THE ARCTIC COASTAL ENVIRONMENT OF ALASKA

VOLUME I

The Nearshore Marine Environment in Prudhoe Bay, Alaska

H. M. Feder, D. G. Shaw and A. S. Naidu

UNIVERSITY OF ALASKA INSTITUTE OF MARINE SCIENCE

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D. W. Hood
Director

INSTITUTE OF MARINE SCIENCE

University of Alaska

Fairbanks, Alaska

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EXECUTIVE SUMMARY

Introduction

It is important that some knowledge of the present oceanographic regime at Prudhoe Bay, Alaska, and a review of existing knowledge about that bay (and arctic ecosystems in general) should be documented, monitored and understood in order to determine the impact of oil and gas development at this site.

Volume I of this report considers the results of three investigations; biological, geological, and hydrocarbon chemistry conducted in Prudhoe Bay and approaches in August 1974. The three studies are closely interrelated. Volume II is a compilation and review of scientific literature about the arctic marine environment.

The investigations described in Volume I were at and near the site of a causeway construction project on the west side of Prudhoe Bay, and had as their objectives:

1. Biology - Document the distribution and density of benthic animals in order to develop a benthic biological base.
2. Geology - Document the grain size distributions, geochemical properties, sources of and movements of the sediment, and correlate this information with the habitat preferences of the benthic animals.
3. Chemistry - Survey the kinds and amounts of hydrocarbons present in the biota and sediments.

Methodology

Samples gathered and observations made were primarily along two parallel transects from shore to 4,500 feet seaward and approximately 500 feet on either side of the causeway site. Full details of sample gathering and analytical techniques are given under the heading "General Methods" in each chapter.

Results and Discussion

Biology - Thirty eight species of benthic invertebrate animals were collected. The predominant types were annelids (worms) and amphipods (sand fleas). Similar groupings of species have been reported from the Colville River delta and from Point Barrow.

The diversity of species, the number of animals, and the biomass (total amount of living matter) present all tended to increase in the seaward direction. This correlated with a reduction in sediment size seaward, varying from coarse gravel (with scant mud and finely fragmented material) at the beach, to scant gravel (with abundant mud and finely fragmented material) offshore. The sediment trend is probably due to increased wave, and current activity at the shallower shoreward end of the transects. The seaward increase in biomass may also be a function of the same activity, but more importantly a function of habitat preference, and decreased ice scouring.

Two arctic phenomena must be considered in developing a biological monitoring scheme for Prudhoe Bay.

1) The existence of an ice-scour zone in which animals must withstand ice action (as well as wave action in summer) and high salinities accompanied by low oxygen levels in winter.

2) The existence of "local" populations. Many of the species found develop their young directly on the bottom with no free-floating or swimming stage. Therefore, new individuals to a population come from local stocks.

The broad distribution of the more common shallow-water invertebrates along the arctic coast suggests a widely dispersed stock available for repopulation of stressed areas.

The fishes collected during the same period were feeding heavily on many of the common invertebrates collected. It is apparent that the shallow-water benthos in Prudhoe Bay is an important food source for fishes migrating through and resident to the area.

Geology - In addition to reporting variance in sediment size, the geological chapter reports the contents of carbonates, organic carbon, nickel, chromium and vanadium in the sediments.

The high carbonate content found, (which is substantiated by other North Slope investigations) can be explained as terrestrial in origin, introduced by river run-off.

The low content of organic carbon is typical of North Slope deltas and explained on the basis of low biological activity, both on land (the river borne source) and in the deltas.

It is of interest to note that previous work has reported a relative paucity of several elements in sediments of North Slope deltas (copper, iron, magnesium, manganese, sodium, and vanadium). The vanadium content of Prudhoe Bay sediments is low, as expected, but at this stage of the study no explanation can be offered.

Nickel content of the sediments is relatively high, probably because the Brooks Range carbonate rocks contribute a major source of North Slope sediments, and are known to be higher in nickel content than similar carbonate rocks found elsewhere. Nickel content of sediments along the transects increased seaward as did the carbonate content.

The report points out that any marked increase in the mud fraction of sediments ought to be accompanied by an increase of nickel content. The values of nickel, chromium, and vanadium content reported in this study can serve as a baseline for future monitoring.

Chemistry - The hydrocarbon analyses of sediment samples, which contained some organic material (possibly of tundra origin) show nothing of the pattern of *n*-alkanes associated with petroleum.

Fish specimens were collected in Prudhoe Bay and their flesh and skins analyzed for hydrocarbon content. All species collected are highly mobile:

Arctic Cisco (2 specimens)

Four horned sculpin (2 specimens)

Arctic char (1 specimen)

Arctic flounder (1 specimen)

For all specimens, the gas chromatograms do not show any peak of an *n*-alkane. Phytane, a hydrocarbon characteristic of petroleum, is absent.

It is curious that the upper flesh of the Arctic flounder had almost twice the hydrocarbon content of the lower flesh. We know of no physiological reason for this.

The kinds and amounts of hydrocarbons found in fish and sediments of this study are largely or totally the type produced by living organisms.

ACKNOWLEDGEMENTS

We would like to thank the Atlantic Richfield Company for their generous support of this project. We specifically acknowledge Dr. Paul Falls for his assistance in all phases of the study and his skills in logistical coordination. The entire staff of the ARCO base at Prudhoe Bay are to be commended for their support of the field work; we particularly appreciate the assistance and advice given generously by Angus Gavin. All diving activities were organized and accomplished by Rick Rosenthal of Dames and Moore of Anchorage and Lou Barr of the National Marine Fisheries Service, Auke Bay Biological Laboratory, Auke Bay, Alaska. We thank the following University of Alaska personnel: John Hilsinger for his most competent assistance in the field, and Doug Schamel for very able taxonomic assistance and aid in preparation of the benthic biological section of this report and for assistance with the literature survey of marine birds. Special appreciation is given to Andrew Grossman for his conscientious efforts in the preparation of most of the biological literature sections of Volume II. Grant Matheke prepared the literature review on ice algae, benthic microalgae, and primary production. Dr. Rita Horner prepared the literature compilations on physical oceanography, plankton, and benthic algae in Volume II. George Mueller, Director of the Marine Sorting Center of the University of Alaska, provided assistance with logistics, taxonomic determinations and editing skills in the organization of portions of the manuscript section on benthic biology. We are grateful to R. Furniss, Alaska Department of Fish and Game, for collection of fishes used in hydrocarbon determinations. Grateful thanks are extended to Dr. Peter W. Barnes, Marine Geology Office, U.S. Geological

Survey (Menlo Park) for kindly providing splits of sediment samples from the Prudhoe Bay area.

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GENERAL INTRODUCTION

The North Slope of Alaska has received increasing attention since the discovery of oil at Prudhoe Bay in 1968. The development of oil and gas reserves will not proceed without some degree of impact on the natural environment. Prudhoe Bay and the surrounding coastal zone will be especially affected not only because this area encompasses the northern terminus of the trans-Alaska pipeline, but also because of increased marine traffic and offshore drilling expected here. A knowledge of the present local oceanographic regime and the information available in the published literature are essential in order to establish a basis for documenting and monitoring, for regulatory purposes, the impact of industrial development on the marine ecosystem at Prudhoe Bay. This report, in two volumes, presents information that should contribute to this goal. The first volume considers the results of benthic biological, geological and hydrocarbon investigations accomplished in Prudhoe Bay in August 1974. Volume two represents a compilation of the major scientific literature available for the Alaskan and Canadian arctic marine environment.

Chapter 1

GEOLOGICAL STUDIES

A. S. Naidu

INTRODUCTION

The size distributions of the continental margin sediments of the North Slope have been described by a number of investigators (Dygas *et al.*, 1972; Tucker, 1972; Wiseman *et al.*, 1973; Naidu and Mowatt, 1974a, 1974b, 1975; Barnes, 1974; Barnes and Reimnitz, 1974). Reimnitz *et al.* (1972), Barnes and Reimnitz (1974), and Reimnitz and Barnes (1974) have been concerned with the sediment deposition-erosional action of sea ice. Aspects of beach dynamics and nearshore morphology has been a subject of concern for Short *et al.* (1974). The river overflow on sea ice at spring breakup in the arctic Alaskan coast has been described by Reimnitz and Bruder (1972) and Walker (1974). During the past few years efforts have been made to document and understand the chemistry of the deltaic sediments of the North Slope rivers (Naidu, 1972; Naidu and Mowatt, 1974a, 1975). However, much of the geochemical work carried out to date by Naidu has been related to the major chemical constituents of sediments (e.g. alkali and alkaline earth elements, Fe, Mn, organic carbon and carbonate). Except for the analyses of Cu and Co by the above, and more recently of Hg by Weiss *et al.* (1974), no quantitative analysis is available on the trace metal contents in sediments of the continental margin environment of the North Slope. However, Barnes (1974) has presented semi-quantitative data for Hg, Cu, Pb, Zn and As in various sediment size grades.

The importance of collecting geochemical data in any ecological investigation cannot be overemphasized. Geochemical parameters particularly appropriate for study in Prudhoe Bay include organic carbon, Ni and V. Organic carbon measurements provide an index to the amount of food available to deposit feeding benthic organisms. Nickel and V are worthy of attention because their concentrations in the sediments may be influenced by crude oil input - either from past natural seepages or future production mishaps.

OBJECTIVES

The prime objectives of the geological investigations has been to provide basic physical and chemical parameters in support of the other aspects of this project. Parameters measured include grain size distribution, and content of organic carbon, Ni and V in sediments. The purpose of the analysis of clay mineral compositions of sediments has chiefly been to understand the source, migratory paths and depositional sites of fine-grained particles in the Prudhoe Bay area, and to identify any correlation between chemistry and mineralogy of fine-grained particles.

MATERIALS

Sediment samples from the causeway site were collected and provided by Drs. H. Feder and D. Shaw. As such, the methods of collecting those samples as well as their locations is referred to in the sections dealt with by Drs. Feder and Shaw of this report. Most of the sediment samples from the rest of the Prudhoe Bay and the adjacent shallow marine environment were provided by Dr. Peter W. Barnes of the U.S. Geological Survey. These samples were collected by a van Veen, or a Shipek grab sampler. Locations of the latter samples are included in Table I. All stations referred to in this report are found in Figure 1.

Table I. Locations and the depth of waters for sediment samples collected from the Prudhoe Bay and the adjacent shallow marine environment by the U.S. Geological Survey between 1970 and 1972.

Sample No.	North Latitude	West Longitude	Depth (m)
70 BS 18	70°22. 7'	148°09.8'	2.0
70 BS 19	70°30. 9'	148°35.4'	13.0
70 BS 21	70°31. 4'	148°34.6'	16.0
70 BS 22	70°36. 3'	148°25.3'	20.0
71 AJT 1	70°24. 6'	148°23.2'	3.2
71 AJT 2	70°20. 6'	148°23.3'	2.5
71 AJT 3	70°27. 0'	148°15.3'	8.5
71 AJT 4	70°30. 0'	148°00.0'	11.3
71 AJT 5	70°26. 2'	148°00.0'	6.7
71 AJT 6	70°22. 6'	148°00.0'	4.6
71 AJT 15	70°23. 8'	148°29.0'	2.6
71 AJT 16	70°26. 5'	148°30.0'	7.0
71 AJT 18	70°31. 0'	148°45.0'	13.7
71 AJT 19	70°29. 2'	148°30.0'	8.8
71 AJT 20	70°31. 8'	148°30.0'	14.6
71 AJT 22	70°35. 5'	148°30.0'	20.4
71 AJT 41	70°32. 0'	148°18.0'	14.0
71 AJT 42	70°34. 3'	148°05.0'	22.0
71 AJT 45	70°24. 0'	148°15.0'	3.4
71 AER 15	70°19. 0'	148°19.0'	1.0
72 AJT 3	70°29. 0'	149°03.3'	3.0
72 AJT 4	70°29. 5'	149°07.6'	2.4
72 AJT 5	70°27. 2'	148°10.3'	7.3
72 AJT 6	70°25. 2'	148°10.2'	5.5
72 AJT 7	70°22. 8'	148°10.8'	2.4
72 AJT 8	70°21. 4'	147°56.7'	3.7
72 AER 20	70°25.72'	148°50.8'	1.2
72 AER 22	70°26.41'	148°50.5'	1.0
72 AER 23	70°26.86'	148°50.0'	1.8
72 AER 24	70°27.26'	148°48.9'	1.7
72 AER 25	70°27.45'	148°61.1'	2.2
72 AER 26	70°26.45'	148°54.0'	2.0
72 AER 129	70°29.40'	148°20.3'	3.0
72 AER 134	70°31.95'	148°12.8'	14.5
72 AER 137	70°29.90'	148°00.4'	12.5
72 AER 165	70°30.25'	148°19.2'	10.5
72 AER 166	70°26.57'	148°34.3'	7.0
72 AER 167	70°25.92'	148°34.5'	5.5
72 AER 168	70°25.32'	148°34.6'	3.5
72 AER 188	70°24.90'	148°30.8'	15.0

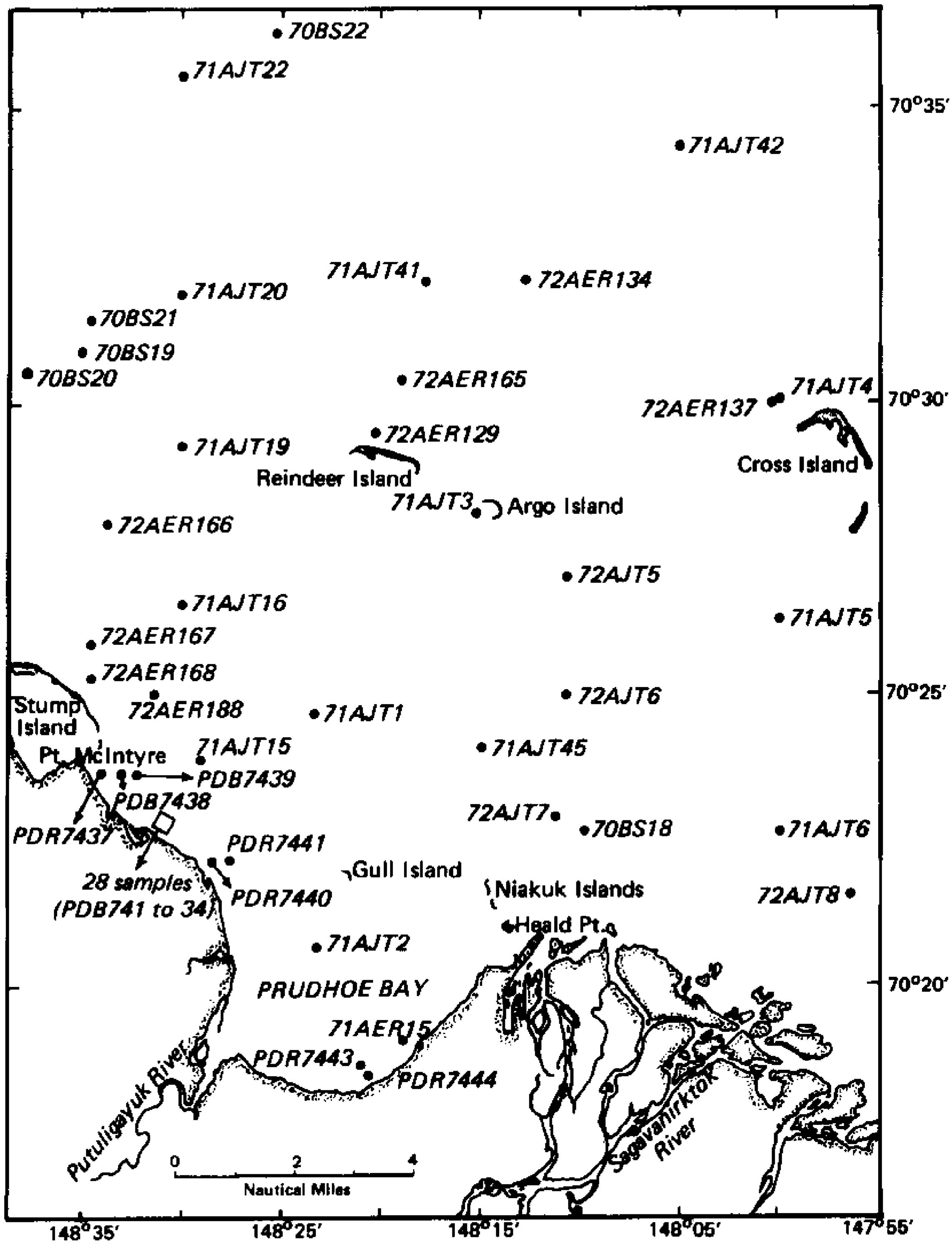

Figure 1. Locations of sediment samples in the Prudhoe Bay and adjacent shallow marine environment of north arctic Alaska.

ANALYTICAL METHODS

Grain-size distributions of sediments were achieved by the conventional combined sieving-pipetting method. Statistical size parameters were calculated by using the formulae given by Folk and Ward (1957).

For chemical analysis, representative portions (about 20 gm) of each of the sediments were first dried at 105°C and then pulverized into fine powders using an agate mortar and pestle. Prior to powdering all particles greater than the gravel size were picked out. Vanadium and Ni were analyzed from HF-HNO_3 digested sediment solutions by atomic absorption spectrophotometry, using a Perkin-Elmer Model 306 unit. The precision of Ni and V analysis was about 12 percent, whereas their accuracies of determinations were checked by analyzing the U.S. Geological Survey standard rock sample AGV-1 and comparing the results thus obtained with those summerized by Flanagan (1969). The values of Ni and V in this study have been rounded off to the nearest 5 ppm.

Carbonate contents in the sediments were analyzed manometrically (Hülsemann, 1966). Organic carbon abundances in the sediments were determined from the differences between total carbon and carbonate carbon in the sediments. Total carbon was analyzed in a Leco, TC-12, automatic carbon determinator.

The clay mineral compositions of the less than 2 mμ fraction of sediments were analyzed by x-ray diffraction technique, following the method elaborated by Naidu *et al.* (1971).

RESULTS AND DISCUSSION

Sediment Texture

Table II gives the grain-size parameters of sediments at the new causeway site, and Table III shows the grain-size parameters of sediments of the region adjacent to the causeway in Prudhoe Bay. The gravel-sand, silt and clay percentages of the above sediments are plotted on a trilinear diagram (Fig. 2). In attempting to understand the relationships between the different statistical size parameters, several scatterplots have been drawn (Figs. 3, 4 and 5). For the purpose of comparison with the sediments at the new causeway site, scatterplots relating to grain size distributions from other depositional facies of the North Slope deltaic complex have also been depicted in Figures 2 through 5, and the raw data for these plots were extracted from Naidu and Mowatt (1974b). Sediments of the bay facies in the above figures represent samples collected from the Harrison Bay and the outer Prudhoe Bay.

Almost all of the sediments from the new causeway site (1 to 34, Table II) are moderately to poorly sorted sands, silty sands or sandy silts, with positive to very positively skewed as well as leptokurtic to very leptokurtic size distributions. Gravel is recorded in 75 percent of the above sediments; however, only three of the samples (1, 24 and 25, Table II) have gravel contents notably high (Table II). It is to be noted that the latter three samples were collected from the foreshore of the coastal beach in northwestern Prudhoe Bay, while the rest of the causeway samples were obtained from offshore. In Figures 3 and 4 it is displayed that sorting and skewness values of size distributions of causeway sediments have a positive covariance with the sediment mean size.

Table II. Size distribution* of sediments from the new causeway site, Prudhoe Bay, arctic Alaska.

Sample No.**	Gravel %	Sand %	Silt %	Clay %	Md	M_z	σ_I	SK_I	K_G
1	33.27	63.58	2.30	0.9	0.8	0.53	1.31	-0.29	0.68
2	1.38	80.80	11.31	6.5	2.2	2.57	1.96	0.41	2.68
4	0.32	90.66	5.21	3.8	2.4	2.57	0.77	0.33	1.18
6	0.05	63.59	31.55	4.8	3.5	3.40	1.60	-0.11	1.56
7	2.27	33.72	54.50	9.5	4.3	4.67	2.18	0.30	1.17
8	0.23	44.90	49.86	5.0	4.1	4.17	1.43	0.08	1.50
9	0.63	38.40	46.96	14.0	4.3	5.03	2.20	0.55	1.41
10		47.28	47.21	5.5	4.2	4.50	1.30	0.39	1.79
15	0.22	34.03	52.24	13.5	5.0	5.23	2.13	0.18	1.53
16		32.24	53.75	14.0	4.8	5.27	1.84	0.37	0.90
17	1.20	71.80	19.00	8.0	3.9	4.40	1.48	0.71	5.16
18	1.39	52.24	36.61	9.5	4.0	4.10	1.53	0.14	2.08
19	1.23	56.16	39.10	3.5	3.8	3.83	1.07	0.67	2.10
20	0.47	76.47	18.05	5.0	3.5	3.50	1.39	0.00	3.18
21		92.70	5.09	2.2	2.6	2.60	0.69	0.00	1.70
22	0.59	93.44	1.96	4.0	2.0	2.07	0.83	0.17	2.05
23	0.46	96.82	1.71	1.0	2.0	2.07	0.57	0.20	1.43
24	25.86	71.52	0.61	2.0	0.7	0.83	0.80	0.22	0.36
25	35.00	62.90	0.80	1.3	0.6	0.47	1.19	-0.14	0.50
26	0.50	83.49	13.00	3.0	2.6	2.73	1.21	0.20	1.48
27		97.80	1.40	0.8	2.0	2.07	0.58	0.20	1.29
28		99.60	0.38		2.1	2.17	0.33	0.33	1.64

Table II. (Continued)

Sample No.	Gravel %	Sand %	Silt %	Clay %	Md	M_z	σ_I	SK_I	K_G
29	0.17	79.93	17.89	2.0	3.2	3.30	0.97	0.18	1.48
30	0.10	56.69	40.40	2.8	3.8	3.87	0.83	0.17	2.05
31		81.50	9.00	9.5	3.8	3.90	1.36	0.23	7.00
32	0.43	50.00	6.56	43.3	5.6	7.00	3.18	0.57	0.55
33	0.30	41.39	48.80	9.5	4.3	4.80	1.80	0.52	2.08
34		66.00	27.50	6.5	3.6	3.93	1.39	0.56	2.31
37		85.00	9.00	6.0	3.5	3.53	0.94	0.20	7.37
38		84.76	11.23	4.0	3.6	3.60	0.67	0.00	2.54
39		89.95	6.54	3.5	3.3	3.10	0.91	-0.33	1.37
40		90.43	7.46	2.1	2.2	2.40	0.90	0.38	1.23
41		53.00	41.50	5.5	3.9	3.80	2.04	-0.03	0.96
43		96.52	2.67	0.8	2.4	2.53	0.62	0.33	1.00
44		96.46	1.53	2.0	2.3	2.37	0.71	0.14	1.23

* The statistical grain size parameters are after Folk and Ward (1957).

**All sample numbers have a prefix PDB74 (Fig. 1).

Table III. Size distribution of sediments of the Prudhoe Bay and the adjacent shallow marine environment, north arctic Alaska.

