THE ARCTIC COASTAL ENVIRONMENT OF ALASKA

VOLUME III

The Nearshore Marine Environment in Prudhoe Bay, Alaska

by

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

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EXECUTIVE SUMMARY

This is the third volume of reports on the marine environment of Prudhoe Bay, Alaska sponsored by the Atlantic Richfield Company. Volume I considered the results of geological, hydrocarbon and biological investigations conducted by the Institute of Marine Science, University of Alaska, in summer 1974. Volume II was a compilation of major scientific literature on the arctic marine environment.

Volume III contains the results of studies made in summer 1975. It consists of chapters on geological studies, hydrocarbon studies, benthic biological studies, plus general discussion, further scientific references, conclusions and recommendations.

Geological Studies

The objectives of the investigations of sediments and their chemistry have been to identify the changes, if any, within the immediate vicinity of the new causeway. Three attributes of the bottom sediments were investigated: 1) grain-size, 2) the source, migrating pathways, and eventual depositional sites of fine-grained clay minerals of land origin, and 3) the concentration of certain heavy metals (copper, chromium, nickel and vanadium) and organic carbon and phosphorus in the sediments.

Samples of sediments were obtained from all stations sampled in the previous year except those stations now occupied by the causeway. Generally speaking, there was a coarsening of the bottom sediments in the study area. While the gravel content remained the same, there was a significant increase in sand content and a decrease of silt and clay. No change was observed in the relative concentration of the clay minerals.

Geochemical analyses, so far, show that the mean concentration of organic carbon has increased significantly but without the concommitant increase of nickel that the 1974 data had lead us to predict might take place with changes in lithology. We cannot, at the moment, explain the phenomena of nickel content, but are inclined to relate the observed increase in organic carbon to the notable increase of the total benthic biomass referred to in Chapter III. It is possible that summer storm activity could explain the observed differences in sediment composition.

Hydrocarbon Studies

The objectives of the hydrocarbon portion of the study have been to survey the kinds and amounts of hydrocarbons present in the sediment and biota in the vicinity of the newly constructed causeway. The 1974 samples indicated that hydrocarbon content in the biota and sediments were largely biogenic in origin. The 1975 samples, analyzed with more sensitive techniques, indicate both biogenic and some petroleum origins for the hydrocarbons found. The 1975 data lead us to the conclusion that the marine sediments collected during both 1974 and 1975 contained both petroleum based and biogenic based hydrocarbons, the latter being largely of tundra origin. Concentrations were roughly comparable between the years. Where data for both years are available, no trend of increase or decrease in hydrocarbon concentration is evident. Kinds and amounts of hydrocarbons present in fish collected to date are largely or totally biogenic in origin.

Benthic Biological Studies

The purpose of the benthic studies was to determine the possible effect of causeway construction on the resident benthic (bottom-living) organisms at selected areas in Prudhoe Bay. In general, the 1975 data were similar to those collected in 1974. The distributional trends of species, numbers of individuals, and biomass (total weight of living matter) again showed an increase in a seaward direction, reaching a maximum at about 3,500 ft. from shore. However, in 1975 an overall increase in species density and biomass was observed at all causeway, Point McIntyre and Gull Island stations. It is suggested that summer storm activity was probably responsible for the extensive inshore translocation of benthic organisms. Thus, replenishment of bottom-dwelling invertebrates to inshore waters at Prudhoe Bay can be expected to operate in three ways: (1) settling of young, (2) slow movement of adults into the area, and (3) rapid storm-generated translocation of adults from nearby areas.

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 information available in 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, the third of three volumes, presents information that should contribute to this goal. The first volume considers the results of geological, hydrocarbon, and benthic biological investigations accomplished in Prudhoe Bay in August 1974 (Feder *et al.*, 1976a*). Volume two represents a compilation of the major scientific literature available for the Alaskan and Canadian arctic marine environment (Feder *et al.*, 1976b*). The present volume contains the results of geological, hydrocarbon, and benthic biological studies in Prudhoe Bay in August 1975.

Additional detail data have been compiled separately as, "The Arctic Coastal Environment of Alaska, Data Supplement, 1976". Information concerning purchase of this data supplement can be obtained from the Institute of Marine Science, University of Alaska, Fairbanks.

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*See References, Chapter III

Chapter I

GEOLOGICAL STUDIES

A. S. Naidu

INTRODUCTION

In a recent review paper (Feder *et al.*, 1976b) Naidu has made attempts to summarize all the investigations that have been carried out up to 1974 on the grain size distributions, mineralogy, and chemistry of the continental margin and continental shelf sediments of the Beaufort Sea. Very limited additional sedimentological data have been published, and those worthy of mention include lithological-geochemical work carried out by Naidu (Feder *et al.*, 1976a; Burrell, 1976) in the vicinity of the ARCO causeway site in Prudhoe Bay, as well as on the continental shelf of the Beaufort Sea.

OBJECTIVES

The objectives of the sedimentological-geochemical investigations in the present study have been to identify the changes, if any, in certain aspects of the physicochemical nature of sediments within a small stretch of the continental margin on the North Slope of Alaska, subsequent to the construction of the ARCO new causeway. In order to achieve this objective, a variety of attributes of the bottom sediments have been analyzed. The main purpose of the grain-size analyses in the above area has been to monitor the changes in bottom lithology, which has implications on the understanding of benthic faunal habitat and sediment chemistry. The clay mineral investigations have been pursued to identify changes in the source, migrating pathways and depositional sites of fine-grained terrigenous particles, which may have been introduced in the vicinity of Point McIntyre, Prudhoe Bay, consequent to construction of a causeway by ARCO. In addition, analyses of certain attributes of the bottom sediment chemistry have been continued to monitor the concentrations of a suite of heavy metals (Cu, Cr, Ni and V). Organic carbon and phosphorus have been analyzed to verify any perturbations in the availability of nutrients to benthic detritus feeders, prior and subsequent to the causeway construction.

MATERIALS

Sediment samples from the causeway site were collected and provided by Dr. H. Feder. Each sample was collected by a diver who was given a container which he filled directly at the bottom. The container was returned to the boat and capped. In addition, a Fager core sample (see Chapter III for discussion of this sampler) was taken for sediment chemistry. Samples were collected from all those stations established in 1974 in the vicinity of the new ARCO causeway site, except of course, from the area which has been subsequently occupied by the causeway. To be more specific, no sediment samples were collected from the stations 16 through 25 conforming to the 1974 grid. All sediment samples were stored in a frozen state until analysis.

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. Copper, Cr, V, and Ni were analyzed from 10% V/V HNO_3 acid sediment solutions by atomic absorption spectrophotometry, using a Perkin-Elmer Model 306 unit. Details on the methods that were adopted to bring sediments into acid solutions have been dwelt upon by Naidu and Hood (1972). The precision of the trace metal analysis was about 12%, 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). Total phosphorus in the above solutions were analyzed colorimetrically, following the method given by Murphy and Riley (1962).

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, and carbonate contents in the sediments were analyzed manometrically (Hülsemann, 1966).

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

RESULTS AND DISCUSSIONS

Sediment Texture

Table I gives the percentages of gravel, sand, silt and clay as well as the statistical grain size parameters of bottom sediments in the vicinity of the new causeway site. In attempting to identify the changes in the nature of sediment substrate in the above area, subsequent to the causeway construction, grain-size distributions pertaining to bottom sediments collected in the summers of 1974 (Feder *et al.*, 1976a) and 1975 (Table I, this report) have been compared on a station to station basis. With the exception of station 25 there is apparently no significant change in the gravel contents of the bottom sediments. It would seem, with the exception of station 28,

Table I. Grain size distributions of sediments, around the ARCO new causeway site, Prudhoe Bay, north arctic Alaska. Sediment samples were collected in summer 1975.

Sample No.	Gravel %	Sand %	Silt %	Clay %	Md	M_z	σ_I	Sk_I	K_G
PDB 75-1	12.6	86.9	0.5	0	1.60	1.6	1.01	-0.31	2.41
PDB 75-2	0.5	95.5	3.3	0.7	2.20	2.2	0.66	0.13	1.23
PDB 75-3	0	94.1	5.9	0	2.5	2.4	0.69	0.24	1.52
PDB 75-4	0	86.3	13.7	0	2.4	2.4	0.79	0.19	1.64
PDB 75-5	0	93.4	6.0	0.6	2.72	2.73	0.80	0.14	1.15
PDB 75-6	0	94.1	5.6	0.3	2.80	2.83	0.72	0.10	0.94
PDB 75-7	0	79.0	21.0	0	3.50	3.50	0.90	0.05	1.69
PDB 75-8	0	61.7	36.4	1.9	3.80	4.00	1.09	0.34	1.43
PDB 75-9	0	80.4	18.5	1.1	3.60	3.63	0.71	0.17	1.98
PDB 75-10	0	83.1	15.9	1.0	3.60	3.60	0.64	0.32	1.98
PDB 75-25	38.9	61.1	0	0	0.41	-0.03	1.58	-0.30	0.52
PDB 75-26	0.5	94.2	4.7	0.6	2.20	2.20	0.72	0.14	1.43
PDB 75-28	0.4	98.5	1.1	0	1.91	1.87	0.51	0.19	1.00
PDB 75-29	0.3	97.1	2.2	0.4	2.10	2.10	0.62	0.02	1.08
PDB 75-30	0	80.7	18.3	1.0	3.49	3.50	0.91	0.12	1.90
PDB 75-31	0	59.3	37.2	3.5	3.80	4.03	1.40	0.37	1.39
PDB 75-32	0	68.7	31.1	0.2	3.70	3.80	0.94	0.14	1.69
PDB 75-33	0	83.5	15.4	1.1	3.29	3.07	1.18	-0.10	1.03
PDB 75-34	0	76.9	21.2	1.9	3.40	3.33	1.39	1.26	1.67
PDB 75-37	0	48.2	46.8	5.0	4.03	4.53	1.37	0.56	1.55
PDB 75-38	0	98.2	1.8	0	3.40	3.40	0.32	-0.05	1.13
PDB 75-39	0.9	93.6	5.5	0	2.48	2.53	0.78	0.09	1.38
Gull Is. (East)	0	90.2	9.6	0.2	3.60	3.60	0.38	0.17	1.54
Gull Is. (West)	0	69.6	29.8	0.6	3.79	3.90	0.73	1.51	1.58
Gull Is. (North)	0	75.9	22.9	1.2	3.78	3.80	0.72	0.25	2.3

there has been evidently, a coarsening in the substrate throughout the studied area, subsequent to the causeway construction. This is quite evident from the statistically significant increase (at 99% confidence level based on 't' test calculations) in sand contents of sediments with a concomittant decrease in the silt and/or clay contents. In addition, there is a relative increase in the mean (Figs. 1, 2, and 3) and median sizes of sediment grains. With the exception of this, apparently there is no significant change in the other grain size parameters (Figs. 1, 2, 3, and 4). However, there is presently some difficulty to explain, in terms of the prevalent hydrodynamic conditions,

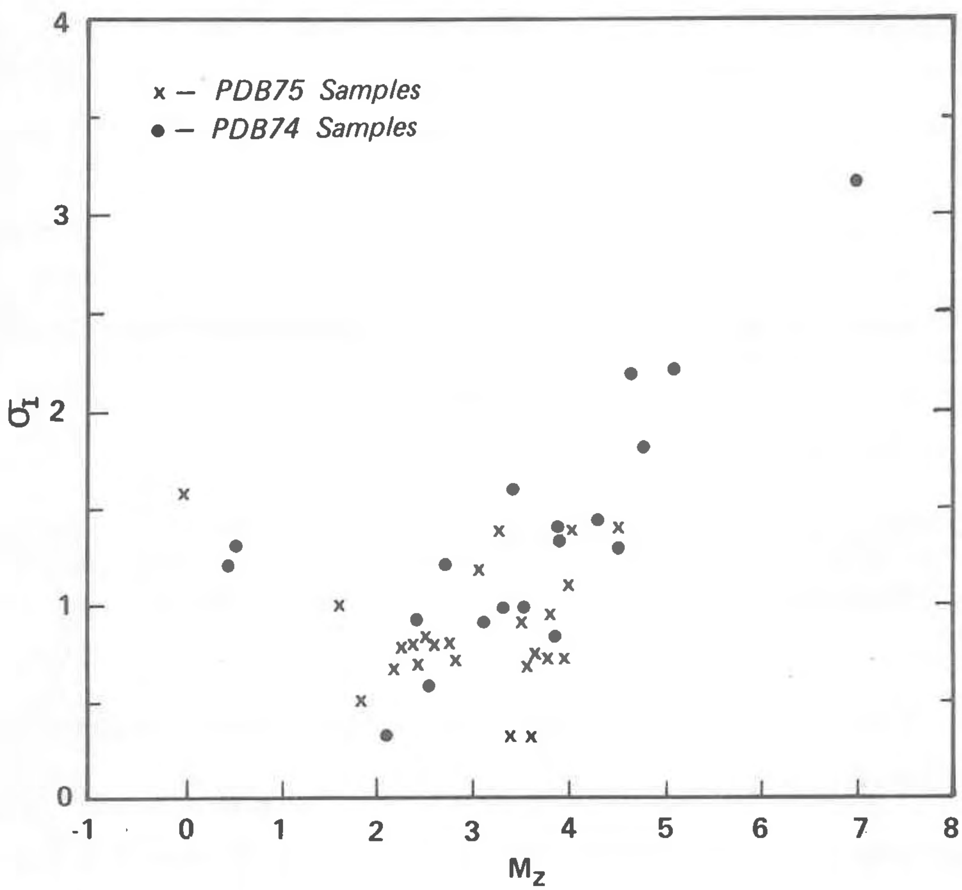

Figure 1. Scatterplots showing the relation between the mean sizes and sorting coefficients of sediments collected prior (PDB74) and subsequent to (PDB75) the causeway construction.

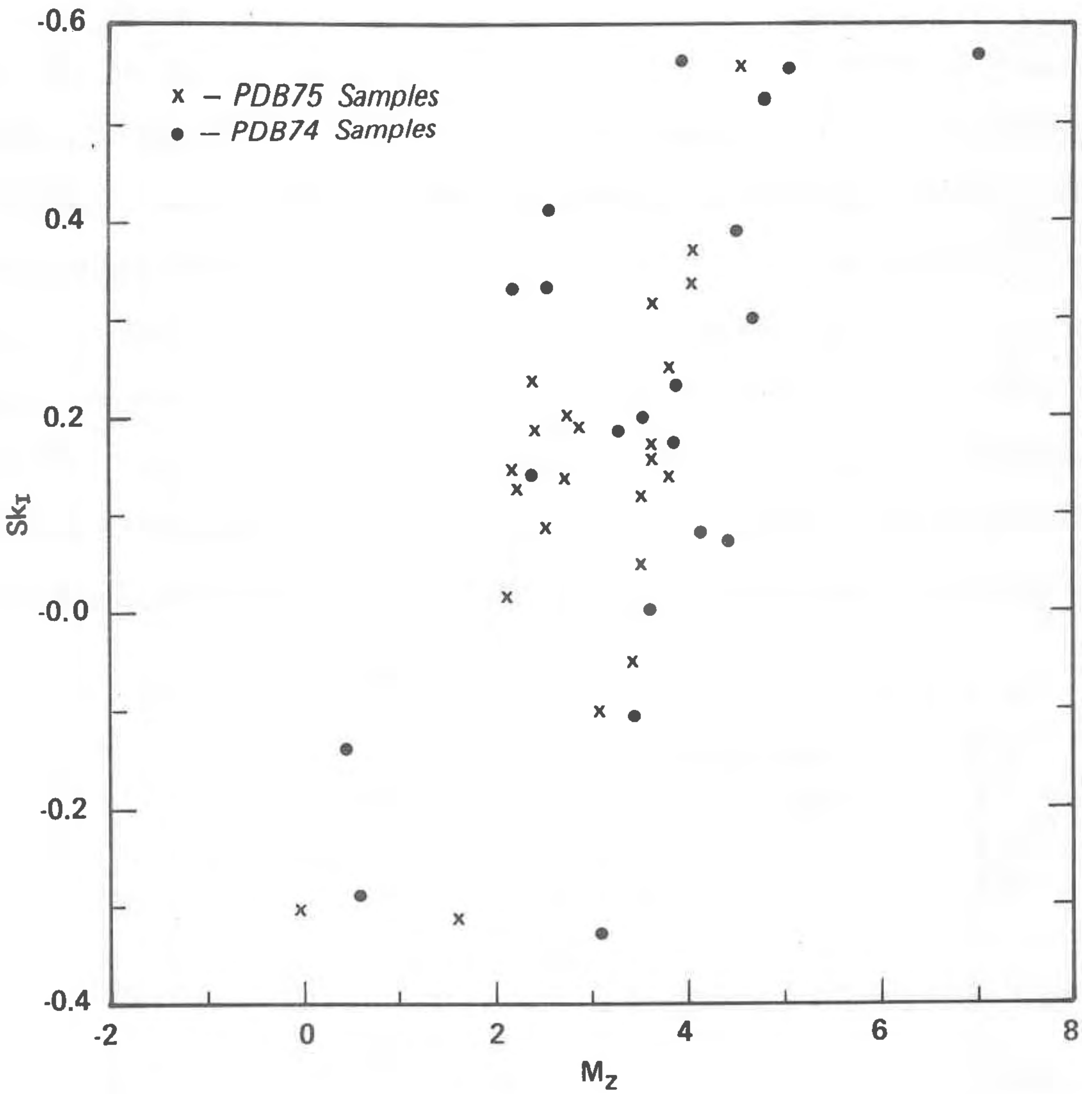

Figure 2. Scatterplots showing relation between the mean sizes and skewness of size distributions of sediments, collected prior (PDB74) and subsequent to (PDB75) the causeway construction.

the factors that might have contributed to bringing about a general coarsening in the substrate deposits consequent to the causeway construction. The continental margin environment of the North Slope of Alaska is a low energy depositional environment, except during occasional high storms (Naidu and Mowatt, 1975). Therefore, any alterations in the sediment depositional regime, because of anthropogenic or natural perturbations in the coastal

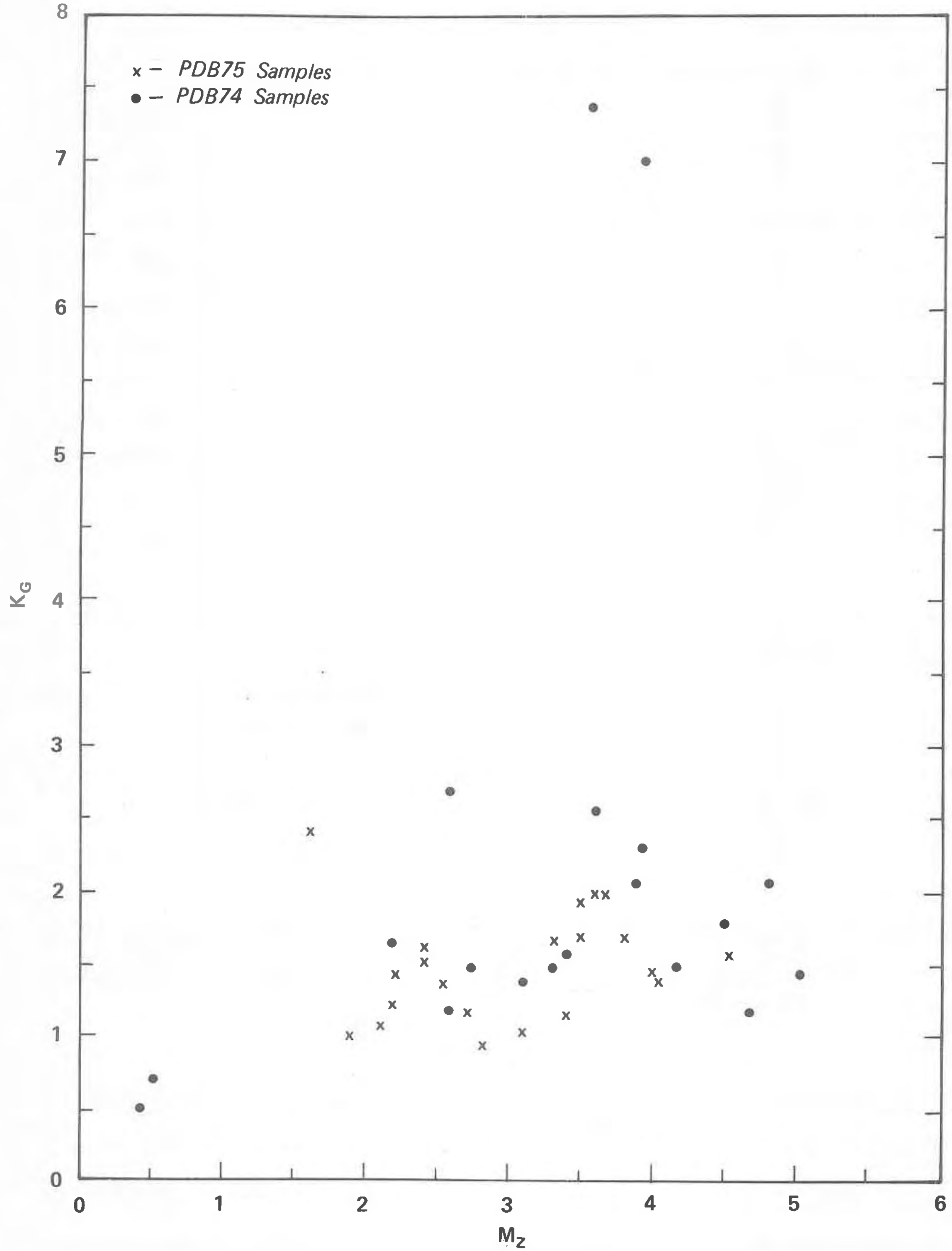

Figure 3. Scatterplots showing the relationship between the mean sizes and kurtosis of size distributions of sediments, collected prior (PDB74) and subsequent to (PDB75) the causeway construction.

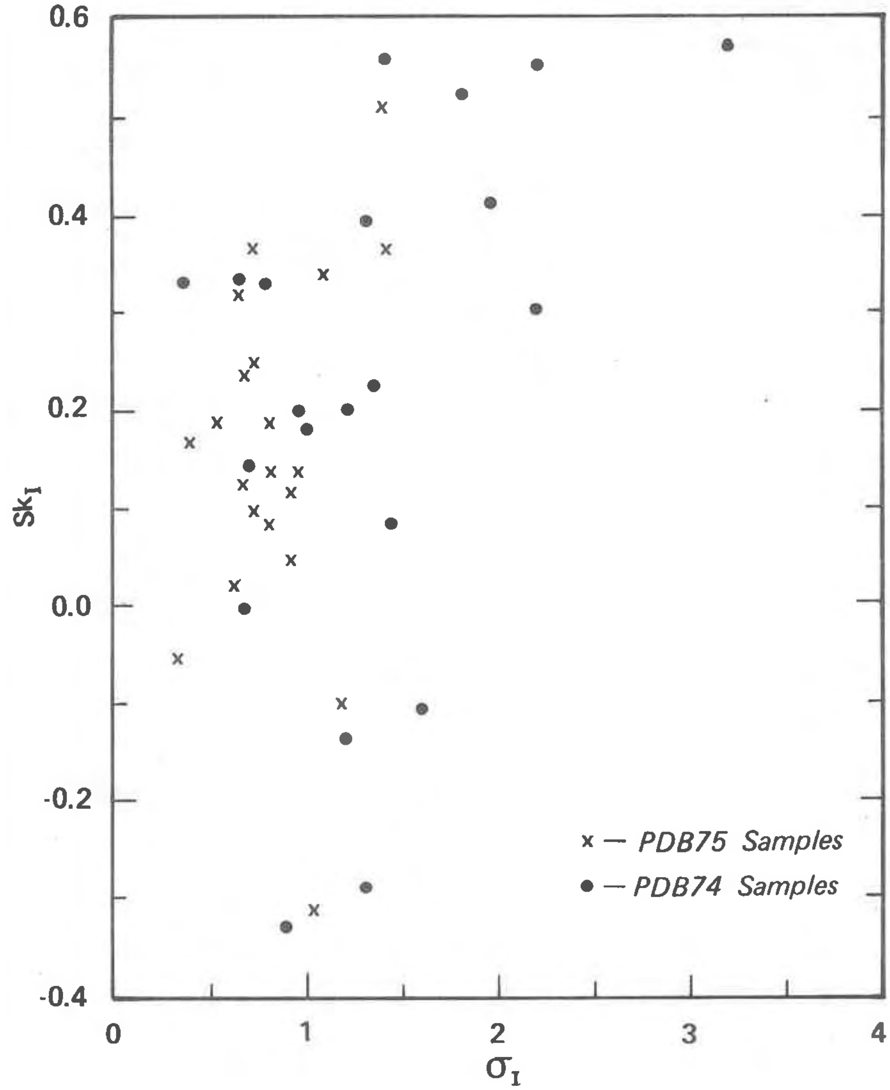

Figure 4. Scatterplots showing the relationships between the sorting coefficients and skewness values of size distributions of sediments, collected prior (PDB74) and subsequent to (PDB75) to the causeway construction.

geomorphology, most likely would be gradual. As such it is difficult to conceive that during the span of one year (from 1974 summer to 1975 summer) there would be recognizable changes in the sediment textural attributes resulting entirely from the causeway construction. The other possible factors that could have contributed to the observed coarsening in the sediment substrate, after the causeway construction, relate to sediment sampling error and infiltration of coarse fluvial material during the causeway construction process.

Clay Mineralogy

Table II shows the weighted peak area percents (Biscaye, 1965) of clay minerals in the less than 2 μm size fraction of representative sediment samples in the vicinity of the causeway. On comparing the clay mineral data pertaining to sediment suites collected prior and subsequent to the causeway construction (Feder *et al.*, 1976a; Table II in this report), it is observed that there is no significant difference in the relative concentrations of the various clay minerals. This suggests that the nature of the terrigenous source of fine-grained sediments for the causeway environs has not significantly changed subsequent to the causeway construction. Therefore, the primary terrigenous source of the fine-grained detritus in the vicinity of the causeway most probably remains to be the Sagavanirktok River as observed earlier (Feder *et al.*, 1976a).

Sediment Geochemistry

Table III gives the contents of organic carbon and carbonate in the gravel-free sediments that were collected in the vicinity of the causeway in the summer of 1975. Table IV cites the concentrations of Cu, Cr, Ni, and V in the above deposits. Table V shows the phosphorus contents on bottom sediment samples that were collected in the vicinity of the causeway in the summers of 1974 and 1975, prior and subsequent to the causeway construction, respectively. Table VI presents baseline phosphorus data on sediment samples obtained from the Prudhoe Bay area prior to the construction of the causeway.

Table II. Weighted peak area percents of clay minerals in the < 2 μm fractions of sediments around the ARCO causeway site and the Gull Island, Prudhoe Bay, arctic Alaska. Sediment samples were collected in summer 1975.

Sample No.	Smectite	Illite	Kaolinite	Chlorite	Kaol./Chlo.	Illite/Smectite
PDB 75-2	2	63	12	23	0.5	32
PDB 75-3	2	62	12	24	0.5	31
PDB 75-4	3	64	11	22	0.5	21
PDB 75-5	3	62	12	23	0.5	21
PDB 75-6	4	58	14	24	0.6	15
PDB 75-7	3	62	14	21	0.7	21
PDB 75-27	5	63	13	19	0.7	13
PDB 75-28	2	62	13	23	0.6	31
PDB 75-29	4	62	12	22	0.6	16
PDB 75-30	5	61	10	24	0.4	12
PDB 75-31	2	69	10	19	0.5	35
PDB 75-32	8	59	11	22	0.5	7
PDB 75-33	5	64	12	19	0.6	13
PDB 75-34	3	63	12	22	0.6	21
PDB 75-37	2	66	11	21	0.5	33
PDB 75-38	3	61	13	23	0.6	20
PDB 75-39	4	62	11	23	0.5	16
Gull Is. (North)	6	61	11	22	0.5	10
Gull Is. (West)	4	66	10	20	0.5	17
Gull Is. (East)	3	62	13	22	0.6	11

Table III. Organic carbon and carbonate contents in gravel-free sediments collected around the ARCO new causeway site, Prudhoe Bay, in summer 1975. All concentrations are expressed on dry weight basis.

Sample No.	Organic C (%)	$CO_3^{=}$ (%)
PDB 75-1	1.34	4.38
PDB 75-2	0.08	6.01
PDB 75-3	0.11	10.79
PDB 75-4	0.18	15.95
PDB 75-5	2.12	15.00
PDB 75-6	0.51	16.96
PDB 75-7	1.78	16.61
PDB 75-8	2.34	15.46
PDB 75-9	1.26	15.56
PDB 75-10	0.69	16.86
PDB 75-26	0.18	6.83
PDB 75-27	0.04	7.30
PDB 75-28	0.02	4.18
PDB 75-29	0.04	11.10
PDB 75-30	1.22	15.52
PDB 75-31	1.47	15.89
PDB 75-32	1.66	13.53
PDB 75-33	0.66	14.33
PDB 75-34	0.80	16.83
PDB 75-37	0.34	16.80
PDB 75-38	0.17	18.49
PDB 75-39	0.85	9.61
Gull Island (East)	0.20	18.32
Gull Island (North)	0.62	16.69
Gull Island (West)	0.84	16.40
Averages	0.78	13.42

Table IV. Concentrations of copper, chromium, nickel and vanadium in gravel-free sediment fractions, around the ARCO new causeway site, Prudhoe Bay. All concentrations are expressed in ppm on dry weight basis. Samples collected in summer 1975.

Sample No.	Cu	Cr	Ni	V
PDB 75-1	6	45	19	35
PDB 75-2	6	43	23	38
PDB 75-3	8	42	26	45
PDB 75-4	8	24	23	40
PDB 75-5	26	57	61	95
PDB 75-6	14	69	54	73
PDB 75-7	23	75	59	93
PDB 75-8	20	87	63	110
PDB 75-9	18	74	61	90
PDB 75-10	16	67	54	83
PDB 75-26	6	48	28	43
PDB 75-27	5	46	19	40
PDB 75-28	6	22	14	35
PDB 75-29	6	42	30	48
PDB 75-30	17	75	52	85
PDB 75-31	19	73	59	98
PDB 75-32	13	64	44	80
PDB 75-33	11	63	47	73
PDB 75-34	17	50	59	65
PDB 75-37	11	30	42	45
PDB 75-38	12	36	52	55
PDB 75-39	9	21	30	40
Gull Island (East)	12	34	47	68
Gull Island (West)	17	52	59	70
Gull Island (North)	18	49	59	55
Averages	13	52	43	64

Table V. Concentrations of phosphorus in gravel-free sediments collected at the ARCO new causeway site, Prudhoe Bay, in summer 1974 (PDB 74 series) and 1975 (PDB 75 series). All concentrations are expressed as weight percents on a dry weight basis.

Sample No.	PDB 74 Sample Series	PDB 75 Sample Series
1	0.034	0.063
2	0.065	0.066
4	0.070	0.066
5	-	0.060
6	0.091	0.056
7	0.125	0.088
8	0.223	0.097
9	0.331	0.084
10	0.097	0.072
15	0.210	-
16	0.079	-
17	0.078	-
18	0.190	-
19	0.083	-
20	0.244	-
21	0.080	-
22	0.056	-
23	0.079	-
24	0.060	-
25	0.050	-
26	0.075	0.044
27	0.072	0.053
28	0.044	0.044
29	0.128	0.066
30	0.091	0.079
31	0.122	0.081
32	0.080	0.079
33	0.115	0.060
34	0.081	0.084

Table V. (Continued)

Sample No.	PDB 74 Sample Series	PDB 75 Sample Series
37	0.154	0.066
38	0.101	0.058
39	0.122	0.072
41	0.141	–
43	0.103	–
Gull Island (East)	0.113	0.069
Gull Island (North)	0.097	0.078
Gull Island (West)	0.078	0.081
Averages	0.101	0.069

Table VI. Concentrations of phosphorus in gravel-free sediments collected from the Prudhoe Bay and adjacent shallow marine environment (Fig. 1). All concentrations are expressed on a dry weight basis. Samples collected in summer 1974.

Sample No.	Phosphorus %
70 BS-18	0.084
70 BS-19	0.075
70 BS-21	0.113
70 BS-22	0.091
71 AJT-5	0.078
71 AJT-16	0.091
71 AJT-18	0.109
71 AJT-19	0.081
71 AJT-20	0.098
71 AER-15	0.069
72 AJT-3	0.075
72 AJT-4	0.079
72 AJT-5	0.069
72 AJT-6	0.098
72 AJT-7	0.078
72 AJT-8	0.088
72 AER-20	0.059
72 AER-22	0.100
72 AER-23	0.090
72 AER-24	0.091
72 AER-25	0.100
72 AER-26	0.140
72 AER-129	0.094
72 AER-134	0.110
72 AER-137	0.091
72 AER-166	0.104
72 AER-167	0.075
72 AER-168	0.079
Average	0.090

Student 't' tests were conducted, in an attempt to determine if there had been any significant alterations in the mean concentrations of the analyzed chemical parameters of sediments, prior and subsequent to the causeway construction. Results of these tests are shown in Table VII, which suggest that there have been no significant changes in the analyzed components, with the exception of a relative increase in the organic carbon contents.

The variations in the concentrations of Ni in the 1975 series of sediment samples do not conform to the pattern of prediction established upon the basis of the Ni covariance with other sediment parameters in the baseline sediment samples collected in 1974, and the lithological changes identified in the 1975 sediment samples. Results from the study of 1974 sample series (Feder *et al.*, 1976a) suggested that any significant decrease in the overall mud, organic carbon, and carbonate contents in sediments in the causeway area would most probably also lead to a simultaneous decrease in the overall Ni concentrations in those sediments. However, as mentioned earlier, results on the 1975 sample series have been contrary to expectation, inasmuch as the mean concentrations of Ni in the above samples have not altered significantly although the contents of mud have decreased drastically and the mean concentrations of organic carbon have significantly increased (Table VII). The foregoing "discrepancy" most likely relates to sediment sampling errors, and possibly to conclusions drawn on limited statistical evaluations. During the summers of 1974 and 1975 single sediment samples were collected from each of the several stations established on a simple grid pattern. However, it would seem statistically more appropriate to obtain replicate sediment samples (a minimum of four) from at least one-third of the total number of stations occupied. The stations with multiple sample locations around them could then be considered as sampling cells. The mean, as well

Table VII. Differences in the average concentrations of organic carbon, carbonate, phosphorus, and some heavy metals in bottom sediments collected in the summers of 1974 and 1975 at the ARCO new causeway site. All concentrations are on a dry weight basis.

Chemical Component	1974 Samples	1975 Samples	Student 't' Test Results
Org. C (%)	0.36	0.78	Significant*
$CO_3^=$ (%)	13.67	12.91	Insignificant
P (%)	0.111	0.069	Insignificant
Cr (ppm)	50	53	Insignificant
Ni (ppm)	35	42	Insignificant
V (ppm)	52	64	Insignificant

*Differences significant at 95% confidence level.

as the standard deviations, on each of the textural and chemical parameters analyzed for the suite of replicate samples for the individual cells must then be determined. Such data obtained for one summer could then be compared with similar data collected during subsequent summers. Furthermore, the significance in the variance correlation between one parameter and another (e.g., organic carbon contents vs Ni contents, mud contents vs Ni contents, etc.) for the sample suites collected during any one summer, must be statistically checked by the calculation of correlation coefficients rather than depending on the semiquantitative method based on graphical determinations via scatterplots.

Some data are currently available on partition patterns of Cu, Cr, Ni, and V between the lithogenous (detrital, crystal lattice-held) and nonlithogenous (nondetrital, relatively more 'mobile' phase) sediment components (Chester and Hughes, 1967) of a few sediment samples collected during the summer of 1974 in the vicinity of the causeway site. These data have been gathered by Naidu (Burrell, 1976) under the auspices of a NOAA/OCS sponsored project. It would seem that on an average 19% of the Cu, 4% of the Cr, 6% of the Ni, and 13% of the V in the gross sediment are partitioned in the nonlithogenous phase.

As of this stage of study, it would seem that the observed significant increase in the mean concentrations of organic carbon in the 1975 sediment suite over that of the 1974 sediment suite (Table VII) most likely relates to a notable increase in the total benthic biomass (refer to Feder's chapter in this report).

REFERENCES

Biscaye, P. E. 1965. Mineralogy and sedimentation of recent deep-sea clays in the Atlantic and adjacent seas and oceans. *Geol. Soc. Am. Bull.* 76: 803-832.

Burrell, D. C. 1976. Natural distribution of trace heavy metals and environmental background in three Alaska shelf areas. Annual Report submitted to the NOAA-OCS Office, Boulder, Colorado. Inst. Mar. Sci., Univ. Alaska. 122 p.

Chester, R. and J. Hughes. 1967. A chemical technique for the separation of ferro-manganese minerals, carbonate minerals and adsorbed trace elements from pelagic sediments. *Chem. Geol.* 2:249-262.

Feder, H. M., D. G. Shaw and A. S. Naidu. 1976a. The nearshore marine environment in Prudhoe Bay, Alaska. *In* The Arctic Coastal Environment of Alaska, vol. 1. Inst. Mar. Sci., Univ. Alaska, Fairbanks, Report R76-1. 161 p.

Feder, H. M., D. G. Shaw and A. S. Naidu. 1976b. A compilation and review of scientific literature of the arctic marine environment. *In* The Arctic Coastal Environment of Alaska, vol. 2. Inst. Mar. Sci., Univ. Alaska, Fairbanks, Report R76-5. 201 p.

Flanagan, F. J. 1969. U.S. Geological Survey Standards-II. First compilation of data for the new U.S.G.S. rocks. *Geochim. et. Cosmochim. Acta* 33:81-120.

Folk, R. L. and W. C. Ward. 1957. Brazos River bar - a study in the significance of grain size parameters. *J. Sedimentary Petrology* 27:3-26.

Hülsemann, J. 1966. On the routine analysis of carbonates in unconsolidated sediments. *J. Sedimentary Petrology* 66:622-625.

Murphy, J. and J. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chem. Acta* 27: 31-36.

Naidu, A. S., D. C. Burrell and D. W. Hood. 1971. Clay mineral composition and geological significance of some Beaufort Sea sediments. *J. Sedimentary Petrology* 41:691-694.

Naidu, A. S. and D. W. Hood. 1972. Chemical composition of bottom sediments of the Beaufort Sea, Arctic Ocean. Proc. 24th Intn'l. Geol. Congress, Montreal, Canada 10:307-317.

Naidu, A. S. and T. C. Mowatt. 1975. Depositional environments and sediment characteristics of the Colville and adjacent deltas, northern arctic Alaska. *In: Deltas Models for Exploration*, M. L. S. Broussard, ed. Houston Geol. Soc., Houston, Texas. 283-309 pp.

Chapter II

HYDROCARBON STUDIES

E. R. Smith, G. W. Smith and D. G. Shaw

INTRODUCTION

This study continues work begun in 1974 to ascertain the effects of a gravel causeway that extends 4400 feet into Prudhoe Bay. The results of the 1974 sampling indicated that all the hydrocarbons in the biota and sediments of Prudhoe Bay were largely biogenic in origin.

Those samples were taken in August 1974, before the gravel causeway was built. The samples discussed here were collected in August 1975, after the causeway was already in place. This year's work, using more sensitive analytical methods, indicates that both petroleum and biogenic hydrocarbons are present in Prudhoe Bay sediments.

Objective

The objectives of the hydrocarbon portion of this project have been to survey the kinds and amounts of hydrocarbons present in the sediments and biota of Prudhoe Bay and adjacent waters, and to indicate any changes that have occurred since the 1974 study was conducted.

