ENVIRONMENTAL STUDIES OF AN ARCTIC ESTUARINE SYSTEM

Final Report

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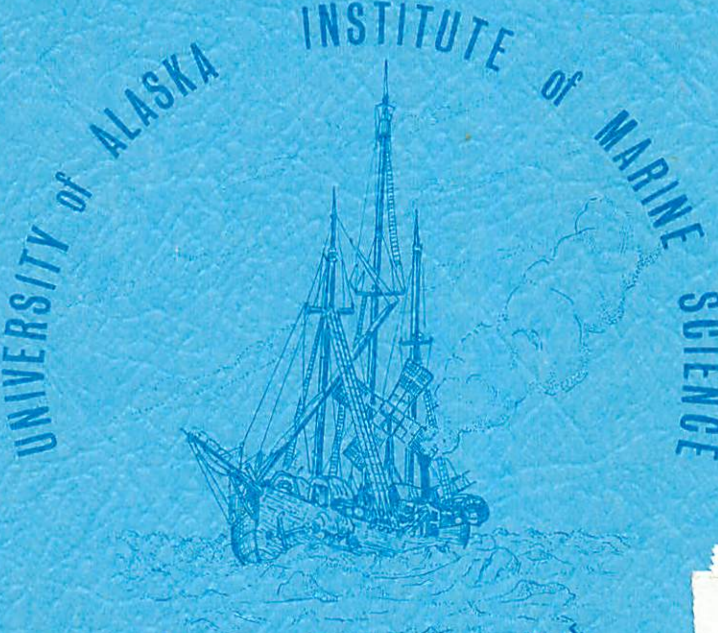

IMS Report R74-1
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CHAPTER 1 .

SUMMARY

The Colville River estuarine system has been studied with respect to physical, chemical, geomorphological and biological factors in as great detail as possible over a period of four years. Initially logistics were the major emphasis, but as the program developed, a considerable mass of baseline data was accumulated on this previously rather unknown area. North slope river deltas differ significantly from deltas elsewhere, particularly with respect to geological and biological aspects, but also in the extreme importance of ice cover to the annual physical regime. Climatological extremes are a major feature of the environment, and the contrasting effects of the cold, dark winter months with nearly complete ice cover and the continuous daylight summer period with melting ice or open water can be considered a major environmental factor influencing both the physical and biological systems.

Basic information has been obtained on the winds, waves and currents of Simpson Lagoon. Predominant wind directions are from the east with a trend towards higher wind speeds and westerly storms during the period from July to October. Predominant current directions are from the west. Linear correlation coefficients of +0.73 and -0.52 have been obtained between wind speed and current velocity and between wind and current directions respectively. Spectral analysis of low pass filtered (cutoff period = 1 day) east to west and north to south components of the current record indicates presence of wind drift currents with a periodicity of 4 to 5 days. It is suggested that current patterns in Simpson Lagoon are controlled predominantly by prevailing wind patterns. Mean breaking wave heights and periods along the Simpson Lagoon coast are about 17.7cm and 2.2 seconds. Results of spectral analysis of wave records for the period from 22 - 28 August, 1972, indicates a significant wave period of

1.87 to 2.14 seconds. Secondary energy peaks with periods of 7.5 to 15.0 seconds are interpreted as swell from the Beaufort Sea. A general trend of increasing spectral wave energy with increasing significant wave period, wind speed and duration has been observed in a comparison of wave spectra with prevailing meterological conditions.

Beach sediments along the Simpson Lagoon coast and barrier islands are characterized as poorly sorted gravelly sandy sediment in a relatively low energy environment in contrast to generally well-sorted unimodal beach sediment in the higher energy environments typically found along coasts with more temperate climates. Sub-freezing temperatures, shore-fast ice and frozen beaches protect the nearshore environment from various processes of sedimentation 8 to 9 months annually. Between break-up and freeze-up (June to October) thermal erosion of beach cliffs and the effects of storm waves and currents have served to erode the Simpson Lagoon coast at a mean annual rate of 1.4 meters. Longshore sediment transport at volumetric rates of up to $36m^3$/day occurs in a westerly direction in response to wind, waves and currents which are predominantly from the east. Spits and bars are oriented towards the west, generally, and results of aerial photographic studies indicate the Thetis Island has accreted at a mean rate of $1580m^2$/yr. Pingok Island has been eroded at its eastern end at a mean rate of $3000m^2$/yr, with deposition occurring at its western end. These results suggest a net sediment transport towards the west both along the Simpson Lagoon coast and barrier islands and in Simpson Lagoon.

Sand-gravel fluvial deposits underlie the mainland shore, Simpson Lagoon and the barrier islands at approximately -8m elevation. The tundra portions of Pingok-Cottle Islands are directly related to the lowest soil surface on the mainland. The deposits are peats which have accumulated in place on top of marine-fluvial sands and silts with some gravels. These deposits have been reworked in places by lacustrine processes. An average rate of coastal retreat of 1.4m/yr for a time span of 22 or 23 years is estimated. Rates ranged from relatively stable sand-gravel beaches to 4.7m/year. The maximum rate occurred on a very localized exposed section of lacustrine beds. Terrigenous input is very important to the river and estuarine system.

The ice-free biological regime is strongly influenced by the river input of low salinity water containing relatively high concentrations of nitrogenous nutrients. Strong salinity and thermal stratification in the shallow delta waters results in a stratification of phytoplankton populations, with the deep water population dominated by diatoms and the surface population containing a greater component of flagellates. Bottom water often had the maximum primary productivity rates. In 1971, maximum rates were 5.8 and 5.9mg-C/m^3•hr. Annual primary production of 10-15g-C/m^2 is estimated. Nitrate supplied by the river appeared to be important in the nearshore nutrient regime. Information has also been obtained on the distribution and activity of phytoplankton in the river system and associated lakes.

Crustaceans, molluscs and polychaetes characterize the macrofauna of the coastal area at depths exceeding 2m, with but few species responsible for most of the abundance and biomass. The large euryhaline isopod *Mesidotea entomon* and the coastal mysid *Mysis oculata* were consistantly the most common organisms sampled in the study. Both occurred within the lagoon at most locations, although they were much more abundant in samples taken seaward of the barrier islands. There was no evidence that the nearshore shallow waters were critical to the reproductive success of either the isopod or mysid populations. Evidence was obtained which suggested that well established populations of nearshore epifauna do occur in the coastal Beaufort Sea, and that recruitment to the shallow lagoons is probably accomplished by small-scale onshore seasonal migrations. Perhaps one of the most interesting biological aspects of this study has been the investigation of overwintering fish in the river system. Fish observed and studied include the humpback whitefish, the broad whitefish, arctic cisco, least cisco and burbot.

The nutrient regime of the offshore area is influenced strongly by the river system. Freshwater input from the north slope drainages adds nitrogen; additional nitrate and ammonia are supplied through erosional processes on the tundra shoreline. With the onset of winter and the formation of ice, solute exclusion into the underlying water concentrates nutrients, and as the ice thickens circulation is restricted by bottomfast ice in shallow bays and lagoons, and hypersalinity occurs. Ammonification was detected in saline waters of the Colville delta, in a delta lake, and in parts of Elson Lagoon, but was undetectable in the fresh waters of the Colville River and in Simpson Lagoon. Nitrification was also active in these waters. Oxygen utilization accompanies these processes, and some reduction in oxygen levels was evident.

CHAPTER 2

INTRODUCTION: RATIONALE, OBJECTIVES AND LOGISTICS

Donald M. Schell

BACKGROUND

Successful human occupation of the Alaskan arctic has hinged primarily on the active and skillful utilization of the marine resources of the region and secondarily on the utilization of terrestrial resources. To a culture based on agrarian and industrial economies, the Arctic in the past has offered little. To the Alaskan Eskimos, however, the marine resources have provided a stable and rich subsistence and their culture is testimony to superb adaptation to a harsh climate and to the development of specialized techniques required in harvesting these resources. Due to the lack of an advanced technology, their past impact on land and sea has been slight and their life style, in general, in harmony with the environment. However, this state of affairs has changed drastically during the twentieth century and the outlook for the Arctic in the near future is a period of radical change and for potentially severe cultural, economic and environmental conflicts.

The first major intrusion of western culture into the Alaskan Arctic resulted from the need for a marine resource - the oil and later the baleen of the bowhead whale (*Balaena mysticetis*). At the height of arctic whaling near the turn of the century as many as 12 ships and 600 men wintered at Herschel Island and many more ships followed the retreating pack ice northward each summer to risk lives and investments in the hazardous winters in pursuit of the great mammals. With the fortuitous development of plastics, the demand for baleen collapsed before the bowhead whale was driven to extinction, but the severely depleted stocks presented difficult times for the native villages that normally relied substantially upon whaling for food and fuel.

For several decades after the whalers departed, arctic Alaska relapsed into obscurity and although the exploration of Naval Petroleum Reserve Number 4 left scars across the landscape and significant quantities of litter at Barrow and at Umiat on the Colville River, the slow restorative processes managed to reduce the reminders of technological impact to a minimum.

Following Alaska statehood and the leasing of Arctic Slope land by the state for oil exploration, the die was irreversibly cast for major change to reach the Arctic. The major oil discoveries at Prudhoe Bay and the prospects of impending competitive state leasing of additional North Slope lands spurred exploration and drilling programs between the Colville River and the Canning River which bounds the Arctic National Wildlife Refuge. Following the leasing which yielded nearly a billion dollars to the State of Alaska, the Arctic lands were no longer an unknown entity but an extremely valuable piece of real estate. The value lay entirely in the oil beneath the ground, however, with little concern as to the potential of the biological resources, aesthetic resources, or as an area for domestic human habitation. To those faced with the problem of getting the crude oil to market, the marine and terrestrial environments typified the "hostile wilderness". At large expense and effort, airfields were built and air traffic to the Arctic was established as a reliable, year-round mode of hauling freight and personnel. During the short open-water season, barge lifts hauled the heaviest equipment around Point Barrow and with difficulty through the loose pack ice to Prudhoe Bay. In the few years between 1967 to present the Arctic coastal plain has undergone more technological impact than all the years previous and with this development has come a myriad of environmentally related problems. Unlike prior developments, however, this time an awareness and concern for the aesthetic and other potential human values that lay in aspects of the Arctic wilderness previously ignored or neglected have prompted a massive and continuing desire to ameliorate the impact of the oil and oil-related technology on the environment and the biota indigenous to the land and sea. The development of Alaskan arctic resources has become a novel experiment - can technology and a fragile ecosystem exist in harmony or at least inconsequentially to each other. The implementing of this experiment has been the source of much debate, litigation and resolution and it has only begun. This experiment will require a thorough knowledge of the arctic coastal ecosystem and the physical parameters of the environment and careful decision-making by those involved. It is the purpose and desire of those involved in this study to present environmental data that may be of value in making these decisions and to suggest critical areas of research needed before further compromising of the coastal resources and ecosystem is undertaken.

STUDY AREA

This study encompassed the Alaskan arctic coastal zone between Point Barrow and Prudhoe Bay, representing a linear distance of approximately 300km (Fig. 1). Although the individual reports following this section will provide details as to the specific locations of study, a general description of the area is given here.

The nearshore area is characterized by shallow water sloping very gently offshore with numerous bars and shoals derived from both ice action and as remnants of past shoreline erosion. Two major lagoon systems - Elson Lagoon near Point Barrow and Simpson Lagoon east of the Colville River delta are separated by stretches of low coastline exposed to the Beaufort Sea and two shallow bays, Harrison Bay and Smith Bay. Bordering the entire coastline is low-lying tundra with a general relief of less than 3m and the 6m bluffs near Cape Simpson represent the extreme. The entire coastal plain is underlain with continuous permafrost to depths in places exceeding 1,000m although much less information exists on the presence of permafrost offshore. Surface features of the tundra

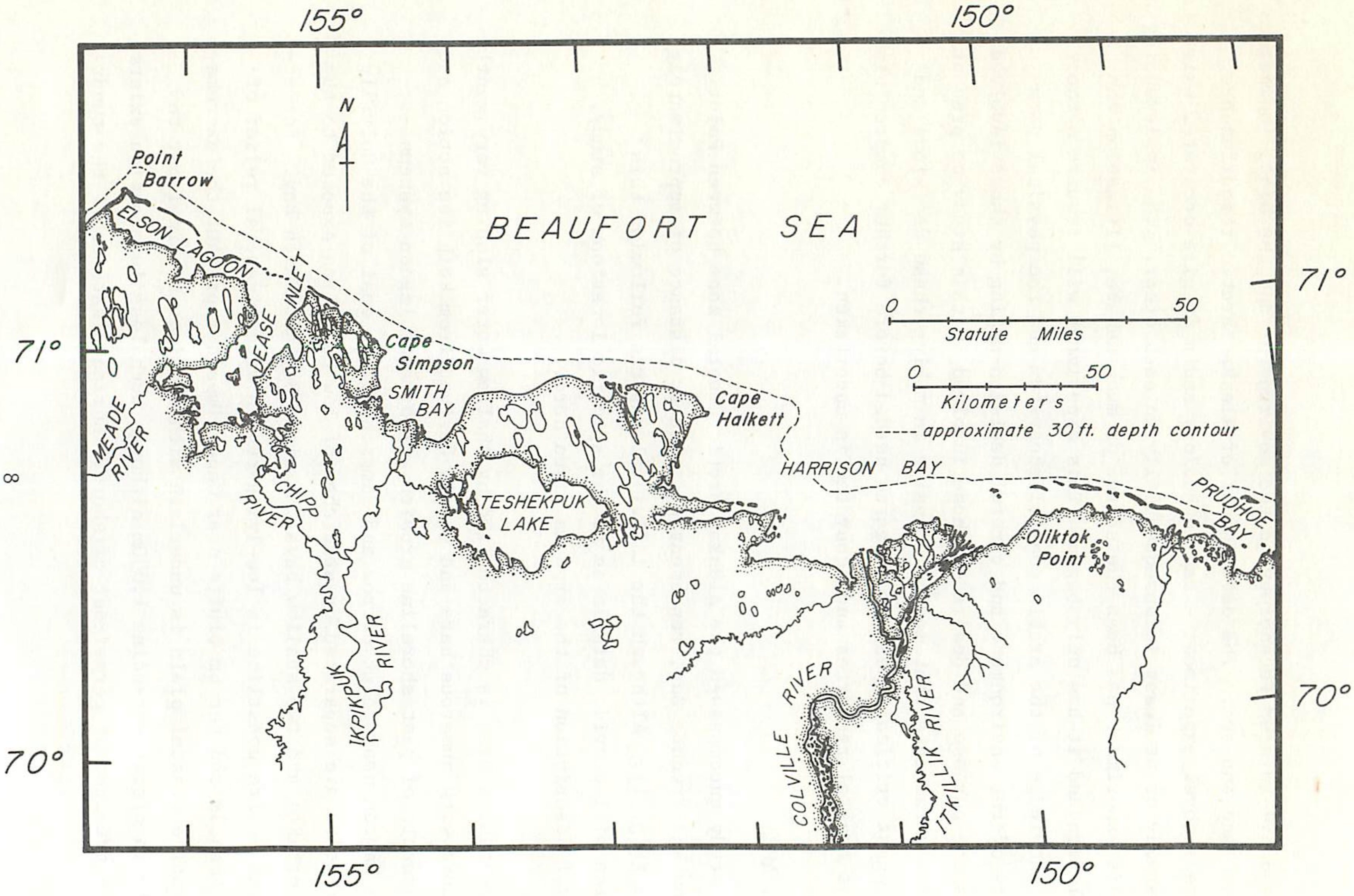

Figure 1. General study area.

reflect the permafrost base, being patterned or polygonal ground covered with decumbent vegetation subject to extremes in density on a microscale. The entire coastal tundra is broken with numerous thaw lakes generally oriented about a NNW-SSE axis and showing signs of active transitional stages between lake and tundra. Most are very shallow (<2m) and freeze to the bottom during winter.

The Colville River is the largest river of the North Slope, entering the Beaufort Sea approximately 200km southeast of Point Barrow. The remaining drainages are considerably smaller and differ in origin, those east of the Colville descending from the northern drainages of the Brooks Range which approaches to within 40km of the coastline at Barter Island.

The currents in shallow waters of the nearshore are dominated by the prevailing winds during the short open-water season. The astronomical tides are small, ranging between 10-20cm but are overridden by meterological tides which cause occasional variations of up to a meter; exceptional storms can cause surges of several meters and result in inundation of the low coastlines. Erosional effects during these storms are drastic and produce changes equivalent to several years of "normal" regime[1].

OBJECTIVES

In anticipation of the extensive developmental activity associated with the Alaskan north slope oil resources and the reestablishment of native communities consequent to the settlement of the Alaska Native Land Claims Act, this project was designed to provide baseline information on both fresh and estuarine environments along the Alaskan arctic coast. Because of the scarcity of existing knowledge, this effort has included basic descriptive work of the aquatic ecosystems. However, special effort was made to identify and understand quantitatively the dynamic environmental processes that operate in this little known region through the annual cycles. In specific terms our objectives were:

1. The establishment of logistic support and the training of personnel in environmental work in the Alaskan coastal zone.
2. To determine physical circulation and flushing of the delta-lagoon barrier island complex.
3. To determine seasonal variations in the conservative chemistry and the nutrient chemistry of the Colville River and nearshore waters.
4. To determine ice structure and properties of ice in the zone of interaction between marine and freshwaters.
5. To study the processes of primary production and interrelationships with the nutrient chemistry of the marine, river and lakewater environments in the Colville River area.
6. To survey the biota of the Simpson Lagoon-Harrison Bay area.
7. To study the clay mineralogy and heavy minerals of the Colville River system and nearshore sediments.
8. To study the beach morphology and the sedimentology of Simpson Lagoon.

The remoteness and extreme climatic conditions of the study area required that the projects funded by the EPA office of Research and Monitoring, the NOAA-Sea Grant Office and the State of Alaska be combined into a single coherent interdisciplinary effort, with no distinction being drawn between the freshwater or marine environments as to application of effort. This allowed an integrated program that in several cases aided in understanding the interrelationships that occurred across the marine-freshwater boundary. In many instances, especially during the first two years, the combination of the logistic difficulties in access to the study areas and the total lack of any previous information on the physical and biological nature of the area required that a thorough reconnaissance be accomplished. As data were acquired and the processes governing some of the basic biological and environmental changes became apparent, attention shifted to attempting to quantify these processes. Thus the initial surveying of chemical nutrients and conservative constituents and sediments in nearshore waters became supplemented by studies on the biological interactions controlling the uptake and regeneration of nutrients and on climatologically governed physical processes such as shoreline erosion, brackish ice formation and under-ice density currents.

TRANSPORTATION AND LOGISTIC SUPPORT

In 1970, the Colville delta area was a "remote" area, and all access was, by necessity, via air support. Therefore our base of operations was established at Point Barrow at the Naval Arctic Research Laboratory (NARL). Lodging and logistic support in the form of light aircraft, cargo aircraft, and small boats provided by NARL proved indispensable to the accomplishment of much of our work. It was, however, desirable to maintain a field camp capable of all-weather access and to provide a reasonably secure and safe base from which to conduct field sampling. Therefore the Aerospace Defense Command was contacted and through their cooperation, we were able to establish a field laboratory, bunkhouse and storage facility at DEWline Station POW-2 located at Oliktok Point. The all-weather airstrip, lodging, heated buildings wherein equipment could be repaired and maintained, ready communications with the "outside" and the cooperative and friendly atmosphere of the POW-2 personnel proved invaluable to much of our research efforts.

For sampling at other locations in the Colville delta, personnel were based at either the NARL camp Putu at the head of the Colville delta or at the homes of Mrs. George Woods on the Nechelik (west) channel, or Mr. Harmon Helmericks at Anachlik Island on the East Channel of the

Colville delta. Operations from the last two sites were very space-limited but at Camp Putu, facilites were adequate for three or four personnel to work effectively. The fisheries research and the nutrient regeneration studies were conducted primarily from Camp Putu while the limnological research was based at Wood's Camp.

Transportation to the study area was by aircraft except for one tractor-train traverse of the coastline between Barrow and Camp Putu. Actual field sampling was accomplished through surface transportation in the field consisting of small boats during the open water season and snowmachines with sleds from October to early June. Our small boats consisted of a 17 ft. Boston Whaler and two Zodiac inflatable boats. The Boston Whaler proved an excellent boat for sampling operations in the lagoon where working over the side with awkward equipment was routine. In shallow waters or among floating ice, the Zodiac inflatables were easier handling and had the added advantage that their light-weight allowed them to be completely hauled up the beach when not in use. This is a real advantage where wind-driven ice and freezing spray are common occurrences. Some additional work was performed in the summer of 1971 using the NARL vessel *NATCHIK*. This 42 ft. vessel allowed sample collecting in offshore Harrison Bay and beyond the barrier islands where smaller boat operation was hazardous.

The relative freedom of movement and evenness of terrain made travel by snowmachine the most efficient method of transportation in areas near Oliktok and the Colville delta during winter months although the Dease Inlet survey was done entirely by using ski-equipped aircraft. The snowmachines were always used in pairs for safety reasons and although the sleds pounded the gear unmercifully passing over the sastrugi, we were able to successfully use such equipment as underwater television systems and portable generators mounted on the sleds with minimal problems. The fisheries research conducted in Fall 1972 by

Dennis Kogl was accomplished using his own dog team for transportation, a mode of travel perhaps safer if not faster than snowmachines for working alone in the arctic winter.

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CHAPTER 3

A STUDY OF WIND, WAVES AND CURRENTS IN SIMPSON LAGOON

Joseph A. Dygas

INTRODUCTION

The primary purpose of the work reported here is to describe coastal wind, wave and current patterns in a coastal polar environment and to provide an initial predictive capability for some future applied problems; especially the transport of natural and man-made materials.

Prior to the initiation of oceanographic studies in the Harrison Bay - Simpson Lagoon area (Fig. 1) by the Institute of Marine Science, University of Alaska from 1970 to 1973, there had been a dearth of coastal oceanographic information. Since the initiation of this study, studies of physical processes along the Beaufort Sea coast have increased significantly; the Symposium on Beaufort Sea Coastal and Shelf Research[1] summarizes some of these more recent studies. In particular, Wiseman *et al.*[2] have been concerned with a comparison of physical procsses and geomorphology along the Chukchi and Beaufort Sea coasts.

SETTING

The Harrison Bay - Simpson Lagoon study area is located about midway across the northern arctic coast of Alaska (Fig. 1). The study area consists of a shallow broad bay open to the Beaufort Sea and a partially enclosed lagoon approximately 7km wide and 25km in length. The Jones Islands, which are a series of low relief barrier islands, form the northern boundary of the lagoon. To the west of Simpson Lagoon lies the Colville River and its delta. The discharge of the Colville River enters Harrison Bay to the west of Simpson Lagoon and the discharge of the Kuparuk River enters Gwyder Bay to the east of

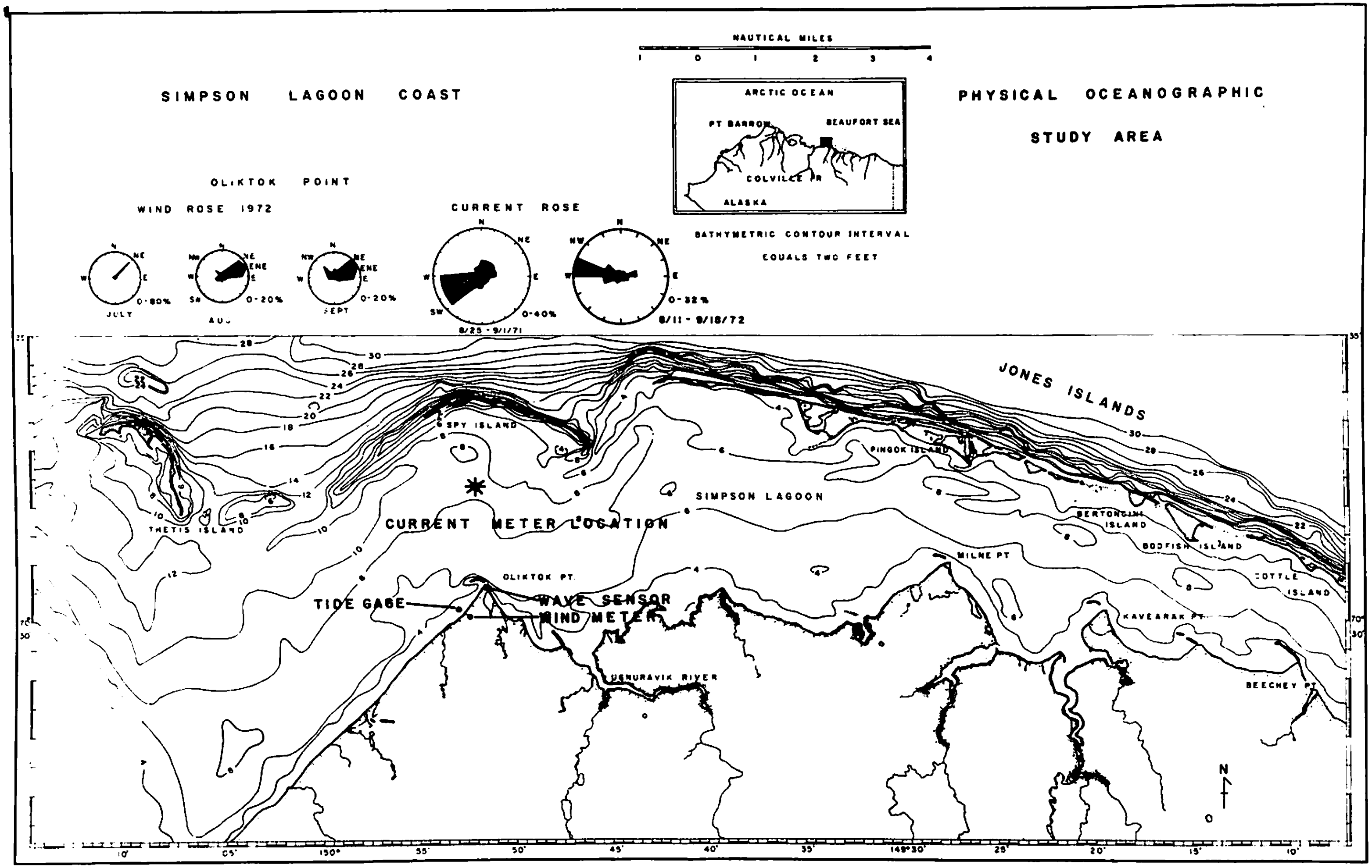


Figure 1. Physical oceanographic study area.

Simpson Lagoon. The bathymetry of Simpson Lagoon is quite shallow with depths being generally less than two meters.

Climatic conditions in the arctic are characterized by (1) an alternation of long periods of daylight and darkness which are associated with a relatively low sun angle and high radiation loss, (2) presence of snow and ice covered water most of the year, (3) a distinctive temperature inversion with increasing altitude, which is related to radiative cooling, and (4) a relatively cold high pressure circumpolar vortex of the upper atmosphere. Fluctuations in the boundaries of the circumpolar vortex affect the movement of surface cyclones and anticyclones which influence regional weather patterns. Surface weather patterns, especially during summer months, along the Beaufort Sea coast are significantly affected by the movement, intensity and frequency of occurrence of cyclones and anticyclones.

The annual range of temperature in the arctic is about 55°C. Temperatures fluctuate about -32°C during the winter and 0°C during the summer[3]. Summer temperatures generally average less than 10°C and July is typically the warmest summer month.

After the thawing of the snow cover on the Alaskan arctic coastal plain and the breakup of the rivers and shorefast ice, a strong temperature gradient exists between the relatively warm land and cold pack ice. In addition the open coastal waters during summer provide a source of moisture which is generally lacking during the winter. Relative humidity over water surfaces reaches a maximum during August. These conditions are generally conducive to the formation of cyclones, which are characterized by centers of low pressure, high winds, precipitation, cloudiness, relatively warmer temperatures, and a sharp frontal structure. Cyclonic storms that have been generated in the Beaufort Sea are often characterized by a relatively cold to warm temperature gradient from the center to the periphery of the cyclone. The ratio of cyclones to anticyclones in the arctic is 2:1. Point Barrow, for example, experiences an average of 19 storms per year[3].

Cyclonic frequency is greatest in a line extending from south of Greenland over Norway and Novaya Zemlya and on into the central arctic. Baffin Bay in the Canadian arctic also has a high frequency of cyclonic activity. The greatest frequency of anticyclones occurs in eastern Siberia across the Beaufort Sea to northwest Canada, and also in Greenland, southern Scandanavia and a northern extension of the main western Siberian anticyclone. About one third of the cyclonic lows occurring in the Beaufort Sea have originated in northern Siberia.

After breakup along the Alaskan arctic coast, surface air temperatures tend to remain near freezing over the pack ice, whereas over land areas on the coastal plain temperatures may rise considerably above freezing (21° to 26°C). Moisture from the warm open coastal waters under relatively mild wind speeds tends to aid the formation of low cloud cover and fog tends to increase towards the end of the summer as the surface of the coastal plain cools relatively more rapidly than the open coastal water.

METHODS

Techniques used in the field to obtain wind, wave and current data have progressed from visual and manual techniques during initial operations in 1970 to continuous recording instrumentation during the summer of 1972. Table 1 summarizes field methods and periods of measurement of wind direction and velocity, wave height and period and current direction and velocity in Simpson Lagoon (Fig. 1). Specific field procedures for the 1970 and 1971 field seasons have been discussed (see Kinney *et al.*[4] and Dygas *et al.*[5]). Wind direction and velocity were

Table 1. TYPE AND PERIOD OF FIELD OBSERVATIONS AT OLIKTOK POINT, ALASKA

Type of Field Technique	1970 July	1970 Aug.	1970 Sept.	1971 July	1971 Aug.	1971 Sept.	1972 July	1972 Aug.	1972 Sept.
Wind									
A		—			—				
B							—	—	—
Waves									
C					—			—	
D								—	
Currents									
E		—	—	—	—	—	—	—	
F		—							
G		—							
H					— 7 days		— 38 days	—	

Where A = Hand held wind meter
B = Recording anemometer and wind vane
C = Visual
D = Portable wave recorder and resistance wave staff
E = Drift cards
F = Drogues
G = Flowmeter
H = Aandera current meter digital recording at 10 min. interval direction, velocity, temperature

recorded with a Rustrak recorder coupled to an anemometer and wind vane (R.M. Young Co.). The sensors were mounted about ten meters above sea level at Oliktok Point. Wind data in an analog form were recorded from 17 July to 20 October, 1972, and subsequently digitized at one hour sample intervals and processed by computer.

Current direction and velocity in Simpson Lagoon, were measured at ten minute sample intervals with an Aandera current meter from 25 August to 1 September, 1971, Dygas *et al.*[5] and 11 August to 18 September 1972. The current meter was moored one meter off the bottom of Simpson Lagoon in water with a total depth of 2.5 meters. Subsequently, the digital data were analysed by descriptive statistical methods, linear correlation and regression techniques and by a modified digital filtering and time series analysis procedure as diagrammed in Figure 2.

Wave heights and periods were recorded from 22 August to 11 September, 1972 with a portable wave recorder and a continuous resistance wire wave staff, (Interstate Electronics Co.). From 22 August to 1 September, 1972, the wave sensor was installed just outside the breaker zone on the northeast facing shore of Oliktok Point. Over the period 1-11 September, 1972, it was installed on the west facing shore. The analog wave data were digitized at 0.3 second time intervals and subsequently analysed with a power spectral analysis computer program developed by Fee[6]. In order to check the precision of the output, an interlaboratory experiment was conducted with Dr. Fee at the University of Manitoba, Canada. Identical outputs were obtained from the same wave data input to the program of Fee by Fee on an IBM/360-65 computer and the author on an IBM/360-40 computer at the University of Alaska.

RESULTS AND DISCUSSION

Introduction

In this study of wind, waves and currents of Simpson Lagoon, emphasis

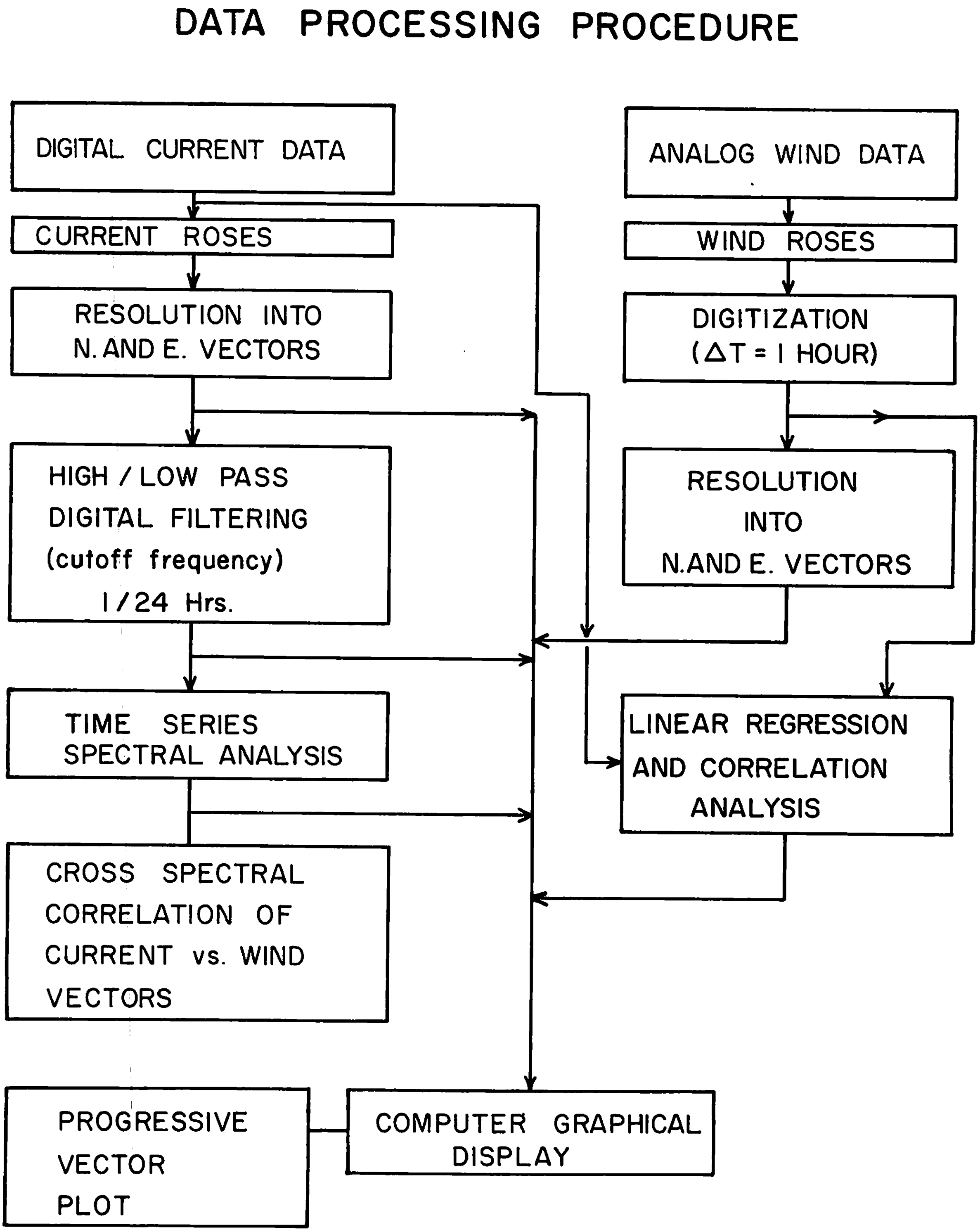


Figure 2. Data processing procedure.

has been placed on a quantification of 1972 field data and presentation of results in a form most useful for predictive purposes. In this regard it is important to appreciate that a single season of field data are not necessarily typical of long term conditions. For example, the difference between the predominant WSW current direction for 1971, and the WNW direction for 1972 shown in Figure 1, is an indication of the annual variability of current records obtained from the same location in Simpson Lagoon. However, 1972 wind direction data from Oliktok Point differs only slightly from longer term wind data from Barter Island (Fig. 3).

Winds

Wind directional values from Oliktok Point for the period July through September 1972 are compared diagrammatically with published long term wind data from Barter Island in Figure 3. Prevailing winds are from east to northeast and west to northwest for both locations. Data in Figure 3 for Oliktok Point indicate a slightly greater percentage of winds from the northeast and northwest than the long term data which consist of prevailing easterlies and westerlies.

The data of Table 2 indicate a general trend from relatively lower wind speeds during the June to July period to higher wind speeds during September and October at Oliktok Point. Table 2 further demonstrates an increase in northwesterly winds from 7.6 percent in July to 25.5 percent in September with a corresponding increase in energy (variance) from 16.4 percent in July to 45.3 percent in September. The tendency for higher wind speeds in September reflects the higher frequency of storm activity during this time of the year. The atmospheric temperature gradient over the land, ocean waters and the pack ice, in addition to the source of heat and moisture from open water, provides conditions

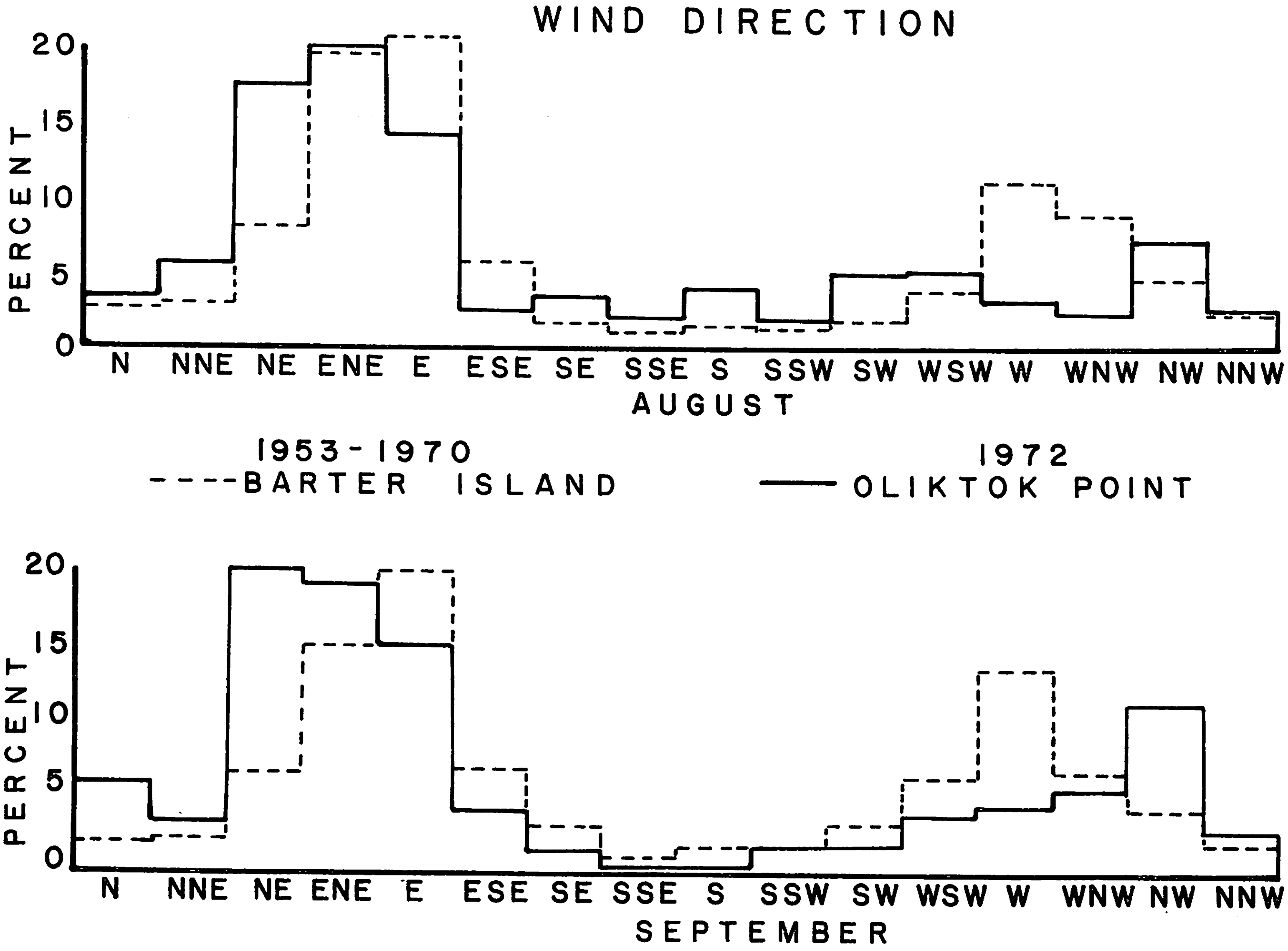


Figure 3. Wind direction histograms for Oliktok Point and Barter Island.

TABLE 2. WIND DIRECTION AND ENERGY DISTRIBUTION FOR OLIKTOK POINT, ALASKA 1972

Wind direction	JULY		AUGUST		SEPTEMBER		TOTAL	
	Frequency, %	Energy, %	Frequency, %	Energy, %	Frequency, %	Energy, %	Frequency, %	Energy, %
N-E	82.3	45.0	57.9	21.4	57.6	27.6	62.9	27.6
E-S	19.6	19.9	12.0	29.5	6.8	4.4	8.9	17.7
S-W	6.1	18.6	15.1	24.0	10.0	22.6	11.1	22.3
W-N	7.6	16.4	15.2	25.0	25.5	45.3	16.9	25.5

that are conducive to the formation of cyclones along the Beaufort Sea coast during summer months[7]. One of these westerly cyclonic storms was experienced in September 1970 during which wind speeds up to 70 knots were recorded at Oliktok Point[8] and in the Canadian arctic[9]. The resultant storm surge in the vicinity of Oliktok Point was estimated to be 2 to 3 meters by DEWline personnel.

Currents

Initial studies and results of surface current directions and velocities in Simpson Lagoon have been previously discussed in part (see Kinney *et al.*[4] and Dygas *et al.*[5]). More recently, Wiseman *et al.*[2] have studied current directions and velocities via drogue measuring techniques on the seaward side of Pingok Island.

Currents in Simpson Lagoon consist primarily of wind drift and tidal currents. Matthews[10] has indicated that the lunar tidal range at Point Barrow is less than 30cm. Dygas *et al.*[5] and Wiseman *et al.*[2] have recognized that the meteorological tidal range may be greater than the lunar tidal range and these authors have also suggested that local meteorological conditions control the prevailing current patterns in Simpson Lagoon and on the seaward side of Pingok Island. An important aspect of the present study has been to quantitatively test this hypothesis.

In order to describe meteorological and tidal periodicities present in the 1972 current record from Simpson Lagoon, a digital filtering and spectral analysis procedure has been used. Results of these procedures are presented in Figures 4 through 11 in terms of percent spectral energy of north - south and east - west current vectors plotted against frequency in cycles per hours. The low frequency (periods greater than one day) current records, given as Figures 8 through 11, have been

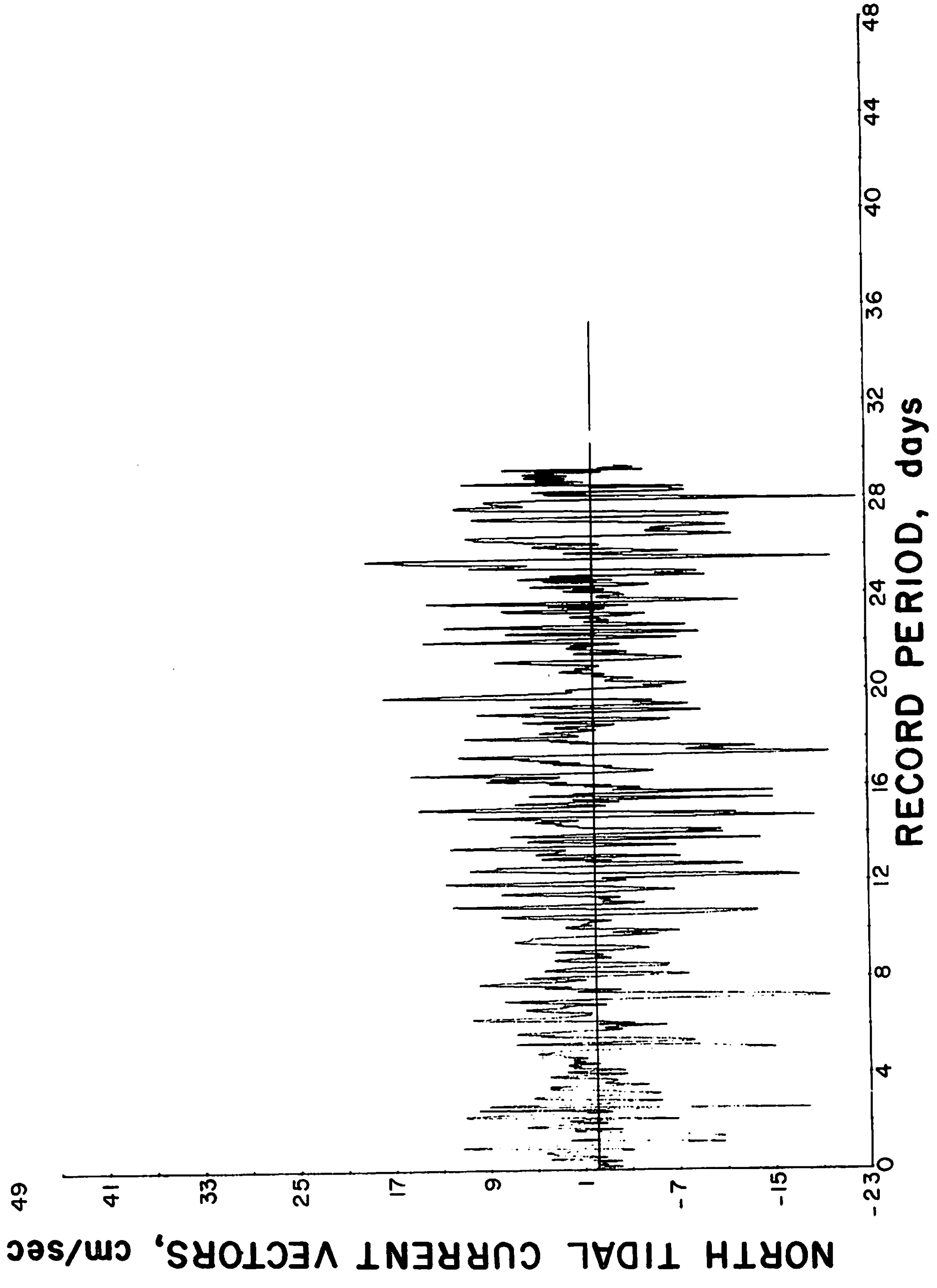


Figure 4. North-South tidal current vectors.

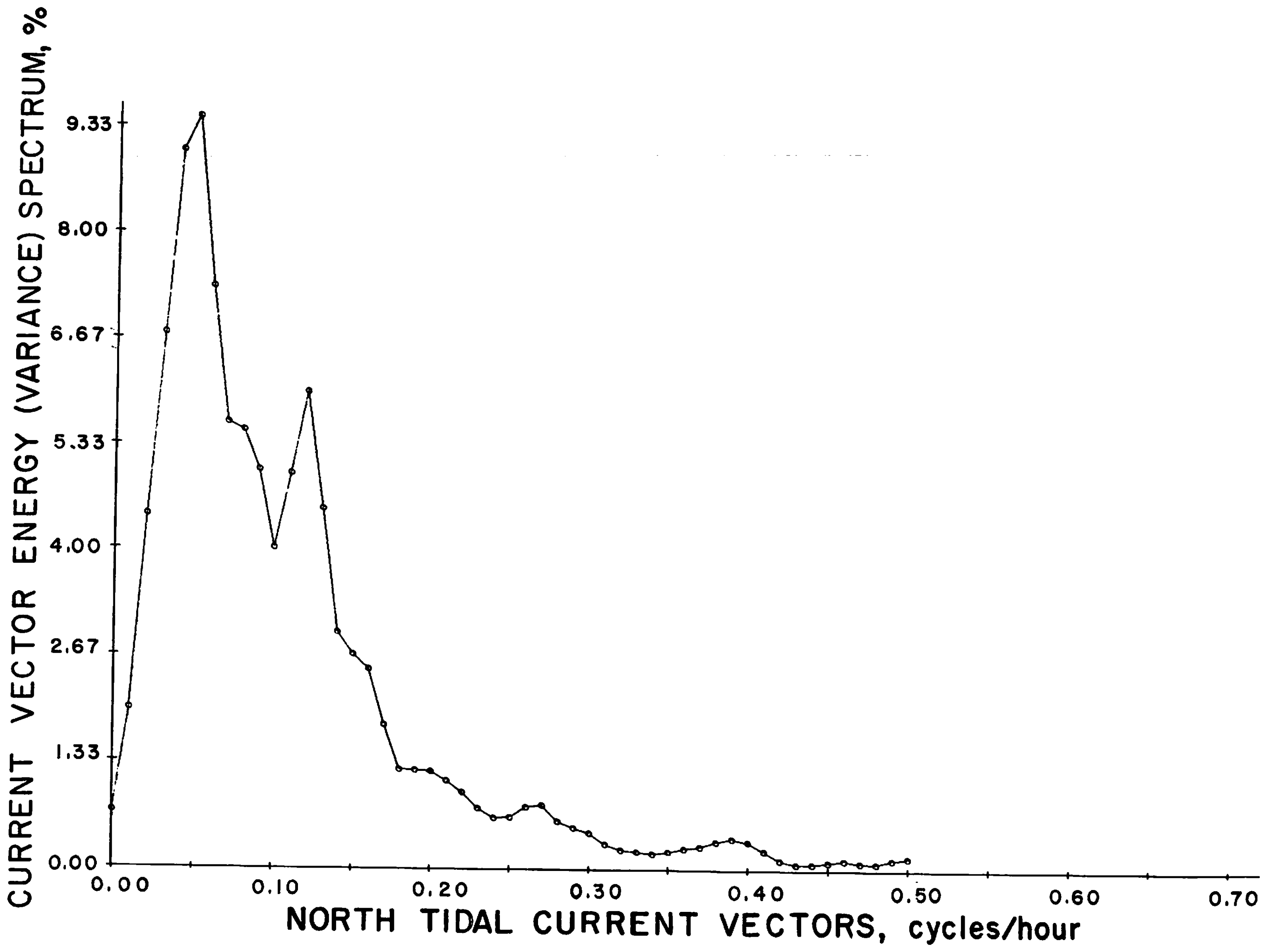


Figure 5. Power spectrum of North-South tidal current vectors.

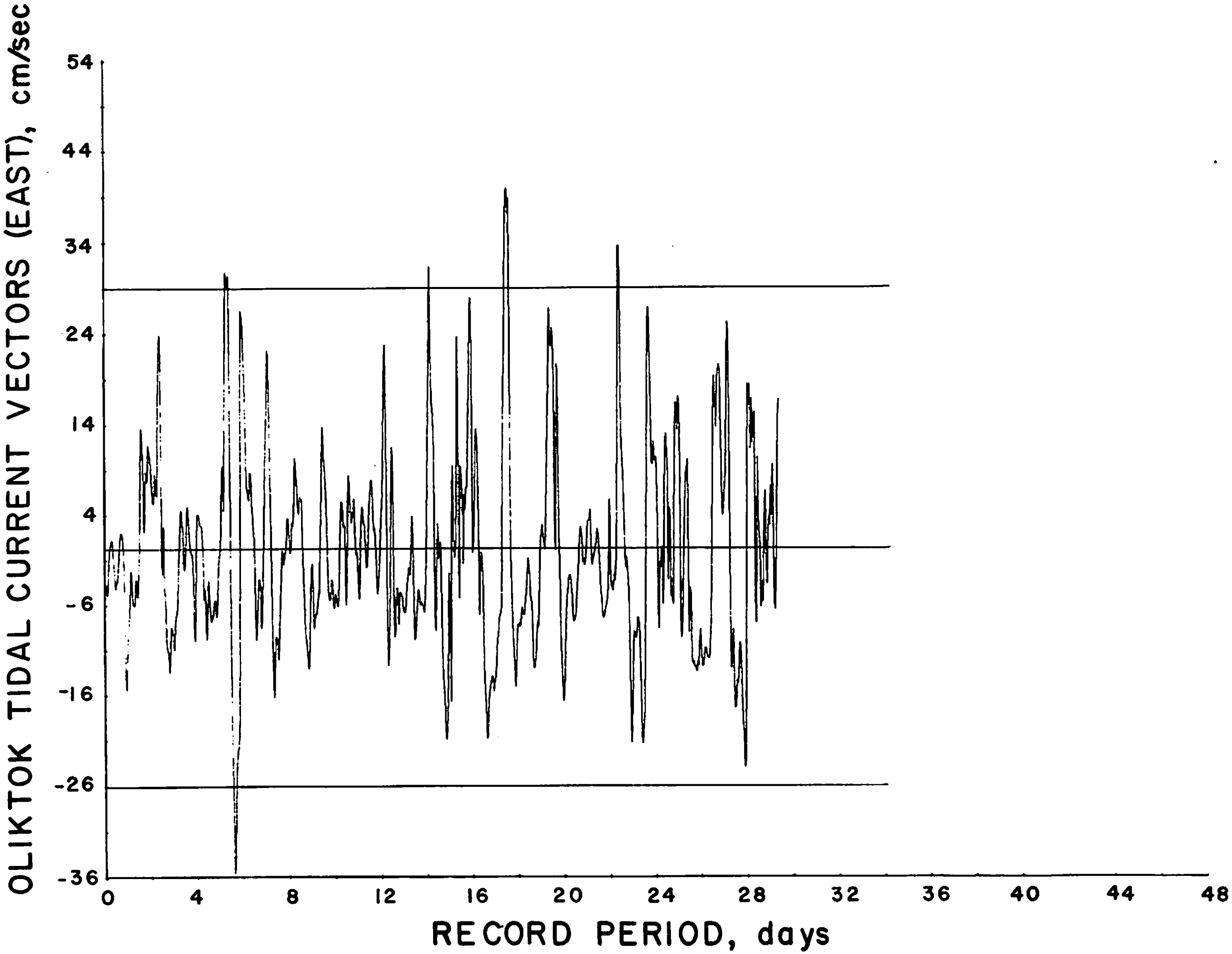


Figure 6. East-West tidal current vectors.

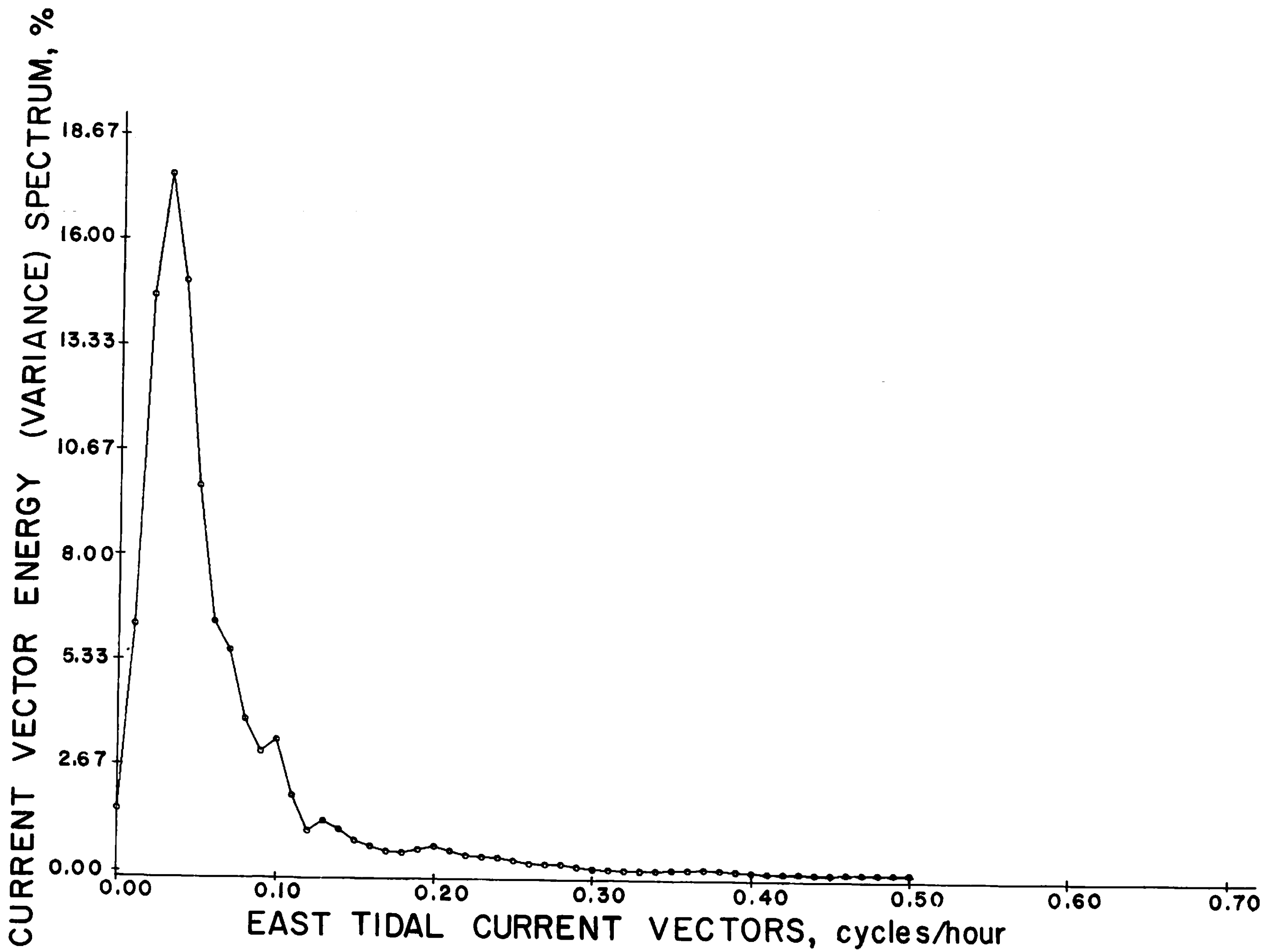


Figure 7. Power spectrum of East-West tidal current vectors.

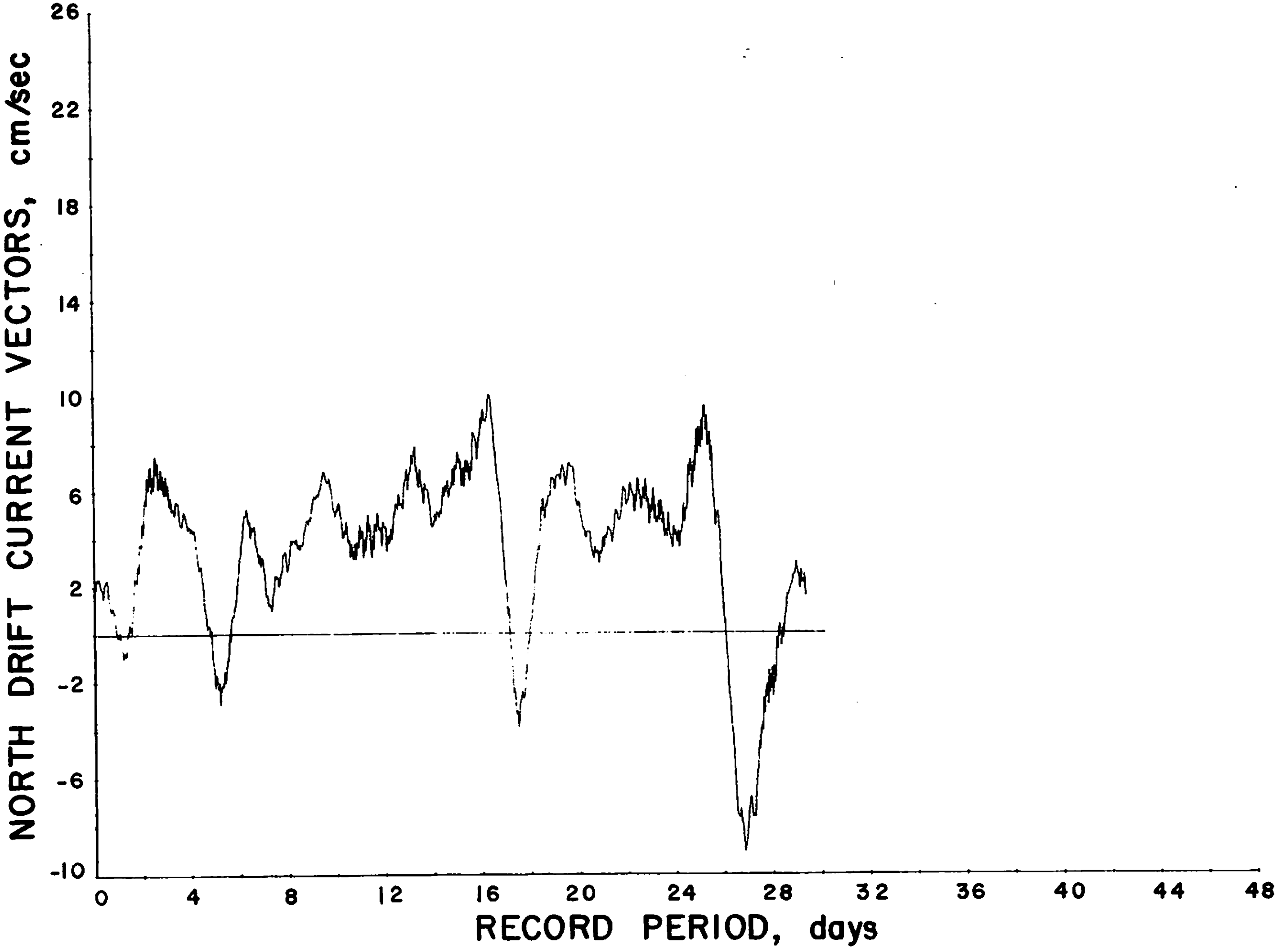


Figure 8. North-South wind drift current vectors.

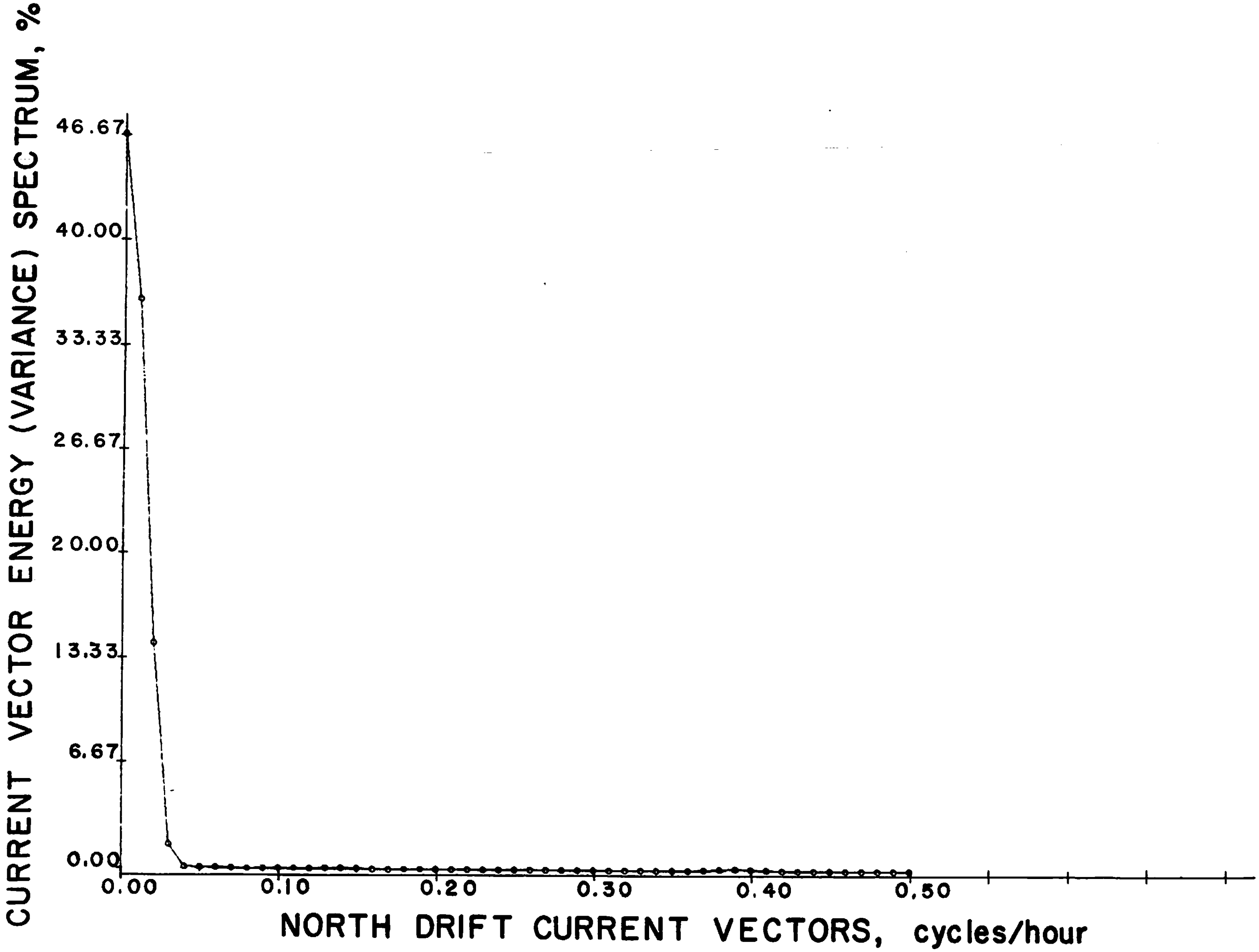


Figure 9. Power spectrum of wind drift current vectors.

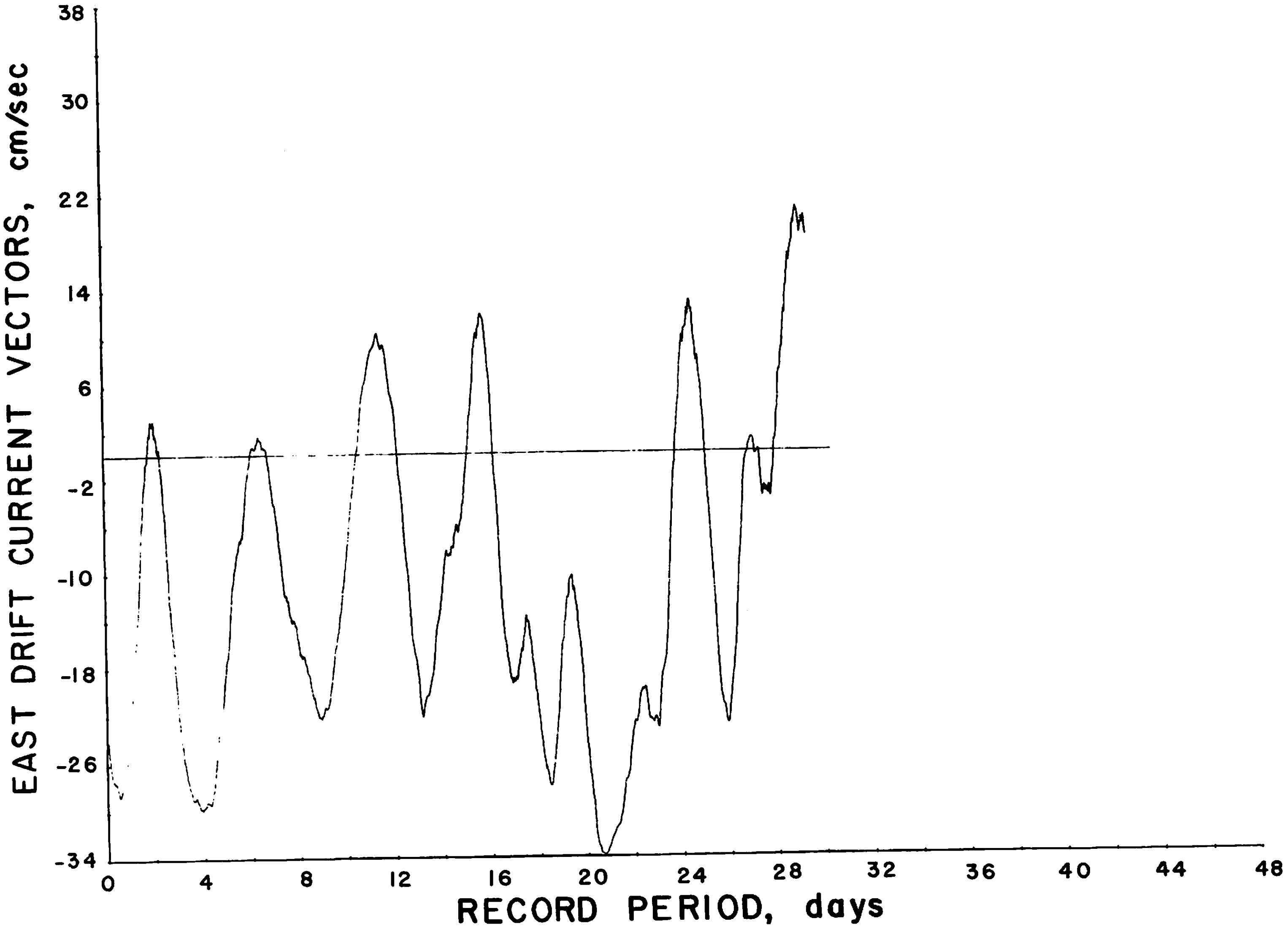


Figure 10. East-West drift current vectors.

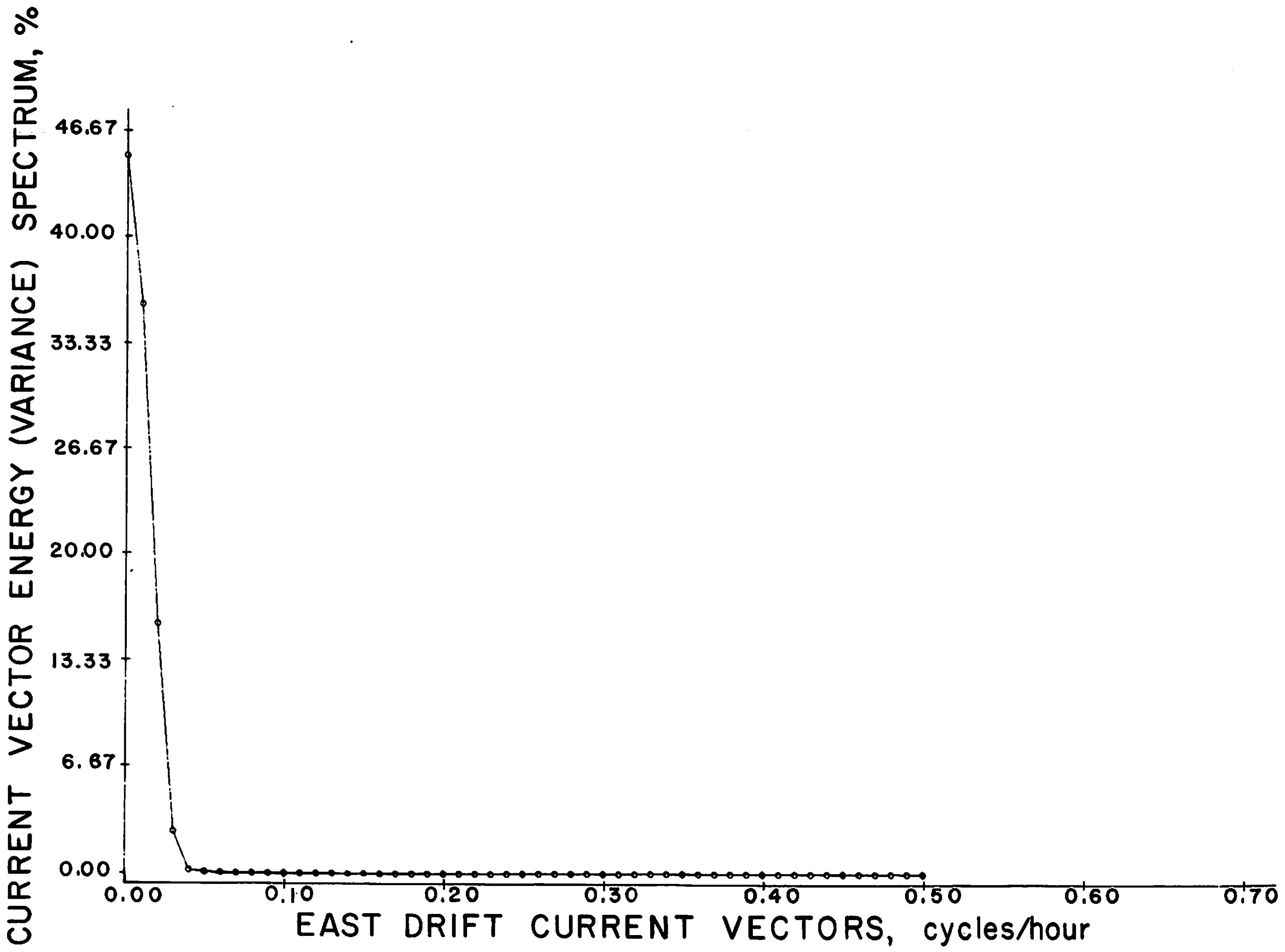


Figure 11. Power spectrum of East-West drift current vectors.

interpreted as essentially wind drift currents. The east - west vector current record has approximately 80 percent of its spectral energy occurring with a period of about four days or longer. From Figure 8, a period of approximately four days has been interpreted as representative of wind drift currents. Here the effects of tidal periodicities have been eliminated by the filtering process. It is further suggested that these low frequency wind drift currents are in response to weekly occurrences of minor westerly storms. It should be noted in Figures 8 and 10 that this weekly periodicity is more pronounced in the east - west component than in the north - south component. Current velocities in an east - west direction are generally greater than those in a north - south direction (Figs. 8-10).

The high frequency (periods less than one day) current records indicate energy peaks with periods of 33 and 10 hours for the east - west components (Fig. 7), and 20-24 hours and 8.3 hours for the north - south component. The 20-24 hour peak in the north - south component suggests the presence of diurnal tidal currents. The 33 hour peak in the east - west component record is considered non tidal. Semi-diurnal tidal periods range from 11.97 to 12.91 hours[11]. Although approximately 5 percent of the spectral energy occurs in the range of semi-diurnal periods, there are no distinctive energy peaks (see Figs. 7 and 9). The 10 hour and 8.3 hour peaks in the east - west and north - south component record, respectively, are not interpreted as semi-diurnal tidal currents. At present, it is tentatively suggested that the 10 hour and 8.3 hour peaks are related to corresponding fluctuations in local meteorological conditions.

Currents in Simpson Lagoon may be further described in terms of a progressive current vector diagram as illustrated in Figure 12. In this diagram there is a general absence of regular oscillatory movement in the progressive drift of the current vectors towards the northwest.

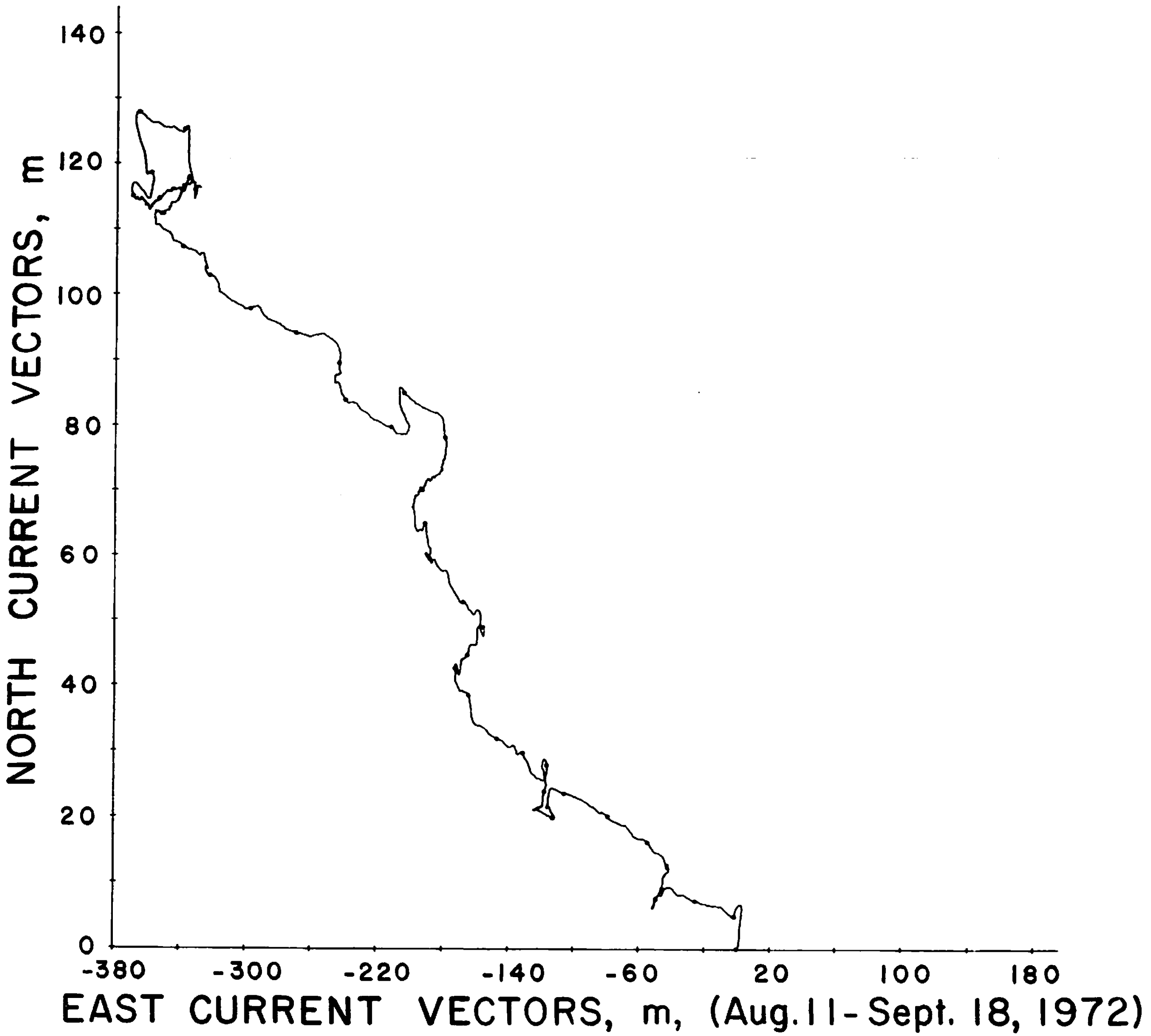


Figure 12. Progressive current vector diagram.

This diagram is interpreted as an indicator of water transport over a distance of 358km for 38 days at a mean vector current velocity of 10.6cm/sec. In contrast, the scalar mean velocity is 24.9cm/sec. The ratio of the mean vector velocity to the mean scalar velocity X100 is defined[12] as a measure of the variability of the current record. The stability for the 1972 Simpson Lagoon current record is 42.5 percent. In comparison, the percent variation of the current velocity that can be attributed to the wind velocity Figure 13, is 100 times the square of the linear correlation coefficient. The variation for the 1972 current record is 54 percent. It is suggested that the influence of surface wind stress accounts for the stability or variability. The remainder of the unexplained variation (46%) is attributed to the effects of tidal currents, waves and other random variations.

Surface currents in Simpson Lagoon tend to flow towards the west under easterly winds and east under westerly winds. In order to quantify this relationship, results of the 11 August to 18 September 1972 current record from Simpson Lagoon (Fig. 13), have been statistically correlated with the wind direction and velocity. Results of this analysis (Figs. 13 and 14), have indicated a significant correlation of 0.73 between wind speed and current velocity and a -0.52 correlation between wind and current directions. These correlations further indicate that about 50 percent of the variability in current velocity is attributed to the wind velocity and 25 percent of the variability in current direction is attributed to the wind direction.

Waves

The primary purpose of this study of waves in Simpson Lagoon has been to provide necessary data for other studies concerning the longshore sediment transport as given in the geological section of this report. In addition, this study of shallow water wind waves in a polar environment has partially filled a gap in present knowledge of coastal

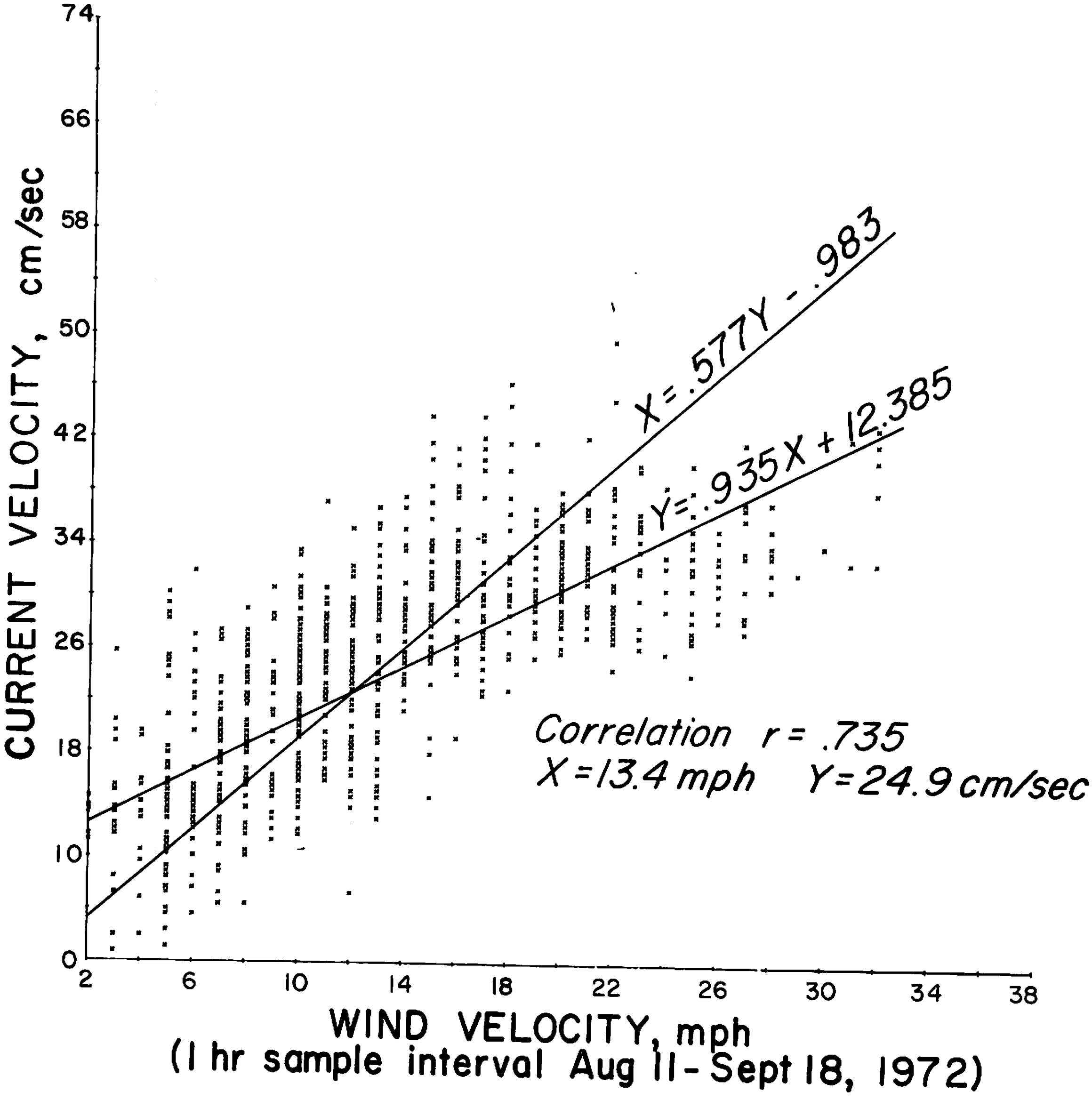


Figure 13. Correlation of wind and current velocity.

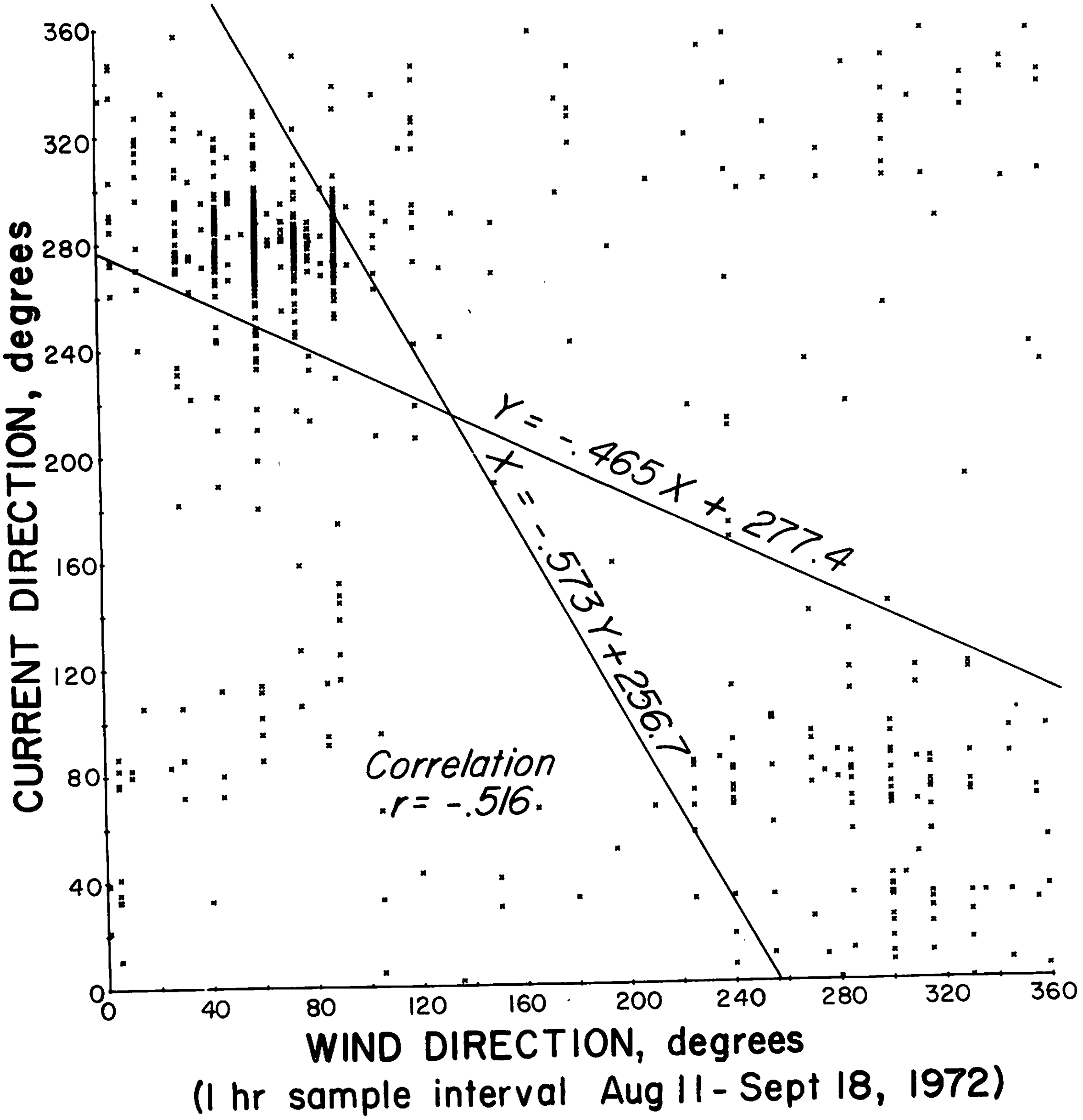


Figure 14. Correlation of wind and current direction.

physical oceanographic processes. This knowledge should also serve as an aid to navigation in the Simpson Lagoon area.

Waves that impinge on the Simpson Lagoon coast consist of local wind-generated waves and small amplitude swell which filters through the barrier island inlets from the open Beaufort Sea. Except for severe storm conditions, breaking waves along the Simpson Lagoon coast are generally of the plunging variety (as described by Dygas *et al.*[5]). Results of wave observations during the 1971 and 1972 field seasons have indicated a mean breaker height of 17.7cm, a significant breaker height of 27.3cm and a mean wave period of 2.2 seconds.

Results of spectral analysis of wave records for the east shore of Oliktok Point are summarized in Table 3. These data indicate that the wave period corresponding to peak wave energy ranges from 1.87 to 2.14 seconds. Also present in the wave spectra are a number of relatively low energy peaks with periods that range from 7.5 to 15.0 seconds. These secondary peaks are interpreted as low energy swell from the Beaufort Sea. The occurrence and observation of swell with any visually distinctive amplitude in the Oliktok Point area is relatively rare[8]. Both the author and Wiseman *et al.*[2] have contemporaneously observed swell with a period of 8.5 to 10.0 seconds impinging on the Jones Islands (see Fig. 1) and the Simpson Lagoon coast. The height of the swell on the north (Beaufort Sea) side of Pingok Island was estimated to be from 1.5 to 2.0m and at Oliktok Point from 10 to 20cm. Unfortunately, sea level at Oliktok Point had dropped below the operational depth of the wave sensor and the breaking waves on the shore of Pingok Island had demolished the wave staffs of Wiseman *et al.*[2] As a result no useful wave records were obtained in this particular case.

Table 3. RESULTS OF SPECTRAL ANALYSIS OF WAVES AT OLIKTOK POINT

Date/Time 1972	Wind speed mph	Wind duration, hrs	Significant wave period, sec	Secondary wave period, sec
Wind Direction N60E				
8/22/1315	10	25	1.87	5.0
8/22/2030	10	32	1.87	7.5
8/23/0900	11	45	1.87	7.5
8/23/1430	17.5	50	2.14	-[a]
8/27/1600	7.5	1	1.07	7.5
8/28/1600	10	6	-	-
8/28/1930	12.5	15	1.87	-
8/29/1530	12.5	35	1.87	7.5
Wind Direction N30E to N45E				
8/23/2030	16	56	2.14	-
8/24/1930	12.5	4	1.87	.9
8/24/1515	10	1	1.07	-
Wind Direction N30W to N60W				
8/25/2020	6	7	-	1.15
8/26/1600	7.5	27	-	0.9
8/30/0800	11	6	1.87	7.5
8/31/2230	20	4	2.5	-
Wind Direction SW				
8/31/1620	13	7	2.5	-
9/11/2400	12.5	26	2.14	-
Wind Direction SE				
8/29/1900	7.5	2	1.66	-

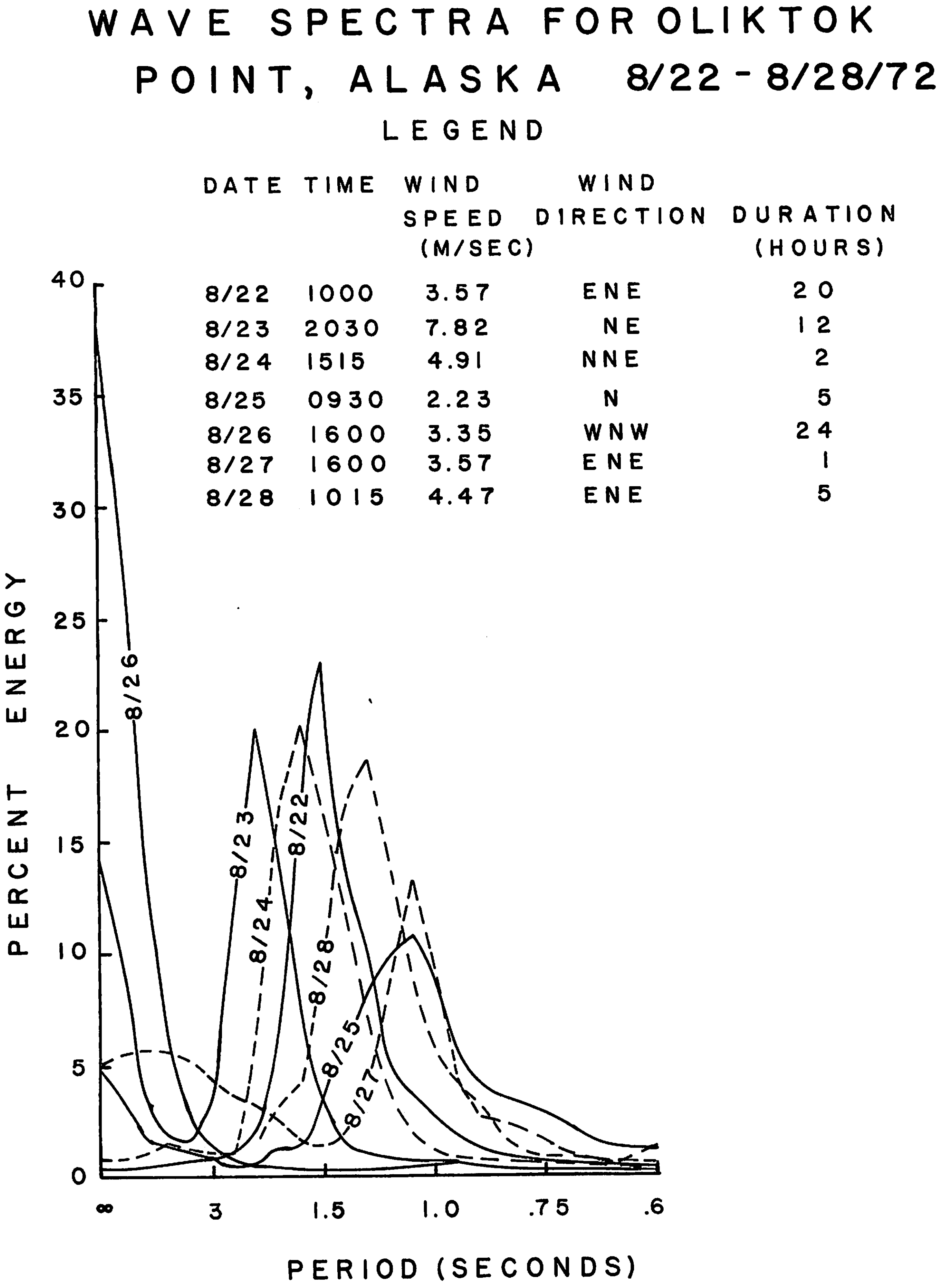
[a] The dash (-) indicates infinite period in seconds.

The wave spectra for the period 22-28 August 1972 indicate a general trend of increasing relative wave energy with increasing wave period (1.0 to 3.0sec.). The short period wind waves are considered to have been generated in the lagoon where the N-S fetch is a constant. Fetch in a northwesterly to westerly direction is not limited by the barrier islands, but by the position of the edge of the arctic pack ice. Wind speeds corresponding to wave spectra in Figure 15 indicate increases from 3.5 to 7.8m/sec.

The effect of long duration and low wind speed in contrast to relatively higher wind speed and shorter duration is indicated in terms of the wave spectra in Figure 15 for 22 and 23 August 1972. The wave spectrum for 22 August indicates a higher level of wave energy at a significant period of 1.5sec. The spectrum for 23 August indicates slightly less peak wave energy but a longer significant period of about 2.0sec. These results suggest that increasing duration increases peak wave energy but not the significant period unless the wind speed also increases. Increasing wind speed increases both peak wave energy and significant wave period. Both Hunkins[13] and Wiseman *et al.*[2] have observed a similar trend for increasing wave energy with increasing significant wave period for waves in the Beaufort Sea.

CONCLUSIONS

It is concluded from the results of this study that wave and current patterns in Simpson Lagoon are affected predominantly by prevailing local meteorological conditions. Northeasterly and northwesterly winds are responsible for predominantly northwesterly and northeasterly flowing currents and the meteorological tidal range is generally greater than the astronomical tidal range. Prevailing wind drift currents control the general current pattern in Simpson Lagoon. Although lunar tidal periodicities may be distinguished in current records from Simpson



DATE	TIME	WIND SPEED (M/SEC)	WIND DIRECTION	DURATION (HOURS)
8/22	1000	3.57	ENE	20
8/23	2030	7.82	NE	12
8/24	1515	4.91	NNE	2
8/25	0930	2.23	N	5
8/26	1600	3.35	WNW	24
8/27	1600	3.57	ENE	1
8/28	1015	4.47	ENE	5

Figure 15. Wave spectra for Oliktok Point - 1972

Lagoon, they are considered to be subsidiary to the wind drift currents in controlling overall current patterns in Simpson Lagoon.

Wave energy in Simpson Lagoon consists predominantly of short period wind waves generated in the lagoon. Presence of the offshore barrier islands effectively reduces the energy level of swell from the Beaufort Sea to negligible amplitudes in comparison with the wind waves in Simpson Lagoon. The general trend for increasing energy with increasing significant period of wind waves generated in Simpson Lagoon has been observed. Fetch in the lagoon is limited to the north and east by the barrier islands. However, to the northwest the fetch is limited by the edge of the pack ice as well as dense concentrations of ice floes.

The arctic climate with its short open coastal water season, presence of snow and ice cover, large temperature gradients between land, water and ice and the circumpolar vortex set the general framework within which regional weather patterns operate. It is within this framework, that the weather patterns along the Beaufort Sea coast as exemplified by the study of Simpson Lagoon significantly affect coastal wave and current patterns. The results of this study in conjunction with meteorological information provide a basis for prediction of wave and current patterns in Simpson Lagoon.

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CHAPTER 4

BEACH MORPHOLOGY AND SEDIMENTOLOGY OF SIMPSON LAGOON

D. C. Burrell, J. A. Dygas, and R. W. Tucker

INTRODUCTION

Objectives

The principal objective of the geological investigations conducted as part of the overall baseline study program has been to determine both the static and dynamic sedimentological regime of the lagoon - barrier island environment immediately east of the Colville River delta. We wished in particular to characterize the surficial sedimentary deposits within Simpson Lagoon (see Figs. 1 through 3) and to evaluate both long and short term sediment movements with particular emphasis upon the beach and barrier island deposits.

This work has been of considerable importance in several respects. In the first place, although shallow water environments have been worked on for a number of years in lower latitude, there is a dearth of information on equivalent areas subject to polar climatic conditions. For example, the only place along the entire Alaska arctic coast where beach movements have been previously studied with any degree of sophistication has been at Point Barrow (Fig. 1). This region, being at the confluence of the Chukchi and Beaufort seas, is unlikely to be typical of Beaufort Sea coastline conditions in general, and certainly the potential shoreline effects of major river inflow cannot be assessed at the latter locality. From a basic science point of view, it was intended to evaluate the characteristics of an arctic lagoonal environment: to compare processes with those determined for more temperate regions and to look for features which might be a function of the prevailing polar climatic conditions.

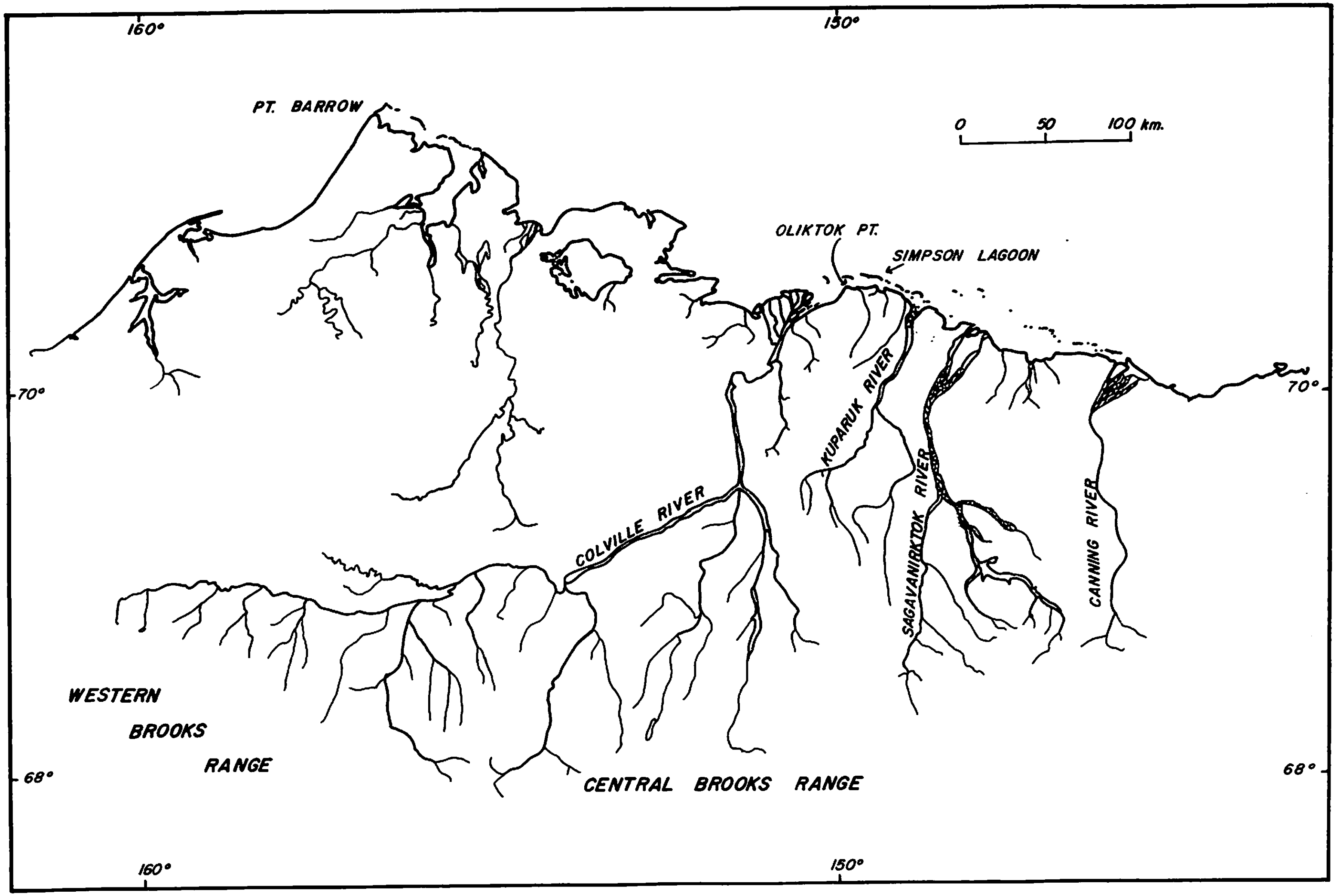

Figure 1. The Arctic coastal plain showing the location of the western and central Brooks Range, Ocean Point and Sentinel Hill, and Simpson Lagoon.

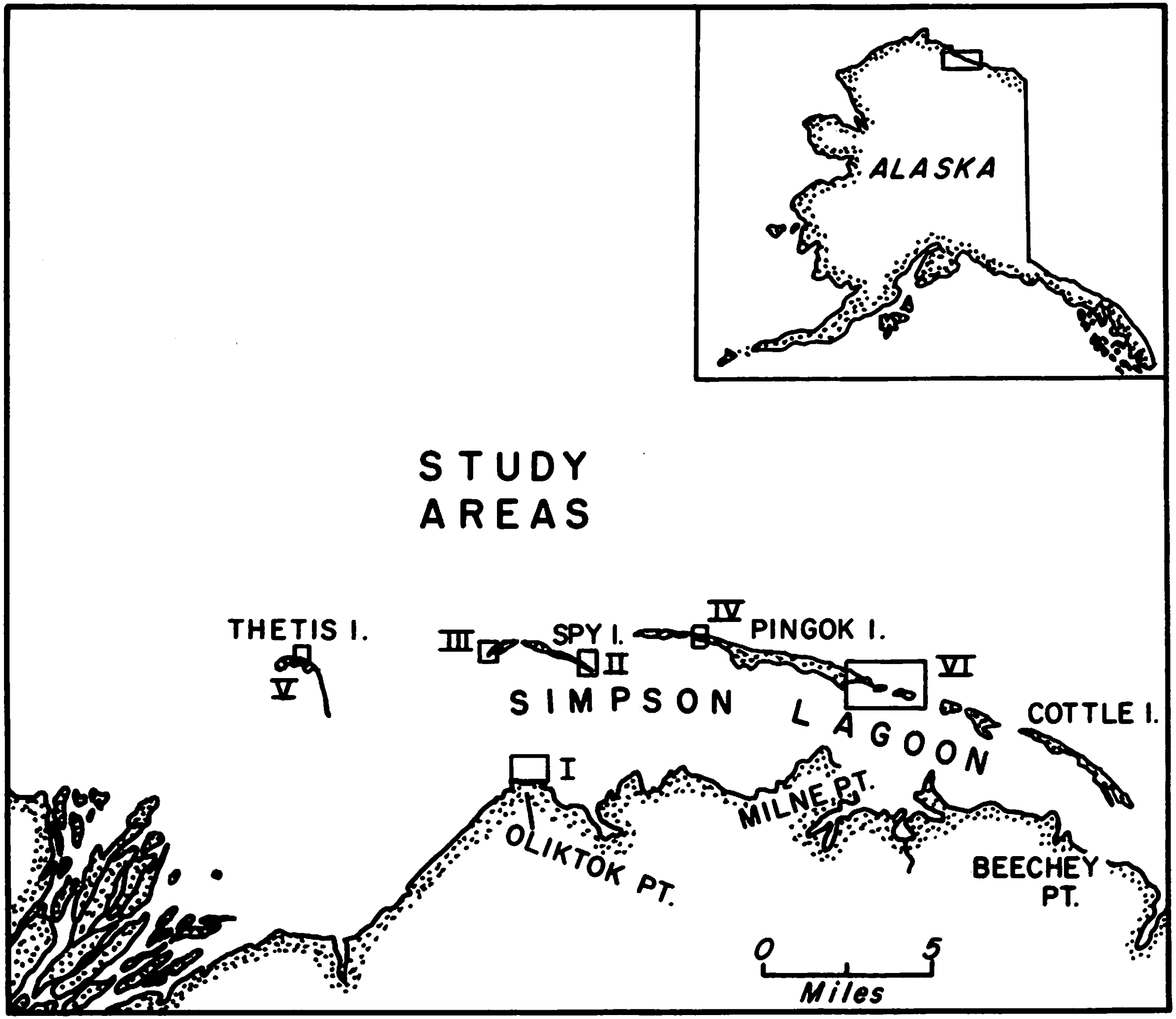

Figure 2. Study Areas.

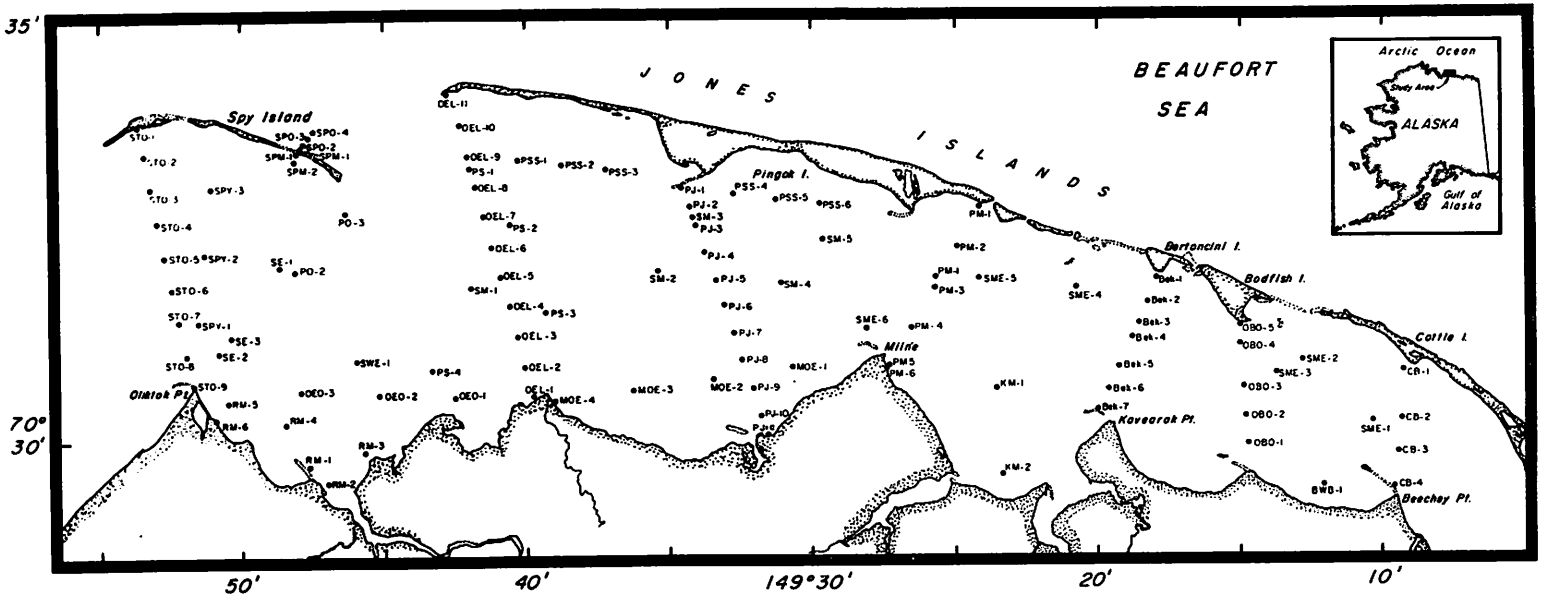

Figure 3. Sample locations in Simpson Lagoon.

In addition, from a short-term, more practical viewpoint, we wished to obtain the necessary background information which would enable some prediction of the potential effects of perturbations of this environment. Coastal zone management has become a topic of considerable relevance in more populous parts of the world. With the initiation of industrial development in arctic regions - and specifically the oil extraction and transportation operations which will shortly commence in this study area - our work is both timely and urgent. Although the geological work described in this section of the report may be considered as an entity, evaluations with regard to resource utilization and perturbations should be made within the context of the complete baseline program: physical, chemical, geological and biological.

As noted above, the work described in this section relates only to the lagoon complex (Simpson Lagoon, Fig. 2) immediately east of the Colville River outfall. Data on Colville River sediments *per se*, and for the areas seaward of the barrier islands are given elsewhere in this report (Chapter 5), but complementary and distinguishing features are cross-referenced where appropriate.

Previous Work

Studies of the geology of this arctic coastal plain region was initiated with the reconnaissance work of Schrader[1]. Leffingwell[2] produced the first detailed map of the Canning River (Fig. 1) area. Data for the western coastal province given by Smith and Mertie[3] are additionally broadly applicable to this area since the Gubik is a relatively homogeneous deposit[4]. Most published work on the north slope has been a result of exploration of the Naval Petroleum Reserve (No. 4). Particulary relevant to this present study area are the data given by Robinson[5] and Black[6]. O'Sullivan[7] and Lewellen[4] have carried out subsequent investigations and an excellent bibliography on the geology of the arctic coastal plain has been issued by Maher and Trollman.[8]

No concerted effort to analyse the sedimentological regime of the near-shore regions has been attempted prior to this study (see also Tucker[9]). McCarthy[10] initiated specific studies concerning shore erosion rates in the Point Barrow area. Subsequent investigations of beach dynamics at Point Barrow have been published by Rex and Taylor,[11] Rex,[12] Hume,[13,14,15] and Hume and Schalk.[16,17] Work on the sedimentological aspects of the Colville River have been authored by, for example, Reimnitz and Bruder[18] and Walker and McCloy.[19]

Carsola[20] and Hoskin *et al.*[21] have presented size fractionation data for Beaufort Sea shelf and slope sediments collected from icebreakers. More recently, Naidu, in a series of publications,[22,23,24,25,26,27] and elsewhere in this report, has described size fractionation facies and the clay mineralogy and geochemistry of the slope and shelf sediments of this region and has compared these open ocean sediments with arctic river and coastal deposits.

SETTING

General Geology and Climate

The arctic coastal plain of Alaska (Fig. 1) is a broad, gently sloping plain dissected by several major northward flowing rivers. It is bounded to the south by the arctic foothills with elevations approaching 200m. Further south, the eastern and central portions of the Brooks Range (see Wahrhaftig[28]) are the source areas for the rivers: chiefly the Colville, Kuparuk, Sagavanirktok and Canning. All the latter rivers provide possible transportation routes for sediments entering the Arctic Ocean.

The major potential sediment sources for Simpson Lagoon - the area of study for this section of the report - are the flanking Colville and Kuparuk rivers (Fig. 1). This area is part of the Teshekpuk section of the Alaskan Arctic Coastal Plain Province. Landward from the coastal margin, the low relief surface consists of perennially frozen ground (permafrost) with numerous shallow oriented lakes and ice-wedge polygons. Surficial deposits of the Teshekpuk section consist of reworked marine sands, silts and gravels in an ice-cemented matrix. This is the Gubik formation[6], which overlies Cretaceous and Tertiary deposits west and east of the Colville River respectively. The extension of the Arctic Coastal Plain into the off-shore region forms the Alaskan arctic continental shelf. This marine area is the Beaufort Sea; a sub-section of the Arctic Ocean. The coastal waters of the Alaskan arctic coast are very shallow (less than 10m) over broad areas (5-6 miles from shore) and are bounded by long chains of barrier islands. Open ocean surface circulation patterns are anti-cyclonic, but longshore currents depend upon wind and wave directions. The surface salinities of the near-shore Beaufort Sea waters range between 20-23 °/₀₀[29], with temperatures always close to 0°C (see Johnson and Hartman[30]). Brackish water from the Colville River may enter the lagoon with salinities as low as 1.5 °/₀₀, and a temperature of around 12°C[29]. Winter ice conditions restrict the circulation, and a salinity of 65.9 °/₀₀ has been measured in Simpson Lagoon during this season. The tidal regime in this part of the Beaufort is relatively simple[31], with a normal diurnal tide of around 20cm amplitude.

Temporal climatic effects on the sedimentological processes in the study area are of major importance. The arctic climate provides only about three months (July-September) of open water conditions. At all other times of the year, processes of erosion or transport are hampered by the presence of as much as 2m of ice in the lagoon[29], by shore-fast ice and by frozen beaches. The effect of pack-ice push on the terrain seaward of the barrier islands has been well documented. Both Carsola[20] and Rex[12] have described micro-relief features associated with ice-gouging in this region, and Hume and Schalk[32] have noted the effects of ice push on the Point Barrow beaches. Lagoonal beaches are protected from further wave erosion early in the winter season via freezing spray deposits (kaimoo structure). Much of the lagoon is frozen to the sediment surface during the winter and the barrier islands protect the lagoonal sediment from ice-push erosional effects.

Air temperatures are relatively cold year-round (-40°C to 10°C) and precipitation is less than 25cm/yr so that the coastal plain is considered an arid region. The annual temperature cycle has a profound effect upon the available sediment supply. Low temperatures prevent significant erosion and expand the permafrost. Spring-summer temperatures allow rapid thaw and surface water run-off and a retreat of the permafrost. In the summer, beach cliffs are thermally eroded and the material may be transported by wave action. The islands which are primarily affected in the latter fashion, are those in the eastern section of the lagoon that are capped with tundra material (see below). The permafrost table is around 0.5m below the beach surface at Oliktok Point (see Figs. 2 and 3) during the summer. Reimnitz *et al.*[33] believe that seismic profiling has recorded massive ice beneath the lagoon floor at a depth of 20-30m. Additionally, since more of the major reflections change character from the shallow water - where permafrost is undoubtedly present - to deeper water areas, these latter authors conclude that permafrost is continuous, at least to the barrier islands.

The surface wind patterns are of supreme importance with regard to the sedimentation dynamics as considered in detail below. The predominance of northeasterly and easterly winds has been a well appreciated phenomenon (e.g., see Lewellen[4]) prior to the detailed analysis presented in this report. However, there is also a westerly mode in the distribution spectrum. Major storms come from the west and may bring winds of up to 70 knots and storm surges of 2-4m. The sedimentological effects of storms are of major importance inasmuch as, depending upon the time-frame considered, the erosional effects may be cataclysmic rather than "steady-state". Much of the published work on beach movements at Point Barrow, for example (e.g., Hume and Schalk[16,32]) has been concerned with storm effects. Even with the relatively short open-ocean fetch between shore and the pack ice edge available during the summer months, storms of considerable ferocity may act upon the beach and island sediments at relatively frequent intervals. Much of the beach movement work reported in this section relates to "normal" erosional process, but the periodic and substantial movements produced by storm effects is obviously a very relevant factor when considering shoreline changes over a decade or more such as is given by comparisons between the various aerial photographic surveys.

The Study Area

Simpson Lagoon (Fig. 1) is located between 70°30' and 70°35'N and 149°10' and 149°55'W. This embayment is approximately 24km E-W and between 1.5-5.0km N-S; wider at the western end. The long axis is parallel to the coast and, except for a channel adjacent to Spy Island (see Fig. 3), the maximum depth noted is slightly in excess of 3m.

Two third-order rivers flow into the lagoon; the Ugnuravik and an unnamed stream which empties into the bay between Milne and Kavearak Points. There are three major outlets to the open ocean, one at each end, and the previously mentioned channel between Spy and Pingok islands. The rivers are small, and flow from them is not considered to be significant in terms of sediment sources.

A chain of islands (the Jones Islands) forms the seaward margin of the lagoon and protects it from action from the open Beaufort Sea. The four most easterly of the major islands are all tundra capped and have permafrost close to the surface often visible in the beach cliffs. Spy Island and the western extension of Pingok Island, together with one island to the west of the lagoon, are composed of gravel with neither tundra nor detectable permafrost. These latter gravel islands show storm wave and sea-ice erosional effects whereas the vegetation and permafrost of the eastern islands seem to protect the surfaces to some extent. Tundra vegetation acts to insulate the ground and inhibit thermal erosion. However, erosion does occur during the summer, and large mats of tundra vegetation are common in shallow water areas. Lewellen[4] has described the potential effects of man's activities in this type of terrestrial environment.

METHODS

Beach Deposits and Dynamics

Two beach study sites were selected at Oliktok Point at the western end of Simpson Lagoon (Fig. 2; Site I) for the study of beach sediment transportation. One locality faced northeast and four profiles at 30m intervals were surveyed in this locality *via* levelling from a fixed reference during the periods July-August 1971 and July-September 1972. Four additional profiles, spaced at 122m intervals, were surveyed over the same time periods on a northwest-facing portion in the same locality. These detailed study sites at Oliktok Point were selected as being reasonably representative of beach conditions along Simpson Lagoon and also because of their proximity to the base camp and the DEWline station. During July-August 1971, breaking wave heights were recorded visually with the aid of a graduated staff and stopwatch (U.S. Navy Hydrographic Office, 1956). Wave heights during the July-September 1972 period were recorded on an x,y recorder using a continuous resistance wire wave staff (Interstate Electronics Corp.). Wind speed and direction data were taken during the earlier sampling period by means of a hand-held indicator and during the following year via continuous recording instrumentation. Longshore current velocities were evaluated by timing the movement of dye patches released along the shore. The breaker angle was measured with a Brunton compass. Beach sediment size analysis was performed using conventional sieving techniques at 0.25 ϕ intervals and by pipet analysis[34].

Sediment transport and shoreline changes along the entire Simpson Lagoon coast and for the barrier islands have been determined by comparison of aerial photographic coverage taken on 7 October 1971 and 4 October 1972, by personnel from the Naval Arctic Research Laboratory (N.A.R.L.) at Point Barrow with similar surveys conducted in 1949 and 1955 by U.S. federal agencies.

Lagoon Sediment Sampling

The ideal sampling procedure would have included the collection of samples during both winter and summer on a grid system with the spacing determined primarily by the size of the features being examined. In the absence of any prior information on the area, sample localities were selected on closely spaced transects determined by the very inaccurate navigation aids available. Only dead-reckoning was possible in the summer between the few available landmarks, and position location by compass-bearing during the winter season. Between the shores, samples were taken at timed intervals traveling at a fixed speed. In this fashion, sampling stations were well distributed throughout the lagoon area, but were neither gridded nor entirely random. Sample locations are shown in Figure 3.

It was not generally possible to collect from the same stations during both winter and summer. All winter sampling was confined to the deeper portions of the lagoon where the water was not frozen to the sediment surface, since the auger used to drill through the ice was not capable of extracting frozen sediment. It was also necessary to complete the winter sampling in as short a time as possible on account of logistic and climatic difficulties.

Summer samples were taken with a Wildco Ponar bottom grab which samples an area about $0.05m^2$ (see also Crane[35]). Winter samples were collected with a clamshell snapper which collected about 250g per drop. The differences in the sampling devices were due to the nature of the sampling method. The choice of winter sampler was predetermined by the size of the hole the auger could drill in the ice. Summer sampling used a different sampler to try to get a larger and more representative sample. Approximately 200 to 1,000g of sample were collected from each station wherever possible; some of the stations did not yield this much despite repeated sampling, especially at the winter stations, and as a result were not useable for some aspects of this study.

Textural Analysis of Lagoon Sediments

The textural analysis of a sediment began with the separation of the coarse and fine fractions from about 200g of sample. This was accomplished with a wet sieve of 230 mesh (61μm) openings, to separate the sand and gravel from the silt and clay. The coarse fraction was dried and the gravel removed with a 2mm (-1 ϕ) sieve. Both fractions were saved. The sand and mud fractions were treated with H_2O_2 to remove organics. The dried sand fraction was then passed through a microsplitter until sub-samples of 2g were obtained for use in size analysis. A flow chart of this procedure is shown in Figure 4.

Sand size analysis has for many years been a tedious process of sieving at standard intervals, weighing fractions and calculating the percentages. Recently, it has become possible to construct an apparatus that will measure the hydraulic diameter of particles much more rapidly. J. A. Dygas and R. W. Tucker constructed a settling tube of the type described by Felix[36] specifically for use in this study. This tube was used for all sand size analyses presented here. The calibration of the tube was accomplished by measuring fall times of known size particles. These particles at first were derived from sieve analysis of natural sands. Subsequently, another calibration was made using glass beads purchased from the 3M Company. The calibration curves presented in Figure 5 were compared with a theoretical fall time calculated from the formula:

$$\left[\frac{4}{3}\rho_p(\pi a^3) - \rho_f\right]g = 6\pi a u U + \pi a^2 U^2 \rho_f \qquad (1)$$

where a = particle radius in mm
u = pure fluid viscosity
U = settling velocity in mm/sec
g = gravitational acceleration
ρ_f = fluid density
ρ_p = particle density

The precision varied with size but was greater than 0.95 for all sizes. This compares favorably with the Emery tube and is close to the precision claimed for sieves[36]. Average time per analysis was less than ten minutes. Gravel was present in a few samples although in small quantities. The size analysis of gravel was done with standard Tyler sieves. This portion of the curve was then added to the sand and mud curves for each sample at the time of plotting.

Standard pipet analysis (e.g., see Royse[34]) was carried out on all samples with a 5 percent mud fraction. After the mud fraction had been treated with H_2O_2, it was heated gently to remove excess H_2O_2, poured into a settling tube and the volume brought to 1,000ml after adding 2g of Calgon. Standard grain size parameters of Folk and Ward[37], and the normalized kurtosis after the method of Royse[34], were calculated.

Heavy Mineral Analysis

The sand fractions of 28 samples were separated by sieving to give 30-60, 60-120 and 120-230 mesh-size sub-samples. These three standard size groups were selected to better evaluate size-density relationships. Subsequent separation of the heavy mineral fractions was according to the method of Krumbein and Pettijohn[38] - using tetrabromethane (density 2.95) - as shown in Figure 6.

Carbon Analysis

Both organic and inorganic carbon were determined for ten sediment samples. Organic carbon analysis was carried out using the procedure outlined by Loder[39]. A small fraction of the sample was ground to powder in an agate mortar and then treated with HCl (20% v/v) to remove to carbonates. Approximately 60mg of sample was weighed into a porcelain boat and run on a dry combustion carbon analyzer of the type described by Loder[39]. Carbonate carbon was determined by a manometric technique as described by Hulsemann[40]. Portions of the powder ground for the organic sand and gravel from the silt and clay. The coarse fraction was dried and the gravel removed with a 2mm (-1 ϕ) sieve. Both fractions were saved. The sand and mud fractions were treated with H_2O_2 to remove organics. The dried sand fraction was then passed through a micro-splitter until sub-samples of 2g were obtained for use in size analysis. A flow chart of this procedure is shown in Figure 4.

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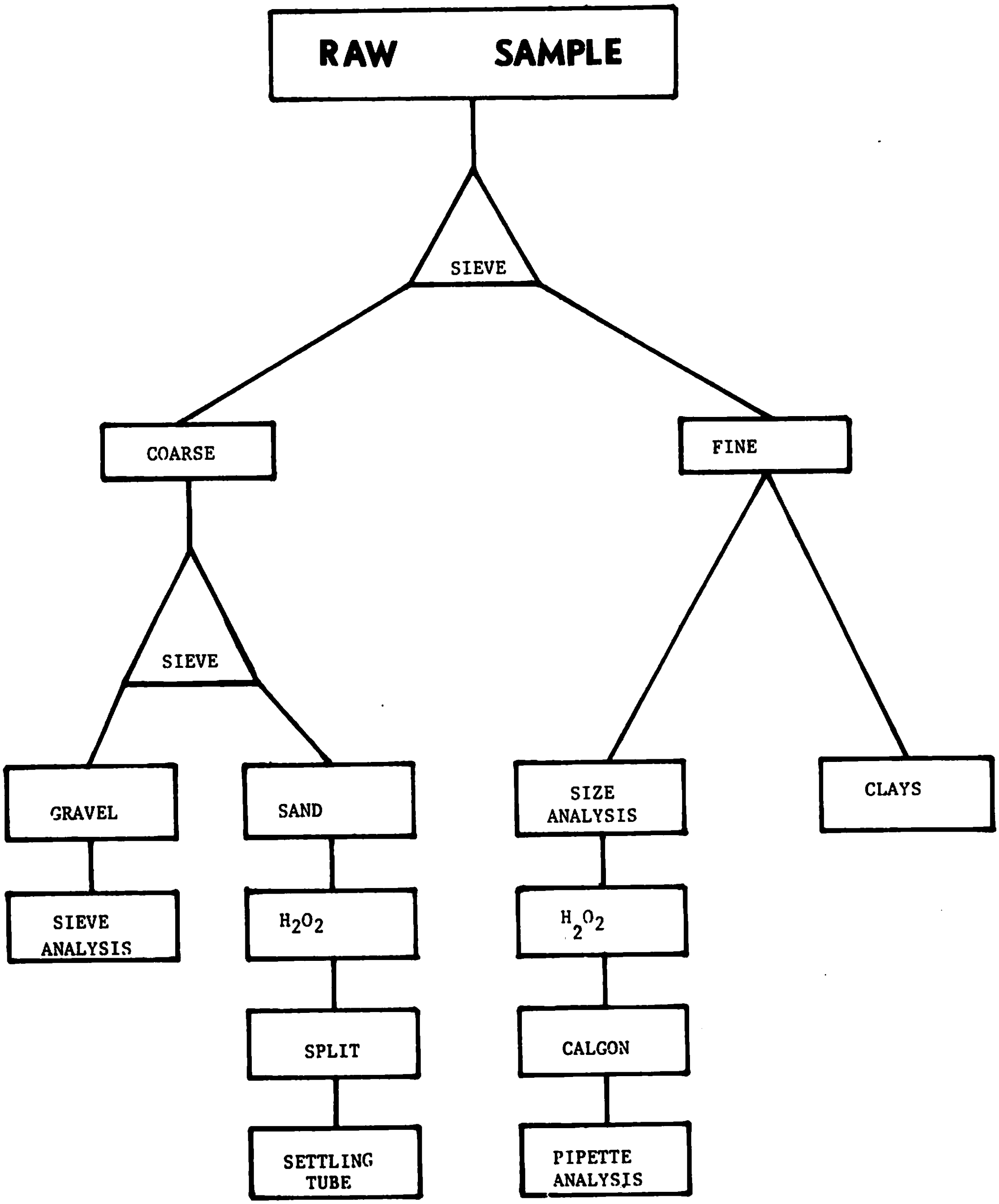

Figure 4. A flow chart of texture analysis.

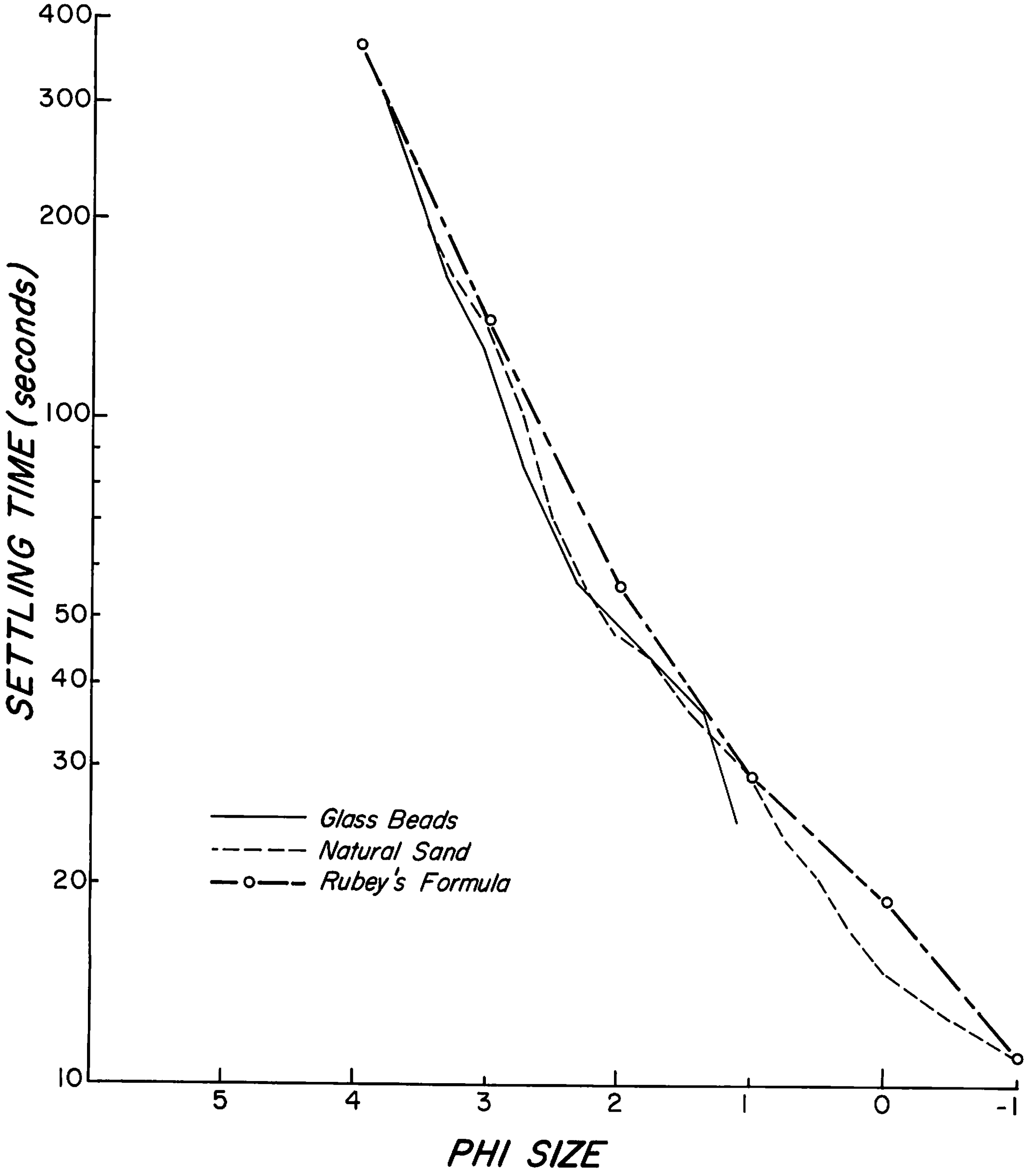

Figure 5. Calibration curves for settling tube analysis.

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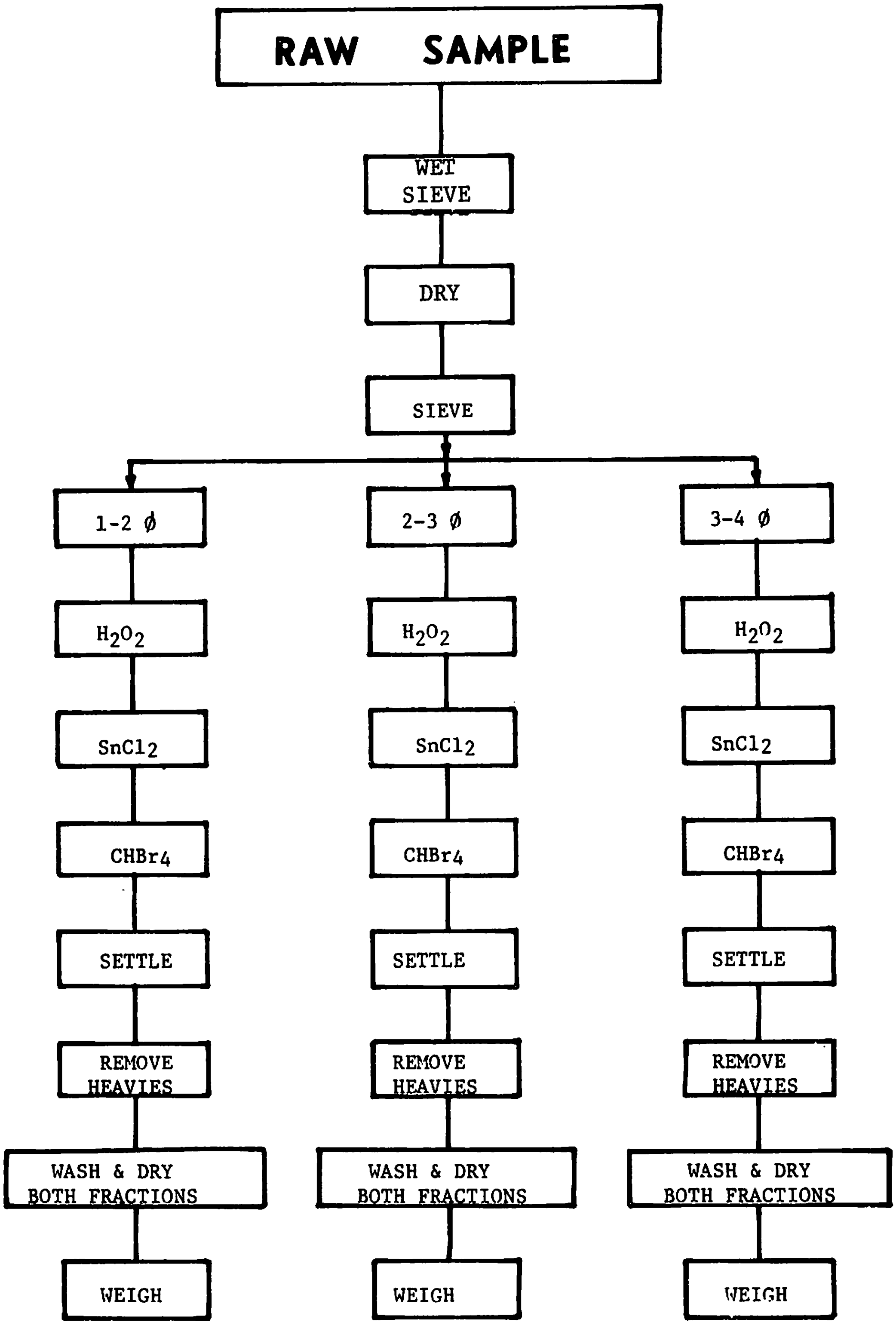


Figure 6. A flow chart of heavy mineral seperation procedures.

carbon analysis were separated before treatment with HCl and used for this analysis.

Clay Mineral Analysis

The 62μm fraction of each sample was treated overnight with H_2O_2 to remove most of the organics, then placed in a settling tube (1000ml) and allowed to stand up to 7 hours until the degree of flocculation could be determined. If necessary, the sample was then treated with a drop or two of NH_4OH to prevent flocculation. After standing for 7 hours, the top 10cm of liquid was siphoned off, centrifuged at 3300rpm for 20 minutes, and the supernatant liquid removed. This treated sample (<2μm) was then transferred to small vials for storage prior to slide preparation.

Slides for X-ray diffraction analysis were prepared from 10 samples (and several duplicates) by the modified smear technique described by Naidu and Mowatt[26]. This was done to obtain a relatively well oriented sample. The slides were placed in an atmosphere saturated with ethylene glycol 24 hours prior to analysis. X-ray patterns were run on a Phillips X-ray diffractometer using Cu $K\alpha$ radiation at 35KeV and 18ma. Patterns were run from 2°θ to 28°2θ on each glycolated sample. A scan speed of 2°2θ/min was used for the full pattern. Slow scan patterns of the peak around 25°2θ were run at 1/4°2θ/min to differentiate kaolinite and chlorite. A number of methods of quantitative analysis were considered, and eventually the weighted peak area percentages of Biscaye[41] were calculated.

Computer Techniques

The textural analysis computations presented in this report were performed on an IBM 360/40 at the University of Alaska computer center. A number of programs were written to calculate various parameters for the analyses. A linear least squares program was used when two variables were being compared, and programs to calculate weight percentage values from raw size analysis data, and to calculate Folk and Ward[37] statistics were also written. The program (Trenmain) used for trend surface analysis (see below) was originally written by Harbaugh[42] and adapted to the University of Alaska computer by Heiner and Geller[43]. This latter program allows the input of x and y coordinates plus a z value for each set of coordinates and calculates and contours the first through sixth degree surfaces and prints the residuals for each surface.

A number of standard methods of mathematical geology are used in this report. The calculation of mean, standard deviation, and correlation coefficients were done by matrix algebra on the computer. Formulas used for these calculations follow:

$$\text{Mean} = \sum_{i=1}^{n} \frac{X_i}{n} \tag{2}$$

$$\text{Standard Deviation} = \sum_{i=1}^{n} \frac{(X_i - \overline{X})^2}{n-1}^{1/2} \tag{3}$$

$$\text{Correlation} = \frac{\text{COV}(X,Y)}{S_x S_y} \tag{4}$$

where x and y = data values from different sets of data

S = the standard deviation

n = the number of data values

$\overline{X}$ = the mean value of x

COV = the covariance

For a complete tabulation of the method of calculations of these parameters see Tucker[9].

Trend Surface Analysis of Lagoon Sediments

Trend surface analysis is a logical extension of linear least squares analysis. A linear least squares fit produces a line fitting a two dimensional array of points. A trend surface analysis produces a least squares surface fitting a three dimensional array of points. The points are actually values assigned to two orthogonal coordinates, hence their three dimensional quality. A trend surface is a mathematical creation determined by bivariate power series expansion. The degree of the surface is denoted by the largest superscript on a term of the equation defining that surface. For example, a first degree equation would be:

$$z = A + b_1x + b_2y \qquad (5)$$

Where x and y = the coordinates
z = the value of the surface at those coordinates

A fourth degree equation would be:

$$z = a + b_1x = b_2y + b_3x^2 + b_4xy + b_5y^2 + b_6x^3 + b_7x^2y + b_8xy^2 + b_9y^3 + b_{10}x^4 + b_{11}x^3y + b_{12}x^2y^2 + b_{13}xy^3 + b_{14}y^4 \qquad (6)$$

The residuals of a surface are the differences between the calculated z values and the actual value input for those coordinates (e.g., see Koch and Link[44]). One of the methods of determining the validity of a surface is the Pearson Product Moment Coefficient of Correlation[45]. This is calculated by the Trenmain program as referenced in the previous section.

A prime problem in the use of trend surfaces has been finding a method to determine if surfaces are significant[46,47,48]. In general, the methods proposed all deal with the sums of squares of the surface of the terms of the equation versus the residual sums of squares. One of the simpler methods is explained by Davis[49]. It consists of calculating an F value for the surface:

$$F = \frac{MS_R}{MS_D} \tag{7}$$

Where MS_R = the regression-mean-squares, or the sum of squares due to the regression, divided by the number of coefficients in the general regression equation (i.e., b_m; eqns. 5 and 6, excluding the A coefficient)

MS_D = the deviation-mean-square of $SS_D/(n-m-1)$

$$SS_D = (z_{iobs.} - z_{iobs.})^2 \tag{8}$$

Where SS_D = the deviation sum of squares

n = the number of sample points

m = the number of coefficients in the general regression equation

In the trend surface program used for this study, the regression sum of squares was calculated from the following equation:

$$E = V - SS_D \tag{9}$$

Where E = the regression sum of squares

V = the total variance[43]

Another method of testing the surfaces for significance tests only the regression sums of squares added by the new terms in each equation[47]. Both these methods were used with confidence levels of 0.10 (Freund[45]; Tables from Selby[50]). Where higher confidence levels were significant, they are reported. These methods provide a test of the statistical significance of the surfaces which is standard but which been questioned as to its validity[48].

Error Analysis

The usual sources of error apply to this as to any similar scientific study. Replicate samples, for example, were not collected, so that an estimate of the local variability at any one sampling location is not available. It is, however, expected to be small compared with parameter variance over the total lagoon area. Statistical parameters calculated from splits of the same sample were generally within ±5 percent. This includes the rounding errors of the computer programs and operator error in the analysis.

The clay mineral analysis procedure employed was only semi-quantitative as noted previously. Precision for the carbon determinations was very good; ±3 percent at the 95 percent confidence level for both organic and carbonate carbon.

RESULTS AND DISCUSSION

Wind Analysis and Longshore Currents

Published long-term meteorological data for the Alaska arctic coast are available only for the geographical extremities at Point Barrow (Fig. 1) and close to the Canadian Border at Barter Island. The wind direction for the latter locality is predominantly bimodal; either from the northeast or from the southwest. Figure 7 shows the cumulative probability distribution for long-term (17 year) wind velocities for the months of June-October at Barter Island. There appears to be a progressive increase in the probability of higher wind velocities (in excess of 9m/sec) from July through October.

