Environmental Assessment of the Alaskan Continental Shelf

Annual Reports Summary for the Year Ending March 1976

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

Alaskan OCS Annual Reports Summary

OUTER
CONTINENTAL
SHELF
ENVIRONMENTAL
ASSESSMENT
PROGRAM

ANNUAL TECHNICAL SUMMARY REPORT

TO THE BUREAU OF LAND MANAGEMENT
FOR THE YEAR ENDING MARCH 1976

ENVIRONMENTAL RESEARCH LABORATORIES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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ANNUAL EXECUTIVE SUMMARY
(April 1, 1975 - March 31, 1976)

Introduction

The Outer Continental Shelf Environmental Assessment Program (OCSEAP) is a part of the National Oceanic and Atmospheric Administration (NOAA) of the U. S. Department of Commerce. Its function is to coordinate all Alaskan marine environmental assessment activities relating to energy development. The program is managed by NOAA under an interagency agreement with the Bureau of Land Management of the U. S. Department of Interior by which most of the funding is provided. This program was initiated in 1974 in response to an appeal by the President for development of new energy sources for the United States. The leasing of tracts for oil and gas development is managed by the Bureau of Land Management; OCSEAP's role is to provide basic data for use by BLM in the preparation of the Environmental Impact Statements and for use in selection of leasing sites.

The multi-faceted program which developed in order to provide the required input for selection or rejection of areas for oil or gas exploration or leasing sites covers a broad spectrum of disciplines and employs hundreds of scientists and their assistants. At the present time there are approximately 175 research units actively engaged in collecting basic data in pursuit of scientific endeavors relating to environmental assessment. These pursuits are carried out by land, ship or air (helicopter) on ice, water, bottom sediments, and shorelines with particular regard to contaminant baselines, sources, hazards, transport, receptors (biota), effects and data management.

The geographic area involved is the Outer Continental Shelf (OCS) of Alaska and it has been subdivided into nine separate lease areas, as shown approximately in the accompanying figure (Fig. 1).

A program of this magnitude can only be accomplished through the coordinated efforts of numerous principal investigators assembled from universities, industry, and government agencies, both federal and state. Approximately 200 scientists are currently involved in various supportive research endeavors.

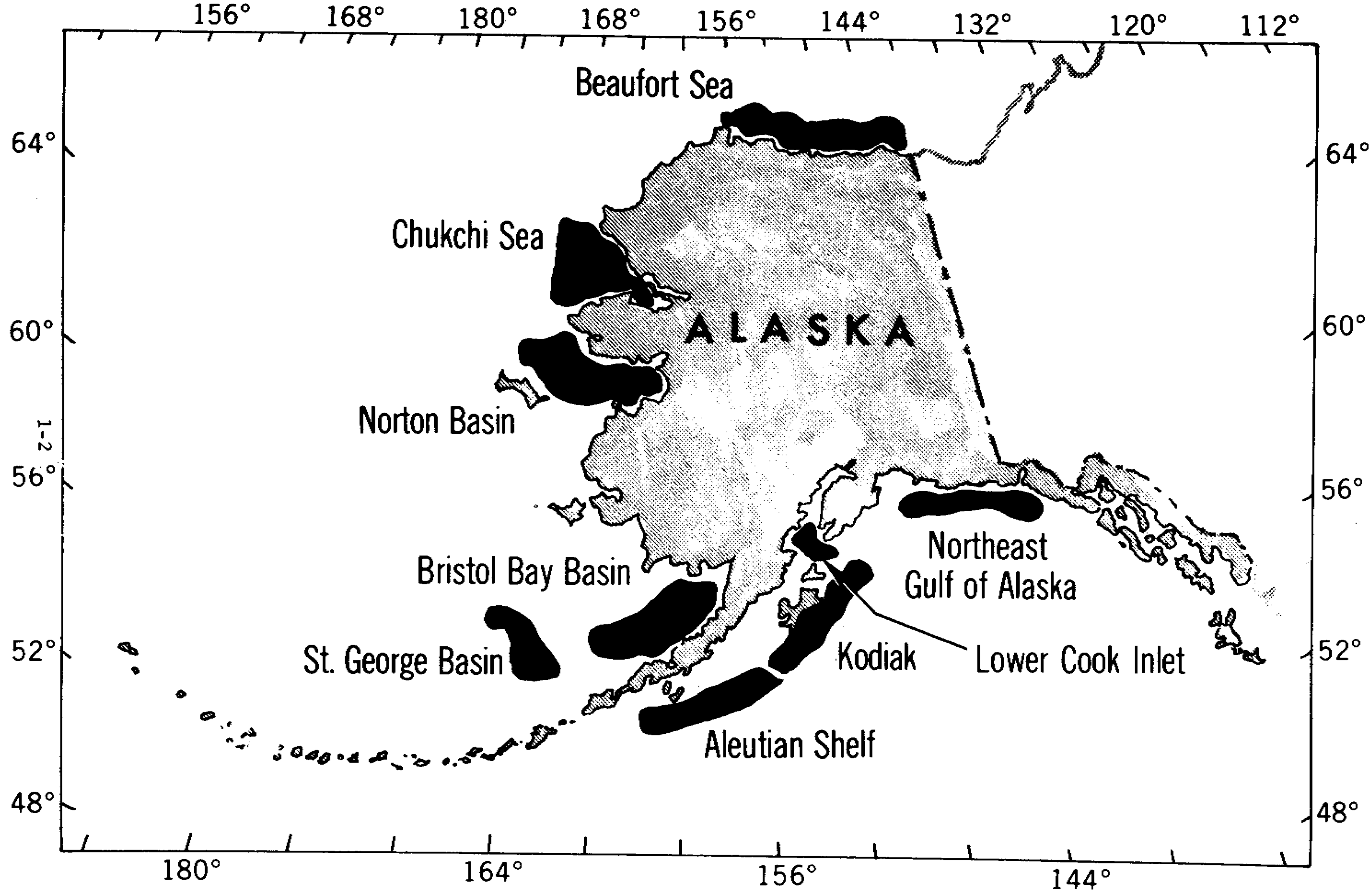


FIGURE 1. ALASKAN OUTER CONTINENTAL SHELF LEASE AREAS

Investigation units are managed by the OCSEAP Office in Boulder, Colorado and through two Alaskan Project Offices (in Juneau and in Fairbanks). The office in Juneau performs a liaison function with the State of Alaska and the one in Fairbanks with the University of Alaska. NOAA staff members from National Marine Fisheries Service (NMFS), National Ocean Survey (NOS) and Environmental Data Service (EDS) as well as representatives from U. S. Fish and Wildlife Service, U. S. Geological Survey, the State of Alaska and the Environmental Protection Agency are liaison members of the Program Office staff.

The objectives of the BLM environmental studies program for all OCS areas, including the nine Alaska areas and a non-specific lease area are:

1. To provide information about the OCS environment that will enable the Department of the Interior and the Bureau of Land Management to make sound management decisions regarding the development of mineral resources on the Federal OCS.

2. To acquire information that will enable BLM to identify those aspects of the environment that might be impacted by oil and gas exploration and development.

3. To establish a basis for prediction of impact on the environment by OCS oil and gas activities.

4. To acquire impact data that may result in modification of leasing regulations, operating regulations, and OCS operating orders, to permit more efficient resource recovery with maximum environmental protection.

A list of six fundamental questions has been developed to achieve the above objectives. Answers to these will yield the required data.

A. WHAT ARE THE EXISTING DISTRIBUTION AND CONCENTRATION OF POTENTIAL CONTAMINANTS ASSOCIATED WITH PETROLEUM DEVELOPMENT?

The distribution of potential petroleum-related contaminants will be described before development of petroleum resources on the OCS. Later changes in the occurrence or concentration of a contaminant could then be detected and compared with environmental changes. Three classes of chemical compounds have been selected for measurement: light hydrocarbons (C_1 - C_4), high molecular weight petroleum hydrocarbons, and selected metals.

Emphasis is on the high molecular weight petroleum hydrocarbons and metals in each lease area. Chemical baseline studies in the Alaskan program are divided into the following classes of sampling effort:

Broad geographic reconnaissance of contaminant distribution in the water, sediments, and selected biota;

Site-specific studies funded in areas (potential sources of contaminants) expected to undergo development and in areas identified as vulnerable or having critical ecological habitats (potential targets);

Periodic sampling to determine whether significant changes have occurred.

B. WHAT ARE THE NATURE AND MAGNITUDE OF CONTAMINANTS AND ENVIRONMENTAL DISTURBANCES THAT MAY BE ASSUMED TO ACCOMPANY PETROLEUM EXPLORATION AND DEVELOPMENT OF THE ALASKAN CONTINENTAL SHELF?

The introduction of contaminants in seawater and construction of facilities may alter or remove habitats and affect circulation patterns in specific areas, or modify behavior of populations. A knowledge of these effects will enable OCSEAP to make adequate plans for future research and establish priorities and timing. The nature of research and the site selection for intensive ecological investigations will also depend on these data.

C. WHAT HAZARDS DOES THE ENVIRONMENT POSE TO PETROLEUM EXPLORATION AND DEVELOPMENT?

Environmental hazards that could damage facilities and structures, potentially resulting in pollution incidents, must be understood. Without this understanding, informed decisions concerning the tradeoffs involved in energy development are questionable. The primary objective is identification and quantification of hazards to ensure that environmental risks will be avoided or minimized by appropriate plans, design, siting, stipulations, and regulations.

Natural hazards present in Alaskan lease areas - such as ice forces, faulting, unstable sediments, bottom scouring by ice and currents, extreme waves, and severe storms - also occur in other shelf areas of the United States. In Alaska, however, problems are especially severe. Therefore, examination of "maximum credible event" scenarios will be very important.

Identification of regional environmental hazards early in the decision-making process is allotted the highest priority as this information will be used to determine which OCS areas are less environmentally hazardous than others, to exclude particular tracts from leasing, and to develop pertinent OCS recommendations for environmental regulations and lease stipulations.

D. HOW ARE CONTAMINANT DISCHARGES MOVED THROUGH THE ENVIRONMENT AND ALTERED BY PHYSICAL, CHEMICAL, AND BIOLOGICAL PROCESSES?

In an assessment of the potential impact of petroleum and associated trace metals on the marine environment, the transport and transformation of contaminants is of key significance. The program is specifically designed to provide data that will enable agencies to:

> Plan offshore petroleum development in order to minimize the potential risk to environmentally sensitive areas.
>
> Provide (in the event of an oil spill or the introduction of other contaminants) trajectories and impact predictions required for cleanup operations.

Assist in planning the location of long-term environmental monitoring stations in the study area.

E. WHAT ARE THE BIOLOGICAL POPULATIONS AND ECOLOGICAL SYSTEMS MOST SUBJECT TO IMPACT FROM PETROLEUM EXPLORATION AND DEVELOPMENT?

A major incentive for conducting studies of biological populations is to determine which populations, communities, and ecosystems risk acute or chronic impacts. Estimates of the distribution and abundance, migration, feeding sites, and behavior of populations are among the first studies performed to indicate vulnerability. Subsequently, detailed studies are undertaken to focus on positions in food webs, mobility, habitat dependence, sensitivity to disturbance, and physiological characteristics of such populations. The latter include studies of the direct effects of hydrocarbons, trace elements, and suspended sediments on the physiology and behavior of target organisms.

F. WHAT ARE THE EFFECTS OF OCS-RELATED CONTAMINANTS AND ENVIRONMENTAL ALTERATIONS ON INDIVIDUAL ORGANISMS, POPULATIONS, AND ECOLOGICAL SYSTEMS?

Knowledge of the effects of petroleum on marine organisms and communities is an essential part of the environmental assessment process. Determination of the deleterious effects of petroleum exposure and threshold concentrations that cause these effects should be attempted. Then, in conjunction with knowledge of the distribution and abundance of organisms and the mode of contaminant transportation and trajectories, the potential risks of lease development can be estimated.

Initial studies emphasize acute toxic effects of contaminants on individuals of selected species. Later in the program this emphasis will shift toward the effects of chronic exposures on populations and ecosystems.

This dimension involves consideration of entire systems as contrasted to individuals and separate populations. Ecosystem studies are complex and difficult, but are necessary because a critical species or process could affect other trophic levels, leading to the demise of populations even when no direct mechanism can be found. The timing of ecological studies is dependent on the schedule of leasing, development of particular tracts, and derivation of an adequate baseline.

END PRODUCTS AND DELIVERABLES

The OCSEAP studies are designed and managed to provide in a timely manner products that are directly and immediately applicable to BLM needs for prediction, assessment, setting stipulations, and regulation. These products are identifiable both within the reports routinely submitted by investigators, and as separate volumes, operational capabilities, and items "on the shelf" on call. Identifiable products from these studies include:

- Models

  a. For calculating oil transport on water, including vertical mixing, evaporation, weathering, biodegradation, and dispersion. This model permits transition from an oil spill to prediction of the characteristics and concentration of oil exposing biota downstream.

  b. For changes in wind with distance from mountainous shorelines for use in calculating oil transport on water.

  c. Of oil transport in ice covered areas. Oil moves both in leads and with the ice when trapped beneath it. The ice movement differs from that of the water currents, so special models are needed for ice conditions.

  d. For estimating and quantifying biological damage. These models can be used in tandem with the transport models to obtain assessments.

e. Of processes in ecosystems and the relationship between species, used for assessing and predicting impacts from released oil, and recovery rates.

f. Of the modification of permafrost by man's activities. These models make it possible to estimate the hazards of permafrost to OCS development.

g. Of ice strength and movement, for use in permitting and in judging industry technology.

- Maps and Charts

a. Of sediment character and stability, potential slump areas, etc., for use in selecting tracts and in specifying further studies to be done in advance of permits.

b. Of earthquake epicenters, and of faults, active and inactive, for the same purposes as above.

c. Of permafrost distribution, for the same purpose as above.

d. Of location, character, and movement of sea ice.

e. Of biological parameters, including food and nutrient distribution, habitats, migratory routes, spawning areas, mortality, major colonies and hauling grounds, seasonal distributions of threatened, endangered and commercial species, and others, for the purpose of selecting sites and assessing impacts, and for design of monitoring programs.

f. Of ocean currents, for use in predicting oil transport through the use of models and for use in determining passive migration of plankton and juvenile fish thru the lease area.

g. Of petroleum, toxic compounds, and metal distributions in the water column, biota, and sediments, for use as a baseline for future assessment of effects.

h. Of possible sources of oil in the environment for use in assessing impact and designing monitoring programs.

i. Of sea floor topography.

- Statistical Probability Distributions

a. For wave heights.

b. For storm surges for use in facility siting and for estimating transport onto the land of marine oil.

c. For depth and frequency of ice gouging in prospective pipeline corridors.

d. For wind speed including extreme winds.

e. Of usual climatological parameters, for use in planning operations and siting.

f. Of atmospheric stability, for use in assessing air pollution from oil and gas development.

g. Of effects on different species from different hydrocarbons and metals associated with oil and gas development, for use in setting standards for concentrations and in regulating sources.

h. Of types and incidence of mortality and disease in biota for later use as background information when monitoring the effects of production.

- Data Sources and Collations

  a. Of data that should be digitized in standard format. This data will be available for future analysis to meet BLM needs not yet identified.

  b. Of data which should not be digitized, but which will be kept in raw form or in smoothed form according to its nature, to meet future BLM needs.

  c. Of biological and physical specimens, for future use in verifying conclusions of investigators, for use in possible legal actions, and in obtaining new chemical analyses.

- Data Summaries and Collations

  a. Collected, summarized, graphed, and plotted data, sometimes subjected to statistical analysis and smoothing, for use in DEIS, FEIS, PDOD, permitting, etc.

  b. Special data products or presentations on request to BLM, such as required input to impact assessment computer models and data syntheses reports.

- Engineering Input Data

  a. On strength, location, movement, and character of sea ice useful for judging adequacy of industry design and for setting stipulations.

  b. On depths and frequencies of bottom gouging by sea ice for input to pipeline specifications.

  c. On properties of permafrost drilling cores.

Reporting

The 15-month FY 1976 environmental assessment program was designed for about 175 selected work statements and an approximate obligation of $27.9 million, plus NOAA's support of three major research vessels or $6.0 million. A separate financial report was submitted.

A large quantity of knowledge in one annual and three quarterly publications of reports from Principal Investigators was made available to BLM in 1976 (the annual reports alone consisted of 14 volumes covering 8 disciplines). These findings constituted new and important information made available for use in the selection and deselection of tracts, the preparation of Environmental Impact Statements, and the derivation of Program Decision Option Documents in advance of sales. About 400 copies of these reports are distributed to BLM and principal investigators, and on their request to other agencies and a few foreign embassies. The distribution lists are continually reviewed and updated. The reports are made available to others through the National Technical Information Service (NTIS). One of the functions of the program management is to subsequently sort, organize and summarize the findings by lease area. These reports compose the "Annual Reports Summaries" also known as the "Annual Technical Reports Summaries" which follow this Annual Executive Summary.

Furthermore, quarterly status reports submitted to BLM contained scientific highlights for each quarter, an evaluation of the status of each study project, a report on data flow, and operations summaries and ship cruise reports. In addition to extensive use of NOAA research vessels Discoverer, Surveyor, and Miller Freeman, limited use was made of cruises by other NOAA ships (Rainier, Oceanographer, Townsend Cromwell). Several weeks of geological, oceanographic and biological research were conducted from vessels of the U. S. Geological Survey (Karluk, Cecil H. Green, and Thompson) as well as of the U. S. Navy (Silas Bent), U. S. Coast Guard (Planetree), Northwest Marine Fisheries Service (North Pacific, Montague), University of Hawaii (Moana Wave), and University of Alaska (Acona).

The schedule of NOAA ship use by investigators and lease areas is shown in Figure 2. It is evident from the figure that the Alaskan investigators and ships operate in more than one lease area, which greatly improves the efficiency and return of the operations, even though the reporting to BLM is thereby made more complex.

Also presented here is a summary table of OCSEAP cruises, except for USGS cruises which do not submit cruise reports. Following a cruise (or its analog using other platforms), a report of the rawdata collected is sent to OCSEAP and entered into the computerized Data Tracking System. This system records the location and progress of the data from raw field form through final entry in the data bank. (The first computer printout of data status was furnished to BLM about June 1976.) Updated printouts are provided quarterly to BLM reflecting the current status of data gathered during that report period as well as for data gathered in earlier periods.

Highlights

Cruises of the Miller Freeman ranged from fish sampling surveys of the Bering Sea to an intensive search undertaken for a missing current meter. Some problems did result from the presence of ice in planned stations as late as the end of May. However, operationally, the spring and summer quarters 1976 were very successful. The ice remained thick enough for helicopter landings early in the spring quarter so that research in the Arctic could start earlier than in 1975.

Availability of helicopters for OCSEAP use has been limited, but another, larger model helicopter was expected to become available for use in September for intertidal studies on Bristol Bay and Kodiak Island. Some shoreline features make it difficult to bring a ship close enough to deploy small craft, but movement of helicopters over terrain such as pressure-ridged ice fields and even over open lanes of water can be accomplished. The helicopter also permits deep penetration into pack ice where ship hulls cannot penetrate.

During cruises of the NOAA Discoverer, physical oceanographic and meteorological data were collected in the Icy Bay/Kayak Island vicinity. The meteorological program included radiosonde releases and boundary layer monitoring as well as shipboard surface observations. Data collected characterized the transition from continental to marine atmosphere in the vicinity of Malaspina Glacier. Other data included samples of bottom organisms, sediments, and surface water. Lower Cook Inlet was sampled for plankton, productivity, and nutrients. Very high phytoplankton concentrations and dense zooplankton layers were found in Kachemak Bay. A late May cruise found evidence of a plankton bloom present at the entrance to Cook Inlet. Relatively high primary productivity was also found at this time in Kamishak Bay.

The NOAA Surveyor made several cruises along the ice front in the Bering Sea during which the Bell 206B helicopter operated from the Surveyor. The helicopter supported bird and mammal observations and collections, as well as sampling above and below the ice and sea surface, aided by ship's divers. The season's first intertidal cruise was conducted in the western Gulf of Alaska, occupying 11 littoral and 10 sublittoral zone sites. Geodetic leveling was conducted to assist in beach profile characterization, and ship's divers participated in the sublittoral studies. During May nearly 100 nautical miles of launch hydrography were completed in Icy Bay to supplement previously charted soundings, in order to determine bottom profiles.

The Surveyor cruise of March-April yielded data for studies of the ringed seal, and trophic relationships of phocid seals. Aerial surveys for spotted seals in April encountered problems based on the existence of a very extensive ice cover serving to widely distribute the marine mammals. April surveys showed that the distribution of breeding adult spotted seals was continuous from Bristol Bay as far west as surveyed, indicating the probability of one single stock in the central and eastern Bering Sea. Higher densities of ringed seals in the Chukchi Sea, in areas of stable shore-fast ice, reflected the better ice conditions and higher overall productivity of Chukchi compared to the Beaufort Sea. It should be noted that the young of one species of this prey group have been identified in the Canadian Beaufort Sea Project Technical Report as being extremely sensitive to oil.

A University of Hawaii charter vessel R/V Moana Wave undertook a benthic biology, light hydrocarbon and trace metals cruise in Lower Cook Inlet during March and April. Successful use was made of seven types of bottom sampling gear with over twice the anticipated number of stations being completed.

A great difference between the 1976 field season and that of 1975 was evident in the belukha and bowhead whale data taken. Over 1300 belukha whales and more than 400 bowheads were counted this season, representing a vast increase over last year's counts. Both aerial and ground counting techniques were employed and found to be definitely compatible. Bowhead whale counts were highest when counted from the ice-based station, but aerial surveys provided data indicating that these whales migrate primarily through nearshore leads, where present information indicates that they will be most vulnerable to oil development if spills occur during April through June. Belukha whale counts were highest from the air, and aerial surveys have also shown that these whales use offshore leads. However, results show that oil spills, wherever they occur, would disturb these whales during May through June.

On May 26, one-half of the total king eider bird population of western North America passed Barrow within a twelve-hour period. Aerial surveys showed that migration was decreasing throughout June, with an increase in density of populations. Large populations of birds, the most abundant being common and thick-billed murres, were observed in the leads and polynias north of the ice edge. Fifteen collecting cruises were undertaken by one bird research group studying the feeding ecology, trophic relationships and population dynamics of marine birds; ranging from Forrester Island in extreme southeastern Alaska to the outer Yukon River delta. A greal deal of cooperation has occurred between this group and other agencies, with support being given by several Alaskan U. S. Fish and Wildlife Refuges, the U. S. Coast Guard, and the Bureau of Land Management. The F/V Nordic Prince, an 85-foot combination crab-shrimp fishing boat from Tacoma, Washington, has supported these studies and others, cataloging and photographically mapping seabird colonies.

The State of Alaska's requirement for Atlantic Richfield Company to undertake environmental analysis resulted in support beginning to shift from OCSEAP to ARCo for studies such as the Beaufort Sea estuarine fish study; this study has utilized an underwater closed circuit television system to determine the presence of fish prior to setting nets under the ice. A preliminary version of a fish identification key, including 65 species, was completed during FY76. Principal investigators have begun to use it and to provide comments and criticisms leading to its improvement.

1976 marked the first real attempt to examine the southern ice-edge zone prior to and during the annual spring plankton bloom. One surprise was the finding of large numbers of birds and marine mammals accumulated in the edge zone well in advance of the bloom. Analyses indicated that these higher trophic levels were feeding on fish larvae and small fishes that were over-wintering as adults or juveniles. Thus some selected products of the previous year's bloom period provide food for seasonal migrants utilizing this region in the late winter and early spring.

The group studying the distribution, abundance, diversity and productivity of the western Beaufort Sea benthos is now confident that a technique has been developed and refined that allows for through-the-ice sampling to be carried out reliably and successfully in all seasons.

Benthic sampling was accomplished by using a NOAA UH-1H helicopter to fly from Barrow to the stations and utilizing the on-Track Navigation System available on the helicopter to determine station locations. This method was an improvement over the range and bearing techniques previously employed.

The study of phytoplankton and primary productivity in the northeast Gulf of Alaska resulted in the striking find that phaeopigment/chlorophyll ratios were highest at the station closest to the petroleum producing area in the northern region of Cook Inlet. The large ratios at this particular station may be an effect of pollutants near the active oil drilling areas just north of the sampling point, but this requires verification.

Baseline studies of demersal resources of the eastern Bering Sea shelf and slope are extensively utilizing computer mapping and plotting techniques. Analysis of historical data has progressed to the point at which computer-drawn maps are available. Analyses of annual variations in relative abundance and species composition have been performed and preliminary analysis of one set of data shows large variations in apparent abundance between years. Sublethal effects studies (as related by morphological, chemical, physiological, and behavioral indices) have shown that the epidermal mucus and skin of coho salmon accumulate lead and cadmium. The rate of uptake of metals in the mucus has been found to be very rapid; within a few hours, substantial amounts of metal are accumulated. Metals have been found to persist in the skin of fish long after they are transferred to clean water, which may result in changes in their disease susceptibility. Clear alterations in rheological properties of fish mucus have been observed after trace metal exposure. This is interpreted as having a potential for causing increased friction between fish body surfaces and water, which could result in decreased ability to capture prey or escape predators.

A significant discovery resulted from gas chromatography and combined gas chromatogrpahy-mass spectrometry analyses of surficial benthic sediments from Prudhoe Bay. These sediments were found to contain normal alkanes, pristane, phytane, and condensed ring aromatics in an array that suggests both petroleum and biogenic sources. Preliminary analysis performed in the past had detected no petroleum. The potential effect of the chronic presence of trace amounts of petroleum on an arctic environment is not clear at this time. It also is not known whether petroleum has been introduced into the Prudhoe Bay environment by development activities in the area or by natural seeps. In the NE Gulf of Alaska and the SE Bering Sea, investigators found appreciable amounts of low molecular weight hydrocarbons (methane, ethane, and ethylene).

The salient feature found in the surface layer of the Gulf of Alaska was a large clockwise gyre west of Kodiak Island advecting methane-rich water from the vicinity of Kayak Island towards the west. The source of this methane is probably organic-rich sediments in the Kayak Trough where relatively high concentrations of methane are observed near the bottom, but surface biological activity cannot be ruled out at this time.

Major progress was made in the development of an operating high frequency current-mapping radar unit. Ocean surface currents previously have been virtually impossible to map except for very few points at a time with drogues or dye markers. The new technique, when perfected, will permit the gathering of data near shore during approximately an hour's scanning period and the results will be processed into a map with arrows showing the magnitude and direction of the surface current at each point. Hourly updates would be possible. This new method will revolutionize the study of nearshore surface currents and greatly improve the prediction of oil spill trajectories.

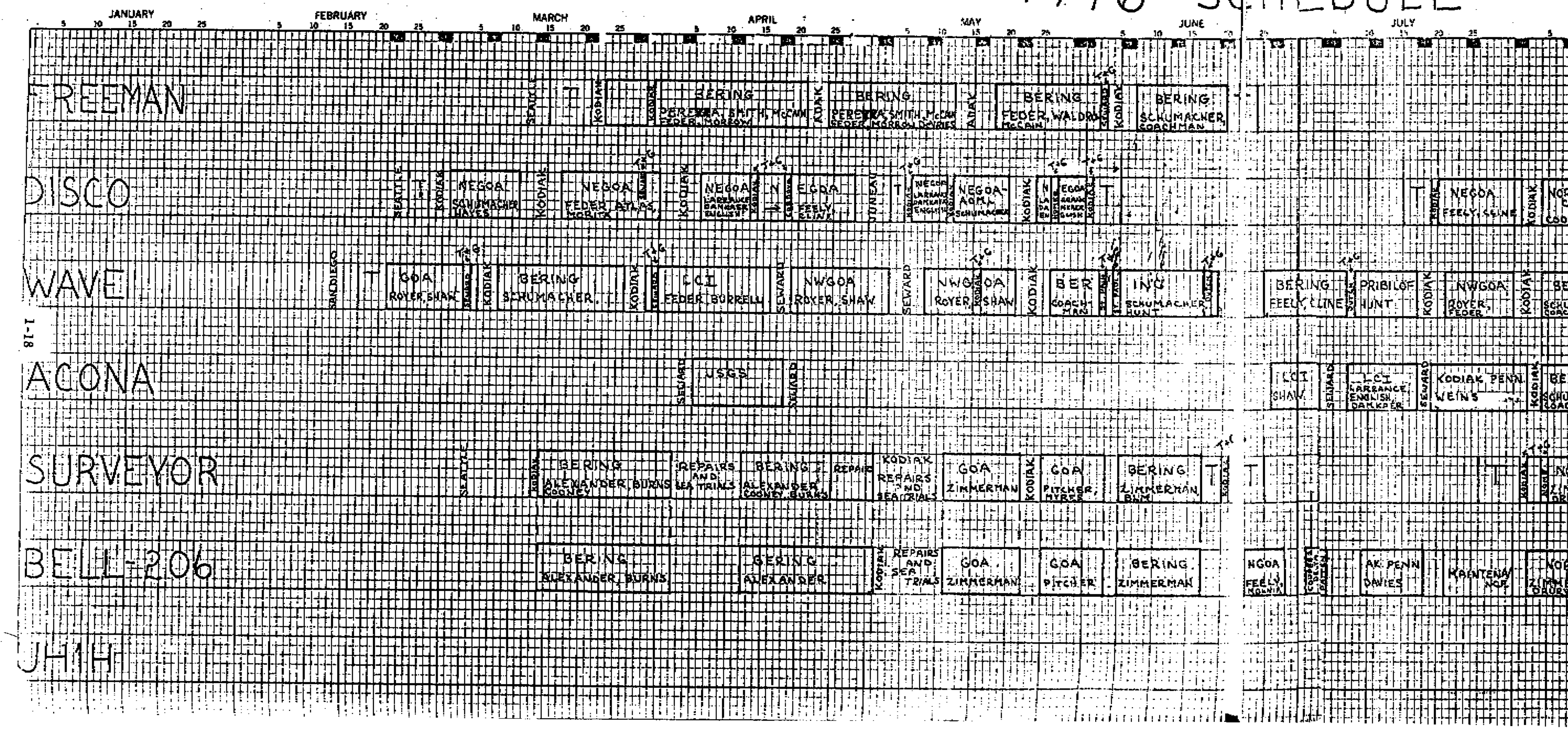
Extensive modeling runs were made of the transport of pollutants in the vicinity of Prudhoe Bay, with seemingly reasonable behavior shown by the model. Ninety-five percent of the data on weather extremes had been compiled, to be incorporated into the atlas being prepared on marine climatology for Alaska.

Several subsea permafrost studies are interfacing well and progress was generally excellent, especially considering that many of these are pioneering work in this discipline. Methods have been tested for penetration to the depth of the subsea permafrost for depth measurement purposes; utilizing lightweight equipment, depths of 45 feet were easily reached.

Ice thickness profiling tests using an impulse radar system in a unique configuration allowed, for the first time, the continuous profiling of first-year and multi-year sea ice thickness from not only the ice surface but also from the air. Good correlation was found between radar-determined ice thicknesses and direct drill measurements, revealing quite clearly the undulating subsurface relief of both the first-year and multi-year ice. A study of experimental measurements of sea ice failure stresses near grounded structures experienced formidable logistic and technological problems. Ideal conditions for this study include ice in constant motion, necessitating the performance of experiments of very short time and space duration. This characteristic also leads to problems such as losing the study site entirely as the ice shifts position.

The preceding highlights were excerpted from the principal investigators' annual reports for the period April 1, 1975 to March 31, 1976, and quarterly reports for April, May, and June 1976.

1976 SCHEDULE



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SUMMARY OF OCSEAP CRUISES
April 1, 1975 TO April 1, 1976

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
SURVEYOR (NOAA)	5-18 APR 75 Leg I	MOLNIA, USGS	NORTHERN GULF OF ALASKA	SUB-BOTTOM GEOLOGICAL STRUCTURE SEA-FLOOR MORPHOLOGY	SEISMIC REFLECTION GRAVITY MAGNETICS BATHYMETRY MAMMAL OBSERVATIONS	(2606 NM TRACKLINE) (2002 NM TRACKLINE) (990 NM TRACKLINE) (2002 NM TRACKLINE)
SURVEYOR (NOAA)	20 APR-2 MAY 75 Leg II	ZIMMERMAN, ABFL MOLNIA, USGS LENSINK, USF&WS	NORTHERN GULF OF ALASKA	INTERTIDAL BIOLOGY/ SEA-FLOOR MORPHOLOGY (HELICOPTER SUPPORT)	LITTERAL ZONE OBS AND SAMPLES BATHYMETRY BIRD/MAMMAL OBSERVATIONS	7 (84 NM TRACKLINE)
RAINIER (NOAA)	21 APR - 7 MAY 75 Leg I	SCHUMACHER, PMEL HAYES, PMEL ROYER, IMS	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD WATER SURFACE TEMP AND SALINITY WATER SAMPLES XBT CURRENT METER ARRAY RECOVERY (STA 62B) DEPLOYMENT (STA 62C,64)	48 85 18 25 1 2
				SEA-FLOOR MORPHOLOGY/	BATHYMETRY MAMMAL OBSERVATIONS	(40 NM TRACKLINE)
RAINIER (NOAA)	9-15 MAY 75 Leg II	HAYES, PMEL SCHUMACHER, PMEL	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD CURRENT METER ARRAY RECOVERY (STA 63 1/2) (PARTIAL RECOVERY STA 63) MAMMAL OBSERVATIONS	84 1

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
SURVEYOR (NOAA)	5-16 MAY 75 Leg III	MOLNIA, USGS LENSINK, USF&WS	NORTHERN GULF OF ALASKA	SUB-BOTTOM GEOLOGICAL STRUCTURE SEA-FLOOR MORPHOLOGY	SEISMIC REFLECTION	(2172 NM TRACKLINE)
					GRAVITY	(1953 NM TRACKLINE)
					MAGNETICS	(582 NM TRACKLINE)
					BATHYMETRY	(1953 NM TRACKLINE)
					SIDE-SCAN SONAR	(8 NM TRACKLINE)
					BIRD/MAMMAL OBSERVATIONS	
TOWNSEND CROMWELL (NOAA)	5-19 MAY 75 Leg I RP4TC75	COONEY, IMS FEDER, IMS SHAW, IMS BURRELL, IMS	NORTHERN GULF OF ALASKA	BIOLOGICAL/ CHEMICAL OCEANOGRAPHY	CTD	19
					SEDIMENT & BENTHIC SAMPLES	16
					WATER SAMPLES	20
					SURFACE WATER TEMP AND SALINITY	29
					NEUSTON TOWS	14
					TUCKER TRAWLS	14
					VERTICAL ZOOPLANKTON NET TOWS	53.
					MAMMAL OBSERVATIONS	
NORTH PACIFIC (NMFS CHARTER)	22 APR- 10 AUG 75	PEREYRA, NWFC	NORTHERN GULF OF ALASKA	DEMERSAL FISH ASSESSMENT	DEMERSAL FISH TRAWLS	127
SURVEYOR	20-30 MAY 75 Leg IV	ZIMMERMAN, ABFL LENSINK, USF&WS	WESTERN GULF OF ALASKA	INTERTIDAL BIOLOGY	LITTORAL ZONE OBS AND SAMPLES (HELO AND LAUNCH)	8
					BIRD/MAMMAL OBSERVATIONS	
DISCOVERER 806 (NOAA) I	15-30 MAY 75 Leg I RP4DI75	COONEY, IMS ALEXANDER, IMS LENSINK, USF&WS DIVOKY, ADF&G MUENCH, IMS BURRELL, IMS	BERING SEA (ICE-EDGE)	ICE-EDGE BIOLOGY AND CHEMISTRY	NISKIN WATER SAMPLES	62
					CTD	~~62~~ 30
					TUCKER TRAWLS	12
					VERTICAL PLANKTON TOWS	17
					ICE CORES	12
					SEDIMENT AND BENTHIC SAMPLES	12
					SURFACE WATER TEMP	
					BIRD/MAMMAL OBSERVATIONS	

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
TOWNSEND CROMWELL (NOAA)	27 MAY- 7 JUNE 75	MOLNIA, USGS	NORTHERN GULF OF ALASKA	LITHOLOGY	SEDIMENT SAMPLES	357
					VAN VEEN GRABS	
					SHIPEK GRABS	
					BOX CORES	
					DART CORES	
					SECCHI DISC CASTS	57
				SUB-BOTTOM GEOLOGICAL STRUCTURE	SEISMIC REFLECTION	(26 NM TRACKLINE)
					MAMMAL OBSERVATIONS	
SURVEYOR (NOAA)	5-13 JUN 75 Leg II	HAYES, PMEL SCHUMACHER, PMEL LENSINK, PMEL	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD	64
					CURRENT METER ARRAY RECOVERY (STA 62C)	1
					DEPLOYMENT (STA 62D)	1
					BIRD/MAMMAL OBSERVATIONS	
ACONA (IMS)	3-13 JUN 75 Cruise 212	ROYER, IMS	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD	60
					WATER SAMPLES	16
					CURRENT METER ARRAY RECOVERY (STA 64)	1

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
DISCOVERER 808 (NOAA) II	2-19 JUN 75 Leg II RP-4DI75	FEDER, IMS ALEXANDER, IMS COONEY, IMS BURRELL, IMS MYRES, U OF CALGARY LENSINK, USF&WS MUENCH, IMS	BERING SEA	ICE-EDGE BIOLOGY AND CHEMISTRY	VAN VEEN GRABS HAPS CORES CTD NISKIN WATER SAMPLES TUCKER TRAWLS VERTICAL PLANKTON TOWS SURFACE WATER TEMP BIRD/MAMMAL OBSERVATIONS	55 19 ~~63~~ 63-81 (19) 63 18 39 270
SURVEYOR (NOAA)	15-31 JULY 75 Leg IB 05532	ZIMMERMAN, ABFL DAVIES, LAMONT GEO.OBS. LENSINK, USF&WS MYRES, U OF CALGARY	BERING SEA	INTERTIDAL BIOLOGY SEISMIC STATION SERVICING	LITTORAL ZONE OBS AND SAMPLES (HELO AND LAUNCH) HELO AND LAUNCH TO SHORE STATIONS BIRD/MAMMAL OBSERVATIONS	10 10 (ALASKA PENINSULA AND ALEUTIANS)

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
SURVEYOR (NOAA)	8-29 AUG 75 Leg 2B	ZIMMERMAN, ABFL DAVIES, LAMONT GEO.OBS. PULPAN, U OF AK LENSINK, USF&WS WEINS, OSU MYRES, U OF CALGARY	WESTERN GULF OF ALASKA AND BERING SEA	INTERTIDAL BIOLOGY SEISMIC STATION SERVICING	LITTORAL ZONE OBS AND SAMPLES (HELO AND LAUNCH) HELO AND LAUNCH TO SHORE STATIONS BIRD/MAMMAL OBSERVATIONS	5 (WESTERN GULF) 3 (BERING) 7 (WESTERN GULF) 11 (ALASKA PENINSULA AND ALEUTIANS)
DISCOVERER 810 (NOAA) IB	9-28 AUG 75 Leg I	COONEY, IMS ALEXANDER, IMS MUENCH, IMS LENSINK, USF&WS HUNT, U OF CAL, DAVIS	BERING SEA	PLANKTON BIOLOGY AND PHYSICAL OCEANOGRAPHY	CTD NISKIN WATER SAMPLES TUCKER TRAWLS VERTICAL PLANKTON TOWS SEDIMENT CORE Birds	49 49 44 60 1
MILLER FREEMAN (NOAA)	11 AUG- 5 SEPT 75 Leg I RP4MF75A M-75-1	PEREYRA, NWFC FEDER, IMS MUENCH, IMS SCHUMACHER, PMEL COACHMAN, U OF WA LENSINK, USF&WS	BERING SEA	DEMERSAL FISH ASSESSMENT BENTHOS PHYSICAL OCEANOGRAPHY	DEMERSAL FISH TRAWLS BOTTOM GRABS CTD XBT BIRD/MAMMAL OBSERVATIONS	86 22 21 88

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
SILAS BENT (USNS)	31 AUG - 14 SEPT 75	ROYER, IMS FEDER, IMS SHAW, IMS BURRELL, IMS LENSINK, USF&WS	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY BENTHOS WATER CHEMISTRY	CTD SURFACE WATER SAMPLES SEDIMENT SAMPLES NEUSTON TOWS SURFACE WATER TEMP BIRD OBSERVATIONS	64 12 33
DISCOVERER (NOAA)	2-11 SEPT 75	SCHUMACHER, PMEL COACHMAN, U OF WA MUENCH, IMS LENSINK, USF&WS	BERING SEA AND WESTERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CURRENT METER ARRAY DEPLOYMENTS (STA WGC-1, BC-1A BC-4A, BC-2A) CTD SURFACE WATER TEMP AND SALINITY BIRD/MAMMAL OBSERVATIONS	4 16
SURVEYOR (NOAA)	2-13 SEPT 75	ZIMMERMAN, ABFL HANSEN, AOML WEINS, OSU LENSINK, USF&WS	NORTHERN GULF OF ALASKA	INTERTIDAL BIOLOGY PHYSICAL OCEANOGRAPHY	LITTORAL ZONE OBS AND SAMPLES (HELO AND LAUNCH) DRIFT BUOY DEPLOYMENTS BIRD/MAMMAL OBSERVATIONS	7 3
MILLER FREEMAN (NOAA)	8-28 SEPT 75	PEREYRA, NWFC FEDER, NWFC SCHUMACHER, PMEL COACHMAN, U OF WA MCCAIN, NWFC LENSINK, USF&WS	BERING SEA	DEMERSAL FISH ASSESSMENT BENTHOS PHYSICAL OCEANOGRAPHY	DEMERSAL FISH TRAWLS BOTTOM GRABS CTD XBT BIRD/MAMMAL OBSERVATIONS	67 12 4 67

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
DISCOVERER (NOAA)	13 SEPT-3 OCT 75	FEELY, PMEL CLINE, PMEL SHAW, IMS BURRELL, IMS LENSINK, USF&WS	BERING SEA	SUSPENDED SEDIMENTS AND WATER/SEDIMENT CHEMISTRY	NISKIN WATER SAMPLES CTD NEUSTON TOWS VAN VEEN SEDIMENT GRABS BIRD/MAMMAL OBSERVATIONS	94 94 20 15
SURVEYOR (NOAA)	16-26 SEPT 75	HAYES, PMEL SCHUMACHER, PMEL WEINS, OSU LENSINK, USF&WS	NORTHERN AND WESTERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD TIME SERIES CURRENT METER ARRAY RECOVERY (STA 62D) DEPLOYMENTS (STA 62E, WGC-2A) BIRD/MAMMAL OBSERVATIONS	1 1 2
SILAS BENT (USNS)	17-28 SEPT 75	ROYER, IMS SHAW, IMS LENSINK, USF&WS	WESTERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY/ LIGHT HYDROCARBONS	CTD CURRENT METER ARRAY DEPLOYMENT (STA 9) SURFACE WATER SAMPLES BIRD OBSERVATIONS	63 1 9
SURVEYOR (NOAA)	3-10 OCT 75	ENGLISH, U OF WA DAMKAER, PMEL LENSINK	PRINCE WILLIAM SOUND AND NORTHERN GULF OF ALASKA	ACOUSTIC PLANKTON SURVEY	TUCKER TRAWLS VERTICAL NET TOWS BONGO NET TOWS NIO NET TOWS 100 KHZ ECHOSOUNDER PROFILES BIRD/MAMMAL OBSERVATIONS	9 30 8 6
MILLER FREEMAN (NOAA)	1-26 OCT 75	PEREYRA, NWFC FEDER, IMS SCHUMACHER, PMEL COACHMAN, U OF WA MUENCH, IMS SMITH, IMS MCCAIN, NWFC LENSINK, USF&WS	BERING SEA	DEMERSAL FISH ASSESSMENT BENTHOS PHYSICAL OCEANOGRAPHY	DEMERSAL FISH TRAWLS BOTTOM GRABS CTD XBT BIRD/MAMMAL OBSERVATIONS	66 15 12

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
DISCOVERER (NOAA) IV B	8-16 OCT 75 Leg IV RP4DI75B	FEDER, IMS SHAW, IMS BURRELL, IMS ATLAS, U OF LOUISVILLE LENSINK, USF&WS	WESTERN GULF OF ALASKA	BENTHOS WATER CHEMISTRY MICROBIOLOGY	CTD NISKIN WATER SAMPLES SURFACE WATER SAMPLES HAPS CORES VAN VEEN GRABS NEUSTON TOWS BIRD/MAMMAL OBSERVATIONS	22 20 16 8 24 18 11 stations, 27 transects
SURVEYOR (NOAA)	14-24 OCT 75 Leg II D	ENGLISH, U OF WA LENSINK, USF&WS	NORTHERN AND WESTERN GULF OF ALASKA	ZOOPLANKTON	NIO NET TOWS BONGO NET TOWS 100 KHZ EXOSOUNDER PROFILES BIRD/MAMMAL OBSERVATIONS	19 24
DISCOVERER (NOAA) V C (I)	21 OCT- 10 NOV 75 Leg I (V) RP4DI75C	FEELY, PMEL CLINE, PMEL ENGLISH, U OF WA DAMKAER, PMEL LARRANCE, PMEL CARLSON, USGS LENSINK, USF&WS	NORTHERN GULF OF ALASKA	HYDROCARBONS SUSPENDED SEDIMENTS ZOOPLANKTON PHYTOPLANKTON PRIMARY PRODUCTIVITY LITHOLOGY	NISKIN WATER SAMPLES BOTTOM GRABS VERTICAL NET TOWS BONGO NET TOWS OIL SEEP INVESTIGATION NEPHELOMETER MEASUREMENTS CONTINUOUS SEA CHEST WATER SAMPLING INCIDENT LIGHT Intensity @ Surface IRRADIANCE MEASUREMENTS BIRD/MAMMAL OBSERVATIONS	51 37 26 51 1 51 Continuous Continuous 7 60 transects, 25 stations
SURVEYOR (NOAA)	28 OCT- 17 NOV 75 Leg III D	ROYER, IMS SHAW, IMS HERTZ, NBS	NORTHERN AND WESTERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY LIGHT HYDROCARBONS	CTD SURFACE WATER SAMPLES BIRD/MAMMAL OBSERVATIONS	124 22

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
MILLER FREEMAN (NOAA)	30 OCT- 8 NOV 75 Leg I	SCHUMACHER, PMEL COACHMAN, U OF WA	BERING SEA	PHYSICAL OCEANOGRAPHY	CTD CURRENT METER ARRAY RECOVERIES (STA WGC-1A - BC-2A, BC-4A) DEPLOYMENTS (STA WGC-1B, BC-1B, BC-2B, BC-3A, BC-4B) MAMMAL OBSERVATIONS	14 3 5 Not given
MILLER FREEMAN (NOAA)	12-26 NOV 75 Leg II	COONEY, IMS ALEXANDER, IMS MUENCH, IMS LENSINK, USF&WS	BERING SEA	ZOOPLANKTON PHYTOPLANKTON PRIMARY PRODUCTIVITY PHYSICAL OCEANOGRAPHY	CTD TUCKER TRAWLS VERTICAL NET TOWS NISKIN WATER SAMPLES BIRD/MAMMAL OBSERVATIONS	40 12 39 39 66
DISCOVERER (NOAA) VI C (II)	17-23 NOV 75 Leg II	HAYES, PMEL SCHUMACHER, PMEL HANSEN, AOML	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD CURRENT METER ARRAY RECOVERY (STA 62E) DEPLOYMENTS (STA ICY-2, -62F, SLS-5) BOTTOM-MOUNTED PRESSURE/TEMP. GAGE ARRAY DEPLOYMENTS (STA SLS-6, SLS-4) DRIFT BUOY DEPLOYMENTS BIRD/MAMMAL OBSERVATIONS	5 1 3 2 2 Not given

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
DISCOVERER (NOAA)	23 NOV- 2 DEC 75	BURRELL, IMS FEDER, IMS ROYER, IMS LENSINK, USF&WS	NORTHERN AND WESTERN GULF OF ALASKA	TRACE METALS BENTHOS PHYSICAL OCEANOGRAPHY	CTD NISKIN WATER SAMPLES VAN VEEN GRABS HAPS CORES BIRD/MAMMAL OBSERVATIONS	38 26 17 17
MILLER FREEMAN (NOAA)	28-29 NOV 75	HAYES, PMEL SCHUMACHER, PMEL LENSINK, USF&WS	WESTERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CURRENT METER ARRAY RECOVERY (STA WGC-1B) DEPLOYMENT (STA WGC-1C) BIRD/MAMMAL OBSERVATIONS	 1 1
MOANA WAVE (U OF HAWAII)	21-FEB- 5 MAR 76	ROYER, IMS SHAW, IMS LENSINK, USF&WS	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY LIGHT HYDROCARBONS	CTD SURFACE WATER SAMPLES NEUSTON TOWS CONTINUOUS SURFACE TEMP AND SALINITY BIRD OBSERVATIONS	88 27 12
DISCOVERER (NOAA)	1-11 MAR 76	SCHUMACHER, PMEL HAYES, PMEL REYNOLDS, PMEL	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY/ METEOROLOGY	CTD CURRENT METER AND PRESSURE GUAGE: RECOVERIES (STA SLS-5, SLS-6, STA 62F) DEPLOYMENTS (STA SLS-7, SLS-8, SLS-9, SLS-10, SLS-11, SLS-12, 62G, 69, 60B, 61B, N1) RAWINSONDE RELEASES ATMOSPHERIC BOUNDARY LAYER MEASUREMENTS SURFACE MET MEASUREMENTS BIRD/MAMMAL OBSERVATIONS DRAGGED FOR BUOY #ICY-2 (UNSUCCESSFUL)	21 3 11 36 5 84 1

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
MOANA WAVE (U OF HAWAII)	8-26 MAR 76 RP4MW76A - II A	SCHUMACHER, PMEL COACHMAN, U OF WA LENSINK, USF&WS	BERING SEA	PHYSICAL OCEANOGRAPHY	CTD CURRENT METER ARRAY RECOVERIES (STA WGC-1B, BC-3A) DEPLOYMENTS (STA WGC-2C, WGC-3A, WGC-1C, BC-13, BC-3B, BC-7A, BC-12) BIRD OBSERVATIONS	30 7
SURVEYOR (NOAA)	14 MAR-2 APR 76 I A	COONEY, IMS ALEXANDER, IMS DIVOKY, ADF&G BURNS, ADF&G LENSINK, USF&WS FAY, IMS	BERING SEA (ICE-EDGE)	ICE-EDGE BIOLOGY AND CHEMISTRY HELICOPTER AND LAUNCH SUPPORT	TUCKER TRAWLS VERTICAL NET TOWS NEUSTON NET TOWS NORPAC NET TOWS CTD NISKIN WATER SAMPLES SIPRE ICE CORES MAMMAL SPECIMENS AND OBSERVATIONS BIRD SPECIMENS AND OBSERVATIONS	9 41 6 30 28 25 3 18 36
DISCOVERER II A (NOAA)	16-30 MAR 76	FEDER, IMS MORITA, OSU ATLAS, U OF LOUISVILLE LENSINK, USF&WS	NORTHERN GULF OF ALASKA	BENTHOS	VAN VEEN GRABS SURFACE WATER SAMPLES BIRD/MAMMAL OBSERVATIONS	39 23
MILLER FREEMAN (NOAA)	23-27 MAR 76	ROYER, IMS	NORTHERN GULF OF ALASKA	CURRENT METER ARRAY SALVAGE	MID-WATER TRAWLING AND/DRAGGING FOR MISSING CURRENT METER ARRAY #9 (UNSUCCESSFUL)	1

SPERATIONS SUMMARY
APRIL 1 - JUNE 30, 1976

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
MILLER FREEMAN (NOAA)	28 MARCH - 21 APRIL 76 MF76A I	PEREYRA, NWFC SMITH, IMS FEDER, IMS MORROW, IM MCCAIN, NWFC LENSINK, USF&WS SHAW, IMS BURRELL. IMS	BERING SEA	DEMERSAL FISH ASSESSMENT BENTHOS PHYSICAL OCEANOGRAPHY	DEMERSAL FISH TRAWLS VAN VEEN GRABS CTD BIRD OBSERVATIONS AND COLLECTIONS MAMMAL OBSERVATIONS	53 22 11
MOANA WAVE (U OF HAWAII)	30 MARCH - 15 APRIL 76 III A	FEDER, IMS BURRELL, IMS SHAW, IMS LENSINK, USF&WS	LOWER COOK INLET	BENTHOS TRACE METALS HYDROCARBONS	OTTER TRAWLS AGASSIZ TRAWLS BEAM TRAWL CLAM DREDGE PIPE DREDGE VAN VEEN GRABS HAPS CORES NISKIN WATER SAMPLES BIRD OBSERVATIONS AND COLLECTIONS MAMMAL OBSERVATIONS	6 9 3 3 12 60 6 34
DISCOVERER III A (NOAA)	6 APRIL - 13 APRIL 76	LARRANCE, PMEL DAMKAER, PMEL ENGLISH, U OF W LENSINK, USF&WS	LOWER COOK INLET/NORTHERN GULF OF ALASKA	PLANKTON BIOLOGY	BONGO NET TOWS NIO NET TOWS NEUSTON NET TOW ACOUSTIC PLANKTON PROFILES VERTICAL NET TOWS MILLER NET TOWS ROSETTE/CTD SECCHI DISC OBS BIRD OBSERVATIONS AND COLLECTIONS MAMMAL OBSERVATIONS	13 13 13 12 13 1 13 10

APRIL 1 - JUNE 30, 1976

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
ACONA (U OF ALASKA)	8-19 APRIL 76 I A	MOLNIA, USGS	NORTHERN GULF OF ALASKA	LITHOLOGY SUB-BOTTOM GEOLOGICAL STRUCTURE	SEDIMENT CORES AND GRABS SEISMIC REFLECTION	UNKNOWN UNKNOWN
SURVEYOR (NOAA)	12-26 APRIL 76 II A	COONEY, IMS ALEXANDER, IMS MUENCH, IMS DIVOKY, ADF&G BURNS, ADF&G SHAW, IMS BURRELL, IMS FISCUS, NWFC FAY, IMS	BERING SEA	ICE-EDGE BIOLOGY AND CHEMISTRY HELICOPTER AND LAUNCH SUPPORT	VERTICAL NET TOWS CTD ICE CORERS NISKIN WATER SAMPLES TUCKER TRAWLS 1-METER VERTICAL NET TOWS OTTER TRAWLS MAMMAL SPECIMENS AND OBSERVATIONS BIRD SPECIMENS AND OBSERVATIONS NEUSTON NET TOWS	15 17 2 15 8 22 17 11 41 14
DISCOVERER IV A (NOAA)	13-30 APRIL 76	FEELY, PMEL CLINE, PMEL FISCUS, NWFC WEINS, OSU LENSINK, USF&WS	NORTHERN GULF OF ALASKA	SUSPENDED SEDIMENTS HYDROCARBONS	NISKIN WATER SAMPLES NEPHELOMETER MEASUREMENTS CTD TIME-SERIES STATION MAMMAL OBSERVATIONS BIRD COLLECTIONS AND OBSERVATIONS	50 46 50 1
MOANA WAVE (U OF HAWAII)	19 APRIL - 2 MAY 76 IV A	ROYER, IMS SHAW, IMS LENSINK, USF&WS	NORTHERN AND WESTERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD SURFACE WATER SAMPLES NEUSTON TOWS BIRD COLLECTIONS AND OBSERVATIONS	98 20 20

OPERATIONS SUMMARY
APRIL 1 - JUNE 30, 1976

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
MILLER FREEMAN (NOAA)	24 APRIL - 13 MAY 76 II A	PEREYRA, NWFC SMITH, IMS FEDER, IMS MORROW, IMS MCCAIN, NWFC LENSINK, USF&WS SHAW, IMS BURRELL, IMS WALDRON, NWFC DEVRIES, SCRIPPS	BERING SEA	DEMERSAL FISH ASSESSMENT BENTHOS PLANKTON PHYSICAL OCEANOGRAPHY	DEMERSAL FISH TRAWLS VAN VEEN GRABS CTD BONGO TOWS NEUSTON TOWS BIRD OBSERVATIONS AND COLLECTIONS MAMMAL OBSERVATIONS	38 14 9 16 16
DISCOVERER V A (NOAA)	5-9 MAY 76	LARRANCE, PMEL DAMKAER, PMEL ENGLISH, U OF W LENSINK, USF&WS	LOWER COOK INLET/NORTHERN GULF OF ALASKA	PLANKTON BIOLOGY	BONGO NET TOWS VERTICAL NET TOWS NIO NET TOW ROSETTE/CTD SECCHI DISC OBS ACOUSTIC PLANKTON PROFILES BIRD OBSERVATIONS AND COLLECTIONS MAMMAL OBSERVATIONS	11 2 1 11 7 (12.6 HRS)
MOANA WAVE (U OF HAWAII)	7-21 MAY 76 V A	ROYER, IMS SHAW, IMS LENSINK, USF&WS	WESTERN AND NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD CURRENT METER DEPLOYMENT (#9) BIRD COLLECTIONS AND OBSERVATIONS	17 1

OPERATIONS SUMMARY
APRIL 1 - JUNE 30, 1976

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
DISCOVERER (NOAA)	12-20 MAY 76	SCHUMACHER, PMEL HAYES, PMEL HANSEN, AOML LENSINK, USF&WS WEINS, OSU MYRES, U OF CALGARY	NORTHERN GULF OF ALASKA	PHYSICAL OCEANOGRAPHY	CTD CURRENT METER RECOVERIES (SLS-9, SLS-8, 62G, 61B, 69A, 60B) [SLS-7 NOT RECOVERED] DEPLOYMENT (SLS-15, SLS-13, SLS-14 62H, 61C, 69B, 60C) DRIFT BUOY DEPLOYMENTS BIRD COLLECTIONS AND OBSERVATIONS MAMMAL OBSERVATIONS	57 6 7 2
SURVEYOR (NOAA)	12-21 MAY 76	ZIMMERMAN, ABFL WEINS, OSU	WESTERN GULF OF ALASKA	INTERTIDAL BIOLOGY (HELICOPTER SUPPORT)	LITTORAL ZONE OBS AND SAMPLES BIRD OBSERVATIONS AND COLLECTIONS MAMMAL OBSERVATIONS SUBLITTORAL ZONE OBS AND SAMPLES	11 10
MILLER FREEMAN (NOAA)	18 MAY - 4 JUNE 76	WALDRON, NWFC FEDER, IMS SMITH, IMS MCCAIN, NWFC LENSINK, USF&WS SHAW, IMS BURRELL, IMS	BERING SEA	DEMERSAL FISH ASSESSMENT BENTHOS PHYSICAL OCEANOGRAPHY	BOTTOM TRAWLS VAN VEEN GRABS PIPE DREDGES CLAM DREDGE NEUSTON/BONGO TOWS XBT BIRD OBSERVATIONS AND COLLECTIONS MAMMAL OBSERVATIONS	16 30 44 1 43 47
DISCOVERER (NOAA)	24-30 MAY 76	LARRANCE, PMEL DAMKAER, PMEL ENGLISH, U OF W MYRES, U OF CALGARY	LOWER COOK INLET/ NORTHERN GULF OF ALASKA	PLANKTON BIOLOGY	BONGO NET TOWS VERTICAL NET TOWS NIO NET TOW ROSETTE/CTD SECCHI DISC OBSERVATIONS BIRD OBSERVATIONS AND COLLECTIONS	12 8 1 12 5

OPERATIONS SUMMARY
APRIL 1 - JUNE 30, 1976

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
SURVEYOR (NOAA)	25 MAY - 3 JUNE 76 IV A	PITCHER, ADF&G LENSINK, USF&WS	NORTHERN GULF OF ALASKA	MARINE MAMMAL SURVEY	MAMMAL COLLECTIONS AND OBSERVATIONS	6
					LAUNCH HYDROGRAPHIC SURVEY (ICY BAY)	(98.3 NM TRACKLINE)
					BIRD OBSERVATIONS AND COLLECTIONS	
MOANA WAVE (U OF HAWAII)	26 MAY - 20 JUNE 76 VII A	SCHUMACHER, PMEL COACHMAN, U OF W HUNT, U OF CAL, IRVINE HANSEN, AOML LENSINK, USF&WS	BERING SEA	PHYSICAL OCEANOGRAPHY PRIBILOF BIRD SURVEY	CTD	154
					CURRENT METERS/PRESS GAGE ARRAYS (BC SERIES)	
					RECOVERIES (2B, 3B, 7A, 13A, 1C) [12A NO RESPONSE 4B INTERROGATED BUT NOT RECOVERED]	4
					DEPLOYMENTS (2C, 3C, 4C, 5A, 6A, 8A, 9A, 10A, 11A, 13B, 14A, 15A)	12
					DRIFT BUOY DEPLOYMENTS	3
					BIRD OBSERVATIONS AND COLLECTIONS	
					MAMMAL OBSERVATIONS	
SURVEYOR (NOAA)	5-20 JUNE 76 V A	ZIMMERMAN, ABFL MYRES, U OF CALGARY HUNT, U OF CAL, IRVINE FISCUS, NWFC	BERING SEA AND GULF OF ALASKA	INTERTIDAL BIOLOGY (HELICOPTER SUPPORT)	LITTORAL ZONE OBS AND SAMPLES	10
					SUBLITTORAL ZONE OBS AND SAMPLES	10
					SEISMIC STATION INSTALLATION AND SERVICING	3
					BIRD OBSERVATIONS AND COLLECTIONS	
					MAMMAL OBSERVATIONS	
					SHIP HYDROGRAPHIC SURVEY (CHIRIKOF IS.)	(95 NM TRACKLINE)

[illegible]
APRIL 1 - JUNE 30, 1976

SHIP	CRUISE PERIOD	PRINCIPAL INVESTIGATOR	WORK AREA	NATURE OF INVESTIGATION	SPECIFIC OPERATIONS	NUMBER OF STATIONS
MILLER FREEMAN (NOAA)	7-23 JUNE 76 IV A	SCHUMACHER, PMEL COACHMAN, U OF W WEINS, OSU LENSINK, USF&WS	BERING SEA	PHYSICAL OCEANOGRAPHY	CTD	19
					CURRENT METERS/PRESSURE GAGE ARRAY RECOVERIES (WGC-2C, WGC-1C, BC-12A, PARTIAL BC-4B) [WGC-2B, WGC-3A NO RESPONSE]	3 1/2
					DEPLOYMENTS (WGC-2D, WGC-3B, WGC-1D)	3
					BIRD OBSERVATIONS AND COLLECTIONS	
					MAMMAL OBSERVATIONS	
Moana Wave	25 June - 8 July VII A	Haslett				
Acona	26 June - 2 July II A					

The following sections are primarily excerpts pertaining to OCSEAP studies from syntheses reports for particular lease areas. These were prepared by the following staff members of Science Applications, Inc. under contract with the OCSEAP Office of NOAA:

Roy Faverty - geology and coastal geomorphology
Jawed Hameedi - physical and biological oceanography
Keith Macdonald - marine geology, intertidal and benthic communities
Richard Tenaza - biology (marine birds and mammals)
Ron Weaver - ice
Edward Wolf - biology (fish, chemistry, and petroleum effects)

SECTION 2

LOWER COOK INLET: PHYSICAL ENVIRONMENT, BIOTA, AND POTENTIAL PROBLEMS RELATED TO OIL EXPLORATION

CONTENTS

Chapter I

ENVIRONMENT

DESCRIPTION OF STUDY AREA

Cook Inlet, located in southcentral Alaska, is a large tidal estuary which flows into the Gulf of Alaska. It trends northeast-southwest, is approximately 370 km in length, and is 139 km wide at the mouth. Knik and Turnagain Arms, branches of the inlet, are 83 and 80 km long, respectively.

Cook Inlet is bordered by several mountain ranges: the Aleutian Range and the Alaska Range to the northwest, the Talkeetna Mountains to the northeast, and the Kenai Mountains to the southeast. Glaciers are common throughout these mountains; the principal rivers (Susitna, Matanuska, and Knik) entering the upper inlet carry heavy glacial sediment loads and have formed active deltas (Fig. I-1). The estuary is generally shallow, averaging only 60 m in depth at the Cook Inlet-Susitna lowlands to the north. The bottom slopes to a depth of more than 200 m just south of Cook Inlet entrance and east of the Barren Islands. These relatively deep areas are apparently swept by vigorous tidal currents.

Five active volcanoes (Augustine, Spurr, Redoubt, Iliamma, and Douglas) border the west side of the inlet. These five volcanoes define a belt of volcanic activity that is contiguous with the arcuate zone of volcanoes trending southwest through the Katmai District and into the Aleutian Archipelago.

GEOLOGY

Structurally, Cook Inlet is a fault-bounded trough. The southeast shore parallels the NE-SW trending Kenai Peninsula fault that extends across the mouth of the inlet and through Kodiak Island. The northwest shore is bordered by the Bruin Bay fault which extends well into the Alaska Peninsula. The Clark-Castle Mountain fault forms the northern limit of the fault trough; offsets in glacial deposits indicate that this fault has been active in recent times (Evans et al. 1972).

The inlet is bordered to the north and west by the igneous and metamorphic terrains of the southern Alaska Range and the Talkeetna Mountains. Coastal lowlands composed of Pleistocene deposits flank the southeast shore and are in turn backed by the meta-volcanics, slates, and greywackes of the Kenai Mountains.

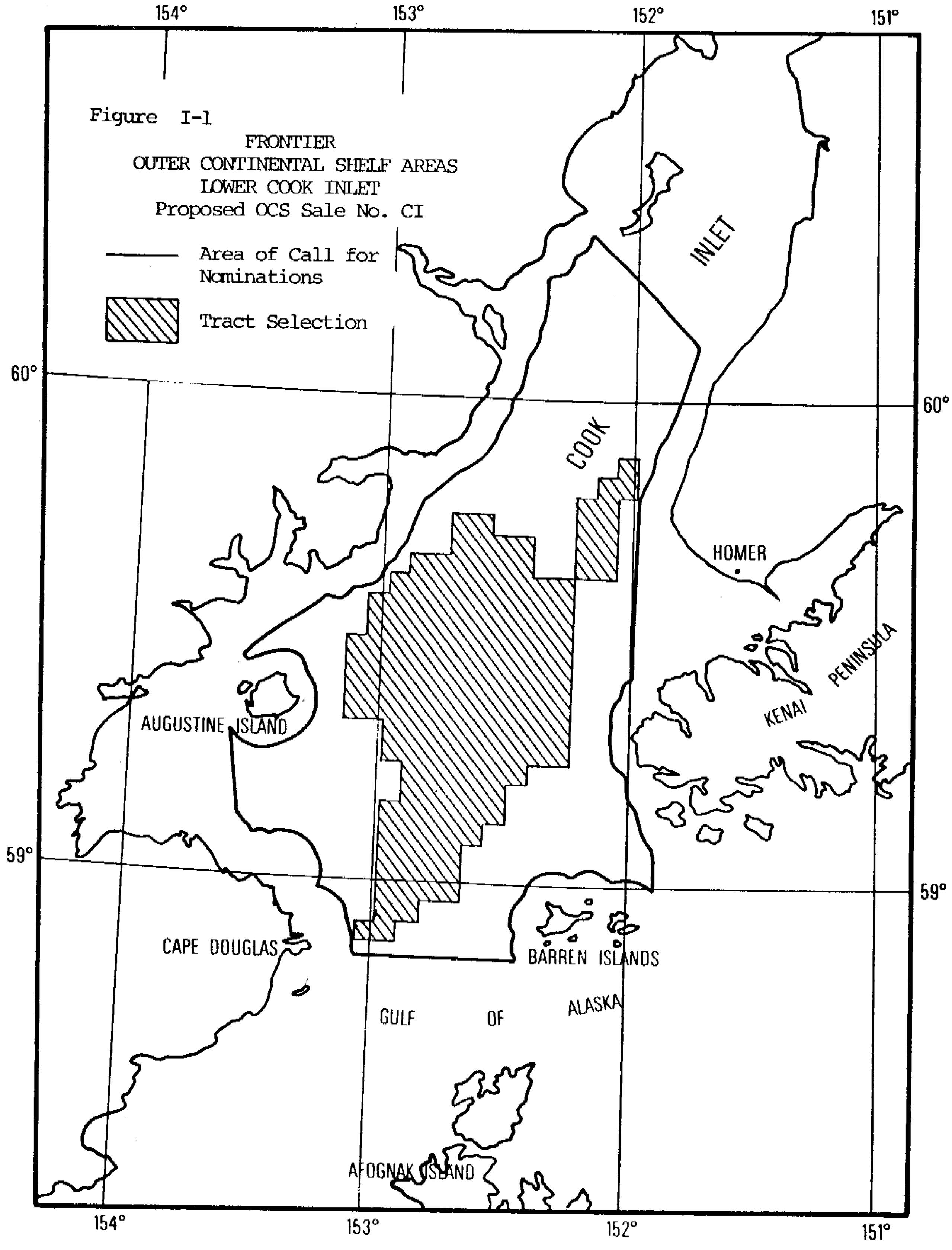
Figure I-1
FRONTIER
OUTER CONTINENTAL SHELF AREAS
LOWER COOK INLET
Proposed OCS Sale No. CI
Area of Call for Nominations
Tract Selection
154°
153°
152°
151°
60°
59°
INLET
COOK
HOMER
KENAI
PENINSULA
AUGUSTINE ISLAND
CAPE DOUGLAS
BARREN ISLANDS
GULF
OF
ALASKA
AFOGNAK ISLAND

Cook Inlet receives large quantities of glacially derived sediment from the Knik, Mantanuska, Susitna, and other rivers. These are redistributed by intense tidal currents that sometimes reach velocities of 6 knots. Most of the fine-grained sediment is carried offshore through Shelikof Strait and is deposited in the Aleutian trench beyond Kodiak Island. The inlet bottom is composed primarily of gravels with minor silt and clay components (Crick 1971). Salinity ranges from 32 ppt (at depth) at Cook Inlet entrance to 8 ppt at the mouth of the Susitna River. Water temperature ranges from 4.3°C (at depth) in Kachemak Bay to 9.4°C at the mouth of the Susitna River.

GENERAL CLIMATE

Cook Inlet occupies a transition zone between the interior with its cold winters, hot summers, low precipitation, and moderate winds and the maritime zone with cool summers, mild winters, high precipitation, and frequent storms. January temperatures are generally warmer toward the southern portion of the inlet while July temperatures are cooler there. (Seldovia: January, -4.9°C; July, +13.2°C). In the northern portion of the area the reverse trend exists (Susitna: January, -10°C; July, 14.3°C). Annual precipitation tends to increase toward the mouth of the inlet, with major precipitation occurring in autumn in the upper inlet. The lower inlet, with its warmer winter temperatures, receives more winter precipitation in the form of rain. The mean total precipitation over the entire Cook Inlet area is 53 cm/year (Evans et al. 1972).

Prevailing winds in Cook Inlet are either from a northerly or southerly direction depending on the season. Winter winds are generally north/northeast, while during the summer months the prevailing direction is southwest. Mean wind speeds are moderate with a yearly average of 14 km/h (Swift et al. 1974). No significant seasonal variation was found. It should be pointed out that "open waters of the inlet, where friction is reduced, are subject to higher winds than onshore areas. Under extreme conditions, winds of 139 to 185 km/h may occur over the open water and storms with 93 to 139 km/h winds are experienced in Cook Inlet every winter" (USDI 1976).

SEA ICE

Sea ice usually forms in Upper Cook Inlet early in December with false freeze-ups occurring in Late October and November. Breakup is generally complete by late April.

The pack ice may extend as far south as Cape Douglas along the western margin and Anchor Point on the east. Ice south of the "Forelands" generally is open pack with small floes (Peyton, pers. comm. 1976). Maximum extent is usually attained in the last half of January. Ice thicknesses may reach 1.5 m (USDI 1976); however, pack ice thicknesses of only 0.5 m were observed during the 1971-72 season (Hutcheon 1973) in the Upper Cook Inlet.

Areas of stable shorefast ice appear in the more sheltered bays, principally Kachemak Bay (where the fast ice extends some 5 km offshore) and Kamishak Bay. Large piles of ice (stamukhi) formed on tidal flats occasionally float off the mudflats during high tides and into the inlet. The stamukhi may reach thicknesses of 12 m and pose a hazard to offshore structures and shipping.

Ice drift in Lower Cook Inlet, south of the "Forelands," tends to follow the western shoreline. The ice begins to ablate and diverge soon after passing Kalgin Island. Therefore, ice conditions in Lower Cook Inlet are probably below 4/10 concentration (Peyton, pers. comm. 1976). This conclusion, however, should be verified, preferably through remote sensing.

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Chapter II

SOURCES

INTRODUCTION

Marine waters contain accumulations of naturally occurring and artificially introduced hydrocarbons and heavy metals. Hydrocarbons are synthesized by phytoplankton and promulgated through the food chain by metabolic breakdown and resynthesis into carbohydrate, protein, and lipid. Hydrocarbons also originate in the marine environment from natural petroleum seeps and through accidental and/or purposeful discharges from oil development, transport, and production. Recreational and other marine transports and various industrial users periodically discharge oil-based effluents. Heavy metals originate from similar sources. Providing the metal loading remains low, the marine environment readily absorbs moderate influxes. Metals, even though some are toxic, are essential to an organism's nutrition. Selected metals are taken up from the water by organisms and may be transported to deep waters; new supplies are carried into the upper layers by upwelling and direct input to the surface waters. Chemical, physical, and biological reactions cause precipitation of excesses and solubilization to offset deficiencies.

In pristine waters such as those found along the Alaskan Outer Continental Shelf, significant inputs of hydrocarbons and metals through oil development and release are readily detectable. OCSEAP-related research is designed to characterize the hydrocarbon and heavy metal levels in the Alaskan marine environment.

C_1-C_4 HYDROCARBONS

C_1-C_4 hydrocarbons are valuable indicators of petroleum contamination because of their relatively high solubility and low natural abundance. Cline and Feely (RU #153) have determined levels of methane, ethane, ethylene, propane, propylene, isobutane, and n-butane in the Gulf of Alaska and southern Bering Sea. No samples were collected in Lower Cook Inlet. Sampling of the Kodiak shelf and Lower Cook Inlet is scheduled for 1976.

Cline and Feely (RU #153) found that methane concentrations in the surface waters of the Bering Sea were generally near atmospheric equilibrium (50-70 $n\ell/\ell$), but in the Gulf methane concentrations were rarely below 100 $n\ell/\ell$. As expected, higher levels were noted in the near bottom waters in both areas.

The C_2-C_3 fractions were generally less variable than methane, but like methane, increased with depth with the exception of propane and propylene; concentrations in the Bering Sea ranged from 0.3 to 1.5 nℓ/ℓ. In the Gulf the C_2-C_3 levels were usually less than 1 nℓ/ℓ. Isobutane and n-butane concentrations reported were generally at or below the detection limit (0.03 nℓ/ℓ) for both marine environments (Cline and Feely, RU #153).

C_1-C_6 hydrocarbons were measured in the sediments near Kodiak Island, Cook Inlet, and the Aleutian Shelf (Kaplan, RU #275). Kaplan found, as did Cline and Feely (RU #153), no definitive evidence of petroleum contamination. Methane was the only low molecular weight hydrocarbon measurable in the sediments, generally 5 ng/g dry sediment. Near bottom methane values reported by Cline and Feely (RU #153) in the northeast Gulf were considerably above atmospheric equilibrium; whereas, Kaplan (RU #275 subcontract) indicated that concentrations in the sediments were similar to those of average seawater.

Concentration levels of C_1-C_4 hydrocarbons in the water in Lower Cook Inlet are not known. But, due to petroleum production activities in Upper Cook Inlet and possible gas seeps in the Forelands area, elevated levels of low molecular weight hydrocarbons are expected. Some variability is present between methane concentrations in sediment pore water and Northeast Gulf water samples; future studies by Cline and Feely (RU #153) in Cook Inlet may better define these differences.

OTHER HYDROCARBONS

Research by Shaw (RU #275), in cooperation with Kaplan (RU #275 subcontract), is designed to determine background hydrocarbon levels in seawater, biota, sediment, and seston and to identify animal tissues that might serve as useful indicators of petroleum pollution. The area studied spanned the continental shelf from Yakutat Bay on the east to Unimak Pass on the west. Five sampling transects were located in the western Gulf. One transect lay northeast of Kodiak Island, projecting into the entrance of Cook Inlet; a second transect was located southeast of Kodiak Island and normal to the Alaska Peninsula. The other transects were to the southwest along and normal to the Alaska Peninsula.

Preliminary results indicate that the hydrocarbon levels in the Gulf of Alaska shelf waters are as low as, or lower than, other areas of the world oceans. No petroleum pollution was apparent in the sampling area. This is indicated by the concentration of hydrocarbons in the ppb range in the water and in the ppm range in the biota, by the absence of indications of petroleum in the gas chromarange in the biota, and by the extremely low abundance of floating tar (mean of 51 tows was 6.6×10^{-4} mg/m^2.

Shaw concluded from chromatographic analyses that the pelagic tar collected in the Gulf of Alaska was more weathered than tar reported in the north Atlantic and probably originated from tanker washings rather than natural seeps.

Bottom sediments from the Gulf of Alaska generally contained <0.1% nitrogen and sulfur. Samples from Cook Inlet were particularly low in carbon, nitrogen, and sulfur. The distribution of saturated hydrocarbons showed no isoprenoids or n-alkanes lighter than C_{19}. The odd/even ratios of n-alkanes over the range C_{21} to C_{31} was >1, and the presence of hydrocarbons $>C_{27}$ indicates that the solvent-extractable components resulted from planktonic and terrestrial plant-derived material.

In a survey of the selected subtidal biota, Shaw (RU #275) noted that tissues of several species have low concentrations of biogenic hydrocarbons. Pollock gills, crab body soft parts and shrimp soft parts are potential indicator tissues for the detection of petroleum contamination. As Shaw points out, the sensitivity of detection by biological tissues is dependent on the biogenic hydrocarbon content of the tissues and the rapidity with which the tissues take up hydrocarbons. Therefore, the high natural hydrocarbon content of Pollock viscera and the low uptake rate in crab leg muscle make these tissues unsatisfactory indicators of petroleum contamination.

HEAVY METALS

Inorganic sediments constitute the largest repository of heavy metals, but those held in the biota are of particular concern to man. The importance of seawater lies not in the absolute amounts or concentration of metals held, but in its role as a mobile phase through which, and with which, these trace constituents can be transported (Burrell, RU #162). Preliminary data indicate that the soluble metal content of Gulf of Alaska and Bering Sea waters were as low or lower than in other coastal regions. Levels in the biota were similarly low. Burrell further stated that the Alaskan shelf environments are quite pristine and any future anthropogenic perturbations should be detectable. He also did not find mild or chronic contamination which might help biota acclimatize to future industrial activities.

MICROBIOLOGY

OCSEAP-related research in microbiology can be subdivided into three categories: (1) characterization of the marine microbiological community, including rates and limiting factors of hydrocarbon degradation and the effects of crude oil on heterotrophic activity; (2) evaluation of the present health status of demersal fishes so that possible environmental perturbations in the future can be evaluated; (3) determination of the potential for release of soluble trace metals following oil impaction of marine sediment, and evaluation of interstitial metal changes due to variations in microbial or biological activity or chemical perturbations within the sediments.

This report includes results from field and laboratory studies by McCain and Wellings (RU #332), Atlas (RU #30), and Barsdate (RU #278). To date these are the only studies conducted on the heterotrophs in the Lower Cook Inlet.

Microbial Abundance and Degradation of Crude Oil

Atlas (RU #30) has shown that heterotrophic populations in the water near Kodiak Island ranged from 1×10^5 to 5×10^5 cells/ℓ, by direct count. Total viable counts were tabulated for growth-temperature preference. Total viable mesophilic heterotrophs in the water ranged from 10^1 to 10^3 cells/mℓ; psychrophilic-psychrotroph count ranged from 10^1 to 10^2 cells/mℓ. Total viable counts of heterotrophs in the sediment ranged from 10^4 to 10^6 cells/gm dry wt. In general, the number of heterotrophs in sediment were several orders of magnitude greater than the number in water, and mesophilic counts in the sediment were slightly higher than psychrophilic-psychrotrophic counts.

Similar numbers of heterotrophs have been reported in more temperate seas and in the Beaufort Sea (Atlas, RU #29; Bunch and Harland, BSPTR #10; Kaneko and Caldwell 1973; Sieburth 1967; Atlas and Bartha 1972).

Oil-utilizing microorganisms were not detected in most samples collected near Kodiak Island and Lower Cook Inlet areas. In most samples the number of oleoclasts was less than 1 cell/10 mℓ. Atlas (RU #30) notes that these values are comparable to other nonpolluted marine areas.

Counts of species considered pathogenic to man were very low. *Pseudomonas* sp., *Salmonella* sp. and "enteric" bacteria were usually 1/mℓ, when detected, in water and sediments samples. Mesophilic *Vibrio* spp. were detected in all samples, and counts as high as 10^4 cells/gm dry wt. sediment were recorded. These counts are consistent with other nonpolluted areas, except that Pseudomonas sp. appears markedly low.

It is evident from these data that the Kodiak Island and Cook Inlet region has a heterotroph complement similar in number to more temperate seas. Mesophilic and psychrophilic-psychrotrophs indicate the potential for heterotrophic activity over the temperature extremes found in these waters. Oleoclastic and pathogenic forms are almost absent in the area; only Vibrio spp. were noted in great abundance. The absence of oleoclasts is indicative of the lack of oil contamination but may also indicate low degradation rates if a spill should occur. Studies currently in progress in the Gulf of Alaska should better define the abundance of oleoclasts and their ability to degrade petroleum (Atlas, RU #30; Morita and Griffiths, RU #190).

Health Status of Demersal Fish

Disease incidence studies have not been reported on in the Cook Inlet lease area. Data to be collected in the Gulf of Alaska will determine the incidence of disease among the demersal species present. Such results may be useful in appraising the effects of anthropogenic perturbations in these waters. Field studies by McCain and Wellings (RU #332) in the southern Bering Sea and Puget Sound indicate that several chronic fish diseases may be present in the Kodiak Island and Cook Inlet areas. Lymphoceptis, epidermal papillomas, and bilateral pseudobranchial tumors have been identified in Puget Sound and southern Bering Sea Fish. Therefore, it is probable that these diseases are also present in fish in the Gulf of Alaska. Although the disease infestations reported for the southern Bering Sea were very species specific, McCain and Wellings (RU #332) point out that these diseases have been identified in other fish species.

RELEASE OF SOLUBLE TRACE METALS

Barsdate (RU #278) has shown in initial laboratory studies that the copper concentration of sediment pore waters may increase following impaction of oil. Tentative results indicate that the effect is ascribed to the occlusion of trace metal binding or exchange sites by components of oil. This is considered to be a physical or chemical reaction rather than the result of microbial activity.

Increases in metal composition of the pore waters after oil impaction may be reflected in the benthic organisms. Such changes may also be noted as increased metal concentrations in the waters above. Should metal levels increase markedly, the species composition in the benthic and pelagic environments may be affected.

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Chapter III

HAZARDS

INTRODUCTION

NOAA-OCSEAP is presently sponsoring two research units concerned with geologic hazards in the proposed Lower Cook Inlet lease area. Pulpan and Kienle (RU #251) are collecting data from a 23 station seismic array to assess seismic and volcanic hazards in the western Gulf of Alaska, and Hampton and Bouma (RU #327) are using a variety of shipboard geophysical techniques to study faulting and instability of continental shelf sediments in the western gulf. A third research unit -- an evaluation of seismic sea wave hazards to potential shore-based facilities (P #27) -- is projected to begin during fiscal year 1977.

In this section preliminary results from RU #251 and RU #327 have been combined with previously available data summarized by University of Alaska personnel (AEIDC 1974). Additional contributions come from Davies et al. (RU #16), Carlson (RU #111), Meyers (RU #352), and SAI (1976).

SEISMICITY

Cook Inlet occupies a portion of an elongated structural basin that extends from the tip of the Alaska Peninsula to the Alaska-Yukon border. It is fault bounded and lies at the leading edge of the North American Plate. It is presently being underthrust by the Pacific Plate along the Aleutian Trench.

The location of Cook Inlet above a zone of active underthrusting results in significant regional siesmic and volcanic hazards. Meyers' (RU #352) summary of Alaskan earthquake epicenter data, for example, indicates that hundreds of seismic events have been recorded from the Cook Inlet region since 1899. At least 17 of these have been marked by earthquakes of magnitude 6 or greater (Fig. III-1 and III-2).

The great Alaska Earthquake of 1964 -- centered near Prince William Sound and with a magnitude of 8.3 to 8.7 -- caused extensive damage in the Cook Inlet area. The central and eastern portions of the inlet subsided 0.6 to 1.3 m, while the western shores were slightly uplifted (<0.6 m). Port facilities at Homer had to be closed because up to 1.5 m of consolidation subsidence occurred along Homer spit (USDI 1976). Possible subsurface fault movements were reflected by extensive ground fissuring and sand boils along a zone 95 km long, 10 km wide, adjacent to the eastern shores of the upper inlet (Foster and

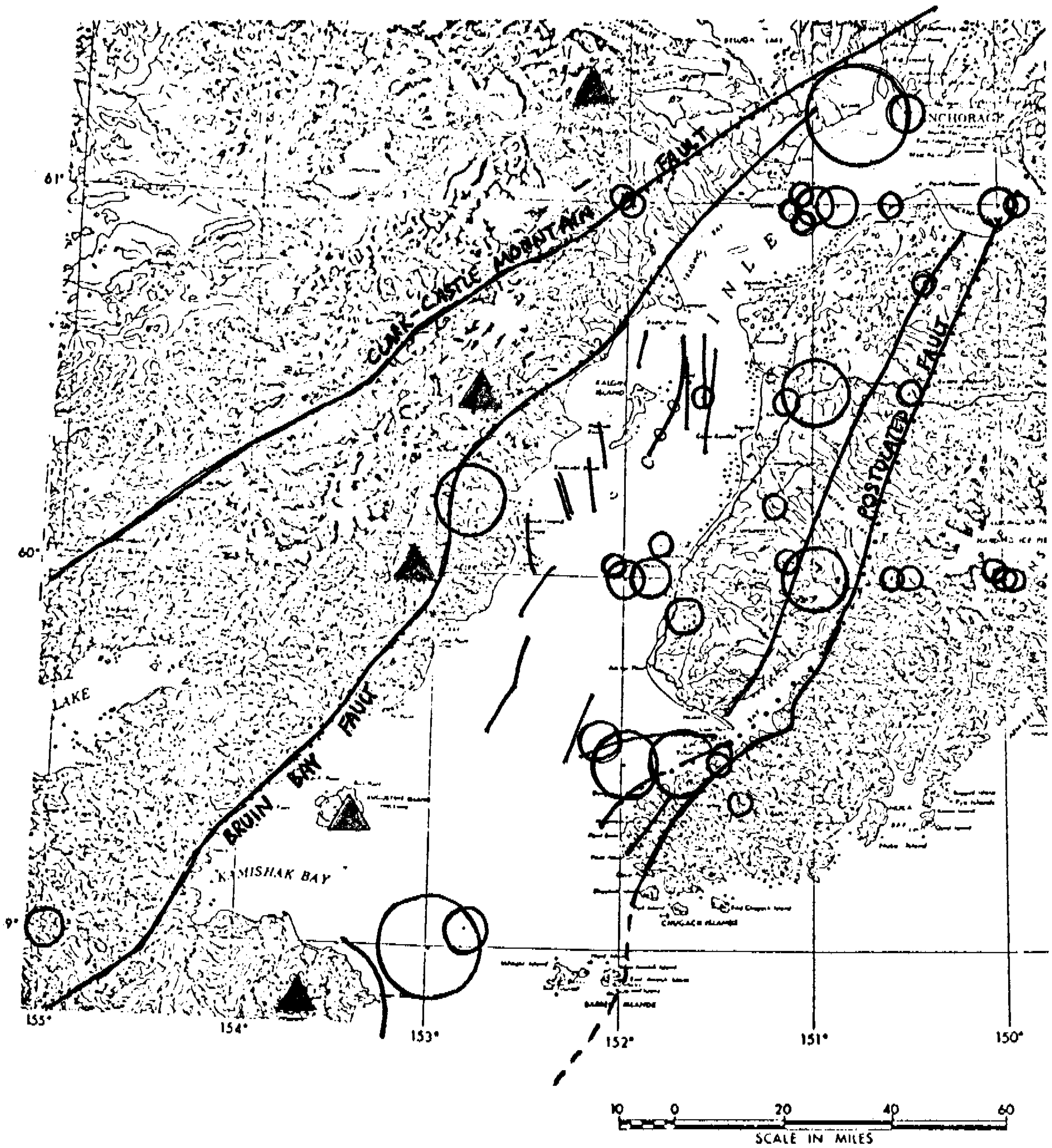

Fig. III-1. Earthquake epicenter map for Cook Inlet Region (SAI 1976).

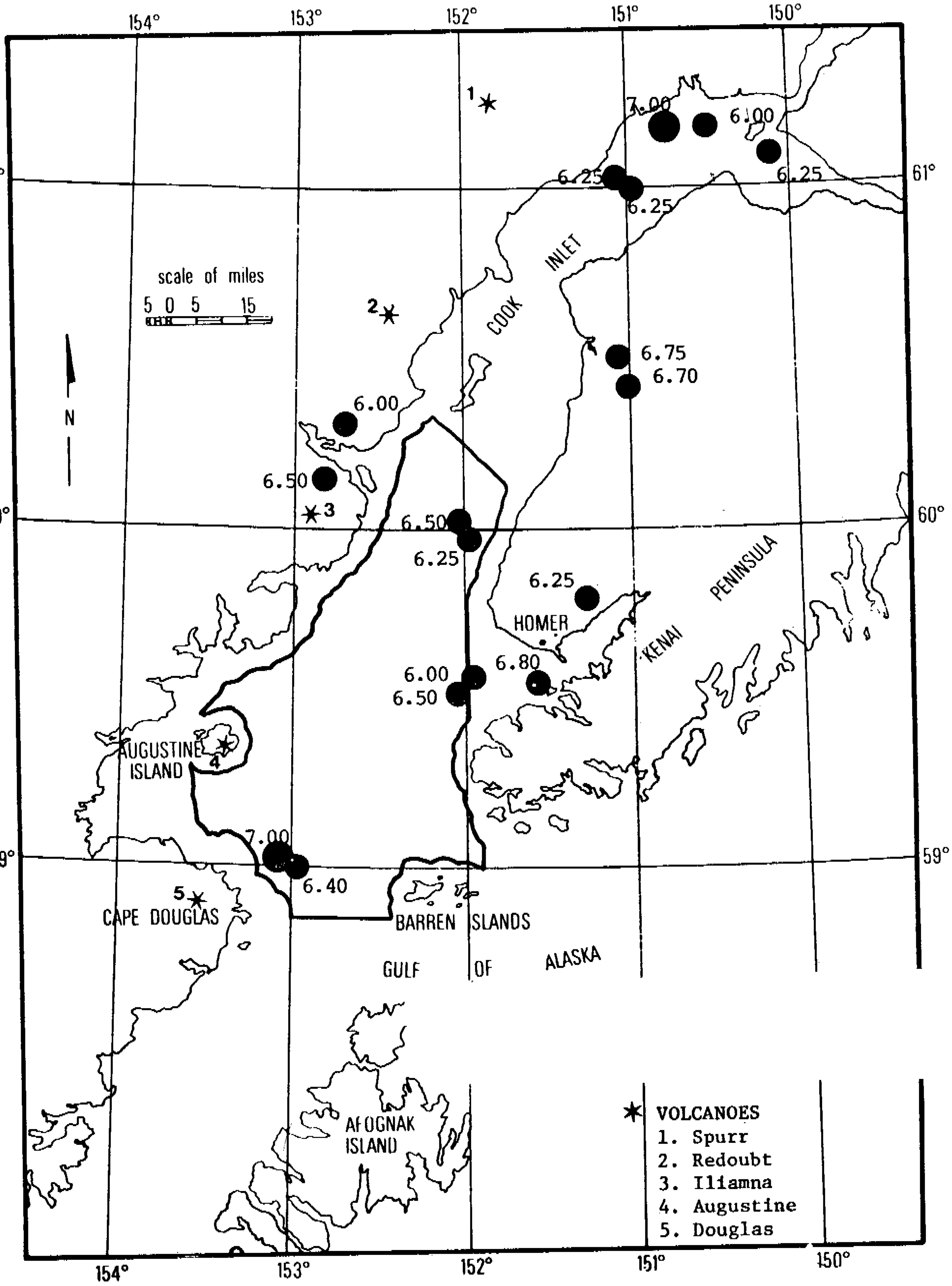

Fig. III-2. Earthquakes with magnitudes ≥6.0, 1899-1974 (USDI 1976).

Karlstrom 1976). Ground shaking accompanying the earthquake caused rock slides, as well as slumping and liquefaction of saturated, unconsolidated sediments (particularly the Pleistocene Bootlegger Cove clay) underlying portions of Anchorage and Homer. Direct structural damage to residential, commercial, and transportation facilities was aggravated by indirect damage resulting from ruptured utility lines and extensive fires. Some additional damage was caused by a regional tsunami that hit Rocky Bay and Seldovia, as well as most of the west coast of the inlet. (Since the 1964 tsunami was generated offshore, the Kodiak Islands shielded Cook Inlet from more serious inundation, see below.)

It is clear from the above that earthquakes pose a substantial hazard within the proposed Cook Inlet lease area. Damage could be caused directly by regional deformation, surface faulting, or ground shaking (causing liquefaction, slumping, and consolidation), as well as indirectly by tsunamis. At present, both the distribution of active surface faulting and the distribution and geotechnical properties of the inlet's bottom sediments, are too little known for adequate hazard prediction (USDI 1976). Pulpan and Kienle (RU #251) are presently delineating onshore-offshore fault zones in the area.

Cook Inlet is included in seismic risk zone 3 -- areas susceptible to earthquakes of magnitude 6.0 to 8.8 and subject to major structural damage. No maximum ground acceleration data for earthquakes in this area have been located; however, the seismic array established by Pulpan and Kienle (RU #251) can provide such data for future earthquakes. Predicted peak accelerations for Nikiski, east-central Cook Inlet, are included in a recent LNG facility risk assessment study (SAI 1976). The maximum tectonic displacements recorded during the 1964 Alaska earthquake -- maximum uplift, 15 m; maximum subsidence, 2.5 m; maximum horizontal movement on land, 19.5 m -- should be carefully considered when design criteria are established for Cook Inlet development.

TSUNAMIS

Tsunamis, or seismic sea waves, are known to occur in the western Gulf of Alaska (Meyers, RU #352). Most Alaskan earthquakes occur along an arc from the Aleutian Islands to Prince William Sound (Kienle 1971, cited in AEIDC 1974), reflecting underthrusting of the Pacific Plate along the Aleutian Trench. An underthrusting movement is usually accompanied by large scale displacement of the sea floor which may cause tsunamis. The manner in which tsunamis are formed is not fully understood but their magnitude appears to be related to the intensity of the submarine earthquake, depth of water, extent and velocity of crustal deformation, and the efficiency with which energy is transferred from the earth's crust to seawater (National Academy of Sciences 1972, cited in AEIDC 1974).

The 1964 Alaska earthquake resulted in extensive seafloor deformation along an axis between Kodiak Island and Prince William Sound (Plafker, 1972). This generated long period seismic sea waves that paralleled the axis of deformation and moved away from it in a perpendicular direction. The southeast facing coasts of Kodiak Island and the Kenai Peninsula received the full force of the tsunami and sustained extensive damage. A maximum wave runup of nearly 18 m was recorded at Narrow Cape, Kodiak. Relatively little of the tsunami's energy penetrated the relatively narrow, oblique entrance of Cook Inlet, although damage was reported from Rocky Bay and Seldovia. Future tsunamis, generated offshore in the central and eastern areas of the Gulf of Alaska, will probably behave in a similar fashion.

It appears likely that a major earthquake will occur in the Shumagin Islands seismic gap within the next decade (Davies et al., RU #16; see KODIAK ISLAND, Section III, of this report). This also will reflect regional underthrusting and can be expected to generate a tsunami. While the consequences of such a tsunami remain to be explored, it seems possible that some wave energy could move up Shelikof Strait and into Cook Inlet.

In addition to regional tsunamis generated offshore, smaller local tsunamis could be generated by movements along active underwater faults located within the Cook Inlet. SAI (1976) recently assessed this hazard in a study of the proposed Nikiski liquified natural gas facility (east-central Cook Inlet). They concluded that a magnitude 7.5 earthquake occurring on the Kenai Peninsular fault where it passes beneath Cook Inlet entrance, could generate a wave somewhat more than 2 m high. Assuming a 170 km wavelength for the tsunami, maximum wave runup at Nikiski would be approximately 7 m (SAI 1976).

Local tsunamis could also be generated within Cook Inlet by major rock-falls and submarine landslides (USDI 1976). A massive mudslide during Mt. Augustine's 1883 eruption caused such a wave, which struck English Bay (see VOLCANIC HAZARDS, following).

An OCSEAP-sponsored study of tsunami hazards to proposed shore-based facilities within the Cook Inlet-Kodiak region (P #27) is planned for fiscal year 1977.

VOLCANIC HAZARDS

Five active volcanoes lie along the western shores of Cook Inlet. From north to south these are: Spurr, Redoubt, Iliamna, Augustine, and Mt. Douglas (Fig. III-2). All but Mt. Douglas have erupted in historic times. In common with other volcanoes in the Aleutian-Alaska Arc, these volcanoes yield andesitic magmas and experience moderate to violent eruptions.

AEIDC (1974) Provides a useful summary of the potential hazards associated with andesitic volcanoes. Primary reuptive phenomena include:

1. Krakatoan eruptions -- explosions with destruction of much of the volcano summit (e.g., 1912 Katmai eruption, Wilcox 1959).
2. Nuee ardente -- swiftly moving clouds of incondescent gases and ejecta (e.g., 1912 Katmai eruption).
3. Pyroclastic eruptions -- block-size ejecta to fine-grained ash that can be carried great distances by the wind.
4. Turbulent ash clouds and columns -- reach heights of 15,000 to 30,000 m; hazardous to local aircraft.
5. Lava flows -- usually minimal due to viscous nature of andesitic magma.

Hazardous secondary phenomena include volcanic mudflows and landslides, flash floods (due to sudden snow melt or breakup of ice-dammed lakes), lightning discharges, corrosive rains, earthquakes, and local tsunamis.

Of the volcanoes adjacent to Lower Cook Inlet, Augustine (Fig.III-2) probably represents the greatest threat to the proposed lease areas. In 1883 a violent eruption of Augustine created a large summit crater.

Augustine is presently building a new lava dome within the 1883 crater and a future, violent eruption is not unlikely. The University of Alaska Geophysical Institute has been monitoring Augustine since 1970 in an effort to refine earthquake prediction techniques. A minor eruption in 1971 was preceded by an increase in microearthquake swarm activity. Comparable studies of Pavlof volcano near the tip of Alaska Peninsula (Davies et al., RU #16) showed no increase in microearthquakes prior to eruptions in 1973. Pulpan and Kienle (RU #251) collected extensive seismic data from Augustine during several eruptions early in 1976; however, the results of their analyses are not yet available.

EROSION AND DEPOSITION

At present no research concerning sediment instability and mass movement, erosion and deposition, or coastal morphology within Cook Inlet is being sponsored by NOAA-OCSEAP. A recent paper by Belon et al. (1975; also RU #267) discusses the use of LANDSAT imagery for measuring suspended sediment concentrations and inferring surface water circulation, within Cook Inlet. They confirm that the Susitna River and Knik Arm, at the head of the inlet, are major sources of sediment. Tital current velocities are sufficient to prevent deposition of muds in the central Cook Inlet basin. Substantial deposition of fine sediments occurs in Kamishak Bay; however, much of the riverborne sediment entering Cook Inlet is carried out into Shelikof Strait (Belon et al. 1975).

COASTAL FLOOD HAZARDS

The data and discussion in R.F. Carlson's Annual Report (RU #111) on the effects of seasonality and variability of streamflow on nearshore coastal areas in the Lower Cook Inlet are preliminary. The study is restricted to the Kenai River Basin, and utilizes nine years of USGS streamflow gage records for the Kenai River. The basin measures 5,210 km^2, discharges into the Lower Cook Inlet just west of the town of Kenai, and is divided into two relatively distinct geomorphic provinces: the Kenai mountains to the east and the (flat to undulating) coastal plain to the west. A coastal terrace borders the eastern margin of the inlet; as a result, the Kenai River is confined near the coast to a distinct channel cutting through the bluff. In addition to the annual snowmelt and groundwater discharge, the Kenai River Basin has six glaciers of varying size and three lakes which contribute to and help regulate the annual discharge of the river. In a geomorphically variable province such as the Kenai Peninsula, snow accumulation and melt patterns are variable, with snow melting first at lower elevations, and as the summer proceeds at higher elevations. This process of snow melting, in itself, tends to regulate river flow during the summer. The flow from lakes and glaciers, as well as distribution and timing of general melting, tend to even out the annual flow curve, minimizing rapid changes in discharge. Perhaps the most serious hazard is the threat of ice dammed lakes bursting beneath or around their ice barriers causing trophic discharges downstream (Post and Mayo 1971) -- a common occurrence in areas of mountain glaciation.

Carlson used remote sensing data to determine peak melting periods and to predict flood occurrences; this is very difficult in the Gulf of Alaska coastal zone due to nearly continuous cloud cover during the months of April and May when snowmelting proceeds rapidly. Carlson did note that snow was still very evident throughout the basin on April 22, 1975, but that much of the basin area below 150 m was free of snow by May 18, 1975.

Table III-1 (Carlson, RU #111) shows the snow depth of the Kenai River Basin as a function of elevation. This increase in snow depth with elevation, coupled with the elevation related snowmelt pattern, contributes to more uniform flow rates.

Table III-1

Site	Elevation	Average Water Content of Snow Pack	Years of Record
Jean Lake	187 m (620 ft)	2.28 cm (0.9 in)	5
Kenai Summit	421 m (1,390 ft)	25.40 cm (10.0 in)	5

Hypsometric analysis, as applied by Carlson, may serve as a means of predicting flood hazards in drainage basins without using gaging station records. The hypsometric curve (Fig. III-3) indicates that high relief terrain represents a relatively small percentage of the Kenai Basin while areas of lowlying relief constitute the greater portion of the landscape. Since large areas of low relief (till plain, coastal terrace, and flood plain) are available for water storage at lower elevations, flood hazards are minimized, as indicated in Fig. III-4.

In conclusion, snowmelt flooding is not a severe hazard in the Kenai River Basin or in other river basins along the Cook Inlet with similar morphometry. However, the threat of glacial lake outbursts is more serious and glacial lead water areas should be inspected carefully for the presence of ice dammed lakes prior to site utilization downstream. The threat of glacial lake outbursts is present not only on the Kenai River but also on the Rude, Knik, Beluga, Chakachatna, McArthur and Big Rivers.

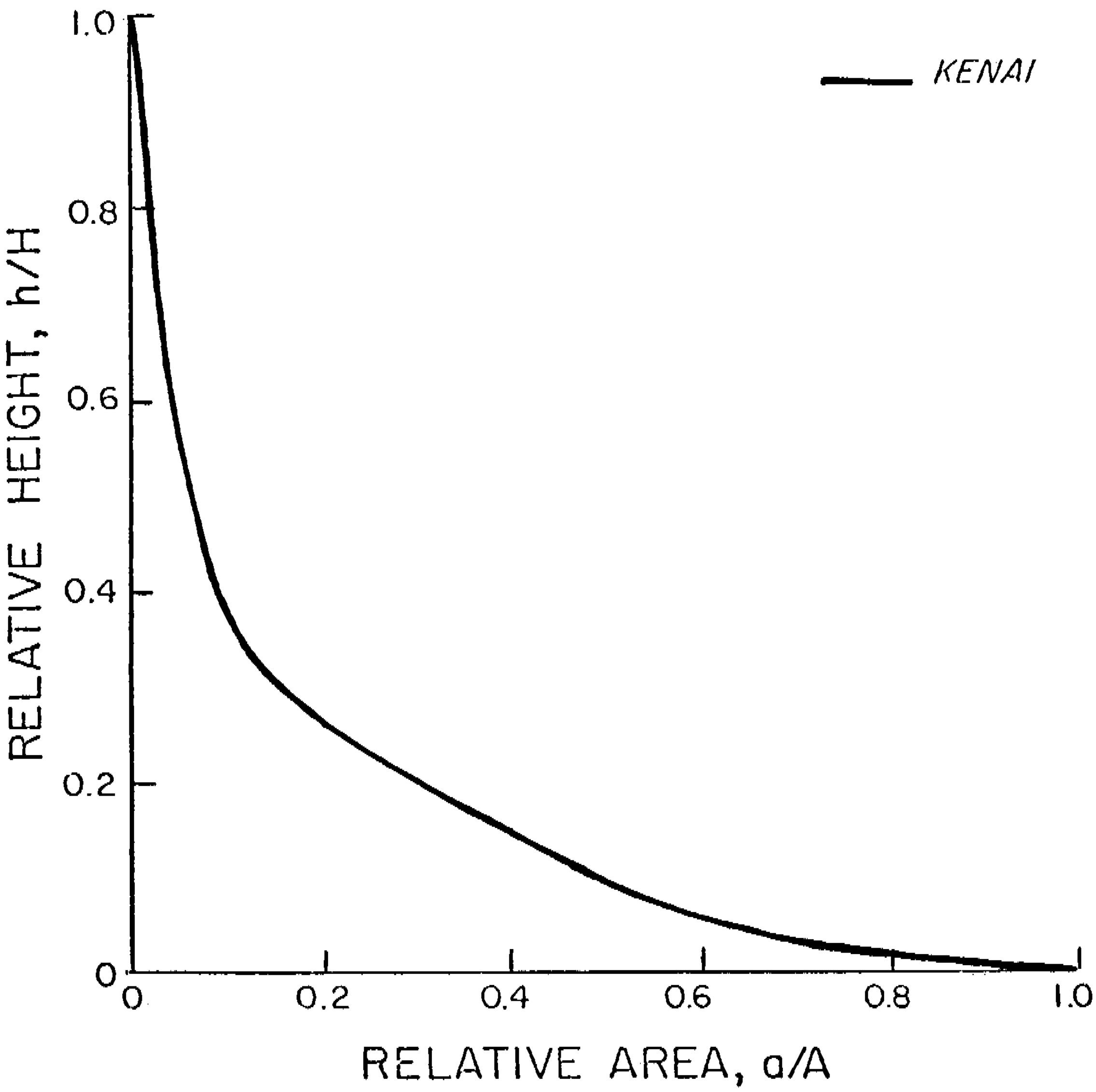

Fig. III-3. Relative hysometric curves for the Kenai River. H = maximum elevation, A = total drainage area, and a = drainage area above a given elevation h.

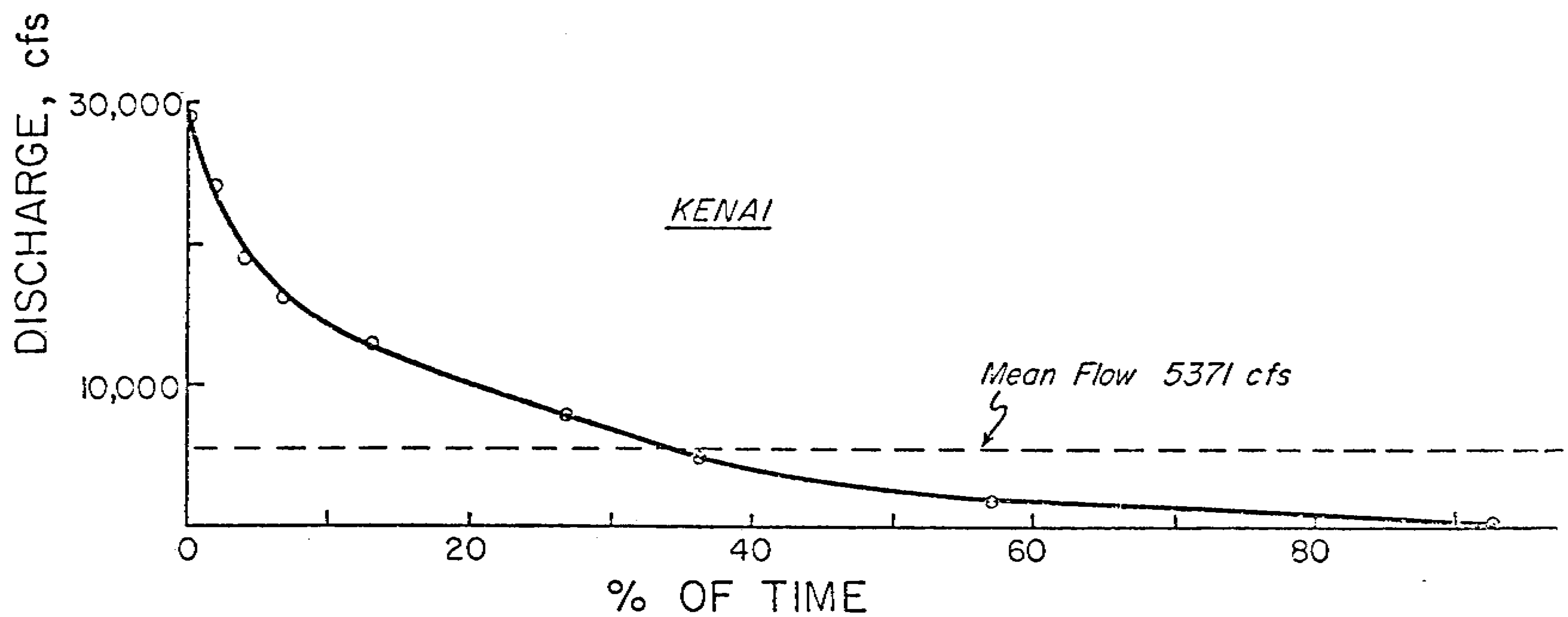

Fig. III-4. Flow duration curve - Kenai River at Soldotna. (Record length - 9 years).

SEA ICE

The severity of ice conditions in Cook Inlet is low to moderate when compared to the more northern areas of the Alaskan Outer Continental Shelf.

Although the actual concentration of pack ice in Lower Cook Inlet is uncertain, it is probably low (Peyton, pers. comm. 1976). Therefore, ice hazards to offshore structures would be greatly diminished. However, no quantitative studies of ice conditions in Lower Cook Inlet have been found.

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Chapter IV

TRANSPORT

GENERAL

No OCSEAP-related research has been conducted in the Lower Cook Inlet lease area to describe the current patterns and assess transport rate, route, and mechanism for spilled contaminants. It is especially important because the general hydrography and seasonal variability of water properties are not known. Due to the apparent lack of data, only a few statements of general applicability are made in this report.

Lower Cook Inlet can be characterized as an estuary with strong tidal influences. Salinity values in the inlet may vary greatly due to the runoff from several small rivers. In the upper part of the inlet, salinity may be as low as 10 ppt whereas near its mouth it may exceed 31 ppt.

Tides in the inlet are typical North American west coast type: a marked diurnal inequality superimposed on semi-diurnal tides. The observed mean and diurnal tidal ranges at Barren Islands are 3.5 m and 4.2 m, respectively; for Kenai these ranges are 5.4 m and 6.3 m. As expected in estuaries and embayments in the Northern Hemisphere, flowing water is primarily concentrated on the eastern side and ebbing water cn the western side of the inlet. A considerable amount of sediment, brought in by rivers, accompanies the outflowing water which continues southward in the Shelikof Strait. Reliable data on current speed and direction are not available. High current speeds, in excess of 6 knots (over 3 m/sec), have been experienced and reported by local fishermen and boaters.

It is possible to estimate an average approximate flow rate for the inlet by calculating the volume of water (Tidal Prism) that must pass through the cross-section area of the inlet in the time period between low and high tides. It is assumed that Cook Inlet is 3.7×10^5 m long, 9.3×10^4 m wide on the average, and 140 m deep at the mouth. The volume of water flowing through the inlet during one-half tidal period is related to the average tidal current velocity $\overline{u}$ (Dietrich 1963):

$$2\eta_o A = S \, \overline{u} \, T/2$$

where $2\eta_o$ is the mean tidal range; A is the area of the inlet; S is the cross-section area at the mouth; and T is the tidal period for semi-diurnal tide 12.42 hrs. With an assumed mean tidal range, the average tidal current velocity may be calculated. Since the maximum velocity is related to the average velocity (Sverdrup, Johnson, and Fleming 1942), its value can be easily calculated. The preceding is a very simplified approach. In order to describe the current regime in the inlet, several other factors, such as inlet contours and configuration, bottom friction, Coriolis effect, and influences of freshwater runoff, must also be considered. During winter, frictional effects caused by ice would also be conspicuous.

Non-tidal currents, for example those caused by wind stress, would also be a significant feature of the inlet. The effect of magnitude of non-tidal currents in this area has not been reported. Winds are particularly strong in this area, especially when westerly winds are intensified by funneling effect due to coastal mountains. A combination of intense tidal current and wind-induced current can create serious sea conditions.

In view of the above, it can be surmised that current velocities in the inlet are high and cause intense vertical turbulence in the water column. It is expected that almost the entire inlet, except for a few sheltered embayments and coves, would be homogeneous or nearly so. (Dietrich 1963).

Recent studies of surface currents in the inlet, using drogues and drift cards, have indicated a net westward transport of surface water from Kachemak Bay to Kamishak Bay (Wennekens 1975). These results are tentative and the data need further study and evaluation.

ICE

Ice Motion

The mean ice motion is similar to that associated with the mean atmospheric pressure field. Mean ice-drift is in the range of 1 to 5 cm/sec (Herlinveaux and de Lange Boom, BSPTR #18) although much higher, over 20 cm/sec, short-term drifts have been noted (Newton and Coachman 1973). Ice motion is determined by the forces of wind (through air-ice stress), currents (through ice-water stress), internal ice stress (resistance of pack to motion within itself), pressure gradients (sea surface slope), and Coriolis effect. Thus, it is difficult to actually project ice movement with wind data alone. Nevertheless, under average conditions, ice is expected to drift at about 2% of the wind speed and approximately 30° to the right of wind direction in the northern regions.

The vigorous nature of the tidal currents in Lower Cook Inlet indicates a high potential for pack ice movement. Oil spills incorporated into the pack ice, either from the ocean below or by direct spill, could be transported several miles before clean-up could be attempted.

be attempted.

Flow and Retention of Oil in Ice

The problem of oil incorporation into sea ice and subsequent transport has been studied in some detail as a part of the Canadian Beaufort Sea Project (Lewis 1976; Wadhams, BSPTR #36; NORCOR, BSPTR #27. These studies apply to ice of vertical crystal orientation.

Martin (RU #87) is studying the movement of oil through grease and pancake ice which have horizontal crystal orientation and are found in Lower Cook Inlet. According to Martin, oil released under grease and slush ice (approximately 40% ice and 60% seawater), which may grow to a thickness of 100 cm in the Bering Sea, comes rapidly to the surface. Furthermore, preliminary experimental results suggest that most of the oil released under a field of pancake ice comes to the surface through the spaces between the cakes, where the oscillatory motion of the pancakes pumps the oil away from the spill site.

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Chapter V

RECEPTORS

FISH

Data from NOAA/OCSEAP funded research in Lower Cook Inlet is limited. A sampling transect system (Pereyra and Nelson, RU #64; English, RU #156a) has been defined for the OCS of the Gulf of Alaska, but only two stations approach the entrance to Lower Cook Inlet. The preliminary data has been integrated into a description of findings for the Gulf of Alaska (see NEGOA Report).

A tentative species list has been compiled from fish reported by English (RU #349 and RU #156a), Morrow (RU # 285), Pereyra and Nelson (RU #64), Smith (RU #284), and AEIDC (1974), assuming that most species collected in the Kodiak Island area would probably be found in Lower Cook Inlet. Comparing the species lists of the two proposed lease areas (Kodiak and Lower Cook Inlet), it was noted that only two species (Pallid eelpout, *Lycodapus mandibularis* and Blue shark, *Prionace glauca*) found near Kodiak Island were not reported in Lower Cook Inlet.

A preliminary species list and a summary of the state of knowledge, by species, may be found in the section of this report on KODIAK ISlAND, Chapter V, Fish. Most of the data presented should have direct application to species found in Lower Cook Inlet. In general, those species most abundant near Kodiak Island will be most abundant in Lower Cook Inlet. Spawning habits, stomach contents, and incubation times should be comparable. Timing of spawning and outmigration, and migratory routes may be slightly delayed or different, resulting from the spatial difference between the areas.

PLANKTON AND BENTHOS

No comprehensive descriptions of the plankton and benthos of Lower Cook Inlet have been published. An intensive evaluation of certain marine biotic communities within the inlet is presently being conducted by Dames and Moore Consultants, under contract to the Alaska Department of Fish and Game. Preliminary results from these studies have been included in the *Lower Cook Inlet, Draft Environmental Impact Statement* recently published by the Department of Interior (USDI 1976), but are not otherwise available. No data are available from OCSEAP-sponsored studies (Kaiser, RU #24; Flagg, RU #27) at this time.

MARINE BIRDS

Introduction

Approximately 112 species of swimming, wading, and plunge-fishing birds, distributed among 17 avian families, occur in the vicinity of Cook Inlet (Isleib and Kissel 1973). Species of major concern in the present account are the swimming birds that feed primarily in marine and estuarine waters.

Seabird Nesting Habitats

In general, marine birds, or seabirds, tend to aggregate into dense nesting colonies during the breeding season. "Colony" is used here to mean a localized aggregation of breeding birds that is geographically distinct from other such aggregations. The location of seabird colonies within the distributional range of populations concerned is determined by requirements for food and safety: colonies must be within economical travel distance of adequate food sources and nests must be inaccessible to mammalian predators, such as foxes and bears, against which seabirds have no adequate defenses. Hence, nests of colonial seabirds generally are located in ledges of perpendicular cliff faces or on islands that are inaccessible to mammalian predators, and nesting colonies are adjacent to seas that are seasonally very productive. Small seabirds, such as storm petrels, puffins, guillemots, and the smaller alcids, nest protected in natural crevices in cliff faces or talus, or in burrows which they excavate themselves in soft earth.

Nesting Seabirds of Cook Inlet

About 25 species of seabirds net within and at the mouth of Cook Inlet. They are distributed among 14 known and eight "suspected" nesting colonies within Lower Cook Inlet, six colonies on the Barren Islands, three colonies on the Chugak Islands, and three colonies on southwest Kenai Peninsula.

Lensink et al. (RU #337) found that "during the summer (June-August) pelagic survey period bird densities along 152^{o}W long. were greatest near the mouth of the inlet -- 1,000 +/km^2 -- tapering to between 50 and 150 birds/km^2 further to the north." However, Lensink et al.'s (RU #337) raw data, extracted from data sheets in their March 1976 Annual Report, show a density of 32.1 birds/km^2 for their June-August census of Cook Inlet (Table V-1). Assuming that the 1,000 +/km^2 figure was obtained at the Barren Islands, this still leaves 18 to 118 birds/km^2 unaccounted for in the area "further to the north."

Aerial surveys, like those of Lensink et al. (RU #337), which are conducted along a predetermined transect line without regard for habitat preferences of the species being surveyed, cannot provide data that are useful for estimating the real abundance or density distribution of birds in Cook Inlet. Their 152^{O}W longitude transect passes over offshore waters -- except at the very mouth of Cook Inlet -- whereas the birds (except shearwaters) tend to stay closer to shore. However, the data show seasonal trends in numbers of individuals and species present in the offshore waters of Cook Inlet (Table V-1 and Fig. V-1). Although the title of their Research Unit is "Seasonal Distribution and Abundance of Marine Birds," Lensink et al.'s (RU #337) stated objective in their Program Work Statement is to survey offshore density distribution of marine birds, rather than to provide a general picture of distribution and abundance.

TABLE V-1

Density of seabirds on offshore waters of Cook Inlet from March to November 1975. Data were extracted from raw data sheets of Lensink and Bartonek (RU #337, Part I: Shipboard surveys) and Lensink, Bartonek, and Sanger (RU #337, Part II: Aerial surveys).

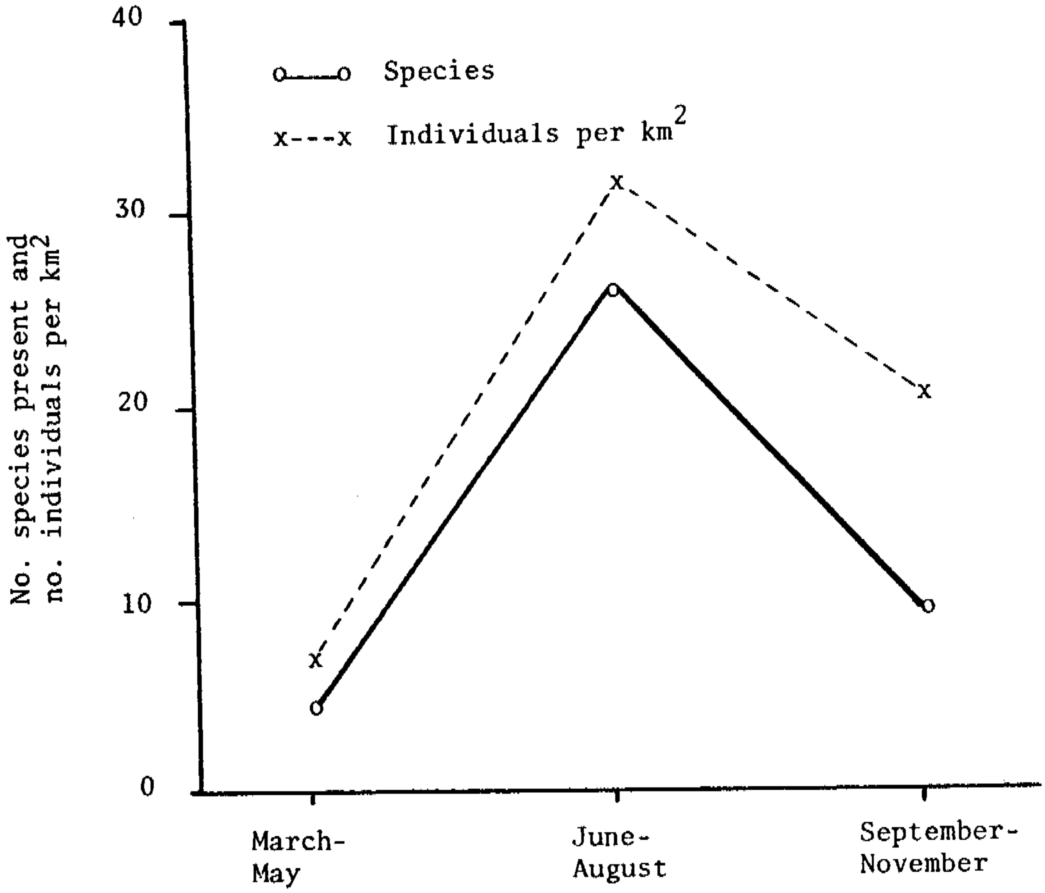
	No. birds/km^2 determined by:						
	Aerial Surveys			Shipboard Surveys			
Species	March-May	June-Aug.	Sept.-Nov.	Sept.	Oct.	Nov.	$\overline{X}$ for Sept.-Nov.
Common loon			0.1				0
Fulmar		2.7		0.8	2.0	1.9	1.6
Sooty shearwater		0.1				0.3	0.1
Unidentified shearwater		15.0	3.5	142.2		1.0	47.8
Fork-tailed storm petrel		1.4		0.4	0.5		0.3
Unid. cormorant	2.4	0.1					0
Unid. scaup		0.1					0
Oldsquaw			0.4				0
White-winged scoter		*					0
Surf scoter		0.9					0
Black scoter		0.8					0
Unid. scoter		0.2					0
Unid. phalarope		0.1	0.3				0
Jaegar		*		0.1			0.03
Glaucous gull		*					0
Glaucous-winged gull	0.2	3.0	5.7	0.2	0.5	1.4	0.7
Herring gull		*					
Mew gull		*					

TABLE V-1 (continued)

Species	No. birds/km² determined by: Aerial Surveys: March-May	Aerial Surveys: June-Aug.	Aerial Surveys: Sept.-Nov.	Shipboard Surveys: Sept.	Shipboard Surveys: Oct.	Shipboard Surveys: Nov.	Shipboard Surveys: $\overline{X}$ for Sept.-Nov.
Unid. or black-legged kittiwake	0.3	4.9	6.1	0.2	0.2	0.5	0.3
Unid. Gull		0.7					0
Arctic tern		1.4					0
Unid. tern		*					0
Unid. murre		1.2	1.0	1.7			0.6
Unid. large alcid	4.1	0.1	1.1				0
Unid. small alcid		0.5		0.2			0.07
Horned puffin		0.1					0
Tufted puffin		0.2	0.7	0.1	1.7		0.6
Unid. bird		*					0
Totals	7.1	32.1	18.8	146.5	4.9	5.0	52.1
Maximum no. species	4	26	8	9	5	5	10

*Less than 0.1/km²

Fig. V-1. Seasonal changes in numbers of individuals and species of seabirds present on offshore waters within Cook Inlet. Data for the graph were summarized from raw data sheets of Lensink et al. (RU #337, Part II). Cf. Table V-1.



Shearwaters

Four species of shearwaters occur in the Gulf of Alaska-Bering Sea region. Because it often is difficult to distinguish them from one another in the field, all four species are usually lumped into the category "shearwater" or "unidentified shearwater" during aerial and shipboard surveys. However, the two most abundant species in Alaskan waters are short-tailed and sooty shearwaters.

Of the 12.6 million birds belonging to about 36 species that Guzman recorded on offshore waters of the Gulf of Alaska-Bering Sea region from June-August of 1975, more than 99% were shearwaters (Guzman, RU #239).

Alaskan shearwaters breed in Chile, New Zealand, and Australia during the austral summer and migrate to Alaskan waters to spend the northern summer. Single concentrations of more than ten million shearwaters have been observed in August near the Pribilofs (Guzman, RU #239), and densities greater than 1,000 shearwaters per km^2 have been recorded around the Barren Islands in July and August (USDI 1976:238; Guzman, RU #239).

Data on the occurrence of shearwaters in Cook Inlet, extracted from raw data sheets of Lensink et al. (RU #337), are summarized in Table V-1. Lensink et al.'s aerial survey data (RU #337, Part II) indicate that in 1975 shearwaters were absent in Cook Inlet from March through May, increased to a density of $15/km^2$ in June through August, then declined to $3.5/km^2$ from September through November. Lensink et al.'s shipboard surveys (RU #337, Part I) cover only the September through November period, and indicate an average density of 47.9 shearwaters per km^2, which is 14 times greater than the density reported from their aerial surveys. Noteworthy discrepancies in the Lensink et al. (RU #337) aerial vs shipboard surveys for the September-November period are as follows:

Species	Birds/km^2 as determined by: Aerial survey	Shipboard survey
Shearwaters	3.5	47.8
Glaucous-winged gull	5.7	0.7
Kittiwakes	6.1	0.3

On the other hand, Lensink et al.'s aerial vs shipboard data (Table V-1) show good correspondence for tufted puffins (0.7 vs 0.6 birds/km^2) and murres (1.0 vs 0.6).

Nonetheless, it is obvious that great caution must be exercised in interpreting and drawing conclusions from these survey data. Systematic, habitat-stratified, replicated sampling rather than counts along a single, offshore transect line, are required if the true seasonal density distribution of shearwaters and other aquatic birds of Cook Inlet is to be defined. However, RU #337 has assumed the task of censusing birds in all of Alaska's offshore waters, which probably makes adequate, site-specific sampling impossible.

Lensink and Bartonek (RU #337, cited in USDI 1976:236) counted birds in Cook Inlet along 152°W longitude during the nesting season and report that bird densities were greatest at the mouth of the inlet and decreased going north into the inlet. Lensink et al.'s (loc. cit.) 152°W transect line passes within 24 km of nesting colonies only at the mouth of Cook Inlet. Hence the most straightforward interpretation of their data is that bird densities decrease with increasing distance from nesting colonies, as one would anticipate.

Overwintering Birds in Cook Inlet

Arneson (RU #3) conducted preliminary coastal surveys of birds in Lower Cook Inlet in February 1975 and presents the following general observations:

1. Most bays on the east side of Cook Inlet, including Kachemak Bay, were ice-choked, and oldsquaws occupied patches of open water amongst broken ice.
2. An "amazingly large group" of shorebirds roosted on ice in Tuxedni Channel close to a small, open lead.
3. The "usual diving and sea ducks" occurred along the entire ice-free coast.
4. There were few alcids in Cook Inlet except at Sadie Cove.
5. Mew gulls were fairly common in association with glaucous-winged gulls at stream mouths and at Homer Spit.
6. Mallards occupied the flats of China Poot Bay (an arm of Kachemak Bay) and the heads of bays around to Point Dick.

Arneson also points out that in December of 1968, ADFG personnel noted a concentration of 10,000 scoters near Dangerous Cape and another 10,000 "dabblers, divers, and sea ducks" at the mouth of Kachemak Bay.

Arneson's (loc. cit.) observations suggest that Cook Inlet provides winter habitat for sizable numbers of gulls, ducks, and shorebirds, but relatively few alcids. The nearest winter concentrations of alcids apparently are at Kodiak Island, where "large numbers of alcids, larids, cormorants, and waterfowl and lesser numbers of geese and shorebirds winter..." (Arneson, RU #3).

Arneson (RU #3) is systematically sampling bird densities in various types of coastal habitats in Cook Inlet, Bristol Bay, along the Alaska Peninsula, around Kodiak Island, and in Prince William Sound. Quantitative analyses of Arneson's data should define the relative importance of Cook Inlet and other areas as wintering grounds for water and shorebirds.

Foods and Feeding Habits of Birds in Cook Inlet

A useful summary of available knowledge of foods and feeding habits of marine birds that occur in the western Gulf of Alaska has been compiled by the Arctic Environmental Information and Data Center (1974), though it lacks specific information on Cook Inlet. Lensink et al. (RU #34) report on stomach contents of Alaskan marine birds (N = 83 birds), of which it is stated that "37% were from Beaufort Sea, through the Bering Sea, and into the Northern Gulf of Alaska" (Lensink et al., RU #341). However, in their tabulation of specimens actually examined (loc. cit.) no birds from either Beaufort Sea or the northern Gulf of Alaska are included. Thus it appears that little information is available on foods and feeding ecology of seabirds in the Cook Inlet-Barren Islands region.

Migrations in Cook Inlet

USDI (1976:251-253) cites the band recovery and migration studies of Lensink and Bartonek (RU #340) among those "which will have direct application in assessing impacts in Lower Cook Inlet..." Lensink and Bartonek's (RU #340) summary of band recoveries includes a few individuals belonging to seabird species that occur in Lower Cook Inlet, but banding and recovery sites are not identified. Lensink and Bartonek's (RU #340) direct studies of migration are being conducted in Unimak Pass, nearly 900 km from the mouth of Cook Inlet, and in the Bering Strait region.

MARINE MAMMALS

Introduction

Ten families and approximately 20 species of marine mammals occur in Lower Cook Inlet. These include sea otters, three species of pinnipeds (seals, sea lion, and fur seals) and 16 species of cetaceans (whales and porpoises). The list (Table V-2) includes six species of whales that are considered to be endangered. However, members of these endangered species are only sporadic visitors to Cook Inlet, mainly around its mouth, and

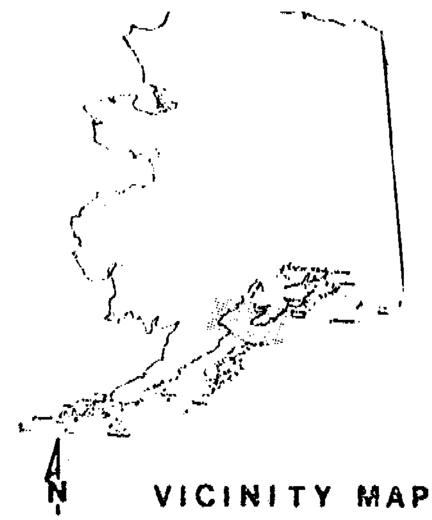
TABLE V-2

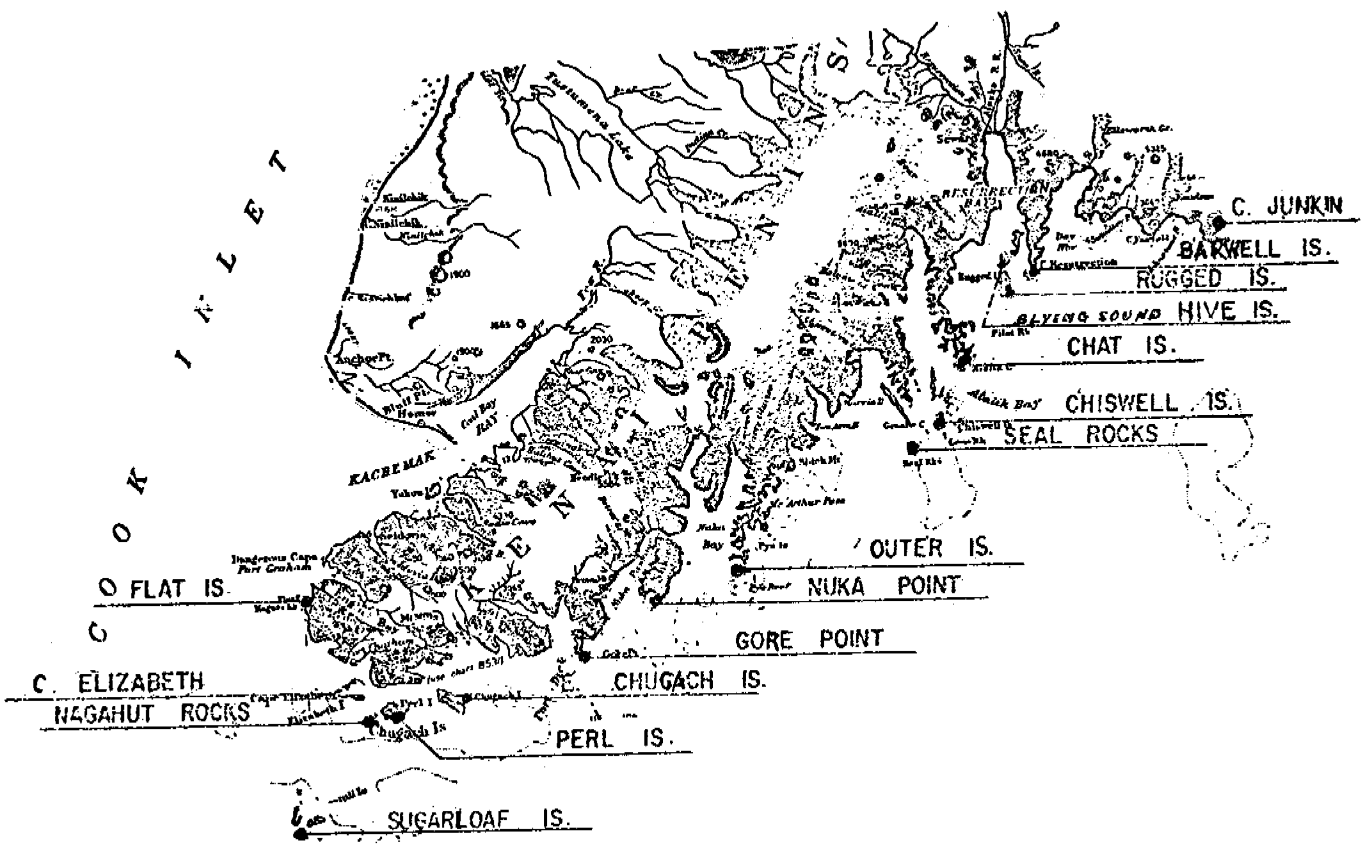
Species of marine mammals known to occur in the vicinity of Lower Cook Inlet including the Barren Islands (USDI 1973; Calkins and Pitcher, RU #243; Pitcher and Calkins, RU #240; Walker 1968).

Family	Species	Status
Ziphiidae	Bottle-nosed whale	Uncommon visitor
	Bering Sea beaked whale	Uncommon visitor
	Goose-beaked whale	Uncommon visitor
Physeteridae	Sperm whale*	Irregular visitor
Monodontidae	Belukha whale	A resident population estimated at 200-400 individuals is suspected to live within Cook Inlet
Delphinidae	Harbor porpoise	Occurs regularly
	Dall porpoise	Occurs regularly
	White-sided dolphin	Occurs regularly
	Killer whale	Occurs regularly
Eschrichtidae	Gray whale*	Occurs regularly
Balaeonopteridae	Fin whale*	Irregular visitor
	Sei whale*	Occurs regularly
	Minke whale	Occurs regularly
	Blue whale*	Irregular visitor
	Hump-backed whale*	Irregular visitor
Balaenidae	Black right whale*	Irregular visitor
Mustelidae	Sea otter	Resident breeding population
Otariidae	Fur seal	Occurs regularly
	Steller's sea lion	Year round resident with established hauling grounds (Fig. V-2)
Phocidae	Harbor seal	Year round resident with established hauling grounds (Fig. V-3)

*Endangered species

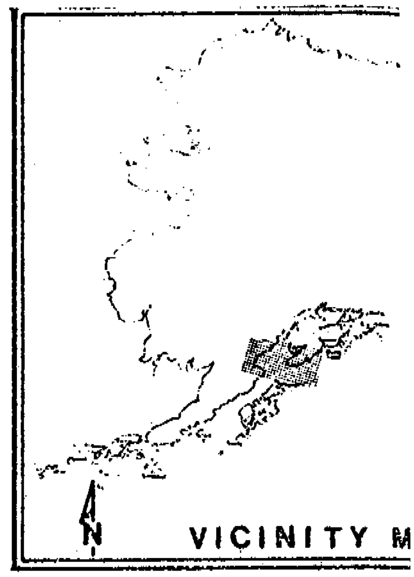
Figure V-2 Sea lion rookeries and hauling areas along the Kenai Coast.

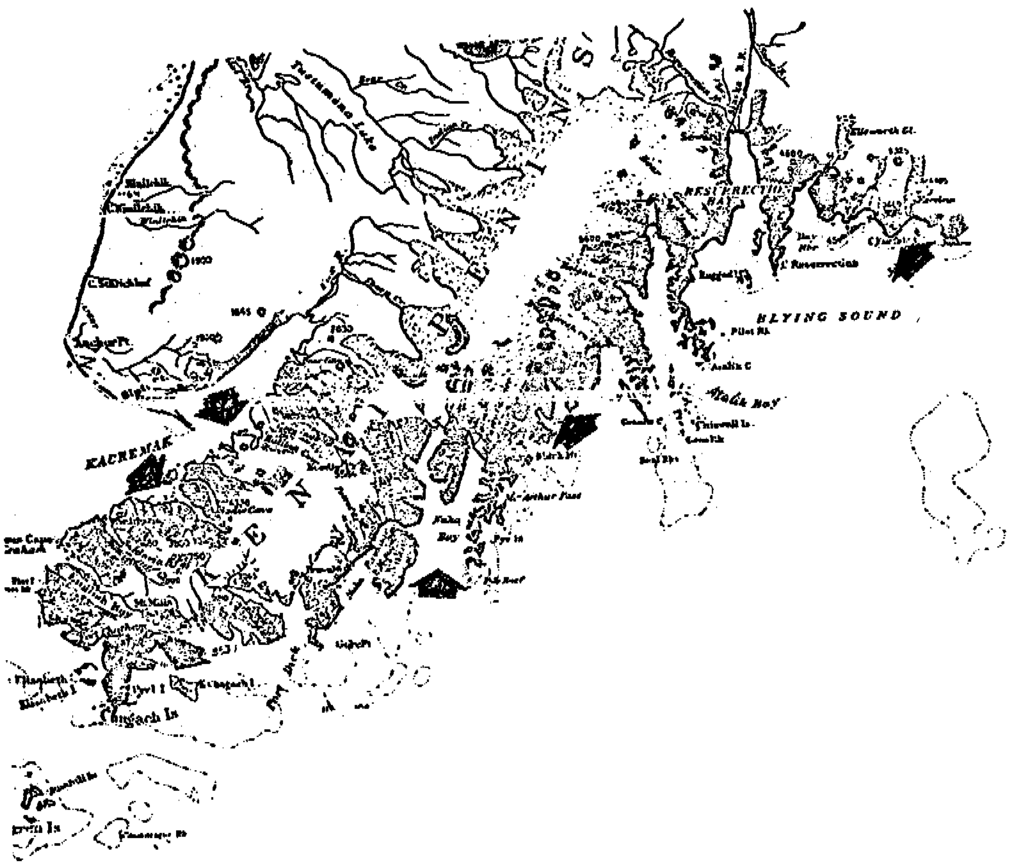




Sea Lion Rookeries and Hauling Areas

Figure V-3 Locations of harbor seal concentrations along the Kenai coast.





it is unlikely that any of them would be subject to serious impact from possible petroleum development in Lower Cook Inlet. This account focuses on belukha whales, sea otters. Steller sea lions, and Harbor seals because significant numbers of them are known to reside in Cook Inlet. Dall porpoises, harbor porpoises, and killer whales also occur regularly throughout Lower Cook Inlet; however, their numbers, critical habitats, and behavior in the inlet are unknown (USDI 1976:774).