Sampling

Sampling at Prudhoe Bay was conducted during August, 1975 at the same stations where 1974 samples were collected. Sediments were collected along transects on either side of the causeway, and along one shorter transect about a mile to the northwest of the causeway. Also, two new stations were sampled at the causeway site. The two stations are located on shore about 500 feet on either side of the causeway and about 200 feet landward of the shoreline. Both of these samples contained plant material as well as sediment. Location of sampling stations is shown in Table I. Sediment was

Table I. Sample locations - hydrocarbons, sediment, biota

Station	
1	1000 feet SE of causeway, onshore
2	1000 feet SE of causeway, 500 feet from shore
4	1000 feet SE of causeway, 1500 feet from shore
6	1000 feet SE of causeway, 2500 feet from shore
8	1000 feet SE of causeway, 3500 feet from shore
10	1000 feet SE of causeway, 4500 feet from shore
25	1000 feet NW of causeway, onshore
26	1000 feet NW of causeway, 500 feet from shore
28	1000 feet NW of causeway, 1500 feet from shore
30	1000 feet NW of causeway, 2500 feet from shore
32	1000 feet NW of causeway, 3500 feet from shore
34	1000 feet NW of causeway, 4500 feet from shore
37	1 mi NW of causeway, 1500 feet from shore
38	1 mi NW of causeway, 2500 feet from shore
39	1 mi NW of causeway, 3500 feet from shore

also collected on the east and west sides of the south spit of Gull Island. Fishes were collected at the west tip of the new causeway by gill net. Only the tail portions of the fish were saved (frozen).

Sediment was collected by divers. The diver was handed a pre-cleaned glass jar which he filled directly at the bottom. The jar was returned to the boat and recapped. Ashore, the jar was frozen until analysis. At two sampling stations, two samples were taken. These samples were analysed separately so that the variability at a given point could be measured. The sediments collected were generally muddy and contained material which appeared to be tundra fragments.

SAMPLE ANALYSIS

Materials

All solvents were redistilled in glass 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 extracting three times with 100 ml of hexane. The hexane extract was concentrated *in vacuo* to 1.0 ml and analysed by GC. The 1N KOH in methanol was also checked in this manner.

All analyses were done on chromatographs with dual column flame ionization detectors. However, two different instruments were used; a Varian 1520 B for the sediment samples and a Hewlett-Packard 5710A for the fish samples. All chromatograms were temperature programmed. Those on the Varian were programmed to run from 60°C to 290°C at 15°C/min. The H-P was programmed to hold the column isothermal at 80°C for two minutes, then approach 280°C at 8°C/min, and hold the temperature at 280°C for 16 min. Columns were 1/8" by 12' stainless steel packed with 3% OV-101 on 100-120 mesh AW-DMCS Chromosorb W.

All saponifications were done in 500 ml flat bottom flasks and 10" reflux condensers. Glassware was precleaned with acetone and hexane prior to use. Dissection apparatus and other metal which came in contact with samples was flamed prior to use. A blank to check for solvent purity and accidental contamination was run with each set of five samples.

Sediment Procedure

After sediment samples were thawed, 70-80 grams of wet sediment was weighed directly into a 500 ml flat bottomed boiling flask to which 100 ml methanol, 100 ml of 1N KOH in methanol and 50 ml H_2O were added. The mixture was refluxed for two hours with continuous stirring, using a teflon coated magnetic stirring bar. At the end of that time, pH of the solution was checked to make sure it was >10 and the solution was allowed to cool.

The methanolic mixture was extracted three times with 100 ml hexane. The hexane used for each extraction was poured into the sediment and shaken well before being poured into the separatory funnel. The combined hexane extracts were extracted once with 150 ml saturated aqueous NaCl solution and allowed to dry over anhydrous Na_2SO_4 overnight.

The dry hexane extracts were concentrated *in vacuo* to exactly 10 ml and a 100 μl aliquot dried and weighed on an electrobalance. The weight of lipid in the aliquot was used to determine how much sample to use in liquid chromatography.

Silica gel was activated at 120°C for 24 hours and deactivated with 5% H_2O. Alumina was activated at 250°C for 24 hours and deactivated with 6% H_2O. Hexane washed, oven dried glass wool was used to plug a 25 ml buret. This was rinsed with hexane immediately before building the column. The column was built of 5 ml alumina over 10 ml silica gel poured in a hexane slurry. This made a column of 11 mm x 17 cm with a pore volume of approximately 5 ml. It was flushed with at least one pore volume of hexane prior to use. Using a portion, or all of the sample, this column was loaded with 2 mg of lipid in < 1 ml hexane. The column packing: lipid weight ratio was 1000:1. (For samples with a higher lipid content, a larger column was used, maintaining that ratio.) Two eluate fractions were collected separately; 20 ml of hexane, and 20 ml of benzene. The two fractions were concentrated *in vacuo* to 1 ml, then transferred to tared glass vials. They were further concentrated under a stream of dry nitrogen to < 1 ml, then weighed and the volume of solvent determined from the density of hexane (.660 g/ml) or benzene (.879 g/ml).

Analysis was then performed by GC. Quantification was done by planimetry using an external standard procedure wherein the area under the curve samples. Only solvents which demonstrated little or no evidence of contamination by this method were used.

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Analysis was then performed by GC. Quantification was done by planimetry using an external standard procedure wherein the area under the curve for a sample is compared to the area under the curve of a standard of known concentration. Efficiency of the procedure is measured regularly by measuring the recovery of an added spike. This factor is taken into account and used in quantitation. The final concentration of hydrocarbons is based on wet weight of the sediment extracted.

One sediment sample was subjected to further GC analysis on a 0.7 mm by 50 m OV 101-support coated open tubular (SCOT) column. Other samples were analysed by a Hewlett-Packard 5930/5933 gas chromatograph-mass spectrometer (GC-MS) system.

Biological Procedure

Samples were thawed at room temperature and about 50 g cut into small pieces with scissors. The fish was weighed and then macerated with 100 ml methanol in a Virtis homogenizer for approximately three minutes. The homogenate was poured into a 500 ml flat bottomed flask, 100 ml KOH methanol and 50 ml H_2O was added. The mixture was refluxed for two hours and then the pH was checked to make sure it was greater than 10.

The samples were prepared for GC analysis in the same manner as the sediment samples. GC analysis and quantification were performed in the same manner also. Final hydrocarbon concentrations are based on the wet weight of the fish extracted. Three samples were analysed by a Hewlett-Packard 5930/5933 GC-MS system.

RESULTS AND DISCUSSION

Weights of hydrocarbons extracted from the sediments are presented in Table II. The chromatograms of all the hexane fractions of the sediments are in Appendix A. Mass spectroscopy of the benzene fractions indicated that the main constituents are methyl esters, results of incomplete saponification. This means that neither the weights of hydrocarbons calculated for these fractions nor their chromatograms are indicative of the aromatic content of the sediments. Therefore, the chromatograms for the benzene fractions are not included in this report. In addition, four samples of sediment collected in 1974 were re-analysed, as the method used in 1975 was so different that comparison with 1974 results was not possible.

The sediments collected from the bay itself were generally sandy to muddy; the sediments collected on the beach near the causeway were sandy

Table II. Hydrocarbons in Prudhoe Bay sediments, expressed in mg/kg based on wet weight of sediment.

Station Number	Hydrocarbon content Hexane Fraction	Benzene Fraction
1	12.5	21.1
2	1.6	3.6
4-1	2.7	2.0
4-2	3.6	7.4
6	5.3	8.1
10	7.3	11.1
25	32.7	39.8
26	5.4	10.6
28-1	0.9	1.1
28-2	2.2	0.7
30	12.8	7.0
32	12.9	5.7
34	10.2	7.8
37	3.4	3.6
38	2.2	1.3
39	1.1	1.6
Gull Is. S. Spit-East	12.2	10.5
Gull Is. S. Spit-West	10.2	10.5
2 (1974)	4.4	5.5
37 (1974)	3.6	10.5
38 (1974)	1.8	0.9
39 (1974)	0.7	1.3

and contained tundra plants. The tundra was collected to determine how much, if any, of the hydrocarbons found in the sediments could be attributed to the tundra fragments in them. The sediments collected at Gull Island were sandy.

Upon examination of the chromatograms, two trends are evident. The beach stations, numbers 1 and 25, show a regular series of normal hydrocarbons starting at n-C_{14} and continuing to n-C_{32} with a general dominance of odd chain lengths. These two stations show no sign of phytane, which indicates that this series is biogenic rather than of petroleum origin. Another sign that this is not petroleum is the absence of the large unresolved envelope which is typical of crude oil.

The stations sampled around the causeway show the same regular series of normal hydrocarbons with a predominance of odd chain lengths. However, the amount of hydrocarbons in these sediments is less than the beach sediments. There is an unresolved envelope in some of the chromatograms, and there are indications of pristane and phytane eluting immediately after n-C_{17} and n-C_{18}, respectively. The presence of phytane in a concentration comparable to pristane is rare in biogenic hydrocarbons, but is typical of petroleum and is found in Prudhoe Bay crude oil. The Gull Island stations are very similar to the bay stations, but the concentrations of hydrocarbons present are higher.

GC-MS analysis of the hexane eluate of column chromatography of Gull Island sediment indicates that all major GC peaks are hydrocarbons. This is not true for the benzene eluate from this sample. GC-MS shows that the major peaks in this eulate are methyl esters. This indicates that the two-hour saponification time used is insufficient for complete ester removal. GC-MS of the benzene eluate using single ion monitoring

(SIM) shows the presence of two, three, four, and five ring condensed aromatics and their alkyl derivatives. This data and analogous data for Prudhoe Bay crude oil which had been subjected to the same column chromatographic separation are shown on Table III. The GC retention times of the molecules listed are the same for both the sediment and crude and are reasonable for the structures suggested. The same SIM analysis, when performed of the blank extraction which had been run with the sediment sample from Gull Island, showed only three ring aromatics in minor amounts compared with the sediment extract and the crude.

Chromatograms of the sediments collected in 1974 and reanalysed this year show the same features as those collected in the same places in 1975. The concentrations are similar.

Table IV presents the weights of hydrocarbons found in the fish collected in Prudhoe Bay. The chromatograms for all the hexane fractions of these samples can be found in Appendix B. All of the species analysed are highly mobile and probably spend considerable time outside Prudhoe Bay itself. As with the sediments, the benzene fractions are not presented because of their predominance of methyl esters.

Three individuals of *Salvelinus alpinus* (Arctic char) were analysed. The gas chromatograms of the hexane eluate show very small concentrations of hydrocarbons with short chains, and one major peak eluting at a retention time that suggests that it is pristane. Further analysis by GC-MS positively identified this peak as pristane. Phytane is not present. Nonadecane is not present in a significant amount in any of the chromatograms, which is a change from the 1974 sample, in which it was present as a large peak. The pattern of the chromatograms is different than that in 1974, also.

Table III. Aromatic hydrocarbons found in Prudhoe Bay sediments and crude oil.

Mass	Consistent structure	Percent of aromatics In sediment	In crude
129	Naphthalene	1.4	9.2
143	Naphthalene + CH_2	11.2	25.8
157	Naphthalene + C_2H_4	20.2	30.5
171	Naphthalene + C_3H_6	19.5	19.2
179	Anthracene or phenanthrene	8.3	2.5
193	Anthracene or phenanthrene + CH_2	14.6	5.1
207	Anthracene or phenanthrene + C_2H_4	8.8	4.8
221	Anthracene or phenanthrene + C_3H_6	4.9	2.4
229	Naphthacene or isomer	1.8	0.2
243	Naphthacene or isomer	2.1	0.3
253	Perylene or isomer	7.3	0

Table IV. Hydrocarbons in Prudhoe Bay fish expressed in mg/kg based on wet weight of animal.

Sample	Hydrocarbon content Hexane fraction	Benzene fraction
Arctic char (6)	7.3	105.2
Arctic char (7)	3.6	18.1
Arctic char (12)	10.0	235.1
Arctic cisco (3)	1.9	1.2
Arctic cisco (9)	3.8	122.2
Arctic cisco (10)	4.0	38.4
Arctic cisco (11)	5.8	51.0
Least cisco (1)	2.6	13.8
Least cisco (2)	.9	.5
Least cisco (5)	2.4	20.4
Least cisco (8)	7.1	2.6

Four individuals of the species *Coregonus autumnalis* (Arctic cisco) were analysed. Pristane is present in these samples, phytane is absent. The concentrations of hydrocarbons are similar to those of the Arctic char, as is the pattern in the chromatogram. But again, the pattern differs widely from what was observed in 1974.

Four individuals of the species *Coregonus sardinella* (Least cisco) were analysed. No Least cisco were collected in 1974. The chromatograms for all four individuals are quite similar, but not identical. Pristane is present; phytane is absent.

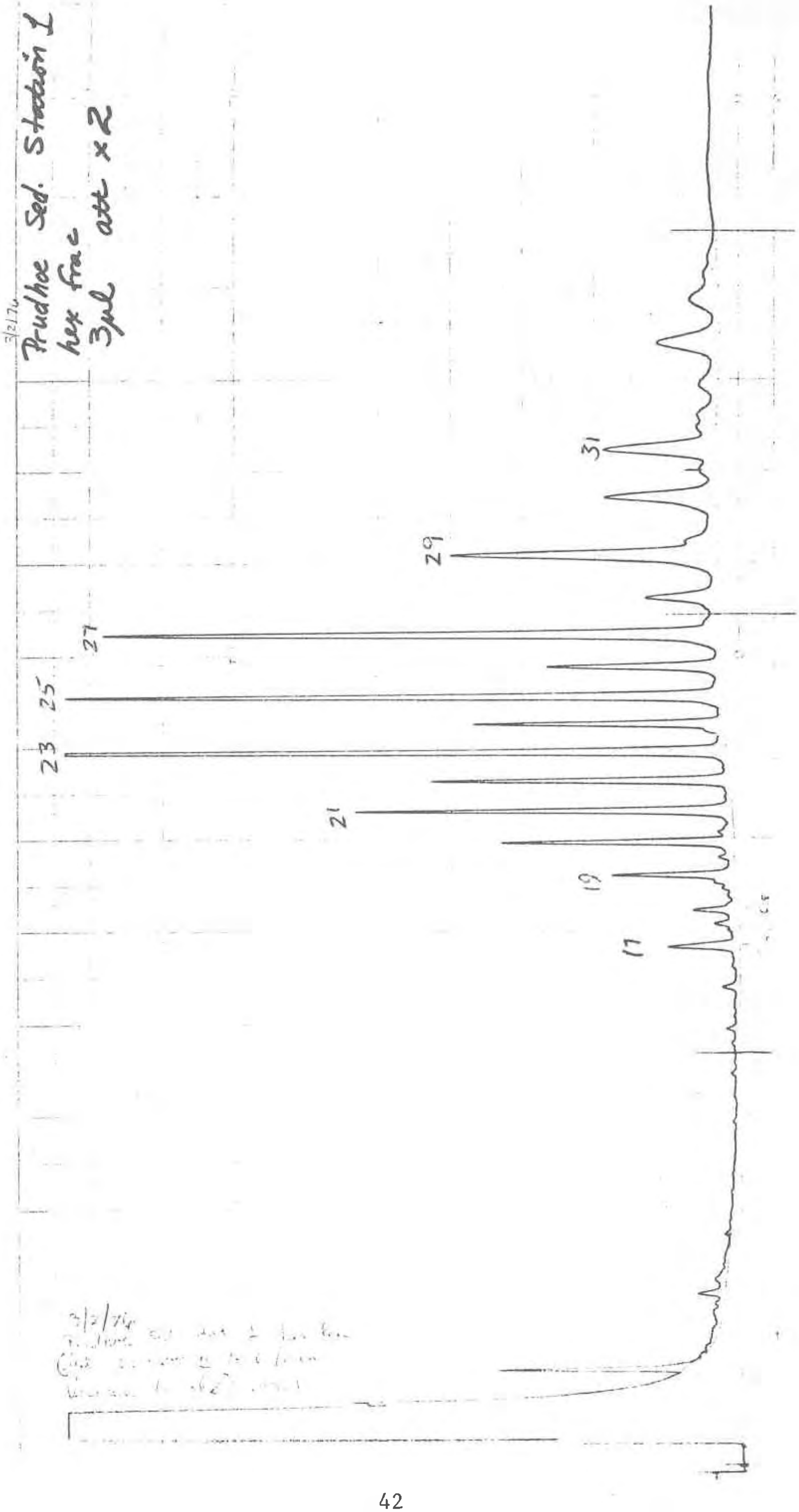
CONCLUSIONS

Based on these results and the recognized differences between petroleum and biogenic hydrocarbons, we conclude that the marine sediments collected during 1974 and 1975 contain both petroleum and biogenic hydrocarbons largely of tundra origin at roughly comparable concentrations. Petroleum is indicated by the presence of all normal hydrocarbons from at least tetradecane to triacontane and by the presence of phytane and aromatic compounds. That biogenic hydrocarbons are also present is indicated by the predominance of odd chain lengths among the normal alkanes. Where data for both 1974 and 1975 are available, no trend of increase or decrease in hydrocarbon concentration is evident.

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

APPENDIX A

Chromatograms of Hexane Fractions of Sediments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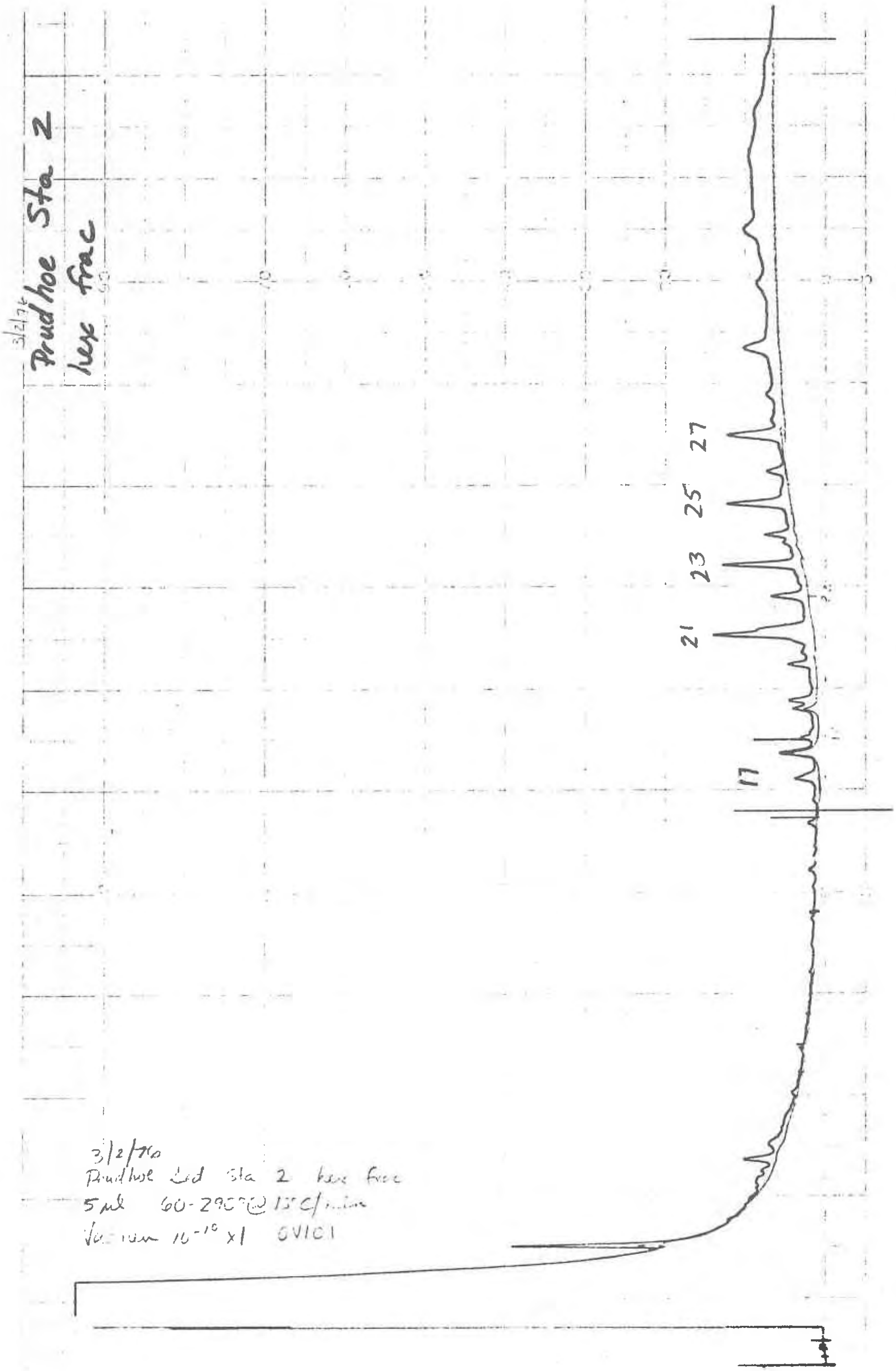
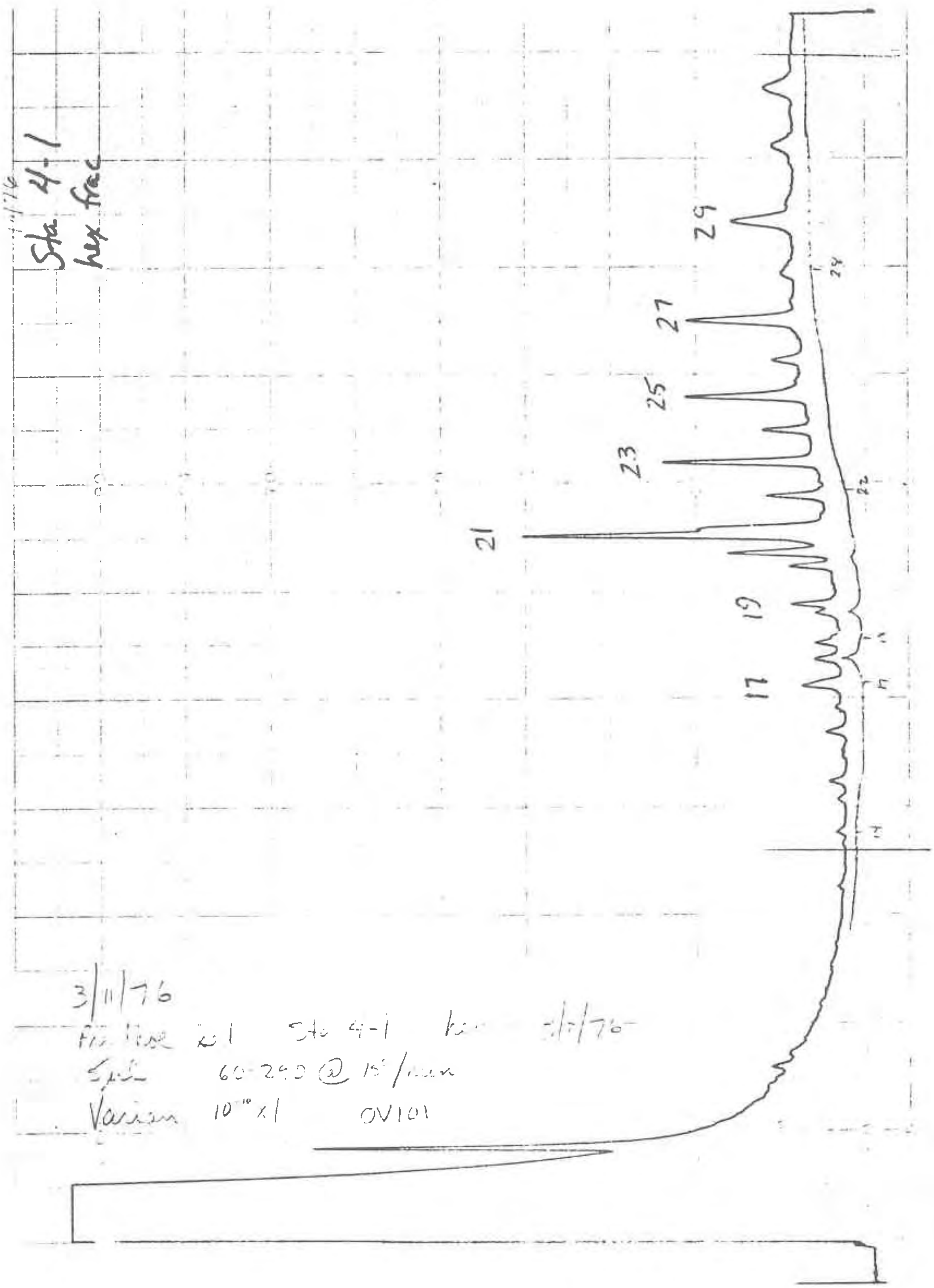
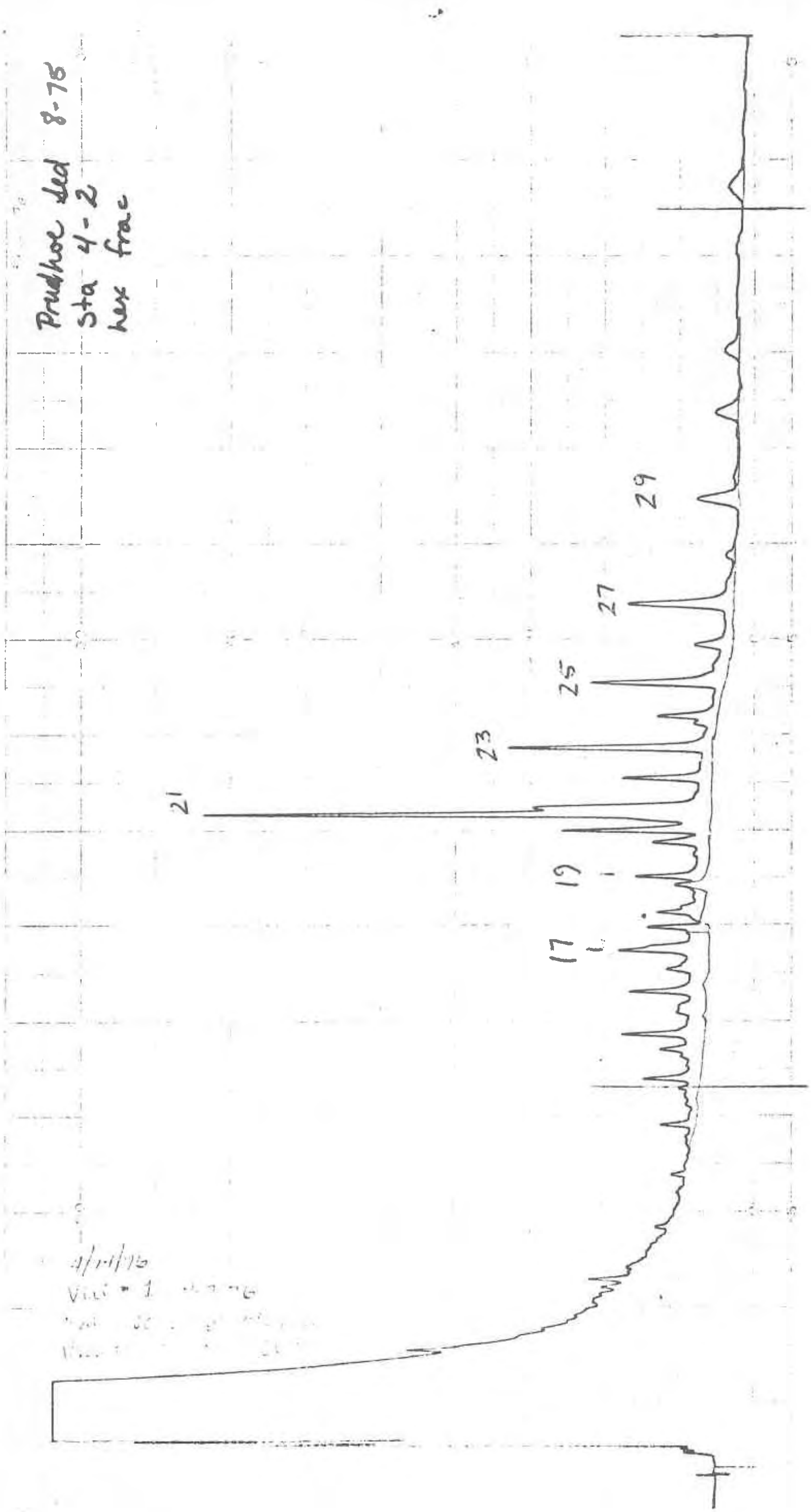
3µl att ×2
17
19
21
23
25
27
29
31



Prudhoe Sta 2
hex frac
17
21
23
25
27
3/2/76


Sta 4-1
hex frac
17
19
21
23
25
27
29
3/11/76
OV101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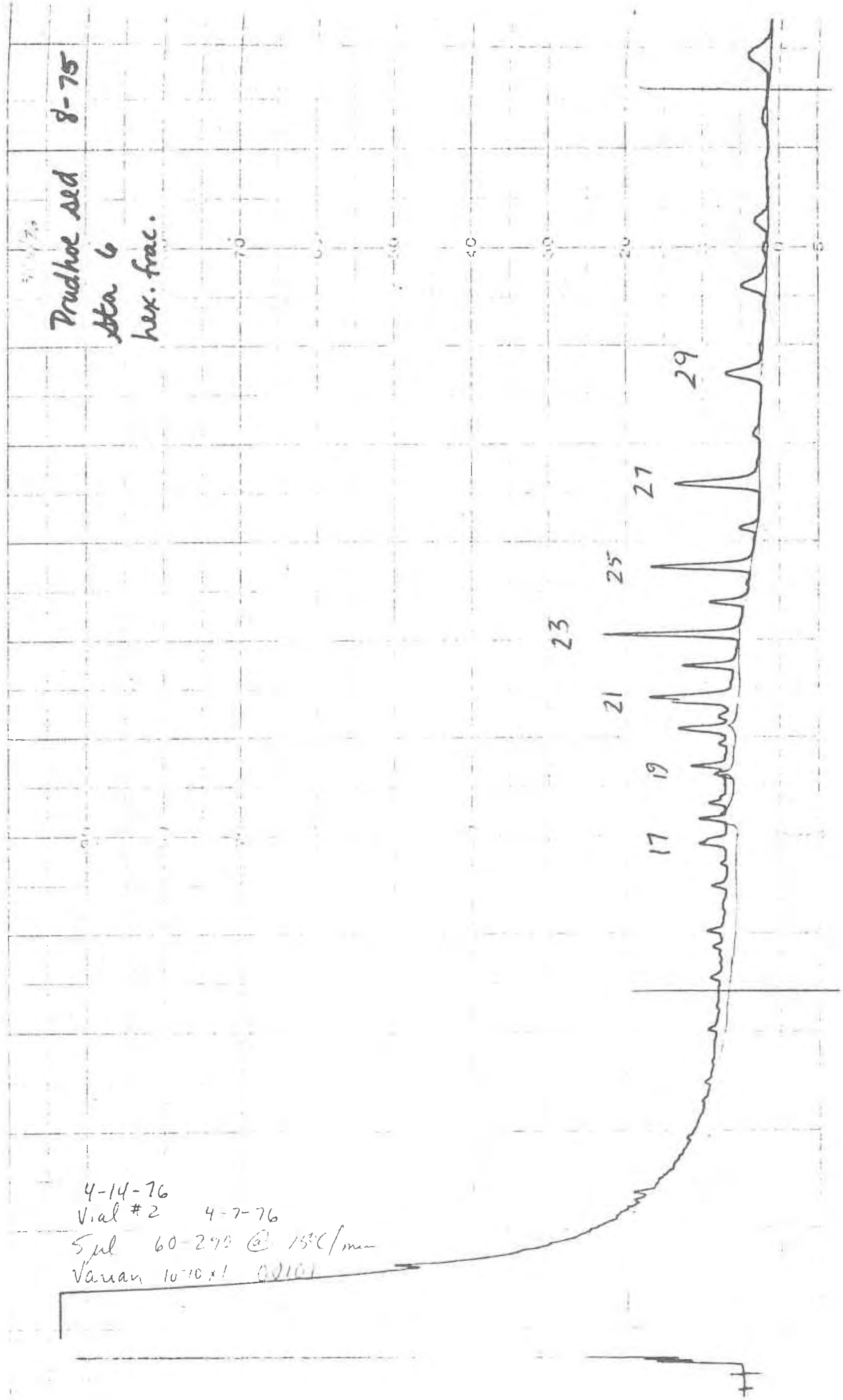
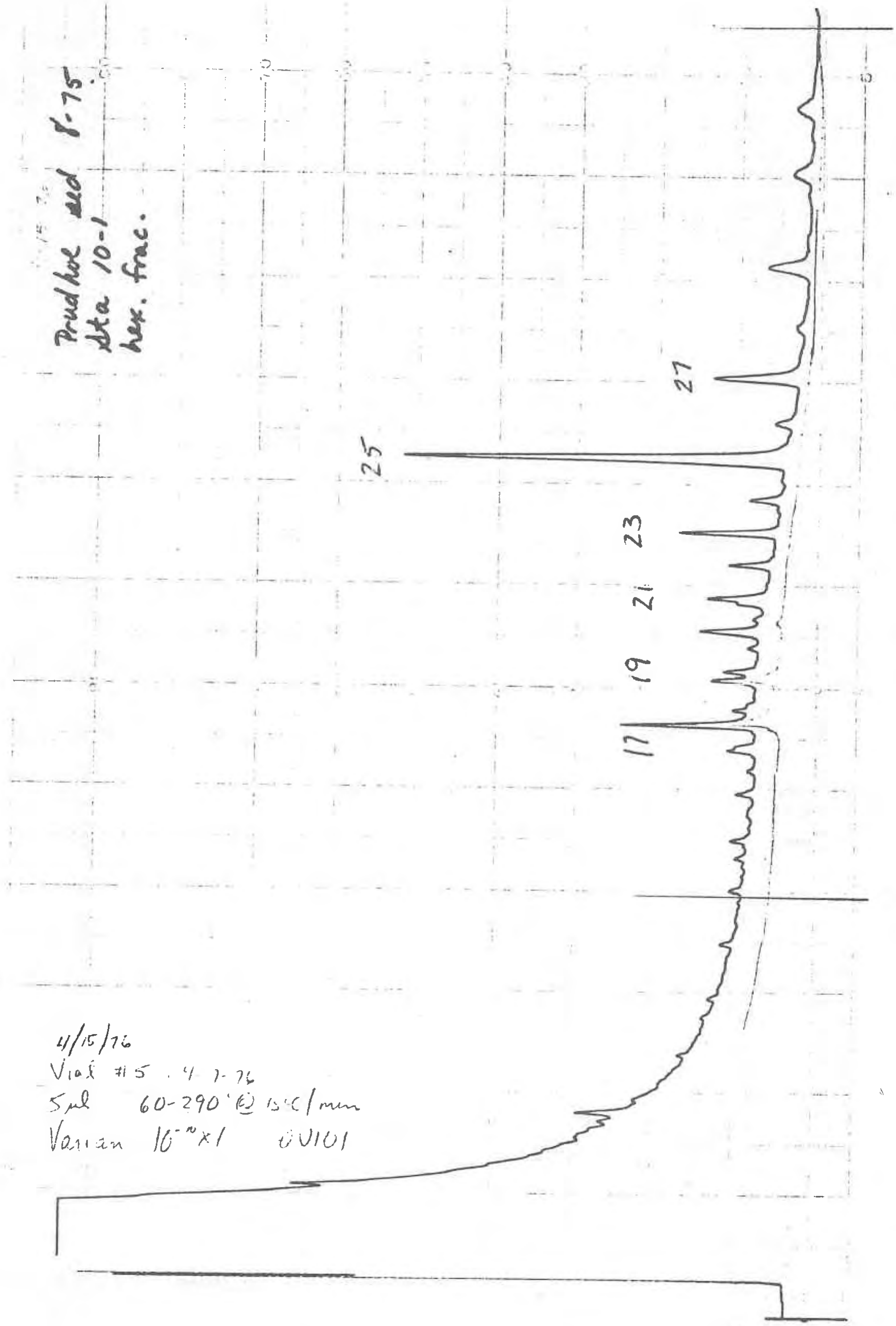
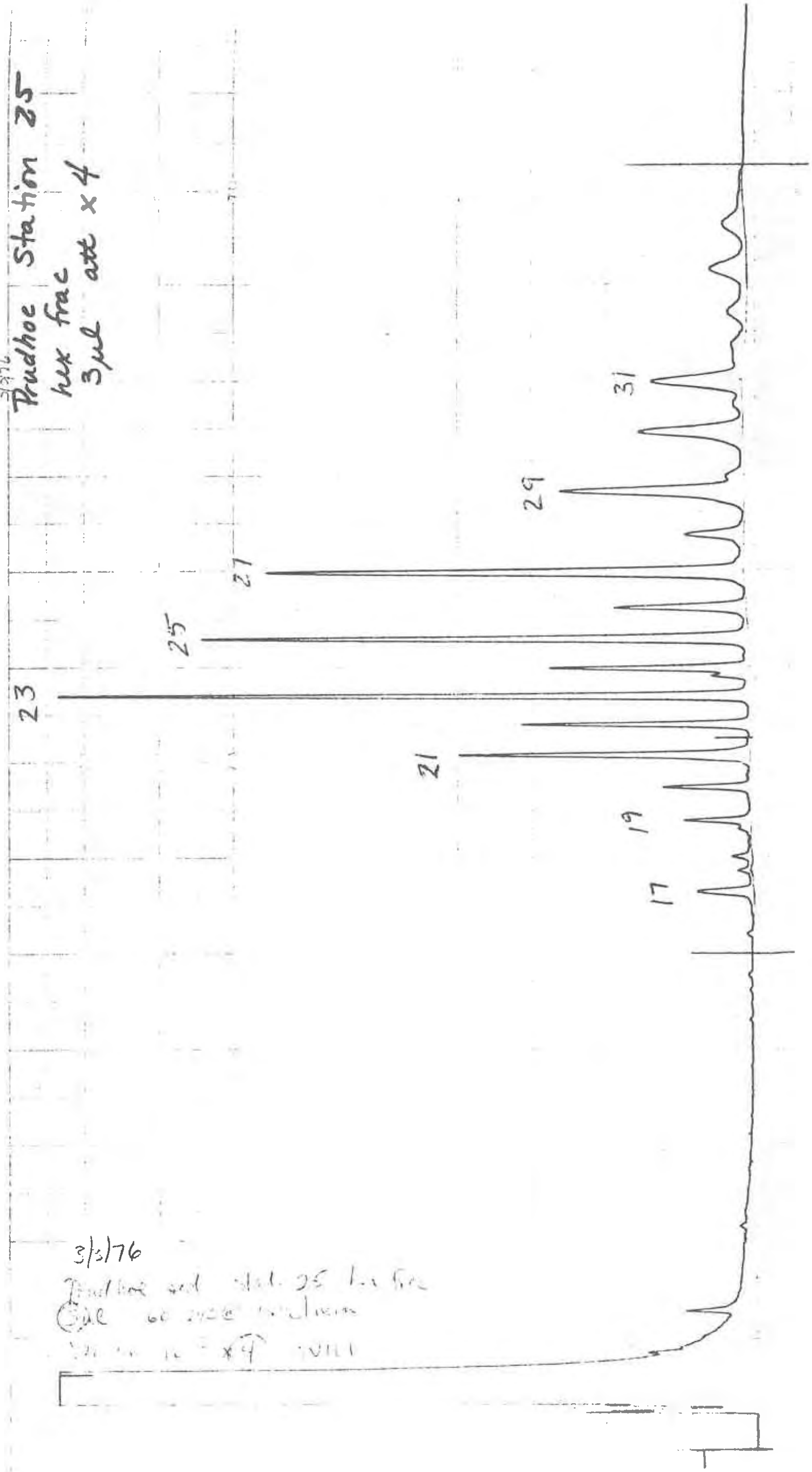
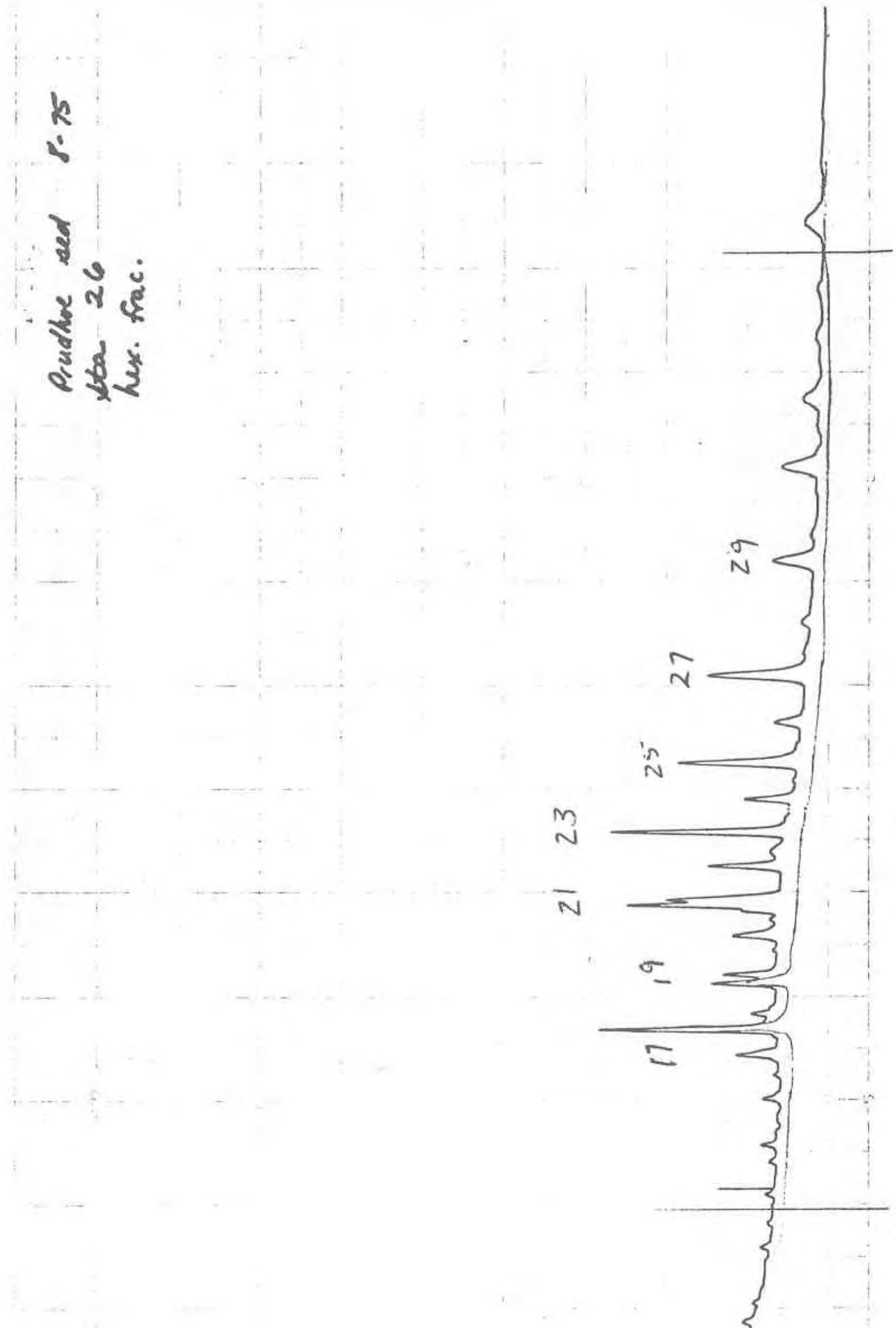
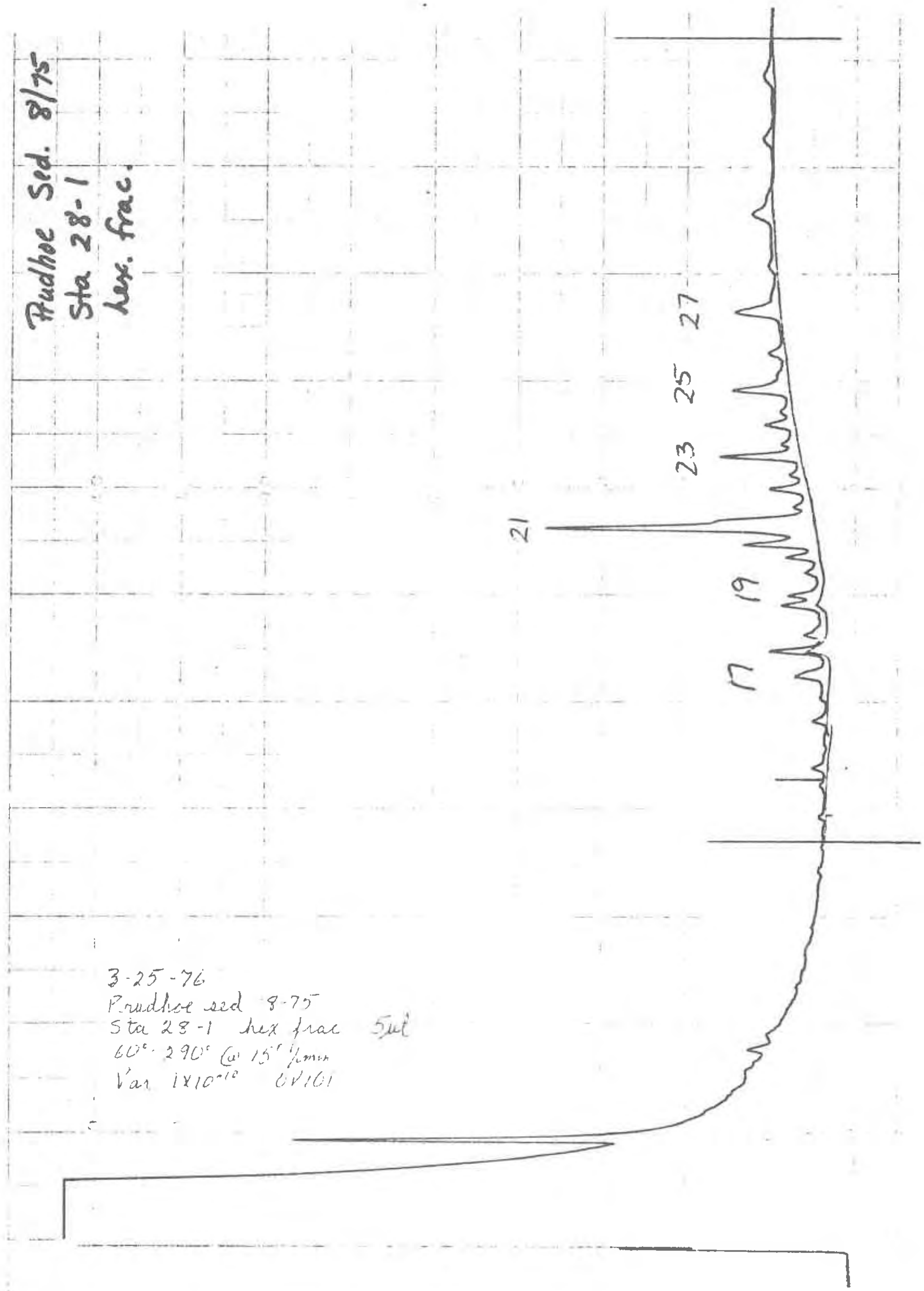
Sta 4-2
hex frac
17
19
21
23
25
27
29