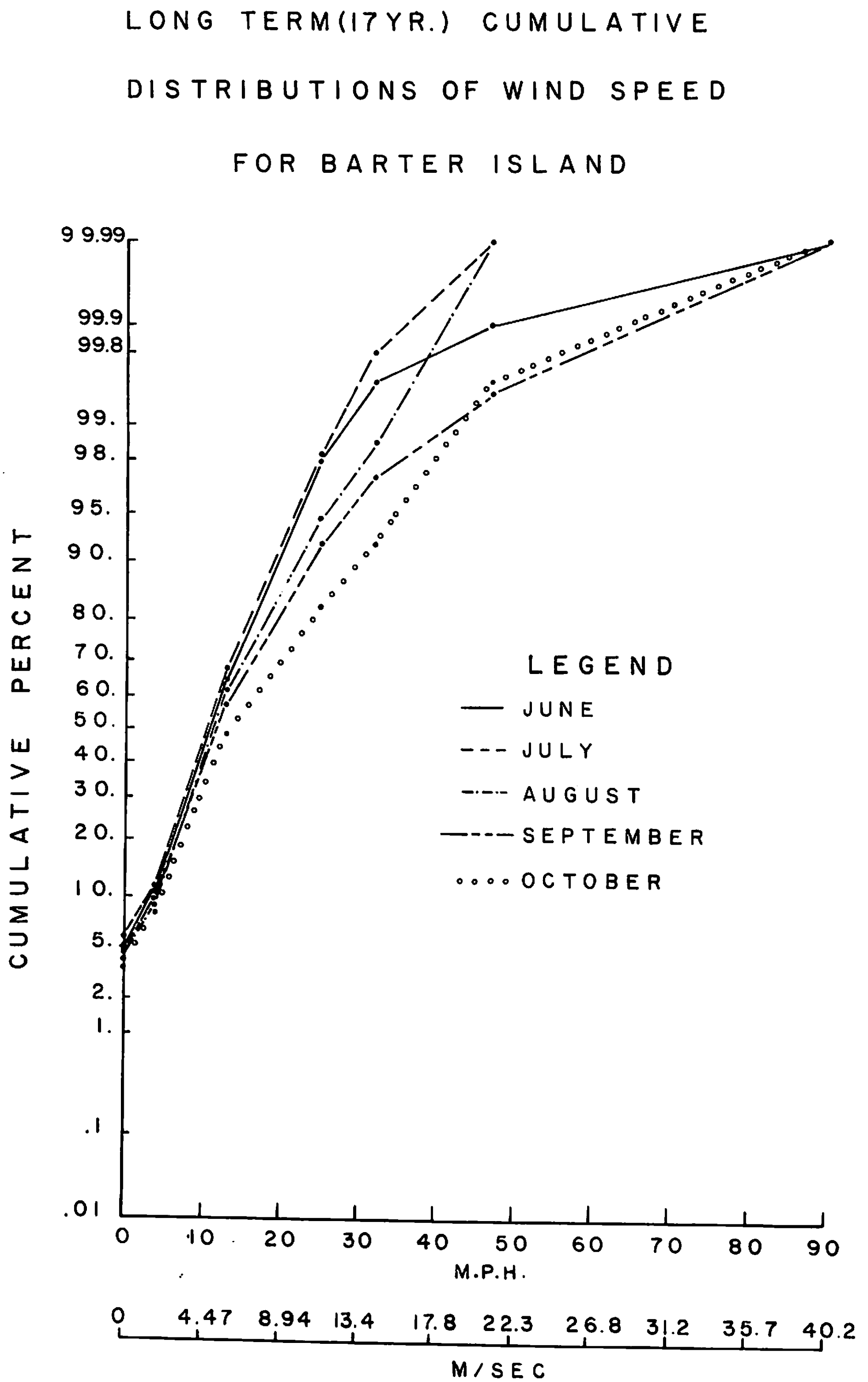


Figure 7. Long term (17 year) cumulative distribution of wind speed for Barter Island.

Wind analysis data recorded at Oliktok Point (Figs. 2 and 3) for the period 18 July to 14 September 1972, are given in Figure 8 and Tables 1 and 2. Where wind energy is represented as the statistical variance of wind velocity *per* direction. Table 2 summarizes these data (% direction and energy) for the four compass quadrants. September shows a larger proportion of higher wind velocities than either July or August. For all three months, the wind from the NE quadrant has a frequency of 57-82 percent of the total spectrum and includes 21-45 percent of the total energy. During July and August - i.e., the bulk of the summer period - the SE quadrant contributes 20-30 percent of the energy, but this is decreased to around 4 percent only in September. Southwesterly winds maintain a relatively constant energy level (18-24%) over the three month period but northwesterly winds increase from 16-45 percent. The frequency of occurrence of northeasterly winds also increases from 8-25 percent from July through September.

We have previously noted the relationship between prevailing wind directions and the coastal water movement patterns in this area[29]. Figures 9 through 11 (from Kinney *et al.*[29]) illustrate the water current velocity and direction distributions and correlations between current and wind speeds and between current and wind directions in Simpson Lagoon. The wave regime and associated longshore currents within the lagoon area are considered to be largely generated by the prevailing winds, and tidal currents are felt to be less important than the wind generated currents. This thesis has important implications for the movement of both beach and lagoonal sediment material, as considered in more detail below.

Long-Term Shoreline Changes

Figure 12 shows linear m/yr erosional rates along the Simpson Lagoon shoreline based upon long-term aerial photographic coverage. Figures 13 and 14 similarly demonstrate detailed shoreline changes on Pingok and

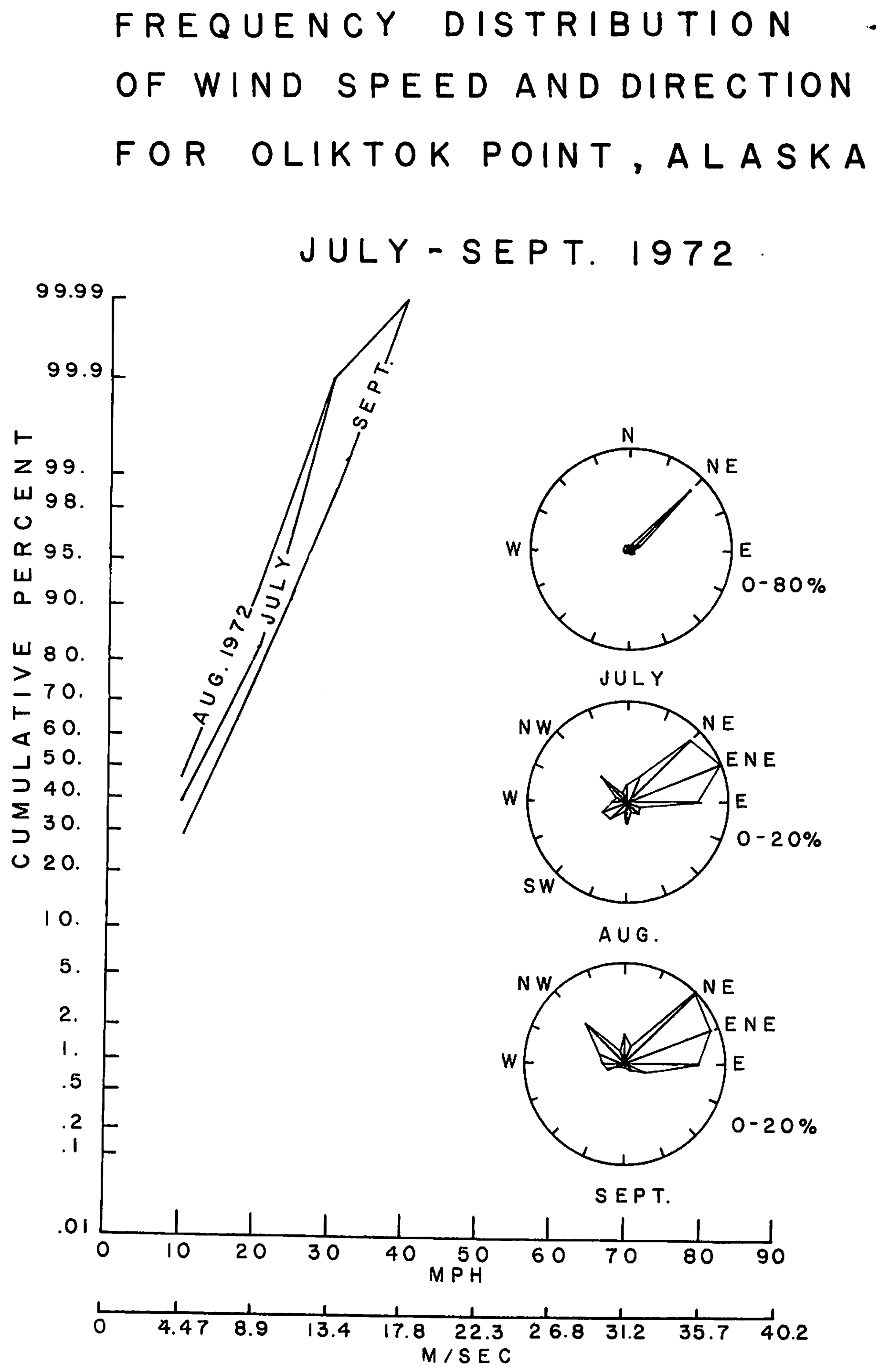


Figure 8. Frequency distribution of wind speed and direction for Oliktok Point, Alaska. July-September 1972.

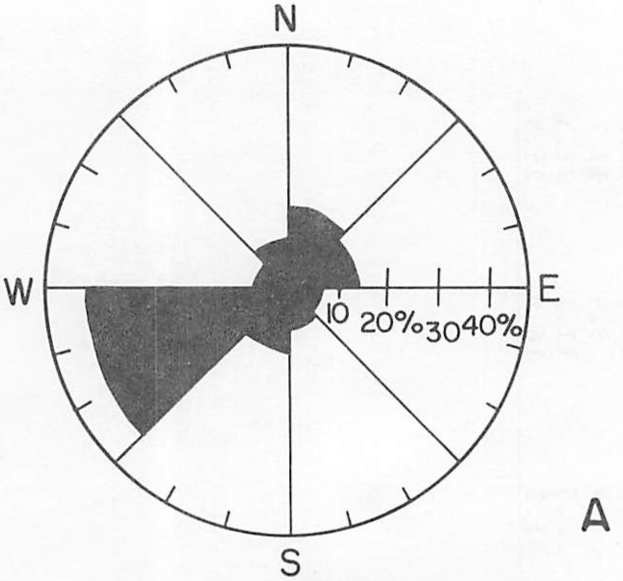
Table 1. WIND DIRECTION AND ENERGY DISTRIBUTION FOR OLIKTOK POINT, ALASKA 1972

	July		August		September		Total	
Direction	Frequency %	Energy %	Frequency %	Energy %	Frequency %	Energy %	Frequency %	Energy %
N	0.4	2.7	3.4	5.4	6.0	9.4	3.9	6.6
NNE	2.9	5.0	5.8	2.3	3.4	2.1	4.9	2.6
NE	67.6	27.2	17.6	2.8	20.1	6.0	28.0	7.9
ENE	8.6	8.2	20.2	4.2	19.0	7.8	17.6	6.3
E	3.2	4.6	14.3	12.1	15.1	11.7	12.4	10.8
ESE	1.4	7.4	2.6	14.4	4.2	3.2	2.9	8.9
SE	1.4	12.5	3.5	3.6	1.6	0.33	2.5	3.6
SSE	0.0	0.0	2.0	6.3	0.5	-	1.2	2.7
S	0.4	0.0	3.9	5.1	0.5	0.9	2.2	2.6
SSW	0.7	0.6	1.9	8.9	0.0	0.0	1.1	3.97
SW	0.7	4.9	5.0	6.8	1.9	7.7	3.0	6.9
WSW	0.4	0.0	5.1	5.4	3.7	11.2	3.2	6.9
W	4.3	13.1	3.1	2.9	4.4	3.7	3.6	4.8
WNW	2.2	4.0	2.3	7.0	5.6	13.0	3.1	9.0
NW	3.6	8.3	7.1	6.6	11.1	10.1	7.9	8.3
NNW	1.4	1.3	2.4	6.1	2.8	12.8	1.9	8.2

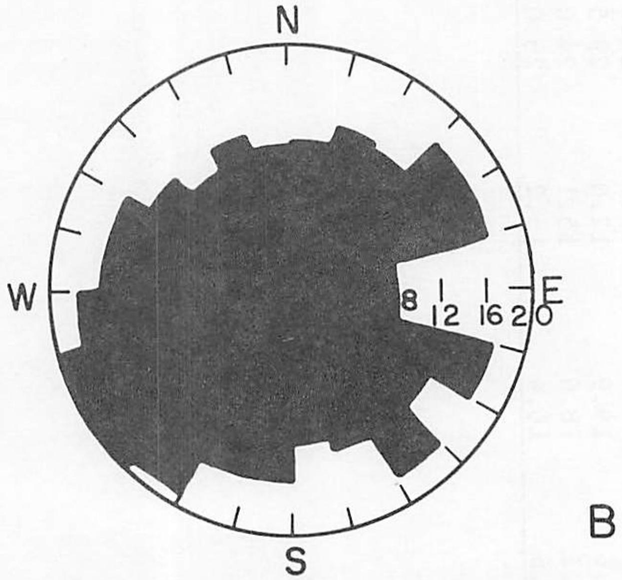
Note: Percent wind energy equals percent of total statistical variance within a given month. Variance is the difference between the mean square and the square of the mean.

Table 2. WIND DIRECTION AND ENERGY DISTRIBUTION FOR OLIKTOK POINT, ALASKA 1972

	July		August		September		Total	
Direction	Frequency %	Energy %	Frequency %	Energy %	Frequency %	Energy %	Frequency %	Energy %
N-E	82.3	45.0	57.9	21.4	57.6	27.6	62.9	27.6
E-S	19.6	19.9	12.0	29.5	6.8	4.4	8.9	17.7
S-W	6.1	18.6	15.1	24.0	10.0	22.6	11.1	22.3
W-N	7.6	16.4	15.2	25.0	25.5	45.3	16.9	25.5



PERCENT DISTRIBUTION OF
CURRENT DIRECTIONS AT
OLIKTOK POINT, 8.25 - 9.1.71



MEAN CURRENT VELOCITY
DISTRIBUTION, cm/sec

Figure 9. Distribution of current velocities and directions in Simpson Lagoon.

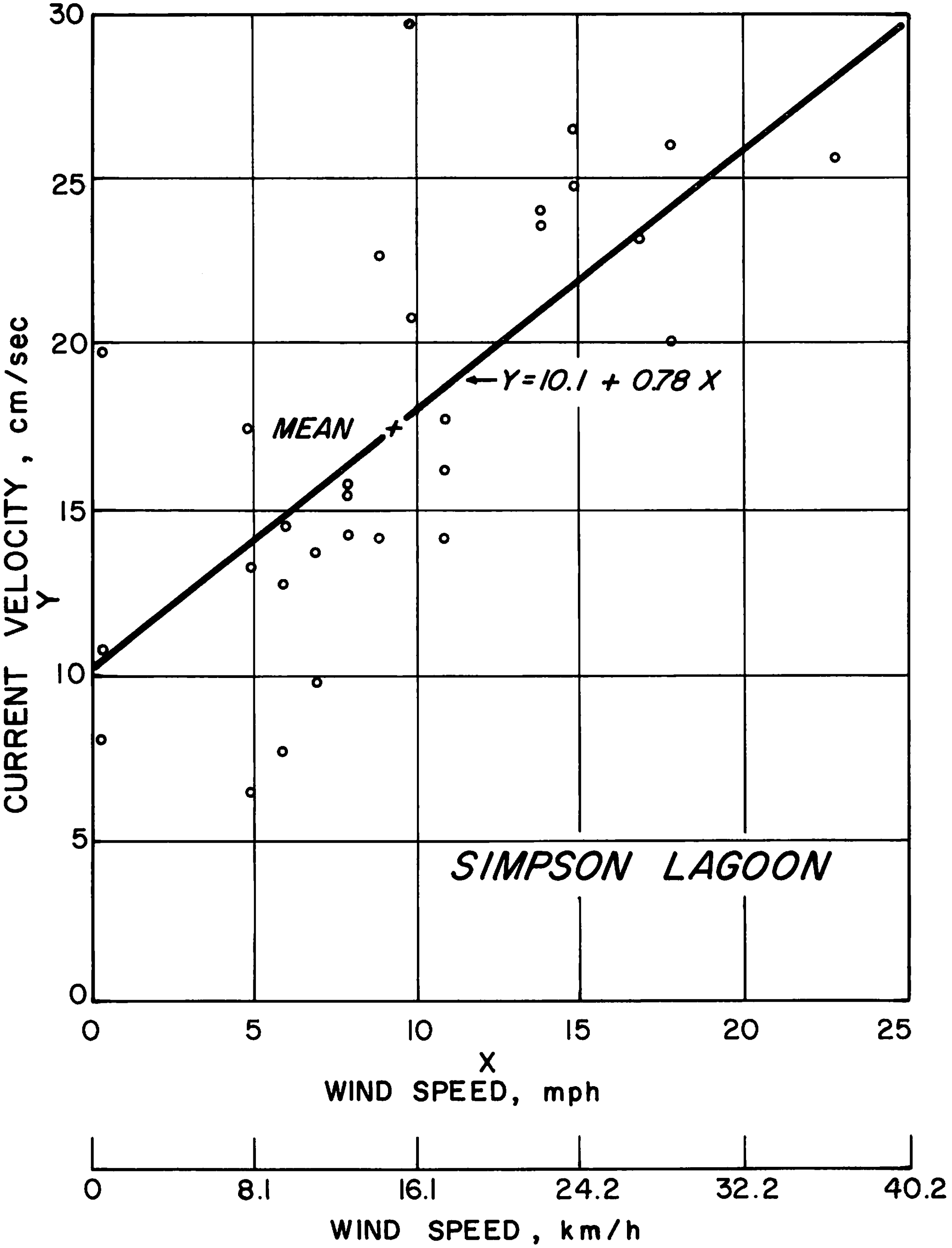


Figure 10. Correlation between recorded current velocities and wind speed.

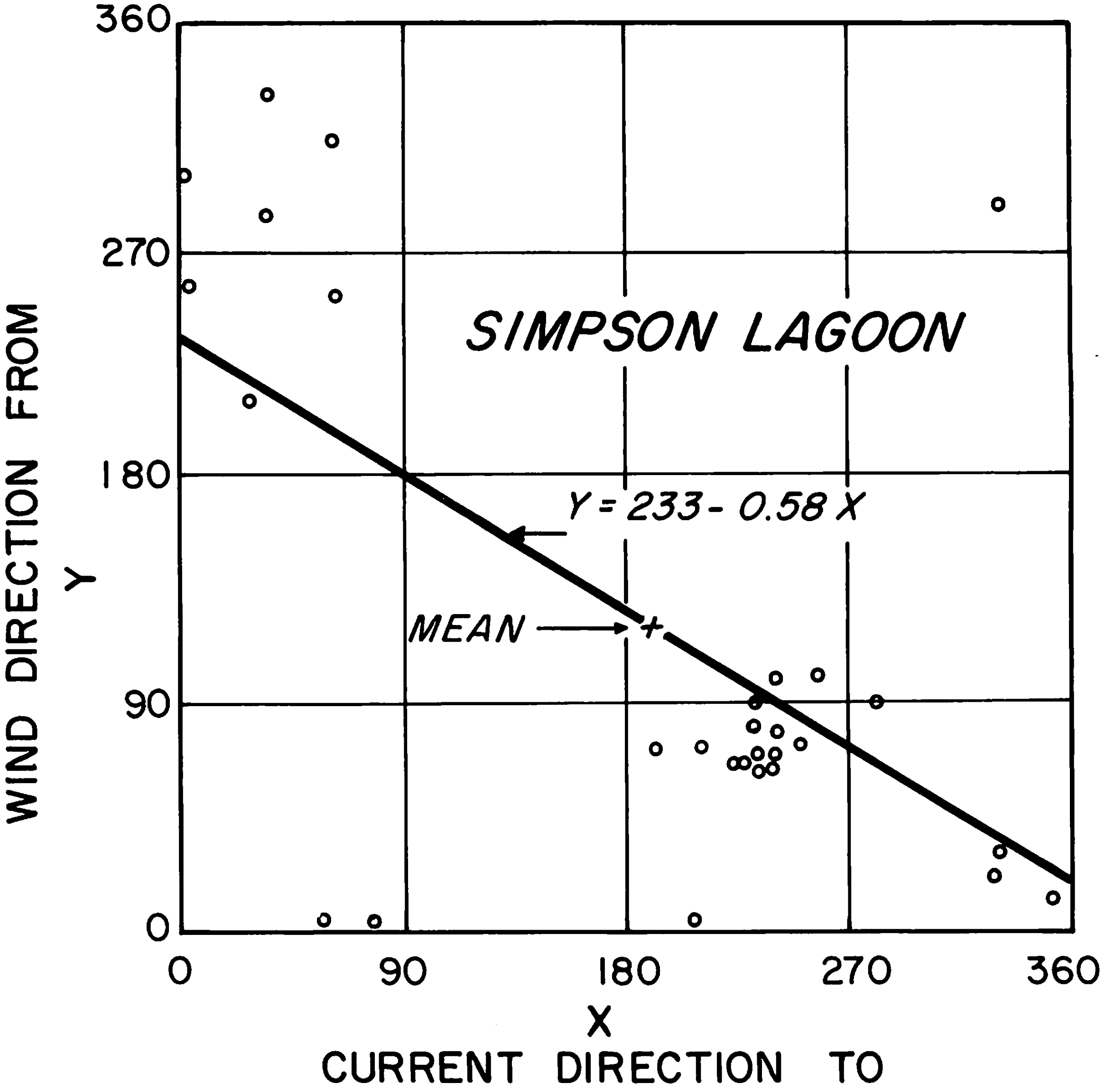


Figure 11. Correlation between recorded current directions and wind directions.

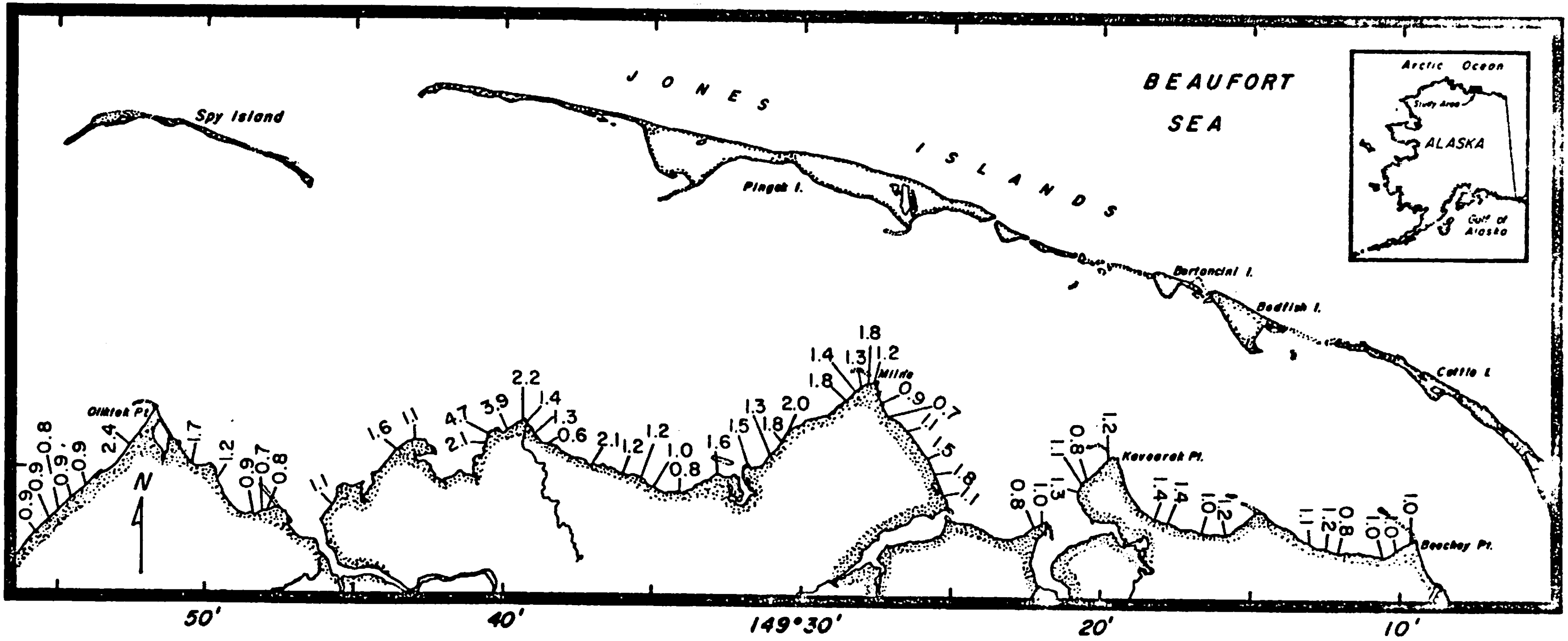


Figure 12. Linear (m/yr.) rates of erosion along the south shore of Simpson Lagoon.

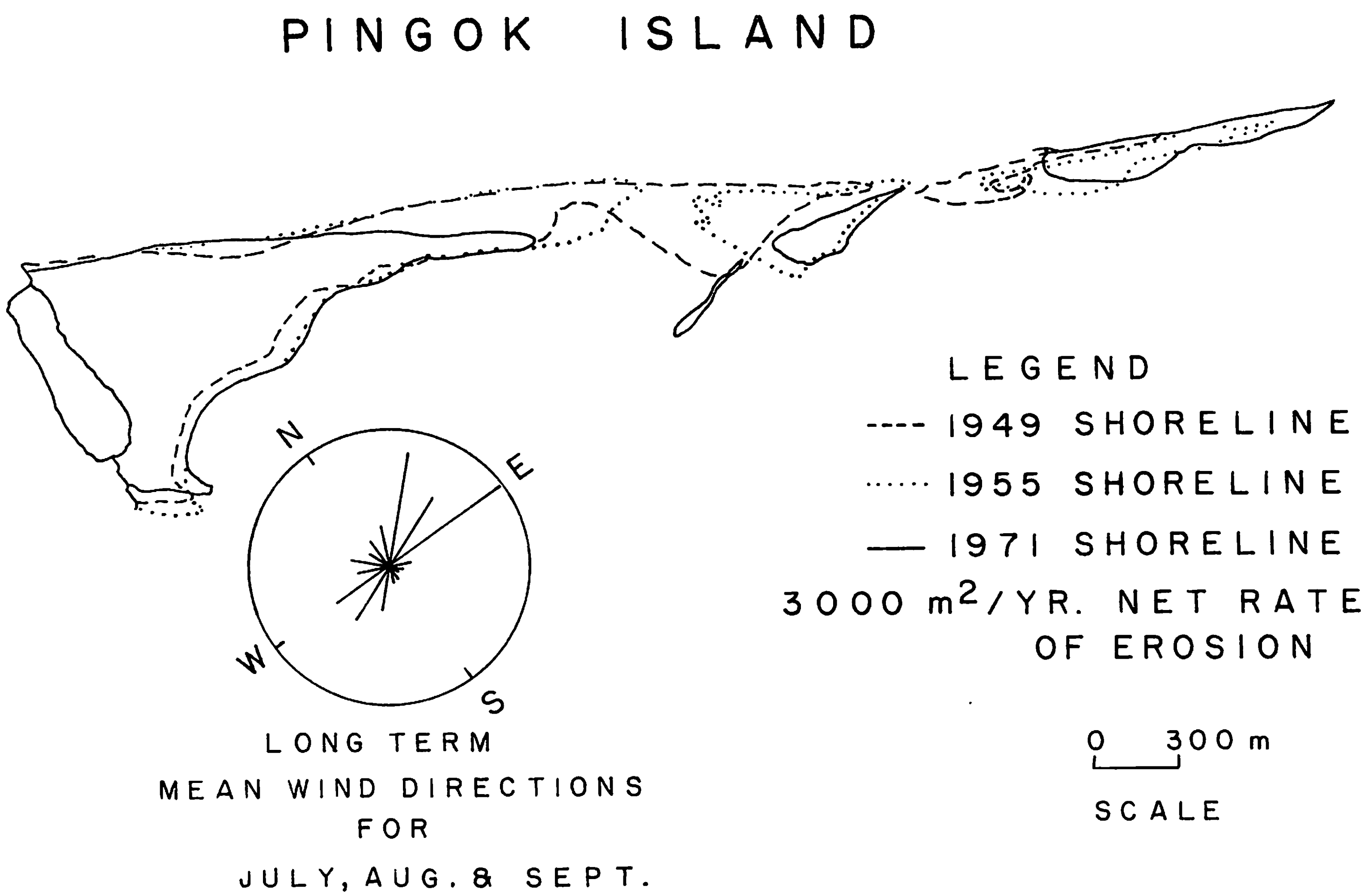


Figure 13. Pingok Island long term mean wind directions for July, August and Sept.

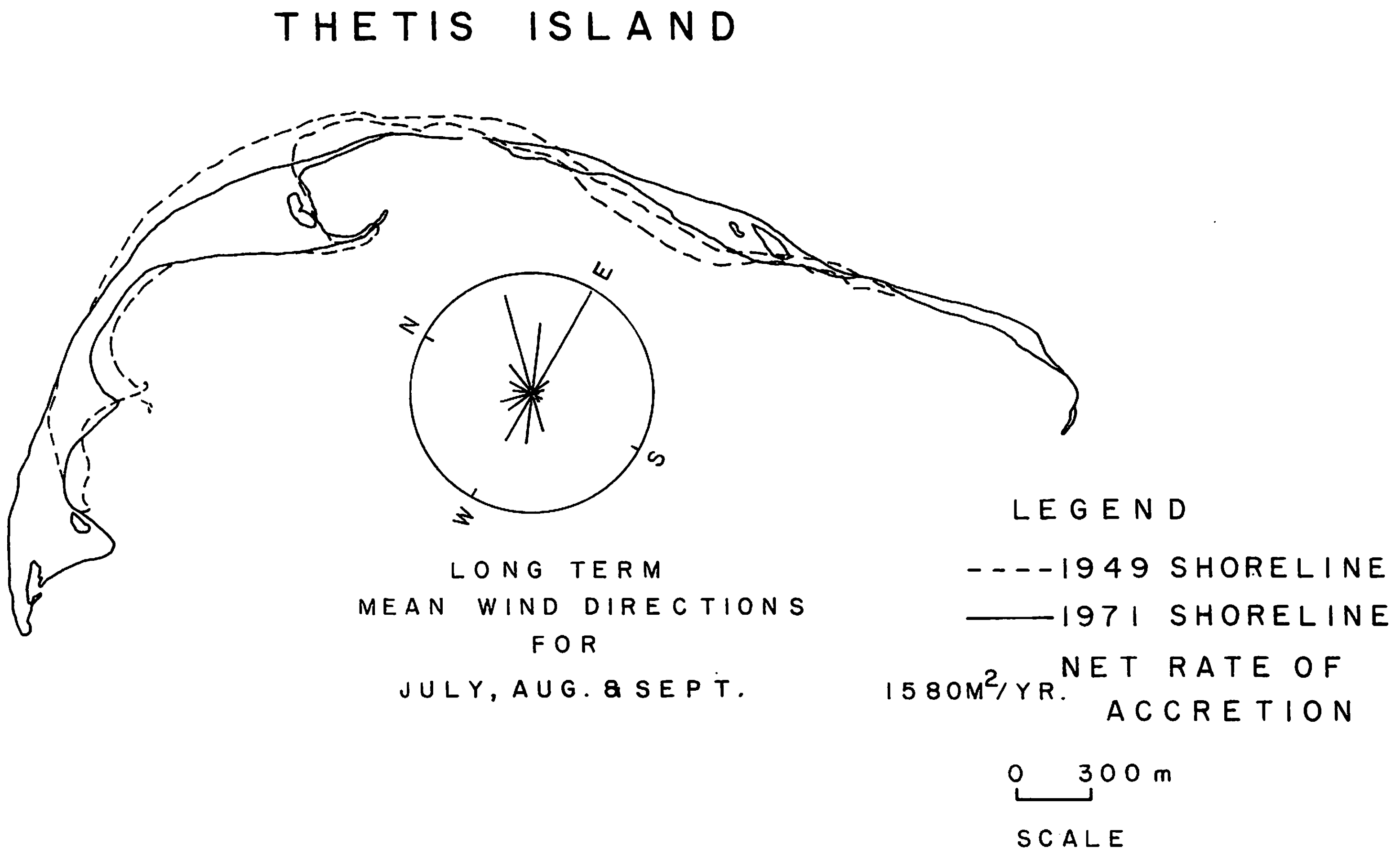


Figure 14. Thetis Island long term mean wind directions for July, August, and Sept.

Thetis Islands (areas V and VI of Fig. 2). The long-term mean wind direction distributions included in these latter two figures are based on Barter Island data[51]. From a comparison of these wind and shoreline data, it is suggested that erosion and transportation from the eastern end of Pingok Island (Fig. 13) are a function of the prevailing southwesterly and northwesterly winds. By contrast, the growth of Thetis Island (Fig. 14) appears to be related to the northeasterly wind direction. The area of greatest accretion is at the western tip of this island. In addition to the characteristic growth configuration of Thetis Island, all the major promontories along the shoreward margin of Simpson Lagoon (i.e., Oliktok, Milne, Kavearak, and Beechey Points; see Fig. 3) have sandy-gravel spits which are oriented in an east-to-west direction. This orientation is interpreted as additional geomorphological evidence for net east to west sediment transport along this particular section of the arctic coast.

Seasonal Variations in Beach Profiles

Figure 15 illustrates grain-size characteristics for two representative profiles on NE- and NW-facing beaches respectively at Oliktok Point. These beaches are typically about 15-25m wide and are terminated landward by either a 2m high permafrost beach scarp capped by a tundra surface or the backshore of the beach may merge into tundra without the scarpment feature. Beach slopes typically range from tan $\theta = 0.044-0.066$.

The locations of the NE beach profiles B-E and NW profiles N and O are shown on Figure 16 (from Kinney *et al.*[29]). All eight of the latter profiles demonstrate net growth over the period 31 July 1971 to 29 August 1972 (Figs. 17-21). Similarly, the two additional profiles of Figure 22, which are located at the western end of the spit at Oliktok Point, demonstrate pronounced growth over the same period. In sections N, O and Q

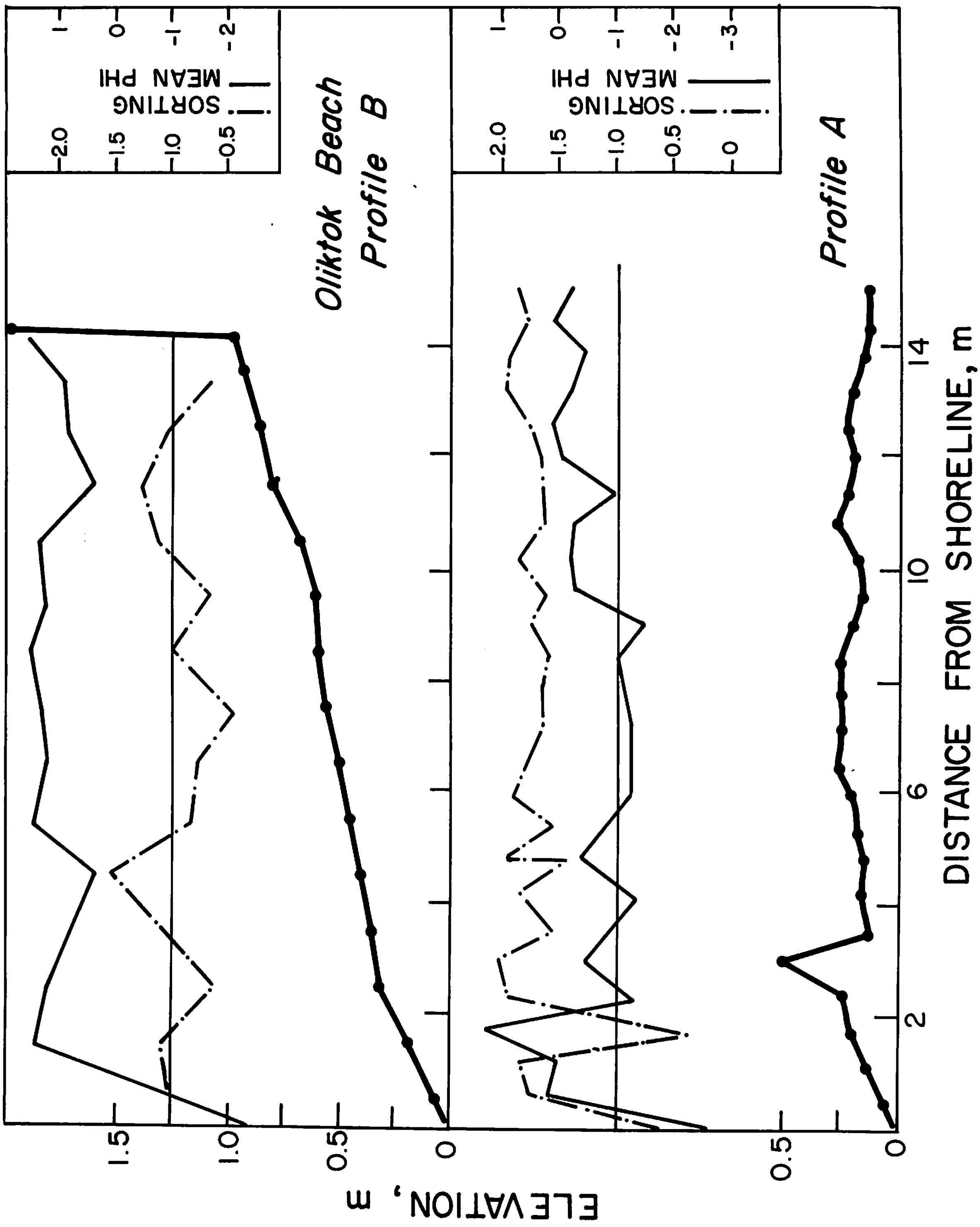


Figure 15. Lateral variation of grain size and sorting.

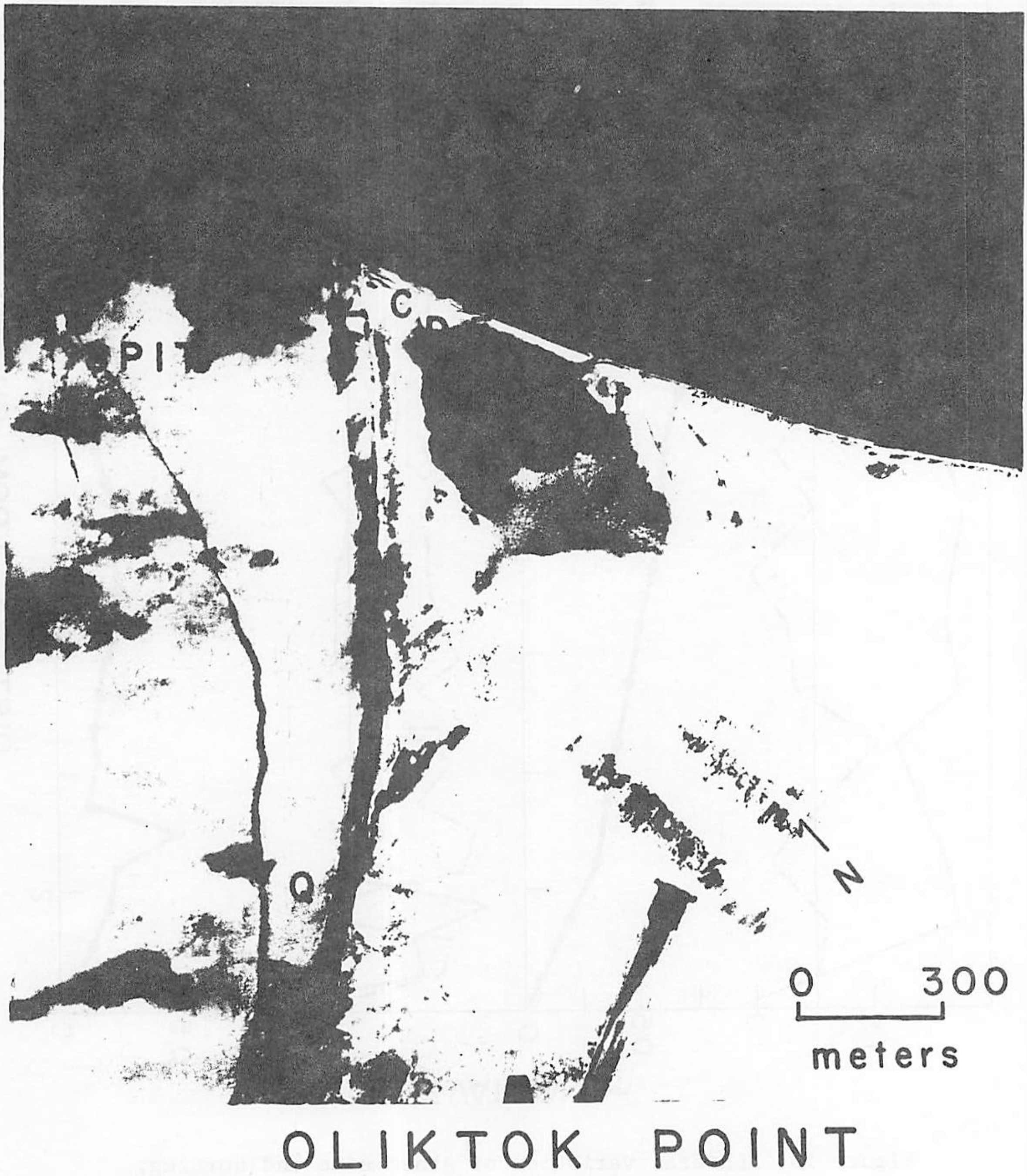


Figure 16. Oliktok Point.

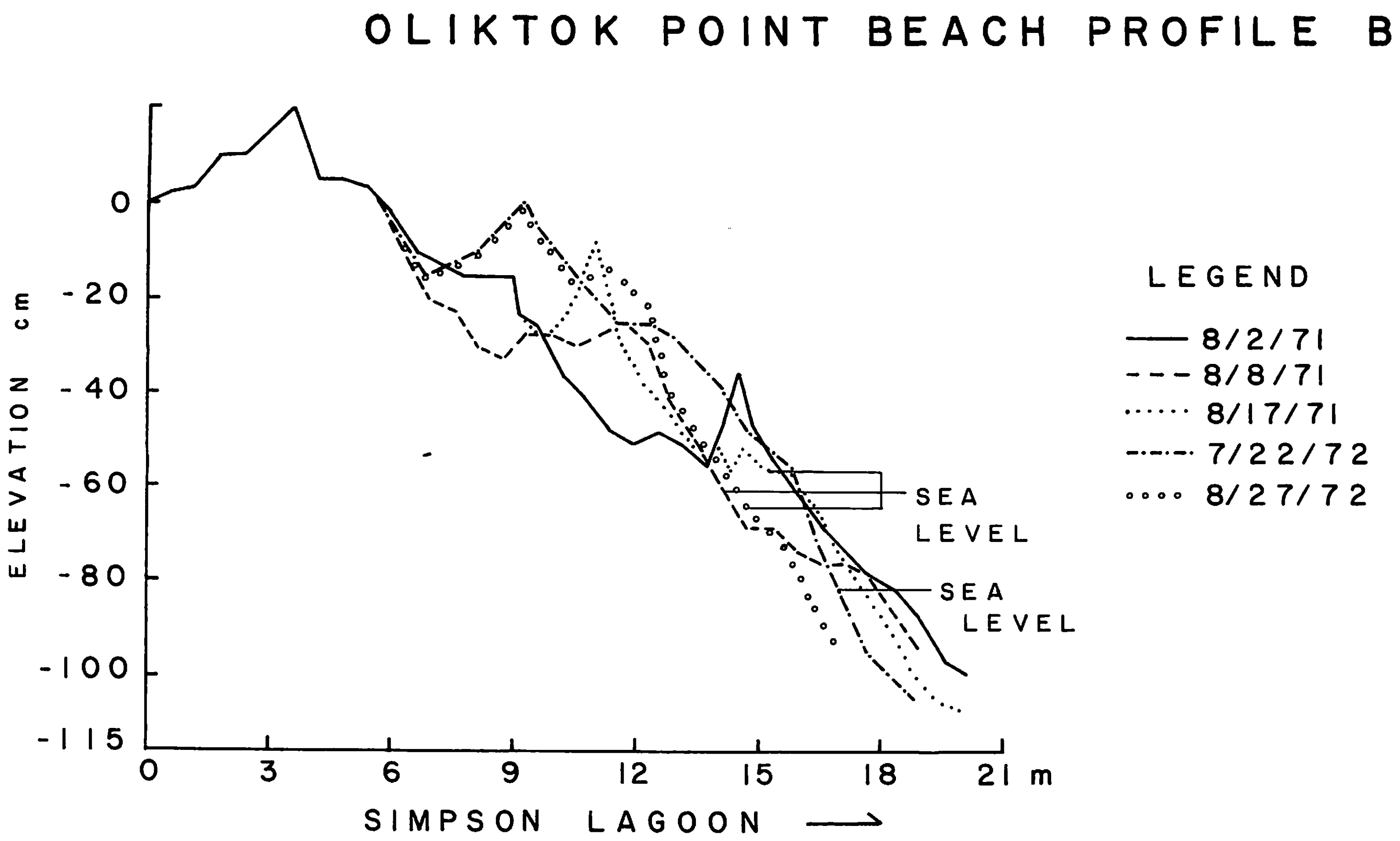


Figure 17. Oliktok Point beach profile B.

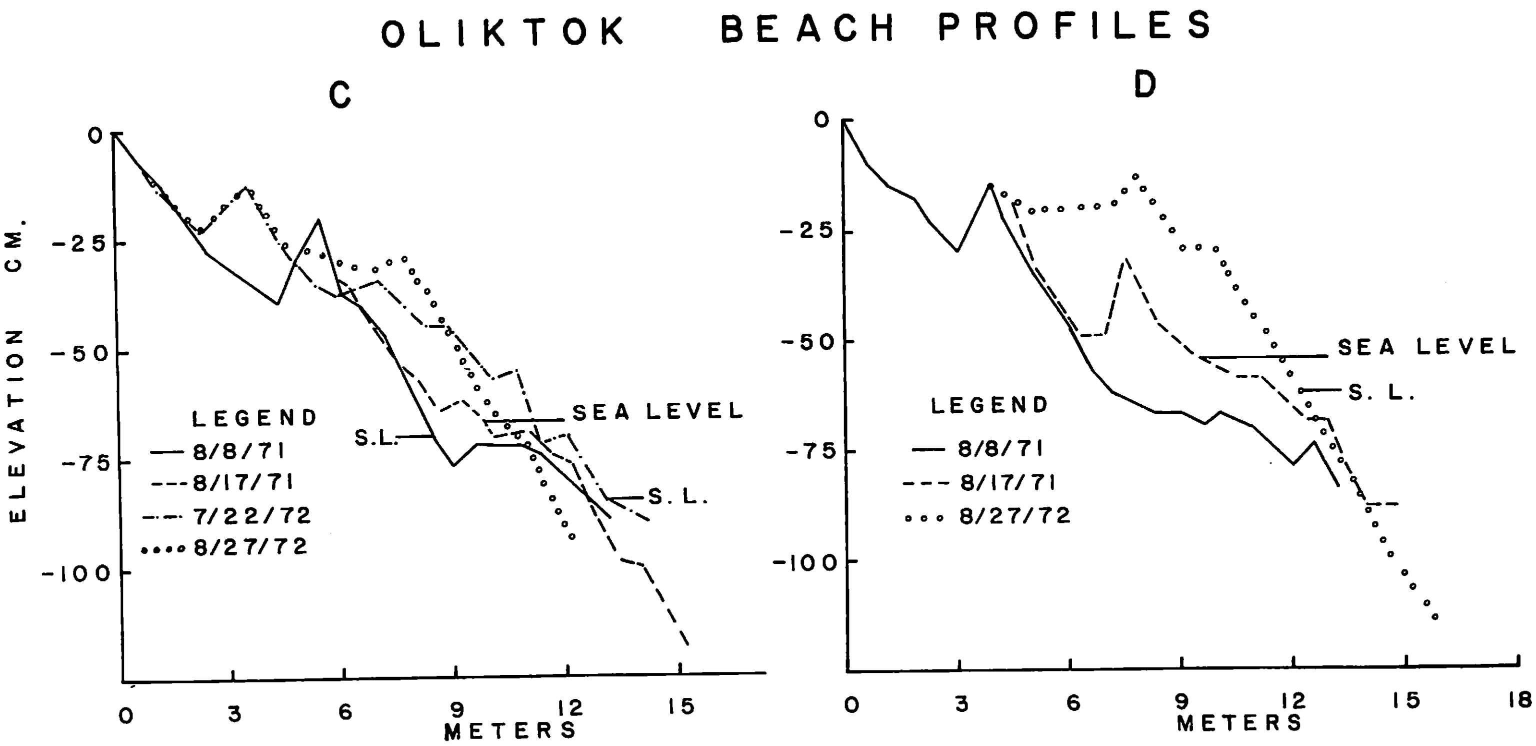


Figure 18. Oliktok beach profiles C and D.

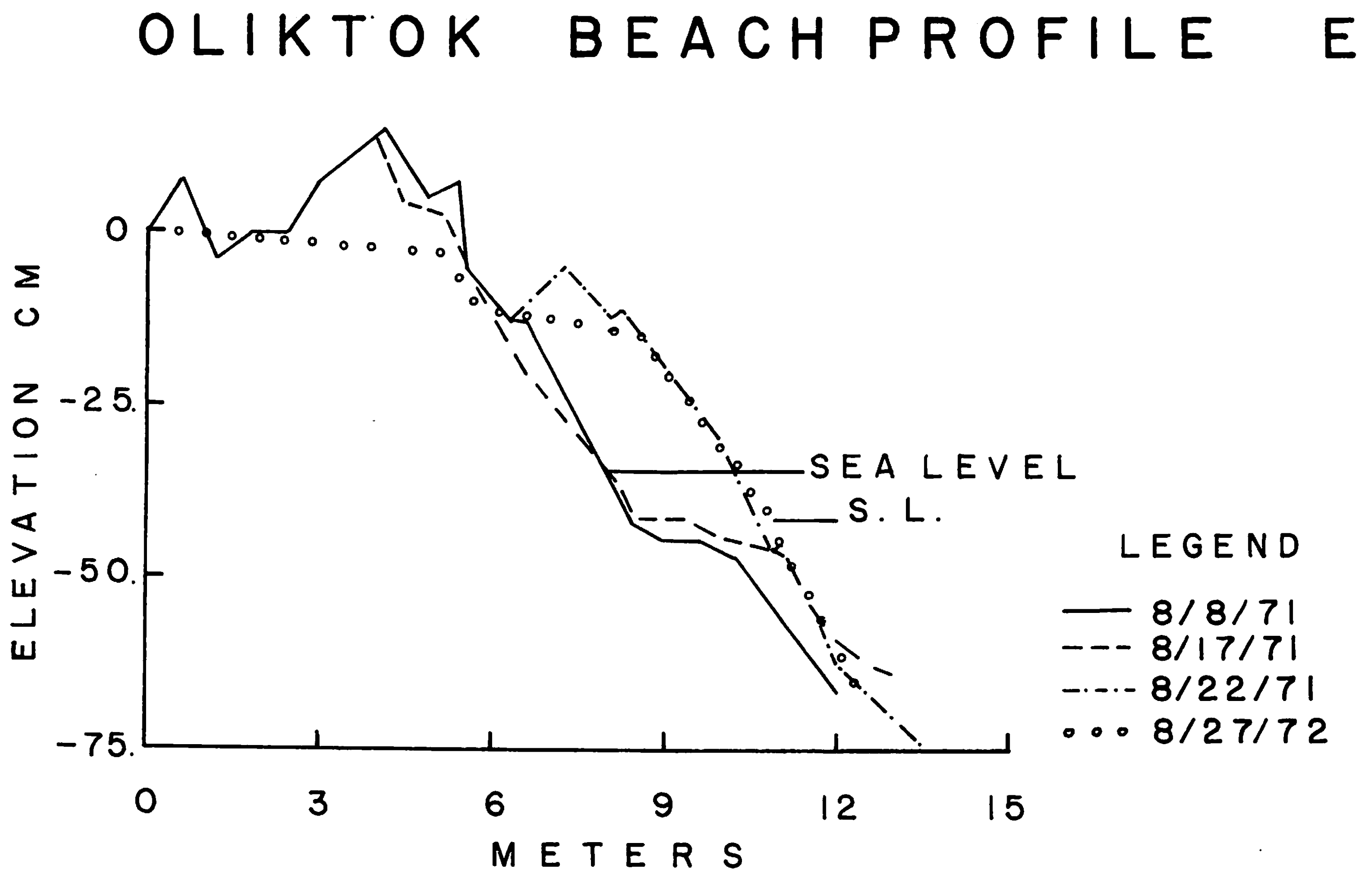


Figure 19. Oliktok beach profile E.

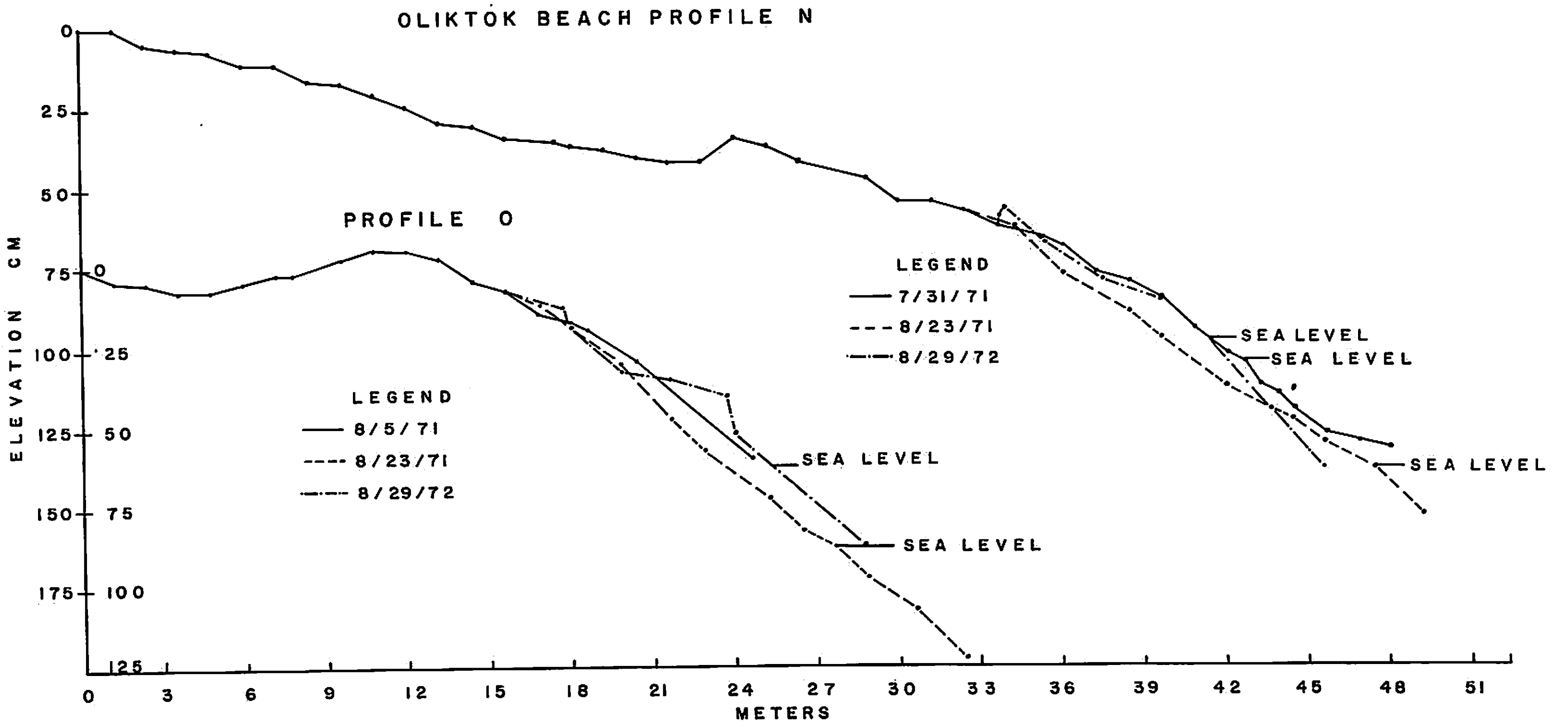


Figure 20. Oliktok beach profile N.

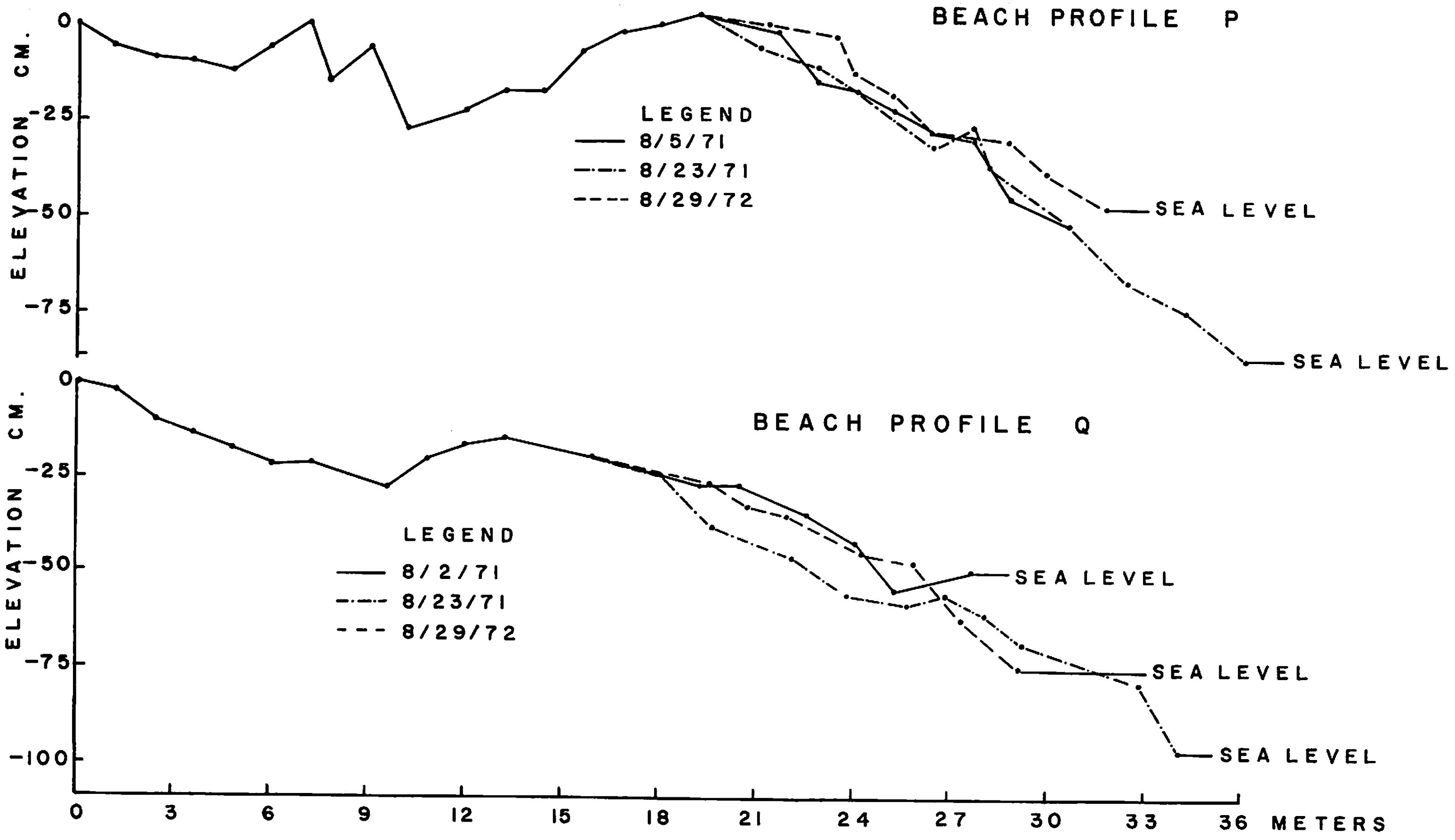


Figure 21. Beach profile P.

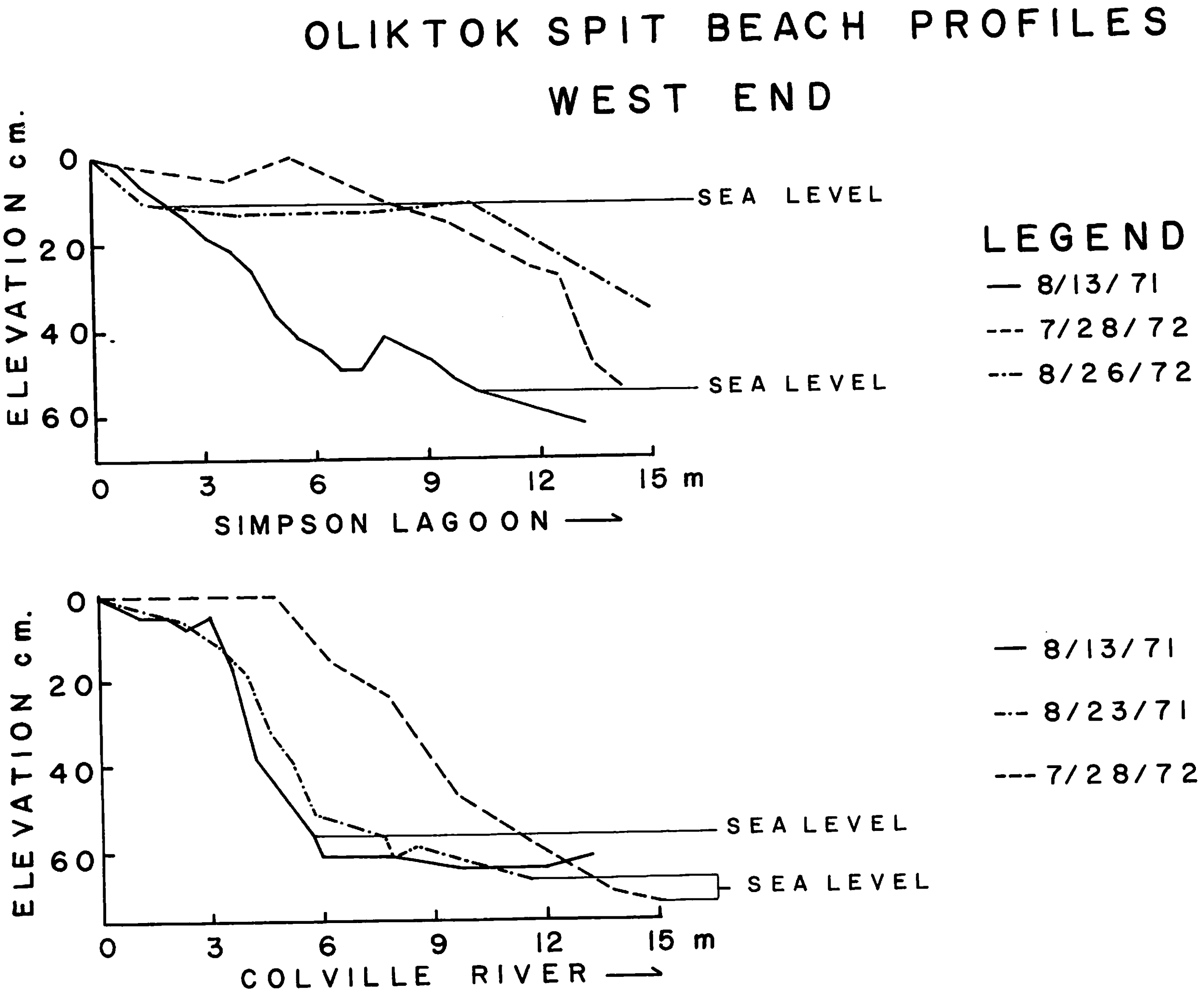


Figure 22. Oliktok spit beach profiles-West end.

(Figs. 20 and 21) there is a distinct pattern of erosion between profiles measured between 8 May and 29 August 1971 and between 2 August and 23 August 1971. The period of accretion from 23 August 1971 to 29 August 1972, is attributed to northwesterly wind and wave effects which occur three times as frequently in September as in July and twice as frequently in August. Freeze-up usually occurs at the end of September or October, and the beaches remain frozen until the following July. In addition, the available wind energy is considerably greater in September than in July (see Table 2). Figure 22 shows definite growth at the western end of the Oliktok spit from 13 and 23 August 1971 to 28 July 1972. This latter growth reflects both accretion due to NW September storms and longshore transport along the length of spit due to NE wind-generated waves. Similarly, sections B and C (Figs. 17 and 18) on the NE facing Oliktok beach show significant growth from 17 August 1971 to 22 July 1972, which again is interpreted as build-up due to NE storms in late August and September. It is further suggested that Oliktok Point serves as a depositional site for sediment moving from east to west along the Simpson Lagoon shore and also for sediment from the mouth of the Colville River.

Quantitative Nearshore Sediment Transport

As noted above, quantitative studies of beach and nearshore sediment transport for the Alaskan arctic coast have been previously carried out only in the Point Barrow area. This present study was conducted at Oliktok Point during the months of July and August in 1971 and 1972.

Most field and laboratory studies of nearshore sediment transport (e.g., Grant,[52] Watts,[53] Caldwell,[54] Savage,[55] Bagnold,[56] Inman and Bagnold,[57] Komar,[58] and Komar and Inman[59]) relate long-shore sediment transport to the longshore component of the energy flux of the breaking wave. Empirical correlations between sediment transport rates and nearshore wave parameters have been made by Caldwell[54], Watts[53] and Savage[55] using the following general relationship for the longshore wave power component, P:

$$P = (EC_n)_b \text{ Sin } \theta_b \text{ Cos } \theta_b \tag{10}$$

Where E = the wave energy density - defined as $(\rho g\, H^2/8)$
ρ = water density
g = gravity acceleration
H = root-mean-square wave height
C_n = the shallow water group velocity and is given by $(gh_b)^{1/2}$ (h_b = depth beneath the breaking wave)
θ_b = the angle between the breaker line and the shoreline and the b subscript refers to relationships in the breaker zone.

Empirical correlations between the longshore component of the wave power and sediment transport rates are statistical estimates only and are not dimensionally correct. A more basic approach has been proposed by Inman and Bagnold[57] in which the sediment transport rate is expressed in terms of immersed weight:

$$I = (\rho_s - \rho_w) \text{ ag } S \tag{11}$$

Where S = the sediment transport volume
ρ_s = the sediment density
ρ_w = the water density
a = pore space correction factor (this usually takes a value of 0.6)

The immersed weight sediment transport rate may be directly related to the wave power component of Eqn. (10): I = kP. Inman and Bagnold[57] suggest that only net current in the littoral zone will produce a net transport if the sediment has already been set in motion by wave action.

Inman and Bagnold[57] express the relationship between I to the longshore current velocity and the maximum orbital horizontal component of the near-bottom orbital wave velocity thus:

$$I = K' \, (EC_n)_b \operatorname{Cos} \theta_b \; V/U_m \tag{12}$$

Where U_m = the maximum horizontal wave velocity
V = the longshore current velocity
K' = the non-dimensional proportionality constant

The advantage of this latter approach lies in the fact that V is not necessarily completely dependent upon the angle of approach of the breaking waves but may be affected also by wind stress and tidal action.

Data for July and August 1971 breaking wave parameters are listed in Tables 3 and 4 for both the NE and NW Oliktok Point beach sites. In addition to the observed mean breaker height ($\overline{H}_b$) and period (T_b), breaker angle (θ_b) and mean longshore velocity (V), the root-mean-square wave height (H_{rms}), depth beneath the breaking wave (h_b), shallow water wave group velocity (Cn_b) and the near-bottom maximum horizontal orbital velocity ($U_m = (H_b/h_b) \; Cn_b/2$) are also included. Using these same parameters, both the longshore energy flux (P) and the immersed weight energy flux $(ECn)_b \operatorname{Cos} \theta_b \; (V/U_m)$; Inman and Bagnold[57] have been calculated and listed in Tables 5 and 6 for comparison.

Sediment Size Distribution Patterns in Simpson Lagoon

Proportions of sand, silt, clay and gravel for the samples collected at the Simpson Lagoon stations shown in Figure 3 are given in Table 7 and are plotted within the triangular diagram given as Figure 23. Sandy muds and sandy silts are the predominant sediment types (nomenclature of Royse[34]) and gravels occur in less than 10 percent of the samples. The general absence of this sized material from the lagoon sediments is a striking feature, since ice rafting from the beaches and gravelly barrier islands

Table 3. NORTHWEST BEACH SITE OBSERVATIONS FOR OLIKTOK POINT, ALASKA 1971

Date/Time	H_b, cm	H_{rms}, cm	T_b, sec	θ_b, deg	h_b, cm	Cn_b, cm/sec	u_m, cm/sec	$u_m \sin \theta_b$, cm/sec	V, cm/sec
7/24/1440	14.1	15.9	2.5	15.0	17.7	131.7	59.1	15.3	-
7/29/0840	20.4	23.0	2.6	24.0	25.5	158.1	71.3	29.0	42.0
7/29/1315	30.7	34.6	3.4	25.0	38.3	193.9	87.5	36.9	65.5
7/29/1617	32.3	36.4	3.6	5.0	40.3	198.9	89.5	7.8	-
7/29/2100	9.8	11.1	1.8	0.0	12.2	109.3	49.8	0.0	0.0
7/30/0940	10.8	12.2	2.3	25.0	13.4	114.9	52.1	22.0	30.7
7/30/1424	16.9	19.1	2.6	25.0	21.1	143.9	65.1	27.5	52.0
7/30/1925	24.4	27.5	2.8	15.0	30.4	172.8	78.1	20.2	70.1
7/31/0930	14.7	16.6	2.3	5.0	18.4	134.2	60.6	5.3	37.6
7/31/1500	8.7	9.8	1.9	5.0	10.8	102.9	46.7	4.1	75.5
8/ 2/2030	26.6	30.0	2.6	0.0	33.2	180.5	81.6	0.0	35.8
8/ 3/0930	27.8	31.4	2.8	10.0	34.7	184.6	83.2	14.4	31.6
8/ 3/1550	21.9	24.7	2.4	0.0	27.4	163.9	73.9	0.0	21.0
8/ 3/2100	29.8	33.6	2.7	0.0	37.3	191.3	86.0	0.0	39.2
8/ 4/0900	28.3	31.9	2.8	10.0	35.3	186.3	83.9	14.6	65.0
8/ 4/1500	30.5	34.4	2.8	10.0	38.0	193.3	87.4	15.2	35.0
8/ 4/2030	27.9	31.5	2.8	10.0	34.8	184.7	83.5	14.5	33.8
8/ 5/0930	22.7	25.6	2.4	5.0	28.4	166.9	75.3	6.6	19.1
8/ 5/1500	15.2	17.1	2.0	8.0	18.9	136.6	61.4	8.5	28.6
8/ 5/2100	12.3	13.9	1.8	25.0	15.4	123.0	55.5	23.5	39.5
8/ 6/0930	11.4	12.9	1.7	15.0	14.2	118.1	53.5	13.9	29.8
8/ 6/1500	13.5	15.2	1.8	0.0	16.9	128.6	57.9	0.0	0.0
8/ 7/0930	16.5	18.6	1.9	15.0	20.5	142.0	64.2	16.6	17.3
8/ 7/1600	18.4	20.8	2.1	10.0	23.0	150.4	67.8	11.7	44.4
8/ 7/2230	6.9	7.8	1.3	0.0	8.6	91.9	41.6	0.0	0.0
8/10/0930	13.7	15.5	2.0	5.0	17.1	129.4	58.7	5.1	23.4
8/10/1530	13.4	15.1	1.9	2.5	16.7	127.9	57.8	2.5	25.2
8/10/2130	12.7	14.3	1.9	0.0	15.9	124.9	56.0	0.0	23.1
8/18/0930	14.6	16.5	2.3	4.0	18.2	133.8	60.5	4.2	23.1
8/18/1630	21.3	24.0	2.3	30.0	26.5	161.4	72.9	36.4	62.3
8/18/2130	21.0	23.7	2.3	5.0	26.2	160.4	72.5	6.3	33.1
8/19/2130	17.6	19.8	2.1	2.0	21.9	146.8	66.1	2.3	14.0

Table 4. NORTHEAST BEACH SITE OBSERVATIONS FOR OLIKTOK POINT, ALASKA 1971

Date/Time	H_b, cm	H_{rms}, cm	T_b, sec	θ_b, deg	h_b, cm	Cn_b, cm/sec	u_m, cm/sec	$u_m \sin \theta_b$, cm/sec	V, cm/sec
7/24/1100	13.7	15.5	2.1	2.5	17.0	129.4	58.7	2.6	-
7/24/1510	20.4	23.0	2.1	2.5	25.4	157.9	71.5	3.1	-
7/24/2035	17.3	19.5	2.3	2.5	21.6	145.7	65.7	2.9	-
7/25/1000	10.3	11.6	2.3	5.0	12.9	112.3	50.7	4.4	-
7/25/1630	27.7	31.2	2.4	5.0	34.6	184.3	82.9	7.2	-
7/25/2100	18.8	21.2	2.5	5.0	23.5	151.9	68.5	5.9	-
7/26/1100	10.6	11.9	1.8	5.0	13.2	113.8	51.3	4.5	-
7/26/1420	20.1	22.7	2.1	5.0	25.1	157.1	70.8	6.2	-
7/27/1030	9.6	10.8	1.6	5.0	11.9	108.2	48.9	4.3	-
7/27/1220	13.2	14.9	1.9	5.0	16.5	127.2	57.5	5.0	5.5
7/28/2120	12.2	13.7	1.7	0.0	15.2	122.2	54.9	0.0	0.0
8/ 1/1650	21.9	24.7	2.1	10.0	27.4	164.0	73.8	12.8	31.0
8/ 1/2100	16.2	18.3	1.9	10.0	20.2	140.9	63.7	11.1	-
8/ 2/1000	7.9	8.9	1.5	0.0	9.9	98.5	44.3	0.0	14.3
8/ 8/1650	10.1	11.4	1.7	15.0	12.6	111.3	50.3	13.0	22.8
8/ 8/2130	12.8	14.4	1.8	0.0	16.1	125.6	56.3	0.0	20.7
8/11/1500	15.4	17.4	1.9	5.0	19.2	137.1	62.3	5.4	-
8/11/2130	12.6	14.2	1.9	0.0	15.8	124.4	55.9	0.0	0.0
8/16/1415	14.8	16.7	2.1	0.0	18.4	134.6	60.8	0.0	0.0
8/19/0930	14.5	16.4	2.0	20.0	18.1	133.3	60.4	20.6	27.7
8/19/1530	5.8	6.5	1.6	2.0	7.2	84.2	37.9	1.3	18.5
8/20/0930	26.0	29.3	2.4	4.0	32.5	178.6	80.3	5.6	12.8
8/20/1545	22.8	25.7	2.4	2.0	28.4	167.1	75.3	2.6	34.0
8/20/2215	22.8	25.7	2.4	2.0	28.4	167.1	75.3	2.6	-
8/21/1030	17.2	19.4	1.9	0.0	21.4	145.1	65.6	0.0	0.0
8/21/1600	17.2	19.4	2.0	0.0	21.5	145.4	65.4	0.0	13.4
8/21/2200	18.3	20.6	2.1	0.0	22.9	149.9	67.5	0.0	0.0
8/22/1100	18.3	20.6	2.1	0.0	22.8	149.7	67.6	0.0	58.0
8/22/1900	19.5	21.9	2.1	0.0	24.3	154.5	69.8	0.0	28.3

Table 5. ESTIMATES OF LONGSHORE ENERGY FLUX FOR OLIKTOK POINT.
N.W. BEACH SITE.

Date (1971)	Time (local)	Longshore energy (P) (ergs/cm-sec x 10^6)	Immersed weight energy (I) (ergs/cm-sec x 10^6)	Ratio (I/P)
7.29	0840	3.80	5.51	1.45
7.29	1315	10.89	19.29	1.77
7.29	16.5	2.80	1.11	0.39
7.30	0940	0.80	0.89	1.11
7.30	1424	2.46	4.65	1.89
7.30	1925	4.00	13.87	3.46
7.31	0930	0.39	2.79	7.15
7.31	1500	0.10	1.94	19.40
8.3	0930	3.81	8.33	2.18
8.4	0900	3.97	17.71	4.46
8.4	1500	4.79	11.05	2.30
8.4	2030	3.84	8.94	2.32
8.5	0930	1.16	3.38	2.91
8.5	1500	0.67	2.25	3.35
8.5	2100	1.12	1.87	1.66
8.6	0930	0.60	1.29	2.15
8.7	0930	1.50	1.56	1.04
8.7	1600	1.36	5.13	3.77
8.10	0930	0.33	1.51	4.57
8.10	1530	0.15	1.55	10.33
8.18	0930	0.31	1.69	5.45
8.18	1630	4.93	8.42	1.70
8.18	2130	0.96	5.01	5.21
8.19	2130	0.25	1.49	5.96

Table 6. ESTIMATES OF LONGSHORE ENERGY FLUX FOR OLIKTOK POINT. N.E. BEACH SITE.

Date (1971)	Time (local)	Longshore energy (P) (ergs/cm-sec x 10^6)	Immersed weight energy (I) (ergs/cm-sec x 10^6)	Ratio (I/P)
7.24	1100	0.16	–	–
7.24	1510	0.44	–	–
7.24	2035	0.29	–	–
7.25	1000	0.16	–	–
7.25	1630	1.90	–	–
7.25	2100	0.72	–	–
7.26	1100	0.17	–	–
7.26	1420	0.86	–	–
7.27	1030	0.13	–	–
7.27	1220	0.30	0.33	1.10
8.1	1650	2.09	5.07	2.42
8.1	2100	0.98	–	–
8.8	1650	0.44	0.77	1.75
8.11	1500	0.44	–	–
8.19	0930	1.41	1.89	1.34
8.19	1530	0.02	0.21	10.50
8.20	0930	1.30	2.98	2.29
8.20	1545	0.47	6.10	12.97
8.20	22.5	0.47	–	–

Table 7. SAMPLE LISTING WITH DEPTH AND PERCENTAGE GRAVEL,
SAND, SILT AND CLAY

Sample	D(m)	% Gravel	% Sand	% Silt	% Clay
BEK-1	1.7	-	96.2	1.7	2.1
BEK-2	2.5	-	37.1	44.74	18.16
BEK-3	2.8	-	21.3	53.5	25.2
BEK-4	2.8	-	55.1	28.0	16.9
BEK-5	2.6	-	66.4	18.0	16.0
BEK-6	2.3	-	94.5	1.6	3.9
BEK-7	1.8	38.0	60.8	0.5	0.7
BWB-1	1.7	-	78.8	11.6	9.5
CB-1	2.0	-	41.6	33.5	24.9
CB-2	2.2	-	27.0	49.0	24.0
CB-3	2.5	-	2.6	62.9	24.5
CB-4	1.5	-	98.2	1.5	0.3
KM-1	2.0	-	55.6	31.0	13.3
KM-2	1.8	-	82.5	7.1	10.4
MOE-1	1.3	-	95.1	2.5	2.4
MOE-2	1.3	-	93.2	3.2	3.6
MOE-3	2.3	1.1	53.2	24.7	21.0
MOE-4	1.1	-	98.0	1.7	0.3
OBO-1	2.5	-	50.1	27.6	22.3
OBO-2	2.8	-	36.2	42.7	21.0
OBO-3	2.7	-	51.2	33.3	15.5
OBO-4	2.0	-	60.2	24.3	15.5
OBO-5	0.9	53.2	42.2	3.0	1.5
OEL-1	1.8	-	73.7	5.7	20.5
OEL-2	2.5	-	62.0	19.4	18.5
OEL-3	2.5	-	21.1	50.8	28.0
OEL-4	2.8	-	67.7	21.8	10.5
OEL-5	2.9	-	47.5	37.3	15.2
OEL-6	2.9	-	40.4	39.3	20.2
OEL-7	2.6	-	42.0	38.4	19.5
OEL-8	2.7	-	43.9	37.1	19.0
OEL-9	2.5	-	30.7	52.5	16.5
OEL-10	2.3	-	41.8	34.5	23.7
OEL-11	1.2	55.4	39.1	2.8	2.6
OEO-1	1.1	-	89.3	1.7	9.0
OEO-2	1.9	-	62.4	21.6	16.0
OEO-3	2.2	-	23.2	63.8	13.0
PJ-1	1.5	-	94.3	2.0	3.7
PJ-2	2.2	-	60.7	17.7	21.5
PJ-3	2.4	-	38.1	38.8	23.0

Table 7. (continued) SAMPLE LISTING WITH DEPTH AND PERCENTAGE GRAVEL, SAND, SILT AND CLAY

Sample	D(m)	% Gravel	% Sand	% Silt	% Clay
PJ-4	2.5	-	27.0	41.7	31.2
PJ-5	2.4	-	42.4	33.5	24.0
PJ-6	2.0	-	46.2	31.8	23.0
PJ-7	2.0	-	42.0	40.0	18.0
PJ-8	2.0	-	37.8	39.4	22.8
PJ-9	2.0	9.5	42.0	28.0	21.0
PJ-10	1.0	12.6	78.8	4.5	4.0
PJ-11	0.7	4.5	90.9	1.3	3.1
PM-1'	2.8	-	19.0	58.0	23.0
PM-1	1.0	-	73.5	25.0	21.0
PM-2	2.2	-	63.1	31.2	5.6
PM-3	2.8	-	96.1	2.9	0.9
PM-4	2.5	-	21.0	61.8	17.1
PM-5	1.9	-	60.8	22.7	16.5
PM-6	0.5	65.0	32.7	0.5	1.8
PS-2	2.5	-	36.3	52.7	12.0
PS-3	2.5	-	26.8	60.5	12.5
PS-4	2.5	-	28.6	60.5	12.0
PS-5	2.2	-	25.0	49.0	26.0
PSS-1	2.0	-	56.8	33.2	10.0
PSS-2	2.0	-	40.1	39.9	20.0
PSS-3	1.9	-	36.7	41.6	21.7
PSS-4	1.8	-	38.0	40.3	21.7
PSS-5	1.8	-	48.8	31.7	19.5
PSS-6	1.8	-	16.1	53.9	30.0
RM-1	1.2	39.5	53.2	1.8	5.4
RM-2	0.8	-	89.4	(11.6)	
RM-3	0.9	-	74.3	11.7	14.0
RM-4	1.8	-	41.0	48.5	10.5
RM-5	2.2	-	24.9	37.1	38.0
RM-6	1.5	34.9	54.0	4.3	6.8
SE-1	2.5	-	45.0	39.4	15.5
SE-2	2.8	-	24.0	49.0	27.0
SE-3	3.1	-	38.0	54.0	8.0
SM-2	3.0	-	28.0	59.0	13.0
SM-3	2.0	-	36.5	45.5	18.0
SME-2	2.4	-	34.0	49.9	24.0
SME-4	2.1	-	30.1	51.0	18.8
SME-5	2.1	-	42.0	38.9	19.0
SME-6	2.7	-	36.3	44.6	19.0

Table 7. (continued) SAMPLE LISTING WITH DEPTH AND PERCENTAGE GRAVEL, SAND, SILT AND CLAY

Sample	D(m)	% Gravel	% Sand	% Silt	% Clay
STO-1	2.4	12.8	26.1	39.0	22.0
STO-2	3.1	-	33.3	41.1	25.5
STO-3	3.1	-	28.8	47.2	24.0
STO-4	3.0	-	38.3	43.6	18.0
STO-5	3.0	-	35.5	46.0	18.5
STO-6	3.0	-	5.3	63.6	31.0
STO-7	2.9	-	52.8	34.1	13.1
STO-8	2.8	-	16.0	61.5	22.5
STO-9	0.9	91.0	8.6	0.2	0.2
SWE-1	2.2	-	59.7	21.8	18.5

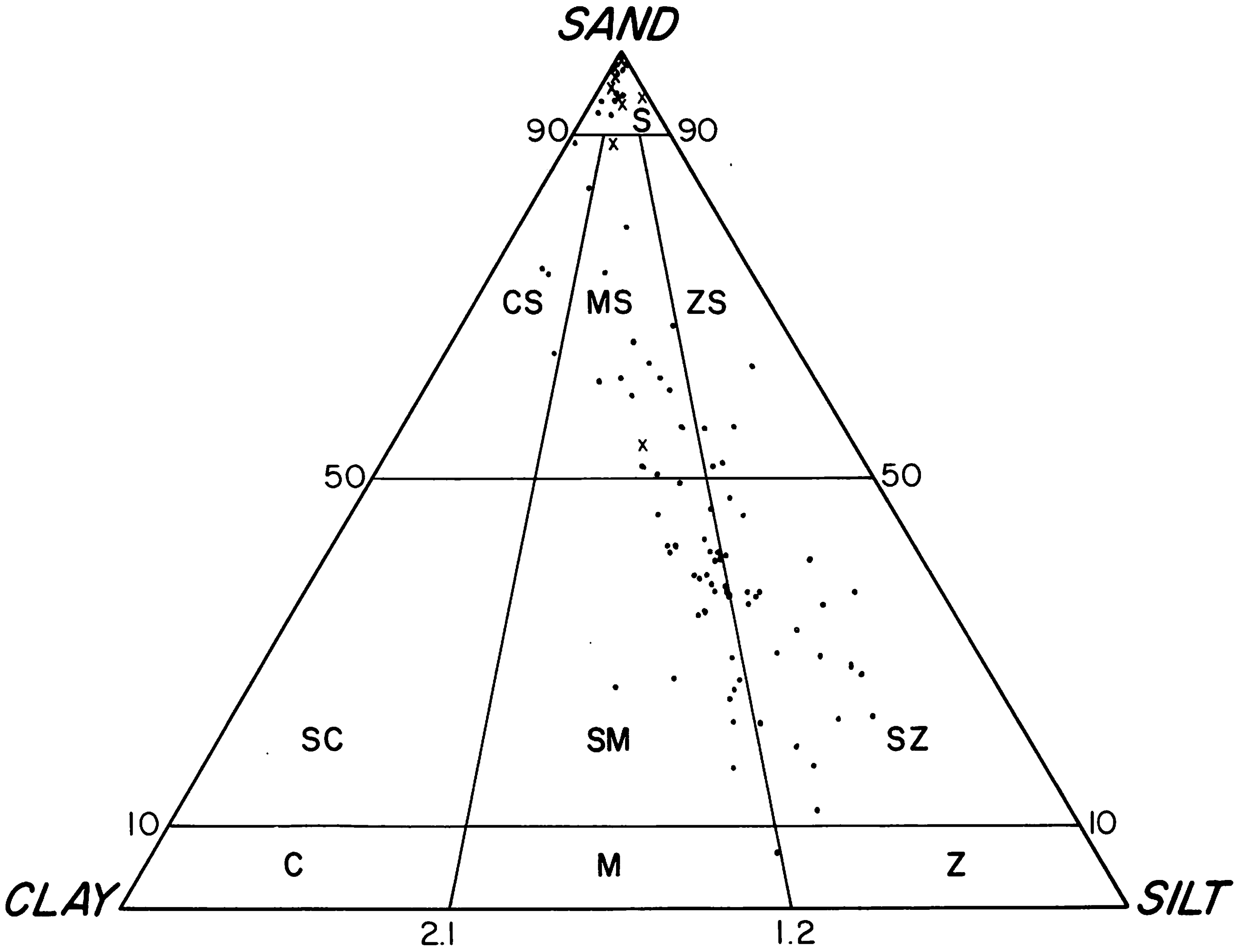


Figure 23. A triangular diagram. X indicates that the gravel percentage has been added to the sand percentage.

might reasonably be expected. Naidu[22] and Naidu and Mowatt[26] have previously commented on the paucity of gravel in the shallow marine sediments of this arctic coast as compared with the Beaufort Sea shelf deposits[21,22] in which gravel-sized material is a common component. Naidu considers the latter to be of relict origin (see Chapter 5 in this report).

A modal analysis of the Simpson Lagoon sediments, utilizing samples from the southern end (shoreward) of several transects, indicates several interesting size distribution characteristics. Sand-sized material provides a prominent mode in sample CB-4 (Fig. 24). This is the most easterly sample. This sand mode then becomes finer in samples from the more westerly portion of the lagoon. It is considered that this mode represents "source" material involved in the east-to-west longshore transportation along the lagoon shore as discussed above. A characteristic and relatively constant silt mode at 6-7 ϕ probably represents the average energy of the "quieter" water.

Table 8 lists the standard sediment size parameter data. Sediment size distribution median values are plotted on a standard CM diagram[60] in Figure 25. Passega[60,61] and Passega *et al.*[62] has exemplified the utility of such plots in differentiating between various broad genetic sediment types as illustrated in Figure 26. It may be seen that the near-shore samples are predominantly segregated on the area characterized by Passega[60] as beach deposited material. The remaining pattern probably corresponds to the "pelagic" suspension category. The use of the settling tube for the coarse fraction analysis may have caused more dispersion than would have been so had sieve analysis been used (see Passega[60]).

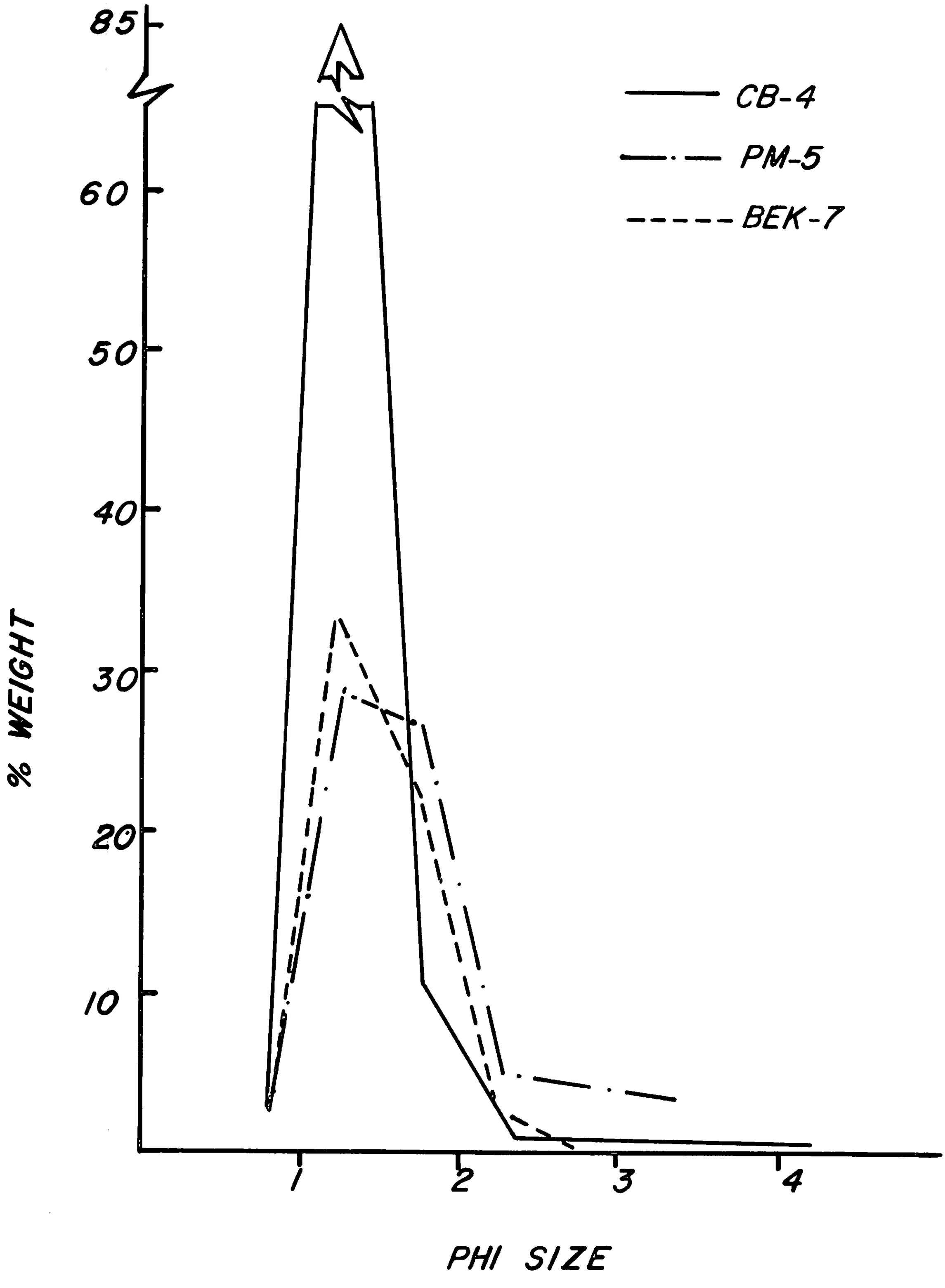


Figure 24. A plot of modes for three samples from Simpson Lagoon.

Table 8. SIZE ANALYSIS STATISTICAL PARAMETERS

Sample	Median	Mean	Sorting	Skewness	Kurtosis	Nkurtosis
BEK-1	2.20	2.29	0.45	0.30	1.10	0.52
BEK-2	4.00	5.15	2.57	0.66	0.89	0.47
BEK-3	6.10	6.63	2.80	0.25	0.97	0.49
BEK-4	3.50	4.57	2.77	0.60	0.84	0.46
BEK-5	2.30	3.79	3.17	0.70	0.95	0.49
BEK-6	1.60	1.77	0.67	0.62	1.73	0.63
BEK-7	1.20	0.22	2.05	-0.57	0.52	0.34
BWB-1	2.20	3.18	2.45	0.74	1.81	0.64
CB-1	5.20	5.57	3.66	0.13	0.69	0.41
CB-2	5.25	5.99	2.87	0.35	0.88	0.47
CB-3	6.20	7.05	2.33	0.46	0.98	0.50
CB-4	1.58	1.66	0.32	0.45	0.92	0.48
KM-1	3.60	4.53	2.30	0.70	1.17	0.54
KM-2	2.10	3.10	2.43	0.76	3.55	0.78
MOE-1	2.00	1.96	0.80	0.20	1.95	0.66
MOE-2	2.45	2.62	0.95	0.61	3.77	0.79
MOE-3	3.50	4.72	3.17	0.54	0.71	0.42
MOE-4	2.47	2.51	0.67	-0.05	2.36	0.70
OBO-1	4.05	5.32	3.29	0.49	0.76	0.43
OBO-2	5.35	5.68	3.02	0.21	0.80	0.44
OBO-3	3.90	4.78	2.45	0.59	1.34	0.57
OBO-4	2.95	4.37	2.58	0.82	1.03	0.51
OBO-5	-1.30	-1.03	1.77	0.29	0.74	0.42
OEL-1	1.50	3.85	4.40	0.63	1.46	0.59
OEL-2	2.90	4.53	2.86	0.78	0.85	0.46
OEL-3	6.00	6.40	2.98	0.21	0.82	0.45
OEL-4	3.50	4.13	1.90	0.71	1.85	0.65
OEL-5	4.10	4.92	2.36	0.60	1.08	0.52
OEL-6	4.50	5.66	2.72	0.58	0.97	0.49
OEL-7	4.60	5.85	2.77	0.60	0.96	0.49
OEL-8	4.50	5.48	2.70	0.52	0.95	0.49
OEL-9	4.10	5.58	2.27	0.42	1.01	0.50
OEL-10	4.80	5.63	3.47	0.30	0.72	0.42
OEL-11	-1.75	-0.90	2.19	0.59	0.73	0.42
OEO-1	2.47	2.63	1.51	0.67	9.60	0.91
OEO-2	3.00	4.33	2.95	0.64	0.96	0.49
OEO-3	5.12	5.44	1.79	0.46	1.38	0.58
PJ-1	2.10	2.07	0.89	0.26	3.01	0.75
PJ-2	2.30	4.58	3.61	0.80	0.70	0.41
PJ-3	5.20	5.68	3.16	0.23	0.76	0.43
PJ-4	6.50	6.50	3.30	0.04	0.68	0.40
PJ-5	4.55	5.68	3.32	0.43	0.79	0.44

Table 8. (continued) SIZE ANALYSIS STATISTICAL PARAMETERS

Sample	Median	Mean	Sorting	Skewness	Kurtosis	Nkurtosis
PJ-6	4.40	5.70	3.05	0.56	0.74	0.43
PJ-7	4.55	5.20	2.69	0.43	0.89	0.47
PJ-8	5.60	6.03	2.82	0.26	0.74	0.43
PJ-9	3.80	4.97	3.94	0.25	1.19	0.54
PJ-11	2.20	2.17	1.09	-0.29	4.25	0.81
PM-1'	5.92	6.42	2.70	0.24	1.11	0.53
PM-1	0.75	3.66	4.39	0.78	1.23	0.55
PM-2	3.70	4.23	2.28	0.49	1.54	0.61
PM-3	1.95	1.93	0.42	-0.07	0.94	0.49
PM-4	6.20	5.78	2.67	-0.08	1.42	0.59
PM-5	2.60	4.10	3.06	0.70	0.78	0.44
PM-6	-1.80	-1.15	1.84	0.53	0.80	0.44
PS-2	4.70	5.20	1.91	0.53	1.25	0.56
PS-3	5.10	5.25	2.22	0.20	1.36	0.58
PS-4	5.40	5.53	2.24	0.20	1.01	0.50
PS-5	5.85	6.22	3.28	0.15	0.91	0.48
PSS-1	3.70	4.38	1.68	0.87	1.37	0.58
PSS-2	4.65	5.80	2.79	0.54	1.01	0.50
PSS-3	5.05	5.87	2.83	0.39	0.89	0.47
PSS-4	4.85	5.98	2.95	0.51	0.89	0.47
PSS-5	4.10	4.98	2.97	0.45	0.77	0.44
PSS-6	6.27	6.82	2.79	0.22	0.84	0.46
RM-1	1.30	0.38	3.33	-0.09	1.23	0.55
RM-3	2.32	3.65	2.91	0.69	1.38	0.58
RM-4	5.65	4.57	3.32	-0.28	0.66	0.40
RM-5	7.05	6.98	2.92	0.02	0.55	0.35
RM-6	1.45	0.55	3.38	-0.09	1.26	0.56
SE-1	4.55	5.04	2.52	0.40	0.80	0.44
SE-2	5.62	6.49	2.94	0.37	0.84	0.46
SE-3	4.72	4.64	2.07	0.13	1.74	0.63
SM-2	5.00	5.30	2.02	0.38	1.23	0.55
SME-2	5.50	5.82	2.43	0.26	0.86	0.46
SME-4	5.60	5.83	2.43	0.21	0.89	0.47
SME-5	4.65	5.25	2.65	0.39	0.79	0.44
SME-6	5.55	5.89	3.34	0.17	0.68	0.40
STO-1	5.10	5.57	4.06	-0.01	1.22	0.55
STO-2	5.65	6.08	3.18	0.22	0.71	0.42
STO-3	5.40	6.28	2.75	0.44	0.78	0.44
STO-4	4.90	5.63	2.29	0.55	1.08	0.52
STO-5	5.00	5.34	2.17	0.37	1.10	0.52
STO-6	6.20	7.12	2.48	0.44	0.74	0.43

Table 8. (continued) SIZE ANALYSIS STATISTICAL PARAMETERS

Sample	Median	Mean	Sorting	Skewness	Kurtosis	Nkurtosis
STO-7	3.90	4.83	2.17	0.72	1.35	0.57
STO-8	5.90	6.32	2.56	0.22	1.21	0.55
STO-9	-2.90	-2.90	1.33	0.19	1.02	0.51
SWE-1	3.65	4.63	2.56	0.62	0.79	0.44

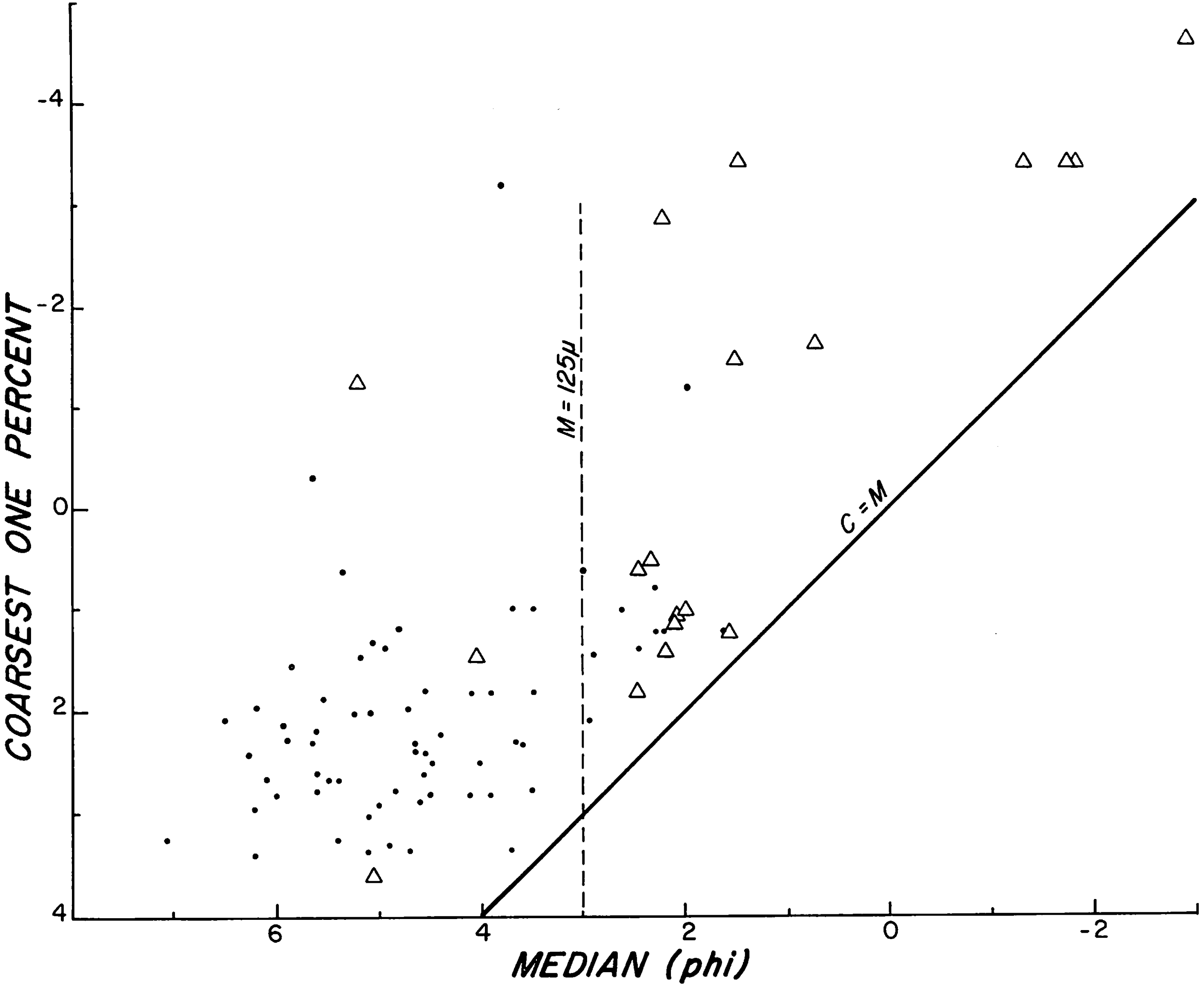


Figure 25. A C-M plot for Simpson Lagoon sediments.

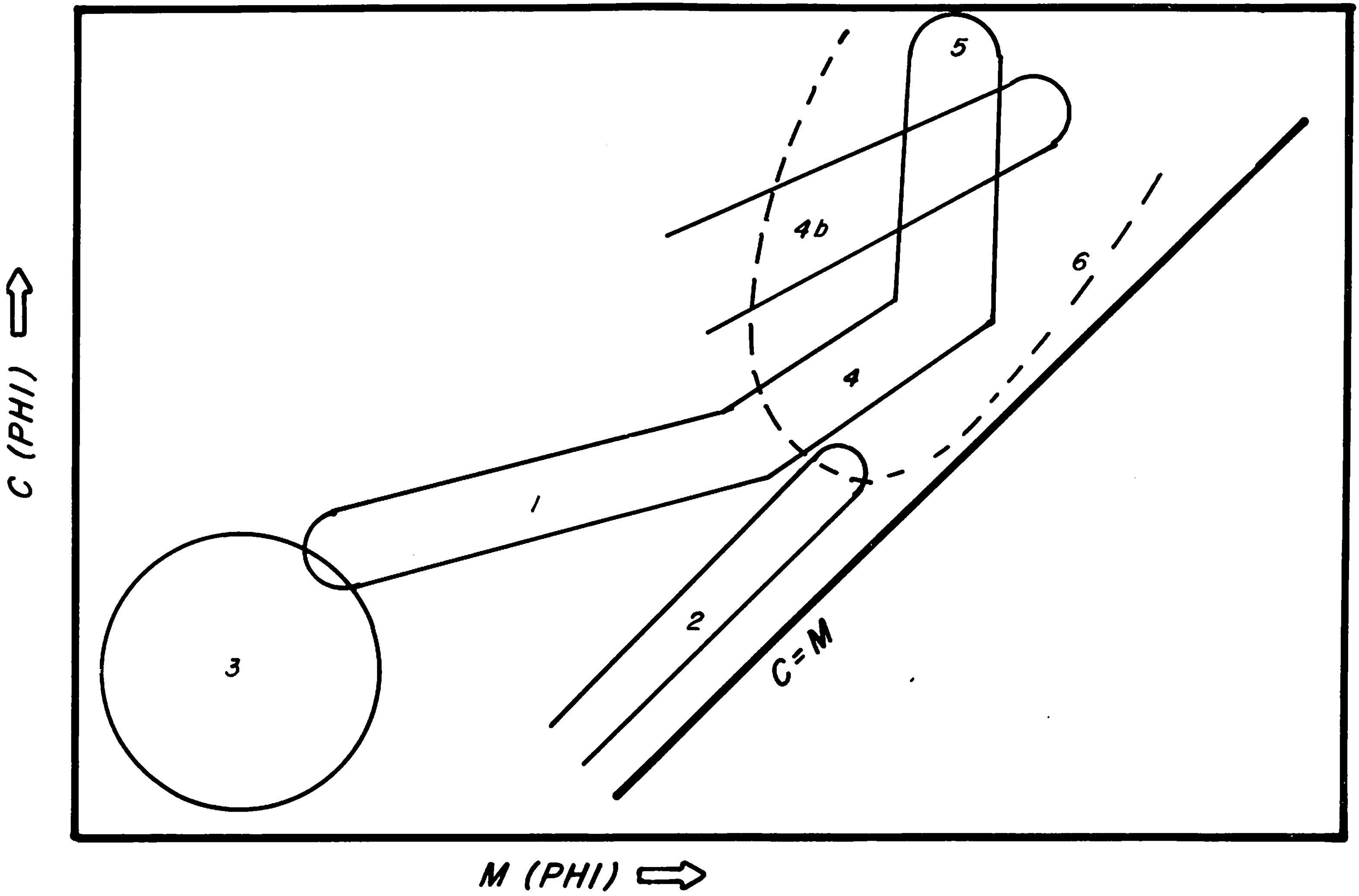


Figure 26. A general C-M diagram showing the fields of different depositional agents. 1.) Uniform suspension. 2.) Turbidity currents. 3.) Pelagic suspension. 4.) Graded suspension. 4b.) Turbidity currents. 5.) Bed load. 6.) Beach deposits.

The mean sediment size values for the samples from Simpson Lagoon range from -2.40 ϕ to 7.12 ϕ (Table 9). The mean size is the average grain diameter. It is often thought of as representing the average energy of the depositional environment and since the time that Folk and Ward[37] used it as a comparison for the other statistical parameters this parameter has been used extensively in binomial plots. However, some more recent investigators feel that it is not a precise enough description of the sediments for differentiation of most environments (e.g., see Friedman[63]). Nevertheless, graphic comparisons between the mean and other statistical parameters are quite common (e.g., see Royse[34]; Cronan[64]), and by means of these plots several environments (e.g., beach, coastal dune, aeolian-flat, fluvial and several others) have been successfully differentiated.

The mean of a majority of the Simpson Lagoon samples lie in the silt size range. This may be explained in a number of ways. The samples may have been drawn from a primarily "quiet" environment, or they could represent a reworked sediment dominated by a silt size mode. In this case, the source sediment is reworked from the Gubik Formation. However, one would also expect a "quiet" environment due to the ice and protection of the barrier islands. Bottom current velocity investigations have shown the existence of currents capable of transporting most of the deep water lagoonal material found[29]. These currents therefore make the "quiet" environment only partly valid. Storms in this region are quite capable of creating waves of 3 second period or longer. These waves would then "feel bottom" and become intermediate or shallow water waves. Much of the lagoon is only 1.5m deep and a wave with a 2 second period would feel bottom. However the mean grain size correlates at the 0.005 level with depth (Table 9) indicating a plausible relationship between energy, as represented by depth, and particle size, and this reinforces the "quiet" water hypothesis.

Table 9. SIZE ANALYSIS CORRELATIONS[a]

Depth	X	Y	Median	Mean	Sorting	Skewness	Kurtosis	Nkurtosis
1.00	-0.156	0.257	0.688	0.550	0.226	0.072	-0.338	-0.298
X	1.0	-0.283	-0.141	-0.010	-0.071	0.150	-0.046	-0.041
Y		1.0	0.178	0.224	0.100	0.129	-0.195	-0.208
MEDIAN			1.0	0.754	0.335	-0.178	-0.208	-0.254
MEAN				1.0	0.396	0.057	-0.274	-0.340
SORTING					1.0	0.046	-0.360	-0.455
SKEWNESS						1.0	0.090	0.135
KURTOSIS							1.0	0.835
NORMALIZED KURTOSIS								1.0

[a] underlined values are significant at the 0.01 level
(a = .01)

Mean size is a parameter which lends itself well to trend surface analysis (e.g., see Koch and Link[44]). The surfaces are used primarily to characterize broad regional areas while the residuals may emphasize detail in local areas. As noted above, a major difficulty in utilizing this analytical technique has been concerned with the delineation of the significance of the surfaces generated (e.g., see Baird *et al.*[48]). Figures 27 through 32 illustrate the first through the sixth degree surfaces of mean size. All are significant at the 0.10 level using the standard F test[49]. Using the Chayes[46] test, however, only the first two surfaces are significant at this confidence level. The first degree surfaces (Fig. 27) indicates the predominance of silt size range sediment within the lagoon with a trend to fineness toward the north. Residuals from the surface (Fig. 33) add localized detail; for example, an area of fine sediment extending easterly from Oliktok Point, the effects of the Kavearak and Milne promontories in funneling coarser grained material into the deep lagoon area, and a general coarsening of material adjacent to the barrier islands. The second degree mean size surface (Fig. 28) relates the mean size in a better fashion to the lagoon topographic character. This surface is significant at the 0.0025 level. The lack of fine material from Harrison Bay is evident, as also is the overall coarseness of the south shore sediments. The residuals from this latter surface (Fig. 34) again emphasize localized deposition effects around headlands, and also indicate the presence of a lobe of finer grained sediment in deeper water at the eastern end of the lagoon.

In the third degree surface (Fig. 29), which employs ten terms rather than the six for the second degree surface, the character of the surface changes little. The coefficient of determination changes only from 0.197 to 0.259 for the third degree surface. The fourth degree surface (Fig. 30) improves this to 0.343; an improvement of 0.084. This latter map shows a decided jag in the mean contours on the south side of the lagoon,

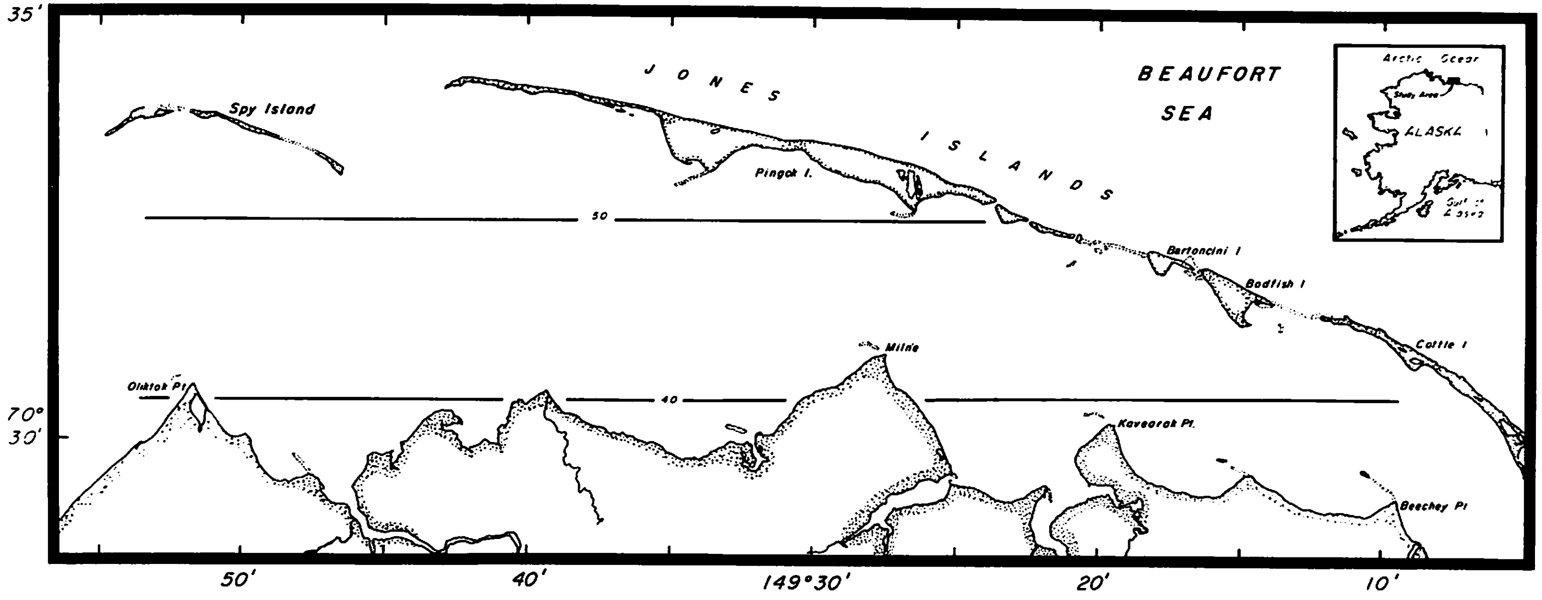


Figure 27. Trend surface map of 1st degree mean trends.

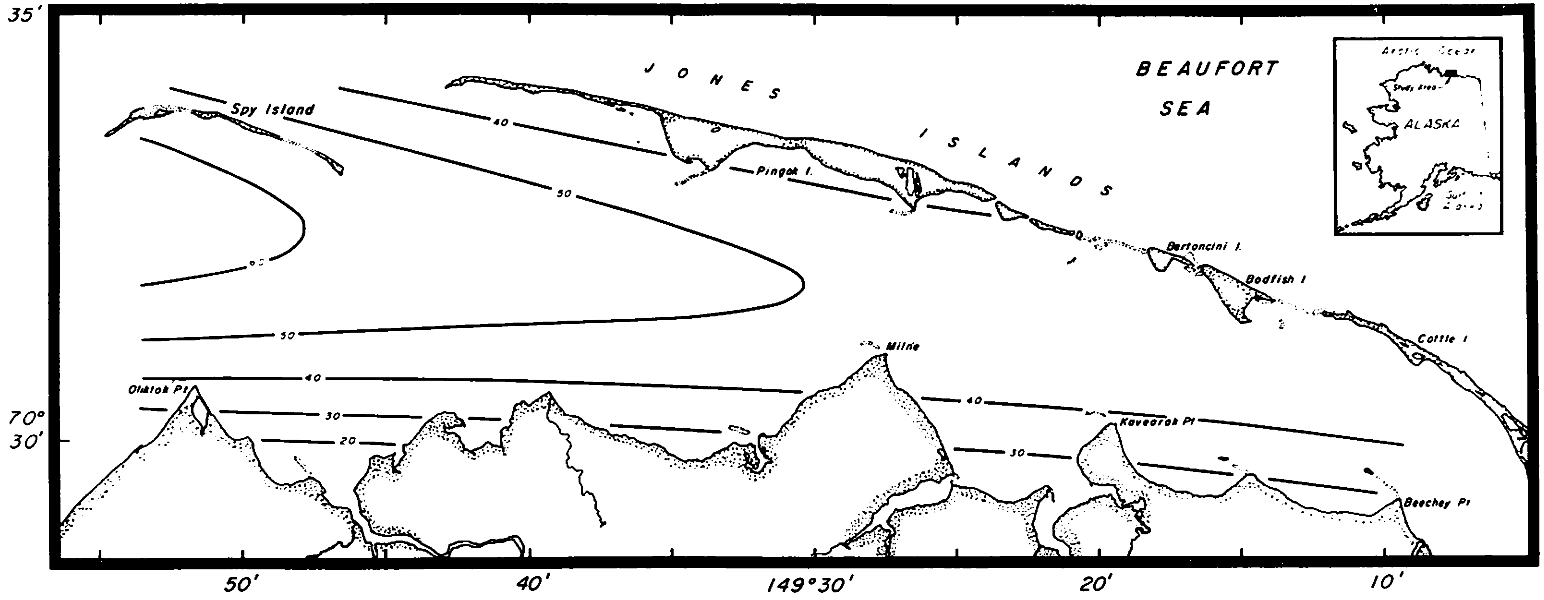


Figure 28. Trend surface map of 2nd degree mean trends.

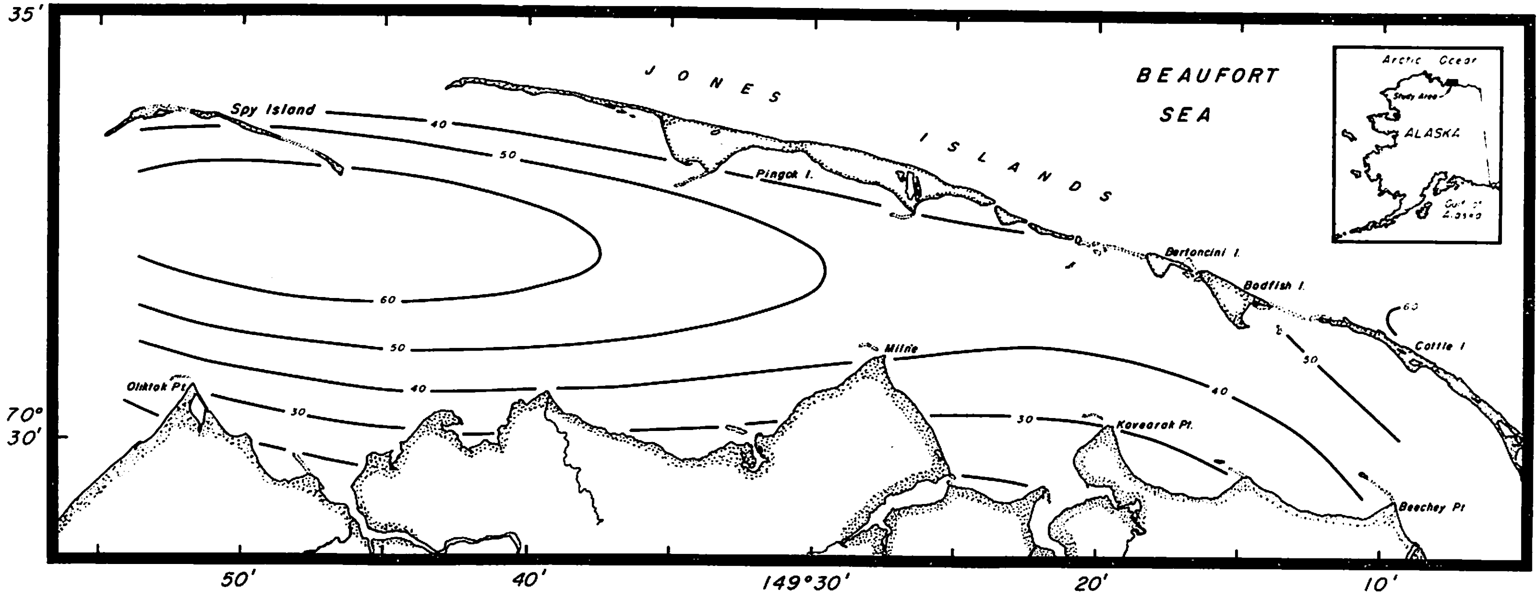


Figure 29. Trend surface map of 3rd degree mean trends.

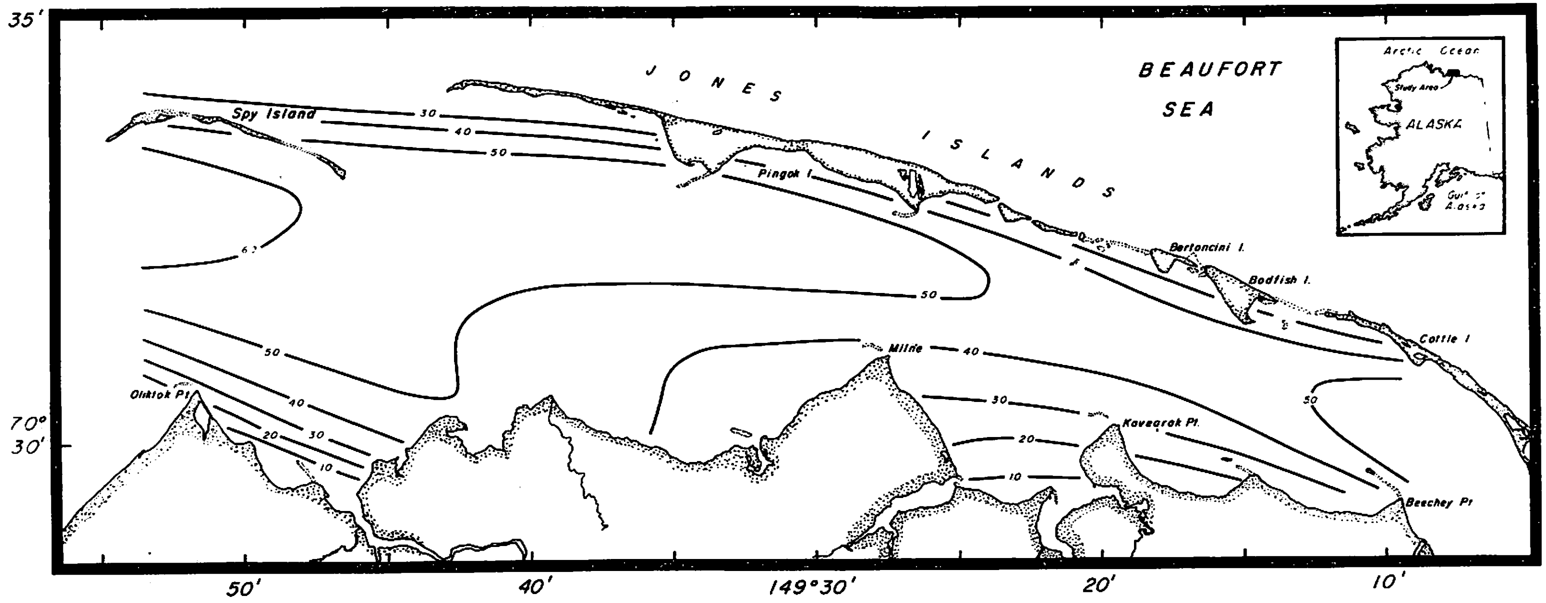


Figure 30. Trend surface map of 4th degree mean trends.

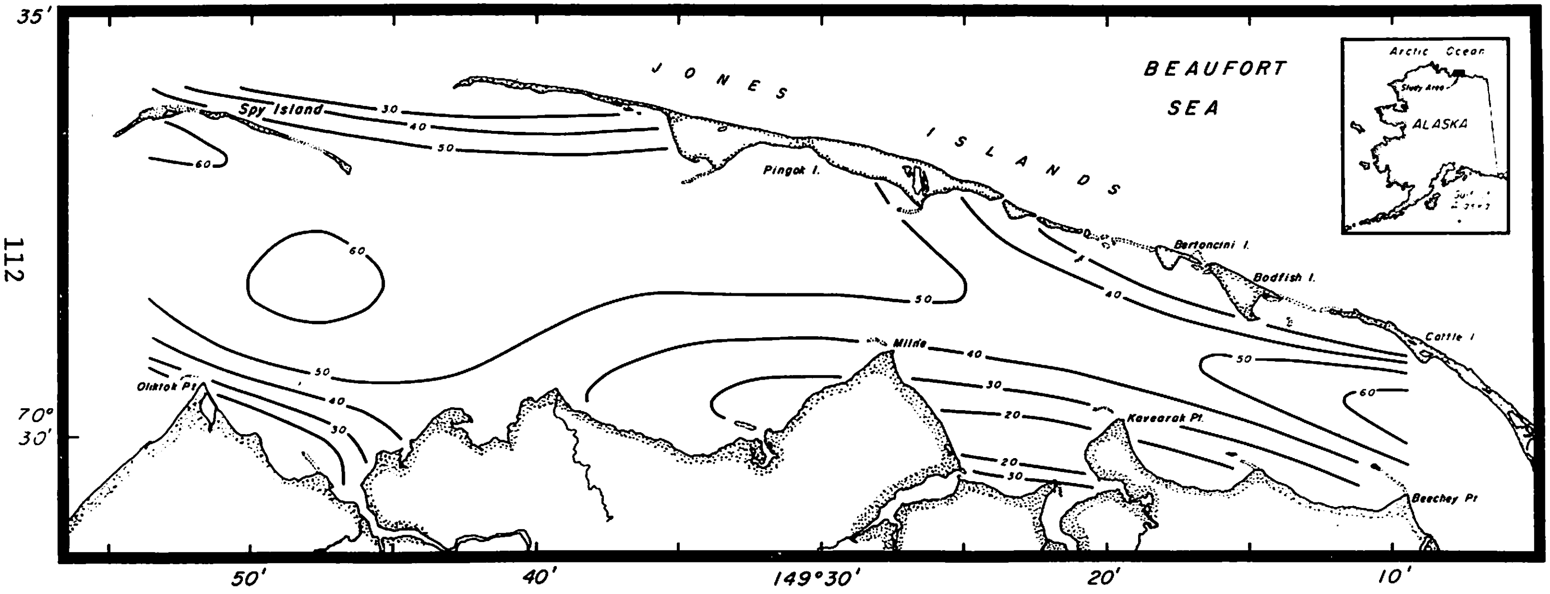


Figure 31. Trend surface map of 5th degree mean trends.

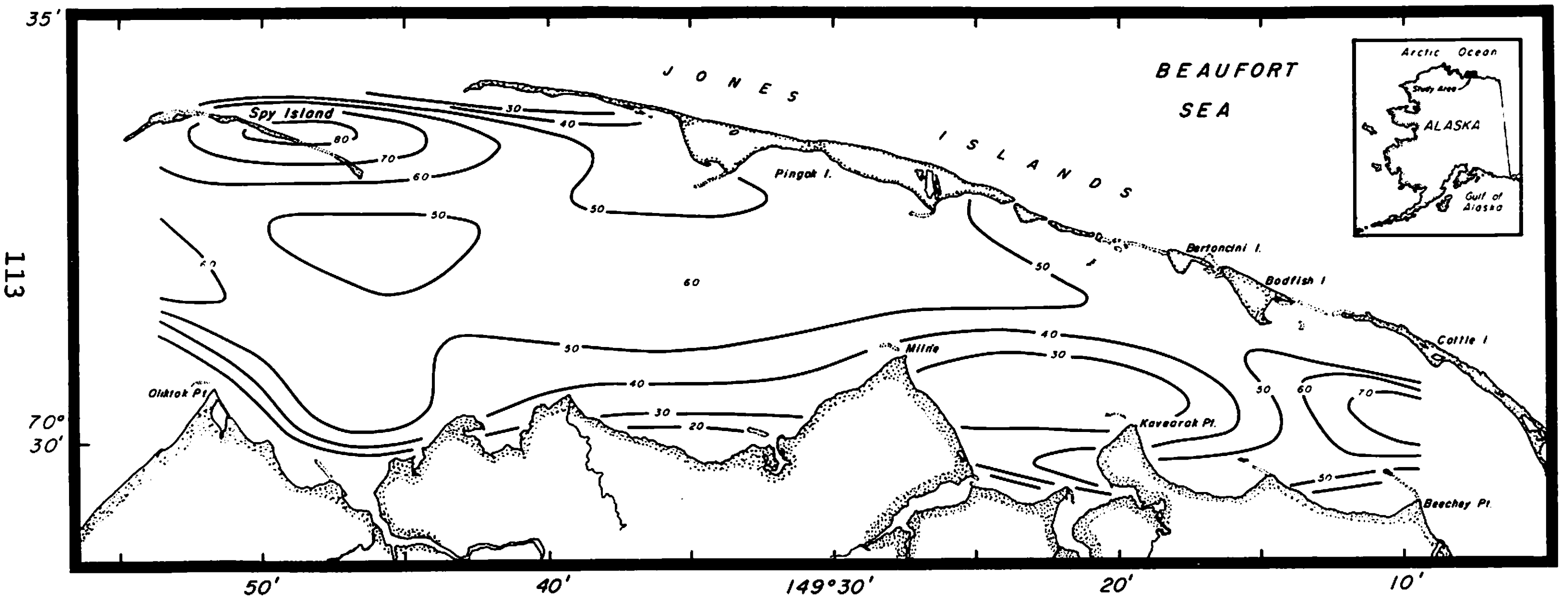


Figure 32. Trend surface map of 6th degree mean trends.

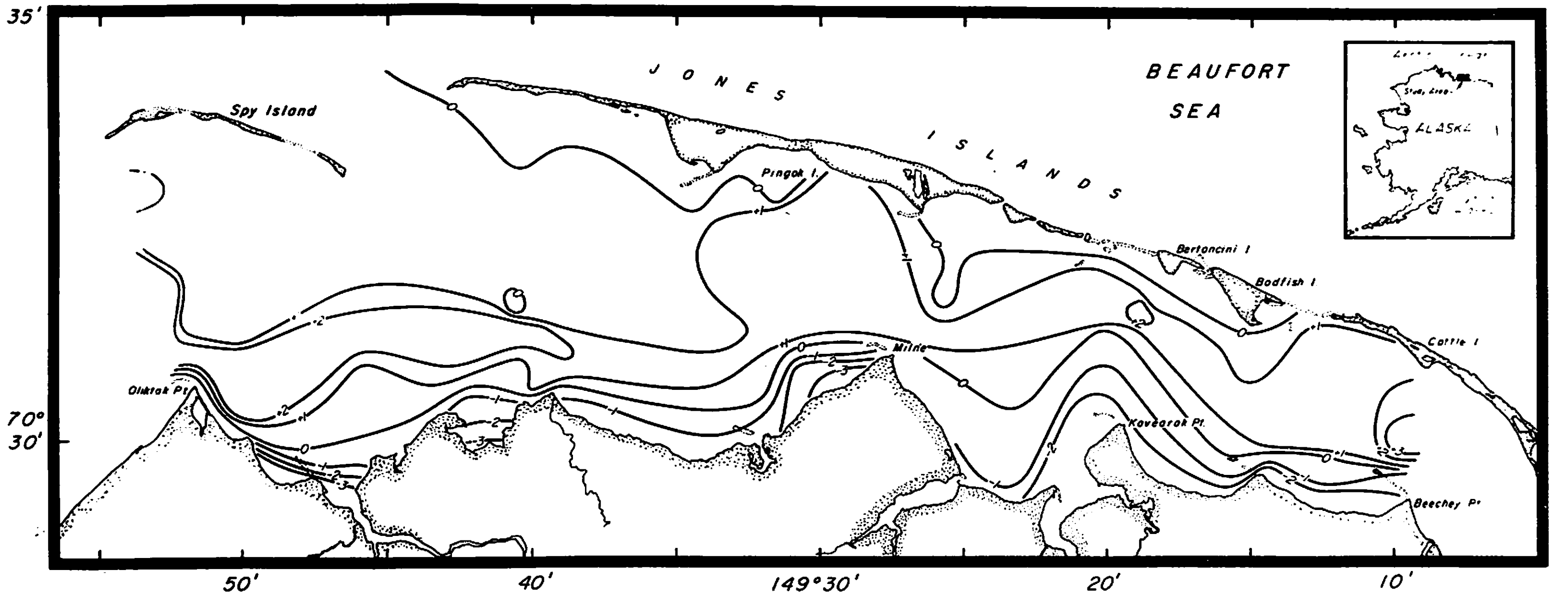


Figure 33. Residuals from First Degree Trend Surface Map. (0.1 ϕ).

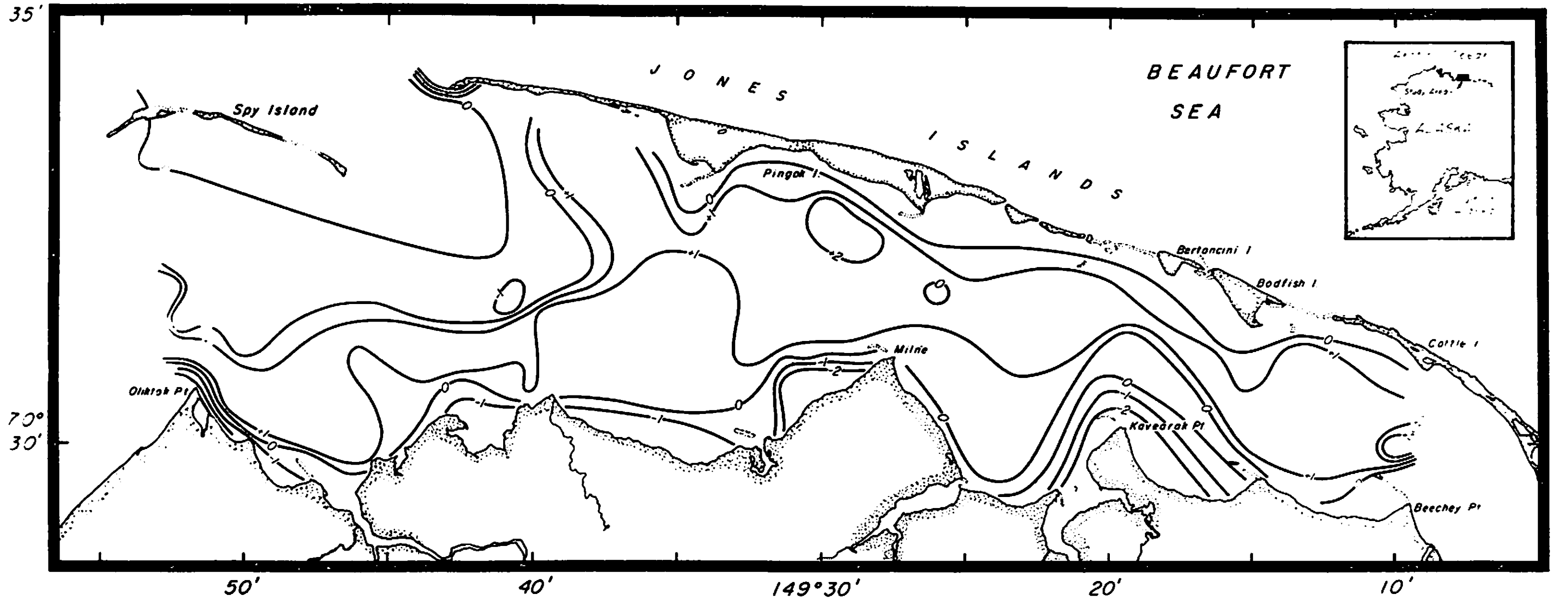


Figure 34. Residuals from Second Degree Trend Surface Map. (0.1 ϕ).

possibly associated with Milne Point and associated shoals. Higher degree surfaces (Figs. 31-32) add finer detail relating to the topography of the area; streams, passes between islands and other such features.

The inclusive graphic standard deviation of Folk and Ward[37] is a measure of the sorting of the sediments. It measures the spread of the central portion of the curve. The plot of sorting versus mean for all samples presented in Figure 35 shows the samples to be generally very poorly sorted. There are, however, samples in every Folk and Ward[37] category. The most easterly sample (CB-4) is very well sorted. This represents the major sand source for the longshore transport. The mean for this sample is 1.66 ϕ making it one of the coarser samples. It was noted above that this sample represents one of the end members of the sand mode decay process (see Fig. 24). The characteristic sinusoidal relationship[65] between mean and sorting is also evident in Figure 35. Poor sorting in sediment appears to be a result of changing competency of the transport media[66] indicating in this case the likelihood of changes in the energy of the lagoon versus the surrounding areas. Considering that strong currents are to be expected between the islands, that the flow rate from the rivers and streams fluctuates seasonally and that a breaker zone exists on the shore, a decrease in competency or energy level (entropy in Greenwood and Davidson-Arnott[66]) in the area of the deep lagoon is exceedingly likely. Another factor expected to result in poor sorting may be the ice cover in winter. By creating very low energy conditions in the lagoon, the winter ice cover allows deposition of fine material which cannot be eroded the following summer[67].

The mathematical basis for the sorting parameter is the second moment measure. The third moment measure is called skewness and was approximated by Folk and Ward[37] as Inclusive Graphic Skewness. This parameter

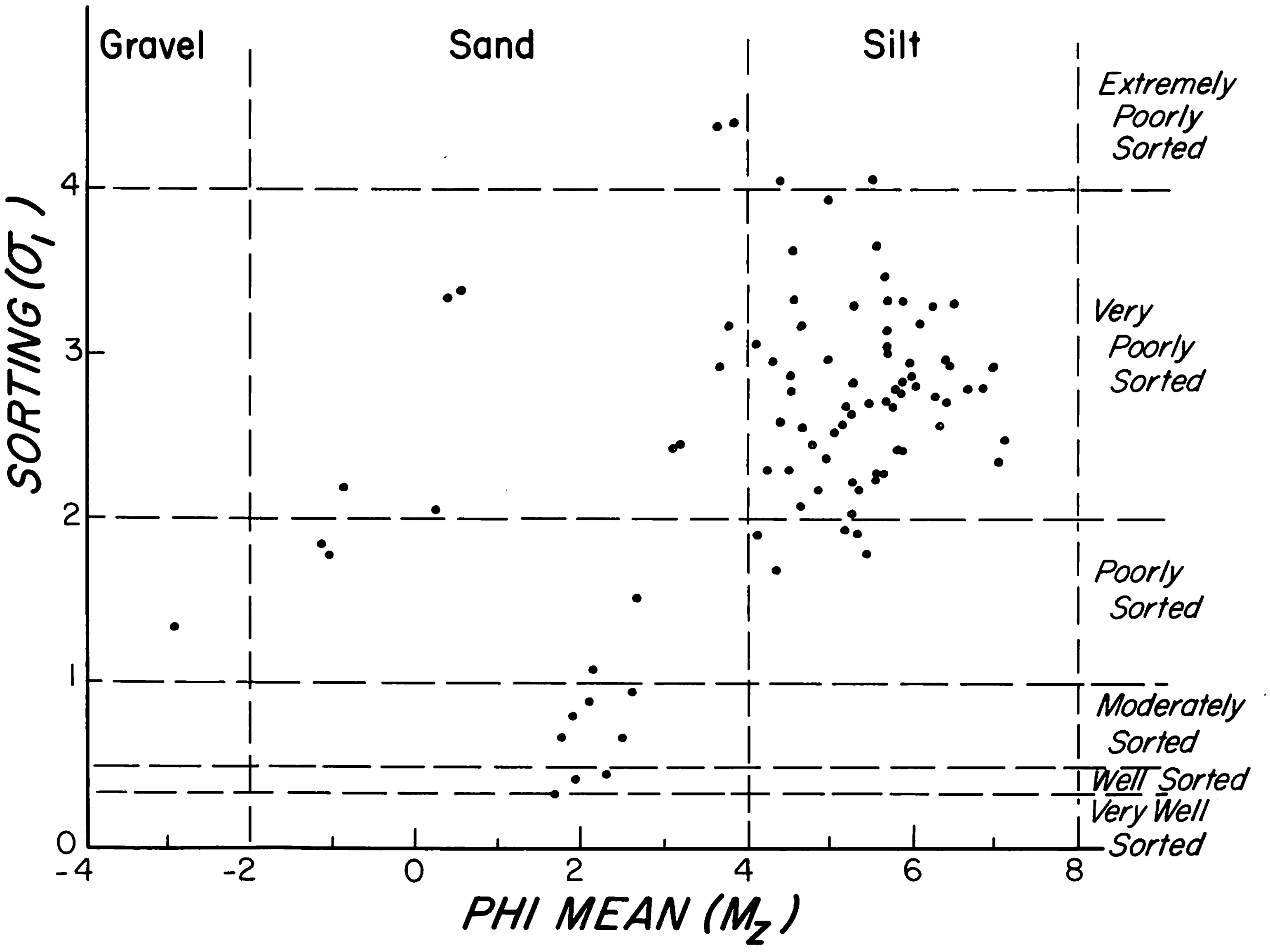


Figure 35. A binary plot of sorting *versus* mean.

measures one deviation of the size distribution from normality. If the distribution is peaked to one side or the other of the mean, it is skewed. The size distribution of Simpson Lagoon sediments shows a pronounced tendency toward positive and very positive skewness as shown in Figure 36.