Sample No.	Gravel %	Sand %	Silt %	Clay %	Md	M_z	σ_I	SK_I	K_G
70 BS 18	3.06	91.65	4.92	0.37	2.40	2.10	1.21	−0.13	1.30
70 BS 21		36.75	60.75	2.69	4.80	5.58	2.76	0.39	0.96
71 AJT 1		84.80	6.80	8.40	3.08	3.33	1.82	0.77	7.45
71 AJT 2		8.90	68.30	22.80	5.95	6.67	2.89	0.47	1.54
71 AJT 3		22.20	31.40	46.50	6.15	6.95	3.54	0.37	0.93
71 AJT 4		70.50	9.80	19.70	3.25	3.77	2.89	0.73	3.31
71 AJT 5		85.00	11.00	4.00	1.70	2.00	2.16	0.26	1.83
71 AJT 6		94.30	2.30	3.30	2.68	2.70	0.52	0.28	2.11
71 AJT 15		65.00	23.30	11.80	3.72	4.87	2.78	0.82	4.50
71 AJT 16		61.69	30.30	8.00	3.40	4.23	1.82	0.68	0.93
71 AJT 18		12.70	49.40	37.80		7.20	2.28	−0.07	
71 AJT 19		45.50	28.30	26.20	4.22	6.08	3.66	0.72	0.95
71 AJT 20		37.42	46.07	16.05	5.40	5.37	2.45	−0.02	0.76
71 AJT 22	24.10	45.20	11.50	19.20	2.15	3.22	6.65	0.29	1.07
71 AJT 41		96.40	3.50			2.75	0.46	−0.39	
71 AJT 42	20.40	46.30	17.30	15.90		2.33	4.86	0.19	
71 AJT 45		99.10	0.90			2.70	0.52	0.25	
71 AER 15		79.48	14.01	6.50	2.00	3.13	2.56	0.65	1.89
72 AJT 3		58.83	33.14	8.00	2.90	3.83	1.95	0.74	0.97
72 AJT 4		40.85	48.64	10.50	4.70	4.47	2.50	−0.14	0.93
71 AJT 5		81.47	14.02	4.50	1.90	2.37	2.19	0.32	1.48
72 AJT 6		97.80	0.99	1.20	0.90	1.07	0.53	0.56	1.64
72 AJT 7		27.99	61.50	10.50	5.80	5.37	2.10	−0.29	0.82
72 AJT 8		13.67	73.82	12.50	6.20	5.93	1.64	−0.29	1.59
72 AER 20		47.00	36.00	17.00	4.40	5.03	2.48	0.36	1.04
72 AER 22		42.92	48.57	8.50	4.60	4.87	1.87	0.22	0.91
72 AER 23		45.84	46.65	7.50	4.10	4.43	2.03	0.25	0.96
72 AER 24		54.02	40.87	5.10	3.80	4.03	1.64	0.23	1.11
72 AER 25		78.40	15.67	5.93	3.25	3.40	1.62	0.24	2.78
72 AER 26		23.00	46.00	31.00	5.90	6.27	2.54	0.20	0.83
72 AER 129		11.45	54.82	33.73	6.60	7.03	2.85	0.11	0.80
72 AER 134		17.10	55.89	27.00	6.30	7.17	3.49	0.33	0.72
72 AER 137		83.98	11.51	4.50	2.90	2.97	1.53	0.10	7.00
72 AER 166		41.41	47.58	11.00	4.40	4.70	2.09	0.22	0.93
72 AER 167		63.32	31.17	5.50	2.80	3.57	2.19	0.51	0.87
72 AER 168		19.97	69.52	10.50	5.30	4.87	2.00	−0.35	2.05

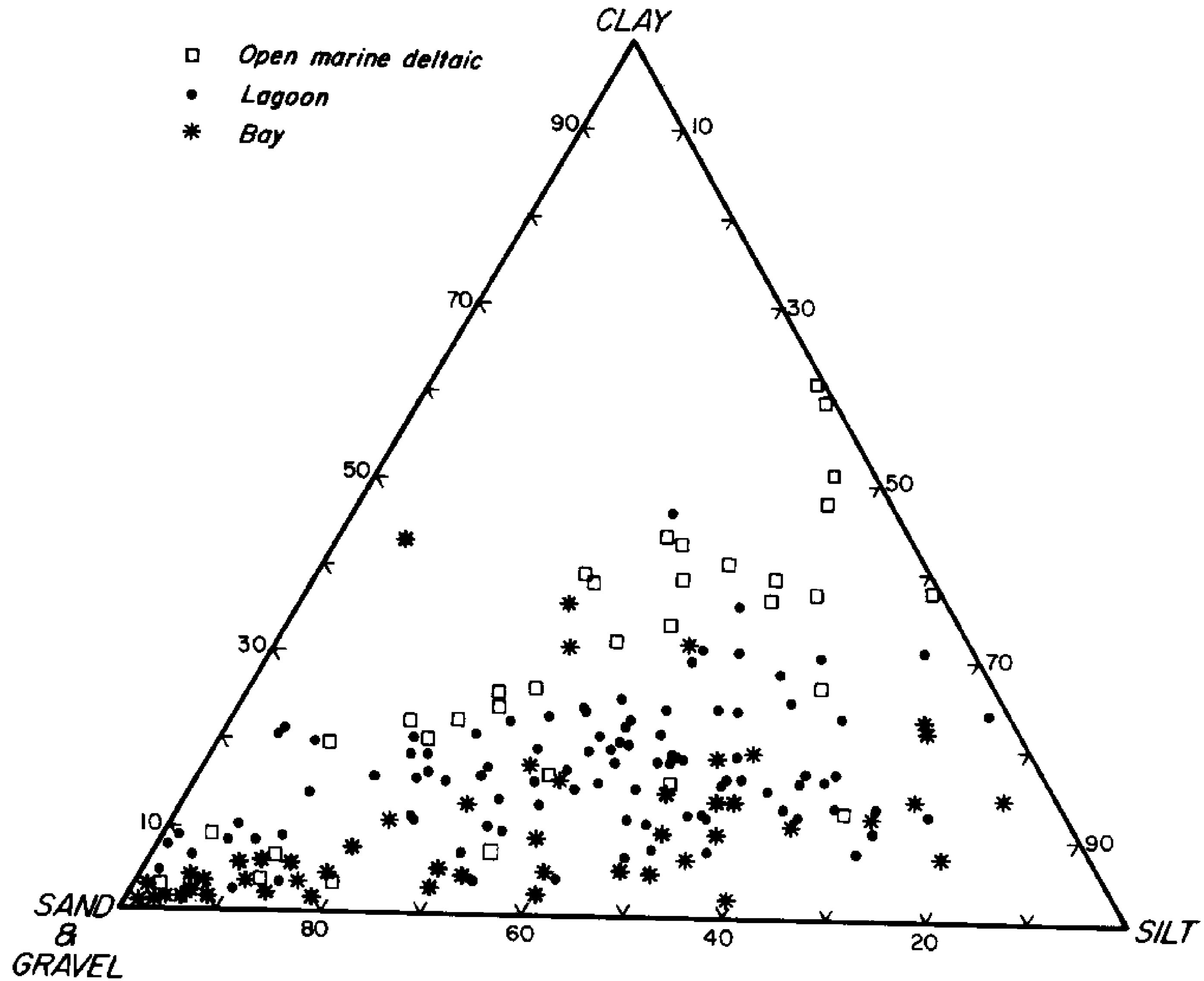

Figure 2. Gravel-sand, silt and clay percents in sediments.

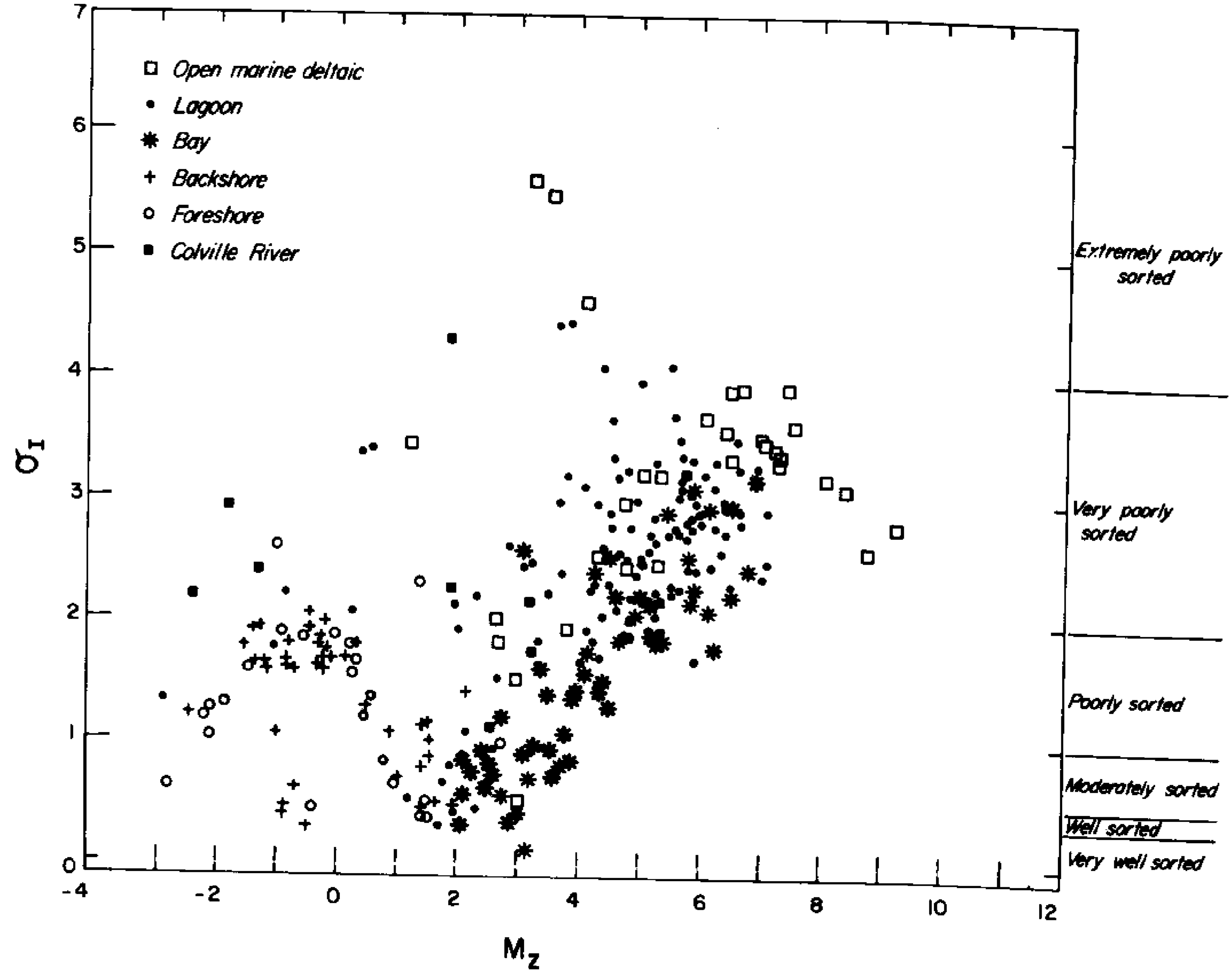

Figure 3. Scatterplot of phi mean size (M_Z) versus standard deviation (σ_I) of sediment size distribution.

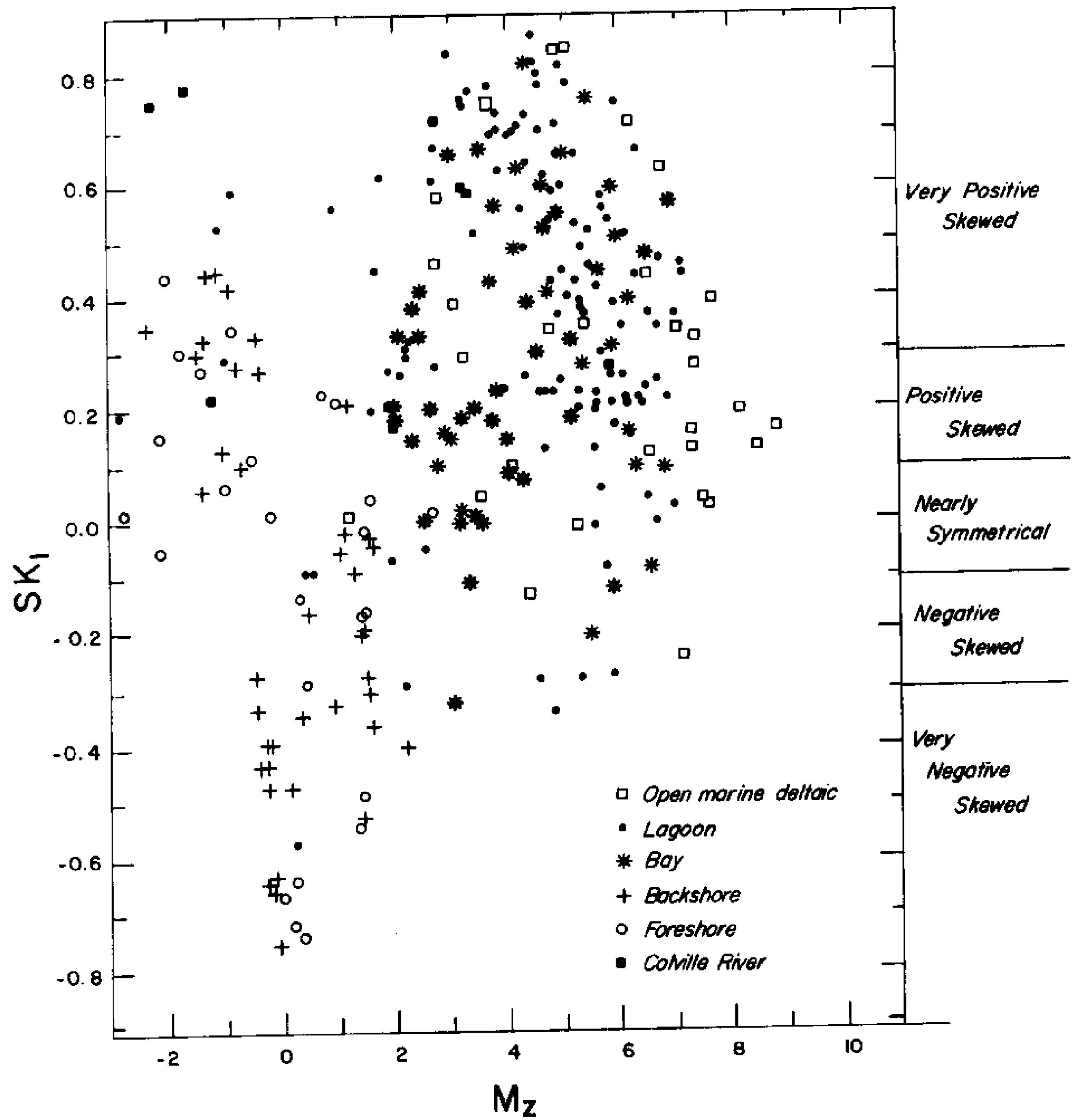

Figure 4. Scatterplot of phi mean size (M_z) versus skewness (SK_I) of sediment size distributions.

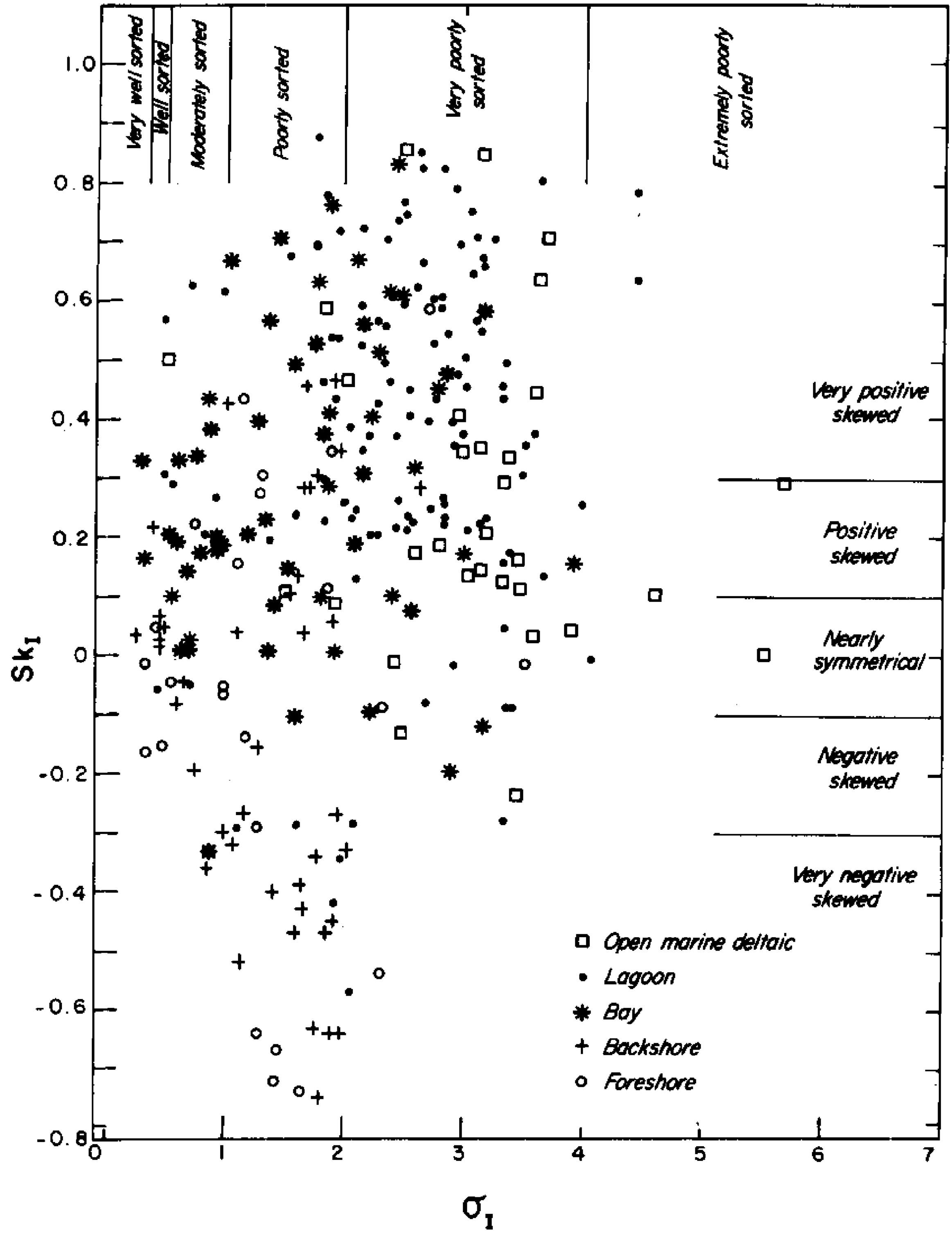

Figure 5. Scatterplots of standard deviation (σ_I) versus skewness of size distributions.

It would seem that almost all of the sediments collected at the new causeway site and from the bay facies of the North Slope deltas (Figs. 2, 3 and 4) have size distributions that pertain to a continuous spectrum. It is apparent that in this spectrum the suite of samples from the new causeway site constitute the end of coarser sized grains as well as better sorted relative to sediments of the bay facies. Such a dispersion of sizes and sorting in the above spectrum probably is attributable to slight differences in the energy levels prevailing within the bay environments of the North Slope. Because the new causeway site samples were collected from shallower waters as well as nearer the shore and thus plausibly under slightly higher energy wave/current actions, it is to be expected that they will be relatively coarser and better sorted. Sediments representing the bay facies (Figs. 2, 3 and 4) on the other hand were obtained from the central and outer Harrison and Prudhoe Bays, which have relatively deeper and quieter waters than at the new causeway site. In fact, within the new causeway site an overall marineward decrease in mean size and sorting of sediments is discerned, which may well be explained by a possible marineward decrease in energy levels.

Size statistical plots of three sediment samples collected at the new causeway site (1, 24 and 25, Table II) do not group closely within the field of plots pertaining to the bay facies (Figs. 3 and 4). This is to be expected because the above three samples were obtained from coastal beaches rather than the adjacent offshore of Prudhoe Bay. As a result the statistical size plots for these samples are clustered within the field characteristic of the coastal beach sediments of the North Slope deltas (Figs. 3, 4 and 5).

Clay Minerals

The weighted peak area percents (Biscaye, 1965) of clay minerals in the <2mμ size fraction of sediments, from the new causeway site are included in Table IV, and those of sediments from elsewhere of the Prudhoe Bay and adjacent shallow marine environment (Fig. 1) are included in Table V. It is observed that there are no significant lateral or marineward variations in the clay mineral assemblages within the region of the new causeway. Illite is the predominant clay mineral, kaolinite and chlorite occur in subordinate amounts, and smectite together with some possible mix layered components is either absent or present in very low amounts. Such a clay mineral suite is almost identical to the suite documented earlier for Prudhoe Bay (Naidu and Mowatt, 1974a and 1975). Results of this study attest to the earlier conclusions by Naidu and Mowatt (1974a and 1975) that there is no significant eastward transport of clay-size sediment particles within the very nearshore marine facies of the North Slope deltaic complex between the Colville and the Sagavanirktok Rivers. Based on the data collected by the above authors, it is concluded that the Sagavanirktok River is the predominant source of the fine grained sediments at the new causeway site, as well as the entire Prudhoe Bay and the shallow marine area due south of the Reindeer and Cross Islands (Fig. 1). North of the above islands the concentration of smectite increases notably, and is attributable to a relative increase in fine-grained sediment influx into this region from the west - most probably from the Colville River.

Geochemistry

The contents of carbonates, organic carbon, Ni and V in sediments of the new causeway site are included in Table VI, and from the rest of the

Table IV. Clay mineral compositions* of the less than two micron fraction of sediments, new causeway site, Prudhoe Bay, north arctic Alaska.

Sample No.	Smectite	Illite	Kaolinite	Chlorite
2		61	12	27
4	1	67	11	21
6	4	62	13	21
8	3	70	11	16
10	1	66	12	21
15	2	62	14	22
17	6	62	7	25
19	2	62	13	23
21	1	68	12	19
23		66	15	19
26	1	64	13	22
28	1	65	12	22
30	1	64	11	24
32		61	15	24
34		61	13	26

* Weighted peak area percents (after Biscaye, 1965).

Table V. Weighted peak area percentages of clay minerals in the less than two micron fraction of surficial bottom sediments of the Prudhoe Bay and adjacent shallow marine environment, north arctic Alaska.

Sample No.	Smectite	Illite	Kaolinite	Chlorite
71 AJT 1	Trace	69	13	18
71 AJT 2	1	71	7	21
71 AJT 3	2	49	12	37
71 AJT 4	2	69	11	18
71 AJT 6	1	68	13	18
71 AJT 15	0	85	4	11
71 AJT 16	4	67	9	20
71 AJT 19	2	71	11	16
71 AJT 20	7	63	8	18
71 AJT 42	4	61	12	23
72 AER 25	7	61	8	24
72 AER 26	6	62	9	23
72 AER 129	4	65	12	19
72 AER 134	8	58	13	21
72 AER 168	2	63	11	24
72 AER 188	2	62	11	25

Table VI. Organic carbon, carbonate, nickel, vanadium, and chromium contents (dry weight) in sediments, new causeway site, Prudhoe Bay, north arctic Alaska.

Station No.	Org. C %	CO_3 %	Ni ppm	V ppm	Cr ppm
1	Trace	3.56	10	25	21
2	0.45	6.28	25	25	31
4	Trace	9.10	25	25	26
6	0.23	14.57	35	25	38
7	1.63	15.14	50	150	69
8	0.63	16.65	35	100	49
9	1.58	16.81	45	150	150
10	0.25	18.07	45	50	54
15	0.44	21.94	50	150	118
16	2.05	14.67	60	75	57
17	0.36	17.37	30	50	42
18	0.11	18.00	30	75	105
19	0.55	16.31	35	100	38
20	0.04	14.81	15	25	63
21	0.01	9.06	30	50	29
22	0.03	4.28	15	25	19
23	Trace	6.42	10	25	24
24	Trace	2.90	10	20	22
25	Trace	2.44	10	25	23
26	0.13	10.04	25	50	32
27	Trace	5.16	15	25	37
28	0.01	5.29	15	25	23
29	0.19	15.25	35	25	49
30	0.35	16.77	45	25	49
31	0.12	18.06	45	50	59
32	0.32	16.92	50	25	46
33	0.62	17.08	50	50	67
34	0.21	17.06	40	50	45
37	0.54	17.17	35	125	78
38	Trace	19.57	45	25	38

Table VI. (Continued)

Station No.	Org. C %	$CO_3^=$ %	Ni ppm	V ppm	Cr ppm
39	Trace	14.89	35	25	47
40	Trace	9.14	25	25	32
41	0.70	11.89	45	25	65
43	Trace	32.42	20	25	33
44	0.16	12.39	30	25	32
Average of the 28 causeway samples 1 to 34.	0.37	12.50	32	53	61

area of study in Table VII. The carbonate contents in sediments of the present investigation are, as in the case of other deltaic sediments of the North Slope, notably higher than those from analogous depositional facies of the tropical and temperate deltas (Naidu and Mowatt, 1974a). Because tropical and temperate oyster reefs constitute an unique environment with sediments enriched in autochthonous calcareous debris, carbonate contents of reef bay facies have been excluded in the above comparison. As observed earlier (Naidu and Mowatt, 1974a and 1975), the high contents of carbonates in the North Slope deltaic sediments are a result of the unusually high influx of terrigenous calcareous clastics (limestone and dolomite grains) introduced into this region. Results of the present study substantiate these conclusions.

Naidu and Mowatt (1974a) have documented that there are significant facial variations in the sediment carbonate contents within the deltaic region of the North Slope. It has been shown by these authors that sediments of the bay facies chiefly represented by the Harrison Bay sediments have the least amount of carbonates (average:4.12%). Results of this study (Tables VI and VII), however, do not support the above view inasmuch as the average carbonate abundance of bay sediments at the new causeway site as well as the adjacent area is similar to that of the North Slope lagoons (12.1%). Likewise, the average abundances of organic carbon in sediments of the new causeway site and the contiguous Prudhoe Bay area (Tables VI and VII) and of the Harrison Bay (Naidu and Mowatt, 1974a) are not similar, although both the suites of samples were collected from bay facies. It is concluded that the differences noted in the carbonate and organic carbon contents between the sediments of Harrison Bay and Prudhoe Bay (including

Table VII. Organic carbon, carbonate, nickel and vanadium contents (dry weight) in sediments of the Prudhoe Bay and adjacent shallow marine environments.

Station No.	Org. C %	$CO_3^{=}$ %	Ni ppm	V ppm	Cr ppm
70 BS 18	Trace	19.02	25	25	31
70 BS 19	Trace	8.30	20	25	23
70 BS 21	0.38	12.18	45	75	60
70 BS 22	0.43	9.81	8	75	58
71 AJT 5	0.08	11.57	25	25	35
71 AJT 16	0.66	16.79	45	50	37
71 AJT 18	1.86	8.98	70	100	93
71 AJT 19	0.70	14.20	35	25	47
71 AJT 20	0.27	12.09	50	75	66
71 AER 15	0.43	11.01	45	50	50
72 AJT 3	1.26	6.83	35	25	46
72 AJT 4	1.23	9.18	45	50	53
72 AJT 5	0.08	13.33	25	25	37
72 AJT 6	Trace	12.93	30	25	15
72 AJT 7	0.57	18.28	50	75	59
72 AJT 8	0.68	17.05	55	75	65
72 AER 20	0.21	10.52	20	25	29
72 AER 22	1.06	15.33	50	75	64
72 AER 23	0.31	18.59	40	50	49
72 AER 24	0.50	18.00	35	25	45
72 AER 25	0.26	17.17	35	50	43
72 AER 26	1.18	6.63	80	175	127
72 AER 129	0.80	11.50	50	100	74
72 AER 134	0.94	10.04	60	100	75
72 AER 137	Trace	11.46	20	25	28
72 AER 166	0.52	16.03	45	50	57
72 AER 167	0.53	9.65	35	25	42
72 AER 168	1.12	13.42	45	50	63
Average of 28 samples	0.57	12.85	40	55	53

the new causeway site) are a reflection of the presence in the two bays of either slightly different sediment textures, coupled with size sorting of the carbonate phase, or sediments of similar size grades but with different carbonate contents because of a difference in terrigenous detrital sources.

