Environmental Assessment of the Alaskan Continental Shelf

Annual Reports of Principal Investigators for the year ending March 1980

Volume VII: Transport
Data Management

U.S. DEPARTMENT OF COMMERCE
National Oceanic & Atmospheric Administration
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SOURCES, TRANSPORT PATHWAYS, DEPOSITIONAL SITES AND DYNAMICS OF SEDIMENTS IN THE LAGOON AND ADJACENT SHALLOW MARINE REGION, NORTHERN ARCTIC ALASKA

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II. INTRODUCTION

General Nature and Scope of Study

This program (Research Unit 529) concerning sedimentological studies is part of a larger interdisciplinary research effort (RU 467), to study the physicochemical and biological processes operative in the barrier island-lagoon ecosystem of the continental margin of the Alaskan Beaufort Sea. Additionally, the general scope of the overall program entails establishment of an ecosystem model which can be put to use in predicting possible impacts resulting from both petroleum exploration and exploitation activities in the barrier island-lagoon complex of the Beaufort Sea coast. Further details on the nature and scope of this study (RU 529) and associated investigations have been enumerated in the original proposal submitted by Naidu to the OCSEAP office in July 1979. Briefly, the scope of the sedimentological studies (RU 529) includes understanding of the sediment dynamics, delineating benthic environments based on lithological attributes, estimating the C, N and P contents in the substrate sediments, establishing the sources and alongshore transport directions of sediments, completing collection of baseline data on a suite of heavy metals for the Simpson Lagoon, Beaufort Lagoon, and adjacent nearshore environment of the Beaufort Sea.

III. OBJECTIVES

The overall objectives of this research unit are as follows:

1. Document and synthesize data on the grain size distributions, mineralogy, organic carbon, nitrogen, phosphorus and first transition row metals in sediments of the nearshore environment of the Beaufort Sea lease area.

2. Define the source, probable migratory pathways and depositional sites of sand and clay-sized particles of the Simpson and adjacent shallow-marine environment.

3. Estimate the sedimentation rates in the Simpson Lagoon and adjacent continental shelf area, via ^{210}Pb dating of sediment layers.

4. Establish empirical relationships between suspension, transport and deposition of sediment particles and the wave-current regime in the Simpson Lagoon, using data gathered by the "Sediment Dynamics Sphere (SDS)".

5. Acquire ground truth to help develop criteria that may be applied to quantify concentrations of suspended particles in the lagoons of north arctic Alaska, using LANDSAT images. This research is in collaboration with A. Belon and T. H. George (OCSEAP RU 267) and G. L. Hufford of NOAA's National Environment Satellite Program (Anchorage).

Relevance to Problems of Petroleum Development

The exploitation of the petroleum reserves in the North Slope of Alaska has commenced with the flow of oil through the trans-Alaska pipeline. The present trend is towards exploration in the adjacent continental shelf of the Beaufort Sea. As a consequence of the OCS petroleum and gas development activities, the nearshore and the open shelf ecosystem of the Beaufort Sea is bound to be subjected to some degree of anthropogenic perturbations. The industrial activities which most likely will be introduced in this area include the construction of artificial islands, causeways and wharfs for the use of drilling operations and docking facilities, dredging for maintaining navigations and laying offshore pipelines, and the exploitation of gravel and sand deposits from several possible sources as construction and fill materials. These activities will almost certainly lead to changes in the present sediment budgets, including sediment accumulation rates. Some of the possible effects of varying the sedimentation rates on nutrient dynamics, feeding habits of the benthic communities (detritus versus suspension feeders), and the modeling of the ecosystem have been discussed earlier (OCSEAP RU 529-78). In another context the redox potential which is an important faunal boundary layer may be influenced by the depositional rate of sediments. Further, the concentrations of a pollutant in the coastal waters may be a function of the accumulation rate of sediments, since suspended particles are effective scavengers of pollutants and post-depositional mobilization of metals at the sediment-water interface is invariably redox controlled. For these reasons study of the dynamics of sedimentation and estimation of depositional rates merits careful consideration.

There is a strong possibility that a variety of pollutants will be introduced into the nearshore environment, resulting either from inadvertent blowouts, oil spills, coastal construction work and intensified navigation within the region, or intentional discharge of mud and cuttings during drilling operations. Some of the pollutants thus discharged may prove toxic through direct assimilation by some faunal communities or indirectly through food chain transfer. Collection of baseline concentrations of heavy metals and an understanding of the speciation of these metals is important, because such a collection can serve as an effective benchmark to monitor pollution in the above area. Additionally, dating of relatively recent sediment sequences (especially using Pb^{210} geochronology) coupled with measurements of heavy metal concentrations with sediment depth profiles have served an useful purpose in the detection of pollution resulting from anthropogenic activities, as surmised by Bruland *et al.* (1974), Erlenkenser (1974), Goldberg *et al.* (1978), Price *et al.* (1978), UNESCO (1978), Bertine (1978), Bertine *et al.* (1978), and Shirahata *et al.* (1980).

Further, it is to be expected that discharge of dredged spoils as well as drilling muds and cuttings during petroleum exploration and exploitation operations will enhance the suspended loads of waters, with possible deleterious effects on nearshore ecosystems. However, without an adequate knowledge of the present baselines of suspended loads and trajectories of turbid sediment plumes, any significant industrial perturbations in the loads or trajectories and consequent impact on ecosystems cannot be comprehended.

Additionally, without cognition of the above it would be difficult to lay guidelines for discharge of dredge spoils to coastal waters of the Beaufort Sea. An useful and ready means for monitoring suspended loads and plume structures of surface waters is through study of LANDSAT images. However, reliable criteria have to be established first based on ground truth to quantify sediment loads from LANDSAT images, and this is one of the objectives of the present research unit.

If the response of the physical environment and biological resources of the area to the industrial changes can be properly assessed, or even predicted, it is quite possible that effective measures can be developed to protect or enhance existing resources. Therefore, unless satisfactory answers are available to account for the sediment fluxes and sources, transport pathways and depositional sites of sediments, and unless adequate knowledge is developed to understand thresholds of sediment movements (as functions of wave-current energy flux), it would not be possible to quantitatively assess — or even speculate — the possible impacts of petroleum exploration and development activities on the Beaufort Sea nearshore ecosystem.

IV. CURRENT STATE OF KNOWLEDGE

Within the past ten years or so, considerable research has been accomplished on the processes and products of sedimentation in the continental margin area of the Alaskan Beaufort Sea. A major portion of this research has been accomplished by scientists from three institutions, namely the University of Alaska (Institute of Marine Science), the U.S. Geological Survey (Marine Geology and Alaska Branches, Menlo Park) and the Louisiana State University (Coastal Studies Institute). In a recent OCSEAP report, Naidu (in Burrell, 1977) has compiled a bibliography of sedimentological and related investigations that have been carried out in the Alaskan Beaufort Sea shelf and coastal area. Barnes *et al.* (1977, 1978) have summarized miscellaneous hydrologic and geologic observations as well as characteristics and changing patterns of ice gouging on the Beaufort Sea shelf. The arctic coastal processes and morphology, as studied by the LSU Group, have been condensed in a report by Wiseman *et al.* (1973). Results of more recent investigations, relative to Late Quaternary geologic history, sedimentation, mineralogy and geochemistry, supported by the BLM-NOAA environmental program in the Beaufort Sea coastal and shelf areas have been compiled in the 1977, 1978 and 1979 OCSEAP Annual and Quarterly Report Volumes, as well as in the two Beaufort Sea synthesis volumes issued by the Arctic Project Office (Fairbanks).

V. STUDY AREA

The region of our investigations is confined to the inner continental margin of the Alaskan Beaufort Sea (Fig. 1). However, more intensive study, for barrier island-lagoon ecosystem modeling purpose, has been limited to the Simpson and Beaufort Lagoon areas (Figs. 2 and 3). The latter two regions,

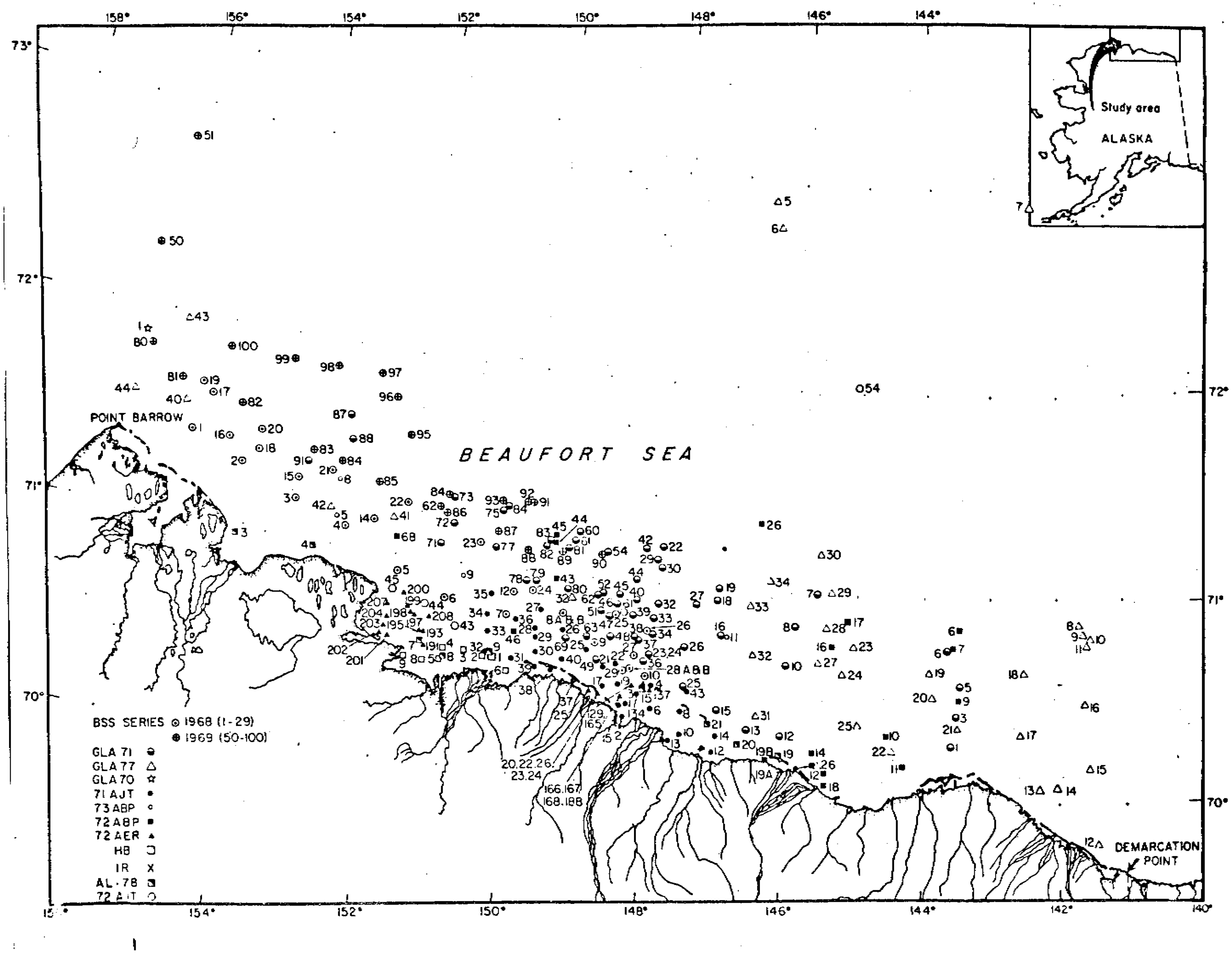

Figure 1. Station locations for Beaufort Sea continental margin region.

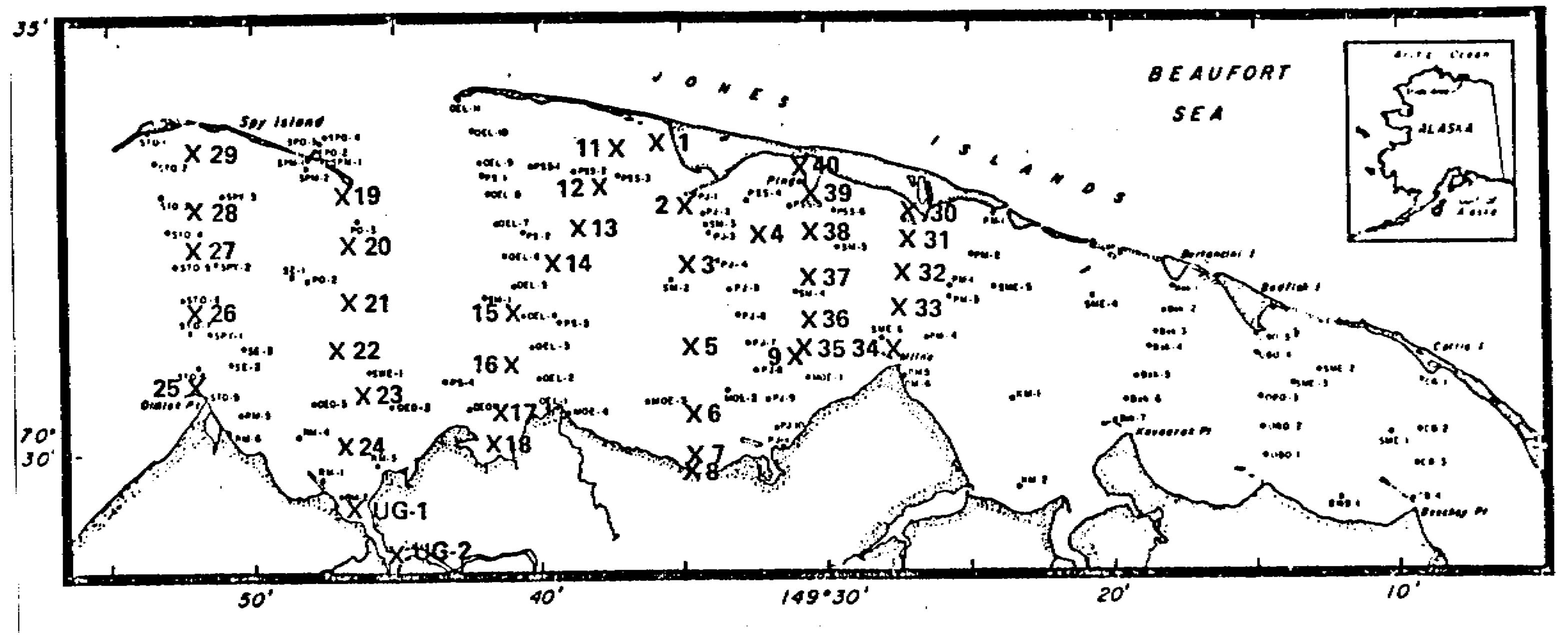

Figure 2. Sample locations in Simpson Lagoon. Locations depicted by heavy crosses indicate samples collected in Summer 1977. The remaining samples were collected by Tucker (1975).

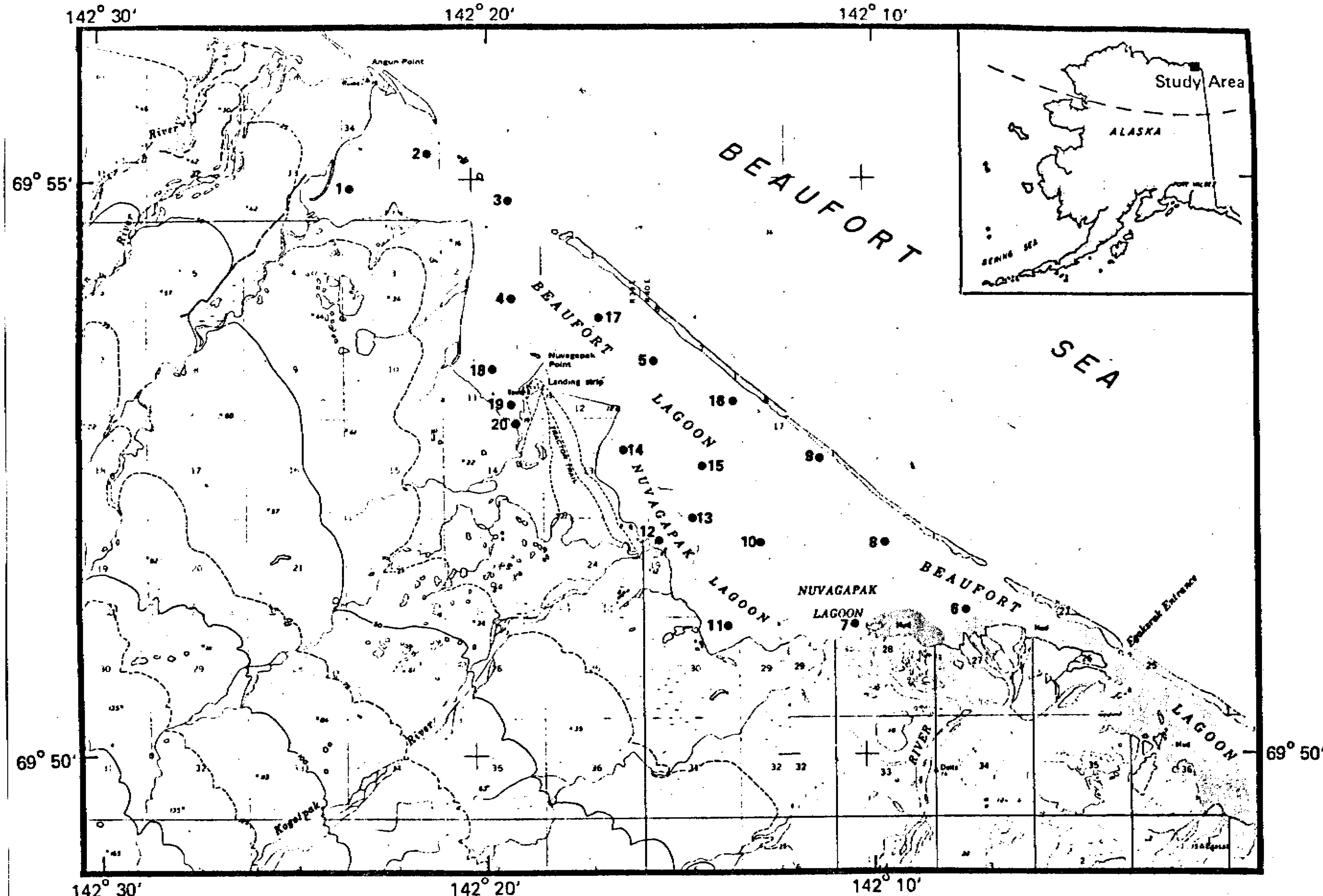

Figure 3. Map showing the locations of sediment samples from the Beaufort Lagoon, north arctic Alaska.

which are widely separated, have been considered as representative type areas for studies of island-lagoon complex along the Alaskan Beaufort Sea coast. In order to obtain a much wider data base and to assess terrigenous sources and transport directions of sediments along the Beaufort Sea coast, it has been imperative to extend sedimentological work to all the major river systems of the North Slope and to the bay environments west and east of the Simpson Lagoon, (Fig. 1).

VI. SOURCES, METHODS AND RATIONALE OF DATA COLLECTION

Field Work and Samples

The field period extended from 20 July 1979 to 12 August 1979, with A. S. Naidu, H. V. Weiss, and L. H. Larsen participating. Milne Point OCS facility was used as the base camp. For the open-water tripod experiment the Sediment Dynamics Sphere (SDS) was installed on a tripod at Deadhorse and air lifted to Milne Point. The SDS package was then deployed in Simpson Lagoon, in 2.9 m water depth, at a site off Milne Point (latitude 70°32.2'N; longitude 149°27.45'W) on 20 July 1979. The tripod was retrieved on 31 August 1979; L. H. Larsen and R. W. Sternberg participated in the latter operation. In continuation of the sediment dynamics studies, relative to the understanding of the resuspension process of bottom deposits and their entrapment in sea ice during the freeze-up process, the instrumented tripod package of SDS was emplaced in the Stefansson Sound Boulder Patch area near K. Dunton's (RU 356) biological study site. To the tripod an independent Aanderra current meter was attached as a back up unit. The entire package was in water from 14 September 1979 to 20 November 1979. Dr. L. H. Larsen of the University of Washington and Drs. P. W. Barnes and E. Reimnitz (RU 205) of the USGS participated in the deployment and the retrieval of the tripod. Unfortunately, the tripod experiment was a partial success, because the SDS unit upon retrieval was found to be flooded with water and sediment.*

Surface water samples were collected and their temperature measured from Prudhoe Bay, Simpson Lagoon and vicinity (Table I) on 24 July as well as on 4,

* Please refer to the detailed report on winter studies which is included as Appendix A.

TABLE I

TEMPERATURE, SALINITY, pH, AND WEIGHTS OF SUSPENDED PARTICLES OF WATER SAMPLES COLLECTED FROM SIMPSON LAGOON AND VICINITY, ON 24 JULY AND 4, 11 AND 12 AUGUST 1979

Station No.	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Suspensate (mg/1)	pH
72479-1	70°19'	148°24'	10.6	8.6	2.51	7.05
72479-2	70°20'	148°17'	12.2	6.2	3.63	7.32
72479-3	70°21'	148°15'	10.1	7.4	6.45	7.20
72479-4	70°24'	148°32'	8.8	9.0	3.59	7.10
8479-1	70°32'	149°26'	6.7	25.0	2.60	7.25
8479-1	70°32'	149°37'	5.0	17.9	1.53	7.25
8479-3	70°33'	149°52'	9.7	15.6	5.61	7.35
8479-4	70°34'	149°42'	5.6	21.8	2.86	7.04
81179-1	70°30'	150°23'	9.8	4.6	119.18	6.75
81179-2	70°32'	150°20'	4.2	31.4	6.02	7.40
81179-3	70°33'	150°09'	3.8	31.2	3.65	7.30
81179-4	70°32'	149°59'	2.5	29.4	2.53	7.50
81179-5	70°33'	149°51'	4.8	24.2	1.74	7.45
81179-6	70°32'	149°52'	5.4	21.4	3.35	7.00
81179-7	70°31'	149°53'	6.4	23.6	9.20	7.00
81179-8	70°32'	149°43'	5.4	23.5	2.15	7.50
81179-9	70°34'	149°41'	5.0	24.5	2.89	7.68
81179-10	70°33'	149°32'	6.3	19.3	3.48	7.25
81179-11	70°32'	149°30'	6.4	18.2	2.96	7.30
81279-1	70°24'	148°32'			1.33	

11 and 12 August 1979. These collections coincided with the passage of LANDSAT II and III satellites over the region, and the purpose was to help develop criteria — based on `sea´ truths — to quantify nearshore suspensate concentrations from LANDSAT images. One-liter aliquots of the water samples were filtered through pre-weighed Nuclepore filter membranes (0.4 μm pore size). Subsequently, the sediments on the membranes were washed with distilled water, and stored in an ice cellar to avoid biodegradation. About 100 ml of the filtered water samples were retained for subsequent salinity and pH measurements, because such data are useful in the understanding of suspensate distribution in conjunction with coastal water mass movement.

On seven separate days, between July 24 and August 4, 1979 (Table II), water samples were collected at the tripod site; from the surface as well as from 2.9 m depth at which the nephelometer was fixed to the tripod. The purpose of this collection was to establish a field calibration for the nephelometer. One-liter aliquots of the samples were filtered through pre-weighed Nuclepore membranes (0.4 μm pore size).

For Pb^{210} geochronologic work, relative to sediment depositional rate estimation, eight core samples were retrieved from Simpson Lagoon and the Harrison Bay region (Table III). Since ice gouging can perturb sediment sequences and since the lagoon and bay waters freeze to about 2 m depth, all core samples by necessity had to be retrieved from deeper waters (i.e., > 2 m depth). A variety of coring units (i.e., Phleger and BENTHOS gravity corer, and a manual unit) was employed on board the R/V *Natchik* to retrieve the core samples. However, the unit which was manually driven into the bottom worked relatively the best. The other units had low penetration in spite of the fact that the units had about 600-lb loading. The sediment cores, thus, collected were at best 32 cm long, but have proved adequate for the depositional rate measurements. Further, one sediment core sample was collected from a coastal lake (named by us the Deline Lake) at about 3.5 m water depth, using the manual coring unit from a float plane. This lake is situated at latitude 70°19'N and longitude 149°56'W. The latter core has been used to estimate the rate of sedimentation in coastal lakes and also in the better understanding of the inordinately low levels of Pb^{210} radioactivity in contemporary sediments from the North Slope coastal area (refer

TABLE II

WEIGHTS OF SUSPENDED PARTICLES IN WATER SAMPLES COLLECTED AT THE SURFACE AND 2.9 m BELOW SURFACE AT THE SDS TRIPOD SITE

(Latitude 70°32.2'N and Longitude 149°27.45'W)

Date	Sample	Time	Suspensate (mg/l)
7/24/1979	surface	4.05 p.m.	2.037
	2.9 m	4.05 p.m.	5.418
7/25/1979	surface	10.05 a.m.	4.215
	2.9 m	10.05 a.m.	4.112
7/26/1979	surface	5.05 p.m.	1.956
	2.9 m	5.05 p.m.	2.611
7/27/1979	surface	5.05 p.m.	2.990
	2.9 m	5.05 p.m.	2.993
7/28/1979	surface	12.35 p.m.	1.806
	2.9 m	12.35 p.m.	2.517
8/02/1979	surface	1.05 p.m.	2.039
	2.9 m	1.05 p.m.	1.997
8/04/1979	surface	11.05 a.m.	1.302
	2.9 m	11.05 a.m.	2.171

TABLE III

LOCATION OF SEDIMENT CORES TAKEN FOR ^{210}Pb GEOCHRONOLOGIC WORK

Core No.	Latitude (N)	Longitude (W)	Water Depth (m)	Environment
878-2	70°32'	149°28'	2.9	Simpson Lagoon
8979-1	70°32'	150°07'	3.9	Harrison Bay
8979-2	70°31'	150°01'	3.6	Harrison Bay
8979-3	70°31'	149°57'	3.3	Simpson Lagoon
8979-4	70°32'	149°53'	3.0	Simpson Lagoon
8979-5	70°32'	149°45'	2.7	Simpson Lagoon
8979-6	70°32'	149°40'	2.6	Simpson Lagoon
8979-7	70°32'	149°35'	2.6	Simpson Lagoon
8579-1	70°32'	149°27'	2.9	Simpson Lagoon
779-1	70°19'	149°56'	3.7	Deline Lake
NW78-1	71°00'	150°00'	24	Open shelf off Colville Delta
PWS75-1	70°19'	148°22'	3.0	Prudhoe Bay

to Naidu's 1979 Renewal Proposal to the OCSEAP office). In addition to the above samples, three other core samples which were collected in summer 1978 by us and Dr. P. W. Barnes have been considered for the Pb^{210} geochronologic work. One of the latter set of cores was from a location off the Colville River mouth (Table III) and presumably representing the 'prodeltaic facies' of the river. The other two cores were from the central Prudhoe Bay and from the tripod site (Table III). One-cm continuous sections from two core samples (i.e., one from the tripod site and another from Deline Lake) were separated at Milne Point camp. One split of each of the 1-cm sections was taken by H. V. Weiss for the Pb^{210} assays, while the remaining second split was retained by A. S. Naidu for textural and chemical analyses. Separation of one-cm continuous sediment sections from remaining of the nine core samples from Simpson Lagoon was accomplished in the Fairbanks laboratory. One-half of these sections was forwarded to H. V. Weiss for Pb^{210}-Po^{210} assays, relative to the sedimentation rate estimation. The remaining one-half of the sections has been subdivided into two samples. One subsample was used for granulometric analysis, while the other has been retained for chemical analysis by A. S. Naidu.

Two separate core samples were collected from the tripod site to obtain interstitial water samples. Interstitial waters were expressed out at the Milne Pt. camp from 1-cm continuous sections from one of the cores, as well as 5-cm sections from the other core. The water samples thus collected were preserved in ULTREX HNO_3 acid and retained by H. V. Weiss for analysis of a variety of metals by neutron activation. The purpose of this analysis is to better understand the postdepositional solution, migration and reprecipitation of metals in Simpson Lagoon.

In attempting to understand the trace-metal chemistry of fine grained particulate matter that is being discharged by the Colville River into the Beaufort Sea, a water sample was collected off the river mouth and filtered through a Nuclepore membrane (0.40 μ aperture). The sediment-bearing membrane has been sent to Dr. R. Feely of PMEL (Seattle) for analysis of a suite of trace-metals by X-ray fluorescence technique.

A sample of mud was collected from the Colville Estuary at the request of Dr. S. Wellershaus of the Institute of Meeresforschung (Bremerhaven), West Germany. As part of his research, Dr. Wellershaus will be studying the effect of organic compounds on flocculation of clays.

Two hours were spent on Flaxman Island, studying and collecting samples of boulders. A suite of 25 samples were obtained for detail thin section petrographic study, which should add on to our understanding of the origin of the boulders. In furthering the above goal sample of a granitic boulder from the Flaxman Island (sample # FLX79) was submitted to Dr. D. L. Turner of the Geophysical Institute, University of Alaska, for dating by the K-Ar technique.

In continuation of our winter sediment dynamics study thawed sections of three Sea-ice core samples were obtained from Dr. T. Osterkamp (RU 253). These samples were collected from Dive Site 11 in the Stefansson Sound, on November 11, 1979.

Most of the sediment samples considered for lithological and chemical analyses in this study were selected from archived suites of samples that were collected either by us or by others between 1968 and 1978 from the Beaufort and Simpson Lagoons, and the adjacent Beaufort Sea.

Analytical Methods

The laboratory methods that have been adopted to analyze sediment samples have been elaborately described in the original proposal (OCSEAP RU 529). Briefly, the sediment size distribution analysis of the grab and core sections was performed by the usual sieve-pipetting method. The clay mineral analysis on the $< 2\ \mu m$ fraction of sediments was accomplished according to the methods elaborated by Naidu *et al.* (1971) and Naidu and Mowatt (1974) using X-ray diffraction technique. Semi-quantitative estimation of the clay minerals are based on Biscaye's (1965) method.

Sediment samples stored in a frozen state were thawed, dried, and two splits of them were considered for geochemical analysis. One split was finely ground while the other split was lightly disaggregated.

Heavy metal concentrations in the sediments were measured by atomic absorption spectrophotometry, using a Perkin-Elmer, Model 603 unit and a Model 360 unit equipped with HGA-2100 graphite furnace. Details on the methods of acid digestion of gross sediments, and determination of accuracy and precision on heavy metal analysis have been discussed by Naidu and Hood (1972), and further elaborated in Table IV. Finely powdered samples were taken for gross metal analysis. To understand metal speciation in sediments, a sequential extraction scheme was followed to isolate various chemical fractions of sediments. Iron, Mn, Cu, Ni, Co, Cr, Zn, and V are being analyzed on these fractions as well as on gross sediments. The scheme was adopted after critical study of the literature. The extraction scheme presumably permits delineation of metals bound in the total ferrimanganic oxidates, carbonates and the exchangeable phase (Chester and Hughes, 1967; Grieve and Fletcher, 1976; Gibbs, 1977), oxidizable organic matter (Cheng, 1961; Anderson, 1962; Gibbs, 1977), particulate organics (Giovannini and Sequi, 1976), as well as in oxides of manganese (Chester and Hughes, 1967; Chao, 1972), amorphous iron (Pawluk, 1972; Schwertmann, 1973; Daly and Binnie, 1974) and crystalline iron (Mehra and Jackson, 1960). For purposes of the above metal extraction coarse ground sediment powder samples were preferred. The portions of extractable (or readily mobilized) metal fractions are considered more relevant for pollution monitoring.

Salinity of the 19 water samples, which were collected from Simpson Lagoon in summer 1979, were measured by using a Beckman, Model RC-19 Conductivity Bridge. Hydrogen ion concentrations (pH) of the water samples were measured by a Coleman, Model 37A potentiometer. Weights of dried suspended particles on 41 Nuclepore filter membranes (constituting the summer 1979 collections) were determined on a Cahn balance. After the weighing the filter membranes were stored in a freezer for further chemical analysis. Organic carbon, nitrogen and hydrogen on seven Simpson Lagoon suspensate samples, collected in summer 1978, were analyzed using a Hewlett-Packard Model 185B CHN analyzer. The suspensates collected on polycarbonate Nuclepore filter membranes (0.4 μm pore size) were isolated by

TABLE IV

AVERAGE CONCENTRATIONS (μg/g, except for Fe which is in 10^4 μg/g) OF SOME HEAVY METALS IN STANDARD U.S. GEOLOGICAL SURVEY ROCKS: AGV-1, BCR-1, & G-2.

U.S.G.S. Standard Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
AGV-1								
This Study -1		9.6		4.67	15.0	13.0	59.2	99
This Study -2	127	12.8	767	4.79	14.6	14.5		
Reported Literature Values								
Flanagan, 1969	121	12.9	728	4.76	15.5	17.8	63.7	112
Flanagan, 1973	125	12.2	763	4.73	14.1	18.5	59.7	84
Range (Flanagan, 1969)	70-171	8-45	640-870	4.26-5.21	10-30	11-27	52-83	64-304
BCR-1								
This Study -1		10.7			33.7	5.9	17.5	136
This Study -2	500	14.6	1425	8.98 8.94	35.7	6.4		
Reported Literature Values								
Flanagan, 1969	384	16.3	1350	9.44	35.5	15.0	22.4	132
Flanagan, 1973	399	17.6	1406	9.37	38	15.8	18.4	120
Range (Flanagan, 1969)	20-700	8-45	1040-1600	9.02-9.97	29-60	8-30	7-33	94-278

TABLE IV

CONTINUED

U.S.G.S. Standard Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
G-2								
This Study	38	10	258	1.58	15	17	7.6	88
Reported Literature Values								
Flanagan, 1969	37.0	9.0	265	1.93	4.9	6.4	10.7	74.9
Flanagan, 1973	35.4	7	260	1.85	5.5	5.1	11.7	85
Range (Flanagan, 1969)	26-60	5-29	180-360	1.53-2.44	2-21	2.14	<2-17	42-138

dissolving the membrane first in 30 ml 6N KOH and by centrifuging the residual. The suspensates thus collected were then washed in double distilled water and treated with 10% HCL to remove the carbonates. The slurries of carbonate-free samples were individually pipetted into sterilized sample boats, dried, weighed in a Cahn balance and loaded into the CHN analyzer. Acetanilide was run as a standard.

Manganese, Fe, Co, Hg, and Zn were analyzed in the sediment interstitial water samples by neutron activation analysis (Weiss, unpublished). This analysis was carried out by H. V. Weiss (NOSC), San Diego, using the TRIGA Reactor facilities at the University of Irvine (California).

The analytical procedure for the determination of ^{210}Po in sediments was based upon the procedures described by Koide *et al.* (1972) and Koide and Bruland (1975). Portions of 1-cm core sections were transferred to a crucible and dried at 110°C. The dried material was ground using a mortar and pestle and ignited at 400°C. A weighed fraction of the ash was leached with HNO_3 acid and ^{208}Po isotopic tracer was added to the leachate. The Po isotopes were then electrodeposited from solution onto a thin silver disc. The alpha particles emitted by $^{208,210}Po$ were finally measured at the General Activation Analysis, San Diego, California, using a barrier detector coupled to a pulse height analyzer. This entire analysis was performed by H. V. Weiss under a separate subcontract from A. S. Naidu. Muscovite grains from a pink granite boulder sample were separated and dated by the K-Ar technique in Dr. D. L. Turner's geochronology laboratory on University of Alaska campus.

In our attempt to synthesize the sedimentological data for the Beaufort Sea, all available published and unpublished lithological and chemical data have been compiled. These data have been fed into a computer, and maps showing distribution of individual sediment attributes for the above sea are being digitally generated.

Correlation coefficients were calculated for textural, chemical, and mineralogical attributes of Simpson Lagoon sediment samples. A Spearman nonparametric correlation problem was adopted. The calculations were done on the Alaskan Honeywell 66/40 computer.

VII. OTHER ACTIVITIES

A. S. Naidu attended the Annual Meetings of the Geological Society of America as well as the U.S. Core Curators Meeting, which were held concurrently in San Diego on 5-8 November 1979. Prior and subsequent to the above meetings Naidu visited with colleagues in the U.S. Geological Survey (Menlo Park), and also with H. V. Weiss and L. H. Larsen of NOSC (San Diego) and Univeristy of Washington (Seattle), respectively, for consultation. At the U.S.G.S. office, Naidu further examined samples of rock types gathered from the Brooks Range and adjacent areas, in attempting to elucidate the source of erratic boulders on the north arctic beaches. Additionally, all available archived (published/unpublished) data on size distributions of Beaufort Sea and adjacent lagoon sediments available with P.W. Barnes and E. Reimnitz were retrieved and tabulated for purpose of synthesizing textural data. At the Core Curators Meeting, Naidu gave the status of archived marine sediment samples of Arctic Alaska.

A. S. Naidu and his graduate student, M. D. Sweeney, participated in a poster session at the 30th Alaska Science Conference on 17-21 September 1979 in Fairbanks. Titles and authors of the posters were as follows:

Poster 1. Partitioning of heavy metals among selected chemical fractions of lagoon sediments, Arctic Alaska. By M. D. Sweeney, A. S. Naidu and H. V. Weiss.

Poster 2. Resuspension of nearshore sediments by wave action in north Arctic Alaska. By A. S. Naidu.

Further, A. S. Naidu participated, by invitation, in the following two OCSEAP sponsored conferences/workshops:

(i) Conference on "slush ice", held in Seattle between February 7 and 8, 1980.

(ii) Workshop on integration of "Winter Ecological Studies", held in Fairbanks, from March 19 to 21, 1980.

Proceedings of these meetings are being forwarded by Dr. L. H. Larsen and Drs. D. Norton and D. Schell to the OCSEAP Office.

VIII. RESULTS

The concentrations (wt. %) of organic carbon, nitrogen and hydrogen in the Simpson Lagoon suspensates appear in Table V. These samples were collected periodically from the central Simpson Lagoon at a location off the Milne Point, in the vicinity of the tripod station (Naidu, 1979).

TABLE V

CONCENTRATIONS (wt. %) OF ORGANIC CARBON, NITROGEN AND HYDROGEN, AND C/N RATIOS IN SIMPSON LAGOON SUSPENSATES

Sample No.	C%	N%	H%	C/N
SL78-10	3.60	0.17	0.88	21.2
SL78-14	3.43	0.17	0.93	20.2
SL78-21	4.08	0.17	0.95	24.0
SL78-31	2.33	0.12	0.72	19.4
SL78-80	2.96	0.31	0.80	9.5
SL78-86	5.39	0.32	0.90	16.8
SL78-96	2.70	0.17	0.69	15.9

In Table I are included the temperature, salinity, pH values and concentrations of suspensates in Harrison Bay, Simpson Lagoon and Prudhoe Bay waters for the period between July 24 to August 12, 1979 when the LANDSAT II and III satellites passed over the area.

The weights of suspended particles, periodically collected at the SDS tripod site are included in Table III. As one would expect the suspensate concentrations are generally higher in the subsurface than in the surface water samples.

In Table VI are shown the concentrations of Mn, Fe, Hg, Zn and Co in interstitial water samples from 1-cm sections of a sediment core retrieved from the Simpson Lagoon. Chromium, Th, Sb, Rb and Sc were the other elements identified in the above water samples, but their concentrations were too low to be reported in a meaningful way. It is quite clear that there is a significant decrease toward the surface of Mn and Fe.

TABLE VI

CONCENTRATIONS (μg/ml) OF SOME ELEMENTS IN INTERSTITIAL WATER SAMPLES FROM 1-cm SECTIONS OF A SEDIMENT CORE TAKEN AT LATITUDE 70°32.20'N AND LONGITUDE 149°27.45'W IN THE SIMPSON LAGOON

Core Section (cm)	Volume (ml)	Mn	Fe	Hg	Zn	Co
0-1	0.75	0.6	-	0.0069 ± 0.0027	0.064 ± 0.027	-
1-2	0.45	0.2	-	0.0133 ± 0.0047	0.284 ± 0.069	0.0037 ± 0.0011
2-3	0.55	0.9	1.50 ± 0.53	0.0080 ± 0.0027	0.096 ± 0.031	0.0038 ± 0.0008
3-4	0.70	0.9	1.43 ± 0.50	0.0079 ± 0.0018	0.121 ± 0.030	0.0021 ± 0.0001
4-5	0.65	-	1.80 ± 0.55	-	0.207 ± 0.048	0.0036 ± 0.0009
5-6	0.40	1.0	3.42 ± 0.95	-	0.315 ± 0.073	0.0030 ± 0.0011
6-7	0.30	1.5	4.07 ± 1.30	0.0256 ± 0.0073	0.325 ± 0.093	0.0054 ± 0.0014
7-8	0.70	1.5	-	0.016 ± 0.004	0.160 ± 0.037	0.0020 ± 0.0007
8-9	0.75	1.4	-	-	-	-
9-10	0.65	1.3	2.40 ± 0.62	0.009 ± 0.004	0.201 ± 0.045	0.0025 ± 0.0001
10-11	0.40	1.2	2.60 ± 0.83	0.015 ± 0.005	0.215 ± 0.052	0.0052 ± 0.0013
11-12	0.50	1.7	2.44 ± 0.72	0.010 ± 0.003	0.218 ± 0.050	0.0060 ± 0.0014
12-13	0.80	1.1	3.38 ± 0.80	0.010 ± 0.003	0.158 ± 0.035	-
13-14	0.45	1.8	1.27 ± 0.60	0.018 ± 0.004	0.33 ± 0.07	0.0041 ± 0.0011
14-15	0.60	1.0	5.7 ± 1.2	0.011 ± 0.003	0.26 ± 0.06	0.0048 ± 0.0011

In Table VII are included revised total concentrations of Fe, Mn, Zn, Ni, Co, Cr, Cu, and V in a suite of samples from the open Beaufort Sea. Previous reported values (Naidu, 1979, p. 53, Table XIII) for these same samples have recently been verified and/or corrected where appropriate for the present report (Table VII). In Table VIII are listed concentrations of Ni, Co, Cr and V in acetic acid hydroxylamine-hydrochloride extracts (Chester and Hughes, 1967) of a suite of sediments samples from the Beaufort Sea.

In Table IX are listed the concentrations of some heavy metals in gross sediments as well as in Chester and Hughes' (1967) extracts of Simpson Lagoon sediments. Additionally, the percents of the total quantity of each metal that was extracted by the Chester and Hughes reagent are included in Table IX. Some tentative elemental data on gross sediments and the extracts were submitted earlier (Naidu, 1979, p. 52, Table XII) for the Simpson Lagoon sediments. The latter data have subsequently been verified and the revised data in Table IX are considered more accurate.

Table X presents average results, based on 6 samples, for the partitioning of Fe and Mn among various chemical fractions in Simpson Lagoon sediment. These chemical fractions represent idealized distinct chemical species contributing to the complex sediment conglomeration of many chemical compounds and minerals. It is assumed that the chemical treatments used (references cited) are specific for the corresponding chemical fraction targeted.