Cadigan[68] considered that skewness measured the relationship between the sorting of the two halves of the size distribution. Poorer sorting in the finer half is termed positive skewness. Allen[69], in studying the Gironde River estuary, found that skewness apparently differentiated between the areas dominated by tidal and wave energy respectively. Skewness is probably most useful in characterizing polymodal sediments where it indicates the unequal mixing of two or more different populations. The study of the Irish Sea sediments by Cronan[64] is particularly illustrative in this respect. Sediments in the latter area are unequally mixed with proportions determined by the velocities of the tidal currents. This produces an alteration in the skewness sign.

As noted above, the Simpson Lagoon grain size distribution is predominantly positively skewed. With only two exceptions, the negatively skewed samples represent nearshore environments, where poorer sorting of the coarse end of the distribution would be expected. The two anomalous samples (PM-3 and 4) were taken from off Milne Point, and this area is likely to be strongly affected by the point itself. Such a predominantly positively skewed size distribution would be expected to be a result of fluctuating energy conditions and the mixing of a well sorted coarse and a poorly sorted fine population. In Simpson Lagoon the energy fluctuates strongly between winter and summer conditions and, as discussed previously, it would appear that (see Fig. 24) a westward moving well sorted coarse population is available from the Beechey Point area. Therefore, it seems likely that the Simpson Lagoon sediment skewness is in fact a

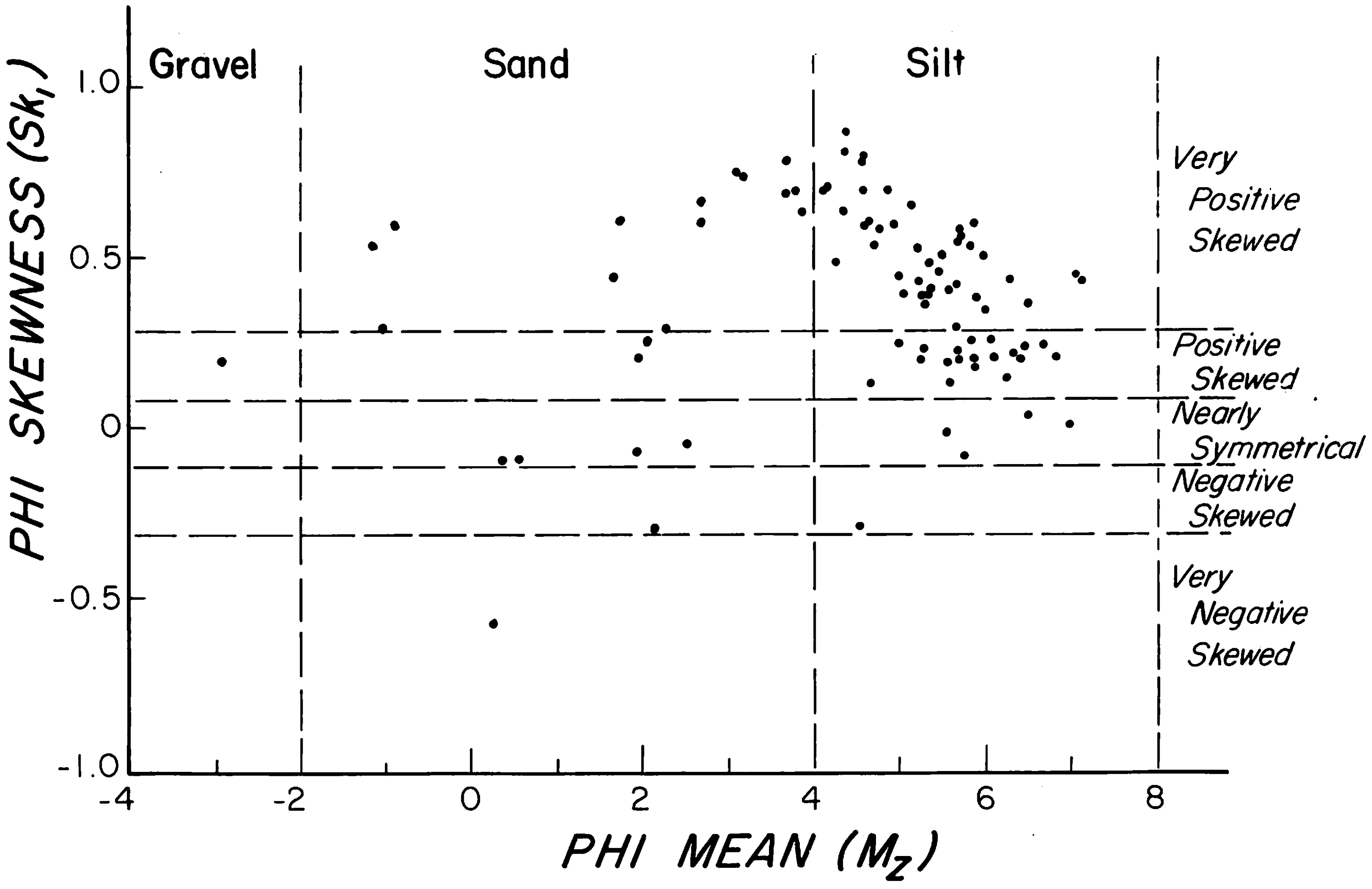


Figure 36. A binary plot of skewness *versus* mean.

result of the mixing of two populations of this type. The binary plot of skewness versus mean size (Fig. 36) very closely resembles - in terms of the inflection points of the sinusoidal curve and the spread in the coarser samples - the distribution given by Cronan[64] for the Irish Sea samples known to be deposited under fluctuating energy conditions.

Very little is understood about the environmental significance of inclusive graphic kurtosis[37]. Kurtosis measures deviations from the standard normal distribution by measuring the relationship between the average slopes of the center and ends of the distribution. The sorting of these areas is by the slope of the curves, so a better sorted center gives a leptokurtic value[68]. Figure 37 shows the binary plot of kurtosis versus mean. Kurtosis values cluster in the mesokurtic-platykurtic region, although a few extremely leptokurtic values are encountered. Sorting and kurtosis correlate well with a negative correlation (0.005 confidence limits). It would appear that the better sorted samples are not better sorted in the center of their distribution, and probably this indicates that modes which are well sorted and subequal are not centered in the distribution.

Normalized kurtosis, a parameter suggested by Royse[34], is shown in Figure 38 as a binary plot with the mean. It exhibits a slight sinusoidal curve. The plot of kurtosis versus mean for this study (Fig. 37) does not clearly show the doubly peaked curve Cronan[64] claims to discern in his plot. Cronan[64] suggests that kurtosis is related to the degree of polymodality and that a small accessary mode increases the kurtosis. Subequal modes produce low kurtosis values, and unimodal sediment tends to be mesokurtic. Kurtosis in Simpson Lagoon is a measure of the relationships between the size modes, perhaps modified in an as yet unknown manner by the energy conditions.

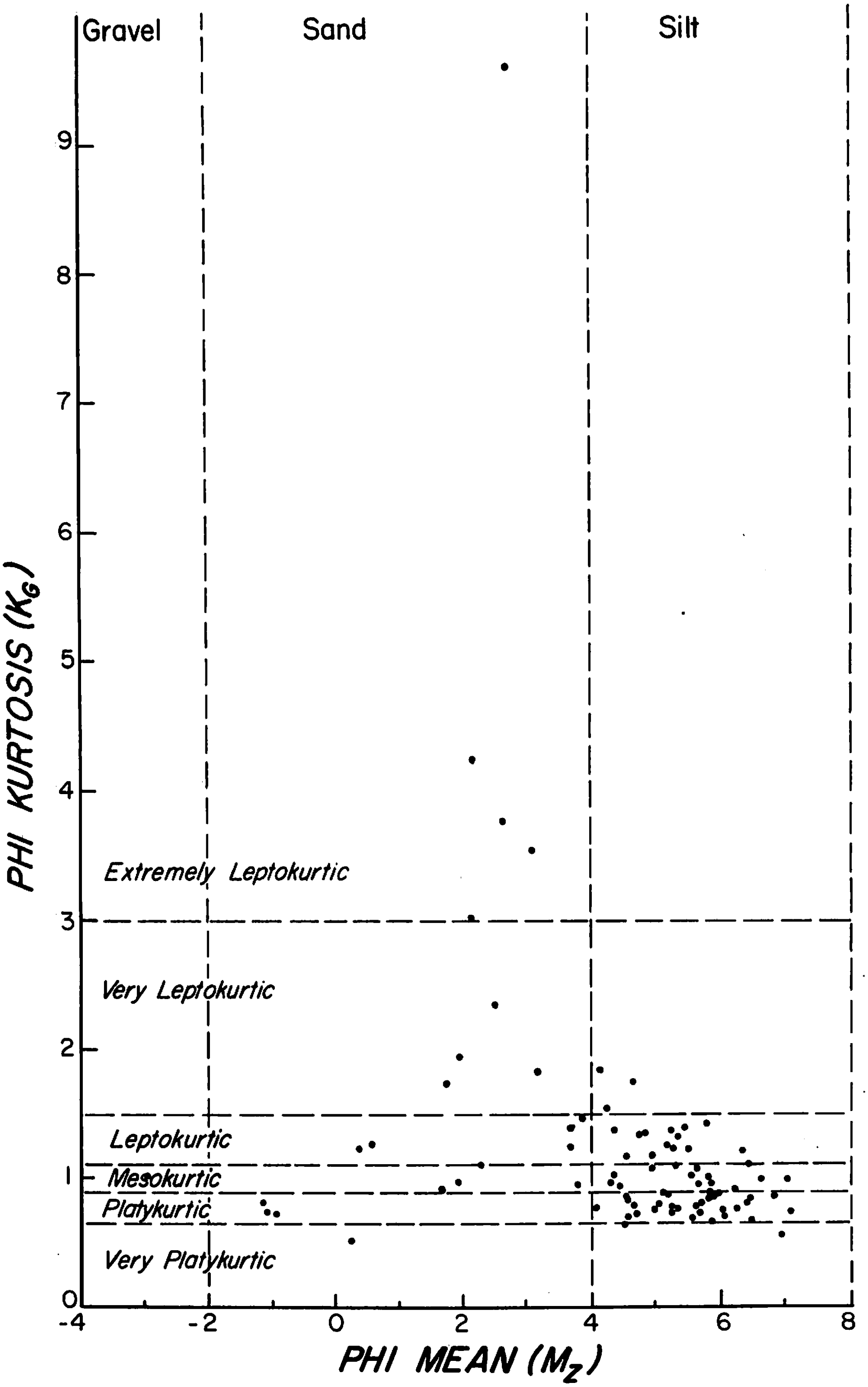


Figure 37. A binary plot of kurtosis *versus* mean.

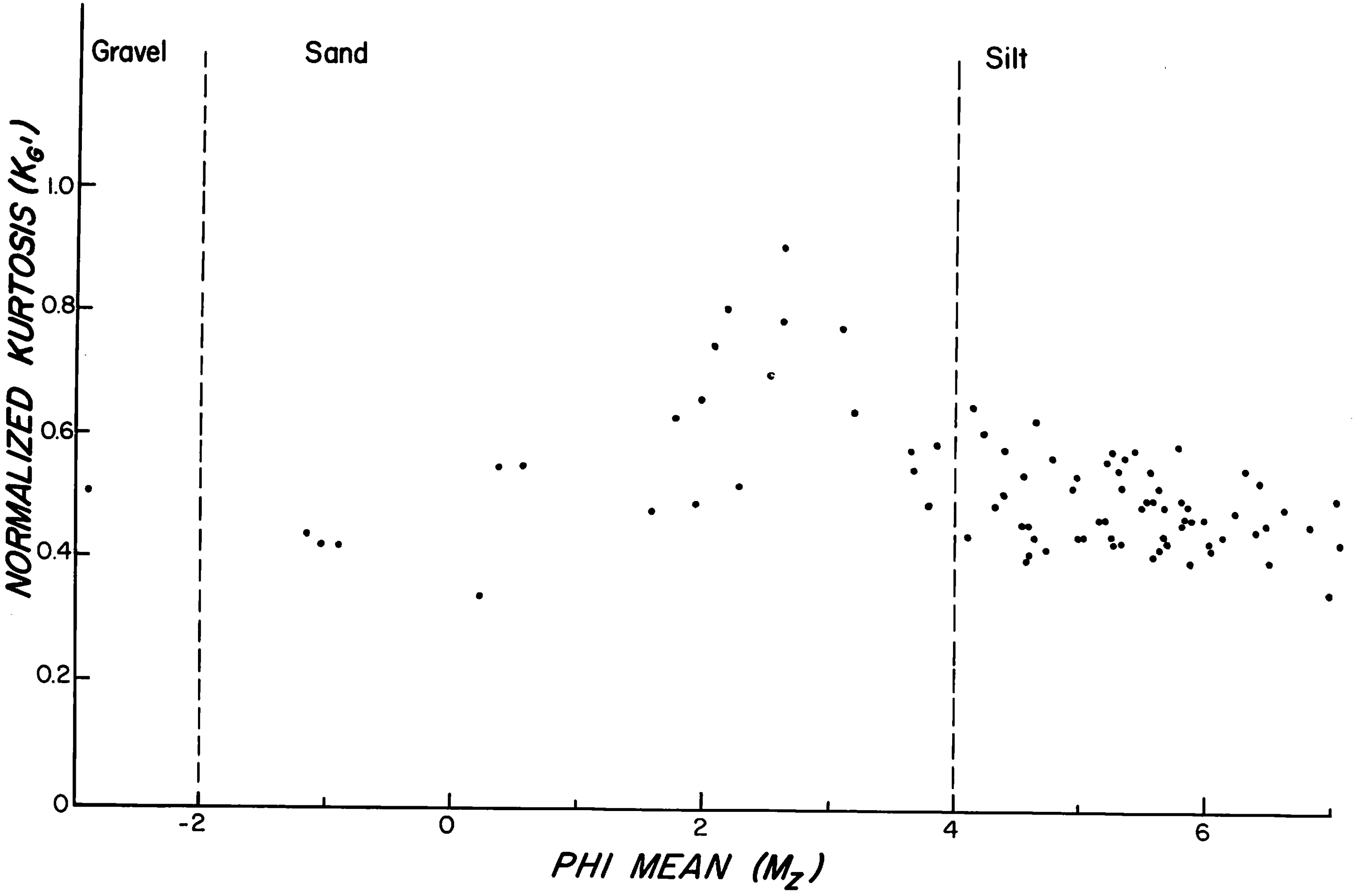


Figure 38. A binary plot of normalized kurtosis *versus* mean.

The third degree kurtosis trend surface proved to be the most significant, with a significance level of 0.05 (standard F test, 0.10 for the Chayes test[47]). This surface (Fig. 39) shows a very simple pattern with kurtosis rising away to both sides of a central trough which cuts diagonally across the lagoon from the northwest to southeast. The contours are mesokurtic to very leptokurtic. The interpretation of kurtosis by Greenwood[70] would then indicate that velocity fluctuations within the lagoon remain in the region capable of carrying particles within the middle of the size distribution (between 25 and 75 percentile) for longer than normal. This perhaps indicates a constancy of energy, with higher values of kurtosis indicating a greater consistency. These interpretations would imply that the energy level of the depositional agent of the lagoon is most consistent near the edges and least consistent along the trough line of the third degree trend surface. Cronan[64] interprets kurtosis somewhat differently. In his study, kurtosis results from mode relationships such that high kurtosis occurs when a small accessory mode exists. By this interpretation, the high kurtosis values - especially along the south shore - would be due to the small silt mode (see previous discussion), and the low kurtosis trough to subequal modes of sand and silt in the central lagoon. Because of the modal nature of the sediment, the interpretation of Cronan[64] may be more accurate for this area.

Heavy Minerals

The percent yield of heavy minerals is given in Table 10. Heavy minerals in the study area are practically non-existent, due primarily to low source area values[7]. The mean value for the 1 to 2 ϕ fraction was 0.08 percent. The other two fractions are not greatly different: 0.27 percent for the 2 to 3 ϕ fraction and 0.55 percent for the 3 to 4 ϕ fraction.

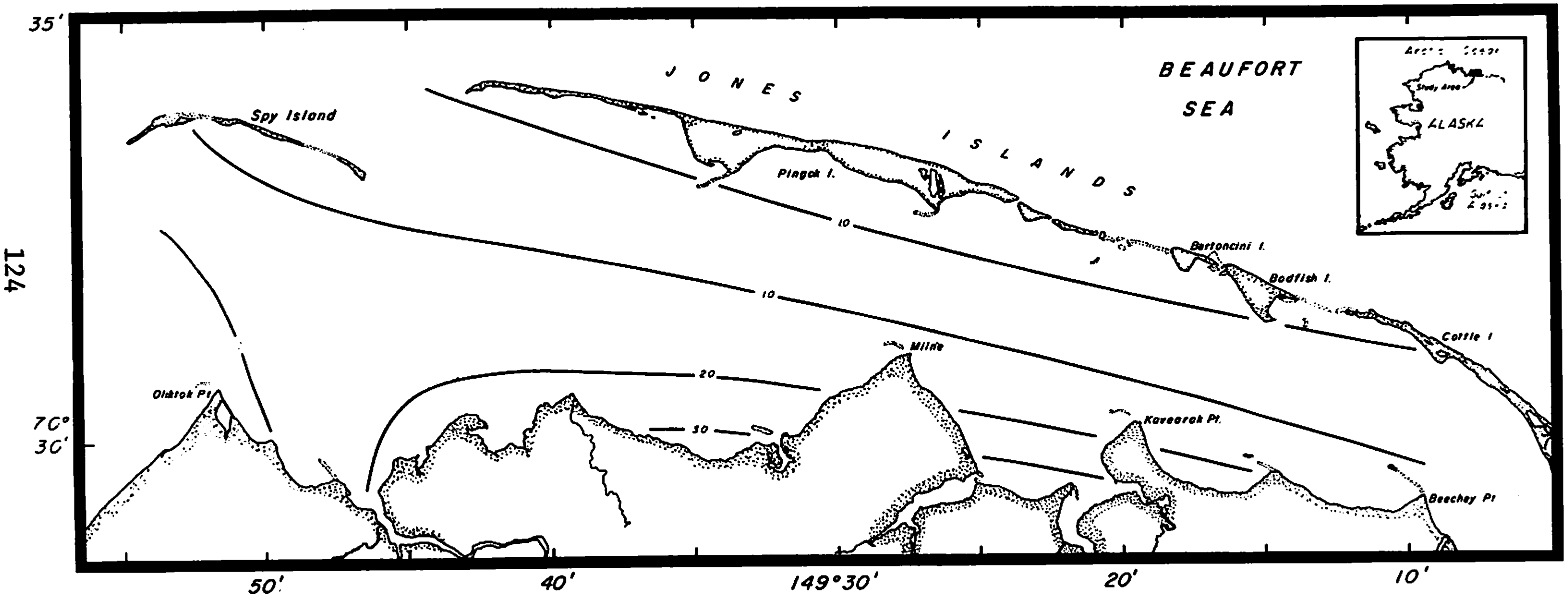


Figure 39. Trend surface map of 3rd degree kurtosis trends.

Table 10. HEAVY MINERAL PERCENTAGES

Sample	1-2ϕ	2-3ϕ	3-4ϕ
BEK-1	0.1	0.3	0.6
BEK-4	0.03	0.3	-
BEK-6	0.03	0.3	0.2
BEK-7	0.1	0.5	1.7
CB-1	0.2	0.4	0.2
CB-2	0.2	0.2	0.1
CB-4	0.1	0.8	0.3
KM-1	1	0.04	1.1
KM-2	0.03	0.3	2.0
OEL-1	0.05	0.02	1.7
OEL-2	0.1	0.3	0.7
OEL-3	0.1	0.1	0.9
OEL-5	-	0.1	0.3
OEL-8	0.1	0.04	-
OEL-11	0.1	0.2	0.2
OBO-1	0.1	0.2	0.3
OBO-3	0.1	0.1	0.2
OBO-5	0.3	0.7	0.1
PJ-2	0.02	0.3	0.4
PJ-5	0.1	0.2	0.1
PJ-10	0.2	0.4	1.3
PM-1	0.04	0.2	0.2
RM-2	0.1	0.6	-
RM-4	0.04	0.1	0.3
SE-1	-	0.04	1.1
STO-1	0.1	0.2	1.6
STO-4	-	1.0	0.01
STO-9	0.1	-	-

No linear correlations between any of the fractions and depth or position within the lagoon were significant at the .05 level or above. High values of the heavy minerals in the 3 to 4 ϕ fraction occur along the south shore of the lagoon opposite Pingok Island (Fig. 40). The 1 to 2 ϕ fraction shows a different pattern of high values (Fig. 41) with the northeast corner of the lagoon near Pingok Island being high as well as the Oliktok east site. Another pattern appears when considering the 2 to 3 ϕ fraction (Fig. 42); high values occur in the west, the Ugnuravik River mouth and the east.

Carbon Analysis

Recent sediments contain two major sources of carbon: organically bound carbon and carbonate carbon. The results of analysis of ten samples for both organic and carbonate carbon are presented in Table 11. Despite the occurrence of tundra mats and other terrigenous detrital vegetable matter in the water, the organic carbon values are very low, with a mean content of 1.12 percent. This is probably due in large part to the energy conditions within the lagoon as discussed previously. Low density organic matter is easily kept in suspension. Carbonate values on the other hand are surprisingly high - a range of 1.6 to 13.4 percent $CO_3^{=}$ - considering the distance from the nearest known source of carbonate rocks in the eastern Brooks Range. Some of the carbonate may be due to shells and other biologic remains, but unfortunately information on benthic organisms has been unavailable. A comparison of these values with other carbonate analysis from the arctic coast area[26] shows good agreement with the data from the nearshore areas further east, but not with the values from the Colville River and Harrison Bay area. Two possibilities are therefore suggested. Firstly, that the major rivers to the east are carrying carbonates from the Brooks Range into the marine environment and the

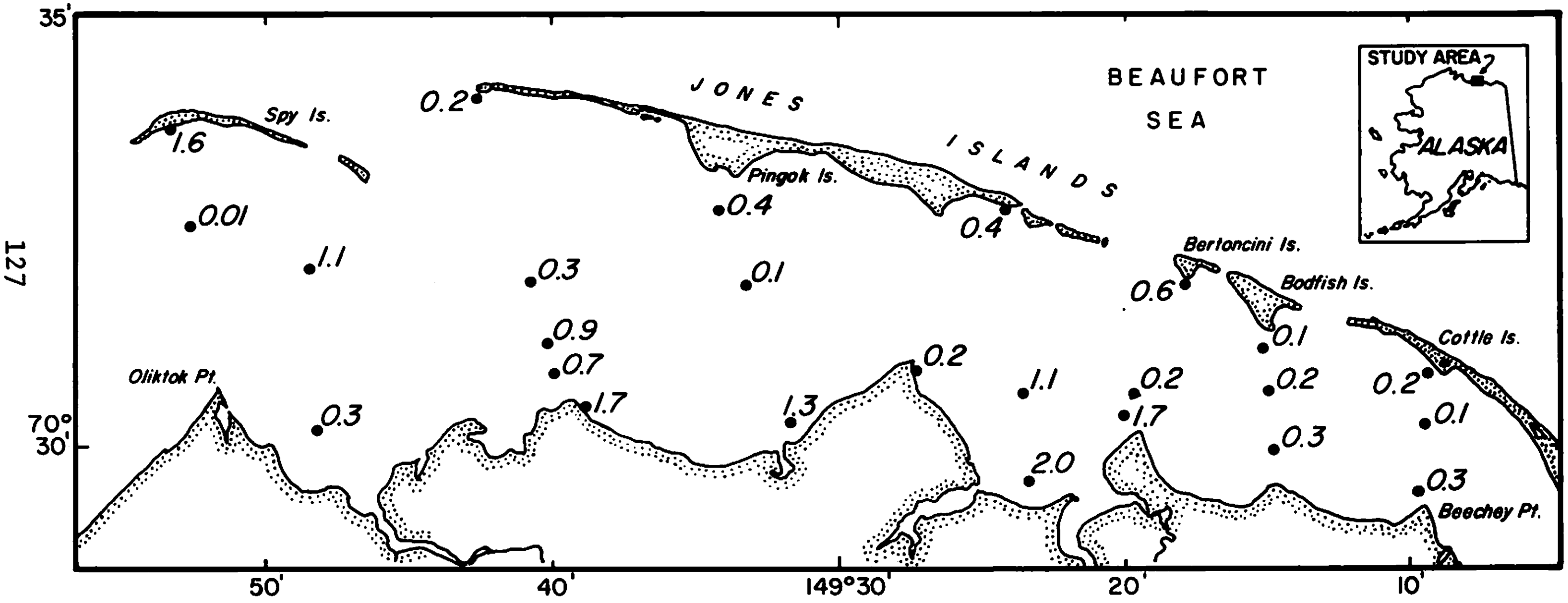


Figure 40. A map showing the distribution of heavy minerals from the three to four ∅ fraction.

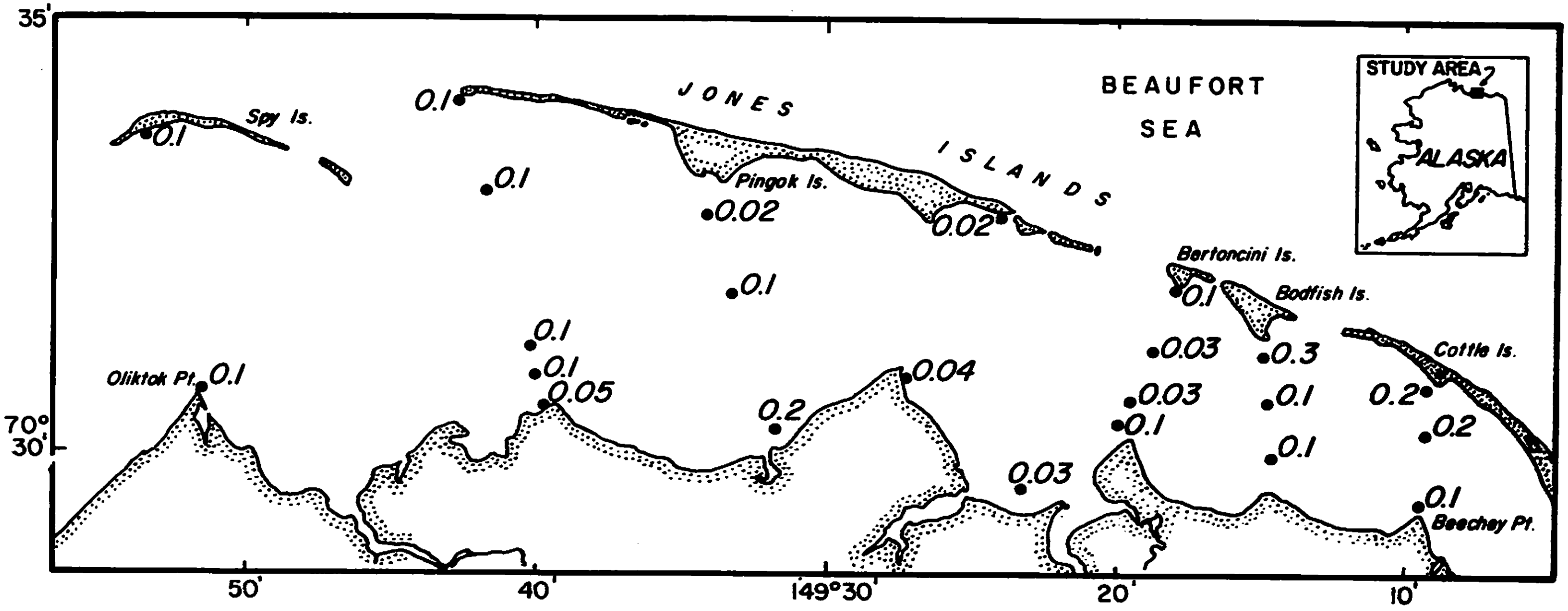


Figure 41. A map showing the distribution of heavy minerals from the one to two ∅ fraction.

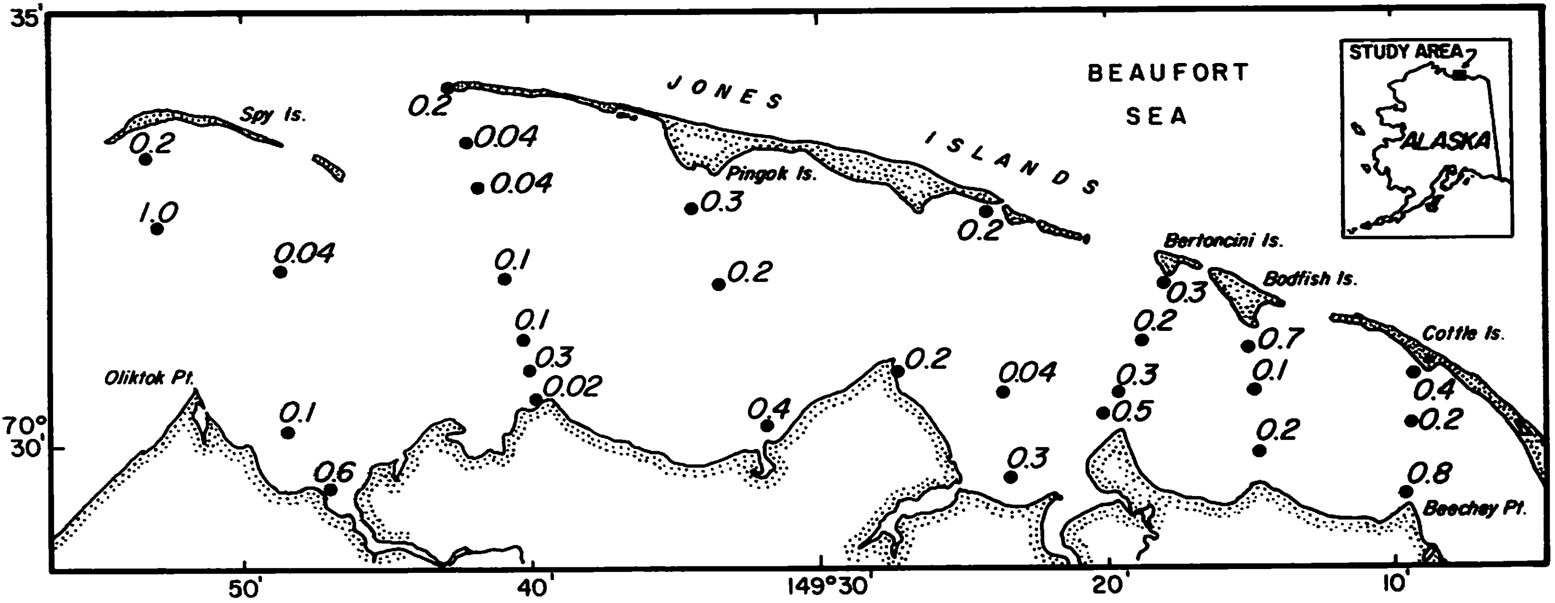


Figure 42. A map showing the distribution of heavy minerals from the two to three ∅ fraction.

Table 12. CLAY MINERAL PERCENTAGES

Sample	Illite	Chlorite	Kaolinite	Smectite
STO-4	61.5	18.0	6.0	10.9
STO-7	65.7	17.4	6.4	9.7
CB-2	72.0	17.5	6.4	4.0
CB-3	69.2	13.3	7.4	7.2
RM-2	72.5	18.1	5.1	4.7
BEK-4	66.0	14.6	14.6	4.9
PJ-5	74.0	12.2	8.7	5.1
PJ-7	66.7	13.4	10.6	9.4
OBO-3	69.0	17.7	4.5	9.1
KM-2	70.0	16.7	9.5	3.9

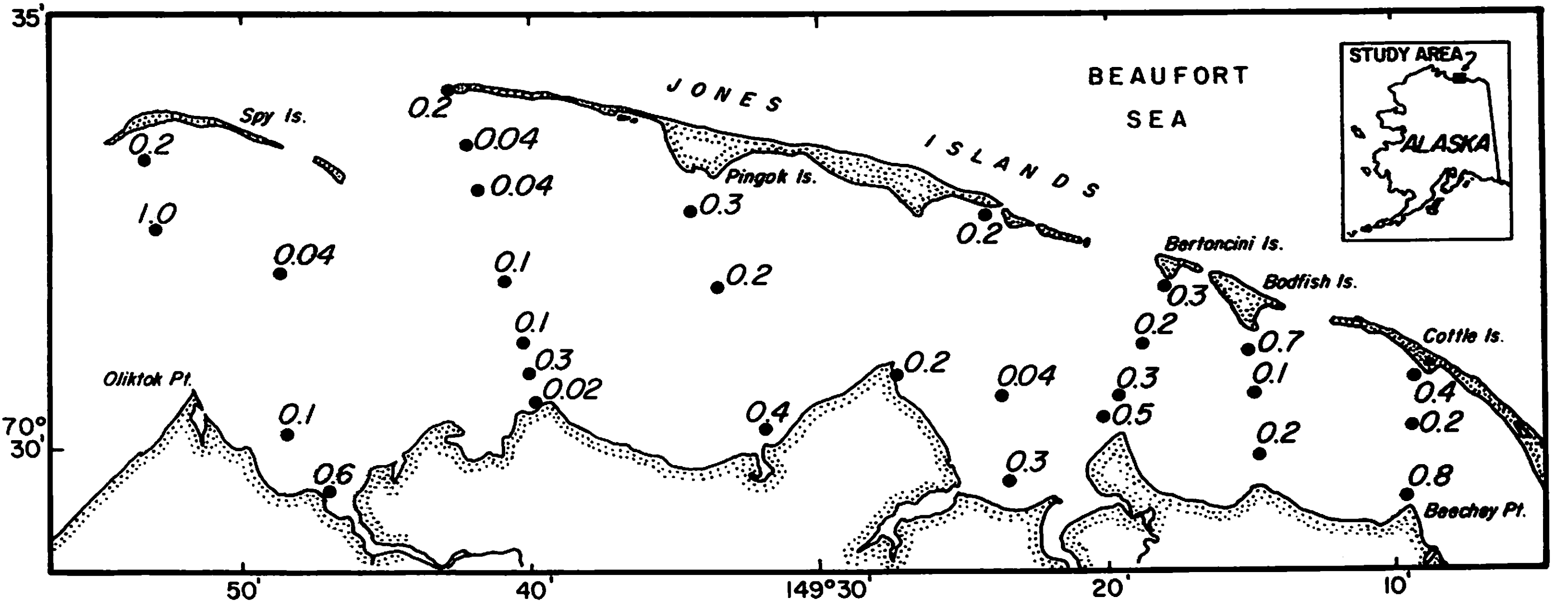


Figure 42. A map showing the distribution of heavy minerals from the two to three Ø fraction.

Table 11. CARBON ANALYSES[a]

Sample	Organic	CO_3	$CaCO_3$	Total Carbon
STO-5	0.8	12.8	21.3	3.4
STO-7	1.3	12.9	21.5	3.9
PJ-7	1.0	12.2	20.7	3.4
PJ-4	1.0	8.4	14.0	2.7
RM-3	2.0	11.3	18.8	4.3
BEK-4	0.9	8.3	13.8	2.6
KM-2	0.4	1.6	2.7	0.7
OBO-3	1.4	12.5	20.8	3.9
CB-1	1.1	9.3	15.5	3.0
CB-3	1.2	13.4	22.4	3.9

[a] All values are percents

Colville is not, or that the conditions for growth of small carbonate shelled organisms are less favorable in the Harrison Bay area.

Clay Mineralogy

Table 12 gives the semi-quantitative[71] clay mineral percentages for ten samples from the lagoon (see Fig. 3 for localities). Illite predominates followed by chlorite and comparable amounts of smectite and kaolinite. Naidu[24,26] has discussed the clay mineralogy of the fine grained sediment fraction from the Colville River and various adjacent near-shore and shelf areas. Comparison of these data with the lagoon proportions illustrated in Table 12 yields added evidence for long-term net transportation through the lagoon from east to west. For example, smectite is relatively impoverished in the lagoon and, in this respect, the sediment is more comparable with the far off-shore areas. The Umiat Beds of the Colville River basin appears to be a major source of smectite to the local marine environment, and Naidu[23] has demonstrated that sediments discharged from the river are much in this component. Smectite from this source is of major importance in the area off the Spy Islands (Fig. 3) but it would appear that Colville River sediment has a negligible impact on the lagoon.

We have been interested in determining whether the clay mineral regime of this area would be diagnostic of high-latitude erosion-transportation-deposition cycles (see also the various publications of Naidu and Chapter 5). Kaolinite and smectite are generally thought to be produced in soils as weathering products (e.g., see Biscaye[41]). Illite is considered to be primarily a detrital product whereas chloride is a high-latitude mineral of primary origin[72,73]. The data of Biscaye[41] and Lisitzin[74] show that while clay minerals may show general latitudinal trends they also vary with changes in the source area. This appears to be the case

Table 12. CLAY MINERAL PERCENTAGES

Sample	Illite	Chlorite	Kaolinite	Smectite
STO-4	61.5	18.0	6.0	10.9
STO-7	65.7	17.4	6.4	9.7
CB-2	72.0	17.5	6.4	4.0
CB-3	69.2	13.3	7.4	7.2
RM-2	72.5	18.1	5.1	4.7
BEK-4	66.0	14.6	14.6	4.9
PJ-5	74.0	12.2	8.7	5.1
PJ-7	66.7	13.4	10.6	9.4
OBO-3	69.0	17.7	4.5	9.1
KM-2	70.0	16.7	9.5	3.9

here also (see also Naidu *et al.*[24]); i.e., that the specific source areas available have a larger impact on the clay mineral ratios (Table 13) than does the climatic environment on the erosion-transportation-deposition cycle. The illite and chlorite percentage of Simpson Lagoon samples are comparable to the data of Lisitzin[74], whereas the smectite values are higher and kaolinite concentrations are standard.

CONCLUSIONS

This section of the report has attempted to evaluate both the static and dynamic sedimentological environment of Simpson Lagoon immediately east of the Colville River delta. Reference should be made to previously published work which has been referenced where appropriate for more detail on particular aspects, and also to other chapters within this report.

The most important conclusion stemming from this work is that sediment transport along this particular section of the Alaska arctic coast is from east to west. This transportation appears to be predominantly a function of the prevailing northeasterly wind regime which is the driving force for the generation of both waves and currents. It is important to note, therefore, that in this specific area the generation of longshore currents is apparently significantly influenced by wind stress as well as by the waves. Evaluation of long-term changes in the shorelines and islands - chiefly from aerial photographic coverage analysis - has shown that, e.g., the growth patterns on Thetis Island and at Oliktok Point are due to transportation and deposition from the east along the lagoon and barrier island chain. Empirical estimates of volumetric sediment transport range from 0-42m^3/day.

Table 13. PERCENT RATIOS CLAY MINERALS

Sample	Kaolinite Chlorite	Smectite Chlorite	Illite Smectite	Smectite Kaolinite	Illite Kaolinite	Illite Chlorite
STO-7	0.4	0.6	7	1.7	11	4
STO-4	0.3	0.6	6	1.8	10	4
CB-2	0.3	0.2	18	0.7	12	4
CB-3	0.5	0.5	10	1.0	10	5
RM-2	0.3	0.3	14	1.0	14	4
PJ-5	0.8	0.4	16	0.6	8	6
PJ-5	0.9	0.7	8	0.8	6	6
KM-2	0.6	0.2	18	0.4	7	4
BEK-4	1.0	0.3	13	0.3	4	4
OBO-3	0.3	0.5	8	2.0	14	4

Analysis of the sediment size statistical parameters is also consistent with net transportation in this direction. For example, the progressive decay of the dominant sand-size mode of the most easterly near-shore sample towards the west. The paucity of smectite in the fine fraction of the lagoon sediments compared with the importance of this mineral in sediments discharged from the Colville River is additional evidence for a minimal impingement of the Colville River on this lagoon.

A majority of the Simpson Lagoon sediments lie in the silt-size range, and the major statistical parameter trends (such as mean and sorting) vary N-S along the short axis of the lagoon. The trend surface maps given are particularly illustrative in this respect. The poorly sorted characteristic of the sediments is indicative of changing competency of the transporting media and we have advanced the concept of a predominating "quiet" water environment for the bulk of the lagoon, with a good correlation between the mean size and depth. It has also been suggested that poor sorting could be due to the effect of winter ice cover. By this thesis, sediment deposited in the winter may not be eroded under open water, summer conditions. This latter point is of some importance since an initial objective of this study was to see if certain sedimentological characteristics could be ascribed to the climatic environment. Most of the work on such lagoon environments to date has been confined to temperate areas. The potential effects of having a short open-water season and approximately nine months of static ice-cover have not previously been evaluated. The positive skewness characteristic is of interest in this respect, since this is consistent with fluctuating summer and winter depositional environments with the westward moving well-sorted coarse population mixing with the lagoon silt. The environment described in this report is essentially the seasonal "steady-state" sedimentological regime. It must be remembered that severe summer storms can severely distort this picture by, for example, transporting in one cataclysmic event quantities of beach material which would normally be accomplished only over many seasons of "normal" conditions. Also, such storms need not act in the prevailing directions of transport. It is not certain at present over how long a period conditions would need to be studied to take account of transport of this type. We have been able, to date, to look at shoreline changes over a period of only a couple of decades.

It was expected initially that the effects of ice-rafting would be evident in the lagoon. This would have been a useful signature of high latitude lagoons, but the absence of gravel from the lagoon has shown that this mechanism is inoperative. Naidu believes that ice rafting of material is not significant even on the shelf areas outside the lagoon; gravels in these areas are believed to be relict. The lagoon is also protected from pack-ice scour, and the barrier islands and frozen beaches protect against ice-push. Heavy mineral distributions show a lack of a definite point source. The south shore beaches are a possible source for the small quantities of heavy minerals found.

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CHAPTER 5

ASPECTS OF SIZE DISTRIBUTIONS, MINERALOGY AND GEOCHEMISTRY OF DELTAIC AND ADJACENT SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA

A. S. Naidu and T. C. Mowatt

INTRODUCTION

Lately it has been realized that there exists, for a number of reasons, a compelling need to preserve both the continental and marine environments in as unpolluted a state as possible. However, in order to detect pollution in an environment it is necessary to have in hand baseline ecological data of that environment in its pristine or unpolluted state. The foregoing statement has special relevance to the North Slope deltaic and shallow marine environments of North Alaska. Although these environments are now apparently free from any appreciable pollution, potential problems may arise in the future as a result of development in that area of newly discovered large petroleum reserves. Realizing this, several Federal, State and private agencies have undertaken to further our knowledge of north arctic Alaska. This report presents preliminary results of baseline studies on the size distributions, mineralogy and chemistry of bottom sediments of the continental margin and the adjacent shallow marine regime of this region.

SETTING

The deltaic region of north arctic Alaska is one of the few transitional natural environments on earth of which we have very limited knowledge. The area under study extends from Harrison Bay in the west to Maguire Island in the east, and from the North Slope coast oceanward to approximately the 18 meter line (Fig. 1).

The transitional environment between Cape Halkett and Canning River mouth (Fig. 1) consists of a complex of several river estuaries, dis-

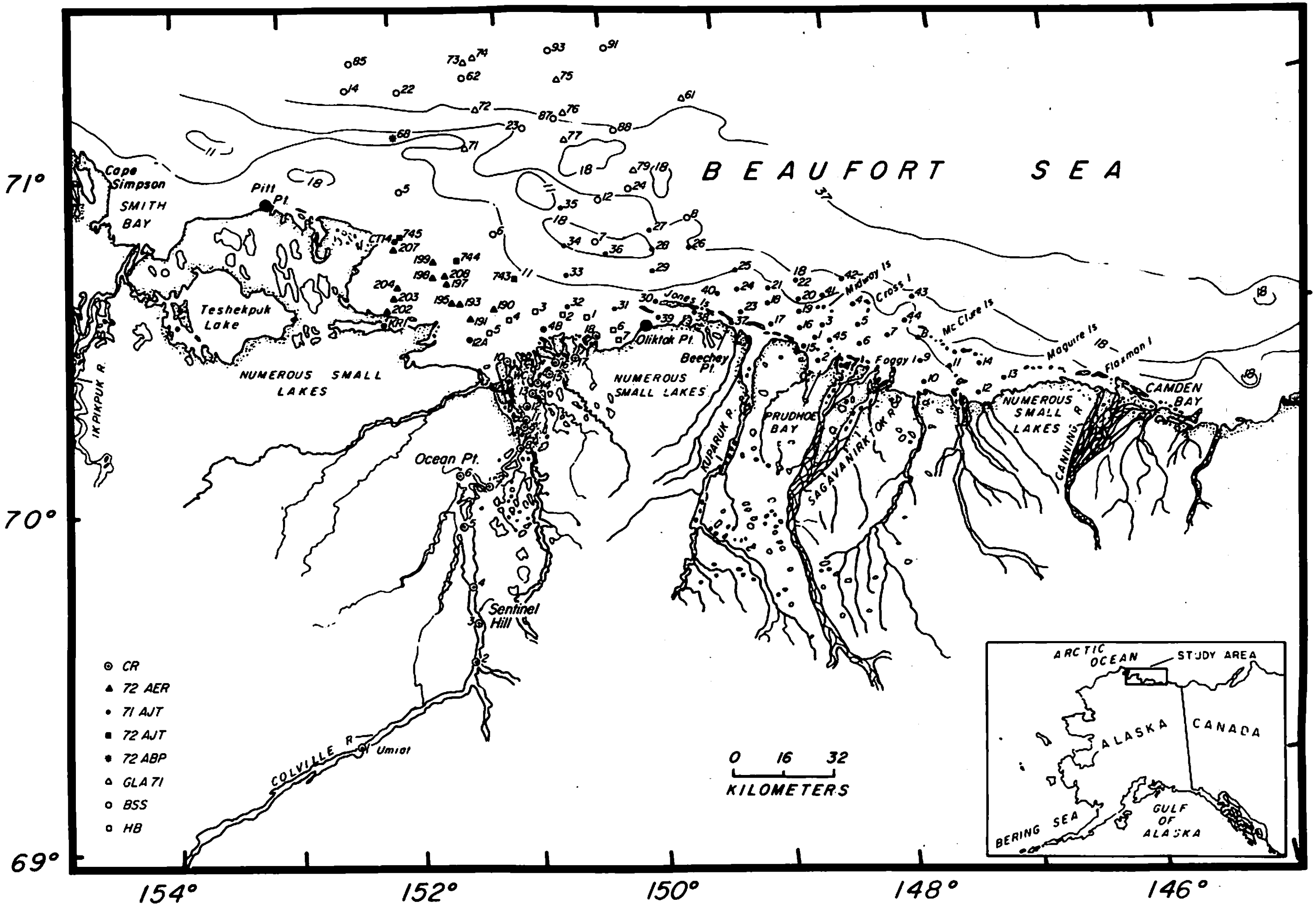

Figure 1. Map of the North Slope of Alaska, showing the deltaic area of study and locations of sediment samples. The depth contours are in meters.

tributary channels, bays, lagoon, barriers, bars, coastal beaches and a deltaic plain consisting of tundra. Several large rivers (e.g. Colville, Kuparuk, Sagavanirktok and Canning) have built deltas which coalesce laterally to form a complex of deltas. The most prominent of the deltas in this region is that of the Colville River, and it greatly influences sedimentation in the nearshore. As such it merits special mention.

The Colville River has a course of approximately 600km, and has built a 560km^2 delta at the mouth. Several distributaries break off from the main channel at the delta head, and as a result several lobate islands have formed in the far downstream end. Most of these islands in the estuary are elongated parallel to the distributary channels. All river channels of the North Slope are highly braided, presumably because of the great seasonal variations in sediment and water discharge. Arnborg *et al.*[1] have calculated that the most striking feature of the arctic rivers is the great concentration of activity in a short period of time. For example, in 1962, 43 percent of the annual discharge ($16 \times 10^9 m^3$) and 73 percent of the total inorganic suspended load (5.8×10^6 tons) were discharged from the Colville River during a three-week period around the spring breakup[1]. The bulk of this sediment-laden fluvial discharge initially flows oceanward over sea ice situated off the river mouths, and settles on the ice as a deposit up to 20mm thick. Finally this sediment finds its way to the bottom through drain holes in sea ice[2] and/or by melting of the ice. According to Reimnitz and Bruder[3], most of this fluvial sediment outfall is deposited on the steeper slopes seaward of the 2m depth contour off the Colville River mouth; this area represents the delta front.

Some detailed morphological and hydrographical attributes of the North Slope river deltas - especially that of Colville River - were recently presented by Walker and McCloy[4], Lewellen[5], Kinney *et al.*[6] and Walker[2], and therefore, particulars of these attributes will not be enumerated here. However, it should be noted that the morphologies of the North Slope deltas do not exactly conform to any of the delta prototypes mentioned in the literature; the closest resemblance, at best, is probably to the arcuate delta type. All North Slope rivers are truly arctic rivers inasmuch as they arise, flow and discharge in arctic Alaska, which is characterized by permafrost terrain. All these rivers are partly or wholly frozen almost eight months of the year.

The mean lunar tidal range in the north Alaskan arctic coast is comparatively very low[7], roughly 0.3 m. Kinney *et al.*[6] have reported that in the lagoons and nearshore during the summer, surface currents may range from 0 to 37 cm/sec (0 to 0.75 knots). Dygas *et al.* (Chapter 3) while observing a good correlation of strength and directions of water currents and wind, concluded that in the Simpson Lagoon the bottom current velocity is in the order of 17.3 cm/sec. However, as a result of storm surge, sea level in the coastal area may vary as much as 1.5 m within a short time[6,7]. Although tidal flats are not extensive in the north coast of Alaska because of low tidal range, some low lying deltaic areas may often become water-logged during the sea level rise resulting from storm surge.

Salinities of waters in the Colville Delta and adjacent continental margin region range from 10 °/oo to 65.9 °/oo[2,6,8]. Presumably, the unusually high saline waters are formed as a result of great concentration of ions in water bodies during formation of ice. The ionic supply arises from solute segregation during freezing. Primary productivity in the lagoonal area is relatively low, most values ranged around 1 μg C-hr[9].

The continental facies of the North Slope Deltas is dominated by the coastal beaches, Harrison Bay, Simpson Lagoon, the far offshore and nearshore barriers. The lagoon and Harrison Bay are shallow, having a depth range of 0.8 to 3.5 m. The barriers and bars are oriented roughly parallel to the deltaic coastline, and locations of all barriers in the area of study are confined to the east of the Colville River confluence. The barrier surfaces consist predominantly of gravels. With the exception of the areas near river mouths, the coastal beach essentially has gravelly and sandy deposits, the size distributions of which have been described by Naidu *et al.*[10] and Dygas *et al.*[11]. The open marine deltaic facies and the adjacent shelf surface is presently being, and/or been modified, by ice gouging[12], and some of the offshore bars seem to have originated by ice push. Comparative aerial photographic studies[13] reveal large scale morphological changes in the Pingok and Thetis Islands over the past 20 years. The arctic deltaic environment under description differs from the low-latitude deltas in several ways. The more notable differences are the absence of extensive sand dunes, flood plains, tidal flats and mangrove swamps, together with the common presence of coastal beach gravel deposits, a deltaic plain dominated by tundra, and subjection of the entire area to strong ice stress conditions for the major part of the year, as well as to thermal erosion.

METHODS

General Procedures

Results presented in this report are based on analyses of surface sediment samples that were collected either by a Van Veen/Shipek grab sampler or a short gravity corer. Most of the samples from the continental margin region were collected from the N.A.R.L. vessel R/V *NATCHIK*, and a few from a Boston Whaler. Samples from the deep water open marine environment were collected during the WEBSEC-71 cruise of the USCGC *GLACIER*. Some additional samples included in this report (BBS Series) comprise a part of the suite of short core sediments that were retrieved from the USCGC *STATEN ISLAND* in 1968. A few of the textural parameters pertaining to open marine deltaic regime, Simpson Lagoon, coastal beach and Harrison Bay have been extracted from Burrell *et al.*[14], Dygas *et al.*[11], Tucker[15], and Barnes and Reimnitz[16].

Grain size distributions of sediments were analyzed by the combined methods of sieving and pipetting. Grain size statistical parameters were calculated using the formulae given by Folk and Ward[17]. Heavy minerals in three size grades of the sand fraction were separated in bromoform (Sp. Gr. 2.85).

Clay mineral analysis was accomplished by X-ray diffraction techniques. A Phillips Electronics Norelco X-ray diffractometer was employed, using Ni filtered Cu K_α radiation. The instrumental parameters used routinely, unless otherwise specified, were 2°2θ per minute scan speed, time constant 2, with 1°-0.006" slits. For bulk clay mineralogy, analysis was routinely carried out on the <2μm e.s.d. (equivalent spherical diameter) size material of sediments, following the method described by Naidu *et al.*[18] Although gross clay mineralogy is normally characterized fairly well by this analysis, often there are ambiguities left unresolved without more detailed investigations. Therefore, clay mineral analyses were also conducted on subfractions of <2μm e.s.d. particle size range for a number of samples from the Colville River and Harrison Bay. The sample preparation and analytical procedures for these subfractions were slightly different than for the <2μm fraction and, therefore are elaborated upon as follows.

The bulk sample was wet-sieved with deionized water, using a 230 mesh (62μm) stainless steel sieve. The resultant <62μm material was treated with H_2O_2, using the method described by Jackson[19] in order to remove organic matter. The pH was monitored during this treatment[20]. The most acidic value observed was 6.6, suggesting little likelihood of significant clay mineral modification resulting from this treatment.

The resultant sedimentary material was suspended in 1000 ml graduated cylinders, in deionized water, and all the <2μm e.s.d. size material was removed by repeated stirring, resuspending and differential settling of the coarser material (i.e. >2μm e.s.d.). The suspended <2μm material was removed by siphoning.

Material less than 2μm was subjected to further particle-size fractionation, using centrifugal sedimentation, following the methods described by Jackson[19]. The <0.3μm e.s.d. size fraction was removed first, followed successively by the 0.3 - <1.0μm e.s.d size fraction, and then the 1.0 - <2.0μm e.s.d. size fraction.

For the resultant materials from station CR-5 (Fig. 2), each of the particle-size fractions obtained was divided into two portions. One aliquot was reserved for analysis as described below, the second aliquot was first subjected to the treatment described by Jackson[19], for the removal of free-iron-oxide from sediment.

For each particle-size fraction, for each sample location, seven specimens were prepared by placing aqueous suspensions on porous ceramic plates. By means of vacuum applied to the underside of each plate, the suspended clay material was sedimented onto the surface of the plate in such a manner that the basal planes of the layer silicate minerals are predominantly aligned parallel to the surface of the plate.

Additional further treatments were performed on the various plate mounts of each particle-size fraction of each sample, followed by X-ray diffraction analysis.

Specific Treatments and Clay Mineralogic Analysis

1. Saturation with Ethylene Glycol - This permits the detection of the

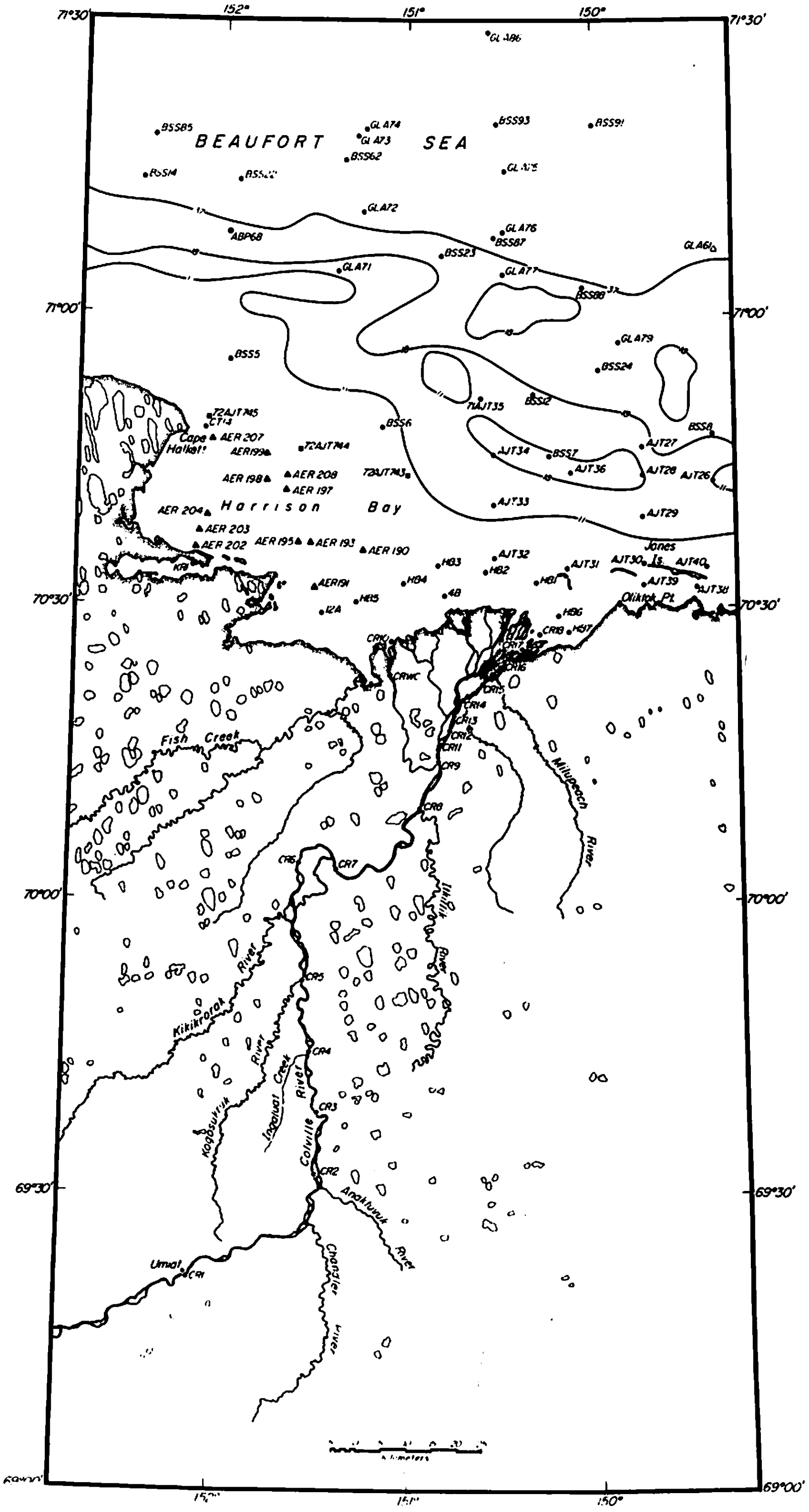

Figure 2. Map of the Colville Delta showing the locations of bottom sediment samples that were taken for clay mineral analysis.

presence of materials (e.g. smectites and some vermiculites, as well as mixed-layered phases containing either of these as component layers) into which molecules of glycol may associate themselves in interlayer structural sites. The resultant interplanar basal repeat distance for smectites is in the neighborhood of 17Å.

2. Saturation with KCl (1N) - This affords the opportunity for exchange of K^+ onto such appropriate interlayer structural sites as may exist in any of the mineral phases present. The present consensus of opinion regarding this phenomenon seems to be that materials variously described (often somewhat nebulously) as "stripped, weathered, degraded" illites or micas, "soil vermiculites," etc. will readily accept K^+ ions into interlayer structural sites formerly occupied by K^+ prior to the "degradation" process. This results in the "collapse" of the degraded structure, and is reflected in the X-ray diffraction analysis as a shift in basal spacings from somewhere >10Å to approximately the 10Å region. The term "illite" might be used to collectively designate materials of this sort, but other studies (e.g. Hower and Mowatt[21]) have indicated that there are other aspects relative to this problem which are difficult to distinguish in working with polyphase assemblages such as the present study. In our present study illite has been adopted as a term of a more descriptive nature, for all "10Å material."

This further leads to the necessity here for a brief discussion of our handling of the matter of "interstratified," or "mixed-layer" materials. In view of the problems regarding the unraveling of diffraction effects from polycomponent assemblages, it seems best to merely generalize in a descriptive manner with respect to mixed-layer materials in our samples. The matter of mixed-layering has been dealt with recently by Hower[22], Reynolds[23] and Reynolds and Hower[24] treating the problem of varying degrees of ordering within these materials, for simplified cases. The natural assemblages are undoubtedly more complex, and thus even less amenable to clear understanding with our present methods. As pointed out by Mills and Zwarich[25], the recognition and interpretations of interstratifications in clay mineral assemblages are often extremely difficult, and in the fine clay fractions attention must also be given to line-broadening effects on diffraction maxima resulting from very small particle sizes.

Smectitic materials are those which possess residual interlayer charges resulting from deviations from electrostatic neutrality within the "basic lattice" of the minerals such that equilibrium exchange of K$^+$ coordinated with water molecules into the interlayer sites is manifested by a basal spacing in the 12.5Å region by X-ray analysis, under our experimental conditions. In "degraded" micas, etc., this residual interlayer charge is somewhat higher (i.e. of a more negative character) such that K$^+$ ions enter the exchange sites without the water molecules, leading to the smaller (i.e. $\sim$10Å) interplanar distances observed. The other treatments described in this section are further examples of this approach.

3. Saturation with NaCl (1N) - This is done in order to ascertain the effects of the interaction between Na$^+$ ions, the various clay mineral phases, and the aqueous phase. The Na$^+$ ion as such is apparently not as stable in the interlayer sites of degraded micas as the larger K$^+$ ion, and its relationship to degraded phases is not clearly defined under our experimental conditions. However, smectitic materials effect an equilibrium with Na$^+$ and coordinated water molecules such that basal spacings in the 12.5Å region are observed by X-ray analysis.

4. Saturation with MgCl$_2$ (1N) - Although both vermiculitic and smectitic phases appear to adopt an equilibrium with Mg^{++} and water such that a basal spacing of about 14Å results, the smectitic materials will subsequently re-equilibrate with ethylene glycol in such a manner that a ba-

sal spacing in the neighborhood of 17Å results, whereas vermiculites do not seem to show the same effect. "Degraded" chlorites, representing the chloritic analogs of vermiculites and "degraded" micas, also readily equilibrate with Mg^{++} ions and the aqueous phase, with a 14Å basal periodicity the result.

5. Saturation with $Ca(C_2H_3O_2)_2$ (1N) - Smectites, Ca^{++}, and water equilibrate in such a manner that a basal spacing of about 15Å results, whereas the behavior of vermiculites and degraded micas is somewhat indeterminate. Although this treatment was not overly useful in itself in delineating clay mineral species, it served as a necessary antecedent in affecting exchange of the same ion onto smectite phases in all samples prior to further heat treatments of these samples. The latter treatments did prove to be quite informative.

6. Saturation with Filtered Sea Water - This treatment was performed in order to investigate the mutual equilibrium relationships among the major cations present in sea water, the aqueous phase, and the clay mineral phases, having analogous data from the other treatments described above for individual cations.

7. Saturation with Ethylene Glycol of each Cation Saturated Sample, after X-Ray Diffraction Analysis - In order to compare the effects of the various cation treatments, each specimen was saturated with ethylene glycol, and re-analyzed by X-ray diffraction. The resultant differences, for a given sample, in peak positions and intensities, were quite informative with respect to characterizing the mineral phases.

8. Heat Treatment - After X-ray analysis, each calcium acetate treated specimen was heated in a muffle furnace for one hour at 300°C, and reanalyzed by X-ray diffraction. This treatment drives off the loosely bound interlayer water molecules from smectitic and vermiculitic materi-

als, but has no appreciable effect on illitic, kaolinitic, or chloritic components. The resultant basal spacing for smectites and vermiculites coincides, in general, with that of illites and micas, in the neighborhood of 10Å. A useful comparison is possible here between the efficacy of KCl treatment and 300°C treatment, for a given sample, in "collapsing" the hydrated "expandable" smectitic-vermiculitic layers present to this 10Å periodicity.

9. Heat Treatments, One Hour at 430°C Followed by One Hour at 550°C - Such step-wise heat treatment helps to differentiate kaolinite from chlorite[26,27]. The same Ca^{++} saturated specimens previously heated at 300°C and 430°C were utilized for the 550°C heat treatment.

10. Slow-Scanning, 20° to 28° 2θ - This was undertaken to resolve the presence or absence of kaolinite and chlorite[28]. For this treatment KCl saturated specimens were considered.

11. HCl Treatment - Aliquots of each particle size from samples KR1 and CR7 were subjected to treatment with 1N HCl at 80°C for 24 hours, and then analyzed by X-ray diffraction, using "slow-scanning" procedure. This method afforded the verification of the presence or absence of chlorite and kaolinite in the clays[28].

Pierce and Siegel[29] have discussed at length the problems encountered with respect to attempts at quantifying clay mineral analyses. For samples under detailed study we determined, following the suggestion of Pierce and Siegel[29], the areas of various diffraction peaks of interest, and tabulated these as our basic data.[*] We have also calculated various ratios of peak areas of interest, and used these in attempting to eluci-

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[*] Basic data obtainable from the authors upon request.

date clay mineral relationships. However, in order to compare our gross clay mineral data (in the <2μm e.s.d. size) with those of other areas of the world we have used the method of attempting to quantify clay mineral analysis given by Biscaye[30].

Total Fe, Mn, Ca, Mg, K, Na, Li, Rb, Cu and Co were analyzed by atomic absorption spectrometry, using a Perkin-Elmer, Model 303 unit. Sample preparation and analytical procedure were similar to those described by Naidu and Hood[31]. Accuracy of the elemental analysis was checked by analyzing U.S.G.S. standard rocks G-2 and AGV-1, and comparing the results with those compiled by Flanagan[32]. The precision in the major elemental analysis was better than ± 4 percent, and for Cu and Co it was about ± 12 percent. Organic carbon was determined in a Beckman disperse-beam infra-red analyzer, following the analytical steps outlined by Loder[33]. Precision and accuracy of the organic carbon analysis are better than ± 5 percent and 11 percent, respectively. Carbonate in sediments was analyzed by the rapid but accurate gasometric method[34].

RESULTS

Textural Analysis

Gravel, sand, silt and clay percentages of the sediments are presented in Table 1. The majority of the sediments are either sands, silty-sands or, have equal proportions of sand, silt and clay. There are only a few samples that have more than 1 percent gravel; the weight percentages of gravel in samples AJT22, AJT29 and KR-1 are 3.84, 24.1 and 12.7, respectively. No marked vertical variations in the lithology were observed in short (1 to 2.5 feet) cores of Simpson Lagoon.

The proportions of gravel-sand, silt and clay in the deltaic sediments of the North Slope under study are plotted in a triangular diagram (Fig. 3). No significant difference exists between the field of plots of

TABLE 1. STATISTICAL GRAIN SIZE PARAMETERS OF DELTAIC AND SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA

Sample No.	Environment[a]	Water depth, m	Gravel %	Sand %	Silt %	Clay %	Median (Md)	Mean (Mz)	Sorting (σ_I)	Skewness (SK_I)	Kurtosis (K_G)
HB-1	HB	3.2		12.1	66.9	21.1	6.60	6.81	2.41	0.10	1.66
HB-2	HB	3.0		68.1	21.0	10.9	2.93	4.26	2.38	0.83	0.89
HB-3	HB	3.0		96.2	1.6	2.2	2.85	2.85	0.33	0.16	1.32
HB-4	HB	3.0		15.3	71.2	13.6	6.88	6.52	2.23	-0.10	0.86
HB-5	HB	3.0		95.9	2.8	1.3	3.00	3.02	0.39	0.15	1.24
HB-6	HB	2.8		6.1	80.1	13.8	5.52	5.88	2.25	0.51	2.12
HB-7	HB	2.3		14.9	78.0	7.1	4.38	5.43	1.83	0.76	1.14
AJT-31	HB	7.6		31.2	50.1	18.8	6.15	5.48	2.90	-0.20	0.72
AJT-32	HB	8.5		55.5	39.1	5.4	3.85	4.10	1.54	0.49	1.87
CT-14	HB		0.2	37.8	26.5	36.6	4.34	5.58	2.76	0.45	0.66
KR-1	LG	0.5	0.5	12.7	77.5	1.8	2.52	2.05	1.90	-0.42	1.78
AJT-1	LG	3.2		84.8	6.8	8.4	3.08	3.33	1.82	0.77	7.45
AJT-2	LG	2.5		8.9	68.3	22.8	5.95	6.67	2.89	0.47	1.54
AJT-3	LG	8.5		22.2	31.4	46.5	6.15	6.95	3.54	0.37	0.93
AJT-4	LG	11.3		70.5	9.8	19.7	3.25	3.77	2.89	0.73	3.31
AJT-6	LG	4.6		94.3	2.3	3.3	2.68	2.70	0.52	0.28	2.11
AJT-8	LG	6.7		55.4	28.2	16.5	3.68	4.82	3.23	0.66	1.39
AJT-10	LG	5.0		81.2	9.4	9.4	2.15	2.87	2.59	0.84	6.78
AJT-12	LG	5.2		31.5	51.8	16.7	4.50	5.87	3.05	0.75	1.28
AJT-13	LG	4.0		28.8	41.8	29.5	6.00	6.62	3.47	0.35	0.96
AJT-14	LG	4.9		17.3	59.5	23.2	4.98	6.23	3.08	0.66	1.28
AJT-15	LG	2.6		65.0	23.3	11.8	3.72	4.87	2.78	0.82	4.50
AJT-37	LG	2.1		58.0	31.5	10.5	2.97	4.21	2.25	0.56	1.01
AJT-38	LG	1.5		43.4	44.7	12.0	4.62	4.79	2.50	0.23	0.95
AJT-39	LG	2.1		23.0	68.8	8.2	4.38	4.76	1.88	0.43	1.54

[a] HB: Harrison Bay; LG: Lagoon and OM: Open Marine

TABLE 1. (continued) STATISTICAL GRAIN SIZE PARAMETERS OF DELTAIC AND SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA

Sample No.	Environment[a]	Water depth, m	Gravel %	Sand %	Silt %	Clay %	Median (Md)	Mean (Mz)	Sorting (σ_I)	Skewness (SK_I)	Kurtosis (K_G)
AJT-33	OM	16.2		34.6	26.9	38.6	6.65	6.50	3.33	0.12	0.82
AJT-34	OM	18.0		59.3	20.2	20.5	3.15	4.79	2.43	0.85	0.62
AJT-35	OM	19.8	0.6	34.0	27.5	37.9	8.25	7.10	3.45	-0.24	0.76
AJT-36	OM	17.1	0.9	92.9	3.0	3.2	3.00	3.02	0.49	0.39	2.88
AJT-25	OM	18.3		50.7	26.2	23.1	3.75	4.10	4.60	0.10	0.81
AJT-27	OM	19.2		49.3	24.7	26.1	4.40	5.37	3.19	0.35	0.68
AJT-28	OM	18.0		49.3	34.6	16.1	4.02	4.74	2.95	0.34	0.98
AJT-29	OM	14.6	24.6	56.1	12.6	6.7	1.52	1.22	3.44	0.01	1.35
AJT-17	OM	4.6		7.1	45.4	47.5	7.72	8.12	3.16	0.20	1.05
AJT-19	OM	8.8		45.5	28.3	26.2	4.22	6.08	3.66	0.72	0.95
AJT-21	OM	16.8		85.7	4.9	9.4	2.58	2.68	1.99	0.46	6.21
AJT-22	OM	20.4	24.1	45.2	11.5	19.2	2.15	3.22	5.65	0.29	1.07
AJT-30	OM	7.6		76.7	19.7	3.6	2.22	2.72	1.80	0.58	1.37
CR-1	CR		81.5	16.8	1.0	0.7		-2.38	2.22	0.75	1.67
CR-2	CR		47.1	50.7	1.9	0.3		-1.32	2.41	0.22	0.65
CR-3	CR		0.3	97.2	2.1	0.4		1.93	0.43	0.22	1.12
CR-4	CR			83.9	10.5	5.6		3.19	2.15	0.59	4.39
CR-5	CR		69.4	25.6	1.0	4.0		-1.78	2.93	0.77	0.63
CR-6	CR			24.0	51.0	25.0		5.86	3.21	0.28	1.26
CR-8	CR		12.0	79.2	4.8	4.0		1.93	2.26	0.17	2.74
CR-9	CR			91.2	2.8	6.0		2.63	1.15	0.72	4.78
CR-10	CR			90.3	1.1	8.6		3.26	1.75	0.59	6.74

[a] HB: Harrison Bay; LG: Lagoon; OM: Open Marine and CR: Colville River

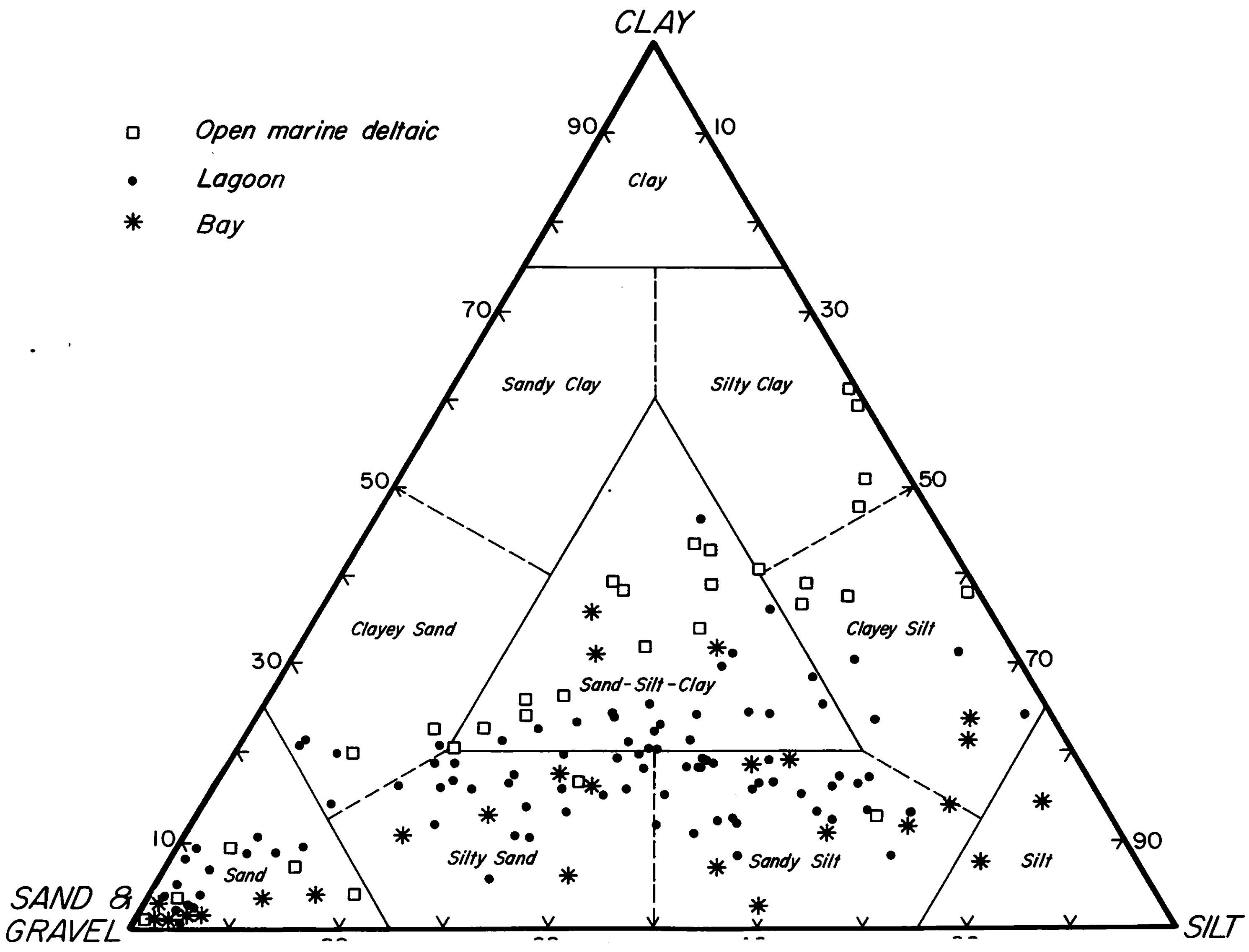

Figure 3. Sand-silt-clay per cents in deltaic sediments of the North Slope of Alaska.

the lagoon and bay sediments, although plots of the open marine deltaic facies can be discriminated. Comparison of the size analysis data in Table 1 and that presented by Burrell *et al.*[14] distinctly show that on the basis of gravel contents offshore deltaic and nondeltaic shelf sediments have different lithologies. The deltaic sediments, as mentioned earlier, rarely have gravels, whereas 72 percent of the shelf sediments of the Beaufort Sea do contain gravels.

Grain-size statistical parameters of the sediments from Harrison Bay, Simpson Lagoon and the adjacent shallow marine environment are similar (Table 1).

The relationships between Phi Mean Size (M_z), and Sorting (σ_I) and Skewness (SK_I) of sediments are illustrated in the form of scatterplots (Figs. 4, 5 and 6). There are definite clusterings of plots for the different environments, although some overlapping of field of the plots is discernible. The trends of the plots including all sediments except those of the Colville River show that there are broad relationships between Phi Mean Size and Sorting (Fig. 4) and Phi Mean Size and Skewness values of sediments for individual environments (Fig. 5). With decreased sorting, the sediment size distributions appear to be less skewed on the finer size grades (Fig. 6).

Heavy Mineral Analysis

There are no unusually high concentrations of heavy minerals in any of the sand sizes (Table 2). In fact, the contents of heavy minerals are quite low. Relatively higher percentages of heavy minerals are generally observed in progressively finer size fractions of any one sand sample.

Clay Mineral Analysis

The weighted peak area percents (after Biscaye[30]) of clay minerals in

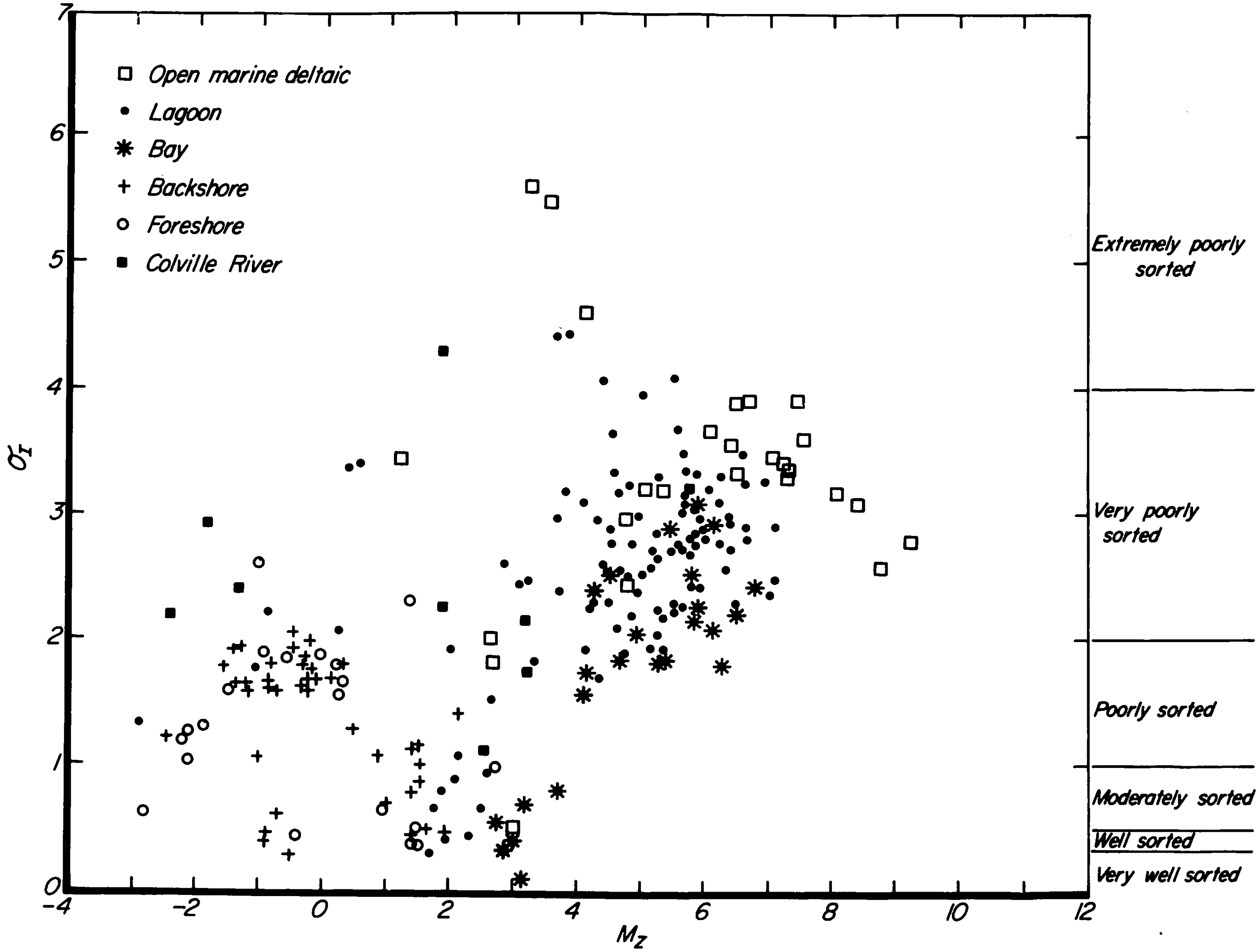

Figure 4. Scatterplot of phi mean size (M_Z) versus standard deviation (σ_I) of sediment size distributions, North Slope of Alaska.

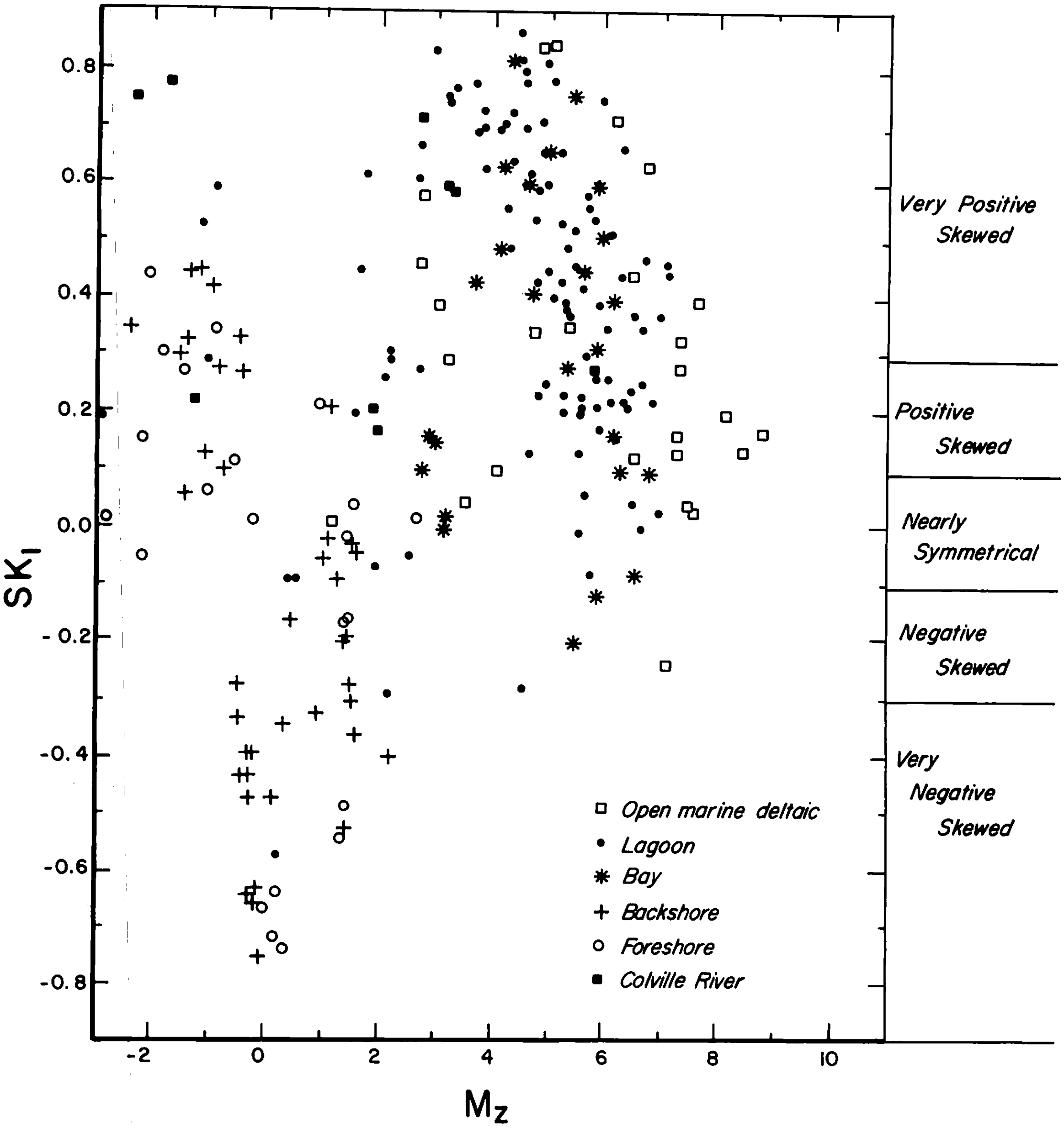

Figure 5. Scatterplot of phi mean size (M_Z) versus skewness (Sk_I) of sediment size distributions, North Slope of Alaska.

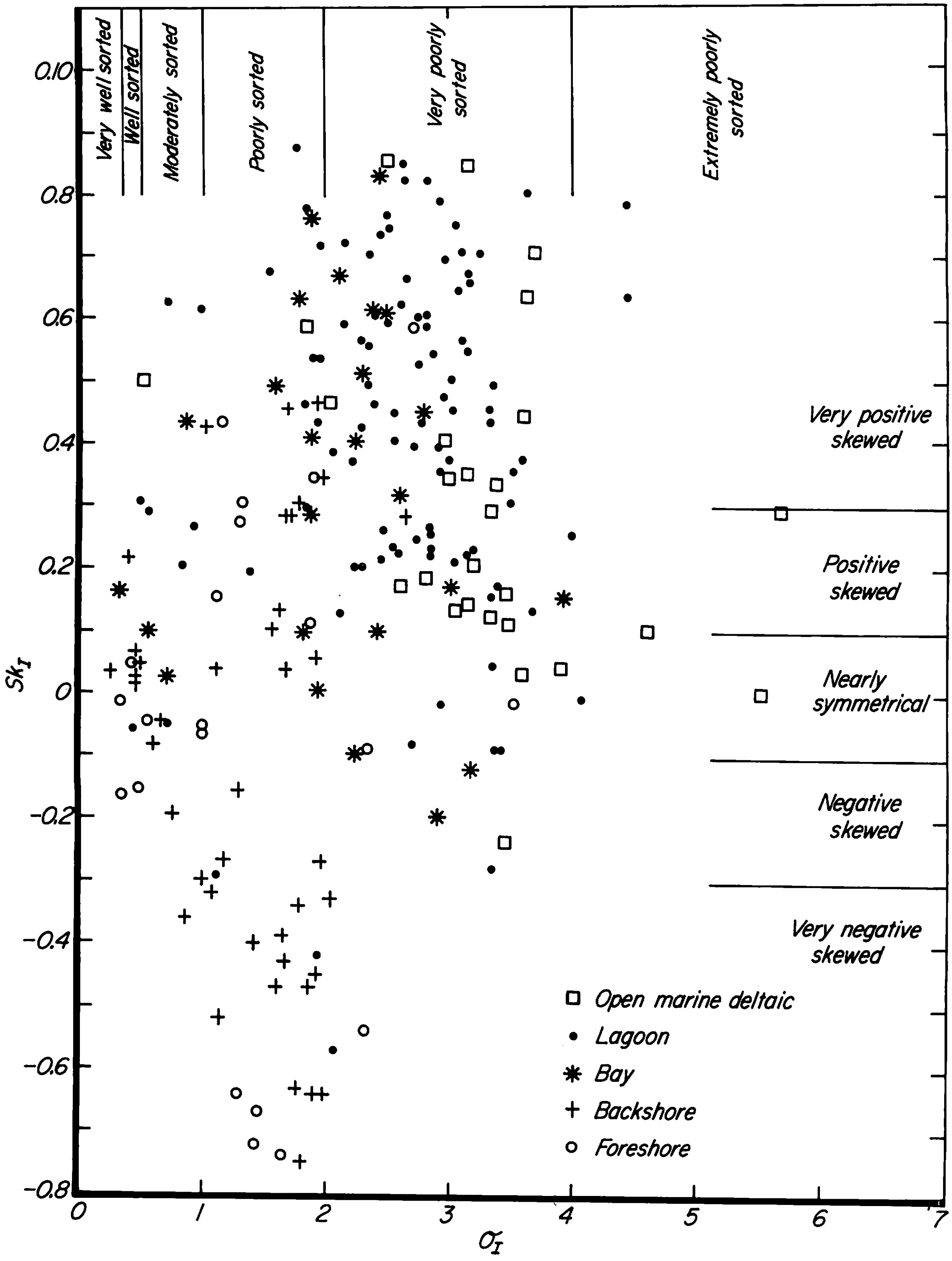

Figure 6. Standard deviation (σ_I) versus skewness (Sk_I) of size distributions, North Slope of Alaska.

TABLE 2. WEIGHT PERCENTAGES OF LIGHT AND HEAVY MINERALS IN THE DELTAIC AND SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA.

SAMPLE NUMBER	+60 mesh (0.75 - 2.0ϕ)		+120 mesh (2.0 - 3.0ϕ)		+230 mesh (3.0 - 4.0ϕ)	
	LIGHT	HEAVY	LIGHT	HEAVY	LIGHT	HEAVY
AJT-2	99.95	0.05	99.20	0.80	98.30	1.70
AJT-6	98.82	1.18	97.30	2.70	90.96	9.04
AJT-10	99.91	0.09	95.21	4.79	86.01	13.99
AJT-12	-	-	-	-	99.05	0.95
AJT-37	99.71	0.29	-	-	-	-
AJT-38	99.92	0.08	99.63	0.37	98.35	1.65
AJT-39	-	-	-	-	99.63	0.37
AJT-17	-	-	-	-	98.00	2.0
AJT-19	98.22	1.78	97.56	2.44	96.65	3.35
AJT-21	99.37	0.63	98.42	1.58	90.18	9.82
AJT-23	99.85	0.15	99.37	0.63	99.17	0.83
AJT-40	-	-	99.69	0.31	98.86	1.14
AJT-43	95.09	4.91	97.47	2.53	94.36	5.64
4-B	-	-	99.92	0.08	99.20	0.80
9-A	99.73	0.27	98.69	1.71	96.70	3.30
HB-1	-	-	97.94	2.06	98.54	1.46
HB-2	99.63	0.37	99.64	0.36	97.14	2.86
HB-3	-	-	98.90	1.10	95.20	4.80
HB-4	-	-	-	-	99.27	0.73
HB-5	-	-	99.91	0.09	73.50	26.50
HB-6	-	-	-	-	99.55	0.45
HB-7	-	-	-	-	99.59	0.41

the <2µm e.s.d. size of the deltaic sediments of north arctic Alaska are presented, together with ratios of these per cents, in Table 3. The percentages are classed according to depositional environments. Some lateral variations in clay mineral assemblages and ratios are apparent. In fact, a line of demarcation between two clay mineral facies can be drawn somewhat arbitrarily from Oliktok Point and extending northward perpendicular to the coast (Fig. 1). To the west of this line sediments are relatively richer in smectite and kaolinite, whereas east of the line relatively higher amounts of illite are encountered. This fact is well exemplified by the presence of higher illite/smectite and illite/kaolinite ratios east of Oliktok Point (Table 3). No progressive downstream changes have been observed in clay mineral assemblages in the <2µm e.s.d. size over the last 161-km length of the Colville River (Fig. 7). The clay mineral assemblages of samples CR4 and CR5 are unusually rich in smectite. It may be noted that at the points where these two samples were collected (Figs. 1 and 2) two tributaries - Ingaluat Creek and Kogosukruk River respectively - flow into the Colville River. Sample 8, which was collected at the point of confluence of the Itkillik River tributary with the Colville River (Figs. 1 and 2), has a great paucity of smectite and notably higher chlorite and kaolinite (Table 3). Typical X-ray diffraction traces of non-glycolated, <2µm e.s.d. sizes of Colville River clays, and to a lesser degree the nearshore deltaic clays as well, show a broad shoulder on the low angle side of the illite peak[32]. The presence of this shoulder suggests that the illite in these samples is associated with some other clay mineral components as mixed-layer phases. Our detailed clay mineral studies indicate the presence of mixed-layered illitic materials with associated interlayers of chlorite and/or smectite components, as well as the possible occurrence of degraded illite and/or chlorite in these sediments.

TABLE 3. CLAY MINERAL COMPOSITIONS[a] OF DELTAIC AND SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA

Sample Number	Smectite	Illite	Kaolinite	Chlorite	Kaolinite/Chlorite Ratios	Smectite/Chlorite Ratios	Illite/Smectite Ratios	Smectite/Kaolinite Ratios	Illite/Kaolinite Ratios	Illite/Chlorite Ratios	Environment[b]
CR-1	9	61	9	21	0.4	0.4	7	1.0	7	3	F(171)
CR-2	9	59	11	21	0.5	0.4	7	0.8	5	3	F(136)
CR-3	17	51	11	21	0.5	0.8	3	1.5	5	2	F(120)
CR-4	55	32	3	10	0.3	5.5	1	18.0	11	3	F(107)
CR-5	44	38	5	13	0.4	3.4	1	8.8	8	3	F(91)
CR-6	14	54	11	21	0.5	0.7	4	1.3	5	3	F(74)
CR-7	15	53	10	22	0.6	0.7	4	1.5	5	2	F(58)
CR-8	2	51	15	32	0.5	0.1	25	0.1	3	2	F(45)
CR-9	13	47	14	26	0.5	0.5	4	0.9	3	2	F(35)
CR-11	43	38	8	11	0.7	3.9	1	5.4	5	3	F(33)
CR-12	53	29	7	11	0.6	4.8	1	7.6	4	3	F(28)
CR-13	40	36	7	17	0.4	2.4	1	5.7	5	2	F(24)
CR-14	31	43	6	20	0.3	1.6	1	5.2	7	2	F(20)
CR-15	22	51	8	19	0.4	1.2	2	2.8	6	3	F(15)
CR-16	31	49	7	14	0.5	2.2	2	4.4	7	4	F(9)
CRWC	14	56	10	20	0.5	0.7	4	1.4	6	3	F(8)
CR-17	41	36	7	16	0.4	2.6	1	5.9	5	2	F(5)
CR-18	30	49	6	15	0.4	2.0	2	5.0	8	3	F(0)
CR-10	12	48	8	32	0.3	0.4	4	4.0	6	6	F(0)
12-A	17	60	11	12	0.9	1.4	4	1.6	6	6	HB
4-B	25	52	5	18	0.3	1.4	2	5.0	10	10	HB
HB-1	22	52	7	19	0.4	1.2	2	3.1	7	7	HB
HB-2	30	40	12	18	0.7	1.7	1	2.5	3	3	HB
HB-3	19	54	7	19	0.4	1.2	3	2.7	8	3	HB
HB-4	24	50	7	19	0.4	1.3	2	3.4	7	7	HB
HB-5	14	61	7	17	0.4	0.9	4	1.9	8	4	HB

[a] Weighted peak area percents (see reference 30)

[b] F: Fluvial Channel (figures in parenthesis indicate distance in km from Colville River mouth)
HB: Harrison Bay
LG: Lagoon
OM: Open Marine
Tr: Trace
Ab: Absent

TABLE 3. (continued) CLAY MINERAL COMPOSITIONS[a] OF DELTAIC AND SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA

Sample Number	Smectite	Illite	Kaolinite	Chlorite	Kaolinite/Chlorite Ratios	Smectite/Chlorite Ratios	Illite/Smectite Ratios	Smectite/Kaolinite Ratios	Illite/Kaolinite Ratios	Illite/Chlorite Ratios	Environment[b]
HB-6	29	46	6	19	0.3	1.5	2	4.8	8	2	HB
HB-7	21	52	5	22	0.2	1.0	2	4.2	10	2	HB
AJT-32	15	58	11	16	0.7	0.9	4	1.4	5	4	HB
AJT-31	14	55	11	20	0.6	0.7	4	1.3	5	3	HB
KR-1	Tr	78	8	14	0.6	---	>78	<0.1	10	6	LG
AJT-30	16	58	9	17	0.5	0.9	4	1.8	6	3	HB
AJT-33	8	61	15	16	0.9	0.5	8	0.5	4	4	HB
AJT-1	Tr	69	13	18	0.7	---	>69	<0.1	5	4	LG
AJT-2	1	71	7	21	0.3	0.1	71	0.1	10	3	LG
AJT-3	2	49	12	37	0.3	0.1	24	0.2	4	1	LG
AJT-4	2	69	11	18	0.6	0.1	35	0.2	6	4	LG
AJT-6	1	68	13	18	0.7	0.1	68	<0.1	5	4	LG
AJT-8	Tr	76	6	18	0.3	---	>76	<0.1	13	4	LG
AJT-10	1	77	7	15	0.5	0.1	77	0.1	11	5	LG
AJT-12	Ab	79	6	15	0.4	---	>79	---	13	5	LG
AJT-13	Ab	80	9	11	0.8	---	>80	---	9	7	LG
AJT-14	1	75	7	17	0.4	0.1	75	<0.1	11	4	LG
AJT-15	Ab	85	4	11	0.4	---	>85	---	21	8	LG
AJT-37	5	70	7	18	0.4	0.3	14	0.7	10	4	LG
AJT-38	13	65	8	14	0.6	1.0	5	1.6	8	5	LG
AJT-39	15	59	12	14	0.8	1.1	4	1.3	5	4	LG
AJT-29	11	68	7	15	0.4	0.7	6	1.6	10	5	OM
AJT-36	14	59	11	16	0.7	0.9	4	1.3	5	4	OM
AJT-28	12	68	7	14	0.5	0.9	6	1.8	10	5	OM
BSS-7	2	67	9	22	0.4	0.1	33	0.2	7	3	OM
AJT-27	5	68	11	16	0.7	0.3	13	0.5	6	4	OM

[a] Weighted peak area percents (see reference 30)

[b] F: Fluvial Channel (figures in parenthesis indicate distance in km from Colville River mouth)
HB: Harrison Bay
LG: Lagoon
OM: Open Marine
Tr: Trace
Ab: Absent

TABLE 3. (continued) CLAY MINERAL COMPOSITIONS[a] OF DELTAIC AND SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA

Sample Number	Smectite	Illite	Kaolinite	Chlorite	Kaolinite/Chlorite Ratios	Smectite/Chlorite Ratios	Illite/Smectite Ratios	Smectite/Kaolinite Ratios	Illite/Kaolinite Ratios	Illite/Chlorite Ratios	Environment[b]
AJT-34	8	60	14	18	0.8	0.4	8	0.6	4	3	OM
AJT-35	2	60	11	27	0.4	0.1	30	0.2	6	2	OM
CT-14	10	67	7	17	0.4	0.6	7	1.4	10	4	OM
BSS-5	6	67	12	15	0.8	0.4	11	0.5	6	5	OM
BSS-6	2	63	7	28	0.3	0.1	32	0.3	9	2	OM
BSS-24	11	64	8	17	0.5	0.7	6	1.5	9	2	OM
GLA-79	14	57	11	18	0.6	0.8	4	1.2	5	3	OM
GLA-71	9	66	9	16	0.6	0.6	7	1.0	7	4	OM
BSS-23	21	55	8	17	0.5	1.0	3	2.7	7	3	OM
BSS-14	16	59	8	17	0.5	1.0	4	2.0	7	4	OM
BSS-88	11	61	11	17	0.7	0.7	6	1.0	6	4	OM
GLA-72	14	56	10	20	0.5	0.7	4	1.5	6	3	OM
BSS-87	7	61	14	18	0.8	0.4	9	0.5	4	3	OM
BSS-62	18	57	9	16	0.6	1.1	3	1.9	6	4	OM
BSS-85	6	63	12	19	0.6	0.3	11	0.5	5	3	OM
BSS-22	15	61	6	19	0.3	0.8	4	2.7	11	3	OM
GLA-74	16	58	10	17	0.6	1.0	4	1.6	6	4	OM
BSS-93	24	54	9	14	0.6	1.8	2	2.8	6	4	OM
BSS-91	5	60	10	25	0.4	0.2	12	0.5	6	2	OM
AJT-17	3	55	12	30	0.4	0.1	18	0.3	5	2	OM
AJT-19	2	71	11	16	0.7	0.1	36	0.2	7	4	OM
AJT-21	5	65	10	20	0.5	0.3	13	0.5	7	3	OM
AJT-22	4	68	6	22	0.3	0.2	17	0.5	11	3	OM
AJT-25	10	67	7	15	0.5	0.7	7	1.5	10	4	OM
AJT-26	5	63	10	21	0.5	0.3	12	0.5	6	3	OM
AJT-40	13	64	6	17	0.3	0.8	5	2.4	5	4	OM
AJT-43	9	67	10	14	0.7	0.6	8	0.9	7	5	OM

[a] Weighted peak area percents (see reference 30)

[b] F: Fluvial Channel (figures in parenthesis indicate distance in km from Colville River mouth)
HB: Harrison Bay
LG: Lagoon
OM: Open Marine
Tr: Trace
Ab: Absent

TABLE 3. (continued) CLAY MINERAL COMPOSITIONS[a] OF DELTAIC AND SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA

Sample Number	Smectite	Illite	Kaolinite	Chlorite	$\frac{\text{Kaolinite}}{\text{Chlorite}}$ Ratios	$\frac{\text{Smectite}}{\text{Chlorite}}$ Ratios	$\frac{\text{Illite}}{\text{Smectite}}$ Ratios	$\frac{\text{Smectite}}{\text{Kaolinite}}$ Ratios	$\frac{\text{Illite}}{\text{Kaolinite}}$ Ratios	$\frac{\text{Illite}}{\text{Chlorite}}$ Ratios	Environment[b]
GLA-86	10	64	6	20	0.3	0.5	7	1.6	11	3	OM
GLA-73	11	67	8	13	0.6	0.8	6	1.3	8	5	OM
GLA-75	20	60	7	13	0.5	1.5	3	2.9	9	5	OM
GLA-77	14	60	10	17	0.6	0.8	4	1.3	6	4	OM
APB-68	5	69	9	17	0.6	0.2	14	0.5	7	4	OM
SAG.R	2	69	6	24	0.3	0.1	40	0.2	12	3	F

[a] Weighted peak area percents (see reference 30)

[b] F: Fluvial Channel (figures in parenthesis indicate distance in km from Colville River mouth)
HB: Harrison Bay
LG: Lagoon
OM: Open Marine
Tr: Trace
Ab: Absent

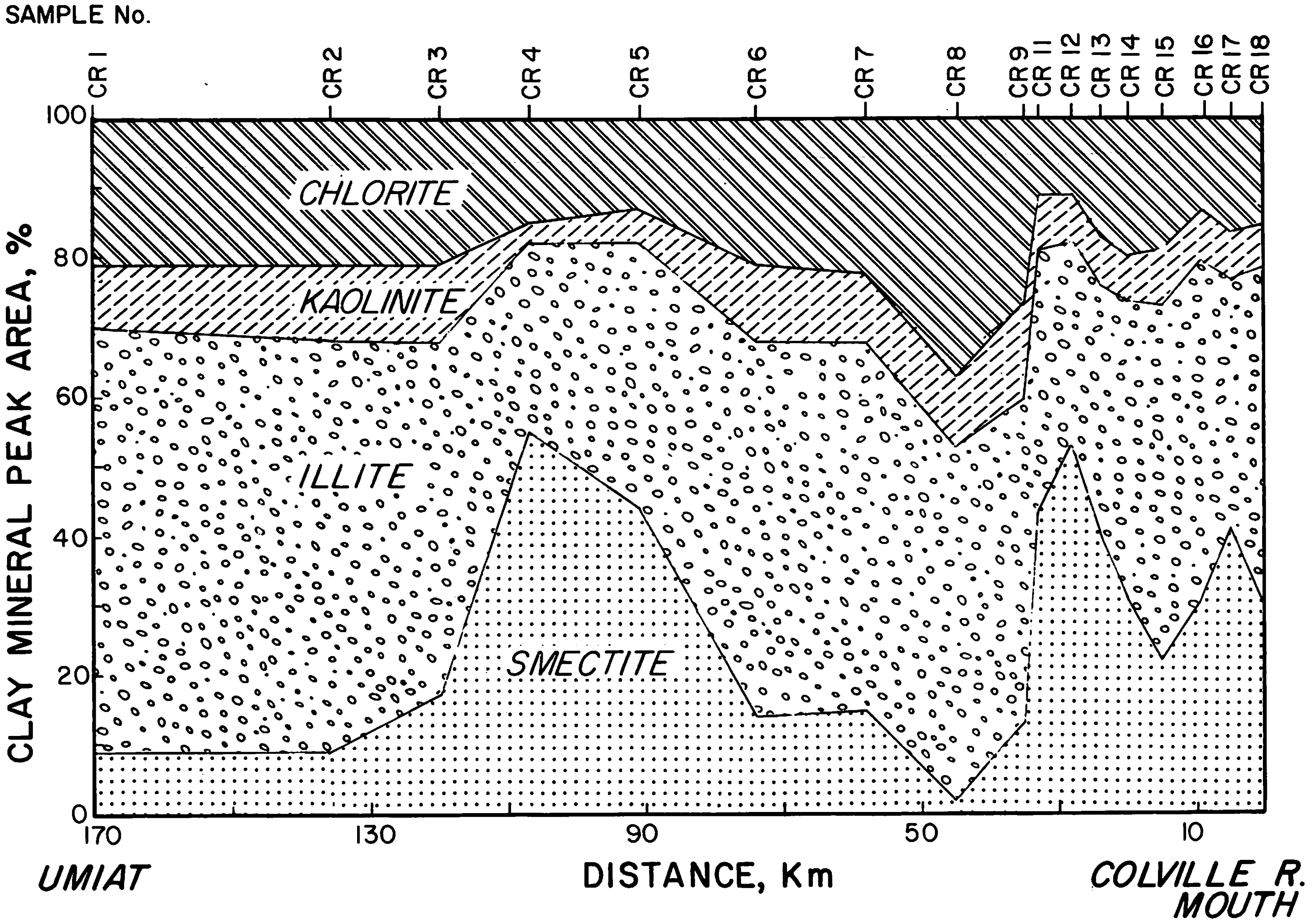

Figure 7. Variations of clay mineral assemblages in the Colville River.

Chemical Analysis

Results of chemical analysis of the deltaic sediments of north arctic Alaska are presented in Table 4. For the purpose of comparison, the average elemental abundances of the deltaic sediments and those of the non-deltaic shelf and extrashelf of the Beaufort Sea[35] are included in Table 5.

Organic carbon contents in the deltaic sediments of north arctic Alaska are significantly lower than those observed in tropical deltaic sediments[36,37]. It is observed that there is a progressive seaward increase in organic carbon and a decrease in carbonate contents of sediments from the delta to the extrashelf through the shelf (Table 5). In fact there is a great enrichment of carbonate and Ca in the deltaic sediments under study.

When compared to sediments of the marine facies of tropical deltas,[38, 39, 40, 41] the concentrations of Fe, Mn, and K are significantly lower and those of Ca, Mg, Na, Co and Cu are higher in the deltaic sediments of north arctic Alaska (Table 5). However, in the far offshore non-deltaic shelf and extrashelf sediments the relative concentrations of all elements except Ca and Co are significantly higher than those observed in the north arctic Alaskan deltas (Table 5).

Within the delta, the order of average carbonate abundance in the various environments is as follows: lagoon (12.06%) > open marine (7.48%) > Harrison Bay (4.12%). On an average the contents of organic carbon are similar in the Bay (0.77%) and lagoon (0.79%) sediments, but sediments of the open marine deltaic facies have relatively lower organic carbon (0.58%).

Table 4. CHEMISTRY OF DELTAIC AND SHALLOW MARINE SEDIMENTS, NORTH ARCTIC ALASKA.
(chemical parameters are in weight per cents.)

Sample	Water depth, m	Gravel %	Sand %	Silt %	Clay %	Org. carbon	$CO_3^=$	Fe	Mn	Ca	Mg	K	Na	Li	Rb	Cu	Co	SMT[a]	ILT[a]	KLT[a]	CLT[a]
AJT 1	3.2		84.78	6.81	8.40	0.22	17.2	1.30	0.022	10.560	0.488	0.604	1.292	0.0018	0.0010	0.0034	0.0025	0.3	69	13	18
AJT 2	2.5		8.92	68.25	22.81	0.98	16.6	1.94	0.026	8.960	1.100	1.225	1.520	0.0033	0.0045	0.0010	0.0025	1	71	7	21
AJT 3	8.5		22.19	31.36	46.47	0.89	13.9	0.91	0.019	7.040	1.604	0.802	1.344	0.0015	0.0017	0.0005	0.0017	2	49	12	37
AJT 4	11.3		70.48	9.83	19.68	0.19	14.2	1.30	0.020	7.640	1.820	0.762	1.356	0.0015	0.0015	0.0020	0.0022	2	69	11	18
AJT 6	4.6		94.34	2.31	3.34	0.30	5.8	1.30	0.028	9.400	0.880	0.564	1.320	0.0013	0.0015	0.0040	0.0022	1	68	13	18
AJT 8	6.7		55.39	28.16	16.45	0.49	12.5	1.72	0.022	6.960	1.524	1.090	1.468	0.0023	0.0025	0.0010	0.0020	0.3	76	6	18
AJT 10	5.0		81.22	9.41	9.37	0.33	3.0	1.51	0.029	2.288	0.644	0.955	1.372	0.0015	0.0038	0.0020	0.0021	1	77	7	15
AJT 12	5.2		31.53	51.75	16.72	0.84	16.9	2.14	0.027	8.720	1.660	1.347	1.460	0.0033	0.0039	0.0145	0.0025	0	79	6	15
AJT 13	4.0		28.75	41.77	29.48	0.78	11.7	2.15	0.032	8.200	1.604	1.329	1.800	0.0032	0.0045	0.0073	0.0042	0	80	9	11
AJT 14	4.9		17.27	59.50	23.23	0.59	15.2	2.36	0.032	9.480	2.044	1.612	1.784	0.0036	0.0058	0.0055	0.0057	1	75	7	17
AJT 15	2.6		64.96	23.29	11.75	2.23	15.3	2.22	0.029	8.200	1.150	0.958	1.494	0.0028	0.0027	0.0067	0.0032	0	85	4	11
AJT 17	4.6		7.08	45.42	47.50	1.36	14.2	3.14	0.046	9.080	1.708	2.013	2.092	0.0048	0.0078	0.0075	0.0055	3	55	12	30
AJT 19	8.8		45.47	28.31	26.22	0.70	14.2	1.85	0.031	6.640		1.122	1.068	0.0028	0.0027	0.0010	0.0030	2	71	11	16
AJT 21	16.8		85.70	4.89	9.41	0.36	4.6	1.41	0.026	2.440	1.044	0.825	1.244	0.0019	0.0016	0.0020	0.0020	5	65	10	20
AJT 22	20.4	24.10	45.23	11.51	19.16	0.38	11.2	2.09	0.033	6.440	2.680	1.230	1.620	0.0023	0.0039	0.0047	0.0022	4	68	6	22
AJT 25	18.3		50.74	26.17	23.09	0.83	4.1	3.20	0.045	5.560	1.876	1.429	1.476	0.0038	0.0053	0.0040		10	67	7	15
AJT 26	17.7	0.15	98.53	0.86	0.46	0.09	4.5	0.99	0.015	1.912	1.000	0.519	1.296	0.0008	0.0027	0.0008		5	63	10	21
AJT 29	14.6	24.64	56.05	12.57	6.74	0.36	2.3	1.45	0.019	1.516	0.680	0.618	0.960	0.0018	0.0024	0.0015		11	68	7	15
AJT 30	7.6		76.68	19.74	3.58	0.42	7.5	1.54	0.022	5.600	0.784	0.658	1.008	0.0018	0.0022	0.0030		16	58	9	17
AJT 31	7.6		31.20	50.05	18.77	1.32	4.0	2.95	0.051	2.668	1.060	1.270	2.092	0.0035	0.0050	0.0032		14	55	11	20
AJT 32	8.5		55.52	39.06	5.41	0.19	5.7	1.42	0.017	5.520	0.884	0.555	0.968	0.0018	0.0016	0.0014		15	58	11	16
AJT 33	16.2		34.56	26.88	38.57	0.67	6.8	2.80	0.030	5.080	1.572	1.338	1.372	0.0038	0.0056	0.0025		8	61	15	16
AJT 35	19.8	0.60	33.99	27.50	37.92	0.61	4.2	3.10	0.042				0.976	0.0037	0.0042	0.0032		2	60	5	27
AJT 36	17.1	0.91	92.85	3.04	3.20	0.19	5.7	1.52	0.024				0.672	0.0016	0.0020	0.0013		14	59	11	16
AJT 37	2.1		57.98	31.53	10.49	1.22	8.1	2.10	0.029	5.840	0.980	0.924	1.292	0.0029	0.0039	0.0022		5	70	7	18
AJT 38	1.5		43.35	44.70	11.95	1.51	10.0	1.80	0.021	6.320	1.004	0.870	1.444	0.0026	0.0038	0.0025		13	65	8	14
AJT 39	2.1		22.96	68.81	8.24	0.53	8.5	2.80	0.032	2.100	1.120	1.068	1.120	0.0030	0.0043	010024		15	59	12	14
AJT 40	10.4		22.78	64.79	12.44	2.25	12.1	2.60	0.036	6.960	1.400	1.608	1.580	0.0033	0.0042	0.0025		13	64	6	17
AJT 43	14.0		17.83	45.66	36.52	0.60	11.8	3.00	0.042	5.920	2.604	1.144	1.792	0.0041	0.0058	0.0030		9	67	10	14
HB 1	3.2		12.05	66.86	21.09	1.13	2.4	3.21	0.058	1.280	2.010	1.194	1.620	0.0038	0.0042	0.0032		22	52	7	19
HB 2	3.0		68.11	20.95	10.94	0.67	7.8	2.50	0.051	0.496	1.388	0.865	2.520	0.0028	0.0025	0.0025		30	40	12	18
HB 3	3.0		96.21	1.56	2.23	0.17	0.9	2.65	0.029	0.820	0.568	0.604	1.600	0.0018	0.0015	0.0007		19	54	7	19
HB 4	3.0		15.25	71.18	13.57	1.40	2.4	3.65	0.051	1.280	1.004	1.491	1.924	0.0043	0.0061	0.0033		24	50	7	19
HB 5	3.0		95.91	2.78	1.31	0.15	1.2	3.10	0.051	2.380	1.004	1.180	2.176	0.0036	0.0045	0.0025		14	61	7	17
HB 6	2.8		6.08	80.13	13.79	1.15	3.1	2.50	0.050	5.880	1.160	0.888	1.444	0.0029	0.0029	0.0027		29	46	6	19
HB 7	2.3		14.85	78.01	7.13	0.80	9.6	2.20	0.032	0.808	0.508	0.537	1.420	0.0018	0.0016	0.0013		21	52	5	22

[a] SMT: Smectite; ILT: Illite; KLT: Kaolinite; CLT: Chlorite

Table 5. AVERAGE ABUNDANCES OF ELEMENTS AND RATIOS IN DELTAIC AND MARINE SEDIMENTS, NORTH ARCTIC ALASKA.
(all elemental abundances are expressed as weight per cent.)

Chemical component	Delta	Nondeltaic shelf (<64m)[a]	Extrashelf (>64m)[a]
Corg	0.72	0.95	1.19
$CO_3^{=}$	8.51	4.80	2.75
Fe	2.11	3.57	3.52
Mn	0.03	0.03	0.09
Ca	5.29	0.42	0.22
Mg	1.28	2.22	1.73
Na	1.47	1.59	1.97
K	1.04	2.30	2.03
Rb	0.0035	0.0097	0.0084
Li	0.0027	0.0047	0.0043
Co	0.0029	0.0029	0.0028
Cu	0.0031	0.0057	0.0059
Mn/Fe	0.02	0.01	0.02
Na/K	1.41	0.69	0.97
Ca/Mg	4.13	0.19	0.13

[a] See reference 31.

DISCUSSION

Sediment Transport and Deposition

Spatial variations in gross texture and grain size parameters of sediments are powerful tools to a sedimentologist in the inference of the sediment source, direction of transport, and deposition, as well as in deducing the physical competency and fluctuation of sedimentation over a depositional area. Research on the deltaic sediments of north arctic Alaska is incomplete and, therefore, some of the following conclusions should be considered tentative.

An interesting observation in the north arctic delta under study is that the sediments of the lagoon, bay and adjacent shallow marine facies (Table 1) lack gravel-sized materials, or, at most contain only insignificant amounts. A similar observation was made by Tucker[15]. He analyzed some 100 sediments from the Simpson Lagoon and found a significant amount of gravel only in about 6 samples, and most of these samples were located near the gravelly coastal or barrier beaches. This paucity of gravel in the deltaic sediments is contrary to expectation, because in the barriers and coastal beaches there is a ready source of gravel. It was expected that the shore fast ice of these areas during spring breakup would pick up gravels, ice raft them offshore, and deposit most of these gravels in the lagoon and shallow marine facies of the delta subsequent to melting of the ice. The aforementioned dearth of gravel in the lagoon, bay and adjacent shallow marine area may be attributed to one or a combination of the following factors: (i) Contemporary transport of gravel from the coastal and barrier beaches to the lagoon, bay and open marine environments of the delta, by ice-rafting and/or currents may be insignificant; (ii) The rate and amount of sand, silt and clay deposition in the deltaic area may be relatively much higher than that of gravel and, therefore, the amount of gravel would be quantitatively greatly "diluted"; (iii) There is a possibility of error arising from the sample collection and analytical methods used; generally about 0.5kg of a sediment sample was collected from each location, and from this about 100gm were taken for size analysis. To consistently detect and measure small amounts of gravel, it might well be deemed necessary to take and utilize larger amounts of sample materials.

Comparison of the size analysis data in Table 1 and that presented by Burrell *et al.*[14] and Naidu[35] clearly shows that, on the basis of gravel contents offshore or the deltaic and the contiguous nondeltaic shelf sediments of north Arctic Alaska have different lithologies. Unlike the deltaic deposits, the shelf sediments frequently (72% of the samples) do have gravels. These lithological differences naturally lead to the question of origin of the gravel on the nondeltaic shelf, which has been discussed at length by Naidu[35]. It is concluded that the bulk of the exposed shelf gravel is a relict sediment. The relict origin for most of the gravel on the shelf is primarily ascribed on the basis of the following premises: (i) Observations to date show that contemporary transport of gravel by ice-rafting to the Beaufort Sea shelf is insignificant[3,16,32]; (ii) There is no coarse to fine sediment gradation from the coast to the outer shelf. This fact may be considered, as suggested by Emery[42], and Swift *et al.*[43], as well as by several others, a reliable criterion in establishing the relict nature of marine sediments; (iii) The shelf gravel appears to be in disequilibrium with present hydrodynamic conditions. Although no long-term data on water currents are available, good reasons exist to believe that at present there are no bottom currents of sufficient strength to transport gravel on the shelf. This is inferred indirectly from the presence of ferrimanganic coatings and of growths of encrusting Bryozoa and tube-forming polychaetous annelids only on the gravel surfaces facing the sediment top. Naidu[35] has interpreted, based on sediment interstitial water studies, that the ferrimanganic coatings are contemporary precipitates. If at present there were strong currents on the shelf to transport these gravels intermittently, it would be expected that the ferri-manganic and biogenic encrustations would not be restricted solely to the present gravel tops. The lack of strong currents at the present time is also substantiated by heavy mineral studies, results of which will be discussed in detail later in this report.

The processes by which the shelf gravels were transported and deposited in the past remains a matter of speculation. Several possible origins - fluvioglacial, glacial, ice-rafting or residual - may be suggested. There is also the possibility that these gravels were laid down under high energy conditions, similar to those prevalent in many littoral environments. On the basis of available data[44,45] it is most improbable that, during the height of the last two major glaciations (i.e. Illinoian and Wisconsin), the continental glacial advances extended into and beyond the northern coastal province of Alaska. As such, a glacial and/or fluvioglacial origin for the shelf gravel seems unlikely. No rock outcrop on the present shelf has ever been reported and, therefore, any possibility that the gravel is a contemporary marine residual deposit is ruled out. Earlier it was observed that there is an absence of any apparent size-density relationship in the heavy mineral distributions in the sand-size particles of the Beaufort Sea shelf. It is concluded from this that these sands were patently not deposited - either now or in the past - under high energy conditions, and most likely similar depositional conditions prevailed when the gravel associated with these sands was laid down.

By a process of elimination it is surmised that the bulk of the gravel on the shelf of the Beaufort Sea is an ice-rafted relict deposit. Substantiating this conclusion McCulloch[46] has stated that some gravels on the edge of the northern coastal plain of Alaska were transported by ice-rafting during the mid-Wisconsin (Woronzofian) transgression, about 25,300 ± 2,300 yrs ago. It is suggested that these ice-rafted gravels together with those on the shelf - and inferred as relict - apparently did not originate either in the Brooks Range or in other bedrock of northern Alaska. This conclusion is based on inferred sea-level position[46] and the extent of the last two glaciations in the region[44,45], as well as from the exotic lithology of the Woronzofian gravels of north arctic coastal Alaska[47,48]. Most probably these gravels were deposited by icebergs similar to the present-day "ice islands" that have originated from ice shelves of Ellesmere Islands in Canada[45]. Our preliminary mineralogic and petrographic studies of 54 specimens of gravel fragments of the Beaufort Sea shelf[49], together with several hundred samples of bedrock materials from the Brooks Range, seem to further substantiate this concept, although we do plan to pursue further work along these lines.

It is concluded that most of the relict gravel has remained exposed on the middle and outer shelf regions, and has not been blanketed by modern deposits, presumably because of relatively low rates of subsequent sedimentation of sand and mud.

The present study has shown that no single environment has characteristic sediment sorting, skewness or kurtosis values (Table 1). As such, grain-size parameters should be considered with great caution in attempted interpretation of depositional environments of high latitude paleodeltaic sediments. Mean size of sediments seems to be the only size parameter that is different for the various environments (Table 1), and presumably this is determined by the varying contents of gravel and sand. Scatterplot diagrams between various grain size parameters (Figs. 4, 5 and 6), however, do appear to have a potential use in paleogeographic studies. The trends of plots in Figures 4 and 5 suggest that, except in the fluvial channel of the Colville River, the sorting and skewness values of sediments in each environment is a function of the Phi Mean Size. Although in three of the scatterplot diagrams some overlapping of field of the plots is discerned, the plots of the coastal deposits (especially of the backshore), can be effectively discriminated. The slight overlapping may be explained on the basis that some sediments, perhaps somewhat arbitrarily classed under a certain environment, in actuality do not belong to that environment. The other possibility could be that such plots represent sediments that were deposited at the transitional zone between discrete environments.

Heavy Mineral Studies

The low concentrations of heavy minerals in the deltaic sediments under investigation (Table 2) may be related to: (i) low concentrations of heavy minerals in Colville River sands[13], which presumably are an important primary source of the deltaic sands, and/or (ii) lack of prolonged hydraulic conditions sufficient to concentrate heavy minerals in the sand fraction. Except during infrequent storms the continental margin and shallow marine environments of north arctic Alaska are essentially low energy depositional areas, and as such it is believed that sands of these regions are not exposed to extended mineral sorting by hydraulic action.

The relatively higher percentages of heavy minerals that are observed in successively finer sand size grades in almost any one of the sediments (Table 2) show that heavy mineral distributions in the present deltaic environment conform to the hydraulic equivalent concept[50] and to the size-density relationships that usually exist in water-laid sands[51].

Observations made on the heavy mineral distributions in the offshore deltaic sediments (Table 2) are contrary to those made on the adjoining fluvial sediments[13] and on far offshore nondeltaic shelf sediments of the Beaufort Sea[52], inasmuch as the size-density relationship does not exist in sediments from the latter two environments. Considering these differences, it would seem that in the deltaic marine area mineral sorting is brought about more effectively, presumably because of the prevalence there of stronger and prolonged hydraulic action. However, differences in hydraulic action can not be invoked to explain the observed differences between concentrations of heavy minerals in any one size of sand in the shelf and the delta. The fact that there are relatively higher contents of heavy minerals in sands of the shelf, in spite of the presumed lower energy conditions prevailing there, suggests that the bulk of the shelf sands have originated from somewhere else than the delta. We hope to clarify this suggestion by detailed heavy mineral studies of sands from the delta and the shelf.

The preceding conclusions seem to support the earlier contention that transportation of sand from the delta to the shelf by contemporary ice-rafting is insignificant. If ice transport, and associated *in toto* deposition of deltaic sands from the ice were important on the shelf, then it would be expected that both in the delta and on the shelf the total concentrations of heavy minerals and their distributional patterns in various sand sizes would be similar. This, as mentioned earlier, is not true however.

Causes and Significance of Clay Mineral Variations

Results of our study do not show any clear cut progressive downstream changes in the bulk <2µm size clay mineral assemblages over the lower 161-km length of the Colville River (Fig. 7, and Table 3). These observations run counter to those made in low-latitude estuaries by several investigators[41,53], who noted clay mineral changes with increased salinities of water progressively downstream. These systematic downstream variations in clay minerals have been generally attributed either to: (i) gradual reconstitution of one mineral to another through exchange/adsorption of ions, or (ii) continuous regeneration of degraded clay minerals by an increase in interlayer ion adsorption commensurate with increasing salinities, or (iii) physical sorting of various clay minerals because of differential settling of the various species induced by changing salinities of water. Thus it would seem that downstream variations in clay mineral assemblages in the Colville River are either not influenced by hydrographical factors or that there are other agents which tend to overcompensate the effects of these factors. We believe that clay mineral variations in the Colville River are largely influenced by local influxes of various detrital clay minerals, rather than to changes in the depositional environment. This is suggested by the abrupt increase in smectite and an attendant decrease in other clay minerals in samples 4 and 5 (Table 3; Fig. 7). Likewise in sample 8 a notable increase in kaolinite and chlorite, and an abrupt drop in smectite concentration is observed. It is relevant to note that all these samples were gathered at or immediately downstream of the confluence points of the tributaries Ingaluat Creek, Kogosukruk River, and Itkillik River, respectively, with the Colville River. It is quite obvious from this relationship that the Kogosukruk River and the Ingaluat Creek flow through a smectite-rich terrain (presumably the Umiat Bentonite beds[54]), and that the Itkillik River drains a terrain - perhaps the greywackes of the Torok Formation - relatively enriched in kaolinite and chlorite and poor in smectite.

There is another possibility which merits mention in attempting to explain the apparent lack of systematic downstream changes in clay mineral compositions in the Colville River. This is related to the presence of irregularly distributed and isolated pockets of highly saline waters (up to 40 °/₀₀ salinity) in the lower Colville River channels[8]. These pockets of water are formed during winters by sealing off the shallow portions of the river by the formation of bottom-fast ice, and apparently have little or no connection with the saline water that is reported to penetrate upstream at this time[1]. The possibility does exist that some of our samples, which were collected in the summer, within the 50-km Colville Estuary, were either deposited in or were in contact at sometime with such pockets of brine. In view of the assumption that salinities of these brines would vary haphazardly[8] it would be expected, as seen in the present case, that there would not be any systematic downstream changes in clay mineral types.

The data in Table 3 show that in the <2µm size of Colville deltaic sediments there is a notable increase in the illite/smectite ratio and an attendant decrease in smectite/kaolinite ratio, from the Colville fluvial channels to the relatively more saline fluviomarine and open marine regions off the river mouth. These changes in clay mineral assemblages are at least in part presumably due to reconstitution in the more saline environment, through K^+ adsorption and/or cation exchange, of either degraded illites and/or mixed-layered illite-smectite derived from the nonsaline Colville River channel. This inference is supported by our detailed mineralogical studies on clay minerals within subfractions of the <2µm e.s.d. particle size (Figs. 8 to 15), and by the results of laboratory investigations on <2µ size fresh and brackish water clays of the Colville River with sea water and at slightly above freezing temperatures[55]. Detailed clay mineralogical examination (refer to Appendix) shows that the Colville River clays are, in fact, highly reactive. However, the changes in clay minerals, especially the overall significant decrease in smectite from river to open sea, cannot be adequately explained solely on the basis of the processes mentioned above. Considering results of the detailed studies by Anderson and Reynolds[54], as well as ours (refer to Appendix), it is difficult to envision that a smectite such as the Umiat Bentonite will undergo any significant reconstitution when passed on from fresh water fluvial channel to the open marine saline environment. Thus, some alternative mechanism must be invoked to explain the observed decrease in smectite in the fluviomarine and marine facies of the Colville Delta. At this stage of our knowledge we suspect that an appreciable amount of

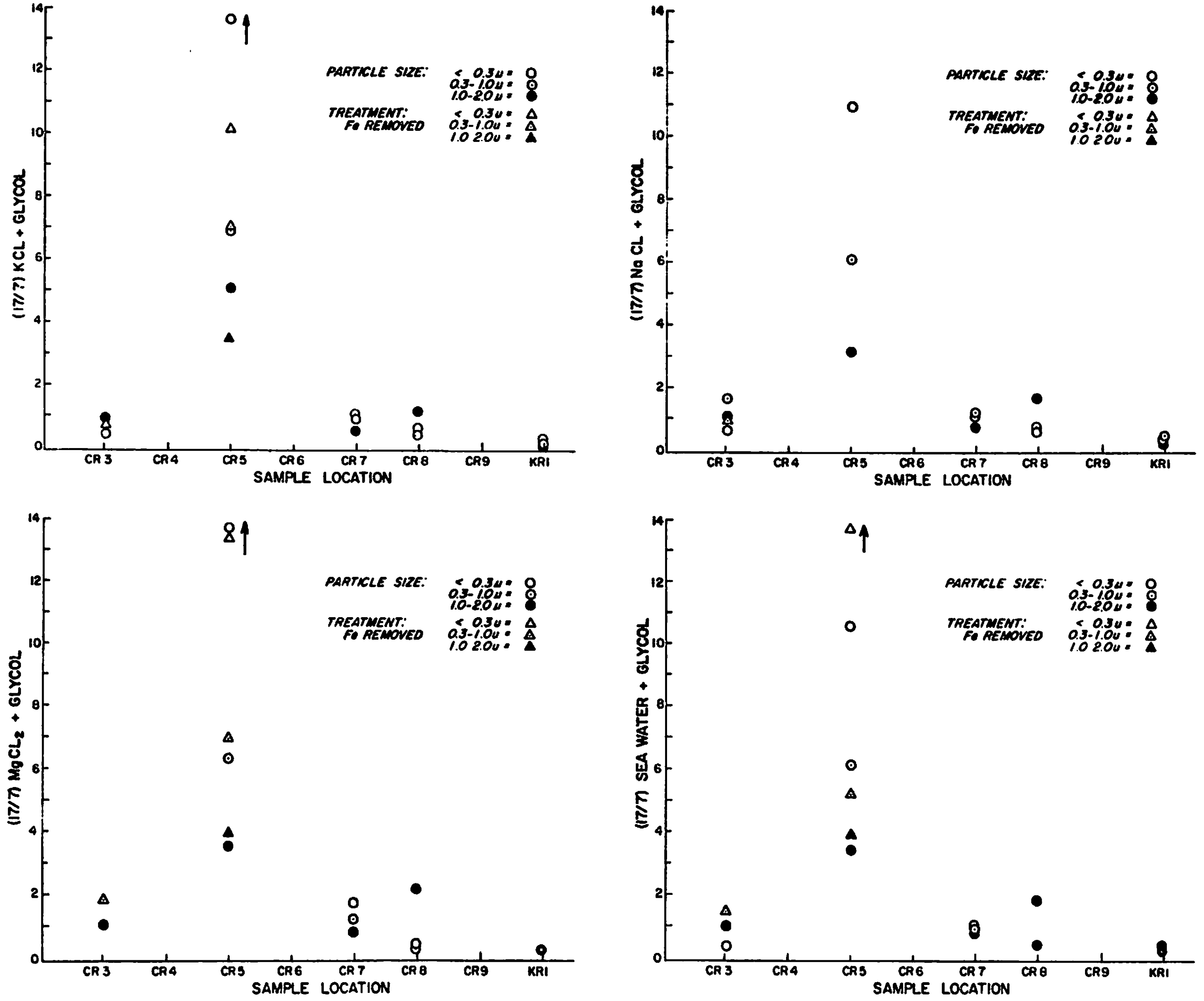

Figure 8. Smectite (17Å)/Kaolinite + Chlorite (7Å) ratios of Colville River clays after treatment with various cations and glycolation.

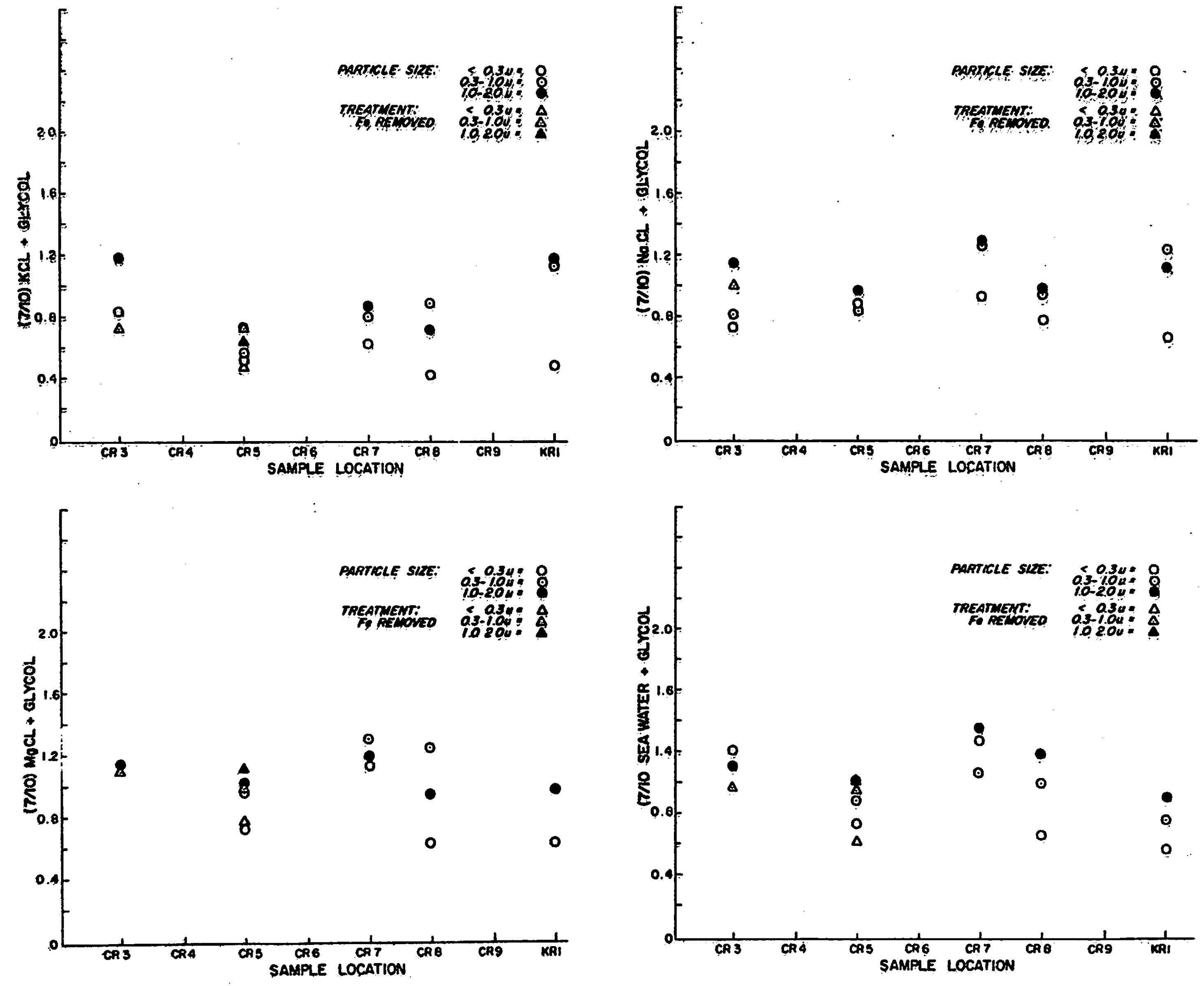

Figure 9. Smectite (17Å)/Illite (10Å) ratios of Colville River clays after treatment with various cations and glycolation.

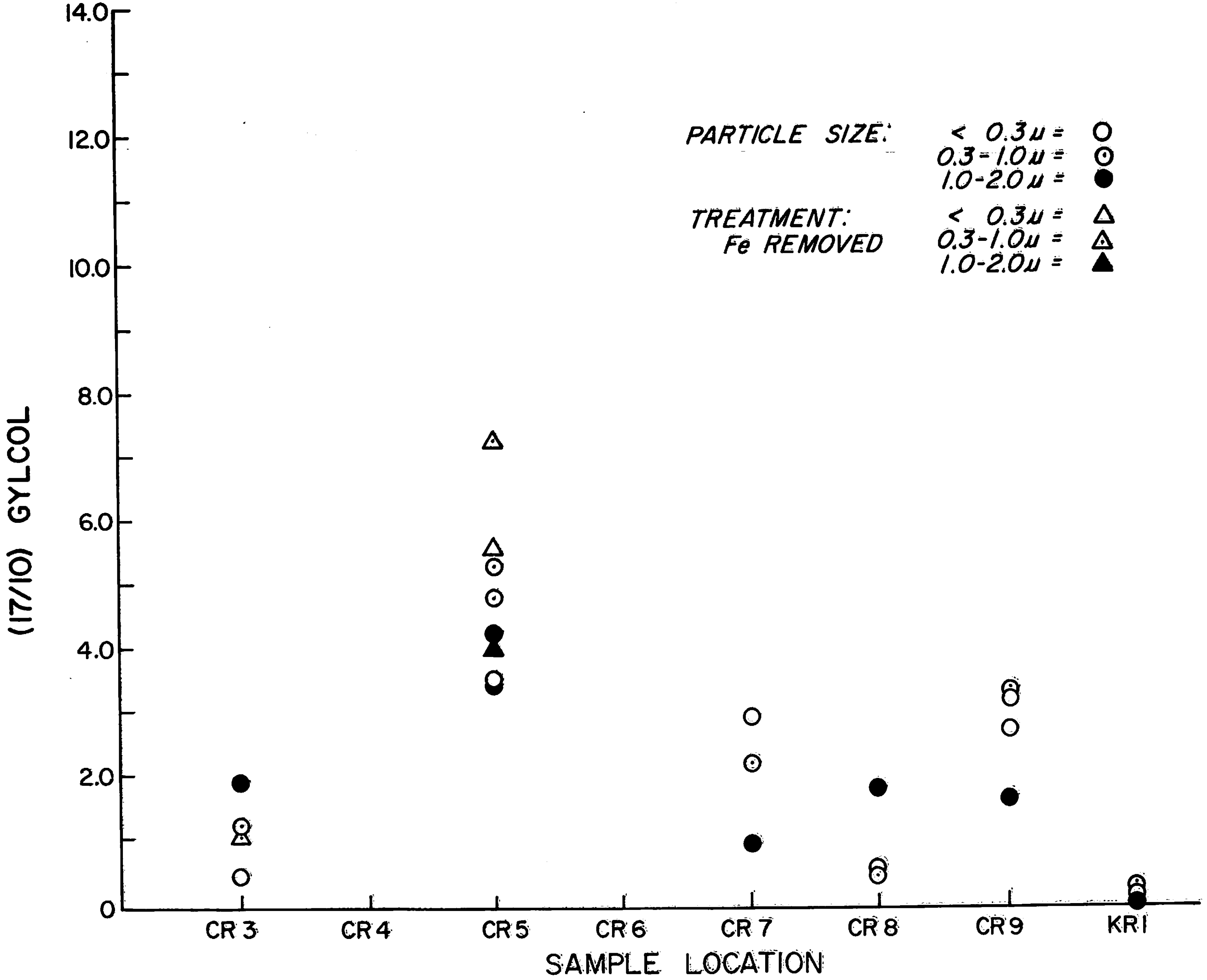

Figure 10. Smectite (17Å)/Illite (10Å) ratios after glycolation.