The contents of organic carbon at the new causeway site (Table VI; average:0.37%) and in the adjacent area of study (Table VII) are significantly lower than those generally observed in shallow marine sediments of the tropical and temperate deltaic regions. In fact, the low concentrations of organic carbon appears to be a typical characteristic of all deltaic sediments from the North Slope, and is explicable on the basis of earlier observations that the above region has relatively low biological productivity as well as low yearly supply of terrigenous organic detritus (Naidu and Mowatt, 1974a).

Concentrations of V in sediments at the new causeway site (Table VI) and the rest of the Prudhoe Bay area (Table VII) are generally lower than those in sediments collected from similar environments of tropical and temperate regions. It is of interest to note that a relative paucity of several other elements (e.g., Mg, K, Na, Fe, Mn and Cu) in the North Slope deltaic sediments have been documented earlier (Naidu and Mowatt, 1974a and 1975). However, no definite explanation can be given at this stage for the regional differences in chemical composition mentioned above.

Unlike V, the concentrations of Ni (Tables VI and VII) in the sediments at the new causeway site and the other areas of this study are comparative to those in nonpolar deltaic sediments as well as to those in sediments of the nearby Mackenzie Delta (Dewis *et al.*, 1972).

In attempting to understand the partition pattern of Ni scatter-plots were drawn for Ni against clay, organic carbon and carbonate contents of sediments (Figs. 6, 7 and 8). On the basis of these plots it would seem that bulk of the Ni is associated with the carbonate fraction, in the mud grade (less than 62 mμ size particles) of sediments. Naidu and Mowatt (1974a) have documented a strong covariance of Cu and carbonate in deltaic sediments of the North Slope. In light of the above and the data gathered in this study it is logical to conclude that both Cu and Ni are most probably associated with carbonate terrigenous detrital grains, plausibly in some discrete sulphide mineral phase. It would seem such a conclusion is further attested to with the finding of both Cu and Ni in carbonate rocks of the Brooks Range at concentrations generally higher than those reported as averages for analogous rocks elsewhere (Mowatt *et al.*, in progress; Mr. T. C. Trible, personal communication). The Brooks Range rocks constitute a major source for the North Slope sediments, including the carbonates in them.

No significant correlations have been observed between contents of V, carbonate, mud, and organic carbon in sediments of the new causeway site nor in other areas included in this study.

There is an overall marineward increase in Ni contents in sediments of the new causeway site. Such an increase in Ni can best be explained by the observed simultaneous marineward increase in carbonate and clay contents in sediments.

On the evidence gathered in the present study it is suggested that any marked increase in the mud fraction of sediments at the new causeway site will very likely also alter the level of Ni concentration in sediments of that area. It is therefore suggested that a long term sediment and geochemical monitoring program for Prudhoe Bay be instituted. The values of Ni and V

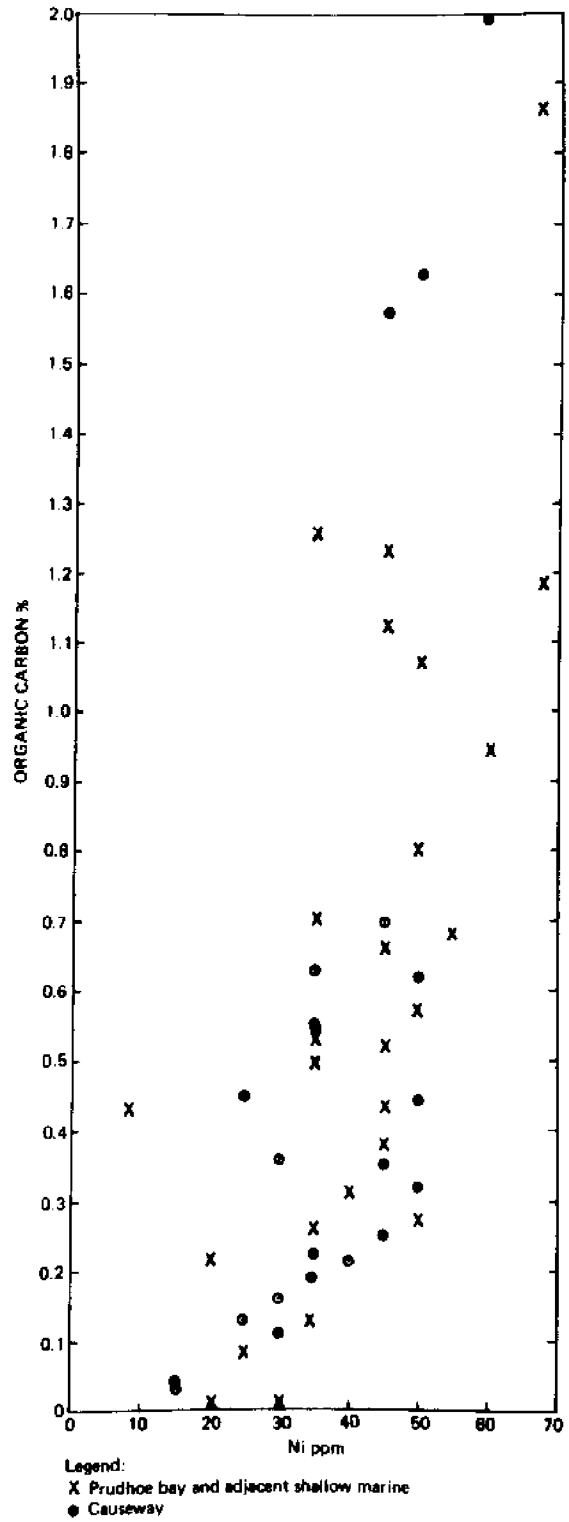

Figure 6. The relationship between Nickel and organic carbon content of sediments from Prudhoe Bay and adjacent shallow marine areas.

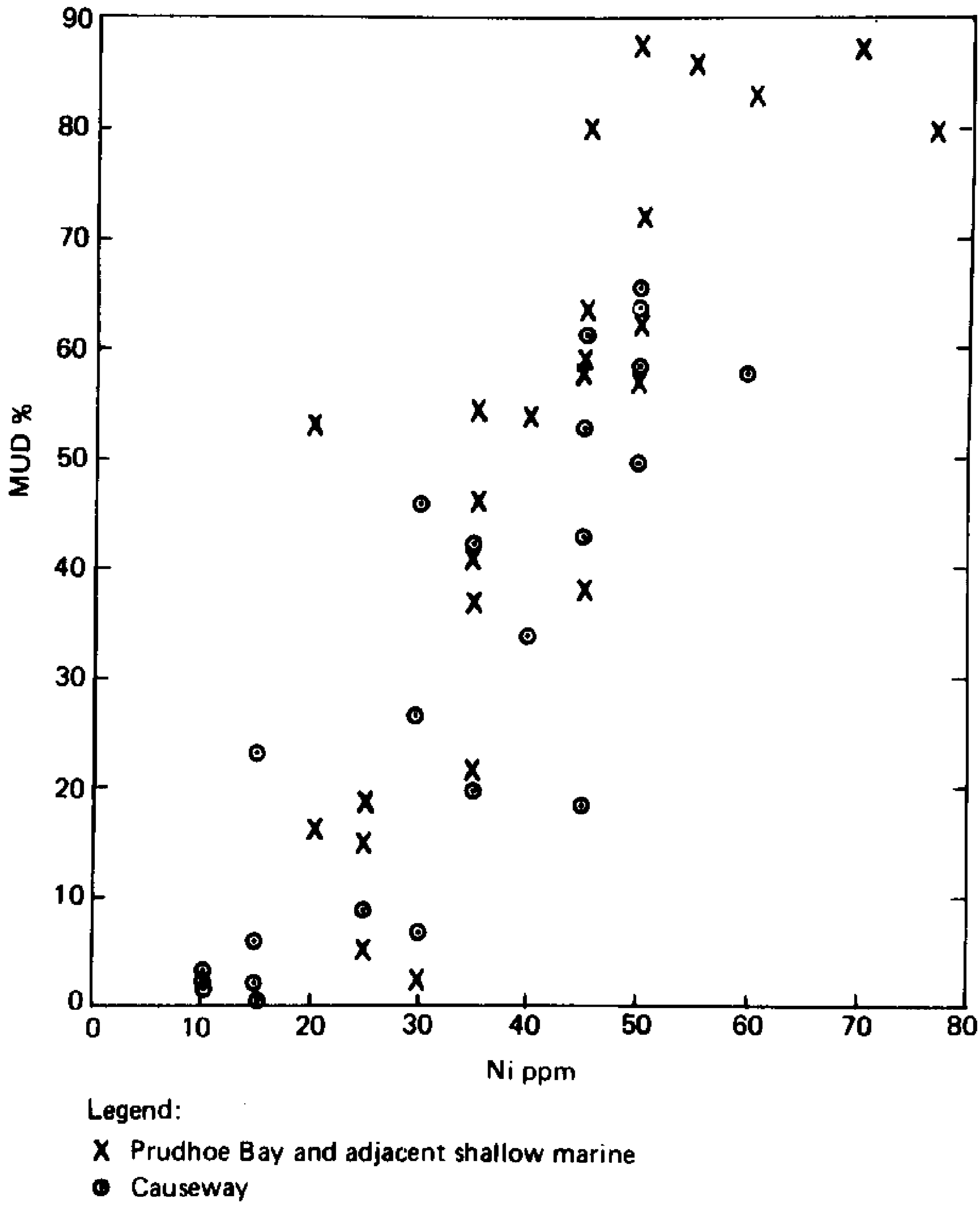

Figure 7. The relationship between Nickel and mud percentage of sediments from Prudhoe Bay and adjacent shallow marine areas.

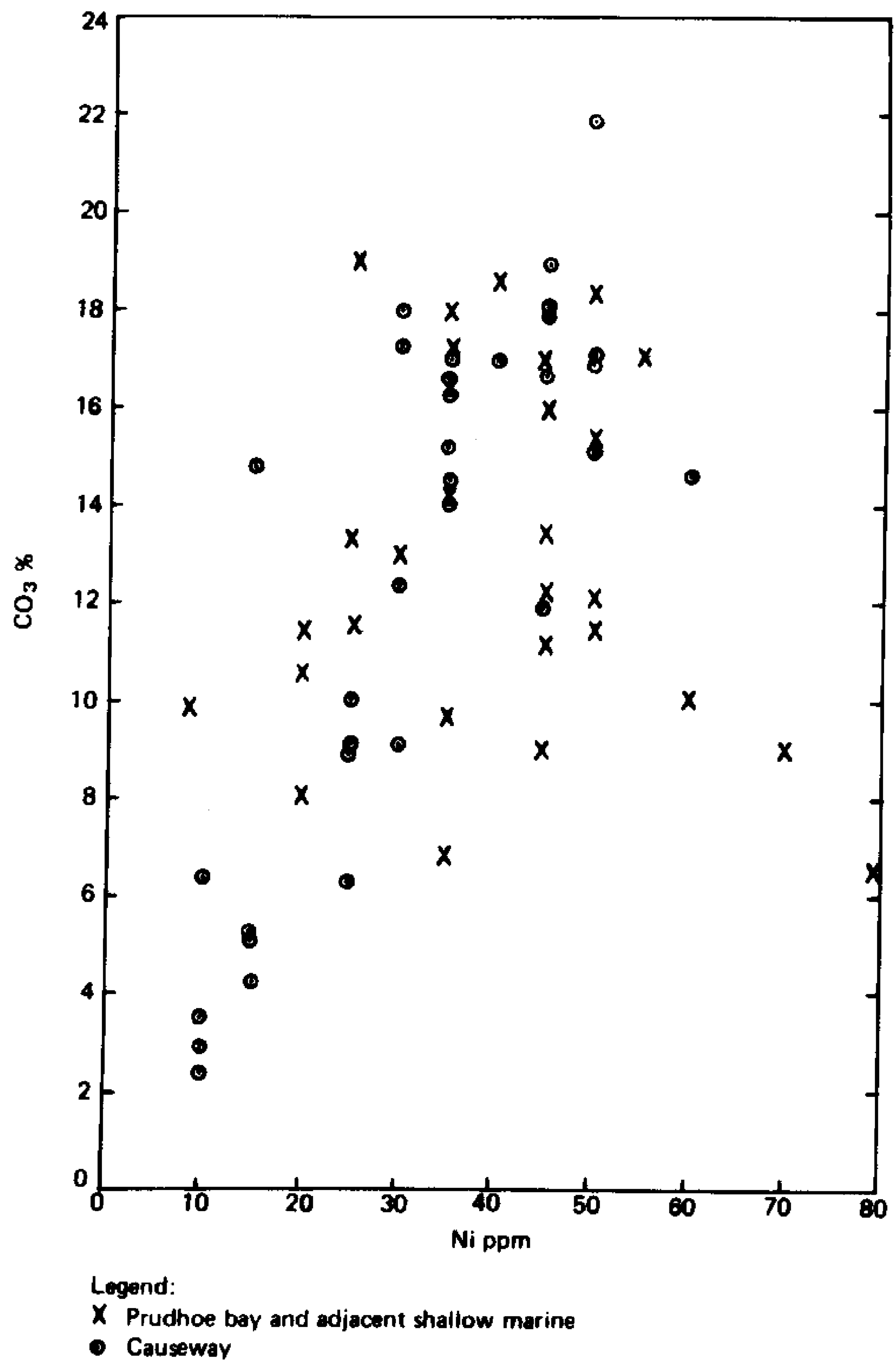

Figure 8. The relationship between Nickel and carbonate content of sediments from Prudhoe Bay and adjacent shallow marine areas.

included in Tables VI and VII should be a baseline to detect any pollution in the above region, subsequent to the development of oil-related activities, especially relating to these two metals.

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Chapter 2

HYDROCARBON STUDIES

D. G. Shaw

INTRODUCTION

Work in north temperate regions has suggested that petroleum hydrocarbons may be taken up by marine species. To understand the movement of petroleum hydrocarbons through food webs in the arctic marine environment at Prudhoe Bay, we must have knowledge of food habits of benthic species to determine trophic interactions to be expected there.

Such understanding also requires direct measurement of the kinds and amounts of hydrocarbons now present in various elements of the food webs. Our hydrocarbon measurements serve a double purpose since they also provide baseline information on hydrocarbons in Prudhoe Bay organisms. It is reasonable to expect that some arctic marine organisms accumulate unusally large amounts of fats and oils during the summer to provide sources of energy and carbon during the long, sunless winter. Such animals might also have an enhanced tendency to retain petroleum following exposure.

In the summer of 1974 a continuing program of environmental studies at Prudhoe Bay, Alaska was begun. These studies include investigations of benthic biota (Chapter 3 of this report), sediment characteristics (Volume II, Chapter 1) and the ambient levels of hydrocarbons in and around Prudhoe Bay. Prudhoe Bay, like many embayments of the Beaufort Sea, is very shallow - depths seldom exceed seven feet. In this setting, a pier to receive seagoing barges required a gravel causeway extending approximately 4400 feet into the bay. The effects of this causeway on the benthic environment of Prudhoe Bay are the immediate subject of the study reported here. Understanding these effects is particularly important since similar gravel structures are contemplated for the extension of petroleum exploration and development into other parts of the Beaufort Sea.

OBJECTIVE

The objective of the hydrocarbon portion of this project is to survey the kinds and amounts of hydrocarbons present in the biota and sediments of Prudhoe Bay and adjacent waters.

LOGISTICS AND SAMPLING

Prudhoe Bay largely freezes to the bottom each winter. This has limited our sampling activities to a single collection during the summer. Sediment samples for hydrocarbon analysis were collected before the causeway was built on two transects approximately 500 feet on either side of its projected location. Beginning 500 feet from shore, samples were collected every 1000 feet to 4500 feet from shore. In this way a loop of ten sediment samples for hydrocarbon analysis was collected around the causeway site. Shorter transects were sampled about one mile on either side of the causeway site. Additional sediment samples were obtained at other nearshore locations within Prudhoe Bay and in the vicinity of Gull, Niakuk and Argo Islands. Fishes collected by gill net at the causeway site were made available to us for hydrocarbon analysis by the Alaska Department of Fish and Game. Our sampling stations are shown in Figure 1 of Chapter 3 of this report and Table I. The difficulty of winter sampling has already been mentioned. Even in summer logistic problems for this work, like most arctic work, are considerable. A small boat which can operate in less than two feet of water is essential for work within Prudhoe Bay. Thus, many standard oceanographic and marine biological sampling techniques that require large platforms and winches are impractical. The principal collecting procedure used was divers using scuba gear. Operating out of an open, shallow draft boat also limited sampling activities to near-

Table I. Sample locations - Hydrocarbons

Station	Location
2	1000 feet S.E. of causeway, 500 feet from shore
4	1000 feet S. E. of causeway, 1500 feet from shore
6	100 feet S.E. of causeway, 2500 feet from shore
8	1000 feet S.E. of causeway, 3500 feet from shore
10	1000 feet S.E. of causeway, 4500 feet from shore
26	1000 feet N.W. of causeway, 500 feet from shore
28	1000 feet N.W. of causeway, 1500 feet from shore
30	1000 feet N.W. of causeway, 2500 feet from shore
32	1000 feet N.W. of causeway, 3500 feet from shore
37	1 mile N.W. of causeway, 1500 feet from shore
38	1 mile N.W. of causeway, 2500 feet from shore
39	1 mile N.W. of causeway, 3500 feet from shore
40	1 mile S.E. of causeway, 1500 feet from shore
41	1 mile S.E. of causeway, 2500 feet from shore
43	Adjacent to old causeway

perfect weather and conditions. To collect a sediment sample for hydrocarbon analysis, a diver was handed a pre-cleaned glass jar. The diver filled the jar directly at the bottom. The jar was returned to the boat and recapped. Ashore the jar was frozen until analysis. The sediments were generally sandy and contained organic material which appeared to be tundra fragments.

SAMPLE ANALYSIS

Materials

All solvents were redistilled prior to use. Purity was established by concentrating *in vacuo* 400 ml of the redistilled solvent to approximately 1.0 ml. Five µl of the resulting solution was analysed by gas chromatography (GC) under the same conditions used for hydrocarbon samples. Only solvents which demonstrated little or no evidence of contamination by this method were used.

Distilled H_2O was redistilled in glass from $KMnO_4$ and assayed for contaminants by a procedure similar to that used for sediment samples.

A Varian 1520 gas chromatograph with dual column flame ionization detector was used in all analyses. All chromatograms were temperature programmed: the column was isothermal at 60°C for four minutes following injection, and then approached 270°C at 15°C/minute.

Columns 1/8 inch by 6 feet stainless steel packed with Apiezon L 3 percent on 70/80 Anakrom Q were used for sediment. The biological materials were analysed using 1/8 inch by 6 feet stainless steel columns packed with 1.5 percent OV-101 on 80/100 mesh chromosorb W-HP.

All Soxhlet extractions were done with 500 ml flat bottom flasks and 5 cm Soxhlet extractors. Cellulose thimbles (Whatman 43 x 123 mm) were pre-extracted with 300 ml benzene/methanol 1/1 (v/v). Thimble extraction was continued until the *in vacuo* concentrated extract showed no evidence of contaminants on analysis by gas chromatography.

Procedure for Sediments

Partially thawed sediment samples were loaded into dry, tared, pre-extracted cellulose extraction thimbles. While being loaded, the sediment was examined and obvious organisms removed with forceps. The sediment was extracted for 48 hours with 300 ml benzene/methanol 1/1 (v/v). At least once midway through the extraction period the sediment was stirred with a glass rod to preclude channeling effects.

The benzene/methanol solution was liquid-liquid extracted in a 1000 ml separatory funnel with three 100 ml portions of hexane. The combined hexane extracts were washed with 100 ml saturated aqueous NaCl and then dried with anhydrous Na_2SO_4 overnight.

The hexane solution was concentrated *in vacuo* first in a 500 ml round bottom flask, then in a 25 ml pear-shaped flask to approximately 1.0 ml. During the final stages of concentration, powdered copper metal in hexane was added to remove any sulfur. After concentration the sample was loaded on a chromatography column and eluted with hexane. Silica gel and alumina were each activated at 250°C for two days and then deactivated with H_2O 5 percent and 6 percent respectively. Hexane washed, oven dried glass wool was used to plug a nine inch pasteur pipet. The pipet and glass wool were rinsed with hexane before adding a hexane slurry of silica gel to approximately 3.5 cm above the glass wool. The column was completed by topping with another 3.5 cm of a hexane slurry of alumina. At least one column volume of hexane was flushed through the column before any sample was added. Two 4.0 ml fractions were collected in tared vials. The hexane fractions were evaporated to no less than 0.5 ml under a stream of nitrogen.

Analysis by gas chromatography was performed. Yields were determined during analysis by gas chromatography. The tared sample vial plus concentrated sample solution was weighed and the solution volume determined from the density of hexane (0.66 g/ml). An aliquot of the solution was withdrawn (usually 100 μl), evaporated in air, and weighed on an electrobalance. In this fashion the weight of extracted hydrocarbon could be determined.

Procedure for Fish

Frozen fish specimens were allowed to thaw in their separate glass jars at room temperature. When thawed the specimens were prepared for homogenization. The samples were cut with scissors into small pieces, weighed and homogenized in a minimum amount of methanol in a Virtis homogenizer at high speed for approximately one minute. The homogenate was poured via funnel into a pre-extracted cellulose thimble and the homogenization flask rinsed with several washes of methanol making a total methanol volume of 150 ml. Then 150 ml benzene was used to rinse the homogenization flask and the solvent added to the cellulose thimble. The sample was Soxhlet extracted for at least 48 hours.

The Soxhlet extract was liquid-liquid extracted into three 100 ml portions hexane in a 1000 ml separatory funnel. The combined hexane extracts were evaporated to just dryness on a rotary evaporator in a 50 ml round bottom flask. Then 10 ml benzene, 10 ml 0.5 N KOH (methanol), 5 ml H_2O and a boiling chip were added and the sample saponified in a hot water bath for at least two hours.

The saponified mixture was liquid-liquid extracted with three 50 ml portions hexane in a 250 ml separatory funnel. The combined hexane extracts were washed with 50 ml saturated aqueous NaCl and dried overnight with Na_2SO_4.

The dry hexane solution was concentrated in a 150 ml pear-shaped flask to approximately 2.0 ml. The concentrated sample was then run through an 18 cm x 16 mm column filled half way with silica gel (5% · H_2O) and topped with alumina (6% · H_2O) both in hexane. Using hexane as the solvent two fractions were collected: fraction 1 of 15 ml was collected in a 25 ml pear-shaped flask, fraction 2 of 30 ml was collected in a 50 ml pear-shaped flask. The fractions were concentrated on a rotary evaporator and finally the samples were transferred in hexane to a tared sample vial. The volume was adjusted to a workable concentration under a stream of dry nitrogen.

At this point the samples were subjected to gas chromotography on OV-101 1.5 percent on 80/100 Chromosorb W. Quantitation was carried out in the same manner as described for sediments.

RESULTS AND DISCUSSION

Weights of aliphatic hydrocarbons extracted from sediments are presented in Table II. These weights were determined gravimetrically. We now believe that this procedure gives values that may be high because in the weighing process the possibility exists of including extraneous materials such as silica from the previous analytical step. These weights are probably best regarded as upper limits.

The sediments from Prudhoe Bay were generally sandy and contained some organic material which appeared to be tundra fragments (Chapter 1). None of the samples shows the regular pattern of *n*-alkanes associated with petroleum. Samples from stations 26, 28, 30 and 32 do show an unresolved envelope of the type associated with weathered petroleums. However, this same envelope also appeared in the blanks for these samples and was subsequently identified as material being leached from a rubber bulb. Thus, these large

Table II. Hydrocarbons in Prudhoe Bay Sediments, Expressed in mg/kg Based on Wet Weight of Sediment.

Station	Extractable Hydrocarbons
2	7.1
4	5.3
6	23
8	43
10	27
26	26
28	26
30	10
32	18
37	35
38	6.8
39	5.2
40	5.2
41	56
43	2.2
ARGO	6.5
GULL	1.8
NIAKUK	11

envelopes are analytical artifacts and do not indicate the presence of weathered petroleum in these samples.

There is considerable variability among the hydrocarbons extracted from the 18 sampling locations in the Prudhoe Bay area. However, no clear trends in the data are apparent. The lowest concentration of hydrocarbons in sediment was found at Gull Island. The sediment collected at that location was coarser than the others and did not appear to contain tundra fragments.

[Second year sampling (August 1975) included acquisition of tundra fragments from on shore and replicate sampling at one location to provide information about the degree of variance at a given point. This should aid in our understanding of the first year sediment hydrocarbon data presented here.]