In Table XI appear the Po activities (d/m/g) relative to 1-cm sections of the 12 cores that have been analized (refer to Table III for core locations and depositional environment). At the observed levels of activity and the counting periods followed the statistical counting error is about 5-10%. When the Po^{210} activities are plotted against sediment depth in a sediment core, no continuous logarithmic decrease in the activities is noticed from the top to the bottom of the cores. Although for several cm length in a core a net decreasing trend in the Po^{210} activity can be identified, above or below such sections a significant scatter in the activity is noticeable. Additionally, in case of tripod core 779-1, the Po^{210} activity seems to be relatively higher in the lower portions of the core. By comparison the

TABLE VII

TOTAL CONCENTRATIONS (μg/g) OF SOME HEAVY METALS IN BEAUFORT SEA SEDIMENTS

Sample #	Depth (m)	V	Cr	Mn	Fe 10^4 μg/g	Co	Ni	Cu	Zn
Deep Sea (>1000m)									
GLA77-5	3593	220	103	4650	5.40	28	55	50	121
GLA77-6	3566	252	117	3950	6.05	28	63	57	144
GLA77-7	3566	234	110	3050	5.39	26	58	53	116
Averages		235	110	3880	5.60	27	59	53	127
Continental Slope (64-1000m)									
GLA77-10	678	183	96	4400	4.64	21	49	32	98
GLA77-16	118	148	89	406	3.50	16	41	24	112
GLA77-18	80	114	66	741	3.13	10	27	25	84
GLA77-23	109	150	98	546	4.16	21	45	38	121
GLA77-42	149	150	90	365	4.08	17	39	23	102
Averages		149	88	1290	3.92	17	40	28	103
Continental Shelf (<64m)									
GLA77-12	22	119	86	351	3.65	15	37	28	102
GLA77-15	54	166	98	634	4.51	20	49	39	121
GLA77-17	51	180	108	620	4.90	22	57	41	140
GLA77-20	57	125	70	690	4.07	14	35	24	100
GLA77-22	32	127	84	351	3.81	15	36	30	107
GLA77-31	28	126	80	355	3.51	13	31	26	107
GLA77-33	66	112	74	946	3.97	14	36	38	107
Averages		137	86	562	4.05	16	40	33	112
U.S.G.S.-G2		38	10	258	1.58	15	17	7.6	88

TABLE VIII

CONCENTRATIONS (μg/g) OF NICKEL, COBALT, CHROMIUM, AND VANADIUM IN ACETIC ACID-HYDROXYLAMINE HYDROCHLORIDE EXTRACTS (CHESTER AND HUGHES, 1967) OF BEAUFORT SEA SEDIMENTS

For sample locations refer to Naidu (1978)

Sample No.	Ni	Co	Cr	V
		Deep-Sea		
GLA77-5	23.8	23.0	3.1	82.0
GLA77-7	24.0	21.5	4.5	53.0
GLA77-8	18.5	22.0	3.4	70.0
GLA77-30	18.0	21.0	6.5	43.0
		Continental Slope		
GLA77-19	13.0	10.5	5.0	26.0
GLA77-23	16.0	19.0	3.7	17.0
GLA77-42	10.0	7.0	6.0	24.0
BSS -80	14.5	8.5	6.5	21.5
BSS -81	13.0	5.5	3.2	24.0
		Continental Shelf		
GLA77-12	7.5	6.5	3.0	13.5
GLA77-15	16.0	14.5	4.5	17.0
GLA77-17	18.0	14.0	2.5	11.0
GLA77-18	11.0	12.0	4.0	19.0
GLA77-22	11.0	7.0	4.0	14.5
GLA77-24	8.5	8.0	2.5	17.0
GLA77-25	7.5	5.5	1.0	12.0
GLA77-26	7.5	4.5	2.5	10.5
GLA77-31	10.0	9.5	5.0	14.5
GLA77-32	9.0	7.0	2.8	14.0
GLA77-40	13.0	12.5	5.5	18.5
Averages:				
Deep-Sea (> 1000 m)	21.1	21.9	4.4	64.5
Continental Slope (64-1000 m)	13.3	10.1	4.9	22.5
Continental Shelf (< 64 m)	10.8	9.2	3.4	14.5

TABLE IX

CONCENTRATIONS (μg/g, except Fe which is in 10^4 μg/g) OF SOME HEAVY METALS IN THE TOTAL (T) AND THE ACETIC ACID-HYDROXYLAMINE HYDROCHLORIDE EXTRACTS (E), WITH CALCULATED PERCENT EXTRACTABLE QUANTITIES (%E)* FROM SIMPSON LAGOON SEDIMENTS

	Vanadium			Chromium			Manganese			Iron			Cobalt			Nickel			Copper			Zinc		
Sample	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E
SL877-1A	43	1.9	5	23	0.22	1	118	48	41	1.13	0.112	10	4.3	0.72	17	11	0.89	8	8.0	1.9	24	34	5.4	16
1B	36	1.8	5	19	0.27	1	114	41	36	1.02	0.094	9	3.1	0.44	14	8.1	0.67	8	8.3	1.7	21	-	4.0	-
1C	41	2.4	6	21	0.65	3	155	90	58	1.10	0.142	13	4.1	0.88	21	11	1.2	11	5.4	1.6	30	-	4.7	-
1D	42	1.9	5	21	0.39	2	126	44	35	1.08	0.078	7	4.4	0.55	13	9.2	0.72	8	6.5	1.2	18	45	4.4	10
1E	42	2.3	6	24	0.90	4	139	54	39	1.23	0.125	10	4.4	0.85	19	13	1.5	12	7.1	1.8	25	45	5.5	12
2	36	2.0	6	21	0.44	2	146	80	55	0.95	0.110	12	3.6	0.66	18	11	1.0	9	11	1.1	10	28	3.0	11
3	84	5.2	6	59	1.8	3	419	240	57	2.51	0.332	13	7.6	2.7	36	29	4.4	15	17	2.6	15	94	15	16
4	101	7.3	7	70	2.0	3	554	365	66	2.92	0.465	16	8.2	3.5	43	32	5.3	17	28	4.8	17	120	21	18
5A	69	3.6	5	39	1.5	4	273	155	57	1.82	0.228	13	6.2	1.9	31	22	3.3	15	14	2.4	17	78	11	14
5B	62	3.6	6	38	1.4	4	235	128	55	1.79	0.207	12	5.8	1.9	33	21	2.7	13	23	8.4	36	73	19	26
5C	69	4.1	6	46	1.4	3	344	208	61	2.08	0.271	13	8.0	2.6	33	23	3.7	16	16	2.9	18	82	13	16
5D	70	3.6	5	46	1.0	2	316	169	54	2.17	0.225	10	8.6	1.9	22	23	3.1	13	21	2.9	14	80	13	16
6	75	4.9	7	54	1.7	3	369	218	59	2.30	0.307	13	7.9	2.3	29	28	5.1	18	23	2.8	12	84	16	19
7	45	1.6	4	26	0.5	2	150	45	30	1.22	0.039	3	5.5	0.63	11	13	1.0	8	11	2.6	24	33	4.0	12
8	61	2.7	4	32	0.98	3	200	125	63	1.33	0.120	9	6.8	1.0	15	19	3.8	20	12	1.5	13	52	6.1	12
9	80	5.2	7	55	2.1	4	514	340	66	2.48	0.301	12	9.2	2.9	32	29	5.5	19	27	3.7	14	91	18	20
11	84	5.9	7	56	1.7	3	268	122	46	2.34	0.262	11	8.5	2.1	25	29	3.9	13	18	3.1	17	87	17	20
12	81	4.7	6	54	0.9	2	278	136	49	2.39	0.250	11	9.8	2.5	26	29	3.8	13	20	3.0	15	83	16	19
13	79	5.1	7	60	1.8	3	467	300	64	2.64	0.370	14	9.2	3.0	33	29	5.0	17	23	3.5	15	88	18	20
14	73	4.2	6	47	1.3	3	361	208	58	2.26	0.270	12	8.9	2.6	29	26	3.8	15	17	2.6	15	78	12	15
15	61	3.4	6	38	0.65	2	226	137	61	1.67	0.095	6	9.0	1.9	21	20	3.2	16	15	3.6	24	61	6.4	11
17	49	3.3	7	33	1.2	4	176	110	63	1.31	0.140	11	5.6	2.7	48	20	5.2	26	14	2.3	16	43	11	26
18	74	6.7	9	54	1.7	3	163	60	37	1.93	0.410	21	8.7	3.1	36	27	6.1	23	20	2.3	12	78	22	28
19	61	2.0	3	36	0.35	1	185	64	35	1.75	0.147	8	5.7	1.0	18	19	1.2	6	16	3.5	22	87	11	13
20	43	2.5	6	22	0.38	2	159	80	50	1.31	0.156	12	4.8	1.3	27	11	0.9	8	8.6	1.9	22	42	5.6	13
21A	100	6.5	7	66	1.2	2	370	193	52	2.81	0.355	13	9.6	3.3	34	31	4.7	15	22	3.5	16	100	19	19
21B	96	6.0	6	66	1.4	2	344	165	48	2.76	0.301	11	9.8	3.4	35	29	4.8	17	19	3.0	16	-	17	-
21C	86	6.4	7	61	1.6	3	257	108	42	2.46	0.236	10	8.5	2.5	29	29	3.8	13	17	3.7	22	103	17	17
21D	91	5.3	6	65	1.6	3	324	136	42	2.71	0.280	10	9.6	2.5	26	29	3.7	13	13	3.6	28	91	15	17
22	85	4.0	5	55	1.4	3	302	138	46	2.59	0.263	10	9.6	2.6	27	28	4.0	14	19	2.5	13	89	14	16
23	70	4.4	6	56	1.2	2	378	215	57	2.09	0.248	12	8.4	2.7	32	27	4.7	17	21	2.7	13	93	15	16
24	58	2.8	5	33	0.3	1	154	62	40	1.36	0.085	6	6.1	0.87	14	16	1.4	9	12	2.3	19	51	10	20
25A	57	3.1	5	37	0.94	3	188	78	41	1.72	0.172	10	6.7	1.8	27	17	2.7	16	12	2.3	19	64	11	17
25B	57	2.5	4	33	0.95	3	165	64	39	1.59	0.149	9	6.0	2.2	37	15	2.7	18	16	2.3	14	86	9	11
25C	65	3.1	5	39	1.2	3	199	77	39	1.83	0.182	10	8.4	2.0	24	20	3.4	17	17	2.4	14	75	11	15
26	87	4.3	5	57	1.2	2	375	198	53	2.69	0.285	11	9.3	3.1	33	29	4.9	17	18	3.0	17	88	15	17
27	83	4.8	6	57	1.5	3	295	136	46	2.47	0.256	10	8.8	2.5	28	29	4.7	16	15	2.8	19	79	15	19
28	93	5.1	6	62	1.8	3	291	114	39	2.67	0.274	10	9.3	2.3	25	32	4.3	13	23	2.8	12	100	16	16
29	85	5.6	7	63	1.5	2	291	123	42	2.59	0.326	13	10	2.3	23	27	4.1	15	25	4.0	16	98	18	18
30	29	1.2	4	24	0	0	127	66	52	0.88	0.086	10	3.6	0.53	15	12	0.68	6	6.3	1.7	27	33	3.2	10
31	97	6.2	6	67	1.5	2	313	160	51	2.63	0.300	11	9.5	2.6	27	32	5.0	16	14	3.2	23	100	22	22
32A	97	5.0	5	52	1.5	3	299	198	66	2.25	0.269	12	8.4	2.7	32	27	6.1	23	16	3.1	19	93	23	25
32B	109	4.5	4	63	1.7	3	366	203	55	2.51	0.263	11	9.3	2.8	30	32	5.9	18	20	3.1	16	103	21	20
32C	97	4.2	4	56	1.4	3	302	148	49	2.39	0.234	10	9.3	2.5	27	29	4.7	16	22	2.9	13	98	18	18
32D	83	4.0	5	48	1.1	2	273	146	53	2.12	0.223	11	7.6	2.2	29	28	4.1	15	19	3.2	17	90	17	19
33	63	3.5	6	45	1.4	3	323	182	56	1.65	0.179	11	7.6	2.3	30	25	4.1	16	18	2.3	13	74	14	19
34	35	1.1	3	16	0	0	115	46	40	0.85	0.032	4	3.3	0.25	8	8.4	0.23	3	7.3	1.4	19	31	2.5	8
35	85	4.3	5	54	0.9	2	247	110	45	2.06	0.199	10	7.4	1.8	24	26	3.7	14	1.9	2.8	15	85	16	19
36	88	4.7	5	54	1.1	2	256	112	44	2.32	0.253	11	8.4	2.3	27	27	3.7	14	21	2.7	13	92	16	17
37	82	3.2	4	50	1.0	2	226	89	39	2.16	0.206	10	8.4	1.7	20	25	3.0	12	18	2.3	13	81	13	16
38	95	5.1	5	60	1.1	2	217	82	38	2.26	0.196	9	8.8	2.2	25	27	4.3	16	20	2.7	14	-	18	-
39	85	5.2	6	63	1.0	2	225	80	36	2.20	0.248	11	8.8	1.9	22	28	3.4	12	33	3.9	12	84	18	21
40	63	2.1	3	38	0.07	0	174	73	42	1.80	0.084	5	6.6	0.95	14	18	2.0	11	9.5	2.5	26	-	6.1	-
UG-1	56	3.5	6	46	0.70	2	211	90	43	1.65	0.150	9	6.0	2.1	35	21	4.0	19	16	0.40	3	65	12	19
AVERAGE	71		6	46		2	260		49	2.0		11	7.4		26	23		14	17		18	76		17

* Values rounded to whole digit numbers.

TABLE X

AVERAGES FOR THE PERCENTAGE OF THE TOTAL IRON AND MANGANESE IN SIMPSON LAGOON SEDIMENTS DISTRIBUTED AMONG ARBITRARY CHEMICAL FRACTIONS

Chemical Fraction	Fe	Mn
Exchangeable[1]	0.1	5
Carbonate[2]	1	15
Manganese Oxides[3]	1	5
Amorphous Iron Oxides[4]	17	5
Crystalline Iron Oxides[5]	18	10
Organic Complex[6]	3	10
Residual Components	60	50
Fe-Mn Oxidate-Carbonate--Exchangeable - adsorbed component[7]	13	49

[1]Jackson, 1958
[2]Sibbesen, 1977
[3]Chao, 1972
[4]Schwertmann, 1973
[5]Coffin, 1963
[6]Giovannini & Sequi, 1976
[7]Chester & Hughes, 1967

TABLE XI

STRATIGRAPHIC VARIATIONS IN Po^{210} (d/m/g) IN THREE CORE SAMPLES FROM THE COASTAL AREA OF NORTH ARCTIC ALASKA.

(REFER TO TABLE III FOR CORE LOCATIONS)

	Depth (cm)	Po^{210} d/m/g	Depth (cm)	Po^{210} d/m/g
Core # 8979-1				
	0- 1	1.87±.1	18-19	--
	1- 2	1.69±.18	19-20	1.36±.09
	2- 3	1.81±.15	20-21	1.17±.08
	3- 4	1.70±.1	21-22	1.24±.08
	4- 5	2.16±.1	22-23	1.23±.07
	5- 6	1.43±.1	23-24	1.02±.1
	6- 7	1.70±.09	24-25	1.26±.16
	7- 8	1.04±.09	25-26	--
	8- 9	1.36±.07	26-27	1.32±.1
	9-10	1.25±.09	27-28	1.31±.07
	10-11	--	28-29	1.27±.13
	11-12	1.82±.1	29-30	1.10±.08
	12-13	1.33±.1	30-31	1.0 ±.08
	13-14	1.0 ±.1	31-32	0.85±.06
	14-15	1.1 ±.06	32-33	0.83±.06
	15-16	1.3 ±.1	33-34	0.63±.08
	16-17	1.35±.07		
	17-18	1.34±.09		
Core # 8979-2				
	0- 1	1.51±.15	7- 8	1.09±.09
	1- 2	2.20±.13	8- 9	1.22±.09
	2- 3	1.77±.13	9-10	1.44±.1
	3- 4	1.43±.1	10-11	0.98±.08
	4- 5	1.80±.1	11-12	1.44±.1
	5- 6	1.55±.1	12-13	1.15±.08
	6- 7	1.27±.1	13-14	1.12±.08
Core # 8979-3				
	0- 1	1.51±.08	6- 7	1.10±.07
	1- 2	1.40±.07	7- 8	1.11±.09
	2- 3	1.13±.08	8- 9	1.13±.04
	3- 4	1.05±.06	9-10	0.92±.05
	4- 5	1.12±.09	10-11	0.73±.05
	5- 6	1.10±.07	11-12	0.67±.05

TABLE XI

CONTINUED

	Depth (cm)	Po^{210} d/m/g	Depth (cm)	Po^{210} d/m/g
Core # 8979-3 (Cont'd)				
	12-13	0.63±.06	19-20	0.34±.02
	13-14	0.61±.02	20-21	0.71±.07
	14-15	0.61±.04	21-22	0.78±.05
	15-16	0.58±.04	22-23	0.85±.06
	16-17	0.50±.04	23-24	0.69±.04
	17-18	0.49±.04	24-25	0.71±.05
	18-19	0.49±.04		
Core # 8979-4				
	0- 1	1.39±.09	6- 7	0.81±.1
	1- 2	0.91±.08	7- 8	0.91±.07
	2- 3	1.21±.09	8- 9	1.31±.09
	3- 4	0.85±.07	9-10	0.77±.07
	4- 5	0.96±.07	10-11	1.08±.09
	5- 6	1.18±.06		
Core # 8979-5				
	0- 1	1.47±.1	10-11	0.90±.06
	1- 2	1.76±.1	11-12	0.92±.07
	2- 3	1.48±.1	12-13	0.91±.07
	3- 4	1.55±.1	13-14	0.94±.07
	4- 5	1.55±.1	14-15	0.92±.07
	5- 6	1.29±.09	15-16	0.66±.09
	6- 7	1.42±.09	16-17	0.07±.09
	7- 8	1.62±.01	17-18	0.79±.06
	8- 9	1.15±.08	18-19	{1.16±.1 1.14±.1} Recount
	9-10	1.07±.09		
Core # 8979-6				
	0- 1	1.19±.1	9-10	0.76±.07
	1- 2	1.18±.07	10-11	0.77±.05
	2- 3	1.44±.09	11-12	0.79±.04
	3- 4	1.0 ±.09	12-13	0.70±.06
	4- 5	1.05±.07	13-14	0.82±.05
	5- 6	0.87±.07	14-15	0.69±.05
	6- 7	0.85±.07	15-16	0.82±.05
	7- 8	0.99±.07	16-17	1.13±.04
	8- 9	0.74±.05	17-18	1.02±.07

TABLE XI

CONTINUED

	Depth (cm)	Po^{210} d/m/g	Depth (cm)	Po^{210} d/m/g
Core # 8979-7				
	0- 1	1.37±.09	10-11	0.88±.07
	1- 2	1.31±.08	11-12	1.02±.1
	2- 3	1.66±.1	12-13	0.78±.06
	3- 4	1.28±.08	13-14	0.73±.08
	4- 5	1.19±.07	14-15	0.51±.05
	5- 6	1.06±.08	15-16	1.12±.08
	6- 7	1.12±.08	16-17	1.0 ±.07
	7- 8	1.04±.1	17-18	0.88±.08
	8- 9	0.77±.06	18-19	0.88±.08
	9-10	0.87±.06	19-bottom	0.91±.08
Core # PWB 75-1				
	0- 1	1.15±.08	6- 7	1.32±.07
	1- 2	1.17±.07	7- 8	1.42±.08
	2- 3	1.18±.08	8- 9	1.36±.08
	3- 4	--	9-10	1.31±.08
	4- 5	0.92±.06	10-11	1.33±.08
	5- 6	1.25±.08		
Core # 8579-1				
	0- 1	1.20±.08	9-10	0.72±.05
	1- 2	1.5 ±.15	10-11	0.75±.04
	2- 3	{0.8 ±.06	11-12	0.70±.05
		0.6 ±.05}	12-13	0.75±.05
	3- 4	{1.0 ±.07	13-14	0.6 ±.05
		0.9 ±.05}	14-15	0.85±.06
	4- 5	{1.1 ±.09	15-16	1.2 ±.07
		0.94±.06}	16-17	1.2 ±.06
	5- 6	0.55±.06	17-18	0.9 ±.05
	6- 7	0.40±.03	18-19	--
	7- 8	0.41±.03	19-20	--
	8- 9	0.29±.03	20-21	--

TABLE XI

CONTINUED

	Depth (cm)	Po^{210} d/m/g	Depth (cm)	Po^{210} d/m/g
Deline Lake				
	0- 1	5.1 ±.43	10-11	3.5 ±.16
	1- 2	3.13±.19	11-12	4.14±.19
	2- 3	4.7 ±.22	12-13	5.44±.5
	3- 4	4.9 ±.41	13-14	4.4 ±.17
	4- 5	4.93±.5	14-15	5.3 ±.04
	5- 6	{3.0 ±.14 / 2.93±.14}	15-16	2.9 ±.15
			16-17	2.0 ±.06
	6- 7	3.7 ±.1	17-18	2.6 ±.12
	7- 8	2.6 ±.15	18-19	1.74±.06
	8- 9	{4.2 ±.2 / 4.3 ±.2}	19-20	2.17±.09
			20-21	1.84±.09
	9-10	2.5 ±.19		

TABLE XI

CONTINUED

	Depth (cm)	Po^{210}	Depth (cm)	Po^{210}
Core # 878-2				
	0- 1	1.90 ± 0.1	6- 7	1.40 ± 0.1
	0- 1	1.97 ± 0.14	7- 8	1.32 ± 0.1
	1- 2	1.62 ± 0.1	8- 9	1.60 ± 0.1
	3- 4	1.63 ± 0.16	10-11	1.56 ± 0.09
	5- 6	1.45 ± 0.1	12-13	1.12 ± 0.1
	13-14	1.37 ± 0.09	19-20	1.29 ± 0.06
	14-15	1.03 ± 0.05	20-21	1.61 ± 0.15
	15-16	1.26 ± 0.06	21-22	1.23 ± 0.1
	17-18	1.43 ± 0.09	22-23	1.33 ± 0.08
	18-19	1.51 ± 0.1	23-24	1.20 ± 0.1
	24-25	1.28 ± 0.09		
	24-25	1.20 ± 0.1		
Core # NW 78-1				
	0- 1	1.90 ± 0.18	5- 6	1.40 ± 0.1
	1- 2	1.21 ± 0.12	6- 7	1.24 ± 0.1
	2- 3	1.26 ± 0.12	7- 8	1.37 ± 0.1
	3- 4	1.33 ± 0.06	9-10	1.54 ± 0.1
	4- 5	1.17 ± 0.09	10-11	1.91 ± 0.1
	11-12	1.22 ± 0.1	22-23	1.16 ± 0.04
	13-14	1.14 ± 0.1	25-26	1.08 ± 0.06
	16-17	1.17 ± 0.1	30-31	1.52 ± 0.15
	17-18	1.12 ± 0.1	33-34	1.38 ± 0.06
	20-21	1.13 ± 0.1	34-35	1.02 ± 0.1

Po^{210} activities of all the sediment cores from north arctic Alaska are almost a magnitude lower than values generally reported for coastal sediments of other parts of the world. For purposes of sedimentation rate estimation the Po^{210} values can be directly used on a 1:1 basis to determine the Pb^{210} activity, based on the assumption that secular equilibrium between the two isotopes exists. Therefore, further discussion will be in terms of the Pb^{210} rather than the Po^{210} activities.

A report has been received from Dr. L. H. Larsen summarizing results of the summer 1979 tripod experiment. Since the above work constituted a discrete task of the present overall study (RU 529), results and discussions pertaining to it have been incorporated in this Annual Report as Appendix B. Likewise all phases of the tripod experiment relative to the 1979 Winter Study have been included as Appendix A. As mentioned earlier, the tripod was damaged during the winter 1979 experiments. Dr. Larsen is in correspondence with the insurance company to recover the cost of the damage to the SDS System (Appendix C).

The K-Ar date and other relevant data on muscovites of a pink granite boulder sample (FLX1), which was collected by Naidu from the Flaxman Island, north arctic Alaska, are shown in Table XII. As indicated the granitic boulder is of Archaean age. A separate granitic boulder sample (F79SR01) having a composition similar to the above sample and also collected from the the Flaxman Island area was simultaneously submitted by S. Rawlinson to Dr. Turner for a K-Ar date on the muscovites of that boulder sample. Result of the geochronologic analysis on the latter boulder sample is also included in Table XII for comparison purpose*. It is notable that results of the two analyses are almost identical.

Analyses of the grain size distributions, clay mineralogy and trace-metal concentrations on the Beaufort Lagoon sediments (Fig. 3) are in progress. Preliminary data obtained thus far on some textural attributes (gravel, sand, silt, etc.), clay mineralogy on the < 2 μm size fraction, and trace-metal concentrations on gross sediments, are listed in Tables XIII, XIV, XV and XVI respectively.

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* S. Rawlinson kindly permitted us to use his unpublished data.

TABLE XII

K-Ar DATES AND RELATED ANALYSIS ON MUSCORITES OF GRANITE BOULDERS FROM ARCTIC COAST OF ALASKA

Sample No.	Rock Type	Mineral Dated	K_2O (weight percent)	Sample Weight (grams)	$^{40}Ar_{rad}$ (moles/gm) x 10^{-8}	$\frac{^{40}Ar_{rad}}{^{40}K}$ x 10^{-1}	$\frac{^{40}Ar_{rad}}{^{40}Ar}$ total	Age ± 1 σ (b.y.)
FLX1 (80013)	Granite	Muscovite	10.753 10.760 10.760 $\bar{x}$ = 10.758	0.0999	6.05	2.27	0.981	2.08 ± 0.06
*FLX1 (80035)	Granite	Muscovite	10.753 10.760 10.760 $\bar{x}$ = 10.758	0.0371	6.79	2.55	0.966	2.22 ± 0.07
F 79 SR01 (80032)	Granite	Muscovite	10.743 10.757 10.743 $\bar{x}$ = 10.748	0.0333	7.97	2.99	0.992	2.43 ± 0.07

* Duplicate

TABLE XIII

GRAVEL, SAND, SILT AND CLAY PERCENTS IN
BEAUFORT LAGOON SEDIMENTS

REFER TO FIGURE 3 FOR SAMPLE LOCATIONS

Sample #	Gravel %	Sand %	Silt %	Clay %
BL-1		15.52	61.47	23.01
BL-2		26.00	53.05	20.95
BL-3		98.18	1.19	0.63
BL-4		7.53	66.42	26.05
BL-5		53.94	28.45	17.61
BL-6		77.76	15.52	6.72
BL-7		97.10	1.68	1.22
BL-8		93.23	0.66	1.11
BL-9		32.86	52.23	14.91
BL-10		1.40	64.08	34.53
BL-11		1.61	59.73	39.66
BL-12	60.41	39.59		
BL-14		15.74	60.59	23.67
BL-15		3.36	44.76	51.87
BL-16		9.07	68.08	22.85
BL-17		27.03	51.63	21.34
BL-18	0.37	44.34	18.84	36.45
BL-19	55.70	44.30		
BL-20		87.33	9.55	3.12

TABLE XIV

WEIGHTED PEAK AREA PERCENTAGES (after Biscaye, 1965)
OF CLAY MINERALS IN THE LESS THAN 2 MICRON FRACTION
OF BEAUFORT LAGOON SEDIMENTS, ARCTIC ALASKA

Sample No.	Expandable	Illite	Kaolinite	Chlorite	Illite / Expandable	Kaolinite / Chlorite
BL-1	2	71	4	23	6	0.17
BL-2	5	72	4	19	5	0.21
BL-3	2	74	1	23	23	0.04
BL-4	2	70	3	25	8	0.12
BL-5	2	77	4	17	4	0.24
BL-9	2	73	3	23	8	0.13
BL-11	1	83	2	15	8	0.13
BL-14	2	76	2	20	10	0.10
BL-15	1	76	1	21	21	0.05
BL-16	1	74	2	22	11	0.09
BL-17	4	70	2	24	12	0.08
BL-18	2	73	1	24	24	0.04

TABLE XV

CONCENTRATIONS OF Zn, Co, Ni and Cu IN GROSS SEDIMENTS
OF THE BEAUFORT LAGOON, NORTH ARCTIC ALASKA
REFER TO FIGURE 3 FOR SAMPLE LOCATIONS

Sample No.	Zn	Co	Ni	Cu
BL-1	71	23	43	24
BL-2	71	13	40	23
BL-3	32	28	20	8
BL-4	78	30	48	21
BL-40*	71	25	43	17
BL-5	58	20	33	16
BL-6	62	22	35	20
BL-7	65	22	40	19
BL-8	32	10	18	13
BL-9	72	26	40	28
BL-10	88	32	53	23
BL-11	102	35	58	28
BL-14	70	30	48	25
BL-14D*	65	28	49	20
BL-15	90	32	53	21
BL-16	88	28	48	13
BL-17	75	25	45	21
BL-18	82	29	52	23
BL-20	42	15	30	10

* Duplicate analysis

TABLE XVI

CONCENTRATION OF SEDIMENTS IN VARIOUS SECTIONS OF FOUR SEA-ICE CORE SAMPLES TAKEN FROM DIVE SITE 11 IN STEFANSSON SOUND ON NOVEMBER 11, 1979

SEA-ICE SAMPLES KINDLY SUPPLIED BY DR. T. OSTERKAMP

Core Depth (cm)	mg/ℓ
AV 0-7	209
8-15	123
17-15	92
26-33	98
35-42	221
43-50	110
BV 1-7	37
9-15	66
17-24	44
26-33	43
34-40	281
41-49	127
51-59	192
CV 2-8	260
10-16	352
19-24	52
26-32	42
34-40	41
42-bottom	57
DV 2-8	142
10-17	732
19-25	596
28-35	87
37-42	53
43-bottom	96

Investigations on sea-ice sediments, complimenting our winter sediment dynamic studies, have been initiated. Preliminary data are available. In Table XVI are included concentrations (mg/ℓ) of sediments in various sections of four ice core samples supplied by Dr. T. Osterkamp (RU 253). These core samples were retrieved on November 11, 1979 from Dive Site 11 from the Stefansson Sound. It is notable that the sea-ice sediment concentrations are at least two orders of magnitude higher than those generally observed in open waters of north Alaskan lagoons or adjacent continental shelf regions (Naidu, 1974, 1979).

The above sea-ice sediments are constituted of clean silt and clay, or all plant debris, or various admixtures of silt, clay and plant debris. A few sand grains was observed in one section. The clay mineral assemblage consisted of illite (micas) and chlorite; quartz was the predominant nonclay mineral.

Stratigraphic variations in lithology of 6 short sediment core samples which were retrieved from the Simpson Lagoon were analysed and the gravel, sand, silt and clay percents are listed in Table XVII.

In attempting to characterize grain size distributions of sediments from various depositional environments in arctic Alaska, samples of deposits from three coastal dunes were analyzed for their texture. The statistical grain size parameters for the three samples are included in Table XVIII.

Contents of heavy minerals have been analyzed in two size fractions of sand samples collected from a number of barriers in north arctic. Results of the analysis are presented in Table XIX.

TABLE XVII

STRATIGRAPHIC VARIATIONS IN GRAVEL, SAND, SILT AND CLAY CONTENTS IN SHORT CORE SAMPLES COLLECTED FROM THE HARRISON BAY AND SIMPSON LAGOON IN SUMMER 1979

FOR LOCATION OF THE CORES REFER TO TABLE III

% Gravel	% Sand	% Silt	% Clay	Core Intervals (cm)
		Core # 8979-1		
	3.33	14.85	81.82	0-1
	2.93	16.43	80.65	1-2
	7.41	1.01	91.58	2-3
	9.61	3.63	86.76	3-4
	6.99	11.28	81.73	4-5
	5.85	17.46	76.69	5-6
	9.02	27.74	63.24	6-7
	11.91	36.63	51.45	8-9
	3.90	21.78	74.32	9-10
	2.55	10.78	86.67	10-11
	7.91	16.21	75.89	11-12
	9.83	12.00	78.17	12-13
	15.79	23.92	60.29	13-14
	17.25	14.88	67.87	14-15
	3.19	18.47	78.34	17-18
	9.12	12.04	78.83	19-20
	3.24	69.73	27.03	21-22
	2.63	79.45	17.92	22-23
	1.85	45.55	52.60	23-24
	1.92	44.24	53.84	24-25

TABLE XVII

CONTINUED

% Gravel	% Sand	% Silt	% Clay	Core Intervals (cm)
		Core # 8979-1 Continued		
	3.57	70.76	25.67	25-26
	3.88	57.12	39.01	26-27
	2.93	34.70	62.67	27-28
1.05	18.95	49.30	30.70	28-29
	18.03	44.61	37.37	29-30
0.40	13.90	61.41	24.29	30-31
0.75	25.16	32.22	41.88	31-32
7.92	24.57	32.86	34.64	32-33
0.65	24.68	38.68	36.00	33-34
		Core # 8979-2		
	32.50	28.38	39.12	0-1
	21.83	55.33	22.87	1-2
	25.97	51.01	23.02	2-3
	35.36	31.53	33.11	3-4
	27.57	48.81	23.62	4-5
	18.65	54.82	26.53	5-6
	17.83	72.42	9.74	6-7
	45.47	44.40	10.13	7-8
	27.01	45.41	27.58	8-9
	45.32	44.75	9.93	9-10
	32.10	43.33	25.57	10-11
	7.81	68.55	23.64	11-12
	18.35	69.19	12.46	12-13
	26.39	58.85	14.76	13-14

TABLE XVII

CONTINUED

% Gravel	% Sand	% Silt	% Clay	Core Intervals (cm)
		Core # 8979-4		
	31.35	56.63	12.02	0-1
	46.21	40.67	13.12	1-2
	33.82	40.71	25.47	2-3
	49.36	33.73	16.91	3-4
	31.81	51.18	15.01	4-5
	20.34	67.84	11.82	5-6
	24.48	66.31	9.21	6-7
	72.32	8.37	19.31	7-8
	47.30	43.33	9.37	8-9
	40.57	42.82	16.61	9-10
	42.76	38.14	19.10	10.11
		Core # 8979-5		
	50.86	26.33	22.81	0-1
	38.12	34.59	27.28	1-2
	33.31	36.08	30.61	2-3
	36.21	53.05	10.69	3-4
	35.49	49.05	15.45	4-5
	35.23	51.59	13.18	5-6
	27.02	55.15	17.83	6-7
	34.90	48.35	16.75	7-8
	29.07	53.23	17.70	8-9
	36.53	50.00	13.47	9-10
	28.63	55.27	16.10	10-11
	42.94	39.69	17.37	11-12
	24.23	56.84	18.93	12.13
	31.63	41.74	26.63	13-14

TABLE XVII

CONTINUED

% Gravel	% Sand	% Silt	% Clay	Core Intervals (cm)
		Core # 8979-5 Continued		
	24.89	60.03	15.08	14-15
	31.27	57.52	11.21	15-16
	30.07	56.51	13.42	16-17
		Core # 8979-6		
	42.95	31.58	25.47	0-1
	35.10	41.05	23.85	1-2
	34.63	63.16	12.21	2-3
	32.85	57.63	9.52	3-4
	36.92	53.77	9.32	4-5
	27.15	60.24	12.61	5-6
	30.91	51.03	18.06	6-7
	35.66	50.53	13.81	7-8
	27.39	45.94	26.67	8-9
	31.66	54.51	13.82	9-10
	30.82	59.29	9.89	10-11
	23.71	69.38	6.92	11-12
	29.03	63.65	7.32	12-13
	30.30	61.08	8.63	13-14
	29.60	54.53	15.87	14-15
	21.62	53.05	25.33	15-16
	13.44	78.32	8.24	16-17
	12.96	67.74	19.31	17-18
		Core # 8979-7		
	36.33	27.71	41.96	0-1
	33.39	34.58	32.04	1-2
	27.98	23.20	48.83	2-3

TABLE XVII

CONTINUED

% Gravel	% Sand	% Silt	% Clay	Core Intervals (cm)
		Core # 8979-7 Continued		
	36.46	35.19	28.36	3-4
	30.20	29.67	40.12	4-5
	27.26	33.99	38.74	5-6
	25.45	42.15	32.40	6-7
7.39	22.48	58.55	11.58	7-8
	21.82	61.25	16.94	8-9
	25.57	47.30	27.13	9-10
	26.40	54.64	18.97	10-11
	32.67	52.99	14.34	11-12
	35.86	50.34	13.80	12-13
	37.91	35.91	26.18	13-14
	21.01	57.03	21.95	14-15
	17.72	60.79	21.49	15-16
	16.50	52.02	31.48	16-17
	29.24	52.69	18.08	17-18
	43.01	39.30	17.69	18-19
	33.03	19.91	47.06	19-20

TABLE XVIII

GRAIN SIZE STATISTICAL PARAMETERS (after Folk and Ward, 1957)
OF THREE COASTAL DUNE SEDIMENTS, NORTH ARCTIC ALASKA

Sample Location	Md	M_z	δ_I	Sk_I	K_G
Bodfish Island	1.77	1.81	0.35	0.17	0.95
Cottle Island	1.75	1.74	0.36	-0.03	1.09
Pingok Island	1.55	1.56	0.36	0.04	1.03

TABLE XIX

PERCENTAGES OF HEAVY MINERALS (by wt.) IN BARRIER ISLAND SEAWARD BEACH SANDS, NORTH ARCTIC ALASKA

Sample Number	-60 to +120 Mesh % Heavies	-120 to +230 Mesh % Heavies
Thetis Island # 1	0.24	1.69
Spy Island # 2	0.71	5.93
Leavitt Island # 4	4.39	5.26
Bertoncini # 6	3.77	10.82
Bodfish Island # 7	0.68	5.22
Cottle Island # 9	5.57	28.82
Long Island # 10	2.33	16.18
Egg Island # 11	1.06	3.76
Stump Island # 12	0.10	12.43
Stump Island # 13	1.97	5.01
Gull Island # 15	1.61	2.64
Narwhal Island # 22	5.58	11.59
Reindeer Island # 28	10.86	60.40
Flaxman Island	6.20	9.20
Pingok Island # 1	7.39	4.00
Pingok Island # 2	2.67	6.56
Pingok Island # 5	1.97	4.46
Pingok Island # 6	20.12	72.69

IX. DISCUSSION

Status on Sediment Maps of Beaufort Sea

All available published and unpublished data on texture, clay mineralogy and heavy-metal contents of surficial sediments of Alaskan Beaufort Sea have been compiled and stored on computer discs. Currently, we are in the process of digitally transfering each of the grain size parameters (e.g., gravel, sand, silt percents, mean size, sorting, etc.), clay mineral abundances (e.g., kaolinite, illite percents, etc.), and the individual heavy-metal contents (e.g. Zn, Cr, Cu, etc. concentrations) onto standard maps of the Alaskan Beaufort Sea (scale 1:750,000). Several such maps are already available with us. We are also in the process of statistically testing the distribution of the data before isopleths of statistically acceptable intervals can be digitally/manually drawn for a given sediment parameter for the Beaufort Sea. The final objective of this effort is to show the areal variations in all available sedimentological data and discuss the observed variations within the framework of contemporary processes and the Holocene depositional history. The maps would also show the baseline values of various sediment attributes for the above marine region.

Origin of Exotic Boulders on North Arctic Coast of Alaska

The presence of boulders on the beaches of mainland coast and barriers, and the adjacent littoral and coastal hinterland areas of North Alaskan Arctic has been known from the early part of this century. These boulders generally occur scattered along the coast, except in a few areas such as the Flaxman Island where unusual concentrations are noticed. The origin of these boulders, specially their sources and mode of transport to the present area, has been a subject of debate among geologists working in the Alaskan Arctic.

Our contention is that the arctic Alaskan hinterland - constituted of the Brooks Range, Davidson, British and Romanzov Mountains - and the adjacent Mackenzie River drainage basin were not source areas for the North Slope boulders. This conclusion has been reached after detailed petrographic studies of boulder samples, examination of rock types collected from the above Alaskan-Canadian area,* and survey of gravel compositions along the major North Slope fluvial systems. Admittedly, composition of several coastal boulders are quite close to some rock types outcropping in the Brooks Range (Naidu, 1979), implying a possible source in the Alaskan arctic hinterland for at least some of the coastal boulders. However, this proposition seems untenable, considering a lack of adequate mode of transport of the boulders in the recent geological past from the Alaskan arctic highlands to the north coastal area. Glacial transport of the boulders seems unprobable, because the North Slope presumably was not glaciated during the Quaternary (Coulter and others, 1965; Hopkins, 1967). Moreover, there could be other regions (i.e. the Canadian Archipelago, the Canadian Shield, etc.) having a geology similar to the north Alaskan arctic and the Mackenzie Valley which could have served as alternate source for some of the coastal boulders. Perhaps the key to the elucidation of the erratics' source is in finding the source of the pink to brick-red, coarse-grained granites which are the common boulder types. These latter boulders have a petrography quite in contrast to the granites of the Brooks Range and the adjacent Alaskan-Canadian areas. Substantiating the latter fact are the K-Ar dates on muscovites of the granitic boulders, which suggest an Archaean age (Table XII). All known granitic rock types in the Brooks Range and the Mackenzie Valley are much younger geologically (Geological Society of Canada, 1970; personal communications, Mr. John Dillon, and Dr. T. Mowatt). Study of the geologic and geochronologic data of the Canadian Archipelago and adjacent mainland (Geological Society of Canada, 1970) suggests that the Slave and the Great Bear Provinces of Canada, due south of the Coronation Gulf, could have offered as most probable sources of the granitic boulders. Perhaps such a conclusion also holds true for several other boulders, such as those constituted of diabases and those of acidic, basic and ultrabasic plutonic derivatives. However, the associated varieties of siliceous and calcareous sedimentary boulders could have been derived from anywhere from the Canadian Archipelago

* This examination included archived collections at the U.S. Geological Survey (Menlo Park), and at the State of Alaska Division of Geological and Geophysical Survey, (Fairbanks).

and/or the Coronation Gulf region. Additional studies on the origin of the boulders are in progress. It will suffice to say that some of our earlier views (Mowatt and Naidu, 1974; Naidu and Mowatt, 1974) seem to have been well substantiated by the recently acquired K-Ar dates on granitic boulders. We believe that a more intensive dating program coupled with detailed petrographic studies, and consultation with Canadian geologists, will help to trace more conclusively the source of the coastal boulders in question.

The probable mode of transport of the boulders to the present sites in coastal arctic, and the related paleogeographic implications, have been discussed elsewhere (Naidu and Mowatt, 1974; Naidu, 1974; Hopkins *et al.*, 1978). It is surmised that the boulders were transported by ice-rafting and finally emplaced on the North Slope coasts as dropstones by melting ice-bergs during the Pelukian transgression.

Sediment Geochemistry

The averages of the C/N ratios for suspensate samples (Table V) and bottom grab sediment samples (Naidu, 1978) of the Simpson Lagoon are 18 and 10, respectively. The observed differences in the C/N ratios are attributable either to (i) the method of sampling utilized, or (ii) to the possibility that the suspensates represent sediments that have been eroded and resuspended *in situ* from lagoon substrate layers that have different C/N ratios or, (3) to the possibility that the suspensates do not represent *in situ* resuspended particles and that they were transported to the Simpson Lagoon by lateral littoral currents from adjacent coastal area. There are strong evidences to suggest that in place entrainment of sediments in the Simpson Lagoon does occur during intensified wave action (Naidu, 1979). However, the depth to which the lagoon substrate is eroded is not known. Careful studies relative to stratigraphic variations in the C/N ratios in the Simpson Lagoon presumably will help to resolve the differences observed in the C/N ratios of the suspensates and the substrate sediments. Such a study has been initiated on cm-sections of core samples collected from the lagoon (Table III).

Examination of the stratigraphic variations of the chemical data on interstitial waters (Table VI) adequately substantiates our earlier conclusions (Naidu, 1979) that there is post-depositional dissolution of Mn and Fe in the subsurface reduced sediment layers of the Simpson Lagoon. This observation strengthens the earlier conclusion that dissolved metals can be remobilized into overlying lagoon waters by natural and/or anthropogenic turbation of subsurface sediments. Because oxides and hydroxides of Mn and Fe can serve as very efficient scavengers of heavy metal pollutants, it is implied that dissolution and subsequent mobilization of Mn and Fe into the overlying lagoon waters by occasional turbation could very well be accompanied by a simultaneous release of associated heavy metal pollutants. This observation should be borne in mind when setting guidelines for dredging operations in the north arctic coastal region.

In Table VIII are included the concentrations (μg/g) of Ni, Co, Cr, and V in acetic acid hydroxylamine-hydrochloride extracts (Chester and Hughes, 1967) of a suite of sediment samples from Beaufort Sea. Comparison of the data in Table VIII and those presented in Table VII and earlier (Naidu, 1978) on gross sediments suggests that there is a fractionation of most of the Ni, Co, Cr, and V in the crystal lattice of sedimentary particles. Additionally, with the exception of Cr, the concentrations of all metals associated with the oxides/hydroxides, carbonates and exchangeable/adsorbed phases (e.g., readily mobilized fractions) increase notably in the deep-sea sediments. Presumable, this is related to the muddy nature of all deep-sea sediments and to the relatively low rates of their sedimentation as compared to the continental slope and shelf sediments. Conceivably lower sedimentation rates would promote higher metal adsorption and less dilution by terrigenous particles of metals mobilized and precipitated at the surface from interstitial waters.

As shown in Table IX the concentration of Fe in the gross sediments of Simpson Lagoon, not unexpectedly, dwarfs the quantities of the other metals analyzed. There are two orders of magnitude separating the concentrations of Fe and the second most abundant metal, Mn. In turn, there is slightly more Mn than the combined abundances of the remaining six metals. Similarly, although the extractable Fe is only 11 percent of the total Fe, the absolute quantity of Fe extracted is over an order of magnitude greater than that of Mn.

This complete dominance of Fe over the other metals studied in the extractable phases of Simpson Lagoon sediments provides evidence for the hypothesis that in general the extractable heavy metal distributions are strongly associated with the extractable Fe distributions. A correlation matrix including the heavy metal chemistry for Simpson Lagoon sediments (Table XX) seems to support this proposition.

In summary for Table IX the relative total (T) concentrations (averages) of the heavy metals in Simpson Lagoon sediments in decreasing order are:

Fe >> Mn > Zn ≈ V > Cr > Ni > Cu > Co

The relative portions of the total metal contents extractable by the Chester and Hughes reagent (%E) follow the decreasing order (averages):

Mn >> Co > Cu ≈ Zn > Ni > Fe >> V > Cr

Except for Mn (50 percent) the greatest portion of the total content of the heavy metals in Simpson Lagoon sediments occur in the nonextractable phases.

The Fe-Mn oxidate-carbonate-exchangeable-adsorbed component in Table X corresponds to the acetic acid-hydroxylamine hydrochloride (AAHH) extracts (E, from Table IX). The results of the AAHH treatment have been compared in Table X to the portions of the Total Fe and Mn extracted by each successive chemical treatment in a sequential analysis. The sum of the nonresidual fractions (exchangeable through organic complex) if compared to the AAHH results reveals a contrast between Fe and Mn in extractability. Whereas the AAHH technique removes practically the same quantity of Mn as the sum of the nonresidual components (50 percent) the same technique only removes less than half of the nonresidual Fe (13/40). This indicates that the Chester and Hughes (1967) reagent is suitable to estimate the nonlithogenous Mn in the sediment but is not strong enough to extract some relatively more refractory nonlithogenous Fe phases. It may be interesting to compare the trace metal contents of the more stable Fe oxide phases with those extracted by the AAHH technique.

TABLE XX

CORRELATION COEFFICIENTS[a] FOR CHEMICAL AND TEXTURAL COMPOSITIONS[b] OF 54 SIMPSON LAGOON SEDIMENTS, ARCTIC COAST OF NORTHERN ALASKA

	D	Sd	Cl	Mu	CO_3	OC	NE Fe	E Fe	NE Mn	E Mn	NE Zn	E Zn	NE V	E V	NE Cr	E Cr	NE Ni	E Ni	NE Cu	E Cu	NE Co	E Co
D																						
Sd	-0.630																					
St	0.638	-0.987																				
Cl	0.465	-0.829	0.762																			
Mu	0.630	-1.000	0.987	0.829																		
CO_3	0.490	-0.843	0.829	0.712	0.843																	
OC	0.249*	-0.546	0.520	0.587	0.546	0.413																
NE Fe	0.676	-0.944	0.917	0.841	0.944	0.776	0.520															
E Fe	0.513	-0.841	0.820	0.767	0.841	0.687	0.600	0.844														
NE Mn	0.647	-0.887	0.874	0.793	0.887	0.709	0.546	0.934	0.839													
E Mn	0.353*	-0.696	0.682	0.613	0.696	0.671	0.499	0.680	0.744	0.709												
NE Zn	0.655	-0.817	0.783	0.771	0.817	0.705	0.473	0.847	0.720	0.817	0.580											
E Zn	0.405	-0.813	0.761	0.886	0.813	0.745	0.603	0.776	0.814	0.692	0.598	0.704										
NE V	0.585	-0.876	0.835	0.897	0.876	0.785	0.569	0.916	0.771	0.815	0.608	0.846	0.852									
E V	0.465	-0.853	0.816	0.882	0.853	0.670	0.575	0.846	0.899	0.794	0.631	0.726	0.892	0.832								
NE Cr	0.596	-0.924	0.889	0.908	0.924	0.727	0.568	0.937	0.829	0.898	0.617	0.827	0.843	0.918	0.914							
E Cr	0.399	-0.796	0.774	0.724	0.796	0.716	0.531	0.737	0.863	0.744	0.717	0.661	0.764	0.683	0.825	0.726						
NE Ni	0.587	-0.929	0.894	0.898	0.929	0.788	0.552	0.933	0.817	0.888	0.659	0.821	0.824	0.908	0.882	0.950	0.756					
E Ni	0.313*	-0.755	0.726	0.750	0.755	0.656	0.667	0.709	0.792	0.664	0.732	0.589	0.806	0.729	0.798	0.746	0.811	0.732				
NE Cu	0.301*	-0.680	0.653	0.721	0.680	0.585	0.618	0.674	0.709	0.718	0.574	0.635	0.764	0.693	0.709	0.723	0.616	0.701	0.684			
E Cu	0.482	-0.694	0.652	0.701	0.694	0.659	0.284*	0.749	0.634	0.673	0.567	0.660	0.754	0.698	0.704	0.724	0.579	0.736	0.498	0.579		
NE Co	0.453	-0.717	0.692	0.675	0.717	0.623	0.439	0.757	0.548	0.676	0.433	0.557	0.585	0.730	0.628	0.736	0.473	0.728	0.474	0.588	0.607	
E Co	0.468	-0.778	0.759	0.709	0.778	0.626	0.635	0.777	0.866	0.753	0.772	0.671	0.763	0.729	0.815	0.770	0.797	0.754	0.903	0.649	0.565	0.473

[a] Spearman nonparametric correlation problem. All coefficients are significant at or above the 99.9% confidence level.

* These coefficients are significant only at the 95% confidence level.

[b] The prefix "E" to the heavy metals connotes the amount of the metal extractable by an hydroxylamine hydrochloride-acetic acid leaching procedure (Chester & Hughes, 1967). The prefix "NE" connotes the amount of the metal not extracted by the same reagent. D, Sd, St, Cl, Mu, CO_3, and OC are abbreviations for depth, sand + gravel, silt, clay, mud, carbonate, and organic carbon, respectively.

In summary (Table X) 95 percent of the total Fe in Simpson Lagoon sediments is either in the residual components and/or in an oxide phase. Manganese has a more complex distribution with 25 percent extractable by very mild treatments and 50 percent being residual.

Stratigraphic Variations in Pb^{210} Activities: Sedimentation Rates and Depositional Processes

The observed stratigraphic variations in the Pb^{210} activities for the eleven sediment cores (Table XI) provide some insight into sediment accumulation processes in the Simpson Lagoon, Harrison and Prudhoe Bays, Beaufort Sea shelf, and the Deline Lake. It would seem that any sediment sequences resulting from steady state particle by particle deposition in the shallow portions of the Bays, Lagoon and the Lake are prone to occasional reworking. Ice gouging, biological activities and intensified wave-current churning action during storms are possible factors contributing to the turbation of sediment sequences. As alluded to earlier this fact is notable as it implies that pollutants initially scavenged by solid sediment phases can be subsequently remobilized - in dissolved phases - by natural processes into the overlying water columns of the nearshore. As also mentioned earlier segments within most of the cores investigated do show a net logarithmic linear decrease in Pb^{210} activity. Least square test indicates the decreasing trend to be statistically significant (Table XXI) in all but cores PWS75-1, NW78-1 and 8979-4. Considering the above sediment segments the accumulation rates relative to each of the nine cores have been tentatively estimated (Table XXI).

Considering the 12-21 cm section of the Deline Lake, the sedimentation rate for the lake appears to be 2.1 mm/yr. Likewise taking into account the undisturbed segments of the various cores of the Simpson Lagoon it is tentatively estimated that the sedimentation rates in the lagoon ranges from 1.7 to 10.7 mm/yr. The Prudhoe Bay and Colville 'Prodelta' cores appeared significantly reworked as a result of which no meaningful depositional rate could be estimated for those two areas.

Status of LANDSAT Image Studies

In Table I are included the temperature and salinity values and concentrations of suspensates in Simpson Lagoon and Prudhoe Bay waters for the periods of the passage overhead of the LANDSAT II and III

TABLE XXI

TENTATIVE RESOLUTION OF Po^{210} ACTIVITIES IN CORE SAMPLES AND RATES OF SEDIMENTATION FOR COASTAL AREA OF NORTH ARCTIC ALASKA

FOR SAMPLE LOCATIONS REFER TO TABLE III

Core #	Core Section (cm)	Constants		Correlation Coefficient (r)	Test Values		Sedimentation Rates (mm/yr)
		a	b		99%	99.9%	
8979-1	0-24	1.28	-0.017	0.60	0.53	0.64	18.3
	28-34	50.20	-0.129	0.98	0.92	0.97	2.4
8979-2	0-14	1.82	-0.038	0.72	0.66	0.78	8.2
8979-3	0-20	1.56	-0.067	0.96	0.56	0.68	4.6
8979-4*	0-11	1.11	-0.016	0.27	0.74	0.85	19.4
8979-5	0-19	1.68	-0.040	0.81	0.58	0.69	7.8
8979-6	0-15	1.24	-0.042	0.87	0.64	0.76	7.4
8979-7	0-15	1.57	-0.060	0.89	0.64	0.76	5.2
8579-1	0-9	1.58	-0.187	0.92	0.80	0.90	1.7
878 -2	0-16	1.82	-0.029	0.82	0.68	0.80	10.7
779 -1	12-21	32.2	-0.147	0.89	0.80	0.90	2.1
NW 78-1**	0-17	1.46	-0.011	0.50	0.41	0.61	28.3

* Not Significant; too much scatter in Po^{210} activities

** Significance unlikely

In calculation of the sedimentation rate it is assumed that the half-life of Pb^{210} has been 22.34 years satellites. As noted earlier, these data were collected to serve as 'sea truth' for developing criteria to quantify surficial suspended loads of nearhsore waters, using LANDSAT density sliced images. However, for reasons not definately known as yet LANDSAT images as well as digital data, for the field period covered by us (24 July to 12 August 1979) are not available from NASA and therefore the above criteria could not be developed. In any case, it is of interest to note that there are significant regional differences in the temperatures, salinities, and suspensates of waters (Table I). It would seem that during the period of collection the water masses in Prudhoe Bay and vicinity were more strongly impacted by the fluvial outflows than the Simpson Lagoon region. This is obvious from the relatively warmer and less saline waters that were observed in the bay as compared to the lagoon (Table 1). Sample 81179-1 was collected from the very well delineated Colville River turbid plume. It is of further interest to note that the water west of the new ARCO dock (S. #72479-4) was relatively more saline and cooler than samples from Prudhoe Bay. Obviously, the ARCO dock serves as a partial barrier for the lateral movement westward of Sagavanirktok River outflow.

Plans for summer 1980 call for continuing our efforts to develop criteria to estimate turbidities of North Slope coastal waters from LANDSAT images. 'Sea truth' will be obtained while working in the Harrison Bay region.

