factor 4 and 3 sediment (3.25 and 2.75ϕ) to Factor 2 sediment (2.5ϕ) with over 16 percent silt and clay. Offshore at Station 61 similar changes were not seen, although the silt and clay content increased fivefold to 5 percent over the previous April. Between the river entrance and Site B, the changes were quite dramatic. At Station 27, the bottom sediment coarsened to Factor 1 (2.0ϕ) sediment similar to Station 60. Stations 34, 42, 50, and 51 were much finer, being predominantly silt and clay. The stratified sample collected at Station 51 showed this marked upward textural change. At Stations 30, 33, 39, and 42, silt and clay, although not dominant, amounted to 20 percent at Stations 33 and 39 and over 40 percent at Stations 30 and 42. Station 55 to the north contained 30 percent silt and clay with 20 percent finer than 11ϕ. Generally, the grain sizes decreased offshore and northward.

148. June to August 1975 changes could only be seen at Stations 50 and 51. At Station 50 there was a distinct increase in coarse silt (4.5ϕ) at the expense of the finer silts and at Station 51 the coarse silt (4.5ϕ) and very fine sand (3.25 to 3.75ϕ) increased relative to the finer silts and clays. Stations 35, 45, 48, 49, and 54 also exhibited the marked 4.5ϕ mode.

149. In September 1975, Stations 33, 34, 51, 57, 60, and 61 showed variable amounts of coarsening of texture with a general decrease in silt and clay content. Offshore at Stations 27, 42, and 50, the grain size decreased by the addition of coarse silt (4.5ϕ) at Station 27, coarse silt (4.5ϕ) and very fine sand (3.25ϕ) at Station 42, and finer silt (5.0 to 7.0ϕ) at Station 50. At Stations 54 and 55, the sediment was predominantly Factor 6 sediment (4.5ϕ) and between June and August or September a significant decrease in clay (12ϕ) and very fine sand (3.25ϕ) fractions occurred. As in June, the grain sizes generally decreased offshore and northward.

150. The December 1975 cruise collected repeat samples only from Stations 34, 45, 50, and 51, all of which exhibited coarsening of the bottom sediment texture and a great reduction or almost complete disappearance of the silt and clay fractions.

151. Comparison of the December 1974 and 1975 samples generally showed similarity of textures and distribution with a tendency for the 1975 samples to be coarser (Stations 51, 52, and 56).

152. The northern stations for which there were seasonal data were 64 to 70. With the exception of two samples at different stations (C7501-641 at Station 69 and C7501-647 at Station 68), there was very little seasonal change detected. On first inspection, the tendency was

to reject those two samples because the other winter samples from the general area did not contain such high concentrations of Factor 6 (4.5ø) sediments. If the two samples were initially rejected, no change would be seen between September 1974 and January 1975 at Station 70. No appreciable change can be detected in the four samples collected at Station 64 between January and September 1975. Stations 65, 66, and 67 contained appreciably more silt than the shoreward stations. Station 66 lay within the offshore Factor 3 (2.75ø) sediment zone, and Stations 65 and 67 were along the boundary between Factor 4 (3.25ø) and 3 (2.75ø) sediments. Station 65 exhibited a slight coarsening in texture from January to April, but then changed little in the June and September samples. Station 67, with only two samples, showed a decrease in grain size between January and August. A special group of samples, collected in August to investigate the apparent problem at Stations 68 and 69 and also to fill gaps in previous sampling patterns, produced interesting results. The series of samples S06 to S11 (Plates A1 and A2), collected on Cruise C7508 along the steep north slope of the outer tidal delta, showed the deeper samples (S07, S09, and S11) to have northward decreasing concentrations of the 4.5ø size class of 28, 21, and 16 percent, respectively. A September 1974 sample (C7409-46) just to the north contained 16 percent of the 4.5ø size class. Samples S06, S08, and S10 immediately east of the above contained 9, 7, and 5 percent, respectively, of the 4.5ø size class. Station 68 included an August sample with 24 percent of the 4.5ø size class. Obviously there was a seasonal variation in texture in the northern area, but the details were not apparent because of the lack of good seasonal coverage. August 1975 samples contained more 4.5ø size fraction than nearby September 1975 samples, which in turn contained more than nearby September 1974 samples. It appeared that the major change occurred during August when the texture of the sediments at most locations became finer by the addition of coarse silts. None of this discussion permits acceptance or rejection of the validity of the uniquely large concentrations of 4.5ø size fractions in January 1975 samples from Stations 68 and 69.

Site G textural distribution

153. Predisposal bottom sample locations are shown in Figure A92, September postdisposal samples in Figure A93a, October samples in Figure A93b, and December samples in Figure A93c. Factor loadings for Factors 5 (3.75ø mode), 6 (4.5ø mode), and 7 (12ø mode) sediment collected within experimental Site G never exceeded 0.4 and therefore are not discussed in this section. Although efforts were made to obtain repeat samples from a number of stations each month after disposal, such attempts were generally unsuccessful due to weather and sea conditions.

154. Figures A94 to A101c show the temporal changes in the distribution of Factor 1 sediment (1.75, 2.0, or 2.25ø mode), Factor 2 sediment (2.5ø mode), Factor 3 sediment (2.75 or 3.0ø mode), and Factor 4 sediment (3.25ø mode), respectively. The effect of the disposal experiment on the sediment texture at Site G was quite obvious from comparisons of the predisposal and postdisposal contours of the four

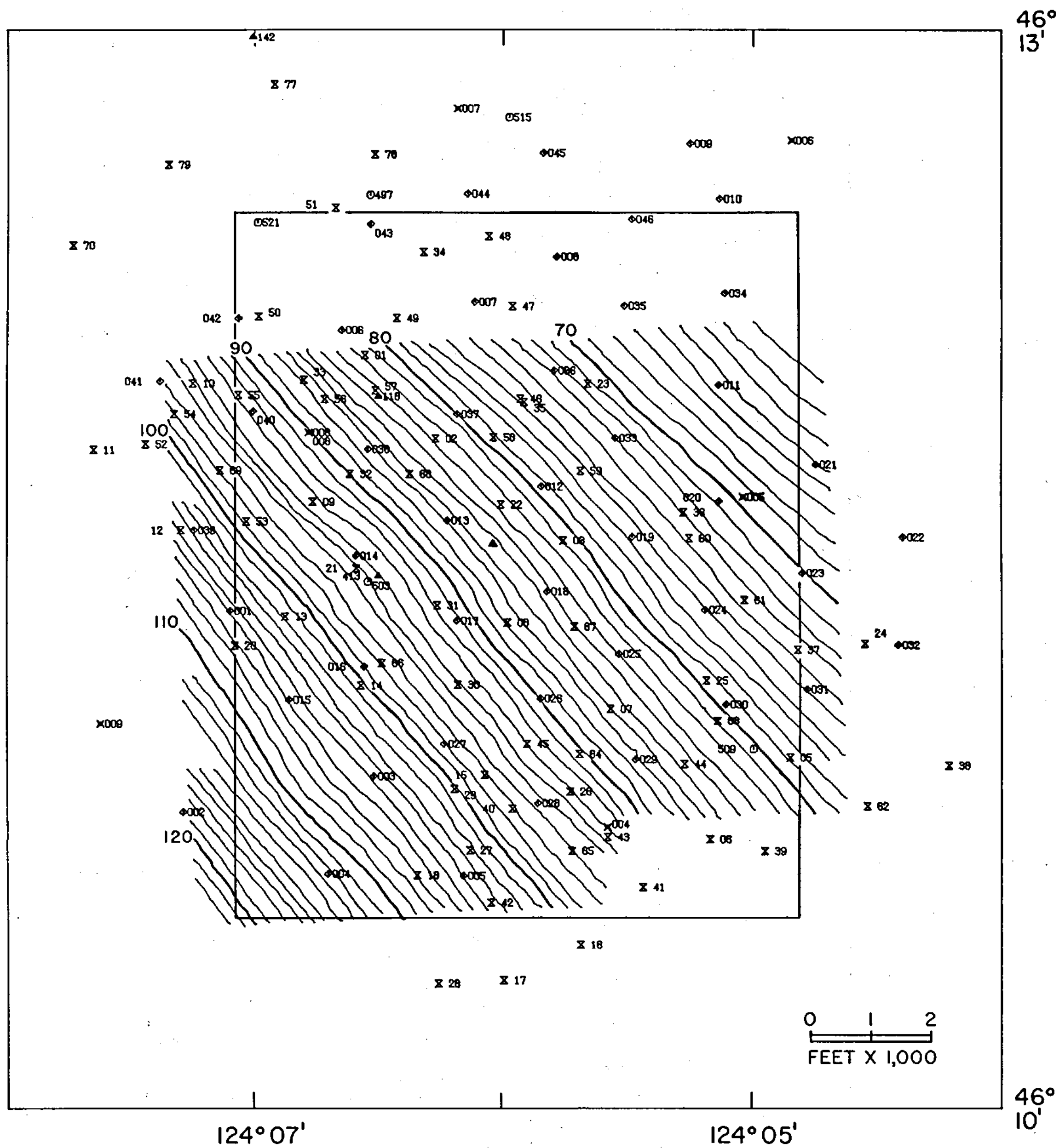

Figure A92. Predisposal bathymetry and location of bottom samples collected from experimental Site G before the controlled disposal. Contours are in feet. Disposal Buoy D is shown as . Samples are from the following cruises; C7409-⌧; C7412-⌶; C7412B-△; C7501-Ⓒ; and WN001-◇. (Figures of a, b, and c are enlargements of the inner rectangular areas)

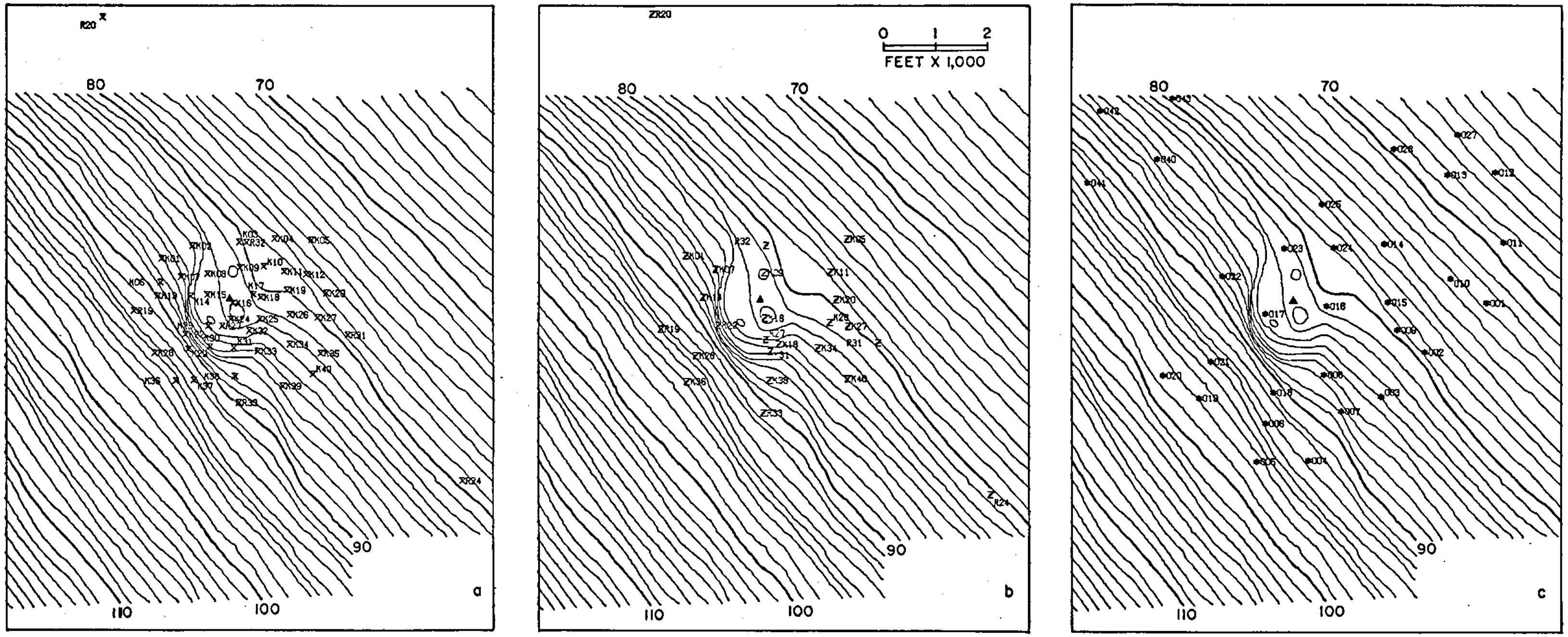

Figure A93a, b, and c. Postdisposal bathymetry and location of bottom samples collected after the experimental disposal at Site G. Samples were collected in September 1975 on cruise C7509 (a); October 1975 on cruise C7510 (b); and December 1975 on cruise WN002 (c). Bathymetric contours are in feet. Disposal Buoy D is shown as ▲

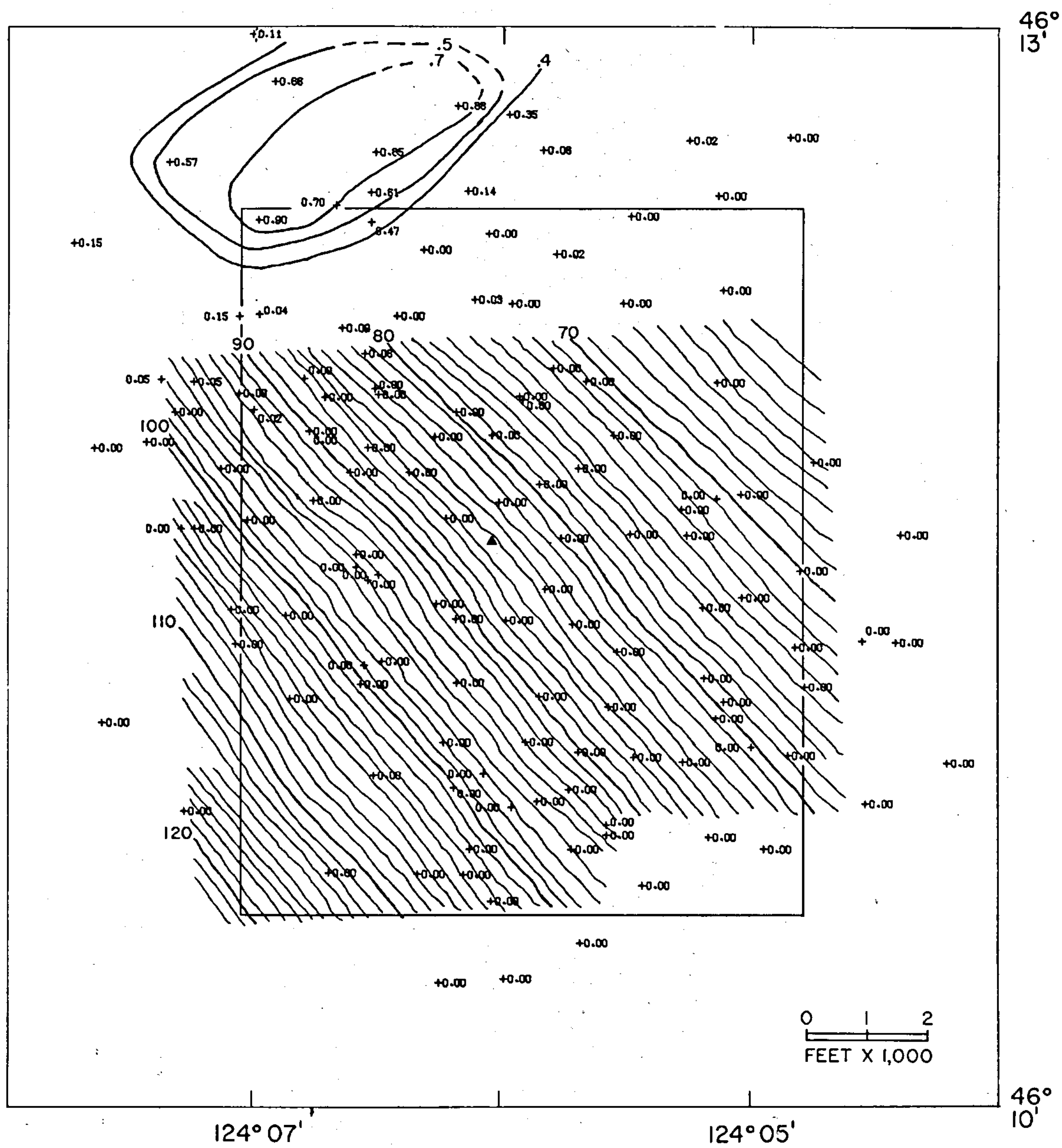

Figure A94. Areal distribution of Factor 1 (1.75, 2.0, or 2.25ϕ mode) sediment within experimental Disposal Site G before the controlled disposal. Contours of loading values at 0.4, 0.5, 0.7, 0.9. Bathymetric contours are in feet. Disposal Buoy D is shown as ▲. (Figures 95a, b, and c are enlargements of the inner rectangular area)

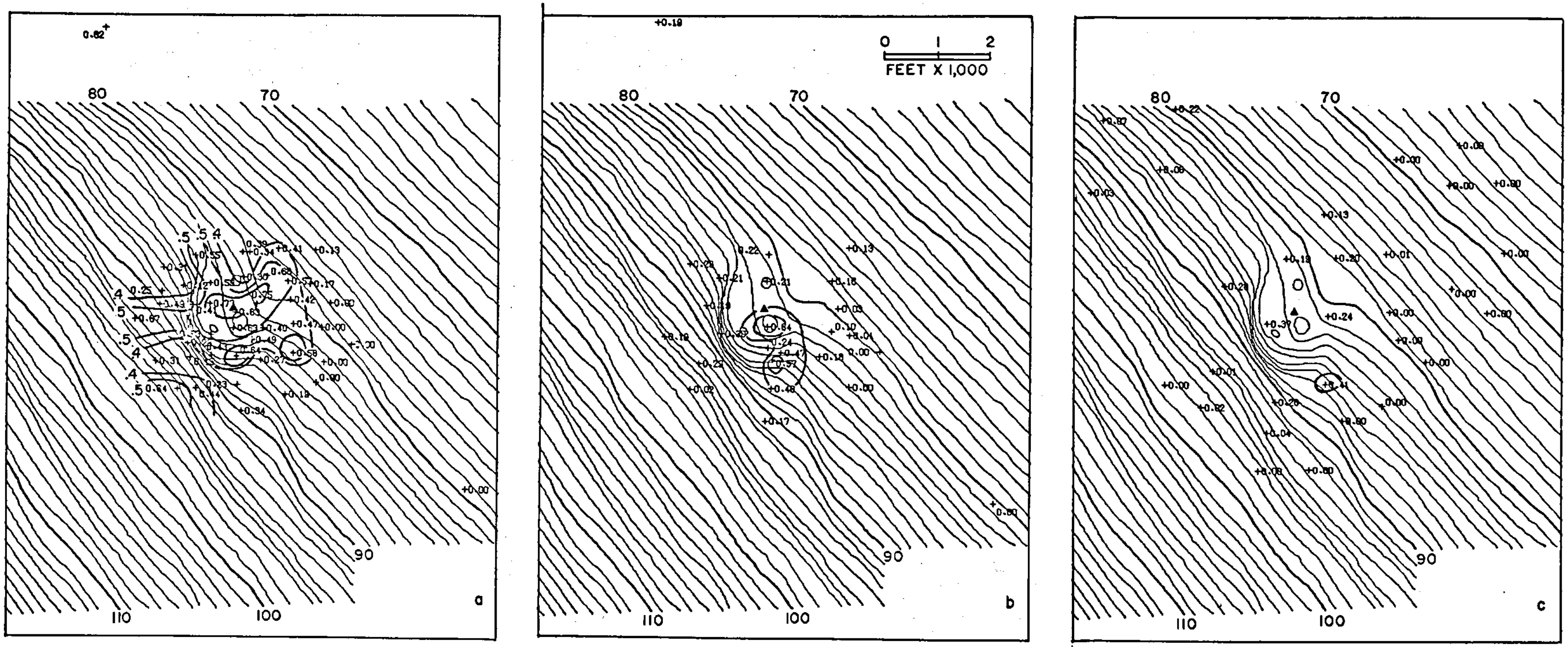

Figure A95a, b, and c. Areal distribution of Factor 1 (1.75, 2.0, or 2.25ϕ mode) sediment within experimental disposal Site G after the controlled disposal. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Bathymetric contours in feet. Disposal Buoy D is shown by ▲. Samples a - September 1975; b - October 1975; and c - December 1975

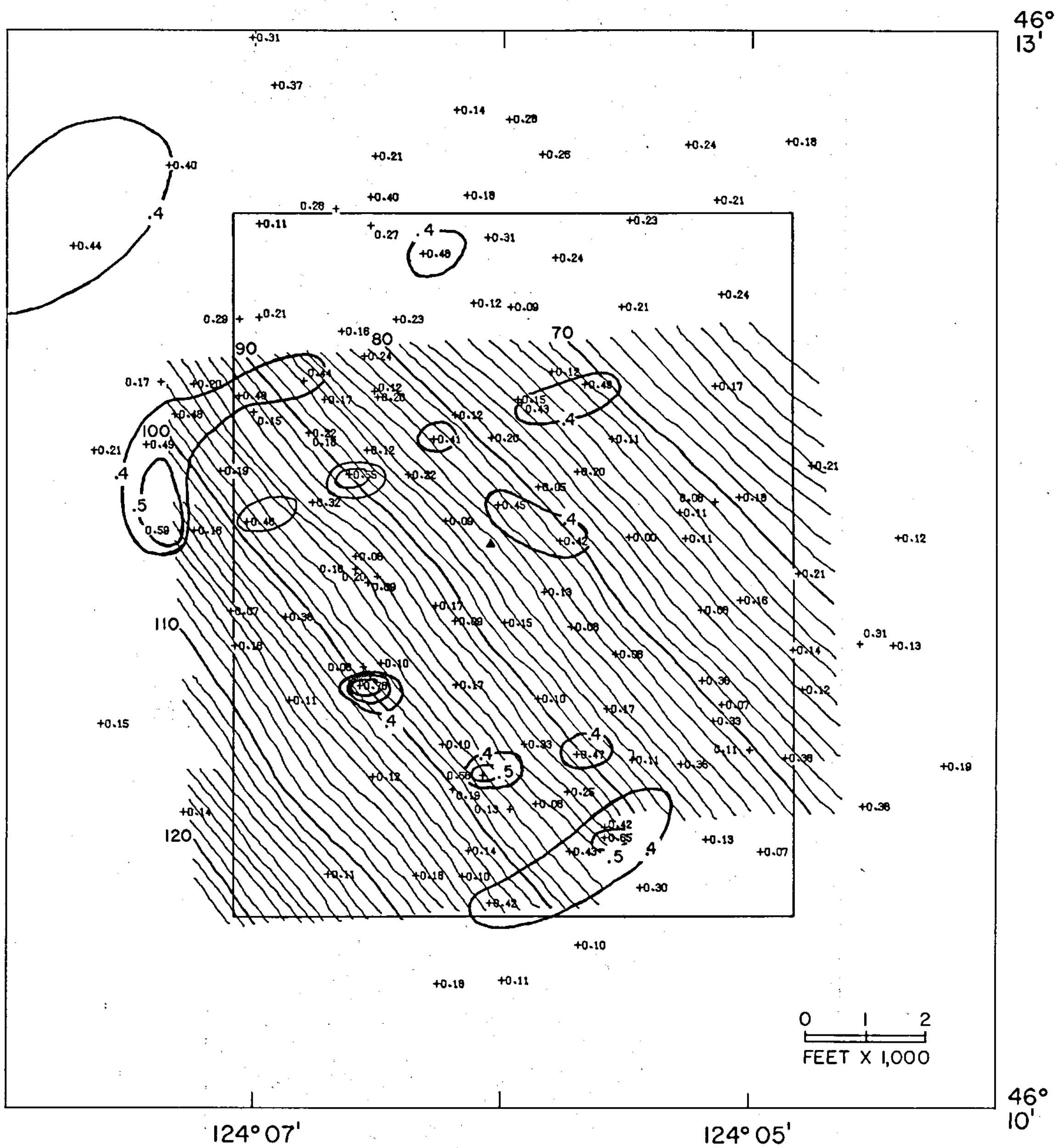

Figure A96. Areal distribution of Factor 2 (2.5ϕ mode) sediment within experimental Disposal Site G before the controlled disposal. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Bathymetric contours are in feet. Disposal Buoy D is shown as ▲. (Figures 97a, b, and c are enlargements of the inner rectangular area)

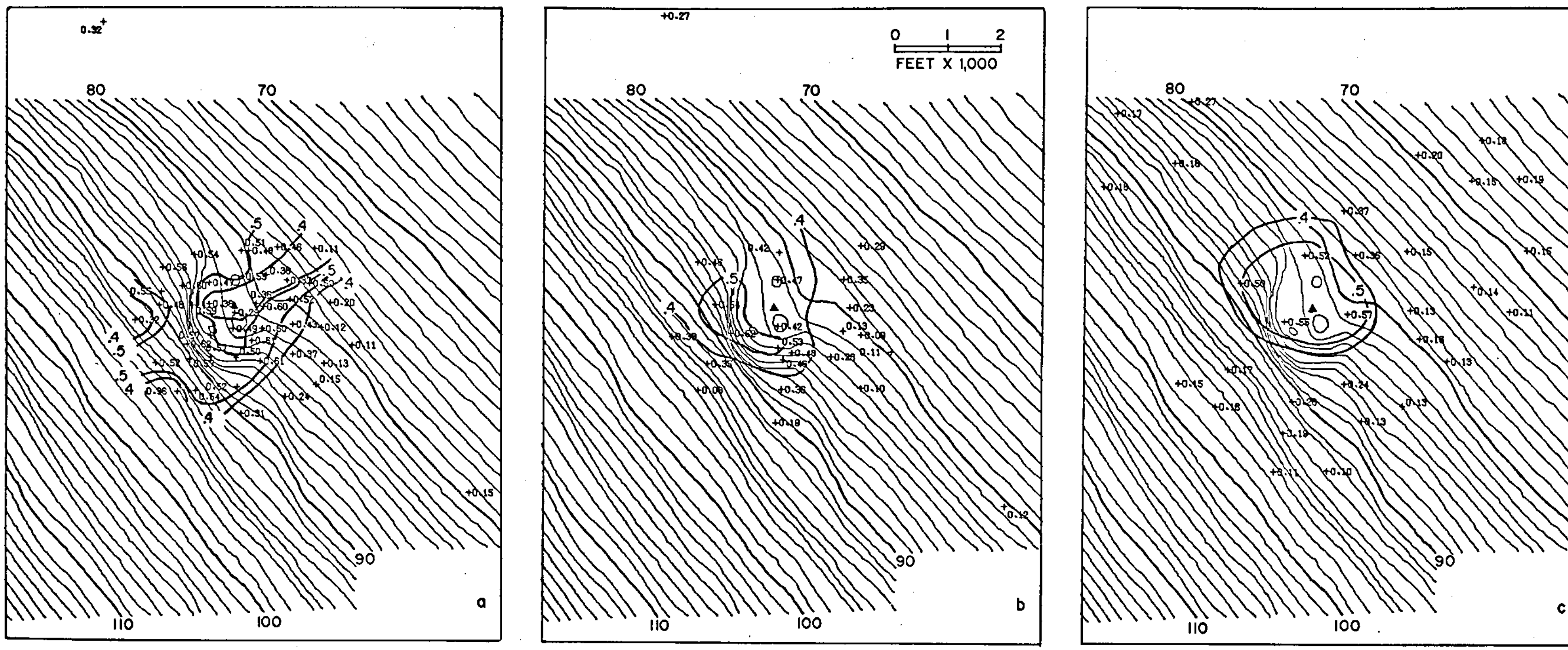

Figure A97a, b, and c. Areal distribution of Factor 2 (2.5ø mode) sediment within experimental disposal Site G after the controlled disposal. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Bathymetric contours in feet. Disposal Buoy D is shown by ▲. Sample a - September 1975; b - October 1975; and c - December 1975

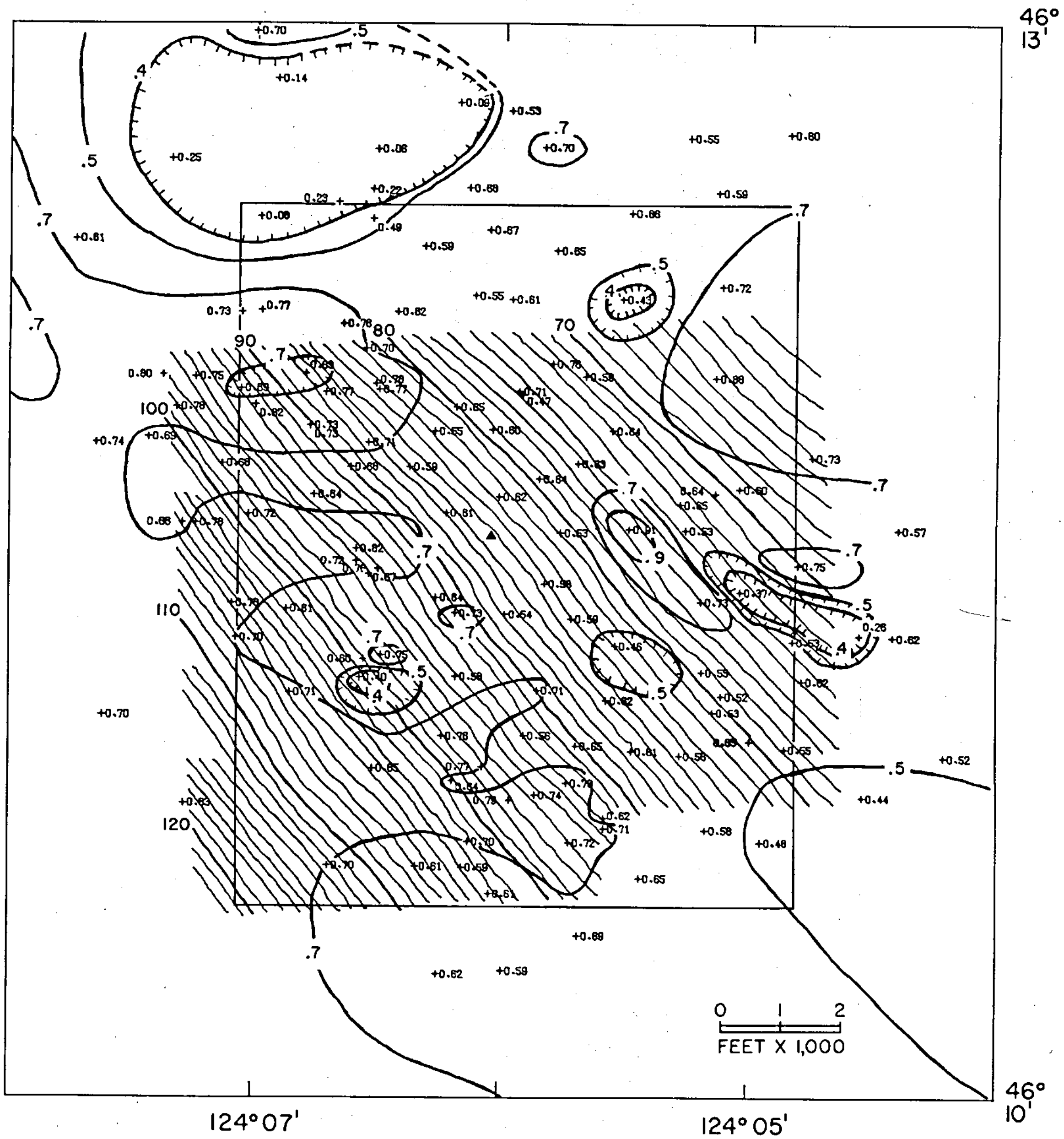

Figure A98. Areal distribution of Factor 3 (2.75 or 3.0ϕ mode) sediment within experimental Disposal Site G before the controlled disposal. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Bathymetric contours are in feet. Disposal Buoy D is shown as ▲. (Figures 99a, b, and c are enlargements of the inner rectangular area)

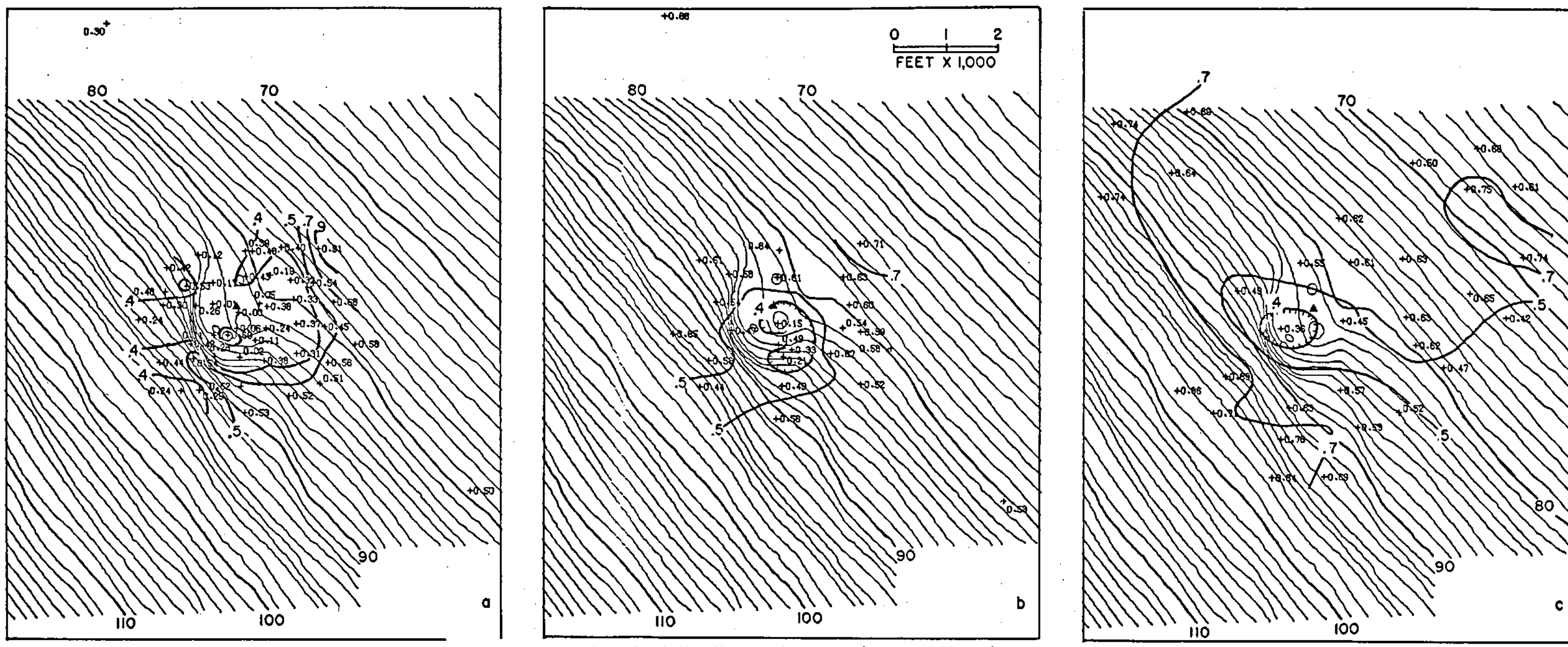

Figure A99a, b, and c. Areal distribution of Factor 3 (2.75 or 3.0ϕ mode) sediment within experimental disposal Site G after the controlled disposal. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Bathymetric contours in feet. Disposal Buoy D is shown by ▲. Sample a - September 1975; b - October 1975; and c - December 1975