Table III gives concentrations of aliphatic hydrocarbons from fish collected at Prudhoe Bay. All of the species analysed are highly mobile; the individuals analysed probably spent considerable time outside Prudhoe Bay itself. It is possible to interpret these results to a greater extent than for the sediments because: 1) in some cases more than one individual of a given species was analysed, 2) better resolution was obtained in gas chromatography by the use of the OV-101 liquid phase.

Flesh from two individuals of the species *Coregonus autumnalis* (common name: Arctic cisco) were analysed separately. In both the total concentrations of hydrocarbon (Table III) and in the array of hydrocarbons shown in the gas chromatograms (Fig. 1, A and B) these two individuals are similar, but not identical. The total concentrations are within experimental error and are thus equivocal; however, the gas chromatograms, while qualitatively similar, show several differences in intensities of smaller peaks. The only peak identified is pristane (marked: Pr). None of the other major peaks has the retention time of an *n*-alkane. These peaks are probably terpenoid hydrocarbons.

Table III. Hydrocarbons in Prudhoe Bay Fish Expressed in mg/kg Based on Wet Weight of Animal.

Sample	Extractable Hydrocarbons
Arctic cisco (1), flesh	10
Arctic cisco (2), flesh	13
Arctic cisco (1 + 2), skin	50
Fourhorned sculpin (1), flesh	3.8
Four horned sculpin (2), flesh	4.2
Arctic char, flesh	3.6
Arctic flounder, dorsal flesh	5.2
Arctic flounder, ventral flesh	9.6

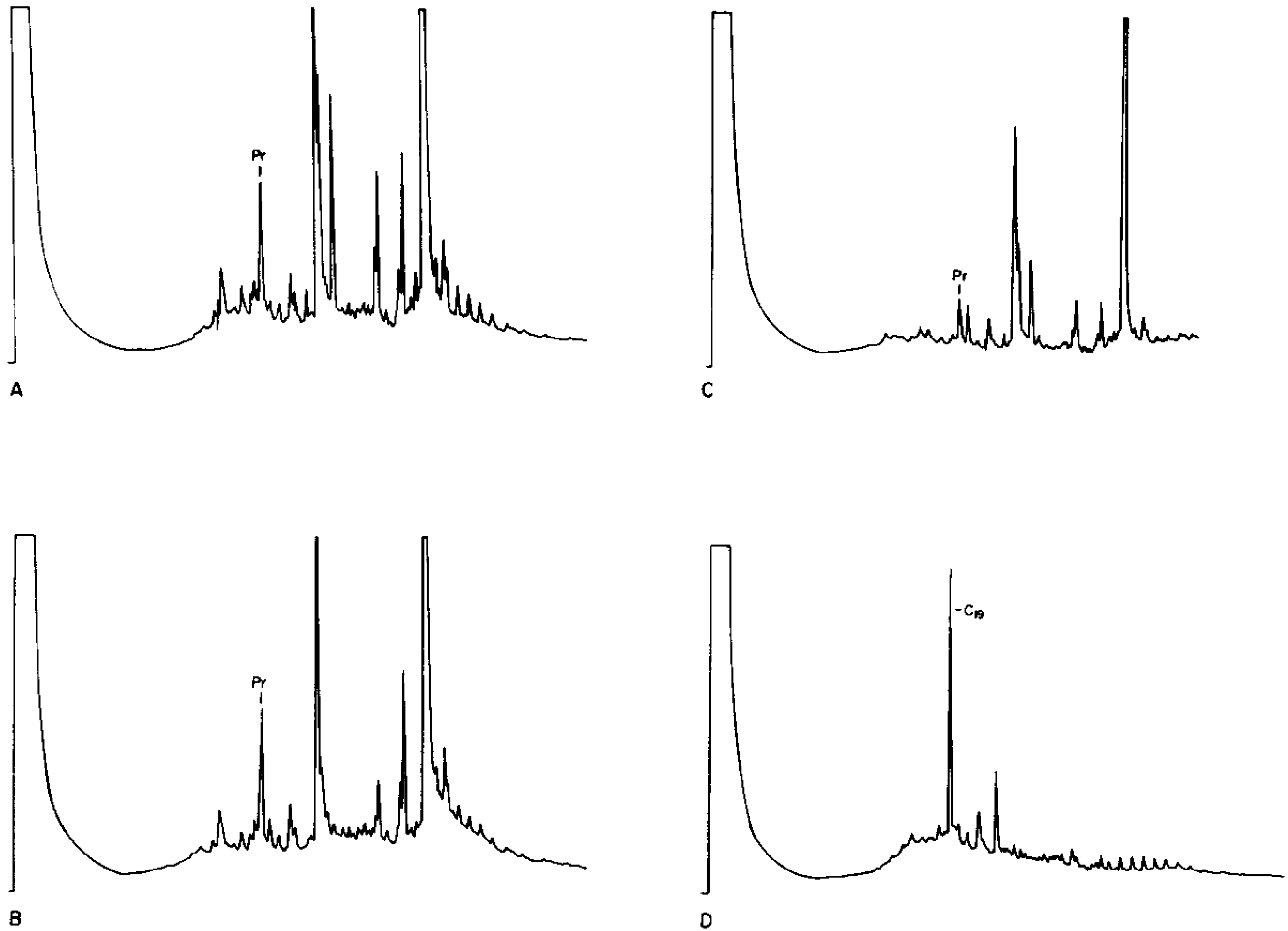

Figure 1. Gas chromatograms of fishes from Prudhoe Bay.

Phytane, a hydrocarbon characteristic of petroleum, is absent.

Skin from the two Arctic ciscos was pooled and analysed. The gas chromatogram (Fig. 1, C) is qualitatively similar to those of the flesh (Fig. 1, A and B). The total concentration of hydrocarbons in the skin (Table II) is significantly higher than the flesh. This observation is in keeping with the fact that these fish store oil subcutaneously. In the skinning process these oils go with the skin.

Table III also shows the results of the analysis of two individuals of the species *Myoxocephalis quadricornis* (common name: four horned sculpin). As with the Arctic ciscos, the total hydrocarbon concentrations for the two individuals show similar hydrocarbon contents. Also the gas chromatograms are generally similar (to each other, but not to the ciscos).

A single individual of the species *Coregonus sardinella* (common name: Arctic char) was analysed. The gas chromatogram (Fig. 1, D) of the hydrocarbons from the Arctic char show a quite different pattern. In the char nonadecane is the major peak. Again phytane is absent.

Flesh of a single individual of the species *Liopsetta glacialis* (common name: Arctic flounder) was divided into dorsal and ventral portions which were analysed separately. The total concentrations by hydrocarbons were 9.6 and 5.2 μg/g respectively. We are aware of no metabolic or structural feature of the flounder that would lead to this nearly twofold enrichment of the dorsal flesh in hydrocarbons. Additional analyses of *Liopsetta glacialis* will be required to substantiate or disprove this finding. The dorsal and ventral gas chromatograms are quite similar. This similarity is not readily apparent on casual inspection of the chromatograms, but detailed inspection shows that retention times and peak ratios correlate quite closely.

The kinds and amounts of hydrocarbons present in fish and sediment from Prudhoe Bay indicate that these hydrocarbons are largely or totally biogenic in origin.

Chapter 3

BENTHIC BIOLOGICAL STUDIES

H. M. Feder

INTRODUCTION

Limited data on the biology of the Alaska arctic coastal marine environment is currently available. The only seasonal data are the primary productivity and phytoplankton studies of Horner (1969, 1972, 1973), Matheke (1973) and Alexander (1974) at Point Barrow and the Colville Delta and the benthic studies of MacGinitie (1955) at Point Barrow. Additional information on the phytoplankton and the benthos from the Colville Delta marine area is available in Crane (1974), Kinney *et al.* (1971, 1972) and Alexander *et al.* (1974). Also, some shallow-water summer benthic samples from the western Beaufort Sea are described by Carey (Carey *et al.*, 1974). Phytoplankton, primary productivity, zooplankton and hydrographic data are available for Prudhoe Bay and nearby lagoon areas (Coyle, 1974; Horner, *et al.*, 1974). Exploratory dives and underwater photography of the benthos near Prudhoe Bay, accomplished during a phytoplankton study, should serve as guides to future investigations in the area (Horner, G. Matheke, E. Maynard, unpublished). In addition, under-ice video tapes of the benthos of Prudhoe Bay, made in March 1975 as a byproduct of seismic studies, suggest the potential usefulness of this tool to qualitatively examine the benthos during the ice-fast season (R. Rosenthal, Dames and Moore, unpublished data). No published information on the benthic environment in Prudhoe Bay is currently available, but data resulting from biological explorations along the Canadian arctic coast, the Colville Delta and Point Barrow should be valuable since many arctic species are widespread (Crane, 1974; Ellis, 1960 and literature review in this report; MacGinitie, 1955) and might be expected to occur adjacent to, and within the Bay.

Benthic invertebrate organisms (infauna, sessile and slow-moving epifauna) can be useful as indicator species for a disturbed area (Mileikovsky, 1970) because many tend to remain in place, some react to long-term perturbations (Mileikovsky, 1970; Perkins, 1974), and generally tend to reflect the composition of the substratum (Lie, 1968). The importance of the benthic fauna as a monitoring tool in the arctic may be magnified by the fact that species with direct development (brood their young or produce attached, demersal, yolky eggs) are more prevalent here than in temperate regions where most of the species have planktonic larvae (a phase of the young dispersed by the water currents) (Chia, 1970; Mileikovsky, 1971; Thorson, 1950). Many arctic species do have pelagic larvae but such a planktonic stage is greatly abbreviated here (Mileikovsky, 1971). A possible consequence of direct development and a short pelagic larval stage is the establishment of local populations that recruit new individuals largely from the local stock or immediately adjacent areas. Although local perturbations may affect an area for only a relatively short period of time, extensive disruption to benthic communities over a wide area might require a longer time for recovery. Replacement of adults from adjacent areas could be slow and, with the slow growth and development to sexual maturity typical of arctic forms (Ellis, 1960; Thorson, 1950), the re-establishment of a benthic assemblage of species will require many more years here than in temperate waters (Chia, 1970; also see Mileikovsky, 1970 for review on marine larvae and pollution problems). Replacement of species to impacted arctic benthic communities depends upon many additional factors as well, including the larval development patterns of species affected, the distance to the nearest upcurrent source of these species, the velocity of the currents, and the condition of the local substrate on the arrival of the larvae (Mileikovsky, 1970) or adults.

Insufficient long-term information about the environment and the basic biology and recruitment of species in that environment can lead to the erroneous interpretation of drastic changes in types and density of species that might occur if an area becomes altered (Nelson-Smith, 1973; Pearson, 1971, 1972; Rosenberg, 1973 for general discussions of benthic biological investigations in industrialized marine areas). Populations of marine species fluctuate over a time span of a few to 30 years (Lewis, 1970 and personal communication). Such fluctuations are typically unexplainable because simultaneous long-term physical, chemical, and biological data are seldom gathered (Lewis, 1970 and personal communication). Additionally, the presence or absence of benthic species can be in part determined by the nature of the substrate. Specifically, the close relationships of benthic faunal assemblages to particular sediment characteristics have been shown for some areas (Jones, 1950; Sanders, 1968). Furthermore, the ability of larval forms of benthic species to select or reject a substratum on the basis of physical and chemical properties has been determined experimentally (Wilson, 1953). Thus, changes in the substrate character may be reflected by changes in resident fauna. However, such changes can be properly interpreted only if the biota and associated substrata are investigated over a reasonable time base prior to and after disturbance of the particular area (see Rosenberg, 1973 for such an approach for monitoring areas affected by industrial activity).

Work in north temperate regions has shown that petroleum hydrocarbons can be taken up by marine species (Stegeman and Teal, 1973). To understand the movement of petroleum hydrocarbons through food webs in the arctic marine environment at Prudhoe Bay, we must have knowledge of food habits of benthic species to determine trophic interactions found there.

The investigation described here was designed to provide biological information for the nearshore invertebrate benthos in Prudhoe Bay in the summer and in association with geological and hydrocarbon investigations to develop a data base suitable for long-range monitoring of the area. The study examined the distribution and relative density of both infaunal and slow-moving epifaunal species, and was conducted in conjunction with a causeway construction project in Prudhoe Bay funded by Atlantic Richfield Company.

OBJECTIVES

The investigation described here was designed to provide biological information for the nearshore invertebrate benthos in Prudhoe Bay in the summer. The study considered infaunal and slow-moving epifaunal species, and was conducted in conjunction with a causeway construction project funded by Atlantic Richfield Company. The sampling procedures contributed to the following goals:

1. Documentation of the distribution and relative density of benthic macrofaunal organisms.
2. Examination of the benthic biota in relation to physical and chemical characteristics of the sediments.
3. Development of a biological data base suitable for initiation of a site-specific monitoring scheme.

METHODS

The study was conducted on the west side of Prudhoe Bay, Alaska (70° 23' N, 148° 31' W) from 15 August to 25 August, 1974 (Fig. 1). Tidal fluctuations in the area average 15 cm. Two parallel offshore transects, each

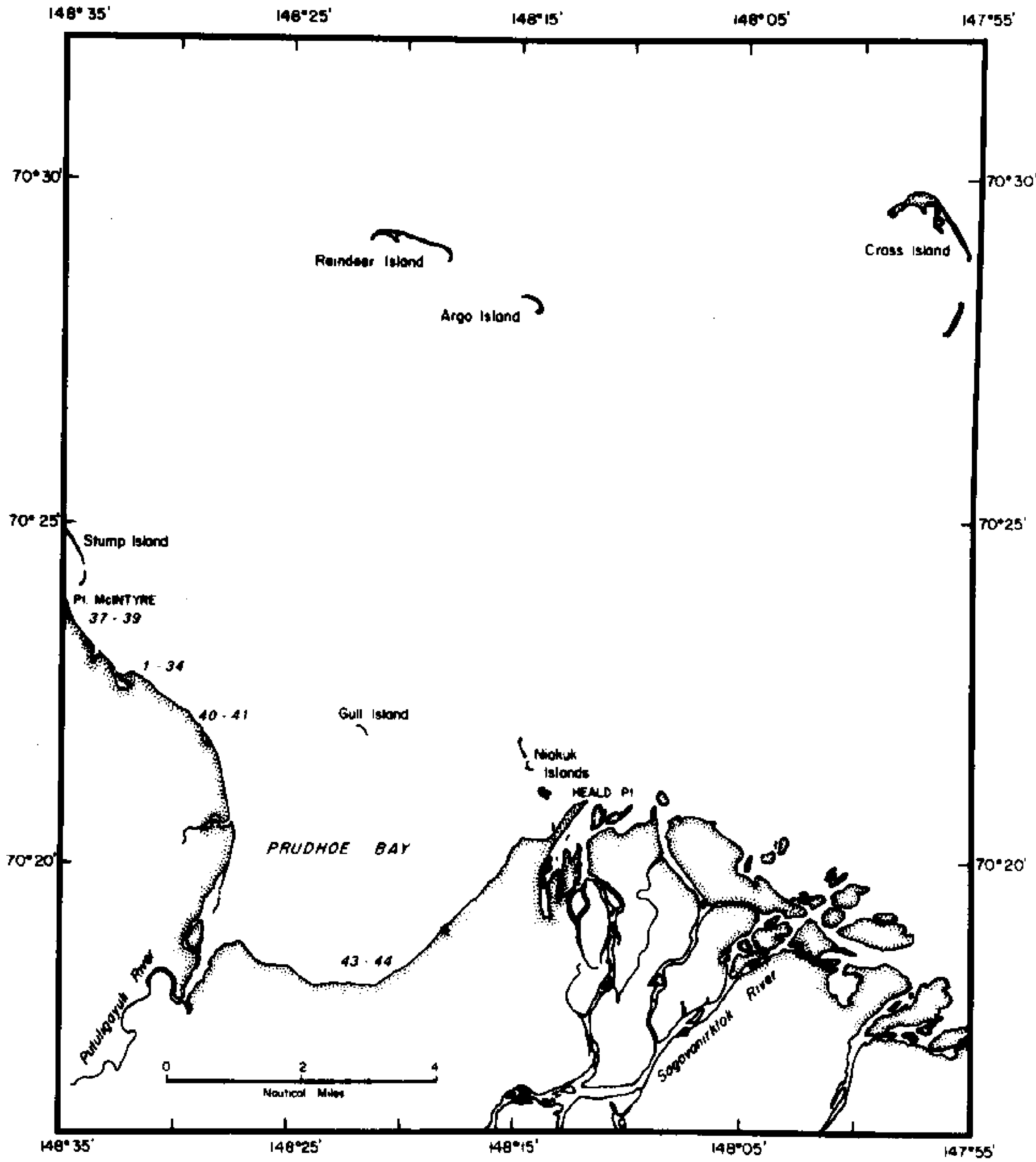

Figure 1. Station locations occupied in Prudhoe Bay for this study.

4500 feet in length, were established 500 feet on either side of a projected offshore causeway. Biological sampling stations were established onshore and 500, 1500, 2500, 3500 and 4500 feet from shore along each transect (12 stations), stations were marked with anchored crab-pot floats. Geological (Chapter 1) and hydrocarbon (Chapter 2) samples were taken at all biological stations. Two additional transects were established one mile on each side of the new causeway site; only the outermost stations were sampled on these transects due to time and weather constraints. Stations were also established adjacent to the existing causeway and off Argo, Gull and the Niakuk Islands (Fig. 1; Tables I, II).

Samples were taken primarily by way of divers operating from a 16 foot river skiff powered by a 35 HP jet outboard motor. Three Fager core (Fager *et al*, 1966) replicates (each .0064 m^2) and at least two airlift replicates (each 0.25 m^2) were taken at each station. Both methods sampled to a depth of approximately 4 cm. Limited underwater observations were made by the divers (Appendix I). Sampling was also accomplished on selected stations with a small sea sled and minnow traps baited with cooked halibut. Examination of the shore and the narrow intertidal zone was made by way of random holes excavated at the bases of all transects with *in situ* examination of the sediment for organisms.

Whenever time and logistics permitted, baited minnow traps were deployed for 24 to 48 hours at selected stations. Some of the traps were covered with gunny sacking to retain small organisms. In addition, short sea-sled traverses were made at various stations. Qualitative as well as limited quantitative sampling was accomplished by diving activity at Gull, Niakuk and Argo Islands. A helicopter was used for transportation of the divers and their equipment to the offshore islands.

Table I. Stations sampled August 1974 in Prudhoe Bay.

Station	Distance from Shore (ft.)	Depth (ft.)	Bottom
A. Station located on two transects on either side of the projected causeway.			
East Transect			
2	500	3	sand-gravel-mud
4	1500	3	sandy-mud
6	2500	4.5	muddy-sand
8	3500	5.5	mud
10	4500	6	mud
West Transect			
26	500	3	sand-gravel-mud
28	1500	3.5	sandy-mud
30	2500	5	muddy-sand
32	3500	5.5	mud
34	4500	6	mud
B. Stations located on additional transects.			
37	1500	3	sandy-mud
38	2500	2	sandy-mud
39	3500	3	sandy-mud
40	1500	4	sandy-mud
41	2500	4.5	sandy-mud
C. Stations occupied at selected localities.			
43	nearshore	2	sandy-mud
44	nearshore	2	sandy-mud
Gull Island	nearshore	-	sandy-mud
Argo Island	nearshore	-	sandy-mud
Niakuk Island	nearshore	-	sandy-mud

Table II. Number of species collected at stations occupied in Prudhoe Bay, August 1974.

Station	Number of species	Distance from shore (ft.)
2	9	500
4	9	1500
6	18	2500
8	16	3500
10	22	4500
26	11	500
28	9	1500
30	17	2500
32	24	3500
34	25	4500
37	14	1500
38	8	2500
39	8	3500
40	9	1500
41	14	2500
43	1	300
44	1	300

All biological materials were immediately transferred to plastic bags in the field and preserved in 10 percent Hexamine-buffered formalin. Samples were passed through a 1.0 mm mesh Nitex screen in the laboratory. Species identifications, counts, and biomass determinations were made at the Marine Sorting Center, University of Alaska, Fairbanks.

Species diversity was determined by the Gleason Index and the Shannon-Wiener Index (Lie, 1968). The former index is a ratio of total number of species to total number of individuals. It does not weigh the contribution of each species to total diversity. The Shannon-Wiener Index is a stepwise summation of the ratio of numbers of individuals of each species to total number of individuals. This method thus weighs the contribution of each species to total diversity. In both methods, index values are positively correlated with diversity. Since these indices are based on different calculations, their numerical values are not directly comparable. However, they are measures of the same phenomena, and trends should be similar.

RESULTS AND DISCUSSION

Quantitative Studies - Fager Cores and Airlifts

No macrofaunal marine invertebrates were found on or within the sediment of the beach or along the narrow intertidal zone.

The Fager cores were satisfactory for sampling the sedentary polychaetous annelids, but many of the motile species, inclusive of infaunal crustaceans, readily avoided the coring tube or escaped through the top. The airlift was satisfactory for sampling most infaunal burrowing polychaetes and crustaceans and slow-moving epifaunal species. The larger sedentary polychaetes were not sampled quantitatively by this technique.

Thirty-eight invertebrate species representing eight phyla were collected from the subtidal transect stations (Table III). Polychaetous annelids (13 species) and amphipod crustaceans (13 species) were the dominant groups present.

Three of the four transects occupied (encompassing stations 2, 4, 6, 8, 10, 26, 28, 30, 32, 34, 40 and 41) showed similar physical and faunal trends with increasing distance from shore. A sediment transition was observed along these transects, varying from coarse gravel (with scant detritus and mud) at the inner stations to scant gravel (with abundant detritus and mud) at the outer stations. Species diversity, density, and biomass all tended to increase with increasing distance from shore (Figs. 2, 3, 4 and 5).

Polychaetes followed the same basic trend as that noted above (Figs. 6 and 7). The polychaete biomass discrepancies between Fager cores and airlift samples at stations 32 and 34 (Fig. 6) can be largely attributed to differences in sampling devices. This is more striking when it is noted that the sampling method with the greatest surface coverage (airlift) resulted in a lower total polychaete biomass. A similar polychaete biomass discrepancy occurred to a lesser extent at stations 8 and 10 (Fig. 6). The airlift sampler was unable to pick up many individuals of the larger polychaete *Ampharete vega* before they moved deeper into their tubes as indicated by the many empty ampharetid tubes in these samples. Fewer empty tubes appeared in the Fager core samples.

Amphipods tended to increase in species but decrease in biomass outward from shore along the transects (Figs. 8 and 9). The change in biomass can be attributed primarily to the distribution of a single species, *Pontoporeia affinis*. This species greatly decreased in abundance seaward. Even so, it represented a large proportion of the total amphipod biomass

Table III. A list of species collected at 15 stations in the vicinity of the new causeway area, Prudhoe Bay. The types of larval development for these species (P=pelagic; D=direct).