Sediment Dynamics Studies

As indicated earlier preliminary results of our summer and winter studies relative to sediment dynamics, as reported by Dr. Larsen, are appended with this report (Appendix A and B). Additionally, it would seem that the processes of sediment entrainment, transport and deposition in summer 1979 in the Simpson Lagoon were not the same as those which prevailed in summer 1978. Plotting of the summer 1978 time-series data exhibited apparent correlations between wind strengths and suspensate concentrations at the Milne Pt. tripod station. On the basis of those correlations, Naidu (1979) suggested that the threshold of wind to induce wave-current sediment resuspension in Simpson Lagoon at the tripod station was about 8 m/sec. That conclusion does not seem to be well substantiated by the summer 1979 data which indicate quite suspension-free waters at 10.5 to 13 m/sec winds at the tripod station (about 2.9 m water depth) in the Simpson Lagoon. It is to be noted that in 1979 the spring break-up was unusually earlier, and in middle and late summer (August-September) abnormally high sediment-laden fluvial discharge was observed. Implication of these unusual events, if any, on summer 1979 suspended load budgets could not be assessed because of lack of LANDSAT images for the period.

Conceptual Model For Sediment Concentration in Frazile Sea-ice of North Arctic Alaska

The presence of sediments in frazile sea-ice, in concentrations 2 to 3 orders of magnitude higher than in ambient coastal waters, has been an enigma to investigators working on sea-ice problems in the nearshore of Beaufort Sea. The question that has been time and again raised refers to the mechanism which leads to the entrapment of sediments in unusaul concentrations in the ice. Many ideas have been presented, but none seem to have offered a satisfactory answer. A commonly held notion has been that occurrence of storms during the incipient freeze-up period is critical to entrain large quantities of sediments into the water column, and that the subsequent freezing up of the suspension-charged water could account for the unusual particle concentration in the sea-ice. Although this idea may be acceptable in a few cases, it would seem untenable in most cases. It is hard to believe that in the Beaufort Sea nearshore intensified wave action during occasional storms is capable of suspending fine sediments in concentrations as much as 200 to 750 mg/ℓ - the levels generally observed in sea-ice (Table XIV)*. Alternate ideas for the unusual sediment accumulation in sea-ice refer to possible anchor ice sediment entrainment, or to occasional 'ducking' and sediment scraping

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* The extremely turbid water debouching from the North Slope rivers generally has between 70-100 mg/ℓ of suspended particles, and this fluvial plume stands out in LANDSAT images. None of the LANDSAT images during freeze-up time (or storms) show such turbid waters offshore.

by highly fragmented frazile ice by storm surge wave action. The lack of any textural correlation between sediments of substrate and overlying sea-ice for any specific inshore region, does not seem to add much credence to the thesis of sea-ice scraping bottom sediments. Additionally, the occasional scrapping process would tend to be manifested in sediments occurring as streaks, blebs, and bands in an otherwise clean sea-ice, which is definitely not observed.

In the following is presented a hypothesis that might explain the processes leading to the unusual sediment concentrations in sea-ice. During freeze-up period* when continuous fluxes of suspended particles, borne in laterally moving currents of water impinge on highly porous, undulating slushy** sea-ice the particles are assumed to adhere to the rough ice surface. It is further contended that as the sea-ice grows, fresh surfaces are successively exposed for continuous accumulation of suspended sediment particles. Moreover, ocurrence of storms during freeze-up time would seem to be a critical factor for the sediment accumulation at the sea-ice/water interface, because higher water turbulence will maintain the slushy nature of the accreting sea-ice surface in addition to providing larger fluxes of suspended particles for potential accumulation at the surface. For particles to accumulate at concentration levels equivalent to those generally observed in the ice (i.e., 200 to 750 mg/ℓ; Table XVI) it would be crucial that the concentrations, supply and accumulation rates of particles at the sea-ice/water interface are sustained at a certain optimum level and are commensurate with the sea-ice growth rate. It would seem that in the Beaufort Sea nearshore the critical particle supply and accumulation rates are adequately carried, as suggested by the followup computations. Assuming that during freeze up period the mean suspensate concentration in the nearshore waters is about 1 mg/ℓ, mean current strength is at 10 cm/sec, and the slush-ice accretion rate is about 1 cm/day, it is estimated that the maximum possible sediment accumulation on sea-ice will amount to about 850 mg/ℓ. However, it is most likely that the suggested sediment accumulation process is less than 100 percent efficient.

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* After the formation of pan-cake ice

** Slushy and rough nature of sea-ice seems critical for particle adherence

Assuming that the process is only 25 percent efficient it would still be possible to adequately explain, within the said process framework, the nearly 200 mg/ℓ sediment concentrations generally observed in frazile sea-ice (Table XVI).

The general lack of sediment concentrations in the lower segments of sea-ice is perhaps attributable to the process by which those segments are formed. Accretion of sea-ice in the lower portions presumably occurs as relatively smooth, horizontal, and consolidated sheets rather than as porous, undulating slush. The lack of slushiness seems to be promoted by relatively tranquil waters, which in turn obviously results from the lack of fetch sometime after the initial frazile ice formation. It is surmised that the horizontal consolidated sheets do not offer as effective a surface as the rough surface of slush ice for sediment accumulation.

The hypothesis presented above is of course conceptual in nature, and must be verified by laboratory experiments conducted in freezing tanks.

Beaufort Lagoon Sediments

Textural analysis of grain size distributions on Beaufort Lagoon sediments has been completed. Although gross textural attributes (e.g., sand, silt, clay, etc. percents) are available (Table XIII) the conventional statistical grain size parameters (Folk and Ward, 1957) have yet to be computed. The clay mineral assemblages in the < 2 μm size fraction, and a few heavy metal concentrations have been analyzed on gross sediments (Tables XIV and XV). On basis of the limited data available it would seem that the Beaufort Lagoon sediments are significantly different in several aspects than the Simpson Lagoon deposits. The latter sediments are relatively finer grained, have higher amounts of expandable clay minerals, and the concentrations of Co and Ni in them are much lower than those in the Beaufort Lagoon. These differences are attributable primarily to variations in the terrigenous sources of the two lagoon sediments. This suggests that all lagoons in north arctic Alaska may not have a similar depositional regime. Further work calls for completing data collection on the Beaufort Lagoon sediments, and testing the sediment variability of the Beaufort and Simpson Lagoons through conventional statistical analysis.

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APPENDIX A

Winter Studies Report
September 1979-March 1980

SEDIMENT TRANSPORT AND INCLUSION INTO THE ICE COVER

by

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March 1980

I. SUMMARY OF OBJECTIVES

As a result of field studies conducted over the past few years it has become evident that nearshore arctic ice can contain a large sediment load. The sediment content in the ice is variable year to year and in any given year is rather patchy. Sediment-laden ice may be found at least out as far as the stamukhi zone. The available evidence suggests that windy conditions during freeze-up are important in incorporating sediment into the ice. Alternative mechanisms that can operate after freeze-up have also been proposed. The objective of this study is to determine the mechanisms by which sediment is concentrated within the ice cover.

Conclusions

Observations that nearshore ice often contains sediments date back to the earliest days of exploration (Kindle, 1924). To answer the question of why should we now be interested in pursuing a program of studies of sediment-laden ice, we held a conference in Seattle in February 1980. Approximately 20 people from government, industry, and universities actively participated in the discussion. A report of this meeting has been submitted to the OCSEAP Arctic Project Office. Briefly, the major conclusions are:

1. Sediments transported when the ice canopy is in motion can comprise a significant portion of the total near-shore sediment flux.
2. Unique biological communities exist in the dirty frazil ice and the reduction of light penetration through the ice cover is significant.
3. The mechanisms that apply to cause the sediment-laden ice may be equally efficient at including industrial discharge material into the ice canopy.
4. The source of the sediment that is found in the ice canopy is not known.

In addition to the conference we undertook a pilot field program deploying the SDS tripod near to dive site 11 in Stefansson Sound. A most significant observation is that it does not appear that near bottom water temperature equaled the freezing point during the experimental period. The closest approach to freezing occurred on October 18 at the time when the tripod was toppled over. The water was .05°C above freezing. A figure close to but above the instrument's accuracy. The puzzle however is complicated by the observations of rocks and shells in the ice canopy at the dive site.

Physical measurements argue against anchor ice, yet how else could the massive material get into the ice cover?

Implications with Respect to OCS Oil and Gas Development

The very mechanisms that concentrate sediments within the ice cover would also tend to concentrate materials like drilling muds. Thus, ice could act as a valuable disperser for such material preventing locally excessive concentrations. However, if one desires to leave such material in a local area, its incorporation into ice would pose a serious problem. If sediment-laden frazil ice were drawn into a pump the sediment as well as the ice could have a detrimental effect on the machinery through abrasive action and flow restriction.

The above are rather obvious consequences of sediment laden ice, less concrete but perhaps more fundamental is the lack of understanding about the conditions that form dirty ice. Would small increases in turbidity by man's activity snowball to major fluctuations in arctic sediment transport and light penetration through the ice? Sediment concentrations in the ice far exceed that in the normal water column pointing to the need for a concentrating mechanism. How is this triggered?

Sediments within the ice affect light transmission and most probably ice strength. Again the implications and consequences to operations are speculative. Both early and late winter operations could be affected.

An interesting question is that if frazil ice sweeps up sediments to high concentrations, could it do the same with oil?

A mechanism that satisfies the known facts is proposed in the discussion section. If this is the real mechanism then great difficulties exist in constructing and maintaining offshore islands.

II. INTRODUCTION

Instruments whose records will be discussed in this document were deployed in Stefansson Sound during the 1979 freeze-up period. In addition to the field work we have tried to bring together knowledgable scientists to discuss the problems and consequences of sediment-laden ice. The problem is interdisciplinary with geological, biological, and pollutant transport implications. Entire communities of fauna exist within the sediment-laden slush ice that have no alternate habitat. The way in which ice freezes may have impact on estimates of the heat budget of arctic regions since freezing occurring during storms when frazil ice forms may require less latent heat than under calm conditions.

There are many aspects to the sediment in ice problem. Some involve the crystallography of ice, some aspects are best addressed by wide spread core sampling. This program of studies was designed to test some ideas on the causes of sediment-laden ice. Ice within the nearshore environment of Prudhoe Bay and other nearshore areas of the Beaufort Sea is often observed to contain sediment layers in the solid ice and a frazil layer below the solid ice which is richer in sediments than the water column. To gain some insight in the physical processes that occur during freeze-up we undertook the following investigation.

The sediment dynamics system (SDS) was in Prudhoe Bay at the end of the summer of 1979 following its work in Simpson Lagoon. In a session held at Prudhoe Bay between Peter Barnes, Dick Stenberg and Larry Larsen, the possibility of deploying the tripod for a fall experiment was discussed. The experiment although risky seemed feasible and we decided to go ahead with the experiment. Accordingly, the electronics were dismantled, carried to Seattle, and modified to fit a sediment temperature probe that was assembled in Menlo Park. In mid-September the system was reassembled in Prudhoe Bay and deployed on September 20, 1979 by the R/V *Karluk*. The tripod was then hoisted on a frame by hand winch until it surfaced. We then made certain that it cleared the hole and with helicopter assistance it was pulled clear of the ice.

Unfortunately, following recovery of the tripod, it was found that the instrument had flooded through the O-ring at deployment. All records from the SDS system were lost, however the current meter attached to the leg of the tripod functioned throughout the deployment and its record provides valuable insight as to events that took place in the fall of 1979. For example, the tripod was toppled on its side on October 18. The top of the tripod was two meters above the sea floor, the water depth was 7 m. The keel depth of an ice floe to topple the tripod would have been 5 m, this inside of the barrier islands. Brian Matthews current meters were also lost, perhaps by the same event. The tripod was insured, the details are presented in Appendix C.

Sediments were found in layers in the ice as we carved the recovery hole as well as a dirty slush ice layer beneath the solid cover. The ice above the tripod was somewhat ridged, 50 cm typical relief, and of 70 to 100 cm thickness. Only 20 m away at the dive hole the ice was 30 cm thick with much less sediment-laden ice beneath it. These very observations prompted the discussion that lead to the formation of the February meeting on dirty ice.

III. OBJECTIVES

The objective of this study is to determine the mechanisms by which sediment is concentrated within the ice cover.

Relevance

Sediment-laden ice affects arctic operations, constitutes a major pathway for sediment transport, and reduces light penetration affecting spring growth in the benthic community.

IV. STATE OF KNOWLEDGE

We attempted to define the current state of knowledge at the February slush ice meeting. The full report is attached. To summarize:

1. The mechanisms promoting sediment inclusion into the ice canopy are speculative.
2. There is much uncertainty concerning the amount of sediments in nearshore ice. Silts and clays are preferentially included in the ice canopy.
3. The soft ice layer is associated with the presence of several mobile organisms that are not seen under cleaner congelation ice. These include amphipods, polychaetes, and copepods.
4. Soft turbid ice completely blocks light transmission through the ice canopy. Linear growth in the brown algae is reduced by 50% under soft turbid ice and epontic algae appear to be absent.

V. STUDY AREA

Stefansson Sound, dive site 11.

VI. METHODS OF DATA COLLECTION

The SDS is a pyramid structure 2 m in length on each side of the base triangle and 2.3 m in height. The electronics including a microprocessor are housed in a 22" diameter sphere which has a window through which bottom photographs are taken.

Currents are measured with a Savonius rotor 1 m off the seabed. The microprocessor in the sphere is programed to calculate the vector average velocity, averaging samples taken once per second during the 15 minute sample period. In addition to the vector average velocity, the instrument also records total rotor runs, instantaneous direction and a histogram which contains the percentage of rotor counts taken when the vane was in any one of 16 sectors of the compass. Pressure is sampled with a vibratron pressure sensor with a resolution of .6 mm of water. Mean pressure and a variance measure, sigma

$$\text{sigma} = \frac{1}{N} \Sigma \left| P_i - P_A \right|$$

where N is the number of sample points, P_i the instantaneous pressure and P_A the average pressure of the proceeding cycle, are recorded each 15 minutes. The quantity sigma is .8 of the standard deviation if the data sample comes from a normal population. Temperature and nephelometer sensors are sampled once a cycle. For this experiment the temperature to be measured was that of a sediment probe buried adjacent to the tripod.

During calm periods when little wave activity is present, only the means for a cycle were recorded. However, when sigma exceeds a preset value the system records 1024 values of the instantaneous pressure at a time interval of one second. This data is used to estimate the near bottom velocities associated with the waves.

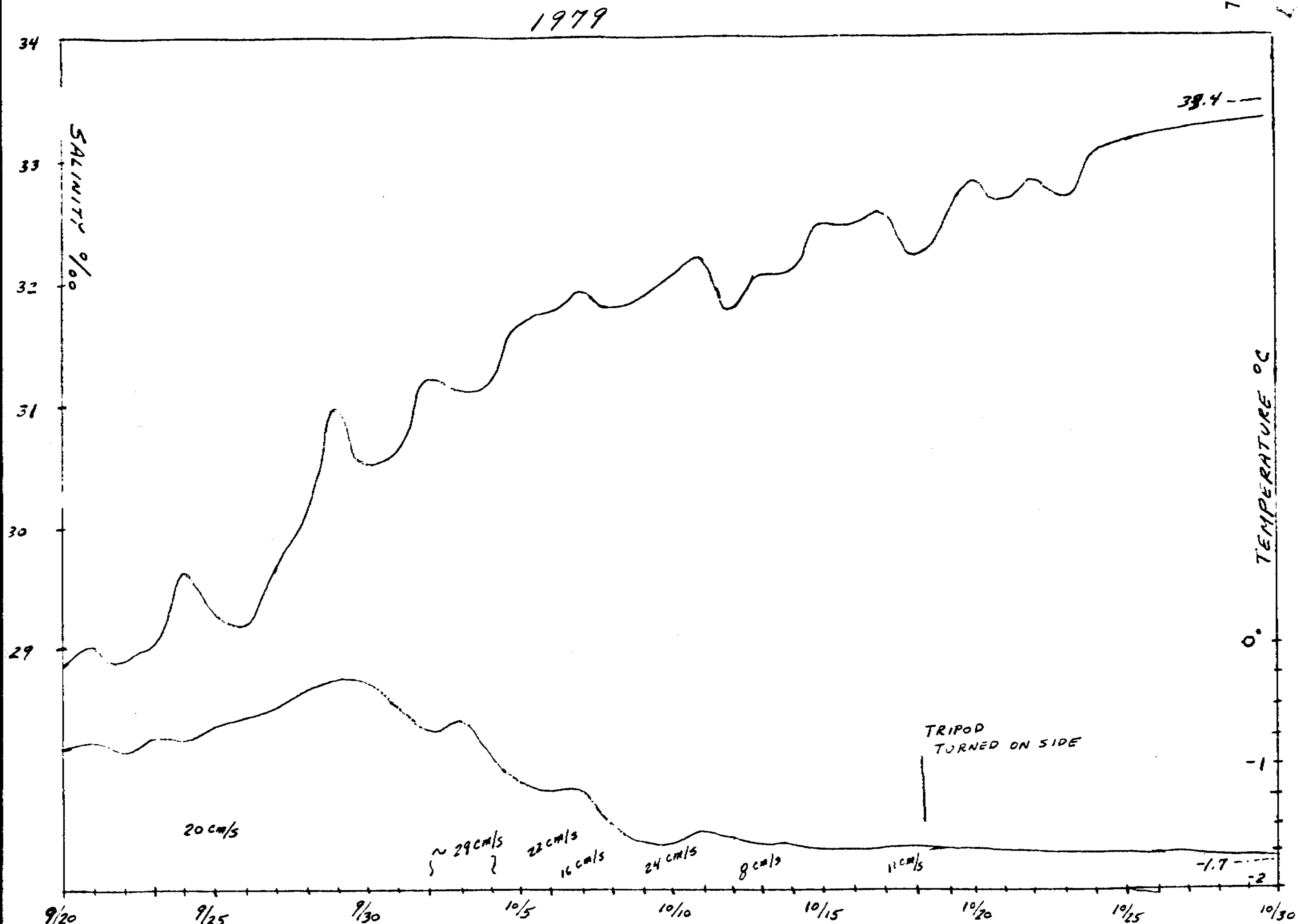
In order to measure water temperature and salinity we attached an Aanderra current meter to one leg of the tripod. This was a fortunate addition since the tripod flooded and the current meter functioned throughout the study. The Aanderra current meter functioned throughout the study. The Aanderra current meter records temperature and conductivity. Salinities are calculated using the Institute of Oceanography, Wormly, England, routine programed by Trevor Sankey. The accuracy of the program exceeds that of the recording instrument.

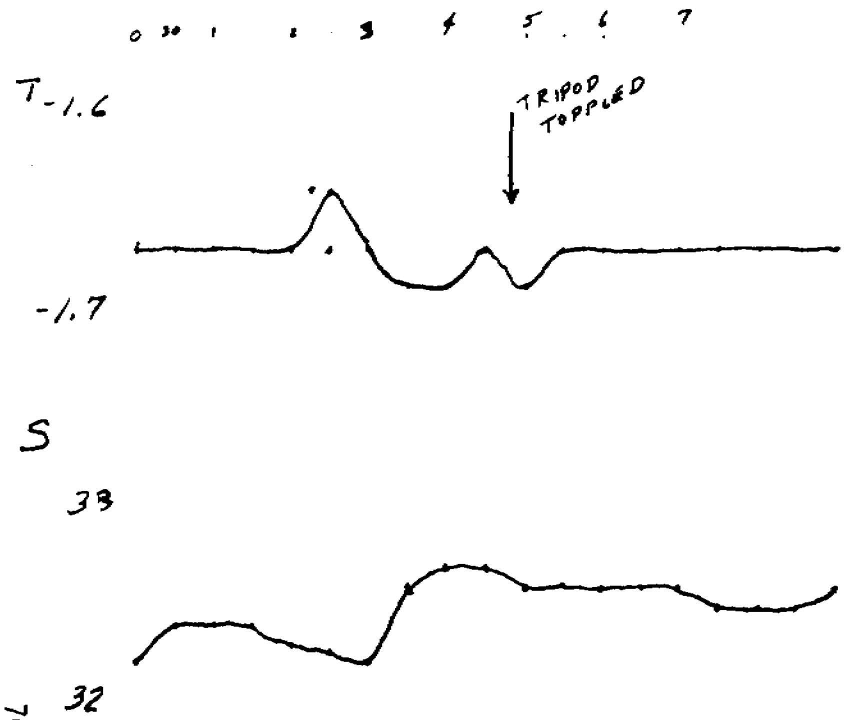
VII. RESULTS

Data on current speed, salinity and temperature were recovered from the fall experiment in Stefansson Sound. These data are shown in Figure 1. The most dominant feature is the complete change over from a brackish lagoon in summer to a hypersaline environment by late fall. The salinity at deployment on September 20 was below 29 ppt. In late November at recovery time it was 33.4 ppt. Typical values for Beaufort Sea water lie between 31 and 32 ppt, thus we see a total change in estuary classification from normal to what might be considered an evaporative lagoon. Any water with a salinity greater than 32 ppt must originate from salt efflux from the ice in the near shore environment. Current speeds are indicated on the bottom of Figure 1. The full record shows significant fouling by kelp on the rotor. The high currents observed showed up when kelp was free of the rotor and almost certainly are wave pumping velocities. The values should not be interpreted as mean currents. Rather the high speeds indicate the times of storm activity.

The salinities and temperatures are shown up to October 25. After October 25, there were but gradual changes in the water column properties. The salinity monotonically increassed from 33.2 to 33.4 ppt and the temperature remained at -1.7°C. The freezing point of water at 33.2 ppt is -1.81°C and is .01°C lower at 33.4 ppt. Thus during late fall the salinities were too high for the water to be at freezing temperatures.

The tripod toppled over between 0230 and 0300 local Alaskan time on October 18. Peak currents were on the order of 11 cm/s. Salinity and temperature observations for this period are shown in Figure 2. The current meter rose 2 m through the water column on the overturning event. There is no indication of stratification in the system. At 32 ppt the freezing point


1979
SALINITY ‰
TEMPERATURE °C
34
33
32
31
30
29
33.4
0°
-1
-1.7
-2
TRIPOD TURNED ON SIDE
20 cm/s
~ 29 cm/s
22 cm/s
16 cm/s
24 cm/s
8 cm/s
11 cm/s
9/20
9/25
9/30
10/5
10/10
10/15
10/20
10/25
10/30



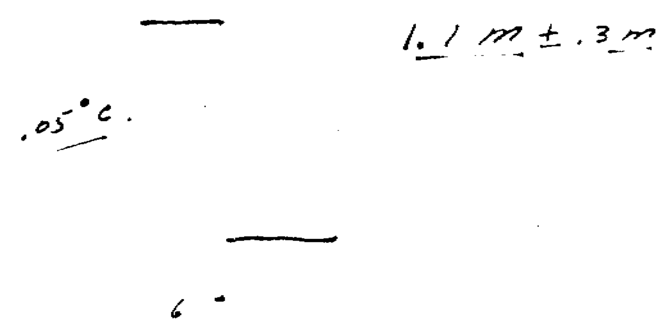


Fig 2
will be redrawn.

of sea water is -1.74°C. Thus the water was at about .05°C above freezing. This is the closest observation that we have of the water approaching the freezing point. These findings will be further substantiated when data from Brian Mathews equipment is processed.

VIII. DISCUSSION

This was a year of extremely dirty ice. It was a year in which a major storm occurred near to the time of freeze-up. Because of ridging and the toppling of the tripod we suspect it was a year with much ice movement well after initial freezing. Since the water near to the bottom does not appear to have ever been at freezing temperature, the importance of a storm in fall is highlighted to abet the formation of dirty ice. The best estimate for the source of the material in the ice is thus the barrier islands. Sediment sources nearer to shore are unlikely because that ice freezes first and is fast. It is unfortunate that turbidity measurements were not obtained because we need some idea about the water in the sound itself.

To speculate on a mechanism for the formation of dirty ice we favor a model involving the formation of a deep slush ice layer. This can occur rapidly, two or three days to create slush to a depth of 3 m or more. This slush is swept along by wind and wave power. Should the slush strike the bottom as it would do on crossing the shoals at the barrier islands, sediments would be captured by the ice. Subsequent freezing would solidify the upper layers, entraping sediments in the hard ice. The soft dirt-laden ice beneath the hard cover simply has not yet had time to gel by late fall. If this mechanism is correct it predicts a shoreward flux of sediments, fall erosion of the barrier islands, and much difficulty for those wishing to construct new offshore islands.

In this scenario the sediment source is the barrier islands, perhaps to depths of 3 m. A certain amount of sediment rain in the deeper lagoon to the sea floor is anticipated. Rocks could be swept up from the shoal areas and included in the ice. No bottom freezing is required. Reverse currents could sweep sediment-laden ice offshore to the stamukhi zone.

Perhaps this shoreward flux of sediments is the reason for the absence of delta formations where otherwise they would be expected. Clearly more study is needed to examine this hypothesis. We put it out as a straw man.

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APPENDIX B

SUSPENDED SEDIMENTS
SIMPSON LAGOON, ALASKA

Larry H. Larsen

Suspended Sediments
Simpson Lagoon, Alaska

Larry H. Larsen

Introduction

This study is a contribution towards understanding the nature of sediment transport in the arctic regions of Alaska. We have tried in these studies to document the transport of suspended material in Simpson Lagoon at a station half way between Milne Point and Pingok Island. The particular site was determined by the necessity that there be in excess of 2.3 m of water to fully submerge the instrumentation.

Nature and operational problems have not been cooperative in this study. The 1978 experiment was cut short by a vessel striking the instrument and in 1979 no significant storms were to be had. In 1978 the data that was recovered showed a sediment laden flow too dense for film exposure and off scale of the nephelometer. In 1979 the water was of such clarity that ambient light influenced the operation. At no time during the experiment could we get a photo during day time because of the intense light at the bottom. Nephelometer readings did not at night exceed 11 percent of full scale of the instrument. These correspond to extremely low sediment concentrations. We have sediment samples with which to calibrate the nephelometer. It will be done when the instrument returns from the Arctic in December 1979. However, it is unlikely that sediment concentrations in excess of 3 mg/l will be found. During the observation period in 1979 there was a net deposition in spite of two storms that had sustained winds of 20 knots for two days. It must require more severe storms than these to promote extensive bottom erosion in the Lagoon.

The years 1978 and 1979 exhibit different behavior. We will be examining the meteorological records to see if the differences can be identified in this way. We also know from satellite observations that sediment laden water occurs in streaks and patches as a consequence of minimal lateral mixing. What is the probability of streaks of sediment laden water being at a particular location? This non-trivial question may loom in importance should an oil spill occur, since the fate of oil may depend on the clay content of the water. In the San Francisco oil spill, oil was observed to coagulate and sink to the bottom in the presence of suspended clay sediments.

Tripod Observations

The tripod was deployed at 10:30 on 23 July 1979 local Alaska time. The deployment followed the assembly of the tripod in the ERA helicopter hanger in Prudhoe Bay and transport to Milne Point by a NOAA helicopter. Final preparations were done at Milne Point to set the instrument for operations. The instrument was then flown slowly out to site marked by buoys and deposited in the water. The operation was extremely smooth considering that it was the first time we had attempted helicopter deployment and long flights with the tripod suspended beneath a helicopter.

The tripod was set to record samples at 1/2 hour intervals and to take photographs at 2 hour intervals. Portions of the data gathered are shown in figures 1, 2 and 3. In Table 1 we list the data available.

TABLE 1

Photographs	24 July - 1 September
Nephelometer	23 July - 23 August
Temperature	23 July - 23 August
Current Direction	23 July - 23 August
Current Speed	23 - 24 July
Waves	1 record
Sea level	23 July - 14 August

On July 24 winds were from the east in the 15-20 knots range. The lagoon was extremely rough. Shortly after 5:00 p.m. on 24 July, the currents were registering 50-55 cm/s. These currents plus the wave activity or possibly debris resulted in knocking the rotor off its bearings. The rotor had previously operated in 120 cm/s currents but not with high frequency (2-3 second) waves. As a consequence, further current information is not reliable although the rotor did turn some of the time. The current of 55 cm/s is larger than any reported by Dygas (1975). Sea level measurements were made until 14 August at which time the batteries were too far drained of power to operate the sensor.

We normally expect 6 weeks operation of the pressure sensor. A failure in one of the rechargable batteries would account for the failure. The battery pack consists of a parallel combination of two sets of four 7.5 V batteries wired in series. Power loss in one of the parallel sets would cut available power in half. The use of quartz crystal rather than the vibration pressure sensor would substantially cut the power requirement for pressure measurements.

Internally recorded measurements of temperature, current direction and nephelometer continued for one month before low voltages on the tape recorded introduced sporadic errors in tape writing. This is a shorter recording period than was expected. It resulted because of the low voltage on the pressure sensor which then gave erratic signals. These were interrupted as waves and the system went into a rapid record mode. As a result, we used more than twice the amount of tape (and power) as would be expected in normal operations. Photographs were taken as long as the system had sufficient power to advance the film. The stroke is on an independent 225 V power source.

Unlike in 1978 the waters of Simpson Lagoon were extremely clear for the duration of our observations. Bottom photos taken in 1978 were black. Not even the top of the current meter could be seen. In 1979 the compass near to the bottom is visible in most photographs. The system was designed for operations in ambient darkness. The camera shutter is opened for 2 seconds during which time the strobe flashes. This is a consequence of the basic one second timing interval used in the computer. The ambient light washed out all day time photos. However, we have available those from the midnight hours.

The high ambient light levels also influenced the nephelometer. In spite of the shielding above the light beam, readings except during the night are severely contaminated by daylight. There were few storms of significance in 1979 which undoubtedly accounts for the water clarity. We will be examining meteorological records to see if 1979 was an unusual year or if August was simply an unusual month. During 1977 and 1978 diving operations by LGL at Milne Point were hindered by the murky water. In 1979 we could see the base of the tripod from a small boat. Nevertheless there were storm events that put small amounts of sediments into suspension. We describe these events in the following.

Observations

Figure 1, 2 and 3 show selected portions of the data gathered with the tripod along with winds for the month of August at Prudhoe Bay. The wind data was given to us courtesy of the personnel at the airport tower. Unfortunately they had already forwarded July wind data to NOAA. We show only the nighttime nephelometer data because the daytime data was daylight contaminated. We have not tried to detail the winds but rather to present the general pattern. This is because winds at Milne Point will be different except for the major events which have a large spatial scale. All temperature data is included as well as sea level when available. This study is preliminary as we wish to obtain better meteorological records before attempting explanations of specific features. Such data as needed is taken at Oliktok Point. However there is a time delay before the records are available. Selected bottom photographs are available with Dr. A. S. Naidu. We will reference these by the time (local Alaskan) that the photos were taken. Since the clock in photos was set on Seattle time, two hours need to be substracted from the times in the photographs. Due to time constraints in shipping, we were not able to correct the clock for the 30 day month of May. Accordingly, one day should be added to each of the dates shown in the photographs.

The largest storm event experienced occurred from 5 August to 7 August with winds from the ENE in the range of 20-25 knots at Prudhoe. The sea level rises in Simpson Lagoon approximately 30 cm during the storm. The water temperature drops from 7°C to 4.2°C as water from the Beaufort Sea is pushed into the Lagoon. Sediment concentrations rise during the storm from 5 percent of full scale to 11 percent of full scale. This was the greatest sediment concentration found during the observation period. Following the storm there is a gradual warming period of waters in the lagoon most likely due to radiative heating in the shoal reaches of the estuary. Currents were to the west during the storm.

That there is an inverse relation between temperature and sediment concentrations can be explained in several ways.

1. The incoming Beaufort Sea water picks up sediments as it passes through the east entrances to the lagoon. This sediment-laden water mixes with Simpson

Lagoon water slowly lowering the temperature and increasing the sediment concentrations.

2. Sediments are picked up by shore erosion in Simpson Lagoon, the concentrations increasing with time as a result of continued wave activity. Temperatures are lowered by the influx of clear Beaufort Sea water.

3. Little erosion occurs in Simpson Lagoon but the Beaufort Sea water entering the east end of the lagoon is sediment-laden. If this were the situation, we would see an abrupt increase in sediment concentrations when the Beaufort Sea water reached the tripod. We see a gradual increase.

The currents during such a storm are apt to be in the 30 cm/s range (Dygas, 1975). Given a 40 km length of the lagoon, it would take 1.5 days for water to traverse from the east end of the estuary to the tripod site. Temperatures begin to fall almost immediately with the start of the storm. This can only occur if water enters the lagoon through the island passes, and not only at the major channel on the east end of the lagoon. This water would pick up sediments in passing through the shallows. Thus there must be net erosion of the passes such as that between Pingok and Bodfish Islands.

Since the seaward beaches are pebble to boulder beaches, we expect that the major source of sediments would be just inside of the lagoon. That is, the landward side of the outer islands is eroded during an easterly storm. We cannot say for certain whether or not local erosion occurred at the tripod site.

If a reading of 11 percent on the nephelometer were to correspond to 3 mg/1, the currents were 30 cm/s and taking the cross section area of the lagoon at Milne Point as 6×10^3 m^2. There is a transport of 500 tons of sediment per day. This figure can be compared with the Colville River which during spring runoff may carry 2.7×10^5 tons/day.

The tripod was located nearer to the northern shore of the lagoon than to the south. Had we been located nearer to the southern shore the temperature decrease with the onset of the storm might not be seen as the Beaufort Sea water need not influence the entire basin. Then we would have seen warmer water with increasing sediment concentration reflecting erosion from the southern shors of the lagoon. The water clarity improved dramatically with the end of the storm indicating cessation of erosion. Temperatures remained low, thus we expect Beaufort water was still entering the lagoon. However, without wave activity, it must pass into the lagoon picking up little sediment.

A smaller wind event that followed on 10 and 11 August had little suspended sediments being brought in by Beaufort Sea water. Possibly the waves were less or the previous storm had already eroded the loose sediments. The temperature drop during this storm indicates a rapid influx on Arctic Ocean water.

On 20-22 August a storm with westerly winds in range of 20-23 knots influenced the lagoon. Water temperatures at the tripod site rose rapidly with the onset of the storm. Sediment concentrations increased only slightly. Current flow was easterly at the tripod. This storm, not that different in intensity from the early August storm, had a vastly different impact on the lagoon. Certainly if erosion took place in the deeper sections of the lagoon we would observe the sediment concentrations increase at the tripod. For easterly currents the water passing the tripod would have passed over deeper portions of the estuary.

Sea level was observed to rise from 30 July to 1 August, indicative of westerly winds. Water temperature dropped, indicative of Arctic water input to the lagoon. Yet, suspended sediments showed but minor increases in concentration. Why was this storm so different from the following storm on 5-6 August? When we get the wind data we will attempt to answer this question.

It is interesting to speculate on what might happen if the major channels at the east end of the lagoon were closed. Then a strong easterly wind would push water out of the lagoon lowering sea level at the east end. Sediments would still be eroded from the island passes. On cessation of the storm the water would start back into the lagoon with easterly flow. This water would contain suspended sediments that could be deposited at the east end of the lagoon. The present openings eliminate the return flow following a storm with easterly winds.

Our studies of the data and analysis will continue. This report is based on a firts look at the information and is therefore speculative. An important step will occur when we have models or hypotheses that can be compared with the sediment characteristic patterns that have been prepared by Naidu. We will also be able to place absolute numbers on the sediment concentrations following calibration procedures and analysis of samples taken in the summer of 1979. Table 2 contains a synopsis of the current direction, and temperature and nephelometer data. Clearer and warmer water flows to the east.

TABLE 2

Distribution of Flow Directions at 0/00 Each Day

Direction (T)	No. Obs.	Mean Nephelometer	Temp.
0 - 22.5	1	3.5	5.9
22.5 - 45	1	5.1	6.6
45 - 77.5	2	5.8	7.45
77.5 - 90	1	4.3	6.1
90 - 112.5	1	5.7	8.1
112.5 - 135	3	5.5	6.7
135 - 157.5	0		
157.5 - 180	0		
180 - 202.5	0		
202.5 - 225	1	8.4	8.0
225 - 247.5	0		
247.5 - 270	12	5.7	6.6
270 - 292.5	3	7.1	5.4
292.5 - 315	3	6.1	7.1
315 - 337.5	2	4.7	5.8
337.5 - 360	1	5.9	5.9

	Avg. Westerly Flow (247-360)	Avg. Easterly Flow (0-135)
Neph.	5.9	4.7
Temp.	6.3	6.9

Photo comments*

24 July	Follows a period of strong currents, bottom cloudy, compass barely visible
25 July	Compass barely visible, rising sea level and lowering temperature, probable east winds
26-29 July	Compass clearly visible
30 July	Compass barely visible
31 July	Compass barely visible, streamer visible
1-5 August	Clear water, no sediments on compass
6 August	Compass not visible
10 August	Compass visible
11-15 August	Cloudy periods, sediment on compass following events
16 August	Both streamer visible and moving, lower streamer ∿ 10 cm above bed, upper ∿ 30 cm
17 August	Bottom shows clearly, small bump shows to left of compass
18 August	Bump disappers between 0137 and 0337, possibly it was a worm
19 August-1 September	Clear water throughout period

*Underwater photographs of the Simpson Lagoon bottom may be obtained from A. S. Naidu, Institute of Marine Science, Fairbanks, Alaska.

APPENDIX C

Mr. Floyd Barker, Supervisor
Claim Department, Aetna Insurance Co.,
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Dr. Mr. Barker:

The sediment dynamics system (SDS) was constructed in 1975 and 1976 for the purpose of measuring the physical parameters such as waves and mean currents that are associated with the resuspension of sediments. Since 1977 the system has been operational and involved in a number of scientific programs. The total investment in the system in in excess of $200,000. Most of the funds were involved in the initial development program. The system employs the elements of an Intersil microprocessor, the Intercept Jr., for its basic operations control. The reason that a computer was included in the basic design is that flexibility in sampling techniques exists and that certain hardware problems may be coded into the software of the computer program. The result is a flexible instrument capable of evolving as the questions asked in different experiments vary. Unfortunately, or perhaps inevitably, certain of the components and technology available in 1975 no longer exist or have been superceeded with newer elements. An example is the A/D converter. The original converter is no longer manufactured. Newer low power computers are available which diminish the costs of wiring one's own electronics. The latter is however not without its pitfalls for one pays the price in the time spent in reprograming the software, an expensive proposition for a single device. The original pressure sphere was aluminum, 22" in diameter, and prohibitively expensive today. An alternative is a titanium sphere which was available in 1975 at a cost of $3,000. In considering the problems of reconstructing the system, we have adopted the following guidelines.

1. No change should be made in the basic control unit since this would constitute development costs above replacement of the original unit to 'as is' status.
2. The original pressure housing should not be replaced, rather the system be subdivided into units contained in less expensive pressure housings.

3. Substitution of unavailable components should be made with units of comparable price to the original.

The trade between developing hardware and the expenditure of funds for rewriting software has been made with the idea of reproducing the functional equivalent of the original system at the lowest cost possible.

Photographs of the original unit are shown in Appendix A. Picture 1 is the complete system ready for deployment. The sphere containing the electronics is partially hidden behind the buoyant spheres used in recovery. Upon acoustic command electronics inside the sphere fires explosives releasing the byoyant spheres in such a way that they surface with a line attached to the tripod. Figures 2, 3 and 4 in Appendix A show the electronics as it existed prior to its demise. The main wire board which houses the computer contains the three large white elements. The greenish colored cards contain the acoustic release electronics. The large capacitors are used with the strobe for the camera which is hidden beneath the base plate on which the electronics are fastened. The blue cards contain the basic oscillator or timing circuits, the analog to digital converter (A/D), and the driver card which couples the microprocessor to the sensors.

The tripod was used in Alaska in conjunction with the outer continental shelf program supported by NOAA, the National Oceanographic and Atmospheric Administration, for studies within the barrier island protected lagoon system. The latest deployment was made on September 20, 1979 in an area about 15 miles east of Prudhoe Bay and in 21 feet of water. The pressure housing leaked upon deployment resulting in salt water flooding of all electronics. When recovered the sealing rubber O-ring was in its proper place and all bolts were observed to be torqued to their proper amounts. Yet the sphere had leaked, destroying all of the components interior to the pressure housing. The sphere was a 22" diameter sphere held together with 6 bolts located equidistant around the circumference. We have not been able to determine why the sphere leaked nor if it leaked through the sealing ring. However, all indications are that the seal failed. Because of inclement weather we have not been able to reseal the pressure case and test it in the water. This will be done, however we feel that with the history of a leak the pressure housing cannot be trusted. The alternatives are to purchase a new housing at todays costs or to slightly modify the system and purchase pressure housings of lower cost. We have opted for the latter choice, and intend to accomplish this by isolating three portions of the original system. First the camera and flash are removed from the main instrument. These took up most of the volume of the original sphere. Second, the use of an independent release mechanism removes additional electronics from the sphere. As a result we can package the system with minimal redesign into three units contained in inexpensive cylinders. In 1975 spheres cost on the order of $3000, today we can build the smaller cylinders for about $3000. Given the inflation factors, the difference in cost is more than offset by a small increment in redesign. This change saves more than $600 in replacement cost. Titanium has doubled in price in the last month.

The photographs in Appendix B show the damage that occurred to the electronics. Much of the goop in the pictures is from the water sogged batteries.

System Components

1. Main computer board: This is an Augat wire wrap board. It is machine wired with instructions to the machine contained on punched cards. The wiring is done at the Applied Physics Laboratory of the University of Washington. The cost is about $500 for the 896 different connections that must be made. The components on the board are the microprocessor, the memory elements, and associated interfacing elements. These cost $400. The board itself costs $200.
2. Oscillator card: This board contains the crystal oscillator ($200) which controls the timing for the instrument and some additional components of cost ($100). It is wired by hand.
3. Driver card: This board contains about $100 worth of electronic components and serves as the power source for operating the various sensors. It is wired by hand.
4. Analog card: This board contains the A/D converter and miscellaneous electronics. The original A/D converter cost $845, however it is no longer manufactured. We have found a replacement for $250. Other components on the board total $75. This board is wired by hand.

5. Camera: The camera is an oscilloscope camera purchased surplus from B&F Enterprizes in Massachusetts for $200. It has a data frame in which we insert a watch ($50) to provide time in each photograph. Electronics to operate the camera will cost about $130. In the reconstruction we will put the camera into its own pressure case made from a 12" diameter aluminum cylinder.

6. Tape recorder: The unit used is made by Memodyne and is a low power digital cassette recorder ($700).

7. Pressure sensor: The pressure sensor is made by Paroscientific Inc. located in Redmond, Washington. The sensor costs $1950, and the shock mounting $85. This is the most expensive single element in the SDS system.

8. Pressure cases: These will be made at the University of Washington with about $400 of material in each case. This is a far less expensive alternative than the large sphere which would cost $3000 at least.

9. Chasis construction: In order to mount the electronics we will construct a structure to support the circuitry. Material costs are small on the order of $130. Repair of the frame will cost $200.

10. Release: The original system employed the electronics used in an AMF accoustic release. This is an expensive unit. However there is a less expensive alternative on the market which we will explore. One unit is being purchased by the Department of Oceanography for $850. We will test this unit and if successful we will use it in the SDS system. It will be necessary to build a pressure case for this unit since, as it comes, it can only be used in shallow water, less than 30 m. Alternatives are the Helle release at $2700 and the AMF unit which is in excess of $5000. We list $1500 for this item.

The following is an estimate of costs that will be incurred. Depending on problems of procurement or problems occurring in assembly, actual costs will differ from these estimates.

Major Components			
Pressure sensor	1950		
Shock mount	85		
Camera	200		
Release	1500		
Chassis	130		
Frame	200		
Watch	50		
Oscillator	200		
A/D converter	250		
Driver card	100		
Tape recorder	700		
Wire wrap board IC's	400		
Wire wrap board	200		
Rechargable batteries	250		
Water tight connectors	400		
Cables	300		
Miscellaneous electronics	600		
Pressure cases (3)	1200		
Shop costs	200		
Total		8915	
Taxes		600	
Labor*			
Pressure cases	2000		
Electronic Engineer	1500		
Programing Consultant	600		
Assembly	800		
Wire wrapping	500		
Total		12600	
Grand total			23010

The labor anticipated is 15 days to make the pressure cases, and 48 hours of electronic engineer time. The electronic engineer is used for consultation and to aid in testing circuits once they have been wired. The programing consultant is needed to modify the software to eliminate the camera from the computer program. This is done in machine language. The assembly will be done by a student working half-time over the next six months.

*costs include University overhead.

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Research Unit #531
Reporting Period: 1 April 1979 - 31 May 1980

Annual Report

J. C. H. Mungall

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August 1980

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Diffusion experiment:
- Phil Carpenter — KLI
- Dan Hansen — Oceanographic Services, Inc.

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- Peter Wilde — KLI

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- Dale Harber — KLI
- Steve Pace — KLI
- Howard Teas — KLI

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- Tom Kozo — Polar Science Center, University of Washington

Report Preparation:
- Deborah Tuel — KLI

Particular thanks are due to the Helmericks family of Colville Village, Alaska, for their hospitality and advice, and to personnel of the Naval Arctic Research Laboratory for their assistance with radio communications.

PRUDHOE BAY DIFFUSIVITY MEASUREMENTS

Introduction

A precision small scale drifter tracking experiment was conducted in Prudhoe Bay (see Figure 1) during the summer open water season on 25 August 1979. The objective of the experiment was to determine values for the eddy diffusion coefficients as needed for realistic diffusion modeling. Due to weather and logistic constraints, only half a day was available for actual tracking. Although this did not reduce the validity of the results, since after a certain period of time inhomogeneity sets in, it meant that the experiment was not repeated.

Experimental Procedure

Nine drifters were constructed using 20 ft^2 sails, weighted at the bottom. Weights were adjusted so that a minimum of float area was presented to the wind. Identification flags were used in order that the position of each drifter could be determined uniquely. A Motorola Miniranger radar frequency range-range system was used, with transponders being placed as high as possible on the operations building on the end of the ARCO West Dock (70° 24.02' N, 148° 31.6' W), and on a tower on Heald Point (70° 20.86' N, 148° 12.2' W). Height and aiming problems resulted in a maximum effective range of about 12000m.

The drifters were deployed initially at 1630, 25 August 1979 in 18 ft of water in the approximate form of a cross. The initial separation between drifters was of the order of 40 m. The initial centroid location was at 70° 25.57' N, 148° 14.62' W. The drifters were visited at hourly intervals, with ranges being obtained from the Miniranger as the boat passed by each drifter at low speed. The experiment continued for some 5 hours, after which time the drifters had moved sufficiently far to the west so that the Heald Point transponder no longer provided a range reading.

Winds

Winds at Cottle Island (as provided by Tom Kozo of the Polar Science Center, University of Washington), as shown in Table 1, were primarily from the south-east and south-south-east over the measurement period. The average velocity was 11.5 mph from 150°. Prior to the measurement the wind had been blowing from the north-west for some 9 hours.

Date	Hour Alaska Time	Direction (From) Degrees True	Speed Miles Per Hour
25 Aug. 1979	0000	130	14.5
	0300	130	18.0
	0600	130	20.5
	0900	280	11.5
	1200	300	16.5
	1500	340	3.0
	1800	130	9.5
	2100	160	12.5
26 Aug. 1979	0000	190	8.0
	0300	200	8.5
	0600	120	7.5

Table 1. Cottle Island Winds.

Analysis

The data were analyzed following the methods of Okubo et al. (1976) and Ichiye et al. (1978). The range-range position data were converted first to latitude and longitude (using spherical trigonometry) and then to localized cartesian coordinates. Variances σ_x^2, σ_y^2 and covariances σ_{xy} were then computed. From these values major and minor ellipse semi-axes lengths σ_x^2 and σ_y^2, were computed by rotation such that σ_{xy} vanished.

It was found that two drifters, 4 and 9, appeared to move somewhat anomalously. Calculations were therefore made with all 9 drifters and with drifters 4 and 9 excluded. Figures 2 and 3 show the general movements of the centroids, along with the computed ellipses. Figures 4 and 5 show similar ellipse formation on a larger scale, and also show the individual drifter locations. It is at once apparent that the dispersion tends to be greatest approximately in the direction of the current.

The computed data are summarized in Tables 2 through 5. In addition to separate computations being made for the entire group and for the entire group less drifters 4 and 9, computations were repeated using all 5 times, and then with the first time excluded. The tables show the data used in drawing Figures 6 and 7. The major and minor ellipse axes are a and b, respectively. The methods developed by Okubo and others involve the computation of diffusivities based on the slopes of the lines formed by the various sets of points: the set $a^2/4$ yielding the eddy diffusivity K_x, $b^2/4$ yielding Ky and ab/4 yielding the mean eddy diffusivity $\bar{K}$.

The resulting eddy diffusivities are shown below in units of $10^4 cm^2/sec$.

	5 groups		last 4 groups	
	all drifters	less 4 & 9	all drifters	less 4 & 9
Kx	1.99	1.550	2.31	1.890
Ky	0.74	0.078	0.84	0.053
$\bar{K}$	1.22	0.400	1.40	0.440

Conclusions

In general, the order of magnitude of the computed eddy diffusivity is $10^4 cm^2/sec$, with numbers ranging from $0.05 \times 10^4 cm^2/sec$ to $2.31 \times 10^4 cm^2/sec$. Although these may seem small when compared to oceanic values, the values are consistent with the length scales (separation between drifters) involved. The four-thirds power law of Ichiye and Olsen (see Hill (1962), p. 819) is:

$$F(\ell) = 0.02461 \ell^{4/3},$$

where ℓ is the neighbor separation in centimeters and $F(\ell)$ is the diffusivity in centimeters squared per second. On substituting typical separation limits, $50 \times 10^2 cm$ and $500 \times 10^2 cm$, one obtains respectively $0.2 \times 10^4 cm^2/sec$ and $4.5 \times 10^4 cm^2/sec$ -- values consistent with measured values.