Summaries of available knowledge on mammals of the Cook Inlet region are included in environmental statements compiled by the U.S. Department of the Interior (1973, 1974, 1976). The 1974 statement, while not specific for Cook Inlet, contains particularly detailed species accounts and is richly referenced.

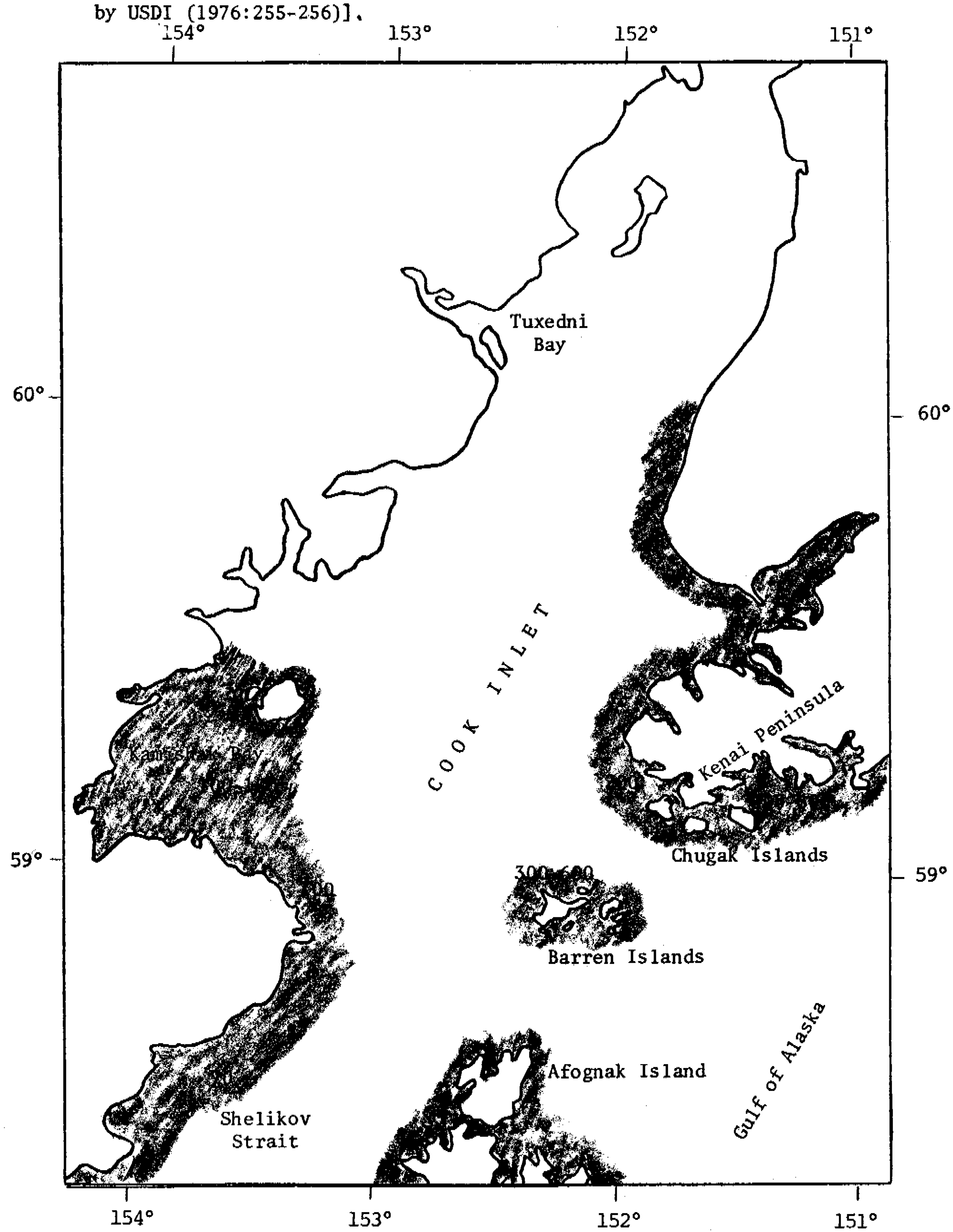
Sea Otter

The sea otter population of Cook Inlet is estimated at 2,000 to 3,000 individuals, or approximately 0.2% to 0.3% of the estimated 100,000 to 125,000 otters in the entire Alaskan population (USDI 1976:255). Distribution and notable concentrations of sea otters in the Cook Inlet region are shown in Fig. V-4.

Unlike most marine mammals, sea otters lack an insulating layer of subcutaneous fat, depending instead on an insulating layer of air trapped in their thick fur. Oiling causes the fur to lose its thermal insulating properties. This makes sea otters particularly susceptible to direct impact from oil slicks. An oiled sea otter would likely die of exposure in a short time (Schneider, RU #240).

Sea otters were nearly exterminated by 1910, after 170 years of being commercially hunted for their pelts (Walker 1968). The Alaskan population in 1911 consisted of fewer than 2,000 individuals. Under legislative protection, the population reached at least 20,000 to 35,000 otters by 1965 and by 1976 it was estimated at 100,000 to 125,000 (USDI 1976). With this phenomenal growth of its population, the Alaskan sea otter is expanding back into portions of its former range, including Cook Inlet (Fig. V-4). According to Schneider (RU #240), "the outer Kenai Peninsula was repopulated by sea otters immigrating from Prince William Sound and perhaps the Barren Islands"...and..."the only significant range expansion (in the Kenai Peninsula area now) is occurring in Kachemak Bay and Lower Cook Inlet." A remnant population within Cook Inlet may have survived the hunting era, in Kamishak Bay (Schneider loc. cit.).

Fig. V-4. Distribution of sea otters in the Cook Inlet region (shaded). Numbers indicate sizes (no. individuals) and locations of larger concentrations of sea otters [determined from Schneider (RU #240) and sources summarized by USDI (1976:255-256)].



Schneider (RU #240) believes that all suitable habitat on the outer Kenai Peninsula is now occupied. A plot of numbers of sea otter population of the Barren Islands from 1931 to 1970 suggests that the sea otter population of the Barren Islands has reached the habitat's carrying capacity and ceased growing (Fig. V-5).

Steller Sea Lion

Size estimates of the Alaskan population of Steller sea lions vary from 200,000 (ADFG, cited by USDI 1976) to 300,000 individuals (Kenyon and Rice, cited by USDI 1974). Approximately 13,000 to 8,000 of them inhabit rocky promontories and islands at the mouth of Cook Inlet (Calkins and Pitcher, RU #243; USDI 1974, 1976).

Locations of traditional sea lion congregating grounds in the Cook Inlet-Barren Islands area are shown in Fig. V-6. Of these it appears that only Sugarloaf Island has been identified as a breeding and pupping ground, or rookery, and the rest are hauling grounds (USDI 1976:258; Calkins and Pitcher, RU #243). The Sugarloaf Island rookery has an estimated population during the breeding season of 10,000 to 12,000 Steller sea lions and produces about 5,000 pups per year (USDI 1974, 1976). Pitcher and Calkins (RU #243) branded 719 pups at the Sugarloaf rookery in July of 1975 in order to study their movements and dispersal. They counted 4,588 Steller sea lions at the Sugarloaf rookery in October 1975. Whether they represented an overwintering population, animals that were late in leaving the rookery, or had some other origin, is not clear.

Calkins and Pitcher (RU #243) examined reproductive tracts of three 3 to 9 year old female Steller sea lions collected in Prince William Sound. A 3 or 4 year old female was pregnant for the first time, whereas one 7 year old and one 9 year old female both were multiparous. This shows that females can start breeding as early as 3 to 4 years of age, but more data are required to determine the modal and average ages at first breeding.

Calkins and Pitcher (loc. cit.) also collected sixteen 1 to 5 year old male Steller sea lions. The largest of these was five years old, 249 cm long, and weighed 375 kg, which is approximately 100 cm and 200 to 700 kg short of full adult male size (cf. Walker 1968). Hence no information on reproduction was obtained from these male specimens. However, they report a restricted diet consisting of 88% fish and 12% cephalopods (Table V-3). Most of the stomachs that Calkins and Pitcher (loc. cit.) examined (N = 18) were of animals, mainly subadult males, collected in Prince William Sound

Fig. V-5. Numbers of sea otters counted during surveys of the Barren Islands, illustrating rapid population growth that occurred between 1931 and 1957. The apparent relative stability of the population from 1957 to 1970 suggests that it has reached the carrying capacity of the environment. Data points are from literature summarized by Schneider (RU #240).

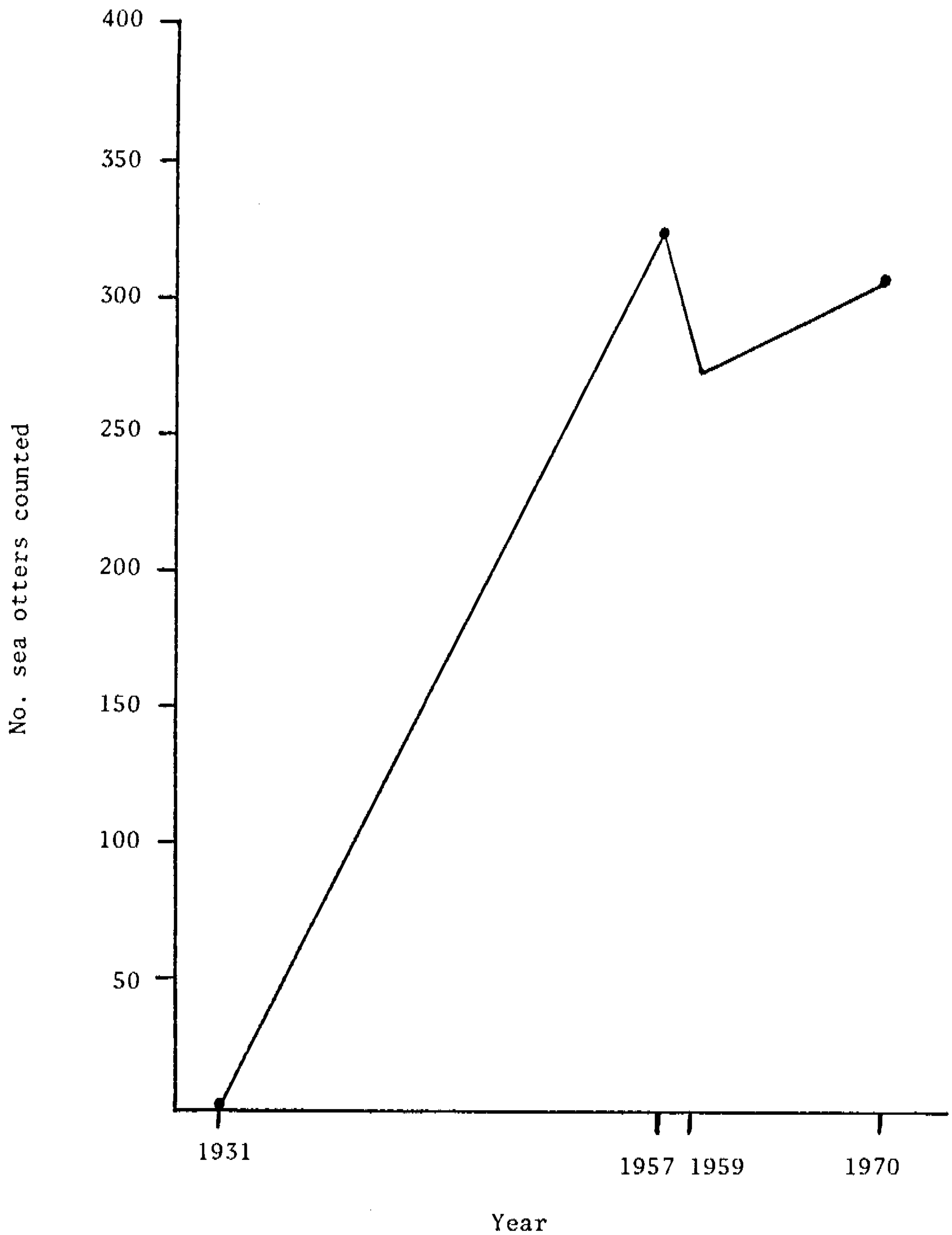


Fig. V-6. Locations of traditional Steller sea lion congregating grounds in the Cook Inlet region (after Calkins and Pitcher, RU #243 and USDI 1976: 258). Sugarloaf Island has been identified as a rookery, whereas the other sites apparently are hauling grounds (see text).

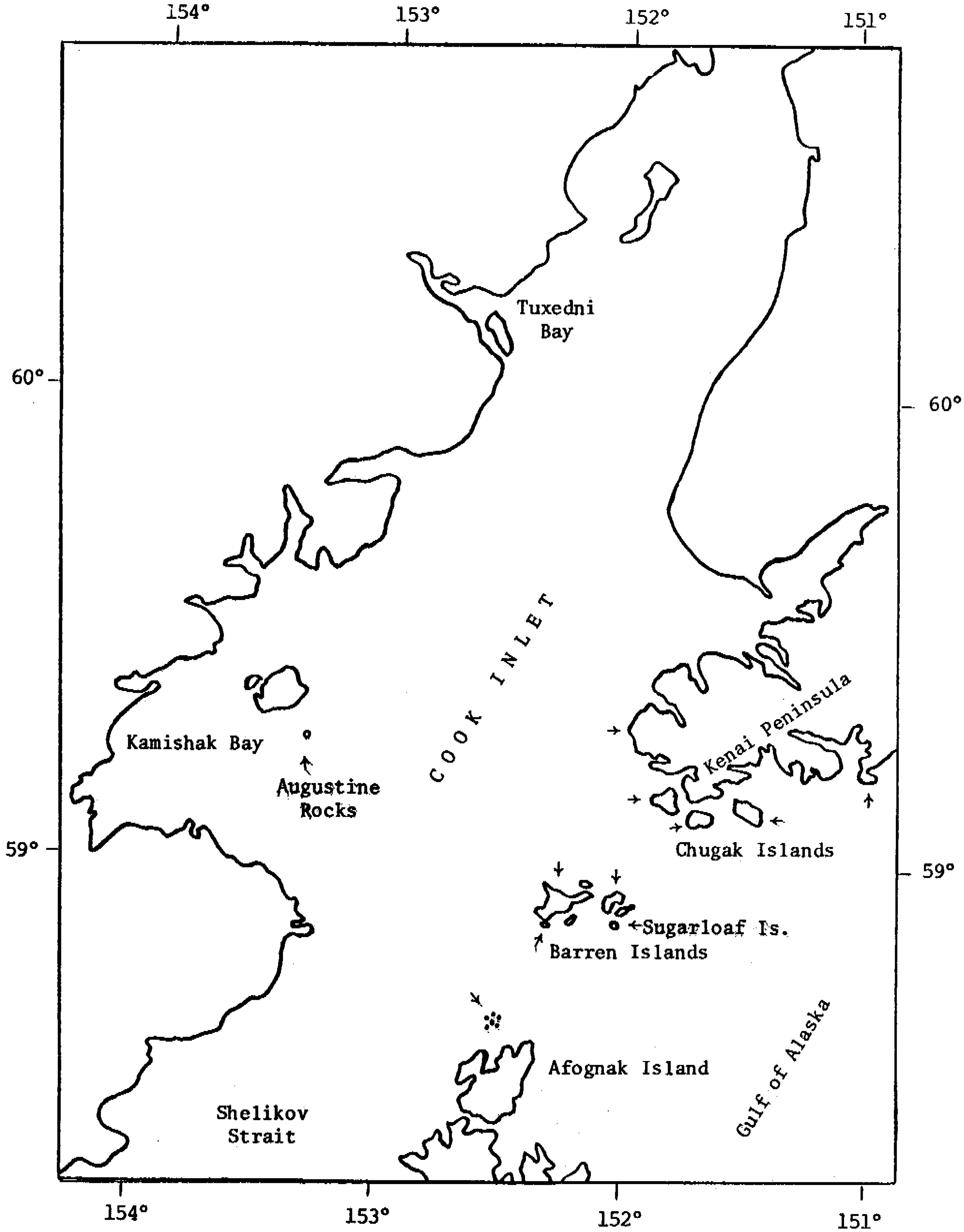


TABLE V-3

Comparative fall food habits of harbor seals and Steller sea lions. All specimens were taken in October and November 1975, mainly in Prince William Sound. Adapted from Calkins and Pitcher (RU #243) and Pitcher and Calkins (RU #229).

[1] Food item by family:	[3] Percent of total food items eaten by: Harbor seals (N = 23 stomachs)	Sea lions (N = 18 stomachs)
[2] Gadidae (cod, 5 species)	65.1	72
Pleuronectidae (flatfishes, 3 spp.)	9.3	8
Osmeridae (smelt, s sp.)	2.3	0
Bathylagidae (deep sea smelt, 1 sp.)	2.3	0
Zoracidae (eelpout, s sp.)	2.3	0
Scorpaenidae (Perch, rockfish, 1 sp.)	2.3	0
Hexagrammidae (greenling, 1 sp.)	2.3	0
Clupeidae (herring, 1 sp.)	0	8
Cephalopoda (octopus, squid, ? sp.)	13.9	12

[1] Except cephalopoda.

[2] Pollock (Theragra chalcogramma, Gadidae) was the single most important food item, contributing 46% of the total in harbor seals and 48% in Steller sea lions.

[3] This is a percent occurrence analysis, e.g., five gadid fish (5 items) out of ten items in a stomach would constitute 50% of total food items in that stomach. Stomach contents of all harbor seals and all sea lions were lumped to obtain the data presented here.

in October 1975. Hence their sample is biased as to age, sex, locality, and season. Calkins and Pitcher (loc. cit.) are planning to broaden their data base by collecting specimens at various seasons and locations.

Harbor Seal

Harbor seals occur throughout Cook Inlet, from the Barren Islands and Kachemak Bay in the south to the Susitna River delta, at the northern end of the inlet (USDI 1976). Major concentrations within this area occur at the Barren and Chugak Islands, Kamishak Bay, Kachemak Bay, Tuxedni Bay, and Chinitna Bay (USDI 1976; Pitcher and Calkins, RU #229). Acknowledging an inadequate data base, USDI (1976:260) estimates the harbor seal population of the Cook Inlet region at less than 5,000 seals. The entire Alaskan population of land-breeding harbor seals (as opposed to the ice-breeding form that occurs north of the Alaska Peninsula) has been estimated at from 100,000 (USDI 1976) to 200,000 (USDI 1974) individuals.

Analysis of female reproductive tracts indicates that females begin ovulating and conceiving at 3 to 4 years of age (Pitcher and Calkins, RU #229).

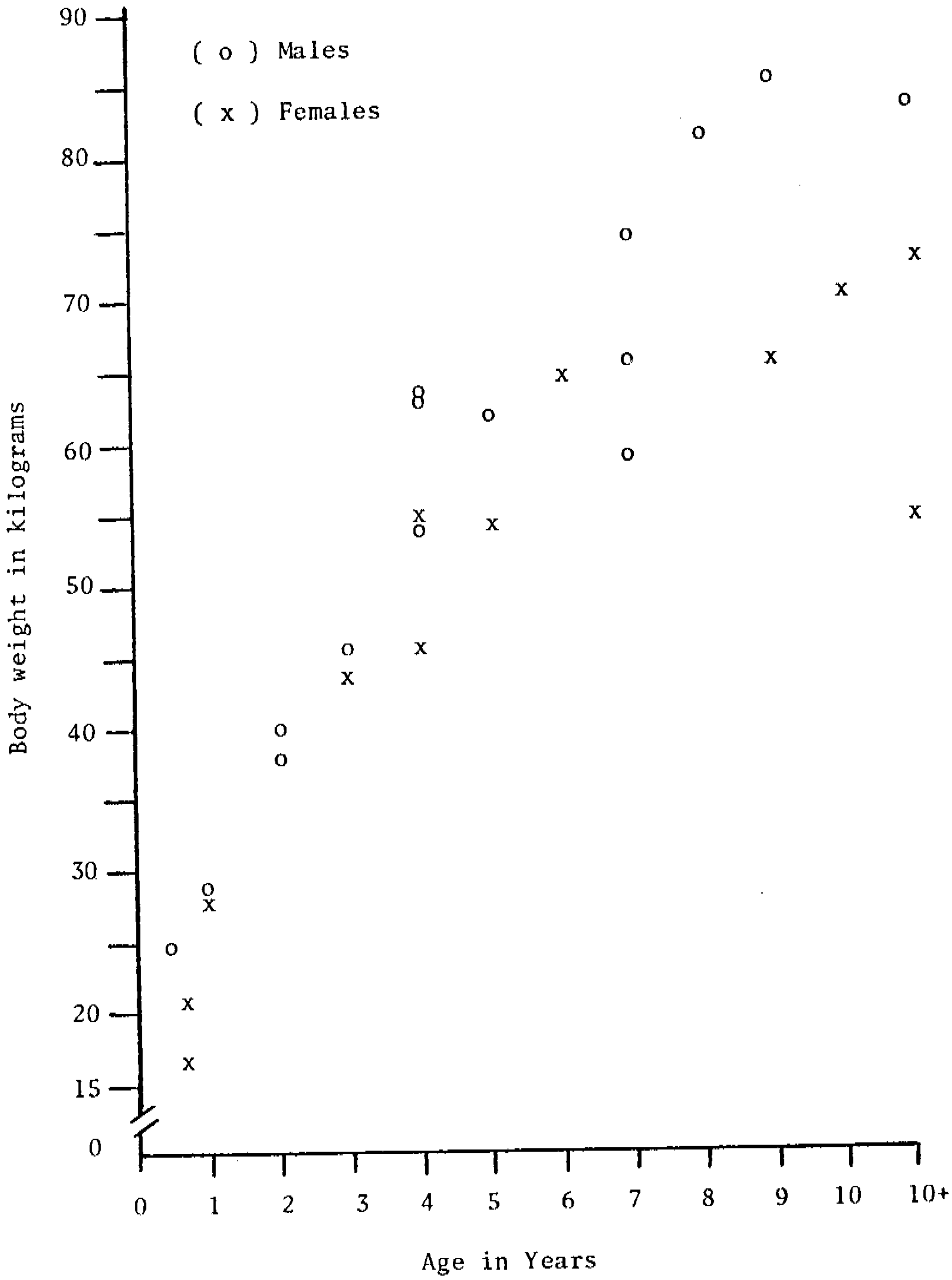
Pitcher and Calkins collected their male specimens during October and November, a period of sexual inactivity. Although this precludes analysis of sperm production relative to age, the following data, summarized from Tables 3 and 4 of their report (Pitcher and Calkins, RU #229), suggest that males attain physical and sexual maturity when 6 to 7 or more years old:

Age (Years)	N	$\bar{X}$ Testis Volume (cc)	$\bar{X}$ Body Weight (Kg)
0.4- 3	5	5.6 (R = 4- 9)	35.7 (R = 25-46)
4- 5	4	15.5 (R = 9-22)	60.7 (R = 53-64)
7-11	6	37.6 (R = 25-51)	75.1 (R = 59-86)

If opportunities to achieve successful copulations increase with body size among harbor seals, as they do in most other pinnipeds, we might anticipate from their growth curve that male harbor seals do not reach full reproductive maturity (i.e., maximum body size) until they are 8 to 9 years old (Fig. V-7), even though their gonads mature earlier. The growth curve (Fig. V-7) also indicates that females mature considerably earlier than males.

Stomach contents of 23 harbor seals, mainly from Prince William Sound, were analyzed by Pitcher and Calkins (RU #229). They found the diet to consist of 86% fish and 14%

Fig. V-7. Scatter diagram comparing growth in body weight of male and female land-breeding harbor seals. Female body weight begins levelling off at 6 to 7 years of age, whereas males continue gaining weight at a rapid rate until they are at least 8 to 9 years old. Data points are extracted from a table in Pitcher and Calkins (RU #229).



cephalopods (Table V-3) which is in general agreement with the USDI (loc. cit.) description.

Diets of ice inhabiting harbor (spotted) seals vary with season, consisting mainly of fish in spring and summer and of invertebrates in winter (Refs. in Lowry and Burns, RU #232). Seal diets also can vary significantly among nearby localities (Lowry and Burns, RU #232; USDI 1976). Although diets of harbor seals in Cook Inlet still are unknown, Pitcher and Calkins (RU #229) plan to collect land-breeding harbor seals throughout the year at various locations in the northern and western Gulf of Alaska, including Cook Inlet, to determine seasonal and geographic differences in their diets.

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Chapter VI

EFFECTS

The general nature and purpose of NOAA-OCSEAP effects research have been summarized in the Kodiak Island-Effects section of this report. In most cases the effects studies are not site specific but instead are expected to yield results that will be generally applicable in broadly separated proposed lease areas.

Pollution History

Offshore petroleum development in upper Cook Inlet and petroleum products shipped through Cook Inlet have resulted in several oil spills in excess of 1,000 barrels. In most cases only aerial observations and measurements were made on these spills, and few environmental studies were conducted to assess damage to the biotic resource. (AEIDC 1974).

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SECTION 3

KODIAK ISLAND: PHYSICAL ENVIRONMENT, BIOTA, AND POTENTIAL PROBLEMS RELATED TO OIL EXPLORATION

CONTENTS

Chapter I

ENVIRONMENT

DESCRIPTION OF STUDY AREA

The Western Gulf of Alaska extends from Middleton Island south of Prince William Sound to the south side of the Kodiak Island archipelago. The area is composed of several mountain ranges and an intermittent coastal shelf. The westernmost range, the Kodiak Mountains, occupies the eastern two-thirds of Kodiak Island. Separated only by a narrow channel, Afognak Island adjoins Kodiak on the north. Along the southwestern part of Kodiak Island the coastline is relatively smooth with no major fiord indentations. Erosion is slow due to the resistant nature of the bedrock cliffs, but in some tertiary sediment areas erosional rates are more rapid (Fig. I-1).

The Kenai-Chugach Mountains border the north coast of the Gulf of Alaska from the Kenai Peninsula to near Alaska's eastern boundary. Rugged, east-trending ridges and mountain peaks are separated by a network of narrow valleys and passes. The area has been heavily glaciated and extensive icefields and glaciers persist throughout. The south coast is typically fiord-indented with a few narrow beaches interrupting the generally steep, rocky shore. Streams flowing into the gulf are short, swift and mostly glacial.

GEOLOGY

The continental shelf near Kodiak Island extends to about 240 kilometers offshore and is marked by numerous rises, valleys, and smooth plains. Relief is due primarily to warping and buckling of the earth's crust that is modified by erosional and depositional processes. Outer continental shelf areas are typified by plateaulike surfaces with depths ranging from 60-100 meters and of gentle slope. These underwater plateaus are interrupted in places by isolated banks and shoals that rise above the shelf surface. The plateaus are separated from each other by large sea valleys which are flat-bottomed depressions with gentle slopes -- a typical example is Shelikof Strait -- although the shelf is also incised by several other deep channels. The distribution and composition of offshore sediments vary because of bottom relief, sediment sources, and size of materials. The sediments in the offshore areas have been derived mainly from adjacent mountain areas during periods of glacial activity. In some localities volcanic materials make up a large portion of the

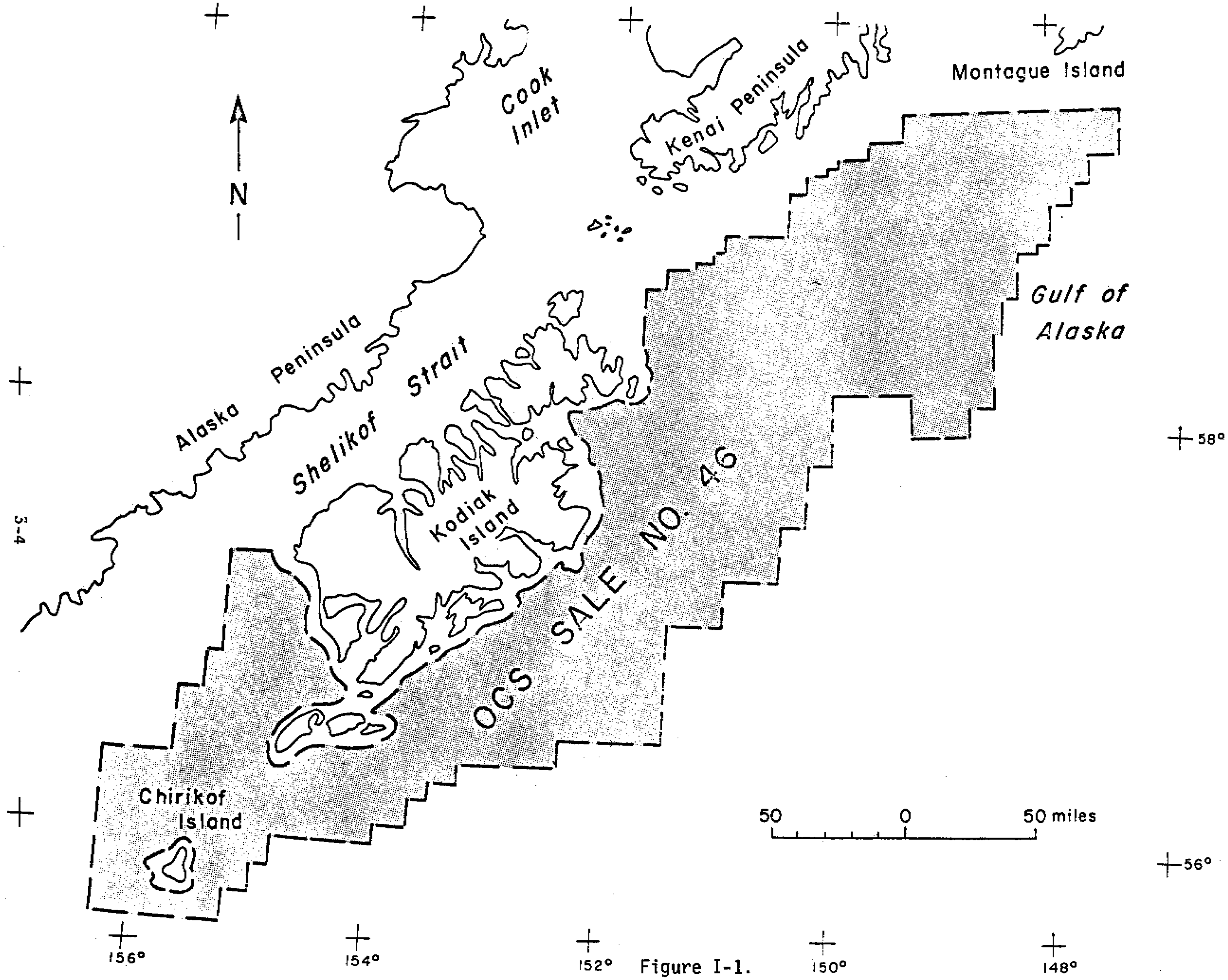
Cook Inlet
Kenai Peninsula
Montague Island
N
Alaska Peninsula
Shelikof Strait
Kodiak Island
Gulf of Alaska
OCS SALE NO. 46
Chirikof Island
50
0
50 miles
58°
56°
156°
154°
152°
150°
148°

Figure I-1.

sediments. Particle size decreases seaward, producing a graded distribution of sediments. Sediment layers are characteristically thin and irregular in thickness, and bedrock may be exposed at the sea bottom surface; however, much of the area is made up of Holocene sediment in thicknesses varying from less than 5 m to greater than 300 m. The sediment, whether supplied by river, glacial runoff, or wind, is subject to the rigors of the near-shore currents which, with the exception of local eddies, move in a counter-clockwise direction similar to the offshore Alaska current (Reimnitz and Carlson, 1975). This movement transports the suspended sediment in a westerly direction. Very little suspended matter accumulates in the Middleton Island platform due to the scouring action of the frequent storm waves that are particularly large and forceful during the winter season.

The coastal zone from Prince William Sound westward is prone to frequent and severe earthquakes. During the last 70 years, eight seismic events have equalled or exceeded magnitude 8. The largest recorded earthquake on the North American continent was that of March 1964, and was centered beneath Prince William Sound.

CLIMATE

During the summer months a weak or shallow thermal low devleops over interior Alaska along with a high pressure area located near 40^{o}N, 150^{o}W in the Pacific Ocean. This synoptic situation creates a significant pressure gradient across the Alaska Gulf coast and causes the generation of strong winds (>50 kts) across mountain passes, along valleys inland from the coast and in the waterways along the Alaskan panhandle. Also during these months, sea-breeze effects along the coast can become quite strong at times. This sea-breeze effect can be considered as a wind superimposed on the general synoptic flow. The pressure gradients are quite weak over the area and the passage of fronts brings generally low-level clouds and associated rain and drizzle. Strong frontal activity with high wind conditions are generally absent at this time.

With the coming of winter, the weak thermal low pressure of summer is replaced by prevailing high pressure in the interior of Alaska. The Aleutian low pressure area becomes more developed and storm tracks are diverted around the state instead of into the interior. This is a period of transition bringing strong frontal systems throughout the Gulf area. The winter conditions are basically opposite of those present during the summer. The combination of a very strong, cold high pressure area over the interior of Alaska with the

Aleutian low over the gulf leads to a strong pressure gradient across the coast and pointing outwards. This leads to the occurrence of very strong (>100 kts) winds flowing out over the passes. These winds extend out over the water for 20-25 miles, and extremely turbulent conditions are present. The coming of summer again brings the system into transition where lows moving through the gulf gradually become less severe.

SEA ICE

Sea ice does not form in the more exposed areas of the Kodiak lease area. Some fast ice occurs in sheltered bays and harbors, especially where fresh water from rivers and streams flows into them.

Occasionally thick ice cakes or stamuhki from Upper Cook Inlet drift through the Shelikof Strait. Under particularly severe wind and temperature conditions, ocean spray may cause icing on ships and/or offshore structures (AEIDC 1974).

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CHAPTER II

SOURCES

The material given in Chapter II of the LOWER COOK INLET section of this report is equally applicable to KODIAK ISLAND.

Chapter III

HAZARDS

GEOLOGIC SETTING

The Shumagin-Kodiak Shelf, site of the proposed Kodiak lease area, separates the Alaska Peninsula from the Aleutian Trench. The shelf is readily divided into two geologically distinct provinces: The Kenai-Kodiak Mesozoic province and the Kodiak Tertiary province (Fig. III-1, von Huene et al. 1971). The former consists of a thick sequence of partly-metamorphosed Mesozoic flysch deposits that have been intruded by early Tertiary granitic plutons and uplifted. These rocks form the core of Kodiak Island, as well as the Kenai and Chugach Mountains to the northeast; they probably also underlie the continental shelf offshore from Kodiak. During Tertiary times these uplifted areas provided a source of both clastic and volcanic sediments to a series of depositional basins that lay at the outer edge of the present continental shelf. AEIDC (1974), summarizing the work of several different authors, noted that the Kodiak Tertiary province can be divided into five separate subprovinces (Fig. III-2). Moving offshore from Kodiak Island, in a southeasterly direction, these include:

(1) A zone of folds and faults up to 30 km wide that extends between Kodiak Island and Prince William Sound (Figs. III-2, III-3). Some of these faults are exposed along the southeast coast of Kodiak; they typically dip and are usually less than 30 km long. Offshore seismic profiles indicate that some faults show fresh, steep scarps that suggest recent activity (Hampton and Bouma, RU #327).

Following the 1964 Alaska earthquake Plafker (1972) demonstrated that this fault zone corresponds approximately to the area of most intense aftershock activity and strain release, (see Seismicity section, following).

(2) A sedimentary basin (Albatross Basin) filled with 3 to 4 km of late Tertiary sediments that accumulated seaward of the fault zone (Fig. III-4).

(3) A broad uplifted arch (Albatross Bank; Fig. III-4) that forms the edge of the present continental shelf. This arch represents an area of ongoing tectonism in which tilting, folding, faulting, and truncation are still taking place. Plafker (1972) documented up to 9 m of uplift along the axis of the arch during the 1964 Alaska earthquake. Much of Albatross Bank was probably exposed during glacial periods of lowered sea level (AEIDC 1974; Hampton and Bouma, RU #327).

(4) The steep, rugged continental slope that drops more than 5,000 m to the Aleutian Trench in a distance of 30 to 80 km. U.S. Geological Survey studies of the continental slope off Kodiak Island (von Huene 1972; Piper et al. 1973, cited in AEIDC 1974) indicate that the upper slope is smooth and gentle with slope angles of 3° to 10°. The lower slope is rough and steep with slope angles up to 40° being recorded. There is abundant evidence of large rotated blocks, slumps, and slides.

(5) The Aleutian Trench--which consists of an asymmetrical, flat-floored, sediment-filled depression some 20 to 30 km wide.

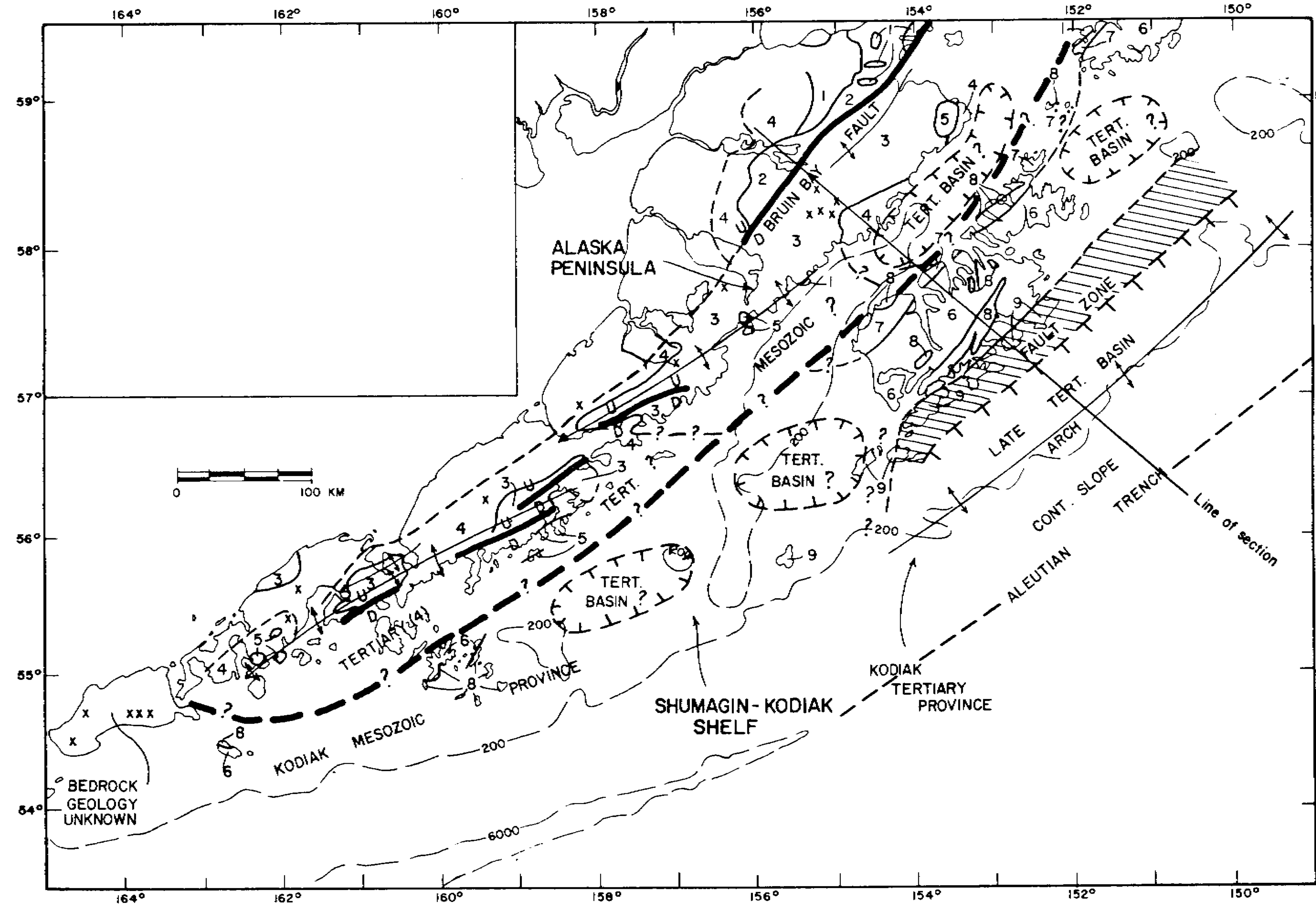


Fig. III-1. Generalized bedrock geologic map, Western Gulf of Alaska (AEIDC 1974).

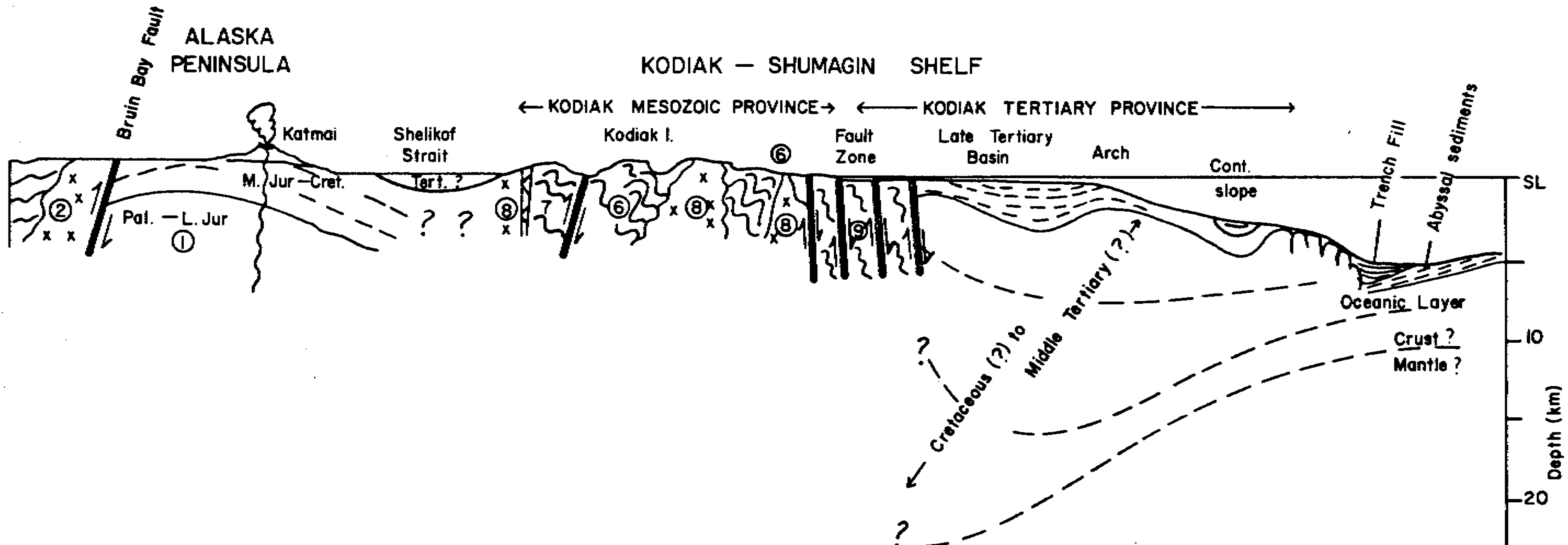


Fig. III-2. Generalized cross-section, Western Gulf of Alaska (adapted from von Huene et al. 1971 and von Huene 1972, cited in AEIDC 1974).

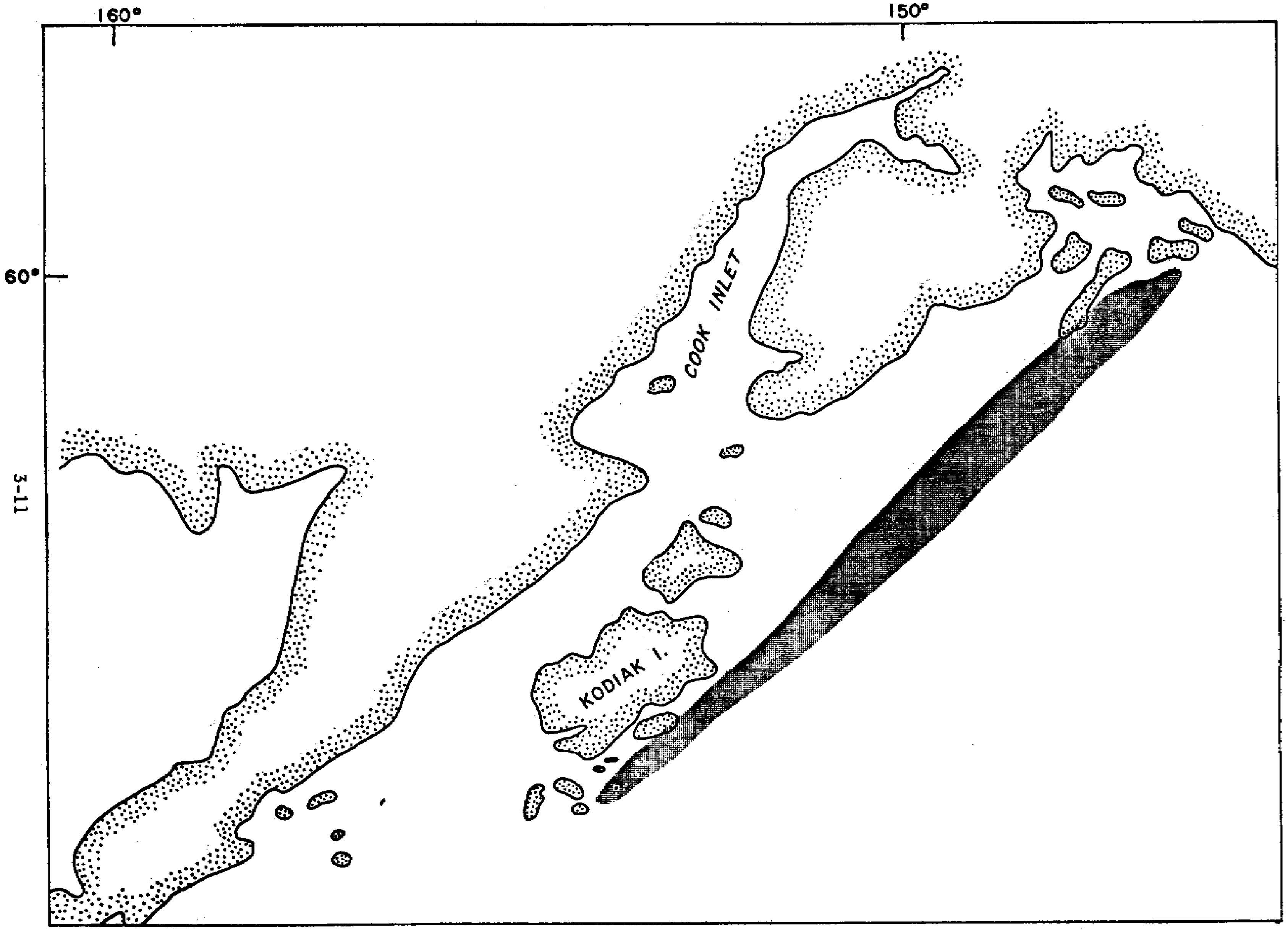


Fig. III-3. Generalized zone of faulting, Kodiak Island to Montague Island (Hampton and Bouma, RU #327).

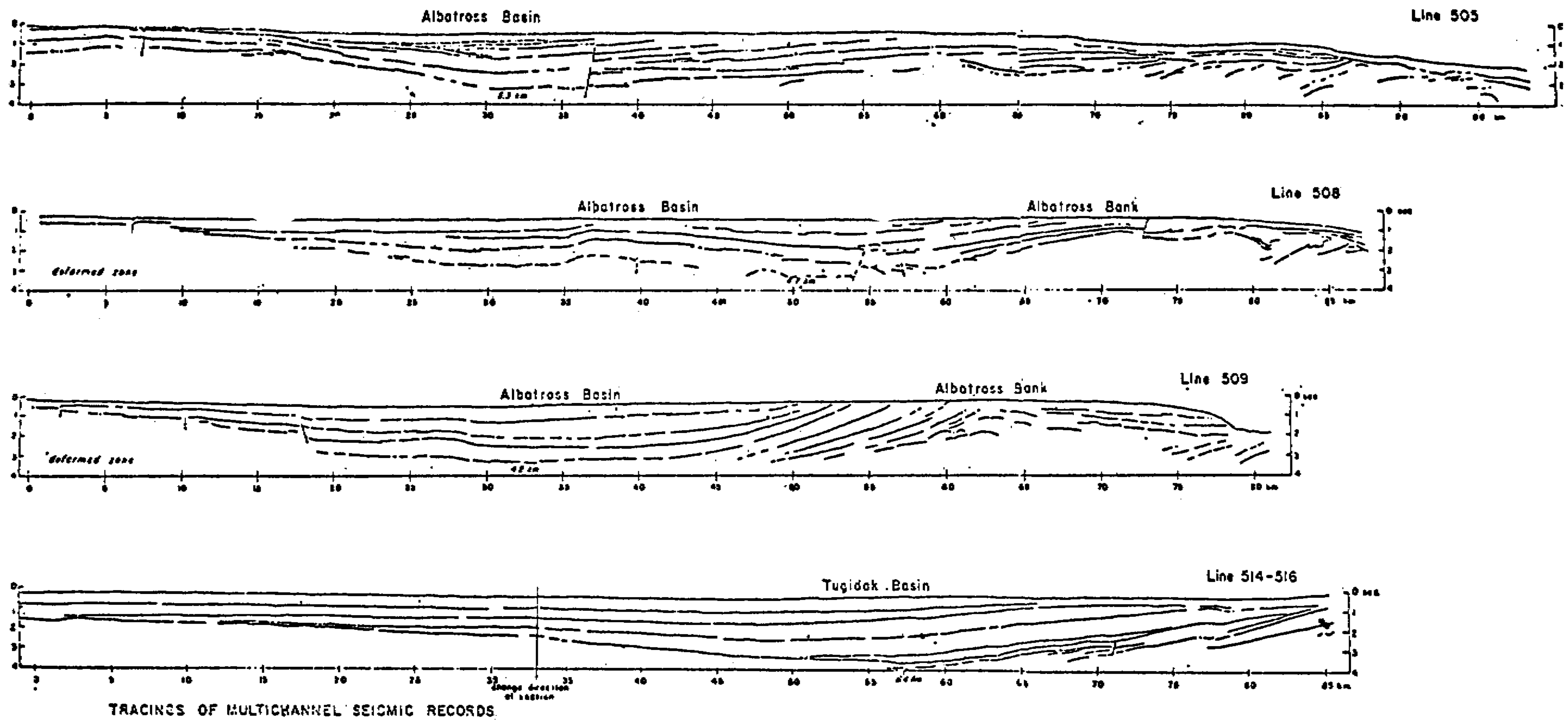


Figure III-4. Structural profiles across Albatross Bank and Albatross Basin. (Hampton & Bouma, RU #327).

According to Plate Tectonic Theory, the Shumagin-Kodiak shelf represents the leading edge of the North American Plate which is presently being underthrust by the Pacific Plate along the Aleutian Trench region. The area is one of active tectonism as indicated by the numerous earthquake epicenters recorded in the area (Meyers, RU #352), recent earthquake deformation, and the chain of active volcanoes along the adjacent Alaska Peninsula.

SEISMICITY

The proposed Kodiak lease area lies within an active seismic belt and is extremely susceptible to earthquake damage. Underthrusting of the Pacific Plate beneath the North American Plate provides the mechanism for the seismicity. Hundreds of seismic events have been recorded in the area since 1899 (Fig. III-5), including approximately 30 earthquakes of magnitude 6.0 or greater, on the Modified Mercalli Intensity scale of 1931 (Fig. III-6, Meyers, RU #352). The susceptibility of the region to earthquake damage was made particularly evident during the great 1964 Alaska earthquake (AEIDC 1974).

During fiscal year 1976, OCSEAP sponsored a significant expansion of the seismic recording network operated by Pulpan and Kienle (RU #251; Fig. III-7). This implements more complete and accurate monitoring of seismic events within the Kodiak offshore area. Pulpan and Kienle (RU #251) are exchanging data with Davis et al. (RU #16), working to the southwest of Kodiak, in an effort to produce a more fully integrated picture of regional seismic hazards.

As expected, a major portion of Alaskan earthquake energy is released during large earthquakes. Such events probably represent rupture along major crustal blocks whose shapes can be defined by the distribution of aftershocks. A plot of these aftershock zones (Sykes, 1972) suggests a regular space-time pattern for the earthquakes and also identifies major gaps in seismic activity. These gaps are regarded as likely sites for future large earthquakes. Significantly, the only large earthquake in Alaska during 1972 occurred in one of these seismic gaps: Sitka earthquake, July 1972, magnitude 7.2.

While each of four different approaches used yielded somewhat different earthquake recurrence rates, the overall results can be summarized as follows:

(1) Seismic events of magnitude ≥7.0 can be expected to recur at 8 to 14 year intervals (extreme case 3 to 26 intervals), with the next event occurring before 1990 and probably before 1978.

Figure III-5 **EARTHQUAKES IN AND NEAR ALASKA (THRU 1974)** from Meyers (RU #352)

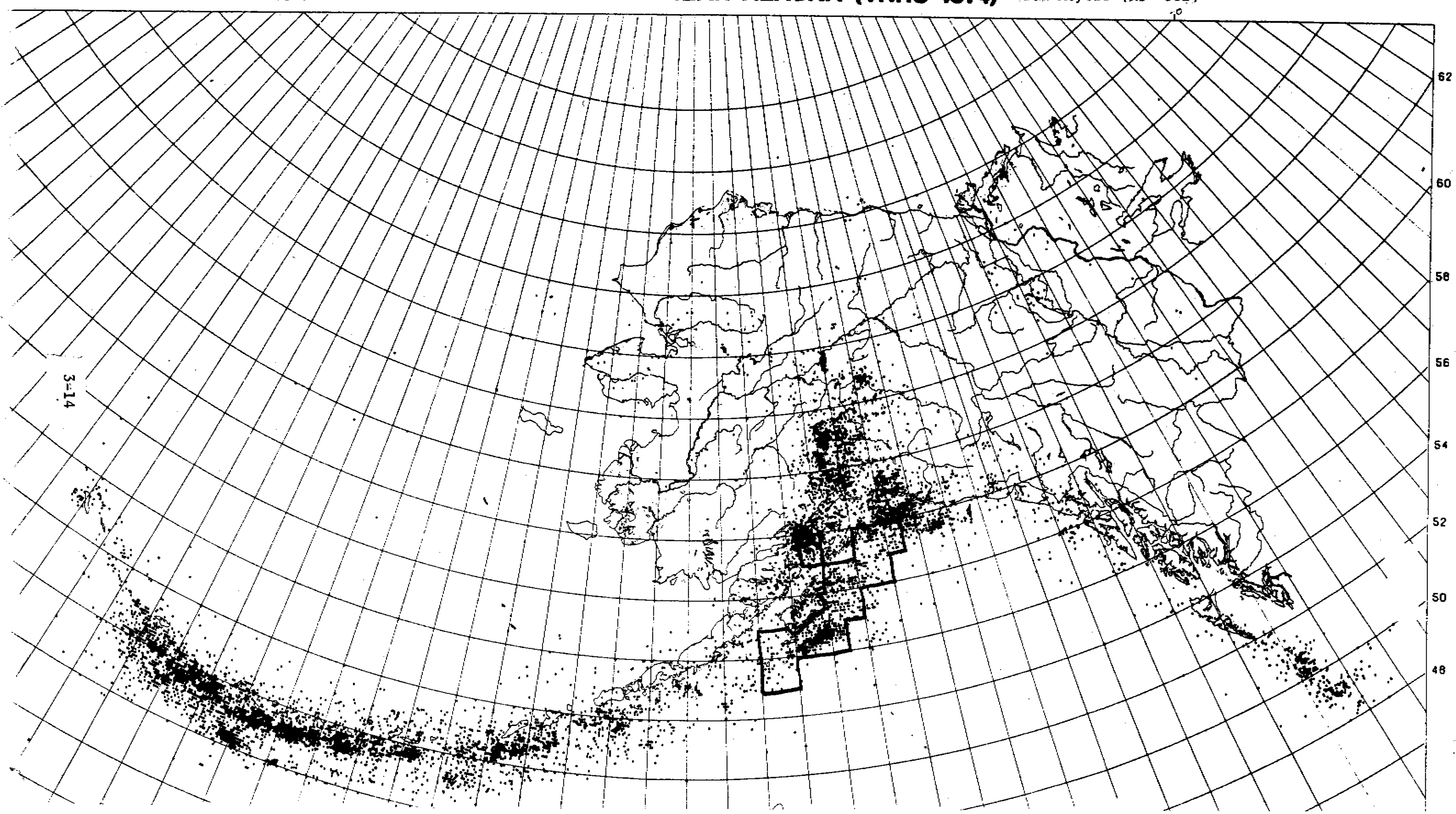
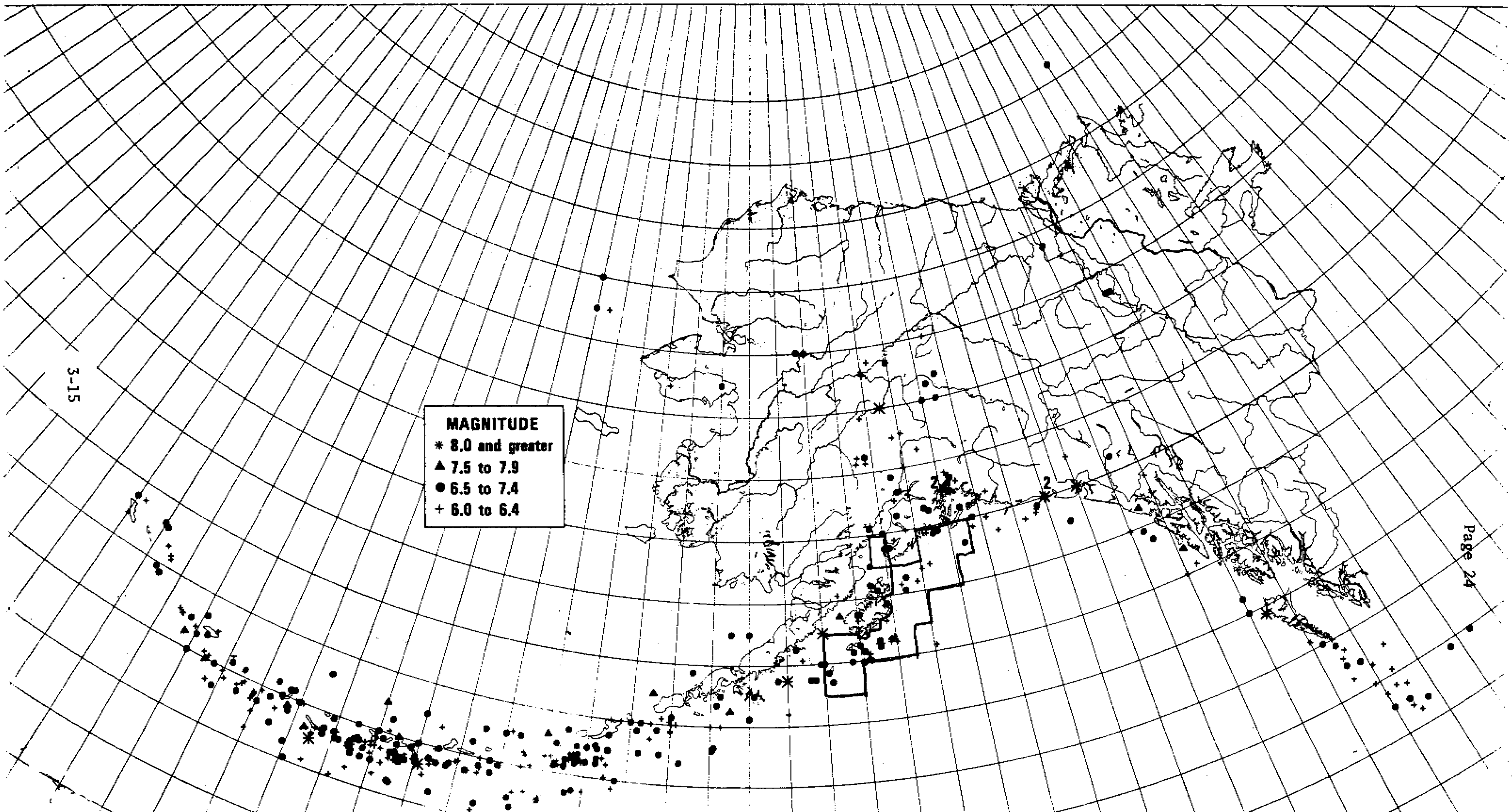


Figure III-6 .**MAJOR EARTHQUAKES IN ALASKA (1899-1974)**



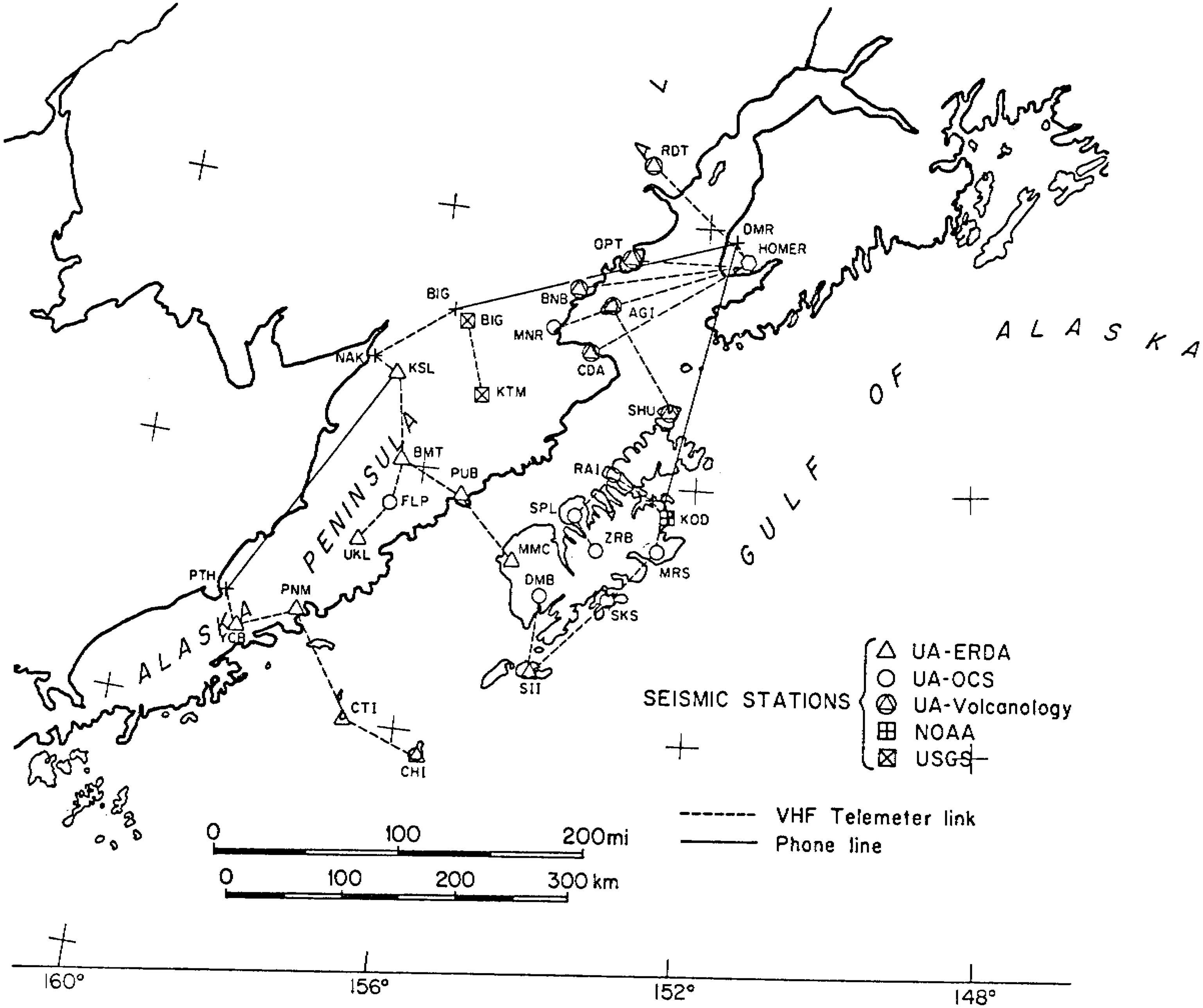


Figure III-7 Western Gulf of Alaska seismic network, recorded in Homer. (Pulpan and Kienle, RU #251)

(2) Seismic events of magnitude ≥7.9 can be expected to recur at 60 to 87 year intervals (extreme case 26 to 360 year intervals), with the next event occurring before 2288 and probably between 1998-2025.

Statistically, therefore, it is almost certain that an earthquake of magnitude ≥7.0, and even one of magnitude ≥7.9 will occur within the Shumagin Island area during the 20-year oil development time-frame. An underthrusting movement, such as would be expected along this portion of the plate boundary, is usually accompanied by large-scale displacements of the sea floor, which could generate a major tsunami. Such a tsunami could cause extensive damage to low elevation, nearshore facilities throughout the Shelikof Strait-Kodiak-Cook Inlet region. An evaluation of seismic sea wave hazards to potential shore-based facilities in these areas is planned for fiscal year 1977.

The Kodiak-Shumagin seismic gap, located southwest of the proposed Kodiak lease area, has been seismically quiet since the 1938 Shumagin Islands earthquake and could experience a major earthquake before 1980 (Kelleher 1970). Davies et al. (RU #16) are presently focusing their research on the seismic characteristics of this gap. Several lines of evidence are consistent with the interpretation that a north-south transverse fault cuts the Pacific Plate as it dips beneath the Shumagin Islands. These include the shape and position of the 1938 aftershock zone, the offset of deep (>60 km) seismicity, a 15^{0} to 20^{0} bend in the trendline for volcanoes east and west of the Shumagin Islands, and present differences in both seismicity and volcanic activity to the east and west. At NOAA's request, Davies et al. (RU #16), calculated the probable repeat times for major earthquakes within the Shumagin Islands area.

TSUNAMIS

While seismic sea wave hazards have already been mentioned in the previous section, it is appropriate to review the nature of the tsunamis which may accompany earthquakes. Because of their extremely long wavelengths and relatively small height, tsunamis are seldom detectable in the open ocean. As they approach shore, however, they build waves many meters high that can cause extensive flooding and structural damage in low-lying, nearshore areas. Future major earthquakes in the region of Kodiak Island and the Kenai Peninsula are likely to produce destructive tsunamis and the construction of shore facilities on Kodiak should be planned with this in mind. A major earthquake in the Shumagin seismic gap, southwest of Kodiak, can also be expected to generate a major tsunami that might have a significant impact on the Kodiak coast, as well as the Alaska Peninsula.

VOLCANIC HAZARDS

The general nature of volcanic hazards in western Alaska has already been reviewed in the Lower Cook Inlet portion of this report. There are no active volcanoes on Kodiak Island or elsewhere in the proposed lease area. Several active volcanoes are present along the coast of the Alaska Peninsula, northwest of Kodiak. In the event of a major eruption comparable with that of Katmai in 1912--and depending upon local wind and weather conditions--Kodiak Island, and much of the proposed Kodiak lease area, could experience significant ash falls (≥15 cm deep) and possible corrosive rains (AEIDC 1974).

SURFACE AND NEAR-SURFACE FAULTING

AEIDC (1974) recently drew attention to an elongated zone of surface faulting located off the southeast coast of Kodiak Island and extending northeastward to Prince William Sound (Fig. III-3). Hampton and Bouma (RU #327) are presently using a variety of shipboard geophysical techniques to study the distribution and displacement history of these faults. After reviewing previously unpublished U.S. Geological Survey seismic profiles, and collecting new data aboard *M/V CECIL H. GREEN* during 1975, they concluded:

> "Active surface faulting has been identified within and near the proposed Kodiak lease area. The major zone of faulting identified along the offshore of the southeast cost of Kodiak Island shows fresh, steep scarps that suggest recent activity. The less extensive zone southwest of Middleton Island, in line with the Kodiak fault zone, has experienced movement as recently as 1964. Scattered surface faults have been identified near the edge of the continental shelf on Albatross bank and tectonic deformation of the bank in 1964 suggests that at least some of the faults are active." (Hampton and Bouma, RU #327)

As noted in the seismic hazards section above, any pipelines between Kodiak Island and possible offshore oil facilities, would have to be laid across this fault zone. There is good evidence to believe that at least some of these faults are active. Maximum observed uplift, subsidence, and horizontal displacement on land, during the 1964 Alaska earthquake, were 15 m, 2.5 m, and 19.5 m, respectively. This suggests the magnitude of regional deformation and should be considered in designing pipelines to cross the Kodiak-Montague Island fault zone. During the 1976-77 field season, Hampton and Bouma (RU #327) will delineate zones of surface faulting, map individual faults, and determine their ages and states of activity.

SEDIMENT INSTABILITY AND MASS MOVEMENT

During fiscal 1975-76 Hampton and Bouma (RU #327) initiated a three-year project that will answer the following questions:

1. What are the distribution, thickness, and physical properties of unconsolidated Quaternary sediments within the Kodiak lease area?
2. What is the distribution of areas of slope instability?
3. What are the dispersal patterns of recent sediments which might also reflect dispersal and storage sites for introduced contaminants?

Their initial results indicate that the Kodiak lease area can be divided between the nearshore, plateau-like surfaces and sea valleys (Fig. III-8). The nearshore varies from 5 to 8 km wide, reaches 30 to 50 m deep, and is characterized by fiords. The gently sloping plateaus are in water depths of 80 to 120 m and cover most of the shelf. Several sea valleys cut across the plateaus and exhibit typical characteristics of glacially formed channels. Other features, such as the margin of Portlock Bank and the Amatuli Trough, appear to be tectonic.

The majority of unconsolidated sediments on the Kodiak shelf are probably land derived, and were transported and deposited by glacially associated processes during Pleistocene low stands of sea level. Sandy sediments with pebbles and shell material predominate. Only a thin veneer of sediments is present over bedrock on the plateaus; very little sediment deposition is presently occurring, apparently because of lack of a sediment source. Unconsolidated sediment thicknesses increase to 50 to 100 m on the slopes and bottoms of the sea valleys; sediments are finer grained there.

Hampton and Bouma have not found any evidence of slope instability--slumps, slides, etc.--on the seismic profiles presently available. They note that the thin, coarse-grained plateau sediments are unlikely to suffer major slumping. Major slumping might occur on the steeper slopes--the sides of sea valleys, inside coastal fiords, or on the continental slope--where the sediments are both thicker and finer grained. It appears that the sea valleys would act as dispersal routes for contaminated sediments, most of which would probably be carried over the shelf edge to be deposited on the continental slope or within the Aleutian Trench (Hampton and Bouma, RU #327).

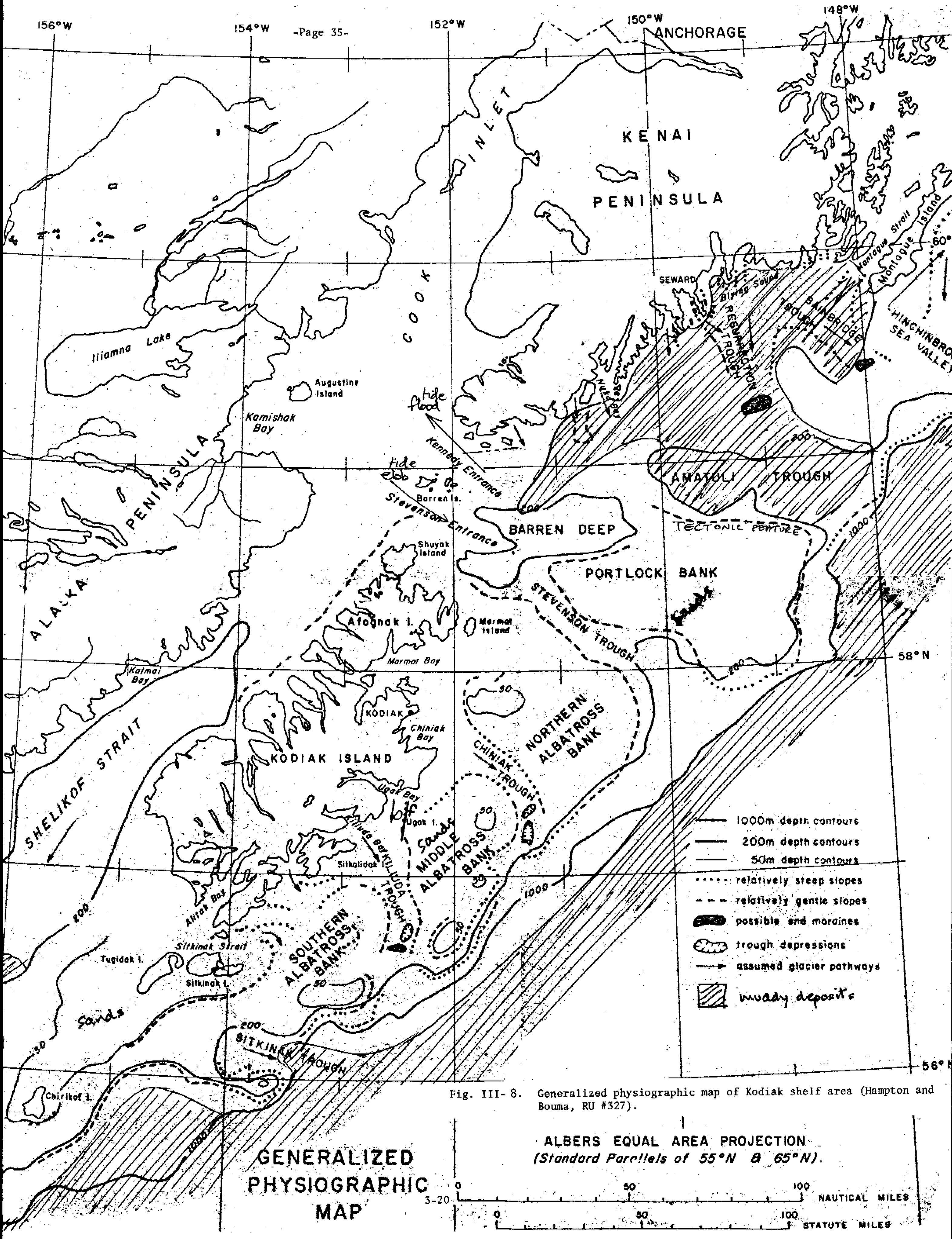


Fig. III- 8. Generalized physiographic map of Kodiak shelf area (Hampton and Bouma, RU #327).

COASTAL EROSION

No research units concerned with coastal morphology or erosion are presently being sponsored by OCSEAP in the Kodiak area. Some data may be forthcoming during an evaluation of seismic sea wave hazards to potential shore-based facilities, proposed for 1977.

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Chapter IV

TRANSPORT PROCESSES

INTRODUCTION

Only a limited amount of data are available on the distribution of mass, currents, water transport, and other oceanographic features and water masses. General pattern of currents is described for the Gulf of Alaska by Ingraham, Bakun, and Favorite (RU #357). Some data and information relevant to this lease area was compiled in the AEIDC Report for the BLM in 1974.

On the basis of the presently available information, a coherent, meaningful picture of the oceanographic processes and transport mechanism cannot be constructed. Although a substantial number of temperature, salinity, and meteorological data are available, most are aperiodic, non-synoptic, and lack appropriate area coverage and repetitive information. According to Ingraham, Bakun, and Favorite (RU #357), oceanic regime is turbulent and can only be characterized by rigorous statistical analyses of long-term, time-series data.

For the nearshore environment in the western gulf or off Kodiak Island, even less is known. It is quite likely that offshore circulation in this part of the gulf would have major influence on coastal and nearshore circulation pattern. However, in these waters, variation in local bathymetry, local freshwater runoff, and tidal currents would be the determining factors for the distribution and dispersal of contaminants associated with seawater.

A large part of this chapter is based on information provided by Ingraham, Bakun, and Favorite (RU #357). OCSEAP research units are currently involved in the study of the entire gulf (Hayes and Schumacher, RU #138; Royer, RU #289). Naturally, areal coverage and field spacing of data collection are limited.

MAJOR HYDROGRAPHIC FEATURES

The dominant physical phenomenon in the Gulf of Alaska is the Aleutian low pressure system whose center moves clockwise out of the northern Bering Sea in early autumn, crosses the Alaska Peninsula, and attains a mean position of about 55°N, 155°W in the gulf in late fall and early winter. During winter, it moves southwestward before returning northward to the western Bering Sea in spring. This cyclogenesis of cold air advection determines the extent and intensity of water overturn and divergence as well as climatic features.

According to Royer (1972), surface water variations on the shelf are primarily in response to atmospheric pressure fields over the area.

An analysis of available data clearly demonstrates that there is a northward sweep of warmer water into the gulf on the eastern side. On the western side, intrusion of cold water is recognized in the offshore areas. Both of these features are known to exist at all depths. A gradual lowering of water temperature from 5° to $4^{\circ}C$ in an east-west direction at about 200 m is represented as far west as east of Kodiak Island. Data obtained east of Kodiak Island in spring 1972 (Fig. IV-1) indicate characteristics of the distribution of 4° to $5^{\circ}C$ water (Ingraham, Bakun, and Favorite, RU #357).

Surface water temperature off Kodiak Island ranges from 1° to $12^{\circ}C$. This range is larger than the one for the eastern part of the gulf, from 5° to $14^{\circ}C$.

Extensive runoff from land occurs around the gulf in spring and summer. Data from continuously recording salinograph obtained in spring 1972 have shown the existence of a frontal zone at the edge of the continental shelf delineating dilute coastal water with saline oceanic water (Fig. IV-2). Little is known about the effect of land runoff in waters nearshore.

MASS DISTRIBUTION

Detailed information on different water masses in the Gulf of Alaska is not available. Ingraham, Bakun, and Favorite (RU #357) have pointed out that the water mass at the head of the gulf is formed from the merger of three northward moving water masses along the central and eastern sections (Fig. IV-3). This water mass is characteristic of the western and southwestern part of the gulf. Three domains of distinct surface water are recognized: Central Alaskan Gyral, west flowing Alaska Stream, and Coastal Water. In summer, a weakening of the Alaska Stream and large land runoff expands the Coastal Water domain over most of the shelf (AEIDC 1974).

Two current research units (Hayes and Schumacher, RU #138; Royer, RU #289) are collecting STD (salinity-temperature-depth) and other data to determine the mesoscale oceanographic processes and water masses in the gulf. So far no new findings are reported. It is reiterated that seawater overlying the continental shelf shows seasonal variability due to input of heat and variation in wind stress. Water properties inshore and westward of Middleton Island are different from those of the southwestward moving water from Kayak

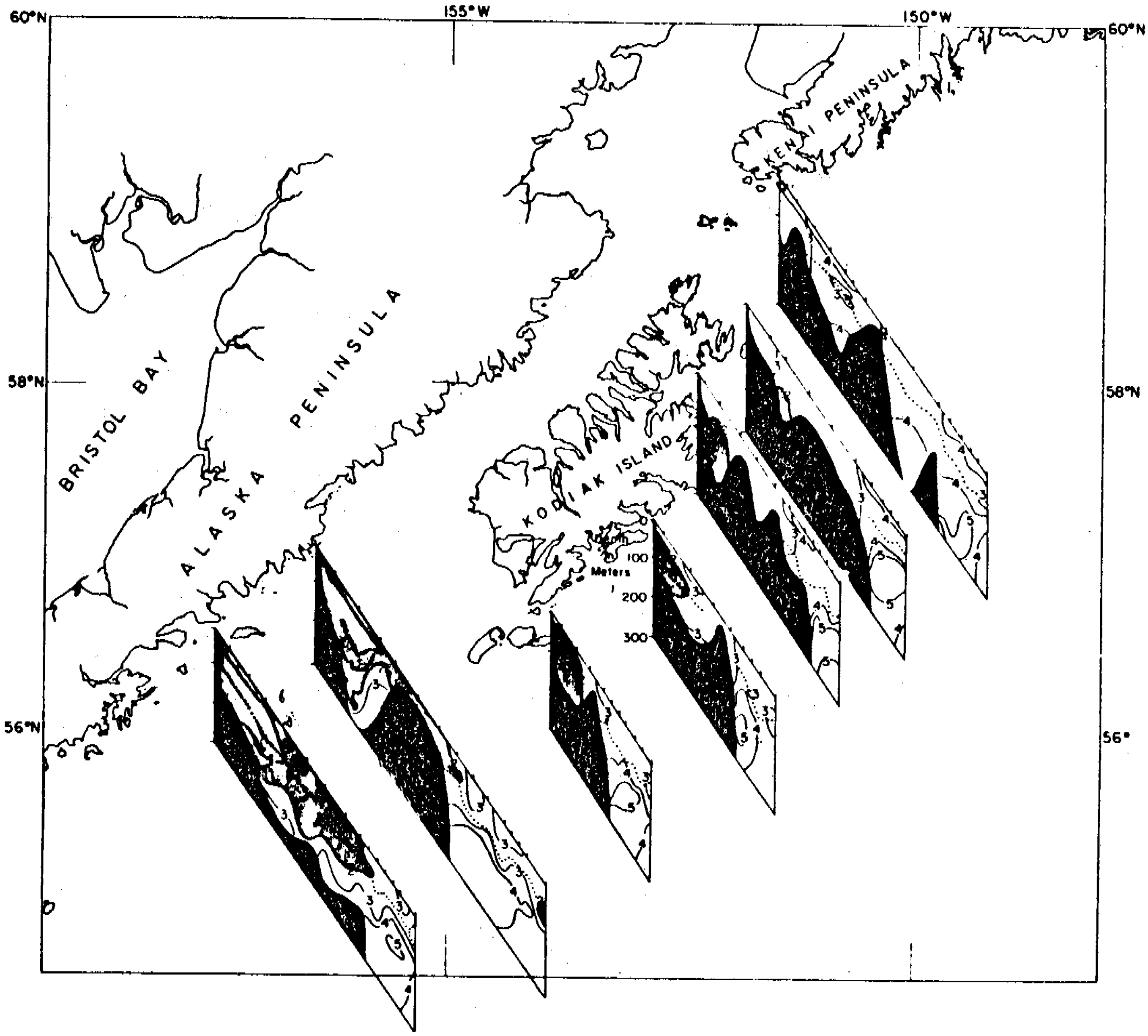

Fig. IV-1. Vertical temperature profiles (°C) along transects in the vicinity of Kodiak Island and Alaska Peninsula. Data were collected in spring 1972. Figure reproduced from Ingraham, Bakun, and Favorite (RU #357).

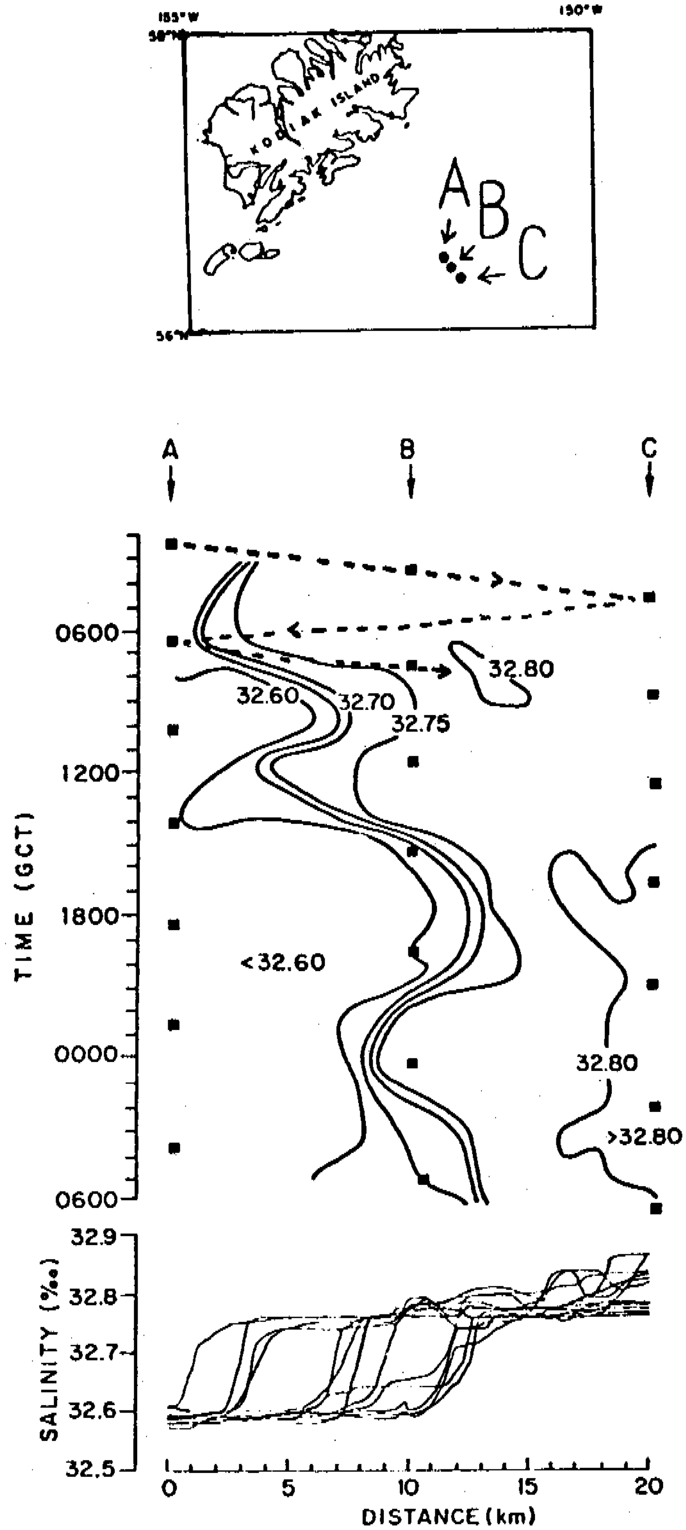

Fig. IV-2. Surface salinity front detected seaward of Kodiak Island in the vicinity of the continental shelf. Repetitive measurements were obtained at three stations, A, B, and C in spring 1972. Dashed lines indicate vessel movement. (reproduced from Ingraham, Bakun, and Favorite, RU #357)

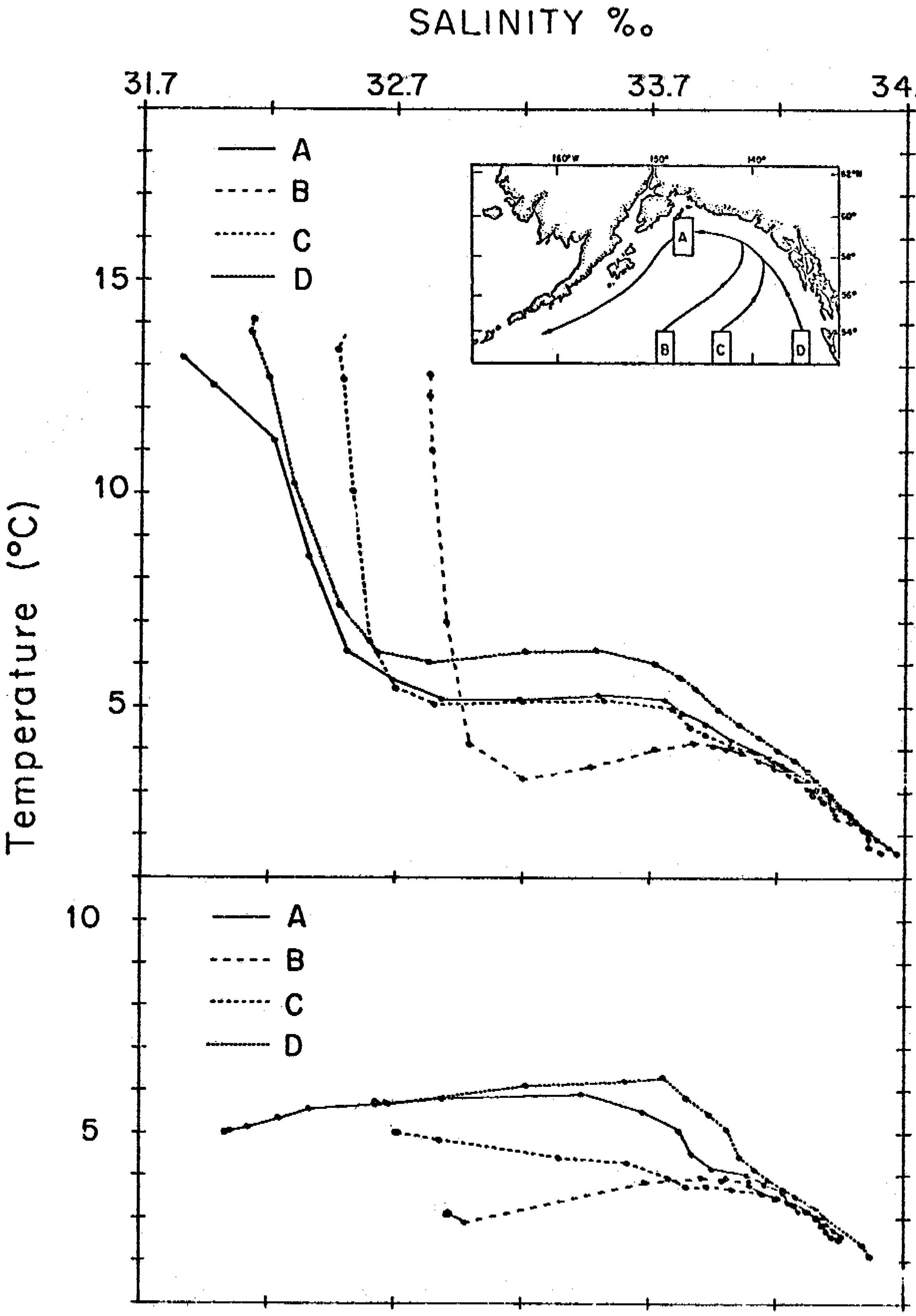

Figure IV-3. Long-term summer and winter mean temperature-salinity (T-S) relations at standard depths in the indicated 2x2° guadrangles showing characteristics of the various water masses funneling into the gulf (RU#357).

Island to Kodiak Island (Royer, RU #289).

CURRENTS

A large amount of data and information are available on the pattern and intensity of currents in the Gulf of Alaska. The major feature of the current system, counterclockwise circulation, has been recognized for a long time. It is generally believed that this current (Alaska Stream) is much more intense in the western part of the gulf off Kodiak Island than in the eastern part.

Drift Bottles

Early drift bottle studies, 1930-34, have demonstrated the northward flow in the eastern part of the gulf and southwestward flow in the western part. Bottles released along an east-west line in the gulf were recovered in Cape St. Elias and Cook Inlet; those released just east of Kodiak Island were recovered not only along the southern coast of the island and along Alaska Peninsula but also in Shelikof Strait. Recoveries from two releases at about 55^{o}N, 142^{o}W in February and August 1957 were only on the western side. Recoveries from the winter release were made as far north as Pribilof Islands, as far west as Amchitka Island, as far southeast as Washington-Oregon-California coast, and as far south as Hawaiian and Wake Islands (Fig. IV-4). Such dispersal has profound implications if one considers possible distribution of biota, nutrients, and contaminants (such as oil) on surface waters. It should be emphasized that drift bottle data only provide gross features of circulation as trajectories of flow cannot be ascertained.

Geostrophic Currents

Isopleths for the entire gulf based on geopotential anomalies, averaged by 2^{o} x 2^{o} quadrangles are provided by Ingraham, Bakun, and Favorite (RU #357). The longitude of the topographic low, 149^{o}W, is the same for all seasons. The latitude shifts from 53^{o}N in spring to 55^{o}N in summer. Its winter position is 54^{o}N; autumn data are insufficient for such details. Although the difference between geopotential topographies in the middle of the gulf and in coastal areas may be 15 to 20 dynes/cm, isopleths are not continuous around the gulf. They may represent a discontinuity of flow, primarily due to the narrow width of the boundary current in the northern and western parts of the gulf. In spring 1972, when closely spaced data were obtained along transects on the continental shelf and slope off Kodiak island, it was found that 70% of the westward flow out of the gulf occurred within

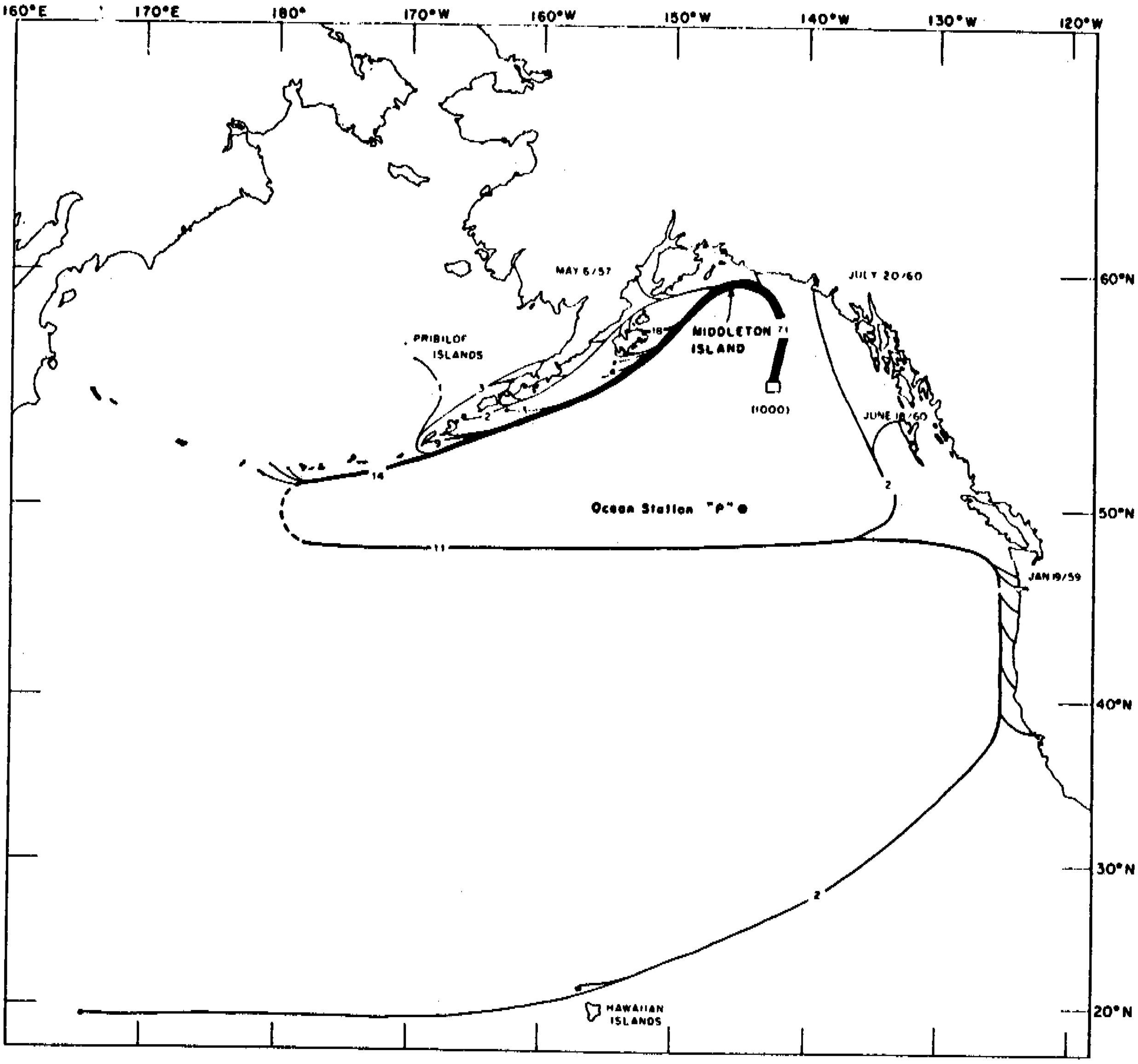

Fig. IV-4. Release and recovery sites of drift bottles released in February 1957 showing wide dispersal; figure reproduced from Ingraham, Bakun, and Favorite (RU #357).

50 km of the shelf. Geostrophic velocities of 50 cm/sec (referred to 1,000 decibars) were calculated within a narrow band of 10 km. No major perturbations were evident (Ingraham, Bakun, and Favorite, RU #357). In general, however, widespread irregularities in geopotential topography are noted. These result in extreme perturbations in the calculated flow regime. It is possible that the flow is actually a turbulent regime made up of eddies of various dimensions. Hansen (RU #217), working in the northeast part of the gulf, noted the presence of eddies in the lee of Fairweather Ground. On the other hand, it is also possible that inferred topographies are affected by inadequacy of the method (boundary conditions) or paucity of data.

Baroclinic currents reported by Royer (RU #289) are stronger in the western part of the gulf, 45 cm/sec, than in the northeastern part, 30 cm/sec. He also reported that the presence of Middleton Island causes perturbations in density and currents structure in waters in the vicinity of Cook Inlet and northeast of Kodiak Island. Water transport calculated to the baroclinic mode relative to the deepest common depth of stations is estimated from 6 to 11 Sv (1 Sverdrup = 10^6 m^3/sec, measure of transport).

Hayes and Schumacher (RU #138) reported mean current speeds of the order of 25 cm/sec, flowing westward; flow was found to be weaker east of Kayak Island, 21 cm/sec, than in the western part off Kodiak Island, 33 cm/sec. In winter, storm induced changes in current speeds are of the same order as the mean and may be due to the barotropic mode. Correlation between velocity and pressure changes was found to be large. Progressive vector diagram (PVD) for current measurements at a station off Kodiak Island, 57°27'N, 150°30'W, is shown in Fig. IV-5. The direction of the flow is southwest; at this station the direction fluctuated about the true axis by ±25°.

Wind Stress

As the available data are scant, possible effects of wind stress on seawater are estimated from data on the distribution of sea level pressure. The nature of coupling of energy between wind stress and water transport is not fully known. When water is warmer than the air, a turbulent boundary layer exists and exchange of energy is more effective than when water is colder than the air; in such case a stable air is formed.

Total meridional transport, M_y, is related to the curl of the wind stress by

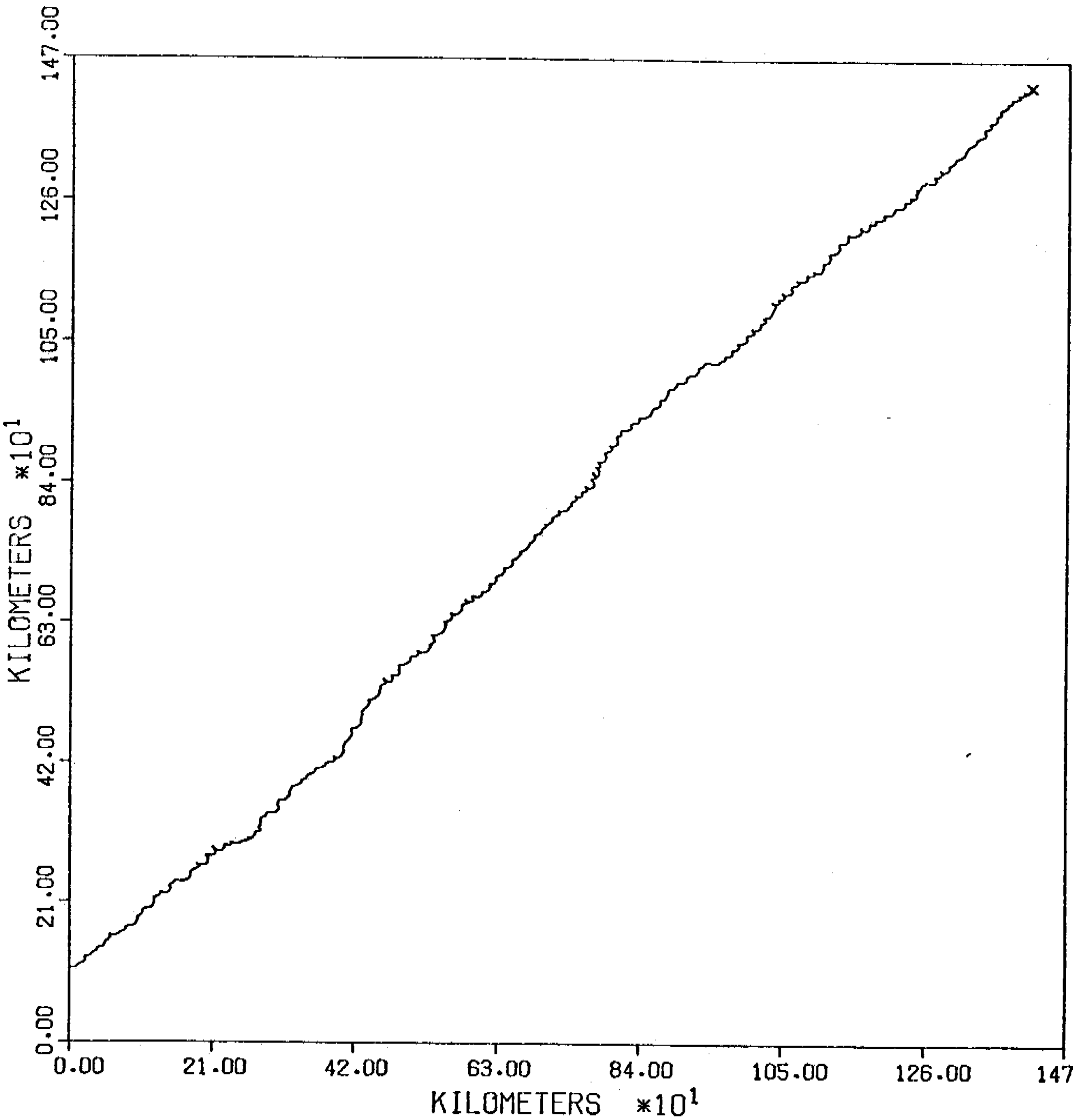

Fig. IV-5. PVD constructed from current measurement data from station WGC-2, September-November 1975. Mean flow is directed at 229° (TN). Figure reproduced from Hayes and Schumacher (RU #138).

the following expression:

$$M_y = \left(\frac{\partial\tau_y}{\partial x} - \frac{\partial\tau_x}{\partial y}\right)/\beta$$

where τ is wind stress and β is the variation with latitude of the Coriolis parameter $\frac{\partial f}{\partial y}$. Seasonal mean transport values generally vary from 1 to 15 Sv and show a general cyclonic flow with pronounced intensification in winter. Maximum computed transport values were in excess of 19 Sv and were noted in winter (Ingraham, Bakun, and Favorite, RU #357).

The divergence of Ekman Transport integrated over the width of coastal divergence/convergence boundary zone per unit length of the coast is apparently given by the offshore component. Ingraham, Bakun, and Favorite (RU #357) called it Coastal Divergent Index (CDI) whereas Bakun (1973) called it the Upwelling Index. Its units were metric tons/sec/100 m length of the coast. Offshore, this index is called Offshore Divergent Index (ODI). The area northeast of Kodiak is characterized by the dominance of 'A' type of classification (see Fig. IV-6) as it occurs eight months of the year, September to April. The coastal area off the lower Alaska Peninsula is, on the average, under type 'C' situation over most of the year.

WAVES AND TIDES

No OCSEAP-related research is specifically concerned with the study of waves and tides in this area. Observations collated by the U.S. Naval Hydrographic Office (Climatological and Oceanographic Atlas for Mariner, 1961) suggest that in stormy season in this area, no more than 10% of waves would have heights greater than 3 m.

Royer (RU #289) has described results from 10 days of wave data obtained off Middleton Island. Hourly spectra in the early part of the record reveal a peak around 0.065 Kz which moved toward greater frequencies for about 18 hrs. The frequency remained constant for about 24 hrs, after which it again increased. These changes were well correlated with a large storm that remained stationary in the north Pacific.

CONCLUSION

Most of our knowledge regarding transport mechanism in this lease area is sporadic and tentative. The details of the nature of variability in circulation patterns are not understood. It is not known if drifting objects are trapped by coastal and shelf flow regime or

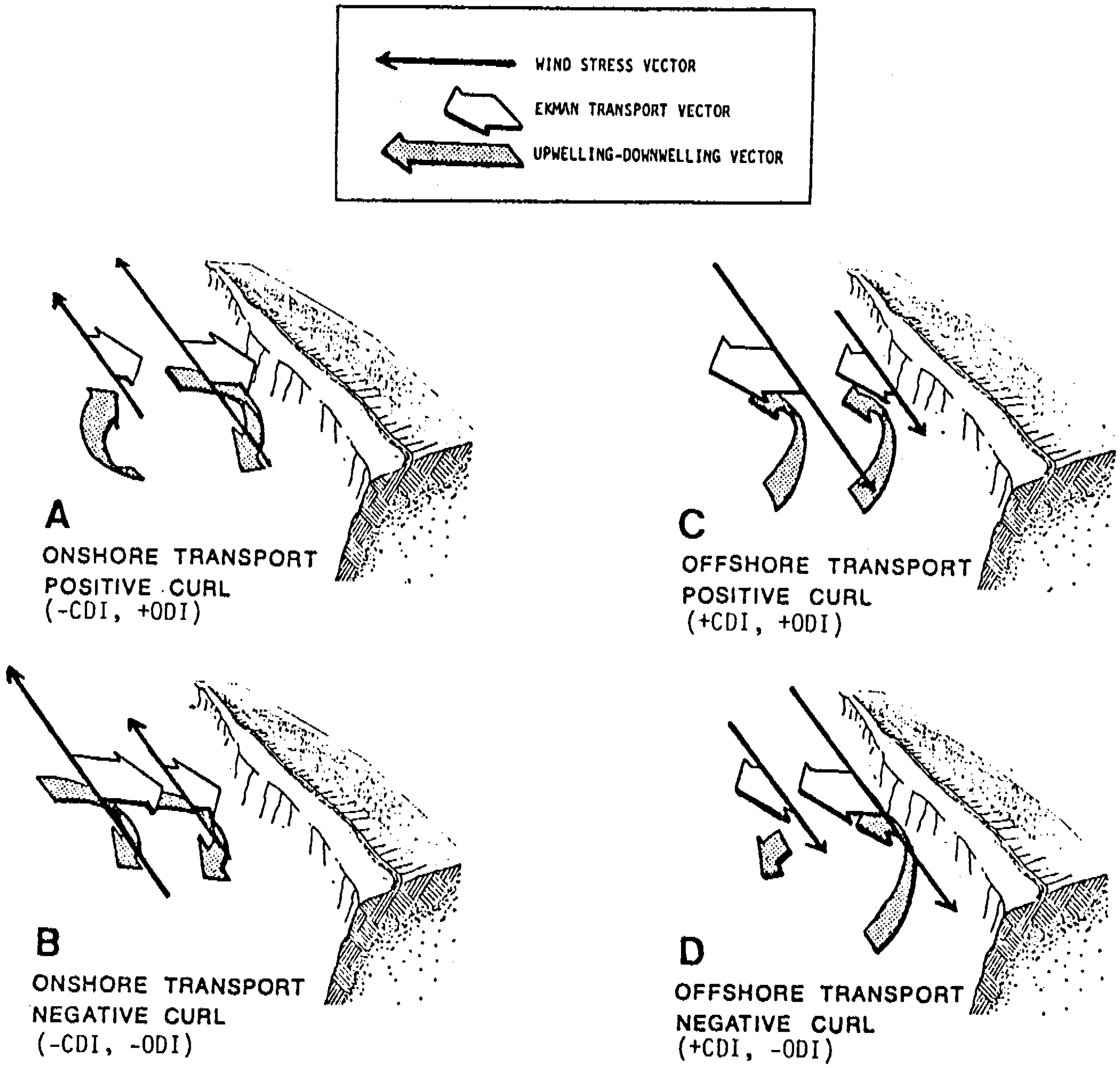

Fig. IV-6. Classification of indicated events according to combination of coastal and offshore convergence or divergence. A. Onshore Ekman transport and positive wind stress curl; convergence and downwelling at the coast, divergence and upwelling offshore. B. Onshore Ekman transport and negative wind stress curl; convergence and downwelling at the coast, continued convergence offshore. C. Offshore Ekman transport and positive wind stress curl; divergence and upwelling at the coast, continued divergence offshore. D. Offshore Ekman transport and negative wind stress curl; divergence and upwelling at the coast, convergence offshore. (Reproduced from Ingraham, Bakun, and Favorite, RU #357) by tidal currents. On the basis of drift bottle release and recapture data (limited dependability), it can be stated that floating material on seawater in the eastern part of the gulf may drift into coastal embayments (e.g., Prince William Sound), inlets (e.g., Cook Inlet), or move southward on either side of Kodiak Island. A potential for wider dispersal should also be recognized. No surface current measurements are being made by either Hayes and Schumacher (RU #138) or Royer (RU #289).

According to the data available, seasonal variability in either the water mass structure or current patterns is not resolved. The possible effects and magnitude of eddies are not understood. Information on coastal and inshore circulation and dynamics is not available.

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Chapter V

RECEPTORS

FISH

This section summarizes the field sampling programs and historical data analysis relating to fish and being conducted under NOAA/OSCEAP sponsorship. Pereyra and Nelson (RU #64) and English (RU #156a) are engaged in field collection of non-salmonid pelagic fish and ichthyoplankton. Smith (RU #284) is compiling data on the feeding habits of demersal fish, including some pelagic species, from field data and literature sources. English (RU #349) and Morrow (RU #285) are preparing taxonomic keys of Gulf of Alaska fish from field and archived samples and historical records. A literature review (Pereyra and Nelson, RU #64) is also being conducted under these programs. Many of these efforts are in initial phases with little data reported at this time.

A summation of the state of knowledge, by species is largely the work of Hart (1973) and AEIDC (1974), since few data are currently available from OCSEAP funded programgs. Only data collected in OCSEAP studies are noted here.

Theragra chalcogramma, Walleye Pollock

Pollock occur throughout the North Pacific from central California to St. Lawrence Island in the Bering Sea. This species occurs throughout the western Gulf of Alaska but little information is known about its life history. Eggs are pelagic and larvae have been collected in late April and May in Straits of Georgia.

Stomach contents of fish collected in the Gulf of Alaska were dominated in both frequency and volume by euphausiids (Smith, RU #284). Various fish, shrimp, and cephalopods followed euphausiids in order of abundance, even though amphipods were second in occurrence.

Pollock are an important food of fur seals, Steller Sea Lions, and Harbor seals. Pitcher and Calkins (RU #229) and #243), working in the western Gulf of Alaska, found that the frequency of pollock in stomachs of Harbor seals and Steller Sea Lions was 46% and 48% respectively.

Pleuronectidae

Atheresthes evermanni, Arrowtooth flounder

This species ranges from central California to the eastern Bering Sea is abundant throughout the Gulf of Alaska, and is caught at depths down to 900 m.

Eggs are presumably pelagic, rising into the surface waters and hatching in spring. Larvae remain pelagic and may be caught in the upper 200 m.

Smith (RU #284) found that the frequency of occurrence of teleosts and euphausiids in flounder guts was 40% and 36%, respectively. Teleosts included pleuronectiformes, pollock, Arrowtooth flounder, herring, zoarchids, and Capelin and constituted about 65 to 75% of the volume consumed.

Hippoglossoides elassodon, Flathead sole

Flatheads extend from northern California into the Gulf of Alaska and the southern Bering Sea but are not found in the northern Bering and Chukchi Seas. Flathead sole are common throughout the western Gulf of Alaska, particularly northeast of the Shumagin Islands, through the Shelikof Strait, and along the coast and shelf northeast of Kodiak Island. This species is found at depths ranging from the surface to 550 m.

Much of the life history and feeding habits is lacking for these fish in the Gulf of Alaska (Smith, RU #284). Spawning occurs in late winter and the pelagic eggs hatch in 9 to 20 days, depending on incubation temperature. Although no data are available on the feeding habits of this species in the Gulf of Alaska, juvenile flatheads in Puget Sound feed on clams, worms, and crustaceans in shallow, nearshore waters. Stomachs collected from Bering Sea specimens indicate that feeding varies seasonally and geographically, and the contents were ophiuroids, shrimp, amphipods, fish remains and molluscs, listed as to frequency of occurrence (Smith, RU #284).

Hippoglossus stenolepis, Pacific halibut

Halibut inhabit Pacific Ocean waters from Southern California to the Gulf of Alaska and are abundant in the Bering Sea north to Norton Sound. This species has been collected from the surface to depths of 1,100 m but based on catch statistics, this species is most abundant along the continental shelf and slope areas in water depths between 55 and 422 m. Trawl studies indicate that the major areas of halibut abundance in the western Gulf of Alaska are southwest and northeast of Kodiak Island (AEIDC 1974).

Spawning occurs from late fall to early spring in the Gulf of Alaska and at depths from 275 to 412 m. Eggs and larvae are pelagic; newly hatched larvae are commonly found below 200 m. As the juveniles grow, they begin to rise in the water column and by three to five months are found near 100 m, but six to seven months juveniles move inshore and begin a demersal existence. As the fish mature and increase in size, they begin to migrate to deeper waters. Extensive spawning migrations have also been noted. Smith (RU #284) also reports that immature halibut are relatively nonmigratory but adults from the Gulf of Alaska are known to migrate up to 1,100 km (700 miles).

Feeding habits of halibut in the Gulf of Alaska are poorly known. Smith (RU #284) reports that in the southeastern Bering Sea juveniles feed largely on crustaceans. Of the stomachs examined, 89% contained crustaceans. He also noted that dietary preference shifts to fish as the halibut increase in size. Medium sized halibut contained various teleost species in 61% of the guts examined; only 33% contained crustaceans. Teleosts included pleuronectiformes, smelt, Capelin, pollock, and sand lance. Halibut, larger than 60 cm, fed predominant on Yellowfin sole.

Lepidopsetta bilineata, Rock sole

Sole are common throughout the North Pacific Basin, extending throughout the Bering Sea. In the western Gulf of Alaska major concentrations of this species have been identified south of Unimak Island, south of the Shumagin Islands, along the Semidi Islands, and west of Kodiak Island (AEIDC 1974). This species has been collected from the surface to 366 m, but reportedly is scarce below 183 m. During the summer they move into shallow water. In Canadian waters Rock sole are usually caught at depths of 37 to 55 m.

Rock sole are winter spawners, spawning between February and mid-April in the Puget Sound area. Eggs are demersal and adhesive with a specific gravity around 1.047. Depending on incubation temperature, hatching occurs in two to four weeks. Larvae are common in the shallow nearshore waters.

Smith (RU #284) reported that little information was available on general life history and feeding habits of this species in the Gulf of Alaska. Rock sole exhibit feeding and distributional changes over the year; in the Bering Sea little or no feeding occurs on the wintering grounds; feeding activity begins slowly in April, intensifying in June and July.

Bering Sea Rock sole stomach contents include polychaetes, molluscs, crustacea, and some fish and echinoderms (Smith, RU #284). Reportedly this species forms dense schools during summer and winter in the Bering Sea (Smith, RU #284). Little information is currently available on the Gulf of Alaska races but major schools may be identified as research in RU #175 and #284 progresses.

Scorpaenidae

Sebastes alutus, Pacific Ocean perch

Perch are found mainly offshore from southern California to the Bering Sea. In the western Gulf of Alaska major concentrations are located near Unimak Pass, the Shumagins and Kodiak Island from May through September. This species is commonly found throughout the water column to depths of 640 m. In summarizing data from Lyubimova (1964), Smith (RU #284) reported that this species segregates vertically in the water column by size, the largest fish being taken at greater depths (Fig. V-1). In addition to supporting a major commercial fishery, perch are readily eaten by Albacore and halibut.

This species is a live bearer, incubating the eggs within the female body cavity. Larvae are born during winter and remain in the upper pelagic waters for two to three years.

In the Gulf of Alaska, Smith (RU #284) reports that juveniles feed primarily on planktonic crustaceans. As the fish matures and seeks greater depths, the dietary composition includes euphasiids and pandalid shrimp. Stomachs of adult perch contained 75% crustacea, 15% squid, and 6% to 7% fish. He also reports that some Russian studies have shown this species to feed only during the spring and summer. In addition to supporting a major commercial fishery, perch are readily eaten by Albacore and halibut.

BENTHOS

University of Alaska personnel (AEIDC 1974) have provided a useful summary of published data describing both the benthic and intertidal invertebrate communities of the Kodiak Shelf. A broad literature search and synthesis on Gulf of Alaska benthos is also being conducted by Feder (RU #282). Thus far more than 1,500 references have been gathered for review. Feder has also been collecting and analyzing quantitative samples of benthic organisms from the Gulf of Alaska; however, the samples collected from the proposed Kodiak lease area still await analysis.

Three additional OCSEAP-sponsored studies being pursued in the Kodiak region include:

1. Analysis of the density and distribution of razor clams, Siliqua patula (Dixon) by Kaiser and Konigsberg (RU #24).
2. Baseline characterization of the littoral biota of the Gulf of Alaska (Zimmermann and Merrell, RU #78).
3. Detailed studies of the Kenai Peninsular littoral zone (Flagg, RU #27).

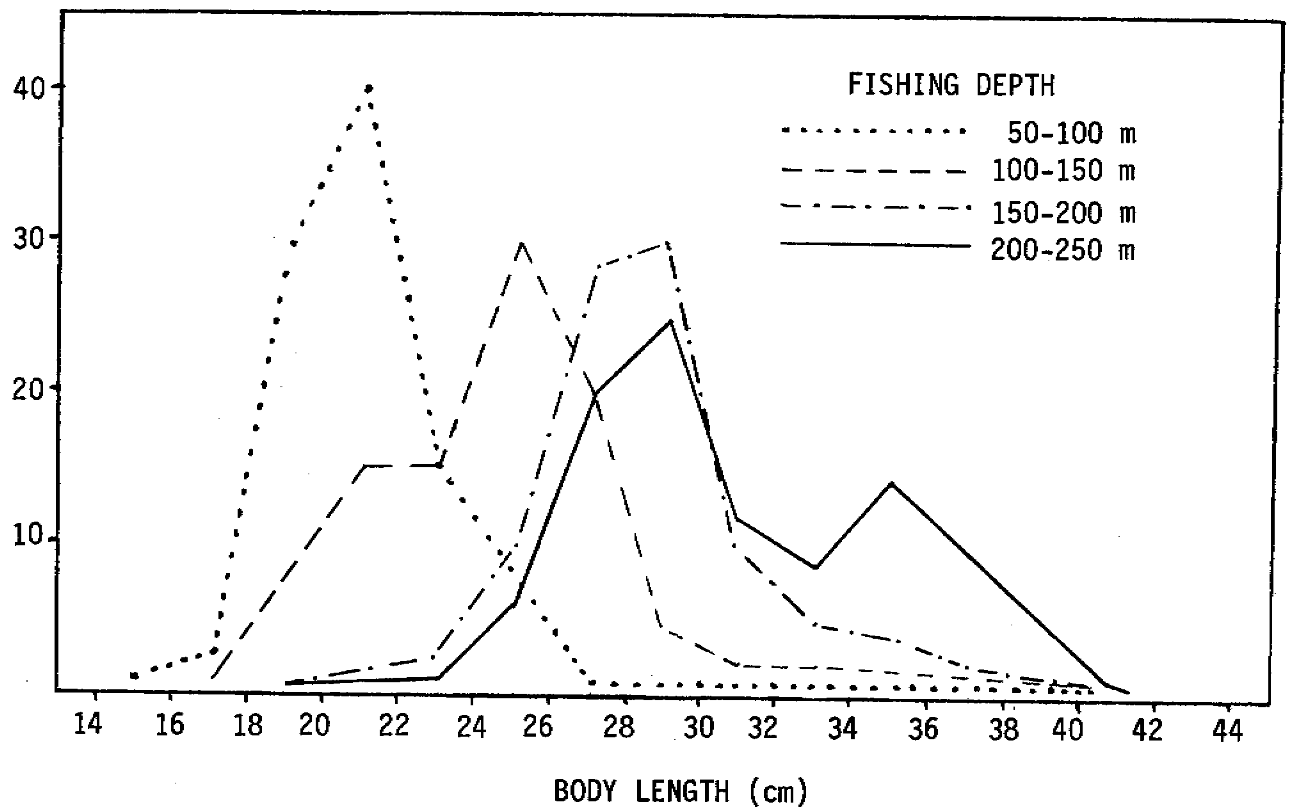


Fig. V-1 Body lengths of Pacific Ocean perch taken in the Gulf of Alaska at various depths (from Lyubimova 1964, as reported by Smith, RU #284).

A fourth study (Smith, RU #284 -- seeking to characterize food and feeding relationships in benthic and demersal fishes of the Gulf of Alaska -- will undoubtedly yield additional data important to our understanding of Kodiak's benthic ecosystems. All of these studies are still in the data collection and/or analysis phase (at least for sampling stations within the Kodiak Shelf region) and significant results have not yet been forthcoming.

Much remains to be learned about biological resources and about their possible interactions with or dependence upon other members of the benthiccommunity. The data presently available are insufficient to accurately predict the impact of oil and gas development in the Kodiak area upon these organisms and the ecosystem to which they belong.

PLANKTON

Compared with data and information available for benthic organisms in the western Gulf of Alaska - Kodiak region, studies on phytoplankton and zooplankton are few, meager, and incomplete. No OCSEAP-related research is specifically concerned with plankton studies in this area. Anderson and Lam (RU #58) are compiling data on phytoplankton standing stock and productivity and related physical and chemical factors to provide a description of the seasonal variability and geographical distribution of phytoplankton in the Gulf of Alaska. So far no results from literature survey are reported. A major part of their Annual Report is concerned with numerical modeling of primary productivity based on data from ocean weather station 'P' (50^oN, 145^oW), which is considerably south of the gulf and is outside of the proposed lease areas. Based on only the temperature data from station'P', hypothetical profiles of vertical mixing coefficient, K_z, distribution with depth are obtained. For winter, a maximum surface K_z value of about 60 cm^2/sec is suggested.

In view of the major oceanographic features and mixing processes in this area (see Chapter IV of this section), one would expect that primary productivity will not be limited by a nutrient. Inorganic micronutrients, such as nitrate and phosphate, in nearshore and shelf waters would be brought into surface layers by strong wind-induced mixing (wind storms are common in the area), by turbulent mixing in regions where the Alaska Stream meets shelf flow or tidal currents, and also from coastal runoff. Nutrient budgets and seasonal variability of nutrient input are not presently known.

MARINE BIRDS

Introduction

A complete list of swimming and wading birds of the Kodiak Island group probably would resemble that prepared for Lower Cook Inlet (see section on Lower Cook Inlet). Ths USDI "Bird Check List for Kodiak Island" contains useful information on the status of 13 families and 60 species of swimming and wading birds of Kodiak Island but it cannot be considered a complete inventory (Table V-1). Even some common species, such as mallards and scoters, are excluded from it (Table V-2).

Seabird Nesting Colonies

Lensink and Bartonek (RU #338) have mapped and summarized size estimates for seabird nesting colonies in the Kodiak Basin region. Their maps show several colonies that are absent from their data summaries and they present size estimates for several colonies whose locations are not indicated. Altogether, Lensink and Bartonek map or summarize data, or both, for 56 colonies on Kodiak-Afognak and the Trinity Islands. They present size estimates for 19 of the 56 colonies. Average estimated size of these 19 colonies is 725 birds (R = 7 - 3,000). Species that Lensink and Bartonek indicate as nesting among the colonies are:

1. Double-crested cormorant
2. Pelagic cormorant
3. Steller's eider
4. Glaucous-winged gull
5. Mew gull
6. Kittiwake
7. Unidentified tern
8. Unidentified murre
9. Tufted puffin
10. Horned puffin
11. Pigeon guillemot

TABLE V-1

Status of swimming and wading birds of Kodiak Island (after USDI 1974: 334-336. The list is incomplete (see text).

Family	Species	Status
Gaviidae	Common Loon	Pr-c
	Yellow-Billed Loon	*
	Arctic Loon	WV-c
	Red-Throated Loon	TV-c
Popicipedidae	Red Necked Grebe	Pr-c
	Horned Brebe	SR-c
Diomedeidae	Short-Tailed Albatross	*
	Black-Footed Albatross	AV-r
	Laysan Albatross	*
Procellariidae	Fulmar	SR-o
	Sooty Shearwater	SR-c
	Slender-Billed Shearwater	SR-a
Hydrobatidae	Fork-Tailed Petrel	TV-r
	Leach's Petrel	*
Phalacrocoracidae	Double-Crested Cormorant	PR-a
	Red-Faced Cormorant	SR-c
Ardeidae	Great Blue Heron	*
Anatidae	Whistling Swan	SR-u
	Trumpeter Swan	*
	White-Fronted Goose	TV-o
	Emperor Goose	WR-o
	"Lesser Goose: (Lesser Canada Goose?)	
	Cackling Canada Goose	TV-o
	Dusky Canada Goose	TV-o
	Black Brant	TV-u
	Mallard	PR-c
	Pintail	PR-c
	Gadwall	PR-c
	Green-Winged Teal	PR-u
	American Widgeon	PR-c
Scolopacidae	Short-billed Dowitcher	*
	Long-Billed Dowitcher	*
	Western Sandpiper	SR-c
	Hudsonian Godwit	*
	Bar-Tailed Godwit	*
	Sanderling	*
Phalaropidae	Red Phalarope	*
	Northern Phalarope	TV-c
Stercorariidae	Pomarine Jaeger	*
	Parasitic Jaeger	SR-u
	Long-Tailed Jaeger	*

TABLE V-1 (continued)

Family	Species	Status
Laridae	Glaucous Gull	*
	Glaucous-Winged Gull	PR-a
	Herring Gull	PR-u
	Mew Gull	SR-c
	Bonaparte's Gull	SR-c
	Black-Legged Kittiwake	SR-a
	Sabine's Gull	*
	Arctic Tern	SR-c
	Aleutian Tern	*
Alcidae	Common Murre	PR-c
	Thick-Billed Murre	*
	Pigeon Guillemot	PR-u
	Marbled Murrelet	PR-u
	Kittlitz's Murrelet	*
	Ancient Murrelet	WR-u
	Cassin's Auklet	WR-u
	Parakeet Auklet	*
	Crested Auklet	PR-a
	Horned Puffin	SR-c
	Tufted Puffin	SR-c

Status

PR - Permanent Resident
SR - Summer Resident
WV - Winter Visitor
SV - Summer Visitor
TV - Transient Visitor
AV - Accidental Visitor
WR - Winter Risident
* - Status not indicated by USDI

Abundance

a - abundant
c - common
u - uncommon
o - occasional
r - rare

TABLE V-2

Numbers of swimming birds counted during shipboard surveys by Kodiak National Wildlife Refuge personnel, Jan. 25-Feb. 8, 1973 and Feb. 5-22, 1975 (adapted from Arneson, RU #3, p. 10). The survey also included corvids, raptors, and shorebirds, which are excluded from this list.

	1973	1975
Loon sp.	424	83
Grebe sp.	7	72
Red-necked	1	
Cormorant sp.	1,982	1,728
Emperor Geese	621	52
Mallard	700	2,556
Pintail	200	4
Gadwall	30	75
Dabbler sp.	-	50
Scaup (Greater)	80	15
Goldeneye sp.	1,142	1,205
Common	146	
Barrows	24	30
Bufflehead	36	27
Harlequin	691	675
Eider sp.	67	1,745
Common	4,512	58
King		4,654
Steller's	340	1,176
Oldsquaw	7,863	9,410
Scoter sp.	3,192	994
Black	2,154	1,402
White-winged	3,059	2,073
Surf	1,194	327
Merganser sp.	39	27
Common	21	21
Red-breasted	13	34
Gull sp.	124	1,589
Glaucous-winged	32	923
Mew	356	731
Murre sp.	8,420	14,994
Common		179
Thick-billed	66	
Pigeon guillemot	46	106
Horned Puffin		1
Tufted Puffin		1
Crested Auklet	15,033	7,011
Murrelet sp.	63	280
Ancient	3	
TOTALS	52,731	54,303

Comparing the preceding list with the inventory of permanent resident and summer resident bird species (Table V-1), which (except shearwaters) presumably breed on the islands, it seems clear that Lensink and Bartonek have not yet identified all of the seabird species that actually breed on the Kodiak Island group. Lensink and Bartonek's colony location summary resembles an earlier summary by Bartonek and Sowl (Fig. V-2).

Nesting habitats of seabirds have been briefly characterized in the section on Lower Cook Inlet. Distribution of seabirds in other terrestrial habitats on Kodiak Island is being determined by Arneson (RU #3), who is employing a habitat-stratified sampling paradigm in aerial surveys. His sampling and data analyses are not yet completed.

Offshore abundance of Aquatic Birds in Summer

Lensink and Bartonek (RU #337, Part I) present data from shipboard surveys on the offshore abundance of seabirds in Kodiak Basin by month (Table V-3). A graph of their data for all species combined (except shearwaters) during the seven survey months is presented in Fig. V-3. The abrupt decline of offshore density of birds from May to June corresponds to a behavioral shift from pre-breeding activities to the incubation period, during which one parent of each pair (all of the seabird species in Table V-3 are monagamous) incubates the egg(s) while the other forages at sea. Density rises in July, when both parents must forage at sea simultaneously to feed themselves and their nestling offspring; this also is a time when birds that have attempted unsuccessfully to breed might begin leaving the breeding colonies. The balance of the graph (Fig. V-3) probably results from a combination of dispersal and dynamic migration phenomena.

Fig. V-2 . Locations of seabird colonies on Kodiak-Afognak Islands (copied from USDI 1974;341). Larger scale maps of the Kodiak-Afognak colonies are available in Lensink and Bartonek (RU #338).

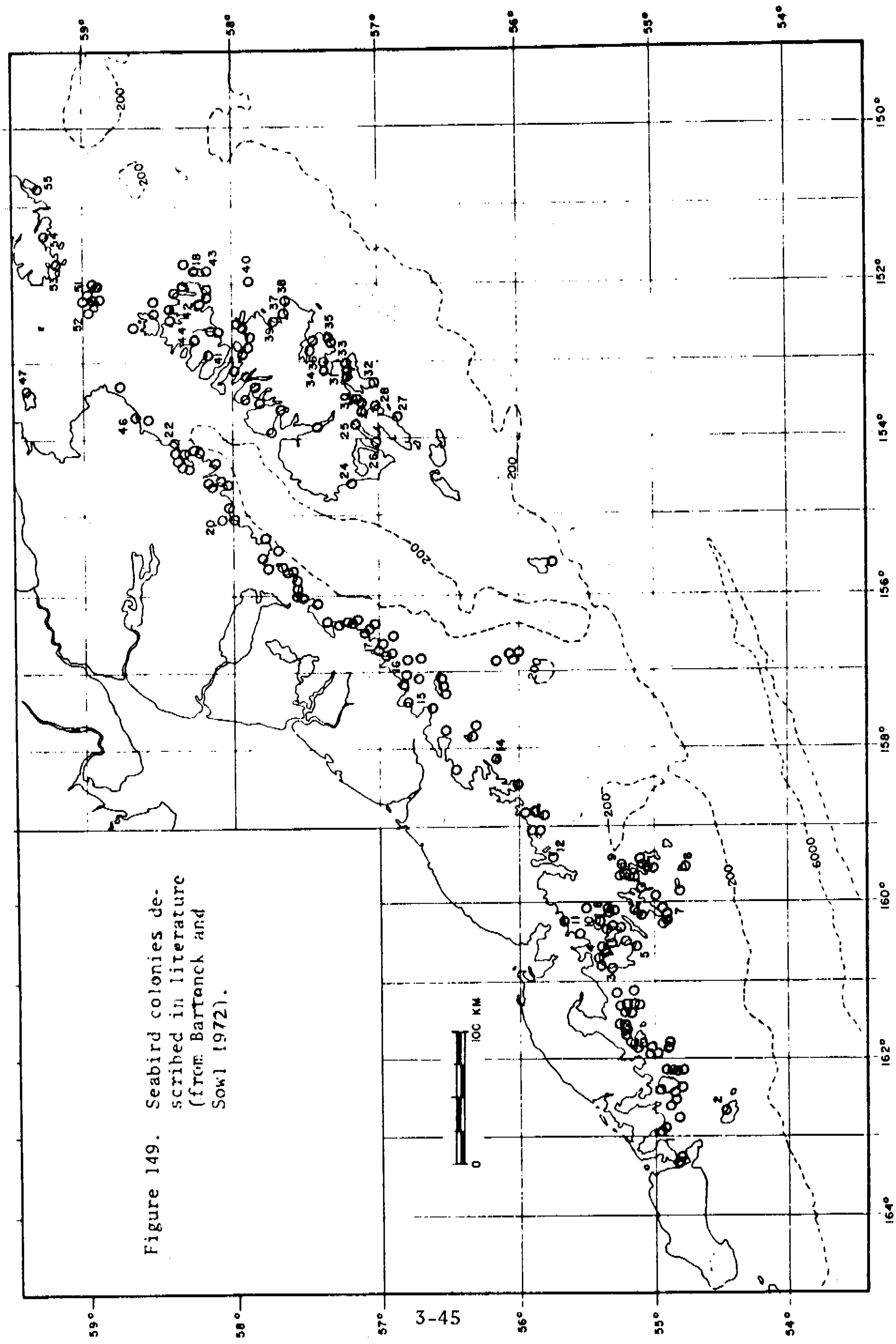


TABLE V-3

Offshore densities of seabirds in the Kodiak Basin by month as determined in shipboard surveys. Data are summarized from data sheets prepared by Lensink and Bartonek (RU #337, Part I).

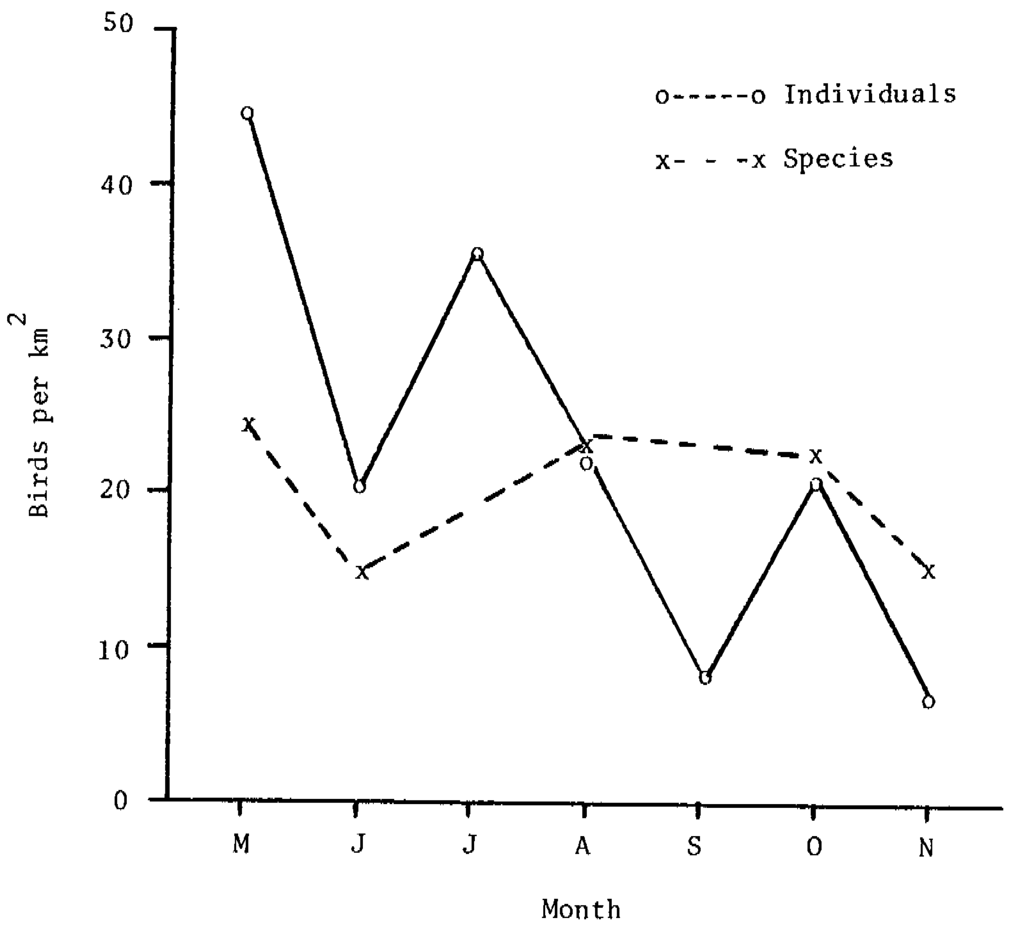
	Birds/km^2						
Species	May	June	July	Aug.	Sept.	Oct.	Nov.
Common Loon			*				*
Yellow-billed Loon						*	
Arctic Loon						*	
Unidentified Loon						*	*
Black-footed Albatross	*	*	*	0.3	0.1	0.9	
Laysan Albatross				*	*	0.5	
Fulmar	8.7	5.2	6.6	2.8	1.6	13.7	2.4
Sooty Shearwater	16.8	0.7	13.8	4.7	1.7	2.9	
Short-tailed Shearwater					19.1	0.1	
Unidentified Shearwater	2.3	0.7		17.4	55.5	7.2	4.2
Fork tailed Storm Petrel	1.0	0.1	2.65	2.2	0.7	1.9	0.2
Leach's Storm Petrel	*	1.1	0.1	0.7	0.1	0.3	
Unidentified Storm Petrel	1.0	0.2	0.2	0.2	0.1	*	
Brandt's Cormorant	0.3						
Pelagic Cormant	*				0.2	*	
Unidentified Cormorant		*	0.4	0.2		0.5	
Pintail					0.1		
Oldsquaw	0.1						
Harlequin duck							0.1
White-winged Scoter	0.1						0.2
Surf Scoter							*
Rudy Turnstone				0.1			
Whimbrel					*		
Red Phalarope	*		*				
Northern Phalarope			*	0.1		*	
Unidentified Phalarope	0.1		*				
Unidentified Shorebird				0.1			
Pomarine Jaeger			0.1	0.2	0.1		
Parastic Jaeger	0.1	*	0.1	0.1	*		
Long-tailed Jaeger	0.1		*	0.1			
Unidentified Jaeger	0.1		0.1	0.1	0.1	*	
Glaucous-winged Gull	1.3	0.4	0.2	0.4	*	1.2	1.2
Herring Gull	*				*		
Thayer's Gull					*		
Mew Gull							*
Unidentified Kittiwake	3.9	1.5	2.4	2.0	0.2	0.7	0.1
Black-legged Kittiwake			0.3	0.1	0.3	1.1	0.2
Unidentified Gull	0.1		0.1	0.1	*		
Arctic Tern	0.6	*	0.2	0.4	0.1		
Common Murre				0.1	0.3		
Unidentified Murre	16.6	2.1	1.1	3.3	0.3	1.0	1.9

TABLE V-3 (continued)

	Birds/km^2						
Species	May	June	July	Aug.	Sept.	Oct.	Nov.
Pigeon Guillemot	0.3	0.1		0.1		*	
Unidentified Large Alcid				*	*		
Marbled Murrelet	0.1			0.1		*	
Kittlitz's Murrelet	*						*
Ancient Murrelet	0.3	0.2		0.1			
Unidentified Murrelet					*		
Cassin's Auklet	*		1.0		*	*	
Rhinoceros Auklet					*		
Unidentified Small Alcid	2.6	0.2	0.4	3.0	0.9	0.3	0.4
Horned Puffin	0.3	0.1	0.5	1.0	0.2	0.2	
Tufted Puffin	5.7	8.6	20.8	5.1	2.5	0.5	0.2
Savannah Sparrow					*		
Totals	63.6	21.4	50.6	44.8	84.1	33.3	11.3
Species #	24	15	19	23	22	20	16

Present in densities less than 0.1/km^2

Fig. V-3 Monthly abundance of birds on offshore waters around Kodiak Island. Data points are from Table V-5.