TAXON		SPECIES	COMMON NAMES	TYPE LARVAL DEVELOP.
Phylum Porifera				
	Order Haplosclerida,	*Haliclona rufescens*	sponge	P
Phylum Platyhelminthes				
	Class Turbellaria	unknown species	flatworm	D
Phylum Nemertea				
		unknown species	proboscis worm	P
Phylum priapulida				
		Halicriptus spinulosus		D
Phylum Mollusca				
	Class Gastropoda			
	Family Trochidae	*Margarites helicina*	Margarites	D
	Class Pelecypoda			
	Family Hiatellidae	*Cyrtodaria kurriana*	Northern Propeller clam	P
	Unknown family	unknown species		
Phylum Annelida				
	Class Polychaeta			
	Family Phyllodocidae	*Eteone longa*	bristle worm	P
	Family Nereidae	*Nereis zonata*	bristly worm	P

Table III (continued)

	Family Orbiniidae	*Phylo* sp.	bristle worm	P
	Family Spionidae	*Spio mimus*	bristle worm	P
		Scolecolepides arctius	bristle worm	P
		Prionospio cirrifera	bristle worm	P
		Pygospio elegans	bristle worm	D
	Family Cirratulidae	*Cirratulus cirratus*	bristle worm	D
		Chaetozone setosa	bristle worm	P
	Family Capitellidae	*Capitella capitata*	bristle worm	D
	Family Ampharetidae	*Ampharete vega*	bristle worm	P
	Family Sabellidae	*Chone duneri*	bristle worm	D
	Family Sphaerodoridae	*Sphaerodoropsis minuta*	bristle worm	P
	Class Origochaeta			
	Unknown family	unknown species		D
Phylum Arthropoda				
	Class Crustacea			
	Subclass Ostracoda			
	unknown order	unknown species		P
	Subclass Copepoda	unknown species		P
	Subclass Malacostraca			
	Order Mysidacea	*Mysis* sp.		D
	Order Cumacea	*Diastylis sulcata*		D
	Order Isopoda	*Saduria entomon*	pill bug	D
	Order Amphipoda	*Pontoporeia affinis*	sand flea	D
		Pontoporeia femorata	sand flea	D
		Pseudalibrotus sp.	sand flea	D
		Onisimus sp.	sand flea	D
		Monoculopsis longicornis	sand flea	D
		Oediceros saginatus	sand flea	D
		Paroediceros lynceus	sand flea	D
		Gammaracanthus loricatus	sand flea	D
		Apherusa megalops	sand flea	D
		Gammarus zaddachi	sand flea	D
		Aceroides latipes	sand flea	D
Phylum Chordata	Class Ascidiacea	unknown species	sea squirt	P

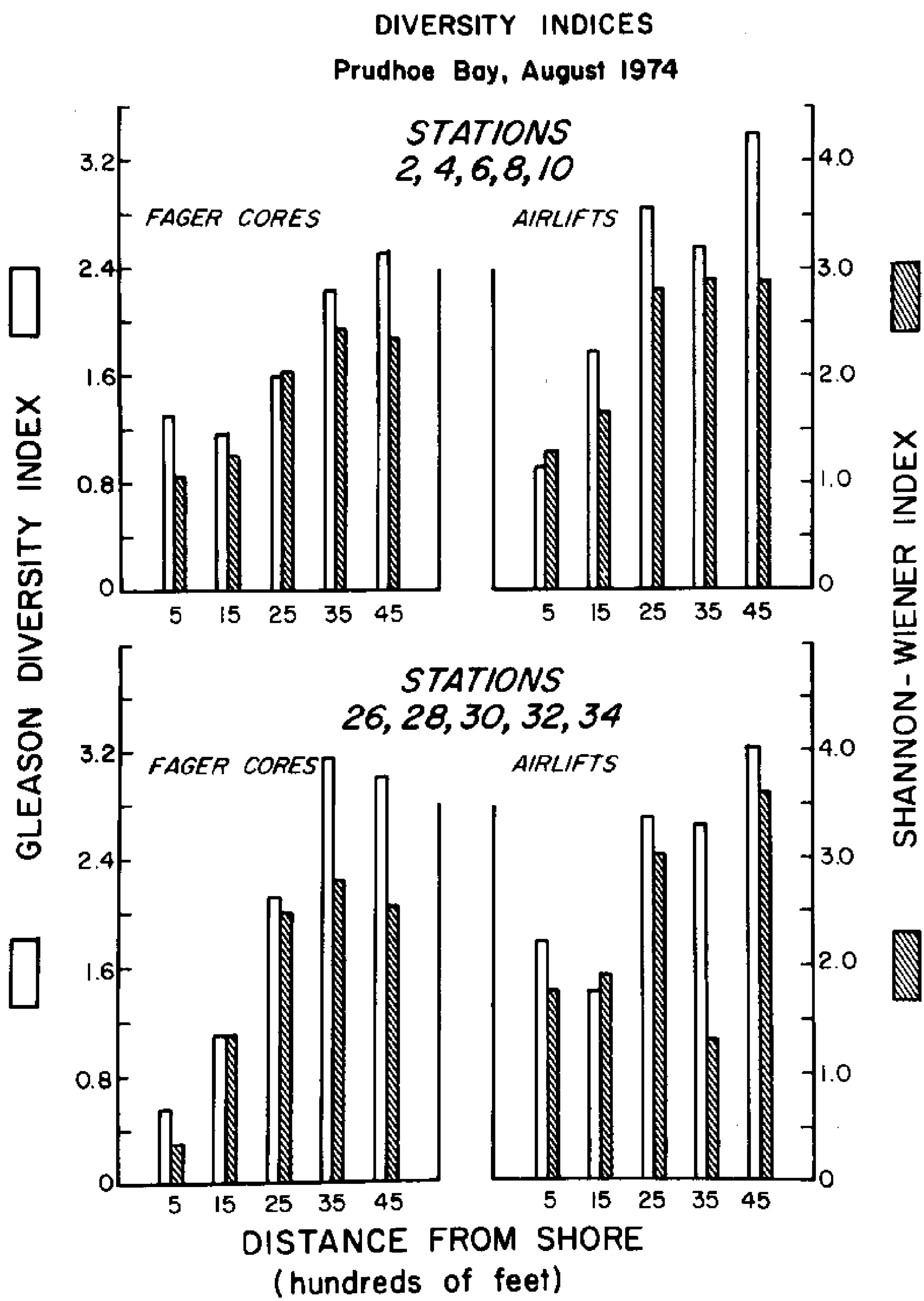

Figure 2. Diversity indices for Biological Stations 2-34 adjacent to causeway site. Sampling by Fager cores and airlifts. Stations 2-10 are represented by the distances 500-4500 ft. from shore respectively. Stations 26-34 are represented by the distances 500-4500 ft. from shore respectively.

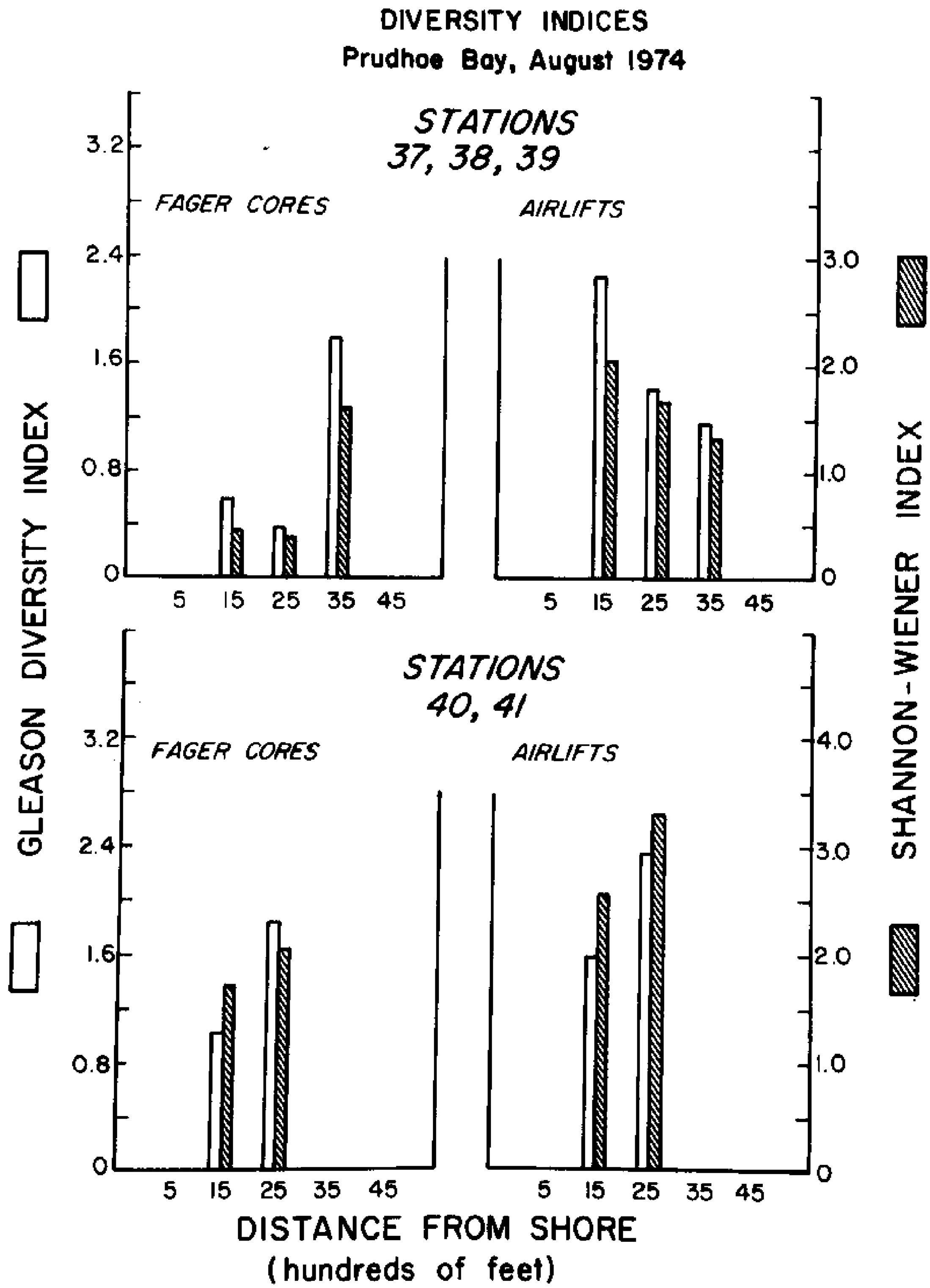

Figure 3. Diversity indices for Biological Stations 37-41. Sampling by Fager cores and airlifts. Stations 37-39 are represented by the distances 1500-3500 ft. from shore respectively. Stations 40 and 41 are represented by the distances 1500 and 2500 ft. from shore respectively.

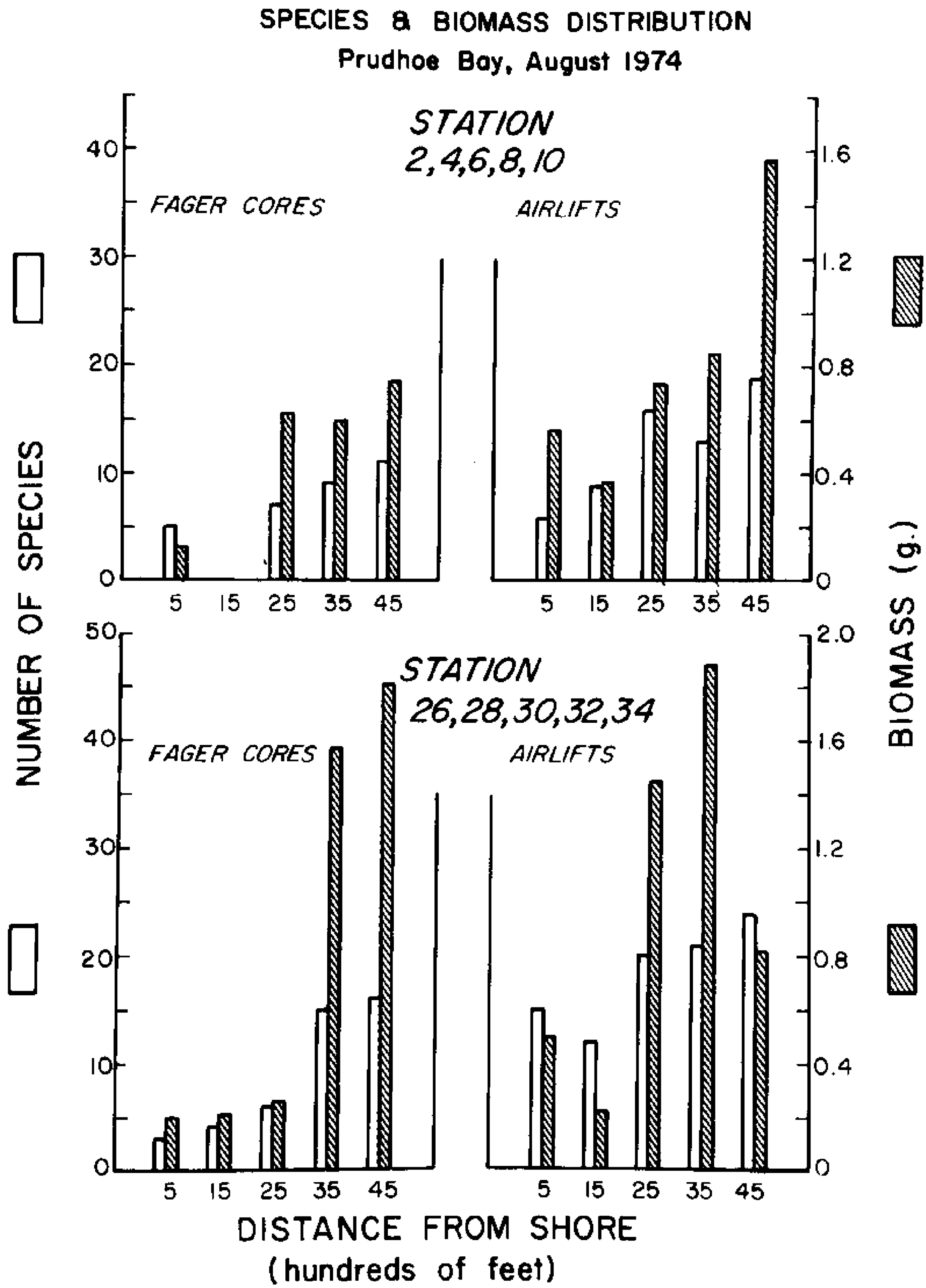

Figure 4. Species and biomass at Biological Stations 2-34 adjacent to causeway site. Sampling by Fager cores and airlifts. See Figure 2.

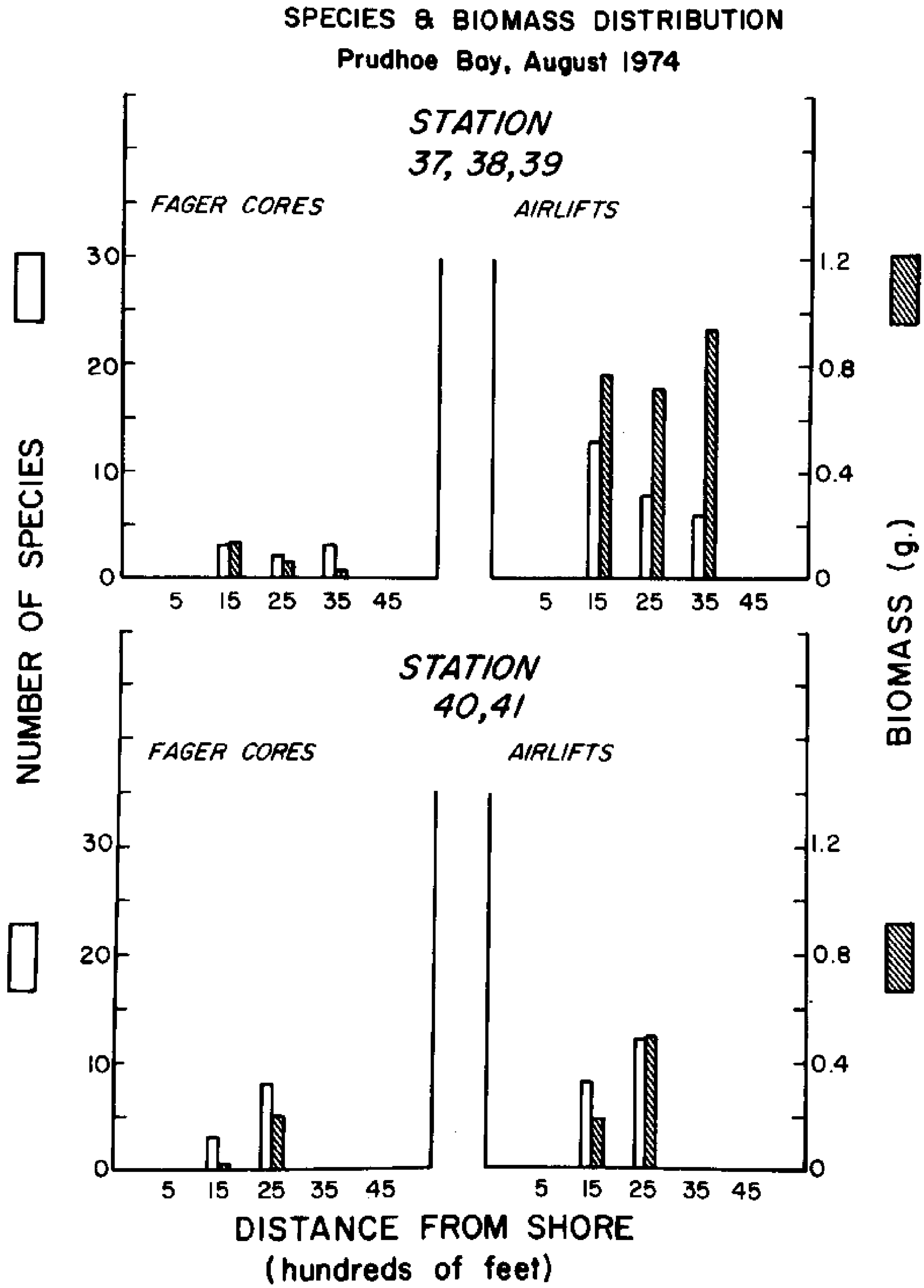

Figure 5. Species and biomass at Biological Stations 37-41.
Sampling by Fager cores and airlifts. See Figure 3.

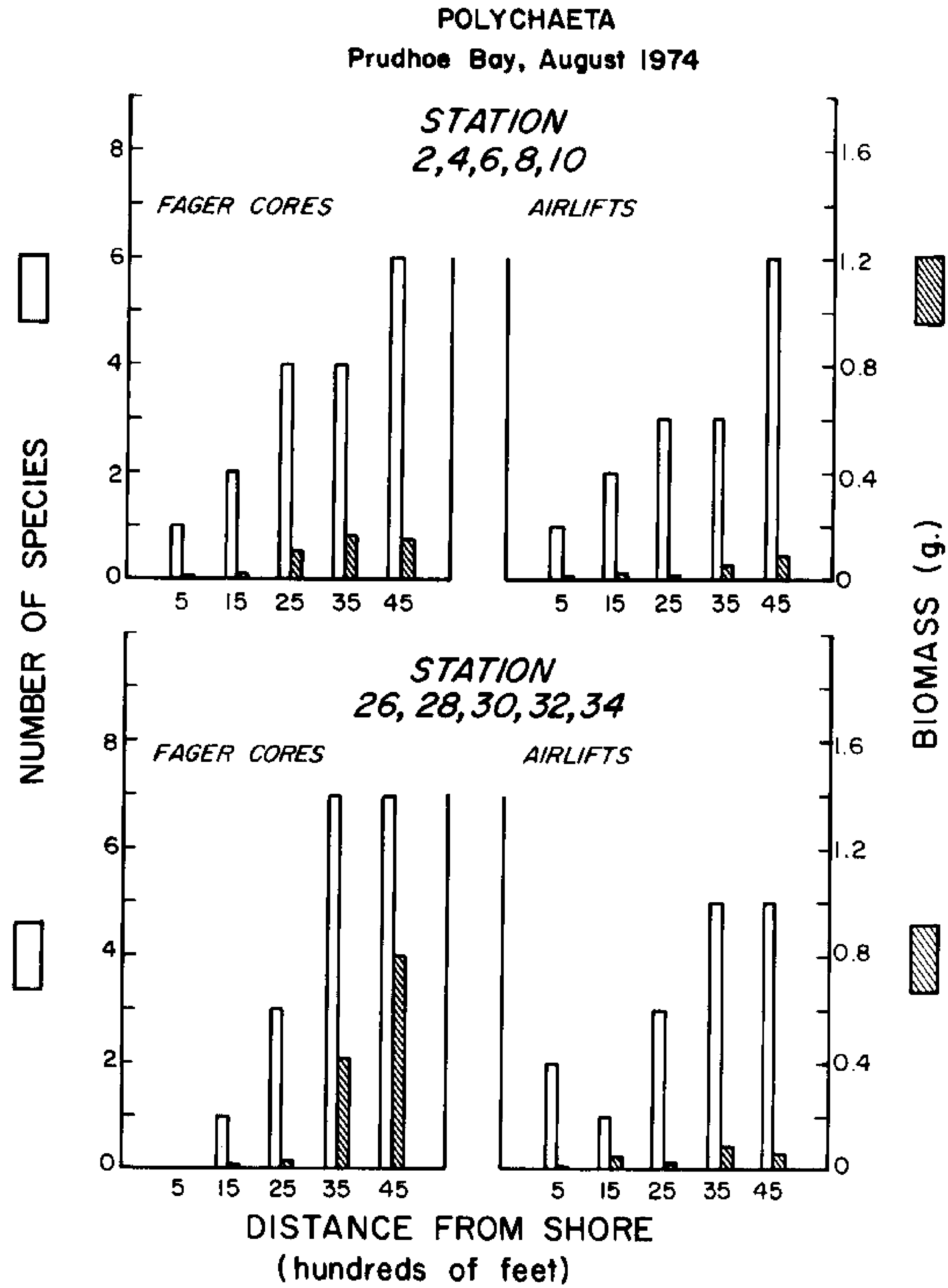

Figure 6. Distribution of polychaetous annelids at Biological Stations 2-34 adjacent to causeway site. Sampling by Fager cores and airlifts. See Figure 2.

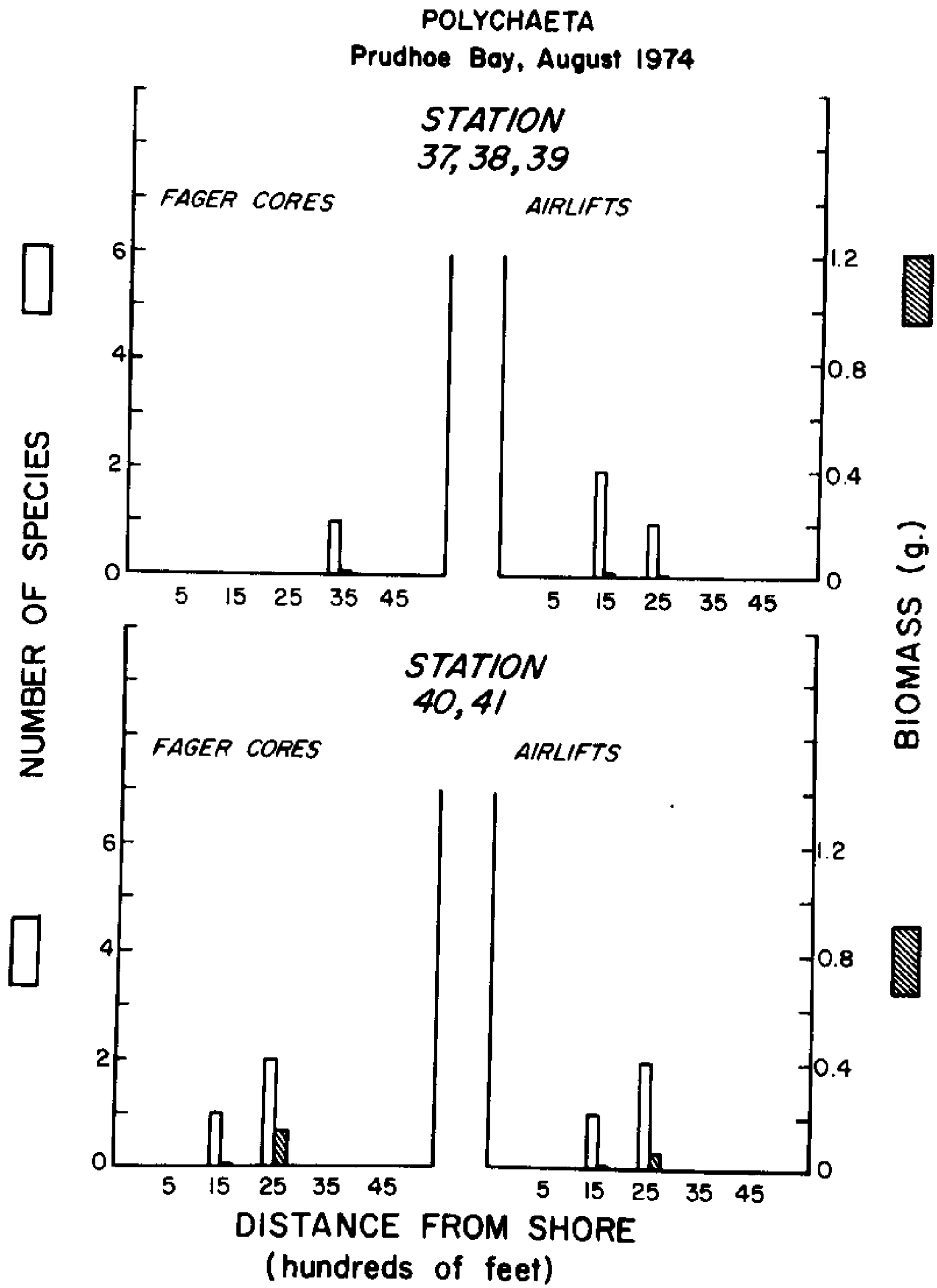

Figure 7. Distribution of polychaetous annelids at Biological Stations 37-41. Sampling by Fager cores and airlifts. See Figure 3.