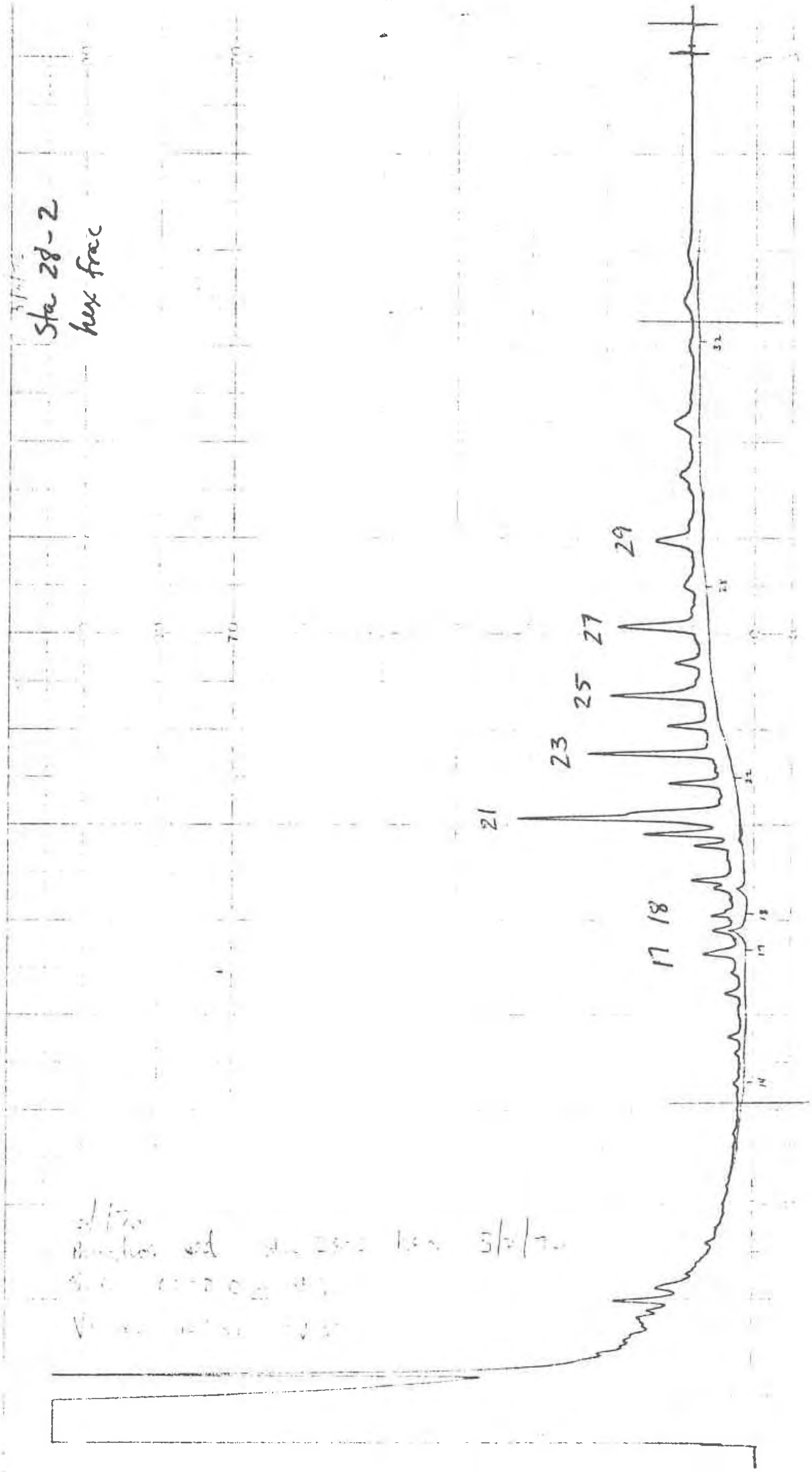

Prudhoe sed 8-75
Sta 6
hex. frac.
17
19
21
23
25
27
29
4-14-76
Vial #2 4-7-76

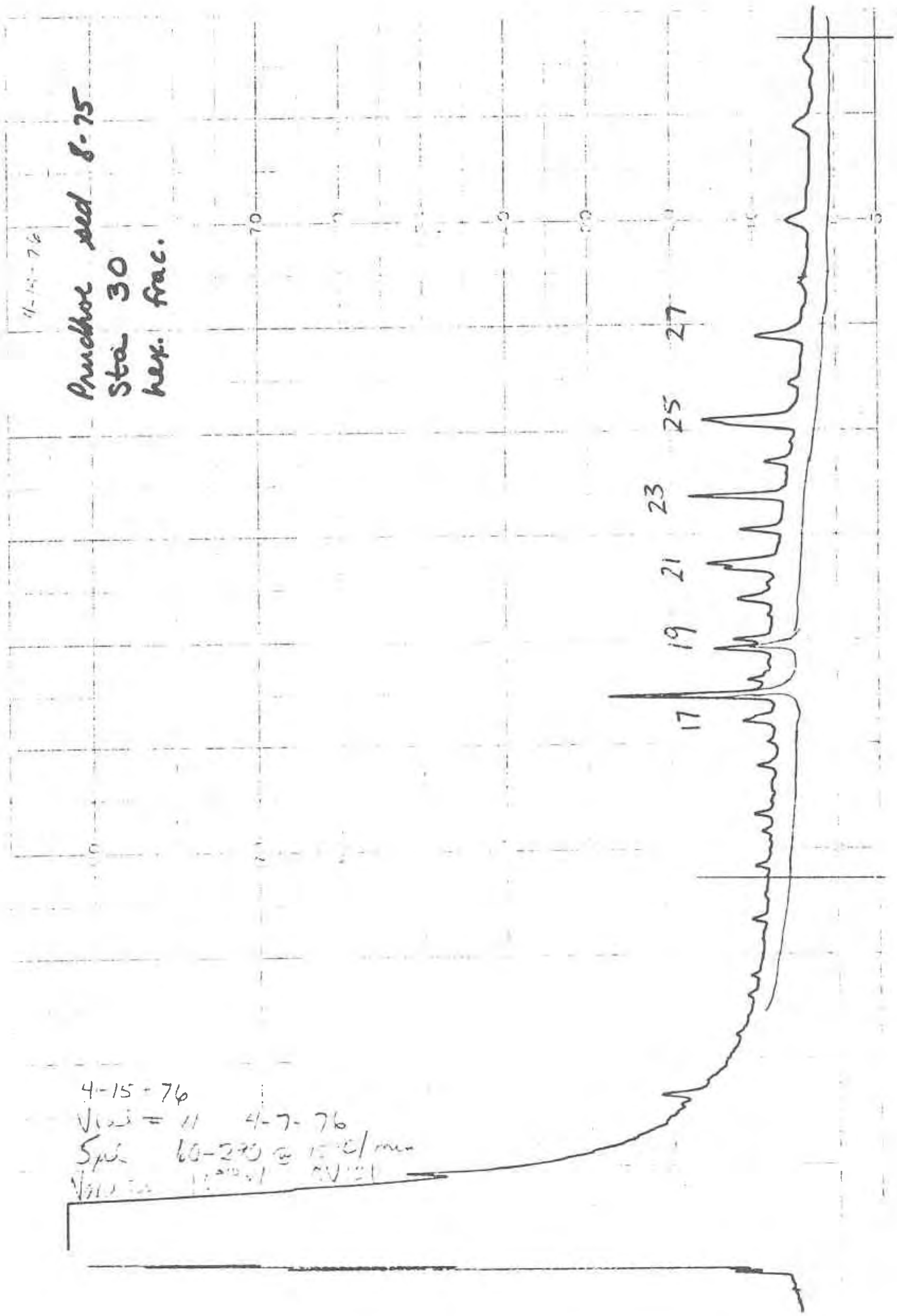

Prudhoe sed 8-75
Sta 10-1
hex. frac.
25
27
23
21
19
17
4/15/76

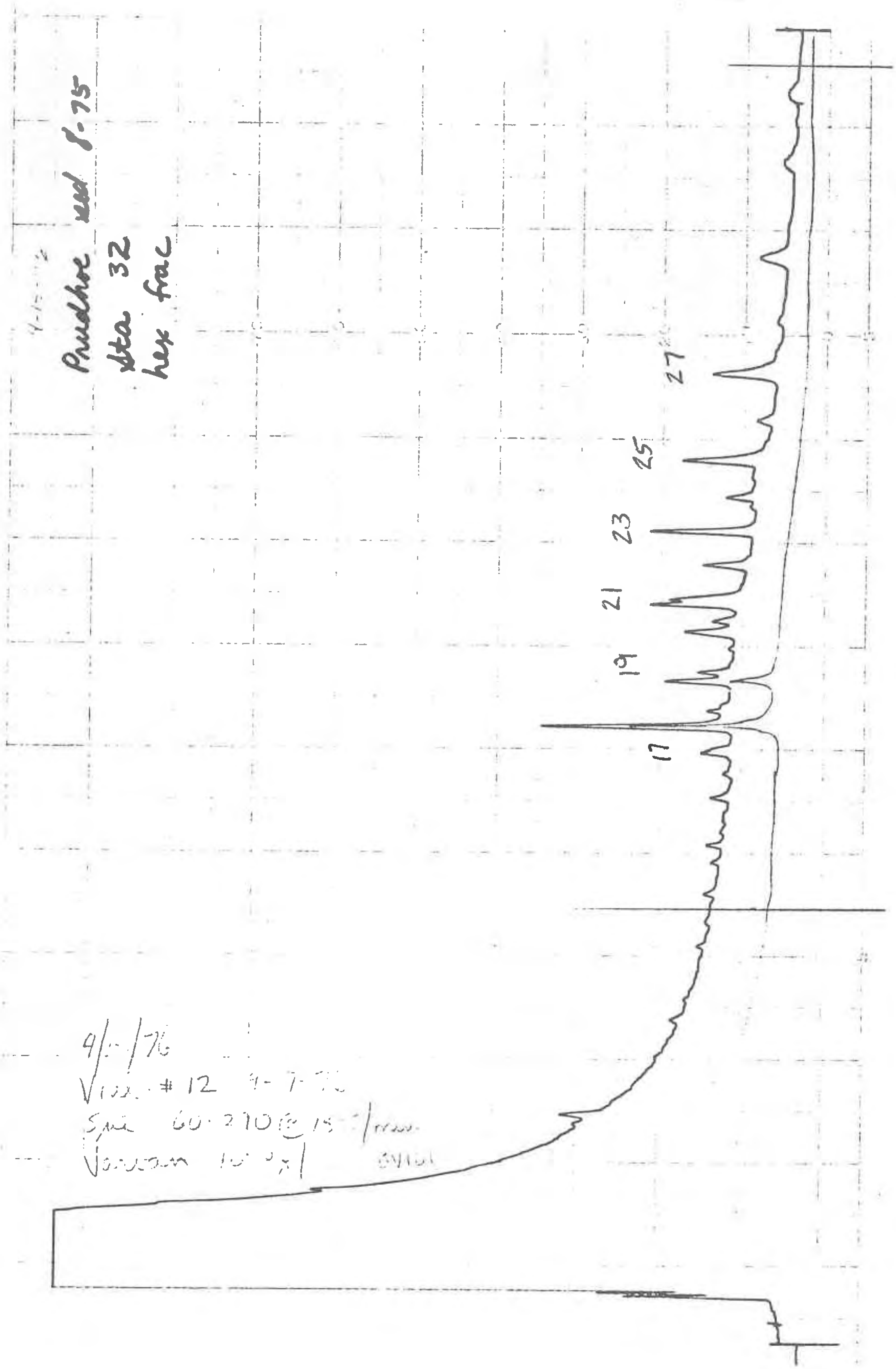

Prudhoe Station 25
hex frac
3μl att ×4
3/3/76
17
19
21
23
25
27
29
31

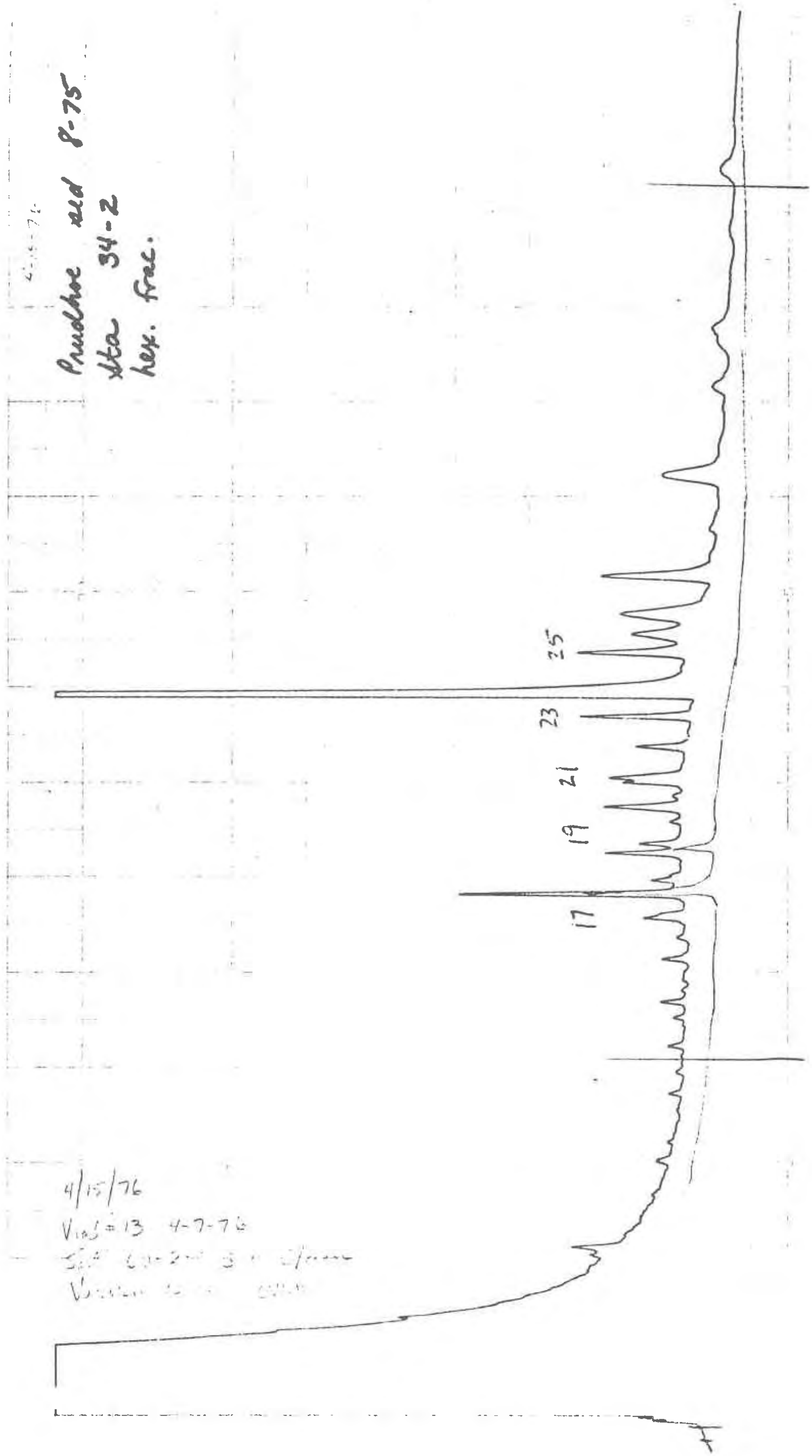

Prudhoe sed 8-75
sta 26
hex. frac.
17
19
21
23
25
27
29

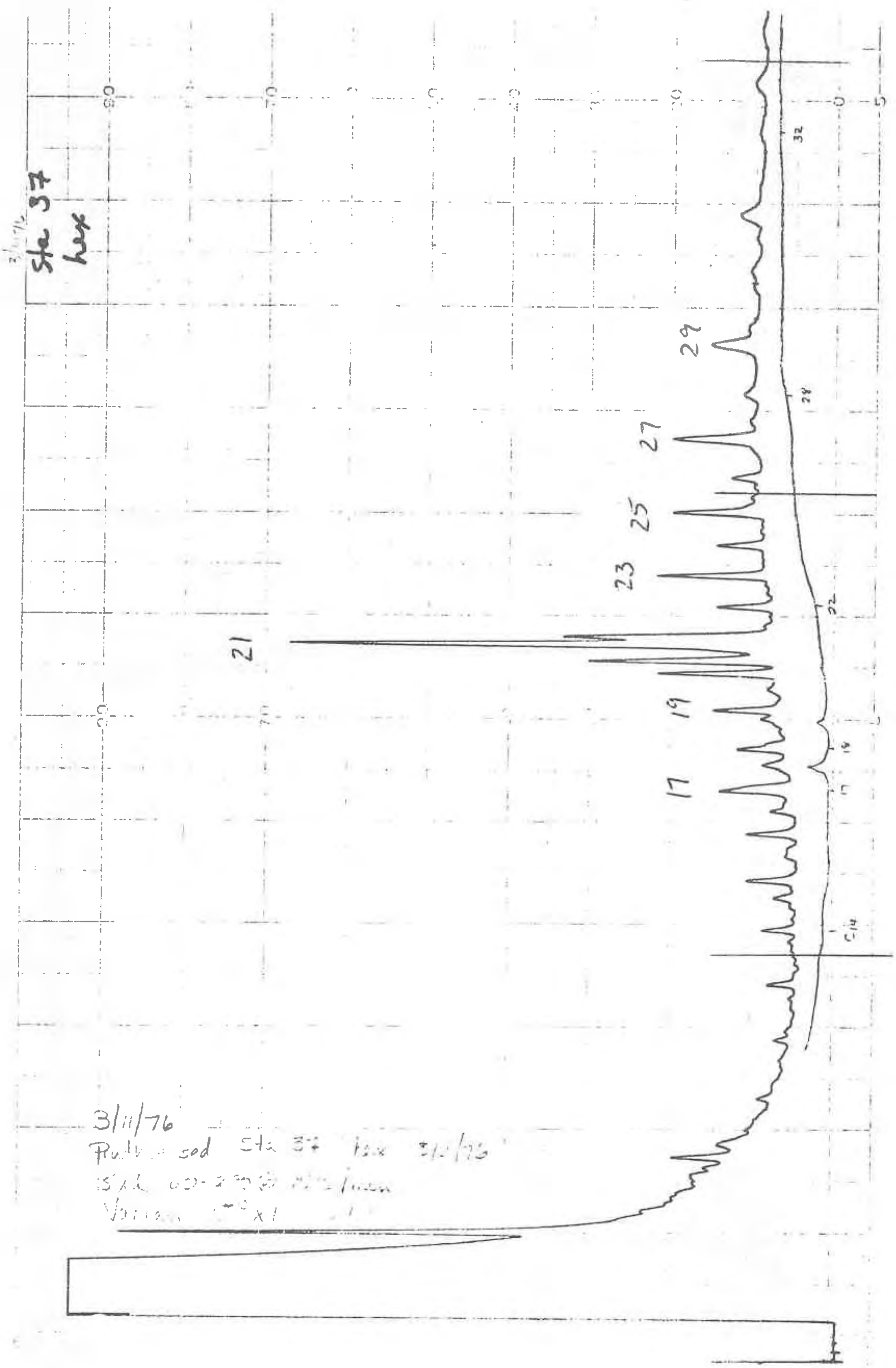

Prudhoe Sed. 8/75
Sta 28-1
hex. frac.
27
25
23
21
19
17
3-25-76
Prudhoe sed 8-75
Sta 28-1 hex frac 5µl
60°-290° @ 15°/min
Var 1x10-10 OV101