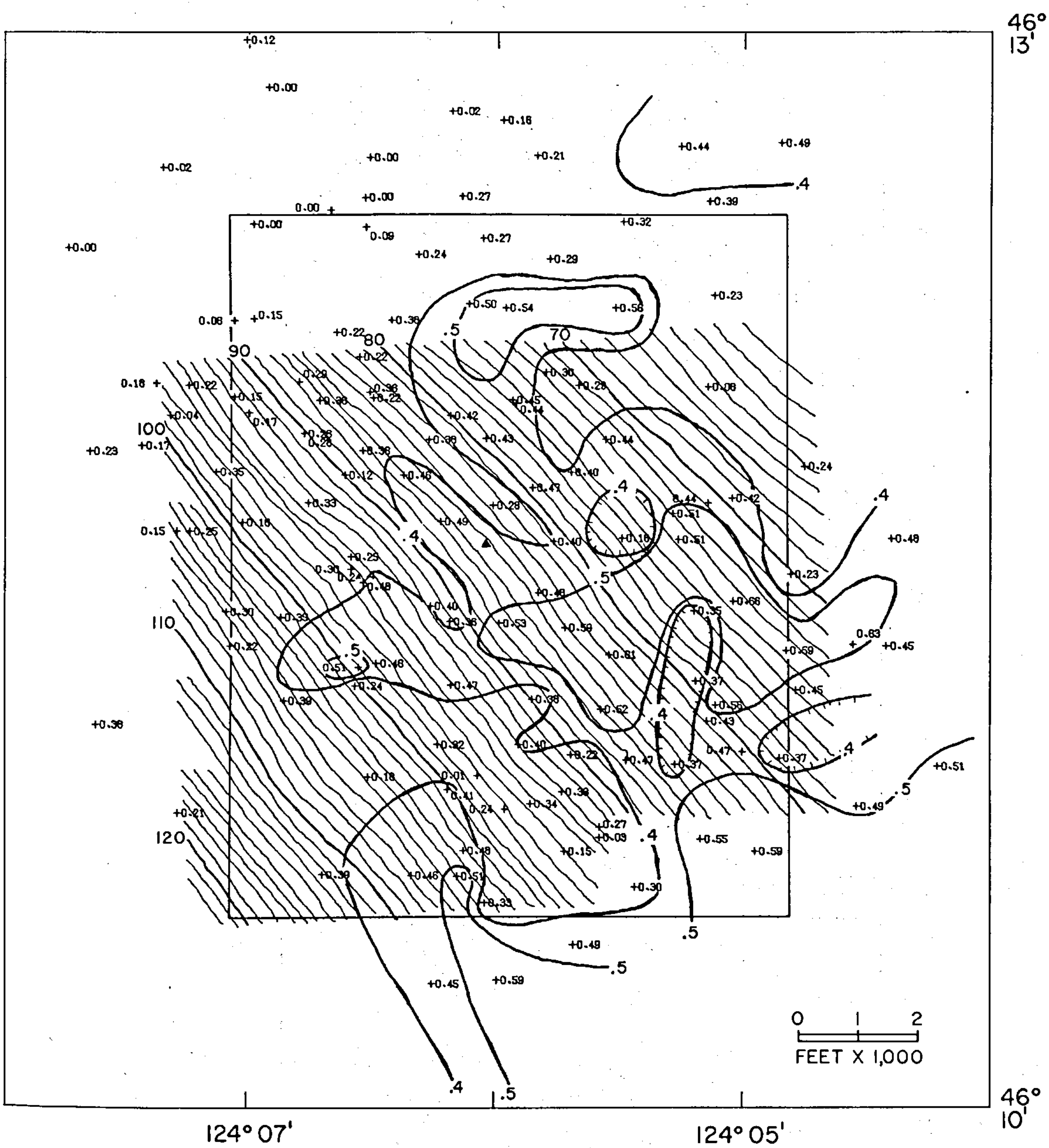

Figure A100. Areal distribution of Factor 4 (3.25ø mode) sediment within experimental Disposal Site G before the controlled disposal. Contours of loading values at 0.4, 0.5, 0.7, 0.9. Bathymetric contours are in feet. Disposal Buoy D is shown as ▲. (Figures A101a, b, and c are enlargements of the inner rectangular area)

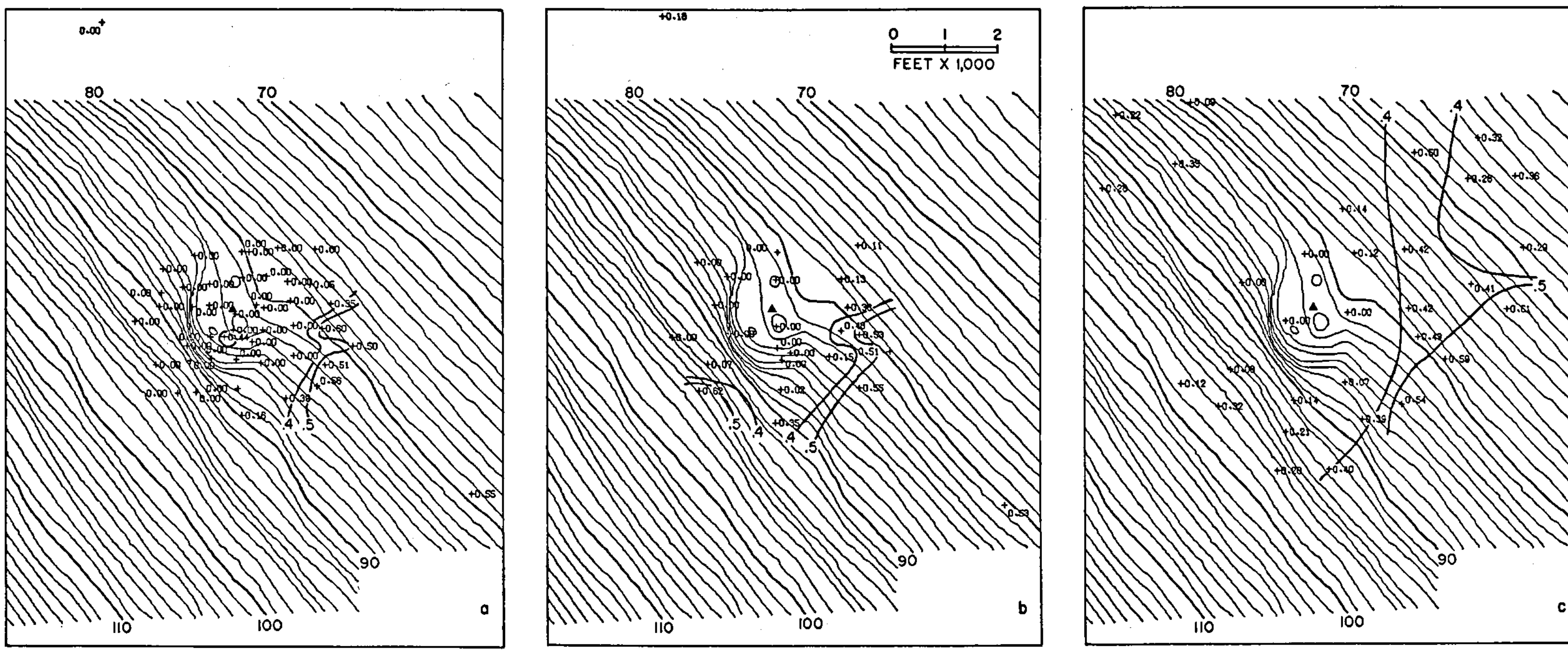

Figure A101a, b, and c. Areal distribution of Factor 4 (3.25ϕ mode) sediment within experimental disposal Site G after the controlled disposal. Contours of loading values at 0.4, 0.5, 0.7, and 0.9. Bathymetric contours in feet. Disposal Buoy D is shown by ▲. Sample a - September 1975; b - October 1975; and c - December 1975.

dominant factors. Before the experiment, Site G was characterized by a dominance of Factor 4 and 3 sediment and there was little Factor 2 and no Factor 1 sediment.

155. In September, after the disposal experiment, the Factor 1 sediment (2.0 to 2.25ϕ) was generally confined to distances of 1400 ft from the buoy and was concentrated along the curved disposal arc south of the buoy. The largest concentration of Factor 2 sediment (2.5ϕ) formed a halo around the Factor 1 sediment. Factor 3 sediment (2.75ϕ) was present as a halo around Factor 2 sediment and Factor 4 sediment was present only in the southeast corner of the sampled area.

156. Two anomalous samples occurred in the data. Sample C7509-K36 was more coarse grained, and sample C7509-R27 more fine grained (similar to the ambient predisposal Factor 3 sediment) than adjacent sediments. Sample C7509-R27 was omitted from Figures A95b and A97b for clarity but can be seen in Figures A99b and A101b.

157. Although the sampling density during the October cruise was not great, general changes in the bottom sediment texture were still quite distinct. The areal extent of Factor 1 (2.0ϕ) sediment had diminished to a narrow north-south band south of the buoy. Factor 2 (2.5ϕ) sediment still occurred as a halo around Factor 1 sediment but, because contouring was confined to loadings of 0.4 and greater, appeared to exist only to the north and west. However, the factor loading values showed that the halo was also present to the east and south (Figure A97c). In October, Factor 3 (2.75ϕ) sediment was confined to a region much nearer the buoy than in September, and Factor 4 (3.25ϕ)

sediment had reappeared in the southwest corner.

158. Although the December coverage in the area immediately south of the buoy was poor, a comparison of loading values for Factor 1 (2.0 to 2.25ϕ) with October data showed that the importance of this type of sediment was continuing to diminish. Similarly, this was true for Factor 2 (2.5ϕ) sediment where only four samples exceeded loadings of 0.4. Of these four samples, three had almost equal loadings of Factors 2 (2.5ϕ) and 3 (2.75ϕ). In fact, without knowledge of the experiment, the December distribution of Factors 2 (2.5ϕ) and 3 (2.75ϕ) appeared enough like the predisposal distributions that the disposal perturbation might not be detected. Factor 4 (3.25ϕ) sediment showed negligible return toward the predisposal distribution.

159. Table A11 lists the grain-size distributions for the stations resampled within Site G and includes size distributions of typical dredge-bin samples taken from the BIDDLE and HARDING during the disposal experiment. The Site G samples are also plotted in Figure A102. Upon deciphering the dredging logs of the BIDDLE and HARDING from 9 July to 26 August 1975, it was possible to assign, with some confidence, the source of over 50 percent of the loads collected from the Columbia River entrance. The texture of the sediment recovered from the dredge bins suggested that there were both temporal and spatial variations at the dredging locations. Sample B0775-118 was dredged between Buoys 4 and 6 on 10 July 1975. Samples H7875-10 and H7875-24 were dredged between Buoys A and 8 on 17 July and 11 August, respectively. Samples B0775-213 and H7875-28 were dredged between Buoys 8 and B on 16 July and 15 August, respectively. Factoring of the dredge bin

Table A11

Grain-Size Distributions (Percent by Weight) for Those Samples Near Site G Collected Within 0.1 Minutes of Latitude or Longitude (600 ft) in Different Months*

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
71	C7509 K01 WAA	0	0	0	0	0	1	2	5	13	20	26	21	6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K01 WAA	0	0	0	0	0	1	2	5	11	17	24	21	7	7	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1
72	C7506 032 WAA	0	0	0	0	0	0	0	0	1	5	13	22	18	21	10	5	2	1	0	0	0	0	0	0	0	0	0	0	1
	C7509 K03 WAA	0	0	0	0	1	1	3	6	14	21	24	19	6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 R32 WAA	0	0	0	0	0	0	2	5	13	21	26	21	6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 R32 WAA	0	0	0	0	0	0	1	3	9	17	25	25	9	6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 023 WAA	0	0	0	0	0	0	1	3	9	18	26	24	8	6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1
73	WN001 012 WAA	0	0	0	0	0	0	0	0	1	4	11	24	17	21	11	6	2	1	0	0	0	0	0	0	0	0	0	0	1
	C7509 K04 WAA	0	0	0	0	1	1	3	7	14	19	22	19	7	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 024 WAA	0	0	0	0	0	0	1	3	8	14	20	23	11	11	4	2	1	0	0	0	0	0	0	0	0	0	0	0	1
74	C7412 059 WAA	0	0	0	0	0	0	0	0	2	5	14	25	16	19	9	5	2	1	0	0	0	0	0	0	0	0	0	0	1
	C7509 K05 WAA	0	0	0	0	0	0	1	2	5	12	20	25	26	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K05 WAA	0	0	0	0	0	0	1	2	6	12	20	26	13	12	4	2	1	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 014 WAA	0	0	0	0	0	0	0	1	2	6	14	24	16	20	9	5	1	1	0	0	0	0	0	0	0	0	0	0	1
75	WN001 013 WAA	0	0	0	0	0	0	0	0	1	4	12	23	17	21	11	6	2	1	0	0	0	0	0	0	0	0	0	0	1
	C7509 K07 WAA	0	0	0	0	0	0	1	3	9	19	29	26	8	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
76	C7412 022 WAA	0	0	0	0	0	0	0	0	1	5	14	26	17	19	9	5	2	0	0	0	0	0	0	0	0	0	0	0	0
	C7509 K09 WAA	0	0	0	0	0	0	2	5	12	20	25	21	7	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K09 WAA	0	0	0	0	0	0	1	3	10	19	27	25	8	4	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
77	C7509 K11 WAA	0	0	0	0	1	1	4	9	17	20	20	16	5	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 K12 WAA	0	0	0	0	0	0	1	3	8	16	23	24	10	8	3	2	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K11 WAA	0	0	0	0	0	0	1	3	7	13	21	24	12	12	4	2	1	0	0	0	0	0	0	0	0	1	0	0	0
78	C7509 K22 WAA	0	0	0	0	0	0	1	4	11	21	28	22	6	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7510 K22 WAA	0	0	0	0	0	0	1	4	12	23	28	21	6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
79	C7506 027 WAA	0	0	0	0	0	0	0	0	1	5	13	26	17	21	9	5	1	1	0	0	0	0	0	0	0	0	0	0	1
	C7509 R27 WAA	0	0	0	0	0	0	0	0	2	6	14	23	16	20	10	6	2	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 K24 WAA	0	0	0	0	1	1	4	10	21	27	22	10	2	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7510 K16 WAA	0	0	0	0	1	1	4	10	20	26	22	11	2	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
80	C7509 K18 WAA	0	0	0	0	0	0	1	4	12	22	27	21	6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1

*Each group is identified as a station whose location can be found in Figure A102. Also listed are

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
	WN002 016 WAA	0	0	0	0	0	0	1	4	12	21	27	22	6	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
81	C7412 003 WAA	0	0	0	0	0	0	0	0	1	5	13	23	17	20	11	6	2	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 K19 WAA	0	0	0	0	0	1	3	7	15	21	24	18	6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K20 WAA	0	0	0	0	0	0	0	1	3	7	16	23	14	18	8	5	2	0	0	0	0	0	0	0	0	0	0	0	2
82	C7509 K26 WAA	0	0	0	0	1	1	4	8	15	19	21	18	6	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C7510 K26 WAA	0	0	0	0	0	0	1	2	4	7	13	20	15	19	9	6	2	1	0	0	0	0	0	0	0	0	0	0	1
83	C7412 031 WAA	0	0	0	0	0	0	0	0	1	5	14	25	17	19	11	5	2	0	0	0	0	0	0	0	0	0	0	0	1
	C7509 K28 WAA	0	0	0	0	0	0	1	5	12	19	24	21	8	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K28 WAA	0	0	0	0	0	0	2	4	10	16	20	22	10	10	3	2	1	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 021 WAA	0	0	0	0	0	0	0	1	3	8	19	32	17	14	4	1	0	0	0	0	0	0	0	0	0	0	0	0	1
84	C7509 K31 WAA	0	0	0	0	1	1	3	10	22	29	22	9	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 R27 WAA	0	0	0	0	0	0	1	3	11	21	27	22	7	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K18 WAA	0	0	0	0	0	0	2	7	16	23	25	17	5	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	C7510 K31 WAA	0	0	0	0	1	1	3	9	19	26	24	13	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
85	WN001 018 WAA	0	0	0	0	0	0	0	0	1	5	13	23	16	21	11	7	2	0	0	0	0	0	0	0	0	1	0	0	0
	C7509 K34 WAA	0	0	0	0	1	1	4	9	17	20	19	16	5	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K34 WAA	0	0	0	0	0	0	1	3	7	12	19	24	13	12	4	3	1	0	0	0	0	0	0	0	0	0	0	0	1
86	C7509 K37 WAA	0	0	0	0	0	1	3	7	16	23	24	17	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 018 WAA	0	0	0	0	0	0	2	5	9	13	17	22	12	11	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0
87	C7412 008 WAA	0	0	0	0	0	0	0	0	1	5	11	23	16	21	12	6	2	0	0	0	0	0	0	0	0	1	0	0	0
	C7509 K38 WAA	0	0	0	0	0	0	1	4	10	19	25	24	8	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 K38 WAA	0	0	0	0	0	1	3	6	12	17	20	19	8	7	3	2	1	0	0	0	0	0	0	0	0	0	0	0	1
	WN002 008 WAA	0	0	0	0	0	1	3	6	13	14	17	21	10	9	3	2	0	0	0	0	0	0	0	0	0	0	0	0	1
88	C7506 033 WAA	0	0	0	0	0	0	0	0	1	5	12	23	17	22	11	6	2	0	0	0	0	0	0	0	0	0	0	0	0
	C7509 R33 WAA	0	0	0	0	0	1	3	5	10	14	18	20	10	11	4	2	1	0	0	0	0	0	0	0	0	0	0	0	1
	C7510 R33 WAA	0	0	0	0	0	1	2	4	5	9	15	20	12	16	8	6	1	0	0	0	0	0	0	0	0	0	0	0	1
DREDGED BETWEEN BOUYS 4 AND 6 10 JULY 1975																														
	B0775 118 DHA	0	0	0	0	1	1	4	9	13	16	17	20	9	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
DREDGED BETWEEN BOUYS A AND 8 11-28 JULY 1975																														
	H7875 H04 DHA	0	0	0	0	0	0	0	1	7	19	32	27	7	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0

STATION NO.	SAMPLE NUMBER	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
	H7875 H08 DHA	0	0	0	0	0	0	1	3	10	22	32	23	5	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	H7875 H09 DHA	0	0	0	0	0	0	1	2	7	18	31	27	7	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	H7875 H10 DHA	0	0	0	0	0	0	1	3	9	19	32	24	7	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	H7875 H11 DHA	0	0	0	0	0	0	1	3	10	20	29	24	7	4	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	H7875 H14 DHA	0	0	0	0	0	0	1	3	9	19	29	26	7	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	H7875 H16 DHA	0	0	0	0	0	0	1	2	10	22	29	23	7	4	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
DREDGED BETWEEN BOUYS A AND 8 29 JULY-19 AUGUST 1975																														
	H7875 H12 DHA	1	2	3	6	10	10	20	18	13	8	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	H7875 H22 DHA	0	0	0	0	0	0	2	5	16	27	28	16	3	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	H7875 H24 DHA	0	0	0	0	0	0	1	3	13	28	31	17	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	H7875 H29 DHA	0	0	0	0	0	1	2	4	12	23	29	19	5	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	H7875 H30 DHA	0	0	0	0	0	0	1	3	12	28	32	18	4	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	H7875 H32 DHA	0	0	0	0	0	0	1	4	11	20	26	23	8	5	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
DREDGED BETWEEN BOUYS 8 AND B 15-18 JULY 1975																														
	80775 199 DHA	0.	0	0	0	0	1	3	8	19	28	23	12	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	80775 213 DHA	0	0	0	0	1	2	6	12	21	24	19	11	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	80775 223 DHA	0	0	0	0	1	1	4	11	23	27	20	9	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	80775 241 DHA	0	0	0	0	0	0	2	6	17	28	27	14	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	H7875 H13 DHA	0	0	0	0	1	1	4	10	22	28	21	9	2	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
DREDGED BETWEEN BOUYS 8 AND B 12-24 AUGUST 1975																														
	H7875 H25 DHA	0	0	1	2	5	5	14	21	26	16	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	H7875 H27 DHA	0	0	0	1	2	3	9	18	28	22	11	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	H7875 H28 DHA	0	0	0	1	3	4	13	20	26	18	8	3	1	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0
	H7875 H34 DHA	0	0	0	0	1	2	6	16	23	24	17	7	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	H7875 H35 DHA	0	0	0	0	0	0	2	7	22	31	23	10	2	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	H7875 H38 DHA	0	0	0	1	2	5	16	24	25	15	7	3	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
GRAB SAMPLES NEAR BOUY 8 26-27 JUNE 1975																														
	C7506 CR1 WAA	0	0	0	0	0	0	1	5	14	23	24	19	6	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 CR2 WAA	0	0	0	0	0	0	0	2	10	23	29	21	7	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 CR3 WAA	0	0	0	0	0	0	1	5	14	25	27	17	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 CR4 WAA	0	0	0	0	0	0	0	3	15	26	27	19	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	C7506 CR5 WAA	0	0	0	0	0	0	1	6	17	26	25	16	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

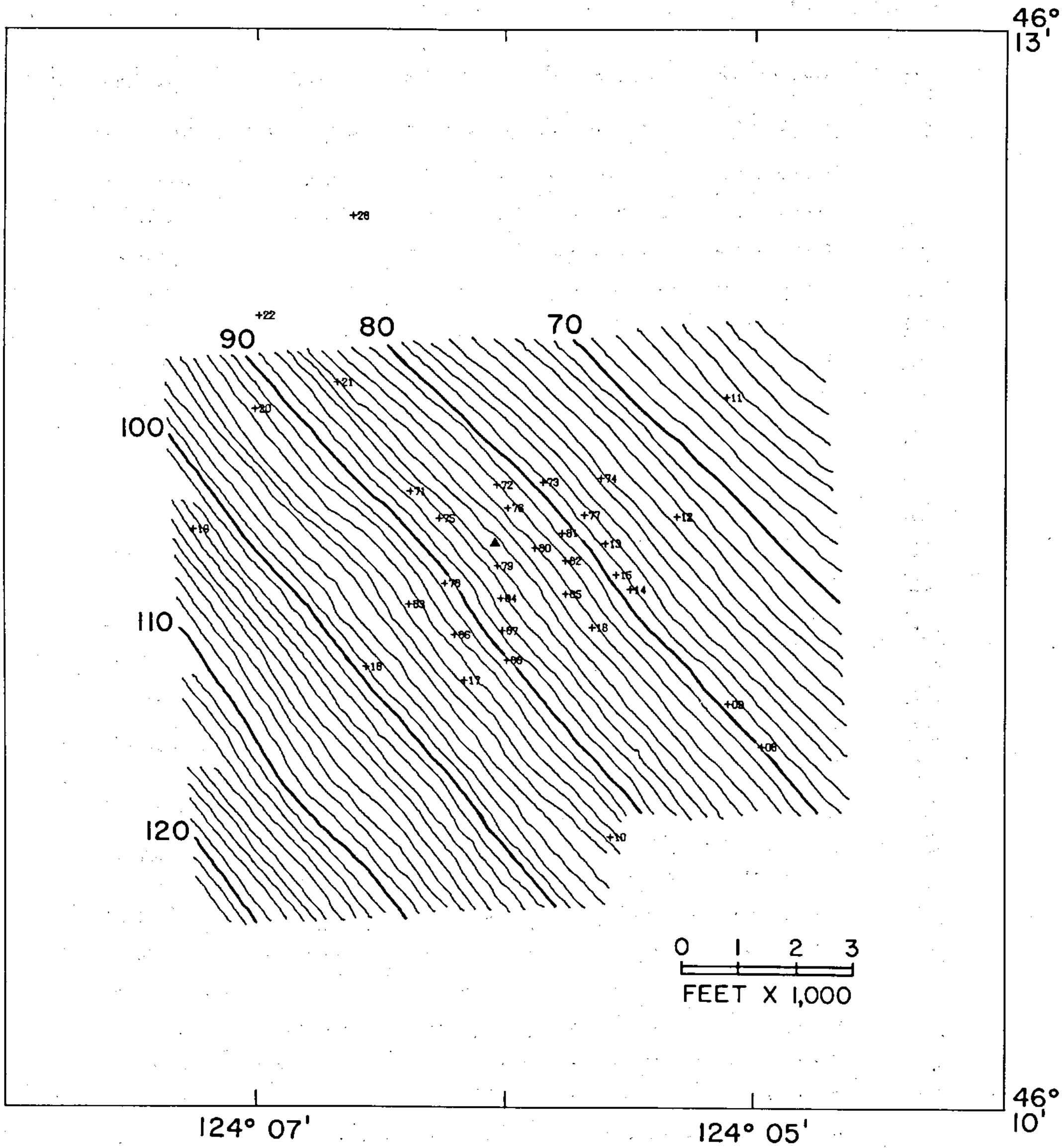

Figure A102. Locations of groupings of samples near Disposal Site G collected within 0.1 minutes of latitude or longitude (600 ft) of each other in different months. Each grouping is referred to as a station (see Tables A10 and A11). Disposal Buoy D is shown by ▲. Bathymetric contours are in feet samples produced the same factors, except for Factor 1 (2.0 to 2.25ø) as in the Site G area. The extremal for Factor 1 sediment among the dredge bin samples was H7875-28. The common Factor 1 extremal sample had a loading of 0.92 when compared to H7875-28.

160. In an upstream direction from the river entrance, the material dredged in July increased in grain size from Factor 3 (2.75ø), to Factor 2 (2.5ø), to Factor 1 (2.0 to 2.25ø) sediment. Between Buoys A and 8, Factor 2 (2.5ø) sediment loading increased from 0.75 to 0.96 between July and August, with attendant increases in the percentages of 2.25ø and coarser fractions. Between Buoys 8 and B, Factor 1 (2.0ø) loadings increased from 0.64 to 1.00 with an attendant shift in modal size from 2.25 to 2.0ø. The similarity of these samples to five surface samples collected in June in the vicinity of Buoy 8 (Table A11) suggests that the sediment textures as determined from bin samples were not overly biased by the dredging operation.

161. As expected, the September stations nearest Disposal Buoy D contained samples most similar to the dredged material samples. For example, Stations 79 and 80 appeared very similar to dredge bin sample B0775-213. Conversely, samples from stations distinct from Disposal Buoy D, such as 74, 87, and 88, showed characteristics of both ambient sediment and dredged material.

162. Stations 74, 81, 83, and 87 were the best examples of the perturbation of the ambient depositional environment caused by the experimental disposal. The sediment at Station 74 was considerably enriched in 3.0ø and coarser fractions during disposal operations, but

by December 1975 it had returned to a size distribution indistinguishable from the prior December. At Station 81, the size distribution was perturbed even more than at Station 74, yet by October it had returned almost to ambient conditions. Stations 83 and 87 showed less complete return to ambient conditions but were distinctly trending in that direction. Station 72 is an example of a location that experienced only slight return to ambient.

Mineralogical properties

163. Mineralogical analyses of Columbia River bedload sediment and beach, midshelf, and outer shelf sediment have been conducted by Ballard (1964), Andrews (1965), Kulm and Byrne (1966), Runge (1966), White (1967), Hands (1968), Fullam (1969), Whetten, Kelley, and Hanson (1969), Scheidegger, Kulm, and Runge (1971), Venkatarathnam and McManus (1973), and Kulm et al. (1975). Direct comparison of the results from this study with those referenced above is not possible due to the variety of analytical techniques used by the different research groups. Moreover, the high density sampling program used in this study provides mineralogical information not previously available. As a consequence, no attempt will be made to discuss previous results, although reference to previous work will be made when comparable results are available.

164. Columbia River bottom sediment. Sediment of the Columbia River bed is composed primarily of debris derived from mechanical weathering of andesitic volcanic material of the Cascade Range (Whetten et al. 1969). The most abundant single constituent in this sediment is fragmented, fine-grained, porphyritic andesite.

Phenocrysts of oscillatorily zoned plagioclase, prismatic hypersthene needles, and equant, anhedral clinopyroxene grains, in an aphanitic groundmass, are the primary constituents in the lithic fragments. There is neither significant mineralogical variation nor significant mineralogical alteration evident in this lithic material.

165. The bulk of the remaining sand grains are composed of fragments of oscillatorily zoned plagioclase, identical in all respects to phenocrysts in the fresh lithic fragments. Euhedral orthopyroxene and anhedral clinopyroxene are also present as single grains in amounts approximating their relative abundances in the lithic fragments. The optical properties suggest that these mineral species are derived from the andesitic lithic material through mechanical degradation of the latter.

166. These mineral and lithic species account for a minimum of 50 percent of the total volume of material transported by the Columbia River as bedload. The remainder of the sediment is a mixture of mineral and lithic fragments derived from a variety of sources.

167. Quartz, making up 10 to 20 percent of the sediment, is of unknown origin. Although quartz could be a primary constituent of andesitic volcanic rocks, the possible reservoirs for quartz in this region are many (Tertiary and Recent sedimentary material and igneous and metamorphic rocks pre-dating the Pliocene to Recent andesitic volcanic material of the Cascade Range). Primary source area characteristics that would identify the provenance for these grains are lacking.

168. Potassium feldspar, either as microcline or intermediate orthoclase, is a common minor constituent of the bottom sediment. The structural state of this mineral suggests that it was derived either from intermediate to high grade metamorphic rocks, or from intrusive rocks of intermediate to high potassium content. Possible source areas for this mineral species are the crystalline core of the North Cascades, or the intrusive and metamorphic rocks of north-central and eastern Washington and Idaho.

169. A variety of amphiboles of contrasting origin are present. Basaltic hornblende of volcanic origin is present in trace amounts and is probably derived from the andesitic volcanic rocks of the Cascade Range. Blue-green hornblende, unquestionably from a low to intermediate grade metamorphic terrain, is more abundant but remains a minor constituent. Rare fragments of brown hornblende of high-grade metamorphic(?) origin can occasionally be observed.

170. Rare in these bulk samples are opaque oxides, altered lithic fragments, basaltic lithic fragments, epidote, and other assorted mineral species associated with low grade metamorphic terrains.

171. The bulk mineralogy demonstrates that the dominant influences on the Columbia River bedload mineralogy is the andesitic Cascade Range, with minor contributions from the underlying crystalline basement that extends to the east of the Cascades. Although material derived from the Tertiary Coast Ranges is present, its trace abundance demonstrates that its contribution to the bedload is proportionately small.

172. Detailed examination of grain morphology and grain textures of minerals presumed derived from the andesitic rocks reveals that most surfaces are cleavage or fracture surfaces, with little evidence of smoothing, rounding, or frosting. Indeed, it is not uncommon to find highly scoriaceous glass attached to pyroxene and plagioclase grains. It thus seems apparent that residence time of these grains in the river environment is relatively short.

173. Detailed analysis of 15 samples of Columbia River bed material, obtained from the HARDING and BIDDLE, demonstrated that mineralogical contrasts between samples were restricted to a limited range of complementary variations in MI and MR. The result is that virtually all Columbia River bedload samples plot on a line on an MI vs. MR diagram, with little scatter about the line (Figure A103). Such variation in bedload sediment suggests that sample-to-sample contrasts result from sorting of material derived from a homogeneous source. This conclusion is compatible with the observation that the andesitic Cascade Mountains are the primary source area for the bedload material.

174. <u>Ambient shelf sediment</u>. Shelf sediments beyond the bathymetrically recognizable Columbia River tidal delta, excluding the historic Disposal Site B, had mineralogical characteristics that were distinct from those of Columbia River bed material. The primary contrasts in mineralogical characteristics resulted from the fact that the continental shelf sediments had low abundances of fresh plagioclase but were rich in either altered lithic fragments or opaque material (primarily magnetite). The abundances of orthopyroxene and andesitic

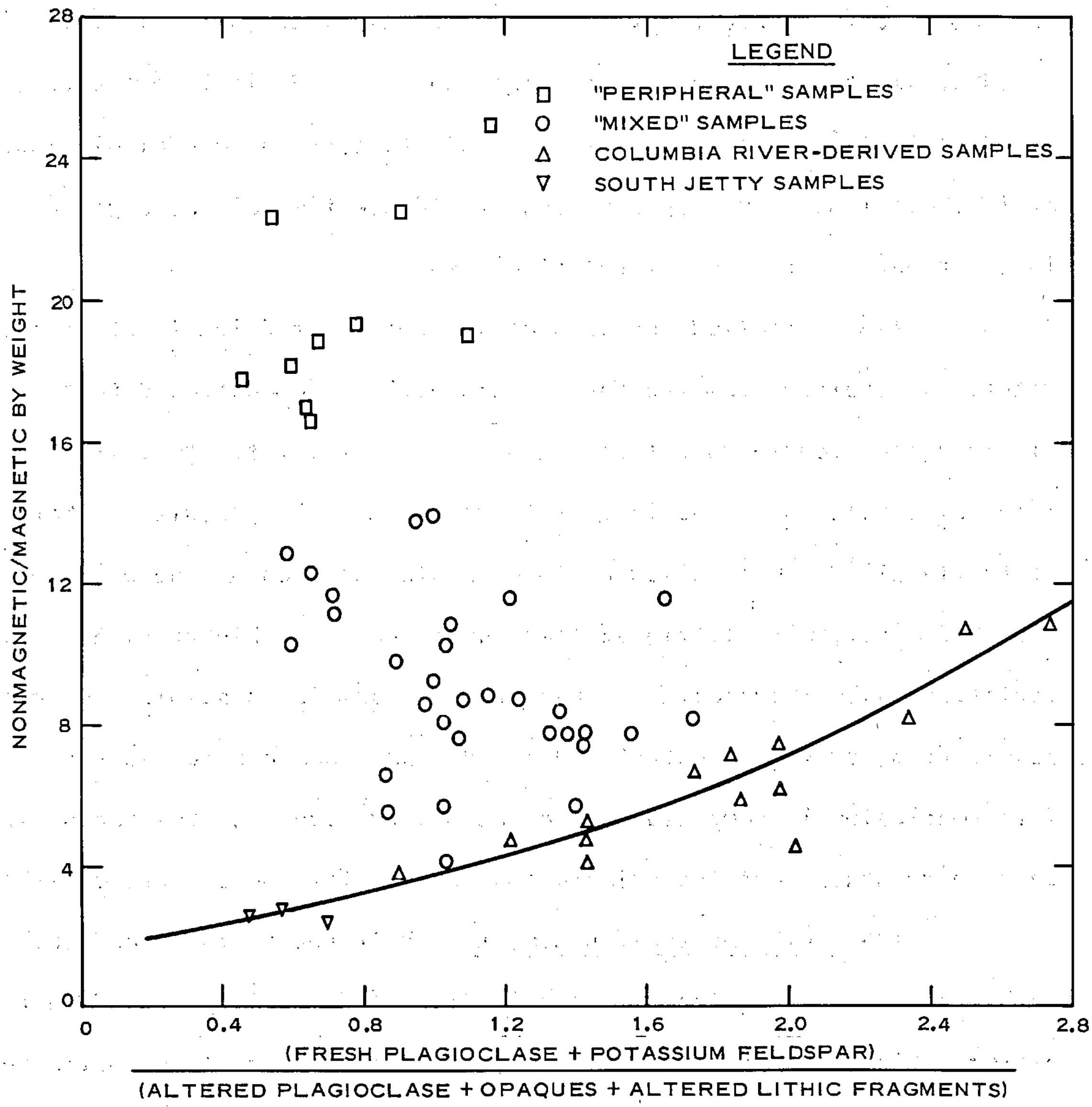

Figure A103. Mineral index (MI) vs. magnetic ratio (MR) variation diagram. The solid line is the visual best fit through points representing sediment derived from the Columbia River bed.

lithic fragments also appeared to be low, but clinopyroxene, altered plagioclase grains, and basaltic lithic fragments were enriched, relative to Columbia River sediment. As discussed later, it is these mineralogical contrasts that make it possible to mineralogically recognize Columbia River sediment that has been placed in the midshelf environment as a result of dredging activity.

175. The shelf sediments exhibited systematic mineralogical variations that appeared to correlate with water depth. In Figures A104 and A105 the regional variations in MI and MR are shown, based on samples collected in the fall and winter of 1974.