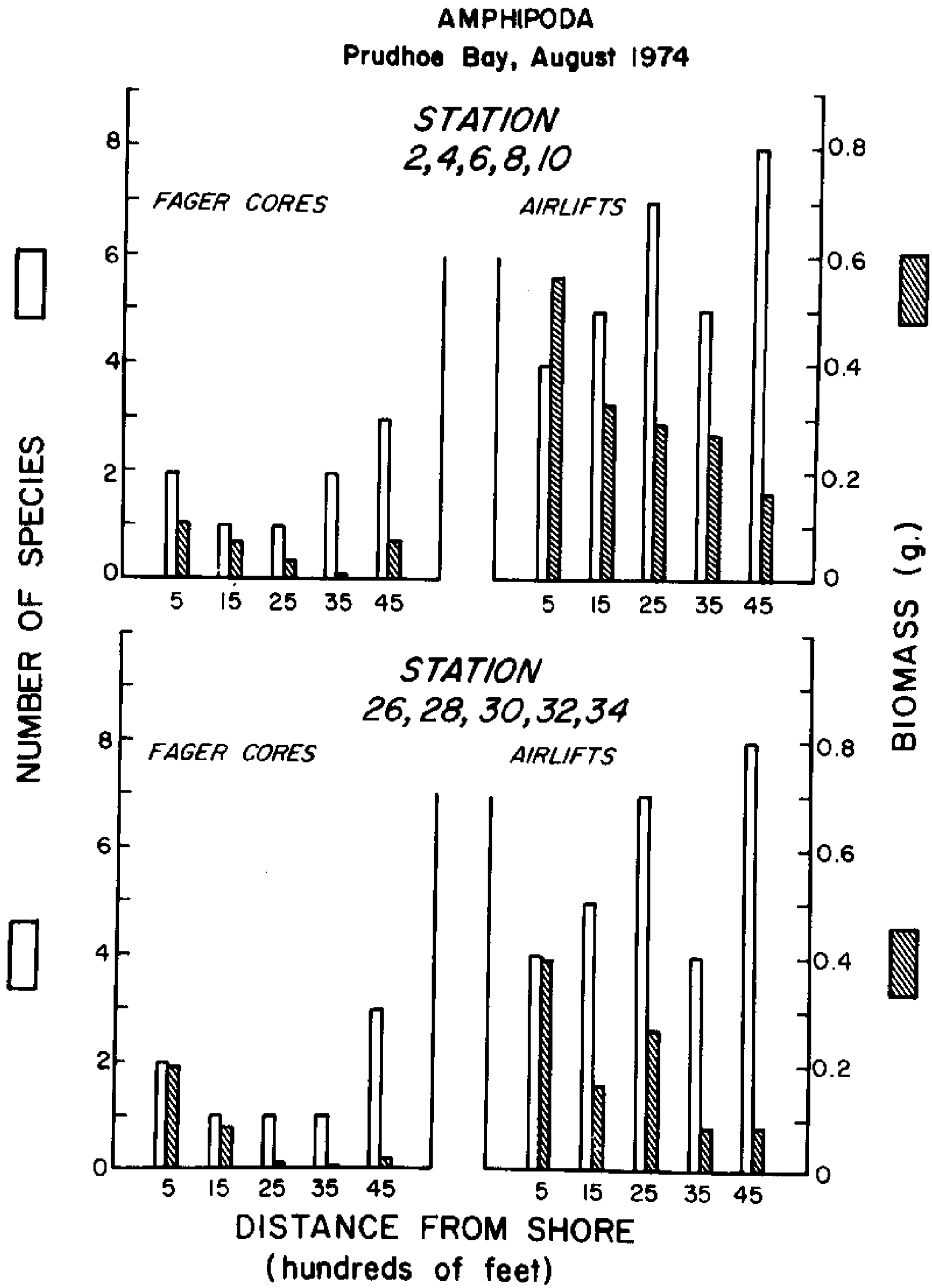

Figure 8. Distribution of amphipod crustaceans at Biological Stations 2-34 adjacent to causeway site. Sampling by Fager cores and airlifts. See Figure 2.

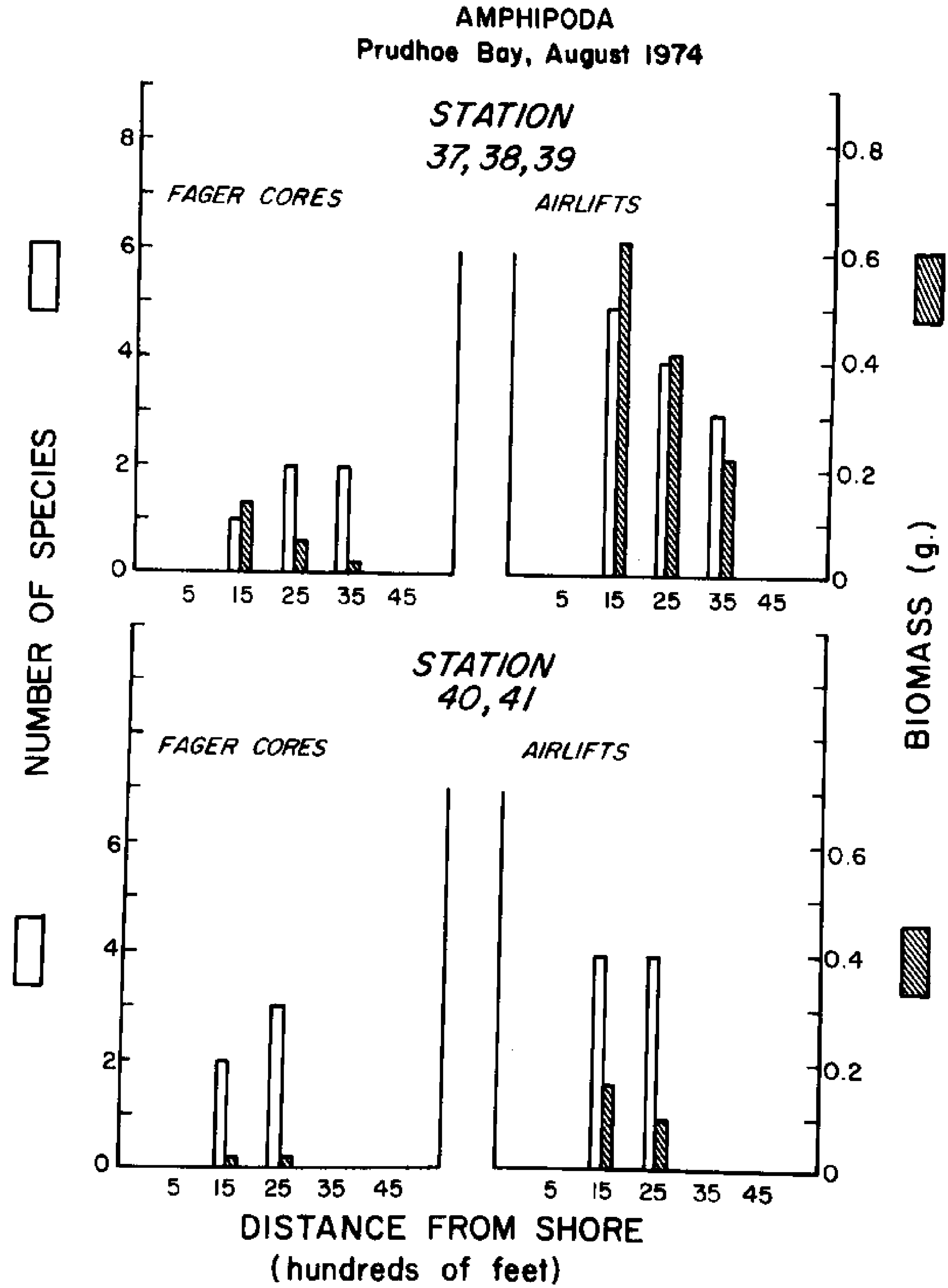

Figure 9. Distribution of amphipod crustaceans at Biological Stations 37-41. Sampling by Fager cores and airlifts. See Figure 3.

at all stations. At the outer stations, *Pontoporeia affinis* seemed to be partially replaced by *Pontoporeia femorata*.

The clam *Cyrtodaria kurriana* occurred only at the deeper stations, beginning at 2500 feet from shore and in at least 4.5 feet of water (Figs. 6, 7, 10 and 11).

The isopod *Saduria entomon* showed no major pattern of distribution of either numbers or biomass at any of the stations, but occurred primarily at stations deeper than 4.5 feet.

The fourth transect, encompassing stations 37, 38 and 39 differed from the other three. All stations on this transect physically and faunistically resembled the shallower portions of the other transects. The stations of the fourth transect are quite shallow (2 to 3 feet), and are subject to ice scour and wave action. All three stations were poor in detritus. This may be due to the action of ice and wind and/or distance of the stations from nearby rivers which carry tundra debris to the coast. Currents run from east to west along the Beaufort Sea coast (Burrell *et al.*, 1973), and the nearest supply of detritus east of the transect is the Putuligayuk River, some 3.6 miles away (Fig. 1). All of the other transects are closer to this river. In this shallow transect, the tube-dwelling polychaete *Ampharete vega* and the clam *Cyrtodaria kurriana* were not present. However, at the stations in deeper water along the other transects, the two species occurred together in large numbers. *Pontoporeia affinis* was the most common amphipod throughout this transect, whereas it was most prevalent nearshore in the other transects. The amphipod *Pseudalibrotus* sp. was found at all stations in this transect, but occurred only at the shallow stations in the other transects.

Numerous polychaetes collected during this study were bearing eggs. However, many of the amphipods and cumaceans had reproduced prior to our

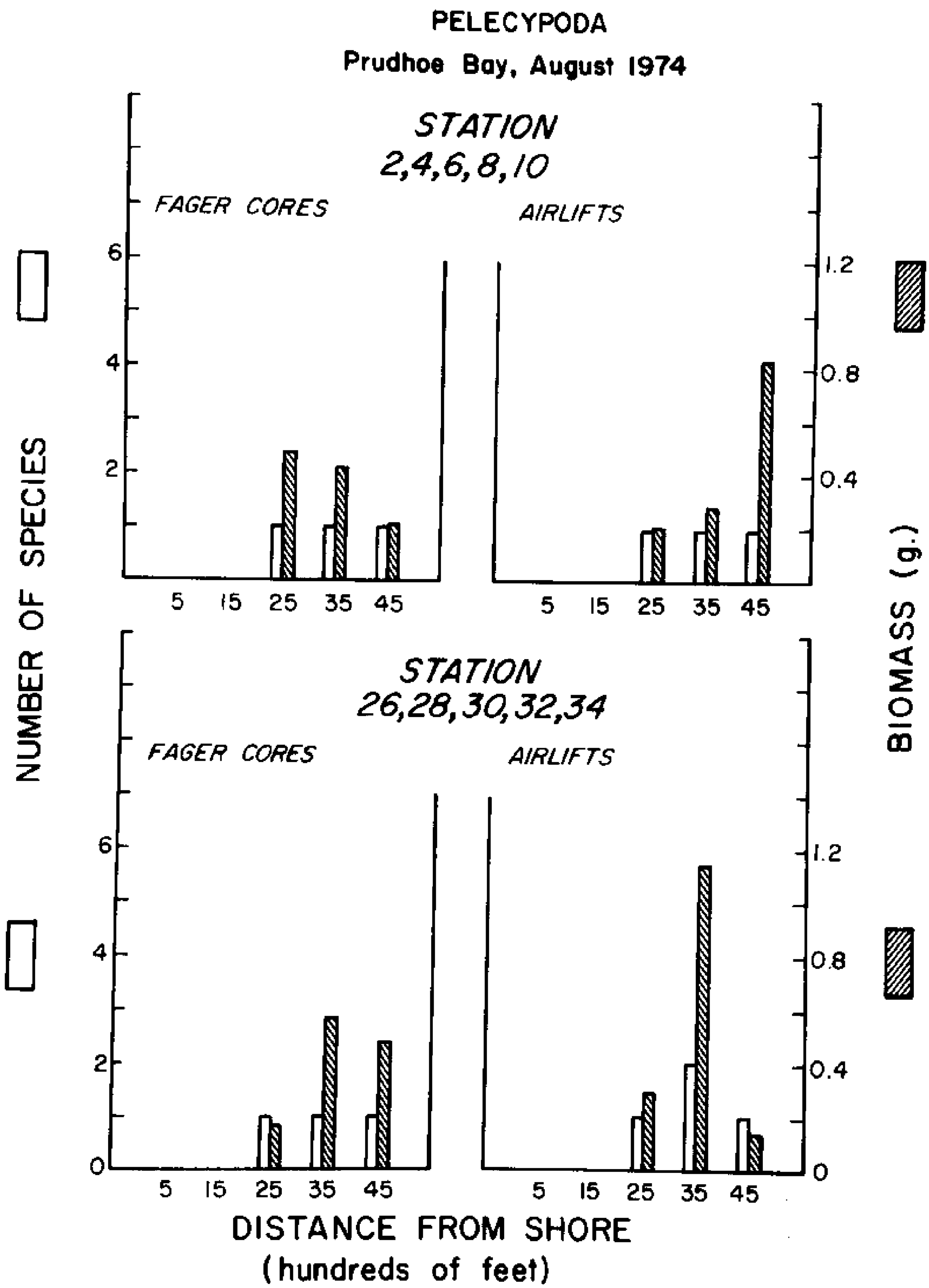

Figure 10. Distribution of the pelecypod mollusk, *Cyrtodaria kurriana* at Biological Stations 2-34 adjacent to causeway site. Sampling by Fager cores and airlifts. See Figure 2.

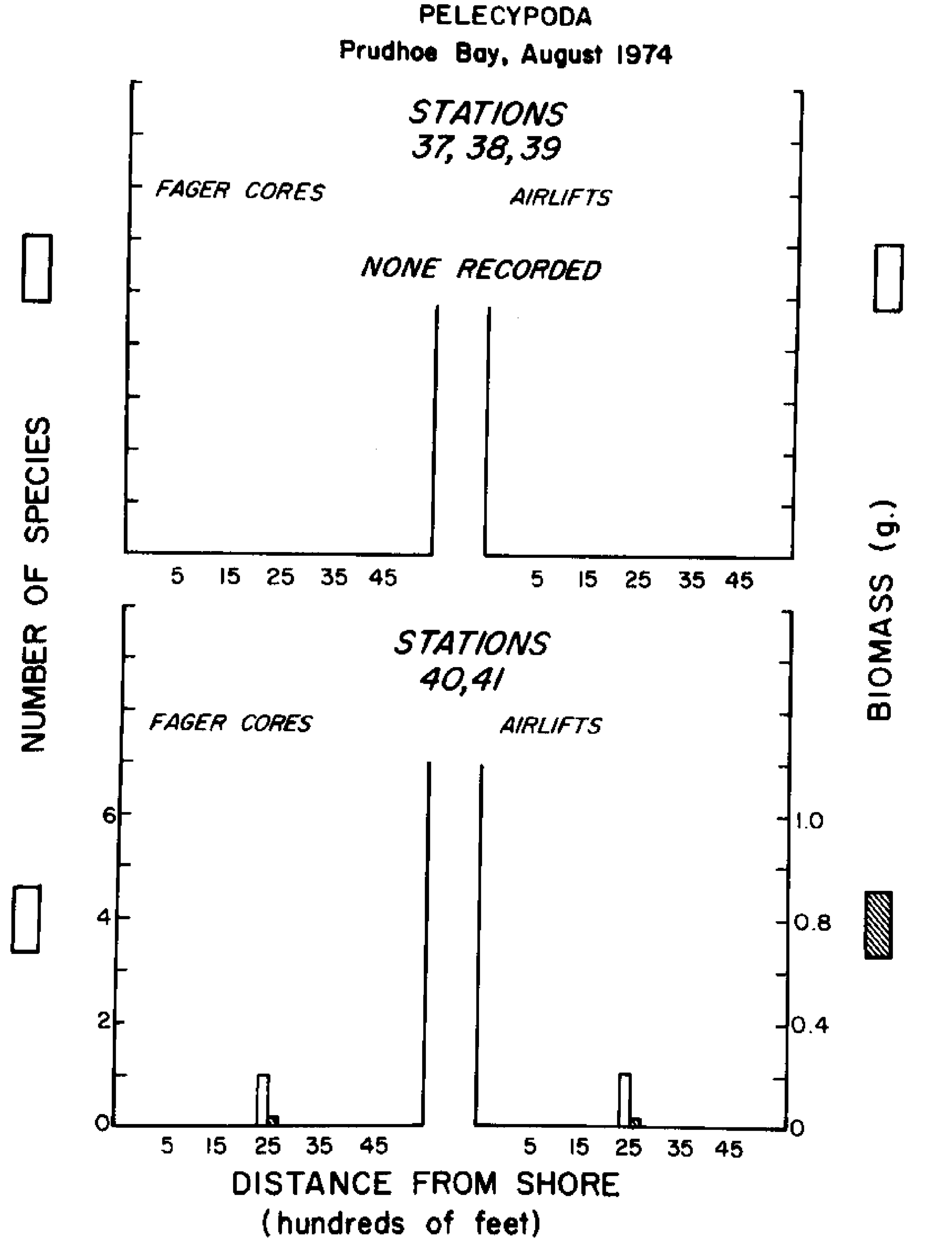

Figure 11. Distribution of the pelecypod mollusk, *Cyrtodaria kurriana* at Biological Stations 37-41. Sampling by Fager cores and airlifts. See Figure 3.

collection, as indicated by the tiny individuals of the amphipods *Onisimus* sp. or *Pseudalibrotus* sp., *Pontoporeia femorata*, *Pontoporeia affinis*, and the cumacean *Diastylis sulcata*. One isopod (*Saduria entomon*) was carrying eggs and one had an inflated but empty brood pouch. This reproductive pattern generally agrees with MacGinitie (1955), who found reproduction of invertebrate species at Point Barrow, Alaska (approximately 195 miles to the west of Prudhoe Bay) to last from early summer through October. Summer production of the pelagic larvae of benthic species (Redburn, 1974) and the benthic young of *Saduria entomon* (Bray, 1962; Crane, 1974) have been recorded in the arctic. Only 15 (42 percent) of the total species (Table III) and 6 (32 percent) of the Biologically Important Species (Table IV; see Feder *et al*, 1973 for criteria) in this study release pelagic larvae. Thorson (1950) stated that 70 percent of the worldwide benthic species have pelagic larvae, with extremes of near zero in polar regions and 90 to 95 percent in the tropics.

Most of the polychaetous annelids and a number of the amphipods collected are sessile, tube-dwelling species with most members of the former group primarily deposit feeders. The feeding methods used by most of the amphipods are unknown. However, based on collections made in baited traps, at least some of the amphipod species (*Pseudalibrotus* sp., *Onisimus* sp. and *Gammaracanthus loricatus*) can function as scavengers. Only three suspension-feeding species were identified, the sponge *Haliclona rufescens*, the clam *Cyrtodaria kurriana*, the polychaete *Chone duneri*, and a tunicate. The remaining species appear to be primarily scavengers or deposit feeders (Table V).

A qualitative description of diving observations is included in Appendix I. Species density and biomass per station are tabulated in Appendix II.

Table IV. A list of the Biologically Important Species (BIS) at the 15 stations at the new causeway area, Prudhoe Bay, Alaska. August 1974. (see Feder *et al.*, 1973 for criteria).

TAXON	
Phylum Porifera	
	Haliclona rufescens
Phylum Nemertea	
	unknown species
Phylum Mollusca	
	Margarites helicina
	Cyrtodaria kurriana
Phylum Annelida	
	Eteona longa
	Scolecolepides arctius
	Pygospio elegans
	Cirratulus cirratus
	Ampharete vega
	Chone duneri
Phylum Arthropoda	
	Mysis sp.
	Diastylis sulcata
	Saduria entomon
	Pontoporeia affinis
	Pontoporeia femorata
	Pseudalibrotus sp.
	Onisimus sp.
	Monoculopsis longicornis
	Oediceros saginatus

Table V. Feeding methods used by invertebrate species collected at the 15 stations at the new causeway area, Prudhoe Bay. Phylum: P=Porifera, F=Platyhelminthes, N=Nemertea, L=Priapulida, R=Arthropoda, C=Chordata, A=Annelida (based on Feder *et al.*, 1973 and Mueller and Feder, unpub. data).

Species	Phylum	Deposit Feeder	Suspension Feeder	Scavenger	Predator	Unknown
Haliclona rufescens	P		X			
Flatworms (1 species?)	F			X		
Proboscis worms (2 species?)	N				X	
Halicriptus spinulosus	L					X
Margarites sp.	M	X?				
Cyrtodaria kurriana	M		X			
Eteone longa	A				X	
Nereis zonata	A	X		X	X	
Phylo sp.	A	X				
Spio mimus	A	X				
Scolecolepides arctius	A	X				
Prionospio cirrifera	A	X				
Pygspio elegans	A	X				
Cirratulus cirratus	A	X				
Chaetozone setosa	A	X				
Capitella capitata	A	X				
Ampharete vega	A	X				
Chone duneri	A		X			

Table V (continued)

Species	Phylum	Deposit Feeder	Suspension Feeder	Scavenger	Predator	Unknown
Sphaerodoropsis minuta	A	X				
Oligochaete (1 species?)	A	X				
Ostracod (1 species?)	R					X
Copepod (1 species?)	R					X
Mysis sp.	R					X
Diastylis sulcata	R	X				
Saduria entomone	R			X		
Pontoporeia affinis	R					X
Pontoporeia femorata	R					X
Pseudalibrotus sp.	R			X		
Onisimus sp.	R			X		
Monoculopsis longicornis	R					X
Oediceros saginatus	R					X
Paroediceros lynceus	R					X
Gammaracanthus loricatus	R			?		
Apherusa megalops	R					X
Gammarus zaddachi	R					X
Aceroides latipes	R					X
Tunicate (1 species)	C		X			

Qualitative Studies - Seasled, Baited Trap and Selected Qualitative Sampling Around Three Barrier Islands.

Seasled Samples

The following species were collected at the old causeway site (Station 43; see Figs. 1 and 12 for location of sample sites): unknown cnidarian (anemone), *Mysis* sp., *Pseudalibrotus* sp., *Onisimus* sp., *Gammaracanthus loricatus*, *Pontoporeia affinis*, *Monoculopsis longicornis*, *Oediceres saginatus*. With the exception of the cnidarian, all of the species are epifaunal and motile. Very minor changes in water depth occurred over the sampling stations with depths ranging from 6 to 12 inches. There was a decided increase in numbers of *Mysis* sp. outward from shore as indicated by the intensive sampling of 24 August (see Fig. 13 and Appendix I for data). On 25 August the numbers of mysids showed marked changes. The data indicate that the numbers of mysids fluctuate in space and time, and that further sampling would be necessary if they were to be utilized in quantitative studies.

The limited sampling at the new causeway site resulted in the following array of species: *Mysis* sp., *Monoculopsis longicornis*, *Saduria entomon*, *Pontoporeia affinis*, *Diastylis sulcata*, *Gammaracanthus loricatus*, *Oediceros saginatus*, *Pseudalibrotus* sp., unknown copepoda.

Fish-trap Samples

At the old causeway, only one species was collected, the amphipod *Pseudalibrotus* sp. The number of individuals collected were as follows:

	Day	Trap Covered with Gunny Sack (no. individuals)	Trap Not Covered by Gunny Sack (no. individuals)
Station 43			
	August 24	269	123
	August 25	143	242
Station 44			
	August 24	177	-
	August 25	35	-

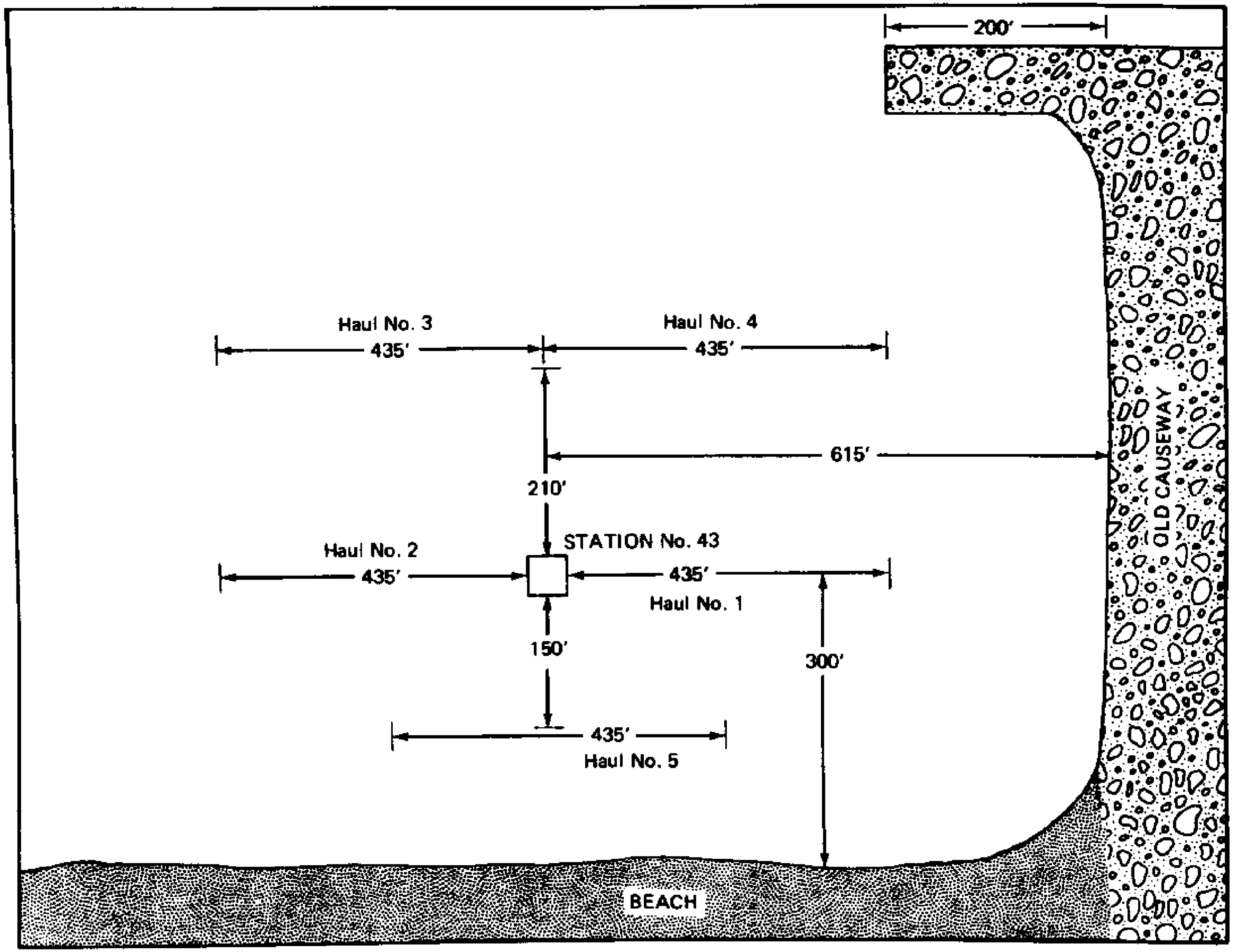

Figure 12. The sampling scheme used for sea-sled activities at Station 43.