If one selects the calculations made with drifters 4 and 9 excluded, the eddy diffusivities based on the 5 groups are: approximately $1.55 \times 10^4 cm^2/sec$ for the major axis; $0.078 \times 10^4 cm^2/sec$ for the minor axis; and $0.40 \times 10^4 cm^2/sec$ for the overall eddy diffusivity. The values for the two axes are consistent with a major axis to minor axis length ratio of 4.5, as can be seen in Figure 3. The major axis lies approximately along the trajectory formed, with the direction and eccentricity being related to current shear.

In the absence of additional experimental evidence, it is suggested that use be made of the pronounced diffusion tendency discussed above. In particular in trajectory simulations, a Monte Carlo technique might be used in which a quasi-random offset is computed for each particle. The probabilities would be based on two distributions, one related to $K_x = 1.55 \times 10^4 cm^2/sec$ in the general current direction, and $K_y = 0.078 \times 10^4 cm^2/sec$ perpendicular to the current direction.

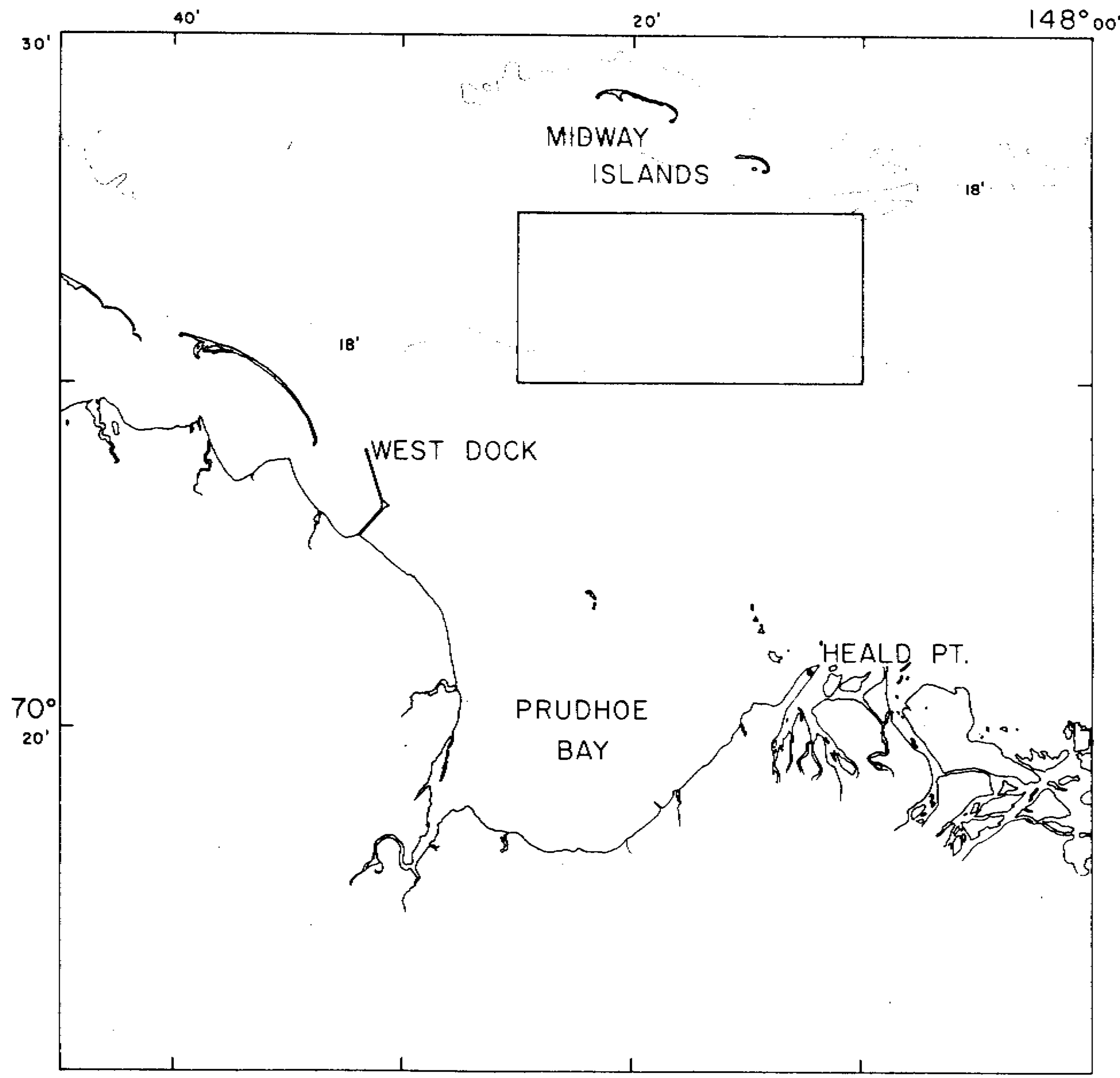


Figure 1. Prudhoe Bay diffusivity measurement location map.

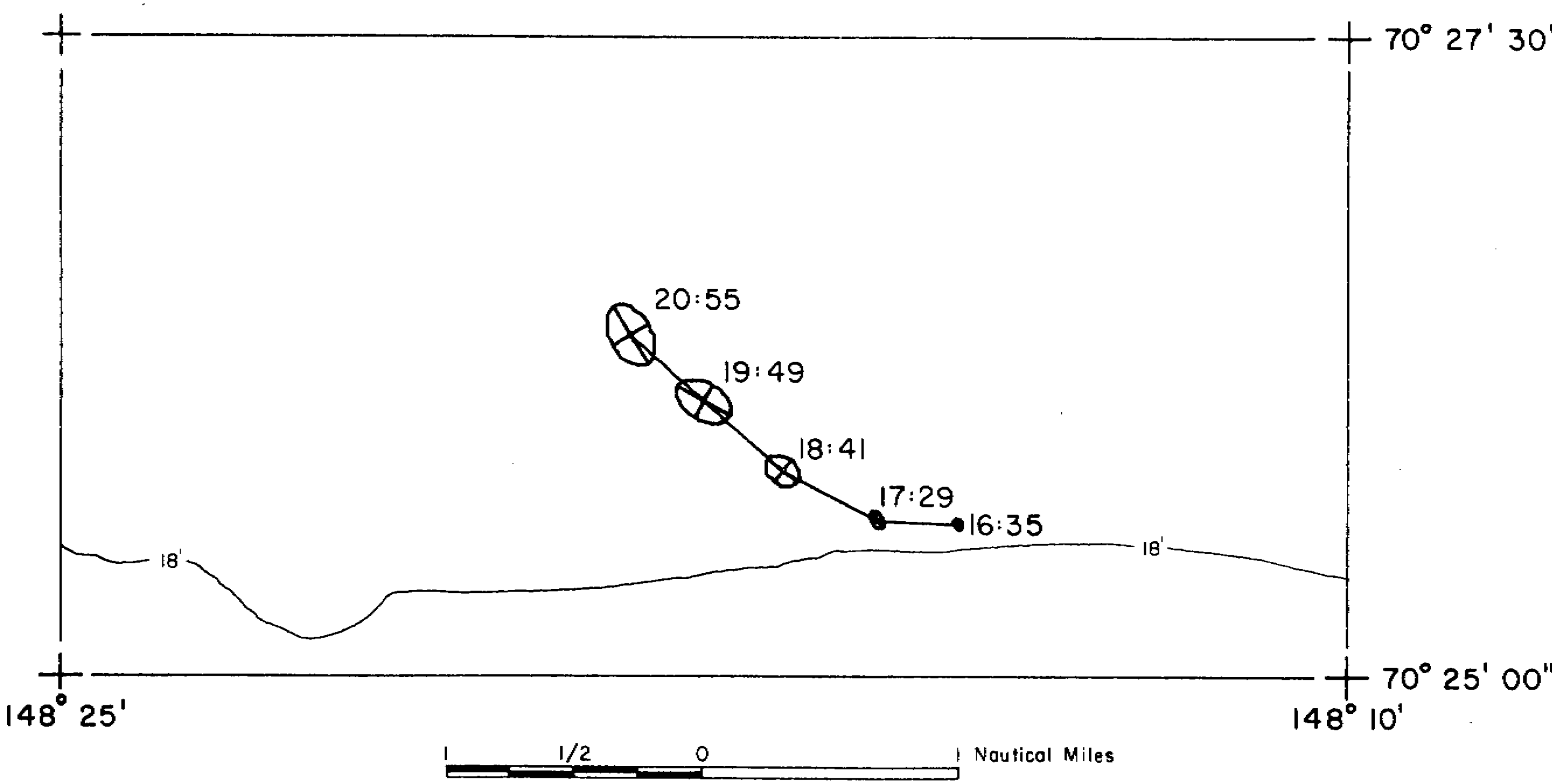


Figure 2. Ellipses and mean times (25 August 1979) of drifters 1 - 9. Boundary corresponds with that shown in Figure 1.

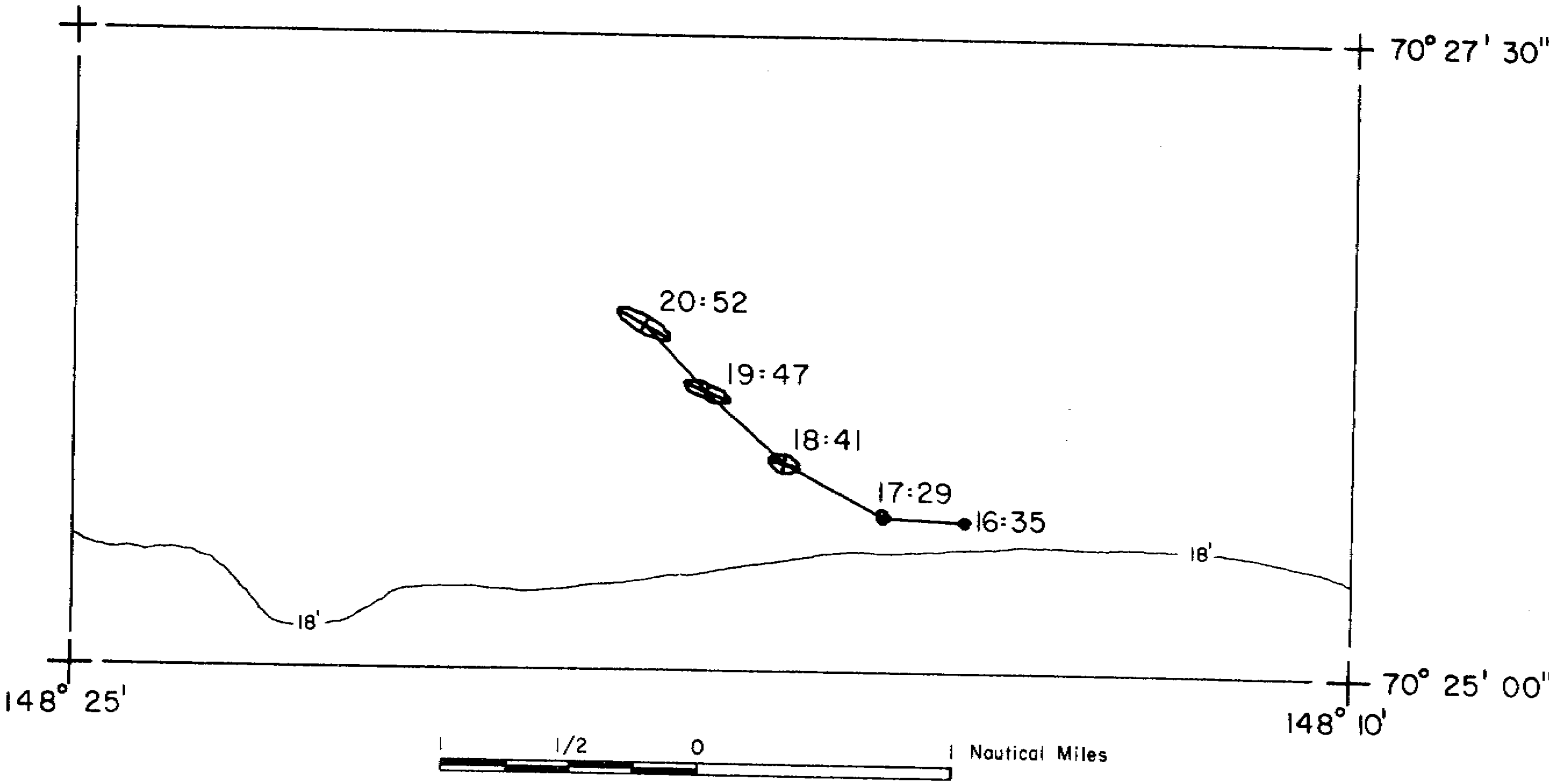


Figure 3. Ellipses and mean times (25 August 1979) of drifters with 4 and 9 excluded. Boundary corresponds with that shown in Figure 1.

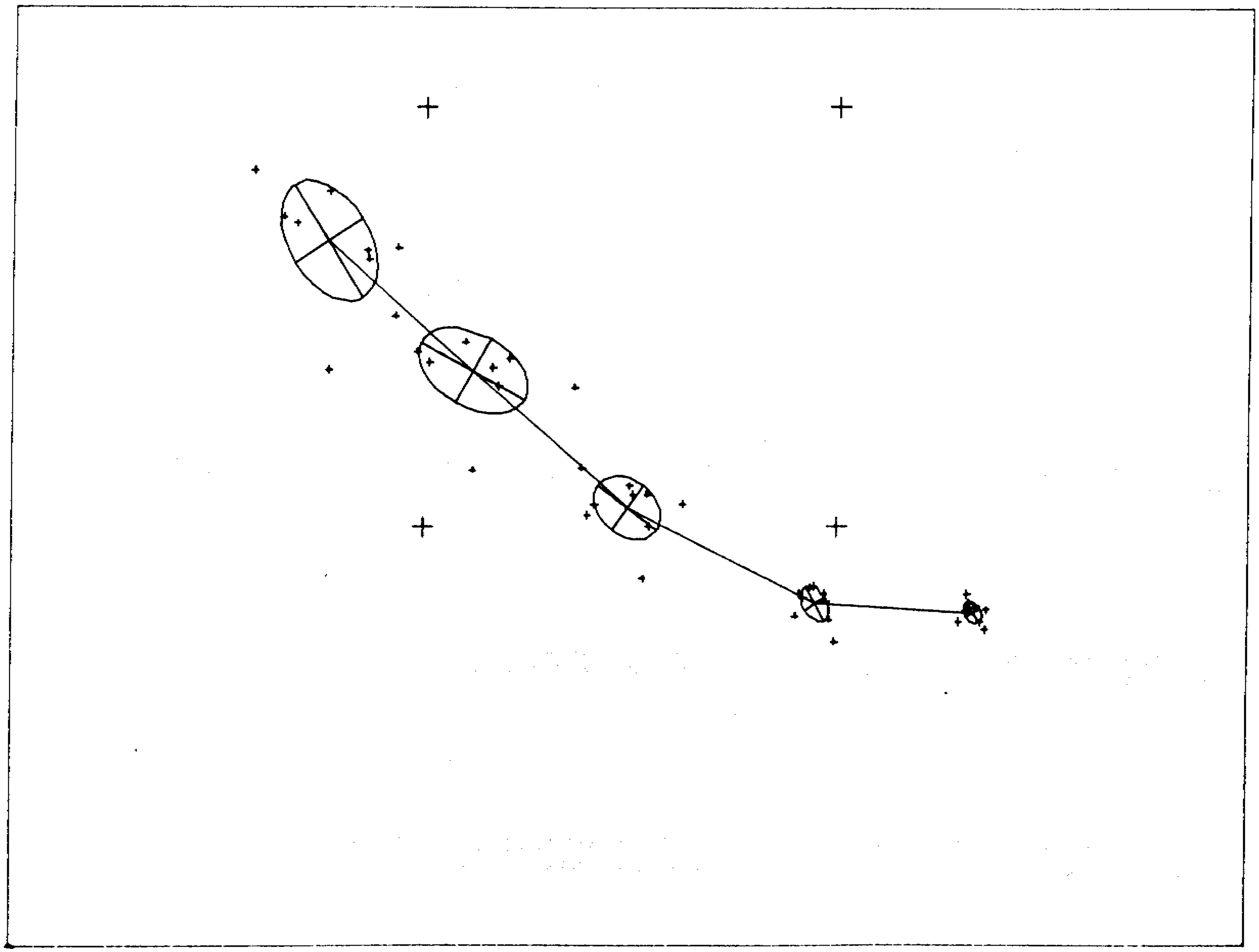


Figure 4. Enlarged drifter location map (all drifters); 5000 ft between large crosses.

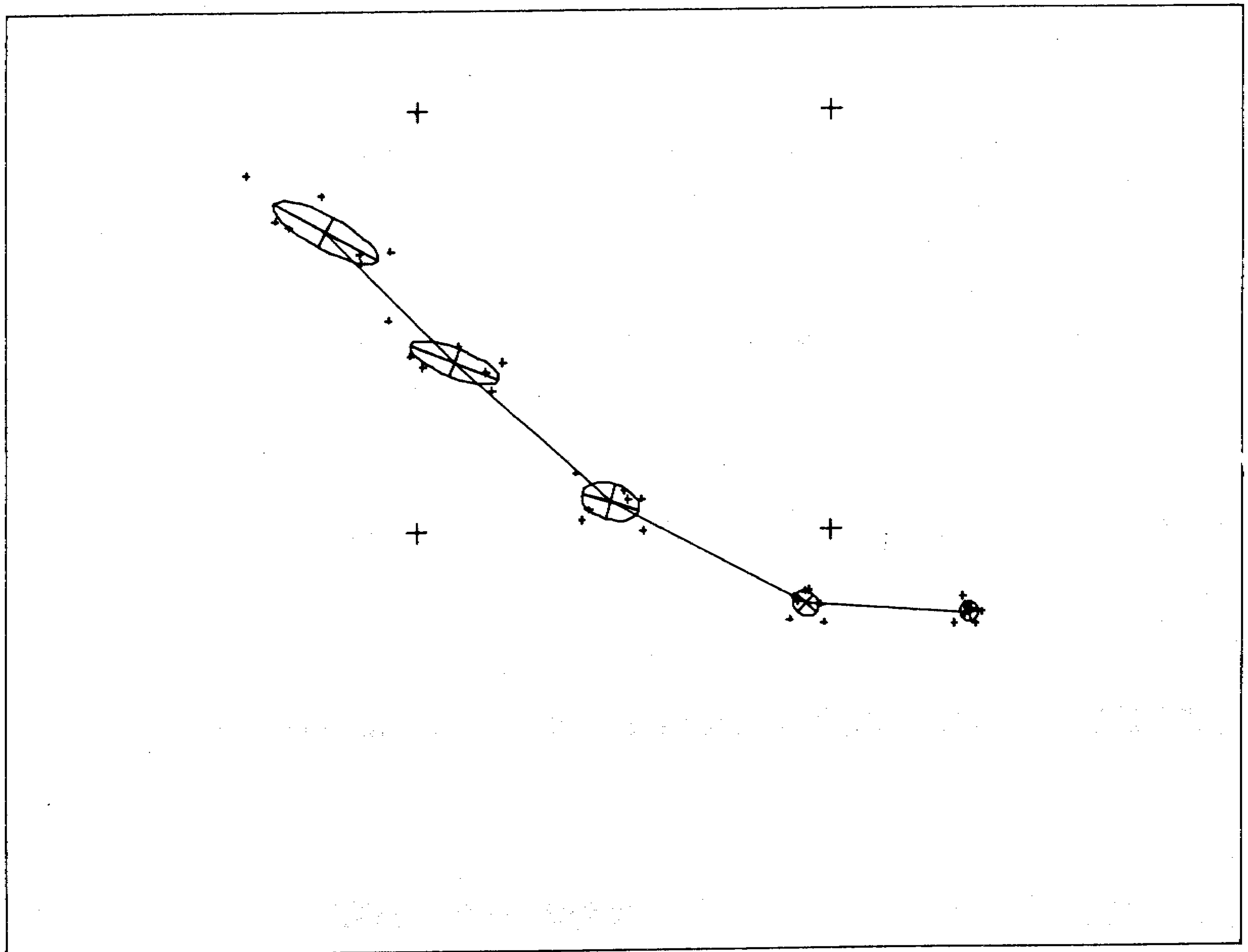


Figure 5. Enlarged drifter location map (with drifters 4 and 9 excluded): 5000 ft between large crosses.

Table 2

Mean times - all drogues
5 groups

Time hours	Major Axis a m	Minor Axis b m	$a^2/4$ m^2	$b^2/4$ m^2	$ab/4$ m^2
0.0	84.0	59.9	1764	897	1258
0.9074	144.2	84.2	5198	1772	3035
2.0963	274.3	197.8	18810	9781	13564
3.2297	437.3	266.3	47808	17729	29113
4.3297	484.5	297.5	58685	22127	36035

x in seconds

$a^2/4 = -3841 + 3.98314x$

$b^2/4 = -850 + 1.48711x$

$ab/4 = -1916 + 2.43465x$

slopes: $\frac{1}{2}\frac{d}{dt}(\sigma x^2) = 1.99 \times 10^4 cm^2/sec$

$\frac{1}{2}\frac{d}{dt}(\sigma y^2) = 0.74 \times 10^4 cm^2/sec$

$\frac{1}{2}\frac{d}{dt}(\sigma x \sigma y) = 1.22 \times 10^4 cm^2/sec$

Table 3

Mean times - less drogues 4 & 9
5 groups

Time hours	Major Axis a m	Minor Axis b m	$a^2/4$ m^2	$b^2/4$ m^2	$ab/4$ m^2
0.0	73.1	66.2	1336	1096	1210
0.9143	102.3	85.8	2616	1840	2194
2.1143	222.9	129.0	12421	4160	7189
3.2119	349.3	106.2	30503	2820	9274
4.2952	436.6	121.4	47655	3684	13251

x in seconds

$a^2/4 = 4545 + 3.09176x$

$b^2/4 = 1529 + 0.15692x$

$ab/4 = 566 + 0.79863x$

slopes: $\frac{1}{2}\frac{d}{dt}(\sigma x^2) = 1.55 \times 10^4 cm^2/sec$

$\frac{1}{2}\frac{d}{dt}(\sigma y^2) = 0.078 \times 10^4 cm^2/sec$

$\frac{1}{2}\frac{d}{dt}(\sigma x \sigma y) = 0.40 \times 10^4 cm^2/sec$

Table 4

Mean times - all drogues
last 4 groups

Time hours	Major Axis a m	Minor Axis b m	$a^2/4$ m^2	$b^2/4$ m^2	$ab/4$ m^2
0.0	95.5	76.5	2280	1463	1826
0.9074	164.5	56.9	6765	809	2340
2.0963	361.5	177.8	32671	7904	16069
3.2296	398.8	239.5	39760	14340	23878
4.3083	426.1	302.5	45390	22877	32224

x in seconds

$a^2/4 = -11255 + 4.61559x$

$b^2/4 = -3159 + 1.68410x$

$ab/4 = -6114 + 2.79275x$

slopes: $\frac{1}{2}\frac{d}{dt}(\sigma x^2) = 2.31 \times 10^4 cm^2/sec$

$\frac{1}{2}\frac{d}{dt}(\sigma y^2) = 0.84 \times 10^4 cm^2/sec$

$\frac{1}{2}\frac{d}{dt}(\sigma x \sigma y) = 1.40 \times 10^4 cm^2/sec$

Table 5

Mean times - less drogues 4 & 9
Last 4 groups

Time hours	Major Axis a m	Minor Axis b m	$a^2/4$ m^2	$b^2/4$ m^2	$ab/4$ m^2
0.0	76.7	64.7	1471	1047	1241
0.9143	111.2	80.6	3091	1624	2241
2.1143	242.1	120.8	14653	3648	7311
3.2119	380.6	99.5	36214	2475	9467
4.2952	475.2	115.5	56454	3335	13252

x in seconds

$a^2/4 = -12471 + 3.77261x$

$b^2/4 = 2114 + 0.10670x$

$ab/4 = -303 + 0.87325x$

slopes: $\frac{1}{2}\frac{d}{dt}(\sigma x^2) = 1.89 \times 10^4 cm^2/sec$

$\frac{1}{2}\frac{d}{dt}(\sigma y^2) = 0.053 \times 10^4 cm^2/sec$

$\frac{1}{2}\frac{d}{dt}(\sigma x \sigma y) = 0.44 \times 10^4 cm^2/sec$

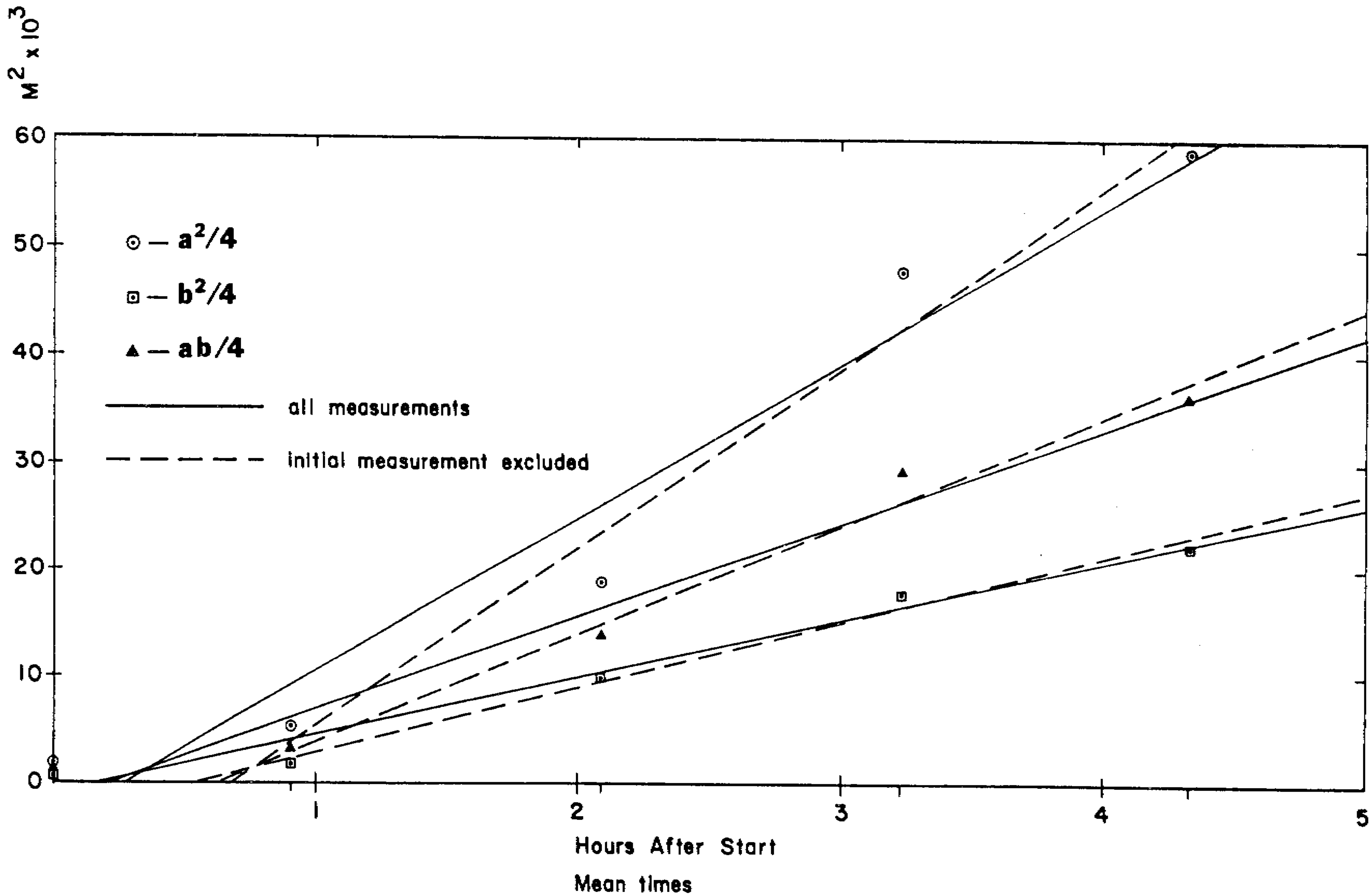


Figure 6. Variances computed using all drifters.

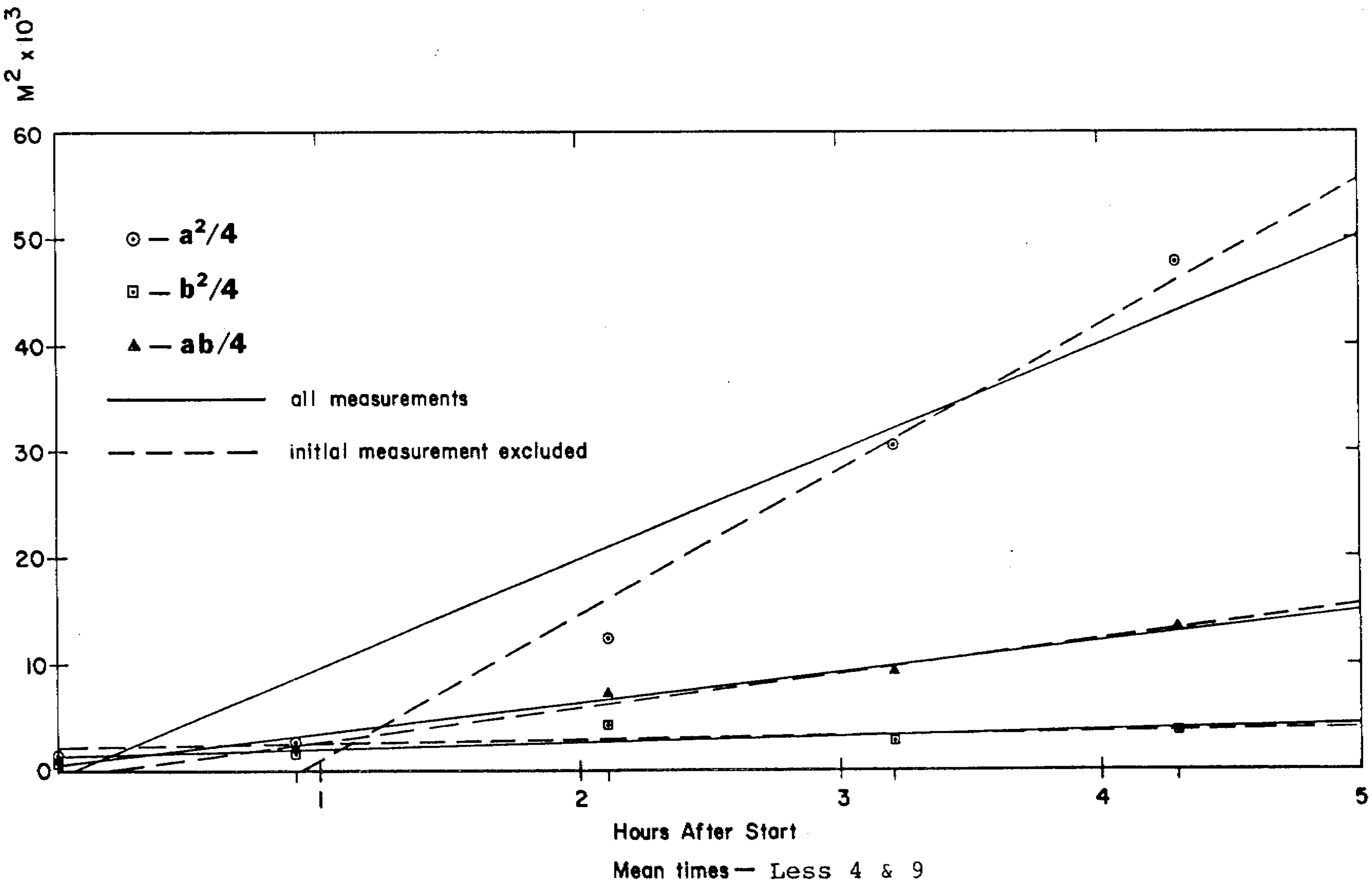


Figure 7. Variances computed using all drifters less 4 and 9.

CAUSEWAY EFFECTS: THEORETICAL STUDIES

1. Introduction

This section is concerned primarily with theoretical aspects of causeway effects, measurements in Prudhoe Bay during the 1979 open water season having been restricted to an eddy diffusion coefficient study. Furthermore the section is restricted to physical oceanographic topics. The limited studies discussed here include brief comments on the likely effect of causeways in the light of classical hydromechanics theory and include a summary of the results of a one-month numerical modeling effort aimed at studying currents around causeways of simple shape.

One of the principal ways in which theoretical physical oceanography can assist causeway studies is in the determination of the likely extent of the region of influence, and the approximate nature of the flow. An obvious first approach is to make use of the solutions for flow around objects of cylindrical or other simple shape that exist already in hydrodynamics publications. Unfortunately the effect of surface forces, such as local wind, is normally ignored, and the results must be used with caution. When this approach has been taken to its limits, recourse can be had to hydrodynamic models tailored to the problem on hand. This latter approach offers great flexibility but can result in incorrect solutions due to numerical errors associated with the finite-difference equation formulations. As always the modeling should be supported by field measurements whenever possible.

2. Flow Around Half-Cylinders and Other Objects of Simple Shape

As is customary when investigating flow problems, a preliminary step is to evaluate the likely magnitude of the Reynolds number. Measurements in Prudhoe Bay conducted in the summer 1979 open water season resulted in eddy diffusion coefficients (associated with a length scale of 500 m) to be of the order of 10^4 cm^2/s. In the absence of any other measurement this value will be taken as being indicative of the eddy viscosity coefficient. The small number, when compared to open ocean values, is probably related to the four-thirds power law of Ichiye and Olsen (see Hill (1962), p. 819). The formula quoted is

$$F(\ell) = 0.02461\ell^{4/3},$$

where ℓ is neighbor separation in centimeters and $F(\ell)$ is the diffusivity in centimeters squared per second. A value for ℓ of 5×10^4 cm yields a value for $F(\ell)$ of about 5×10^4 cm^2/s; when ℓ is increased to 5×10^5 cm (5 km), $F(\ell)$ increases to 10^6cm^2/s.

The appropriate formula for the Reynolds number, R, is

$$R = \frac{U \times \ell}{\nu},$$

where U, ℓ, and ν are, respectively, appropriate values of current, length scale, and kinematic viscosity. If one selects ℓ as 5 km, U as 0.15 m/s (found by taking one three-hundredths of the prevailing wind speed of about 5m/s), the following values result for various viscosities:

Eddy viscosity ν, cm^2/s	Reynolds number R
10^4	750
10^5	75
10^6	7.5

The range of R thus likely to be encountered covers the region from where flow ceases to be governed primarily by viscous forces, to where the flow around an object results in alternating vortices or other complex flow forms. Since a considerable body of literature exists concerning flow around cylinders, half cylinders and various bluff objects, attention will be restricted to the range $1 < R < 500$, thus covering the most likely situations to be expected.

Flow around a half cylinder

An idea of the flows typical in the region $5 \leq R^* \leq 100$ can be seen in a series of figures obtained numerically by Dennis and Chang (1970). (See also section 4.12 in Batchelor (1970) for actual photos.) Below R=7 the flow is of the viscous type, with no backflow occurring in the lee of the cylinder. At R =7 an eddy complete with back-flow forms. (In the literature one also encounters the words "vortex" and "wake bubble".) The appearance of the eddy is shown schematically in Figure 8, along with some characteristic lengths.

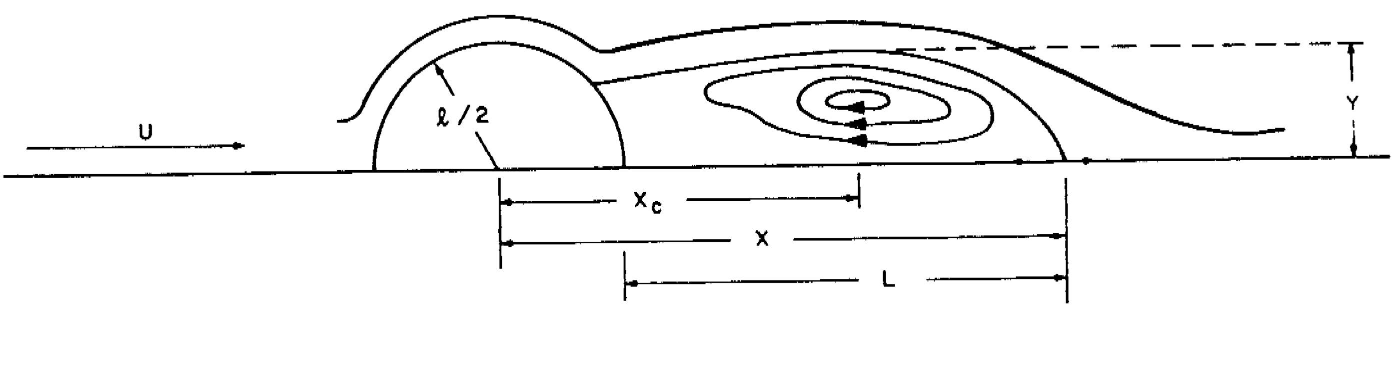


Figure 8. Eddy with characteristic lengths used in the text.

* Where R for a cylinder is taken as U x 2 x radius/ν.

As R increases the length of the eddy L grows approximately linearly with R. Along with this increase is a corresponding increase in the X_c (equal to less than X/2), along with an increase in Y that at R=100 is approximately equal to $\ell/2$. The length of the wake L increased linearly from 0.19r at R=7 to 13.11r, where r is the radius ($r=\ell/2$) at R=100. Experimental figures for flow around a half cylinder (Acrivos and others, 1968) yield a relationship $X/\ell \approx 0.065$ R for $20 < R < 100$, which agrees well with the numerical solution method. X_c/X was found to be approximately equal to 1/3 (where X_c and X are now measured from the back of the cylinder).

The width of the eddy is approximately equal to the radius of the cylinder, and was found experimentally by Acrivos and others to be of the order of 1.25r for a half cylinder.

Information on the back-flow velocity in the eddy has been found experimentally by Grove and others (1964) using a full cylinder and splitter plate. The maximum back-flow velocity increased with increasing R to 0.23U, where U is the undisturbed far-field velocity. The value 0.23U was reached at about R=200. Of interest is the rate of growth of the eddy; this is covered in Son and Hanratty (1969).

Flow around bluff objects

Experiments on the flow around objects such as thin plates extending perpendicular from a straight side are described by Acrivos and others (1968). The range covered was $20 < R < 140$. Their first experiments were a repeat of Grove and others, but with a flat plate instead of a cylinder. The limiting backflow velocity was found to be approximately 0.17 of the background velocity.

Acrivos and others (1968) also describe flow around a backward facing step.(See Figure 9 for characteristic lengths.)

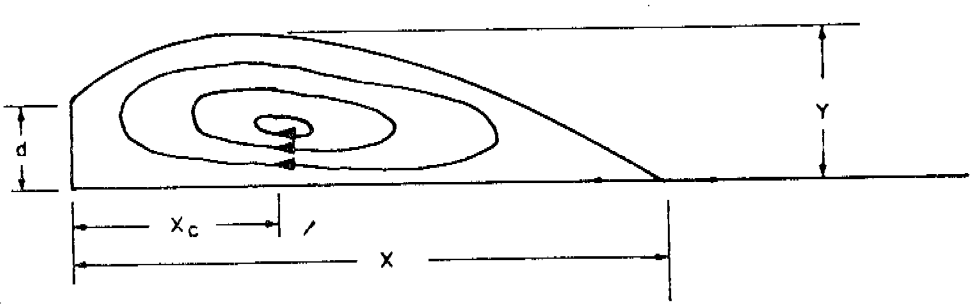


Figure 9. Eddy formed in lee of backward facing step.

Xc/X is again approximately equal to 1/3, Y/d is approximately equal to 2 in the limit, and X/d=0.357 R where $R=Ud/\nu$. It thus appears that the wake length is more than 1.25 times that of a half-cylinder of r=d, if one uses ℓ=r when computing the Reynolds number for the cylinder. The same paper goes on to provide some information concerning the velocity field external to the eddy, and then includes some results on confined cavities.

Existence of an eddy

Seemingly of importance is an understanding of the mechanism responsible for the growth and maintenance of eddies. Elementary textbook theory takes the following approach for the formation of an eddy (Whitaker, (1968), p. 448):

The objective is to determine the conditions under which separation takes place.

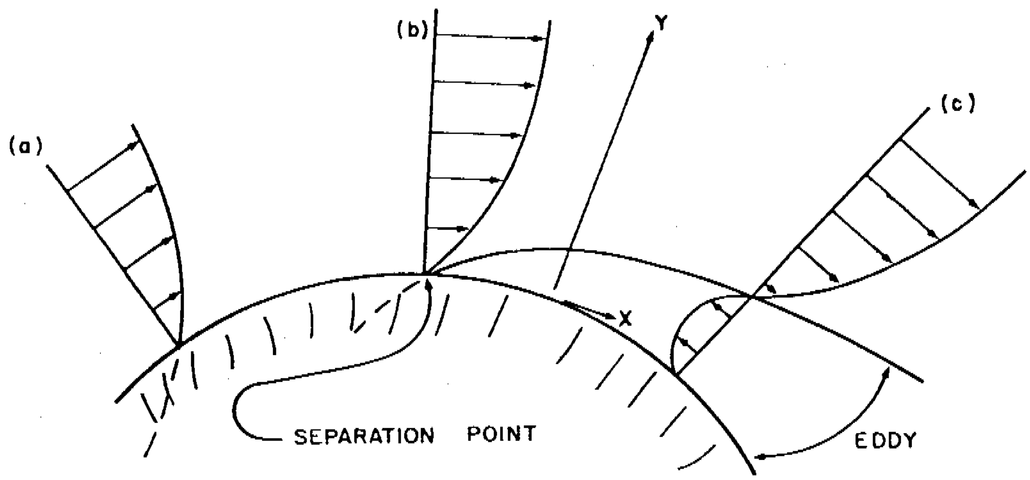


Figure 10. Separation of laminar boundary layer from a cylinder (Whitaker, 1968).

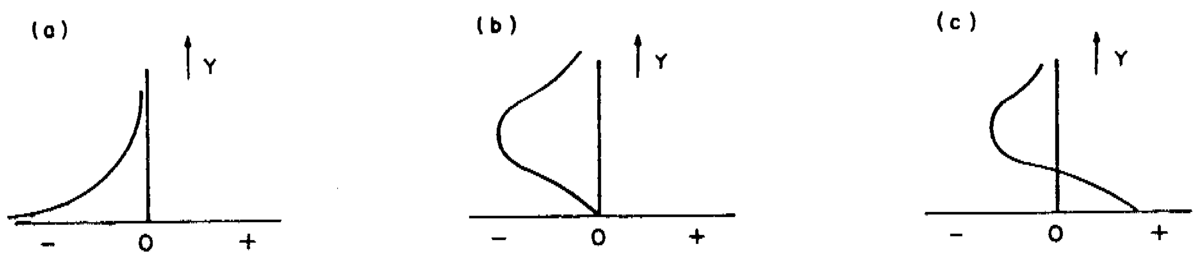
Taking local coordinates as in Figure 10, we have for the x-axis (where the variables are as traditionally used, and F_x is a surface force):

$$P\left(v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_y}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 v^2 x}{\partial x^2} + \frac{\partial^2 v^2 y}{\partial y^2}\right) + F_x \quad .$$

At a solid surface V_x and V_y are zero, so approximately,

$$\frac{\partial p}{\partial x} - F_x = \mu \frac{\partial^2 v_x}{\partial y^2}$$

If one examines $\frac{\partial^2 v_x}{\partial y^2}$ for cases (a), (b), and (c) one finds that it has the following forms:



$$\frac{\partial^2 v_x}{\partial y^2} \qquad \frac{\partial^2 v_x}{\partial y} \qquad \frac{\partial^2 v_x}{\partial y^2}$$

At the point of separation $\frac{\partial^2 v_x}{\partial y^2}$ is zero, and becomes negative for back-flow. The pressure gradient term and the external force F_x must, as a whole, be negative for an eddy to exist. It is for this reason that one requires a point of low pressure on the downstream face of the cylinder. It is suspected that with small back currents and a local wind force, the term $(\frac{\partial^2 v_x}{\partial y^2} - F_x)$ may not be able to become positive, so that the formation of an eddy is less likely.

A more detailed analysis of the situation could probably be arrived at following the arguments of Batchelor (p. 257 ff, 1970), or could be investigated via an inspection of the magnitude of the various terms in the finite-difference equations of an appropriate numerical model.

3. Numerical Studies of Idealized Causeways

In this section are described the results of a month's numerical modeling study as to the effect of idealized causeways on locally wind-driven currents. The causeways were composed of rectangular elements arranged in a manner suggestive of, but not similar to, the ARCO Prudhoe Bay causeway.

Model Geometry

The model used was a two-dimensional (depth-mean) model with a grid consisting of 22 x 45 rectangles, each 1000 ft x 1000 ft in size (Figure 11). The right-hand side of the model consisted of solid land, with a simulated barrier island lying 4000 ft offshore. The following causeway shapes were studied:

1) a
2) a+b
3) a+b+c
4) a+b+d
5) a+b+c+e.

In the first set of runs, the water depth below mean sea level was a constant 5 ft; in the second set of runs (made with causeway types (1) and (5), depths increased in 1 ft intervals from 1 ft to 21 ft.

Equations

The U.S. Army Corps of Engineers' model (Reid and others, 1977) was extended for this study so as to include convective acceleration and Coriolis acceleration terms, along with lateral eddy viscosity terms:

$$\frac{\partial U}{\partial t} + \frac{\partial uU}{\partial x} + \frac{\partial vU}{\partial y} = fV - gD\frac{\partial H}{\partial x} + Twx - Tbx + \varepsilon\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right)$$

$$\frac{\partial V}{\partial t} + \frac{\partial uV}{\partial x} + \frac{\partial vV}{\partial y} = -fU - gD\frac{\partial H}{\partial y} + Twy - Tby + \varepsilon\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right)$$

$$\frac{\partial H}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = R \quad ,$$

where:

H = surface elevation above mean sea level
U,V = x and y components of flow rate per unit width
u,v = x and y current components
D = water depth
Tw,Tb = wind and bottom stress
ε = lateral eddy viscosity coefficient
R = rainfall rate,
and the remaining constants are as traditionally used.

Boundary Conditions

1) on open boundaries: no change of normal component of current with distance (i.e., flow-through conditions).

2) on solid boundaries: a) normal current component equals zero, b) no change of lateral current component with distance (free slip).

3) surface stress: wind of 17.5 ft/s (≈12 mph) directed along shore towards barrier island.

Run descriptions

All runs were computed for 30 hours of real time. In the constant depth case, the time step was 45 sec, in the variable depth case the time step was reduced to 22.5 sec. To speed up convergence to a steady state, winds and friction were tapered over the first two hours. Heights, flow rates and currents were printed every 5 hours, and the final heights and flow-rates were written on disc for further processing. Tests were run both with lateral eddy viscosity coefficients of 10 ft^2/s (as measured in Prudhoe Bay in the summer of 1979), and 0.1 ft^2/s -- the latter value being used in an attempt to increase the likelihood of eddies.

Displays

Two types of display were produced for each run: current vectors and trajectories. (These are shown combined in Figures 12 through 18.) In the former, the length of the arrow (from the "+" sign denoting the location of the current, to the tip of the arrow) indicates the strength of the current. Since the "+" sign may not show up in reproductions, care should be taken not to confuse the arrow head size with the current magnitude; this is only likely to be a problem in the lee of the causeway.

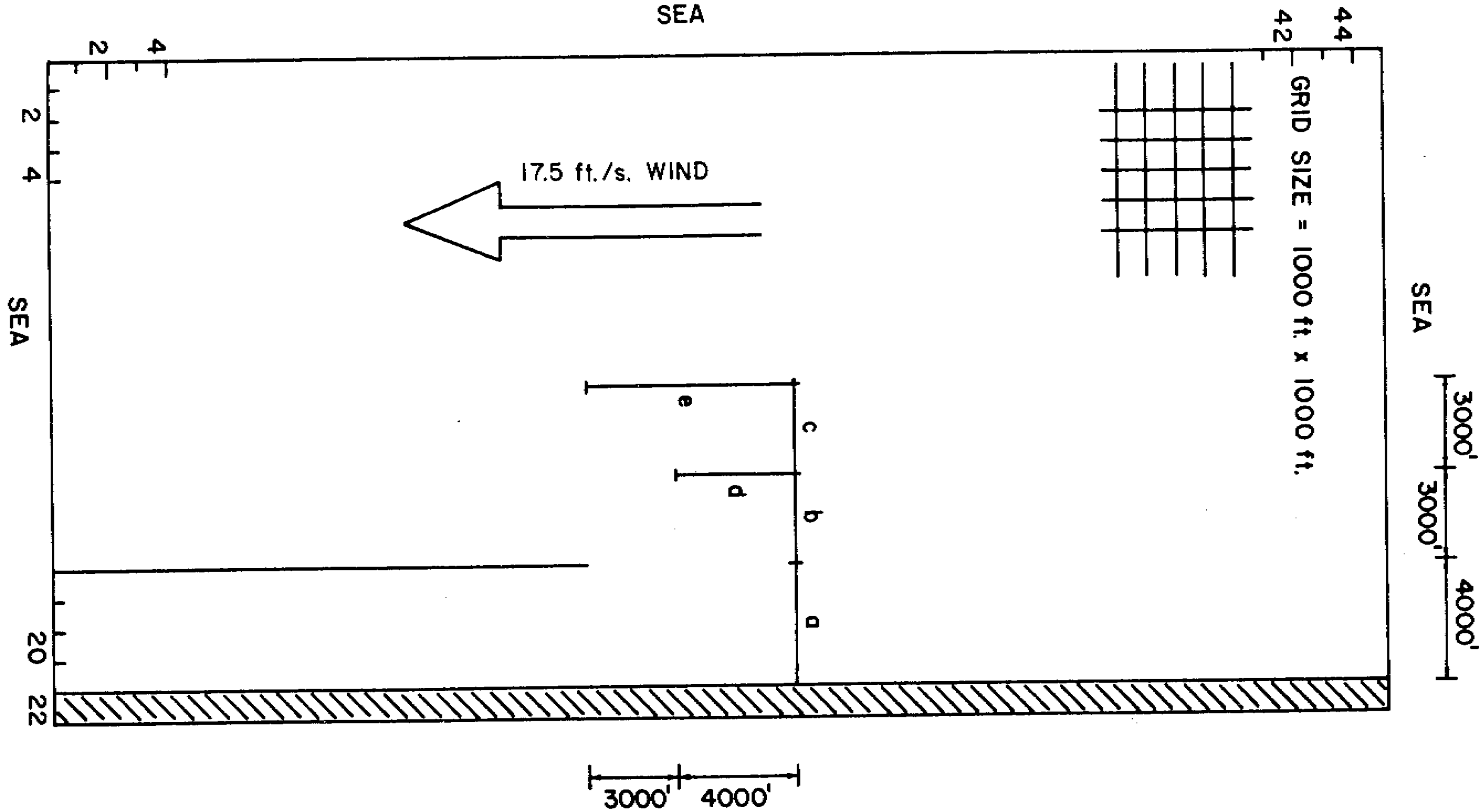


Figure 11. Idealized causeway model geometry.