176. South of the Columbia River mouth, the MI increased westward from a low of 0.2 nearshore to a high of about 1.2 in the midshelf region. The MI decreased further west to a value of about 0.7. The MR, on the other hand, increased steadily from values of about 1 nearshore to values greater than 15 near the shelf break. The contrasting behavior of these parameters resulted from the fact that magnetite abundance decreased rapidly offshore, while the amount of altered lithic fragments and altered plagioclase was high in the outer shelf region. As a result, the MR values steadily increased seaward, while the MI initially increased as magnetite became less abundant offshore, but decreased to the west beyond the midshelf region as the altered lithic fragments and altered plagioclase became more abundant (assuming all other mineral species in the MI remained approximately constant). This same general pattern appeared to be evident north of the Columbia River mouth, although superimposed on this

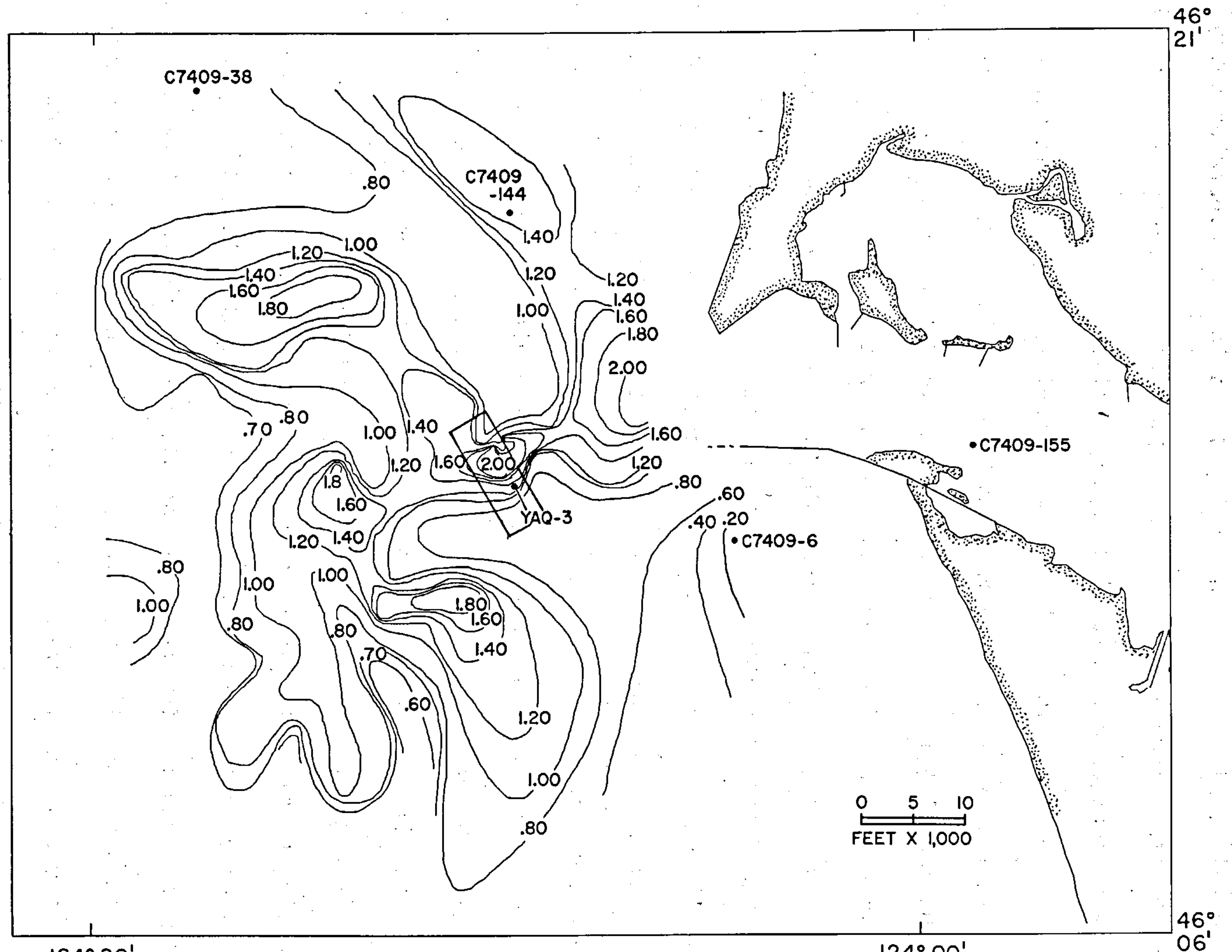

Figure A104. Contoured values of mineral index (MI) within the study area. The contours were based on data obtained on cruises completed in September and November of 1974. Locations (•) are shown for the five extremal samples defined by the mineralogical factor analysis.

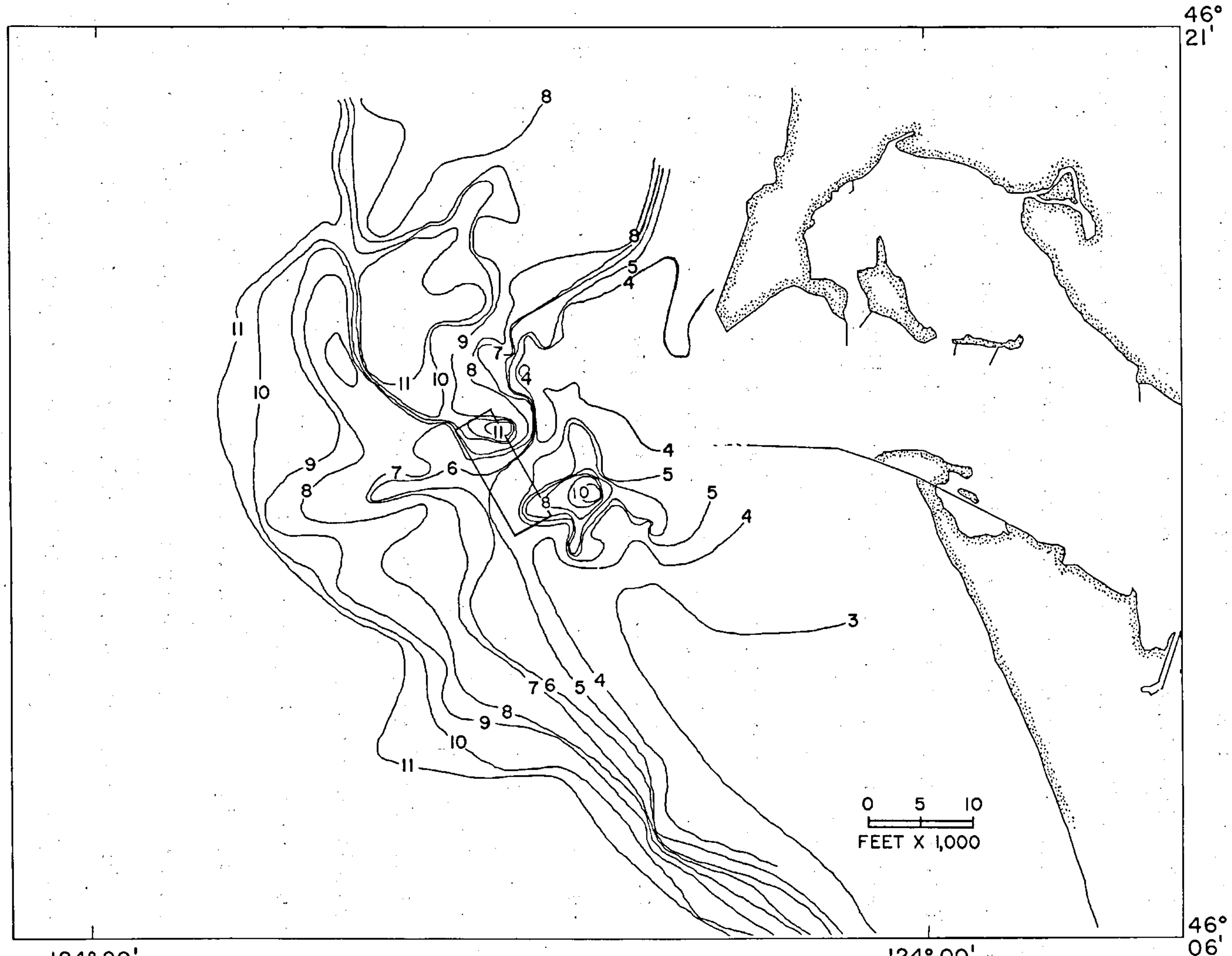

Figure A105. Contoured values of magnetic ratio (MR) within the study area. The contours were based on data obtained on cruises completed in September, November, and December of 1974 and on samples supplied by the benthic study group during 1975 pattern were the effects resulting from sediment input to the marine environment by the Columbia River, and dredged material disposal. Especially evident were the high MR values near the shelf break and the lower MR values immediately north of the Columbia River mouth.

177. The mineralogical contrasts between the nearshore and Columbia River sediments, and the outer shelf sediments are emphasized in Figure A103. The outer shelf sediments have MR values exceeding 15, whereas the coarser-grained nearshore and Columbia River bedload material fall along a linear trend with MR values between 2.0 and 11.0. All mid-shelf sediments fall at values intermediate between the inner and outer shelf samples.

178. Further analysis of the mineralogy was attempted using Q-mode factor analysis (see, Part IV: Methods) on the point counting results. Factor loadings were calculated for five mineralogical factors that accounted for over 98 percent of the sample variance, with the exception of four samples in which a minimum of 96 percent of the variance could be described.

179. Percentages of mineral constituents in the extremal samples associated with the five mineralogical factors are shown in Figure A106. Figures A107 through A111 depict the regional distributions of each of the five factors. Mineralogical Factor 3 (Figure A109) sediment was characterized by high proportions of fresh plagioclase and andesite. The sample was obtained from the plume that extends off the Columbia River mouth (Figure A104), and probably developed through winnowing and concentration of plagioclase and lithic fragments (the

light fraction) from Columbia River bed material. High loadings of this mineralogical factor occurred in regions that were characterized by values of MI greater than 1.0 to 1.2, with the exception that relatively high loadings of this factor occurred in the southwest portion of the study area, where the outer shelf sediments had MI values less than 0.8. This material occurred primarily in regions where Factor 3 (2.75ϕ) loadings of the grain-size analysis were large.

180. Mineralogical Factor 4, composed principally of magnetite (Figure A110), correlated strongly with the samples that occurred south of the south jetty (Figure A104) in a region where magnetite was abundant. High loadings of this factor were restricted to regions where MI and MR values were low due to the abundance of magnetite. Detailed analysis of samples with high mineralogical Factor 4 loadings demonstrated that the magnetite made up the 3.25ϕ size fraction that was common in these samples. Low factor loadings in other areas where a 3.25ϕ size fraction was abundant demonstrated, however, that this size fraction was not exclusively magnetite-rich.

181. Mineralogical Factor 2, characterized by a dominance of altered lithic fragments (Figure A106) corresponded with the outer shelf sediments (Figure A104). Samples with high loadings of this factor had low MI values but high MR values. In the outer shelf region there was a weak correlation between this factor and the 3.25ϕ material (grain-size Factor 4).

182. The extremal sample for mineralogical Factor 1 was collected in the lower Columbia River estuary. Its primary constituent was andesitic lithic fragments, with a strong component of fresh

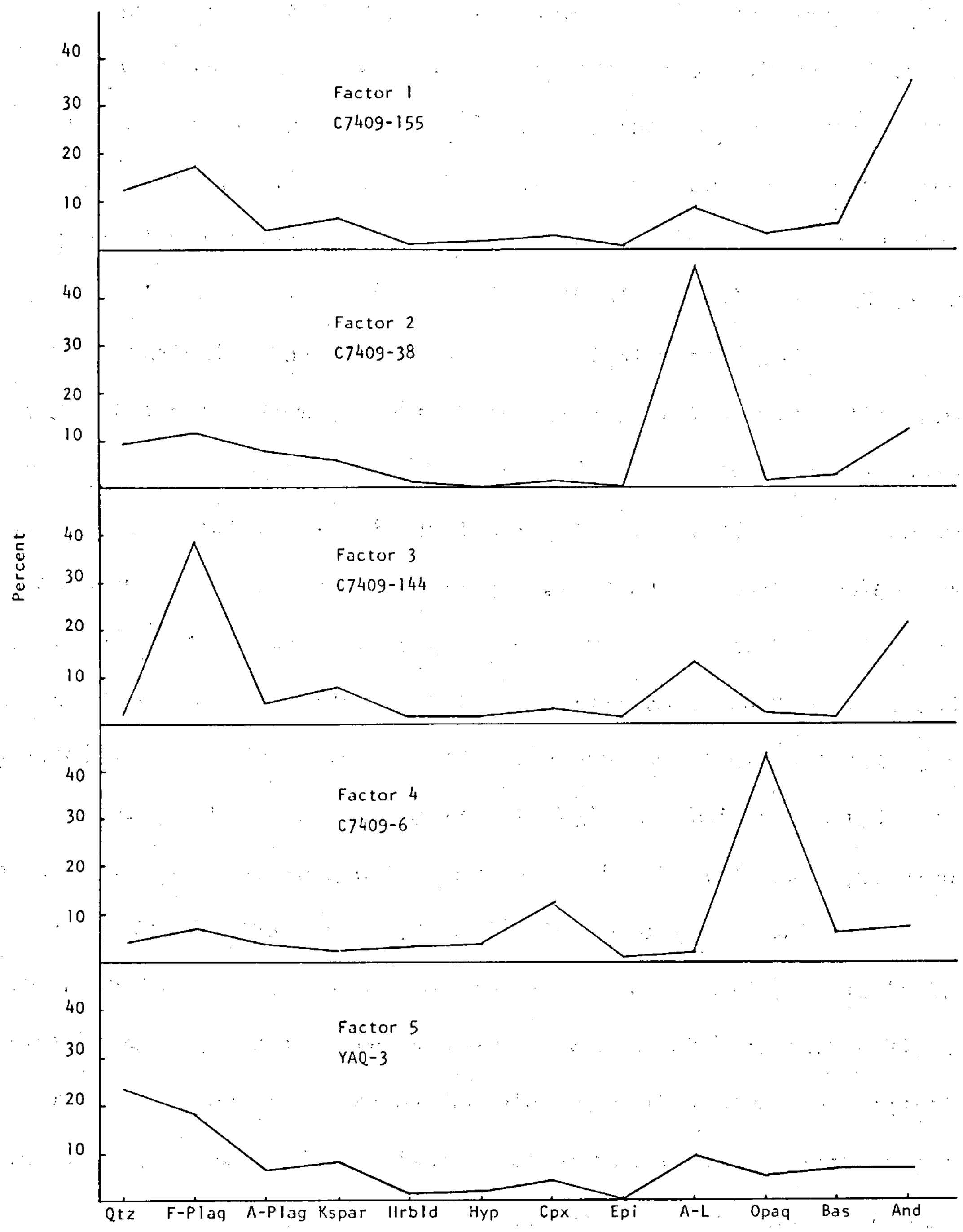

Figure A106. Graphs of mineral abundances in the extremal samples defined by the mineralogical factor analysis (Qtz - quartz, F-plag - fresh plagioclase, A-plag - altered plagioclase, Kspar - potassium feldspar, Hrbld - hornblende, Hyp - hypersthene, Cpx - clinopyroxene, Epi - epidote, A-L - altered lithic fragments, Opaq - opaques, Bas - basaltic lithic fragments, and And - andesitic lithic fragments) plagioclase (Figure A106). The regional distribution of mineralogical Factor 1 mimicked the distribution of high values of MI and, in conjunction with mineralogical Factor 3, virtually defined the fields for MI values exceeding 1.0.

183. Mineralogical Factor 5 was composed primarily of quartz and fresh plagioclase, with minor contributions from other components (Figure A106). There were few samples with high loadings of this factor, and its distribution showed no strong correlation with any of the obvious patterns, with the exception that it was the only factor that occurred at significant values in the region immediately due north of Site B, where size Factor 4 (3.25ϕ) was concentrated.

Site B mineralogical properties

184. The area immediately east of Disposal Site B had MI (Figure A104) and MR (Figure A105) values similar to those of the Columbia River bed material. Detailed petrographic examination of these samples demonstrated their high abundance of fresh plagioclase and andesitic lithic fragments (Figures A107 and A109). These mineralogical characteristics suggest that this sediment is dredged Columbia River bed sediment.

185. In the northern corner and just outside the eastern corner of Site B, there were pockets of sediment that had high MR values, adjacent to other areas possessing lower MR values (Figures A104, A105, and A112). These pockets of material were only evident in the immediate vicinity of the disposal site.

186. High MI values (Figure A104) were concentrated along a northwesterly plume extending seaward from the Columbia River mouth, as

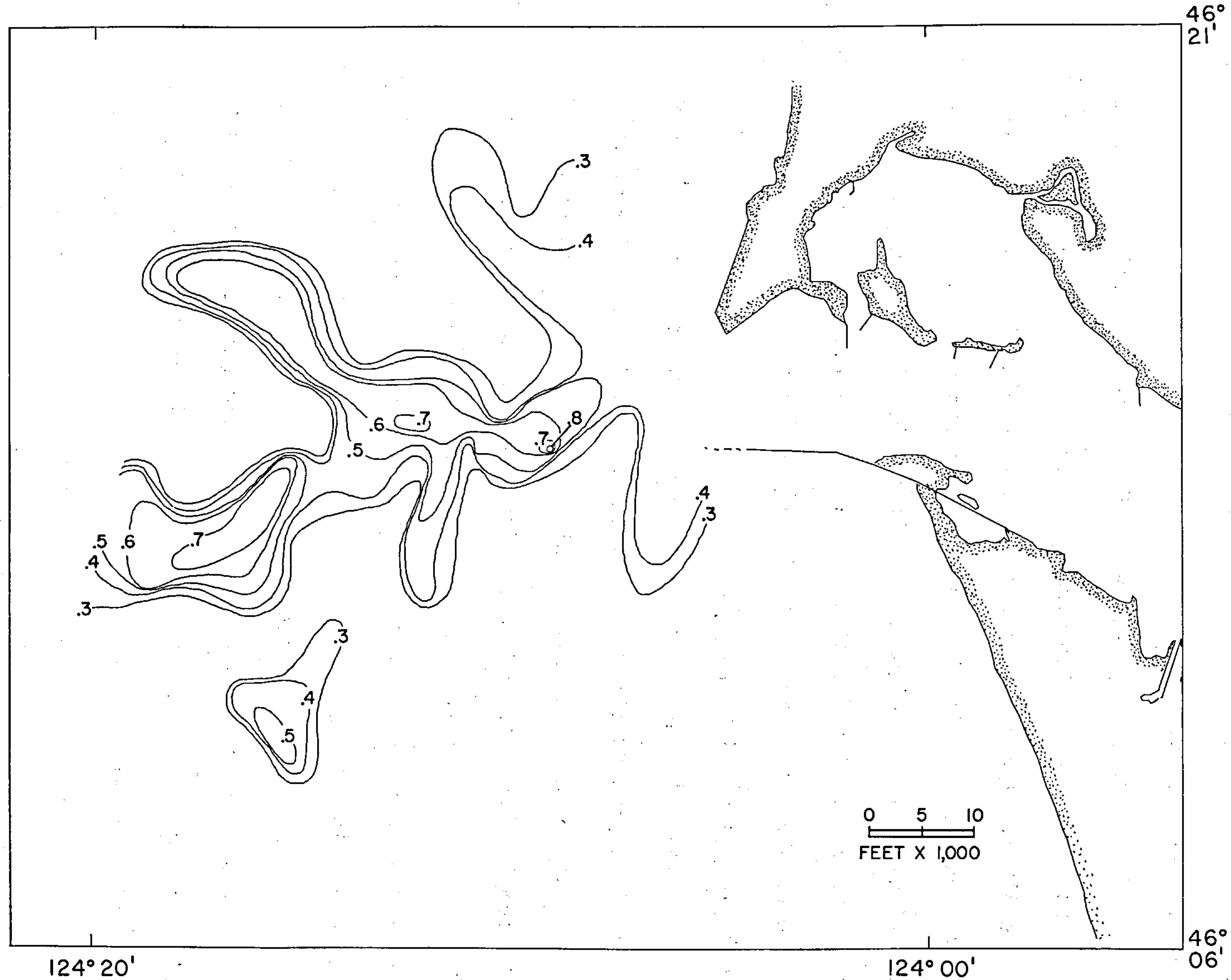

Figure A107. Contoured loadings of mineralogical Factor 1, based on samples from December 1974 and June 1975. Only those data points with factor loadings greater than 0.3 have been used in the figure.

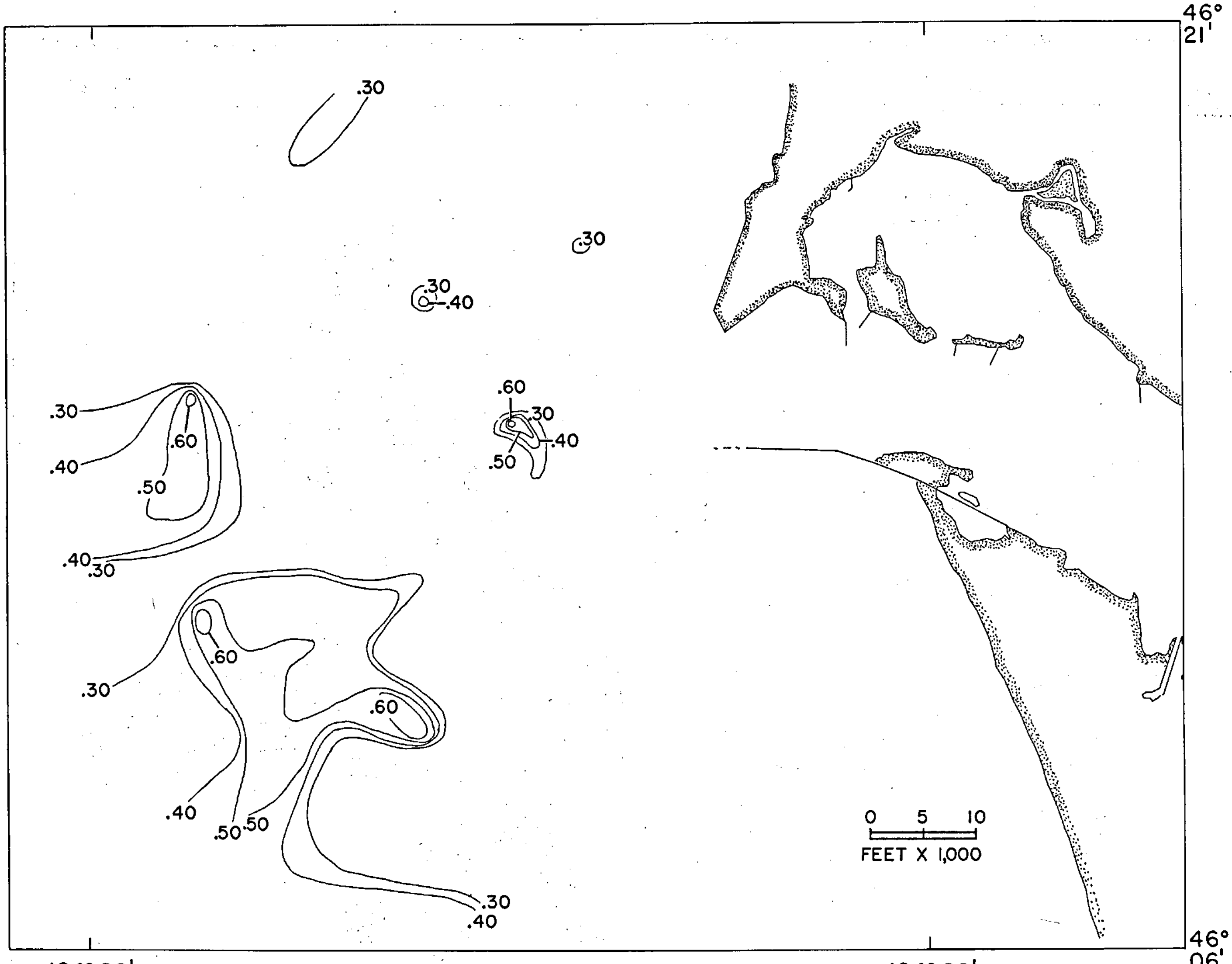

Figure A108. Contoured loadings of mineralogical Factor 2, based on samples from December 1974 and June 1975. Only those data points with factor loadings greater than 0.3 have been used in the figure.

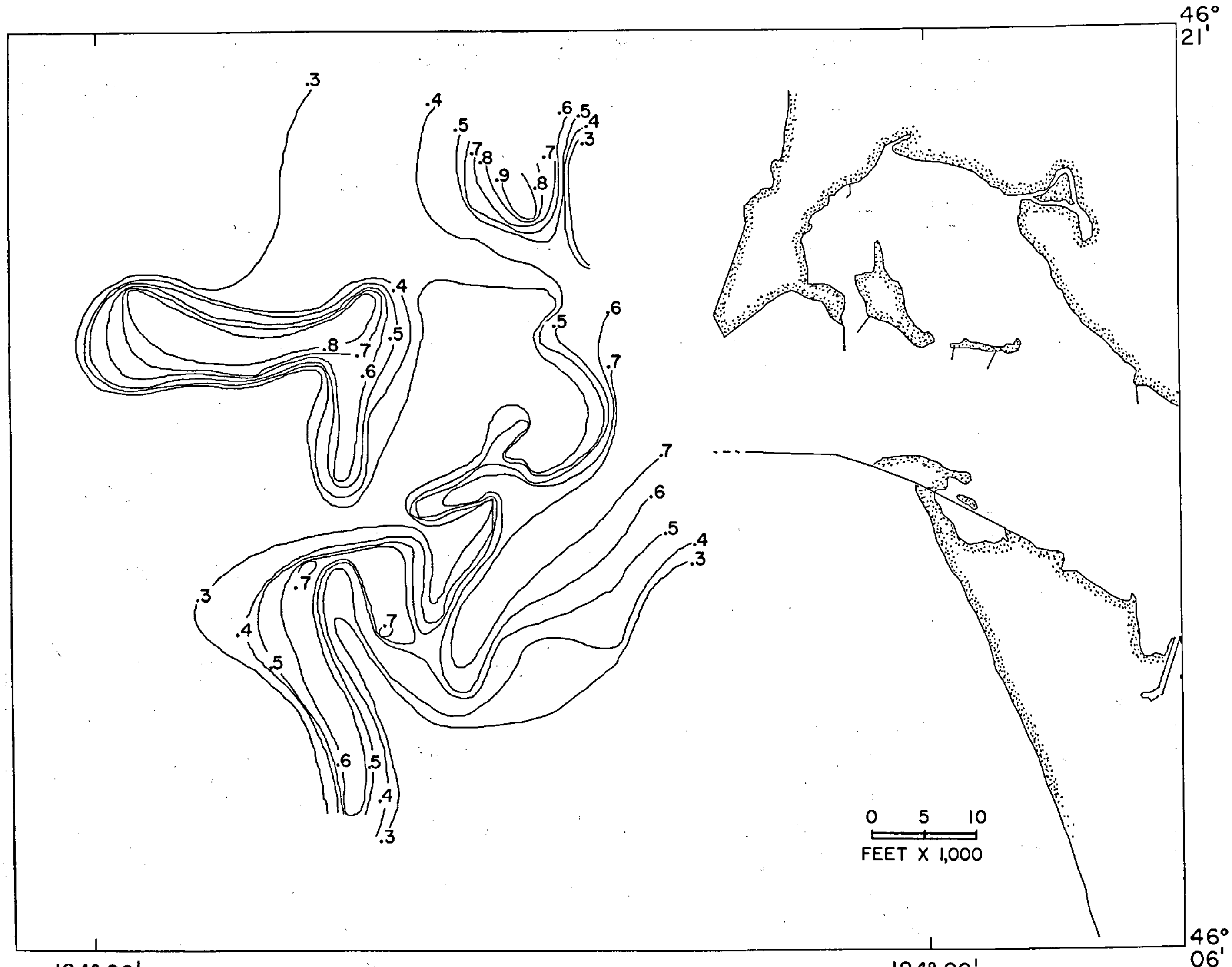

Figure A109. Contoured loadings of mineralogical Factor 3, based on samples from December 1974 and June 1975. Only those data points with factor loadings greater than 0.3 have been used in the figure.

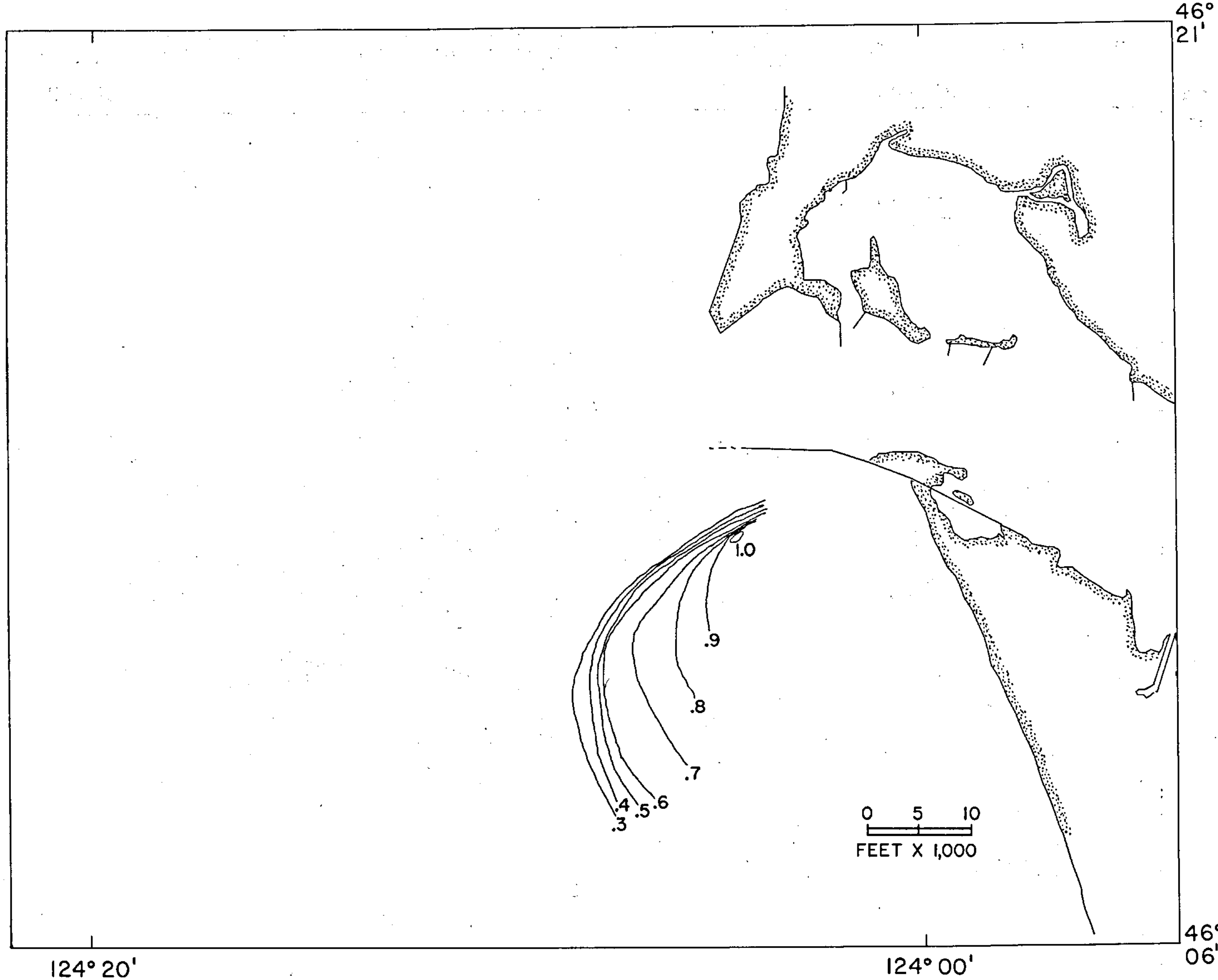

Figure A110. Contoured loadings of mineralogical Factor 4, based on samples from December 1974 and June 1975. Only those data points with factor loadings greater than 0.3 have been used in the figure.

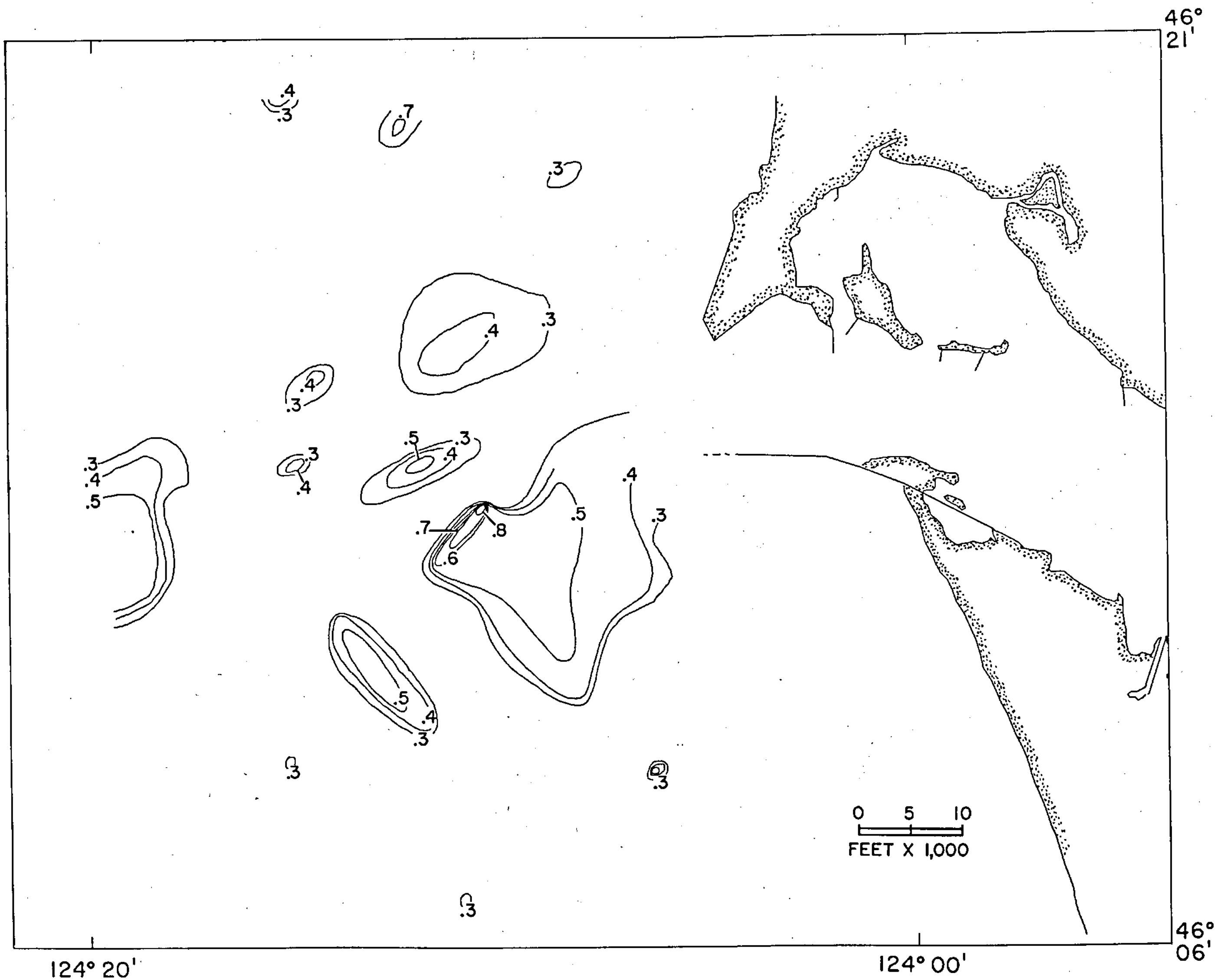

Figure A11. Contoured loadings of mineralogical Factor 5, based on samples from December 1975 and June 1974. Only those data points with factor loadings greater than 0.3 have been used in the figure.