Shearwaters, as explained in the section on Lower Cook Inlet, breed in the southern hemisphere during austral summer and spend the boreal summer in the norther seas. In the Gulf of Alaska, the general pattern of their spring arrival, summer increase in abundance, and fall emigration probably is well illustrated by Lensink and Bartonek's (RU #337, Part I) shipboard survey data from Kodiak Basin (Fig. V-4).

Relative Abundance of Aquatic Birds in Winter

Surveys conducted by Kodiak National Wildlife Refuge personnel indicate that 90% to 94% of the swimming birds occurring in bays, lagoons, and coastal waters of Kodiak Island in January and February are anatids and alcids (Fig. V-5). The five most abundant species or species groups are: 1. Murres (2 species, 22% of total), 2. Crested auklets (21% of total), 3. oldsquaws (16% of total), 4. scoters (3 species, 13% of total), and 5. eiders (2 species, 12% of total). Mallards were the most abundant dabbling ducks present during the two sampling years, making up 90% of the dabblers and 3% of the total for all species (actual counts for all species are included in Table V-2).

Food Habits

Lensink, Bartonek, and Sanger (RU #341) have analyzed stomach contents of 83 marine birds collected in Alaskan waters. Their 83 specimens include four short-tailed shearwaters taken offshore of southern Kodiak Island in spring. One specimen contained mainly fish, another fish and squid, and two contained "other and unidentified" material (Lensink et al., loc. cit., p. 14). Nine out of ten specimens from other areas contained squid, compared to only one of four among the Kodiak specimens.

The three major categories of food items that Lensink et al. found in stomachs of four species of seabirds taken in Alaskan offshore waters are shown in Fig. V-6. The degree to which results can be generalized from area to area remains to be determined.

MARINE MAMMALS

Introduction

The marine mammal list for the Kodiak Island group and surrounding waters is essentially identical to that of the Lower Cook Inlet region (see Cook Inlet section and USDI 1974). Fur seals and the endangered gray whale are among key species of the Kodiak archipelago because their major migration route through the Gulf of Alaska passes offshore

Fig. V- 4 Seasonal density of shearwaters (all species) on offshore waters of Kodiak Basin. Data are from Table V-5. The curve has been smoothed by using a 3-point moving average and assuming zero birds present from December to March.

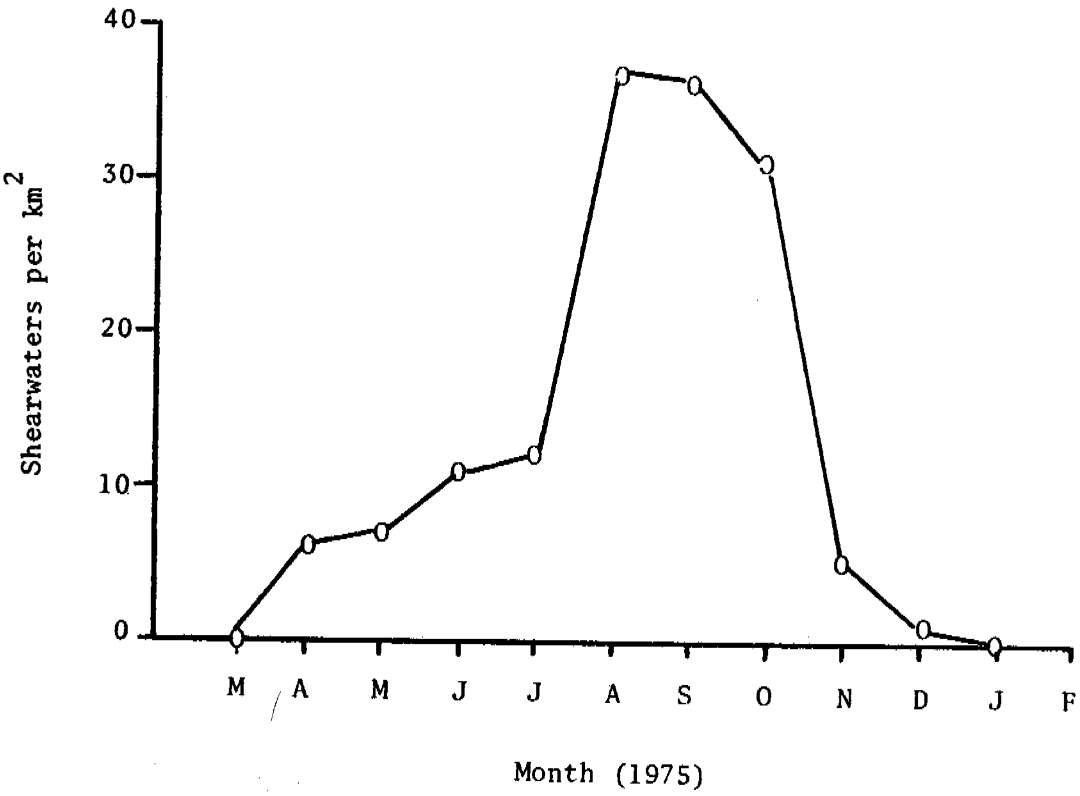


Fig. V- 5 Relative abundance of aquatic birds (grouped by family) on coastal waters of Kodiak Island in January-February of 1973 and 1975. Numbers for the two years are summed; range for the four largest groups in the two sample years is indicated by the vertical lines at bar tops. Data are from a table by Arneson (see Appendix I).

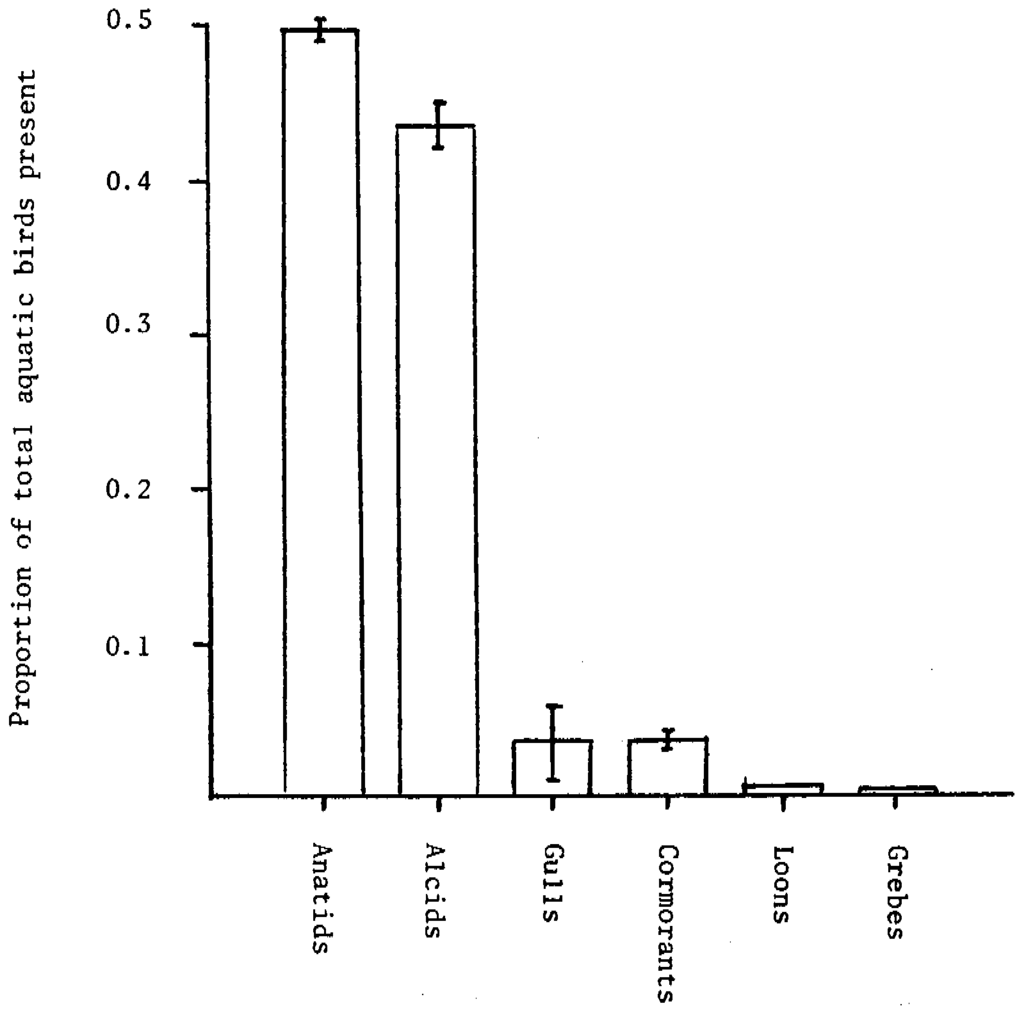
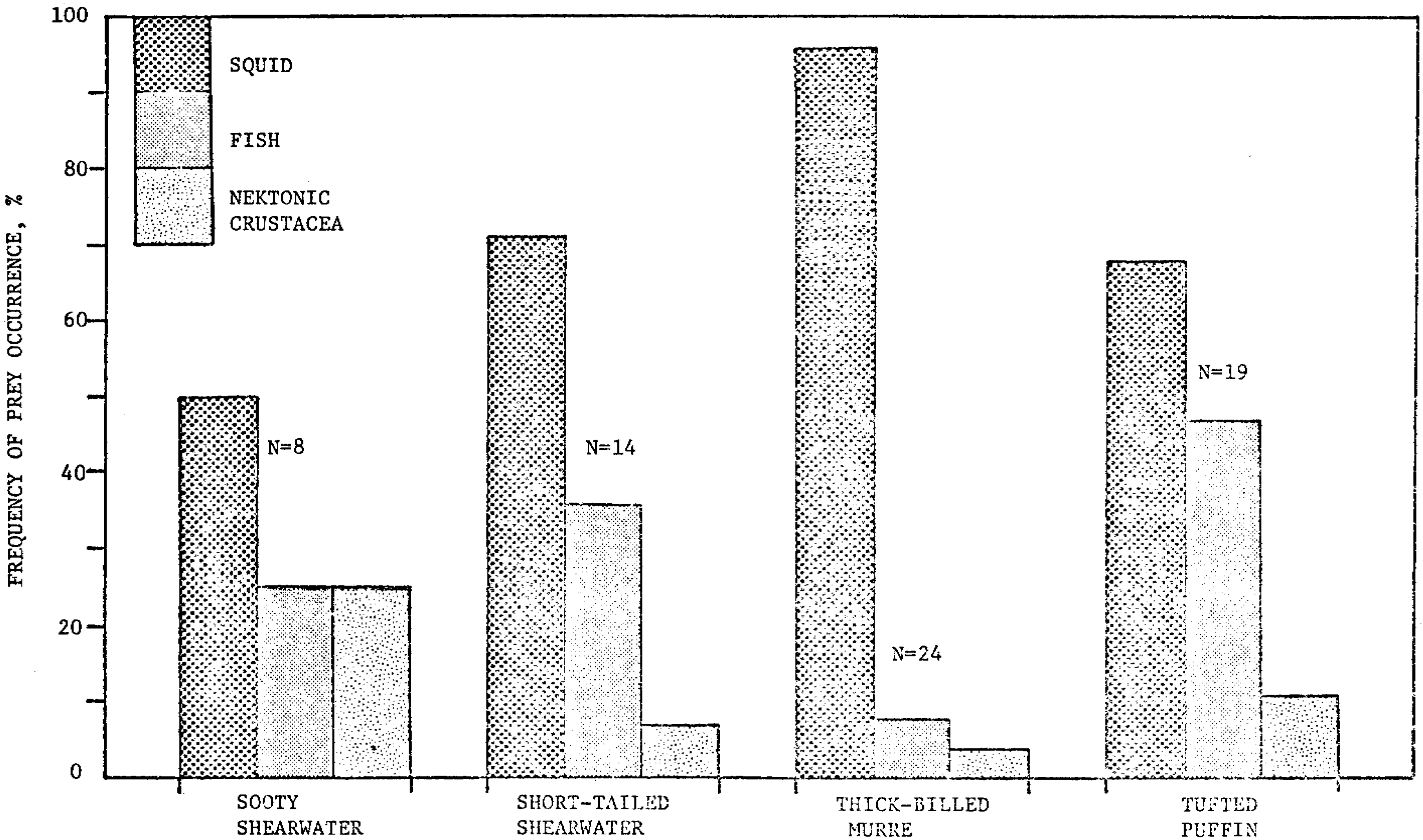


Fig. V-6. Frequency of occurrence of the three major prey categories in stomachs of four species of marine birds from Alaskan waters (copied directly from Lensink, Bartonek, and Sanger, RU #341 p 20). Of specimens represented here, only four (all short-tailed shearwaters) are from the Kodiak region (see text).



of eastern Kodiak (USDI 1974). Sea otters, Steller sea lions, and Harbor seals are of major importance because of their abundance and permanent residency in the archipelago. In addition to the gray whale, the following cetaceans reportedly are of common or moderately common occurrence around Kodiak: killer whale, Harbor porpoise, Dall's propoise, sperm whale, fin whale, sei whale, and minke whale. Other species of cetaceans occur but are rare in the area (USDI 1974:363).

Emphasis here is upon sea otters, Steller sea lions, and Harbor seals. OCSEAP field studies of these species in the Kodiak region are being conducted by Calkins and Pitcher (RU #243), Pitcher and Calkins (RU #229), and Schneider (RU #240). Background information on these and other species is presented in the Lower Cook Inlet section of this report.

Sea Otter

Schneider (RU #240) summarizes reports showing that sea otters occur throughout coastal areas of the Kodiak archipelago, from Shuyak Island in the north to the Trinity Islands in the south. Local concentrations vary from three to nearly 300 individuals and the total population of the Kodiak archipelago (including the Barren Islands) is estimated at "well over 2,000 animals" and appears to be rapidly expanding (Schneider loc. cit.). The most densely populated area is, according to Schneider, the north coast of Afognak Island between Ban and Marmot Islands. Productivity is high and Schneider anticipates large scale emigration into other parts of the archipelago over the next few years.

Steller Sea Lion

USDI (1974:356-357, 361; after ADFG) identifies 14 major congregating grounds, or "rookeries and hauling grounds," of Steller sea lions on the Kodiak-Afognak-Shuyak Island group. Total population of the 12 congregating grounds for which USDI (loc. cit.) presents data is 16,265 sea lions. Average size of the 12 aggregations is 1,355 animals (R = 50-10,000). The largest aggregations are on Marmot Island (10,000 animals) and Latax Rocks (3,500 animals). Calkins and Pitcher (RU #243) identify six additional "hauling areas" on Afognak and northern Kodiak Islands.

In October 1975, Pitcher and Calkins (RU #243) surveyed Afognak congregating grounds of Steller sea lions and found approximately 7,995 animals on Marmot Island, 625 on Sea Lion Rocks, and 625 on Latax Rocks. These numbers are lower than those reported by

USDI (above) perhaps because they were obtained in fall, after some dispersal from the breeding grounds.

In July 1975, Pitcher and Calkins (RU #243) marked (hot-branded) 600 Steller sea lion pups at the Marmot Island rookery. This will allow them in future years to study movements and dispersal of the marked animals.

Data on food habits, reproduction, and populations of Steller sea lions are considered in the section on Cook Inlet.

Harbor Seal

Harbor seals are distributed throughout coastal areas of the Kodiak archipelago, with notable concentrations at Tugidak Island, Sitkalidak Island, Ugak Bay, Cape Chiniak, Ugak Bay, Tonki Bay, Perenosa Bay, and Shuyak Island (USDI 1974:360). Pitcher and Calkins (RU #229, p. 10) identify additional concentrations on Marmot Island, Sea Lion Rocks, and Seal Bay.

Population estimates and Pitcher and Calkins (RU #229) data on food habits, growth, and reproduction of Harbor seals and sea lions are presented in the section on Cook Inlet.

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Chapter VI

EFFECTS

EFFECTS OF CONTAMINANTS ON MARINE ORGANISMS

The primary purpose of OCSEAP research on the effect of contaminants is to evaluate deleterious effects of oil contamination on selected marine organisms and their habitats. These studies generally encompass economically and ecologically important species of the Alaskan Outer Continental Shelf.

Rice and Karinen (RU #72) are measuring the acute and chronic effects of water soluble fractions of Cook Inlet crude oil, fuel oil, and selected oil fractions (e.g., benzene and naphthalene) on selected Arctic and sub-Arctic organisms. Chronic tests included observations on the growth rates, embryonic development, recovery, histopathological changes in various tissues, and behavior modification. In addition, hydrocarbon uptake, depuration, and metabolism of hydrocarbons will be determined.

Cooperative efforts will be conducted with Malins et al. (RU #73 and #74) to assess the sublethal effects of Prudhoe Bay crude oil fractions on structural and ultrastructural changes in internal tissues, perturbation of chemosensory systems of selected marine biota, sensitivity of life stages of molluscs and crustaceans, and changes in the physiochemical properties of mucus. These effects and others will be noted in response to accumulation, specific sites of accumulation, and the metabolic stability of accumulated aromatic hydrocarbons. Similar tests will be conducted on the effects of lead, cadmium, and vanadium contamination.

INVERTEBRATES

Few data have been gathered for the effects of crude oil and its water soluble fractions on Arctic and sub-Arctic species (Rice and Karinen, RU #72). Available effects data mostly concern adult life stages of temperate latitude species, Cancer Magister Dana (Caldwell, RU #183). which are generally more resistant to contaminants than the early life Data collected on temperate latitude species may be extrapolated to similar Arctic species, but a difficulty arises in that the history of pollution exposure varies between these geographic areas. Species indigenous to the Alaskan OCS have received little previous pollution stress and, as a result, may be less resistant than their counterparts at more southerly latitudes.

ACUTE EFFECTS

Initial studies with stage V larvae of Spot shrimp (Pandalus platyceros) indicate that naphthalene is acutely toxic (Malins et al., RU #74). Concentrations of 10 ppb naphthalene and naphthalene bound to bovine serum ablumin (BSA) caused 100% mortality in 36 hrs in Malins et al. (RU #74) studies. Rice and Karinen (RU #72) reported the 96 hr TL_{50} (the tolerance limit at which 50% of the test population will survive exposure to the specified concentration for 96 hrs) for Eualus sp. (shrimp) exposed to water soluble fractions of Cook Inlet crude oil was 0.11 and 0.206 ppm ultraviolet optical density (UVOD) at $4^{o}C$. The variability in survival was dependent upon the aromatic mix of the water soluble fraction of crude oil. (Although the UVOD was similar, gas chromatographic analysis revealed marked differences in the aromatic fractions.) The lowest 96 hr TL_{50} value was derived for the higher aromatic mix.

Rice and Karinen (RU #72) have found that 96 hr TL_{50} concentrations reported in the literature for various invertebrates may be excessive because of latent mortality. Using Stage IV Pink scallops (Chlamys sp.), they observed latent mortality for one to three weeks after the 96 hr test exposure had been terminated and the scallops were returned to fresh seawater. Since latent mortality was observed, Rice and Karinen (RU #72) contend that these deaths should be considered in computation of the 96 hr TL_{50}. If not, the 96 hr dose computed may be excessively high. Similar results were noted by Thatcher et al. (1975) in crayfish (Pacifastacus sp.) exposed to chlorine.

CHRONIC TOXICITY

Taylor et al. (RU #272, 1976) observed that the effect of Prudhoe Bay crude oil on the clam (Macoma balthica) was dependent on the degree of tidal mixing. In these studies few mortalities occurred, but the presence of water soluble fractions and oil contaminated sediments inhibited clam burrowing and caused the clams to move to the surface. The calculated dose at which 50% of the clams would respond by burrowing to the surface within three days is 0.436 ppm of naphthalene equivalents (static conditions). In a flow through system, the concentration at which 50% of the clams burrowed to the surface was calculated to be 0.367 ppm naphthalene equivalents. Although the clams did not die as the result of desiccation and subject the clams to increased predation.

Malins et al. (RU #74) found that starved Stage V Spot shrimp rapidly extract naphthalene and naphthalene BSA from the water, reaching maximum accumulations in 8 hrs. Although the level of accumulated naphthalene was higher than naphthalene BSA after 8 hrs, the quantity of metabolized naphthalene was the same. These investigators also noted, using carbon-14 labelled naphthalene, that shrimp exposed for 24 hrs to the naphthalene and then returned to fresh seawater, still retained one third of radioactive tracer five days later.

Rice and Karinen (RU #72) exposed spawning female King (Paralithodes sp.) and Tanner (Chionectes sp.) crabs for 24 hrs to water soluble fractions of Cook Inlet crude oil. Their preliminary findings indicate that the oil had little effect on the water hardening of the eggs or on the attachment of eggs to the pleopodal setae; however, development may be affected.

Although no concentrations were reported by Rice and Karinen (RU #72), water soluble fractions of Cook Inlet crude oil, benzene and naphthalene caused depression of juvenile King crab heart rate and oxygen consumption. Of the three oil fractions tests, benzene caused the most rapid decline in heart rate but the sublethal does of the water soluble fraction of crude oil resulted in the greater depression of heart activity. Maximum depression of heart activity, relative to the controls, was 52% for the water soluble fraction of Cook Inlet crude, 50% for benzene, and 20% for naphthalene. Juvenile crabs exposed to these products were returned to fresh seawater at the end of exposure period; generally all crabs recovered and the heart rate returned to normal.

Other sublethal effects being monitored by Rice and Karinen (RU #72) indicate that the growth rate of pink scallops may be reduced as the result of oil exposure.

FISH

Acute Toxicity

As with invertebrates, few data have been accumulated on the effects of crude oil on Arctic and sub-Arctic fish species. DeVries (RU #62) reported that the 96 hr TL_{50} for Saffron cod (Eleginus gracilis) exposed to water soluble fractions of Cook Inlet crude oil was 2.28 ppm as determined by infrared spectrometry (IR) and at 0.092 UVOD at 3^oC and 1.029 ppm IR and 0.034 UVOD at 8^oC. UVOD is indicative of the naphthalene equivalents or the level of the aromatic fraction. DeVries (RU #62) also reported that the 96 hr TL_{50} for

Arctic flounder (Liopsetta glacialis) was >3.6 ppm IR and >0.228 UVOD at $8^{o}C$.

Chronic Toxicity

Rice and Karinen (RU #72) noted that breathing rates of Pink salmon fry (Oncorphynchus gorbuscha) increased significantly during exposures to water soluble fractions of Cook Inlet crude oil as low as 30% of 96 hr TL_{50} as determined by UV spectroscopy.

Malins et al. found that Steelhead trout (Salmo gairdneri) fed Prudhoe Bay crude oil contaminated food (2.5mℓ oil/kg Oregon moist) for two wks had essentially no glycogen stores in the liver. This species, when fed oil contaminated food for 2.5 months, had a 70.5% weight gain as compared to 95.5% increase in weight of control fish. Glycogen reserves were depleted, i.e., only rarely was a cell found that contained glycogen; lipid reserves also decreased in the oil fed fish. Histological surveys showed no gross differences between g' ', skin, spleen, kidney, and gill tissues of control and oil fed fish. It was also found in this study that feeding Steelhead trout an average of 3.57 g of Prudhoe Bay crude oil over six months did not impair reproductive capabilities, based on egg fertilization and initial embryo development.

Exposure for two hrs, 24 hrs, and five days to water soluble fractions of Prudhoe Bay crude also caused reduction of glycogen and lipid reserves in Steelhead and English sole (Parophrys vetalus). The reduction of these energy reserves may reduce the organism's ability to survive stress conditions.

Carbon-14 labelled naphthalene was used by DeVries (RU #62) to observe uptake of petroleum fractions from the water by the sculpin (Megalocottus sp.). He noted that measurable levels of naphthalene had accumulated in various tissues after 3 hrs exposure to concentrations as low as 0.035 ppm (Table VI-1). Although significant amounts were found in the blood and brain tissues, most of the radioactive tracer was isolated in the liver. In an effort to define long term effects, DeVries (RU #62) is trying to determine if hydrocarbon accumulation and subsequent detoxification in the liver will affect the "antifreeze: production by the liver. No data are available on the effect of oil on this mechanism, but since the liver is the source of "antifreeze" production, interferences as noted by reduced glycogen reserves may also interfere in "antifreeze" synthesis. The loss of such a mechanism could be lethal to fish in the Arctic where winter water temperature drops below $0^{o}C$.

TABLE VI-1

Accumulation of C^{14}-naphthalene in various tissues of a 30 g *Megalocottus* after three hrs exposure to one microcurie of C^{14}-naphthalene in 1 ℓ of seawater. Comparisons were made between extractable radioactivity and total radioactivity in the tissue (from DeVries, RU #62).

Tissue	cpm/100 μℓ of 2.5 mℓ chloroform-methanol extract of 100 mg tissue	cpm/100 mg of solubilized tissue
White muscle	16	1,195
Gill	32	656
Kidney	30	865
Gut	70	1,500
Brain	55	2,329
Blood	30	2,361
Liver	1,314	29,000

These studies (Rice and Karinen, RU #72; Malins et al., RU #73 and #74; Caldwell, RU #183; DeVries, RU #62) are continuing to answer the questions as to what the effects of petroleum products on Arctic and sub-Arctic vertebrate and invertebrate species may be. Additional efforts are in progress analyzing the effects of oil on the roe of the Pacific herring (Clupea harengus pallasi), (Smith, RU #123) and the sea grass (Zostera marina) (Pearson, RU #305). Malins and Stansby (RU #75) are compiling a bibliography on the interactions and effects of oil in the environment. These references (over 1,500) will be critically reviewed and a summary written under 20 specific headings, e.g., interactions of oil and ice, effect of oil on biota, effect of sold temperatures on oil spills, drilling operations, weathering of oil, etc.

This study (Malins and Stansby, RU #75) will incorporate much of the known oil interaction data but, as to the effects on biota, species-to-species and site-to-site differences make extrapolation from temperature areas to the Arctic difficult. Tests with indigenous Arctic biota will provide data that typify the response under Arctic conditions or may validate extrapolations from non-Arctic species and waters.

SUMMARY

Dispersed crude oil interacts with both the air and water phases. The light end and/or low boiling point fractions readily dissipate into the atmosphere but are also the most water soluble of oil components. Once in the aqueous phase short-chain aliphatics may be degraded by microorganisms. From the data presented, it is evident that these fractions are also the most toxic. Although most hydrocarbon fractions are only slightly soluble in water, increased agitation by waves or dispersants can induce the oil into the water column either as solutes or finely dispersed globules. In either case, planktonic or pelagic species may contact these pollutants. The effects produced may be directly lethal, sublethal, or behavioral.

Planktonic larvae, usually the most sensitive life stages, may encounter toxic levels of soluble fractions in the near surface waters. Deep water dwelling adults may be influenced by settling fractions that cause smothering or may be dispersed to areas remote from the petroleum contamination. Acutely toxic levels are rarely encountered, but behavioral responses to low level contamination may disperse organisms into a hazardous predator-prey environment and ecological death. Nearshore and intertidal species may encounter toxic levels resulting from increased agitation by waves or smothering by deposits of crudes remaining after tidal and storm surge retreats.

In conjunction with these laboratory analyses Malins and Stansby (RU #75) are critically evaluating the literature on the effects of oil in the environment.

DeVries (RU #62) is determining the acute effects of Prudhoe Bay crude fractions on various Arctic fish and the effect of oil on survival mechanisms of these fish at freezing temperatures. He proposes to develop the "antifreeze" mechanism as a model for determining sublethal oil toxicity and the fish's ability to survive these doses in the Arctic.

Acute effects on herring roe (Smith, RU #123), Dungeness crab larvae (Caldwell, RU #183) and seagrass (Pearson, RU #305) are also being determined. Some chronic toxicity tests will also be conducted on these organisms.

In all of these toxicity tests, toxicant exposure will be conducted under static or flow-through conditions with oil concentrations in the water analyzed at regular intervals. Since the oil fractions of most concern are the water soluble aliphatics and the mono- and dinuclear aromatics, infrared and ultraviolet spectrometry are being used routinely to

measure hydrocarbons extracted from water and biota tissue. Radioactive tracers, e.g., carbon-14 naphthalene, are also being used to identify sites of accumulation in organism tissues.

Most test species are being collected near Auke Bay, Alaska, but additional test species are being collected from Norton and Prince William Sounds. Some specimens are also taken from Yaquina Bay, Oregon and Puget Sound, and from laboratory reared stocks.

EFFECTS OF CRUDE OIL ON MICROBIAL ACTIVITY

Morita and Griffiths (RU #190) initially assessed the effects of petroleum contamination on Beaufort Sea microorganisms. Their efforts have been summarized in this report under Beaufort Sea-Effects. Comparable studies are being extended to the microflora of the Gulf of Alaska.

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SECTION 4

NORTHEAST GULF OF ALASKA: ENVIRONMENT, BIOTA, AND POTENTIAL PROBLEMS RELATED TO OIL EXPLORATION

A Scientific Report Based Primarily on
OCSEAP-Sponsored Research

CONTENTS

Chapter I

ENVIRONMENT

DESCRIPTION OF STUDY AREA

The Gulf of Alaska is considered to extend southward from the Alaskan coast to a line along the 54°N latitude from Dixon Entrance to Unimak Pass. The Kenai-Chugach Mountains border the north coast of the Gulf. The rugged, east-trending ridges and massive mountain peaks are separated by a network of narrow valleys and passes. Vast icefields and valley glaciers persist throughout the area. To the southeast of the Chugach Mountains are the St. Elias Mountains with peaks rising to 5,800 m. They are largely ice covered and are drained by extensive valley glaciers. Many fiords extend into the southeast coast of Alaska creating a very jagged coastline.

The shoreline along the southeast gulf is primarily rocky and deeply incised with numerous glacial fiords and rocky islands. East of Prince William Sound to Yakutat Bay the shoreline is characterized by wave-washed beaches and heavy sedimentation from glacier-fed streams. A prominent feature of the area is the Copper River delta and a barrier island chain dominated on the ocean side by wave-washed beaches.

SHELF GEOLOGY

The continental shelf in this area ranges in width from 13 to 105 km, with the widest point just north of the Kodiak Island group. The shelf topography consists of a series of broad plateaus interrupted by banks and shoals such as

Fairweather Ground, Middleton Platform, and Tarr Bank which range in depths from 37 to 100 m. The shelf also contains a number of clearly defined submarine valleys, probably of glacial origin. The continental slope is extremely steep, descending to 4,000 m east of Kayak Island on to 4,500 m to the west.

The main sediment source in the northern part of the Gulf is the Copper River which annually supplies an estimated 107 x 10^6 metric tons of sedimentary material (Reimnitz, 1966). Suspended sediment is supplied by the Bering and Malaspina piedmont glaciers and, to a lesser degree, by north winds funneling silt seaward through the copper River Gorge (Molnia and Carlson, RU #212).

Sediments supplied by rivers, glacial runoff, or wind are subject to transport by nearshore currents; much of the Copper River sediment is carried into the Prince William Sound through channels east and west of Hinchinbrook Island. Sediments which are part of the Bering Glacier runoff plume are carried around Kayak Island.

CLIMATE

Climate in the area is influenced by the arcuate mountain barrier of the Alaska and coastal ranges and the waters of the Gulf of Alaska. The more polar continental climate of the northern coast contrasts with the warmer winter and cooler summer temperatures of the southern coast. Annual precipitation increases gradually from west to east, and heavy snowfall and frequent rain result in an average yearly precipitation of over 250 cm in coastal areas. Typical weather consists of high humidity, precipitation, clouds, and fog. During winter there is an extreme outflow of cold continental air masses causing an unstable air-sea temperature difference of approximately 8°C (Galt 1975). This condition results in an intense air-sea heat exchange, providing frequent storms. Storm waves as high as 9 m have been reported.

Open water areas are generally free of ice, except in protected coastal waters where sheet ice forms during winter. Calving of coastal and fiord glaciers cause occasional icebergs.in the in the eastern Gulf.

CIRCULATION

Circulation in the Gulf of Alaska is dominated by the relatively warm Alaska Current flowing counterclockwise, roughly paralleling the coastline. In the eastern segment of the region from Yakutat to Cape St. Elias, where the shelf is narrow, the current flows near the shelf break and follows the 150 m isobath.

In the western segment of the region (Cape St. Elias to Seward), the relatively wide shelf behind Middleton Island is not influenced significantly by this flow. The currents in this region are affected by local winds, shelf topography, and freshwater discharge from the Copper River.

Tides in this area are a mixed, semi-diurnal type with marked diurnal inequality. They have a considerable influence on water circulation, especially within estuaries and between island passes. When coupled with the influence of the frequent winter storms in the Gulf they create a major hazard in the shallow island straits (Searby 1969).

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Chater II

SOURCES

Introductory statements may be found in the BRISTOL BAY/BERING SEA, KODIAK, and LOWER COOK INLET sections of this report.

C_1-C_4 HYDROCARBONS

Cline and Feely (RU #153) have stated that light molecular weight hydrocarbons (LMWH) are useful indicators of petroleum contamination, due to their high solubility and low natural abundance. These investigators have shown the spatial variations of LMWH in the northeast Gulf of Alaska, including Prince William Sound. Methane concentrations in the near-surface waters were rarely below 100 nℓ/ℓ except at stations seaward of the shelf break (Fig. II-1). The highest surface concentration (250 nℓ/ℓ) was noted in the area of Kayak Island. In the near-bottom samples, the methane content was never lower than 200 nℓ/ℓ, with a maximum of 1,577 nℓ/ℓ recorded south and east of Hinchinbrook and Montague Islands (Fig. II-2). The data illustrated (Fig. II-2) also show that a plume of high methane concentration near the bottom apparently moves eastward away from Montague Island under the plume of the Copper River in response to estuarine circulation. Since no sediment samples were collected, the source of this high concentration of methane is not known; however, Cline and Feely (RU #153) believe it does not originate in Prince William Sound.

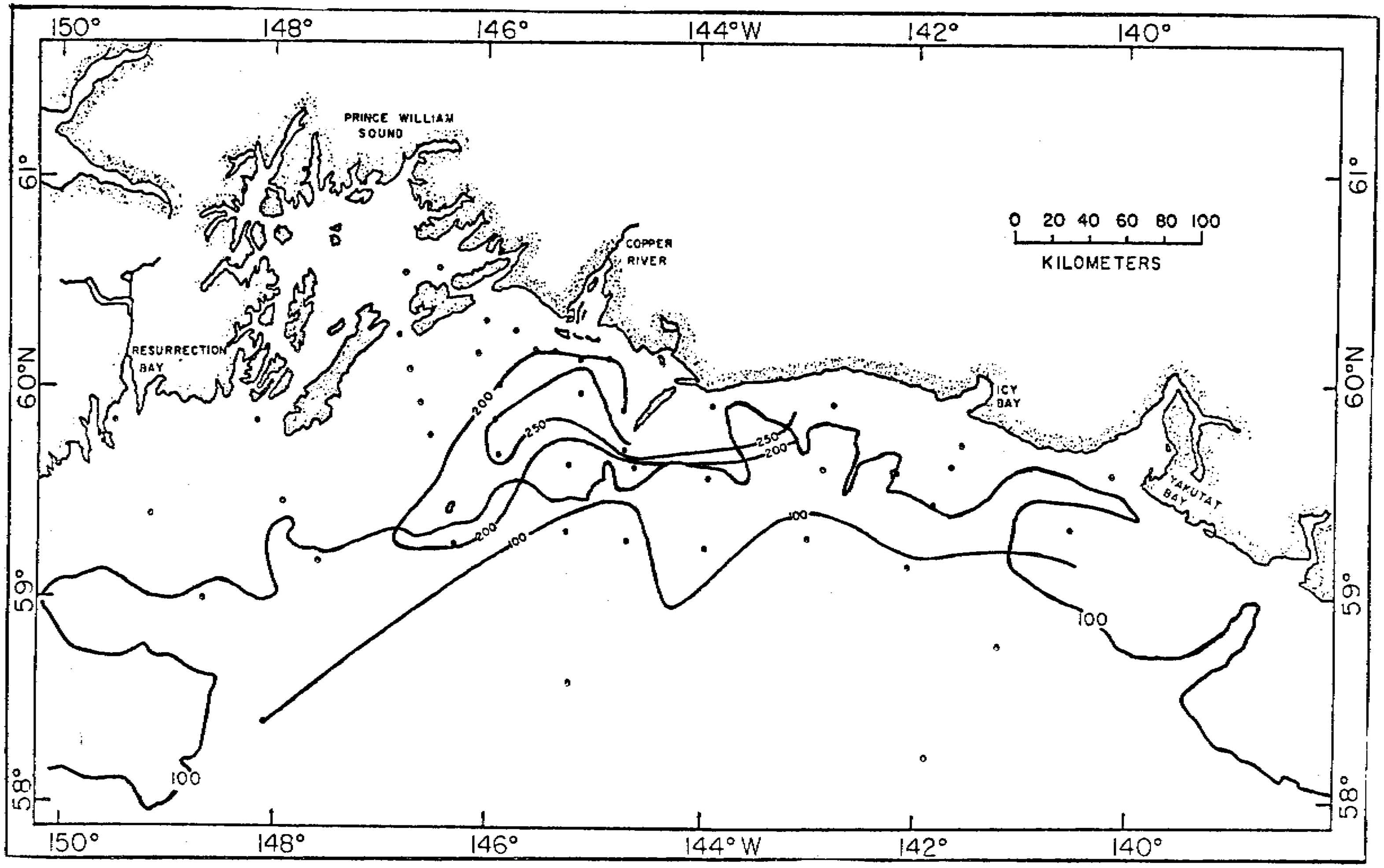

Fig. II-1. Surface distribution of methane in the northeast Gulf of Alaska during October-November 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

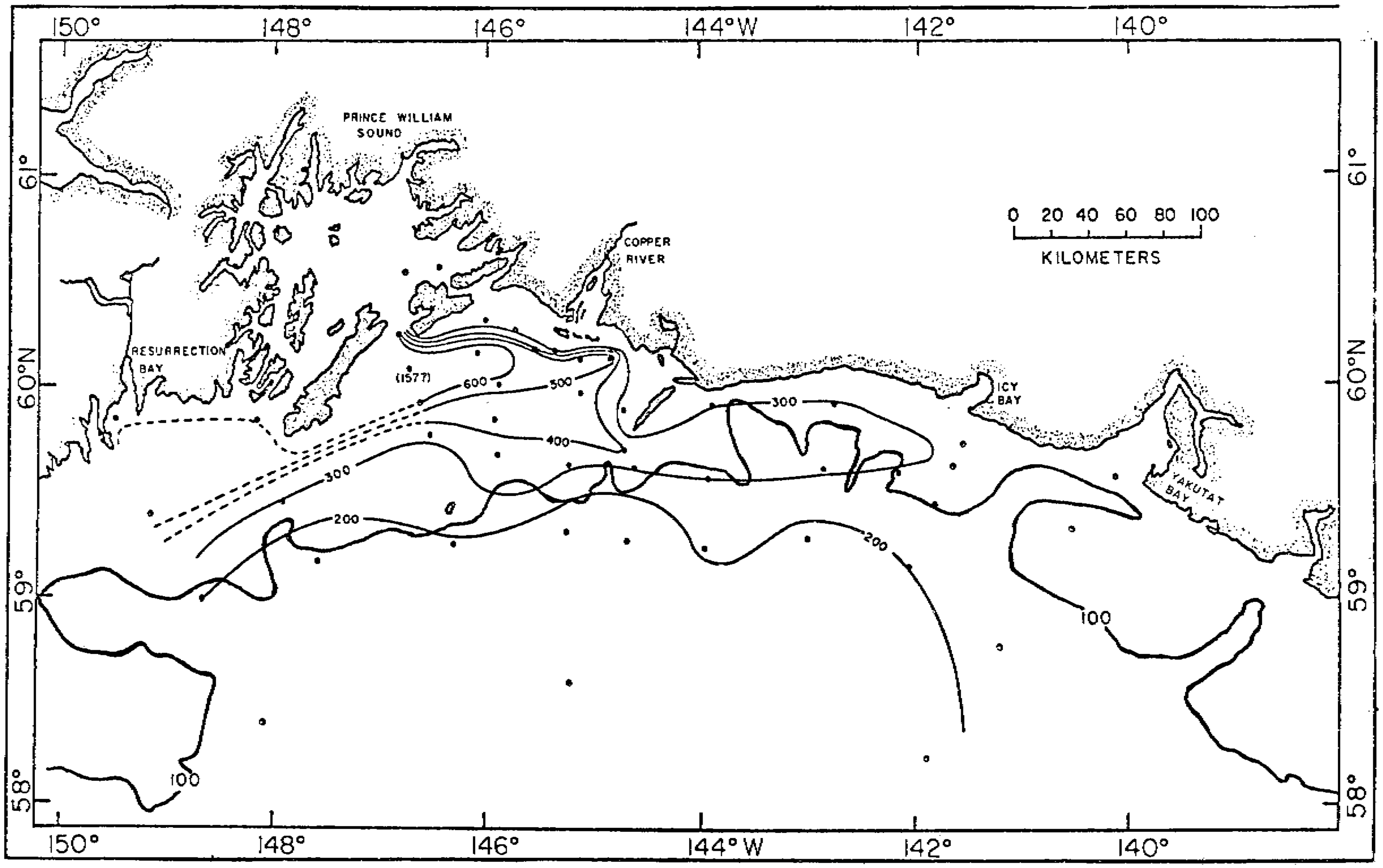

Fig. II-2. Areal distribution of methane 5 m from the bottom in the northeast Gulf of Alaska during October-November 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

There is very little spatial variation in the near-surface and -bottom ethane concentrations (Figs. II-3 and II-4). Surface water concentrations of ethane averaged 0.3 ± 0.2 nℓ/ℓ. West of Kayak Island, Cline and Feely (RU #153) noted an exceptionally high ethane concentration (1.4 nℓ/ℓ). The significance of this high concentration is not known. In general, the near-bottom concentrations of ethane were higher than those recorded in the surface waters. Average near-bottom concentration was 0.5 ± 0.2 nℓ/ℓ but ethane levels of 1.0 and 1.1 nℓ/ℓ were measured west-southwest of Kayak Island near the 180 m isobath (Fig. II-4). Relatively high values of ethane were also noted over the shelf south of Resurrection Bay. The source and the significance of the above average concentrations are not known at this time.

Ethylene levels in the near-surface and -bottom waters were generally higher and more variable than ethane. Concentrations at the surface averaged 0.7 ± 0.2 nℓ/ℓ and 1.1 ± 0.3 nℓ/ℓ near the bottom. Cline and Feely (RU #153) also noted that the highest levels in the near-bottom waters occurred generally in shallow shelf regions, particularly in areas of the Copper River, Kayak Island, and south of Prince William Sound (Fig. II-5).

Surface water concentrations of propane showed little variation and averaged 0.2 ± 0.1 nℓ/ℓ; however, south and west of Kayak Island, the surface levels ranged from 0.3 to 0.4 nℓ/ℓ. Near-bottom propane concentrations averaged 0.2 ± 0.04 nℓ/ℓ and little spatial variation was noted (Fig. II-6). In contrast to the near-surface waters, the elevated concentrations noted near Kayak Island were not observed in water samples collected near the bottom.

Propylene, n-butane, and iso-butane concentrations in the water were also measured. In general, these LMWH were at or below the detection limit

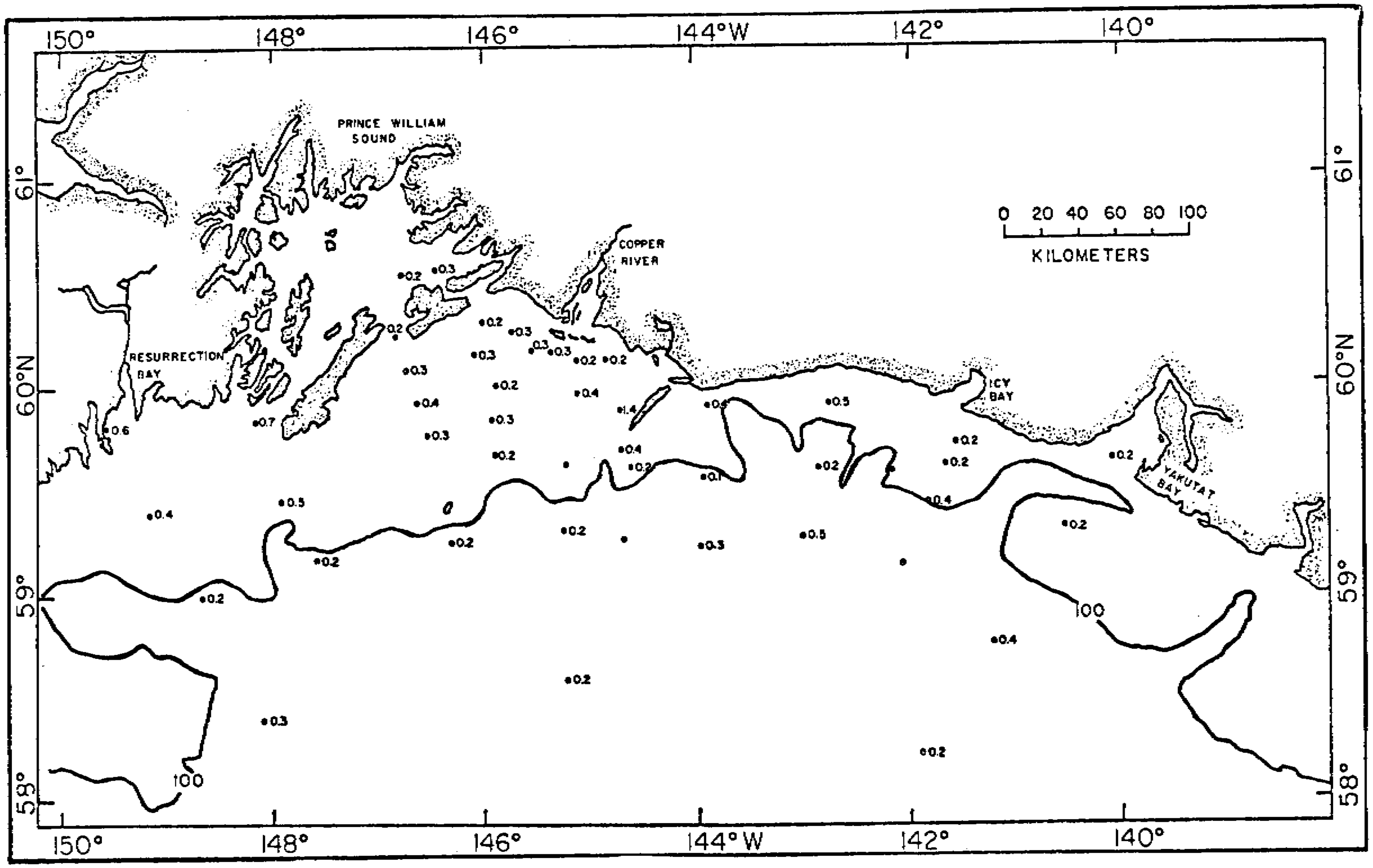

Fig. II-3. Surface distribution of ethane in the northeast Gulf of Alaska during October-November 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

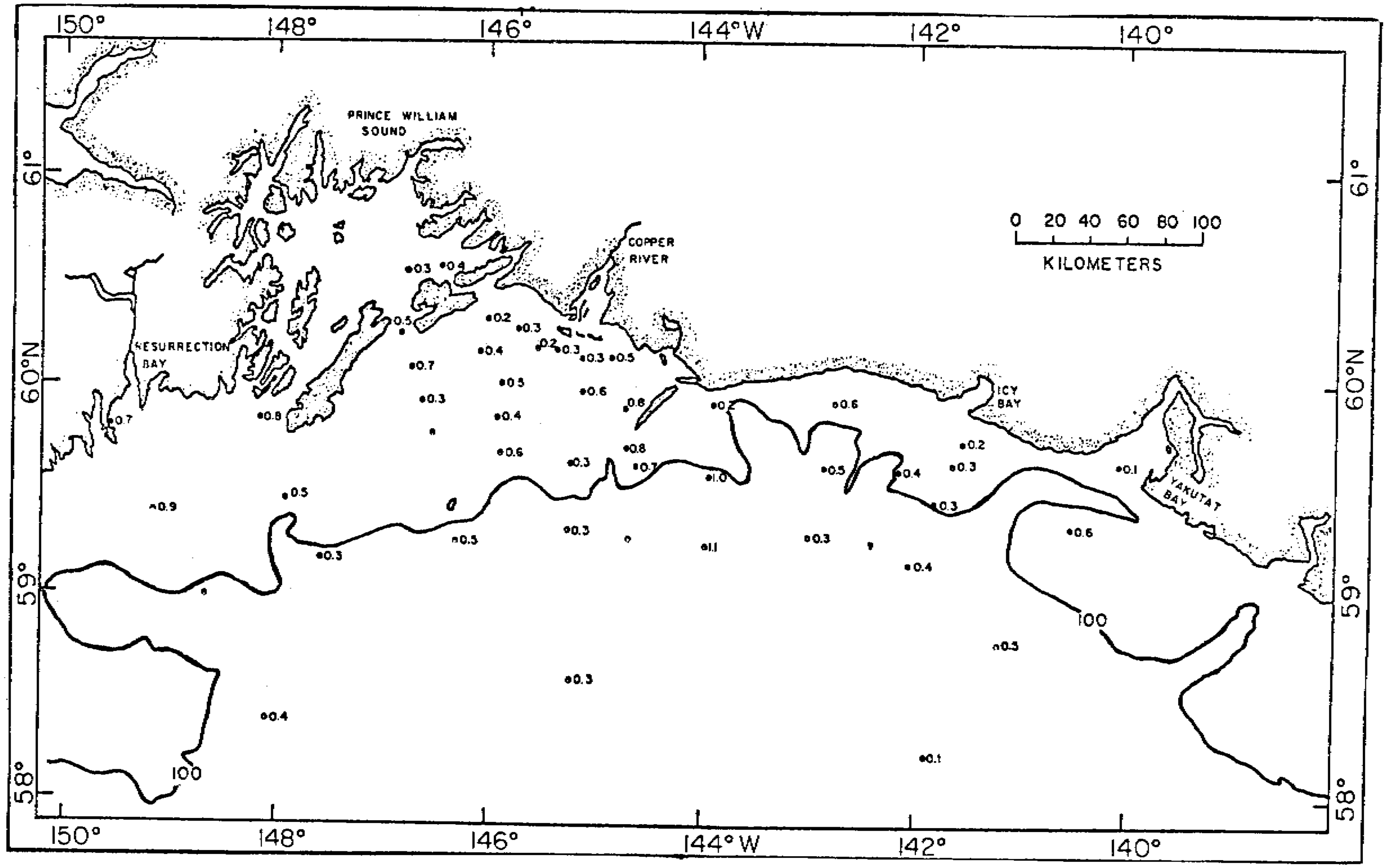

Fig. II-4. Areal distribution of ethane 5 m from the bottom in the northeast Gulf of Alaska during October-November 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

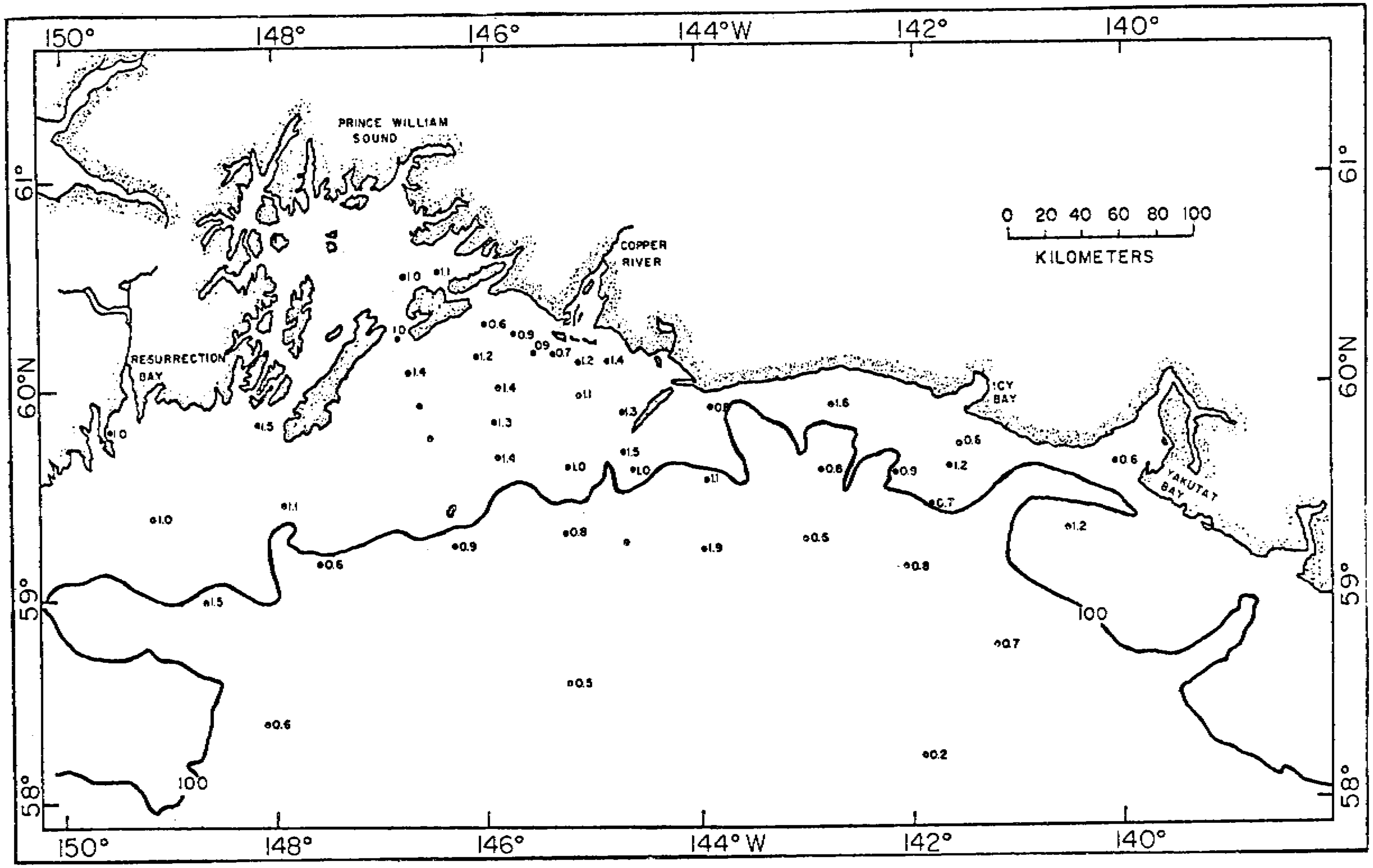

Fig. II-5. Areal distribution of ethylene 5 m from the bottom in the northeast Gulf of Alaska during October-November 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

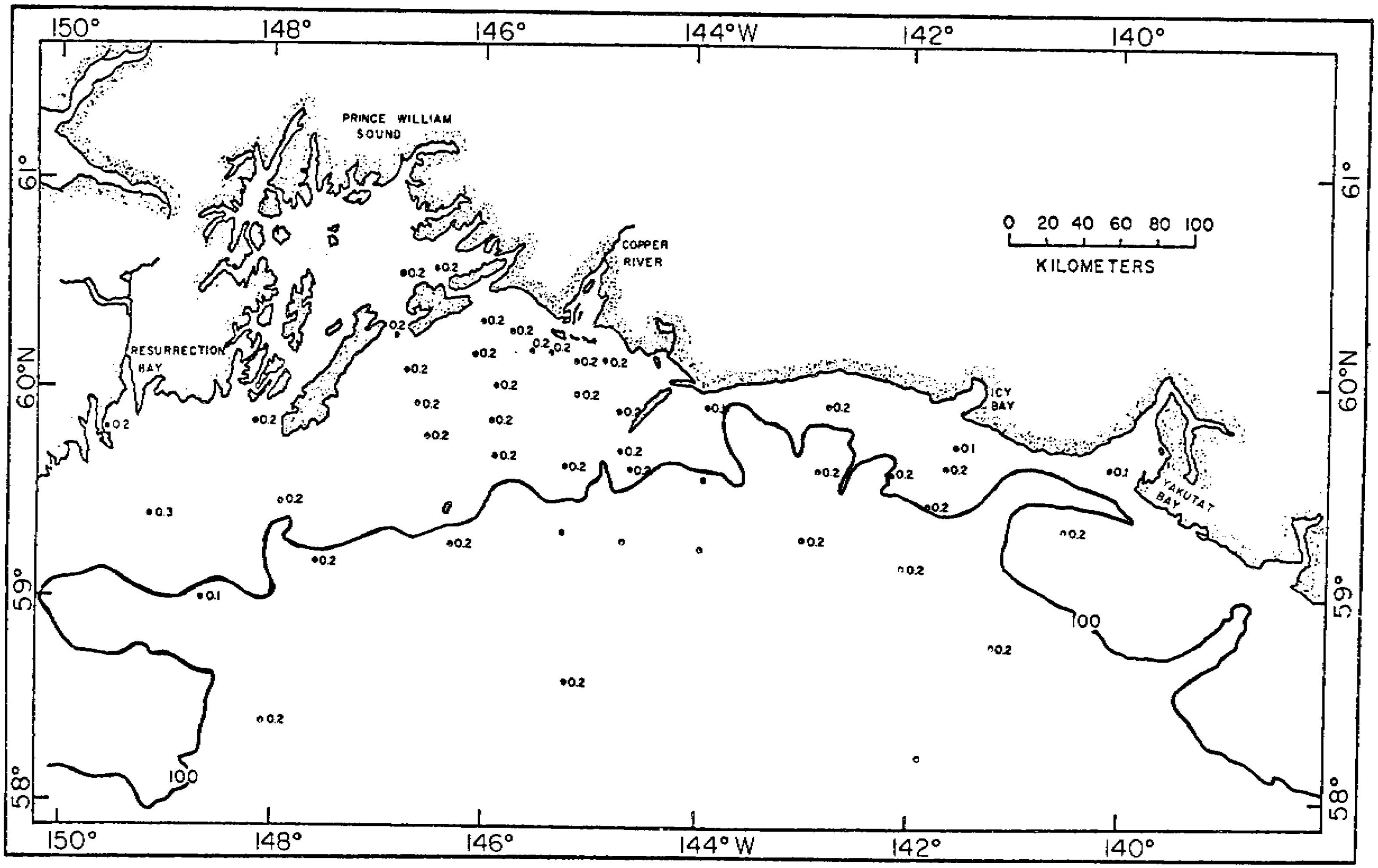

Fig. II-6. Areal distribution of propane 5 m from the bottom in the northeast Gulf of Alaska during October-November 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

of the gas chromatographic method used. Measurable quantities of propylene were noted west and south of Kayak Island and the levels ranged from 0.2 to 0.3 nℓ/ℓ. Even though propane-propylene discrimination was difficult, Cline and Feely (RU #153) noted that propylene was uniformly low throughout the region. They postulate from Lamontagne et al. (1973) that the low propylene concentrations were due to the season of the year (fall) and the corresponding reduction in photosynthetic activity.

Cline and Feely (RU #153) also conducted time series and vertical distribution studies on concentration changes in LMWH. Two stations were selected for time series studies: Station 046 located south of Hinchinbrook Entrance on Tarr Bank and Station 062 sited southwest of Icy Bay near the 180 m isobath. Data illustrated in Fig. II-7 for Station 046 show little variation at the surface, but an 8 hr periodicity with asymmetrical amplitude was noted in the near-bottom methane levels. Surface methane concentration variability at Station 062 was similar to the variation noted at Station 046; however, the bottom values at Station 062 were less variable. Since the time series could not be conducted for longer periods and the tidal and current data have not been fully analyzed, probable causes of this variability were not defined.

Vertical profiles of LMWH at Station 021, located south of Kayak Island near the 180 m isobath, and at Station 045, located south of Hinchinbrook Entrance are shown in Fig. II-8. At both stations the concentrations of methane, ethane, and ethylene increased with depth. Propane levels were similar throughout the water column. A mid-water high of methane and ethylene was recorded at 100 m at Station 021. This peak is possibly due to lateral advection of hydrocarbon-rich waters or possibly due to intense biological activity at the 100 m depth.

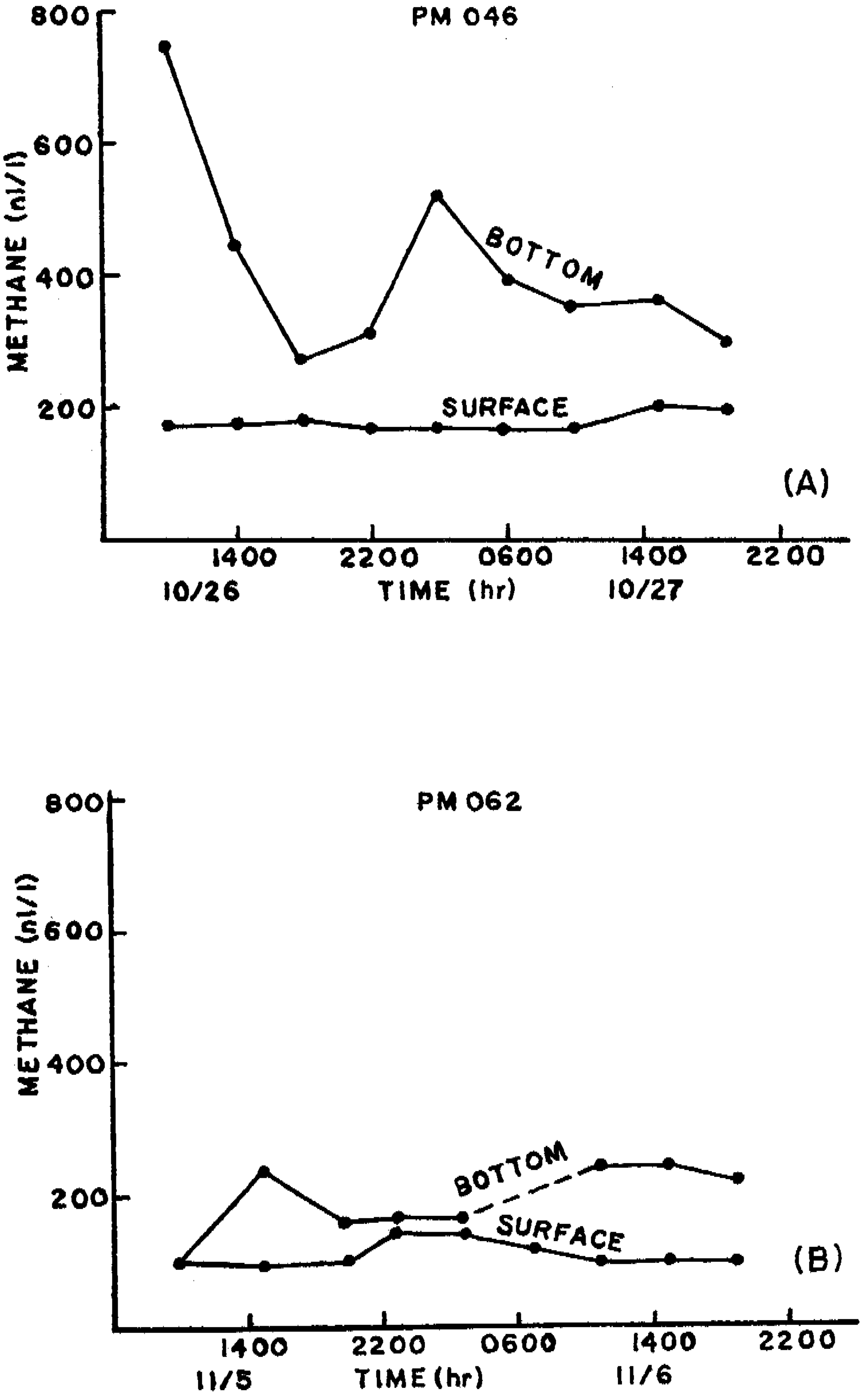

Fig. II-7. Diurnal variations in the concentration of methane at the surface and 5 m from the bottom at stations PM 046 (A) and PM 062 (B). Observations were conducted in the northeast Gulf of Alaska during October-November 1975 (from Cline and Feely, RU #153).

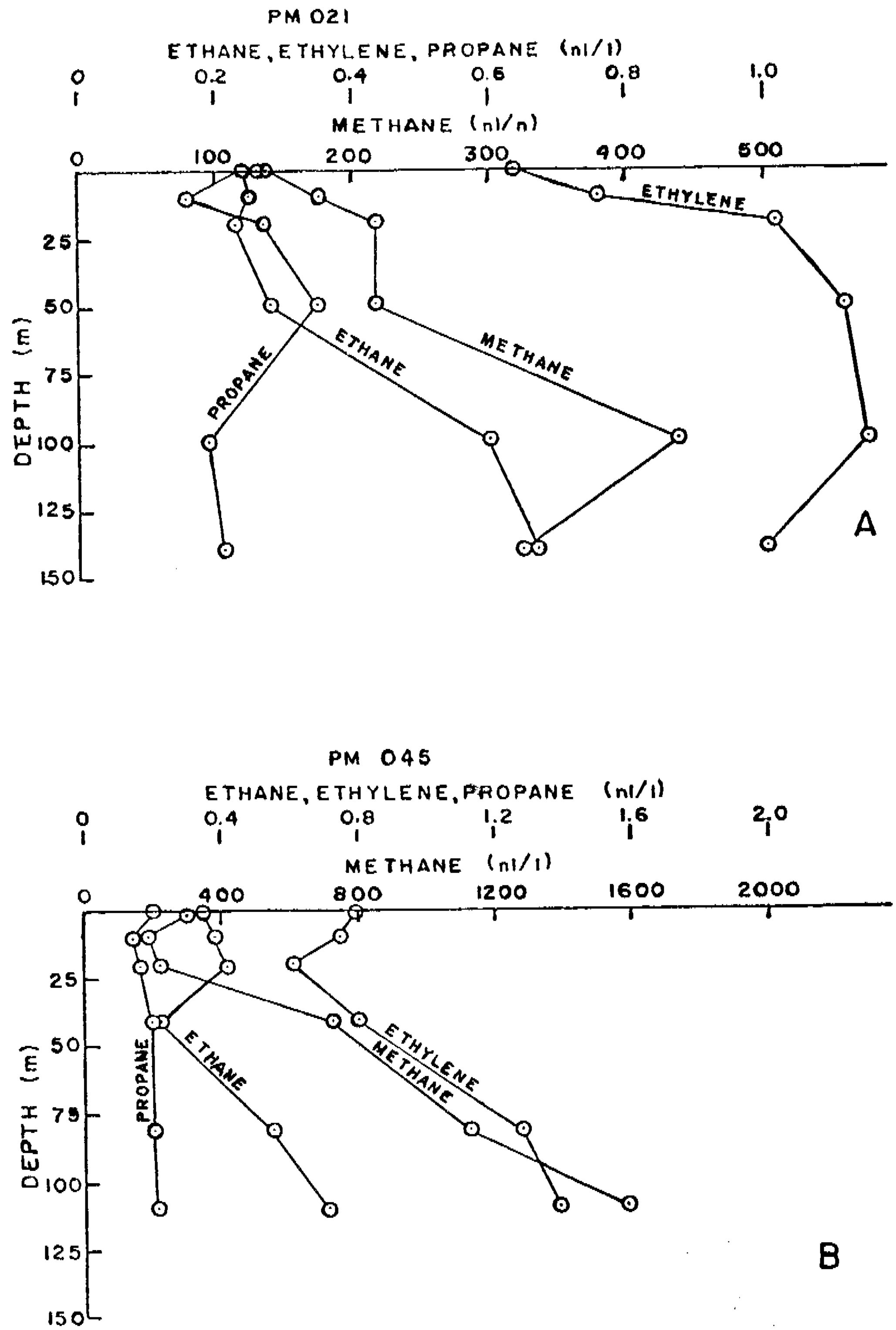

Fig. II-8. Vertical distributions of methane, ethane, ethylene, and propane at two stations in the northeast Gulf of Alaska, PM 021 (A) and PM 045 (B). Observations were conducted during October-November 1975 (from Cline and Feely, RU #153).

No data have been reported on the LMWH concentration in the sediments of the northeastern Gulf; however, a discussion of LMWH in sediment can be found in the KODIAK ISLAND and BERING SEA-Sources sections of this report.

In summary, it should be noted that Cline and Feely (RU #153), although detecting major LMWH concentrations near Kayak Island, did not identify any natural petroleum or gas seepage. Correlation analyses also indicated that ethane, ethylene, and methane originate from common sources, most likely biogenic.

OTHER HYDROCARBONS

In the northeast Gulf Shaw (RU #275), in cooperation with Kaplan (RU #275 subcontract), sampled the shelf area from Yakutat Bay to Resurrection Bay, including Prince William Sound. Sediment samples analyzed by Kaplan (RU #275) contained from 140 to 200 ppm extractable component. The paraffinic content of the extracted component ranged from 2 to 8 ppm. Kaplan (RU #275) also reports that the distribution pattern of saturated hydrocarbons showed no pristane or phytane, or n-alkanes lighter than C_{19} (Table II-1). He also concludes that based on an odd/even carbon number ratio >1 and the presence of hydrocarbons $>C_{27}$, the hydrocarbon distribution pattern results from a mixture of planktonic and terrestrial plant derived material. There was no evidence that the hydrocarbons identified originated from petroleum sources.

Additional discussion of hydrocarbon levels in the Gulf of Alaska is presented in the KODIAK ISLAND-Sources section of this report.

MICROBIOLOGY

Microbial Abundance and Degradation of Crude Oil

OCSEAP-related research on microbial abundance in the Gulf of Alaska has been centered in the western Gulf. Related research on possible microbial abundance

TABLE II-1

GAS CHROMATOGRAPHIC DATA - High Molecular Weight Hydrocarbons
(from Kaplan, RU #275)

COMPOUND	CONCENTRATION (μg/g dry sediment)						
	GASS 41	GASS 43	GASS 50	GASS 51	GASS 52	GASS 55	PWS 107
nC_{15}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nC_{16}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nC_{17}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pristane	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nC_{18}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phytane	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nC_{19}	0.0	0.0	0.043	0.067	0.0	0.0	0.425
nC_{20}	0.0	0.060	0.199	0.327	0.329	0.462	0.713
nC_{21}	0.110	0.163	0.574	0.394	0.966	0.996	0.406
nC_{22}	0.438	0.322	0.737	0.628	1.269	1.393	0.765
nC_{23}	0.531	0.432	0.724	0.641	1.362	1.438	1.083
nC_{24}	0.523	0.207	0.557	0.505	0.365	1.119	0.117
nC_{25}	0.702	0.201	0.727	0.463	0.368	1.338	0.149
nC_{26}	0.671	0.152	0.582	0.376	0.230	0.759	0.088
nC_{27}	0.790	0.189	0.499	0.449	0.412	0.245	0.233
nC_{28}	0.715	0.134	0.460	0.423	0.247	0.213	0.069
nC_{29}	0.984	0.187	0.758	0.415	0.138	0.248	0.194
nC_{30}	0.573	0.077	0.541	0.166	0.095	0.082	0.045
nC_{31}	0.499	0.083	0.394	0.160	0.171	0.094	0.134
nC_{32}	0.052	0.0	0.0	0.0	0.0	0.0	0.0
Total n-Alkanes	6.588	2.206	6.795	5.014	5.952	8.387	4.421
Odd/Even Ratio	1.217	1.230	1.195	1.923	1.348	1.082	1.223
Total Isoprenoid	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Major Peak	nC_{29}	nC_{23}	nC_{29}	nC_{23}	nC_{23}	nC_{23}	nC_{23}
Pristane/Phytane	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nC_{17}/Pristane	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nC_{18}/Phytane	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unresolved background	0.70%	88.6%	77.19%	80.8%	46.5%	45.9%	64.3%

and petroleum degradation, is discussed in the KODIAK ISLAND-Sources section of this report.

Health Status of Demersal Fish

McCain and Wellings (RU #332) proposed to determine the incidence of chronic disease in Gulf of Alaska, Bering Sea, and Beaufort Sea fish. To date, their reports have only included data on disease incidence in the Bering Sea. Since most of the diseases reported for the Bering Sea are found in the North Pacific, a discussion of the related research may be found in the BERING SEA-Sources section of this report.

HEAVY METALS

The discussion of the heavy metal research in the Gulf of Alaska sponsored by NOAA/OCSEAP has been discussed in the COOK INLET and KODIAK ISLAND-Source sections of this report.

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Chapter III

HAZARDS

GEOLOGIC AND SEISMIC HAZARDS

The Northeast Gulf of Alaska lies within the Gulf of Alaska Tertiary Province. This province includes Tertiary rocks exposed along the mainland coast and their presumed offshore extensions, and extends westward 998 km from Cross Sound to about 148°W longitude. Tectonic and glacial influences are reflected in the extremely irregular and rugged topography of the coastal zone. Several peaks of the coastal ranges exceed 3,000 m, with Mt. St. Elias exceeding 5,486 m only 32 km from the coast. Extensive ice fields cover the crest of the Chugach/St. Elias Mountains, and in some areas extend down onto the coastal plain. Fiords incise the coastline and are often deeper than the inner continental shelf. The continental shelf is incised in several areas by sea valleys and canyons. Nearshore bottom topography is highly irregular, a result of submerged moraines and other glacial landforms. In other areas, e.g., where the Copper River discharges, deltaic sedimentation predominates.

The NEGOA coastal zone includes a chenier-like plain marked by longitudinal beach and dune ridges backed by marine terraces that rise as high as 244 m above sea level. The plain is crossed by braided outwash streams heavily laden with glacial silt which empty into the northeastern Gulf of Alaska. In other areas, glacial moraines extend onto or across the plain.

The NEGOA continental shelf area includes 51,800 km^2 with maximum water depth of 200 m. Shelf width increases from 13 km on the eastern margin to 105 km at the western end. For the most part, except near shore where moraines are present, the topography of the shelf is gently undulating with well-defined submarine canyons and valleys. Prominent shallow areas include Fairweather Ground, Middleton Platform, and Tarr Bank.

SEISMICITY

The NEGOA lease area lies within an active seismic belt, making development susceptible to earthquake hazards. Underthrusting of the Pacific Plate beneath the North American Plate is the cause for the seismicity. Hundreds of seismic events have been recorded within the northeast Gulf of Alaska since 1899 (Fig. III-1, Meyers, RU #352) with ten of these in the lease area having magnitudes exceeding 5.99 on the 1931 Modified Mercalli Intensity Scale (Fig. III-2, Meyers, RU #352). Such high magnitude earthquakes in the area cannot be considered a rare phenomenon. The susceptibility of the region to severe earthquake damage is evident from the events of the great 1964 Alaskan earthquake at Cordova, Valdez, and on the Copper River Delta (Reimnitz 1972; Reimnitz and Marshall 1965). This earthquake, with a magnitude of 8.4, resulted in a 2 m uplift at Cordova. Prince William Sound and the Yakutat area experienced local uplifts exceeding 10 m; and the Copper River Delta may have been uplifted as much as 3.5 m with severe damage where sediments were thick. At Valdez large areas of the dock area slipped into the bay as liquefaction of underlying sediments resulted from the shock wave. The Yakutat area had experienced an earlier earthquake of magnitude 8 about]900 (Lahr and Page, RU #210). Because of the historic record of seismic

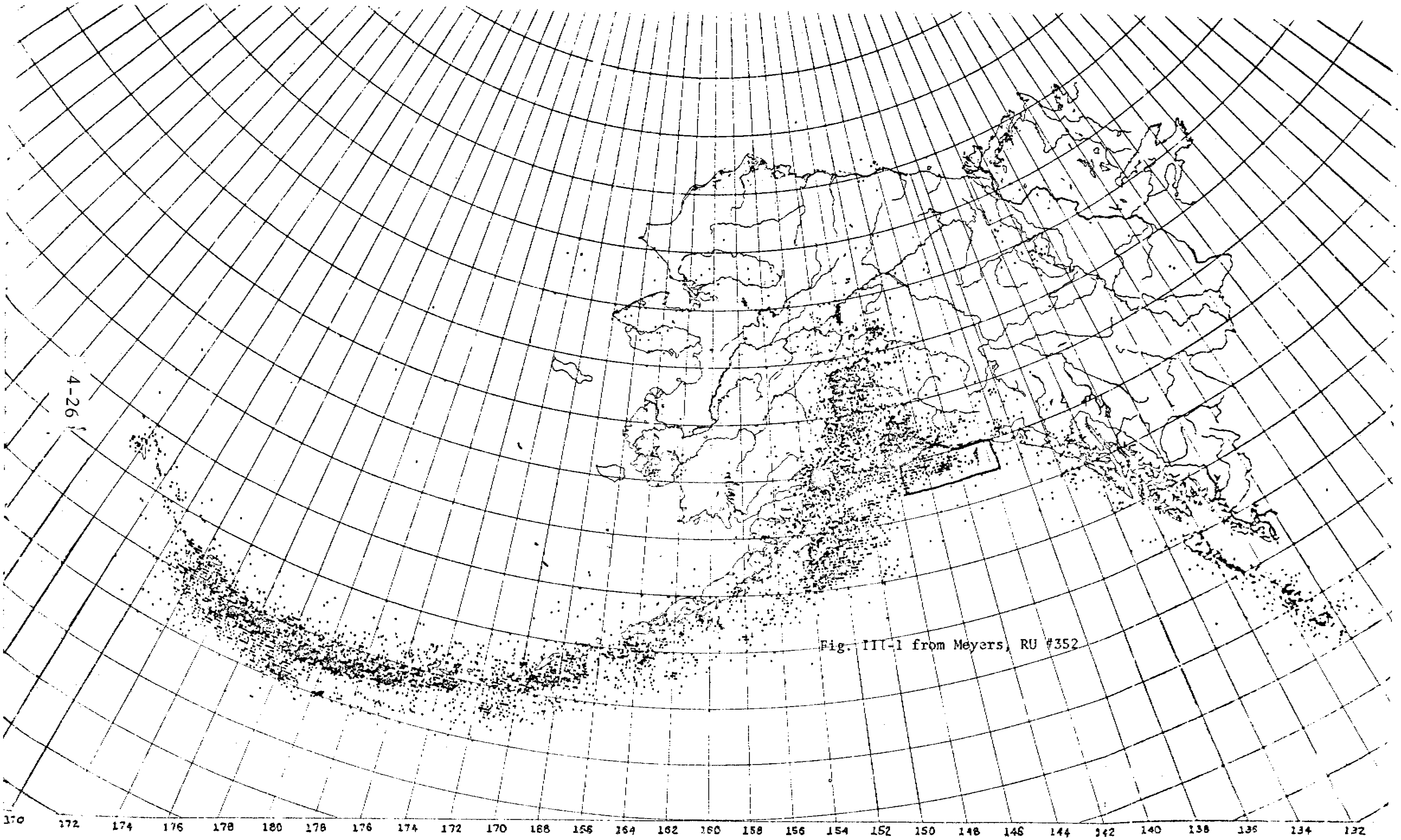

Fig. III-1 from Meyers, RU #352

MAJOR EARTHQUAKES IN ALASKA (1899-1974)

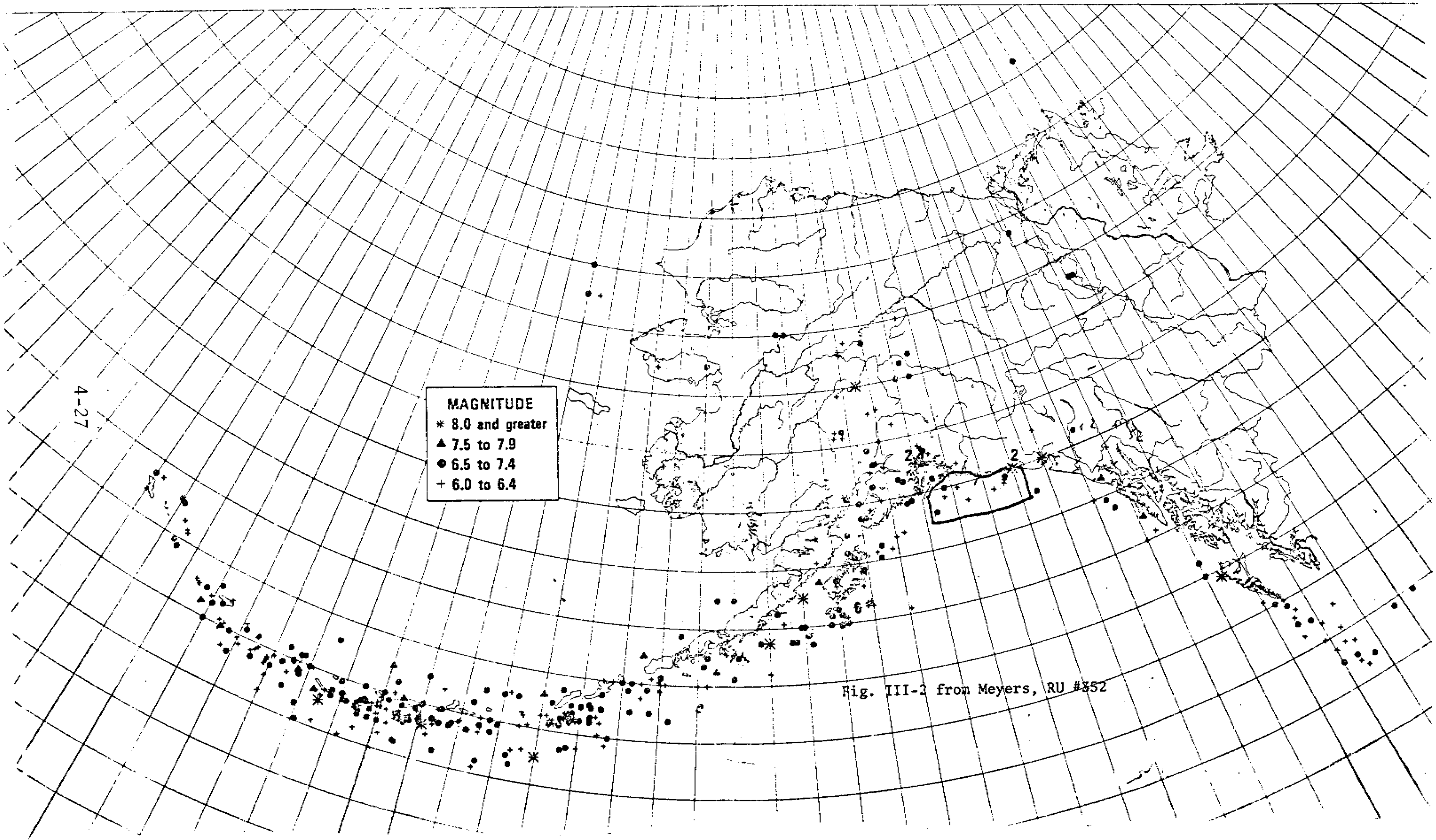

Fig. III-2 from Meyers, RU #352

events and the present understanding that the NEGOA overlaps the boundary between the two aforementioned crustal plates, NEGOA has been identified as a likely location for earthquakes as large as magnitude 8 to occur in the future (Lahr and Page, RU #210). The eastern Gulf of Alaska appears to be particularly susceptible to a magnitude 7 or 8 earthquake within the next few decades. This area has been seismically quiet at least since offshore monitoring began in 1974 but because of its tectonic setting and the presence of many onshore and offshore mapped faults may be the most probable site for a major earthquake in the NEGOA.

During the period of July 1, 1975 through March 31, 1976 Lahr and Page (RU #210) conducted a thorough review of known seismic activity in the NEGOA Tertiary Province. The review is based on an analysis of USGS seismicity records from some 25 shore based, short-period, seismograph stations and 6 strong motion instruments. All but two of these stations are located within 50 km of the coast between Montague Island (148°W) and Yakutat Bay (140°W).

Of the 25 short-period seismographs that are located throughout the coastal region, 23 of these record the vertical component of ground motion and 2 record and measure the north/south and east/west motion. Data from these stations are used to compute the epicenter, depth, magnitude, and focal mechanism of the regional seismic events, which may be as small as magnitude 1. Six additional strong motion instruments are designed to trigger during large earthquakes and give high quality records of large ground motions needed for engineering design purposes.

Lahr and Page's analysis of seismic data obtained between September 1974 and December 1975 revealed three principal sites of offshore seismicity: (1) the entrance of Icy Bay; (2) the Pamplona Ridge located to the southwest of Icy Bay; and (3) a localized area of continental shelf approximately 50 km due south of Yakutat Bay. A diffuse pattern of seismic activities was also noted throughout the Prince William Sound-Montague Island area.

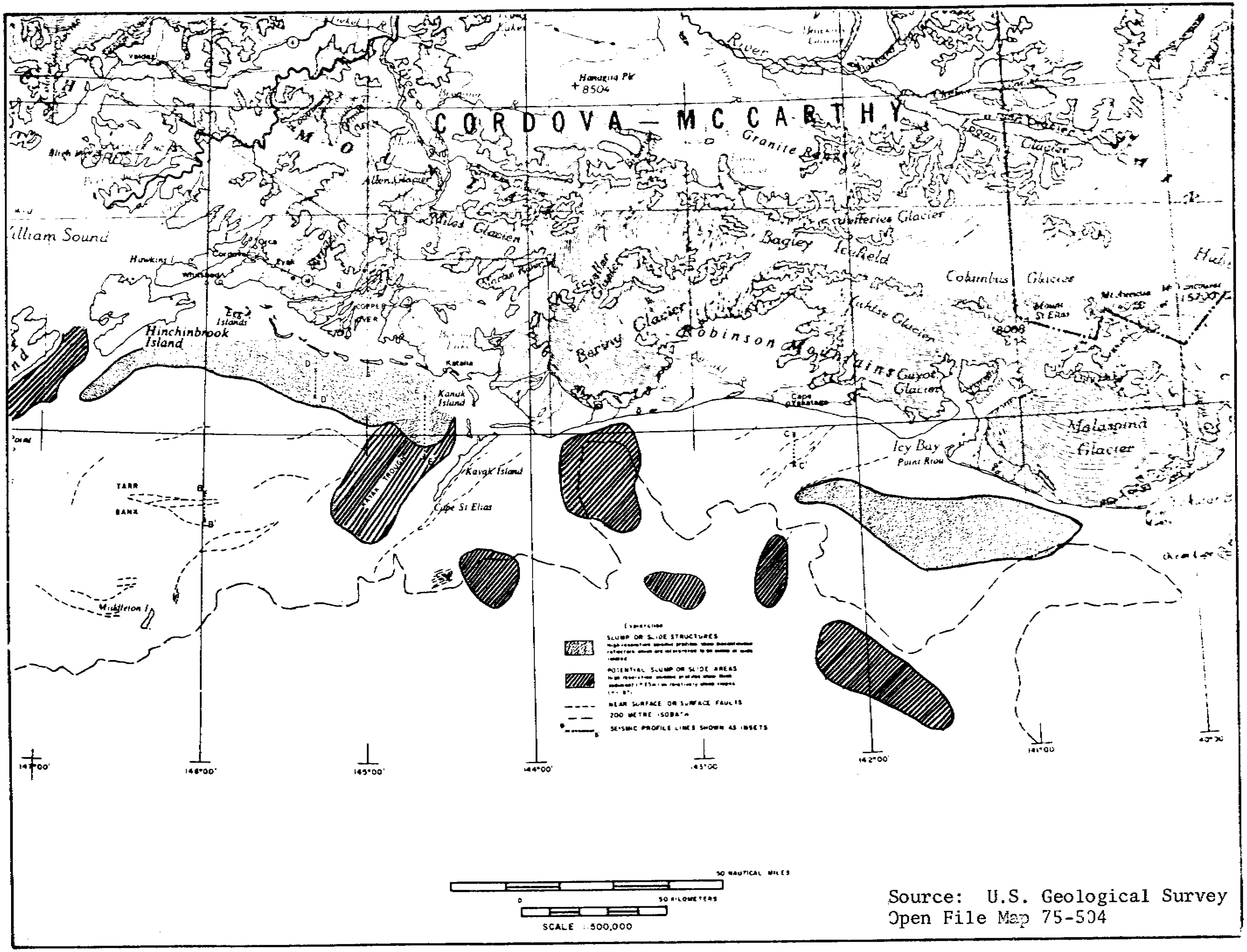

Fig. III-3 . Submarine slides and near-surface faults, northern Gulf of Alaska (from Carlson and Molnia, RU #216).

For the most part, these areas of pronounced seismicity are associated with recognized faulting (Fig. III-3). The area just east of the entrance to Icy Bay, the Chaix Hills, is a recently uplifted area bounded on the south by a thrust fault and on the southwest of the entrance by an anticlinal structure with a fault on its south side (Bruns and Plafker 1975). Both of these faults may be capable of generating earthquakes. Immediately to the west of the Icy Bay entrance two earthquakes of magnitude 8 were recorded in 1899 (Fig. III-2). The Pamplona Ridge "experienced three magnitude 6 shocks in 1970" (Lahr and Page, RU #218) which are probably associated with an adjacent fault striking northeast, identified by seismic profiling of the bottom sediments (Carlson and Molnia, RU #216). Seismic profiling has not been extended to the third mentioned zone of intense activity 50 km due south of Yakutat Bay, which is a considerable distance outside of the proposed lease areas. As a result, faulting associated with seismic activity there has not been identified.

Due to the extreme seismicity, six potentially serious hazards exist in the NEGOA lease area : (1) abrupt fault displacements that can exceed 10 m; (2) pervasive ground shaking; (3) onshore and submarine slumps and slides; (4) turbidity flows; (5) regional uplift or subsidence; and (6) tsunamis. Design must take these potential hazards into account if the safety of lives and equipment is to be assured.

SUBSEA FAULTING

The eastern Gulf of Alaska is tectonically complex and many faults have been mapped. A significant number of faults were identified by Carlson and Molnia (RU #216) at or near the seafloor on Tarr Bank, around Middleton and Kayak Islands, near structural highs south of Cape Yakataga, and adjacent to Pamplona Ridge (Fig. III-3). On shore, a series of lineaments at large angles to the coastline were identified between Yakutat Bay and Dry Bay on side-looking airborne radar imagery and interpreted by Cannon (RU #99) to be faults with vertical offsets of as much as 2.5 meters.

Faults of Quaternary age are potential hazards on the outer continental shelf of Alaska. Most faults that reach the seafloor displace sedimentary units of probable Pliocene-Pleistocene age. Several of these faults show 5 to 20 m offsets along the seafloor. By implication these are active faults (Carlson and Molnia, RU #216). Existing faults in the northeast Gulf of Alaska interpreted from geophysical data collected aboard the R/V. THOMPSON are shown in Fig. III-3. Seismic reflection and sediment sampling are the principal sources of data. Figures III-4 and III-5 represent the seismic profiling tracklines and Fig. III-6 shows the location of sediment sampling stations.

Seismic profiling evidence of (Quaternary) faulting at or near the seafloor has been found in Tarr Bank, around Middleton and Kayak Islands, near structural highs south of Cape Yakataga, and adjacent to Pomplona Ridge. Most of the faults that approach or reach the seafloor cut strata that may be Plio-Pleistocene in age. A few of the faults appear to cut Holocene sediments (deposited during the last 10,000 yrs) but none of these have resulted in offsets of the seafloor. The absence of evidence for offset of the seafloor does not, however, preclude the possibility of sudden slippage along these faults in the near future, generating large magnitude shocks and damage. These faults are, by any standards, on the active list and represent zones of severe hazard.

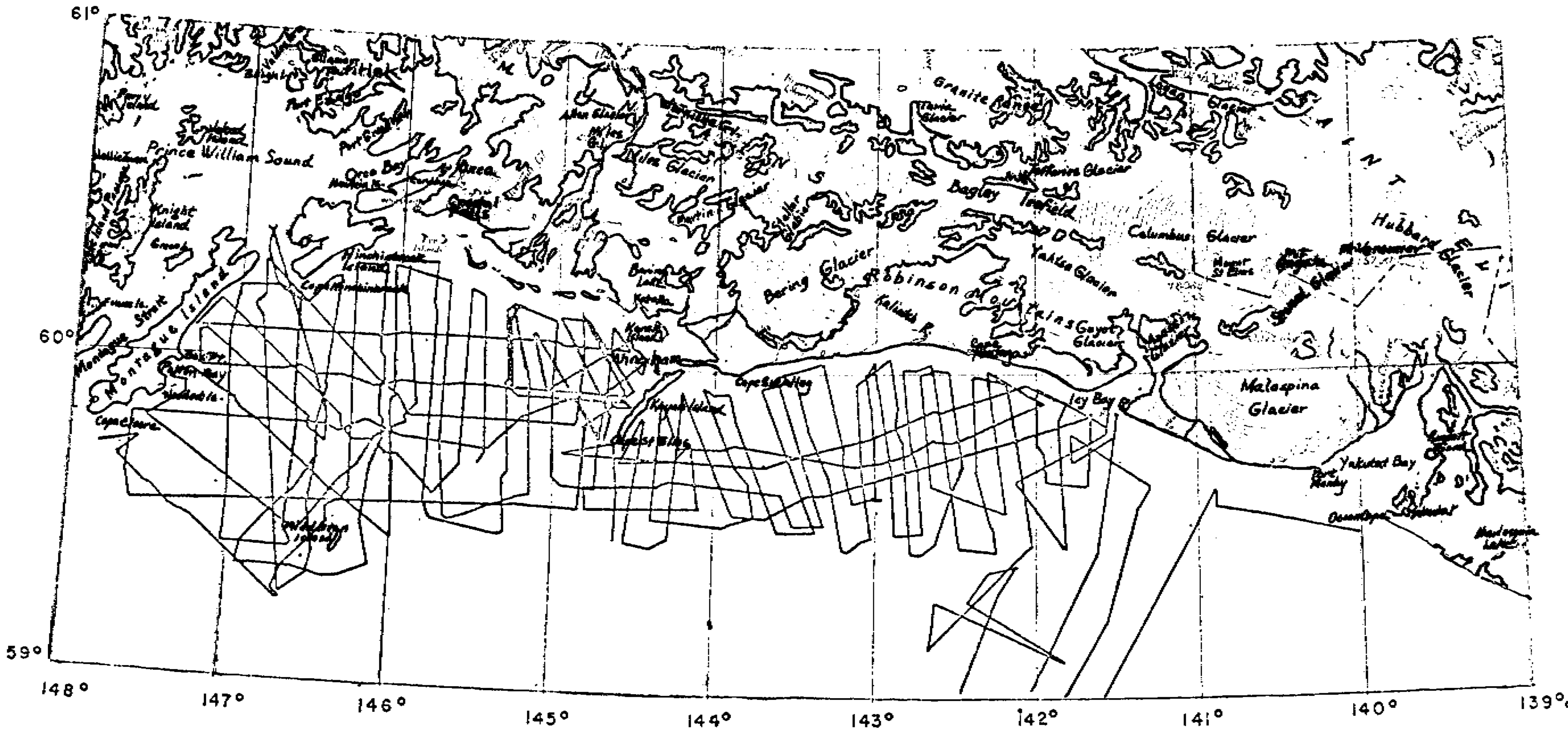

Fig. III-4. Tracklines of R/V THOMPSON Cruise (September-October 1974).

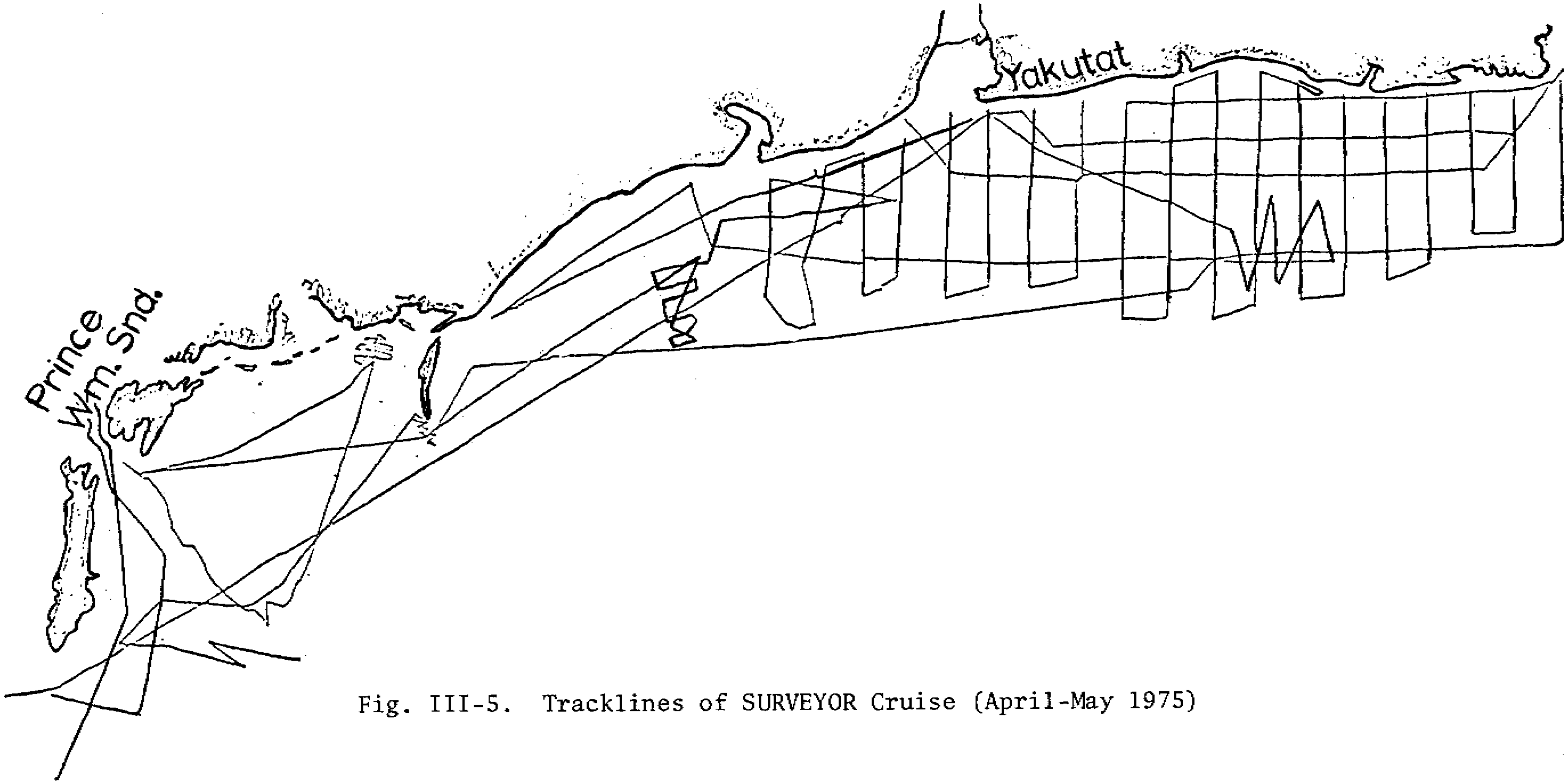

Fig. III-5. Tracklines of SURVEYOR Cruise (April-May 1975)

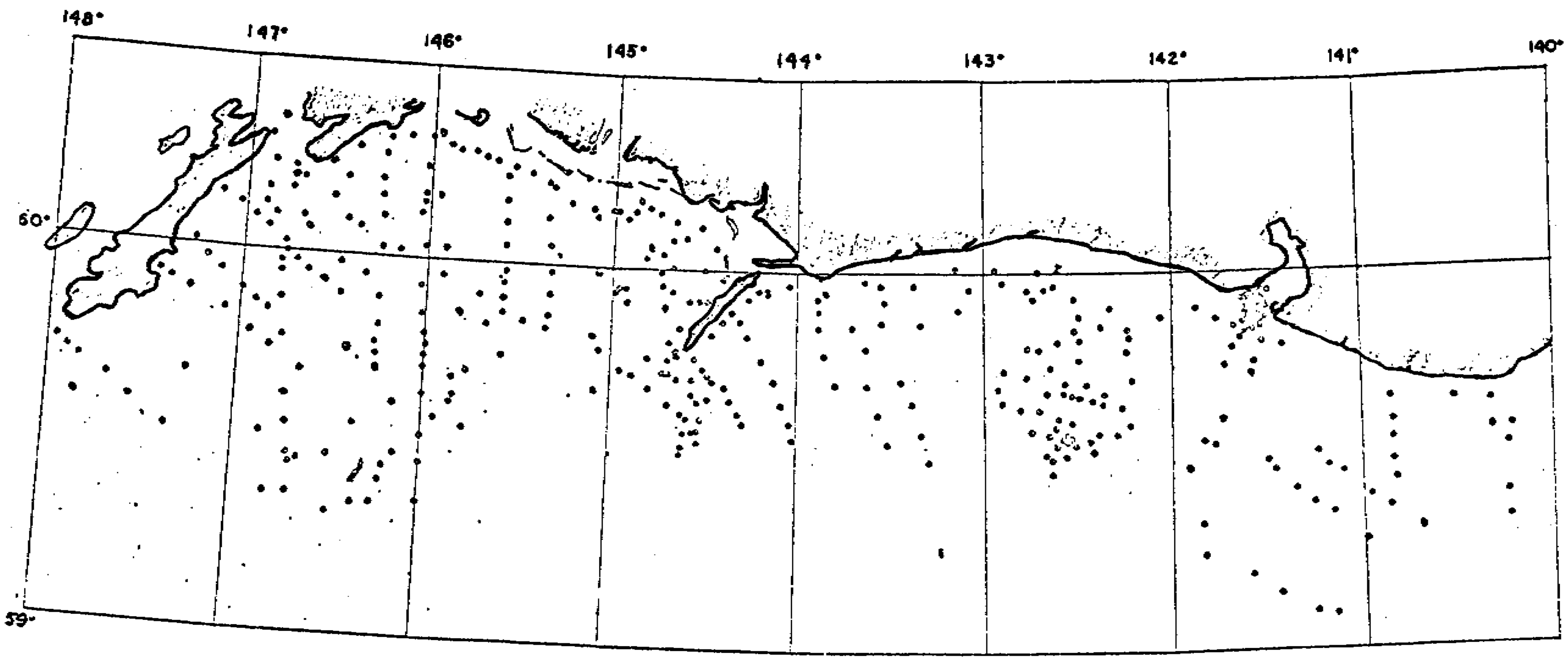

Fig. III-6. Location of seafloor samples; FRS CROMWELL (May-June 1975) and DISCOVERER (October 1975)

SEDIMENTATION AND SEDIMENT INSTABILITY

The main sources of sediment in the NEGOA are the Copper River and the Bering and Malaspina Glaciers. Glacial sediments are primarily suspended matter and the plumes where the sediments are discharged into Icy Bay and the Gulf of Alaska are visible 30 km from the coast on satellite imagery (Reimnitz and Carlson 1974). A significant secondary source is the Copper River plateau and delta where fine sediments are carried out to sea by strong north winds during fall and winter (Molnia and Carlson, RU #212).

The general transport of these sediments as they enter the Gulf of Alaska is to the west. Some of the Copper River sediment is carried west into Prince William Sound and large amounts of sediments that are part of the Bering Glacier runoff plume are transported around Kayak Island with some suspended sediment probably settling out over Kayak Trough. Seismic profiles indicate that very little sediment accumulates on Tarr Bank or on the Middleton Island platform, probably as a result of scouring by strong bottom currents and frequent storm waves occurring there in winter (Molnia and Carlson, RU #212).

Due to the regional tectonic/seismic environment, frequent storms, the large annual sediment discharge, and the resulting rapid sediment accumulation rates, the outer continental shelf seafloor is potentially hazardous. Glacially derived sediments deposited during the last 10,000 years are for the most part neither compacted nor cemented. Analysis of high resolution sub-bottom (HRSB) profiling data indicates that unconsolidated Holocene sediments blanket much of the NEGOA outer continental shelf (Fig. III-7, Molnia, and Carlson, RU #212). Sediment thicknesses vary from less than 5 m to more than 300 m. For example, Copper River prodelta sediments -- a wedge of fine sands, and clayey silts -- reach a thickness of about 350 m just east of the main river

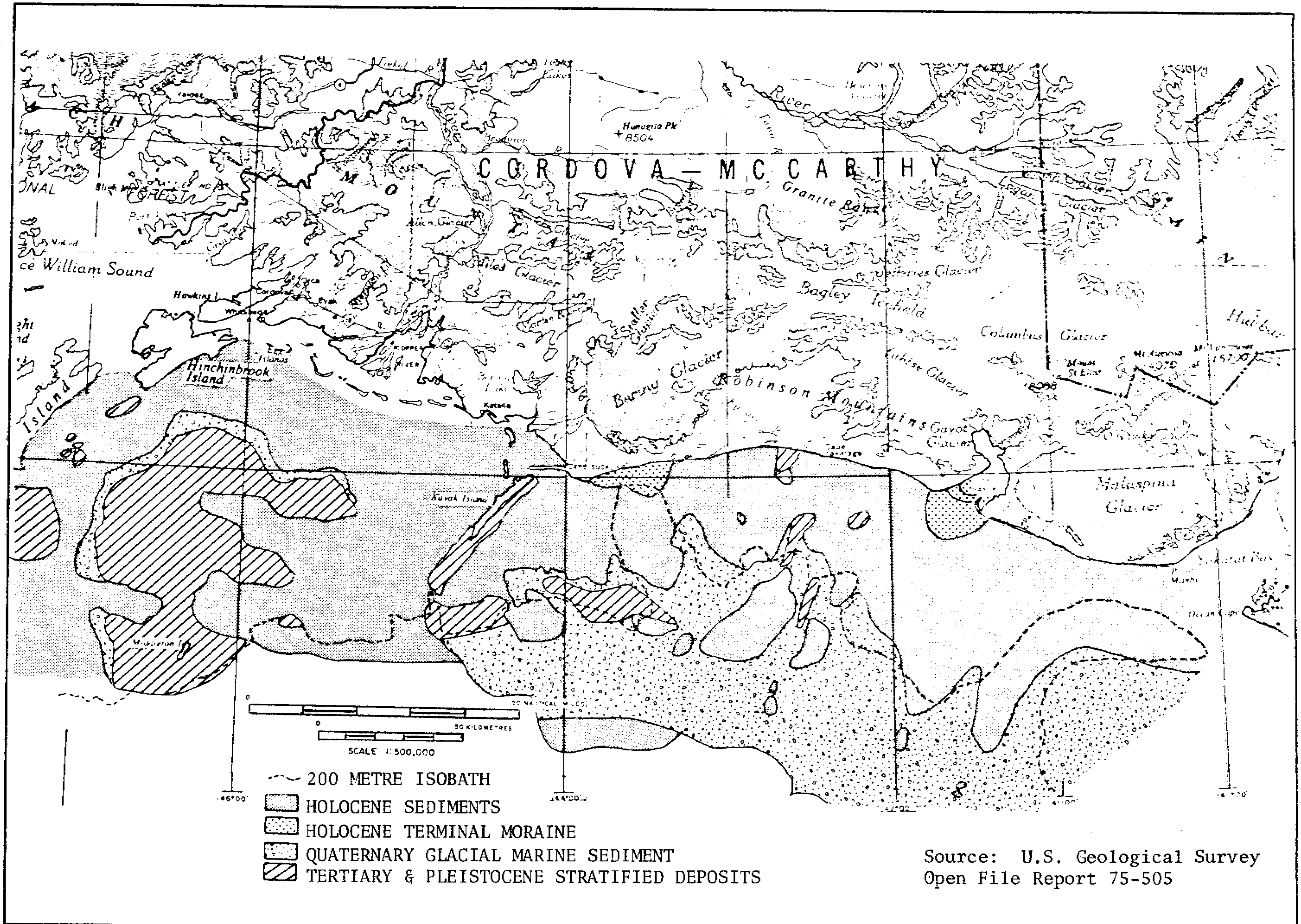

Fig. III- 7. Surface sediment distribution, northern Gulf of Alaska (from Molnia and Carlson, RU #212).

channel. Thick sequences of unconsoliated sediments are also found seaward of heavily glaciated areas such as the Malaspina and Bering Glaciers, where thicknesses of 260 m and 200 m, respectively, are found Between Hinchinbrook and Montague Island unconsolidated sediments are about 250 m thick, and at the southwest end of Kayak Trough, 155 m thick.

This "rapid accumulation of the glacially eroded sands, silts, and clay results in high pore-water pressures and underconsolidation of the sediment, making submarine slides or slumps likely even on slopes of less than one degree" (Molnia and Carlson, RU #212). Where sediment slopes exceed 1°, clayey silts with peak vane shear strengths of 0.01 to 0.09 kg/km^2 are highly susceptible to slumping, sliding, and turbidity flows. Therefore, in areas where slopes exceed 1°, large earthquakes providing rapid ground acceleration, tsunamis, or storm waves, could disrupt the seafloor causing slope failure, and severe damage to structures anchored in the sediments (Carlson and Molnia, RU #216).

Molnia and Carlson (RU #212) have conducted a HRSB seismic survey of the bottom sediments in the NEGOA outer continental shelf to determine areas of sediment erosion, deposition, instability, and mass movement. As a result, four major sedimentary units, characterized by their seismic signatures, have been mapped across the continental shelf: "(1) Holocene sediment-sands to silty clays; (2) Holocene ... moraines; (3) Quaternary glacial marine sediments -- primarily pebbly muds; and (4) Tertiary and Pleistocene stratified deposits -- dense, well-cemented sandstones to poorly consolidated pebbly mudstones. Most widespread of the two Holocene units is the clayey silt that appears on seismic profiles as relatively horizontal, parallel reflectors, except where disrupted locally by slides and slumps. The second Holocene unit appears as a jumbled mass of irregular reflectors representing recent ... moraines of the Malaspina and Bering Glaciers" (Fig. III-7, Molnia and Carlson, RU #212). The Holocene sediments overlie both the irregularly distributed glacial marine sediments and the Tertiary and Pleistocene lithified deposits.

In addition to the thick Holocene surface deposits in the Gulf of Alaska, large areas of the indurated Tertiary and Pleistocene rocks outcrop. These outcrops, commonly fold and faulted, appear on the seafloor south of Montague Island, at several localities southeast and southwest of Cape Yakataga. A thin veneer of Holocene sediments (<2 m), transparent to the HRSB system, was determined to exist on parts of Tarr Bank from sediment samples collected by Molnia and Carlson (RU #212). This thin veneer over Tertiary rock probably would have little significant effect on platform stability; the anchoring of platform foundations would penetrate through the sediments and hold fast to the indurated Tertiary rock.

"Two areas, both more than 1,700 km^2, of thick Holocene sediment show evidence of submarine mass movement: (1) south of Icy Bay and of the Malaspina Glacier and (2) seaward of the Copper River. Several other areas have been mapped as potentially unstable because of relatively thick accumulations of Holocene sediment on slopes greater than one degree" (Molnia and Carlson, RU #212).

On the shelf edge and the continental slope slumping is a common feature. A large number of discontinuous step scarps near the shelf edge south of Kayak Island cut the surficial sedimentary units of probable Tertiary age. Two scarps have 2 to 5 m relief, and possibly delineate slump blocks at the edge of the shelf, presenting serious hazards to seafloor construction (Fig. III-3, Carlson and Molnia, RU #216).

SUSPENDED PARTICULATES

Suspended particulates are of great importance to the regulation of chemical forms, the distribution, and the final deposition of many petroleum related marine pollutants. The primary process that makes knowledge of suspended sediment distribution significant is the absorption of petroleum pollutants onto the surface of suspended particles, which then settle with the absorbed pollutants to the sediments. The distribution of suspended particulates in the Gulf of Alaska is controlled by two factors, sources and circulation. East of Kayak Island the dominant sources of suspended sediments are the glacial melt waters of the Bering, Guyot, and Malaspina Glaciers, which contribute large volumes of rock flour. Analysis of ERTS imagery indicates that this material, when discharged into the Gulf, is entrained by westward flowing currents along the coast until it reaches Kayak Island. There it is deflected south and intercepted and entrained by a seasonal clockwise gyre (Fig. III-8, Sharma et al. 1974). To the west of Kayak Island the main source of sediments is the Copper River. Upon entering the Gulf of Alaska, the suspended sediment load of the Copper River is entrained by coastal currents and carried northwest until it reaches Hinchinbrook Island where the current and its sediment load are divided, one portion passing north of the island into Prince William Sound and the remaining portion being carried southwest along the Montague Island coast (Feely and Cline, RU #152).

The suspended particulate content in the water column was sampled in 1975 between October 21 and November 10 at 50 separate stations (Fig. III-9, Feely and Cline, RU #152). Figures III-9 through III-11 show the distribution of total suspended matter in the NEGOA area.

Fig. III- 8. ERTS-1 image of the region between Montague Island and Kayak Island showing the large clockwise gyre southwest of Kayak Island. The image was obtained on August 14, 1973. (Feely and Cline, RU #152)

Data derived from suspended sediment samples collected at stations 40, 41, 42, 43, and 44 support the conclusion drawn from the ERTS imagery that Copper River sediments are entrained by northwest flowing currents and divide at Hinchinbrook Island with a portion entering Prince William Sound, where it presumably settles. Concentrations of surface particulate matter near the Hinchinbrook Entrance were relatively high (1.71 mg/ℓ at station 44). Surface concentration decreased rapidly within the sound indicating rapid dispersal and settling (Feely and Cline, RU #152). Therefore, Prince William Sound is a potential principal receptor for petroleum pollutants with concurrent effects on its salmon and other aquatic resources.

Feely and Cline have arrived at the following conclusions regarding suspended particulates in the water column:

> "In general, concentrations of suspended matter in the Gulf of Alaska are high at the surface with an average concentration of 1.02 mg/ℓ. Beneath the surface concentrations generally decrease with depth until the seafloor is approached. Close to the seafloor suspended matter concentrations begin to increase sharply and the highest concentrations of suspended matter are found within 5 meters of the seawater-sediment interface. In general, a bottom turbidity layer can be found throughout most of the gulf .... Near topographic highs such as the transects across Tarr Bank, the ... suspended matter profiles increase sharply very close to the bottom. In these regions, the bottom nepheloid layer is quite thin (<20 m). Resuspension and transport of bottom materials can be expected to dominate these areas.
>
> In contrast, transects along topographic depressions such as the transect along Kayak Trough show ... suspended matter distributions which increase gradually to the bottom. There, the bottom nepheloid layer is quite thick (>50 m) and rapid sedimentation can be expected to occur...."

Benthic communities indigenous to the topographic depression may be receptors of high concentrations of toxic petroleum pollutants that may result in major shifts in highly productive ecosystems to less productive habitats. On the other hand, persistent scouring of the topographic highs will result in areas of relatively low toxicity. What remains to be demonstrated is the positive relationship between suspended particulates entering the NEGOA at or near the surface and the sediment being deposited at the bottom.

COASTAL MORPHOLOGY AND EROSION

The first two years of OCSEAP-funded studies of the coastal zone have concentrated on detecting and mapping areas where change is occurring with the objective of establishing an understanding of process and rates of change. Two separate teams have addressed this task: Cannon (RU #99) has been using side-looking airborne radar (SLAR) as a principal aerial survey tool while Boothroyd and others (RU #59) have been working on a field program studying glacial deposition and coastal processes.

Application of SLAR

Cannon (RU #99) has been investigating a narrow strip of coastal plain, 1 to 40 km wide, stretching 600 km from Icy Point to the western margin of the Copper River delta. The initial phase of the study was to evaluate the applicability of SLAR imagery to the reconnaissance mapping of geologic and geomorphic features under atmospheric conditions unfavorable to photographic surveys. Three maps representing the utility of SLAR are currently in preparation: (1) a map of the environemntal geologic hazards and shoreline stability; (2) a map of the major

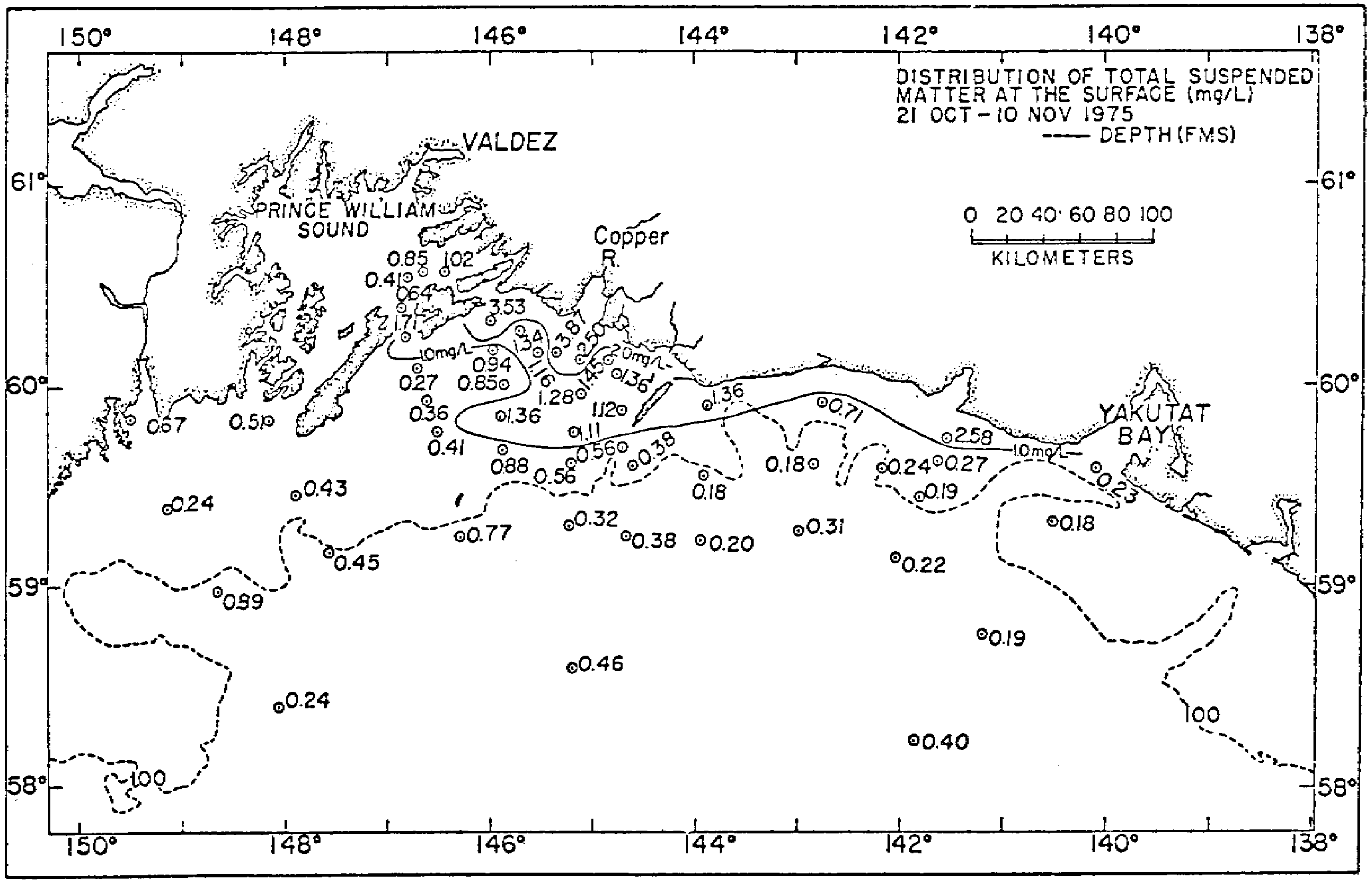

Fig. III-9. Distribution of total suspended matter at the surface in the northeastern Gulf of Alaska (Cruise RP-4-Di-75C-I, October 21-November 10, 1975) (from Feely and Cline, RU #152).

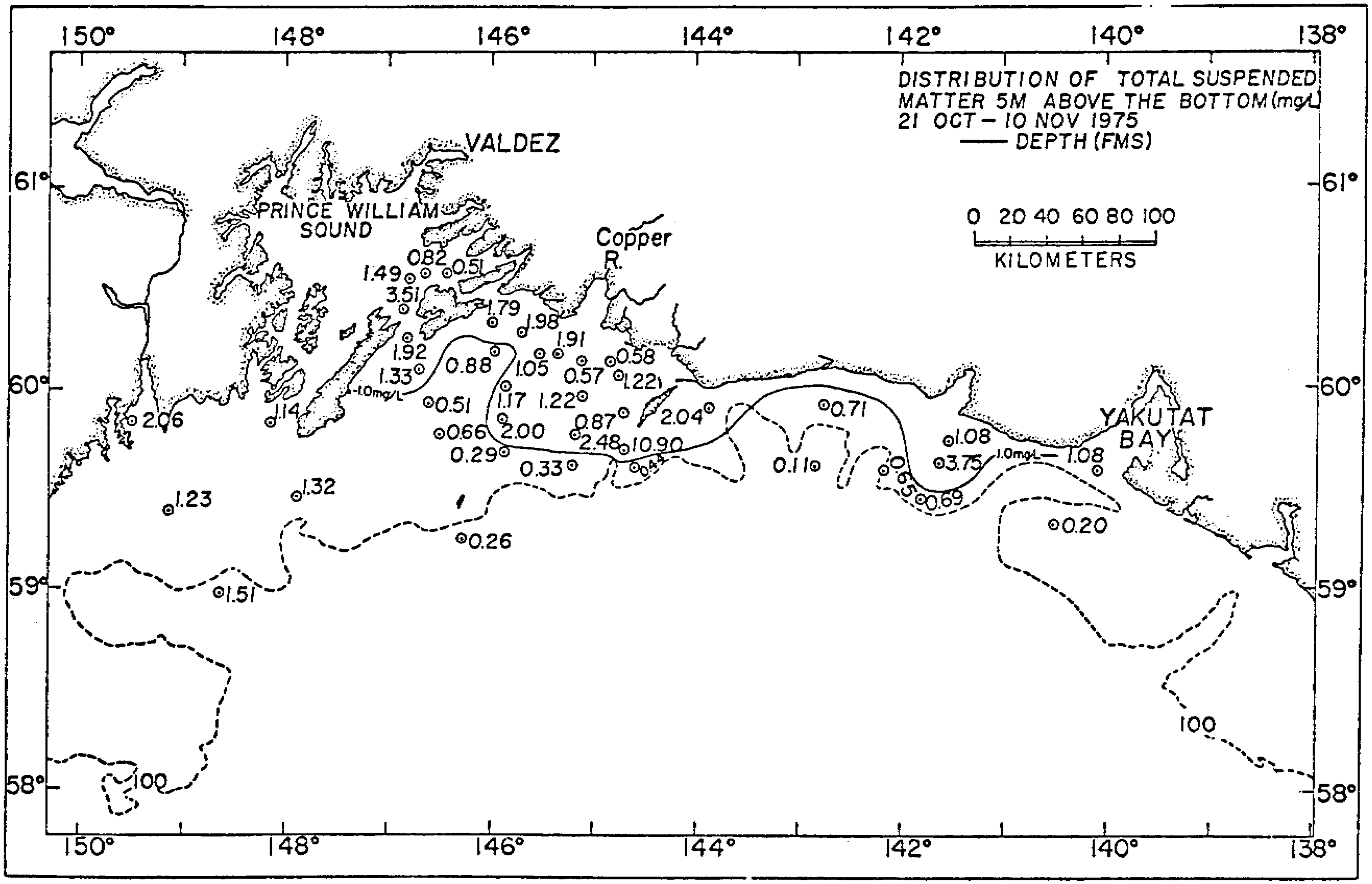

Fig. III-10. Distribution of total suspended matter at 5 meters above the bottom in the northeastern Gulf of Alaska (Cruise RP-4-Di-75C-I, October 21-November 10, 1975) (from Feely and Cline, RU #152).

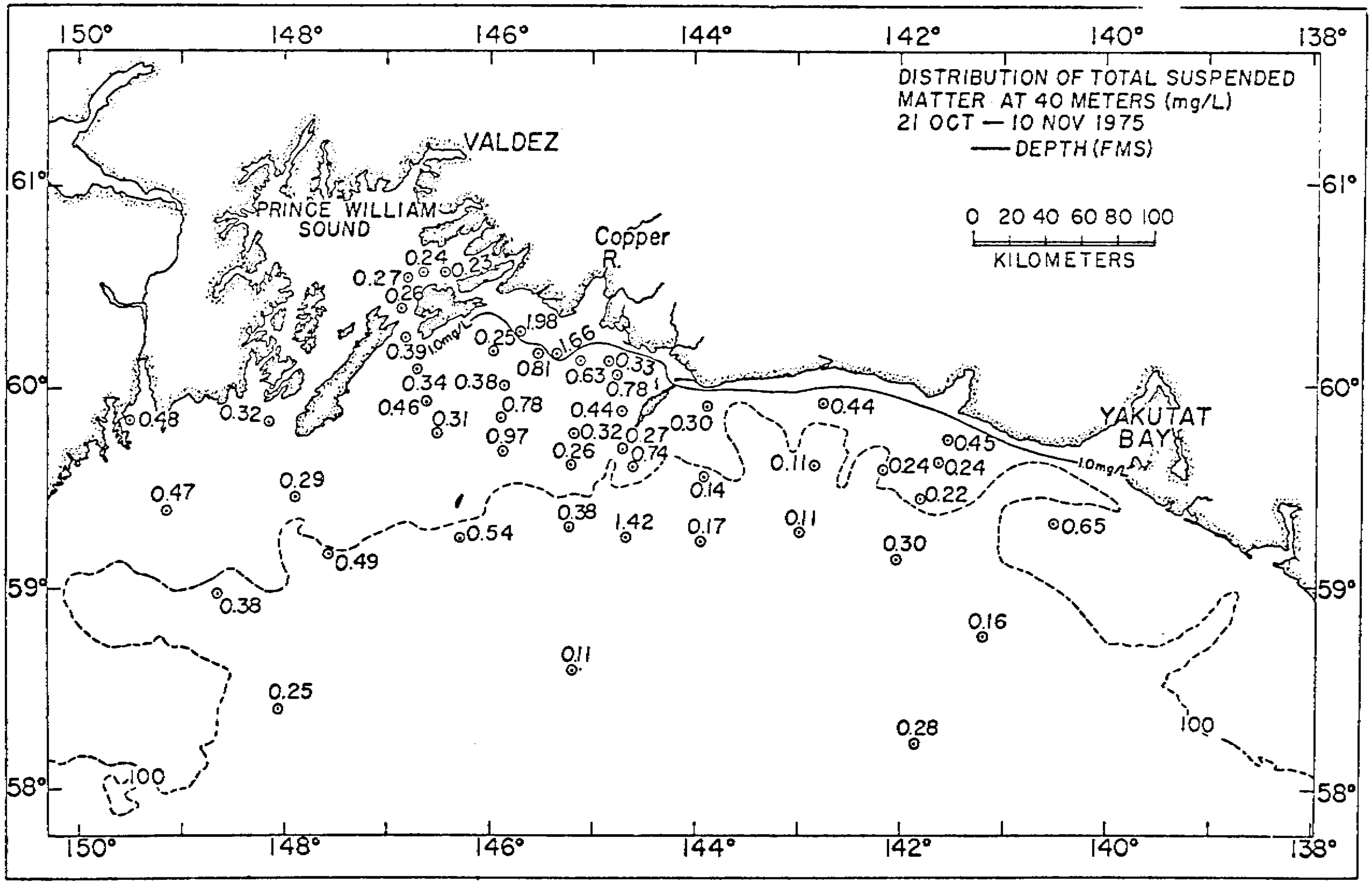

Fig. III-11. Distribution of total suspended matter at 40 meters in the northeastern Gulf of Alaska (Cruise RP-4-Di-75C-I, October 21-November 10, 1975) (from Feely and Cline, RU #152).

coastal landforms; and (3) a map of major beach materials. Two additional products will be a report on the applicability of SLAR to hazards mapping of the coastal zone and an annotated SLAR coastal mosaic to explain and demonstrate its uses.

Hazardous Coastal Landforms

The work of Boothroyd and others (RU #59) on analysis and mapping of the coastal morphology, and glacial deposition and sedimentation in the NEGOA has thus far concentrated on the east margin of Icy Bay (offshore and onshore) and the West Malaspina glacial foreland. The objectives of this field project are identification and qualitative analysis of the hazards related to glacial and proglacial landforms, processes, and zones of deposition. Several types of zones of hazards were identified in the forelands of the Malaspina and neighboring glaciers where onshore petroleum-related facilities might conceivably be planned. These include: (1) potential flood bursts from ice dammed glacial lakes; (2) glacial surges -- rapid extension of the ice terminus; and (3) stagnant ice masses and buried ice blocks -- areas of ground instability due to slumping as the ice melts.

Coastal erosion was observed, but estimates of rates remain to be determined. Morphology of nearshore sediments were measured and qualitatively evaluated from 70 km of high resolution bottom profiles. Emphasis was on prodelta morphology on the east side of Icy Bay. The normal path of heavy drift ice that originates from the calving of glaciers extending into the upper ends of Icey Bay was mapped and considered a serious hazard to navigation. The results of the field program were compiled in three geologic/geomorphic maps.

Conclusions regarding several areas of Icy Bay were drawn. It is not feasible to use the Icy Bay north of Kichyatt and Kagut Points because of heavy ice drifts in all seasons, active glaciers posing the threat of surges and flood bursts, steep bedrock cliffs without portage, and submerged stagnant ice masses. The Caetani, New Yahtse, and Kettlehole delta areas are in the forelands of active glaciers, areas of buried stagnant ice and subject to inundation by flooding. The delta front slopes are areas of severe slumping and general slope failure and would involve high risks for development. All other areas are considered less hazardous for potential sites for nearshore or onshore development.

Volcanoes are not considered a hazard in this area. Tsunamis and seiches may be hazards, but these have not yet been addressed by any of the research units.

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Chapter IV

TRANSPORT PROCESSES

INTRODUCTION

A large number of oceanographic studies have been carried out in the Gulf of Alaska during the past two decades. General physical oceanographic features and circulation patterns for the gulf have been periodically reviewed. Data collected at the Canadian weather ship station "P" represents a very useful time-series of observations. Tabata (1965) summarized the available data and information from station "P" to assess the variability in oceanographic conditions and rates of water transport and to estimate heat and salt fluxes. Ingraham, Bakun, and Favorite (RU #357) have compiled existing data and results pertaining to the Gulf of Alaska. Nearly all of these data are from offshore waters and are aperiodic, non-synoptic, and lack the necessary area coverage and repetitive observations. A complete and coherent picture of oceanographic phenomena and features for the northeast Gulf of Alaska in general and the proposed lease areas in particular cannot yet be constructed. According to their review, present knowledge of physical processes is not adequate to forecast pattern of flow and transport of pollutants. In conclusion, these authors have stated that "a normal advance from the descriptive phase of presenting observed and steady state conditions to the analytical phase of understanding processes and forecasting various time-dependent phenomena has not taken place."

Other OCSEAP-related research projects applicable to this area are being conducted by Royer (RU #289), Hayes and Schumacher (RU #138), Hansen (RU #217), and Barrick (RU #48). In addition, hydrodynamic numerical modeling and simulation studies of oceanographic processes proposed by Galt (RU #140) and Laevastu (RU #235) are being formulated and tested.

MAJOR HYDROGRAPHIC FEATURES

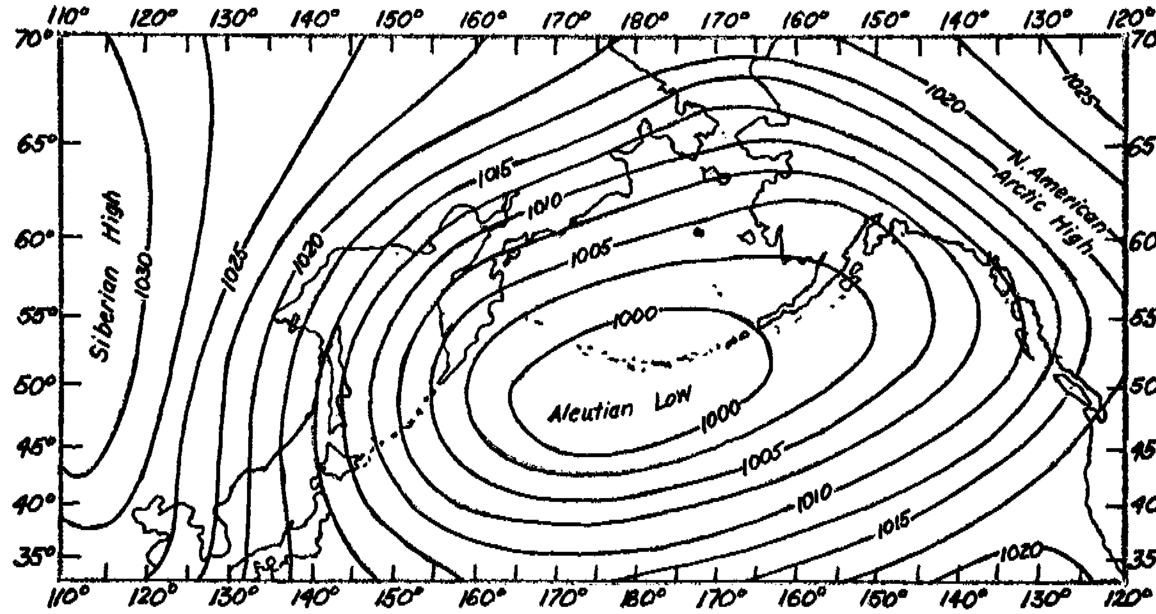
According to Royer (1975), the Gulf of Alaska is subjected to the advection of cold, dry Arctic air masses and rapid modification of the atmosphere. The dominant synoptic meteorological feature in the area during late fall and winter is the Aleutian Low (Fig. IV-1). During the spring and early summer when the surface temperature differential between the continents and the ocean is lessened, the Aleutian Low begins to expand onto the continent. Eventually the Siberian and North American land masses become warmer than the Bering Sea/Gulf of Alaska waters. At the same time, the Eastern Pacific High pressure system, which is present year round and reaches its maximum intensity in summer, covers most of the Gulf. It prevents the intrusion of most cyclonic systems into the Gulf. The remnant of the Aleutian Low over the Bering Sea moves toward the Arctic and dissipates. It is not evident in July; this results in fair weather and calm seas in summer in the Gulf.

As autumn approaches, the continental cooling results in the Aleutian Low reforming over the Bering Sea. The cyclonic systems move eastward where they are deflected by cool continental air masses and mountain barriers southward over the Gulf waters, which being warmer serve to strengthen them. This southward movement is also influenced by the Eastern Pacific High whose northern margin occurs farther and farther south with the passing of autumn. During winter, especially in January, the center of the Aleutian Low is shifted over the western Aleutian Islands. Due to the rapid and frequent movement of this system, the autumn-winter season in the Gulf is characterized by severe storms and high seas.

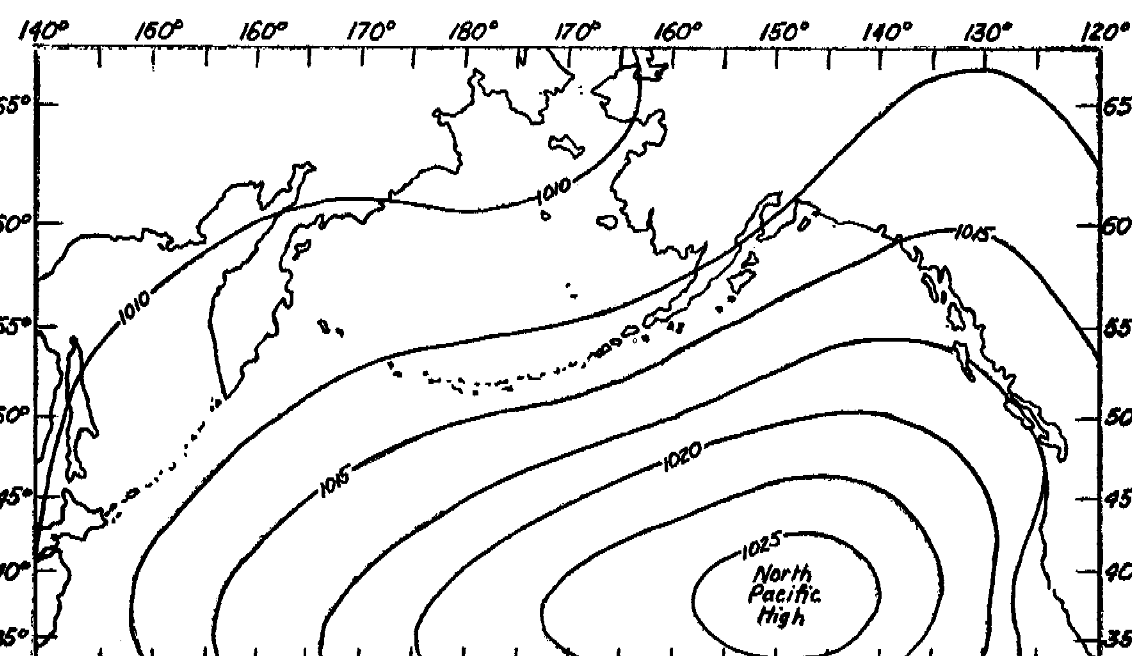
The effect of the Aleutian low pressure system on oceanic properties and circulation is summarized by Ingraham, Bakun, and Favorite (RU #357) as follows:

> "The cyclogenic and cold air advection in the gulf associated with the mean position of the low pressure center in fall and winter determines the extent and intensity of winter overturn and vertical divergence, as well as the containment of precipitation, in the form of ice and snow along the coast and in the snowshed ringing the gulf which determines to a great extent the amount of dilution in coastal waters in spring and summer."

They also describe seasonal cycle of temperature along the periphery of the Gulf. From January to March in waters over the shelf to a depth of 122 m, near isothermal conditions



Mean Sea Level Pressure (Millibars), Winter



Mean Sea Level Pressure (Millibars), Summer

Fig. IV-1. Mean atmospheric pressure distribution over the North Pacific for winter and summer (Galt and Royer 1975).

are present in the upper 100 m. This mixed layer represents the winter convective overturn. Winter convection also results in the formation of a temperature-minimum layer, ~ 3°C, at a depth of 75 to 150 m. During summer, a warm surface layer, 20 to 30 m deep, overlies a sharp thermocline extending to the depth of winter overturn. Further warming of the surface layer results in a reduction of the thickness of the temperature-minimum stratum; however, it is not completely eliminated. At about 122 m depth over the shelf and slope area, a warm-water layer of 4.5 to 4.0°C is identified as a subsurface temperature-maximum layer. Plots based on mean temperature values from long-term data at depths from 200 to 2,000 m indicate the northward sweep of warm water into the gulf in the eastern side and the permanence of cold water intrusion isolated offshore on the western side. In deep water off Yakutat, a subsurface termperature-minimum at 80 m and a maximum at 130 m were noted by Galt and Royer (1975) in July 1974. According to these authors both of these features indicated water that was not formed locally. The subsurface maximum layer was identified as water that was formed near the surface in the vicinity of the North Pacific drift, probably at subarctic convergence. The water in the temperature-minimum layer was believed to have been formed "south of the region of interest [NEGOA]... somewhere in the central part of the gyre."