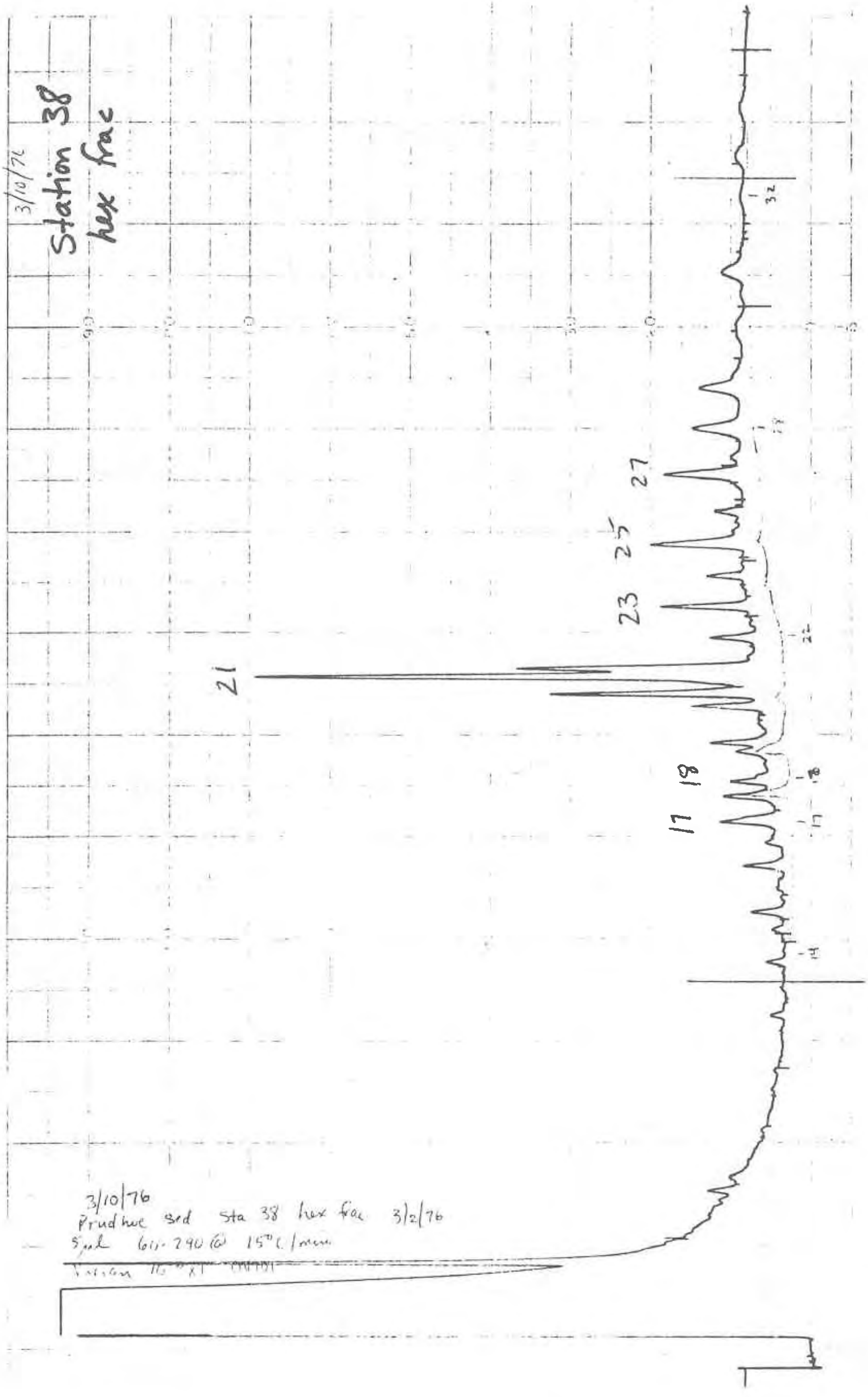

Sta 28-2
hex frac
17
18
21
23
25
27
29

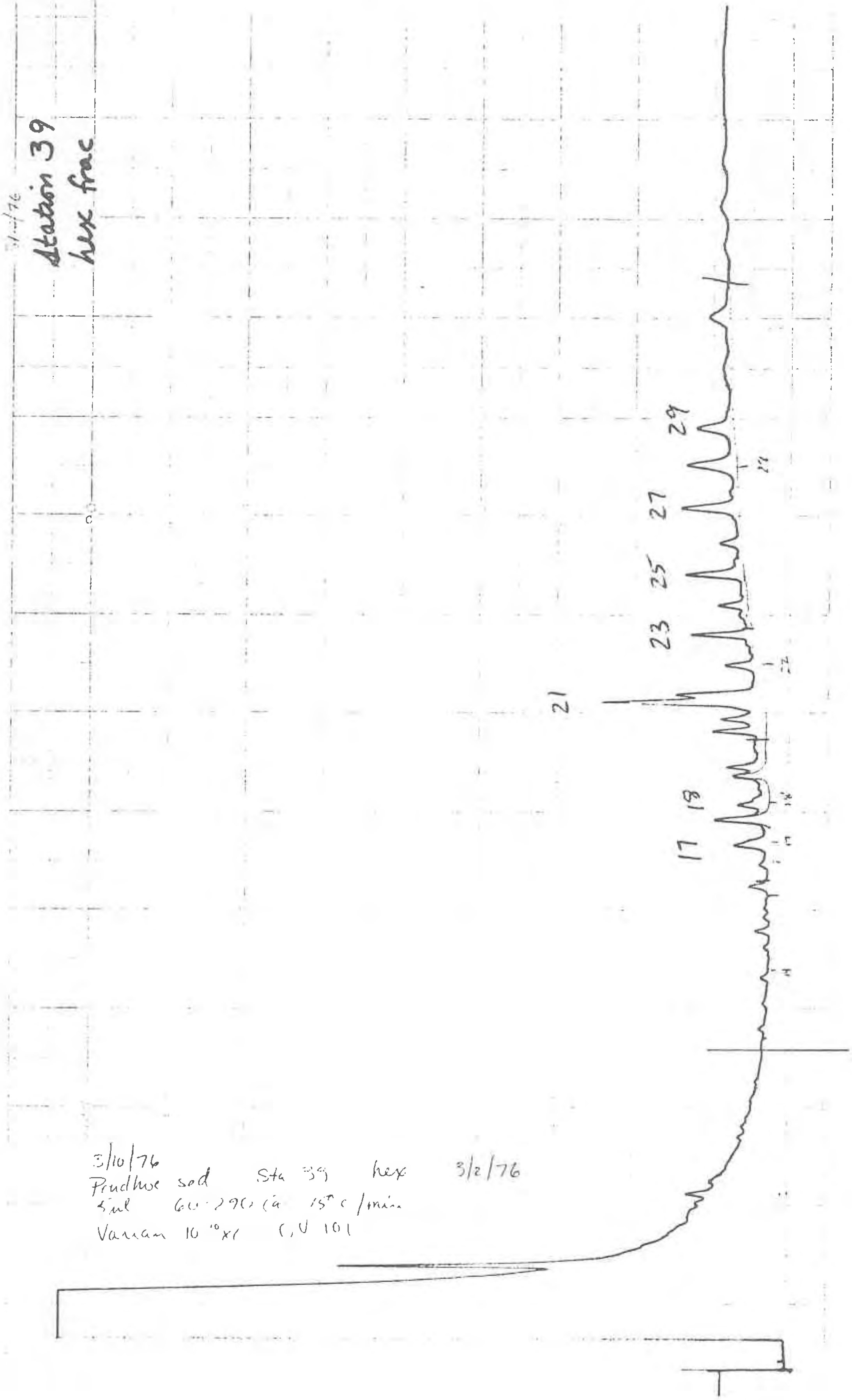

Prudhoe sed 8-75
Sta 30
hex. frac.
17
19
21
23
25
27
4-15-76

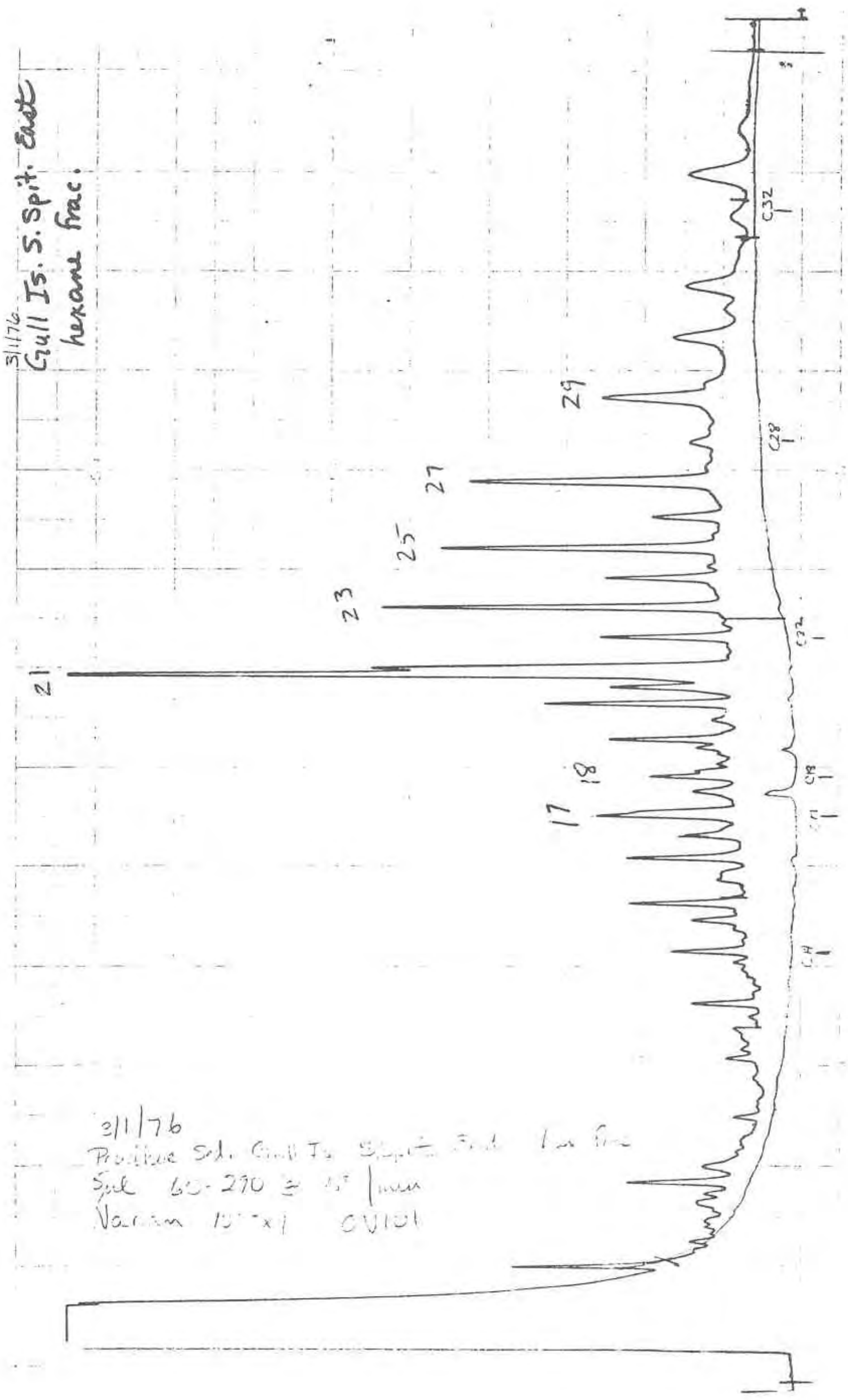

Prudhoe sed 8-75
Sta 32
hex frac
17
19
21
23
25
27

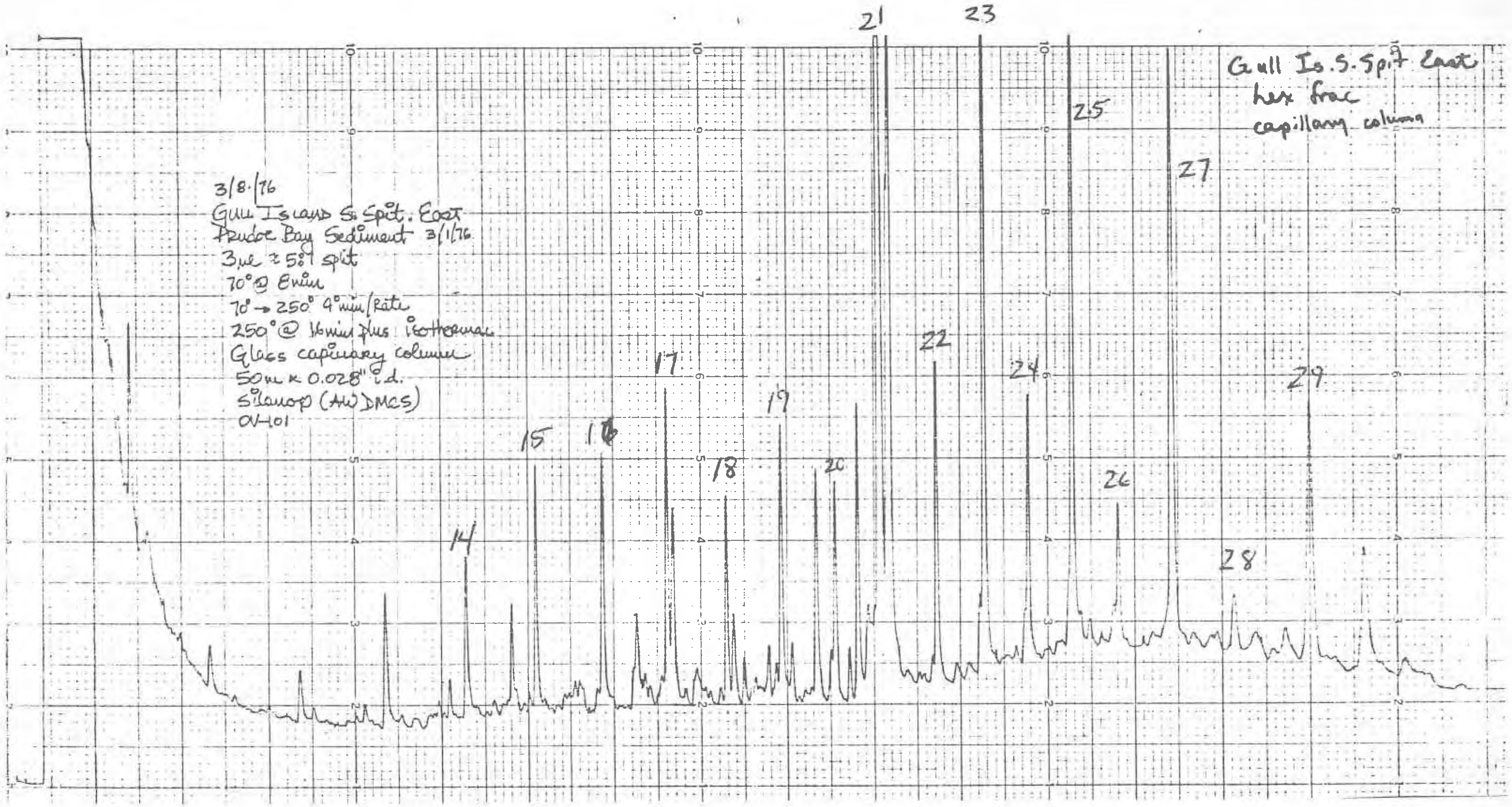

Prudhoe sed 8-75
Sta 34-2
hex. frac.
17
19
21
23
25
4/15/76
Vial # 13 4-7-76

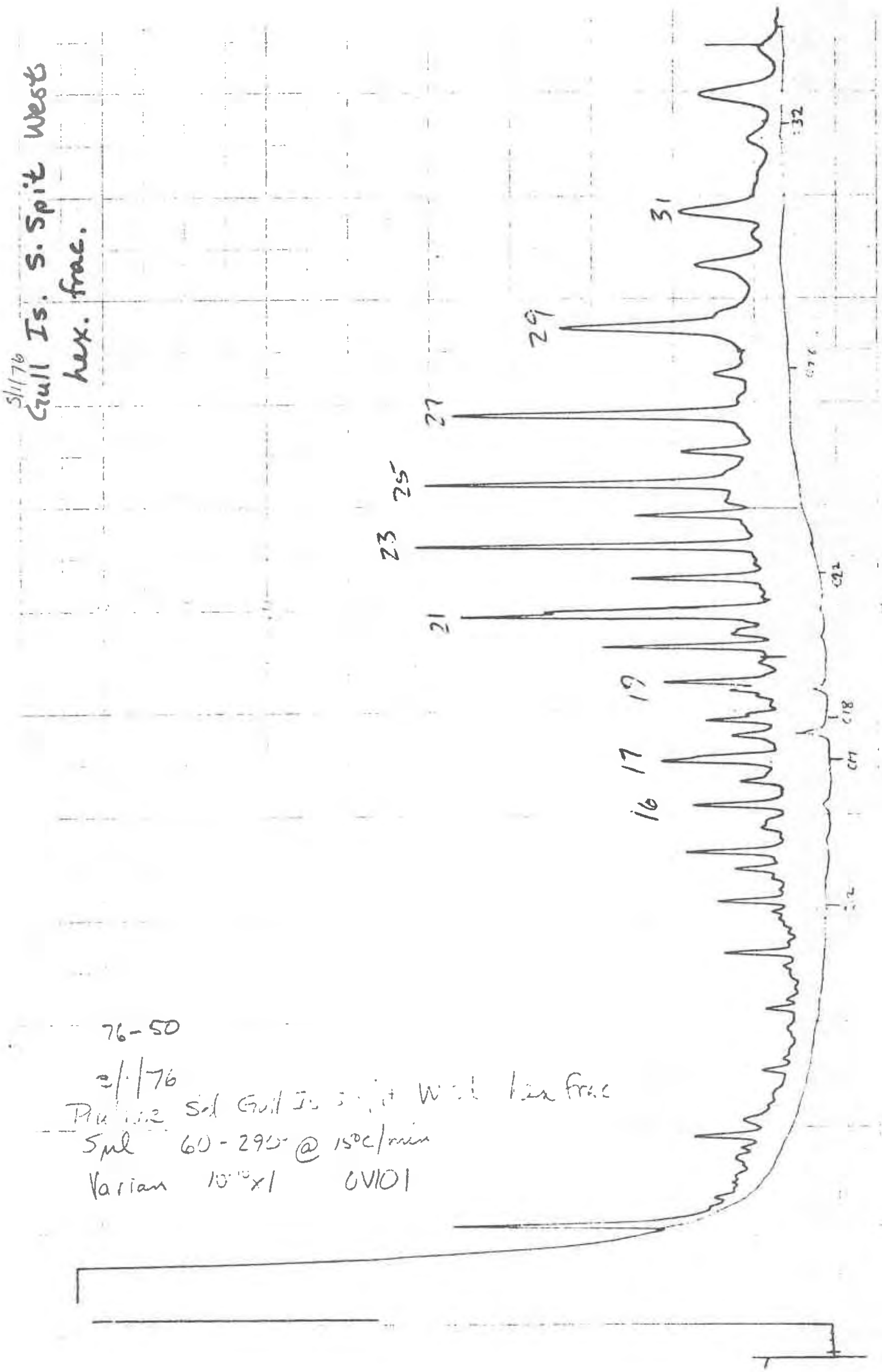

Sta 37
hex
3/11/76
17
19
21
23
25
27
29

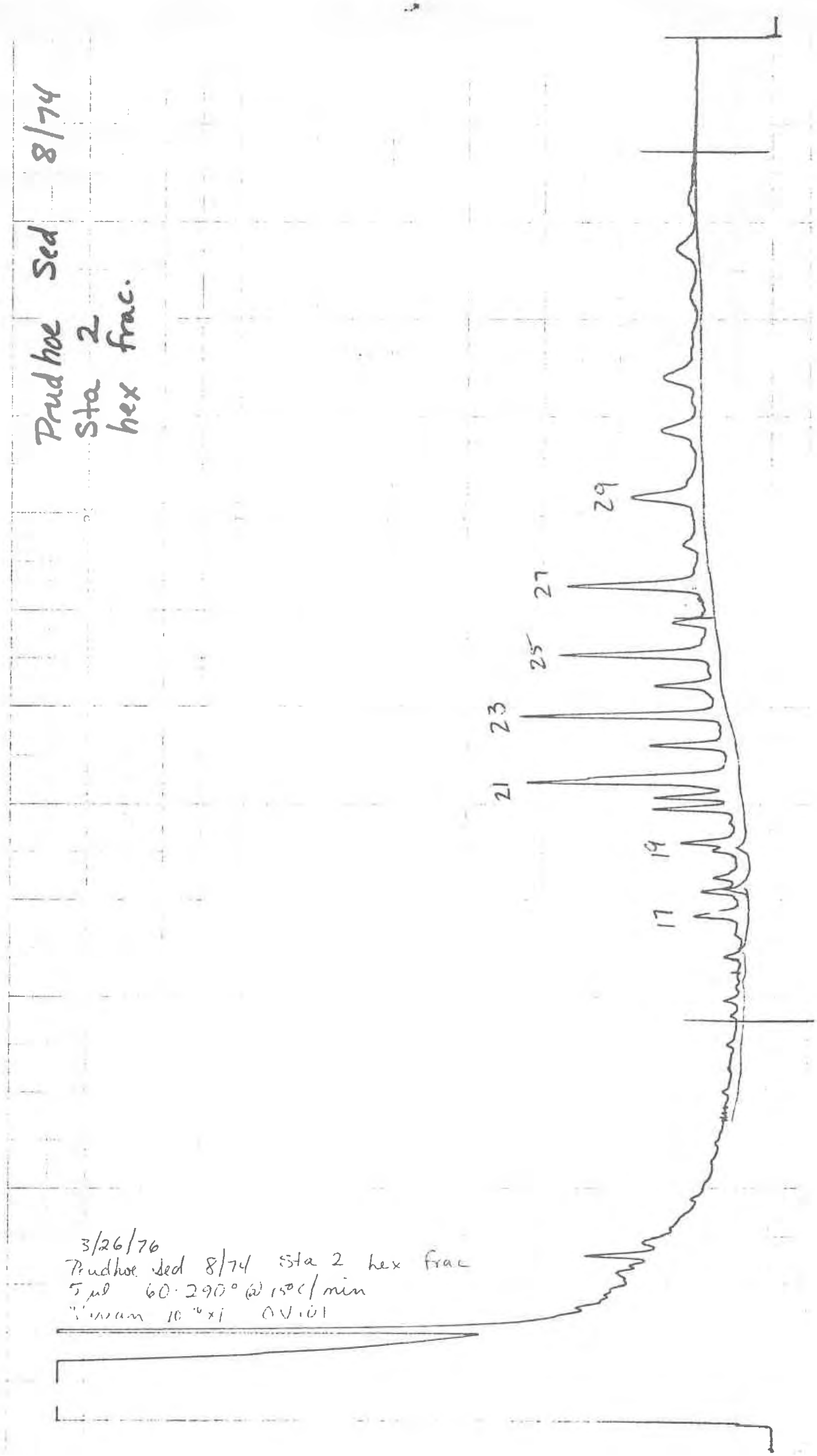

3/10/76
Station 38
hex frac
21
23
25
27
17
18
3/10/76
Prudhoe sed Sta 38 hex frac 3/2/76
5 µl 60-290 @ 15°C/min

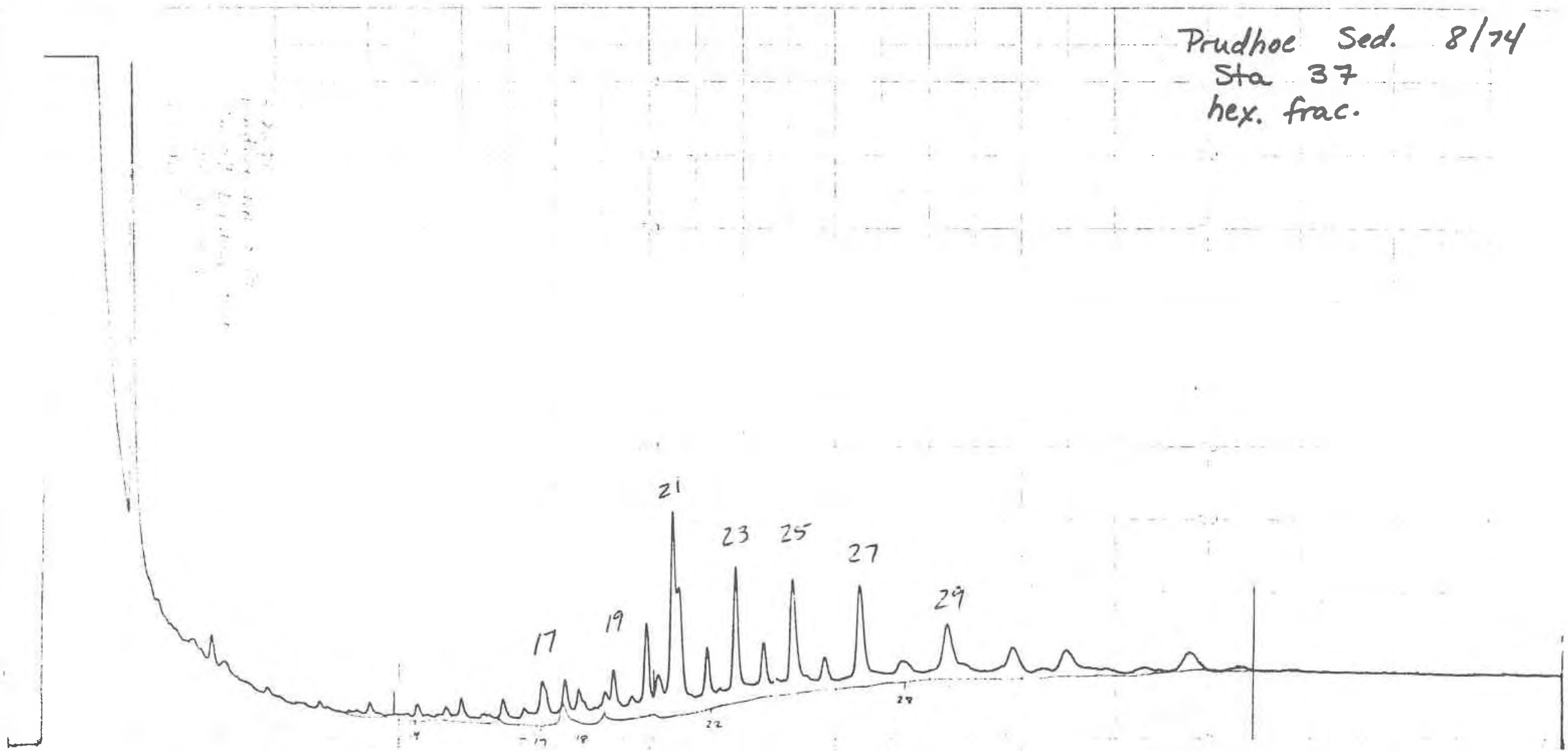

Station 39
hex frac
17
19
21
23
25
27
29
3/10/76
Prudhoe sed Sta 39 hex 3/2/76
Varian


3/1/76
Gull Is. S. Spit. East
hexane frac.
17
18
21
23
25
27
29
C28
C32
3/1/76

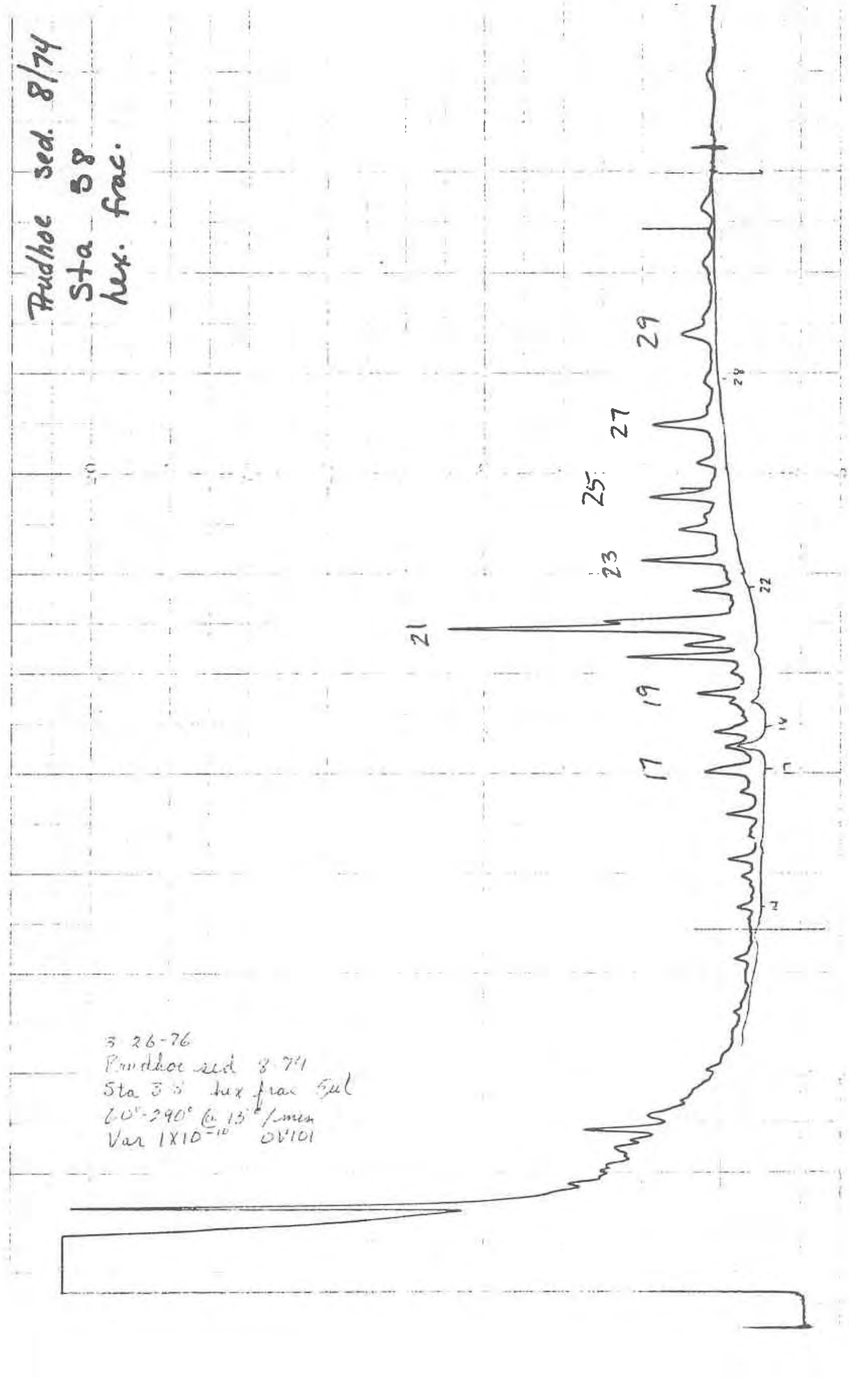

Gull Is. S. Spit East
hex frac
capillary column
3/8/76
Gull Island S. Spit. East
Prudoe Bay Sediment 3/1/76
3μl @ 5:1 split
70° @ 8 min
70° → 250° 4°min/Rate
250° @ 16 min plus isothermal
Glass capillary column
50m x 0.028" i.d.
Silanox (AW DMCS)
OV-101
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29

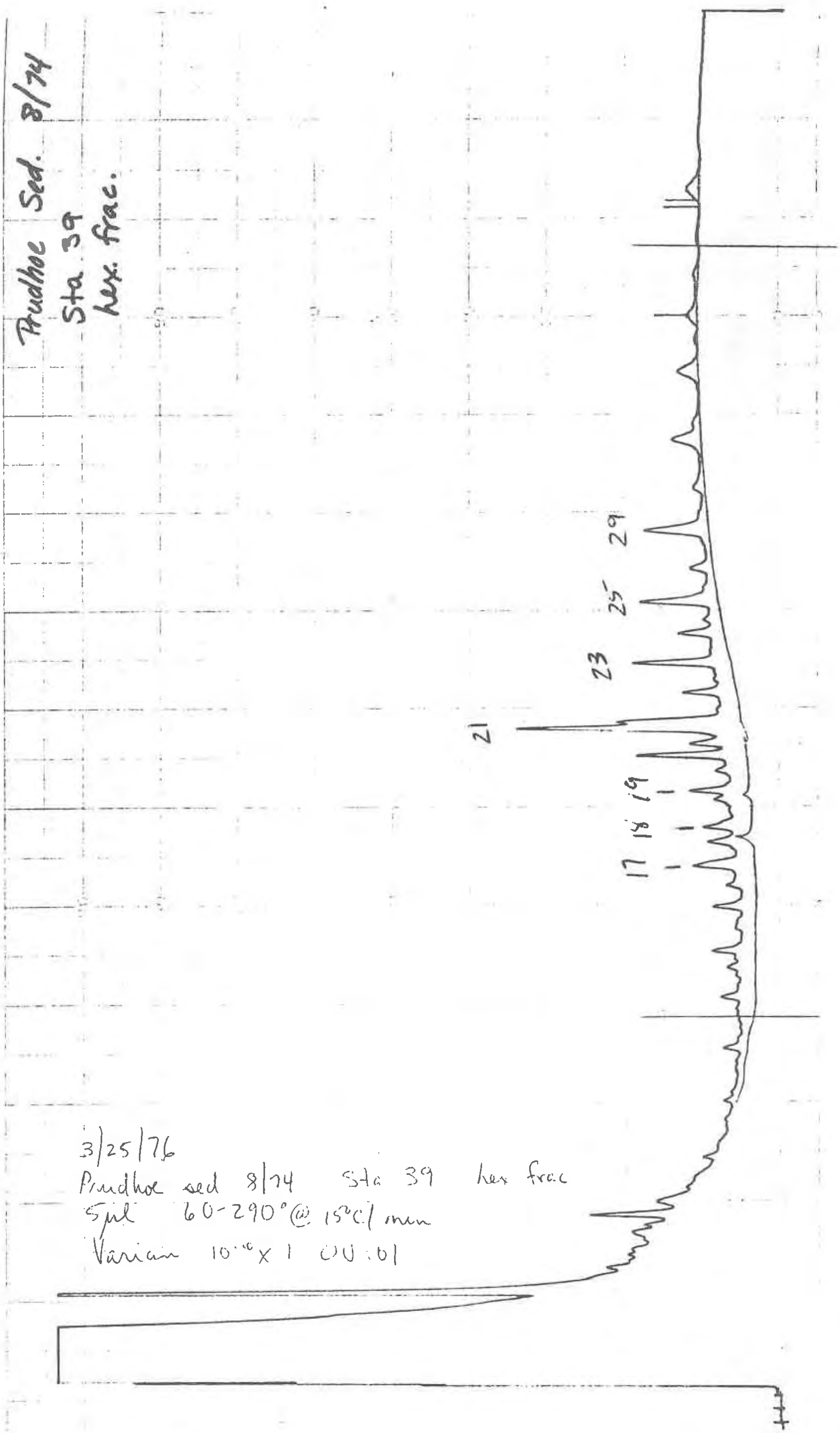

5/1/76
Gull Is. S. Spit West
hex. frac.
16
17
19
21
23
25
27
29
31
76-50
5μl 60-295° @ 15°C/min
Varian
OV101


Prudhoe Sed 8/74
Sta 2
hex frac.
17
19
21
23
25
27
29
3/26/76
Prudhoe Sed 8/74 Sta 2 hex frac
5 µl 60-290° @ 15°C/min



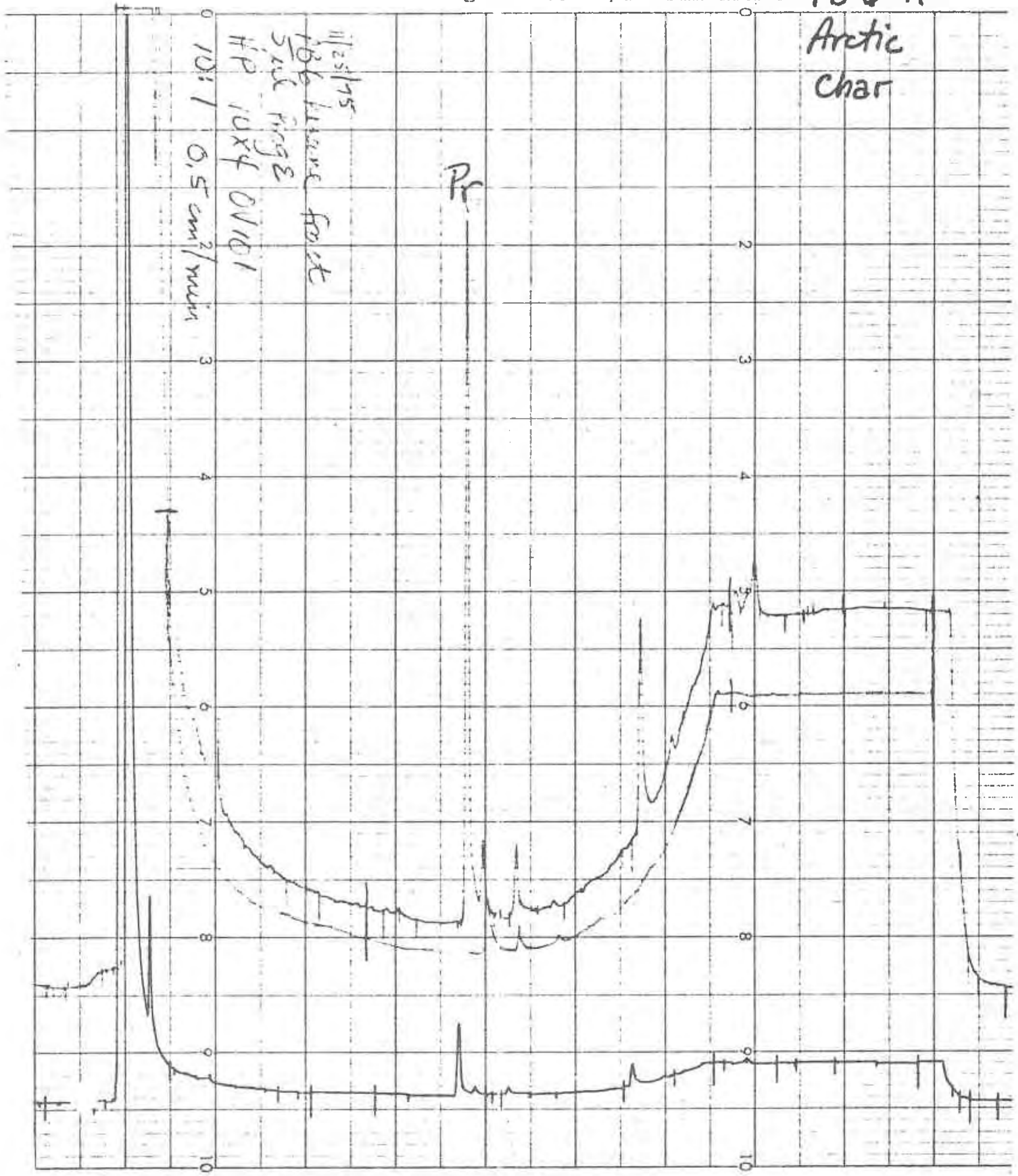
Prudhoe Sed. 8/74
Sta 37
hex. frac.
17
19
21
23
25
27
29

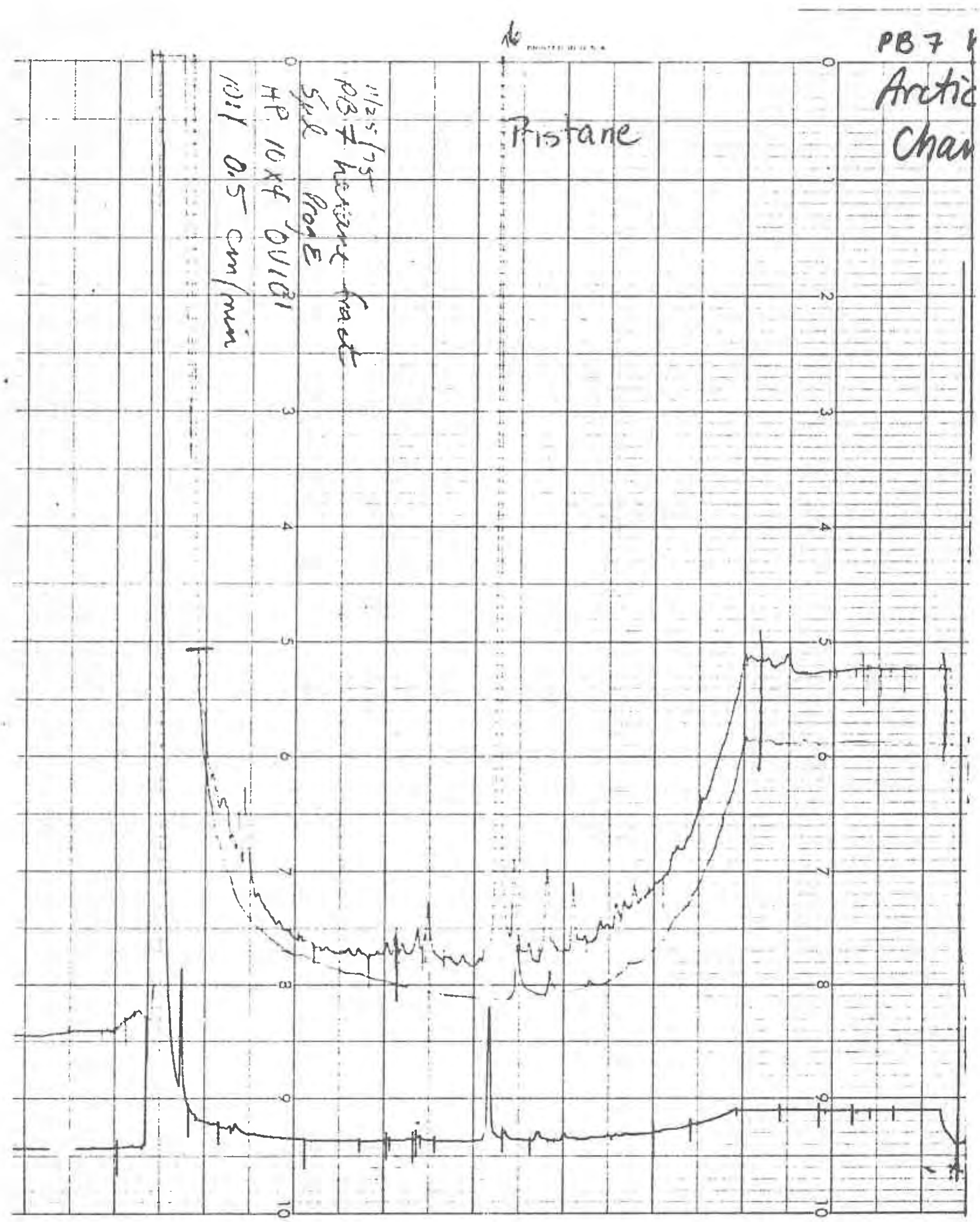

Prudhoe sed. 8/74
Sta 38
hex. frac.
17
19
21
23
25
27
29
3-26-76
Prudhoe sed 8-74
Sta 38 hex frac 5ul
60°-290° @ 13°/min
Var 1X10-10 OV101

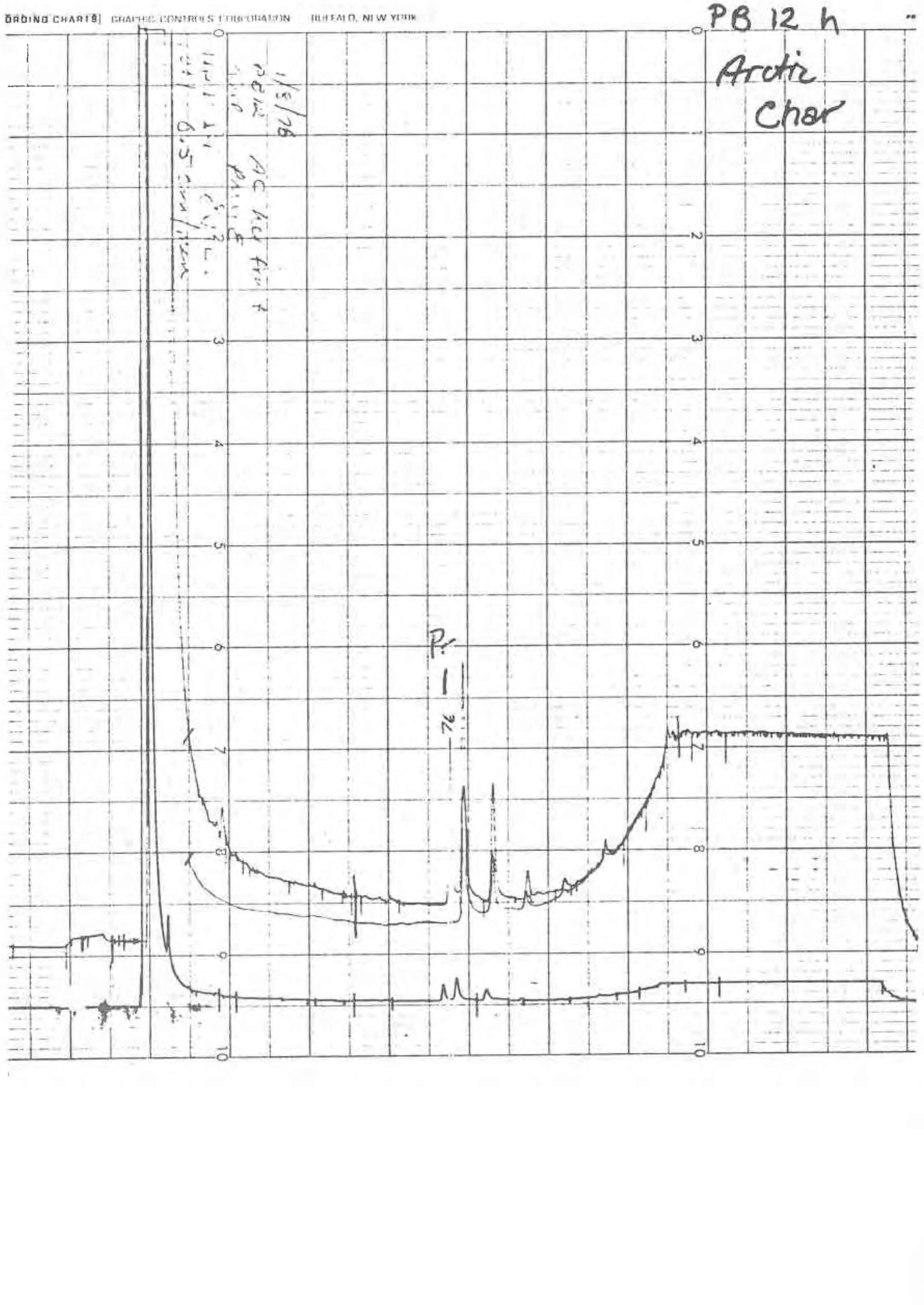

Prudhoe Sed. 8/74
Sta 39
hex. frac.
17 18 19
21
23
25
29
3/25/76
Prudhoe sed 8/74 Sta 39 hex frac
5μl 60-290° @ 15°C/min
Varian 10⁻⁹ x 1 OU :01

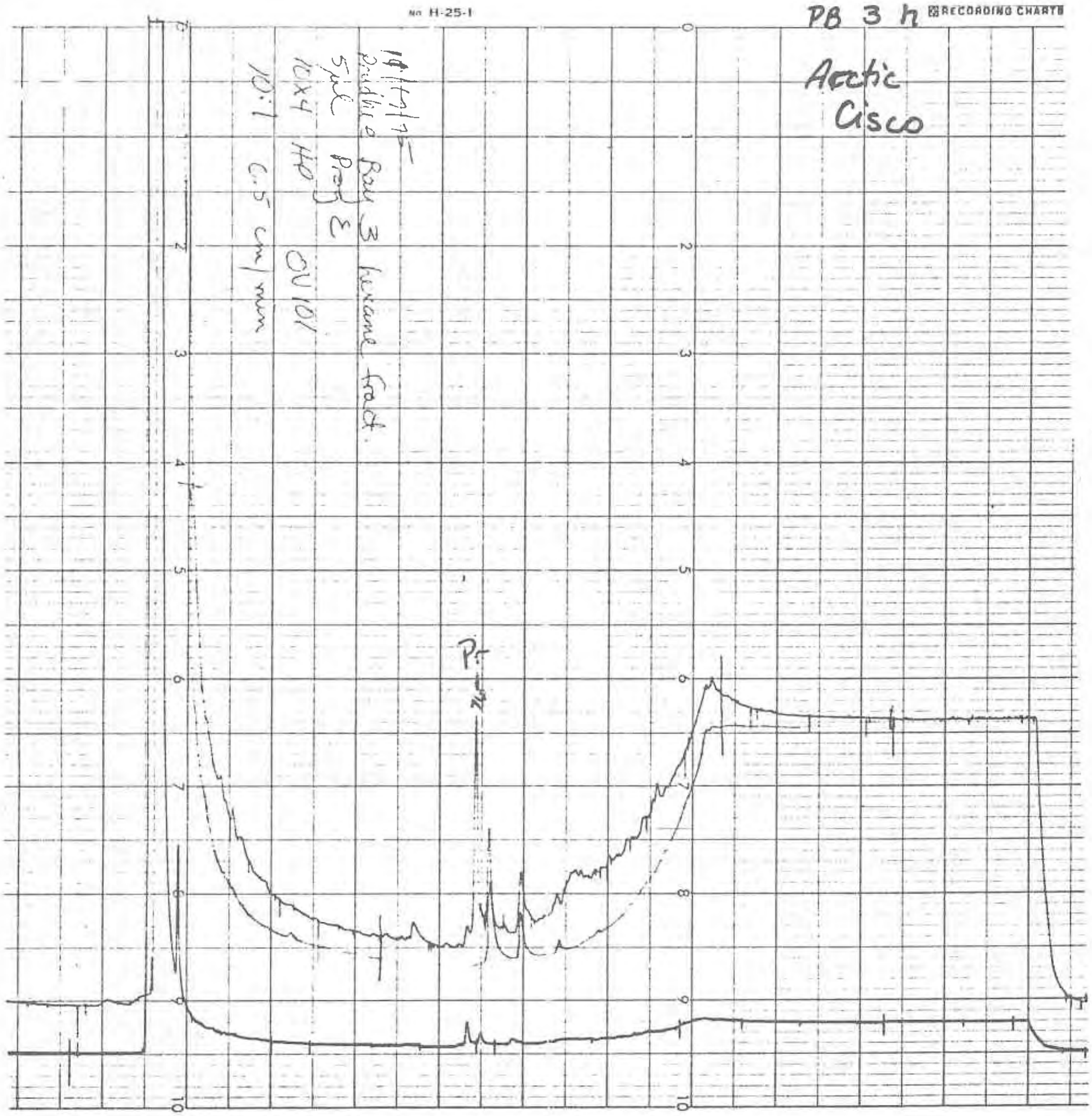
APPENDIX B

Chromatograms of Hexane Fractions of Fishes

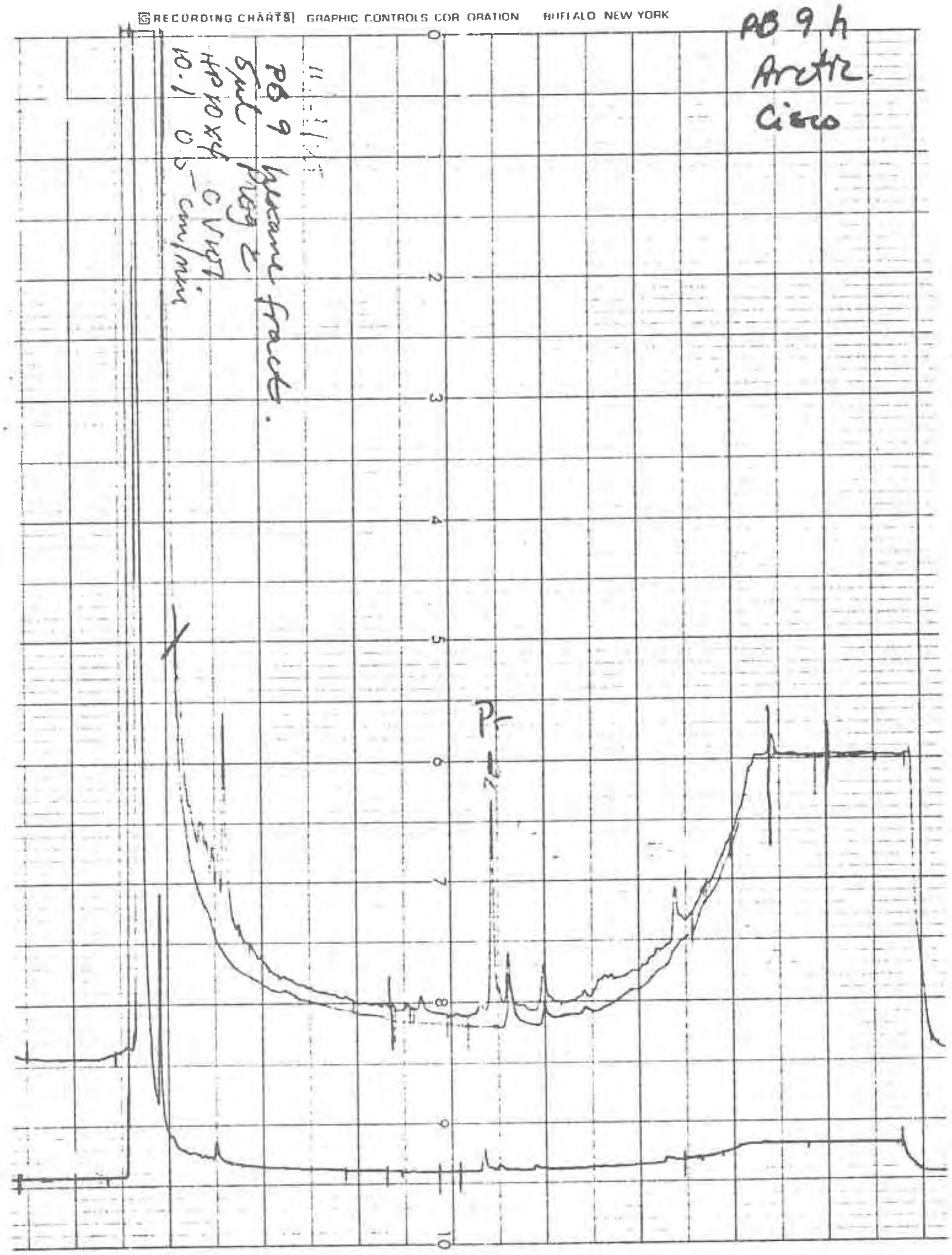

PB 6 h
Arctic
Char
Pr

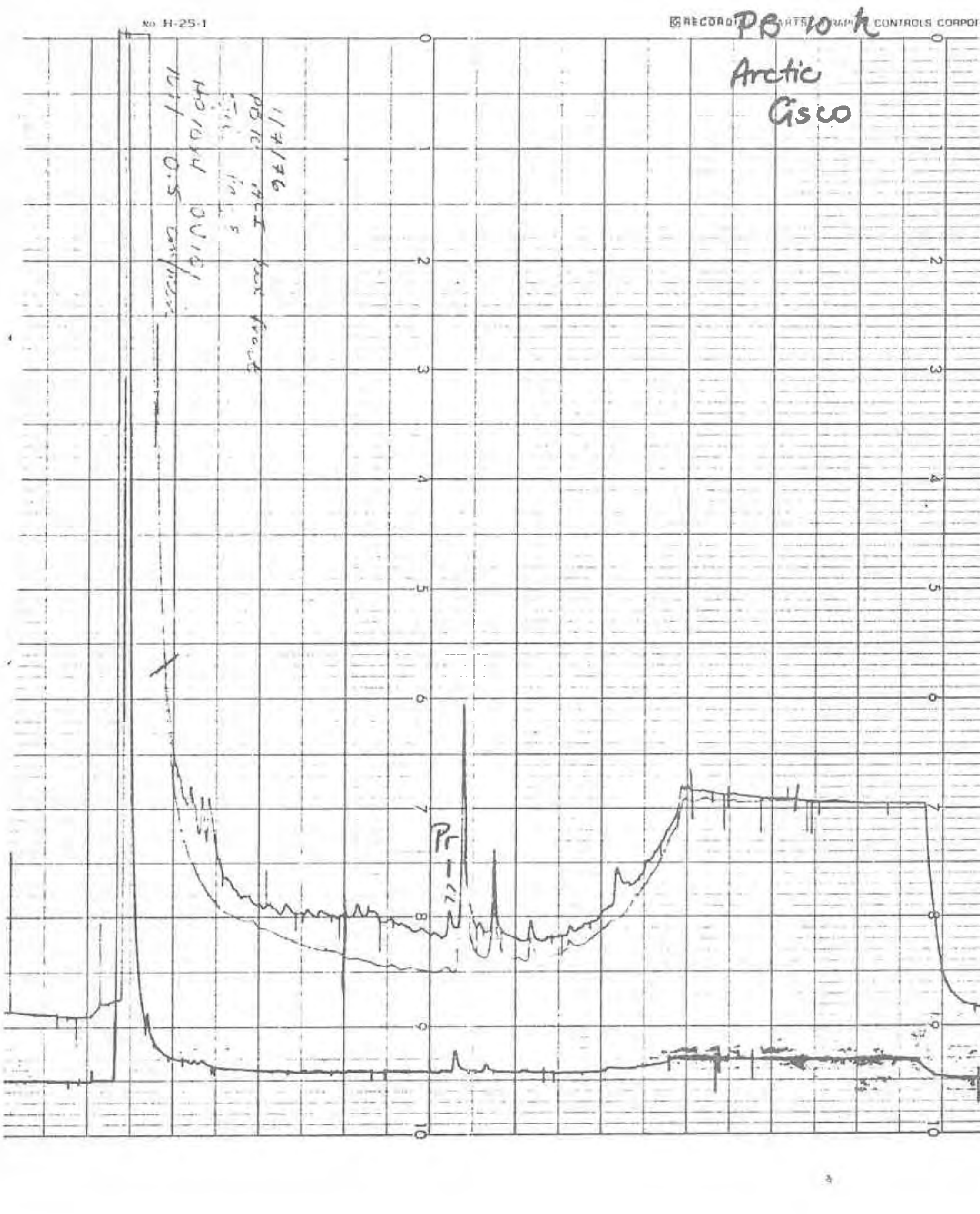

PB 7
Arctic
Chan
Pristane
11/25/75
PB 7 hexane fract
5µl Probe
HP 10x4 OV101
10:1 0.5 cm/min