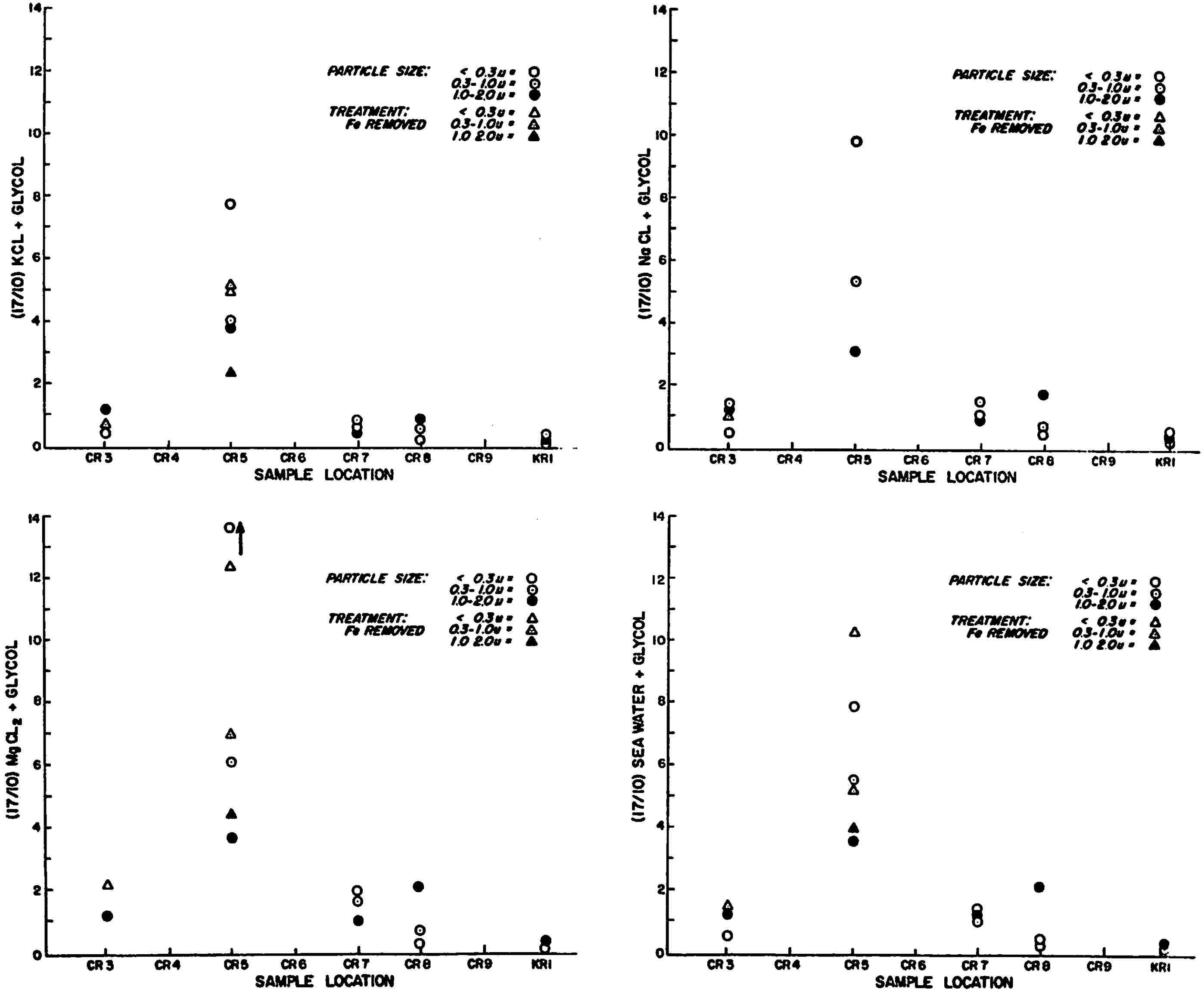

Figure 11. Kaolinite + Chlorite (7Å)/Illite (10Å) ratios of Colville River clays after treatment with various cations and glycolation.

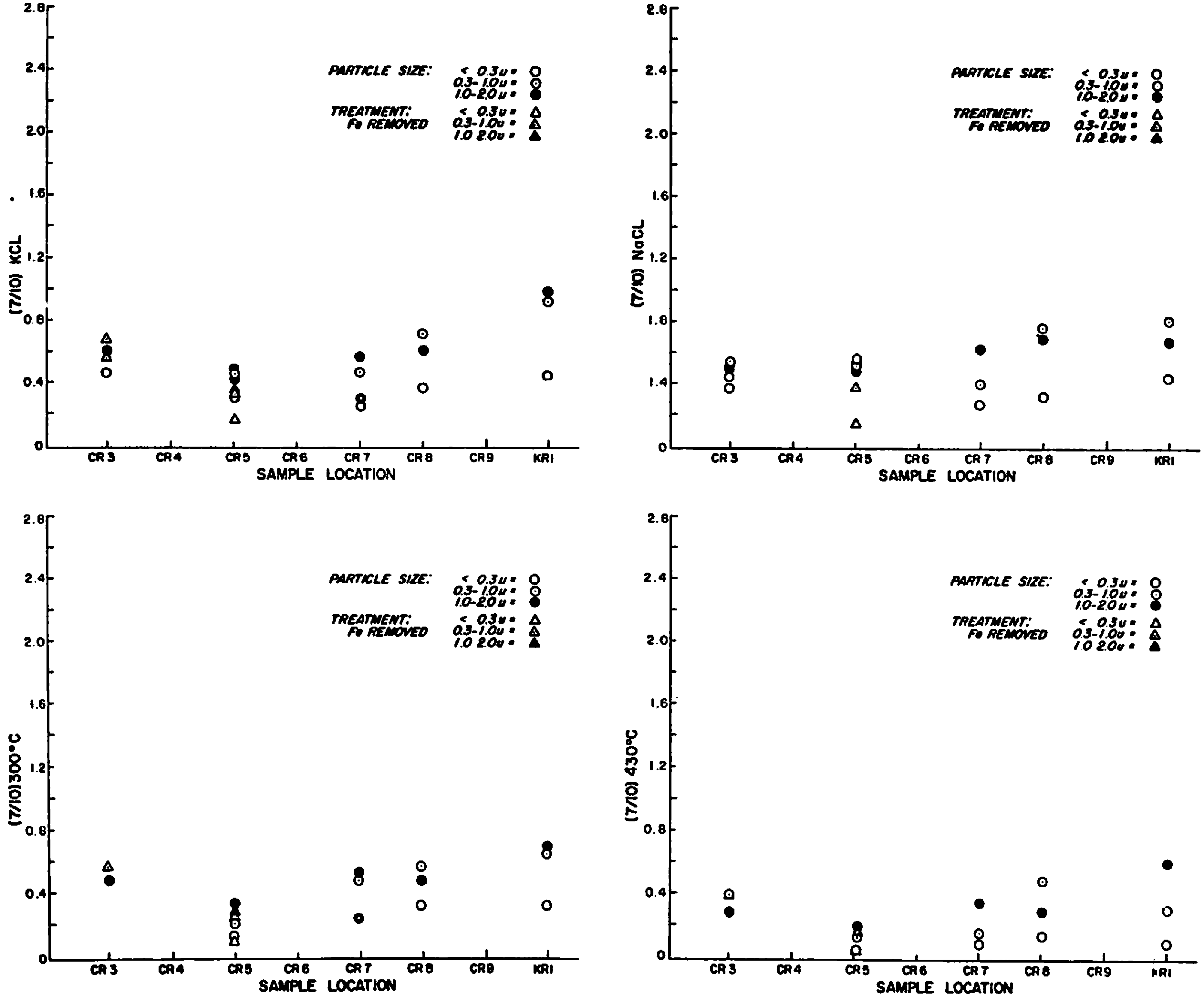

Figure 12. Kaolinite + Chlorite (7Å)/Illite (10Å) ratios of clays from the Colville River after treatment with various cations and subjection to heat.

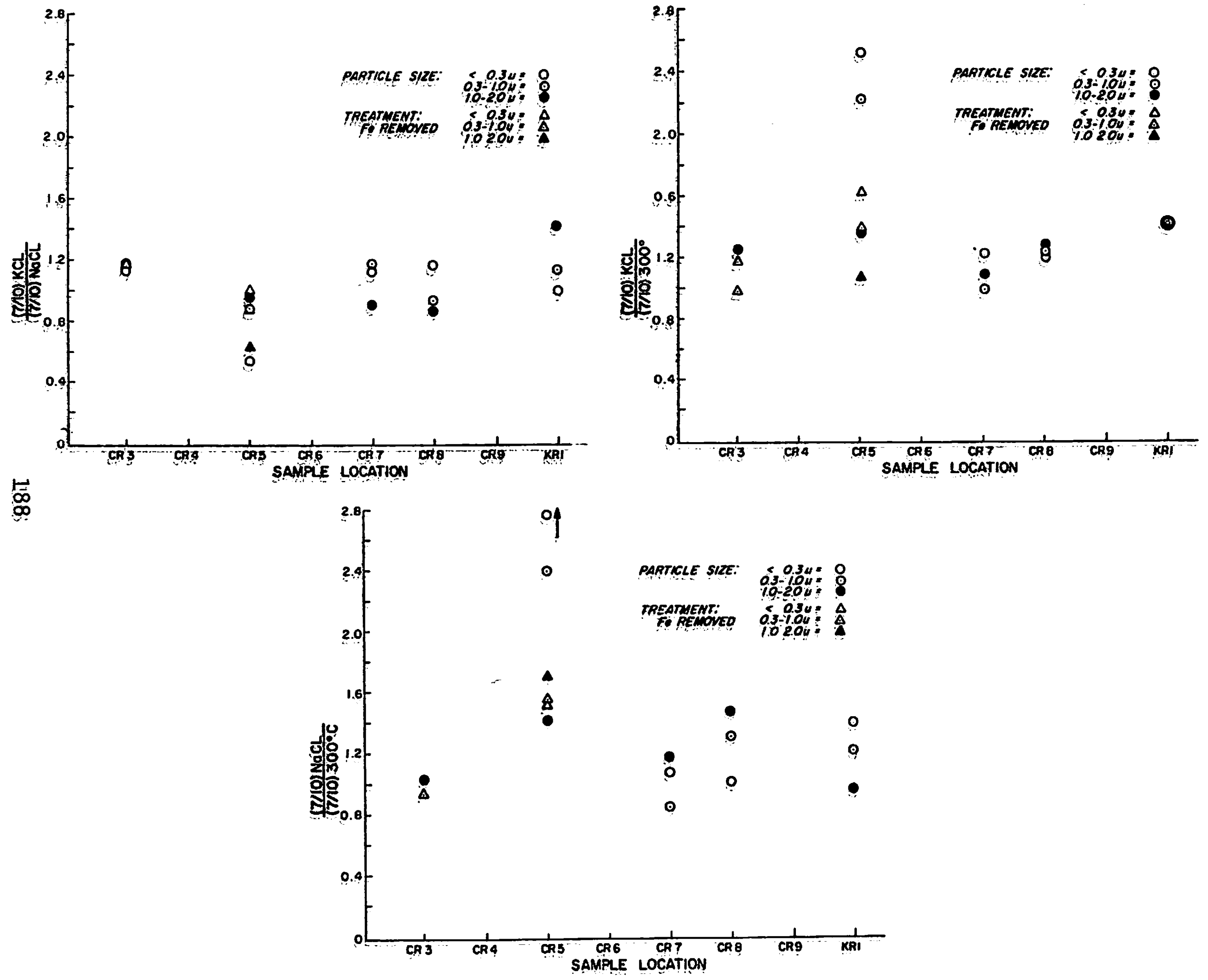

Figure 13. 7Å/10Å ratios of clays for NaCl vs KCl treated samples, and KCl and NaCl vs heat treated samples of the Colville River.

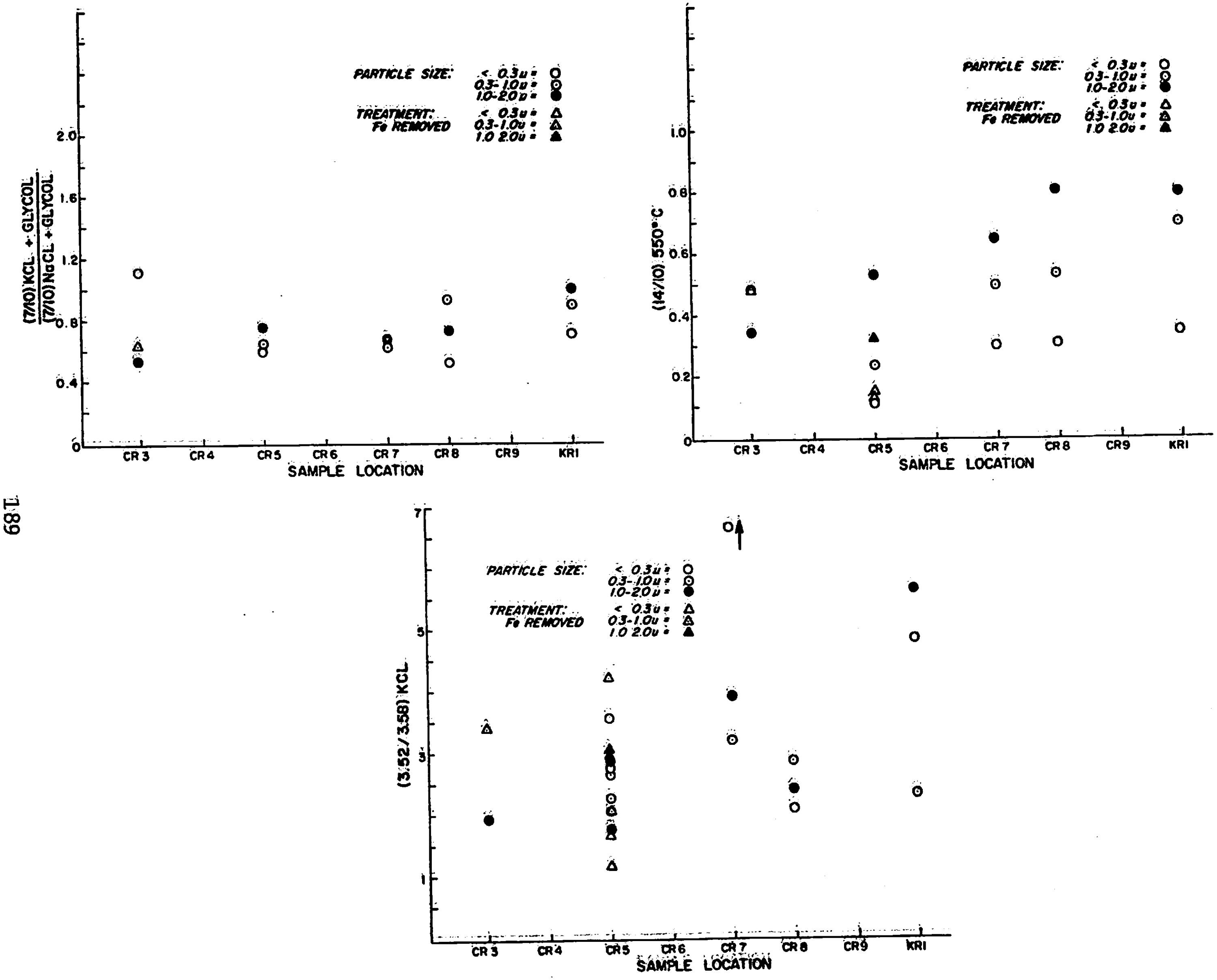

Figure 14: 7Å/10Å ratios of Colville River clays for NaCl vs KCl treated glycolated samples; 14Å/10Å ratios after heating the clays to 550 C, and ratios of 3.52Å/3.58Å after treating the clays with KCl.

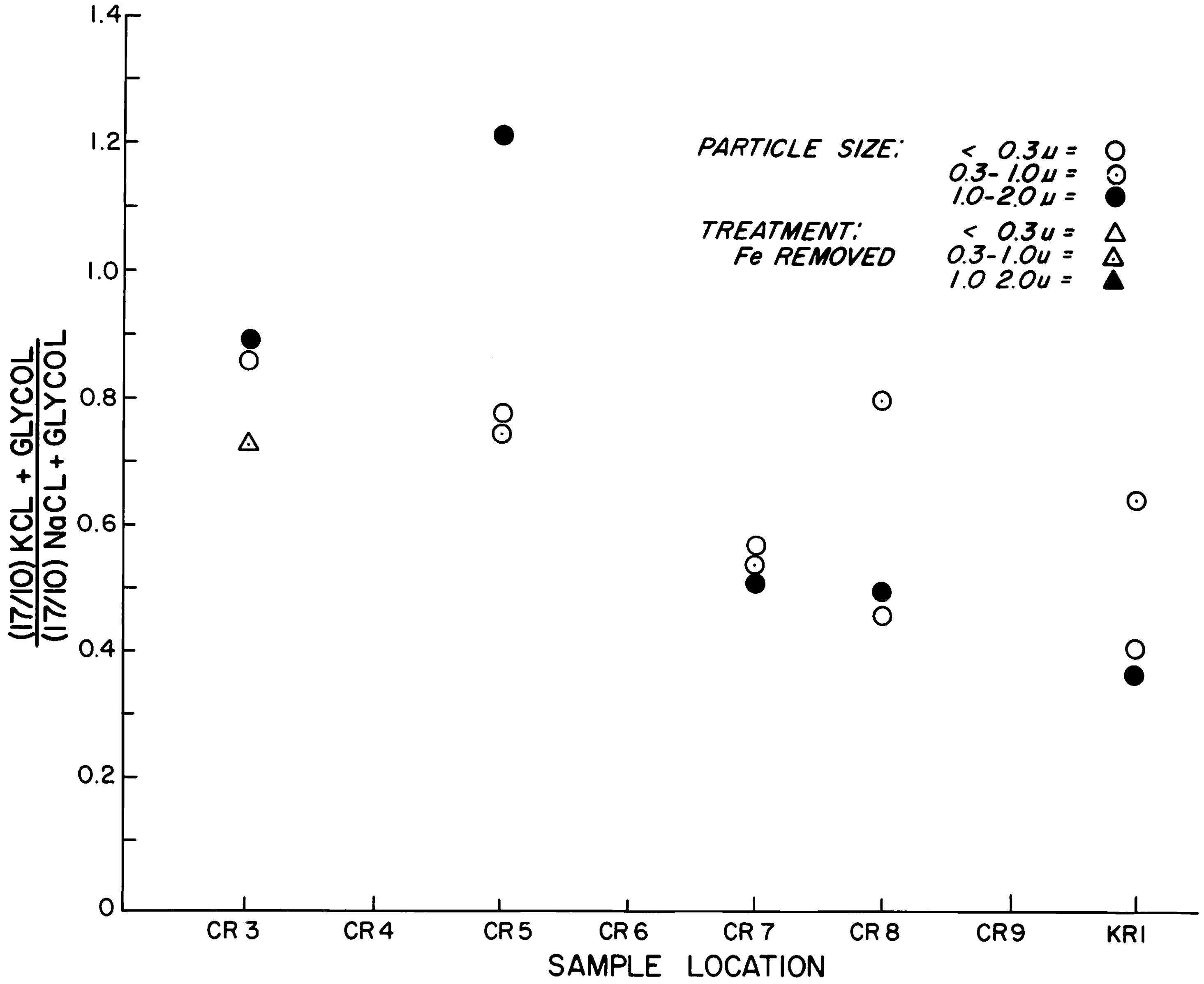

Figure 15. Ratios of 17Å/10Å of Colville River clays for KCl vs NaCl glycolated samples.

the smectite in the Colville River is somehow deposited at the mouth of the fluvial channels. Such a conclusion is supported by our detailed clay mineralogical studies on subfractions of clays within the <2μm e.s.d., and as well by the predominance of illite and chlorite with subordinate smectite in the suspensates collected at sample location CR8 (Figs. 1 and 2). We are, however, not sure on the mechanism which brings about such a deposition of smectite. On the basis of experimental data gathered by Whitehouse and Jeffrey[56] differential settling of smectite over illite, chlorite and kaolinite, induced by flocculation would seem an improbable factor. However, mineral sorting based purely on the primary nonflocculated size of detrital particles of smectite could be an important process in this context.

Data in Table 3 bear out that there are two major clay mineral zones in the shallow marine facies of the deltaic complex under study. Clays west of Oliktok Point have markedly lower illite/smectite and illite/kaolinite ratios than clays east of this point. These lateral variations in clay mineral types within contiguous areas are most probably attributable to differences in terrigenous clay mineral sources and their dispersal patterns, rather than to differences in depositional environments[57]. Sedimentation in the eastern lagoonal area well east of Oliktok Point is chiefly influenced by the sediment outfall of the Sagavanirktok River, whereas sedimentation in Harrison Bay and the offshore open marine deltaic area west of Oliktok Point is largely affected by the Colville River discharge. The clay mineral compositions of these two rivers are significantly different, inasmuch as the Colville River transports far more smectite and kaolinite than the Sagavanirktok River (Table 3). We feel that offshore dispersal of the clays discharged by the Colville River is chiefly confined to the area west of Oliktok Point and much of it does not move into the Simpson Lagoon. The Sagavanirktok River sediment outfall does not seem to move far away from the river mouth. Dispersal patterns of the above clays are largely supported by the known mean current directions of waters over the area, which is towards the southwest[6]. Such a prevalence of currents would tend to push the Colville River flume away from the Simpson Lagoon area. A similar dispersal of the Sagavanirktok River clay is largely inhibited because of the fact that Simpson Lagoon lies sheltered between the mainland coast and the barriers and thus is largely in the shadow area for the open marine southwest prevailing currents.

Our studies on clay mineral compositions of sediments from the continental margin and open marine environments of north arctic Alaska have not been completed. However, the preliminary results do indicate the potential value of this approach in the interpretations of paleogeography and paleocurrent of past depositional basins. The relevance of our clay mineral studies in environment and pollution studies has been discussed[55].

Sediment Geochemistry and Element Partition Patterns

The contents of organic carbon in the deltaic and adjacent shallow marine sediments of north arctic Alaska are significantly lower (Table 4) than those observed in tropical deltaic sediments[36,37]. This may be due to the very low organic productivity in the Alaskan deltaic region as supported by phytoplankton productivity and ^{14}C primary productivity studies[9], and low yearly supply of terrigenous detrital organic matter. It seems improbable that low organic carbon in our sediments is a result of relatively higher oxidative decomposition of organic matter in the region of our study. This conclusion is based on the fact that for most of the year the continental margin environment of north Alaska is covered with ice, and as such it would be expected that the environment overlying the sediments will be less ventilated and thus less oxygenated also.

The progressive increase seaward of sediment organic carbon (Table 5) is contrary to the commonly observed pattern of organic carbon distributions in marine sediments[36,57,58]. The generally observed seaward decrease in organic carbon of marine sediments has been attributed to: (i) seaward decrease of terrigenous organic supply, and (ii) seaward increase in organic decomposition[58]. However, on the basis of the above two factors obviously the observed seaward differences in organic carbon contents in the Beaufort Sea (Table 5) cannot be explained. It is believed that in the present situation the regional differences in sediment organic carbon are determined by the variations in lithology. Such a conclusion is supported by the strong negative correlation observed between organic carbon and sand contents of the deltaic (Table 6) and nondeltaic sediments[31]. Presumably as a result of seaward decrease in sand (Table 1; Naidu and Hood[31]) there is lesser seaward 'dilution' of sediment organic matter by sand size inorganic mineral particles, as well as concomitant decrease in oxidative decomposition of organic matter resulting from lower porosity of mud. From the correlations of organic carbon and sediment size grades it is inferred that the bulk of the organic carbon in the deltaic sediments is associated with the silt fraction (Table 6) whereas in the nondeltaic marine sediments it is concentrated in the clay fraction[31]. Possibly this is related to the differing hydrodynamical conditions of deposition, and the probable result of size fractionations of detrital organic particles as a function of distance from the shore.

As compared to the nondeltaic shelf and extrashelf sediments of the Beaufort Sea, there is a notable enrichment of Ca and carbonate in the deltaic sediments (Table 5). Plausibly this is due to the presence of relatively higher contents of calcareous lithogenous and bioclastic components in the deltaic sediments. The bulk of the Ca appears to be tied up in the carbonate, as attested by a strong covariance between the two (Table 6; and Naidu and Hood[31]). However, there also seems to

Table 6. CORRELATION COEFFICIENTS FOR CHEMICAL, TEXTURAL AND CLAY MINERAL COMPOSITIONS OF DELTAIC SEDIMENTS, NORTH ARCTIC ALASKA.[a]

	Depth	Sand	Silt	Clay	Org. carbon	$CO_3^=$	Fe	Mn	Ca	Mg	K	Na	Li	Rb	Cu	SMT	ILT	KLT	CLT
Depth	1.000																		
Sand	-	1.000																	
Silt	-0.406	-0.915	1.000																
Clay	-	-0.624	-	1.000															
Corg	-	-0.569	0.578	-	1.000														
$CO_3^=$	-	-	-	0.387	-	1.000													
Fe	-	-0.508	0.478	-	0.406	-	1.000												
Mn	-	-0.420	0.402	-	0.350	-0.333	0.858	1.000											
Ca	-	-	-	0.371	-	0.763	-	-	1.000										
Mg	0.374	-0.399	-	0.638	-	0.329	-	-	-	1.000									
K	-	-0.578	0.424	0.563	0.478	-	0.647	0.528	-	0.566	1.000								
Na	-0.371	-	-	-	-	-	0.545	0.655	-	-	0.471	1.000							
Li	-	-	0.549	0.541	0.513	-	0.876	0.733	-	0.454	0.836	0.531	1.000						
Rb	-	-0.588	0.449	0.538	0.403	-	0.739	0.572	-	0.478	0.869	0.498	0.877	1.000					
Cu	-	-	-	-	-	0.380	-	-	0.433	0.334	0.473	-	0.410	0.376	1.000				
SMT[b]	-	-	0.345	-0.343	-	-0.572	0.411	0.505	-0.668	-	-	-	-	-	-	1.000			
ILT[b]	-	-	-	-	-	0.465	-	-0.436	0.540	-	-	-	-	-	0.383	-0.798	1.000		
KLT[b]	-	-	-	-	-0.340	-	-	-	-	-	-	-	-	-	-	-	-	1.000	
CLT[b]	-	-	-	0.471	-	-	-	-	-	-	-	-	-	-	-	-	-0.488	-	1.000

[a] Only figures that are significant at 95% confidence level (r = 3.325) cited in the table.

[b] SMT: Smectite, ILT: Illite, KLT: Kaolinite, and CLT: Chlorite

be some sorting of calcium carbonate based on size in the different environments. It is apparent (Table 6) that calcium carbonate in the deltaic sediments is concentrated in the clay fraction, whereas in the nondeltaic marine sediments most of it occurs in the sand fraction[31].

Interelement correlations (Table 6) have been used by us in attempting to understand element partitions in these regions. The strong covariance between all alkali metals (Table 6) is to be expected because of their similar geochemical behavior. However, on the basis of the existing correlations (Table 6) it would seem that except for Na all the alkali metals are predominantly tied up with the clay fraction (plausibly in adsorbed/exchangeable sites of clay minerals), and with the organic matter. The association of alkali metals with organic matter is related to primary fixation of the metals by living organisms through metabolic activities; such a fixation is now well-known and appears to need no further elaboration here. It is apparent that the bulk of the Na has been distributed in some other sediment phase than the argillaceous or the biogenic fraction. The strong covariance of all alkali elements, particularly Na, with both Fe and Mn is difficult to explain unless the premise is made that the alkalies, Fe, and Mn have, at least in part, a common derivation in interstitial water. Sodium being a thallasophile element, a large amount of it can be accounted for in salts solidified from interstitial water, and to a smaller extent this is also applicable to other alkali metals.

The strong covariance of Fe and Mn suggests that a significant part of this element has either coprecipitated as ferrimanganic hydrate or is associated in a common sediment phase. Assuming that this is true it is suggested that a part of this precipitate has originated from interstitial water. This does not seem untenable, in view of the fact that a few inches of the surface sediment have been analyzed in this study, and that post-depositional upward migration of soluble Fe and Mn, with oxidative precipitation of these elements at the sediment surface would not be an unusual occurrence in this region. Naidu[35] has shown that in fact such a precipitation of Fe and Mn is taking place on the adjoining shelf and extrashelf sediment surfaces of the Beaufort Sea. However, it is strongly suspected, from the data in Table 6, that the predominant part of the total Fe and Mn is tied up with organic matter, and in the silt size fraction of sediments - in heavy minerals or discrete ferrimanganic particles.

There are strong positive correlations between smectite, Fe and Mn (Table 6), but we are not sure of the significance of these correlations, because no significant covariance has been observed between Fe, Mn and the clay size fraction (of which latter smectite is of course a part). Assuming that the Fe-Mn-Smectite correlations are true, it follows that some of the Fe and Mn is associated with either adsorbed or exchangeable sites of smectite, and/or in basic lattice (octahedral, presumably) positions in smectites. The work of Anderson and Reynolds[54] with the Umiat Bentonite does not suggest any appreciable nontronitic character of that material. Of course, this does not preclude the occurrence of nontronite clays elsewhere in the Colville River drainage area. However, we have observed in our detailed work (refer to Appendix for details) that the sediments at various sample locations along the Colville River contain varying amounts of ferruginous materials, much of it of an X-ray amorphous "limonitic" character, intimately associated with the clay minerals.

It seems quite probable that Mg, along with Ca, is related to the argillaceous and/or carbonate fraction of the deltaic sediments. Preliminary attempts made to understand the partition pattern of Co suggest that Co is being scavenged by ferric hydroxide[55].

The geochemistry of Cu in the deltaic sediments is not well understood, especially because of its positive correlations restricted to Ca, Mg, K, Li, Rb, illite, and carbonate fraction of sediments. A natural conclusion of such an association would be that Cu is chiefly bound with the carbonate phase, and possibly to a limited extent with the argillaceous fraction. Limestone and dolomite grains of terrigenous origin probably constitute the major portion of the carbonate material in these sediments. Copper is likely to be present in these grains as fine disseminations, probably of discrete sulphide phases. Preliminary data from a geochemical-mineralogical study of carbonate rocks in the Brooks Range, presently being undertaken by the Alaska State Geological Survey and others (Mowatt *et al.*, in progress), indicate the common presence of copper associated with these rocks at levels slightly to moderately above reported averages for analogous rocks elsewhere. This coupled with the fact of known extensive, high-grade copper mineralization in parts of Brooks Range (e.g. the Bornite-Ruby Creek deposits) in carbonate rocks seems to corroborate the suggested correlations we observe in the sediments of north arctic Alaska.

The possible argillaceous association of Cu is inferred indirectly from the strong covariances of Cu with K, Li, Rb and illite, and the presumption that illite is the predominant clay mineral in the clay mineral in the clay fraction (Table 3). This further suggests that much of this "illite" actually represents detrital micaceous materials, and, further that a considerable portion of this may well be vermiculitic, and represent altered/weathered trioctahedral mica, which would be anticipated to be somewhat higher in octahedral copper than dioctahedral micas. Illite resulting from the prograde reconstitutive sequence (diagenetic and anchi-metamorphic) smectite → mixed-layer smectite/ illite → illite, suggested by Hower and various coworkers[21,59,60] would not be expected to contain as much Cu in octahedral sites as illite representing "degraded" micas, due to the differing geologic environments associated with micas as opposed to smectites. Admittedly smectites associated with alteration zones proximal to hydrothermal Cu mineralization would be exceptions to the foregoing generalizations.

Interelement correlations have a potential use in understanding differences in elemental abundances between different environments (Table 5), provided the distributions of the elements are governed by similar geochemical rules, and involve the same sediment phases. At this stage of our study we can not conclusively say what the geochemical factors are that determine the differences observed between the chemistry of the deltaic, nondeltaic shelf and the extrashelf sediments (Table 5). It is strongly suspected that lower rates of sedimentation, and higher salinities of interstitial waters in the offshore nondeltaic area contribute to the relatively higher alkali contents observed in that area, as compared to the delta (Table 5).

Considering all factors, it is concluded that the seaward increase in both Fe and Mn (Table 5) is most probably due to simultaneous seaward decrease in the solubility of Fe and Mn. It is also concluded that the differences observed in the Fe and Mn contents between the deltaic and nondeltaic shelf sediments (Table 5) are not due to possible differences in the rates and amounts of mobilization and precipitation of Fe and Mn from interstitial waters in the above two environments. This conclusion is arrived at after considering the factors that govern the mobilization and precipitation of elements from interstitial waters[58]. The factors which point to the insignificant role of interstitial waters in this context are the relatively higher contents of organic carbon and plausibly higher rates of sedimentation in the deltaic region, as compared to the nondeltaic area.

The above interpretations on element partition patterns are chiefly based on correlation coefficient calculations for the gross sediments, and thus we present them with some reservations. However, in order to better understand the geochemistry, and to predict the partition patterns of the elements with more confidence, it would be necessary to analyze elements in different sediment phases. The lithogenous (lattice-bound), nonlithogenous (adsorbed/exchangeable phases), and various biogenous and chemogenous components of the sediments would have to be analyzed. Our future plans call for such a detailed study.

Elemental concentrations cited in Table 4 and 5 should be useful as baseline data to detect any chemical pollution in the deltaic and marine environments of north arctic Alaska.

ACKNOWLEDGEMENTS

We wish to thank Joe A. Dygas for his help in analyzing the carbonate contents in sediments. The statistical analysis and the X-ray analysis were kindly conducted by Bob Tucker and Mrs. Namok C. Veach, respectively.

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CHAPTER 6

FAST ICE ON THE NORTHERN COAST OF ALASKA

T. E. Osterkamp and R. D. Seifert

INTRODUCTION

The impending industrial development on the Northern Coast of Alaska has stimulated an interest in the fast ice. Since numerous rivers and streams enter into the Beaufort Sea in this region, it might be expected that large areas of the fast ice would be brackish ice rather than sea ice. However, the drainage basins of these rivers and streams lie entirely in areas of continuous permafrost and their flow nearly ceases during the winter months.[1] Therefore, this study was undertaken to determine the distribution of brackish ice in the fast ice cover.

Our observations by light aircraft and snow machine during 1970, 1971, and 1972, as well as long-term observations made by the native peoples,[2] indicate that extensive areas of fast ice exist along the northern coast of Alaska each year. The extension of this ice seaward appears to be governed by several factors - including the presence of offshore islands, water depth, storms, and the presence of large grounded ice islands. These factors usually limit the seaward boundary of the fast ice to a distance of 10-15km from the coastline between Barrow and Flaxman Island and much less than this from Camden Bay eastward to Herschel Island. The variability of the fast ice is demonstrated by the fact that in May, 1970, it extended 35km from Oliktok to a line of large ice islands grounded in 30m of water and was almost non-existent at Barter Island.

METHODS

During April and May of 1971 and 1972, a total of 60 ice cores were taken from the fast ice with a 7.5cm diameter SIPRE corer between Barrow and Cross Island at the locations shown in Figure 1. These cores were transported by snow machine and aircraft to Fairbanks, Alaska, where they were stored in a freezer at -25°C. The crystallographic structure of these cores was determined by standard petrofabric techniques using a Rigsby Universal Stage[3] and the salinity of each core was measured with a Beckman RB-3 Solu-Bridge.

In addition, absorption coefficients of the shore-fast ice were obtained in 8 core holes by suspending selenium photocells from an aluminum rod at various depths within the ice cover to measure the relative light intensity as a function of depth in the ice cover. A milli-ammeter was used to monitor the photocells. Weller and Schwerdfeger[4] have shown that the errors introduced by this bore-hole installation are small. The results were assumed to follow the well-known Bouger's law for absorption and the absorption coefficients were determined from a semi-logarithmic graph of relative light intensity versus depth in the ice cover.

Since the properties and structure of brackish ice are not well-known, it was necessary to adopt criteria for its identification (see also Dykins, 1969[5]). These criteria were developed from observations of laboratory-grown brackish ice and sea ice and from fast ice cores. For the purpose of this study, brackish ice was tentatively defined as first year ice that had a salinity of 3 °/₀₀ or less, an obscure or non-existent platelet substructure, and small, discontinuous brine pockets (<0.03mm in diameter) when compared to sea ice brine pockets. A horizontal thin section of brackish ice from a depth of 35cm in the ice cover is shown in Figure 2.

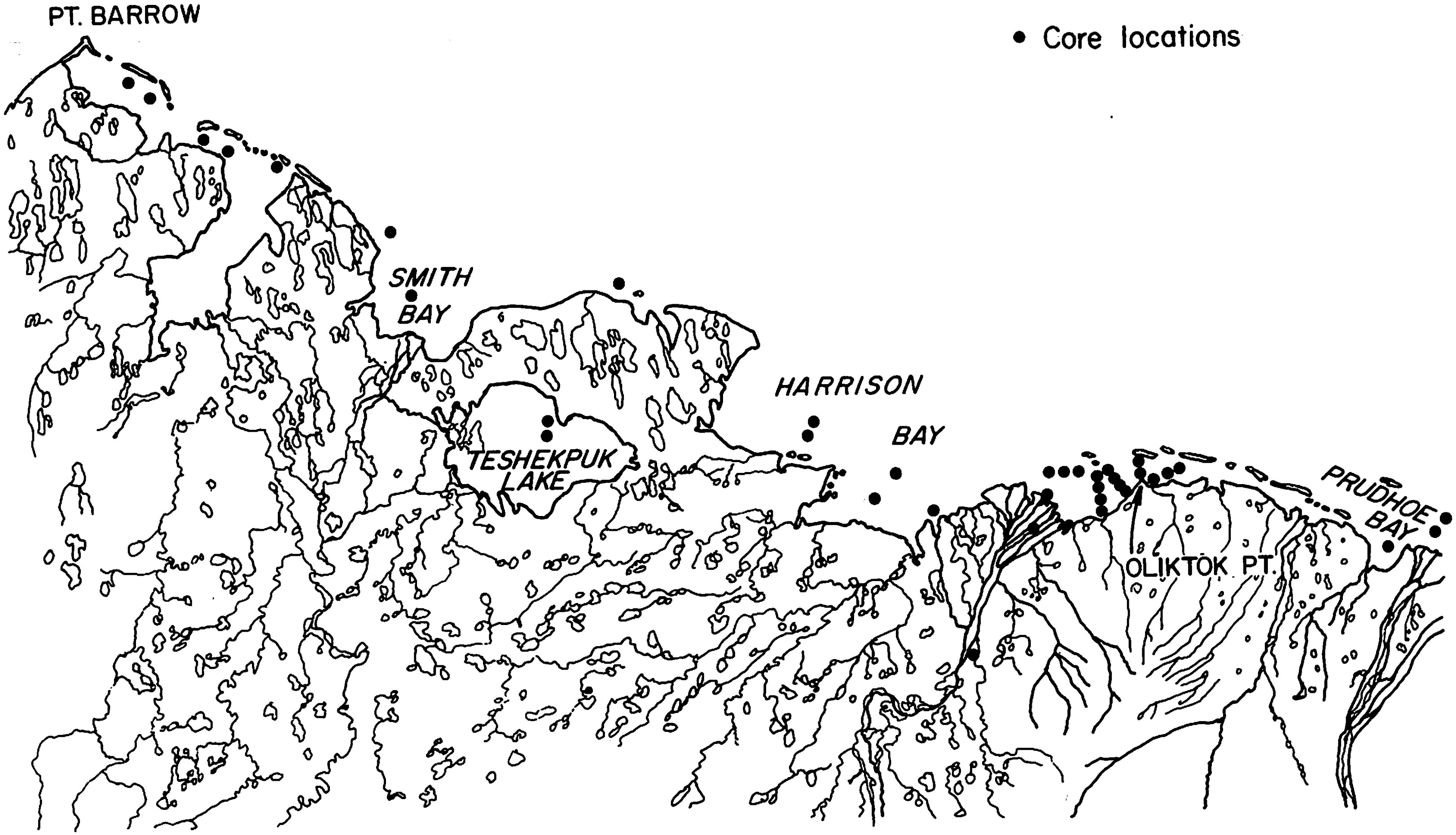

Figure 1. Location of ice cores taken during April and May of 1971 and 1972. Each solid circle represents one or more ice cores.

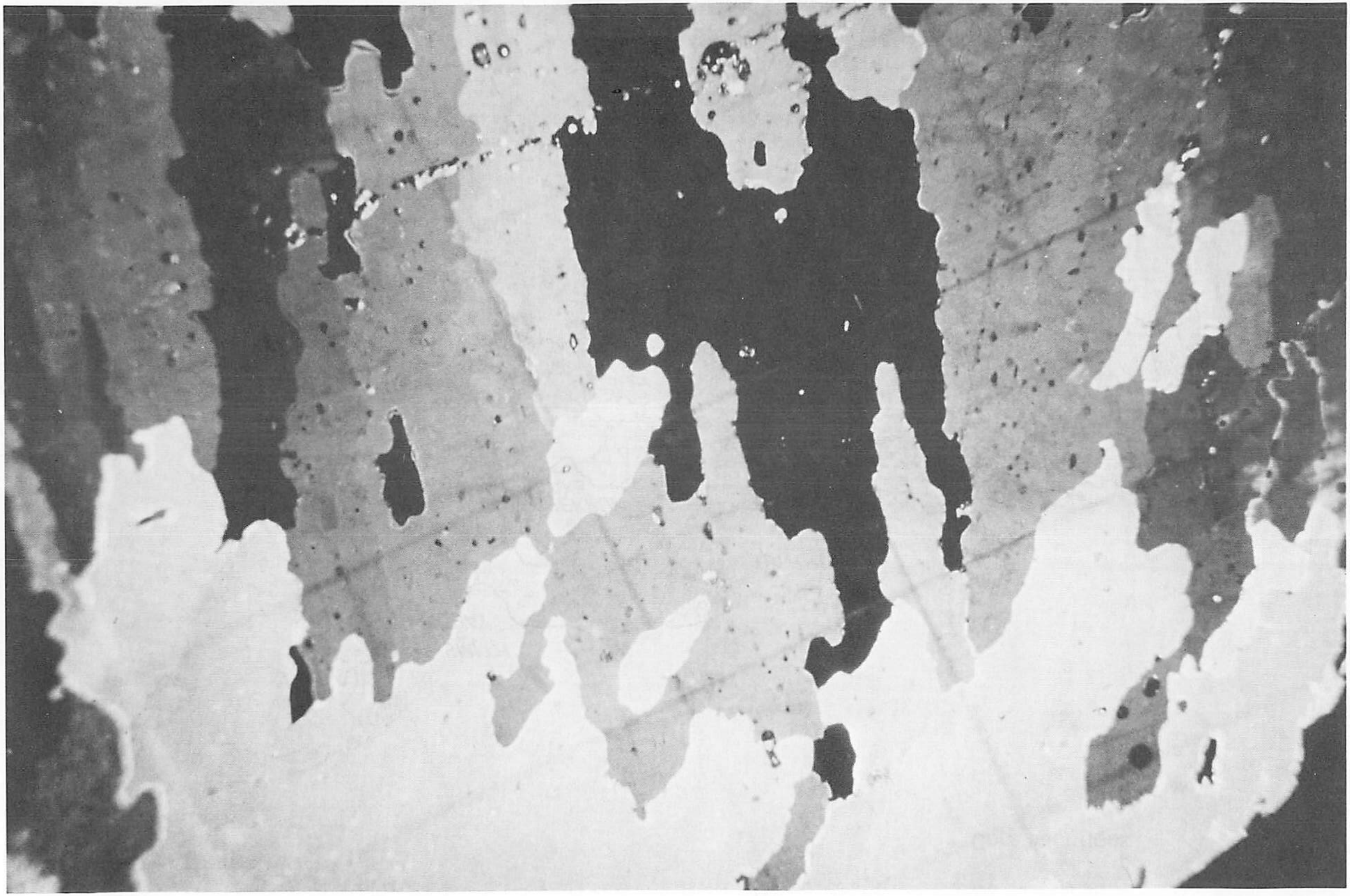

Figure 2. Photograph of a horizontal thin section of brackish ice from a depth of 35 cm in the ice cover taken between crossed polaroids. The grid spacing is 1 cm.

RESULTS AND DISCUSSION

The cores from the fast ice cover were sea ice except for those cores taken from the Colville River estuary which contained brackish ice. Since the petrofabrics of sea ice cores are well-known, these results are not reported here (see Seifert, 1973[6] for details on the petrofabrics of brackish ice and sea ice). A core taken 4km upstream from the mouth of the east channel of the Colville River in May 1972, was predominantly brackish ice and cores taken from Harrison Bay near the Colville River in May, 1971, consisted of brackish ice in the top 1/3 (∿60cm) and sea ice in the lower 2/3 of the fast ice cover. An estimate of the extent of brackish ice in Harrison Bay based on our limited core data is given in Figure 3. All ice cores taken from areas other than Harrison Bay were sea ice. Therefore, we expect that the shore-fast ice on the North Slope of Alaska is primarily sea ice.

Walker[7] suggests that the layered ice cover is a result of sea water encroachment up the Colville River because of cessation of flow in the fall. It is assumed that the time of cessation of flow corresponds to the time of the transition from brackish ice to sea ice in the ice cover. A simple calculation of this time can be obtained using Stefan's equation (see Pounder, 1965[8]) and Barrow weather data. It is calculated that this transition from brackish ice to sea ice in the ice cover occurred in November 1970 and in January 1971.

A typical graph of relative light intensity versus depth in the ice cover is shown in Figure 4. The absorption coefficients of the fast ice ranged from 0.006cm^{-1} to 0.016cm^{-1} except for two cases where they were 0.028cm^{-1} and 0.11cm^{-1}. In these two cases, the cores taken from the ice cover contained sediment near the surface. The above values of the absorption coefficients compare favorably with values obtained by Thomas[9]

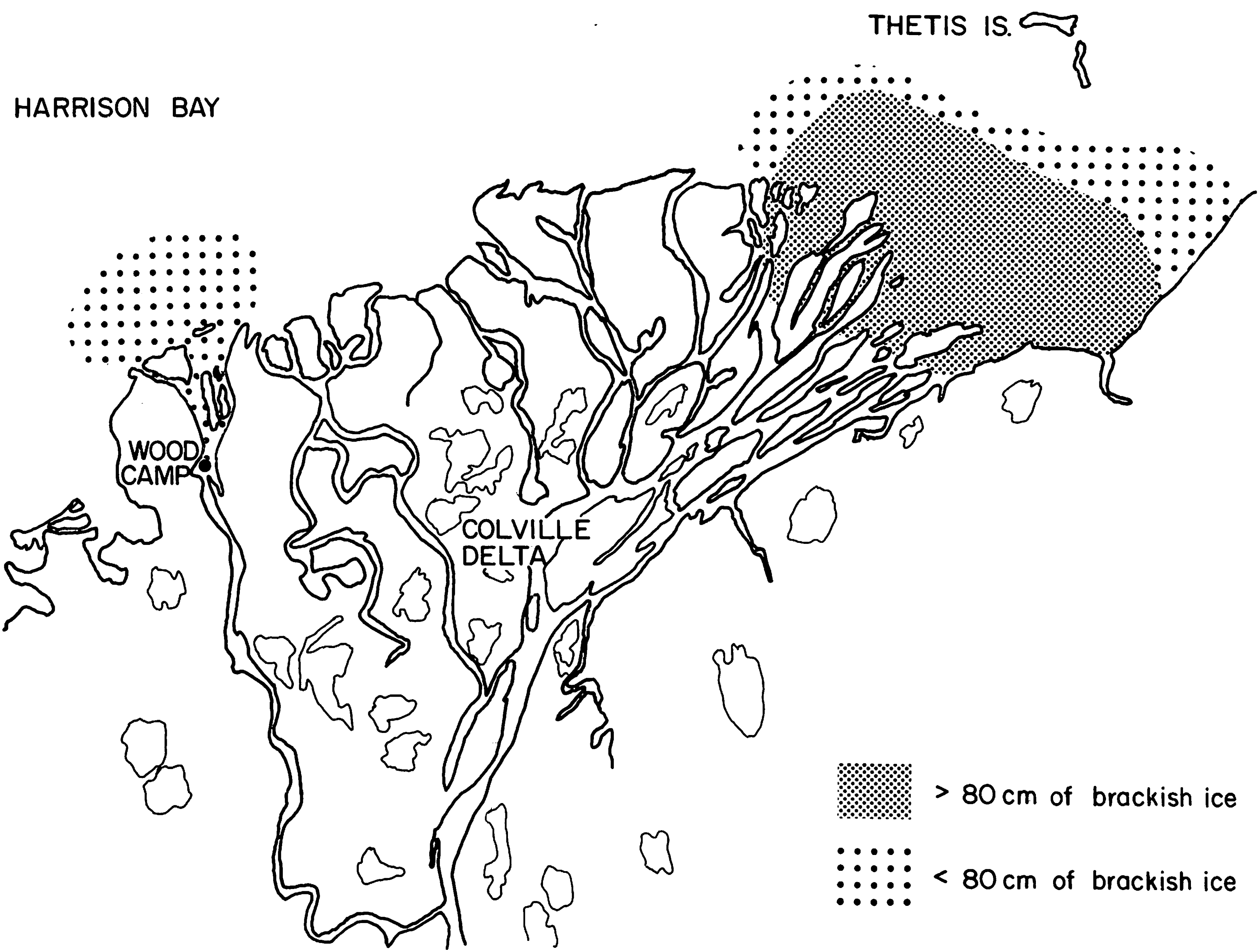

Figure 3. Brackish ice in Harrison Bay. Ice cores taken outside of the shaded areas were entirely sea ice.

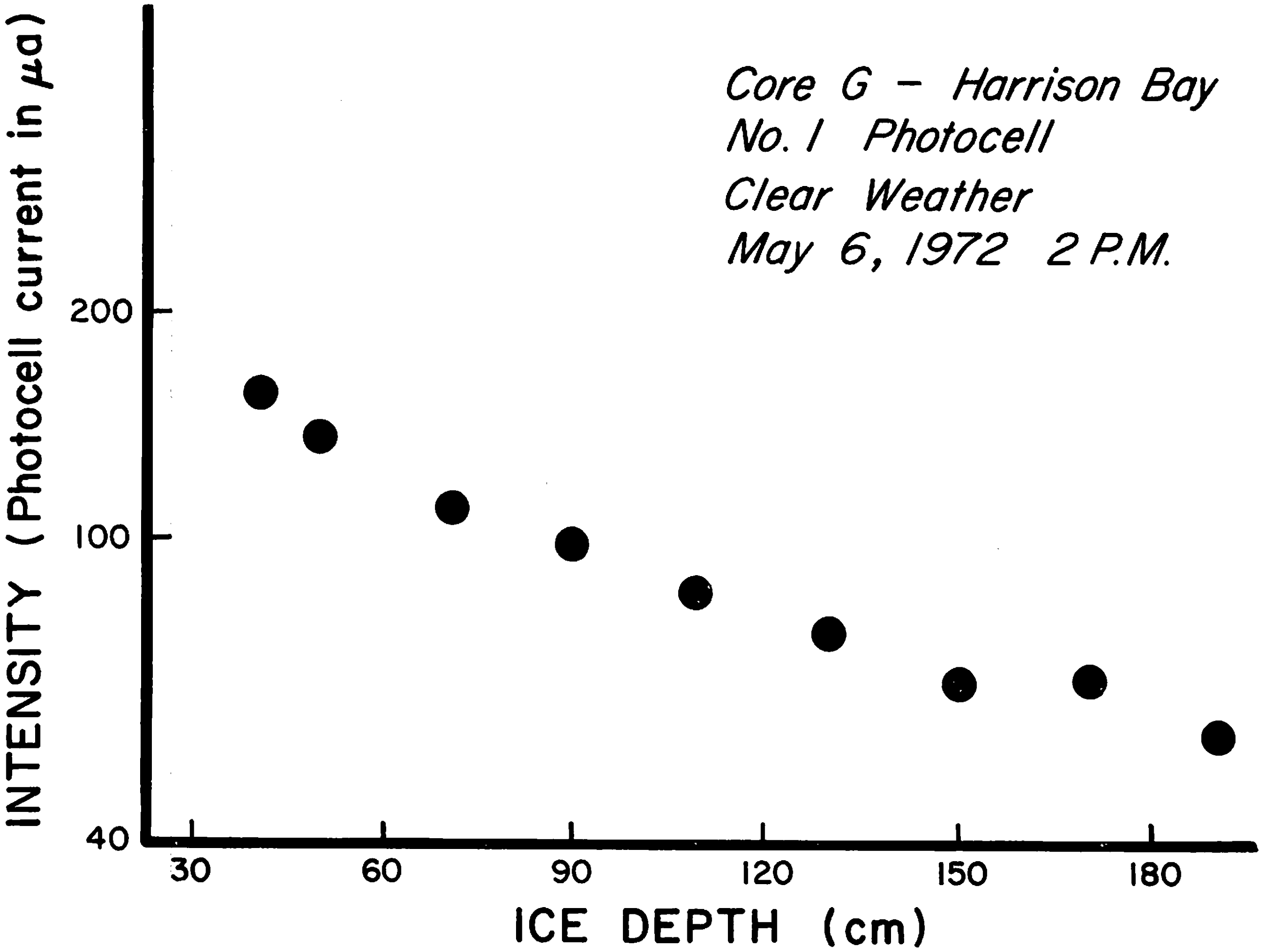

Figure 4. Relative light intensity vs. depth in the ice cover.

for pack ice (0.011 cm^{-1}) and fast ice near Barrow (0.0219 cm^{-1}) which also contained sediments. Our attempts to correlate the light absorption coefficients with crystal size and orientation were unsuccessful.

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CHAPTER 7

SEASONAL VARIATION IN THE NUTRIENT CHEMISTRY AND CONSERVATIVE CONSTITUENTS IN COASTAL ALASKAN BEAUFORT SEA WATERS

Donald M. Schell

INTRODUCTION

In relation to the warmer waters of the earth, the marine environment of the Arctic is comparatively unknown. Also, by virtue of the fact that most arctic oceanography has been accomplished from large platforms such as icebreakers or floating ice stations (e.g., Fletcher's Ice Island T-3), the preponderance of data collected to date has been obtained from oceanic waters or at least well offshore. Minimal information is available on the physical and chemical processes that occur in the coastal environment of the arctic regions with its severe environmental stresses.

This chapter reports the seasonal response of nutrient concentrations and conservative parameters to the environmental extremes of winter and summer along the Alaskan arctic coast. Information was obtained over the period September 1969 to April 1973, although most data collected was during late spring when conditions are good for travelling over the ice and during the short open water period of late July and August.

Chemical data on the water column of the Beaufort Sea has been reported in detail by Kinney, *et al.*[1] and isolated samplings have been made by others[2,3,4]. Codespoti and Richards[5], in describing the summer nutrient concentrations of the East Siberian and Laptev Seas, noted that the effects of the Lena River on phosphate and nitrate concentrations in the Laptev Sea were pronounced with a severe phosphate deficiency in the fresher waters. Variability in surface nutrients was ascribed primarily to phytoplankton utilization, although N:P ratios in the Laptev Sea were much closer to 15:1 than in the East Siberian Sea where evidence of nitrogen deficiency was found. Data concerning nearshore Alaskan arctic waters is extremely sparse. Arnborg, *et al.* presents data on the major cations and anions entering Harrison Bay via the Colville River and on the suspended sediment load[6,7]. Data regarding nutrient concentrations obtained by the author and colleagues have been described in preliminary reports[8,9], and average nutrient concentrations in Colville delta water samples beneath maximum winter ice has also been reported[10].

SETTING

Geographic Description

The arctic coastline in the study area is characterized by low-lying gently undulating tundra completely under-lain by continuous permafrost. The relief at the edge of the water is gentle along most of the coast with the 6m high bluffs in the vicinity of Cape Simpson representing the extreme. Lagoons and shallow bays comprise most of the coastline between Barrow and Beechey Point, and the approximate location of the 5 fathom (9m) contour varies from 5 miles offshore near Cape Simpson to 15 miles in Harrison Bay (Fig. 1). Much of the shoreline undergoes active thermal and wave erosion during the summer months[11], and the combined effects of ice push and wave action keep the shapes and relief of the offshore islands in transit.

Freshwater addition to the coastal marine water comes primarily from the various rivers and streams of the North Slope which drain into the Arctic Ocean. The largest of these is the Colville River, the major river system in the study area. Colville River flow measurement for

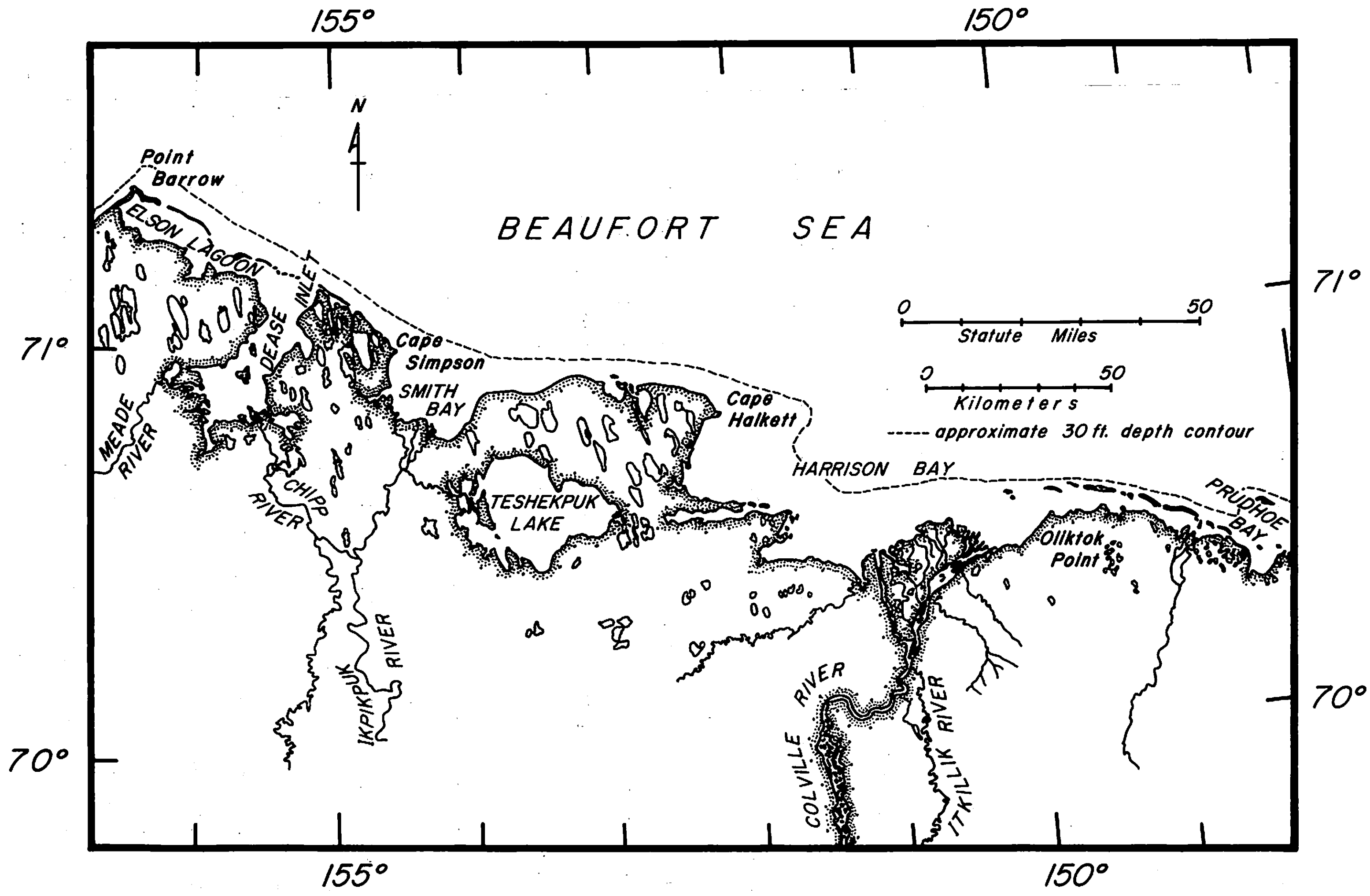

Figure 1. Baseline data study area, Alaska.

the hydrologic year 1962 yielded an input of 16 x 10^9m^3 to the Harrison Bay-Simpson Lagoon area[6].

The Meade River draining into Dease Inlet and the Ikpikpuk River draining into Smith Bay are the two next largest freshwater sources, but these represent a much smaller volume than the Colville.

Climatic Conditions

The entire arctic coast of Alaska is typified by extremely cold maritime climatic conditions. The data for Barrow, although differing slightly from Oliktok Point in response to the more peninsular setting and higher latitude, are similar to locations along the coast and serve to illustrate the environmental conditions. Air temperatures remain below freezing for most of the year, reaching above 0°C on an average of 109 days a year and reaching 0°C or below as a daily minima for 324 days. By February, the coldest monthly mean is attained, -27.9°C. Warming is rapid during May, and by mid-June the average daily temperature reaches freezing. July, the warmest month, has a normal mean of 3.9°C.

Solar radiation is an extremely important climatic and biological factor in the arctic environment. Although the sunlight duration increases rapidly in the spring and becomes continuous at Barrow between 10 May and 3 August, the increased radiation brings a corresponding increase in fog and cloud cover. Solar angles are low and, when coupled with the high albedo of the snow-covered ice, result in low efficiency in heating. The low rate of heating is somewhat offset by the long days, but the latent heat required to remove the ice of winter results in a seasonal lag of over 30 days. Once ice-free, however, the shallow waters respond rapidly to stretches of warm (or cold) weather. By late October, incoming radiation drops to negligible levels, and the sun disappears below the horizon in late November. By 21 December, the

Barrow sun is -4°48' below the horizon at noon, and twilight conditions persist for only 2-3 hours daily.

METHODS

Sampling: Locations and Procedures

The area chosen for study encompassed the nearshore region from Point Barrow, Alaska, southeastward to the eastern end of Simpson Lagoon (Fig. 1). Detailed investigations throughout the annual cycle were made from DEWline Station POW-2 at Oliktok Point and at Point Barrow (Fig. 2). Intermittent year-round work was accomplished from the Naval Arctic Research Laboratory's (NARL) Camp Putu and from the home of Mrs. George Woods in the Colville River delta. A transect of the coastline between Point Barrow and Camp Putu was made utilizing a tractor-train operated by NARL during the maximum ice period of April to May 1971 (Fig. 3). Additional sampling during winter and early spring of the Harrison Bay area and the Colville delta was accomplished using ski-equipped Cessna 180 aircraft.

Water sampling was conducted primarily from either snowmachines and sleds or from small boats. Occasionally a dog team and ski or float equipped aircraft were employed, depending upon the season. The open water season was sufficiently short and the hazards of fog and floating ice great enough so that snowmachines were the preferred transportation.

Water samples were taken with a 2 liter, plastic van Dorn bottle. If sampling was through ice, a gasoline-powered 20cm diameter ice auger was used to drill through the ice. When ice cores were desired, the powerhead was used to drive a SIPRE corer. Two meters of seawater ice could be drilled in 5-10 minutes, although freshwater ice took considerably longer. At air temperatures of -10°C or warmer, transfer of the

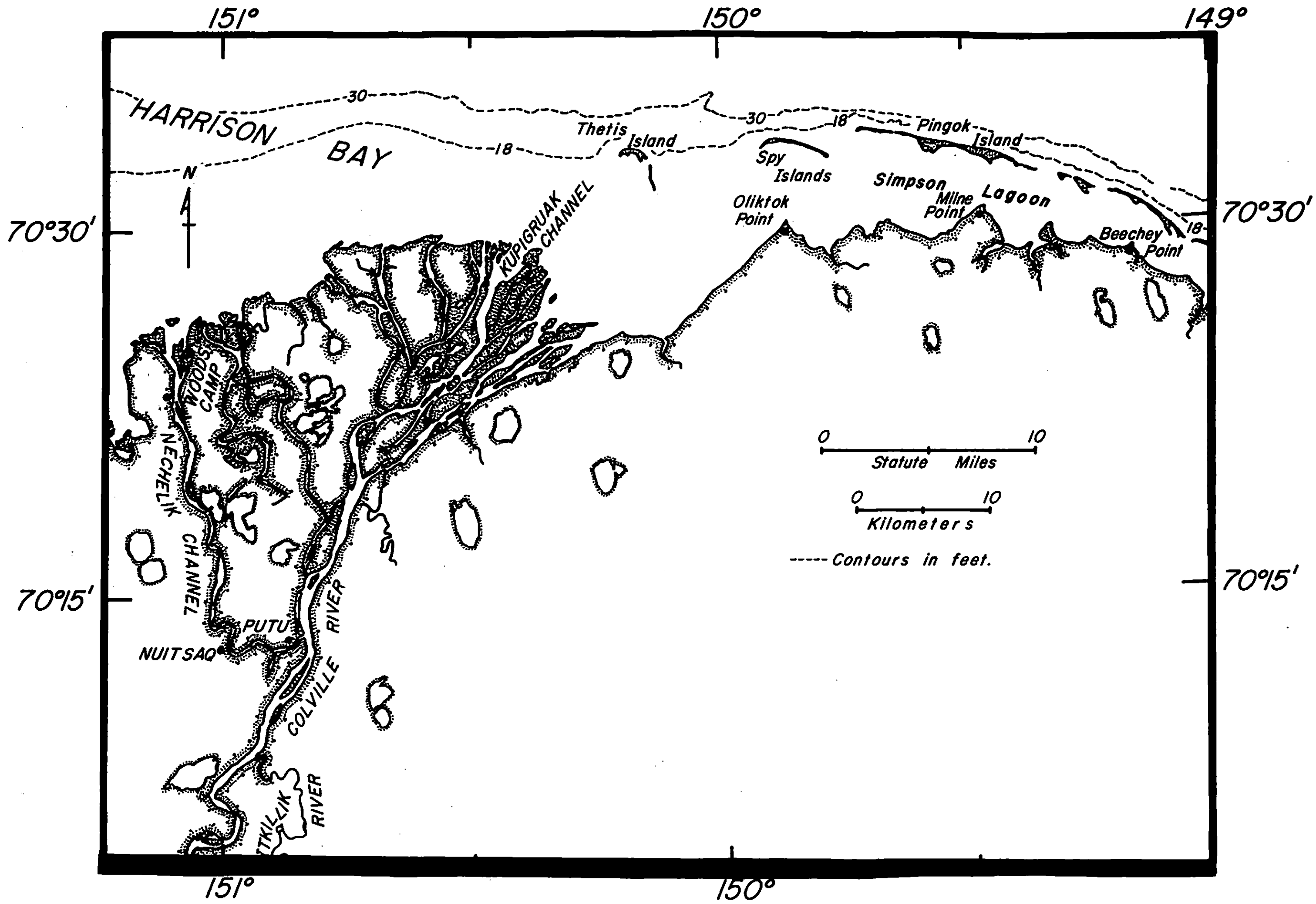

Figure 2. Colville River delta vicinity.

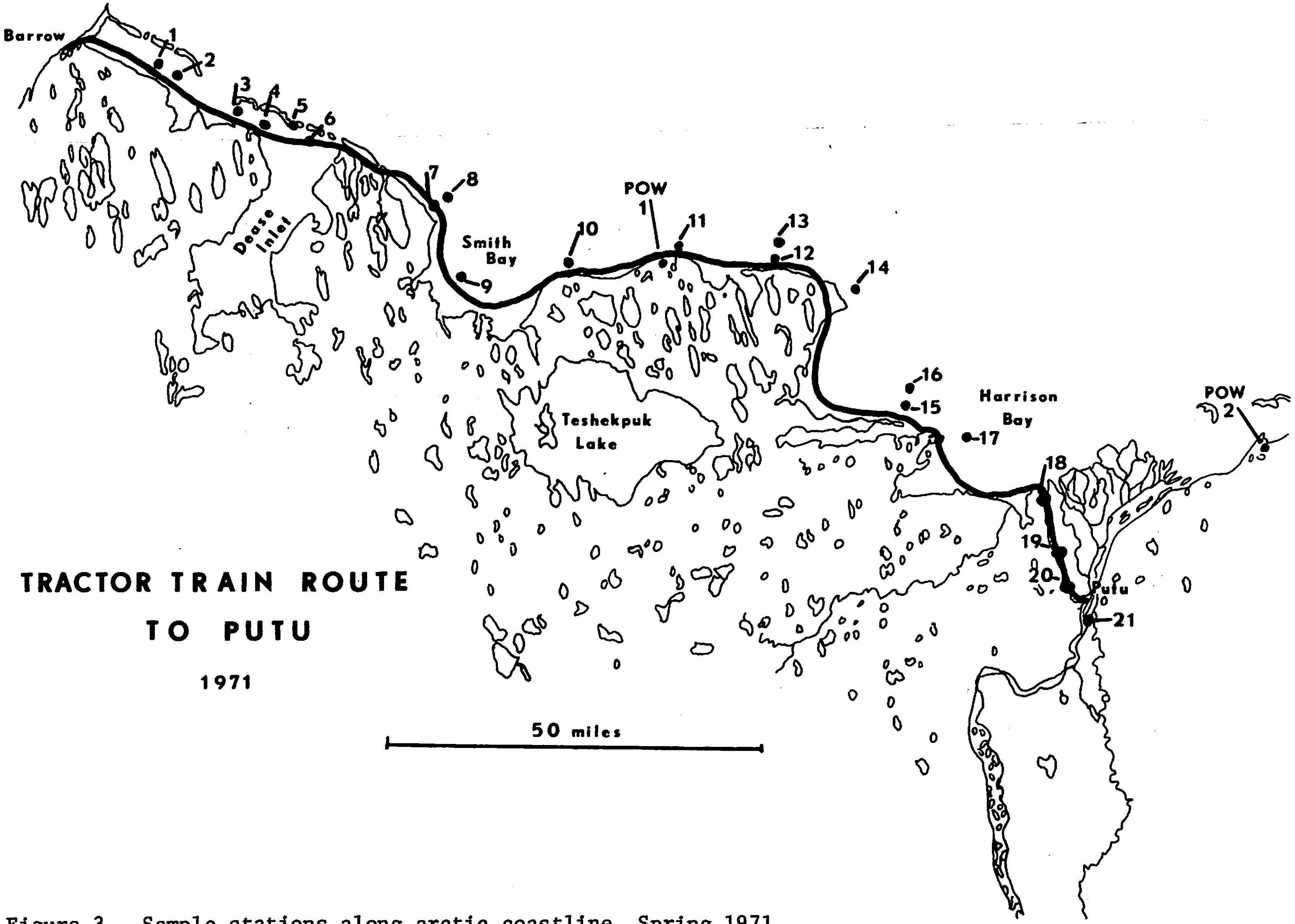

Figure 3. Sample stations along arctic coastline, Spring 1971.

water samples to oxygen bottles or sample bottles presented no difficulties; at lower temperatures the valves and tubing often froze, making accurate dissolved oxygen determinations a problem. At -40°C or colder, ice formation during the rinsing of bottles was sufficient to introduce appreciable error in salinity, and nutrient determinations and collection of dissolved oxygen samples was not attempted. Since several hours often elapsed between sampling and filtering, samples were stored in a wooden box which was heated with pocket hand warmers in cold weather. On returning to base camp, the samples were filtered through glass fiber ultrafilters with gentle suction (<25cm Hg) and the filtered water was frozen immediately. In summer, filtered samples were preserved with $HgCl_2$ (3ppm) if a freezer was not available.

Chemical Analysis

Silicate, phosphate, nitrate and nitrite analyses were determined by the methods of Strickland and Parsons[12] and ammonia by the method of Head[13]. All nutrient analyses were performed on a Technicon Autoanalyzer II system.

Dissolved oxygen was determined with a modified Winkler method[12], and most of the salinity determinations were made using a Beckman model RS-7B salinometer. *In situ* measurements of salinity were determined with a Beckman RS-5 salinometer.

Dissolved organic nitrogen was determined by the method of Strickland and Parsons[12]. Water samples were oxidized in 10ml quartz tubes by a 4 hour irradiation with a 1200 watt Hanovia ultraviolet lamp. Each sample was treated with one drop of 30 percent H_2O_2 prior to irradiation as this was found to shorten the time required for complete photochemical combustion. The irradiation apparatus held 24 tubes, allowing 12 samples to be run in duplicate. Dissolved organic nitrogen was determined by subtracting the initial concentrations of nitrate, nitrite and ammonia from the sum of these parameters following irradiation. Replication between duplicate samples averaged about 5 percent unless large quantities of nitrogen were present (>30μg-atoms N/liter), in which case variability between samples was sometimes as high as 15 percent.

Nitrification and Ammonification Procedures

The nitrification-ammonification experiments were all conducted through direct measurement of changes in nutrient concentrations in samples incubated *in situ* beneath the ice. Five or six one-liter Pyrex bottles, previously aged in seawater, were filled with a water sample and treated as follows: Bottle 1, sample with nothing added; Bottle 2, sample poisoned with $HgCl_2$; Bottles 3-6, innoculated with various substrates such as ammonia, glycine, glutamic acid, and urea in amounts of 5, 10, or 20μg-atoms N/liter.

Samples were incubated for periods ranging from between 30 to 160 days. After filling and innoculating the bottles, they were secured to a length of rope and lowered through a drill-hole in the ice. If the water depth was shallow, the samples were lowered to the bottom and enough weighted rope let down to insure sufficient length for recovery later. The sites were then adequately flagged to allow locating the spot in the winter darkness after several weeks of blowing snow.

Recovery of the samples after incubation was accomplished by drilling a hole close beside the rope and then catching the line beneath the ice with a pole and hook. Upon removal from the water, the samples were all immediately poisoned with $HgCl_2$ and refrigerated until analysis.

RESULTS AND DISCUSSION

Seasonal Variations in Nutrients and the Aqueous Environment

Summer Conditions - Summer in the nearshore arctic is most easily defined as the period of open or near open water. During June, the ice becomes covered with standing water which then erodes melt-holes and drains through and the ice cover breaks free of the beach. The melting ice is of low salinity and low nutrient content and results in the formation of extreme haloclines in the surface water. As melting progresses, the amount of open water increases rapidly, and during the second or third week of July the tides and/or offshore winds clear the remaining ice from the lagoons. The shorefast sea ice outside the lagoons usually melts somewhat slower and begins to move in late July. During any time of the summer, onshore winds can bring pack ice in tight along beaches exposed to the ocean, and this is often the case in the Cape Simpson and Cape Halkett areas. The shallower waters of Smith and Harrison Bay are relatively immune from pack ice intrusion as the larger pieces of ice become grounded and act as barriers against further onshore movement. The smaller pieces that do enter the bays are rapidly eroded by the warmer water and wave action. The major lagoon systems of Elson Lagoon and Simpson Lagoon are similarly subject to pack ice intrusion only in the deeper passes between the barrier islands. Wind-driven mixing of the nearshore waters is effective once the ice cover is removed.

The salinity-depth profiles shown in Figure 4 illustrate the effects of wind-mixing in Simpson Lagoon near Oliktok Point. In spite of the large amount of freshwater entering from the Colville River, the halocline is readily attenuated by mixing. During a period of calm weather, however (e.g. 26 August), the stratification becomes pronounced, only to be destroyed by the resumption of the winds.

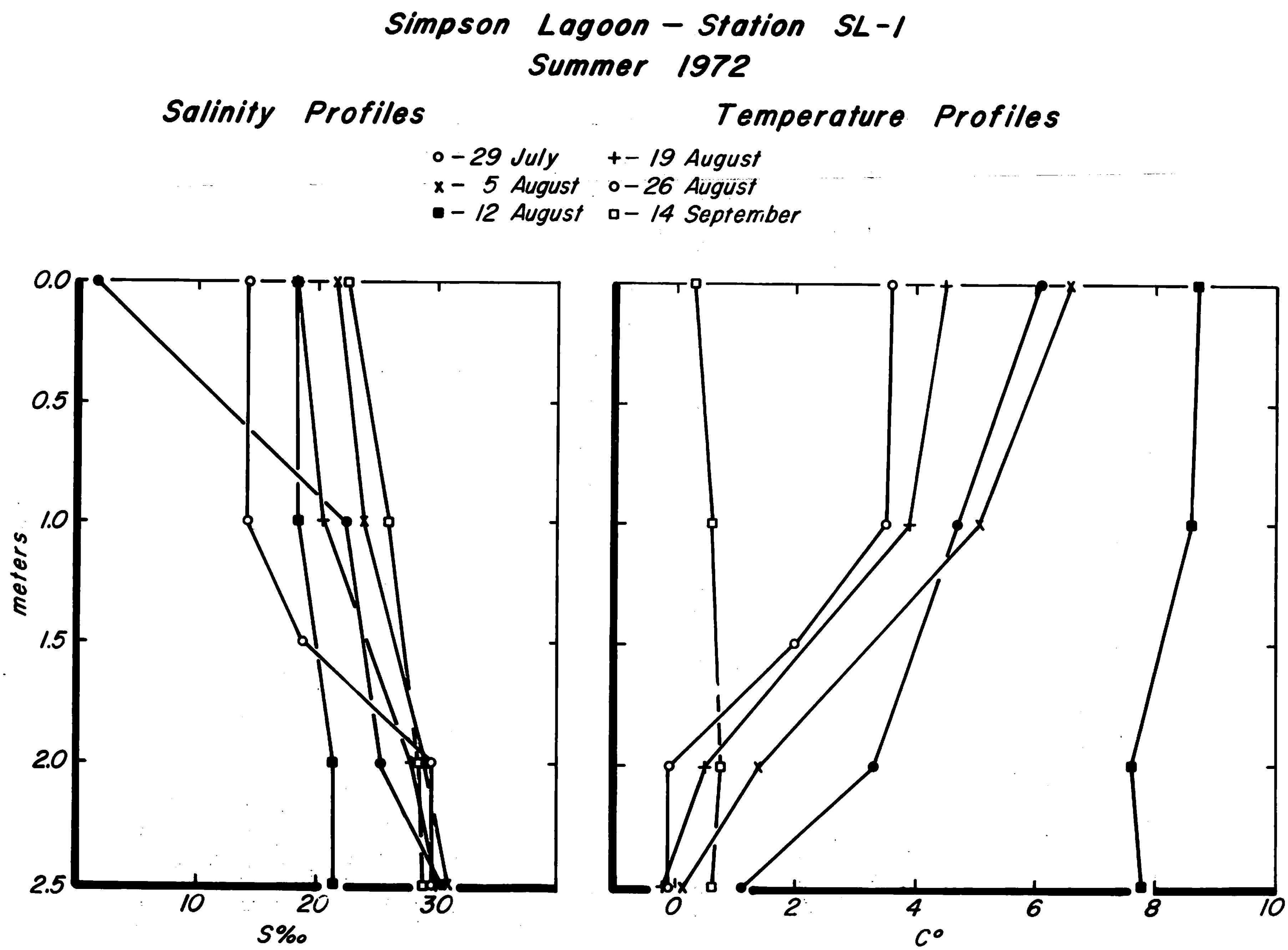

Figure 4. Salinity and temperature profiles, Simpson Lagoon, Summer, 1972.

Salinities for the Harrison Bay-Simpson Lagoon area reflect the high input of freshwater. The Beaufort Sea waters, with salinities near 30 °/₀₀ outside the barrier islands, are represented by samples from near-bottom depths (2.0 - 2.5m) in Simpson Lagoon. As Figure 4 shows, these values are fairly constant throughout the open water period in spite of the considerable variability of the surface layers. In Elson Lagoon near Barrow, the input of freshwater from terrestrial sources is much less than in the Harrison Bay area, and the salinity profiles show pronounced haloclines only during the period of melting ice cover. By late July or early August, the ice cover is gone and the unhindered wind action rapidly mixes the water column to the bottom of the shallow lagoon.

The nutrient regimes of the freshwater and marine environments were found to reflect and respond to the climatic extremes imposed by the harsh climate. Thus, the nutrient chemistry is described below primarily in context with the seasons rather than separately as freshwater or saline environments. In general, the data presented are to describe process effects on the nutrient chemistry rather than detail specific nutrient concentrations at specific locations.

<u>Nitrate-nitrite and ammonia</u> - The information obtained from Elson Lagoon and Simpson Lagoon indicate that the inorganic nitrogen present at the start of summer is rapidly depleted through biological utilization, and concentrations fall to levels that are limiting to many neritic diatoms[14,15]. By August, nitrate-nitrite concentrations represented <0.2μg-atoms N/liter and ammonia, less than 1.0μg-atom N/liter. These values offer no indication of the severity of nutrient limitation in themselves, as the rate of ammonia supply through zooplankton regeneration was not measured (see Chapter 8). In a mass balance context, however, the low concentrations of inorganic nitrogen available during sum-

mer compared to phosphate availability indicate that nitrogenous nutrients are limiting phytoplankton productivity.

Relative to nitrogen, the phosphate concentrations were extremely variable, ranging from approximately 0.1 to 1.0μg-atoms PO_4- P/liter in Elson Lagoon, yielding average N:P ratios of approximately 2.5:1. Samples taken outside of the barrier islands of Simpson Lagoon indicated even more severe nitrogen limitation, with a N:P ratio of approximately 0.5.

Phosphate and silicate - During the summer months, the silicate and phosphate variations in the Harrison Bay-Simpson Lagoon area reflect very strongly the effects of the freshwater addition by the Colville River. Reactive phosphate was extremely low in the freshwater, ranging between 0.04-0.15μg-atom PO_4-P/liter, and averaged about 0.08μg-atom PO_4-P/liter. Many of the freshwater lakes and ponds sampled were below these levels, and phosphate concentrations were near undetectable (see Chapter 8). In the seawater, however, phosphate concentrations were much higher, and ranged between 0.2-0.8μg-atoms/liter PO_4-P/liter. Simpson Lagoon samples averaged approximately 0.3μg-atom PO_4-P/liter or about 0.1μg-atom P/liter less than the average of samples taken outside the barrier islands. Little variation in phosphate concentrations was noted over the course of the open water period.

Silicate concentrations in the Colville River waters were markedly higher than in any of the marine waters sampled. The river water contained silicate at concentrations ranging between 21.0-57.6μg-atoms Si/liter. The highest values were found in zones of initial mixing with seawater and may be due to reactions releasing silicate with clays or polymeric silica in the freshwater.

After mixing with seawater and being transported into Harrison Bay and Simpson Lagoon, the overall silicate concentrations declined markedly. This was due to mixing with the seawater and the increased utilization by phytoplankton. The pronounced stratification that occurred during calm periods as the river flowed out onto Harrison Bay was reflected in the silicate concentrations. Station SL72-1 (26 August 1972) contained 51.1μg-atoms Si/liter in the surface water (1.46 °/oo salinity) and 6.1μg-atoms Si/liter at 2.0m depth (25.27 °/oo).

Although the silicate concentrations are depleted in the offshore waters and were as low as 3.0μg-atoms Si/liter beyond the barrier islands, it is unlikely that silicate is a principal limiting nutrient to the diatom populations in view of the severe nitrogen depletion in these waters. Furthermore, the river water contains such high concentrations of silicate that, upon mixing with the seawater, the resulting available silicate would be in excess of that required by populations stimulated by the input of the inorganic nitrogen contained in the freshwater.

The extreme stability of the summer water column that results from the melting of ice and consequent low surface salinities, coupled with the wind fetch limited by offshore pack ice, prevents effective advection of nutrients from deeper waters. Thus, the only important sources of "new" nitrogen to the nearshore surface waters (<5m) result from terrestrial input. The two major mechanisms contributing to the Simpson Lagoon-Harrison Bay area will be considered below.

Freshwater systems - The nutrient data obtained from a survey of the Colville River between Umiat and the Colville delta revealed that large differences in nutrient concentrations existed when the river waters were compared with the lake and pond waters along the river course. The Colville River, and the Anaktuvuk, Chandler, and Itkillik Rivers at their confluences with the Colville, were compared with ten lakes and ponds sampled near the Colville. These data are presented in detail in Chapter 10. In all cases, nutrient levels were much lower in the ponds than in the turbid waters of the Colville and its tributaries. Most remarkable were the contrasting high nitrate (+ nitrite) concentrations in the Colville River and its tributaries (2.34-4.8μg-atoms NO_3-N/liter) with the almost undetectable nitrate concentrations in the lakes and ponds (0.00-0.45μg-atoms NO_3-N/liter). Two possible sources of the high nitrate concentrations in the river are (1) a lack of biological utilization downstream of high nitrate input at headwater sources (i.e., rain and snowmelt) or (2) derivation from the seepage of groundwater containing high nitrate concentrations into the river. The high nitrate concentrations persist until the water reaches Harrison Bay, whereupon biological utilization removes all of the nitrate present soon after mixing with seawater.

Winter Conditions: Bays and Lagoons - With the onset of freezing in the coastal Arctic, the aqueous habitat undergoes a radical shift in environmental conditions. The continuous daylight, rapid temperature fluctuations and wind-mixing that typify the open-water season are replaced by increasing darkness, temperatures below 0°C and restricted circulation of the water. For nearly six months the increase in ice thickness is virtually linear with time as the thickening ice cover is further cooled by the falling temperatures of winter. Along the coast, ice accretes at approximately 1.0cm/day from about 25 September-1 October to the end of the following March. There is considerable variability as to actual freeze-over dates due to weather conditions and wind stress. Often, two weeks will pass between the appearance of the first new ice around the leeward shores to when the ice completes coverage. Once started, however, freezing can be very fast. On 1 October, 1971, ice was forming on Elson Lagoon and drifting before the wind in air temperatures of -4°C.

On the windward side, ice crystals were forming in open water; but on the leeward side, very loose slush had accumulated to a depth of 10cm. When the wind dropped on 2 October and temperatures continued downward, the ice cover stiffened and consolidated. By 10 October, the entire lagoon with the exception of thin ice in the passes, would support a man and snowmachine. Ice thickness was between 13 to 16cm. Figure 5 shows ice measurements taken at various stations along the arctic coast over 4 winters. These data include those stations away from the effects of bluffs and riverbanks and represent typical ice thicknesses. The variability in thickness caused by differing snow cover and sub-ice conditions is readily apparent as the season progresses. Figure 6 illustrates the process of freshwater ice accretion during freeze-up in the west and east channels of the Colville delta during fall 1972. The similarity during the last three years in total ice accretion is illustrated in Figure 7 which shows the ice thickness of Imikpuk Lake at Barrow. Between freeze-up and 31 March, an average ice accretion rate of 0.94mm/day was found, remarkably close to the rate of seawater ice formation.

<u>Freezing effects on seawater environments</u> - The arctic winter, as in more temperate latitudes, is a period of nutrient replenishment in the upper water column primarily through advective mixing with deep or offshore waters.

The mechanisms, however, are different from those usually responsible for turnover in the water column in warmer climates. Unlike the nearshore waters of southeastern Alaska, for example, the surface temperatures of the coastal marine waters rarely exceed 10°C as summer maxima, and the primary source of stability in the upper waters is the halocline resulting from the melt of nearly 2m of sea ice. Thus, as autumn cooling commences, the stability is not destroyed except in the shallow lagoons where wind mixing is effective and even there formation of ice cover may

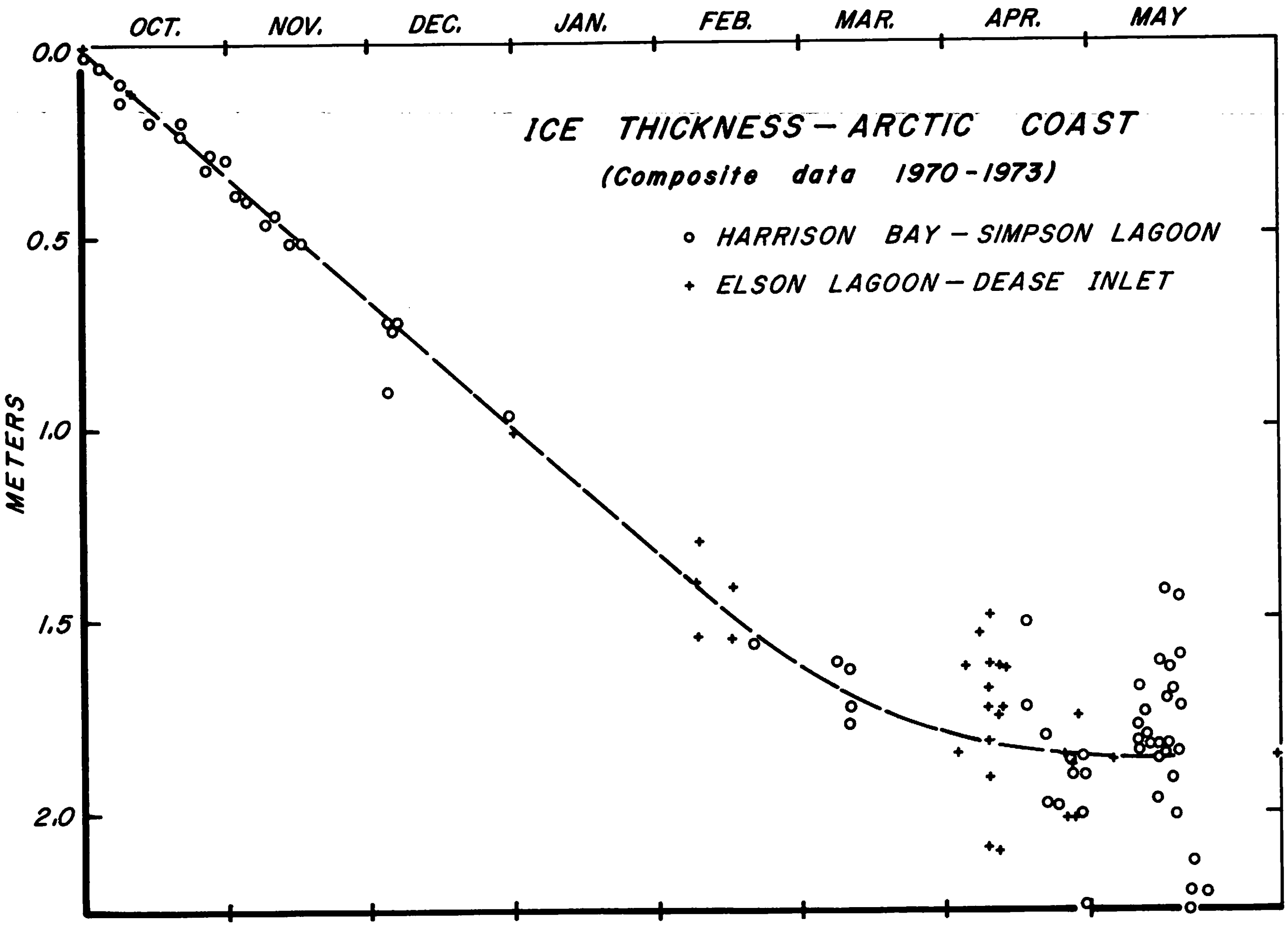

Figure 5. Composite ice thickness data, Arctic Coast.

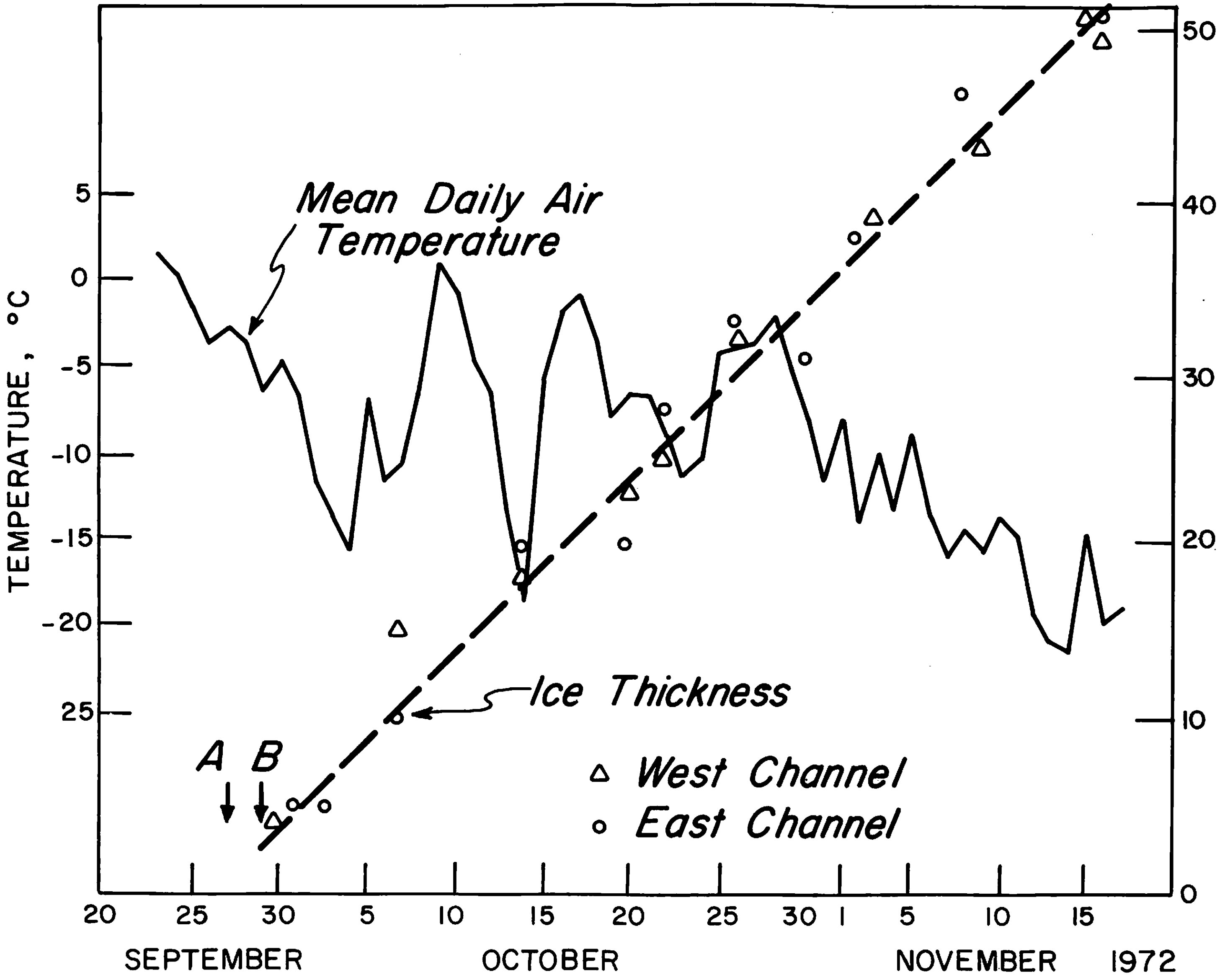

Figure 6. Ice formation and average air temperature at Putu, Colville delta.
A = first complete freeze-over of Nechelik (West) Channel,
B = first freeze-over of East Channel.

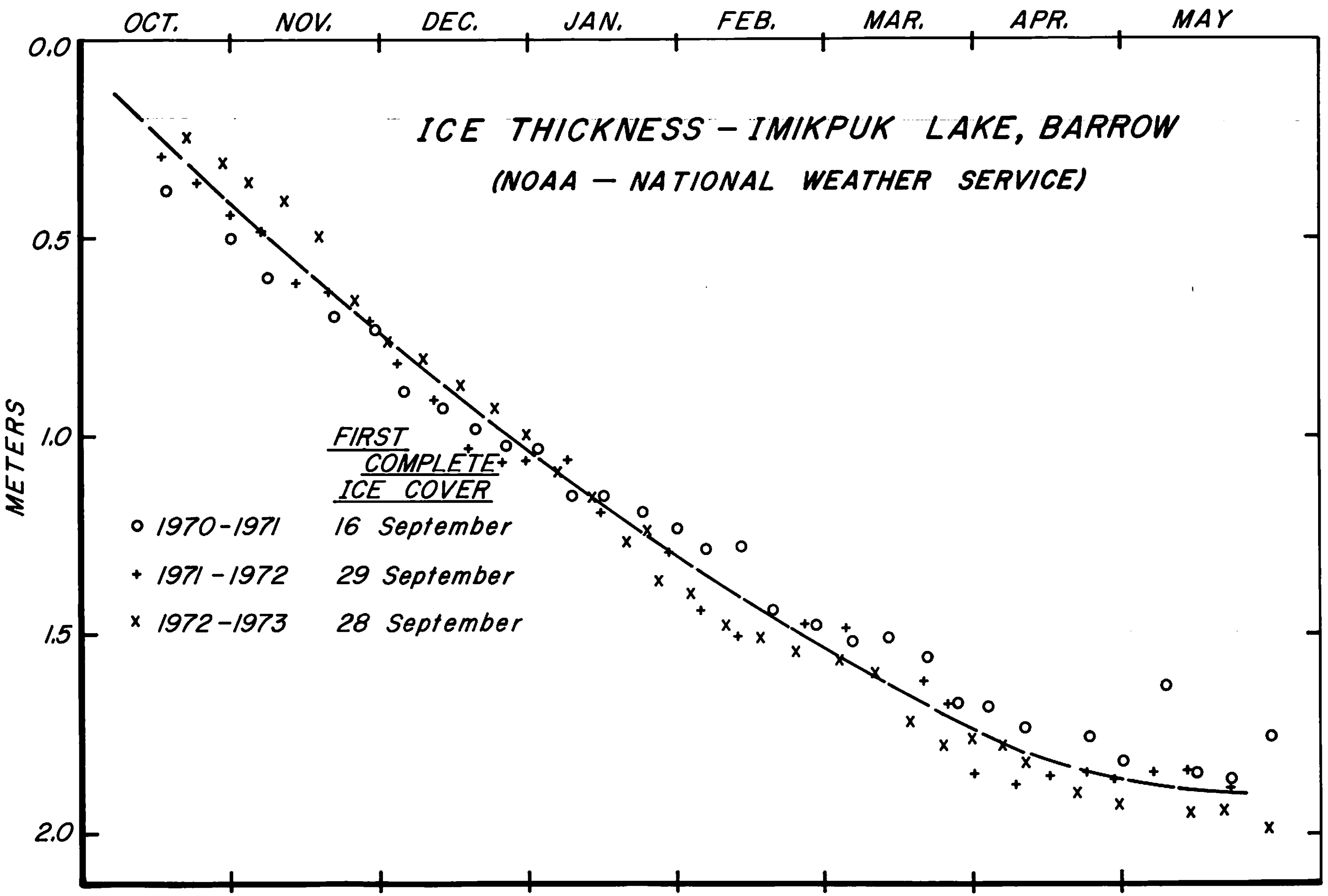

Figure 7. Ice thickness, Imikpuk Lake, Point Barrow.

precede halocline destruction. The appearance of ice radically alters the water structure, however, for the solute segregation during freezing results in a rapid increase in salinity at the surface where cooling is also the fastest. Thus, shortly after the formation of the first new ice, the salinity of the surface water exceeds that of the water below and the process of mixing the water column begins. As temperatures fall and winter progresses, the rapid increase of salinity continues and in the nearshore areas, dynamic exchanges of water between the shallows and offshore balances the rates of freeze-induced salinity increases in the lagoon and nearshore waters. Further offshore, the increase in surface salinity alone serves to cause mixing.

The formation of 2m of ice over the course of the winter has a profound effect on the biological environment of the shallow bays and lagoons of the coastal Arctic. Approximately 80-85 percent of the solutes are excluded in freezing; thus, the potential for rapid increases in salinity is greatest in the shallow waters. As freezing progresses downward, shallow bays become isolated by bottomfast ice or sufficiently restricted to prevent ready exchange of the hypersaline water. Examples of this "psychrogenic hypersalinity" were evident in many water samples taken along the coast during late winter. Figures 8 and 9 show under-ice salinities for Elson Lagoon near Barrow and Dease Inlet, respectively. Offshore salinities under the ice were approximately 30-32 °/₀₀, yet the restricting caused by the barrier islands was readily evident even though the deep passes were open to the sea. The Elson Lagoon data (Fig. 8) show the effect of a shallow bar on the salinity of the waters restricted behind it. Although the narrow channel was open to the lagoon and hence the sea, salinities were nearly doubled progressing to the end of the channel. The two dates of sampling illustrate the rapid rise in salinity as the ice nears the bottom. A hole drilled to 1.0m in the ice over the bar hit brine at the mud-ice interface with a salinity of

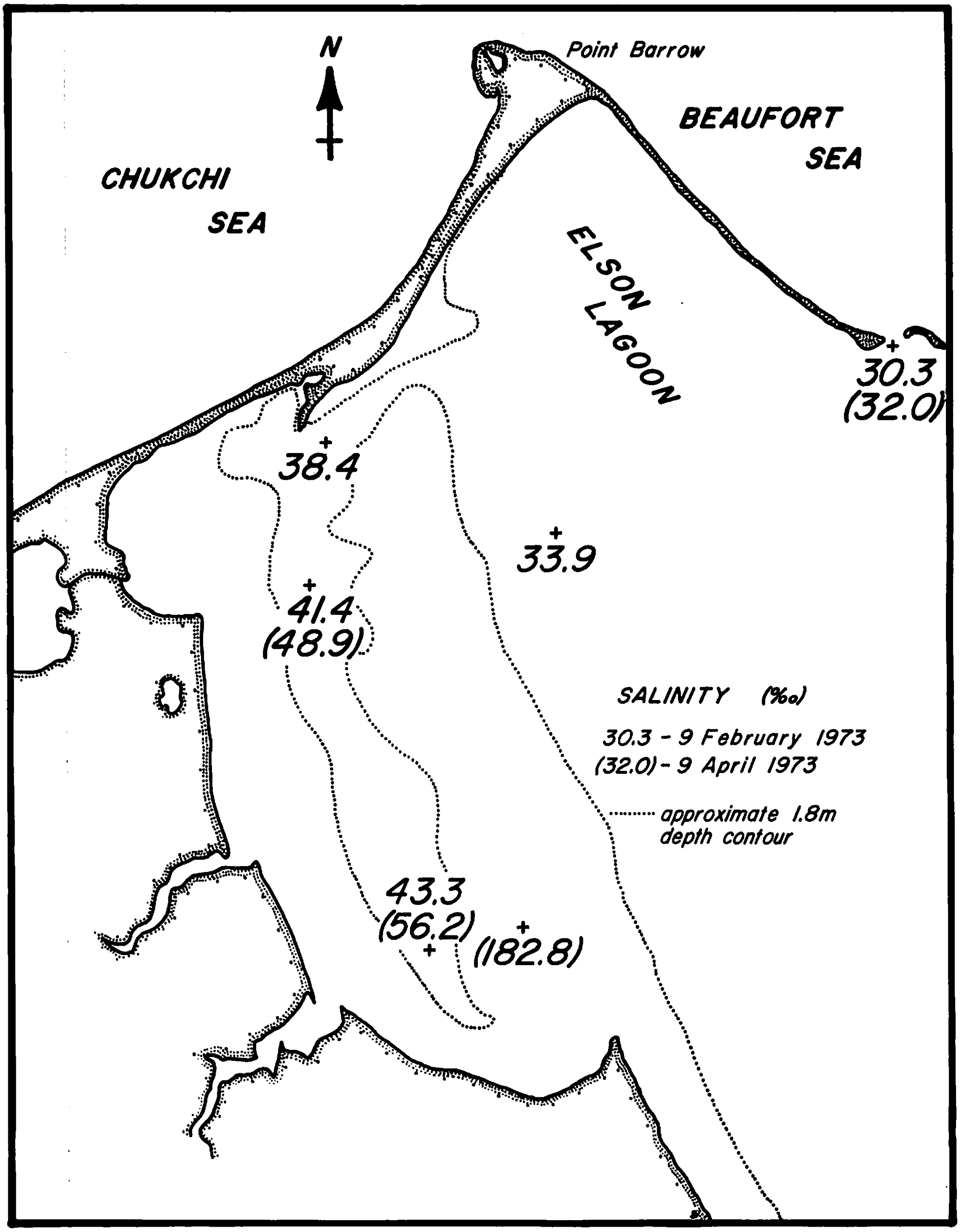

Figure 8. Under-ice salinities, Elson Lagoon.

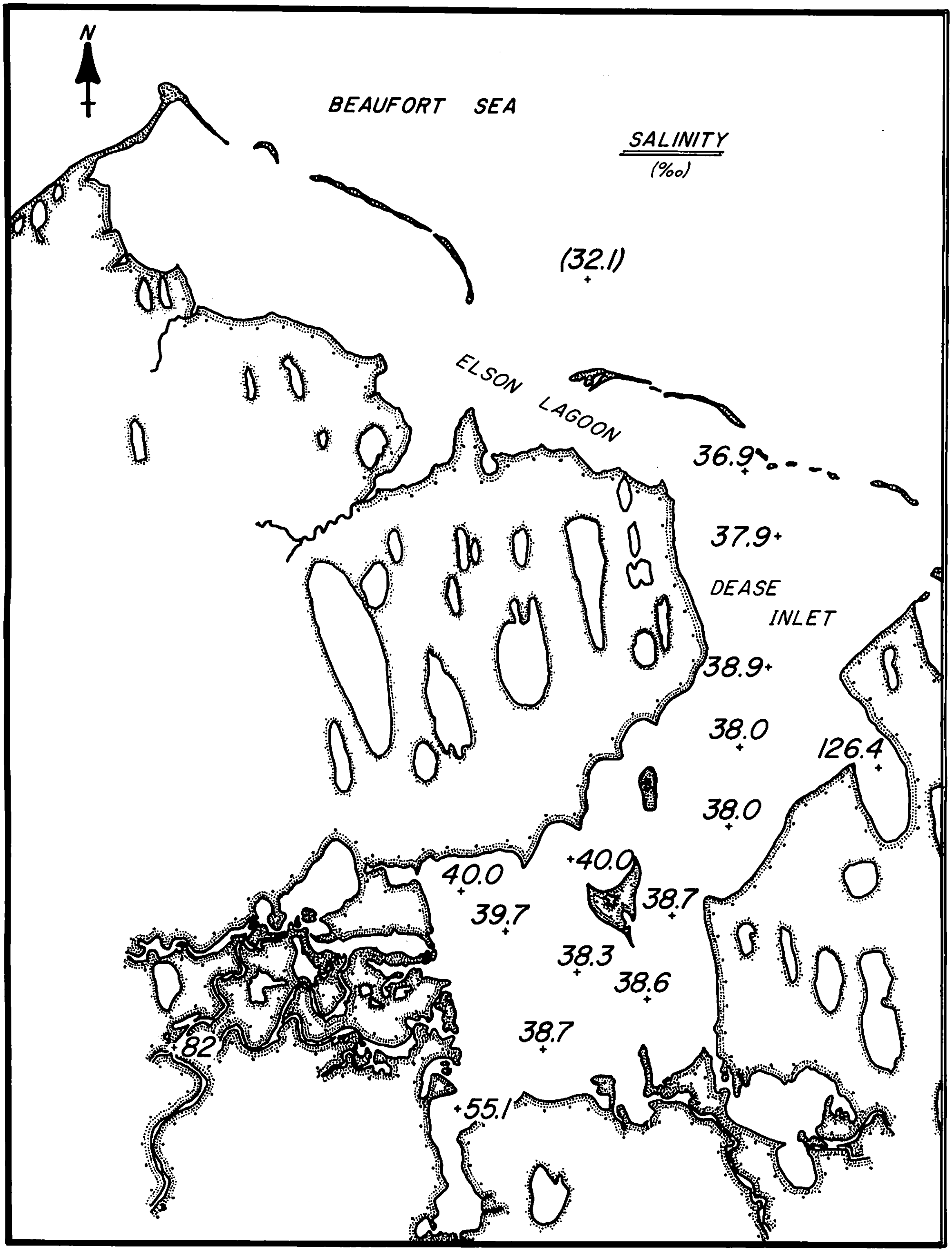

Figure 9. Under ice salinities, Dease Inlet, April 1973.

182.8 °/oo. This brine was at a temperature of -12°C and illustrates the severity of such habitat to benthic organisms.

The Dease Inlet data reflect the combination of active water exchange in the deeper sections and the restriction to circulation in the shallower sections. When the water beneath the ice shallows to less than 0.5m, the effects of freezing are pronounced and psychrogenic hypersalinity soon results as shown by the salinities at the head of the bay. Note that saline intrusion had proceeded at least 20km up the channels of the Meade River, and no fresh water was evident beneath the ice. Since the drainage basin of the Meade River is considerably smaller than that of the Colville River and drains tundra with gentle relief, freezup and complete cessation of flow occurs earlier in the fall; and the river probably has little or no effect on the waters of Dease Inlet after October. Thus, the variations in salinity must be ascribed primarily to freezing effects. Of interest is the small eastern arm of Dease Inlet, Kurgorak Bay, which is shallower at its connection to Dease Inlet. Here a sample of water taken at 1.4m had a salinity of 126.4 °/oo. Only a few cm separated the ice and mud.

Where the access to the open seawater is relatively unrestricted, such as in the central portion of Dease Inlet, the circulation of less saline water into the bay and the draining of the hypersaline water is quite rapid. By assuming a simple vertical-sided shape for Dease Inlet, a mean depth of 2.3m and using a freezing rate of 1.0cm/day, the time required for the water to exchange can be approximated. The measurements of salinity made at 1.6m ice cover show a progressive rise in under-ice salinity from 36.9 °/oo at the entrance to 40.0 °/oo in the more restricted waters near the head of the inlet. Assuming no water movement and an 83 percent exclusion of solutes during freezing, the formation of 10cm ice (10 days) should be reflected in a salinity rise of about 4.3

°/₀₀. Over the entire length of Dease Inlet (excepting Station 14 which was very shallow), however, the measured under-ice salinity increase was only 3.1 °/₀₀, which indicates that the exchange occurs throughout the entire inlet in approximately 7 days. A combination of tidal pumping and density currents must account for the rapid exchange rate. Tidal fluctuations, although averaging only 10-20cm, change a large percentage of the water volume beneath the winter's ice cover. In the case of Dease Inlet, an average tidal amplitude of 15cm represents at least 21 percent of the water volume. Thus the diurnal tides over 7 days serve as ample mechanism to flush the high salinity waters from the head of the bay. The currents induced beneath the ice by the tides must be appreciable as the movement of water out of the inlet in 7 days requires a net current of 5.8cm/sec in the above situation. Larger fluctuations in sea level (50-75cm), which are occasionally induced by wind and barometric pressure changes, would also have very pronounced effects in flushing hypersaline waters from coastal inlets and the shallow bays.

Examples of psychrogenic hypersalinity are obtainable beneath maximum winter ice cover all along the shallow coast in waters of 2.5m or less. Salinities of 60.4 °/₀₀ were recorded in Smith Bay, 65.9 °/₀₀ in Simpson Lagoon and 72 °/₀₀ in Prudhoe Bay[16]. Figure 10 shows under-ice salinities in Simpson Lagoon from May 1971. The severe stress that this cold and extremely saline water would place upon the benthic biota perhaps explains the general dearth of benthic fauna and absence of macrophytes in the nearshore habitats (see Chapter 9.)

Seawater nutrient chemistry - The mixing of the under-ice waters during winter serves to replenish the nutrients depleted during summer and to supply oxygenated water to the shallower environments. The replenishment of nitrogeneous nutrients occurs through several pathways in the nearshore:

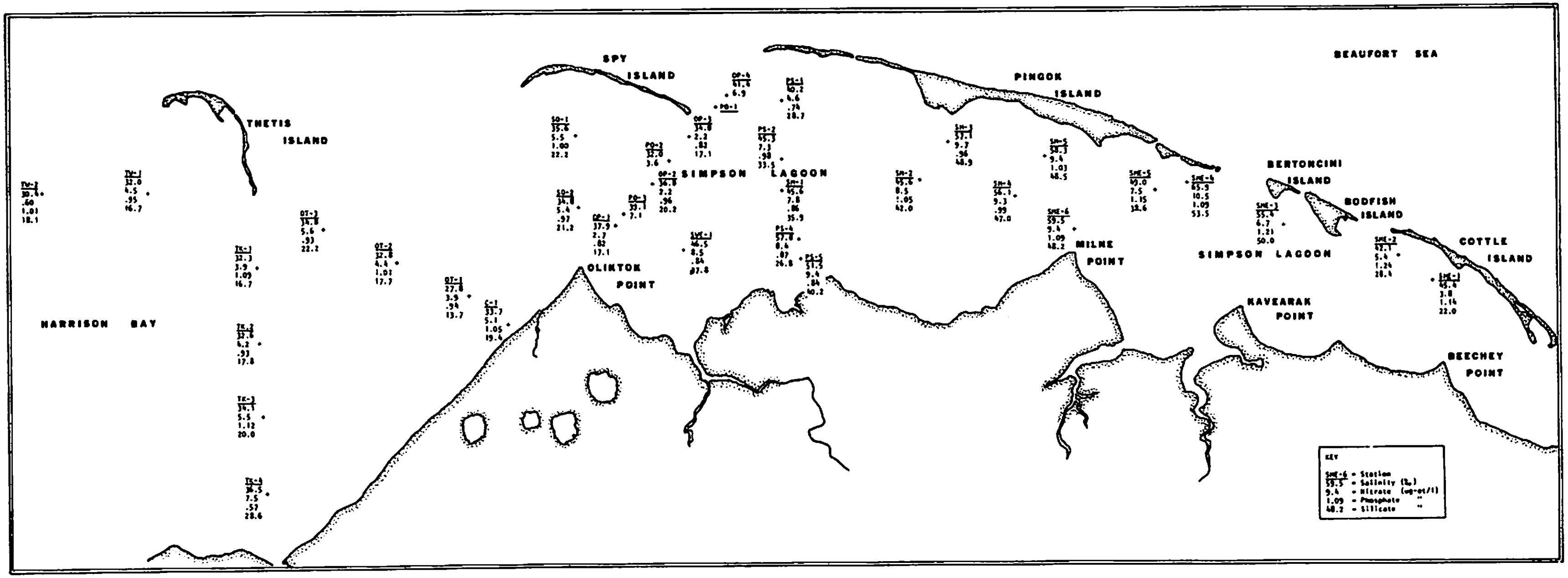

Figure 10. Salinities and nutrients, under-ice waters of Simpson Lagoon, May 1971.

1) Nitrate from deep water is mixed with surface waters.
2) Ammonia is released from zooplankton grazing and is not reassimilated by phytoplankton.
3) Dissolved organic nitrogen is consumed heterotrophically producing ammonia.
4) Nitrification processes convert fractions of the ammonia to nitrate and nitrite.
5) Release of ammonia and dissolved organic nitrogen from detritus and from the sediments is important in some areas.

The regeneration processes occurring *in situ* are discussed below in more detail. The mixing of offshore deep water through exchange with more saline water in the lagoons and inlets results in reasonably uniform nutrient concentrations in waters having access to the open ocean. Figures 11-14 show the distribution of nitrate (+nitrite), ammonia, dissolved organic nitrogen and total dissolved nitrogen in relation to salinity in Dease Inlet (Fig. 9) during April 1973. Ammonia and nitrate + nitrite in general reflected the increase in salinity up the inlet (about 5-8%), whereas the dissolved organic nitrogen concentrations doubled over the length of the inlet. Thus, an input of dissolved organic nitrogen must have been present and this is perhaps the reason for the observed decline in dissolved oxygen (Fig. 15). This rapid increase in dissolved organic nitrogen concentration is perhaps in part due to the shallowness of the southern end of the inlet which would magnify a small rate of addition in the deeper waters of the northern end. It is interesting to note, however, that except for the southernmost sample, the ammonia concentrations were not very high. This implies that little ammonia was being released in spite of the increased carbon respiration as evidenced by the depletion of oxygen shown in Figure 15. The nitrogen may have been converted to a lower molecular weight organic form such as urea.

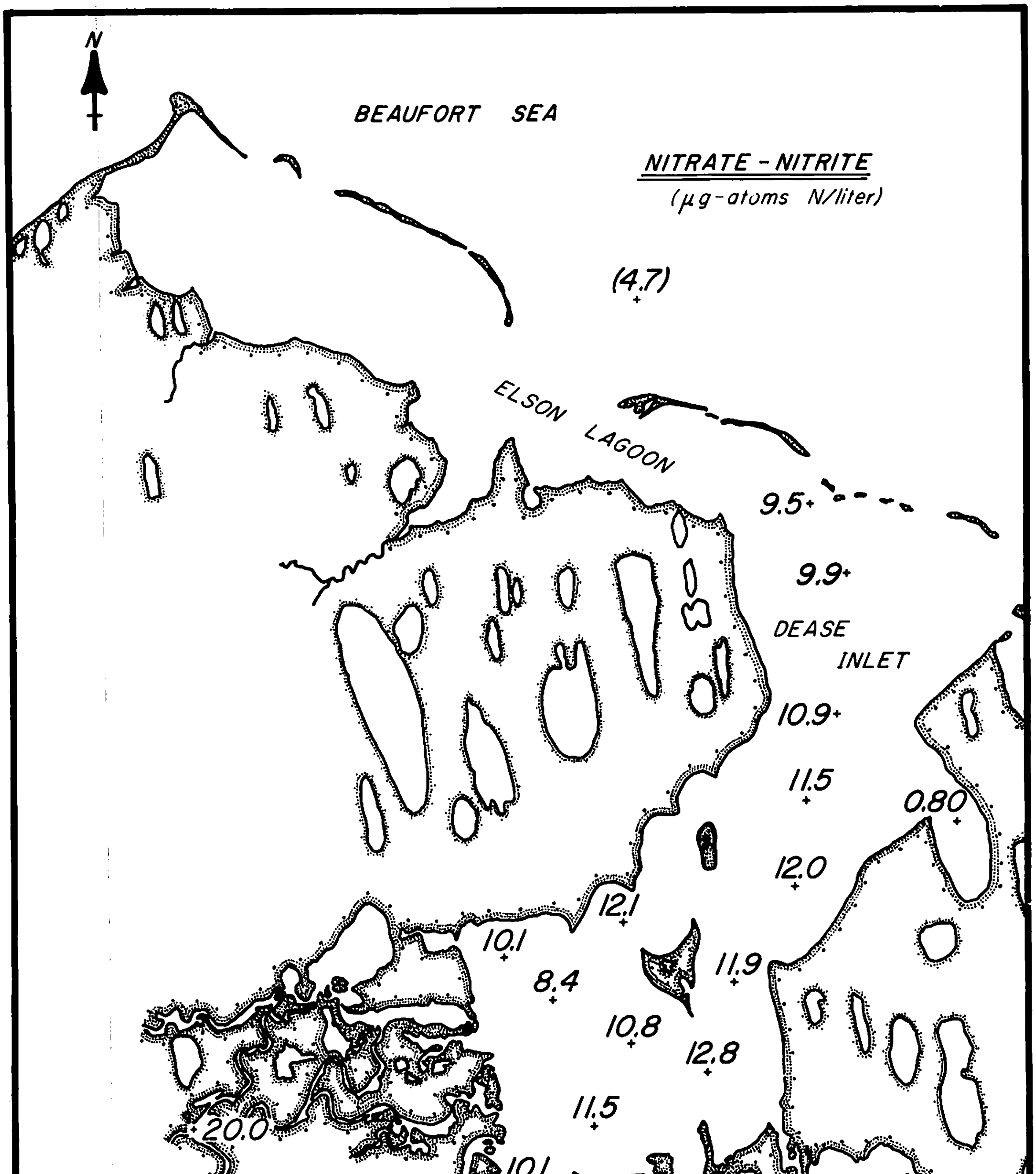

Figure 11. Nitrate and nitrite concentrations, Dease Inlet, April 1973.

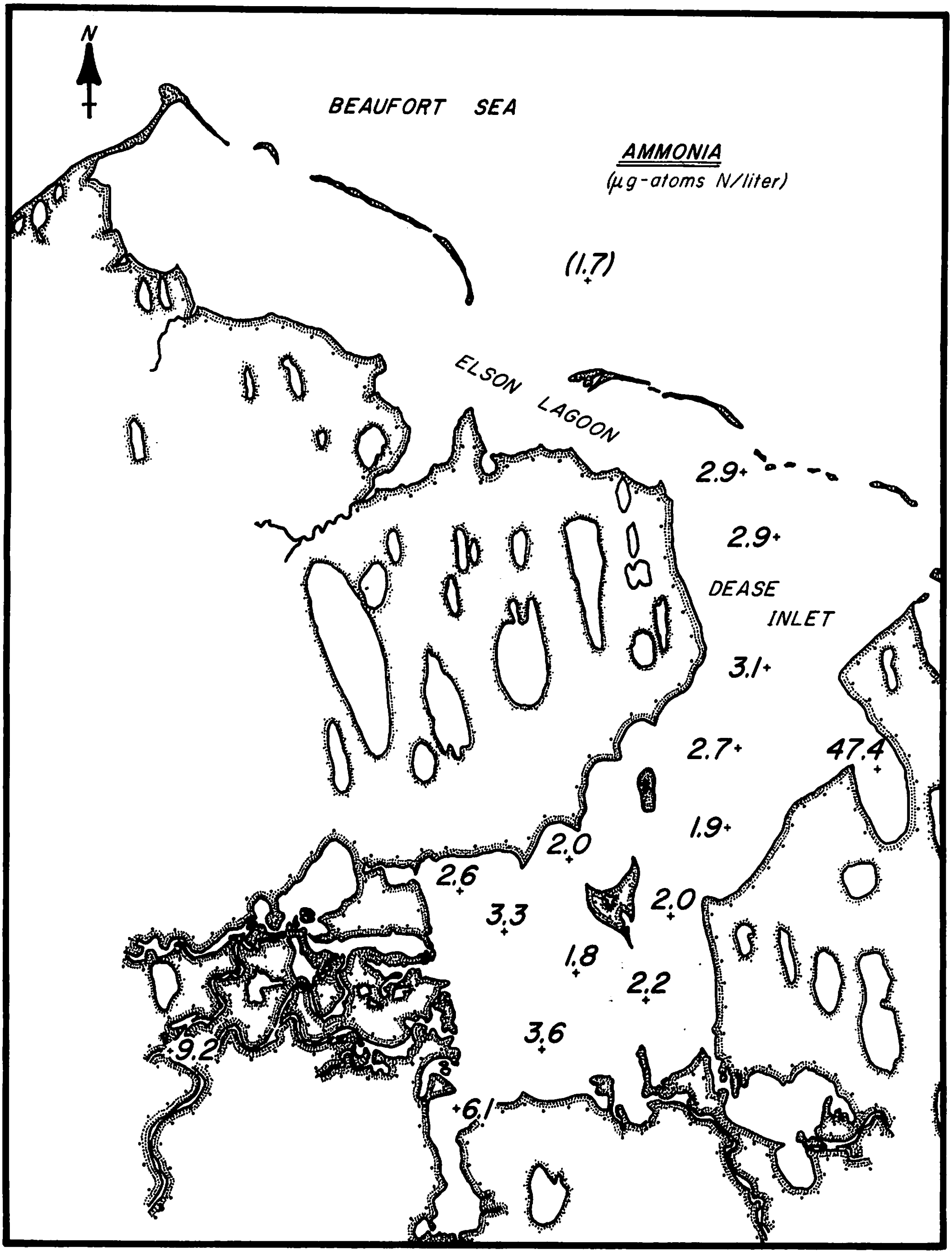

Figure 12. Ammonia concentrations, Dease Inlet, April 1973.

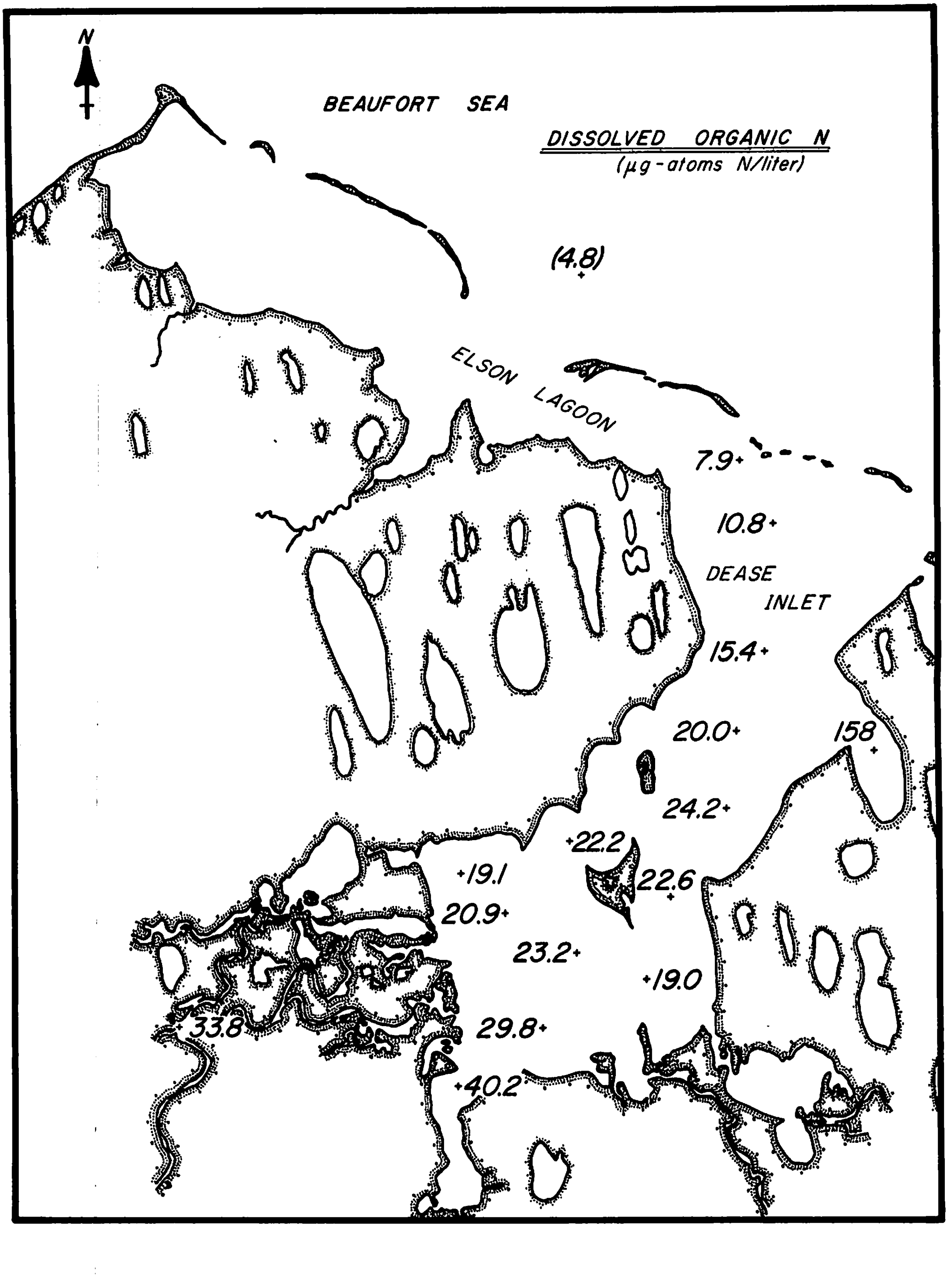

Figure 13. Dissolved organic nitrogen concentrations, Dease Inlet, April 1973.

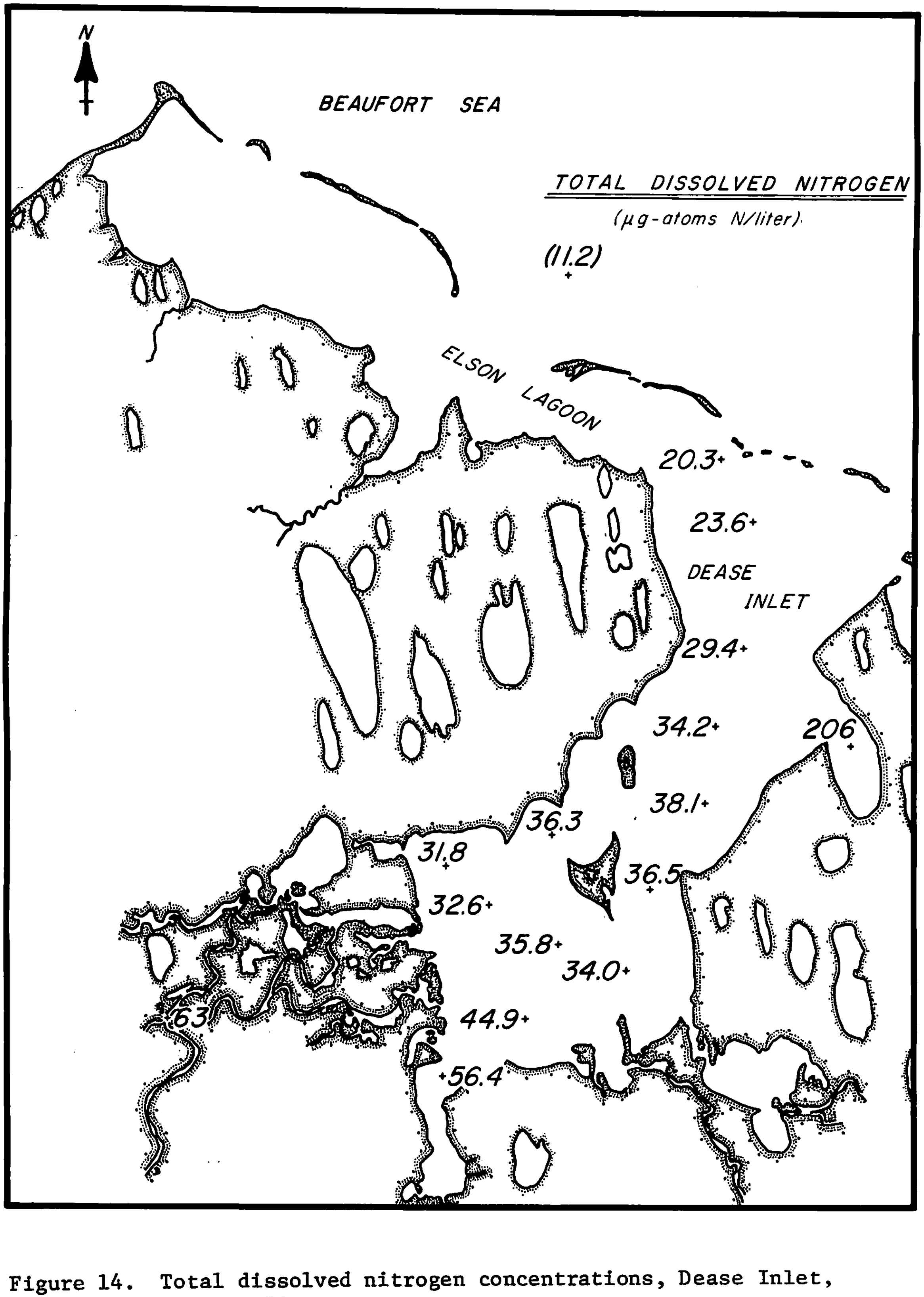

Figure 14. Total dissolved nitrogen concentrations, Dease Inlet, April 1973.

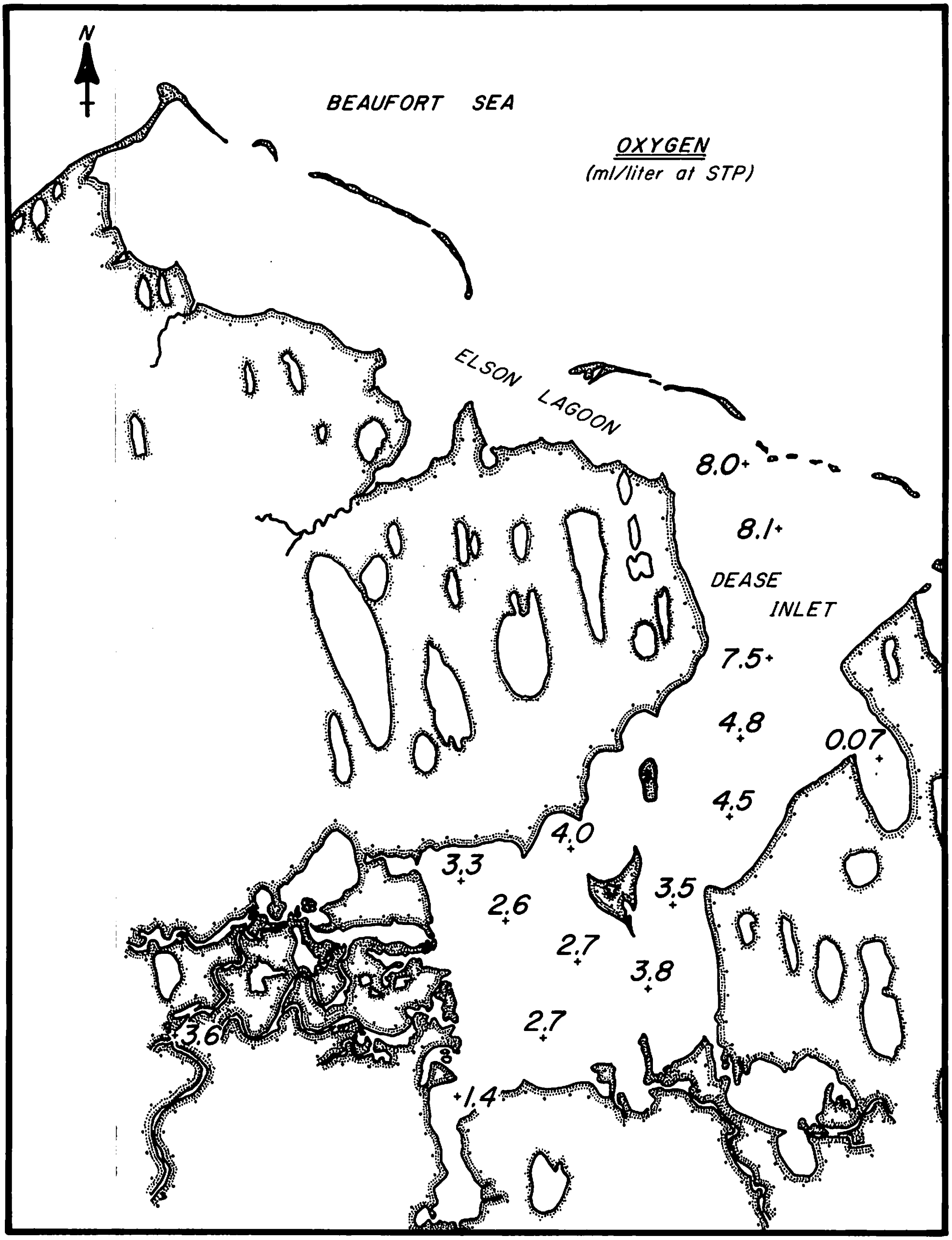

Figure 15. Dissolved oxygen concentrations, Dease Inlet, April 1973.

Phosphate concentrations in Dease Inlet gave strong evidence of uptake in the inlet, as shown by the pattern in Figure 16. This is somewhat surprising although the dissolved oxygen consumption would indicate an active population of heterotrophs present. The lowest phosphate concentration of the Dease Inlet samples was in the low salinity waters of the Meade River which is in line with the general phosphate regime of the freshwaters. Silicate concentrations were conservative over the length of Dease Inlet, generally reflecting the salinities.

Stations monitored over the winter months at Eluitkak Pass near Point Barrow and data obtained from the tractor train traverse of the coastline in April 1971 showed that the concentrations of nutrients in the offshore waters rose to near maximum annual concentrations soon after freezeup in the fall. Thus, although 1 October 1971 samples at Eluitkak Pass yielded undetectable amounts of nitrate-N, by 23 November, the concentrations had risen to 4.3μg-atoms NO_3-N/liter. Concentrations remained near this level until biological uptake became evident the following spring. Similar concentrations were determined from the offshore samples taken on the tractor train, the range spanning 3.15-5.16μg-atoms NO_3-N/liter, in part reflecting freeze concentration in the samples taken closest to shore. Ammonia -N concentrations averaged less than 1.0 μg-atoms NH_3-N/liter for almost all samples taken in offshore waters on the tractor-train.

Under-ice oxygen - Following the formation of a shore-fast ice cover during the fall, the underlying water is isolated from further input of atmospheric oxygen for the winter. Photosynthetic oxygen production is non-existent and remains so until the growth of epontic algal communities commences in the following late April or May. Although biological oxygen demand might therefore be expected to result in a steadily decreasing oxygen concentration in the water column, such is occasionally

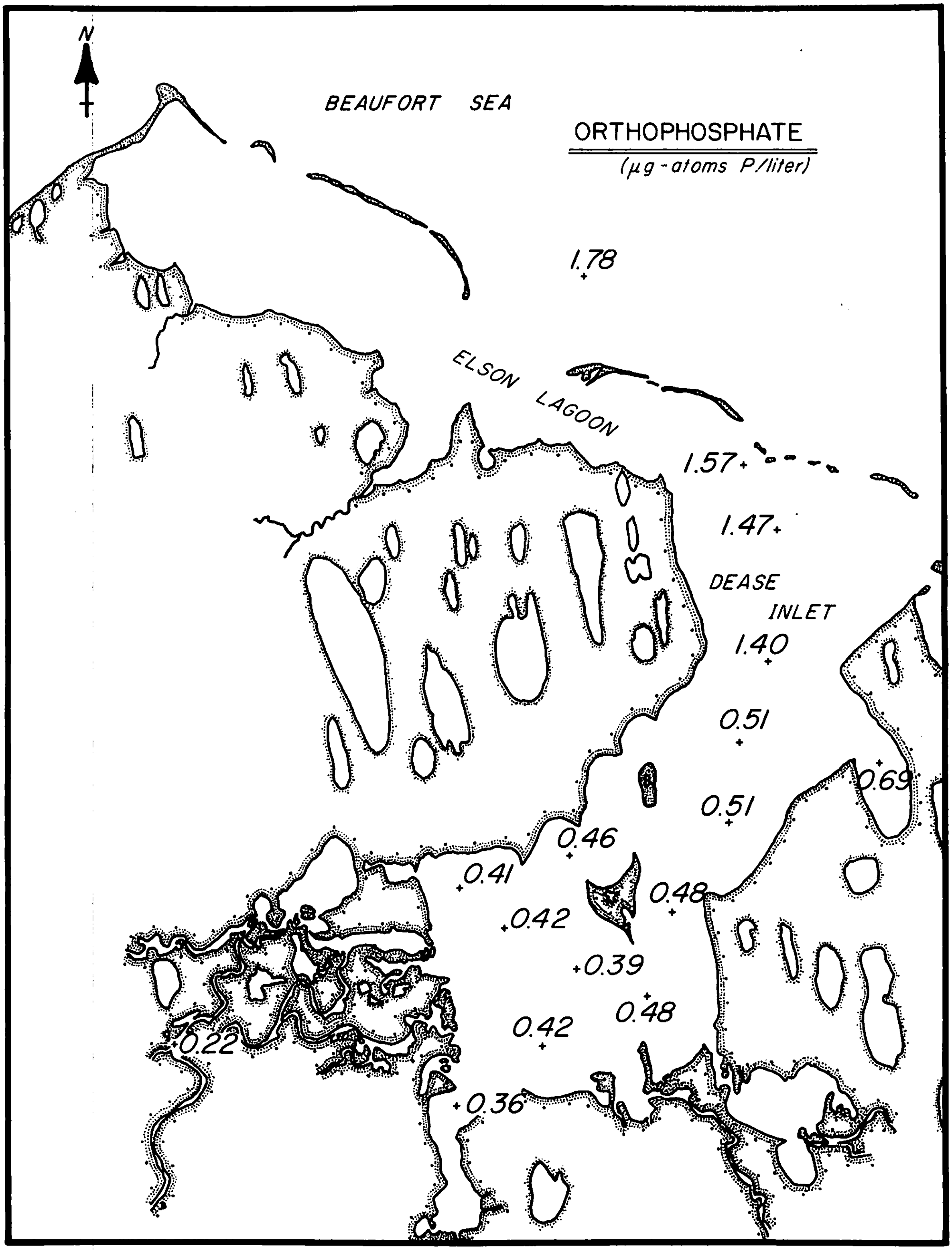

Figure 16. Phosphate concentrations, Dease Inlet, April 1973.

not the case in areas of low biological activity since during the freezing process oxygen is excluded into the water below. Often, therefore, oxygen tensions can remain high throughout the winter in nearshore arctic waters. If the rate of utilization is very low, oxygen concentrations can measurably increase during winter although in most cases, consumption exceeds concentration by freezing and the oxygen levels decrease.

Oxygen data collected at stations along the coastal Beaufort Sea in late April 1971 (Fig. 3) reflect the wide range of concentrations resulting from the combination of biological consumption and freeze concentration processes. At Stations 7, 8, and 10-14, in which the under-ice water was in ready exchange with offshore waters, dissolved oxygen concentrations were relatively high, ranging between 5.65 to 6.80ml O_2/liter. At stations in more restricted waters such as in Elson Lagoon (Stations 1-5) and nearshore Harrison Bay, (Stations 15-17) the range dropped to between 4.33 to 5.72ml O_2/liter and the lowest values, from either isolated hypersaline waters (Stations 6, 9) or from the channels of the Colville delta ranged from 1.79 to 3.73ml O_2/liter. It is interesting to note, however, that at none of the stations in Figure 3 were anoxic waters encountered.

Oxygen tensions approaching undetectable concentrations were never found in waters that were relatively unrestricted and in only one case in saline waters, Kurgorak Bay on the eastern side of Dease Inlet (Fig. 15). This instance represents an extreme case of isolation and freeze concentration and is not typical of the lagoons or inlets where circulation, however limited, occurs beneath the ice. In comparing the relative concentrations of nitrate and ammonia in the Kurgorak Bay sample with others in Dease Inlet, there are strong implications that nitrate reduction and the production of ammonia has also occurred.

The overall pattern of oxygen concentrations in Dease Inlet reflects the isolation of the seawater from atmospheric input of oxygen and the distance from the oxygenated waters derived from offshore. Although it is tempting to speculate that if Dease Inlet were longer, the waters would at some point become anoxic, the decrease in oxygen probably also reflects in part the decreasing depth and perhaps an increase in organic content of bottom sediments at the southern end. It should be noted that although saline intrusion had occurred at least 20km up the delta channels of the Meade River, the average oxygen concentration was 3.6 ml O_2/liter in the one deep channel sampled.