It can be seen from Fig. IV-2 that the warm water is not in the form of a broad uniform layer but as a relatively narrow band. A plot of depth where sigma-T value is 26.4 connects the isolated parcels of this water. Nearshore, off Icy Bay, temperature profile shows that subsurface maximum layer contacts the shelf at about 150 m (Fig. IV-3). West of Port Elias, where the continental shelf is wide, there is little evidence of a well-defined core of warm water (Galt and Royer 1975). On the contrary, several small-scale perturbations in

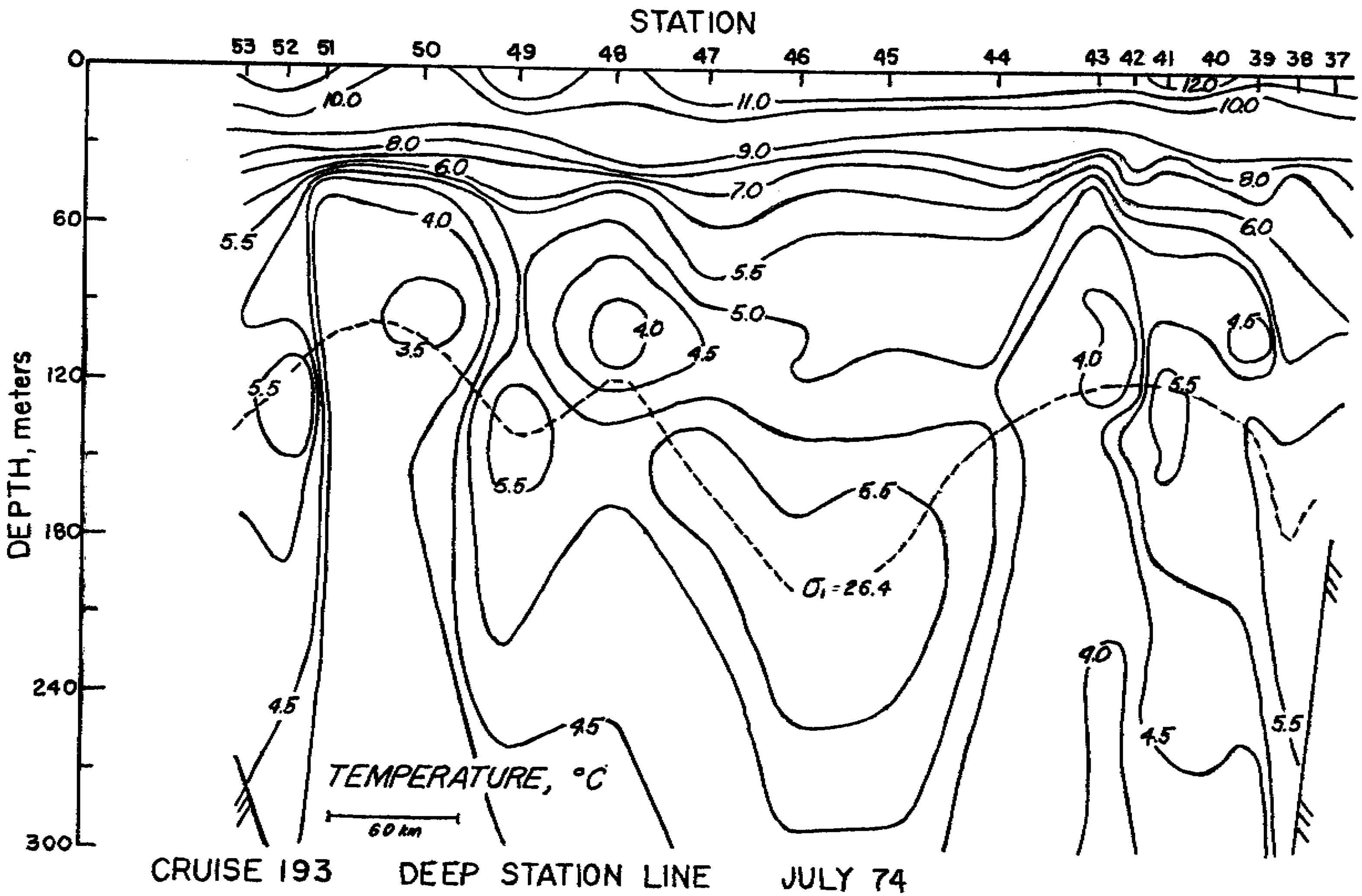


Fig. IV-2. Vertical section of temperature versus depth extending, offshore from Yakutat (STA 37-STA 43), west across the deeper offshore section of the Gulf of Alaska (STA 43-STA 51), and onshore to the continental shelf off Seward (STA 51-STA 53). The depth of the sigma-T = 26.4 surface is given by the dotted line (Galt and Royer 1975).

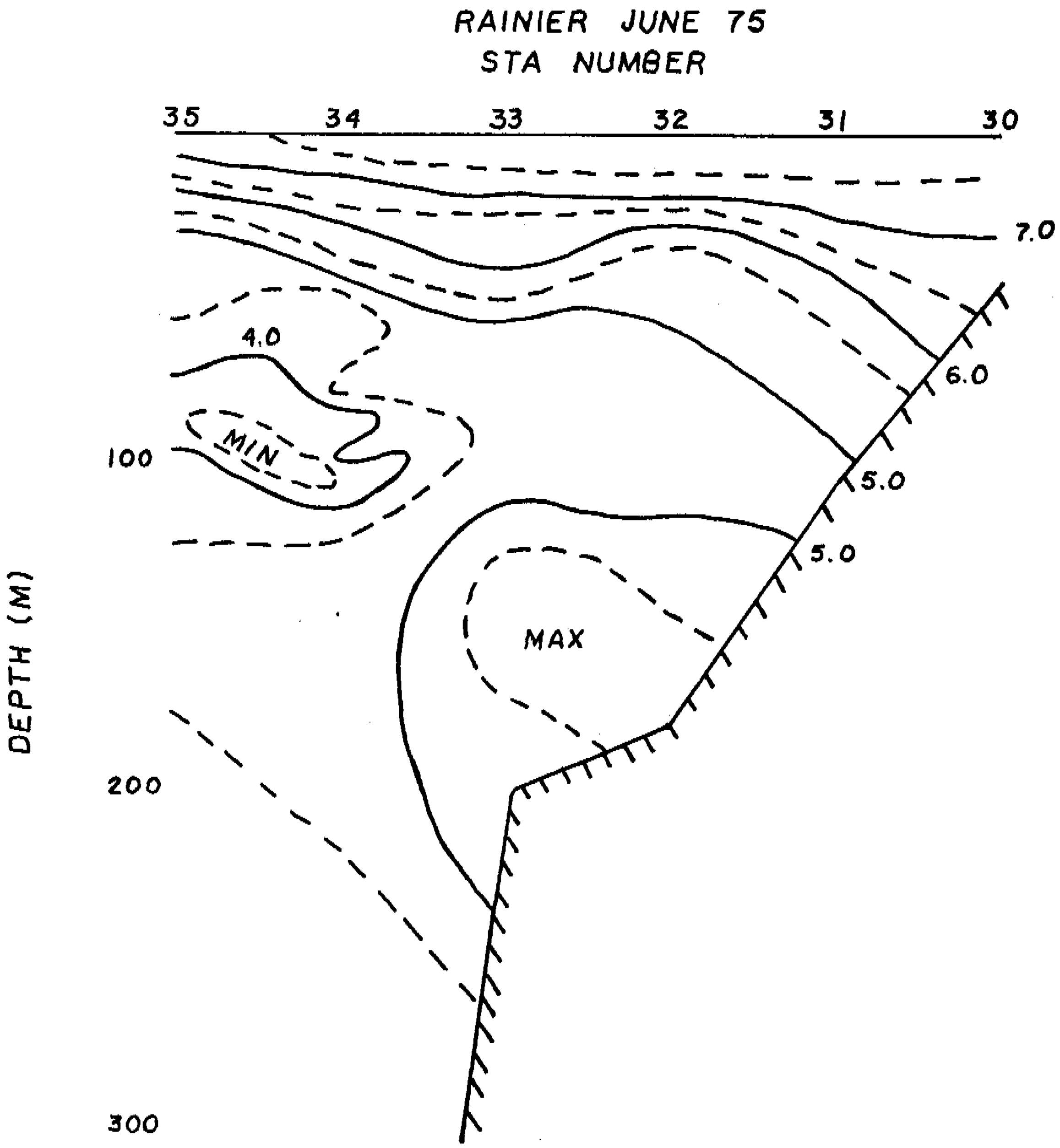


Fig. IV-3. Vertical section of temperature (°C) versus depth (meters) on a line of stations extending across the continental shelf off of Icy Bay (Galt and Royer 1975).

water properties are noted west of Port Elias which may be caused by the presence of Middleton Island and a change in flow direction from zonal to meridional (Hayes and Schumacher, RU #138; Royer, RU #289).

Extensive freshwater runoff around the Gulf dilutes the coastal waters, however, due to the paucity of data, its effect has not been quantitatively evaluated. Maximum average discharge from the Copper River occurs in July and is about 3,000 m^3/sec; minimum outflow is from December to April. Seasonal effect of this dilution is not easily evident. In summer, however, the 32 ppt isohaline moves as far as 200 km offshore compared to its position in winter (Ingraham, Bakun, and Favorite, RU #357). Seasonal variation in salinity at a station, described as "innermost on the Seward line," shows strong freshwater input in the surface layers in summer and early fall (Galt and Royer 1975). It should be noted that accompanying the dilution of surface layers there is an increase in salinity of near-bottom water (Fig. IV-4). This could be due to the large-scale wind stress changes as the mean upwelling index is correlated with the salinity changes in near-bottom layers. According to Galt and Royer (1975), during upwelling offshore, moving surface water is replaced by higher salinity near-bottom water which moves onshore. Downwelling in winter appears to act as a flushing mechanism that removes the high salinity water from deeper layers.

MASS DISTRIBUTION

Detailed information on water masses and their distribution in the Gulf of Alaska is not available presently. Ingraham, Bakun, and Favorite (RU #357) have stated that water mass at the head of the Gulf is formed from the merges of three water masses moving northward along the central and eastern sections of the Gulf.

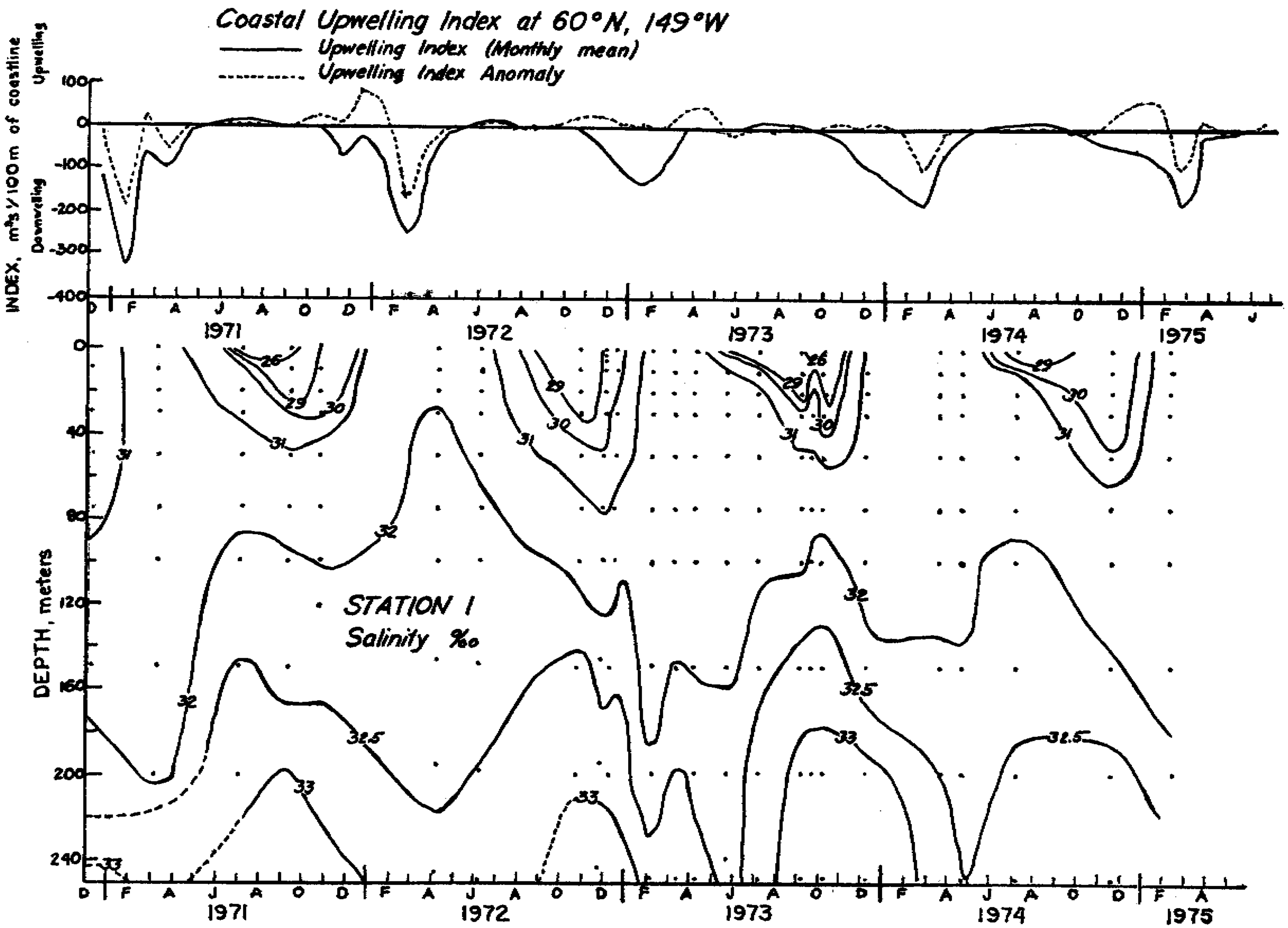


Fig. IV-4. Time series cross-section of salinity for station 1 in Gulf of Alaska and the monthly mean upwelling index and its anomaly (Galt and Royer 1975).

Salient features of these water masses are shown in Fig. IV-5. The following account, describing the properties of water masses, is reproduced from Ingraham, Bakun, and Favorite (RU #357):

> "In general, these water masses have equivalent surface temperaturs during the periods of maximum heating (summer, 13-14°C) and cooling (winter, 4-5°C), except in area B where winter temperatures of 3°C are evident, and there is a noticeable decrease in surface salinity shoreward from areas B to D, the greatest dilution occurring in area A. The elimination in winter of the temperature gradient, or thermocline, evident in the upper 50-75 m of the water column during summer, is readily apparent in all areas. There are marked differences in temperatures from 100 and 300 m, about 3°C, between areas B and D; conditions at these depths in areas C and A reflect an admixture of the water masses in areas B and D, although the temperature maximum between 150 and 250 m is maintained. There is also a suggestion of a downward diffusion of summer heating below 125 m during winter. Below 300 m the T-S curves in areas A, B, and C are similar and follow the trend of the general Subarctic Water Mass curve, however, there is a significant departure from this curve in area D attributed to northward flow along the coast."

Royer (1975) noted that at a station south of Cape Cleare at about 38°20'N, the range of temperature and salinity values was different than previously reported and that the variability in these two properties was quite large. A temperature-minimum layer at about 100 m was observed in data from April, June, and October 1972. In April, the water column was nearly homogenous to a depth of 50 m at a temperature close to 3°C. Standard deviation for temperature values (four cruises) in the upper 150 m varied from 1.2 to 3.8°C, whereas for salinity data it varied from 0.15 to 0.33 ppt. Greatest changes in salinity were between 100 and 150 m. According to Royer these changes are caused by advection of high salinity water onto the shelf.

Hayes and Schumacher (RU #138) and Royer (RU #289) have collected new STD (salinity, temperature, and depth) data in this area. So far no substantial new information on water masses of this area has been reported.

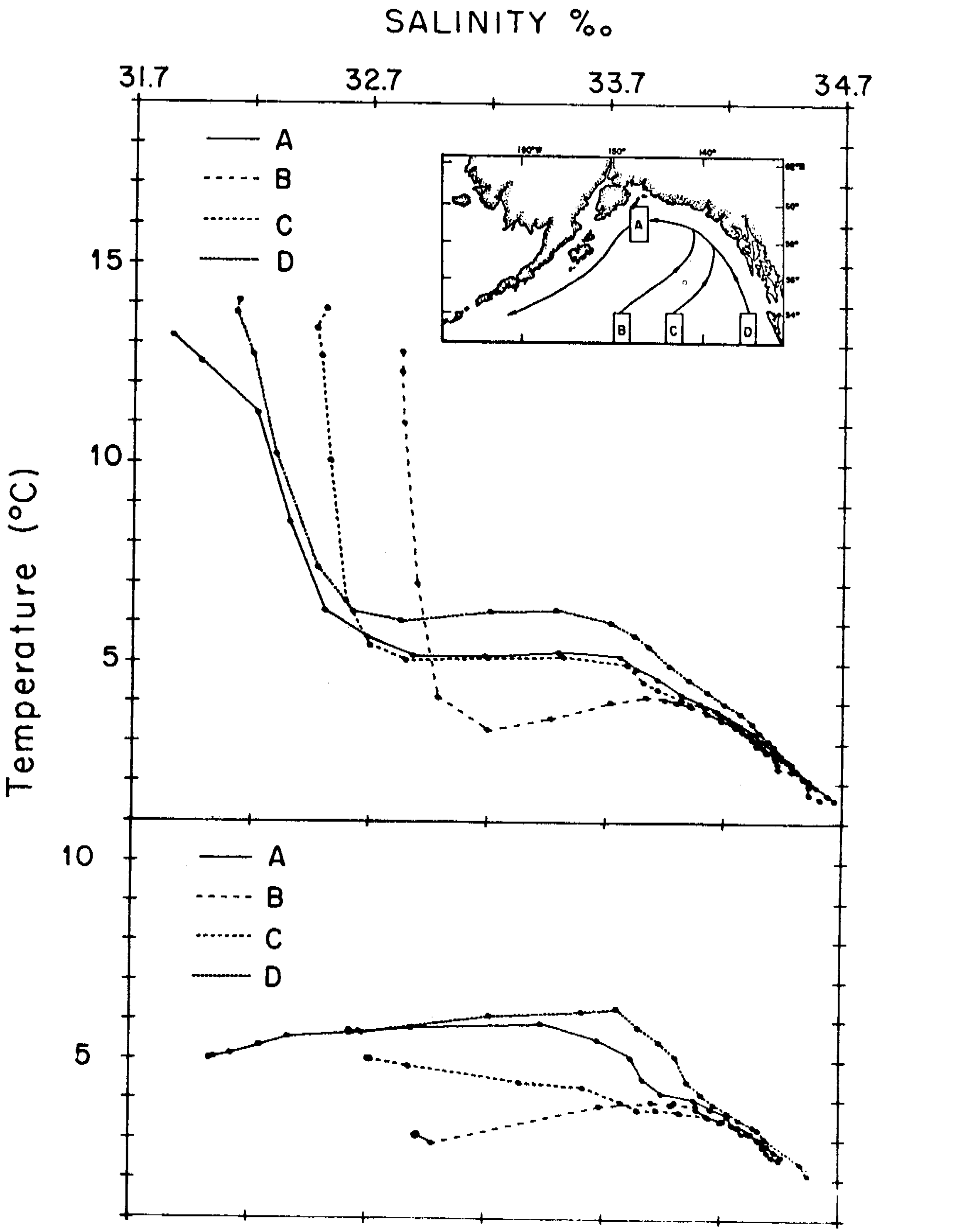


Fig. IV-5. Long-term summer and winter mean temperature-salinity relations at standard oceanographic sampling depths in the indicated 2°x2° quadrangles showing characteristics of various water masses funneling into the gulf (Ingraham, Bakun, and Favorite, RU #357).

CURRENTS

Geostrophic Calculations

Isopleths and geopotential topography in the Gulf of Alaska, based on long-term means for different seasons for intervals 0-300 db and 0-2,000 db are presented by Ingraham, Bakun, and Favorite (RU #357). Seasonal mean fields for 0-300 db layer were similar for winter, spring, and summer (Fig. IV-6). Only very few data were available for fall. The longitude of the topographic [geopotential] low, 149°W, was the same for all seasons but its latitude shifted from 53°N in spring to 55°N in summer. It was also noted that even though the difference between geopotential topographics in the middle of the Gulf and the nearshore areas may have been 15 to 20 dyn cm, isopleths were not continuous around the Gulf. They may represent a discontinuity of flow primarily due to the narrow width of currents in the northern and western parts.

Baroclinic currents, based on data collected in September 1975, appeared to be stronger in the western part of the Gulf, 45 cm/sec, than in the eastern part, 30 cm/sec. Estimated transport rates for the northeastern part of the Gulf ranged from 0.03 to 4 Sv (Royer, RU #289). If the barotropic component, estimated at 20 cm/sec, was added to these values, current speeds of about 1 knot were obtained. In a study carried out in April 1972, surface geostrophic component at two stations (#7 and 11) south of Cape Cleare, relative to their common pressure surface (250 db), was 9 cm/sec (Royer 1975). However, if 1,000 db surface was considered as true level surface and if the geostrophic component of 250 db relative to 1,000 db between stations 11 and 20 (station 20 was in deep water) was added to the surface of 250 db component, a current velocity of 23 cm/sec was obtained. This value compared favorably with direct current observations.

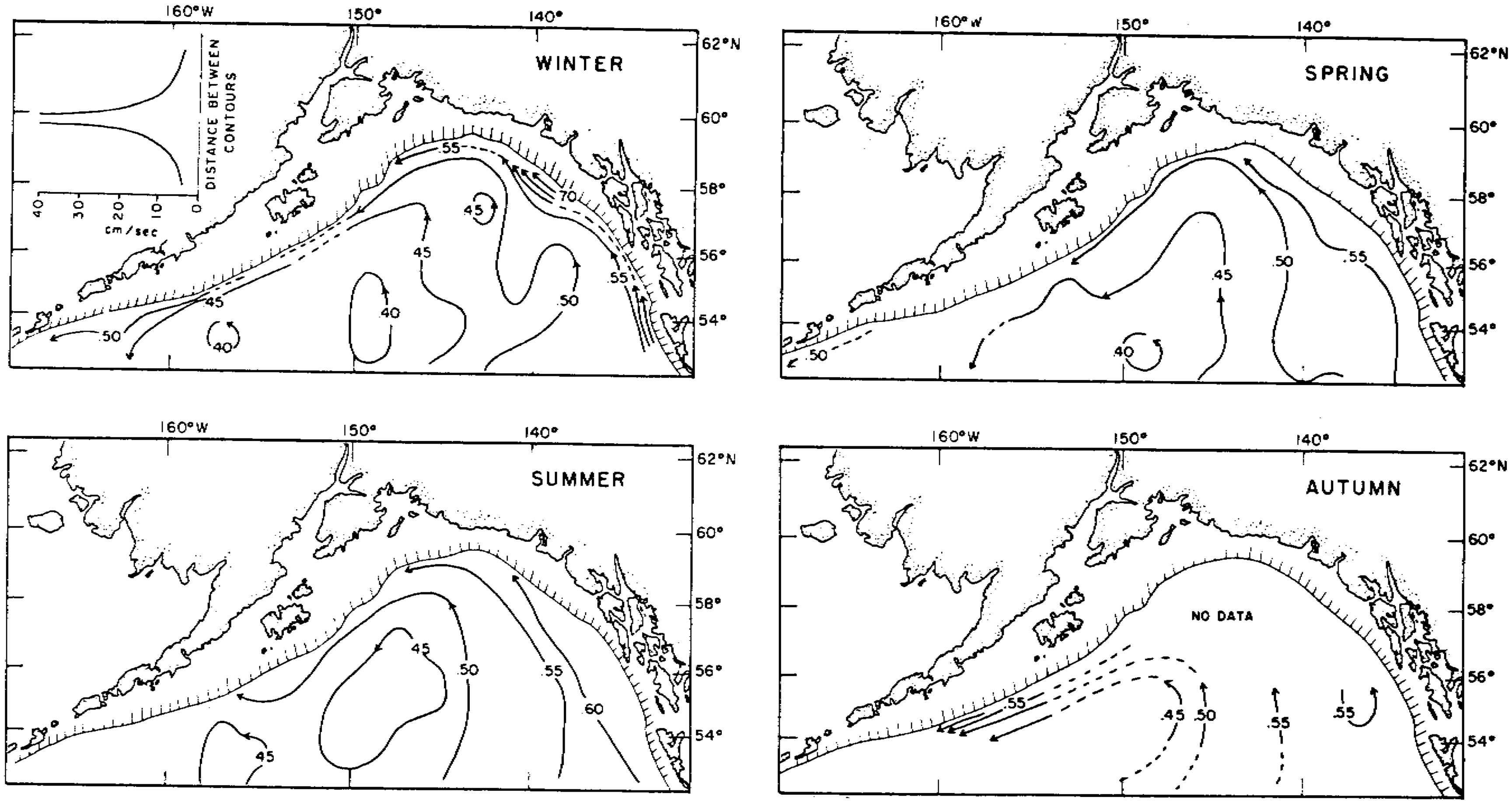


Fig. IV-6. Long-term seasonal mean geopotential topographies, 0/300 db, (based on 2°x2° grid) showing variability in geostrophic flow particularly the high velocities at the eastern side of the gulf (the broad grid spacing prevents showing the boundary current at the western side). (Ingraham, Bakun, and Favorite, RU #357)

A review of geostrophic current and water transport rates for the Gulf indicates that the choice of an appropriate reference level has been subjective and varied. Levels near 3,000 to 4,000 db are considered to be more representative of actual flow than shallower levels (Favorite 1974). Estimates of flow in waters over the shelf should be interpreted with caution. Intensified cyclonic flow observed near the shelf edge in this area may affect the flow regime over the shelf as an inshore countercurrent is usually detected in geostrophic computations (Ingraham, Bakun, and Favorite, RU #357). According to these authors, "it is not clear whether this is an aspirative phenomenon not uncommon under such circumstances, whether it is merely an error caused by inadequacies in the method ..., or whether it is largely the effect of eddies or shelf waves along the edge of the continental shelf." Galt and Royer (1975) have stressed that first-order currents in this area are not locally driven although there is a marked effect of local bathymetry (also see Hayes and Schumacher, RU #38). They also note that "perturbations in flow ... cannot be discussed without input data from the large-scale systems."

Direct Observations

Several sets of current meter data have been obtained recently in the Gulf of Alaska (Fig. IV-7). Current meter data reported by Galt and Royer (1975) indicated a westward flow at station 61 at both the sampling depths, 20 m and 162 m. Mean flow generally followed local bathymetric contours. Current meter data from station 61, as average values for each week, are given as progressive vectors

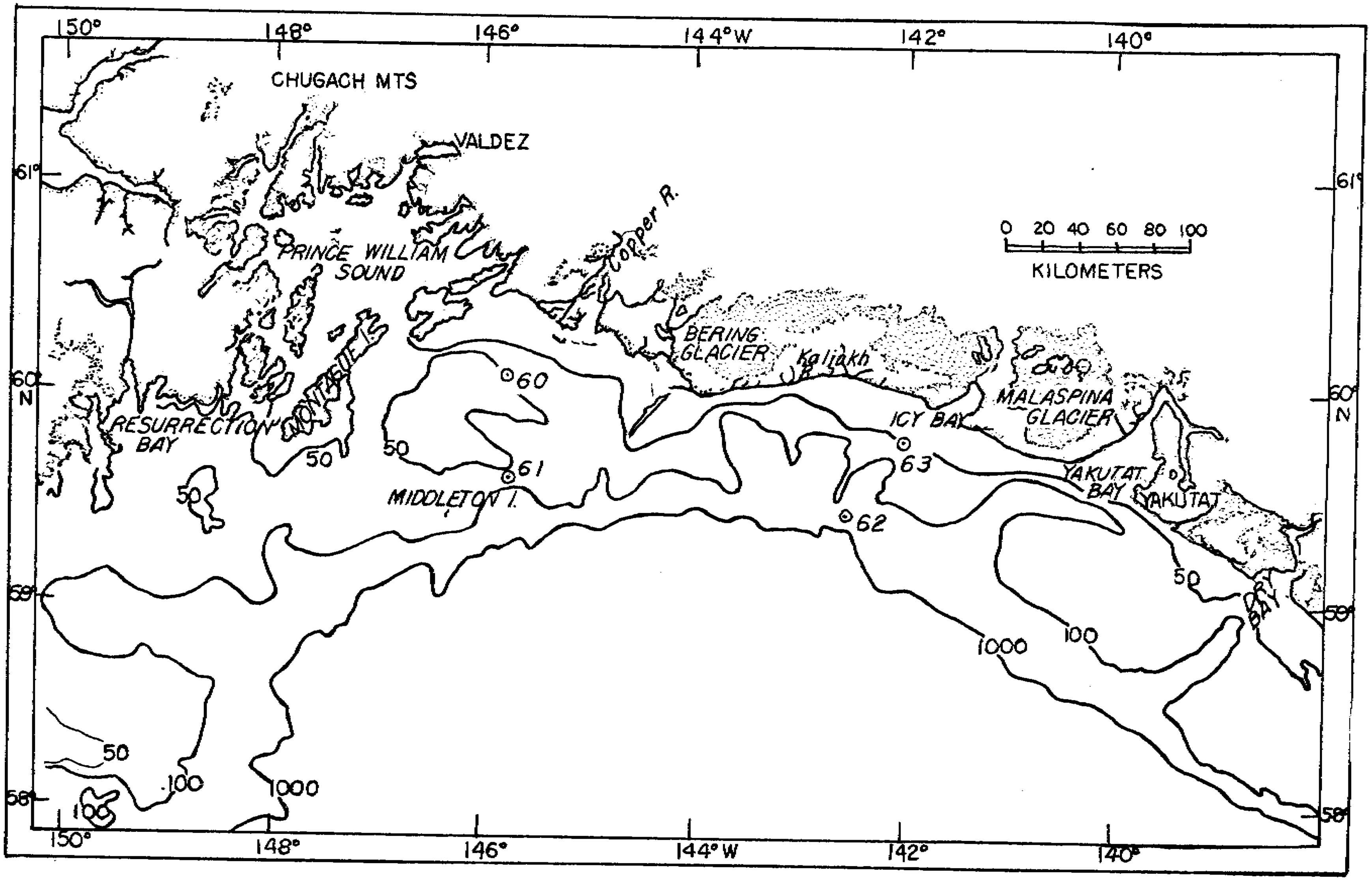


Fig. IV-7. Region of study in the Gulf of Alaska. Depth contours given in fathoms and station locations for moored current meter arrays are indicated by station number (Galt and Royer 1975).

(Fig. IV-8). An increase in velocities was noted in the latter part of the sampling period, October to November, at both depths but the response was weaker at 120 m. At Station 62, a 22-week record, from August 1974 to February 1975, also indicated a consistency in the direction of flow but primarily in north-northwest direction at both sampling depths, 24 m and 178 m (Fig. IV-9). As in case of Station 61, an increase in current speed was noted in the fall. This increase is apparently caused by the "barotropic pressure gradient that would be created with the buildup of seasonal downwelling in response to the fall-winter regime" (Galt and Royer 1975). At Station 60, due to numerous perturbations in the flow regime, average conditions were difficult to describe. Current meter records, from July to August 1974, are reported by Royer (RU #289). He noted that on a time-scale of 1 hr, there was decreasing randomness and magnitude of motion with depth. Surface boundary layer and baroclinic motions were of greatest influence at 20 m and 30 m, whereas rotary motions showing topographical influences were more significant at 90 m depth.

Mean flow rates, obtained by Hayes and Schumacher (RU #138), from five locations in the northern and western parts of the Gulf are given in Table IV-1. As expected, current speeds at 100 m are lower than at 20 m. A westward flow was noted in the northern Gulf, whereas strong southeast flow was observed off Kodiak Island (Fig. IV-10). Progressive Vector Diagrams (PVD) for current records at Stations 60 and 61 are given in Fig. IV-11. Flow at Station 60 lacked consistency in direction. It should be noted that flow recorded by lower current was very much lower than at 20 m and had a net offshore drift.*

*Locations of Stations 60 and 61 shown by Hayes and Schumacher (RU #138) and by Royer (RU #289 ; also see Galt and Royer 1975) are nearly the same. It is not obvious if the same current meter data are reported by the two research units. For Station 61, Hayes and Schumacher reported current meter data from depth, of 20 m and 100 m, whereas Galt and Royer reported results from 20 m and 162 m (Fig. IV-8).

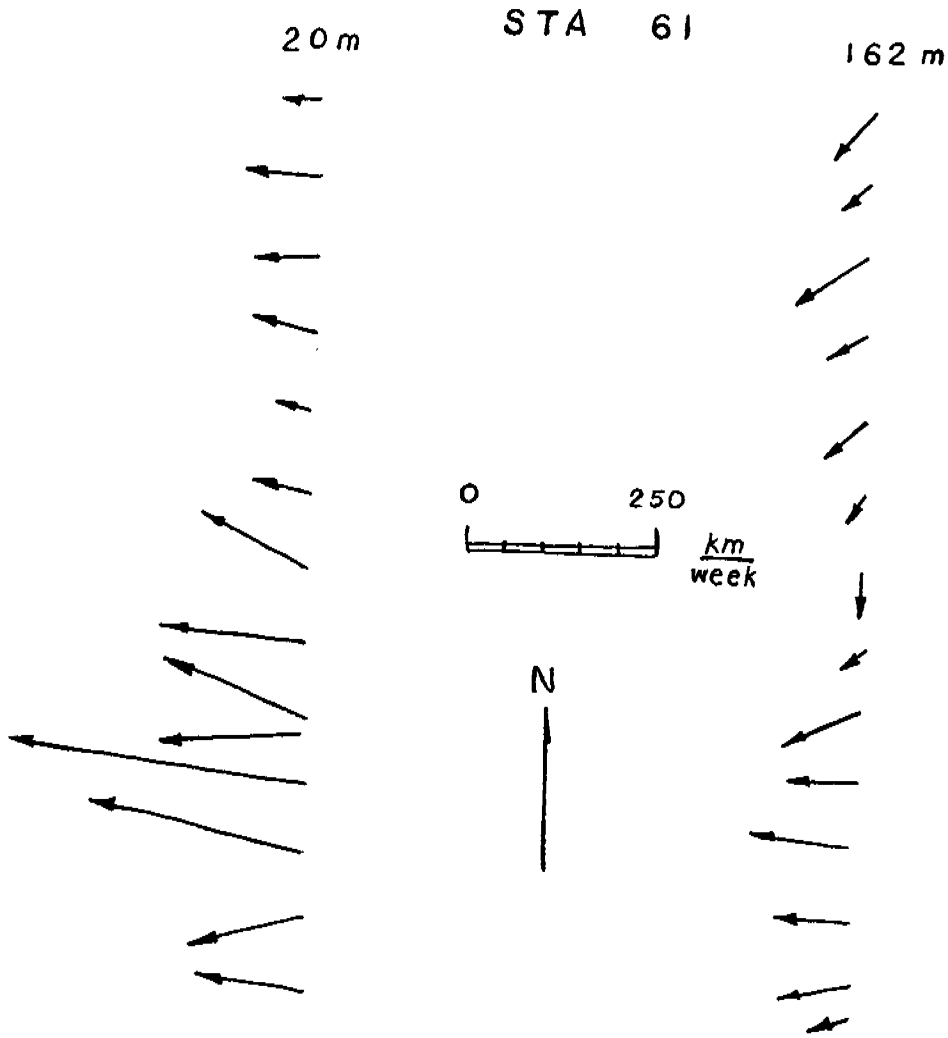


Fig. IV-8. Average weekly displacement for station 61 covering the period from August to November 1974. Values given for an upper meter (20 m depth) and a lower meter (162 m depth) (Galt and Royer 1975).

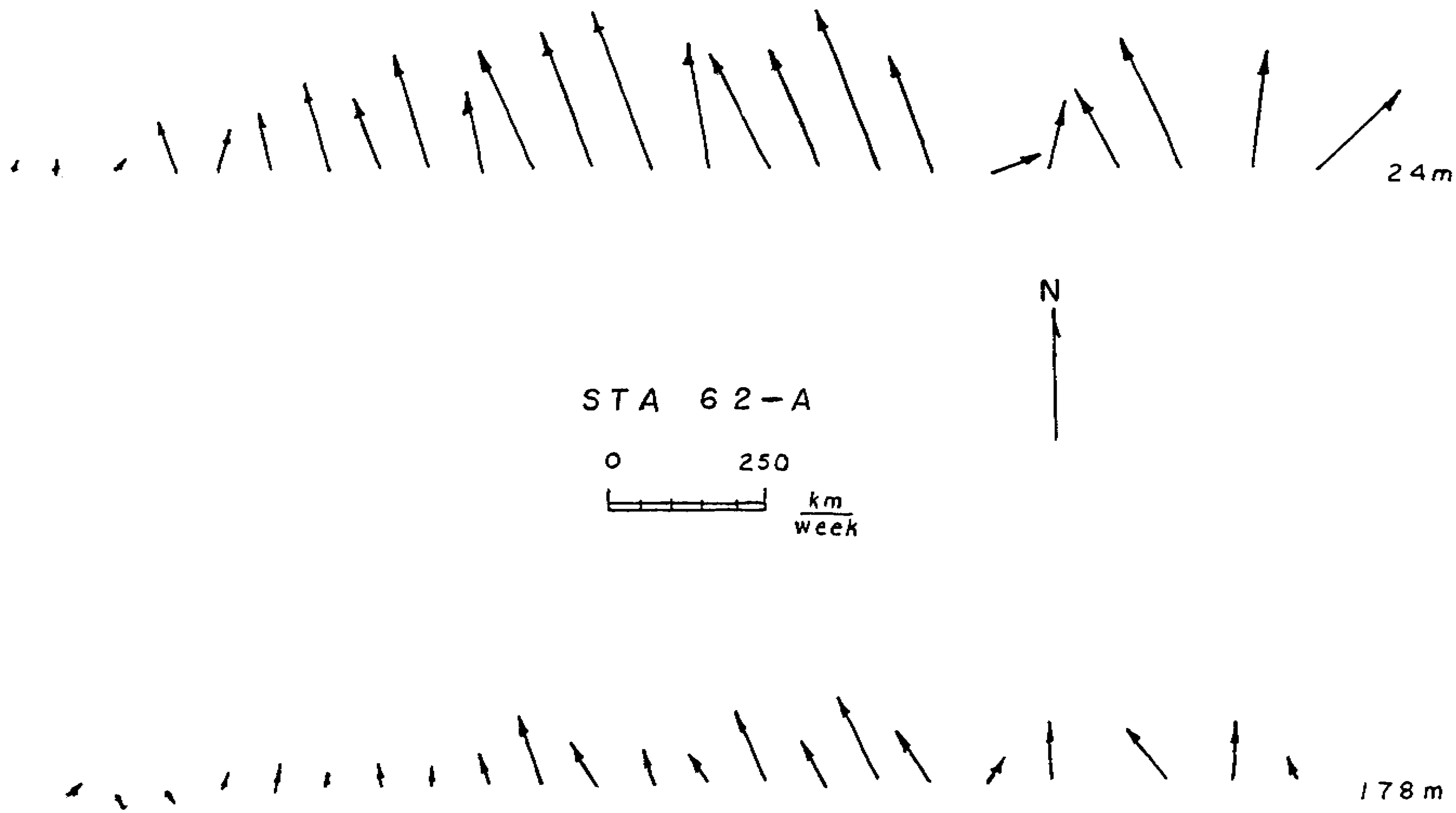


Fig. IV-9. Average weekly displacements for station 62 covering the period from August 1974 to February 1975. Values given for an upper meter (24 m depth) and a lower meter (178 m depth) (Galt and Royer 1975).

TABLE IV-1

Mean Flow Rates, cm/sec, and Direction (TN) From Moored Current Meter Arrays, at 20 and 100 m, From Stations in the Gulf of Alaska (Hayes and Schumacher, RU #138)

Station	Observation Period	Mean Flow	Direction
62E, 20 m	Sept. 20-Nov. 21, 1975	21.9	308
100 m		13.7	311
61, 20 m	Aug. 16-Nov. 15, 1975	18.9	283
100 m		1.8	303
WGC-1, 20 m	Sept. 5-Nov. 2, 1975	27.0	263
100 m		15.0	257
WGC-2, 20 m	Sept. 22-Nov. 28, 1975	32.9	229
100 m		25.6	226
60, 20 m	July 2-Aug. 26, 1974	7.3	277
100 m		1.2	156

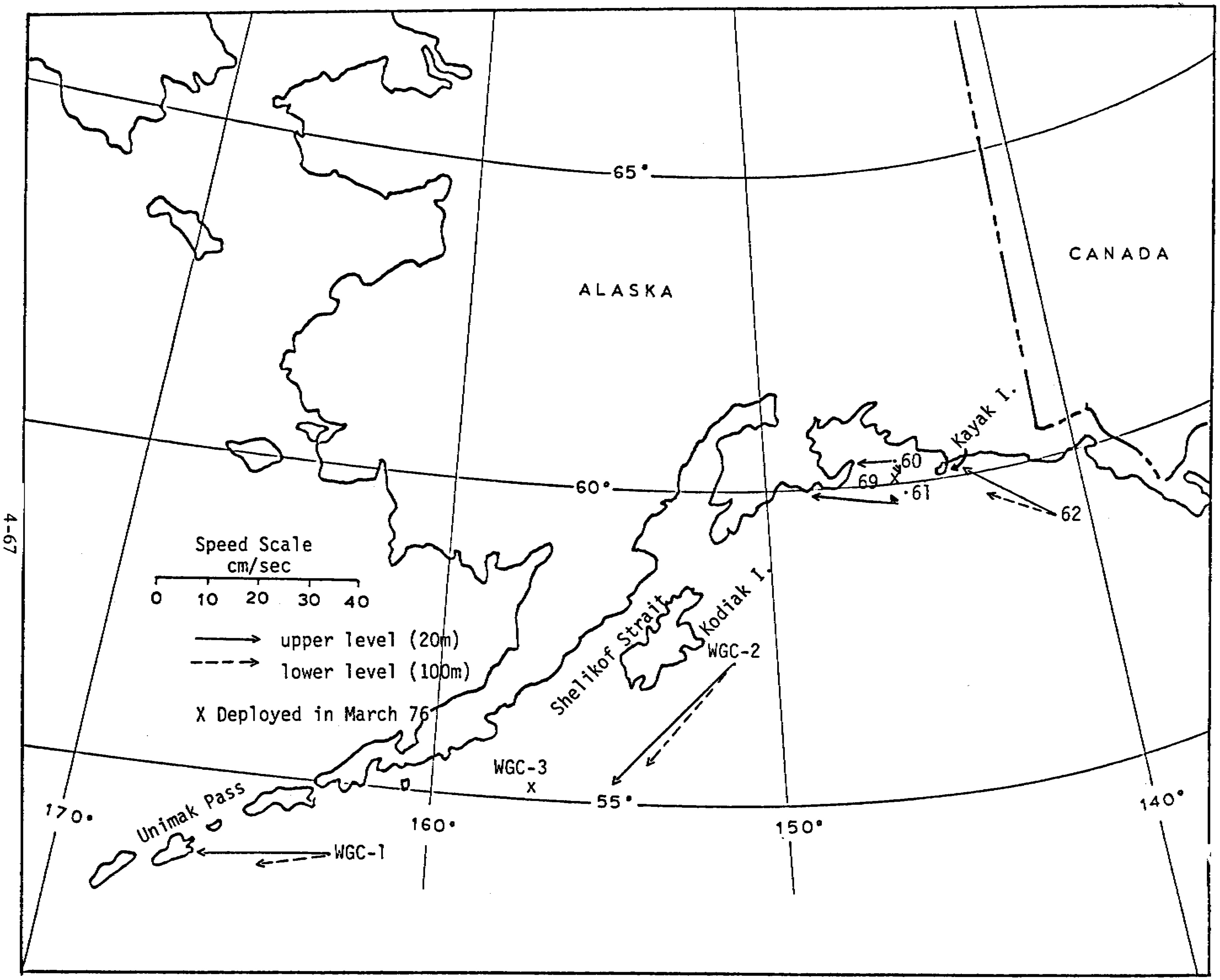


Fig. IV-10. Mean flow at various locations in the Gulf of Alaska (Hayes and Schumacher, RU #138).

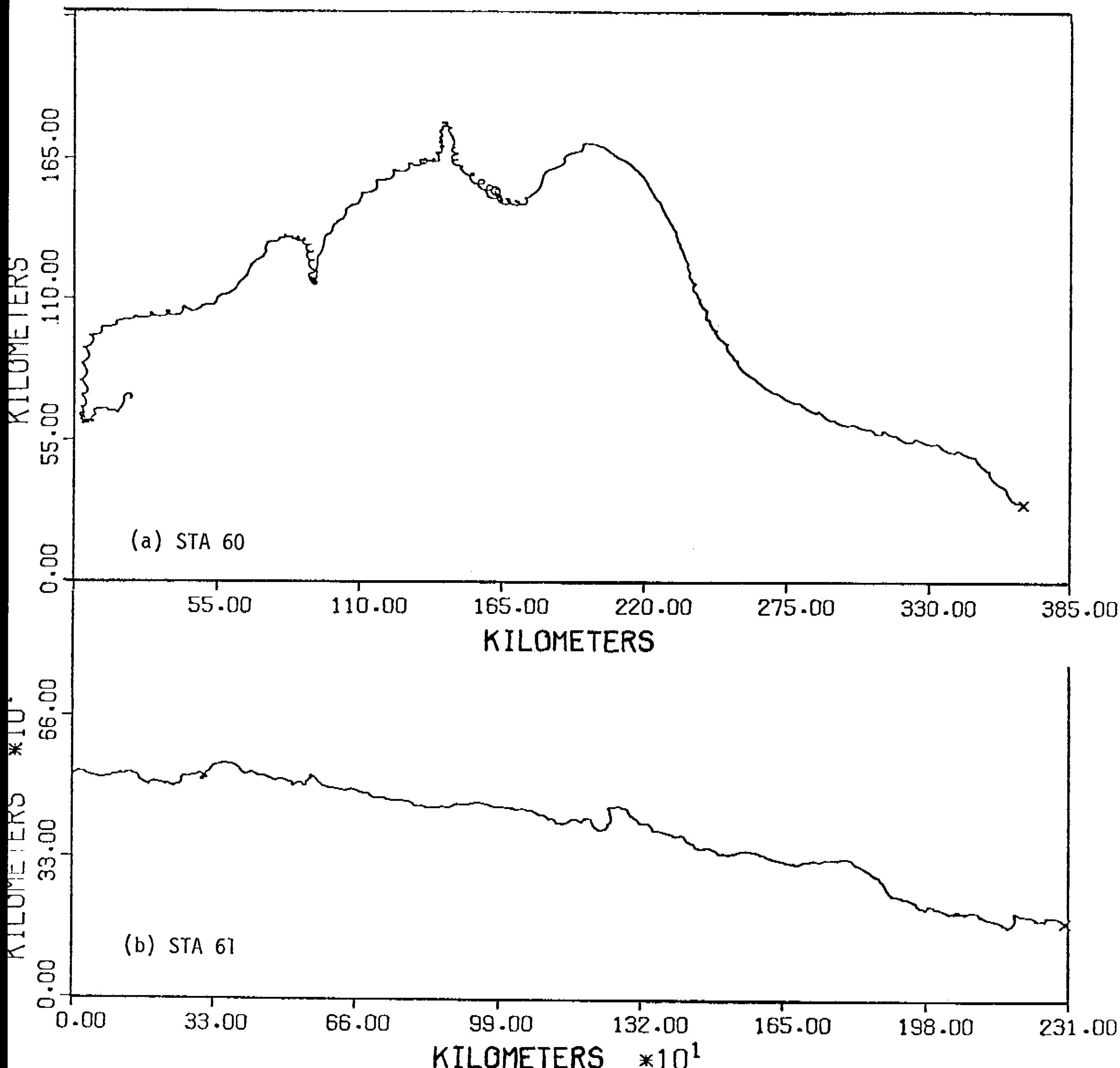


Fig. IV-11. PVD constructed from measurements at (a) STA 60 and (b) STA 61 during summer regime 1974 (Hayes and Schumacher, RU #138).

Time-series data collected off Icy Bay, February to May 1975, in the vicinity of Station 62 show the storm-induced response in currents and bottom pressure measurements. Responses were closely correlated in February rather than in March or April. High wind velocities in February, especially on February 17, 22, and 26, were reflected in increased bottom pressure and current speeds (Fig. IV-12). Increase in daily mean alongshore velocity of about 40 cm/sec were observed at 20 m and 50 m. These velocity changes were accompanied by 15 cm increase in bottom pressure. It should also be noted that ocean response to wind changes was quite rapid. Storm-induced velocity changes were of about the same magnitude as the mean flow. On March 20, on the other hand, current meter records at Station 62-B at 20 m showed a large increase, up to 50 cm/sec, but this increase was not associated with changes in bottom pressure or reflected in data from SLS-1.

There was a marked similarity in current patterns at 20 and 100 m at 62-B, indicating a barotropic response. A high correlation between velocity and bottom pressure during winter was calculated; correlation was insignificant for spring data (Hayes and Schumacher, RU #138). A lack of significant coherence between bottom pressure at Yakutat and calculated wind field was also noted for spring data. Hayes and Schumacher have suggested that either the baroclinic or non-local effects may be more important in spring.

Hansen (RU #217) provided results from the release of two telemetering free-floating buoys in the eastern part of the Gulf in September 1975. Both buoys were initially trapped in eddy-like features for a day or so around the release site, south of Yakutat in the vicinity of Fairweather Ground, before being carried westward. The buoy released closer to shore traveled farthest and fastest (Fig. IV-13). The flow appeared to be highly intermittent and

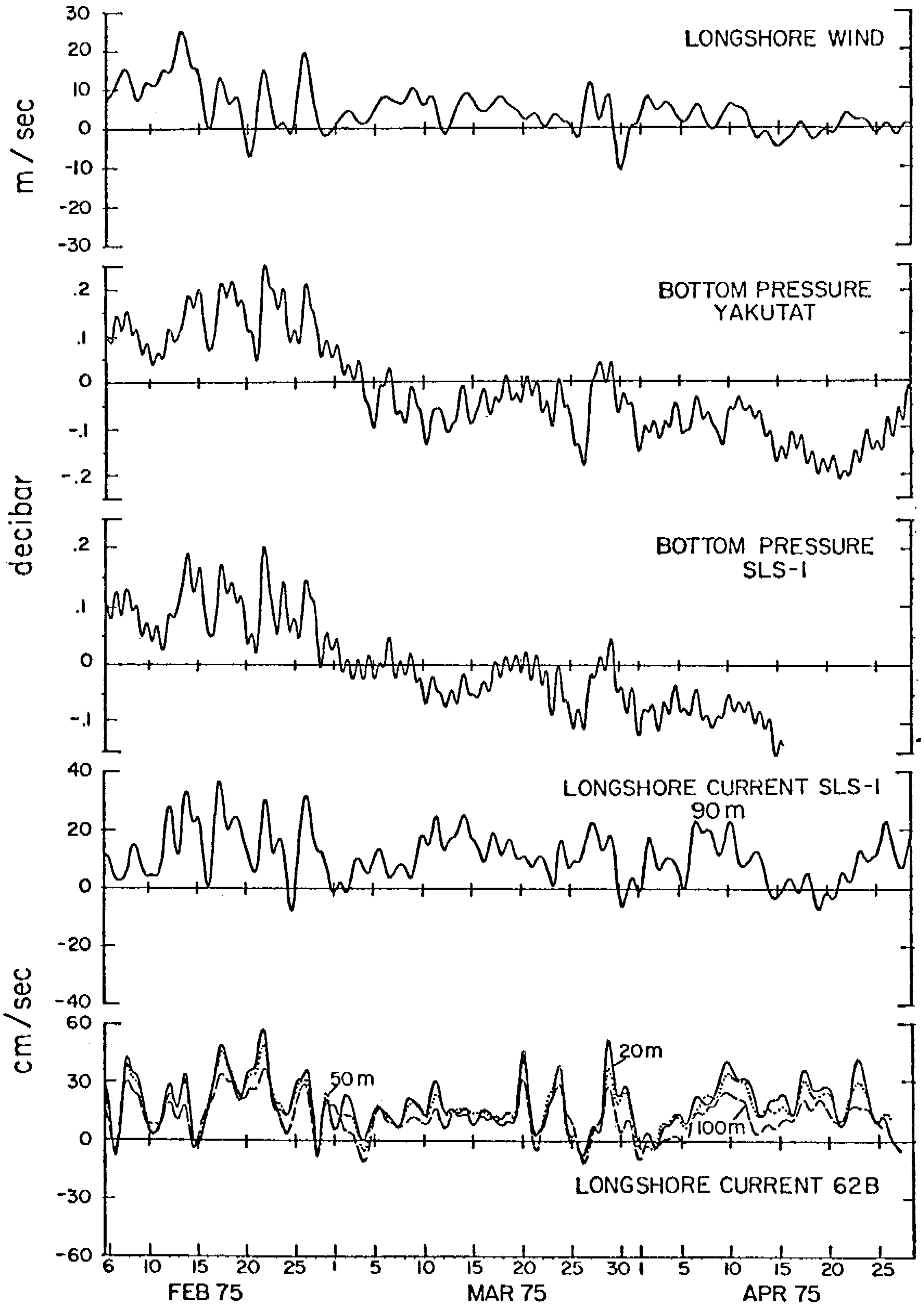


Fig. IV-12. Time series of measurements from Icy Bay pilot experiment February to May 1975 (Hayes and Schumacher, RU #138).

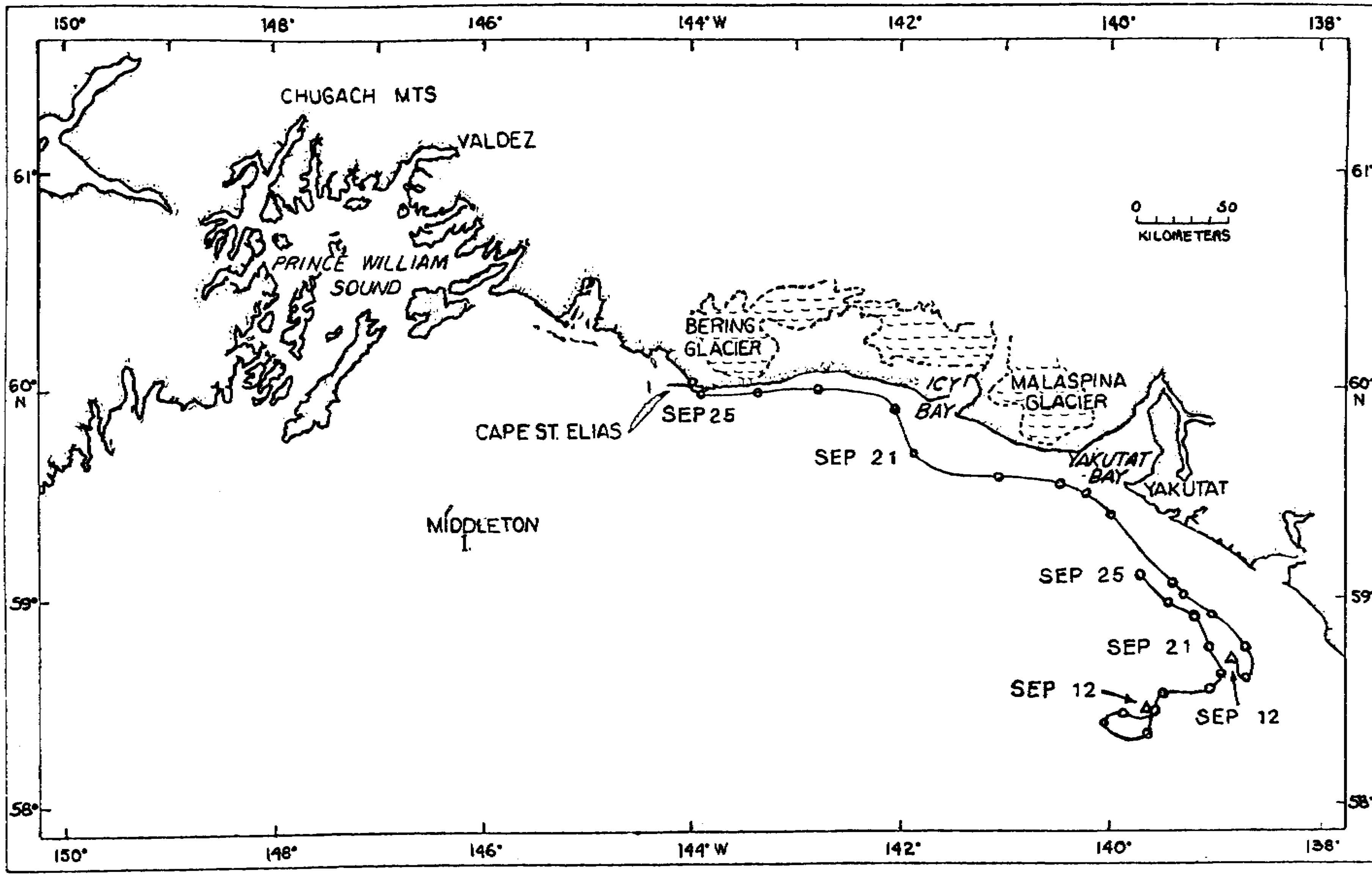


Fig. IV-13. Lagrangian drogue trajectories for set released south of Yakutat September 1975 and tracked via satellite (from Galt 1976).

apparently showed strong influence of local bathymetry. Estimated current speeds varied between 15 to 51 cm/sec (0.3 to 1.0 knot).

Estimates of current directions and transport of suspended sediment in nearshore waters in the northern Gulf were obtained by ERTS imagery in September 1972 and 1973 (Fig. IV-14). The following conclusions pertaining to ERTS data are reproduced below from EIS for the northern Gulf of Alaska:

> "The synoptic coverage afforded by ERTS indicates that overall circulation in the nearshore near surface waters of the Gulf of Alaska is counterclockwise at least during clear weather--consistent with the flow of the Alaskan gyre.
>
> The least cloud covered ERTS imagery of the southcentral Alaskan coastal zone was obtained during the period of August-October. The large number of cloudy days, the low sun angles in the winter, and the 18-day cycle of the satellite greatly restricted additional coverage which is necessary in order to obtain a more complete model of circulation. The results shown here represent the infrequent fair-weather conditions.
>
> Complicated flow patterns (flow reversals, complex gyres, and zone of convergence and divergence) develop within the nearshore zone and can be seen clearly on the green and red bands of ERTS images. These flow patterns are affected by tides, winds, and topography."

A transportable, easily assembled and operated radar unit capable of producing current maps at specific sites is under development (Barrick, RU #48). Signals broadcast and received are converted to digital bit streams, filtered, and Fourier transformed in the field in real-time. The outputs are expected to be sea-echo Doppler spectra which will contain identifying features of current patterns. More information on the unit or any results obtained is not available to us presently.

WIND STRESS EFFECTS

Wind stress transport mechanisms and indices of onshore-offshore movement of water, such as the Coastal Divergent Index (CDI) in the Gulf were briefly

Fig. IV-14. Near surface current directions in the Gulf of Alaska as interpreted from ERTS imagery of September 1972 (solid arrow) and September 1973 (dashed arrows) (from EIS, Northern Gulf of Alaska, BLM, 1976).

described in the KODIAK ISLAND-Currents Section of this report. A detailed account is given by Ingraham, Bakun, and Favorite (RU #357).

Monthly mean conditions of coastal and offshore divergence indices at various locations in the gulf, as identified by various combinations of wind stress, Ekman Transport, and upwelling-downwelling vectors (Fig. IV-15) are given in Table IV-2. Three locations (59°N 151°W, 60°N 146°W, and 59°N 141°W) are in the northern part of the gulf and are characterized by a stable and possibly low-energy situation in the summer (type D). Winter is characterized by highly energetic pulsations and relaxations of coastal divergences throughout the area.

NUMERICAL MODELING

Ingraham, Bakun, and Favorite (RU #357) have provided estimates of water transport based on results from a numerical model first described by Galt (1973) for the Arctic Ocean. This model provides time-dependent solutions of the transport stream functions which, when presented in maps and contoured, give transport stream lines. The basic governing equations of the model are: continuity equation (Eq. A), vorticity equation (Eq. B), and an expression relating vorticity and the stream function (Eq. C). In non-dimensional form these equations are as follows:

Equation A ....
$$\frac{\partial}{\partial x}(hu) + \frac{\partial}{\partial y}(hv) = 0$$

Equation B ....
$$\frac{\partial \xi}{\partial t} = (\nabla x \psi \vec{k}) . \nabla (\frac{\alpha \xi + f}{h}) + \beta \nabla^2 \xi - \frac{\gamma}{h} \left[\xi + \nabla \psi \cdot \nabla (\frac{1}{h}) \right] + \nabla x (\frac{\tau}{h})$$

Equation C ....
$$\nabla \left(\frac{1}{h} \nabla \psi \right) = \xi$$

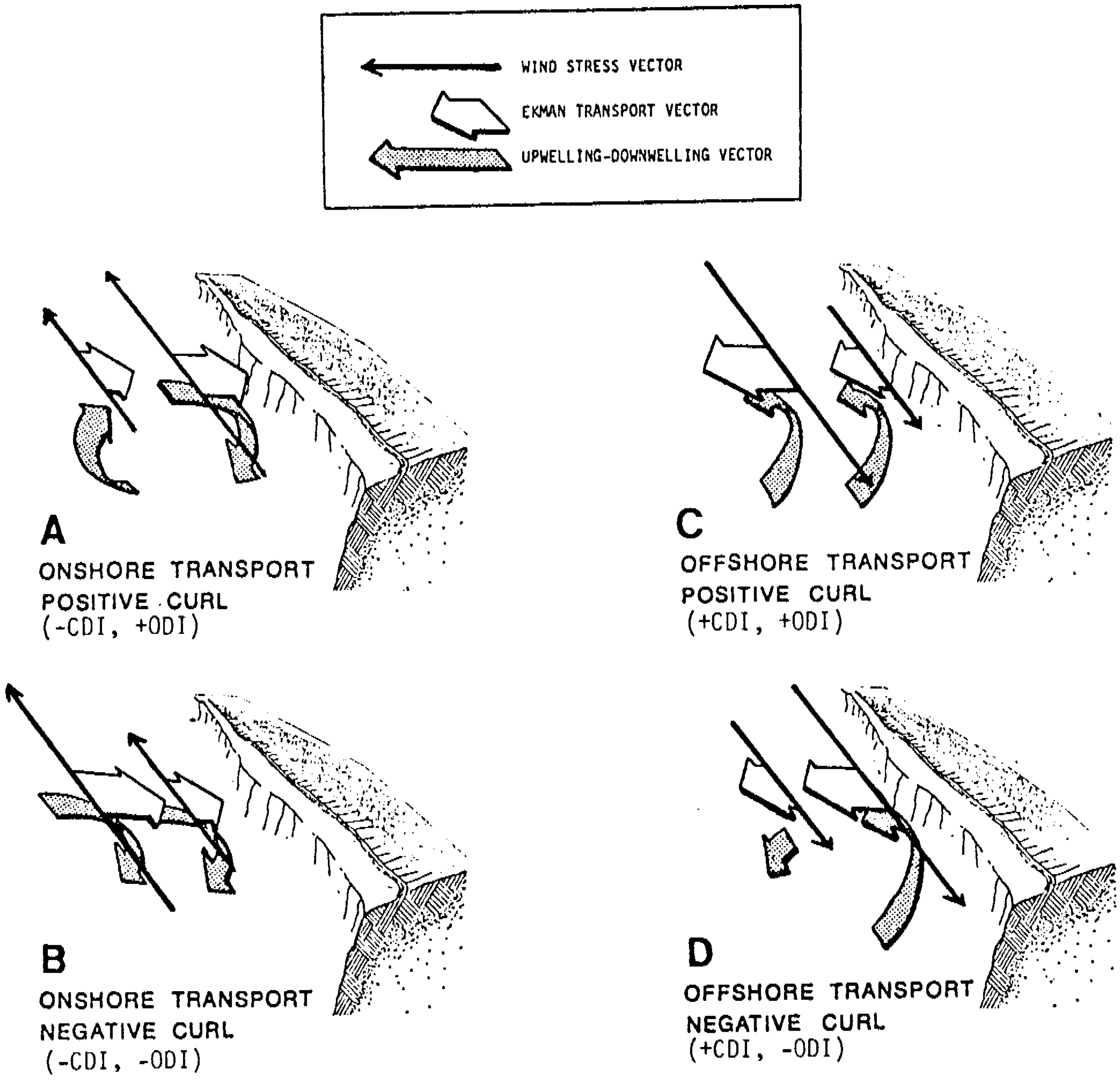


Fig. IV-15. Classification of indicated events according to combination of coastal and offshore convergence or divergence. A. Onshore Ekman transport and positive wind stress curl; convergence and downwelling at the coast, divergence and upwelling offshore. B. Onshore Ekman transport and negative wind stress curl; convergence and downwelling at the coast, continued convergence offshore. C. Offshore Ekman transport and positive wind stress curl; divergence and upwelling at the coast, continued divergence offshore. D. Offshore Ekman transport and negative wind stress curl; divergence and upwelling at the coast, convergence offshore (Ingraham, Bakun, and Favorite, RU #357).

TABLE IV-2

Monthly Mean "Types" of Convergence-Divergence Couple, According to the Classification Shown in Fig. IV-15 (Ingraham, Bakun, and Favorite, RU #357)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
54N, 164W	B	A	A	C	C	C	C	C	C	C	C	C
55N, 160W	B	A	A	C	A	C	C	C	C	C	C	A
57N, 156W	B	A	A	C	A	C	C	C	C	A	A	A
59N, 151W	A	A	A	A	B	D	D	C	A	A	A	A
60N, 146W	A	A	A	A	B	D	D	D	A	A	A	A
59N, 141W	A	A	A	A	B	D	D	B	A	A	A	A
57N, 137W	A	A	A	B	B	B	B	B	B	A	A	A
54N, 134W	A	A	A	A	B	B	A	A	A	A	A	A

In these equations, ξ is the vertical component of vorticity; h is the depth of water; t is the Coriolis parameter; α, β, and γ are constants that specify non-linear advection, horizontal and vertical friction forces, respectively; ψ is the transport stream function; and τ is wind stress. The constants, α, β, and γ, govern the character of the solution. For example, setting $\alpha = 0$ removes the non-linear advective terms from the model. The magnitude of β determines the importance of lateral friction in the solution.

Initial conditions of ψ and ξ are provided for $t = 0$; ψ is also specified on the region boundary for all time. The model reaches steady state when vorticity dissipation (for example, due to frictional effects) and vorticity input (due to wind-stress curl field) are in balance. Further details of these equations, such as integration procedure, computation of new values of stream function from Equation C, and finite-difference analog representations, are provided by Galt (1973.

Model results based on seasonal mean wind stress data (1950-74), a 10% bathymetry factor (bathymetry is scaled relative to the mean depth), and a 6-hr time-step (possibly due to sampling interval of wind data), are shown in Fig. IV-16. Simulated flow pattern shows the general features of observed flow. Autumn and winter transport pattern are much more intense. Maximum transport of 63 Sv across 54°N (between 130° and 160°W) occurred under autumn conditions; winter transport values were 51 Sv, summer with 13 Sv, and spring with 11 Sv. Western boundary intensification and asymmetry in the cyclonic gyre are also reproduced.

A large difference in mean flow due to relative wind stress was also noted. In winter 1969, a high transport value was 83 Sv, whereas it was 22 Sv in 1963 (not illustrated here). The greatest departure from average yearly conditions

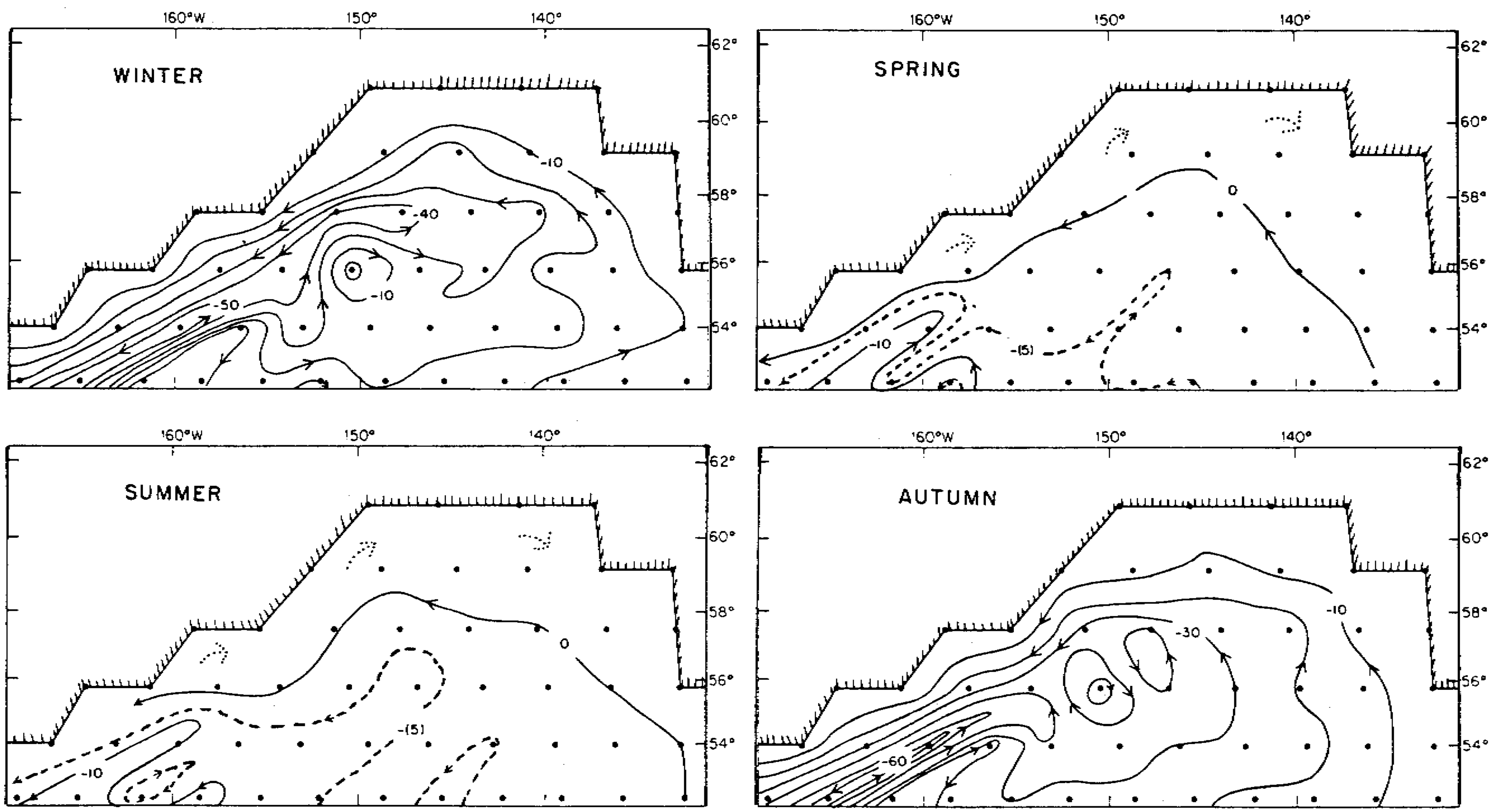


Fig. IV-16. Seasonal mean transports (Sv) in the gulf obtained from numerical model studies (Ingraham, Bakun, and Favorite, RU #357).

occurred in the eastern part of the Gulf where the easterly flow was farther south than under average conditions and resulted in a more intense northwesterly flow along the coast. This was apparently associated with strong, positive wind-stress curl in the eastern Gulf in that year (Ingraham, Bakun, and Favorite, RU #357).

Few results from a revised version of the numerical model previously described are given by Galt (1976). This model also incorporates density variations, sea bottom and coastal configuration effects, as well as "wind driven surface flows and frictional currents along the bottom." The report describing the details of the model formulation and equations is not available to us presently. In the first case (Fig. IV-17), for which density variations caused by temperature and salinity were not considered, a westward but weak flow was noted over the shelf between Middleton Island and the Copper River Delta. In the second case (Fig. IV-18), in which density variations were included, a much stronger westward flow was noted. In addition, two gyres and meandering currents were observed over the shelf. East and south of Cape St. Elias, flow in both cases was consistently westward. Inshore of Middleton Island, perturbations in the flow were apparently related to the influences of Copper River discharge. It is speculated by Galt (1976) that at times of low runoff gyre formation would be less developed and westward flow may be more consistent and prominent. Effects of strong autumn-winter winds may, however, make the pattern more complex.

Velocity fields recorded at Stations 61 and 62 (for locations, see Fig. IV-7) were also simulated by the model. As shown in Fig. IV-8, simulated flow at Station 61 was west of west-northwest (Fig. IV-19). A northwesterly flow observed at Station 62 (Fig. IV-9) is also depicted by the model (Fig. IV-20).

It is obvious that the preliminary results from numerical modeling of flow regimes in the Gulf of Alaska are very encouraging. However, the limitation of considering only the barotropic flow in the first model and the diagnostic nature of the second, should be kept in perspective. Commenting on their results, Ingraham, Bakun, and Favorite (RU #357) have stated: "Caution must be taken when interpreting the results because of the barotropic assumption which allows minor changes in deep bathymetry to affect flow. Further, short (one month or less)

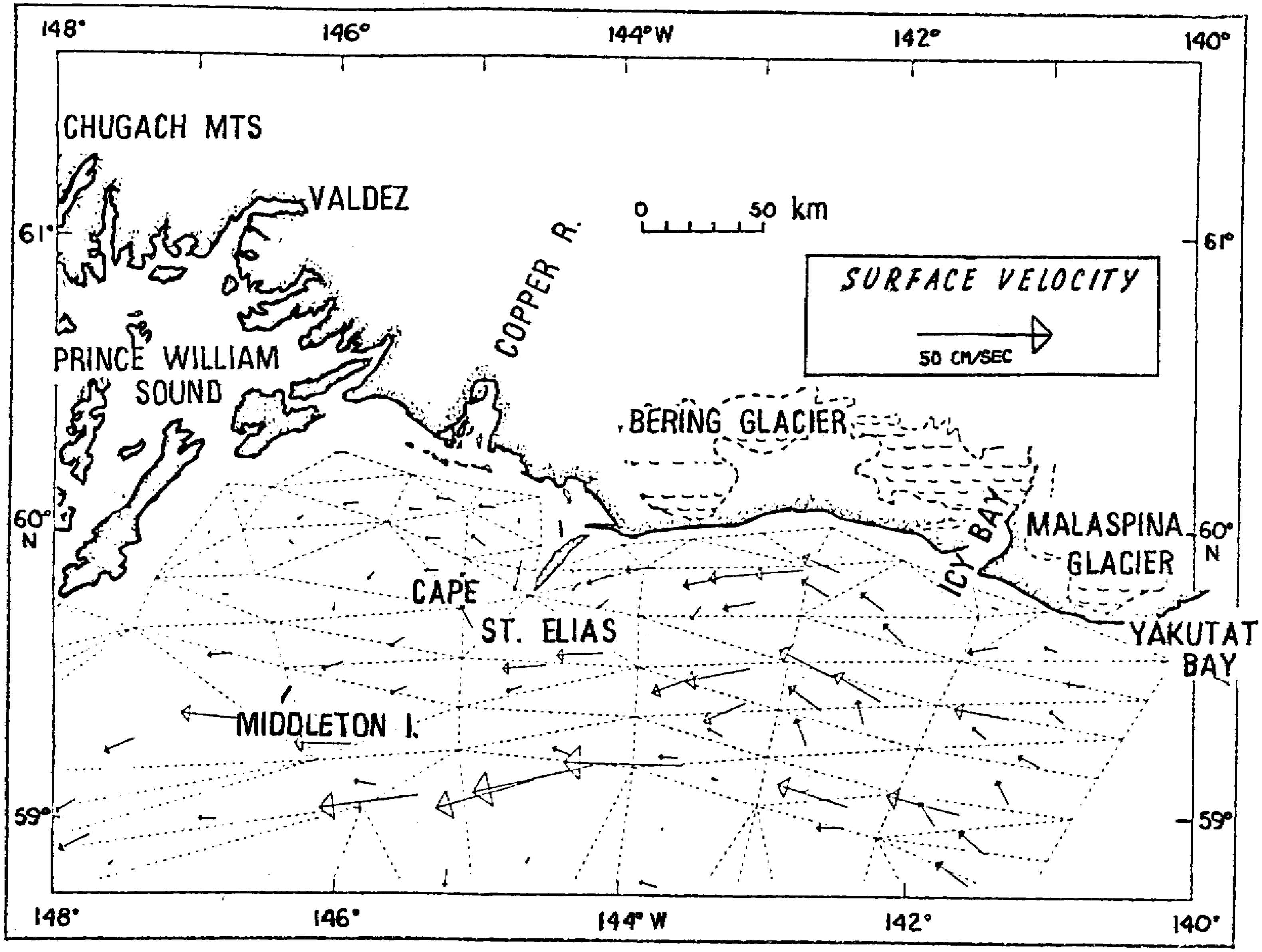


Fig. IV-17 Numerical modeling results for test case assuming homogeneous water. Vertices of triangles indicate oceanographic station locations used for input data (Galt 1976).

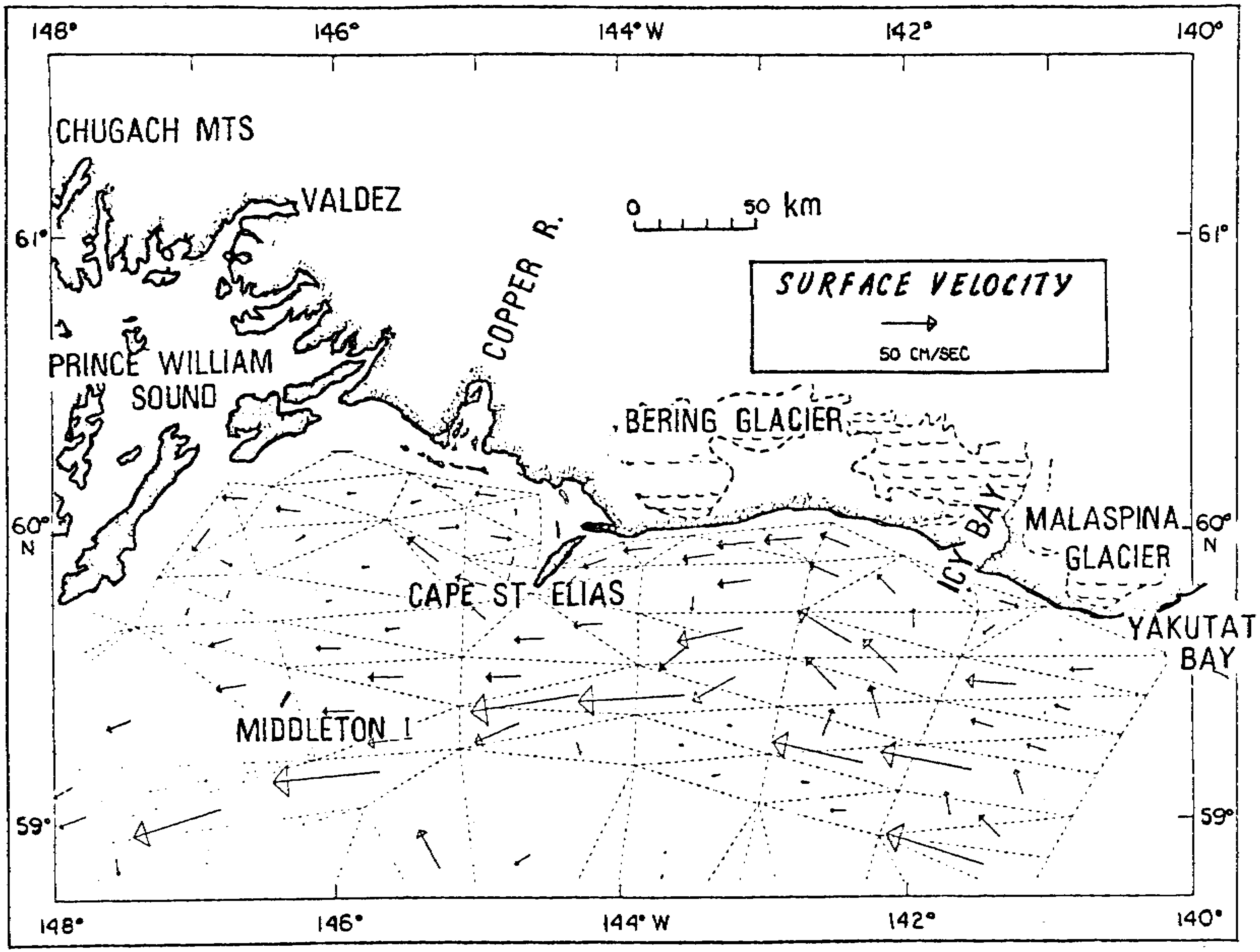


Fig. IV-18. Numerical model results for test case using density data collected July 1974. Vertices of triangles indicate oceanographic station locations used for input data (Galt 1976).

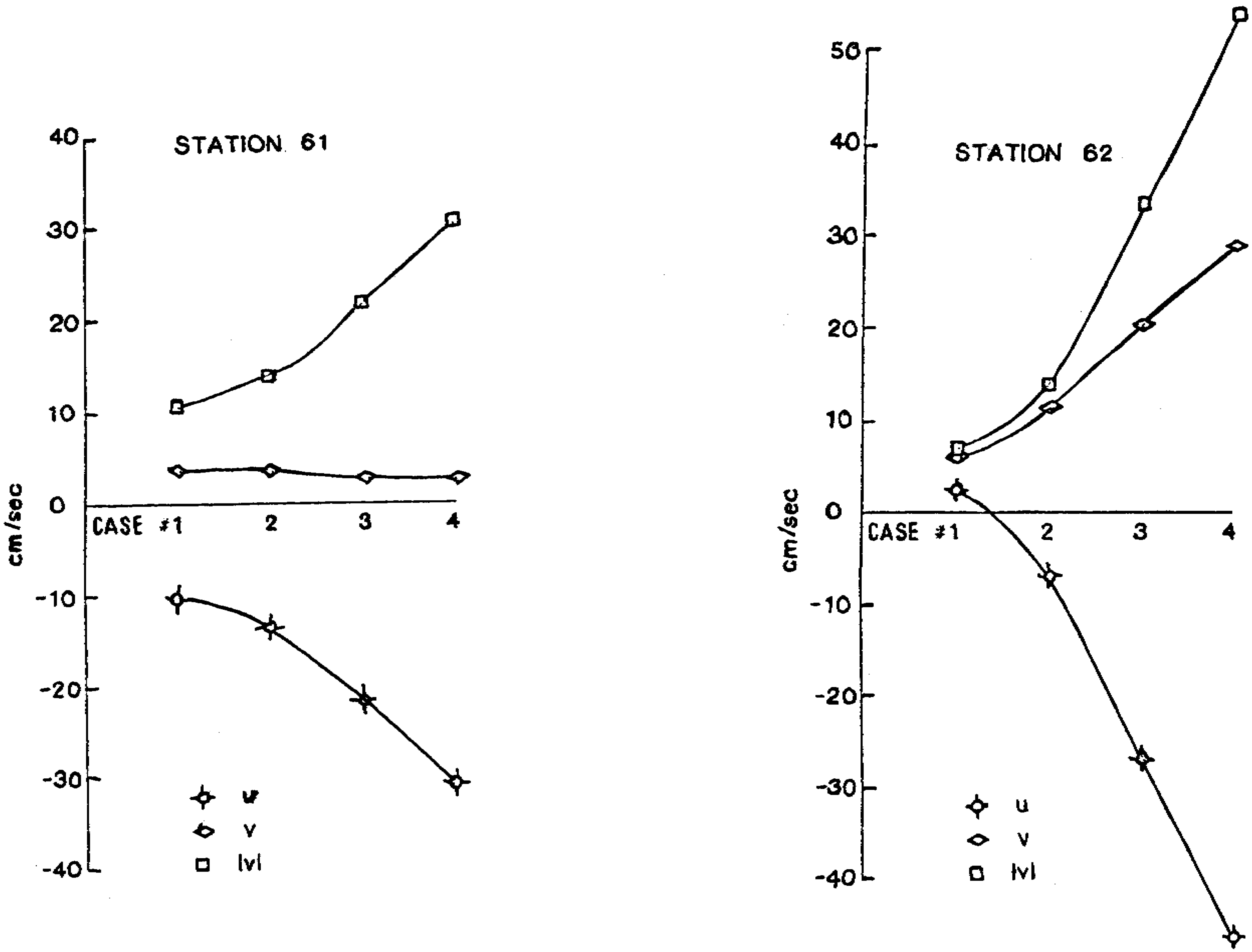


Fig. IV-19 and IV-20. Currents predicted by the numerical model for the location of current meter Station 61 and 62. Cases one through four represent various setting on the boundary conditions. u is the east-west component of the current (east positive). v is the north-south component of the current (north positive). |v| is the magnitude of the current. (Galt 1976) periods of usually intense wind stress curl patterns give unrealistically high transports if run to a steady state solution a considerable time beyond their actual duration."

Modeling studies of coastal oceanic areas and near-surface layer of the atmosphere are also being conducted by Laevastu (RU #235). He has stressed that driving forces, such as surface winds, should be included in detail, especially when evaluating effects of rare, violent events (storms). The details of the methodology employed and any results obtained by this research unit are not available to us presently.

WAVES AND TIDES

No OCSEAP-related research Annual Report specifically describes and evaluates the phenomena of waves and tides. The following information is taken from EIS for the northern Gulf of Alaska (BLM 1976):

> Waves: Wave heights in the gulf vary extremely according to season. In summer, seas are the calmest; in autumn they are the roughest. North Pacific storms cause large waves of irregular periods and heights with a trochoidal form which affects ships disproportionately to their absolute size. Fetch for storm winds can exceed 1,850 km and can create waves as high as 15 m (50 ft) with an 18 second period. Reports of waves that large are unsubstantiated though reliable witnesses have reported waves of 9 m (Searby 1969).
>
> According to a report by the Gulf of Alaska Operators Committee, there is a 25% probability that waves will exceed 4 m (14 ft) during October, November, and December. Sea state probabilities for seas exceeding 1.5, 2.4, and 3.6 m (5, 8, and 12 ft, respectively) were computed by Searby (1969) and his results are shown in Fig. IV-21 (a-c).
>
> Tides: Tides in the Gulf of Alaska which usually range between 2 to 4 m (6-12 ft) are west coast mixed tides with marked diurnal inequality superimposed on the semidiurnal tide. Tidal influence on the regional circulation patterns is significant, especially for estuaries and island passages. Coupled with major storms, tidal currents can prove hazardous in shallow straits.
>
> A summary of discussion of mean and diurnal tidal ranges along the coast from Cape Spencer to Kodiak Island is provided by Searby (1969).

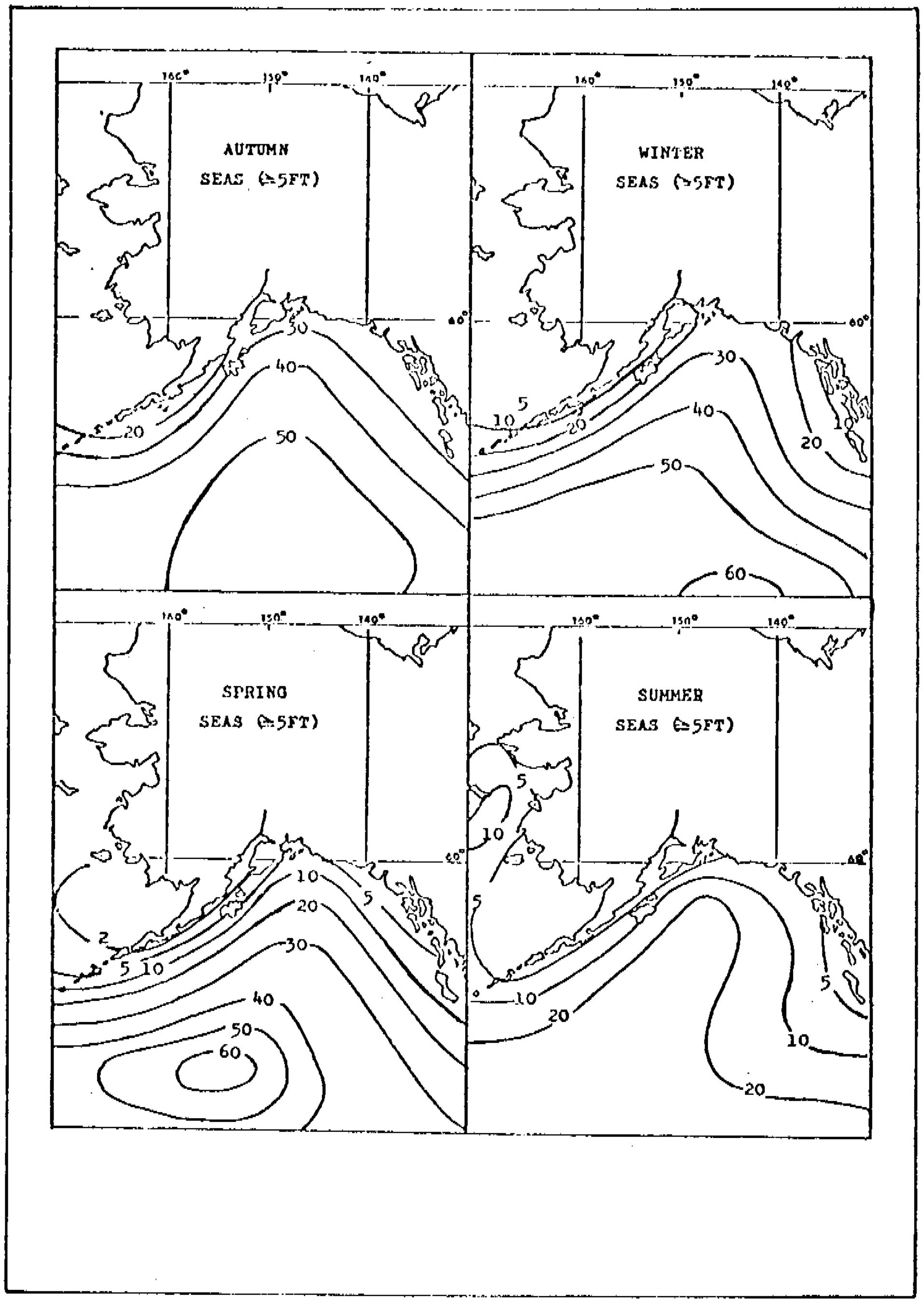


Fig. IV-21(a). Percentage frequency of seas ≥ 5 ft (Searby 1969).

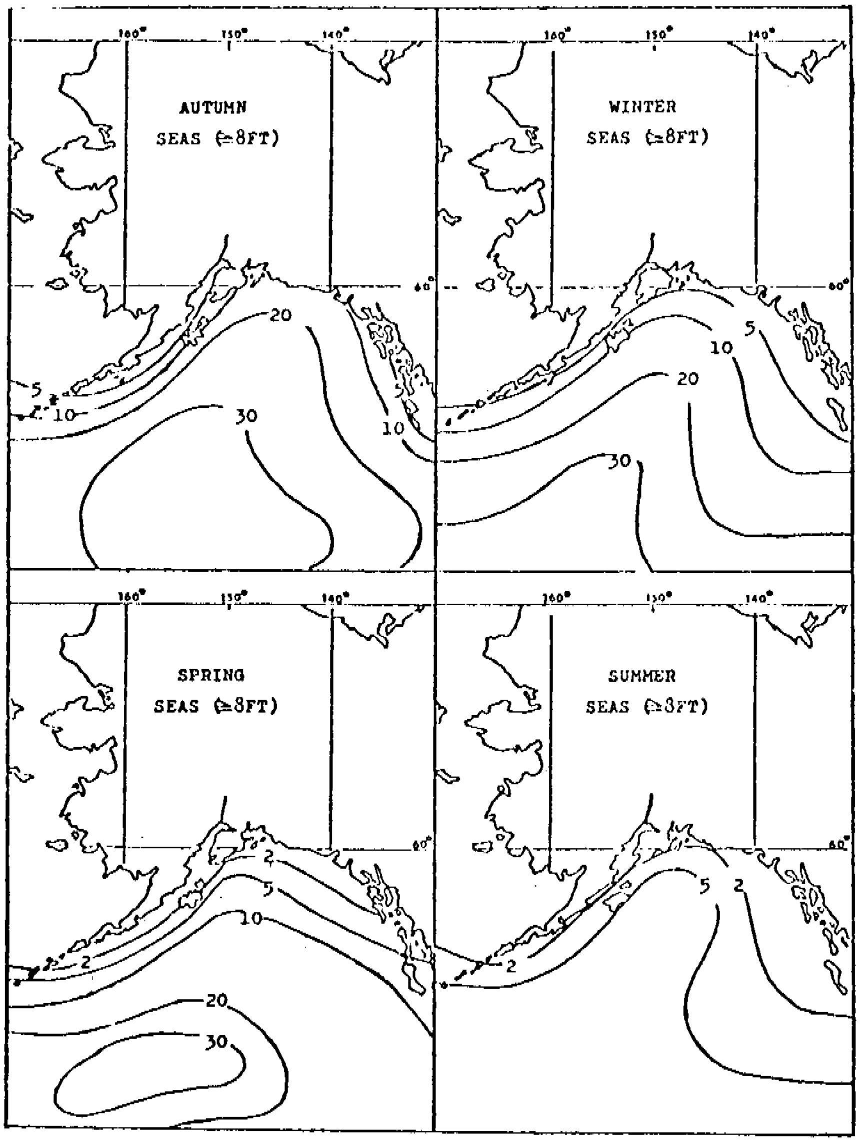


Fig. IV-21(b). Percentage frequency of seas ≥ 8 ft (Searby 1969).

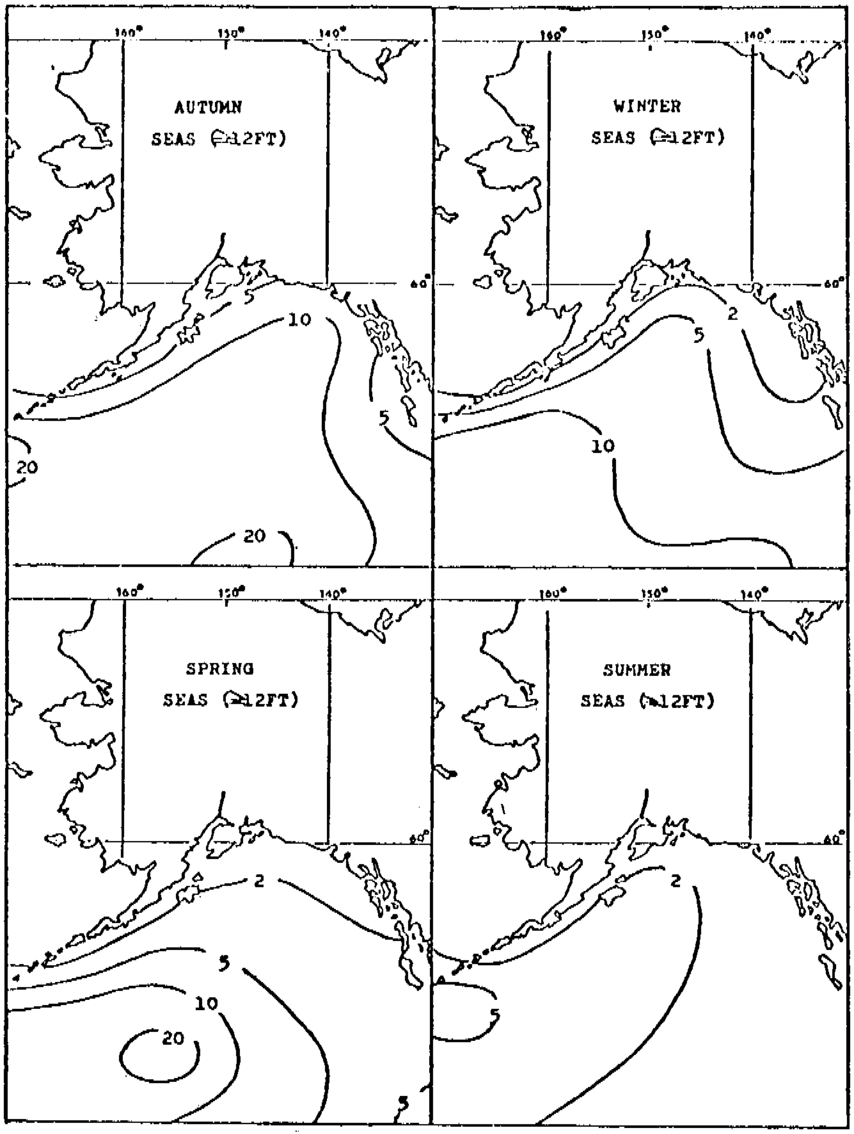


Fig. IV-21(c). Percentage frequency of seas ≥ 12 ft (Searby 1969).

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Chapter V

RECEPTORS

FISH

In this section field sampling programs and historical data review relating to northeast Gulf of Alaska (NEGOA) fisheries, conducted under NOAA/OCSEAP sponsorship, are summarized. English (RU #349 and 156) has formulated a taxonomic key of the ichthyoplankton and provided data on its abundance. Samples collected in the pelagic zone in October 1975 contained eggs and larvae of 13 families and 11 species. These represent adults that typically range in the near-surface pelagic zone, deep dwelling bathypelagic area, or bottom dwelling benthic or epibenthic region. A copy of the preliminary taxonomic key for pelagic fish eggs has been included (Table V-1). It is suggested by English (RU #349) that the key be verified in the field to confirm and judge its applicability and utility.

Other NOAA/OCSEAP funded studies in progress include an analysis of the abundance of demersal fish (Pereyra, RU #174), food and feeding relationships of demersal fish (Smith, RU #284), preparation of a taxonomic key based on skeletal remains and otoliths of forage fish (Morrow, RU #285), and a review of the literature and historical data on non-salmonid pelagic fish (Pereyra and Nelson, RU #64). Much of the effort during the first annual reporting period was ordered to compile field data and samples, literature, and historical records, with the analyses scheduled during the second half of the contract period. Smith (RU #284)

TABLE V-1

Preliminary Key to the Pelagic Fish Eggs of Alaskan Waters (from English, RU #349)

1a. Eggs spherical or nearly so . . . 2a.

1b. Eggs ellipsoidal. . . . *Engraulis mordax*

2a. Eggs with oil globules . . . 3a.

2b. Eggs without oil globules. . . . 7a.

3a. Eggs with single oil globule. . . . 4a.

3b. Eggs with 5-6 oil globules, diminishing to 2-3 in late stages of development. Shell with reticulate network, diameter 1.19-1.81 mm. . . . *Theragra chalcogramma*

4a. Oil globule larger than 0.30 mm. . . . *Merluccius productus*

4b. Oil globule smaller than 0.30 mm . . . 5a.

5a. Perivitelline space wide . . . *Sardinops caerulea*

5b. Perivitelline space narrow . . . 6a.

6a. Oil globule about 0.26 mm. . . . *Scomber japonicus*

6b. Oil globule about 0.10 mm. . . . *Citharichthys sordidus* . . . or *Citharichthys stigmaeus*

7a. Eggs with large, wide perivitelline space . . . *Hippoglossoides elassodon*

7b. Eggs with small, narrow perivitelline space . . . 8a.

TABLE V-1 (continued)

8a.	Eggs with diameter larger than 1.9 mm.	9a.
8b.	Eggs with diameter smaller than 1.9 mm	12a.
9a.	Shell punctured, honeycombed or wrinkled	10a.
9b.	Shell smooth	11a.
10a.	Shell punctured or with honeycomb appearance	*Hippoglossus stenolepis*
10b.	Shell wrinkled with a raised vermiculate pattern	*Microstomus pacificus*
11a.	Egg diameter greater than 3.0 mm	*Reinhardtius hippoglossoides*
11b.	Egg diameter smaller than 3.0 mm	*Anoplopoma fimbria*
12a.	Shell with hexagonal and/or pentagonal sculpturing	13a.
12b.	Shell not sculptured	14a.
13a.	Width of hexagon large, 0.042 mm	*Pleuronichthys coenosus*
13b.	Width of hexagon small, 0.037 mm	*Pleuronichthys decurrens*
14a.	Pigment spots present on late developing embryo	15a.
14b.	Pigment spots absent on late developing embryo.	*Eopsetta jordani*
15a.	Pigment spots on embryo and yolk	16a.
15b.	Pigment spots on embryo only	18a.

TABLE V-1 (continued)

16a. Eggs larger than 1.4 mm. . . . . *Lyopsetta exilis*

16b. Eggs smaller than 1.4 mm . . . . 17a.

17a. Chromatophores yellow . . . . *Platichthys stellatus*

17b. Chromatophores tan or brown . . . . *Psettichthys melanostictus*

18a. Egg diameter larger than 0.9 mm . . . . 19a.

18b. Egg diameter smaller than 0.9 mm. . . . . *Limanda aspera*

19a. Egg shell smooth, diameter 1.07-1.25 mm . . . .*Glyptocephalus zachirus*

19b. Egg shell minutely wrinkled, diameter 0.87-1.05 mm. . . . . . . *Parophrys vetulus*

Note: The characteristics in this key apply mainly to live materials, but may also be applicable to some preserved materials. Several species of commercial value are not included in the key because of lack of information.

provides preliminary data on four demersal fish species and their dietary habits in the Gulf of Alaska. His research has been reviewed in the KODIAK ISLAND-Fish section of this report.

A preliminary species list (Table V-2) has been compiled from those fish listed in the NEGOA Environmental Impact Statement and from those listed by Smith (RU #284), Pereyra (RU #175), McCain (RU #332), Morrow (RU #285), English (RU #156 and 349), and Pereyra and Nelson (RU #64). From historical records and field collections, 42 families and 165 species have been noted in NEGOA.

Few data specific to species in the northeast Gulf are currently available. Species-specific data of selected species, which are also common in NEGOA, have been discussed in the KODIAK ISLAND, BERING SEA, COOK INLET-Fish sections of this report.

TABLE V-2

Fish of the Northeast Gulf of Alaska

Family and Species	Common Name
Clupeidae	
Alosa sapidissima (Wilson)	American shad
Clupea harengus pallasi Valenciennes	Pacific herring
Salmonidae	
Oncorhynchus gorbuscha (Walbaum)	Pink salmon
O. keta (Walbaum)	Chum salmon
O. kisutch (Walbaum)	Coho salmon
O. nerka (Walbaum)	Sockeye salmon
O. tschawytscha (Walbaum)	Chinook salmon
Salmo clarki Richardson	Cuthroat trout
S. gairdneri Richardson	Rainbow trout
Salvelinus malma (Walbaum)	Dolly varden
S. alpinus (Linnaeus)	Arctic char
Thymallus arcticus (Pallas)	Arctic grayling
Gadidae	
Gadus macrocephalus Tilesius	Pacific cod
Merluccius productus (Ayres)	Pacific hake
Microgadus proximus (Girard)	Pacific tomcod
Theragra chalcorgramma (Pallas).	Walleye pollock
Anoplopomatidae	
Anoplopoma fimbria (Pallas)	Sablefish
Erilepis zonifer (Lockington)	Skilfish
Pleuronectidae	
Atheresthes stomias (Jordan and Gilbert)	Arrowtooth flounder
Embassichthys bathybius (Gilbert)	Deepsea sole
Eopsetta jordani (Lockington)	Petrale sole
Glyptocephalus zachirus Lockington	Rex sole
Hippoglossoides elassodon Jordan and Gilbert	Flathead sole
Hippoglossus stenolepis Schmidt	Pacific halibut
Isopsetta isolepis (Lockington)	Butter sole
Lepidopsetta bilineata (Ayres)	Rock sole
Limanda aspera (Pallas)	Yellowfin sole
Lyopsetta exilis (Jordan and Gilbert)	Slender sole
Microstomus pacificus (Lockington)	Dover sole
Parophrys vetulus Girard	English sole
Platichthys stellatus (Pallas)	Starry flounder

TABLE V-2 (continued)

Pleuronectidae (cont.)	
Pleuronichthys coenosus Girard	C-O sole
P. decurrens Jordan and Gilbert	Curlfin sole
Psettichthys melanostictus Girard	Sand sole
Reinhardtius hippoglossoides (Walbaum)	Greenland halibut
Scorpaenidae	
Sebastes aleutianus (Jordan and Evermann)	Rougheye rockfish
S. alutus (Gilbert)	Pacific ocean perch
S. babcocki (Thompson)	Redbanded rockfish
S. brevispinis (Bean)	Silvergray rockfish
S. caurinus Richardson	Copper rockfish
S. ciliatus (Tilesius)	Dusky rockfish
S. crameri (Jordan)	Darkblotched rockfish
S. diploproa (Gilbert)	Calico rockfish
S. elongatus Ayres	Greenstriped rockfish
S. entomelas (Jordan and Gilbert)	Widow rockfish
S. flavidus (Ayres)	Yellowtail rockfish
S. helvomaculatus Ayres	Rosethorn rockfish
S. maliger (Jordan and Gilbert)	Quillback rockfish
S. melanops Girard	Black rockfish
S. mystinus (Jordan and Gilbert)	Blue rockfish
S. paucispinis Ayres	Bocaccio
S. proriger (Jordan and Gilbert)	Redstripe rockfish
S. ruberrimus (Cramer)	Yelloweye rockfish
S. variegatus Quast	Harlequin rockfish
S. zacentrus (Gilbert)	Sharpchin rockfish
Sebastolobus alascanus Bean	Shortspine thornyhead
S. altivelis Gilbert	Longspine thornyhead
Scombridae	
Sarda chiliensis (Cuvier)	Pacific bonito
Scomber japonicus Houttuyn	Chub mackerel
Thunnus alalunga (Bonnaterre)	Albacore
T. thynnus (Linnaeus)	Bluefin tuna
Bothidae	
Citharichthys sordidus (Girard)	Pacific sanddab
C. stigmaeus Jordan and Gilbert	Speckled sanddab
Osmeridae	
Hypomesus pretiosus (Girard)	Surf smelt
Mallotus villosus (Müller)	Capelin
Osmerus mordax (Mitchill)	Rainbow smelt

TABLE V-2 (continued)

Osmeridae (cont.)	
Spirinchus starksi (Fisk)	Night smelt
S. thaleichthys (Ayres)	Longfin smelt
Thaleichthys pacificus (Richardson)	Eulachon
Hexagrammidae	
Hexagrammos decagrammus (Pallas)	Kelp greenling
H. lagocephalus (Pallas)	Rock greenling
H. octogrammus (Pallas)	Masked greenling
H. stelleri Tilesius	Whitespotted greenling
Ophiodon elongatus Girard	Lingcod
Pleurogrammus monopterygius (Pallas)	Atka mackerel
Zoarcidae	
Bothrocara brunneum (Bean)	Twoline eelpout
B. molle Bean	Soft eelpout
Lycenchelys jordani (Evermann and Goldsborough)	Shortjaw eelpout
Lycodapus fierasfer Gilbert	Blackmouth eelpout
L. grossidens Gilbert	Bigtooth eelpout
L. mandibularis Gilbert	Pallid eelpout
Lycodes brevipes Bean	Shortfin eelpout
L. diapterus Gilbert	Black eelpout
L. palearis Gilbert	Wattled eelpout
Lycodopsis pacifica (Collett)	Blackbelly eelpout
Trichodontidae	
Trichodon trichodon (Tilesius)	Pacific sandfish
Bathymasteridae	
Bathymaster signatus Cope	Searcher
Ronquilus jordani (Gilbert)	Northern ronquil
Stichaeidae	
Anoplarchus insignis Gilbert and Burke	Slender cockscomb
A. purpurescens Gill	High cockscomb
Bryozoichthys marjorius McPhail	Pearly prickleback
Chirolophis nugator (Jordan and Williams)	Mosshead warbonnet
C. polyactocephalus (Pallas)	Decorated warbonnet
Lumpenella longirostris (Evermann and Goldsborough)	Longsnout prickleback
Lumpenus maculatus (Fries)	Daubed shanny
L. sagitta Wilimovsky	Snake prickleback
Phytichthys chirus (Jordan and Gilbert)	Ribbon prickleback
Poroclinus rothrocki Bean	Whitebarred prickleback
Xiphister atropurpureus (Kittlitz)	Black prickleback

TABLE V-2 (continued)

Pholidae	
Apodichthys flavidus Girard	Penpoint gunnel
Pholis laeta (Cope)	Crescent gunnel
Pholis ornata (Girard)	Saddleback gunnel
Cryptacanthodidae	
Delolepis gigantea Kittlitz	Giant wrymouth
Lyconectes aleutensis Gilbert	Dwarf wrymouth
Ammodytidae	
Ammodytes hexapterus Pallas	Pacific sand lance
Ptilichthyidae	
Ptilichthys goodei Bean	Quillfish
Stromateidae	
Icichthys lockingtoni Jordan and Gilbert	Medusafish
Melamphaeidae	
Melamphaes lugubris Gilbert	Highsnout melamphid
Poromitra crassiceps (Günther)	Crested malamphid
Lampridae	
Lampris regius (Bonnaterre)	Opah
Trachipteridae	
Trachipterus altivelis Kner	King-of-the-salmon
Cottidae	
Blepsias bilobus Cuvier	Crested sculpin
Cottus aleuticus Gilbert	Coastrange sculpin
C. asper Richardson	Prickly sculpin
Dasycottus setiger Bean	Spinyhead sculpin
Hemilepidotus hemilepidotus (Tilesius)	Red Irish lord
H. jordani Bean	Yellow Irish lord
H. spinosus (Ayres)	Brown Irish lord
Hemitripterus bolini (Myers)	Bigmouth sculpin
Icelinus borealis Gilbert	Northern sculpin
I. oculatus Gilbert	Frogmouth sculpin
Icelus spiniger Gilbert	Thorny sculpin

TABLE V-2 (continued)

Cottidae (cont.)	
Leptocottus armatus Girard	Pacific staghorn sculpin
Malacocottus kincaidi Gilbert and Thompson	Blackfin sculpin
Myoxocephalus polyacanthocephalus (Pallas)	Great sculpin
Psychrolutes paradoxus Günther	Tadpole sculpin
Radulinus asprellus Gilbert	Slim sculpin
Rhamphocottus richardsoni Günther	Grunt sculpin
Triglops macellus (Bean)	Roughspine sculpin
T. pingeli Reinhardt	Ribbed sculpin
Agonidae	
Agonus acipenserinus Tilesius	Sturgeon poacher
Anoplagonus inermis (Günther)	Smooth alligatorfish
Asterotheca alascana (Gilbert)	Gray starsnout
A. infraspinata (Gilbert)	Spinycheek starsnout
Bathyagonus nigripinnus Gilbert	Blackfin poacher
Bothragonus swani (Steindachner)	Rockhead
Hypsagonus quadricornis (Cuvier)	Fourhorn poacher
Pallasina barbata (Steindachner)	Tubenose poacher
Bathylagidae	
Bathylagus stilbius (Gilbert)	California smoothtongue
Myctophidae	
Stenobrachius leucosparus (Eigenmann & Eigenmann)	Northern lampfish
Gasterosteidae	
Gasterosteus aculeatus Linnaeus	Threespine stickleback
Pungitius pungitius (Linnaeus)	Ninespine stickleback
Anarhichadidae	
Anarhichthys ocellatus Ayres	Wolf-eel
Notacanthidae	
Macdonaldia challengeri (Valliant)	Longnose tapirfish
Sphyraenidae	
Sphyraena argentea Girard	Pacific barracuda
Opisthoproctidae	
Macropinna microstoma Chapman	Barreleye

TABLE V-2 (continued)

Bramidae	
Brama japonica Hilgendorf	Pacific pomfret
Carangidae	
Trachurus symmetricus (Ayres)	Jack mackerel
Zaproridae	
Zaprora silenus Jordan	Prowfish
Scomberesocidae	
Colobabis saira (Brevoort)	Pacific saury
Acipenseridae	
Acipenser medirostris Ayres	Green sturgeon
A. transmontanus Richardson	White sturgeon
Rajidae	
Raja binoculata Girard	Big skate
R. kincaidi Garman	Black skate
R. rhina Jordan and Gilbert	Longnose skate
Cyclopteridae	
Aptocyclus ventricosus (Pallas)	Smooth lumpsucker
Careproctus gilberti Burke	Smalldisk snailfish
Eumicrotremus orbis (Günther)	Pacific spiny lumpsucker
Liparis dennyi Jordan and Starks	Marbled snailfish
Petromyzontidae	
Entosphenus tridentatus (Gairdner)	Pacific lamprey
Lampetra japonica (Martens)	Arctic lamprey
Lemnidae	
Cetorhinus maximus (Gunnerus)	Basking shark
Lamna ditropis Hubbs and Follett	Salmon shark
Squalidae	
Squalus acanthias Linnaeus	Spiny dogfish
Carcharhinidae	
Prionace glauca (Linnaeus)	Blue shark

BENTHOS

Introduction

Due to their limited mobility and interaction with the substratum, marine benthic organisms have often been considered as potentially useful indicators of ecological disturbance. A close relationship among the type of bottom sediment and a series of physical-chemical environmental parameters and benthic biological population has been recognized for decades. Quantitative aspects of these relationships have not yet been established for most marine environments. Benthic organisms also constitute a significant part of trophicdynamics of an area.

Over the years, benthic communities have been recognized either as convenient statistical units for mapping purposes or as fundamental ecological units with well-defined regulation of composition and variability. Generally, the overall stability and productivity of species populations along with the biotic and abiotic factors are considered to constitute community organization. Due to the many parameters involved, the concept of community organization has had varied interpretations. It can be described in terms of trophic web in the community, spatial distribution pattern or seasonal succession of organisms in the community. Only very sporadic and incomplete data and information are available on the distribution and ecology of benthic organisms in Alaskan waters.

The plants and animals of the intertidal zone along the coastline in the northeast Gulf of Alaska are rich both in variety and biomass. These organisms provide a vital and significant source of food and shelter to marine birds, mammals and fish. Certain species of the intertidal zone are also harvested commercially. Intertidal organisms and the substratum are also potentially subject to repeated and direct contact with contaminants brought into the area by currents. Significant contamination, reduction, or removal of crucial species or communities as a whole may adversely affect feeding, physiological and behavioral patterns of other larger animals that may have commercial or recreational significance.

An inventory of benthic species, both intertidal and sub-tidal, and their distribution and abundance is therefore fundamental to the understanding of ecosystem structure and function in the Gulf of Alaska.

Intertidal Biota

Zimmerman and Merrell (RU # 78, 79) are studying the intertidal fauna and flora in the Gulf of Alaska and the southern Bering Sea. Specific objectives of their research are to determine the densities and distribution of biological populations within these habitat types. Habitat types were identified primarily by visual reconnaissance of the area from aircraft. Other methods such as color or false color infrared photography were also used. Rock biota were sampled from sampling frames (1/16 m^2) which were laid at regular intervals along a transect extending from the highest area of tidal influence to the water edge at low tide. The area under each frame was photographed and biota scraped from the rocks and preserved in 10% formalin. Each sample was identified from its location and elevation. Samples from large boulders with irregular topography were obtained by first sketching a facsimile of the rock and the biotic zonation on it on a sheet of Mylar. plastic. Numbered, homogeneously arrayed dots were placed on the sketch. Sampling locations were randomly chosen and projected for sampling sites.

Samples for "nested quadrat samples," consisting of 16 squares each 1/64 m^2, were collected to assess the adequacy of different sample sizes and the variability between samples.

At sandy and muddy sites, samples were obtained with a cubical corer (10 cm on each side) along transect lines. The corer was often used twice, the second time to collect biota from the 10 to 20 cm level. It should be noted that samples from sandy/muddy substrata were obtained on a volume basis, those for rocky areas on an area basis.

The number of samples collected in 1974-75 in the northeast Gulf of Alaska are listed in Table V-3. These samples represent a part of nearly 1,500 samples collected at different locations in the Gulf of Alaska and southern Bering Sea.

Only a small fraction of the collected samples have been analyzed so far for taxonomic composition, population densities or biomass. For example, out of 114 samples collected at Cape Yakataga, data on only 36 samples (11 collected September 12, 1974 and 25 on September 13, 1974) are provided in the Annual Report as Appendix A. A list of species from Cape Yakataga (Table V-4) and a table (Table V-5) of population densities and biomass of various species and sample data are included here as examples of data output.

A preliminary comparison of mean number of species and their biomass (wet weight) for three types of habitat is shown in Table V-6 . The substratum composition varied from rocky (Macleod Harbor) to sandy (Yakutat) to muddy (Boswell Bay). Both the number of species and biomass were significantly higher at Macleod Harbor than at Boswell Bay or Yakutat-Yakataga region.

Data obtained from Squirrel Bay on September 14, 1974 have been analyzed for the adequacy of quadrat size, to determine the degree of variability in samples, and to estimate the number of samples needed to determine statistically significant differences, 95% confidence level, for a 0.5 $\overline{X}$ change in population. The regional sample size varied from 6 for Musculus discors (mussel) sampled with 1/16 m^2 quadrats to 1,256 for Fucus distichus (seaweed) sampled with 1/64 m^2 quadrat (Table V-7).

It was found that for comparing species richness, the 1/16 m^2 quadrat was adequate and significantly more efficient than the 1/64 m^2 quadrat. It was

TABLE V-3

Quantitative Intertidal Samples Collected in the Northeast Gulf of Alaska in 1974-75
(Zimmerman & Merrell, RU #78, 79)

Region	Location	Rocky Fall 74	Rocky April 75	Rocky May	Rocky June	Rocky July	Rocky August	Rocky August	Rocky September	Muddy Fall 74	Muddy April 75	Muddy May	Muddy June	Muddy July	Muddy August	Muddy August	Muddy September	Sandy Fall 74	Sandy April 75	Sandy May	Sandy June	Sandy July	Sandy August	Sandy August	Sandy September	TOTAL
Yakutat-Cook Inlet																										
	Yakutat	5			15				12																9	41
	Cape Yakataga	30			41				39																4	114
	Katalla	15	33						37																	85
	Kayak Island								19																	19
	Middleton Island									10	10						10									30
	Boswell Bay		2						5	44	22						30									103
	Port Etches		15																							5
	Zaikof Bay	16	44						41																	101
	Macleod Harbor	34	17						33																	84
	LaTouche Point	25																								68
	Squirrel Bay	37																								37
	Day Harbor	23	19						44																	86
																										750

TABLE V-4

SPECIES OF CAPE YAKATAGA
(Zimmerman & Merrell, RU #78, 79)

CHLOROPHYTA
- Ulothrix sp.
- Ulothrix laetevirens
- Enteromorpha linza
- Ulva lactuca
- Rhizoclonium riparium
- Urospira mirabilis
- Chaetomorpha sp.
- Codium fragile

PHAEOPHYTA
- Phaeophyta
- Ectocarpus parvus
- Ectocarpus simulans
- Pylaiella littoralis
- Ralfsia pacifica
- Elachistea fucicola
- Haplogloia andersonii
- Soranthera ulvoidea
- Scytosiphon lomentaria
- Laminaria sp.
- Fucus distichus

RHODOPHYTA
- Rhodophyta
- Cryptosiphonia woodii
- Lithothamnion sp.
- Callophyllis flabellulata
- Gigartina papillata
- Gigartina latissima
- Halosaccion glandiforme
- Rhodymenia palmata
- Pterosiphonia bipinnata
- Odonthalia floccosa

CNIDARIA
- Hydroidea
- Sertularella tricuspidata
- Anthrozoa

TURBELLARIA
- Turbellaria

RHYNCHOCOELA
- Rhynchocoela
- Emplectonema sp.
- Emplectonema gracile

NEMATODA
- Nematoda

ANNELIDA
- Annelida

ANNELIDA cont.
- Polychaeta
- Eteone pacifica
- Eulalia viridis
- Typosyllis sp.
- Typosyllis pulchra
- Typosyllis fasciata
- Typosyllis a. adamantea
- Exogone verugera
- Nereis sp.
- Spionidae
- Spio filicornis
- Capitella captiata
- Sabellidae
- Chone infundibuliformis
- Fabricia sabella
- Enchytraeidae

MOLLUSCA
- Mytilus edulis
- Protothaca staminea
- Gastropoda
- Collisella sp.
- Collisella pelta
- Littorina sitkana
- Littorina scutulata
- Lacuna sp.
- Lacuna carininata
- Lacuna marmorata
- Nucella lamellosa

PYCNOGONIDA
- Pycnogonid

CRUSTACEA
- Harpacticoida
- Balanus sp.
- Balanus glandula
- Pentidotea resecta
- Pentidotea wosensenskii
- Gnoramosphaeroma sp.
- Gnoramosphaeroma oregonensis
- Amphipoda
- Ampithoe sp.
- Ampithoe rubricata
- Ampithoe rubricatoides
- Calliopiidae
- Oligochinus lighti
- Calliopiella pratti
- Paramoera columbiana

TABLE V-4 (contd.)

CRUSTACEA cont.
- Pontogeneia kondakovi
- Anisogammarus subcarinatus
- Hyale sp.
- Parallorchestes sp.

INSECTA
- Insecta
- Chironomidae

BRYOZOA
- Bryozoan
- Microporina sp.

ASTEROIDEA
- Leptasterias hexactis

TABLE V-5. BIOTIC DENSITIES OF INTERTIDAL ORGANISMS FROM THE EASTERN GULF OF ALASKA
FALL 1974 (Zimmerman & Merrell, RU #78, 79)

STATION NBR: 2 YAKATAGA DATE: 10/12/74
LATITUDE: 60 3 80 N LONGITUDE: 147 25 90 W
STATION INVESTIGATED FOR 2.0 HOURS BEGINNING AT 1:30 IN TIME ZONE: + 9
CATALOG NBR: A8740372 ZONE/TRANSECT: 1 SUBSTRATE: NO INFORMATION
PHOTOGRAPH NBR: 7402010396 METER NBR: 10 SURFACE TOPOGRAPHY: NO INFORMATION
SAMPLING TIME: 2:30 ARROW NBR: GEAR: TRANSECT
ELEVATION: 1.36 METERS QUADRAT SIZE: .0625 SQUARE METERS SEDIMENT VOLUME: 0. LITERS

SPECIES IDENTIFICATION	SEX	CONDITION	COVRG	COUNT	WET WEIGHT (GRAMS)	DRY WEIGHT (GRAMS)
CHLOROPHYTA						
ULOTHRIX LAETEVIRENS	ND				15.261	9.546
ENTEROMORPHA LINZA	ND				12.040	3.424
UROSPIRA MIRABILIS	ND				.013	0.
CLADOPHORA SP	ND				.442	0.
PHAEOPHYTA						
ECTOCARPUS SIMULANS	ND				8.293	4.130
FUCUS DISTICHUS	ND	STRL			1.387	.994
TURBELLARIA						
TURBELLARIA	ND			1	.001	0.
RHYNCHOCOELA						
RHYNCHOCOELA	ND	FRAG		1	.007	0.
EMPLECTONEMA GRACILE	ND	FRAG		1	.089	0.
ANNELIDA						
ETEONE PACIFICA	ND			8	.006	0.
NEREIS SP	ND			22	.032	0.
SPIONIDAE	ND			7	.002	0.
ENCHYTRAEIDAE	ND			117	.029	0.
MOLLUSCA						
MYTILUS EDULIS	ND			1107	4.593	0.
LACUNA MARMORATA	ND			170	.245	0.
CRUSTACEA						
BALANUS GLANDULA	ND			466	12.325	7.751
GNORIMOSPHAEROMA SP	ND			48	.319	0.
AMPITHOE RUBRICATOIDES	ND			24	.136	0.
CHIONOECETES SP	ND			1	.003	0.
INSECTA						
INSECTA	ND			1	.001	0.
CHIRONOMIDAE	ND	IMTR		51	.048	0.

TABLE V-6

Comparison of Mean Numbers of Species and Wet Weight Biomass From Three Different Habitat Types (s = standard deviation) (Zimmerman & Merrell, RU # 78, 79)

Habitat Type	Mean Number of Species	s	Mean biomass (grams)	s	Sample Size
Rocky (Macleod Harbor)	30.3	14.5	243.6	231.4	15
Muddy (Boswell Bay)	21.6	5.6	8.5	8.5	14
Sandy (Yakutat - Yakataga)	1.5	1.1	0.02	0.02	6

TABLE V-7

Estimates of the Number of Random Samples Required to Compare Two Means With 90% Probability of Showing a Statistically Significant Difference at the 95% Level When the Experimental Mean Differs as Much as 50% From the Control Mean (Zimmerman & Merrell, RU #78, 79)

Species	Quadrat type	
	1/64 m^2 square	1/16 m^2 square
Mytilus edulis	353	97
Musculus discors	20	6
Lacuna marmorata	87	21
Lacuna vincta	385	231
Fucus distichus	1,256	251
Rhodymenia palmata	44	13
Oligochaetes	457	122
Polychaetes	184	21

also noted that organisms had an aggregated pattern of abundance; random sampling may not be feasible over large areas in rocky zones.

Results from other statistical analyses, such as a correlation matrix for six taxa (Musculus sp., Rhodymenia sp., Mytilus sp., Alaria-Fucus sp., Polychaetes and Oligochaetes), and the correlation between percent cover and biomass values of five algal species (Fucus sp., Halosaccion sp., Odonthalia-Rhodymela sp., Rhodymenia sp., Alaria sp.) are also presented. The correlation matrix is shown in Table V-8 and is self-explanatory. It was also found that for small algal species, biomass was highly correlated with percent cover; for Alaria sp. there was no significant correlation.

This report also contains a few preliminary calculations of species diversity index based on Brillouin's formula. It should be reiterated that the results of statistical analyses are based on a limited amount of data (samples collected from one area and on one day) and should be interpreted accordingly.

Drift Zone Studies

A listing of beach drift biota (shells and fragments, decomposing mass) is provided in the RU #78, 79 Annual Report (Appendix C) for Yakutat, Cape Yakataga and Middleton Island. These biota may be used as indicators of pollution effects. The relative composition of drift biota is shown in Table V-9.

A description of the data and their interpretation is excerpted below from the Annual Report:

> Drift accumulation was considered light to moderate at all three localities during all seasons sampled. Total number of drift items was greater at Yakutat during all seasons sampled than at the other two localities.
>
> Yakutat: The drift at Yakutat was characterized by empty razor clam (Siliqua patula) shells, Dungeness crab (Cancer magister) carapaces, and unidentified jelly fish and ctenophores. Except for razor clam shells, whose numbers remained constant, all other items decreased in abundance from summer through winter.

TABLE V-8

Correlation Coefficient Matrix for Six Species from Station A, Squirrel Bay, Computed from Sixteen 1/64 m^2 Quadrats and Four 1/16 m^2 Quarters (Zimmerman & Merrell, RU #78 and 79)

	Musculus discors	Rhodymenia palmata	Alaria-Fucus sp.	Mytilus edulis	Polychaete sp.	Oligochaete sp.
Musculus discors: 1/64	1.0000	0.6682**	-0.0353	-0.1017	0.1294	-0.1385
1/16	1.0000	0.9938**	-0.4164	0.2487	-0.0344	0.1304
Rhodymenia palmata: 1/64	----	1.0000	0.0570	0.1637	0.2359	0.1113
1/16	----	1.0000	-0.3426	0.1741	-0.1096	0.0564
Alaria - Fucus sp.: 1/64	----	----	1.0000	0.3369	0.3646	0.3097
1/16	----	----	1.0000	-0.0584	0.0603	0.0057
Mytilus edulis: 1/64	----	----	----	1.0000	0.8408**	0.9822**
1/16	----	----	----	1.0000	0.9595**	0.9927**
Polychaete sp.: 1/64	----	----	----	----	1.0000	0.8443**
1/16	----	----	----	----	1.0000	0.9862**
Oligochaete sp.: 1/64	----	----	----	----	----	1.0000
1/16	----	----	----	----	----	1.0000

(* = P<0.05; ** = P<0.01)

TABLE V-9

Composition of Drift Biota Occurring at Three Study Localities between August 15, 1975 and February 25, 1976, Based on an Estimate of Percent Cover and Biomass (Zimmerman & Merrell, RU #78, 79)

Drift Item	Yakutat	Cape Yakataga	Middleton Island
Algae	<1	<1	94
Invertebrates	99	99	5
Fish	<1	<1	<1
Birds	<1	<1	<1
Mammals	<1	<1	<1
Other	<1	0	0

Very little drift kelp occurred at Yakutat. Although no measurements were made, total daily accumulation was estimated at less than 5 kg (wet weight) during all seasons sampled.

Cape Yakataga: Drift at Cape Yakataga was characterized by invertebrate remains, i.e., sponges, razor clam shells (*Siliqua patula*), worm tubes (*Eudistylia* sp.), and limpet shells (*Notoacmaea persona*). All these items exhibited at least a two-fold increase from autumn to winter. Accumulation of drift kelp was estimated at less than 2 kg (wet weight) per day during both seasons sampled.

Middleton Island: The drift at Middleton Island was characterized by drift algae and invertebrate remains. The most abundant algae during both seasons sampled were *Laminaria* spp. followed by *Nereocystis luetkeana* and *Cymathere triplacata*. Daily accumulation rates of *Nereocystis* appeared to be directly related to the rate of accumulation of algal drift at Middleton Island. Autumn accumulation rates of algal drift were estimated at hundreds of kg (wet weight) per day, and the winter rate at tens of kg (wet weight) per day.

Invertebrate remains at Middleton Island were characterized by limpet (*Acmaea mitra*) and snail (*Fusitriton oregonensis*) shells, and sponges.

Subtidal Benthos

Feder (RU #281) is studying the abundance, distribution and community organization of benthic fauna in the northeast Gulf of Alaska. Specific objectives of his research program are as follows:

i. A qualitative and quantitative inventory census of dominant benthic species within the identified lease areas.

ii. A description of spatial and seasonal distribution patterns of selected species in the designated study areas, with emphasis on assessing patchiness and correlation with microhabitat.

iii. A preliminary comparison of the distribution of dominant species with physical, chemical, and geological features with emphasis on the latter parameters.

iv. Preliminary observations of biological interrelationships between selected segments of the benthic biota in the designated study areas.

Feder (RU #282) is also compiling and summarizing existing literature on the systematics, abundance, and feeding ecology of the marine organisms in the Gulf of Alaska and the Bering Sea. This information is necessary to achieve an historical perspective against which the currently obtained data can be interpreted. So far, about 1,500 references pertaining to the North Pacific and the Bering Sea have been punched on computer cards.

Data from a large number of samples have been reported in the Annual Report. The station grid was established in conjunction with other OCSEAP-related studies in the northern Gulf of Alaska (Fig. V-1). Station transects generally extended seaward from the coastline and covered an area from Resurrection Bay to Yakutat Bay. Data included in the Annual Report are primarily from the following cruises:

R/V	*Acona*	July, October, November 1974
R/V	*Oceanographer*	February 1975
R/V	*Discoverer*	March-April 1975
R/V	*Townsend Cromwell*	May 1975
USNS	*Silas Bent*	September 1975
R/V	*Discoverer*	October 1975
R/V	*Discoverer*	November-December 1975
M/V	*North Pacific*	at various times

Grab samples: Samples were collected with a 0.1 m^2 van Veen grab which typically provided 13 to 19 ℓ of sediment. Only at stations with coarse sand or sand-gravel substratum, were smaller volumes of sediment obtained. Stations where less than 5 ℓ of sample was obtained are considered "qualitative". A total of 311 species have been identified and reported from these samples. Fourteen phyla are represented. Polychaetes were the most abundant groups, represented by 132 species. Molluscs were represented by 69 species, crustaceans by 66, and echinoderms by 24 species. A large part of the data from this Annual Report has been incorporated in the "Benthic Biology" chapter of the first-year NEGOA report, titled "Environmental Assessments of the Northeast Gulf of Alaska.

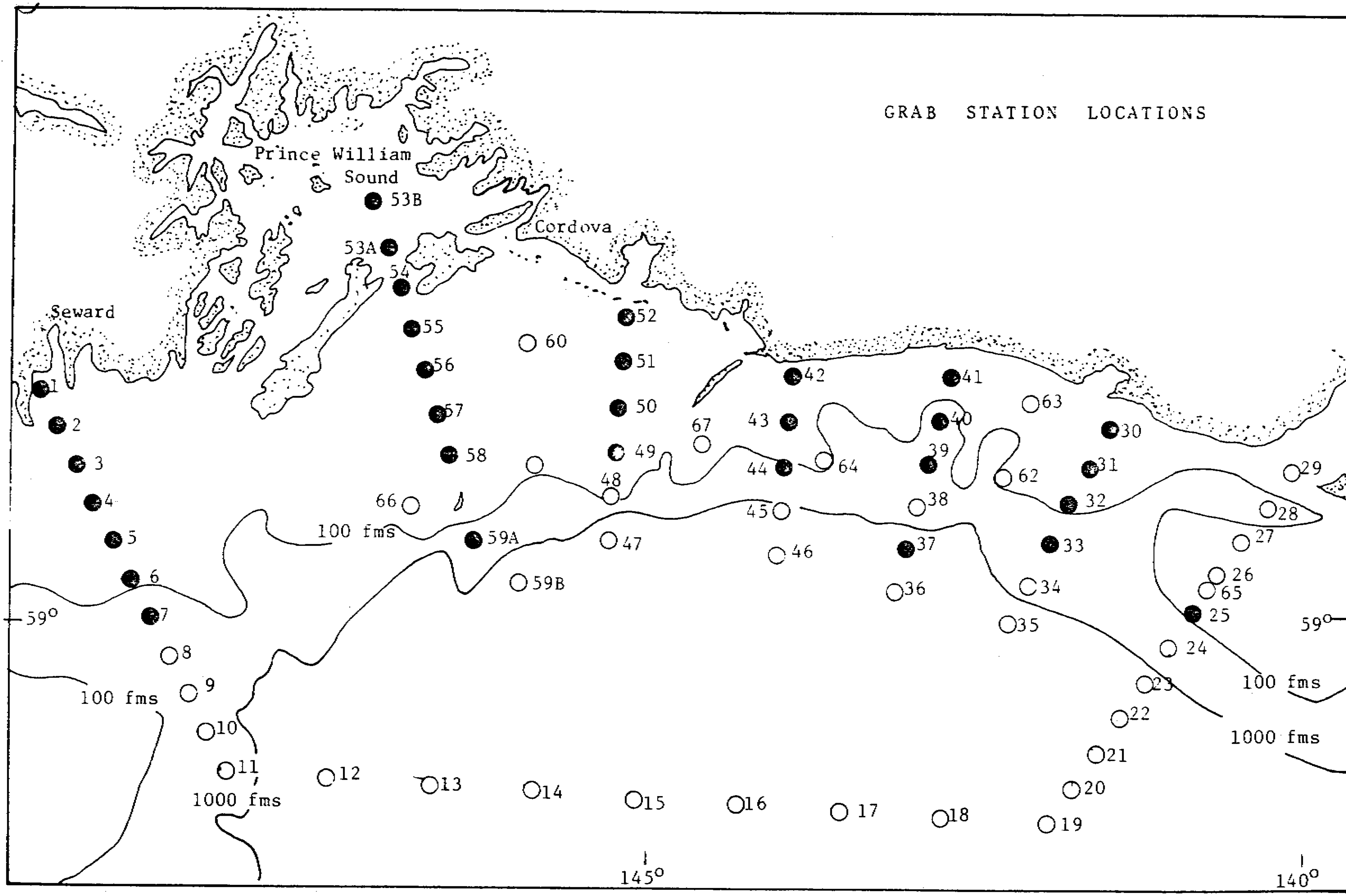

Fig. V-1. Station grid established for oceanographic investigations in the study area. Dark circles are stations occupied by a grab sampler (Feder, RU #281).

Species Distribution: Distribution charts, based on pressure/absence interior, of the following species are provided in the RU #281 Annual Report. No information on abundance or biomass of species is yet available.

Polychaeta:	Sternapsis scutata, Myriochele leeri, Onuphis geophiligormis, Lumbrineris similabris, Melinna cristata, Terebellides stroemi, Ammochares fusiformis, Asychis similis, Ampharete geesi, and Notoproctus pacificus.
Cumacea:	Eudorella emarginata
Isopoda:	Gnathia sp.
Brachiopoda:	Terebratulina unguicula
Sipunculida:	Golfingia margaritacea
Pelecypoda:	Nuculina pernula, Yoldia scissurata, Nucula tenuis, Yoldia sp., Astarte polasis, Astarte montegui, Psephidia lordi, Portlandia arctica, Siliqua media, Axinopsida serricata, Crenella dessucata, Macoma calcaria, and Cyclopecten randolphi
Scaphopoda:	Dentalium sp.
Aplacophora:	Chaetoderma robusta
Asteroidea:	Ctenodiscus crispatus
Holothuroidea:	Molpadia sp.
Echinoidea:	Brisaster townsendi
Ophiuroidea:	Ophiura sarsi, Diamphiodia periercta, and Unioplus macraspis

The following taxa were most widely distributed as they were found in samples from more than 20 stations:

1. Nemertean worms
2. Glycera capitata (Annelida)
3. Onuphis geophiliformis (Annelida)
4. Lumbrineris similabris (Annelida)
5. Sternapsis scutata (Annelida)
6. Meldanidae - unidentified (Annelida)
7. Myriochele heeri (Annelida)
8. Terebellides stroemi (Annelida)
9. Nucula tenuis (Mollusca)

10. *Nuculana pernula* (Mollusca)
11. *Axinopsida serricata* (Mollusca)
12. *Ctenodiscus crispatus* (Echinodermata)
13. *Ophiura sarsi* (Echinodermata)

Grouping of Stations and Species: Station groupings formed by average linkage sorting strategy are shown in Fig. V-2. Three clusters of stations were recognized:

I. Group of stations south of Prince William Sound
II. A pair of stations close to shore
III. Group of stations at or near the shelf

Other grouping or clustering techniques were also applied. These included Motyka quantitative similarity coefficient for both the single linkage and average linkage sorting strategies, and the two-way coincidence table comparing the species groups with station groups. Grouping of stations according to Motyka single linkage classification is shown in Fig. V-3.

Nine species groups were also identified. These groups are listed in Table V-10. Each species is also identified for its mode of feeding.

The following account of the description and interpretation of grouping of stations and species is reproduced from RU #281 Annual Report:

1. Station Group III, which is composed of 4 stations near the shelf break (Fig. V-3) is characterized by large number of individuals in species Group I (Table V-10) and species Group V (Table V-10).

2. Station Group IV (station 57) appears to be characterized by species Groups II and IV (Table V-10). Station 57 contains many species in common with station Group III (shelf break stations) and station Groups I and V which form a clump of stations just south of Prince William Sound. However, those species that characterize station Group III (i.e. species Group I) are found in smaller numbers in station 57. This may indicate that they are existing near the limits of their environmental tolerances.

3. Species in species Groups I, II, III and IV are almost exclusively restricted to station Groups III and IV, which obviously indicates that there are some favorable conditions existing at these stations not present elsewhere, thereby enabling these species to become more abundant in these areas.

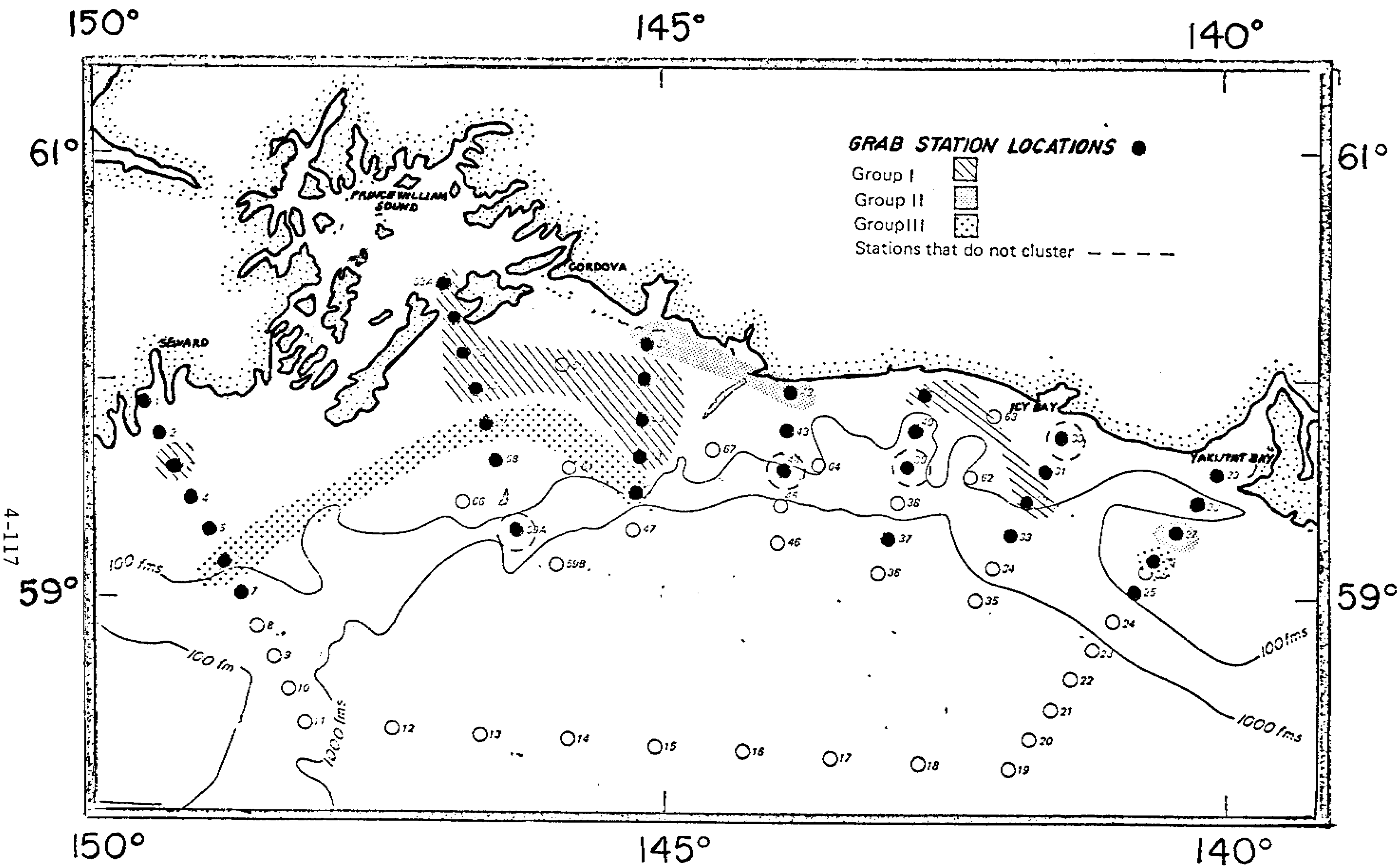

Fig. V-2. Qualitative and quantitative stations clustered using Sørensen (presence-absence) coefficient with average linkage sorting. Dashed circle represent stations that do not cluster (Feder, RU #281).