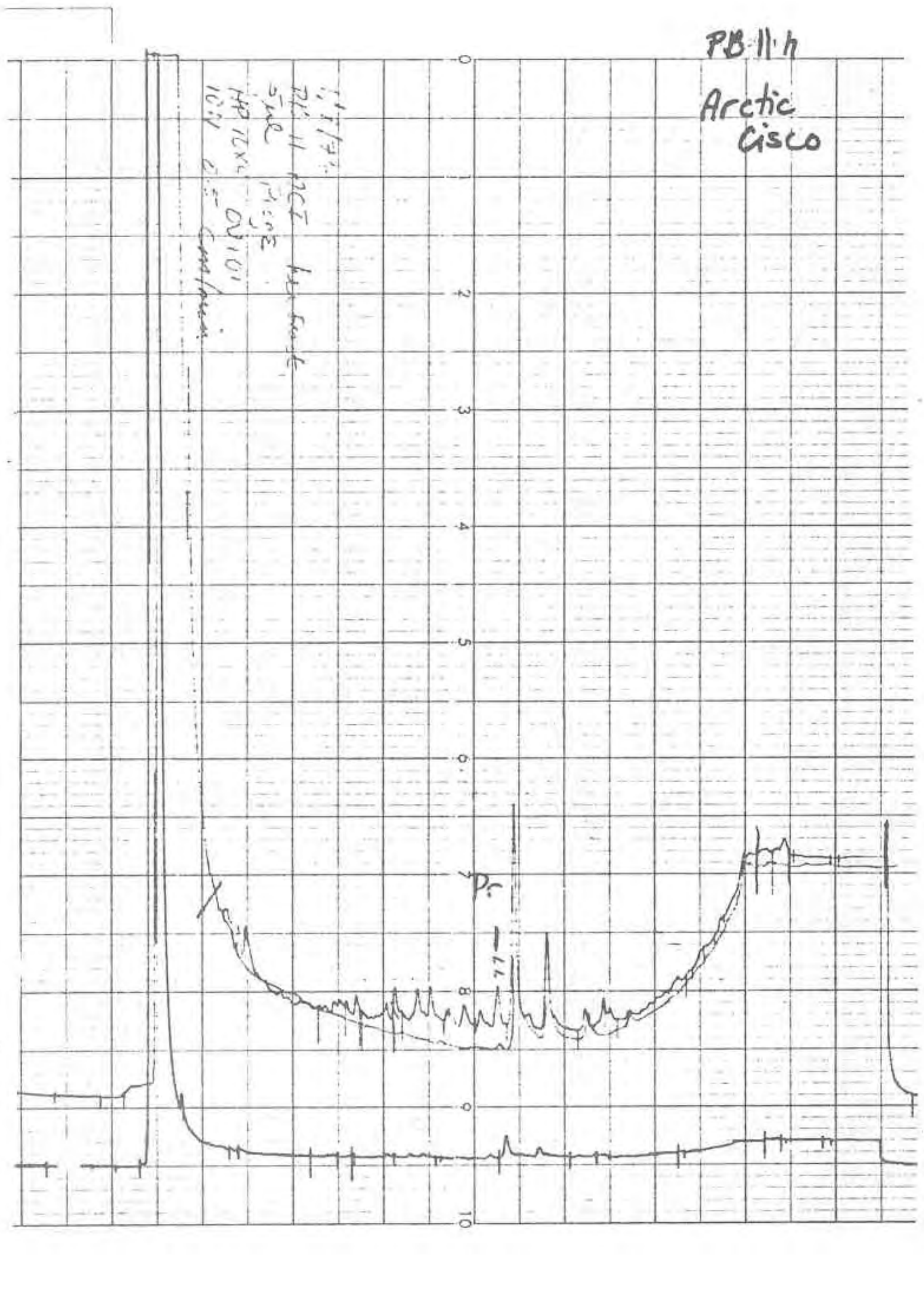

RECORDING CHARTS | GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK
PB 12 h
Artic Char
1/8/78

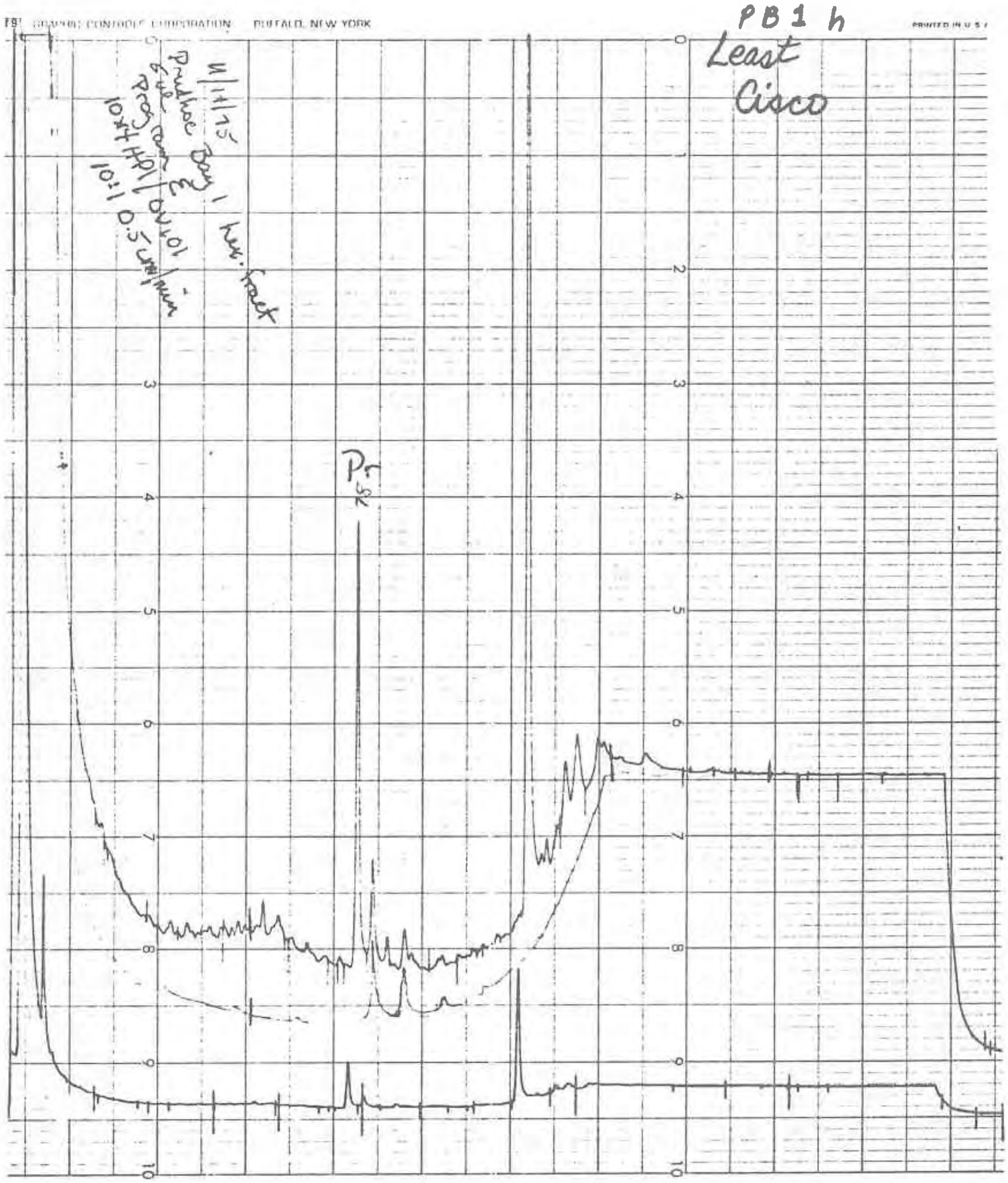


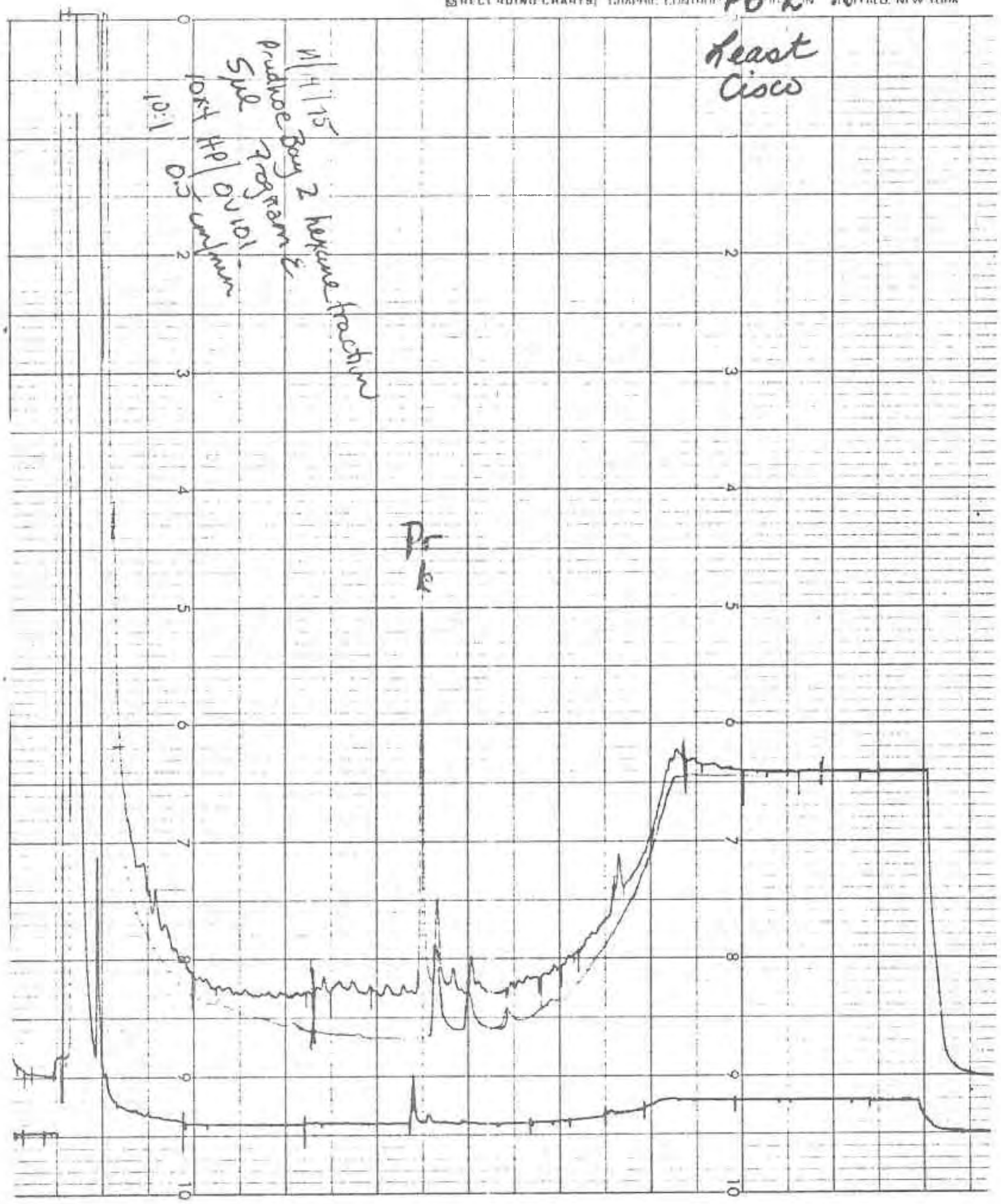
No H-25-1
PB 3 h
RECORDING CHARTS
Arctic Cisco

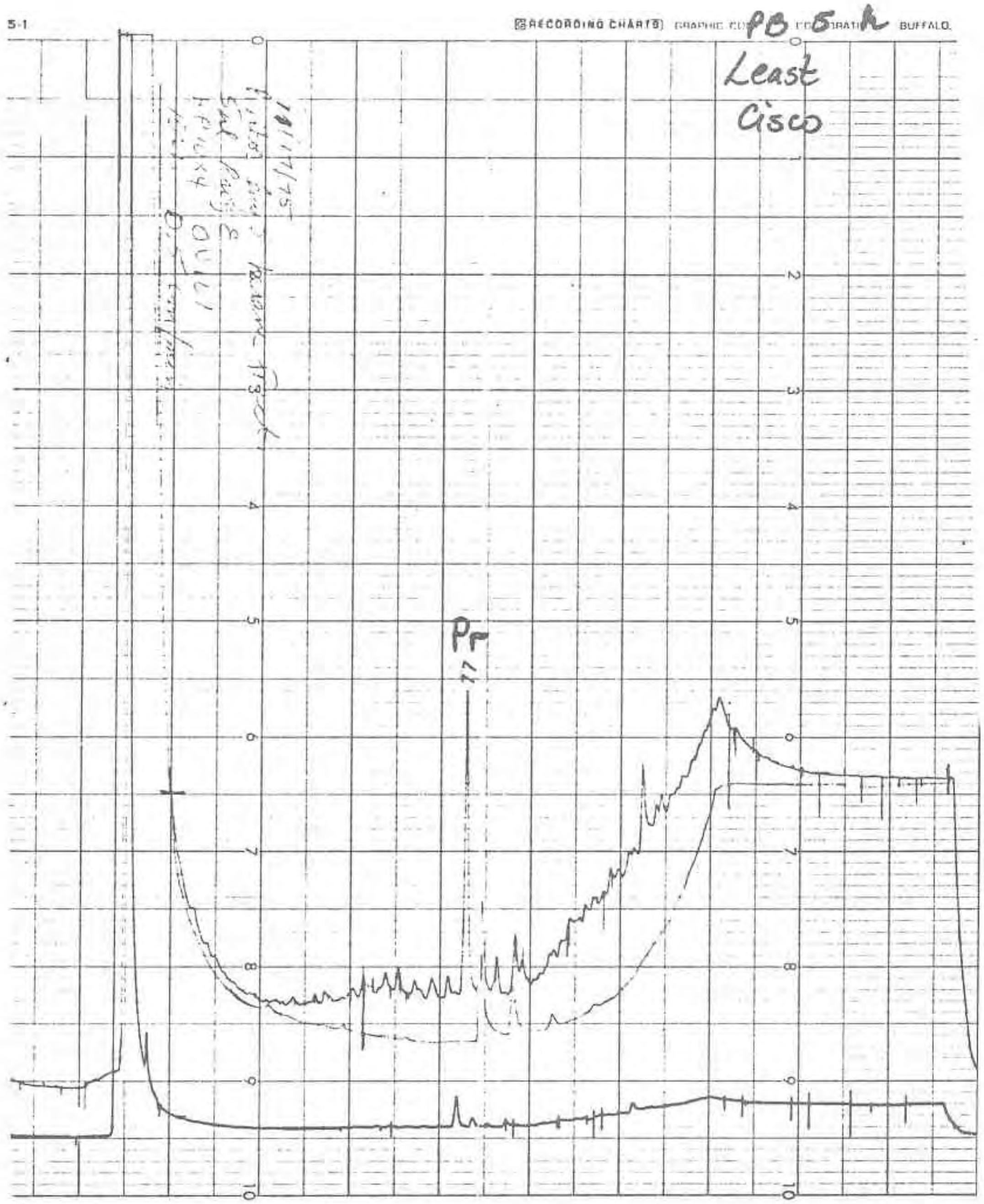

RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO NEW YORK
PB 9 h
Arctic
Cisco
PB 9 hexane fract.
Pr

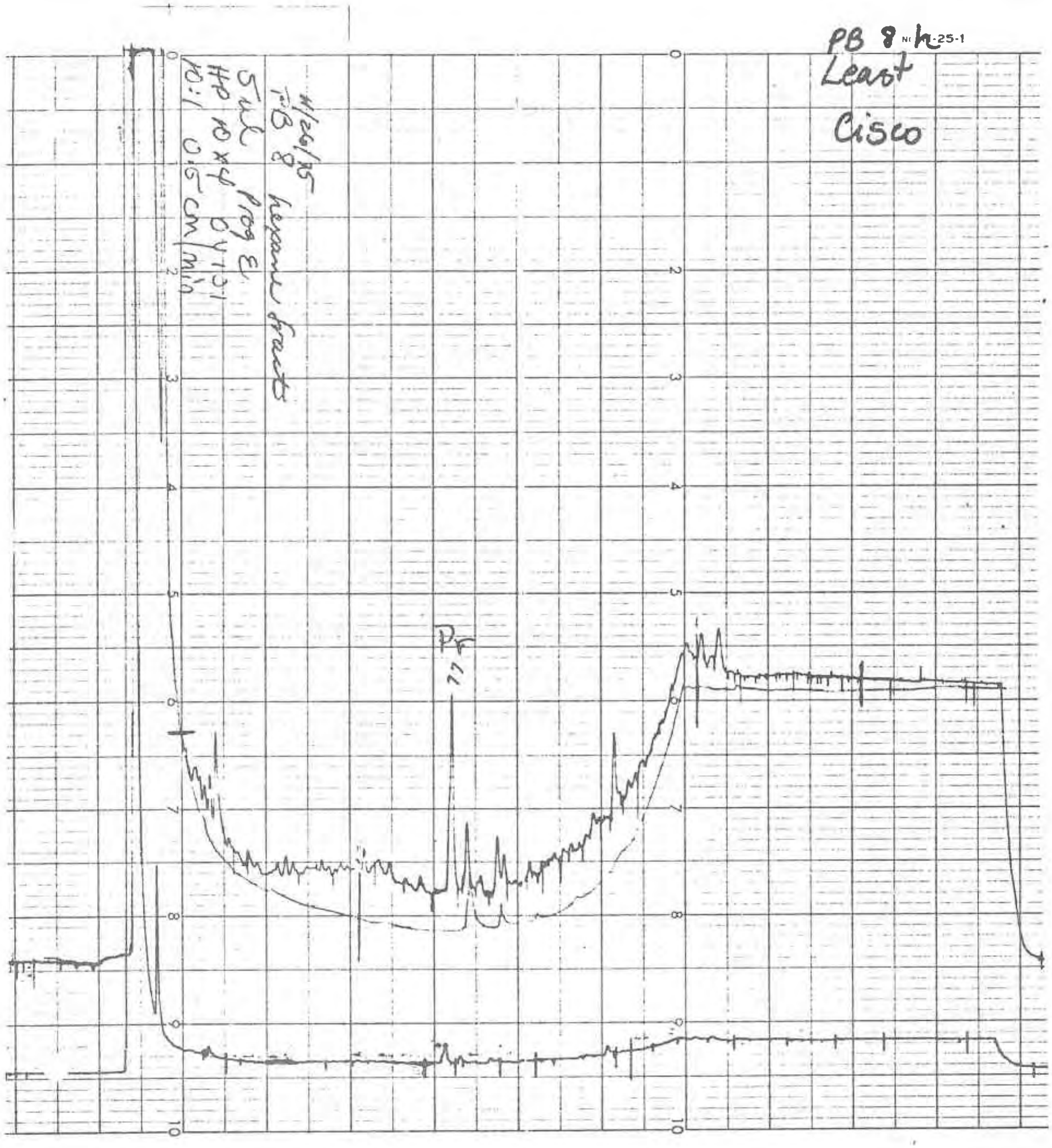

No. H-25-1
PB 10 h
Arctic
Cisco
Pr


PB 11 h
Arctic Cisco


BUFFALO, NEW YORK
PB 1 h
Least
Cisco


RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK
PB 2 h
Least Cisco
11/4/75
Prudhoe Bay 2 hexane fraction
Spl Program
Port HP OV101
10:1 0.5 cm/min
Pr


5-1
RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO
PB 5 h
Least
Cisco
Pr



PB 8 NI h-25-1
Least
Cisco
11/26/85
PB 8 hexane fracts
5 ul Prog E
HP 10x4 OV101
10:1 0.5 cm/min

Chapter III

BENTHIC BIOLOGICAL STUDIES

Howard M. Feder and Douglas Schamel

INTRODUCTION

Limited data on the biology of the Alaska arctic coastal marine environment is currently available (see Feder *et al.*, 1976b for literature review). 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 in the Colville Delta and the benthic studies of MacGinitie (1955) at Point Barrow. Data from summer studies of the phytoplankton and benthos from the Colville Delta area are available in Crane (1974), Crane and Cooney (1973), Kinney *et al.* (1971, 1972) and Alexander *et al.* (1974). Some shallow-water summer benthic samples from the western Beaufort Sea are also described in Carey *et al.* (1974). Information from biological explorations along the Canadian arctic coast should be valuable for comparison with Alaskan studies since many arctic species are circumpolar in distribution (Ellis, 1960; Feder *et al.*, 1976b). Phytoplankton, primary productivity, zooplankton and hydrographic data are available for Prudhoe Bay and nearby lagoon areas (Coyle, 1974; Horner *et al.*, 1974). However, prior to the studies by Feder *et al.* (1976a) there was no published information on the benthos for this area, although some qualitative data were obtained near Prudhoe Bay during exploratory dives in conjunction with phytoplankton research (Horner, Matheke and Maynard, unpublished data).

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 (see 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). Such fluctuations are typically unexplainable because simultaneous long-term physical, chemical, and biological data are seldom gathered (Lewis, 1970). 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 Pearson, 1970 and Rosenberg, 1973 for such an approach for monitoring areas affected by industrial activity).

OBJECTIVES

The investigation described here is the second part of a two-year study, and 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 living adjacent to a causeway constructed by the Atlantic Richfield Company in the late summer and early fall of 1974 (Fig. 1). The sampling procedures contributed to the following goals:

1. A continuing documentation of the distribution and relative abundance of nearshore benthic organisms in the summer.
2. A continuing examination of benthic species in relation to the physical characteristics of the sediment.

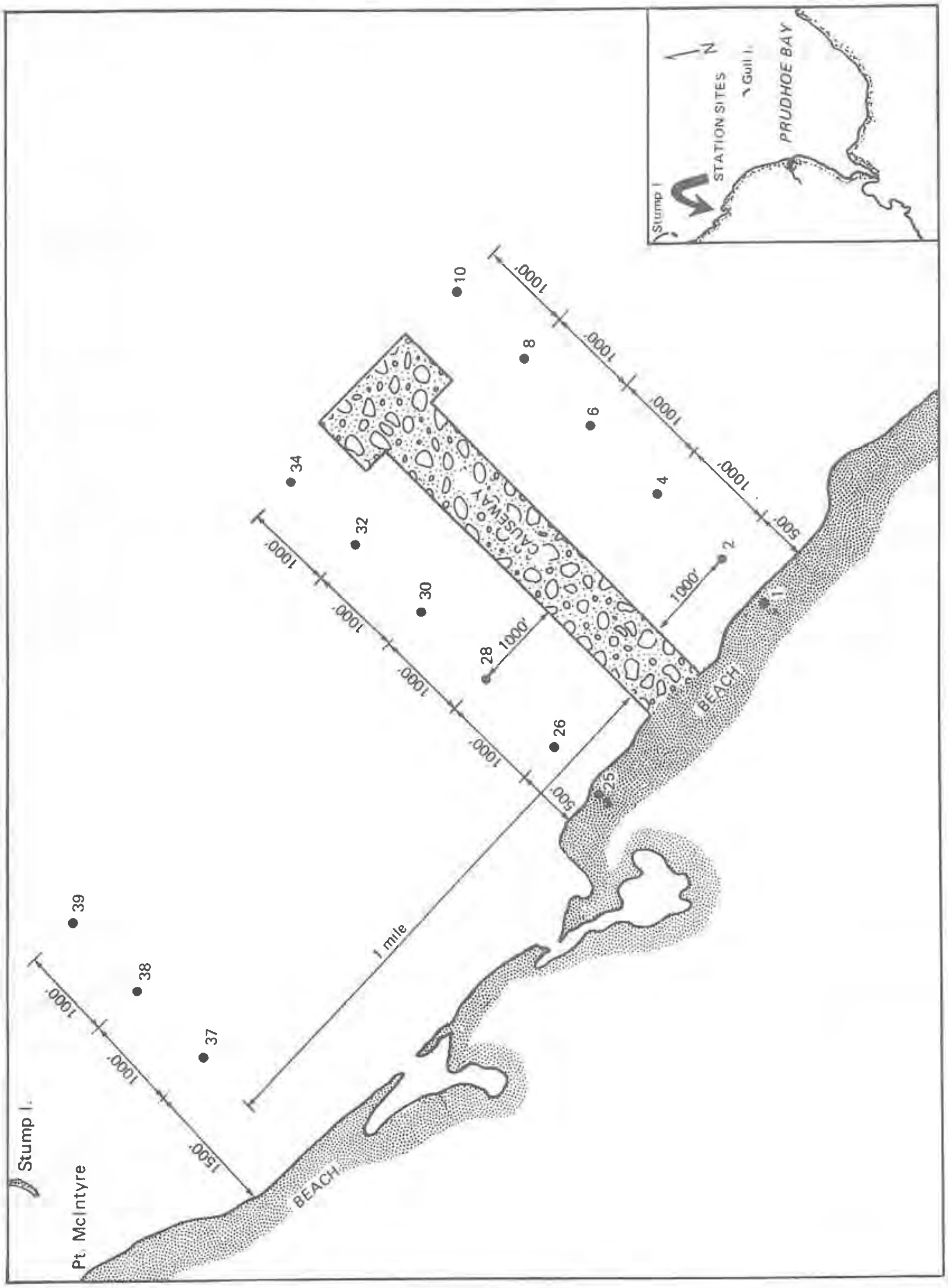


Figure 1. Stations located adjacent to the causeway in Prudhoe Bay, August 1974 and 1975.

3. A continuing accumulation of a 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 12 August through 22 August, 1975 (Fig. 1). Tidal fluctuations in the area average 15 cm. Two parallel offshore transects, each 4500 feet in length, were established 500 feet on either side of the causeway. The base of each transect was established by way of flagged, rebar stakes that had been placed on the beach in August of 1974 (Feder *et al.*, 1976a). Biological, sediment and hydrocarbon sampling stations were established onshore and 500, 1500, 2500 and 4500 feet from shore along each transect (12 stations); stations were marked with floats anchored with concrete blocks. One additional transect was occupied one mile west of the causeway near Point McIntyre; 3 stations located 1500, 2500 and 3500 feet from shore were marked with floats and sampled (see Chapter II, Table I for specific station numbers and locations). Three stations were occupied at Gull Island (Station A (=50*): northern end of island; Station B (=52*): east side of southern sand spit; Station C (=51*): west side of the southern sand spit) (Appendix A, Fig. 1).

Samples were taken by divers operating from a 16-foot river skiff or a small Zodiac. Infaunal samples taken near the causeway were collected by a diver operating an airlift equipped with a nylon collection bag. The diver dropped to the bottom and planted a 0.25 m^2 quadrat with pegs to prevent

*Station number cited in The Arctic Coastal Environment of Alaska, Data Supplement, 1976. (See General Introduction, this report.)

its movement after sampling commenced. Sediment within the quadrat was removed to a depth of 4 to 7 cm. Mesh sizes for the collection bags were 0.5 to 1.0 mm on a side.

Fager cores (.006 m^2) were collected at Gull Island by manually thrusting the core into the sediment, digging away the sediment around one side and sliding a metal plate under the core to retain the contained sample. The core was then extracted from the sediment and returned to the boat (Fager *et al.*, 1966).

Limited underwater observations were made by the divers (Appendix A).

Qualitative samples were collected at selected stations by small, 1.0-mm mesh traps (24" x 14" x 14"). The traps were baited with meat scraps and were deployed for 24 to 48 hours. 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.

All biological materials were immediately transferred to plastic bags in the field and preserved with 10 percent Hexamine-buffered formalin. Species identifications, counts and biomass determinations were made at the Marine Sorting Center, University of Alaska, Fairbanks.

Species diversity was determined by the Gleason, Shannon-Wiener and Simpson Indices (Lie, 1968; Simpson, 1949). The former index is a ratio of total number of species to total number of individuals and 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 numbers of individuals. This method weighs the contribution of each species to total diversity. In both methods, index values are positively correlated with diversity. Since the former two 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. The Simpson Index is an index of dominance. A maximum value of 1 is obtained when there is only one species (complete dominance).

Biologically Important Species (BIS) were determined by the abundance and distributional criteria established by Feder *et al.* (1973).

There has been a change in nomenclature since the last report (Feder *et al.*, 1976a). *Onisimus* sp. of 1974 becomes *Boekosimus affinis* in 1975. *Pseudalibrotus* sp. of 1974 becomes *Onisimus* sp. in 1975. The latter organism is occasionally taken to the species level in 1975, based upon the spination of uropod III.

RESULTS

General

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

The airlift system was satisfactory for sampling most infaunal burrowing polychaetes and crustaceans as well as most epifaunal species. The larger polychaetes were not sampled quantitatively by this technique. The Fager coring technique satisfactorily sampled polychaetes and amphipods in the Gull Island area, but apparent patchiness of faunal components here suggests that many additional cores are needed for quantitative results.

The fish traps were effective in the collection of mobile epifaunal scavengers such as the isopod *Saduria entomon* and the amphipods *Gammaracanthus loricatus*, *Gammarus zaddachi*, *Boekosimus affinis* and *Onisimus littoralis*.

Thirty-six invertebrate species representing five phyla were collected from the subtidal transect stations (Table I). Polychaetous annelids (13 species) and amphipod crustaceans (11 species) were the dominant groups. Two new polychaete species (*Rhynchospio* sp. and *Arenicola glacialis*), two new gastropod species (*Amauropsis purpurea* and one unidentified species) and one new amphipod species (*Monoculodes* sp.) were determined. A small number of uncommon species collected in 1974 were not found in 1975 (the sponge *Haliclona rufescens*, an unidentified clam, the polychaetes *Phylo* sp. and *Nereis* sp., the amphipods *Paroediceros lynceus, Apherusa megalops* and *Aceroides latipes* and an unidentified tunicate).

Quantitative Studies - Airlifts

Two of the three transects occupied (encompassing stations 2, 4, 6, 8, 10, 26, 28, 30, 32, and 34) showed an increase in number of species with increasing distance from shore (Fig. 2). An increase in biomass occurred from shore to stations 8 and 32 (3500 feet from shore) with a decrease noted at stations 10 and 34 (4500 feet from shore). An increase in the Gleason Diversity Index with increasing distance from shore (Figs. 2 and 3) in general reflects the increase in species along these transects. The Shannon-Wiener Index shows the same trend, though less pronounced (Fig. 3). A slight decrease in dominance with increased water depth is seen in the Simpson Index (Fig. 4).

Polychaete species tended to increase with increasing distance from shore. The trend was more apparent in stations 26 through 34 than in stations 2 through 10 (Fig. 5). An increase in biomass occurred along the transects to stations 8 and 32 with a decrease observed at stations 10 and 34 (4500 feet from shore; Fig. 5). The biomass trends are primarily a reflection of the numbers and biomass of one species, the tube-dwelling *Ampharete vega*.

Table I. A list of species collected at 13 stations in the vicinity of the new causeway, Prudhoe Bay, 1975.

Taxon		Species	Common Names
Phylum Nemertea		unknown species	proboscis worm
Phylum Priapulida		*Halicryptus spinulosus*	
Phylum Annelida	Class Polychaeta		
	Family Phyllodocidae	*Eteone longa*	bristle worm
	Family Spionidae	*Prionospio cirrifera*	
		Scolecolepides arctius	
		Spio mimus	
		Rhynchospio sp.*	
		Pygospio elegans	
	Family Cirratulidae	*Cirratulus cirratus*	
		Chaetozone setosa	
	Family Capitellidae	*Capitella capitata*	
	Family Arenicolidae	*Arenicola glacialis**	
	Family Ampharetidae	*Ampharete vega*	
	Family Sabellidae	*Chone duneri*	
	Family Sphaerodoridae	*Sphaerodoropsis minuta*	
	Class Oligochaeta		
	Unknown family	unknown species	
Phylum Mollusca	Class Gastropoda		
	Family Naticidae	*Amauropsis purpurea**	Icelandic moon shell
	Unknown family	unknown species	
	Class Pelecypoda		
	Family Hiatellidae	*Cyrtodaria kurriana*	Northern propeller clam

Table I. Continued

Taxon	Species	Common Names
Phylum Arthropoda		
Class Crustacea		
Subclass Ostracoda	unknown species	
Subclass Copepoda	*Limnocalanus grimaldii*	
Subclass Malacostraca		
Order Mysidacea	*Mysis* sp.	
Order Cumacea	*Diastylis sulcata*	
Order Isopoda	*Saduria entomon*	
Order Amphipoda	*Gammaracanthus loricatus*	
	Gammarus zaddachi	
	Pontoporeia femorata	
	Pontoporeia affinis	
	Boekosimus affinis	
	Onisimus glacialis	
	Onisimus littoralis (=*Pseudalibrotus*)	
	Monoculodes sp.*	
	Monoculopsis longicornis	
	Oediceros saginatus	

*Collected in 1975 only; see Feder *et al.*, 1976a for list of species taken in 1974.

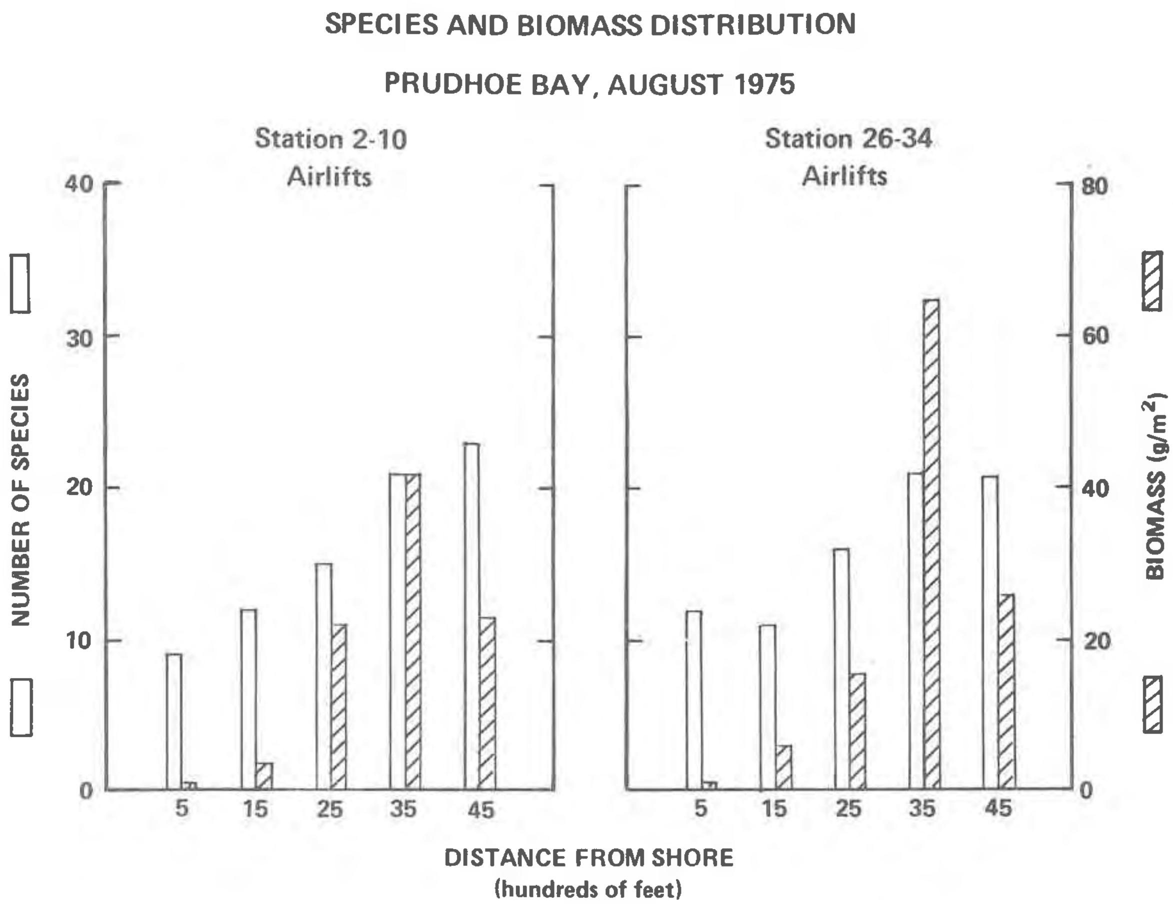


Figure 2. Species number and biomass distribution at the new causeway area. Prudhoe Bay, August 1975. Stations designated 2-10 refer to stations 2, 4, 6, 8, 10; stations 26-34 refer to stations 26, 28, 30, 32, 34. See Fig. 1 and Chapter II, Table 1 for details on station numbers and locations. All subsequent references to the above stations in figures imply the same numerical designations.