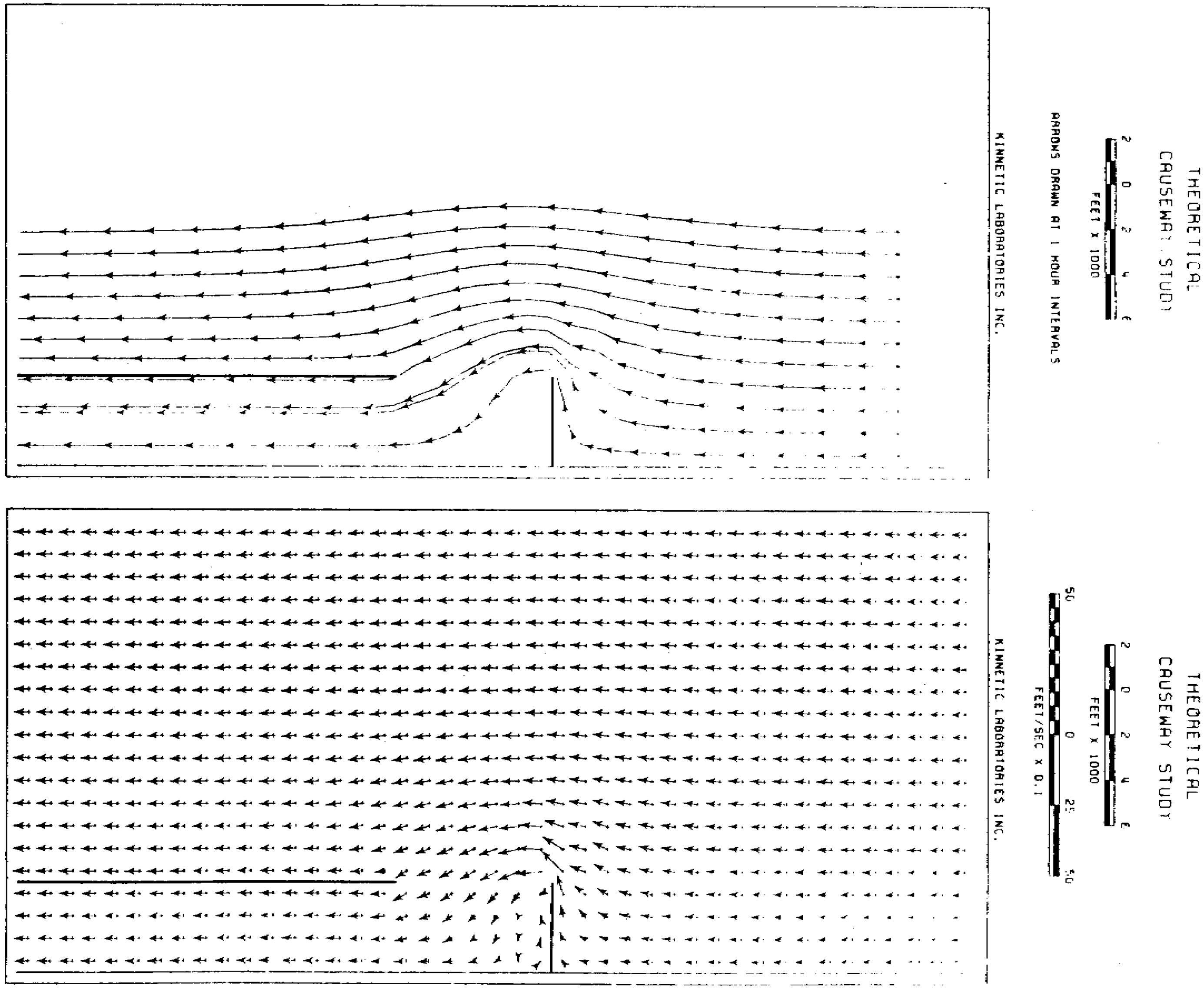


Figure 12. Idealized causeway, type 1; constant depth.

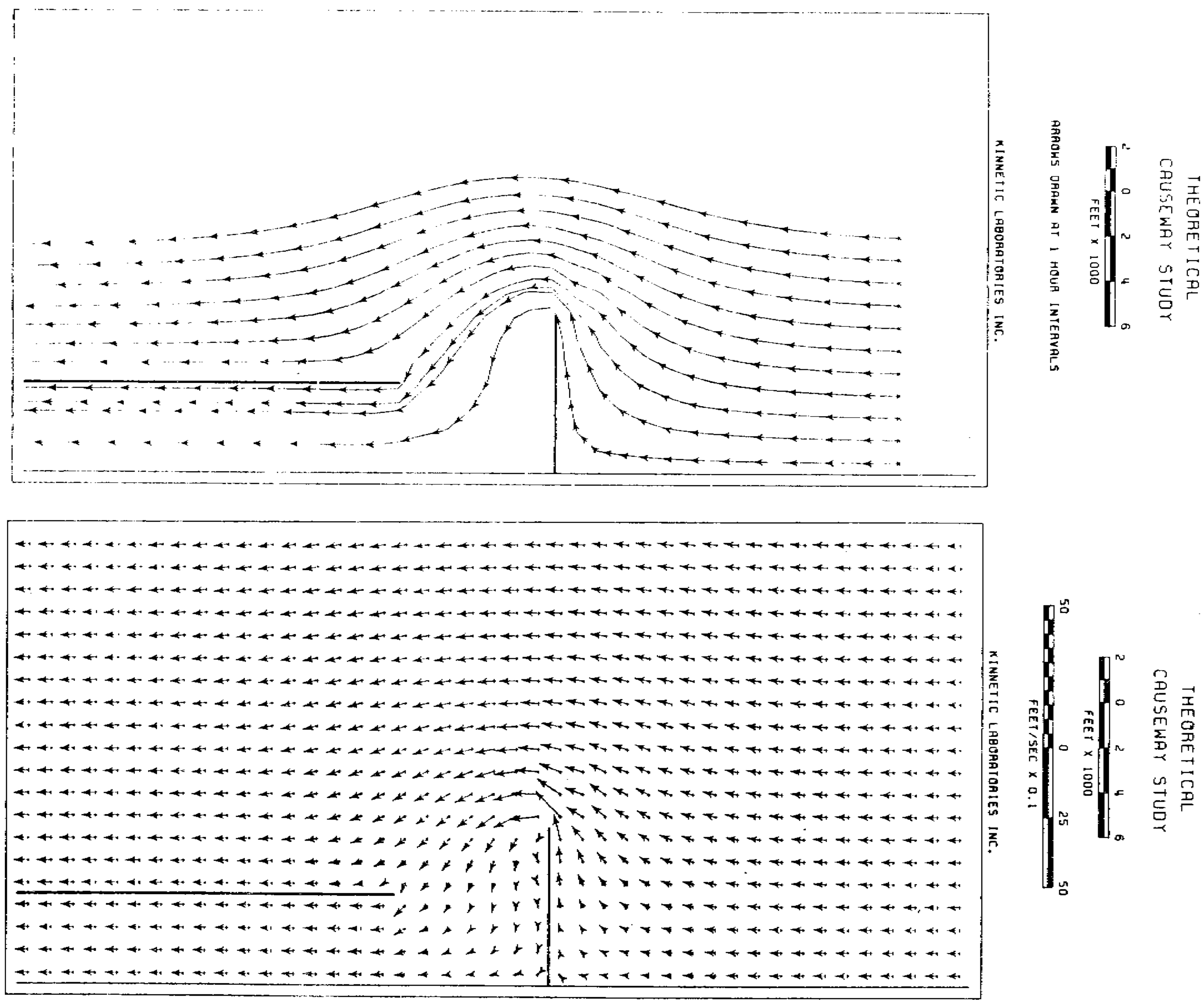
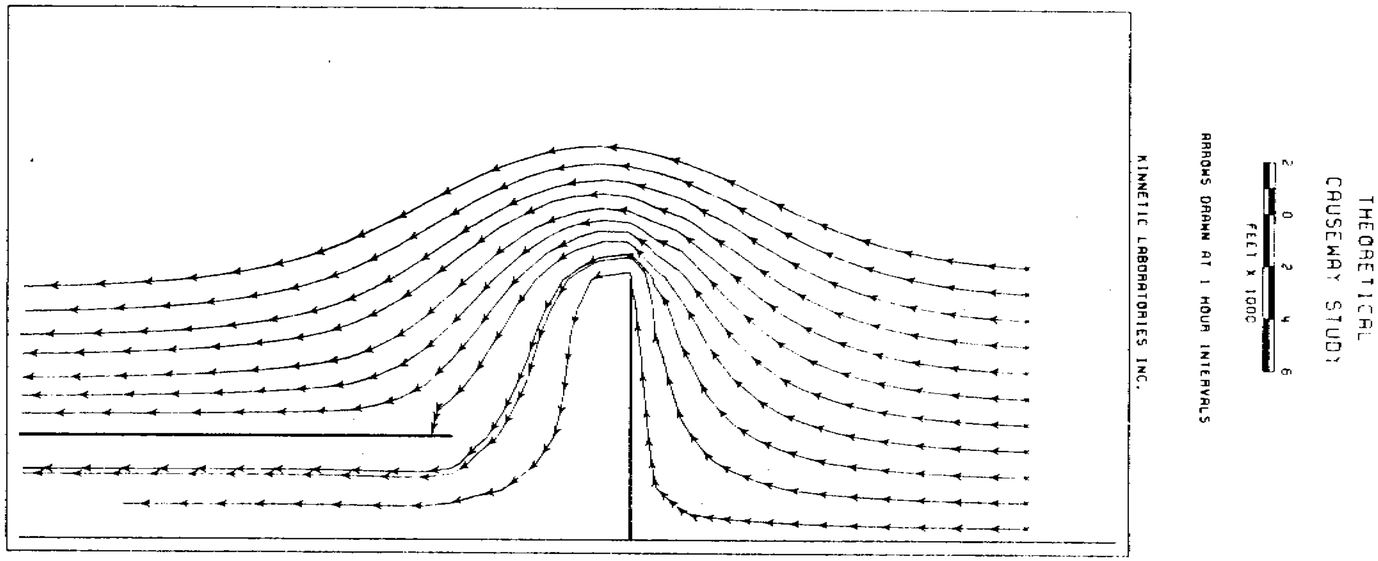


Figure 13. Idealized causeway, type 2; constant depth.



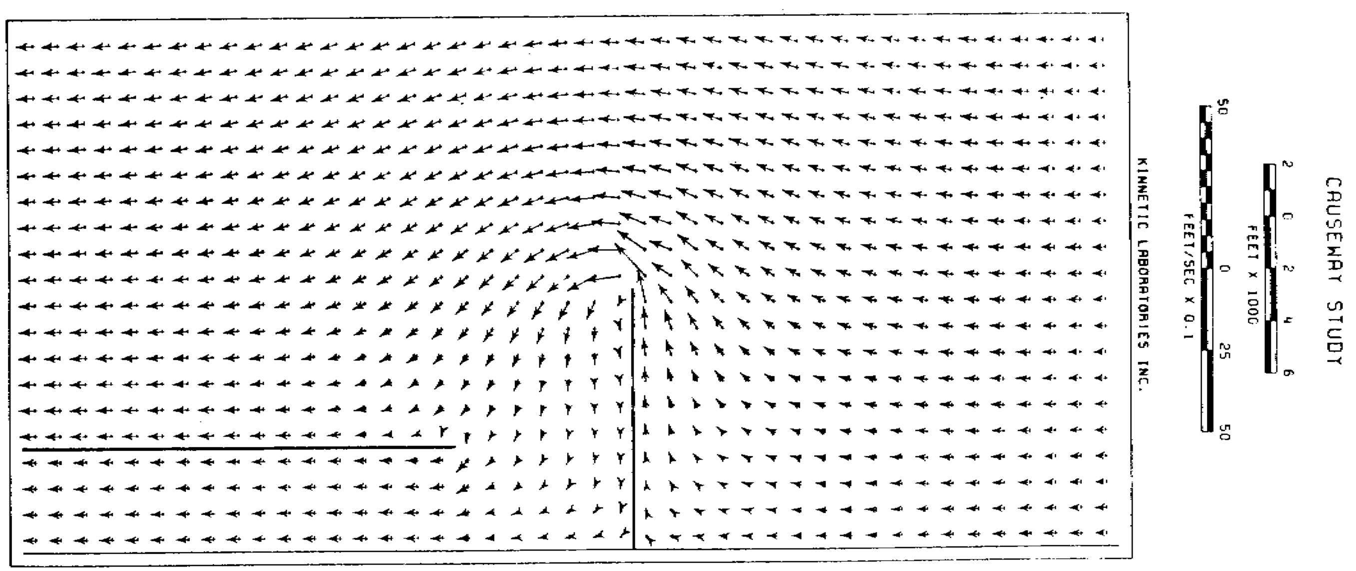
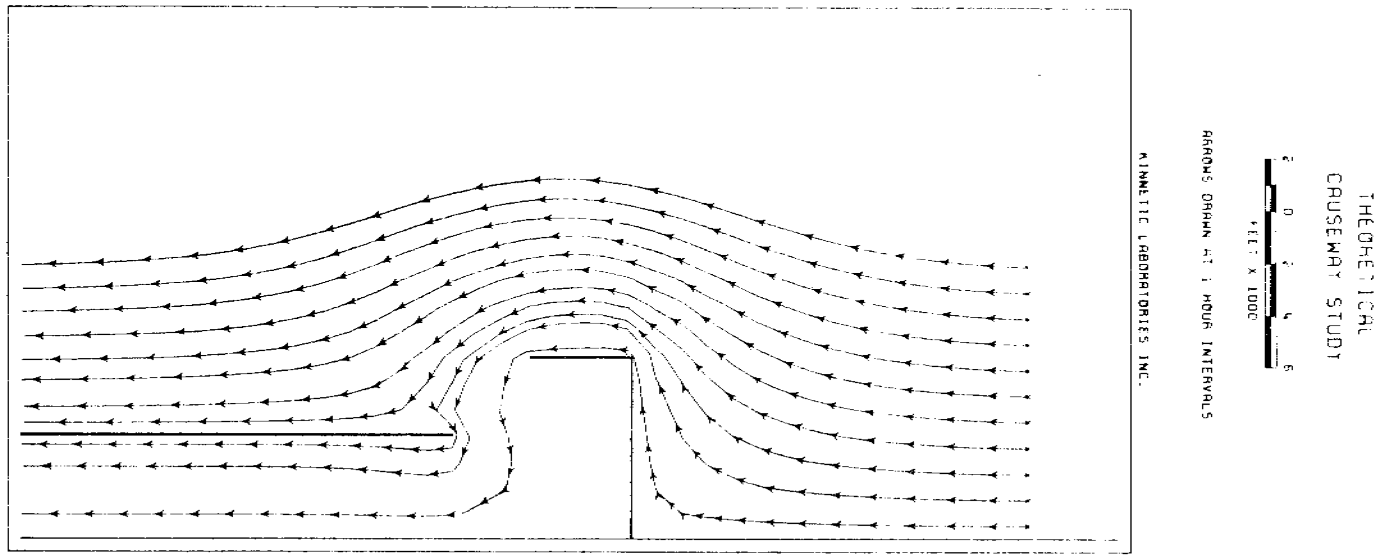


Figure 14. Idealized causeway, type 3; constant depth.



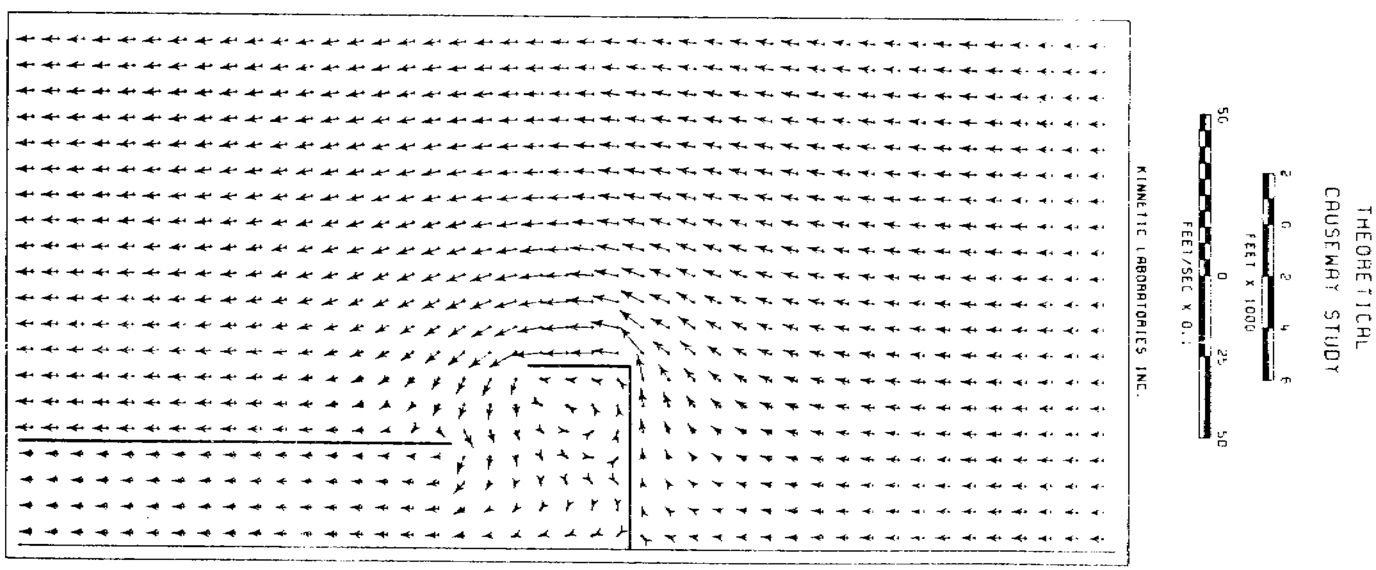


Figure 15. Idealized causeway, type 4; constant depth.

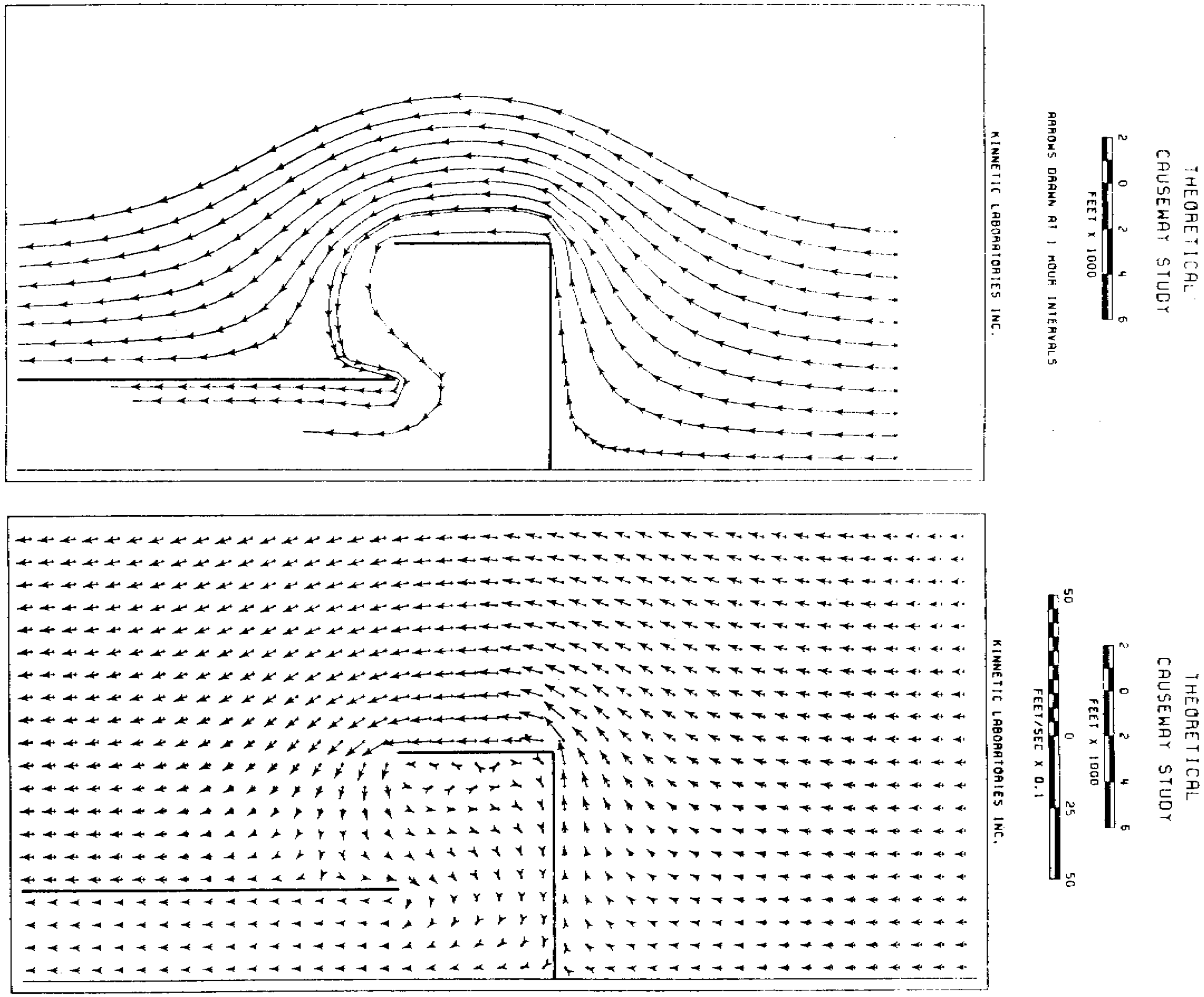


Figure 16. Idealized causeway, type 5; constant depth.

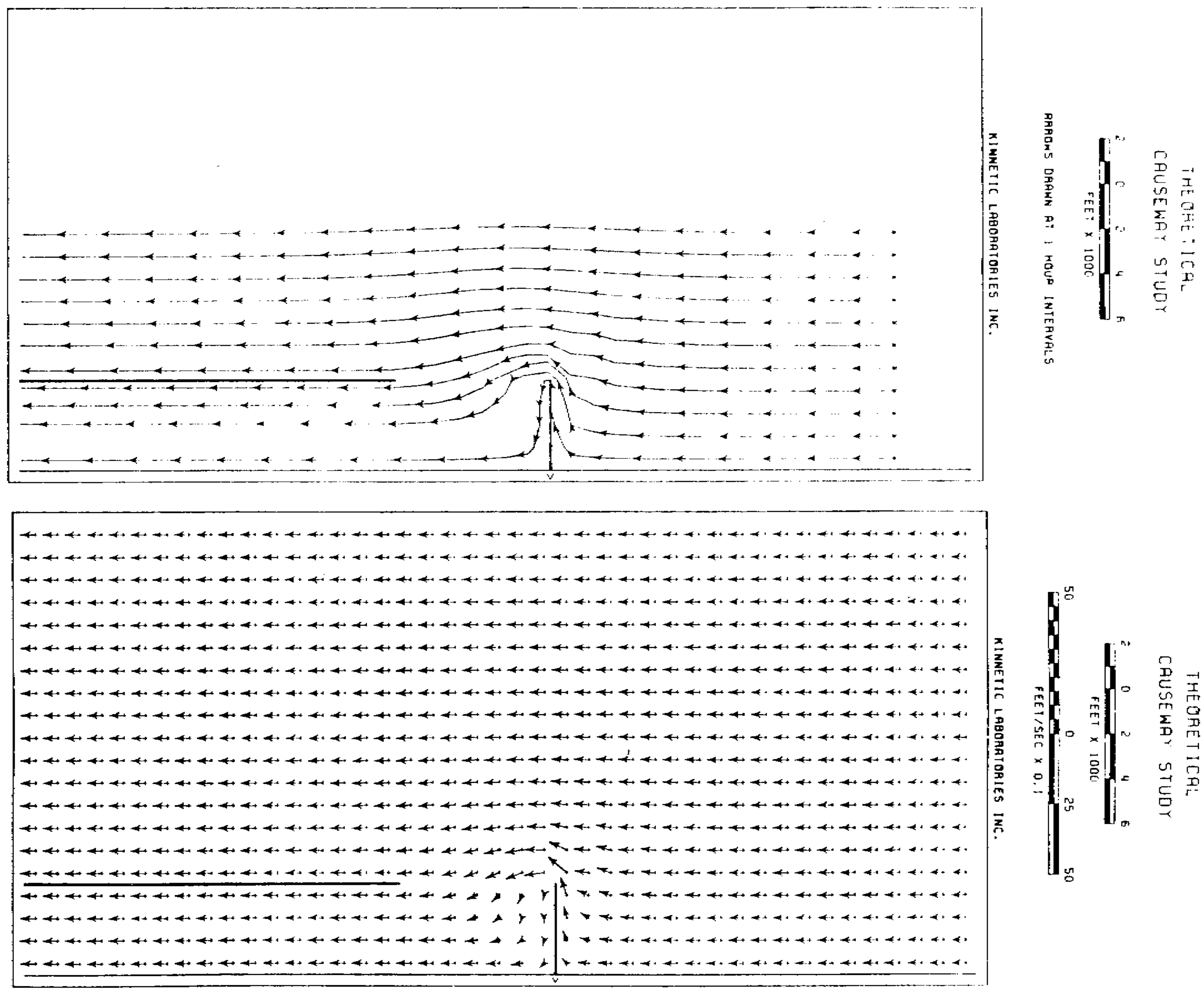


Figure 17. Idealized causeway, type 1; linearly-increasing depth.

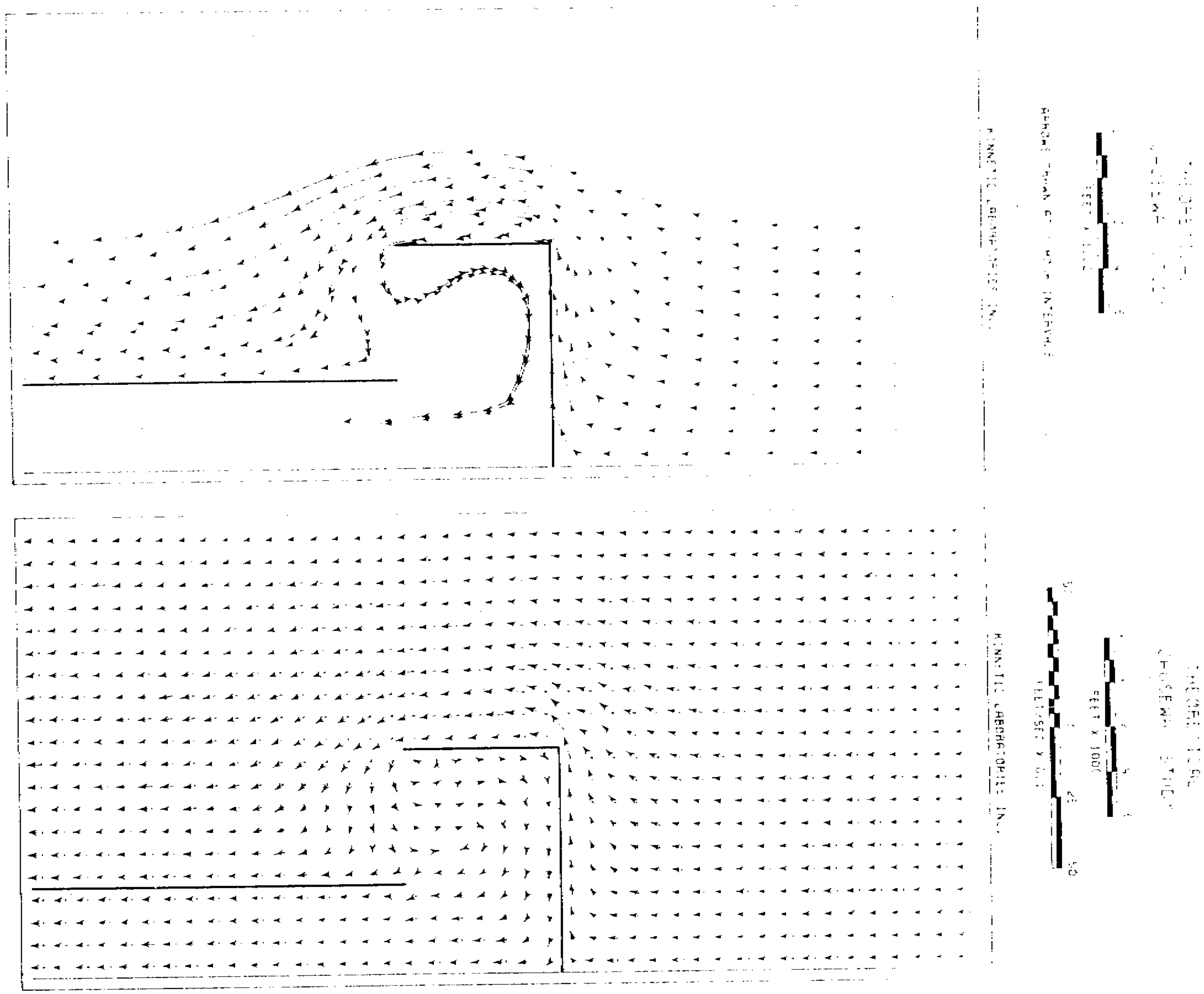


Figure 18. Idealized causeway, type 5; linearly-increasing depth.

Trajectories were computed using the current field. Hypothetical particles were released in the centers of the first 11 grid squares along a line extending perpendicularly from the shore in the fourth row from the top of the model. Arrow heads were placed along the trajectories at intervals of one hour. Particles were tracked until they reached a location from which they could proceed no further or reached an open bondary, or until a period of 41.5 hours had elapsed, whichever occurred first. The trajectory computation algorithm merely moved the particle according to the average velocity in each grid square; no artificial refinement due to interpolation of the model velocities was attempted.

Preliminary Results

1) Reduction in flow rates inside the barrier island due to sheltering effect of causeway:

To allow for differences between model runs attributable to the limited study area, the following computation was made:

$$E = \frac{Qb}{Qu},$$

where:

E = Efficiency

Qb = Flow rate over a 4000 ft section between the barrier islands

Qu = Flow rate over a 4000 ft section extending normally away from the shore at the upstream end of the model.

Constant Depth		Variable Depth	
Causeway Shape	E	Causeway shape	E
1	.96	1	.98
2	.96		
3	1.00		
4	.82		
5	.75	5	.92

2) Effect of causeway shapes on salinity or temperature distributions:

An idea of the changes in salinity or temperature patterns likely to be expected can be gained by assigning steadily changing salinity or temperature values to each of the streamlines. Diffusion is not taken into account, and only a general picture will result. Such a method is at best approximate, and it should be realized that the precise location of nearshore streamlines downshore from the causeway is limited by the coarseness of the grid in the neighborhood of the tip of the causeway. It will be seen in some of the displays that the so-called streamlines often become suspiciously close together -- a situation that would normally indicate increased currents. In general high currents only occured at the tip of the causeway.

3) Eddy formation:

Before running the simulations, it had been anticipated that an eddy of dimensions similar to that of the causeway would form in the lee of the causeway. This did not in general occur, although computations were run for a wide range of lateral eddy viscosity coefficients. The only time an "ideal" eddy of such a magnitude formed was with a "bent" causeway in the absence of the barrier island (Figure 19). It is suspected that the reason for the lack of appearance of a well-developed eddy is the local wind. The question is of some importance, for a well-developed eddy might reduce the flow into the barrier island entrance.

A small eddy (approximately 1500 ft in extent) formed when the causeway was short and straight. An eddy some 4000 ft in extent formed in the case of a short, bent causeway (Figure 15). The size of the eddy became smaller (being reduced to some 2000 ft when the causeway was extended). This is probably because the 'driving' effect created by water being drawn between the barrier island and the shore is lessened. When comparison is made between runs of the extended, bent causeway with constant depth and with linear depth increase, it is seen that in the latter case the eddy became even less pronounced, and reverse flow took place further from shore. It will be noted that no circular trajectories are in evidence. This is probably because no particle can enter the eddy; one would have to locate a particle within the eddy at the start of the tracking computation.

It should be recalled that the flow regime calculations were made with idealized depths. Conclusions as to the actual effect of causeways should be based on actual topography. Furthermore three-dimensional effects such as the possible replacement of water in the lee of the causeway have not been modeled. (If such modeling is to be meaningful, computations would have to be made over a range of arbitrary coefficients, and the effect of such choices on the final results clearly delineated.) Further studies taking these effects into account would be of great interest in that they might indicate means by which causeway shape could be used to minimize hydrographic changes.

Preliminary conclusions

Neglecting the effect of depth changes caused by sedimentation, the flow-rate reduction is not as large as one might intuitively expect. The reduction does however increase with bending of the causeway. It is also of interest that the reduction was less when bathymetry of a linearly-increasing type was modeled. The model could of course easily be re-run with more realistic depths, and, since the original model already includes algorithms for flow over short-crested and broad-crested wiers, the effect of breeches could be simulated with a fair degree of realism.

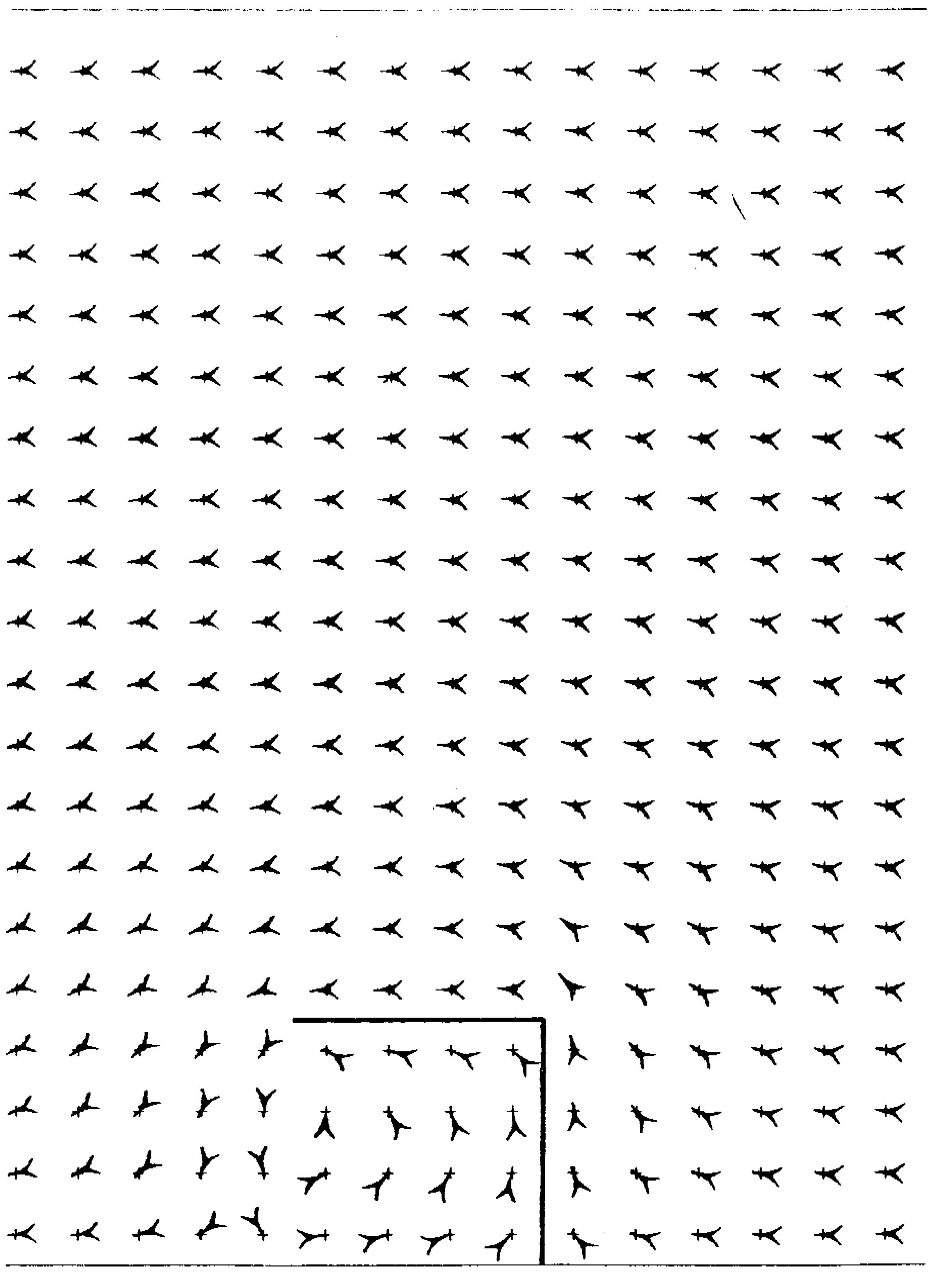


Figure 19. Eddy formed by "dog-let" causeway (no barrier island).

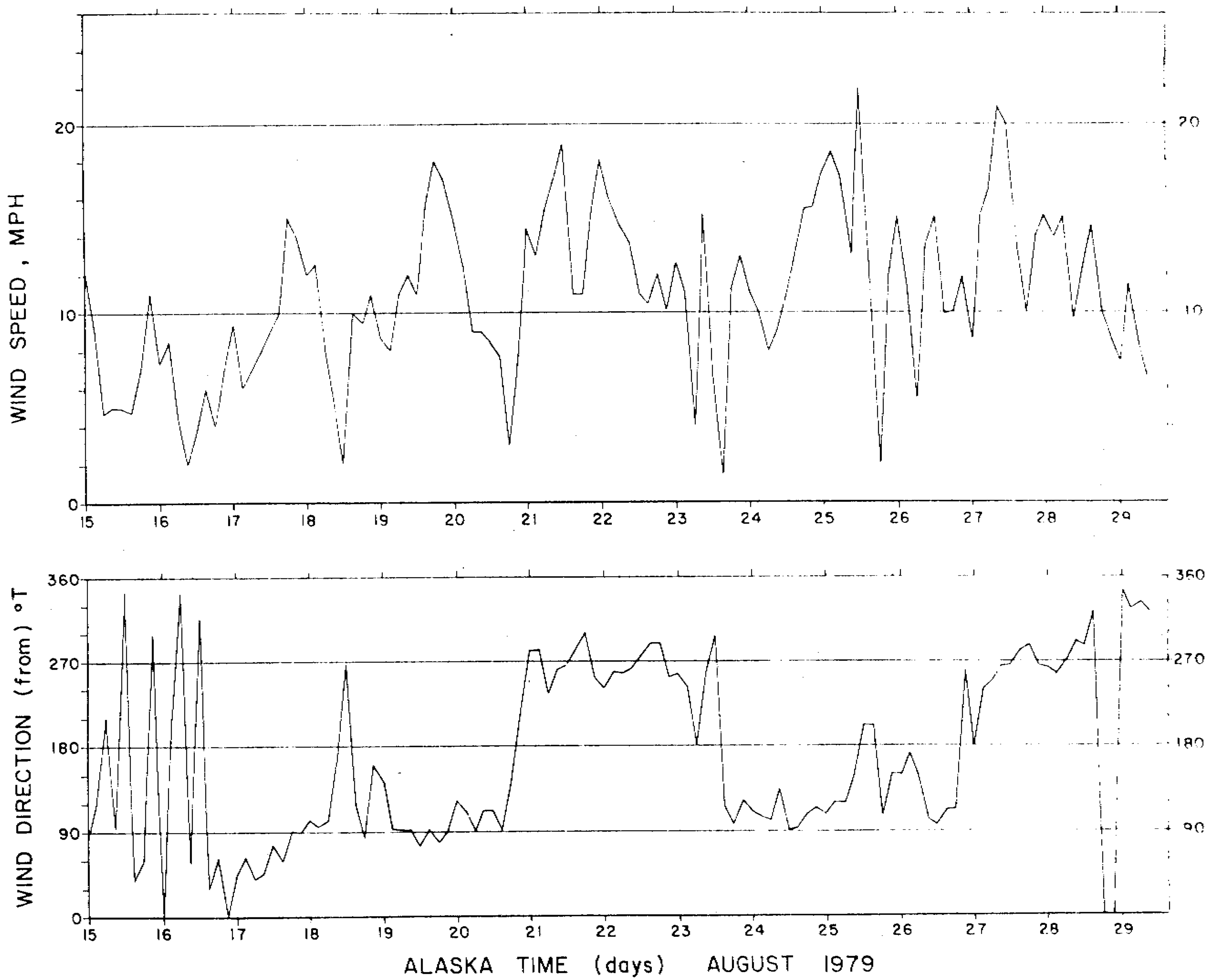


Figure 20: Narwhal Island winds

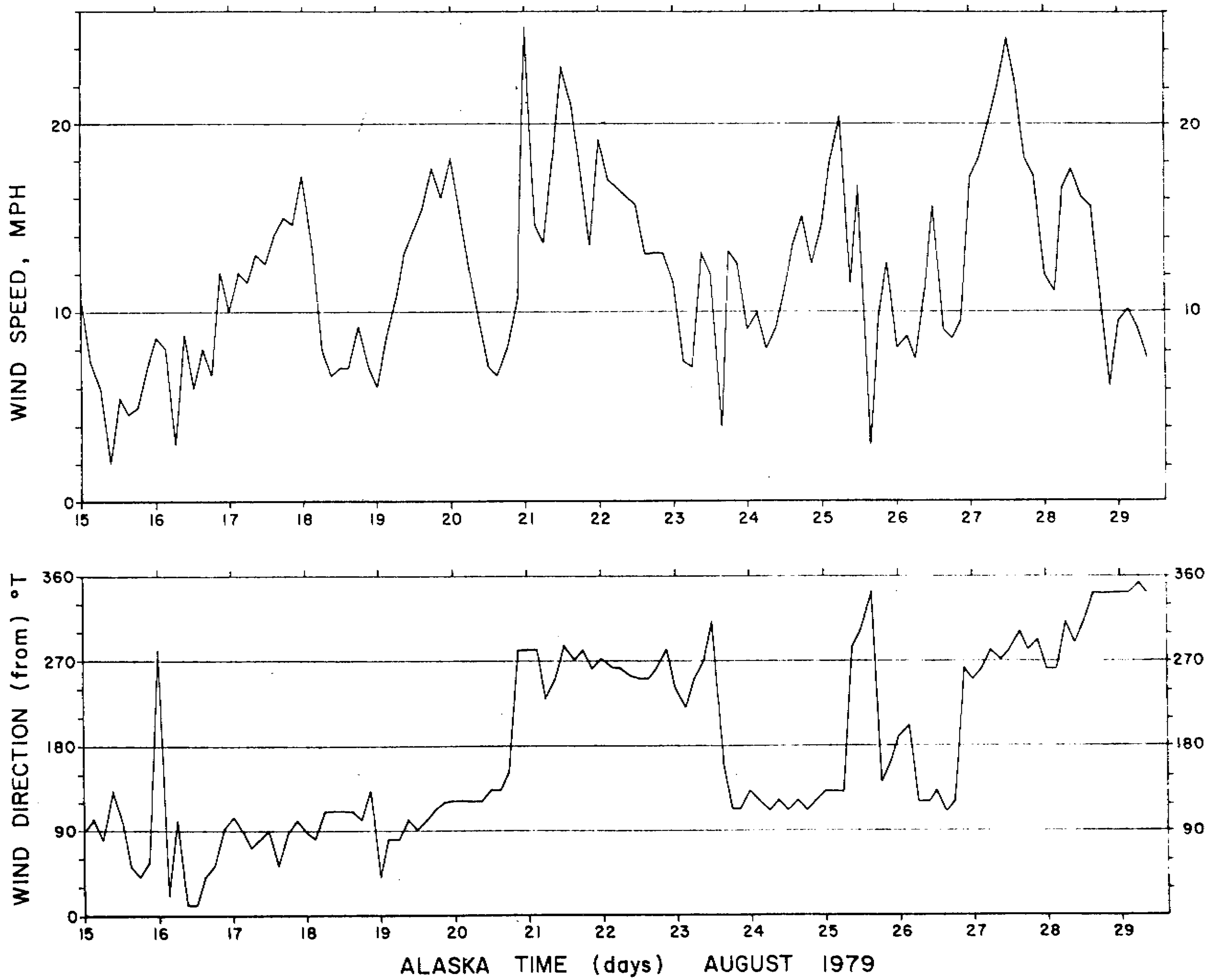


Figure 21. Cottle Island winds
Source: Tom Kozo, University of Washington

RADIO DIRECTION FINDER (RDF) DRIFTER-TRACKING EXPERIMENTS

Introduction

Radio-beacon equipped free-drifting buoys were released during three different experiments in order to ascertain typical nearshore current velocities. Each buoy contained either a 4 Mhz or 6 Mhz transmitter that emitted a characteristic "beep" capable of being tracked by shore-based Radio Direction Finding (RDF) stations. In a typical experiment, 3 to 7 buoys would be released from a taxiing float-plane at appropriate points between the shore and the ice-edge (some 3-5 miles offshore). Two stations, each consisting of a two-man team, tents, RDF set, etc., would be located at points satisfying the criteria of float-plane accessibility and navigational line-of-position (LOP) quality. Due to the short base-line that resulted from the combination of small offshore buoy location and need for at least 30° between LOP's, frequent station movement was desirable--a requirement that could not always be dealt with due to poor flying conditions.

Experiment No. 1 - 18 August to 22 August 1979

The first tracking experiment was started in a period of easterly winds (see Figures 20 and 21) with the objective of studying flow trajectories into Harrison Bay. Three buoys were released off the eastern end of Pingok Island:

6209.0 Khz buoy ∿ 1 mi offshore
6200.0 Khz buoy ∿ 2 mi offshore
6236.0 Khz buoy ∿ 3 mi offshore

Due to mechanical problems, a poor connection only was possible between the hull and the current drogue of the 6200.0 Khz buoy. Probably the failure of this connection and the subsequently assumed horizontal position caused this buoy to go off the air prematurely.

Regrettably, after moving the two stations to the west on 20 August, the wind changed direction and blew from the west. The consequent wave heights made it impossible to relocate the stations in time to achieve good LOP's.

The resulting bearings from each station are shown in Table 6. Due to lack of sun and absence of landmarks, compasses had to be used to establish reference angles. The bearings shown in Table 6 and in subsequent tables are in degrees TRUE, as computed by adding 30° to the RDF set bearings (in turn based on magnetic reference bearings). The sudden change of angle at Cape Halkett at 1100 hrs, 21 August cannot be explained: it could be real, or it could be due to a failure of the bearing readout circuitry.

(The set had to have repairs made to the power supply after the experiment.)

Experiment No. 2 - 26 August to 28 August 1979

The second experiment had to be conducted with only one RDF set--the other having been taken to Prudhoe Bay for repairs. This required considerable work on the part of the pilot (Jim Helmericks) and the field party (Dale Harber, Steve Pace, Howard Teas). Buoy positions could only be established by the "running" fix method. One buoy (4144.8 Khz) was placed on Jeanette Island (70° 22' N, 147° 25' W) in the McClure Islands group so as to provide an RDF bearing check. In addition, 4 free-drifting buoys were released as follows:

4125.6 Khz buoy	∿	1 mi W of Lion Pt., Tigvariak Island
4162.2 Khz buoy	∿	1 mi W of Pole I, Stockton Islands group
4187.6 Khz buoy	∿	1 mi S of Karluk I, McClure Islands group
4222.3 Khz buoy	∿	1.5 mi W of Karluk I, McClure Islands group

RDF angles (as in experiment 1) are shown in Tables 7 and 8, along with the theoretical angles computed using latitudes and longitudes of the reference buoy (4144.8 Khz) and of the stations. (The angles were computed using the program listed in Appendix A). The rather wide scatter between the measured and computed angles can be attributed variously to operator problems (mostly due to the awkward running fix method), RDF set problems, and perhaps magnetic reference bearing problems.