Winter Conditions: Freshwater Systems - The data acquired on freshwater systems during the winter months are extremely limited. The shallow ponds freeze solid and few large lakes were readily accessible from Oliktok. The Colville delta channels become totally saline during early winter after the river flow ceases and the freshwater is replaced by seawater. Freshwater could be obtained only by traveling several kilometers upstream from the delta. However, Lake II near Woods Camp and the Colville River were sampled during the early spring and late fall, 1972. The data thus obtained gives some insight into the nutrient chemistry during winter months. Nitrate (+nitrite) concentrations in the freshwater of the Colville River increased over the course of the winter. The range for freshwater samples taken during November 1972 at the confluence of the Itkillik River and 6km further upstream was 8.48-9.90 μg-atoms NO_3-N/liter, with an average concentration of 8.97 (n=10). Ammonia-N concentrations were much lower, between 0.4 to 1.4μg-atoms/liter, averaging 0.5 (n=10). Phosphate concentrations ranged from undetectable to 0.12μg-atoms P/liter with the average value, 0.05.

Nitrogenous nutrient concentrations were higher in spring samples than those from fall. Samples collected during April and May from the Colville at three locations upriver from the confluence with the Itkillik River contained nitrate in the range 24.8-42.5μg-atoms NO_3-N/liter and ammonia-N concentrations of 0.7 to 7.0μg-atoms/liter. The higher levels of inorganic N in the spring samples probably reflect concentration by freezing processes over the winter. Since the above samples represent different hydrologic years, however, the extent of the freeze-concentration effects cannot be ascertained.

The nutrient concentrations in lakewater samples from Lake II at Woods Camp showed the effects of isolation and oxygen depletion during overwintering. In November, 1971, the average nitrate-N concentration was 2.5μg-atoms/liter - by 12 April 1972, 17.2; by 21 May, 3.6; and by 26 May, 3.1μg-atoms NO_3-N/liter. The ammonia concentrations for the same dates, in order: 3.1, 4.7, 8.8 and 12.5μg-atoms NH_3-N/liter. Oxygen measurements showed 1.1ml O_2/liter on 12 April and one subsequent measurement (21 May) gave near undetectable oxygen. Apparently nitrification and freeze concentration increased nitrate concentrations over winter with concurrent oxygen depletion until at some point in April the lake became anoxic. Nitrate reduction and the production of ammonia followed. Unfortunately, no other lakes in the delta were investigated so it cannot be determined if this shift to anoxic conditions is typical of arctic lakes of this general size. Similar regimes have been described, however in subarctic lakes of the Alaskan interior[17].
Data on oxygen concentrations in the freshwater system are largely confined to the Colville River channels during late Fall with lesser comparative data collected in the spring which probably represent oxygen minima for these locations.

Table 1 shows oxygen concentrations in the East and Nechelik Channels of the Colville delta at Putu during fall of 1972. At the end of the sampling period, saline waters had intruded to this point and contained

Table 1. DISSOLVED OXYGEN, COLVILLE DELTA, FALL 1972

STATION PUTU - EAST				STATION PUTU - WEST			
Date	Depth, m	Salinity, S °/oo	Oxygen, ml/liter STP	Date	Depth, m	Salinity, S °/oo	Oxygen, ml/liter STP
24 Sep	0	<0.2	4.87	24 Sep	0	<0.2	5.05
	2	(Fresh	5.12		2	--	5.05
	4	water)	4.91		4	--	5.01
7 Oct	0	--	4.94	7 Oct	0	--	5.36
	2	--	4.94		2	--	5.22
	4	--	4.98		5.5	--	5.26
14 Oct	0	--	4.87	14 Oct	0	--	5.05
	2	--	4.87		2	0.89	4.91
	4	--	4.91		5.5	3.46	4.49
20 Oct	0	--	4.71	20 Oct	0	0.33	5.22
	2	--	4.56		2	4.12	4.31
	4	--	4.56		4	6.59	4.21
	6.5	--	4.49		5.5	7.93	4.17
2 Nov	0	--	4.52	2 Nov	0	2.18	4.77
	2	--	4.52		2	12.36	3.96
	4	7.67	4.21		4	13.23	3.86
	6.5	9.67	4.07		8.8	13.50	3.93
8 Nov	0	0.42	4.52	9 Nov	0	3.03	5.05
	2	0.18	4.70		2	12.91	3.58
	4	5.31	4.14		4	13.74	3.72
	6.2	8.59	4.10		8.2	13.96	3.65
15 Nov	0	0.14	4.59	15 Nov	0	4.30	--
	2	0.16	4.63		2	13.58	3.61
	4	6.85	4.35		4	14.14	3.58
	6	8.62	3.96		9	14.28	3.54

sharply lower oxygen concentrations. By April and May, oxygen concentrations in the freshwater environments became minimal although no river samples were found to be anoxic. Lake II, as previously described, became anoxic at this time but oxygen samples in freshwater of the Colville River in April 1972 contained 3.91 O_2/liter at locations approximately 12km and 17km upriver from the confluence with the Itkillik River. In brackish water at the mouth of the Itkillik River, S ‰ = 11.4 - 16.1) oxygen concentrations ranged from 3.78ml O_2/liter at the under-ice surface to 3.50 at 5.5m depth. Sampling at the same site in April 1973, however, yielded oxygen concentrations of only 1.61 - 2.30 ml O_2/liter indicating large year-to-year variability. Salinity values in 1973 were higher (14.8 - 18.0 ‰) but a downstream station at Putu with salinities between 23.8 and 24.2 ‰ contained oxygen concentrations of 3.85-4.27ml O_2/liter indicating that advection of more saline water upstream was not the cause of lowered oxygen tensions. The presence of fish populations near the mouth of the Itkillik River was confirmed by netting efforts in April 1973 and may be the cause of the lowered oxygen concentrations.

Nutrient Addition To Nearshore Waters

Nutrient Input from the Colville Drainage System - Considerable inorganic nitrogen is added to the Harrison Bay area via the Colville River. The turbidity and extreme phosphate deficiency of the river are apparently sufficient to prevent much biological consumption of inorganic nitrogen in the river waters and the nutrient levels entering the coastal waters are relatively high, ranging between 3.6 to 6.9μg-atoms inorganic-N/1. Phosphate concentrations remained very low, between 0.02 to 0.18μg-atoms P/1 and averaged only 0.08μg-atoms P/liter. Thus the river water had an average N:P ratio of 53:1. The seven sampling intervals ranged from break-up until after new ice cover had formed in the fall and although closely spaced sampling was not performed during the maximum flood at break-up, the variations in concentration were sufficiently limited to feel the above values are representative. If the total annual discharge for 1971 is taken using the volume given by Walker[18] at $9.7 \times 10^9 m^3$ this implies an addition of 557 metric tons of inorganic fixed nitrogen to the adjacent coastal environment. This nitrogen is rapidly assimilated in the nearshore area as evidenced by the rapid depletion in the low salinity waters of Simpson Lagoon and Harrison Bay.

Input of Nitrogen by Erosional Processes - Another source of nutrients to the nearshore waters results from the active erosion of the shorelines bordering much of the Arctic coast. Leffingwell[19] describes peak wave and thaw induced erosional rates at near 9m/year for Flaxman Island and as high as 30.5m/year at Cape Simpson and Point Drew. These rates were exceptionally rapid and most areas were either stable or eroding at rates of only a few meters/year. Erosion of the Elson Lagoon shoreline averaged 1.3m/year over a 20 year period[20] based on field measurements and the comparison of aerial photographs.

Studies of erosional rates in Simpson Lagoon and the resulting input of nitrogenous nutrients were undertaken during the summer of 1972. Vertical sections of actively eroding bluffs were taken and from the aerial photography of the shoreline, an average shoreline retreat of 1.4m/year was calculated for the previous 22 or 23 years at 62 stations between Beechey Point and a location approximately 4km southwest of Oliktok.

The processes are in a sense constant and not catastrophic as major storms are a normal component of the Arctic environment. From shoreline elevations, which ranged from stable beaches of very low relief to bluffs of 2.5 to 4.4 meters in height, approximate volumes of eroded material were calculated. In the 40.5km of coastline investigated, 9.7 km were stable sandy-gravel beaches, 1.3km of estuaries, 16.6km of low ground lacustrine beds (0.4 - 2.0) and 12.9km of high ground

(>2.0m). The composition of both the low-ground lacustrine beds and the high-ground materials were essentially similar with the top 1-2 meters being peats, lacustrine silts and ground ice. Underlying the peats and silt were usually coarse grained sandy soils of low nutrient content. Analyses of a vertical section of the tundra bluff at Oliktok Point are presented in Figure 17. Of particular interest are the high nitrate concentrations in the top of Oliktok Soil Section #1. Apparently nitrification of ammonia derived from organic material is an important process in well-drained arctic soils in spite of the low temperatures present. Similar high nitrate concentrations were found at Milne Point and Oliktok Soil Section #2 surface samples.

In order to estimate the input of nitrogen to the lagoon system, several assumptions were made based on preliminary data obtained along the lagoon coast.

1) There is no erosional input from stable gravel or sand beaches.
2) There is no input through erosional processes in the 1.3km of estuaries. The drainages emptying into Simpson Lagoon between Beechey Point and Oliktok are very small and the input via these sources is probably insignificant during the open water season.
3) The low tundra (old lacustrine beds) was estimated to have an average relief above sea level of 1.5m.
4) The organic mat and peat layer was estimated at 1.0m thick and below this depth was assumed to be mineral soils typical of Oliktok Section 1.
5) Bulk densities of 1.1g/cc for organic peats and 2.5g/cc for mineral soils were assigned.
6) Once eroded, the soils were assumed to be worked to 0.5m below mean sea level.
7) Nutrient concentrations of the Oliktok Section 1 are typical for that area.

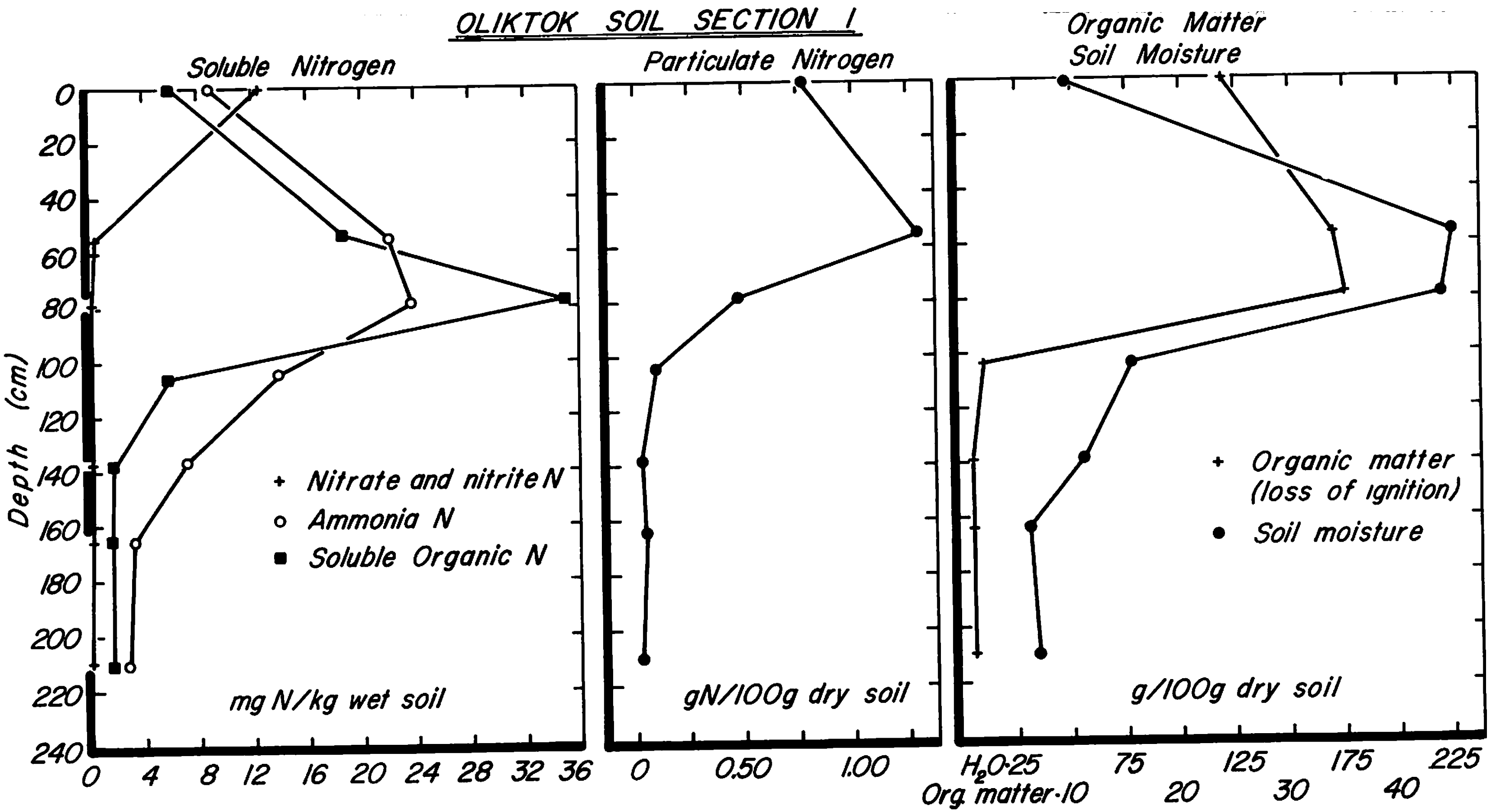

Figure 17. Nitrogen, water, and organic matter content of Oliktok soil.

Similar assumptions were used in calculating the erosion of the 12.9km of "high" tundra except the peat layer was taken at 1.5m thick and the average relief above sea level was taken as 3.0m. Although these assumptions leave considerable room for error, the uniformity of the geomorphological processes acting on the low tundra of this section of arctic coastline make these assumptions reasonable.

Using this data and calculating the eroded volume gives $50.3 \times 10^3 m^3$ of peat soils, $59.3 \times 10^3 m^3$ of mineral soils or a total of $109.6 \times 10^3 m^3$ of tundra eroded during an "average" open water season. If the processes are fairly uniform year-to-year and microbial degradation coupled with the physical wave action and leaching processes returns all of the soil nitrogen to the water column, then a maximum input of 252 metric tons is added each year. In actuality, considerable nitrogen is probably lost to the sediments through entrainment of peat and some may be lost through denitrification processes. Appreciable loss of eroded nitrogen to the lagoon system may also occur through transport of the peat out of the lagoon by wind-driven currents.

Nitrogen Fixation - In spite of the apparent excess phosphate concentration in the nearshore marine waters, no known nitrogen fixing algae were identified in the marine waters and no evidence of nitrogen fixation was found in estuarine water samples taken near Wood's Camp. Although the nearshore nutrient regime favors the occurrence of nitrogen fixing organisms, the extreme low temperatures may severely inhibit the nitrogenase enzyme and prevent successful growth. The ponds and wet coastal tundra, however, warm rapidly on sunny days and active nitrogen fixation is a major input to arctic coastal tundra systems[21,22]. Thus it appears that terrestrial sources constitute the principal source of "new" nitrogen to the nearshore waters during summer months. The high discharge columns in the rivers during the run-off season add needed inorganic nitrogen to the surface layers and this is supplemented during the summer by nutrients contained in soils wave-eroded from the low coastline subject to thaw. The large amounts of organic nitrogen introduced by both the river and through erosional processes probably do not contribute directly to much phytoplankton nutrition. However, as discussed below, this organic nitrogen may be important as a nutritional source for heterotrophs during winter months.

Regeneration of Nitrogenous Nutrients

Due to the difficulties inherent in conducting winter water sampling programs in the nearshore arctic, minimal data have been obtained from the nearshore environments on the physical and chemical processes that occur in response to the severe climatic regime. This section reports findings on the nutrient regeneration processes governing the conversion of organic nitrogen to ammonia (ammonification) and the further oxidation of ammonia to nitrite or nitrate (nitrification) in the nearshore waters of the Beaufort Sea.

The measurement of nitrite and nitrate formation in oceanic waters has been severely hindered by the extremely slow rates of production and direct measurements on incubated samples have been fruitless in the past. Recently, however, a series of papers[23,24,25,26] describing nitrate-nitrite-ammonia interrelationships in northern Pacific waters has yielded considerable insight into the processes governing the movement of nitrate into the nitrite fraction. Through the use of new analytical techniques capable of detecting changes in nitrite concentrations as low as 0.001μg-atom NO_2-N/liter[23], the reduction of nitrate to nitrite by phytoplankton assimilation and by nitrate-reducing bacteria in deep waters, has been successfully measured. No significant production of nitrite through ammonia oxidation was measured in tropical oceanic waters but in the nearshore waters of Sagami Bay, ammonia oxidation was of the same order of magnitude as nitrate reduction to nitrite. The overall rates for nitrate assimilation by phytoplankton were several times greater than the rate of nitrite production from nitrate or through ammonia oxidation. No measurements were obtained, however, on the rate of ammonia oxidation to nitrate.

During the initial phases of investigation of the marine chemistry of the Colville River delta, interesting and unexplained data concerning oxidized nitrogen concentrations were obtained from winter samples of hypersaline waters collected from near the mouth of the west channel[8]. Nitrate and nitrite concentrations were in considerable excess of the amounts which would have resulted from the solute segregation processes during ice formation. Further sampling in other coastal locations, including a lake in the Colville delta indicated that anomalously high nitrate concentrations were not common but did occur in very dissimilar environments. Thus during the winters of 1971-72 and 1972-73, a series of experiments were conducted to determine rates and directions of nitrogen oxidation-reduction processes within the aqueous environment.

Circumstantial evidence suggesting the occurrence of nitrification in the nearshore underice waters of the arctic coast was obtained from routine nutrient data taken during 1970. Figure 18 shows a plot of salinity and nitrate + nitrite concentrations from spring samples of underice waters of the Harrison Bay-Simpson Lagoon area and from Dease Inlet near Barrow. The trend of the points was along a straight line with concentrations directly proportional to the salinity indicating solute exclusion during freezing. However, samples obtained from Wood's Camp in the Colville delta were far out of line with excess nitrate. The points from Dease Inlet were with one exception suggestive of nitrification over most of the inlet. No values were obtained for nitrate concentrations earlier in the fall and this conclusion is therefore not certain. The data points from the Colville delta were so striking, however, that this location was selected for the first set of measurements.

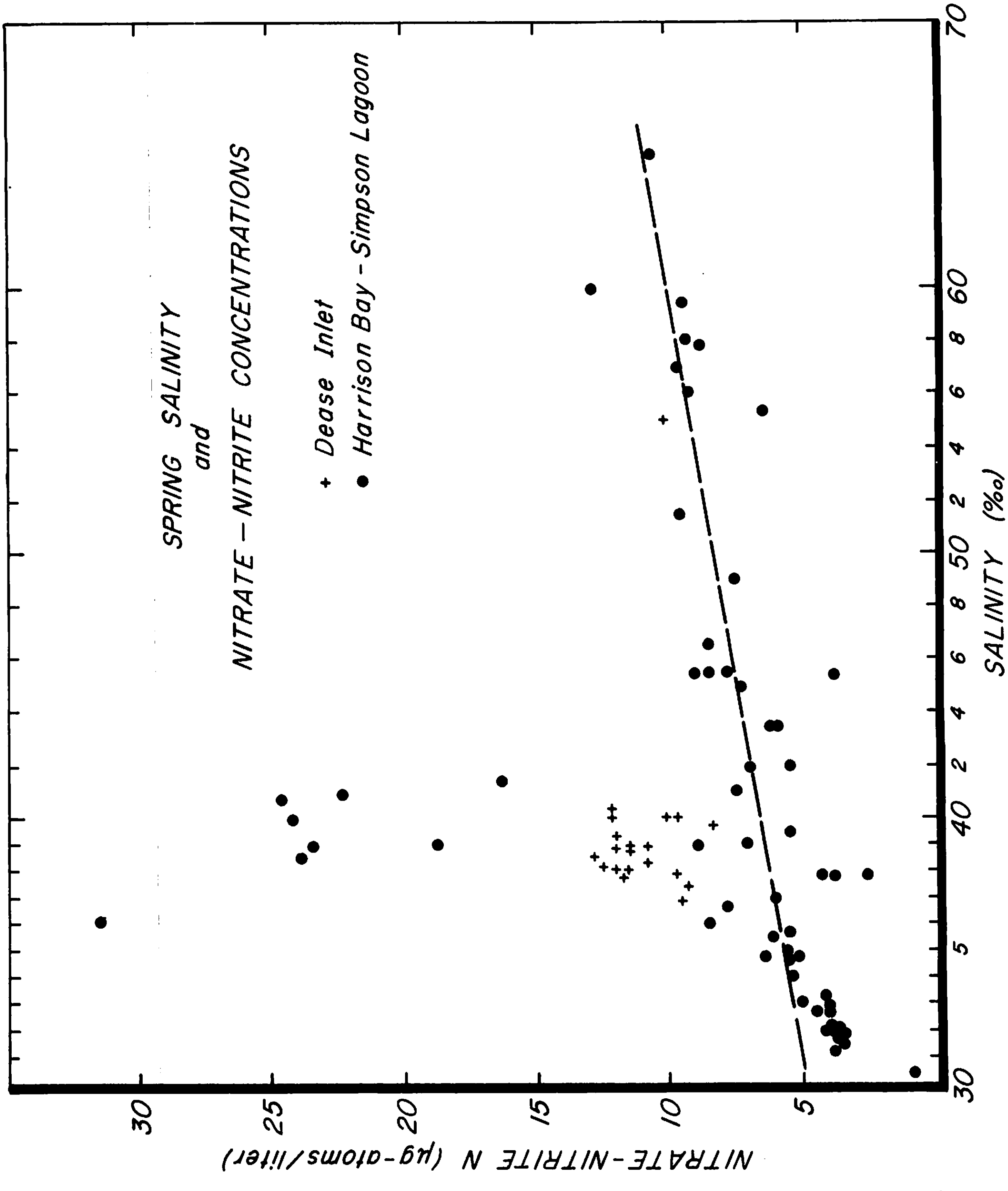

Figure 18. Spring under-ice concentrations of nitrate and nitrite and salinity.

Further evidence of nitrification was obtained from Elson Lagoon at Point Barrow. A portion of this lagoon is nearly separated from the rest by a shallow bar and during fall, the ice freezes down to the bar completely restricting circulation to the small opening at the end of the bar. In Figures 8 and 19-22 the nutrient concentrations and salinities from open lagoon waters and locations behind the bar are compared. Increases in salinity during the period of 28 days in the isolated channel were pronounced, amounting to an 18.1 percent rise in mid-channel and a 29.8 percent rise near the end whereas samples from the less restricted waters of the lagoon rose only 5.6 percent. A hole drilled over the bar hit brine at 0.8m of 182.8 °/₀₀ salinity indicating that restriction of hypersaline water is essentially complete once the ice is bottomfast or nearly so. The nitrogenous nutrient composition in the water behind the bar shifted markedly during this same one month interval. At mid-channel, nitrate and nitrite concentrations increased 44.1 percent and at the end of the channel, 58.1 percent. If the increase in salinity is taken into account and the nutrient concentrations adjusted to constant salinity, these increases amount to 36.2 percent at mid-channel and 40.9 percent at the end. The ammonia and dissolved organic nitrogen concentrations responded oppositely. In spite of freeze concentration, ammonia concentrations decreased at both locations as did dissolved organic nitrogen. Nutrient analyses run on ice cores taken at these stations indicated no preferential inclusion (or exclusion) of these nutrients into the ice column in relation to conservative parameters. When a mass balance is calculated on the water, correcting for freeze concentration, the nitrate increase at mid-channel amounts to a gain of 3.7μg-atoms of nitrate + nitrite-N/liter and a loss of 6.3μg-atoms of trivalent N/liter (D. O. N. + ammonia). At the end of the channel, the gain of nitrate and nitrite-N is 3.8μg-atoms/liter and the loss, 10.3μg-atoms/liter of D. O. N. and ammonia nitrogen. This indicates a nitrification rate of about 0.13μg-atoms NO_3-N/liter-day. The apparent loss of N could be accounted for through 1) inclusion of nitro-

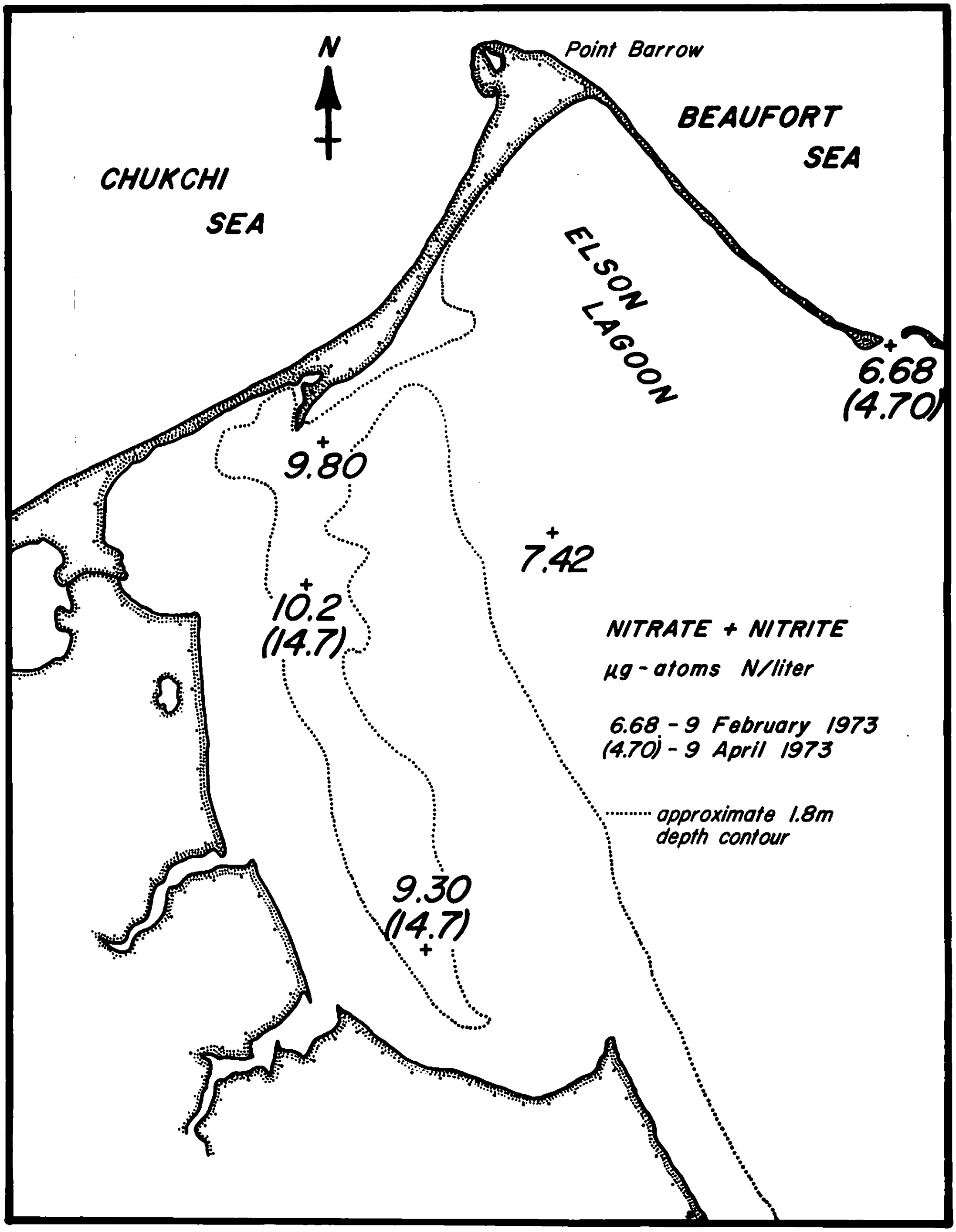

Figure 19. Nitrate and nitrite concentrations, Elson Lagoon under-ice waters.

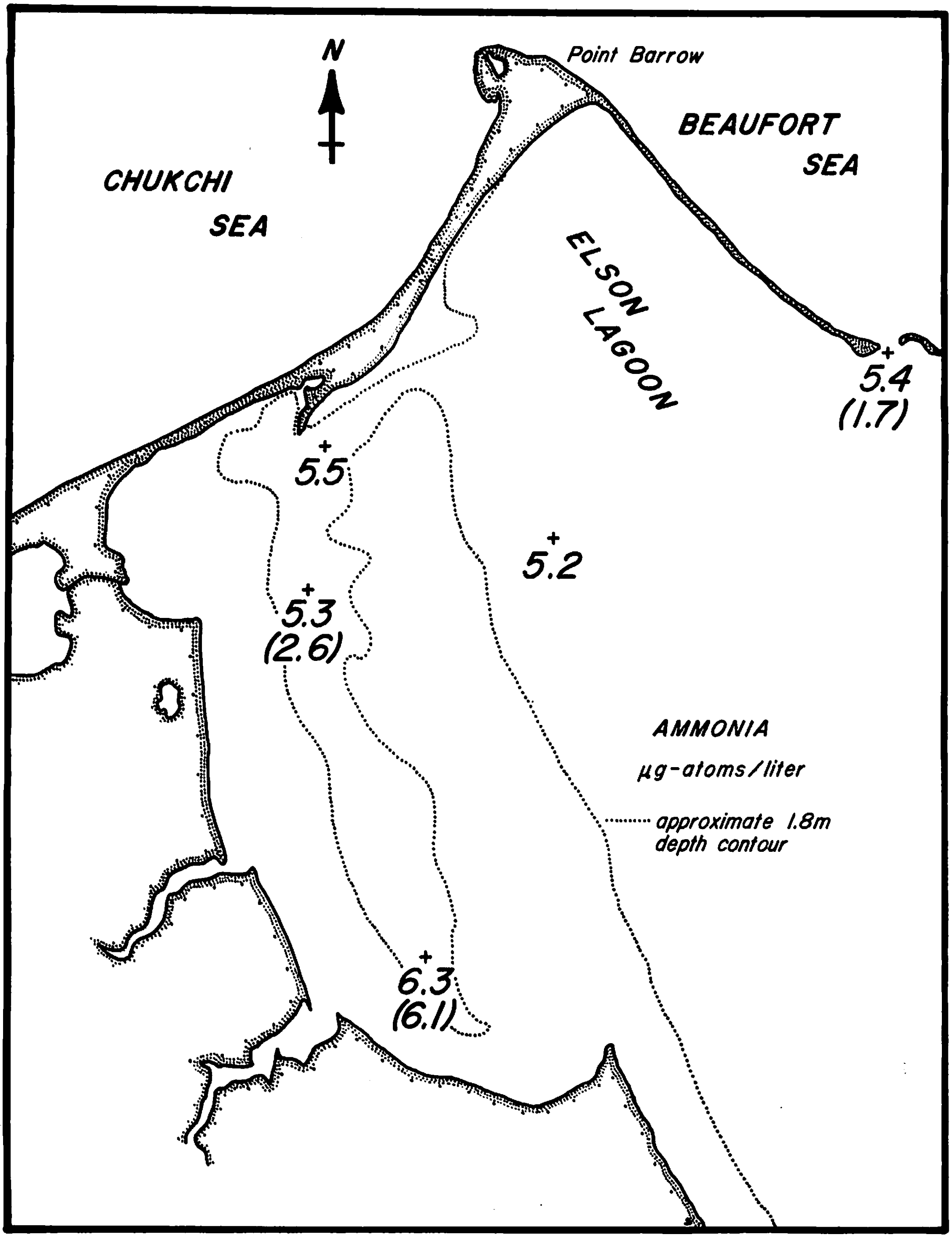

Figure 20. Ammonia concentrations, Elson Lagoon under-ice waters.

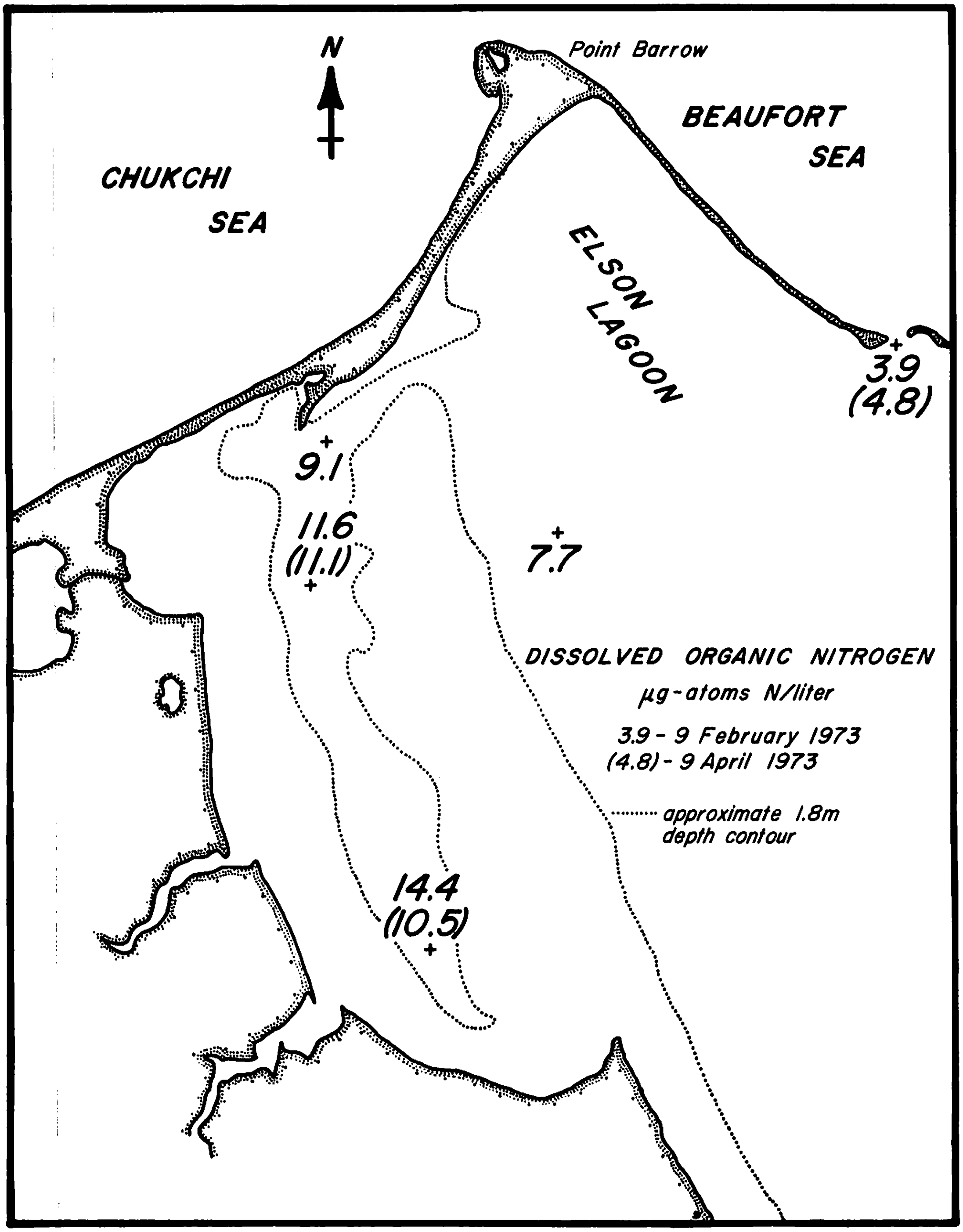

Figure 21. Dissolved organic nitrogen concentrations, Elson Lagoon under-ice waters.

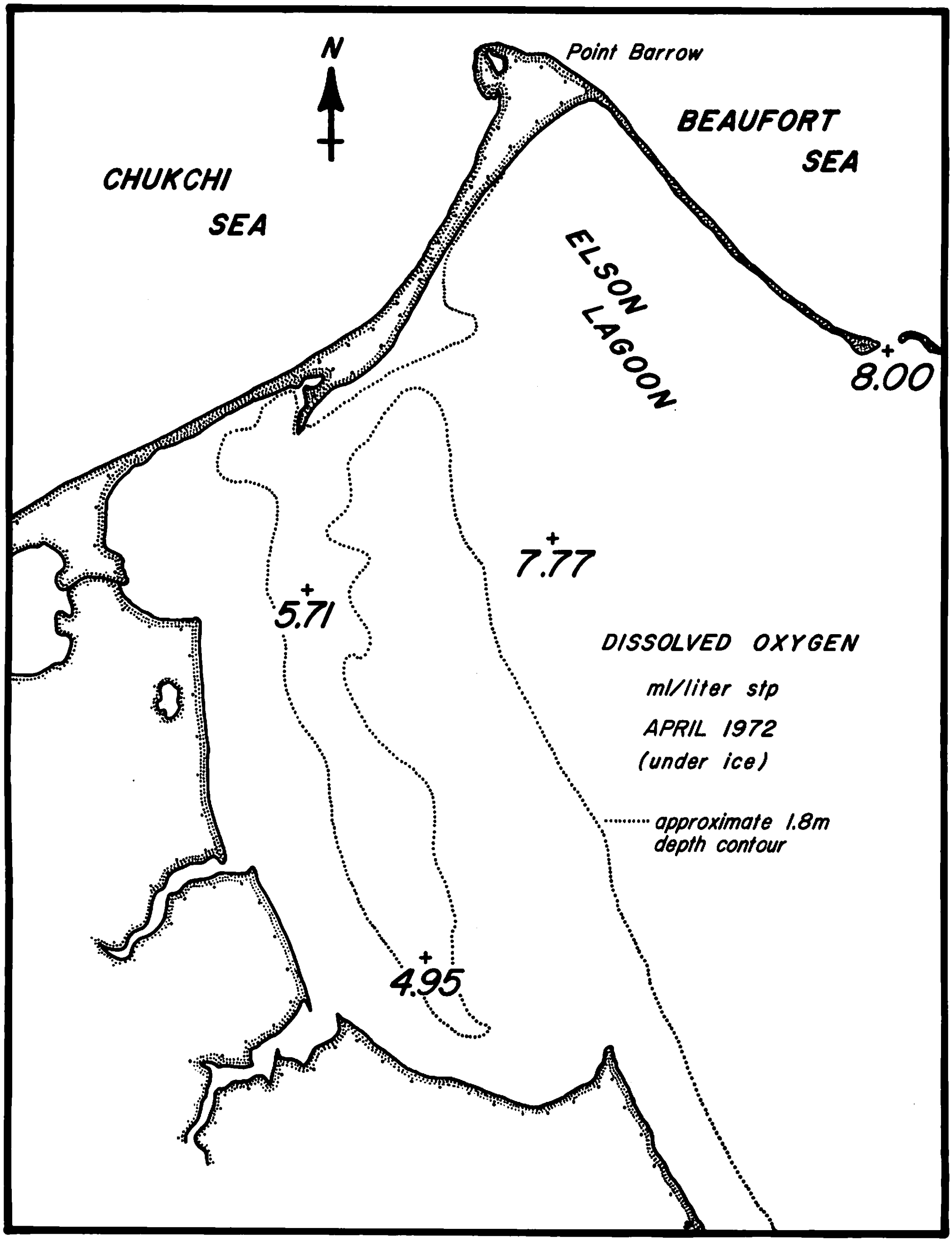

Figure 22. Dissolved oxygen concentrations, Elson Lagoon under-ice waters.

gen into the particulate fraction, 2) loss through denitrification or, 3) be due to errors induced by movement of hypersaline waters of differing N concentrations under the sampling locations. Of these possibilities, inclusion into the particulate fraction is felt to be most likely since the nitrification would indicate actively growing populations of microorganisms that would be expected to incorporate a fraction of the nitrogen into cellular material.

Similar treatment of observational data has been performed on nutrient concentrations found at Putu at the head of the West Channel of the Colville delta. Saline intrusion reached the bottom waters at the head of the channel on 14 October 1972 and by 18 November all fresh water had been displaced from the channel. During this period the channel became isolated from the main (East) channel by bottomfast ice at the shallow bar at its connection and the deep pool where the measurements were made was isolated during the winter months. During the 158 day period between the last fall sampling and the resumption of sampling in April 1973, freeze concentration increased salinity from 14.1 °/₀₀ to 27.6 °/₀₀, but nitrate and nitrite concentrations increased from 4.0 to 44.4μg-atoms N/liter. In November 1972, of the 24.4μg-atoms/liter of dissolved nitrogen, ammonia comprised 36.0 percent, nitrate and nitrite 16.5 percent and dissolved organic nitrogen, 47.5 percent. By April 1973, ammonia comprised only 9.7 percent, dissolved organic nitrogen, 30.4 percent and nitrate and nitrite, 59.9 percent of a total pool of 73.8μg-atoms N/liter. If these concentrations are adjusted to constant salinity as shown in Figure 23, the shift in proportions is readily evident. Of interest is the fact that there appeared to be no change in the concentration of dissolved organic nitrogen in spite of an apparent nitrification rate of 0.23μg-atoms NO_3-N/liter-day. However, unlike Elson Lagoon, a net gain of 37.7μg-atoms N/liter indicates that during this period, active input of nitrogen to the water had occurred.

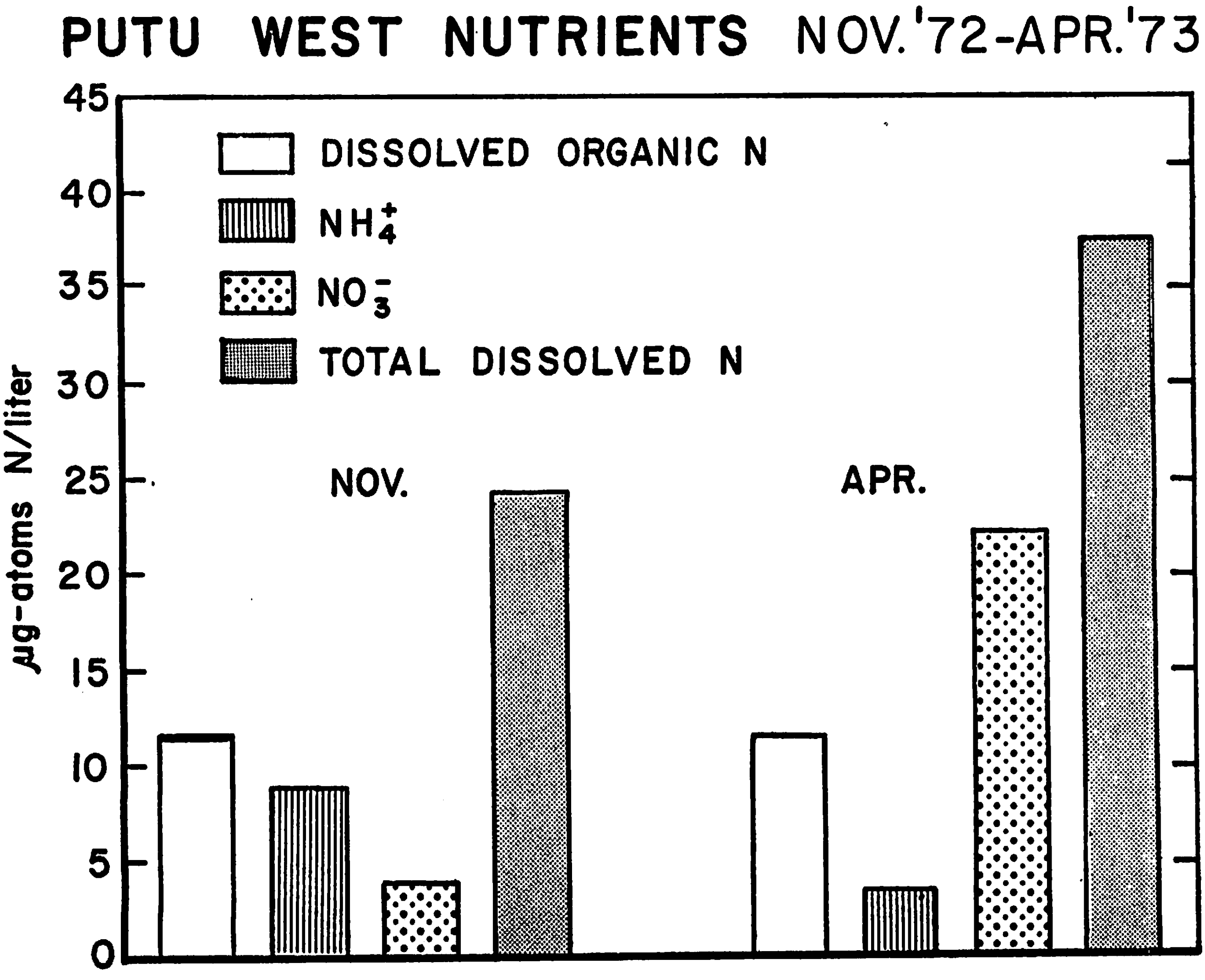

Figure 23. Nitrogenous nutrients in the under-ice water in the west channel of the Colville delta at Putu. The April concentration values have been adjusted to salinity equal to the November samples.

The source of this additional nitrogen could not be quantitatively determined but evidence that direct biological input was active is based on observational data obtained by an underwater television reconnaissance in Spring 1972 and fishing information from both Fall 1972 and Spring 1973 (see Chapter 10). During fall, after freshwater flow had essentially ceased and salt-water intrusion was active in the west channel, gill netting at the head of west channel produced catches of arctic cisco (*Coregonus autumnalis*), least cisco (*C. sardinella*) and occasional four-horned sculpins (*Myoxocephalus quadricornus*). Previous to the saline intrusion, spawning populations of humpbacked whitefish (*C. pidschian*) had also been present. Although spring gill netting did not give evidence of the presence of fish other than four-horned sculpin in the west channel, both television viewing and hook-and-line fishing gave ample evidence of abundant populations of these fish. Stomachs examined were usually full of fish eggs which were eyed at this time (May). Thus, it is felt that feeding and subsequent excretion of ammonia and urea is very likely the major source of the nitrogen added to the total dissolved pool over the course of the winter. Although diffusion from the sediments is another possible source, it is felt that this is minor both from the observation that much of the deeper channels have gravel bottoms and that the shallower mud bars are frozen by bottomfast ice. If diffusion rates of ammonia were high from the sediments, it might be expected that the Elson Lagoon stations would have also shown net increases in the dissolved nitrogen factions.

The first definitive evidence of nitrification was obtained in the saline waters at Wood's Camp in the Colville River delta. In March 1971, a nitrification experiment was conducted on channel waters and the results are shown in Figure 24. Ammonia was the sole added substrate. The maximum rate of nitrification which occurred in the bottle with 20 μg-atoms NH_3-N/liter added, gave an average rate of 0.15μg-atoms NO_3 N/liter-day and the bottle with 10μg-atoms NH_3-N/liter added averaged

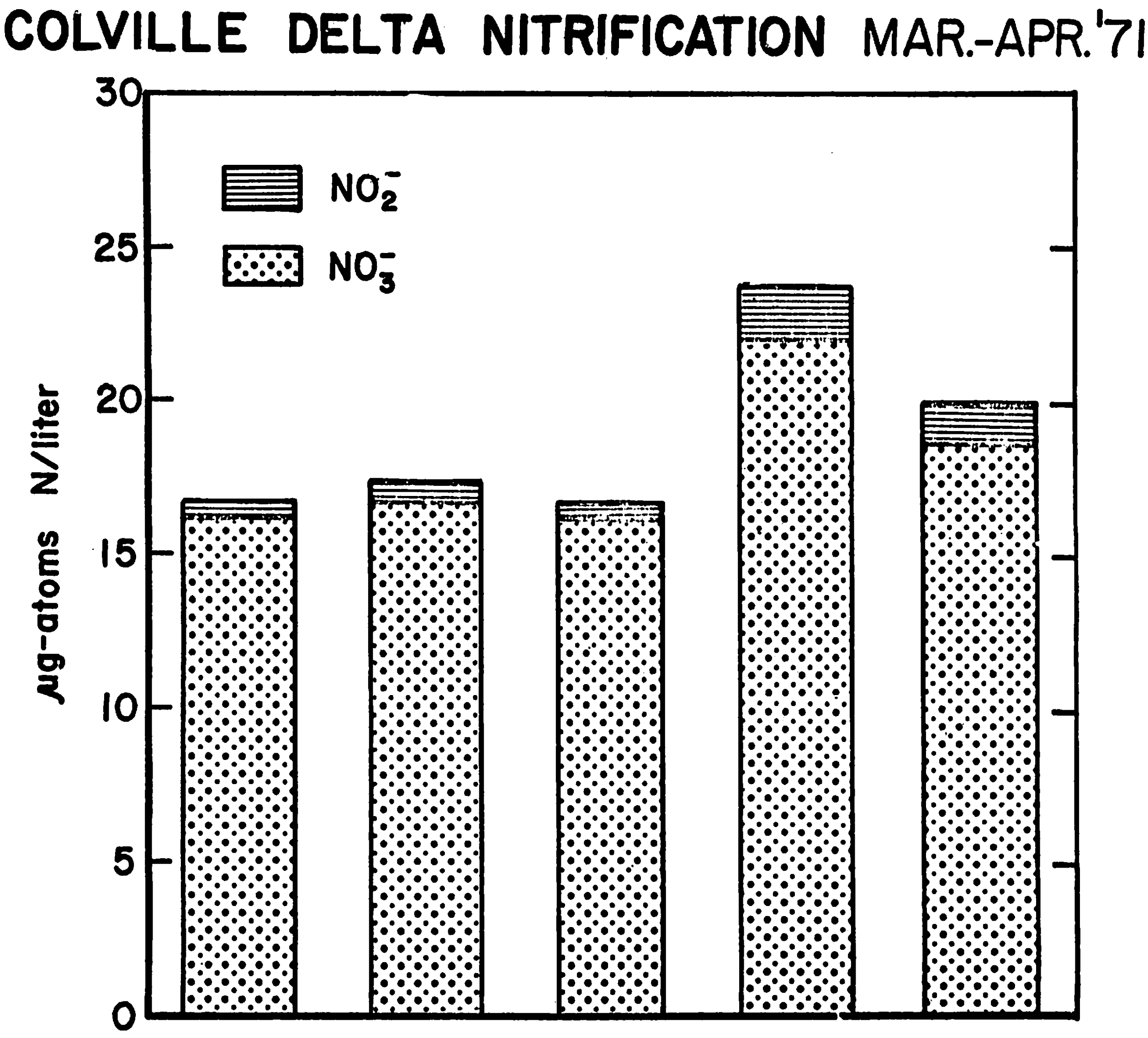

Figure 24. Effects of ammonia addition on samples of saline water at Wood's Camp, Colville delta. From left to right: 1) Control, poisoned with $HgCl_2$, 2) water sample with nothing added, 3) sample with 20 μg-atoms NH_3-N/liter and $HgCl_2$ added, 4) sample with 20 μg-atoms NH_3-N/liter added, 5) sample with 10 μg-atoms NH_3-N/liter added. Samples incubated 50 days *in situ*.

0.068μg-atoms NO_3-N/liter-day. The sample with no ammonia added (channel water) gave an average nitrification rate of 0.016μg-atoms NO_3-N/liter-day. During the same period, the channel water at Wood's Camp increased by 3.9μg-atoms NO_3-N/liter. If the effects of freeze concentration are subtracted and it is assumed that no movement of water occurred in the channel during this period, the rate of nitrification averaged 0.07μg-atoms NO_3-N/liter-day. Thus the unconfined channel water was apparently nitrifying at a rate equal to the bottled river water with 10μg-atoms NH_3-N added. This implied that either the bottled samples were giving low values for nitrification rates or that a source of ammonia was present in the channel water either through excretion of ammonia from higher organisms or through heterotrophic bacterial consumption of freeze-concentrated dissolved organic nitrogen.

To test for heterotrophic activity, the experiment was repeated during Winter 1971-72 in the saline waters at Wood's Camp and in a nearby lake. In addition to ammonia, glutamic acid, glycine and urea were added as organic nitrogen sources. The results for the saline water (Fig. 25) and for the lake water (Fig. 26) indicate that heterotrophic consumption of the added amino acids and urea occurred and that a large fraction of the nitrogen was further nitrified to nitrate.

During the 160 days of incubation, nitrification rates in the different bottles of saline water varied by an order of magnitude with the maximum rate, 0.09μg-atoms N/liter-day, occurring in the sample with added ammonia. Glutamic acid was converted to nitrate at about twice the rate of glycine, (0.025 versus 0.01μg-atoms NO_3-N/liter-day). The nitrification rates in the bottles with urea added and with nothing added were similar, 0.009μg-atoms NO_3-N/liter-day, suggesting urea was a poor substrate for this water.

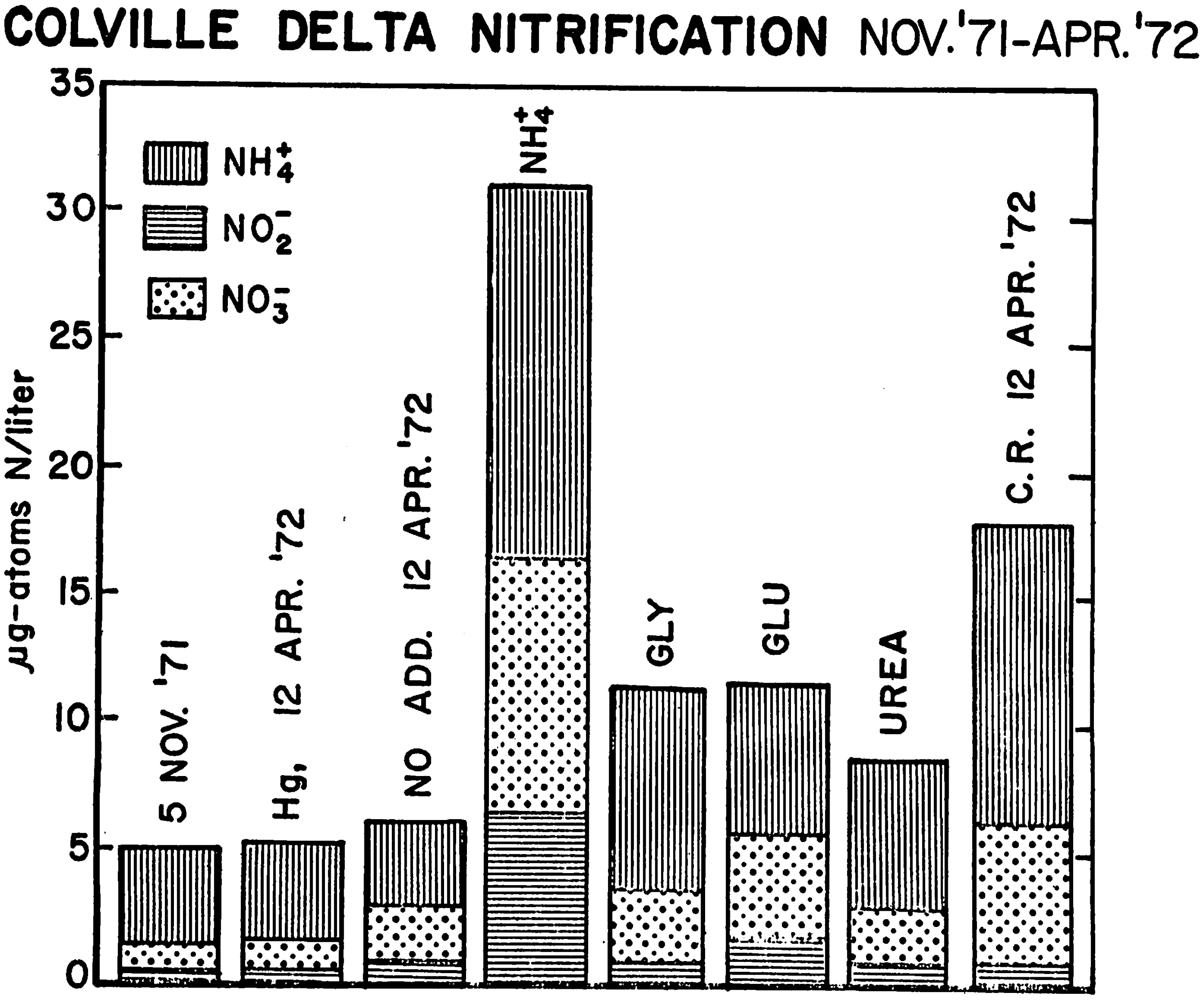

Figure 25. Effects of organic nitrogen and ammonia addition to saline water at Wood's Camp, Colville delta. From left to right: 1) Initial nutrient concentrations, 2) control sample poisoned with $HgCl_2$, 3) sample with nothing added, 4) sample with 20 µg-atoms NH_3-N/liter added, 5) sample with 10 µg-atoms glycine -N/liter added, 6) sample with 10 µg-atoms glutamic acid -N/liter added, 7) sample with 10 µg-atoms urea -N/liter added, 8) nutrient concentrations in channel waters, 12 April 72.

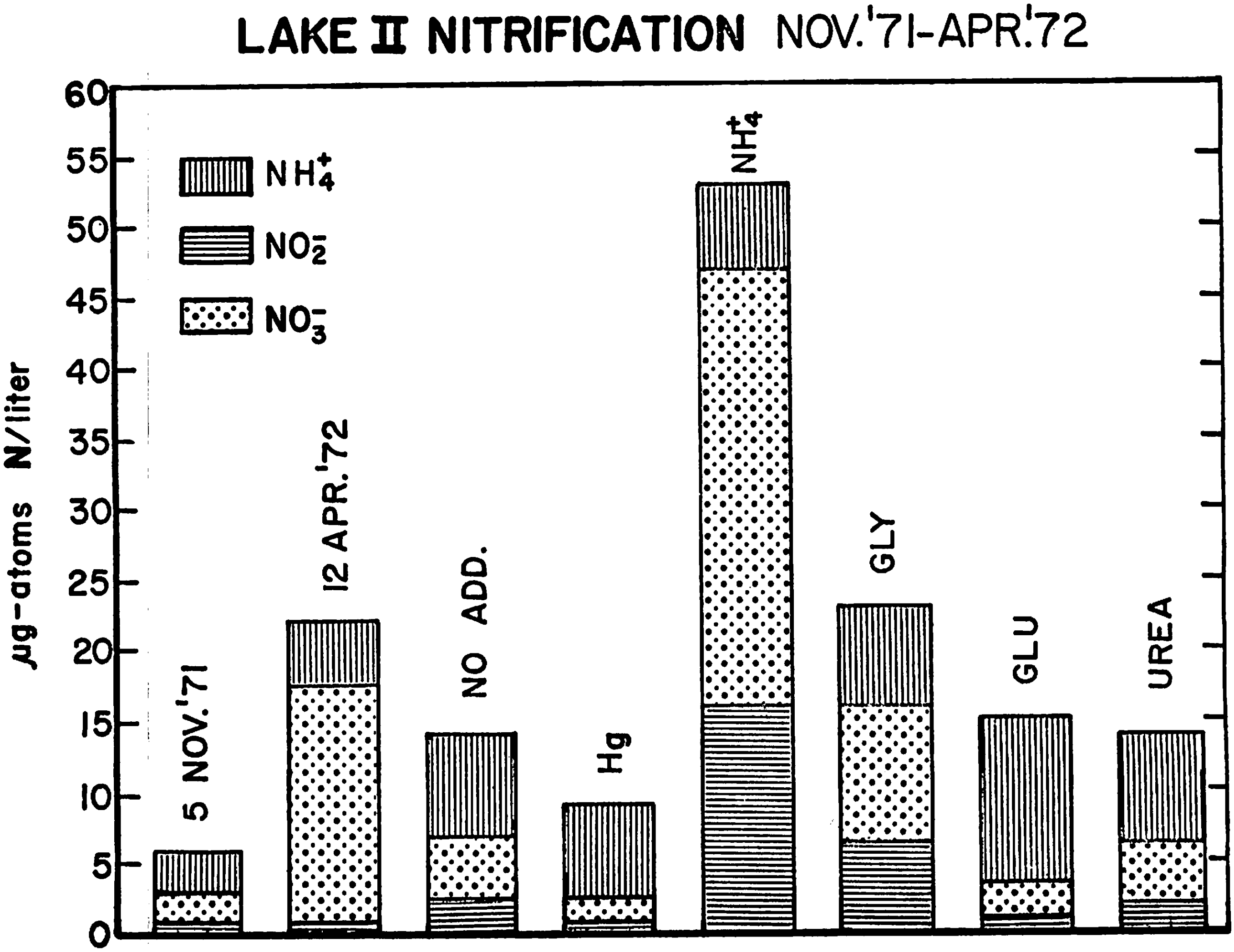

Figure 26. Effects of organic nitrogen and ammonia addition to lakewater at Wood's Camp, Colville delta. From left to right: 1) Initial nutrient concentrations, November 1971, 2) nutrient concentrations, April 1972, 3) sample with nothing added, 4) control sample poisoned with $HgCl_2$, 5) sample with 40 μg-atoms NH_3-N/liter added, 6) sample with 10 μg-atoms glycine -N/liter added, 7) sample with 10 μg-atoms glutamic acid -N/liter added, 8) sample with 10 μg-atoms urea -N/liter added.

The lake water samples showed the highest rate of nitrification, 0.28 μg-atoms N/liter-day in the bottle with ammonia added. However, the organic substrates were utilized in some bottles and appeared to inhibit nitrification in other samples. The bottles with glycine and urea gave the higher rates of nitrification, 0.088 and 0.027μg-atoms N/liter-day respectively, while glutamic acid gave a nitrification rate of only 0.008μg-atoms NO_3-N/liter-day, a value equal to 25 percent of the rate for lake water with nothing added. No reason for this effect was determined. Large increases in the ammonia fraction indicated that the added organic carbon was being assimilated but was not being further oxidized to nitrate-nitrite. Since the bottles with the organic substrates all showed increases in ammonia concentrations during incubation, it was suggested that the nitrification in these waters is at least in part dependent upon prior heterotrophic assimilation of the organic nitrogen and release of ammonia.

The source of the ammonifiers was next sought and in the fall of 1972, two experiments were conducted, one in the fresh waters of the Colville River and another at Oliktok Point in saline waters. The freshwater samples were interesting in that almost no microbiological activity was discernible. The bottle innoculated with ammonia showed no evidence of nitrification and the samples with added amino acids and urea showed no evidence of ammonification.

At Oliktok Point, however, the added organic substrates were actively converted to ammonia. The results in Figure 27 are interesting in another respect: the bottle of incubated seawater with nothing added did not show any increase in ammonia concentration in spite of a measured concentration of 10.0μg-atoms N/liter of dissolved organic nitrogen suggesting that the dissolved organic nitrogen present in those waters was resistant to microbiological degradation. The average ammonification rates of the added organic substrates ranged from 0.04μg-atoms

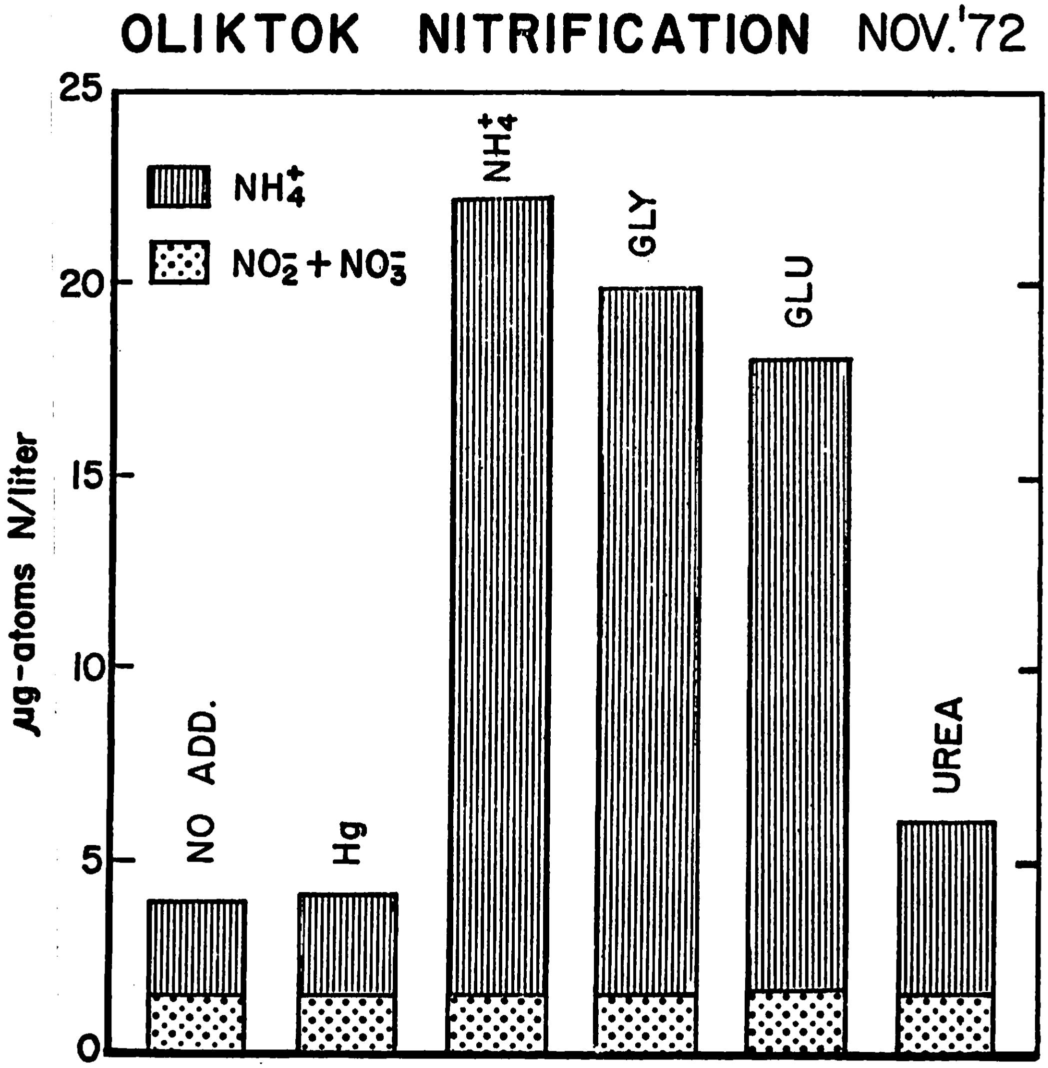

Figure 27. Addition of ammonia and organic nitrogen to Oliktok seawater samples. From left to right: 1) Seawater sample with nothing added, 2) control poisoned with $HgCl_2$, 3) sample with 20µg-atoms NH_3-N/liter added, 4) sample with 20µg-atoms glycine -N/liter added, 5) sample with 20µg-atoms glutamic acid -N/liter added, 6) sample with 4µg-atoms urea -N/liter added.

NH_3-N/liter-day in the bottle with added urea to a maximum of 0.49μg-atoms NH_3-N/liter-day in the bottle with glycine. Since the glycine and glutamic acid substrates were almost completely ammonified by the time the bottles were recovered (30 days), these rates are probably underestimated. None of the bottles showed evidence of nitrification.

To test if the nitrifiers were present in the river water, the experiment was repeated with Oliktok seawater, but 100ml of freshwater from the Colville River was added to each sample bottle. The results were virtually identical with those obtained with plain seawater - nearly complete ammonification of added organic nitrogen but no nitrification detectable, suggesting that nitrifers were not present in either the seawater off Oliktok Point or in the freshwater of the Colville River channel.

CONCLUSIONS

The biological and climatological influences on the nutrient chemistry of arctic estuarine waters appear to be fully as complex, if not more so, than in more temperate climates. As the data acquired over the course of this project has been assimilated, the pronounced interactions and responses of the biologically influenced chemical processes to the environmental conditions has become more and more evident. In summary, the several aspects of the variations in these processes over the arctic seasons can be reviewed:

1) Phytoplankton uptake of nutrients in the coastal arctic commences well before the ice cover begins to melt. Uptake by epontic communities is followed by uptake throughout the water column resulting in the exhaustion of the nitrogenous nutrient pool. Subsequent primary production is probably limited thereafter by the regeneration rates of ammonia until light limitation and freeze-up occur in late September due to the extreme stability of the water column resulting from melting and the pack-ice-limited wind fetch. Phosphate appears to be well in excess of

limiting concentrations throughout the year in the marine environment.

2) In spite of an ice-cover that persists from late September to the following June, biological oxygen depletion beneath the ice does not appear to lower the concentration to critical values except in the lakes and marine areas where the ice is nearly bottomfast and possibly in isolated areas of the Colville River channels. In the Colville delta channels, the ecological implications may be of concern regarding the management of fishery resources.

Fish populations representing a valuable food resource to the native people of the Arctic have been found to use the delta as spawning grounds and as overwintering areas. When considering the duration of the ice cover and the formation of bottomfast ice barriers in shallow channels, these channels may comprise a delicately balanced environment in which the nitrogenous excretion products of fish and other fauna are assimilated and nitrified by microflora at expense to the oxygen necessary to the survival of the biota in this temporarily closed community. It follows that any human activity that would appreciably increase the loading of dissolved organic nitrogen into the water such as accelerated riverbank erosion or the input of sewage, especially during fall periods of low or non-existent water flow, could have deleterious effects on this environment.

Available data regarding the circulation of offshore water beneath the ice is insufficient, thereby prohibiting statements regarding the effects that might be caused by the addition of nutrients in a form such as primary or treated sewage. It can be generalized that oxygen concentrations seem to reflect good circulation in the deeper waters; much further work on the circulation patterns induced by hypersaline water formation during winter freezing will be required before the mechanics of pollutant dispersion can be approximated.

3) Due to the aforementioned extreme water stability from melt and limited wind-fetch, the principle sources of "new" nutrients to the surface layers of the nearshore Beaufort Sea during summer arise from the input of rivers and from the erosion of the low-lying coastline. These two sources constitute a source of nitrogen to phytoplankton populations showing strong evidence of nitrogen limitation. The relative importance of river input to erosional input was not determined but they are believed to be approximately equal along the coastline between Barrow and Prudhoe Bay.

4) In spite of psychrogenic hypersalinity and well below 0°C temperatures, underice populations of microorganisms actively regenerate nutrients in arctic Alaskan coastal waters throughout the winter months. The rates of nitrification and ammonification determined through the use of *in situ* experiments agree well with the rates calculated from observed changes in nutrient concentrations in underice waters over the winter season. However, the absence of nitrification in the seawater at Oliktok Point is more difficult to explain in view of the physical similarity of Simpson and Elson Lagoons and the active nitrifying populations in the Colville delta not far away. The author feels that perhaps the underice water contained dissolved organic nitrogen that was resistant to ammonification. Since this water was in ready exchange with offshore seawater it further suggests that conditions for nitrification and ammonification in offshore areas may be far from optimal.

The nitrification and ammonification capacity of the underice microbial populations has an environmental significance in that it enables the conversion of dissolved organic nitrogen to ammonia and nitrate during winter months. These nutrients are then available to epontic algae when light intensities rise in the spring and photosynthesis resumes.

5) The formation of approximately a centimeter of ice per day between October and the end of March results in rapidly increasing salinities and falling temperatures in nearshore lagoons and channels. Where

open-ocean access to lagoon and inlet waters is readily available, the density gradients formed by solute segregation during freezing when coupled with tidal action, cause rapid flushing. If flushing is slight or non-existent, salinities beneath the ice rise over the course of the winter to final concentrations measured as high as 186 °/₀₀.

The freeze-induced rise in surface salinity appears to be the principle driving force for turnover in the nearshore water column, contrasting the Beaufort Sea with waters such as in southeastern Alaska where turnover is due primarily to cooling and wind-mixing. However, during autumns marked by strong southwesterly storms with the pack-ice well offshore, the process of wind-mixing may become of primary importance.

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CHAPTER 8

STUDIES OF PRIMARY PRODUCTIVITY AND PHYTOPLANKTON ORGANISMS IN THE COLVILLE RIVER SYSTEM

Vera Alexander with Christopher Coulon and John Chang

INTRODUCTION

The Colville River is a relatively unknown drainage system in terms of its aquatic biological components. For this reason, biological studies formed an important part of this baseline study. This portion of the report deals specifically with phytoplankton organisms, which received a considerable amount of attention because: 1) they form the basis upon which the aquatic biological system exists, and 2) even the most elementary taxonomic work has not been done in this region.

Somewhat more information exists for the zooplankton of the Colville River system and offshore Beaufort Sea than for phytoplankton. In the case of microcrustacea, this is due to the work of Reed[1] and the offshore work of Johnson[2]. No similar work has been done for phytoplankton. A basic study by the Environmental Protection Agency on the neighboring Sag River included work on benthic invertebrates. Finally, Alaska Department of Fish and Game personnel have studied fish in the Colville River (summer of 1969, 1970), and we were fortunate to be able to utilize their logistics and include some primary productivity and water chemistry work. The fish data are included in an Alaska Department of Fish and Game report, and we have followed up on this by inviting the field biologist who had completed their fish field efforts to join our project for a period of work closer to the delta region. These results are discussed elsewhere in this report (Chapter 10). This, then, is about the extent of information available on the river system itself at the time the present study was initiated. There was a similar dearth of low trophic level biological information for the offshore area and the river delta itself. Apart from the work of Horner[3] and Horner and

Alexander[4] as well as Clasby, Horner and Alexander[5], very little work has been accomplished on primary productivity in the nearshore arctic coastal waters. Some phytoplankton distribution work had been done earlier[6,7,8]. The significance of the results reported here is enhanced by comparison with parallel simultaneous work undertaken at Prudhoe Bay under the direction of Dr. Rita Horner. The sum of these studies should constitute a good beginning to the understanding of Alaskan arctic nearshore productivity, and the influence of the major river systems.

STRATEGY AND SCHEDULE

Simpson Lagoon and Harrison Bay primary productivity stations were occupied the early spring ice-covered period in 1970 and during the open water season in 1970, 1971 and 1972. Carbon-14 primary productivity and ^{15}N uptake were the principle measures of phytoplankton activity, with biomass and population composition also examined at each sampling date. During the first two years, entire transects were sampled only a few times, with a relatively large number of stations occupied. These are shown on maps accompanying the data. During the summer of 1972, two stations were visited with greater frequency to obtain a seasonal picture.

For the river system, a preliminary survey was conducted during the summer of 1970. Transportation was by river boat from Umiat, and sampling was thus restricted by accessability. During the second summer season (1971), two surveys were carried out encompassing a large number of sampling stations in ponds, lakes and rivers and streams. The first was a raft trip from Umiat to Woods Camp, carried out in early July. The second, which also included lakes higher up in the Brooks Range foothills, was a one-day float plane sampling of carefully selected lakes. During this summer (1971), the intensive work at the Wood's Camp lakes began. This was the major fresh water emphasis during the final summer, 1972.

The schedule followed is summarized below:

1970 - Initiate survey field work based at Umiat in conjunction with ADF&G (Pedersen);

1971 - Survey work continues through
  1) Raft trip from Umiat to Wood's Camp (Hall, Clasby, Joeb Woods);
  2) Survey of Colville River drainage lakes by air, primary purpose taxonomy and distribution of phytoplankton (Coulon, Holmgren);
  Wood's Camp intensive limnological program initiated (Chang);

1972 - Wood's Camp intensive limnological program continued and completed (Chang).

METHODS

Sampling

Water samples were collected with a PVC water sampling bottle or scooped from the surface with a plastic container. Nutrient samples were stored frozen in previously aged polyethylene bottles following filtration through glass micropore filters. All water for experimental work was dispensed immediately into the experimental vessels.

Chemical Determinations in the Field

Total alkalinity was obtained by titrating with 0.01N HCl, using a pH meter to determine the end-point. The azide modification of the Winkler method was used for dissolved oxygen analysis.

Phytoplankton Methods

Chlorophyll was determined by extracting particulate material retained on a glass micropore filter with 90 percent acetone at 5°C for 24 hours and scanning the centrifuged extract using a Perkin-Elmer 202 recording spectrophotometer. The method of Strickland and Parsons[9] was used for the calculation. Phytoplankton samples were preserved in a modified Lugol's solution (10g I_2, 20g KI, 20ml acetic acid, 50ml distilled H_2O). Quantitative and qualitative observations were made either using a Zeiss chamber and inverted microscope or using the settling method of Coulon and Alexander[10].

Primary productivity was measured by the ^{14}C method. One ml of a 5µCi/ml solution of $^{14}C\text{-}HCO_3^-$ was added to water samples in both light and dark 125ml glass-stoppered bottles. Incubation was carried out *in situ*. Following incubation, the samples were filtered through 0.45µM Millipore filters and dried. Counts were obtained on a gas-flow counter, with calculation according to Strickland and Parsons[9].

Phytoplankton enumeration was conducted with a Carl-Zeiss inverted-compound-phase microscope using a standard Carl-Zeiss 5ml counting chamber. Samples were thoroughly mixed and resuspended by shaking the sample bottles. Immediately, a portion of the sample was transferred to the counting chamber which was then covered with a glass plate and sealed with silicon stopcock grease. The samples were allowed to settle overnight. Seventy-five fields of the counting chamber were counted at 500 x magnification.

It was necessary to assume that the phytoplankton were evenly and randomly distributed on the bottom of the counting chamber, so that the number of phytoplankton cells per liter of sample water could be calculated. Since different species differed greatly in dimensions, cell numbers alone do not give a good description of the actual biomass[11]. Therefore, the phytoplankton biomass (in μ^3/liter) was estimated by multiplying the number of cells by the average cell volume for each species.

Nitrogen Uptake

Nitrogen uptake was measured using ^{15}N labeled compounds. The procedure was as follows: 1) ^{15}N-labeled nitrogen compounds (NO_3^- or NH_4^+) were added to sea water samples enclosed in clear glass bottles (1000ml); 2) the bottles were incubated under *in situ* or simulated *in situ* conditions; 3) the samples were filtered through glass micropore filters (Hurlburt 984H ultrafilters) to recover the particulate material; 4) nitrogen compounds retained on the glass filter were converted to N_2 by a Dumas method[12]; and 5) the nitrogen isotope ratio (^{15}N : ^{14}N) was determined by mass spectrometry. For this work, a modified Bendix Time-of-Flight Model 17-210 mass spectrometer or an AEI MS-20 mass spectrometer was used. Following mass spectrometry, the variables $V_{NO_3^-}$ and $V_{NH_4^+}$ were obtained:

$$V_{NO_3^-} = \frac{\rho_{14}}{N_1} = \frac{\frac{da_1}{dt}}{a_4 - a_1} \qquad (1)$$

where $V_{NO_3^-}$ = velocity of uptake of nitrogen in units of $time^{-1}$

ρ_{14} = absolute rate of transport of nitrogen from the inorganic nutrient compartment, 4, (labeled) into the unlabeled (initially) particulate nitrogen compartment, 1

N_1 = concentration of nitrogen in the particulate nitrogen fraction

a_4 = atom percent excess ^{15}N in the nutrient compartment

a_1 = atom percent excess ^{15}N in the particulate nitrogen compartment

Then to obtain absolute uptake rates:

$$\rho_{14} = N_1(V_{NO_3^-}) \qquad (2)$$

Ammonification was measured by an isotope dilution method. Labeled ammonia was added to a sample of water, and, after equilibration, a subsample was removed (for zero time isotope ratio determination), preserved with $HgCl_2$ and preferably rapidly frozen. The remainder of the sample was incubated either *in situ* or at an *in situ* temperature, and, following incubation was treated in an identical manner to the "zero time sample" discussed above. The samples were kept frozen pending further processing in the laboratory. The ammonia fraction was recovered from the samples by vacuum distillation using MgO as a buffer, and with a stream of air swept through the apparatus carrying the distillate through the condenser into dilute H_2SO_4. The distillate was then boiled down to a few ml volume, and converted to N_2 with alkaline hypobromite in a vacuum manifold, cleaned with liquid nitrogen and subjected to mass spectrometry as described above. The difference in ammonia nitrogen isotope ratio between the initial and incubated sample gives a rate of dilution of the added labeled ammonia by unlabeled ammonia from other nitrogen fractions in the water. From this, the absolute ammonia supply rate is calculated, which represents only the *in situ* internal regeneration rate, and excludes any consideration of advection.

$$\Delta N = \frac{(a_{f_o} - a_{f_t})\, N_a A_a}{a_{f_o} \quad a_{f_t}} \tag{3}$$

where ΔN = change of ammonia concentration during course of experiment (μg-atom of ammonia nitrogen)

a_{f_o} = atom percent ^{15}N at time zero

a_{f_t} = atom percent ^{15}N at time t

N_a = amount of tracer added

A_a = atom percent of tracer added

Nitrogen Fixation

Nitrogen fixation was measured using the acetylene reduction method of Stewart *et al.*[13]. Incubation vessels were 40ml glass vials with rubber septa. A 20ml water sample or a $1cm^3$ of soil sample from the sediment surface from the lakes and channel were injected with 4ml C_2H_2 using a disposable syringe, and the samples were incubated *in situ* or in a tray of water for 6 to 12 hours. Vacutainers^R were used to collect and store gas samples as described by Schell and Alexander[14]. An F and M Model 700 gas chromatograph with a flame ionization detector and a 12 foot stainless steel column with Porapak-R gave excellent separation of ethylene and acetylene at 40°C. A commercially prepared standard was used for calibration.

Physical Data

For the Wood's Camp freshwater work, incoming solar radiation was recorded by a pyranometer (Middleton & Co. Pty. Ltd., Model CN7-156) and a portable recorder (TOA Electronic Ltd., Model EPR-2T) during the ^{14}C primary productivity incubation periods.

Water transparency was measured with a Secchi Disc. Water temperature was measured with a portable YSI model 54 oxygen meter, which had a temperature sensor inside the probe. Air temperature and wind speed were measured with a pocket thermometer and a wind meter.

Miscellaneous Methods

Particulate nitrogen was measured using a Coleman nitrogen analyzer on particulate material retained by a glass millipore filter.

Nutrient chemistry (discussed in Chapter 7) will be only mentioned here where relevant to discussion.

RESULTS AND DISCUSSION

Studies in the Simpson Lagoon-Harrison Bay Area

Primary Productivity - Analysis of the primary productivity of an estuarine system incorporates two important aspects. One is the near-shore primary productivity regime of the particular geographical region in question, and the second, and in this case highly revelant, the impact of the river system on the particular local situation studied. It is essential, then, in discussing the specific Colville River area results, to consider also the available data on arctic coastal primary productivity where no major river system affects the regime. The strategy in this report will be to present the data obtained during the course of this three year study, and finally to discuss it in context of available data.

During the survey period in this work (1970 and 1971) a large number of stations were occupied (Figs. 1,2). We found that all indices of primary productivity in the immediate offshore area were low, and that there were no consistent trends along the transects (Figs. 3,4,5,6, Tables 1,2). In 1971, primary productivity rates seldom exceeded 2mg C/m^3•hr. Although very little had been done in terms of depth series experiments for primary productivity during 1971, a possible trend for increase with depth and toward the shore was observed. This was confirmed in 1972, when intensive sampling of two stations (Fig. 7) was carried out. The highest productivity rates clearly occurred in the deeper cold, more saline water (Table 3). During the summer of 1971, the chlorophyll *a* levels were also low, with a maximum of 1.76 mg/m^3 at 3 m at a July 28 station. The maximum primary productivity rates detected during that year were 5.80 and 5.88mg C/m^3•hr at the surface at Station T1 on the same date and at 2m at SL 16 on August 11, 1971 respectively. These levels of activity and biomass agree with the observations of Horner[3], who found a maximum chlorophyll concentration of $3mg/m^3$ off Point Barrow. Note, however, that this maximum level measured by Horner included the entire euphotic zone, rather than just surface and below surface measurements. Clasby, Horner and Alexander[5], on the other hand, found $4.41mg/m^3$ chlorophyll-*a* on June 8, 1972 off Point Barrow, with a maximum productivity slightly in excess of $1mg/m^3$•hr.

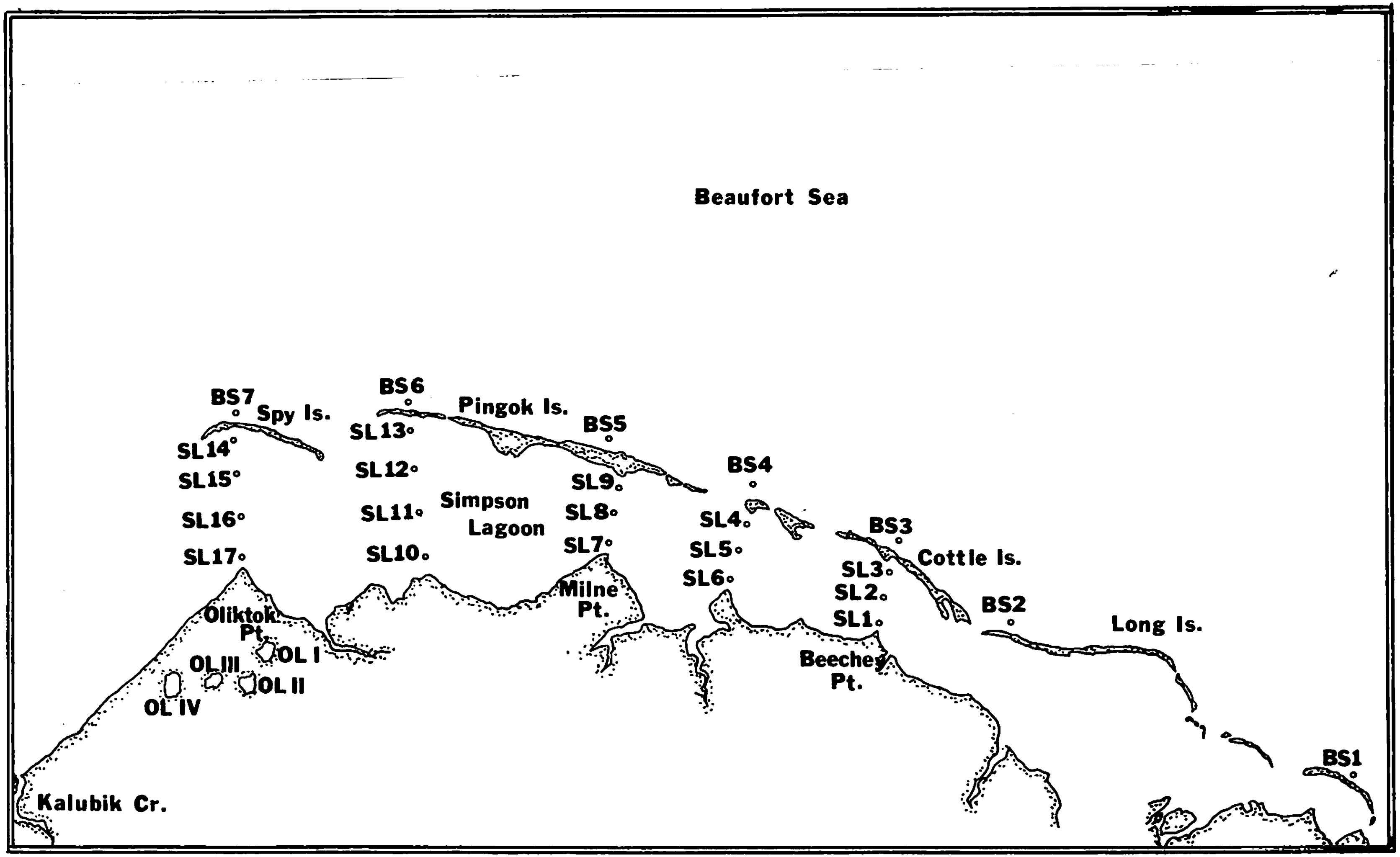

Figure 1. Station, locations - Harrison Bay.

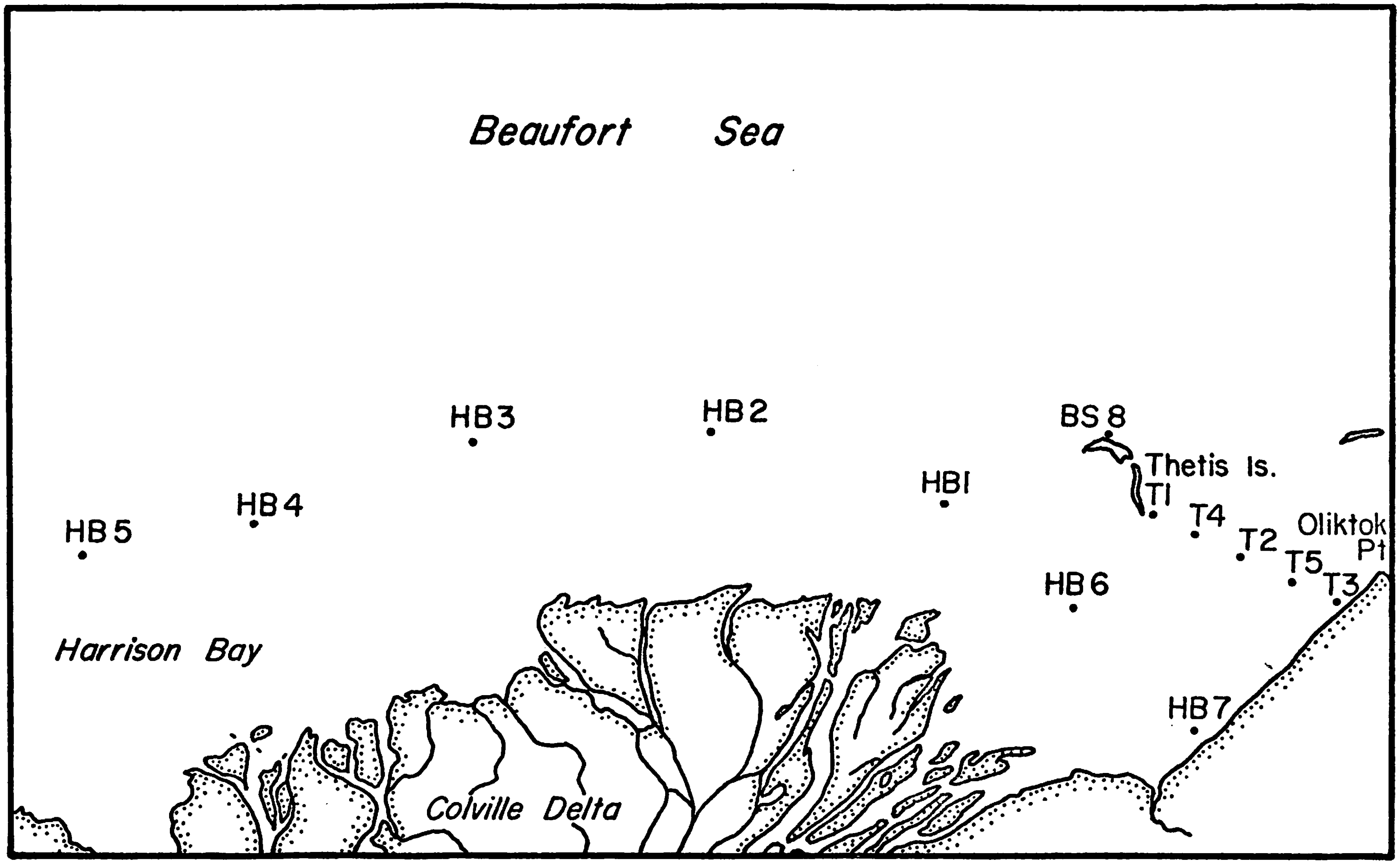

Figure 2. Station locations - Simpson Lagoon.

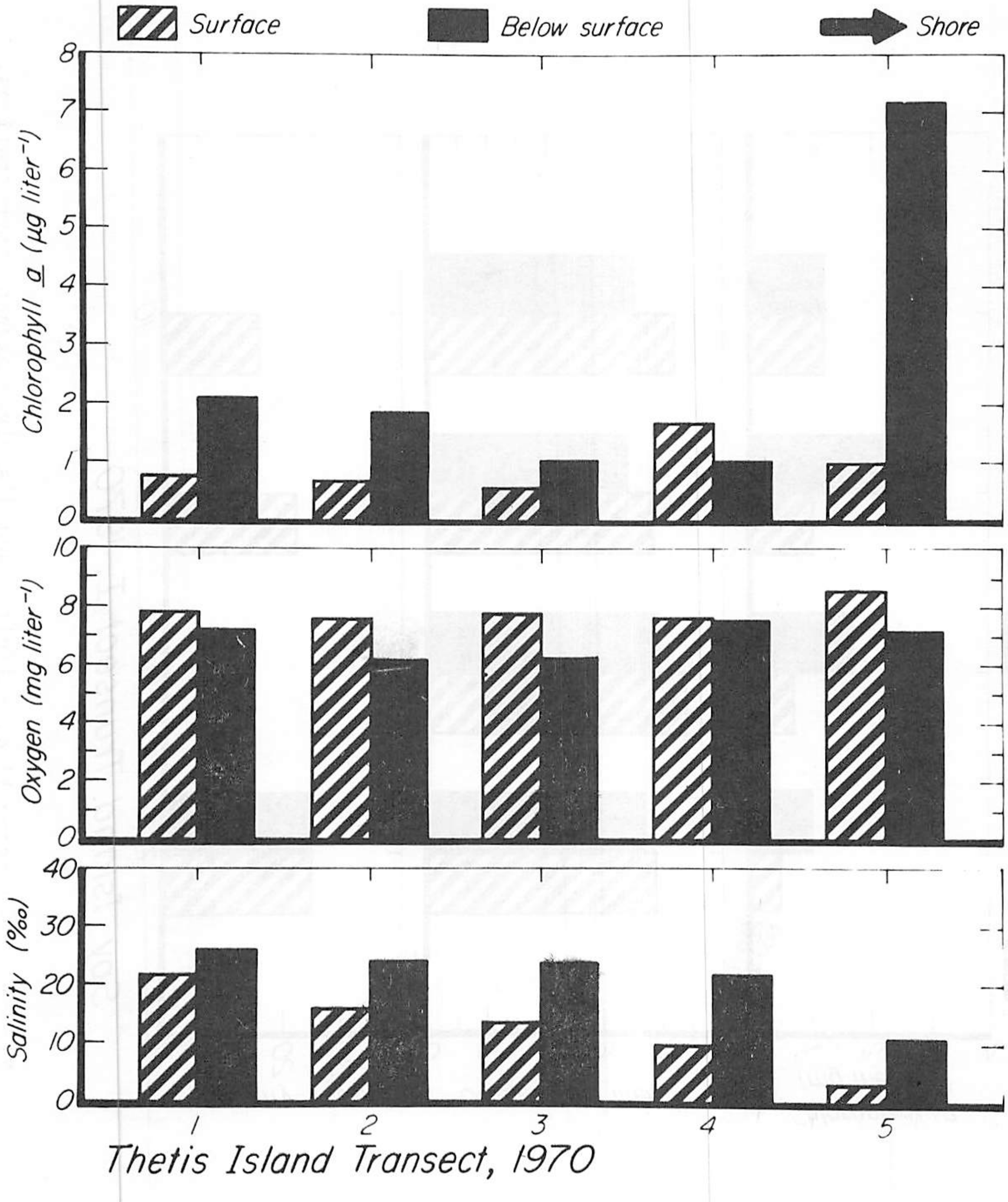

Figure 3. Chlorophyll *a*, salinity, and dissolved oxygen concentrations, eastern Harrison Bay, 1970.

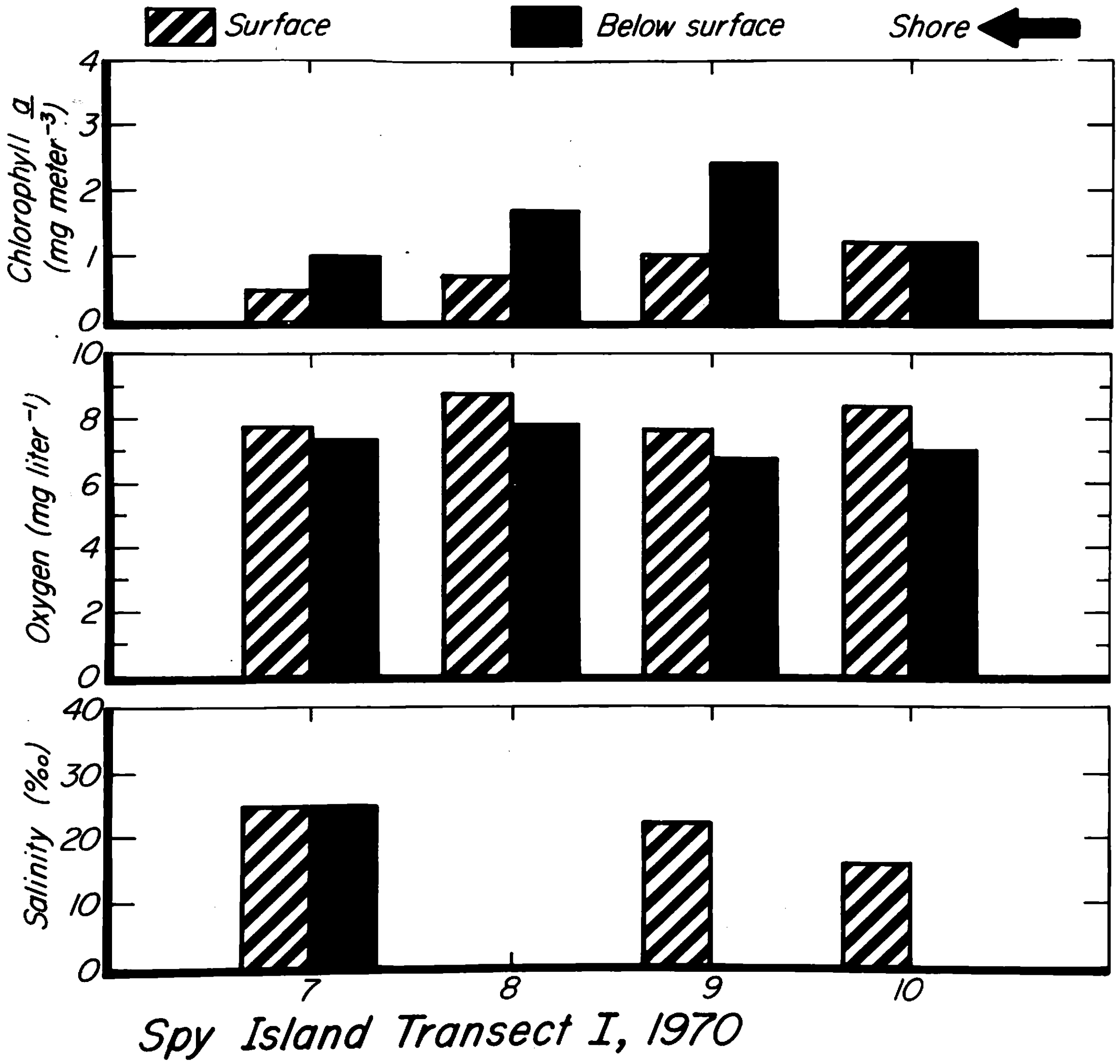

Figure 4. Chlorophyll *a*, salinity, and dissolved oxygen concentrations, Simpson Lagoon, 1970.

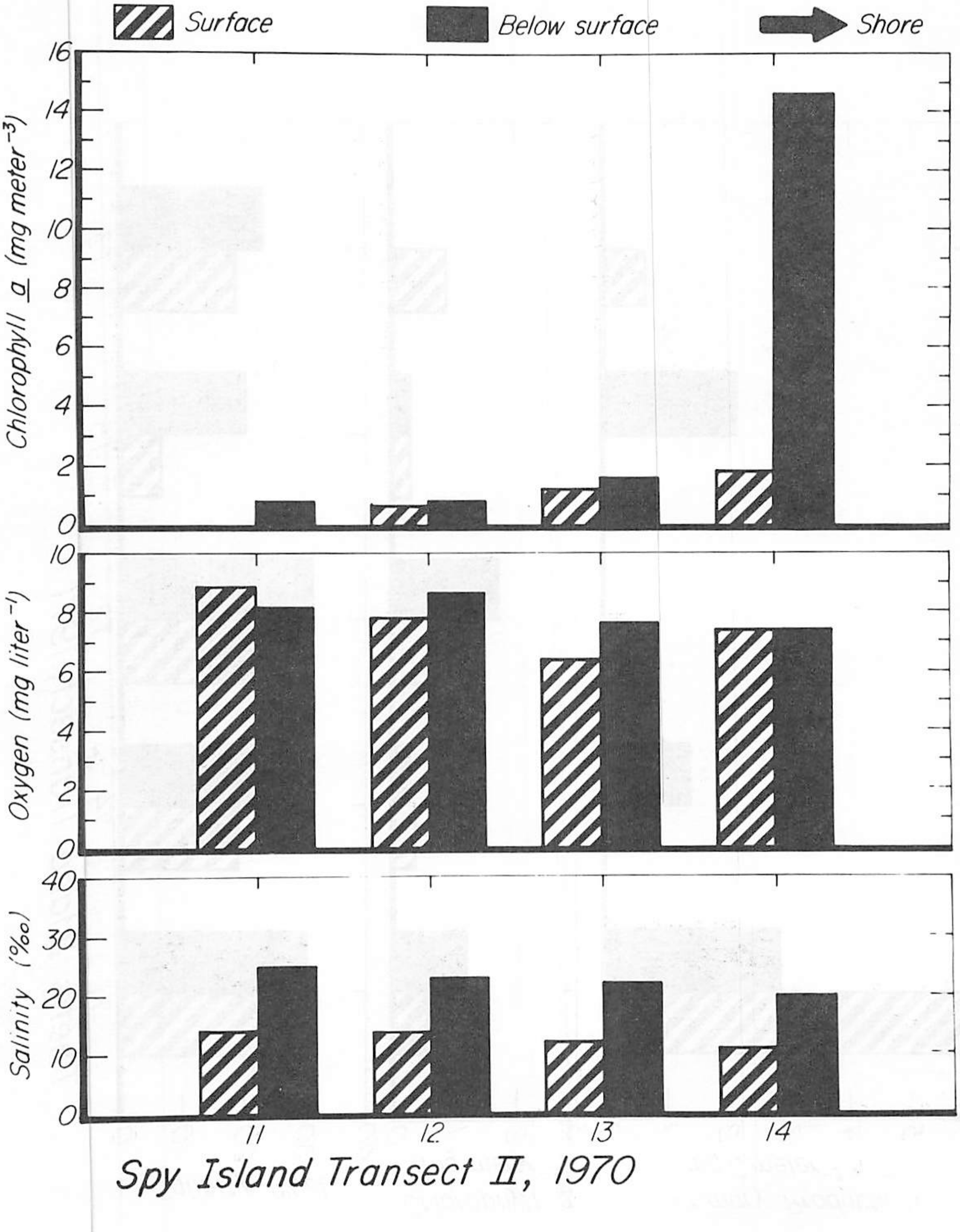

Figure 5. Chlorophyll *a*, salinity, and dissolved oxygen concentrations, Simpson Lagoon, 1970.

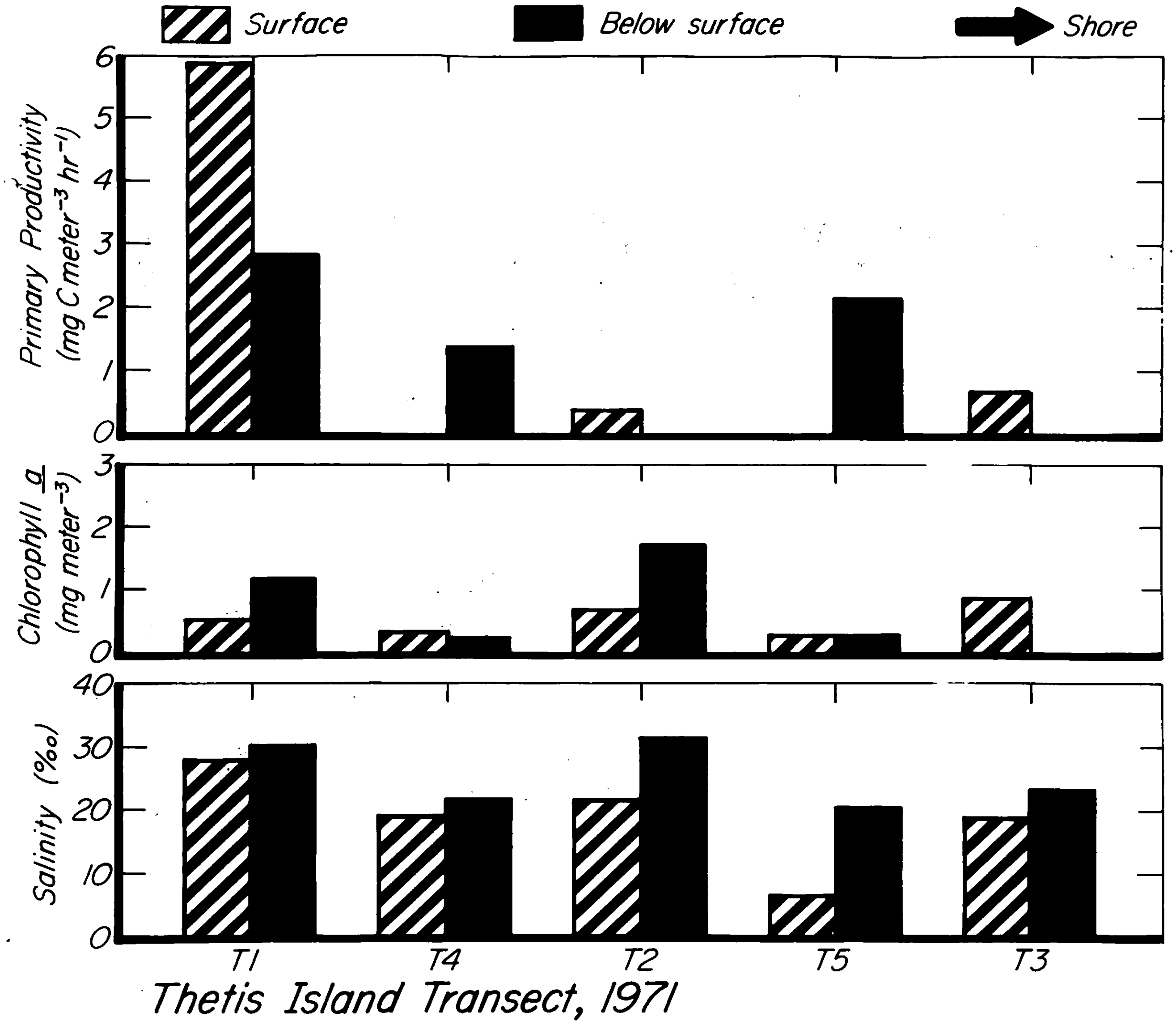

Figure 6. Chlorophyll *a*, salinity, and primary productivity concentrations, eastern Harrison Bay, 1971.

Table 1. TABULATED DATA - SIMPSON LAGOON TRANSECTS 9 AUGUST-1 SEPTEMBER, 1970

Site	Temp. °C	Depth of samples, m	pH	Dissolved O_2, mg/1	Chlorophyll *a*, μg/1	Alkalinity, $mgCaCO_3/1$	Salinity, °/₀₀
A Thetis Island Transect							
Station 1							
70-HBE3	--	0	--	7.8	0.78	--	21.8
		3.7		7.4	2.14		25.8
Station 2							
70-HBE2	--	0	--	7.6	0.67	--	15.8
		3.7		7.2	1.87		23.6
Station 3							
70-HSE4	--	0	7.2	7.9	0.58	78.9	13.5
		3.2	7.4	7.3	1.12	99.6	23.6
Station 4							
70-HBE5	--	0	--	7.7	1.74	--	10.1
		3.0		7.6	1.12		21.9
Station 5							
70-HBE6	--	0	--	8.3	1.03	--	3.4
		2.1		7.2	7.20		11.4
B Spy Island Transect I							
Station 7							
70-SL1	5.6	0	7.2	7.8	0.46	105.28	24.9
		2.7	7.0	7.9	1.04	105.28	24.9
Station 8							
70-SL2	5.6	0	7.1	8.4	0.72	104.34	
		2.8	7.0	7.9	1.74	105.28	

Table 1. (continued) TABULATED DATA - SIMPSON LAGOON TRANSECTS 9 AUGUST-1 SEPTEMBER, 1970

Site	Temp. °C	Depth of samples, m	pH	Dissolved O_2, mg/l	Chlorophyll *a*, µg/l	Alkalinity, mgCaCO$_3$/l	Salinity, °/°°
Station 9							
70-SL3	5.6	0	7.2	7.7	1.04	104.81	22.1
		2.8	7.1	7.4	2.45	105.28	
Station 10							
70-SL4	5.6	0	7.2	8.4	1.15	105.28	16.5
		2.5	7.0	7.1	1.15	104.81	
Spy Island[B1] Transect II							
Station 11							
70-SL24	4.7	0		8.9	NIL		13.8
		2.6	7.2	8.4	0.77	111.86	25.4
Station 12							
70-SL25	4.7	0	7.3	7.5	0.66	83.66	13.9
		2.8	7.0	8.7	0.80	95.41	22.7
Station 13							
70-SL26	4.7	0	7.0	6.4	1.25	76.14	12.2
		2.8	7.2	7.6	1.57	86.01	22.3
Station 14							
70-SL27	4.7	0	7.0	7.4	1.79	74.73	11.4
		2.2	7.1	7.4	14.59	87.42	19.7
Range	4.7° to 5.6°	--	7.0 to 7.4	6.4 to 8.9	NIL to 14.59	62.98 to 111.86	3.4 to 15.8
Mean	5.15	--	7.14	7.73	1.86	93.62	17.7

Table 2. PRIMARY PRODUCTIVITY AND RELATED FACTORS - 1971

Station	Date	Depth, m	Salinity °/oo	pH	Chlor. *a*, mg/m^3	Phaeo., mg/m^3	Primary Productivity, mgC/m^3·hr
T-1	28 Jul	0.0	27.9	6.8	.55	.15	5.80
		1.0	30.2	6.6	1.24	.55	2.87
		2.2	30.5				
T-2	28 Jul	0.0	23.4	6.6	.63	.12	.37
		1.0	27.6				
		2.0	29.6				
		3.0	30.9	6.7	1.76	2.31	.75
T-3	28 Jul	0.0	18.4	6.8	.62	.20	.63
		1.0	22.0				
T-4	11 Aug	0.0	19.0	6.7	.22	.03	
		2.5	20.1	6.7	.17	.06	1.39
T-5	11 Aug	0.0	7.0	6.7	.22	.07	
		2.5	20.0	6.7	.23	.10	1.62
BS-1	1 Aug	0.0	20.0	6.6	.09	.27	
		2.0	20.3	6.7	.09	.14	
		4.0	22.0	6.8	.05	.21	
BS-2	1 Aug	0.0	20.5	6.6	.09	.23	
		2.0	21.0	6.6	NIL	.29	
		4.0	24.5	6.4	NIL	1.42	
	15 Aug	2.0					.32
BS-3	1 Aug	0.0	20.6	6.5	.09	.27	
		2.0	23.5	6.6	.09	.04	
		4.0	25.9	6.6	.21	NIL	
	15 Aug	2.0					.46
BS-4	1 Aug	0.0	22.5	6.3	NIL	.25	
		2.0	23.8	6.6	.14	.06	
		4.0	25.9	6.6	.02	.20	
	9 Aug	2.0					.45
BS-5	1 Aug	0.0	21.2	6.3	NIL	.39	
		2.0	23.8	6.3	NIL	.25	
		4.0	26.6	6.3	-	-	

Table 2. (continued) PRIMARY PRODUCTIVITY AND RELATED FACTORS - 1971

Station	Date	Depth, m	Salinity, °/oo	pH	Chlor. *a*, mg/m^3	Phaeo., mg/m^3	Primary Productivity, mgC/m^3•hr
BS-6	1 Aug	0.0	22.2	6.2	NIL	.52	
		2.0	26.8	6.3	NIL	.71	
		4.0	28.2	6.3	.14	.52	
BS-7	9 Aug	0.0	21.1	6.7	.11	.02	
		2.0	21.1	6.6	.07	.18	
		4.0	23.1	6.5	.27	.17	
BS-8	11 Aug	0.0	19.8	6.6	.21	NIL	
		2.0	20.5	6.6	.28	.01	.41
		4.0	22.0	6.5	.48	.09	
SL-1	8 Aug	0.0	16.5	6.8	.60	.57	
		1.0	16.5				
	15 Aug	0.0					1.49
SL-2	8 Aug	0.0	17.2	6.6			
		1.0	17.2	6.6			
		1.5			.43	.25	
		2.0	17.2				
	15 Aug	1.0					1.02
SL-3	8 Aug	0.0	17.6	6.6	.21	.22	
		1.0	17.7	6.6	.32	.24	
	15 Aug	1.0					.53
SL-4	9 Aug	0.0	17.2	6.6	.33	.18	
		1.0	17.2	6.6	.26	.66	1.07
SL-5	9 Aug	0.0	16.8	6.6	.33	.34	
		1.0	17.1		.46	.21	
		1.5	18.0	6.6	.53	.17	.91
SL-6	9 Aug	0.0	16.6	6.6	.53	.17	
		1.0	17.5	6.6	.75	.75	1.81
SL-7	9 Aug	0.0	16.3	6.5	.81	.31	
		1.0	19.4	6.6	1.07	.40	2.96
SL-8	9 Aug	0.0	16.7	6.5	.27	.42	
		1.5	19.5	6.6	.75	.34	1.84
SL-9	9 Aug	0.0	16.4	6.6	.14	.32	
		1.5	17.5	6.6	.24	.35	1.02
SL-10	10 Aug	0.0	15.9	6.6	.31	.27	
		1.0	15.9				

Table 2. (continued) PRIMARY PRODUCTIVITY AND RELATED FACTORS - 1971

Station	Date	Depth, m	Salinity, °/oo	pH	Chlor. *a*, mg/m^3	Phaeo., mg/m^3	Primary Productivity, mgC/m^3·hr
SL-11	10 Aug	0.0	19.9	6.5	.18	.21	
		1.0	19.1	6.6	.18	.21	
SL-12	10 Aug	0.0	20.6	6.7	.18	.02	
		1.5	20.0	6.6	.23	.06	
SL-13	10 Aug	0.0	20.6	6.7	.18	.06	
		1.5	20.6	6.7	.16	.29	
SL-14	10 Aug	0.0	21.7	6.7	.35	.08	
		1.0	21.6	6.7	.31	.18	
	11 Aug	1.0					.51
SL-15	10 Aug	0.0	20.7	6.7	.20	.13	
		2.0	20.8	6.7	.28	NIL	
	11 Aug	2.0					2.82
SL-16	10 Aug	0.0	18.2	6.7	.32	.19	
		2.0	19.8	6.8	.23	.26	
	11 Aug	2.0					5.88
SL-17	10 Aug	0.0	13.7	6.7	.64	.27	
		1.5	19.2	6.7	1.07	.69	
	11 Aug	1.5					2.16
HB-1	12 Aug	0.0	18.7	6.7	.25	.27	
		2.0	25.8	6.7	.65	.33	1.59
HB-3	12 Aug	0.0	19.2	6.8	.12	.22	
		2.0	26.3	6.8	.19	.25	
	13 Aug	2.0					.37
HB-5	12 Aug	0.0	23.0	6.7	.14	.15	
		2.0	25.0	6.7	.33	.13	
	13 Aug	2.0	25.0				.24
HB-6	13 Aug	0.0	18.6	6.7	.14	.15	
		2.0	19.5	6.7	.47	.19	.27

Table 2. (continued) PRIMARY PRODUCTIVITY AND RELATED FACTORS - 1971

Station	Date	Depth, m	Salinity, °/₀₀	pH	Chlor. *a*, mg/m^3	Phaeo., mg/m^3	Primary Productivity, mgC/m^3·hr
HB-7	13 Aug	0.0	18.4	6.8	.25	.19	
		1.5	18.6	6.8	.37	.19	.59
OL-I	17 June	0.0			.21	NIL	
OL-II	17 June	0.0			.26	NIL	
OL-III	17 June	0.0			.43	NIL	
OL-IV	17 June	0.0			.79	.11	
Wood's Pond	30 June	0.0			.92	NIL	

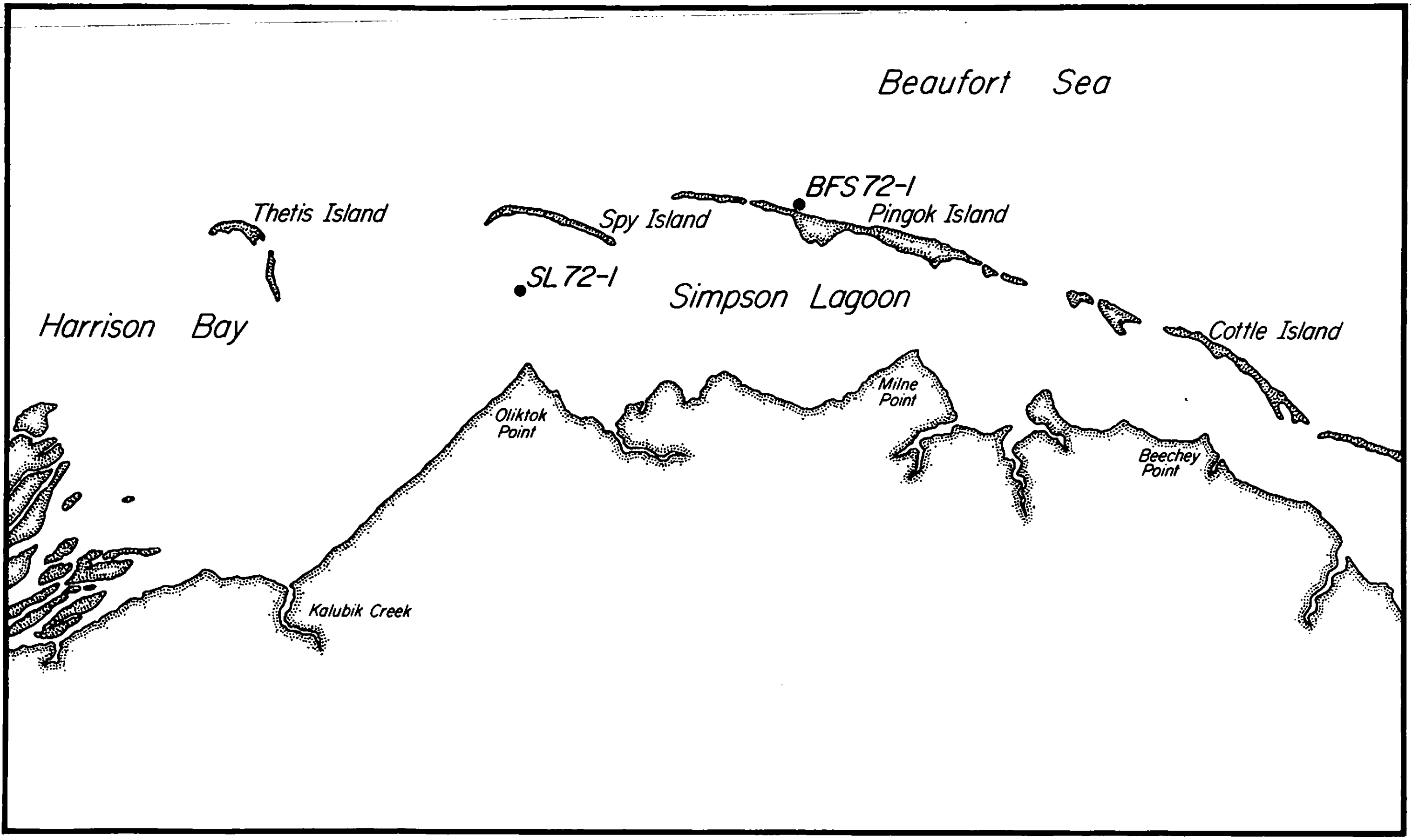

Figure 7. Intensive study stations, Summer, 1972.

Table 3. PRIMARY PRODUCTIVITY AND CHLOROPHYLL *a* STANDING STOCK, 1972.

	Depth, m	pH	Alkalinity, meq/l	Available C, mg/l	Net prim., mgC/m^3·hr	productivity mgC/m^2·hr
Simpson Lagoon 72-1						
July 29	0.0	7.68	3.02	38.2	4.98	(11.98)
	2.0	7.95	3.09	38.3	3.01	
August 5	0.0	8.16	3.30	40.50	1.08	(22.66)
	2.0	8.26	3.66	44.92	14.03	
August 12	0.0	8.12	1.68	20.62	1.70	(4.45)
	2.0	8.05	1.86	22.88	1.27	
August 19	0.0	7.78	1.82	22.83	1.11	(2.94)
	2.0	7.78	2.07	25.97	0.85	
August 26	0.0	7.54	1.10	14.22	0.12	(0.33)
	2.0	8.00	2.04	25.15	0.10	
Beaufort Sea 72-1						
August 1	0.0	8.02	2.26	27.86	0.89	(23.30)
	2.0	7.86	3.13	39.01	3.08	
	4.0	7.84	3.52	43.87	5.01	
	6.0	7.91	3.88	48.15	6.23	
August 15	0.0	8.01	1.76	21.70	0.50	(11.95)
	2.0	7.94	1.76	21.79	0.70	
	4.0	7.97	2.20	27.18	2.69	
	6.0	8.00	2.25	27.74	4.67	
August 29	0.0	8.15	2.27	27.86	0.60	(6.91)
	2.0	8.08	2.24	27.49	0.69	
	4.0	8.07	2.30	28.23	1.30	
	6.0	8.27	2.29	28.10	2.33	

In the Simpson Lagoon-Harrison Bay area, strong salinity and thermal stratification complicates the picture. The intensity of stratification varies depending on the volume of river flow and wind action. Probably as a result of the salinity: depth gradient, a high proportion of the phytoplankton in the deep water is composed of diatoms, whereas the surface population contains flagellates in addition to diatoms.

The 1972 primary productivity results (Table 3) have clarified the depth/productivity relationship, and also provided information on seasonal trends. Relatively high primary productivity rates were found offshore in the deeper layers. The Beaufort Sea station, immediately off Pingok Island, invariably had the highest rates in the bottom 6 meters of water. These ranged from 2.33 to 6.23mg C/m^3•hr. At this station, intergration of the primary productivity depth curves results in 23.3, 12.0, 6.9mg C/m^2•hr on August 1, 15 and 29, respectively. Assuming a 20 hour active day (not directly based on quantitative information, and therefore to be considered an informed guess), and taking the mean of the results of the three days (281.3mg C/m^2-day), it is determined that 8.72g C/m^2 fixed during the month of August. These values are somewhat but not markedly lower than the primary productivity rates reported for the Bering Strait region by McRoy *et al.*[15]. Based on these results, we suggest that the productivity of this near-shore Beaufort Sea may not be extremely low. The photosynthetic organisms seem to prefer the high salinity deeper water over the more brackish surface water. We may even further suggest that this river enhancement of productivity is the result of a relatively high rate of nutrient supply. As will be shown below, this is almost certainly true for nitrogen nutrients.

The 1972 Simpson Lagoon station did not show the tendency for stratification of primary production with depth except on 5 August. This day was characterized by extremely low nitrate and ammonia concentrations at all depths, and even silicate levels were low in the bottom water. This suggests intense removal of nutrients from the bottom water, but does not in itself offer an explanation of the extremely high productivity rates measured (maximum 14mg C/m^3•hr).

The overall seasonal trend at both stations was a steady decline in productivity both on a volume and a surface area basis. This, again, may be related to nutrient input, (discussed in Chapter 7).

Much of the low arctic ocean productivity has been attributable to the lack of vertical stability of the water column. This is not a problem, of course, in nearshore shallow regions. In the Colville Delta area, shallow depth coupled with nutrient supply by the river system results in relatively high productivity levels in comparison with many arctic regions previously described[16]. We had totally underestimated productivity based on the 1970 and 1971 sampling design. The complex distribution pattern, whereby most of the nutrient input occurs in low salinity water and most of the production occurs in higher salinity bottom water may be a complicating factor in relating the dynamics of nutrient input and primary productivity.

Phytoplankton Populations - While detailed taxonomic work was not within the scope of our program, we did take a look at the phytoplankton populations in terms of major groups and principal species. In common with many arctic observations, we found that a large proportion of the cells are extremely small, within the size range generally designated nannoplankton. The species composition in the Beaufort Sea-Simpson Lagoon varied with depth and season, and indeed also between seasons. The sampling was closely related with the primary productivity sampling, such that we have a wider areal coverage for 1970 and 1971, but more detailed observations on a limited number of stations for 1972.

This makes it difficult to make comparisons from year to year, but there did appear to be a real difference between 1971 and 1972, with a relatively high diatom component in 1972 compared with 1971. In Simpson Lagoon in 1971, cryptophytes and chrysophytes were relatively important components of the populations. However, in 1971 there was a difference in the relative proportions of diatoms from Simpson Lagoon toward Harrison Bay. The populations in 1971 appeared to be somewhat lower in total biomass. A similar pattern holds for the Beaufort Sea station. A change in structure with depth is also apparent, with dinoflagellates or silicoflagellates often increasing with depth, as well as diatoms. Total biomass tends to increase with depth. A transect across Harrison Bay is shown in Figure 8.

Tables 4 through 7 list the major phytoplankton species found in the samples. Total cell numbers and total biomass for surface samples and average total cell numbers and biomass for all depths are shown in Figures 9 to 12. Total cell numbers varied between 10^5 to 10^7 per liter, and biomass between 10^7 and $10^9 \mu m^3$ per liter. Phytoplankton composition in terms of biomass and cell numbers is presented in Figures 13 to 18. The change in composition along a transect from Simpson Lagoon to Harrison Bay for 1971 is shown in Figure 19.

Some of the organisms present appear to be derived from the freshwater environment. In particular, *Rhodomonas minuta* and *Chromulina* sp. are typically freshwater forms very abundant in northern Alaskan waters. In 1972, such organisms dominated only on a couple of occasions, and only in surface water; they may have been related to especially marked salinity stratification. We do not know to what extent these organisms photosynthesize and reproduce effectively in the marine environment. At one station (BFS-1) on 29 August, 1972, unidentified, light-green 2-3μm spherical cells were dominant in the 0, 4 and 6 meter samples, but fewer were found in the 2 meter sample. *Platymonas*

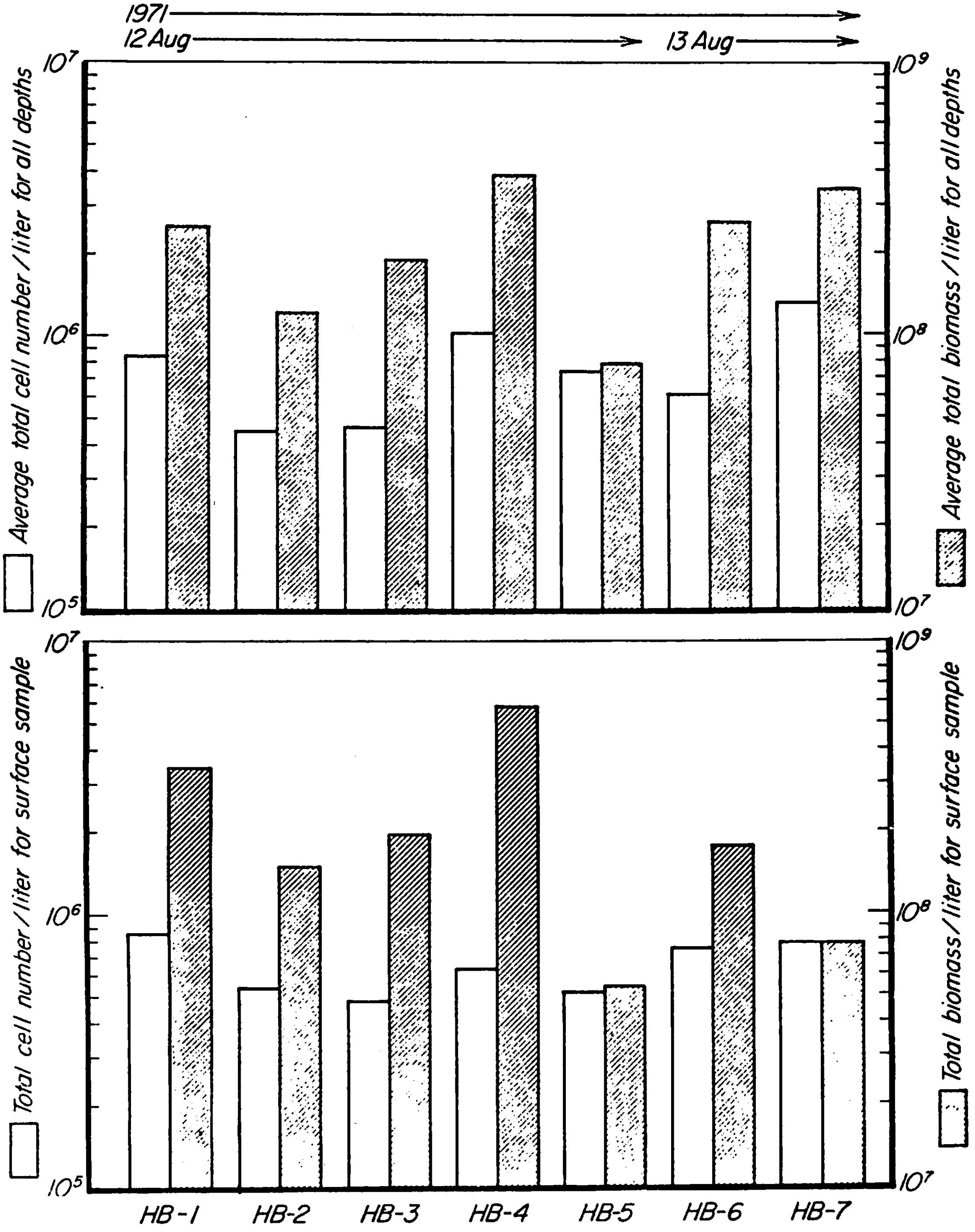

Figure 8. Biomass and number of cells, Harrison Bay transect.

Table 4. Phytoplankton numbers and biomass - Simpson Lagoon, 1971

	8 AUGUST					9 AUGUST												10 AUGUST							
	SL71-1	SL71-2		SL71-3		SL71-4		SL71-5		SL71-6		SL71-7		SL71-8		SL71-9		SL71-11	SL71-13	SL71-14	SL71-15	SL71-16		SL71-17	
	0m	0m	1.5m	0m	1m	0m	1m	0m	1.5m	0m	1m	0m	1m	0m	1.5m	0m	1.5m	0m	0m	1m	2m	0m	2m	0m	1.5m
Bacillariophyceae	144.6*	72.3	72.3	32.1	72.3	48.2	378.8	24.1	72.3	24.1	72.3	72.3		24.1	72.3		168.7	72.3	48.2			361.5	192.8	353.6	273.2
	30.7**	27.3	67.8	2.5	16.3	18.8	19.2	6.9	8.2	84.6	5.6	27.1		6.9	56.4		54.2	110.0	52.9			146.8	24.6	375.4	251.2
Chaetoceros spp.																						72.3	24.1		
																						23.0	0.6		
Nitzschia spp.																	120.5					24.1			
																	26.4					5.6			
Nitzschia closterium																							24.1		
																							7.5		
Navicula spp.	144.6	72.3	48.2			48.2				24.1									32.1						
	30.7	27.3	60.1			18.8				84.6									49.8						
Others			24.1	32.1	72.3		378.8	24.1	72.3		72.3	72.3		24.1	72.3		48.2	72.3	16.1			265.1	144.6	353.6	273.2
			7.7	2.5	16.3		19.2	6.9	8.2		5.6	27.1		6.9	56.4		27.8	110.0	3.1			118.2	16.5	375.4	251.2
Chlorophyta	48.2	96.4	168.7	32.1	144.6	24.1	24.1	48.2	144.6	48.2	144.6	96.4	120.5	48.2	144.6	24.1	24.1	60.2	128.5	289.1	96.4	48.2	168.7	16.1	16.1
	4.5	9.1	15.9	3.0	13.6	2.3	2.3	12.6	5.7	4.5	3.6	9.1	4.7	1.9	2.1	1.6	3.1	2.0	8.4	18.9	6.3	2.1	11.0	1.1	1.1
Platymonas sp.	48.2	96.4	168.7	32.1	144.6	24.1	24.1	24.1	144.6	48.2	144.6	96.4	120.5	48.2	144.6	24.1	24.1	60.2	128.5	289.1	96.4	48.2	168.7	16.1	16.1
	4.5	9.1	15.9	3.0	13.6	2.3	2.3	2.3	5.7	4.5	3.6	9.1	4.7	1.9	2.1	1.6	3.1	2.0	8.4	18.9	6.3	2.1	11.0	1.1	1.1
Chrysophyta		313.2	120.5		72.3					24.1				48.2		72.3	72.3	84.3	224.9		144.6	144.6	192.8		
		20.5	7.9		1.0					0.4				2.7		1.1	3.1	6.0	15.7		13.3	8.2	13.7		
Dinobryon spp.														48.2			48.2	84.3	208.8		144.6	144.6	168.7		
														2.7			2.7	6.0	14.8		13.3	8.2	11.9		
Dinobryon petiolatum																			16.1				24.1		
																			0.9				1.8		
Chromulina spp.		313.2	120.5		72.3					24.1						72.3	24.1								
		20.5	7.9		1.0					0.4						1.1	0.4								
Cryptophyta	1060.6	529.2	746.9	192.8	120.5	265.0	313.2	650.1	891.5	1951.7	1108.3	1783.0	1526.0	602.4	1132.4	168.7	265.0	216.9	64.3	176.7	289.1	506.0	674.7	208.8	289.2
	132.5	106.7	97.8	25.2	15.8	34.7	41.0	85.2	388.4	255.5	145.1	233.4	303.9	78.8	148.2	22.1	34.7	28.4	8.4	23.1	37.9	66.2	88.3	27.3	64.9
Rhodomonas minuta	1060.6	505.1	746.9	192.8	120.5	265.0	313.2	650.1	891.5	1951.7	1108.3	1783.0	1405.5	602.4	1132.4	168.7	265.0	216.9	64.3	176.7	289.1	506.0	674.7	208.8	273.1
	132.5	63.1	97.8	25.2	15.8	34.7	41.0	85.2	388.4	255.5	145.1	233.4	184.0	78.8	148.2	22.1	34.7	28.4	8.4	23.1	37.9	66.2	88.3	27.3	35.8
Cryptomonas spp.		24.1											120.5												16.1
		43.6											119.9												29.1
Dinophyceae	96.4	72.3	48.2	32.2						48.2		216.9	80.3		48.2		48.2							48.2	48.2
	21.0	15.8	25.2	478.4						9.7		47.2	13.4		4.1		55.4							3.2	2.5
Gymnodinium lohmanni				16.1																					
				147.8																					
Peridinium spp.				16.1																					
				330.6																					
Others	96.4	72.3	48.2							48.2		216.9	80.3		48.2		48.2							48.2	48.2
	21.0	15.8	25.2							9.7		47.2	13.4		4.1		55.4							3.2	2.5
Silicoflagellates	24.1				24.1													12.1							
	221.7				221.7													110.9							
Flagellates	241.0	337.4	385.6.	48.2	337.4	457.9	168.7	182.8	120.5	433.8	819.4	144.6	923.7	241.0	216.9	385.6	216.9	144.6	112.4	337.4	337.3	289.2	313.3	64.2	32.1
	3.0	13.4	15.1	4.3	17.3	33.3	10.2	13.5	10.5	21.0	143.5	8.3	36.8	3.8	9.8	10.9	18.8	7.5	2.4	12.5	8.5	11.6	4.9	1.4	0.5
Mixed sizes	48.2	168.7	192.8	16.1	168.7	289.2	72.3	110.5	72.3	289.2	674.8	96.4	843.4	192.8	144.6	289.2	168.7	36.2	80.3	241.0	289.1	192.8	168.7	32.1	
	0.3	2.3	2.5	2.2	6.2	22.2	4.0	8.8	7.3	11.5	134.0	7.6	31.5	2.7	5.1	9.5	15.6	0.4	1.9	11.1	5.3	5.3	2.8	0.9	
3μ - 5μ flagellates ♉	192.8	168.7	192.8	32.1	168.7	168.7	94.6	72.3	48.2	144.6	144.6	48.2	80.3	48.2	72.3	96.4	48.2	108.4	32.1	96.4	48.2	96.4	144.6	32.1	32.1
	2.7	11.1	12.6	2.1	11.1	11.1	6.2	4.7	3.2	9.5	9.5	0.7	5.3	1.1	4.7	1.4	3.2	7.1	0.5	1.4	3.2	6.3	2.1	0.5	0.5
Unidentified cells		24.1	144.6		216.9	135.0	48.2	24.1	96.4	53.8	1927.6		1124.5	361.4	241.0	24.1	96.4						24.1	48.2	
		2.7	84.6		72.5	93.5	51.2	10.5	25.8	72.3	119.8		44.9	95.6	66.5	6.5	52.0						6.5	10.5	
Total	1614.9	1444.9	1686.8	337.4	988.1	930.2	933.0	929.3	1325.3	2583.9	4072.2	2313.9	3775.0	1325.3	1855.4	674.8	891.6	590.4	578.3	803.2	867.4	1349.5	1566.4	739.1	658.8
	413.4	195.5	314.3	513.4	358.2	182.6	123.9	128.7	438.6	448.0	417.6	325.1	403.7	189.7	287.1	42.2	221.3	264.8	87.8	54.5	66.0	234.9	149.0	418.9	320.2

Table 5. Phytoplankton numbers and biomass, Thetis Island and Harrison Bay station, 1971

	11 AUGUST				12 AUGUST										13 AUGUST			
	THE71-4		THE71-5		HB71-1		HB71-2		HB71-3		HB71-4		HB71-5		HB71-6		HB71-7	
	0m	2.5m	0m	2.5m	0m	2m	0m	2m	0m	2m	0m	2m	0m	2m	0m	2m	0m	1.5m
Bacillariophyceae	16.1*	80.4	112.4	128.5	160.7	96.4	96.5	96.4	160.6	80.3	80.4	144.6	16.1	32.1	96.4	72.3	48.2	433.7
	1.3**	7.0	52.6	26.0	97.6	64.4	48.9	46.7	10.7	9.9	42.5	33.7	1.7	15.0	13.8	31.4	12.3	453.4
Chaetoceros spp.						32.1						48.2						
						3.9						12.3						
Nitzschia closterium		16.1				16.1		32.1	32.1	16.1		24.1			24.1	48.2		
		2.0				2.5		10.0	5.0	5.0		1.5			5.6	26.0		
Navicula spp.			80.3		16.1	16.1	64.4					24.1						24.1
			27.5		56.4	51.4	47.2					9.1						73.3
Others	16.1	64.3	32.1	128.5	144.6	32.1	32.1	64.3	128.5	64.2	80.4	48.2	16.1	32.1	72.3	24.1	48.2	409.6
	1.3	5.0	25.1	26.0	41.2	6.6	1.7	36.7	5.7	4.9	42.5	10.8	1.7	15.0	8.2	5.4	12.3	380.1
Chlorophyta	32.2	305.2	16.1	594.3	96.4	96.4	241.0	64.3	80.3		144.6	674.7	64.3	610.4	24.1	843.3	80.4	192.8
	3.1	20.0	1.1	38.9	6.3	6.3	15.8	4.2	5.3		2.0	44.2	4.2	40.0	1.6	55.2	3.7	12.6
Platymonas sp.	16.1	305.2	16.1	594.3	96.4	96.4	241.0	64.3	80.3		144.6	674.7	64.3	610.4	24.1	843.3	64.3	192.8
	1.1	20.0	1.1	38.9	6.3	6.3	15.8	4.2	5.3		2.0	44.2	4.2	40.0	1.6	55.2	2.2	12.6
Chrysophyta	321.3	208.8	96.4	96.4	192.7	32.1			48.2	48.2			48.2	96.4	216.9	144.6	32.2	
	15.0	10.8	8.1	2.9	6.7	0.2			0.2	0.2			3.0	1.8	6.7	9.8	3.2	
Dinobryon spp.	208.8	176.7	80.3	32.1	112.4								16.1	16.1	72.3	24.1	32.2	
	11.8	8.7	4.5	1.8	6.4								0.9	0.7	4.1	1.9	3.2	
Dinobryon petiolatum	32.1		16.1	16.1											24.1			
	1.8		3.6	0.4											0.6			
Chromulina spp.	80.4	32.1		48.2	80.3	32.1			48.2	48.2			32.1	80.3	120.5	120.5		
	1.4	2.1		0.7	0.3	0.2			0.2	0.2			2.1	1.1	2.0	7.9		
Cryptophyta	224.9	96.4	208.8	224.9	321.3	562.2	128.5	96.4	48.2	176.7	208.8	530.1	305.2	176.7	241.0	1180.6	337.3	939.7
	29.4	66.5	27.3	29.4	69.1	73.6	16.8	12.6	6.3	16.2	27.3	69.4	40.0	23.1	31.5	154.5	44.2	123.0
Rhodomonas minuta	224.9	64.3	208.8	224.9	305.2	562.2	128.5	96.4	48.2	176.7	208.8	530.1	305.2	176.7	241.0	1180.6	337.3	939.7
	29.4	8.4	27.3	29.4	40.0	73.6	16.8	12.6	6.3	16.2	27.3	69.4	40.0	23.1	31.5	154.5	44.2	123.0
Cryptomonas spp.		32.1			16.1													
		58.1			29.1													
Dinophyceae	80.3	16.1			16.1	16.1	16.1	16.1	32.2	48.2		24.1			24.1	24.1		24.1
	97.3	80.1			73.9	9.7	48.2	16.4	148.2	155.9		22.7			110.9	85.3		5.2
Gymnodinium spp.	32.1					16.1		16.1				24.1						
	68.9					9.7		16.4				22.7						
Gymnodinium lohmanni		16.1			16.1		16.1		16.1						24.1	24.1		
		80.1			73.9		48.2		145.5						110.9	85.3		
Silicoflagellates			16.1	16.1							16.1							24.1
			250.6	498.9							498.9							5.2
Flagellates		80.3	48.2	128.5	48.2	16.1	48.2	64.3	96.4	80.5	176.8	24.1	80.3	16.1	144.6	192.8	265.1	168.7
		3.8	0.7	5.1	1.4	0.6	15.5	3.1	18.6	8.4	4.2	0.4	3.9	0.2	9.5	5.2	12.8	8.3
Mixed sizes		80.3	48.2	128.5	48.2	16.1	48.2	64.3	96.4	80.5	128.6	24.1	64.2		48.2	192.8	96.4	168.7
		3.8	0.7	5.1	1.4	0.6	15.5	3.1	18.6	8.4	3.5	0.4	3.7		3.2	5.2	10.4	8.3
3μ – 5μ flagellates ♉											48.2		16.1	16.1	96.4		168.7	
											0.7		0.2	0.2	6.3		2.4	
Unidentified cells			32.2	16.1	32.1		16.1	16.1	16.1			48.2		16.1				24.1
			11.9	18.5	98.1		1.1	4.3	4.3			23.6		18.5				6.5
Total	674.8	787.2	530.2	1204.8	867.5	819.3	546.4	353.6	482.0	433.9	626.7	1445.8	514.1	947.8	747.1	457.7	763.2	1783.1
	146.1	188.2	352.3	619.7	353.1	154.8	146.3	87.3	193.6	190.6	574.9	194.0	52.8	98.6	174.0	341.4	76.2	609.0

Table 6. SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR BEAUFORT SEA (BFS), 1971

Genus Species	Station BFS71-6 - 1 Aug.			Station BFS71-7 - 9 Aug.			Station BFS71-8 - 11 Aug.		
	Surf	2m	4m	Surf	2m	4m	Surf	2m	4m
Bacillariophyceae	48.2[a] 202.0[b]	64.3 22.7	120.1 206.7	16.1 15.9	48.2 114.0	32.1 5.8	48.2 20.2	48.2 8.8	64.3 29.4
Chaetoceros spp.	32.1 83.6								
Nitschia closterium		16.1 8.2				32.1 5.8			16.1 1.6
Navicula spp.				16.1 15.9	48.2 114.0				
Thalassiosira sp.	16.1 118.4								
Others		48.2 14.5	120.1 206.7				48.2 20.2	48.2 8.8	48.2 27.8
Chlorophyta			313.3 88.0	32.1 2.1	64.3 4.2	417.6 27.3	16.1 1.1	578.3 37.9	594.3 38.9
Platymonas sp.			120.5 4.7	32.1 2.1	64.3 4.2	417.6 27.3	16.1 1.1	578.3 37.9	594.3 38.9
Chrysophyta	32.1 1.8			530.1 18.7	32.2 1.8		192.8 15.0	144.6 6.6	96.4 8.8
Dinobryon spp.	32.1 1.8			530.1 18.7	16.1 1.2		192.8 15.0	80.3 5.7	
D. petiolatum					16.1 0.6				64.3 8.3
Chromulina spp.								64.3 0.9	32.1 0.5

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[a] cells (thousands/liter)

[b] biomass (m^3/liter)

Table 6. (continued) SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR BEAUFORT SEA (BFS), 1971

Genus Species	Station BFS71-6 - 1 Aug.			Station BFS71-7 - 9 Aug.			Station BFS71-8 - 11 Aug.		
	Surf	2m	4m	Surf	2m	4m	Surf	2m	4m
Cryptophyta	241.0[a] 31.5[b]	192.8 25.2	216.9 28.4	96.4 12.6	64.3 8.4	192.8 25.2	64.3 8.4	417.6 54.7	112.4 14.7
Rhodomanas minuta	241.0 31.5	192.8 25.2	216.9 28.4	96.4 12.6	64.3 8.4	192.8 25.2	64.3 8.4	417.6 54.7	112.4 14.7
Dinophyceae		16.1 523.1		16.1 766.4		16.1 167.9			
Gymnodinium lohmanni		16.1 523.1							
Peridinium spp.						16.1 167.9			
Silicoflagellates			24.1 375.8						32.1 295.7
Flagellates	64.3 0.9	16.1 0.2	72.3 21.4	80.4 0.6	64.3 16.9	160.6 10.6	32.1 2.1	128.5 1.5	
Mixed Sizes	48.2 0.7	16.1 0.2	48.2 19.8	64.3 0.3	64.3 16.9	160.6 10.6	32.1 2.1	32.1 0.1	
3-5 μ flagellates	16.1 0.2		24.1 1.6	16.1 0.3				96.4 1.4	
Unidentified cells	16.1 8.4	64.3 31.4	265.1 73.9					32.2 57.5	16.1 4.3
Total	401.7 244.6	353.6 602.6	1011.8 794.2	771.2 816.3	273.3 145.3	819.2 236.8	353.5 46.8	1349.4 167.0	915.6 391.8

[a] cells (thousands/liter)

[b] biomass (m^3/liter)

TABLE 7. SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR SIMPSON LAGOON (SL), 1972.