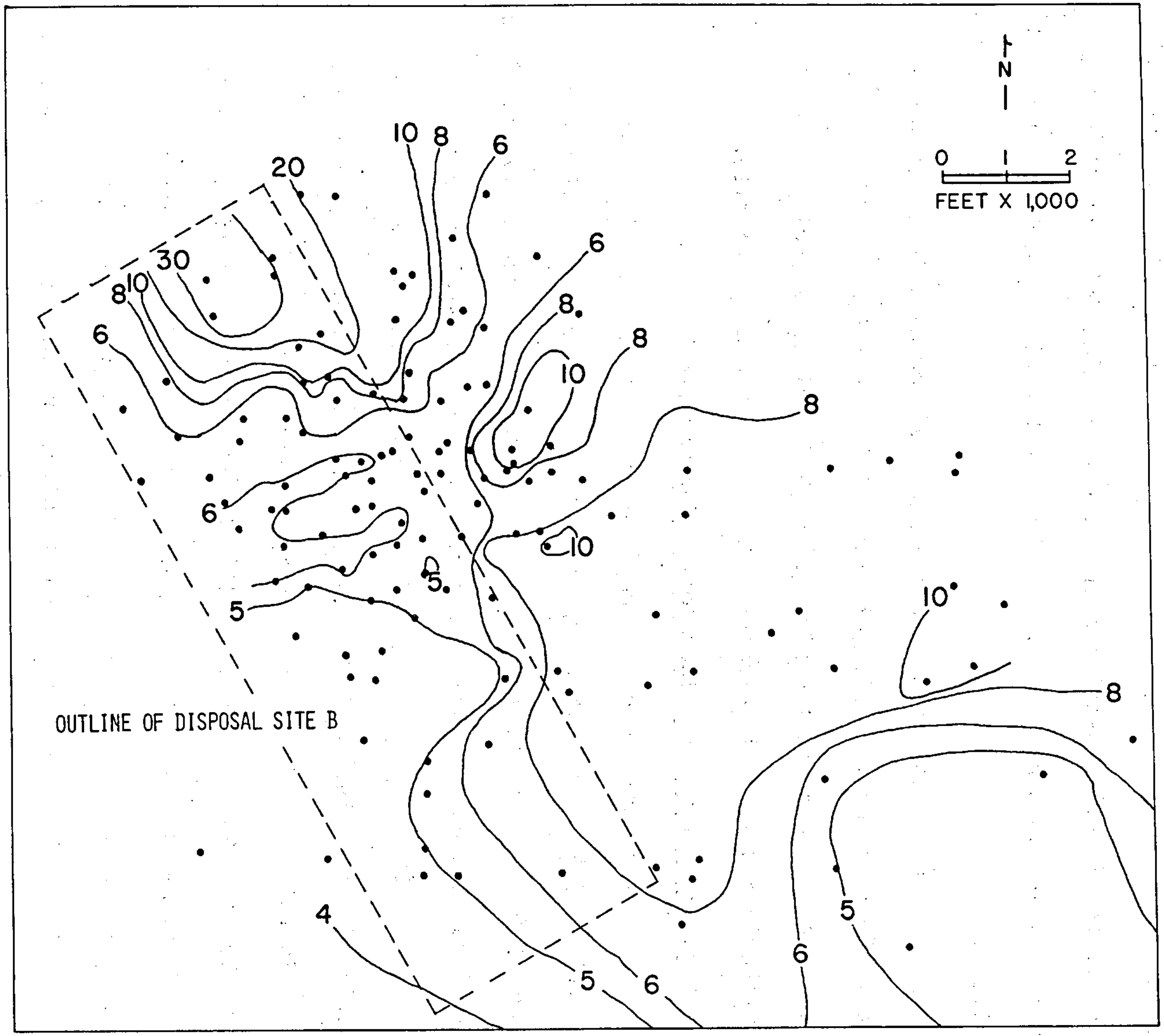

Figure A112. Contoured values of magnetic ratio around Site B based on samples collected in November 1974. The dashed rectangle outlines Disposal Site B. Sample locations are shown (•).

well as a plume that trended northwesterly away from Disposal Site B. These plumes were rich in fresh plagioclase and andesitic lithic fragments and were poor in other constituents. The plumes in both locations were mineralogically very similar to Columbia River bed material; they were also directly associated with sites at which Columbia River bed material was concentrated, i.e., the Columbia River mouth and Disposal Site B.

187. Also evident was a plume of low MR values extending north from the western side of Disposal Site B (Figure A105). This plume was adjacent to the plume of high MI values extending in a northerly and westerly direction seaward of the disposal site.

Seasonal variations in mineralogical properties

188. High density sampling was conducted at Site B in November 1974 and December 1975 and at Site G in December 1974 and June 1975 prior to the experimental disposal. This repetitive sampling provided data pertaining to temporal variation in sediment distribution.

189. Site B. Maps of the MR values for samples collected during November 1974 and December 1975 indicate major fluctuations in the mineralogy of sediment near the disposal site. The results for the November 1974 cruise (Figure A112) showed that high MR values (>10) were obtained immediately north of the disposal site. Since no indication was evident from the point count analysis that anything but Columbia River sediment was present in this region, the high MR values were interpreted as representing winnowing and sorting of original Columbia River sediment. East of Site B, MR values continuously increased.

190. Results from the December 1975 cruise (Figure A113) showed that within the Disposal Site B boundaries, there were major changes in the location of contours and their absolute magnitudes, but MR distribution patterns remained similar to those found during the November 1974 cruise. To the east of the disposal site, however, MR values decreased consistently, in contrast to the regular eastward increase evident from the November 1974 results.

191. Site G. Site G was intensively sampled in December 1974, June 1975, September 1975, and December 1975 (Figures A114, A115, A116, and A117). The December 1974 and June 1975 cruises were conducted prior to the experimental disposal operation and thus provided baseline data for seasonal variation studies.

192. The results of the December 1974 and June 1975 cruises (Figures A114 and A115) demonstrated that no significant areal change in sediment mineralogy can be recognized; seasonal variation in mineralogy thus seems to be inconsequential in this region. Magnetic ratio values were consistently low, never exceeding 5.0, with 90 percent of the area characterized by values less than 2.0. Minor variation in contour location was evident, however, because the mineralogical characteristics of the sediment exhibited small-scale areal variability, shifts in the contours could readily result solely from the fact that it was impossible to precisely reoccupy previous sampling stations.

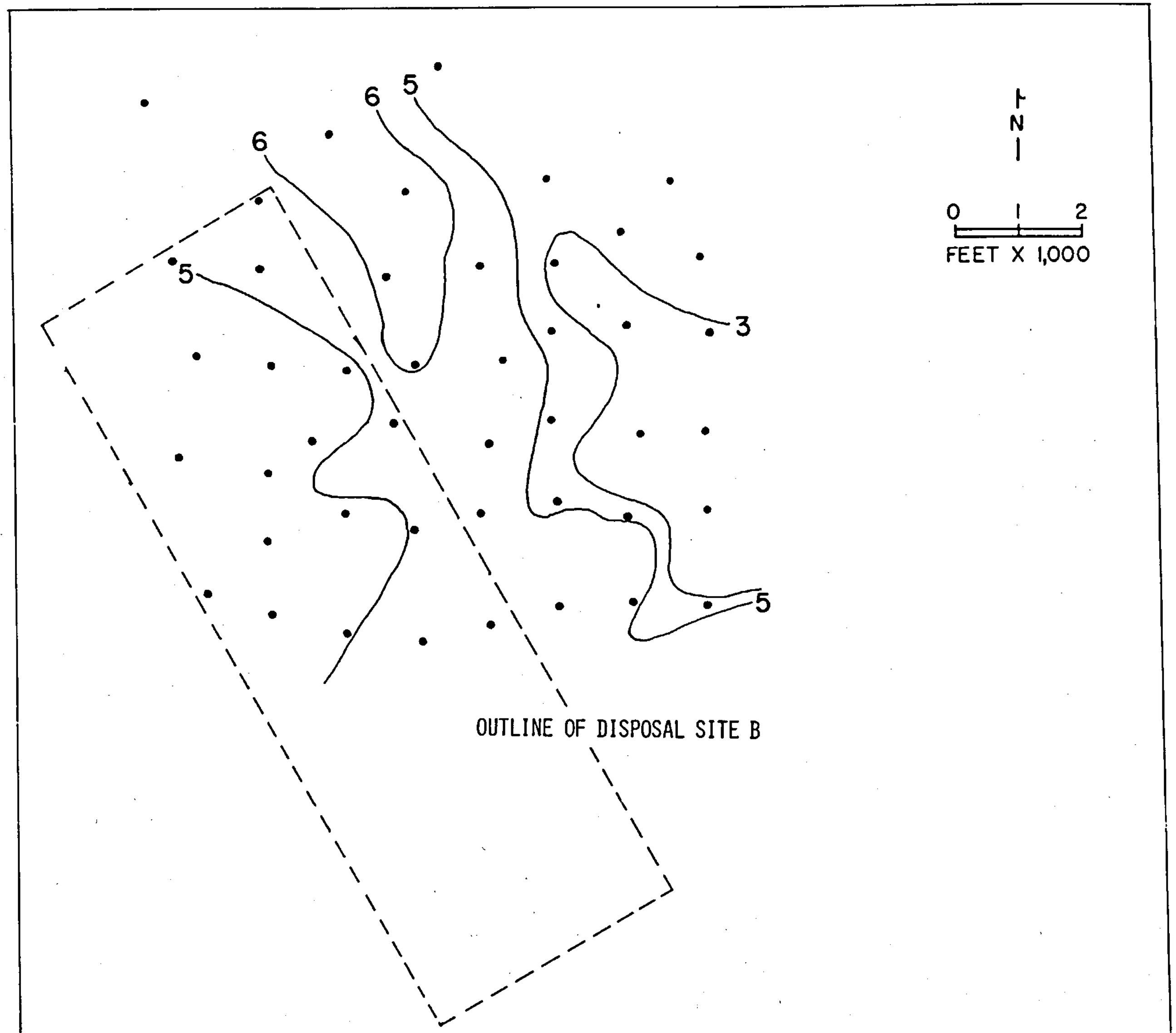

Figure A113. Contoured values of magnetic ratio around Site B based on samples collected in December 1975. Sample locations are shown (•).

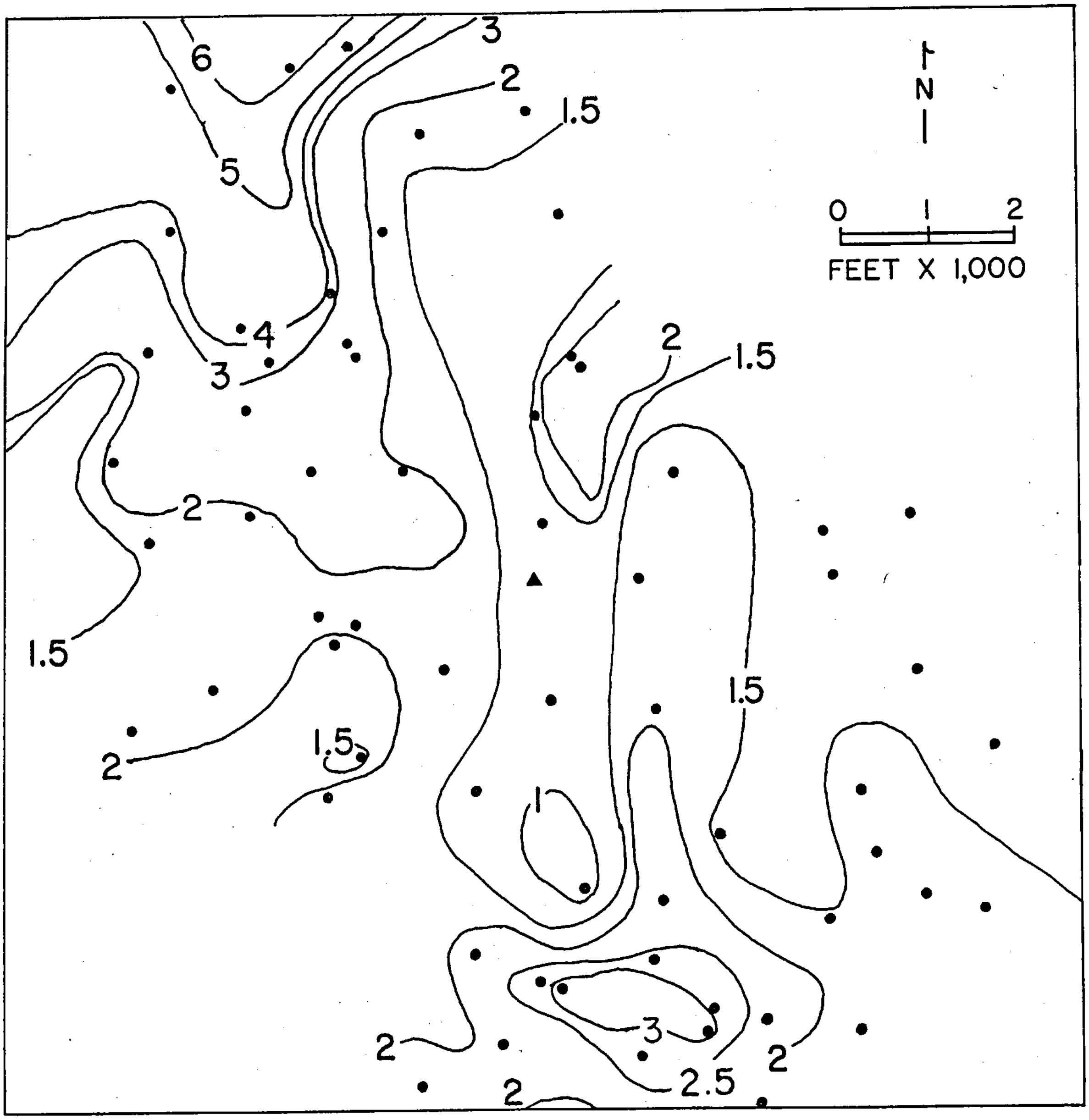

Figure A114. Contoured values of magnetic ratio around Site G, based on samples collected in December 1974. The solid triangle is the position of Disposal Buoy D

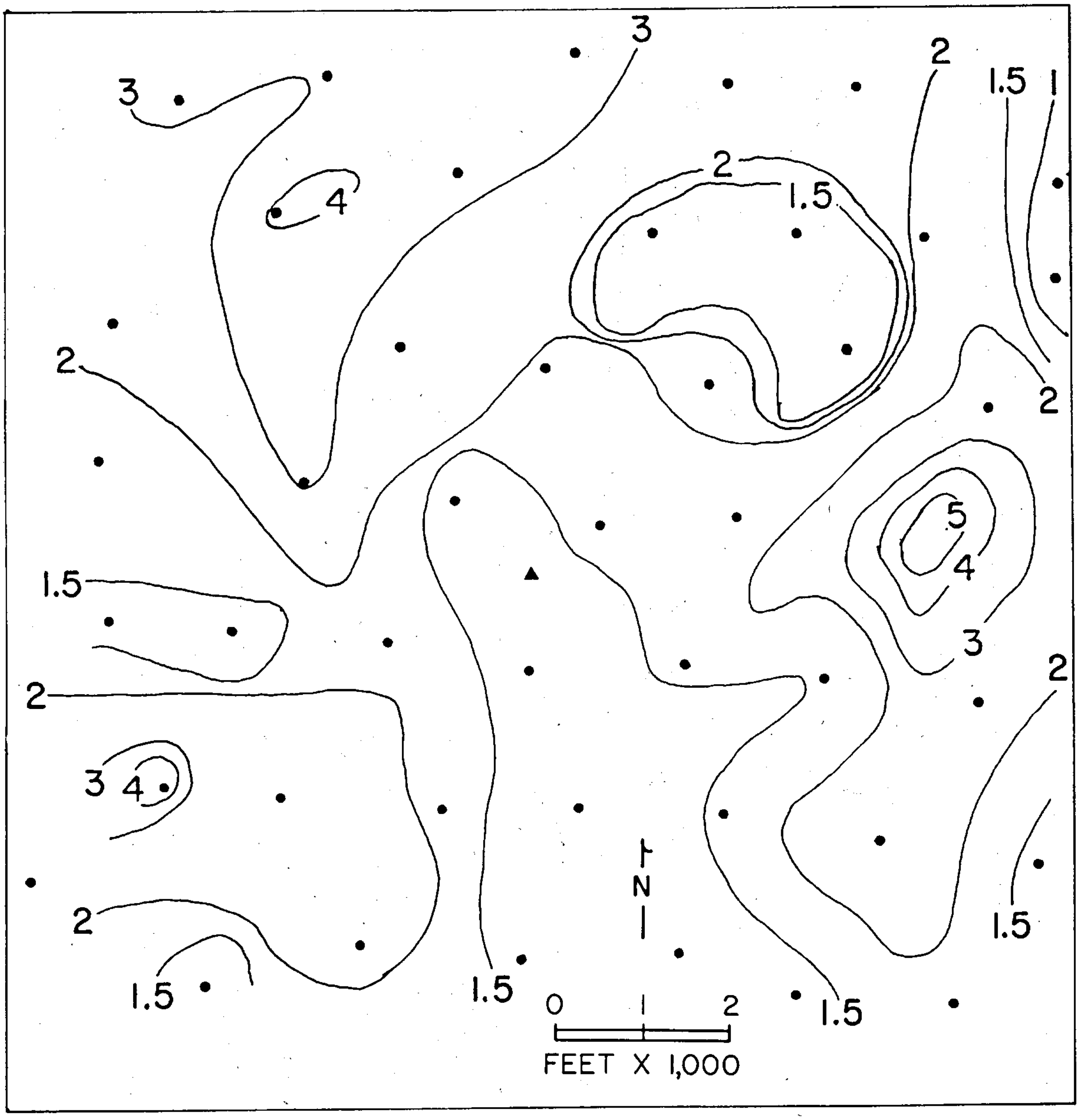

Figure A115. Contoured values of magnetic ratio around Site G, based on samples collected in June 1975. The solid triangle is the location of Disposal Buoy D

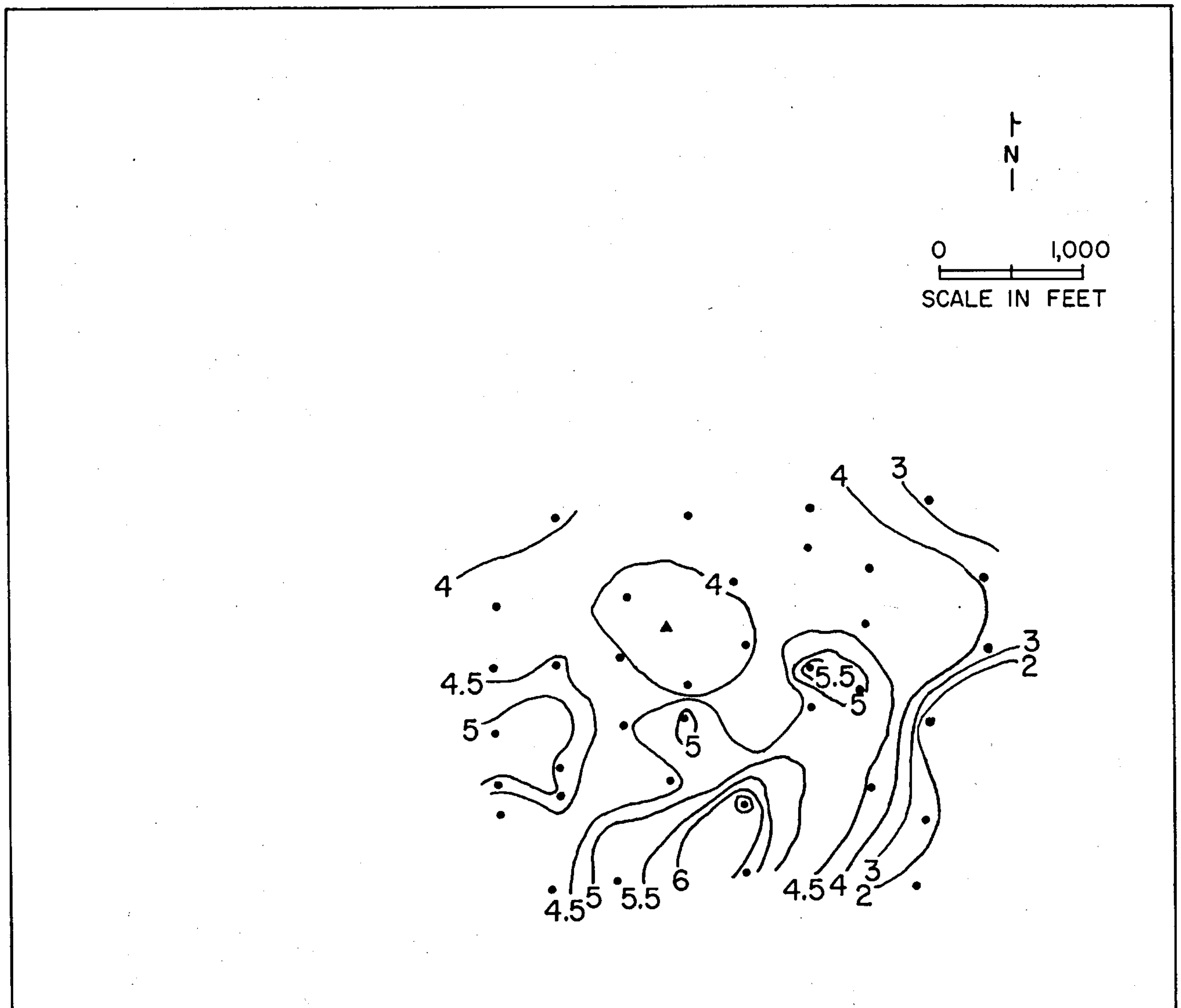

Figure A116. Contoured values of MR around Site G based on samples collected immediately after termination of the experimental disposal operation, September 1975. The solid triangle is the location of Disposal Buoy D. Sample locations are shown (•).

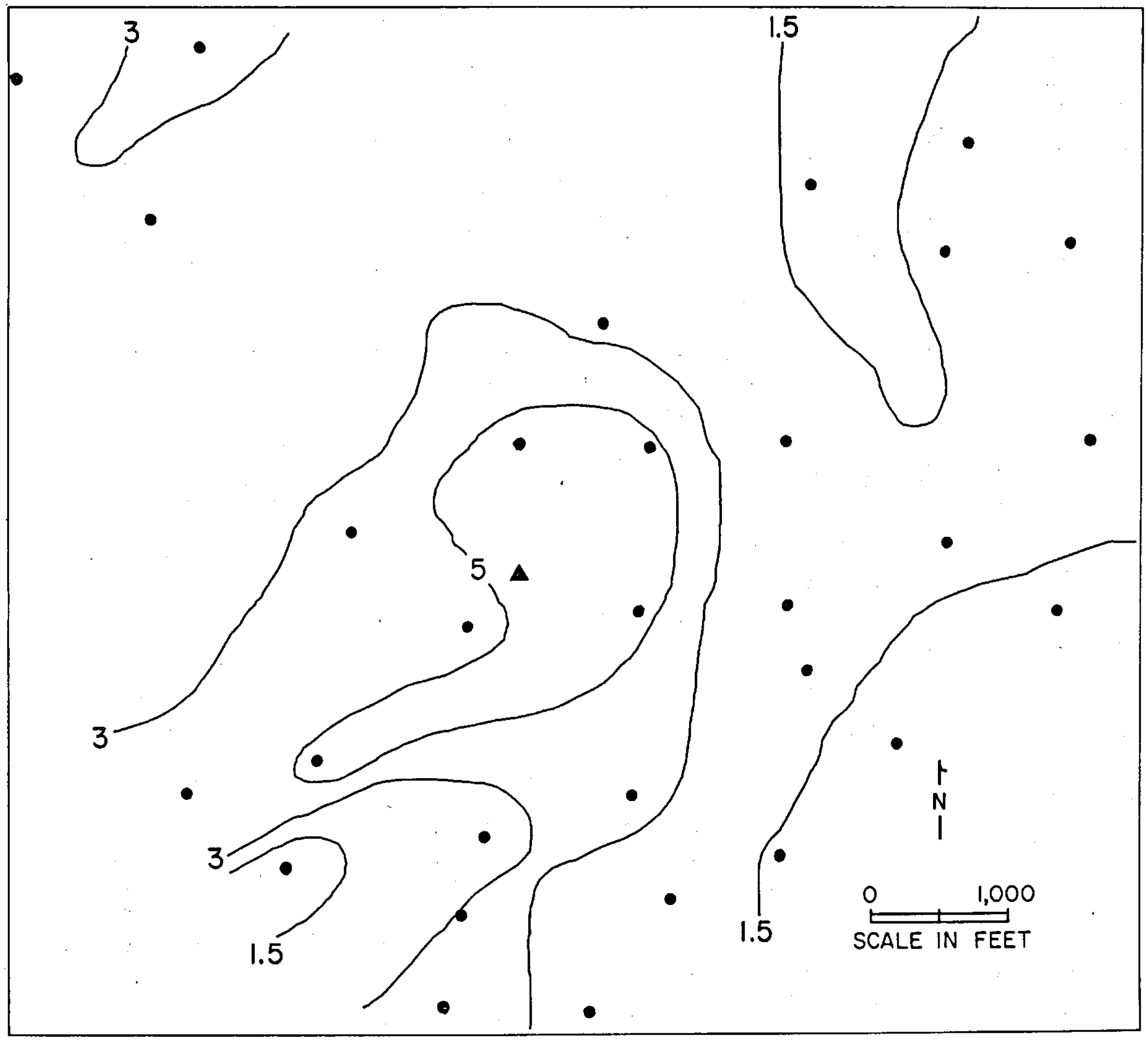

Figure A117. Contoured values of MR around Site G based on samples collected in December 1975. The solid triangle is the location of Disposal Buoy D. Sample locations are shown (•)

PART VI: DISCUSSION

Bathymetry

193. Figures A118 and A119, representing bathymetry changes from 1964-1965 and 1965-1966, show no systematic erosion or deposition on the tidal delta. This suggests that the magnitude of bathymetric changes in 1 yr is on the same order as the resolution of the analytical technique. Maps spanning 3-7 yr (Figures A120-A122), however, indicate a tendency for the southern side of the tidal delta to experience net erosion while the northern side extends northward through net deposition. Regions of net deposition and erosion agree with those of Lockett (1963), based on offshore scour and shoal volumes for 1926-1958.

194. The outer tidal delta (Figures A22 and A23) is skewed toward the north in conformity with the net northerly longshore transport system of this coast. Data collected during this study indicated that the tidal delta has continued to extend northward by net deposition since Lockett's 1958 calculations. The surface of this depositional feature is marked by the 60-ft isobath. The steeper outer depositional slope extends to just beyond 100 ft, except directly off the Columbia River entrance at Site B where dredged material has been deposited for years. The rate of deposition of this material has been greater than the rate of removal due to natural processes, producing a secondary positive bathymetric feature between 72 and 118 ft.

195. Prior to the summer 1975 experimental disposal of approximately 600,000 cu yd of sediment, bathymetric contours at Site G were regular and shoaled to the northeast (Figure A24). Postdisposal bathy-

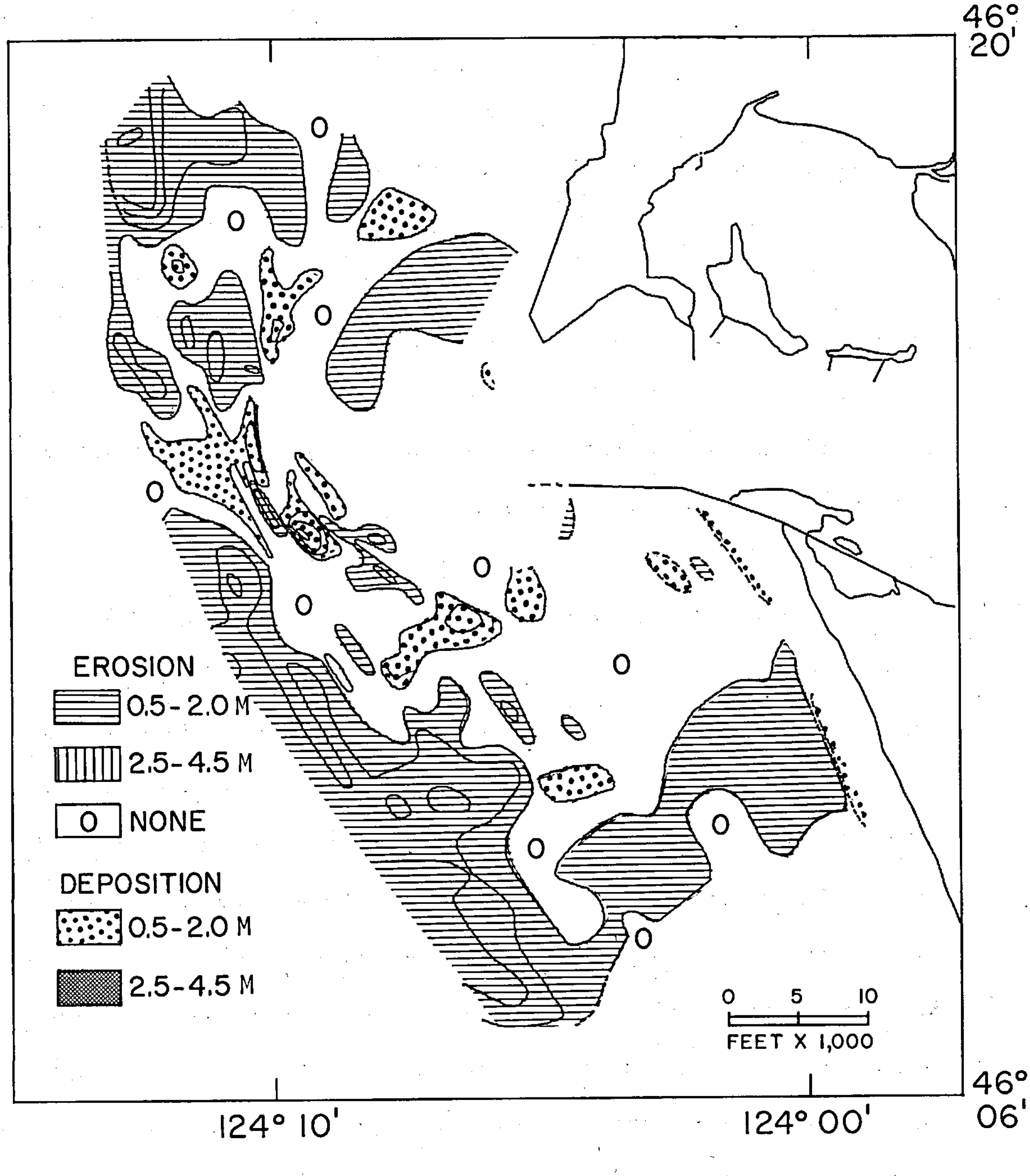

Figure A118. Bathymetric changes in study area from 29 June 1964 to 5 August 1965. Contour interval is 0.5 m

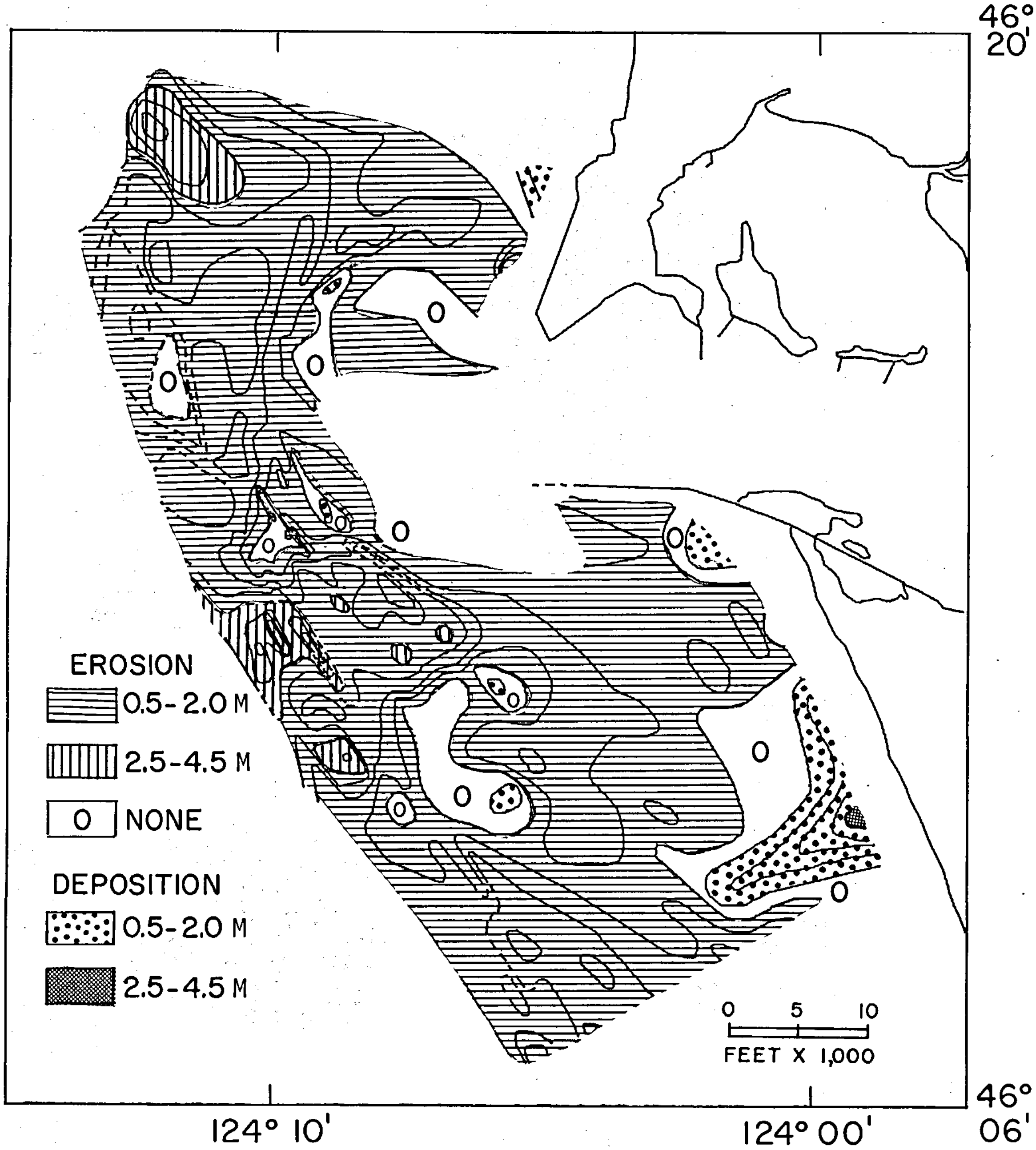

Figure A119. Bathymetric changes in study area from 5 August 1965 to 7 September 1966. Contour interval is 0.5 m

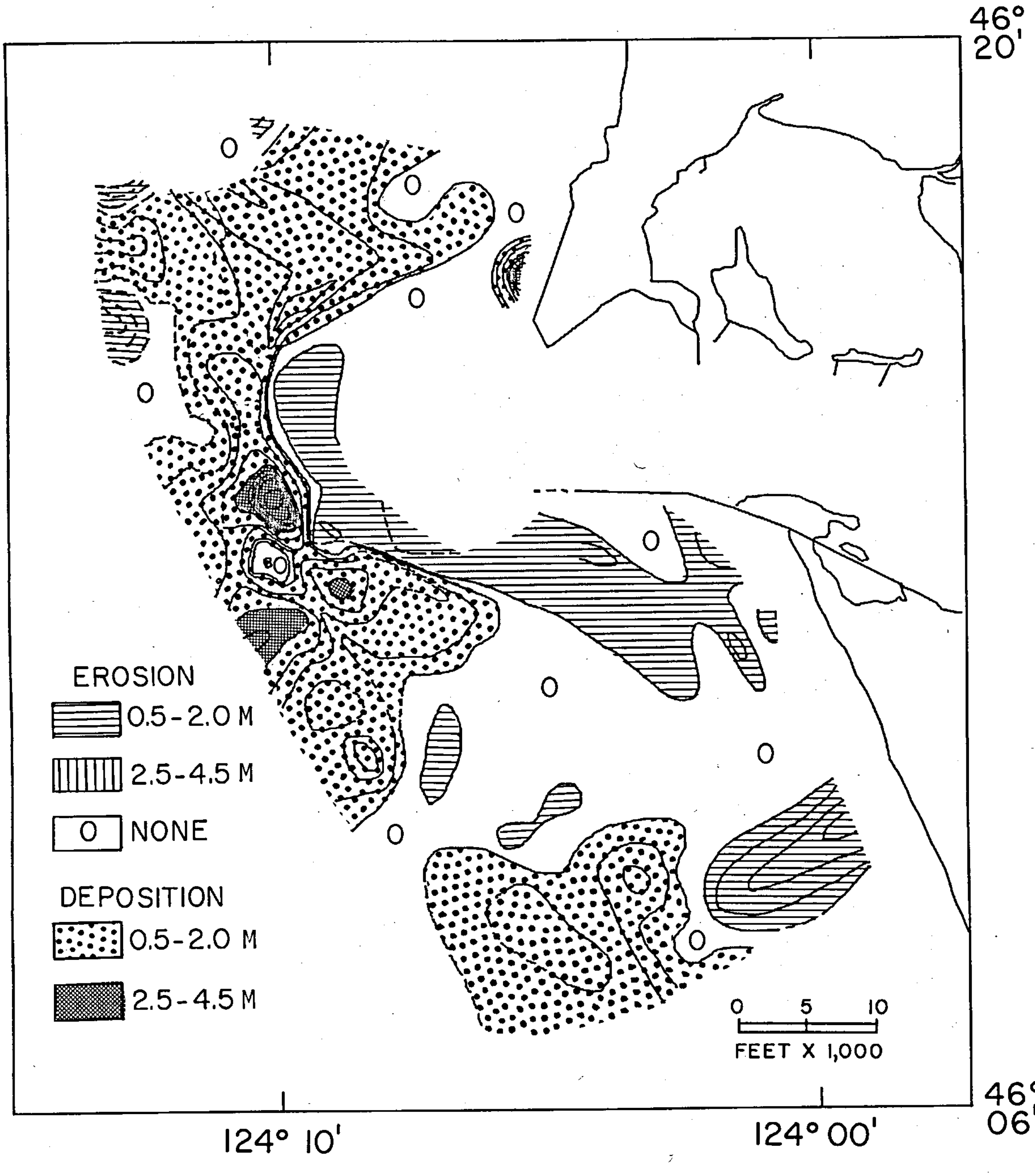

Figure A120. Bathymetric changes in study area from 7 September 1966 to 17 June 1971. Contour interval is 0.5 m