Experiment No. 3 - 30 August to 2 September 1979

The third and last experiment, carried out with 2 RDF sets, was hampered both by nearshore ice, and poor flying weather. Six free-drifting buoys were deployed as follows:

4118.3 Khz buoy	2½ mi ESE of Karluk I, McClure Islands group
4245.6 Khz buoy	2 mi ESE of Karluk I, McClure Islands group
4295.6 Khz buoy	½ mi ESE of Karluk I, McClure Islands group
4274.1 Khz buoy	1 mi SW of Jeanette I, McClure Islands group
4183.2 Khz buoy	2 mi SW of Jeanette I, McClure Islands group
4137.6 Khz buoy	3 mi SW of Jeanette I, McClure Islands group

The 4144.8 Khz buoy continued to act as a check.

In spite of the difficulties (Bullen Point was manned by one person, Steve Pace, in circumstances made difficult by high winds), the experiment went well, with little scatter in the reference angles from Foggy Island Bay and Heald Point. The explanation for the consistently smaller reference angles at Bullen Point is not known.

Preliminary Conclusions

No final plotting of the trajectories will be shown at this time owing to ongoing tracking studies being scheduled in Harrison Bay during August 1980. The program listed in Appendix A may be used by those requiring a quick look at the data. (The program has been checked using the angles to the 4144.8 Khz buoy.) It is planned that plots will be made using first the angles in the tables, then with corrections made to the angles in experiments 2 and 3 based on differences between measured and computed stationary buoy angles.

Table 6

Experiment No. 1. True Bearings

Date	AK Time	Buoy Frequency in Khz 6200	6209	6236	6200	6209	6236
		Colville Village (70°26.2'N,150°22.6'W)			Milne Point (70°30.8'N,149°27.4'W)		
18 Aug. 79	2000	063	069	058			
	2200	058	062	057	321	324	319
19 Aug. 79	0000	054	056	053	313	311	310
	0200	049	049	048	309	311	310
	0400	047	049	043	310	309	310
	0600	off air	045	039	off air	309	305
	0800	"	043	037	"	310	306
	1000	"	037	036	"	307	298
	1400	"	032	028	"	303	298
	1800	"	017	014	"	–	–
	2200	"	355	356	"	300	299
20 Aug. 79	0200	"	340	340	"	297	294
	0600	"	330	328	"	294	294
	1000	"	327	324	"	294	293
					Eskimo Islands (70°34.5'N,151°53.5'W)		
	1400	"	326	320	"	060	064
	1800	"	324	317	"	065	067
		Cape Halkett (70°50.8'N,152°18.7'W)					
	2200	"	106	112	"	068	071
21 Aug. 79	0200	"	100	107	"	069	075
	0600	"	103	105	"	073	077
	1100	"	121	121	"	076	079
	1400	"	122	121	"	084	082
	1800	"	124	122	"	086	086
	2200	"	127	122	"	–	084
22 Aug. 79	0200	"	127	123	"	087	085
	0600	"	123	119	"	086	088

Table 7

Experiment No. 2. True Bearings (Uncorrected) from Tigvariak Island

Date	AK Start Time	AK End Time	Buoy Frequency in Khz 4125.6	4144.8	4162.2	4187.6	4222.3
			Tigvariak Island (70°12.7'N, 147°16.0'W)				
26 Aug. 79	1525	1605+	321	332	014	340	331
27 Aug. 79	1130	1155+	069	338	058	016	020
27 Aug. 79	1650	1735+	087	338	061	036	047
28 Aug. 79	1035	1055+	no signal	342 346	064	069	069
28 Aug. 79	1630	1650+	"	346	072	078	080

Note: True bearing of buoy with frequency of 4144.8 Khz should be: 342° T from Tigvariak Island.

Table 8.

Experiment No. 2. True Bearings (Uncorrected) from Foggy Island and Point Gordon

Date	AK Start Time	AK End Time	Buoy Frequency in Khz 4125.6	4144.8	1462.2	4187.6	4222.3
			Foggy Island (70°16.9'N, 147°47.0'W)				
26 Aug. 79	1645	1710+	099	054	075	060	057
27 Aug. 79	1245	1310+	095	052	081	076	077
27 Aug. 79	1828	1907+	091	045	075	071	073
			Point Gordon (70°11.1'N, 146°37.0'W)				
28 Aug. 79	1140	1155+	no signal	305	008	026	014
28 Aug. 79	1730	1745+	"	306	018	036	045

NOTE: True bearing of buoy with frequency of 4144.8 Khz should be:
055°T from Foggy Island
304°T from Point Gordon

Table 9

Experiment No. 3. True Bearings (Uncorrected) from Foggy Island Bay and Heald Point

Date	AK Start Time	AK End Time	4118.3	4137.6	4144.8	4183.2	4246.6	4274.1	4295.6
			Foggy Island Bay (70°12.2'N, 147°41.0'W)						
30 Aug.79	1820	1940	047	027	026	030	048	033	042
31 Aug.79	0004	0121	043	026	026	027	043	030	032
31 Aug.79	0628	0720+	030	024	025	024	034	024	027
31 Aug.79	1209	1248	016	011	026	014	018	015	017
31 Aug.79	1755	1848	008	000	026	009	010	010	009
1 Sept.79	0010	0120+	002	348	025	357	359	000	358
1 Sept.79	0620	0722	356	339	025	344	357	347	356
			Heald Point (70°20.8'N, 148°12.3'W)						
1 Sept.79	1230	1336	053	016	083	023	061	025	055
1 Sept.79	1800	1912	052	014	080	352	056	357	056
2 Sept.79	0010	0015+	051	013	080	348	040	351	054
2 Sept.79	0600	0718	056	026	081	338	023	349	048
2 Sept.79	1200	1256	053	no signal	082	321	007	343	021

Note: True bearings of buoy with frequency of 4144.8 Khz should be:
029°T from Foggy Island Bay
085° from Heald Point

Table 10

Experiment No. 3. True Bearings (Uncorrected) from Bullen Point

Date	AK Start Time	AK End Time	4118.3	4137.6	4144.8	4183.2	4246.6	4274.1	4295.6
					Bullen Point (70°11.3'N, 146°51.0'W)				
30 Aug.79	1800	1850+	306	300	303	299	301	297	298
31 Aug.79	0000	0100+	305	301	306	294	299	297	301
31 Aug.79	0600	0700+	305	296	307	293	302	296	302
31 Aug.79	1200	1300+	302	296	306	267	301	295	301
31 Aug.79	1800	1900+	306	293	308	299	303	299	304
1 Sept.79	0000	0100+	303	295	305	300	196	297	306
1 Sept.79	0600	0700+	303	299	300	298	301	298	302
1 Sept.79	1200	1320+	303	303	303	301	303	300	305
1 Sept.79	1800	1910+	301	303	303	301	300	299	300
2 Sept.79	0005	0110+	301	303	303	299	301	304	302
2 Sept.79	0600	0710+	302	303	304	297	299	304	301
2 Sept.79	1200	1310+	305	no signal	303	296	298	304	no signal

NOTE: True bearings of buoy with frequency of 4144.8 Khz should be:
313°T from Bullen Point

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APPENDIX A

RDF SPHERICAL TRIANGLE SOLUTION PROGRAM LISTING

The program listing on the following pages contains the following symbol transposition failures due to the use of a non-ASCII type set:

< has been printed as @

> has been printed as #

^ has been printed as ¢

\ has been printed as %

```
10 REM **** PROGRAM RDF3 ****
20 PRINT%PRINT
30 PRINT TAB(9),"****USE OF BASIC14 IS SUGGESTED****"
40 PRINT%PRINT
50 PRINT "PROGRAM IS SET UP FOR STATIONS A AND B, AND THE BUOY,"
60 PRINT TAB(10),"TO BE IN THE NORTHERN HEMISPHERE"
70 PRINT%PRINT
80 DIM A$(1),B$(1)
90 X=0
100 INPUT "DIAGNOSTIC PRINTOUT ? (Y OR N) ",C$
110 IF C$="Y" THEN X=1
120 P1=3.14159
130 P2=P1/2
140 R1=P1/180
150 PRINT "WEST LONGITUDES WILL BE PRINTED AS NEGATIVE"
160 PRINT "STATION B SHOULD BE CLOSER TO NORTH POLE THAN STATION A"
170 PRINT
180 INPUT "LATITUDE  OF STATION A, WHOLE DEGREES ? ",L1
190 INPUT "LATITUDE  OF STATION A, MINUTES       ? ",L5
200 L1=L1+L5/60%L1=L1*R1
210 PRINT
220 INPUT "LONGITUDE OF STATION A ? @E#AST OR @W#EST ",A$
230 IF A$="E" THEN 250
240 IF A$@#"W" THEN 220
250 INPUT "LONGITUDE OF STATION A, WHOLE DEGREES ? ",L2
260 INPUT "LONGITUDE OF STATION A, MINUTES       ? ",L5
270 L2=L2+L5/60
280 IF A$="W" THEN L2=-L2
290 L2=L2*R1
300 PRINT
310 INPUT "LATITUDE  OF STATION B, WHOLE DEGREES ? ",L3
320 INPUT "LATITUDE  OF STATION B, MINUTES       ? ",L5
330 L3=L3+L5/60%L3=L3*R1
340 PRINT
350 INPUT "LONGITUDE OF STATION B ? @E#AST OR @W#EST ",B$
360 IF B$="E" THEN 380
370 IF B$@#"W" THEN 350
380 INPUT "LONGITUDE OF STATION B, WHOLE DEGREES ? ",L4
390 INPUT "LONGITUDE OF STATION B, MINUTES       ? ",L5
400 L4=L4+L5/60
410 IF B$="W" THEN L4=-L4
420 L4=L4*R1
430 IF L3#=L1 THEN 500
440 L5=L3%L6=L4
450 L3=L1%L4=L2
460 L1=L5%L2=L6
470 PRINT
480 PRINT "**** CAUTION: STATIONS A AND B HAVE BEEN REVERSED ****"
490 PRINT "STATION B IS ALWAYS MADE THE STATION NEAREST THE POLE"
500 J1=P2-L1%REM COLAT A
```

```
510 J2=P2-L3%REM COLAT B
520 J3=ABS(J1-J2)%REM ****************** ?
530 J4=ABS(L4-L2)%REM *****ABSOLUTE LONGITUDE DIFFERENCE
540 C=COS(J3)-SIN(J1)*SIN(J2)*(1-COS(J4))
550 C=ATN(SQRT(1-C*C)/C)
560 PRINT
570 IFX=1THEN PRINT "DISTANCE BETWEEN A AND B (DEG) = ",%#5F1,C/R1
580 J5=ATN(SIN(J1)*COS(J4)/COS(J1))
590 B1=(SIN(J5)*SIN(J4))/(SIN(J2-J5)*COS(J4))
600 B1=ATN(B1)
610 IF B1@0 THEN B1=P1+B1
620 A1=SIN(J4)*SIN(J2)/SIN(C)
630 IF ABS(A1)@1 THEN 670
640 A1=P2
650 IF A1@0 THEN A1=-P2
660 GOTO 680
670 A1=ATN(A1/(SQRT(1-A1*A1)))
680 PRINT
690 A2=A1
700 B2=B1
710 IFX=1THEN PRINT "ANGLE @POLE A B# = ",A2/R1
720 IFX=1THEN PRINT "ANGLE @POLE B A# = ",B2/R1
730 PRINT
740 IF L2#L4 THEN 780
750 REM STATION A WEST OF STATION B
760 A2=A2%B2=P1*2-B2
770 GOTO 790
780 A2=P1*2-A2%B2=B2
790 IFX=1THEN PRINT "ANGLE @POLE A B# FROM TRUE NORTH = ",A2/R1
800 IFX=1THEN PRINT "ANGLE @POLE B A# FROM TRUE NORTH = ",B2/R1
810 PRINT
820 REM CALCULATIONS  IN TRIANGLE A BUOY B
830 PRINT "ENTER NEGATIVE ANGLE TO END"
840 INPUT "TRUE BEARING OF BUOY FROM A (DEG) ? ",A
850 IF A@0 THEN 1440
860 INPUT "TRUE BEARING OF BUOY FROM B (DEG) ? ",B
870 A=A*R1
880 B=B*R1
890 A3=ABS(A2-A)
900 B3=ABS(B2-B)
910 IF A3#=P1 THEN A3=2*P1-A3
920 IF B3#=P1 THEN B3=2*P1-B3
930 PRINT%PRINT "WARNING ..."
940 PRINT "SELECTED ANGLE @B A BUOY# (DEG) = ",%#5F1,A3/R1
950 PRINT "SELECTED ANGLE @A B BUOY# (DEG) = ",B3/R1
960 C3=SIN(A3)*SIN(B3)*COS(C)-COS(A3)*COS(B3)
970 C3=ATN(SQRT(1-C3*C3)/C3)
980 IF C3@0 THEN C3=P1+C3
990 PRINT
1000 IFX=1THEN PRINT "ANGLE @A BUOY B# = ",C3/R1
```

```
1010 PRINT
1020 REM COMPUTE SIDE (STATION B, BUOY)
1030 A4=SIN(A3)*SIN(C)/SIN(C3)
1040 A4=ATN(A4/SQRT(1-A4*A4))
1050 IF A4@0 THEN A4=P1+A4
1060 REM COMPUTE SIDE (STATION A, BUOY)
1070 B6=SIN(B3)*SIN(C)/SIN(C3)
1080 B6=ATN(B6/SQRT(1-B4*B4))
1090 IF B6@0 THEN B6=P1+B6
1100 IFX=1THEN PRINT "DISTANCE STATION A TO BUOY (DEG) = ",B6/R1
1110 IFX=1THEN PRINT "DISTANCE STATION B TO BUOY (DEG) = ",A4/R1
1120 PRINT
1130 REM CALCULATIONS IN TRIANGLE (POLE B BUOY)
1140 B4=B
1150 IF B4#=P1 THEN B4=2*P1-B4
1160 IFX=1THEN PRINT "ANGLE @POLE B BUOY# = ",B4/R1%PRINT
1170 J5=ABS(A4-J2)
1180 B5=COS(J5)-SIN(A4)*SIN(J2)*(1-COS(B4))
1190 B5=ATN(SQRT(1-B5*B5)/B5)
1200 IFX=1THEN PRINT "DISTANCE BETWEEN POLE AND BUOY (DEG) = ",%8F4,B5/R1
                                                          PRINT
1210 L7=90-(B5/R1)
1220 IFX=1THEN PRINT "BUOY LATITUDE (DEG) = ",%8F4,L7
1230 J5=ATN(SIN(A4)*COS(B4)/COS(A4))
1240 A5=(SIN(J5)*SIN(B4))/(SIN(J2-J5)*COS(B4))
1250 A5=ATN(A5)
1260 IF A5@0 THEN A5=P1+A5
1270 IFX=1THEN PRINT "ANGLE @B POLE BUOY# (DEG) = ",A5/R1
1280 L8=L4+A5
1290 IF B#=P1 THEN L8=L4-A5
1300 L8=L8/R1
1310 M1=SGN(L7)*INT(ABS(L7))
1320 M2=ABS((L7-M1)*60)
1330 IF M2@59.95 THEN 1350
1340 M1=M1+SGN(L7)%M2=0
1350 M3=SGN(L8)*INT(ABS(L8))
1360 M4=ABS((L8-M3)*60)
1370 IF M4@59.95 THEN 1390
1380 M3=M3+SGN(L8)%M4=0
1390 PRINT%PRINT
1400 PRINT "BUOY  LATITUDE = ",%4I,M1," DEG  ",%5F1,M2," MIN"
1410 PRINT "BUOY LONGITUDE = ",%4I,M3," DEG  ",%5F1,M4," MIN"
1420 PRINT%PRINT
1430 GOTO 820
1440 PRINT%PRINT "NORMAL END OF PROGRAM"%PRINT
1450 END
```

Fifth Annual Report

Bristol Bay Oceanographic Processes (B-BOP)

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Table of Contents

I. Summary

The current reporting period, April 1979 through March 1980, was a period of data digestion and the formulation of a comprehensive understanding of physical oceanographic processes occurring within Bristol Bay. Analysis efforts have continued into the features of fine structure, fronts, tides and tidal currents, eddy circulation off the shelf, and the mean and low frequency flow through the area. The continuing effort has lead to a resonable synthesis of the regional physical oceanography which will appear in the Bering Sea Shelf: Oceanography and Resources (D.W. Hood, editor).

II. Introduction

A. Objectives

This work unit attempts to relate oceanic advective and diffusive processes to problems that petroleum development may cause. Specific goals are:

1. To describe and understand the general water circulation and hydrographic structure in the study area through the year; and,
2. To determine the spatial and temporal variabilities of the velocity and hydrographic fields and understand their causes.

B. Tasks

1. Hydrographic Data: The thrust of hydrographic data acquisition and analysis has been to: (1) refine the spatial and temporal resolution of structure fronts; (2) determine the hydrographic structure during winter; (3) further investigate the fine structure near the shelf break; (4) examine the hydrographic structure with respect to tidal variation; and (5) examine the deep eddy observed south of the continental slope.

2. Current Meter Data: We are using current meters to: (1) elucidate the tides; (2) examine the velocity field details across structure fronts; (3) investigate low frequency flow; and (4) to continue definition of the mean flow.

3. Pressure Gauge Data: This data is being used to support current meter data in understanding the dynamic balances associated with different flow components, specifically tidal and low frequency flow.

4. Meteorological Data: This data is required to correct pressure gauge data to water level data; and to examine the oceanic response to atmospheric forcing.

III. Study Area

The study area continues to be the southeastern Bering Sea, approximately bounded by the Alaskan coast from Unimak Pass to Nunivak Island, thence by a line running southwest to the Pribilof Islands and then by the shelf break to Unimak Pass. Efforts of this period have extended over the shelf area to the north of this area, over the shelf area to the north of this area, over the continental slope and rise to the south of this area, and in the waters surrounding the Probilof Islands. More detailed descriptions of the area may be found in previous annual reports and publications listed.

IV. Present Status

A. Introduction: During FY-80, funding was allocated to produce five chapters for the Bering Sea: Oceanography and Resources (see IV.F.) and drafts have been submitted to D. W. Hood, editor. The following manuscripts also represent information attained during OCSEAP studies. For example, the Tide Experiment (TX) was supported by OCSEAP shiptime and equipment, while processing, analysis and interpretation were base funded.

A meeting to discuss further BLM information needs in St. George basin and north Aleutian shelf lease area was held in Juneau in Mid January 1980. During this meeting, two field programs were identified: 1) an examination of currents in the vicinity of Unimak Pass and 2) an oil transport processes experiment in the north Aleutian lease area. The following is a brief statement of the relation of these new experiments to previous work and experimental design.

What determines the fate of oil on the sea? Conventional wisdom suggests that oil is primarily transported by wind-stress and currents. Recent observations during the Campeche oil spill indicate that wind and wave action can also mix oil downward 10 to 20 m (Galt, personal communication); interactions between suspended particulate matter and oil within the water column may also be an important pathway which must be examined in oder to determine fate of oil. Further, when stirring extends to the water/sediment interface, oil can be removed from the water column and its transport is then associated with sediment transport. Preliminary resuts (Cline, 1980)* indicate that coastal waters in the vicinity of Port Moller are a source of methane. The observations suggest that methane is transported alongshore toward the northeast; however, there was little or no suggestion of a cross-frontal flux. An understanding of the distribution of methane will also serve to elucidate important transport processes on this lease area.

From current meter, pressure gage, XBT and CTD data collected during FY-76 to FY-78 programs, several conclusions regarding circulation and hydrography have been made. These have been presented in FY 76-79 Annual Reports, at PI Workshops, AGU meetings and in the scientific literature (see Section V). Previous studies

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* Cline, J.D., 1980. Distribution of dissolved low molecular weight hydrocarbons in Bristol Bay, Alaska and their implication to furthre gas and oil development. In Bering Sea: Oceanography and Resources, D. Hood, Ed.

(Kinder and Coachman, 1978; Schumacher et al., 1979; (see Section VI), Kinder and Schumacher,*1980b) indicate that tides consititute the majority of the horizontal kinetic energy over the southeastern Bering Sea shelf; however, meterological forcing and baroclinic pressure gradients are important at sub-tidal frequencies and may result in the observed mean flow (Figure 1). Numerous questions have been generated from the previous studies, and those which are relevant to fate of oil in the north Aleutian and St. George Basin (Unimak Pass lease areas are:

1) What is the nature of flow in the vicinity of Unimak Pass?
2) Is the inner front a convergence zone which acts as a barrier to cross-front fluxes?
3) What is the observed long term (10-month) net flow along the peninsula and do the baroclinic or barotropic pressure gradients drive low frequency flow?
4) What is the response of the upper-mixed layer to winds, and how does this response depend on mixing energy and buoyancy?
5) What is the vertical tidal current shear and is it a function of frequency and stratification (Väisälä frequency)?

Objectives:

The general objective of this research unit is to provide physical oceanographic data and interpretations leading to improved undertanding of transport processes in the study region. During FY-80, this will consist of two field experiments; one in Unimak Pass and one in the north Aleutian lease area. The letter experiment will be recovered and redeployed in January 1981, with final recovery in June 1981.

* Kinder, T.H. and J.D. Schumacher, 1980. Circulation over the continental shelf of the southeastern Bering Sea. In Bering Sea: Oceanography and resources, D. W. Hood, Editor.

Physical oceanographic field work in FY-80 and FY-81 will be conducted during two experiments:

1) Unimak Pass: Three moorings, each consisting of 2 Aanderaa RCM-4 current meters and 1 Aanderaa TG-3 pressure gage are to be deployed in mid-March during a PROBES cruise. These moorings are to be recovered at the end of the north Aleutian lease area cruise in mid-August. Data will provide the first direct observation of currents in Unimak Pass, and just north of the pass in the region where intermittent flow into Bristol Bay is suggested (Fig 1). The pressure gage data may allow us to understand observed flow.

Mooring ID	Position	Water Depth(m)	Instruments
UP1	54°33'N 165°22'W	85	1 Aanderaa RCM-4 and 1 bottom pressure gage
UP2	54°18.2'N 164°00.0'W	78	same
UP3	54°11.0'N 164°00.0'W	72	same

2) North Aleutian Shelf Transport Processes (TP): This region includes both middle shelf and coastal water domains (Kinder and Schumacher,* 1980). It may be an important pathway for salmon migration into Bristol and Kvichak bays, and supports an active crabbing effort. The Transport Process experiment will begin during August 1980 and continue with one recovery/deployment in January 1981 with moorings to remain through June 1981. The transport processes experiment (TP) will incorporate five moorings and one shore-based wind sensor:

* see Section IV. F.

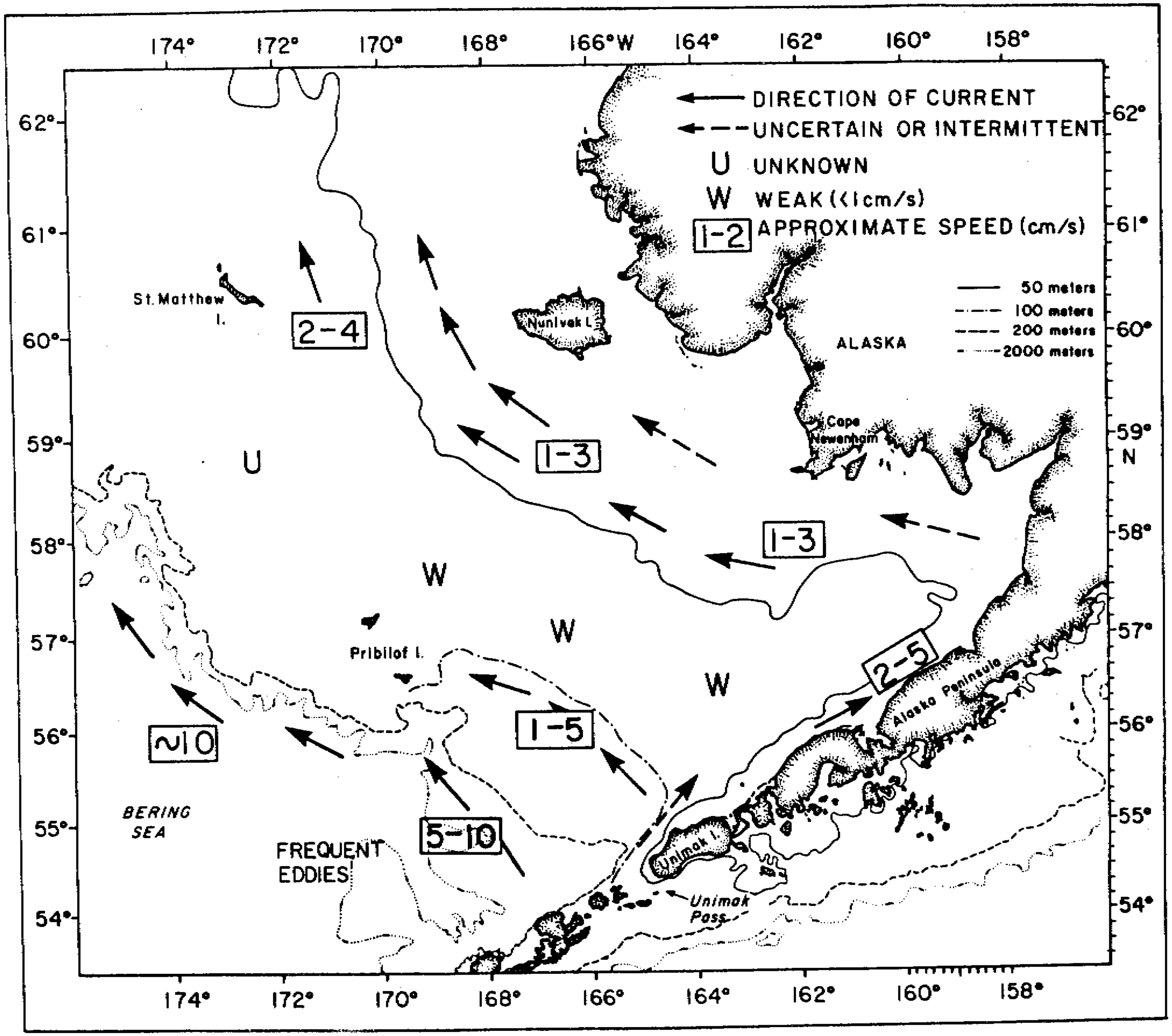

Fig. 1. General circulation over the Berings Sea shelf as determined by current meter, hydrographic and satellite tracked drifter data (from Kinder and Schumacher, 1980).

Mooring ID	Approximate Position	Water Depth	Instruments
TP 1*	45°01'N 161°97'W	Lagoon Pt Wind Sta	wind recorder
TP 2	56°03.5' 161°18.0'W	26 m	2 cm's: 1 ACM 1 Aanderaa w/ transmissometer 1 pressure gage
TP 3*	56°19.5'N 161°34.0'W	70 m	Surface mooring 1 wind recorder Temp/Cond chain 7 ACM
TP 4	56°20.0'N 161°34.0'W	68 m	2 cm's: 1 ACM 1 Aanderaa w/ transmissometer 1 Pressure gage
TP 5	56°29.0'N 160°07.0'W	28	2 cm's: 1 ACM 1 AAnderaa w/ transmissometer 1 pressure gage
TP6	45°45.0'N 160°23.0'W	59 m	3 cm's, 1 PG: 1 ACM 2 Aanderaa, 1 w/ transmissometer 1 Pressure gage

NOTE: ACM is a Neil Brown current meter.
*These instruments will be deployed and recovered during August cruise.
Transmissometers will not be redeployed in January 1981

CTD casts will be taken during deployment and recovery. In addition, XBT data will be collected and CTD stations will be taken on 12 lines normal to the peninsula and at about 50 locations in the St. George lease area and across the Alaska Stream. There will be approximately 126 casts and 120 XBT's

The proposed array of TP moorings CTD, and XBT stations are designed to provide observations of:

a) along and cross shelf (i.e. across the inner front) currents, bottom pressure, and mass distribution;

b) comparison at three locations between Aanderaa and ACM records; and

c) time series of current, temperature and conductivity versus depth and surface winds (TP3).

These data will be used to address questions 2-5 over the 10 month observation period. Because of severe conditions, TP3 will be recovered during the August 1980 cruise and converted to a subsurface mooring for deployment in January 1981. Not only will these be the first winter records from this lease area, but they may provide further information on response of the velocity field to ice cover, the impact of ice melt on stratification and frontogenses. Such data are necessary to understand the fate of oil during winter conditions.

The following are abstracts of papers to be given at the Second International Symposium on Stratified Flows Trondheim, 24-27 June 1980. Manuscripts are to be published in a proceedings volume.

B. Frontal Systems of the Southeastern Bering Sea Shelf

L.K. Coachman[1], T.H. Kinder[2], J. D. Schumacher[3], R.B. Tripp[1]

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[3]PMEL/NOAA

The eastern Bering Sea continental shelf is extremely broad (∿500 km). Its bottom grades smoothly off-shore to a relatively deep (∿170 m) shelf break. In Bristol Bay, the southeastern portion of the shelf, the 50- and 100-m isobaths divide the shelf into three extensive depth domains. The 50-m contour lies 80-150 km from shore, and the 100-m contour is 100-150 km landward of the shelf break, leaving a central region over 200 km broad with intermediate depths. Numerous data define in both T/S properties and stratification three hydrographic domains essentially coincident with the depth domains.

Numerous moored current meter data together with the hydrographic material and drogue deployments show the field of motion to be overwhelmingly dominated by tidal currents (> 90% of the total energy variance). Thus the eastern Bering Sea shelf is a classic example of the shelf sea of Csanady (1976). Because some freshwater is continually added from land while the long-term salinity field is relatively invariant, on-off shelf fluxes of freshwater and salt are continuous and primarily tidally-driven.

Three fronts separate the hydrographic domains: *outer*, centered over the shelf break; *inner*, closely following the 50-m isobath; and *middle* along the 80-100 m depth contours.

The *inner* front extends along the whole eastern Bering Sea shelf from Unimak Is. to Cape Navarin. Its signature is an enhanced gradient of mean salinty ($\frac{\Delta\bar{s}}{\Delta x}$ $\sim$ 10 x 10^{-3} gm km^{-1} km^{-1}) increasing seaward (as well as of other non-conservative properties). The *middle* front is also witnessed by an enhanced horizontal mean salinity gradient of the same order, while in the domain between $\frac{\Delta\bar{s}}{\Delta x} \sim 0$. The *middle* front also demarks a change in vertical water column structure. Landward of the front the central shelf domain is two-layered, while seaward the upper and lower, relatively well-mixed layers are separated by a third layer replete with finestructure. The *inner* front, located along the 40-50 m isobaths and about 10 km wide, is demarked by a change in water column structure, from the two-layered central shelf domain to the vertically well-mixed coastal domain. The central shelf domain exhibits low horizontal salinity gradients ($\sim$2 x 10^{-3} gm kg^{-1} km^{-1}) which are even less across the inner front; within the coastal domain, these gradients are an order larger.

The *outer* front is characteristic of shelf break fronts previously described from middle latitude shelves (e.g., New England, Nova Scotia); the *inner* front appears to be analogous in many respects to the fronts around the British Isles; we have found no analogy in the literature for the *middle* front.

We explore qualitatively and quantitatively the causes and consequences of the fronts. The changes in water column structure in the three domains, where the fronts denote the region of transition, are due to changes in primary mixing energy balance as a function of depth. The primary mixing energy sources are from wind and tidal current shear propagating into the water columns from their respective boundaries. The changes in stratification lead to significant changes in the modes or mechanisms of horizontal flux in the three domains, to which the marked changes in mean horizontal salinity gradients are related.

C. ENERGY BALANCE IN A HIGHLY STRATIFIED EMBAYMENT: NORTON SOUND, ALASKA

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Norton Sound, a broad (∿100 km), shallow (20-30 m) subarctic coastal embayment indenting the Alaskan coast in the northeastern Bering Sea, exhibits a strongly two-layered hydrographic structure during summer. The interface between upper and lower layers in the eastern sound is characterized by extreme vertical gradients which intensify slightly over the course of the summer. Temperature gradients across this interface are as high as $4^{o}C\ m^{-1}$, salinity gradients are about $1.5^{o}/oo\ m^{-1}$, and the corresponding Väisälä frequencies are about $0.1\ sec^{-1}$. Conservation of heat arguments yield estimated vertical eddy coefficients through the interface of order $10^{-2}\ cm^{2}\ sec^{-1}$, an unusually small value. Estimated interfacial Richardson Numbers are of order 10^{2}, suggesting vertical turbulence is greatly suppressed.

The interface is a nearly horizontal boundary between a well-mixed bottom layer and a stratified upper layer. The layered structure reflects an unusual balance between buoyancy input and turbulent mixing in which the turbulence is inadequate to vertically mix the entire water column despite shallow depths and 20 cm sec^{-1} tidal currents. Buoyancy input is large, of order 10^{-3} W m^{-2}, and provided by advective freshwater addition and solar insolation, which is trapped near-surface by high suspended sediment concentrations. The buoyancy input is confined almost entirely to the upper layer by the extremely low fluxes of heat and salt across the interface. Turbulent kinetic energy is available due to tidal dissipation at the bottom, estimated as 200×10^{-4} W m^{-2}, current shear at the interface, and winds. Interfacial Froude Numbers of order 10^{-1} suggest that internal wave breaking due to interfacial shear does not contribute significantly to mixing. It was impossible to quantitatively estimate the wind energy input, though a study of local climatological parameters suggests that it is not large during summer. It has been determined for other shelf regions that given tidal currents of the order occurring in Norton Sound, 1-2% of the tidal dissipation is sufficient to mix water columns of order 50 m. However in Norton Sound buoyancy input is of order 5% of the tidal dissipation, a uniquely high value. Thus even though the water column is only 20-30 m deep there is insufficient mixing energy available,and a mid-depth interface develops and increases in intensity over the summer.

The following two manuscripts are preliminary results from the summer 1979 Tide Experiment (TX):

D. OBSERVATIONS OF CURRENT METER FOULING BY MEDUSAE IN THE BERING SEA

Prepared by:

Gary Lagerloef
Ocean 433
February 28, 1980

ABSTRACT

The degradation of current records from Bristol Bay is documented as stemming from medusae interfering with current meter rotors. Medusa tentacles bound to the stem and bearings of the rotor shafts increased the resistance to rotor turning. A significant percentage of false readings of zero speed resulted. The degree of influence on moorings bracketing a structural front possibly suggest a gradient in medusae concentration across the front.

INTRODUCTION

In recent years physical oceanographers have accumulated a great deal of information on circulation over continental shelves. Experiments were designed to examine shelf dynamics and verify theoretical models; however new theories are often needed to explain unexpected observations. All observations from the field must be critically examined keeping in mind the limits of the instrumentation used to collect the data. Presented here is a case where unusual records from a series of current meter moorings defied an acceptable theoretical explanation. Instead, the anomalous records were evidently due to mechanical interference with the meters by marine organisms.

The current records in question were collected as part of a study into the circulation of Bristol Bay, Alaska, a shallow shelf region constituting the southeastern portion of the Bering Sea (Figure 1). The bay is typically ice covered in winter. Ice melt initiates stratification where water depth exceeds 50m and the insolation during the extended day light hours at high latitudes allows the surface waters to be warmed considerably (10-15^{o}C) and a strong thermocline to be developed. Currents over the shelf are dominated by strong tides and tidal mixing generates an inshore region where the water column is nearly homogeneous. (Schumacher, et al 1979). The boundary between this domain and the deeper stratified middle shelf domain constitutes a structure front aligning itself along the 50m isobath (Schumacher, et al, 1979). Sites adjacent to the front, occupied in 1976, showed inexplicable periods of no energy (ie, no indicated water movement) during summer. The purpose of the present experiment was to examine this phenomenon and the general frontal dynamics in more detail.

METHODS OF OBSERVATION

Current meter moorings named TX1 and TX2 were deployed 30Km apart along a line intersecting the front in depths of 75m and 35m respectively (Figure 1). The deployment lasted from July 23 to August 12, 1979, yielding 20 days of data with a sampling interval of 10 minutes. Mooring TX1 had instruments at depths of 15m, 20m, 25m, 30m, 50m and 70m while TX2 had them only at the 25m and 30m depths. The data tapes from the current meters were processed by a standard in house system (Charnell and Krancus, 1976) to produce the records shown in figure 2. Data from the 50m and 70m depths at TX1 and the 30m depth at TX2 were not useable due to various malfunctions.

Upon recovery, the instruments were heavily entangled with flesh and tentacles apparently of the scyphomedusa Cyanea Capillata. This was the first direct evidence of this type of fouling to these instruments. The current meters were photographed to document the degree of fouling. (Figure 3). One rotor was observed to have a restoring force. When it was turned a small angle then released it returned to its original position.

In conjunction with the above observations, a series of CTD casts were made in the vicinity of each mooring just prior to recovery. Representative profiles from each mooring appear in figure 4.

DISCUSSION

Occurance of Cyanea:

A historical footnote shows that interference by these medasae is nothing new. Rathbun (1894) reports that in this region there were "large concentrations of jelly fish, brownish or rusty in color measuring 6 to 18 inches across with long tentacles having great stinging powers." They were not observed on the surface, but concentrations appeared abruptly in early July and interfered with fishing hooks, cod trawls and anchors (Rathbun, 1894). More recently, C. Capillata has been reported in this region by Cooney (1978) in concentrations described as "common" in comparison to other macroplankton species. There has also been suggested a relationship between Cyanea and various gadoid fish (Hardy, 1965, Hay and Adams 1975) and Bristol Bay is coventionally known to have a highly productive fishery of gadoid species. All evidence shows that high concentrations of C. Capillata, or similar medusae, are common during the summer months in Bristol Bay.

Fouling:

The primary effect of fouling by medusae was interference with the free spining of the rotor. This was brought about by accumulations of tentacles around the rotor shaft and bearings which increased the threshold velocity that initiates turning of the rotor. While it is difficult to distinguish records of low speeds as being either real or biased, it is certain that extended periods of zero speed are indicative of fouling. Figure 2 shows several records from TX1 with numerous zero speed periods evident. A statistical estimate was made of the degree of interference by comparing the number of zero speed records to the total number of records. These estimates are shown in Table 1.

TABLE 1. Percentages of records with zero speed.

Mooring ID	Current meter depth (meters) 15	20	25	30
TX1	12.5	13.5	6.4	17.7
TX2	--	--	4.2	--

The mean of the four TX1 percentages is 12.5% with a standard deviation of 4.7% and a 95% confidence interval of $\pm$ 14.8%. For TX2, the single observation of 4.2% has a 95% confidence range of 2.1% to to 8.4%. There appears to be a statistically higher degree of fouling at TX1 than at TX2 and this suggests that the medusae concentrations were higher at the TX1 mooring.

Figure 4 depicts the profiles from CTD stations at TX1 and TX2. It is clearly evident that the water column structures differ sharply at the two stations. The aforementioned structure front separates the domains and the degree of lateral mixing across the front has not been determined. Qualitatively, drogue and drifting studies conducted during the 1979 cruise indicated surface convergence toward the front (personal observation). Such convergence would have tended to isolate the water masses and possibly the medusae populations as well.

Given that the medusae at TX1 and TX2 were separated by an effective boundary, it is interesting to speculate why concentrations appeared to be greater at TX1. Jelly fish enter the medusa stage in spring or early summer when conditions are well sutied to their proliferation. Perhaps the medusae originated primarily in the midshelf stratified region and were not readily conveyed across the front. The one environment possibly was preferred over the other. Jelly fishes are the culmination of a food chain based on dinoflagellates and microflagellates which are favored over other primary producers in stratified, low nutrient waters (Greve and Parsons, 1977).

The sampling technique is by no means rigorious and these observations are weak statistically. The data do suggest, however, that there was a measurable gradient of medusea concentrations across this structure front and justify, perhaps, a more thorough investigation.

The data are significant, however, in describing the original problem. The medusae pose a considerable difficulty in obtaining reliable measurements during the summer. Considering that one meter experienced 17% of its records obliterated and an unknown number reduced in magnitude, the entire record is not suitable for a rigorous analysis.

The impact of these findings should be toward improved design of future experiments. The ultimate solution would be instrumentation significantly less susceptable to interference by these type of organisms. The remaining option is planning the experiment around the periods of high medusa concentration. However this will again prevent complete reliable measurements of the seasonal behavior of the velocity field. An intercomparitive experiment is planned for 1980 in which acoustical current meters, less likely to be affected, will be moored simultaneously with rotor type meters. Hopefully, these data will allow us to quantify the problem in more precise terms.

SUMMARY

C. Capillata and/or similar medusae adversly interfered with normal functioning of savonius rotor current meters during the summer in southern Bristol Bay. This conclusion is evidenced by entangled masses of tentacles and flesh on the instruments when they were recovered and by a significant number of zero speed readings by the recording current meters. The latter are presumed due to the medusae tentacles resisting rotor turning and thereby increasing the threshold speed. Using the percentage of zero readings as a measure, the data suggest that the stratified middle shelf domain had a higher concentration of medusae than nearby (30Km distant) unstratified coastal domain.

Acknowledgements

James Schumacher, David Pashinski and Hal Mofjeld, who designed and implemented this experiment, are to be thanked for allowing me to use the data for this report. Michael Grigsby's efforts in the mooring deployment and data processing are sincerely appreciated. The officers and crews of the NOAA Ships SURVEYOR and DISCOVERER are to be commended for their excellent field support.

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FIGURE 1.

Showing the locations of moorings Tx1 and Tx2.

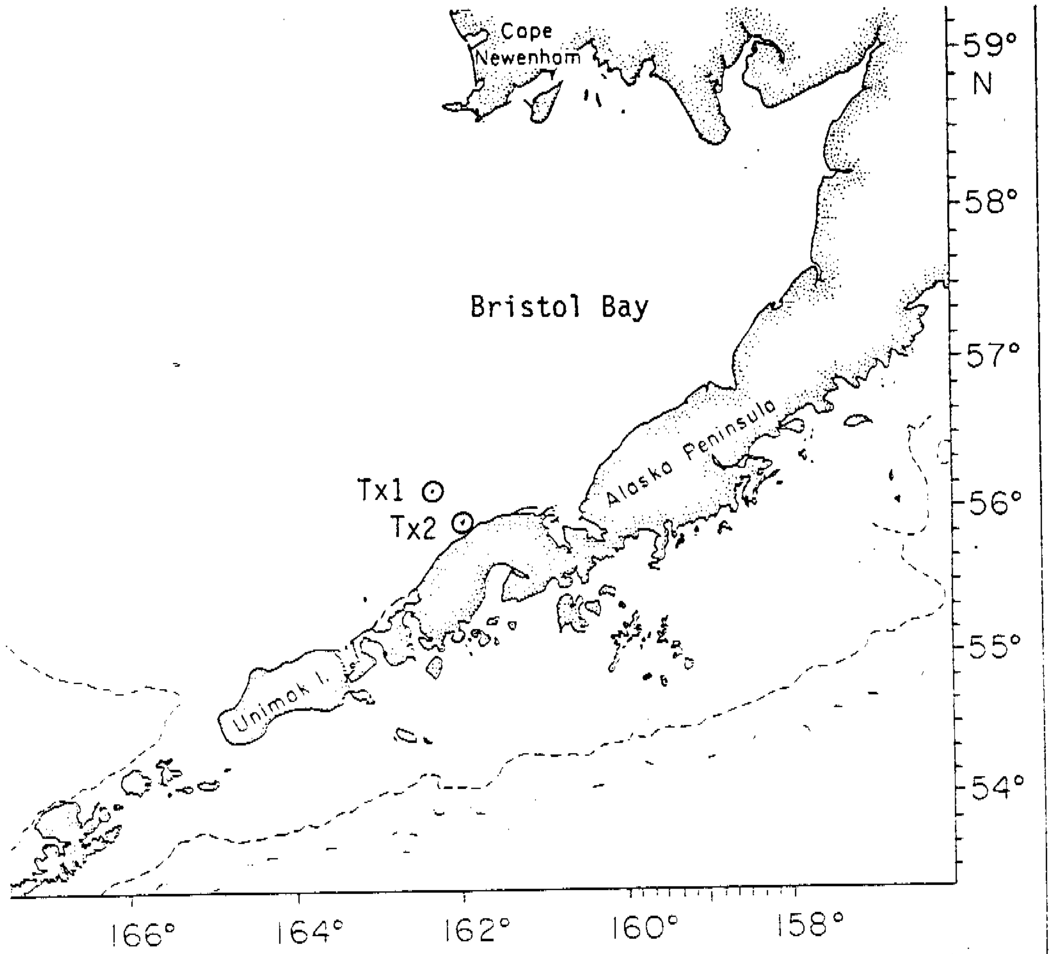

FIGURE 2. Current meter speed records.

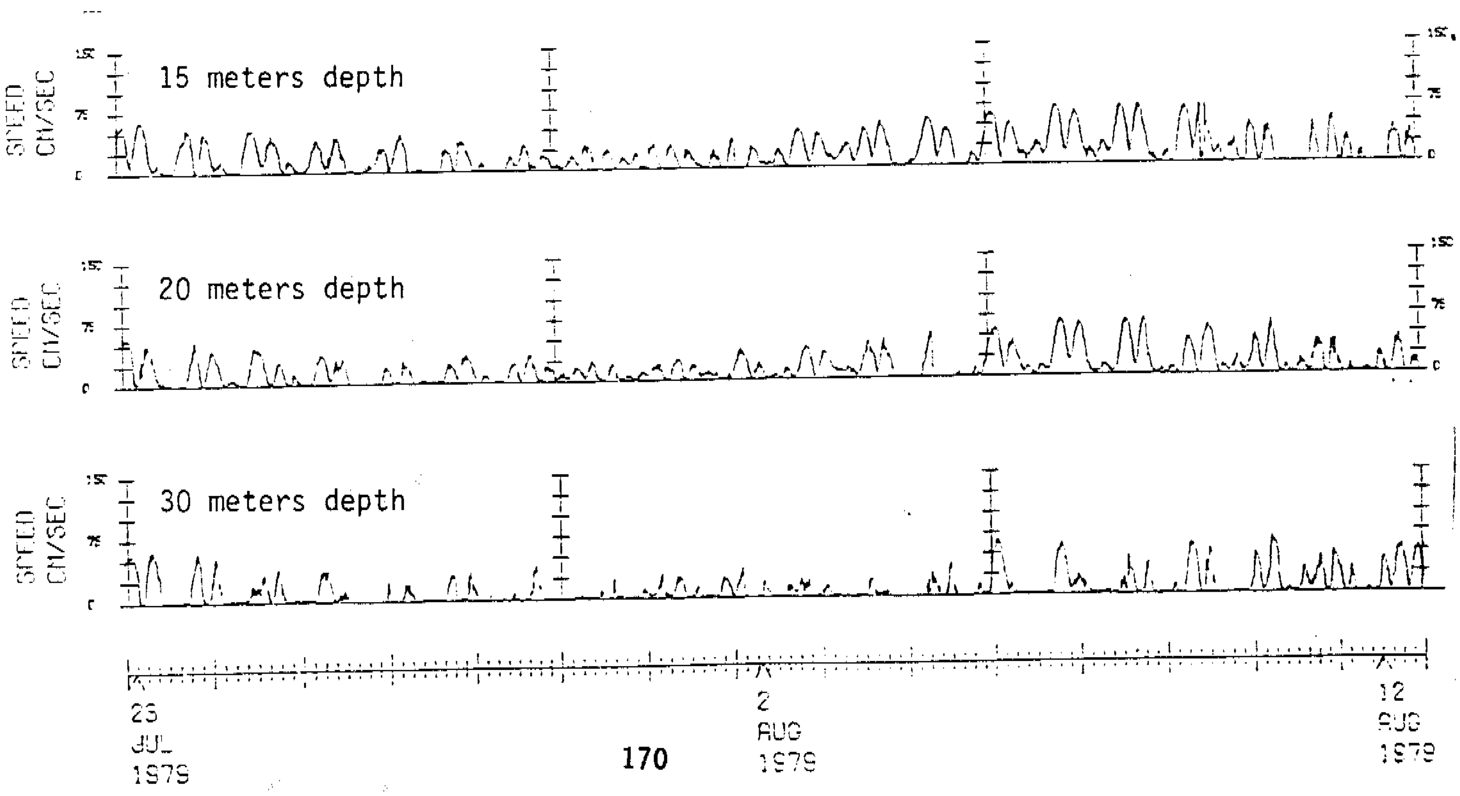

FIGURE 3. Examples of medusa fouling at Tx1.

This figure was not included in this report as its quality was not suitable for reproduction.