	29 July		5 Aug.		12 Aug.		19 Aug.		26 Aug.		19 Sept.	
	0m	2m	0m	2m	0m	2m	0m	2m	0m	2m	0m	2m
Bacillariophyceae	753.2[a] 243.9[b]	441.7 379.6	47.9 20.6	4302.2 2435.7	490.1 993.1	394.5 546.1	246.4 360.9	179.4 71.4	191.4 186.7	72.0 34.4	328.8 222.4	418.9 255.3
Chaetoceros spp.	537.8 90.4	239.0 29.2		669.2 361.5	35.9 6.2	59.8 14.9	44.8 7.7				107.6 8.2	215.1 37.5
Ch. compressus				23.9 63.4				23.9 20.6				
Ch. socialis				2724.7 376.1		23.9 0.3		35.9 1.3				
Nitzschia spp.	47.9 10.9	24.0 5.4	23.9 1.8	370.5 65.7	322.7 34.2	251.0 36.0	123.2 214.4	23.9 1.1		12.0 1.6		12.0 2.1
N. closterium		12.0 3.4		262.9 24.2			11.2 4.1	47.8 14.6			23.9 7.3	59.8 7.3
Navicula spp.	59.8 7.8	47.1 40.5	24.0 18.8	12.0 2.5	23.9 61.9			12.0 13.2	12.0 1.7	12.0 3.4	12.0 3.2	47.9 6.9
Thalassiosira spp.	83.7 130.6			71.7 877.1	59.8 494.9				12.0 99.0		23.9 160.4	47.8 173.0
Th. nordenskiöldii		107.6 244.0		167.3 665.2	47.8 395.9	59.8 494.9						
Others	24.0 4.2	12.0 57.1					67.2 134.7	35.9 20.6	167.4 86.0	48.0 29.4	161.4 43.3	35.9 28.5
Chlorophyta	23.9 3.5	23.9 5.2		119.5 17.5		107.6 4.5	89.6 3.7	12.0 0.2		47.9 5.3	764.8 17.9	47.8 4.7
Ankistrodesmus falcatus												

[a] cells (thousands/liter)

[b] biomass (millions μ^3/liter)

TABLE 7. (continued) SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR SIMPSON LAGOON (SL), 1972.

	29 July		5 Aug.		12 Aug.		19 Aug.		26 Aug.		19 Sept.	
	0m	2m	0m	2m	0m	2m	0m	2m	0m	2m	0m	2m
Oocystis submarina v. mirabilis	23.9[a] 3.5[b]			47,8 15.8						35.9 4.0	23.9 0.6	23.9 4.1
Platymonas sp.		23.9 5.2		71.7 1.7		107.6 4.5	89.6 3.7	12.0 0.2		12.0 1.3	740.9 17.3	23.9 0.6
Chrysophyta	12.0 0.1		23.9 1.8	35.9 1.4								
Dinobryon spp.				23.9 1.3								
Chromulina spp.	12.0 0.1		23.9 1.8	12.0 0.1								
Cryptophyta	59.8 14.7	59.8 24.8	239.0 25.4	35.9 13.2		227.1 39.6		12.0 1.2		95.6 10.8		83.7 9.2
Rhodomonas minuta	35.9 4.7		119.5 7.8	12.0 1.3		179.3 22.8		12.0 1.2		95.6 10.8		83.7 9.2
Cryptomonas spp.	23.9 9.9	59.8 24.8	119.5 17.6			47.8 16.8						
Dinophyceae		23.4 5.9					11.2 17.9					12.0 13.2
Silicoflagellates						47.8 1379.6						
Flagellates	24.0 1.3			12.0 2.0		24.0 4.3						24.0 7.4
Unidentified cells			23.9 9.1			107.6 26.7			12.0 2.6	23.9 1.8	12.0 0.9	12.0 1.0
Total	872.9 263.4	548.8 415.5	334.7 56.9	4505.5 2469.8	490.1 993.1	908.6 2000.8	347.2 382.5	203.4 72.8	203.4 189.3	259.4 52.3	1105.6 241.2	598.4 290.8

[a] cells (thousands/liter)

[b] biomass (millions μ^3/liter)

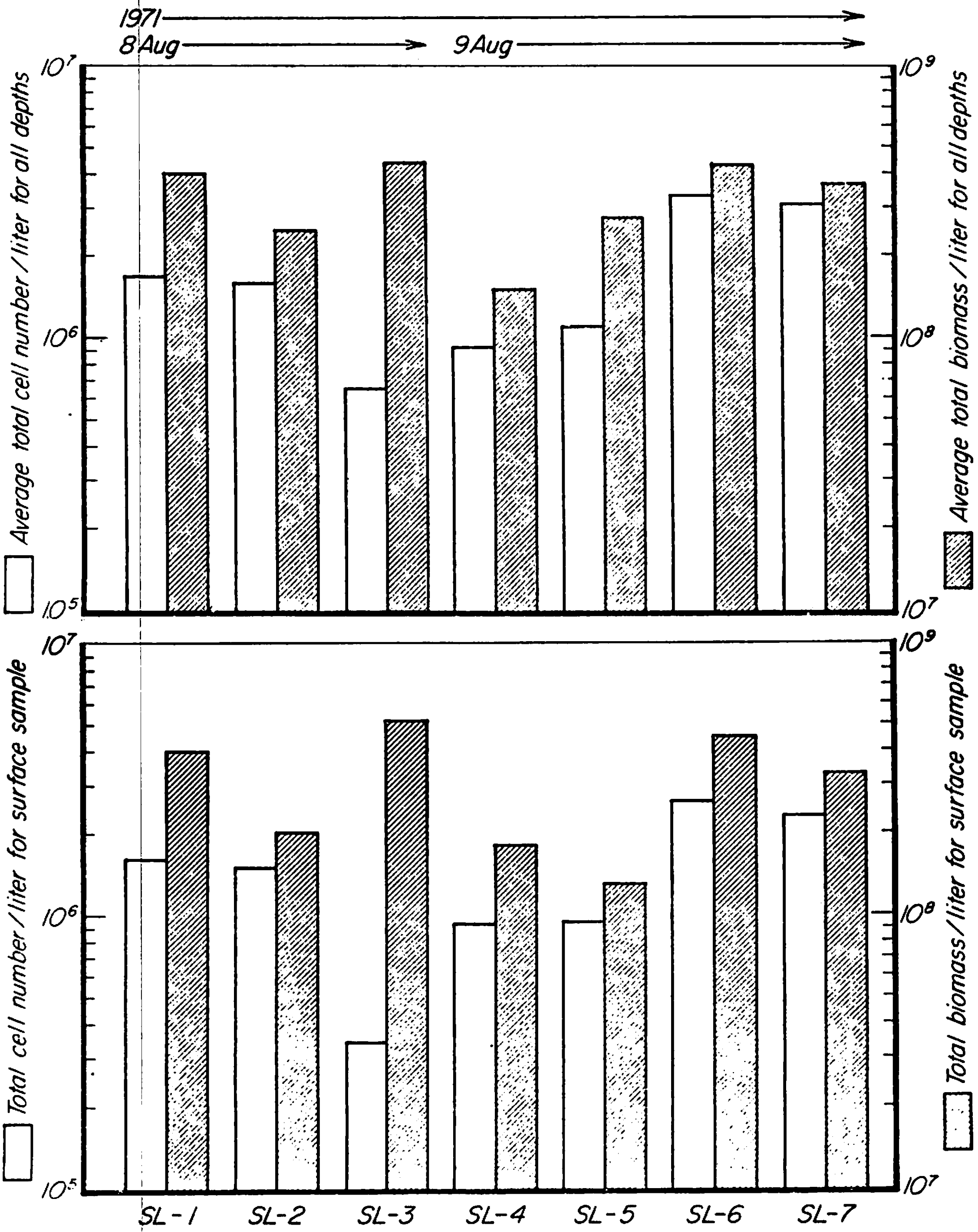


Figure 9A. Biomass and number of cells, Simpson Lagoon transects.

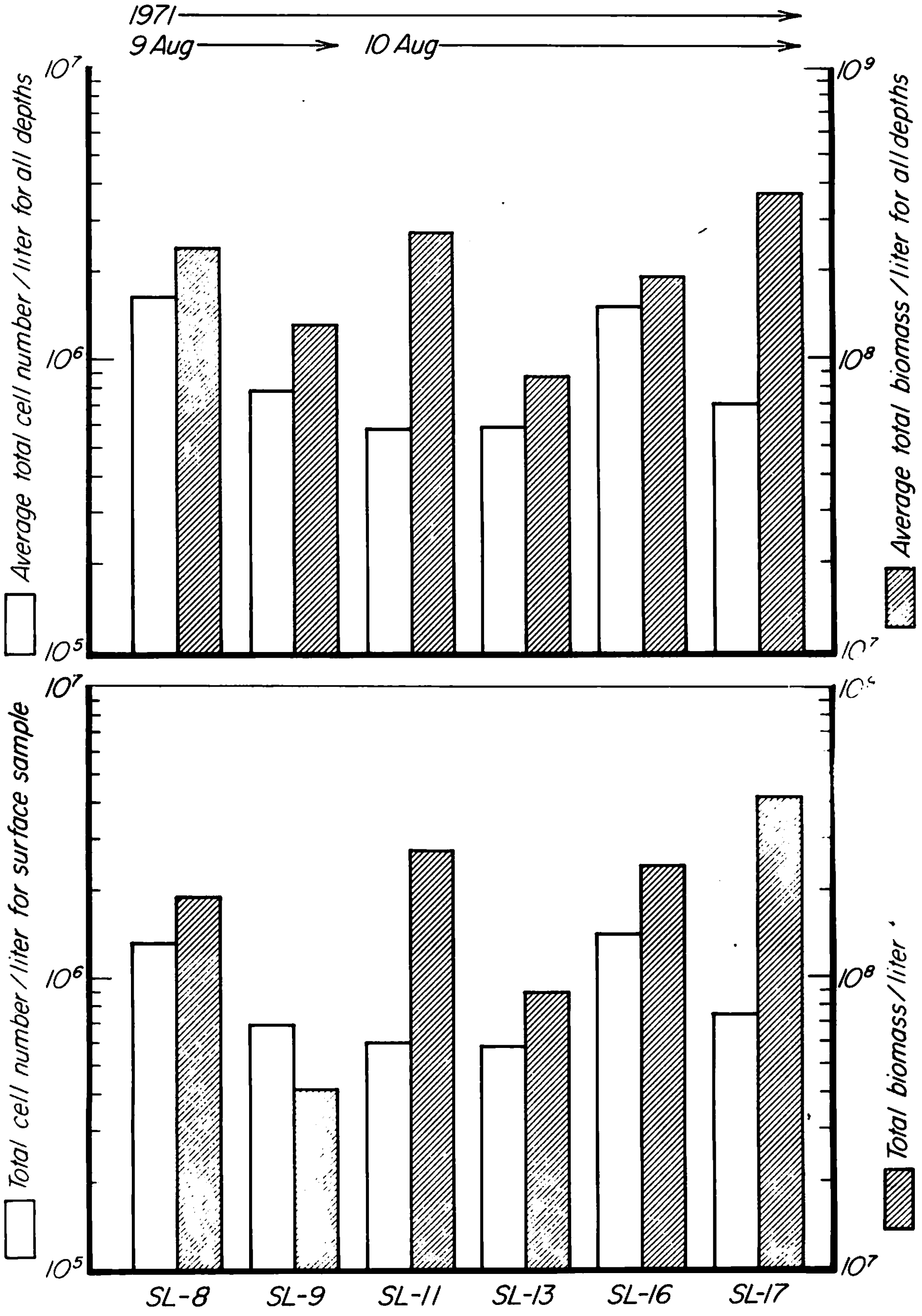


Figure 9B. Biomass and number of cells, Simpson Lagoon transects.

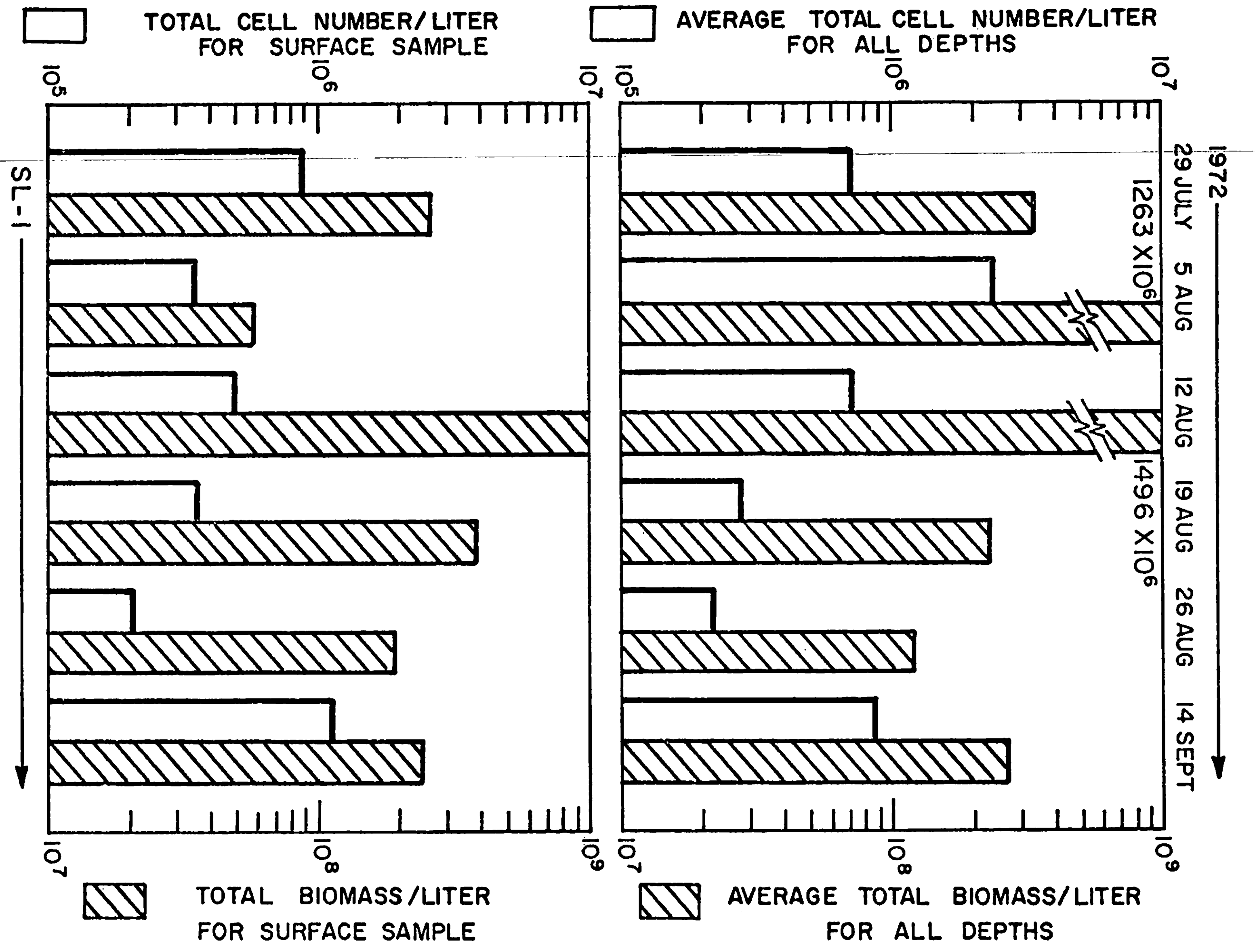


Figure 10. Biomass and number of cells, Simpson Lagoon Station SL-1, 1972.

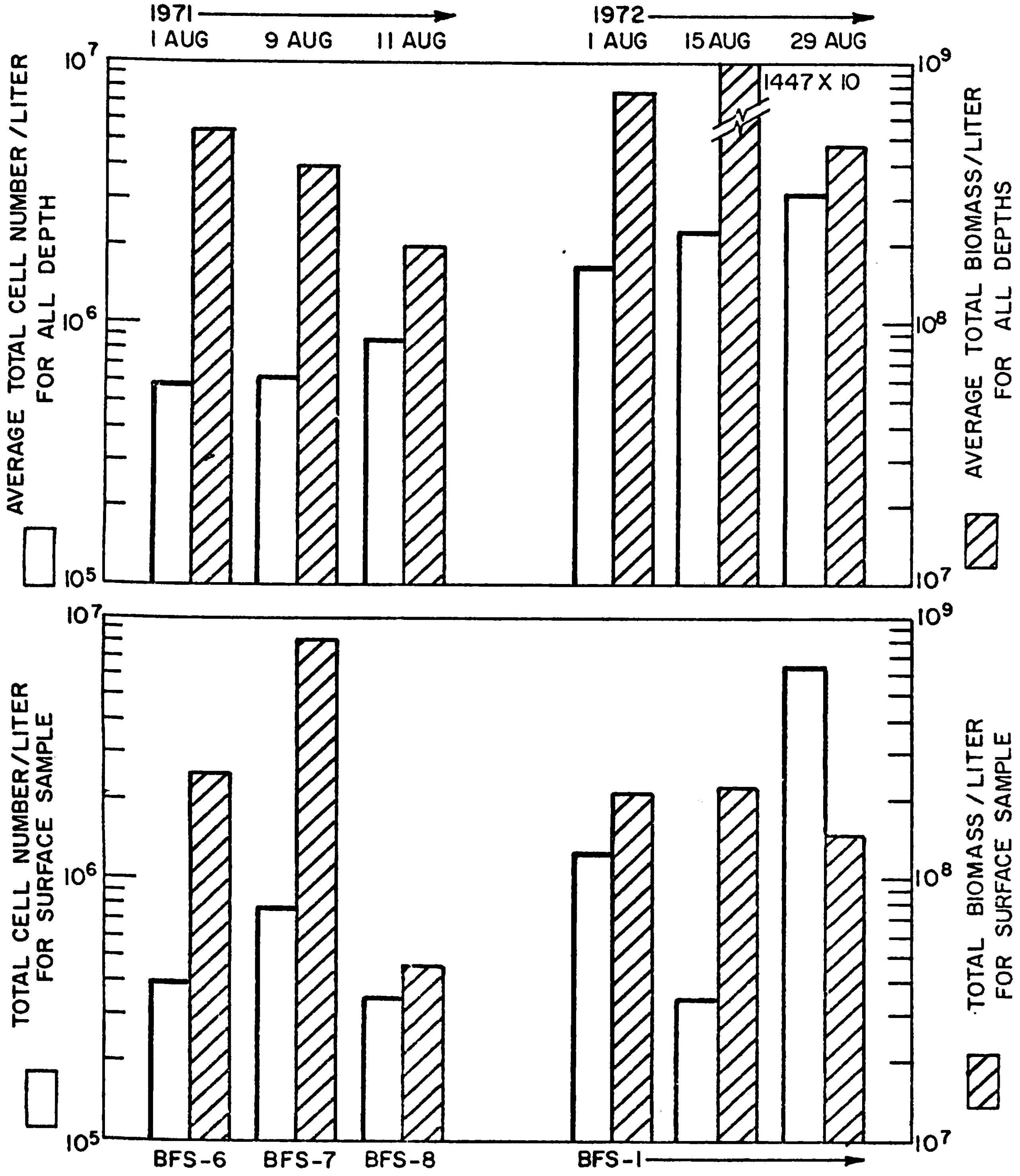


Figure 11. Biomass and number of cells, Beaufort Sea stations, 1971 and 1972.

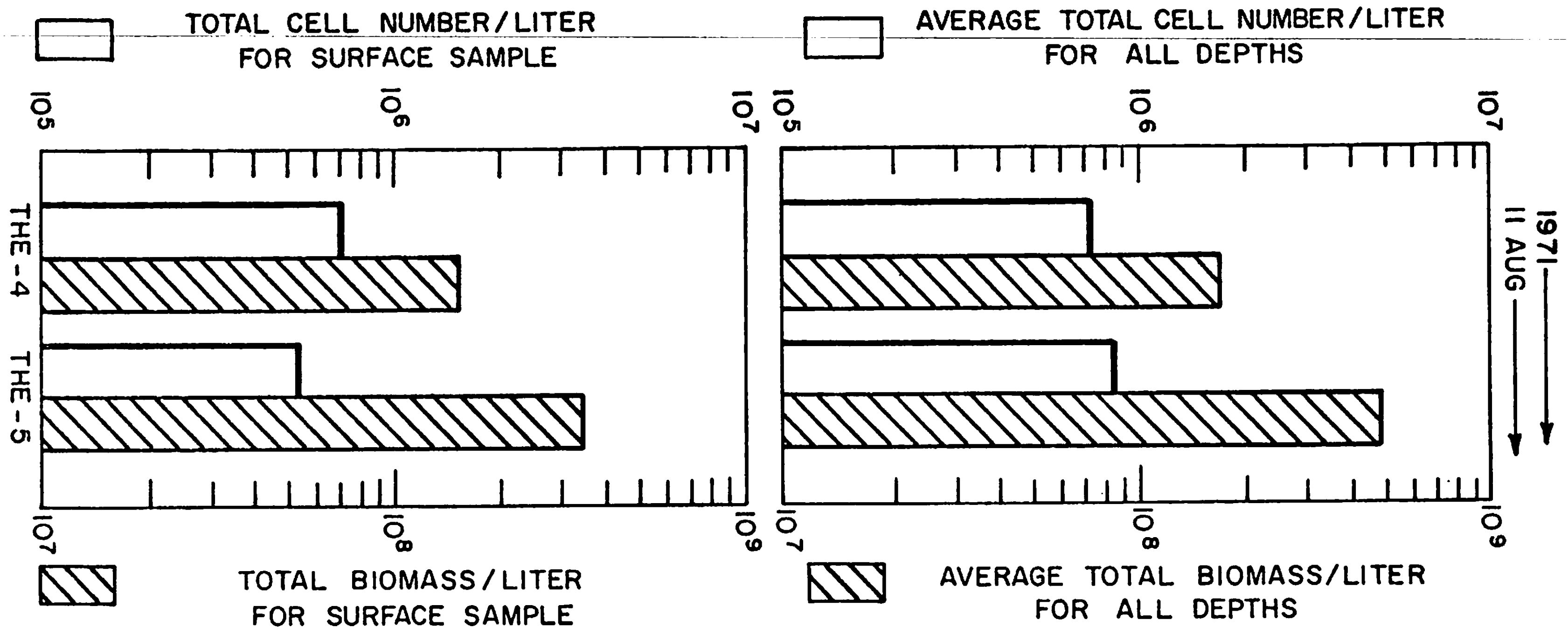


Figure 12. Biomass and number of cells, Thetis Island transect stations, 1971.

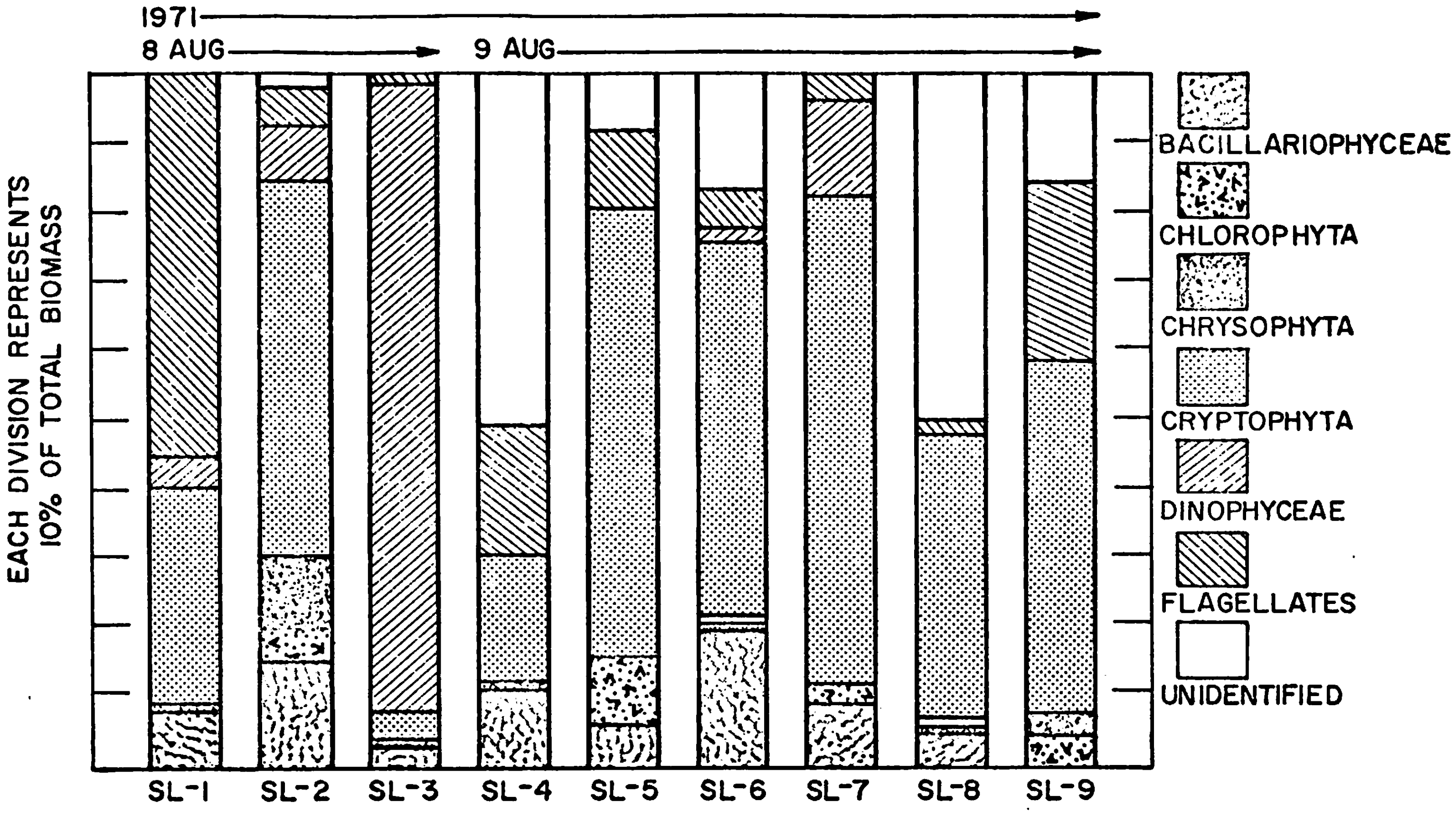


Figure 13A. Composition of phytoplankton biomass, Simpson Lagoon, 1971 and 1972.

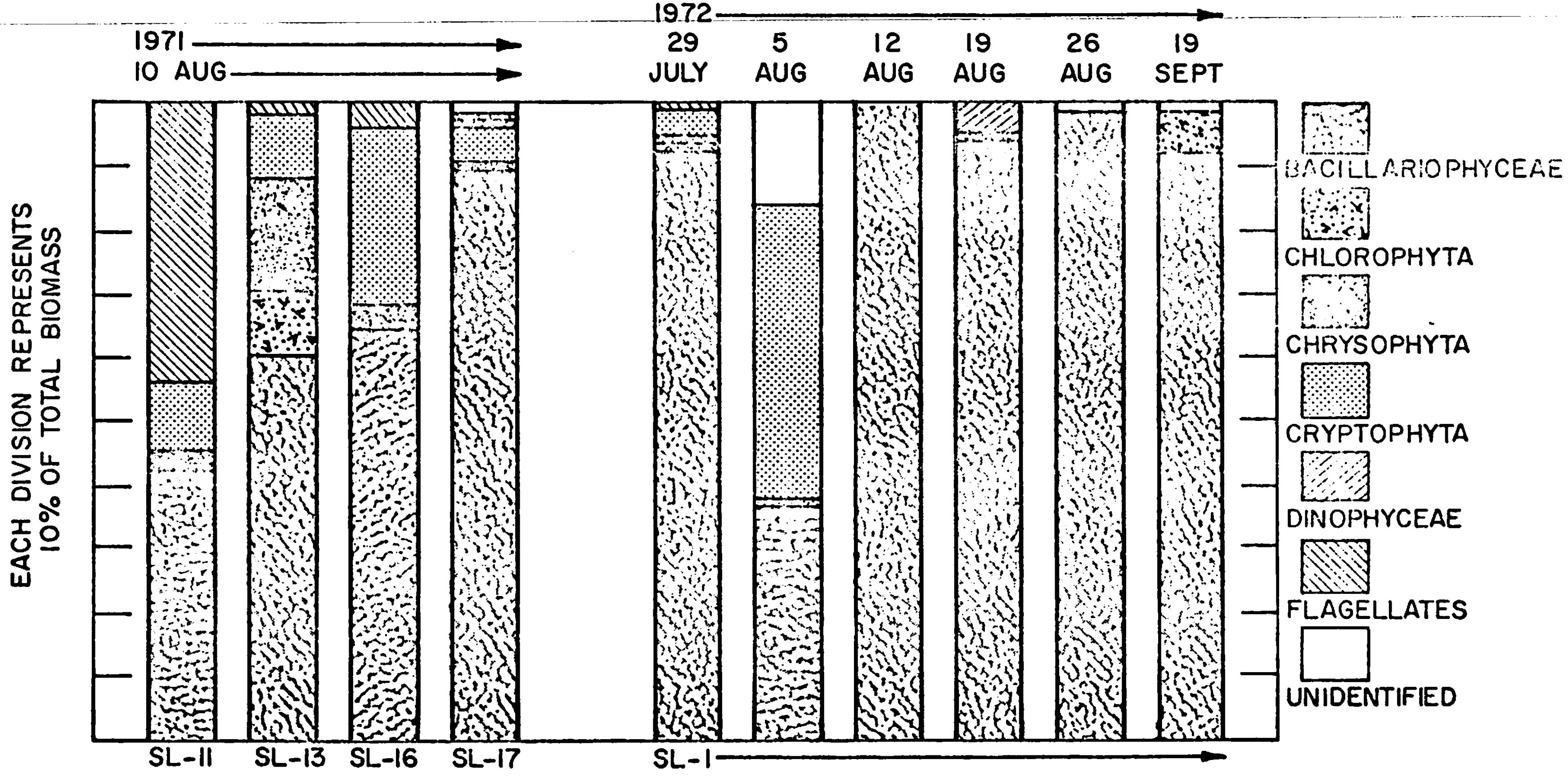


Figure 13B. Composition of phytoplankton biomass, Simpson Lagoon, 1971 and 1972.

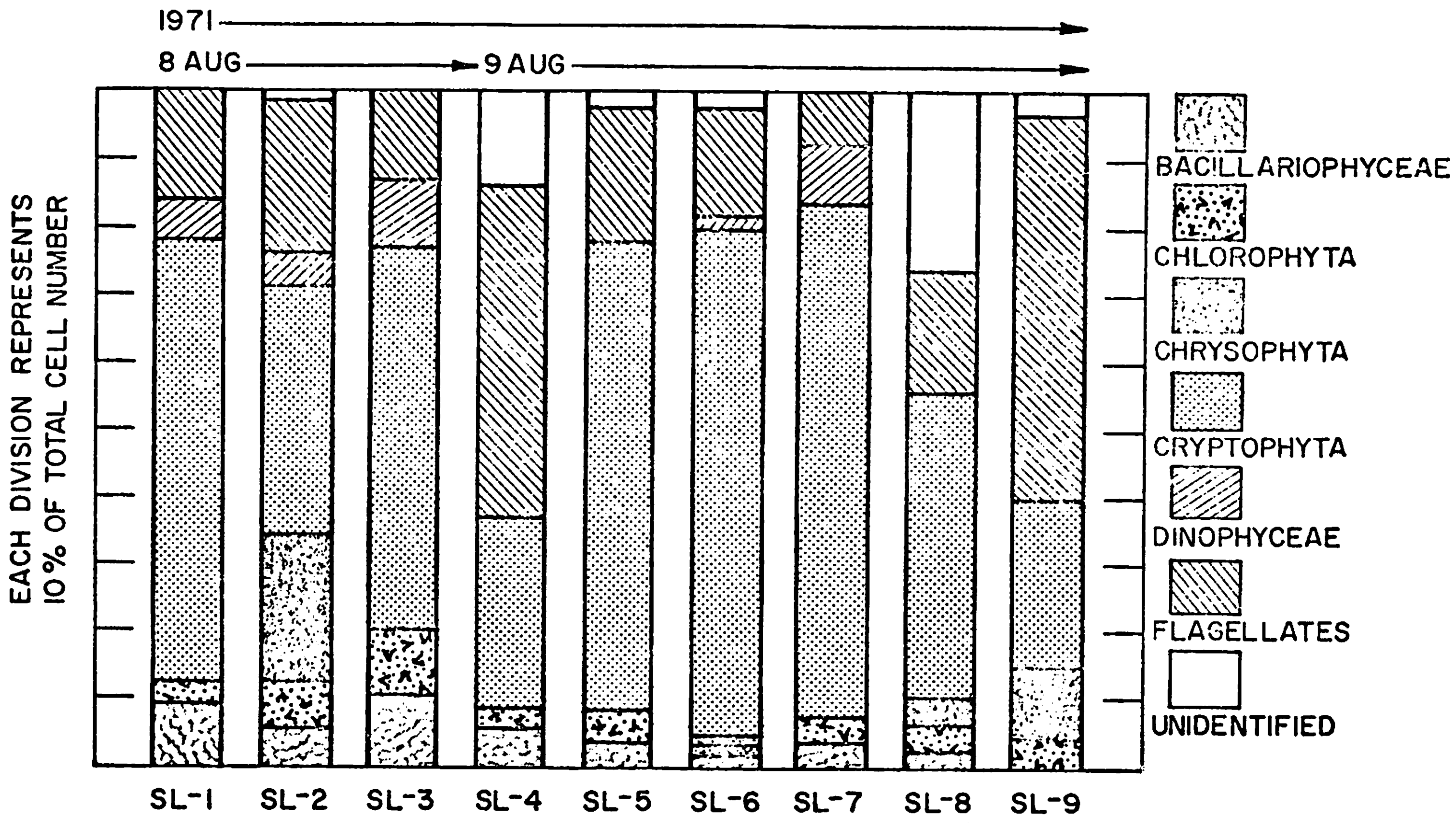


Figure 14A. Composition of phytoplankton cells, Simpson Lagoon, 1971 and 1972.

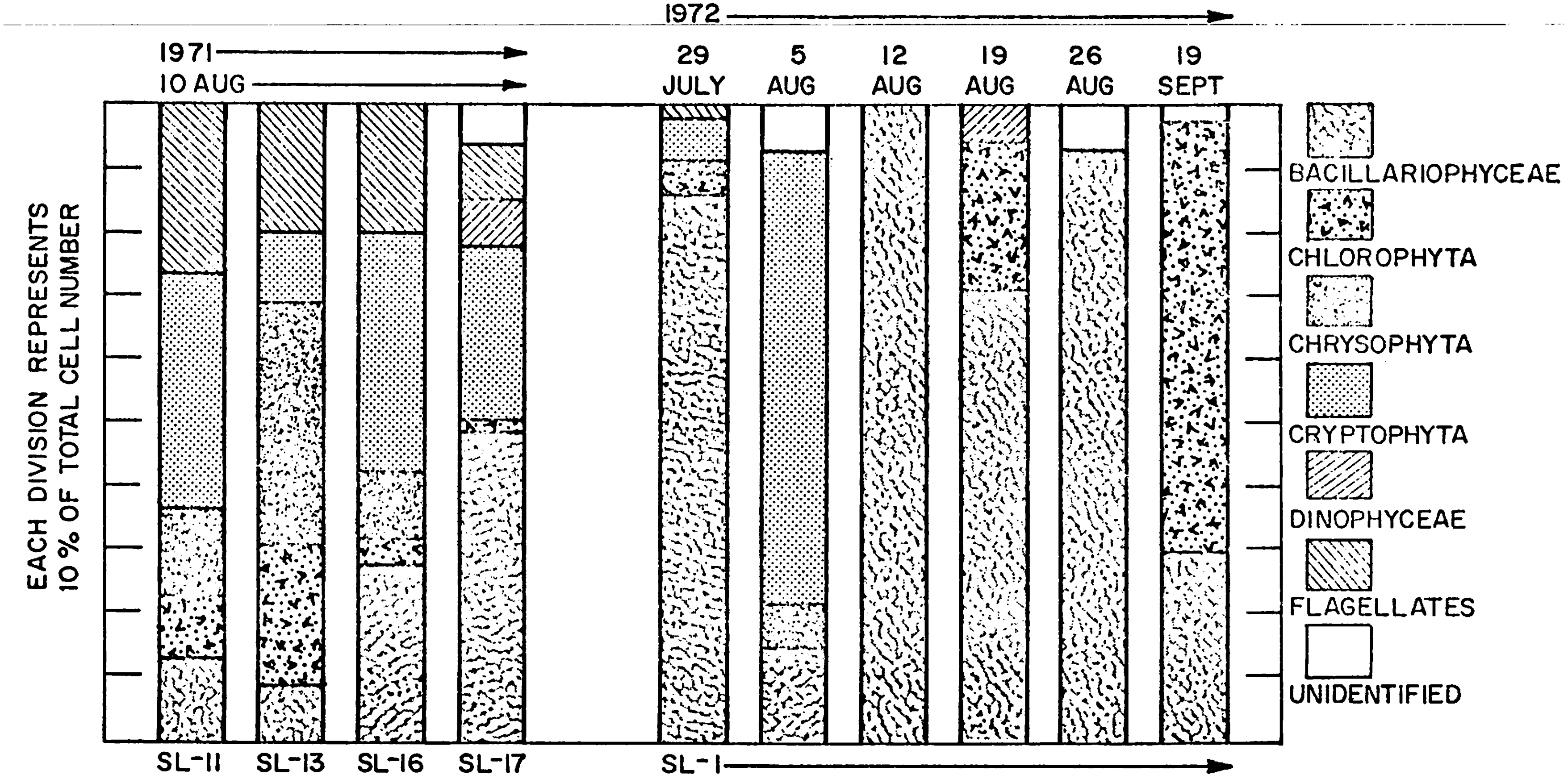


Figure 14B. Composition of phytoplankton cells, Simpson Lagoon, 1971 and 1972.

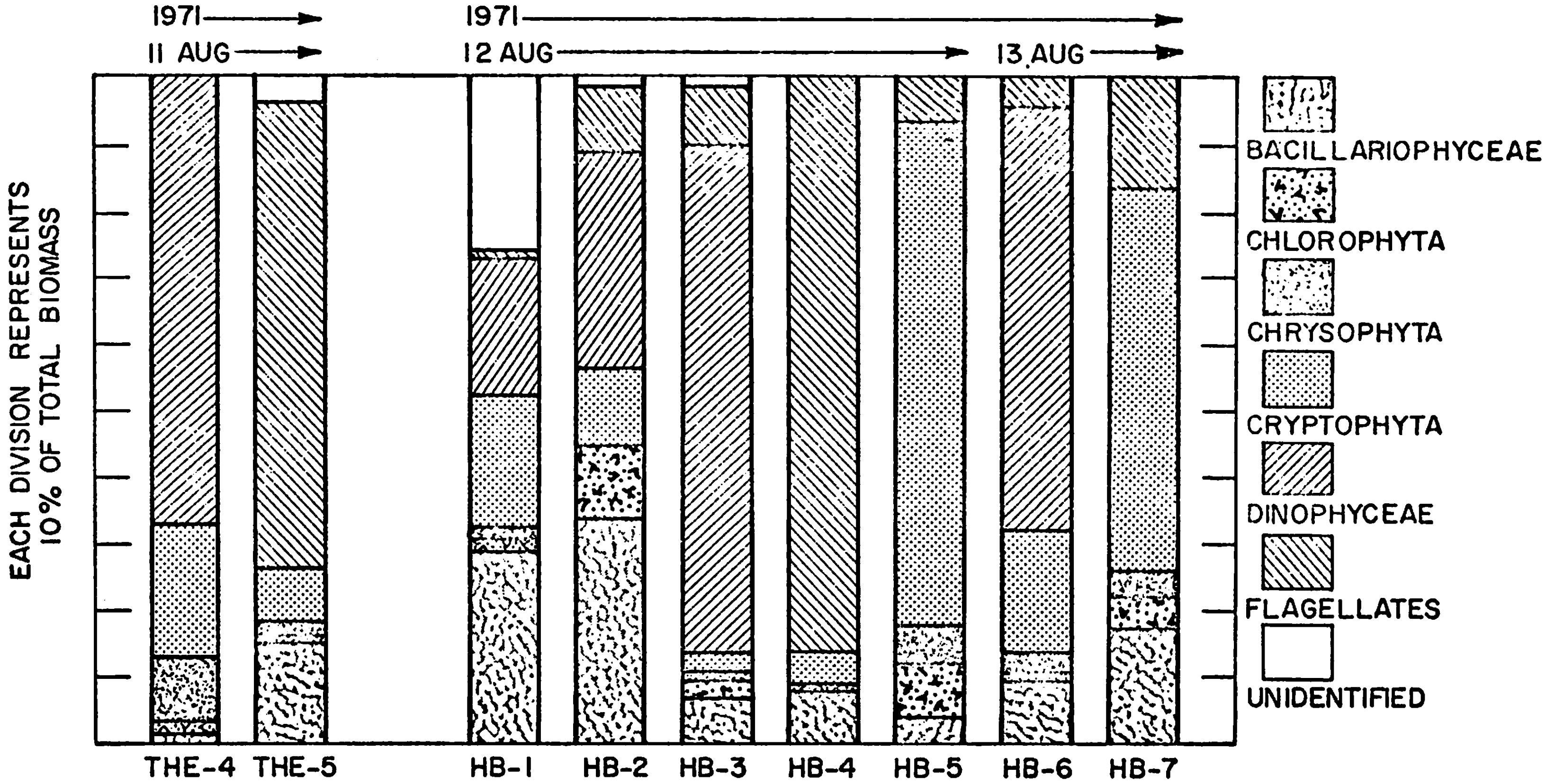


Figure 15. Composition of phytoplankton biomass, Harrison Bay, 1971.

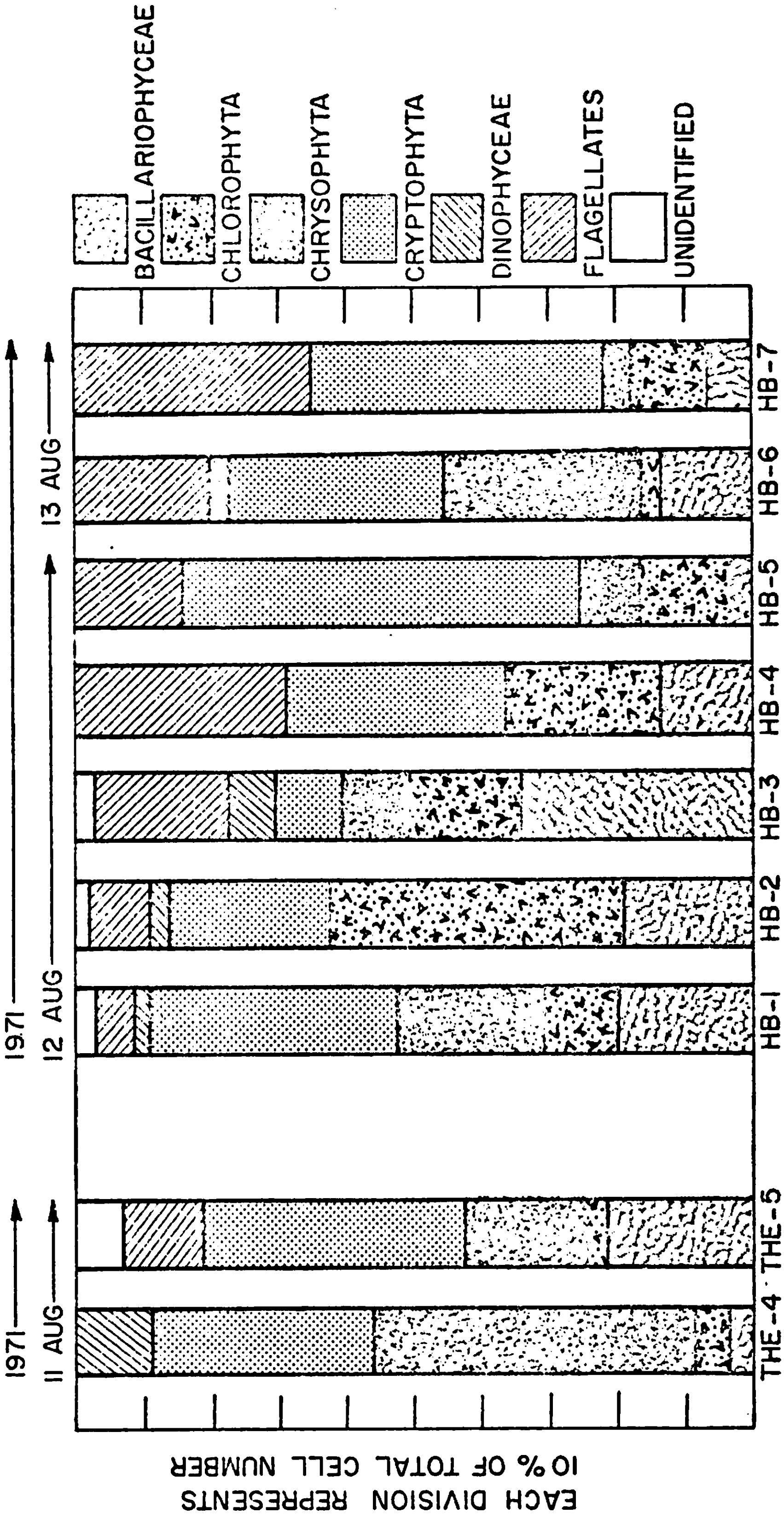


Figure 16. Composition of phytoplankton cells, Harrison Bay, 1971.

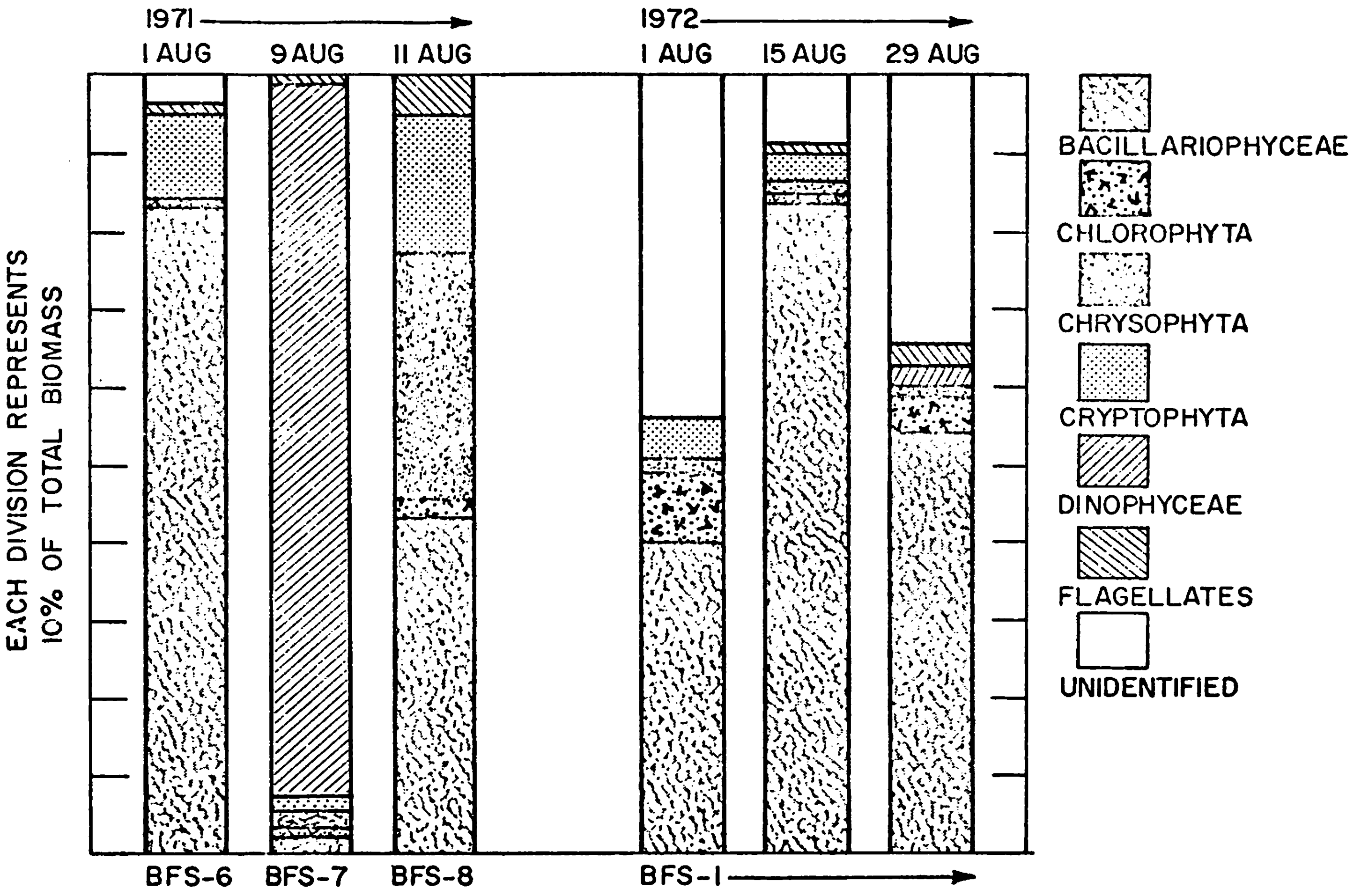


Figure 17. Compostion of phytoplankton biomass, Beaufort Sea stations, 1971 and 1972.

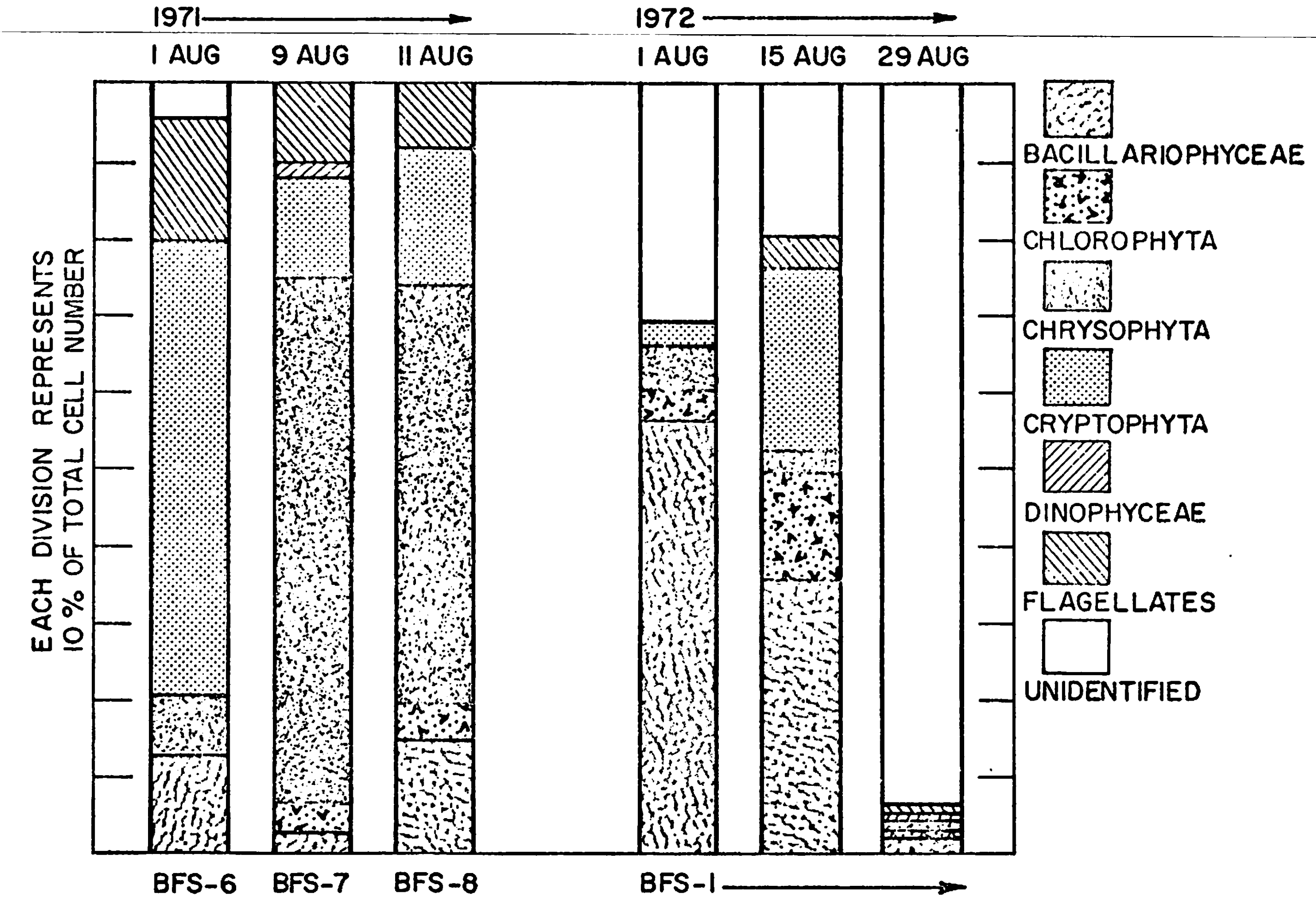


Figure 18. Composition of phytoplankton cells, Beaufort Sea stations, 1971 and 1972.

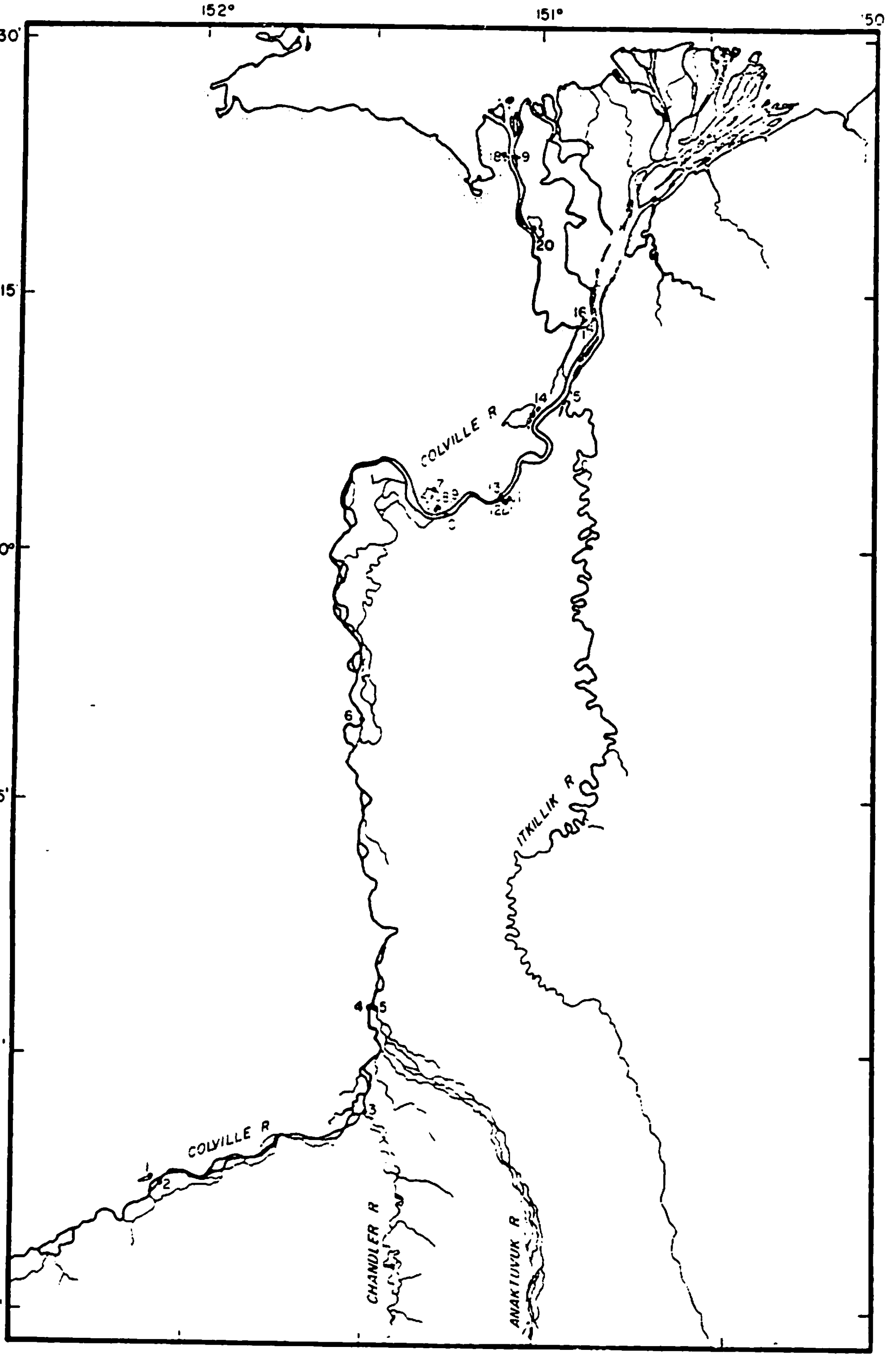


Figure 19. Colville River, Alaska, with raft trip station locations, 24-30 June 1971.

spp., *Rhodomonas minuta, Dinobryon* spp., *Chromulina* and very small flagellates (3-5μm) were very abundant in 1971, whereas in 1972 *Chaetoceros* spp., *Nitzschia closterium, Navicula* spp., *Thalassiosira* spp. were abundant.

Although the data are insufficient to make definite correlations, the higher biomass levels in 1972 did appear to be correlated with a higher primary productivity. Also, the somewhat less stratification in 1971 as compared with 1972 may have played a role.

Nitrogen uptake results - Nitrate and ammonia uptake were measured during the summer of 1972 at the Simpson Lagoon and Beaufort Sea primary productivity stations. The experiments were conducted as described above, with six (on occasion, eight) hour incubations. For ammonia, isotope additions were made at several concentrations in order to assess uptake versus concentration. This can give an idea whether nitrogen is limiting and can also give information on the physiological characteristics of the population. Nitrate was added at a single concentration.

There was no consistent response of uptake to increasing ammonia concentrations which suggests that uptake at the lowest level supplied was already at V_{max}. Inorganic nitrogenous nutrient concentrations found at Station SL-1 during the summer were very low indicating that the nitrogen added by the Colville River has been completely assimilated before the water is transported as far as Simpson Lagoon. The sole observed exception to this was during a very calm period around 26 August 1972 when Colville River water spread over the surface into Simpson Lagoon. Low uptake rates were measured in this fresh water and it is likely that subsequent mixing with the deeper phosphate-rich water would then result in assimilation by marine phytoplankton. The high proportion of nitrate assimilated, especially in the case of Simpson

Lagoon, suggests that the advection of nitrate by the river system and by runoff from the adjacent tundra areas and the delta plays an important role in nutrient supply, since it is extremely unlikely that *in situ* regeneration to nitrate can occur at a sufficient rate to account for the measured uptake. Beyond the barrier islands, nitrate transport from the deeper waters is the major source of new nitrogen to the euphotic system. Nitrate is always considered a "new" nitrogen source which is provided by advection, whereas ammonia is frequently supplied primarily by regeneration *in situ*[17]. The percentage of nitrate uptake in our experiments approaches that found for the Bering Sea by McRoy *et al.*[15]. In the case of a river system, the situation is somewhat different. Both nitrate and ammonia are supplied at high concentration through the river water, in our case with the nitrate levels considerably above the ammonia. There is, thus, an adequate source of nitrate to account for the measured uptake. We have also measured ammonification rates in the water at both stations, and find relatively high rates compared with uptake, again sufficient to account for the ammonia taken up.

The levels of nutrients in the river channel will be discussed elsewhere in this report. However, a brief discussion of the relative proportions of nitrate and ammonia advected by the river system to the offshore area is included here.

The data shown in Table 8 are for surface waters of the various channels of the Colville River. It is interesting to note that the percentage nitrate remains high regardless of the overall total nitrogen in the water. This supports the suggestion that nutrient input from the river is important to the primary productivity of the offshore region. Declining offshore productivity as the season progresses may correlate with declining levels of nitrogen nutrients supplied by the river. The volume of river flow is usually greatest following break-up and declines during summer. Phosphate is always rather low in the river water, and is probably the limiting nutrient in the freshwater system. The nitrogen uptake data reflects the importance of the river as a source of nutrients in that nitrate uptake is higher closer to the river mouth than outside of Pingok Island. This is shown in the difference between station SL 72-1 and BFS-1.

TABLE 8. NITRATE AND AMMONIA NITROGEN LEVELS IN SURFACE WATERS OF THE COLVILLE RIVER

Location	Nitrate-N, µg/l	Ammonia-N, µg/l	Percentage Nitrate-N $\frac{NO_3^-}{NO_3^- + NH_4^+} \times 100$
29 May - Nechelik Channel	18.2	16.2	52.9
27 June - Nechelik Channel	45.5	12.6	78.3
30 July - Nechelik Channel	67.8	14.0	83.3
16 August - Main Channel	30.0	3.9	88.5
23 August - Main Channel	28.0	5.6	83.3
23 September - Main Channel	44.8	1.4	96.9

Survey Studies of the River System

Preliminary data collected in cooperation with the Alaska Department of Fish and Game during the summer of 1970 is shown in Table 9. The picture which emerges from this preliminary work is one of low chlorophyll levels, high oxygen, and pH generally well above 7. Summer temperatures were fairly high in most of the streams and parts of the river (mean of 11.3°C). In the case of the lakes, chlorophyll levels

Table 9. PRIMARY PRODUCTIVITY AND RELATED FACTORS

Location	Air temp, °C	Water temp, °C	pH	Alkalinity, meq/1	Net Prod., μgC/1-hr	Concentrations (μg-at/1)				Chlor. *a*, μg/1	Phaeo., μg/1
						NO_3^-	NO_2^-	SiO_3^{-2}	PO_4^{-3}		
Lakes											
1-Umiat Pond(6/24)	18.5	18.5	8.45	0.170	1.69	0.00	0.13	2.0	0.04	0.232	0.466
7-Ocean Pt. Lake(6/27)	7.0	6.0	7.4	0.350	0.49	0.00	0.00	8.9	0.10	-	-
8-Ocean Pt. Pond(6/27)	7.0	9.0	7.7	0.290	1.27	0.00	0.02	2.6	0.01	0.926	0.557
9-Ocean Pt. Polyg(6/27)	7.0	8.0	7.6	0.330	0.51	0.00	0.07	6.5	0.03	0.890	0.300
11-Lake A(6/28)	5.0	5.5	7.6	0.405	1.11	0.00	0.08	15.0	0.06	0.922	0.786
12-Pond nr. Lake A(6/28)	-	-	-	-	-	0.30	0.07	-	-	0.572	1.158
14-Lake B(6/28)	5.0	5.0	7.0	0.440	0.99	0.09	0.05	11.3	0.06	1.966	0.438
16-Putu Pond(6/29)	2.0	5.0	7.5	0.595	0.54	0.45	0.06	-	-	0.649	0.204
18-Woods Pond(6/30)	3.5	5.5	7.8	0.750	1.12	0.30	0.11	-	-	-	-
20-Nanuk Lake(6/30)	8.0	5.5	-	-	-	3.30	0.17	17.9	0.07	-	-
Rivers and streams											
2-Colville (Umiat) (6/24)	14.5	16.00	-	-	-	2.91	0.09	31.0	0.12	-	-
3-Chandler R.(6/25)	13.5	15.5	-	-	-	2.34	0.07	27.9	0.06	0.028	0.185
4-Colville above Anaktuvuk (6/25)	20.5	17.0	-	-	-	2.85	0.08	30.6	0.10	-	-
5-Anaktuvuk R.(6/25)	20.5	14.0	-	-	-	4.71	0.06	30.7	0.09	-	-

Table 9. (continued) PRIMARY PRODUCTIVITY AND RELATED FACTORS

Location	Air temp, °C	Water temp, °C	pH	Alkalinity, meq/1	Net Prod., µg C/1-hr	Concentrations (µg-at/1)				Chlor. *a*, µg/1	Phaeo., µg/1
						NO_3^-	NO_2^-	SiO_3^{-2}	PO_4^{-3}		
6-Colville at Sentinel Hill(6/26)	7.0	13.5	-	-	-	3.57	0.04	34.2	0.34	-	-
10 Colville (Ocean Pt) (6/27)	7.0	11.0	-	-	-	3.60	0.08	34.0	0.03	-	-
13-Colville at Lake A (6/28)	5.0	-	-	-	-	4.08	0.12	-	-	-	-
15-Itkillik River(6/28)	9.0	12.0	-	-	-	3.78	0.07	24.0	0.06	-	-
17-Colville at Putu (main channel) (6/29)	2.0	10.5	-	-	-	3.84	0.10	33.5	0.04	-	-
19-Colville at Wood's Camp (3/30)	3.5	5.5	-	-	-	4.35	0.18	21.4	0.08	-	-

were higher, with very high values on two occasions, in both cases at a depth below the surface. In one of these, Tanigak Lake, we found unusually high primary productivity rates also. In the other, Umiat Lake, no primary productivity was run on the same date as the chlorophyll but on two other sampling days (19 and 26 July, 1971) reasonably high rates were found here also.

A second survey of the river system with its adjacent lakes was carried out on 24 June, 1971 during a week-long trip from Umiat to Wood's Camp by Messrs. Robert Clasby and G. E. Hall. A Zodiac and an Avon boat were utilized for transportation, and Mr. Joeb Woods assisted during the trip. Ten points along the river and ten lakes were sampled. Details are given in Report R72-3. The following determinations were made, using the methods described above: nutrients, temperature, plant pigments and particulate nitrogen. Carbon-14 primary productivity was measured in the lakes and ponds only. The results are given in Tables 10 and 11 with the station locations shown in Figure 19.

The primary productivity levels were similar to those obtained during the previous summer. Once again, Umiat Pond had a relatively high rate. Note the rather high nitrate concentrations in the river system, similar in magnitude to those discussed in connection with the offshore primary productivity and nitrogen uptake for 1972. Nitrate and phosphate are both low in concentration in the lake and pond waters. Unfortunately, we do not have ammonia data for these samples, and therefore cannot make assumptions about nutrient limitation. However, it can be noted that in the Barrow ponds studied by the U.S.I.B.P. Tundra Biome, nitrogen limitation does not occur in spite of very low nitrate concentrations, and phosphorus is the major limiting nutrient[18]. The 1970 and 1971 surveys provided information on the primary productivity levels and plant pigment concentrations, and served also to begin description on the phytoplankton distribution. No great differences were apparent

Table 10. PHYSICAL AND CHEMICAL DATA (LAKES).

Location and date	Depth, m	Temp., °C	Dissolved O_2, mg/liter	Alkalinity mg$CaCO_3$/liter	pH	Chlorophyll *a*, µg/1
Umiak Lake						
(Float plane						
lake) 70-CR11 7/19	0.0	17.8	8.4	43.24	7.6	1.15
	1.7	17.8	7.9	43.05	7.5	1.30
Tanigak						
Lake 70-CR27 8/8	0.0	11.1	9.3	37.60	7.4	3.74
70-CR27 8/9	1.2	11.1	8.1	40.42	7.7	18.12
70-CR27 8/9	0.0		9.0	36.66	7.5	3.72
Umiat						
Lake 70-CR11 8/10	0.0		10.6	43.24	7.6	0.66
70-CR11 8/18	0.0	12.2	9.4	42.77	7.6	0.86
70-CR11	1.7		9.1	44.18	7.8	3.96
Tulugak						
Lake 70-CR34	0.0	6.1	11.8	78.02	7.8	
Shainin						
Lake 70-CR37 8/31		8.9		102.6	8.5	
Noluck						
Lake 70-CR40 9/5		3.9		51.3	7.0	
Itkillik						
Lake 70-CR38 9/1		8.3		136.8	9.0	
Kurupa						
70-CR39 9/4		6.7		68.4	8.0	
Liberator						
70-CR42 9/6		3.9		51.3	7.0	

Table 11. PHYSICAL AND CHEMICAL DATA (RIVERS)

Location and date		Depth, m	Temp., °C	Dissolved O_2, mg/1	Alkalinity, meq/1	pH	Chlorophyll *a*, μg/1
Seabee Creek							
70-CR7	7/10	0.0	13.9	8.76	42.77	7.5	0.48
70-CR12	7/21	0.0	15.0	8.22	40.89	7.3	2.05
70-CR7	7/25	0.0					
70-CR7	8/17	0.0	12.7	9.00	51.70	8.0	0
70-CR7	8/18	0.0	10.9	6.48	56.40	7.2	0
70-CR7	8/29	0.0	10.0		119.70	8.0	
Killik River							
70-CR8	7/14	0.0	14.4	8.41	56.40	8.2	0.26
70-CR8	8/19	0.0	12.7	9.54	50.76	7.7	1.08
70-CR35	8/24	0.0	5.6		68.40	7.5	
Colville River (above Killik River) 70-CR9	7/14	0.0	15.0	7.92	52.83	8.1	0.92
70-CR26 (Umiat)	8/17	0.0	11.1	9.30	47.94	7.8	0.24
70-CR26 (Ocean Pt.)	8/18	0.0	11.1	8.82	49.82	7.6	0
70-CR28	8/19	0.0	13.3	9.24	62.98	7.9	0
70-CR30	8/19	0.0	12.7	8.94	48.88	7.6	1.26
70-CR26 (Umiat)	8/20	0.0		9.00	50.76	7.7	0.49
70-CR26	8/21	0.0		9.00	48.41	7.7	1.26
70-CR26	8/24	0.0	8.9		102.60	7.7	
just above Chandler							
70-CR3	6/25		12.8			7.5	
Colville/ Chandler mouth							
70-CR2	7/17	0.0	17.2	8.64	90.71	8.1	0.32

Table 11. (continued) PHYSICAL AND CHEMICAL DATA (RIVERS)

Location and date		Depth, m	Temp., °C	Dissolved O_2, mg/1	Alkalinity, meq/1	pH	Chlorophyll *a*, µg/1
Chandler River							
30 miles up							
70-CR10	7/18	0.0	17.2	8.24	89.23	8.2	0.08
2 miles up							
70-CR17	7/30	0.0	13.9	9.12	105.28	8.0	0.08
Mouth							
70-CR2	6/25	0.0	12.8		102.6	8.0	
Anaktuvik River							
70-CR1	7/23	0.0	11.1	8.64	108.57	8.0	0.40
2 miles up							
70-CR16	7/30	0.0	12.7	10.66	120.52	7.9	0.66
70-CR1	7/2	0.0		9.48	123.14	7.9	0.14
70-CR31	8/20	0.0	10.9	9.90	114.21	7.9	0
70-CR32	8/22	0.0	6.1	10.91	136.77	7.9	1.01
Mouth							
70-CR1	6/25	0.0	10.9		102.6	8.5	
Ikagiak Creek							
70-CR13	7/27	0.0	8.9		39.48	7.9	lost
70-CR14	7/27	0.0	8.9		30.55	7.8	0.21
Kiruktagiak Creek							
70-CR15	7/27	0.0	17.2		133.95	7.8	
Etivluk River							
70-CR18	7/31	0.0		9.48	62.51	7.7	0.20
Itkillik River							
70-CR4	8/31	0.0		9.60	85.54	8.0	0.10
70-CR4	6/25	0.0	15.6		85.5	8.0	

Table 11. (continued) PHYSICAL AND CHEMICAL DATA (RIVERS)

Location and date		Depth, m	Temp., °C	Dissolved O_2, mg/1	Alkalinity, meq/1	pH	Chlorophyll *a*, µg/1
Fossil Creek 70-CR20	8/6	0.0	13.3	9.96	81.78	7.8	0.88
Prince Creek 70-CR21	8/6	0.0	10.0	9.00	56.40	7.5	0.35
Oolamnavik River 70-CR29	8/19	0.0	9.6	9.48	43.24	7.5	0
Greyling Creek 70-CR33	8/22	0.0	3.3	10.32	84.6	7.9	0
Unidentified Creek near Kurupa River 70-CR36	8/25	0.0	6.1		34.20	6.5	
Kikiakrorak River 70-CR5	6/25	0.0	17.8		85.5	8.0	
Creek into Noluck L. 70-CR41	9/5		0.6		102.6	7.5	

between the two seasons. Seasonal cycles and small scale distribution variations were not attainable by the survey approach. We therefore undertook intensive studies on the Wood's Camp area lakes to provide more detailed information.

During the course of this study, three major freshwater habitats were sampled in 1970 - ponds and lakes, rivers and the marine environment. Of these, the lakes showed the greatest variety of plankton and also the largest populations. The lakes behaved in a manner similar to the offshore areas, in that diatoms were much higher in numbers at the bottom than in the surface waters, and this accounts for the difference in biomass (chlorophyll) between surface and bottom samples. This was the case for Umiat and Tanigak Lakes, noted for their relatively high productivities and chlorophyll content. This type of stratification seems to be widespread among the relatively deep aquatic environments in this coastal and coastal plain region. By the time the river water reached Oliktok, many of the plankters were marine forms, and included the following:

Chaetoceros wighami
Diatoma elongatum
Gyrosigma spp.
Nitzschia delicatissima
Nitzschia closterium
Thalassiosira spp.
Various small pennate diatoms
Platymonas sp.
An unidentified 3 micron flagellate
2 micron flagellates

Several organisms appeared to be identical to those seen in the Colville River, and they occupied a small fraction of many of the samples. Examples of these fresh water forms are *Ceratonies arcus*, *Diatoma elongatum*, *Rhodomonas* sp., *Cosmarium* sp., *Ankistrodesmus falcatus*, *Arthrodesmus* sp., *Chromulina* sp., *Cryptomonas* sp., and *Dinobryon* sp.

Sampling of the river was less systematic than either the marine or pond environments. A large area was covered with widely scattered samples taken over a period of 37 days. Any comparison of plankton abundance or even composition would, therefore, not be meaningful.

Generally, diatoms were the most numerous fraction in the river samples. A variety of small pennate diatoms usually composed the largest fraction of the diatom count. Only in three samples (Colville River below Killik River, Fossil Creek, and Seabee Creek) were flagellates more numerous than diatoms. In all three samples the major flagellate was a small 3 micron organism (*Kephyrion* sp.?) common in all the lake samples. All the organisms identified in the river samples were seen in lake samples with the possible exception of *Ceratonies arcus*.

The 1971 Phytoplankton Survey

Study of the phytoplankton of Harrison Bay, Simpson Lagoon, and the Colville River from the summer of 1970 had shown that a major contribution to the phytoplankton of the Arctic Ocean in the area of the Colville River delta were freshwater forms from the river itself.

Since the study of the river proved difficult and unreliable due to the large amounts of sediment, another approach had to be used. It was decided to study the source waters, i.e., the ponds and lakes that contribute water to the Colville River, for an approximation of the amounts of phytoplankton that could be contributed to the river. Since there are hundreds, perhaps thousands, of such lakes, only a very small percentage could be studied. Expenses limited the sampling period to one day (27 July, 1971).

A total of ten lakes was selected in two transects. Seven of the lakes lay in an approximately east-west line extending 140km immediately north of the Brooks Range; they ranged between 600 and 1000m in altitude. Four of the lakes lay in an approximately north-south transect of 160km and ranged from 800m to 46m in altitude (Fig. 20).

A Hiller six-passenger turboprop float plane was chartered for the trip; wind velocity and air temperature were measured with the airplane's instruments. Even with such an efficient vehicle, a rigid sampling schedule allowing only five minutes per lake had to be maintained in order to complete the sampling of all ten lakes.

27 July 1971 was an unusually warm day with a partly cloudy sky (M3 to M5) and very uniform weather conditions prevailed throughout the sampling area. A strong, gusty wind of 5 to 10m/sec from the south south-west was recorded at each lake, which probably contributed to good mixing of phytoplankton. Air temperature ranged from 12°C at the highest altitude to 22°C close to sea level, with a mean of 15.7°C.

A number 20 plankton net was used for the net samples. Immediate preservation was in 6 percent glutaraldehyde (adjusted to a pH of 7 with NaOH). Live samples were later preserved in modified Lugol's after observation. A total of seven samples was taken at each lake as follows: (1) a quantitative sample of zooplankton taken by filtering 10ℓ of water through the net; (2) a larger net sample for rare forms which would be missed in the counts; (3) an unpreserved net sample for observation of live phytoplankton; (4) a 55ml sample of water for quantitative phytoplankton counts; three chemistry samples for (5) nutrients, (6) major cations, and (7) heavy metals. The chemistry samples were frozen upon arrival in Prudhoe Bay for future analysis at Barrow.

Water temperatures were taken at the surface of each lake with a

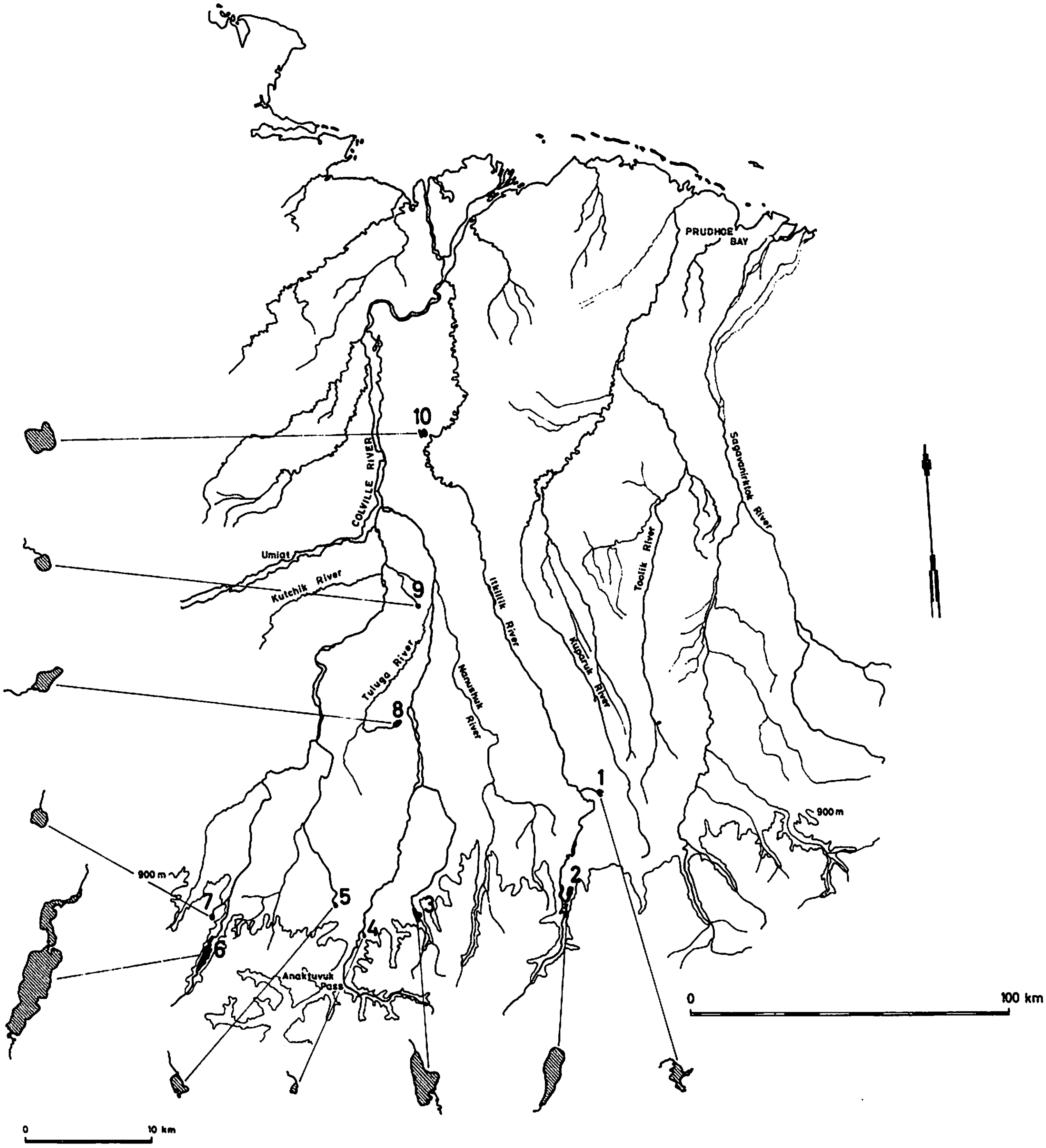


Figure 20. Lakes sampled by float plane, 27 July 1971.

thermometer. Live samples were kept refrigerated and were observed the following day in Fairbanks with inverted and phase microscopes for positive identification of the major species.

Ten ml of the preserved quantitative phytoplankton samples were settled on an area of 2.27cm^2 on microscope slides. Permanent slides were made of the settled material with a sliding chamber modification of the Utermöhl technique[10]. Permanent quantitative zooplankton slides were also made using the same technique.

Counts were made with a phase contrast microscope at 200X and 320X for phytoplankton and 20X and 80X for zooplankton. The dimensions of each species of phytoplankton were measured during the counts and cell volumes were estimated by assigning each species to one or a combination of two of seven basic shapes (sphere, prolate spheroid, oblate spheroid, cone, box, cylinder and ellipse X height) according to the closest approximation of actual volumes. Volume estimates of the larger species of zooplankton were taken from the volume estimates given by Nauwerk[19] for the species in the Swedish Lake Erken.

The species lists (phytoplankton, Table 12; zooplankton, Table 13) were compiled from the counts, preserved samples and living samples. The "LP" in the phytoplankton list shows the overlap with species found in a more intensive study of Lake Peters, which lies 200km to the east of Itkillik Lake[20]. Phytoplankton and zooplankton biomass (Figs. 21 and 22)and their relative composition (Fig. 23 and Table 14) are presented in mg/m^3. Nutrient chemistry is presented in Table 15. Species diversity indexes (Fig. 24) were calculated using numbers of organisms per liter rather than biomass by the following formula:

$$H = \frac{n_i}{N} \log_2 n_i$$

Korshikoviella gracilipes (Lambert) Silva	4
Pediastrum duplex Meyen	8,9
" integrum Naeg.	8
" boryanum (Turp.) Menegh.	9,10,LP
" tetras (E.) Ralfs	9,LP

Table 12. PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Lake no. (see Figure 20)

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
Lagerheimia citriformis (Snow) G. M. Smith	5,6
" *subsalsa* Lemm.	9,LP
Chodatella citriformis Snow	1
Chlorella pyrenoidosa Chick	1,2,5,LP
" sp.	1,8,LP
Oocystis submarina var. *variabilis* Skuja	1,8,9,10,LP
" *lacustris* Chodat.	2,9,LP
Kirchneriella lunaris Moeb.	10
Tetraëdron minimum fa. *tetralobulatum* Reinsch.	6,8,10,LP
" *caudatum* (Corda) Hansg.	10
" *limneticum* Borge	10
Scenedesmus balatonicus Hortob.	8
" *arcuatus* Lemm.	1
" *denticulatus* Lagerh.	1
" *quadricauda* (Turp.) Breb.	8,9,10,LP
Tetrallantos minor sp. n.	1,8,10
Dictyosphaerium simplex Skuja	1,LP
" *pulchellum* Wood.	10
Crucigena rectangularis var. *catena* var. n.	1,5,9
" *tetrapedia* (Kirshn.) W. *et* G. S. West	8,LP
Coelastrum cambricum Arch.	9,10
Selenastrum minutum (Naeg.) Collins	10

thermometer. Live samples were kept refrigerated and were observed the following day in Fairbanks with inverted and phase microscopes for positive identification of the major species.

Ten ml of the preserved quantitative phytoplankton samples were settled on an area of 2.27cm^2 on microscope slides. Permanent slides were made of the settled material with a sliding chamber modification of the Utermöhl technique[10]. Permanent quantitative zooplankton slides were also made using the same technique.

Counts were made with a phase contrast microscope at 200X and 320X for phytoplankton and 20X and 80X for zooplankton. The dimensions of each species of phytoplankton were measured during the counts and cell volumes were estimated by assigning each species to one or a combination of two of seven basic shapes (sphere, prolate spheroid, oblate spheroid, cone, box, cylinder and ellipse X height) according to the closest approximation of actual volumes. Volume estimates of the larger species of zooplankton were taken from the volume estimates given by Nauwerk[19] for the species in the Swedish Lake Erken.

The species lists (phytoplankton, Table 12; zooplankton, Table 13) were compiled from the counts, preserved samples and living samples. The "LP" in the phytoplankton list shows the overlap with species found in a more intensive study of Lake Peters, which lies 200km to the east of Itkillik Lake[20]. Phytoplankton and zooplankton biomass (Figs. 21 and 22)and their relative composition (Fig. 23 and Table 14) are presented in mg/m^3. Nutrient chemistry is presented in Table 15. Species diversity indexes (Fig. 24) were calculated using numbers of organisms per liter rather than biomass by the following formula:

$$H = \frac{n_i}{N} \log_2 n_i$$

Table 12. PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
CYANOPHYTA	
CHROOCOCCALES	
Aphanocapsa *delicatissima* W. *et* G. S. West	1,9,LP
" sp.	1
Aphanothece *clathrata* W. *et* G. S. West	1,2,8,9,10,LP
Chroococcus *turgidus* (Kg.) Naeg.	1,2,10,LP
" *varius* A.Br.	10
" *limneticus* Lemm.	3
Merismopedia *glauca* (E) Naeg.	8,LP
" *elegans* A. Br.	1,5,7,8,10,LP
Eucapsis *alpina* Clements *et* Shantz	10
Coelosphaerium *kuetzingianum* Naeg.	1,5,8,10
Gomphosphaeria *lacustris* Chod.	9, LP
" *robusta* Skuja	8,9,LP
HORMOGONALES	
Oscillatoria *agardhii* var. *isothrix* Skuja	1,9,10,LP
" *rubescens* De Candolie	4
Pseudanabaena sp.	9,10
Anabaena *lapponica* Borge	1,8,9,LP
" *flos-aquae* (Lyngb.) Breb.	1,8,9,10
" *circinalis* R.B.H.	9
Nostoc *kihlmani* Lemm.	9,10,LP
CHLOROPHYTA	

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
PROTOBLEPHARIDINAE	
PROTOBLEPHARIDALES	
Scourfieldia cordiformis Takeda	4,10
Pyramidomonas tetrathynchus Schmarda	10
Spermatozopsis exultans Korschik	10
Gyromitus cordiformis Skuja	1
Nephroselmis sp.	1,4,6,8,LP
EUCHLOROPHYCEAE	
VOLVOCALES	
Carteria sp.	3
Chlamydomonas passiva Skuja	1,2,3,4,5,6,7,10,LP
" *caroleae* sp. n.	2,LP
" spp.	1,9
Volvox aureus E.H.R.	8
Chlorogonium cf. *minimum* Playf.	4
Gemellicystis neglecta Teiling *et*. Skuja	3,5,LP
Gloeocystis planctonica (W. *et* G. S. West) Lemm.	10
Gloeococcus schroeteri (Chod.) Lemm.	1,3,4,5,10,LP
CHLOROCOCCALES	
Paulschulzia pseudovolvox (Schulz, Teil.) Skuja	8,10
Korshikoviella gracilipes (Lambert) Silva	4
Pediastrum duplex Meyen	8,9
" *integrum* Naeg.	8
" *boryanum* (Turp.) Menegh.	9,10,LP
" *tetras* (E.) Ralfs	9,LP

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
Lagerheimia *citriformis* (Snow) G. M. Smith	5,6
" *subsalsa* Lemm.	9,LP
Chodatella *citriformis* Snow	1
Chlorella *pyrenoidosa* Chick	1,2,5,LP
" sp.	1,8,LP
Oocystis *submarina* var. *variabilis* Skuja	1,8,9,10,LP
" *lacustris* Chodat.	2,9,LP
Kirchneriella *lunaris* Moeb.	10
Tetraëdron *minimum* fa. *tetralobulatum* Reinsch.	6,8,10,LP
" *caudatum* (Corda) Hansg.	10
" *limneticum* Borge	10
Scenedesmus *balatonicus* Hortob.	8
" *arcuatus* Lemm.	1
" *denticulatus* Lagerh.	1
" *quadricauda* (Turp.) Breb.	8,9,10,LP
Tetrallantos *minor* sp. n.	1,8,10
Dictyosphaerium *simplex* Skuja	1,LP
" *pulchellum* Wood.	10
Crucigena *rectangularis* var. *catena* var. n.	1,5,9
" *tetrapedia* (Kirshn.) W. *et* G. S. West	8,LP
Coelastrum *cambricum* Arch.	9,10
Selenastrum *minutum* (Naeg.) Collins	10

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
Rhaphidionema nivalis Lagerh.	2
Ankistrodesmus falcatus (Corda) Ralfs.	1,2,4,5,8,9,LP
" " var. *setiformis*	1,6
" *spiralis* (Turner) Lemm.	6,LP
Elakatothrix gelatinosa Wille	4,LP
Quadrigula closterioides (Bohlin) Printz	1,8,LP
ULOTHRICHALES	
Gloeotila pelagica (N.Y.G.)	1,5,6
CONJUGATAE	
DESMIDIALES	
Genicularia spirotaenia De Bary	8
Gonatozygon monotaenium De Bary	10
Closterium intermedium Ralfs.	8
" *pritchardianum* Ralfs.	8
" *pseudoeunula* Borge	8
Closterium rostratum Ehrenb.	8
Pleurotaenium ehrenbergii var. *undulatum* Schaarschm	8
Pleurotaenium trabecula (Ehrenb.) Näg.	8
Eaustrum ansatum Ralfs.	8
Micrasterias rotata (Grev.) Ralfs.	8
Xandthidium antilopaeum var. *polymazum* Nordst.	8
Arthrodesmus triangularis var. *limneticus* Teiling	8
Staurastrum anatinum fa. *curtum* (G.M. Smith) Brook	8

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
" *arctiscon* (Ehr.) Lund	8,10
" *armigeruna* var. *furcigerum* (Breb.) Teiling	8
" *petsamoense* Jarnelelt	8
" " var. *minus* (Messik) Thomasson	8
Spondylosium *korvum* sp. n.	1
" *planum* (Wolle) W. *et* W.	1,5,8,10
Teilingia *granulata* (Roy & *et* Biss) Bourr.	8,10
EUGLENOPHYTA	
EUGLENALES	
Euglena *pisciformis* Klebs.	8,10
" *oxyuris* Schmarda	9
" sp.	8,10
Phacus *longicauda* (Ehr.) Duj.	9
Trachelomonas *hispida* var. *duplex* Defl.	8
" " var. *punctata* Lemm.	1,8
" *oblonga* var. *attenuata* Playf.	8
CHRYSOPHYTA	
CHRYSOPHYCEAE	
CHRYSOMONADIDAE	
CHROMULINALES	
Chromulina spp.	1,2,4,9,LP
Phaeaster *aphanaster* (Skuja) Bourr.	1,2,4,5,8,9,10,LP
Chrysococcus sp.	1,LP

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
Kephyrion boreale Skuja	2,LP
Mallomonas akrokomos Ruttner	4,9,LP
" *tonsurata* Teiling	1,2,3,5,6,LP
" *caudata* Iwanoff	1,3,5,LP
" *elongata* Rev.	1,2,5,6,LP
" *acaroides* Perty.	5,LP
" *pseudocoronata* Prescott	1,2
" *pumilio* Harris *et* Bradley	3
" *globosa* Schiller	1,6
ISOCHRYSIDALES	
Synura petersenii Korsch.	8
" *uvella* Ehr. *et* Korsch.	2,LP
OCHROMONADALES	
Ochromonas spp.	2,LP
Uroglena americana Calkins	2,3,8,10,LP
Eusphaerella turfosa Skuja	8
Pseudokephyrion alaskanum Hilliard	10
Chrysosphaerella longispina Lauterb.	8
Dinobryon acuminatum Ruttner	1,6,8,LP
" *attenuatum* Hilliard	6,LP
" *sertularia* Ehr.	2,3,5,LP
" " var. *protuberans* (Lemm.) Krieger	2,LP
" *cylindricum* var. *palustre* Lemm.	1,2,3,4,6,8,10,LP

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
" " var. *alpinum* (Imhof.) Bachm.	3,5,10,LP
" *bavaricum* Imof.	1,3,4,6,8,10,LP
" *sociale* Ehr.	1,5,8,LP
" " var. *americanum* (Brunnth.) Bachm.	6,LP
" *divergens* Imhof.	2,3,10,LP
" *njakajaurense* Skuja	5,6,10
Chrysoikos skujai (Nauw.) Willen	6,8,LP
Bitrichia longispina (Lund) Bourr.	5,10
CHRYSOSPHAERALES	
Stichogloea doederleinii (Schmidle)	1,2,LP
RHIZOMASTIGALES	
Bicoeca ainikkiae Järnfelt.	6
" sp.	1
Monosiga sp.	1
DIATOMEAE	
CENTRALES	
Cyclotella stelligera Cl. *et* Grun.	1,2,3,5,6
" *comensis* Grun.	10,LP?
" *comta* (Ehr.) Kuetz.	1,2,3,4,5,6,7,10,LP
" *bodanica* Eulenst.	1,2,3,5,6,LP
" sp.	5,6,10
Stephanodiscus astraea (Ehr.) Grun?	1,2,3,5,6
" *hantzschii* Grun.	1,LP

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
Rhizosolenia eriensis H.L. Smith	
PENNALES	
Tabellaria fenstrata (Lyngb.) Kuetz.	1,5,7,LP
" " *intermedia* Grun.	
" *flocculosa* (Roth) Kuetz	
Fragilaria crotonensis Kitton	9,LP
" sp.	4,6
Diatoma elongatum (Lyngb) A.G.	6
" sp.	6
Synedraacus var. *angustissima* Grun.	6,9,LP
Cymbella sp.	1,2,4,5,6,8,9,10
Gomphonema sp.	9
Cocconeis diminuata Pant.	4,6,10
Asterionella formosa Hass.	1,3,4,5,6,8,LP
Gyrosigma cf. *acuminatum* (Kuetz.) R.B.H.	9
Nitzchia actinastroides (Lemm.) Van Goor	5
Cymatopleura solea (Breb.) W. Sm.	9,LP
Surirella sp.	9
HETEROKONTAE	
HETEROCOCCALES	
Botryococcus braunii Kuetz.	8,10
Centritractus belonophorus Lemm. var. *itkillikus* var.n.	1,2
PYRROPHYTA	

Table 12. (continued) PHYTOPLANKTON SPECIES FOUND IN LAKES OF THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20) LP = found also in Lake Peters
CHLOROMONADOPHYCEAE	
CHLOROMONADOPHYCEAE	
CHLOROMONADALES	
Vacuolaria virescens var. *praegnans* Skuja	1
CRYPTOPHYCEAE	
CRYPTOMONADALES	
Rhodomonas lacustris Pascher *et* Ruttner	7,LP
" *minuta* Skuja	all lakes
Cryptomonas spp.	1,2,3,4,5,6,8,9,10,LP
Katablepharis ovalis Skuja	1,2,3,4,5,6,8,9,10,LP
Sennia parvula Pascher *et* Skuja	4,LP
DINOPHYCEAE	
GYMNOLDINALES	
Amphidinium spp.	1,5,6,8,LP
Gymondinium helveticum Penard fa. *alaskanum* fa. n.	2,3,5,8,10,LP
" *uberrimum* (Allm.) Kofoid *et* Swezy	7,LP
" *veris* Lindem	10,LP
" spp.	6,10
Peridinium willei Huitf.-Kaas	2,3,4,5,7,10,LP
" *cinctum* (Mueller) Ehr.	1,3,LP
" *inconspicuum* Lemm.	8,10,LP
Ceratium hirundinella (O.F.M.) Schrank.	2,3,4,5,6,7,10

Table 13. ZOOPLANKTON SPECIES FOUND IN LAKES OF

THE COLVILLE RIVER DRAINAGE AREA

Species	Lake no. (see Figure 20)
Copepoda	
Diaptomus sp.	1 - 10
Cyclops sp.	1 - 10
Cladocera	
Bosminia coregoni	5
Daphnia cf. *longispina*	5
Holopedium gibberum	8,9
Rotatoria	
Conochilus unicornis	1, 2, 3, 8, 10
Kellocottia longispina	1 - 10
Keratella cochlearis	2, 3, 4, 6, 7, 8, 9, 10
Keratella quadrata	2, 3, 4, 6, 8, 10
Polyarthra cf. *vulgaris*	1, 2, 3, 6, 7, 8, 10
Synchaeta sp.	8
Trichocerca sp.	3
Ciliata	
Difflugia limmetica	8, 9
Strombidium sp.	1
Tintinnopsis lacustris	10
Vorticella sp.	1, 6, 8, 9, 10

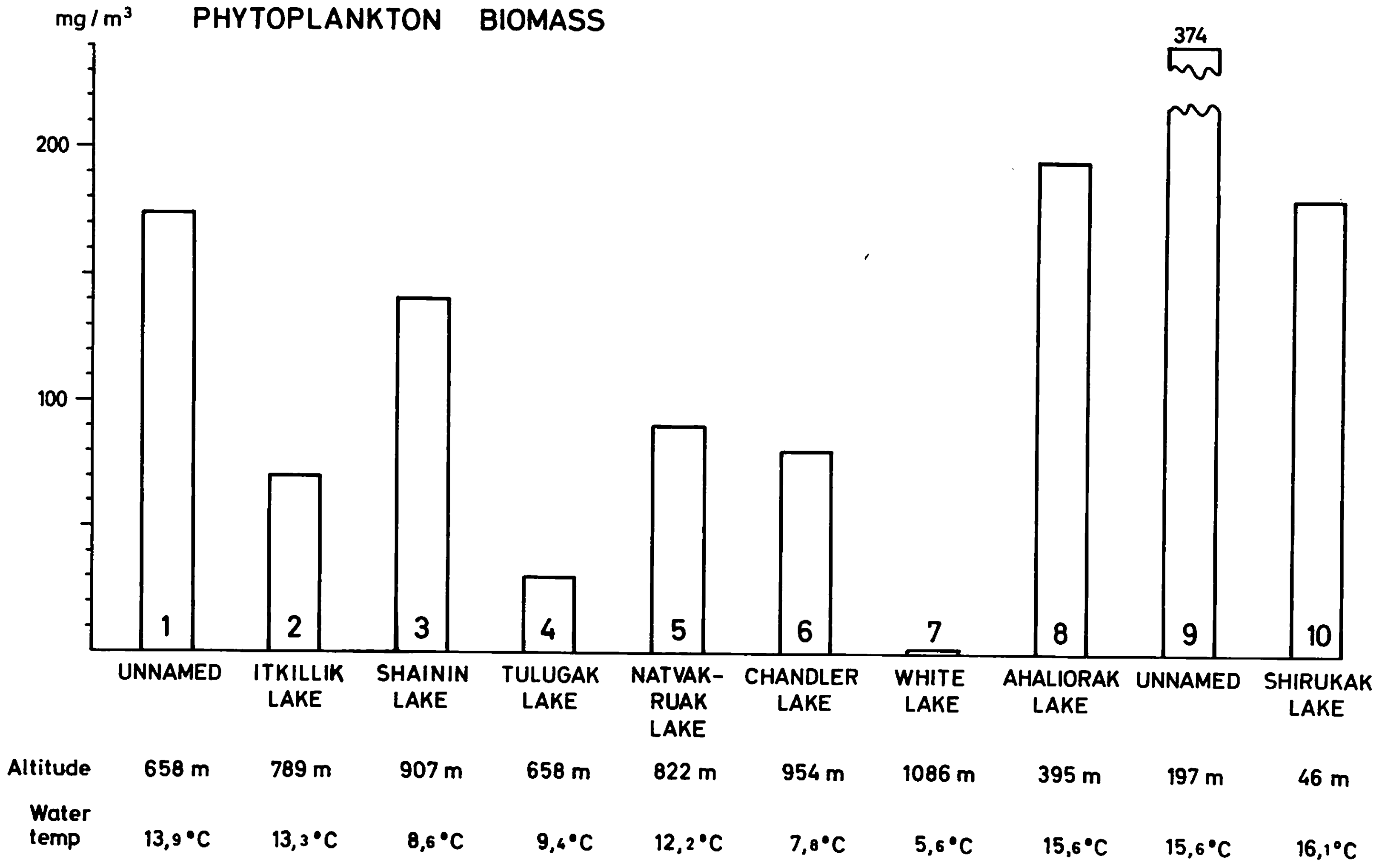


Figure 21. Phytoplankton biomass of lake waters sampled by float plane, 27 July 1971.

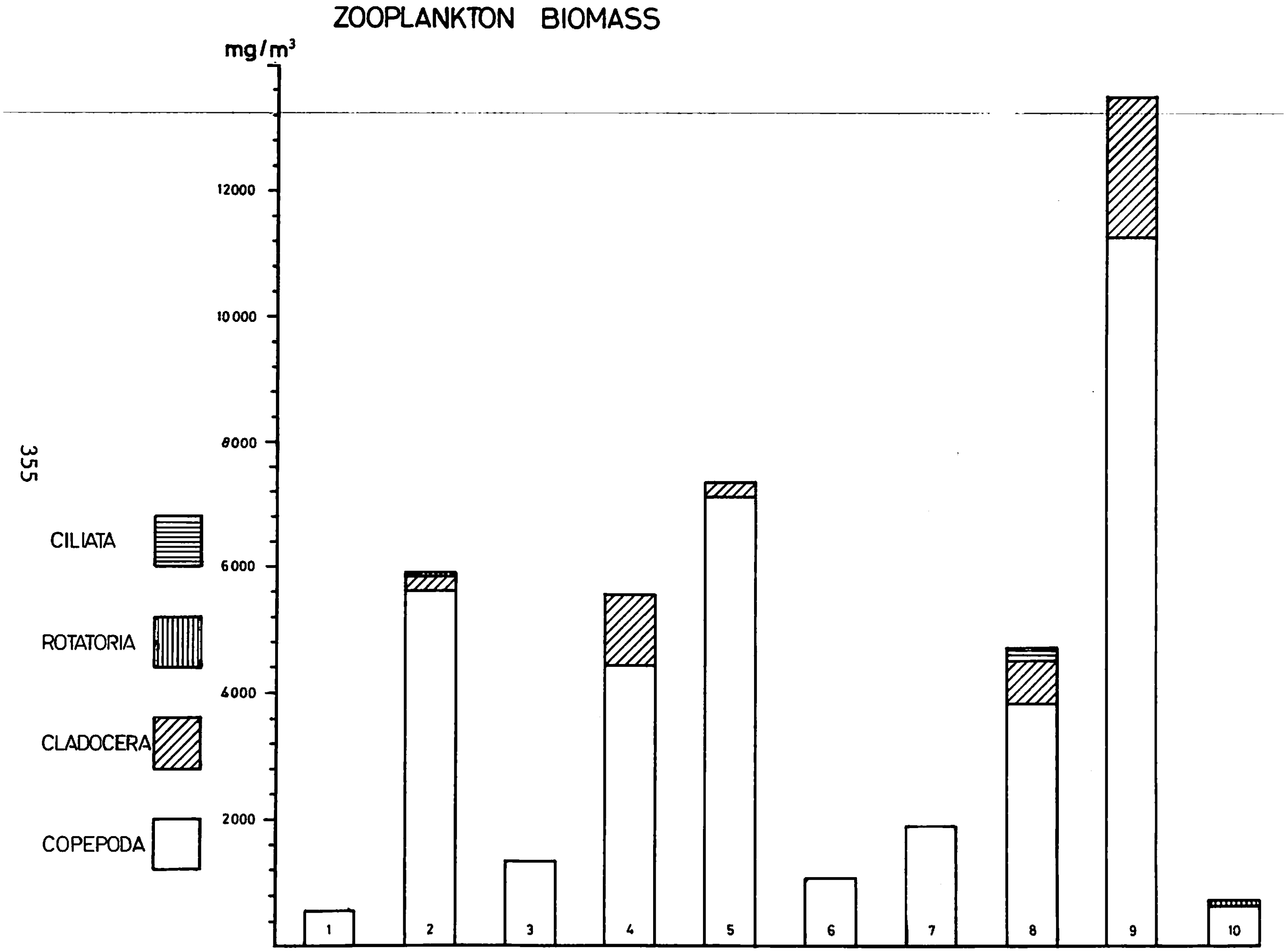


Figure 22. Zooplankton species composition, of lake waters sampled by float plane, 27 July 1971.

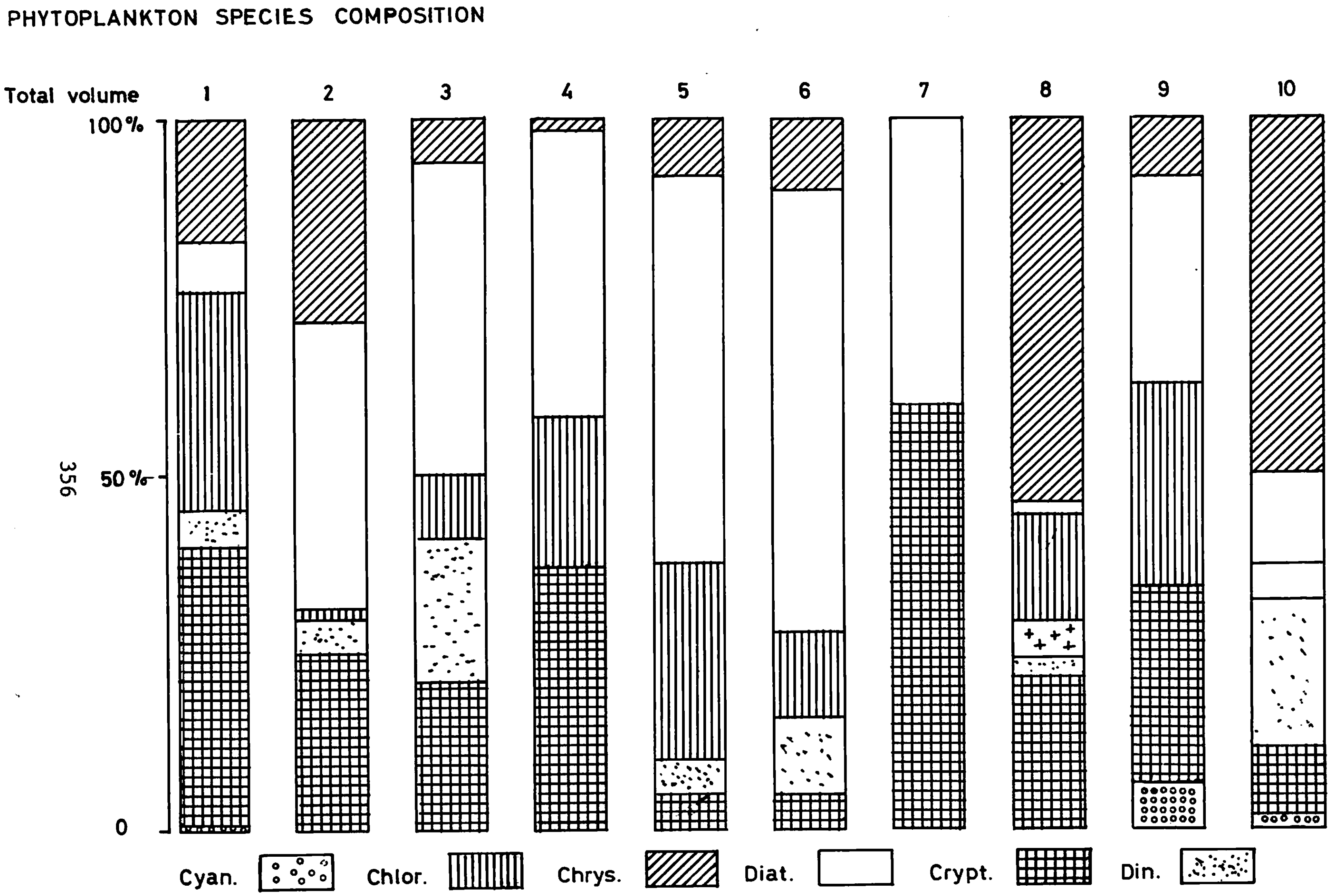


Figure 23. Phytoplankton species composition of lake waters sampled by float plane, 27 July 1971.

Table 14. LAKE ZOOPLANKTON COMPOSITION

	PHYLA (BIOMASS in mg/m^3)			
Lakes	Copepoda	Cladocera	Rotatoria	Ciliata
Unnamed (1)	5829.1	-	3.7	0.1
Itkillik	5635.5	280.0	24.6	-
Shainin	1341.3	-	2.9	-
Tulugak	4457.5	1124.0	1.2	-
Natvakruak	7130.9	204.0	4.3	-
Chandler	1093.5	-	9.3	1.2
White	1885.1	-	13.4	-
Ahaliorak	3817.2	690.0	21.1	184.5
Unnamed (9)	11221.0	2210.0	5.4	29.3
Shirukak	646.7	-	70.1	22.9

Table 15. LAKE NUTRIENT CHEMISTRY

Lake	SiO_3^{-2} mg/m^3	PO_4^{-3} mg/m^3	NO_2^- mg/m^3	NO_3^- mg/m^3
Unnamed (1)	243.6	2.79	0.84	nil
Itkillik	616.0	2.48	0.28	nil
Shainin	492.8	2.79	0.84	1.20
Tulugak	943.6	3.10	0.70	15.96
Natvakruak	280.0	353.40	0.56	nil
Chandler	420.0	3.41	0.42	2.10
White	644.0	93.93	3.78	176.40
Ahaliorak	58.8	9.30	1.40	nil
Unnamed (9)	39.2	6.51	0.84	nil
Shirukak	98.0	4.34	1.54	nil

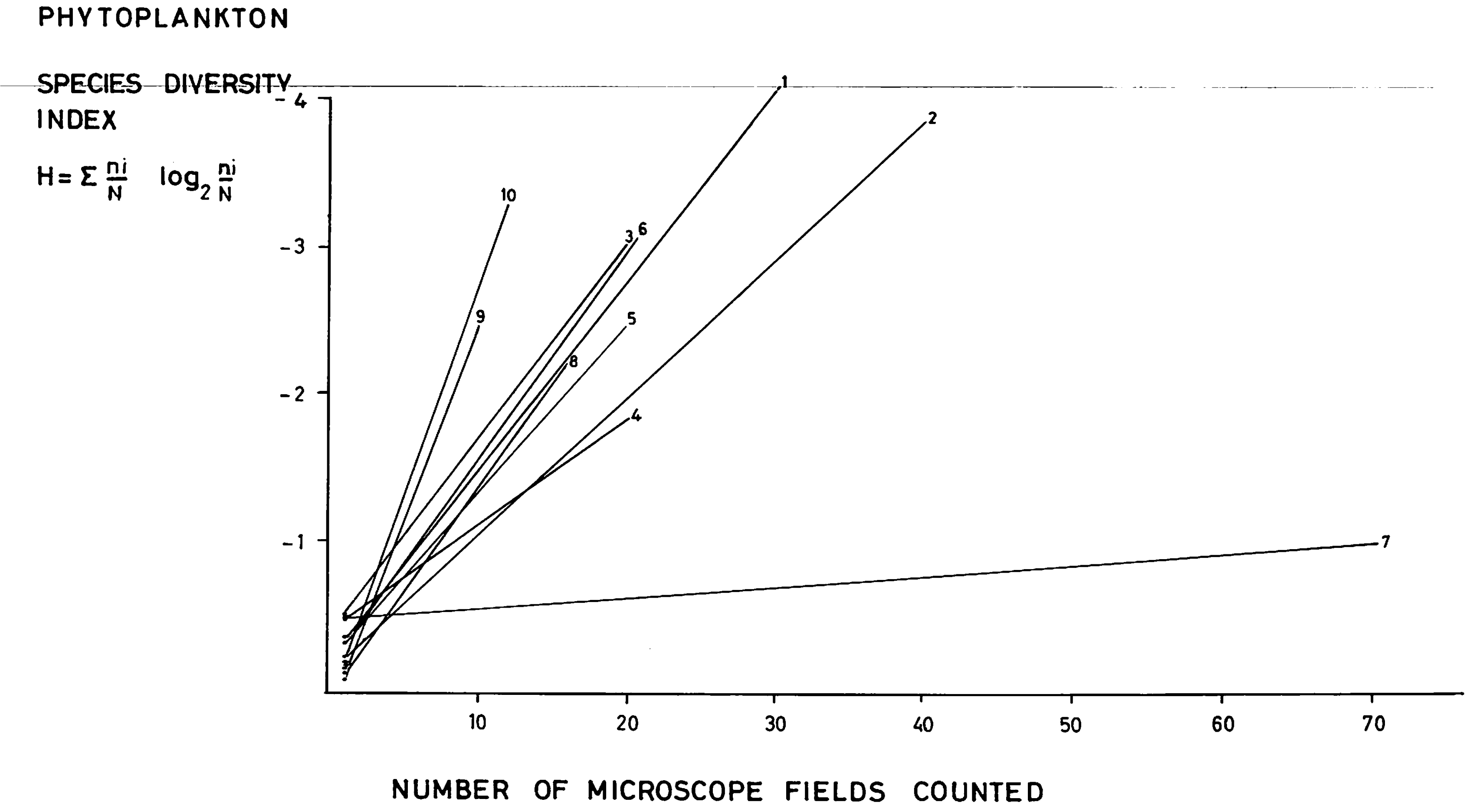


Figure 24. Phytoplankton species diversity in lake waters sampled by float plane, 27 July 1971.

where H = species diversity index

n_i = number per liter of a given species

N = total number of organisms per liter

Since only one sample was taken from each lake, species diversity indexes had to be plotted against the number of fields counted in order to compare the slopes. Since equal volumes were settled on equal areas for each lake and only the 320X counts were used, the species diversity index per number of fields slopes should be comparable, with the error being proportional to the degree of departure of actual settled distribution from an evenly distributed pattern.

Correlation coefficients were calculated as follows:

Altitude	:	Water temperature	0.86
Zooplankton biomass	:	--	0.37
Phytoplankton biomass	:	--	0.72
Chrysophyta biomass	:	--	0.71
Diatomeae biomass	:	--	0.69
Chlorophyta biomass	:	--	0.35
Pyrrophyta biomass	:	--	0.02
Cryptophyta biomass	:	--	0.34
Species diversity indexes	:	--	0.46
Zooplankton	:	Phytoplankton	0.23
Phytoplankton biomass	:	SiO_3^{-2}	0.80
Chrysophyta biomass	:	--	0.56
Diatomeae biomass	:	--	0.53
Phytoplankton biomass	:	PO_4^{-3}	0.24
"	:	NO_2^-	0.25
"	:	NO_3^-	0.48

The amount of phytoplankton varied from 30 to 324mg/m^3. In White Lake, however, only 1mg/m^3 of phytoplankton was found. This lake had very turbid water and evidently not enough light could penetrate for any appreciable primary production to occur. This was probably not always the case since a large zooplankton assemblage thrived in the lake. The other lakes can be divided into two categories, the first being near the Brooks Range with phytoplankton biomasses up to 100mg/m^3 and the second on the northern slope with biomasses over 200mg/m^3. Most of the lakes in the first category lie at higher altitudes and have correspondingly harder climatic conditions than those in the second. These two categories are probably generally valid in spite of exceptions produced by differences in water chemistry and local edaphic conditions. Lakes 2-7 belong to the first category and lakes 1, 8, 9 and 10 belong to the second. Lake 3 falls in between the two categories but can still be included in the first group.

The chemical data do not correlate very well with the phytoplankton biomasses, but too little information is obtained on only one sampling occasion for any really meaningful interpretation. In the case of White Lake the high nutrient concentrations can be explained by its low production. The surprisingly high phosphate value in Natvakruak is somewhat suspect. It may be an error in the analysis or a contamination. If that is true the highest phosphate concentrations are found in the lakes with the largest biomasses, i.e., 8, 9, and 10. No correlation seems to exist between diatom biomass and concentrations of silicon. A negative correlation is usually found[20].

Diatoms (see Fig. 23) were dominant in most of the lakes (2, 3, 4, 5, 6, 7, 8 and 9). The most common genera were *Cyclotella, Asterionella* and *Synedra*. A very substantial part, however, was contributed by benthic forms that may have been washed up into the pelagic water by the strong winds. In five lakes *Stephanodiscus astreae* were found. This has been used as an indicator organism for eutrophic lakes, and therefore the form found here is probably a new ecotype. Morphologically, no difference from Ehrenberg's description could be observed.

A similarly surprising organism was *Ceratium hirundinella*, which is often considered a warm water form, occurred in 7 of the 10 lakes. It normally survives the cold part of the year as cysts. There seems to be an arctic ecotype, however, that is found all year. It has been observed in lakes around Lake Peters and under ice in Char Lake in northern Canada.[20]

Cryptophyceae was an important algal group in most of the lakes. The dominant genera were *Rhodomonas*, *Katablepharis* and *Cryptomonas*.

Chlorophyta formed a substantial part of the biomass in lakes 1, 3, 4, 5, 6, 8 and 9. Important genera were *Oocystis*, *Ankistrodesmus*, *Scenedesmus* and small forms of the order Chlorococcales. A fairly rich desmid flora was found in the net samples from lake 8 and 10, but it had no importance in the biomass.

Chrysophyceae were important in lakes 1, 2, 8 and 10. This is somewhat surprising, since this group is usually the dominant one in arctic and boreal lakes.[20,21,22,23,24] It is, of course, possible that Chrysophyta were common also in the other lakes earlier in the season. Most of the biomass of this group was composed of small forms in the genera *Chromulina*, *Ochromonas*, *Pseudokephyrion*, *Dinobryon*, *Mallomonas* and *Uroglena*.

Dinophyceae were of importance only in lakes 3 and 10. Again it is very possible that this group was more common at other times of the year in the other lakes. Dinophyceae usually form an important part of the phytoplankton in arctic lakes, especially early in the season (Holmgren, unpublished). Important genera were *Gymnodinium*, *Amphidinium*, *Glenodinium* and *Peridinium*.

Cyanophyta were insignificant in all lakes. That is to be expected since this phylum is typical of warm rich lakes. The genera that occurred in the lakes all belonged to the oligotrophic forms of the groups: *Chroococcus, Eucapsis, Merismopedia, Anabaena, Aphanocapsa,* and *Aphanotheke.*

It is difficult to draw conclusions from only one sampling occasion, since there are large natural seasonal variations in the amount of algae in such bodies of water. Usually there is a biomass increase during and after ice melt followed by a decrease in the middle of the summer. In late summer a new growth of the algal assemblage usually occurs again. Since biomass can fluctuate by an order of magnitude during a cycle of a season, it is necessary to know where in the cycle the samples were taken before a comparison with other lakes can be made. Fortunately, intensive studies were made in 1968 of the lakes at the headwaters of the Sadlerochit River, about 200km east of this study. The biomasses of phytoplankton there in late July and early August in 1968 were slightly higher than the average of the season.[20] Works from northern Scandinavia covering whole seasons reveal the same tendency.[20,21,19] It is therefore reasonable to assume that waters leaving the upper lakes have concentrations of 50 to 100mg/m^3 of phytoplankton during the ice free season as compared to 100 to 200mg/m^3 from the lower lakes. Lakes on the coastal plain have higher biomasses (about 300mg/m^3) but their contribution to the river is insignificant because of the very poor drainage there. If the water budget is known, the transport of phytoplankton to the sea can be roughly estimated. This way of estimating the contribution is, of course, inaccurate; many organisms would certainly not survive the journey to the ocean. Any such estimation therefore, should only be used to predict theoretical maximum values.

New or Unusual Species Descriptions

Chlorophyta

Protoblepharidales

1. *Gyromitus cordiformis* Skuja (Plate 1)

   Cells 11μ x 14μ with two flagella arising from an interior depression. Slightly smaller than Skuja's description.

Chlorococcales

2. *Tetrallantos minor* sp. n. (Plate 2)

   Cells 1.5μ x 3.6μ typically forming radially arranged groups of four pairs of cells, but also forming arrangements in groups of four cells joined by their ends to form a circle. Short chains are formed by either arrangement or a combination of both. Cells have one pyrenoid, and vacuoles at or near each end. Cells are kidney-shaped and held together by gelatinous material at the point of contact. Some specimens from Shirukak lake differed from the others by their lack of kidney shape and by their rigidly square arrangement of four cells. The Shirukak form may constitute another variety.

3. *Crucigena rectangularis* (A. Br.) Gay var. *catena* var. n. (Plate 2)

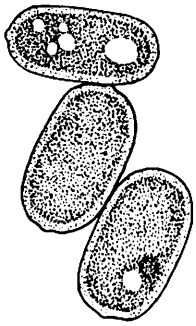
   Cells 6-7μ x 12-15μ, groups of four cells usually within the parent cell wall. The cells are slightly larger than those described in Prescott, 1951 and agree with the maximum size given for *Crucigena irregularis* Wille in Korschikov.[22] There is little variation in cell size, however, and the cells consistently form long chains in orderly rows of paired cells by the end-to-end linking of the four-cell groups.

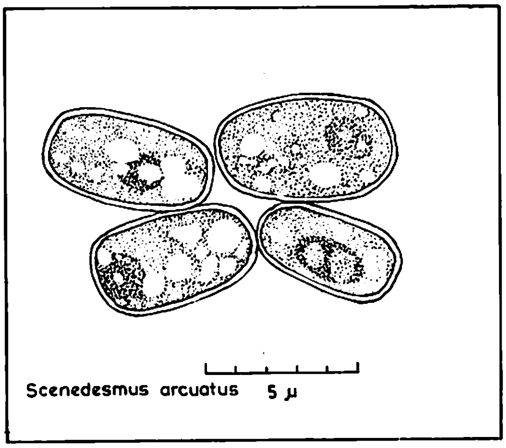
4. *Kirschneriella lunaris* Moeb. (Plate 2)

   Cells 3.5μ thick in conspicuous mucilage forming partial rings of 7μ diameter. Parent cell wall retained for a time after division.

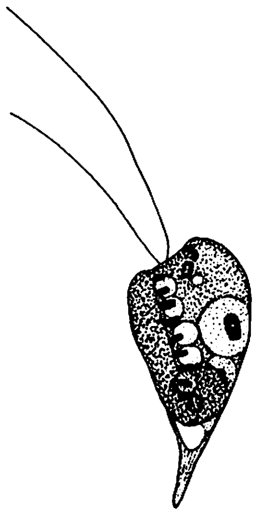
5. *Lagerheimia citriformis* (Snow) G. M. Smith (Plate 2)

   Cells 4μ x 9.5μ occurring in twos within a parent wall of 8.5μ x 16μ. A single pyrenoid and a single chloroplast are present in each cell. Setae are 4 per cell, 24μ long.

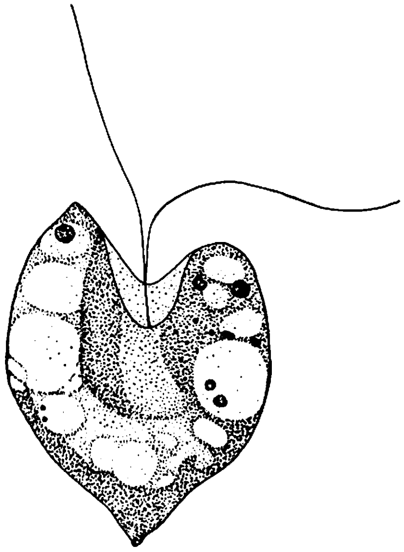




Scenedesmus arcuatus



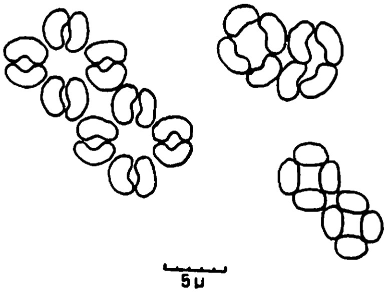
Rhodomonas minuta



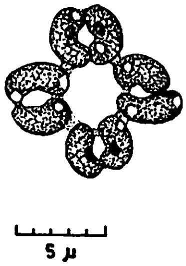
Gyromitus cordiformis

5 µ

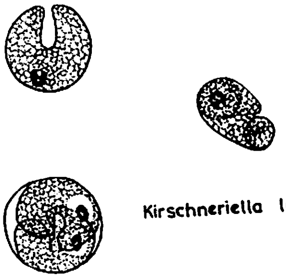
Plate 1.



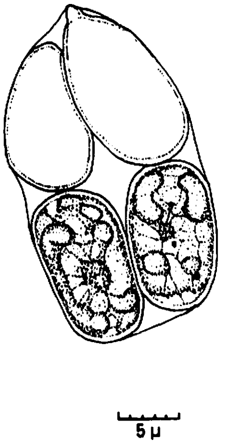
Tetrallantos minor

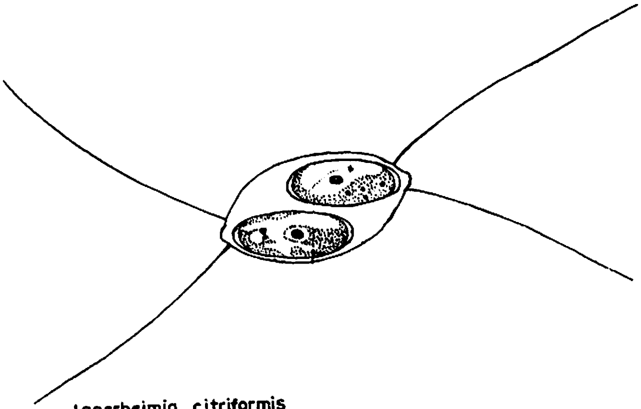


Tetrallantos minor

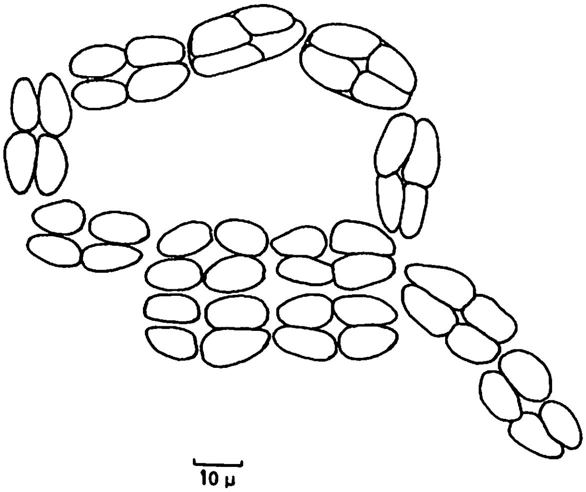


Kirschneriella lunaris

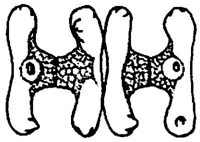




Lagerheimia citriformis



Crucigena rectangularis var. catena



Spondylosium karvum

Plate 2.

6. *Scenedesmus arcuatus* Lemm. (Plate 1)

Cells 2.5μ to 3.6μ x 5μ to 6μ. Usually singly or in clusters up to 8 cells with no apparent order of arrangement. Starch granules often numerous and variable in size but may be lacking. Pyrenoid indistinct and often difficult to see.

Desmidiales

7. *Spondylosium korvum* sp. n. (Plate 2)

Half cells are 2.5μ x 10.5μ with the width of the isthmus being equal to the width of the half cell. There was consistently one pyrenoid per cell. The ends of the half cells have one or sometimes two subterminal, bluntly tapering points. The cells were most often observed singly.

Pyrrophyta

Cryptophyceae

8. *Katablepharis ovalis* Skuja (Plate 3)

These conform in size to Skuja's description but have a more angular outline, and consistently have large, clear, posterior food vacuoles. Also, all the specimens observed had a small anterior extension of the cell forming a flap over the insertion of the flagella. A small percentage of the cells were observed to have four flagella and a more definite nucleus.

9. *Rhodomonas minuta* Skuja (Plate 1)

These organisms are variable in individual characteristics such as the presence or absence of a posterior leucosin body and the general dimensions. However, they appear to fall into two size ranges in the ponds of Alaska's north slope. The smaller size group is from 4μ to 5.5μ x 8μ to 12μ and corresponds closely to *Rhodomonas minuta* var. *nannoplanktica* Skuja. It is in this smaller size group that the leucosin body is commonly observed. The larger group consists of a size range of 5μ to 7μ x 12μ to 18μ and appears to be

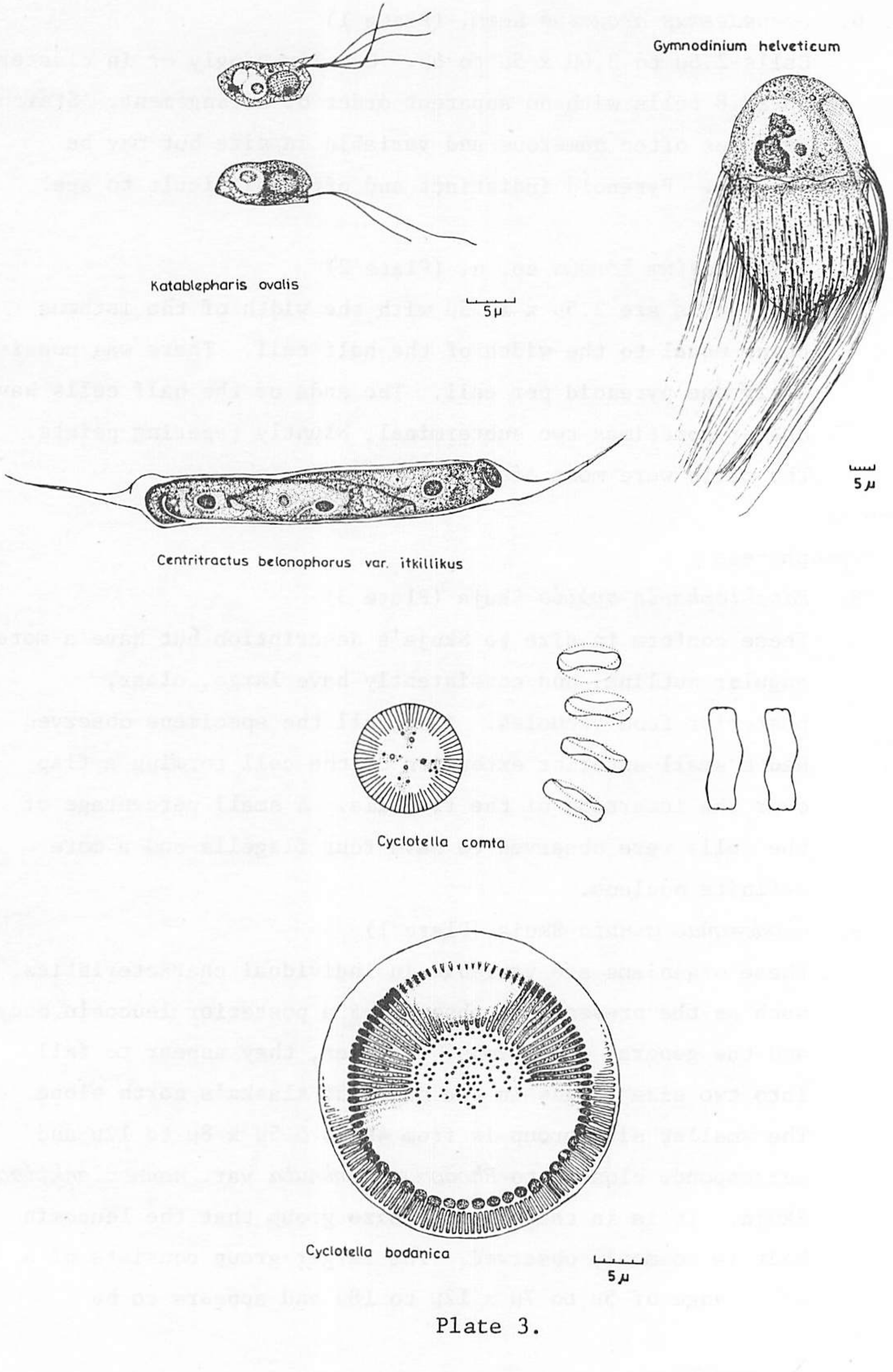

Katablepharis ovalis
5μ
Gymnodinium helveticum
5μ
Centritractus belonophorus var. itkillikus
Cyclotella comta
Cyclotella bodanica
5μ

Plate 3.

limited in distribution to the Barrow area. Both forms differ from Skuja's descriptions in the more differentiated nature of their posterior horns, the consistently different appearance of preserved forms, and their pigments in life. In these forms the posterior horn appears to be extracellular in nature, perhaps of a gelatinous material. In live specimens the pigments are of a pale blue-green color.

Dinophyceae

10. *Gymodinium helveticum* Penard fa. *alaskanum* fa. n. (Plate 3)

Cell 30μ x 50μ with a deep longitudinal furrow in the epivalve and a shallow groove in the hypovalve. Gelatinous threads arising from trichocysts in the hypovalve and epivalval margin of the equatorial furrow were observed in one specimen. The dimensions and general characteristics fit the descriptions of Penard and Skuja with the exception of the deep epivalval longitudinal furrow.

Chyrsophyta

Heterokontae

11. *Centritractus belonophorus* Lemm. var. *itkillikus* var. n. (Plate 3)

Cells in twos overlapping within the parent cell wall. Cells 5μ x 28μ, parent cell wall ca. 40μ exclusive of tapering ends. Cells with two to three pyrenoids. The ends of the cells are dissimilar, the proximal end being tapered to a narrow tip, the distal end being folded and thicker. Junctures of the wall sections lie at one and possibly both ends of the cell but are very inconspicuous. The cells were consistently thinner than those described in Prescott,[23] and differed by their occurrence in pairs and in the inconspicuous nature of the cell wall junctures.

Diatomeae

12. *Cyclotella comta* (E.) Kg. (Plate 3)

The cells are between 5.5μ and 12μ in diameter with 20 to 22 striae per 10μ. Cells occur singly or in short colonies of either closely spaced or loosely spaced cells. Cells are often irregularly distorted in cross section.

13. *Cyclotella bondanica* Eulenst. (Plate 3)
    Cells around 30μ in diameter with the striae occupying 2/3 of the diameter. The striae are differentiated into two distinct areas; the outside area consists of uniform striae of 16 per 10μ and occupies almost 1/3 of the striated area. The inner striae arise from every other one of the outside striae, producing a ratio of 2 inner striae to 3 outer striae. The inner striae are much less regular than the outer and vary in thickness and in length. The outermost center punctae have a 1 to 1 correspondence with the tips of the longest inner striae.

Limnological Studies in the Wood's Camp Area

Intensive studies were conducted in two lakes (designated Lake I and Lake II, see map in Figures 25 and 26 for locations) and Nechelik Channel, all close to Woods Camp in the western part of the Colville River delta. These studies were done during the summers of 1971 and 1972.

Three or four separate phytoplankton samples collected at different sites on a transect across a lake or the river were pooled to form a 60ml phytoplankton sample. These were collected either by skimming 15-20ml of water from the surface with a 100ml graduated cylinder or by pouring out 15 or 20ml of water from the water sampler.