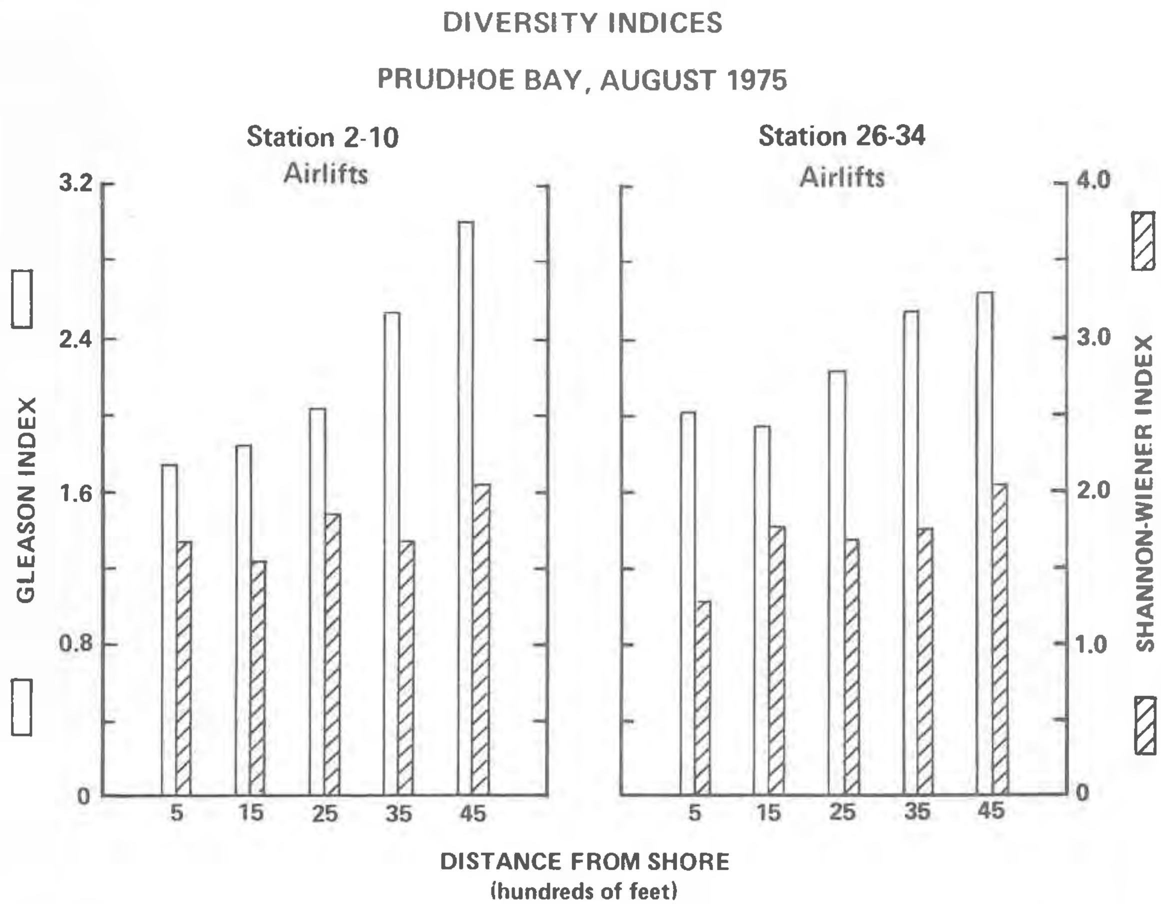


Figure 3. Gleason and Shannon-Wiener diversity indices at the new causeway area. Prudhoe Bay, August 1975.

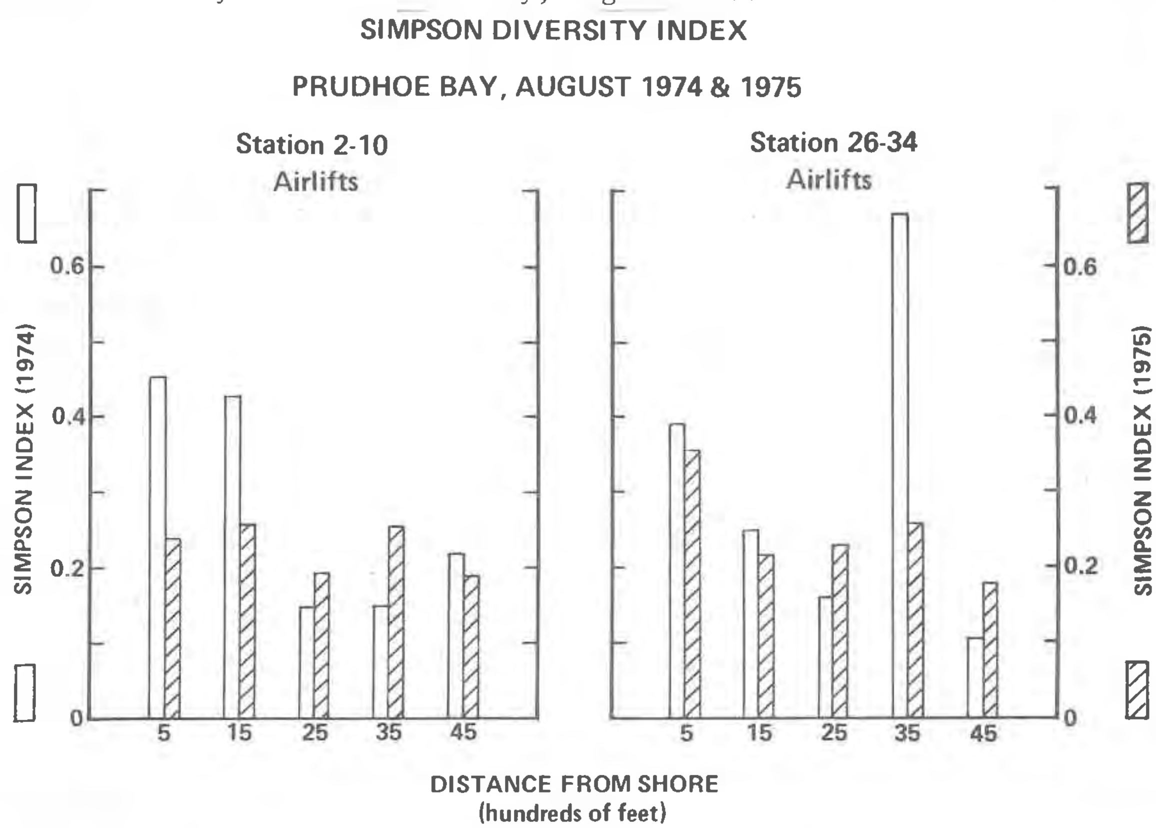


Figure 4. Simpson diversity index at the new causeway area. Prudhoe Bay, August 1974 and 1975.

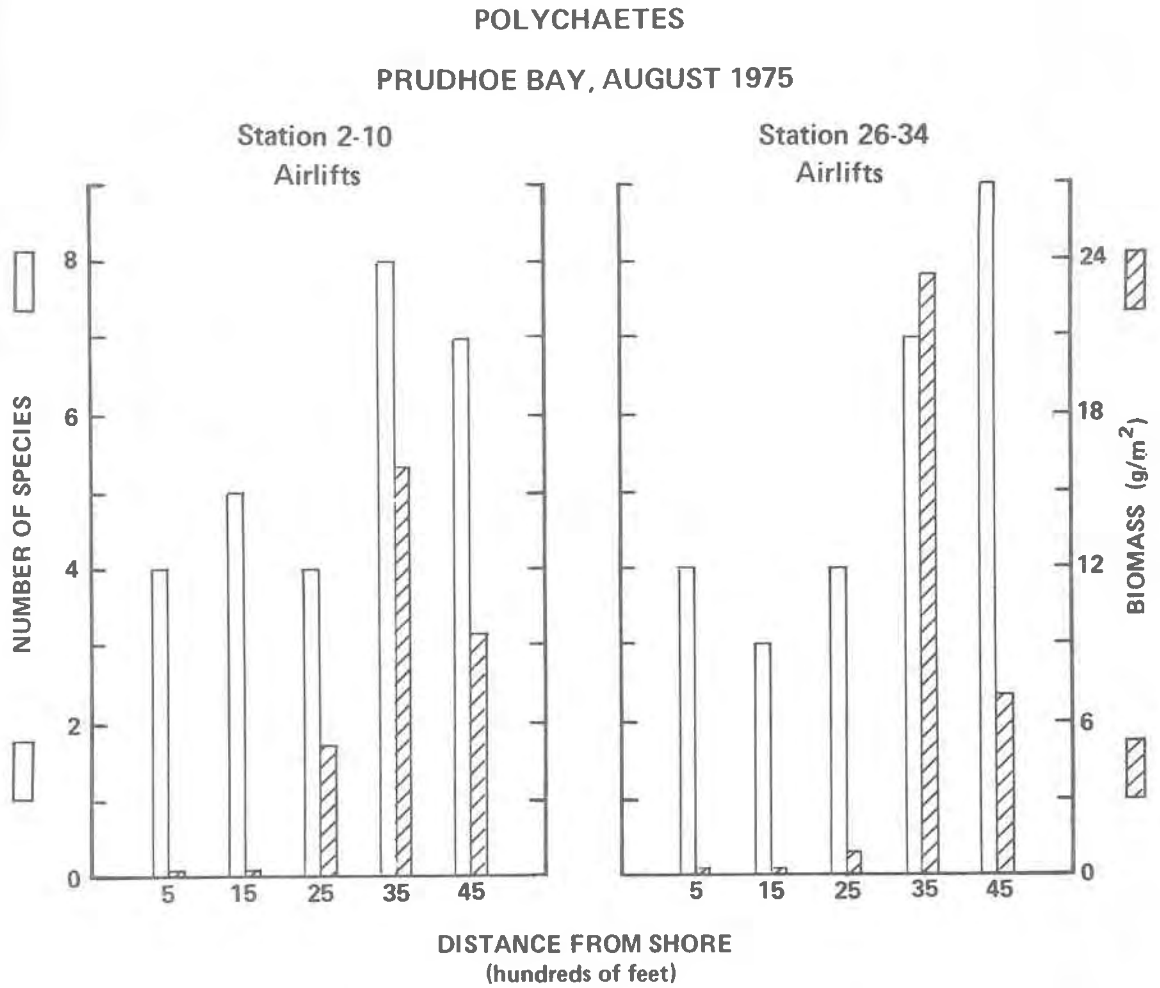


Figure 5. Species number and biomass distribution of polychaetes at the new causeway area. Prudhoe Bay, August 1975.

Amphipod species increased from the shore along stations 2 through 10 (Fig. 6). A general increase in biomass was noted through station 8; a biomass decrease was recorded for station 10 (Fig. 6). Although no marked species trend was noted for stations 26 through 34, the same biomass trend as noted above was seen. Changes in biomass were attributed to the distribution of two species, *Pontoporeia affinis* and *Onisimus* sp.

The clam *Cyrtodaria* occurred at the deeper stations on one causeway transect (stations 30, 32, and 34), but was collected closer to shore in the other causeway transect (stations 4, 6, 8, and 10; Fig. 7). The greatest clam density and biomass were found at station 32 (Fig. 7; Arctic Coastal Environment of Alaska, Data Supplement, 1976).

The isopod *Saduria entomon* tended to increase in numbers with distance from shore to stations 8 and 32. A decrease in numbers of this isopod occurred at the outer stations. Size distributions for both years are given in Figure 8, and a comparison of this isopod in the two main transects for 1975 is included in Figure 9.

The transect near Point McIntyre, encompassing stations 37, 38, and 39, differed from the other two transects. The stations of this transect are all shallow. The sediment is sand; gravel and mud are notably absent. Neither the tube-dwelling polychaete *Ampharete vega* nor the clam *Cyrtodaria kurriana* were found at these stations. No obvious change in species number was noted with increasing distance offshore. However, a decrease in number of individuals and biomass was observed with increasing distance from shore (Table II). An increase in the Gleason and Shannon-Wiener Indices and a decrease in the Simpson Index were noted with increasing distance from shore (Table II). Polychaete species increased with increasing distance offshore. No obvious trend in the number of amphipod species along the transect was seen, but a

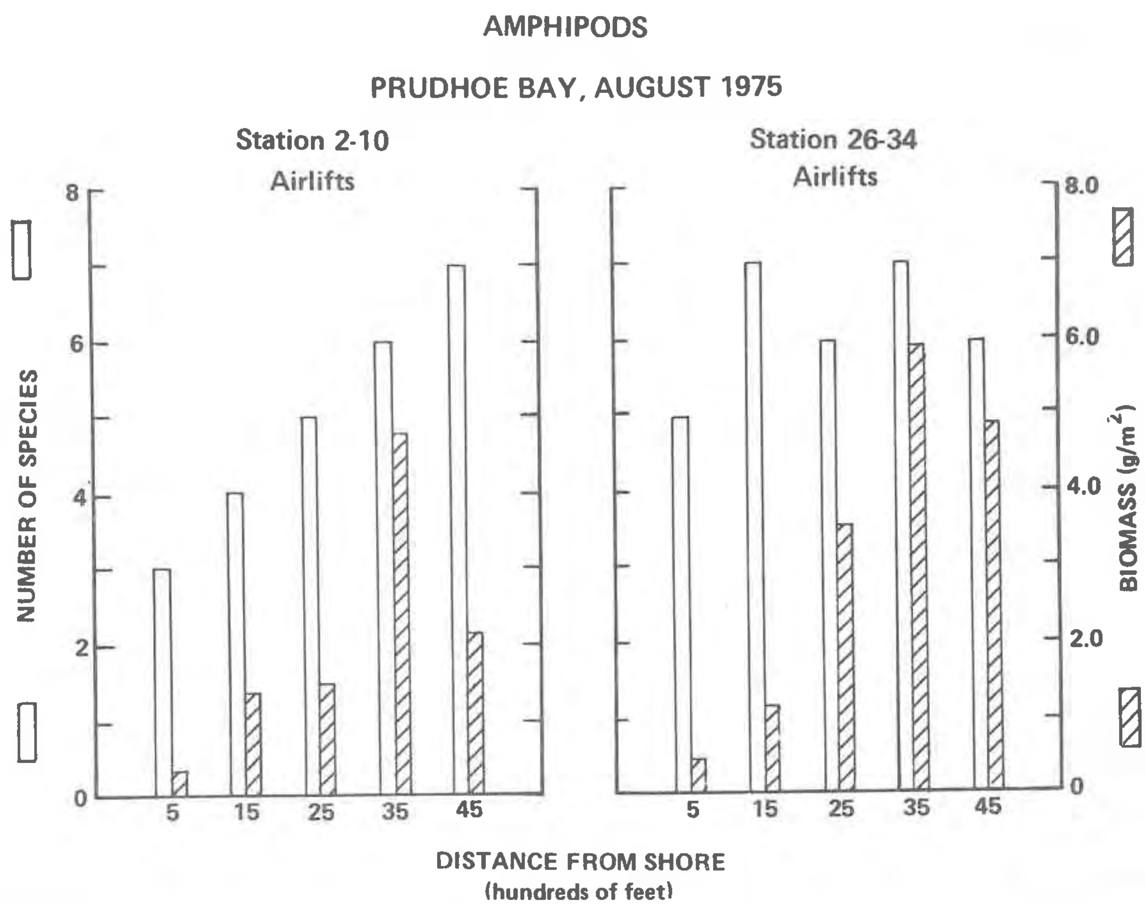


Figure 6. Species number and biomass distribution of amphipods at the new causeway area. Prudhoe Bay, August 1975.

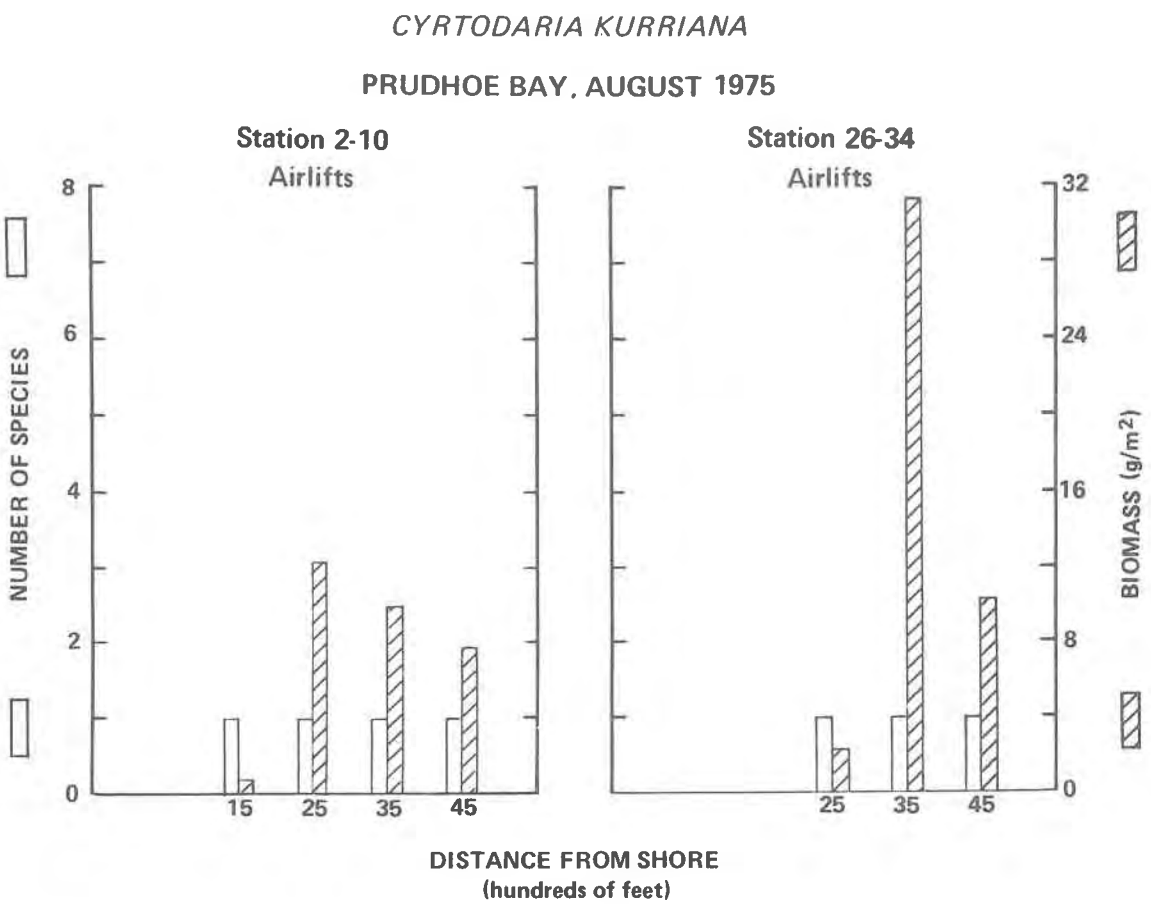


Figure 7. Species number and biomass distribution of the clam *Cyrtodaria kurriana* at the new causeway area. Prudhoe Bay, August 1975.

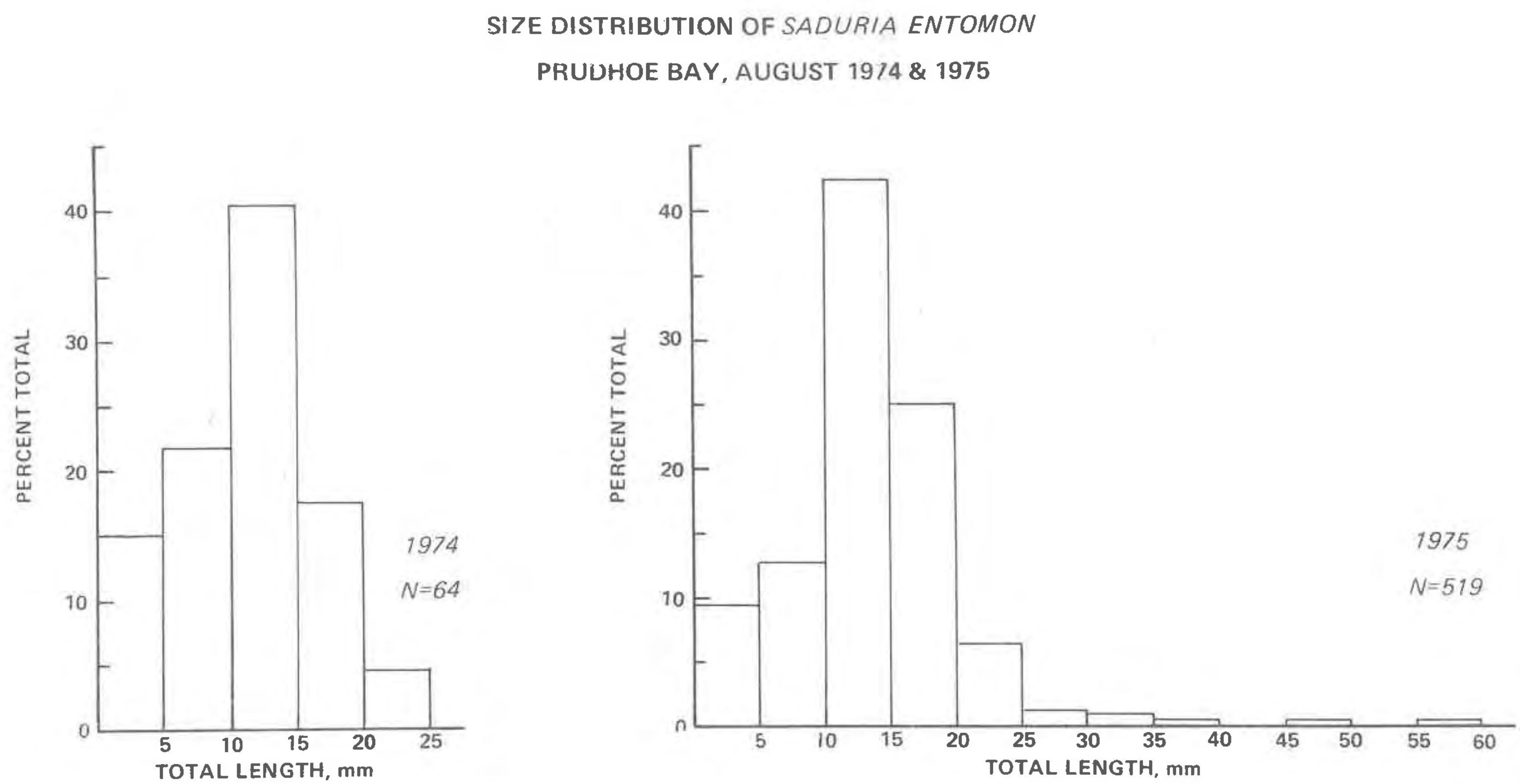


Figure 8. Size distribution of the isopod *Saduria entomon* in the new causeway and Point McIntyre areas, Prudhoe Bay. August 1974 and 1975. Airlift samples only.

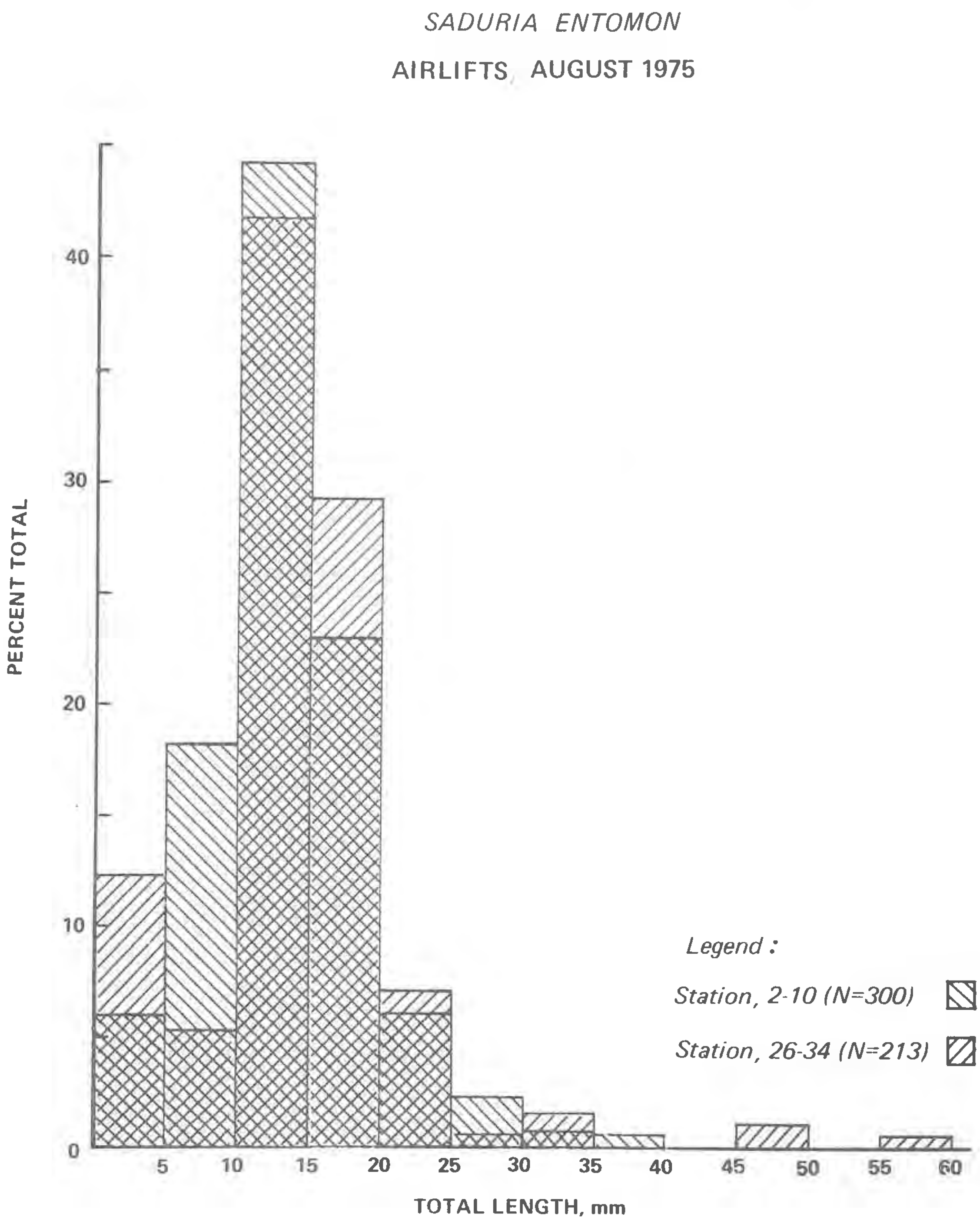


Figure 9. Size distribution of the isopod *Saduria entomon* in the new causeway area. Prudhoe Bay, August 1975. Airlift samples only. Crosshatching indicates overlap.

marked decrease in biomass was noted (Table II). The latter trend was primarily a reflection of the decrease in one species, the amphipod *Pontoporeia affinis*, along the transect.

Most of the polychaetous annelids collected in the new causeway area were sessile, tube-dwelling species (Table III). The majority are also deposit feeders. The feeding methods used by most of the amphipods are unknown. However, based on collections made in baited traps, at least some amphipod species (*Boekosimus affinis, Onisimus* sp., *Gammaracanthus loricatus* and *Gammarus zaddachi*) can function as scavengers. Only two suspension-feeding species were identified in 1975, the clam *Cyrtodaria kurriana*, and the polychaete *Chone duneri*. The remaining species appear to be primarily scavengers or deposit feeders (Table III).

The Biologically Important Species (BIS) for 1974 and 1975 are listed in Table IV. In general, a species may be rated BIS by any of three criteria; ubiquity, biomass or numbers of individuals. A species needs to be rated BIS at only one station in order to be listed in Table IV. As such, many of the species that were BIS in a single year only were important at one station (the sponge *Haliclona rufescens*, an unknown nemertean, the snail *Margarites helicina*, the polychaete *Chone duneri* and the amphipod *Pontoporeia femorata*). With these five species "removed" from the list, the similarity between the two years is almost exact. The only remaining species not occurring as a BIS both years, *Halicryptus spinulosus*, gained BIS status through ubiquity in 1975.

Qualitative Studies - Baited Trap and Selected Sampling at Gull Island

Amphipod numbers in the fish traps peaked 3,500 feet from shore (Table V), as was seen in the airlift samples. The most numerous amphipod,

Table II. A comparison of airlift samples at stations 37, 38, and 39. August 1974 and 1975.*

Station No.	No. Species 1974	No. Species 1975	No. Indiv/m^2 1974	No. Indiv/m^2 1975	Biomass(g/m^2) 1974	Biomass(g/m^2) 1975	Gleason Index 1974	Gleason Index 1975	Shannon-Wiener Index 1974	Shannon-Wiener Index 1975	Simpson Index 1974	Simpson Index 1975
37	13	11	392	438	1.534	3.996	2.28	1.76	2.09	0.74	0.34	0.71
38	8	10	268	173	1.426	2.138	1.43	1.68	1.67	0.93	0.41	0.61
39	6	13	188	155	1.888	1.681	1.16	2.24	1.28	1.84	0.47	0.21

Station No.	Polychaetes No. Species 1974	Polychaetes No. Species 1975	Polychaetes Biomass (g/m^2) 1974	Polychaetes Biomass (g/m^2) 1975	Amphipods No. Species 1974	Amphipods No. Species 1975	Amphipods Biomass (g/m^2) 1974	Amphipods Biomass (g/m^2) 1975
37	2	-	0.012	-	5	7	1.280	3.741
38	1	2	0.004	0.008	4	5	0.860	1.871
39	-	4	-	0.127	3	6	0.444	1.007

*No clams were collected at these stations.

Table III. Feeding methods used by invertebrate species collected at stations in Prudhoe Bay in August 1974 and 1975. 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				
Rhynchospio sp.	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			
Arenicola glacialis	A	X				
Sphaerodoropsis minuta	A	X				

Table III. Continued

Species	Phylum	Deposit Feeder	Suspension Feeder	Scavenger	Predator	Unknown
Oligochaete (1 species?)	A	X				
Ostracod (1 species?)	R					X
Copepod (1 species?)	R					X
Mysis sp.	R					X
Diastylis sulcata	R	X				
Saduria entomon	R			X		
Pontoporeia affinis	R					X
Pontoporeia femorata	R					X
Boekosimus affinis	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			?		
Aceroides latipes	R					X
Tunicate (1 species)	C			X		

Table IV. A list of the Biologically Important Species (BIS) at the 13 stations at the new causeway area, Prudhoe Bay, Alaska. August 1974 and 1975. (See Feder *et al.*, 1973 for criteria).

Taxon	
Phylum Porifera	
	Haliclona rufescens[a]
Phylum Nemertea	
	unknown species[a]
Phylum Priapulida	
	Halicryptus spinulosus[b]
Phylum Mollusca	
	Margarites helicina[a]
	Cyrtodaria kurriana[c]
Phylum Annelida	
	Eteone longa[c]
	Scolecolepides arctius[c]
	Pygospio elegans[c]
	Cirratulus cirratus[c]
	Ampharete vega[c]
	Chone duneri[a]
Phylum Arthropoda	
	Mysis sp.[c]
	Diastylis sulcata[c]
	Saduria entomon[c]
	Pontoporeia affinis[c]
	Pontoporeia femorata[a]
	Boekosimus affinis[c]
	Onisimus glacialis[c]
	Onisimus littoralis[c]
	Monoculopsis longicornis[c]
	Oediceros saginatus[c]

[a]BIS 1974 only.

[b]BIS 1975 only.

[c]BIS 1974 and 1975.

Table V. Amphipod and isopod (*Saduria entomon*) numbers taken in fish traps, August 1975.

Amphipod Species	Distance from shore (ft.) 500	1500	2500	3500	4500
Gammaracanthus loricatus	34	23	10	22	1
Gammarus zaddachi	14	4	7	6	4
Boekosimus affinis	56	106	153	701	366
Onisimus glacialis	1	–	5	–	2
Onisimus littoralis	1	16	2	–	6
TOTAL	106	149	177	729	379

Saduria entomon	Stations 2	4	6	8	10
Age/Sex	Distance from shore (ft.) 500	1500	2500	3500	4500
Adult male	50	15	1	4	2
Adult female	257	18	2	7	–
Juveniles	27	22	14	33	2
TOTAL	334	55	17	44	4

Boekosimus affinis, was primarily responsible for the above trend. The other four species showed no real trends in distribution. *Pontoporeia* sp. is notably absent from the traps.

Isopod numbers decreased with increased water depth (Table V), a reverse of the airlift trend. Adults were most prevalent in shallow water, whereas juveniles were fairly evenly dispersed throughout the sampling area. The size distribution and sex composition of isopods is given in Figure 10.

In 1974, a total of only three cores were taken at Gull Island. *Saduria entomon* was the most common organism found. *Chone duneri* and *Prionospio cirrifera* were also found. In 1975, five replicate cores were taken from each of three stations (Appendix A, Fig. 1; The Arctic Coastal Environment of Alaska, Data Supplement, 1976). *Onisimus glacialis* was the dominant organism and was found in all but two of the cores. Only one individual of *Saduria entomon* was found. Five of the six new species found in 1975 (an unknown nemertean, the polychaete *Cirratulus cirratus*, the cumamean *Diastylis sulcata* and the amphipods *Pontoporeia affinis* and *Monoculopsis longicornis*) were neither numerous nor widespread. *Pygospio elegans*, the last new addition in 1975, was abundant only at Station B (Appendix A, Fig. 1).

Reproductive Activity

Reproductive activity is outlined in Table VI. Four species of polychaetes were bearing eggs. One species of amphipod was brooding young and tiny individuals of four other species were noted. The fact that several individuals of *Diastylis sulcata* had empty brood pouches indicates the recent release of young. Individuals of *Saduria entomon* were found in all stages of reproduction (Fig. 11), indicative of a long reproductive period.

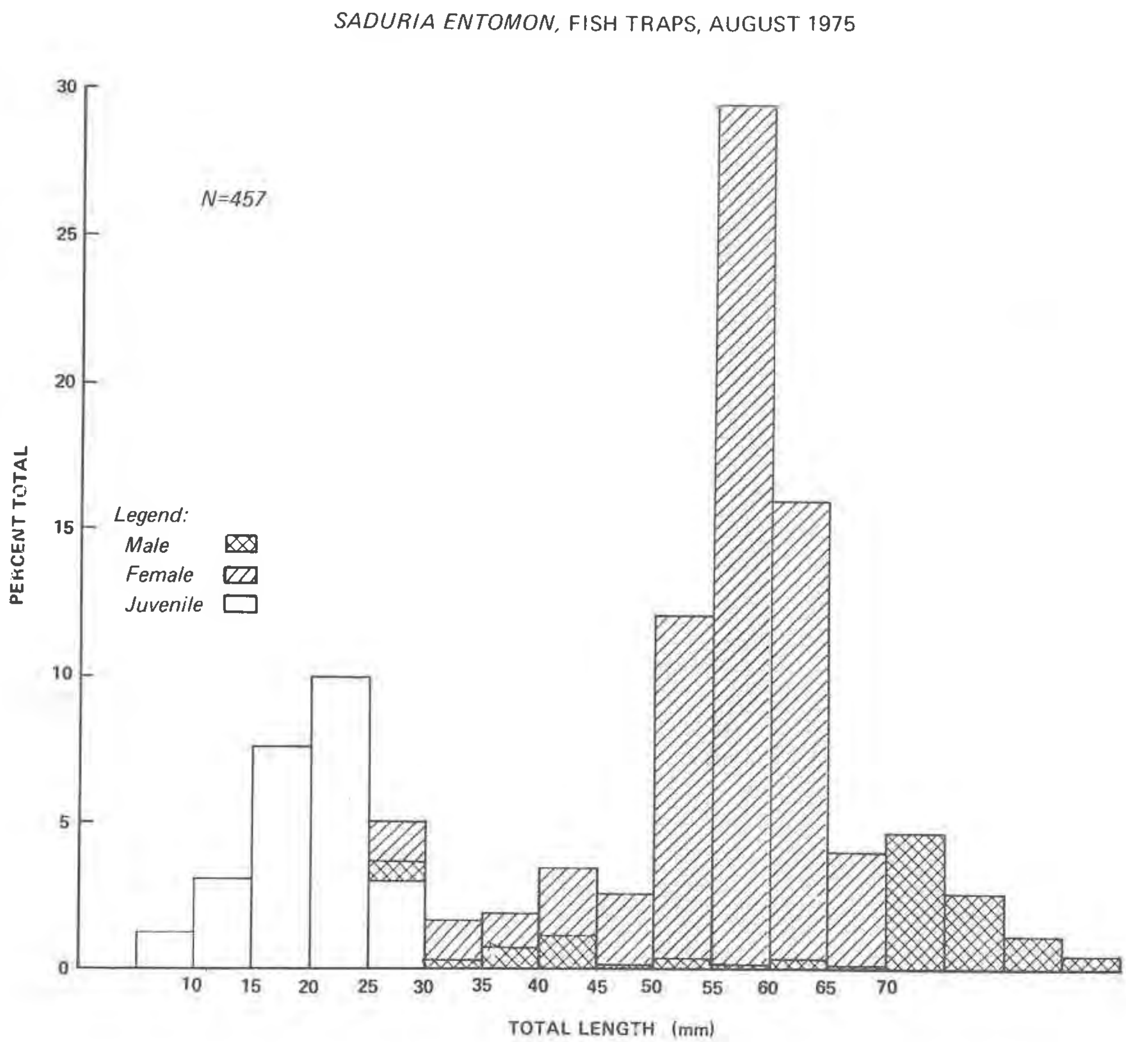


Figure 10. Size distribution, by age and sex, of the isopod *Saduria entomon*, Prudhoe Bay. August 1975. Fish traps.

Table VI. Reproductive activity, Prudhoe Bay. August 1975.