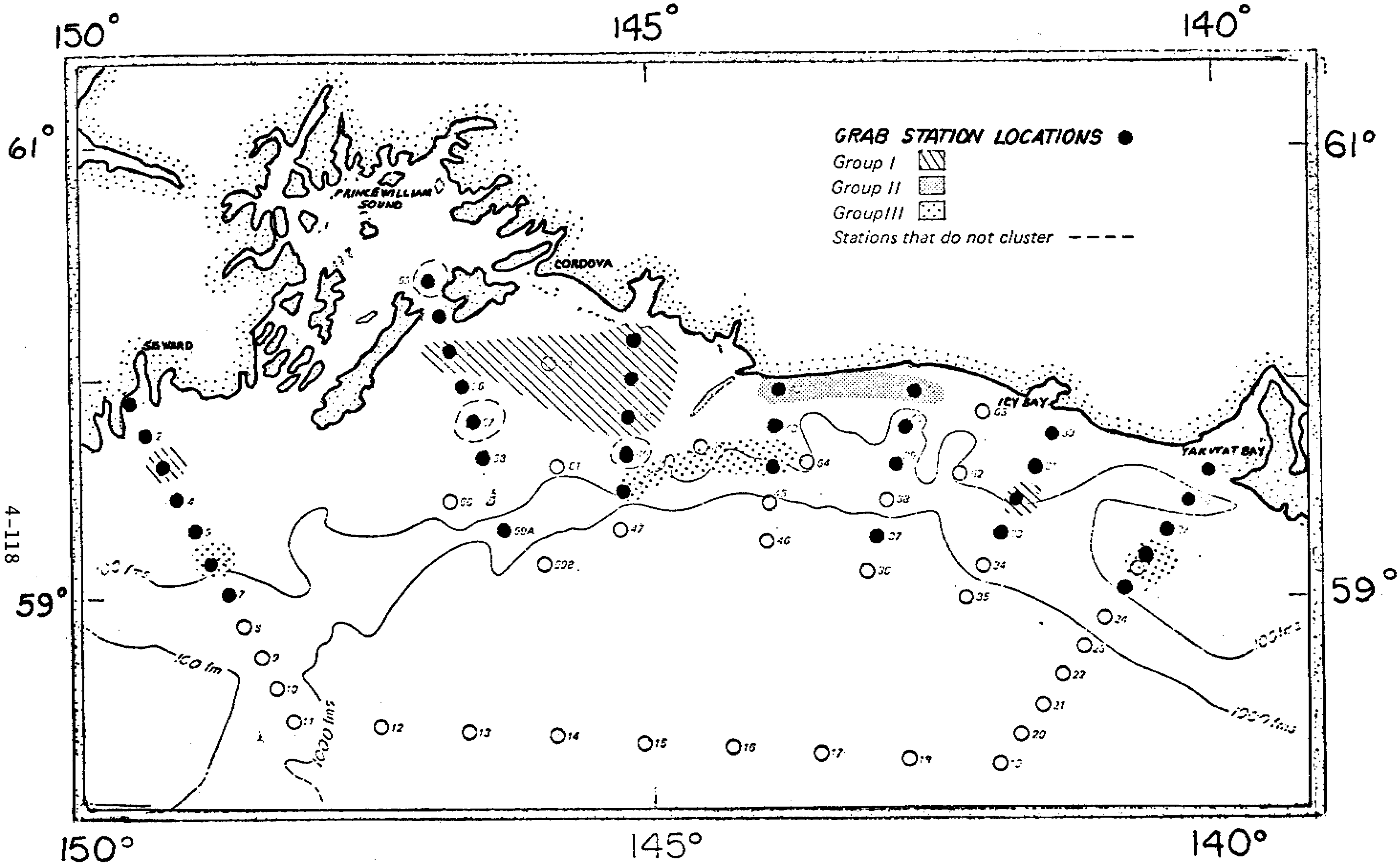

Fig. V-3. Quantitative stations only clustered using Motyka coefficient with single linkage sorting (Feder, RU #281).

Table V-10. Gulf of Alaska Species Groups resulting from cluster analysis (see Table 9) and feeding types of species in the groups. DF=Deposit Feeder, S=Scavenger, SF=Suspension Feeder, P=Predator, G=Grazer. Data sources for feeding types are Feder *et al.* (1973) and Feder and Mueller (1975).

Species No.		Feeding Type
	Group I	
46	Crustacea Harpacticoida	S(?), G
54	Crustacea Amphipoda *Haploops tubicula*	S
20	Polychaeta Maldanidae *Maldane glebifex*	DF
55	Crustacea Amphipoda *Harpinia* sp.	S
21	Polychaeta Maldanidae *Notoproctus pacificus*	DF
35	Mollusca Pelecypoda *Dacrydium* sp.	SF
12	Polychaeta Paraonidae *Aricidea jeffreysii*	DF
57	Sipunculida *Golfingia magaretacea*	DF
49	Crustacea Isopoda *Gnathia* sp.	Parasite on fishes
6	Polychaeta syllidae *Langerhansia cornuta*	P
56	Crustacea Amphipoda *Harpiniopsis sandpedroensis*	S
5	Polychaeta Polyodontidae *Peisidice aspera*	S
36	Mollusca Pelecypoda *Cyclopecten randolphi*	SF
19	Polychaeta Maldanidae *Asychis similis*	DF
	Group II	
52	Crustacea Amphipoda *Byblis* sp.	S
60	Brachiopoda Articulata *Terebratulina unguicula*	SF
53	Crustacea Amphipoda *Byblis crassicornis*	S
51	Crustacea Amphipoda *Ampelisca macrocephala*	S
58	Bryozoa *Clavopora occidentalis*	SF
42	Mollusca Pelecypoda *Clinocardium fucanum*	SF
38	Mollusca Pelecypoda *Astarte montegui*	SF
34	Mollusca Pelecypoda *Crenella dessucata*	SF
	Group III	
1	Sponges	SF
59	Brachiopoda	SF
37	Mollusca Pelecypoda *Astarte* sp.	SF(?)
62	Echinoderm Echinoidea *Brisaster townsendii*	DF
	Group IV	
29	Mollusca Pelecypoda *Nucula tenuis*	DF, SF
43	Mollusca Pelecypoda *Psephidia lordi*	SF
14	Polychaeta Spionidae *Spiophanes cirrata*	DF
30	Mollusca Pelecypoda *Nuculana pernula*	DF, SF
11	Polychaeta Lumbrineridae *Lumbrineris similabris*	DF
15	Polychaeta Magelonidae *Magelona japonica*	DF
	Group V	
24	Polychaeta Oweniidae *Myriochele heeri*	DF, SF
65	Echinoderm Ophiuridae *Ophiura sarsi*	P
50	Crustacea Amphipoda (mixed species)	S

Table V-10 Continued

Species No.		Feeding Type
40	Mollusca Pelecypoda *Axinopsida serricata*	SF
10	Polychaeta Onuphidae *Onuphis geophiliformis*	DF
17	Polychaeta Sternaspidae *Sternaspis scutata*	DF
	Group VI	
32	Mollusca Pelecypoda *Portlandia arctica*	DF, SF
61	EC. AS. Porcellanasteridae *Ctenodiscus crispatus*	DF
3	Cnidaria Anthozoa Sea Pen	SF
	Group VII	
44	Mollusca Pelecypoda *Macoma calcarea*	DF, SF
66	Echinoderm Holothurcoidea *Molpadia* sp.	DF
48	Cr Cumacea Leuconidae *Eudorella emarginata*	DF
9	Polychaeta Glyceridae *Glycera capitata*	P
18	Polychaeta Capitellidae *Heteromastus filiformis*	DF
25	Polychaeta Ampharetidae *Melinna cristata*	DF
26	Polychaeta Terebellidae *Terrebellides stroemi*	DF
16	Polychaeta Cirratalidae *Tharyx* sp.	DF
22	Polychaeta Maldanidae *Praxillella gracilis*	DF
45	Mollusca Scaphopoda *Dentalium* sp.	DF
4	*Nemerteans (Rhynchocoela)*	P
	Group VIII	
28	Mollusca Aplacophora *Chaetoderma robusta*	DF
31	Mollusca Pelecypoda *Nuculana minuta*	DF
41	Mollusca Pelecypoda *Thyasira flexuosa*	SF
8	Polychaeta Nepthydidae *Nepthys ferruginea*	P
	Group IX	
33	Mollusca Pelecypoda *Yoldia* sp.	DF, SF
63	Echinoderm Amphiuridae *Unioplus macraspis*	DF
7	Polychaeta Syllidae *Haplosyllis spongicola*	P
23	Polychaeta Oweniidae *Owenia fusiformis*	DF, SF(?)

4. Stations Group II is characterized primarily by high numbers of species Groups IV and V. Station Group II is similar to station Groups I and V except that station Group II (station 41 and 42) contains fewer species and individuals per species in species Groups VI, VII and VIII.

5. The primary difference between station Groups I and V (which overlap geographically) appears to be that station Group V contains fewer species and fewer individuals per species in species Groups IV through VIII.

Biologically Important Taxa: Many of the collected species were classified as Biologically Important Taxa (BIT). A taxon was included in this group if it met at least one of the following criteria:

i) It was distributed in 50 percent or more of the total stations sampled.

ii) It was over 10 percent of either the composite population density or biomass at any one station.

iii) Its population density was significant at any given station. A percentage was calculated for each taxon, with the sum of population density of all taxa equalling 100 percent. After ranking the percentages in descending order, the taxa whose sum of percentages reached the cutoff point of 50% were designated as BIT. Similar procedure was used with biomass rankings.

Ninety-five (95) species were designated as BIT. Only three species were found to meet all of the above criteria: Onuphis geophiliformis (Polychaeta), Ctenodiscus crispatus (Asteroidea), and Ophiura sarsi (Ophiuroidea).

Diversity Indices: Species diversity was examined by calculating the following indices:

i) Shannon-Wiener Index
ii) Simpson Index
iii) Brillouin Index

Other related parameters to determine community structure were also determined: Shannon-Wiener Evenness Component, Brillouin Evenness Component.

Diversity indices were used to obtain an objective, quantitative appraisal of dominance of species, and community organization in the study area.

The indices calculated reflect both the dominance of a few species (Simpson Index) and the influence of rare species (Shannon-Wiener and Brillouin Indices). The numerical values of various indices based on the data from July 1974 to May 1975 are given in Table V-11. In this table each row describes the location [by cruise number (193) and station number (003)], the number of specimens (51), the number of species (21), and values of Simpson Index (0.061961), Shannon-Wiener Index (2.757249), Shannon-Wiener Evenness Component (2.085319), Brillouin Index (0.993179), and Brillouin Evenness Component (0.911455). Examples of numerical values in parentheses are for the first row in Table V-11.

The author has pointed out that diversity indices should be interpreted with caution and no comparison be made until more data are available for each station. In a few instances, diversity indices have been found to vary at different times of the year. Dispersion pattern and seasonal succession of both the individuals and species would be needed to address this problem.

Various other analyses, such as the Principal Component analysis, Canonical Correlation analysis, Principal Coordinate analysis, and Multivariate Regression analysis, are also envisaged to investigate the relationships among habitat diversity, species distribution, community structure, and environmental parameters.

Trawl Program: Samples were collected with a commercial size 400 mesh Eastern otter trawl at predetermined locations in the Gulf of Alaska (Fig. V-4) from April to August 1975. Non-commercial invertebrates were sorted out on board ship, counted, and weighed. Only a fraction of catch was retained for analysis. Final taxon identifications were made at the Marine Sorting Center, Fairbanks. The collected samples provided a basis for semi-quantitative census of larger, more motile epifaunal species.

TABLE V-11

Diversity Indices and Evenness Measures for all Quantitative Stations Occupied by van Veen Grab in the Gulf of Alaska, July 1974 through May 1975 (Feder, RU #281)

03/12/76 15.7122

STATION	NO. IND	NO.SPEC	SIMPSON	SHANNON	SW EVEN	BRILLOUIN	BRILL EVEN
193003	51.0	21.0	0.061961	2.757249	2.085319	0.993179	0.911455
193006	342.0	79.0	0.031212	3.727787	1.996065	1.507667	0.870156
193026	135.0	43.0	0.039912	3.324649	2.072063	1.292416	0.902361
193032	98.0	33.0	0.036819	3.247819	2.138814	1.223369	0.931034
193041	258.0	31.0	0.127620	2.502198	1.677794	1.012611	0.726832
193042	392.0	38.0	0.135785	2.491299	1.577431	1.020745	0.682527
193044	166.0	51.0	0.040526	3.467721	2.030793	1.335156	0.884986
193048	194.0	57.0	0.033919	3.628206	2.066324	1.407312	0.901290
193050	57.0	27.0	0.040727	3.055586	2.141724	1.093408	0.933838
193052	241.0	37.0	0.125761	2.593619	1.653881	1.036395	0.715240
193055	128.0	32.0	0.091781	2.869763	1.906629	1.104813	0.824974
193059	23.0	9.0	0.166008	1.858761	1.947892	0.636673	0.845621
200050	140.0	35.0	0.058787	3.054237	1.978045	1.184803	0.860240
200052	191.0	36.0	0.084982	2.934917	1.885827	1.159862	0.817901
200053	269.0	37.0	0.108611	2.720957	1.735081	1.097235	0.752237
200057	368.0	73.0	0.047788	3.533722	1.896462	1.415739	0.824382
202001	20.0	11.0	0.105263	2.154783	2.069136	0.707067	0.902239
805031	113.0	28.0	0.060209	2.941255	2.032435	1.133742	0.883518
805032	161.0	50.0	0.028106	3.606649	2.122844	1.388103	0.925984
805040	123.0	35.0	0.048914	3.160702	2.046997	1.212286	0.892822
805041	157.0	30.0	0.088519	2.760782	1.869029	1.086305	0.811190
805042	45.0	19.0	0.090909	2.531967	1.980027	0.901504	0.862842
805043	32.0	13.0	0.137097	2.154619	1.934227	0.751353	0.839418
805044	19.0	11.0	0.076023	2.232694	2.143951	0.728442	0.943271
805049	154.0	39.0	0.065529	3.103912	1.950840	1.203837	0.847056
805051	53.0	23.0	0.071843	2.752791	2.021543	0.987843	0.881931
805053	29.0	15.0	0.093596	2.404905	2.044828	0.817083	0.886500
805054	108.0	24.0	0.158532	2.448742	1.774179	0.939609	0.765240
805055	79.0	27.0	0.057124	2.947102	2.058947	1.098618	0.895726
805056	384.0	71.0	0.102127	3.278286	1.770842	1.311503	0.766404
805057	66.0	35.0	0.030769	3.326573	2.154421	1.189017	0.940998
805058	133.0	26.0	0.185578	2.280293	1.611545	0.883574	0.692167
807002	90.0	42.0	0.026966	3.500732	2.156620	1.282988	0.941369
807004	77.0	24.0	0.094668	2.637334	1.910819	0.985753	0.829767
807005	170.0	35.0	0.109154	2.736344	1.772166	1.072310	0.767277
807007	38.0	23.0	0.072546	2.812754	2.065577	0.956209	0.904035
807025	53.0	23.0	0.062409	2.827799	2.075626	1.015195	0.906350
807026	78.0	30.0	0.066600	2.950235	1.997287	1.083027	0.871021
807027	249.0	42.0	0.279052	2.219129	1.367091	0.871490	0.582650
807028	164.0	34.0	0.064268	2.926171	1.956391	1.177096	0.850995
807050	66.0	24.0	0.070862	2.806988	2.033738	1.032333	0.885761
807052	36.0	19.0	0.052381	2.745778	2.147233	0.948218	0.936546
807053B	8.0	5.0	0.107143	1.559581	2.231256	0.462504	1.000000

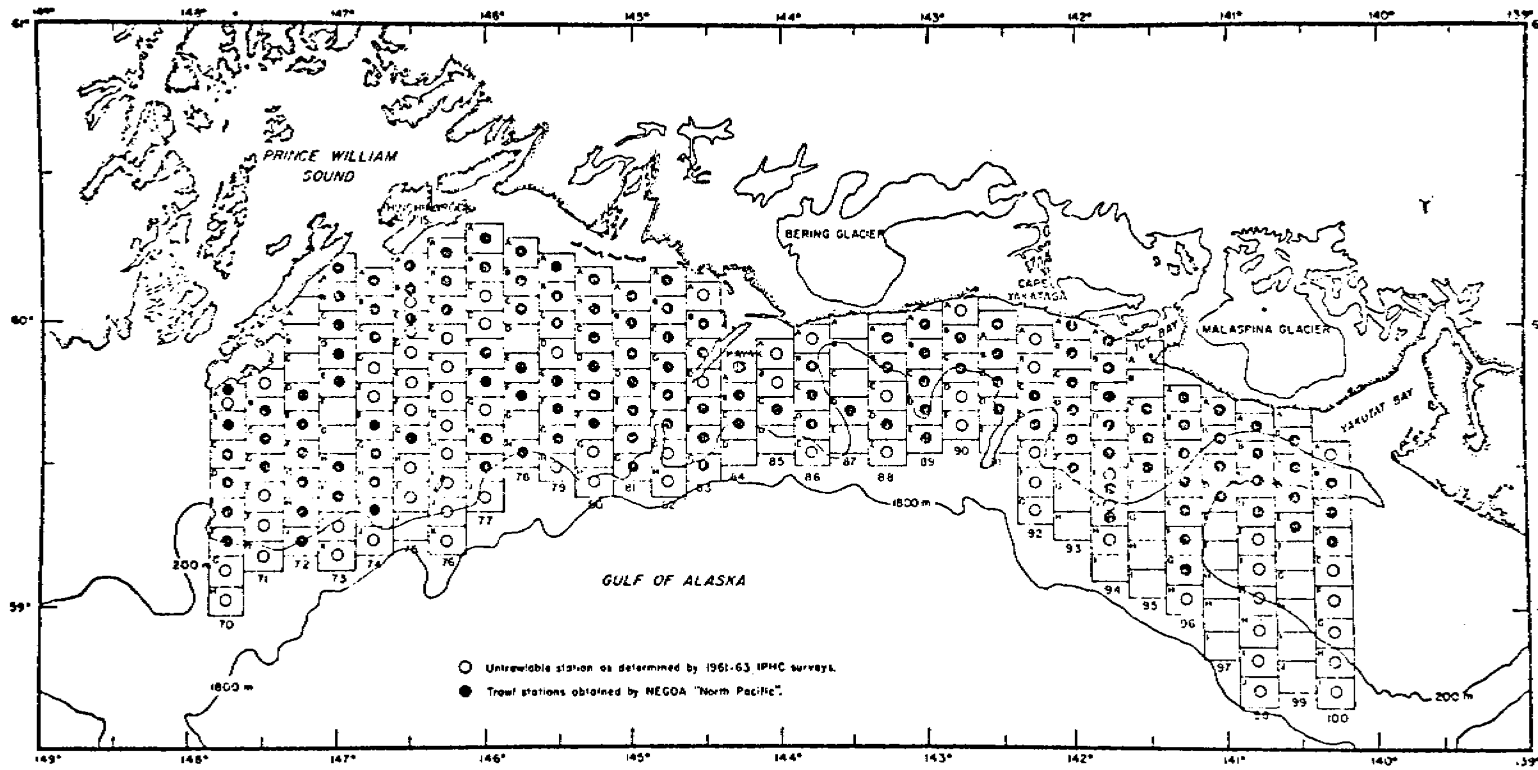

Fig. V-4. Station grid established for trawl survey on the shelf of the northeastern Gulf of Alaska (Feder, RU #281).

A total of 168 species were identified from the samples; the species represented 9 phyla, 19 classes, and 82 families (Table V-12). Molluscs and crustaceans were represented by 47 and 42 species, respectively. Echinoderms (36 species) and annelids (30 species) were next in abundance. The relative abundance of various taxonomic groups of the phyla Mollusca, Arthropoda, and Echinodermata is given in Table V-13. There was wide variation in the number of species between stations.

In terms of biomass, the commercially important Tanner crab, Chionoectes bairdi, and the shrimp, Pandalus borealis, were the dominant species; these species were collected at a rate as high as 1,343 kg/hr and 168 kg/hr. Two echinoderms, the sea star, Ctenodiscus crispatus, and the sun star, Pycnopodia helianthoides, were also abundant and contributed significantly to the biomass of the trawl catch. As many as 5,581 specimen of Ctenoidscus crispatus, average mass 10 g/specimen, were collected per hour at two stations, 73D and 80B. In case of Pycnopodia helianthoides, a much larger species (average mass in excess of 450 g/specimen), 190 specimen were collected per hour at station 93C. The brittle star, Ophiura sp., was most abundant at station 81D where 125,000 specimens were caught in one hour but because of its small size, biomass contribution of this species was not very high.

Earlier reports from the northeast Gulf of Alaska had reported that the deposit-feeding heart urchin, Brisaster townsendi comprised of about 50% of the invertebrate catch, 534 kg/hr (Hitz and Rathjen 1965, cited in Feder, RU #281). A high catch of this species is reported by Feder (RU #281) in Kayak Canyon, Icy Canyon, and Yakutat Canyon.

A high diversity of invertebrate species and an abundance of the Pacific halibut, Hippoglossus stenolepis, were noted at station 74C, south of Prince

Table V-12. A list of species taken by trawl from the Northeast Gulf of Alaska (NEGOA) on board the National Marine Fisheries Service charter vessel M/V *NORTH PACIFIC*, 25 April - 7 August 1975. (Feder, RU #281)

Phylum Porifera

Phylum Cnidaria
- Class Hydrozoa
- Class Scyphozoa
  - Family Pelagiidae
    - *Chrysaora melanaster* Brandt
- Class Anthozoa
  - Subclass Alcyonaria
    - *Eunephthya rubiformis* (Pallas)
    - Family Virgulariidae
      - *Stylatula gracile* (Gabb)
    - Family Pennatulidae
      - *Ptilosarcus gurneyi* (Gray)
    - Family Actiniidae
      - *Tealia crassicornis* (O. F. Müller)

Phylum Annelida
- Class Polychaeta
  - Family Polynoidae
    - *Arctonoe vittata* (Grube)
    - *Eunoe depressa* Moore
    - *Eunoe oerstedi* Malmgren
    - *Harmothoe multisetosa* Moore
    - *Hololepida magna* Moore
    - *Lepidonotus squamatus* (Linnaeus)
    - *Lepidonotus* sp.
    - *Polyeunoe tuta* (Grube)
  - Family Polynodontidae
    - *Peisidice aspera* Johnson
  - Family Euphrosinidae
    - *Euphrosine hortensis* Moore
  - Family Syllidae
  - Family Nereidae
    - *Ceratonereis paucidentata* (Moore)
    - *Ceratonereis* sp.
    - *Cheilonereis cyclurus* (Harrington)
    - *Nereis pelagica* Linnaeus
    - *Nereis vexillosa* Grube
    - *Nereis* sp.
  - Family Nephtyidae
  - Family Glyceridae
    - *Glycera* sp.
  - Family Eunicidae
    - *Eunice valens* (Chamberlin)
  - Family Lumbrineridae
    - *Lumbrineris similabris* (Treadwell)
  - Family Opheliidae
    - *Travisia pupa* Moore
  - Family Sabellariidae
    - *Idanthyrsus armatus* Kinberg
  - Family Terebellidae
    - *Amphitrite cirrate* O. F. Müller

Family Sabellidae
Euchone analis (Kröyer)
Family Serpulidae
Crucigera irregularis Bush
Family Aphroditidae
Aphrodita japonica Marenzeller
Aphrodita neglegens Moore
Aphrodita sp.
Class Hirudinae
Notostomobdella sp.

Phylum Mollusca
Class Polyplacophora
Family Mopaliidae
Class Pelecypoda
Family Nuculanidae
Nuculana fossa Baird
Family mytilidae
Mytilus edulis Linnaeus
Musculus niger (Gray)
Modiolus modiolus (Linnaeus)
Family Pectinidae
Chlamys hastata hericia (Gould)
Pecten caurinus Gould
Delectopecten randolphi (Dall)
Family Astartidae
Astarte polaris Dall
Family Carditidae
Cyclocardia ventricosa (Gould)
Family Cardiidae
Clinocardium ciliatum (Fabricius)
Clinocardium fucanum (Dall)
Serripes groenlandicus (Bruguière)
Family Veneridae
Compsomya subdiaphana Carpenter
Family Mactridae
Spisula polynyma (Stimpson)
Family Myidae
Family Hiatellidae
Hiatella arctica (Linnaeus)
Family Teredinidae
Bankia setacea Tryon
Family Lyonsiidae
Class Gastropoda
Family Bathybembix
Solariella obscura (Couthouy)
Lischkeia cidaris (Carpenter)
Family Naticidae
Natica clausa Broderip and Sowerby
Polinices monteronis Dall
Polinices lewisii (Gould)
Family Cymatiidae
Fusitriton oregonensis (Redfield)
Family Muricidae
Trophonopsis stuarti (Smith)

Family Buccinidae
Buccinum plectrum Stimpson
Family Neptuneidae
Beringius kennicotti (Dall)
Colus halli (Dall)
Morrisonella pacifica (Dall)
Neptunea lyrata (Gmelin)
Neptunea pribiloffensis (Dall)
Plicifusus sp.
Pyrulofusus harpa (Mörch)
Volutopsius filosus Dall
Family Columbellidae
Mitrella gouldi (Carpenter)
Family Volutidae
Arctomelon stearnsii (Dall)
Family Turridae
Oenopota sp.
Leucosyrinx circinata (Dall)
Family Dorididae
Family Tritoniidae
Tritonia exsulans Bergh
Tochuina tetraquetra (Pallas)
Family Flabellinidae
Flabellinopsis sp.
Class Cephalopoda
Family Sepiolidae
Rossia pacifica Berry
Family Gonatidae
Gonatopsis borealis Sasaki
Gonatus magister Berry
Family Octopodidae
Octopus sp.

Phylum Arthropoda
Class Thoracica
Family Lepadidae
Lepas pectinata pacifica Henry
Family Balanidae
Balanus hesperius
Balanus rostratus Hoek
Balanus sp.
Class Isopoda
Family Aegidae
Rocinela augustata Richardson
Family Bopyridae
Argeia pugettensis Dana
Class Decapoda
Family Pandalidae
Pandalus borealis Kröyer
Pandalus jordani Rathbun
Pandalus montagui tridens Rathbun
Pandalus platyceros Brandt
Pandalus hypsinotus Brandt
Pandalopsis dispar Rathbun
Family Hippolytidae
Spirontocaris lamellicornis (Dana)

Spirontocaris arcuata Rathbun
Eualus barbata (Rathbun)
Eualus macrophthalma (Rathbun)
Eualus suckleyi (Stimpson)
Eualus pusiola (Kröyer)
Family Crangonidae
Crangon communis Rathbun
Argis sp.
Argis dentata (Rathbun)
Argis ovifer (Rathbun)
Argis alaskensis (Kingsley)
Paracrangon echinata Dana
Family Paguridae
Pagurus ochotensis (Benedict)
Pagurus aleuticus (Benedict)
Pagurus kennerlyi (Stimpson)
Pagurus confragosus (Benedict)
Elassochirus tenuimanus (Dana)
Elassochirus cavimanus (Miers)
Labidochirus splendescens (Owen)
Family Lithodidae
Acantholithodes hispidus (Stimpson)
Paralithodes camtschatica (Tilesius)
Lopholithodes foraminatus (Stimpson)
Rhinolithodes wosnessenskii Brandt
Family Galatheidae
Munida quadrispina Benèdict
Family Majiidae
Oregonia gracilis Dana
Hyas lyratus Dana
Chionoecetes bairdi Rathbun
Chorilia longipes Dana
Family Cancridae
Cancer magister Dana
Cancer oregonensis (Dana)

Phylum Ectoprocta

Phylum Brachiopoda
Class Articulata
Family Cancellothridae
Terebratulina unguicula Carpenter
Terebratalia transversa (Sowerby)
Family Dallinidae
Laqueus californianus Koch

Phylum Echinodermata
Class Asteroidea
Family Asteropidae
Dermasterias imbricata (Grube)
Family Astropectinidae
Dipsacaster borealis Fisher
Family Benthopectinidae
Luidiaster dawsoni (Verrill)
Nearchaster pedicellaris (Fisher)

Family Goniasteridae
Ceramaster patagonicus (Sladen)
Hippasterias spinosa Verrill
Mediaster aequalis Stimpson
Pseudarchaster parelii (Düben and Koren)
Family Luidiidae
Luidia foliolata Grube
Family Porcellanasteridae
Ctenodiscus crispatus (Retzius)
Family Echinasteridae
Henricia aspera Fisher
Henricia sp.
Poraniopsis inflata Fisher
Family Pterasteridae
Diplopteraster multipes (Sars)
Pteraster tesselatus Ives
Family Solasteridae
Crossaster borealis (Fisher)
Crossaster papposus (Linnaeus)
Lophaster furcilliger Fisher
Lophaster furcilliger vexator Fisher
Solaster dawsoni Verrill
Family Asteridae
Leptasterias sp.
Lethasterias nanimensis (Verrill)
Stylasterias forreri (de Loriol)
Pycnopodia helianthoides (Brandt)

Class Echinoidea
Family Schizasteridae
Brisaster townsendi
Family Strongylocentrotidae
Allocentrotus fragilis (Jackson)
Strongylocentrotus droebachiensis (O. F. Müller)

Class Ophiuroidae
Family Amphiuridae
Unioplus macraspis (Clark)
Family Gorgonocephalidae
Gorgonocephalus caryi (Lyman)
Family Ophiactidae
Ophiopholis aculeata (Linnaeus)
Family Ophiuridae
Amphiophiura ponderosa (Lyman)
Ophiura sarsi Lütkin

Class Holothuroidea
Family Molpadiidae
Molpadia sp.
Family Cucumariidae
Family Psolidae
Psolus chitinoides H. L. Clark

Class Crinoidea

Phylum Chordata

Class Phlebobranchia
Family Rhodosomatiidae
Chelyosoma columbianum Huntsman

Class Stolidobranchia
Family Pyuridae
Halocynthia aurantium Oka

Class Chondrichthyes
  Subclass Elasmobranchii
    Order Squaliformes
      Family Squalidae
        Squalus acanthias Linnaeus
    Order Rajiformes
      Family Rajidae
        Raja binoculata Girard
        Raja kincaidi Garman
        Raja rhina Jordon and Gilbert
        Raja stellulata Jordon and Gilbert
Class Osteichthyes
  Subclass Teleostei
    Order Salmoniformes
      Family Osmeridae
        Thaleichthys pacificus (Richardson)
    Order Gadiformes
      Family Gadidae
        Gadus macrocephalus Tilesius
        Microgadus proximus (Girard)
        Theragra chalcogramma (Pallas)
      Family Zoarcidae
        Lycodes brevipes Bean
        Lycodes palearis Gilbert
    Order Scorpaeniformes
      Family Scorpaenidae
        Sebastes aleutianus (Jordon and Everman)
        Sebastes alutus (Gilbert)
        Sebastes babcocki (Thompson)
        Sebastes brevispinis (Bean)
        Sebastes entomelas (Jordon and Gilbert)
        Sebastes flavidus (Ayres)
        Sebastes variegatus Quast
        Sebastolobus alascanus Bean
      Family Hexagrammidae
        Ophiodon elongatus Girard
      Family Anoplopomatidae
        Anoplopoma fimbria (Pallas)
      Family Cottidae
        Dasycottus setiger Bean
        Hemilepidotus jordani Bean
        Ulca bolini (Myers)
      Family Agonidae
        Agonus acipenserinus Tilesius
    Order Perciformes
      Family Bathymasteridae
        Bathymaster signatus Cope
      Family Stichaeidae
        Lumpenus sagitta Wilimovsky
    Order Pleuronectiformes
      Family Pleuronectidae
        Atheresthes stomias (Jordon and Gilbert)
        Glyptocephalus zachirus Lockington
        Hippoglossoides elassodon Jordon and Gilbert
        Hippoglossus stenolepis Schmidt
        Isopsetta isolepis (Lockington)
        Lepidopsetta bilineata (Ayres)
        Microstomus pacificus (Lockington)

Table V-12 (contd.)

Parophrys vetulus Girard
Platichthys stellatus (Pallas)
Family Cryptacanthodidae
Delolepis gigantea Kittlitz

TABLE V-13

The Number and Percentage of Species of Subgroups of Mollusca; Arthropoda and Echinordermata Collected by Commercial Trawl in the Northeast Gulf of Alaska (NEGOA) on the M/V *North Pacific*, Collections made May-August, 1975 (Feder, RU #281).

Phylum	Subgroup	No. of Species	% of Species
Mollusca	Gastropoda (snails, nudibranchs)	24	51.1
	Pelecypoda (clams, scallops)	18	38.3
	Cephalopoda (octopus, squid)	4	8.5
	Polyplacophora (chitons)	1	2.1
	TOTAL	47	100.0%
Arthropoda	Decapoda (crabs, shrimp)	36	85.7
	Thoracica (barnacles)	4	9.5
	Isopoda	2	4.8
	TOTAL	42	100.0%
Echinodermata	Asteroidea (sea stars)	24	66.7
	Ophiuroidea (brittle stars)	5	13.9
	Echinoidea (sea urchins)	3	8.3
	Holothuroidea (sea cucumbers)	3	8.3
	Crinoidea (feather star)	1	2.8
	TOTAL	36	100.0%

William Sound. Out of the 47 species of invertebrates,]4 belonged to Crustacea, 13 to Mollusca, and 13 to Echinodermata. The halibut catch was nearly 1,400 kg/hr, and the average mass of fish collected was 18.5 kg.

Two other fish species were well-respresented in trawl catches. The Starry flounder, Platichthys stellatus, at stations 94A and 94B, south of Icy Cape, and juvenile Walleye pollock, Theragra chalcogramma, at station 94B, formed a significant part of trawl catches.

Fish Stomach Contents: Feder's report (RU #281) also provides results from analysis of stomach contents of the Pacific cod, Gadus macrocephalus, collected during 1972, 1973, and 1974 ADF&G King Crab-Snow Crab Indexing Studies. The identified stomach contents belonged to 49 genera representing 9 phyla (Table V-14). These data are based on the examination of over 2,000 stomachs out of which 1,183 were obtained in 1974. As can be noted from this table, snow crabs, fishes, amphipods, and shrimp were important constituents of cod food. Among the fishes, eelpouts and flatfishes were the dominant food source. It was also noted by Feder (RU #281) that larger specimens of fish consumed larger organisms rather than large quantities of small organisms.

Stomach contents of the Starry flounder, Platichthys stellatus, caught off Icy Bay on June 3, 1975, included three species of lamellibranchs, Yoldia sp., Siliqua sp., and Macoma sp. No other animals were found and stomachs were full. This seems to be a reflection of seasonal trends in feeding intensity as this species does not feed from January to June.

Commercially Important Shellfish

Razor Clam Survey: A research program to assess the relative abundance and distribution patterns of the Pacific Razor Clam, Siliqua patula, along the Gulf of Alaska coastline is in progress (Kaiser/Konigsberg, RU #24).

TABLE V-14

Frequency and percent of occurrence of specific food items in stomachs of *Gadus macrocephalus* (Pacific cod) as related to Alaska Department of Fish and Game Indexing Studies: 1972, 1973 and 1974. N=stomachs examined. (Feder, RU #281)

Food Items	1972:N=147		1973:N=689		1974:N-1183	
	Number	Percent	Number	Percent	Number	Percent
Coelenterata						
Hydrozoa (hydroids)	-	-	2	0.2	-	-
Anthozoa (anemones)	-	-	5	0.7	3	0.3
Mollusca[1]						
Amphineura (chitons)	1	0.6	-	-	1	0.1
Pelecypoda (clams, mussels, cockles)						
Cardita crassidens	-	-	1	0.1	1	0.1
Clinocardium sp.	-	-	1	0.1	-	-
Glycymeris subobsoleta	-	-	1	0.1	-	-
Hiatella arctica	-	-	1	0.1	-	-
Macoma expansa	-	-	1	0.1	-	-
Macoma sp.	-	-	1	0.1	1	0.1
Musculus olivaceus	-	-	1	0.1	1	0.1
Nucula tenuis	-	-	1	0.1	-	-
Nuculana fossa	-	-	7	1.0	43	3.6
Panomya ampla	-	-	1	0.1	-	-
Psephidia lordi	-	-	1	0.1	-	-
Velutina velutina	-	-	1	0.1	-	-
Yoldia beringiana	-	-	2	0.2	-	-
Yoldia spp.	-	-	28	4.0	6	0.6
Unidentified	13	8.8	15	2.1	27	2.3
Gastropoda (snails)						
Amphissa columbiana	-	-	1	0.1	-	-
Buccinum sp.	-	-	1	0.1	-	-
Cylichna alba	-	-	1	0.1	-	-
Fusitriton sp.	-	-	1	0.1	-	-
Natica aleutica	-	-	1	0.1	2	0.2
Neptunea sp.	-	-	1	0.1	-	-
Polinices sp.	-	-	2	0.2	1	0.1
Trichotropis cancellata	-	-	1	0.1	1	0.1
Turridae	-	-	1	0.1	-	-
Unidentified gastropods	5	3.4	6	0.8	26	2.2
Cephalopoda						
Octopus - squid	11	7.4	53	7.6	109	9.2
Annelida						
Polychaeta						
(segmented worms)	8	5.4	15	2.1	63	5.3

TABLE V-14 (contd.)

Food Items	1972:N=147 Number	Percent	1973:N=689 Number	Percent	1974:N-1183 Number	Percent
Arthropoda						
Crustacea						
Malacostraca						
Euphausiacea (krill)	1	0.6	20	2.9	34	2.9
Isopoda (pill bugs)	-	-	3	0.4	4	0.3
Amphipoda (sand fleas)	30	20.6	192	27.8	195	16.5
Decapoda						
Pandalidae (shrimp)	4	2.7	67	9.7	118	10.0
Crangonidae (shrimp)	1	0.6	77	11.1	95	8.0
Unidentified shrimp	55	37.4	131	19.0	82	6.9
Lithodidae (crabs)						
Paralithodes camtschatica	-	-	2	0.2	9	0.8
Paguridae (hermit crabs)	5	3.4	24	3.4	21	1.8
Cancridae (crabs)						
Cancer oregonensis	1	0.6	4	0.5	1	0.1
Telmessus cheiragonus	-	-	1	0.1	-	-
Pinnotheridae (pea crabs)						
Pinnixa occidentalis	1	0.6	5	0.7	36	3.0
Majidae (spider crabs)						
Chionoecetes bairdi	49	33.3	281	40.7	428	36.2
Hyas lyratus	5	3.4	13	1.8	44	3.7
Oregonia gracilis	4	2.7	-	-	3	0.3
Unidentified crabs	2	1.3	12	1.7	3	0.3
Echinodermata						
Asteroidea (starfish)	-	-	1	0.1	2	0.2
Echinoidea (sea urchins)	-	-	1	0.1	-	-
Holothuroidea (sea cucumbers)	1	0.6	2	0.2	5	0.4
Ophiuroidea (brittle stars)	-	-	-	-	3	0.3
Chordata						
Urochordata	1	0.6	-	-	-	-
Vertebrata						
Osteichthyes						
Clupeidae (herring)						
Clupea harengus pallasi	5	1.7	6	0.8	1	0.1
Osmeridae (smelts)	-	-	3	0.4	2	0.2
Gadidae						
Theragra chalcogramma	1	0.6	7	1.0	13	0.9
Gadus macrocephalus	1	0.6	12	1.7	32	2.7
Zoarcidae (eelpouts)	5	3.4	29	4.2	9	0.8
Scorpaenidae (rockfish)	-	-	1	0.1	1	0.1
Cottidae (sculpins)	1	0.6	8	1.1	27	2.3
Cyclopteridae (lumpsuckers)	-	-	1	0.1	1	0.1
Pleuronectidae (flatfishes)	4	2.7	22	3.1	21	1.8

TABLE V-14 (contd.)

Food Items	1972:N=147 Number	Percent	1973:N=689 Number	Percent	1974:N-1183 Number	Percent
Vertebrata						
Osteichthyes						
Ammodytidae (sand lance)						
Ammodytes hexapterus	-	-	20	2.9	20	1.7
Stichaeidae (pricklebacks)	-	-	14	2.0	-	-
Crypacanthodidae (wrymouth)						
Lyconectes aleutensis	4	2.7	9	1.3	4	0.3
Unidentified fish	22	14.9	256	37.1	476	40.2
Stomachs empty	6	4.0	39	7.6	59	5.0

[1]All mollusc identifications were verified by Mr. Rae Baxter, Alaska Department of Fish and Game, Box 96, Bethel, Alaska.

Razor clams are important in this area from both commercial and recreational aspects. No beaches have been sampled within the framework of this project. It is planned that sampling will be made at selected sites at different tidal levels along transects within the boundaries of razor clam populations.

Geographical locations of known razor clam populations are shown in Fig. V-5. Out of the 49 identified locations on the map, about 20 locations have yielded commercially exploitable populations. Most of these locations are concentrated in the western part of the Gulf, locations numbered 20 to 30 (Fig. V-5). In the northern Gulf, Cape Suckling-Orca Inlet area (140 miles long) is recognized to yield sizeable harvests for both the commercial and recreational purposes. The following account of historic razor clam population and yield is extracted from RU #24 Annual Report:

> From 1916-73, 53 million pounds (24 million kg) of razor clams have been harvested from Cordova area, an average yearly production of 930 thousand pounds (422 thousand kg). From areas around the Alaskan Peninsula, average yearly output from 1922-71 of 163 thousand pounds (74 thousand kg) is calculated; for the Cook Inlet area the average yearly value for 1918 to 1971 is 51 thousand pounds (23 thousand kg). In recent years, harvest has dwindled considerably, to about one-half of its former level. This may be in part due to reduction in stocks (Cordova area) or due to marketing factors (Alaskan Peninsula, Cook Inlet).
>
> In different parts of Kaguyak Bay (Shelikof Strait), studies have continued since 1972. It has been found that at Swikshak Beach population density of razor clam is between 0.03 to 1.2 individuals sq. yard (.02 to 1.00 ind/sq. m), total population of clams larger than 115 mm is estimated as 1.4 million. At Big River Beach, 1.3 million clams, larger than 115 mm, are estimated with an average density of 1.6 individuals/sq. yd. (1.34 ind./sq. m) (unpublished data reported by the author.)

Trawl Catches: Average catch statistics, pounds per hour of trawling, for shrimp, including Pink Shrimp, *Pandalus borealis*, side-stripe shrimp, *Pandalopsis dispar*, spot shrimp, *Pandalus platyceros*, and coon-stripe shrimp, *Pandalus lypsinotus* (Fig. V-6), Dungeness crab, *Cancer magister* (Fig. V-7), King crab, *Paralithodes camtschatica* spp. (Fig. V-8), and Tanner crab,

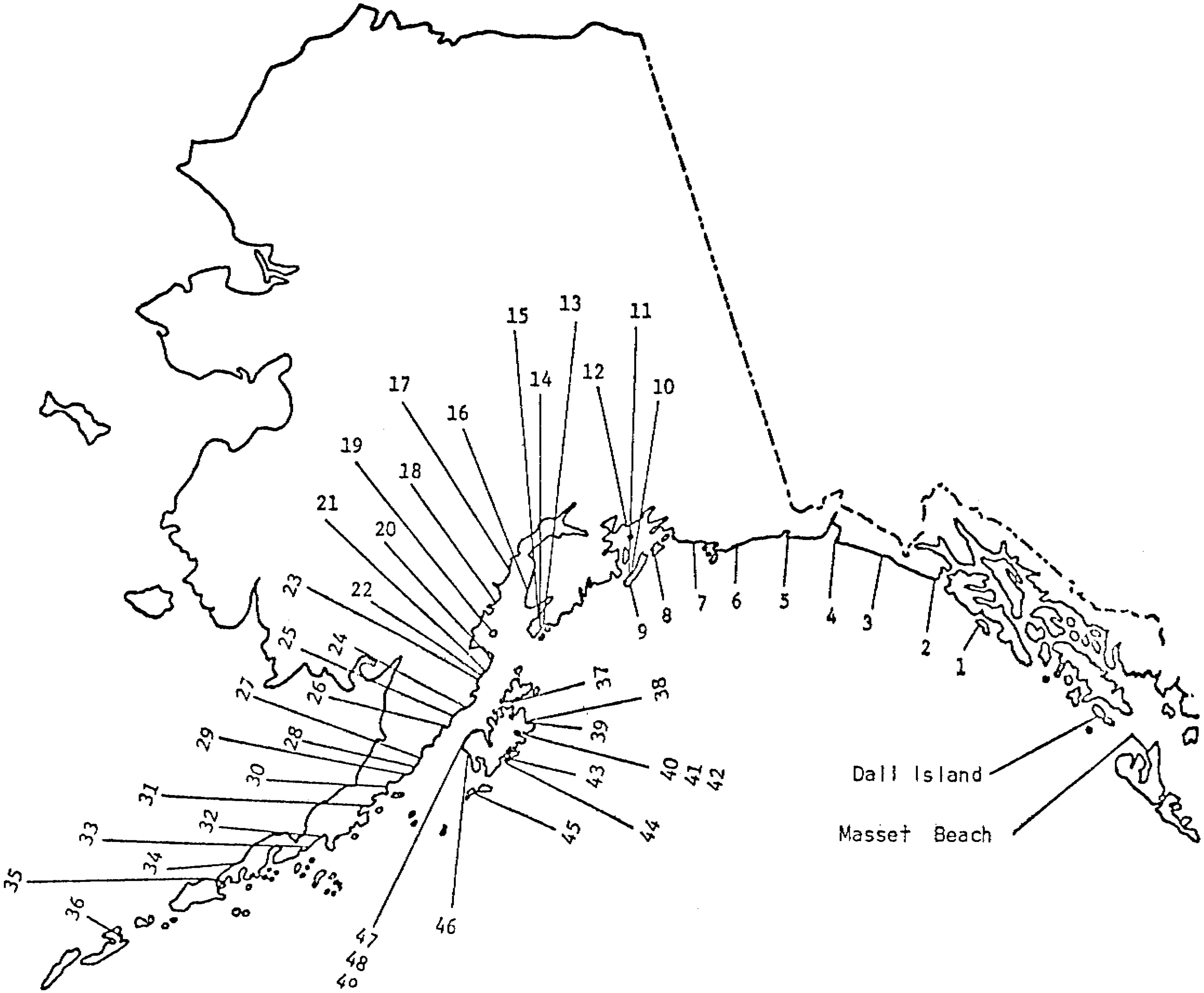

Fig. V-5. Geographic locations of known razor clam growing areas in Alaska (Kaiser, RU #24).

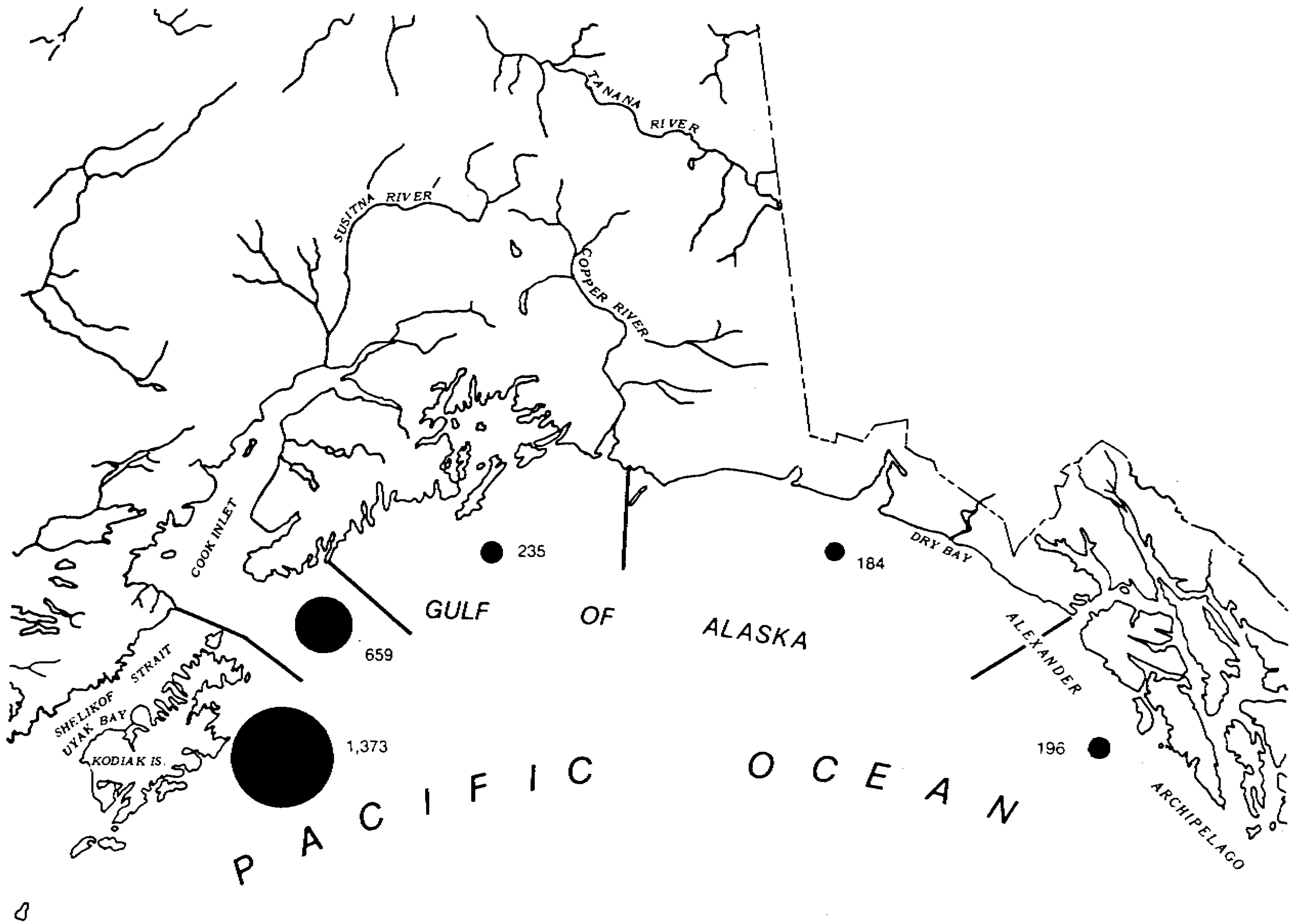

Fig. V-6. Average catch in pounds per hour of trawling by regions for shrimp based on drags producing 10 pounds or more (Maturgo 1972).

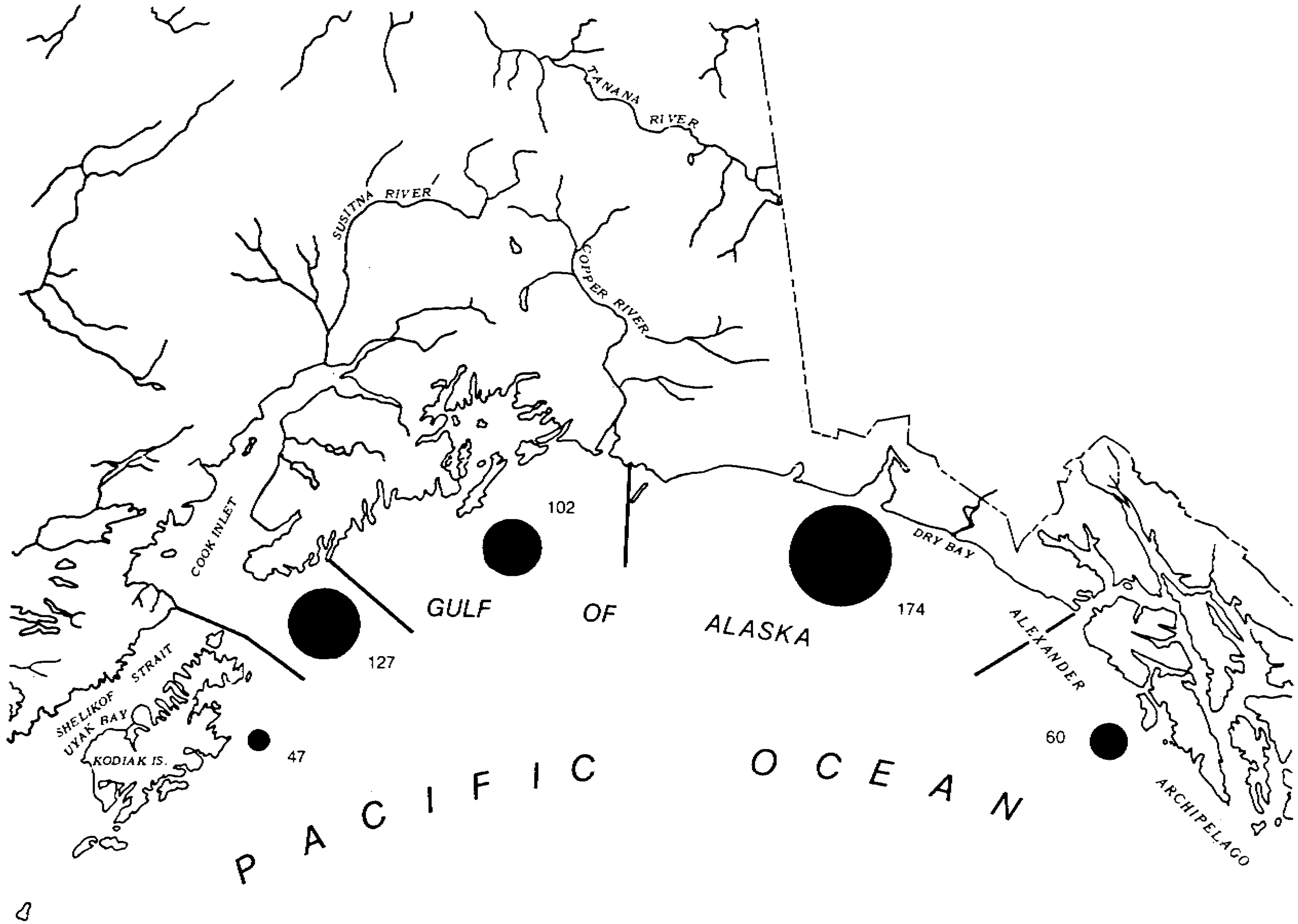

Fig. V-7. Average catch in pounds per hour of trawling by regions for dungeness crab based on drags producing 10 pounds or more (Maturgo 1972).

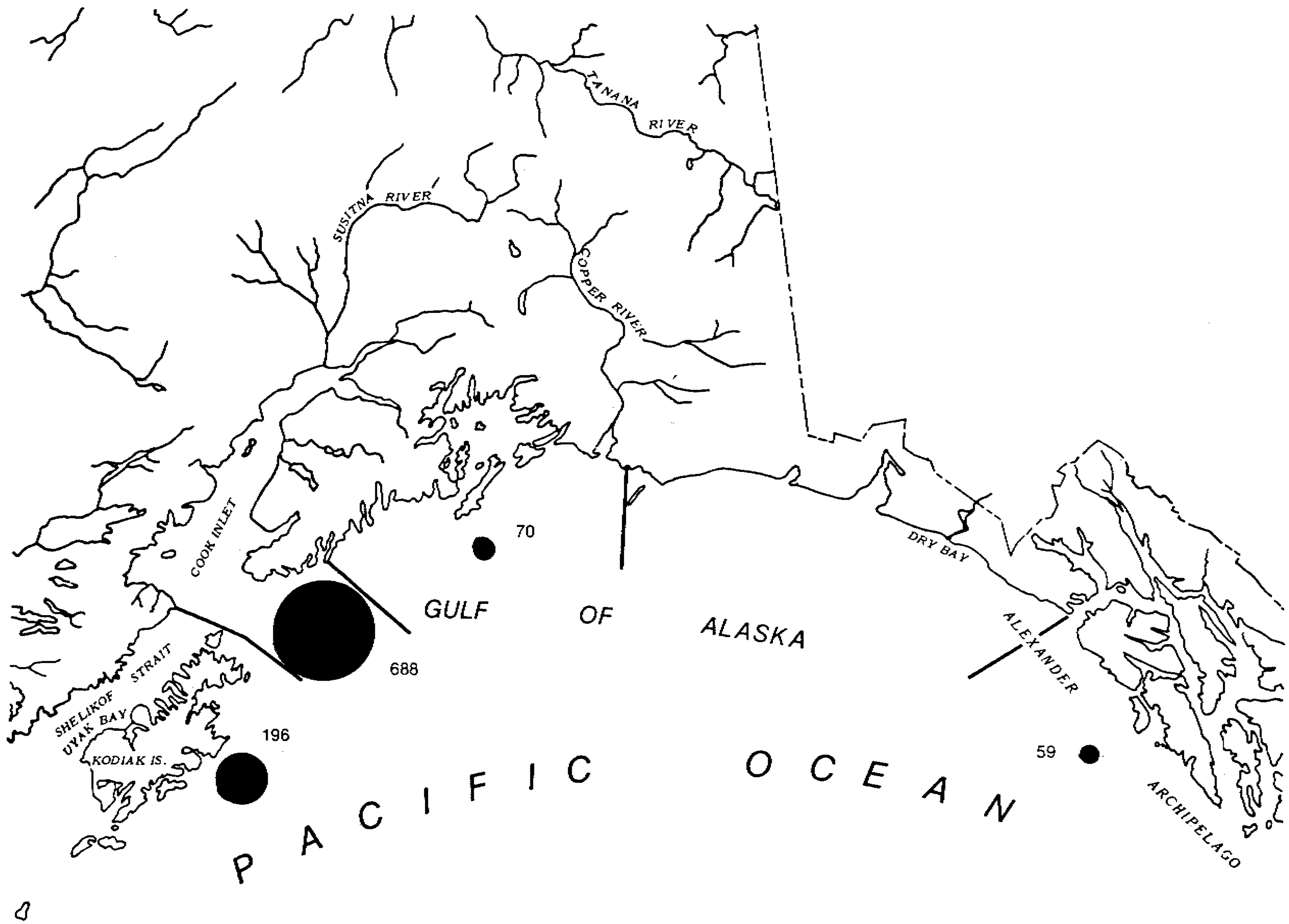

Fig. V-8. Average catch in pounds per hour of trawling by regions for king crab based on drags producing 10 pounds or more (Maturgo 1972).

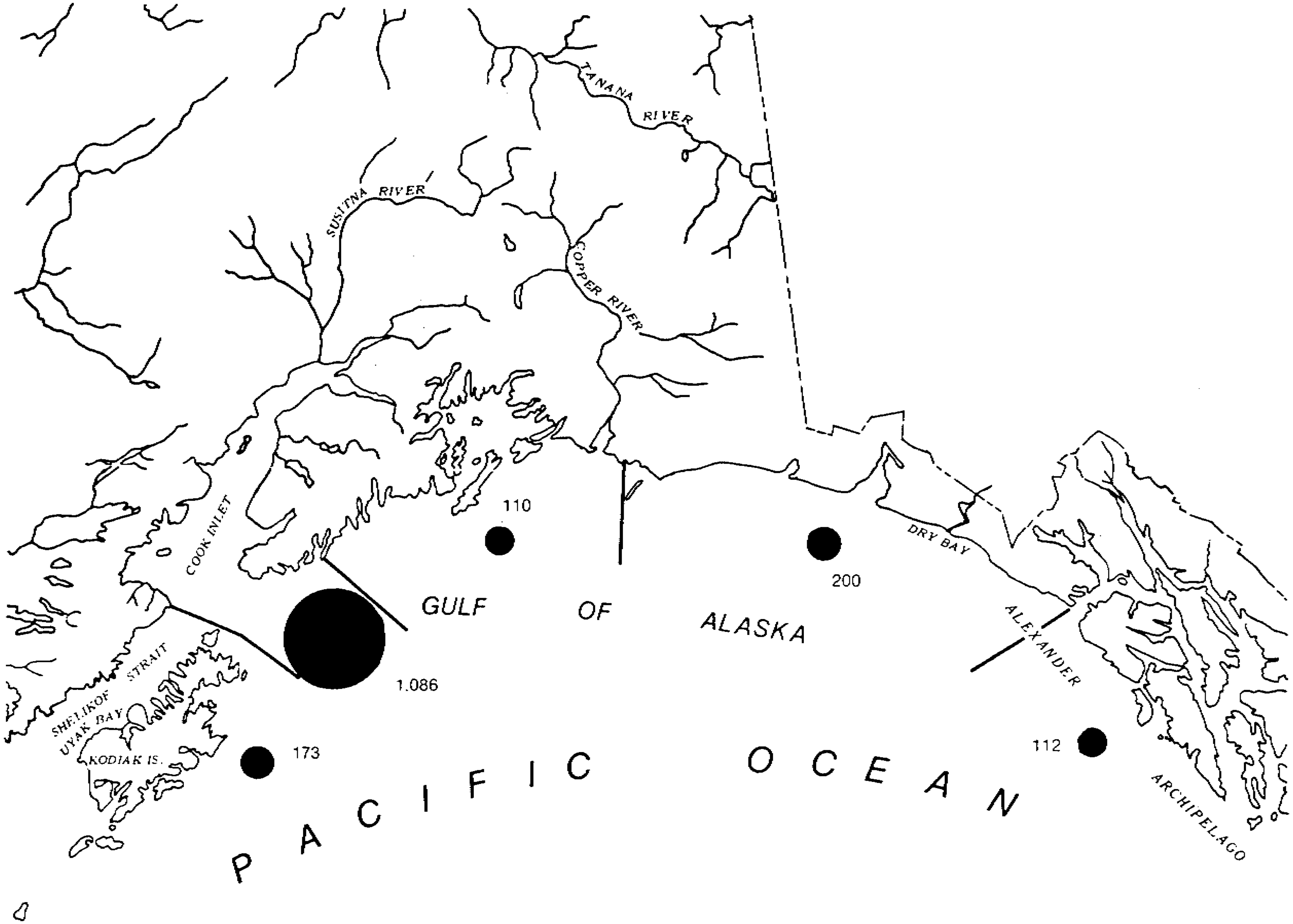

Fig. V-9. Average catch in pounds per hour of trawling by regions for tanner crab based on drags producing 10 pounds or more (Maturgo 1972).

Chionoectes bairdi (Fig. V-9), show that except for Dungeness crab, relative abundance of these species is higher in the western part of the Gulf. These figures are based on catch statistics data from about 2,500 exploratory drags by the National Marine Fisheries Service from 1950 to 1968 in the Gulf of Alaska and compiled in a report for Shell Oil Company (Maturgo 1972).

PLANKTON

Plankton studies in the Gulf of Alaska have been conducted for many years. Data collected at the Canadian Weather Ship station "P", 50°N, 145°W, represent a very useful time-series of observations on nutrients and plankton. In addition, extensive records of physical properties and features of the water, as well as meteorological conditions, have been kept for a number of years. Nearshore, studies on phytoplankton dynamics have been carried out in Auke Bay and other estuaries and embayments in the inside passage.

Koblentz-Mishke et al. (1970) summarized the available literature and unpublished data on primary productivity for the world's oceans. According to this review, the average daily rate of primary productivity for the eastern part of the Gulf of Alaska is expected to be over 500 mgC/m^2, and between 250-500 mgC/m^2 for the northern and western parts. Their estimates, also followed by the UN Food and Agricultural Organization, were reported in the draft Environmental Impact Statement (EIS) for Lower Cook Inlet. Phytoplankton biomass at station "P" remains relatively constant throughout the year. For Prince William Sound, net annual primary productivity is estimated to be 185 gC/m^2 (Goering et al. 1973, cited by Larrance, RU #156-C).

Much fewer data are available for zooplankton biomass and distribution in the Gulf of Alaska.

In view of the existing information and data, Larrance (RU #156-C) has pointed out the following:

"1. The existing information described, primarily the southern offshore portion of the Gulf of Alaska and limited data, are available along the northern Gulf of Alaska continental shelf.

2. No sampling program has produced phytoplankton and primary production data applicable to the OCSEAP objectives in terms of spatial and temporal continuity and frequency in the study region.

3. A coherent picture of phytoplankton species distribution cannot be presented from information in existing reports."

Phytoplankton

Larrance (RU #156-C) has reported new data on phytoplankton from the proposed lease areas in the northeast Gulf of Alaska. These data were collected from October 21 to November 14, 1975, from various stations located between Yakutat Bay and Resurrection Bay. Anderson and Lam (RU #58) are compiling existing data on plankton and related physical and chemical properties in the Gulf of Alaska to describe temporal and geographical variation in phytoplankton standing stock, productivity, and species composition. In addition, a numerical model of phytoplankton to identify major factors affecting primary production, based on data from station "P", is planned.

Chlorophyll *a*

Water samples were collected at different depths in the upper 50 m of the water column. Chlorophyll *a* concentration was determined fluorometrically. Concentration values are given per square meter for the 50 m water column. Higher concentrations were found at stations offshore of the shelf (mean value, 33 mg/m^2) than in waters over the shelf, excluding data from Prince William Sound (mean value, 18 mg/m^2). At station 40, in Prince William Sound, there was about twice as much chlorophyll *a*, 80.6 mg/m^2, as the next highest value measured, 45.5 mg/m^2, at station 13 in offshore waters. This high concentration may have been associated with a localized, short-term phytoplankton bloom in the sound. Figure V-10 shows the distribution pattern of chlorophyll *a* concentration in the upper 50 m.

Successive observations made at Station 46 (n = 10), located in relatively shallow water southwest of the Copper River delta, and at Station 62 (n = 9), located near the 183 m depth contour southwest of Icy Bay, showed that within-station variability was not very large. At Station 46, mean chlorophyll *a* concentration was 14.6 mg/m^2 (standard deviation, 3.5), whereas at Station 62 mean and standard deviations were 34.7 and 10.1 mg/m^2, respectively.

Species Composition

Water samples preserved in buffered, 1% formalin have been examined for taxonomic analysis of phytoplankton using the Utermöhl inverted microscope technique. Results from preliminary analysis of 10 m samples from 31 stations have been reported (Larrance, RU #156-C).

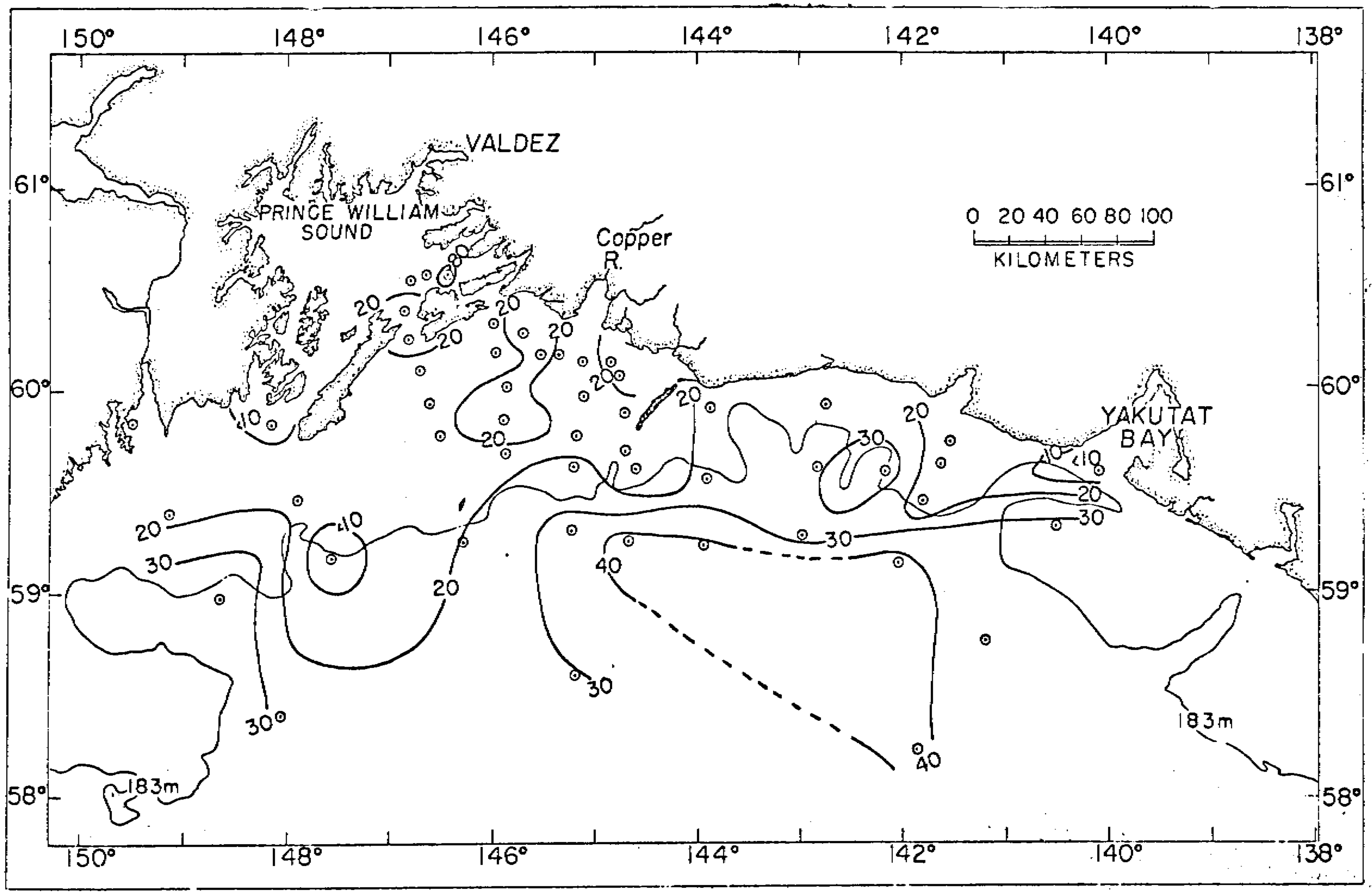

Fig. V-10. Isopleths of chlorophyll a concentration in the upper 50 m, mg/m^2, based on data obtained in October to November 1975. A 183-m depth contour is also shown (figure reproduced from Larrance, RU #156-C).

Unidentified microflagellates, 5-25 μ in diameter, were found to be ubiquitous in the research area. They comprised the most abundant group at 15 stations and were among the top five most abundant groups in the examined samples from all stations, except Station 40. Ranking, according to relative abundance, of phytoplankton taxons is given in Table V-15. At Station 40, Skeletonema costatum, a centric diatom, and at Station 34, Thalassionema nitzschioides, a pennate diatom, were the most abundant species.

The distribution of substantial numbers of cells, > 100/ℓ, of two species, Thalassionema nitzschioides and Fragillariopsis sp., were nearly mutually exclusive (Fig. V-11). Mean concentration of T. nitzschioides was 2,000 cells/ℓ, that of Fragillariopsis sp., 1,700 cells/ℓ. These two species occurred simultaneously at only three stations. The silicoflagellate, Dictyocha fibula, was limited to the western part of the research area (Fig. V-12). In Prince William Sound diatoms accounted for almost all the phytoplankton; Skeletonema costatum was highly abundant, up to 1.7×10^6 cells/ℓ (Larrance, RU #156-C).

Primary Productivity

Phytoplankton productivity was estimated by measuring the carbon assimilation rate by the carbon-14 method. Assimilated carbon-14 was analyzed by the liquid scintillation technique. Water samples, from five to seven depths in the upper 50 m, were collected according to light transmission ratings of neutral density filters used for incubations: 95, 75, 50, 30, 18, 5.5, and 2% of incident light. Incubations were from dawn to local apparent noon (LAN) or from LAN to sunset.

Daily rates of primary productivity, integrated from surface down to 1% light depth, ranged from 39 to 736 mgC/m^2 except at Station 40 when the rate was 2.9 gC/m^2. The spatial distribution pattern of levels of primary productivity

TABLE V-15

Rank Order of Cell Concentrations of Most Frequently Recurring Phytoplankton Groups (taken from Larrance, RU #156-C)

Station	microflagellates	*Thalassionema nitzschioides*	*Fragillariopsis* sp.	*Dictyocha fibula*	*Skeletonema costatum*	*Thalassiosira* sp.	Coccolithophorids
1A	2			1			
2	1	4		2		5	
3	1	2		4		3	5
4	3	2		1		4	
49	2	1		3		5	
50	3	1		2		4	
51	3	2		1		4	
51A	3	1		2		5	
48	2	1		3			
45	1	2		3			
43	2	1				4	
42	3				1	5	
40		2			1		
39	2	1		5			
38	2	1					
27	2	1				5	3
34		1		2		4	
33	1	2		3		4	
32	1	2					
5	1		2				
31	1						
30	1		3				
21	1	3	2				
20	1		2				5
19	1		2			5	3
18	1	3					
13	1		3				2,4
12	1		2				3,5
11	5	1					2
8	1	3	5				2,4
7	2		1				3

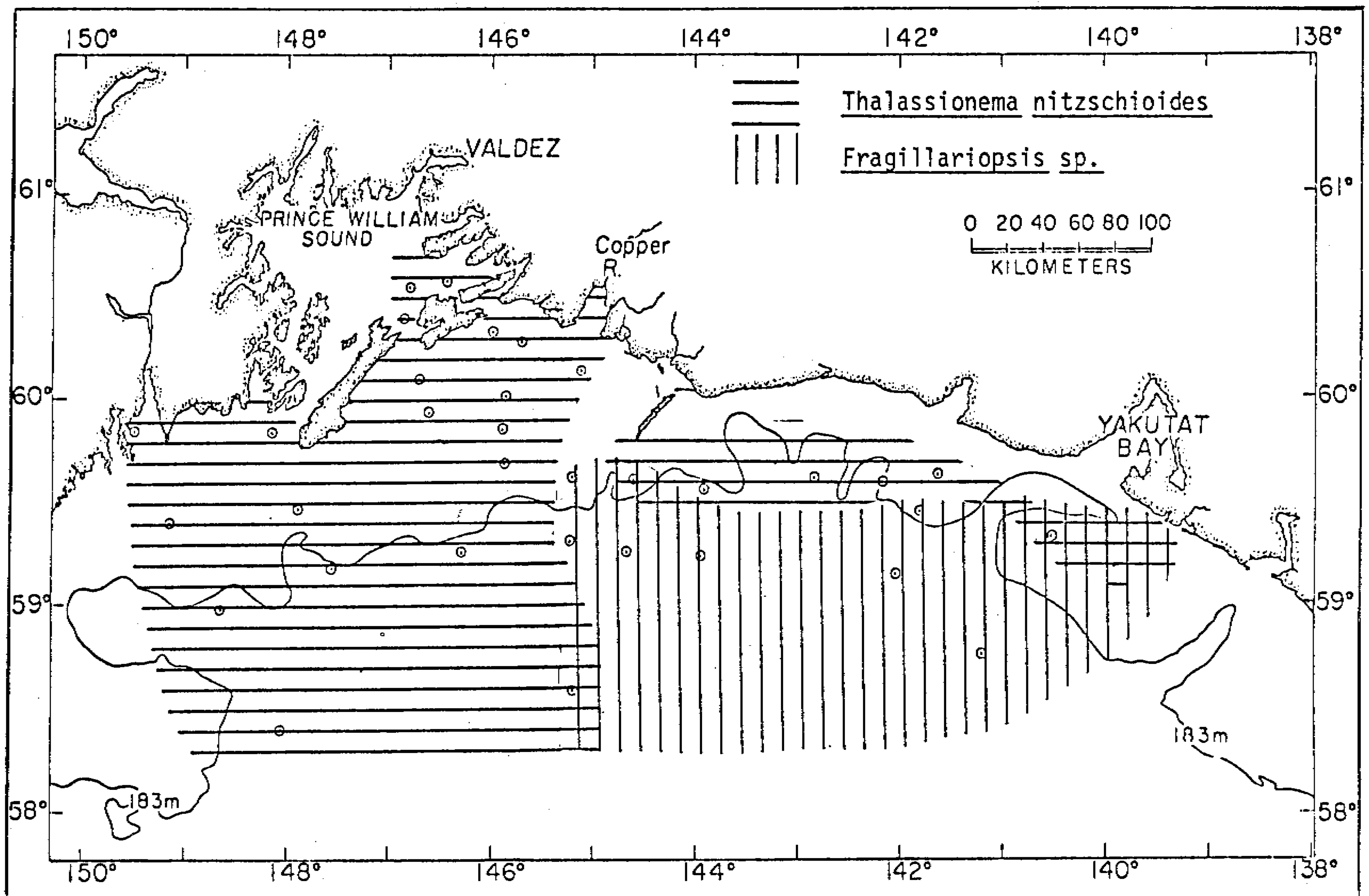

Fig. V-11. Distribution of Thalassionema nitzschioides and Fragillariopsis sp. at 10 m, October to November, 1975. (taken from Larrance, RU #156-C)

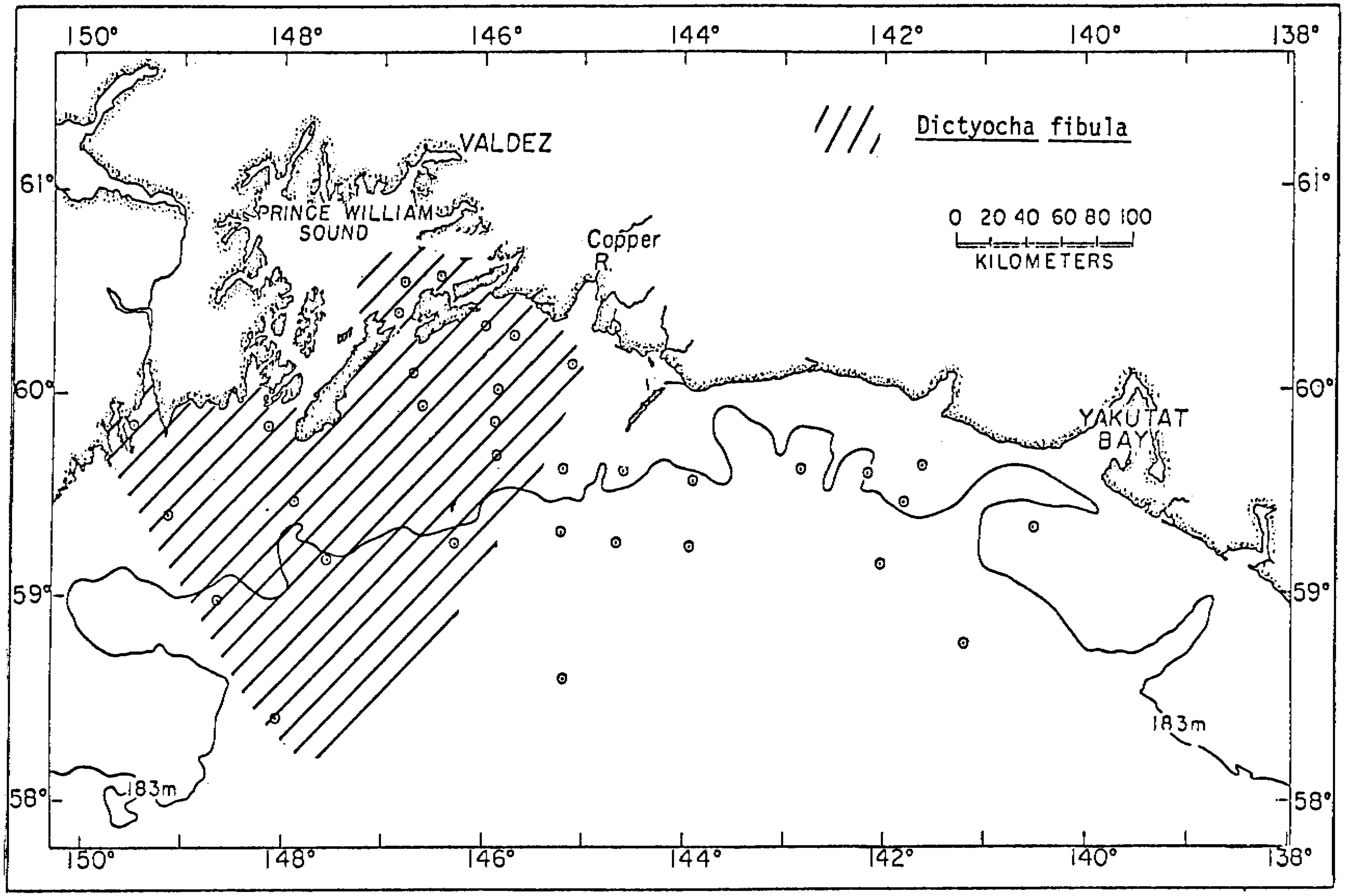

Fig. V-12. Distribution of Dictyocha fibula at 10 m, October to November, 1975. (taken from Larrance, RU #156-C)

(Fig. V-13) generally followed that of chlorophyll a. From results for individual stations, it was noted that a subsurface maximum in primary productivity occurred between 5 and 15 m.

Values of chlorophyll specific primary productivity, mgC [mg Chl a]$^{-1}$ per day, calculated for Table 1 (Larrance, RU #156-C), show a narrower range, from 4 to 52.

Nitrate-N concentration in surface layers was between 3 and 12 mg-at/m^3; other inorganic nutrients were also present in appreciable quantities. Phytoplankton productivity was probably not nutrient limited; light may have been a major controlling factor at the time of observations. However, from the date provided in Table 1 (Larrance, RU #156-C), there does not appear to be a recognizable pattern of relationship between incident solar radiation and specific primary productivity. It is, however, noted that the difference between the two incubation periods may not be significant due to large variability in respective values: $\bar{d}$ = 239, sd = 760. Data on primary productivity and available light for each sample would be needed to examine any quantitative relationship between light and primary productivity. An analysis of plankton photosynthesis response to light will be carried out by Larrance.

Numerical Modeling

A numerical model describing primary productivity and the distribution of phytoplankton standing stock is proposed by Anderson and Lam (RU #58). An adequate evaluation of the magnitude and variability of vertical mixing in the water column is essential for such studies. It is assumed by Anderson and Lam that temperature and phytoplankton are both mixed by the same vertical mixing process. It is further assumed that time rate of change of temperature is sufficiently small so that temperature distribution can be regarded at steady

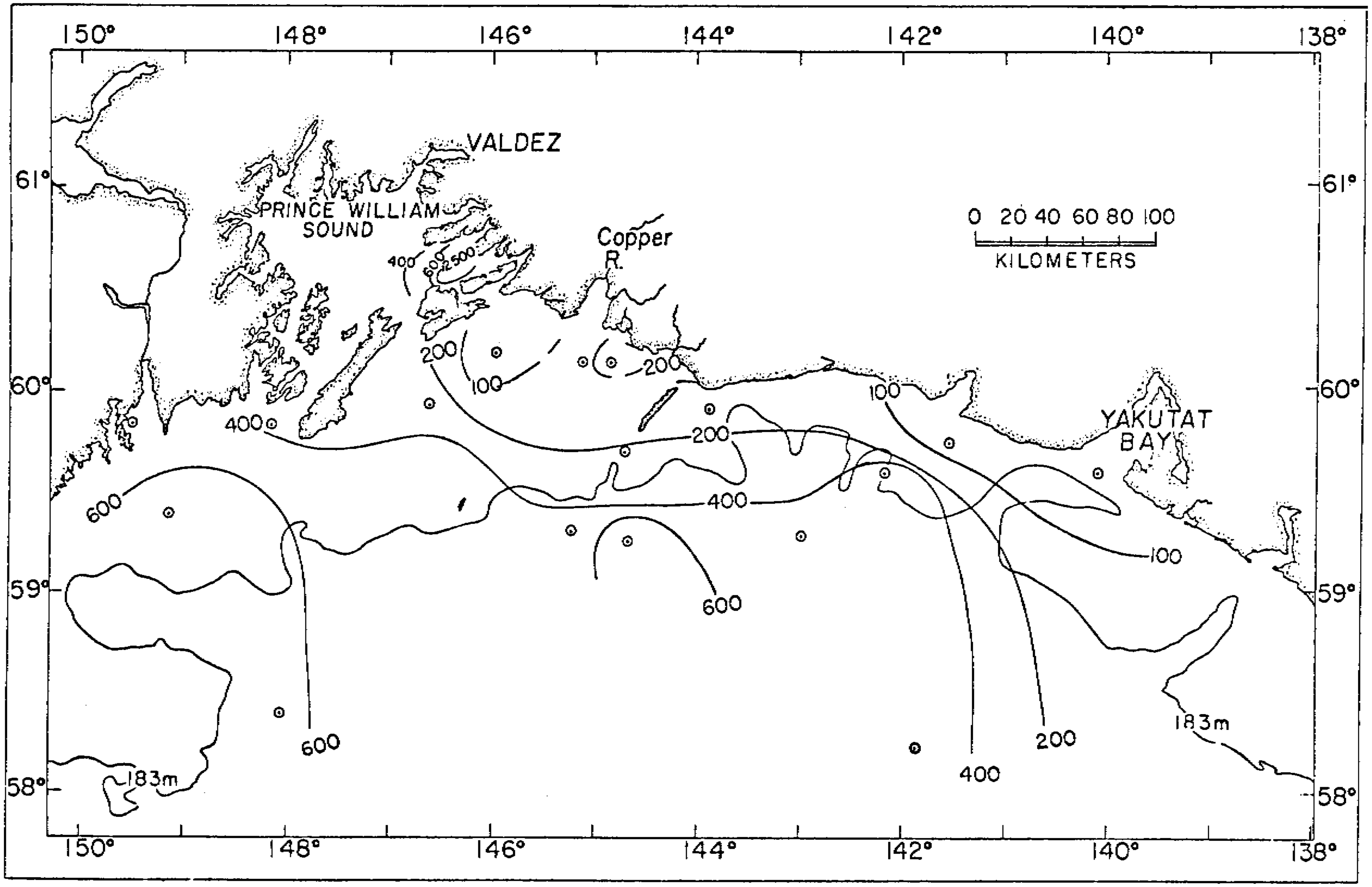

Fig. V-13. Primary production (mgC/m^2-day) in the euphotic zone, October to November, 1975. (taken from Larrance, RU #156-C) state. Profiles of the vertical mixing coefficient, K_z, with depth are calculated from temperature data from station "P" obtained in 1970, following $K_z \propto \left(\frac{\partial T}{\partial z}\right)^{-1}$ (Fig. V-14). Maximum surface K_z value of 60 cm^2/sec is estimated from winter data.

Zooplankton

Zooplankton samples were collected in Prince William Sound, September-October 1975, and in the northeast Gulf of Alaska, October-November 1975 (Damkaer, RU #156-B). Samples were collected with closing ring nets (ring diameter 60 cm, mesh size 211 μ) from discrete depth strata: 25-0 m, 50-25 m, 100-50 m, 300-100 m, 500-300 m, near the bottom - 500 m. Additional samples were collected with Tucker trawl, NIO net, and the bongo net. In Prince William Sound, 143 samples were collected with the closing net, 9 with Tucker trawl, 6 with NIO net, and 8 with the bongo net. Over the shelf 125 samples were collected with the closing net and 101 with the bongo net. Zooplankton biomass is given as settled volume. The amount of water filtered was calculated from the mouth area of the net and wire length assuming 100% filtration. The reported results are for Prince William Sound samples; only the settled volume data for two 36-hr stations on the shelf are provided.

Settled Volume

At one station in Prince William Sound, deeper than 700 m, zooplankton settled volume varied from 0.1 to 7.4 ml/m^3. A consistent increase in settled volume was noted in samples collected at night in the upper 100 m than those collected in the day; the corresponding numerical increase was small. It could have been due to diel migration of predominantly large zooplankters. Settled volume values integrated to the deepest sampling depth at one station, about

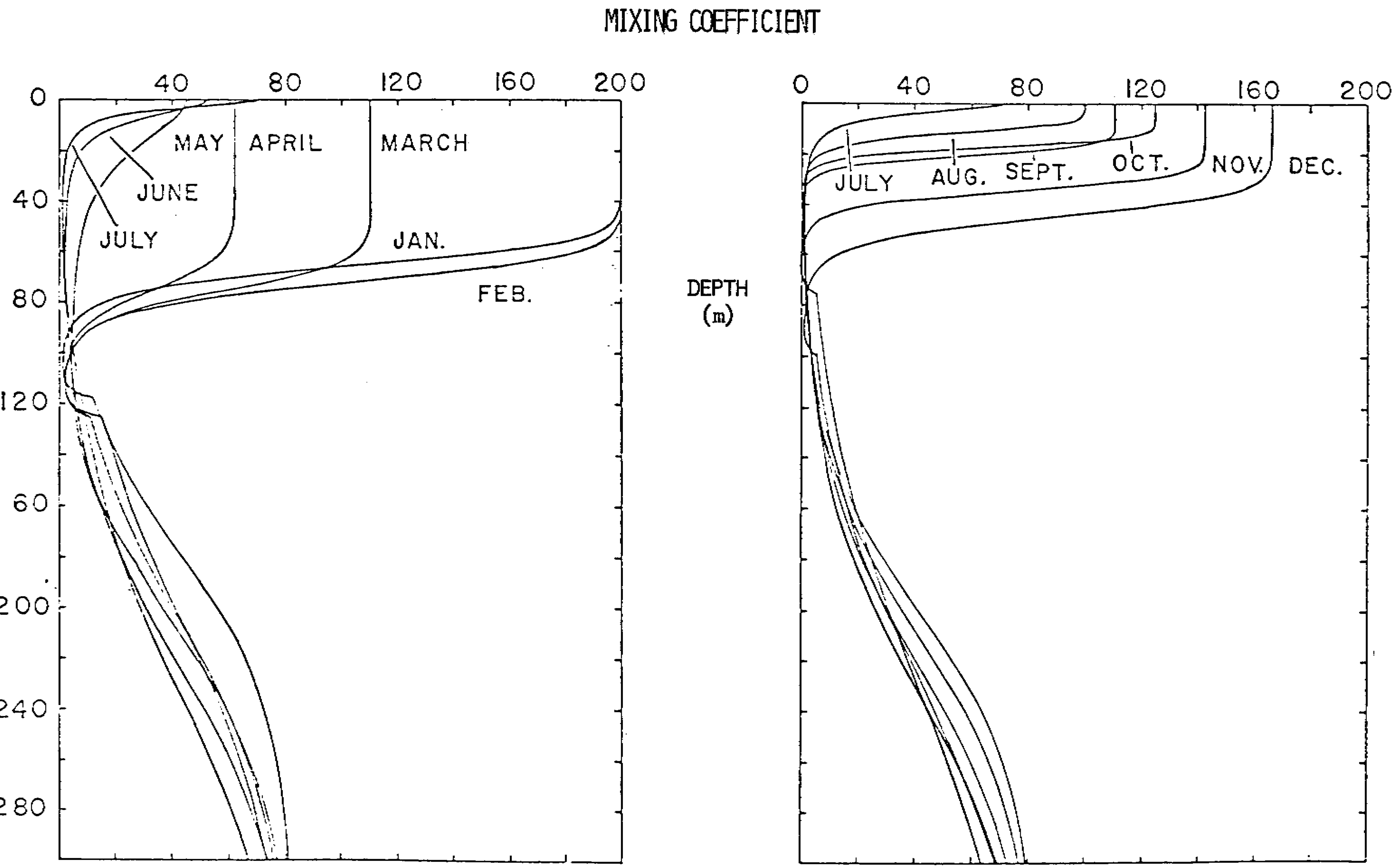

Fig. V-14. Profiles of mixing coefficients calculated from temperature data (station "P", 1970). The magnitude of K_z is in arbitrary units (figure reproduced from Anderson and Lam, RU #58).

710 m, gave an average of 1,100 ml/m^2 for day-time samples and 1,500 ml/m^2 for night-time samples. The average settled volume in the upper 25 m at day stations was 0.76 ml/m^3 (range 0.3 to 1.4) and 2.14 ml/m^3 (range 0.4 to 4.9) for night stations.

At each of the two stations on the shelf occupied for 36 hours, the average settled volume for two-day and two-night sampling periods did not indicate a marked increase in night-time samples. It is possible that this was due to shallower depths at these stations compared with stations in Prince William Sound.

Species Composition and Diel Vertical Migration

About 30 species of copepods were identified from samples collected in Prince William Sound (Table V-16). Small copepods, such as *Acartia longiremis*, *Oithona similis*, and adult *Pseudocalanus* spp., were most abundant in upper layers, up to 2,000 individuals/m^3. Other small copepods, such as *Microcalanus* spp., *Oncaea borealis*, and juvenile *Pseudocalanus* spp., were more evenly distributed. Species found in deeper water included *Calanus cristatus*, *Calanus marshallae*, and *Calanus plumchrus*. These species, when abundant, have a marked effect on the phytoplankton cycle (see Chapter V, BRISTOL BAY-ST. GEORGE BASIN Report).

Both *Metridia lucens* and *M. okhotensis* were abundant and showed diel vertical migration.

Five species of euphausiids were found: *Euphausia pacifica*, *Thysanoessa inermis*, *Thysanoessa longipes*, *Thysanoessa raschii*, and *Thysanoessa spinifera*. *T. longipes* adults were relatively most abundant, 1 to 3 individuals/m^3, and showed some vertical migratory patterns. Juvenile euphausiids were restricted mostly within the upper 25 m, day and night.

TABLE V-16

Copepoda, Prince William Sound, Alaska, October 1975
(from Damkaer, RU #156-B)

Calanidae

Calanus cristatus
C. marshallae
C. pacificus
C. plumchrus
C. tenuicornis

Eucalanidae

Eucalanus bungii

Pseudocalanidae

Microcalanus spp.
Pseudocalanus spp.

Aetideidae

Aetideus pacificus
Chiridius gracilis
C. poppei
Gaetanus sp.
Gaidius variabilis

Euchaetidae

Euchaeta elongata

Metridiidae

Metridia curticauda
M. lucens
M. okhotensis
Pleuromamma robusta

Centropagidae

Centropages abdominalis

Heterorhabdidae

Heterorhabdus tanneri

Candaciidae

Candacia columbiae

Acartiidae

Acartia longiremis

Oithonidae

Oithona similis
O. spinirostris

Oncaeidae

Lubbockia wilsonae
Oncaea borealis
Oncaea sp.

Among amphipods, Cyphocasis challengeri, Parathemisto japonica, and Primno sp. were most numerous. Only C. challengeri showed a pattern of diel vertical migration.

No consistent patterns of the distribution of zooplankton biomass in Prince William Sound can yet be ascertained.

A summary of migratory pattern of these and other species is given in Table V-17. It should, however, be pointed out that these patterns (Table V-17) are based on observations for a limited time period and may not be consistent and definitive. Different patterns and/or different species abundant at other times of the year may change or modify the pattern of diel migration described herein. No consistent pattern of geographical distribution can yet be discerned (Damkaer, RU #156-B).

TABLE V- 17

Zooplankton Vertical Distribution Patterns, Prince William Sound, Alaska, October 1975 (from Damkaer, RU #156-B)

I. Surface, day and night

Copepoda: Acartia longiremis, Oithona similis, Pseudocalanus spp. (adults)

Euphausid juveniles

Chaetognatha: Sagitta elegans

II. Fairly uniform with depth

Copepoda: Microcalanus spp., Oncaea borealis, Pseudocalanus spp. (juveniles)

Amphipoda: Parathemisto japonica, Primno sp.

III. Only at depth

Copepoda: Calanus marshallae, C. plumchrus

Chaetognatha: Eukrohnia hamata

IV. Diel migrators

Copepoda: Euchaeta elongata, Metrida lucens, M. okhotensis

Euphausiacea: Thysanoessa longipes (adults)

Amphipoda: Cyphocaris challengeri

Ostracoda

Pteropoda: Spiratella helicina

MARINE MAMMALS

Introduction

Status and food habits of the 22 species of marine mammals known to occur in the northern Gulf of Alaska are presented in Table V-18 (after USDI 1976). Three OCSEAP studies deal specifically with mammals in the northeastern Gulf of Alaska (NEGOA): Pitcher and Calkins (RU #229) and Calkins and Pitcher (RU #243) are studying ecology and reproduction of Harbor seals and Steller's sea lions and Fiscus and Braham (RU #68) are assessing the abundance and distribution of all marine mammals in the Gulf. However, none of these research units presented data from NEGOA in their 1975 annual reports. Hence, the present account is based on information from other sources, principally the U.S. Department of Interior (1976).

Cetaceans (Whales and Porpoises)

Eighteen of the 22 marine mammal species occuring in NEGOA are cetaceans, including six endangered species (Table V-19). Those which may be subject to greatest impact from petroleum development in this region are species present in large numbers, either in an absolute sense or relative to total population size. They are (based on information in USDI 1976):

1. Gray whale: An estimated 1,100 individuals (10% of world population) migrate through the northern Gulf in spring and fall.

2. Fin whale: An estimated 1,000 individuals (5-10% of world population) occur in the Gulf from May to November.

3. Blue whale: An estimated 120 individuals (8-9% of world population) visit the Gulf in summer.

4. Black right whale: The 50 individuals estimated to occur in the Gulf represent 20 to 25% of the total (estimated) North Pacific population, which is one of three distinct world populations.

5. Killer whale: Although the number of killer whales in the northern Gulf has been estimated at only 100 animals (Table V-18), up to 500 individuals have been sighted near Middleton Island in April (UDSI 1976). Whether they represent an endemic breeding population is unknown.

TABLE V-18

Marine Mammals of the Northern Gulf of Alaska (adapted from USDI 1976)

Species	Residence Status	Occurrence Coastal	Occurrence Offshore	Estimated Population	Food
Sea Otter	Pr	x		5,000	Benthos Demersal Fish
Steller Sea Lion	Pr	x		8,500	Fish
Northern Fur Seal	Se		x	20,000	Fish
Harbor Seal	Pr	x		15,000 25,000	Fish Crustaceans, Molluscs
Gray Whale*	Se		x	1,100	Benthic invertebrates
Fin Whale	Se		x	1,000	Euphausiids, fish
Sei Whale*	Se	x	x	300	Fish, euphausiids, copepods
Minke Whale	Pr	x	x	200	Euphausiids, fish
Blue Whale*	Se		x	120	Euphausiids
Black Right Whale	Se		x	50	Small plankton
Humpback Whale*	Se	x	x	20	Macroplankton, fish
Sperm Whale*	Se		x	600	Squid
Beluga Whale	Pr	x		350	Fish, squid, bivalves, crustaceans
Killer Whale	Pr?	x	x	100	Fish, pinnipeds, cetaceans, birds
Bering Sea Beaked Whale	Se		x	R	Fish, squid
Goose-Beaked Whale	Se		x	R	Fish, squid
Giant Bottlenose Whale	Se		x	R	Fish, squid
Pilot Whale	Se	x	x	R	Fish, squid
Dall Porpoise	Pr	x	x	2,000	Fish, squid
Harbor Porpoise	Pr	x		1,000	Fish
North Pacific White-side Dolphin	Se		x	R	Fish
Northern Right-Whale Dolphin	Se		x	R	Fish

Pr - Permanent Resident   Se - Seasonal Entrant   R - Rare

* - Endangered species

TABLE V-19

Steller's Sea Lion Rookeries in the Vicinity of the NEGOA Lease Area (after USDI 1976)

Location	Estimated Population
Sitkagi Bluffs	140
Cape St. Elias/Southeast Rock	1,566
Seal Rocks	1,750
Porpoise Rocks	50
Knowles Head	200
Fox Point	20
Fountain Rock	No estimate
Middleton Island (north end)	1,000

6. Dall porpoise: Most commonly seen cetacean in the Gulf; estimated size of the resident population is 1,000 individuals.

7. White-sided dolphin: Although said to be rare in the northern Gulf (Table V-18), single sightings of up to 2,000 individuals have been made near Yakutat Bay (USDI 1976).

8. Harbor porpoise: Sizable resident population.

The three species of beaked and bottlenose whales and the northern right-whale dolphin are endemic to the North Pacific, but little is known of their status in the Gulf of Alaska. Sperm whales, sei whales, minke whales, humpbacked whales, and belugas occur regularly in the Gulf but in numbers that are small (less than 2%) relative to total population size. The pilot whale is extremely rare in the Gulf.

Pinnipeds (Seals, Fur Seals, and Sea Lions)

The three species of pinnipeds in the northern Gulf of Alaska are about four times more abundant than all other marine mammals combined (see figures in Table V-18). General natural history and Pitcher and Calkins' (RU #229; Calkins and Pitcher, RU #243) data on reproduction, growth (Harbor seals only), distribution and food habits of Harbor seals and Steller's sea lions in the northwestern Gulf are discussed in the section on COOK INLET.

The population of Harbor seals in NEGOA from Prince William Sound to Yakutat Bay is estimated at 15,000 to 20,000. About 6,000 of these inhabit the Copper River Delta; "several thousand" Harbor seals have been observed hauled out on ice floes in Icy Bay; and Harbor seals are present throughout Yakutat Bay. Notable concentrations also occur in shallow water areas of Dry Bay, Dangerous River tidal flats, Bering River, and Controller Bay (USDI 1976).

About 4% (8,500/200,000) of the Alaskan population of Steller's sea lions resides in the northern Gulf (USDI 1976). These include more than 4,700 animals distributed among eight rookeries in the vicinity of the NEGOA lease area (Table V-19).

Approximately 1.2 million (75% of the estimated world population) fur seals inhabit breeding grounds on the Pribilof Islands from about May to November. In winter, there is a sexual segregation of adults. Many, perhaps most, adult males winter in the northern Gulf of Alaska while females and young migrate to offshore feeding grounds on both sides of the Pacific from the Bering Sea southward to California and Japan (USDI 1976). The spring migration route through the Gulf of Alaska back to the Pribilofs apparently follows the counterclockwise Alaskan Gulf Stream to Unimak Pass, then veers northwestwards towards the Pribilofs (see Fig. V-41 in the KODIAK section). Scheffer (cited by USDI 1976) estimated that no more than 20,000 fur seals occur in the northwestern Gulf of Alaska in spring and fall. This figure probably is an estimate of standing stock rather than total number of animals moving through the area, which must be considerably higher.

USDI (1976) describes the fur seal as "Economically ... the most important pinniped which occurs in the Gulf. The annual harvest of about 40,000 to 50,000 fur seals on the Pribilof Islands yields over $3 million."

Sea Otter

In the NEGOA region, sea otters occur from Prince William Sound east to Yakutat Bay, but they are not abundant anywhere east of Kayak Island. Otter concentrations in the vicinity of the NEGOA lease area are located at Kayak, Hinchinbrook, and Montague Islands. Coasts of these islands, together with Prince William Sound, are inhabited by an estimated 5,000 sea otters (USDI 1976). Background information on the natural history of sea otters is presented in the section on COOK INLET.

MARINE BIRDS

Introduction

The list of swimming and wading birds occurring in the northern Gulf of Alaska is identical to that presented in the section on COOK INLET. A low estimate of standing stocks of seabirds in this region is (from USDI 1976):

	Winter	Summer
Albatrosses		30,000
Shearwaters		4,250,000
Fulmars	100,000	
Storm petrels	6,000	715,000
Phalaropes		
Gulls and terns	550,000	50,000
Jaegers		
Alcids	360,000	4,000,000
TOTALS:	1,016,000	9,045,000

OCSEAP-related research on marine birds in this region include studies on the breeding biology of herring and glaucous-winged gulls (Patten and Patten, RU #96), structure of the offshore bird community (Wiens, RU #108), seasonal distribution and abundance of marine birds on offshore waters (Lensink and Bartonek, RU #337), locations and sizes of seabird colonies (Lensink and Bartonek, RU #338), and quantitative description of the structure and use by aquatic birds of coastal habitats (Arneson, RU #3).

Seabird Nesting Colonies

USDI (1976) summarizes Lensink and Bartonek's (RU #338) data on locations and sizes of 25 major seabird colonies situated in the proposed northeastern Gulf of Alaska lease sale area (Cape Spencer to Montague Island). Total population of these colonies is estimated at 140,000 birds, with the precautionary statement that "present information ... is only accurate within orders of magnitude" (USDI 1976). According to the USDI summary, the following three families and 12 species of seabirds breed among the 25 major colonies:

I. Phalacrocoracidae

1. Double-crested cormorant
2. Pelagic cormorant

II. Laridae

3. Glaucous-winged gull
4. Mew gull
5. Black-legged kittiwake
6. Arctic tern

III. Alcidae

7. Common murre
8. Thick-billed murre
9. Pigeon guillemot
10. Ancient murrelet
11. Horned puffin
12. Tufted puffin

In addition, several small colonies at the eastern mouth of Prince William Sound and the larger colonies (ca. 180,000 birds) on Middleton Island, south of Prince William Sound, may be subject to impact from petroleum development in the northeast Gulf of Alaska (USDI 1976).

Breeding Ecology of Herring Gulls and Glaucous-winged Gulls

Patten and Patten (RU #96) are analyzing breeding ecology of glaucous-winged gulls on Egg Island (colony size =]2,000-20,000 birds), one of the barrier islands in front of the Copper River Delta, and comparing results with smaller mixed colonies of herring and glaucous-winged gulls to the southeast at Dry Bay and North Marble Island (Glacier Bay). In all three areas, herring gulls and/or glaucous-winged gulls nest in colonies on meadows, where their nests are readily accessible for examination. Relative to OCSEAP objectives, the rationale behind this study is that since breeding ecology of these gulls can readily be monitored and related to environmental conditions, the gulls can be used as "indicators of the health of the environment" (Patten and Patten, RU #96). The following account is taken from Patten and Patten (loc. cit).

In 1975, the peak of egg laying was in the last week of May on Egg Island and during the first week of June at Dry Bay (1972-73 mid to late May for North Marble colony). Egg laying continued into early July, highly likely replacement clutches following subsistance egging by fishermen. Clutch size, fledging success, and territory size are given in Table V-20. About 40% of the eggs on Egg Island and 18% of those at Dry Bay were lost to predators, i.e., humans, parasitic jaegers, crows, ravens, and (mainly) conspecific gulls. An additional 2% of the Egg Island eggs were infertile (1.8%) or pipped but did not hatch (0.2%). The incubation period is 24 to 27 days, during which 18% of egg weight is lost.

Fifty-nine percent of chicks that hatched on Egg Island fledged. Chick mortality (40%) was due mainly to killing and cannibalism by adult gulls, perhaps made worse by a period of inclement weather in early August which weakened chicks directly and reduced their food supplies (through reduced foraging efficiency of their parents). Egg and chick mortality combined totalled 66% on Egg Island, so that total reproductive success (chicks fledged per egg laid) was only 34%.

Juvenile gulls banded on Egg Island have been recovered as far away as Vancouver, B.C., nearly 2,000 km from Egg Island.

Offshore Seabird Densities

Lensink and Bartonek (RU #337, Part I) obtained data on offshore densities of birds for the northeastern Gulf of Alaska (Table V-21) and Prince William Sound in 1975 (Table V-22). Graphic comparison of results from these two areas suggests a higher density of resident birds and perhaps lower species diversity in Prince William Sound than exist on open waters of the Gulf, at least in late

TABLE V-20

Clutch Size, Fledging Success and Territory Size of Herring and Glaucous-winged Gulls in 1972-1976 (from Patten and Patten, RU #96).

Colony	No. Nests Examined	$\overline{X}$ Clutch Size*	$\overline{X}$ No. Fledging Per Clutch	$\overline{X}$ Territory Size
N. Marble (1972-73)	191	2.9	1.77	18.0 m^2
Dry Bay (1975)	100	2.9 (?)	?	29.8 m^2
Egg Island (1975-76)	153- 186	2,4	1.03 1.08	28.9 m^2

* Known for N. Marble; presumed for Dry Bay and Egg Island.

TABLE V-21

Monthly Density of Birds on Offshore Waters of the Northeastern Gulf of Alaska as Determined by Shipboard Surveys in 1975 (From data sheets compiled by Lensink and Bartonek, RU #337, Part I).

Species (N = 46)	Birds per km^2							
	Feb.	April	May	June	Aug.	Sept.	Oct.	Nov.
Common Loon			0.6					
Arctic Loon			0.2					
Unidentified Looan			1.0	0.1		*	*	*
Black-footed Albatross		*	0.1	*	0.3	0.2	0.1	*
Laysan Albatross							*	
Fulmar	2.5			2.2	5.8	1.8	2.3	3.2
Sooty Shearwater		423.9	302.1	17.2		0.8	3.3	*
Short-tailed Shearwater						0.2	*	*
Unidentified Shearwater			*	0.1		3.7	1.4	0.8
Fork-tailed Storm Petrel	0.1		0.5	1.6	1.7	0.3	3.5	0.1
Leach's Storm Petrel				0.1				
Unidentified Storm Petrel				0.2		0.1		
Double-crested Cormorant			*	*			*	
Pelagic Cormorant		0.6	0.1	*			0.1	
Red-faced Cormorant								*
Unidentified Cormorant	*	*	0.1	0.1		*	0.1	*
Black Brant			*					
Mallard							*	
Pintail						*		
American Widgeon			*					
Greater Scaup							0.1	
Oldsquaw			0.7	*				0.2
White-winged Scoter			*					
Surf Scoter			*	*				
Unidentified Scoter				*			0.1	
Unidentified Duck							*	
Red-breasted Merganser							*	
Northern Phalarope			8.5			*		
Unidentified Phalarope						*		
Pomarine Jaeger			*	*		0.1	*	
Parasitic Jaeger		0.1	*	0.1				
Long-tailed Jaeger			*	*		*		
Unidentified Jaeger				*	0.3	*	*	
Glaucous Gull	*	0.2	*				*	
Glaucous-winged Gull	3.3	1.6	1.9	0.2		0.1	1.5	0.5
Herring Gull	*	0.2	3.3	0.4		0.1	0.2	0.2
Herring/Gl.-winged Hyb.						*		
Mew Gull	0.1	0.1	0.1				*	*
Unidentified Kittiwake	3.1			*	1.9	0.6	0.2	*
Black-legged Kittiwake			3.8	4.9		0.7	*	0.2

TABLE V-21 (continued)

Species (N = 46)	Birds per km^2							
	Feb.	April	May	June	Aug.	Sept.	Oct.	Nov.
Sabine's Gull				0.5			*	
Unidentified Gull			0.1	0.1		0.2	0.1	0.1
Arctic Tern			1.7	1.5		*		
Unidentified Tern	2.4	11.2						
Common Murre						*		
Unidentified Murre			1.2	0.5		0.1	*	1.0
Pigeon Guillemot			*					
Unidentified Large Alcid						0.2	*	
Marbled Murrelet	0.1		0.1	0.1		*		
Kittlitz's Murrelet		0.1		*				
Xantus Murrelet			*					
Ancient Murrelet			*	0.1			*	
Cassin's Auklet				0.1			*	*
Parakeet Auklet							*	
Rhinocerous Auklet				*		*		
Unidentified Small Alcid	0.2	1.2		1.6		0.2	0.2	0.2
Horned Puffin				*				
Tufted Puffin	0.2	0.9	1.0	1.5		0.8	0.1	0.1
Unidentified Puffin	*							
Bohemian Waxwing							*	
Pine Siskin							*	
Pectoral Sandpiper						*		
Unidentified Shorebird						*		
Totals	11.9	440.2	327.1	31.2	10	10.3	13.8	6.6
# Species	11	11	28	27	5	24	25	16

* Present in densities less than 0.1/km^2

TABLE V-22

Bird Density on Offshore Waters of Prince William Sound as Determined by Shipboard Surveys in 1975 (summarized from data sheets of Lensink and Bartonek, RU #337, Part I).

Species (N = 29)	Bird per km^2				
	April	May	June	Sept.	Oct.
Common Loon		0.2			*
Arctic Loon		0.1			
Unidentified Loon	0.2	2.0			*
Horned Grebe	0.1				
Black-footed Albatross					*
Sooty Shearwater		48.7			
Unidentified Shearwater					0.1
Fork-tailed Storm Petrel					0.7
Unidentified Storm Petrel					0.1
Double-crested Cormorant					0.1
Pelagic Cormorant	0.2				*
Red-faced Cormorant		0.2			0.3
Unidentified Cormorant	1.5				0.5
Oldsquaw	1.2	1.1			
White-winged Scoter		0.1			*
Surf Scoter		0.2			*
Red-breasted Merganser					*
Bald Eagle		0.1			*
Northern Phalarope		17.7			0.2
Unidentified Jaeger		0.2			0.1
Glaucous Gull	0.2				0.3
Glaucous-winged Gull	4.9	2.9	1.2		0.4
Herring Gull	0.2	0.1	0.4		0.7
Mew Gull	1.2	0.1			0.5
Bonaparts Gull		0.2			
Unidentified Kittiwake	5.6	5.8	16.5		1.0
Black-legged Kittiwake					0.3
Unidentified Gull	1.1				4.7
Arctic Tern		3.1	0.5	1.2	*
Unidentified Murre	3.0	5.2	1.0		0.1
Unidentified Guillemot					0.4
Pigeon Guillemot	1.5	0.2			*
Marbled Murrelet	0.2		3.0		
Rhinocerous Auklet			0.2		
Unidentified Small Alcid	0.5	12.1	14.9		
Tufted Puffin	0.7	1.9			
Common Raven					0.4
Dunlin		0.1			
Unidentified Bird					0.1
Totals	21.6	102	37.7	1.2	10.5

* Present in densities less than $0.1/km^2$

spring and early summer (Fig. V-15). If southern hemisphere shearwaters are included, densities are greater in the Gulf.

Shearwaters apparently were absent from the northeastern Gulf of Alaska in February but abundant (424/km^2) in April, placing their arrival approximately in March. Density of shearwaters dropped sharply in June and apparently remained low for the rest of the season (Table V-22). However, data for July and August needed to evaluate this impression are lacking. Guzman (RU #239) found, in surveys of the central gulf, that shearwaters there attained densities greater than 1,000 birds per km^2 in mid-July (Fig. V-16).

Wiens (RU #108) is studying community structure, including offshore density distribution of marine birds in the Gulf of Alaska, but his data were not analyzed in time for inclusion in the March (1976) Annual Report. Arneson (RU #3) plans to extend his study of avian coastal habitats into the NEGOA region but this was not accomplished in 1975.

Breeding Waterfowl of the Copper River Delta

It has been calculated that approximately 17,385 (in 1975) to 23,500 (in 1974) ducks, 12,000 dusky Canada geese, and 550 trumpeter swans (ca. 20% of the world's population) breed on the Copper River Delta. Additional waterfowl, as well as seabirds and shorebirds, nest on the chain of barrier islands in front of the delta (USDI 1976).

Migration

The standing stock of birds at sea in the northern Gulf of Alaska reaches an estimated peak of 48.5 million in April, the height of spring migration. Since this estimate does not take population turnover into account, the actual number of birds migrating through the area may be considerably greater than 48.5 million (USDI 1976).

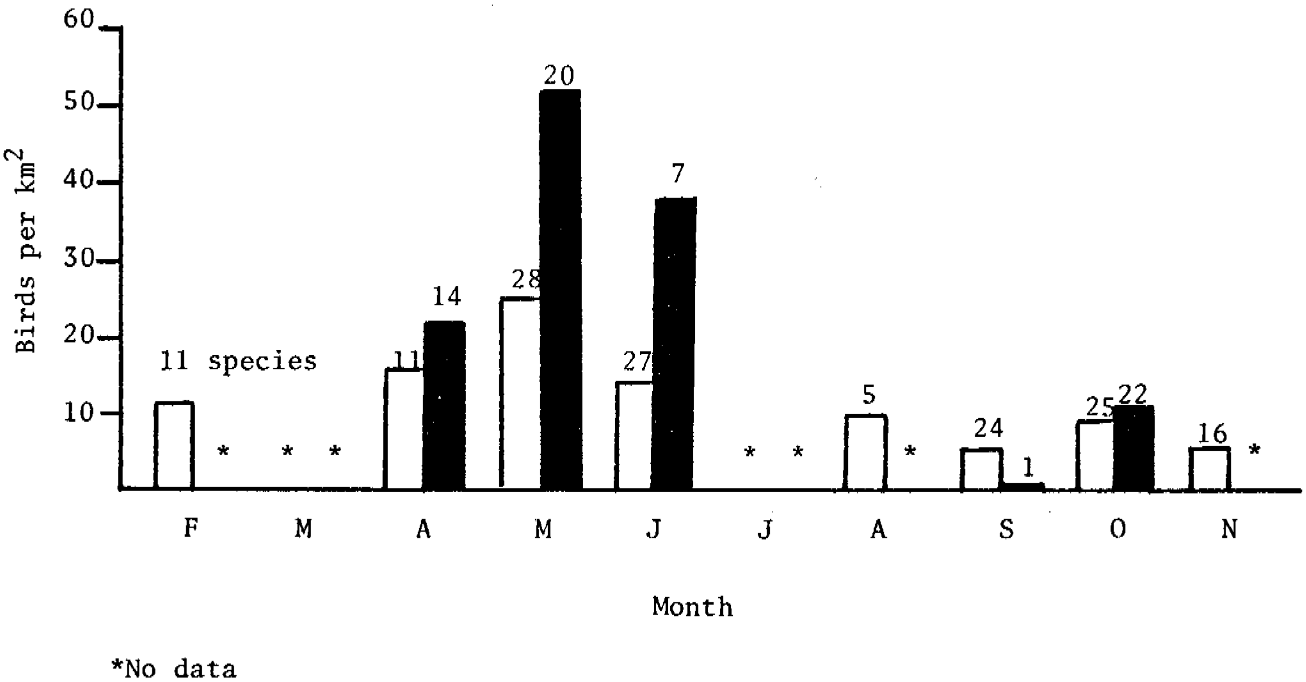

Fig. V-15. Comparative density of birds (excluding shearwaters) on offshore waters of the northeastern Gulf of Alaska (open bars) and Prince William Sound (shaded bars) in 1975. The number above each bar indicates the number of species represented in the sample. Data are from Tables V-21 and V-22.

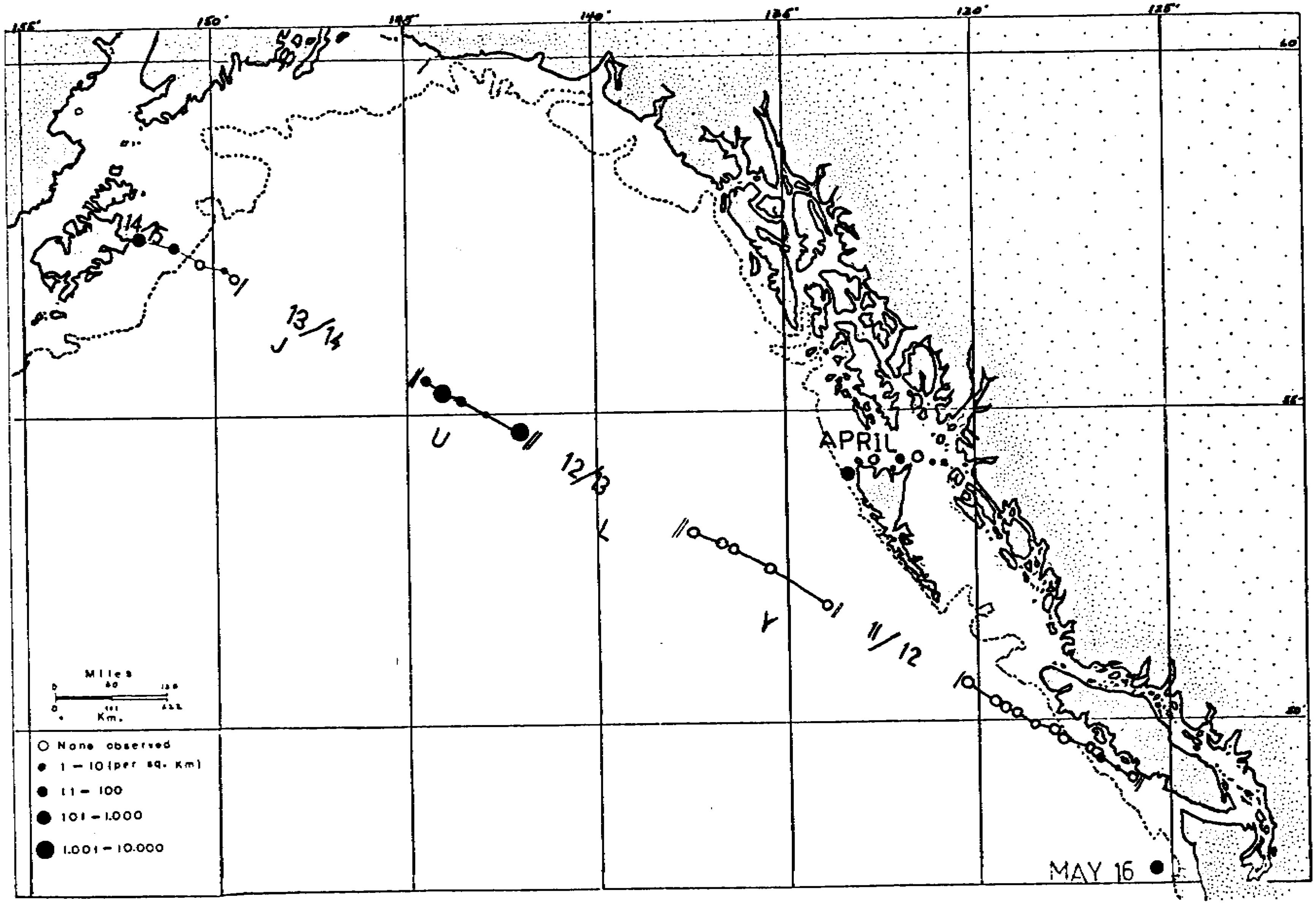

Fig. V-16. Densities of shearwaters encountered in a shipboard transect of the Gulf of Alaska from July 11-14, 1975 (copied from Guzman, RU #239). Breaks in the line showing the ship's route represent night, when no observations were made.

The reason for such heavy usage of the northern Gulf by migrating birds is identified by Isleib and Kessel (cited by USDI 1976):

> "Large concentrations of migrating birds are found in the north Gulf coast region because geographically, the region is along the main Pacific route of northern latitude breeders migrating to the northwestern limits of the North American continent; the high, rugged topography of the coastal mountain systems, coupled with the northern arc of the Gulf of Alaska, forces the great majority of migrants to funnel through the region along a narrow coastal corridor; restriction of certain avian habitats within the region accounts further for phenomenal concentrations in a few specific areas, especially in the Copper River Delta; and finally, concentrations are enhanced by the fact that the duration of the migration period is telescoped at these northern latitudes, with the main passage extending over little more than five weeks."

Migrating shorebirds and waterfowl heavily utilize tidal flats of the Copper River Delta and Prince William Sound. More than 96,000 shorebirds per km^2 have been observed on the Copper River tidal flat in May and shorebirds and waterfowl rest and forage there during each spring migration (USDI 1976). Net movements of 500 whistling swans, nearly 1,000 shorebirds, and about 5,500 pintail ducks per hour have been counted passing coastal points (Orca Inlet and Strawberry Point) in the northern Gulf during spring migration (USDI 1976). It is estimated that in fall migration about one million black brant, Canada geese, white-fronted geese, snow geese, and ducks migrate directly across the northern Gulf (USDI 1976).

Winter

Only four avian families are represented on offshore waters of the northern Gulf in winter: Laridae, Alcidae, Procellariidae, and Hydrobatidae. The total number of birds present is estimated at 1 to 1.5 million. Distribution of these birds is described as follows (USDI 1976):

> "The larids and alcids are widely distributed whereas the procellariids and hydrobatids are generally found over waters beyond the 100 fathom contour; i.e., beyond the continental shelf. According to Isleib (1975), there is a relatively high degree of winter dependence by larids and procellariids

to a narrow surface area above the upper portion of the continental slope. Of the alcids, murres were grouped throughout the region, murrelets were widely dispersed, and puffins were largely restricted to areas seaward of the slope. Hydrobatids were recorded only in oceanic waters."

According to Arneson (RU #3), the relative scarcity of birds on the northern Gulf in winter is "because of (the Gulf's) exposure to the open ocean."

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Chapter VI

EFFECTS

NOAA/OCSEAP-sponsored research on the effects of hydrocarbon and heavy metal contamination on fish and shellfish has been discussed in the KODIAK ISLAND-Effects section of this report.

SECTION 5

BRISTOL BAY-ST. GEORGE BASIN: ENVIRONMENT, BIOTA, AND POTENTIAL PROBLEMS RELATED TO OIL EXPLORATION

A Scientific Report Based Primarily on
OCSEAP-Sponsored Research

CONTENTS

Chapter I

ENVIRONMENT

DESCRIPTION OF STUDY AREA

Bristol and St. George are adjacent basins occupying the southeast Bering continental shelf. Bristol Basin lies westward from the Alaska mainland, bounded to the south by the Alaska Peninsula, terminating near the 90 m isobath. St. George Basin occupies the southwestern terminus of the outer continental shelf north of Unimak Island to St. George Island bounded on the east by the 90 m isobath and the continental slope to the west.

The region is of maritime climate, typified by regional storms and fog in areas where the warm Pacific waters meet with those of the colder Bering Sea. Rainfall has been noted at 76 to 102 cm annually, with a mean air temperature of 1.6°C (35°F).

Many streams enter the southeastern Bering Sea, the largest of which include the Togiak, Wood, Nushagak, Kvichak, Naknek, Egegik, and Ugashik. Annual discharge of these systems is regulated by climatic conditions causing peak runoff during periods of high snow and glacier melt. Still others are more influenced by seasonal precipitation and the storage capacity of head water lakes.

COASTAL PHYSIOGRAPHY

The eastern and southern margins of Bristol Bay are bordered by the Alaska Peninsula. The Aleutian Range forms the backdrop from which the elevation drops to a coastal plain. This plain extends 16 to 80 km to a coast which is typified by sandy beaches and brackish coastal lagoons. Bars, spits, and barrier islands are numerous throughout the nearshore region. To the north the shoreline includes several large estuaries and lagoons, interspersed with sandy beaches and coastal bluffs.

The Pribilof Island group consists of two major islands, St. George and St. Paul, and several small inlets. The coastline of St. Paul Island consists generally of unstable sandy beaches. Steep cliffs and rocky shores are also present, but restricted primarily to the western coast. The coastline of St. George Island is characterized by steep bluffs and cliffs.

CONTINENTAL SHELF GEOLOGY

The continental shelf is very smooth and extends approximately 800 km from the head of Bristol Bay westward to a depth of about 200 m near the Pribilof Islands. Mean water depth within the Bristol Bay is only 40 m. Nearshore, sediments consist of gravel and coarse sand, while offshore areas are covered with muds and fine to medium sands. The mean sediment size decreases with increasing water depth. Pleochroic hornblende, a characteristic reddish-brown constituent of basic and ultra-basic rocks exposed in the Alaska Peninsula, is prevalent in most sediments, suggesting that a significant source of sediments is from the Alaska Peninsula. However, high grade metamorphic minerals, sillimanite, garnet, stauralite, and epidote in the sediments also indicate the metamorphic province of the Alaska mainland as a source (Sharma 1974).

CIRCULATION

The seasonal atmospheric circulation in the region is influenced primarily by the Aleutian low, and to some extent by eastern Siberian high and east

Pacific high pressure systems. The Aleutian low pressure system is noticeable throughout the year except in July. From August to December, it migrates southeastward from the Aleutian Island arc to the Gulf of Alaska; in January it shifts back to the western Aleutian Islands (Favorite, Dodimead, and Nasu 1974).

Water circulation pattern in the Bering Sea is intrinsically controlled by meteorological conditions and water mass distribution. Locally, surface currents may vary greatly in speed and direction. Nearshore currents in the region are primarily tidal and current velocities of 6 knots have been reported.

ICE

Southeastern Bering Sea is located in an area of transition between seasonal ice and open sea. The pack ice persists for some six to eight months of the year, reaching its maximum usually in March or April. Fluctuation of the ice edge increases eastward from Bristol Bay toward the St. George Basin. The pack ice edge in eastern Bristol Bay seems quite stable through the winter. On occasion the pack ice edge may be found well south of the Pribilof Islands; however, the frequency of occurrence is not known (Potocsky 1975; Swift et al. 1974).

The southern part of the ice pack in the area of the Bristol Bay and St. George Basin consists of broad belts and strips of brash ice, and small floes, interspersed with areas of open water. This seasonal ice is usually 30 to 70 cm thick in unstressed floes. Compact ice belts routinely move southward, under the influence of northerly winds, into the St. George Basin late in the melt season (Konishi and Saito 1974).

Fast ice is scant or absent along the open coast of the Alaska mainland and larger islands, but forms broad expanses in bays and other locations where it is sheltered. An estimated 97% of ice in the Bering Sea is formed locally with only minor contributions from rivers and adjacent seas. A more detailed discussion of ice distribution is contained in the Hazards section of this report.

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Chapter II

SOURCES

INTRODUCTION

Marine waters contain accumulations of naturally occurring and artificially introduced hydrocarbons and heavy metals. Hydrocarbons are synthesized by phytoplankton and promulgated through the food chain by metabolic breakdown and resynthesis into carbohydrate, protein, and lipid. Hydrocarbons also originate in the marine environment from natural petroleum seeps and through accidental and/or purposeful discharges from oil development, transport, and production. Recreational and other marine transports and various industrial users periodically discharge oil-based effluents. Heavy metals originate from similar sources. Providing the metal loading remains low, the marine environment readily absorbs moderate influxes. Metals, even though some are toxic, are essential to an organism's nutrition. Selected metals are taken up from the water by organisms and may be transported to deep waters; new supplies are carried in to the upper layers by upwelling and direct input in the surface waters. Chemical, physical, and biological reactions cause precipitation of excesses and solubilization to offset deficiences.

In pristine waters such as those found along the Alaskan Outer Continental Shelf, significant inputs of hydrocarbons and metals through oil development and release are readily detectable. OCSEAP-related research is designed to characterize the hydrocarbon and heavy metal levels in the Alaskan marine environment.

C_1-C_4 HYDROCARBONS

Cline and Feely (RU #153) propose that light molecular weight hydrocarbons (LMWH) are valuable indicators of petroleum contamination, as the result of high solubility and low natural abundance. These investigators, following the IMS sampling grid for collecting water from various depths, have shown the spatial variations of LMWH in the Bering Sea.

Methane concentrations in the surface waters were generally near atmospheric equilibrium, 50 to 70 nℓ/ℓ (Fig. II-1). Only in the vicinity of Herendeen Bay and Izembek Lagoon were recorded values markedly above atmospheric equilibrium (100 to 150 nℓ/ℓ). The lowest values were recorded in delta regions of the Kuskokwim and Kvichak Rivers. LMWH data from samples collected near the bottom of the water column indicate the influence of benthic sources. The maximum concentration recorded was 700 nℓ/ℓ north of Unimak Pass; however, there is a general increase in near bottom levels from the inner Bristol Bay area to the outer shelf and slope (Fig. II-2). This increasing concentration is borne out by the organic carbon levels recorded by Sharma (1974).

Cline and Feely (RU #153) also noted a zonal plume near 58°N latitude, possibly resulting from cold water intrusion. Organic carbon analyses of the sediments and sediment size frequency indicate that the increased methane concentrations in the zonal plume originate from an advective source (Sharma 1974).

Very little spatial variation was noted in the near-surface water concentrations of ethane. The levels ranged from 0.3 to 0.6 nℓ/ℓ and averaged 0.5 nℓ/ℓ. The highest surface ethane concentrations appear to originate near the lagoons of the Alaska Peninsula and move counterclockwise through the eastern Bering Sea (Fig. II-3). The peak level recorded was near the entrance to Herendeen Bay. Near bottom concentrations of ethane formed a pattern similar to methane, i.e., the highest levels noted were near the bottom and toward the outer shelf (Fig. II-4).

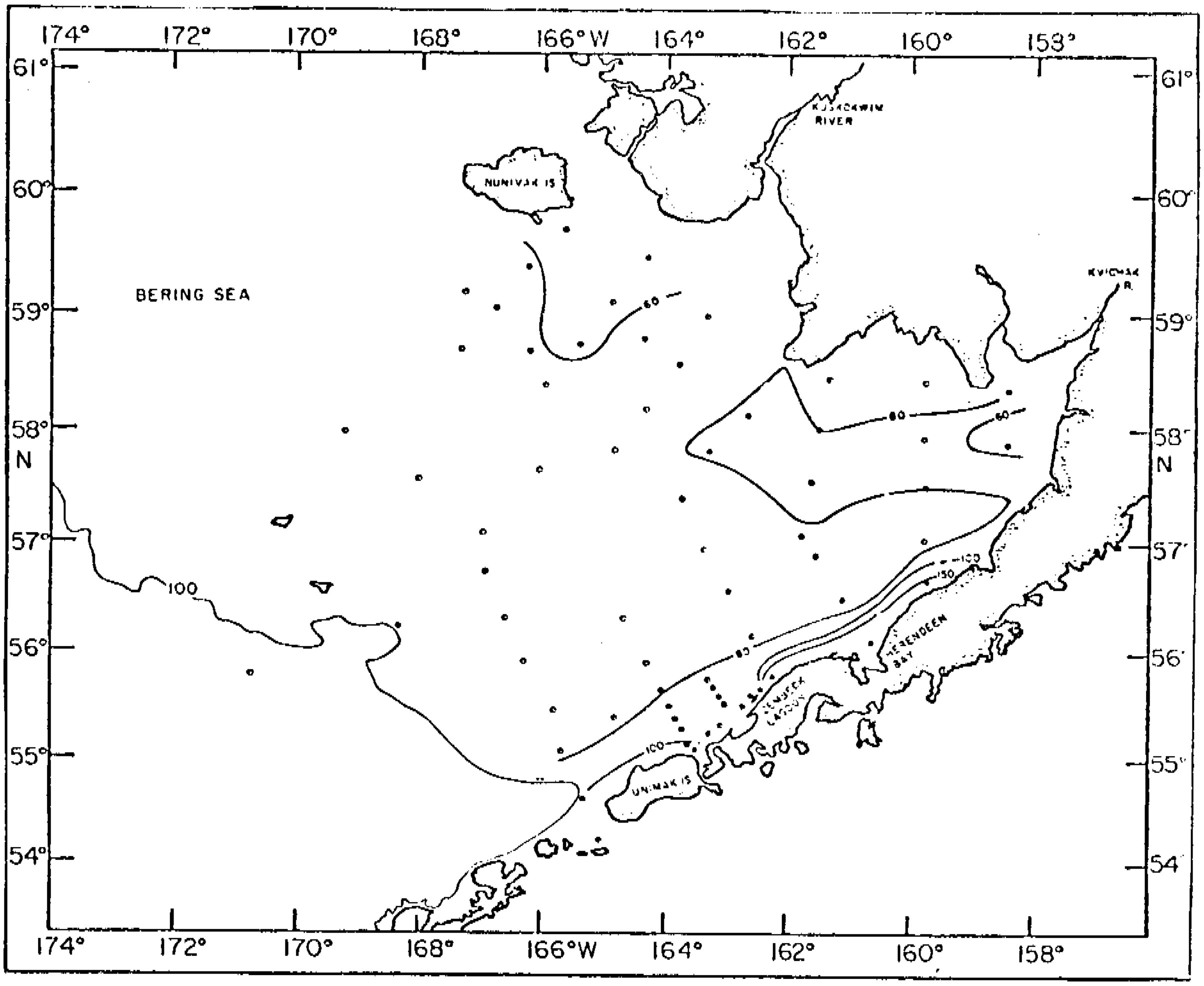

Fig. II-1. Surface distribution of methane in Bristol Bay during September to October 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

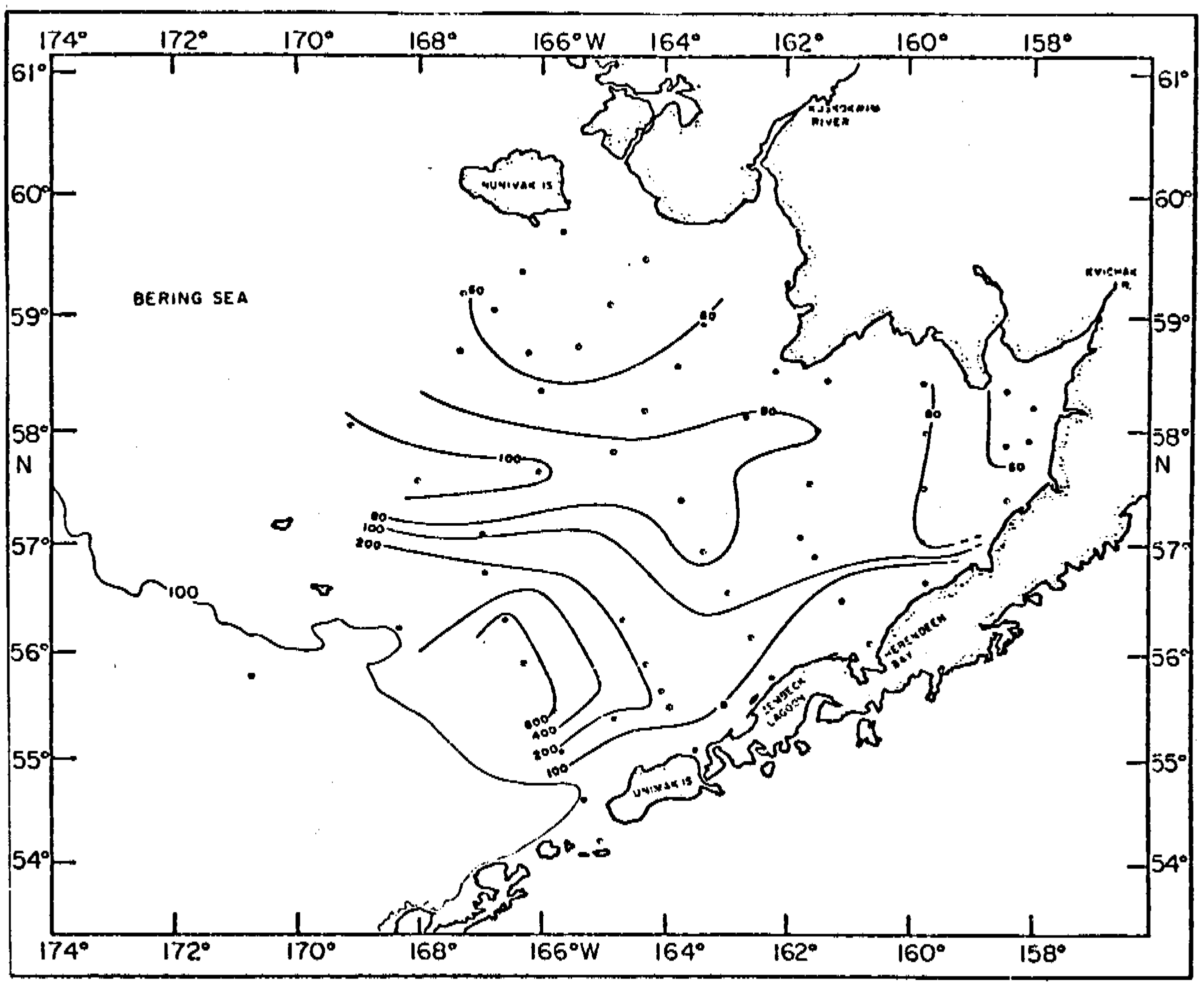

Fig. II-2. Areal distribution of methane 5 m from the bottom in Bristol Bay during September to October 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

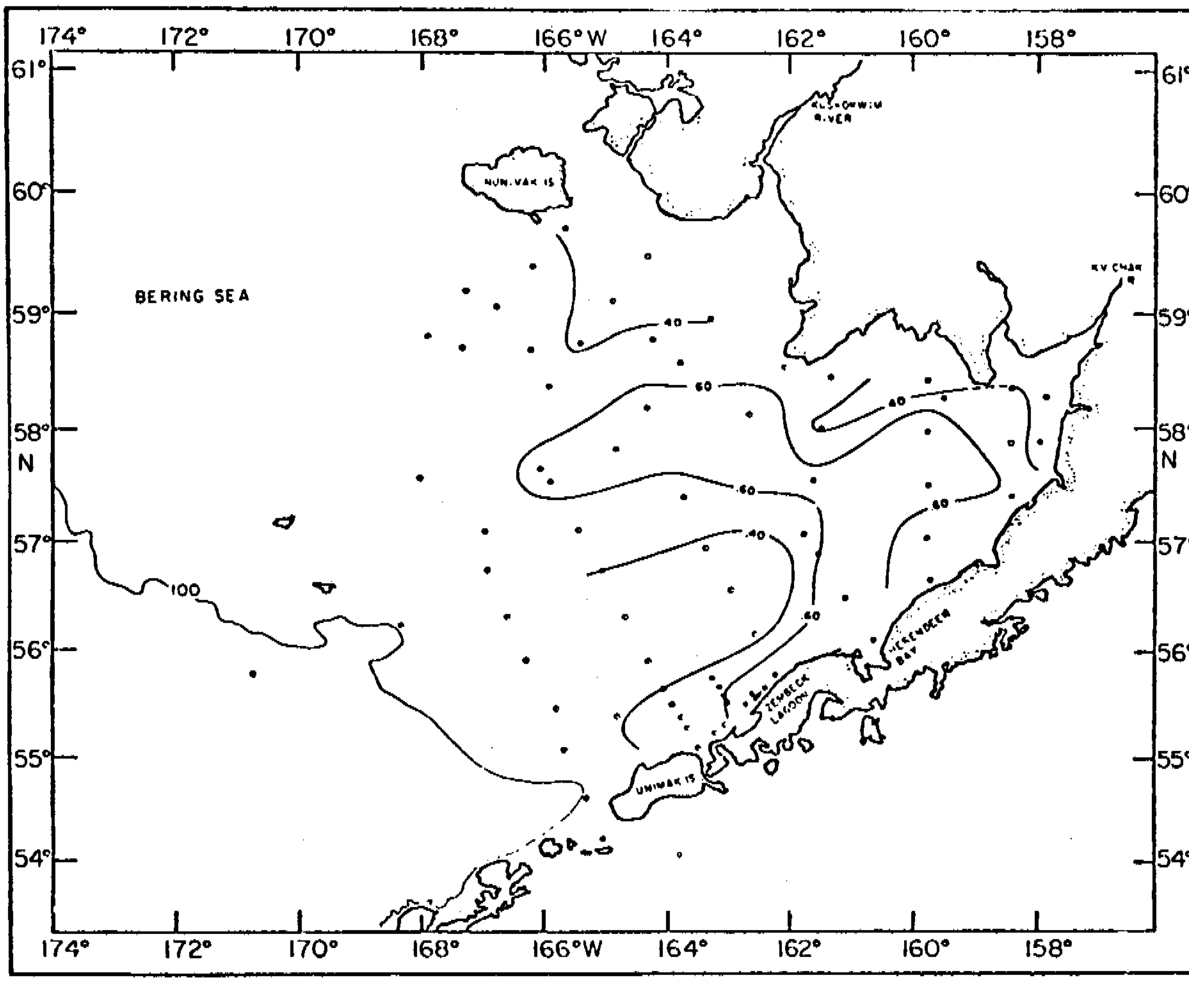

Fig. II-3. Surface distribution of ethane in Bristol Bay during September to October 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

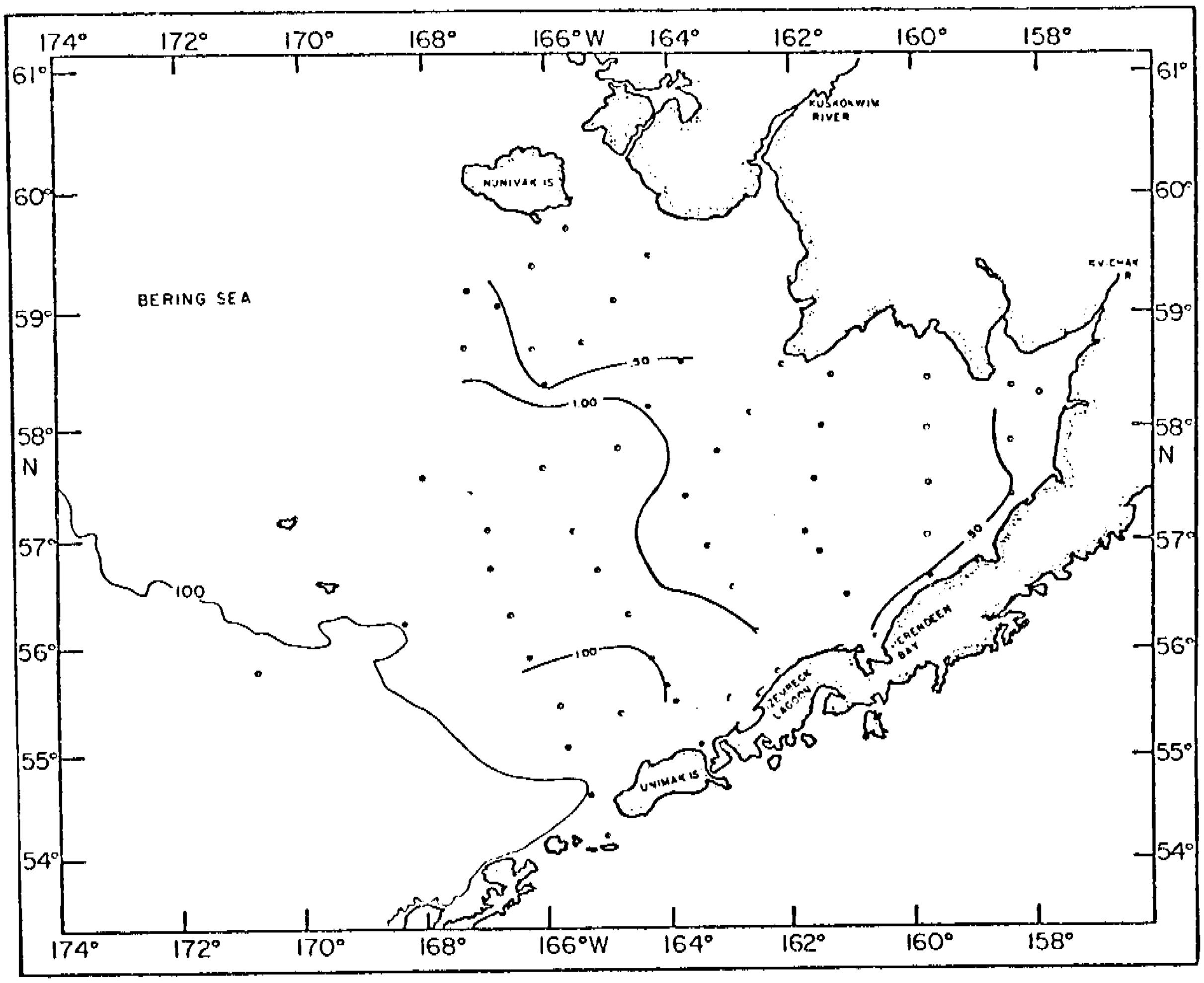

Fig. II-4. Areal distribution of ethane 5 m from the bottom in Bristol Bay during September to October 1975. Concentrations are given in nℓ/ℓ (NPT) (from Cline and Feely, RU #153).