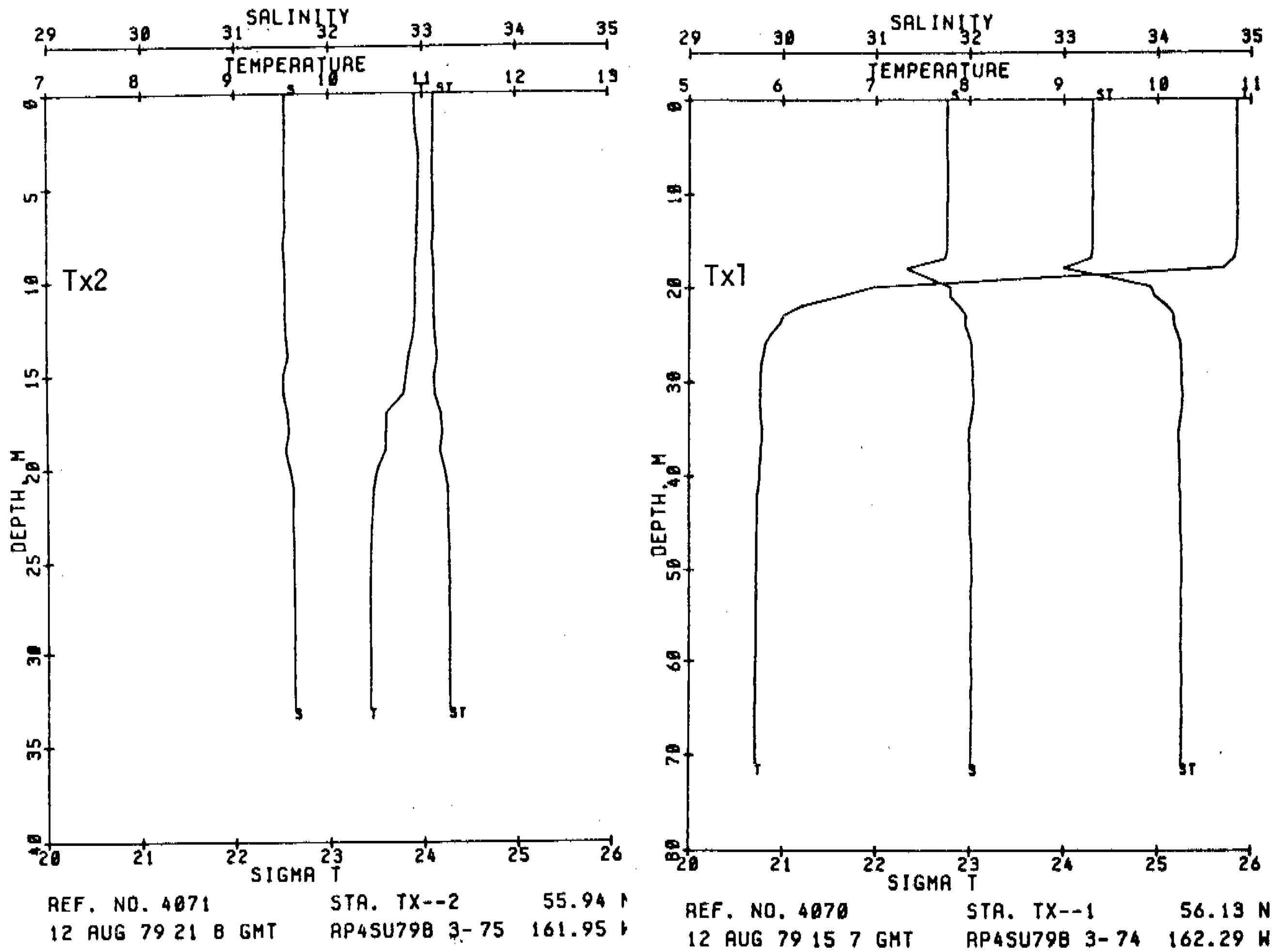

FIGURE 4. Showing profiles of temperature, salinity and sigma-t.

Note: The spikes in the salinity and sigma-t curves at Tx1 are artifacts of the instrument response time as it descended through the thermocline.

The following three manuscripts are chapters on the Bering Sea: Oceanography and Resources:

E. HYDROGRAPHIC STRUCTURE OVER THE CONTINENTAL SHELF OF THE SOUTHEASTERN BERING SEA

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ABSTRACT

We synthesize recent work conducted over this exceptionally broad (~500 km) shelf which generally has only slow mean flow (≤2 cm/s). Hydrographic structure is little influenced by this flow, but rather is formed primarily by boundary processes: tidal and wind stirring; buoyancy input from insolation, surface cooling, melting, freezing, and river runoff; and lateral exchange with the bordering oceanic water mass. Three distinct hydrographic domains can be defined using vertical structure to supplement temperature and salinity criteria. Inshore of the 50 m isobath, the coastal domain is vertically homogeneous and separated from the adjacent middle domain by a narrow (~10 km) front. Between the 50 m and 100 m isobaths, the middle domain tends toward a strongly stratified two-layered structure, and is separated from the adjacent outer domain by a weak front. Between the 100 m isobath and the shelf break (~170 m depth), the outer domain has surface and bottom mixed layers above and below a stratified interior. This interior has pronounced finestructure, as oceanic water intrudes shoreward from the weak haline front over the slope, and shelf water (middle domain) intrudes seaward across the 100 m isobath. These domains and their bordering fronts tend to persist through winter, although the absence of positive buoyancy often makes the middle shelf vertically homogeneous.

INTRODUCTION

We selected the title hydrographic "structure" rather than simply "hydrography" because we wish to emphasize the structure, or organization, that is inherent in the hydrographic distributions. This approach focuses on the shapes of vertical profiles, or rather classes of shapes (e.g. two-layered). This is contrasted with focusing on values of temperature and salinity or their correlation (TS diagrams). Thus, we find a large region of the shelf where the temperature and salinity is vertically homogeneous throughout the year, although the values of temperature and salnity fluctuate over a wide range. We concentrate on the persistent vertical homogeneity and label this region a hydrographic domain. Because vertical profiles control the hydrostatic stability of the water column, and because stability influences vertical mixing, this approach is physically meaningful and useful.

We also concentrate on characteristics of small size, on what can be called the spatial variability. Thus the fronts that separate regions of uniform hydrographic structure (hydrographic domains) are discussed in some detail, as is the finestructure that is found over the outer shelf. One front, for example, has a width of only 10 km and the finestructure has a typical vertical extent of 5 m. It is now possible to resolve features such as fronts and finestructure because of closer spatial sampling than previously available.

Our emphasis on hydrographic structure and small spatial scales is not opposed to examination of TS properties or broader spatial scales, but complementary to it. Our description of the shelf hydrographic structure is more meaningful in the perspective of shelf environment from a more climatic viewpoint. We mostly ignore changes at periods longer than annual, although interannual hydrographic variability is significant (e.g. Overland's and Niebauer's chapters on weather and Ingraham's chapter on shelf environment). The major features that we discuss here, however, were observed both in 1976 (the winter of 1975-1976 was exceptionally cold, with extensive ice cover) and in 1977 (the winter of 1976-1977 was exceptionally mild, with reduced ice cover). Although altered by interannual changes, the features that we describe persist through these long-term variations.

Because mean flow over the shelf is small, changes in hydrographic properties are more straightforwardly attributed to local processes rather than to advection. For instance, cold temperatures in the lower layer of the middle shelf persist throughout summer (Figure 4). This was once believed to be evidence of mean flow from the northern shelf, but the cold temperatures are caused by local processes: heat loss at the sea surface and complete vertical mixing during winter, followed by the establishment of strong stratification during spring and summer. This stratification insulates the lower layer from downward heat transfer. Especially over the inner two thirds of the shelf, important characteristics of the hydrography can be explained by local phenomena and advective effects are unimportant.

We complete the introduction by briefly discussing the oceanographic setting, reviewing previous work, and discussing the data. Then we define the hydrographic structure by discussing salient characteristics: domains, fronts, finestructure, winter structure, and river plumes. We then discuss some processes that affect the hydrographic structure: stirring and buoyancy addition, heat and salt transport, and upwelling. Finally we discuss and speculate about aspects of the hydrographic structure.

Setting. The southeastern continental shelf is bordered by the Alaska Peninsula, the Alaska mainland, and by a line running southwest from Nunivak Island to the Pribilof Islands and thence following the shelf break southeastward to Unimak Pass. Waters above the shelf receive an annual excess of precipitation over evaporation, as well as freshwater runoff from numerous rivers. Estimating precipitation from either Jacobs (1951) or from station data reported by Bower et al. (1977), and evaporation from Jacobs, a net of about 1% of the volume of water over the southeastern shelf is added annually by precipitation minus evaporation.[1] An additional 1% is added by river runoff, principally from the Kuskokwim and Kvichak (1500 to 2000 m^3/s average discharge from all rivers; Roden 1967, Favorite et al. 1976). During winter ice covers over 50% of the shelf, initially appearing inshore during November, often expanding to cover more than 80% of the shelf by March, and rapidly disappearing between late April and early June (Favorite et al. 1976; Muench and Ahlnas 1976). Ice appears to form near shore and is blown southward during the freezing season (see Chapters on ice by Pease and McNutt). Current meter records show that most of the horizontal kinetic energy of the shelf water is tidal: 60 to 95% of the variance in records of 9 to 332 days length was tidal (see Kinder and Schumacher, following Chapter). Vector mean speeds ($\leq$2 cm/s) were one order of magnitude lower than tidal speeds (~20 cm/s).

Historical Review. There has been considerable Japanese, Soviet, and American work done on this shelf. Results from this work have been effectively summarized (Ohtani 1973, Takenouti and Ohtani 1974, Arsen'ev 1967, Dodimead et al. 1963, and Favorite et al. 1976), and this brief review places more recent results in perspective.

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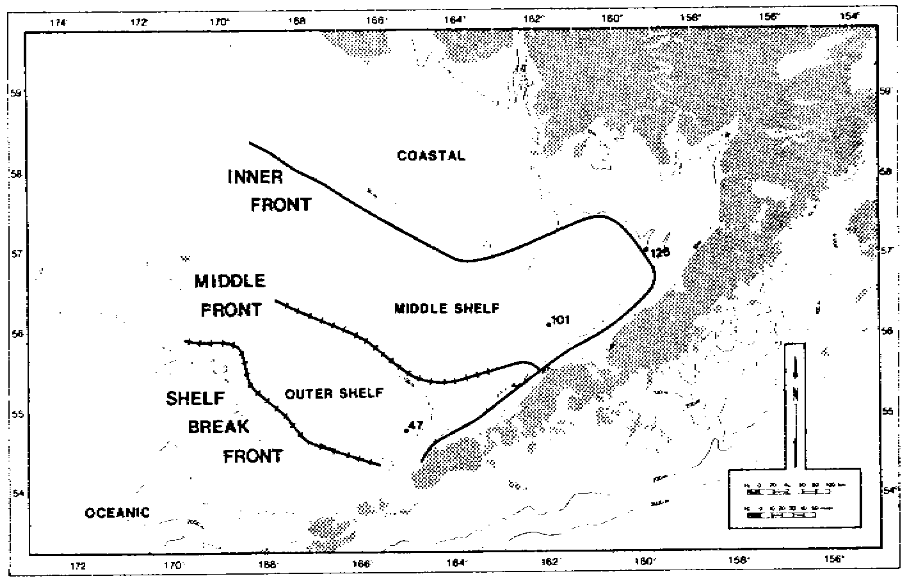
[1] Using recent precipitation estimates by Reed and Elliott (1979) would increase this to nearly 2%. Reed and Elliott state, however, that their estimates may be inaccurate in the subarctic Pacific.

Takenouti and Ohtani (1974) discussed waters above the shelf, which they realized were separated from ocean waters by a "discontinous zone" (cf. Kinder and Coachman 1978). They further reported that the cold (<1.0°C) water near the bottom in the middle shelf (cf. Fig. 4) was not advected from the Gulf of Anadyr as Kitano (1970) believed, but was formed in situ during winter and insulated by strong stratification during summer. Their proposed classification for water masses over the southeastern shelf, has been modified by recent findings. Takenouti and Ohtani defined a CW (Coastal Water) region by its low salinity, but we have found that at the end of winter the salinity may be higher there than in the adjacent convective area (CA - roughly corresponding to our middle domain). Additionally, the Alaskan Stream (AS) region near the shelf break is misnamed - direct connection with the westward flowing Alaska Stream, which exists south of the Alaska Pennisula and Aleutian Islands is unproven. At the same time, our map of hydrographic domains (Fig. 1) is congruent with theirs, and builds upon their insights.

Ohtani (1973) discussed the southeastern shelf in more detail. He mentioned the thermal front that forms between the middle and coastal domains (cf. Fig. 6 and Schumacher et al. 1979), and correctly suggested the importance of tidal stirring in forming this front. Ohtani also emphasized vertical stratification in defining shelf water masses, and dwelt less on arbitrary temperature and salinity limits. Again, net inflow of Alaskan Stream water is more tenuous than Ohtani suggested; properties are certainly



* I-4-1 Schumacher

exchanged through the eastern Aleutian Passes by vigorous tidal currents, but the net flux of water is not known, and is probably small in any case because of small cross sectional area (Favorite 1967).[1]

Arsen'ev (1967) wrote about water masses and currents of the entire Bering Sea, using many sources, but highlighting Soviet work. He discussed the importance of water mass transformation by freshwater runoff, insolation, cooling, melting, and freezing. He also recognized the separation of oceanic and shelf waters, but virtually ignored the southeastern shelf in favor of the western shelf, especially the Gulf of Anadyr.

Dodimead et al. (1963) and Favorite et al. (1976) summarized the regional oceanography of the North Pacific, including the Bering Sea. Dodimead et al. (1963) included an appendix on Bristol Bay, and noted several features that have been elaborated only recently. They reported the inner front that separates the coastal and middle domains as a sharp boundary (cf. Schumacher et al. 1979), and also reported "marked changes" near the shelf break that correspond to the weak haline front there (cf. Kinder and Coachman 1978, Coachman and Charnell 1979). They also noted the cold patch of surface water within Bristol Bay, which they attributed to upwelling. Favorite et al. (1976) showed three domains across the shelf: shelf edge, mid-shelf, and West Alaska Coast (their Fig. 33). Their geographical

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[1]Favorite (personal communication 1979) has pointed out that the distribution of a temperature maximum along the eastern Bering Sea continental slope suggests net inflow to the Bering Sea through passes west of Unimak Pass between 170°W and 172°W.

boundaries were nearly coincident with the three domains that we describe in the next section, but they were apparently based on TS relations (cf. Chapter on shelf environment by Ingraham). Favorite et al. (1976) also discussed the frontal zone over the slope.

Thus, many of the features that we now recognize as important components of the hydrographic structure of the shelf were reported previously. Among these features are the front over the slope and the inner front farther inshore, the division of shelf waters into distinct domains, and the possible upwelling in Bristol Bay. While we now know more details and have better understanding of these features, it is clear that our progress has benefited from these earlier works.

Data. From August 1975 to February 1978, hydrographic casts were made with profiling instruments: STD (salinity, temperature, depth), CTD (conductivity, temperature, depth), or XBT (expendable bathythermograph). Covering all months from February to October, these 1064 STD and CTD casts are biased towards summer (Table I). This bias is not a serious limitation because of adequate coverage in February.

The STD and CTD data were calibrated by a water sample, normally taken at the bottom during alternate casts. Calibration temperatures were determined by reversing thermometer and salinity by portable induction salinometer. We claim an accuracy of $\pm 0.02^{\circ}C$ and ± 0.02 g/kg. The XBT profiles were calibrated against nearby CTD casts, and we claim $\pm 0.1^{\circ}C$. Unusual data processing was necessary to examine details of finestructure in vertical profiles of salinity, and this processing is discussed elsewhere (Coachman and Charnell 1979).

TABLE I

Summary of STD and CTD Data

MONTH	NUMBER OF CASTS
February	117
March	65
April	34
May	159
June	213
July	122
August	152
September	184
October	18
Total	1064

These casts were taken during the period August 1975 to February 1978.

HYDROGRAPHIC STRUCTURE

Three Hydrographic Domains. We have divided the shelf into three structural domains, called the coastal, middle, and outer domains (Fig. 1). These domains are nearly congruent with geographical boundaries previously defined by water masses (e.g. Favorite et al. 1976), and are approximately separated by the 50 m isobath, the 100 m isobath, and the shelf break (close to the 200 m isobath). Our structural domains broaden the criteria previously used for defining the shelf water masses, emphasizing the potential for stratification of the water column (Table II; also cf. Fig. 24 in Coachman and Charnell 1979). These domains are most prominent in summer, but are also discernible

TABLE II

Hydrographic Domains in Summer

	COASTAL	MIDDLE	OUTER
vertical structure	homogeneous	two-layer	surface mixed layer stratified interior bottom mixed layer finestructure
stratification	very low	very high	moderate
depth	<50 m thickness of bottom (tidal) mixed layer	50 m≤depth<100 m thickness of surface + bottom mixed layer	≥100 m ≥surface + bottom mixed layers, thus an interior region exists
temperature	very warm in late summer (efficient heat transfer throughout water column) (~8 to 12°C)	very cold bottom temperature throughout summer (vertical heat transfer impeded by stratification) (~-1 to 3°C)	moderate (~3 to 6°C)
salinity	generally low (<31.5 g/kg), but may be relatively high following winter (>32 g/kg: brine drainage during freezing)	moderately low (~31.5 g/kg)	high (>32 g/kg)
influences	river runoff freezing	melting	adjacent water overlying deep basin; Bering Slope Current

This table emphasizes summer conditions, when the domains are most clearly established and when our data are most extensive. These domains remain useful throughout the year: see the section in this chapter on winter structure.

during the other seasons. Lying seaward of the outer domain, and separated from it by a weak haline front (shelf break front), is the oceanic domain. The oceanic domain completes our scheme, but it is outside the geographic focus of this chapter (Sayles et al. 1979 concentrate on the water overlying the deep basins).

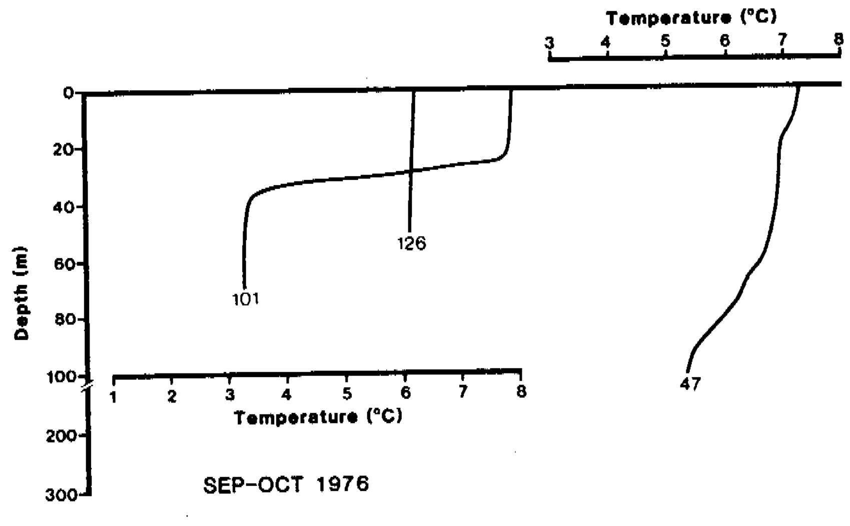
Defining water masses is most useful where temperature and salinity vary slowly at a location (e.g. no surface cooling), or where significant mean advection makes water masses a useful tracer of flow. Thus tracing water masses has usefully revealed mean flows in the deep ocean. On this shelf, however, large changes in water mass properties occur annually (Coachman and Charnell 1979, Kinder et al. 1978), and there is little mean flow. Additionally, seemingly reasonable temperature-salinity parameters may prove deceptive. For example a criterion previously used to describe coastal water has been its low salinity (Takenouti and Ohtani 1974, Favorite et al. 1976), but we now know that during early spring the coastal domain may be more saline than the adjacent middle shelf water (Kinder 1977).

To overcome some of these ambiguities, we have added vertical structure to the criteria. Instead of water mass, we use the word domain, favored by Dodimead et al. (1963) to connote broader criteria than simply temperature-salinity correlations. These domains are geographic entities: energy balances forming vertical structure are closely tied to local geography, so that the domains are also nearly fixed geographically (see stirring and buoyancy addition in next section of this Chapter).

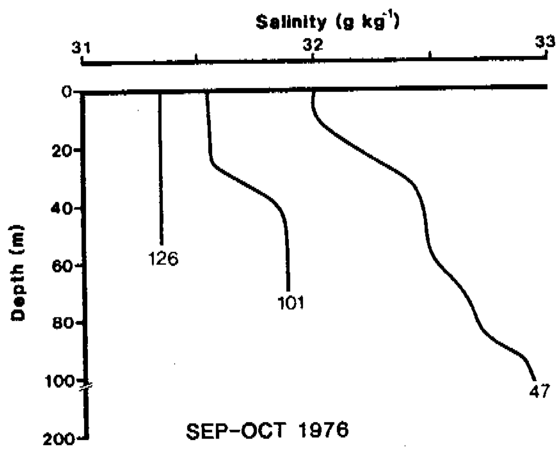
During summer, vertical structural criteria permit easy separation of the shelf into three domains: homogeneous (coastal), two-layered (middle), and stratified interior (outer; see Table II). These categories are insensitive to particular values of temperature and salinity which vary from year to year (see Niebauer's Chapter on variations of sea surface temperature and Ingraham's Chapter on shelf environment for interannual hydrographic variations), but depend on the influence of buoyancy input, which tends to stratify the water column, and tidal stirring, which tends to mix the water column.

An example from each domain from early autumn 1976 (Fig. 2) illustrates the three structures. Station 126, in about 50 m of water, is nearly homogeneous in both temperature and salinity, while station 101, in about 70 m of water is strongly two-layered with vertical temperature and salinity differences of 4°C and 0.4 g/kg. In still deeper water, station 47 has a surface layer, a bottom layer (not completely mixed), and a stratified interior. Many stations in the outer domain display strong finestructure in temperature and salinity (Coachman and Charnell 1977, 1979; Kinder 1977; Kinder et al. 1978), but we smoothed the profiles in Figure 2 to emphasize larger scale features.

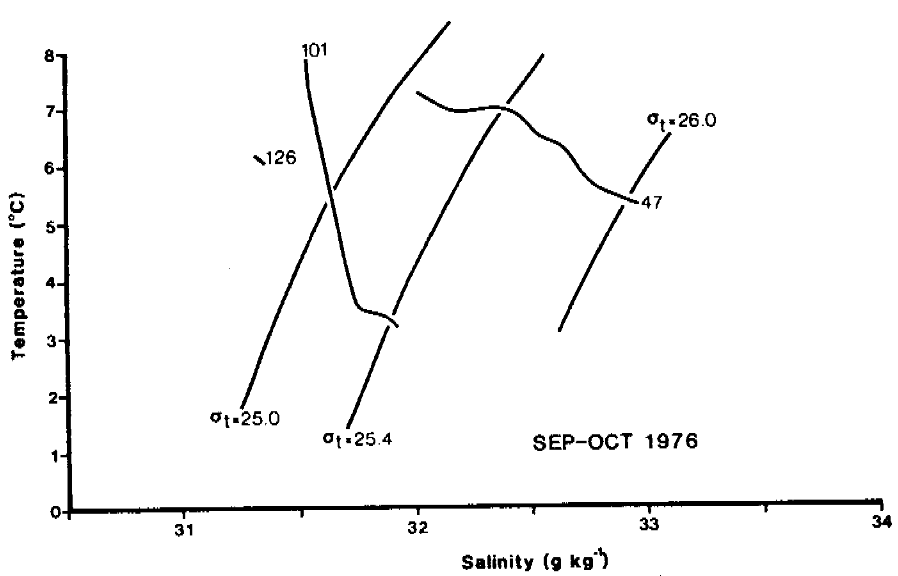
A companion view of these domains is shown by plotting vertical temperature differences across the shelf in early autumn 1976 (Fig. 3). Shoreward of the 50 m isobath, this difference was generally $\ll 1$°C, while between the 50 and 100 m isobaths it commonly exceeded 7°C. Nearer the shelf break, intermediate values near 4°C obtained. A plot of bottom temperature in autumn 1976 (Fig. 4) illustrates the strong insulating effect of the stratification displayed in Figure 3. Even in September, cold temperatures (<0°C) remained from the preceeding winter, isolated by the very strong two-layered stratification in the middle domain. In contrast, the coastal domain was well mixed and bottom temperatures exceeded 9°C. In the deeper a

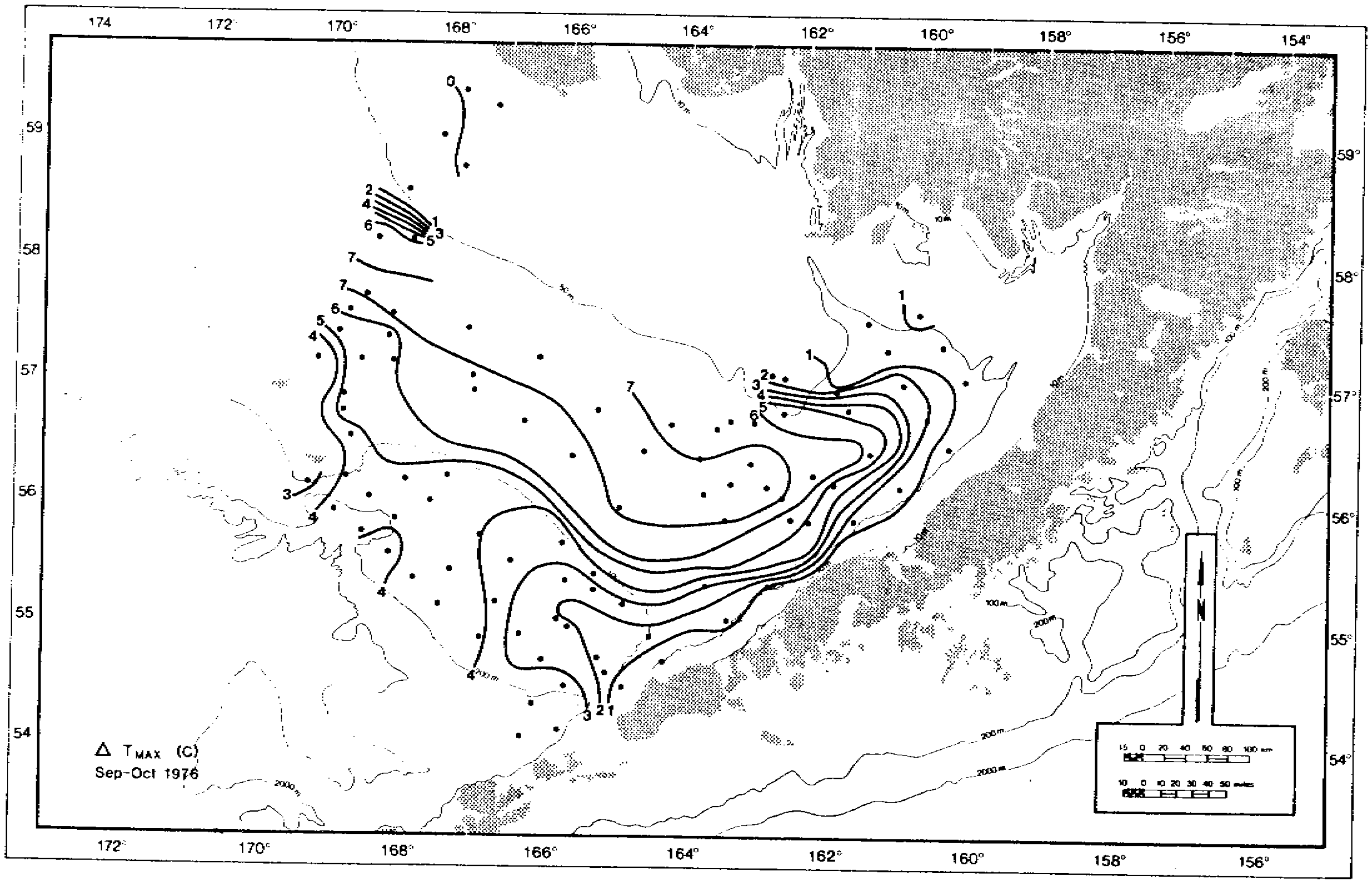

Temperature (°C)
3 4 5 6 7 8
0
20
40
60
80
100
200
300
Depth (m)
126
101
47
1 2 3 4 5 6 7 8
Temperature (°C)
SEP-OCT 1976

b


Salinity (g kg⁻¹)
31 32 33
0
20
40
60
80
100
200
Depth (m)
126
101
47
SEP-OCT 1976

C


101
126
σt=26.0
47
σt=25.0
σt=25.4
SEP-OCT 1976
Temperature (°C)
0 1 2 3 4 5 6 7 8
31 32 33 34
Salinity (g kg⁻¹)



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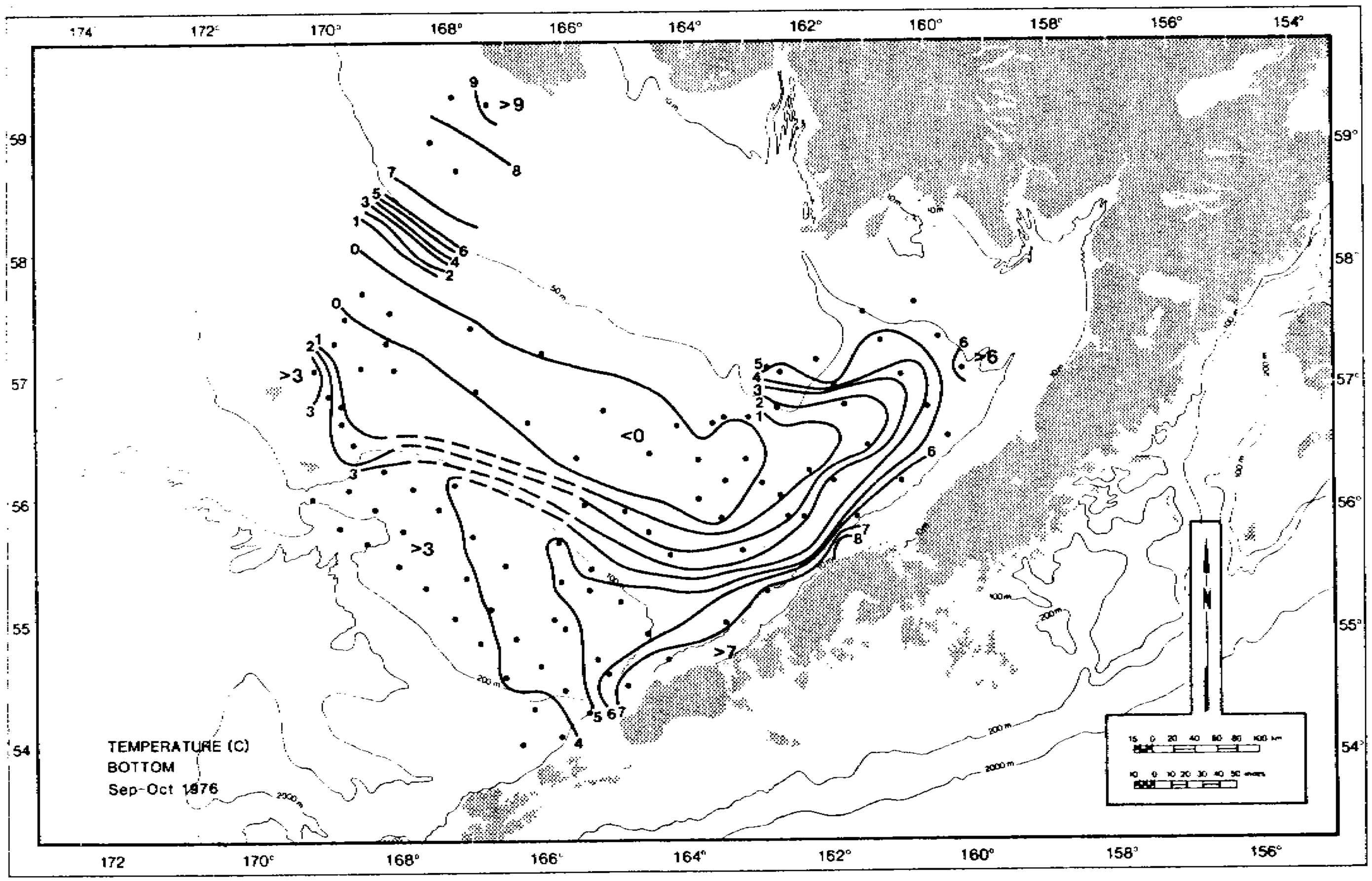

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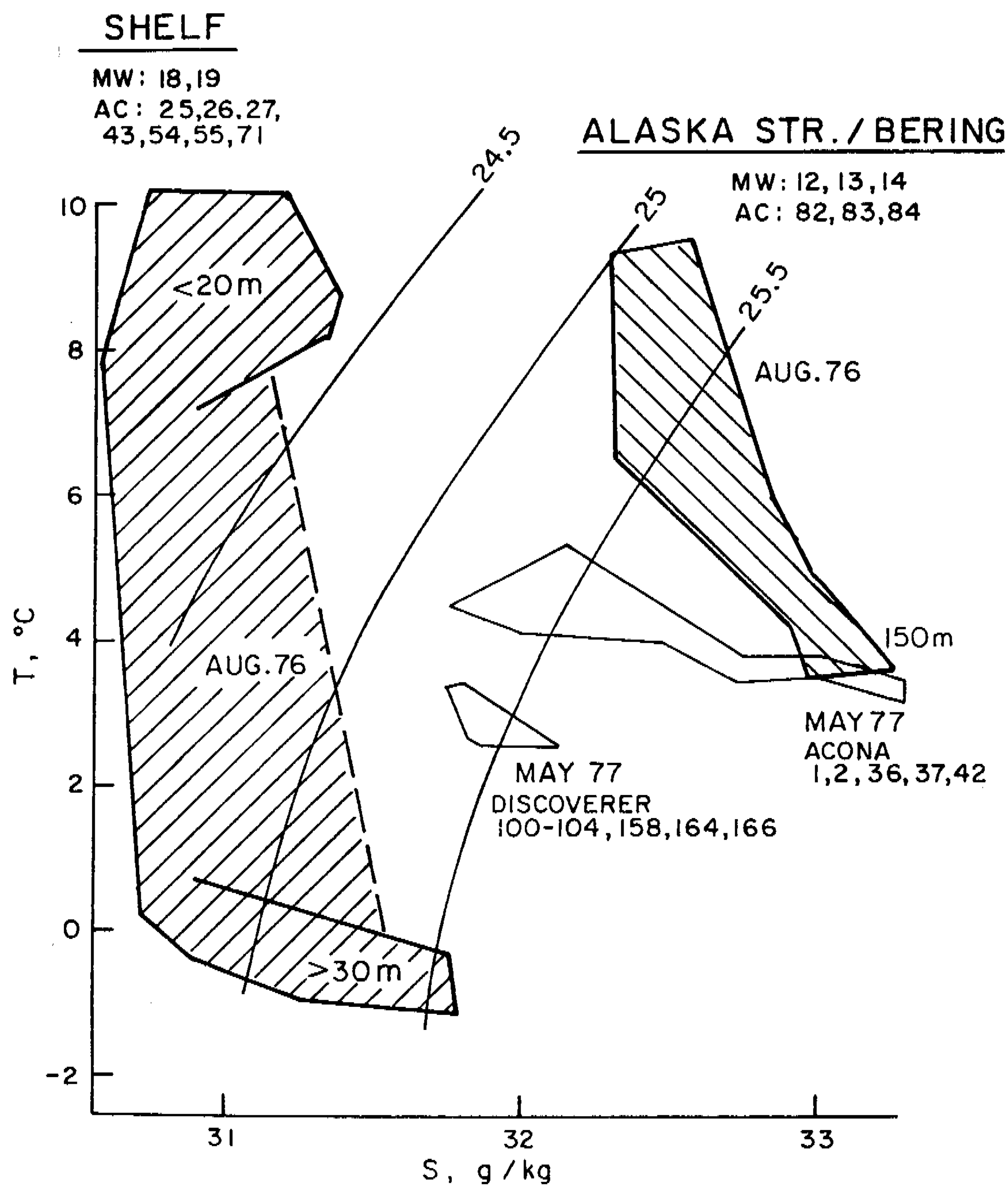
water of the outer domain bottom temperatures were intermediate, generally 3 - 6°C. Obviously, stratification is an important factor for understanding the shelf.

Using stratification as an adjunct to water mass analysis is valuable, but Coachman and Charnell (1979) also used the traditional method successfully. They defined a shelf water mass, found in the middle domain, and an oceanic ("Alaska Stream/Bering Sea") water mass, found above the continental slope (Fig. 5). They were then able to explain much of the structure of the outer domain in terms of the lateral mixing along isopycnal surfaces between the shelf and oceanic water masses. The shelf water mass was always less saline and, below 30 m depth, colder than the adjacent oceanic water. In spite of annual and interannual variations, there exists throughout the year two water masses, one cold and fresh, and the other warm and saline, in juxtaposition along the outer shelf. One important evidence of the interaction of these water masses, finestructure in vertical profiles, is discussed further below in a separate section.

A combination of categorizing by vertical structure and by traditional water mass techniques is more useful than either used separately. On examining the shelf alone, structural categories are most distinct, but in understanding interaction with waters overlying the deep basin, water mass analysis is useful. As Coachman and Charnell (1979) implied, these two views are interdependent.

Fronts. The four hydrographic domains (coastal, middle, outer, and oceanic) are separated by three fronts. The front separating the coastal and middle domain is much narrower than the domains themselves, and so is legitamately called a front. The other two transitions are much broader relative to their


SHELF
MW: 18,19
AC: 25,26,27,
43,54,55,71
ALASKA STR./BERING
MW: 12, 13, 14
AC: 82, 83, 84
24.5
25
25.5
<20m
AUG.76
>30m
AUG.76
150m
MAY 77
ACONA
1,2,36,37,42
MAY 77
DISCOVERER
100-104, 158, 164, 166
T, °C
10
8
6
4
2
0
-2
31
32
33
S, g/kg

I-4-5

adjoining domains, but they have been called fronts (e.g. Iverson et al. 1980), so we adopt this usage also. Proceeding seaward, we label these fronts as inner, middle, and shelf break (Fig. 1).

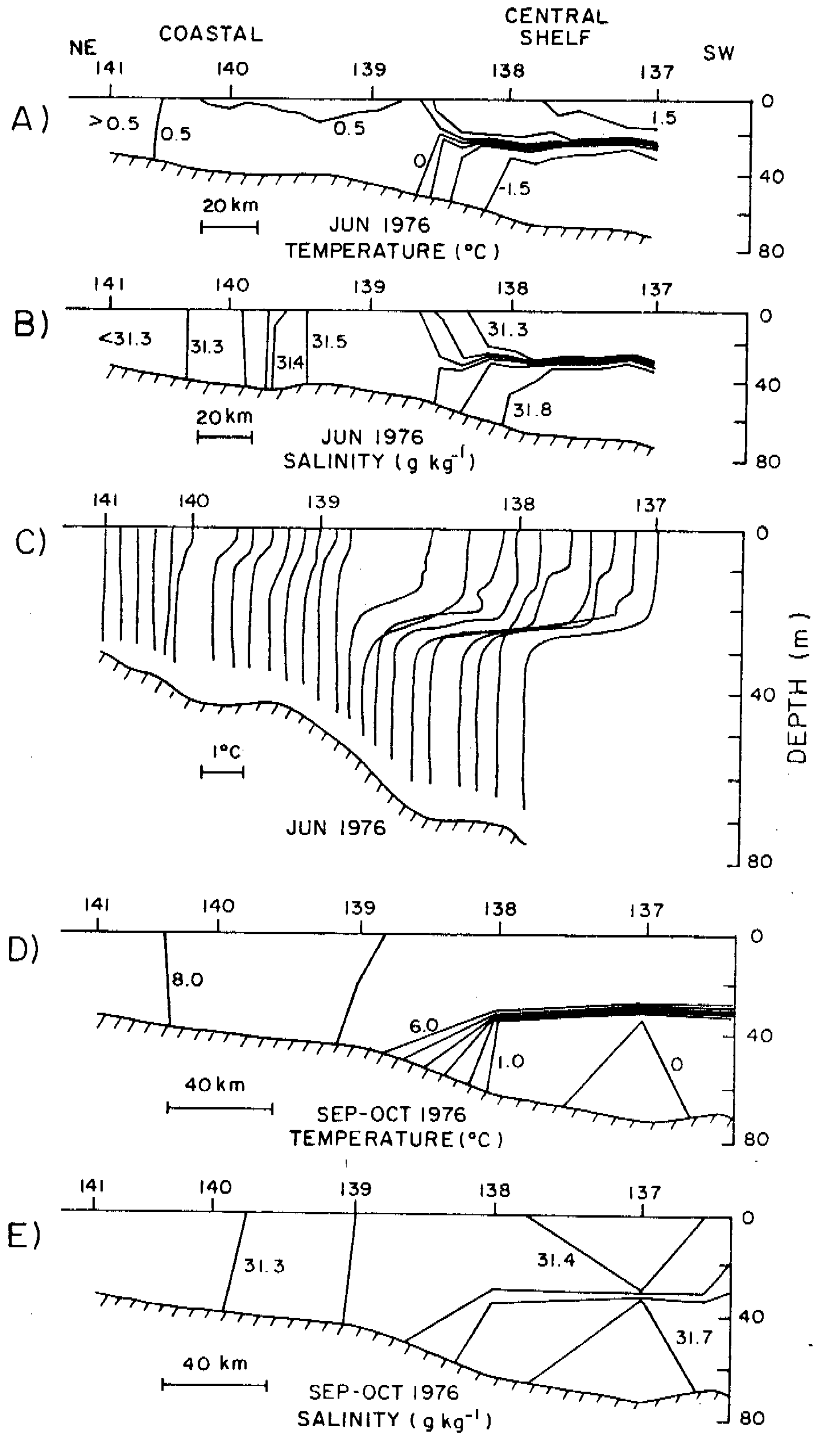
The inner front separates the homogeneous coastal domain from the two-layered middle domain. It was hinted at by Dodimead et al. (1963), and noted by Muench (1976) farther north. Schumacher et al. (1979) have called it a structural front, to stress the separation of two vertical structures or marked change of stratification rather than the separation of two water masses. The front is about 10 km wide and generally follows the 50 m isobath (Fig. 1). Approaching shallower water from the middle domain, isotherms, isohalines, and isopycnals all spread from the thin thermocline, halocline, and pycnocline over the middle shelf (Fig. 6). Within 10 km the vertical hydrographic structure changes from distinctly two-layered to nearly homogeneous. Away from the front, within the strongly stratified middle domain, the thickness of the bottom mixed layer (as judged by nearly isothermal and isohaline profiles) is nearly 50 m, about the same as the total water depth where the front is found. In general, we find that over the middle shelf the bottom mixed layer is ~50 m thick, the surface mixed layer is 15-20 m thick, and the front occurs where the water depth approximately equals the thickness of the bottom mixed layer (i.e. 50 m), and the strongest stratification occurs where the sum of the bottom and surface mixed layer thickness equals the water depth (i.e. 20 m + 50 m = 70 m).

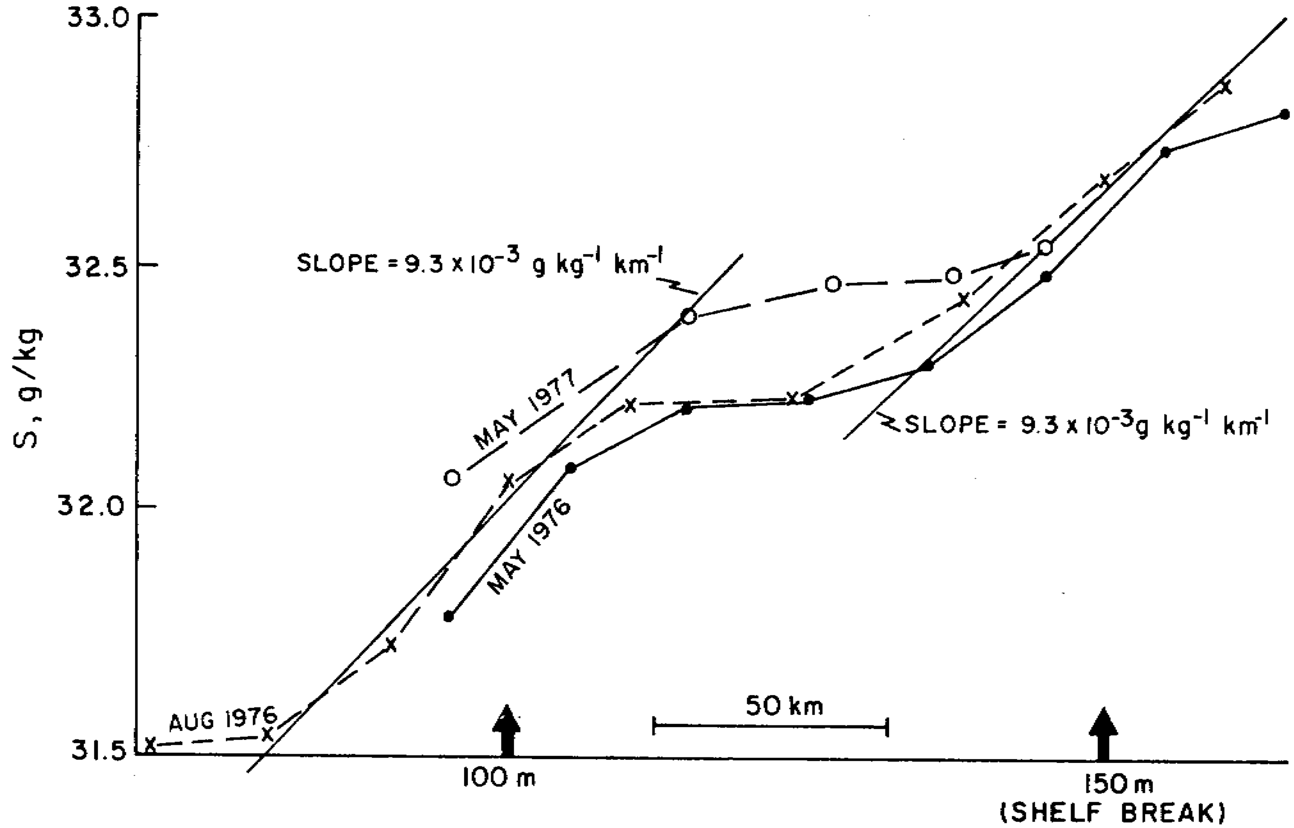
During winter, the middle and coastal domains are nearly vertically homogeneous following surface cooling, freezing, and vigorous wind stirring during fall and winter (but see our section on winter structure for an important exception). Frontogenesis occurs with the addition of meltwater during the ice breakup in spring. As this initial stratification forms, it is reinforced by insolation, so that later in summer thermal stratification is primarily responsible for vertical density differences. Schumacher et al. (1979), Kinder (1977), and Kinder et al. (1978) reported details of this front, and Simpson and Pingree (1978) summarized features of similar fronts over the European continental shelf.

The shelf break and middle fronts are less clearly describable. Overlying the continental slope, the shelf break front separates the oceanic domain from the outer domain, but the width of this front is similar to that of the outer domain. Similarly, the middle front which divides the middle and outer domains near the 100 m isobath (Fig. 1), is broad and ill-defined compared to the inner front. Nevertheless, the shelf break and middle fronts are both real and important components of the hydrographic structure.

Kinder and Coachman (1978) described the shelf break front and recognized its essentially haline character. The front is manifest by a change in the horizontal salinity gradient (from nearly zero over the deep basin to about 4×10^{-3} g $kg^{-1} km^{-1}$ over the outer shelf), by isopycnals extending from the shelf to intersect the sea surface above the slope, and by isolines downwarped beneath the front. Available winter data show that this front persists throughout the year.

Coachman and Charnell (1979) and Coachman (1978) examined this region in more detail, and described this transition zone as two broad fronts, one over the slope and one farther inshore near the 100 m isobath. Between these two transitions, each with large horizontal salinity gradients ($\sim 10 \times 10^{-3}$ g kg^{-1} km^{-1}) is a region of very small gradient (Fig. 7). The transition near the shelf break corresponds to the front described by Kinder and


NE
COASTAL
CENTRAL SHELF
SW
A)
141
140
139
138
137
>0.5
0.5
0.5
0
-1.5
1.5
20 km
JUN 1976
TEMPERATURE (°C)
B)
<31.3
31.3
31.4
31.5
31.3
31.8
20 km
JUN 1976
SALINITY (g kg⁻¹)
C)
1°C
JUN 1976
DEPTH (m)
D)
8.0
6.0
1.0
0
40 km
SEP-OCT 1976
TEMPERATURE (°C)
E)
31.3
31.4
31.7
40 km
SEP-OCT 1976
SALINITY (g kg⁻¹)
0
40
80



33.0
32.5
32.0
31.5
S, g/kg
SLOPE = 9.3 x 10^-3 g kg^-1 km^-1
SLOPE = 9.3 x 10^-3 g kg^-1 km^-1
MAY 1977
MAY 1976
AUG 1976
50 km
100 m
150 m
(SHELF BREAK)

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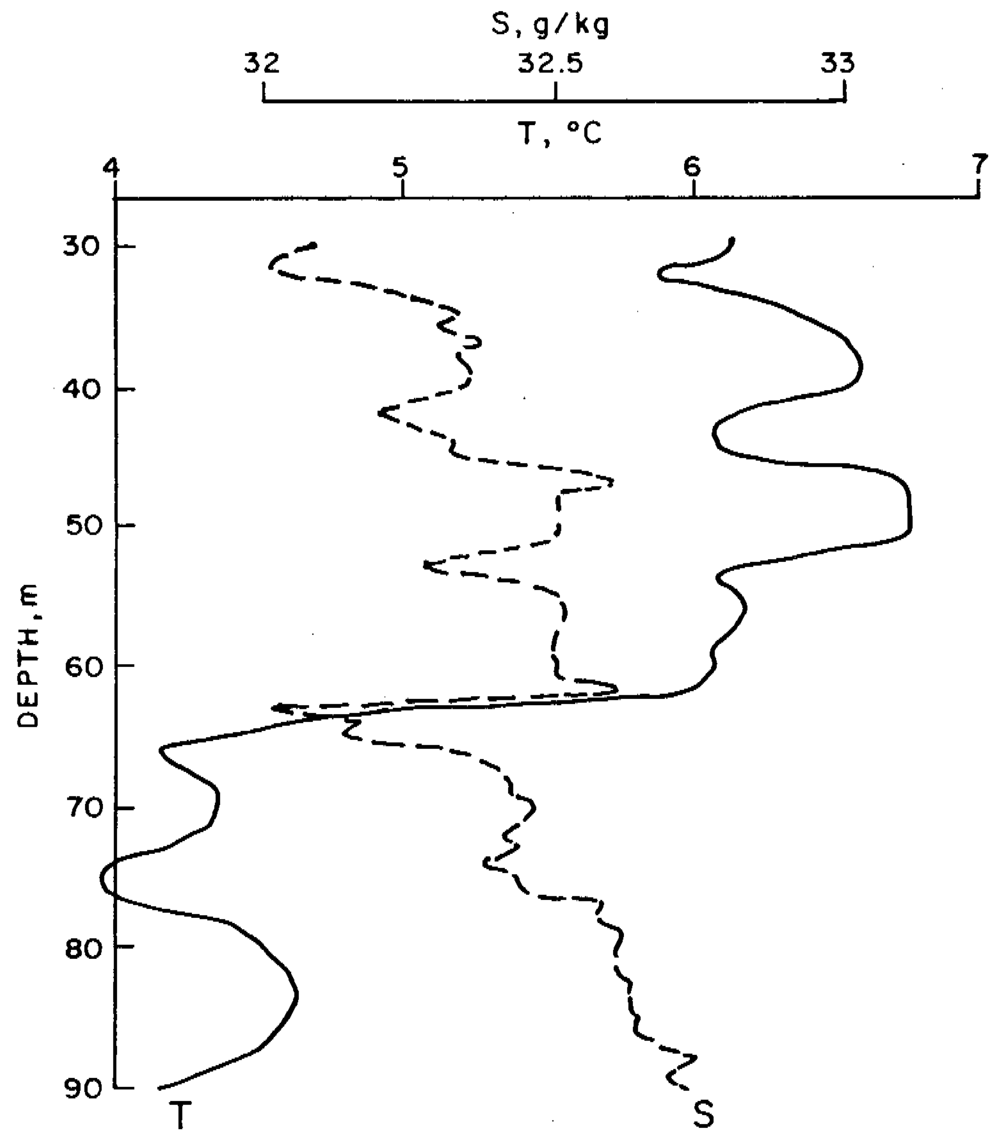
Coachman (1978), while the inner transition corresponds to the middle front separating the middle and outer domains (Fig. 1).