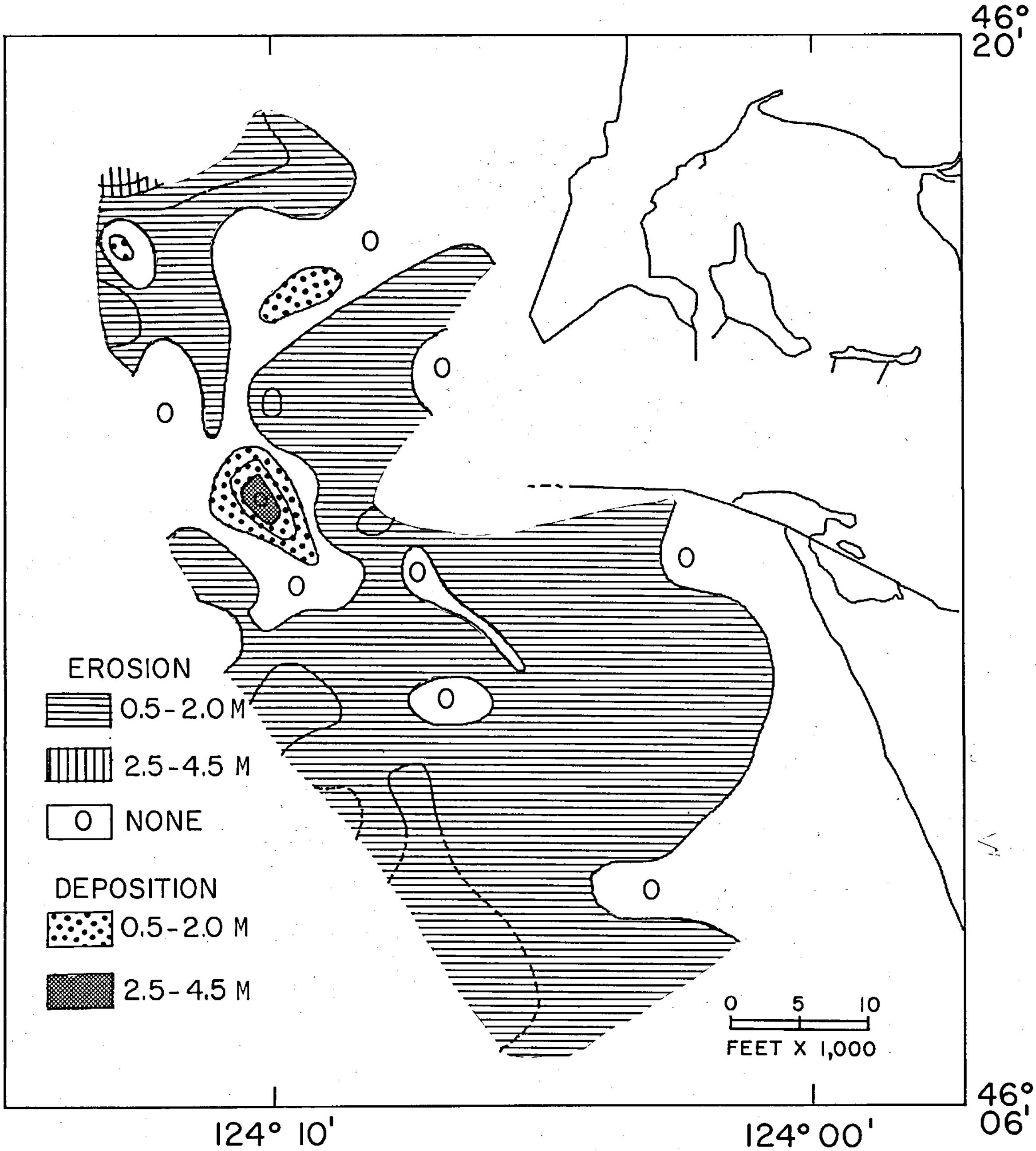

Figure A121. Bathymetric changes in study area from 29 June 1964 to 17 June 1971. Contour interval is 1.0 m

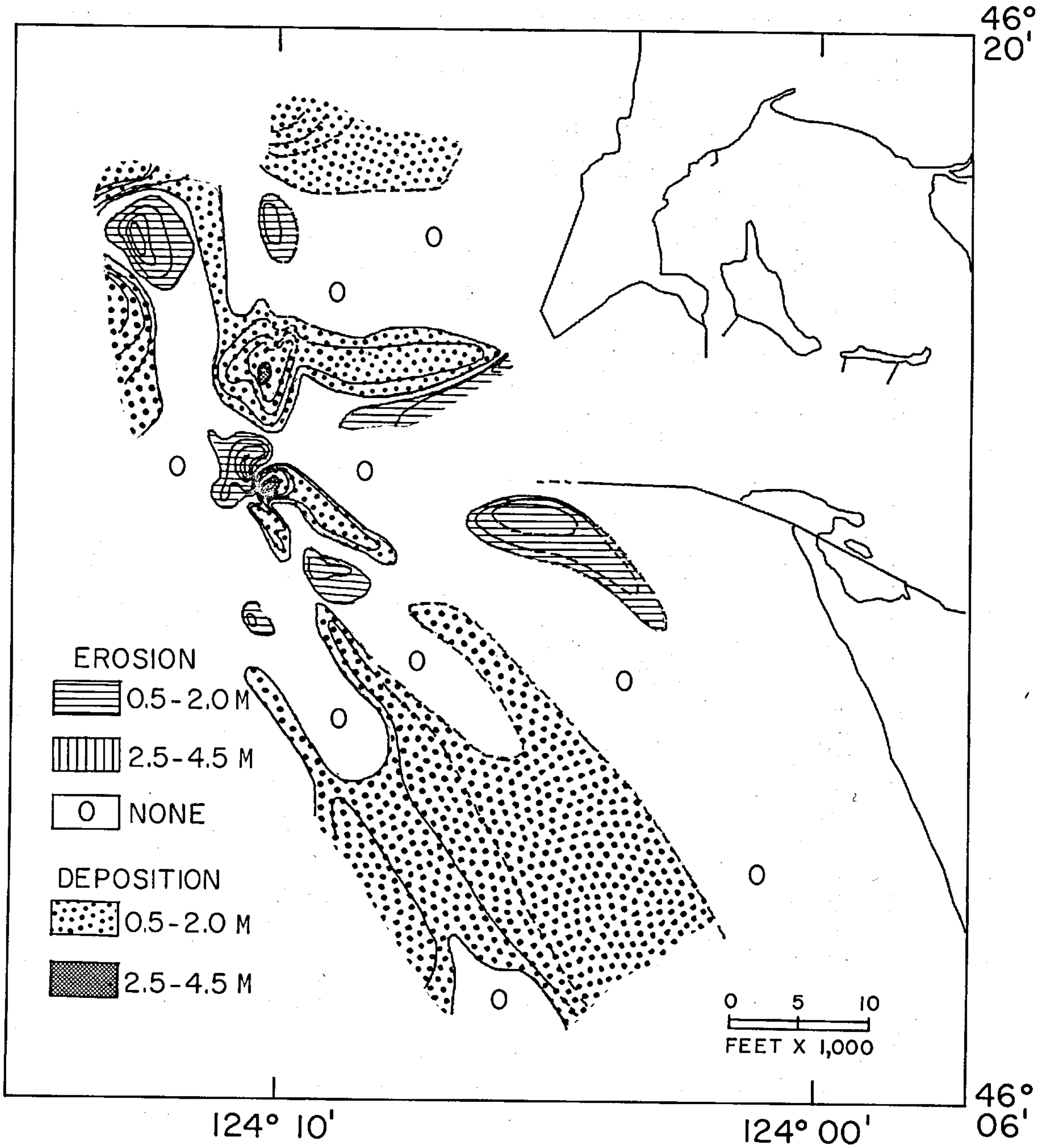

Figure A122. Bathymetric changes in study area from 17 June 1971 to 3-7 September 1974. Contour interval is 0.5 m metry (Figure A25) indicates that the measurable effect of the disposal was confined to a 1500-ft radius about Disposal Buoy D, with accumulation dominantly to the south and west of the buoy. A comparison of the predisposal and postdisposal bathymetry, in the form of an isopach map, is shown in Figure A123. The measurable sedimentary deposit immediately following the disposal experiment had a volume of 424,000 cu yd. This represented 71 percent of the total quantity of dredged material reported to have been dumped at this site.

Bottom Currents

196. Bottom currents in the study area are complex in both space and time and appeared to be the result of four interacting phenomena: tides, river hydraulics, winds, and waves. Semipermanent ocean circulation may influence the coastal zone but its contribution to the velocity field in this region was not evaluated in the present study. Each of the recognizable velocity components has its own speed and direction characteristics and is also related to the bathymetry of the river mouth and seasonal variability. Singularly they may or may not have sufficient strength to move sediment; however, the sum of several velocity components may exceed the threshold requirements for grain motion and thus play a significant role in local sedimentation.

Tidal currents

197. The system of tidal currents was considered as the basic velocity component upon which all others are superimposed. At numerous times during the measurement periods, conditions were such that tidal currents were the dominant component of bottom flow and thus could be

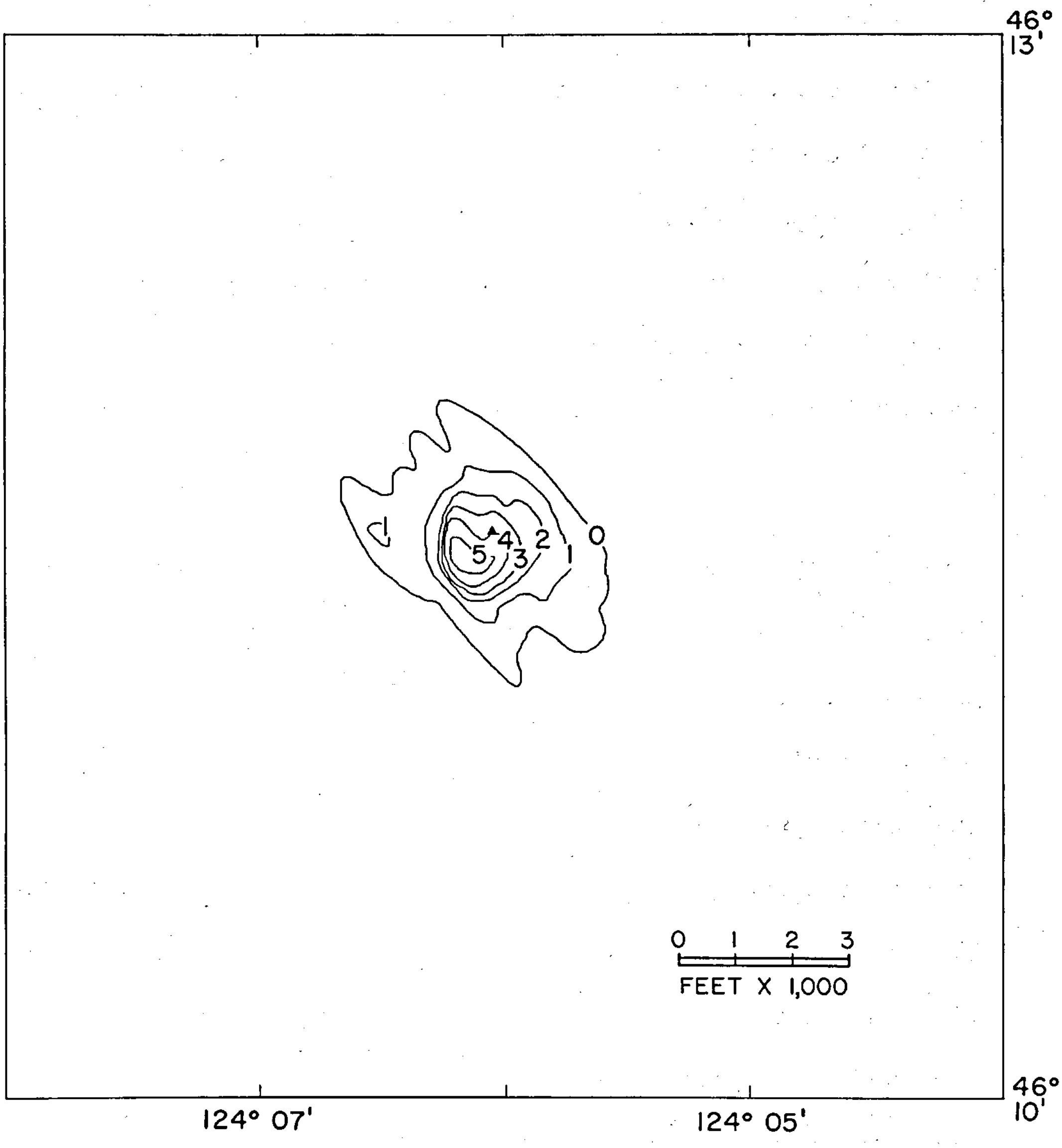

Figure A123. Bathymetry change at Site G due to experimental disposal. Disposal Buoy D is located at ▲. Contour interval is expressed in feet evaluated. Estimates of tidal currents for the study area are tabulated in Table A12. These estimates show that the maximum tidal component of $\bar{U}_{100}$* was approximately 15 to 20 cm/sec with flood currents trending northerly and ebb currents southerly more or less parallel to the isobaths. The magnitude of the tidal component of $\bar{U}_{100}$ tended to be slightly greater at the northern Stations 1, 2, and 6 (15 to 20 cm/sec) than at Stations 4 and 5 on the southern side of the study area (10 to 15 cm/sec). This difference may be related to topographic effects and/or interactions with the salt-wedge intrusion.

River hydraulics

198. The velocity component resulting from the estuarine flow near the river mouth was very difficult to interpret. The general characteristics of the seawater intrusion and the flow characteristics in the lower estuary are reasonably well documented (e.g., Hubbell et al. 1971); however, as the river plume enters the sea as a turbulent jet, it becomes subjected to, and interacts with, a new set of environmental circumstances. The river injects low salinity surface water that mixes with the surrounding water as a function of wind, tide, discharge, and surf conditions (Budinger et al. 1964). Entrainment of water into the plume from below also takes place, and patches of effluent water break off and are seen as short-period fluctuations in the various water properties such as salinity, nutrient content, or speed (Duxbury and

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*$\bar{U}_{100}$ generally refers to the mean velocity (over a 30-min period) 100 cm above the seabed; however, it is also used to denote specific components of the bottom velocity in which case it is preceded by the appropriate modifier.

Table A12

Maximum Tidal Current Characteristics in the Study Area

Station	Current Meter Elevation, m	Maximum Flood U cm/sec	Maximum Flood V cm/sec	Maximum Flood Range of Direction	Maximum Ebb U cm/sec	Maximum Ebb V cm/sec	Maximum Ebb Range of Direction
1	1.0	-15*	15	330°-40°	-15	15	200°-250°
2	1.0	-15	18	340°-20°	-15	-18	165°-180°
3	1.0	-12	16	355°-15°	-12	16	100°-200°
4	1.0	- 7	11	355°-10°	7	11	180°-200°
5	1.0	-10	11	355°-10°	10	11	160°-180°
6	1.0	-15	18	340°-25°	15	18	170°-200°
South Jetty	4.6	50	60	N	70	60	S
	9.4	50	70	N	70	60	S
North Jetty	2.8	100	80	NE	150	60	SW
	16.5	100	50	NE	150	100	SW
Buoy 1	11.4	28	28	330°-30°	40	35	160°-200°

*A negative sign refers to a south or west direction; the other directions are north or east.

McGary 1968). The result is a complex and highly variable water mass which undergoes continual change and varies on time scales ranging from seconds to months. Considering the complexities discussed above and the sampling density in space and time in this study (Table A8), it was virtually impossible to depict the total bottom velocity field resulting from the river hydraulic system. A large number of measurements were made, however, and are discussed below.

199. Results from the moored current meters suggest that the maximum seawater intrusion into the river mouth occurred from the southern regions of the study area. The near-bottom flow in the vicinity of the south jetty was the only station showing a dominant net flow direction into the river (Figure A50). Bottom currents measured at tripod Station 3 also showed a weak easterly net flow toward the river mouth (1.1 cm/sec). Station 3 was located approximately 2 nmi southwest of the south jetty. All other bottom current measurements made during this study exhibited a net flow parallel to the coastal trend, that is, south to north or northwesterly. The current meter station at the north jetty measured a net westerly flow or ebb dominance in this region (Figure A50).

200. Maximum discharge. Comparison of the salinity profiles at Station Kay-3 over the Columbia River tidal delta shows that the base of the low-salinity effluent layer varied between about 13 and 33 ft in depth (Figure A55). The base of the effluent layer rises and falls on a tidal basis as low salinity water is stored in the river during hig tide (pycnocline depth ~16 ft) and released on the falling ebb (pycnocline depth ~33 ft). The profiles shown in Figure A55 are typical of

conditions along the north side of the entrance region (e.g., Station J D, Figure A48); while in contrast, Station Carol on the south side of the entrance region does not show the influence of the effluent plume (Figure A56) and has previously been described as a region of upwelling (Duxbury 1967). These results suggest that the main river discharge is along the northern part of the channel, which is in agreement with the current meter observations and the observations of other workers (e.g., see Lockett 1963).

201. The characteristics of the $\bar{U}_{100}$ record from tripod Station 3, which overlaps in time the measurements discussed above illustrate the complexity of the flow in the vicinity of the river mouth during high discharge. The U and V components at Station 3 (Figure A45) were characterized by their complex nature with fluctuations occurring on a semidiurnal, diurnal, and about a 3-hr periodicity. These short-period fluctuations had a magnitude of $\bar{U}_{100}$ of about 15 to 20 cm/sec. This phenomenon is possibly referred to by Duxbury and McGary (1968) who emphasized that during periods of high river discharge, pockets of dilute surface water separate from the plume and cause significant short-period fluctuations in the water properties measured at a point. These fluctuations may also be associated with entrainment of seawater from below.

202. Minimum discharge. Instrumented tripod Stations 4 and 5 were occupied during the time of minimum river discharge (August/September) and were located approximately 1 to 1.5 nmi south of the Station 3 location. [Some of this difference must be due to the fact that Station 3 was located closer to the river mouth and was subjected

to greater fluctuations in velocity due to the river flow.] The characteristics of $\bar{U}_{100}$ during September were less complex than during June. The semidiurnal tidal component tended to dominate the velocity record and shorter period fluctuations occurred less frequently than during the time of maximum discharge. This general observation was also made by Duxbury and McGary (1968), who stated that the reduced river flow in September allows the effluent a longer residence time in the region near the mouth, during which mixing processes create a more uniform horizontal distribution. Also during low discharge the estuary tends toward vertical homogeneity (Neal 1972), which would be associated with minimal fluctuations in water properties.

Winds

203. The importance of wind stress in generating and maintaining water movements along the Washington-Oregon coast has been well documented and discussed in detail by many authors (e.g., Collins and Pattullo 1970, Hopkins 1971, Smith and Hopkins 1972, Huyer et al. 1974, Smith 1974). In the study area, winds play an important role in generating water movements and a visual correlation is seen to exist between the occurrence of strong winds and the nontidal component of $\bar{U}_{100}$. This relationship is best observed by comparing mean winds and bottom currents from the various stations shown in Figures A124-A127. All data in these figures were averaged over 25-hr periods to remove tidal and diurnal variations and plotted as a vector for each 8 hr or three vectors per day. The wind speed vectors were shifted to represent the direction toward which the wind is blowing, thus coinciding with the directional sense of the $\bar{U}_{100}$ vectors. These vector representations

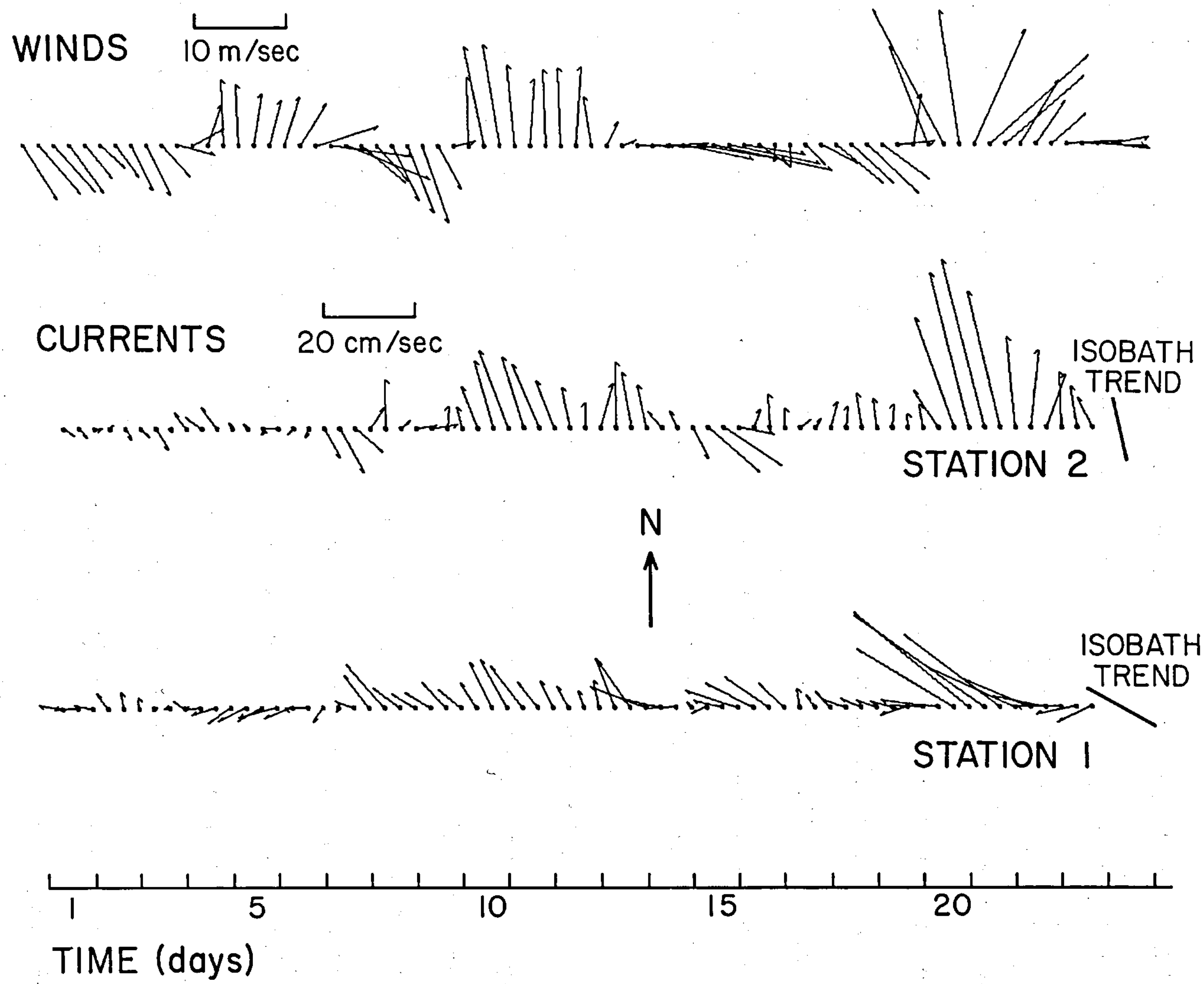

Figure A124. Columbia River Lightship winds and the nontidal component of $\bar{U}_{100}$ vs. time for Stations 1 and 2 during the period 1900 12 Apr 75 and 0800 6 May 75. All data were averaged over 25-hr periods and plotted as the direction toward which the flow was moving. The trend of the isobaths at the stations is also shown

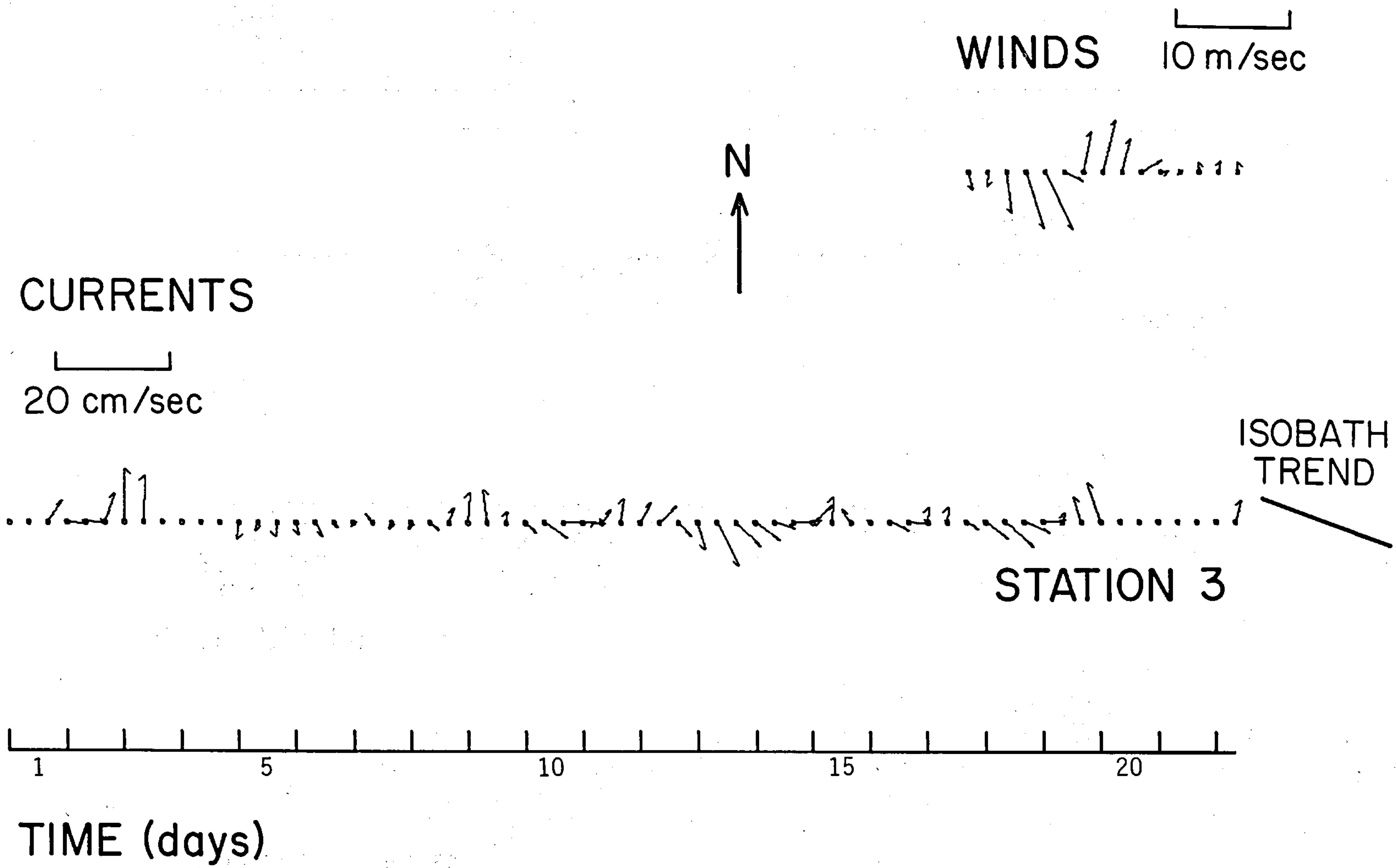

Figure A125. Columbia River Lightship winds and the nontidal component of $\bar{U}_{100}$ recorded at Station 3 during the period 15 June 1975 and 8 July 1975. All data were averaged over 25-hr periods and plotted as the direction toward which the flow was moving. The trend of the isobaths at the station is also shown

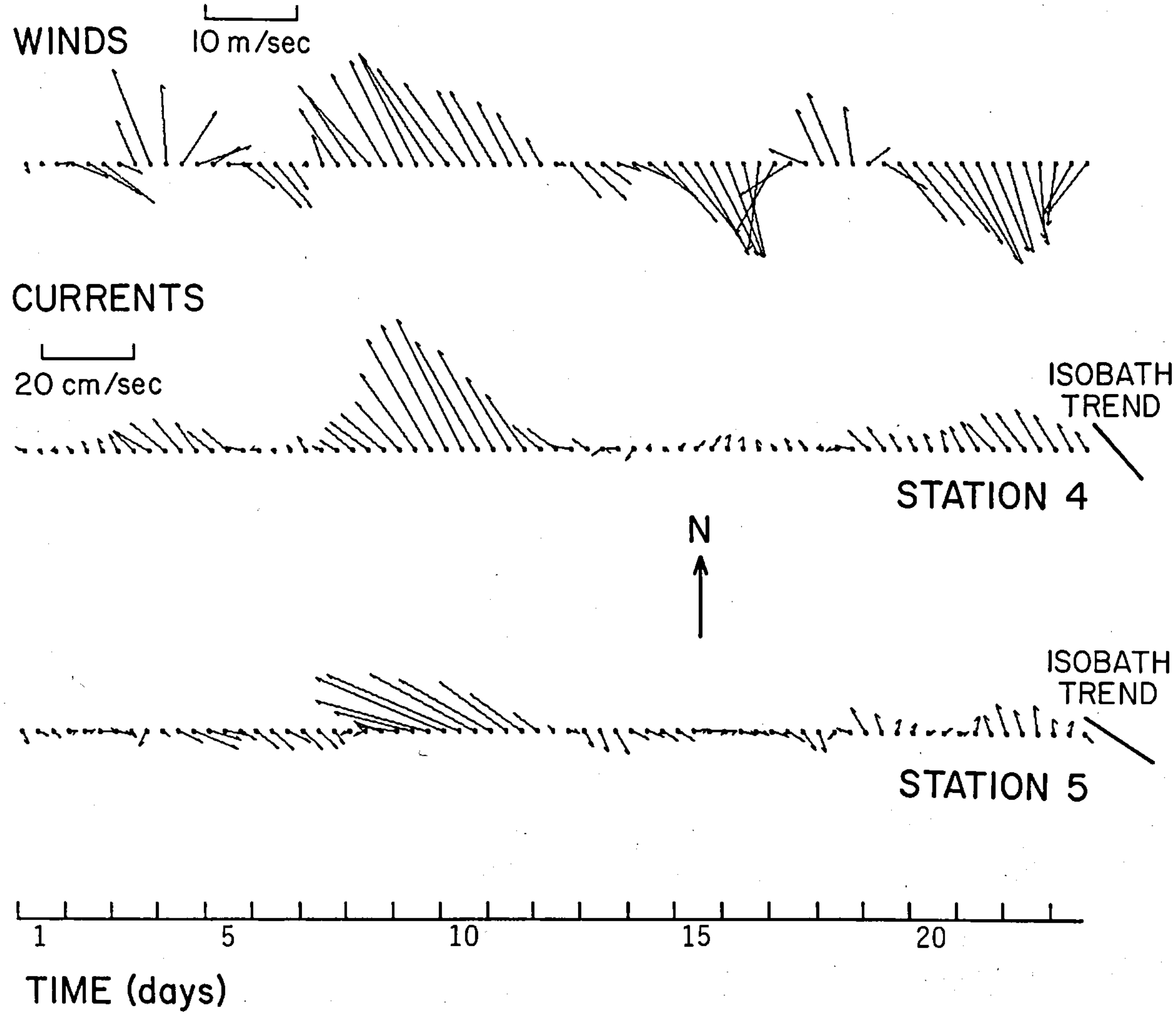

Figure A126. Columbia River Lightship winds and the nontidal component of $\bar{U}_{100}$ recorded at Stations 4 and 5 during the period 1300 19 Aug 75 and 0800 12 Sept 75. All data were averaged over 25-hr periods and plotted as the direction toward which the flow was moving. The trend of the isobath at the stations is also shown.

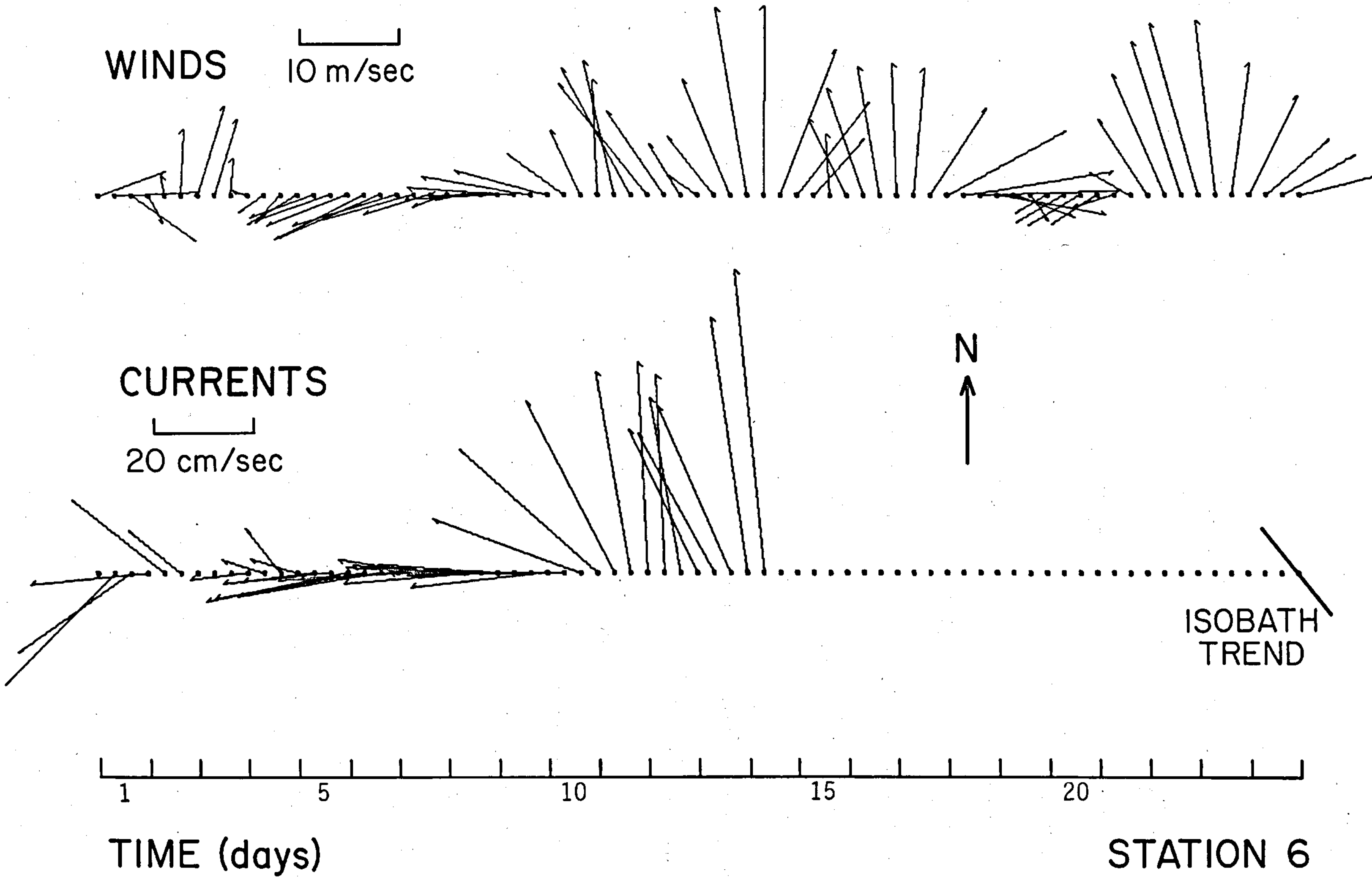

Figure A127. Columbia River Lightship winds and the nontidal component of $\bar{U}_{100}$ recorded at Station 6 during the period 0000 12 Dec 75 and 2400 6 Jan 76. All data were averaged over 25-hr periods and plotted as the direction toward which the flow was moving. The trend of the isobath at the station is also shown show that the stronger southerly winds are associated with strong bottom flows to the north. In most cases the direction of the nontidal components of $\bar{U}_{100}$ was approximately parallel to the bottom contours, which are also shown in Figures A124-A127. The best examples of the correlation between winds and currents were observed during storms occurring on record day 20-23 of Station 1 and 2 (Figure A124); record day 7-11 of Stations 4 and 5 (Figure A126); and record day 10-11 of Station 6 (Figure A127). The relationship between wind speed and the nontidal component of $\bar{U}_{100}$ for the three major storms described above are plotted as a linear regression in Figure A128. These data show that wind-generated bottom currents may exceed 60 cm/sec for the more severe storms that occur.