Ethylene levels ranged from 0.1 to 1.5 nℓ/ℓ with the highest value recorded near the bottom. Surface values averaged 0.5 nℓ/ℓ.

As the result of inadequate chromatographic separation of propane and propylene, integrated values are recorded. Propane plus propylene concentrations ranged from 0.3 to 0.9 nℓ/ℓ and averaged 0.5 nℓ/ℓ. Two major sources of propane-propylene were noted in the central Bristol Bay and near Herendeen Bay (Fig. II-5). The average bottom concentration was 0.4 nℓ/ℓ, slightly less than surface values.

N-butane and isobutane levels were near or below the detection limit of the gas chromatograph and extraction method employed.

Time series studies conducted in central Bristol Bay and near Unimak Pass indicate little variation in the central bay. A twofold variation was noted at the Unimak Pass station, possibly reflecting tidal influence (Cline and Feely, RU #153).

Vertical distribution of LMWH at selected stations indicate that the bottom influence on LMWH is minor near Cape Newenham. Near Unimak Pass levels of methane, ethylene, and ethane rapidly increase with depth, indicating a bottom source. Propane-propylene concentrations are relatively uniform throughout the water column, indicating that the sediment is not the source of the C_3 LMWH.

Kaplan (RU #275) measured the levels of C_1-C_6 hydrocarbons in sediments throughout the Bristol Bay-St. George Basin region. Methane concentrations ranged from 0.0 to 20.9 ng/g dry sediment. Preliminary evidence indicates that the highest level of methane recorded was in the central bay, midway between the Pribilof Islands and Kvichak Bay.

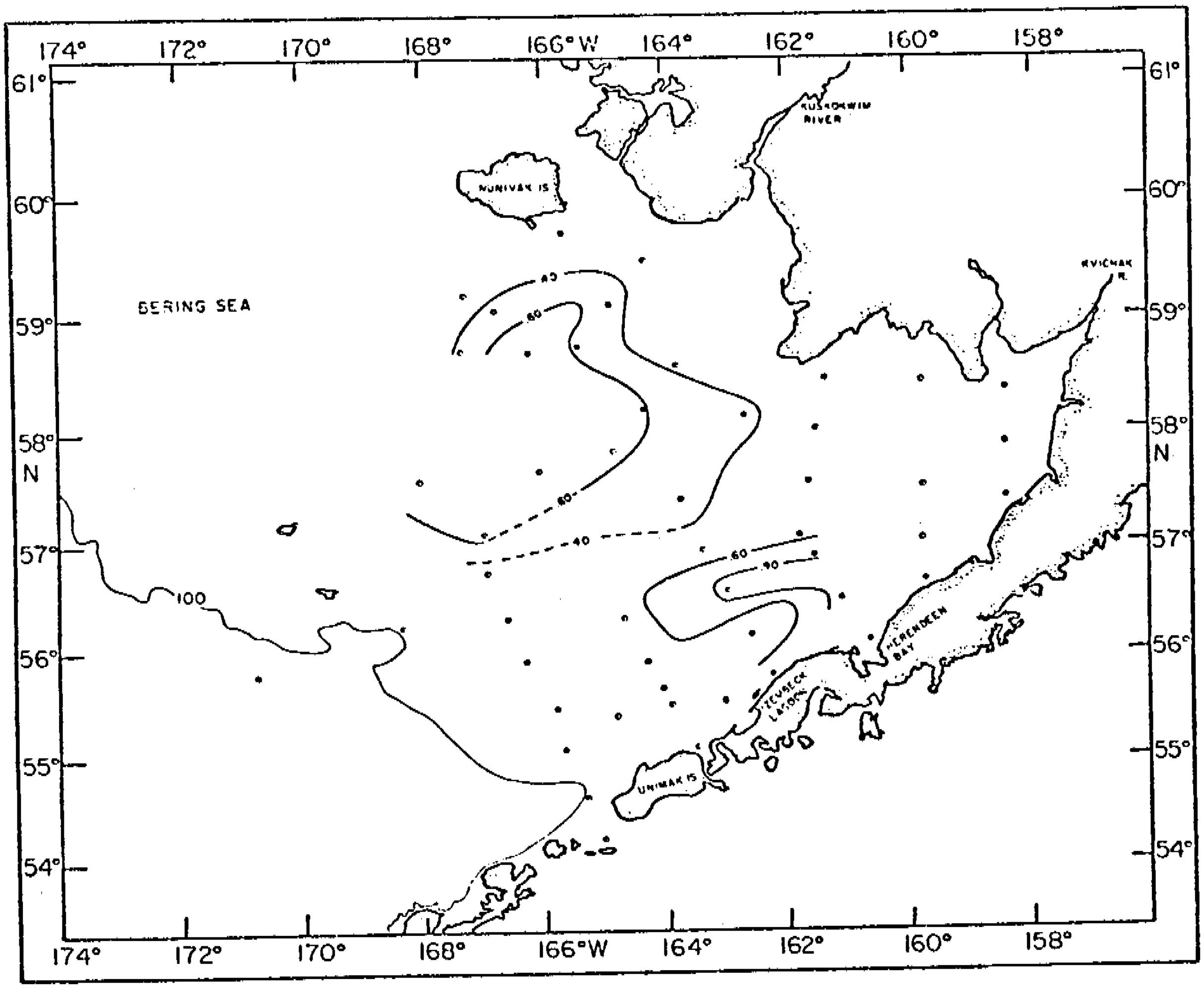

Fig. II-5. Areal distribution of propane plus propylene 5 m from the bottom in Bristol Bay during September to October 1975. Concentrations are given in nℓ/ℓ (NPT). Approximately two thirds of the total is propylene, based on complete chromatographic analysis at selected stations (from Cline and Feely, RU #153).

Methane data reported by Kaplan (RU #275) appear extremely variable, in contrast to the patterned results for methane in the near bottom (5 m) water (Cline and Feely, RU #153). Since much of the data reported by Kaplan (RU #275) and Cline and Feely (RU #153) are preliminary, much of the variability between data reported may be resolved in the final analyses.

In summary, the methane concentrations were highest in the near bottom waters and specifically in the region north of Unimak Pass, the "Golden Triangle." Concentrations also increased over the outer shelf and slope areas. No evidence was found that the LMWH originated from petroleum seepage.

OTHER HYDROCARBONS

Research by Shaw (RU #275), in cooperation with Kaplan (RU #275 subcontract), is designed to determine background hydrocarbon levels in sea water, biota, sediment, and seston and to identify animal tissues that might serve as useful indicators of petroleum pollution. The sampling area in the Bering Sea included the area enscribed by the western coast of Alaska and bounded on the northwest by St. Matthew Island and on the southwest by Unalaska Island.

Preliminary results indicate that the hydrocarbon levels in the Bering Sea are as low as, or lower than, other areas of the world oceans. No petroleum pollution was apparent in the sampling area. This is indicated by the concentration of hydrocarbons in the ppb range in the water and in the ppm range in the biota, by the absence of indications of petroleum in the gas chromatograms of biota tissue extracts, and by the extremely low abundance of floating tar. Tar samples reported by Shaw (1975, cited by Shaw, RU #275) in the Bering Sea were included with those collected in 1975 in the Gulf of Alaska. The mean tar abundance for these two areas was 3.3×10^{-3} mg/m^2. Although this value is greater than reported for the Gulf of Alaska, the concentration is quite low by global standards (Shaw, RU #275).

Bottom sediments from the Bering Sea were particularly low in carbon, nitrogen, and sulfur, containing < 1% organic carbon and < 0.1% nitrogen and sulfur.

In a survey of the selected subtidal biota from the Bering Sea and Gulf of Alaska, Shaw (RU #275) noted that tissues of several species have low concentrations of biogenic hydrocarbons. Pollock gills, crab body soft parts, and shrimp soft parts are potential indicator tissues for the detection of petroleum contamination. As Shaw points out, the sensitivity of detection by biological tissues is dependent on the biogenic hydrocarbon content of the tissues and the rapidity by which the tissues take up hydrocarbons. Therefore, the high natural hydrocarbon content of Pollock viscera and the low uptake rate in crab leg muscle make these tissues unsatisfactory indicators for petroleum contamination.

MICROBIOLOGY

Microbial Abundance and Degradation of Crude Oil

OCSEAP-related research on microbial abundance in the Bering Sea and degradation of crude by these heterotrophs has not been initiated. In reference to possible microbial abundance and petroleum degradation, related OCSEAP research has been discussed for the Beaufort Sea and Kodiak Island proposed lease areas. (See BEAUFORT SEA-Sources and KODIAK ISLAND-Sources section of this report).

Health Status of Demersal Fish

McCain and Wellings (RU #332) assessed the incidence of chronic disease and its effect on demersal fish, characterized and isolated disease associated microorganisms, and noted the age and sex frequency of diseased fish in the Bering Sea.

The results of field investigations by McCain and Wellings (RU #332) indicate various chronic diseases occur in demersal fish of the southern Bering Sea. The most common diseases identified include lymphocystis, epidermal papillomas, and bilateral pseudobranchial tumors. "Green liver" and "ulcers and boils" disease have also been characterized in demersal fish. Seven pseudomonad bacteria were consistently found in fish showing "green liver" symptoms.

Of the 25 demersal fish species examined, only three were found to have a significant pathological condition. One percent of the Rock sole (Lepidopsetta bilineata) had skin tumors, epidermal papillomas. The disease frequency in Rock sole ranged from 0% to 23%, with the highest occurrence at sampling stations around the periphery of the Bering Sea (Fig. II-6). Rock sole bearing papillomas range from three to 11 years, with peak frequency of occurrence in the five to six and nine to ten year classes. Sex and length determinations indicate that 64% of the tumor bearing fish were males; and all infected specimens were smaller than normal fish of the same age.

Lymphocystis was identified only in Yellowfin sole (Limanda aspera). The frequency of occurrence ranged from 0% to 15% (average 2.1%) and the disease was most common in fish collected in the southern sampling area (Fig. II-7). Lymphocystis lesions were always noted on the blind side of this flatfish and most common the pectoral fin and in larger fish (24 cm).

Tumors associated with the pseudobranch were found in 7.4% of the Pacific cod, Godus macrocephalus, collected. The frequency ranged form 0% to 100% and

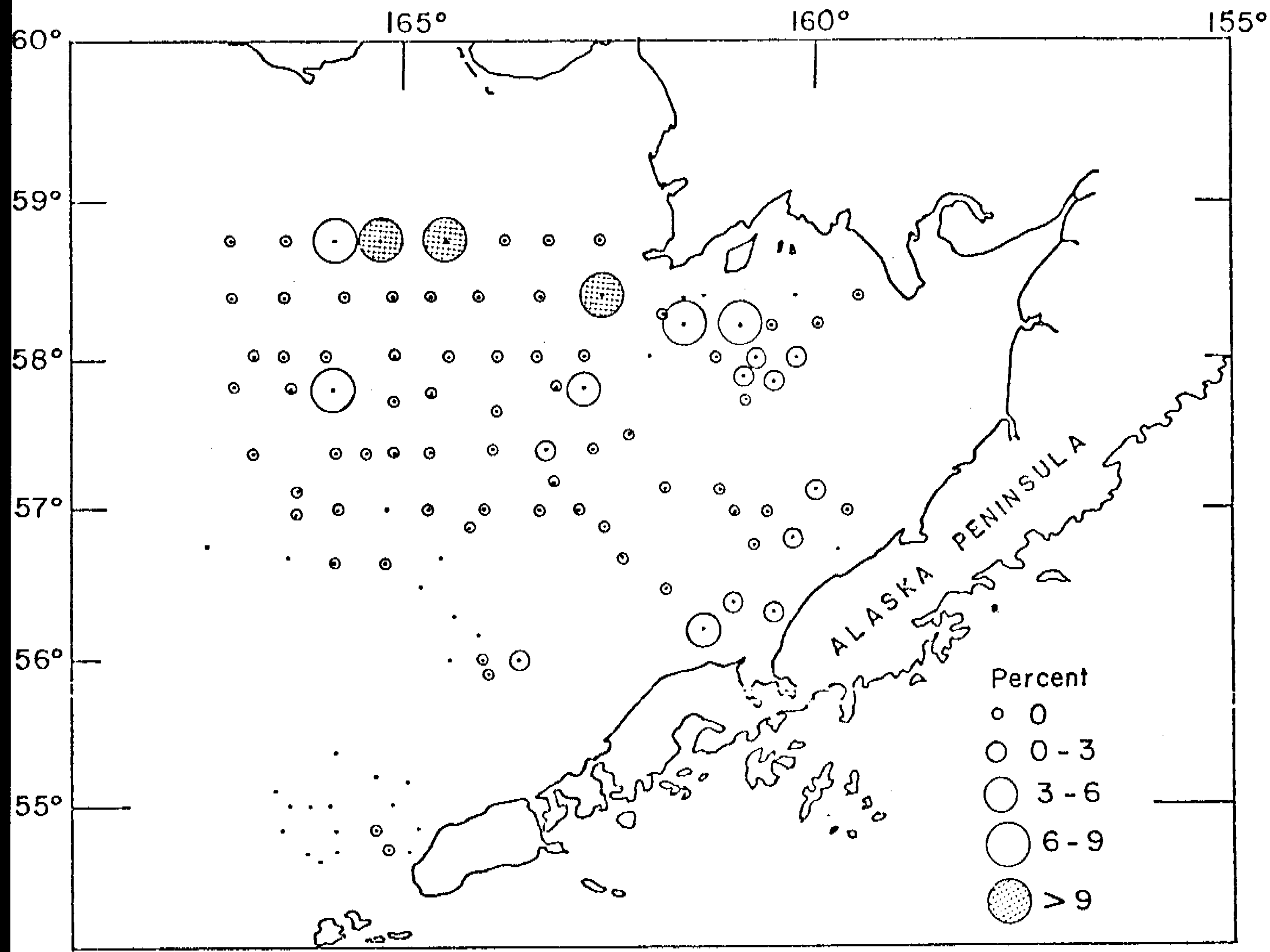

Fig. II-6. Approximate frequencies of Rock sole with papillomas at sampling stations in the Bering Sea where Rock sole were captured (from McCain and Wellings, RU #332).

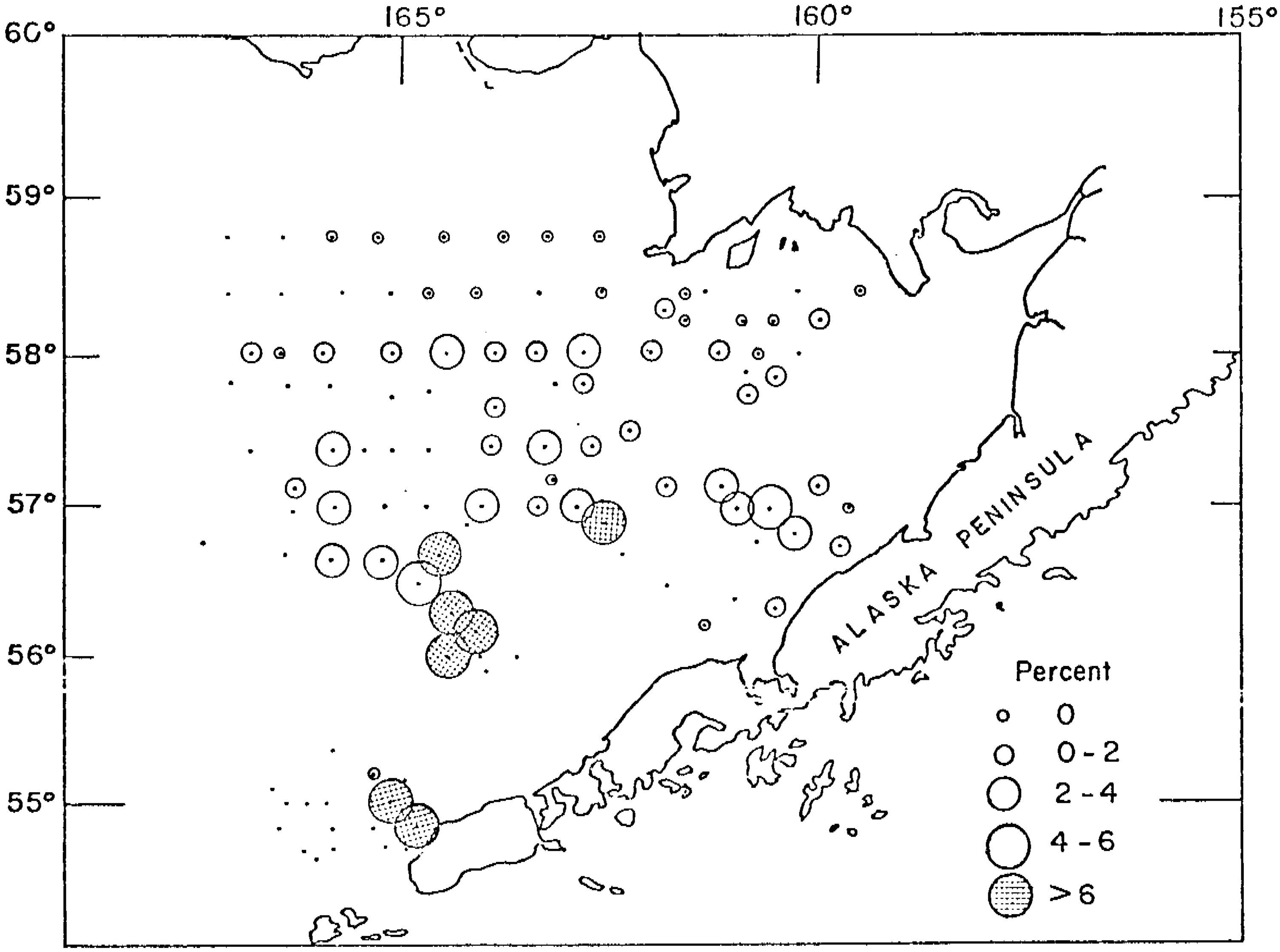

Fig. II-7. Approximate frequencies of Yellowfin sole with lymphocystis at sampling stations in the Bering Sea where Yellowfin sole were examined for the disease (from McCain and Wellings, RU #332).

was most common in cod caught in the south and southeastern Bering Sea (Fig. II-8). The tumors were always bilateral and associated with remnants of normal appearing, pseudobranchial tissue.

"Green liver" disease was identified in Pacific pollock (*Theragra chalcogramma*) and "ulcers and boils" disease was found in Pacific cod. "Green liver" disease may not be pathological. McCain and Wellings (RU #332) characterized "ulcers and boils" disease as a type of epidermal hyperplasia with focal necrosis.

Histopathological studies indicate that epidermal papillomas contained X-cells, a tumor specific cell. Hypertrophied lymphocystis cells were common in lymphocystis growths and virus particles were abundant. The tumors of the pseudobranch were shown to be associated with the pseudobranch tissue, but epidermal tissue was the specific site of tumorigenesis.

In the Bering Sea these diseases appear very species specific; however, McCain and Wellings (RU #332) report that these diseases have been found in various species of fish collected in other marine systems.

Disease data will provide the necessary background to aid in understanding possible causes of pathological abnormalities in demersal fish and the effect of oil on the frequency of disease occurrence.

Release of Soluble Trace Metals

Barsdate (RU #278) has shown in initial laboratory studies that the copper concentration of sediment pore water extracted from Izembek Lagoon sediments may increase following oil impaction. Preliminary results indicate that the effects are ascribed to the occlusion of trace metal binding or exchange sites by components of oil. This is considered to be a physical or chemical reaction rather than the result of microbial activity.

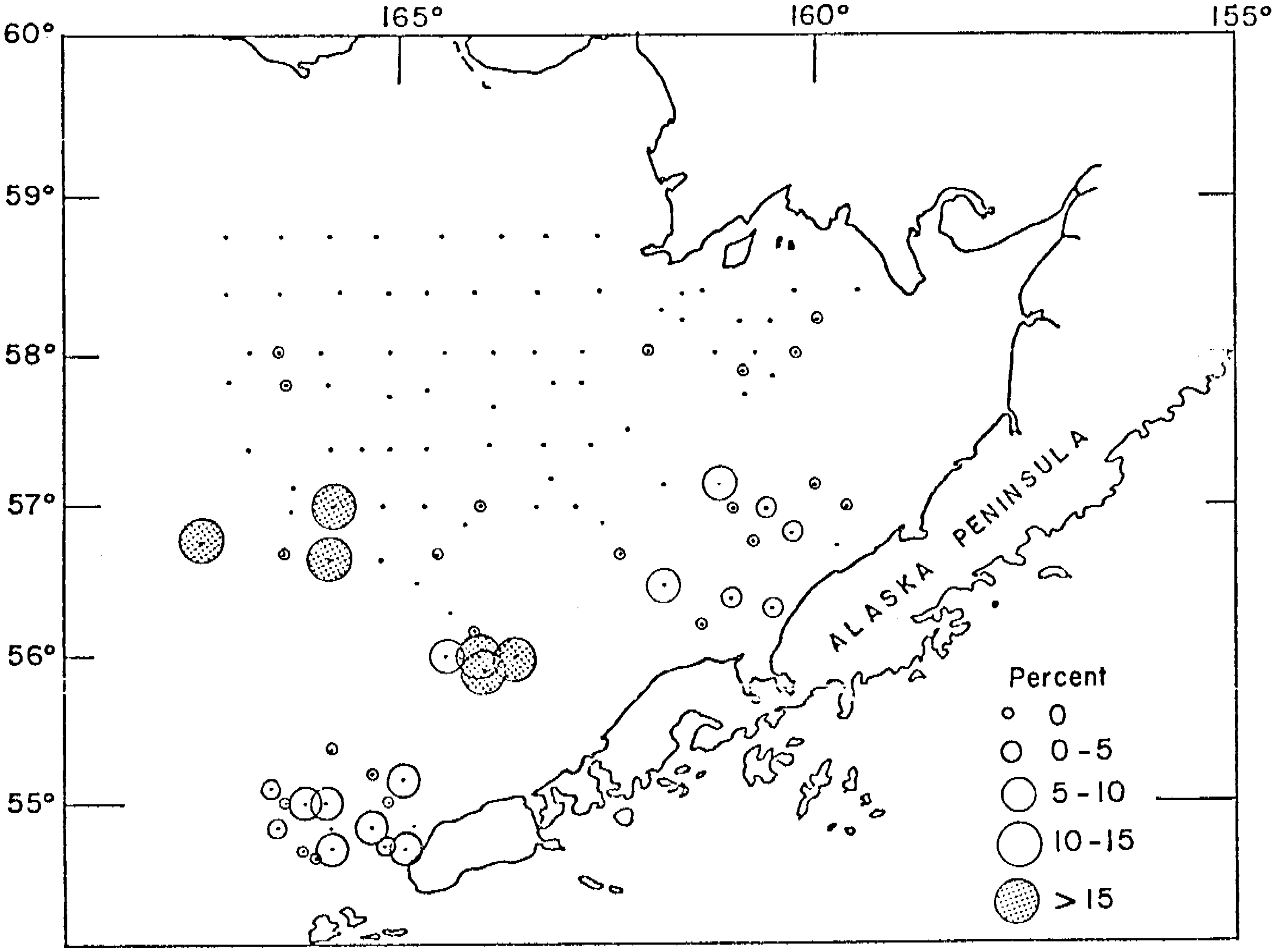

Fig. II-8. Approximate frequencies of pseudobranchial tumors of Pacific cod at sampling stations in the Bering Sea where this species was captured (from McCain and Wellings, RU #332).

Increase in metal composition of the pore waters after oil impaction may be reflected in benthic organisms. Such changes may also be noted as increased metal levels in the waters above the sediment. Should metal concentrations increase markedly, the species composition in the benthic and pelagic environments may be affected.

HEAVY METALS

Inorganic sediments constitute the largest repository of heavy metals, but those held in the biota are of particular concern to man. The importance of sea water lies not in the absolute amounts or concentration of metals held, but in its role as a mobile phase through which, and with which, these trace constituents can be transported (Burrell, RU #162). Preliminary data indicate that the soluble metal content of the Bering Sea water and sediment were as low or lower than in other coastal regions (Tables II-1, II-2, II-3). Levels in the biota were not analyzed but are expected to be similarly low. Burrell further stated that the Alaskan shelf environments are quite pristine and any future anthropogenic perturbations should be detectable. He also did not find mild or chronic contamination which might help biota acclimatize to future industrial activities.

TABLE II-1

Southern Bering Sea

Total Contents of Heavy Metals in Unfiltered Water (μg/ℓ)
R/V Discoverer June 2 to 19, 1975
(from Burrell, RU #162)

Station No.	Depth	Cd	Pb	Cu	Ni
02	0	0.06	--	0.45	0.65
	40	0.06	0.18	0.45	
06	0	0.03	0.17	0.32	0.45
	40	0.06	0.16	0.45	
08	0	0.03	0.22	0.75	0.95
	15	0.10	0.30	0.80	
10	0	0.03	0.20	0.50	0.60
	60	0.04	0.14	0.35	
12	0	0.03	0.12	0.32	0.60
	75	0.06	0.55	0.74	
13	0	0.04	0.07	0.36	0.60
	75	0.09	0.40	0.44	
14	0	0.04	0.14	0.35	0.70
	130	0.09	0.39	0.50	
17	0	0.04	0.31	0.39	
	110	0.11	0.16	0.58	
19	0	0.03	0.14	0.27	0.80
	65	0.05	0.16	0.36	
21	0				0.50
	40	0.03	0.16	0.38	
24	0	0.03	0.14	0.46	0.45
	40	0.02	0.20	0.46	
26	0	0.04	0.20	0.46	0.55
	45	0.03	0.15	0.35	
30	0		(0.55)	0.46	
31	0	0.06	0.15	0.32	
	150	0.10	1.28	0.24	
34	175	0.06	0.10	0.26	
39	0	0.02	0.14	0.34	0.40
	60	0.05	0.23	0.40	
41	0	0.04	0.14	0.35	0.65
	25	0.03	0.09	0.33	
42	0	0.03	0.10	0.32	0.55
43	0	0.02	0.07	0.30	
	30	0.02	0.08	0.32	
46	0	0.03	0.08	0.33	0.55
	60		0.20	0.34	
48	0	0.06	0.36	0.49	0.60
	145	0.06	0.11	0.23	
53	0	0.06	0.58	0.30	0.60
54	0	0.05	0.16	0.20	
	100	0.12	0.45	0.48	

TABLE II-1 (continued)

Station No.	Depth	Cd	Pb	Cu	Ni
56	0	0.03	0.25	0.40	
	62	0.11	0.20	0.45	
57	45	0.03	0.16	0.40	0.40
59	30	0.02	0.07	0.33	0.35
60	0	0.02	0.13	0.35	0.70
	25	0.02	0.16	0.42	
62	0	0.02	0.09	0.30	0.65
	45	0.03	0.08	0.35	
64	80				0.60
65	0*	0.04	0.30	0.52	
	100		0.18	0.92	
69	0				
	105				0.50

*Filtered sample

TABLE II-2

Southern Bering Sea

Soluble Cr Data (μg/ℓ) R/V Discoverer Leg III
September 25 to October 3
(Filtered samples at 0.45μ)
(from Burrell, RU #162)

Station No.	Depth (m)	Filtered	Unfiltered
48	3	0.29	0.69
	150		0.14
51	3		0.16
	1500	0.14	
54	3	0.15	
	98		0.07
66	134		0.03
56	61		0.04
59	3	0.02	0.14
	33	0.12	0.11
41	3	0.73	
	28	Tr	
24	3	0.37	
	40	Tr	
8	3	0.30	
	18	0.27	
12	3	0.06	
	76	0.13	
35	3		0.22
	155		0.07
19	71	0.14	
46	65	0.92	
37	3	0.59	
	70	0.08	
17	114	Tr	

TABLE II-3

Southern Bering Sea

Total Chromium Contents of Particulate Sediment (μg/ℓ co-existing water; particulate material defined by 0.45μ membrane filter)
R/V Discoverer September 13 to October 3, 1975
(from Burrell, RU #162)

Stations	Depths (m)	Cr (μg/ℓ)*
8	3	Tr
	18	n.d.
12	3	n.d.
	76	n.d.
17	3	Tr
19	3	n.d.
	71	n.d.
24	3	n.d.
	40	0.14
41	3	0.36
	28	n.d.
46	3	0.12
54	3	n.d.
59	3	0.2
	33	n.d.
PMEL 46	3	n.d.
Off Nelson Lagoon		Tr
Izembeck Lagoon		n.d.

*n.d. - not detectable above background
Tr - 0.04 - 0.10 μg/ℓ above background

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Chapter III

HAZARDS

GEOLOGIC SETTING

The Bering Shelf is one of the most extensive continental shelves in the world, underlying almost half of the Bering Sea. The proposed Bristol Bay and St. George Basin lease areas occupy the southeastern portion of the shelf. The shelf extends some 800 km between the head of Bristol Bay and the Pribilof Islands yet reaches maximum water depths of only 180 m. In addition to its very gentle offshore slope, shelf topography is unusually smooth and level.

Bristol Bay is a shallow, triangular embayment bounded to the north by the Kuskokwim Mountains and to the east and south by the Alaska Peninsula. Several rivers drain into the bay, the largest of which are the Nushagak and Kvichak, both with active deltas. The mouth of the still larger Kuskokwim River empties into the Bering Sea somewhat north of Bristol Bay. The St. George Basin is one of several subsurface structural basins located near the seaward edge of the Bering Shelf, adjacent to the Pribilof Islands (Fig. III-1). Immediately west of the Pribilof Islands the ocean bottom drops off sharply to the floor of the Aleutian Basin or Bering Abyssal Plain. The continental slope is cut by several of the world's largest submarine canyons -- eroded by the Yukon and other rivers that flowed across the shelf during periods of Pleistocene lowered sealevel (Nelson et al. 1974; Sharma 1974).

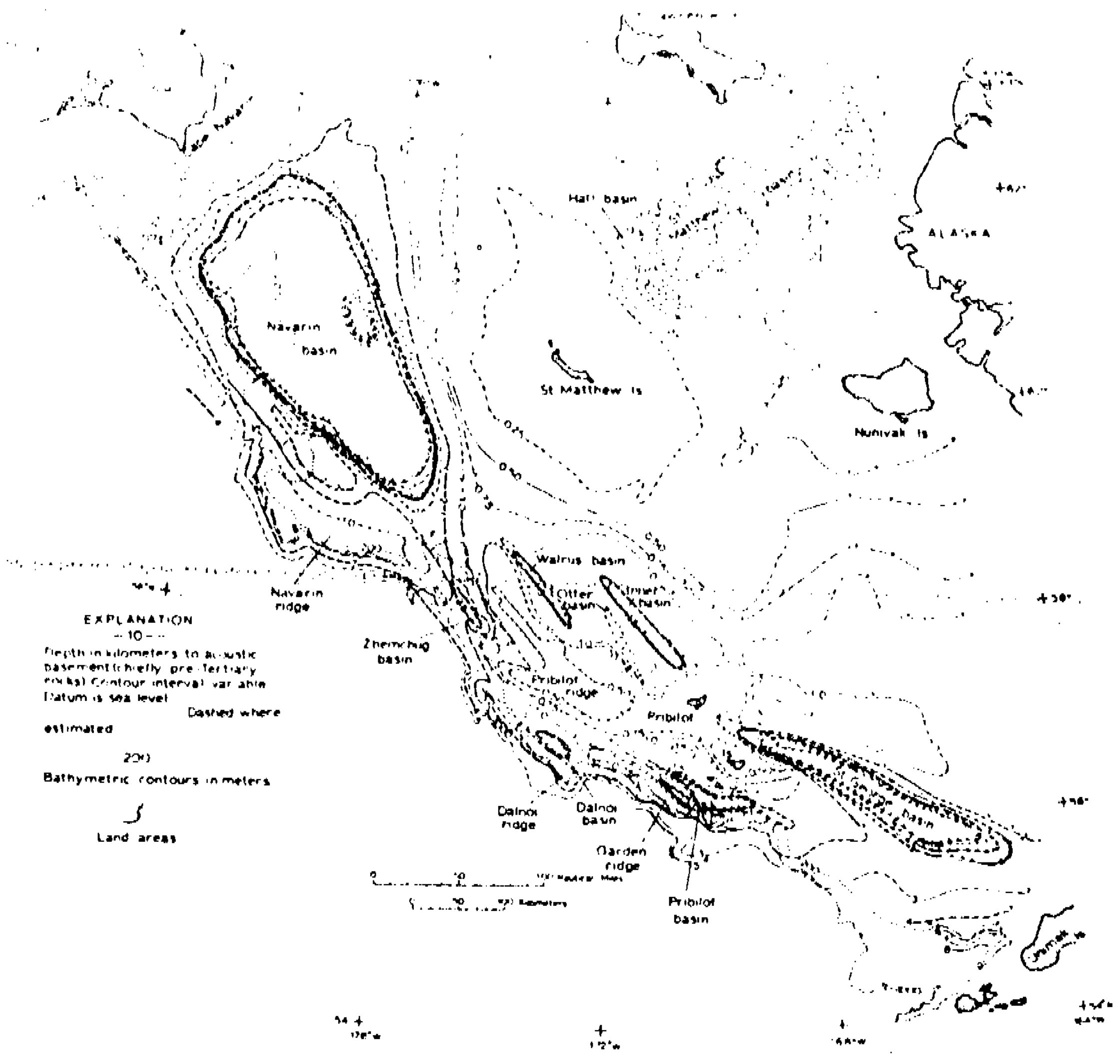


Fig. III-1. Structure-contour map of acoustic basement on southern continental shelf of Bering Sea (from Marlow et al. 1976, in Hopkins, RU #209). Subsurface basins are outlined.

The tectonics of the Bering Shelf are dominated by the Alaskan orocline on the east and the Siberian, Chukotkan orocline on the west. Both oroclines turn south and intersect beneath the Bering Sea -- probably reflecting bending of Siberia relative to North America as a consequence of rifting in the Atlantic and Arctic Basins (Nelson et al. 1974). At least two probable axes of uplift and two major fault systems cut across the St. George Basin-Briston Bay shelf region.

"Major environmental problems are related to slope instability and active faulting. Steep slopes along the shelf break and around the sides and ends of the canyons, headward eroding canyons, and thick accumulations of young thixotropic sediments promote slope instability. Fault scarps cut the sea floor in the St. George Basin area and frequent earthquakes jar the region, particularly in the southern part" (Vallier and Gardner, RU #206).

SEISMICITY

Much of the seismicity recorded in Alaska is generated by underthrusting of the Pacific Plate beneath the American Plate, along the Aleutian Trench. Earthquake hypocenters generally occur at increasingly greater depths within the crust as one passes across the Aleutian volcanic arc from south to north. Most seismic events occur along or to the south of the arc, with relatively few being recorded from the Bering Shelf to the north.

Meyers' tabulation of Alaskan earthquakes recorded between 1899 and 1974 (RU #352) includes some 17 epicenters located within or adjacent to the proposed Bristol Bay lease area (Fig. III-2). Three of these events exceeded magnitudes of 6.5; the greatest reached a magnitude of 6.7 (modified Mercalli Scale, Meyers, RU #352). Another nine of ten epicenters have been recorded

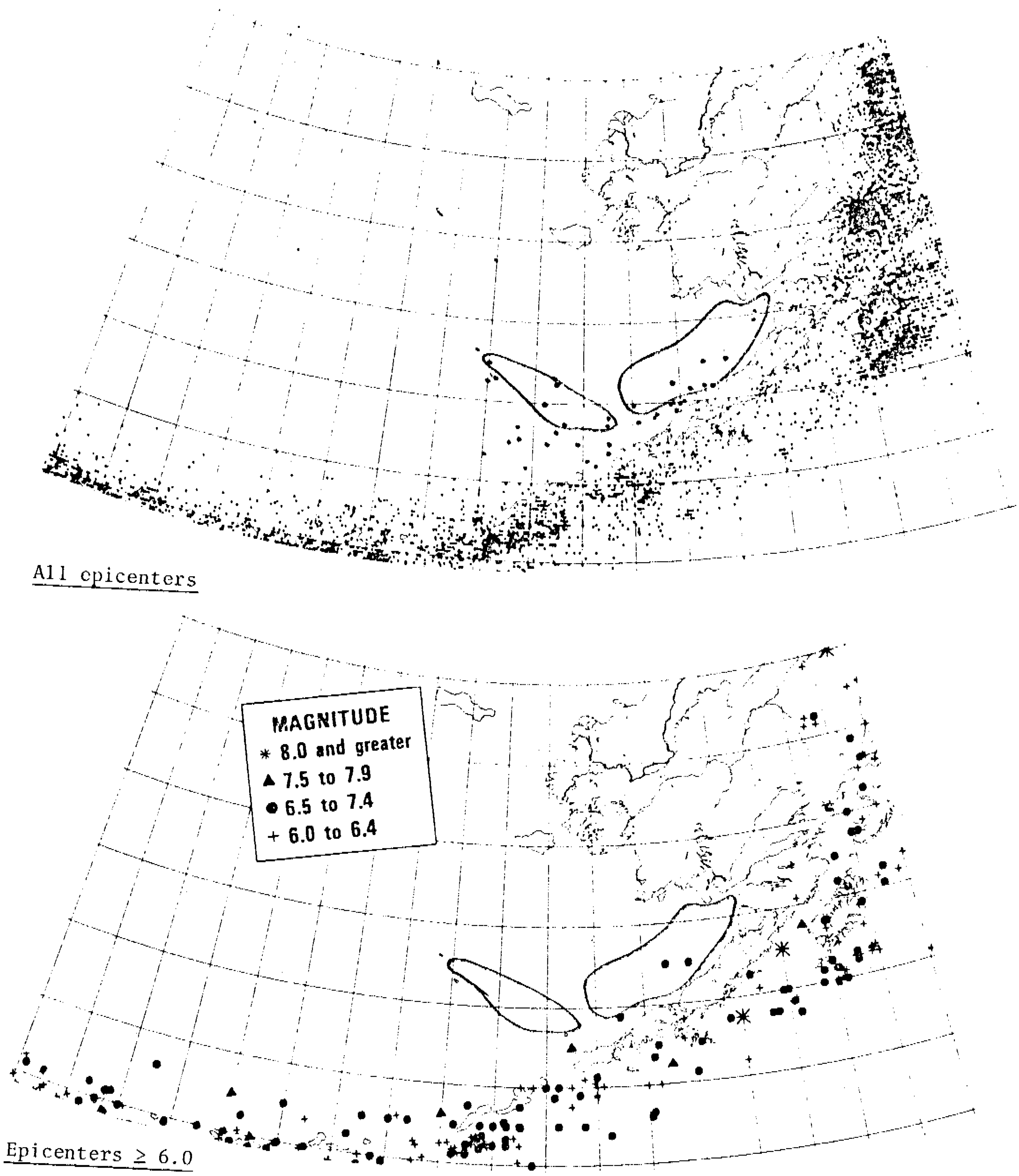


Fig. III-2. Earthquakes in and near the proposed Bristol Bay and St. George Basin lease areas (Meyers, RU #352).

recorded from the proposed St. George Basin lease area (Meyers, RU #352). None of these exceed magnitudes of 4.8 on the modified Mercalli scale.

No tsunamis or seiches have been recorded from either the shores of Bristol Bay or the Pribilof Islands (Meyers, RU #352). Since major sea floor displacements related to underthrusting are restricted to the south side of the Aleutian Arc-Alaska Peninsula line, it is unlikely that either Bristol Bay or the Pribilofs will experience serious tsunami hazards in the future.

SURFACE AND NEAR-SURFACE FAULTING AND SLOPE INSTABILITY

Faulting and instability of the sea bottom in the St. George Basin and Bristol Bay is the subject of two NOAA-OCSEAP programs (Hopkins, RU #209; Vallier and Gardner, RU #206).

Hopkins is evaluating the frequency of faulting and volcanic eruptions on and around the Pribilof Islands. (Rates and direction of changes of island shorelines and the nature of island soils and their susceptibility to erosion are also being examined.)

Faulting and volcanism are recognized as ongoing processes in the Pribilof Islands area. There is a general correlation between the fault pattern density, the amount of fault separation, and the age of features affected (i.e., oldest faults exhibit greatest scarps). It appears that faulting is episodic, with movements occurring at about 10,000 year intervals. Hopkins has produced detailed fault maps for both St. Paul and St. George Islands (Fig. III-3, III-4). Reconnaissance mapping of faulting between the islands has also been completed (Fig. III-5). The most significant faulting identified to date is a northwest trending, 15 m deep, graben recently named the St. Paul Rift

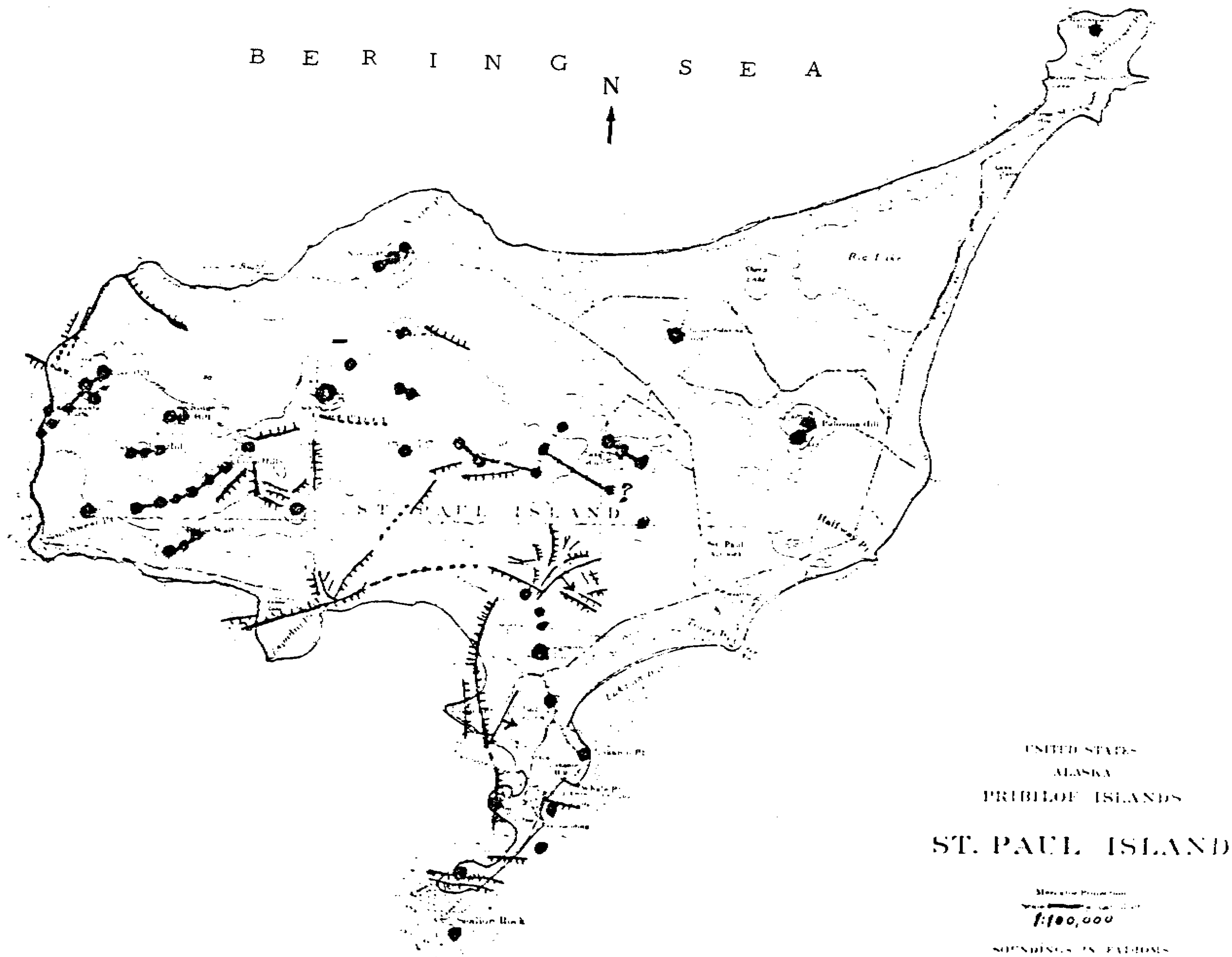
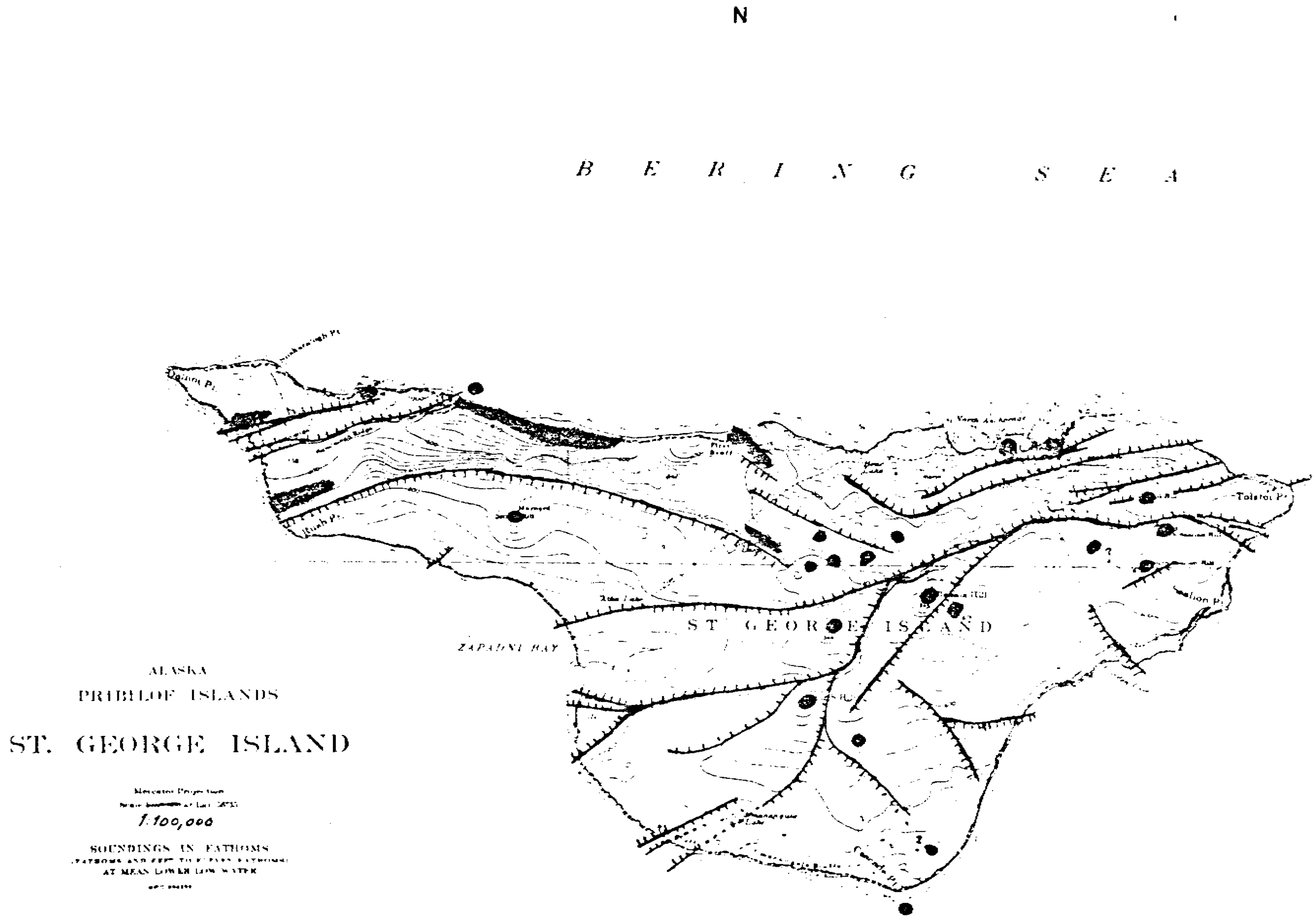


Fig. III-3. Faults and volcanic vents on St. Paul Island (from Hopkins, RU #209).



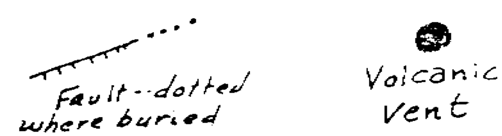


Fig. III-4. Faults and volcanic vents on St. George Island (from Hopkins, RU #206).

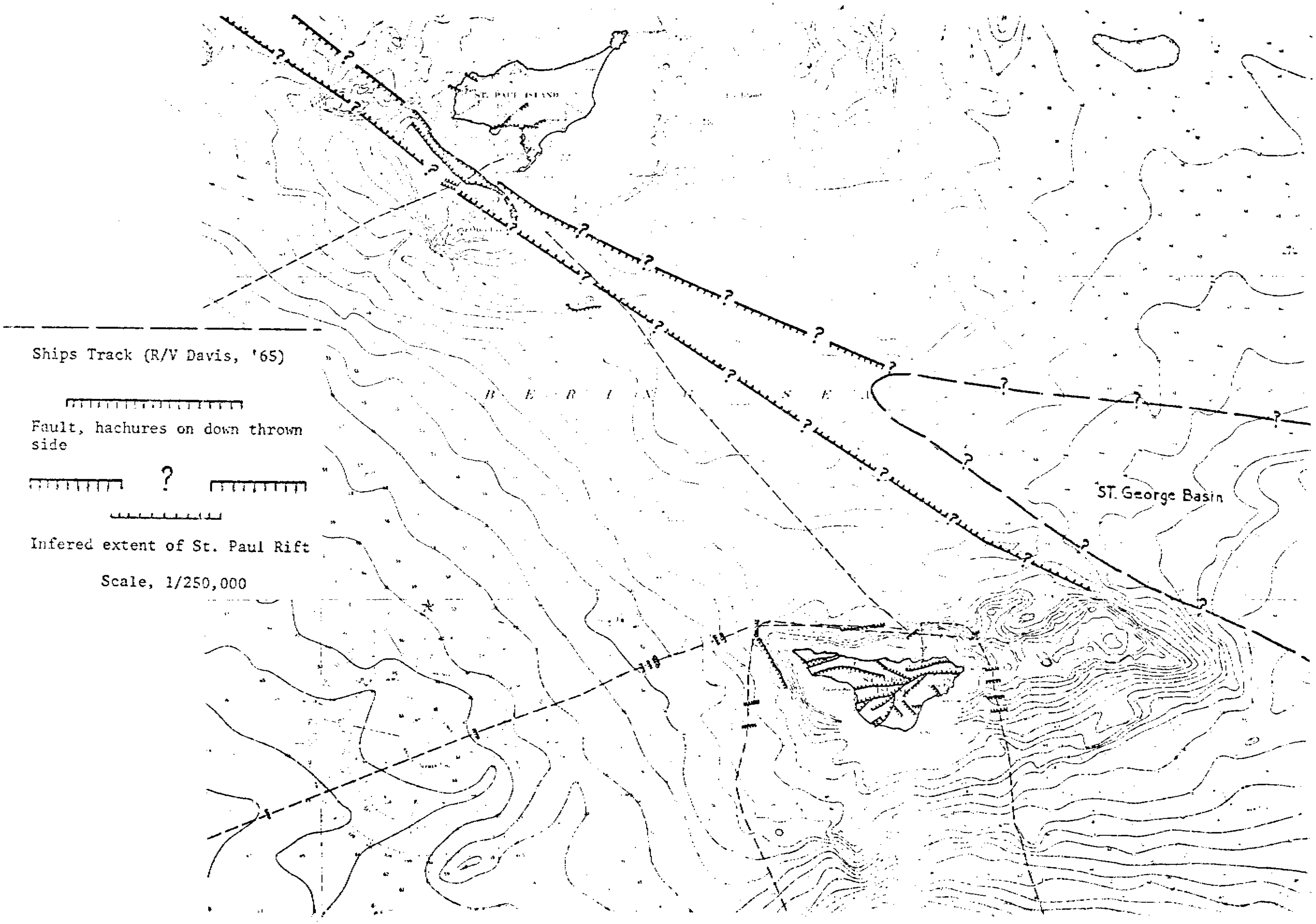


Fig. III-5 (From Hopkins, RU #209)

(Hopkins, RU #209). This rift parallels the trend of, and links the St. George Basin and Otter Basin. The extent and orientation of the rift, and its associated volcanism, suggests it is part of a major right-lateral fault that has a long history of past movement and is still active.

Hopkins (RU #209) draws on several lines of evidence -- "the long recurrence interval between volcanic eruptions, the small net displacement on faults cutting young lavas, the lack of clear evidence of faults cutting sand dunes and the youngest volcanic features, and the low level of seismicity recorded by a siesmometer on St. Paul Island" -- to conclude that fault displacement episodes are widely separated in time. He further concludes that: "The odds are very small that displacement will take place within a given decade on any given fault. Nevertheless, the odds that movement will take place on some fault, onshore or offshore, are far from negligible. It is important to recognize that any pipeline connecting a producing area in the St. George Basin and a terminal and transhipment facility on the Pribilof Islands would <u>have</u> to cross an active fault (Hopkins, RU #209)."

Ship and equipment failures have delayed results in Vallier and Gardner's program (RU #206); they should be providing important data on faulting and areas of slope instability in the near future. Preliminary analyses of existing high-resolution (but generally poor quality) seismic records from the St. George Basin region suggests the presence of numerous faults and extensive areas of slope instability near the shelf edge.

VOLCANIC HAZARDS

The Pribilof Islands area has been the center of persistent basaltic volcanism for the last eight million years (Hopkins, RU #209). Volcanic vents are apparently associated with tensional fractures located along the St. Paul rift zone and have migrated through time. During the last 300,000 years volcanism has been restricted to the St. Paul Island vicinity. Thirty-six volcanic vents have been active on St. Paul (Fig. III-3); 11 have erupted in the last 120,000 years, two in the last 10,000 years. Hopkins (RU #206) concludes that eruptions have been spaced fairly evenly at about 10,000 year intervals. Clearly, the probability of a volcanic eruption on St. Paul Island is very small and practically nil in other parts of the proposed St. George Basin lease area (Hopkins, RU #206).

Several more explosive andesitic volcanic centers are located along the Alaska Peninsula, bordering the proposed Bristol Bay lease area to the south. It is unlikely that even major eruptions from these locations would have direct effects on Bristol Bay. However, it is possible that indirect effects such as ash falls and corrosive rains could produce some impacts in the lease area (see LOWER COOK Section, Hazards Chapter).

COASTAL EROSION

NOAA-OCSEAP supported studies of coastal erosion within the proposed southeast Bering Shelf lease areas include Hopkins' studies on St. Paul Island, in the Pribilofs (RU #209), and Dupre and Hopkins' study of the Yukon Delta (RU #208).

The Pribilof Islands

Hopkins reported that shoreline changes on St. Paul Island between 1897 and 1955 (RU #209) indicates that longshore drift and deflation are responsible for beach erosion rates of several tens of meters per century (Fig. III-6).

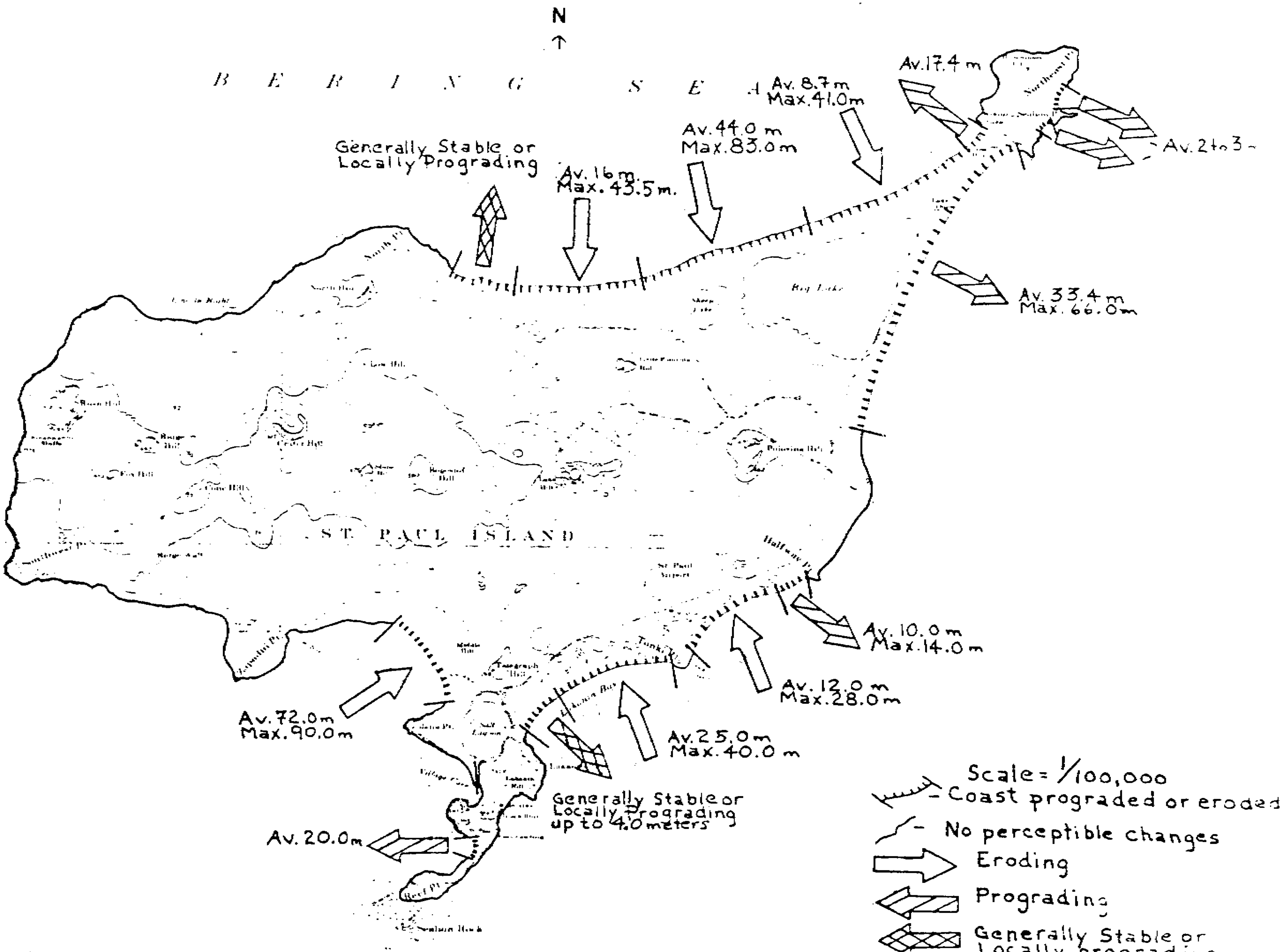


Fig. III-6. Amounts and direction of shoreline changes on St. Paul Island between 1897 and 1955 (from Hopkins, RU #209).

Much of the sand removed from the beaches by the wind is forming active coastal dunes. Cliffed shorelines around St. Paul -- more stable than the beaches and dunes -- are subject to rock falls.

As much as 30% of St. Paul Island is covered with vegetation-stabilized dune sands. These areas offer flat, well drained and convenient sites for onshore facilities associated with regional oil and gas development. Should the vegetative cover be disturbed, however, the dunes will be extremely susceptible to wind erosion.

Installation of docks, breakwaters, and onshore pipeline terminals must also be carefully planned, taking into account the dynamic and unstable nature of the island beaches. Hopkins (RU #209) also notes that deflation following construction could produce adverse effects upon the suitability of the beaches and dunes for continuing use by sea mammal and bird fauna of the Pribilof Islands.

Yukon-Kuskokwim Delta

Dupre and Hopkins (RU #208) have provided a qualitative assessment of geologic processes active within the Yukon-Kuskokwim delta. They provide an excellent summary of their present conclusions, which is quoted, in part, below:

"1. The Yukon-Kuskokwim delta region is characterized by Quaternary tectonism. Northwest-trending faults and structurally-controlled volcanic vents are mainly restricted to the onshore extension of the Nunivak Arch, previously recognized only in the offshore.

2. The coastline is highly variable with respect to its morphology, processes, and overall coastal stability. Of particular importance in determining the relative coastal stability is the proximity of the Yukon River sediment input, local protection by barrier islands and early-forming shorefast ice, laterally migrating tidal inlets, and local tectonic patterns. In spite of its heterogeneity, however, the dominant direction of longshore drift is toward the north, coincident with the oceanic and wind-generated currents.

3. Whereas the absolute rate of change along the shoreline has been relatively slow, rapid changes have occurred along the major rivers, particularly during breakup. Relatively rapid erosion can also occur along the edges of many of the large lakes, particularly during the late summer/early fall storms.

4. Much of the delta plain is underlain by active and relict permafrost, the distribution of which appears to be a complex function of the age of the depoits, their physical properties, and the microclimate."

SUSPENDED PARTICULATE MATTER

Many marine pollutants (particularly petroleum hydrocarbons) are adsorbed onto the surface of supsended particules and are removed from the water column as the particles settle to the bottom. Sedimentation of oil residues may impact benthic faunas altering their abundance, species composition, or survival. This, in turn, may impact fish and shellfish species -- including commercially significant forms -- that feed upon the benthos (Pererya et al., RU #175). An understanding of the processes controlling the distribution, composition, and transport of suspended particulate matter is thus essential to assessing the fate of toxic pollutants in marine environments. Feely and Cline (RU #152) are presently developing such an understanding through examination of ERTS imagery and analysis of water samples from the southeast Bering Shelf. Their preliminary conclusions are as follows:

1. Suspended material from the Kvichak and Nushagak Rivers at the head of Bristol Bay moves west to Cape Newenham where it combines with material introduced from the Kuskokwim River to form a large sediment plume offshore. A second plume extends southwest from Kuskokwim Bay (Fig. III-7).

2. Surface concentrations of suspended particulate matter drop off sharply away from the coast along the Alaska Peninsula as relatively clear Pacific Ocean water moving through the Aleutian Island passes dilutes the turbid Bristol Bay waters (Fig. III-7).

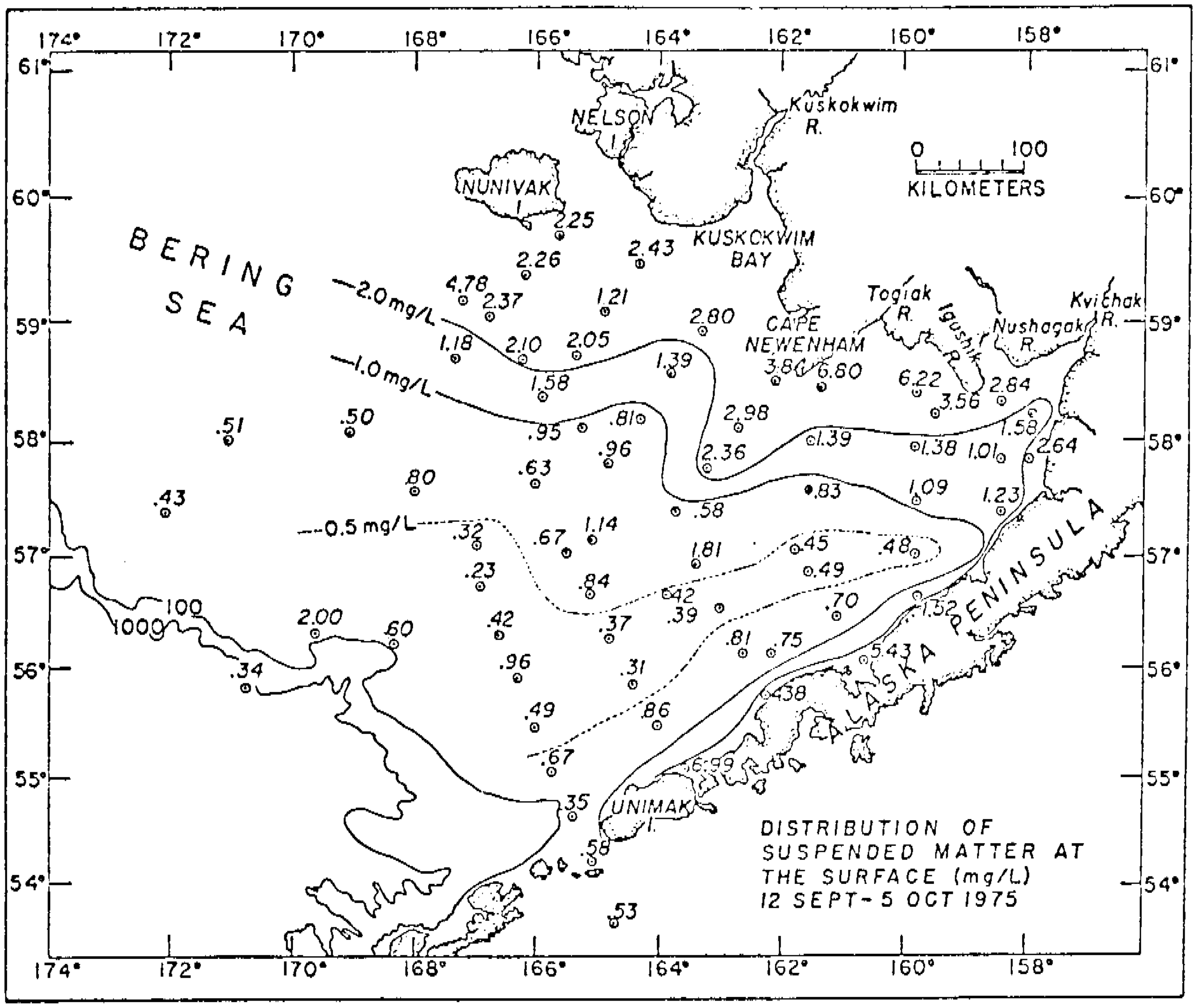


Fig. III-7. Distribution of total suspended matter at the surface in the southeastern Bering Shelf (Cruise RP-4-Di-75B-III, 12 Sept.-5 Oct., 1975) (from Feely and Cline, RU #152).

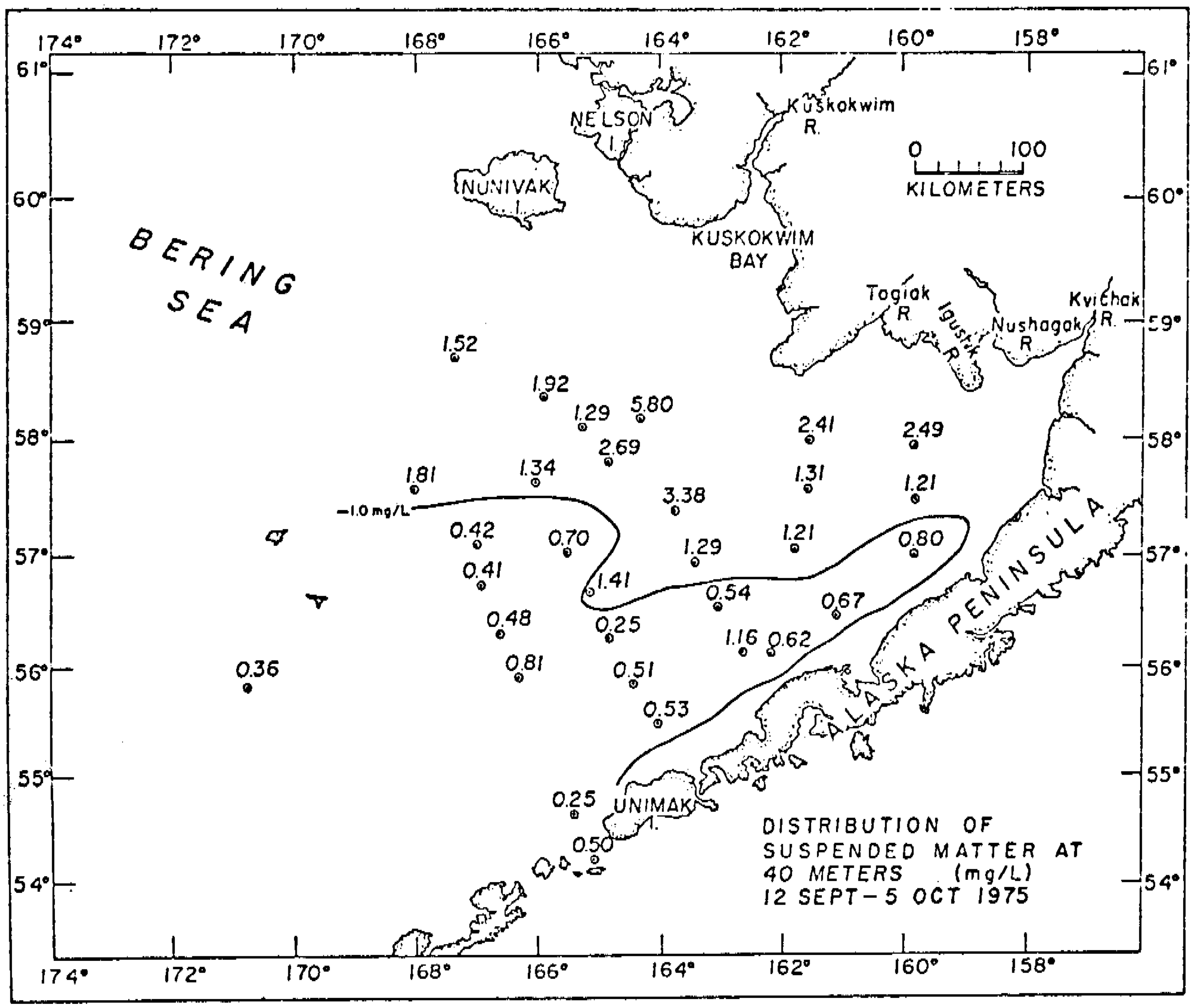


Fig. III-8. Distribution of total suspended matter at 40 meters in the southeastern Bering Shelf (Cruise RP-4-Di-75B-III, 12 Sept.-5 Oct., 1975) (from Feely and Cline, RU #152).

3. Subsurface distributions of suspended particulate matter (Fig. III-8) mirror those at surface; semi-permanent counterclockwise Bristol Bay circulation apparently controls suspended matter distributions throughout water column. Concentrations increase sharply near the sea bottom, probably due to resuspension of settled material by waves and tides.

4. Preliminary C-H-N results indicate that both near-surface suspended matter in northern Bristol Bay and near-bottom material are >70% inorganic and probably of terrestrial origin. Along the Alaska Peninsula the material is <50% inorganic and predominantly of marine origin. Major and trace element composition of the suspended material is under investigation also, but the data are not yet available.

The ultimate fate of the suspended particulate matter moving out of Bristol Bay remains unknown. If mass transport within the bay follows the gyral pattern suggested by several workers, then much of the particulate matter probably stays within the southeast Bering Sea and eventually settles out. If the gyre is incomplete as suggested above (see Transport section of this report) then the suspended material either continues north along the Kuskokwim-Yukon Delta coast, or is carried westward across the continental shelf and slope.

SEA ICE

Stringer (RU #257) has initiated mapping of nearshore ice conditions. Preliminary results include the following information about ice distribution:

1. "Unlike ice conditions along the Beaufort Coast, ice conditions along the Bering Coast are highly variable. Dynamic ice events are possible in the nearshore areas during the entire ice season except for the most highly protected bays and inlets. The nature of these events is highly dependent on location and meteorological conditions."

2. Along the northern coast of the Alaska Peninsula general ice movement is from the north. The locations of apparently grounded shear ridges appear to be related to a uniform distance from shore and not to water depth. Ice which remains stationary with respect to the shore "is located within well protected areas and in some locations as a narrow apron close to the shore." This region appears to be an area of convergence for pack ice which builds large shear ridges along the coast.

3. Along the north side of Bristol Bay (Kvichak River to Cape Pierce) typically "ice is pulled away from the coast and ... new ice is being constantly formed between the ice edge and the coast.... At times aprons of ice extend seaward several kilometers from moderately well protected areas but eventually these areas break up and drift off during times when the ice pack has been pulled away from the shore" (Also mentioned by Potocsky 1975).

The mean ice edge location for southern Bering Sea is given by Patocsky (1975), and mean pack ice concentrations are given by Potocsky (1975) and Swift et al. (1974).

Diffuse concentrations of pack ice, when moved by sudden and intense storms, may converge forming close pack ice fields creating potentially dangerous environmental conditions around offshore structures. Certainly high concentrations of pack ice associated with wind and wave action in the area of an oil spill will delay, and possibly rule out, containment and clean-up efforts. No research on the frequency of visits of highly concentrated pack ice fields in either lease area is known. The hazards associated with oil movement within the pack which relates to potential oil spill clean up are discussed in the Transport Chapter, Ice section.

In reference to offshore oil and gas development Stringer (RU #257) concluded that: "It is not possible to depend on a stable sheet of ice from which to conduct exploration and other related activities ... except in a few highly localized areas."

He further points out that ice conditions are influenced by two factors: (1) significant tidal fluctuations and (2) exposure to the open sea. The tidal range is sufficient to break up and raft away grounded ice. Open sea adjacent to the ice pack permits the liberated ice to move away from the coast and into other regions. As the ice moves away in the winter, new ice is formed in the nearshore environment.

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Chapter IV

TRANSPORT PROCESSES

INTRODUCTION

Oceanographically, Bering Sea is a unique environment: it has sharp, well-defined boundaries; there are distinct passages for water flow both to the south and to the north; and it is characterized by dramatic changes in water properties when ice covers half of the sea in winter and then melts away completely in summer. A vast amount of observations related to water mass characteristics and current patterns in the eastern part of the Bering Sea have been made in relation to studies on salmon, ground fish, king crab, and other commercial biotic resources. Most research activities have, however, been limited to those conducted on board single vessels and are intermittent and sporadic. There have been a few attempts to synthesize the available knowledge to a coordinated whole.

From the available information and data it can be surmised that a large scale exchange of water takes place between the Bering Sea and the North Pacific Ocean through various passes and openings along the southern boundary of the Bering Sea. Favorite (1967) lists 39 openings through the Aleutian-Commander Island arc. Only five of these contribute over 99% of all flow penetrating through the arc: East Aleutian, Central Aleutian, West Aleutian, Commander-Near Strait, and Kamchitka Strait. In the Bristol Bay-St. George Island region, Unimak and Samalga are the only major passes.

A review of oceanographic observations and data for the Bering Sea with special reference to flow of water through the Aleutian Island passes is provided by Favorite (1974). Water mass characteristics are discussed by Takenouti and Ohtani (1974) and circulation patterns, especially for the western Bering Sea, are given by Hughes, Coachman, and Aagaard (1974).

Current OCSEAP-related research in this area is being conducted by Muench (RU #307) and by Schumacher and Coachman (RU #141). Muench is evaluating historic and ship-of-opportunity data to describe the spatial and temporal variability in the temperature and salinity characteristics of water masses. Data will also be examined to discern large-scale circulation pattern and mixing processes and to deduce horizontal and vertical advective fields. Schumacher and Coachman are collecting data to characterize the water mass, mixing processes, and the velocity field. Also included in their research program is determination of sea level changes and to examine their relationship, if any, with storm surges.

Schumacher and Coachman (RU #141) have deployed long-term moored arrays with current meters (Aanderaa type) and pressure gauges (Aanderaa type) at four sites. Each array is designed to provide data on current speed and direction, conductivity and temperature of seawater, and pressure. All data are recorded on magnetic tape. CTD (conductivity-temperature-depth) measurements are also made at a number of stations on a grid covering the entire research area. Collected data are few and results are tentative. No conclusions can be deduced at this time.

MAJOR HYDROGRAPHIC FEATURES

Freshwater input into Bristol Bay is principally from Kuskokwim River. In addition, a number of small rivers such as Nushagak River discharge variable, but significant amounts of freshwater at various sites. Dilution of surface layers by land runoff, the intrusion of warm, saline water, and strong vertical mixing associated with winter cooling contribute to a rather complex temperature and salinity structure. As the bay lies near the southern boundary of the area of seasonal ice formation, a marked seasonality is seen in surface temperature and salinity values.

It is probable that water flows from the Alaskan Stream into the Bering Sea through numerous passes, but it is not clear through which passes and in what amounts. No net exchange is considered to occur through the eastern Aleutian passes. Northerly flow through the Bering Strait is estimated to be less than 5% of total inflow into the Bering. However, a considerable amount of fresh water from coastal runoff and snowmelt along the eastern Bering Sea is removed with this flow.

Data on temperature and salinity have been collected for a number of years. Available data from the eastern Bering Sea up to 1973 have been compiled by Ingraham (1973, cited by Muench, RU #307). A notable feature of the area is the presence of tongue like extensions of cold water from the northwest along the central shelf into mid-Bristol Bay. This feature may be an artifact of winter convection associated with ice formation which is subsequently shaped by advection. A very high correlation (r = 0.95) was found between mean bottom layer temperature of the southeastern shelf in June (largely conditioned by the minimum temperature of "cold tongue") and degree days of frost of previous winter (Coachman [unpublished data], cited by Muench, RU #307). Favorite and Ingraham (1973) reported an anomalous surface tongue of diluted water extending over 200 km southward of Pribilof Islands in spring 1971.

General circulation in Bristol Bay-St. George Island region is cyclonic. Water movement is eastward along the north side of Alaska Peninsula, and north and northwesterly along the southwestern Alaskan coast. It is not certain if this flow continues to form a complete gyre. If the tongue like features are persistent and have a southeasterly trend (from the northwest), they are incompatible with continuous northwesterly flow of surface water to form the cyclonic gyre.

Schumacher and Coachman (RU #141) have reported that sea level changes are related to pulses in the mean flow which may be caused by movement of water onto or off the shelf.

Studies of turbulent upwelling in the vicinity of Samalga Pass have been summarized by Kelley, Hood, Groves, and Longerich (1973). More recently, upwelling in this area has been reported by Swift and Aagaard (1976) during summer. The upwelled water is inferred from relatively saline water, poor in oxygen, and rich in nutrients and is apparently driven by subsurface convergence. Upwelling is also noted by Muench (RU #307) in the central Bristol Bay during summer. An obvious manifestation of upwelling in this case is noted to be the upward doming of isotherms and higher surface nitrate levels. A possible mechanism for such upwelling could be the bottom Ekman layer generated by the cyclonic circulation. An inward directed flow in this bottom layer would, by volume continuity, tend to force deep water toward the surface.

MASS DISTRIBUTION

Due to the complex and variable temperature and salinity structure, water masses in this area are not clearly defined, though attempts have been made by Kihara and Uda (1969, cited by Favorite, Dodimead, and Nasu 1974), Kitano (1970), and Takenouti and Ohtani (1974).

Schumacher and Coachman (RU #141) have considered Alaska Stream water and Bering Sea water as one water mass. Convective Area water (Shelf Water) is found on central shelf in a tongue-shaped extension from the northwest (Muench, RU #307).

Schumacher and Coachman (RU #141) have emphasized that boundaries and extent of these water masses vary greatly. They note that Alaska Stream water has, in some years, been found much farther in the bay and farther up on the shelf east of the Pribilof Islands than originally determined. The boundary between Convective Area water and Coastal Water is sharper and is located close to the 50 m depth contour. They also report that a frontal system between warmer and less saline coastal water and colder more saline water exists close to the 50 m depth contour (Fig. IV-1). Changes in its position were related to pulses in the mean flow regime (see following section on Currents).

CURRENTS

Information on currents in the Bristol Bay-St. George Island area is from deductions made from water mass distributions, current meter data, drift bottle release and recovery data, and from sea ice drift. Reported results are few and incomplete. In some instances conclusions about mean current speed or direction could not be deduced due to strong tidal signals. A general cyclonic circulation is recognized by most workers. As mentioned in the previous section, this circulation may not be in the form of a complete gyre. Hebard (1961) obtained

Along the coast and in the eastern part of the bay, suspended sediment has been observed to follow counterclockwise current pattern. It has also been noted that suspended material of marine origin is carried into Bristol Bay along with eastward flowing water on the northern coast of Alaska Peninsula (Feely and Cline, RU #152).

Data (September to November 1975) from two moored current meter arrays (BC-2A and BC-4A, Fig. IV-2) have been recorded and analyzed by Schumacher and Coachman (RU #141). Records were filtered to remove noise with 2.86 hr low-pass

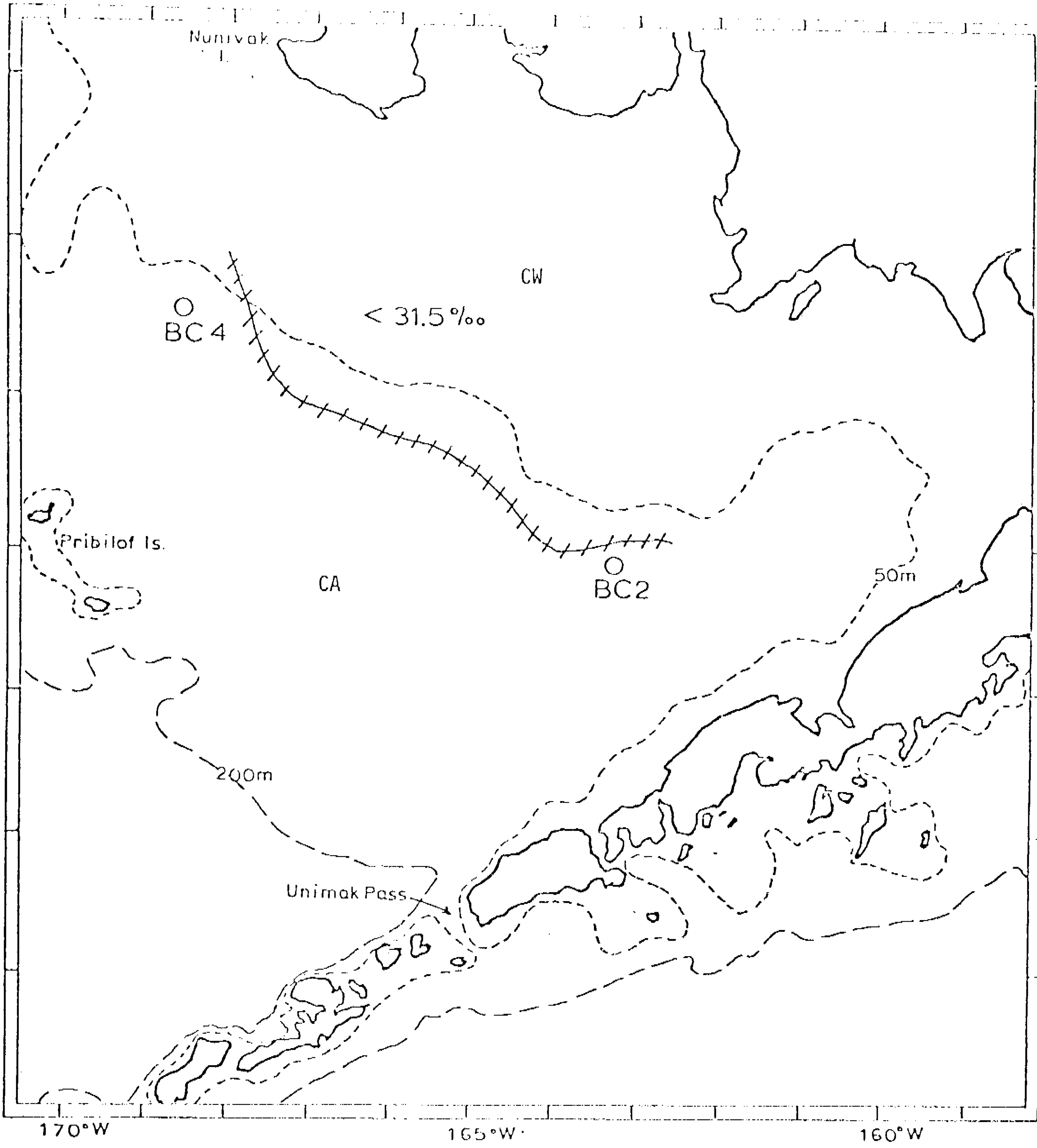

Fig. IV-1. Location of the frontal system defining the boundary between Coastal Water (CW) and Convective Area (CA) water, based on data from September 1975 (figure reproduced from Schumacher and Coachman, RU #141).

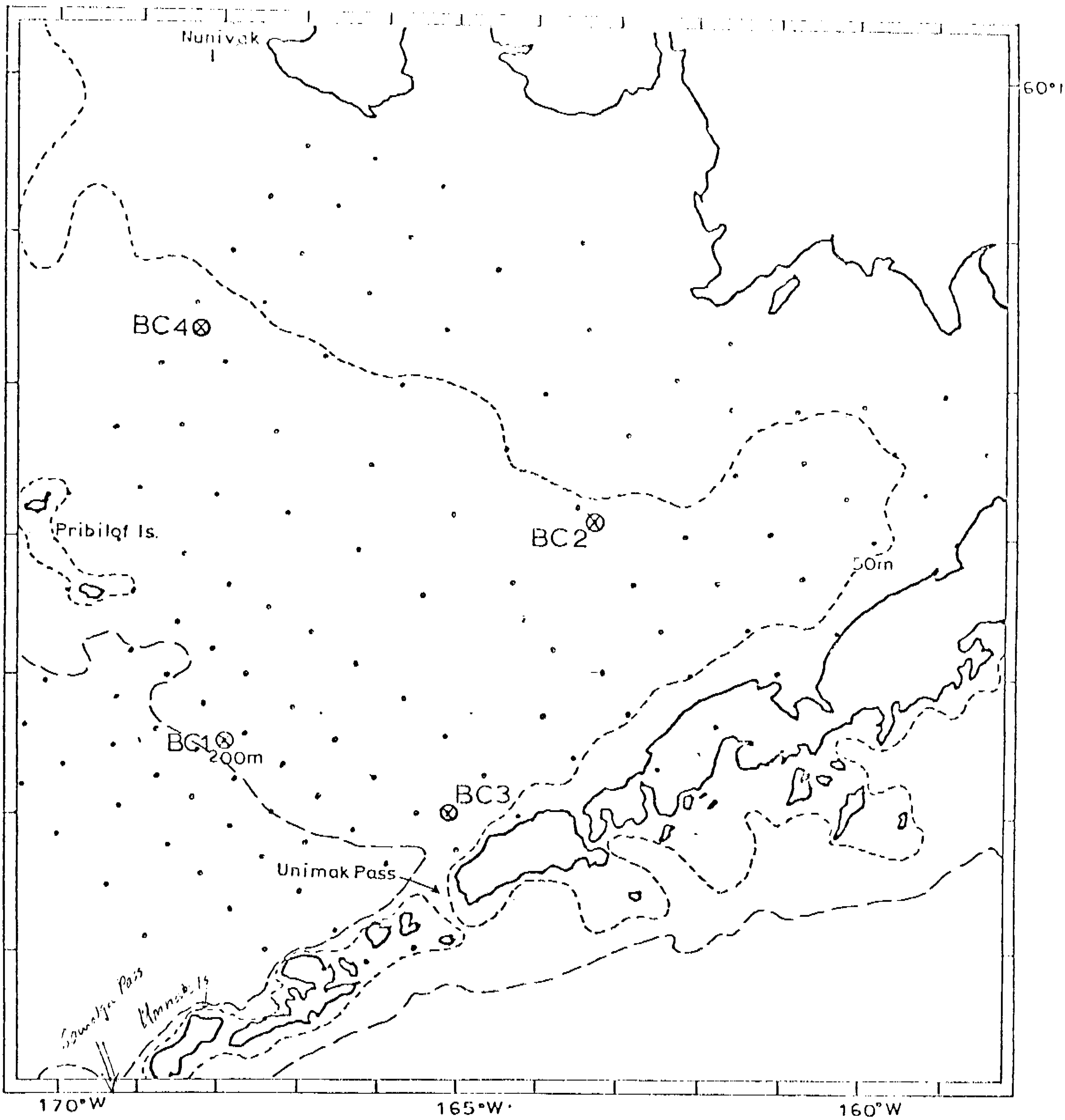

Fig. IV-2. Master CTD grid (·) and moored array locations (figure reproduced from Schumacher and Coachman, RU #141).

filters and 35 hr low-pass filters. The second filter essentially removes tidal and inertial effects and yields net flow. The 2.86 hr filtered data are used to construct the Progressive Vector Diagrams. Analysis of the 58 day current record indicated that in general flow was dominated by tidal activity and that there was only little residual mean flow. Observed mean flow values are as follows:

BC-2A:	20 m	0.60 cm/sec at 304°TN (WNW)
	50 m	0.95 cm/sec at 300°TN (WNW)
BC-4A	30 m	2.56 cm/sec at 297°TN (WNW)
	47 m	0.53 cm/sec at 206°TN (SSW)

It should be pointed out that the residual flow was highly variable but in general northwestern flow parallel to 50 m isopleth was noted. Most of the variance energy was found in tidal frequencies. At BC-2A at 20 m, total recorded variance (after 2.86 hr filtering) was 436.3 cm^2/sec^2, A tidal analysis program, based on harmonic constants measured at Dutch Harbor, generated a predicted tidal series containing a variance of 308.5 cm^2/sec^2, indicating that approximately 71% of variance in current record was due to tidal activity (Schumacher and Coachman, RU #141).

A major event in this area is the occurrence of pulses in the mean flow on which flow is raised from nearly zero to 30 cm/sec in about three days and then returns back to zero. Changes in relative sea level are also associated with it. There is evidence of two advective pulses from data from station BC-2A at 50 m. The Progressive Vector Diagram (Fig. IV-3) shows that the majority of motion is in fluctuating paths with only a few clear paths of activity. Two pulses in flow, one in the northerly and the other in northwesterly direction, are easily recognized. In both cases flow was in agreement with observed mean flow direction.

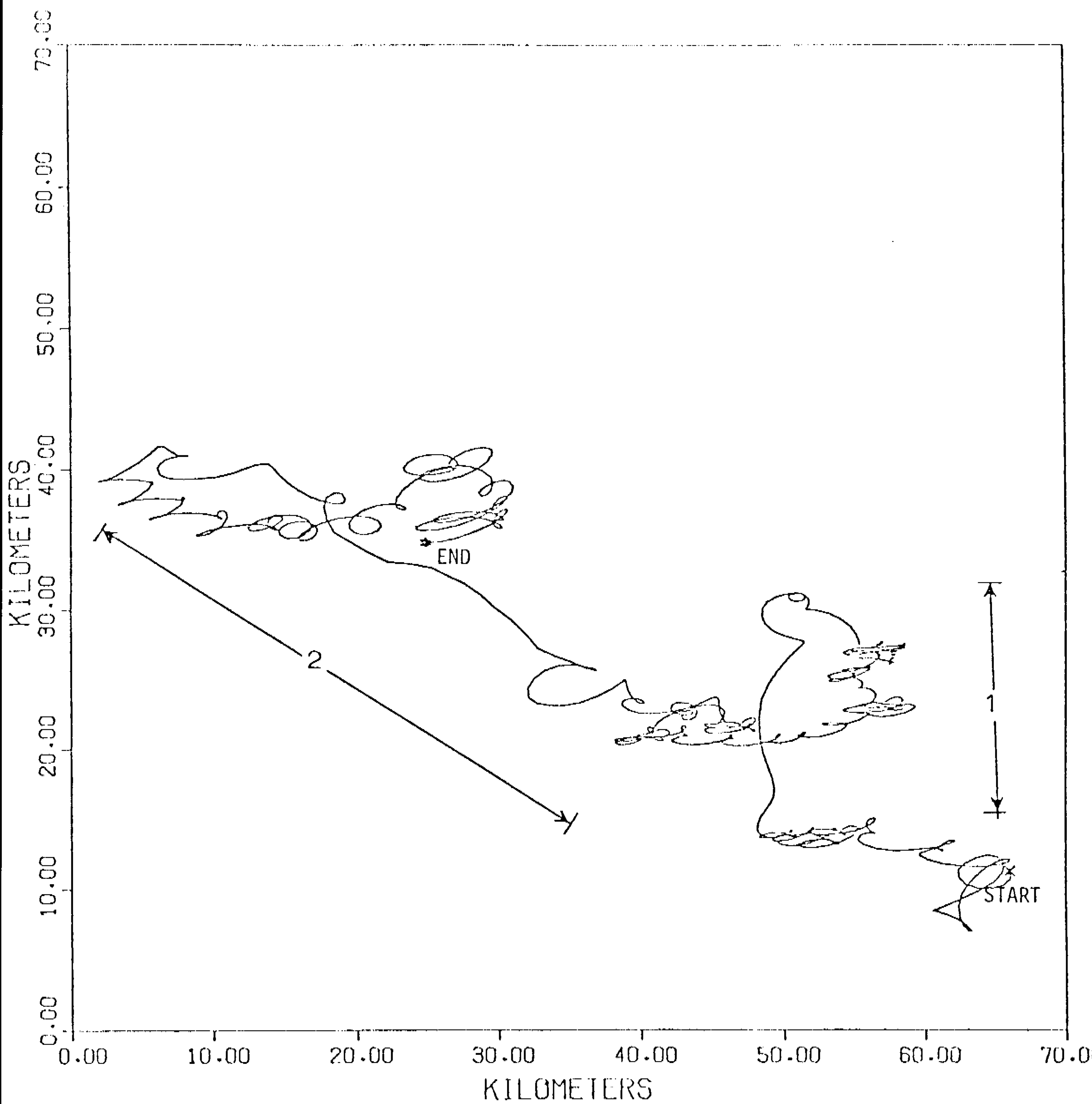

Fig. IV-3. Progressive Vector Diagram constructed from current meter records from 50 m at Station BC-2A. Two observed pulses (first in September and second in October 1975) in the mean flow are easily recognized (figure reproduced from Schumacher and Coachman, RU #141).

WAVES AND TIDES

No data on waves and tides have been reported from OCSEAP-sponsored research. Waves in this area appear to be locally formed although significant waves may be generated by local storms.

Tidal range in this area varies considerably; mean ranges from 0.6 to 5.6 m have been reported. Tidal currents are strong and dominate the current field. In Nushagak Bay tidal velocities as high as 125 cm/sec have been observed (US NOS data, cited by Feely and Cline, RU #152).

ICE

Ice Motion

Ice motion is determined by forces of wind (through air-ice stress), currents (through ice-water stress), internal ice stress (resistance of pack to motion within itself), pressure gradients (sea surface slope), and Coriolis effect. The combination of these forces generally leads to a complex resultant force on the ice sheet which cannot be totally predicted. Work of several investigators suggests, however, that ice motion is primarily determined by the wind stress (Markham, BSPTR #26; Konishi and Saito 1974). Ice floes in relatively open water (less than 4 oktas) will drift at 1% to 3% of mean windspeed and to the right of the wind direction in northern regions (Herlinveaux and deLange Boom, BSPTR #18). In the eastern Beaufort Sea, the mean ice drift angle, as determined by Landsat imagery, was 22° to the right of the wind direction and at 3% of the windspeed (Markham, BSPTR #26).

Surface winds in the Bering Sea are strongly influenced by the Aleutian low in winter. The resulting northerly and northeasterly winds tend to transport ice in southerly and westerly directions.

During late spring the Aleutian low is weakened and the winds become generally southerly, resulting in a northward movement of the pack ice (Dunbar 1966). Quite often compact pack ice belts under the influence of northerly airflow move southward into the St. George Basin relatively late in the melt season (konishi and Saito 1974).

Flow and Retention of Oil in Ice

Lewis (1976) offers findings that apply to ice of vertical crystal orientation, while Martin (RU #87) is studying the movement of oil through grease and pancake ice which have horizontal crystal orientation and are found in the Bristol Bay-St. George Basin area. According to Martin, oil released under grease and slush ice (approximately 40% ice adn 60% seawater and which may grow to a thickness of 100 cm in the Bering Sea) comes rapidly to the surface. Furthermore, preliminary experimental results suggest that most of the oil released under a field of pancake ice comes to the surface through the spaces between the cakes, where the oscillatory motion of the pancakes pumps the oil away from the spill site.

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Chapter V

RECEPTORS

FISH

This section summarizes the field sampling programs and historical data analysis relating to fish, conducted under NOAA/OCSEAP sponsorship. Pereyra et al. (RU #175) and Smith (RU #284) are engaged in analyzing field collection of the demersal fish resource. Emphasis by these investigators has been on the spatial and temporal distribution and feeding habits of the commercially important species caught in the Bering Sea. Jackson and Warner (RU #19) are cataloging osmerid and clupeid spawning habitats and the abundance of spawners throughout the eastern Bering Sea. Taxonomic keys are being prepared by English (RU #349) and Morrow (RU #285) from field collected specimens, including ichthyoplankton, and museum collections. All of these investigators are compiling literature pertinent to demersal fish in the Bering Sea and Gulf of Alaska. Much of the research effort is in the initial phase with little data reported at this time.

From preliminary species lists in the principle investigator annual reports and the International Symposium for Bering Sea Study (Hood and Kelley 1974) a preliminary species list has been compiled for the Bristol Bay and St. George Basin areas. Twenty-nine families and 96 species have been compiled (Table V-1).

TABLE V-1

Fish of Bristol Bay and St. George Basin

Family and Species	Common Name
Clupeidae	
Clupea harengus pallasi Valenciennes	Pacific herring
Salmonidae	
Oncorhynchus gorbuscha (Walbaum)	Pink salmon
O. keta (Walbaum)	Chum salmon
O. kisutch (Walbaum)	Coho salmon
O. nerka (Walbaum)	Sockeye salmon
O. tschawytscha (Walbaum)	Chinook salmon
Salmo gairdneri Richardson	Rainbow trout
Salvelinus malma (Walbaum)	Dolly varden
S. alpinus (Linnaeus)	Arctic char
Thymallus arcticus (Pallas)	Arctic grayling
Gadidae	
Gadus macrocephalus Tilesius	Pacific cod
Microgadus proximus (Girard)	Pacific tomcod
Theragra chalcogramma (Pallas)	Walleye pollock
Anoplopomatidae	
Anoplopoma fimbria (Pallas)	Sablefish
Pleuronectidae	
Atheresthes evermanni Jordan and Starks	Kamchatka flounder
A. stomias (Jordan and Gilbert)	Arrowtooth flounder
Eopsetta jordani (Lockington)	Petrale sole
Glyptocephalus zachirus Lockington	Rex sole
Hippoglossoides elassodon Jordan and Gilbert	Flathead sole
H. robustus Gill and Townsend	Bering flounder
Hippoglossus stenolepis Schmidt	Pacific halibut
Lepidopsetta bilineata (Ayres)	Rock sole
Limanda aspera (Pallas)	Yellowfin sole
Microstomus pacificus (Lockington)	Dover sole
Platichthys stellatus (Pallas)	Starry flounder
Pleuronectes quadrituberculatus Pallas	Alaska plaice
Psettichthys melanostictus Girard	Sand sole
Reinhardtius hippoglossoides (Walbaum)	Greenland halibut
Scorpaenidae	
Sabastes alutus (Gilbert)	Pacific ocean perch
S. brevispinis (Bean)	Silvergray rockfish

TABLE V-1 (continued)

Family and Species	Common Name
S. ciliatus (Tilesius)	Dusky rockfish
S. crameri (Jordan)	Darkblotched rockfish
S. mystinus (Jordan and Gilbert)	Blue rockfish
S. proriger (Jordan and Gilbert)	Redstripe rockfish
Bothidae	
Citharichthys sordidus (Girard)	Pacific sanddab
Osmeridae	
Mallotus villosus (Müller)	Capelin
Osmerus mordax (Mitchill)	Rainbow smelt
Thaleichthys pacificus (Richardson)	Eulachon
Cottidae	
Blepsias bilobus Cuvier	Crested sculpin
Dasycottus setiger Bean	Spinyhead sculpin
Enophrys diceraus (Pallas)	Antlered sculpin
Hemilepidotus hemilepidotus (Tilesius)	Red Irish lord
H. spinosus (Ayres)	Brown Irish lord
Hemitripterus bolini (Myers)	Bigmouth sculpin
Icelinus borealis Gilbert	Northern sculpin
Icelus spiniger Gilbert	Thorny sculpin
Myoxocephalus polyacanthocephalus (Pallas)	Great sculpin
Nautichthys pribilovius (Jordan and Gilbert)	Eyeshade sculpin
Psychrolutes paradoxus Günther	Tadpole sculpin
Triglops macellus (Bean)	Roughspine sculpin
T. pingeli Reinhardt	Ribbed sculpin
Agonidae	
Agonus acipenserinus Tilesius	Sturgeon poacher
Asterotheca alascana (Gilbert)	Gray starsnout
A. infraspinata (Gilbert)	Spinycheek starsnout
Bathyagonus nigripinnus Gilbert	Blackfin poacher
Hypsagonus quadricornis (Cuvier)	Fourhorn poacher
Bathylagidae	
Bathylagus stilbius (Gilbert)	California smoothtongue
Myctophidae	
Stenobrachius leucosparus (Eigenmann & Eigenmann)	Northern lampfish
Symbolophorus californiense (Eigenmann & Eigenmann)	Bigfin lanternfish

TABLE V-1 (continued)

Family Species	Common Name
Chauliodontidae	
Chauliodus macouni Bean	Pacific viperfish
Anarhichadidae	
Anarhichas orientalis Pallas	Bering wolffish
Hexagrammidae	
Hexagrammos lagocephalus (Pallas)	Rock greenling
H. stelleri Tilesius	Whitespotted greenling
Pleurogrammus monopterygius (Pallas)	Atka mackerel
Zoarcidae	
Bothrocara brunneum (Bean)	Twoline eelpout
B. molle Bean	Soft eelpout
Lycodes brevipes Bean	Shortfin eelpout
L. diapterus Gilbert	Black eelpout
L. palearis Gilbert	Wattled eelpout
Trichodontidae	
Trichodon trichodon (Tilesius)	Pacific sandfish
Bathymasteridae	
Bathymaster signatus Cope	Searcher
Ronquilus jordani (Gilbert)	Northern ronquil
Stichaeidae	
Acantholumpenus mackayi (Gilbert)	Pighead prickleback
Alectridium aurantiacum Gilbert and Burke	Lesser prickleback
Bryozoichthys lysimus (Jordan and Snyder)	Nutcracker prickleback
Gymnoclinus cristulatus Gilbert and Burke	Trident prickleback
Lumpenus maculatus (Fries)	Daubed shanny
L. sagitta Wilimovsky	Snake prickleback
Phytichthys chirus (Jordan and Gilbert)	Ribbon prickleback
Poroclinus rothrocki Bean	Whitebarred prickleback
Stichaeus punctatus (Fabricius)	Arctic shanny
Pholidae	
Pholis laeta (Cope)	Crescent gunnel
P. ornata (Girard)	Saddleback gunnel

TABLE V-1 (continued)

Family Species	Common Name
Cryptacanthodidae	
Delolepis gigantea Kittlitz	Giant wrymouth
Lyconectes aleutensis Gilbert	Dwarf wrymouth
Ammodytidae	
Ammodytes hexapterus Pallas	Pacific sand lance
Notacanthidae	
Macdonaldia challengeri (Valliant)	Longnose tapirfish
Ptilichthyidae	
Ptilichthys goodei Bean	Quillfish
Bramidae	
Brama japonica Hilgendorf	Pacific pomfret
Cyclopteridae	
Aptocyclus ventricosus (Pallas)	Smooth lumpsucker
Eumicrotremus orbis (Günther)	Pacific spiny lumpsucker
Liparis sp.	Snailfish
Melamphaeidae	
Melamphaes lugubris Gilbert	Highsnout melamphid
Lamnidae	
Lamna ditropis Hubbs and Follett	Salmon shark
Squalidae	
Squalus acanthias Linnaeus	Spiny dogfish

To this number can be added the seasonal influx of massive numbers of salmonids, i.e., Oncorhynchus soo, Mallotus sp, and Osmerus sp, and clupeids migrating to and from nearshore spawning and nursery areas to the pelagic regions of the open sea. Even though some of these species and the bathypelagic forms spend much of their life history on/or near the bottom, many have near-surface dwelling larvae and/or developing eggs.

Species belonging to the families, cottidae, liparidae, stichaeidae, pleuronectidae, zoarcidae, agonidae, scorpaenidae, and salmonidae, represent 73% of the total number of species reported in the Bering Sea (Wilimovsky 1974). Wilimovsky also noted that the Bering Sea fauna is unique in having a higher proportion of cottids and liparids than any other sea in the world. This highly productive shelf area of the eastern Bering Sea is also unique in that the world's largest sockeye salmon runs occur in Bristol Bay.

It should also be noted that unique areas, in terms of fish life histories, exist in the area of the proposed petroleum lease sales. The major outmigration route for sockeye lies along the north shore of the Alaska Peninsula from the head of Bristol Bay to Port Moller. Sockeye spawners enter the parent streams through the central and along the north coast of the bay. Major concentrations of demersal species are located in the central Bristol Basin, north of Unimak Island and east and south of the Pribilof Islands. The southeast Bering Sea is a major wintering and feeding area for halibut and Flathead sole. Osmerids spawn throughout the sandy beach system of the north coast of the Alaska Peninsula into Bristol Bay. Herring primarily spawn in the Togiak Bay area.

A summation of the state of knowledge, by species, follows. Species selection was based on available data and commercial significance. The preliminary evidence compiled in the OCSEAP-funded programs has been integrated with data presented by Hart (1973) and Hood and Kelley (1974). Additional species-specific data have been discussed in detail in the KODIAK ISLAND-Sources section of this report.

Clupeidae

Clupea harengus pallasi, Pacific herring

Herring occur in the coastal zone from Baja, California into the Bering Sea; catches have also been recorded in the Chukchi and Beaufort Seas.

Togiak, Bechevin, and Herendeen Bays are the principal spawning areas for herring within the southeastern Bering Sea (Jackson and Warner, RU #19). Jackson and Warner reported that much of the beach system along the Alaska Peninsula and throughout Bristol Bay is inadequate for herring spawning. These beaches are generally sandy with little rock and vegetation.

Additional species-specific data have been discussed in the KODIAK ISLAND-Source section of this report.

Salmonidae

Oncorhynchus nerka, Sockeye salmon

Sockeye or Red salmon range from northern California to Kotzebue Sound in the Chukchi Sea and throughout the Aleutian Islands. This species is most abundant north of the Columbia River, with the largest spawning runs in the world occurring in Bristol Bay. Sockeye are limited to spawning streams that include a lake in their system. Long spawning migrations up the parent river through lakes are common, with spawning occurring in streams above the lakes. Sockey spawners enter Bristol Bay moving rapidly through the surface water to the home stream. Spawners reporedly migrate at about 30 nautical mi per day and feed excessively as they move toward the spawning stream. Much of the run passes into the freshwater streams within one week.

Outmigrating sockeye are commonly found east of Port Heiden from late May to early August. After early August most outmigrants have passed Port Heiden and are most abundant near Port Moller.

Other research on sockey has been done by Nishiyama (1974), Bakkala (1969), and Straty (1974).

Gadidae

Theragra chalcogramma, Walleye pollock

Pollock occur throughout the North Pacific from central California to St. Lawrence Island in the Bering Sea. Preliminary catch statistics (Pereyra et al., RU #175) indicate that this is the most abundant commercially caught demersal fish in the eastern Bering Sea (Table V-2). Pollock are most abundant throughout the outer shelf and slope areas with trawl catches averaging 469 lbs per 0.5 hr northwest of the Pribilof Islands, and 1,197 pbs per 0.5 hr southeast of this island group; up to 9,300 lbs per 0.5 hr were recorded southeast of the Pribilof Islands and west and south of St. Matthew Island (Fig. V-1).

Additional species-specific data have been discussed in the KODIAK ISLAND-Sources section of this report.

Pleuronectidae

Hippoglossus elassodon, Flathead sole

Smith (RU #284) reports that sole feeding in the Bering Sea varies seasonally and geographically. He found that feeding is least intensive during winter, based on the percentage of empty stomachs. Sole feed intensively in the southeast Bering Sea; however, feeding was considerably reduced in the central Bering Sea. Food items, in declining frequency of occurrence, include ophiuroids, shrimp, amphipods, fish and molluscs. Smith also noted that the prey preference changes from echinoderms and shrimp to amphipods, euphausiids, and chaetognaths as this species moves from its southern wintering grounds in the Bering Sea. It appears that the southeastern Bering Sea feeding areas and the summer season are the critical areas and period in the life of Flathead sole.

Additional species-specific data have been discussed in the KODIAK ISLAND-Sources section of this report.

TABLE V-2

Summary of Catches by Sub-area of the Principal Commercial Species of Crab and Groundfish Taken During the BLM-MARMAP Trawl Survey in the Eastern Bering Sea* (from Pereyra et al., RU #175)

Species rank	Occurrence in hauls Percent	Average catch per 30-min. tow	Species rank	Occurrence in hauls Percent	Average catch per 30-min. tow
NORTHWESTERN SUB-AREA Depth range 29-240 fathoms Total hauls 205			NORTHEASTERN SUB-AREA Depth range 13-57 fathoms Total hauls 133		
Groundfish		Pounds	Groundfish		Pounds
Pollock	97	469	Yellowfin sole	95	253
Greenland turbot	92	69	Alaska plaice	87	64
Flathead sole	92	23	Pollock	83	127
Pacific cod	63	28	Greenland turbot	74	12
Rock sole	53	8	Rock sole	71	22
Arrowtooth flounder	20	3	Pacific cod	32	2
Yellowfin sole	20	3	Flathead sole	25	5
Alaska plaice	7	< 1	Arrowtooth flounder	2	< 1
Pacific ocean perch	3	< 1	Blackcod	0	--
Blackcod	1	< 1	Pacific ocean perch	0	--
Crabs			Crabs		
Tanner crab	98	140	Tanner crab	65	84
King crab	21	4	King crab	15	3
SOUTHWESTERN SUB-AREA Depth range 42-210 fathoms Total hauls 93			SOUTHEASTERN SUB-AREA Depth range 15-52 fathoms Total hauls 113		
Groundfish		Pounds	Groundfish		Pounds
Pollock	97	1,197	Yellowfin sole	100	715
Flathead sole	95	94	Rock sole	94	79
Arrowtooth flounder	92	32	Pollock	84	58
Pacific cod	87	47	Pacific cod	65	7
Greenland turbot	76	16	Alaska plaice	59	24
Rock sole	53	43	Flathead sole	58	11
Yellowfin sole	41	78	Greenland turbot	55	5
Alaska plaice	27	7	Arrowtooth flounder	13	1
Pacific ocean perch	11	2	Blackcod	2	< 1
Blackcod	6	< 1	Pacific ocean perch	0	--
Crabs			Crabs		
Tanner crab	96	97	King crab	81	128
King crab	41	53	Tanner crab	64	56

*Figures are preliminary and subject to correction.

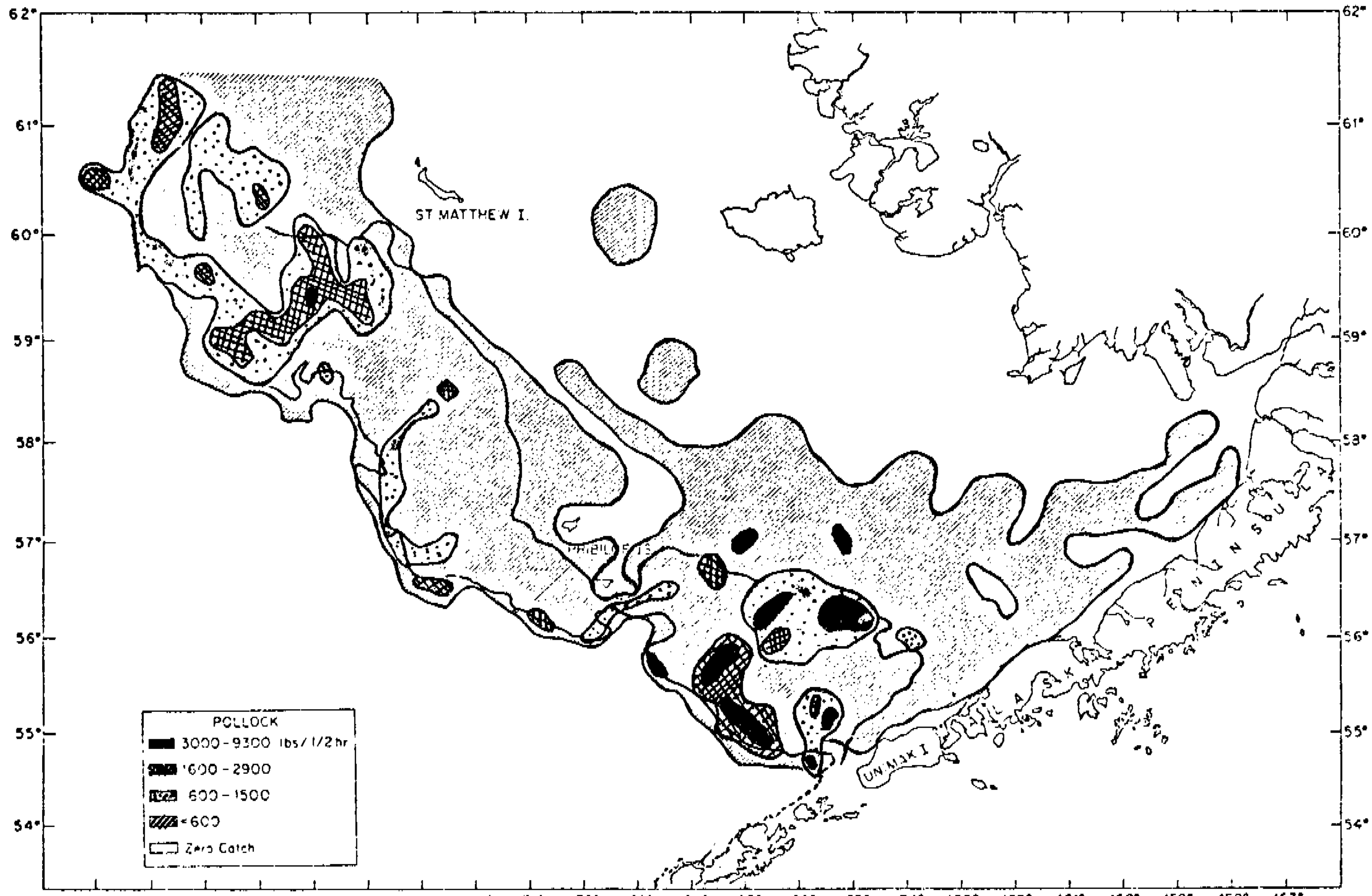


Fig. V-1. Distribution and apparent abundance of pollock in the eastern Bering Sea, August to October 1975 (from Pereyra et al., RU #175).

Hippoglossus stenolepis, Pacific halibut

Smith (RU #284) has illustrated the migratory habits of halibut (Fig. V-2). During winter this species is most abundant in the outer shelf and slope areas between the Pribilof Islands and the Aleutian chain. In May, the principal migratory route leads the fish into Bristol Bay; some also move north and are located east of the Pribilof Islands. As summer progresses, halibut are located throught the shelf areas of Bristol and St. George Basins. Before the southerly, winter migration begins, this flatfish moves north to St. Lawrence Island. These migrations may be in response to spawning, feeding, and seasonal temperature changes.

Additional species-specific information can be found in the KODIAK ISLAND-Sources section of this report.

Lepidosetta bilineata, Rock sole

Rock sole are common throughout the southern Bering Sea; however, the two commercially exploited populations are located north of Unimak Island and in central Bristol Bay (Smith, RU #284).

Additional evidence on feeding habits of this species in the Bering Sea has been discussed in the KODIAK ISLAND-Sources section of this report. Other species-specific data are also contained in this section.

Limanda aspera, Yellowfin sole

Yellowfin sole range from southern British Columbia to the Chukchi Sea, but are not common from Hecate Strait to Kodiak Island. This is the dominant flatfish in the Bering Sea and has been collected by Pereyra et al. (RU #175) throughout much of the eastern shelf area (Fig. V-3). Sole are most abundant in the shallower shelf areas, with trawl catches averaging 253 lbs per 0.5 hr

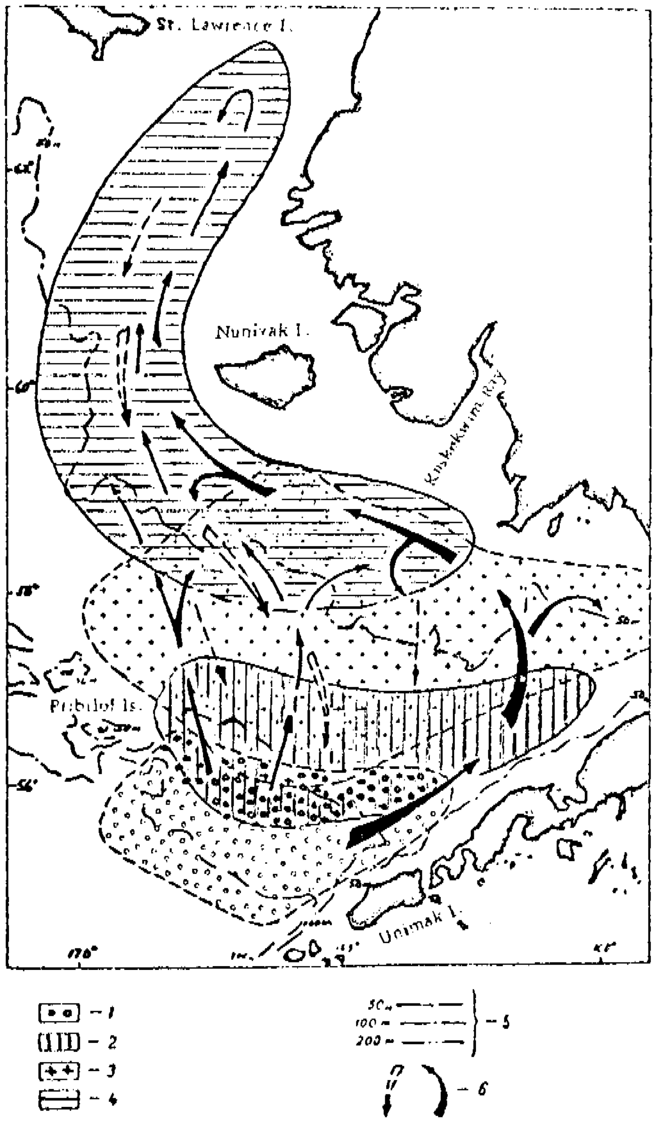


Fig. V-2. Diagram of the seasonal distribution and migration of the halibut in the southeastern Bering Sea:

1 - January to April; 2 - May; 3 - June; 4 - June to September; 5 - isobaths; 6 - direction of migrations

(from Smith, RU #284)

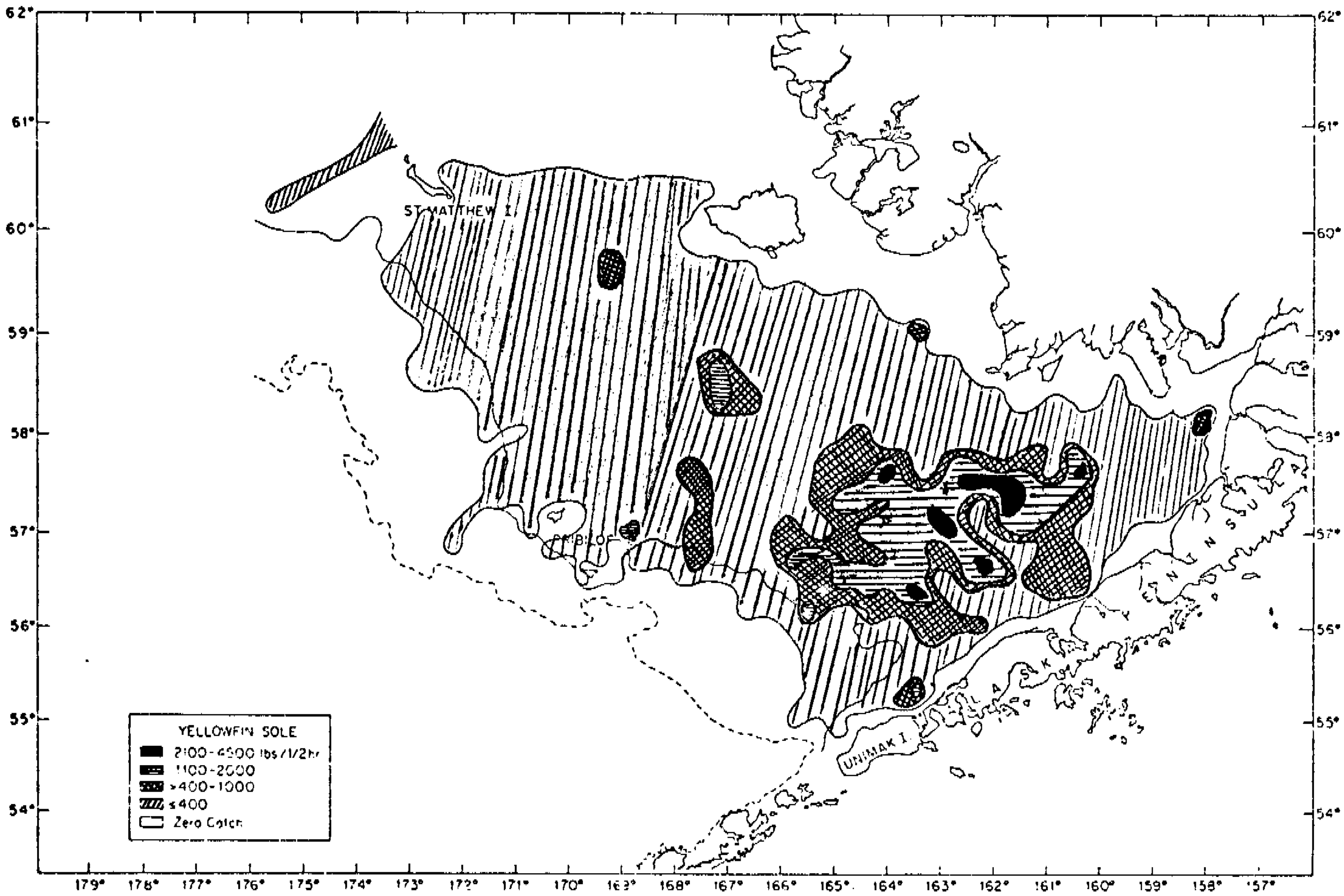


Fig. V-3. Distribution and apparent abundance of Yellowfin sole in the eastern Bering Sea, August to October 1975 (from Pereyra et al., RU #175).

in the north-central region of Bristol Bay, and 715 lbs per 0.5 hr in the inner Bristol Bay and along the north coast of the Alaska Peninsula. Pereyra et al. (RU #175) made catches of up to 4,500 lbs per 0.5 hr trawl in pockets north of Unimak Island and in central Bristol Bay (Fig. V-3).

Little is known about the life history and food habits of this species (Hart 1973). Hydroids, worms, molluscs, and brittle stars have been collected from stomachs of this species.

Scorpaenidae

Sebastes alutus, Pacific ocean perch

Ocean perch population aggregates show marked seasonal changes in geographic distribution and predatory habits (Smith, RU #284). In the Bering Sea, from January to May, this species forms dense concentrations of adults in Bristol Bay and south of the Pribilof Islands. During the remainder of the year major concentrations are found well into the central Bristol Bay region.

Feeding habits of perch in the Bering Sea varies with: (1) depth at which the fish is located and (2) the fish size. Smith (RU #284) reported that perch on the shelf feed mainly on calanoid copepods; euphausiids are primary food organisms in the slope area (200 to 300 m). At depths below 300 m this epibenthic species feeds mainly on mysids and squid

It was also noted by Smith (RU #284) that Pacific ocean perch is a declining species, suggesting that unregulated commercial fishing or major environmental perturbations could endanger this demersal resource.

Other species-specific characteristics of perch have been discussed in the KODIAK ISLAND-Sources section of this report.

Osmerids

Osmerids occur from the Demarcation Point throughout the Aleutian Islands. Jackson and Warner (RU #19) report that large numbers of Capelin (Mallotus villosus) spawn along the Alaska Peninsula from Moffett Point to Port Heiden. Their findings indicate that the sandy beaches along the north coast of the peninsula are favorable for osmerid spawning. It is suspected that Capelin also spawn from Urilia Bay on into Bristol Bay.

The most frequently occurring species collected by Pereyra at al. (RU #175) were generally those of commercial importance. These investigators found that Walleye pollock (Theragra chalcogramma) was the most abundant of the demersal species (Fig. V-4), followed in order of abundance by Yellowfin sole (Limanda aspera), Rock sole (Lepidopsetta bilineata), Greenland turbot (Reinhardtius hippoglossoides), Flathead sole (Hippoglossoides elassodon), and Pacific cod (Gadus macrocephalus). Other species collected in lesser abundance were Alaska plaice (Pleuronectes quadretuberculatus), Arrowtooth flounder (Atheresthes stomias), Pacific ocean perch (Sebastes alutus), and Blackcod (Anoplopoma fimbria). Greenland turbot, Walleye pollock, Flathead sole, Pacific cod, and Arrowtooth flounder were more frequently collected in the deeper outer shelf regions; whereas, Alaska plaice, Yellowfin sole, and Rock sole were collected most frequently in shallower areas (Table V-3).

Commercial Catch

Commercial catch statistics indicate that the fishery resource is being exploited more each year. Some statistics are provided by Wilimovsky 1974. The projected harvest of ground fish in 1975 was 1.6×10^6 metric (Table V-4). It is of note that the estimated sustained yield was 1.3×10^6 metric tons.

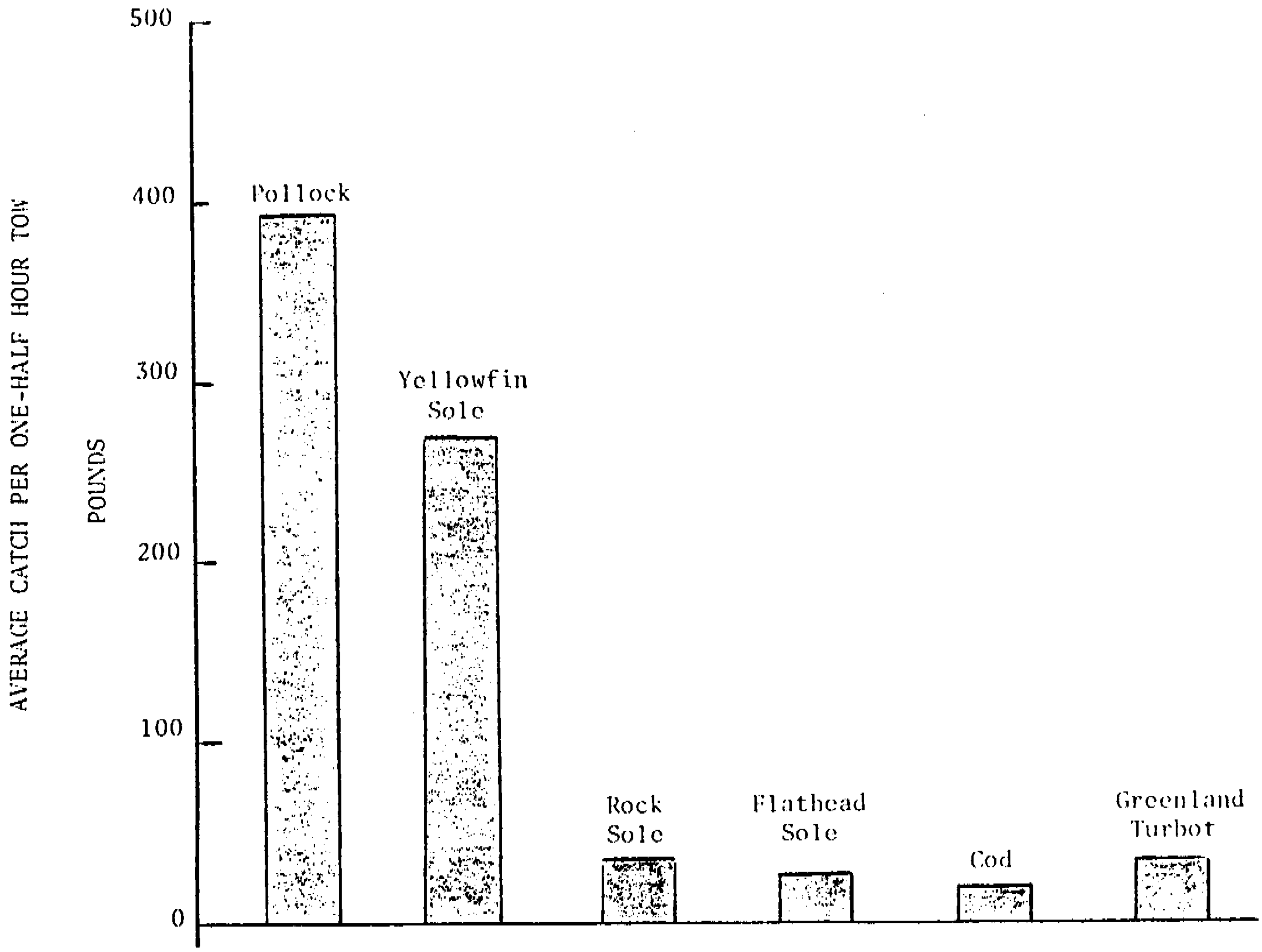


Fig. V-4. Average catch per one-half hour tow of the most freqently encountered species of demersal fishes occurring in the survey area (all subareas combined) August to October 1975 (from Pereyra et al., RU #175).

TABLE V-3

Percent Frequency of Occurrence of Principal Species Taken in Trawls From Deep and Shallow Shelf Areas (from Pereyra et al., RU #175)

Species	Deep Shelf Areas (II)	Deep Shelf Areas (III)	Shallow Shelf Areas (I)	Shallow Shelf Areas (IV)
Pollock	97	97	83	84
Greenland turbot	92	76	74	55
Flathead sole	92	95	25	58
Pacific cod	63	87	32	65
Rock sole	53	53	71	94
Yellowfin sole	20	41	95	100
Alaska plaice	7	27	87	59

TABLE V-4

Expected Fisheries Catch in the Eastern Bering Sea and Aleutians in 1975
(thousand of metric tons)*
(from Favorite and McAlister, RU #77)

Country	Pollock	Pacific Ocean perch	Yellowfin Sole and other	Herring	Totals
Japan	1,100	11	214	18	1,343
USSR	210	148	---	30	383
Other	3	---	---	--	3
Total	1,313	159	214	48	1,734
Estimated Sustainable Yield	1,000	350		40	1,390

*Letter October 17, 1975, Dr. D. L. Alverson to Hon. Mike Gravel, U.S. Senate.

From these data it can be calculated that if the estimated yield was similar from 1969 to 1975, the commercial catch would have depleted this resource at a rate of 0.3 to 2.7 x 10^6 metric tons per year.

In addition to this catch, 48,000 metric tons of herring were expected to be taken in 1975. Most of these fish are caught by foreign fishing interests or by U.S. vessels for sale to foreign markets. The U.S. fishing industry concentrates on salmon and halibut in the Bering Sea. For the period 1969 to 1973 the commercial salmon catch was 261.0 x 10^6 lbs (R. Engelmann, pers. commun. 1976).

Favorite and McAlister (RU #77) also report that marine birds and mammals consume approximately 17% of the finfish stock in the eastern Bering Sea (Table V-5). Their data also show that when combined with the estimated commercial catch, 27% of the estimated stock of finfish are consumed. Man, birds, and mammals utilize comparable species, i.e., Walleye pollock, Yellowfin sole, salmon, halibut, herring, and Greenland turbot. Since it is now known as to which species were categorized in the estimated stock of finfish, the value may be misleading.

TABLE V-5

Consumption of Fish in the Eastern Bering Sea and Aleutian Areas
(from Favorite and McAlister, RU #77)

	Thousands of Metric Tons
Estimated finfish consumed by fur seals	439
Estimated finfish consumed by other pinnipeds	2,414
Estimated finfish consumed by sea birds*	50
Estimated vertebrate predation	2,903
Estimated 1975 catch by commercial fishery	1,734
Estimated total catch plus vertebrate predation	4,637
Estimated stock of all finfish†	17,000
Percent standing stock annually consumed by man and other vertebrates--approximate	27%
Percent consumed by fur seals--approximate	3%
Percent consumed by marine mammals and birds--approximate	17%
Percent consumed by fisheries--approximate	10%

*From Sanger 1974, cited by Favorite and McAlister.

†From Pruter 1973, cited by Favorite and McAlister.

BENTHOS

Introduction

The southeast Bering Sea, particularly the estuarine shallows of Bristol Bay (National Estuary Study 1970), is widely known for its high biological productivity. Seabirds, shorebirds, waterfowl, and marine mammals all abound (Arneson, RU #3; Hickey, RU #38; Favorite and McAlister, RU #77; Guzman, RU #239), and regional demersal fish and shellfish resources have supported an intensive foreign fishery since the mid-1950's (Wilimovsky 1974; Pereyra et al., RU #175). Nevertheless, present knowledge of intertidal and benthic organisms within the southeast Bering Sea remains relatively limited.

Intertidal Biota

Intertidal biotas are frequently abundant and rich in species. Many of their component organisms are sessile and thus unable to avoid possible adverse impacts of ocean-borne pollutants. In some cases such biotas include commercially important species, while in others their components provide important links in food webs supporting marine fish, birds, and mammals. Meaningful assessment of possible adverse impacts upon these biotas -- related to OCS development or accidental oil spills -- cannot proceed until the composition, abundance, natural variability, and ecological interrlationships of the biotas are known. Little such data are presently available for the Bering Sea coast.