The lakes selected for this study, designated Lake I and Lake II were small with a surface area of about $6.5 \times 10^5 m^2$ for Lake I, and about $10.5 \times 10^5 m^2$ for Lake II. The surrounding land is typical arctic tundra of low relief. Lake I is located on the west bank of Nechelik

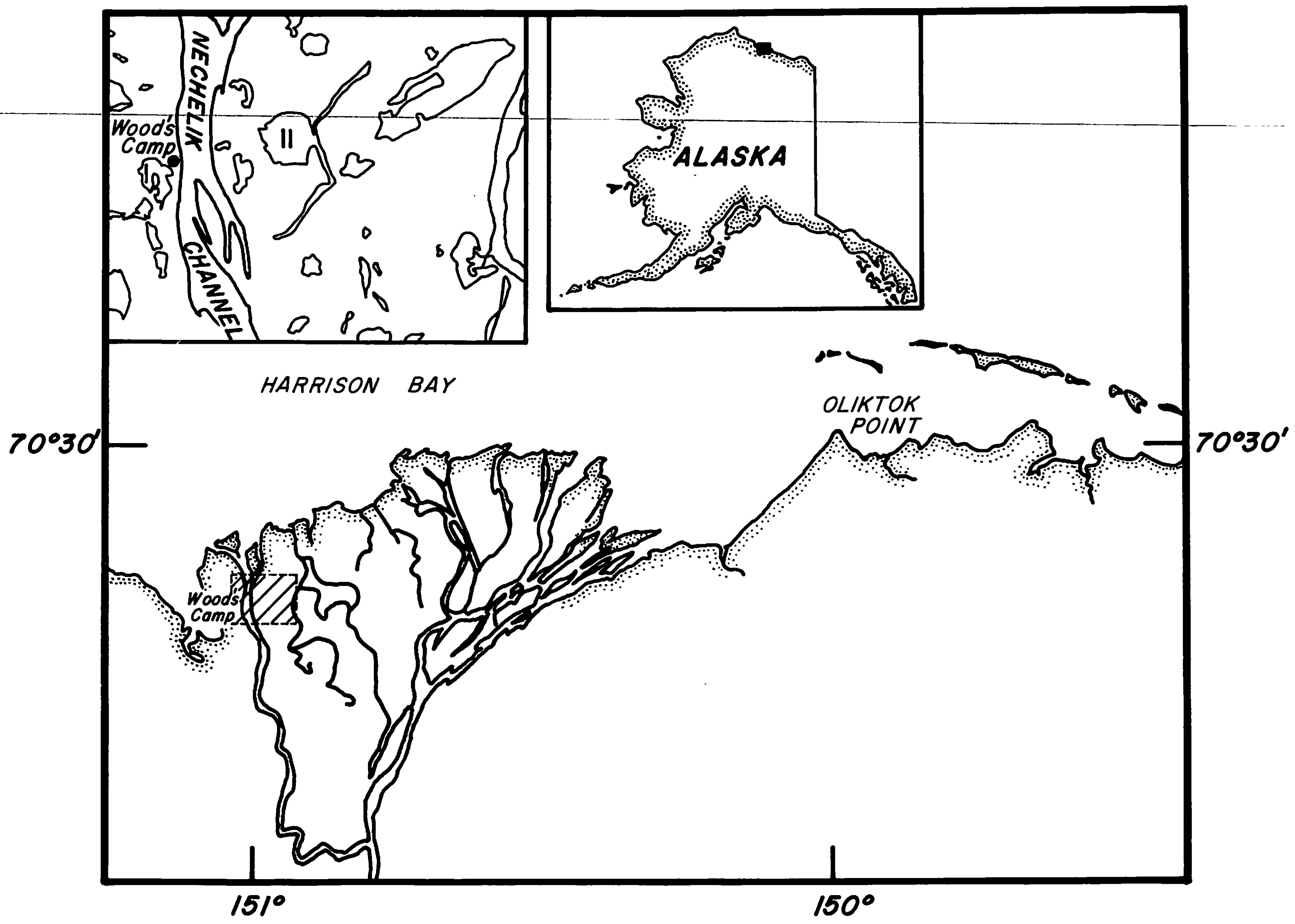


Figure 25. Wood's camp vicinity and locations of lakes I and II, Colville River delta, Alaska.

Figure 26. Aerial views of Wood's camp and riverbank at Wood's camp.

Channel, 100 yards southwest of Wood's Camp. Between Lake I and the camp site there is a trash dump, which could possibly cause enrichment of the lake during the time of the year when there is considerable surficial runoff. The shape of the lake is irregular and its bank is about 0.5 to 1 foot above the water level. The maximum depth of Lake I is 1.5m, which is very shallow compared with Lake II (3.5m) and Nechelik Channel (8m). Lake I was frozen to the bottom in May 1972 and therefore no data is available for this month. The bottom of Lake I is composed of black-colored mud. The odor of H_2S was sensed and water was light brown during the sampling period. Lake II is located east of Nechelik Channel opposite Wood's Camp. The lake is circular and the bank is 1 to 3 feet above the surface of the water. During the summer emergent rooted plants grow on the east shore of Lake II. The bottom of the east side of Lake II is a mixture of sand and dead plants. The bottom of the west side is sandy. The water of Lake II is clear. Nechelik Channel is about 1000 feet wide at Wood's Camp and the deepest area, which is closer to the west bank of the channel, is 8m. The east bank of Nechelik Channel is about 1 foot high and the west bank is about 5 feet high. The east side of the channel bottom is muddy and the west is sandy. Due to erosion of the channel, the west bank collapses when the permafrost melts during the summer. The water of the channel is turbid and transparency is low (Table 16).

The phytoplankton counts, biological data, salinity, inorganic nutrients and physical parameters are all listed on Tables 17 to 21. All the figures and the correlation coefficients in this report are calculated from mean values of the data listed in Tables 16 to 21. Physical, chemical and biological information for the lakes and channel are also given in Figures 27 to 37.

The two habitats sampled, the lakes and the channel, were significantly different (Tables 17, 18 and 19). The lakes had a greater variety of

Table 16. CHEMICAL AND PHYSICAL DATA - WOOD'S CAMP STUDIES

Station	Date	Inc. solar rad., langley min^{-1}	Transp., m	Depth, m	Temp. °C	Dissolved O_2 ppm	pH	Total alk. meq/ℓ	Part N, μg-N/ℓ
Nechelik Channel	29 July 1971	0.127	1.0	0	11.0	11.0	7.85	1.34	116.2
				1.5	11.0	10.7	7.95	1.35	175.2
				3.5	11.0	10.7	7.95	1.33	231.4
				5.5	11.0	10.5	7.95	1.75	282.0
	4 Aug. 1971		0.75	0	7.0	12.4	7.7	1.56	
				1.0			7.9	1.57	
				2.5			7.9	1.64	
	9 Aug. 1971		1.5	0	8.5	12.2	7.9	1.50	
				3.5	7.5	12.2	7.9	1.62	
				7.0	7.5	11.9	8.0	1.68	
	22 May 1972	1.143		3.0	-1.0		7.07	3.95	
				5.0	-1.0		7.20	3.45	
	25 May 1972	0.946		3.0	-1.0	4.29	7.13	3.45	
				5.0	-1.0	7.11	7.07	3.44	
	27 June 1972	0.367	0.5	0			7.7	0.83	
				2			7.45	0.74	
				6			7.41	0.76	
	29 June 1972			0	9.5	11.8			
				2	9.5	11.6			
				4	9.5	11.5			
				6	10.0	11.5			
				8	10.0	11.5			
	1 July 1972	0.120		0	11.0	12.0	7.71	0.749	79.1
				2	10.5	11.4	7.77	0.760	72.9
				4	10.5	11.2			75.9
				6	10.0	11.2	7.91	0.793	67.8
				7	10.0	11.2			134.1

Table 16. (continued) CHEMICAL AND PHYSICAL DATA - WOOD'S CAMP STUDIES

Station	Date	Inc. solar rad. langley min^{-1}	Transp. m	Depth, m	Temp. °C	Dissolved O_2 ppm	pH	Total alk. meq/ℓ	Part N, μg-N/ℓ
Nechelik Channel	27 July 1972	0.245	0.25	0	9	11.8	7.7	1.129	132.9
				2	8.5	11.6			95.5
				4	8.5	11.5			126.0
				6	8.5	11.4	7.7	1.097	108.2
				7.5	8.5	11.4			168.2
				8	8.5	10.9			
	30 July 1972	0.095	0.25	0	10.5	11.4	7.8	1.162	
				2	10.2	11.2			
				4	10.2	11.2			
				6	10.1	11.1	8.0	1.184	
				7.5	10.1	11.1			
	29 Aug. 1972	0.095	0.20	0	9.0	12.0	7.7	1.021	92.9
				2	9.0	11.8			418.1
				4	9.0	11.8			413.7
				6	9.0	11.7	7.7	1.010	128.3
				7.5	9.0	11.7			129.3
	31 Aug. 1972	0.067	0.20	0	7.7	12.2	7.6	0.977	
				2	7.7	12.2			
				4	7.7	12.0			
				6	7.7	11.9	7.65	0.977	
				7.5	7.7	11.8			
Lake I	31 July 1972	0.127	0.75	0 (center)	10.0	11.5	8.2	2.69	
				1	10.0	10.8	8.3	2.73	
				0 (shore)			8.3	2.69	115.9

Table 16. (continued) CHEMICAL AND PHYSICAL DATA - WOOD'S CAMP STUDIES

Station	Date	Inc. solar rad. langley min^{-1}	Transp. m	Depth, m	Temp. °C	Dissolved O_2 ppm	pH	Total alk. meq/ℓ	Part N, μg-N/ℓ
	5 Aug. 1972		1.0	0 (center)	6.0	12.0	8.15	2.78	
				0.5	6.0	12.0			
				1.0	6.0	12.0	8.10	2.79	
				1.5	5.5	1.8			
				2.9 (bottom)	5.0	0.8			
				0 (shore)			8.20	2.77	128.6
Lake I	28 Aug. 1971	0.458	1.5 (bottom)	0	9.0		7.91	1.69	142.2
	2 July 1972	0.156	1.5 (bottom)	0	15.0	11.3	8.19	1.85	
	28 July 1972	0.128	1.5 (bottom)	0	8.5	11.8	8.23	2.90	149.6
	31 July 1972	0.128	1.0	0	12.0	10.8	8.20	2.85	
	30 Aug. 1972	0.135	1.0	0	7.0	11.9	8.15	3.160	239.6
	1 Sept. 1972		1.0	0	3.5	12.5	8.10	3.160	
Lake II	2 Aug. 1971	0.402	2.0	0	10.0	11.2	7.40	0.67	
				1.0	10.0	10.8	7.35	0.67	
				2.5	10.0	10.7	7.35	0.68	

Table 16. (continued) CHEMICAL AND PHYSICAL DATA - WOOD'S CAMP STUDIES

Station	Date	Inc. solar rad. langley min^{-1}	Transp. m	Depth, m	Temp. °C	Dissolved O_2 ppm	pH	Total alk. meq/ℓ	Part N, µg-N/ℓ
	8 Aug. 1971		2.0 (Site I)	0	8.0	12.2			
				1	8.0	12.1			
				2	8.0	12.1			
			2.25 (Site II)	0	8.0	12.3			
				1.0	8.0	12.3			
				2.5	8.0	12.3			
			2.25 (Site III)	0	8.0	12.3	7.4	0.71	63.18
				1	8.0	12.3			
				2	8.0	12.4	7.4	0.70	
				3	8.0	12.4	7.15	0.67	
	21 May 1972	0.333		2.0	0.0	0.28	7.0	1.357	148.4
				2.5	2.0	0.31	7.1	1.032	176.3
Lake II	26 May 1972	0.944		2.0	2.0		6.6	1.499	103.5
	28 June 1972	0.458	2.5 (bottom)				7.16	0.434	73.8
	2 July 1972	0.156	2.5 (bottom)	0	11.0	11.0	7.69	0.424	
				0.5	10.5	10.7			
	28 July 1972	0.128	2.5 (bottom)	0	9.0	11.5	7.65	0.619	105.1
				0.75	8.5	11.0			

Table 16. (continued) CHEMICAL AND PHYSICAL DATA - WOOD'S CAMP STUDIES

Station	Date	Inc. solar rad. langley min^{-1}	Transp. m	Depth, m	Temp. °C	Dissolved O_2 ppm	pH	Total alk. meq/ℓ	Part N, μg-N/ℓ
	1 Aug. 1972	0.261	2.5 (bottom)	0	10.0	11.3	7.75	0.630	
	30 Aug. 1972	0.135	2.5 (bottom)	0	6.0	11.4	7.50	0.630	84.5
	1 Sept. 1972		2.5 (bottom)	0	4.0	11.9	7.40	0.630	

TABLE 17. SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR LAKE I, COLVILLE RIVER DELTA

	1971		1972					
	31 July 1971 Mix (0,1)	5 Aug. 1971 Mix (0,1)	28 June 1972 Om	2 July 1972 Om	28 July 1972 Om	31 July 1972 Om	30 Aug. 1972 Om	1 Sept. 1972 Om
Bacillariophyceae	342.8[a] 91.0[b]	259.9 320.8	9404.7 1090.7	1167.8 112.0	2036.6 546.6	1161.3 343.6	429.1 193.6	353.6 162.3
Nitzschia closterium	177.7 13.1	67.9 8.7			50.5 2.8	25.3 1.7		25.3 1.4
Nitzschia spp.	5.6 7.3	4.0 1.0						101.0 4.5
Navicula spp.	88.5 38.9	49.3 10.2			50.5 2.1		126.2 139.4	151.5 64.0
Tabellaria fenestrata v. asterionelloides	2.4 0.3	1.6 0.2	8142.3 1073.3	725.9 95.7	942.6 463.9	1085.6 141.1		50.5 17.8
Diatoma elongatun		5.7 0.5			959.4 24.9			
Cyclotella glomerata	2.4 0.8	15.4 1.3					277.7 30.7	
Amphiprora gigantea	0.4 2.4	6.1 212.0						25.3 74.7
Chaetoceros spp.			1262.4 17.4	252.5 5.2				
Cocconeis spp.	7.3 0.5	32.3 2.7						
Cyanophyta	1024.9 4.5	619.7 6.8					580.7 5.2	1868.4 32.9
Merismopedia glanea	978.8 3.0	595.8 6.1					303.0 1.3	1413.9 5.9

[a] cells (thousands/liter)

[b] biomass (μ^3/liter)

TABLE 17. (continued) SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR LAKE I, COLVILLE RIVER DELTA

	1971		1972					
	31 July 1971 Mix (0,1)	5 Aug. 1971 Mix (0,1)	28 June 1972 Om	2 July 1972 Om	28 July 1972 Om	31 July 1972 Om	30 Aug. 1972 Om	1 Sept. 1972 Om
Lyngbya limnetica	46.1[a] 1.5[b]	17.4 0.6						50.5 0.5
Chlorophyta	5.7 0.2	81.2 11.3	63.1 4.0	126.3 18.7	302.9 35.6	454.5 23.5	100408.8 969.6	6738.5 651.5
Ankistrodemus falcatus v. spirilliformis		52.1 0.6		31.6 0.3	84.2 1.0		25.3 2.7	227.2 4.5
v. mirabilis						101.0 1.1	328.2 2.2	
Oocystis submarina v. variabilis		7.3 0.4				101.0 1.9	353.5 39.0	126.2 3.4
Chlorella spp.		2.0 0.2						66905.5 615.7
Chlamydomonas spp.			63.1 4.0	63.1 0.5	134.6 11.4	151.1 16.7	101.0 4.2	
Kirchneriella obesa							101.0 5.6	
Dictyosphaorium simplex		16.2 0.4					99474.7 915.4	
Salenastrum bibraianum					50.5 20.9	101.0 3.8		126.2 27.8
Chrysophyta	3.6 1.9	1447.9 26.4	13696.7 139.3	4323.6 90.5	10073.7 133.0	27873.2 320.5	111012.7 2043.9	92228.7 1819.9
Dinobryon petiolatum				189.4 27.9				

[a] cells (thousands/liter)

[b] biomass (μ^3/liter)

TABLE 17. (continued) SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR LAKE I, COLVILLE RIVER DELTA

	1971		1972					
	31 July 1971 Mix (0,1)	5 Aug. 1971 Mix (0,1)	28 June 1972 0m	2 July 1972 0m	28 July 1972 0m	31 July 1972 0m	30 Aug. 1972 0m	1 Sept. 1972 0m
D. sertularia		4.4[a] 0.5[b]						
D. spp.			378.7 13.9				50.5 0.9	
Chromulina spp.		1440.7 24.8	13128.6 120.8	4008.0 61.9	101.0 2.4	303.0 1.3	252.5 83.7	50.5 5.2
Chrysococeus spp.		2.8 1.1				303.0 22.3		
Ochromonas spp.			189.4 4.6	126.2 0.8		631.2 6.9		
Cryptophyta		42.8 7.1	2524.7 371.8	852.1 230.4	723.8 217.0	1085.6 293.4	1136.2 221.2	732.2 126.9
Rhodomonas minuta			2524.7 371.8	789.0 116.2	690.1 156.1	908.9 205.6		580.7 64.1
Cryptomonas spp.		21.8 4.2		63.1 114.2	33.7 60.9	176.7 87.8		151.5 62.7
Flagellates	4.8 0.8	17.7 1.0	2714.1 229.7	189.3 10.4	151.5 13.6	176.7 13.9		25.3 0.7
Unidentified cells		32.4 12.9			4174.3 203.5	6008.9 55.3	454.4 193.3	151.5 11.2
Total	1381.8 98.3	2502.4 386.9	28403.3 1835.6	6659.1 462.0	17462.8 1149.1	36760.2 1050.3	214021.9 3651.0	162770.1 2809.3

[a] cells (thousands/liter)

[b] biomass (μ^3/liter)

TABLE 18. SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR LAKE II, COLVILLE RIVER DELTA

	1971						1972						
	2 Aug.		8 Aug.		6 Nov.		21 May	28 June	2 July	28 July	1 Aug.	30 Aug.	1 Sept.
	0m	2.5m	0m	3m	0m (ice)	Bottom (ice)	Mix (1.5,2)	0m	0m	0m	0m	0m	0m
Bacillariophyceae	597.4[a] 68.3[b]	1758.2 254.8	393.3 41.7	1803.4 636.7		15.8 1.7	117.7 194.4	555.4 73.2	454.5 270.0	168.3 22.1	101.0 9.7		25.3 24.1
Nitzschia closterium		180.3 23.0											
Nitzschia spp.	3.2 6.1		85.6 13.1	144.3 22.1									
Navicula spp.			5.7 2.5	288.5 59.5			16.8 1.1			16.8 2.8	33.7 2.3		25.3 24.1
Tabellaria fenstrata v. asterionelloides	477.5 41.8	1239.8 108.5	264.1 23.1	1100.1 375.3			16.8 4.2	555.4 73.2	336.6 68.5	84.2 14.8	16.8 3.4		
Diatoma elongatum										67.3 4.6	33.7 3.5		
Cyclotella glomerata													
Amphiprora gigantea													
Chaetoceros spp.													
Cyanophyta	12.5 0.4	180.3 5.8	83.2 0.4	144.3 4.7			33.7 1.1	33.7 1.1					
Merismopedia glanca													
Lyngbya limnetica	12.5 0.4	180.3 5.8	9.7 0.3	144.3 4.7			33.7 1.1	33.7 1.1					
Chlorophyta			246.3 2.1	306.6 1.3				100.9 8.6	50.5 2.2		101.0 10.2	84.2 1.9	

[a] cells (thousands/liter)

[b] biomass (μ^3/liter)

TABLE 18. (continued) SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR LAKE II, CÓLVILLE RIVER DELTA

	1971						1972						
	2 Aug.		8 Aug.		6 Nov.		21 May	28 June	2 July	28 July	1 Aug.	30 Aug.	1 Sept.
	0m	2.5m	0m	3m	0m (ice)	Bottom (ice)	Mix (1.5,2)	0m	0m	0m	0m	0m	0m
Ankistrodemus falcatus								16.8[a] 0.2[b]					
Chlorella spp.													
Chlamydomonas spp.								84.1	50.5	101.0	84.2		
Chrysophyta	12.9 0.5	1258.0 25.1	1881.1 159.1	2218.2 234.2	15.8 2.3		151.5 11.1	488.1 12.0	134.6 20.0	12618.9 405.5	10493.3 330.7	4780.2 7.5	25550.4 239.0
Dinobryon petiolatum													
D. sertularia												33.7 3.7	12.6 1.9
Chromulina spp.		1149.7 13.5	1745.4 143.9	1731.3 142.7	15.8 2.3		50.5 3.6	437.6 6.2	117.8 7.6	1430.7 96.6	1211.9 77.5	101.0 7.4	25499.9 234.7
Chrysococcus spp.	1.6 0.04						101.0 7.5						
Ochromonas spp.								16.8 1.2	16.8 12.4	151.5 4.2	336.6 6.2	33.7 3.7	37.9 2.5
Peudokephyrion spp.	11.3 0.4	135.3 11.5	96.9 13.3	396.7 90.9				33.7 4.6					
Cryptophyta	219.8 39.5	225.4 84.2	238.3 106.4	234.4 78.2	284.0 71.4		858.4 87.7	218.8 32.3	185.1 31.8	757.4 198.0	538.6 121.8	589.1 24.7	883.7 57.7
Rhodomonas minuta		157.8 13.4	107.4 6.6	108.2 16.5	236.7 34.9				168.3 24.8	740.6 167.5		521.8 14.8	

[a] cells (thousands/liter)

[b] biomass (μ^3/liter)

TABLE 18. (continued) SELECTED COUNTS OF MAJOR PHYTOPLANKTON SPECIES FOR LAKE II, COLVILLE RIVER DELTA

	1971						1972						
	2 Aug.		8 Aug.		6 Nov.		21 May	28 June	2 July	28 July	1 Aug.	30 Aug.	1 Sept.
	0m	2.5m	0m	3m	0m (ice)	Bottom (ice)	Mix (1.5,2)	0m	0m	0m	0m	0m	0m
Cryptomonas spp.		67.6[a] 70.8[b]	130.8 99.9	126.2 61.7	47.3 36.5				16.8 7.0	16.8 30.5		67.3 9.9	
Flagellates	6.4 3.3	338.2 7.4	12.9 1.3		47.4 45.1	15.8 5.2		117.8 5.6	235.6 43.1	16.8 1.8	101.0 27.0	67.3 11.6	37.9 6.6
Unidentified cells	16.0 22.9	586.1 183.5	516.1 187.6	2145.9 410.7			286.1 36.6	639.6 150.3	488.1 110.9	101.0 0.9	1582.2 338.0	1767.3 212.1	1350.7 335.6
Total	865.0 134.8	4373.2 560.8	3371.1 498.6	6582.9 1365.8	347.2 118.8	6.9 31.6	1464.2 341.7	2036.5 371.5	1845.4 478.0	13662.4 628.4	12917.1 837.4	7304.9 328.1	27848.0 663.1

[a] cells (thousands/liter)

[b] biomass (μ^3/liter)

TABLE 19. CORRELATION COEFFICIENTS BETWEEN PHYTOPLANKTON BIOMASS, BIOLOGICAL, CHEMICAL AND PHYSICAL PARAMETERS. (no. of stations = 3, degree of freedom = 14.)

Parameter	Chlorophyll-*a*	^{14}C primary productivity	Silicate-Si	Phosphate-P	Ammonia-N	Nitrate-N	Incoming solar radiation	Water temperature
Total phytoplankton biomass	0.744[a]	0.576[b]	-0.474	-0.281	-0.055	-0.243	-0.259	-0.029
Bacillariophyceae biomass	0.064	0.699[a]	-0.431	-0.291	0.313	-0.236	-0.183	0.160
Cyanophyta biomass	0.789[a]	0.248	-0.269	-0.105	-0.051	-0.144	-0.197	-0.151
Chlorophyta biomass	0.786[a]	0.313	-0.218	-0.073	-0.095	-0.107	-0.177	-0.143
Chrysophyta biomass	0.783[a]	0.378	-0.311	-0.159	-0.148	-0.158	-0.218	-0.100
Cryptophyta biomass	0.222	0.759[a]	-0.555[b]	-0.356	0.178	-0.235	-0.133	0.124
Flagellates biomass	-0.144	0.306	-0.354	-0.230	0.362	-0.068	-0.022	0.129
^{14}C primary productivity	0.348		-0.546[b]	-0.340	-0.167	-0.333	-0.403	0.352

[a] >0.497 significant at 5% level (from Snedecor 1967).

[b] >0.623 significant at 1% level.

TABLE 20. PHYTOPLANKTON NUMBERS AND CARBON AND NITROGEN DYNAMICS IN FRESHWATER ENVIRONMENTS

Location	Date	Depth m	Total phytoplankton		Chlorophylls mg/m^3			^{14}C primary productivity µg C/1-hr	^{15}N uptake µg N/1-hr		NH_4^+ supply µg at/1-hr	Turnover time for NH_4^+, hrs
			$10^3/1$	$m^3/1$	a	b	c		NO_3^-	NH_4^+		
Nechelic Channel	29 July 1971	0	469.4	152.7	2.22	0	0.94					
		1.5			4.06	0	1.43					
		3.5			4.26	0	1.04					
		5.0			6.23	0	2.08					
	4 Aug. 1971	0	235.4	220.4	1.44	0	0.64	4.24				
		1.0			2.69	0	1.36	5.13				
		2.5			2.25	0	0.93	7.00				
	9 Aug. 1971	0	972.6	316.1	1.13	0	0.46					
		3.5	303.0	171.8	2.24	0	1.14					
		7.0			2.88	0	1.00					
	22 May 1972	3	437.7	16.8	0.12	0.15	0.41	0	0.05	0.07	0.37	34.1
		5			0.06	0.05	0.54	0				
	25 May 1972	3			0.12	0.14	0.40	0	0.12	0.00		
		5			0.08	0.09	0.25	0				
	27 June 1972	0	387.1	77.1	0.30	0.33	1.43	1.32				
		2			0.10	0	0.42	2.03				
		6			0.19	0.23	0.64	1.88				
	1 July 1972	0	572.4	87.5	0.25	0	0.60	3.14	0.07	0.30	0.56	3.4
		2			0.40	0	0.66	3.32	0.03	0.23		
		6			0.36	0.09	0.95	2.97	0.03	0.28		
	27 July 1972	0	206.6	59.7	0.32	0.05	1.27	1.15	0.00	0.11	0.00	--
		6	227.1	72.1	0.15	0.18	0.51	0.78	0.02	0.10		
	30 July 1972	0	706.8	166.7	0.13	0.15	0.43	2.85				
		6	1148.7	1686.1	1.43	0.14	1.06	7.21				

TABLE 20. (continued) PHYTOPLANKTON NUMBERS AND CARBON AND NITROGEN DYNAMICS IN FRESHWATER ENVIRONMENTS

Location	Date	Depth m	Total phytoplankton		Chlorophylls mg/m^3			^{14}C primary productivity μg C/l-hr	^{15}N uptake μg N/l-hr		NH_4^+ supply μg at/l-hr	Turnover time for NH_4^+, hrs
			10^3/l	m^3/l	a	b	c		NO_3^-	NH_4^+		
Nechelik Channel	29 Aug. 1972	0	140.2	105.1	0.67	0.43	2.44	0.18	0.06	0.08	0.45	1.3
		6	189.2	99.2	0.41	0.48	1.36	0.17	0.50	0.27		
	31 Aug. 1972	0	189.4	57.2	0.74	0.85	2.87	0.17				
		6	126.2	100.6	0.69	0.63	2.41	0.23				
Lake I	31 July 1971	0 (center)	1381.8	98.3	1.08	0	0.48	3.70	0.13	0.01		
		1			4.70	0	1.48	5.05	0.11	0.02		
		0 (shore)			1.56	0	0.59					
	5 Aug. 1971	0 (center)	2502.4	386.9	1.12	0.06	0.70	2.14	0.09	0.08		
		1			8.44	0	2.98	3.63	0.08	0.01		
		0 (shore)			0.96	0	0.43					
	28 June 1972	0	28403.3	1835.6	0.89	0	0.36	9.04	0.00	0.38	0.00	--
	2 July 1972	0	6659.1	462.0	0.43	0	0.33	3.60				
	28 July 1972	0	17462.8	1149.1	0.92	0	0.90	9.65	0.01	0.66	1.62	2.1
	31 July 1972	0	36760.2	1050.3	0.90	0	0.40	16.26				
	30 Aug. 1972	0	214021.9	3651.0	3.14	0.13	1.25	8.95	0.06	0.67	1.45	1.3
	1 Sept. 1972	0	162770 1	2809.3	3.13	0.09	1.80	4.48				

TABLE 20. (continued) PHYTOPLANKTON NUMBERS AND CARBON AND NITROGEN DYNAMICS IN FRESHWATER ENVIRONMENTS

Location	Date	Depth m	Total phytoplankton 10^3/l	m^3/l	Chlorophylls mg/m^3 a	b	c	^{14}C primary productivity μg C/l-hr	^{15}N uptake μg N/l-hr NO_3^-	NH_4^+	NH_4^+ supply μg at/l-hr	Turnover time for NH_4^+, hrs
Lake II	2 Aug. 1971	0	1145.2	348.6	1.94	0	0.63	2.05	0.15	0.06		
		1.0			1.89	0	0.77	1.60	0.17	0.02		
		2.5	4373.2	560.8	6.50	0	2.28	2.51				
	8 Aug. 1971	0 (Site II)	3371.1	498.6	1.74	0	0.73	2.55	0.25	0.06		
		2			1.58	0	0.75					
		3	6582.9	1365.8	11.42	0	3.26	7.35	0.13	0.02		
	21 May 1972	1.5	1464.2	341.1	0.73	0.25	0.98	0.50				
		2.0			1.09	0.38	1.47	0.94	0.00	0.03	0.98	9.0
	26 May 1972	2			0.22	0.02	0.17	0.01				
	28 June 1972	0	2036.5	371.5	0.42	0.01	0.24	1.88	0.03	0.25	0.42	8.6
	2 July 1972	0	1845.4	478.0	0.28	0	0.35	1.95				
	28 July 1972	0	13662.4	628.4	0.38	0.07	0.69	2.72	0.04	0.33	0.36	0.8
	1 Aug. 1972	0	12917.1	837.4	0.61	0.09	0.52	4.13				
	30 Aug. 1972	0	7304.9	328.1	1.22	0.13	1.59	2.46	0.05	0.32	0.02	16.0
	1 Sept. 1972	0	27848.0	663.1	1.32	0.25	1.93	0.97				

TABLE 21. SALINITY AND INORGANIC NUTRIENT DATA

Station	Date	Depth m	Salinity °/₀₀	Silicate-Si μg at/l	Phosphate-P μg at/l	Ammonia-N μg at/l	Nitrate-N[a] μg at/l	Nitrite-N μg at/l
Nechelik Channel	30 June 1971	0	-	21.4	0.08	6.5	4.3	0.18
	29 July 1971	0	3.45	21.0	0.04	0.4	1.3	0.11
		1.5	9.92	12.7	0.56	0.4	0.1	0.07
		3.5	12.04	10.1	0.08	0.3	0.0	0.03
		5.0	-	6.3	0.04	0.3	0.0	0.03
	4 Aug. 1971	0	9.93	13.8	0.07	0.0	0.3	0.02
		1	9.99	13.8	0.07	0.0	0.2	0.02
		1.5	10.48	13.1	0.08	0.1	0.3	0.06
	9 Aug. 1971	0	6.14	19.6	0.18	0.1	0.8	0.11
		3.5	9.38	15.6	0.07	0.2	0.4	0.05
		7.0	10.09	15.6	0.09	0.4	0.5	0.10
	23 Aug. 1971	0	6.33	17.9	0.15	0.5	1.0	0.15
		3	6.17	17.7	0.15	0.7	1.1	0.14
		4.5	9.26	14.8	0.11	0.7	0.6	0.15
	5 Nov. 1971	0	17.16	16.2	0.11	5.3	-	-
		2	20.55	10.6	0.34	3.3	-	-
		4	24.14	6.7	0.15	1.3	-	-
		6	24.52	6.7	0.19	1.5	-	-
		7	24.65	6.0	0.19	1.7	-	-
	15 May 1972	1.8	36.23	45.5	0.30	11.6	30.5	1.03
		4.0	39.22	35.4	0.35	13.6	18.7	0.93
		6.0	41.40	30.6	0.47	15.5	16.7	1.00
		7.0	40.95	43.0	0.31	19.4	22.4	1.05
	22 May 1972	3	36.23	45.0	0.32	12.6	29.8	0.89
		5	35.71	28.8	0.42	16.6	15.4	0.84

[a] where nitrite is not reported, nitrate value = nitrate + nitrite.

TABLE 21. (continued) SALINITY AND INORGANIC NUTRIENT DATA

Station	Date	Depth m	Salinity °/₀₀	Silicate-Si µg at/l	Phosphate-P µg at/l	Ammonia-N µg at/l	Nitrate-N[a] µg at/l	Nitrite-N µg at/l
Nechelik Channel	27 June 1972	0	-	36.5	0.18	0.9	3.25	-
		2	-	36.3	0.10	1.8	2.90	-
		4	-	36.6	0.20	1.5	3.15	-
		6	-	36.5	0.20	1.0	3.23	-
		7.5	-	36.0	0.32	1.0	3.30	-
	1 July 1972	0	-	38.8	0.16	1.9	2.84	-
		2	-	38.0	0.29	1.6	3.00	-
		4	-	38.7	0.21	2.2	2.86	-
		6	-	38.8	0.24	0.8	2.76	-
		7	-	38.1	0.18	1.1	2.84	-
	27 July 1972	0	-	47.5	0.01	1.1	5.84	-
		2	-	23.8	0.00	1.1	5.36	-
		4	-	27.0	0.00	1.3	5.28	-
		6	-	35.8	0.00	1.3	5.32	-
		7.5	-	45.0	0.01	1.3	4.80	-
	30 July 1972	0	-	43.7	0.18	1.0	4.84	-
		2	-	37.8	0.01	1.0	5.32	-
		4	-	45.8	0.02	1.1	5.86	-
		6	-	38.7	0.03	0.9	4.12	-
		7.5	-	30.4	0.04	7.3	2.62	-
	29 Aug. 1972	0	-	69.2	0.02	0.6	3.00	-
		2	-	73.7	0.04	0.6	3.00	-
		4	-	73.6	0.03	1.1	3.00	-
		6	-	73.0	0.04	1.1	3.00	-
		7.5	-	74.5	0.04	1.3	3.00	-
	31 Aug. 1972	0	-	57.2	0.08	-	2.54	-
		2	-	53.1	0.11	1.0	2.56	-
		4	-	56.0	0.06	1.0	2.56	-
		6	-	57.1	0.10	1.1	2.56	-
		7.5	-	57.6	0.06	1.4	2.80	-

[a] where nitrite is not reported, nitrate value = nitrate + nitrite.

TABLE 21. (continued) SALINITY AND INORGANIC NUTRIENT DATA

Station	Date	Depth m	Salinity °/₀₀	Silicate-Si µg at/l	Phosphate-P µg at/l	Ammonia-N µg at/l	Nitrate-N[a] µg at/l	Nitrite-N µg at/l
Lake I	30 April 1971	2.1	4.99	30.0	0.15	23.4	4.0	0.27
	31 July 1971	0 (shore)	9.91	1.5	0.04	5.0	0.0	0.03
		0 (center)	10.10	1.5	0.04	4.5	0.0	0.05
		1 (center)	10.06	1.2	0.06	3.8	0.1	0.07
	5 Aug. 1971	0 (shore)	10.27	1.0	0.03	4.4	0.1	0.10
		0 (center)	8.10	1.2	0.07	4.8	0.0	0.12
		1 (center)	10.16	1.0	0.04	4.7	0.0	0.12
	28 June 1972	0	-	0.3	0.03	14.4	4.8	-
	2 July 1972	0	-	0.0	0.04	5.0	2.3	-
	28 July 1972	0	-	0.5	0.03	3.4	0.1	-
	31 July 1972	0	-	1.5	0.04	0.6	0.1	-
	30 Aug. 1972	0	-	3.5	0.04	1.9	0.8	-
	1 Sept. 1972	0	-	2.6	0.07	2.2	0.9	-
Lake II	30 April 1971	2.1	29.64	44.5	0.39	24.0	10.9	0.02
	2 Aug. 1971	0	1.33	8.1	0.01	0.4	0.0	0.01
		1	1.85	0.0	0.00	0.5	0.0	0.01
		2.5	1.99	0.2	0.00	0.4	0.0	0.00

[a] where nitrite is not reported, nitrate value = nitrate + nitrite.

TABLE 21. (continued) SALINITY AND INORGANIC NUTRIENT DATA

Station	Date	Depth m	Salinity °/°°	Silicate-Si µg at/l	Phosphate-P µg at/l	Ammonia-N µg at/l	Nitrate-N[a] µg at/l	Nitrite-N µg at/l
Lake II	8 Aug. 1971	0	1.22	-	-	0.2	0.0	0.02
		1.5	1.90	-	-	0.2	0.0	0.02
		3.0	1.94	0.0	0.0	0.5	0.0	0.05
	6 Nov. 1971	0	2.26	0.7	0.15	4.3	-	-
		1.0	2.22	0.7	0.07	3.0	-	-
		1.5	2.23	0.5	0.08	2.8	-	-
		2.0	2.23	0.7	0.06	3.3	-	-
	12 April 1972	2.0	4.23	20.0	0.20	4.7	17.2	0.14
	21 May 1972	1.5	3.42	21.6	0.10	8.8	3.6	0.31
	26 May 1972	2.0	4.37	26.9	0.10	12.5	3.1	0.22
	28 June 1972	0	-	4.3	0.03	3.6	0.4	-
	2 July 1972	0	-	2.8	0.02	1.5	0.0	-
	28 July 1972	0	-	2.8	0.02	0.3	0.0	-
	1 Aug. 1972	0	-	2.2	0.00	0.1	0.0	-
	30 Aug. 1972	0	-	1.5	0.00	0.3	0.0	-
	1 Sept. 1972	0	-	1.5	0.00	0.5	0.0	-

[a] where nitrite is not reported, nitrate value = nitrate + nitrite.

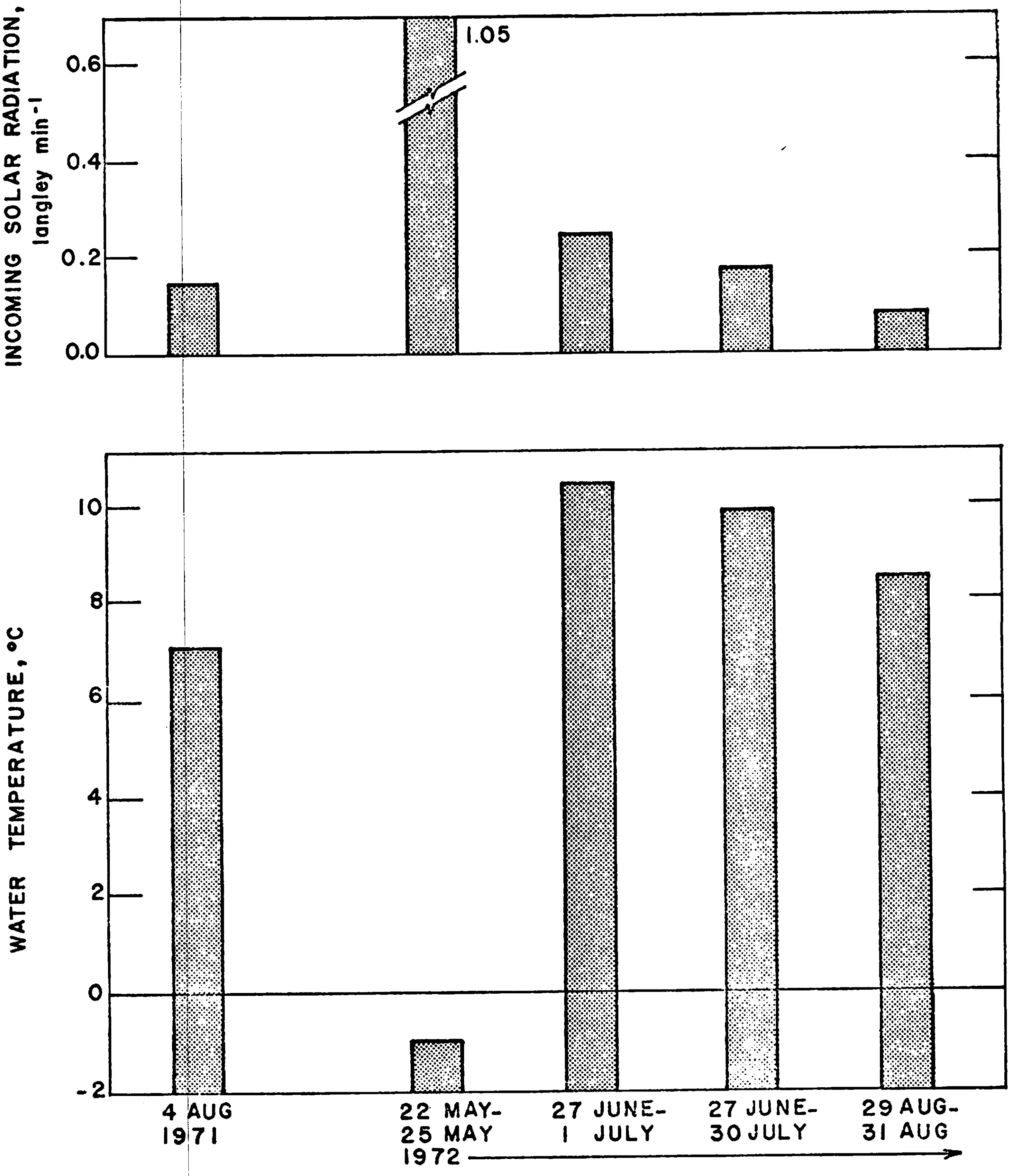


Figure 27. Water temperature and incoming radiation, Nechelik (West) Channel, Colville River delta.

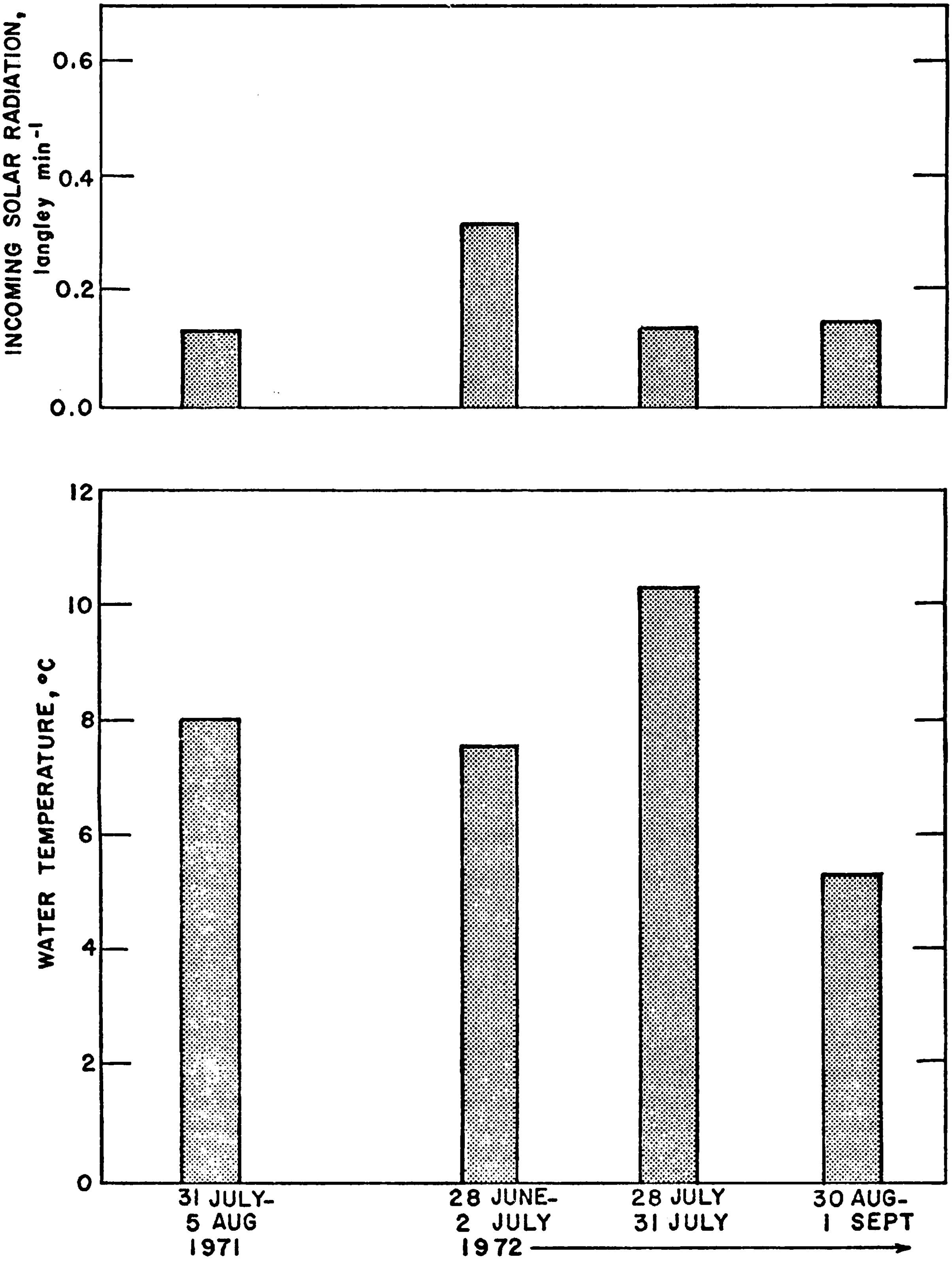


Figure 28. Water temperature and incoming radiation, Lake I.

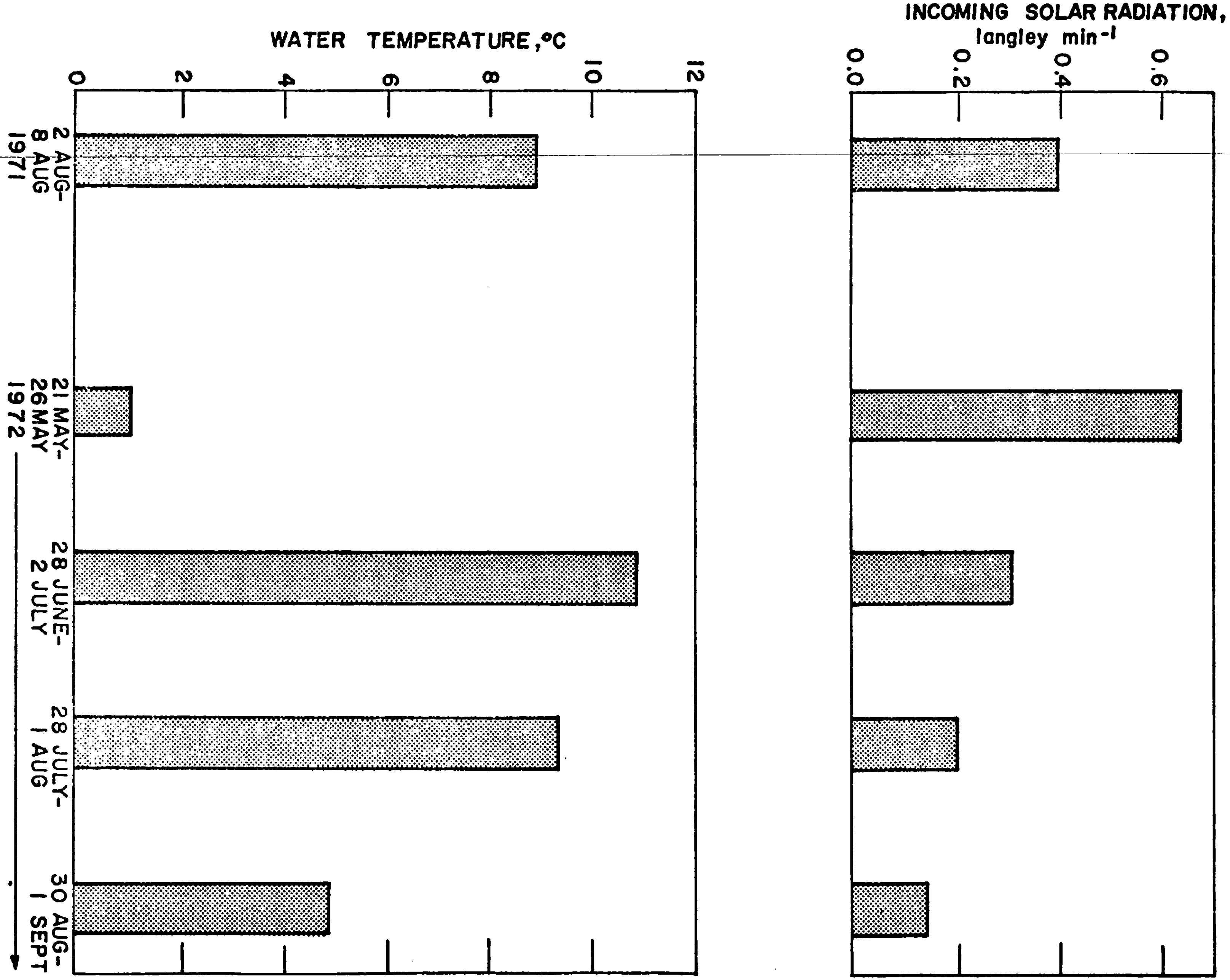


Figure 29. Water temperature and incoming radiation, Lake II.

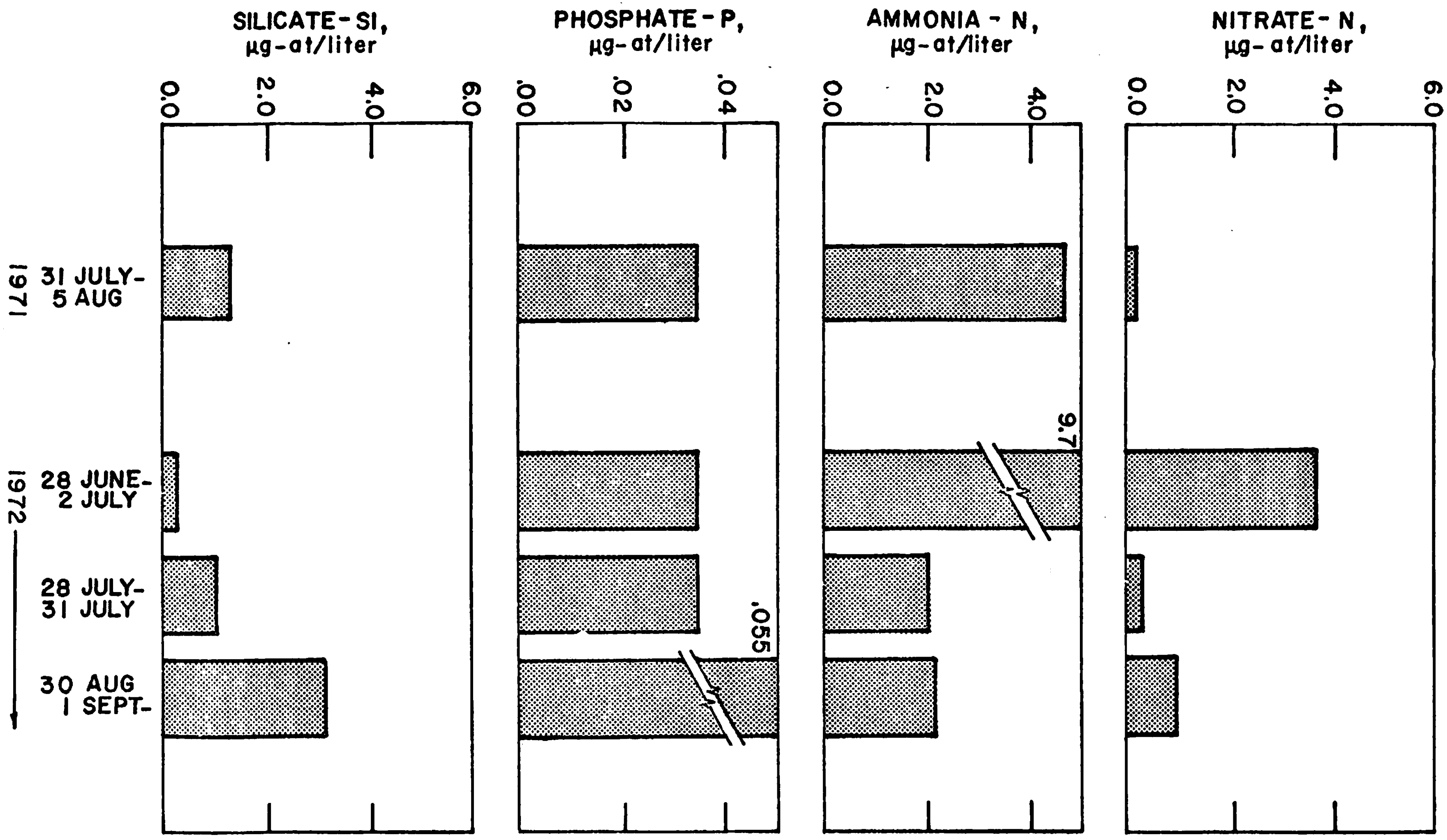


Figure 30. Nutrient concentrations, Nechelik (West) Channel, Colville River delta.

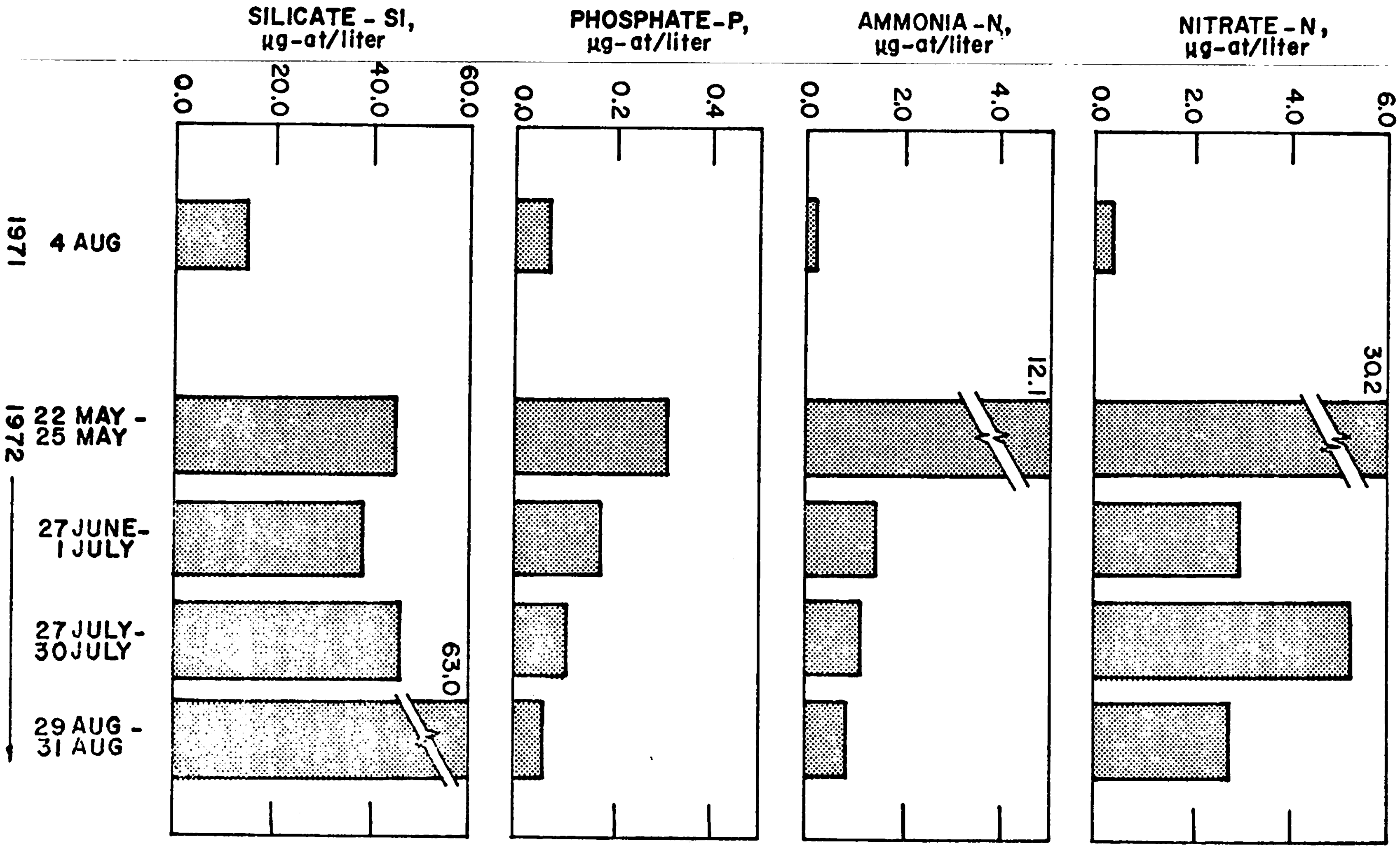


Figure 31. Nutrient concentrations, Lake I.

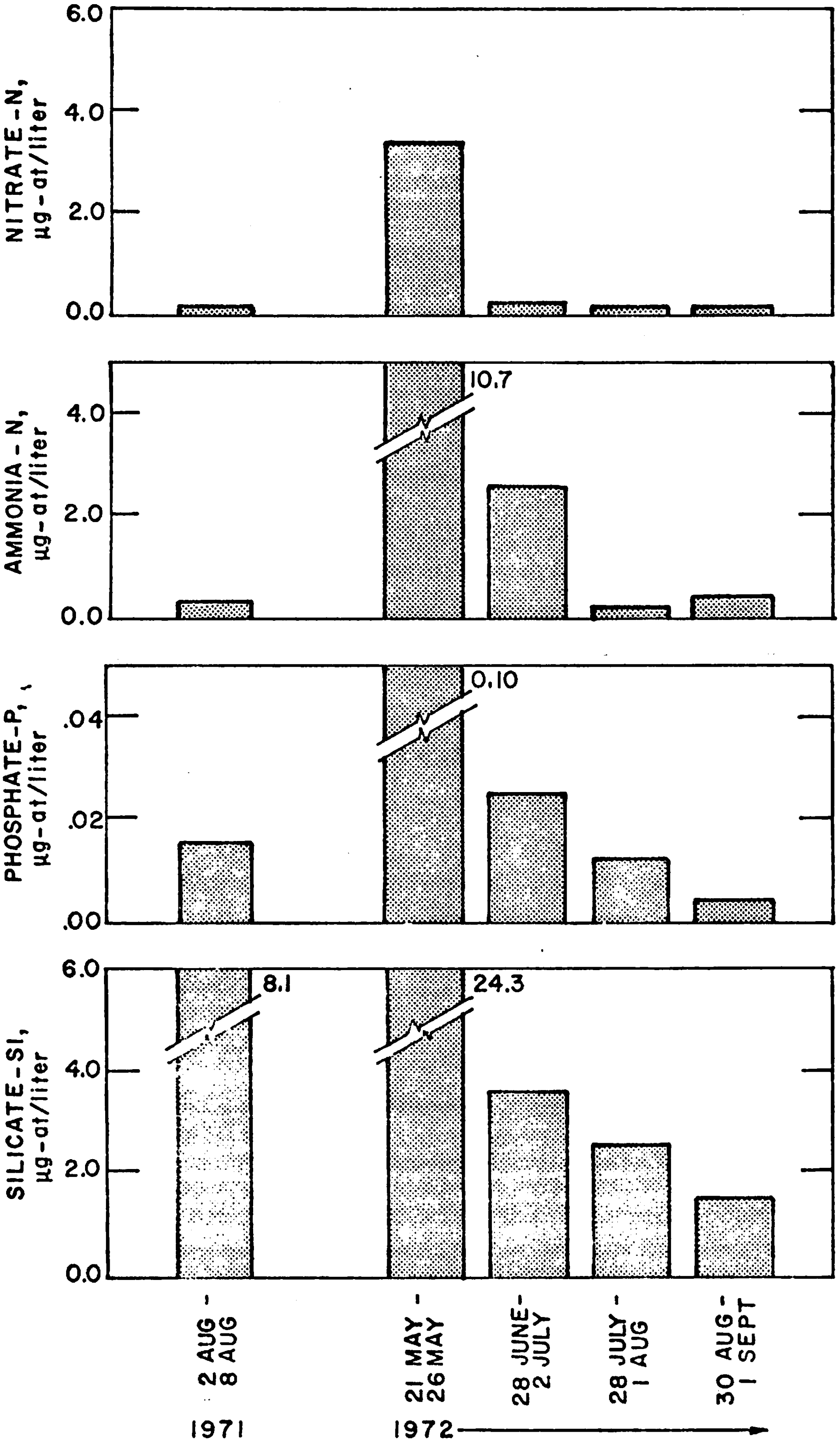


Figure 32. Nutrient concentrations, Lake II.

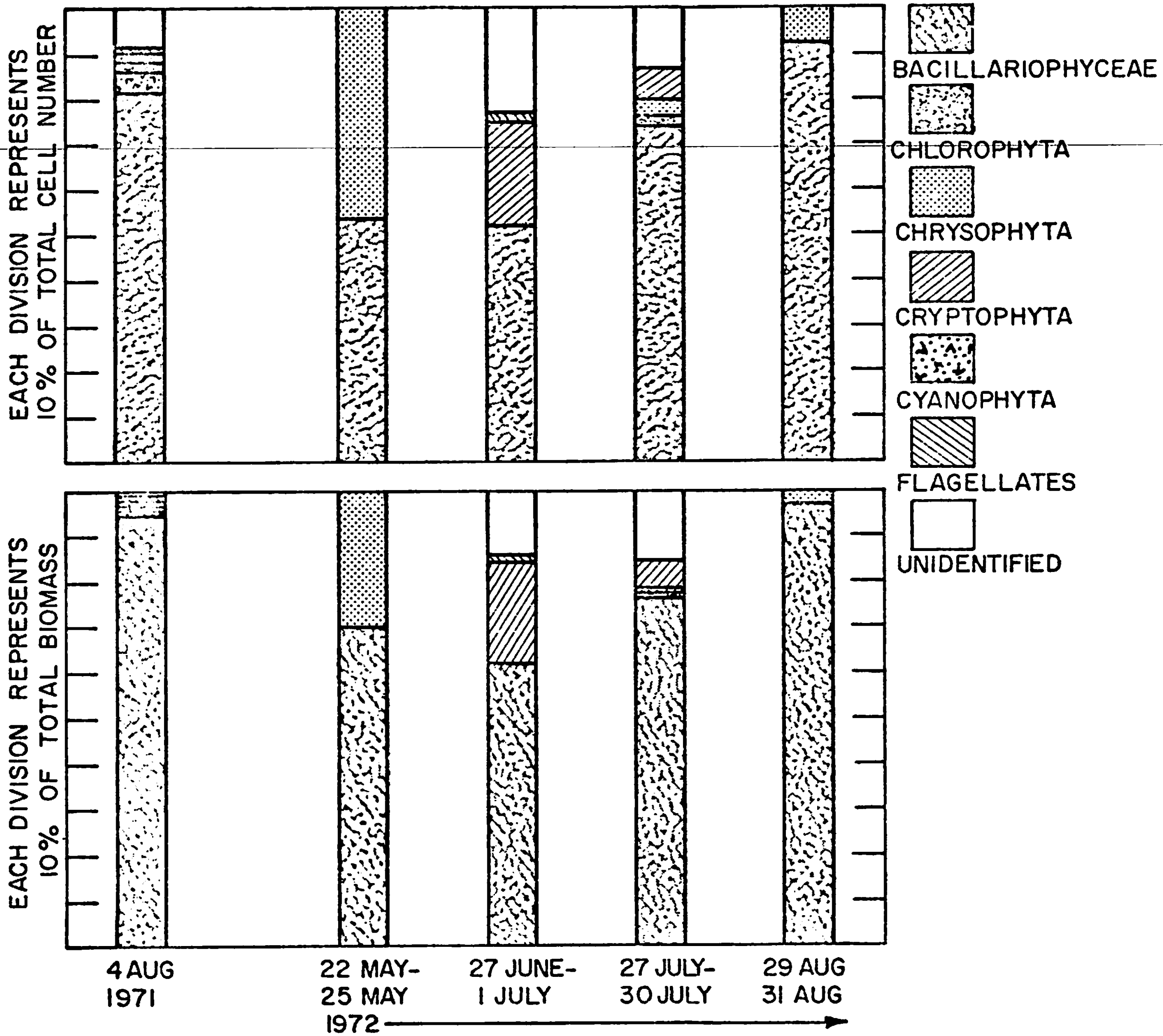


Figure 33. Phytoplankton composition in terms of cell numbers and biomass, Lake I.

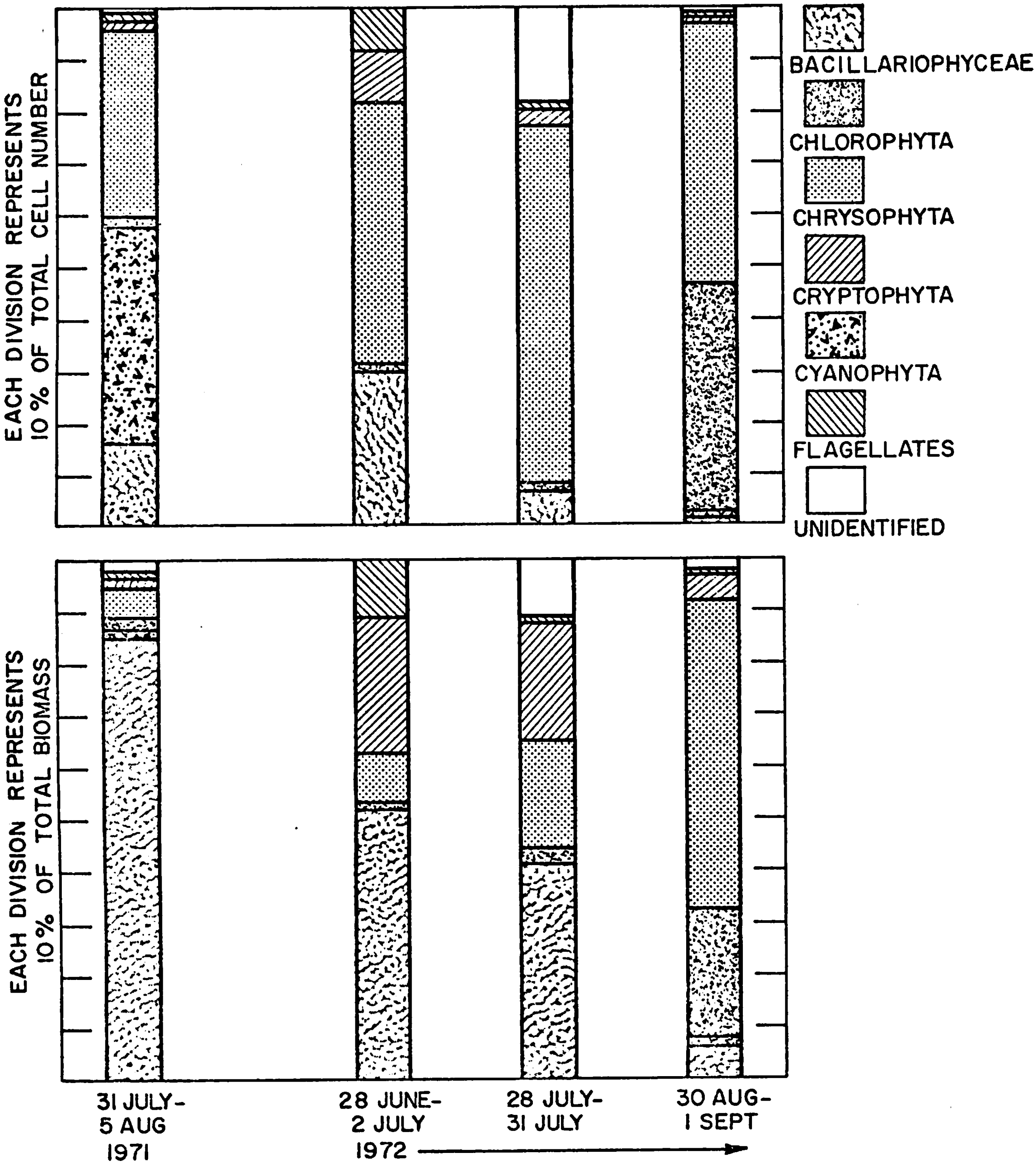


Figure 34. Phytoplankton composition in terms of cell numbers and biomass, Lake II.

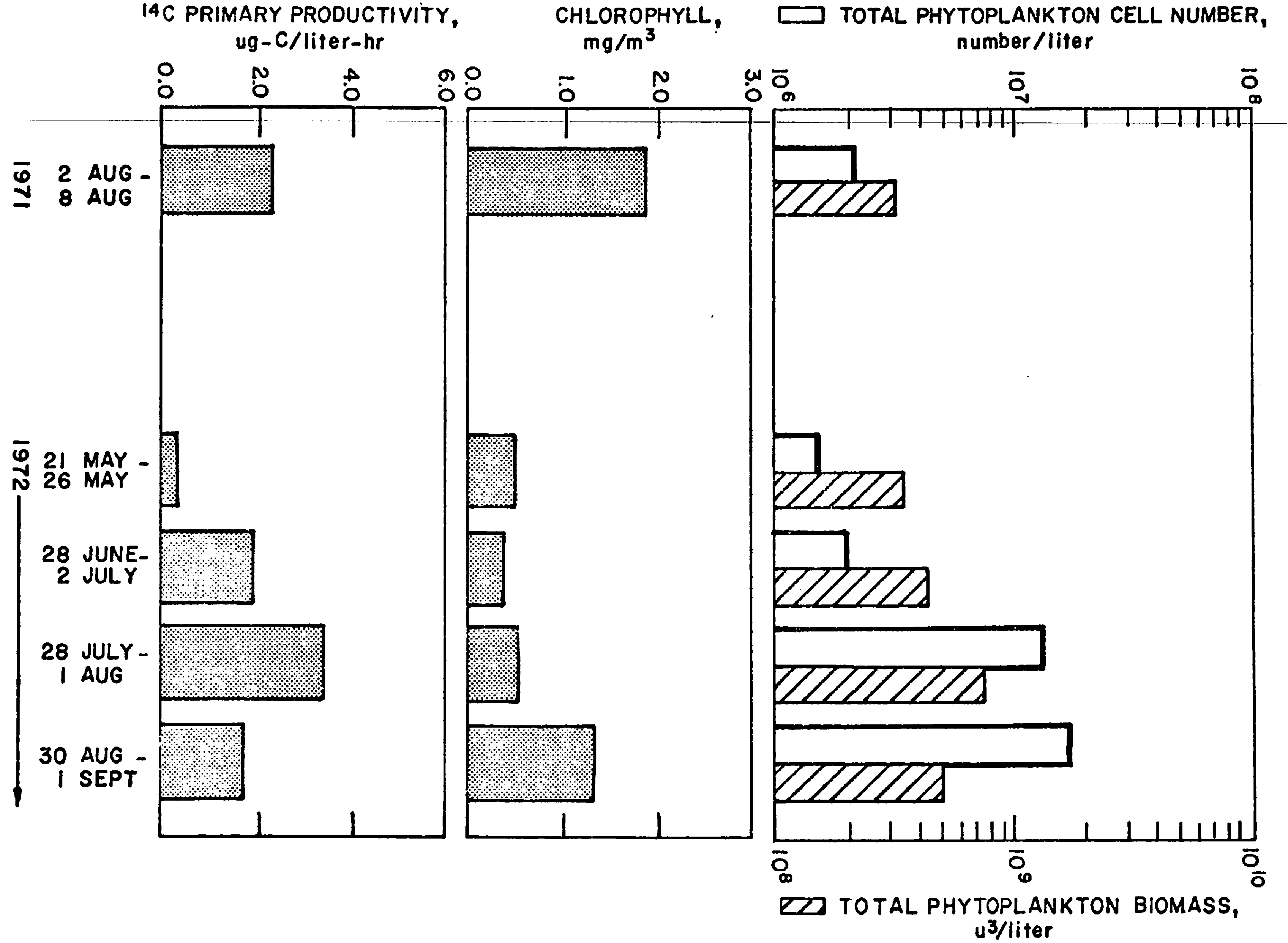


Figure 35. Primary productivity and related data for Nechilik (West) Channel, Colville River delta

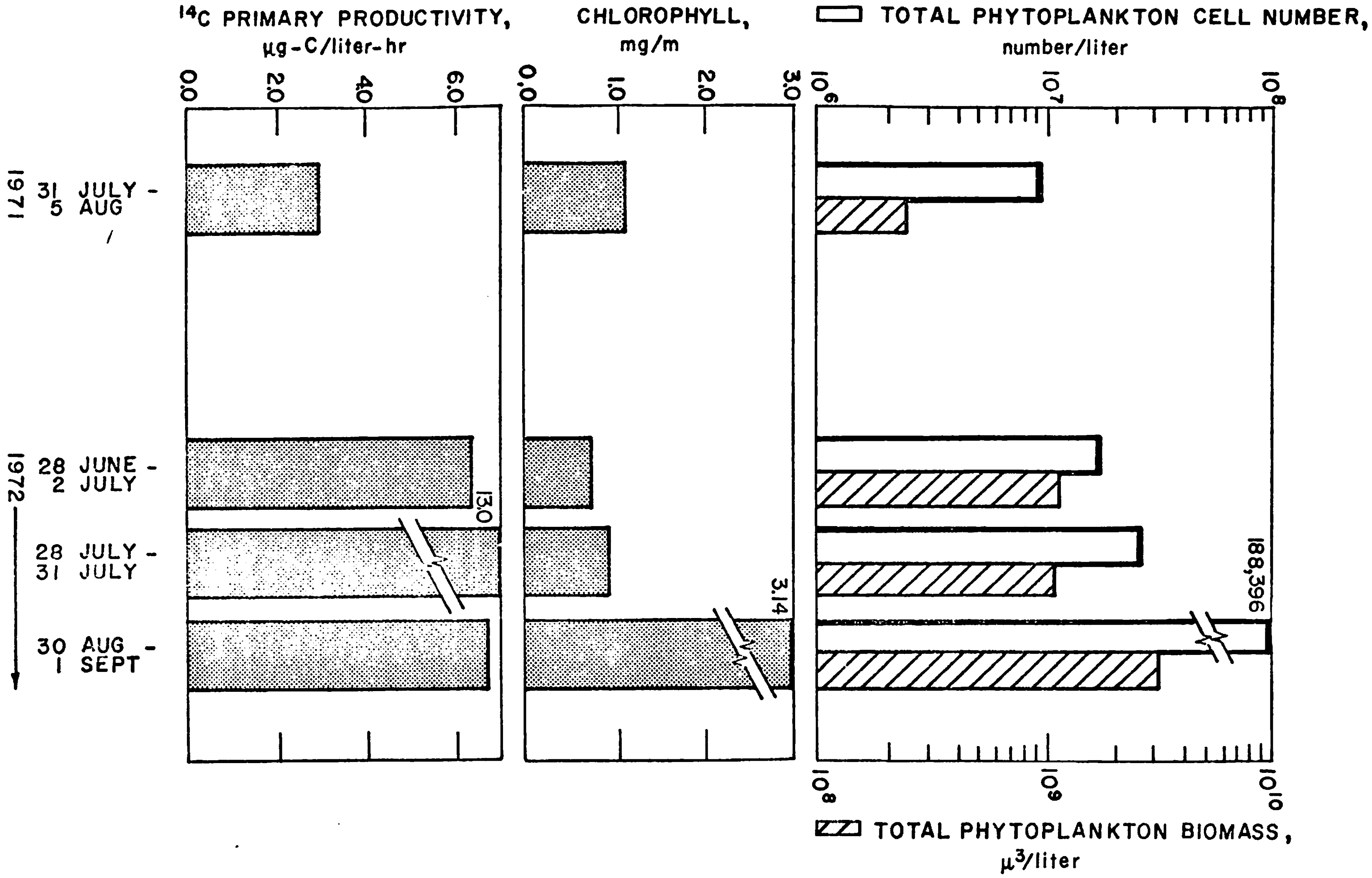


Figure 36. Primary productivity and related data for Lake I, Colville River delta.

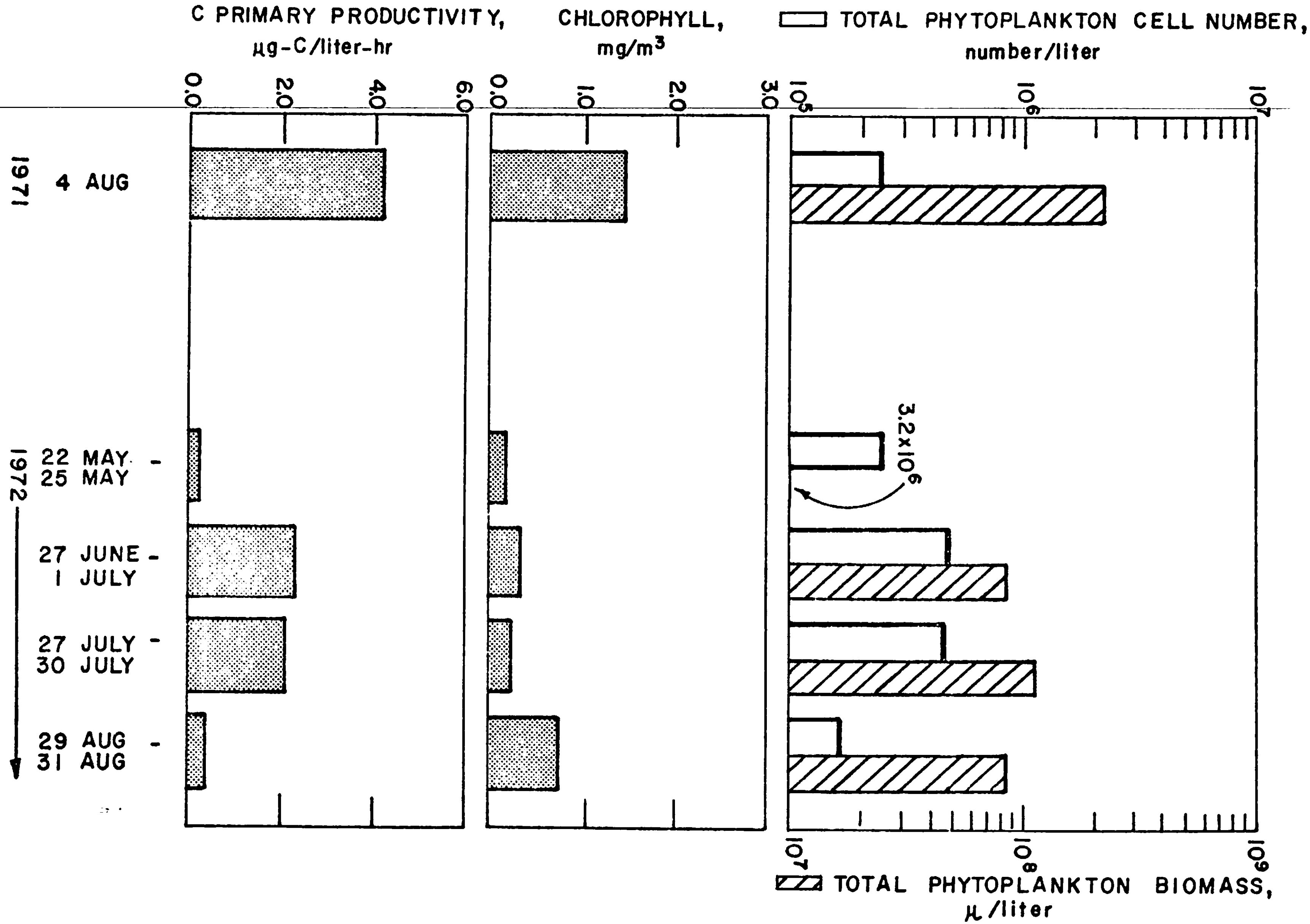


Figure 37. Primary productivity and related data for Lake II, Colville River delta.

phytoplankton and also larger populations, often an order of magnitude higher than the channel.

In general, Bacillariophyceae (diatoms) were the most numerous fraction in the river. *Nitzschia* spp., *Navicula* spp., and *Tabellaria fenestrata v. asterionelloides* composed the majority of the diatoms. The phytoplankton concentration in the surface and deep water samples of Nechelik channel were similar, except on 9 August 1971, when the phytoplankton concentration of deep samples was much smaller than the surface. This condition was reversed on 30 July 1972.

The lakes had a greater number of phytoplankton species. The most abundant phytoplankton populations were usually some combination of diatoms, Chrysophytes, and Cryptophytes. *Tabelleria fenestrata v. asterionelloides, Chromulina* spp. *Rhodomonas minuta* and *Cryptomonas* spp. were commonly found. Cyanophytes were usually observed in the lakes in late summer, but hardly seen in the channel (Tables 17, 18 and 19). In general, most phytoplankton identified in the channel were present in the lakes. Usually only surface samples were collected from the lakes, except on 2 August and 8 August 1971 at Lake II. The data collected from these two days showed the phytoplankton populations in the surface samples were smaller than the deep samples (Table 18).

Correlation coefficients between phytoplankton biomass, and biological, chemical, physical parameters are listed in Table 20. The total phytoplankton biomass has a significant correlation coefficient with chlorophyll *a* (0.744, at 1% level) and with primary productivity (0.576, at 5% level).

Chlorophyll *a* values range from 0.06 to 11.42μg/liter, chlorophyll *b* values range from 0 to 0.85 and chlorophyll *c* values range from 0.17 to 3.26 (Table 21). The average concentrations of chlorophyll *a* in

Nechelik channel were generally lower than in the lakes.

Primary productivity rates in Nechelik channel and Lake I, Lake II during the summer of 1971 and 1972 may give an indication of the productivity levels of the summer season. These range from 0 to 16.26μg-C/liter-hr (Table 21). The highest average value of primary productivity was observed in Lake I. The primary productivity of Nechelik channel is usually lower than the lakes (Figs. 35, 36, and 37).

Ammonia uptake in Nechelik channel was more important than nitrate. In 1971 the nitrate uptake in the lakes was more important, while in 1972 ammonia was more important. The turnover times for NH_4^+-N were estimated by means of the NH_4^+-N supply rate using the formula[24]:

$$\text{Turnover time (in hours)} = \frac{NH_4^+\text{-N conc. present } (\mu\text{g-atoms/liter})}{NH_4^+\text{-N supply rate } (\mu\text{g-atoms/liter-hr})}$$

The turnover times for NH_4^+-N were less than 24 hours during the summer, with a range between 0.8 to 16 hours. Ammonia turnover times are only valid if no significant change in the ammonia concentration in the water occurs[24]. The ammonia concentrations were appreciably fluctuating during the sampling period, but during the summer they were relatively constant (Figs. 30, 31 and 32). Therefore, the ammonia turnover times were reasonable estimated values.

Nitrogen fixation was not detectable in any of the samples of the summer of 1971 and 1972. Phytoplankton enumerations indicated the reason. Nitrogen-fixing blue-green algae were not found in the two lakes or the channel (Tables 18, 19, and 20).

The salinity of the channel under the ice was high in May (between 35.72 to 41.40 °/₀₀). In summer, it was between 3.456 to 24.66 °/₀₀.

Since the phytoplankton were exposed to a drastic change in salinity in moving down the channel, this may be the major factor causing reduction of phytoplankton population. The salinity of the lakes, which ranged from 1.23 $^{\circ}/_{\circ\circ}$ to 29.64 $^{\circ}/_{\circ\circ}$ (Table 21), is higher than that of the average fresh water lake.[30] The high salinity was probably due to the flooding of the lower delta during the spring and fall of 1970. This brought in coastal water of a higher salinity to the lakes.

Nechelik Channel had relatively high silicate, phosphate and nitrate concentrations, but ammonia concentrations were generally higher in the lakes than in the channel (Fig. 30 and Table 21). It appears that inorganic nutrients are not limiting factors for phytoplankton populations in the channel, but silicate and phosphate may be the limiting factors in the lakes. Inorganic nutrients were negatively correlated with total phytoplankton biomass, but they were not significant (Table 20). It may be too little information was obtained for a valid interpretation.

Incoming solar radiation ranged from 0.067 to 1.143 langley/min. During the summer, light is probably not a limiting factor in the lakes because the water is shallow and clear; however the channel is deep and has very turbid water and possibly not enough light can penetrate for any appreciable primary production to occur.

The level of dissolved oxygen in the lakes and the channel appeared to be near saturation in the summer. This was probably due to the low water temperature and mixing action of the wind (a wind speed as high as 30mph was recorded on 29 July 1971). The dissoved oxygen ranged from 10.5 to 12.5ppm. The readings taken on 5 August 1971 at the bottom of Lake I were exceptions; they were 0.8ppm and 1.8ppm at 1.5m and 2m. The depletion of oxygen may have been caused by oxidation of organic materials by bacteria. During the winter, the dissolved oxygen under the ice was low, between 0.28 to 7.11 ppm. Values for pH of the water ranged from 6.6 to 8.3 and total alkalinity ranged from 0.424 to 3.95meq/1. In general, Lake II had relatively lower pH and alkalinity than Lake I and Nechelik channel.

Lake I and Lake II were more productive than the channel and had a greater variety of phytoplankton species. Inorganic nutrients did not appear to be limiting factors for the growth of phytoplankton populations in the channel. The low productivity in the channel may be caused by the high turbidity and the drastic change in salinity. Silicate and/or phosphate may be the limiting factors in Lake I and Lake II. In order to more fully understand the inorganic nitrogen cycle, primary productivity and phytoplankton fluctuations, a more closely spaced sampling program is necessary and wider range of lake types should be studied.

CONCLUSIONS

The aims of this study were primarily to obtain baseline data on a relatively unknown area, where increased human use requires such background information. A wide variety of environments were encompassed, and clearcut conclusions are not possible. Primary productivity rates are low in the offshore area, but are considerably higher than those found in the open Arctic Ocean, possibly in part as a result of nutrient supply by the Colville River. Inorganic nitrogen compounds brought down by the river are removed rapidly in Simpson Lagoon. Relatively high nitrate uptake rates suggest that there is significant utilization by the offshore phytoplankton of nitrate brought down with the river water. Maximum offshore productivity rates are usually found in the deeper, colder, more saline waters. An especially high rate in deep water outside Pingok Island at the Beaufort Sea station may be related to upwelling in this area, and thus nutrient enrichment.

The offshore area shows strong salinity and thermal stratification, and this results in stratification of phytoplankton populations. There usually exists a clear increase in biomass with depth, but also there is a qualitative change. Surface populations contain a component derived from the fresh water environment, presumably carried down by the river. Studies of the river system indicate that a considerable biomass of phytoplankton probably do get into the river in the further upstream region. The river system itself has phytoplankton populations dominated by diatoms, and most of the organisms found in the river occur in the lakes also. The phytoplankton biomasses in the lakes of the drainage increase as the ocean is approached. A considerable amount of taxonomic information has been obtained during this study, and some interesting new forms described.

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CHAPTER 9

THE NEARSHORE BENTHOS

James J. Crane* and R. Ted Cooney

INTRODUCTION

Although comprehensive benthic invertebrate surveys have been conducted in certain arctic nearshore regions of the world (Greenland, northeastern Canada, Scandinavia), almost no work has been carried on in the nearshore lagoons of Arctic Alaska[1]. In contrast, the Russians have extensively surveyed their Arctic coastal lagoons in Siberia[2].

In Alaska most studies have been carried out south of the Bering Strait[1]. Work originating north of the strait generally has been associated with the Naval Arctic Research Laboratory at Point Barrow, Alaska; consequently, most of these studies are of the Barrow region. One of the most complete surveys of this portion of the Arctic coast was made by MacGinitie from 1948-1950 using dredges, nets, and beachcombing. From the material collected, a fairly complete picture of the species present in the region was obtained. Before 1948, a few ships and expeditions, the *Yukon*, a USCGS schooner under Dall (1880), the *Corwin* under Healy (1884-1885), and the Canadian Arctic Expedition (1913-1918), collected some of the marine fauna in the Barrow region[1]. Taxonomic studies of the local molluscs and polychaetes were reported by MacGinitie[3] and Pettibone[4]. A limited study of mysids was conducted near Point Barrow in 1961[5].

In 1953, the U.S. Coast and Geodetic Survey aboard the *LCM Red* sampled 18 stations of the nearshore Arctic coast from Barter Island to Barrow

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collecting by hand, basket dredges, and otter trawls (Fig. 1). The faunal composition of this material was described as benthic Tanaidacea and Isopoda[6], Cumacea[7], Pelecypoda[8], and Bryozoa[9].

In 1959, a nearshore area from Cape Seppings to Point Hope on the northwest coast of Alaska was examined using dredges and otter trawls (Fig. 2). A species checklist emerged from this investigation[10].

In 1970, the University of Alaska, supported jointly by the National Sea Grant Program and the Environmental Protection Agency began an investigation of the Simpson Lagoon, Colville River Delta area. This study, an extension of the University's original effort, was designed to quantitatively evaluate the status of the nearshore benthic fauna in the lagoons at the mouth of the Colville River and outside the barrier islands. Apparently no investigation of this type has previously been made on the Alaskan Arctic nearshore benthos.

METHODS

General

Most sampling was carried out from the Naval Arctic Research Laboratory's R/V *Natchik*, a fishing boat equipped with an A-frame and two power winches. Some supplementary samples were taken from a skiff (Fig. 3).

Equipment

The shallow waters of the Colville region restrict sampling to gear that is small and light enough to be handled easily from a small boat. Epifauna was collected using a 2m benthic trawl (Fig. 4). The trawl consisted of two steel strap runners held together by three 2m angle-iron sections. A knotless nylon net with 2.8mm mesh was attached to eyelets on the frame forming an opening approximately 2 x 0.5m. The lower and upper edges of the net were tied on the frame to provide a

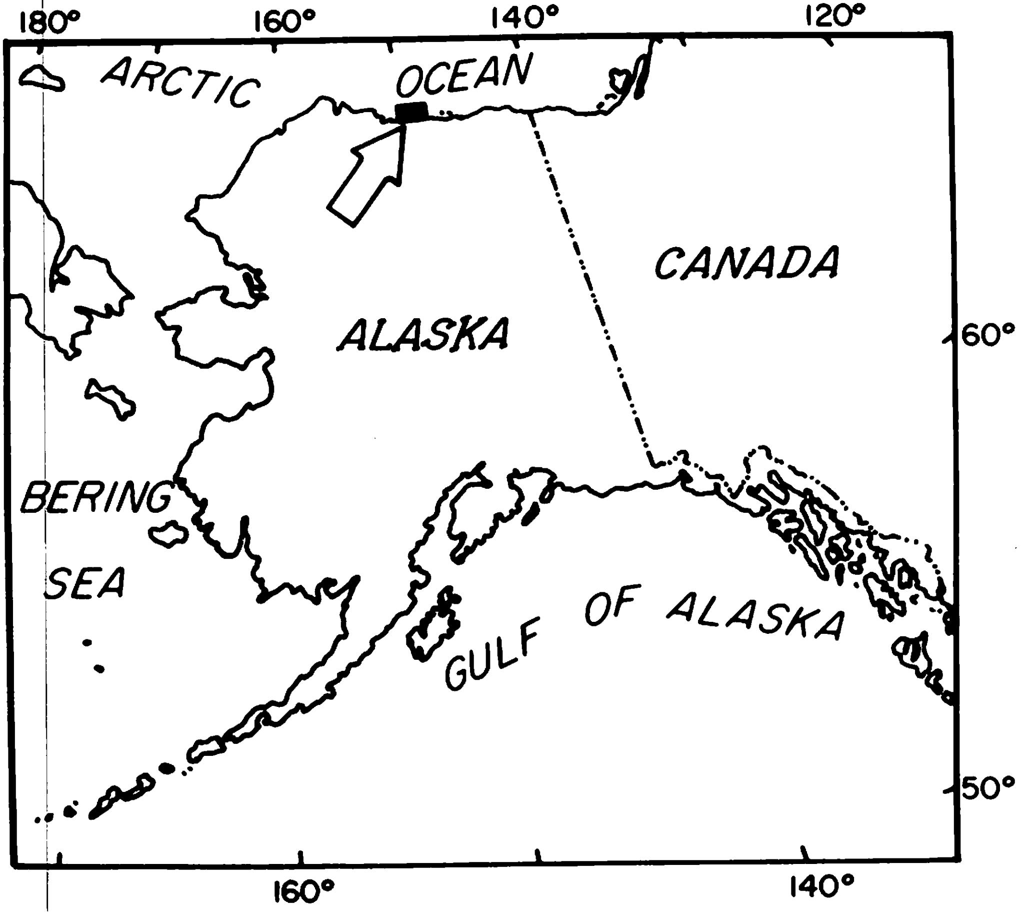

Figure 1. Map of Alaska showing the study area in relation to the Alaskan coast.

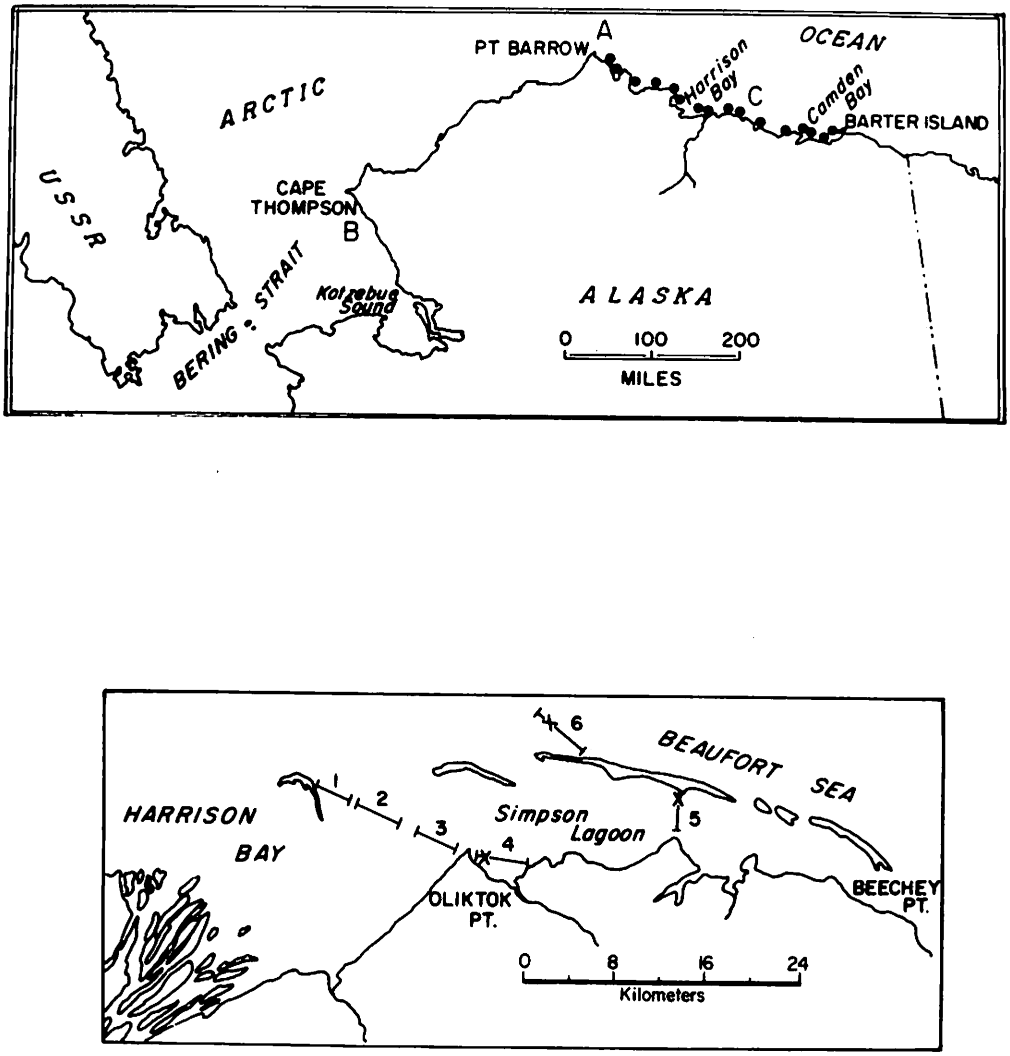

Figure 2. Map of Arctic Alaska showing the locations of previous Arctic Alaskan studies of the benthos.

Upper: Early studies of the arctic coast by MacGinitie (A), Sparks and Pereya (B), and the LCM Red Expedition (C).

Lower: Recent studies of the Colville River Delta estuarine benthos.

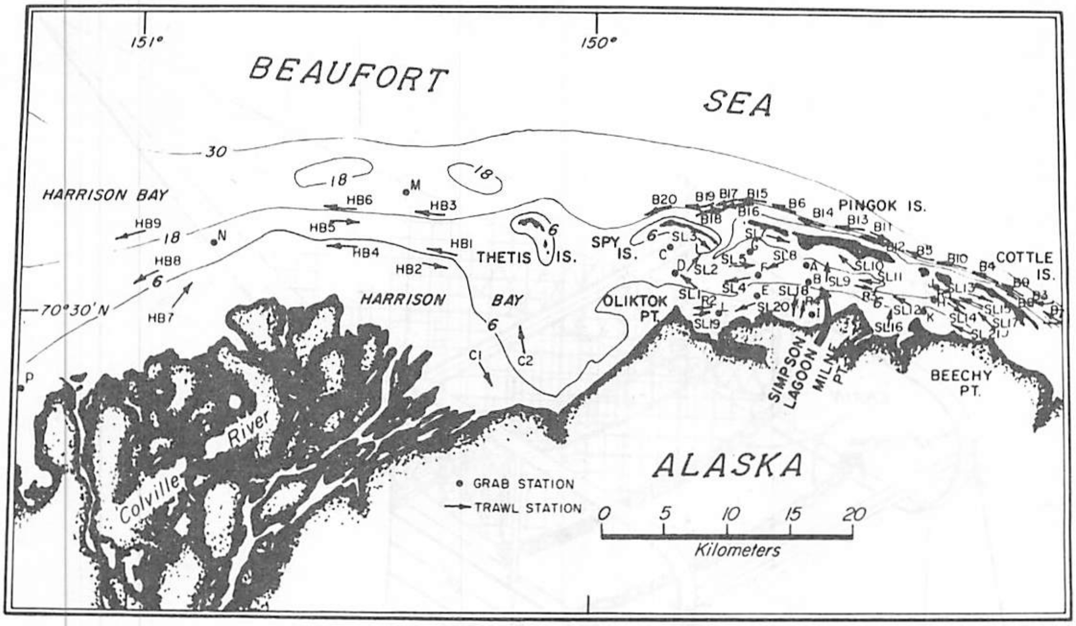

Figure 3. Stations occupied in August 1971. Arrows mark benthic trawl stations, dots indicate grab stations.

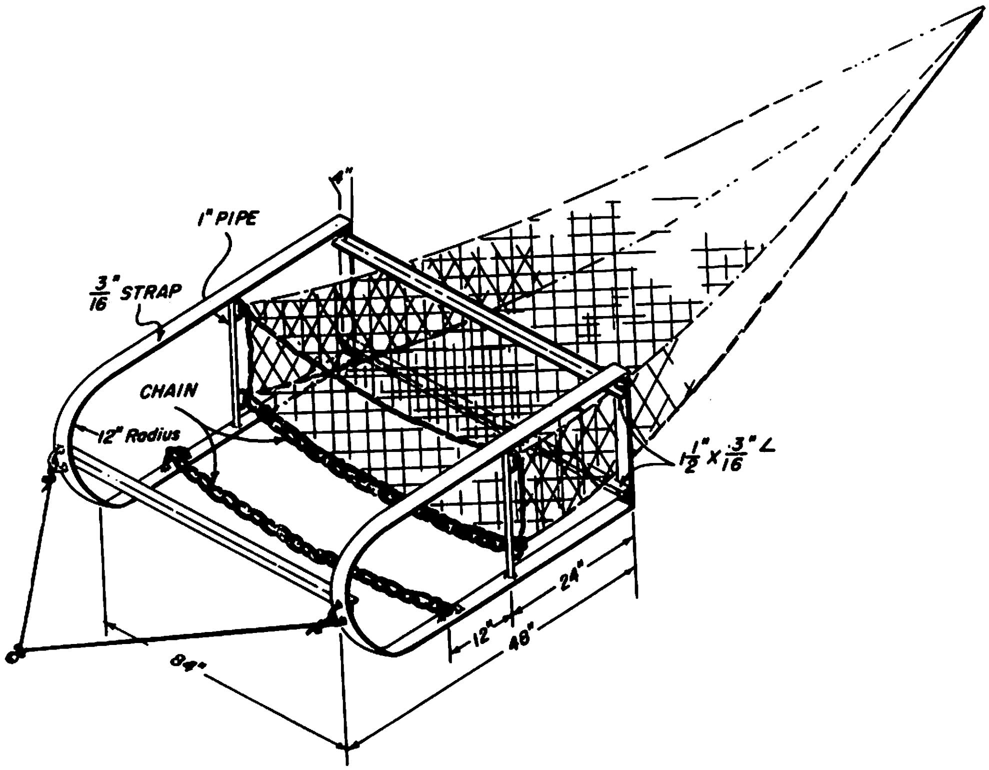

Figure 4. Epibenthic trawl (2m X .5m).

constant opening. A tickler chain was stretched across the runners 15cm ahead of the lower edge of the net and a chain was tied to the footrope. The height of the lower edge of the net above the bottom was adjustable. A steel cable bridle was attached to eyelets on the front of the runners by shackles.

Infauna was collected using a Wildco Ponar bottom grab that sampled an area about .05 m^2. The grab had screen panels to prevent washout and reduce shock waves, and side panels and a lower edge plate that prevented loss of sediment during retrival. A total weight of 28 kg provided good penetration except in coarse sediments.

Field Sampling Procedures

The number of stations occupied was dependent on availability of boat time, the duration of the ice-free season (mid-July to mid-September), and the daily weather. As many stations as permitted by the above limitations were sampled. These included 12 trawl stations in deep Simpson Lagoon (1.8 to 2.8 m), 12 in shallow Simpson Lagoon (<1.8 m), 11 in Harrison Bay, and 18 in the nearshore Beaufort Sea. Three grab stations were occupied in Harrison Bay and 11 in Simpson Lagoon (Fig. 3). Replicate grabs were taken at each station.

A tow of five minutes duration at about 1.5 m/sec covering an area of about 1125 m^2 was found suitable to capture the organisms known to be in the area, yet did not provide more material than could be adequately handled on the boat. The height of the lower edge of the net above the bottom was adjusted until attached hydroids and shallow burrowing molluscs were collected indicating the trawl was actually fishing the bottom.

The starting point of a run was first determined within each area using a grid and random number table. The direction of tow was then chosen by selecting direction cards in a similar manner. When the direction chosen was impossible to follow because of hazards, or the tow would terminate outside the study area, new directions were chosen. When the net was overturned by bottom obstacles or some part of the sampling procedure varied, the haul was repeated.

The ratio of tow-cable length to fishing depth was approximately 10:1. A stopwatch was utilized to time cable out, towing, and cable retrieval. Following a haul, the sample was placed in labelled plastic bags, preserved in 10 percent formalin, and sealed. Later onshore the solutions were changed and the bags were resealed.

A grid and random number table were used to choose the location of grab stations in Simpson Lagoon (Fig. 3). Initially from the *Natchik* the grab was lowered rapidly by a power winch; later in the skiff it was lowered by hand. The material collected was poured into a measuring bucket to determine the volume of sediment taken and then the sample was sieved through a 3mm screen. Silty-clay sediments and the lack of running water made it impractical to use a smaller mesh. Organisms were preserved in 10 percent formalin and labeled. Samples for sediments were taken at most stations.

Laboratory Methods

Organisms from all samples were sorted into taxonomic categories and keyed to species; a list was compiled for each area. Three numerically dominant species were chosen for additional study, the isopods *Mesidotea entomon* and *M. sibirica*, and the mysid *Mysis oculata*.

In trawl samples, only *Mesidotea entomon* and *Mysis oculata* were counted. Samples of *Mysis oculata* were split down to a subsample of 100-200 organisms using a mechanical zooplankton subsampler[11]. Total mysids for each station were estimated by multiplying subsample counts by

2^n where n is equal to the number of half-splits required to produce the final subsample. All organisms in grab samples were counted.

Morphometric measurements consisted of telson length for all *M. entomon* and total length (base of split notch on the middle of the head to the end of the telson) for some representative sizes. The total length (tip of head to end of telson) of all the *M. sibirica* was recorded. For *Mysis oculata*, the total length from the middle of the eyes to the tip of the uropods was measured.

M. entomon were categorized male, female, or juvenile. Males are recognized by an opening in the median pair of papillae on the ventral, posterior segment of the thorax; females have no papillae[12]. Juveniles were designated as those animals with telson lengths less than 9 mm that could not be sexed. Brood pouches and their contents were also recorded for *M. entomon*.

Formalin dry weights of *Mesidotea entomon* and *Mysis oculata* were measured for some individuals in each size class, and for all organisms in grab samples. Specimens were dried in an oven for a minimum of 16 hours at 60°C or until a constant weight was reached.

Carbon analysis of a number of organisms was determined using a Perkin-Elmer Model 240 Elemental Analyzer. Specimens of *M. entomon* and *Mysis oculata* from representative size classes were ground in a mortar, analyzed, and an average carbon content for each species calculated. For comparative purposes seven other local species were also analyzed to determine their average carbon content.

Statistical Methods

Statistical analyses were performed to test hypotheses and relationships between variables, and to provide estimates of variability. For trawl data, a one-way analysis of variance (ANOVA) was used to determine if the abundance of organisms was similar at different depths within areas. In cases where these subareas were similar ($\underline{P}>0.05$), station counts were combined for further comparisons. After the areas to be compared were determined, another analysis of variance for one-way design was utilized to test the significance of abundance differences between areas. A computer program using untransformed and base-ten logarithmic transformed data was used for this analysis[13]. This procedure was also used for grab abundance and biomass data except that only untransformed counts were used and only standard deviations derived. Snedecor[14] explains the use and value of the analysis of variance for testing hypothese and developing confidence limits.

To compare trawl abundance data between areas, geometric means were plotted with confidence limits ($\underline{P}=0.05$) and ranges for each category of organism. Confidence limits were determined by the equation:

$$CL = \bar{x}_{geo} \; x/\div[\text{antilog } (t\sqrt{\frac{MSE}{n}})]$$

Where CL = upper and lower confidence limit
t = Student's t at $\underline{P} = 0.05$
MSE = within cell variance
n = number of observations

When the mean of one area fell within the confidence limits of another, the two were not considered to be different in terms of average abundance.

The model used for all regression relationships was:

$$Y = a + \beta x$$

Where Y = dependent variable
a = intercept on vertical axis by plot line
β = slope of plot line
x = independent variable

Regression equations were compared by a test outlined in Lark[15].

The test compares error variances using the F test and regression coefficients using the t test. When the equations compared were found to be the same, the equations were combined.

Standard deviations were calculated for trawl data, grab data, telson-length versus total length regression equations, dry weight grab data, dry weight versus telson length regression equations, and carbon versus length regression equations.

To determine the distributional patterns of the fauna collected in grabs, a coefficient of dispersion was used[16]. The coefficient is calculated using the equation:

$$CD = \frac{\Sigma\ (x-\bar{x})^2}{\bar{x}\ (n-1)} \qquad (3)$$

Where CD = coefficient of dispersion

x = number of individuals per grab

$\bar{x}$ = mean number of individuals per grab

n = number of grabs

A CD >1 points to aggregations; CD = 1 indicates a random dispersion; and CD <1 points to uniform dispersion of organisms.

Standing Stock Estimates

Standing stock values for the two dominant species collected by trawling were estimated by the equation:

$$S.S. = CF_x \frac{[\Sigma(N \cdot D)]}{T \cdot A} \qquad (4)$$

Where S.S. = standing stock in mgC/m^2

CF_x = conversion factor for dry weight to carbon

N = number of organisms in a size class

D = average formalin dry weight

T = number of hauls taken in an area

A = area in m^2 covered by any single five minute haul

For *M. entomon* N was determined directly. For *Mysis oculata*, the number of animals in each size class was determined from size frequency information and the total number of mysids sampled.

RESULTS

The Nearshore Benthos

Forty-seven species were identified from 53 trawl hauls and 33 grab samples taken in three study areas; 15 species were common to all (Table 1). In the trawl samples, Simpson Lagoon and Harrison Bay had 18 species in common, Simpson Lagoon and the nearshore Beaufort Sea shared 19 species, and Harrison Bay and the nearshore Beaufort Sea were characterized by 18 species in common. In the grab samples, 3 species were common to both Harrison Bay and Simpson Lagoon.

The fauna collected by the trawl was dominated numerically by isopods, amphipods, mysids, and cumaceans; crustaceans were of lesser importance in the grab samples. In the context of this investigation, a species is considered: 1) ubiquitous (U), if it occurs in 67 percent to 100 percent of the samples taken within an area; 2) common (C), if it occurs in 34 percent to 66 percent of the samples; and 3) rare (R), if it occurs in fewer than 34 percent of the samples. The isopod *Mesidotea entomon*, the mysid, *Mysis oculata*, and the amphipod, *Acanthostepheia behringiensis* (?), were ubiquitous in all three areas investigated by trawl. The amphipod *Gammarocanthus loricatus* was ubiquitous within two of the three areas while the amphipods *Pseudalibrotus litoralis* and *Gammarus locustus* and the cumacean *Diastylis* sp. were common in two of the three areas trawled. On the basis of occurrence, *Mesidotea entomon* and *Mysis oculata* were chosen for additional studies of size, biomass, and distribution. Two additional species of *Mesidotea* were examined, since, they sometimes were found in the same haul with *M. entomon*. This consequence led to a closer investigation of these closely related isopods.

Table 1. ORGANISMS COLLECTED AND THEIR OCCURRENCE IN THE STUDY AREAS, 1971.

	TRAWL			GRAB	
Category	Harrison Bay	Beaufort Sea	Simpson Lagoon	Harrison Bay	Simpson Lagoon
Porifera					
Echinoclathria beringensis	-	R	-	-	-
Hydroidea					
Tubularia indivisa	R	R	U	-	R
Filellum serpens?	-	R	-	-	-
Grammaria immersa?	-	R	-	-	-
Nemertea					
Species I	-	R	-	-	-
Species II	-	R	-	-	-
Cerebratulus marginatus	-	-	-	-	R
Polychaeta					
Harmothoe imbricata	R	R	-	-	-
H. extenuata	-	C	R	-	-
Sphaerodorum minutum	-	R	R	-	-
Spio filicornis	R	R	-	C	R
Ampharete vega	-	-	-	-	C
Terebellides stroemi	-	-	-	-	R
Chone duneri	-	-	-	-	R
Bryozoa					
Eucratea loricata	R	R	R	-	-
Priapulida					
Priapulus caudatus	-	R	-	-	C
Mollusca					
Liocyma fluctuosa	R	R	-	-	-
Yoldia arctica	C	R	R	-	R
Axinopsis serricata	R	R	R	-	-
Mya pseudoarenaria	-	R	-	-	-
Cyrtodaria kurriana	R	-	R	-	C
Mytilus edulis	R	-	-	-	-
Cylichna occulta	R	-	R	-	-

Table 1. (continued) ORGANISMS COLLECTED AND THEIR OCCURANCE IN THE STUDY AREAS

Category	TRAWL			GRAB	
	Harrison Bay	Beaufort Sea	Simpson Lagoon	Harrison Bay	Simpson Lagoon
Pycnogonida					
Nymphon grossipes	-	R	R	-	-
Isopoda					
Mesidotea entomon	U	U	U	R	U
M. *sibirica*	R	C	R	-	-
M. *sabini*	R	R	-	R	-
Cumacea					
Diastylis sp.	U	C	C	-	R
Amphipoda					
Acanthostepheia behringiensis?	U	U	U	-	-
Pseudalibrotus litoralis?	C	U	C	-	R
Gammaracanthus loricatus	R	C	C	-	-
Gammarus locustus	R	C	C	-	-
Byblis gaimardii?	R	R	R	-	-
Acanthonotozoma inflatum?	-	R	-	-	-
Hyperia medusarum	-	R	-	-	-
Pseudalibrotus sp.	-	R	-	-	-
Weyprechtia pinguis	-	R	R	-	-
Amphipod A	R	-	R	-	-
Amphipod B	R	R	R	-	-
Amphipod C	-	-	R	-	-
Amphipod D	-	-	-	-	C
Amphipod E	-	-	-	R	U
Mysidacea					
Mysis oculata	U	U	U	-	-
Mysis sp.	-	-	R	-	-
Chordata					
Molgula oregonia	-	R	R	-	R
Tunicate sp. I	-	R	-	-	-
Tunicate sp. II	-	-	R	-	-
Total	22	34	26	4	16

Dominate species occurring in grab samples were the polychaetes *Spio filicornis* and *Ampharete vega*, the pelecypod *Cyrtodaria kurriana*, the priapulid *Priapulus caudatus*, the isopod *M. entomon*, and an amphipod designated amphipod E. Five of the above species were common in at least one of the two areas investigated while *M. entomon* was ubiquitous within one of the two areas.

Abundance

The three major study areas were examined to determine whether they could be divided into subareas on the basis of distribution patterns related to depth. The Beaufort Sea nearshore was treated as a whole since no attempt was made to stratify the sampling outside the barrier islands while Simpson Lagoon and Harrison Bay were subdivided. Four zones were considered in Harrison Bay: 1) deep water (>6.5 m); 2) intermediate water (1.8 to 6.5 m); 3) shallow water (<1.8 m); and 4) a zone close to the river channel where salinities were lower than in the other subareas. Simpson Lagoon was divided into deep water (>1.8 m), and shallow water (<1.8 m).

Catches within subareas for these two locations were compared using an analysis of variance for one-way design (Table 2).

Logarithmically transformed data were used since the standard deviations of untransformed observations appeared strongly correlated with arithmetic means. This relationship was not apparent in the transformed observations (Fig. 5). The null hypothesis of no depth effect was accepted ($\underline{P}>0.05$) for both *Mesidotea entomon* and *Mysis oculata* in Harrison Bay, and the data pooled for further analyses. In Simpson Lagoon, a depth effect was significant ($\underline{P}<0.05$) for juvenile, female, and total *Mesidotea entomon*, yet not statistically a factor ($\underline{P}>0.05$) for males and *Mysis oculata*. These data were not pooled. Following the evaluation of differences within study areas, the four primary

Table 2. THE STATISTICAL SIGNIFICANCE OF SUBAREAS (DEPTHS) ON THE DISTRIBUTION OF *M. ENTOMON* AND *M. OCULATA*.

Location	Source of Variation	
	Sub-areas[a]	
Harrison Bay	F[b]	df
Mesidotea entomon		
Juveniles	NS	3, 7
Males	NS	3, 7
Females	NS	3, 7
Total	NS	3, 7
Mysis oculata	NS	3, 7
Simpson Lagoon		
Mesidotea entomon		
Juveniles	c	1, 22
Males	NS	1, 22
Females	d	1, 22
Total	e	1, 22
Mysis oculata	NS	1, 22

[a] H_o: subarea effect = 0

[b] NS = $P>0.05$

[c] NS = $P<0.01$

[d] NS = $P<0.05$

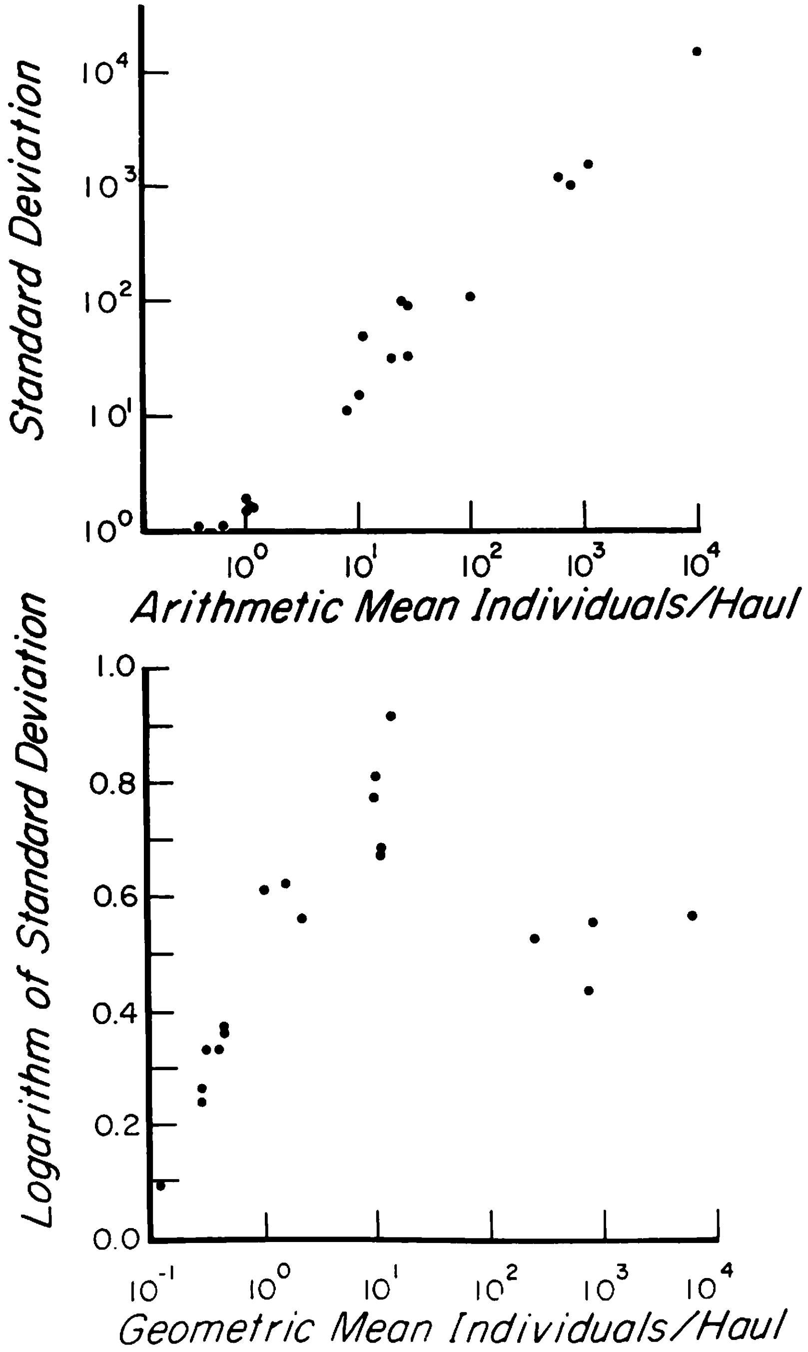

Figure 5. Abundance data showing linear relationship between the standard deviation and the arithmetic mean (upper) and the non-linear relationship after logarithmic conversion (lower).

study units, Harrison Bay, nearshore Beaufort Sea, deep Simpson Lagoon, and shallow Simpson Lagoon were compared. Significant differences ($\underline{P}<0.05$) between areas were apparent for all categories (Table 3).

Geometric means, confidence limits ($\underline{P}=0.05$), and ranges in catch for *Mesidotea* and *Mysis* were plotted by location (Fig. 6). *Mysis* was equally abundant in Harrison Bay and shallow Simpson Lagoon, and also found in similar abundance in deep and shallow Simpson Lagoon (Fig. 7). For juvenile *Mesidotea entomon*, the nearshore Beaufort Sea and deep Simpson Lagoon were similar, for males, deep Simpson Lagoon and shallow Simpson Lagoon were the same, and for females, shallow Simpson Lagoon and Harrison Bay did not differ. The abundance of total *M. entomon* was similar in shallow Simpson Lagoon and the nearshore Beaufort Sea.

Mysis oculata, and *Mesidotea entomon* males and females, were much more abundant outside the barrier island than in either Harrison Bay or Simpson Lagoon. Juvenile *M. entomon* were sampled in equal abundance both in the lagoon and outside of the islands.

Abundance of organisms collected by grab sampling was also determined (Table 4). For deep Simpson Lagoon the average number of total organisms was 313 ± 230 ind/m^2, for shallow Simpson Lagoon 28 ± 29 ind/m^2, and for Harrison Bay 22 ± 33 ind/m^2. The null hypothesis of no area effect ($\underline{P} = 0.05$) was rejected when all three areas were compared, when deep Simpson Lagoon and Harrison Bay were compared, and when deep Simpson Lagoon and shallow Simpson Lagoon were compared. The hypothesis was accepted when shallow Simpson Lagoon and Harrison Bay were tested (Table 5). The pelecypod, *Crytodaria kurriana* with 112 ± 167 ind/m^2, the polychaete *Ampharete vega* with 101 ± 105 ind/m^2, and two species of amphipods (combined) with 51 ± 87 ind/m^2 were the most abundant species in Simpson Lagoon Deep. No infauna was collected in Simpson

Table 3. THE STATISTICAL SIGNIFICANCE OF DIFFERENCES IN CATCH BETWEEN AREAS FOR *MESIDOTEA ENTOMON* AND *MYSIS OCULATA*

Categories	Source of Variation	
	Areas[a]	
	F[b]	df
Mesidotea entomon		
Juveniles	c	3, 49
Males	c	3, 49
Females	c	3, 49
Total	c	3, 49
Mysis oculata	c	3, 49

[a] H_o : Area effect = 0

[b] NS = $P>0.05$

[c] NS = $P<0.01$

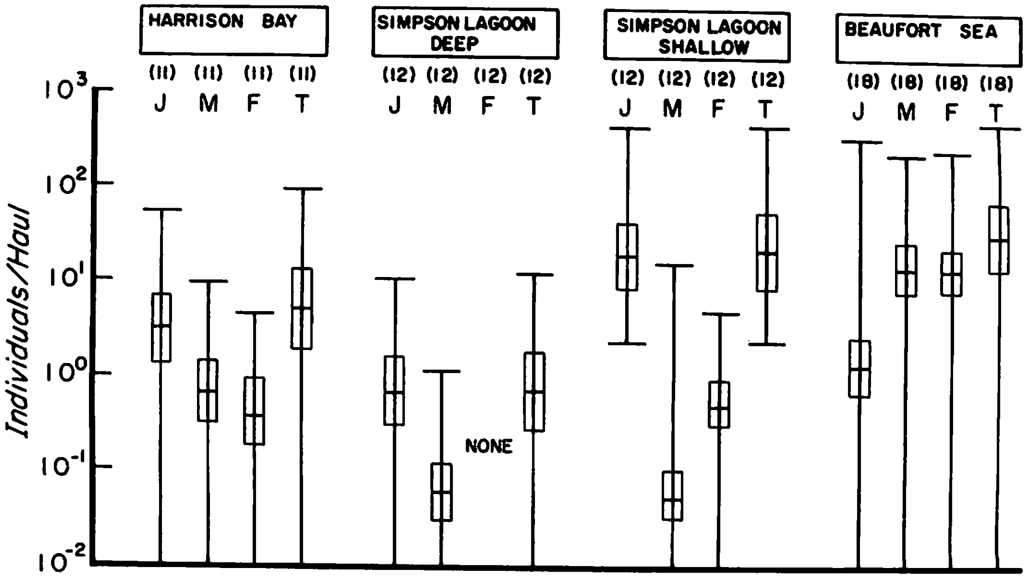

Figure 6. Abundance of juvenile (J), male (M), female (F), and total (T) *Mesidotea entomon entomon* in four study areas during August 1971. Data presented as geometric mean, range, and 95% confidence interval about the mean. Lower limits of range are zero unless otherwise indicated.

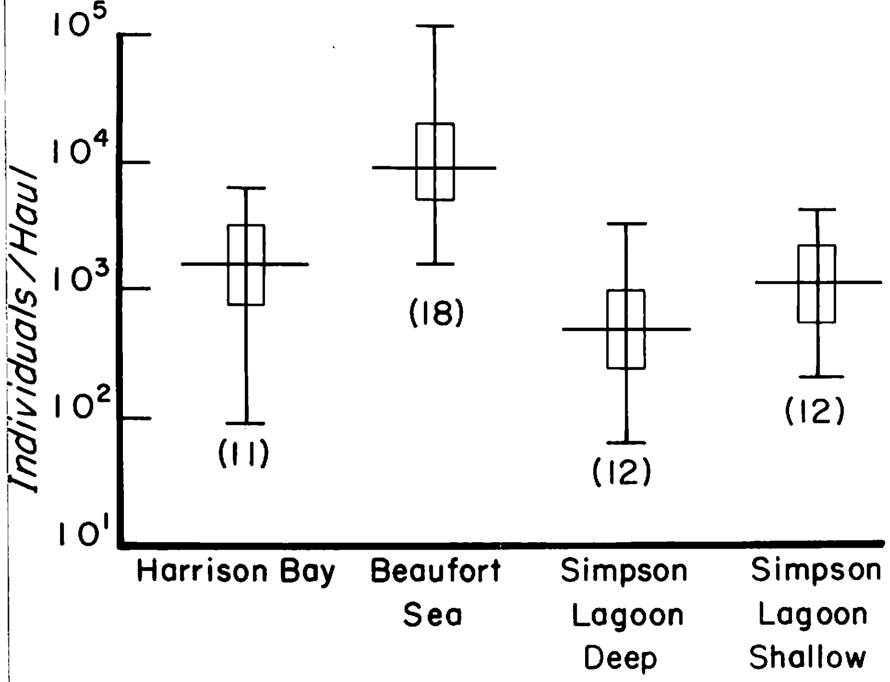

Figure 7. Abundance of *Mysis oculata* in four study areas during August 1971. Data presented as in Figure 6.

Table 4. THE DISTRIBUTION OF ABUNDANCE (N/m^2) AND BIOMASS (DRY WEIGHT g/m^2) OF ORGANISMS TAKEN IN GRAB SAMPLES; AUGUST, 1971.

Species	Harrison Bay		Simpson Lagoon Deep		Simpson Lagoon Shallow	
	N/m^2	g/m^2	N/m^2	g/m^2	N/m^2	g/m^2
Tubularia indivisa			4±17	0.10±.48		
Cerebratulus marginatus			0±4	0.04±.17		
Ampharete-vega			101±105	0.19±.17		
Terebellides stroemii			0±4	0.02±.10		
Spio filicornis	6±14	0.03±.00	1±5	0.01±.00		
Chone duneri			3±17	0.02±.10		
Priapulus caudatus			11±18	0.21±.36		
Cyrtodaria kurriana			112±167	9.61±13.69		
Yoldia arctica			7±20	0.66±2.04		
Mesidotea entomon	2±7	0.09±.28	6±11	0.08±.24	18±19	0.44±.43
Mesidotea sabini	2±7	0.32±.95				
Diastylis sp.			2±9	0.00±.00		
Gammaracanthus loricatus			0±4	0.02±.10		
Pseudalibrotus litoralis			1±5	0.00±.00		
Amphipod X			35±65	0.10±.20		
Amphipod Z	11±33	0.03±.00	16±22	0.04±.00	10±14	0.02±.00
Molgula oregonia			4±8	0.29±.85		
Total	22+33	0.48+.94	313+230	11.74+13.58	28+29	0.46+.44

Table 5. THE STATISTICAL SIGNIFICANCE OF AREAS ON THE DISTRIBUTION OF ABUNDANCE AND BIOMASS OF ORGANISMS TAKEN IN GRAB SAMPLING.

Location	Source of Variation	
	Subareas[a]	
	F[b]	df
Harrison Bay, Shallow Simpson Lagoon, Deep Simpson Lagoon		
Total organisms	c	2, 38
Total biomass		
Harrison Bay, Shallow Simpson Lagoon		
Total organisms	NS	17, 1
Total biomass	NS	17, 1
Harrison Bay, Deep Simpson Lagoon		
Total organisms	c	1, 29
Total biomass		1, 29
Deep Simpson Lagoon, Shallow Simpson Lagoon		
Total organisms	c	1, 30
Total biomass	c	1, 30

[a] H_o: Area effect = 0

[b] NS = $\underline{P}>0.05$

[c] NS = $\underline{P}<0.01$

Lagoon Shallow and only one organism, a tube polychaete *Spio filicorms*, was collected in Harrison Bay.

A distributional index, the coefficient of dispersion, was used to investigate whether organisms collected by grab were aggregated (Fig. 8). A coefficient greater than unity points to aggregation of the organisms. Infaunal species exhibited this characteristic while the epifaunal organisms appeared to be more dispersed.

Size Classes

Length-frequency plots were made for a collection of *M. entomon* taken in August, 1970, in Harrison Bay, Simpson Lagoon, and nearshore Beaufort Sea (Fig. 9). A similar plot was drawn for the *M. entomon* sampled in the same areas in August, 1971 (Fig. 10). The 1970 juveniles are not comparable with the 1971 juveniles because a larger mesh otter trawl was used in the first survey. The Simpson Lagoon information is limited by the small numbers of isopods collected in 1970. Harrison Bay and Beaufort Sea males and females seem to exhibit similar size distributions both years. Males in all areas reach much longer lengths than the females.

Length-frequency distributions were plotted for all *M. sibirica* sampled in 1971 (Fig. 11) and *Mysis oculata* (Fig. 12). Two large female *M. sibirica* (58-60 mm total length) were collected as well as 40-50 smaller size (16 mm). An intermediate size class appears not to be in the area or at least was not collected.

All three species appear to have three size classes or modes into which most of the organisms fall (Fig. 13). For *M. entomon*, the first mode (0-2 mm) represents recently released juveniles, the second, the one-year-olds, and the third (very low), the two-year-olds. Three size classes are vaguely seen in the distribution of *M. sibirica* although

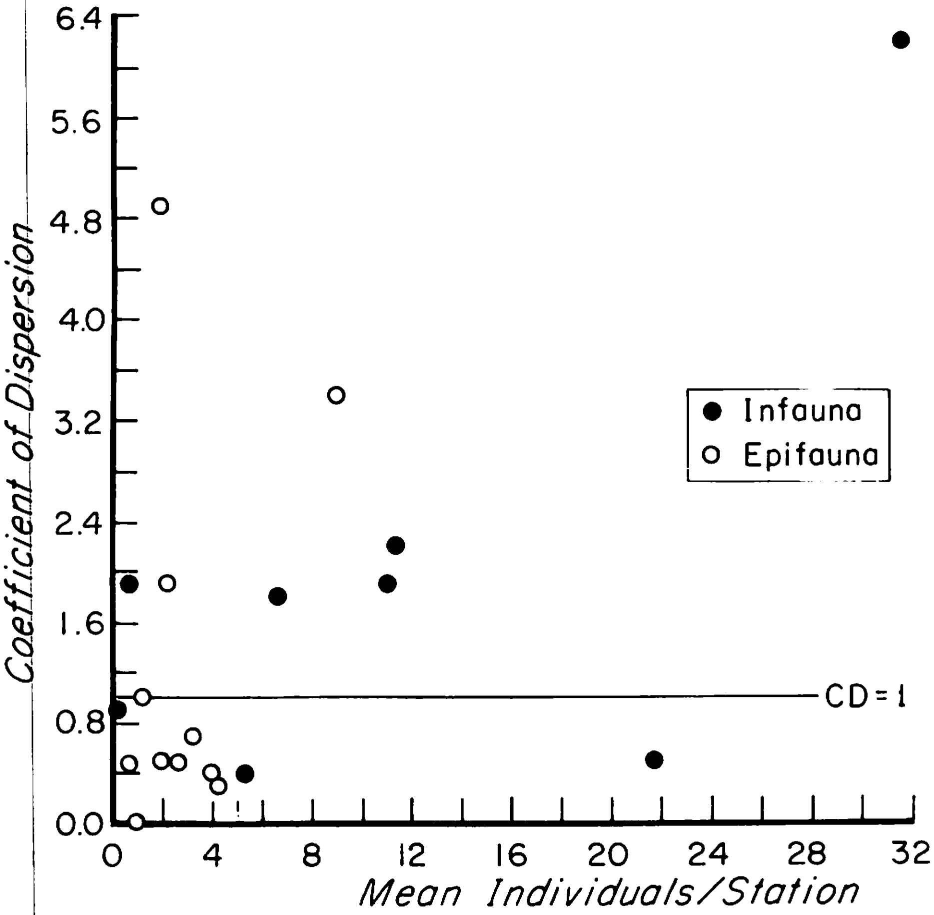

Figure 8. Relationship between the coefficient of dispersion and the mean number of individuals/haul for infauna (●) and epifauna (o) from grab samples.

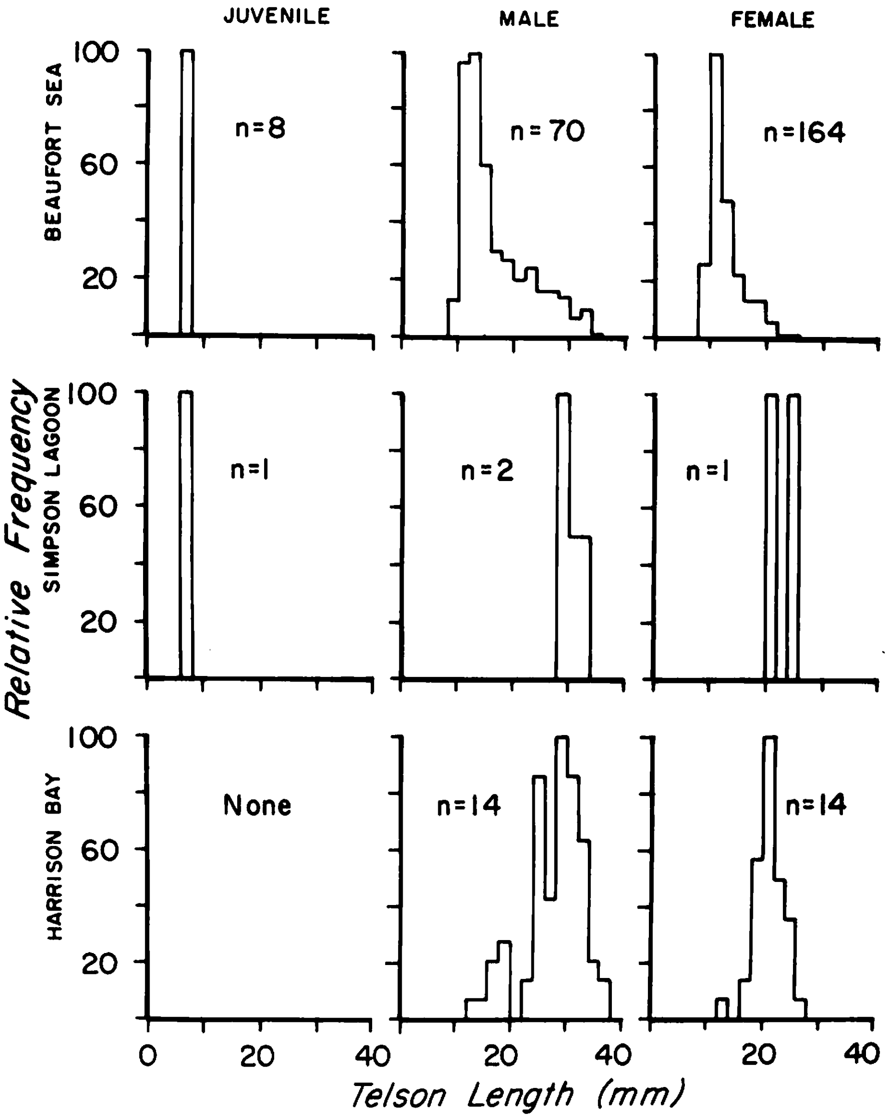

Figure 9. Distribution of size classes for *M. entomon* categories in the study areas taken August 1970; n is the number of organisms in the size class with the greatest number of organisms.

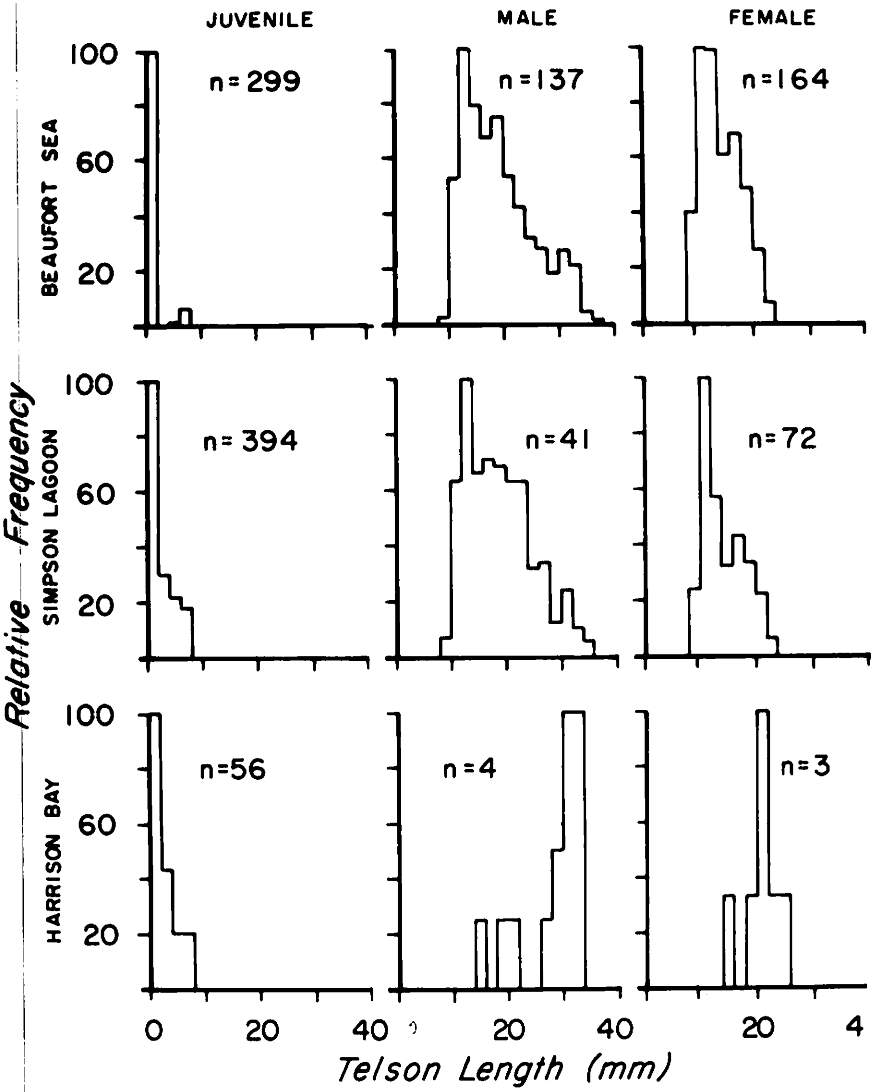

Figure 10. Distribution of size classes for *M. entomon* categories in the study areas taken August 1971; n is the number of organisms in the size class with the greatest number of organisms.

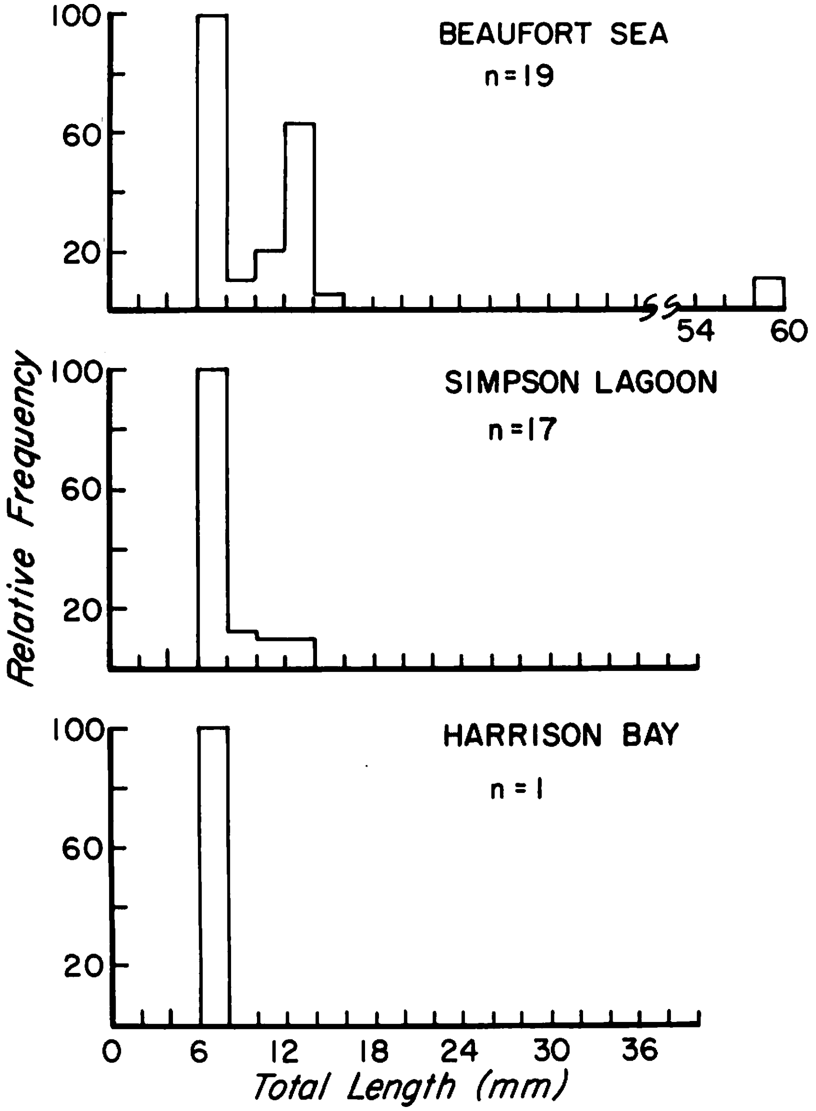

Figure 11. Distribution of *Mesidotea sibirica* size classes in study areas taken in August 1971.