Species	Female w/eggs	Female w/young	Female w/empty brood pouch	Tiny individuals
Cirratulus cirratus	X	–	–	–
Ampharete vega	X	–	–	–
Scolecolepides arctius	X	–	–	–
Chaetozone setosa	X	–	–	–
Boekosimus glacialis	–	X	–	–
Diastylis sulcata	–	–	X	–
Oediceros saginatus	–	–	–	X
Gammaracanthus loricatus	–	–	–	X
Onisimus affinis	–	–	–	X
Pontoporeia affinis	–	–	–	X
Saduria entomon	X	X	X	X

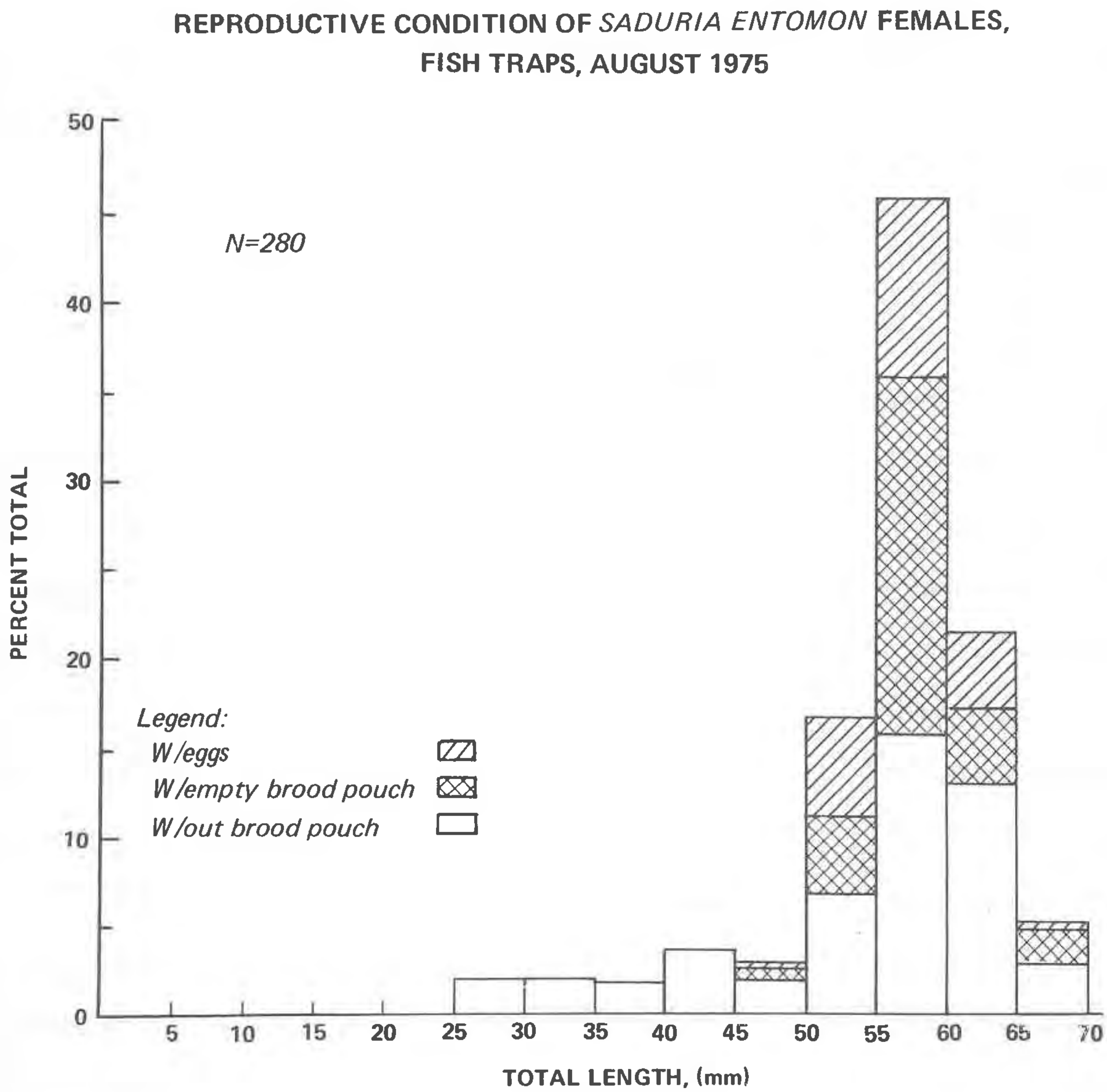


Figure 11. Reproductive condition of *Saduria entomon* females. Prudhoe Bay, August 1975. Fish traps.

The presence of more gravid and brooding females in 1975 as compared to 1974 (see comments in Feder *et al.*, 1976a) indicates either, 1) a phenological delay in reproductive activity, or 2) an extension of the reproductive period.

For a review of reproductive patterns in the arctic, see Feder *et al.* (1976a, p. 55; Feder and Schamel, 1976).

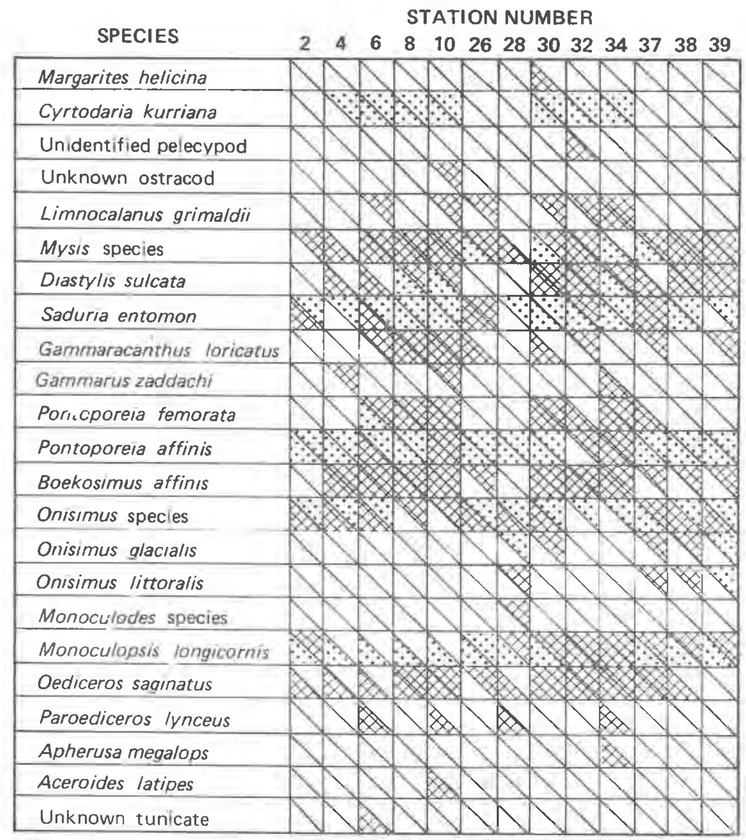
For detailed data for all species used for generation of tables and figures in this report see Appendix B.

DISCUSSION AND COMPARISON OF THE RESULTS OF 1974 AND 1975

Distribution and Relative Importance of Species

Distribution and relative importance of species in the new causeway area are summarized for 1974 and 1975 in Table VII (also see Table I for listing of species and common names). Some similarities and differences between years are worth reviewing briefly. *Eteone longa* occurred at all water depths and was present at more stations in 1975. *Scolecolepides arctius* was widely distributed but tended to be more numerous in shallow water. It was present in the Pt. McIntyre transect in 1975 but not 1974. *Spio mimus* was more common in 1975; in 1974 it was found in Fager cores only. *Pygospio elegans* was found only in the more shallow stations whereas *Cirratulus cirratus*, *Chaetozone setosa* and *Chone duneri* were limited to deeper water in both summers. *Ampharete vega* was also limited to deeper water and occurred in large numbers, particularly in 1975. *Sphaerodoropsis minuta* was found only at station 34 both years. *Halicryptus spinulosus* was found at more stations in 1975, usually in deeper water. *Cyrtodaria kurriana* was limited to deeper water where it occurred in large numbers; it was found at one additional station in 1975. *Diastylis sulcata* was most common in deeper water in 1974 and 1975. *Diastylis* males

Table VII. Species distribution and importance in the new causeway area, Prudhoe Bay, Alaska. August 1974 and 1975. Airlifts. BIS = Biologically Important Species.



occurred in the shallow Pt. McIntyre area in 1975. Both *Mysis* sp. and *Saduria entomon* were present throughout the study area both summers, with the latter species abundant throughout. *Gammaracanthus loricatus* was found at all depths in 1974 and 1975, though it was most prevalent in deeper water. *Pontoporeia affinis* showed the opposite trend; it was most common in shallower water. *Pontoporeia femorata* was limited to deeper water. *Boekosimus affinis* (= *Onisimus* sp. in 1974) was found in all but the shallowest water near the causeway. It occurred at the Pt. McIntyre transect only in 1975. *Onisimus* sp. (= *Pseudalibrotus* in 1974) was much more numerous and widespread in 1975 than in 1974. It was found in large numbers throughout, though somewhat less prevalent in deeper water. *Monoculopsis longicornis* was much more abundant in 1974 than in 1975. *Oediceros saginatus* was less widespread in 1975 than it had been in 1974.

The greatest difference between the two years involved the large increase of the amphipods *Onisimus* sp. and equally large decrease of *Monoculopsis longicornis*. The increased distribution of the priapulid *Halicryptus spinulosus* and the polychaete *Eteone longa* may also be meaningful differences. The distributions of both the clam *Cyrtodaria kurriana* and the polychaete *Ampharete vega* were extended into slightly shallower water in 1975. The latter species was also far more important numerically in 1975 than it had been in 1974.

The Distribution of Species Numbers, Biomass and Diversity

The general distributional trends of species, numbers of individuals and biomass were similar over the two years (Figs. 12, 13, and 14). Numbers of individuals and biomass peaked at 3500 feet from shore. All diversity indices showed an increase of diversity and a tendency for a loss of dominance

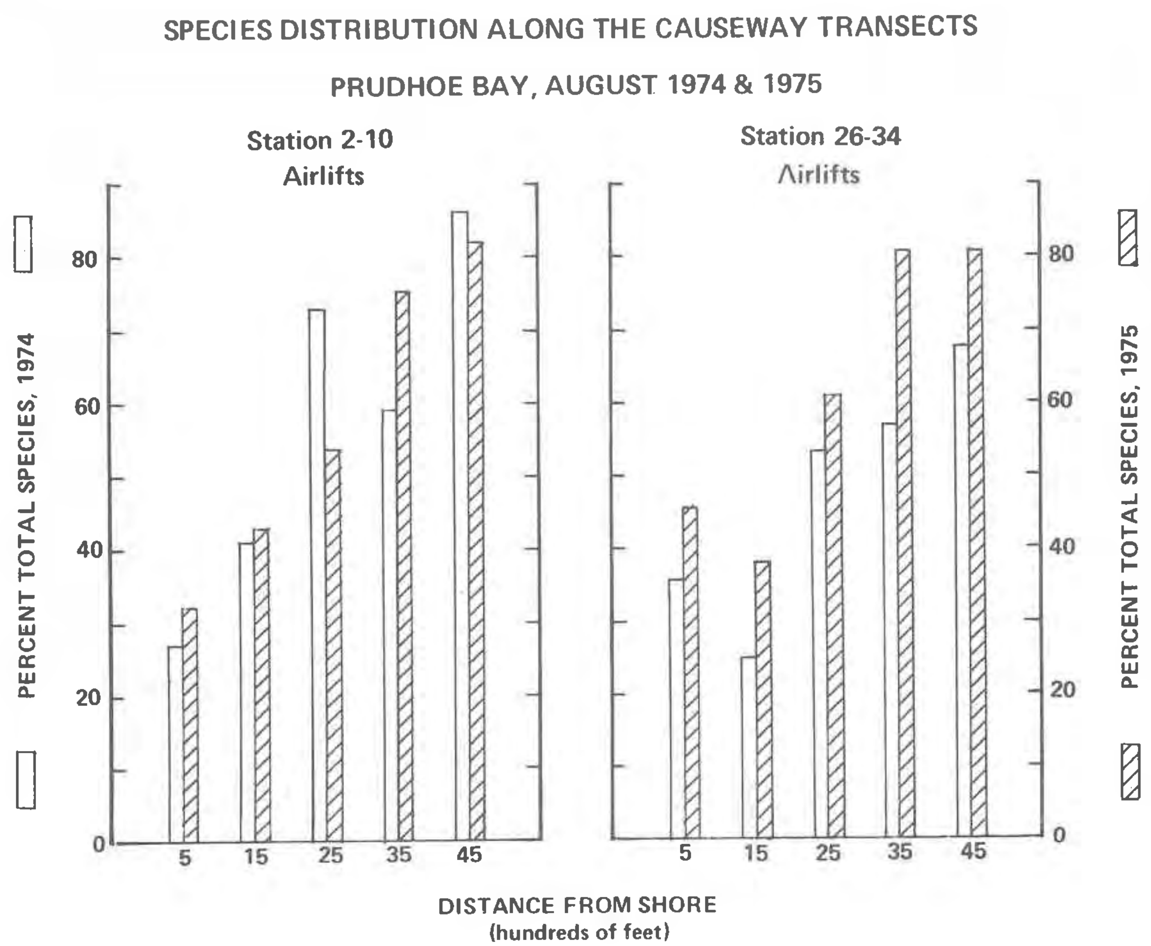


Figure 12. A comparison of species distribution along the causeway transects, Prudhoe Bay. August 1974 and 1975.

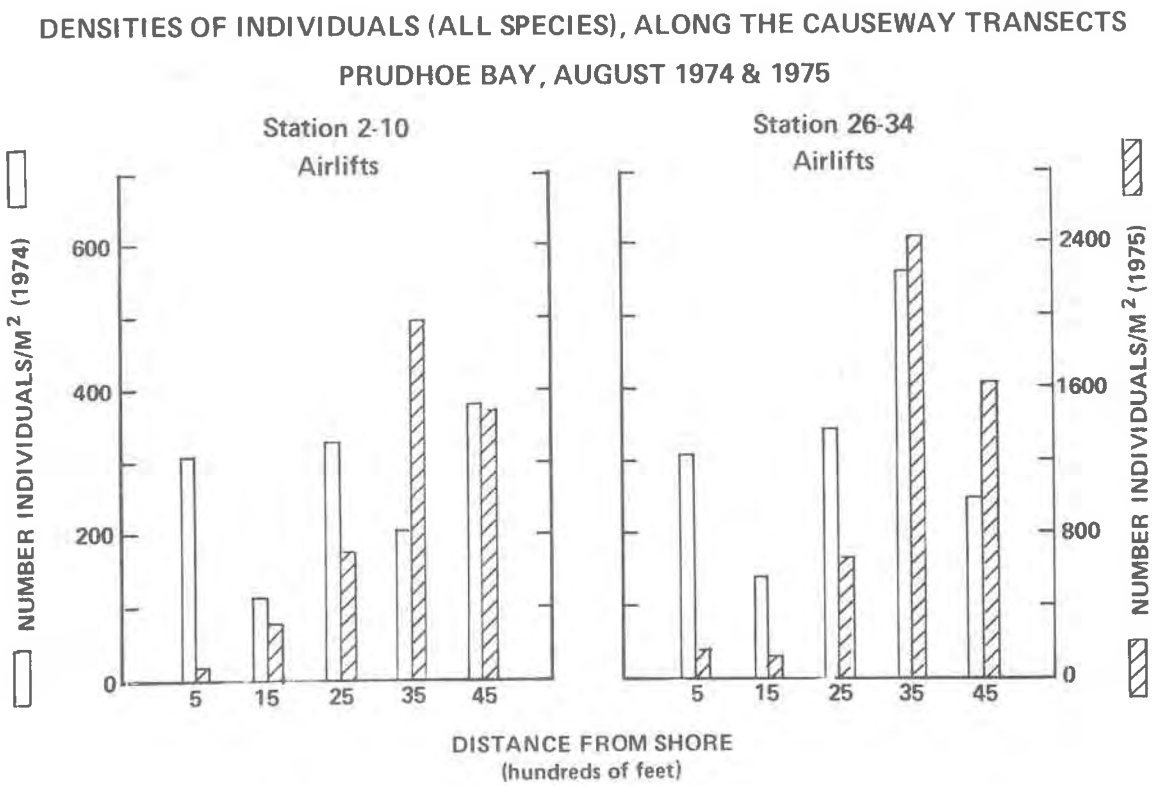


Figure 13. A comparison of densities of individuals along the causeway transects, Prudhoe Bay. August 1974 and 1975. Note expanded ordinate for the 1975 data.

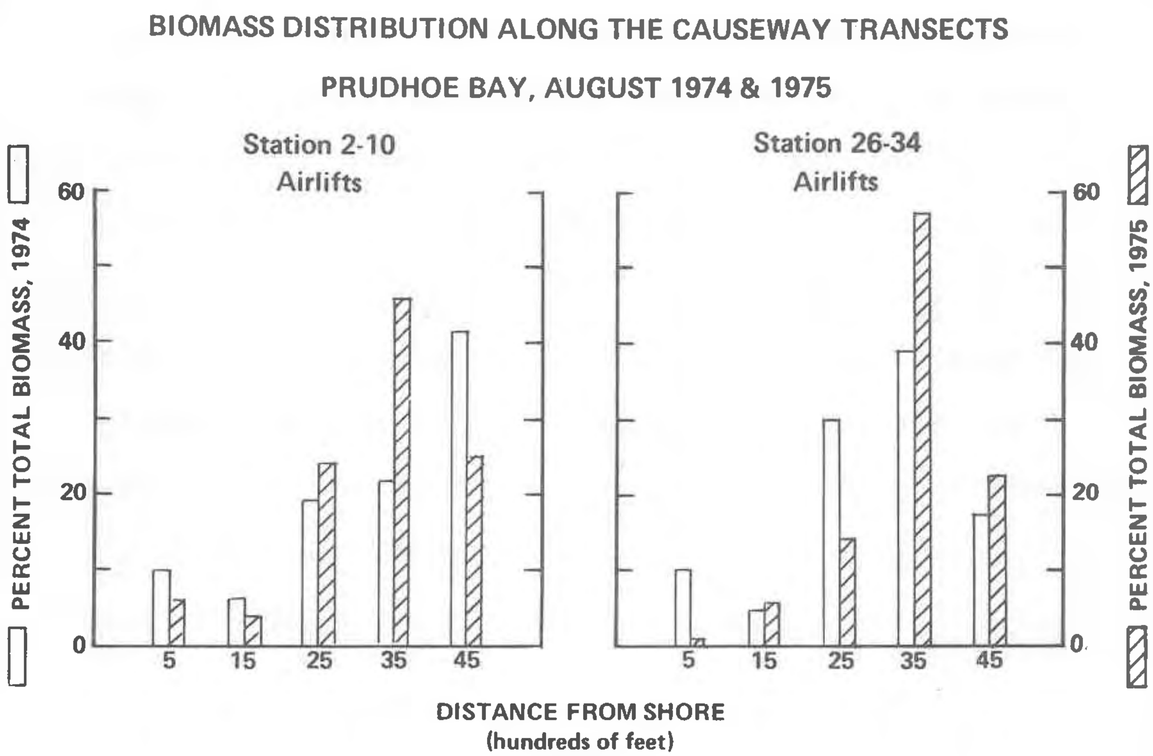


Figure 14. A comparison of biomass distribution (in percent of total biomass) along the causeway transects, Prudhoe Bay. August 1974 and 1975.

with increased water depth (Figs. 4, 15 and 16). In 1975, the Shannon-Wiener Index figures were somewhat lower than the preceding year, suggesting a somewhat less diverse benthic assemblage. Distributional trends for polychaetes and pelecypods were similar both years. Amphipods showed an increased number of species with increased water depth in both 1974 and 1975 (see Feder *et al.*, 1976a for all 1974 data). However, the amphipod biomass decreased with increasing water depth in 1974; in 1975 the biomass tended to increase with increasing water depth.

Although the distributional trends between the two years were very similar, the actual density of each species differed considerably. In 1974 the density of individuals ranged from approximately 100-550/m^2. In 1975 the range was 100-2400/m^2, a five-fold increase (Fig. 13). Biomass figures show even greater differences. In 1974, the range was 0.4 to 3.8 g/m^2, while in 1975 it was 0.5 to 65.4 g/m^2, a 15-fold increase (Table VIII). All three major groups of organisms (polychaetes, amphipods and pelecypods) showed large biomass increases in 1975 (see Feder *et al.*, 1976a; Figs. 5, 6 and 7; The Arctic Coastal Environment of Alaska, Data Supplement, 1976).

Baited Traps and the Gull Island Samples

Amphipods showed a 10-fold increase in the baited traps in 1975. Isopods were also considerably more abundant in 1975, particularly in shallow water (Table V and Feder *et al.*, 1976a, p. 84 for comparative values of 1974). These numerical increases complement those found in the quantitative studies.

The amphipod *Onisimus glacialis* dominated the Gull Island samples in 1975. It was not present in 1974. The absence of some species (i.e., species taken in 1974) and the addition of new species, with the exception

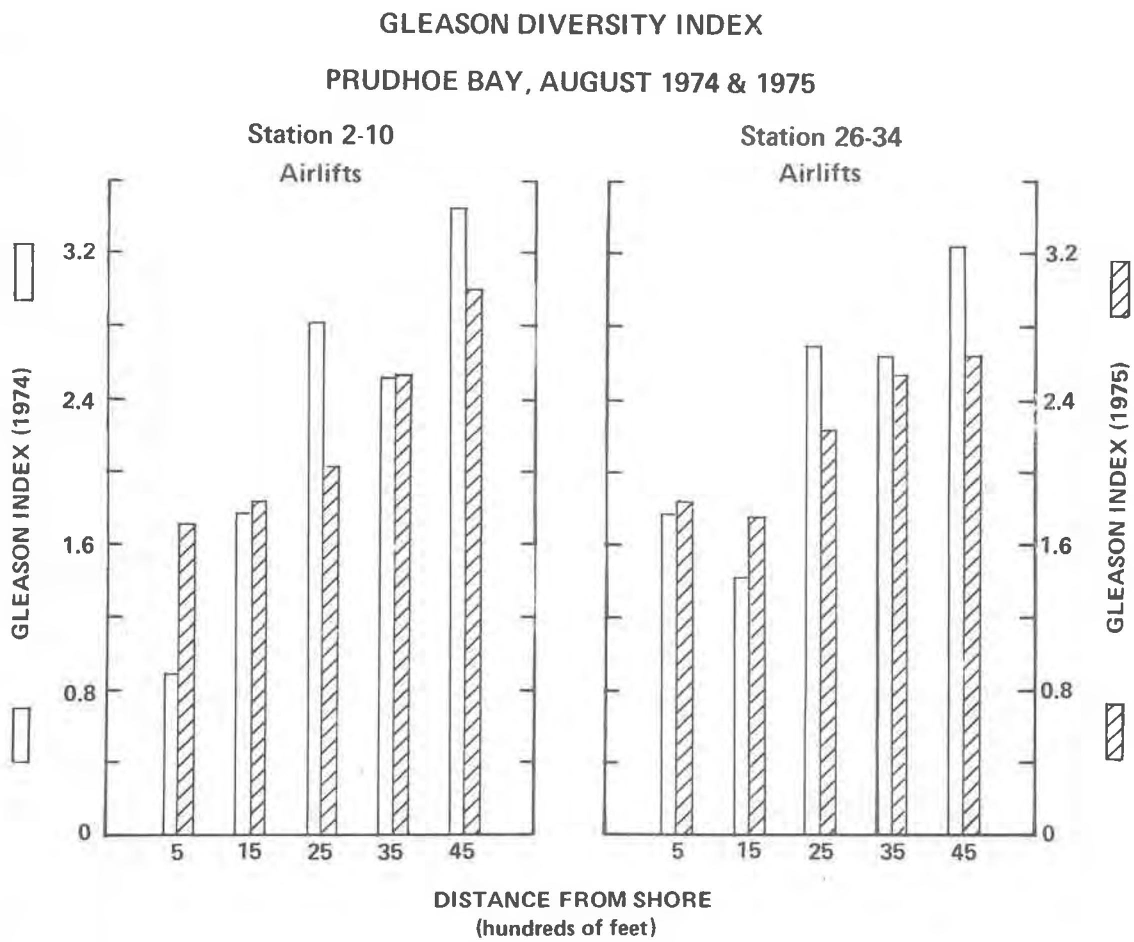


Figure 15. A comparison of the Gleason Diversity Index along the causeway transects, Prudhoe Bay. August 1974 and 1975.

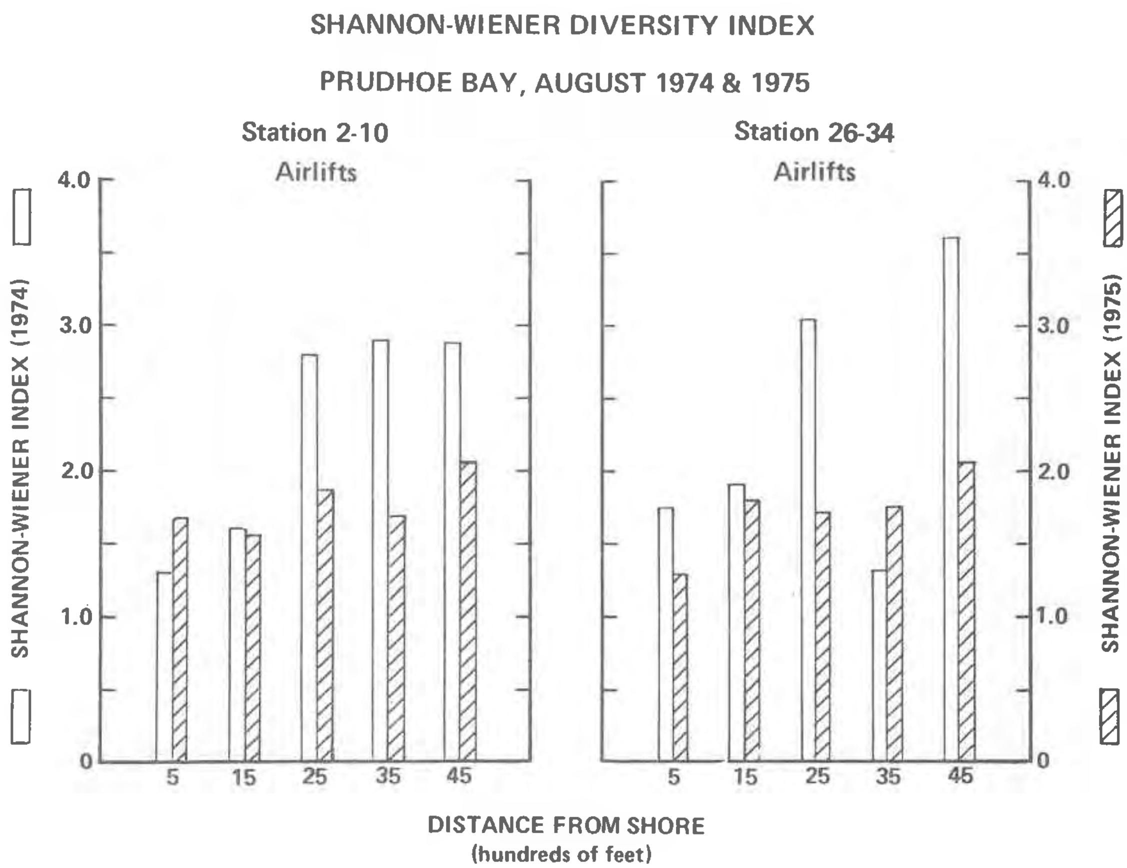


Figure 16. A comparison of the Shannon-Wiener Diversity Index along the causeway transects, Prudhoe Bay. August 1974 and 1975.

Table VIII. A comparison of biomass at the causeway stations, Prudhoe Bay. August 1974 and 1975. Airlift samples only.

	Biomass (g/m^2)	
Station No.	1974	1975
2	0.763	0.590
4	0.488	3.638
6	1.578	22.312
8	1.660	42.078
10	3.138	23.273
26	0.988	0.519
28	0.438	6.434
30	2.916	15.726
32	3.780	65.382
34	1.626	26.076

of *O. glacialis*, were probably due to sampling error. The 1974 stations were not marked for re-occupation in 1975; thus, the 1975 stations (see Appendix A, Fig. 1) were only approximations. In addition, many Fager cores are probably required here to obtain meaningful data when organisms are clumped or highly dispersed, as they appear to be at Gull Island.

Possible Explanations for Discrepancies Between 1974 and 1975 Data

There are many possible explanations for the large biomass differences found in the 1974 and 1975 samples. The simplest explanation pertains to differences in sampling methodology. In 1974, airlift samples were taken to a depth of 4 cm, while in 1975 they were taken to depths of 4 to 7 cm. The addition of one size class of the clam *Cyrtodaria* in 1975 and the presence of more individuals from larger size classes (Fig. 17) indicate that deeper sampling in 1975 may have increased the total take of clams, particularly the larger individuals. However, we suggest that most of these clams, based upon typical siphon to shell length ratios (G. Mueller, pers. comm.), live no deeper than 4 cm. We doubt that sampling deeper than 4 cm would yield a 10-fold increase in clams. As noted in 1974 (Feder *et al.*, 1976a), ampharetids were probably undersampled by the airlift. Deeper sampling in 1975 increased the total numbers significantly. In view of the comment made by D. Lee (Appendix A) concerning the depth to which ampharetid tubes extend into the sediment, the 1975 numbers are probably more accurate. Therefore, the 10-fold increase in ampharetid numbers may not represent a real increase from 1974 to 1975. On the other hand, the three-fold increase in amphipods is certainly real since these organisms are epifaunal.

Patchiness can sometimes account for large biomass differences in numerical estimates, particularly when a small number of samples is involved

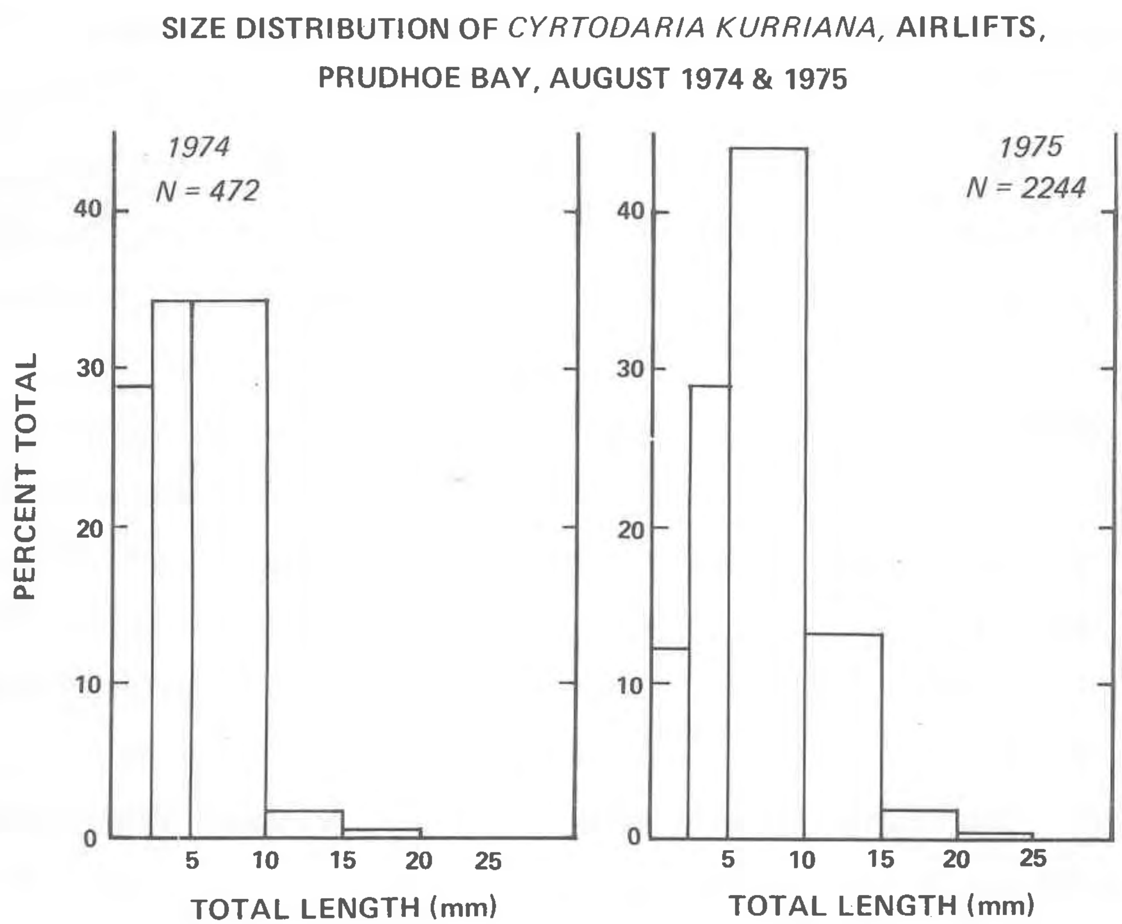


Figure 17. Size distribution of *Cyrtodaria kurriana* in the new causeway area, Prudhoe Bay. August 1974 and 1975.

or a small sample enclosure is used. The consistency of trends between years indicates that patchiness is probably not the explanation for the 1975 increase.

Thus, the observed biomass increase is real and the problem now becomes one of determining whether the change was brought about by the presence of the causeway or by some other phenomenon. In Chapter I, Naidu reports only two statistically significant geological differences between the 1974 and 1975 sediment samples: 1) an increase in organic carbon and, 2) a coarsening of the sediment. He suggests that the increase in carbon is related to the increase in benthic organisms in 1975. In fact, the distribution of organic carbon and total biomass show the same trends (Figs. 14 and 18). This biomass increase affected both sides of the causeway essentially equally. Naidu (Chapter I) found it unlikely that the differences in sediment grain sizes between 1974 and 1975 could be attributed entirely to change in sediment budgets subsequent to causeway construction; the movement of coarse sediments is generally associated with storms.

We cannot associate the increased abundance of organisms with causeway construction. Not only did both sides of the causeway show equivalent increases, but the Pt. McIntyre and Gull Island areas also showed noticeable increases. Naidu's comment (Chapter I) pertaining to the Prudhoe area as a usual low energy depositional environment poses an intriguing possibility. We suggest that the increase in biomass was brought about by the translocation of benthic organisms during storms. The 10-fold increase of clams is not due to recruitment of young (Fig. 17), nor is it due entirely to sampling error, as discussed previously. We suspect that storm waters may move a significant number of benthic organisms towards shore, including both mobile and sessile species. MacGinitie (1955) reported a similar occurrence at Point Barrow, Alaska.

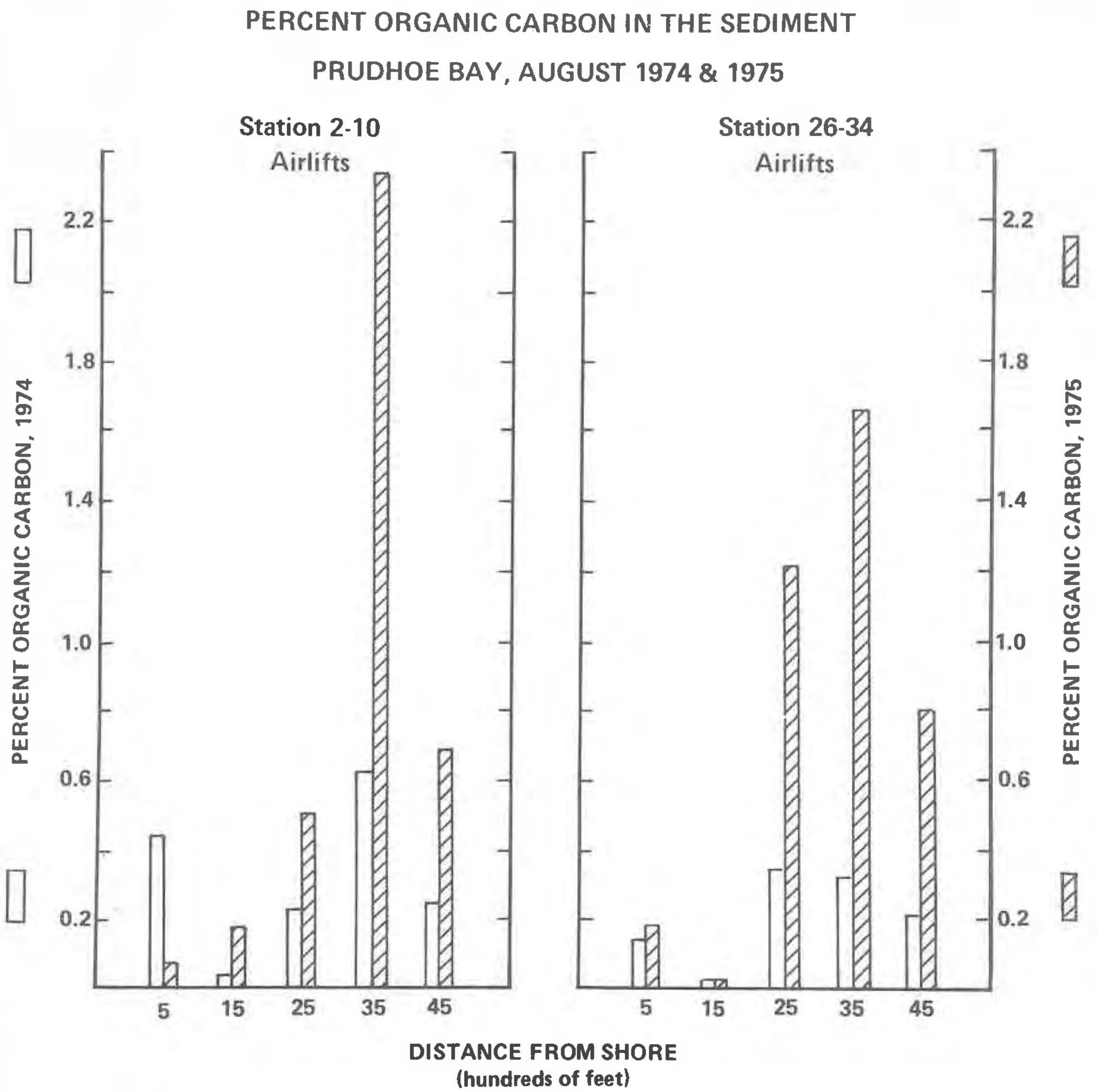


Figure 18. A comparison of the percent organic carbon in the sediments, Prudhoe Bay. August 1974 and 1975.

Also, note that clams and *Ampharete vega* occurred in shallower water in 1975 (Table VII). Organic debris is probably also moved towards shore at such times. The latter material, and animals killed by the storms, would attract mobile scavengers such as amphipods and isopods. An increase of these scavengers was noted in 1975. Weather records from Prudhoe Bay are not readily available but those from Barter Island (U.S. Dept. Commerce, 1974) show that winds averaging greater than 30 mph struck the coast during mid and late September 1974. Such storms could be of sufficient force to translocate organisms.

REFERENCES

Alexander, V. 1974. Primary productivity regimes of the nearshore Beaufort Sea, with reference to the potential role of ice biota. *In* J. C. Reed and J. E. Sater, eds. The Coast and Shelf of the Beaufort Sea. Proc. of a Symposium on the Seacoast and Shelf Research, San Francisco. Arctic Inst. N. Am. 750 pp.

Alexander, V., D. C. Burrell, J. Chang, T. R. Cooney, C. Coulon, J. J. Crane, J. A. Dygas, G. E. Hall, P. J. Kinney, D. Kogl, T. C. Mowatt, A. S. Naidu, T. E. Osterkamp, D. M. Schell, R. D. Seifert and R. W. Tucker. 1974. Environmental Studies of an Arctic Estuarine System, Final Report. Inst. Mar. Sci., Univ. of Alaska, Fairbanks, R74-1, Sea Grant Report 73-16. 539 pp.

Carey, A. G., R. E. Ruff, J. G. Castillo and J. J. Dickinson. 1974. Benthic Ecology of the western Beaufort Sea continental margin: Preliminary results. Symposium on Beaufort Sea Coastal and Shelf Research Program, San Francisco, January 1974. The Arctic Inst. of N. Am. (AINA).

Coyle, K. O. 1974. The ecology of the phytoplankton of Prudhoe Bay, Alaska, 1974. Alaska Dept. Fish and Game. 16 pp.

Crane, J. J. 1974. Ecological Studies of the Benthic Fauna in an Arctic Estuary, M.S. Thesis, Univ. of Alaska, Fairbanks. 105 pp.

Crane, J. J. and R. T. Cooney. 1973. The nearshore benthos. 411-466 pp. *In* Alexander, V. *et al.* 1973. Environmental studies of an arctic estuarine ecosystem. Final Report. Inst. Mar. Sci., Univ. of Alaska, Fairbanks R74-1. 539 pp.

Ellis, D. V. 1960. Marine infaunal benthos in Arctic North America. Arctic Inst. of N. Am. Tech. Paper No. 5. 53 pp.

Fager, E. W., A. O. Flechsig, R. F. Ford, R. I. Clutter and R. J. Ghelardi. 1966. Equipment for use in ecological studies using Scuba. *Limnol. and Oceanogr.* 11:503-509.

Feder, H. M., and D. Schamel. 1976. Shallow-water benthic fauna of Prudhoe Bay. *In* D. W. Hood and D. C. Burrell, eds, Assessment of the Arctic Marine Environment: Selected Topics. Inst. Mar. Sci., Univ. of Alaska, Fairbanks. Occas. Publ. 4 (in press).

Feder, H. M., G. J. Mueller, M. H. Dick and D. B. Hawkins. 1973. Preliminary Benthos Survey. Ch. 9, 305-391 pp. *In* D. W. Hood, W. E. Shiels and E. J. Kelley, eds., Environmental Studies of Port Valdez. Inst. Mar. Sci., Univ. of Alaska, Fairbanks, Occas. Publ. 3. 495 pp.

Feder, H. M., D. G. Shaw and A. S. Naidu. 1976a. The arctic coastal environment of Alaska. Volume 1. The nearshore marine environment in Prudhoe Bay, Alaska. Univ. of Alaska, Inst. Mar. Sci., Fairbanks R76-1, Sea Grant Rept. 76-3. 161 pp.