This situation is presently being remedied by Zimmerman and Merrell (RU #78, #79), who are conducting an extensive baseline characterization of the littoral biota of the Bristol Bay-Alaska Peninsula region. Their two principal objectives are: (1) to determine the distribution of different habitat types along the coast and (2) to identify and quantify the various species populations that characterize the different habitat types. The first task is being accomplished through detailed aerial reconnaissance of the coastal zone. The results of this habitat survey will be compiled into atlas form using the format illustrated in Fig. V-5. It is presently anticipated that this atlas will become available at the end of 1976.

Data describing the occurrence and density of plants and animals within the different intertidal habitat types are being collected from selected sites around the southeast Bering Sea (Fig. V-6). Table V-6 records the distribution and numbers of quantitative samples collected during the 1974-75 field season. Sorting of these samples necessarily proceeds slowly and to date no results are available.*

Zimmerman and Merrell (RU #78, #79) have advanced the following tentative, but highly significant, conclusions based upon their field observations and preliminary sample analyses:

1. Along the shores of the southern Bering Sea, rocky intertidal areas yield more species and biomass than do sand or mud substrates. Because of the effects of ice scour, this does not appear to be true in the northern Bering Sea.

2. In the Pribilof Islands and at Cape Pierce in northern Bristol Bay (Fig. V-6). rocky shores were almost bare 60 cm or more above MLLW -- except for scattered algae (*Fucus* and *Halosaccion*) and small numbers of littorine snails. The lower intertidal and subtidal zones in these areas yielded a lush biota more comparable with that of rocky shores further south.

3. The biota of the Pribilof Islands region is of particular significance for it includes several previously undescribed organisms not found elsewhere in western North America. (A partial listing of the Pribilof Island biota is provided in Table V-7.) Whether these unique species are derived from Asian sources or are endemic to the Pribilofs is not yet known; however, Zimmerman and Merrell (RU #78, #79) conclude that:

*RU #78, #79 also include studies of the Gulf of Alaska; these are considerably more advanced with 200 sample analyses already published.

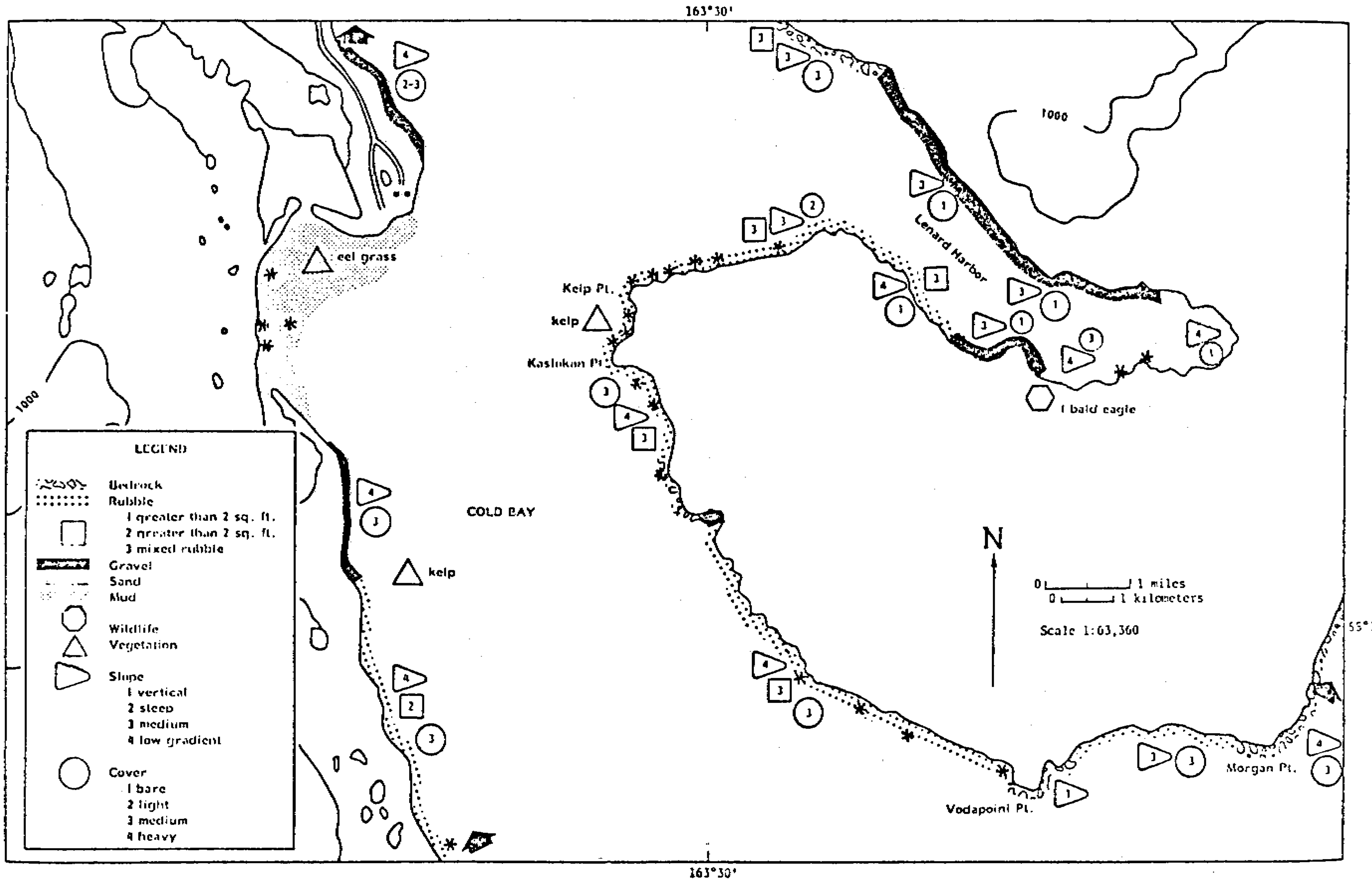


Fig. V-5. Prototype diagram used to represent results of the aerial reconnaissance of aerial habitats (Zimmerman and Merrell, RU #78,79).

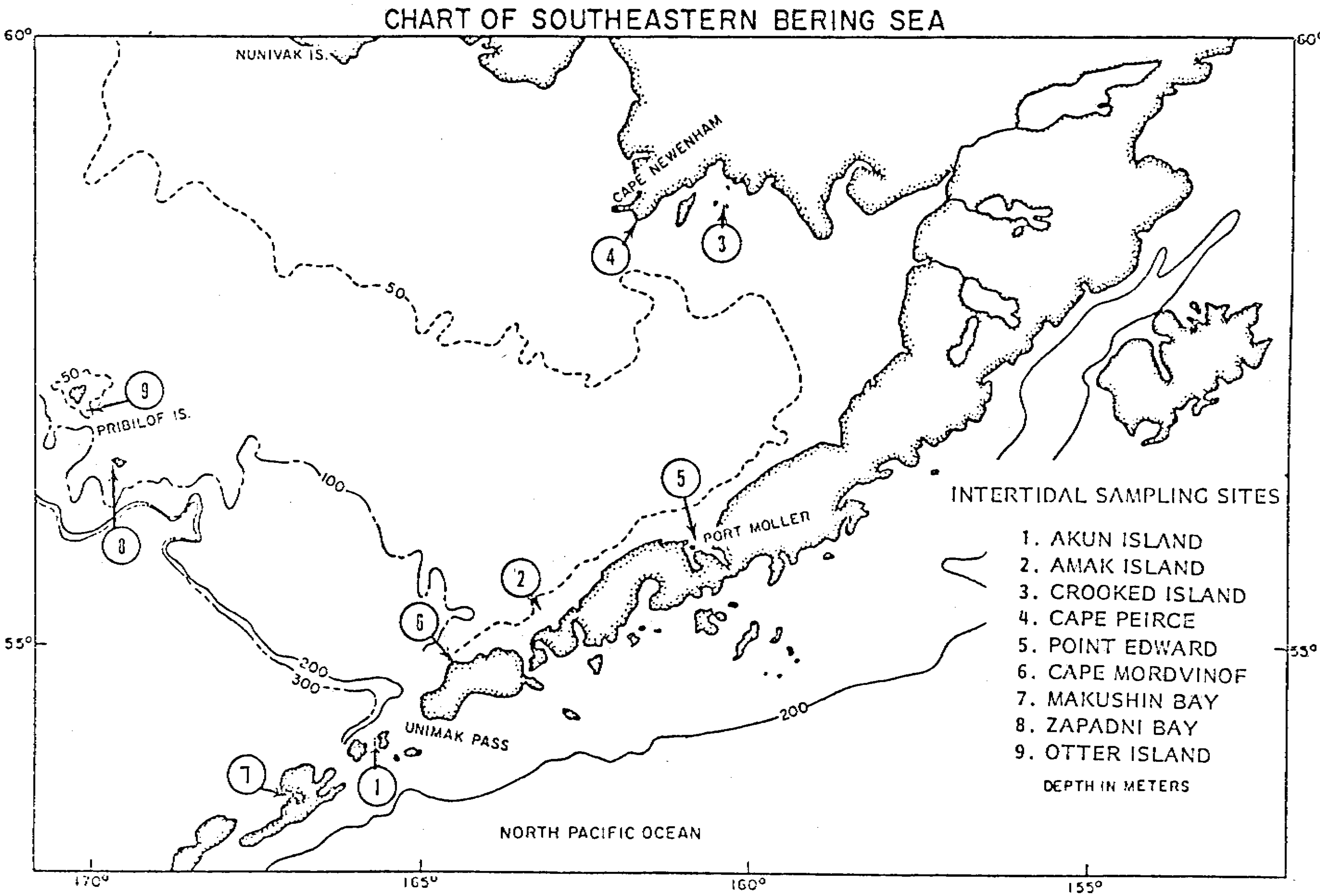


Fig. V-6. Intertidal study sites in the Bering Sea (Zimmerman and Merrell, RU #78,79).

TABLE V-6

Quantitative Intertidal Samples Collected from the Southeast Bering Sea in 1974-75
(Zimmerman and Merrell, RU #78,79)

Region	Location	Rocky								Muddy								Sandy						
		Fall 74	April 75	May	June	July	August	August	September	Fall 74	April 75	May	June	July	August	August	September	Fall 74	April 75	May	June	July	August	September
Unalaska-Kvichak Bay																								
	Akun Island					28																		
	Amak Island					20																		
	Crooked Island					17																		
	Cape Pierce					17																		
	Point Edward													38										
	Port Moller													6								4		
	Cape Mordvinof					12																		
	Makushin Bay					23		21																
Pribilof and Nunivak Island																								
	St. George							42																
	Otter Island (Pribilofs							37																
	Cape Mendenhall (Nunivak)	Cruise Terminated																						
	Cape Mohican (Ninivak)	Cruise Terminated																						

TABLE V-7

Species Collected in Nonquantitative Samples from St. George, Pribilof Islands (Zimmerman and Merrell, RU #78,79)

Phaeophyceae*
- Cymathere triplicata I
- Laminaria yezoensis I
- Alaria marginata I
- Alaria sp. I
- Fucus distichus I

Rhodophyceae*
- Rhodymenia palmata I
- Rhodymenia sp. I
- Cirrulicarpis gmelini I
- Constantinea rosamarina I
- Halosaccion glandiforme I
- Phycodrys riggii I
- Iridaea sp. I
- Odonthalia kamschatica S
- Schizomenia pacifica S
- Ptilota pectinata

Porifera
- Demospongiae
- Halichondria panicea I
- Chonrocladia alaskensis S
- Mycale adhaerens S
- Leucandra heathi I
- Myxilla incrustans I
- Forcepia uschakowi S
- Sponge I

Cnidaria
- Eunephyta sp. 1 S
- Eunephyta sp. 2 S

Anthozoa
- Haliclystis steknergeri I
- Haliclystis sp. I
- Epiactis marsupialis I
- Anemone S Q I

Rhynchocoela
- Rhynchocoela

Annelida
- Polynoidea S Q
- Harmothoe extenuata I

Annelida (cont.)
- Eteone longa I
- Phyllodoce maculata S Q
- Autolytus sp. I
- Autolytus prismaticus I
- Typosyllis alternata S Q I
- Typosyllis pulchra I
- Exogone gemmifera S Q I
- Paraspaerosyllis sp. I
- Nereis sp. S Q I
- Glycera capitata S Q
- Protodorvillea gracilis S Q
- Nainereis quadricuspida S Q
- Spio filicornis I
- Cirratulus cirratus S Q I
- Ammontrypane aulogaster S Q
- Phloe minuta I
- Capitellid S Q
- Capitella capitata S Q
- Maldanid S Q
- Nicolea zostericola S Q
- Terebellides stroemi I
- Chone gracilis S Q
- Potamilla sp. S Q I
- Potamilla neglecta I
- Pseudosabellides littoralis S Q
- Fabricia sabella I
- Pseudopotamilla reniformis I
- Pontogenia andrijaschevi I
- Oligochaete S Q I

Mollusca
- Schizoplax brandtii I
- Tonicella rubra S I
- Cryptochiton stelleri S
- Musculus discors S I
- Mytilus edulis I
- Hiatella arctica S I
- Pododesmus macroschisma S
- Modiolus modiolus S
- Nudibranch S Q
- Volutharpa perryi S I
- Volutharpa ampullacea S I
- Collisella pelta I

I = Intertidal S = Subtidal Q = Quantitative

TABLE V-7 (continued)

Mollusca (cont.)
- Nucella lima S I
- Velutina plicatilis I
- Margarites helicinus S
- Littorina sitkana I
- Fusitriton oregonensis I
- Notoacmaea scutum S
- Margarites giganteus S I
- Lamellaria stearnsi S
- Acmaea mitra S
- Spongidradsia aleutica S
- Onchidiopsis hannai S
- Bulbus fragilis S I
- Natica clausa S
- Buccinum sp. S Q
- Mitrella rosacea S Q
- Doridae I
- Naticidae I

Pycnogonida
- Ammothea pribilofensis S Q I
- Achelia spinosa I
- Ammothea alaskensis S I
- Ammothea spp. S I
- Nymphon phoxichilidium I
- Phoxichilidium femoratum S

Crustacea
- Balanus rostratus S
- Leptochelia sp. S
- Idotea ochotensis I
- Amphipod I
- Melita sp. 2 S Q
- Parallorchestes ochotensis I
- Anonyx multiarticulatas S Q
- Ischyrocerus sp. 1 I
- Calliopiella sp. I
- Ampithoe rubricatoides S Q
- Ampithoe sp. I
- Parapleustes cf. P. johanseni S Q
- Pleustes panopla S Q
- Caprellid S Q I
- Caprella cristibranchium I
- Dermaturus mandtii S I

Crustacea (cont.)
- Pagurus dalli I
- Cancer oregonensis S
- Pugettia gracilis S

Insecta
- Coleoptera I

Bryozoa
- Bryozoan I

Asteroidea
- Henricia leviuscula S
- Henricia eschrictii S I
- Leptasterias sp. S I

Echinoidea
- Strongylocentrotus droebachiensis S Q I

Ophiuroidea
- Ophiopholis aculeata var. kennerlyi S
- Ophiuroid S Q

Holothuroidea
- Sea cucumber S Q
- Cucumaria pseudocurata I

Sipunculida
- Sipunculid S Q

Hemichordata
- Tunicata I
- Sigillinaria sp. I
- Polyclinidae S I
- Species 1 I
- Species 2 S
- Species 3 (aplidium?) S
- Species 4 S
- Styela (clava?) S
- Species 5 S

Teleostei
- Liparid S Q
- Liparis cyclopis I

*This represents only part of the algae collection at St. George. There are a number of subtidal species which are unique (i.e. not found elsewhere on American coasts). Zimmerman and Merrell are seeking help from Japanese experts in identifying these species.

"... Extraordinary measures should be taken to maintain the intertidal and shallow subtidal areas of the Pribilof Islands in an undisturbed state because they may contain unique species and ecological relationships."

4. The littoral biota, particulary of rocky shores, exhibits great variability between sites and it may prove impossible to accurately predict the flora and fauna expected in unstudied areas. Preliminary analyses indicate that certain dominant species associations are correlated with other groups of more variable species. Zimmerman and Merrell anticipate that environmental monitoring and pollution effects prediction will rely heavily upon studies of these dominant species.

Studies of beach drift biota (i.e., animal carcasses and larger organic remains washed up onto beaches) from the Gulf of Alaska are also included in RU #78, #79. These data can provide an indirect measure of high marine mortality and might reflect pollution effects. Similar drift zone studies could be usefully extended into the Bering Sea study area.

An ongoing literature search by Zimmerman and Merrell has thus far identified only 12 publications specifically related to intertidal communities in the Gulf of Alaska and Bering Sea. More than 500 general references on marine algae and invertebrates from the northern Pacific, Bering Sea, and Arctic Ocean have also been collected and cataloged.

Benthic Biota

The benthic biota of the southeast Bering Shelf is taxonomically well known and some distribution data are available. In general, however, biomass, productivity, and trophic relationships are not known. Rhoads (1974), however, has demonstrated some properties of benthos.

OCSEAP-sponsored benthic research includes:

1. Field studies of the distribution, abundance, diversity and productivity of benthic organisms in the Bering Sea (Feder, RU #5).

2. A review of relevant literature (Feder, RU #282).

3. A study of benthos-sedimentary substrate interactions (Hoskin, RU #290).

Pereyra (RU #175) presents data on commercially significant benthic organisms, principally King and Tanner crabs. Alton (1974) has described the role of Bering Sea benthos as a food resource for demersal fish populations, and Barsdate et al. (1974) summarize contributions to regional productivity derived from coastal lagoons bordering the Bering Sea.

Feder (RU #282) has identified 1,500 references concerning the North Pacific and the Bering Sea, but an extensive search has failed to locate any major sources of unpublished data or archived biological samples suitable for analysis.

Feder's field program (RU #5) involves faunal analyses of both bottom grab-samples and otter trawl tows. Replicate van Veen grab samples (0.1 m^2 surface area, 10-14 ℓ volume) were collected at 77 permanent stations* laid out in a grid across the southern Bering Shelf. These samples will provide quantitative data on the distribution and abundance of benthic organisms -- particularly smaller species and infaunal forms. A program of one-half hour and one hour tows using a 400 mesh Eastern otter trawl yielded supplementary data on demersal fish and larger epifaunal invertebrates.

To date approximately one-third of the grab-sample material has been fully analyzed. 426 species have been isolated; 304 identifications have been confirmed. Thirteen phyla were represented, with Annelida (180 species), Arthropoda (120 species), Mollusca (93 species), and Echinodermata (17 species) predominating. The remaining phyla were represented by three or fewer species

*Other programs -- physical and chemical oceanography, sedimentology, trace metal chemistry, hydrocarbon analysis, zooplankton -- are sampling these same stations, thus maximizing opportunities of complete data integration.

each. As would be expected, the trawl samples yielded rather different material with molluscs, arthropods, and echinoderms succeeding one another in declining order of species abundance (56, 37, and 19 species, respectively). Feder noted that several species recorded as common over a decade ago (McLaughlin 1963, in Feder, RU #5) were apparently less abundant today.

Polychaete worms clearly dominate the infauna of the southern Bering Shelf, while molluscs and crustaceans are the most abundant epifaunal organisms. While much data still await analysis, it is clear that most benthic species exhibit markedly patchy distributions. In several cases a single species dominated the benthic biomass at one station, but was uncommon or absent elsewhere. Relatively few species were widespread -- only three were recorded from at least 20 of the 27 stations analyzed to date (Phloe minuta, a polychaete; Nucula tenuis, a bivalve; and Cerebratulis albifrons, a nemertean). An additional seven species occurred in 12 or more station-collections.

Simpson, Shannon, and Brillouin indices are being calculated to provide a summary quantitative measure of faunal diversity for future comparisons. When all of these data become available, they will be examined for meaningful regional trends. Feder is also compiling information on feeding biology for the more abundant infaunal species; this will be integrated with distributional data in order to enhance understanding of the Bering Shelf benthic ecosystem. Hoskin's (RU #290) analysis of the grain-size characteristics of the shelf sediments should also help explain the species distribution patterns identified by Feder (RU #5). Feder concludes his Annual Report by noting that:

> "Initial assessment of the (benthic) data suggests that 1) Sufficient station uniqueness exists to permit development of a monitoring program based on species composition at selected stations utilizing both grab and trawl sampling techniques, and that 2) Adequate numbers of unique, abundant, and/or large species are available to ultimately permit nomination of likely monitoring candidates for the area once industrial activity is initiated."

An important aspect of the Bering Shelf benthic fauna is its relationship to commercial shellfish and fisheries production. Alton (1974) found benthic standing crop is lower in the Bristol Bay-St. George Basin area ($55g/m^2$) than in other regions of the Bering Shelf, yet this area yields the greatest numbers of fish. He also doubts that these benthic food resources directly support more than a few percent of the local commercial fishery, but he suggests important trophic pathways that could channel considerable benthic productivity into fish populations of use to man. These studies are presently being expanded by Pereyra et al. (RU #175), who also provide distribution data on Tanner crab and King crab in the eastern Bering Sea (Fig. V-7, 8).

PLANKTON

Phytoplankton: Historic data on phytoplankton standing stock and primary productivity of the southeastern Bering Sea, (Motoda and Minoda, 1974, especially for the eastern part of Bristol Bay, are very scarce. The following features applicable to the Bristol Bay lease area are noted:

1. In terms of phytoplankton cell concentration, Bristol Bay is one of the poorest areas in the Bering Sea, 10^5 cells/m^3. Surface diatoms standing stocks in the Bering Sea range from 10^5 to 10^9 cells/m^3.
2. In eastern Bering Sea shelf waters, _Chaetoceros-Phaeoceros_ diatom community dominates.
3. In the southeastern part of Bering Sea observed phytoplankton primary productivity was about 3 mg C/m^3/hr or 1.2 mg C/mg Chl _a_/hr.

Alexander (RU #156-E) has listed Chl _a_ conc. data from a number of stations in the Bristol Bay-St. George Island area (Fig. V-9). Data on phytoplankton studies along sea-ice edge were collected primarily north and northeast of the Pribilof Islands. Stations were groups according to their vicinity to the ice-edge.* Two groups of stations are labeled "In-ice stations"; it is not

*Distance between stations is expressed in miles; it is not specified whether in statute or nautical miles. Conversion to kilometers cannot be made.

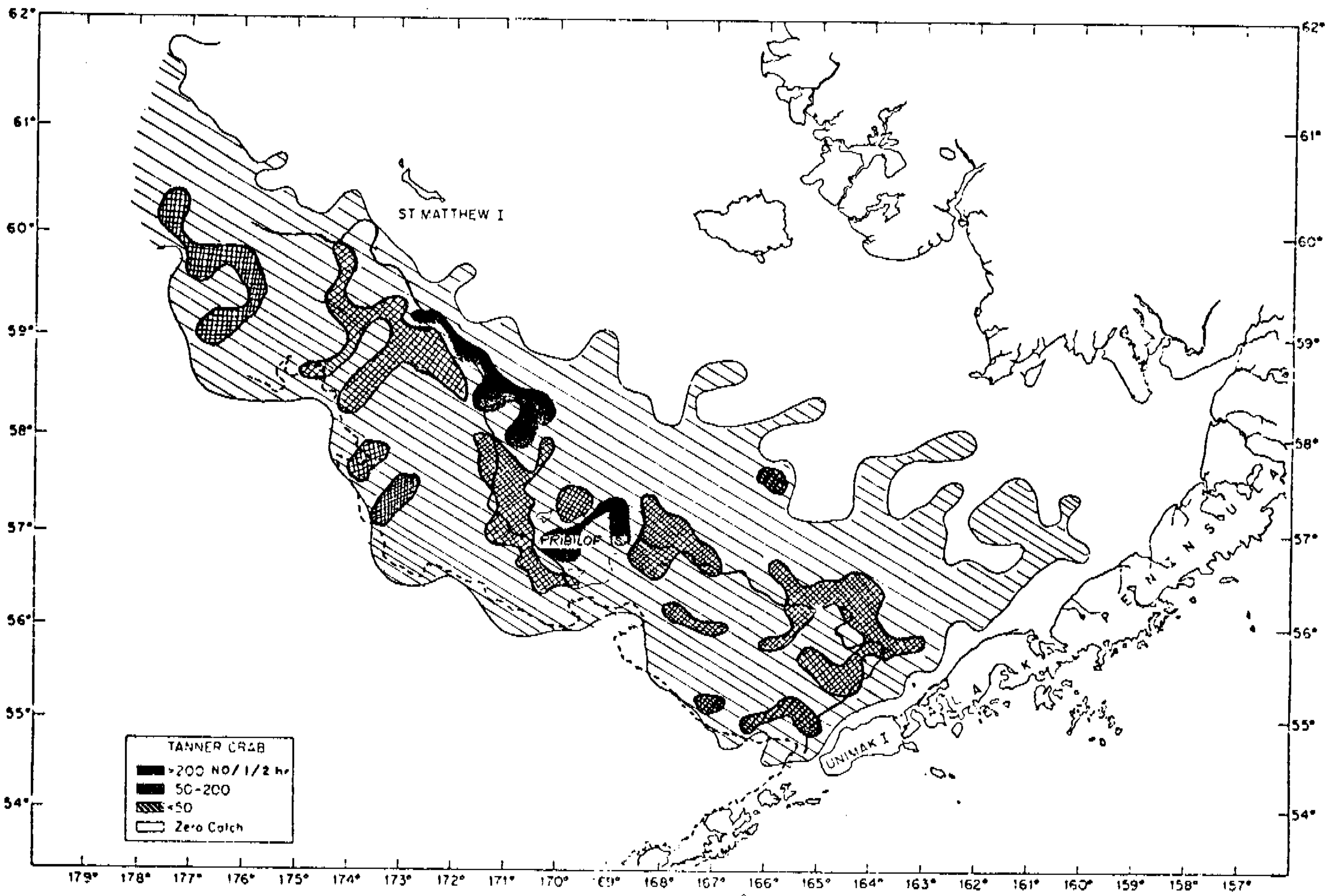


Fig. V-7. Distribution and apparent abudance of legal (males >110 mm carapace width) Tanner crab in the eastern Bering sea, August to October 1975 (Pereyra et al., RU #175).

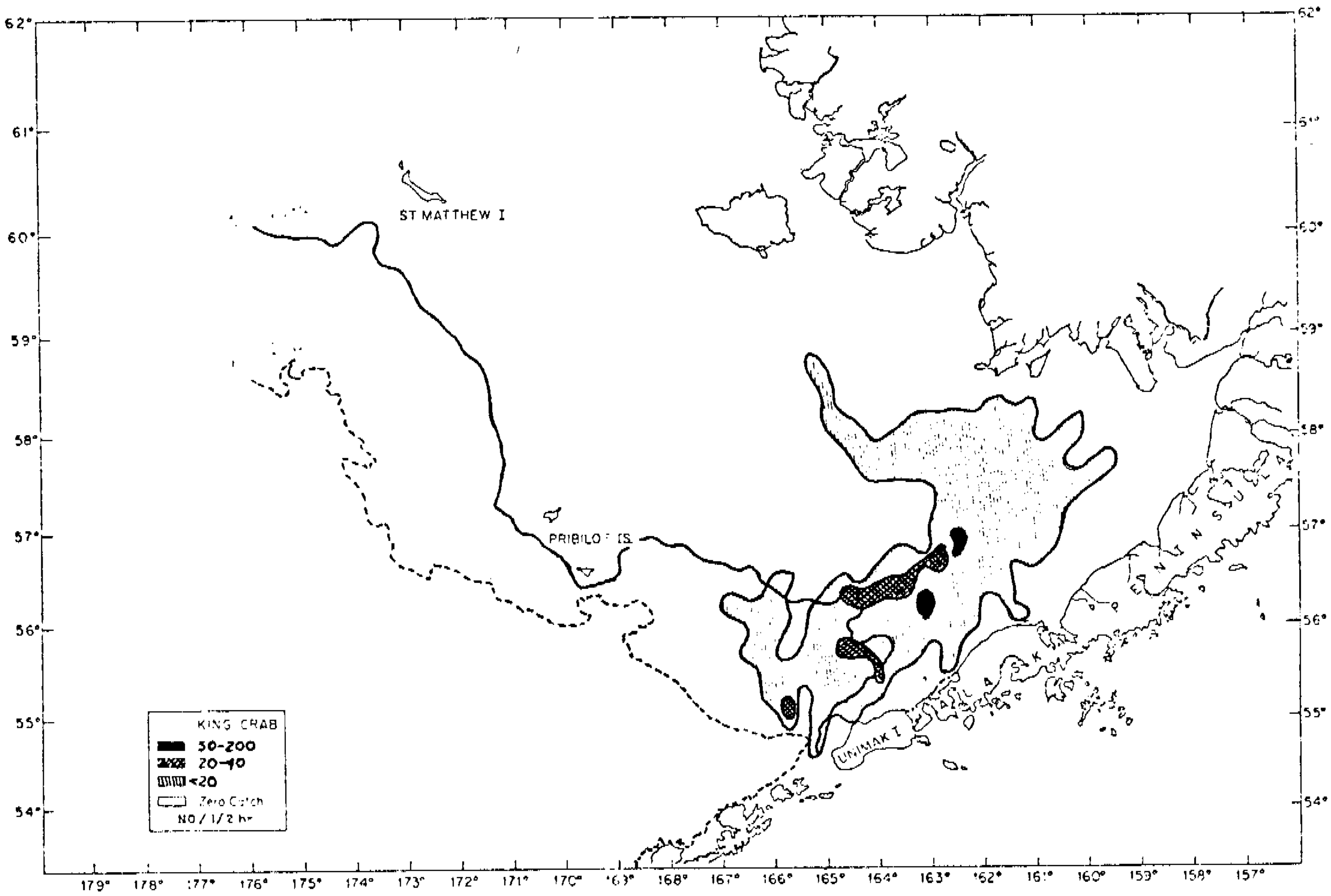


Fig. V-8. Distribution and apparent abundance of legal (males >134 mm carapace width) King crab in the eastern Bering Sea, August to October 1975 (Pereyra et al., RU #175).

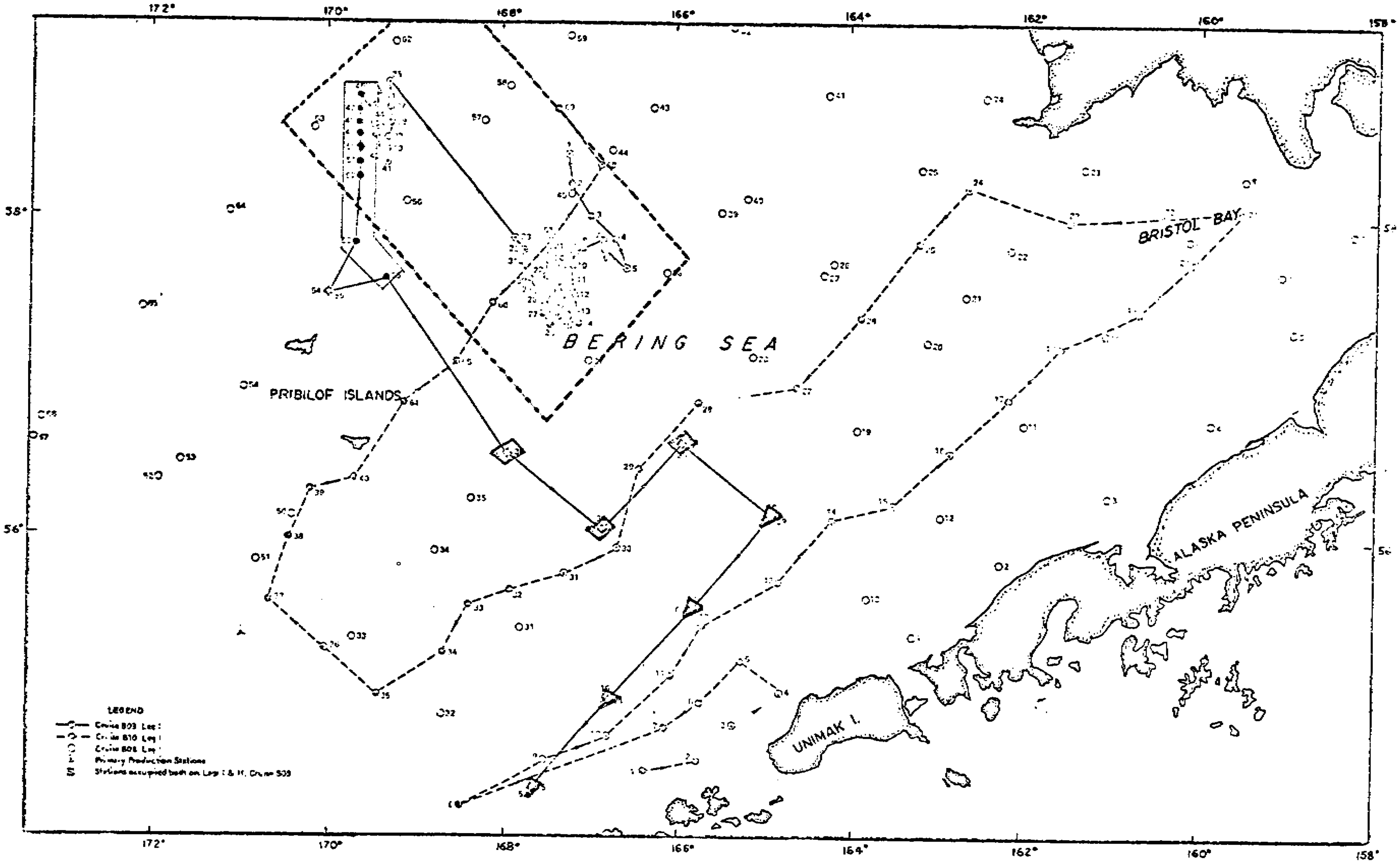


Fig. V-9. Location of stations for which chlorophyll a data are provided: stations 1 to 46 (Ice-edge studies, broken line), stations 46 to 55 (transect from the ice-edge, solid line), stations 56, 57, 58 (along 50 m contour, rectangles), stations 59 to 62 (Aleutian Pass area, triangles) (from Alexander, RU #156-E).

clear how these two groups were different from each other. Other data were collected with reference to 50 m depth contour, and northwest of Unimak and Umnak Islands.

Means and standard deviations of Chl a conc. at four depths, 0 m, 10 m, 20 m, and 40 m, for various station groups were calculated from data provided by Alexander (RU #156-E). No further statistical analyses or tests based on these data are incorporated here as data analyses will be carried out by Alexander. Within location-depth variability was very large; a trend of increase or decrease in Chl a conc. with distance from the ice-edge cannot be ascertained (Table V-8). It is, however, stated by Alexander that "At the ten mile stations ... phytoplankton populations as evidenced by chlorophyll and cell count data were somewhat lower than at 5 miles." From Table V-8, it can be seen that mean chlorophyll values at these locations at 0 m and 10 m were nearly the same; there was an increase in mean Chl a conc. from 9.4 μg/ℓ for stations 5 miles from the ice-edge to 14.9 μg/ℓ for station 10 miles from the ice-edge. Only for one station in each location were the cell count data provided; no conclusions can be drawn.

At an unspecified station within ice, low "species diversity, apparently considered synonymous with species numbers, was noted. At this station, phytoplankton was dominated by Fragilariopsis sp., Melosira moniliformis, and Parvicobicula socialis. At a station "outside of the ice-edge," increased diversity was observed; phytoplankton was dominated by *Fragilariopsis* spp., *Chaetoceros socialis*, *Thalassiosira nordenskioldi*, and Choanoflagellates. At stations near the ice-edge, *Melosira moniliformis* and *Thalassiosira rotula* were also well represented but not in surface layers (Alexander, RU #156-E).

In samples collected along a transect from the ice-edge to 100 miles from it, it was noted that the highest Chl a conc., 8.7 μg/ℓ, was found at 40 m at the station farthest away from the ice-edge (Table V-9). No trends for a progressive increase or decrease in Chl a conc. with distance from the ice-edge are noted, although a decline from the ice-edge to 30 miles is stated by the author (p. 20, RU #156-E, Annual Report).

Samples collected at three stations along the "50 m contour" indicated moderate amounts of Chl a down to 60 m. In the upper 40 m, Chl a conc. varied from 4 to 16 μg/ℓ; at 60 m it ranged from 2 to 11 μg/ℓ. It appears that samples were obtained at locations seaward of the 50 m depth contour. *Chaetoceros debilis* was the dominant species in these samples.

A notable feature of Chl a data from four stations in the eastern Aleutian Islands area (stations 59, 60, 61, and 62) is that the average concentrations in the upper 30 m at stations 60 and 62, 5.0 and 6.2 μg/ℓ, respectively, are much lower than those from stations 59 and 61, 12.6 and 15.6 μg/ℓ, respectively. No explanations are provided. The author merely states that substantial levels of Chl a was observed at these stations. Most abundant species in surface water samples included *Cheatoceros septenrionalis*, *Thalassiosira decipiens*, *Thalassiosira nordenskioldi*, and *Cheatoceras septenrionalis*. *Phaeocystis* sp. accounted for more than 70% of total population.

As the data are incomplete, the significance of the observed Chl a conc. and phytoplankton cell counts cannot be assessed presently. It is not possible to explain the relationship between cell count and chlorophyll concentration: at station 1 (10 m), 2.5 μg/ℓ of Chl a corresponded to 1.71×10^6 cells/ℓ whereas at station 32 (10 m), 35.8 μg/ℓ of Chl a corresponded to the same number of cells. Primary productivity data or species composition of phytoplankton were not included in the Annual Report.

TABLE V-8

Mean values ($\bar{x}$) and Standard Deviation (sd) of Chlorophyll a Concentrations, mg/m, Based on Data Provided by Alexander (RU #156) in Table I of the Annual Report. The number of stations for each location (n) is given in parentheses.

Location		Depths, m 0	10	20	40
In Ice Station: Group 1	$\bar{x}$	12.56	12.62	5.46	1.80
(n = 6)	sd	(11.23)	(11.25)	(5.96)	(1.38)
Group 2	$\bar{x}$	21.82	24.07	6.41	2.89 (n = 7)
(n = 8)	sd	(8.16)	(7.81)	(2.55)	(1.42)
5 mi from Ice-edge:	$\bar{x}$	20.84	17.95	9.36	4.39 (n = 8)
(n = 9)	sd	(8.14)	(7.86)	(10.85)	(2.96)
10 mi from Ice-edge:	$\bar{x}$	19.94	18.16	14.94	3.65
(n = 7)	sd	(4.97)	(3.90)	(3.69)	(1.66)
15 mi from Ice-edge:	$\bar{x}$	15.73	17.76	16.50	4.74
(n = 7)	sd	(2.99)	(3.07)	(5.95)	(1.96)
20 mi from Ice-edge:	$\bar{x}$	16.08	15.68	15.46	5.96
(n = 7)	sd	(9.80)	(7.59)	(7.32)	(2.08)
25 mi from Ice-edge:	$\bar{x}$	15.80	17.64	8.39	7.35
(n = 4)	sd	(6.15)	(8.14)	(1.73)	(2.32)

TABLE V-9

Chlorophyll Concentration, µg/ℓ, and Phytoplankton Cell Count, cells/ℓ, at Nine Stations along a Transect from the Ice-Edge to 100 Miles from it (data from Alexander, RU #156). Mean values and standard deviations for station groups, according to depth, are also given.

Depth (m)	Station	Phytoplankton (cells/liter)	Chlorophyll a (µg/liter)	Mean/ Standard Deviation
0.0	46 (ice edge)	-	21.24	
	47 (5 miles)	-	8.89	
	48 (10 miles)	-	10.94	
	49 (15 miles)	-	15.04	
	50 (20 miles)	3.46×10^6	27.48	
	51 (25 miles)	-	18.88	
	52 (30 miles)	-	19.98	
	53 (50 miles)	-	13.49	
	55 (100 miles)	-	5.11	15.67/6.93
10.0	46	-	20.17	
	47	-	10.28	
	48	-	10.31	
	49	-	21.94	
	50	4.68×10^6	23.99	
	51	-	17.45	
	52	-	23.70	
	53	-	15.06	
	55	-	4.41	16.37/6.86
20.0	46	-	11.53	
	47	-	10.43	
	48	-	8.54	
	49	-	23.84	
	50	2.51×10^6	26.31	
	51	-	8.52	
	52	-	25.15	
	53	-	4.04	
	55	-	5.40	13.75/8.83

TABLE V- 9 (continued)

Depth (m)	Station	Phytoplankton (cells/liter)	Chlorophyll a (μg/liter)	Mean/ Standard Deviation
40.0	46	-	2.26	
	47	-	2.33	
	48	-	1.68	
	49	-	4.79	
	50	-	5.36	
	51	-	4.21	
	52	-	5.56	
	53	-	5.50	
	55	-	8.69	4.49/2.19

Zooplankton and Micronekton: As in case of phytoplankton, a review of zooplankton and micronekton studies in the Bering Sea is provided by Motoda and Minoda (1974).

Cooney (RU #156-D) is studying the seasonal density distributions and food requirements of principal species of zooplankton and micronekton in the Bristol Bay-St. George Basin lease areas. Samples were collected from vertical hauls from 10 m off the bottom to the surface by a 1-m diameter plankton net, 0.333 mm mesh size. Micronekton was sampled by a 2 m NIO Tucker trawl in the upper 75 m. A total of 102 Tucker trawl samples and 229 1-m net samples were collected in May-June, August and November 1975 (Figs. V-15 and V-16). A sampling strategy based on stratified random sampling in two areas (eight sub-regimes, four in each area) is envisaged. Based on previous experience, the author has stated that between 6 and 10 observations/sub-regime are expected to achieve precision to detect differences of one-half order of magnitude or more. Data will be analyzed by the Analysis of Variance and Cluster Analysis to infer the seasonal and spatial distribution patterns. So far no such analyses have been carried out.

The collected samples have been examined for species composition; data on their numerical abundance are not presented. Over 150 different species have been identified from 1-m net samples and are listed in the RU #156-D Annual Report. Most of these belonged to Copepoda (38 species) and Amphipoda (36 species). Other groups represented by 10 or more species were Hydrozoa (16 species), Polychaeta (12 species), and Mysidacea (10 species). The numerically dominant species in both the 1-m net and Tucker trawl samples are listed in Table V-10.

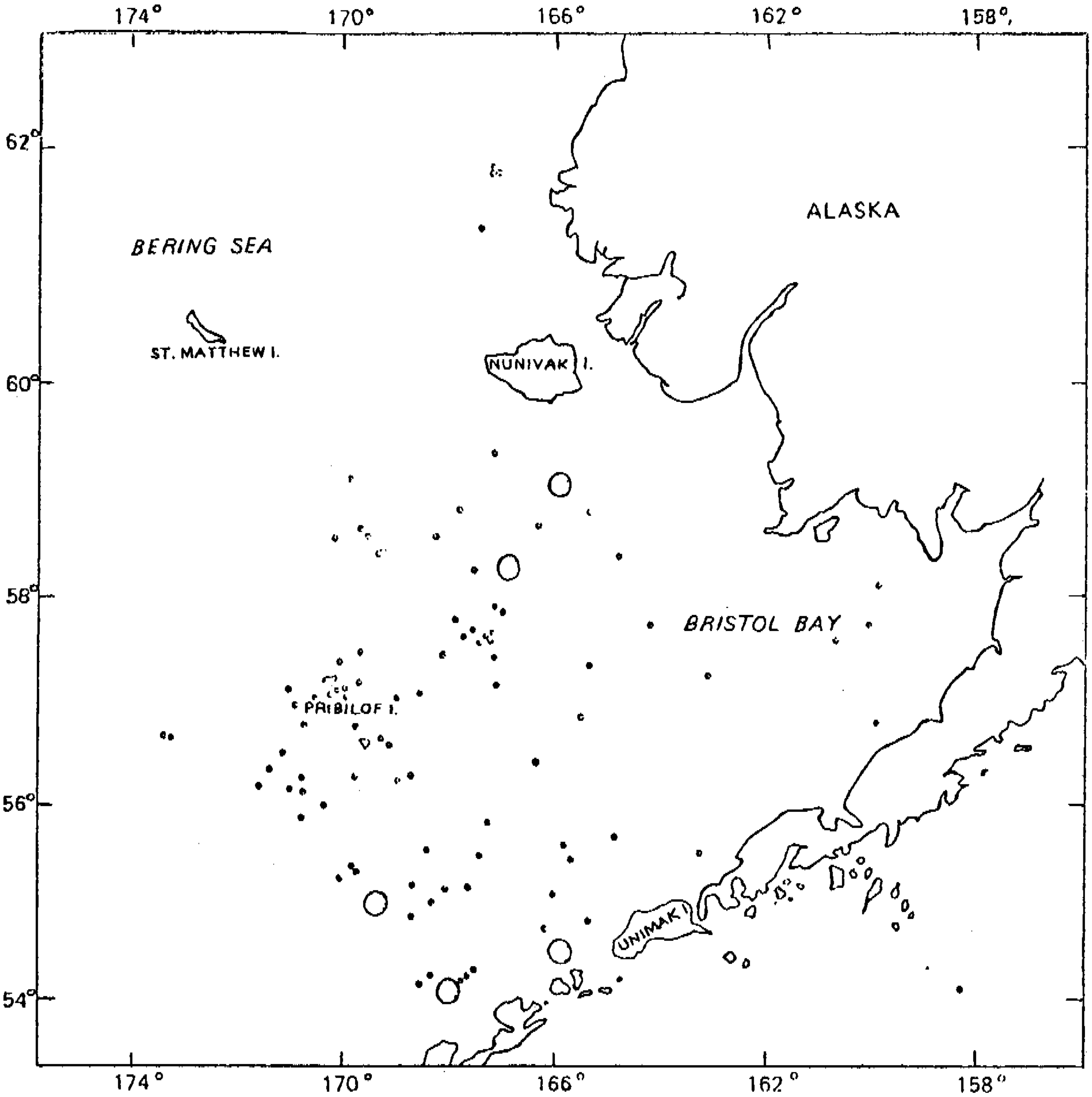


Fig. V-15. The distribution of Tucker trawl samples in the southeast Bering Sea. Large closed circles indicate locations which have been samples on more than one cruise (reproduced from Cooney, RU #156-D).

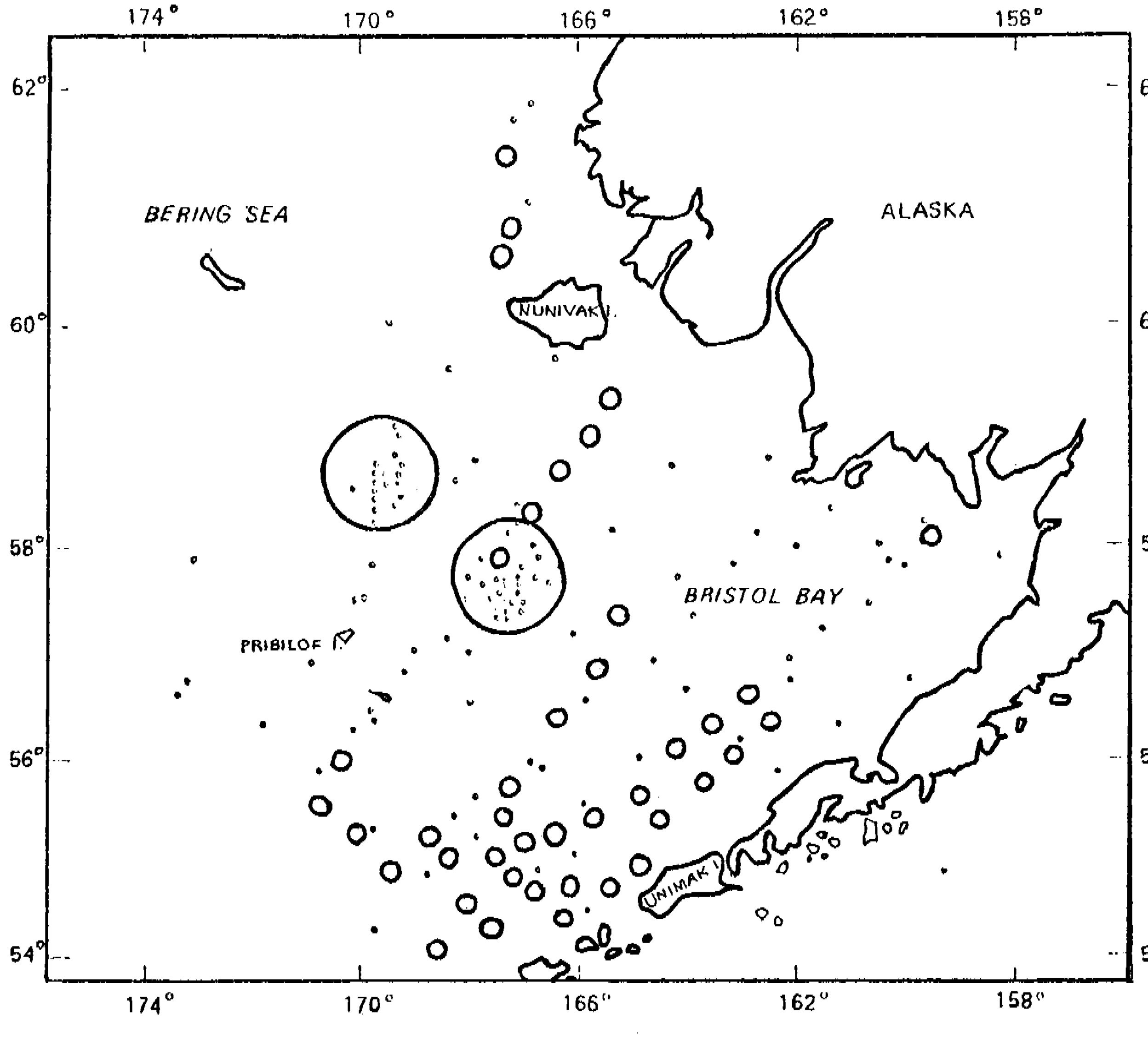


Fig. V-16. The distribution of 1-m net samples in the southeast Bering Sea. Large closed circles indicate locations that have been occupied on more than one cruise (reproduced from Cooney, RU #156-D).

TABLE V-10

The Numerically Abundant Zooplankton and Micronekton Species in Samples Collected by 1-m Diameter Plankton Net and by Tucker Trawl, May-June and August 1975 (Table reproduced from RU #156-D Annual Report).

1-m net	2-m Tucker trawl
Copepoda	Hydrozoa
Calanus marshallae	*Aglantha digitale*
Pseudocalanus spp.	
Eucalanus bungii bungii	
Metridia lucens	Chaetognatha
Acartia longiremis	*Sagitta elegans*
Oithona helgolandica	*Eukrohnia* spp.
Amphipoda	Copepoda
Parathemisto pacifica	*Eucalanus bungii bungii*
Euphausiacea	Euphausiacea
Thysanoessa raschii	*Thysanoessa raschii*
	T. longipes
Chaetognatha	Cumacea
Sagitta elegans	*Distylis bidentata*
	Amphipoda
	Parathemisto libellula
	P. pacifica
	Decapoda
	Hymenadora frontalis
	Chionoecetes megalopa
	Oregoniinae zoeae
	Teleostei
	Mallotus villosus
	Reinhardtius hippoglossoides
	Stenobrachius leucopsarus
	Bathylagus stilbius schmidti

The following features are noted from the data and results by Cooney (RU #156-D), especially in relation to data provided by Motoda and Minoda (1974):

1. Amphipods were represented by 48 species, although only three species were numerically abundant. Motoda and Minoda listed only six species for the Bering Sea, five of which were present in samples collected in this area. The amphipod, Hyperoche kroyeri, considered a dominant species for this area by Motoda and Minoda is not listed as one of the identified species by Cooney.

2. Megalopa larvae of snow crab showed a remarkably patchy distribution but were abundant in waters near the Pribilof Islands.

3. The copepod, Oithona similis, was considered as an abundant species by Motoda and Minoda. It appears that Oithona helgolandica, listed as an abundant species by Cooney, was identified as Oithona similis by Motoda and Minoda.

3. A much larger number (110) of copepod species were listed by Motoda and Minoda than by Cooney. A recently described calanoid copepod, Calanus marshallae, was found to be an abundant species; its females are closely related to Calanus glacialis and males to Calanus finmarchicus. This species was apparently described as Calanus glacialis by Motoda and Minoda.

About 90 species were recognized in samples collected along a transect from northwest of Umnak Island, station 2, to southwest of Nugashak Peninsula, station 136 (Fig. V-12). The collected samples were grouped into four zones according to the depth of water: Open Water, Shelf Break, Shelf, and Coastal. Seven out of fourteen samples were from the Shelf zone. Five species were represented in all four zones: Aglantha digitale (Hydrozoa), Calanus marshallae, Acartia longiremis, Pseudocalanus sp., and Oithona spinirostris (all copepods). The copepod species, Metridia lucens, Eucalanus bungii bungii, and Calanus plumchrus occurred in densities between 10^2 and 10^4 individuals/m^2 in samples seaward of mid-shelf where their number diminished rapidly. Similar pattern was shown by the oceanic amphipod, Parathemisto pacifica. Among the amphausiids, Thysanoessa longipes appeared to be more oceanic in distribution.

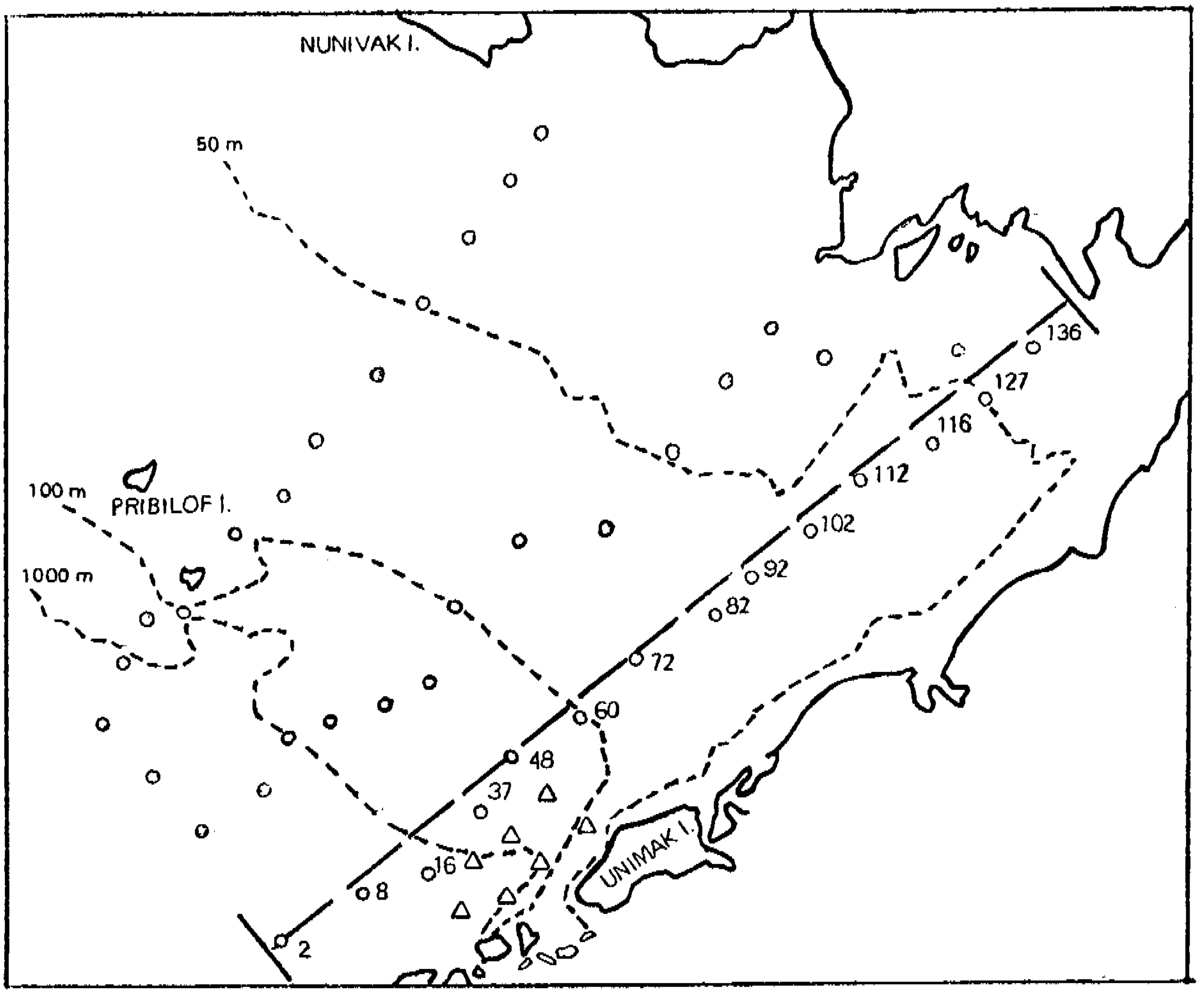


Fig. V-12. The August 1975 cross-shelf transect. Numbers refer to oceanographic station name (reproduced from Cooney, RU #156-D).

The lantern-fish, Stenobrachius leucopsarus, is being studied to evaluate its position and significance in trophicdynamics in the oceanic and slope regimes. Three size classes and frequency of their occurrence are recognized on the basis of 1,156 specimens collected at night during May-June 1975. It is speculated that its spawning season coincides with spring peak in primary productivity (Cooney, RU #156-D).

Plankton Trophicdynamics: In view of available data, it is a little too early to address features of trophic relationships between phyto- and zooplankton. It should be recognized, however, that in areas where the copepod, Calanus plumchrus, is the dominant grazing species, phytoplankton standing stock is suppressed early in spring and no "spring bloom" develops. This is because in this species neither the breeding nor the size of new brood depends on the amount of phytoplankton present. Females have reduced masticatory edges on ma dibles and do not feed. Species overwinters at depths exceeding 200 m and survives on stored fat; it reproduces in late winter. New brood reaches the late naupliar or copepodite I stage and ascends into surface layers by the time spring phtyoplankton productivity starts. These larval stages exert intense grazing pressure on phytoplankton and grwo rapidly. Consequently, phytoplankton does not reach a marked peak in standing stock in spring. Yearly maximum of the species biomass occurs in spring after which the species descends out of the photic zone.

A markedly different situation occurs in areas dominated by the copepod, Calanus finmarchicus (and possibly Calanus glacialis as well), in which both the timing and size of brood depend on the availability of food. There is a lag period between the period of phytoplankton growth and the beginning of intensive grazing by larval stages of this species. During this period of low mortality, phytoplankton standing stocks continues to accumulate and "spring bloom" is developed. This species attains its maximum biomass in summer.

Small copepods, such as Oithona helgolandica, Acartia lo n giremis, and Pseudocalanus sp., have several broods per year which depend on food supply. Species remain in upper layers throughout the year and continue grazing on the available phytoplankton.

The details of life histories of dominant copepods in the northern North Pacific Ocean and the Bering Sea and their effect on phytoplankton cycles are given by Heinrich (1961, 1962). According to Heinrich (1962), phytoplankton is more efficiently utilized when herbivorous are found in ol der stages during the period of phytoplankton maximum or when there are several broods per year (also see Fulton 1973). It would appear that in parts of the Bristol Bay-St. George Island area, grazing influence of different copepods (Calanus plumchrus, Calanus marshallae/Calanus glacialis, Eucalanus bungii bungii, and small copepod species) may have profound effect on primary productivity cycles. These effects should be addressed when pelagic ecosystem studies are undertaken in this area.

Cooney (RU #156-D) has made a few statements about the utilization of annual algal production by zooplankton. Unfortunately the conversion factor used to transform the average wet weight of zooplankton standing stock to carbon, 0.1 x wet weight, is incorrect. In view of the ususally accepted conversion factors for zooplankton, dry weight = 0.13 wet weight and organic carbon = 0.4 dry weight (Mullin 1969), organic carbon should be 0.052 x wet weight of zooplankton. Consequently, the statement that nearly two-thirds of organic matter produced by phytoplankton is available to benthos may be inappropriate. Nonetheless, it is entirely possible that in the nearshore environment, a large fraction of phytoplankton may not be consumed by herbivorous zooplankton and may sink to the bottom.

MARINE BIRDS

Introduction

A partial list of swimming and wading birds of the St. George Basin-Bristol Bay area is in Table V-11. [Emphasis in this section is upon presenting data on species and habitats which are the focus of OCSEAP studies.] General background information on Alaskan swimming and wading birds presented in the sections on Cook Inlet, Kodiak Island, and the Beaufort Sea is not repeated here.

The U.S. Dept. of Interior (1970) characterizes the aquatic avifauna of this region as follows:

> "In the Bristol Bay region, bird life is remarkably abundant. The area is the crossroads for waterfowl coming from wintering areas as divergent as Japan and Mexico and headed for breeding areas as far east as Melville Island in northern Canada and as far west as the delta of the Lena River in central Siberia. Dr. Ira Gabrielson, in 'The Birds of Alaska,' describes Bristol Bay as the southern terminus of the 'Arctic bird migration route.' He also notes that birds from an 'Asiatic Route,' a 'mid-Pacific Route,' and the North American 'Pacific Flyway' funnel through this area. This is truly one of the world's great bird migration crossroads. Bristol Bay and the Alaska Peninsula coastal zone are more than a way point on these extensive migration routes. This region is the last staging and feeding area for vast numbers of birds awaiting spring breakup in the Arctic each year. Likewise, birds fleeing the early Arctic freezeup linger in this rich coastal environment for weeks to rest and feed before continuing their migration south. Bristol Bay and its coastal zone is also the breeding ground for colonial sea birds numbering in the millions. It is the winter habitat of hundreds of thousands of diving ducks and sea birds, and the summer habitat for large numbers of shearwaters and other species that nest in the southern hemisphere. Shore birds from the entire Pacific Basin pause and rest in this area en route to Arctic nesting areas."

Pribilof Islands Seabird Colonies

The two main islands of the Pribilof group are St. Paul and St. George which are about 72 km apart. The following species of seabirds breed on both of these islands:

Cliff-ledge nesters	Hole nesters
Thick-billed Murre	Least Auklet
Common Murre	Parakeet Auklet
Black-legged Kittiwake	Crested Auklet
Red-legged Kittiwake	Horned Puffin
Fulmar	Tufted Puffin
Red-faced Cormorant	

According to Hickey (RU #38) the 10.6 km of lower cliffs on St. George Island support about 40,000 breeding birds of the 11 species, whereas the 37.5 km of high cliffs house over 200,000 Least Auklets, at least 400,000 Murres, and smaller numbers of the other species.

Seabird population sizes on St. Paul Island have not been estimated. However, according to Hunt (RU #83) the Thick-billed Murre is found on all cliffs of the island and is the most abundant breeding bird there.

The seabird nesting season on St. Paul extends from late May to early June (Fig. V-18). Hunt's (RU #83) data on reproductive success of five species are summarized in Table V-12. Extrapolating hypothetical replacement rates from Hunt's data, it is seen that population turnover probably is rather slow; on the average it takes a breeding pair several years to produce two offspring which survive to breeding age (Table V-13). Hence recovery from a natural or human-caused disaster which eliminated significant number of birds would take many years.

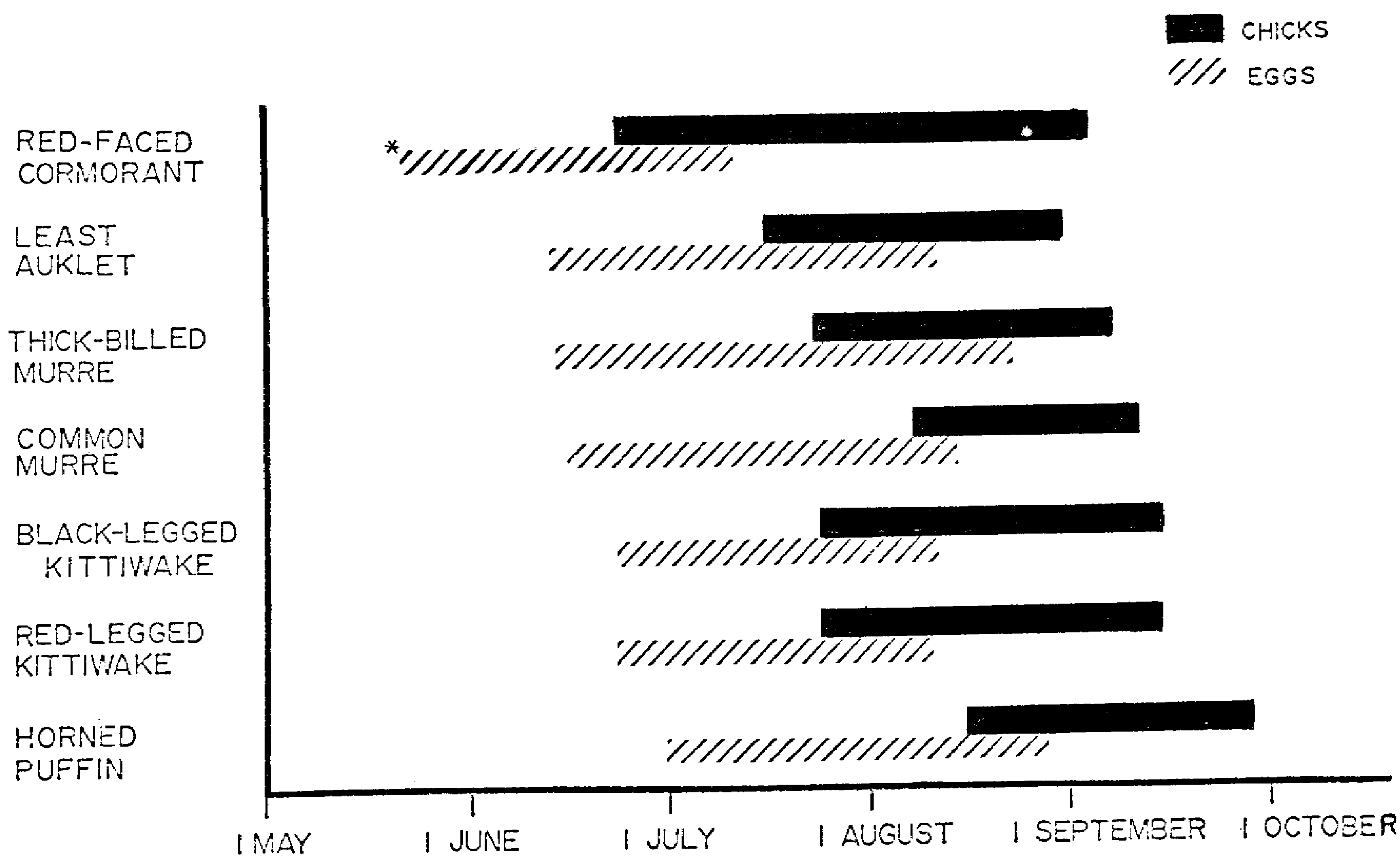
Fish, squid, and crustaceans are the main foods of Pribilof seabirds during the breeding season (Table V-14). Birds feeding at sea around the Pribilofs concentrate within 10 to 30 km of the islands. The greatest concentrations of birds counted offshore of the Pribilofs from August 20-23, 1975, occurred between St. Paul and St. George, where densities of approximately 300 to 430

TABLE V-11

An Incomplete Listing of Swimming and Wading Birds of the Bristol Bay-St. George Basin Region (R. Engelmann, pers. commun.; Lensink and Bartonek, RU #337, Part 1)

Family	Species	Family	Species
Gaviidae	Red-throated loon	Scolopacidae	Common snipe
	Arctic loon		Wandering tattler
	Common loon		Greater yellowlegs
Podicipedidae	Red-necked grebe		Aleutian sandpiper
			Least sandpiper
Diomedeidae	Black-footed albatross		Dunlin
	Short-tailed albatross		Shortbilled dowitcher
			Sharp-tailed sandpiper
Procellariidae	Slender-billed shearwater		Pectoral sandpiper
	Sooty shearwater		
	Short-tailed shearwater	Phalaropidae	Northern phalarope
	Pacific fulmar		
		Stercorariidae	Parasitic jaeger
Hydrobatidae	Fork-tailed petrel		Pomarine jaeger
	Leach's petrel		Long-tailed jaeger
Phalacrocoracidae	Pelagic cormorant	Laridae	Black-legged kittiwake
	Red-faced cormorant		Red-legged kittiwake
	Double-crested cormorant		Glaucous-winged gull
			Mew gull
Anatidae	Black brant		Ivory gull
	Emperor goose		Herring gull
	Buffleheads		Sabine's gull
	Oldsquaw		Arctic tern
	Harlequin duck		Glaucous gull
	Mergansers		
	Greater scaup	Alcidae	Common murre
	Canada goose		Thick-billed murre
	Steller's eider		Pigeon guillemot
	Common eider		Marbled murrelet
	Black scoter		Ancient murrelet
	White-winged scoter		Crested auklet
	Surf scoter		Horned puffin
	Pintail		Tufted puffin
	Whistling swan		Parakeet auklet
			Least auklet
Hematopodidae	Black oystercatcher		Cassin's auklet
Charadriidae	Ruddy turnstone		
	Black turnstone		
	Golden plover		

*A complete check list would resemble that in the section on Cook Inlet.



*Extrapolated from hatching dates.

Incubation period = 1 month

Fig. V-18. Timing of nesting activities on St. Paul Island in 1975 (copied directly from Hunt, RU #83).

TABLE V-12

Breeding Success of Five Species of Seabirds on the Pribilof Islands in 1975.*

Species	No. nests	$\overline{X}$ Clutch size	Hatchings† success	Fledging success of: Eggs laid	Eggs hatched	$\overline{X}$ no. chicks produced per nest
Red-faced Cormorant	33	3.00	38-44%	23-30%	59-68%	0.79
Black-legged Kittiwake	87	1.44	57-67%	38%	57-68%	0.55
Red-legged Kittiwake						
St. Paul Island	9	1.00	56%	44%	80%	0.44
St. George Island	19	1.00	79%	63%	80%	0.63
Common Murre						
Solitary pairs	18	1.00	11%	0	0	0
Pairs in groups	31	1.00	29%	ca. 19%	ca. 66%	ca. 0.19
Thick-billed Murre						
Solitary pairs	66	1.00	51%	38%	73%	0.38
Pairs in groups	23	1.00	65%	ca. 48%	ca. 73%	ca. 0.48

*Unless otherwise noted, data are from St. Paul Island. Data are summarized from Hunt (RU #83).

†Percent of all eggs laid that hatched.

TABLE V-13

Hypothetical Replacement Rates for Breeding Seabirds of the Pribilof Islands, Illustrating the Slow Rate of Natural Turnover in Seabird Populations.*

	Average time required for a pair to produce two reproductive offsprings assuming:	
	No post-fledging mortality†	70% post-fledging mortality¶
	----------years----------	
Red-faced Cormorant	2.5	8.4
Black-legged Kittiwake	3.6	12.1
Red-legged Kittiwake		
St. Paul	4.5	15.2
St. George	3.2	10.6
Common Murre	10.5	35.1
Thick billed Murre	4.2	13.9

*Figures in the first column are derived from Table V-9.

†Mortality after fledging and before attaining breeding age.

¶70% average mortality before attaining breeding age seems to be a close approximation to reality (Lack 1954). The species considered here begin breeding at 3 to 4 years of age.

TABLE V-14

Food Habits of Pribilof Islands Seabirds as Determined by Stomach Content Analyses.
(copied directly from Hunt, RU #83, Table

Species	# samples with food	# occurrences	PERCENT BY OCCURRENCE								
			Cephalopoda	Copepoda	Amphipoda	Euphausiacea	Decapoda	Brachipoda	Fish	Debries	Plastic Spheres
Fulmar	1	1	100%	-	-	-	-	-	-	-	-
Red-faced Cormorant	2	2	-	-	-	-	-	-	100%	-	-
Black-legged Kittiwake	53	69	9%	-	14%	4%	1%	-	62%	6%	3%
Red-legged Kittiwake	8	8	-	-	-	-	-	-	88%	12%	-
Common Murre	22	22	9%	-	-	-	-	-	91%	-	-
Thick-billed Murre	19	19	5%	-	16%	-	5%	5%	68%	-	-
Parakeet Auklet	22	22	-	-	14%	5%	-	-	55%	14%	14%
Least Auklet	45	48	-	44%	8%	17%	6%	-	0%	15%	-
Crested Auklet	5	5	-	-	80%	-	-	-	20%	-	-
Tufted Puffin	2	2	50%	-	-	-	-	-	50%	-	-
Horned Puffin	5	5	-	-	-	-	-	-	80%	20%	-

birds per km^2 were observed; 84% to 95% of them were murres [these minimal estimates are derived from data (shipboard counts) presented by Hunt, RU #83].

Cape Newenham and Walrus Islands Seabird Colonies

Although no OCSEAP projects are specifically dealing with them, important seabird colonies exist at Cape Newenham and the Walrus Island. These colonies are described as follows by the U.S. Dept. of the Interior (1970):

> "Cape Newenham, on the north side of Bristol Bay, has some 20 miles of cliffs rising to 1,500 feet. In the summer, these cliffs are covered with nesting kittiwakes, murres, guillemots, auklets, and puffins. It is estimated that there are at least one million birds in this colony. Round Island and other islands in the Walrus Islands group also have huge bird colonies."

Offshore Densities of Shearwaters

The most abundant birds on offshore waters of the Bering Sea in summer are shearwaters (see COOK INLET section). Guzman (RU #239) conducted shipboard censuses of shearwaters in the Bering Sea and Gulf of Alaska from June through August 1975. The greatest concentration of shearwaters Guzman observed was northeast of the Pribilofs on August 17, where over ten million short-tailed and sooty shearwaters were present over a transect distance of 48 km (Guzman, RU #239).

The densest concentration of shearwaters that Hunt observed during surveys around the Pribilofs from August 20-23, 1975 was within 10 to 20 km southwest of St. Paul Island. Although Hunt's survey area contained no concentrations as large as those reported by Guzman (above), shearwaters occurred in 93% (50/54) of the quadrants that he sampled (Hunt, RU #83).

Data acquired by Lensink and Bartonek (RU #337, Part I) indicate that the greatest densities of shearwaters in outer Bristol Basin from June through

November 1975 occurred in June, when 507 shearwaters per km^2 were censused (Table V-15). Apparent discrepancies among data acquired by Lensink and Bartonek, and Hunt and Guzman are due to the movements and patchy distribution of shearwater concentrations.

Stomach contents of 22 sooty and short-tailed shearwaters taken in Alaskan offshore waters contained 50% to 75% squid, with fish and crustaceans making up the balance (Lensink and Bartonek, RU #341).

Offshore Densities of Other Seabirds

Monthly variation in the density or abundance of birds other than shearwaters on offshore waters of Bristol Basin is summarized in Fig. V-19 and data for each species are presented in Table V-15. Basic features of the curve resemble those of the comparable curve for the Kodiak region (see KODIAK ISLAND section). A hypothetical explanation to account for part of the July peak in abundance is suggested in the section on Kodiak Island.

Migrations

Unimak Pass

Assistants of Lensink and Bartonek (RU #340) counted seabirds, which they presumed were migrating, at Unimak Pass from August 12-23, 1975. Their schedule was as follows:

Location	Dates	Man hours counting
Cape Sarichef	August 12-23	3.5
Mile 5-Sennet-Big Hill*	August 14-17	2.1
Scotch Cape	August 17-21	2.3
	TOTAL:	7.9 man hours

*5 Mile Cabin, Sennet Point, and Big Hill Shelter

TABLE V-15

Species and Density of Birds Observed on Offshore Waters of Bristol Bay Basin, June to November 1975. Data were extracted from data sheets of Lensink and Bartonek (RU #337, Part I).

Species	Birds per km^2:					
	June	July	Aug.	Sept.	Oct.	Nov.
Common Loon					*	
Arctic Loon				0.1	0.1	
Red-throated Loon					0.1	
Unidentified Loon				0.1	0.1	
Red-necked Grebe				*		
Fulmar		0.5	*	1.3	2.4	
Sooty Shearwater		65.9	*			
Short-tailed Shearwater		20.8		38.5		
Unidentified Shearwater	507.2	37.3	16.6	4.1	35.4	
Fork-tailed Storm Petrel		0.2	*	0.6	0.2	
Unidentified Storm Petrel			*			
Pelagic Cormorant				*	0.1	
Red-faced Cormorant	0.1					
Unidentified Cormorant		0.3		0.3		
Black Brant				0.2		
Emperor Goose				0.1		
Unidentified Goose				0.1	0.1	
Pintail				*		
Oldsquaw					*	
Harlequin Duck					0.1	
Steller's Eider				*		
Common Eider					*	
Unidentified Eider					0.1	
White-winged Scoter			*		0.5	
Black Scoter				*		
Unidentified Duck				*	0.1	
Golden Plover				0.1	0.1	
Sharp-tailed Sandpiper				*		
Pectoral Sandpiper				0.3		
Northern Phalarope				0.4		
Unidentified Phalarope				*	*	
Unidentified Shorebird			0.2	0.1		
Pomarine Jaeger	0.1	0.1	0.5	0.3	0.1	
Parasitic Jaeger	*	0.2	0.1		0.1	
Unidentified Jaeger	*	0.4	0.1	0.1	*	
Glaucous Gull					*	0.1
Glaucous-winged Gull	0.1	0.5	0.1	0.3	0.7	2.1
Unidentified Kittiwake	1.5	2.9	5.2	1.7	3.7	
Black-legged Kittiwake				0.9		1.5

TABLE V-15 (continued)

Species	Birds per km^2:					
	June	July	Aug.	Sept.	Oct.	Nov.
Unidentified Gull	0.1	0.2	0.5		0.2	
Arctic Tern		0.1	0.2	1.0		
Unidentified Murre	10.9	46.7	3.3	2.6	1.8	0.5
Unidentified Guillemot		0.6				
Pigeon Guillemot			0.5			
Marbled Murrelet					*	
Ancient Murrelet			0.1	0.1	0.8	
Cassin Auklet		0.2	0.1			
Parakeet Auklet			0.1	0.5	0.2	
Crested Auklet				0.2	*	0.5
Least Auklet					0.3	
Unidentified Small Alcid	0.1	2.3	1.6	0.2	1.4	
Horned Puffin			*	0.1		
Tufted Puffin	0.2	9.0	0.4	0.7	0.1	0.8
Tree Swallow				*		
Unidentified Passerine			*			
Totals	520.3	188.5	29.3	53.9	48.7	5.4

*Present in densities less than 0.1/km^2

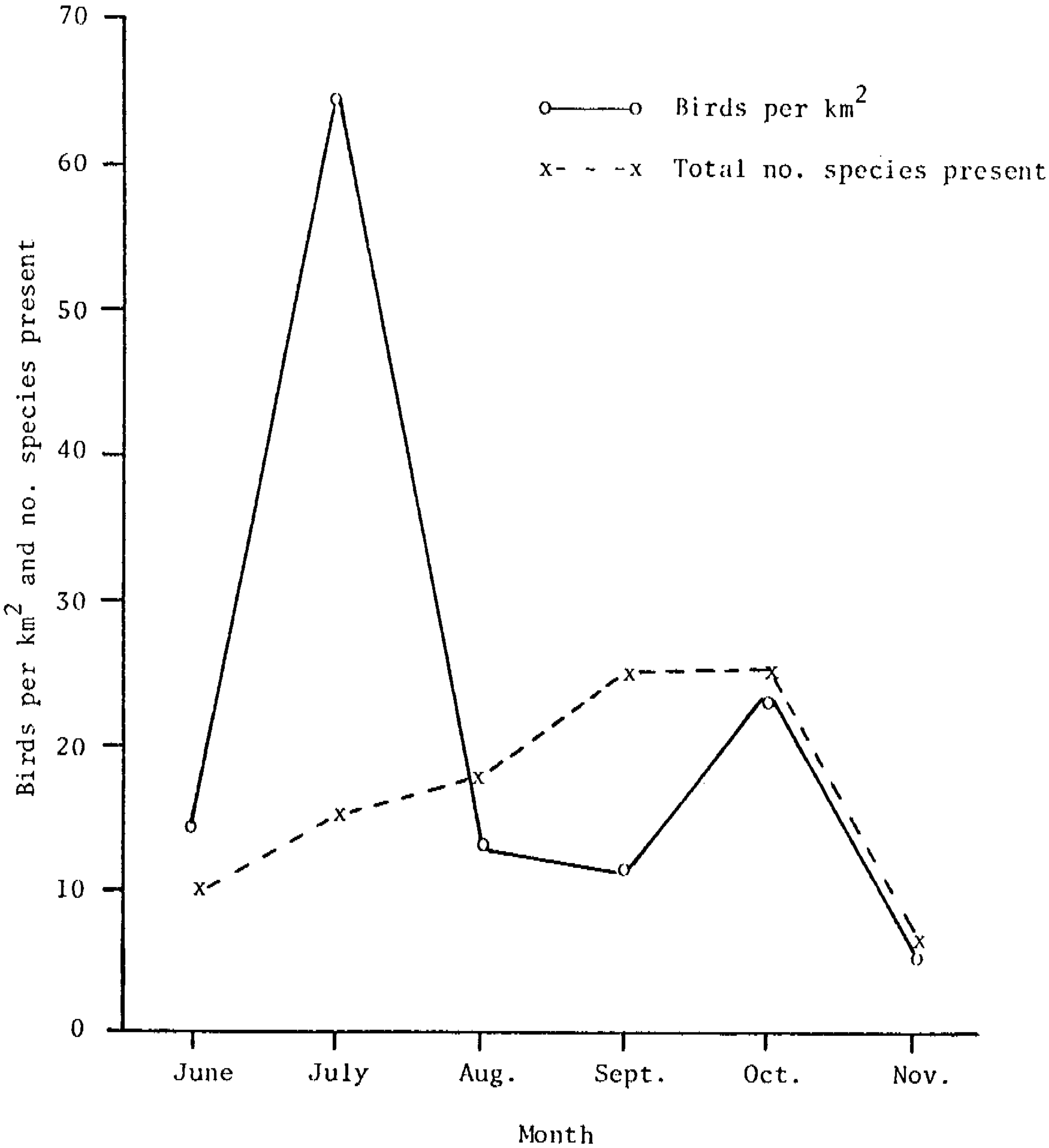


Fig. V-19. Abundance of individuals and species (excluding shearwaters) on offshore waters of Bristol Bay Basin, June to November 1975. Data points are from Table

One counting method ("Type I") was to count all birds visible in a variable area (about 45% size variance among areas sampled) and the other ("Type II") was to count all birds entering the field of view of a spotting scope during 5-minute sampling periods. More than 50% of the birds counted by both methods were murres. Relative abundance of the eight commonest species as determined by Type I counts is illustrated in Fig. V-20.

Lensink and Bartonek (loc. cit.) assumed that the numbers of birds counted flying (in any direction) and sitting on the water represented the numbers migrating through Unimak Pass. Based on this assumption, they estimated that murres were "... rounding Cape Sarichef at the rates of 3,731 and 5,951 birds per hour as determined by two different counting techniques."

Alaska Peninsula

Arneson (RU #3) is studying the use of coastal habitats by migratory swimming and wading birds along the north (Bristol Bay) side of the Alaska Peninsula. He delineates 1,425 km of beaches and 128,831 hectares of avian habitat behind the beaches. Sixty percent of the beachline and 85% of bird habitat behind the beaches is associated with lagoons and estuaries, and the remainder is along the outer beach (Table V-16). According to Arneson (loc. cit., p. 5):

> "The most important function of the intertidal zone of the north side of the Alaska Peninsula is as a staging area for migrant birds. The lagoons and estuaries provide excellent habitat for spring migrants waiting for northern areas to thaw. More spectacular are the concentrations of waterfowl using the area in the fall. King and Lensink (1971) stated: 'The entire world population of American emperor geese and black brant can be found in this area in October. Most of the cackling Canada geese, large numbers of lesser Canada geese and substantial numbers of snow geese can also be found here in October.' Ducks and shorebirds exceed the geese in abundance although the timing of their migration may differ. The most renowned estuary is Izembek Lagoon which contains the largest eelgrass beds in the world. Migrating black brant utilize this plant to acquire sufficient energy stores for their sustained migration across the Gulf of Alaska. Jones (in press) reported that most bird species in the Cold Bay area depend on the eelgrass beds of Izembek Lagoon either directly or indirectly."

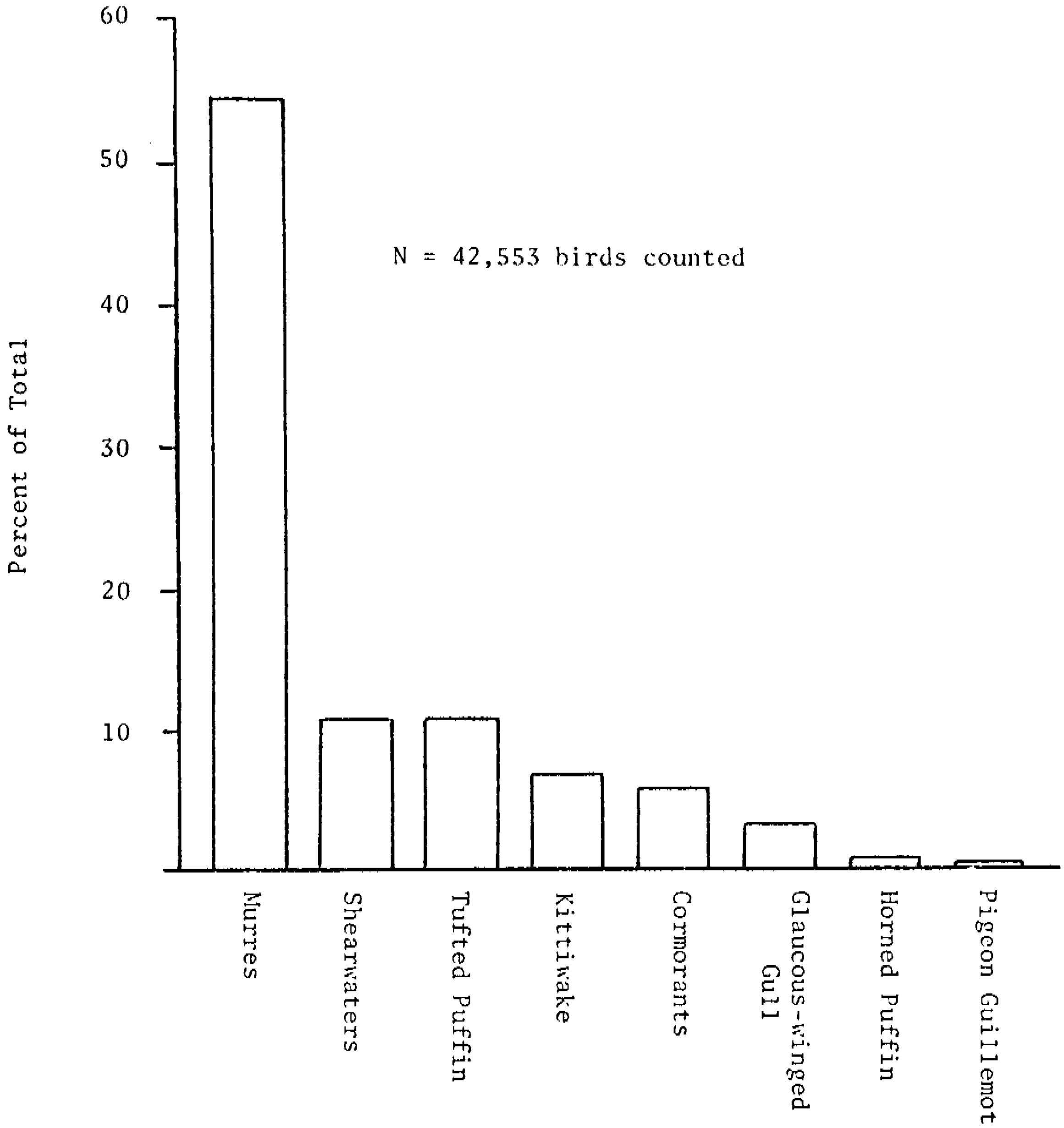


Fig. V-20. Relative abundance of the eight commonest seabird species occurring on nearshore waters of the Unimak Pass from August 12-25, 1975, during fall migration. Counts were made from shore with 8-power binoculars or a 25-power spotting scope. Data are from Table by Lensink and Bartonek (RU #340).

TABLE V-16

Extent of Coastal Bird Habitats on the Bristol Bay Side of the Alaska Peninsula (adapted from Arneson, RU #3).

A. BEACHES (linear km)

	Total extent of habitat type on:	
Habitat type	Outer Beach	Estuaries
Sandy beach	554 km (98.4%)	358 km (41.6%)
Rocky beach	0	11 km (1.3%)
Gravel beach	9 km (1.6%)	66 km (7.6%)
Mud	0	427 km (49.5%)
TOTALS:	563 km	862 km

B. BEHIND BEACHES (hectares)

Sedge meadow	12,235 ha (65%)	31,790 ha (29%)
Sand	0	7,247 ha (7%)
Beach rye	5,755 ha (31%)	8,822 ha (8%)
Mud flat	777 ha (4%)	62,205 ha (57%)
TOTALS:	18,767 ha	110,064 ha

Aerial surveys of estuaries along the north side of the Alaska Peninsula from March to October indicate that the highest concentrations of ducks and geese occur in October, when up to 625,000 have been counted. The greatest concentration within one estuary was observed in Port Moller on October 4, 1971, when 444,655 ducks and geese were counted (Arneson, RU #3).

Relative abundance of birds in four estuarine habitats is illustrated in Fig. V-21 and specific habitat preferences are described in Table V-17.

Overwintering Birds

According to U.S. Dept. of Interior (cited by Arneson, RU #3), hundreds of thousands of diving ducks and seabirds spend the winter in Bristol Bay.

Population and Ecosystem Dynamics

Studies of marine bird population dynamics (Lensink and Bartonek, RU #342) and ecosystem dynamics (Favorite and McAlister, RU #77) encompassing the Bristol Bay-St. George Basin region are in progress, but data from these studies are not yet available.

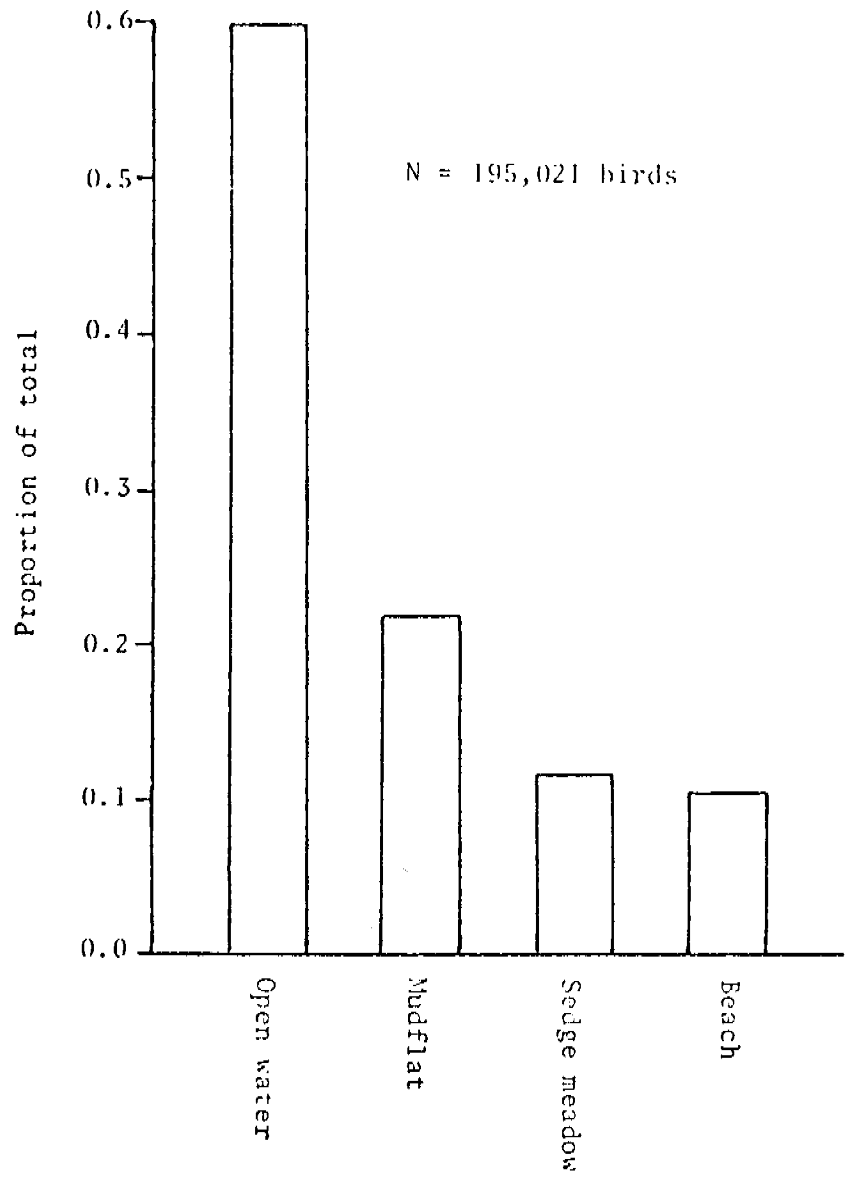


Fig. V-21. Relative abundance of swimming and wading birds in estuarine habitats on the north side of the Alaska Peninsula in October 1975, during fall migration (drawn from survey counts by Arneson, RU #3, Table 8).

TABLE V-17

Coastal Habitat Preferences of Swimming and Wading Birds on the North Side of the Alaska Peninsula in October 1975 During Fall Migration (based on Arneson, RU #3, p. 23).

Species	Habitat Association or Preference	
Gulls	Tended to congregate at stream mouths all along the peninsula.	
Scoters and eiders	Outer coast:	Associated mostly with the steepest shorelines.
	Estuaries:	Congregated on leeward sides of barrier islands and sand spits near mouths of estuaries.
Emperor geese	Found mainly on exposed beaches in association with estuaries. Roosted on sandy beaches and on mudflats. Also joined Canada geese in wet sedge meadows.	
Canada geese	"Inhabited the mudflat-sedge meadow ecotone or sedge meadows innundated by tidal waters."	
Shorebirds	Mainly on exposed beaches in association with estuaries. Tended to be dispersed over mudflats at low tide and concentrated in flocks on sandy beaches at high tide.	

MARINE MAMMALS

Introduction

Twelve families and about 25 species of marine mammals occur in the Bristol Bay-St. George Basin region of the Bering Sea (Table V-15). The main difference between this list and the one for Gulf of Alaska (see COOK INLET section) is that the following ice-adapted species occur north, but normally not south, of the Alaska Peninsula: walrus, bearded seal, ringed seal, ribbon seal, bowhead whale, narwhale, and polar bear. In addition, the ice-breeding form of the Harbor seal (= spotted seal) predominates north of Alaska Peninsula, whereas only the land-breeding form occurs south of the Peninsula (discussed further below).

A characteristic feature of the Bering Sea that is lacking from the Gulf of Alaska is seasonal pack ice. Fay (1974) aptly characterizes the role of Bering Sea pack ice in the ecology of marine mammals as follows:

> "The ice pack of the Bering Sea is a major component of the habitat of about one million marine mammals.... It is widely recognized that the ice of this and other sub-polar and polar seas is important to such mammals in at least two ways: first, it serves as a substrate on which pinnipeds haul out to sleep and bear their young, and second, it forms a rigid barrier through which pinnipeds and cetaceans alike must find or make holes in order to have access to the air that they breath and the sea that holds their food. For some species of polar marine mammals, the quality and quantity of ice may be as important in habitat selection as are terrain and vegetation to terrestrial mammals. For others, the mere presence of ice may be disadvantageous and may require them to undergo extensive migrations in order to avoid it. The study of ice as a major factor in the ecology of polar marine mammals is still in a rudimentary stage. In recent years, however, it has become increasingly apparent that ice plays many roles in the ecology of marine mammals and that its full importance to them has been greatly underestimated in the past."

The relative degree to which marine mammals in the Bering Sea are associated with sea ice is indicated in Table V-18 (after Fay 1974).

TABLE V-18

Marine Mammals of the Bristol Bay-St. George Basin Region (after Fay 1974)

Family	Species	Contact with sea ice: None	Some	Regular
Ziphiidae	Bottle-nosed whale		+	
	Stejneger's beaked whale		+	
	Goose-beaked whale		+	
Physeteridae	Sperm whale		+	
Monodontidae	Beluga whale			+
	Narwhale			+
Delphinidae	Killer whale		+	
	Dall porpoise	+		
	Harbor porpoise		+	
Balaenopteridae	Humpback whale		+	
	Blue whale	+		
	Sei whale	+		
	Minke whale		+	
	Fin whale		+	
Eschrichtidae	Gray whale		+	
Balaenidae	Bowhead whale			+
Otariidae	Northern fur seal	+		
	Steller's sea lion		+	
Odobenidae	Walrus			+
Phocidae	Harbor seal			
	Ice-breeding form			+
	Land-breeding form	+	+	
	Ringed seal			+
	Ribbon seal			+
	Bearded seal			+
Ursidae	Polar bear			+
Mustelidae	Sea otter		+	

Sea Otter

Some background information on the natural history of sea otters is summarized in the Cook Inlet section (also see ADFG 1973). The Bristol Bay population is estimated at 8,000 to 10,000 otters (ADFG 1973, cited by Schneider, RU #241), which are concentrated along the Alaska Peninsula from Unimak Island to Ugashik Bay (Fig. V-22). This population apparently has grown out a remnant population at Unimak Island and Izembek Lagoon that survived the era of commercial exploitation (Schneider, RU #241).

According to Schneider (RU #241) the Unimak-Alaska Peninsula population "... appears to be the most likely source of otters that will repopulate the Fox and Krenitzin Islands, the largest area of unpopulated sea otter habitat remaining in Alaska." However, Fiscus and Braham (RU #67) briefly surveyed Unalaska (one of the Fox Islands) and the Krenitzin Islands in June 1975 and counted 139 otters. Whether these otters represent an endemic breeding population or were immigrants from other areas apparently is unknown.

As pointed out in the section on Cook Inlet, the sea otter is highly vulnerable to direct effects of oil pollution because it lacks an insulating layer of fat and the thermal insulation normally provided by its fur is destroyed by soiling.

Pinnipeds: Numbers, Biomass, and Food Consumption

Favorite and McAlister (RU #77) have, in their development of a marine ecosystem model, compiled estimates of abundance, biomass, and food consumption of pinnipeds in the eastern Bering Sea. According to their estimates (which exclude walruses), pinnipeds in the eastern Bering Sea consume about 4.2

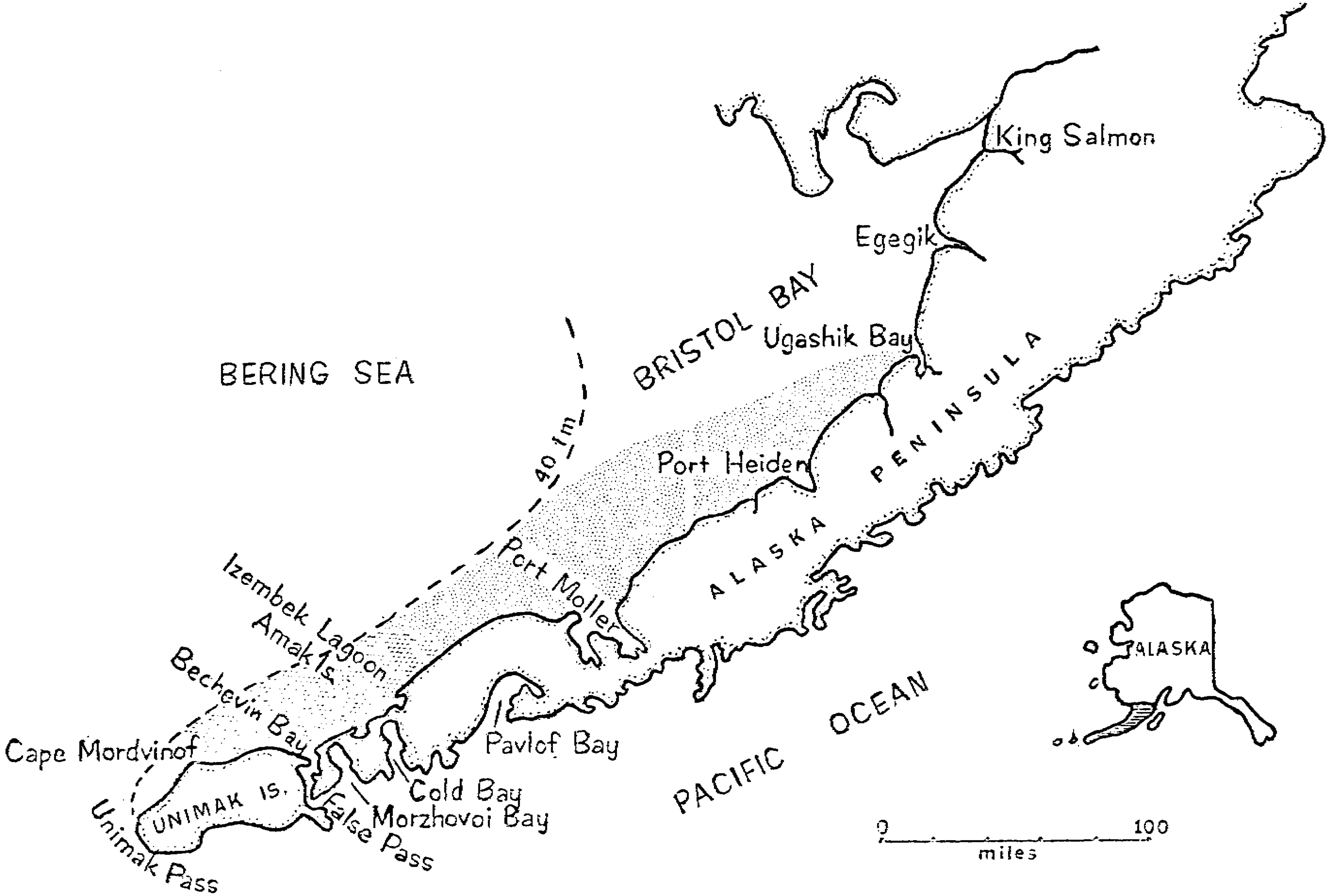


Fig. V-22. Distribution of sea otters in Bristol Bay (copied directly from Schneider, RU #241). The population is growing and small numbers of otters are found beyond the range shown here.

million metric tons of food per year (Table V-19). About 50% of the food consumed by all species combined consists of finfish (Table V-20). Favorite and McAlister's (loc. cit). most extensive data on specific food habits are for the fur seal, which subsists mainly (67% of diet) on pollock (Table V-21). [Data on specific food habits of other pinniped species are presented in the sections on Cook Inlet and the Beaufort Sea.]

Summer Abundance of Pinnipeds on the Coast and Islands of Bristol Bay

Fiscus and Braham (RU #77) counted pinnipeds along the coast of Bristol Bay between the Walrus Islands and Umnak Island on June 17-20, 1975. Their results are as follows:

Numbers counted:

Walrus	Steller's Sea Lion	Harbor Seal
3,524	16,109	30,927

All of the walruses were on Round Island (Walrus Island group), where the authors also counted 5,362 walruses on August 9. Ninety-six percent (29,730/30,927) of the Harbor seals counted were on the Alaska Peninsula. The largest concentrations of sea lions were at Ugumak Island (3,940 animals), Cape Morgan (2,894), and Sea Lion Rock (2,006).

Winter Distribution of Bering Sea Pinnipeds

The winter distribution of ice-dwelling pinnipeds if shown in Fig. V-23, illustrating that:

1. Ringed seals are restricted to landfast ice.
2. Bearded seals are widespread on the Bering Sea ice north of the southern edge of seasonal pack ice (but are confined to landfast ice north of Bering Strait).

TABLE V-19

Population Sizes, Body Weights, and Total (Estimated) Food Consumption of Pinnipeds in the Eastern Bering Sea (after Favorite and McAlister, RU #77).*

Species	Total Alaska Population Size ($x10^3$)	Average Animal Weight, kg†	Population Size in the Eastern Bering Sea:		Food Consumption in the Eastern Bering Sea (thousands of metric tons):			
			Summer	Winter	Summer	Winter	Annual	% of Total
Northern Fur Seal	1,300	50.3	55,000	96,650	380	67	447	11
Steller's Sea Lion	225	400	100,000	50,000	549	275	824	19
Harbor Seal (land-breeding)	270	140	65,000	65,000	365	605	970	23
Harbor Seal (ice-breeding)	250	140	125,000	250,000				
Ringed Seal	250	65	125,000	250,000	112	223	335	8
Ribbon Seal	100	80	50,000	100,000	55	110	165	4
Bearded Seal	300	240	150,000	300,000	494	988	1,482	35
		TOTALS:	670,000	1,111,650	1,955	2,268	4,223	100

*To estimate food consumption, Favorite and McAlister assume a daily intake equalling 7.5% of the body weight for a season of 183 days.

†Multiply average anumal weight by population size to obtain estimate of population biomass.

TABLE V-20

Annual Food Consumption of Finfish by Pinnipeds in the Eastern Bering Sea (thousands of metric tons) (from Favorite and McAlister, RU #77)

Pinniped	Food (thousands of metric tons)	Percent finfish	Finfish consumption (thousands of metric tons)
Northern fur seal	447	84	375
Steller's sea lion	824	90	742
Harbor seal	970	50	485
Ringed seal	112s/223w*	90w/40s	246
Ribbon seal	55s/110w	90w/40s	121
Bearded seal	1,482	10	148
TOTALS:	4,223		2,117

*s = summer; w = winter

TABLE V-21

Estimated Amount of Food Consumed by Northern Fur Seals in the Eastern Bering Sea, by Food Type, Based on Relative Food Consumption Observed During July-September 1973 (from Favorite and McAlister, RU #77).

Food type	Percent of total	Proportionate weight of food consumed (in thousands of metric tons)		
		Summer	Winter	Annual
Walleye pollock	67	254.4	44.9	299.3
Unidentified gadid	15	56.9	10.0	66.9
Gonatid squid	11	41.8	7.4	49.2
Bathylagid smelt	4	15.2	2.7	17.9
Greenland turbot	2	7.6	1.3	8.9
All others	1	3.8	0.7	4.5
TOTALS:	100	379.7	67.0	446.7

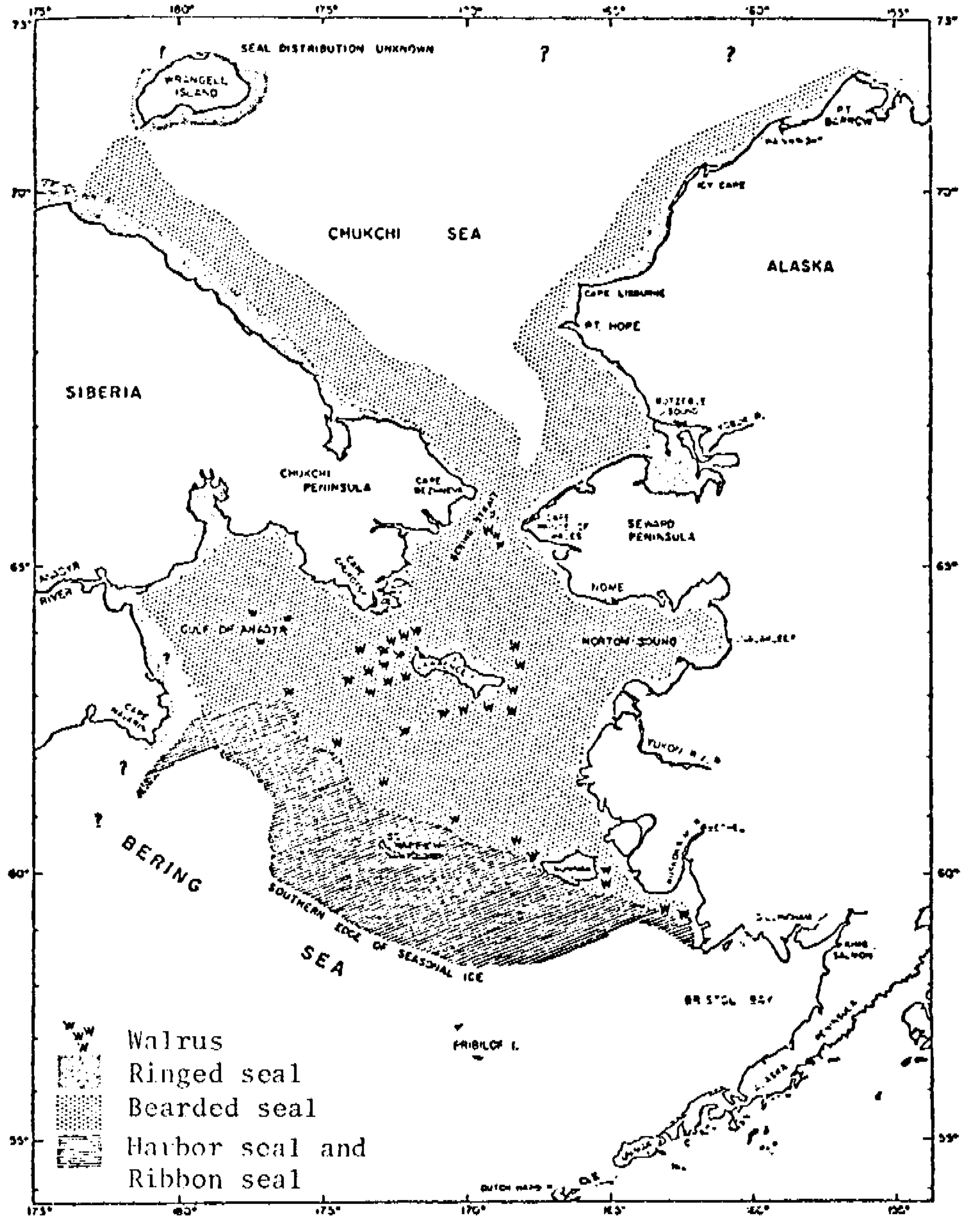


Fig. V-23. Winter distribution of ice-dwelling pinnipeds in the Bering Sea (copied from Burns et al., RU #248).

3. Spotted seals and ribbon seals inhabit the southern edge of seasonal pack ice in the Bering Sea (which consists mainly of small floes formed by disintegration of heavier pack ice).

4. Walrus are associated with the Bering Sea ice cover north of the seasonal pack ice, but tend to avoid the north side of islands, where convergence zones form in the southward ice drift pattern.

All of these ice-dwelling pinnipeds breed on the ice. As the ice disintegrates in spring and early summer, most of the walruses, bearded seals, Harbor seals, and ringed seals move northward and maintain association with ice in the Chukchi and Beaufort Seas throughout the summer. Most ribbon seals, on the other hand, apparently remain in the Bering Sea and become pelagic in summer (Burns et al., RU #248; Fay 1974).

Most of the fur seals that inhabit the Bristol Bay-St. George Basin region of the Bering Sea in summer move southward in fall, wintering in the North Pacific from the Gulf of Alaska to California and Japan. Steller's sea lions, by contrast, remain in the Bering Sea throughout the winter and are abundant along the ice front from Bristol Bay to the International Date Line (Fay 1974).

Effects of Oil on Pinnipeds

Gentry and McAlister (RU #71) are studying the effects of oil-fouling on diving behavior of instrumented, free-ranging fur seals (and possibly Harbor seals) on the Pribilof Islands. Preliminary trials on unfouled fur seals in 1975 have demonstrated the feasibility of the experiment. Data on oiled animals is to be collected in summer of 1976.

Experimental application of Norman Wells crude oil on ringed seals and harp seals in Canada had results varying from no persistent effects to sudden death (Smith and Gerachi, BSPTR #5).

Polar Bear

Polar bears are not abundant anywhere south of St. Lawrence Island (Fay 1974), and occurrences in the Bristol Bay region probably should be considered accidental. Their distribution is determined primarily by the abundance of their major prey, i.e., ringed seals and (secondarily) bearded seals (see BEAUFORT SEA section).

Belugas, Bowheads, and Other Cetaceans

The majority of Bering Sea belugas and bowhead whales spend the winter along the Bering Sea ice front and migrate northward in spring, as leads in the sea ice open, to summer feeding grounds in the Chukchi and eastern Beaufort Seas (Fay 1974; also see BEAUFORT SEA section). However, some belugas also spend the summer in the Bering Sea, including Bristol Bay (Fay 1974). The Bristol Bay beluga population is thought to reside there permanently and is estimated at 1,000 to 1,500 individuals (Klinghart 1966).

Other cetaceans of major importance in this region are gray whales and fin whales, whose north-south migration routes pass east of the Pribilofs, through the proposed St. George Basin lease area (see map of migration routes in KODIAK section). During an aerial survey along the northern coast of the Alaska Peninsula from June 17 to 20, 1975, Fiscus and Braham (RU #67) counted 124 live cetaceans, of which at least 68% were gray whales (Table V-22).

Fiscus and Braham (loc. cit). also sighted five whale carcasses during their survey, of which four were identified as gray whales (fifth was unidentified). Fay (RU #194) surveyed 754 km of the north coast of the Alaska Peninsula from July 22 to 25, 1975 to determine species, numbers, and causes of death of marine mammal carcasses. Eleven of the 12 (92%) whale carcasses that he found

TABLE V-22

Cetaceans Observed During an Aerial Survey Along the Northern Coast of the Alaska Peninsula, June 17-20, 1975 (data from Fiscus and Braham, RU #67)

Species	No. observed: Individuals	Groups	Group size: $\bar{X}$	Range
Gray whale	84	55	1.5	1-4
Beluga	2	2	1.0	1
Minke whale	4	4	1.0	1
Harbor porpoise	19	14	1.4	1-3
Unidentified whale	14	12	1.2	1-3
Unidentified porpoise	1	1	1	1
Totals/Averages:	124	88	1.4	1-4

were small gray whales; the twelfth was a minke whale. At Cape Newenham, Fay (loc. cit.) found one carcass each of gray whale, minke whale, killer whale, and Baird's beaked whale.

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Chapter VI

EFFECTS

Acute and chronic toxic effects of oil on fish and invertebrates and the effect of oil on microbial activity have been described in the KODIAK ISLAND-Effects section. These studies are not site specific, but obtained results are generally applicable to other proposed lease areas.

PHYTOPLANKTON

Alexander (RU #156-E) has reported results from experiments in which the effect of addition of copper, from 2 to 8 µg/ℓ, on plankton cell volume was studied. Although the number of observations were few and the uncontrolled variables many, she has inferred that plankton volumes, especially for larger microplankton, were almost always suppressed by added metals [copper].

A major problem with the interpretation of data provided in her Annual Report is that details of methods are not given. For example, it is not stated how the samples were incubated or whether cells were exposed to natural night or to a continuous, artificial light source. The initial concentrations of nutrients are not provided, so one cannot judge the significance of the addition of 0.3 µg-at PO_4-P and 4.5 µg-at NO_3-N [presumably per liter] to the samples. Procedures to "avoid trace metal contamination" and for the removal of zooplankters are not given either.

Several stations were occupied along an east-west transect from 167°E to 163°W in the Bering Sea. Only station 15 was located in the Bristol Bay region.

Two experiments were conducted on samples collected at this station; one to show the effect of the addition of copper and the other of both copper and naturally occurring polychaete larvae on plankton volumes after 100 hrs of incubation. Results for these two experiments are illustrated in Figs. VI-1 and VI-2, respectively.

It can be seen from Fig. VI-1 that in cells less than 8 μ in diameter, there was no appreciable effect of addition of 2 μg/ℓ of copper and a marked reduction with 8 μg/ℓ of copper. For cells with 8 to 10 μ diameter, effects of different copper concentrations were nearly indistinguishable. For cells with 22 μ diameter, more plankton value was noted in experimental chambers with 8 μg Cu/ℓ than in those with 4 or 2 μg Cu/ℓ; infact cell volumes in chambers with 4 or 8 μg Cu/ℓ were appreciably higher than in the control chamber. In cells with diameter larger than 22 μ no pattern of increase or decrease in cell volume was discernible.

From Fig. VI-2 it appears that polychaete larvae in experimental chambers (population density not known) greatly reduced cells with diameters smaller than 15 μ. All three curves representing effects of addition of copper in the medium, 2, 4, and 8 μg/ℓ, show higher volumes than the control for the entire size range studied, especially in cells with diameters larger than 20 μ. Only in the case where 2 μg Cu/ℓ were added, cells smaller than 10 μ in diameter showed volumes lesser than the control; the difference was not large, however.

In all experiments, including those in the western Bering Sea (not illustrated here), the initial population was nearly always lower than the populations exposed to different concentration of copper. Phytoplankton may have been nutrient limited.

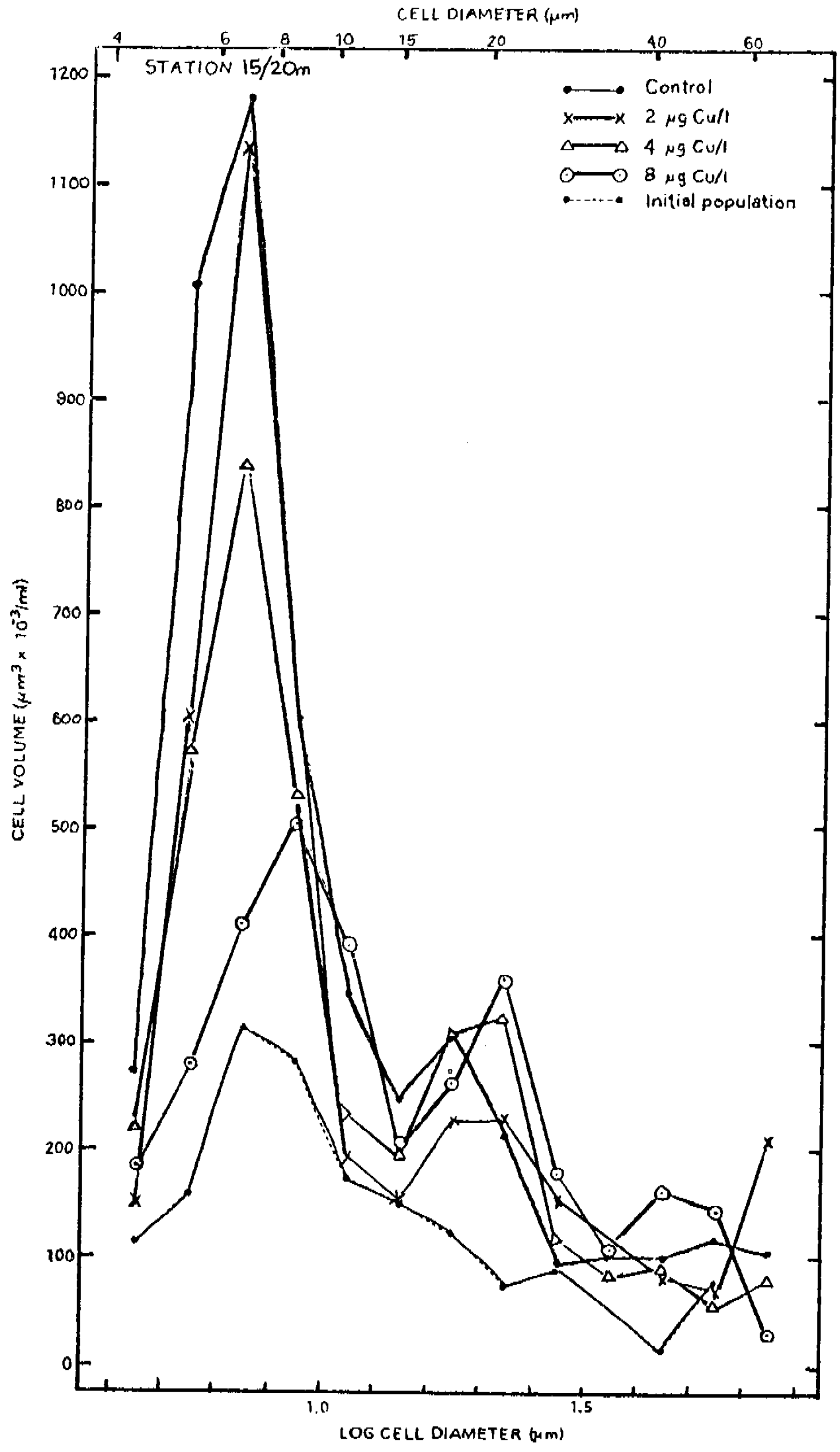

Fig. VI-1. The effect of addition of copper on plankton cell volume after 100 hr incubation at station 15, outer Bristol Bay (figure reproduced from Alexander, RU #156-E).

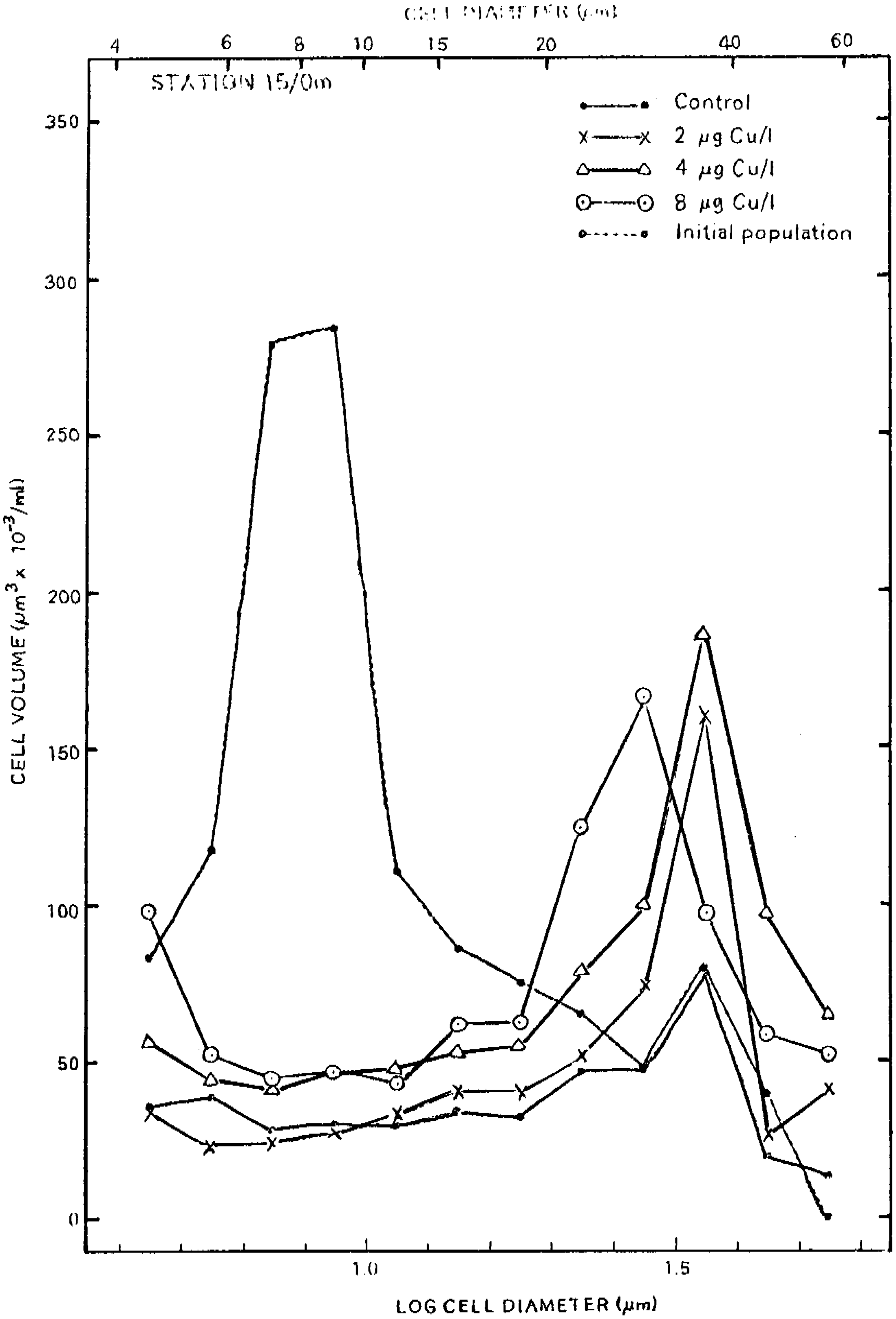

Fig. VI-2. The effect of naturally occurring polychaete larvae and the addition of copper on plankton cell volume at station 15, outer Bristol Bay (figure reproduced from Alexander, RU #156-E).

In view of the above, it is not possible to concur with Alexander's inferences regarding suppression of phtyoplankton biomass (volume) by the addition of copper without qualifications and restraint.

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SECTION 6

BEAUFORT SEA AND SHELF: PHYSICAL ENVIRONMENT, BIOTA, AND POTENTIAL PROBLEMS RELATED TO OIL EXPLORATION

A Scientific Report Based on Primarily
OCSEAP-Sponsored Research

CONTENTS

Chapter I

ENVIRONMENT

DESCRIPTION OF STUDY AREA

The Beaufort Sea differs from the seas surrounding other OCS lease areas in that its surface is covered with ice most of the year. It acts as a lid, tending to isolate water from the atmosphere. The isolation is not complete as ice never forms one complete solid and continuous cover.

A general description of the ice cover in the Beaufort Sea has been given by Kovacs and Mellor (1974). The southern Beaufort Sea (below 75°N) can be broadly subdivided into three ice zones: (1) Fast Ice Zone; (2) Seasonal Pack Ice Zone including the nearshore shear zone; and (3) Polar Pack Ice Zone.

> The Fast Ice Zone consists of a continuous sheet of normally smooth, seasonal ice stretching from the shore to anchoring points on grounded pressure ridges or ice island fragments. The outer edge generally coincides with the 18 to 20 m depth contour by winter's end, and its outer portions may include heavy ridging or rubble fields generated by early winter storms and subsequently is "frozen in place." Depending upon snow cover the undeformed ice normally reaches a thickness of approximately 2 m. Detailed descriptions of this zone are given by Cooper (1974) and Stringer (1974).
>
> The Seasonal Pack Ice Zone is subdivided into a narrow shear zone of brecciated ice and a larger region of deformed and partly deformed seasonal ice extending generally 100 to 200 m to the edge of the continental shelf. The nearshore shear zone consists of rapidly deforming, heavily ridged and highly irregular ice acting as a boundary layer between the circulating ice of the Beaufort Gyre and the fast ice. The outer section of the seasonal pack ice zone contains first-year ice which has undergone some deformation but with some multi-year floes and ice islands fragments also present. The undeformed seasonal ice in this zone reaches an average thickness of 2 m and has a salinity of 3 to 14 ppt.

The Polar Pack Ice Zone which extends into the Arctic Basin is composed of thick multi-year floes which are surrounded in summer by open water or thin ice and in the winter by first-year ice sandwiched between them. The low-lying terrain of old multi-year floes varies in thickness from 2.1 to 4.5 m, and the ice has a salinity of 0 to 6 ppt (Kovacs and Mellor 1974).

The pack ice floe size is quite variable and grades from large multi-year floes in the eastern sector to a mixture of small, fragmented first-year and multi-year floes on the west (Ramseier 1975a). Along a constant latitude line, the mean flow diameter decreases from 25 to 100 km in the east to 1 to 2 km in the west. The average roundness of the floes decreases from east to west (Campbell et al. 1974; Ramseier et al. 1975b).

In the summer months the fast ice breaks up and disperses along with some floes from the seasonal pack ice zone which forms an open water zone that may extend up to 200 km from the coast. Since the polar pack ice is never far away from the first two zones, it can be driven in toward the coast at any time by a strong onshore storm wind.

GEOLOGY

The coastal morphology of the Alaskan Arctic coast from Point Barrow to Demarcation Point was studied extensively by McIntire et al. (1973). Although this coast is influenced primarily by an Arctic environment, it exhibits a range of coastal landforms comparable to those found throughout the world. The 816 km of coast between Point Barrow and the Demarcation Point contain four irregular, discontinuous barrier island chains that occupy 52% of the coast. The gross morphology of the chains appears to be influenced by lineaments which cause them to trend approximately 35°; the first three chains roughly overlap from east to west. Both the islands and their beaches are composed of coarse sand and gravel with distinct bimodality in the beach zone. In addition, tundra bluffs extend along 260 km (32%) of the coast, and the Colville and Ikpikpuk River deltas take up 135 km (16%).

A major feature of the Beaufort Sea coast of Alaska is the fact that all major rivers of Arctic Alaska emerge along this coast. The courses of the rivers are generally correlated with the major northeast lineaments. The overall river discharge results in large deposits of sediment along the nearshore zone, causing local flattening of the offshore slope and resulting in the accumulation of large coastal deltas which account for 135 km of the coast east of Point Barrow.

A prominent geologic feature of the Alaskan Arctic coast is the presence of a continuous layer of permafrost where the temperature never rises above 0°C. The maximum thickness for permafrost has been found to be 548 m in the Prudhoe Bay area, 405 m at Barrow, and 357 m at Cape Thompson. Between the surface and the permafrost layer is an "active layer" (from a few centimeters to a couple of meters thick) which thaws in summer and freezes in winter. The depth and rate of soil thaw depend primarily on the amount of incoming solar radiation but is also influenced by soil texture, soil water content, winter snow cover, and the vegetation canopy. Water derived from rain, snow, and thawing of the subsoil accumulates above the permafrost forming a liquid layer beneath the vegetative mat.

Permafrost and frozen sub-seabottom materials also occur under much of the coastal waters of the Beaufort Sea, though little is known about their areal distribution, thickness, nature, and equilibrium. In a recent study, carried out as part of the Canadian Beaufort Sea Project, Hunter et al. (BSPTR #22) concluded that as a result of large changes in the surface thermal regime in the recent geological past, nonequilibrium conditions are probably found in most areas; hence permafrost is aggrading downwards from the sea floor in the offshore, and is degrading in the inshore region. Based on seismic refraction studies, it is estimated that the permafrost thickness varies from 600 m at the shoreline to a thickness of 100 m in the offshore. It is also estimated that the upper boundary of ice-bonded permafrost can occur at depths between seabottom and 200 m below.

GENERAL CLIMATE

The climate along the northern Alaskan coast is classified as Arctic by the National Weather Service. During most of the year, the Arctic is covered by a shallow layer of stable cold air which is effectively isolated from the atmosphere above. Winter temperatures average -26°C to -32°C with winds producing wind chill factors to -46°C and lower. The warmest months, July and August, have an average temperature of +4°C and +3°C, respectively, though freezing temperatures and snow are not uncommon during these months. Freezeup generally occurs in September following which there is no appreciable thawing until the following June. It should be noted, however,that freezeup and breakup dates are extremely variable from year to year.

Precipitation over most of the Arctic coast is very light with a total mean average of less than 25.4 cm. Precipitation is highest in July and August and is generally in the form of rain. In winter the cold air can hold little water vapor and the frozen ocean surface slows evaporation of water into the air. The relative humidity in the Arctic is generally high with values averaging from 60% to 90% throughout the year. During the warmer months, fog frequently reduces visibility along the coast and may be expected to occur on at least 90 days each year.

Surface winds are common along the Beaufort Sea coast and blow at a fairly constant speed. The yearly average wind speed is 24 to 32 km/h in relatively exposed areas. Both ocean and coastal zones may also experience high winds at times. Wind speeds equal to or greater than 40 km/h occur on an average of 5.5 days per month.

The high northern latitudes of the northern Alaskan coast from Demarcation Point (69° 32' N) to Barrow (71° 25' N) provide continuous sunlight in summer and long periods of darkness in winter. At Barrow the sun is continuously above the horizon from May 10 to August 2 and continuously below it from November 18 to January 23. A more detailed description of the climate of the Alaskan Arctic North Slope can be found in Searby (1968) and in Searby and Hunter (1971).

SEA ICE

Research efforts related to OCSEAP have concentrated on mapping the seasonal distribution of certain morphological ice types in the landfast ice zone using satellite and airborne imagery (Stringer, RU #257; Weeks and Kovacs, RU #88) and attempting to link ice movements to climate and other factors (Barry, RU #244). Preliminary conclusions reported by Stringer include the following:

> "Within a certain range of variability, ice conditions along the Beaufort Coast are predictable: for several months a great deal of reliability can be placed on the existence of a stable sheet of ice extending to roughly the location of the 10 fathom (18 m) contour... Beyond this stable ice boundary, dynamic ice events can occur at any time depending largely on meteorological conditions." Furthermore, "ice translation during mid-winter shearing events is often quite small -- on the order of 10 to 20 km."
>
> Nearshore ice morphology is generally similar from Barrow to Barter Island; the overall pattern of ice conditions repeats from one year to the next. Specific features such as ridges, hummock fields, or smooth ice areas, are somewhat predictable and are formed relatively early in the ice season. By mid-February the seaward limit of ice contiguous with the shore can be well beyond the 18 m depth contour. When shearing takes place, it tends to be located seaward in mid-winter and moves shoreward as the season advances.

In other studies of ice morphology, Weeks reports from preliminary analysis of airborne laser profiles that:

"Striking differences in ridging intensity were noted both along and normal to the coast with most intense deformation occurring in the vicinity of Barter Island." (Weeks and Kovacs, RU #88)

Both Barry (RU #244) and Belon (RU #267) have attempted computer-aided classification and mapping of surface morphological features using multi-spectral Landsat digital data. In both cases the working hypothesis is that the statistically clustered multi-spectral information may be linked in a consistent manner to surface morphological features such as smooth ice ridges or hummock fields of the nearshore ice. If such a computer-aided system could be developed, then large areas could be mapped in a uniform and rapid manner. However, neither project has proved (or disproved) the utility of such computer-aided ice morphological classifications.

Barry (RU #244) has developed a potentially useful synoptic scale surface/atmospheric pressure classification system for comparison of general atmospheric circulation to ice response on a seasonal basis. "The method selects certain key patterns from about a 50 month sample of daily pressure data at 36 grid points and then classifies all days into one of the several 'Key day' patterns using a 'most similar' statistical test based on standard deviations of normalized daily pressures. The rationale for this typing procedure is that each Key day is a good representation of a group of pressure patterns which reappear in the sector through time. The synoptic-scale atmospheric history is thus composed of these types plus a small group of unclassified patterns." (Barry, RU #244)

Stratifications of temperature departures and geostrophic wind directions by synoptic type indicate consistent positive (or negative) temperature departures from seasonal means and unique geostrophic wind direction may be associated with some of the patterns in the synoptic type catalog

Of the most frequent synoptic types which constitute 78% of the days in the 1969-74 sample, three are associated with below normal and four with above normal temperatures. The geostrophic wind analysis for the same types indicate that at least in winter, the warmer types exhibit southerly and the colder types northerly surface geostrophic flow.

Barry also concludes from examination of the geostrophic wind indices that in eight of the ten warmest Julys at Barrow, the wind direction was generally between 130° and 220°. At Barter Island, the five warmest Julys had winds between 100° and 285°. Of the 12 colder Julys at Barrow only one had southerly flow and at Barter Island only one of five colder Julys had southerly flow. Thus, the direction of transport is closely related to the relative anomaly of temperature at these stations.

Compilation of freezing degree days (FDD), thawing degree days (TDD), and lake ice thicknesses by Barry indicates that a direct correspondence between these three terms does exist but exact relationships have not yet been established. It is also of interest that the daily occurrence of warm synoptic types peaked during the 1966-67 winter when lake ice thickness and FDD were both at a minimum.

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Chapter II

SOURCES

INTRODUCTION

Marine waters contain accumulations of naturally occurring and artificially introduced hydrocarbons and heavy metals. Hydrocarbons are synthesized by phytoplankton and promulgated through the food chain by metabolic destruction and resynthesis into protein, carbohydrate, and lipid. Hydrocarbons also originate in the marine environment from natural petroleum seeps and through accidental and/or purposeful discharges from oil development, transport, and production. Recreational and other marine transports and various industrial users periodically discharge oil-based effluents.

Likewise, heavy metals originate from similar sources. Providing the metal loading remains low, the marine environment readily absorbs moderate influxes. Metals, even though some are toxic, are essential to an organism's nutrition. Selected metals are taken up from the water by organisms and may be transported to deep waters; new supplies are brought into the upper layers by upwelling and direct input in the surface waters. Chemical, physical, and biological reactions cause precipitation of excesses and solubilization to offset deficiencies.

In pristine waters such as those found along the Alaskan Outer Continental Shelf, significant inputs of hydrocarbons and metals through oil developments and releases are readily detectable. The OCSEAP-related research is designed to characterize both the hydrocarbon and metal levels in the Alaskan marine environment.

C_1-C_4 HYDROCARBONS

C_1-C_4 hydrocarbons are valuable indicators of petroleum contamination because of their high solubility and low natural abundance. Cline and Feely (RU #153) have determined levels of methane, ethane, ethylene, propane, propylene, isobutane, and n-butane in the Gulf of Alaska and southern Bering Sea. No samples were collected from the Beaufort Sea, therefore it is not known what the concentration levels would be. Due to its historical isolation and cold, nonproductive waters, the expected values may be more comparable to the Bering Sea (See Bristol Bay-St. George Basin Report).

OTHER HYDROCARBONS

Research by Shaw (RU #275), in cooperation with Kaplan subcontracted under (RU #275), is designed to determine background hydrocarbon levels in sea water, biota, sediment, and seston and to recognize organismic tissues which may serve as indicators of petroleum pollution. So far samples from Gulf of Alaska and Bering Sea have been analyzed. No data from the Beaufort Sea have yet been obtained, though results are expected to be comparable to Bering Sea analyses (See Bristol Bay Report).

HEAVY METALS

Inorganic sediments constitute the largest repository of heavy metals, but those held in the biota are of particular concern to man. The importance of sea water lies not in the absolute amounts or concentration of metals held, but in its role as a mobile phase through which, and with which, these trace constituents can be transported (Burrell, RU #162).

It should be pointed out that data from Beaufort Sea have not been obtained.

MICROBIOLOGY

OCSEAP-related research in microbiology can be subdivided into three categories: (1) characterization of the marine microbiological community, including rates and limiting factors of hydrocarbon degradation and the effects of crude oil on heterotrophic activity; (2) evaluation of the present health status of demersal fishes so that possible environmental perturbations in the future can be evaluated; (3) determination of the potential for release of soluble trace metals following oil impaction of marine sediment, and evaluation of interstitial metal changes to variations in microbial or biological activity or chemical perturbations within the sediments.

This report includes results from field and laboratory studies by McCain and Wellings (RU #332), Morita and Griffiths (RU #190), Atlas (RU #29), Barsdate (RU #278), and by Bunch and Harland (BSPTR #10). To date these are the only studies conducted on the heterotrophs in the Beaufort Sea.

Microbial Abundance and Degradation of Crude Oil

Atlas (RU #29) has shown that population levels of microorganisms in Beaufort Sea water were 10^5 to 10^6 organisms/mℓ. Comparable population levels, 10^6 to 10^7 Colony Forming Units/ℓ, were noted by Bunch and Harland (BSPTR #10) for the eastern Beaufort Sea. Samples collected from the ice provided counts similar to those in the water (Atlas, RU #29). Direct counts from sediment samples were one to two orders magnitude higher than in the water or ice (Atlas, RU #29). Studies by Morita and Griffiths (RU #190) utilizing the maximum potential uptake of glutamic acid, have shown that rates of uptake in nearshore sediments may be 400 times higher than in the water column.

These microbial levels have been compared by Bunch and Harland (BSPTR #10) to levels found in more temperate seas. Even though sampling techniques vary with investigations, similar values were found in the estuaries and offshore areas of the New England coast (Kaneka and Colwell 1973; Sieburth 1967; Atlas and Bartha 1972).

Although heterotrophs are present in the Beaufort Sea, the presence of oleoclastic-psychrophilic forms is essential to degradation of oil. Atlas (RU #29) found one organism/10 mℓ of the psychrophilic-psychrotropic oil-utilizing variety in water samples. Generally, these species were higher in sediment samples. Atlas also found that oleoclastic-psychrophilic microorganisms occurred in most water, ice, and sediment samples collected. A comparison of samples from the Prudhoe Bay and Barrow areas indicated that although no difference was generally noted in the total heterotrophs, there was a significantly higher number of oleoclasts in Prudhoe Bay.

Bunch and Harland (BSPTR #10) and Morita and Griffiths (RU #190) found that isolates of Beaufort Sea hydrocarbon degrading heterotrophs did degrade Alaskan and Canadian crudes. Bunch and Harland noted a delayed reaction of four weeks before measurable degradation occurred. Morita and Griffiths did not see this delay, but as in the Canadian study, both teams of investigators noted stimulation after degradation was initiated. This was explained as more heterotrophs are capable of utilizing metabolic products than are capable of degrading crude.