204. Analyses of winds measured from the Columbia River Lightship were represented in vector form for each month during 1975 (Appendix A'). These data show that in 1975 southerly winds with mean speeds >10 m/sec occurred for a total of 36 days, while northerly winds >10 m/sec occurred for 5 days (Figure A129). Strong winds were most frequent in February, March 1976, and October, November, and December 1975. The maximum wind speed that occurred (25-hr mean) was 20 m/sec. Due to the observed association between wind speed and the nontidal component of $\bar{U}_{100}$ (Figures A124-A127), an empirical relationship was established to relate winds and concomitant bottom currents. The wind speed range, 13 to 20 m/sec, was associated with nontidal components of $\bar{U}_{100}$ ranging from 24 to 60 m/sec (Figure A128). Bottom current speeds of this magnitude were within the range or very close to those speeds

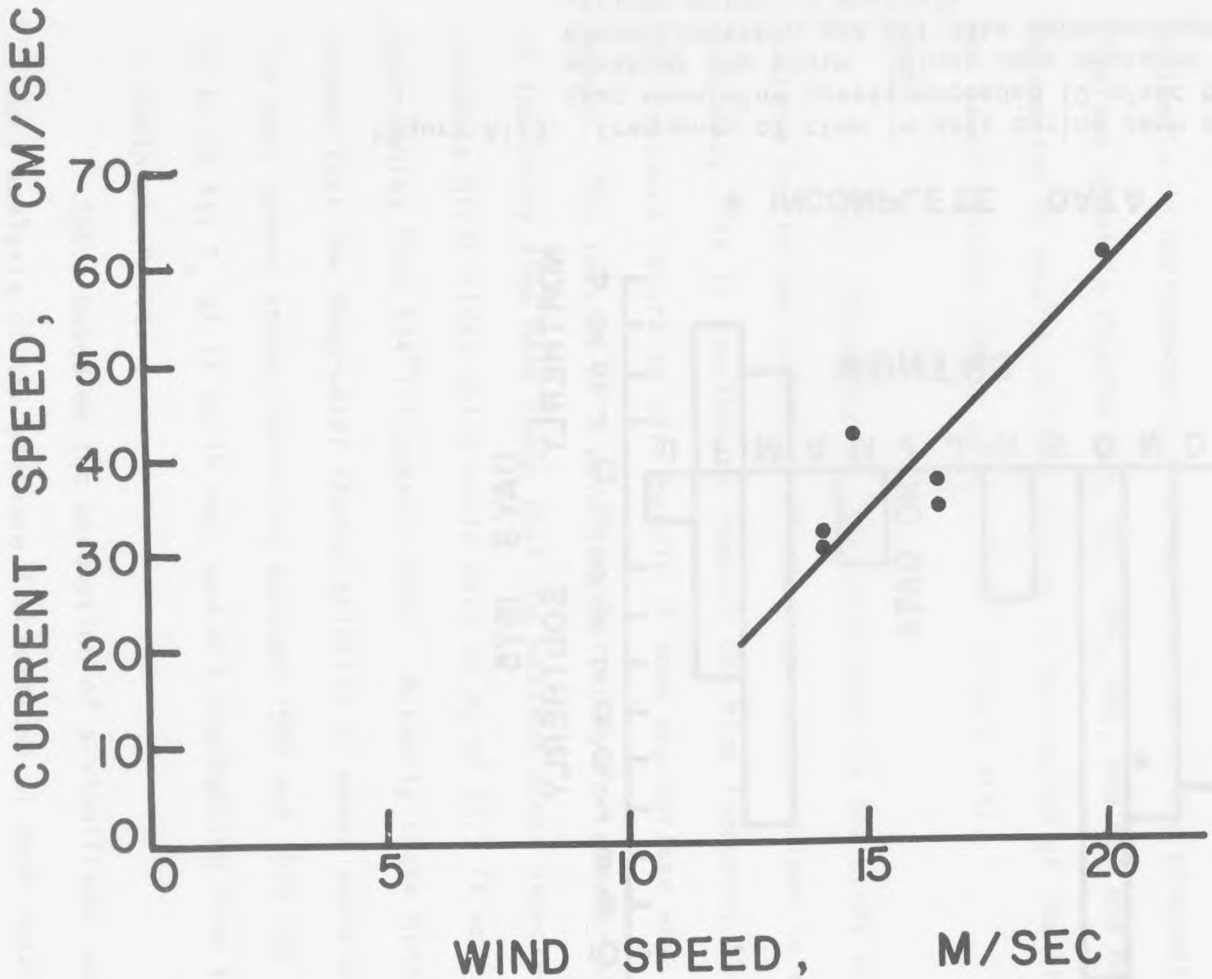

Figure A128. Maximum nontidal component of bottom current speed ($\bar{U}_{100}$) vs. maximum mean wind speed for storm events where winds exceeded 13 m/sec during the sampling periods. All data were averaged for 25-hr periods prior to analysis

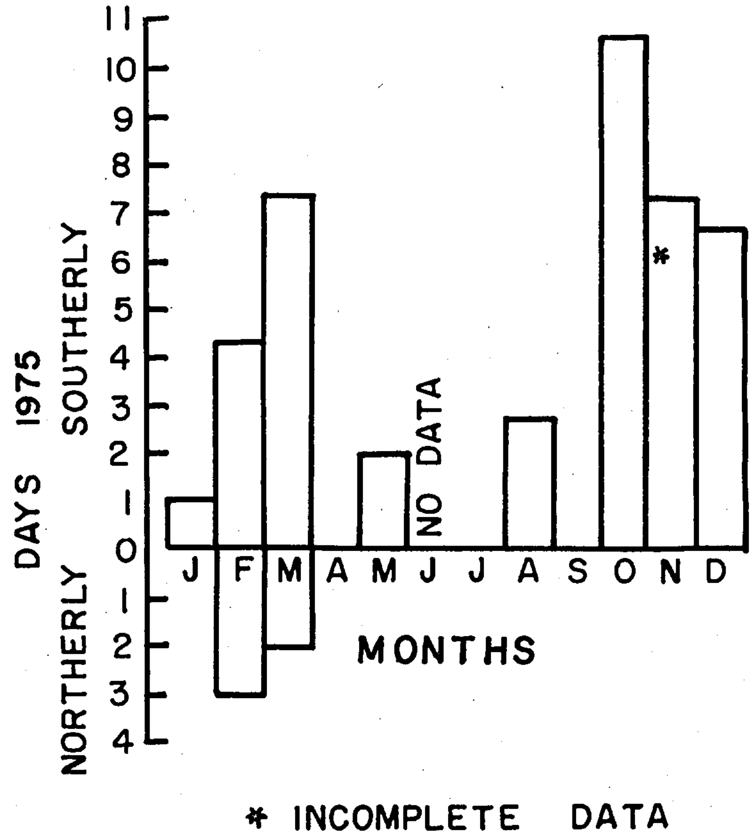

Figure A129. Frequency of time in days during each month of 1975 that mean wind speeds exceeded 10 m/sec blowing from the north or the south. Winds were measured at the Columbia River Lightship and all data were averaged for 25-hr periods prior to analysis required to cause sediment erosion, hence these stronger wind conditions were important not only in the magnitude of the currents they generated and the amount of sediment moved, but in their preferred directional orientation. The stronger wind-generated bottom flows exhibited a northerly set that persisted even when superimposed upon the tidal currents and the hydraulic regime seaward of the river mouth. This net northerly or northwesterly flow was observed in the progressive vector diagrams shown in Figures A36, A37, A46, A66, and A67 and has also been documented by seabed drifter studies in the region of the river mouth and lower estuary (Morse et al. 1968) (Figure A15).

Waves

205. Estimates of wave conditions in the study area were limited due to the inability of the instrumented tripod to resolve wave frequency. It is possible to convert the high frequency fluctuations of the pressure record to wave height if some appropriate wave period is chosen. The results of a wave-hindcast study for a deep-water site west of the study area have shown that the maximum waves expected over the Columbia River tidal delta would have an H_s of 33.5 ft and a T_s of 13 sec approaching from $234^{\circ}T$ (Lockett 1962). Actually these hindcast studies showed that the deep-water characteristics of waves associated with the ten most severe storms occurring between 1950 and 1959 had H_s values of 23 to 30 ft; T_s of 11 to 14 sec, and all propagating from the southwest or south-southwest.

206. Based on the assumption of a significant wave period of 12 sec, analysis of the pressure fluctuations at each station revealed that waves occurring over the study site varied from 0 to 32 ft. The

larger waves accompanied the passage of the most severe storms such as on 3 May at Stations 1 and 2 when H_s reached 32 ft (Figure A28) and 26, 27 December at Station 6 (Figure A71) where an H_s of 28 ft occurred. It should be noted that the 12-sec wave period was chosen to best determine the larger waves over the study site. Smaller waves, which are also associated with shorter wave periods, would be underestimated by the wave height scales placed on Figures A28, A41, A45, A58, and A71. For example, an instrumented tripod measurement of ΔP equal to 1 recorder unit at Station 1 would represent a 12-sec wave with H_s equal to 8.5 ft or a 10-sec wave with H_s of 11.1 ft. Because a 10-ft wave probably has a shorter period than 12 sec, then the scale used would underestimate the wave height by as much as 30 percent depending on the difference between its actual period and 12 sec. If the actual period was greater than 12 sec, then the scale used would overestimate the wave height.

207. The level of wave activity measured in the study site generally agreed with the wind conditions observed along the coast (Figure A129). Estimated wave heights during the April-May period (Figure A28) were frequently between 5 and 10 ft and exceeded 30 ft during the passage of a major storm. During the June and August-September tripod stations, wave heights were generally less than 5 ft with only two occurrences when heights exceeded 10 ft (Figures A41 and A58). The December-January period (Station 6) was characterized by frequent storms, and the Station 6 wave record (Figure A71) showed the most frequent wave height as 10 to 15 ft with two occurrences exceeding 25 ft.

208. The frequency distribution of wave height as determined by hindcast methods over a 3-yr period: 1956, 1957, 1958 (National Marine Consultants 1961) is shown in Figure A130. According to these determinations, waves 10 ft or greater occur 48 days per year (6.5 percent of the time for sea conditions and 6.5 percent of the time for swell conditions), and waves 20 ft or greater occur about 3 days per year (0.4 percent of the time for sea conditions and 0.4 percent of the time for swell conditions).

Sediment Transport

Frequency of movement

209. The prediction of grain movement by bottom currents is an inherently difficult task due to the complex nature of bottom flows and the present inexact knowledge of the phenomenon of grain motion itself. Competency curves used to predict the threshold conditions for grain movement are published in the geological literature and to a certain degree have been evaluated in the shallow marine environment (Sternberg 1971). Examples of threshold of grain-motion curves are shown in Figure A131, which are based on the movement of grains having a specific gravity of 2.65 and steady uniform flow conditions. The data points included in Figure A131 were from field measurements made in marine tidal flows. For this study the two curves shown in Figure A131A and B are considered to be error bands separating the regions of grain motion and no grain motion. The threshold velocities for each of the various modal grain sizes comprising the factor extremals characterizing the bottom sediments in the study area were determined from

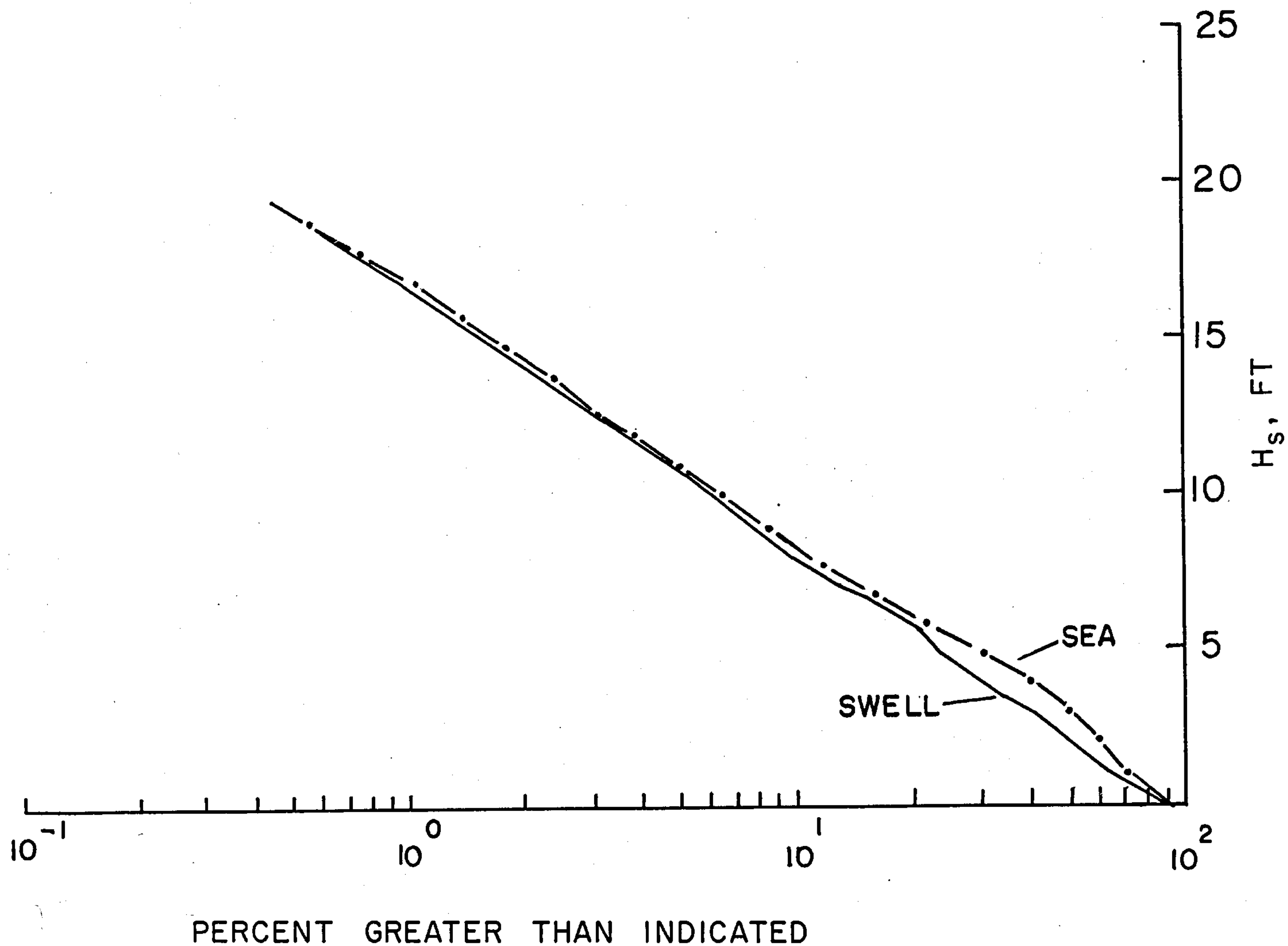

Figure A130. Frequency of occurrence in percent of time for various significant wave heights (H_S) off the Washington coast. Individual curves for sea and swell conditions were included. Data based on 3-yr hindcast studies (after National Marine Consultants 1961)

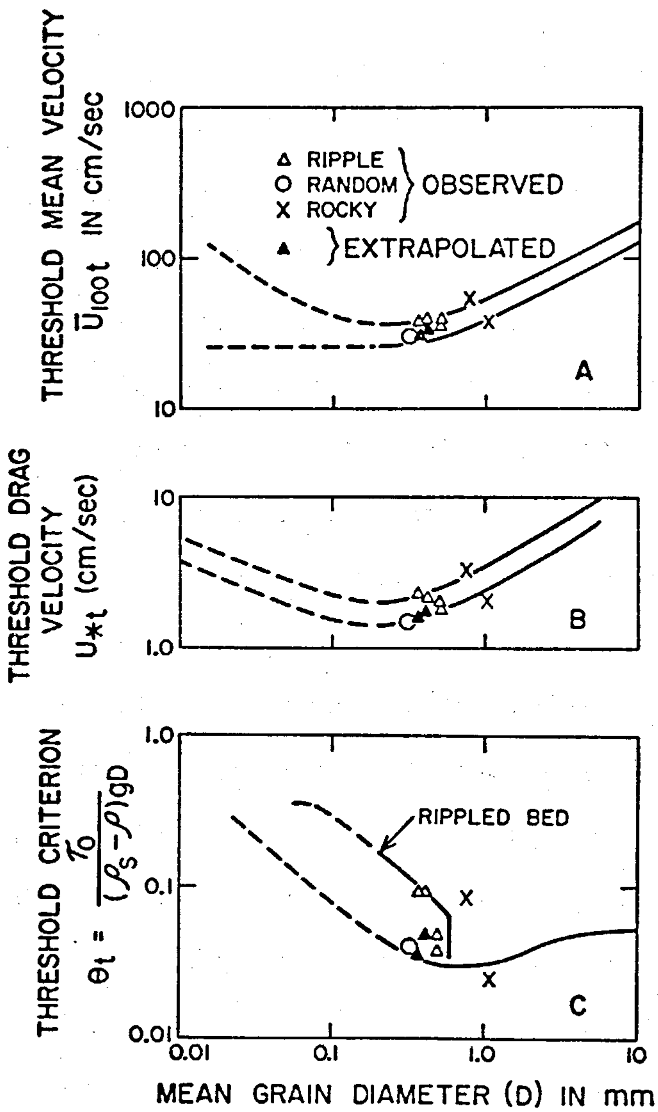

Figure A131. Threshold criteria for initiation of grain movement as a function of grain diameter (after Sternberg 1971)

Figure A131 and are shown in Table A13. The lower region of the error band in Figure A131 was used for this determination, which for the finer sizes ($>4\phi$ or <0.0625 mm) assumed that relatively little consolidation occurred, thus cohesive forces between grains were relatively small. This assumption appears to be valid because of the mobile nature of the silty sediments in the area and along the coast in general.

210. The frequency of sediment motion is related to the nature of the bottom currents in the study area and the characteristics of the bottom sediment. In order to estimate the frequency of grain motion resulting from the bottom flows, the current records from the instrumented tripod stations were analyzed to reveal the percent of time that threshold conditions as predicted by Figure A131 were exceeded. The results of this analysis, tabulated in Table A13, showed that bottom current induced grain motion did not occur during some summer months (i.e., Station 3 in the June-July period), but occurred as frequently as 20 days/month (66 percent) in the December-January period (Station 6). Sediment movement during the transition periods (April-May and Aug-Sept) may be expected to vary greatly from year to year depending on the storm conditions. During 1975 the frequency of time that threshold conditions were exceeded averaged 3 days/month (10 percent) for the April-May period (Stations 1 and 2) and 1 day/month (3 percent) for the August-September period (Stations 4 and 5).

211. In general, it would be expected that the frequency of motion estimates from bottom currents would compare with the severity and frequency of storms as shown in Figure A129. Sediment movement would occur on almost a daily basis during the winter season as a result

Table A13

Required Bottom Currents for Bedload and Suspended Load Transport and the Percent of Time that these Conditions were Exceeded at the Tripod Stations

	Factor*							
	1		2	3	4	5	6	7
Modal Size (ϕ)	2.00 -	2.25	2.5	2.75	3.25	3.75	4.5	6.0
Modal Size (mm)	0.25 -	0.21	0.18	0.15	0.11	0.071	0.044	0.016
Bedload, $\bar{U}_{100}$	30 -	29	29	29	29	29	29	29
Suspended, $\bar{U}_{100}$	156	118	90	65	34	29	29	29
Station 1								
Threshold Exceeded	8		8	8	8	8	8	8
Suspended Load	0		0	0.2	5	8	8	8
Station 2								
Threshold Exceeded	11		11	11	11	11	11	11
Suspended Load	0		0	0.1	6	11	11	11
Station 3								
Threshold Exceeded	0		0	0	0	0	0	0
Suspended Load	0		0	0	0	0	0	0
Station 4								
Threshold Exceeded	3		3	3	3	3	3	3
Suspended Load	0		0	0	2	3	3	3
Station 5								
Threshold Exceeded	3		3	3	3	3	3	3
Suspended Load	0		0	0	2	3	3	3
Station 6								
Threshold Exceeded	66		66	66	66	66	66	66
Suspended Load	0		0	4	43	66	66	66

*The factors whose distribution is most associated with the modal sizes shown below.

of strong wind-generated bottom currents; whereas during the summer period when bottom currents are primarily caused by the tides, weeks could pass without threshold conditions being exceeded. Wave motions in the study area tend to suspend bottom sediment and are discussed in a later section of this report.

Mode of transport

212. Sedimentary particles may move by rolling or sliding along the bottom within several grain diameters of the bed (bedload transport) or may be carried up into the flow and maintained by turbulent forces and be transported as suspended load transport. These two models of transport are end-member conditions and are separated by a transition type. The mobility of sedimentary particles is strongly dependent on the mode of transport. As bedload, sand grains migrate along the bed in the form of ripples whose migration rates are typically 0.01 cm/sec (Sternberg 1971). At the other extreme, particles suspended in the flow move at the flow rate and hence may be carried great distances as determined by the characteristics of the water movement.

213. Determination of the condition of suspended transport is made by some form of the equation (Inman 1963):

$$\frac{Cz}{Ca} = \left(\frac{z + z_o}{a + z_o}\right)^{-\frac{Ws}{kU_*}} \qquad (1)$$

where: Cz, Ca = concentrations at level z and a, respectively
z = height above the bed
a = reference height
z_o = roughness length
Ws = settling velocity for sediment
k = von Karman's constant

U_* = friction velocity $(\tau_o/\rho)^{\frac{1}{2}}$ with τ_o = the boundary shear stress and ρ = the fluid density. U_* must be greater than $U_{*}t$ as shown in Figure A131.

As discussed by Smith and Hopkins (1972), the exponent in Equation 1 can be used to determine the mode of transport as follows:

Bedload Transport	Transition Region	Suspended Load Transport	
$\frac{Ws}{kU_*} > 2$	$2 > \frac{Ws}{kU_*} > 0.8$	$\frac{Ws}{kU_*} < 0.8$	(2)

Using this criterion, the critical values of $\bar{U}_{100}$ that must be exceeded to produce various modes of transport were computed and are given in Table A13. Also presented is the percent of time during each tripod station that these conditions were exceeded.

214. This analysis showed that the coarser sediments in the study area do not undergo the suspended mode of transport. For example, even during the strongest currents observed in the area, Factor 1 (2.0-2.25ø) and 2 (2.5ø) sediments were not suspended. The size limit for full suspension appeared to be Factor 3 (2.75ø), which was suspended during 4 percent of the winter experiment (Station 6) and only for a small percentage of the time during the spring experiment (Stations 1 and 2). The finer sized sediments (Factors 5, 6, and 7) will normally be carried in suspension once threshold conditions are surpassed, hence the percentages under the suspended transport are the same as for the "threshold exceeded" values. Factor 4 was transported more frequently in suspension than as bedload and hence is also quite mobile.

215. Although all possible environmental conditions were not

investigated by this 19-month study, the separation between those sediment sizes that move as bedload and those that are transported in suspension as shown in Table A13 is quite pronounced. For example, the threshold value of $\bar{U}_{100}$ for suspended load transport for Factor 2 sediment is 90 cm/sec. Admittedly, it would not be surprising for $\bar{U}_{100}$ to exceed 90 cm/sec (80.1 was the maximum recorded value from the present experiments), but this condition would not occur for more than a very few hours per year, hence the percentage of time for suspended transport of Factor 2 sediment would be very low indeed. The observed division between the Factor 1 and 2 sediments that move as bedload and the Factor 4, 5, 6, and 7 sediments that move primarily as suspended load strongly influences the degree to which sediments introduced in the study area can be dispersed and redistributed.

Bedload transport

216. The results shown in Table A13 suggest that the Factor 1 and 2 sediments are only transported as bedload. Due to the complexities of the bottom flows, it was difficult to find flow conditions where computation of bedload transport on a reasonably steady basis was possible. Two complete storm episodes and part of a third did occur during measurement periods and resulted in relatively steady bottom currents that exceeded the threshold of grain motion. The first occurred on 26-30 August and was recorded at Stations 4 and 5 (Figure A126). Mean winds of 13.5 m/sec occurred and the nontidal component of $\bar{U}_{100}$ was 31 cm/sec. An actual bottom current speed ($\bar{U}_{100}$) of 42 cm/sec was recorded at both stations during the period of maximum wind speed (Figures A60 and A62). The second storm was recorded on 21-24 December.

Mean winds reached 14.8 m/sec and the nontidal component of $\bar{U}_{100}$ was 41.9 cm/sec (Figure A127). A more severe storm immediately followed the 21-24 December disturbance with mean winds of 20 m/sec. Bottom currents with a nontidal component of $\bar{U}_{100}$ reached 60.8 cm/sec with a maximum observed value of 80.1 cm/sec (Figure A73). The instrumented tripod at Station 6 became damaged during this storm, hence data were cut off about midway through the disturbance.

217. Data collected during the 2-1/2 storm periods were used to estimate the bedload mass transport of sand. Calculations were based on a procedure described by Sternberg (1972). This technique was developed for an environment characterized by quasi-steady bottom currents (including tidal flows), sand-sized sediment, and relatively low concentrations of suspended sediment. All of these conditions were met in the vicinity of Site G and hence the technique is considered feasible for application in this region. Estimates of ripple migration distances associated with a given storm were made using am empirical relationship described by Chang (1939) and modified according to data collected from the marine environment (Kachel and Sternberg 1971; Sternberg 1971). The storms analyzed represented different levels of intensity, and a very crude indication was obtained regarding the quantities of sand transported by a given storm and the distance of sand migration. The results of these calculations are given in Table A14. The partial measurement of storm conditions from the 24-26 December period was also included in these calculations, for even though the storm was not fully documented, this was one of the most severe storms during the year and the results were of interest.

Table A14

Estimates of Mass Transport as Bedload

and Travel Distance of Sand During Severe Storms

	Station			
	4	5	6	6
	26-30 Aug	26-30 Aug	21-24 Dec	24-26 Dec*
Mean wind speed, m/sec	13.5	13.5	14.8	20.0
Sediment modal size at station, ø	2.75	2.75	2.5	2.5
Bedload transport				
gm/cm/storm	9.2	7.7	68.0	4.3×10^3
gm/deposit/storm	4.8×10^5	4×10^5	3.5×10^6	2.2×10^8
cm^3/deposit/storm	3.0×10^5	2.5×10^5	2.2×10^6	14.0×10^7
yd^3 /deposit/storm	0.4	0.3	2.9	183
Transport distance				
m/storm	2.1	1.8	11.0	53

*Data collection was interrupted about midway through the passage of the storm, hence these values represent about 60 percent of the total (see Fig. A73).

218. It should be emphasized that the computations of this nature are subject to large errors. For example, precision of current meters was on the order of ± 10 percent of the measured speed. For mean values of $\bar{U}_{100}$ of 50 cm/sec a 10 percent precision error could produce a 20 percent difference in calculations of boundary shear stress (τ_1), a 34 percent difference in energy expended on the bed by the fluid, and a 200 percent difference in calculations of mass transport as bedload. Other sources of error probably occur in the empirical coefficients, but their range of variation has not been evaluated. The consideration of mass transport by bedload movement therefore is an order of magnitude estimate.

219. The bedload values shown in Table A14 were calculated in terms of mass sediment transported per unit width of the bed per second (grams per centimeter per second). These numbers were summed over the duration of each storm and tabulated as grams per centimeter per storm and later multiplied by the east-west width of the Site G disposal deposit (1700 ft) to show the mass of sand transported northward across the total deposit per storm (grams per deposit per storm). Additionally, the mass transport was converted to volume transport as follows:

$$Q\rho s\ (0.6) = j' \qquad (3)$$

where Q = the volume transport in centimeter^3/deposit/storm
ρs = the sediment density
0.6 converts sediment density to bulk density (Kachel and Sternberg 1971)
j' = the mass transport in grams/deposit/storm

Applying these results at the study area as a whole suggests that a given storm may transport on the order of 0.4 - 330 cu yd of medium to fine sand corresponding to modal sizes of Factor 1 and 2 sediments.* The distance travelled by these sediments would be on the order of 2 to 100 m, respectively. In an effort to estimate the annual mass transport as bedload, these results were plotted in Figure A132, which shows an empirical relationship between the volume transport and distance transport per storm vs. the nontidal or wind-generated component of $\bar{U}_{100}$. Combining Figure A132 with the mean wind speed-bottom current relationship in Figure A128, and reviewing the annual wind pattern (Appendix A1), provides a means of estimating the annual transport as bedload in the study area. This comparison was carried out and the results are tabulated in Table A15. This analysis suggested that storms occurring in the study area transported on the order of 830 cu yd of sediment northward as bedload from Site G during 1975. The travel distance for this material was on the order of 1450 ft or 0.25 nmi for the year. It should be emphasized that these estimates should only be considered as order of magnitude approximations. They do suggest, however, that the characteristic sediments placed at Site G by the disposal experiment will tend to be dispersed very slowly if at all and would show a net displacement in a north-northwest direction at a very slow rate. This prediction assumes that the deposit remains uncovered by seasonal deposits of silty sediments which would tend to protect it from further erosion. The annual mass transport is estimated at only 0.2 percent of

*The 24-26 December calculations from Table A14 have been multiplied by 1.8 to account for data lost from instrument failure after recording about 55 percent of the storm.

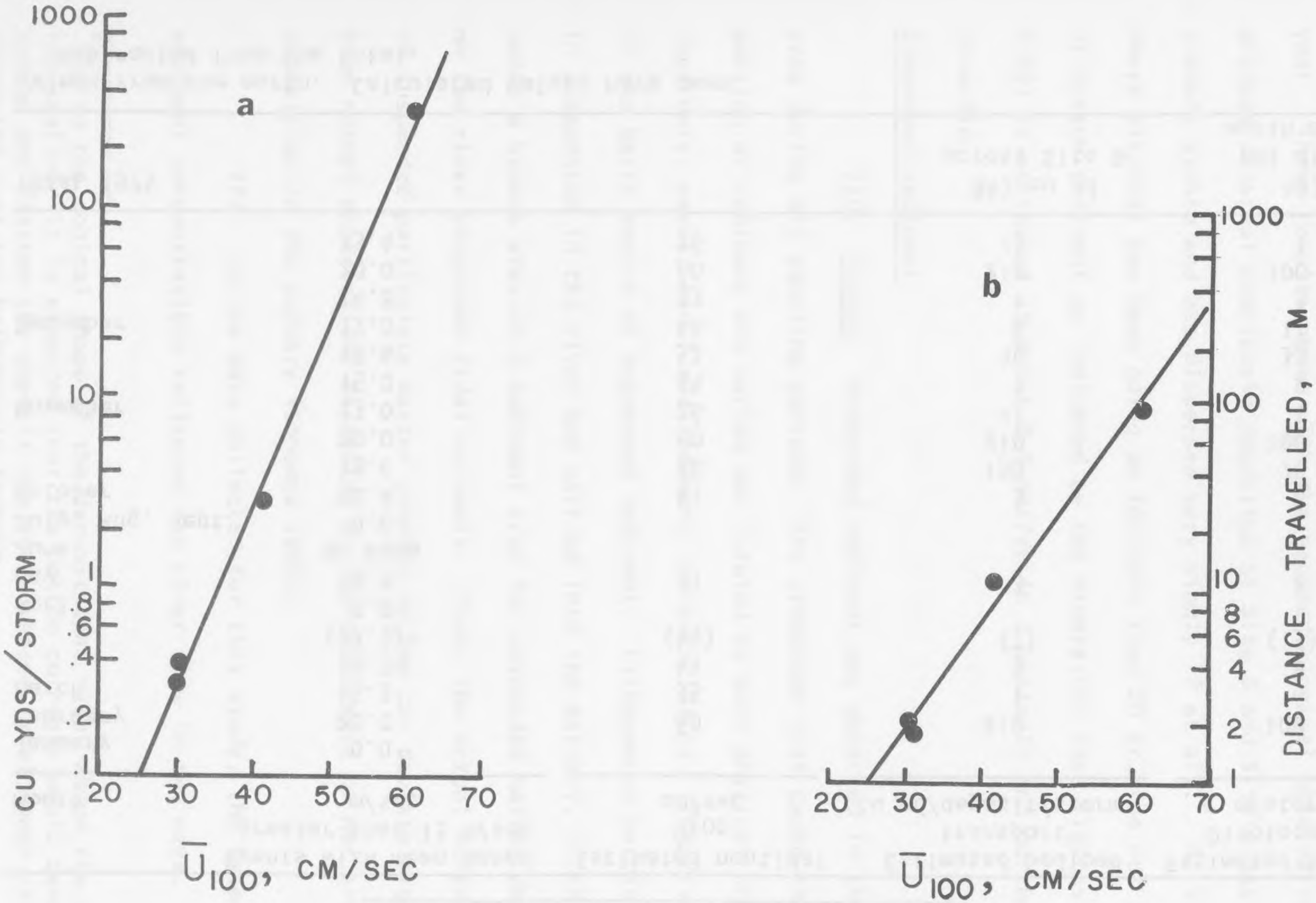

Figure A132. Estimates of sediment transport as bedload (a) and sediment migration distances (b) vs. the maximum nontidal bottom velocity ($\bar{U}_{100}$) associated with individual storms occurring in the study area. The volume transport is computed as cu yd/storm travelling across the total width of the disposal deposit.

Table A15

Calculations of Mass Transport and Displacement of Sediments Due to Storm Activity in 1975

Month	Events with mean speed greater than 13 m/sec m/sec	Estimated nontidal $\bar{U}_{100}$ cm/sec	Estimated bedload transport cu yd/deposit/storm	Estimated Sediment Displacement m/storm
January	0.0			
February	20.0	60	210	100
March	15.3	35	1	4
	16.4	41	3	8
	(17.3)*	(45)	(7)	(13)
April	0.0			
May	16.4	41	3	8
June	No Data			
July, Aug, Sept	0.0			
October	16.4	41	3	8
	19.6	58	150	75
	20.0	60	210	100
November	13.0	26	<1	1
	15.0	34	1	2
	18.6	52	40	33
December	17.0	44	6	11
	14.8	33	1	3
	20.0	60	210	100
	13.4	26	<1	1
TOTAL 1975			847 cu yd across Site G	467 = 0.24 nmi displaced north of Site G

*Winds from the north. Calculated values have been subtracted from the total.

the total deposit at Site G, and migration is only about 0.25 nmi per year. These results agree with the sedimentological observation that dredged material previously deposited at Site B and Site A has been extremely stable and has dispersed very slowly if at all.* At Site B, where disposal has been going on for more than 20 yr, the net transport of bottom sediment as indicated by the mineralogy (see Figures A104 and A105) is estimated at about 0.3 nmi/yr in a westerly and northwesterly direction.

Suspended sediment

220. Causes. Suspended sediment was observed in the study area during all sampling periods. The processes that cause the suspension of sediment are varied and related to both physical processes (currents, waves, etc.) and sediment characteristics. The river system is the basic source of suspended sediment. Lithogenous particles kept in suspension in the river are carried into the estuary, which represents a bypass area or a sediment trap for suspended matter depending on the river stage and tidal currents. Thus, the actual concentrations of suspended particulate matter carried to sea can deviate significantly from normal expectations depending on the occurrence of net erosion or deposition in the estuary (Conomos 1968).

221. In the data collected for this study, the suspended sediment concentrations reflected the river flow in two ways. The first

*Due to the conical shape of the deposit that rises above the surrounding seafloor it is expected that the bottom currents would tend to spread and flatten the deposit due to increased local shear stresses generated over the bathymetric feature.

was the occurrence of sharp, transient peaks in the bottom concentration of particulate matter. These marked fluctuations were very irregular and were possibly related to turbulent eddy motions in the bottom flow rather than the tidal movements of the salt wedge which would tend to produce regular fluctuations that could be correlated to the tides. Examples of these fluctuations were best observed at Station 3 (Figure A43) which was located closer to the river mouth than other tripod stations. Mixing of water across the effluent pycnocline appeared to be relatively strong during high river runoff (Duxbury and McGary 1968), which could also account for the short-period fluctuations observed at Station 3 (taken during June-July 1975).