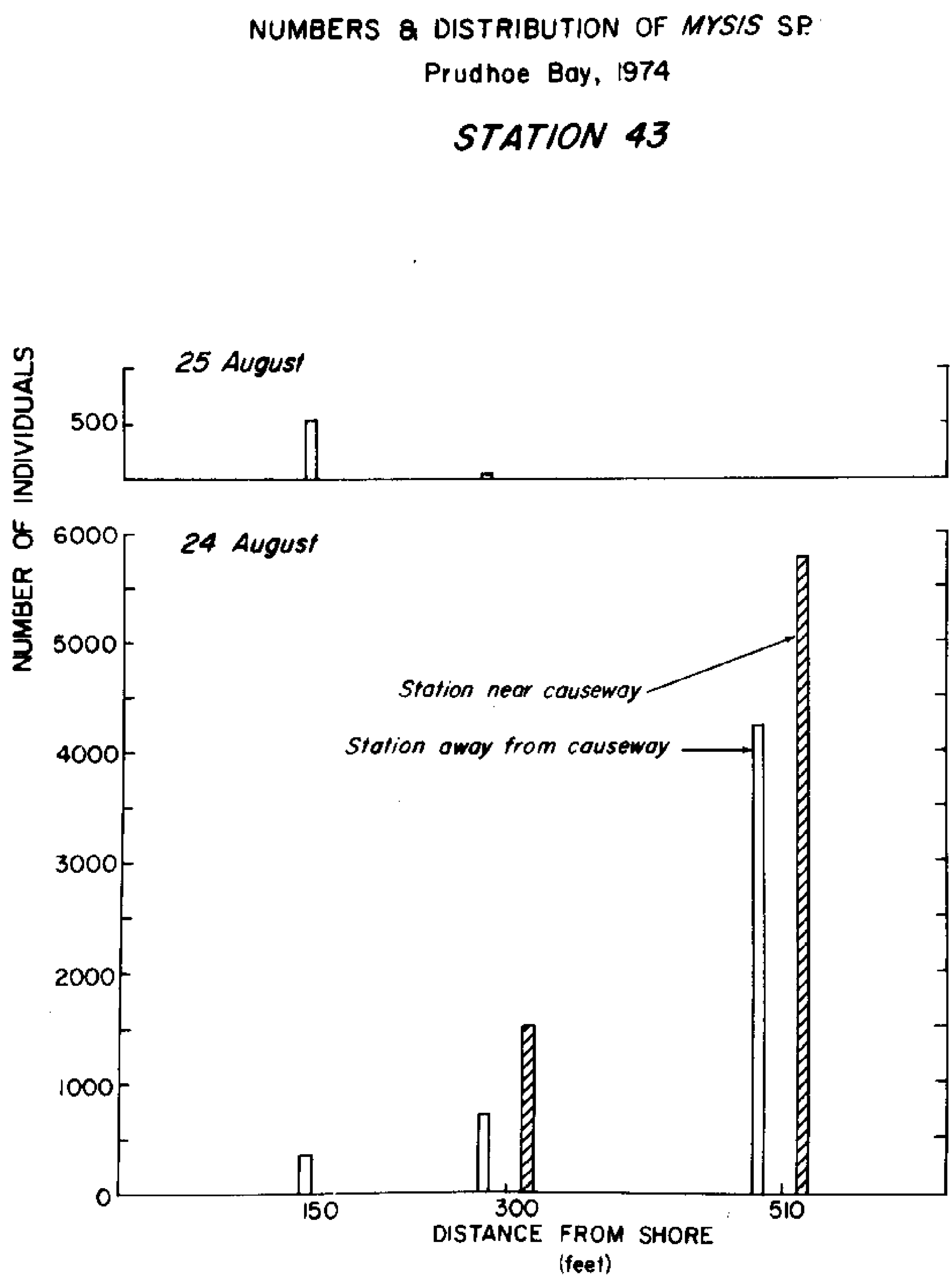

Figure 13. Distribution and numbers of *Mysis* sp. at Biological Station 43 adjacent to the old causeway at Prudhoe Bay 1974. Sampling by Seasled. See Figure 12 for the location of sample tracks.

No trends were noted. Great variability between days and sampling methods was evident. More intensive sampling is indicated for development of quantitative studies.

At the new causeway four species were collected: *Saduria entomon*, *Onisimus* sp., *Pseudalibrotus* sp., *Gammaracanthus loricatus*. The following trends were noted for the three species of amphipods:

Species	Distance from shore (number of individuals) 1000 ft.	1500 ft.	2500 ft.	3500 ft.
Gammaracanthus loricatus	1	0	0	0
Onisimus sp.	2	1	20	29
Pseudalibrotus	18	14	4	9

The tendency for *Onsisimus* to increase in density with increased water depth and *Pseudalibrotus* to decrease in density with increased water depth was also noted in the Fager and airlift samples. The following trends were noted for the isopod *Saduria entomon*:

Age/Sex	Distance from shore (numbers of individuals) 1000 ft.	1500 ft.	2500 ft.	3500 ft.
Adult/male	0	10	4	4
Adult/female	0	11	1	2
Juveniles (less than 7 mm)	0	0	1	6

Adults of both sexes were most numerous 1500 feet from shore; juveniles tended to increase with increase in water depth. Additional sampling is essential to document trends.

Samples From the Barrier Islands

Two Fager cores were taken at Gull Island, Niakuk Island and Argo Island (see Appendix II for additional diver observational data). At Gull Island three species were collected: *Saduria entomon*, *Prionospio cirrifera*, *Chone duneri*. All samples were taken in 2 feet of water. The number of individuals of each species was low. The two polychaetes taken (*Prionospio* and *Chone*) were previously found only at the deeper stations (at least 4.5 feet of water) at the new causeway site.

At Niakuk Island three species were collected: *Saduria entomon, Pontoporeia affinis, Monoculopsis longicornis*, all samples taken in 2 to 3 feet of water. The species collected were widely distributed in the areas sampled in Prudhoe Bay, and did not characterize any particular water depths. They were found at all of the stations sampled at the new causeway site.

At Argo Island 11 species were collected: unknown oligochaete, unknown bryozoan, unknown tunicate, *Ampharete vega, Halicriptus spinulosa, Castalia* sp., *Terebellides stroemi, Chaetozone setosa, Sphaerodoropsis minuta, Cirratulus cirratus, Haploscoloplos elongata*. Both cores were taken on the lee side of the island with one in 6 feet and the other in 10 feet of water. The core from the shallower depth had only the unknown oligochaete, the unknown bryozoan and the unknown tunicate. The few species and numbers of individuals taken in the core may be due to a single sample taken in a locally impoverished area and/or the effects of ice scouring. More intensive sampling is indicated here to determine the quantitative nature of the distribution of the biota. The core from 10 feet contained three new species (ones not noted at any other station occupied in Prudhoe Bay), *Castalia* sp., *Terebellides stroemi* and *Haploscoloplos elongata*. *Castalia* sp. was found only at the deeper subtidal stations in the Canadian arctic (Ellis and Wilce, 1961). All of the other species were found only at the deeper stations of the new causeway transects.

GENERAL DISCUSSION

Most of the species collected in Prudhoe Bay are known taxonomically, and biological information based on studies elsewhere, is available for some of the common species from Colville Delta and Point Barrow (Crane, 1974; MacGinitie, 1955). The presence of an over-lapping group of species from Point Barrow in the Chukchi Sea (MacGinitie, 1955), the Colville Delta region (Crane, 1974) and Prudhoe Bay (present study) together with biological information for some of the species suggest that chances are excellent for the shallow-water benthos of the arctic coast to be effectively monitored during long-term industrial activity there.

Two nearshore arctic phenomena must be considered in the development of an environmental monitoring scheme for Prudhoe Bay; the existence of ice scour zones and the establishment of "local" populations of species. In the present study, species diversity, numbers and biomass all increased seaward. These general trends are widespread in arctic waters, and are thought to be mainly wave and ice related phenomena (Crane and Cooney, 1973; Ellis and Wilce, 1961; Sparks and Pereyra, 1966). Much of the shallow marine area investigated in the present study is ice stressed for eight to nine months of the year, and shows a typical low species diversity (see Dunbar, 1968 for discussion of arctic marine ecosystems). This low diversity was especially obvious at the nearshore stations on the causeway transects with nine species found at both stations 4 (3 ft. in depth) and 28 (3.5 ft. in depth). The number of species at the outer stations on these transects increased to 22 and 25 at stations 10 and 34 respectively (Tables I and II). Those organisms within the zone of ice scour must withstand wave and/or ice action in spring, summer and fall as well as high salinities accompanied by low levels of dissolved oxygen in winter (Crane, 1974). The present study involved transects with sampling stations within as well as below the zone of ice scour. This should permit assessment of any differential effects of perturbations upon the stressed and relatively unstressed benthic assemblages.

The monitoring of widespread perturbations may be facilitated by the existence of "local" populations. Such populations recruit new individuals largely from the local stock or immediately adjacent areas. Many of the benthic species collected in our study are motile and their young undergo direct development. Thus, their replacement over a wide area would depend upon nonpelagic individuals migrating from peripheral areas. On the other hand, species with pelagic larvae may be able to colonize a perturbed area more readily, and such a situation would result in an alternation of the species composition of that area. Restricted reproductive periods of the species involved might also hamper repopulation, particularly if the effects of the disturbance lasted through the settling period.

The apparent broad distribution of the more common shallow water marine invertebrate species along the arctic coast suggests a widely dispersed brood stock available for repopulation of stressed areas there. The monitoring scheme developed for this study should permit long-term assessment of many of the species from the shallow benthos in the nearshore waters of Prudhoe Bay. These biological studies coupled with simultaneous examination of the sediment and hydrocarbon composition of continually monitored stations should make it possible to demonstrate the fluctuation of conditions here in space and time under naturally or unnaturally stressed conditions.

Fishes, collected by Rick Furniss (Alaska Department of Fish and Game) in Prudhoe Bay during the same period as the benthic investigation reported here were feeding heavily on the common crustaceans collected by our sampling gear (Furniss, in press). Amphipods, isopods, and mysids were the major benthic species used by the least cisco (*Coregonus sardinella*), arctic char (*Salvelinus alpinus*), arctic cisco (*Coregonus autumnalis*), fourhorn sculpin (*Myoxocephalus quadricornis*), broad whitefish (*Coregonus nasus*) arctic grayling

(*Thymallus arcticus*) and arctic flounder (*Liopsetta glacialis*). Thus, the shallow water marine benthos is an important food source for fishes migratory through and resident to Prudhoe Bay.

Of the two diver-operated sampling devices, the airlift system consistently collected more species at each station than the Fager corer. The former device, therefore, is more reliable for sampling the benthos of such a region as Prudhoe Bay where fauna is relatively sparse and patchy in distribution. However, the few larger sedentary polychaete species are not sampled quantitatively by the airlift. Further sampling will primarily utilize the airlift system for quantitative studies, but Fager cores should be taken, when the time permits, at the few stations where the larger sedentary polychaetes live.

APPENDIX I

Samples collected at Prudhoe Bay in August 1974 by Fager core and air-lift.

The values presented for each station represent the combined numbers and formalin wet weights (grams) from all replicates taken for each sampling device used at that station. The number in parenthesis after each Fager core and airlift sample for each station represents the total number resulting from the pooled replicates. The area of each individual Fager corer is .0064 m^2; the area of each individual air lift is 0.25 m^2. The data for each individual trap and sea-sled collected are presented separately.

Prudhoe Bay
Station 2

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	17	81.0	0.103	92.8
Monoculopsis longicornis	1	4.8	0.002	1.8
Pygospio elegans	1	4.8	0.001	0.9
Diastylis sulcata	1	4.8	0.004	3.6
unknown Oligochaete	1	4.8	0.001	0.9
	21		0.111	

Prudhoe Bay
Station 2

August 1974
Airlift Sample (3)

Taxon	Total #	%	Total wt.	%
Saduria entomon	5	2.2	0.009	1.6
Pontoporeia affinis	95	40.9	0.415	72.4
Monoculopsis longicornis	125	53.9	0.120	20.9
Pseudalibrotus sp.	3	1.3	0.005	0.9
Oediceros saginatus	3	1.3	0.024	4.2
Pygospio elegans	1	0.4	0.001	0.2
	232		0.574	

Prudhoe Bay
Station 4

August 1974
Fager core (2)

Taxon	Total #	%	Total wt.	%
Diastylis sulcata	1	7.1	0.002	2.2
Pontoporeia affinis	10	71.4	0.072	80.0
Scolecolepides arctius	2	14.2	0.017	18.8
Eteone longa	1	7.1	0.001	1.1
	14		0.092	

Prudhoe Bay
Station 4

August 1974
Airlift Sample (3)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	52	58.4	0.265	72.2
Monoculopsis longicornis	26	29.2	0.025	6.8
Pseudalibrotus sp.	2	2.2	0.025	6.8
Scolecolepides arctius	3	3.4	0.011	3.0
Eteone longa	1	1.1	0.006	1.6
Diastylis sulcata	2	2.2	0.005	1.4
Onisimus sp.	1	1.1	0.003	1.3
Oediceros saginatus	1	1.1	0.009	2.4
Mysis sp.	1	1.1	0.018	4.9
	89		0.367	

Prudhoe Bay
Station 6

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Cyrtodaria kurriana	5	11.4	0.480	76.7
Ampharete vega	3	6.8	0.031	5.0
Pontoporeia affinis	7	15.9	0.035	5.6
unknown Orbiniid	1	2.3	0.002	0.3
Scolecolepides arctius	24	54.5	0.066	10.5
Diastylis sulcata	2	4.5	0.005	0.8
Eteone longa	2	4.5	0.007	1.1
	44		0.626	

Prudhoe Bay
Station 6

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Saduria entomon	2	1.0	0.053	7.2
Oediceros saginatus	8	4.1	0.066	8.9
Paroediceros lynceus	1	0.5	0.001	0.1
Onisimus sp.	1	0.5	0.002	0.3
Pseudalibrotus sp.	1	0.5	0.015	2.0
Pontoporeia affinis	15	7.7	0.069	9.3
Monoculopis longicornis	42	21.5	0.043	5.8
Cyrtodaria kurriana	28	14.4	0.207	28.0
Mysis sp.	29	14.9	0.126	17.0
Diastylis sulcata	12	6.2	0.035	4.7
unknown Nemertea	2	1.0	0.019	2.6
Prionospio cirrifera	1	0.5	0.001	0.1
Ampharete vega	2	1.0	0.002	0.3
unknown Tunicate	1	0.5	0.004	0.5
Pontoporeia femorata	17	8.7	0.094	12.7
Scolecolepides	3	1.5	0.002	0.3
	165		0.739	

Prudhoe Bay
Station 8

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Saduria entomon	1	2.8	0.032	5.4
Cyrtodaria kurriana	15	42.8	0.418	71.0
Ampharete vega	8	22.8	0.141	23.9
Diastylis sulcata	3	8.6	0.006	1.0
Onisimus sp.	2	5.7	0.003	0.5
Cirratulus cirratus	3	8.6	0.007	1.2
Pontoporeia affinis	1	2.8	0.004	0.7
Eteone longa	1	2.8	0.009	1.5
Scolecolepides arctius	1	2.8	0.001	0.2
	35		0.621	

Prudhoe Bay
Station 8

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Cyrtodaria kurriana	24	22.2	0.292	34.2
Diastylis sulcata	13	12.0	0.043	5.0
Saduria entomon	3	2.8	0.103	12.1
Oediceros saginatus	7	6.5	0.082	9.6
Monoculopsis longicornis	22	20.4	0.026	3.0
Pontoporeia affinis	19	17.6	0.130	15.2
unknown Nemertean	1	0.9	0.003	0.4
Ampharete vega	3	2.8	0.050	5.8
Onisimus sp.	2	1.8	0.024	2.8
Gammaracanthus loricatus	1	0.9	0.007	0.8
Mysis sp.	5	4.6	0.065	7.6
Scolecolepides arctius	2	1.8	0.003	0.4
Prionospio cirrifera	1	0.9	0.002	0.2
	103		0.830	

Prudhoe Bay
Station 10

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Ampharete vega	9	17.6	0.132	17.8
Cyrtodaria kurriana	10	19.6	0.209	28.2
Saduria entomon	2	3.9	0.280	37.8
Onisimus sp.	2	3.9	0.039	5.3
Eteone longa	1	2.0	0.003	0.4
Cirratulus cirratus	21	41.2	0.046	6.2
Pontoporeia affinis	2	3.9	0.017	2.3
Capitella capitata	1	2.0	0.001	0.1
Scolecolepides arctius	1	2.0	0.005	0.7
Pontoporeia femorata	1	2.0	0.007	0.9
Chone dumeri	1	2.0	0.001	0.1
	51		0.740	

Prudhoe Bay
Station 10

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Cyrtodaria kurriana	82	42.7	0.836	53.3
Diastylis sulcata	22	11.4	0.055	3.5
Ampharete vega	5	2.6	0.078	5.0
Saduria entomon	13	6.8	0.344	22.4
Gammaracanthus loricatus	1	0.5	0.008	0.5
Pontoporeia affinis	5	2.6	0.054	3.4
Pontoporeia femorata	11	5.7	0.026	1.6
Paroediceros lynceus	1	0.5	0.001	0.1
Onisimus sp.	1	0.5	0.002	0.1
Monoculopsis longicornis	27	14.1	0.025	1.6
Oediceros saginatus	6	3.1	0.043	2.7
Mysis sp.	8	4.2	0.081	5.2
unknown Nemertea	1	0.5	0.005	0.3
Aceroides latipes	1	0.5	0.001	0.1
Prionospio cirrifera	2	1.0	0.001	0.1
Eteone longa	1	0.5	0.001	0.1
Capitella capitata	2	1.0	0.002	0.1
Scolecolepides arctius	2	1.0	0.004	0.2
Chaetozone setosa	1	0.5	0.002	0.2
	192		1.569	

Prudhoe Bay
Station 26

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	34	94.4	0.184	93.9
unknown Oligochaete	1	2.8	0.001	0.5
Pseudalibrotus sp.	1	2.8	0.011	5.6
	36		0.196	

Prudhoe Bay
Station 26

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Monoculopsis longicornis	55	35.2	0.056	11.3
Pontoporeia affinis	81	51.9	0.327	66.2
Pseudalibrotus sp.	3	1.9	0.008	1.6
Saduria entomon	6	3.8	0.037	7.5
Gammaracanthus loricatus	1	0.6	0.001	0.2
Mysis sp.	5	3.2	0.057	11.5
unknown Nemertean	2	1.3	0.002	0.4
unknown Gastropod	1	0.6	0.002	0.4
Nereis zonata	1	0.6	0.002	0.4
Scolecolepides arctius	1	0.6	0.002	0.4
	156		0.494	

Prudhoe Bay
Station 28

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	10	66.7	0.077	37.0
Diastylis sulcata	1	6.6	0.005	2.4
Scolecolepides arctius	3	20.0	0.007	3.4
Saduria entomon	1	6.6	0.119	57.2
	15		0.208	

Prudhoe Bay
Station 28

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	19	26.8	0.098	44.7
Monoculopsis longicornis	34	47.9	0.036	16.4
Scolecolepides arctius	12	16.9	0.052	23.7
Mysis sp.	3	4.2	0.008	3.6
Oediceros saginatus	1	1.4	0.008	3.6
Paroediceros lynceus	1	1.4	0.001	0.4
Pseudalibrotus sp.	1	1.4	0.016	7.3
	71		0.219	

Prudhoe Bay
Station 30

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Saduria entomon	1	5.9	0.052	19.8
Cyrtodaria kurriana	4	23.5	0.166	63.4
Scolecolepides arctius	3	17.6	0.008	3.0
Pseudalibrotus sp.	1	5.9	0.009	3.4
Cirratulus cirratus	4	23.5	0.004	1.5
Ampharete vega	1	5.9	0.021	8.0
Margarites helicina	2	11.8	0.002	0.8
	16		0.262	

Prudhoe Bay
Station 30

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Saduria entomon	5	2.9	0.743	51.0
Cyrtodaria kurriana	42	24.4	0.290	19.9
Pontoporeia affinis	19	11.0	0.100	6.9
Pontoporeia femorata	11	6.4	0.041	2.8
Monoculopsis longicornis	37	21.5	0.039	2.7
Onisimus sp.	5	2.9	0.061	4.2
Diastylis sulcata	12	7.0	0.043	2.9
Eteone longa	2	1.2	0.005	0.3
Scolecolepides arctius	4	2.3	0.006	0.3
Mysis sp.	28	16.3	0.098	6.7
unknown Nemertean	3	1.7	0.010	0.7
Oediceros saginatus	1	0.6	0.015	1.0
Gammaracanthus loricatus	1	0.6	0.001	0.0
Pseudalibrotus sp.	1	0.6	0.004	0.3
Cirratulus cirratus	1	0.6	0.002	0.1
	172		1.458	

Prudhoe Bay
Station 32

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Saduria entomon	5	6.0	0.319	20.2
Cyrtodaria kurriana	29	34.9	0.573	36.2
Ampharete vega	24	28.9	0.300	19.0
Cirratulus cirratus	4	4.8	0.004	0.2
Eteone longa	1	1.2	0.001	0.1
Spio mimus	2	2.4	0.003	0.2
Chone duneri	5	6.0	0.005	0.3
Halicriptus spinulosus	2	2.4	0.016	1.0
Phylo sp.	1	1.2	0.002	0.1
Chaetozone setosa	3	3.6	0.105	6.6
unknown Nemertean	3	3.6	0.226	14.3
Pontoporeia femorata	1	1.2	0.001	0.1
Diastylis sulcata	1	1.2	0.010	0.6
unknown Annelid	1	1.2	0.017	1.1
unknown Oligochaete	1	1.2	0.001	0.1
	83		1.583	

Prudhoe Bay
Station 32

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Cyrtodaria kurriana	229	81.5	1.143	60.5
unknown Pelecypod	1	0.4	0.002	0.1
Saduria entomon	11	3.9	0.521	27.6
Ampharete vega	5	1.8	0.065	3.4
Onisimus sp.	1	0.4	0.024	1.3
Cirratulus cirratus	1	0.4	0.001	0.0
Eteone longa	3	1.1	0.008	0.4
Scolecolepides arctius	5	1.8	0.009	0.5
Diastylis sulcata	10	3.6	0.041	2.2
Oediceros saginatus	2	0.7	0.022	1.2
Monoculopsis longicornis	2	0.7	0.005	0.3
Pontoporeia femorata	3	1.1	0.028	1.5
Mysis sp.	2	0.7	0.007	0.4
Halicriptus spinulosus	1	0.4	0.003	0.2
unknown Ostracoda	4	1.4	0.004	0.2
Phylo sp.	1	0.4	0.007	0.4
	281		1.890	

Prudhoe Bay
Station 34

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Diastylis sulcata	1	0.7	0.004	0.2
Cirratulus cirratus	32	22.4	0.060	3.3
Ampharete vega	56	39.2	0.716	39.3
Spio mimus	1	0.7	0.001	0.0
Chone duneri	26	18.2	0.012	0.6
Scolecolepides arctius	2	1.4	0.003	0.2
Cyrtodaria kurriana	9	26.3	0.479	26.3
Saduria entomon	6	4.2	0.438	24.0
unid. *Turbellaria*	1	0.7	0.001	0.0
unknown Ostracoda	1	0.7	0.001	0.0
unknown Nemertean	2	1.4	0.076	4.2
Pontoporeia affinis	1	0.7	0.018	1.0
Pontoporeia femorata	1	0.7	0.001	0.0
Capitella capitata	2	1.4	0.003	0.2
Onisimus sp.	1	0.7	0.002	0.1
Sphaerodoropsis minuta	1	0.7	0.006	0.3
	143		1.821	

Prudhoe Bay
Station 34

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Cyrtodaria kurriana	11	8.8	0.138	17.0
Ampharete vega	2	1.6	0.033	4.0
Pontoporeia affinis	5	4.0	0.011	1.4
Pontoporeia femorata	9	7.2	0.031	3.8
Paroediceros lynceus	1	0.8	0.001	0.1
Monoculopsis longicornis	4	3.2	0.003	0.4
Gammarus zaddachi	1	0.8	0.012	1.5
Apherusa megalops	4	3.2	0.005	0.6
Sphaerodoropsis minuta	1	0.8	0.012	1.5
Scolecolepides arctius	3	2.4	0.002	0.2
Chone duneri	24	19.2	0.010	1.2
Cirratulus cirratus	5	4.0	0.004	0.5
Mysis sp.	18	14.4	0.126	15.5
Diastylis sulcata	22	17.6	0.030	3.7
unknown Ostracoda	4	3.2	0.004	0.5
Oediceros saginatus	1	0.8	0.010	1.2
Saduria entomon	6	4.8	0.370	45.5
Onisimus sp.	3	2.4	0.010	1.2
unknown Copepoda	2	1.6	0.001	0.1
	125		0.813	