Feder, H. M., D. G. Shaw and A. S. Naidu. 1976b. The Arctic Coastal Environment of Alaska. Vol. II. A compilation and review of scientific literature of the arctic marine environment. Univ. of Alaska, Inst. Mar. Sci., Fairbanks R76-5, Sea Grant Rept. 76-9. 200 pp.

Horner, R. 1969. Phytoplankton studies in the coastal waters near Barrow, Alaska. Ph.D. Thesis, Univ. Washington, Seattle. 261 pp.

Horner, R. 1972. Ecological studies on arctic sea ice organisms. Inst. Mar. Sci., Univ. of Alaska, Fairbanks, R72-17. 179 pp.

Horner, R. 1973. Studies on organisms found in arctic sea ice. Final report to the Arctic Inst. of N. Am. No report number.

Horner, R., K. O. Coyle and D. R. Redburn. 1974. Ecology of the plankton of Prudhoe Bay, Alaska. Inst. Mar. Sci., Univ. of Alaska, Fairbanks R74-2, Sea Grant Rept. No. 73-15. 100 pp.

Jones, N. S. 1950. Marine bottom communities. *Biol. Rev.* 25:283-313.

Kinney, P., D. Schell, V. Alexander, A. S. Naidu, C. P. McRoy and D. C. Burrell. 1971. Baseline data study of the Alaskan arctic aquatic environment: eight month progress report, 1970. Inst. Mar. Sci., Univ. of Alaska, Fairbanks, R71-4. 176 pp.

Kinney, P., D. Schell, V. Alexander, D. C. Burrell, R. Cooney and A. S. Naidu. 1972. Baseline data study of the Alaskan arctic aquatic environment. Inst. Mar. Sci., Univ. of Alaska, Fairbanks, R72-3. 271 pp.

Lewis, J. R. 1970. Problems and approaches to baseline studies in coastal communities. FAO Technical Conference on Marine Pollution and its Effect on Living Resources and Fishing. FIR:MP 70/E-22. 7 pp.

Lie, U. 1968. A quantitative study of benthic infauna in Puget Sound. Washington, USA in 1963-1964. *Fisk. Dir. Skr.* (Ser. Havunders.) 14: 223-356.

MacGinitie, G. E. 1955. Distribution and ecology of the marine invertebrates of Point Barrow, Alaska. *Smithson, Misc. Coll.* 128:1-201.

Matheke, G. E. M. 1973. The ecology of the benthic microalgae in the sublittoral zone of the Chukchi Sea near Barrow, Alaska. M.S. Thesis, Univ. of Alaska, Fairbanks. 114 pp.

Nelson-Smith, A. 1973. *Oil Pollution and Marine Ecology.* Paul Elek (Scientific Books) Ltd., London. 260 pp.

Pearson, T. H. 1971. The benthic ecology of Loch Linnhe and Loch Eil, a sea loch system on the west coast of Scotland. III. The effect on the benthic fauna of the introduction of pulp mill effluent. *J. Exp. Mar. Biol. Ecol.* 6:211-233.

Pearson, T. H. 1972. The effect of industrial effluent from pulp and paper mills on the marine benthic environment. *Proc. Roy. Soc. London B.* 130:469-485.

Rosenberg, R. 1973. Succession in benthic macrofauna in a Swedish fjord subsequent to the closure of a sulphite pulp mill. *Oikos* 24:244-258.

Sanders, H. L. 1968. Marine benthic diversity: a comparative study. *Amer. Naturalist* 102:243-282.

Simpson, E. H. 1949. Measurement of diversity. *Nature* 163:688.

U. S. Dept. Commerce. 1974. Local climatological data. Annual summary with comparative data. Barter Island, Alaska.

Wilson, D. P. 1953. The settlement of *Ophelia bicornis* Savigny larvae. *J. Mar. Biol. Ass., U.K.* 31:413-438.

APPENDIX A

Field notes of Dennis C. Lees (Dames and Moore, Anchorage) following diving activities at Prudhoe Bay in August 1975.

DESCRIPTION OF COLLECTION METHODS

Infaunal samples were collected by a diver operating an airlift equipped with a nylon collection bag. The diver dropped to the bottom, planted a .25 m^2 quadrat with pegs to prevent its movement after sampling commenced, and then opened the air valve and adjusted the air flow. Sediment within the quadrat was removed to a depth of 3 to 7 cm. Mesh sizes for the collection bags were 0.5 to 1.0 mm on a side.

Accuracy of the collected volume was only moderate because surrounding sediment sloughed into the resulting excavation and the depth of the excavation was only roughly controlled. Efficiency of the airlift varied with sediment type and visibility. Fine sand was most efficiently sampled, whereas the sticky clay and gravel were less so. Poor visibility reduced efficiency because flow rate could not be monitored and optimized.

Samples requiring Fager core collection were collected by manually thrusting the core into the sediment with a vibratory action, digging away the sediment around one side to allow sliding a metal plate under the core to retain the sample contained within, then extracting the core, plate, and sample from the sediment and returning them to the boat for sample curation. Additional sediment samples were collected with a butter dish by scraping it in the upper several centimeters of sediment. Hydrocarbon samples were similarly collected in a glass jar; care was taken not to contaminate the sample or jar with the hands.

FIELD NOTES

August 14, 1975

Weather was good. Tom and I spent the morning and part of the afternoon setting up the Zodiac and compressors, filling tanks, unpacking and checking gear after the trip from Homer to Prudhoe Bay. All the gear arrived in good condition. Motor problems for the University crew caused a slight delay in commencement of sampling, but we were able to take Doug Schamel on the Zodiac and commence sampling at about 1700 hours at the shallowest station on the transect west of the causeway. Depth was approximately 1.2 m. The substrate was not visible because of high turbidity. Touch indicated that the sediment was composed mainly of medium fine sand. Because of poor visibility, faunal observations were impossible.

Sampling with the airlift was slow for several reasons, including poor visibility, shallow depth and clogging of the 0.5 mm mesh collection bag on the airlift. Poor visibility hampered operations because of the inability to see the operation of the airlift and make appropriate adjustments in air flow rate and technique. Only one station was sampled on this day.

August 15, 1975

Weather was good. We utilized a larger collection bag with a 1.0 mm mesh for airlift operations to increase efficiency. We sampled five (three airlift) stations on the transect east of the causeway on this day. Depth ranged from about 2 to 2.5 m; water transparency was about 30 cm. The sediment in the area was silty clay of a sticky, jello-like consistency, similar to that observed in large harbors in southern California; very little shell debris was observed, and suspended organic debris was scarce, but a moderate amount was observed buried in the sediment. The primary source of organics appeared to be tundra; algal material was not observed. Gravel was abundant in patches in certain areas. Ripple marks about 8 by 1 cm were observed.

The airlift stations were dominated by tubiculous worms, probably *Ampharete vega*. This species was distributed in a patchy manner, approaching 200 animals per square meter in some areas. Because the tubes extend more than 10 cm into the sediment (probably at least 30 cm, judging from the 0.5 mm tube diameter), I am convinced that the abundance of this species is largely underestimated. Other organisms observed include the isopod *Saduria entomon*, several species of gammarid amphipod and some sponges living partially buried in the sediment.

During the day, one quadrat was lost and another was broken.

August 16, 1975

Weather was poor, wind averaging about 15 to 20 knots, with scattered showers; chill factor became an important consideration as both divers were dressed in wet Unisuits. Wind chop reached about 45 cm, making operations difficult and uncomfortable at the shallow stations. Sediment in the area was generally medium sand with some silt. Water depth was approximately 1.5 m, somewhat deeper than at comparable stations on the west transect; water temperature was about 7°C; visibility was poor.

We used both the large and small mesh collection bags temporarily but hoped to use only the large mesh bag in order to facilitate collection as it was so much more efficient. Because of poor visibility, faunal observations were impossible.

We completed sampling on the transect east of the causeway at about 1700 hours. I halted field work at that time so the divers could return to ARCO base and get a good night rest as we both had been up late for three nights with preparation, travel, and work on this project, and insufficient sleep was exacerbating the cold conditions.

August 17, 1975

Weather was again poor, with winds approaching 25 knots and their temperature at about 1°C; chill factor was about -14°C. We sampled at six (two airlift) stations on the transect west of the causeway. Depth ranged from 1 to 1.5 m; visibility of the water was 15 cm or less, water temperature had decreased to about 5.5°C.

Sediments varied from silty sand to silty clay. Clods of tundra were observed in many locations. During the sampling, we observed the isopod *Saduria entomon* on the bottom and gammarid amphipods in the water column. It appears that the gammarids use the tundra clods as a substrate. It further appears that the large isopods and *Ampharete* are more abundant at the stations with fine sediments (either silt or clay).

August 18 & 19, 1975

Inclement weather; winds continue at 25 knots or greater, causing an unpleasant combination of wind chop and chill.

August 20, 1975

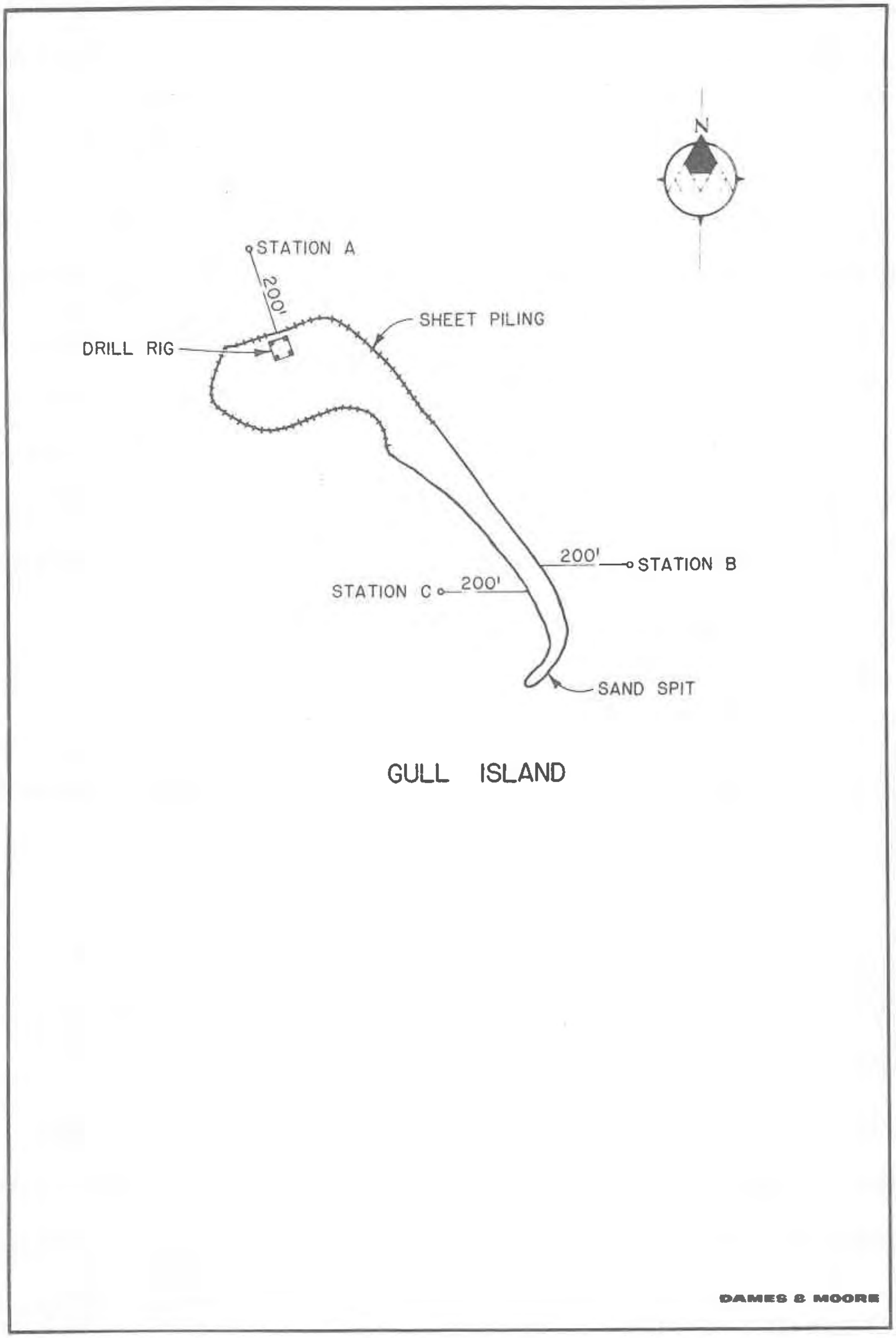
Weather conditions were greatly improved; wind decreased to 5 knots or less. We sampled at the outer stations on the transect west of the causeway, completing the causeway sampling program. Depth was approximately 2 m; visibility in water still poor as a result of previous weather so there were no observations on the fauna. Sediments in this area were the sticky, jello-like clay.

In the evening, Tom and I took the Zodiac to Gull Island (transit time about 15 minutes) where we collected samples at three locations (Appendix A, Fig. 1). At each station we collected five Fager cores for infaunal analysis, 1 Fager core for sediment analysis, and 1 butter dish for sediment analysis. All stations were located approximately 200 feet from Gull Island. Station A was at the northern end of the island at a depth of 1.3 m. The sediment was fine silty gray-brown sand; gravel dominated about 30 m offshore. The water was too turbid to make faunal observations. Station B was located on the east side of the southern sand spit in a depth of 1 m; visibility in the water was about 15 cm. Water temperature was about 6°C. The sediment was a fine silty brown sand; ripple marks were about 5 cm apart and irregular. Gammarid amphipod and small isopod trails were observed on the bottom. Station C was located on the west side of the southern sand spit in a depth of 0.8 m; visibility in the water was about 15 cm. The sediment was a sandy, sticky clay with indistinct ripple marks. Numerous large trails, probably made by isopods, were observed throughout the area.

August 21, 1975

Tom and I returned to Stations B and C on Gull Island to obtain hydrocarbon samples overlooked on the previous day.

We then sampled three airlift stations on a transect off Point MacIntyre, west of the causeway. Five .25 m^2 airlift samples and miscellaneous sediment samples were collected at each station. Depths ranged from 0.8 to 1.3 m; visibility in the water was about 0.7 m. The sediment at all stations was fine clean yellow-brown sand with some silt, little shell debris, and a moderate amount of suspended organic debris. Gravel was present and patchy, located mainly below the sediment surface. Ripple marks were quite



Appendix A Figure 1. Map of Gull Island, Alaska, showing sampling locations, Prudhoe Bay. August 1975.

regular, about 6 cm by 1 cm. Mysids and gammarid amphipods were noted at the water/sand interface, but few other live animals were collected. Drilled pelecypod shells were common in the area, but were possibly introduced by ice transport.

GENERAL COMMENTS

The invertebrate fauna observed in the study area seems primarily dependent upon suspended particulate organic debris, and is apparently mainly supported by tundra. The only large invertebrate capable of utilizing plankton for food was the clam *Cyrtodaria*. Principal predators in the system appear to be several species of fish, mainly arctic char, gadids, and possibly grayling. There was also questionable evidence of a predatory gastropod drilling small clams.

In view of the apparently large amount of organic debris in the sediment, the absence of deposit feeders in the samples is surprising, but may be a consequence of the shallowness of sampling. My experience suggests that many deposit feeders live deeper than 10 cm in the sediment.

Biomass and the numbers of species and individuals per unit area are quite low compared to other areas I have examined, and support the hypothesis that the system is stringently physically accommodated. This, of course, is to be expected in such shallow water in the Beaufort Sea. The physical rigor of the sampling area would suggest that the infaunal invertebrates are all annuals and that the substrate is inhabited only during the period of the year when the water is not frozen to the bottom. However, the apparent size distribution of the isopod *Saduria entomon* is at least bimodal, suggesting at least two size classes. This distribution suggests that either the population migrates to deeper water in the winter or that at least two species are included in the taxon referred to as *S. entomon*. The latter hypothesis is supported by observations that the larger specimens are generally more abundant on clay substrate whereas the smaller specimens are more abundant on sandy substrate. It would be useful to collect considerable data on size and reproductive condition to resolve this apparent discrepancy. (A third, highly improbable, alternative is that the population somehow overwinters in the sediment under the ice in shallow water.)

RECOMMENDATIONS

1. The amount of time allocated for the field portion of this survey should be increased from the present 7 days to 10 days since the number of replicates at each station has been increased by 150 percent since the last survey.
2. The sampling operation should be streamlined to increase efficiency. This can be accomplished by:
   a) increasing the number of collection bags to at least four;
   b) modifying the airlift so that bag exchange at the surface is more rapid; and
   c) improving wash down techniques for the samples in the collection bag, allowing more rapid removal of the sample.
3. Use of a cofferdam quadrat to eliminate sloughing and current induced filling of the excavation, and thereby improve the quantitative aspects of the samples. Also, a frame could be incorporated into the cofferdam to allow closer control of the depth sampled by the airlift.

4. Sediment samples are far more efficiently collected using a small diver-held corer and Whirl-Pak bags than with the Fager corer and butter dishes. Furthermore, loss of fine sediments is reduced. Consequently, the resulting sample is much more representative of real conditions than a bottom scraping.
5. Collect a few 1/10 square meter samples at least 45 cm deep throughout the area to determine if any organisms live deeper than 10 cm in the sediment.

APPENDIX B

Detailed data for all species used for generation of Tables and Figures in this report.

Key for sizes classes recorded in Tables I through IX.

Size classes:

1	0 - 5 mm	10	45 - 50 mm
1A	0 - 2.5 mm	11	50 - 55 mm
1B	2.5 - 5 mm	12	55 - 60 mm
2	5 - 10 mm	13	60 - 65 mm
3	10 - 15 mm	14	65 - 70 mm
4	15 - 20 mm	15	70 - 75 mm
5	20 - 25 mm	16	75 - 80 mm
6	25 - 30 mm	17	80 - 85 mm
7	30 - 35 mm	18	85 - 90 mm
8	35 - 40 mm		
9	40 - 45 mm		

APPENDIX B TABLE I

Shell lengths of the clam *Cyrtodaria kurriana* from stations 6, 8, and 10. Collection of August 1974.

	Size Class							
	1A	1B	2	3	4	5	6	Total
Sta. 6								
Sample F1[a]	–	2	–	–	–	–	–	2
2	–	–	–	–	1	–	–	1
3	1	1	–	–	–	–	–	2
A1[b]	8	4	–	–	–	–	–	12
2	7	6	3	–	–	–	–	16
Total	16	13	3	0	1	0	0	33
Percent	48.5	39.3	9.3		3.9			
Sta. 8								
Sample F1	2	1	1	–	–	–	–	4
2	1	3	–	1	–	–	–	5
3	–	1	4	–	–	–	–	5
A1	8	–	3	–	–	–	–	11
2	5	4	4	–	–	–	–	13
Total	16	9	12	1	0	0	0	38
Percent	42.1	23.7	31.6	2.6				
Sta. 10								
Sample F1	1	2	2	–	–	–	–	5
2	–	–	–	–	–	–	–	–
3	1	1	3	–	–	–	–	5
A1	10	9	6	–	–	–	–	25
2	17	25	15	–	–	–	–	57
Total	29	37	26	0	0	0	0	92
Percent	31.5	40.2	28.3					

[a]F = Fager core collection.

[b]A = Airlift collection.

APPENDIX B TABLE II

Shell lengths of the clam *Cyrtodaria kurriana* from stations 30, 32, and 34. Collection of August 1974.

	Size Class							
	1A	1B	2	3	4	5	6	Total
Sta. 30								
Sample F1[a]	–	–	1	1	–	–	–	2
2	1	–	–	–	–	–	–	1
3	1	–	–	–	–	–	–	1
A1[b]	12	5	2	–	–	–	–	19
2	12	8	3	–	–	–	–	23
Total	26	13	5	1	0	0	0	45
Percent	59.0	26.0	10.0	2.0				
Sta. 32								
Sample F1	1	7	5	1	–	–	–	14
2	2	4	3	–	–	–	–	9
3	–	3	3	–	–	–	–	6
A1	20	36	64	4	–	–	–	124
2	22	33	35	2	–	–	–	92
Total	45	83	110	7	0	0	0	245
Percent	18.4	33.9	44.9	2.8				
Sta. 34								
Sample F1	–	2	1	–	–	–	–	3
2	–	–	2	–	1	–	–	3
3	–	2	–	–	–	–	–	2
A1	2	–	–	–	–	–	–	2
2	3	3	3	–	–	–	–	9
Total	5	7	6	0	1	0	0	19
Percent	26.3	36.8	31.6		5.3			

[a]F = Fager core collection.

[b]A = Airlift collection.

APPENDIX B TABLE III

Shell lengths of the clam *Cyrtodaria kurriana* from stations 4, 6, 8, and 10. Collection of August 1975.

	Size Class 1A	1B	2	3	4	5	6	Total
Sta. 4								
Sample 1	–	–	1	–	–	–	–	1
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	–	–	–	1	–	–	–	1
5	–	–	–	–	2	–	–	2
Total	0	0	1	1	2	0	0	4
Percent			25.0	25.0	50.0			
Sta. 6								
Sample 1	6	15	13	1	–	–	–	35
2	6	7	7	1	–	–	–	21
3	16	19	16	–	–	1	–	52
4	12	12	29	10	–	1	–	63
5	22	18	41	15	–	1	–	97
Total	62	71	106	27	0	3	0	269
Percent	23.0	26.4	39.4	10.0		1.1		
Sta. 8								
Sample 1	14	48	78	16	–	–	–	156
2	8	58	82	6	4	–	–	158
3	14	29	50	6	–	–	–	99
4	8	12	22	3	1	–	–	46
5	2	13	11	3	–	–	–	29
Total	46	160	243	34	5	0	0	488
Percent	9.4	32.8	49.8	7.0	1.0			
Sta. 10								
Sample 1	–	4	14	1	–	–	–	19
2	4	4	20	1	–	–	–	29
3	7	22	68	12	–	–	–	189
4	6	19	32	5	–	–	–	62
5	5	23	28	5	–	–	–	61
Total	22	72	162	24	0	0	0	280
Percent	7.8	25.7	57.8	8.6				

APPENDIX B TABLE IV

Shell lengths of the clam *Cyrtodaria kurriana* from stations 30, 32, and 34. Collection of August 1975.

	Size Class							
	1A	1B	2	3	4	5	6	Total
Sta. 30								
Sample 1	–	3	5	1	–	–	–	9
2	–	1	1	4	–	–	–	6
3	–	2	7	1	1	–	–	11
4	1	3	7	1	–	–	–	12
5	–	1	5	5	–	–	–	11
Total	1	10	25	12	1	0	0	49
Percent	2.0	20.4	51.0	24.5	2.0			
Sta. 32								
Sample 1	20	72	40	20	8	–	–	160
2	23	30	43	30	3	–	–	129
3	18	38	66	15	2	–	–	139
4	12	21	64	30	12	–	–	139
5	40	35	84	30	5	–	–	194
Total	113	196	297	125	30	0	0	761
Percent	14.8	25.7	39.0	16.4	3.9			
Sta. 34								
Sample 1	4	57	54	27	–	–	–	142
2	1	5	6	2	–	–	–	14
3	8	41	46	20	–	–	–	115
4	11	27	33	13	–	–	–	84
5	4	10	18	6	–	–	–	38
Total	28	140	157	68	0	0	0	393
Percent	7.1	35.6	40.0	17.3				

APPENDIX B TABLE V

Lengths of the isopod *Saduria entomon* from stations 2, 4, 6, 8, 10, 26, 28, 30, 32, 34, 37, and 38. Collection of August 1974.

	Size Class 1	2	3	4	5	6	7	8	Total
Sta. 2									
Sample F1[a]	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
A1[b]	2	–	–	–	–	–	–	–	2
2	1	–	–	–	–	–	–	–	1
3	1	–	–	–	–	–	–	–	1
Total	4	0	0	0	0	0	0	0	4
Percent	100.0								
Sta. 4									
Sample F1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
A1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
Total	0	0	0	0	0	0	0	0	0
Percent									
Sta. 6									
Sample F1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
A1	–	1	1	–	–	–	–	–	2
2	–	–	–	–	–	–	–	–	–
Total	0	1	1	0	0	0	0	0	2
Percent		50.0	50.0						
Sta. 8									
Sample F1	–	–	1	–	–	–	–	–	1
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
A1	–	1	2	–	–	–	–	–	3
2	–	–	–	–	–	–	–	–	–
Total	0	1	3	0	0	0	0	0	4
Percent		25.0	75.0						

APPENDIX B TABLE V (Continued)

	Size Class 1	2	3	4	5	6	7	8	Total
Sta. 10									
Sample F1	–	–	1	–	–	–	–	–	1
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	1	–	–	–	1
A1	–	2	–	–	–	–	–	–	2
2	1	5	5	–	–	–	–	–	11
Total	1	7	6	0	1	0	0	0	15
Percent	7.7	46.6	40.0		7.7				
Sta. 26									
Sample F1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
A1	3	–	–	–	–	–	–	–	3
2	2	–	–	–	–	–	–	–	2
Total	5	0	0	0	0	0	0	0	5
Percent	100.0								
Sta. 28									
Sample F1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	–	–	–	1	–	–	–	–	1
A1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
Total	0	0	0	1	0	0	0	0	1
Percent				100.0					
Sta. 30									
Sample F1	–	–	1	–	–	–	–	–	1
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
A1	–	–	–	1	1	–	–	–	2
2	–	–	2	–	1	–	–	–	3
Total	0	0	3	1	2	0	0	0	6
Percent			50.0	16.7	33.3				
Sta. 32									
Sample F1	–	1	–	1	–	–	–	–	2
2	–	–	–	–	–	–	–	–	–
3	–	–	1	1	–	–	–	–	2
A1	–	2	5	1	–	–	–	–	8
2	–	–	2	1	–	–	–	–	3
Total	0	3	8	4	0	0	0	0	15
Percent		20.0	53.3	26.7					

APPENDIX B TABLE V (Continued)

	Size Class 1	2	3	4	5	6	7	8	Total
Sta. 34									
Sample F1	–	–	1	–	–	–	–	–	1
2	–	–	–	1	–	–	–	–	1
3	–	1	1	2	–	–	–	–	4
A1	–	–	–	–	–	–	–	–	–
2	–	2	2	2	–	–	–	–	6
Total	0	3	4	5	0	0	0	0	12
Percent		25.0	33.3	41.7					
Sta. 37									
Sample F1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
A1	–	–	–	–	–	–	–	–	–
2	–	–	1	–	–	–	–	–	1
Total	0	0	1	0	0	0	0	0	1
Percent			100.0						
Sta. 38									
Sample F1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–
A1	–	–	–	–	1	–	–	–	1
2	–	–	–	–	–	–	–	–	–
Total	0	0	0	0	1	0	0	0	1
Percent					100.0				

[a]F = Fager core collection

[b]A = Airlift collection

APPENDIX B TABLE VI

Total lengths of the isopod *Saduria entomon* taken by airlift from stations 2, 4, 6, 8, and 10. Collection of August 1975.

	Size Class 1	2	3	4	5	6	7	8	Total
Sta. 2									
Sample 1	–	–	1	–	–	–	–	–	1
2	1	–	–	–	–	–	–	–	1
3	2	–	–	–	1	–	–	–	3
4	–	–	–	–	–	–	–	–	–
5	2	–	–	–	–	–	–	–	2
Total	5	0	1	0	1	0	0	0	7
Percent	71.4		14.3		14.3				
Sta. 4									
Sample 1	1	1	–	–	–	–	–	–	2
2	1	–	–	1	–	–	–	–	2
3	2	–	2	–	–	–	–	–	4
4	–	–	3	–	–	–	1^{F}	–	4
5	–	–	–	–	–	1	–	–	1
Total	4	1	5	1	0	1	1	0	13
Percent	30.8	7.7	38.5	7.7		7.7	7.7		
Sta. 6									
Sample 1	–	1	1	–	–	–	–	–	2
2	–	3	9	10	4	2	1	–	29
3	–	1	2	2	–	–	–	–	5
4	1	4	4	3	1	1	–	–	14
5	1	–	8	8	1	–	–	–	18
Total	2	9	24	23	6	3	1	0	68
Percent	2.9	13.2	35.3	33.8	8.8	4.4	1.5		
Sta. 8									
Sample 1	–	5	18	18	3	1	–	–	45
2	–	16	16	22	8	–	–	–	62
3	–	–	1	–	–	–	–	1^{F}	2
4	–	–	–	–	–	–	–	–	–
5	1	–	–	–	–	–	–	–	1
Total	1	21	35	40	11	1	0	1	110
Percent	0.9	19.0	31.8	36.4	10.0	0.9		0.9	

APPENDIX B TABLE VI (Continued)

	Size Class 1	2	3	4	5	6	7	8	Total
Sta. 10									
Sample 1	-	1	-	-	-	-	-	-	1
2	4	1	6	-	-	-	-	-	11
3	2	9	22	3	-	-	-	-	36
4	1	8	19	1	-	-	-	-	29
5	-	5	19	1	-	-	-	-	25
Total	7	24	66	5	0	0	0	0	102
Percent	6.9	23.5	64.7	4.9					

APPENDIX B TABLE VII

Total lengths of the isopod *Saduria entomon* taken by airlift from stations 26, 28, 30, 32, and 34. Collection of August 1975.

	Size Class 1	2	3	4	5	6	7	8	9	10	Total
Sta. 26											
Sample 1	–	–	–	–	–	–	–	–	–	–	–
2	–	–	1	–	–	–	–	–	–	–	1
3	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–
Total	0	0	1	0	0	0	0	0	0	0	1
Percent			100.0								
Sta. 28											
Sample 1	–	–	1	1	–	–	–	–	–	–	2
2	–	–	2	2	1	–	1^F	–	–	–	6
3	–	–	1	1	–	–	–	–	–	1^M	3
4	1	–	–	4	–	–	–	1^F	–	–	6
5	–	–	1	3	1	–	1^F	–	–	–	6
Total	1	0	5	11	2	0	2	1	0	1	23
Percent	4.3		21.7	47.8	8.7		8.7	4.3		4.3	
Sta. 30											
Sample 1	–	1	14	14	–	–	–	–	–	–	29
2	–	–	1	4	2	1	–	–	–	–	8
3	–	–	–	2	2	–	–	–	–	–	4
4	–	–	–	6	–	–	–	–	–	–	6
5	–	–	5	11	2	–	1^F	–	–	1^F	20
Total	0	1	20	37	6	1	1	0	0	1	67
Percent		1.5	29.8	55.2	8.9	1.5	1.5			1.5	
Sta. 32											
Sample 1	4	–	16	–	–	–	–	–	–	–	20
2	6	–	–	–	–	–	–	–	–	–	6
3	5	10	8	5	2	–	–	–	–	–	30
4	6	–	12	–	3	–	–	–	–	–	21
5	–	1	15	5	–	–	–	–	–	–	21
Total	21	11	51	10	5	0	0	0	0	0	98
Percent	21.4	11.2	52.0	10.2	5.1						

APPENDIX B TABLE VII (Continued)

	Size Class 1	2	3	4	5	6	7	8	9	10	Total
Sta. 34											
Sample 1	1	–	6	–	–	–	–	–	–	–	7
2	1	–	–	–	–	–	–	–	–	–	1
3	–	–	–	–	–	–	–	–	–	–	–
4	2	–	6	–	2	–	–	–	–	–	10
5*	–	–	–	4	–	–	–	–	–	–	4
Total	4	0	12	4	2	0	0	0	0	0	22
Percent	17.4		52.2	17.4	8.7						

*Also 1^M in Size Class 12 with percent of 4.3

APPENDIX B TABLE VIII

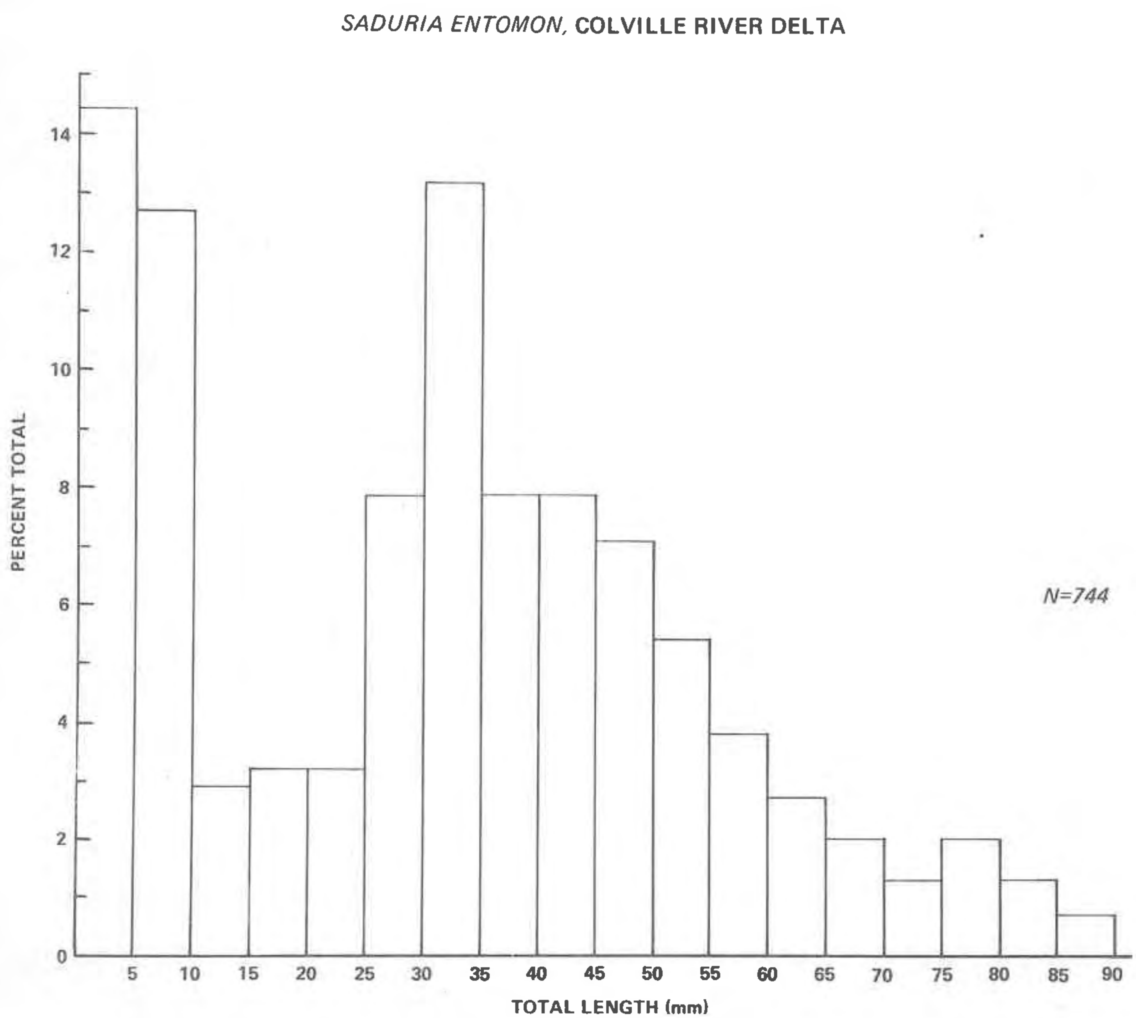
Total lengths of the isopod *Saduria entomon* taken by airlift from stations 37, 38, and 39. Collection of August 1975.

	Size Class 1	2	3	4	5	6	7	Total
Sta. 37								
Sample 1	1	–	–	–	–	–	–	1
2	1	–	–	–	–	–	–	1
3	1	–	–	–	–	–	–	1
4	–	–	–	–	1	–	–	1
5	–	–	–	–	–	–	–	–
Total	3	0	0	0	1	0	0	4
Percent	75.0				25.0			
Sta. 38								
Sample 1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–
5	–	–	–	–	1	–	–	1
Total	0	0	0	0	1	0	0	1
Percent					100.0			
Sta. 39								
Sample 1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–
5	1	–	–	–	–	–	–	1
Total	1	0	0	0	0	0	0	1
Percent	100.0							

APPENDIX B TABLE IX

Total lengths of the isopod *Saduria entomon* taken from fish traps at stations 2, 4, 6, 8, and 10. Collection of August 1975.

	Size Class																		
Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
2	-	-	3	7	15	6	5	6	12	11	47	119	63	16	16	5	5	1	334
4	-	-	-	6	10	10	2	1	3	0	4	5	7	1	2	3	0	1	55
6	-	3	2	7	4	2	-	-	-	-	1	-	-	-	-	-	-	-	19
8	-	2	7	13	9	4	0	1	0	0	1	4	0	0	2	1	-	-	44
10	-	1	1	-	-	-	-	-	-	-	-	1	-	-	-	2	-	-	5
Unk. 0																			
Total	0	6	13	33	35	22	7	8	15	11	53	129	70	17	20	11	5	2	457
Percent	0	1.4	3.0	7.6	8.0	5.0	1.6	1.8	3.4	2.5	12.1	29.5	16.0	3.9	4.6	2.5	1.1	0.4	



Appendix B Figure 1. Size distribution of *Saduria entomon*. Colville River delta (adapted from Crane and Cooney, 1973).

GENERAL DISCUSSION

The studies described in this report were carried out to generate a basic body of information for the environment adjacent to a causeway site in Prudhoe Bay, Alaska. Although considerable data are available for the near-shore arctic marine environment elsewhere (see Feder *et al.*, 1976b for a literature survey of the arctic marine environment), limited information was previously available for Prudhoe Bay. Thus, the benthic biological and hydrocarbon data included here represent 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 (see Feder *et al.*, 1976a, Chapter II for literature review).

Our work in Prudhoe Bay addressed 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 work reported here constitutes a beginning towards answering these questions.

All of the sediments collected at the new causeway and the adjacent transect were moderately-to poorly-sorted sands, silty sands or sandy silts. However, the sediments at the stations adjacent to the causeway showed an overall seaward decrease in mean size and sediment sorting. The benthic biota at these stations, in general, appeared to correlate with this seaward sediment transition with species diversity, density and biomass 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 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 of the common fishes of Prudhoe Bay indicate that these fishes are feeding primarily on crustaceans characteristic of shallow-sandy stations such as those at Point McIntyre.

We concluded, after the first year study, that the existence of ice-scour zones and the establishment of "local" populations must be considered in the development of a biological monitoring scheme for Prudhoe Bay (Feder *et al.*, 1976a). Now, after a second season of field work, we feel that our original ideas may have been too simplistic. It now appears that storms during the open water period may effect rapid and profound changes in the biota. Such storm-induced changes appear to be much greater than the combined effects of ice-scour and "normal" recruitment patterns.

The implications of storm translocation of adult benthic individuals, force us to revise our earlier predictions (Feder *et al.*, 1976a) on repopulation of a local area. The recruitment of the sessile benthos can, thus, take at least three forms: (1) settling of larvae, (2) slow movement of adults into an area, and (3) storm-generated translocation of adults from nearby areas. It appears quite possible that the destruction of nearshore benthos could easily go unnoticed by a monitoring scheme such as ours if storms occurred after the destruction and before the next sampling period.

The next logical step in monitoring the Prudhoe Bay benthos appears to be the determination of the distribution of the clam *Cyrtodaria kurriana*, an essentially sessile species, in the local area. If its distribution is limited strictly to the nearshore area or if its size changes with water depth, it could be the key species for separating internal changes in the nearshore benthos from translocation changes.

The kinds and amounts of hydrocarbons now present in the sediment and fishes of Prudhoe Bay indicate that these hydrocarbons are both petrogenic and biogenic in origin. The fact that most of the benthic invertebrate species collected are apparently either deposit feeders or scavengers suggests that any petroleum hydrocarbons added to their environment might be picked up by them during their feeding activities. However, this has not yet been observed. Petroleum hydrocarbons can be readily monitored through their detection in the sediment, in the tissues of some of the benthic invertebrates, and also in the tissues of fishes utilizing some of these invertebrates for food. To date, fishes but not benthic invertebrates have been analysed for hydrocarbons at Prudhoe Bay.

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. In view of the compact nature of the sediments of most of the stations occupied it is strongly recommended that diver-operated sampling devices continue to serve as the basic collecting tools in the causeway area. However, 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 at least 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. An intensive study of the distribution and growth of the clam *Cyrtodaria kurriana* should be initiated immediately.

3. Hydrocarbon - Based on the first and second year's work, 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.