222. The second type of river influence observed in the suspended sediment appeared to be related to migration or shifts of the salt-wedge intrusion. The best example of this was observed at Station 6 between 12-22 December 1975. This period was characterized by continuously turbid bottom water (Figure A77) and westerly bottom flows which were most pronounced between 16-22 December (Figure A127). After 22 December, the advent of a severe storm with southerly winds caused strong northward bottom flows and a significant decrease in bottom turbidity in spite of increased currents and wave activity (Figures A76 and A77). The increased bottom turbidity appeared to be a combination of (a) easterly winds; (b) very high river runoff, in fact, higher than during the 1975 spring discharge maximum (Figure A9); and (c) a large influx of suspended river sediment. Typically, river flooding is associated with the seaward withdrawal of the salt wedge and the lowering of the zone of suspended sediment maximum from the

top of the salt wedge to the river bottom. The suspended sediment concentration at all depths is increased and great amounts of sediment are carried to sea in the bottom waters (Meade 1972). As evidenced by the westerly bottom flows at Site B, the seaward withdrawal of the salt wedge appeared to coincide with a period of a large volume of suspended sediment bypassing the estuary. This was followed by a strong northerly coastal flow (driven by winds) which shifted the bottom flow from the river northward around the north jetty and replaced the bottom water at Site B with coastal water having much lower concentrations of suspended sediment.

223. Resuspension of sediments by bottom currents is another important sedimentary process within the study area. As shown in Table A13, the finer sediments will move primarily in suspension, e.g., Factors 5, 6, and 7 (modal sizes 3.75, 4.5, and >6ϕ, respectively). During the winter season it is expected that resuspension would occur frequently and in fact the observations at Station 6 indicated that threshold conditions were exceeded 66 percent of the time. Also, the distribution of finer sediments seaward of the river mouth is expected to change seasonally in relation to river flooding. During periods of high runoff such as May-June or November-December, significant quantities of fine sediments are carried through the estuary and deposited in the study area. During the remainder of the year, these fine materials are winnowed from the bottom sediments and transported north and westward along the continental shelf (Smith and Hopkins 1972, Sternberg and McManus 1972). Factor 3 sediment (2.75ϕ) is transitional between those sediments moved as bedload and those carried in suspension (Table A13).

Sediments finer than Factor 3 (e.g., Factors 4, 5, 6, and 7) are quite mobile and are expected to be widespread in their distribution.

224. Bottom oscillatory currents generated due to surface wind waves are a third process that can cause the resuspension of bottom sediments. Visual analyses of bottom photographs during periods of low bottom currents, but significant wave motion, were made to determine the threshold conditions responsible for significant bed deformation (wave-generated ripples), hence sediment movement. This subjective observation indicated that threshold conditions occur when the pressure fluctuations measured by the tripods (Delta P) surpassed 0.7 psi. Bottom pressure fluctuations were related to wave height and period using linear wave theory and the combination of these two variables would produce sediment movement as shown in Figure A133. For example, the threshold of grain motion is exceeded by a wave with a T_s of 8 sec and H_s of 13.6 ft. An 11-sec wave must only exceed 6.5 ft to cause the same oscillatory velocity on the bottom.

225. Data collected during the various seasons suggested the seasonal variability of sediment suspension by waves. In the August/September period, threshold conditions (Delta P >0.7 psi) were exceeded 6 percent of the time; in the April/May and June/July periods, 21 percent of the time; while in December/January, waves suspended bottom sediment 93 percent of the time.

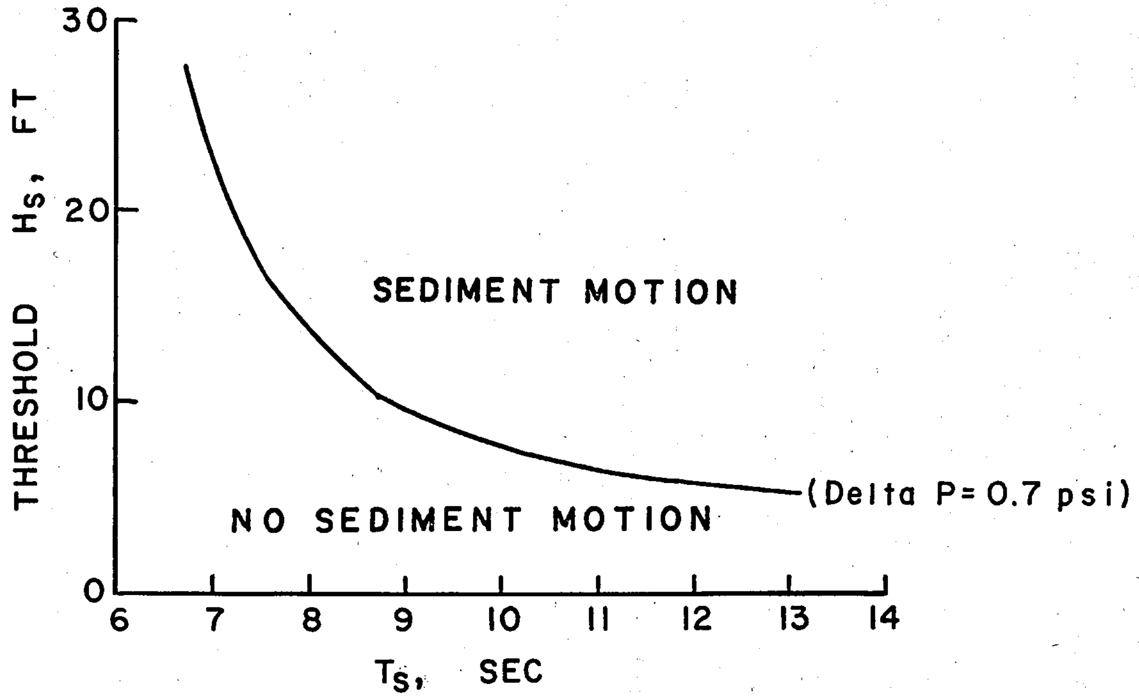

Figure A133. Combination of significant wave height (H_s) and wave period to cause sediment motion in the study area. Threshold conditions were determined by observation of bottom photographs during various wave conditions

Station	Dates	Percent of Time Threshold Conditions Exceeded (Delta P > 0.7 psi)
1,2	4/12 to 5/6	21
3	6/15 to 7/8	21
4,5	8/19 to 9/12	6
6	12/12 to 1/6	93

The nature of this sediment suspension varies depending on the waves and bottom sediment. With significant quantities of fine material included in the bottom sediment, the suspensions tend to persist, thus causing continual turbidity (e.g., Stations 1 and 2). Coarser sediments, which are not carried far from the bed and tend to settle back rapidly, are suspended intermittently and may not cause continual turbidity (e.g., Station 6 after 23 December; Figure A77).

226. Quantities of suspended load. The quantities of material carried in suspension were quite variable depending on their source and the mechanism for suspension. General background levels of suspended sediment concentrations were 1 to 2 mg/ℓ (Figure A68), while the short-period fluctuations associated with the river effluent system had concentrations that often exceeded 100 mg/ℓ (Figures A47 and A68). Concentrations of suspended sediment associated with wave motion varied considerably. During record day 5 and 6 of Stations 4 and 5 (Figure A68), the threshold wave condition was only slightly exceeded and concentrations reached 5 to 10 mg/ℓ. Station 4 was located closer to the river mouth, however, and numerous short-period fluctuations in light attenuation were superimposed on the transmissometer record. Bottom sediment at Stations 4 and 5 contained less than 3 percent silt and

clay and wave-generated suspensions were on the order of 5 to 10 mg/ℓ. On the other hand, sediments at Stations 1 and 2 contained 55 percent and 52 percent silt and clay, respectively, and turbidity values were high (≥ 50 mg/ℓ) and persisted throughout the sampling period (Figure A39).

227. Dispersal routes. The primary mechanisms associated with suspended sediment are river effluent which carries it into the study area and wave motions which frequently cause resuspension. These mechanisms produce random flow directions, hence the dispersal paths of suspended sediment are related to the mean bottom currents during the time when suspensions occur. Since wave motions are dominant in the winter months when maximum currents are generated by storm activity, there should be a strong tendency for materials introduced by river effluent and resuspended by waves to be carried north and west by coastal currents. Undoubtedly some of the suspended load of the Columbia River carried during the spring discharge maxima is deposited south of the river when northerly winds caused a deflection of the plume to the south. This material is temporarily deposited in the summer, but will be subsequently resuspended from the bottom sediments during the following winter season and transported northward, thus taking part in the general shelf transport regime as well documented by many workers and summarized in Pruter and Alverson (1972) and Smith and Hopkins (1972).

228. In reference to the experimental disposal at Site G, the dredged material contained very low percentages (<1 percent) of materials finer than fine sand (>3ϕ) and was characterized by modal sizes of

1.75 to 2.5ø. As shown in Table A13, this size material was rarely if ever transported in suspension, hence considerations of suspended load transport were not applicable to Site G except for the very small percentages of included fine materials. This conclusion was further corroborated by the fact that significant bottom turbidity did not occur as a result of the disposal experiment at Site G. Stations 4 and 5 were located north and south of the disposal site and measurements were begun during the last 8 days of the disposal experiment during which time a total of 59,958 cu yd of dredged material was dumped. The turbidity levels during the first 8 record days of Stations 4 and 5 (Figure A68) did not show abnormally high background levels. Some sediment resuspension was observed during record days 5-9 when significant wave motion did occur (Figure A58). The degree of resuspension due to these waves may have reflected the surface accumulation of a small percentage of fine sediments differentiated upon settling from the dredged material disposal; however, the level of turbidity (5 to 10 mg/ℓ) was not great enough to draw any conclusions regarding the effects of this experiment on background levels of suspended sediment in the study area.

Bottom Sediment Texture

Sedimentary environment

229. The sedimentary environments of the continental shelves to the north and south of the Columbia River are distinctly different (Gross et al. 1967, Harman 1972, McManus 1972, Kulm et al. 1975). South of the river, at least to Tillamook Head, the bottom is covered with modern nearshore sand to depths of approximately 230 ft beyond which the

topography is rough and surface sediment appears to be relict. Kulm et al.(1975), on the other hand, suggested that what had been parallel zones of progressively finer sands offshore near and south of Tillamook Head are truncated between Tillamook Head and the Columbia River by an east-west zone of 3.25ø mode sand that extends between depths of 165 to 330 ft. The inner limit (165 ft) is only a minimum depth as the researchers did not sample to shallower depths near the Columbia River. They suggest that the source of this 3.25ø sand is the Columbia River and this accounts for the east-west lineation.

230. Sediment north of the Columbia River over the inner shelf to depths of 165 to 193 ft is modern Columbia River sediment (Harman 1972, McManus 1972, Smith and Hopkins 1972). The middle shelf to about 330 ft is characterized by a zone of mixed sand and silt, which Smith and Hopkins (1972) suggested is a modern Columbia River derived silt overlying or variously mixed with relict fine sand. Based upon textural analyses made by McManus (1972), Smith and Hopkins (1972) recognized the quarter-phi fractions designated 3.0 and 3.5ø as the important modes in the system with the 3.0ø size probably relict and the 3.5ø size as the mobile sand fraction that can be transported in suspension under modern conditions. Therefore, Smith and Hopkins recognized the inner shelf by the abundance of 3.5ø fraction and a middle shelf over which this mode decreases in importance, permitting the relict 3.0ø mode to increase in importance. Silt from the Columbia River is transported in suspension during storms in a north-northwest direction from the Columbia River toward the head of Willapa Canyon (Smith and

Hopkins 1972). Barnes and Gross (1966) originally suggested this direction of transport of fine fraction based upon distribution of radionuclides originating in the Columbia River. Hence, during nonstorm periods, temporarily deposited silt would be a significant component of the bottom sediment in middle shelf regions between the Columbia River and Willapa Canyon.

231. The size analysis methods used by McManus produced results indicating that the major sand modes near the Columbia River were 3.0 and 3.5ø. The method used in this study and by Kulm et al. (1975) resulted in modes at 2.75 and 3.25ø. The results in rerunning some of McManus' samples were quite inconclusive in rectifying this discrepancy. The 2.75 and 3.25ø modal classes used in this study were considered to be respectively equivalent to McManus' 3.0 and 3.5ø modes when reporting the results in relation to the reports by McManus (1972) and Smith and Hopkins (1972). (It is to be noted that Factor 4 sediment along the southern edge of the study area was in part composed of 3.0ø mode sediment.)

232. The sedimentary environment near the mouth of the Columbia River is composed of at least three subelements: (1) the relict sediment and topography associated with the recent rapid rise in sea level; (2) the modern shelf sediment associated with the present sedimentary environment that would prevail without the influence of the river; and (3) the sediment and sedimentary environment produced by the river itself. The shelf south of Tillamook Head as described by Kulm et al. (1975) is probably characteristic of the shelf environment that would prevail if the river were not present. Information collected

during this study does not deny the Kulm et al. (1975) suggestion that the east-west enrichment of 3.25ϕ fraction in the sediment south of the river entrance is the result of summer flooding in combination with a general summer surface current set to the south and west. A similar distributional pattern for pennate diatoms and tintinnids (Harman 1972) supports this suggestion. If this is true, then the Factor 4 (3.25ϕ mode) sediment projecting northward from the southern margin of this study was originally discharged in suspension with the Columbia River effluent during the summer floods, carried south with the plume, and temporarily deposited south of the study area. These sediments are subsequently resuspended during the winter storm conditions and transported northward back through the study area. The inshore lobe may be the result of modern transport; however, the outer lobe has different mineralogy and may be relict from an earlier low stand of sea level (see next section for mineralogy). If the inner lobe is the result of a modern transport phenomenon, then continued monitoring of sediment at experimental Site G will provide evidence of the rates of transport. By December 1975, the Factor 4 sediment type had shown little sign of returning to its ambient distribution and concentrations before the controlled disposal.

233. The large prominent outer tidal delta deposit off the Columbia River entrance must have grown to its present dimensions since the last jetty construction completed in 1917 (Lockett 1959). The position of the 60-ft contour marking the seaward edge of the flatter top of the tidal delta off the entrance requires a shoaling from over 90 ft since 1902 (Figure A23). Most of this shoaling has probably

occurred since 1917. Therefore nearly all sediment used in construction must be modern and have a river source. The much steeper western and northern slopes of the tidal delta must mark the areas of maximum growth and growth rate.

234. All navigational charts of the area show that the river passes through the north side of the entrance adjacent to Cape Disappointment and then turns sharply southwest. During the maximum floods of both winter and summer season, the tendency of the surface effluent layer of the river would be to leave the entrance on a westerly course thus depositing the bulk of the sediment load north and west of the entrance. This is readily apparent in the historical presence of a massive shoal extending seaward from the north side of the entrance and in the asymmetry of the Factor 3 (2.75 or 3.0ø mode, Figure A84) sediment distribution. The predominance of Factor 3 sediment out across and onto the seaward face of the shoal must require that this sediment type constitute the bulk of the near-surface sediment on the northern portion of the tidal delta. This deposit coarsens toward the river entrance where it is a mixture of Factor 2 (2.5ø) and Factor 3 (2.75 or 3.0ø) sediments. Patches of Factor 2 sediment are seen trending seaward along the southern edge of the shoal, also suggesting this as a river transport direction (Figure A82) and that the river during flood distributes this as the coarsest size sediment. Possibly, during flood stage, only the upper portion of the flow passes seaward across the northern half of the tidal delta. The lower portion of the flow turns southwest following the thalweg of the main channel. This division of flow would provide coarser sediment to the southern tidal delta and account for coarser grained sediment

trending seaward southwest from the south jetty. The presence today of recognizable dredged material deposits at Site A (Figure A79)(which has been used as a disposal site only sparingly since 1957) suggests that there has not been much permanent deposition on this portion of the tidal delta for some time. Samples taken at Station 28 (Table A10) in June and October 1975 show the temporary presence of Factor 3 (2.75 or 3.0ø) sediment at Site A. Therefore, although there is not a permanent deposition of river-borne sediment at this site, there is at least seasonal deposition from the river. The very abrupt termination of the inshore north-trending lobe of Factor 4 (3.25ø mode) sediment along a line projecting southwest from the end of the south jetty (Figures A86 and A100) suggests that additional Factor 3 (2.75 or 3.0ø) and possibly Factor 2 (2.50ø) sediment is deposited annually southwest of Disposal Site A for some unknown distance.

235. The large area of Factor 3 (2.75 or 3.0ø) sediment covering the western portion of the study area probably represents relict middle and outer shelf sands discussed by all previous authors. North of the latitude of Site B, the type of sediment that might be collected will vary depending upon the distribution of temporarily deposited silts to be discussed below.

236. The distribution of Factor 2 (2.50ø mode) sediment is difficult to understand particularly in view of the calculations and hydraulic measurements from this study (Table A15) and previous work which suggest that such coarse sediment is probably only carried as bedload and experiences only minor amounts of transport. Although not exhibiting high factor loadings, a significantly large, elongate area

of Factor 2 sediment occurs along the entrance range aligned with the river channel as it turns south and passes through the entrance (Figures A82 and A83). The one dredge bin sample (B0775-118; Table A11) that can be said to have been collected from the dredging area between Buoys 4 and 6 contained 17 percent 2.5ϕ size sediment. The Factor 2 loading of this bin sample was 0.33, not enough to appear on the Factor 2 distribution map, but enough to suggest continuity between the Factor 2 sediment of the entrance channel and the Factor 2 sediment offshore to the southwest. Factor 2 sediment is the dominant type dredged at the entrance between Buoys A and 8. It is suggested that occasionally river discharge in this direction is sufficiently strong to transport this size sediment to the extreme limits of the observed depths of 180 ft. The distribution of the Factor 3 (2.75 or 3.0ϕ) sediments west and north of the north jetty and southwest of the south jetty is probably an artifact caused by the disposal of sediment at Site B. Otherwise it is to be expected that these sediments would be distributed across the entire outer tidal delta and extend farther seaward along the alignment of the main channel southwest of the south jetty.

237. The remaining patches of Factor 2 sediment in the western region of the study area are associated with presumed relict Factor 3 sediment. This size is apparently not being continually supplied to the region and cannot be traced to a source with the information available. Factor 2 sediment probably does not terminate north and west of its apparent area of distribution (Figure A82), but is masked by the increase in fine fraction to the north. The patchy concentrations in the vicinity of Site G were probably more related to the

higher mobility of Factor 3 (2.75 or 3.0ϕ) and Factor 4 (3.25ϕ) sediment than to what was happening to Factor 2 (2.5ϕ) sediment.

238. The distributional patterns of Factor 4 (3.25ϕ), Factor 6 (4.5ϕ), and Factor 7 (silt and clay modes) sediments, when considered in conjunction with the distribution of the silt- and clay-size fractions (Figure A82, A86, A88, and A89), clearly show a Columbia River source and transport toward the north and northwest. The details of the transport system and the timing of movement were obscured by the lack of adequate seasonal and areal sampling.

239. In general, the line of maximum concentrations of Factor 4 (3.25ϕ) sediment trends N15-20°W. The silts and clays appear to have a much more northwesterly transport direction. On the basis of current measurements made north of this study area at depths of 165 and 260 ft, Smith and Hopkins (1972) reported that at the 165-ft depth, near-bottom currents recorded for December would have resulted in a sediment transport direction of N15-30°W. Also, in 260 ft of water, during storms that would have transported the average bottom sediment, transport would have been N20°W, but the net direction including transport after the storms would have been N33°W. In deeper water the offshore component was larger. The distribution of silt for the southern Washington shelf (McManus 1972) suggests that the silt fraction is transported N25°W from the Columbia River. From this study it would appear that the Factor 4 (3.25ϕ) sediment approximates the above transport directions quite closely, but that the silt and clay fractions have a more westerly component permitting them to be

distributed diagonally across the more northerly trending coarser deposits of Factor 3 (2.75 or 3.0ø) and Factor 4 (3.25ø) sediment.

240. Most, if not all, Factor 4 (3.25ø) and finer sediment transported by the Columbia River is dispersed north of the entrance. Ignoring seasonal perturbations caused by temporary deposition of silts, Factor 4 (3.25ø) sediment is deposited over the steep outer tidal delta slope north of the entrance from the north side around to a position offshore from the south jetty where the deposit projects eastward across the contours toward the jetty. These east-west deposits off the south jetty must exist in a region of lesser bottom current speeds. This Factor 4 (3.25ø) sediment separates the two deposits of Factor 3 (2.75 or 3.0ø) sediment that project west and southwest from the entrance. The six August 1975 samples (C7508-S06 to S11) discussed previously (page 199) which were collected from the steep northern outer tidal delta slope show the coincidence of steep bottom slope with steep gradient of change in sediment type. Over a distance of 1000 to 1500 ft with a depth change of 72 to 94 ft, the bottom sediment changes from Factor 4 (3.25ø) sediment with less than 10 percent silt fraction to a Factor 6 (4.5ø) sediment with up to 28 percent silt fraction.

241. Although the Factor 6 (4.5ø) sediment appears as rather substantial isolated deposits (Figure A82), the class grades chosen make this factor appear more important than it is. Total silt content seldom exceeded 25 to 30 percent of any but the farthest offshore samples. Seasonally, however, Factor 6 varies as a result of river flooding and is frequently resuspended, thus these sediments are

considered transient. This is particularly true along the northern half of the tidal delta.

242. The early summer flooding of the Columbia River deposits a layer of silt along the outer edge of the tidal delta to at least as far south as Station 27 (Figure A90). By December most of this silt has been resuspended and transported northward out of the area or buried (stratified sample from Station 51, Table A10). Observed seasonal variations in the bottom sediment indicated that the December 1975 flood either did not transport quantities of silt or transport conditions along the outer tidal delta did not permit deposition. The winter 1974 flooding was minor compared to December 1975 (Figure A9) and so did not provide the opportunity to check on winter deposition. Comparison of December 1974 and 1975 samples from Stations 51, 52, and 56 (Table A10) suggests that the sediments were coarser in 1975, substantiating the lack of winter flood deposition near the river entrance. The little seasonal information available in the northern portion of the study area suggests that the texture of the bottom sediment is modulated by temporary deposition of silt. The irregular nature of the Factor 4 (3.25ø) sediment distribution and patchiness of Factor 6 (4.5ø) sediment substantiate this view.

Impact of disposal at Site B on the sedimentary environment

243. Among the significant impacts of the disposal of more than 28×10^6 cu yd of foreign sediment is the difficulty it causes in attempting to interpret the natural sedimentary environment. Most of the dredged material disposed within Site B was deposited seaward of

navigational Buoy 1 on the steep face of the outer tidal delta, producing a readily distinguishable bathymetric feature (Figure A23). Based on the geometry of the bathymetric feature at Site B, the volume of this deposit is 10×10^6 cu yd, which accounts for only a third of the 28×10^6 cu yd disposed since 1956 (Portland District records). Although over 14×10^6 cu yd were dredged before 1956 (Lockett 1963), the disposal sites are not known. The discrepancy between the total volume disposed and the volume of the recognized disposal deposit at Site B can probably be accounted for by the variability in the actual disposal site. Recorded locations for disposal at Site B held by the Portland District Corps of Engineers Office show that actual disposal locations varied by over 2000 ft, which is greater than the size of the recognized deposit. Hence, the disposal was spread over a much greater area than can be identified in the local bathymetry. Most of the positions recorded on disposal records are north of the disposal site.

244. If the Columbia River main channel range has not been changed since 1962, then presumed Site B is shown by Lockett (1962) to have been a mile south of its present location and bordered by the range line (Figure A12). General Map MC-1-305 (Portland District, Corps of Engineers) used for dredging in 1956 shows Disposal Site B as extending east of the main channel range line. Given the condition under which the dredges operate, some unkown quantity of the sediment designated as having been disposed at Site B must have been placed in Site B other than on the bathymetric feature recognized as the disposal deposit or at another site. The various locations for Site B explain the presence of Factor 1 (1.75, 2.0, or 2.25ϕ) sediment in and beyond the south-

eastern portion of Site B as recognized in this study (Figure A80). Also, some of the sediment disposed at Site B was of a size that could be resuspended during storms and relocated and hence not be included in the volume calculations. The shape of the disposal deposit and its placement along the western side of the tidal delta undoubtedly changes the wave refraction patterns and results in focusing of wave action on the nose, producing increased bottom currents and turbulence to levels higher than normal conditions. This deposit might also produce a sheltering effect for the tidal delta to the north. A cursory comparison of the size distributions for some of the dredged material samples collected between Buoys 4 and 6 and A and 8 with some of the bottom samples indicated distinct differences including less 2.5 to 2.75ϕ fractions and more 1.75 to 2.0ϕ fractions at the disposal site. The loss of sediment that would account for these changes in size distribution is probably in the range of 20 percent. Even less would have been lost from sediment dredged between Buoys 8 and B.

245. The significant concentrations of silt and clay that occur west of the disposal deposit at Site B and trend north-northwest along the contours at about 180 to 190 ft (Figures A88 and A89) are a feature that is difficult to explain using textural data. This sediment cannot have the Site B disposal area as a source because the disposed sediments are essentially void of silt and clay sizes (Table A11). The association is probably mere coincidence. If a line were projected from the end of the south jetty across the southern end of this area of high silt and clay concentration, it could be seen that this line almost delimits the southern extent of Factor 6 (4.5ϕ) sediment off the river

mouth (Figures A82 and A83). From this it is suggested that this silt-clay zone represents the natural position for deposition of these sizes originating in the Columbia River. The regular offshore decrease in grain size north of Site B from sand to silt to clay serves to corroborate this suggestion. The seaward extent of this zone to about 200-ft depths coincides with most definitions of an inner shelf zone by previous authors.

246. The disposal of dredged material that is coarser than would normally be found at Site B certainly appears to have little influence in affecting the sedimentary environment beyond the confines of the disposal site. There does not appear to have been major redistribution of the disposed sediment in spite of the differences between disposed and calculated volumes

Impact of the experiment disposal at Site G

247. Weather and sea conditions prevented collection of bathymetric data soon after the 2-3 September survey. Additional data were collected in January 1976; however, sufficient time for analysis did not remain before the end of the contract period. Extreme weather conditions also made it impossible to collect all the desired sediment samples. To bring this portion of the study to a fruitful conclusion will require continued monitoring of the experimental site for at least another year.

248. Bathymetric data collected prior to and immediately following the disposal experiment show that the Site G deposit could be readily detected and that the deposit size represented 71 percent of the

disposed volume. Also the disposed material was easily detected by its characteristic grain-size distribution. Sediment character was a much more sensitive tool than bathymetric change in defining the extent of the dredged material deposit because of the difficulty in resolving depths to 1 ft and the striking differences between the textures of the disposed and ambient sediments.

249. In spite of the irregular appearance of the contours of factor loadings in Figures A95a and A97a, the halo of Factor 2 (2.5ϕ) sediment surrounding Factor 1 (1.75, 2.0, or 2.25ϕ) sediment suggests a size grading of the dredged material deposit away from the point of initial bottom contact. This size grading is thought to be caused by currents generated by the fall and impact of the bulk of the disposed sediment and to some extent by the different settling rates for some of the falling grains. Although bottom impact-generated turbidity currents were not observed in this study, such currents are reported by Nittrouer and Sternberg (1975).

250. Investigation of the changes in the Site G dredged material deposit subsequent to the disposal showed that Factor 3 (2.75 or 3.0ϕ) sediment was beginning to cover the dredged material deposit. Factor 3 sediment did not appear to be returning from any preferred direction and the deposit (Factor 1, 1.75, 2.0, or 2.25ϕ sediment) was being covered from all sides. Factor 2 (2.5ϕ) sediment was present in the site before disposal; therefore, it must represent the coarsest mobile sediment in this region and this accounts for its not having been covered as quickly as the Factor 1 sediment, which appeared to be static on the bottom.

251. The previous discussion of Factor 4 (3.25ϕ) sediment distribution in this area suggested that its source was from the south and for some reason it did not extend north much beyond Site G. This suggestion was corroborated by this experiment. The rate of return of Factor 4 sediment was very slow compared to Factor 3 sediment, possibly because of its tendency to be transported in suspension (Table A14) rather than migrate along the bed.

Bottom Sediment Mineralogical Variations

Regional mineralogical variations

252. The regional pattern of sediment distribution appears, in general, to be an expression of contrasts in hydraulic characteristics of different mineral species; high density grains (e.g., the 3.25ϕ magnetite, and ortho- and clinopyroxenes) are concentrated in the nearshore region, while the less dense and smaller altered lithic fragments and altered plagioclase blanket the outer shelf region.

253. In the nearshore region, 3.25ϕ magnetite occurs in concentrations greater than 40 percent by number. It has been observed in this study that in such high concentrations, magnetite grains are magnetically attracted to each other, producing large magnetite aggregates of high density that would be transported only in high energy environments. Evidently, coarse-grained plagioclase (2.75ϕ) is hydraulically equivalent to these magnetite grains, thus accounting for the bimodal grain-size distribution in this region. When plotted in Figure A103, samples from this region fell directly on an extension of the line through Columbia River bottom sediment. The source for this

magnetite-rich sand thus appears to be Columbia River bed material that is sorted, resulting in concentrations of magnetite, and thus developing this mineralogically unique sediment. Lack of seasonal variation in this sediment suggests that the sediment is in dynamic equilibrium with its environment.

254. It is suggested that this nearshore zone will act as an effective trap for magnetite. The magnetite from any sediment passing through this region will be deposited because the magnetite will be attracted and bound magnetically by the ambient magnetite and bottom currents may not be sufficient to overcome this "magnetic cohesiveness."

255. Progressively lighter or smaller grains will be in equilibrium with the shelf energy environment in progressively deeper water. In the southern midshelf and outer shelf regions, areas of 2.75ø material are found; even though grain size is rather uniform, the mineralogy changes dramatically, with the relatively denser fresh plagioclase of the Columbia River dominating the midshelf region and the less dense altered lithic fragments restricted primarily to the outer shelf region.

256. In the northern half of the study area, sediment injected into the marine environment by the Columbia River mineralogically masks the regular distribution pattern observed in the south (Figures A104 and A105). Nevertheless, the persistence of the high MR material near the shelf break and the concentration of low MR material north and west of the river mouth suggests that the overall dynamics of the depositional system remain unchanged and, except for the masking by Columbia River sediments, a continuous sediment distributional pattern similar

to that farther south would extend throughout the shelf region.

257. The plume of high MI values extending northwesterly off of the Columbia River mouth suggests transport of Columbia River sediment in that direction. The very high values of MI along this plume suggest that transport of this material away from the Columbia River mouth involves sorting of sediment, with the result that plagioclase, quartz, and andesitic lithic fragments are concentrated along the plume, and heavier magnetic mineral species are left as a lag deposit along the west and central parts of the tidal delta.

258. Immediately to the west of this plume is a broad region of intermediate MI and MR values. It is in this region that mineralogical Factor 5 has its greatest loadings. Although this material has no mineralogical counterpart in the study region, its location and mineralogy suggest that it can be interpreted as material transported by the Columbia River, possibly as suspended load, and settled out of the water column after it is injected into the marine environment. A similar interpretation was developed from analysis of the grain-size distribution previously discussed. It is this material that appears to mask the regular distribution pattern discussed above.

Mineralogical variations at Site B

259. Sediment with high MI and intermediate MR values is concentrated at Site B, and also extends in a plume away from Site B in a north-northwesterly direction. This material is mineralogically indistinguishable from Columbia River bottom sediment and is believed to be sediment derived from dredged material disposed at the site.

This conclusion is supported by the fact that in no other part of the study area does sediment of similar mineralogical character exist at similar water depths.

260. Immediately north of Site B is a concentration of material with MR values exceeding 10 (Figures A105 and A112). These unusually high values occur in conjunction with material having MI values greater than 1.0. This suggests that sediment deposited at Site B during disposal operations is subsequently subjected to sorting processes that transport fresh plagioclase, quartz, and andesitic lithic fragments away from the site in a northwesterly direction.

261. The transport of magnetic material, primarily pyroxene, also seems to be important because a north-northwesterly plume of low MR material can be seen to extend away from Site B (Figure A105). This north-northwesterly plume of material is less extensive than the plume of high MI values, suggesting that annual transport rates for the magnetic material are lower than for the plagioclase and quartz material. The fact that these plumes cannot be recognized on the basis of grain-size variation suggests that Columbia River sediment, that is hydraulically equivalent to the ambient shelf sediment, has a grain-size distribution similar to the middle-shelf sediments.

262. The area of the sediment blanket enclosed by the 1.00 MI contour (Figure A102) near Site B was 4.04×10^7 sq yd. The volume of the bathymetric feature associated with Site B was approximately 10×10^6 cu yd. Assuming that a total of 30×10^6 cu yd of dredged material had been deposited at Site B, 20×10^6 cu yd of material should have

been within the 1.0 MI contour. Such a blanket of material would have a thickness of 14.6 in., assuming the material was uniformly distributed within the contour. The estimate of the total amount of material released at Site B was based solely on cursory examination of yearly averages and assumed disposal at the site for about 20 yr; as previously pointed out (page 2), this figure is a maximum. In reality, it is likely that at the margin of the plumes, the thickness of material becomes vanishingly small; seasonal mixing, mixing of sediment along the plume margins, variations in true thickness, and a decrease in thickness away from the source area would all contribute to a decrease in thickness away from the disposal site.

263. From Disposal Site B to the most westerly point of the 1.00 MI contour on the north-northwesterly plume, the total distance is 5.51 nmi. If disposal operations have been taking place at this location for 20 yr, the rate of transport for the material at the head of the plume is 0.27 nmi/yr. If disposal at this site dates back 40 yr, transport rates drop to 0.13 nmi/yr. These figures are compatible with those suggested as possible on the basis of current velocity determinations (see Sediment Transport).

264. Seasonal variations in sediment mineralogy in the vicinity of Site B can be evaluated on the basis of the prewinter storm (November 1974) and postwinter storm (December 1975) bottom samples (Figures A112 and A113). It must be noted, however, that the complex physical regime of this area and the absence of a long time base data array does not permit conclusive statements regarding seasonal variations.

The following remarks regarding seasonal variations must therefore be considered tentative.

265. Within the boundaries of the Disposal Site B, no significant change in the trend of MR values was noted between the two cruises, although differences in magnitude did exist. However, a regular eastward increase in MR values was observed for the November 1974 samples, but a regular eastward decrease was evident from samples collected in December 1975; MR values east of Site B for the December 1975 cruise approached those typical of the magnetite-rich sands south of the river mouth. The significant contrast in mineralogical trends east of Site B can be attributed to the local storm pattern. The November 1974 cruise was made prior to the storm period of that winter. The December 1975 sampling cruise, however, took place during a break in severe weather conditions. This pattern of weather change and sediment mineralogy variation suggested the interpretation that during the relatively calm spring-summer seasons, unsorted Columbia River sediment is deposited immediately seaward of the Columbia River mouth. During the winter storm season, this material is sorted such that fresh plagioclase and quartz are removed (transported along the plume extending from the Columbia River mouth?) and pyroxenes and magnetite left behind as a lag deposit, eventually to be deposited in the area south of the river mouth, or else the high MR sediment is covered by sediment transported from the area south of the river mouth.

266. The fact that high rates of transport appear to occur east of Site B, even though little change is evident at Site B, must

reflect differences in flow conditions between the two regions (see Sediment Transport section).

Mineralogical variations at Site G

267. The two pre-experimental disposal surveys demonstrated that no significant seasonal change in sediment distribution could be recognized on the time scale of the sampling. Values of MR varied from 1.5 to 2.5 over most of the area (Figures A114 and A115). Differences in contour locations were due primarily to different sampling density and locations. This area was suggested for the experimental site because the mineralogy of this region provided the greatest contrast with Columbia River sediment; the absence of significant seasonal variations in ambient sediment distribution was an additional positive aspect.

268. The first postdisposal survey, September 1975, demonstrated that the experimentally disposed material completely blanketed the ambient sediment, although unaffected ambient material could be detected along the eastern fringe of the study area (Figure A116). Also, immediately around the buoy a region of lower MR values developed, presumably reflecting the fact that disposal of the sediment by the dredge was systematically accomplished along turns around the buoy, rather than along runs directly over the buoy. Also evident was a sporadic halo of higher MR values (greater than 5.0) around the outer portion of the southern half of the study area (Figure A116). These high values were interpreted as representing concentrations of lighter minerals (nonmagnetic silicates, primarily feldspar and quartz) whose settling velocities are less than those of the denser pyroxene, hornblendes, and iron-titanium oxides. The slower settling fraction (both less dense

minerals and smaller grains) presumably would experience a slightly greater horizontal transport during settling than the more rapidly settled fraction, thus concentrating in down drift regions. Bottom current data collected north and south of Site G (Figures A64 and A65) indicate that tidal currents were the dominant velocity component during the time of the disposal operation thus the slower settling fractions would be dispersed in all directions.