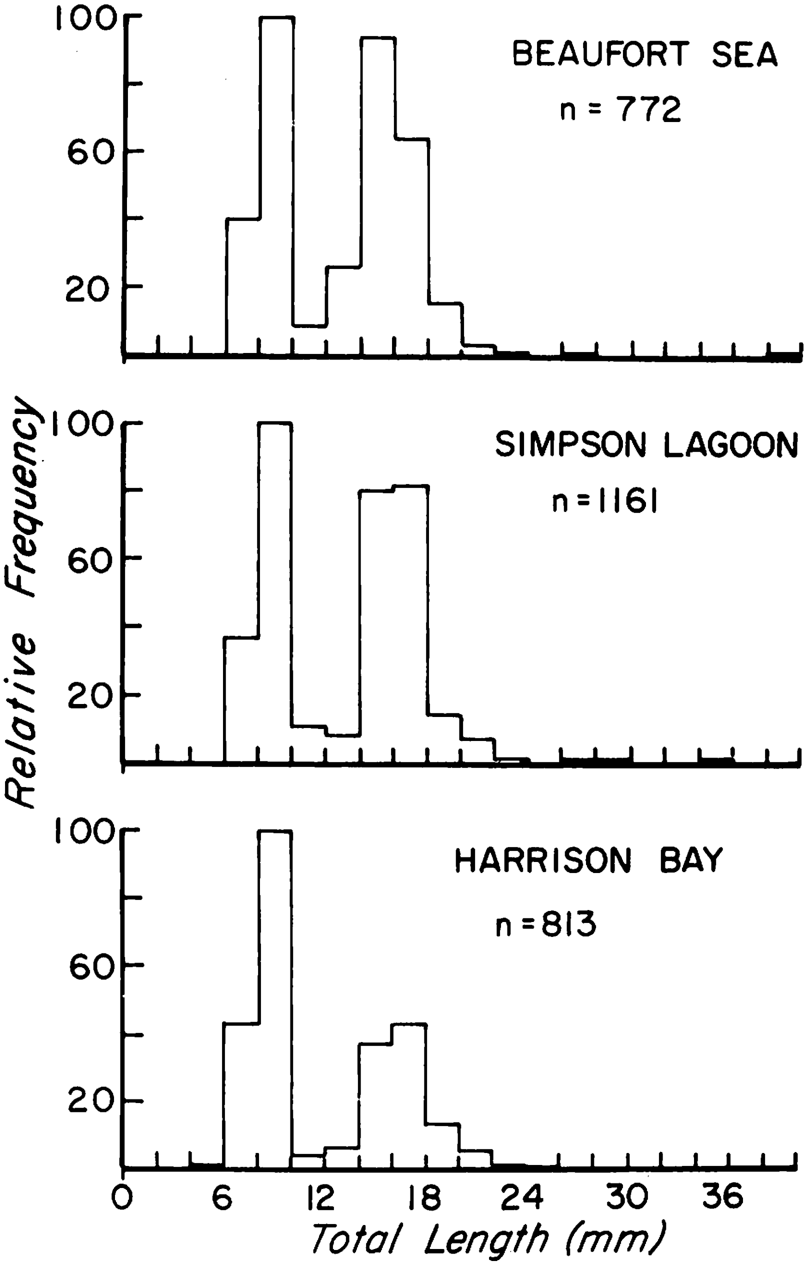

Figure 12. Distribution of *Mysis oculata* size classes in study areas taken in August 1971.

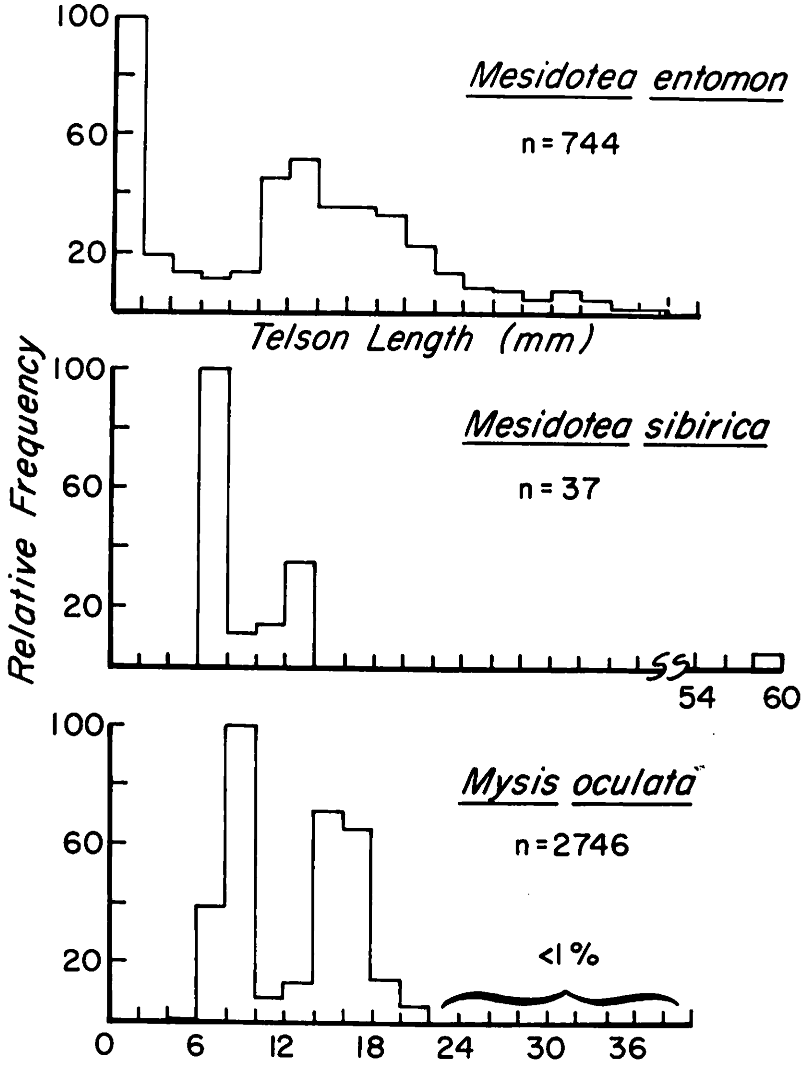

Figure 13. Distribution of *Mesidotea entomon*, *Mesidotea sibirica*, and *Mysis oculata* size classes in the Colville study area.

some sizes may be missing which could change the position of the modes. *Mysis oculata* is characterized by animals of three distinct sizes with the two-year-olds again in very small numbers.

In *M. entomon* and *M. sibirica* the very large "two-year-olds" often had brood pouches with eggs, no eggs, or small isopods which form the first size class when released.

Telson length was measured for all *M. entomon* and plotted against the total length of selected specimens. The equation for the regression of total length on telson length is:

$$Y = 2.602 + 2.532x \qquad (5)$$

Where Y = total length in millimeters

x = telson length in millimeters

Using this relationship plotted in Figure 14, the total lengths of individuals whose telsons have been measured can be determined. Telson length was considered the most representative measure because the telson apparently does not change its length with preservation. Of the three species of *Mesidotea* found, two are similar as adults, but easily distinguished when very young. The paper by Menzies and Mohr[6] describes the differences between the juveniles of all three species, but does not separate the adults adequately. Gurjanova[17] has written a key to arctic isopod adults but this work is in German and the use of terms is confusing. To identify these isopods, a key based on Gurjanova and the observations noted here is proposed (Table 6). The ratio of the telson length to total length is used as an identifying characteristic in this key.

Biomass

Formalin dry weights were measured for *Mesidotea entomon* juveniles, males, females, and for an aggregate of *Mysis oculata*. These weights

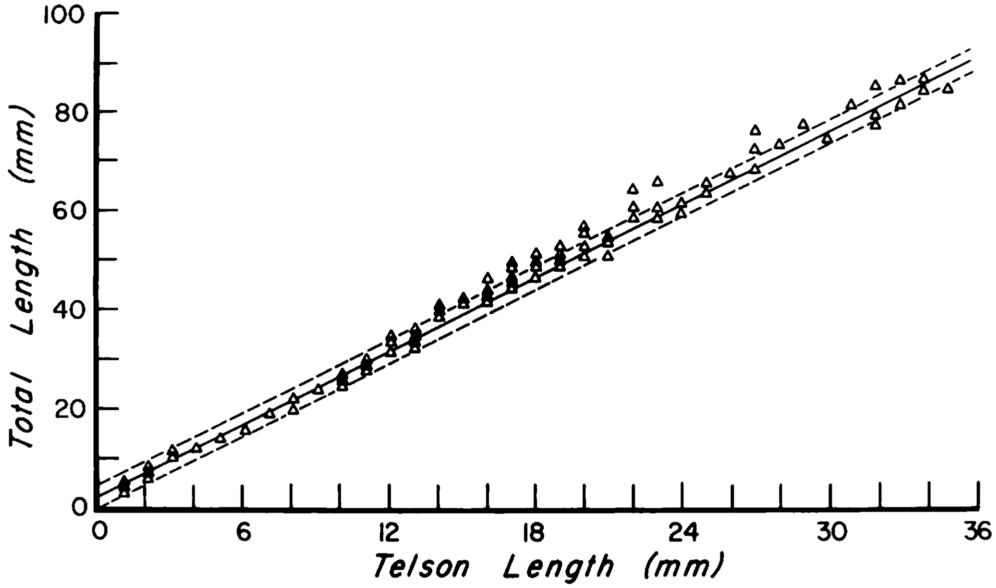

Figure 14. Relationship between total length and telson length for *Mesidotea entomon entomon*. Regression line and one standard deviation about the line for juveniles, sub-adults, females, and males plotted.

Table 6. KEY TO THE ISOPOD GENUS *MESIDOTEA* IN THE NEAR-SHORE COLVILLE REGION, BEAUFORT SEA

1(2) Eyes lacking . . . . *Mesidotea sabini sabini*

2(1) Eyes present 3

3(6) Telson short and broad, flagellum has less than 12 segments 4

4(5) Epimere 1 or 2 has hairs on margin, telson: total length = approx. (.27) . . . *M. sibirica* adult

5(4) Epimeres bare and smooth, telson: total length = approx. (.30+) . . *M. sibirica* juvenile

6(3) Telson long and thin, flagellum has 12 or more segments 7

7(8) Telson: total length = approx. (.35 to .40) . . . . *M. entomon entomon* adult

8(7) Telson: total length = approx. (.25 to .32) . . . . *M. entomon entomon* juvenile

---

were then regressed on measures of length for purposes of converting size-class information to estimates of dry weight:

$\text{Log } Y_J = (-1.9867 + 0.3372\ X)-2$; Juveniles . . . . . . (E)

$\text{Log } Y_F = (0.1132 + 0.0697\ X)-2$; Females . . . . (F)

$\text{Log } Y_M = (0.339 + 0.055\ X)-2$; Males . . . . (G)

Where Y = predicted formalin dry weight in milligrams for size class X (telson length)

the integer (2) corrects for coding

Using Lark's test,[15] the regressions were found to differ significantly by category (Fig. 15).

Two equations are necessary to describe the relationship between formalin dry weight and length for *Mysis oculata*:

$\text{Log } Y_I = (-2.3310 + 0.2012X)-3$ . . . .(H)

$\text{Log } Y_{II} = (0.1946 + 0.0371)-3$ . . . .(I)

Where Y = predicted weight for a mysid in size class X

H = mysids of total length from 7 to 15mm

I = total lengths of 15 to 39mm (Fig. 16)

Mesidotea entomon and *Mysis oculata* were further analyzed for carbon content and equations calculated relating the organisms size and carbon content (Fig. 17):

$Y_{mo} = 50.92 - 0.039\ X$; *Mysis oculata* . . . .(J)

$Y_{me} = 31.34 + 0.0295\ X$; *Mesidotea entomon* . . . .(K)

Where Y = percentage carbon per unit dry weight

X = telson length (isopod) or total length (mysid) in millimeters

This data was also used to convert dry weight to carbon for standing stock estimates.

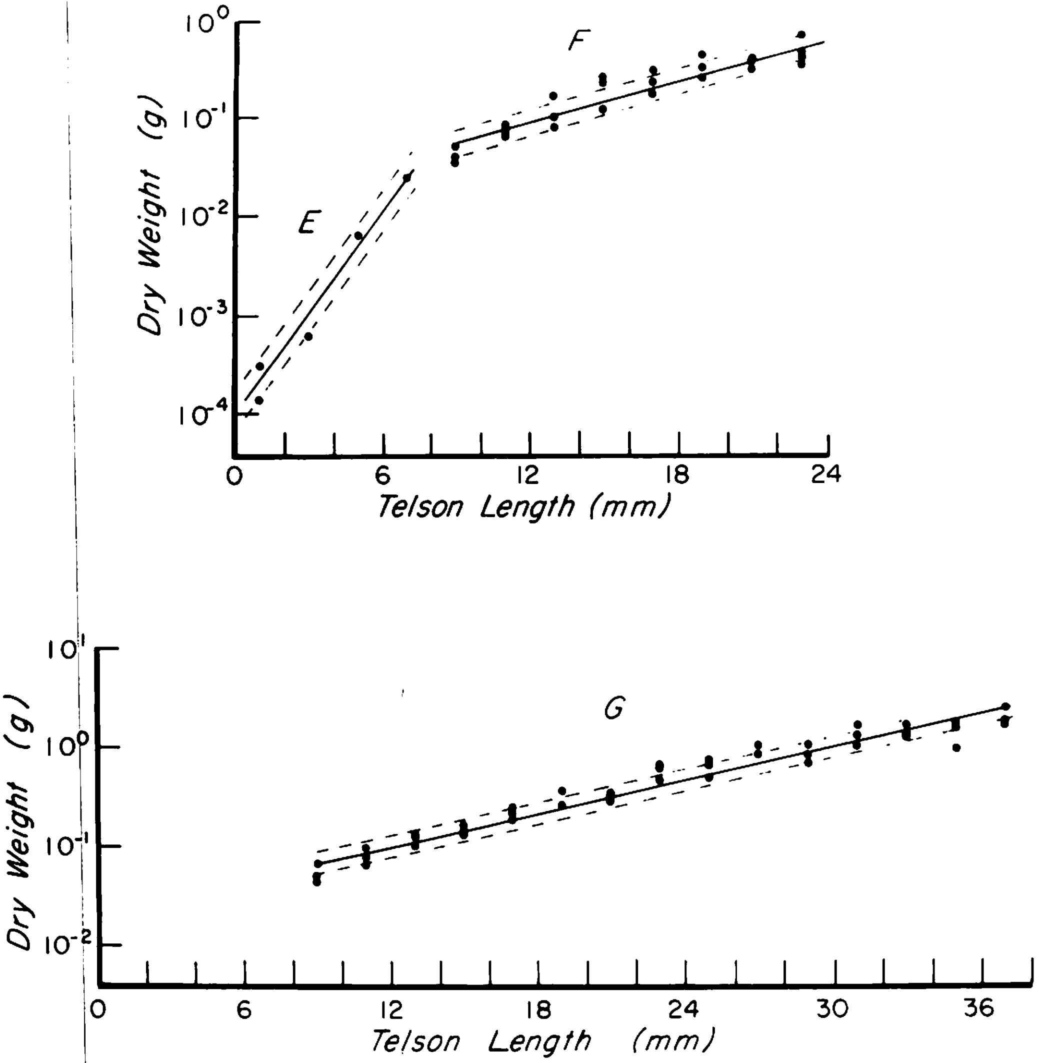

Figure 15. Relationship between dry weight and telson length for *Mesidotea entomon entomon* males (G), females (F) and juveniles (E). Regression line and one standard deviation about the line plotted.

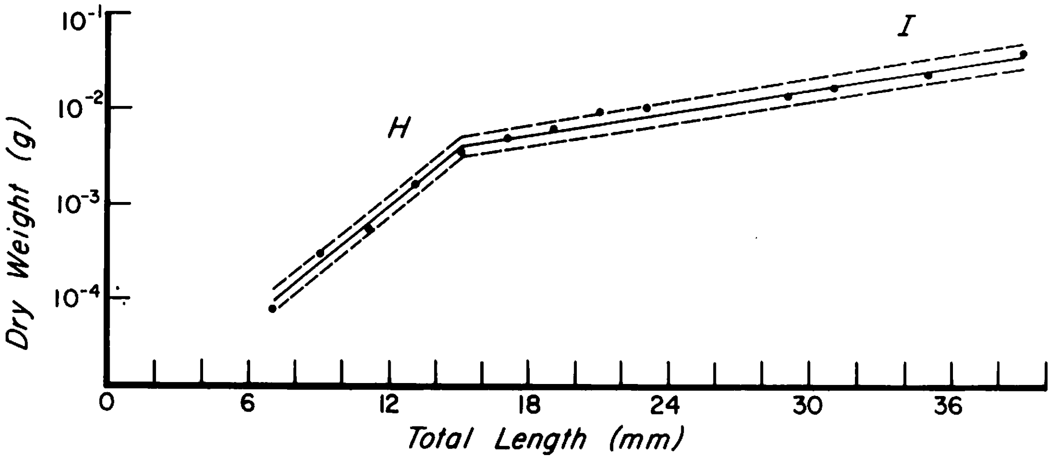

Figure 16. Relationship between dry weight and total length for *Mysis oculata*. Regression line and one standard deviation about the line plotted.

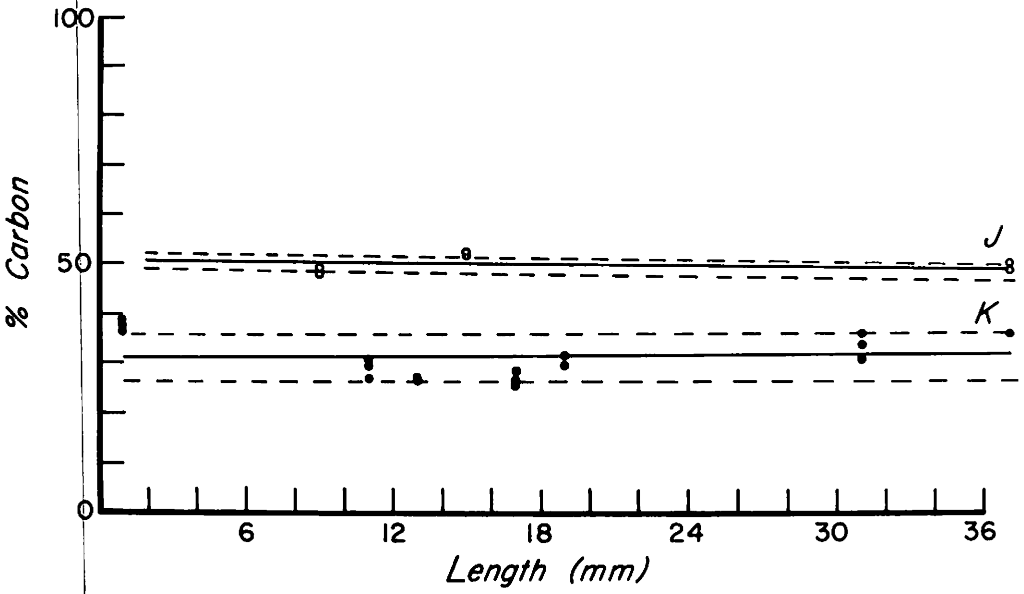

Figure 17. Carbon content as a percentage of the dry weight in relation to total length for *Mysis oculata* (J) and to telson length for *Mesidotea entomon entomon* (K).

Selected other common species were analyzed for carbon (Table 7). Carbon content of these organisms ranged from a low of about 16 percent for juvenile *M. sibirica* and *Acanthostepheia* sp. (amphipod) to about 51 percent for *Mysis oculata* and 31 percent for *M. entomon*; the content for other species fell within this range (Table 7).

Estimates of standing stock carbon were made for male, female and juvenile *Mesidotea entomon*, and *Mysis oculata* using data from trawl samples (Table 8). The highest mysid standing stock, 28.26 mgC/m^2, occurred in the nearshore Beaufort Sea while the stock in Harrison Bay and Simpson Lagoon was much lower. For most *Mesidotea entomon*, the nearshore Beaufort Sea also exhibited the highest stock; juveniles were the sole exception. The biomass of all *M. entomon* outside the barrier islands averaged 9.24 mgC/m^2. The standing stock of *Mysis oculata* was consistently higher than that of *M. entomon* in all areas. In Harrison Bay, the total mysid stock was approximately six times greater than that of isopods, while in the nearshore Beaufort Sea the mysids were three times greater. In Simpson Lagoon the mysid stock exceeded the isopods by an order of magnitude.

Dry weights were also determined for all organisms collected in the grab samples (Table 4). For deep Simpson Lagoon the average biomass was 11.74 ± 13.58 g/m^2 (dry weight); for shallow Simpson Lagoon 0.46 ± 0.44 g/m^2; and for Harrison Bay 0.48 ± 0.94 g/m^2. The total organism biomass in deep Simpson Lagoon differed significantly ($\underline{P}<0.05$) from that in the other two areas; shallow Simpson Lagoon and Harrison Bay were similar in biomass. The pelecypod *Cyrtodaria kurriana* with its shell accounted for the largest average biomass (9.61 ± 13.69 g/m^2) in deep Simpson Lagoon. This organism was not collected in either of the other areas. Another pelecypod, *Yoldia arctica* and a tunicate, *Molgula oregonia* account for a large portion of the weight of the infauna of deep Simpson Lagoon at 0.66 ± 2.04 g/m^2 and 0.29 ± 0.85

Table 7. AVERAGE CARBON CONTENT OF SOME COMMON SPECIES COLLECTED IN THE COLVILLE REGION. (per cent)

Species	Carbon Content
Mysis oculata	50.12
Ampharete vega	46.54
Gammarus locustus	46.05
Gammaracanthus loricatus	46.05
Cyrtodaria kurriana	43.98
Yoldia arctica	37.52
Pseudalibrotus litoralis	37.39
Mesidotea entomon	31.85
Mesidotea sibirica (juveniles)	17.89
Acanthostepheia behringiensis	16.46

Table 8. ESTIMATED STANDING STOCK OF M. ENTOMON AND MYSIS OCULATA

(mg C/m^2)

	Harrison Bay	Beaufort Sea	Simpson Lagoon	Deep Simpson Lagoon	Shallow Simpson Lagoon
Mysis oculata	3.36	28.26	1.99	--	--
M. entomon					
Juveniles	.01	.01	.02	.001	.07
Males	.52	6.61	.07	.04	.20
Females	.02	2.60	.02	0	.05
Total	.58	9.24	.18	.04	.31

g/m^2 respectively. No infaunal animals occurred in shallow Simpson Lagoon and only one infaunal species, a polychaete *Spio filicornia*, was found in samples from Harrison Bay. In both of these areas, the epifaunal amphipods and isopods made up the bulk of the meager biomass.

CONCLUSIONS

Introduction

The northernmost arctic coast of the United States is characterized by numerous shallow lagoons and bays where ice is present at least 11 months of the year, sometimes all year round[18]. Due to the shallow nature of these estuaries, the shorefast ice in many areas is frozen into the sediments for much of the year. The bottom water remaining in isolated deeper areas is high in salinity, sometimes "ultrasaline," is generally below 0°C., and may be deficient in oxygen[19]. As the ice breaks up, the bottoms of the estuaries near shore are ground and scoured by the moving flows.

In the months of open water, melting sea ice and runoff from adjacent streams and rivers produces turbid, low salinity water near the coast subject to occasional drastic wind influenced changes in sea level[20].

The Nearshore Benthos

The shallow nearshore environment would seem to be unfit for any kind of biota; indeed, the beaches surrounding the Colville estuarine complex bear out this contention as they are seemingly barren of macroscopic life. On the other hand, the deeper waters (> 2 m) of Simpson Lagoon, Harrison Bay, and especially the nearshore Beaufort Sea support a biota in which a number of species are present in some abundance. Organisms living in the region must be able to cope with low temperatures, salinities varying over a wide range, being frozen in and scoured by ice, and perhaps subjected to conditions of low oxygen.

Crustaceans, molluscs, and polychaetes characterize the fauna of the area with a few species responsible for most of the abundance and biomass. This is to be expected since the population encountered is representative of the biota of most arctic environments[21,22,23]. Physical factors here are probably more important in determining the composition of the biota than biological interactions such as competition and predation[24,25]. In nearshore Antarctic studies[26] it was demonstrated that biological competition and predation is almost non-existent in the ice scour zone. Similarly, in arctic environments the number of predators is few, biological competition is at a minimum[21] and species diversity in terms of an absolute number of species is low[23].

In this general context, pressures from the physical environment appear to mediate the species composition, abundance, and biomass of the nearshore community of the Colville River estuary. The physical harshness of this nearshore region is evidently responsible for a low number of predator-prey relationships. Only two epifaunal predators occurred in samples, the sea spider *Nymphon grossipes*[27], and *Mesidotea entomon*[28], and only one of them, the former, is partially carnivorous. However, *Nymphon grossipes* is rare in the region and *M. entomon* is usually classified as a scavenger. Two infaunal predators were present, the priapulid *Priapulus caridatus* and one specimen of a nemertean, *Cerebratulus marginatus*[27].

Harsh physical conditions may also be responsible for the low species diversity observed in samples; only 47 species were collected using a trawl and grab. In order to compare the number of species observed in the Simpson Lagoon-Harrison Bay area with Sanders[29], we chose data from 6 randomly selected grab samples (each 0.05 m^2). A total of 17 species occurred in our combined sample, while a second composite of six additional grabs contained no organisms. In comparison with values published by Sanders for other marine and estuarine environment where between 0.3 and 0.8 m^2 of sea bed were examined, this arctic estuary exhibits very few species (Table 9).

Environmental Interactions

Three factors--ice, salinity variations, and perhaps concentrations of dissolved oxygen--affect the organisms in the region. Simpson Lagoon would appear to be the most physically stressed area because, its shallow depths are subject to severe current fluctuations in the ice-free season. In the winter when the water in Simpson Lagoon is isolated from both Harrison Bay and the Beaufort Sea by bottom fast ice, the pools of high salinity water (up to 68 °/₀₀) that form beneath the ice undoubtedly have a detrimental effect on the fauna. Since the average depth of this lagoon is but two meters, only a small portion, a narrow trough running the length of the lagoon, would not be frozen to the bottom. It is also quite probable that dissolved oxygen values drop to very low levels in these isolated pockets; areas of this type (very low dissolved O_2 values) have been found in the nearby Colville Delta[30].

Since *Mesidotea entomon* is known to be tolerant of salinities ranging from very dilute (even freshwater) to normal salinity[31], it is easy to understand why this species occurs in Simpson Lagoon during the ice-free season. However, since the literature on *M. entomon* places its upper range of salinity tolerance at "normal" oceanic seawater[32], we would not expect the organism to survive in ultra-saline pockets of water under the ice. We suspect that *Mesodotea entomon* migrates outside the barrier islands or into deeper Harrison Bay where "more" oceanic salinities are found

Table 9. A COMPARISON OF THE NUMBER OF SPECIES OCCURRING FOR VARIOUS MARINE AND ESTUARINE ENVIRONMENTS IN 0.3-0.8 m^2 OF SEA-BED

Type	No. species/station	Author
Arctic estuary	0-17	This Study
Boreal estuary	10-30	Sanders, 1968
Tropical estuary	21-26	Sanders, 1968
Stress shallow tropical marine	30-33	"
Boreal shallow water	16-21	"
Tropical shallow marine	39-11	"
Outer continental shelf	51-75	"
Deep sea (slope)	47-96	"

during the period of ice cover. *Mysis oculata* also exhibits a salinity tolerance range from very dilute water to oceanic salinities, and so this species probably migrates offshore as the ice forms. Thus, in areas where ice extends into the bottom, the mobile organisms either migrate to deeper oceanic water or perish. Holmquist has noted that individuals of the genus *Mysis* cannot survive freezing[5]. We believe it is unlikely that *Mesidotea* could survive for extended periods in the ice. In the Antarctic, epifaunal species were found to migrate from the zone of ice scour until open water occurred[26]. A third stress, that of low oxygen values, perhaps even anoxic conditions in the isolated deeper pockets in Simpson Lagoon, would also be an incentive promoting seasonal migration.

The infauna constitute another situation since they are not highly mobile. These organisms either survive high salinity, possibly near anoxic conditions, and being frozen into the ice, or die and are replaced by recruitment from deeper water. Certain molluscs are known to survive in ice without ill effects[6]. In addition living *Cyrtodaria kurriana, Yoldia arctica*, and tube polychaetes were found living in the shallow water just under the ice. Similar fauna were found existing in anoxic conditions under one meter of ice in Safety Lagoon near Nome, Alaska[18]. It may be reasonable to suppose then that at least some molluscs and tube dwelling polychaetes can survive the stressed environment under and in the ice.

It is apparent that in the very shallow parts of the lagoon, ice scouring prevents organisms from establishing populations. No infaunal species were found in either Simpson Lagoon or Harrison Bay in the grab samples taken at depths of less than two meters. Only mobile epifaunal species occurred in these shallow depths. This pattern may also be influenced by the quality of the substrate since sand and gravel predominated in the shallower depths while sandy mud (more suitable for burrowing) was found in the deeper zones. However, it is most probable that the shallows are rarely populated by infauna or non-motile epifauna because of the effects of bottom-fast ice over most of the year and scouring during breakup. Even hydroids which attach to gravel were absent.

Distribution Patterns

Three species of *Mesidotea*, *M. entomon*, *M. sibirica*, and *M. sabini* were found together at at least two stations, and *M. entomon* and *M. sibirica* occurred in common at twelve stations. According to Dunbar[21], arctic areas have a small number of niches, so it seems curious that three species of the genus *Mesidotea*, all thought to be scavengers or detritus feeders, would be found in the same environment. Gurjanova[17], reports that *M. sabini* is a deep water form. However, this species was found in Harrison Bay and Simpson Lagoon in less than three meters of water. The *LCM Red* expedition[10] also found *M. sabini* in Harrison Bay. *M. sibirica*, considered a more oceanic form[33], was not very abundant although they were more numerous than *M. sabini*, and because of their low numbers, they probably do not enter into direct compition with the *M. entomon*. Simpson Lagoon and the river delta area also have a great deal of peat and organic detritus deposited in them. Such high concentrations of detritus could support a large variety of omnivorous scavengers[28].

The distribution of organisms within the areas examined was very patchy. Trawl catch values ranged from 0 at one station to hundreds at another for isopods, and from approximately 1,600 to 120,000 individual mysids. Grab catches were variable from station to station indicating the patchy nature of the benthos. An index of dispersion has shown the infauna to be more patchy than the epifauna.

Abundance and biomass data determined from trawling for *Mysis oculata*, *M. entomon* (males, females, total excluding juveniles), and amphipods show that both are many times more numerous in the zone outside the barrier islands (>4.8 m) than in either Harrison Bay or Simpson Lagoon. Catch records from the Colville region for the summer of 1970, although not quantitative due to varying times of tows and the use of a wide-mesh otter trawl, indicate that only a few *M. entomon* were collected within Simpson Lagoon while hundreds were found just outside of the barrier islands[30]. This information indicates that at least for adult *M. entomon*, our results are supported by the data from the previous summer. Due to their smaller size, *Mysis oculata* were not compared since the 1970 trawl mesh was too large.

Although MacGinitie[1] suggested that *M. entomon* preferred very dilute salinity water, we found the greatest numbers of this species in the higher salinity waters outside of the barrier islands. The only *M. entomon* found in the lagoon in any abundance were the recently released juveniles which occurred in the same number as juveniles found in the off-island areas. *M. entomon* generally were more abundant in the shallower parts of the lagoon than in the deeper areas. This distribution may be related to substrate preference, or to reproductive or developmental processes.

The grab survey revealed that the biomass and abundance of infauna in Simpson Lagoon and Harrison Bay was very low. These values correspond closely to the barren zone of 0-5 m found in other arctic areas of Eastern Canada and Scandinavia[16]. The next deeper zone starting at about 5 m, has much higher biomass and abundance values. The Soviets also consider 5 m to be the depth at which the littoral zone of the Chukotsk Sea begins to be populated by benthic organisms[2].

The survey of the western Alaskan arctic coast above the Bering strait[10] concluded that benthic invertebrate populations are probably not established in water less than 20 ft due to the effects of ice scour, and that only highly motile forms that move in and out with the seasons occur there. The low salinity lagoons behind the barrier beaches did not contain large populations of invertebrates. The animals present in these lagoons were either euryhaline forms or those washed in from the sea. In general, these distribution patterns were also observed in the Colville area. Our results of much greater abundance of benthos beyond the 5 m depth come from trawl data only, but it is likely that a grab survey outside the barrier islands would demonstrate larger populations of infauna than were found in either Harrison Bay or Simpson Lagoon. Estimates of standing stock from this arctic estuary are probably comparable only to other high latitude estuaries, some areas of the deep sea, and some polluted areas (Table 10).

The molluscs *Hiatella arctica* and *Nucula tenuis* were the most common nearshore pelecypods found by MacGinitie[1], in the Barrow region. These species were not found in either our samples or in those of the *LCM Red*. On the other hand, *Cyrtodaria suniana* and *Yoldia arctica*, the most abundant species found in this investigation and that of the *LCM Red*[8] were not reported by MacGinitie[1] at all.

Comparing size-frequency histograms for *M. entomon* sampled in 1970 and 1971 (Figs. 9 and 10), it appears that the size distributions are not significantly different except that some smaller isopods are missing from the 1970 data presumably because of the otter trawl mesh size. Since both sets of data were taken in August and the results are seemingly similar, and a 2+ year life span is indicated, it is possible to estimate the productivity of the *M. entomon* as biomass at the time of collection divided by the turnover time of the population assuming steady state conditions. Since arctic species generally reproduce non-pelagically and recruitment is at a low uniform

Table 10. ABUNDANCE AND BIOMASS VALUES OF BENTHIC ORGANISMS THROUGHOUT THE WORLD

	Abundance	
Area	No/m^2	Author
Simpson Lagoon-Harrison Bay	22±33-313±230	This Study
Elbe Estuary	7,025-20,100	Hedgpeth, 1957
North Baffin Island (0-3m)	381	Ellis, 19
Frustration Bay (5m)	282	Ellis, 19
Buzzards Bay	39,628	Sanders, 1958
Sargasso Sea abyss	30-130	Sanders *et al.*, 1965
Gulf Stream abyss	150-270	Sanders *et al.*, 1965
Continental slope	120-750	Sanders *et al.*, 1965
	Biomass	
	g/m^2	
Simpson Lagoon-Harrison Bay	.46±.44-11.74±13.58 (dry wt.)*	This Study
North European estuary	16 (rough weight)	Hedgpeth, 1957
Puget Sound	8-19 (dry wt.)*	Lie, 1968
Chukchi Sea sublittoral	200 (wet wt.)	Zenkevitch, 1963
Chukchi Sea littoral	24 (wet wt.)	Zenkevitch, 1963
Pacific deep sea (950-6000 m)	0.01-6.94 (wet wt.)	Zenkevitch, 1963
Antarctic benthos	400-500 (wet. wt.?)	Knox, 1970
Bering Sea Strait	500+ (wet. wt.)	Zenkevitch, 1963
North Baffin Island (0-3m)	31 (wet wt.)	Ellis, 1960
North Baffin Island (5-14m)	201 (wet wt.)	Ellis, 1960
Frustration Bay (5m)	35 (wet wt.)	Ellis, 1960
Frustration Bay (15m)	210 (wet wt.)	Ellis, 1960

*Wet wt. = 2 to 3 X dry wt.

rate, and the annual turnover appears to be small, the annual production will probably be less than the standing stock at any one time[23,16]. This is in contrast to more temperate regions where the productivity may be 2-5 times greater than the standing crop at any one time[34]. Therefore the standing crop figures found in Table 8 must be considered maximum vales for productivity in g•C/m^2/yr since the population turnover probably exceeds one year; reducing these values by a factor of 2.0 would perhaps provide more realistic estimates of isopod annual productivity. Similar reasoning can also be applied to the populations of *Mysis oculata*.

Life History and Production

Mesidotea entomon, Mesidotea sibirica, Mesidotea sabini and *Mysis oculata* all brood their young[27]. The eggs are spawned in a pouch where they develop to juveniles. These organisms, as is characteristic for most arctic species, do not have pelagic larval stages[22].

M. entomon appears to have continuous egg laying and development throughout the year according to MacGinitie[1]. This statement is based on the fact that he found young isopods in the brood pouches in mid-July and newly spawned eggs in late October. Generally the eggs are spawned from late August to at least late October and the young develop in the brood pouches until they are released the following summer. Other species of isopods have been found to hold their eggs for as long as 102 days depending on the temperature. The arctic species probably have slower development[22,21]. Dunbar[21] states that many arctic species spawn in late fall or early winter when the food supply is supposed to be at a minimum. In August 1971, young *Mysis oculata* were collected as well as adult females with empty brood pouches. The young appear to be released in summer as with the isopods.

Three size classes are noted on the length frequency diagrams for *M. entomon* and *Mysis oculata*. This indicates that the organisms probably live fewer than three years. The smallest group is the recently hatched juveniles, the second size class corresponds to the one-year olds, and the third group is comprised of two-year old individuals. Only two size classes are found for *M. sibirica*, but a large gap occurs in the frequency distribution suggesting that an intermediate mode exists somewhere, perhaps outside of the sampling area. Dunbar[21] suggests that the two year life span is actually quite common in the arctic. Growth and development are retarded such that a species that has a one year life span and spawns more than once a year in temperate zones may have a two year or prolonged life span and spawn only once a year in the arctic[21,35].

Trophic Relations

Standing stock as gC/m^2 has been calculated for *Mesidotea entomon* and *Mysis oculata* (Table 10, and the carbon content of other species presented measured (Table 7). Curl[36] discussed the analysis of carbon and its significance. Unfortunately carbon values give only a rough indication of how much value a species may be to predators since it is not known how much of the carbon can be utilized. However, it is known though that mysids, isopods, and amphipods are a part of the diet of various arctic fish such as arctic char (*Salvelinus malma*), the sculpin (*Myoxocephalus quadricornis*), and the "white fish", *Coregonus* spp.[37]. Since most of the benthic organisms in the region are scavengers, and deposit or suspension feeders, they probably have an adequate supply of food. Suspended organics are supplied in great quantity by the river; large lumps of peat occurred in trawl samples taken inside the barrier islands.

Sources of Error

Experimental error in sampling procedure, measurements, and computation of standing stock estimates could account for some of the variability in the abundance and biomass values, but care was taken to minimize those sources that could be practically lessened. Other sources of variability are inherent in the methods used and are difficult if not impossible to overcome.

The use of a .05m^2 grab rather than a .1 or .2m^2 sampler introduces sampling error,[38] but the size and weight of the gear was governed by the type of vessel which was available to work the very shallow lagoons. Attempts were made to keep only samples that collected three or more liters of sediment. With the smaller sampler, certain deep burrowing organisms may be missed such as *Mya* spp. or *Echuirus* spp. However, since over 90 percent of the organisms occur in the upper 15cm or so, most of the organisms present were probably sampled.

To reduce a source of error that could affect the comparison of mysid and isopod abundance differences between areas, geometric rather than arithmetic means were examined. Arithmetic means of data sets are in most instances much higher than geometric means, an effect observed when extremely wide ranges of values are encountered. The geometric mean, already slightly negatively biased, lessens the effect of the very divergent values.

The estimates of isopod and mysid standing stocks are variable depending on the deviations of dry weight values from the mean that was used for the calculation, the loss of weight reflected in the dry weight values caused by preservation in formalin, the effect of formalin preservation on average carbon contents of the organisms, and for the mysids the variability inherent in the splitting of samples into subsamples. The effect of formalin preservation on the carbon content is not known; formalin leaching reduces dry weights by 10 percent or more. The variability caused by subsampling is relatively minimal[11].

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CHAPTER 10

COLVILLE RIVER DELTA FISHERIES RESEARCH

Dennis Kogl and Donald Schell

INTRODUCTION

The rivers emptying into the Arctic Ocean along the coast of Alaska have been utilized for their fisheries resources by the Eskimos since prehistoric times. During the initial exploration of the coast, Simpson[1] purchased char from natives who were gill-netting with nets made from fine strips of bowhead whale baleen. Leffingwell[2] describes the gill-netting of whitefish and char in the coastal waters near Flaxman Island and the seining of grayling from the Sagavanirktok River by natives. Further references to the fisheries of the arctic coast, especially in the Colville River delta area, are made by Jenness[3], who observed that under-ice gill-netting was continued into December with sufficient success to support both families and dog teams. Thus, for perhaps centuries past and continuing until the present, the fisheries resources of the rivers and estuaries have been a valuable supplement to the marine mammal resources of the sea.

The Colville River, as the largest river on the Alaska north slope, has perhaps the most extensive and commercially valuable fishery resources. Nevertheless, by virtue of its remote location from Barrow, the closest population center, this fishery has never been intensively exploited. The often severe summer ice conditions in the Cape Simpson and Cape Halkett areas prevent ready access to Barrow by water, and the load limitation imposed in the past by dog sled travel have made winter hauling marginally feasible. In recent years, however, the situation has changed as the population of Barrow has grown to the point that the pressure by local subsistence hunters and fishermen is severe. Better modes of transportation have become available. Fishermen on the Meade, Chipp, and Colville rivers are now flying their catches to Barrow where the consumption is primarily local with a fraction being purchased by the Naval Arctic Research Laboratory for animal food. Some fish of lower value have been back-hauled on aircraft bringing fuel and "outside" supplies to the Helmericks camp in the delta. These found utilization primarily as dog food in the Fairbanks area.

The fall 1972 commercial fishery in the Colville delta consisted of the Woods family on the Nechelik Channel, the Tukle and Ahvakana families on the Kupigruak Channel and the Helmericks family on the Anachlik Channel (easternmost). Most of the fishing is done in the immediate vicinity of the family dwellings although utilization of choice net sites near the divergence of the eastern channels has been shared (Fig. 1).

The immediate future promises a rapidly increased exploitation of Colville River fisheries. The re-establishment of the village of Nuitsaq on the west channel of the Colville delta during spring of 1973, as a result of a village land allotment by the Alaska Native Claims Act, has brought several new families into the delta. Their livelihood will depend heavily upon fishing; and the choice locations for net sites are limited and have already proved a source of contention among the few families that have been inhabiting the delta. The need for information regarding Colville fisheries resources sufficient to allow realistic harvest limits for sustained yield is urgent and beyond the scope of this project. Our intent was to utilize our logistic base to provide data relating the existing environmental conditions to fish populations in the delta channels.

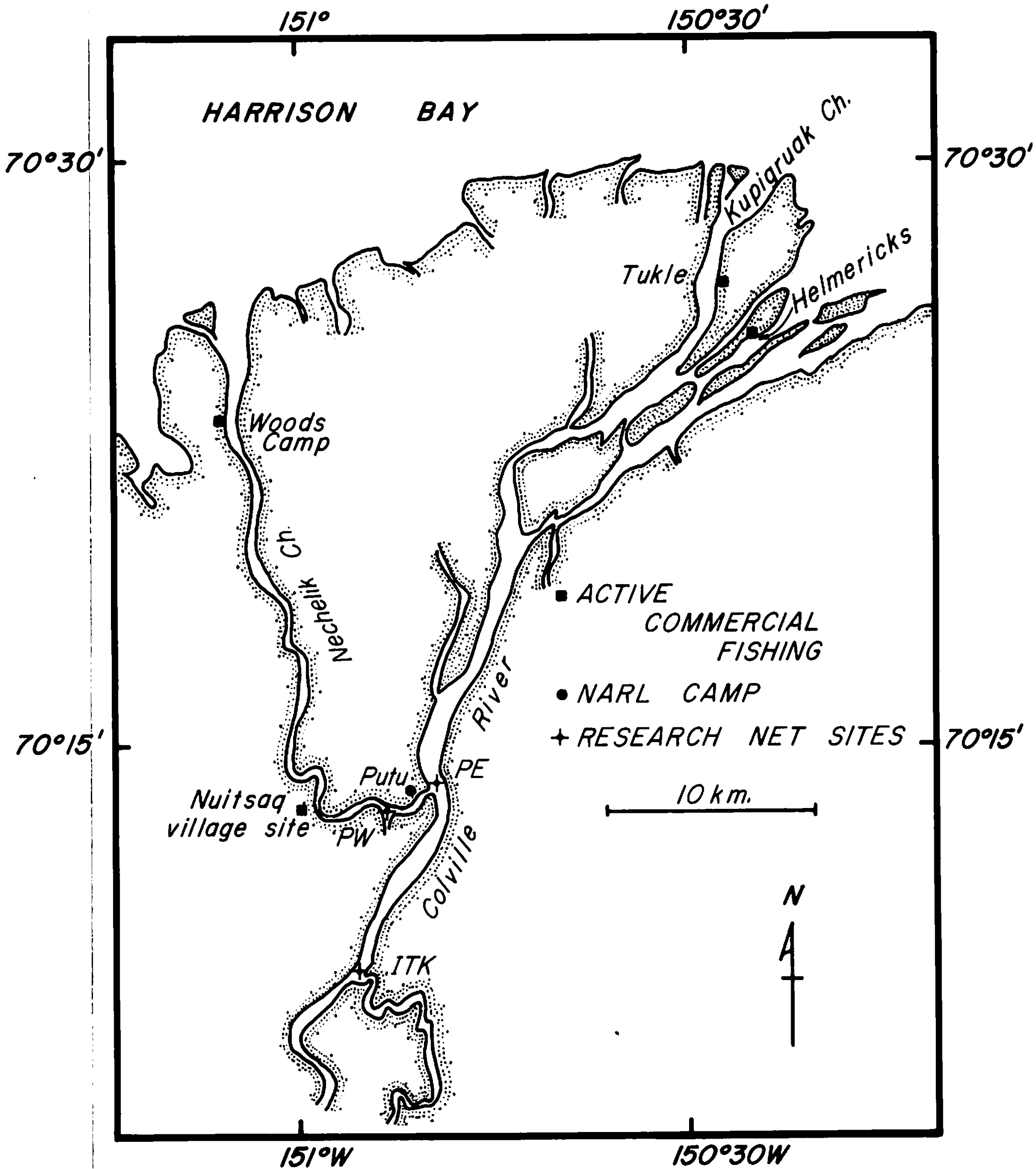

Figure 1. Fisheries study area.

PRELIMINARY LIST OF COLVILLE RIVER FISHES

Fishes that (are known to) occur in the Colville River are: Arctic cisco *(Coregonus autumnalis)*, least cisco *(C. sardinella)*, broad whitefish *(C. nasus)*, humpback whitefish *(C. pidschian)*, round whitefish *(Prosopium cylindraceum)*, Arctic grayling *(Thymallus arcticus)*, lake char *(Salvelinus namaycush)*, (Arctic) char *(Salvelinus alpinus* complex), chum salmon *(Oncorynchus keta)*, pink salmon *(Oncorynchus gorbuscha)*, burbot *(Lota lota)*, long nose sucker *(Catostomus catostomus)*, nine spine stickleback *(Pungitius pungitius)*, four-horn sculpin *(Myoxocephalus quadricornis)*, rainbow smelt *(Osmerus mordax)*, Arctic flounder *(Liopsetta glacialis)*, and slimy sculpin *(Cottus cognatus)*.

The Arctic char complex will likely be split into two or possibly three species: an anadromous form which is similar to the Dolly Varden char *(Salvelinus alpinus)*; and a poorly known char that has a very restricted range (springs entering Tulugak Lake, Anaktuvuk River drainage).

A lamprey occurs in the Colville but it has not been identified. It is probably the Arctic Lamprey *(Lampetra japonica)*.

Shee fish *(Stenodus leucichthys nelma)* and sturgeon *(Acipenser* sp.) have been reported both in early writings, pertaining to the waters of the North Slope and the Colville River, and in recent oral communication with natives. None of these reports are documented although McPhail and Lindsey[4] cite a shee fish record from the Ikpikpuk River which is the first drainage west of the Colville.

Aside from sporadic fish collecting by taxonomists, little information on the fish biota of the Colville River has been available until 1969 when the Alaska Department of Fish and Game monitored the summer commercial fishery[5], and 1970 when the department made a more comprehensive, albeit preliminary survey of the river with emphasis on life history of sport and commercial species.[6,7]

METHODS

The initial fishing effort involved an underwater television reconnaissance of the Colville delta in spring 1972 and an aerial survey of the headwaters of the Chandler River, in which a light aircraft was chartered to fly tributary streams of the Colville River in spring prior to ice breakup to determine the extent and quality of potential fish overwintering sites.

Fish were caught with gill nets and hook and line. The net most frequently used was 24.4m x 2.4m with 89mm stretch mesh. A 15.3m x 1.8m net with 127mm stretch mesh and 38.1m x 1.8m variable mesh net composed of five monofilament panels ranging in size from 25mm to 127mm stretch mesh were used to a lesser extent. Nets were set perpendicular to channels in depths of about 3m in open water and 4-7 meters for fishing under ice cover.

Fish were measured to the nearest millimeter in fork length. Scales were taken from fish and mounted dry between glass microscope slides for examination with a binocular microscope to determine age. Gonads and stomach contents were examined on fresh specimens. Egg diameters were measured on a millimeter rule.

Fish that were soon to spawn or were ripe were designated "potential spawners." Those that had completed spawning were termed "spawned out." Other fish were termed either "immature," or as having "some development," or as being "non-spawners."

Gill netting was begun on 23 September and continued intermittently until 15 November 1972. Most fishing was done in the main channel of the Colville River immediately east of the NARL Camp Putu cabins (PE). Additional stations were in the Nechelik Channel about 1.5km downstream from its head (PW) and in the main river about 0.2km below the mouth of the Itkillik River (ITK) (Fig. 1).

At the completion of fall fishing, the nets were removed and the net lines left in place after being weighted to hold them on the bottom. These same lines were used for spring fishing.

Fishing was resumed from 18 April to 24 April 1973. The method of line retrieval and setting gill nets in spring was as follows: four contiguous holes were drilled with a Hoffco 8 inch power auger next to the line passing through the ice; the line was caught with a hook below the ice and pulled to the surface; a gill net was fixed to an end of the line and pulled beneath the ice from the other end. To decrease the rate of freezing, four auger holes were equally distributed around the net holes and placed at about three inches from it. As added protection, snow blocks were placed over all holes.

During fishing operations, water samples were collected for dissolved oxygen and nutrient chemistry. Water temperatures were taken at net locations.

RESULTS AND DISCUSSION

Between 11 May and 15 May 1972, an underwater television system was used to view the channel bottom at various locations in the delta in an attempt to determine if the channels are used by over-wintering fishes. The area sampled included the Colville east channel at Putu, several sites along the west channel, and upriver at the mouth of the Itkillik River. No whitefish were observed although four-horn sculpin were abundant in the saline waters of both channels. In most cases, the presence of these fish was correlated with a gravel bottom. Many of these fish were taken on hook and line. The predominant item in sculpin stomachs was fish eggs, which at this time were eyed. The eggs were approximately the same size as humpback whitefish eggs. Amphipods and shrimp occurred to a lesser extent. Freshwater sample sites above the Itkillik River were too shallow to use the underwater television.

Due to inclement flying weather, only the Chandler River, from its headwaters to its mouth, was flown. A single area of open water due to ground water seepage was observed at a point approximately 72km from its mouth. Digging with a shovel and net for eggs or alevins of char gave negative results. However, several juvenile grayling were seen.

A fall catch of 834 fish was made in 1,131 net-hours. The catch consisted mainly of humpback whitefish *(Coregonus pidschian)* (HWF), broad whitefish *(C. nasus)* (BWF), Arctic cisco *(C. autumnalis)* (ACi), and least cisco *(C. sardinella)* (LCi). Fishes taken in lesser numbers were burbot *(Lota lota)* (BB), char *(Salvelinus alpinus* complex) (AC), four-horn sculpin *(Myoxocephalus quadricornis)* (FSc), and long nose sucker *(Catostomus catostomus)* (S) (Table 1). Nine spine stickleback *(Pungitius pungitius)*, a small char, and the remains of a lamprey were recorded from burbot stomachs.

The catch of humpback whitefish was high in late September and early October and rather sharply declined to a stable level for the duration of fishing. Much the same pattern was observed with broad whitefish although they were not present in sizeable numbers. Nets set in the main

TABLE 1. FALL 1972 CATCH

					Species and No. Captured							
Date	Station	Depth, m	Net	Net, hrs	HWF	BWF	ACi	LCi	BB	AC	FSc	S
24 Sept.	PE	3	80	21	2							1
25 "	PW	4	80	26	23	2						1
25 "	Putu Channel	2	80	24	1							
3 Oct.	PE	2	50	22	1	1		1				
4 "	PE	4.5	80	24	61	5	3	2				
4 "	PE	2	50	24		1						
5 "	PE	4.5	80	24	50	11		4				
5 "	PE	2	50	24	2	4						
6 "	PE	4.5	80	24	122	1	1	1				
14 "	PE	4.5	80	24	38	4						
15-16 "	PE	4.5	80	48	40	4	1	2				
18 "	ITK	7	80	24	53	19			1			
19 "	ITK	7	80	26	30	1						
19 "	PE	4.5	50	24		2			1			
20 "	PE	4.5	80	20	12	5						
22 "	PW	6	80	21			10					
23 "	PE	6.5	80	48	14	1	1	3				
25 "	PW	6	80	20	1		2	1			6	
26 "	PW	6	80	21			11					
27 "	PE	6.5	80	24	9				1			
28 "	PE	6.5	80	24	9							

Table 1. (continued) FALL 1972 CATCH

Date	Station	Depth, m	Net	Net, hrs	Species and No. Captured							
					HWF	BWF	ACi	LCi	BB	AC	FSc	S
29 Sept.	PW	6	80	24			1				1	
30 "	PW	6	80	24			4					
31 "	PE	6.5	80	20	6							
1 Nov.	PE	4.5	80	23	8	3	2					
2 "	PE	4.5	80	24	7	1	3		1			
2 "	PE	6.5	Exp	24	12	1	5	7	1		1	
3 "	PE	6.5	Exp	24	17		2	14	1			
4 "	PW	6	80	22			2				3	
4 "	PE	6.5	Exp	24	6		1	13	4			
5 "	PE	6.5	Exp	24	9	1		7	2			
5 "	PW	6	80	22			12				2	
6 "	ITK	7	80	22	9	1			1			
6 "	PE	6.5	80	22	5			6	1			
9 "	PE	6.5	Exp	28	6			5	1	1		
10 "	PW	6	80	24				1				
10 "	PE	6.5	Exp	24	6		1	4	4			
11 "	PW	6	80	26								
11 "	PE	6.5	Exp	25	3		1	4				
13 "	PW	6	80	48								
13 "	PE	6.5	Exp	48	6		2	4	2			
14 "	PW	6	Exp	24			2	1			1	
15 "	PW	6	Exp	24			2	6			2	
15 "	PE	6.5	80	24	3							
Totals				1,131	571	68	69	86	21	1	16	2

channel rarely took more than a few Arctic cisco even when the variable mesh net was employed. Arctic cisco were more abundant near the head of the west channel (PW) where the process of seawater incursion was more advanced.

Stenohaline forms, i.e., grayling, lake char, round whitefish, and sucker, have apparently left the delta by October for upriver spawning or overwinter areas.

In spring, 1973, three gill nets were fished for 299 hours. An average of 10 manhours was required to set a net when two augers were in simultaneous use. Ice formation in net holes was negligible despite air temperatures of -12°C to -23°C. At the Itkillik River, six least cisco and one humpback whitefish were taken. One four-horn sculpin was caught at Putu-west, and no fish were taken at Putu-east. Baited fry traps fished at Putu-west and at Itkillik River for fourteen hours were empty. Stomachs of least cisco were empty while the humpback whitefish stomach contained a moderate amount of amphipods and shrimp. The four-horn sculpin was feeding on unidentified eggs. Water quality characteristics at the fishing sites are presented in Table 2.

In view of the number of hours fished at Putu-west and Putu-east in comparison with the Itkillik site, there is a strong likelihood that few if any whitefish frequent the relatively colder, saltier waters found at the former. More extensive sampling effort is needed to determine if this preliminary finding can be generalized for the whole delta. Presumably, the abundance of whitefish would increase with fresher water upriver from the Itkillik site.

TABLE 2. SPRING SALINITY AND DISSOLVED OXYGEN, COLVILLE DELTA FISHING SITES

Date	Station	Depth, m	Oxygen, mg/1	Salinity, °/₀₀
28 April 1971	Wood's Camp	2	4.8	39.6
		4	4.3	38.8
		6	3.6	40.5
		7	3.3	40.8
17 April 1972	ITK	2	5.4	11.4
		4	5.7	15.3
		5.5	5.0	16.1
17 April 1972	PE	2	7.8	20.3
		4	6.2	21.1
		5	7.1	23.2
19 April 1973	PE	2	5.5	23.8
		4	6.0	24.0
		6	6.1	24.2
21 April 1973	PW	2	2.4	27.2
		4	2.3	27.6
		6	-	27.7
		7	2.3	27.7
21 April 1973	ITK	2	2.3	27.7
		4	3.4	15.8
		7.3	3.3	18.0

Based on tag recoveries, Wohlschlag[8] believes that least cisco enter streams of Admiralty Bay to spawn and probably to overwinter. However, Yukheva[9] indicates that least cisco have the capability for overwintering in the sea (Gulf of Tazov) if plankters are available.

Humpback Whitefish

Humpback whitefish spawned in the east channel at Putu as well as in the commercial fishery area of the Kupigruak Channel at the mouth of the Colville. It is likely that spawning occurred at the mouth of the Itkillik River as well. No direct information is available for Nechelik Channel, although in April 1972, eyed whitefish eggs were found in the stomachs of four-horn sculpin at Woods Camp.

The first ripe female was taken under ice in the east channel on 3 October, but presumably spawning had been occurring for some time and was diminishing by 4 October when the first large sample of fish was obtained. Very few immature fish were taken at Putu and none were seen in an inspection of the Helmericks' commercial catch although their nets had a smaller mesh and were, therefore, more likely to select smaller individuals.

There was a large proportion of females which had only some gonadal development yet fell within the length range of potential spawners. Some of these fish had eggs of a previous spawning on the gonads. Egg remnants appeared as broken and atrophied chorii. For comparison, retained eggs of females one month past spawning were turgid and without gross indication of degeneration. Approximate egg diameters for three classes of females were 2.3mm - ripe, 0.9mm - some development, and 0.2mm - spawned out. Immature fish had eggs less than 0.1mm. The length range of six confirmed non-spawners was 362-444 mm with a mean egg diameter of

0.9mm. Although some females appeared to be non-spawners with respect to fork length and egg diameter, no resorbing eggs could be found; and, hence, it was possible that they were not mature fish. Nonconsecutive spawning apparently does not occur in males. The length and maturity data on humpback whitefish appears in Tables 3 and 4 and Figure 2.

During spawning, humpback whitefish consumed large quantities of their own eggs. Feeding on eggs diminished after spawning but was still occurring two weeks after the last ripe female was taken. Amphipods were the predominant item in stomachs. Few fish had empty stomachs. Feeding continued actively despite a water temperature of 0.1°C and a salinity of about 9 °/₀₀ at the termination of fishing.

The spawning habits of whitefishes in Alaskan waters are essentially unknown. The opinion is frequently held that they ascend river systems to the middle reaches or higher and spawn at night over gravel bottoms in velocities of about 6km/hr and in sufficient depth to prevent freezing of the spawn.

Although broad and humpback whitefish ascend the Colville River over 200km from the mouth to spawn (beyond Umiat)[6], they also spawn in the delta. The significance of delta spawning is that eggs are deposited in a freshwater environment, just as they are upstream, but hatching and most of incubation occurs in brackish or marine conditions. At Putu-east two months after egg deposition, the river current is essentially nil, and much of the freshwater has been replaced by saltwater (Table 2). By April, bottom water temperature is approximately -1.1°C with a salinity of 24 °/₀₀. Near the mouth of Kupigruak Channel, where spawning is known to occur, the salinity in April is about 32 °/₀₀, and the whitefish eggs apparently hatch in what is essentially the Arctic Ocean.

TABLE 3. HUMPBACKED WHITEFISH REPRODUCTIVE DATA

Date	Station	Male		Female			Male:Female Ratio
		Potential Spawner	Spawned Out	Potential Spawner	Spawned Out	Some Development[a]	
4 Oct. 72	PE	5	0	4	29	23	1:11.2
5 "	PE	8	0	3	17	22	1:5
6 "	PE	5	2	2	8	14	1:3.4[b]
14 "	PE	31	1	0	4	2	5.3:1
16 "	PE	36	0	0	3	1	9:1
18 "	ITK	35	1	0	4	13	2.1:1
19 "	ITK	20	3	0	4	3	3.3:1
20 "	PE	10	0	0	1	1	5:1
24 "	PE	9	0	0	5	0	1.8:1
27 "	PE	6	1	0	1	1	3.5:1
28 "	PE	5	0	0	0	4	1.3:1
31 "	PE	4	0	0	2	0	2:1
1 Nov. 72	PE	4	0	0	2	2	1:1
2 "	PE	11	1	0	2	5	1.7:1
3 "	PE	7	1	0	3	6	1:1.1
4 "	PE	5	0	0	1	0	5:1
5 "	PE	5	0	0	1	3	1.3:1

[a] Consists mostly of nonspawners, but a few were obviously immature.

[b] A 31 fish subsample of 122 fish total catch.

Table 3. (continued) HUMPBACKED WHITEFISH REPRODUCTIVE DATA

Date	Station	Male		Female			Male:Female Ratio
		Potential Spawner	Spawned Out	Potential Spawner	Spawned Out	Some Development[a]	
6 Nov. 72	PE	2	1	0	1	1	1.5:1
6 "	PE	2	0	0	0	7	1:3.5
9 "	PE	2	0	0	2	2	1:2
10 "	PE	3	0	0	2	1	1:1
11 "	PE	2	0	0	1	0	2:1
13 "	PE	4	0	0	0	2	2:1
15 "	PE	1	0	0	0	2	1:2

[a] Consists mostly of nonspawners, but a few were obviously immature.

TABLE 4. AGE, LENGTH, AND SEX COMPOSITION OF 87 HUMPBACK WHITEFISH, COLVILLE DELTA, FALL 1972

Age Group	No. in Samples	Length Range, mm	Mean Length, mm	Sex	
				Male	Female
IV	1	245	245	1	0
V	1	300	300	0	1
VI	1	330	330	0	1
VII	9	310-399	360	3	6
VIII	27	357-406	382	12	15
IX	24	371-432	399	6	18
X	19	405-463	429	4	15
XI	5	431-469	452	1	4

Male	Number	Percentage	Length Range, mm
Immature	1	3.7	245
Some development	7	25.9	356-379
Potential spawner	14	51.9	370-436
Spawned out	5	18.5	372-463
Nonspawner	0	-	

Female	Number	Percentage	Length Range, mm
Immature	0	0	
Some development	8	13.3	300-382
Potential spawner	4	6.7	358-449
Spawned out	7	11.7	365-443
Nonspawner	41	68.3	362-469

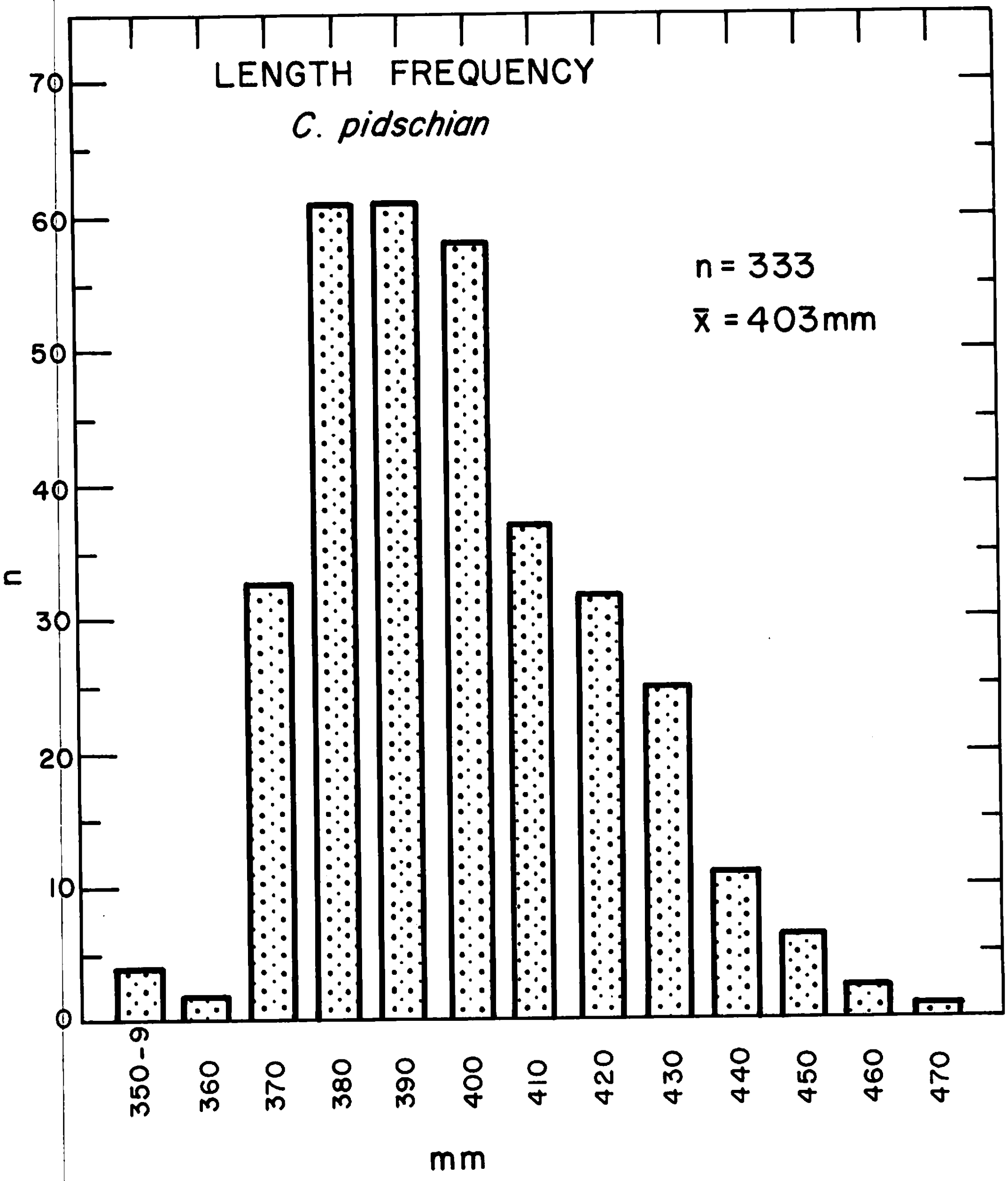

Figure 2. Length frequency (histogram) - humpback whitefish.

Summer samples of humpback whitefish taken at Umiat, although composed exclusively of potential spawners had a mean length of 381mm (N=105), while for the east channel at Putu, in the present study the mean length of spawning fish was 403mm (N=282).

Fifty-five percent of all female humpback whitefish which were within the range of mature fish (360-470mm) were non-spawners. Such a high proportion of non-spawners, although possibly including some females which were developing toward their first spawning in 1973, probably is due to the presence of females in the delta that had spawned upriver in 1971. Further research is needed to determine whether two stocks of humpback whitefish are present or simply that it is a highly adaptable species.

The pattern of fish movements in the delta in response to winter ice formation, the cessation of flow, and the change from river water to seawater is unclear. A local native fisherman believes that the humpback whitefish are coming down the river in October since he had spent several weeks fishing at a point approximately 23km upstream from Putu. This opinion has some support from catch data giving the apparent direction of movement. There appeared to be a slight movement of humpback whitefish downstream during October as most fish entered the net from upstream. However, the east channel at Putu is several hundred meters across and more gear would have been necessary to adequately monitor movements.

A complete reversal of sex ratio in humpback whitefish early in October indicates strong movements of males and females into and out of the fishing area at Putu-east. No upstream movement was detected.

Broad Whitefish

The broad whitefish is the target species of the summer fishery in the Nechelik Channel. Broad whitefish in small numbers were spawning in the delta and apparently in close proximity to humpback whitefish. A few specimens had phenotypes that were intermediate between *C. pidschian* and *C. nasus*, and may be hybrids.

Broad whitefish had a length range of 271-584mm with a mean length of 467mm. The male to female ratio was 2:3. Nonconsecutive spawning, although it may occur, is not typical. Few immature broad whitefish were taken in the delta. Stomachs of spawning and post spawning fish were empty.

Arctic Cisco

The arctic cisco is the most important commercial species in the Colville delta. This species is ubiquitous in coastal Alaskan arctic waters from Point Barrow to Demarcation Point during summer months. Arctic cisco is considered the best table fare by the Eskimos with the broad whitefish ranking a close second. In fall, arctic cisco congregate in the river mouths where they support small commercial fisheries. Fishing is conducted under the ice and the catch flown or sledded to Barrow.

The length range for Arctic cisco taken in the Colville River Delta, fall, 1972, was 228-452mm, with a mean length of 356mm. The age structure of the catch is depicted in Figure 3. Twelve mature females were taken; ten of these were non-spawners and two were spawned out. Arctic cisco younger than age IV were not caught (at Putu) and were apparently not present.

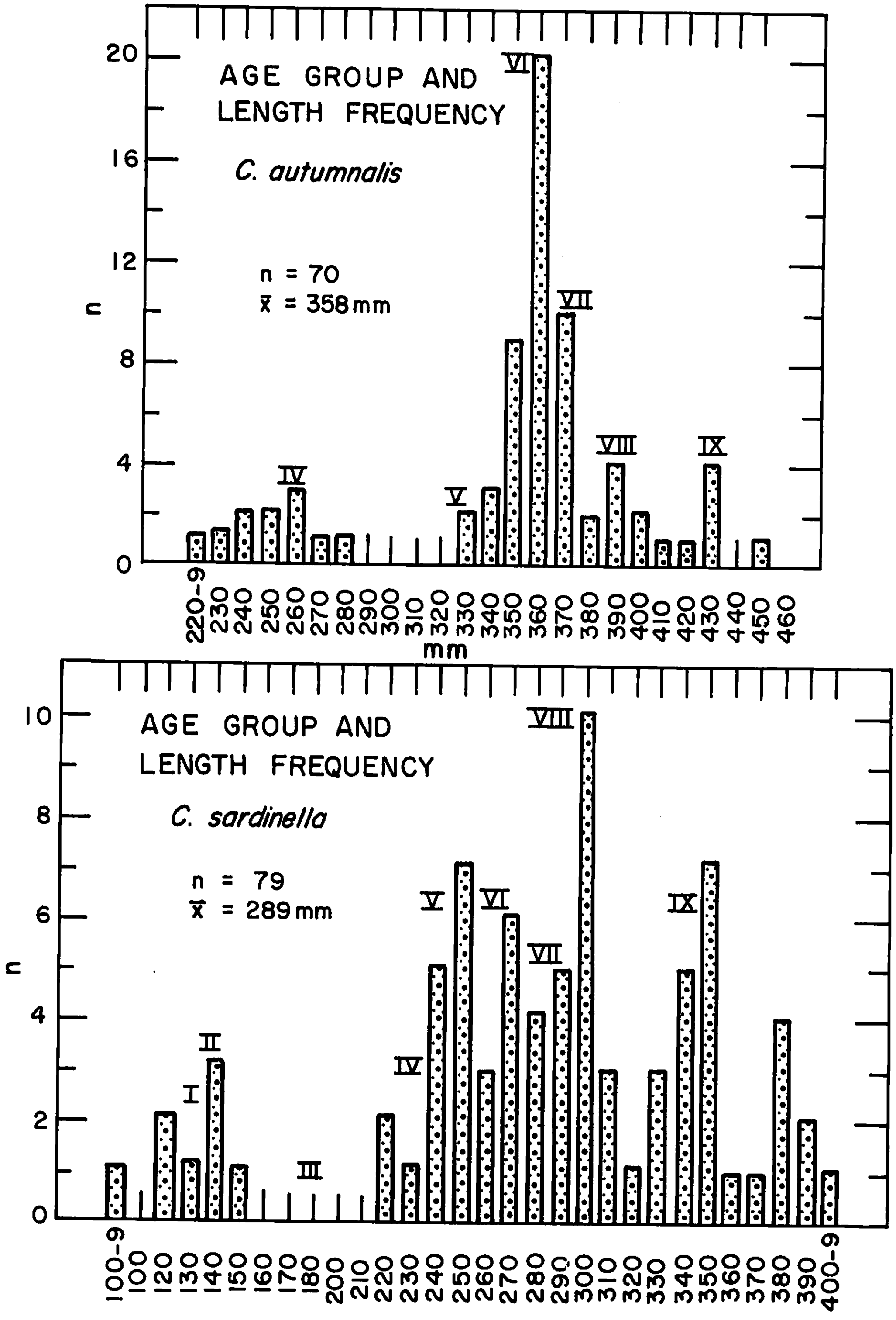

Figure 3. Age group and length frequencies of the arctic cisco (top) and least cisco (bottom).

Least Cisco

These fish occurred in small numbers during the course of fall fishing. Unlike the whitefishes and Arctic cisco, juvenile least cisco were present. The low abundance of least cisco at Putu in the fall as compared with the mouth probably reflects their affinity for brackish water.

Least cisco make up a significant part of the fall commercial catch, not only in the Colville River but in other Arctic rivers. Least cisco are utilized in the animal colony at NARL and as domestic animal food elsewhere.

Burbot

Burbot occur in fair numbers in the Colville Delta. They are taken on hook and line throughout the year. Eskimos relish burbot livers which are rich in oil. This species, due to its predaceous nature and willingness to take a lure has potential for supporting a limited sport fishery. We took six burbot on hook and line in 10 minutes at the Putu-east gill net station. These burbot were attracted to the fish struggling in the net which they adeptly extract from the mesh while eluding capture themselves.

During 72 hours of spring ice fishing in 1972, a single burbot was taken by set line approximately one kilometer downstream from the Itkillik River on the Colville. The bottom temperature was -1.3°C with a salinity of 20.5 °/₀₀. This particular location is common knowledge to all delta natives and apparently has some unique characteristic that causes burbot to congregate there.

Twenty-two burbot were taken by gill net, although only four were gilled, and nine were taken on hook and line. The mean length of these fish was 739mm and they averaged about 2kg each.

Four-horn Sculpin

These fish are probably widely distributed and abundant in the delta although gill net results did not indicate this. Angling and television reconnaissance during spring 1972 revealed four-horn sculpin at most locations investigated and as many as four individuals were in television view at one time. They apparently have little difficulty avoiding a net.

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CHAPTER 11

A SUMMARY OF OBSERVATIONS OF BIRDS AT OLIKTOK POINT AND NOTES ON BIRDS OBSERVED ALONG THE COLVILLE RIVER - SUMMER 1971

George E. Hall

INTRODUCTION

As part of a continuing program to gather baseline data from the Alaskan Arctic environment, the Institute of Marine Science of the University of Alaska supported field work in the area of the Colville River Delta and Simpson Lagoon for the 1971 summer season. An integral part of this survey deals with the macrofauna of the area, with a particular emphasis on waterfowl and other birdlife. An increasing amount of field work is being carried on with regard to waterfowl breeding and migration in this area. Most surveys of this nature are done by aircraft over a large area, with little actual ground work in one location or habitat.

Institute of Marine Science personnel had a unique opportunity to do a more intensive evaluation of a small area, as the sampling program for oceanography was based at Oliktok Point, with facilities at the DEWline site POW-2. This peninsula is just east of the Colville Delta, and juts out into Simpson Lagoon. Major habitat types in the area include sedge-grass marsh, tundra-lacustrine water edge, lacustrine water itself, wet tundra, and some small areas of alluvial deposits and dry tundra (on knolls). A total of forty-three species was recorded at Oliktok Point in an area of a circle with a radius of three miles, the center of which was the tower at the DEWline site. One additional species, surf scoter, was recorded in Harrison Bay but not seen within the circle. Any species recorded in Simpson Lagoon or the Jones Islands were also recorded at Oliktok.

The period of observations covered approximately seven weeks from 12 June until 23 August, and covered the courtship and nesting season, and then the pre-migration period, with some species having left the area by the time observations ended. Major waterfowl movements take place in September and October, and will be studied more closely by aircraft next season. In addition to daily field notes taken at Oliktok Point, several trips either on foot across the tundra, or in skiffs in the Simpson Lagoon and Harrison Bay area, resulted in a broader understanding of species distribution and movements in the area. A riverboat trip was taken from Umiat to NARL Putu camp in the delta in late June to sample the Colville River and some tributaries for water chemistry as well as provide additional data on bird distribution. Twenty-one additional species not recorded at Oliktok Point were seen along the river, bringing the total number of species treated in the annotated list to sixty-five. The following annotated list will sum up the various data on courtship, nesting, post-breeding movements and migration schedules, as well as notes on relative abundance and some unusual occurrences of several species at Oliktok Point in 1971.

ANNOTATED LIST OF BIRDS

An annotated list of species seen in the Oliktok Point area, as well as those noted on the riverboat trip from Umiat to Putu:

Gavia adamsii. Yellow-billed Loon

Seen only on two occasions, both the same day (13 June), this species apparently does not breed in the immediate vicinity of Oliktok, but rather further inland on larger lakes. One bird was seen flying east, the other west; possibly even the same bird. This movement was apparently pre-breeding migration, and no other birds of this species were seen later at Oliktok; one bird seen at Ocean Point 26 June was the only sighting on the Colville.

Gavia arctica. Arctic Loon

The commonest nesting loon at Oliktok Point, this species was seen or heard daily. On 17 June, eight pairs were counted on tundra ponds along a seven mile hike. Nesting had not commenced at that time, but on 25 July, a nest was discovered just west of the hangar at POW-2, with the adults incubating two eggs. Young were seen a week later. By 20 August only one young survived, and as of then had not left the pond. Thirteen arctic loons were seen 16 August in Simpson Lagoon between Spy Island and Cottle Island, all flying singly or in pairs between Beaufort Sea and their tundra nesting sites. This species was also noted on seven occasions at various points along the Colville River from Umiat to Putu, especially at Ocean Point and in the Delta.

Gavia stellata. Red-throated Loon

Seen more frequently than either preceding species, this bird was not found nesting nor seen on the water as often as the arctic. The birds were noted daily in flight, heading out to feed, and on 17 June, ten were counted while on a field trip; only one was on a pond. At least one pair nested in the area as an immature, unable to fly, was found on a pond 19 August. Presumably the bird prefers to nest somewhat further inland than the arctic loon, which was commoner right on the coast. While in Simpson Lagoon 16 August, sixteen red-throated loons were seen in flight, several carrying fish and headed inland. Only four of these birds were noted on the riverboat trip, and again all were in flight along the river.

Olor columbianus. Whistling Swan

This is a bird of the Delta area, and was seen only once at Oliktok Point. On 16 June, three swans, including two adults and one first year bird, stayed on the smaller ponds on the point all day. They were not seen before or after that day. The species was observed in numbers at Putu in April[1] on the open river, waiting for the ponds to open up. It has nested in the past at Oliktok Point, but on the larger ponds more inland. Only one bird was seen upriver from the Delta, just below Ocean Point on a large lake being sampled 28 June. Several swans were seen in the Delta while flying from POW-2 to Barrow 23 August, and five were at Putu camp on the pond 30 June.

Branta canadensis. Canada Goose

This species was not recorded at Oliktok Point. A total of forty-seven birds were seen along the Colville River from Umiat to Ocean Point. Most were in pairs along gravel bars, but two groups of seven and twelve were seen 25 and 26 June. The bird nests along the bluffs of the river and appears restricted to these situations.

Branta nigricans. Black Brant

This species was moving in considerable numbers in mid-June, but did not remain in the area to nest. On 12 June, two birds were seen; 13 June - fourteen fed on the mud flats, and several more flocks were seen in flight; 14 June - one pair on the ponds and forty-five more in flight; 15 June - one flock of thirty-five, six more flocks of ten to twenty birds, all in flight going either east or west. By 16 and 17 June, only a few birds were seen on the ground feeding, or in flight. No birds were seen on the Colville River between 23 June and 1 July. By mid-August, brant were again showing up flying west at Oliktok Point.

Between 16 and 20 August, flocks of eight or a dozen birds were seen each morning and evening, and on 21 August, over seventy-five birds were counted.

Anser albifrons. White-fronted Goose

Like the whistling swan, this is another species that is a common breeder, but more locally in the delta area, and was therefore noted infrequently at Oliktok. On 17 June, while on a tundra field trip, two small groups totaling eight birds flew very close to me and landed a short distance off to watch. A curious species by nature, they were presumably attracted by the water sampling gear. No nesting was noticed, and the species was next seen in August during the post-breeding movements. A flock of six landed at the point 14 August, and twenty-two more were seen 27 June below Ocean Point on the Colville trip. Presumably non-breeders, these birds were feeding along the river bank, and totaled eighteen in number.

Anas platyrhynchos. Mallard

Noted only at Umiat on 23 June. Three birds, one male and two females, were seen on a pond at Umiat. No birds were seen down river or at Oliktok Point.

Anas acuta. Pintail

A very common and widespread species, this bird was resident at the DEW line compound all season and bred within 20 feet of the driveway. Seen daily at Oliktok, and on the Colville River from Umiat to Putu. Seven non-breeding birds were at Oliktok Point from 12 June until mid-August, when they left the area and dispersed. One pair that bred at the site had four eggs by 16 June, and seven by 18 June. However, the nest was located by foxes and destroyed before the clutch was hatched. It is not known whether this pair laid a second clutch. They were not seen in the area after 23 July.

Anas carolinensis. Green-winged Teal

A male of this species was seen on the pond west of the hangar at POW-2 on 12 June. Apparently the bird was out of its normal range and habitat as it is not known to breed in the area and is more commonly found at Umiat and further inland. A bird of brushy sloughs and marshes, this male was not seen again and presumably returned inland. Four pairs were seen in the Umiat area 23 and 24 June.

Mareca americana. American Widgeon

Two males seen on the small pond at Umiat were the only birds of this species noted on the trip 23 June to 1 July. This is another inland bird and was not noted at Oliktok Point.

Aythya marila. Greater Scaup

Another species seen only at Umiat on 23 and 24 June, this bird may have been expected further down river, where it has been recorded by Kessel and Cade[2]. A group of nine birds, which included two of the following species, was noted.

Aythya affinis. Lesser Scaup

The presence of two of these birds with a flock of seven greater scaup at Umiat is significant, in that Gabrielson and Lincoln[3] reports the range as north only to Anaktuvuk Pass. This bird is rare on the north slope and not reported at all by Kessel and Cade[2] on the Colville River. The birds were seen well both on the water and in flight so that head shape and wing markings were noted with certainty. They were both males. The date of sighting was 23 June.

Clangula hyemalis. Oldsquaw

This species was abundant during the entire observation period and must be considered the commonest waterfowl species in the Simpson Lagoon, Harrison Bay area, as well as an abundant breeder and migrant. Flocks of up to twenty-five birds were seen daily on the small ponds at the point, or in the lagoon. At least one pair nested within the POW-2 compound, although the nest of the particular pair could not be located. Two other pairs were resident all summer near the airstrip. On a tundra hike 17 June, eighteen birds, all in pairs, were seen on the ponds over a seven mile transect. Every moderately sized pond had at least one pair. More significantly, a count was made of the non-breeding birds resident in Simpson Lagoon between Spy Island and Cottle Island on 16 August. One flock of five thousand birds was noted near the middle of the Lagoon, and an additional twenty-eight flocks consisting of from five to five hundred birds totaled 2725 in all. The smaller flocks were all near the islands, on both the Lagoon side and the Beaufort Sea side. Most were resting either on shore or among the ice floes, and would fly or dive at the approach of the skiff. These birds increase in number so that by late August the entire lagoon is littered with the feathers from molted birds. The majority of birds had not started to move in numbers by the 23rd of August when observations ceased. According to Gabrielson and Lincoln,[3] these birds will arrive in May and not depart until October when the sea ice is forming and the ponds are already deep with ice. Observations along the Colville were apparently all of resident breeders, and a total of thirty-six birds were seen. These were paired birds, on ponds from Umiat to Putu.

Somateria mollissima. Common Eider

This bird was noted very infrequently at Oliktok Point during the observation periods 12-18 June and 23 July - 23 August. Apparently, they migrate earlier and are settled down by mid-June. Five were seen flying east 13 June, and three more 14 June. None were noted as breeding in the area, and there was no movement by 23 August. None were seen on the Colville River in late June. These birds stage spectacular migrations past the Barrow area, but in general this movement is quite late, into October. They may not be nearly as abundant in the area east of Barrow, or are sufficiently scattered as to be seen only infrequently.

Somateria spectabilis. King Eider

In contrast to the above species, this eider was very common, and the only one apparently breeding in the area or seen other than in migration. Several pairs were noted daily in the small ponds and lagoons at the point from 12-18 June. Occasional flocks of ten or twelve were seen moving by, headed east. On 17 June, this species proved to be the most abundant waterfowl seen on the seven mile tundra hike with a total of twenty-six birds, all in pairs on ponds. As no nests were located, the actual breeding of these birds was not substantiated, but it appeared as though these pairs were courting and on territory. No birds were seen on the Colville River trip, but a block of six males and one female was seen in Simpson Lagoon 16 August, outside of Pingok Island. It would be significant to study the actual breeding record of this species in the area, as the concentration of paired birds was very high at Oliktok Point, and it may prove to be a center of breeding abundance.

Lampronetta fischeri. Spectacled Eider

This is one of those species that appears very hard to pin down with regard to distribution. One pair only was noted at Oliktok Point, and that on 17 June. A male and female flew very low past the observer while at a pond on the tundra. No others were seen in the Lagoon or Delta region. Kessel and Cade[2] reports this bird as commonly seen west of the Delta and later in the Delta itself. Perhaps this species is like the common eider, in that it moves around earlier and later than the observers were present, and would account for its not being seen more frequently. Gabrielson and Lincoln[3] places the center of breeding abundance as east of Point Barrow, so the bird should be noted more frequently.

Melanitta deglandi. White-winged Scoter

The only occurrence of this bird was on 17 June when a pair flew over a tundra pond at Oliktok Point, headed east. Not considered a common bird on the Arctic coast, this species is overshadowed by the more abundant surf scoter. One small flock of eight white-winged scoters was seen 27 June near Ocean Point on the Colville River.

Melanitta perspicillata. Surf Scoter

This bird was not seen at Oliktok Point, but numbers were seen in two locations near the Colville Delta. On 27 June, two rafts totaling 26 birds were seen in mid-river at Ocean Point. In August, while sampling from a launch in Harrison Bay, a very large raft was encountered, and numbered between two and three hundred birds. The boat passed through them for some time, and they continued to fly off or dive so that actual counting proved very difficult. The location was four miles north of the Nechelik channel of the Delta in Harrison Bay.

Oidemia nigra. Common Scoter

This bird has been recorded only once from the Colville Delta region by Gabrielson and Lincoln[3], and so must be considered quite scarce in the region. A single bird was recorded this past season at Oliktok, and unfortunately was a female picked up dead at the base of a radar tower at Oliktok Point. The specimen was very dessicated and somewhat decomposed, and so not salvageable, but the field marks were unmistakable, especially the large white cheek patch and dark legs and feet. It was discovered 14 June, but had been there several days.

Mergus serrator. Red-breasted Merganser

On 17 June, a pair of mergansers flew past the observer on the tundra going east across Oliktok Point. This proved the only sighting of the species in the area, and no evidence of breeding was noted. On the Colville River, red-breasted mergansers were seen three times. Six were seen at the confluence of the Chandler and Colville, a pair at Umiat, and another near Ocean Point, all between 23 and 27 June.

Buteo lagopus. Rough-legged Hawk

The most commonly seen raptor while on the Colville River between 23 and 29 June, rough-legs were encountered along all the bluff areas. Two nests were found at Umiat; one behind the pond being sampled, with three eggs, and one a mile downriver on the bluff of Umiat Mountain. Seven more pairs were seen at intervals as far down as Ocean Point, but no more nests were located. When the air was still, as in four instances and especially at Umiat, the adults could be heard crying at the intruding humans, and this helped to locate the nests that were found, as well as some birds in flight. This species was recorded twice at Oliktok Point in 1970 by Institute of Marine Science personnel; and, therefore wanders to the coast to hunt on occasion, but was not seen this summer (1971) during the observation periods.

Circus cyaneus. Marsh Hawk

One marsh hawk was seen in flight 25 June between the Anaktuvuk and Chandler Rivers on the Colville. No others were seen, and it was not noted on the coast at Oliktok Point.

Falco rusticolus. Gyrfalcon

A bird believed to be this species was watched at length 25 June while perched on a high bluff ten miles north of Umiat. The bird did not fly, but the color and size were indicative of this species rather than *F. peregrinus*, and the species is to be expected regularly along the bluffs. Cade[4] saw several pairs the same week, but our party made no other observations along the Colville, and none were seen in the Delta or Oliktok Point area.

Falco peregrinus. Peregrine Falcon

Much concern over this and the preceding species as to the future success of their nesting has generated intensive research and survey work in the known nesting areas. The bluffs along the Colville are prime areas for nest sites, and so a careful watch was kept. This species was seen on three occasions only, and in each case a bird was in flight along the upper crest of a high bluff. No aeries were found, but one bird landed and perched on a spot that was used frequently due to the abundance of droppings. Undoubtedly they were nesting in the area, as Cade[4] had some success at locating active nests in these same spots between Umiat and Ocean Point. Our observations were made 25 and 26 June. This hawk, as well as all preceding species of raptors, were absent from the coast region around Oliktok Point and Simpson Lagoon during the observation periods in 1971.

Lagopus lagopus. Willow Ptarmigan

When observations began on 12 June at Oliktok Point, two males of this species were in active courtship display in the tundra around the airstrip. They were very conspicuous in their flights and calling, one male frequently chasing another. They were seen for two more days, and then a single male was in the area until 18 June. No females were seen, nor were any nests discovered or family groups noted later in the season. This species is widely scattered along the coast and common further inland as well. They were seen in Umiat 23 June, and one bird at Ocean point on the tundra, 27 June.

Charadrius semipalmatus. Semipalmated Plover

On 24 July, a bird of this species was seen at the edge of a sandy pool behind the warehouse of POW-2. None were seen in the area before or after this one sighting, and presumably the individual was a post or non-breeding wanderer. Plovers were seen at Umiat (one pair) at the campsite on the river edge, and Kessel and Cade[2] reports it to be a common breeder in that area. It apparently did not breed down to the coast area, at least not at Oliktok Point.

Pluvialis dominica. Golden Plover

When observations started in mid-June, these plovers were among many species of shorebirds actively courting. At lease two pairs were seen the first day at the DEW site, and each day thereafter for a week, the courtship flight and call could be heard around the airstrip. A count was made 17 June along a seven mile transect. Nine pairs were seen, and two nests found on the tops of dry knolls. Each contained four eggs, and both adults indulged in distraction displays around the nest area. On 10 August, two flocks of plovers were seen in flight, suggesting flocking for migration. Fifteen birds were counted in two flocks on

Pingok Island on 17 August, and were the only ones seen on a skiff survey of the Jones Islands that day. Two more were seen with *S. squatarola* on 22 August on Oliktok Point. This species was also recorded at two places on the Colville River in June; on the tundra at Ocean Point and at Putu, a total of four pairs was counted.

Squatarola squatarola. Black-bellied Plover

Not normally encountered in wet tundra situations, this species was recorded only twice from the Oliktok area as a post-breeding migrant. 17 August, on Pingok Island, two birds were seen on the beach, and on 22 August, two more were seen on the tip of Oliktok Point with two *P. dominica*. The bird nests on the sandy islands of the Delta, according to Kessel and Cade[2], but none were seen on the Colville between Umiat and Putu, 23 June through 1 July.

Arenaria interpres. Ruddy Turnstone

At Oliktok Point, turnstones were found commonly right along the beach areas, where at least four pairs were resident breeders. They were not encountered back on the tundra at all, but by 25 July, two families each containing four downy young were living at the POW-2 site, feeding around the gravel areas and beach. It was the second commonest shorebird encountered 16 August on the beaches of the Jones Islands, where six groups totaling twelve individuals were counted. They had not left Oliktok by 23 August, and were apparently among the last shorebirds to leave.

Gallinago gallinago. Common Snipe

Heard once and seen twice at Umiat, and on four other occasions on the Colville River as far down as Ocean Point, where an individual was flushed from beside a marshy pond, 27 June. This species was not found at Oliktok Point, nor in the Delta.

Numenius phaeopus. Whimbrel

The only whimbrels seen were four individuals at Ocean Point, 26 and 27 June. Each acted like it was on territory, becoming very disturbed as we walked across the tundra. No nests were found, but these birds were almost certainly breeding there.

Erolia melanotos. Pectoral Sandpiper

This was one of several sandpipers actively courting in mid-June when observations started at Oliktok. Little activity was noted 12 June, but by 14 June, several males could be seen at the site in courtship flight, giving the distinctive "boo-boo-boo" sound from the inflated air sacs. On the tundra hike 17 June, ten pairs were counted, each with a male on territory. Not as much courting behaviour was noted then. By 23 July, very few birds were seen around the Oliktok area, and presumably most birds had moved to other areas. Twelve were seen on Pingok Island 16 August, the last to be seen in the area. Efforts to find nests were unsuccessful at the Point, although it was one of the commonest breeders; therefore, no egg counts could be obtained. The birds were not seen at Umiat, or along the river until at Ocean Point, 26 June, six pairs were counted on the tundra among the ponds being sampled. The males were on territory, but were not courting; incubation was presumably rather far along by that time.

Erolia fuscicollis. White-rumped Sandpiper

A rare bird on the arctic slope, this bird was found only once at Oliktok, as a pair was seen near the shore on tundra 17 June. Whether or not the pair bred could not be determined, and no courtship was noticed.

They were found at Point Barrow, but apparently did not breed according to Norton[5]. Flock[6] reported seeing three white-rumps near Oliktok on 4 August, leading to the conclusion that perhaps a pair or two may have stayed to breed in the area.

Erolia bairdii. Baird's Sandpiper

As many as four males in simultaneous courtship flight were seen at Oliktok between 12 and 18 June. On 15 June, a male was watched hovering and calling at about 150 feet for ten minutes before descending to the ground. They preferred the more open, gravelly areas along the beaches and driveways, in contrast to the semipalmated which was seen in wetter spots in courtship. One nest of *E. bairdii* was found with four eggs 14 June, on a dry knoll just east of the garage at POW-2. The incubating bird was flushed off the nest initially, when it gave a broken wing display. Subsequently, the bird would not display, but flew off rapidly and stayed some distance away. Eight pair were counted 17 June along the seven mile transect. They all were on territory in the drier areas of tundra. The species apparently disperses early, as no birds were found at Oliktok after 23 July and only two were seen 17 August on Pingok Island during the skiff survey of the Jones Islands. Six Baird's were seen at Putu in the Delta 30 June, but none upriver from the Colville Delta.

Erolia alpina. Dunlin

Common at Oliktok Point throughout the observation periods, this bird nested at the site and was the most abundant shorebird on the tundra 17 June; sixteen pairs were counted over a seven mile transect around Oliktok Point. Males were actively courting 13, 14, and 15 June - the flight call and glide being very characteristic. A nest containing four eggs was found and photographed 15 June, by watching the adult from a distance as it returned and settled in the grass. Very well hidden, the nest was in a broad area of wet tundra grass about five inches deep. Thirty-five dunlins were feeding in the shallow lagoon at the tip of Oliktok 17 August; six were seen the previous day in various spots along the Jones Island group. This shorebird was the last migrant in any numbers to be found at Oliktok Point.

Limnodromus scolopaceus. Long-billed Dowitcher

A species that was not seen in the area of Oliktok Point, but on one occasion only along the Colville River, at Ocean Point, 26 and 27 June. A flock of seven landed at the edge of a tundra pond and fed the evening of 26 June and three were seen in the same spot the following day.

Ereunetes pusillus. Semipalmated Sandpiper

Another common peep, this small sandpiper was courting in numbers between 12 and 18 June at Oliktok. It frequented the wetter edges of muddy ponds and marshes exclusively, and was found only in these locations along the tundra hike 17 June, when twenty-four individuals were counted. No nests could be located around Oliktok, although it must have bred abundantly. By 23 July, this bird was generally absent from the area, and a total of seven birds were seen between that date and 1 August. None were seen after that date. While on the Colville River at Putu, *E. pusillus* was seen feeding in the muddy areas 28 and 29 June. A total of eighteen birds was counted, but no nesting was documented in the Delta.

Tryngites subruficollis. Buff-breasted Sandpiper

This is another rare species of the arctic slope and is to be found more abundantly to the east. Some years, they appear to show up in greater numbers, and usually in conjunction with stilt sandpipers, according to Kessel[7]. Both species were reported by Norton[5] in the Deadhorse area the first week of June, but only *T. subruficollis* was noted at Oliktok. On 17 June, while returning on the last mile of the tundra hike, one bird was spotted near the end of the airstrip. It was very wary, and could not be approached. Later, five more were seen in a large open and dry area of tundra near the airstrip. Soon, all six birds could be counted as they performed an elaborate and far-flung display of courtship flights and postures covering an area of hundreds of square yards. When a bird landed, it would raise one or both wings, look about, and usually fly soon toward another individual. The only vocalizations heard were "clicking" sounds when the birds were on the ground. It could not be determined which were females, if any; males are known to display and posture frequently to members of their own sex. This species displays one of the most elaborate and interesting courtships known among shorebirds, and it proved delightful to watch. They were not seen subsequently, and presumably did not stay to breed at Oliktok. No others were seen in the area.

Limosa lapponica. Bar-tailed Godwit

Kessel and Cade[2] reports this species as occurring in the Delta of the Colville, but we observed it only at Ocean Point while on the river. On 26 and 27 June, males on territory were very noisy whenever observers were on the tundra. Five birds were counted near the sampling ponds, and a flock of seven birds flew over 26 June. They were the first birds seen in the area, and continued to be the most conspicuous species due to the incessant alarm call uttered on territory. No nests were located and the bird was not seen down river or at Oliktok Point.

Phalaropus fulicarius. Red Phalarope

When observations commenced 12 June, this bird was the most abundant shore bird at the POW-2 site. Every melt pond had at least a pair feeding. On 13 June, forty-seven individuals were counted along the mile long spit at the point. They were dispersed onto the tundra within a week, and on 17 June thirty paired individuals were counted on the tundra around the site. Although many suitable localities were searched, no nests could be found, and no fledglings noted later in the season. By 23 July, and until 23 August, these birds had dispersed and were not found as commonly as *L. lobatus*. The reverse was true earlier, in June. While surveying the Jones Islands, only nine *P. fulicarius* were seen along the shallows. This species becomes pelagic in the fall, and presumably most had moved further out to sea by late July. Red phalaropes were noted commonly at Umiat and along the river to Putu. More than a dozen were present at Ocean Point alone, on 26 and 27 June. Eight were seen at Putu the following two days, and a total of thirty-five between 23 June and 1 July along the entire Colville River area.

Lobipes lobatus. Northern Phalarope

This species was not nearly as abundant as the preceding, as a breeder at Oliktok Point; the maximum number seen in one day in June was six, in pairs on the tundra 17 June. It apparently overlaps *P. fulicarius* in this coastal region, and is the more common phalarope further inland. However, in July and August, this species is found in numbers while flocking for migration. During a survey of the Jones Islands on 17 August, twenty-five *L. lobatus* were counted. It was the only phalarope seen at Oliktok after the middle of August, with two seen on the end of the point 16 August. Two pair were found at Umiat 23 June, and six birds at Ocean Point plus an additional five at Putu were the total seen along the Colville River by the end of June.

Stercorarius pomarinus. Pomarine Jaeger

Jaeger populations are affected by the abundance of lemmings which are the staple food along the coast, and in the absence of these microtenes, jaegers will be scarce. This was apparently the case at Oliktok Point in 1971, as only two of this species was seen in June, on the 12th, 13th, and 15th. They may have still been in migration and did not stay to breed due to lack of food supply, as no birds were seen the rest of the season. A very high population of lemmings at Barrow created an equally high population of breeding *S. pomarinus* to the exclusion of the other two species. No lemmings were seen at Oliktok Point during the periods of observation, and this must account for a nearly total lack of predatory birds, including hawks, jaegers, or owls. This species was not encountered anywhere along the Colville River, but would not be expected far inland as readily as *S. longicaudus*.

Stercorarius parasiticus. Parasitic Jaeger

With the absence of the larger and more aggressive pomarine species, this bird often fills the gap as a breeder. At Oliktok, *S. parasiticus* was seen flying over tundra 17 June, and a dark-phased bird was at the airstrip for four days the week before. This was the only jaeger seen in July or August, as five birds (three groups) were found among the Jones Islands 17 August while taking a survey by skiff. Parasitic jaegers were also found on four occasions along the Colville; one at Umiat 24 June, two (apparently a breeding pair) at Ocean Point 27 June, and one at Putu the following day.

Stercorarius longicaudus. Long-tailed Jaeger

This jaeger is more at home further inland than Oliktok Point where it does not have to compete with its more aggressive cousins. However, Kessel and Cade[2] reports it out to the Colville Delta, and one bird was seen 17 June on the tundra three miles from the POW-2 site. Several unidentified jaegers were seen out over the tundra between 13 and 16 June which could have been any one of the three species; it was during the period of general movement of these birds, and was more than likely not this species. Long-tails were found at Umiat 24 June, and one bird near the Chandler River 25 June was the only other one seen on the riverboat trip.

Larus hyperboreus. Glaucous Gull

An abundant resident species both as breeder and non-breeder, this gull is ever present along the coast and the outer islands of Simpson Lagoon and Oliktok Point. In mid-June, between the 12th and 18th, at least fifty gulls were in evidence around the site, attracted mainly to the dump area and the mess hall where they would congregate for handouts. Birds in passage overhead, in small groups, were seen constantly. Most of these birds were non-breeders, and the same population appeared stable throughout the season. On trips to the Jones Islands, or in Simpson Lagoon, glaucous gulls in breeding pairs were found at eighteen separate locations, in each case in sandy, exposed spits or narrow islands. On 17 June, while on the tundra hike, only three birds were seen as far as three miles from the coast, and they were all over the largest ponds; a total of eighteen were seen that day, the rest being near shore and excluding the resident site population. In August along the Jones Islands, one hundred twenty glaucous gulls were counted in twenty-eight separate groups, one of which contained twenty-nine birds. The species was second in abundance only to the oldsquaws. Along the Colville River, this gull was also seen commonly from Umiat to Putu between 23 June and 1 July. At least one pair was nesting at the largest pond at Putu, with nineteen more counted at Putu alone.

Xema sabini. Sabine's Gull

Compared to the preceding species, this bird was quite scarce at Oliktok; five seen on 14 June was the highest number at one time, and two birds appeared to take up residence at the edge of a pond on the point, but breeding was not substantiated, and they had left the area by 23 July. One bird was seen over the tundra 17 June, and three counted in the Jones Islands 16 August. Apparently restricted to the coast, this gull may not be an abundant species at any time in the area; Kessel and Cade[2] reports this bird in small numbers also, and none were seen in June 1971 along the Colville or Delta by Institute of Marine Science personnel.

Sterna paradisaea. Arctic Tern

Another widely scattered species, but not abundant in the area of Oliktok Point, arctic terns were seen on three days in June - the 12th, 14th, and 17th. No more than two birds were seen at once, and these may have been a resident pair. It was not known if nesting took place, but the species was more numerous in August among the Jones Islands, where twelve birds, in five separate groups, were seen on the 16th. Another pair was seen at Umiat 23 and 24 June, and a total of five more were seen along the Colville River and at Putu between 24 June and 1 July.

Cepphus grylle. Black Guillemot

Gabrielson and Lincoln[3] are not explicit concerning the range of this bird except to say that it occurs as a straggler off the arctic coast of Alaska. It is seen regularly in Barrow in the summer, and winters in the leads off the coast. The presence of one individual on 16 August in Simpson Lagoon just off Oliktok Point is not unusual, but was unique in that it remains the only record for the area of any *Alcidae* seen by the observers during the periods in June, July, and August 1971. More offshore work would undoubtedly turn up more occurrences of this and perhaps other species like *Uria* sp. The water in Simpson Lagoon is very shallow, less than ten feet in most places, and quite turbid, making the area apparently less attractive to this species than beyond the Jones Islands in the Beaufort Sea.

Nyctea scandiaca. Snowy Owl

A single owl was present at the DEWline site POW-2 from late July through the first week in August and was joined by a second bird 6 August. The species was not present for the breeding season, perhaps due to a lack of microtenes, and was not seen between 23 June and 1 July along the Colville River. One bird was spotted from a Cessna as the plane crossed the Delta 1 July, and the species was seen in abundance as we approached Point Barrow along the coast.

Hirundo rustica. Barn Swallow

At 1445 hours on 15 June, a swallow was observed flying around the buildings and site POW-2. As it passed overhead several times, all field marks were noted, especially the dark and continuous band across the breast. This mark suggests the possibility that the bird seen was the European barn swallow, *H. r. rustica,* which has been recorded once in Alaska at Point Barrow. According to Gabrielson and Lincoln[3], Brower took a bird in June of 1934 which proved to be this race. The bird at Oliktok could not be collected, so the race cannot be substantiated. The range of the American race extends to the Yukon valley, but does not include the arctic slope except for a few isolated records.

Corvus corax. Common Raven

Between 23 and 27 June, while on the Colville River, ravens were conspicuous sights along the bluffs. Fourteen were seen between Umiat and

Ocean Point, mostly singly and apparently not on territory. Kessel and Cade[2] reports this species as nesting along the bluff areas, but we were not able to determine if any we counted were nesting. A single bird appeared at Oliktok Point in early August, and was present intermittently until 23 August when observations ceased. Personnel at the site reported that ravens, attracted by the dump, have stayed quite late into the fall.

Turdus migratorius. Robin

This species was not recorded at Oliktok Point, but was found only at Umiat on 23 and 24 June. Two birds were seen, apparently not a mated pair, in brushy undergrowth, and a singing bird heard 24 June.

Hylocichla minima. Gray-cheeked Thrush

Kessel and Cade[2] reports this bird as far down the Colville River as Ocean Point, therefore careful record was kept of observations below this point. The bird was commonly found all along the brushy areas from Umiat down, and the last sighting was on a bluff at the confluence of the Itkillik River and the Colville about six miles above the Delta, 28 June. They doubtless occur wherever heavy brush is present; the species is known to wander north to the coast as many records from Barrow to the Bering Sea are extant, but the bird was not recorded at Oliktok Point this season.

Phylloscopus borealis. Arctic Warbler

The voice of this species is very distinctive, and once learned serves to identify it at a distance without having to see the bird. Again, records were kept of the distribution of arctic warblers below Umiat on the Colville, and they were heard last about five miles above Ocean Point. Whenever camped or stopped in suitable brushy habitat, the voice could be heard; they may be present to or below Ocean Point, but we were not in the right habitat to hear them. One individual (the last one found) was attracted by a swishing sound and was observed at very close range in the brush to varify the identity. Not normally recorded out of its specific habitat range, arctic warbler was not seen, or expected, at Oliktok Point.

Motacilla flava. Yellow Wagtail

On 15 June, an individual wagtail was observed flying about the tundra near the DEWline site at Oliktok. A distinctive and conspicuous bird when present, the one bird was the only record for the season at Oliktok Point. They were common along the Colville River from Umiat down to Ocean Point. Preferring the taller brush interspersed with open areas, they would hover at 50 feet uttering the incessant alarm call. As many as five males could be seen at one time on 28 June between Ocean Point and the Itkillik River, at the sampling location and campground. None were recorded from the Delta at Putu.

Lanius excubitor. Northern Shrike

One shrike was seen on the Colville River, halfway between the confluence of the Anaktuvuk and Ocean Point, about opposite Sentinel Hill. The bird flew across the river from some high brush on 26 June. Kessel and Cade[2] recorded the species from Umiat, but no further north. Therefore, this sighting may be significant; doubtless the bird is widely scattered throughout the high brush habitat and hard to pin down to a specific distribution. No other sightings were made.

Dendroica coronata. Myrtle Warbler

Being a very common and widespread species in the interior, and having wandered to Barrow at least twice according to Gabrielson and Lincoln,[3] the presence of a single bird at Oliktok was not extraordinary. On 17 June, a small bird was seen flitting around the tundra near shore. Very plain brownish and heavily streaked, with prominent wing bars, the yellowish patch on the rump and crown, with less distinct yellowish wash on the shoulder was diagnostic and left no doubt as to the identity being a female *D. coronata*. It shortly flew some distance away and could not be secured for a specimen; it was not subsequently seen in the area, nor was this species found in Umiat or along the Colville River.

Acanthis hornemanni. Hoary Redpoll

Following the example of Kessel and Cade[2], the references to redpolls on the arctic slope will assume that this species is the one found almost exclusively as far north as the coast at Oliktok Point. Redpolls were seen at Oliktok 15 June, when three birds were feeding at the base of a radar antenna, and 17 June on the tundra two miles from the site. The status, age, or sex could not be determined and speculation as to the birds' breeding in the area remains unsolved. Redpolls are common breeders in all brushy areas along the Colville, and were seen and heard from Umiat to Putu between 23 June and 1 July. They would respond to swishing notes and could be coaxed to investigate the sound at close range, often appearing out of the brush six at a time. From close observation, it appeared as though all individuals seen were *A. hornemanni* rather than *A. flammea*. No actual nests were found.

Passerculus sandwichensis. Savannah Sparrow

Not recorded at Oliktok Point at all, but seen sporadically along the Colville River from Umiat to Putu between 23 June and 1 July. The birds were heard at Umiat on 24 June and ten more heard or seen at the Chandler River, Ocean Point, and Putu in the Delta. Not as conspicuous as some other small passerines, it may be more abundant than these records show for the habitat was ideal all along the river, and Kessel and Cade[2] report the species in several locations as common.

Spizella arborea. Tree Sparrow

Another species that is more restricted to brush areas and small trees, tree sparrows were not encountered at Oliktok Point, but in small numbers at several locations along the Colville River from Umiat as far down as the lake on the east side of the river between Ocean Point and the Itkillik River. A total of thirteen birds were seen or heard; five at Umiat and two at the above-mentioned spot 28 June.

Zonotrichia leucophrys. White-crowned Sparrow

Found as far north as Putu camp in the Delta of the Colville, this conspicuous bird was searched for in particular to determine how far down (north) the river it might occur. One bird was seen at Putu 30 June, several between the Itkillik and Ocean Point, but none at Ocean Point itself. Two were seen and heard at the Chandler River and several more heard at Umiat, especially up Bear Paw Creek, with a pair residing near the camp spot along the Colville. The species was not recorded at Oliktok Point.

Passerella iliaca. Fox Sparrow

Closely associated with other brush-loving passerines, this bird was not found in the vicinity of Oliktok Point, but rather commonly along the Colville River from Umiat to Ocean Point between 23 and 27 June. It was heard all along Bear Paw Creek at Umiat, seen and heard near the Anaktuvuk and Chandler Rivers, and two were heard at Ocean Point 27 June. The fox sparrows were found in denser brush than the other species, and could not be attracted by swishing noises as readily as tree sparrows, redpolls, and white-crowned sparrows. Although apparently breeding as far downriver as Ocean Point, no nests were located.

Calcarius lapponicus. Lapland Longspur

Wherever one went on the arctic slope, with the exception of very extensive brushy areas or the barren outer islands off Simpson Lagoon, this ubiquitous species was the abundant breeder and resident. On the tundra at Oliktok Point, it far outnumbered any other passerine species. On 17 June, thirty-eight birds were counted along a seven mile transect, which included some beach area that was not suitable habitat. All the males were engaged in courtship displays which consist of long flights and glides while singing. One nest containing six eggs was found at the base of a dwarf willow on a hummock. The height of courtship appeared to be at the onset of our observation period, 12 June, and continued for the next week. In late July and August, the birds were not as conspicuous, although several large flocks of up to fifty or sixty birds were seen in mid-August as they gathered for migration. No longspurs were seen after 22 August, but observations ceased at Oliktok at that time, and there may have been some late migrants. As was expected, the longspurs were seen commonly on the tundra above Umiat and in all open areas along the river up to Ocean Point and at Putu between 23 June and 1 July. These birds were all in the process of incubation and very little display activity was noted.

Plectrophenax nivalis. Snow Bunting

At Oliktok Point, this species was restricted to the extreme beach areas of the coast and there they were abundant breeders. From 12 June when observations started, the song of this bird was heard constantly around the site; by 16 June, seven nests had been located within one-half mile of the DEWline modules. Egg dates were kept on record cards and the final clutch sizes ranged from five to a maximum of seven in one nest. At least three more pairs were nesting at the site, and the unusual concentration of these nests must be attributed solely to available habitat, as every nest found was under a discarded fifty gallon barrel imbedded in the sand, providing protection. In other areas along the coast, where the same protection was not available, buntings were scarce. One nest was situated eight inches from a water valve at a storage tank, under a barrel, and was disturbed almost daily by personnel for maintenance. Irregardless, all seven young were raised sucessfully, as were all other clutches apparently. Observers were not present for the hatch period, and undoubtedly some mortality did occur; from 23 July into August, bunting families were feeding and molting down feathers all around the site. A conservative count revealed twenty-five birds within a thousand feet of the modules on 30 July. Site personnel were aware of the nests and respected these conditions, taking personal pride in the numbers of these attractive birds. By mid-August, most of the families had dispersed, and occasional large flocks would be seen feeding around the tundra near shore. Only three birds were counted in the Jones Islands on 16 August, and birds were still present 23 August when observations ceased. Presumably, the species stays on the tundra at least until September, when migrations are noted further inland according to Gabrielson and Lincoln[3]. Snow buntings were not recorded anywhere along the Colville River or at Putu between 23 June and 1 July.

CONCLUSION

The birds noted at Oliktok Point are typical of the avifauna found on the arctic slope of Alaska, and the abundance of certain species of waterfowl and shorebirds points out the tremendous value of this region as a breeding area. This report cannot serve as a comprehensive survey of the birds of the entire region as the areas covered were too small and observation periods limited to seven weeks out of the whole season. However, methods learned this year will be employed and expanded to include a broader scope of future surveys in the area next year. This data should supplement and corroborate much that is known about the distribution of birds in the region, as well as give clues to species that may require more intensive work.

Each season is different with regard to weather patterns and species distribution or abundance. Several species known to occur either as breeders or migrants were not observed by Institute of Marine Science personnel in 1971; field work in the Colville Delta itself would have turned up some of these species, as would surveys just east or inland of Oliktok Point. Hopefully, next season will include extensive aircraft surveys combined with ground work to round out a somewhat sketchy picture, as the main value of this report will be found in its treatment of those species found in the immediate area of Oliktok Point.

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CHAPTER 12

RECOMMENDATIONS

The primary purpose of this study was to obtain baseline data for a previously inadequately studied area, which would then be available for interpretation in the light of increased human activity in the region. Such data now exist as a result of these efforts, and the effects of increased usage can be monitored with reference to this information. In many of the areas of study, it is difficult to make recommendations, and the data and their interpretation must speak for themselves at this stage. However, there are some aspects in which strong suggestions can be made realistically:

1) The development of isolated pockets of hypersaline water during the winter, and the importance of these to fish survival suggests that organic loading would be a serious problem in the lower portions of the Colville River. Already, biological activity reduces oxygen concentrations in the winter, and this activity is remarkably high considering the low temperatures extant. Any increase in rate of oxygen utilization could result in total depletion, with resultant fish kills. The importance of the fish resource as a supplement to coastal marine mammal resources for the native population is well-understood, and increased utilization of freshwater fishes for subsistence and commercial purposes is expected in response to settlement of the Alaska Native Claims Act, which has brought several new families to the area. Waste disposal is thus a potential problem.
2) The influence of man on benthic and planktonic components of the biota is less likely to be extreme, although oil spill hazards are considerable and could change or reduce the populations. In particular, we know nothing of the behaviour of oil with respect to ice cover, and of the possible effects of spills on the ice algae and associated fauna, which form an

important part of the annual primary and secondary productivity regime. We strongly recommend studies along these lines.

3) There is a relatively active movement of beach and barrier upland material from east to west and this will, to a large extent, dictate areas of exploitation. However, considerably larger volumes of sediment may be transported on a sporadic, cataclysmic basis as a result of storm action emanating predominantly from the northwest.

4) Of all the shore zones, the area where submarine/subsurface construction could be accomplished with the greatest facility would be within the lagoon complex. These areas are predominantly frozen to the sediment surface during the winter months and protected from ice scour by the seaward uplands. Potential ecological damage would have to be assessed in each individual case.

APPENDIX - CHAPTER 5*

RESULTS OF DETAILED CLAY MINERAL STUDIES

Sample Location CR 3 (Figures 1 and 2)

Representing material furthest upstream of those sites investigated, the mineralogic relationships were not clearly definable. This material was characterized by an unusually high amount of iron oxide/hydroxide component, coating the other mineral particles, and causing the X-ray diffraction effects to be somewhat difficult to interpret. This was due to the high background resulting from fluorescence of iron caused by the copper K-alpha radiation employed, as well as to the poorly crystalline nature of the ferruginous material, and the masking effect of coatings on the grains of the clay minerals. In order to deal with this problem, the treatment to remove free iron oxides described by Jackson[19] was resorted to. This procedure did indeed result in improved X-ray diffraction effects from the residual materials, but there was cause for concern regarding its effect on the clay mineral phases present, notably the chloritic materials, particularly in the finer particle-size ranges. Thus, we present these data with some reservations with respect to their validity vis-a-vis the natural assemblages, and with respect to comparison with materials from other localities which were not subjected to this treatment. The data on some of the CR 3 samples, as well as for those from locality CR 5, indicate the likelihood that some modifications are effected in the clay mineralogy as a result of this procedure. As the extent of these changes is difficult to assess, the treatment was not used routinely in the further course of this investigation.

Replicate analyses were made of samples selected at random, entailing

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*All figures and references cited are found in Chapter 5.

separate preparation of plates and separate treatments, in order to evaluate the reproducibility of the experimental procedures and allow some estimation to be made regarding experimental error and analytical precision. Given the other complexities of analyses of this sort, it was not deemed appropriate to explore this matter in a more shopisticated manner in the present study.

These data show that the glycol-expandable and non-expandable 2:1 layer lattice silicate components (the smectite, 17Å and "illite", 10Å, respectively) do not vary greatly within the particle size ranges examined. Furthermore, the 17/10 ratio does not exceed 2.0 (Figs. 9 and 10), which suggests that the smectite/illite ratio is rather low in these materials. The 7/10 ratio in unglycolated specimens (Fig. 11), which is interpreted to represent a measure of the amount of combined chlorite plus koalinite (7Å peak) relative to the amount of illite plus vermiculitic material (10Å peak) is lower for the finest particle size fraction and somewhat higher and essentially constant for the two coarser size intervals. This represents another example of the predominance of chloritic and kaolinitic phases in the coarser size ranges of sediments, which has been noted in many other studies reported in the literature. Replicate analyses of the KCl and NaCl treated specimens (Figs. 11 and 12) provided a useful feeling for the significance of variations in the ratios. On this basis, the 7/10 ratios of the glycolated specimens (Fig. 11) appear to be significantly higher, for each particle size fraction, which is most likely attributable to glycolation and expansion of a certain amount of the components recorded as "10Å material" in the anglycolated specimens (Fig. 12). The sense of trend is somewhat different for the glycolated specimens, in that the coarsest fraction shows the highest 7/10 ratio, while the two finer fractions are somewhat lower. However, the overall trend of increasing 7/10 ratio with increasing particle size is discernible in these glycolated specimens (Fig. 11). It is noteworthy that, in each instance, the 7/10 ratio is higher for the KCl versus the NaCl treated samples, for a given particle size interval, for each of the glycolated or non-glycolated suites. This strongly suggests that the 10Å component in these materials does not contain appreciable amounts of vermiculitic material. Indeed, if the differences in the data are significant, as their consistency in sense seems to suggest, this behavior with K^+ and Na^+ exchange is difficult to rationalize on theoretical grounds. It is suggested that perhaps the treatment for removal of free iron oxide may have had some effect here.

The 1/2°2θ per minute scans endeavoring to resolve the 3.52Å and 3.58Å (chlorite and kaolinite, respectively) peaks were intelligible only for the two coarser size ranges (Fig. 14); neither of these peaks was discernible for the <0.3μm specimen. However the mere detection of kaolinite in the coarser size intervals provides useful information within the context of the present study.

In the case of CR-3 specimens, problems of interpretation of the X-ray traces from these assemblages arise due to the rather ill-defined peaks and low peak to background relationships, particularly in the <0.3μm size range. It appears that "mixed-layered" phases resulting from inheritance-weathering-fluvial reconstitution effects are not dominant in this sample. Rather, the minerals present tend to be more representative of "end-member" types, although the relationships are less than well-defined, particularly in the finest size fraction, where line-broadening effects combine with the iron oxide problem to complicate interpretations.

Sample Location CR-5 (Figures 1 and 2)

As mentioned previously, materials from each particle size interval from this locality were divided into two aliquots, in order to assess the effects of the free iron oxide removal treatment.

First the data from the routinely prepared specimens will be discussed, next the analogous specimens which were treated for the removal of free iron oxide will be dealt with, and then comparisons between the treatments will be made.

The smectite/10Å material component appears to decrease with increasing particle size (Figs. 9 and 10). The materials in each of these particle size ranges contain considerable amounts of smectite, ranging from a predominant amount in the <0.3μm size, through dominant in the 0.3-<1.0μm range, to perhaps subequal amounts of smectite, 10Å, and combined 7Å materials in the 1.0-<2.0μm range. Further emphasizing these relationships are lower 7/10 ratios for the KCl+glycol specimens versus the other cation+glycol specimens, for a given size fraction (Fig. 11). This relationship is maintained for the KCl versus the NaCl treated non-glycolated specimens as well (Fig. 12), and strongly suggests that an appreciable portion of the 10Å component consists of "degraded mica/vermiculite" material. As regards the relative proportions of 3.52-3.54Å/3.58Å scattering phases present, essentially the ratio appears to be fairly constant among the three particle size ranges, at a value suggesting a considerably greater proportion of chloritic to kaolinite material (Fig. 14).

In the analogous specimens which were subjected to the free iron oxide removal procedure, the same sense of trends is shown, although there do seem to be several differences in ratio values sufficiently great to cause some concern regarding the effect of this treatment on clay mineral structures, particularly in the finest particle size range (Figs. 11 to 14). In particular, the NaCl and KCl treated specimens appear to have had their characteristics somewhat altered, and in a manner suggesting that fine-grained chloritic phases may well be preferentially susceptible to attack by the reagents employed to remove the "free iron oxide". This might be anticipated, particularly for chlorites containing appreciable iron. Therefore, due to these effects, as well as uncertainties regarding aspects relative to different clay mineral compositions, the free-iron oxide removal procedure was not utilized further during the present study.

This sample station, CR 5, is located at the mouth of the Kogosukruk River, where it enters the Colville River. The Kogosukruk River has its headwaters some 24km to the south, in the region northeast of the settlement of Umiat. This is the area in which the "Umiat Bentonite", a well developed montmorillonitic smectite, with certain beidellitic affinities, outcrops. This material has been studied by Anderson and Reynolds[54], who thoroughly characterized its mineralogic, chemical, and physical properties. Reference to this work, together with personal communications between Reynolds and Mowatt, 1972, affirm that the material represented at sample locality CR 5 contains an appreciable amount of this bentonite component. Thus, an opportunity is afforded to monitor the sedimentologic, mineralogic, and geochemical behavior of this well-defined smectite during the course of its subsequent sojourn in the sedimentary regime from this locality, downstream in the Colville River, and into the marine environment. It is felt that this is potentially a valuable parameter to consider in any attempt to delineate trends and mechanisms of sedimentation and sediment transport in this region, as well as in endeavoring to elucidate mineralogic-geochemical relationships regarding possible diagenetic effects in these environments. The Colville is a truly Arctic river, having its drainage basin entirely north of the Arctic Circle, and this furnishes uniqueness to the setting which is of added interest to the present and planned detailed work.

Detectable amounts of mixed-layer materials appear to be present in each of the particle size intervals, being particularly apparent in the heat-treated specimens. The data suggest that these phases represent interlayered "illite/chlorite", "vermiculite/chlorite", and/or "smectite/

chlorite" components, presumably representing materials resulting from the effects of heritage and weathering prior to deposition at locality CR-5. The large amount of well-defined smectite in these samples precludes clearer elucidation of the nature of the mixed-layer components by the various cation exchange treatments in this instance. However, there does seem to be noticeably less mixed-layer material in the coarsest size fraction, which seems to further support the above contention as to the nature and origin of these components. The X-ray diffraction manifestations of the mixed-layer phases are, if anything, somewhat more clearly defined in the specimens which were subjected to the free iron oxide removal treatment, presumably due to the "cleaning-up" effect relative to the iron oxide. It is difficult to assess any effect of the treatment on the mixed-layer materials themselves, although such effects might be anticipated. It is also entirely possible that an appreciable amount of mixed-layered illite/smectite, a commonly occurring material geologically, might be present in these sediments, but not be detectable due to the high content of discreet smectite.

Sample Location CR-7 (Figures 1 and 2)

The relative amount of smectite to 10Å and combined 7Å materials is considerably less at this sample station, as compared to location CR-5 upstream (Figs. 7 to 10). However, although less striking, the same sense of trend of decreasing 17/10 and 17/7 ratios with increasing particle size is seen at locality CR-7. Similarly, again the KCl+glycol treated specimens show consistently lower 17/10 and 17/7 ratios than their particle-size equivalents which have been treated with NaCl, $MgCl_2$, or sea water (Figs. 8 and 9). This again suggests the presence of a significant component of "degraded mica/vermiculite" in each size fraction of this sample. This is emphasized by the 7/10 relationships for the KCl+glycol versus the other cation+glycol specimens. The X-ray data demonstrate a well-defined trend of increasing 7/10 ratios with increasing particle size, again reflecting increased proportions of the combined chlorite plus kaolinite component relative to the 10Å materials in the larger size ranges. Since the data indicate a predominant amount of chlorite relative to kaolinite, the further interpretation of the 7/10 trend as primarily representing increased amounts of chloritic material relative to "illitic" phases as a function of increasing particle size suggests itself. This is further supported by the trend of the 14/10 ratios.

Again there are indications of the presence of a detectable amount of mixed-layer material in each particle size range, although the proportion is lowest in the coarsest interval. Due to the considerably lower amount of smectite in these samples, as compared to those from CR 5, the interstratified phases are discernible in some of the cation-treated specimens, as well as in the heat-treated specimens. Again, the interpretation is that the mixed-layer materials represent a vermiculite-illite-smectite/chlorite phase, or combination of such phases. Due to their low concentrations in these multicomponent samples, better definition of their nature does not seem feasible. The presence of interstratified illite/smectite is also suggested by the X-ray traces, but difficult to verify more substantially.

Sample Location CR 8 (Figures 2 and 3)

Interestingly, the analyses portray a definable trend of increasing 17/10 and 17/7 ratios with increasing particle size (Figs. 8 and 9). This might be interpreted as reflecting increasing amounts of expandable "degraded mica/vermiculite" as a function of particle size, given the relatively low amount of expandable component in the <0.3μm range, as compared to the materials from locations CR 5 and CR 7. However, this trend might also be interpreted as representing a sedimentologic effect, resulting from non-deposition of finer grained smectitic materials at locality CR-8. These relationships will be discussed in the present paper, but must be appreciated at the present time in order to attempt an evaluation of the clay mineral assemblage at this locality. The data also suggest that a maximum in 7/10 ratios in the intermediate particle size interval, 0.3-<1.0μm represents a greater proportion of chloritic component relative to 10Å phases. The KCl+glycol versus NaCl+, or sea water+glycol relationships suggest that an appreciable portion of this 10Å material represents somewhat expansible degraded illite-mica-vermiculite, the presence of which is most noticeable in the coarsest size fraction, 1.0-<2.0μm. Parallel 7/10 ratios of the KCl+glycol versus $MgCl_2$+glycol and sea water+glycol specimens are worthy of note, although a clearer understanding of the significance of this demands further study, currently in progress. It is tentatively suggested that an appreciable amount of "degraded" chlorite may be present in the 0.3-<1.0μm size range, with resultant "reconstitution" to a better-defined chloritic material attendant upon $MgCl_2$ saturation, and that this material may show a degree of analogous behavior upon KCl saturation. In other words, it may be difficult, with KCl treatment alone, to differentiate between some degraded micas and degraded chlorites. If this interpretation is correct, the usefulness of the variety of treatments used in the present work is further affirmed. The 14/10 ratios confirm the increased proportions of chlorite to illite+smectite+other 10Å phases in the coarser size ranges.

The diffractometer traces indicate the presence of mixed-layer materials in each of the particle size intervals. The phases are more readily discernible in this sample as representing a vermiculite-illite-smectite/chlorite component together with probably vermiculite-illite/smectite as well.

Sample Location KR-1 (Figures 2 and 3)

It is clear that these materials are quite low in smectite, as shown by the 17/10 and 17/7 ratios (Figs. 8, 9 and 10). Any trends as a function of particle size might be felt to be more apparent than real. However, the data seem to indicate a similar sense of trend for the sea water+glycol specimens, although the relationships for the KCl+glycol and NaCl+glycol specimens are not as well defined. Due to insufficient sample material, the $MgCl_2$ saturation treatments were not made of this sample, but the relationships seem to be reasonably interpreted nevertheless. The general trend is one of increasing 7/10 ratio with increasing particle size, The data suggest an appreciable decrease in the relative proportions of chlorite to kaolinite in the 0.3-<1.0μm size range, together with roughly subequal amounts of total 7Å/total 10Å components in the 0.3-<1.0μm versus the 1.0-<2.0μm size intervals. Thus, a significant concentration of kaolinite is seen in the 0.3-<1.0μm size range, superimposed upon the afore-mentioned 7/10 trend as a function of particle size. In the three-size intervals, the contribution to the total 10Å components of any degraded mica/vermiculite materials is not detectable, which is not surprising, given the fact that this sample station represents a marine locality and hence, a departure from the fluvial/deltaic materials previously discussed. An apparent slight maximum in smectite relative to the other phases is seen in the 0.3-<1.0μm size range, together with the somewhat more noticeable maximum in kaolinite. As clearly demonstrated by the 550°C treated materials, the chlorite/10Å materials proportions increase with increasing particle size. This sense of trend is common to the other localities as well and appears to be a characteristic feature of these assemblages.

The diffractometer traces indicate small but significant amounts of mixed-layer components in each of the particle size ranges, again representing a vermiculite-illite-smectite/chlorite and a probable ermiculite-illite/smectite phase, apparently persisting in the marine environment at this locality.

COMPARATIVE MINERALOGY

In this section, an attempt is made to demonstrate and discuss the observed relationships among the clay mineral assemblages representing the five sample sites investigated to date. Figures 8 through 14 illustrate these relationships.

Certain trends are discernible from the figures, presumably reflecting differences in clay mineral suites resulting from various sedimentologic and geochemical factors. Careful scrutiny of some of these data appears to warrant further, more specific comments.

Figures 9 and 10 portray the 17/10 ratios and Figure 9 compares the 17/10 ratios for KCl+glycol versus NaCl+glycol specimens. The latter plot shows a decided trend towards a decrease in the values of this parameter as one proceeds from locality CR-3 to KR-1. Interestingly, this trend, as well as the absolute values for the parameter, in general track quite nicely for the various particle sizes as well. Even the three apparently somewhat "anomalous" high values off this main trend appear to define a sub-trend parallel to the primary one. Admittedly the data are not that abundant to permit a vigorous defense of these apparent relationships, but the trends do seem to be real. Close inspection of Figures 7 through 10 shows that, with the exception of the materials from locality CR-5, where the Umiat Bentonite smectite dominates the assemblage, the 17/10 ratios range in value from a maximum of 2.2 on down to the 0.1 neighborhood. This certainly suggests that the sediments studies are composed of a greater proportion of 10Å materials, relative to smectitic phases, for each of the particle size intervals. This may be primarily a relection of non-deposition of smectite, due to various sedimentologic effects, since the abundance of expandable clay minerals appears higher in marine sediments offshore from the Colville River mouth than in sediments from the adjacent open marine portions of the Beaufort Sea. Part of our further work, now underway, involves study of suspended load material from each of these sample sites, for comparative purposes, in order to more clearly define the situation. Regarding Figure 15 the fact that the value of the parameter 17/10 for KCl+glycol versus NaCl+glycol specimens is less than 1.0 is strong evidence for the presence of a significant amount of degraded 10Å material, in each of the particle size ranges, for every sample (the sole exception is the 1.0-<2.0μm size at station CR-5), and the sense of trend further suggests that this material increases in relative amount with distance downstream. However, this may be illusory, in that the same data might be interpreted as representing more effective exchange of ions from saline water, given the fact that locality KR-1 is a marine site, and shows the lowest values for this trend. In other words, degraded materials which had not yet been exposed to saline water may behave in a somewhat different manner, under our experimental conditions of attempted cation exchange, relative to materials which have had a previous opportunity to effect (or at least approach) equilibrium under saline conditions. This arguement is further strengthened by the relationships shown on Figure 9, in which there appears to be a rather abrupt difference in the 17/10 sea water+glycol specimens between localities CR-7 (fresh water) and CR-8 (which may have been periodically exposed to influx of salt-water coming upstream from the river mouth). Actually, in view of these complexities, it is apparent that a clearer appreciation of the situation awaits the results of our further studies now in progress. In concluding the comments on the 17/10 relationships for the present, we might point out the consistent behavior of the 1.0-<2.0μm size, relative to the finer size materials, at station CR-8 under MaCl, $MgCl_2$, and sea water exchange and reglycolation. The interpretation is tentatively advanced that the coarsest material here is composed of an unusually high amount of degraded micaceous-illitic material, relative to the smaller particles at this site, when comparison of its interaction with KCl+glycol is made. This might be further indicative of the fresh/saline water relationships discussed above, in that it would be anticipated that the finer particles would react more rapidly in effecting exchange equilibrium with the environment of deposition. Thus, this rather subtle feature may be quite important in gaining added insight into the overall relationships. However, alternatively, and perhaps likelier, it may merely represent influx of materials from the Itkillik River, which enters the Colville River at site CR-8.

Figure 8 portrays the 17/7 ratios for the various cation+glycol treated specimens, and are presented more for the sake of completeness of data than for any particularly striking relationships discernible. The trends are consistent with the 17/10 ratios just discussed. Noteworthy is the similar behavior ot the coarsest size fraction of location CR-8 with respect to the accompanying smaller particles in this assemblage. The absolute values of the 17/7 ratio for station CR-5 show the dominance of the smectite component in those materials, the remaining stations investigated yield 17/7 ratios more indicative of subordinate amounts of expandable components in proportion to total chlorite plus kaolinite. Station KR-1, marine, shows the lowest value and may result from various environmental differences. Winnowing and/or non-deposition of smectite, as well as formation of authigenic chloritic material in the marine environment are possible reasons, but differing source materials is another potential factor to be considered.

In order to obtain the maximum amount of information from our data, we have presented in Figures 11 through 13 quite a few of the available 7/10 relationships, for various treatments, and combinations thereof. It is felt that unique definition of the relationships is more likely the more thorough such graphical portrayal of data is attempted. Again, certain trends seem readily discernible, while some subtleties may be variously interpreted, and will remain somewhat unclear until more work is done.

Figure 12 shows the effects of K^+, Na^+ and heat treatments. Evident is the consistently lower 7/10 ratio for the <0.3μm size range of a given locality, denoting lesser amounts of chlorite plus kaolinite relative to 10Å material in this finest size fraction. Further, a trend of increased 7/10 values progressively from CR-5 through KR-1 is seen, for each size interval, which suggests increased chlorite plus kaolinite proportions, with greatest amount in the marine sample location, KR-1. At the latter site, the difference in 7/10 between the 300°C and 430°C treatments of the finest and intermediate particle size materials may reflect a significant amount of authigenic chloritic material of lower thermal stability than the more usual detrital chlorites, which are generally of metamorphic or igneous heritage and thus, more stable under the 430°C treatment than a chloritic material formed under sedimentary conditions. It would be further anticipated that such authigenic phases as might be present would be predominantly in the finer grain sizes, due to probable low growth rates in the temperature-pressure regimen of the sedimentary environment.

The general subequal values for CR-3, CR-7, and CR-8 suggest that the CR-5 assemblage is somewhat unusual and, in effect is a "diluent" to the other suites represented by our sample sites upstream from the delta proper. These latter materials appear to exhibit the "characteristic" 7/10 relationships of Colville River fluvial sediments.

Again, the relationships shown by Figure 13, which portrays the 7/10 ratios for KCl versus NaCl treated specimens, indicates the presence of an appreciable component of degraded 10Å material in the samples studied. However, the fact that those values, except for the <0.3μm smectite-rich specimen from location CR-5, are mainly clustered in the 1.2-1.0 region suggests that this degraded 10Å contribution is relatively minor. Figure 13 compares the 7/10 ratios for KCl versus 300°C treated specimens, and illustrates the general similarities for stations CR-3, CR-7 and CR-8. The exceptions once again occur at CR-5, where the finer size fractions show the dominance of the Umiat smectite, which is not effected by KCl as much as it is by heat treatment. Interestingly, the KR-1 material departs in the same sense as those CR-5 finer materials, from the main sequence of values on Figure 13. Also noteworthy is the agreement, well within the experimental error, of the values for each of the three particle size intervals at station KR-1. This degree of similarity in behavior among the size ranges of one particular sample may merely be fortuitous. However, it seems sufficiently unusual that, in endeavoring to explain this situation, we tentatively suggest that it may represent an effective equilibrium situation having been attained with respect to K^+ exchange at this site in the marine environment such that similar responses (more precisely lack of response) to K^+ exchange under our experimental conditions has resulted. This is admittedly a somewhat speculative suggestion. It is difficult to either corroborate or contradict this assertion with respect to K^+ specifically, upon examination of the data shown in Figure 12, which similarly portrays the 7/10 ratios for NaCl versus 300°C treated specimens. The overall trends among the sample localities are analogous to those in Figure 13 but the three particle size ranges at sample station KR-1 are no longer identical in behavior to one another. This may mean that the NaCl saturation under our experimental conditions was sufficient to disturb the postulated equilibrium, although KCl treatment did not have the same effect. Data are not available for the 7/10 ratios of non-glycolated $MgCl_2$ or sea water treated specimens, so comparisons are not possible at this time, although this will be investigated further. Figure 11 shows the 7/10 ratios for the various cation+glycol treated specimens. The consistent dominance of the 7Å phases with respect to 10Å materials in the coarser size fractions of a given sample is apparent, with the sole exception of the sea water treated material in the <0.3μm interval at station CR-7. It is difficult to discern any really well-defined trends, although the coarser KR-1 materials appear to be somewhat enriched in 7Å components once again. It might be further gleaned from Figure 14, in which the 7/10 ratios for KCl+glycol versus NaCl+glycol samples are compared, that the relative amounts of combined chlorite plus kaolinite versus 10Å materials do not vary greatly among the samples studied, although it would seem that the marine locality, KR-1, has characteristics somewhat different from the fluvial sediments.

Figure 14 portrays the 14/10 ratios for specimens heated for one hour at 550°C. The data from station CR-3 are somewhat suspect, in view of the problems cited earlier regarding the presence of significant amounts of ferriginous materials, attempts at its removal, and consequent uncertainities regarding the nature of the residual assemblages vis-a-vis the natural ones. Thus, we have not considered these data in the following discussion, although the data are shown on Figure 14 for completeness. Clearly seen is a trend toward increasing chlorite relative to 10Å materials (in this case, representing total smectite, illite, and degraded micas-vermiculites) downstream, with the maximum value in the marine locality, KR-1. This trend is well defined, and equally discernible for any given size range among the sample stations, as well as in a broad sense for each entire assemblage. This is quite interesting, and presumably represents the effect of sediment transport and deposition, combined with possible considerations of source material differences, as well as authigenesis in the marine environment. Although our data are insufficient at present to lend strong support to any of these variables, as shown earlier there are some suggestions that a moderate amount of authigenic formation of chloritic material may in fact be occuring in the marine milieu. The apparently lower 7/10 values for $MgCl_2$+glycol and sea water+glycol specimens at KR-1, shown in Figure 11, may also suggest that some of this chloritic component may represent a degraded chloritic component in the river, which subsequently has re-equilibrated with Mg^+ in the marine environment to form a "reconstituted" chlorite. This is little more than speculation at the present stage of our studies, and will be pursued further. Certainly, the relationships are nicely delineated with the 550°C treatment, due to removal of the "chlorite plus kaolinite = 7Å material" problem.

Regarding this latter problem, Figure 14 portrays the data resultant from our attempts to resolve the "3.52/3.58 doublet" resulting from X-ray diffraction maxima for chloritic versus kaolinitic phases, respectively. The lack of apparent trends might suggest little success in this attempt, but, with one exception, the reproducibility represented by the replicate samples shown indicates that the technique inherently has a useful degree of precision. The values for the free-iron oxide removal treated <0.3μm fraction of sample CR 5 suggest an appreciable degree of destruction of fine grained chloritic material. No consistent relationships are apparent from the data presently on hand, but the information portrayed in Figure 14 is felt to be valid in itself, within a given sample site, as well as between sites.

CONCLUSIONS

Detailed studies of mineral assemblages in sedimentary materials seem to be potentially quite useful in enabling an enhanced degree of certainty regarding characterization of the constituent phases. With this knowledge more reliable predictions may be ventured as to the potential behaviour, reactivity, etc. of these materials under various geologic-geochemical conditions, as well as with regard to the probable reaction of these materials in the context of the activities of man.

With regard to the materials discussed in this paper, the ubiquitous presence of smectitic and degraded 10Å phases in the sediments suggests a reasonably high degree of "activity" might be anticipated in their natural environment, with respect to exchange of cations and/or foreign organic matter. However, it must be remembered that the materials studied required "removal" of organic material with hydrogen peroxide in order to permit meaningful X-ray analysis. Thus, the sample data represent material no longer in the natural state. However, the ease of exchanging various cations, as well as ethylene glycol, onto the clays in the laboratory suggests the likelihood of analogous behavior in their natural state as well. Additionally, it should be noted that although smectite is ubiquitous, it is not present in predominant proportions in any of the localities downstream from station CR 5 studied to date. Furthermore, the one marine locality studied, KR1, is notably lower in any expandable phases, which would lead one to predict a coincidentally lower "activity" for these sediments relative to exchange phenomena. Physical adsorption onto clay surfaces, rather than the exchange into interlayer structural sites discussed in the present work, would be an additional mechanism potentially available to add to such "activity" of a sediment, and, for the clay minerals, would be predictable primarily on the basis of a quantitative assessment of particle size distribution within a sediment. Greater activity, in general, would be anticipated with sediments containing greater proportions of finer-grained constituents.

The present study has resulted in a rather detailed characterization of the sediments along the lower Colville River and Delta, and will be useful in endeavoring to elucidate sedimentologic and geochemical relationships in the adjacent areas offshore, along the Alaskan coast, and into the deeper Arctic Basin. This latter work is currently in progress, utilizing the methods described in the present study.