Prudhoe Bay
Station 37

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	24	92.8	0.133	98.5
Halicriptus spinulosus	1	3.8	0.001	0.7
unidentified Turbellaria	1	3.8	0.001	0.7
	26		0.135	

Prudhoe Bay
Station 37

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	102	52.0	0.483	63.0
Monoculopsis longicornis	43	21.9	0.053	6.9
Pseudalibrotus sp.	18	9.2	0.090	11.7
Etcone longa	2	1.0	0.005	0.6
Pygospio elegans	1	0.5	0.001	0.1
Diastylis sulcata	2	1.0	0.005	0.6
Mysis sp.	20	10.2	0.051	6.6
Pontoporeia femorata	2	1.0	0.006	0.8
Saduria entomon	1	0.5	0.034	4.4
Oediceros saginatus	1	0.5	0.008	1.0
Halicriptus spinulosus	1	0.5	0.024	3.1
unknown Nemertean	2	1.0	0.006	0.8
unknown Annelida	1	0.5	0.001	0.1
	196		0.767	

Prudhoe Bay
Station 38

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	13	92.8	0.056	98.2
Monoculopsis longicornis	1	7.2	0.001	2.8
	14		0.057	

Prudhoe Bay
Station 38

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Saduria entomon	1	0.7	0.204	28.6
Diastylis sulcata	5	3.7	0.018	2.5
Pontoporeia affinis	75	56.0	0.315	22.4
Monoculopsis longicornis	42	31.3	0.052	7.3
Oediceros saginatus	2	1.5	0.014	2.0
Pseudalibrotus sp.	2	1.5	0.049	6.9
Eteone longa	2	1.5	0.002	0.3
Mysis sp.	5	3.7	0.059	8.3
	134		0.713	

Prudhoe Bay
Station 39

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Scolecolepides arctius	1	33.3	0.001	5.3
Onisimus sp.	1	33.3	0.017	89.5
Monoculopsis longicornis	1	33.3	0.001	5.3
	3		0.019	

Prudhoe Bay
Station 39

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	29	39.2	0.136	14.4
Monoculopsis longicornis	58	78.4	0.058	6.1
Pseudalibrotus sp.	4	5.4	0.028	3.0
Diastylis sulcata	1	1.4	0.004	0.4
Mysis sp.	1	1.4	0.001	0.1
Haliclona rufescens	1	1.4	0.717	76.0
	94		0.944	

Prudhoe Bay
Station 40

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Monoculopsis longicornis	4	57.1	0.005	25.0
Pygospio elegans	1	14.3	0.001	5.0
Pontopereia affinis	2	28.6	0.014	70.0
	7		0.020	

Prudhoe Bay
Station 40

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	16	18.6	0.030	16.7
Monoculopsis longicornis	45	52.3	0.045	25.0
Pseudalibrotus sp.	6	7.0	0.062	34.4
Mysis sp.	11	12.8	0.018	10.0
Oediceros saginatus	3	3.5	0.020	11.1
Diastylis sulcata	1	1.2	0.001	0.6
Eteone longa	1	1.2	0.002	1.1
unknown Oligochaeta	3	3.5	0.002	1.1
	86		0.180	

Prudhoe Bay
Station 41

August 1974
Fager core (3)

Taxon	Total #	%	Total wt.	%
Oediceros saginatus	1	2.3	0.010	5.2
Scolecolepides arctius	29	67.4	0.099	51.0
Ampharete vega	3	7.0	0.041	21.1
Cyrtodaria kurriana	3	7.0	0.030	15.5
Pontoporeia femorata	1	2.3	0.001	0.5
Pontoporeia affinis	2	4.6	0.010	5.2
unknown Oligochaeta	1	2.3	0.001	0.5
Diastylis sulcata	1	2.3	0.001	0.5
	41		0.193	

Prudhoe Bay
Station 41

August 1974
Airlift Sample (2)

Taxon	Total #	%	Total wt.	%
Cyrtodaria kurriana	7	6.7	0.030	10.4
Oediceros saginatus	2	1.9	0.014	4.8
Pseudalibrotus sp.	4	3.8	0.046	15.9
Monoculopsis longicornis	17	16.2	0.015	5.2
Pontoporeia femorata	4	3.8	0.021	7.3
Diastylis sulcata	3	2.8	0.006	2.1
Scolecolepides arctius	27	25.7	0.057	19.7
Eteone longa	5	4.8	0.004	1.4
Mysis sp.	20	19.0	0.040	13.8
unknown Oligochaeta	1	0.9	0.001	0.3
Halicriptus spinulosus	1	0.9	0.001	0.3
unknown Nemertean	1	0.9	0.001	0.3
	92		0.236	

Prudhoe Bay
Station 3

21 August 1974
Fish trap

Taxon	Total #	%	Total wt.	%
Gammaracanthus loricatus	1	4.8	0.283	35.6
Onisimus sp.	2	9.5	0.115	14.5
Pseudalibrotus sp.	18	85.7	0.375	47.2
Unknown organic fragments	-	-	0.021	2.6
TOTAL	21		0.794	

Prudhoe Bay
Station 21

21 August 1974
Fish trap

Taxon	Total #	%	Total wt.	%
Saduria entomon				
adult male	10	27.8	76.138	63.6
adult female				
with eggs	1	2.8	4.455	3.7
brood pouch, no eggs	1	2.8	4.073	3.4
no brood pouch	9	25.0	33.755	28.2
TOTAL	21	58.4	118.421	98.9
Pseudalibrotus sp.	14	38.9	1.193	1.0
Onisimus sp.	1	2.8	0.065	0.0
TOTAL	36		119.679	

Prudhoe Bay
Station 30

21 August 1974
Fish trap

Taxon	Total #	%	Total Wt.	%
Saduria entomon				
adult male	4	12.1	23.755	86.4
adult female no brood pouch	1	3.0	2.606	9.5
juvenile	1	3.0	0.105	0.4
TOTAL	6	18.1	26.466	96.3
Onisimus sp.	20	60.6	0.790	2.9
Pseudalibrotus sp.	4	12.1	0.239	0.9
Very young *Onisimus* sp. or *Pseudalibrotus* sp.	3	9.1	0.001	-
TOTAL	33		27.496	

Prudhoe Bay
Station 32

21 August 1974
Fish trap

Taxon	Total #	%	Total wt.	%
Saduria entomon				
adult male	4	7.8	26.582	76.2
adult female without brood pouch	2	3.9	5.251	15.0
juveniles	6	11.8	0.630	1.8
TOTAL	12	23.5	32.463	93.0
Pseudalibrotus sp.	9	17.6	0.854	2.4
Onisimus sp.	29	56.9	1.575	4.5
Young *Onisimus* sp. or *Pseudalibrotus* sp.	1	2.0	0.001	0.0
TOTAL	51		34.893	

Prudhoe Bay
Station 43

24 August 1974
Fish trap 2

Taxon	Total #	%	Total wt.	%
Pseudalibrotus sp.	269	100.0	9.085	100.0

Prudhoe Bay
Station 43

25 August 1974
Fish trap 1

Taxon	Total #	%	Total wt.	%
Pseudalibrotus sp.	143	100.0	5.191	100.0

Prudhoe Bay
Station 43

24 August 1974
Fish trap 1

Taxon	Total #	%	Total wt.	%
Pseudalibrotus sp.	123	100.0	4.025	100.0

Prudhoe Bay
Station 43

25 August 1974
Fish trap 2

Taxon	Total #	%	Total wt.	%
Pseudalibrotus sp.	242	100.0	9.193	100.0

Prudhoe Bay
Station 44

24 August 1974
Fish trap

Taxon	Total #	%	Total wt.	%
Pseudalibrotus sp.	177	100.0	6.435	100.0

Prudhoe Bay
Station 44

25 August 1974
Fish trap

Taxon	Total #	%	Total wt.	%
Pseudalibrotus sp.	35	100.0	1.235	100.0

Prudhoe Bay
1 mile E. of Causeway; 500'

17 August 1974
Fish trap

Taxon	Total #	%	Total wt.	%
Saduria entomon adult female w/brood pouch (no young or eggs)	1	2.1	3.722	73.5
Pseudalibrotus sp.	46	95.8	1.327	26.2
Gammaracanthus loricatus	1	2.1	0.012	0.2
TOTAL	48		5.061	

Prudhoe Bay
Station: qualitative-near causeway

21 August 1974
Fish trap

Taxon	Total #	%	Total wt.	%
Onisimus sp.	1	50.0	0.008	88.9
Amphipod fragment	1	50.0	0.001	11.1
TOTAL	2		0.009	

Prudhoe Bay
E. side Gull Island

20 August 1974
Fager (1 core)

Taxon	Total #	%	Total wt.	%
Saduria entomon, juveniles	3	75.0	0.052	98.1
Prionospio cirrifera	1	25.0	0.001	1.9
TOTAL	4		0.053	

Prudhoe Bay
Gull Island, West Side

20 August 1974
Fager (2 cores)

Taxon	Total #	%	Total wt.	%
Saduria entomon, juvenile	1	50.0	0.002	66.7
Chone duneri	1	50.0	0.001	33.3
TOTAL	2		0.003	

Prudhoe Bay
Gull Island

20 August 1974
Qualitative Collection

Taxon	Total #	%	Total wt.	%
Laminaria saccharina	1	-	-	-
Laminaria?	?	-	-	-
Death Array				
Amauropsis sp.	1	-	-	-

Prudhoe Bay
Argo Island (lee side)

20 August 1974
Fager (2 cores)

Taxon	Total #	%	Total wt.	%
Ampharete vega	67	79.8	0.389	13.7
Halicriptus spinulosus	3	3.6	0.413	14.5
Castalia sp.	3	3.6	0.011	0.4
Terebellides stroemi	1	1.2	0.013	0.4
Chaetozone setosa	2	2.4	0.002	0.0
Sphaerodoropsis minuta	1	1.2	0.001	0.0
Cirratulus cirratus	1	1.2	0.001	0.0
Haploscoloplos elongatus	1	1.2	0.001	0.0
Naticidae egg mass	1	1.2	1.637	57.6
Unknown egg	1	1.2	0.032	1.2
Unknown Oligochaete	1	1.2	0.001	0.0
Unknown Bryozoa	1	1.2	0.003	0.0
Unknown Tunicate	1	1.2	0.340	12.0
TOTAL	84		2.844	

Prudhoe Bay
Argo Island (lee side)

20 August 1974
Qualitative

Taxon	Total #	%	Total wt.	%
Unknown Nemertean	1	-	0.608	-
Unknown Tunicate	4	-	4.235	-
Laminaria sp.	4	-	69.005	-
Ampharete vega	2	-	0.009	-
Saduria entomon adult male	1	-	10.962	-
Gammarus wilkitzkii	2	-	0.435	-
Priapulus caudatus	2	-	5.525	-
Unknown Bryzoan	2	-	0.319	-
Unknown Phaeophyte	1	-	1.031	-
Death Array	-	-	-	-
Serripes groenlandica[1]	-	-	-	-
Valutina sp.	-	-	-	-
Buccinum sp.	-	-	-	-
Hyas coarctatus[2]	-	-	-	-

[1]Shells only
[2]Dead animal

Prudhoe Bay
Naikuk Island

20 August 1974
Fager (2 cores)

Taxon	Total #	%	Total wt.	%
Pontoporeia affinis	3	42.8	0.007	7.6
Saduria entomon, juvenile	3	42.8	0.084	91.3
Monoculopsis longicornis	1	14.4	0.001	1.1
TOTAL	7		0.092	

Prudhoe Bay
Station 23

21 August 1974
Sea sled

Taxon	Total #	%	Total wt.	%
Mysis sp.	3,428	67.3	15.056	81.6
Monoculopsis longicornis	1,590	31.2	1.938	10.5
Saduria entomon	5	0.1	0.031	0.2
Pontoporeia affinis	41	0.8	0.215	1.2
Diastylis sulcata	2	0.0	0.008	0.0
Gammaracanthus loricatus	6	0.1	1.088	5.9
Oediceros saginatus	12	0.2	0.083	0.4
Unknown Copepod	1	0.0	0.001	0.0
Pseudalibrotus sp.	5	0.1	0.003	0.2
TOTAL	5,090		18.423	

Prudhoe Bay
Station 43

25 August 1974
Sea sled (track 1, sample 1)

Taxon	Total #	%	Total wt.	%
Mysis sp.	532	98.2	3.722	96.1
Pseudalibrotus sp.	8	1.5	0.144	3.6
Gammaracanthus loricatus	2	0.3	0.014	0.3
TOTAL	542		3.880	

Prudhoe Bay
Station 43

23 August 1974
Sea sled (track 1, sample 2)

Taxon	Total #	%	Total wt.	%
Mysis sp.	1536	99.6	15.691	99.6
Pontoporeia affinis	1	0.1	0.002	0.0
Gammaracanthus loricatus	3	0.2	0.054	0.3
Monoculopsis longicornis	1	0.1	0.001	0.0
Pseudalibrotus sp.	1	0.1	0.004	0.1
TOTAL	1542		15.752	

Prudhoe Bay
Station 43

23 August 1974
Sea sled (track 2, sample 1)

Taxon	Total #	%	Total wt.	%
Mysis sp.	736	99.7	5.497	99.5
Pseudalibrotus sp.	1	0.1	0.020	0.4
Pontoporeia affinis	1	0.1	0.004	0.1
TOTAL	738		5.521	

Prudhoe Bay
Station 43

25 August 1974
Sea sled (track 2, sample 2)

Taxon	Total #	%	Total wt.	%
Mysis sp.	33	-	0.230	-

Prudhoe Bay
Station 43

23 August 1974
Sea sled (track 3, sample 1)

Taxon	Total #	%	Total wt.	%
Unknown Cnidaria	2	0.1	0.004	0.0
Mysis sp.	4,224	99.5	27.273	99.8
Monoculopsis longicornis	16	0.4	0.016	0.1
Pontoporeia affinis	2	0.1	0.002	0.0
Unknown Tunicate	2	0.1	0.038	0.1
TOTAL	4,246		27.333	

Prudhoe Bay
Station 43

23 August 1974
Sea sled (track 4, sample 1)

Taxon	Total #	%	Total wt.	%
Mysis sp.	5760	99.4	42.711	99.9
Oediceros saginatus	28	0.5	0.019	0.0
Gammaracanthus loricatus	2	0.1	0.026	0.1
Pontoporeia affinis	2	0.1	0.002	0.0
TOTAL	5792		42.758	

Prudhoe Bay
Station 43

August 1974
Sea sled (track 5, sample 1)

Taxon	Total #	%	Total wt.	%
Unknown Cnidaria	2	0.6	0.016	0.5
Mysis sp.	348	98.9	3.116	98.0
Gammaracanthus loricatus	2	0.6	0.048	1.5
TOTAL	352		3.180	

Prudhoe Bay
Station 8

19 August 1974
Qualitative

Taxon	Total #	%	Total wt.	%
Saduria entomon, females	2	-	9.662	-
Unknown Tunicate	7	-	17.750	-

Prudhoe Bay
Station 34

19 August 1974
Qualitative

Taxon	Total #	%	Total wt.	%
Saduria entomon juvenile	1	0.153	-	-
Laminaria sp. fragments	-	0.689	-	-
Unknown fragment	2	1.064	-	-

Prudhoe Bay
Beach near causeway[1]

August 1974
Shore collection

Taxon	Total #	%	Total wt.	%
Neptunea sp.	-	-	-	-
Mya truncata	-	-	-	-
Amauropsis sp.	-	-	-	-
Buccinum sp.	-	-	-	-
Colus sp.	-	-	-	-
Astarte cf. A. borealis	-	-	-	-
Musculus sp.	-	-	-	-

[1]Shells only

APPENDIX II

Field notes of Rick Rosenthal (Dames and Moore, Anchorage) following diving activities at Prudhoe Bay in August 1974.

PRUDHOE BAY FIELD NOTES

Rick Rosenthal

Dames, and Moore, Anchorage

16 August

"Arco causeway study" - Moved blocks and equipment out to the proposed study site; however, we ended up a few miles short of the mark. Feder, Shaw and Hilsinger put out station blocks and buoys; L. Barr and I dived in Prudhoe Bay.

Observations

Water temperature 7 to 8°C; underwater visibility less than one foot. A great deal of fresh water was present in the water column-density layers quite visible. Along the shoreline were scattered clumps of tundra; the frequency of occurrence appeared to decerase as we moved seaward. Ripple marks on the sea floor generally parallel to the shoreline. Sediments consisted of sand, gravel, silt, muds and detritus. Encountered an occasional piece of Macro-algae; however, no living plants were seen and most were flaccid and bleached. The most conspicuous invertebrates were mysids, there appeared to be at least three species. Crane (M.S. Thesis) calls one ubiquitous mysid from the Colville River area, *Mysis oculata*. Other animals an unidentified small medusa; unid. mysids; isopod *Saduria (-Mesidotea)*; unid. polychaete casts and tracks on the sea floor. A dupauperate flora and fauna in this shallow water area. It would be a difficult habitat to make a living in-with ice scour, freezing and lack of solid substratum for attachment, etc.

17 August

"Arco causeway study" - Worked off the proposed causeway site. Installed the center transect line and put in the station buoys. We began the biological sampling at the various stations.

Observations

Airlift samples were taken with the "Chess Airlift". Samples taken within a .25 m^2 quadrat. The top 2 to 4 cm of sediment was removed from each quadrat and entrained into a fine mesh bag. The airlift worked well, air consumption 300 to 400 lbs/quadrat. A cursory look at the collection bags revealed amphipods, isopods etc. Bottom samples were also taken with the "Fager Corer". Sediment and hydrocarbon samples were taken at three stations.

Wind and currents made working conditions difficult. Underwater visibility reduced to less then 1 foot; current direction was westerly.

18 August

"Arco causeway study" - Weather, poor, strong winds. We were unable to dive today.

19 August

"Arco causeway study" - Weather improved; helicopter flew Barr and I out to the study site. All of the biological stations were completed.

Observations

Starting from shore the sea floor was relatively homogeneous in appearance; however, it was variable with respect to bottom sediments and biota. The shoreline sediments consisted of coarse sand and small clumps of tundra. Moving seaward the substratum gradually changed from sand into a mixture of sand-silt to mud around the 4000 foot mark. There appeared to be variability or even distinct breaks or changes in the associated benthic fauna. No attached macrophytes were seen in the area. The shoreline habitat was sandy, the conspicuous organisms were crustacean groups, such as amphipods and mysiads. Seaward the bottom community consisted of mud forms such as polychaetes and clams. Polychaete mounds and fecal casts were patchy in their distribution. Crustaceans were generally seen moving over or resting on the surface of the sea floor. A solitary "raisin" shaped ascidian and a large isopod *Saduria (=Mesidotea)* was also common. Removal of the top sediment layer exposed polychaete tubes and small clams. Usually the worm tubes were extended in a vertical position with respect to the surrounding substratum.

20 August

"Offshore sampling" - A helicopter flew L. Barr, Angus Gavin and myself out to Argo Island, Niakuk Island, and Gull Island. Water clarity improved offshore, much of the turbidity appeared to come from the Sagavanirktok River as a silt plume was visible from the air.

Argo Island (south side)

The south side of the island was ice free. The beach consisted of coarse sand and cobbles, with fine silts and muds further offshore. Water temperature was 3.5°C at 3 m. In some locations worm tubes covered an estimated 80 percent of the bottom; polychaete mounds and fecal casts were common on the mud bottom. Mysids were extremely abundant along the sea floor. Other conspicuous organisms were unid. amphipods; *Mesidotea*; solitary ascidian: *Hyas coarctatus* (moult); unid. gastropods and a drifting *Laminaria* sp. attached to a small rock.

Argo Island (north side)

Pack ice on this side of the island. Water temperature was 0°C Area heavily scoured by ice; the biota reflects the rigours of existing in this harsh environment.

The bottom sediments were mostly sand and some cobbles along the shoreline. A few worm mounds and casts were encountered, also a few mysids; amphipods were seen on the undersides of the ice. This side of the island was dramatically different from the south side with respect to sediments and living organisms.

Niakuk Island

We dived on the outside island in this small island chain. Sampled along the north end of the island; underwater visibility was 0m and the water temperature was 5°C. Sediment and hydrocarbon samples were taken while free-diving.

Gull Island

We sampled on the N.E. end of Gull Island; underwater visibility was zero and the water temperature was 5°C. Samples were taken along the S.E. and N.E. tip of the sand spit. Biological and sediment samples were taken and Barr collected drift laminarians.

At each of the islands we took a few photographs; two Fager cores; three sediment sample and one hydrocarbon sample.

21 August

"Prudhoe Bay Study" - Sampling off Pt. McIntyre N.W. of the proposed causeway. The transect (three stations) was west of the causeway site. Biological samples: Air-lift (replicate .25 m^2); Fager cores (triplicate); sediment: Hydrocarbon with a glass jar. Water temperature was 3.5°C; underwater visibility was 1 to 2 feet; pack ice had moved into the area.

Observation

A small pinkish-white gammarid amphipod was burrowed into substratum. However, when I disturbed the sediment with the corer amphipods as far away as .25 m struggled free of the sediment and swam away. The bottom sediment consists of a great deal of sand near shore.

Transect (two stations)

Located approximately one mile east of the oil well. The substratum consisted of more silts and muds in this area, underwater vasibility less than one foot. Fog prevented us from completing the third station so we returned to the Arco base.

22 August

Heavy winds, we were unable to dive.

23 August

Returned to Cordova.

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GENERAL DISCUSSION

The preliminary study described in this report was funded to generate a basic body of information for the nearshore environment adjacent to a projected causeway site in Prudhoe Bay, Alaska. Although considerable data are available for the nearshore arctic marine environment elsewhere (see Volume II of this report for a literature survey of the arctic marine environment), limited information is available for Prudhoe Bay. Thus, the benthic biological and hydrocarbon data included here are the first information of this nature available for the area, and the geological data extends well inshore an existing data base already available for outer Prudhoe Bay.

Our work in Prudhoe Bay has sought to address two related scientific questions: 1) What, if any, environmental changes will be induced by the construction of a gravel causeway into Prudhoe Bay, and 2) What, if any, environmental changes in the marine environment in and around Prudhoe Bay will be induced by ongoing petroleum exploration and development in the area? Our first year's work reported here constitutes a modest beginning toward answering these questions.

All of the sediments collected at the new causeway site and adjacent transects were moderately to poorly sorted sands, silty sands or sandy silts. However, the sediments at the stations within the new causeway site showed an overall seaward decrease in mean size and sediment sorting. The benthic biota at these stations appear to correlate with this seaward sediment transition with species diversity, density and biomass all tending to increase with distance offshore. The transect closest to Point McIntyre (Stations 37, 38, and 39) differed from the other three transects, and physically and biologically resembled the shallower portions of the other transects. Since a change in the sediment budget in this portion (the northwestern region) of Prudhoe Bay can be expected subsequent to the construction of the causeway, the ecological consequences of such a sediment change can perhaps best be gauged by way of a continuing examination of the benthic fauna here. Preliminary studies on the feeding biology of the common fishes of Prudhoe Bay indicate that these fishes are feeding primarily on crustaceans characteristics of shallow-sandy stations such as those at Point McIntyre.

The kinds and amounts of hydrocarbons now present in the sediment and fishes of Prudhoe Bay indicate that these hydrocarbons are largely or totally biogenic in origin. The fact that most of the benthic invertebrates species collected are apparently either deposit feeders or scavengers suggests that any petroleum hydrocarbons added to their environment in the future might be picked up by them during their feeding activities. Petroleum hydrocarbons could then be readily monitored by way of their detection in the sediments, in the tissues of some of the benthic invertebrates, and also in the tissues of fishes utilizing some of these invertebrates for food.

RECOMMENDATIONS

1. Geological - It is suggested that a long-term sedimentological and geochemical monitoring program for Prudhoe Bay be initiated. Additional stations should be established throughout Prudhoe Bay and adjacent areas to determine sediment-transport vectors and quantity of littoral drift of sediments within the Bay. The number of stations within the established transects can probably be reduced where similar sediment parameters are measured at nearby stations on these transects.

2. Biological - A long-term monitoring program should be initiated. It is recommended that diver operated sampling devices continue to serve as the basic collecting tools for examining the shallow nearshore benthos. The similarity of the fauna at some of the adjacent stations along the transects suggests that the number of stations can be reduced, but it is recommended that all stations be sampled for three years before establishing final monitoring positions. Both types of sampling gear (Fager core and airlift) should be used during monitoring activities. Each method effectively samples specific organisms, although the airlift system consistently collects more species per station. It is recommended that additional replicate samples be taken at every station. Fish-trap sampling should be expanded. The latter collection method is relatively simple, yields large numbers of individuals, and can be used in a variety of ways for monitoring purposes (e.g. changes in species composition, general density changes, reproductive biology, growth studies, and hydrocarbon analyses of invertebrate species). More intensive sampling at specific stations around the barrier islands is suggested to establish a firm basis for a monitoring program here. Several additional stations (occupied jointly for sediment, biological and hydrocarbon analyses) should be established in the deeper waters of Prudhoe Bay.

3. Hydrocarbon - Based on the first year results reported here and the preliminary results of the second year's work available at the time of this writing (March 1976), it appears that too great a variability in sampling occurred from year to year to allow a full interpretation of the differences that have been found. Thus, a more extensive and standardized sampling effort is required. Hydrocarbon data on resident benthic biota is also needed in addition to continued information about hydrocarbon levels in highly mobile fishes.