269. Analysis of the December 1975 samples demonstrated that the experimental site had nearly returned to its natural mineralogical state (Figure A117); over 50 percent of the area had returned to MR values less than 2.0, but small patches of high MR values (greater than 5.0) persisted. It cannot be directly ascertained whether the mineralogical changes resulted from the transport of low MR material into the study area or from the removal of high MR material out of the region. Changes in the distribution of high MR material around the buoy demonstrated that transport of high MR material into the area does occur, while the grain-size analysis showed no significant changes in sediment sizes near the patches of high MR material; therefore, it is suspected that both processes must be important.

270. It must be emphasized that even though Site G experienced rapid recovery to a near-natural state, there is no reason to expect Site B to behave similarly if disposal there ceased. Indeed, the lack of change between the November 1974 and December 1975 cruises for the region immediately around Site G suggests that the mineralogical characteristics of this feature will persist over a period of years.

PART VII: CONCLUSIONS

General

Bathymetry

271. Observations of the present bathymetry in the study area and comparisons with past surveys indicate:

- a. The outer tidal delta of the Columbia River has shifted significantly in response to river modifications. Since construction began on the jetty system at the river mouth, the 30-ft isobath has shifted 7,000 ft westward and the outer tidal delta has been displaced 10,000 ft seaward.
- b. Historical changes on the outer tidal delta (Site B region) exhibit a net erosion on the south side and net deposition on the north side, which conforms to the net northerly longshore transport system of this coast.
- c. Disposal Site B is recognized as a distinct bathymetric feature due to continued disposal in this region. The volume of dredged material in this deposit is estimated to be approximately 9.5×10^6 cu yd, which accounts for approximately 33 percent of the material disposed since 1957. Materials discharged at other disposal sites are not recognized as distinct bathymetric features.

Boundary-layer conditions

272. Based on the seasonal measurements made by the instrumented tripods, observed bottom currents are the result of tides, river hydraulic regime, winds, and waves.

a. Tidal currents around Site B are approximately 15 to 20 cm/sec flooding and ebbing to the north and south, respectively.

b. River-related flows are of the same magnitude as tidal currents; however, their distribution in space and time is extremely variable. Seawater intrusion into the river mouth at the bottom tends to occur in the zone landward of the outer tidal delta and mostly from the southern side of the entrance.

c. Wind-generated currents are best developed with strong southerly storm winds and may exceed 60 cm/sec flowing to the north-northwest. During 1975, winds strong enough to generate bottom currents sufficient to move bottom sediments occurred approximately 36 days from the south and 5 days from the north. Strong southerly winds occur primarily in the months of October through March and occur as individual events that continue for 5 to 7 days.

d. Significant wave heights at Site B were estimated to vary from 0 to 33 ft. Wave activity is maximum during the winter months in association with the storm conditions discussed above.

e. Measured bottom currents resulting from the interactions of the components summarized above were generally 15 to 30 cm/sec during the sampling period and exceeded 80 cm/sec on occasion. The stronger currents are associated with extreme storm conditions and flow primarily subparallel to the coast in a northerly direction with a small offshore component.

Sediment movement

273. Based on the measurements of bottom currents, wave motions, and sediment characteristics, calculations of sediment transport suggest:

a. Sedimentary materials 0.18 mm (2.5ø) and coarser can only move as bedload in response to bottom currents measured in the area. These coarser materials are the dominant sizes associated with the Columbia River dredging at the river mouth; hence the dredged material deposits, although agitated frequently by winter storms, would be relatively stable with time. Estimates of mass transport of sediment as bedload suggest that these materials may be transported from Site G on the order of 0.24 nmi/yr primarily in the northerly direction.

b. Sedimentary materials finer than 0.15 mm (2.75ø) are frequently moved as suspended load by waves and currents. Because suspended material moves with the water mass, these finer sediments are very mobile, are frequently deposited between storms and then resuspended, and show significant seasonal variations as a result of seasonal variations in river input and winter storm activity.

c. Frequency of sediment movement as a result of mean bottom currents and wave motions varies significantly on a seasonal basis. Estimates of the percent of time that threshold conditions were exceeded during the sampling periods are summarized below:

		Percent of Time that Threshold of Grain Motion was Exceeded	
Station	Month	Bottom Currents ($\bar{U}_{100}$)	Waves
1,2	Apr/May	11	21
3	June	0	21
4,5	Aug/Sept	3	6
6	Dec/Jan	66	93

d. Concentrations of suspended sediment 4.3 ft above the bed indicate that sediment suspensions are related to both river input and resuspension of bottom sediment. Concentration ranged from 1.5 to 100 mg/ℓ and varied significantly as a function of proximity to the river mouth and content of silt- and clay-size fractions in the bottom sediments. Variations in suspended sediment concentrations due to river discharge tend to show extreme fluctuations that are variable in space and time. Variability is greatest during periods of maximum river discharge (June and December-January) and nearer to the river mouth. High concentrations due to resuspension generally occur in response to winter storms and are more pronounced off the central to north side of the river mouth because of the deflection of the river plume during winter and the higher mud content in bottom sediments in that region.

Sediment Characteristics

Texture

274. The textural analysis of over 800 samples of bottom sediment collected from the study area revealed:

a. The results of the textural analyses of the sediment deposited on the tidal delta are consistent with those obtained by McManus (1972) and Kulm et al. (1975) for Columbia River sediment, although unresolved differences in absolute sizes of the dominant modes are acknowledged. The size modes, according to results of this study, are 2.75 or 3.0ø (Factor 3) and 3.25ø (Factor 4), which correspond to McManus' (1972) 3.0 and 3.5ø modes, respectively. Factor 3 sediment occurs extensively on the northern and nearshore surface of the tidal delta. Toward the river mouth the sediment coarsens with Factor 2 sediment (2.5ø) becoming a prominent element. Some Factor 2

(2.5ø) sediment is also present along the southern edge of the tidal delta suggesting that river transport may distribute some material to the south. However, preservation of dredged material at Site A demonstrates that permanent deposition of sediment by the river is insignificant along this part of the delta.

b. South of the river mouth, Factor 4 (3.25ø) sediment appears to bypass the tidal delta region and forms a widespread deposit normal to the shore south of the study area. This conclusion corroborates the findings of Kulm et al. (1975). This deposit is subsequently resuspended by winter storms and transported northward through the area of Site G.

c. Finer grained material, including Factors 4 (3.25ø), 6 (4.5ø), and 7 (silt and clay modes), is distributed in patterns that clearly suggest a source from the Columbia River sediment load. This material is transported in north and northwesterly directions; Factor 4 (3.25ø) sediment approximates a N15-20^{o}W transport direction; while the finer grained sediment (Factors 5, 6, 7) is transported in a more westerly direction.

d. Superimposed on these general trends are the effects of seasonal variation in sediment distribution. During summer flood the Columbia River deposits silt along the outer edge of the tidal delta. Resuspension and transport of this material northward or burial of the sediment occurs during the winter storm period. Little seasonal variation is evident along the outer shelf; however, concentrations of silt and clay just west of Site B probably delimit significant depositional sites for this material.

e. The grain-size data suggest that mass transport of dredged material deposited at Site B is a process of minor magnitude.

Mineralogy

275. Mineralogical analyses of sediment samples were very helpful in describing the distribution of sediment types in the study area and revealed:

a. Within the study area, high density mineral species, principally magnetite and pyroxenes, tend to be concentrated in the nearshore regions. Particularly high concentrations of magnetite occur in portions of the nearshore environment, especially in the region immediately south of the river mouth. Mineralogical parameters suggest that the material is concentrated from Columbia River transported sediment. Farther offshore less dense mineral and lithic species become dominant, with high concentrations of light, altered lithic fragments occurring along the outer shelf region. In the midshelf environs, fresh plagioclase of moderate density is abundant, apparently derived from the Columbia River.

_b_. Although these general patterns are evident north of the river mouth, significant masking of the patterns results from deposition of material transported by the Columbia River. Especially apparent is a plume of high MI material that originates at the river mouth, and a broad region immediately to the west of the high MI plume within which sediment transported as suspended load by the river is deposited.

_c_. Also superimposed on the regional distribution patterns are the effects of depositing dredged Columbia River material. Because of the latter's characteristic MI and MR values, deposited sediment is readily recognized at Disposal Site B. Sorting and transport of some unknown amount of this material can be recognized as plumes and high concentrations of high MI and high MR material extending northwesterly away from the disposal site. The extent of the plume suggests a north-northwest transport rate of 0.27 nmi/yr (20-yr disposal history) or 0.13 nmi/yr (40-yr disposal history). This is in general agreement with the hydraulic studies.

_d_. Landward of Site B, gross changes in mineralogy of the sediment are evident on a seasonal basis.

Immediately east of Site B, the variation is expressed as a drop in MI values during the winter season, relative to the summer season. This change can be interpreted as resulting either from transport of material from the nearshore region south of the delta on the area east of Site B, or from seasonal sorting and deposition of material by the Columbia River upon its tidal delta.

Site G

276. Due to the special nature of Site G with regard to the disposal experiment, conclusions relating to this particular area are listed below:

a. The sedimentary deposit resulting from the disposal of nearly 600,000 cu yd of dredged material is a recognizable bathymetric feature with a generally conical shape 1500 ft in radius and 5 ft in elevation. The volume of sediment comprising the feature is 424,000 cu yd or 71 percent of the total quantity disposed.

b. The general conclusions listed above regarding (1) the components of bottom currents, their magnitudes, directions, and temporal variations and (2) the frequency and mode of sediment transport, are considered to be applicable to Site G. The limited scope of the study with regard to seasonal maintenance of instrumented tripod stations precludes detailed evaluations of seasonal boundary-layer conditions at each particular site, and hence data are considered as applicable to the study area as a whole.

_c_. Estimates of the flow capacity to transport dredged material northward across the east-west extent of Site G suggest that the dredged material moves as bedload and approximately 830 cu yd of sediment migrates northward over an annual period. The estimated annual migration distance is on the order of 0.25 nmi. This represents less than 0.2 percent of the total dredged material thus suggesting that the deposit will be rather stable over time. Stability of this nature is observed for dredged material previously deposited at Site B and Site A.

_d_. Observations of bottom turbidity in the vicinity of Site G during the latter part of the disposal experiment and immediately following indicated that the disposal experiment did not significantly affect the ambient suspended sediment concentration in the bottom boundary layer.

_e_. The textural and mineralogical study at Site G is incomplete due to the lack of sufficient time for resampling. Nevertheless, useful results were obtained using sediment texture and mineralogy as characterizing parameters. During disposal of coarse river sediment (2.0 and 2.5ϕ), size grading resulted in the development of a halo of finer material around the outer perimeter of the deposited dredged material which was concentrated in a ring around the marker buoy.

f. Subsequent to the conclusion of the disposal operation, Factor 3 (2.75 or 3.00ϕ) material could be seen covering the dredged material deposit at a relatively rapid rate. Factor 4 (3.25ϕ) sediment, although also approaching previous abundance levels, is doing so at a rate substantially slower than Factor 3 (2.75 or 3.00ϕ) material.

g. At the experimental Site G, postdisposal studies demonstrate that energy conditions are such that recovery of the area to its original mineralogical state was nearly complete 4 months after termination of the experimental disposal operation. This change presumably results from the surrounding sediment progressively covering the Site G deposit.

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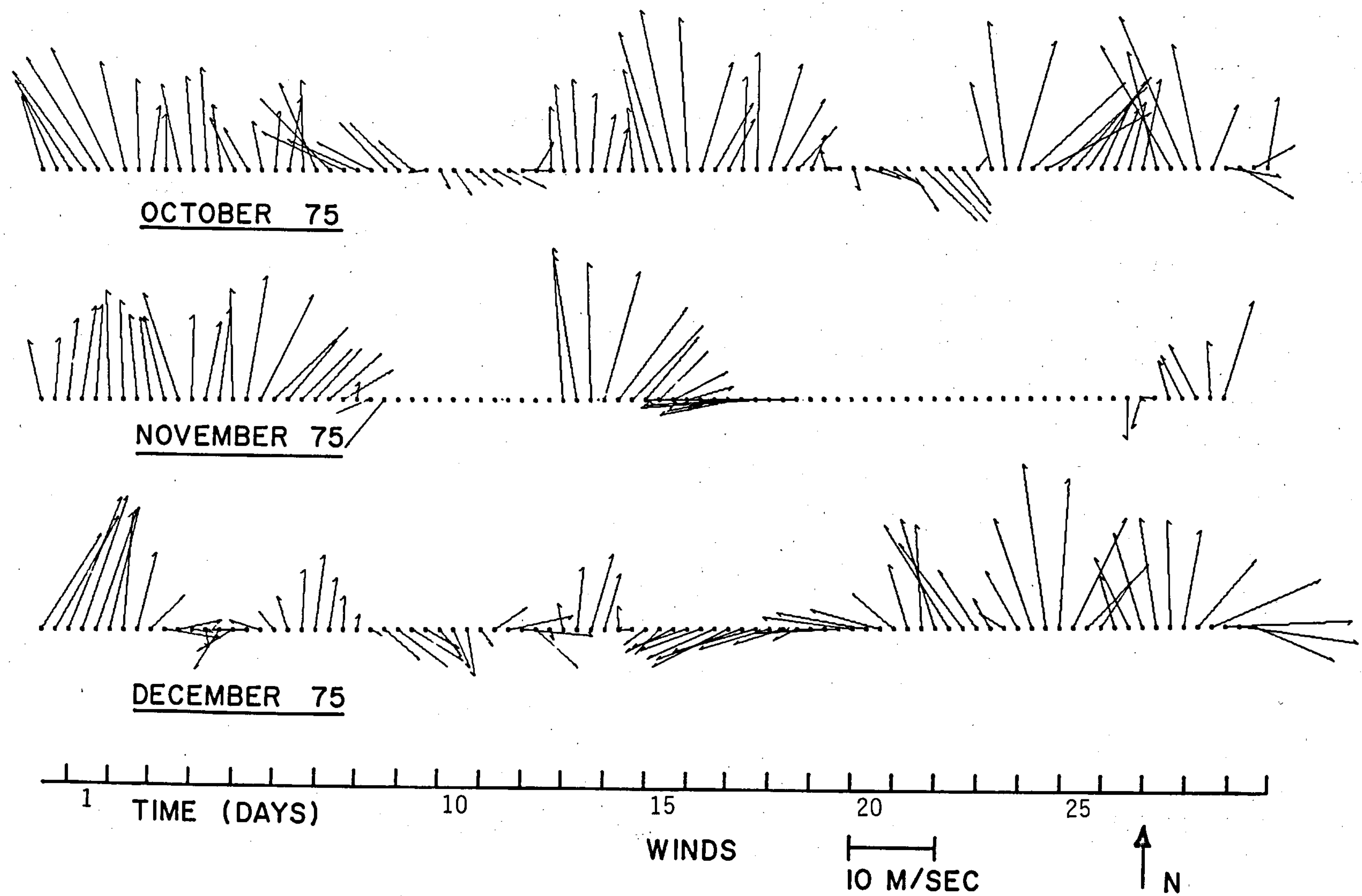
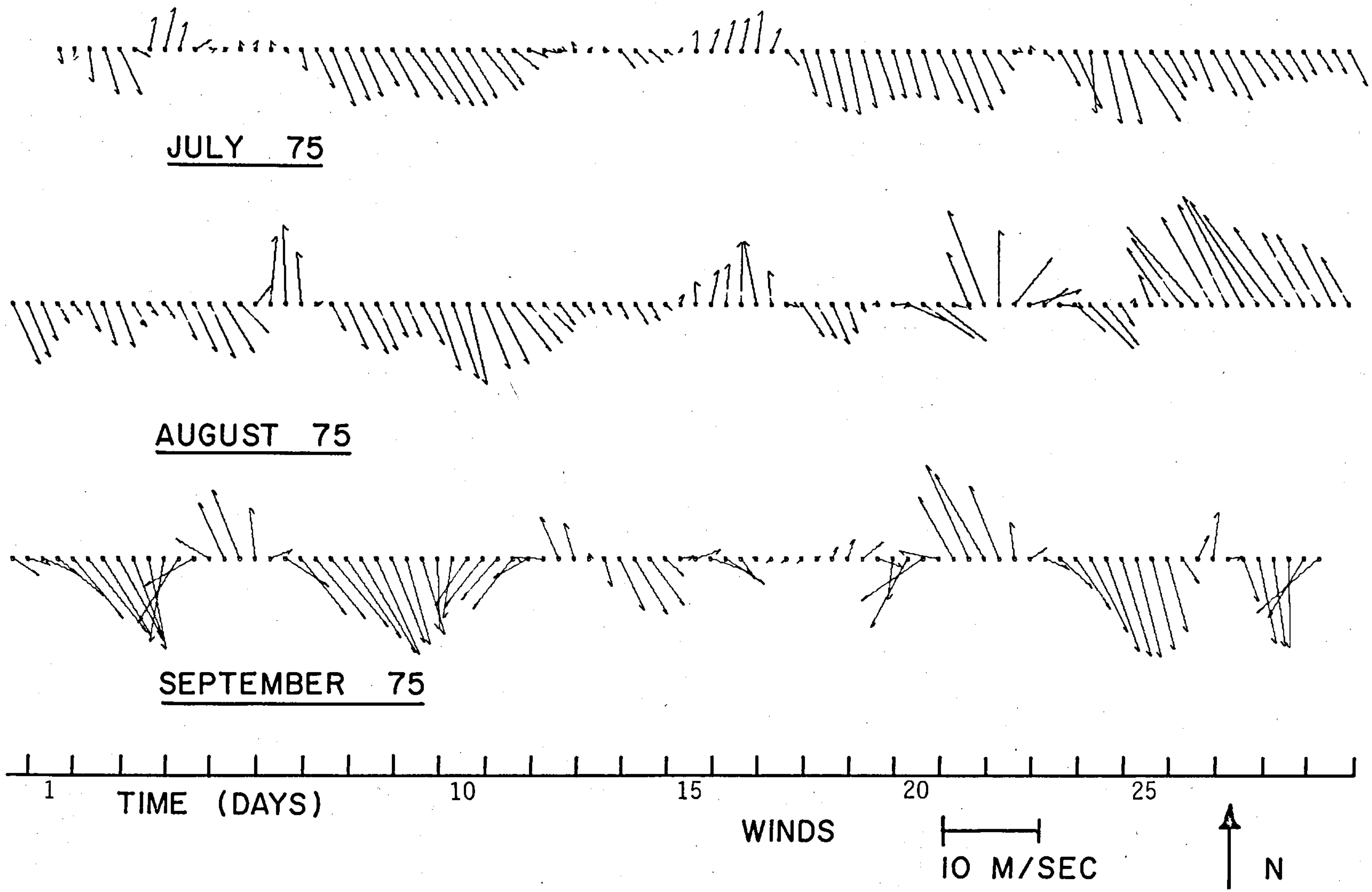
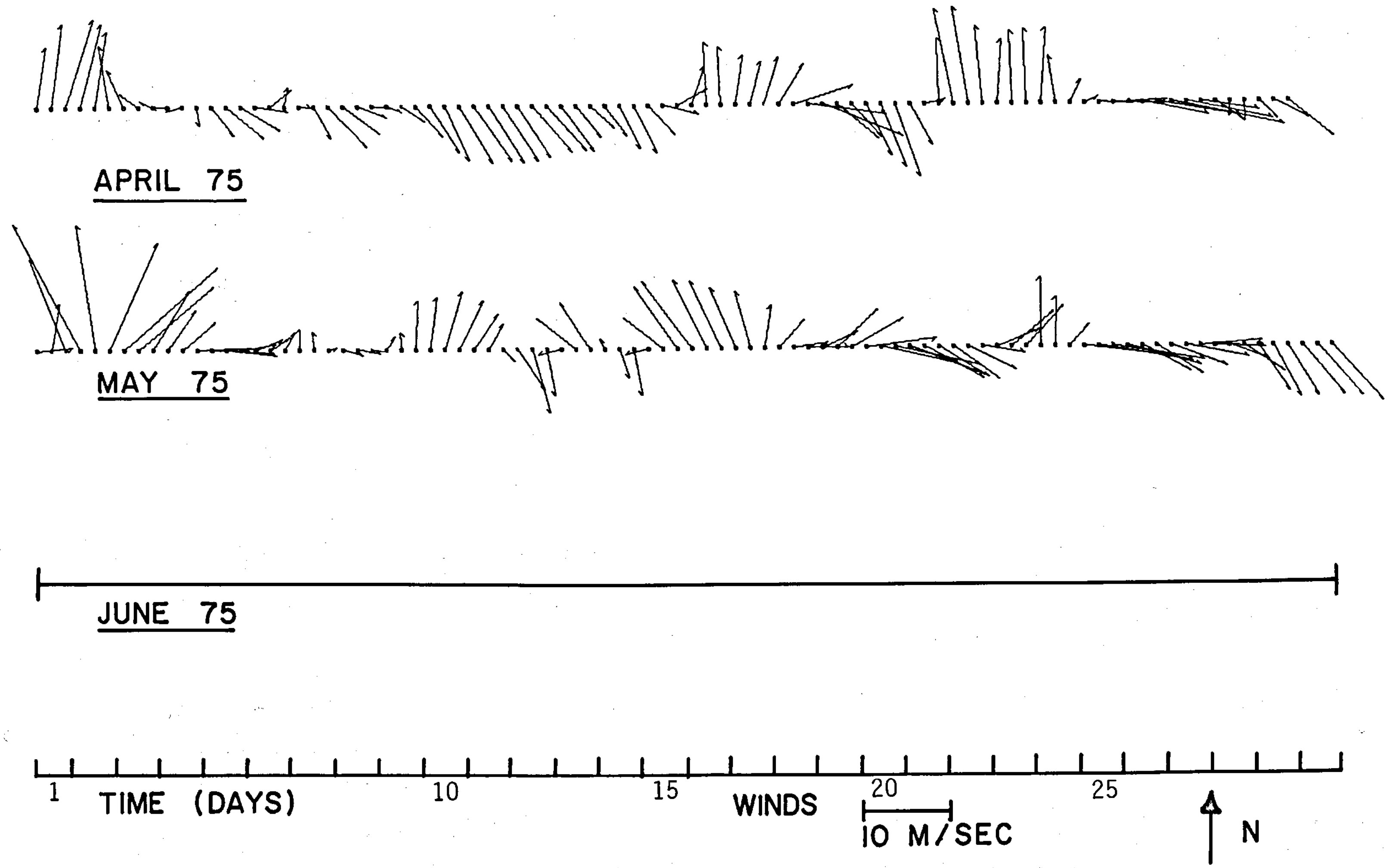
APPENDIX A1. COLUMBIA RIVER LIGHTSHIP WINDS BY THE MONTH FOR 1975

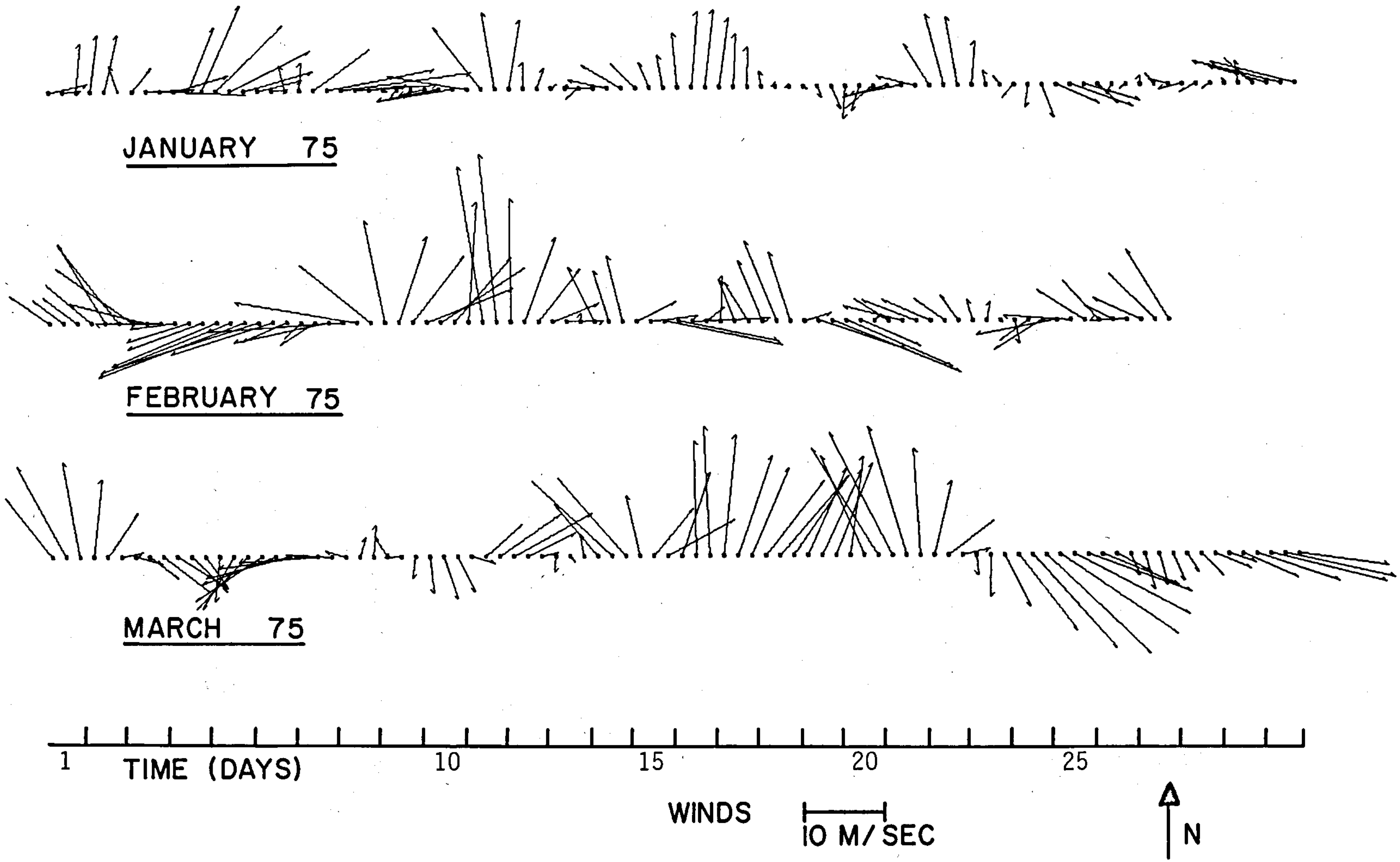
1. The horizontal scale for the following figures is in days. The vector scale is in 10 m/sec/unit. All wind vectors represent 25-hr averages and are plotted as direction toward which winds are blowing.


OCTOBER 75
NOVEMBER 75
DECEMBER 75
1
TIME (DAYS)
10
15
20
25
WINDS
10 M/SEC
N


JULY 75
AUGUST 75
SEPTEMBER 75
1
10
15
20
25
TIME (DAYS)
WINDS
10 M/SEC
N



APRIL 75
MAY 75
JUNE 75
1
TIME (DAYS)
10
15
WINDS
20
10 M/SEC
25
N


JANUARY 75
FEBRUARY 75
MARCH 75
1
10
15
20
25
TIME (DAYS)
WINDS
10 M/SEC
N

1 of 1

APPENDIX A11

CONTINENTAL SHELF SEDIMENTATION

- A BIBLIOGRAPHY -

compiled by

Charles A. Nittrouer

(including references prior to March 1975)

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Joe S. Creager
Principal Investigator

April 1976

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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.

Sternberg, Richard W

Aquatic disposal field investigations, Columbia River disposal site, Oregon; Appendix A: Investigation of the hydraulic regime and physical nature of bottom sedimentation / by Richard W. Sternberg ... [et al.], University of Washington, Department of Oceanography, Seattle, Washington. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. available from National Technical Information Service, 1977.

327, [70] p., 2 leaves of plates (in pocket) : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-30, Appendix A)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW57-75-C-0063 and DACW57-76-C-0088.

Appendix AII on microfiche in pocket.

References: p. 319-327.

1. Bottom sediment. 2. Columbia River. 3. Disposal areas. 4. Dredged material disposal. 5. Field investigations.

(Continued on next card)

Sternberg, Richard W

Aquatic disposal field investigations, Columbia River disposal site, Oregon; Appendix A: Investigation of the hydraulic regime and physical nature of bottom sedimentation ... 1977. (Card 2)

6. Hydraulic regimen. 7. Sedimentation. I. United States. Army. Corps of Engineers. II. Washington (State). University. Dept. of Oceanography. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-30, Appendix A.

TA7.W34 no.D-77-30 Appendix A

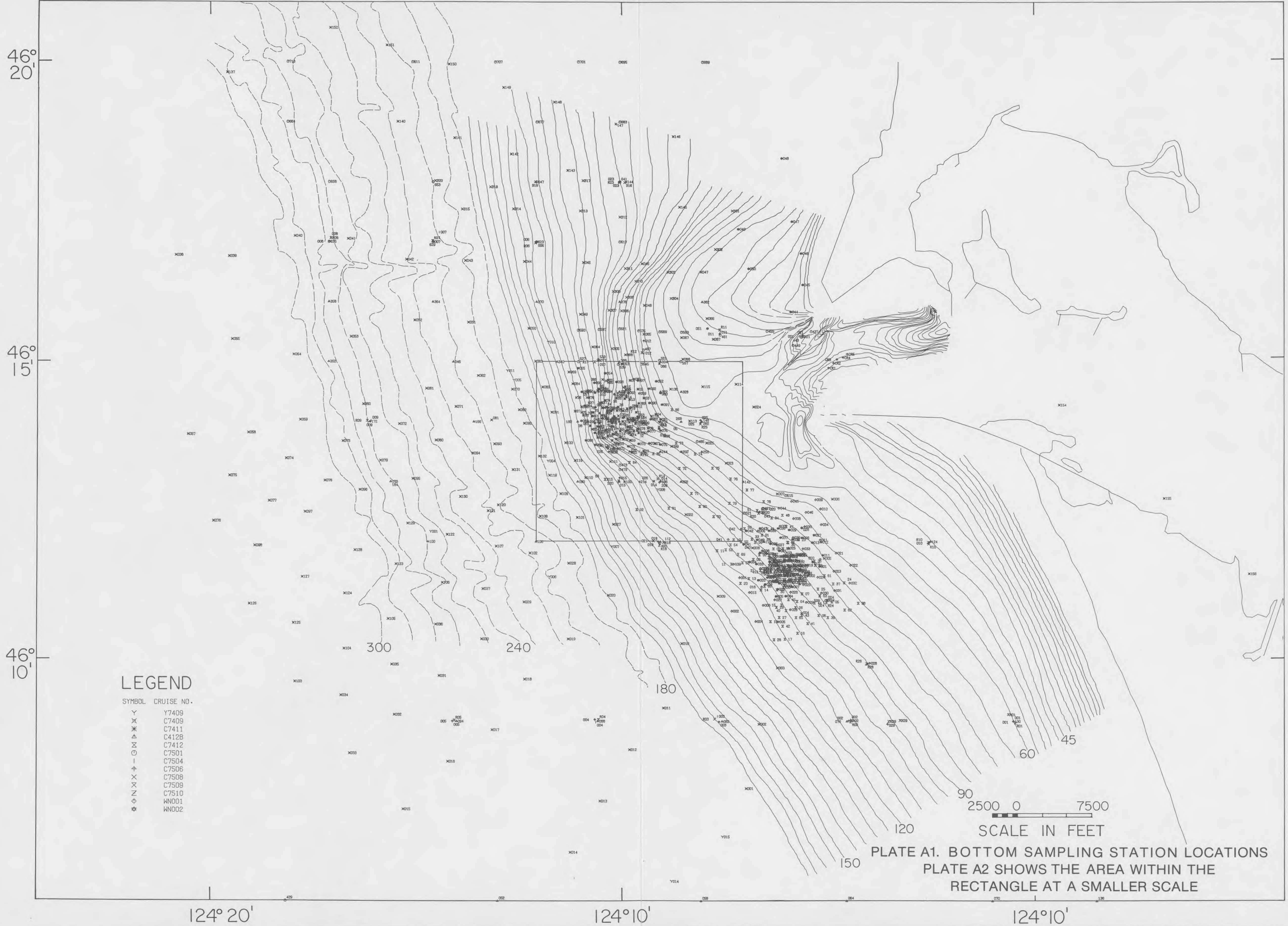

PLATE A1. BOTTOM SAMPLING STATION LOCATIONS
PLATE A2 SHOWS THE AREA WITHIN THE
RECTANGLE AT A SMALLER SCALE

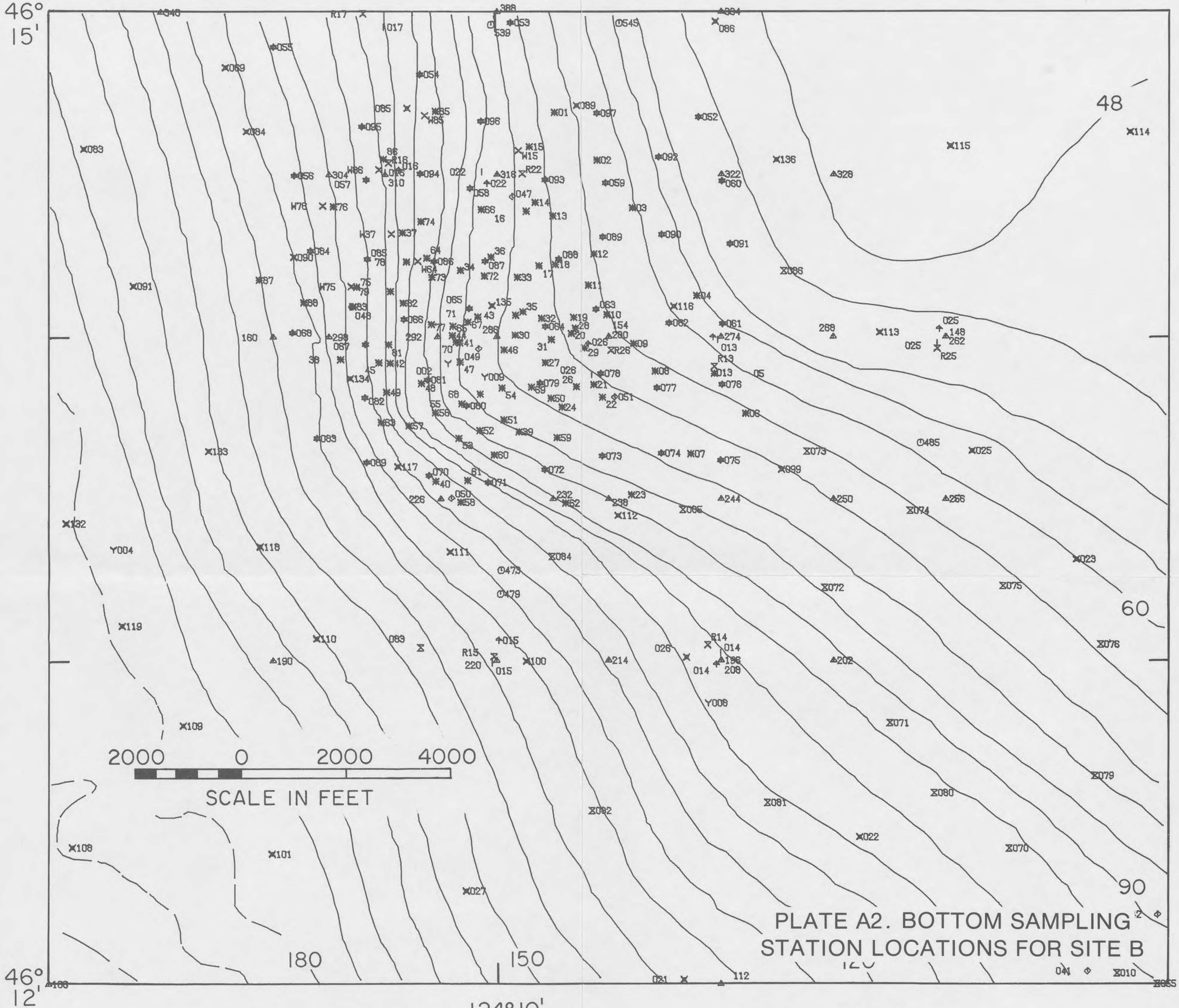

PLATE A2. BOTTOM SAMPLING STATION LOCATIONS FOR SITE B

LEGEND

SYMBOL CRUISE NO.

Y7409
C7409
C7411
C412B
C7412
C7509
C7510
WN001
WN002
C7501
C7504
C7506
C7508

1 of 1 WES TR D-77-30, Jan 78, by R. W. Sternberg et al.
Appendix All.

NTINENTAL SHELF SEDIMENTATION—A BIBLIOGRAPHY

RIAL RESEARCH PROGRAM

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