Morita and Griffiths (RU #190) also isolated sulfate-reducing bacteria from Beaufrot Sea sediments. The growth of Desulfavibrio sp. causes production of hydrogen sulfide. Although a four-week delay was noted before growth appeared, the presence of these organisms should not be overlooked. Hydrogen sulfide is toxic to most marine life. Subsequent development of anoxic conditions could be perpetuated in lagoons by dying organisms enhancing the reduction of oxygen levels.

Presumptive counts of Pseudomonas spp. and Salmonella spp., which are human pathogens, were low or absent in all samples. On the other hand, Vibrio spp. were found in excess of 100 organisms/mℓ. Vibrio spp. were also of the psychrophilic-psychrotophic type.

In conclusion, it is evident from these data that heterotrophic populations in the Beaufort Sea are similar in numbers to those found in temperate seas. It is also evident that petroleum degradation and pathogenic species are present. The pathogenic forms indicate some anthropogenic pollution in the areas of Prudhoe Bay and Barrow. Although petroleum degradation has been shown to occur in laboratory conditions at temperatures similar to those found in the Beaufort Sea, the rate of degradation is in the process of being defined. Preliminary evidence indicates it may take more than one ice-free season to degrade crude oil (Bunch and Harland, BSPTR #10). Further studies are continuing to better define the rate of degradation.

Health Status of Demersal Fish

Disease incidence studies, which may be useful in appraising the effects of man's activities in those waters, have not been initiated in the Beaufort Sea.

Release of Soluble Trace Metals

Barsdate (RU #278) has shown in initial laboratory studies that the copper concentration of sediment pore waters may increase following impaction of oil. Tentative results indicate that the effect is ascribed to the occlusion of trace metal binding or exchange sites by components of oil. This is considered to be a physical or chemical reaction rather than the result of microbial activity.

Increases in metal compostiion of the pore waters after oil impaction may be reflected in the benthic organisms. Such changes may also be noted as increased metal concentrations in the waters above. Should metal levels increase markedly, the species composition in the benthic and pelagic environments may be affected.

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Chapter III

HAZARDS

STORM SURGES

Storm surges, on the order of 1 m in amplitude, occur frequently on the Beaufort Sea coastline, especially during the ice-free period. A major surge can easily flood huge areas of low lying coastal areas on the north Alaskan coast. The combined effects of an oil spill on the sea and a storm surge would probably be disastrous. Storm surges greatly accelerate erosion processes; several normal years of erosion can occur during one storm surge. Water levels 2 m above normal have been known to occur occasionally.

It has been reported that during a storm in the southeastern Beaufort Sea from September 13-16, 1970, three separate occurrences of hurricane strength winds were noted. These winds caused wave heights of up to 7.5 m and storm tides up to 3.6 m high. It was also noted that during the storm, the polar pack ice was more than 160 km north of Herschel Island. Within 36 hrs the winds had driven large amounts of pack ice, including remnants of multi-year ice, into Babbage Bight. A large ice-island came aground about 275 m from shore and broke in two (unpublished report--Study of the Beaufort Sea Storm of September 1970, quoted in Oil Under the Ice, CARC, 1976).

No NOAA/OCSEAP research project specifically deals with the study or simulation of storm surges. It is an important aspect in the evaluation of potential hazards along the north Alaskan coastline, especially in view of the meteorological conditions over the Arctic in general and coastal geomorphology along the western Beaufort Sea.

Data somewhat related to storm surge studies can be made available by investigators working on Transport of pollutants (Callaway, RU #355), Current Structure (Hufford, RU #81), Mass Distribution (Aagaard, RU #151), and Climatology (Searby and Brower, RU #347).

SEA ICE

Stress-Strain Relationships and Ice Forces

Offshore structures in the Arctic must be designed to withstand the forces that can be exerted against them by sea ice. However, little data exists regarding the magnitudes of the forces that can develop within an ice sheet, and the parameters that describe the mechanical properties of sea ice, that are necessary for calculations regarding the interaction of sea ice with structures, are poorly known. OCSEAP-funded projects that are directed towards these problems include: Shapiro and Harrison, RU #250; Nelson and Sackinger, RU #259; and Shapiro et al., RU #265. OCSEAP-funded work to date has been preliminary in nature and has concentrated on: (1) initial field tests of hardware (Shapiro et al., RU #265), (2) general reconnaissance surveys (Shapiro and Harrison, RU #250; Nelson and Sackinger, RU #259) and (3) some theoretical modeling of grounded ridge formation (Shapiro and Harrison, RU #250).

There are numerous problems associated with the experimental determination of the mechanical properties of sea ice. These are primarily related to changes in the physical and chemical properties of the ice during the process of collecting, storing and preparing samples for experiments from which measurements of the various physical properties can be made. A program of _in situ_ determination of mechanical properties of sea ice (Shapiro et al., RU #265) has therefore been initiated in order to verify and supplement laboratory results.

In the *in situ* experiments, flatjacks are frozen into the ice sheet and loaded to generate stress fields. The magnitude of the stress at various distances from the flatjacks, and the resulting strain, are measured by appropriate transducers embedded in the ice sheet. Preliminary results indicate that satisfactory creep and recovery curves can be obtained in this manner. Tests of the strength of ice in direct shear, uniaxial compression, and indirect tension have also been successfully run. The objectives of the first stage of this project, the development of techniques for making the relevant measurements, is therefore essentially complete.

Two other projects (Shapiro and Harrison, RU #250; Nelson and Sackinger, RU #259) are concerned with the mechanism of ridging and hummocking in landfast ice and the magnitude of forces reached during the impact between moving pack ice and landfast ice. Shapiro and Harrison (RU #250) are investigating the formation of shear and pressure ridges and hummock fields, relying primarily on the University of Alaska sea ice radar system at Barrow to provide data on the vectors of ice motion at the time ridges are formed. In conjunction with this, they are adapting a theoretical model of the kinematics of pressure ridging in the open sea, developed by Parameter and Coon (1973), to the case of grounded pressure ridges, and are examining other models of interaction at the offshore face of a growing ridge. In addition, they have conducted field studies of the formation of pressure ridges along the beach at Barrow during early summer ice movements. The results of the field work indicate that stresses associated with failure of the ice in extension and possibly in buckling, were reached locally during the formation of these ridges. Further, in some areas the ice sheet (approximately 1 m thick) was driven up a rubble pile at a 20° angle, then bent back to the horizontal without losing coherence. The ability of the ice to bend through these angles and still retain continuity should be considered in the design of offshore structures such as gravel or ice islands.

RU #259 (Nelson and Sackinger) instrumented a grounded multi-year floe which was imbedded in the nearshore stable landfast ice northeast of Barrow and recorded environmentally induced stresses from pack ice as it sheared past the nearshore ice sheet. Results of the first and, to date, the only experiment 2.2 km offshore from Barrow support the hypothesis that "stresses generated by pack ice impingement on landfast ice are low when the motion is predominantly shearing past the landfast ice. This implies that at certain times, landfast ice may be a safe location for oil exploration or drilling activities." It must be emphasized that this conclusion is based on a single set of measurements and must be considered tentative.

GEOLOGY

Seismic and Volcanic Hazards

The continental shelf of the Beaufort Sea and the adjacent Arctic coastal plain are both seismically quiet regions and neither contains evidence of any volcanic activity. Meyers (RU #352) has recently summarized the available data on approximately 10,000 earthquakes that have been recorded from the Alaska region (defined as extending between latitudes 48^{o}-75^{o}N and longitudes 165^{o}E-125^{o}W) in the years between 1786 and 1974. Only 18 of these historical earthquake epicenters were located between latitudes 68^{o}-74^{o}N and longitudes 125^{o}-168^{o}W (Fig. III-1). Still fewer -- only five events -- have been recorded within the limits of the proposed Beaufort Sea lease area. These five epicenters were all located on the shallow continental shelf northwest of Barter Island, and none exceeded a magnitude of 4.7 on the Modified Mercalli Intensity Scale (Wood and Newmann 1931; Meyers, RU #352). To date only one major earthquake has been recorded relatively close to the Beaufort Sea region. This was an earthquake of magnitude 6.5 that occurred in 1920, whose epicenter was located some 300 km due north of Cape Bathurst (Fig. III-2).

These data indicate that seismic hazards within the proposed Beaufort Sea lease area are relatively slight. No earthquakes with magnitudes greater than 4.7 have been recorded there. No evidence of surface faulting, sustained ground shaking, slope instability, slumping, or sediment liquifaction -- all earthquake-related hazards -- has been noted. Since the slopes encountered on the Beaufort Shelf are very gentle,(Namtvedt et al. 1974) the probability of local, low-magnitude seismic events causing extensive slumping appears minimal.

The records reviewed and summarized by Meyers (RU #352) contained no evidence of either seismic-related tsunamis or seiches having occurred along the coast of the Beaufort Sea since 1786.

No geologic hazards related to past or present volcanism exist within the Beaufort Sea region.

EARTHQUAKES IN AND NEAR ALASKA (THRU 1974)

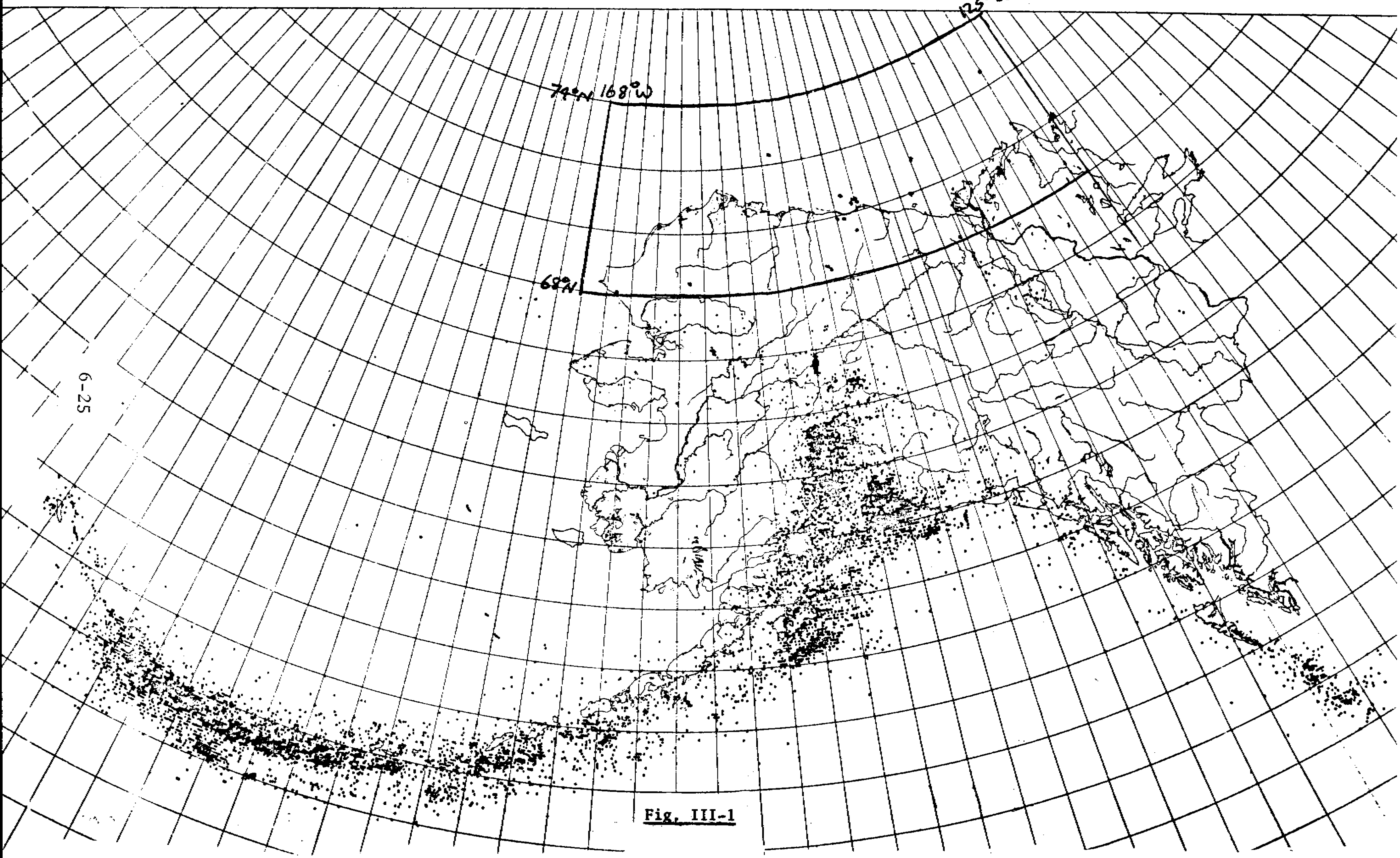

Fig. III-1

MAJOR EARTHQUAKES IN ALASKA (1899-1974)

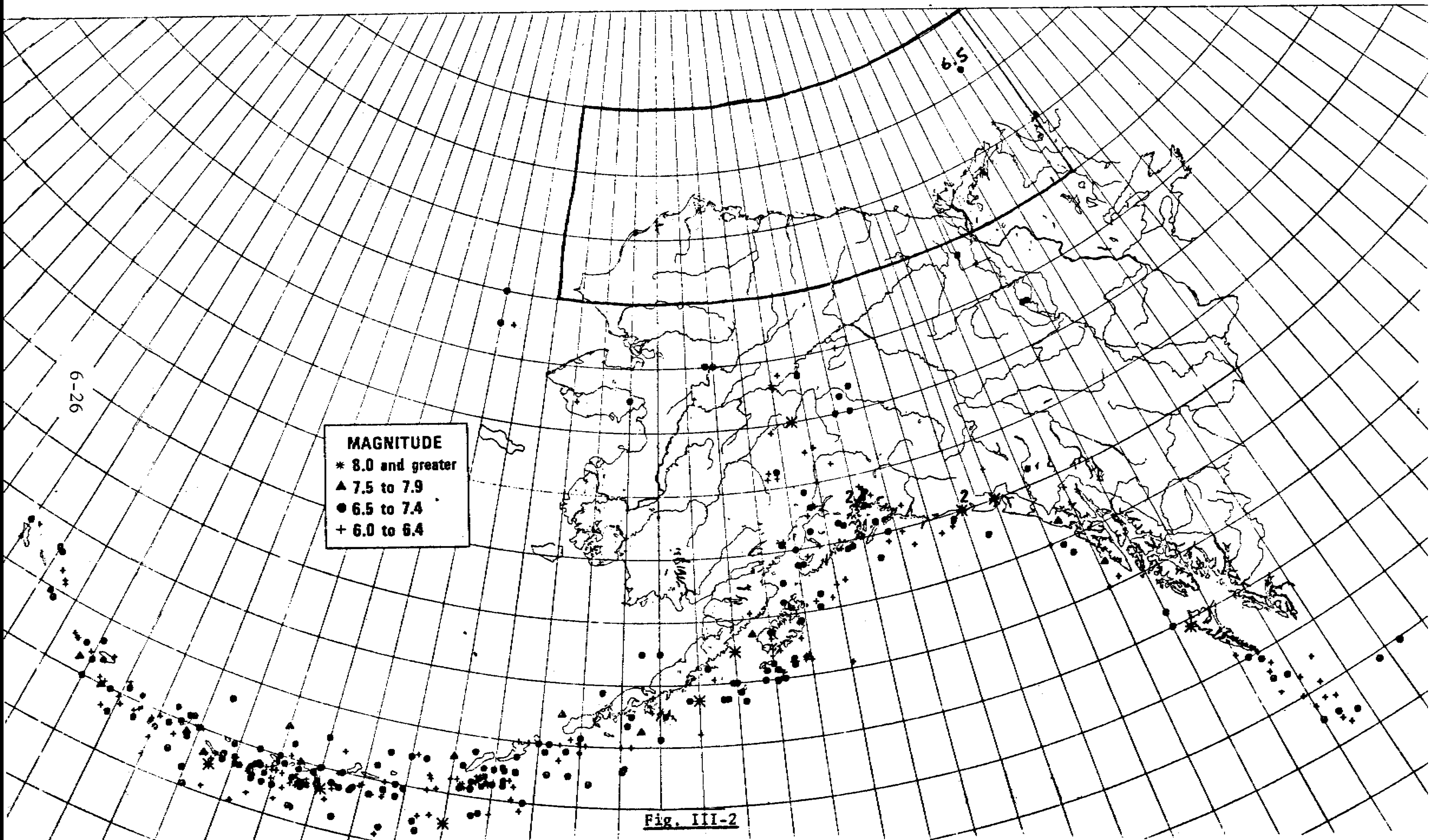

Fig. III-2

Coastal and Barrier Island Erosion and Migration

Coastal erosion along the Alaskan Beaufort shoreline is being estimated by Lewellen (RU #407). Lewellen notes that adequate data exists on coastal erosion in northern Alaska, but that much of the information has never been compiled or published. He has been collecting and comparing old maps, field notes, and sequential aerial photographs taken by various agencies since 1945. Detailed results are not yet available; however, to date, 204 observations or measurements have been made from the aerial photography. The mean thaw-season shoreline erosion rate has been determined as 2.03 m for the 204 observations. The standard deviation is 1.63 m. The rates range from stable or zero to 10.4 m per thaw season. Spits, shoals, barriers, bars, etc. are being formed in many areas.

While Lewellen's conclusions must remain preliminary, they are strongly supported by the findings of Lewis and Forbes (1974) who conducted field research on <u>Sediments and Sedimentary Processes on the Yukon Beaufort Sea Coast</u> for the Canadian Beaufort Sea Project. They concluded that the Canadian Beaufort Sea coast is retreating an average of 5 to 6 m per year. Though this figure is greater than Lewellen's average, the general conclusion that rapid shoreline retreat is the norm for the Beaufort Sea coastline is confirmed.

Several Beaufort Sea offshore barrier islands have been observed by various investigators since 1914 when Leffingwell visited the area. Barnes et al. (RU #205) recently described geomorphological changes and estimated the rates of erosion and migration of Cross Island, located some 18 km north of the Sagavanirktok River delta. Using a number of old and recent charts and aerial surveys of various scales and resolutions, beach retreat along the north shore was measured as slightly less than 50 m between 1949 and 1955, or 8.3 m per year. Between 1949 and 1974 the retreat totaled between 150 m to 170 m, an average retreat of 6 m per year. Barnes et al. concluded that:

Sediment appears to be eroded from the northern shore and transported to, and deposited on, both ends of the island, but movement of beach material seems to be mainly toward the west. On the west end of the island a recurved spit is being formed, that eventually may become similar in shape and morphology to the spits that enclose the two shallow embayments on the landward side of the islands. This would form a third embayment. The embayments enclosed by recurved spits record the migration of the island. The two existing embayments indicate northwesterly migration, the presently forming embayment seems to indicate a shift in migration direction to westerly. A westward migration of Cross Island is in agreement with the migration direction of other barrier islands along this section of the Beaufort Sea coast.

The average rate of barrier island migration to the west is between 6 and 25 m per year (Wiseman et al. 1973). On larger islands such as Pingok, which lies immediately to the west of Cross Island, this erosion results in permanent destruction of the tundra. During 1972 Pingok Island lost 40 m at its eastern end while a 200 m spit was deposited on its western end (Short et al. 1974).

Barnes et al. (RU #205) have stated:

Cross Island is the focal point for the early winter shear lines in the sea ice. Major ridges form close to the island, and ice shove commonly affects the beaches. Other islands in the area, protected from shear zone dynamics, are little affected by ice shove. Ice shove brings cobbles and pebbles, found by diving near the beach at 15 to 20 ft depth, up onto the beach face. This ice shove may be one of the reasons why Cross Island is 4 to 5 ft higher than the characteristic barrier islands along Simpson Lagoon. The bottom off Cross Island also slopes much steeper than off other islands that are protected from shear zone dynamics. Grounded ridges off the island commonly remain stationary throughout the summer. Therefore, the north side is almost completely protected from wave action during the average year.

The above observations on Cross Island may have certain implications for offshore development and construction by man, because of some similarities between the island and artificial drilling islands used elsewhere in the Arctic. It lies further offshore, and in deeper water than those, and is exposed to pack ice drift. In fact, Cross Island controls the pack ice drift, and the extent of the relatively undeformed fast ice. Further studies of ice dynamics in relationship to the island may provide information on the feasibility of modifying the ice zonation off Prudhoe Bay.

Offshore Permafrost

During 1975-76 NOAA/OCSEAP supported four Research Units (#105, 204, 253, and 271) investigating various aspects of the origin, distribution, and engineering properties of offshore permafrost encountered within the proposed Beaufort Sea lease area. Three of these programs (Sellmann, RU #105; Barnes et al., RU #204; Osterkamp and Harrison, RU #253) involve drilling into the sea floor to obtain permafrost samples for direct analysis; in situ measurements of the physical parameters (temperature, pore water salinities, thermal conductivity, etc.) controlling permafrost formation will also be made. The fourth program (Rogers, RU #271) involves an indirect approach in which shallow seismic refraction techniques are being used to map the depth and distribution of subsea permafrost.

Hunter et al. (BSPTR #22) and MacLauley et al. (1976) have reviewed both the geophysical evidence for offshore permafrost and the suitability of industry seismic records for permafrost mapping. Hofer and Varga (1972) gave a generalized velocity-depth function for the Beaufort Sea which suggested that unfrozen near-surface sediment velocities should be quite low (1,800 m/sec). Frozen sediment velocities onshore range in excess of 3,000 m/sec. Rogers et al. (1975) confirmed these velocities in the Barrow area. Significant velocity contrasts such as these (which are typical of coarse sandy materials) should allow easy classification of materials into the frozen or unfrozen state.

Rogers (RU #271) used the seismic refraction approach to examine permafrost distribution beneath both Elson Lagoon, Point Barrow, and Prudhoe Bay. The bottom penetration capability of the equipment he used was about 30 m. In general, the Elson Lagoon data indicated subsurface seismic velocities of 2,000 m/sec or less -- suggesting that no ice-bonded permafrost was present beneath the lagoon at sediment depths of less than 30 m. In Prudhoe Bay, however, a high velocity refractor, characteristic of sub-bottom permafrost, was located near the shore and followed a distance of 1.4 km offshore. The surface of the layer, which dipped downward in the offshore direction, ranged in depth from 12 to 20 m to about 27 to 35 m. The first depth estimates correspond to a distance of approximately 400 m from shore while the latter correspond to a distance of 1.4 km from shore. The permafrost surface was interpreted as being locally irregular, but with an average slope of about 0.8^{o}. (Hunter et al. (BSPTR #22) also found that the buried surface of ice-bound permafrost beneath the Beaufort Sea exhibited quite variable local relief.)

Osterkamp and Harrison (RU #253) successfully completed a subsea permafrost drilling program during 1975-76. They drilled fifteen holes to depths ranging from 3 to 56 m along a transect extending 3.4 km offshore, on the northwest side of Prudhoe Bay. Since their core holes were located immediately adjacent to Rogers' (RU #271) seismic refraction lines, direct comparisons of the results of the two studies are possible.

Osterkamp and Harrison used several different criteria to identify the depth to the surface of the ice-bonded permafrost: (1) direct observations of frozen sediment samples, (2) penetration tests -- in which the blow count increased substantially at the permafrost boundary, and (3) sharp changes in downhole thermal gradients. Temperature and salt concentration gradients were measured in the core holes and several standard engineering soils tests were performed on core samples: Gradation, Hydrometer, Atterburg limits, Specific Gravity, Density, Consolidation, and Triaxial Compression. These latter data, extensively tabulated by Osterkamp and Harrison, are of particular interest, for very few non-proprietary studies of the engineering characteristics of Arctic shelf sediments are presently available (Namtvedt 1974).

Osterkamp and Harrison's preliminary data analysis included the following results:

1. The sea bed at Prudhoe Bay is thawed even though mean annual temperatures are about -1°C. The thickness of this thawed layer increases with distance from the beach and is at least 46 m thick 3,370 m offshore (Fig. III-3).

2. A sharp interface was found between this thawed layer and the underlying ice-bonded subsea permafrost at all positions within 481 m from land.

3. The subsea soils are sandy gravel with some silt overlain by a thin layer of silty sand. This layer of silty sand increases in thickness from a few meters nearshore to about 14 m at 3,370 m offshore.

4. Where ice freezes to the sea bed the mean annual temperature is several degrees Celsius colder and the thickness of the thawed layer is only a few meters. A few hundred meters farther offshore (481 m from the beach) where the ice does not freeze to the sea bed, the thickness of the thawed layer increases rapidly to about 19 m.

5. Sediment pore water salinities where ice freezes to the sea bed range up to 3 to 4 times that of normal sea water. Where there was 10 to 20 cm of water under the ice cover, the salt concentration was about 2 times that of normal sea water. Normal sea water was found under the ice cover 3,370 m offshore where there was about 1 m of water under the ice cover.

6. A few small ice lenses were found in a hole 195 m from shore. No massive ice was found in any of the offshore holes.

7. A coupled heat conduction-salt diffusion model for the formation and melting of subsea permafrost was developed and solved. The results imply that salt diffusion cannot account for the thickness of the thawed layer; some other salt transport process must be rate-controlling. We conclude that salt transport is predominantly by advection, but heat transport is predominantly by conduction.

It is clear that the results obtained through core-hole data are at variance with those obtained from Rogers' (RU #271) seismic refraction studies. The former confirmed that ice-bonded permafrost was present beneath Prudhoe Bay at depths of 46 m or less (the limits of their drilling equipment), between the shoreline and about 0.5 km offshore. No evidence of permafrost was found at depths ≤46 m between 0.5 and 3.4 km offshore. Rogers, however, concluded

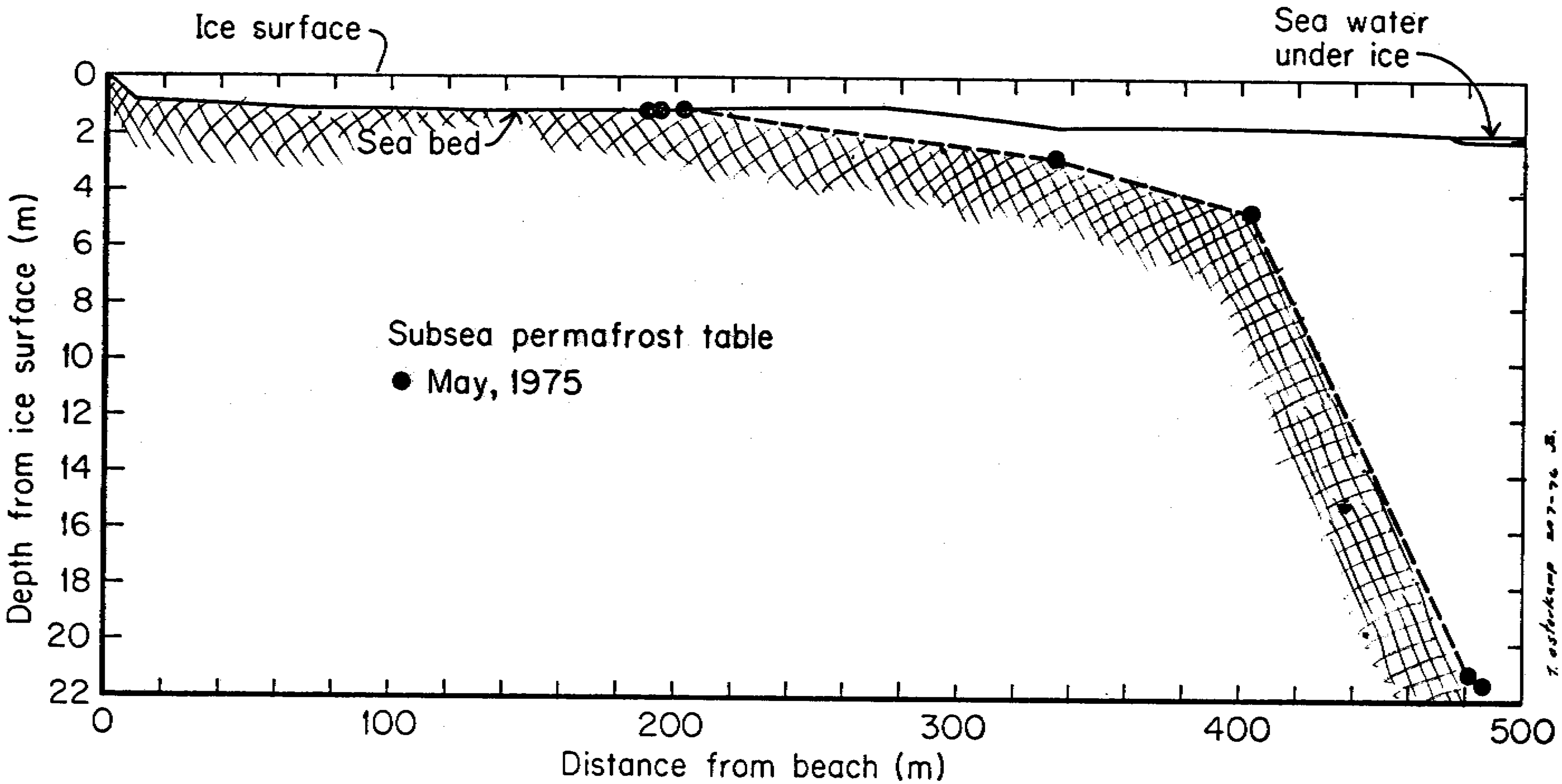

Fig. III-3. (from Harrison and Osterkamp, RU #253)

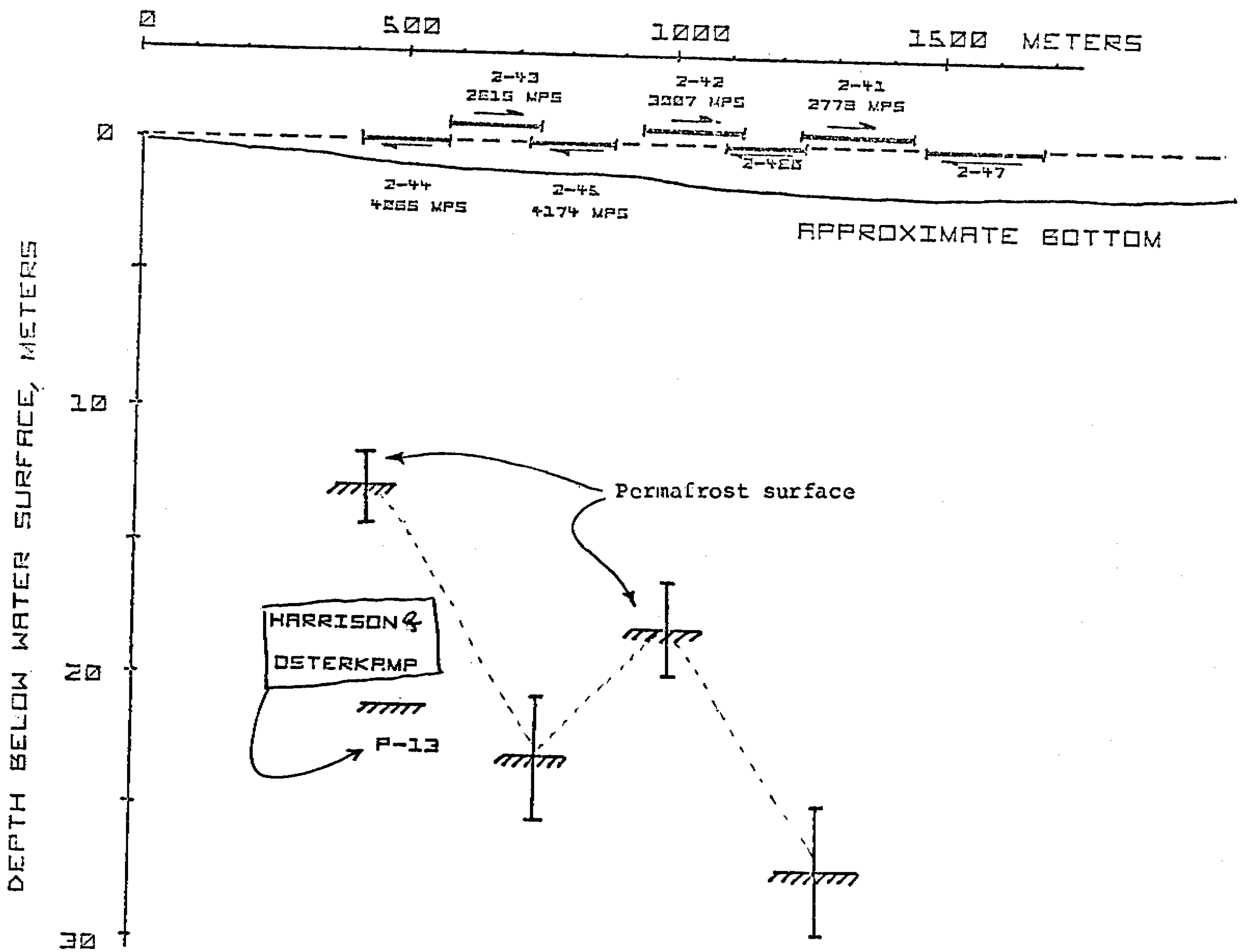

Fig. III-4. Vertical section through Prudhoe Bay track shown in Figure 3. Depths to permafrost surface are shown with error bars (Rogers, RU #271).

that permafrost was present at 30 m or less for the first 1.5 km offshore. Osterkamp and Harrison (RU #253) also noted an abrupt change in slope of the permafrost surface located between 400 and 500 km offshore; no such feature was revealed by the seismic profiling (Fig. III-4).

Hunter et al. (BSPTR #22) have reviewed problems associated with seismic refraction mapping of subsea permafrost in the Beaufort Sea. They found that at certain locations gas hydrates trapped within sea floor sediments exhibited seismic properties indistinguishable from those of ice-bonded permafrost. This problem has not yet been examined by NOAA/OCSEAP investigators and certainly warrants further study.

The two remaining projects funded by NOAA/OCSEAP -- Sellmann (RU #105) and Barnes et al. (RU #204) -- also involve drilling a series of holes into offshore permafrost in the Prudhoe Bay region. The planned holes will be extensively sampled and instrumented for studies of the geothermal, geochemical, and engineering properties of the permafrost, as well as other geologic data. Much of the year was spent organizing the complex logistics of this program (Figs. III-5 and III-6) and drilling was not scheduled to commence until April 1976. It is anticipated that the data collected during these studies will both clarify apparent discrepancies between the seismic and drilling results outlined above and also contribute to our knowledge of the gas hydrate problem.

Shallow reflection seismic studies on the outer portions of the shelf of the Canadian Beaufort Sea have revealed the presence of numerous seabottom mounds interpreted as pingoes (Shearer et al. 1971). A typical pingo-like feature is shown in Fig. III-7. Some of these submarine mounds rise 30 m to within 15 m of the ocean surface. They are believed to have been formed in the bottom of ancient lakes subsequently inundated by rising sea level (Shearer et al. 1971; Hunter et al., BSPTR #22). The distribution and possible engineering

PROGRAM SEQUENCE

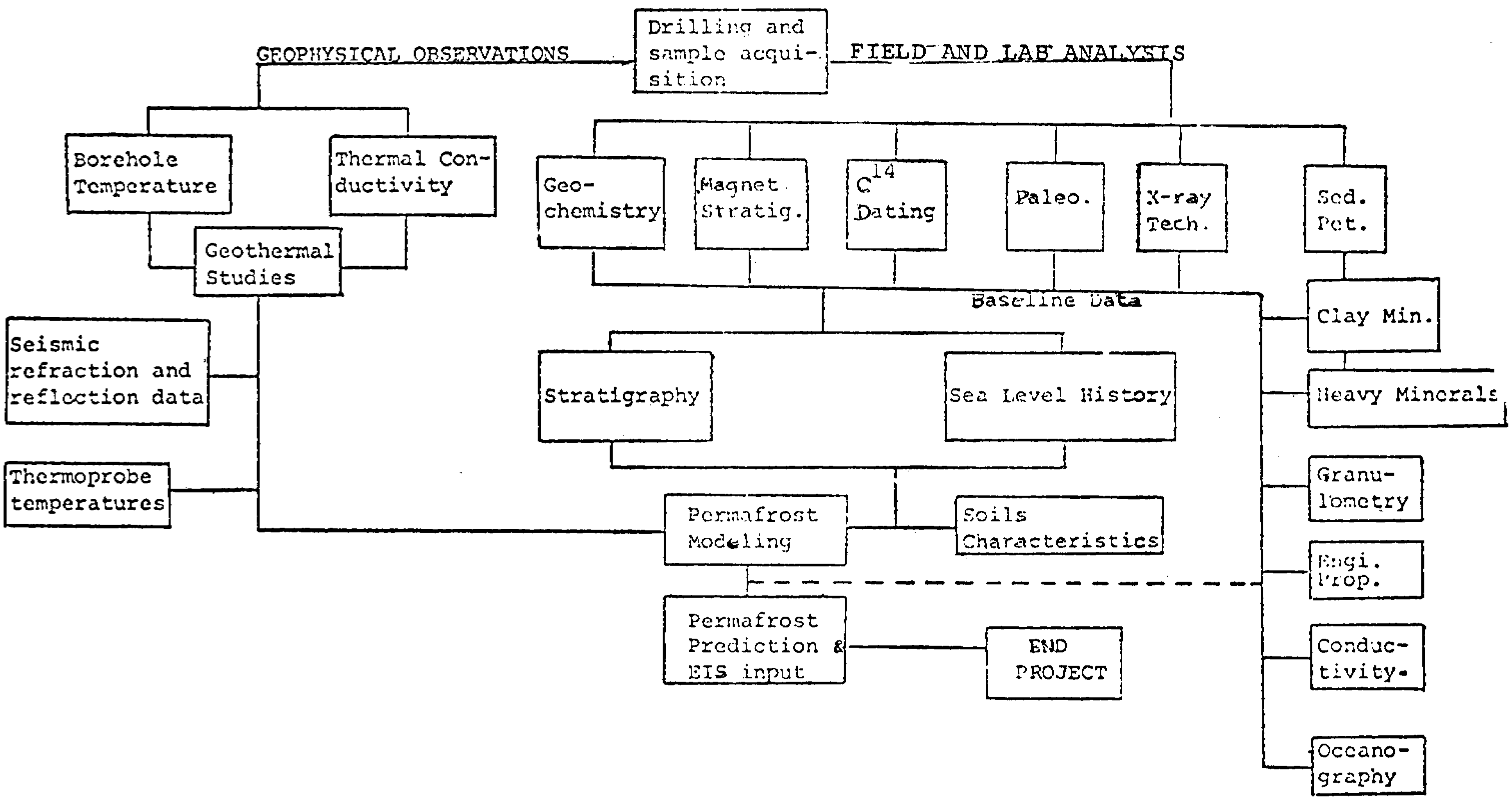

Fig. III-5.

SAMPLE HANDLING SCHEME

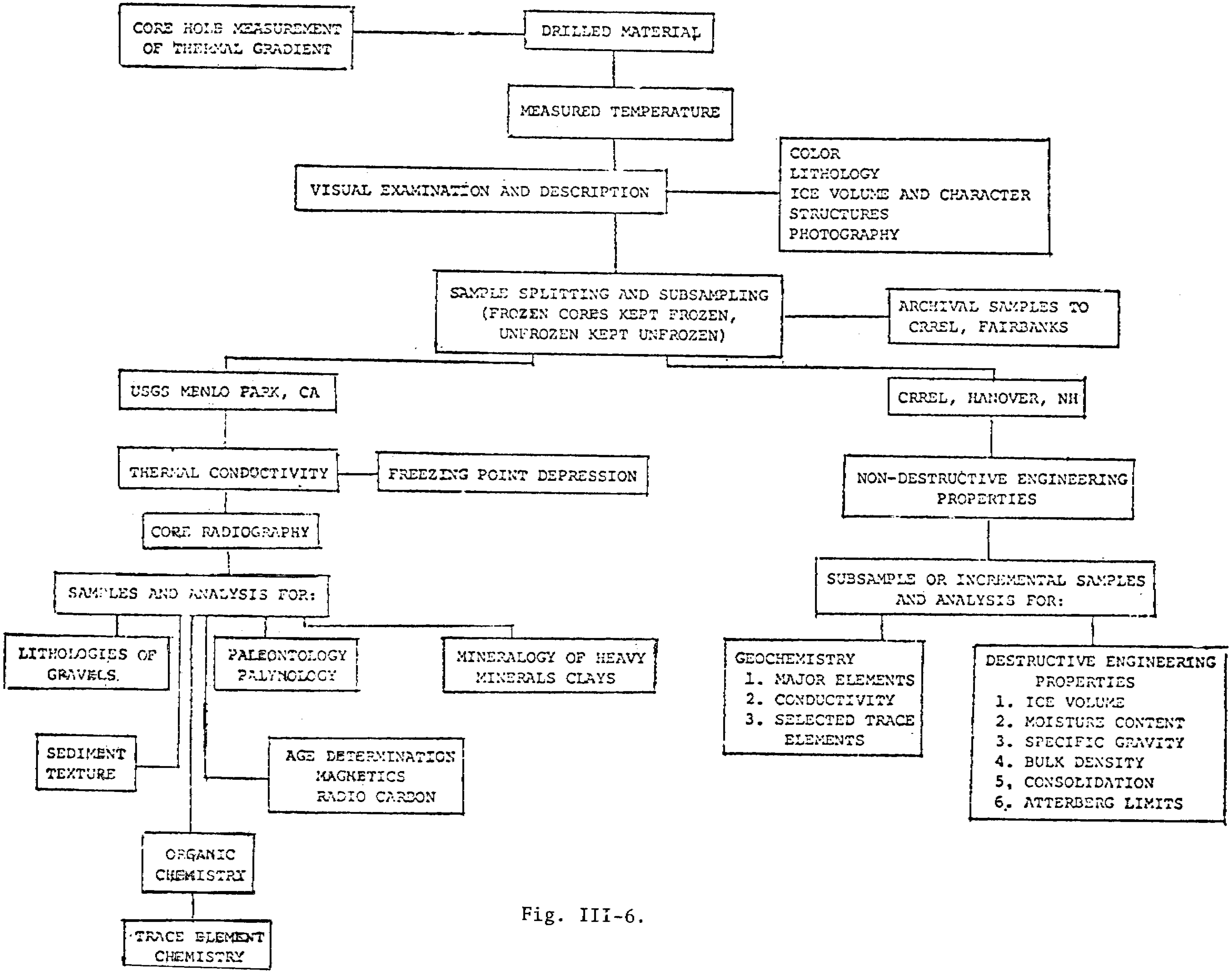

Fig. III-6.

significance of similar features in the proposed Beaufort Sea lease area deserves further study.

Much remains to be learned about offshore permafrost in the Beaufort Sea, however, the relevance of such studies is well pointed out by Osterkamp and Harrison (RU #253) who note the following implications of their work for oil and gas development:

1. The massive ice that exists in the top 25 m of soil on land is probably absent offshore near Prudhoe Bay at water depths greater than 2 m.

2. The presence of the thawed layer offshore indicates that it may be possible to use standard construction techniques for foundations in this layer. The sandy gravel is an excellent foundation material and since the material is already thawed there will not be any settlement due to ice melting. A somewhat different situation will prevail if the foundation penetrates into the ice-bonded subsea permafrost.

3. The presence of a sharp, moving interface between the thawed layer and the ice-bonded subsea permafrost may create problems for structural features that transect this interface (e.g., pipelines, tunnels).

4. The presence of the thawed layer and other physical considerations imply that it may be impossible to freeze structures like ice islands, gravel islands, gravel causeways, etc., into the sea bottom where the water depths exceed a few meters. This would substantially reduce the shearing forces that these structures could withstand.

Ice Gouging

> Knowledge of the repetitive rates and depth of ice gouging on the continental shelf of the Beaufort Sea is important for several reasons: (1) it provides an indirect method of determining the maximum ice-keel depth distribtuion, important for pressure ridge studies, (2) it provides insights on the rates at which bottom sediments and benthic communities are being reworked and disrupted by the physical action of ice, and (3) it can serve as a guide in the planning and design of offshore pipelines and other bottom mounted installations (Barnes et al., RU #205, Attachment E).

Reimnitz and Barnes (1974), two of the principal investigators of RU #205, have provided an excellent summary of the general nature of ice gouging along the Beaufort Shelf:

Moving ice in contact with the shelf surface forms gouges, which can often be related to particular ice types. Gouges generally are 0.5 to 1.0 m deep, but incisions to 5.5 m deep have been measured. Gouge density may be as high as 300 or more per kilometer of ship's track, with gouges oriented generally parallel to the shore or to depth contours. The winter shear zone with major ice pressure ridges, between the fast ice and the offshore ice in the 10- to 30-m-depth range, is an area of high gouge density. Gouge densities are high on relatively steep seaward-facing slopes and topographic highs. Lowest densities are in regions landward of such highs and landward of islands and areas adjacent to river deltas. At depths shallower than 20 m, seasonal gouges may be abundant, but they can be smoothed over by the waves and currents of a single summer. Gouges observed at depths greater than 50 to 70 m are older than those at shallower depths because rates of bottom smoothing are lower, and also because ice with more than about a 50-m draft has not been observed. In shallower water, where currents are strong, the flow around grounded ice is intensified and turbulent, producing current scour depressions at the ice bottom contact.

Other workers have also noted that the distribtuion, density, and depth of ice gouging changes with increasing water depth as one moves offshore across the Arctic shelf, Kovacs, 1972; Løken, 1972; Brooks, 1974.

Only recently have the qualitative results presented by earlier papers begun to be replaced by quantitative ice gouging analyses. The numerous investigators of RU #205, headed by Barnes and Reimnitz, pioneered this quantitative approach during their 1973-75 field studies. For example, several precisely controlled side scan sonar survey lines established in Harrison Bay, Beaufort Sea in 1973 and resurveyed in 1975 establish without a doubt that ice gouge patterns to a depth of 20 m can change substantially within a two year period (RU #205, Attachment E) (see Fig. III-7).

An analysis of these ice gouge recurrence data also permitted Barnes et al. to determine the rate at which the sediments along the survey track are being reworked by ice gouging.

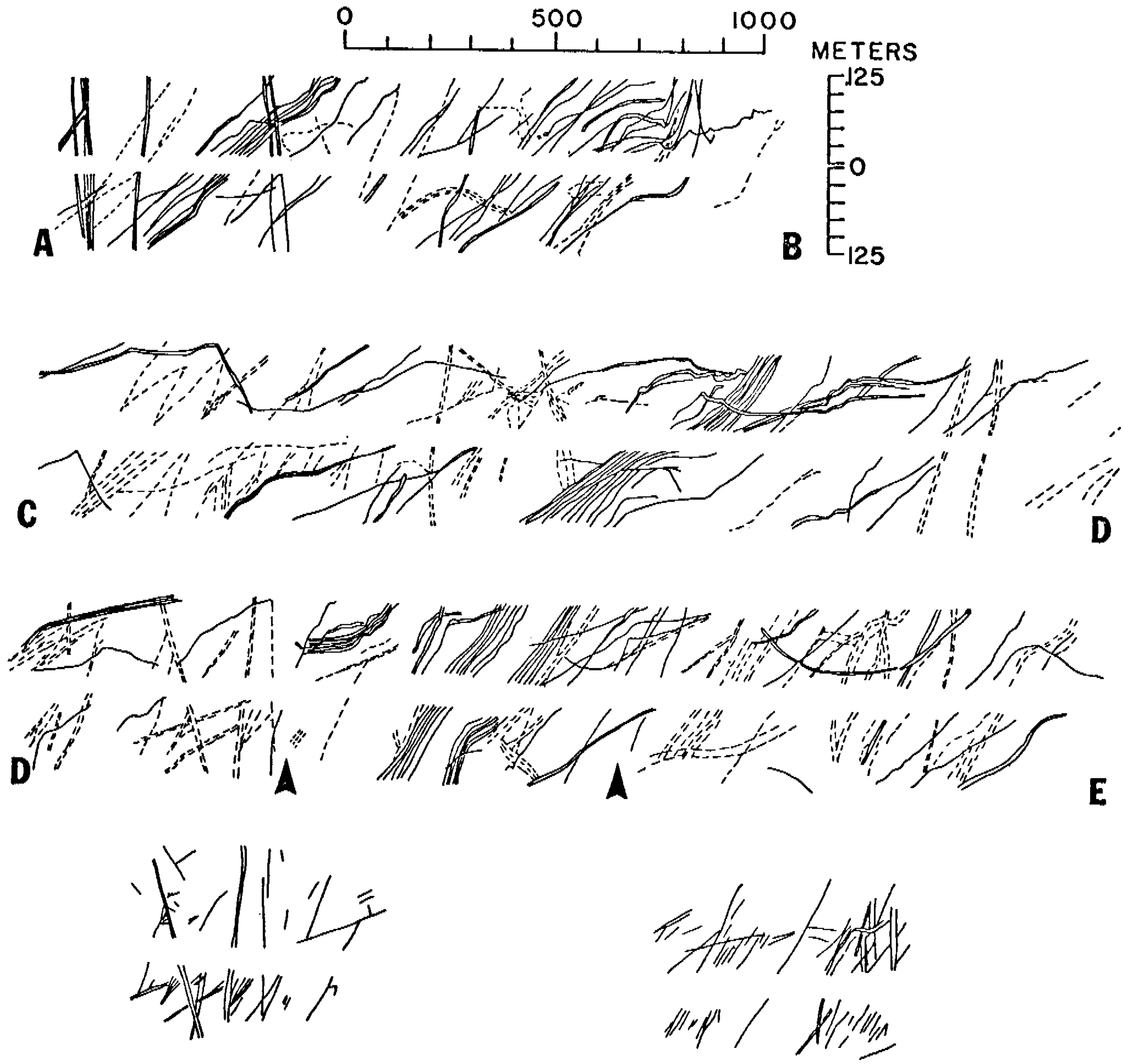

Fig. III-7. The upper three lines were taken from 1975 Harrison Bay sonograph records, showing the 1973 and older gouges as dashed and the post-1973 gouges as solid lines. The bottom line was taken from the 1973 record and shows how the 1973 and 1975 sonograph records can be matched using characteristic gouge patterns seen in both (Barnes et al, RU #205).

> If the present sea level has been constant (within a few meters) over the last 8,000 years, the sedimentation rate along the survey track can be estimated from the thickness of the Holocene marine sediments seen in sub-bottom profiles recorded simultaneously. The average thickness of Holocene sediments is 5 m. The sedimentation rate, therefore, is estimated to be 6.3 cm/100 years for the last 8,000 years. The average gouge depth, also measured off the fathogram, is approximately 30 cm. Within the 30 years that the entire bottom is gouged to an average depth of 30 cm, only 2 cm of sediment will be deposited. Thus, the stratigraphic column should be completely reworked before any sediment is buried deep enough to escape the action of the ice (RU #205, Attachment E).

Such reworking must surely have important consequences for the establishment and stability of benthic communities, as well as the resuspension and remobilization of both sediments and introduced contaminants that might have settled to the sea floor.

Barnes et al's. (RU #205) quantitative approach has also yielded data on the rates of offshore shoal migration under the influence of ice. Grounded ice, apparently of pressure ridge origin, is commonly present on offshore shoals and frequently marks a district boundary between the scattered ice of the inner shelf and tightly packed ice on the central shelf (RU #205, Attachment F).

Barnes et al. found that these shoals:

> (usually pronounced linear topographic highs) on the inner shelf between Prudhoe Bay and Harrison Bay, appear to control shear zone dynamics and stamukhi development. Accurate bathymetry by the U.S.C. and G.S. from 1949-51, was resurveyed in 1975 with excellent navigational control and precision fathometer. These shoals were found to have survived 25 years of ice interaction, but all have shifted landward for distances of 100 to 400 m (Fig. III-8). They believe this shift is related to shear zone processes and stamukhi. This is the first solid evidence for a relationship between offshore shoals on the Arctic shelf and boundary processes of the Beaufort Gyre pack ice (Fig. III-9). These findings have extremely important implications for offshore development in the Arctic especially concerning the construction of artificial islands. We can now make certain predictions regarding the longevity of such structures and on how they will interact with pack ice. It even seems feasible to make the inner shelf ice environment less hostile for man's endeavors by the proper placement of such structures. (RU #205, Attachment E)

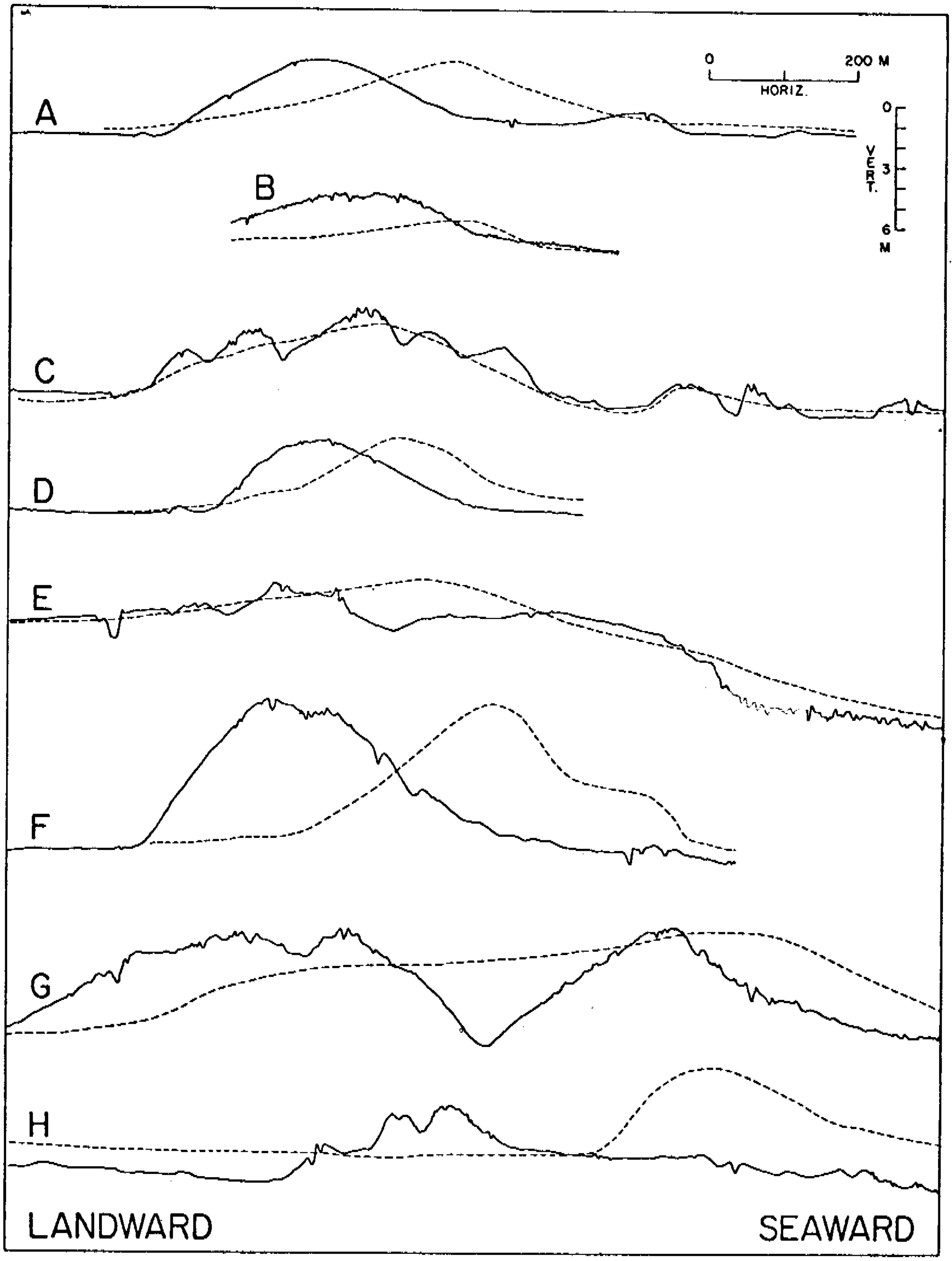

Fig. III-8. Comparison of shoal locations and cross sectional profiles from 1949/51 (dashed line) and 1975 (solid line) surveys. All the shoals but one have migrated landward through distances of 100 to 400 m. Harrison Bay, Beaufort Shelf (Barnes et al., RU #205)

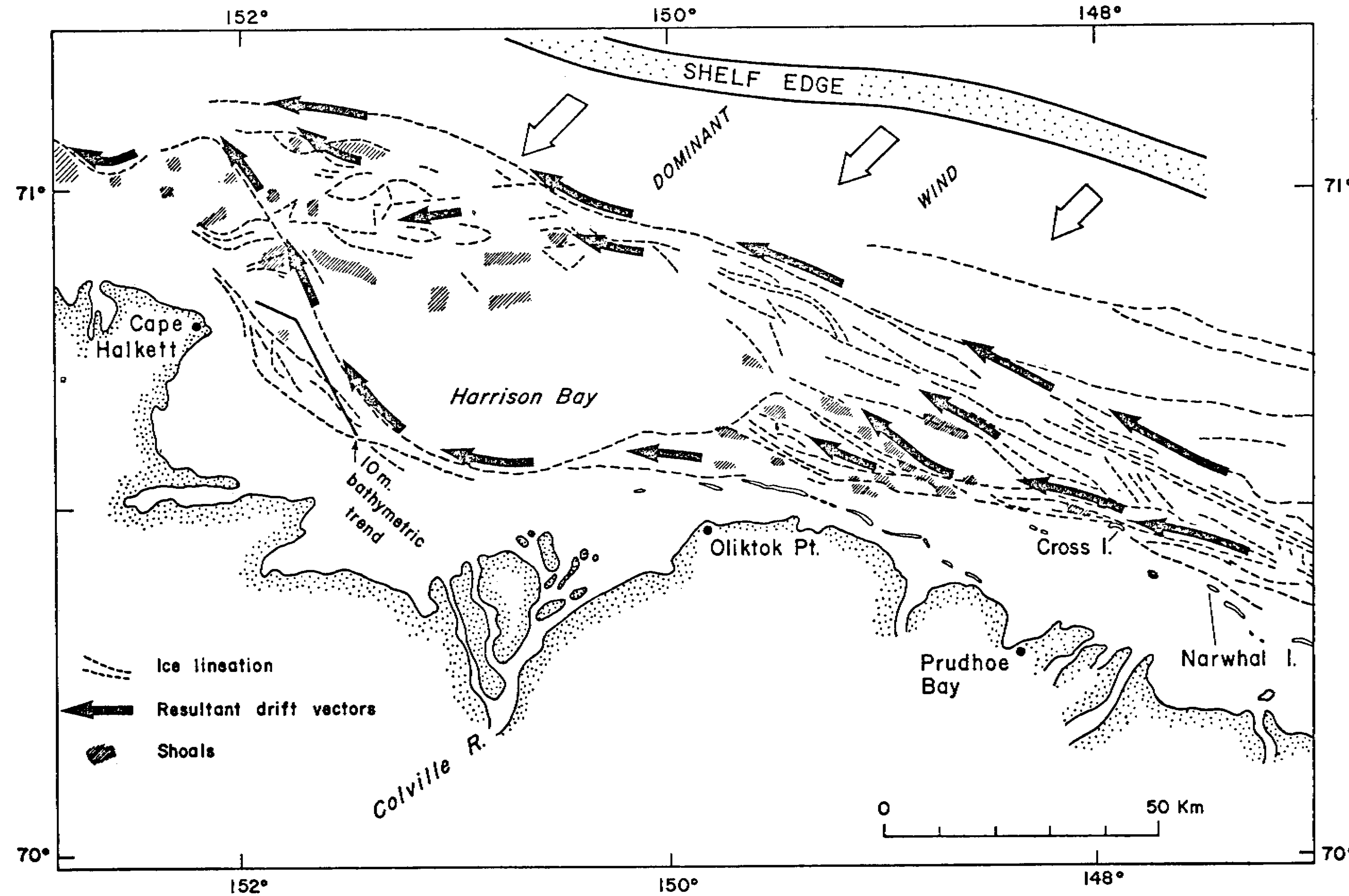

Fig. III-9. Generalized model of ice drift within area of Harrison Bay, indicating movement of pack ice along well defined shearlines, dominant wind direction and location of charted shoals (hatched areas). A striking correlation is seen between distribution of shoals and major ice lineations seen in ERTS-1 images which represent shear ridges, pressure ridges, and linear hummock fields (Barnes et al., RU #205).

Barnes et al's. broadly based studies also revealed that the ice gouging and other ice related processes are important factors in the nearshore environment, at least as far south as Kotzebue Sound, although the influence of currents (related to flow through the Bering Straits and the longer open water period) is more pronounced farther south.

In order to fully evaluate ice gouging hazards, both the frequency of occurrence of such events and the forces transferred from the grounded ice to the bottom sediments (and possible seafloor installations) must be known. Barnes et al. have contributed to the first of these goals.

While considerable data have now been accumulated on the nature and frequency of ice gouging, (Weeks et al., 1971; Kovacs, 1972; Kovacs and Wellor, 1974; Løken, 1974; Wadhams, BSPTR #36) little attention has yet been given to plowing and sliding mechanisms of grounded ice across the sea floor, the structural integrity of the grounded ice keels, or the nature of the forces involved. More such studies are needed; however, we also need to learn more about the environmental implications of the gouge morphology.

These questions clearly deserve more attention, particularly in developing offshore drilling regulations.

Overice Flooding and River Breakup

An understanding of the seasonability and variability of streamflow is of considerable engineering importance to the imminent oil and gas development. Streamflow variability, the effects of seasonal ice, as well as sediment characteristics and ice jam flooding have considerable impact on nearshore and estuarine areas. This is especially so in areas where sea ice remains intact after the initiation of river breakup. This occurs in nearly all rivers and streams in the North Bering, Chukchi, and Beaufort Seas, because of the extensive areas of shorefast ice formed annually in these areas. An analysis of the annual seasonability of streamflow, expected breakup data, expected freezeup data, and sediment characteristics are all necessary information to insure safe and efficient offshore development. (Carlson, RU #111)

Overice flooding and river ice breakup is a spring thaw phenomena. During the winter, shore and bottom fast river ice becomes continuous from the ocean to the headwaters of the streams and rivers. In a few cases where there are deep springs continuously feeding water into the channels, the channel, does have some highly restricted sub-ice flow. The melting of snow and ice on the ocean surface and nearshore lags up to a month behind melting on inland areas, further south. River runoff, resulting from earlier inland melting, is blocked by the winter ice dam downstream. The melt-waters flood their channels and flow over or around the ice-filled channels and ice-mounds, remaining from the past winters icings. These floods often cover large areas and extend several kilometers out to sea over the shorefast sea ice. They also assist in the breakup of the shore ice by carrying relatively warm river water offshore. The hazards of both flooding and river and sea ice breakup are considerable.

Carlson (RU #111) has been contracted by NOAA to investigate the timing and extent of overice flooding and ice breakup and their related hazards. The flow regime of Arctic slope rivers is significantly different from those of mid- and low latitudes. Data for the Kuparuk River, near Dead Horse summarized in Table III-1.

TABLE III-1

Hydrologic Data for the Kuparuk River, Near Dead Horse

Basin Area:	8,107 km^2 (3,130 mi^2)	
Data Period:	3 years	
Mean Annual Flow:		1,600 CFS (winter flow estimated)
Mode:		10 CFS (winter flow estimated)
Standard Deviation:		±31,809 CFS
Range:	Maximum recorded flow --	82,000 CFS
	Minimum recorded flow --	10 CFS
Breakup Period:		Mean 10-day Initiation period -- May 20-June 8
Freezeup Period:		Mean 10-day Initiation period -- September 20-29

It is readily seen from Table III-1 that maximum flow is highly restricted in time, as shown by the flow duration curve indicated in Fig. III-10. Essentially 60% to 80% of the annual flow constitutes snowmelt and occurs during the last week of May and first two or three weeks of June, or 10% of the whole year. It is this tremendous surge of snowmelt runoff -- blocked by the ice occupying the coastline and the shorefast ice -- that causes the overice flooding. The river overflows its ice dam and its banks and floods the area; flood waters flow out over the sea ice in large sheets. Walker (1969 and 1972), and Reimnitz and Bruder (1972) have done studies on overice flooding and river breakup of the Colville River.

The USGS maintains gaging stations on the Kuparuk, Sagavanirktok, and the Putuligayuk Rivers of the northern slope. Each of these are being studied by Carlson (RU #111). His first Annual Report placed emphasis on the Kuparuk River. In the Kuparuk basin, snowmelt is initiated at the higher elevations

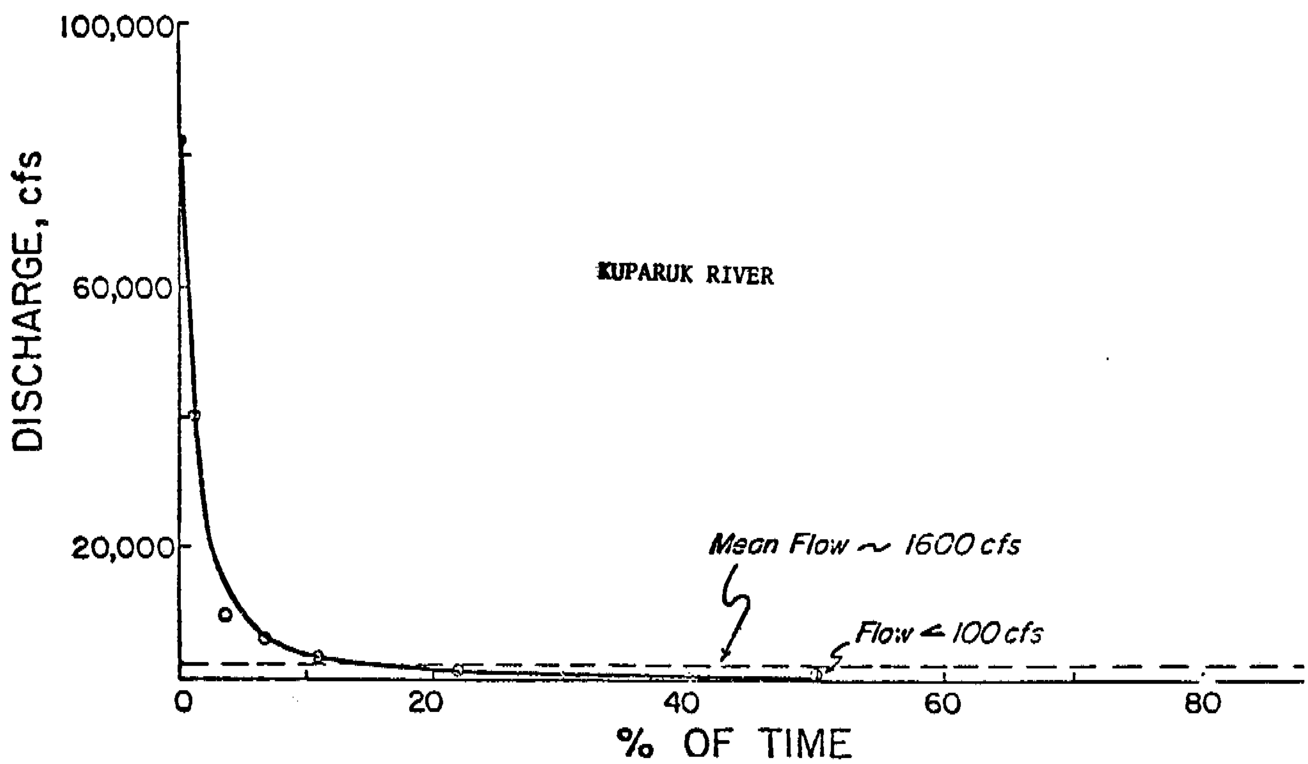

Fig. III-10. Flow Duration Curve - Kuparuk River Near Deadhorse (Record Length - 3 years; from Carlson, RU #111) during the last week in May, and progresses toward the lower, farther north coastal plain, which is the last area to become snowfree. Because of this, meltwater flows down the stream channel, overtops the ice and floods large areas of shorefast sea ice. Melt occurs rapidly and is usually completed by the third week in June, but can be later. In the three years of record, from 60% to 80% of all runoff for the entire year constituted snowmelt runoff in the month of June.

The Kuparuk is characterized by a low gradient, long stream length, and low elevation distribution. The Putuligayuk basin i[illegible]fined to the Arctic coastal plain and reflects huge extremes of seasonability and variability in streamflow. The Sagavanirktok has a steep gradient and is highly braided. All three rivers have high variability in seasonal flow, and the spring snowmelt runoff is the major contribution to flow. Although surface water is frozen in the Arctic for up to eight months of the year, both the Sagavanirktok and Kuparuk are suspected to sustain low levels of flow throughout the winter.

Icings

Icings of rivers and springs refer to an Arctic region phenomenon of progressive ice accretion on a preexisting ice surface. The term, as applied here in reference to Arctic rivers and springs, is used to designate both the process of ice build up and the actual sheet of ice thus formed. The process of icing involves the intermittent or continuous emergence of water onto the land or ice surface during subfreezing winter temperatures. The source of the water may be a seep, spring, or hole in the river ice (Carey 1973, Anisimova 1973).

Icings often occur annually in the same location and in the case of some Siberian river icings, may accumulate up to 25% to 30% of annual discharge of the channel and 60% to 80% of the annual subsurface drainage (Anisimova 1973). The morphology and areal extent of icings is a function of the source of discharge, the hydrostatic head, and the local physiography. Continual growth of icings throughout the winter is an indication both of a source of fresh water and that the river concerned (if its basin is confined to the zone of continuous permafrost) is fed by springs in addition to surface and ground water. These perennial icings can be of value as sources of fresh water. Icings, particularly intermittent ones, could pose serious hazards to both construction camps and transportation routes. Areas of known icings have been mapped (Fig. III-11) and studied by P. Barnes et al. (RU #205) in a field program.

As is apparent in Fig. III-11 of the north slope of Alaska, icings are a widespread phenomena. Their greatest occurrence is east of the Colville River, at the head of deltas and at the mouths of narrow mountain canyons entering the foothills of the Brooks Range. The lack of significant icings along the Colville River is probably a result of the river freezing solid during the winter. This occurrence may also explain the general lack of icings to the west of the Colville River. Attempts to measure any sub-ice flow of water in the Colville during winter indicate that no flow exists. The presence, during winter, of saline water intrusion 60 km upstream below the ice in the channel, plus the apparent absence of springs adjacent to the channel all confirm that there is virtually no flow during the winter months (Walker 1974). The explanation for this probably lies in the fact that most rivers flowing into the Arctic Ocean from the north slope have drainage basins confined to the zone of continuous permafrost. During winter the active soil layer above the permafrost, and any

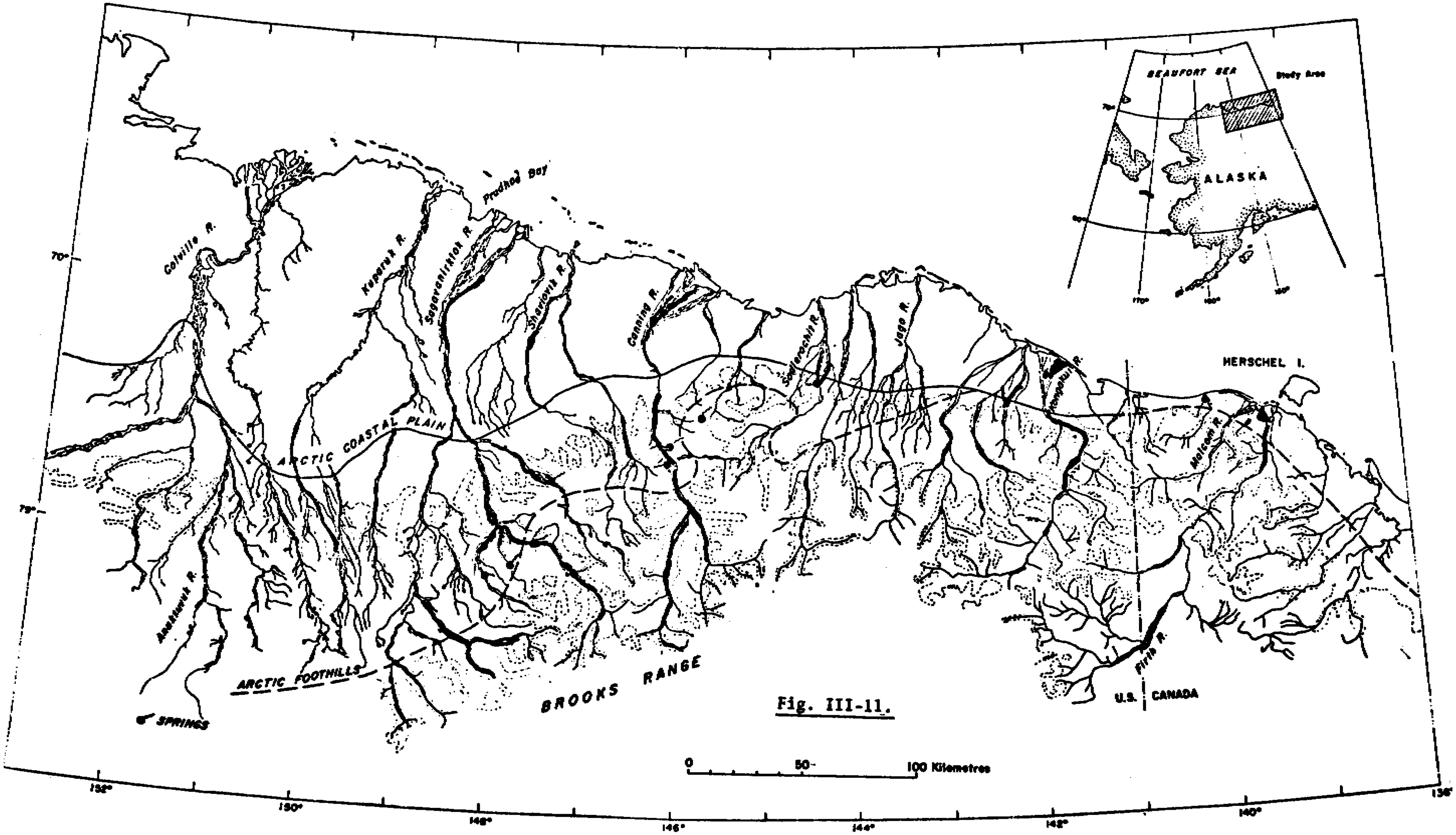

Fig. III-11. Distribution of icings in northeastern Alaska from ERTS imagery (Harden et al., RU #205, Attachment I).

water sources such as shallow lakes, freeze. The frozen soil then acts as a barrier to lateral movement of ground water and discharge of ground water into the streams and rivers approaches zero. A few rivers have continuously flowing springs along their courses and can maintain slight winter flows along their channels (Williams 1970). Much of any continuous winter flow is trapped in icings when bottom fast ice blocks its passage downstream and forces it to the surface; it does not reach the ocean until the spring thaw.

The hazards involved in working around areas of frequent icings need to be more clearly defined. Utilization of icings as fresh water sources may have a significant impact upon the ecology of the channels. Icing source areas provide prime winter habitats for river fish populations. The withdrawal of water from these unfrozen pockets of water at rates in excess of the recharge will effectively begin to restrict the size of winter fish habitats and possibly result in changing the remaining habitats by encouraging salt water intrusion to move upstream (Barnes et al., RU #205).

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Chapter IV

TRANSPORT PROCESSES

INTRODUCTION

Spilled oil on sea water surface, after undergoing initial changes in its composition, i.e., fractionation (most volatile fraction is evaporated), spreads in the form of large patches of tarry masses together with light volatile fraction. Large oil slicks can drift for hundreds of kilometers as continuous masses, as exemplified in the Torrey Canyon case. Transport, dispersion, and dissipation of oil patches is dependent upon oceanic mixing processes, currents, water transport, waves, and ice movement (transport of trapped or diffused oil). Continued evaporation of an oil slick may cause its specific gravity to increase so that oil may sink. Residue from Iranian Heavy Crude has specific gravity of 1.027 which is higher than for most surface waters.

It has been suggested by Schumacher and Coachman (RU #141) that in the event of a massive oil spill, foremost concern should be as to when (speed of flow) and in what concentration (diffusion of oil along trajectories) the spilled oil would reach a certain coastal area. In case of chronic, long-term seepage in small quantities, accumulation of residue is likely to be mixed within the water column and become associated with particulate matter. The study of the distribution of such oil spills would require a knowledge of advective and diffusive fields and mass distribution in the water column.

In instances where currents are not a direct result of winds, e.g., tidal currents nearshore, oil is expected to move in a direction between those of wind and current. No satisfactory explanation exists presently to predict the actual path and exact velocity of an oil patch under such a condition. Other significant, unresolved problems in predicting the consequences or projecting the path of an oil spill include the lack of quantitative estimates of differences in response between oil and sea water to wind stress, etc. Momentum transfer, velocity differential, and relative effects of shearing stress between oil slick and subjacent water are also not understood.

Recent studies have indicated that the western part of the Beaufort Sea may not be an oceanographic entity; in many respects it is characterized by transient and intermittent phenomena as indicated by Herlineaux and de Lange Boom, BSPTR #18, Hufford 1974, Wilson 1974.

MASS DISTRIBUTION

Most previously obtained data are from the open water period in the Beaufort Sea. It is believed that Arctic surface water greatly influences the shelf water in the Beaufort Sea. As expected, variations observed in temperature and salinity in the area can be traced to two causes: seasonal weather changes and water modifying processes. Based on available data, it is recognized that the water originating in the Bering Sea flows northward into the Chukchi Sea and then turns toward the Beaufort Sea. This water, characterized by warmer temperature, flows eastward and may even recirculate along the shelf. Short-term upwelling, as mentioned above, and a westward flowing current, probably caused by the Beaufort Gyre, are likely to affect mass distribution on the shelf. The magnitude and seasonality of these changes cannot be ascertained at this time.

An attempt to determine seasonal pattern of mass distribution is being made by K. Aagaard (RU #151). The project is designed to provide seasonally distributed synoptic temperature-salinity mapping of the Beaufort Sea shelf and dynamically related region of the slope. A digitally recording CTD (conductivity-temperature-depth) profiling system is used. Data are obtained from stations along three transects extending from a 20 m isobath near the coast to deep water over the slope. The system is carried aboard a helicopter and deployed through a hole in the ice.

So far, Aagaard has reported data obtained in October-November 1975 (12 days) and in February 1976 (9 days). Temperature and salinity data are perhaps the first reported for fall and winter months for the Beaufort Sea. Data have not been fully analyzed; all results are tentative and, at times, even speculative. Some of the results are as follows:

1. It appears that in the fall there is strong salinity stratification below 20 m. In upper layers salinity is about 28 to 30 ppt. Shelf water is nearly isothermal with depth, except at the Pitt Point station. In winter, overall stratification is reduced; salinity is generally above 31.0 ppt and water column is nearly isothermal, including Pitt Point station.

2. On the shelf, a series of temperature inversions were noted. The area of temperature inversion sinks from outer shelf down into the slope water.

3. Geostrophic calculations indicated a typical current velocity of 10 cm/sec westward at 50 m relative to 200 m.

An implication of the observed temperature inversions is that Beaufort Sea contributes water near the pycnocline region of the Arctic Ocean. Any contaminant associated with the shelf water may be introduced into the Arctic water in this manner.

CURRENTS

Since the area is ice-covered during most of the year, it is not possible to use routine, standard methods and equipment. Information available in the literature is for open water period only.

K. Aagaard and D. P. Haugen (RU #91) have designed an anchored current meter system to obtain a long-term series of Eulerian current vectors and streamlines, i.e., measurement of current speed and direction at fixed points. A system of acoustic telemetry of data, as well as data collection and retrieval has been devised. This system has not yet been tested in the field.

Each instrument system is comprised of an anchor, an anchor release mechanism, two current meters, data buoy, and floatation mechanism. Power supply, digital tape recorder, timing and control electronics, and acoustic telecommunications system are housed in the data buoy.

Current meters will be deployed on the outer continental shelf and slope areas at a depth of about 100 m to avoid drifting ice. This depth is fairly close to shore near Barrow (projected Station 1) due to the presence of the Barrow Canyon, but is at considerable distance from shore at the other two projected stations. Very little, if any, information will be available for nearshore circulation.

Another study applicable to surface current measurements in the Beaufort Sea is by D. E. Barrick (RU #48). The purpose of this research is to determine the near-surface circulation patterns which can be used to predict the transport of petroleum-related contaminants. A transportable, easily assembled and operated radar unit capable of producing a current map at a particular site in real time will be employed. The radar units will be operated in coastal areas. Units can also be deployed in regions in which controlled oil-spill tests are planned or where free-floating buoys are used to measure surface currents. Regions with limited water areas between the coast and ice-edge and in estuaries and fjords will also be investigated for unique current patterns and trajectories.

Apparently the system can be operated at a temporal sampling interval of 1 hr. Thus, it may be possible to obtain current vector diagrams with the advent and passage of a storm through a coastal area. Similarly, the system can be used to examine effects of various meteorological and tidal conditions in an area.

A detailed account of procurement of hardware and software, in-house fabrication, system simulation, antenna modification, etc., is provided in Barrick's Annual Report. Operational frequencies will be in the range of 25.330 to 28.000 MH_z. A technical report describing the concept, the system design, performance, and simulation showing current field maps will be provided shortly.

Doppler-shift errors may be caused by nonlinear interaction of surface waves. The magnitude of this effect on current data is not fully known; it is expected to be less than 10 cm/sec.

WAVES AND TIDES

No studies specifically on tide and tidal currents or waves are being conducted in the Beaufort Sea related to OCSEAP objectives. Two tide recorders were installed in the Prudhoe Bay area in connection with a study of transport of pollutants (Callaway, RU #335). Both units showed significant inner record gaps. The original intent of collecting tide data was to use Fourier analysis to determine phase and amplitude of major tidal constituents and to determine the direction of incidence of the tidal waves. On the basis of obtained records, this does not seem possible.

A Canadian sponsored study in the southeast Beaufort Sea (Hugget et al., BSPTR #16), found that tides in the area were mixed, predominantly semidiurnal, and of low amplitude. It is probably true that in this region meteorological effects completely mask any true tidal effects.

ICE

Ice Motion

The mean ice motion is similar to that associated with the mean atmospheric pressure field. Mean ice-drift is in the range of 1 to 5 cm/sec (Herlineaux and de Lange Boom, BSPTR #18) although much higher, over 20 cm/sec, short-term drifts have been noted (Newton and Coachman 1973). Ice motion is determined by the forces of wind (through air-ice stress), currents (through ice-water stress), internal ice stress (resistance of pack to motion within itself), pressure gradients (sea surface slope), and Coriolis effect. Thus, it is difficult to actually project ice movement with wind data alone. Nevertheless, under average conditions, ice is expected to drift at about 2% of the wind speed and approximately 30° to the right of wind direction in the northern regions (Herlineaux and de Lange Boom, BSPTR #18).

Ice Deformation

Three areas are of interest to OCSEAP studies related to ice deformation: (1) description of deformation patterns and specific features such as pressure ridging in the landfast ice and nearshore shear zone; (2) monitoring of forces known to cause deformation; and (3) the inter-annual frequency of occurrence of both of these features. Reported OCSEAP research has focused on description of deformation features and estimates of forces necessary to create them. The preliminary results are reported in Chapter III (Hazards).

Weeks and Kovacs (RU #88) through studies of mesoscale ice deformation, using land based radar, intend to supply data related to points 1 and 2 mentioned above. Untersteiner (RU #98) will provide data on large-scale deformation and movement information about the nearshore shear zone. So far the satellite-linked data buoys have been deployed along the Beaufort Sea coast but no data are available.

Flow and Retention of Oil in Ice

The problem of oil incorporation into sea ice and subsequent transport has been studied in some detail (Lewis 1976, Wadhams, BSPTR #36, NORCOR, BSPTR #27).

Previous findings apply to ice of vertical crystal orientation. Martin (RU #87) is studying the movement of oil through grease and pancake ice which have horizontal crystal orientation. According to Martin, oil released under grease and slush ice (approximately 40% ice and 60% sea water), which may grow to a thickness of 100 cm, comes rapidly to the surface. Furthermore, preliminary experimental results suggest that most of the oil released under a field of pancake ice comes to the surface through the spaces between the cakes, where the oscillatory motion of the pancakes pumps the oil away from the spill site.

Much less is known about oil movements when it is released under pack ice. Limited research has been carried out on the problem of "lead pumping" (Løken 1974).

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Chapter V

RECEPTORS

INTRODUCTION

Studies on fish, benthic and planktonic flora and fauna, birds, and mammals are being conducted primarily to determine the variety, abundance, and distribution of the biotic resources in the Beaufort Sea. Another important aspect of these studies is to identify which populations and communities are at risk from either acute or chronic impacts from oil exploration and development. Observations and data to describe the critical habitats, breeding habits, locales and seasons, migratory extent and routes, and trophic relationships will also be made to evaluate mobility of populations, geographical and ecological limits of communities, sensitivity to habitat disturbance, and the Beaufort Sea ecosystem structure and function.

FISH

Data are being obtained from historical records and field programs (Bendock, RU #233; Morrow, RU #348). Additional data are being evaluated to provide taxonomic characteristics of ichthyoplankton and fish utilizing morphological structures, otoliths, and skeletal remains (English, RU #349; Morrow, RU #318).

In Table V-1 a list of 13 families and 37 species of fish is compiled from recent field studies (Percy, BSPTR #8; Kendel et al., BSPTR #6; Bendock, RU #233) and historical evidence documented by Kendel et al. and Morrow (RU #318).

TABLE V-1

Fish of The Beaufort Sea

Family and Species	Common Name
Salmonidae	
Salvelinus alpinus (Linnaeus)	Arctic char
C. automnalis (Pallas)	Arctic cisco
C. sardinella Valenciennes	Least cisco
C. nasus (Pallas)	Broad whitefish
C. pidshiean (Gmelin)	Humpback whitefish
Thymallus articus (Pallas)	Arctic grayling
Stenodus leucichthys nelma (Pallas)	Inconnu
Clupeidae	
Clupea harengus pallasi Valenciennes	Pacific herring
Osmeridae	
Osmeris mordax (Mitchill)	Boreal smelt
Mallotus vilosus (Muller)	Capelin
Pleuronectidae	
Liopsetta glacialis (Pallas)	Arctic flounder
Platichthys stellatus (Pallas)	Starry flounder
Gadidae	
Boreogadus saida (Lepechin)	Arctic cod
Eleginus gracilis (Tilesius)	Saffron cod
Cottidae	
Myoxocephalus quadricornis (Linnaeus)	Fourhorn sculpin
M. scorpius (Linnaeus)	Shorthorn sculpin
M. scorpioides (Fabricius)	Arctic sculpin
Icelus bicornis (Reinhardt)	Twohorn sculpin
I. spatula Gilbert and Burke	Spatulate sculpin
Triglops pingeli Reinhardt	Ribbed sculpin
Artediellus scaber Knipowitsch	Hamecon
Gymnocanthus tricuspis (Reinhardt)	Arctic staghorn sculpin
Ammodytidae	
Ammodytes hexapterus Pallas	Pacific sand lance

TABLE V-1 (continued)

Gasterosteidae	
Pungitius pungitius (Linnaeus)	Ninespine stickleback
Petromyzontidae	
Lampetra japonica (Martens)	Arctic lamprey
Zoarcidae	
Lycodes palearis Gilbert	Wattled eelpout
L. turneri Bean	Polar eelpout
L. polaris (Sabine)	Canadian eelpout
L. rossi Malmgren	Threespot eelpout
L. pallidus Collett	Pale eelpout
L. jugoricus Knitpowitsch	Shalupaoluk
Stichaeidae	
Stichaeus punctatus (Fabricius)	Arctic shanny
Lumpenus fabricii (Valenciennes)	Slender eelblenny
Agonidae	
Agonus acipenserinus Tilesius	Sturgeon poacher
Aspidophoroides olridi Lutken	Arctic alligatorfish
Liparidae	
Liparis sp	Snailfish
L. herschelinus Scofield	Bartail snailfish
L. koefoedi Parr	Galatinous seasnail

Bendock (RU #233), Percy (BPTR #8), and Kendel et al. (BSPTR #6) reported that salmonids are the most common and widely distributed family of fish in the Beaufort Sea. Bendock reported that Arctic char were collected at 74% of his gill net stations. Arctic cisco and least cisco were captured at 65% and 37% of the stations, respectively; and least cisco were the most abundant species collected (in terms of numbers).

Marine species represented 45% of the total catch (Bendock, RU #233).

Preliminary gut analyses indicate that crustaceans (e.g., amphipods, mysids, etc.) are the most common prey of the anadromous species. Marine species also rely on the crustaceans as their primary food source (Bendock, RU #233; Percy, BSPTR #8, Kendel et al., BSPTR #6).

Some of the Beaufort Sea fish support subsistence fisheries for coastal residents. A limited commercial fishery also exists in the area, but with more access and industrial intrusion expanding of sport fisheries are developing (Bendock, RU #233). Other marine and anadromous fish, birds, and mammals feed on many of the species listed in Table V-1.

Potential environmental perturbations, resulting from offshore petroleum development, could affect this fish resource. Knowledge of fish in the Beaufort Sea is minimal, and terrestrial based industries are already beginning to alter the environment of this area. Alterations of the streams and nearshore environment resulting from water and gravel removal are in progress. Such developmental activities affect, for example, migratory pathways, spawning, and feeding of anadromous species and marine fish feeding nearshore.

A summation of the state of knowledge of the Beaufort Sea fish as reported by Bendock (RU #233), Morrow (RU #318), Percy (BSPTR #8), and Kendel et al. (BSPTR #6) follows. Data are more inclusive on species used for subsistence and sport.

The discussion includes relative abundance, sex ratios, spawning areas, migratory pathways, stomach contents, and size ranges, when available. Other fish will be noted only as having been reported in the Beaufort Sea.

Salmonidae

Salvelinus alpinus, Arctic char

Arctic char are found along the entire northern coast of Alaska and support subsistence and expanding sport fisheries (Bendock, RU #233). The anadromous variety of char enters the Beaufort Sea from the rivers at the time of ice break-up and remains in coastal waters until mid-July to September. At this time char return to freshwater to spawn (Bendock, RU #233). The Sagavanirktok River is a major spawning drainage for this species.

While in the Alaskan marine waters, char migrate and feed along the coastline and barrier island system. A tag recovery study by Furniss (1975) indicates that char from the Sagavanirktok River range along the nearshore areas from Point Barrow to Barter Island.

Char sampled during 1975 ranged in size from 170 to 685 mm with a length mode occurring between 520 and 529 mm (Bendock, RU #233). The mean fork length of char in the study area was 427 mm. Fish collected were from 3 to 12 years in age, with the majority between 7 and 9 years. The sex ratio was nearly 2:1 in favor of females in the limited catch data available.

Studies of char stomach contents (Bendock, RU #233) have shown that of guts which were full, the frequency of occurrence was amphipods, 95%; Arctic cod, 42%; mysids, 32%; and isopods, 11%.

Coregonus autumnalis, Arctic cisco

Arctic cisco are one of the most common and widely distributed fish found between the Colville and Mackenzie Rivers of Alaska and Canada (Bendock, RU #233).

A local, subsistence fishery and a small commercial fishery are supported by these species. The spawning habits of this anadromous fish have been studied by Kendel et al., BSPTR #6, Griffiths et al. 1975. Upstream spawning migrations of cisco into the Colville River occur from September to November. The minimum age for maturity reported was five years. These data correspond with those collected by Bendock (RU #233) in which 72% of age class VI fish were immature. The sex ratio reported by Bendock was nearly equal, with slightly more males.

All stomachs analyzed contained food and the frequency of occurrence was mysids, 60%; amphipods, 53%; and vegetation/detritus, 40% (Bendock, RU #233).

Coregonus sardinella, Least Cisco

Least cisco are common to the brackish waters of the Alaskan mainland coast. This is evidenced by the absence of any cisco in catches along the barrier islands (Bendock, RU #233). Least cisco sampled ranged in size from 105 to 360 mm with a mean fork length of 263 mm (Bendock, RU #233). A length mode of 310 to 319 mm was also observed. Age varied from 1 to 11 years, and mature firsh of age class VII or greater represented 55% of the catch. The sex ratio of mature fish was approximately 3:1 females.

Of the]2 fish stomachs examined by Bendock, one was empty and the frequency of occurrence of food items in full stomachs was mysids, 91%; amphipods, 45%; adult dipterans, 27%; isopods, 9%; and vegetation/detritus, 9%, Kendel et al.

Coregonus nasus, Broad whitefish

Broad whitefish are distributed throughout fresh and brackish waters of the Arctic drainage of western North America (Scott and Crossman 1973). Bendock

(RU #233) collected this species along the Alaskan mainland coast between the Kuparuk River delta and the eastern boundary of Foggy Bay. Adult whitefish were caught only in the deltas of the Kuparuk and Sagavanirktok Rivers. However, juveniles appeared to forage along the coastline further removed from the rivers.

In the Mackenzie River, the Broad whitefish spawning migration peaked during September and October (Stein et al. 1973). A comparable timing could be expected in the Alaskan coastal drainages.

Fork lengths of specimens collected ranged from 100 to 555 mm with a mean of 300 mm, and the ages varied from 1 to 13 years (Bendock, RU #233). Age classes V through VIII were absent in the sample. Most fish caught represented age class III. Males were slightly more abundant than females.

Only three of the seven stomachs examined were full. These contained principally chironomid larvae (Diptera); one also contained amphipods (Bendock, RU #233). Similar food contents of stomachs from this species were also reported by Percy (BSPTR #8) and Kendel et al. (BSPTR #6).

Coregonus pidschian, Humpback whitefish

Humpback whitefish are a freshwater, fall-spawning species known to enter brackish waters (Kendel et al., BSPTR #6; Percy, BSPTR #8; Bendock, RU #233). Although not common in catches by Bendock, they do extend from Trent Bay west to Roland Bay along the Yukon coast in heavy concentrations (Kendel et al., BSPTR #6). Those captured along the north Alaskan coast were taken west of Sagavanirktok River delta.

Thymallus articus, Arctic grayling

Grayling have been reported along the northern Alaskan coast to the Mackenzie River delta (Bendock, RU #233; Percy, BSPTR #8; Kendel et al., BSPTR #6). The abundance of this species along the Alaskan coast of the Beaufort Sea is not known.

Osmeridae

Osmeris mordax, Boreal smelt

The occurrence of Boreal smelt in the western Beaufort Sea is represented by a single specimen collected along the western border of Prudhoe Bay (Bendock, RU #233). Variable distributions of this anadromous species were reported along the southern Beaufort Sea coast.

Mallotus villosus, Capelin

Capelin were collected along exposed gravel beaches from Stump Island to Foggy Bay. Catches of smelt were low and sporadic (Bendock, RU #233). Young-of-the-year collected in Prudhoe Bay suggests spawning may occur in the near vicinity. Capelin live to be three years or older. Euphausiids, copepods, marine worms, and small fish are common food items of this species. In the Arctic this species may be eaten by salmonids, cod, seals, and birds (Hart 1973).

Pleuronectidae

Liopsetta glacialis, Arctic flounder

Arctic flounder were collected on the western boundary of Prudhoe Bay (Bendock, RU #233). Roguski and Komarek (1971) reported this species to be found in lagoons along the Beaufort Sea coast of Alaska. Specimens ranged from 185 to 280 mm in length and were collected in waters with salinities as low as 1 ppt (Roguski and Komarek 1971).

Gadidae

Boreogadus saida, Arctic cod

Coastal residents fish Arctic cod for both human consumption and animal food. These fish also constitute a major food source for marine birds, mammals, and other Arctic fish (Bendock, RU #233). Bendock reported that cod were seasonally abundant in his collections, but the seasonal variability may reflect the use of inappropriate gear during the ice-free season.

Specimens captured ranged in size from 20 to 193 mm, with a mean fork length of 120 mm. Fish ranged in age from young-of-the-year through age class III. Females outnumbered males nearly 2:1 in Bendock's (RU #233) collections.

Preliminary evidence indicates that cod forage primarily on mysids.

Cottidae

Myoxocephalus quadricornis, Fourhorn sculpin

Bendock (RU #233) reported that this species is common throughout the northern Alaskan coastal zone. Specimens were collected in nearly all available habitats, including low salinity areas of major river deltas. Several were captured in the nearshore waters of barrier islands. Fourhorn sculpin probably spawn in late winter in the near coastal zone, as evidenced by large numbers of sac fry caught in shallow lagoon areas (Kendel et al. BSPTR #6). Seasonal movements of members of this species are not known but it is suspected that they over-winter in low salinity areas near shore (Griffiths et al. 1975).

Sculpins collected by Bendock (RU #233) ranged in size from 50 to 228 mm with a mean length of 125 mm. A bimodal length distribution was noted to occur between 100 and 109 mm and 160 to 169 mm. Ages of sculpin varied from one through seven years, with the majority in the age classes II and III.

Stomach contents indicate that this species feeds primarily on immature isopods and amphipods (Bendock, RU #233). The remains of juvenile Arctic cod were also found in several stomachs.

This species is an important forage fish for Mew gulls, whitefish, Burbot, Arctic sculpin, eelpout, and Arctic char (Griffiths et al. 1975).

Other sculpin

A list of various species of sculpin reported in the Beaufort Sea (McAllister 1962; Morrow, RU #318) is provided in Table V-1. As indicated for Fourhorn sculpin, these fish are often forage species for marine birds and other marine fish.

Ammodytidae

Ammodytes hexapterus, Pacific sand lance

Sand lance are commonly collected offshore, but frequently are found burying themselves in beach sands (Hart 1973). Although reported along the northern Alaskan coast (McAllister 1962; Morrow 1976). no specimens were collected in Bendock's study (RU #233).

Zoarcidae

These species (Table V-1) have been reported in the Beaufort Sea along the Alaskan and Canadian coasts (McAllister 1962; Morrow, RU #318). Some of these could probably be captured in deep water trawls, but ice conditions in 1975 in the Beaufort Sea limited most studies beyond the barrier islands.

Stichaeidae

Like the eelpouts, these fish are reported at depths greater than those found between the mainland coast and barrier islands. Ice conditions prevented deep water studies during 1975. Therefore, no collections were made in 1975, but these fish have been reported by McAllister (1962) and Morrow (RU #318) in Alaskan Arctic waters.

Agonidae

These species, although reported in the Beaufort Sea (McAllister 1962; Morrow, RU #318) are most abundant in the North Pacific (Hart 1973). Agonidae are most frequently found at moderate depths, but have been collected at depths to 1,200 m (Hart 1973).

Liparidae

Liparus sp. adults, young-of-the-year, and early life stages were collected throughout Prudhoe Bay (Bendock, RU #233). Although the Prudhoe Bay collections have not been identified, two species of snailfish (Table V-1) were reported by McAllister (1962) in the western Arctic.

Conclusion

Most studies have been limited to the nearshore areas of the Beaufort Sea, since ice conditions in 1975 prevented any comprehensive studies beyond the barrier islands.

Data derived from the studies discussed indicate that the knowledge of life histories of fish inhabiting the Beaufort Sea is minimal and species diversity is low. Few data are available on the immature and larval forms of most fish discussed.

BENTHOS

Quantitative data on the abundance and distribution of benthic fauna in the Beaufort Sea are limited, although a large number of species have been identified and listed by MacGinitie (1959) and Wacasey (1974). Carey et al.

(1974) provided an account of species assemblages and distribution of benthos off Prudhoe Bay. It was observed that species were distributed within depth zones. Numerical density and biomass of macrofauna, animals retained on 1 mm screen, increased with depth and distance from shore, reaching a maximum on the upper continental shelf.

Presently the distribution, abundance, and natural variability of benthic fauna are being studied by Carey (RU #6). One of the objectives of this project is to identify benthic communities and to determine their geographical and ecological limits. Possible correlation of various bio-indices with environmental factors will also be evaluated. A technique to collect grab samples (Smith-McIntyre, sampling area 0.1 m^2) through ice has been developed. Field sampling in October 1975 and March 1976, with this technique, has been successful. It is possible to sample at locations up to 75 km offshore with helicopter support and transportation.

Carey (RU #7), in another project, has provided a list of about 600 references and abstracts, when available, of research papers related to Arctic benthos studies. These references cover the entire north polar basin. Carey's Annual Report also provides data collected in 1971 and 1972 (WEBSEC cruises). Based on data from 40 stations, 275 charts of the north Alaskan coast depicting presence of a particular species at various stations are provided. A list of 22 widely distributed species, present at 20 or more sampling locations, from these data is presented in Table V-2. In general, more species of a taxonomic group are reported in this study than by Wacasey (BSPTR #12b); for example, 125 species of amphipods, based on 40 samples, are listed by Carey as compared with 67, based on 70 samples, reported by Wacasey.

Littoral benthic fauna is being studied by Broad (RU #356). A large number (943) of samples from shallow waters, barrier islands, mud flats, lagoons,

TABLE V-2

Species Represented at Twenty or More Stations Occupied in The North Alaska Shelf During Summer 1971

Pelecypoda	Decapoda
Astarte montagui	*Sclerocrangon salebrosa*
Nucula bellotii	Cumacea
Nucula pernula	*Brachydiastylis nimia*
Palliolum groenlandicum	*Diastylis oxyrhyncha*
Portlandia arctica	*Diastylis rathkei*
Portlandia frigida	*Diastylis scorpioides*
Portlandia lanticula	*Eudorella emarginata*
Ophiuroidea	*Leucon acutirostris*
Ophiocten sericeum	Amphipoda
Holothuroidea	*Aceroides latipes*
Myriotrochus rinkii	*Anonyx nugas*
	Arrhis phyllonyx
	Byblis gaimardi
	Haploops tubicola
	Photis reinhardi

and embayments in coastal areas have been collected in summer 1975. A hand operated Ekman grab was used. A number of additional samples were collected by dredges, seines, and traps. Only a small fraction of total samples has been analyzed. Some preliminary results are as follows:

1. Polychaete numbers were greater in samples from depths of about 2 m; two samples contained 7,704 and 5,410 individuals/m^2, respectively.

2. Unexpectedly large numbers of Oligochaetes, as high as 10,604 specimens/m^2, were found in mud flats and shallow water.

3. Principal infaunal animals were recognized to be molluscs and polychaetes.

Conclusion

The results presented in the Annual Reports by the three research units (6, 7, and 356) are fragmentary and do not add materially to our existing knowledge of benthos on the north Alaskan shelf at this time. As has been the case in so many previous biological surveys and population studies, dating back to the Challenger Expedition, many more samples have been collected than can be effectively analyzed and completely reported. Broad (RU #356) collected 943 grab samples in a three month period (July 10 to September 12), out of which 168 have reportedly been analyzed. At this rate, an enormous number of samples will be collected to complete seasonal study. Collected samples may be too many to analyze, study, and report within the time constraints of OCSEAP objectives.

Carey's (RU #7) efforts to provide an alphabetical listing of about 600 references pertaining to the entire north polar basin may be of little use to OCSEAP. Listings according to subject matter or, at least, cross-references should be provided if this bibliography is to serve its intended purpose. Also note that Bibliography of the Naval Arctic Research Laboratory, published in 1973, provides a comprehensive listing, nearly 2,500 citations, of all aspects of research in and around the Beaufort Sea. This bibliography is also alphabetically listed and, therefore, of limited usefulness.

PLANKTON

Plankton studies were carried out by English and coworkers (RU #359) to determine seasonal density and environmental requirements of principal species of phyto-, zoo-, and ichthyoplankton in the Beaufort Sea and to calculate indices of phytoplankton primary productivity. Apparently due to the nonavailability of ship time, field activities were limited to coastal embayments and lagoons in the vicinity of Point Barrow, Smith Bay, and Prudhoe Bay for about one month in summer 1975. A related study was undertaken from June 1 to September 30, 1975 on Fletcher's Ice Island, T-3. During this period, the ice island was offshore, near 75°N latitude and 140-150°W longitude.

Reported data and results are few and incomplete. Some of the reported results are as follows:

Coastal Study

1. In general, chlorophyll a content was low, less than 1 mg/m^3. Nitrate-N content reached low values, less than 0.05 $mg\text{-}at/m^3$, at several stations; ammonium-N concentration was high and ranged from 0.6 to 2.6 $mg\text{-}at/m^3$.

2. Only one phytoplankton species, *Chaetoceros furcellatus*, was recognized. The genus *Thallasiosira* was also noted. No data on zooplankton were provided.

T-3 Study

1. Chlorophyll a was generally much lower, less than 0.05 mg/m^3, in the upper 40 m throughout the sampling period. Few higher concentrations, 0.1 to 0.2 mg/m^3, were observed between 50 and 60 m. Integrated chlorophyll a concentration in the upper 100 m showed wide temporal variation; values ranged from 1.8 to 7.0 mg/m^2.

2. Only 12 out of 994 zooplankton samples have been analyzed. Distribution of only three species, *Calanus hyperboreus*, *Calanus glacialis*, and *Euchaeta glacialis* were considered. Total number of these species showed a maximum in early September; copepodite stage III of *C. hyperboreus* and stages I and II of *C. glacilis* were abundant.

Conclusion

No new result or concept or interpretation of results has been reported. Several studies have been undertaken at the Naval Arctic Research Laboratory, to describe the phytoplankton and primary productivity of coastal waters and lagoons off Barrow. Taxonomic description and ecological notes on phytoplankton have been provided by Horner (1969). In shallow wakes and lagoons, primary productivity of benthic microalgae has been found to be about eight times that of ice-algae and twice that of the phytoplankton (see Horner 1973).

Redburn (Master's Thesis, University of Alaska, data reported in Hornes 1973) recognized 48 taxons of zooplankton in coastal waters off Barrow. Copepods were found to be major constituents in terms of both the numbers and species.

Other zooplankton data relevant to OCSEAP objectives are included in reports by Johnson (1956) and Hand and Kan (1961).

ICE ORGANISMS

Although included in the program objectives by Research Unit #359, data on sea ice microalgae taxonomy or primary productivity were not reported by English and Horner in their Annual Report.

Ice flora has been found to contribute significant fractions of total primary productivity in the water column. More significantly, the presence of this flora probably extends the otherwise short plankton growth season, as productivity in ice generally starts a few weeks prior to that in waters beneath (Alexander 1974). Mechanisms of nutrient supply and growth requirements of ice-algae are discussed by Apollonio (1965), Horner and Alexander (1972), and Meguro et al. (1967).

AQUATIC AND SHORE BIRDS

Introduction

Approximately 163 species of birds occur along the Arctic coast of Alaska. They include about 60 species of swimming and wading birds, distributed among nine avian families (Table V-3). It is these aquatic (swimming) and shore (wading) birds, because they actually enter Beaufort Sea waters, that are most subject among birds to direct impact of OCS development in the Beaufort.

Much useful information on timing of migrations, distributions, population densities, and habitats of aquatic and shore birds of the Alaskan Beaufort Sea is summarized in environmental assessments compiled by the

Alaska Division of Policy Development and Planning (ADPDP 1975), the Arctic Institute of North America (AINA 1974), and the U.S. Department of Interior Alaska Planning Group (USDI 1974). In addition, Watson and Divoky (1974) describe the distribution and relative abundance of marine birds encountered during shipboard surveys in offshore areas of the western Beaufort in August and September and summarize literature pertaining to the offshore distribution of species that they observed. Bailey (1948), Gabrielson and Lincoln (1959), and Pitelka (1974) review the entire north slope avifauna.

TABLE V-3

Birds That Occur in The Western Beaufort Sea Region

Family	Species	*Nesting habitats in western Beaufort: BI	CP	FH	Comments on status in western Beaufort
Gaviidae	Yellow-billed loon	-	+	+	
	Arctic loon	-	+	+	
	Red-throated loon	-	+	+	
Procellariidae	Short-tailed shearwater	-	-	-	Summer offshore resident
Anatidae	Whistling swan	-	+	-	
	Canada goose	-	+	+	
	Black brant	+	+	-	
	White-fronted goose	-	+	+	
	Snow goose	-	+	-	
	Pintail	+	+	+	
	Oldsquaw	+	+	+	
	Harlequin duck	-	-	-	Rare vagrant
	Common eider	+	+	-	
	King eider	+	+	-	
	Spectacled wider	-	+	-	
	White-winged scoter	-	-	+(?)	Mainly a migrant through foothills; not common on coast
	Surf-scoter	-	+	+	
Charadriidae	Semipalmated plover	-	+	+	
	Killdeer	-	-	-	
	Golden plover	-	+	+	
	Black-bellied plover	-	+	-	
Scolopacidae	Common snipe	-	-	+	
	Whimbrel	-	+	+	
	Spotted sandpiper	-	-	+	
	Red Knot	-	+	-	Small numbers in migration
	Pectoral sandpiper	-	+	-	
	White-rumped sandpiper	-	+	-	
	Baird's sandpiper	-	+	+	
	Dunlin	-	+	-	
	Long-billed dowitcher	-	+	+	
	Stilt sandpiper	-	+	-	
	Semipalmated sandpiper	-	+	+	
	Buff-breasted sandpiper	-	+	-	
	Bar-tailed goduit	-	-	-	
	Sanderling	-	-	-	Uncommon migrant
	Rufous-necked sandpiper	-	+	-	Recently discovered
	Baird's Sandpiper	+	+	+	breeding near Barrow
	Sanderling	-	+	-	
	Western Sandpiper	-	+	-	
	Curlew Sandpiper	-	+	-	Rare breeder

TABLE V-3 (cont.)

Family	Species	*Nesting habitats in western Beaufort: BI	CP	FH	Comments on status in western Beaufort
Phalaropidae	Red phalarope	-	+	+	
	Northern phalarope	-	-	+	Fairly uncommon on the coast
Stercorariidae	Pomarine jaeger	-	+	-	
	Parasitic jaeger	-	+	+	
	Long-tailed jaeger	-	+	+	
Laridae	Glaucous gull	+	+	+	
	Slaty-backed gull	-	-	-	Uncommon offshore summer visitor
	Herring gull	-	-	-	Migrant in small numbers
	Black-legged kittiwake	-	-	-	Migrant; young birds summer offshore
	Ross' gull	-	-	-	Migrates into Beaufort in fall; winter resident (?)
	Ivory gull	-	-	-	Migrates into Beaufort in fall; winter resident on pack ice
	Sabine's gull	+	+	-	
	Arctic tern	+	+	+	
Alcidae	Black guillemot	+	+	-	Recently colonized around Barrow; nests in old junk
	Kittlitz's murrelet	-	?	-	Uncommon
	Parakeet auklet	-	-	-	Rare
	Crested auklet	-	-	-	Migrant; some may summer offshore
	Horned puffin	-	-	-	Uncommon; offshore migrant (?)
	Tufted puffin	-	-	-	Uncommon straggler to western Beaufort

* BI = barrier islands; CP = coastal plain; FH = foothills

Habitats

Aquatic and shore bird habitats of the Beaufort Sea which are vulnerable to direct impact of OCS petroleum development are classified by the Alaska Division of Policy Development and Planning (1975).

The alcids (murres, puffins, auklets, and guillemots), which form huge nesting colonies in summer at numerous sites on the western coast of Alaska from Cape Lisburne southward (e.g., ADFG 1975; Swartz 1966; Tuck 1960; Lensink and Bartonek, RU #338/343), do not breed on the north Alaskan Beaufort Sea coast. Presumably, this is because the rocky sea cliffs, talus piles, and loose soil (which can be excavated for nest burrows) where alcids normally nest are absent from the coastal plain and barrier islands of the western Beaufort. For the same reason, alcids do not breed on the Chukchi coast anywhere north of Cape Lisburne, which is the northern limit of Alaskan sea cliffs. The one exception is the black guillemot, which normally nests in protected crevices in talus piles and rocky cliff faces. This alcid recently colonized the Point Barrow area, where it has successfully nested in discarded equipment, empty oil drums, oil buildings, and other debris from scientific and logistic operations that provide protected niches simulating the species' natural nesting crannies (MacLean and Verbeek 1969; Watson and Divoky 1974). These guillemots are increasing in abundance, and measurements of success at 17 nests on Cooper Island, a barrier island about 30 km southeast of Point Barrow, indicate that more than 80% of the young that hatched there in 1975 survived to depart for the sea (Divoky, RU #330). It seems clear in this case that it was the previous lack of safe nesting sites that prevented this species from colonizing the Beaufort Sea coast.

Barrier Islands and the Inshore Zone

A characteristic aspect of the Beaufort Sea coast of Alaska is the series of small, nearshore barrier islands consisting of sand and gravel deposited and shaped mainly by waves, currents, and ice action over the past 5,000 years or so. A thorough summary of literature describing the origins and physical characteristics of these islands is provided by the Alaska Division of Policy Development and Planning (1975).

Delineation of avian habitats on the barrier islands is being undertaken by Divoky (RU #330). Pacific (= common) eiders, king eiders, black brant, pintails, oldsquaws, glaucous gulls, Arctic terns, Sabine's gulls, and members of a few other species nest on some of the barrier islands (Schamel 1974; AINA 1974; Divoky, RU #330).

Data on reproductive success of birds nesting on barrier islands are provided by Schamel (1974).

Divoky (RU #330) began studying reproduction of 17 black guillemot and 51 Arctic tern nests on Cooper Island during the 1975 breeding season. For the guillemots, he found 97% (30/31) hatching success and 81% to 94% (25-29/31) fledging success. Eighty-six percent (83/97) of the tern eggs hatched and 67% (67/97) survived to one week of age, when data collection terminated. According to Divoky (loc. cit,), this is an unusually high nesting success for both species. It is possible that, if they remain cluttered with litter, the barrier islands will become important nesting habitat for black guillemots.

Despite their relative insignificance as a nesting habitat, the barrier islands serve two extremely important functions for coastal avifauna:

1. The islands more than double the extent of shoreline on the Alaskan Beaufort Sea coast that provides feeding habitat for many thousands of shorebirds.

2. The protected waters (Inshore zone) behind the barrier islands provide refuge for millions of water fowl and sea birds which utilize them for feeding, resting, rearing young, staging and moulting; primarily in spring, late summer, and fall. Eiders are the most abundant of these but they also include surf and white-winged scoters; Arctic terns; glaucous, Sabine's and other gulls; red-throated, Arctic, common and yellow-billed loons; and various alcids (ADPDP 1975; Mueller, RU #215).

Individuals of several species that nest on the coast or barrier islands also obtain food in inshore waters while breeding. These include black guillemots, Arctic terns, red-throated loons (Divoky, RU #330), glaucous gulls, eiders (Schamel 1974), and several species of shorebirds (Risebrough and Connors, RU #172).

Divoky (RU #330) obtained data indicating that Arctic terns breeding on Cooper Island feed primarily on insects obtained on the mainland before their eggs hatch and primarily upon Arctic cod after hatching. They also feed upon amphipods in surface waters around the island, but apparently not upon mysid shrimp, which plankton tows showed were far more abundant but tended to stay deeper than the amphipods.

Risebrough and Connors (RU #172) are finding that shorebird diets around Point Barrow include chironomids, amphipods, euphausiids, decapods, copepods, chaetognaths, oligochaetes, barnacle cyprids, and cladocerans. Insects, principally chironomids (adults, papae, and larvae), are the main food of birds feeding at the edges of ponds and protected, low salinity lagoons, whereas individuals feeding along seashores of the mainland and barrier islands prey mainly upon planktonic crustaceans. Phalaropes capture prey while swimming in the nearshore water column, but other shorebirds (e.g., sanderlings, ruddy turnstones, dunlins) work the land-water interface of the seashore, capturing organisms stranded or exposed on the beach.

TABLE V-4

Extent of Barrier Islands in the Alaskan Beaufort Sea from Pt. Barrow to the Canadian Boundary (adapted from Divoky, RU #330/196)

Location	Barrier Islands: No.	Barrier Islands: Area (mi^2)	Area (mi^2) of Protected Waters Behind Islands	Seaward Coastline (mi) of Islands
Pt. Barrow to Cape Simpson	9	2.31	330.6	27.50
Smith Bay	0	0.00	0.0	0.00
Drew Point to Cape Halkett	2	0.74	7.0	3.55
Cape Halkett to Atigaru	2	0.47	18.0	38.00
Atigaru Pt. to Oliktok Pt.	2	0.19	0.0	2.65
Oliktok Pt. to Pt. McIntyre	9	3.17	100.0	28.65
Pt. McIntyre to Bullen	15	2.76	110.0	24.30
Bullen to Brownlow Pt.	8	1.85	60.0	18.75
Brownlow Pt. to Jago R.	6	8.16	38.0	34.30
Jago R. to Canada border	8	3.43	89.1	50.30
TOTALS:	61	23.08	752.7	228.00

Onshore Zone and Barrier Islands

The onshore zone includes the seaward edge of the extensive coastal plain of Alaska's north slope. In addition to sea beaches, it includes all of the characteristic coastal tundra habitats, i.e., wet sedge meadows, tussock tundra, flood plains, river mouths, cut banks, elevated beaches, shallow ponds, and frost polygons. With the possible exception of glaucous and Sabine's gulls and common eiders, all species of aquatic and shorebirds that nest in association with the Alaskan Beaufort Sea (Table V-4) can be found nesting in the onshore zone (as well as further inland).

Barrier islands and lower lying areas of the onshore zone are both subject to periodic inundation caused by storm induced increases in sea level. These "storm surges" usually have an amplitude of about 1 m, but on occasion can exceed 2 m, and last for several hours (Henry, BSPTR #19). According to Mueller (RU #215) and Schamel (1974), storm surges deposit considerable debris on Alaskan barrier islands, well above normal high water mark. They believe that this debris enhances nesting of birds on these islands by providing nests some protection from wind. Since most storm surges occur in fall rather than during the nesting season, they are not believed to be an annual source of nest loss even on the barrier islands (Mueller, RU #215; Schamel 1974).

Storm surges may at present be a statistically relatively innocuous natural phenomenon for birds on the Beaufort Sea coast. However, their potential for transporting vast quantities of oil onto barrier islands and the onshore zone is bound to alter this status with the advent of OCS petroleum development. An oil spill or blowout combined with a storm surge conceivably could contaminate barrier island and onshore nesting and feeding areas for some years thereafter (cf. Beaufort Sea Project 1975).

Offshore Zone

The offshore zone is utilized little, if at all, by breeding birds during the nesting season. Even the few birds that feed at sea while breeding apparently visit only the richer inshore waters (Divoky, RU #330; Watson and Divoky 1974). Nevertheless, several species of marine birds do occur in offshore waters of the western Beaufort in summer. These include sizeable numbers of black-legged kittiwakes, whose nearest nesting cliffs are at Cape Lisburne on the Chukchi Sea (Schwartz 1966) and on Northern Banks Island, in the eastern Beaufort Sea (Manning et al. 1956).

Lensink and Bartonek (RU #337, Part II) aerially surveyed birds on waters of the Alaskan Beaufort on July 2-3, 1975. They report sizeable numbers of King eiders and oldsquaws, but it is impossible to tell from their data whether the birds were in the inshore zone or the offshore zone, since the authors do not differentiate between these. Normally, eiders and oldsquaws are found in the inshore zone or only slightly seaward of the barrier islands (Watson and Divoky 1974; Mueller, RU #215; Johnson 1971; Schamel 1974).

In summary, available information indicates that the offshore zone is an important summer and fall habitat for nonbreeding, post-breeding, and migrating red phalaropes, jaegars (3 species), and gulls (3 species) in late summer and fall. Extensive, systematic, habitat-stratified surveys in spring, summer, and fall are required before the offshore zone's importance to other species can be defined.

Ice and Ice-bounded Habitats

No research has been done by OCSEAP on the subject. See Bailey 1948; Johnson 1971; Schamel 1974; Watson and Divoky 1974; ADPG 1975; ADPDP 1975; Beaufort Sea Project 1976.

Trophic Relationships

There is considerable information on foods and feeding habits of several species of aquatic and shorebirds while they are nesting on tundra near the Beaufort Sea but hardly any on their sea-oriented feeding. This is being rectified for shorebirds in the Barrow area by the work of Risebrough and Connors (RU #172).

Lensink and Bartonek (RU #341) are funded to analyze stomach contents of 227 marine birds taken in Alaskan waters, of which "...37% were from the Beaufort Sea, through the Bering Sea, and into the Northern Gulf of Alaska." However, it appears none of their specimens are actually from the Beaufort Sea (Table 3 in their Annual Report).

If potential impact of OCS development upon Beaufort Sea avifauna is to be evaluated, at least an outline of food web relationships is needed.

Relative Abundance and Importance of Shorebirds and Anatids

In terms of sheer numbers, and perhaps in terms of ecosystem dynamics, shorebirds might be considered the most important element of the avifauna (but see below). Following the breeding season, adult and juvenile shorebirds exhibit a net movement to littoral zone (inshore zone) foraging areas on the coast where they probably build up that fat stores necessary for migration (Risebrough and Connors, RU #172). It appears, then, that late summer is a particularly critical period of inshore zone usage by the numerically largest segment of the Beaufort Sea avifauna.

The family anatidae --ducks, geese and swans --is the second most abundant element of the avifauna, contributing about 15% to the total number of birds present (ADPDP 1975). In terms of biomass, or total weight of birds present, the anatids probably equal or exceed the much smaller bodied shorebirds (no actual calculations are available).

In terms of human ecology and economics, the anatids are considerably more important than any other element of the Beaufort Sea avifauna. Many thousands of eiders and other anatids are taken each fall, during migration, by Innuit subsistence hunters in Canada and Alaska (Johnson 1971).

MARINE MAMMALS

Introduction

About 14 species of mammals in nine mammalian families are associated, either seasonally or permanently, with waters and ice of the western Beaufort Sea. The cetaceans (whales and propoises) are wholly aquatic, whereas polar bears and pinnipeds (walrus, seals, and fur seals) are amphibious, spending part of their time in the water and the balance on ice or land. The Arctic fox scavanges on the landfast ice but probably rarely enters the sea.

Killer whales, gray whales, fur seals, and ribbon seals apparently visit the Beaufort so rarely that they can be considered rather minor elements in the Beaufort ecosystem. Although a few harbor porpoises are seen in the Barrow area nearly every summer, they normally go no further east than Elson Lagoon behind Point Barrow, so they scarcely enter the Beaufort.

Waters of the Bering Sea are warmed by mixing with waters of the north Pacific subtropical gyre. In summer some of this warmer water flows through Bering Strait and travels in surface currents along the Alaskan coast as far north as Point Barrow. It is possible that the distribution of marine mammals is limited by their association with these warmer sub-Arctic waters and avoidance of the colder Arctic waters which prevail in the Beaufort Sea.

The narwhale is such a rare and little known form that its position in the Beaufort ecosystem is difficult to assess. Because of its rarity and its year round confinement to Arctic waters, the narwhale might best be considered important simply because of its critically endangered status.

Finback whales that have been reported in the vicinity of Barrow apparently were gray whales that had been misidentified (Maher and Wilimovsky 1963).

The harbor seal, like the harbor porpoise, occurs in small numbers nearly every summer in the vicinity of Barrow, where a few are taken in spring by Innuit seal hunters.

Walruses also occur, in association with sea ice, along the entire north Alaskan coast in summer. Although commoner in the Chukchi than in the Beaufort Sea, walruses are regularly captured by Innuit hunters at Barrow (Bee and Hall 1956) to whom they provide moderate quantities of meat, tallow, ivory, and oosiks.

Walruses, harbor (= spotted) seals, and ribbon seals that reach the Beaufort Sea in summer spend the winter and breed on the Bering Sea ice pack. As spring breakup of the ice pack proceeds, most of the walruses, many of the harbor seals, and some of the ribbon seals move northward through Bering Strait and disperse to their Arctic summering grounds on the Chukchi and Beaufort Seas (Burns 1970; Burns et al., RU #248).

In terms of ecosystem dynamics, the six most important water- and ice-inhabiting mammal species of the western Beaufort Sea are Bowhead and belukha whales, ringed and bearded seals, polar bears, and Arctic foxes. The balance of this section emphasizes these six species.

Species Accounts

Information on abundance, distribution, migrations, reproduction, food habits, and habitats of the six Key mammal species of the Beaufort Sea is summarized in the following species accounts.

Bowhead Whale

The segment of the Bowhead population that occurs in the Beaufort Sea in summer apparently winters in the Bering Sea. In late March or early April, as leads open, the whales start their spring migration. They move in leads and

and open water at the seaward edge of landfast ice.

Belukha Whale

Belukhas also winter in Bering Sea and migrate in spring to summer feeding grounds in the Canadian Beaufort. Timing of belukha migration is similar or identical to that of the Bowheads'. As soon as leads begin opening in late March or early April, providing travel routes, belukhas start their northward migration. They normally begin arriving in the Canadian Beaufort by early May.

Fiscus and Braham (RU #69 and #70) are conducting aerial surveys of bowheads and belukhas in northern Alaska, but their surveys have been in March, before belukhas move to their summering grounds, and in September, during or after the fall migration. Fiscus and Braham (loc. cit.) saw no belukhas and only two Bowheads along the Beaufort coast of Alaska during their September (1975) survey. Surveys of the Alaskan Beaufort coast during the critical months of April through August are needed to identify the summer status and habitats of Alaskan belukhas. Other studies have been done on Beaufort Sea belukhas by Sargeant and Hoek (1974), and ADPDP (1975).

The presence of belukhas in Bristol Bay throughout the summer suggests that some segments of the Alaskan belukha population may be nonmigratory (Klinghart 1966).

Ringed Seals and Bearded Seals

Aerial surveys in Alaska (e.g., Burns and Harbo 1972) and the preponderance of ringed seals in the Alaskan Innuit seal kill (Burns and Eley, RU #230) indicate that ringed seals outnumber bearded seals in Alaska. Other information is available from Walker (1968), ADPDP (1975), Stirling et al. (BSPTR #1), and Burns (1970). In the Beaufort Sea, ringed seals probably outnumber all other marine mammals combined. In the Canadian Beaufort they are 15 to 18 times more abundant than bearded seals (Stirling et al. BSPTR #1).

Ice Habitats

Breeding and pupping in ringed seals occurs in late spring and early summer, before the landfast ice breaks up. Bearded seal breeding activities extend slightly beyond this period. Since bearded seal females do not den to bear their young, it is less critical for them that pupping precedes breakup. Reproduction of bearded and ringed seals is compared in Table V-6.

In the Canadian Beaufort and Amundson Gulf ringed seal pupping areas are scattered widely over the landfast ice but may be more prevalent in large bays and along Tuktoyaktuk Peninsula than they are elsewhere. Pupping in Canadian Beaufort bearded seals appears to be more limited in distribution, with concentrations along moving lead systems north of Tuktoyaktuk Peninsula and west of Banks Island (Stirling et al. BSPTR #1).

TABLE V-6

Comparative Reproduction of Ringed and Bearded Seals
(Sources: Asdell 1964; Burns and Eley, RU #230; Stirling et al., BSPTR #1)

	Ringed Seal	Bearded Seal
Birth lair	Excavation beneath a snow drift covering and concealing breathing hole	None; pups delivered on exposed ice in moving lead areas
Birth season	March to mid-May; peak from late March to early April	Late April to early May
No. young/birth	Normally one	Normally one
Development	Pups altricial; nursing period about two months or more	Pups precocial; nursing period 12 to 18 days
Mating/impregnation	Within days after birth of pup	Late May to July, after pup is weaned
Delayed implantation period	3½ months	2½ months
Normal interval between births	1 year	2 years
Age at sexual maturity	Males -- 7 years; females probably younger	Males -- 7 years; females -- 6 years

Ice habitat studies have been conducted by Burns and Harbo 1972; Stirling 1974; ADPDP 1975; Stirling et al., BSPTR #1.

Food habits. Lowry and Burns (RU #232) are determining stomach contents of seals taken in spring and early summer by Innuit hunters at sites between Mekoryuk, Nunivak Island, and Point Barrow. Data on ringed and bearded seal diets have been extracted from their report and are summarized in Table V-7. From these data the following conclusions can be drawn.

1. Amphipods are consistently important (10-59% of total) in diets of ringed seals but not in diets of bearded seals (less than 1%, perhaps ingested inadvertently or in fish guts).

2. Clams are locally important (up to 54% of total) in bearded seal diets but they are rarely or never eaten by ringed seals.

3. Decapod crustaceans (shrimp and crabs) are consistently very important (21-73% of total) in bearded seal diets and can be locally important (up to 45% of total) in ringed seal diets. This taxon contributed more than any other to bearded seal diets at four out of the five sampling areas and was second to clams at the fifth.

4. Fish are a staple food of both species (2-59% of total for ringed seals, 10-31% for bearded seals).

Data on winter food habits of ringed seals in Alaskan waters was obtained by Johnson et al. (1966) at Point Hope and Kivalina. They found that ringed seals ate mainly (90% or more of total) benthic fishes from November through February, then switched to a diet consisting predominantly of invertebrates during spring and summer. No data are available on winter food habits of Alaskan bearded seals.

Also no data on seal food habits are available for the Beaufort Sea east of Point Barrow. Samples obtained between Barrow and the Canada border are needed, since it cannot be safely assumed that diets of seals in the Beaufort Sea will closely resemble those in the Chukchi and Bering Seas.

TABLE V-7

Comparative food habits of ringed seals (RS) and bearded seals (BS) during spring and summer. Numbers are percent volumes of stomach contents contributed by prey types. An asterisk (*) indicates that no sample was obtained. The most important prey type for each species and locality is bracketed.

Prey Taxon		N=9 BS Barrow	N=19 RS,22 BS Wainwright	N=12 RS, 6BS Diomede	N=2 BS Gambell	N=9 BS Savoonga	N=6 RS,12 BS Mekoryuk
Amphipods	RS	24	10.2	[58.8]	*	*	14.1
	BS	*	<1	<1	<1	<1	<1
Euphausids	RS	[72.5]	<1	0	*	*	<1
	BS	*	0	0	0	0	0
Mysids	RS	0	1.5	<1	*	*	17.5
	BS	*	<1	0	0	<1	<1
Isopods	RS	<1	5.1	0	*	*	0
	BS	*	3.1	<1	0	0	10.5
Decapods	RS	<1	[45.1]	17.5	*	*	3.5
	BS	*	20.5	[41.3]	[73.3]	[65.8]	[56.8]
Fish	RS	2.0	25.2	13.8	*	*	[58.5]
	BS	*	10.4	30.8	20.6	12.8	19.2
Clams	RS	0	0	0	*	*	0
	BS	*	[54.2]	8.5	1.8	10.7	0
TOTAL Invertebrates	RS	98	69.8	86.2	*	*	41.5
	BS	*	88.1	68.7	78.3	80.1	76.2

Summary

One of the six major questions formulated in the NOAA General Study Plan for the Alaskan continental shelf (NOAA 1976) is "What are the biological populations and ecological systems most subject to impact from petroleum exploration and development?" An attempt is made to provide some partial answers to this question relative to acute effects upon sea-oriented birds and mammals of the Beaufort Sea region. In large part it is a summary and discussion of information previously presented.

The ecosystem subject to impact is, of course, the Beaufort Sea, including its shores, floor, barrier islands, waters, ice, and biota. Bird and mammal populations subject to major impact from perturbations in the ecosystem are those which include a majority of individuals that depend upon the Beaufort Sea for performance of reproduction or critical life processes (e.g., feeding, resting, moulting, migration) during some or all of the year.

Among mammals, definitely critical populations are those of bowhead and belukha whales, ringed and bearded seals, and polar bears. The narwhale might also be placed on the list because destruction of a few individuals might be equivalent to destroying the entire Beaufort Sea population of this species.

Critical habitats of definitely critical mammal species vary with season. From November to April certain barrier islands and onshore areas provide maternity denning sites for polar bears. Serious pollution or activities that would make these areas unavailable to pregnant female bears could lower reproductive output of this already endangered species.

Bearded seals and ringed seals require open leads and breathing holes where they can enter the sea to feed before spring breakup. In the event of a major oil well blowout or comparable disaster, leads as well as breathing holes could be blocked and seals would become oiled.

Extensive contamination of spring leads also would affect whales and aquatic birds. Bowhead and belukha whales both migrate in open leads. Direct physiological effects of crude oil on cetaceans is unknown. Even if there are none, which is doubtful, whales might be deterred from reaching their summer feeding grounds in the eastern Beaufort if leads enroute were blocked by oil. Some and perhaps all pregnant bowheads and belukha give birth just before migration or while enroute to the summering grounds. Effects on the calves might be more detrimental than effects on adults.

Like the whales, seabirds and waterfowl migrating to the Beaufort from the Bering Sea in spring follow open leads along the coast. It has been observed that when the leads open and then refreeze, many thousands of birds perish of starvation. In the event of oil blockage of leads birds would be killed by effects of landing in the oil as well as by starvation. In terms of numbers and biomass subject to impact, eiders probably would be the hardest hit.

Contamination of the barrier islands and shore could disrupt breeding of some polar bears, guillemots, waterfowl, terns, and gulls. But a more serious effect is the potential reduction or destruction of shorebird populations that depend upon the barrier island and mainland shores for feeding in spring, late summer, and fall. Numerically, these birds contribute 60-70% of the coastal plain avifauna. One species of shorebird that could quickly be eliminated from the Alaskan avifauna is the rufous-necked sandpiper, whose entire North American breeding population consists of a few individuals in the vicinity of Point Barrow (Risebrough and Connors, RU #172).

Protected waters behind the barrier islands provide critical feeding, resting, staging, and moulting habitat for millions of seabirds and waterfowl. Contamination of these waters could drastically reduce or even eliminate entire breeding populations.

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Chapter VI

EFFECTS

EFFECTS OF CONTAMINANTS ON MARINE ORGANISMS

The primary purpose of OCSEAP research on the effect of contaminants is to evaluate deleterious effects of oil contamination on selected marine organisms and their habitats. These studies generally encompass economically and ecologically important species of the Alaskan Outer Continenal Shelf. Little data are being generated on species common in the Beaufort Sea.

Dispersed crude oil interacts with both the air and water phases. The light end and/or low boiling point fractions readily dissipate to the atmosphere but are also the most water soluble of oil components. Once in the aqueous phase short-chain aliphatics may be degraded by microorganisms. The unsaturated naphthenic acids and mono- and dinuclear aromatics are least degraded; these fractions are also considered as the most toxic crude fractions (Percy and Mullin, BSPTR #11; Rice and Karinen RU #72; Malins et al. RU #73,74,75). Most hydrocarbon fractions are only slightly soluble in water, but increased agitation by waves or dispersants can induce the oil into the water either as solutes or finely dispersed globules. In either case, planktonic or pelagic species may contact these pollutants. The effects produced may be directly lethal, sublethal, or behavioral. Tissue damage may occur (Wolf and Strand 1973); furthermore, as Malins et al. (RU #75) point out, activities related to feeding, avoidance, escape, reproduction, settlement site selection, and homing may be adversely affected.

Effects of Crude Oil on Microbial Activity

In analyzing microbial populations emphasis is generally placed on determining if the heterotrophs present degrade petroleum. This concept has been extended to include adverse effects of oil on the total heterotrophic population. In most cases, it was noted that weathered or fresh Canadian crude oil did not significantly inhibit the rate of mineralization of glutamic acid by the predominate flora. Often the rate of mineralization was enhanced. Enhancement may have resulted from increased utilization of glutamate by the presence of crude oil or as a marked increase in the oleoclastic flora.

Morita and Griffiths (RU #190) studied the effects of curde oil on the uptake and respiration (mineralization) of glutamic acid and acetate. Although these results are preliminary, differences between non-oil and oil exposed cultures were observed. Initially there was no significant effect of crude oil on microbial activity. However, as the incubation period increased, inhibition of activity was followed by enhancement. The highest population levels noted in two experiments occurred after days 5 and 7 in the exposure period and increased measurably with incubation. It was also noted that over the incubation period the total heterotrophic population, including oleoclasts, increased over the nonexposed groups. Similar delays in other mineralization experiments have not been noted, but a four-week delay before any measurable degradation occurred has been observed (Bunch and Harland, BSPTR #10).

It is apparent from these preliminary efforts that neither the Alaskan or the Canadian crude adversely affects heterotrophic populations isolated from the Beaufort Sea. Enhancement readily occurs, but the initiation of degradation is variable between these studies. Differences in methods and source of isolates may account for these variations.

Invertebrates

Few data have been gathered on the effects of crude oil and its water soluble fractions on Arctic species (Rice and Karinen, RU #72). Although available data are few, it is unlikely that sufficient knowledge exists on the effects of crude oil on Beaufort Sea species. Some data obtained during the Canadian Beaufort Sea Project on Mackenzie Delta species are available (Percy and Mullin, BSPTR #11), but the results seem questionable because of the unknown variability of exposure levels.

The available data are limited mostly to adult life stages of temperate water species (Caldwell, RU #183) which are generally more resistant than the early life stages. Data collected on temperate water species may be extrapolated to similar Arctic species, but a difficulty arises in that the history of pollution exposure varies between these geographic areas. Species indigenous to the Arctic have received little previous pollution stress and as a result, may be less resistant than their counterparts at more southerly latitudes.

Larval stages of crabs and shrimp were affected by 1 to 100 ppb of various oil products (Mironov 1969). Katz (1973) also found reduced survival of crab larvae exposed to 10 mℓ/ℓ of Venezuelan crude oil. Initial studies with stage V larvae of Spot shrimp indicate that naphthalene is acutely toxic (Malins et al. RU #74). Concentrations of 10 ppb naphthalene caused 100% mortality in 36 hrs in Malins et al. (RU #74) studies. Rice and Karinen (RU #72) reported the 96 hr TL_{50} for Eualus sp (shrimp) was 0.11 and 0.206 ppm naphthalene equivalents at 4°C. The variability was dependent on the aromatic mix of the water soluble fraction of crude oil. Although the ultraviolet optical density was the same, gas chromatographic analysis revealed marked differences in the aromatic fractions. The lowest 96 hr TL_{50} value was derived for the higher aromatic mix. Taylor et al. (1976) observed that the effect of oil on

Macoma was dependent on the degree of tidal mixing. In these studies few mortalities occurred, but the presence of water soluble fractions and oil contaminated sediments inhibited clam burrowing and caused the clams to move to the surface. Although the clams did not die as the result of crude oil exposure, burrowing to the surface during low tides may increase mortality from dessication and subject the clams to increased predation.

These data indicate that crude oil will cause deleterious effects in various invertebrates under laboratory conditions. Species-to-species and area-to-area variability should be investigated for species indigenous to the Beaufort Sea. In situ studies would also enhance the applicability of laboratory data to the natural environment.

Fish

As with invertebrates few data have been accumulated on the effects of crude oil on Beaufort Sea fish. DeVries (RU #62) reported that the 96 hr TL_{50} for Saffron cod (Eleginus gracilis) exposed to water soluble fractions of crude oil was 2.28 ppm as determined by infrared spectrometry (IR) and at 0.092 ultraviolet optical density (UVOD) at 3°C. UVOD is indicative of the naphthalene equivalents or the level of the aromatic fraction. DeVries (RU #62) also reported that the 96 hr TL_{50} for Arctic flounder (Liopsetta glacialis) was >3.6 ppm IR and >0.228 UVOD at 8°C.

Acute toxicity tests indicate potential effects, but in the event of an oil spill these acute levels may be only localized. Levels of contamination outside of the surface slick are generally much less than the 96 hr TL_m concentrations. Lower or chronic levels are generally the rule, but the known response of fish to these is minimal.

Rice and Karinen (RU #72) noted that breathing rates of Pink salmon fry (Oncorhynchus gorbuscha) increased significantly during exposures to oil concentrations as low as 30% of 96 hr TL_{50} as determined by UV spectroscopy.

Malins et al. (RU #73b) report that in studies by Jacobson and Boylan (1973) the chemosensory system of marine organisms was abolished by water soluble fractions of petroleum at levels of 1 ppb. Malins et al. also found that Steelhead trout (Salmo gairdneri) fed oil contaminated food (2.5 mℓ oil/kg Oregon moist) had essentially no glycogen stores in the liver. Lipid reserves were also depleted. Exposure of Steelhead and English sole (Parophrys vetalus) for five days to water soluble oil fractions also caused reductions in glycogen and lipid reserves. The reduction of these energy reserves may reduce the organism's ability to survive stress conditions.

DeVries (RU #62) studied the effect of oil on the "antifreeze" mechanism of the sculpin, Myoxocephalus sp. No data are available on the effect of oil on this mechanism, but since the liver is the source of "antifreeze" production, interferences as noted by reduced glycogen reserves may also interfere in "antifreeze" synthesis. The loss of such a mechanism could be lethal to fish in the Arctic where winter water temperature drops below 0°C.

Other studies are available in the literature on comparable species but since it has been readily documented that species-to-species differences exist, any comparison would be speculative. Indigenous fauna are needed as test organisms to account for species-to-species differences and differences related to existence in a pristine environment.

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