At different times when examined by different distributions, these broad transitions do appear truely frontal. For instance Coachman and Charnell (1979) showed a mean cross shelf temperature section for August 1976 that clearly showed a thermal front near the 100m isobath, and Coachman (1978) showed strong evidence for a front delineated by particulate and chlorophyl a concentrations in April 1978. Over the slope Kinder and Coachman (1978) showed a shallow weak density front in an August 1972 section, and we show a weak salinity front from February 1978 (Fig. 9b). Kinder and Coachman (1978) also showed large dissolved phosphate and nitrate gradients across the shelf break front in July 1974. Both the middle and shelf break fronts generally appear broad and therefore weak, but occasionally they are manifest as sharp fronts in various properties. The shelf break front, however, can always be detected as a weak front in salinity.

Finestructure and Density Inversions. Finestructure, the layering of vertical profiles on scales from 1 to 25 m (Fig. 8), is a salient feature of the outer domain (Table II). The distribution of the finestructure and the mixing physics associated with it are clues to understanding cross shelf fluxes.

Horizontal distributions of the occurrence of finestructure over the shelf showed that it was common between the shelf break and the 100 m isobath, and occurred elsewhere only rarely. During 1976, a year when the shelf was surveyed extensively, finestructure in the outer domain was reported in March (Coachman and Charnell 1977), in June (Kinder 1977), in August (Coachman and Charnell 1979), and in September-October (Kinder et al.



I-4-10 8

1978). Only a few stations with finestructure were reported outside of the outer domain (e.g. Kinder 1977, Fig. 22), and data from 1977 and 1978 also conform to these distributions. As Coachman and Charnell (1979) discussed, the finestructure occurs in the interior of the water column, below the surface mixed layer and above the bottom mixed layer.

Within this interior region, warmer and saltier oceanic water intrudes shoreward while cooler and fresher shelf water intrudes seaward. As interpreted by Coachman and Charnell (1977, 1979) the outer domain is a region of lateral (i.e. cross-flow, and here also cross-isobath) water mass interaction with interleaving of water masses occurring at finestructure scales. Such interleaving, when water masses of similar density but differing temperature and salinity values mutually intrude, has been observed in many other locations (e.g. see J. Geophys. Res. 83 (C6) 1978). Occurrence of finestructure throughout the outer domain, best documented in 1976 (a year with extensive ice cover and late ice breakup) but also observed in 1977 and 1978, implies that finestructure is an inherent part of mixing across the outer domain. An essential stage in mixing large masses of water is the reduction of the spatial scale of identifiable water parcels, eventually reaching a scale at which molecular diffusion is effective. As the spatial scales decrease, spatial gradients increase as does the surface area of the boundary, and so mixing progresses. Interleaving on finestructure scales is the initial scale reduction. While finestructure features are only a few meters in vertical extent, they apparently extend horizontally for tens of kilometers. In both March and August 1976, Coachman and Charnell (1977, 1979) traced temperature-salinity correlations within layers for distances of about 100 km.

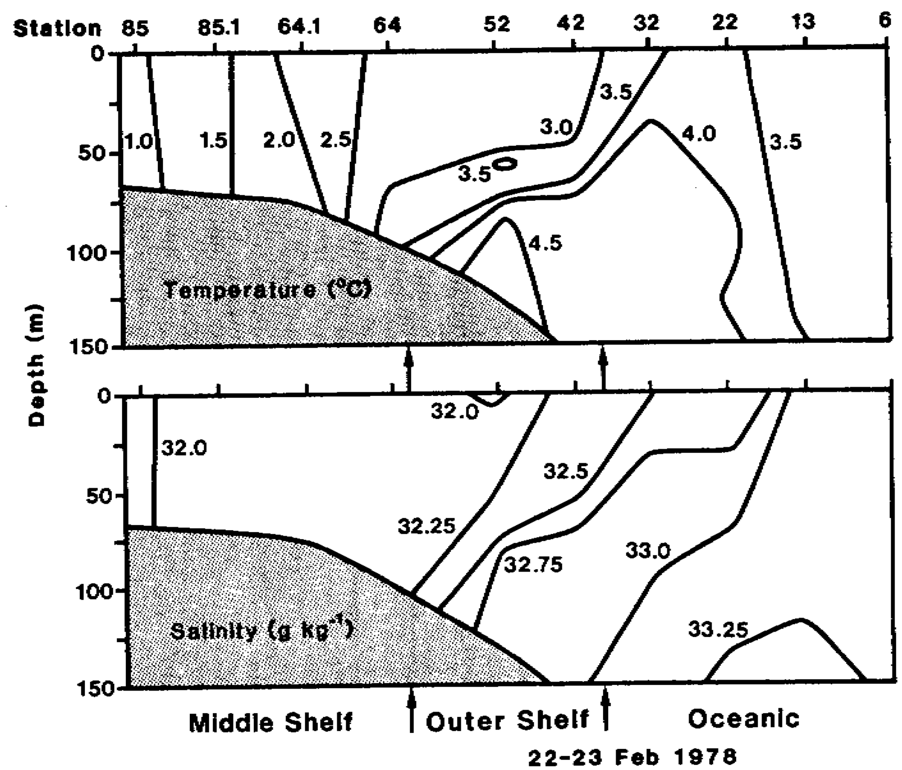
One startling result of Coachman and Charnell's work was the discovery of a static instability of a layer about 10 m thick in March 1976, and many smaller scale instabilities of a few meters thickness in their summer data. The larger instability was clearly resolved by the instrumentation used (standard CTD vertical profiling system), and had an apparent lifetime of about one week. They speculated that it was formed by interaction between strong winds and the seasonal ice cover. The smaller instabilities were poorly resolved by the standard CTD profilers used, but Postmentier and Houghton (1978) measured nearly identical features over the oceanographically similar slope region south of New England using a higher resolution profiler. Both Coachman and Charnell (1979) and Postmentier and Houghton (1978) invoked differential diffusion of temperature and salt to explain the smaller instabilities. Because heat diffuses more rapidly than salt at molecular scales (it is easier to transfer energy than mass), adjacent layers of water can become convectively unstable on small scales, either through salt fingers (warm and saline water overlying cool and fresh water) or through double diffusion (cool and fresh water above warm and saline water). In the outer domain, the conditions for salt fingers exist at the lower interface of shoreward intruding basin water, while the conditions for double diffusion exist at the upper interface.

Winter Structure. The discussion of hydrographic domains and fronts mostly reflected summer conditions, but winter conditions are more interesting than might be expected. During winter waters above most of the shelf usually are vertically homogeneous, with two exceptions. In the outer domain warmer (but more saline and therefore denser) water from the oceanic domain intrudes beneath cooler and fresher shelf water, thus maintaining stratification.

Elsewhere, low salinity water from melting ice may stratify water that was previously well mixed during autumn and winter (by wind stirring and surface cooling).

A cross section taken from southeast of the Pribilofs toward Cape Newenham during February 1978 (Fig. 9) illustrated intrusion of the basin water. Between the shelf break and 100 m isobath (i.e. outer domain) water warmer than 3.5^{o}C and saltier than 32.5 g/kg intruded beneath shelf water which was both colder and fresher. Inshore of the 100 m isobath the water column was well mixed, colder (<2.5^{o}C), and fresher (<32.25 g/kg). Several stations with similar profiles, saltier and warmer near the bottom, were also taken near the Pribilof Islands during April and May 1978, and Coachman and Charnell (1977) showed data with this character taken in March 1976. There is sufficient coverage of the outer domain during late winter and early spring to suggest that cold and fresh shelf water overlies warmer and more saline basin water, and that this domain remains stratified during winter.

Melting ice in the middle shelf can also cause stratification during winter, but inshore within the coastal domain mechanical stirring keeps the water column well mixed. In February 1978 we observed (by satellite imagery, see Figure in next Chapter) that ice near Nunivak Island moved about 100 km southeast, into an area previously free of ice. About ten days later we measured hydrographic properties near this ice, which was melting. Away from the ice ($\sim$20 km), sea surface temperatures were near 0^{o}C, and temperature profiles were vertically homogeneous (Fig. 10). Within the ice (where water depths exceeded 50 m), however, the water column was stratified in two layers. In the shallow layer temperatures were near freezing ($\sim$-1.73^{o}C) and the salinity was lower than in the homogeneous water. Below the weak



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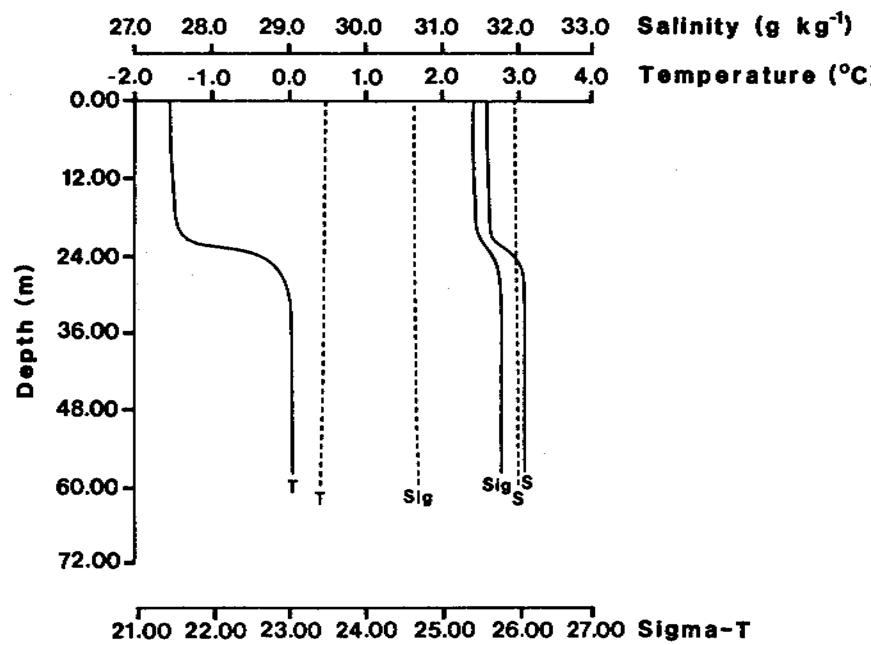


I-4-10 Schumacher

pycnocline, salinity and temperature were similar to values away from the ice. The decrease of temperature and salinity probably resulted from ice melting, about 30 cm of ice for Figure 10. The transition between two-layered and homogeneous conditions occurred near the 50 m isobath, as in summer. Inshore of the 50 m isobath, the water column was homogeneous with or without ice.

We do not know how persistent this winter stratification is, but we suspect that the weak stratification found in water deeper than 50 m water was fragile, dependent in part on the continued presence of ice. Once the upper layer cools to the freezing point, ice would stop melting. As stirring erodes the pycnocline, however, heat remaining in the bottom layer is mixed upward, presumably melting ice and adding light meltwater. The continued presence of ice above a stratified water column in winter apparently favors continued stratification: suppressing wind stirring, limiting surface heat loss, and maintaining a reservoir of potential meltwater. The question of whether ice cover generally affects the hydrographic structure over the middle shelf during winter, and to what extent this structure in turn influences the resulting stratification during the ice-free season is unanswered, but the ice may be an important factor through the following summer. It is clear that the eventual melting of ice during spring is important in stratifying the middle shelf domain (Schumacher et al. 1979).

<u>River Plumes</u>. The local effects of river discharge have received little attention because most oceanographic data has been collected away from the coast. Satellite images and sparse hydrographic data suggest that river plumes (defined, say, by salinity lower than 25 g/kg) remain near shore, flowing anti-clockwise around Bristol Bay, and exiting the southeastern shelf

to the north (much of this water may flow through Etolin Strait, inshore of Nunivak Island). Large discharges of freshwater can stratify the water column in the coastal domain, and may form fronts (e.g. Garvine and Monk 1974 describe the frontal plume of the Connecticut River in Long Island Sound).

Straty (1977) reported observations made in Bristol Bay during 1966. He traced the anti-clockwise near-shore flow of river water around Bristol Bay using dye, drift cards, and salinity measurements. He reported no fronts associated with these rivers (Naknek, Kvichak, Egegik, and Ugashik), probably because of vigorous tidal stirring in the shallow (less than 20 m depth) Bay. Conditions may be similar in Kuskokwim Bay farther west, but we have no data there. The direct effects of the river discharges appear to remain within a few tens of kilometers of the coast, providing an inshore boundary of the coastal domain.

PROCESSES THAT AFFECT THE HYDROGRAPHIC STRUCTURE

Many processes can form, alter, or erase features of the hydrographic structure. We have grouped such processes into three somewhat arbitrary catagories. First, we discuss the addition of heat and salt and their transport across the shelf, processes which directly transform water masses. Second, we focus on the interplay of mechanical stirring and buoyancy addition. These processes determine the stratification, a key element of the structure and a strong influence on the transport. Finally, we speculate on the possibility of upwelling, which may affect the hydrographic distributions in Bristol Bay.

Heat and Salt Transport. As previously noted, transformations of water masses on this shelf occur locally through the addition of heat and salt.

Cooling and heating at the surface, evaporation and precipitation, freezing and melting: relatively large fluxes of heat and salt occur at the sea surface. To a lesser extent horizontal mixing and river runoff at lateral boundaries influence temperature and salinity. Because of the low mean flow on the shelf, and because of the shelf's great width, water mass properties are more likely to result from local phenomena (e.g. insolation and melting) than from advection. Large changes occur annually in the flux of heat and salt at shelf boundaries, so that water masses vary annually also.

In the middle and coastal domains the change in heat content of the water is primarily balanced by heat transfer through the sea surface: horizontal advection and horizontal turbulent diffusion are relatively much smaller. Reed (1978) calculated a heat budget for an area (1° latitude x 2° longitude) of the middle domain for summer 1976. The local rate of heat change was balanced over the summer by net surface exchange within 10% (excellent agreement for such budgets). During summer, most of this surface exchange was radiative, but by early fall, evaporation was important. Over the fall, winter, and early spring, the terms incorporating phase changes (evaporation, freezing, and melting) share importance with radiation terms. The net surface exchange retains its importance, however: Coachman and Charnell (1979) found a high correlation ($r = -0.96$, $n = 12$) between mean lower layer temperatures in June over the middle shelf with degree-days of frost for the preceeding winters. Reeds' (1978) results can probably be extrapolated into the coastal domain also. Although the vertical heat distribution differs there (Fig. 2), the horizontal terms and surface exchanges are probably similar.

In the outer domain, however, horizontal terms apparently are more significant. Mean flow is 2-10 cm/s so that advection cannot be ignored, and lateral exchange, as evidenced by finestructure, may be even more important. Coachman and Charnell (1979) showed a strong annual cycle for this region (approximately the seaward half of the shelf waters and those over the slope), and this was caused by surface exchange. Below the surface mixed layer, however, they showed large amplitude finestructure (Coachman and Charnell 1977, 1979), with warmer shoreward intrusions originating in the oceanic domain and colder seaward intrusions originating over the shelf (Fig. 8). These lateral interleavings are strong evidence of lateral exchanges of heat and salt, with the shelf water (colder and fresher) gaining heat and salt.

Various attempts have been made to estimate the horizontal heat flux in terms of a bulk heat conductivity, such that the turbulent horizontal heat flux is given by:

$$\rho C_p K_h \frac{\partial T}{\partial X} \qquad (\mathrm{J\ m^{-2} s^{-1}})$$

ρ = density of water $(\mathrm{kg/m^3})$,

Cp = heat capacity $(\mathrm{J\ kg^{-1}\ {}^oC^{-1}}$

$\frac{\partial T}{\partial x}$ = horizontal temperature gradient $(^oC/m)$, and

K_h = horizontal conductivity ($m^2/s = 10^4\ cm^2/s$).

This is sometimes a poor approximation of the physical processes (which are hidden within K_h), and K_h is often not constant. Nevertheless, such estimates remain useful for modeling and estimating cross shelf fluxes. Kinder et al. (1978) calculated a heat balance for the lower layer of the middle shelf over summer 1976 and estimated $K_h \sim 1.7 \times 10^6$ cm^2/s (=1.7 x 10^2 m^2/s). They similarly estimated vertical conductivities in the middle shelf, and values ranged from 7 x 10^{-3} cm^2/s to 5 X 10^{-1} cm^2/s. Because of the strong stratification, the lowest values approached molecular diffusion ($\sim$1.4 x 10^{-3} cm^2/s). These estimates by Kinder et al. (1978) were probably maxima, since they assumed that all local change had been caused by the diffusion considered, vertical or horizontal. Coachman and Charnell (1979), applying a model proposed by Joyce (1977), estimated 2.8 x 10^6 cm^2/s and 1 x 10^6 cm^2/s for the middle and shelf break fronts and 20 x 10^6 cm^2/s for the outer domain between fronts.

Kinder and Coachman (1978) calculated a salt budget for the entire shelf. Since freshwater is annually added at the coast by river runoff, and because precipitation exceeds evaporation over the Bering Sea, there must be a flux of salt shoreward to maintain the long-term mean salinity distribution. For the shelf as a whole, the largest term (>99% of salt flux) is advection: relatively saline water from the oceanic domain flows onto the western shelf to supply the Bering Strait outflow ($\sim$1.0 x 10^6 m^3/s). Over the southeastern shelf, however, the salt balance is not advective (because of low mean flow). Kinder and Coachman (1978) estimated a diffusivity of 3 x 10^6 cm^2/s for the cross shelf salt flux. Calculating diffusivity for the middle domain over summer 1976, Kinder et al. (1978) obtained 1.1 x 10^6 cm^2/s, using the same method as for thermal conductivity (the salt diffusion equation was analagous to that of heat).

Kinder and Coachman (1978) suggested that the cross-shelf salt flux was driven by the tides, as a "tidal diffusion", because most ($\sim$90%) of the kinetic energy over the shelf is tidal (see next Chapter). The tidal current, if appropriately correlated with salinity variations over the tidal cycle, could cause a significant flux of salt across the shelf. Coachman and Charnell (1979) illustrated, however, that in the outer domain lateral interleaving on vertical finestructure scales is ubiquitous and this interleaving represents cross shelf mixing. Tidal diffusion still remains tenable for the middle and coastal domains, and the tides do contribute most of the turbulent energy (via the bottom frictional layer and velocity shear) within the outer domain.

Kinder et al. (1978) also reported a separate mode of salt flux, the effect of ice transport. During the ice-covered part of the year, satellite imagery often shows open water south of east-west zonal coasts: south of St. Lawrence Island, south of Nunivak I., and northern Kuskokwim Bay are typical examples (see Muench and Ahlnas 1976 and the Chapters on ice by Pease and McNutt). During the spring of 1976 (Kinder 1977) and to a lesser extent in 1977, water with elevated salinities (>32.5 g/kg in June 1976) was found in Kuskokwim Bay. Our explanation is that ice freezing in Kuskokwim Bay is blown seaward leaving behind the brine that drains during freezing. We do not know accurately the amount of ice exported from the coastal domain annually in this way, nor do we know the salinity of the exported ice. Kinder et al. (1978) estimated that this divigence of ice transport may account for a mean salt flux of 6 t/s (1 t=10^6 g) shoreward from the middle to the coastal domains. This is about 10% of the annual salt flux (50 t/s) estimated by Kinder and Coachman (1978) for the southeastern shelf. As Coachman (1979) pointed out, this mechanism may be generally important at high latitudes: hypersaline water relict from the previous winter, has been found not only in Kuskokwim Bay, but recently in Norton Sound (Muench et al. Chapter 7), Kotzebue Sound (Kinder et al. 1977) and lagoons adjoining the

Beaufort Sea (Wiseman 1979). Since this mechanism causes a net freshening of the middle domain, it may partly explain the correlation that Coachman and Charnell (1979) reported between yearly mean temperatures and yearly mean salinities over the middle shelf: both cooling of the middle shelf waters and the export of ice from the coastal to the middle shelf domains may be casually related to severe (cold and windy) winters, when southward outbreaks of cold and dry continental air cause more ice formation (see Overland, Chapter 3).

Stirring and Buoyancy Additions. A water column is stably stratified if the density increases towards the bottom. During spring and summer, this usually occurs because lighter, more buoyant fluid is added at the surface (ice melting, precipitation, or freshwater runoff) or because the surface waters are made less dense (insolation). Alternately, the addition of dense water at the bottom (intrusion of oceanic regime water onto the shelf) makes the surface waters relatively more buoyant (Fig. 9). We call these processes, that tend to stably stratify the water column by decreasing the density of the near-surface, positive buoyancy addition. If dense water is added at the surface (e.g. brine drainage during freezing) or if the surface waters are made denser (e.g. radiative cooling or evaporation), then the water column becomes less stratified or less stable. If water becomes denser than that below it, than the water column is unstable and vertical mixing (overturn) occurs. We call these processes, that destabilize the water column, negative buoyancy addition. We count as buoyancy addition any change in water properties that alters the mean density of the water column (i.e. as distinguished from mechanical stirring that re-distributes the density).

An important process tending to mix the water column is mechanical stirring. Over this shelf, the main source for stirring is the tidal currents and a secondary source is the wind (Schumacher et al. 1979, Simpson and Pingree 1978). Most tidal stirring power (turbulence) is generated near the bottom, and most wind stirring power (turbulence) at the surface. Thus, we attribute the surface mixed layer to wind stirring, and the bottom mixed layer to tidal stirring. Station 101 in Figure 2 illustrates these two layers in which mechanical stirring is sufficient to keep temperature and salinity homogeneous over layers of 20 m or more thickness. At Station 126, stirring had overcome any stabilizing effects of buoyancy addition, and the entire (50 m) water column was well mixed (neutrally stable).

Another way of viewing these two tendencies is to consider the potential energy of two water columns. Consider the first, like Station 101, to consist of two layers, while the second, like Station 126, is completely mixed. If both columns have the same vertically averaged temperature, salinity, and thus density (assuming a linear equation of state), then all points from both stations would fall on the same straight line on the TS plane; it is the vertical structure that differentiates the two distributions. It requires mechanical work to mix the two-layered water columns so that it looks like the homogeneous water column, because the center of mass of the well mixed water column is higher than in the two-layer case. Over the Bering Sea shelf the primary source of this mixing energy is the tides.

When the cross section across the inner front was made in 1976 (Figure 6) we found two water columns like those just described. The homogeneous water column on the coastal domain side of the front could have been made by completely mixing the water column on the middle domain side of the front. On the shoreward side of the front, the tidal stirring was just competent to overcome the buoyancy addition from melting ice and insolation: thus freshwater and heat were mixed throughout the water column. On the seaward side of the front, however, stirring was inadequte. A wind stirred surface layer and a tidally stirred bottom layer met at a sharp pycnocline.

This interplay of buoyancy addition and stirring has some positive feedback. Stratification suppresses vertical mixing so that mixing is impeded after stratification forms, and as further buoyancy is added stratification increases. This added stratification further suppresses mixing, and so forth. This feedback helps explain why the transition between the coastal and middle domains is so sharp: stratification enhances stratification, while well mixed structure likewise tends to persist. Over the middle shelf the surface mixed layer and the bottom mixed layers meet, making the vertical structure distinctly two-layered. The middle front, separating the middle and outer domains, demarks the limit of the ability of the two homogeneous layers to encompass the entire water column. Seaward of this front, in the outer domain, an interior region exists between the two mixed layers. Finestructure exists only in this interior; elsewhere it would be vertically mixed by stirring. Table III emphasizes the role of stirring and buoyancy addition in formation of the hydrographic domains.

We can get a feeling for the reason why the domains are closely tied to the isobaths (50 m, 100 m, shelf break) by following the formalism of Simpson and Hunter (1974), who examined a front near the British Isles like our inner front. They compared the rate of addition of potential energy by insolation to the rate of stirring energy addition.

For a two-layer water column, potential energy (V) addition rate is approximately:

$$\frac{dV}{dt} = \frac{\alpha Q g h}{2C\rho} \quad (Jm^{-2}s^{-1}) \quad (J = \text{Joule})$$

α: a thermal expansion coefficient ($kg^{o}C^{-1}m^{-3}$)

Q: insolation ($J\ m^{-2}\ s^{-1}$)

g: acceleration of gravity (m/s^2)

h: water depth (m)

c: specific heat ($J\ kg^{-1}\ ^{o}C^{-1}$)

ρ : density (kg/m^3)

The major annual change is in the insolation term (Q); other buoyancy terms (e.g. melting ice) could be added easily.

The turbulent energy available for stirring is simply:

$$\frac{dE}{dt} = k\rho U^3 \quad (J\ m^{-2}\ s^{-1})$$

where:

k = drag coefficient

ρ = density (kg/m^3) and

U^3 = mean of cubed speed (m^3/s^3)

Most of this power (note that 1 J/s = 1 watt) does not mix the water, but the relative amount (1% or so) that does go into mixing seems constant for a given flow regime (e.g. near the inner front).

We can see that the buoyancy addition term has small changes across the shelf in all of its terms but h, while in the stirring term U^3 changes rapidly across the shelf. The tidal current, U, is also a strong function of depth (h) and position on the shelf (Mofjeld et al., Chapter 9), so that both buoyancy addition and stirring are strongly dependent on location. Although neither buoyancy addition nor stirring changes very rapidly at a location, the tidal currents vary significantly over two week cycles (fortnightly tide), winds vary, and buoyancy input changes diurnally and annually, but an important variation across the shelf can be seen by taking the ratio of (dE/dt) and (dV/dt). The result is a constant times (U^3/h); across the shelf, from the outer to the coastal domain, this changing ratio reflects the changing balance between buoyancy and stirring. Nearshore, U^3 is large and h small so stirring prevails. Farther offshore, U^3 decreases and h increases so stratification (given sufficient Q or other buoyancy source) prevails. We even found that this held in February 1978 when we took measurements in melting ice: seaward of the 50 m isobath the water column was two-layered, while shoreward of the 50 m isobath the column was well-mixed (the 50 m isobath coincides with the inner front during summer). Thus the potential for stratification (expressed by (U^3/h)), is always present, requiring only sufficient buoyancy addition to be realized.

Our data do not reveal variability in frontal location, either on short time scales such as diurnal or fortnightly, or longer scales such as interannual. There is undoubtedly some variation in their location on many scales, but the inner front is tied closely to its mean position by the variation of U^3/h, and similar considerations probably affect the middle front's position also. Stirring and buoyancy addition form the vertical hydrographic structure within the coastal and middle domains, and modify the structure of the outer domain.

TABLE III

Stirring and Buoyancy Addition in the Hydrographic Domains

Coastal Domain. Throughout the year tidal and wind stirring produce adequate mixing power to overcome normal sources of buoyancy: insolation, melting ice, and river runoff. Exceptions to this are probably short lived, except in river plumes wihtin 10 to 20 km of the coast. (Water depth $<$ thickness of tidal mixed layer).

Middle Domain. Tidal and wind stirring are inadequate to mix the entire water column during the high buoyancy addition season (spring and summer). The vertical structure during that season is two-layered: a wind stirred surface layer and a tidal stirred bottom layer separated by a sharp pycnocline. During fall and winter, when buoyancy addition is usually negative, the vertical structure is vertically uniform, but the potential for stratification remains. Melting ice can establish two-layered stratification, even winter. (Water depth = thickness of tidal mixed layer + thickness of wind mixed layer).

Outer Domain. The surface mixed layers and bottom mixed layers do not meet; the pycnocline is weaker than in the middle domain and there is an interior region separating the mixed layers. Finestructure is ubiquitious within this stratified interior region. Even in winter, negative buoyancy and stirring are insufficient to mix the water column completely. More saline water from the oceanic regime makes the deep column denser than the surface waters, even if the surface waters are cooled to the freezing point. (Water depth $>$ thickness of tidal mixed layer + thickness of wind mixed layer).

Also see our Table II and Figure 24 in Coachman and Charnell (1979).

Upwelling. The cold surface patch observed in Bristol Bay during summer has been ascribed to upwelling. Myers (1976) documented the frequent occurrence of cooler surface water in Bristol Bay during spring and summer, and our own data also showed this (Kinder et al. 1978). Myers attributed this to upwelling forced by an Ekman covergence in the bottom boundary layer. This convergence was caused by a mean cyclonic flow that approximately follows the 50 m isobath.

Arguments based on hydrographic evidence from 1969-1970 presented by Myers favored upwelling of water originating southwest of the cool surface patch rather than local vertical mixing, but the explanation of this upwelling was incomplete. The mean flow is only about 2 cm/s, while tidal speeds are about 20 cm/s (next Chapter). Thus, the tidal kinetic energy is 100 times that of the mean flow, and tidal effects may be more important than the mean flow. For the Ekman convergence to work, water must be forced upward against stratification, rather than forced horizontally to the west or southwest (where there is no mean flow). Additionally, Myers hydrographically inferred that the source of upwelled water is southwest of Bristol Bay, but his proposed Ekman convergence requires a source to the east and north. Alternately, strong winds during summer are too infrequent to readily account for this persistent feature. In the open ocean, with upper layers moving faster than lower layers, large (nearly-geostrophic) cyclonic features are associated with isopycnals that dome upward, so perhaps the mean flow does influence the observed distributions in Bristol Bay. A secondary circulation would then be necessary to maintain the density structure against tidal stirring and mixing. Alternately, a combination of vertical mixing driven by tidal currents and freshening of inshore waters by river runoff could produce the observed hydrographic distributions. This seems more in harmony with processes over the remainder of the shelf, but is no more proven than the upwelling hypothesis.

In summary, cool surface water appears often in Bristol Bay during spring and summer, and Myers (1976) presented hydrographic evidence that this results from upwelling. Whether this persistent feature results from upwelling, from another dynamic response to the flow regime, or from vertical mixing, however, is not understood.

DISCUSSION

Cross Shelf Fluxes. Based on conservation of heat and salt, we have discussed some estimates of cross-shelf fluxes in terms of diffusion coefficients. Knowledge of these fluxes, and of the mechanisms driving them, is important for both conservative and non-conservative material: larvae, nutrients, plankton, petroleum, etc. Especially during summer, dispersion characteristics differ in the different domains. Vertical exchanges are severely damped in the strongly stratified middle domain, while complete vertical mixing occurs rapidly in the tidally-stirred coastal domain. Dispersion also differs horizontally in the three domains. In the outer domain interleaving on finestructure scales is an important component of mixing processes, but no finestructure is found in the inner two domains. Mixing, although probably driven by the dominant tidal currents in both near-shore domains, differs between the middle and coastal domains. Over the two-layered middle shelf horizontal transport may differ markedly in each layer (e.g. a nearly estuarine two-layer flow), while this is unlikely in the vertically homogeneous coastal domain.

There is also a question of steadiness of these fluxes: How much do they vary and over what time scales? Coachman and Charnell (1979) estimated that the horizontal salt flux in the outer domain was 3 to 4 times greater than the fluxes at the shelf break and middle fronts. This implies a divergence (depletion) of salt transport near the shelf break and a convergence (accumulation) near the 100 m isobath. This imbalance cannot persist over long periods without altering the observed long term salinity distribution. There is some annual variation in fluxes, as the hydrographic structure, wind stress, and ice cover all change significantly over the year.

The variability of these fluxes, and particularly their timing (or phasing) with respect to critical biological events, may be more important than the mean fluxes. As yet, we can only roughly estimate mean values, and we do not understand the processes that drive these fluxes.

Fronts. It is not clear whether the fronts separating the hydrographic domains are convergences or divergences; whether they enhance or inhibit mixing. These boundaries separate distinct hydrographic domains and probably dynamical ones, and they have large gradients in various properties. The methods of transport for passive properties, such as salt and nutrients, and of dynamical properties, such as momentum and vorticity, probably change across these fronts, and these changes are most clearly seen in the vertical hydrographic structure. Intuition suggests that fronts are convergences (e.g. James 1978), and that cross frontal exchanges are impeded (e.g. methane distributions shown by Cline, Chapter). A convergence throughout the depth and length of the inner front, for instance, seems unlikely but neither observation nor modeling have answered the questions of convergence and cross-frontal mixing.

There is evidence of year-to-year (Coachman and Charnell 1979) and annual (Schumacher et al. 1979, Kinder and Coachman and 1978, Coachman and Charnell 1979) variability of the fronts, and Schumacher et al. (1979) reported wavy features in satellite images of the inner front that imply more rapid variability. The longer term fluctuations seem related to changes in atmospheric forcing (e.g. insolation, temperature, storms), and the wavy features may be frontal instability (inherent). Further understanding of these changes will probably add knowledge of variations in cross shelf fluxes.

Role of Ice. Ice, with strong annual and interannual variation, influences the hydrography of this shelf in several different ways. These effects are both local and shelf-wide.

Locally, ice affects the energy balance and vertical distributions. Ice cover effectively insulates the water and slows heat transfer (both radiative and conductive-convective), and ice covered with snow has high albedo, reflecting incoming short wave radiation. Freezing and melting also alter the distribution of heat and salt. Ice acts as a buffer for temperature as changing heat balance alters the amount of ice present at nearly constant temperature. Local freezing and then melting causes a vertical redistribution of salt, so that a water column that has uniform salinity in fall may have haline stratification in spring.

Freezing and melting also influence shelf-wide distributions. Freezing near-shore and melting offshore transport both salt and heat shoreward. Waters offshore are not only cooled directly by the atmosphere, but by melting ice that originally formed nearer shore. Because these processes are directly forced by weather, changes in the winter weather are directly manifest in ice cover and therefore in the shelf hydrography.

Ice processes thus affect the shelf hydrographically in two ways. Through melting and freezing, ice locally redistributes salt and heat in the water column, changing the vertical stratification. Ice also directly influences shelf-wide heat and salt budgets, acting as an insulating cover and transporting salt and heat.

SUMMARY

The southeastern shelf has a distinct hydrographic structure. Proceeding seaward from the coast in summer one encounters the vertically homogeneous coastal domain, the inner (structural) front, the two-layered middle domain, the middle front, the outer domain, the shelf break front, and finally the bordering oceanic domain (Figure 11). These features can best be understood by considering these simplications:

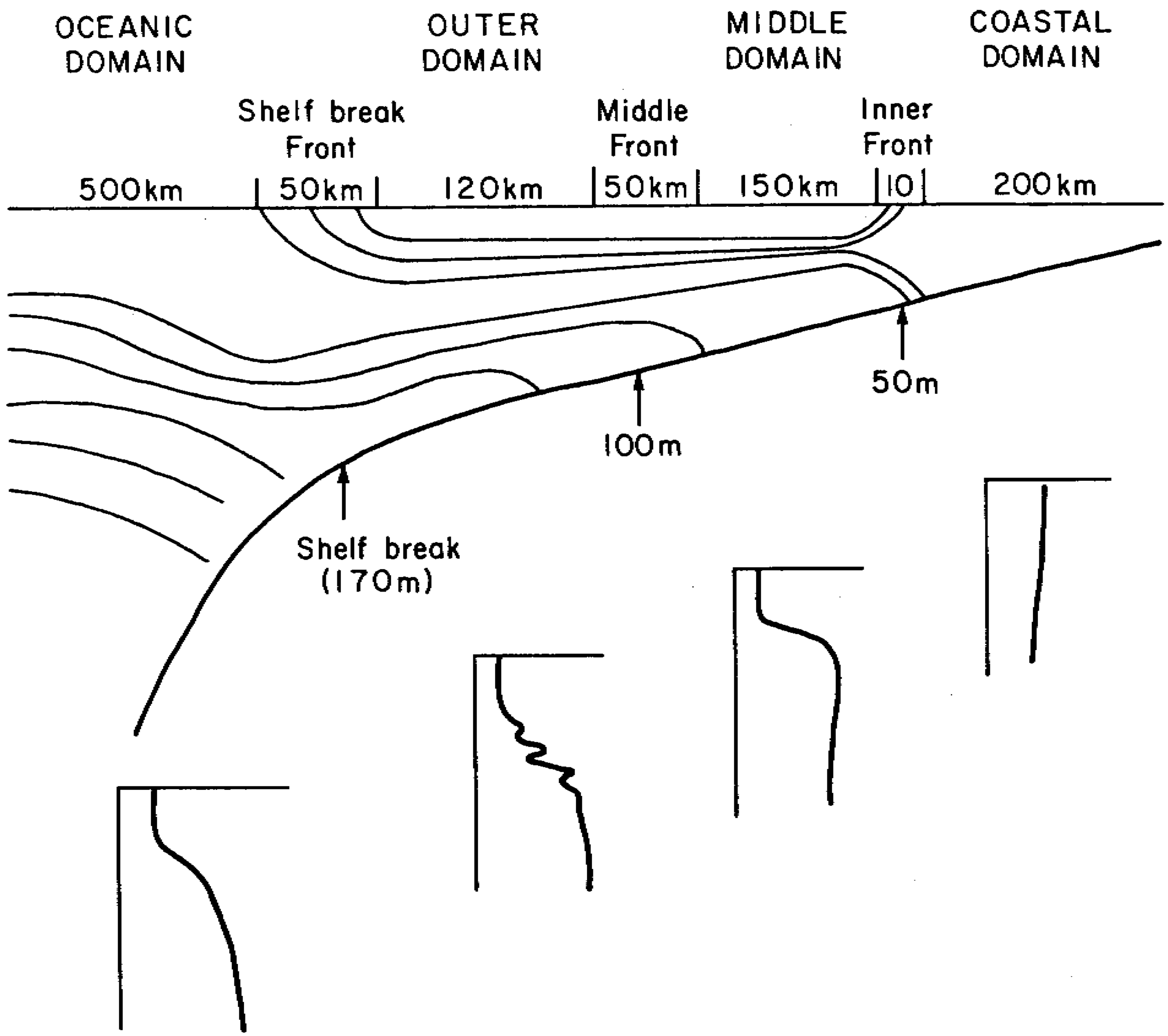
1. In the middle and coastal domains mean advection is negligible.

2. Water mass transformations occur locally, primarily through heat and salt transfer at the surface.

3. Vertical profiles are determined by the interplay of buoyancy addition and mechanical stirring, and in the outer domain also by lateral interleaving between shelf and oceanic waters.

4. Rates of buoyancy addition change annually, while stirring (primarily tidal) remains nearly constant with time and increases shoreward.

During winter, the separation into these domains is less clear, and the addition of negative buoyancy and stronger wind stirring move the boundary of vertically homogeniety seaward through the middle shelf. Even during this season, however, the potential for stratification like that in summer remains, and melting ice can provide sufficient buoyancy to stratify waters in the middle domain.



OCEANIC DOMAIN
OUTER DOMAIN
MIDDLE DOMAIN
COASTAL DOMAIN
Shelf break Front
Middle Front
Inner Front
500km
50km
120km
50km
150km
10
200km
50m
100m
Shelf break (170m)

Fig 11

The hydrographic structure influences mixing, and the system of domains and fronts affects many distributions: salt, heat, momentum, vorticity, sediment, benthos, plankton, nutrients, fish, pollutants, etc. With few exceptions, we do not understand these effects, and in many cases we do not even know what the effects are. As we have suggested, some aspects of salinity and temperature distributions and their interactions with the hydropgraphic structure are straightforward, but many other effects are not. Future studies of the shelf will have to consider the influence of hydrographic structure on many phenomena.

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Bob Charnell was a co-principal investigator on this project, and Pat Laird was frequently chief scientist on project cruises. Both were lost at sea off Hawaii in December 1978.

FIGURE LEGENDS

Figure 1. Approximate boundaries separating the three shelf (coastal, middle, outer) and the oceanic hydrographic domains. The boundaries are three fronts: inner, middle, and shelf break. These fronts roughly coincide with the 50 m isobath, the 100 m isobath, and the 200 m isobath (shelf break). Profiles from the numbered stations appear in Figure 2.

Figure 2. Typical staions from autumn 1976 illustrating the three domains. Coastal (homogeneous), station 126; middle (two-layered), station 101; outer (stratified interior), station 47 (see Table II for domain characteristics). (A) Temperature (°C). (B) Salinity (g/kg). (C) Temperature-salinity (°C, g/kg). Station locations are shown in Figure 1.

Figure 3. Maximum vertical temperature difference, surface minus deep (°C). The largest differences are in the middle domain, and the smallest in the coastal domain (cf. Fig. 1).

Figure 4. Bottom temperature (°C), late September and early October 1976. Even in autumn, low temperatures persist in the bottom layer of the middle domain.

Figure 5. Temperature - salinity correlations, middle domain (SHELF) and oceanic domain (ALASKA STR./BERING). Envelopes drawn from data gathered in August 1976 and May 1977 illustrate the warmer and saltier oceanic water at the same density as the cooler and fresher shelf water, and interleaving occurs across the outer domain (from Coachman and Charnell 1979).

Figure 6. The structural (inner) front separating the coastal and middle domains. This line was between Nunivak Island and the Pribilof Islands. (A,B) Temperature and salinity cross sections, and (C) sequential temperature profiles from June 1976. The sections are based on stations separated by about 10 km. (D,E) The same section based on widely spaced CTD stations in autumn 1976. (From Schumacher et al. 1979).

Figure 7. Vertically (0 - 100 m) and horizontally (along - isobath) averaged sections across the shelf from May 1976, August 1976, and May 1977. Transitions in the salinity gradient mark the 100 m isobath (middle - outer domains; middle front) and the shelf break (outer - oceanic domains; shelf break front). (From Coachman and Charnell 1979).

Figure 8. A "superb" example of temperature and salinity finestructure in August 1976. Finestructure, although often less pronounced than this, was present at most outer domain stations. (From Coachman and Charnell 1979).

Figure 9. Temperature (^{o}C) and salnity (g/kg) across the shelf in February 1978. This section is from southeast of the Pribilofs toward Cape Newenham. In the outer domain the deeper water is warmer, but more saline and therefore denser, than the shallower water.

Figure 10. Temperature (^{o}C), salinity (g/kg), and density (kg/m^3) profiles near the ice edge in February 1978. Dashed profiles were typical away (>20 km) from the ice or where water depth was less than

about 50 m. Solid profiles were typical near the ice where water depth exceeded 50 m.

Figure 11. A schematic of the cross-shelf density structure illustrating the system of hydrographic domains separated by fronts. This picture represents summer conditions, when the structure is clearest. Vertical profiles are shown beneath each domain. See Tables II and III for a tabulation of domain properties.

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F. TIDES OF THE EASTERN BERING SEA SHELF

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ABSTRACT

The acquisition of a substantial amount of pressure gage and current meter data on the Bering Sea shelf has permitted a much more accurate description of the tides than has previously been possible. Cotidal charts are presented for the M_2, and for the first time for the N_2, K_1 and O_1 constituents, and tidal current ellipse charts for M_2 and K_1. S_2, normally the second largest semidiurnal constituent, has not been included because it is anomalously small in the Bering Sea. The tide enters the Bering Sea through the central and western Aleutian Island passes and progresses as a free wave to the shelf. Largest tidal amplitudes are found over the southeastern shelf region, especially along the Alaska Peninsula and interior Bristol Bay. Each semidiurnal tide propagates as a Kelvin wave along the Alaska Peninsula but

appears to be converted on reflection in interior Bristol Bay to a Sverdrup wave. A standing Sverdrup (Poincaré) wave resulting from cooscillation in Kuskokwim Bay is evident on the outer shelf. The semidiurnal tides are small in Norton Sound where an amphidrome is located. The diurnal tides, which can have only Kelvin wave dynamics, cooscillate between the deep basin and the shelf. Amphidromes are found between Nunivak Island and the Pribilof Islands, and west of Norton Sound. Throughout most of the shelf the tide is of the mixed, predominately semidiurnal type; however, the diurnal tide dominates in Norton Sound.

Tidal models by Sündermann (1977) - a vertically integrated M_2 model of the entire Bering Sea; and by Liu and Leendertse (1978, 1979) - a three dimensional model of the southeastern shelf incorporating the diurnal and semidiurnal tides, are discussed. Good qualitative agreement is found between the models and observations.

INTRODUCTION

As with most continental shelves, the tides and tidal currents on the eastern Bering Sea shelf play important roles in the oceanographic processes such as the maintenance of the density structure, sediment resuspension and transport, and the distributions of benthic and intertidal organisms. A knowledge of the tides and tidal currents is therefore necessary for the understanding of the region's oceanography. The tides of the Bering Sea have been of interest to physical oceanographers and astronomers for a long time (e.g. Jeffreys, 1921; Munk and MacDonald, 1963; Cartwright 1979). This interest has been due to the premise that the vast continental shelves of the Bering Sea (Fig. 8-1), with their proximity to the Pacific Ocean, act as a major sink of the world's tidal energy. Yet many aspects of the tides and tidal currents in the Bering Sea have remained unknown because there has been a lack of offshore data from which definitive cotidal charts could be drawn and from which reliable boundary conditions could be obtained for numerical models. Fortunately, in recent years a large number of pressure gage and current meter observations have been made on the eastern Bering Sea Continental Shelf. The new data allow a more detailed description of the tides in the East Bering Sea than was previously possible.

Concurrent with the recent field work has been the development of several numerical models for tides in part or all of the Bering Sea. One of these, the Liu and Leendertse (1978, 1979) model of Bristol Bay will be described in detail. The other models are discussed briefly for completeness and to show the reader the scope of ongoing theoretical work. The field work is also continuing. In a sense then, this chapter is a progress report as well as a review of past work and a description of new results.

The tides that we shall be concerned with are the principal tidal constituents N_2 and M_2 in the semidiurnal band (periods of about 0.5 days) and O_1 and K_1 in the diurnal band (periods of about 1.0 day). Ordinarily, the principal solar semidiurnal constituent S_2 would be included in the discussion. However, S_2 is anomalously small throughout the Bering Sea, possibly because it has small amplitudes in the adjacent North Pacific Ocean. Whatever the reason, no consistent distribution for S_2 appears in the field data above the background noise level. The complicated distributions of semidiurnal and diurnal tides in the Bering Sea produce a rich variety of tidal types, ranging from fully semidiurnal in some regions to fully diurnal in others. Sample time series will be shown later in the chapter to illustrate the tidal types. Probably the most important figures are the cotidal charts for the four principal constituents, because from these charts it is possible to infer much about the dynamics of the tides and to obtain harmonic constants for tidal predictions. Empirical cotidal charts, derived from recent data, and theoretical cotidal charts from models will be presented.

The discussion of tidal currents in the Bering Sea will be presented with less certainty than that of the tides. This is because the few early measurements of tidal currents were of short duration and mostly limited to harbors and nearshore regions, and the recent observations from offshore current meters occasionally suffered from errors due to biological fouling and effects of wave motion. Still, careful study and editing of the recent data allows reasonably accurate tidal current harmonic constants to be obtained for most areas. These results help define the dynamics controlling the tidal motion.

The setting for the tidal and tidal current distributions can be obtained from previous work [Harris (1904), Leonov (1960), Office of Climatology and Oceanographic Analysis Division (1961), Defant (1961), Coachman, et al. (1975)] which for the most part describes the semidiurnal tide. The tide wave enters the Bering Sea as a progressive wave from the North Pacific Ocean, coming mainly through the central and western passages of the Aleutian-Komandorski Islands. The Arctic Ocean is a minor secondary source of tides which propagate southward into the north Bering Sea where they complicate the tidal distributions. The North Pacific and Arctic oceans are also sinks of tidal energy for tides propagating out of the Bering Sea. Tides in the Bering Sea are considered to be the result of cooscillation with large oceans. Once inside the Bering Sea, each tidal constituent propagates as a free wave subject to the Coriolis effect and bottom friction.

The tide wave propagates rapidly across the deep western basin. Part of the tide wave then propagates onto the Southeast Bering Shelf where large amplitudes are found along the Alaska Peninsula and in Kvichak and Kuskokwim Bays. Another part propagates northeastward past St. Lawrence Island and into Norton Sound. Over most of the shelf region the tide is mainly semidiurnal, but in Norton Sound the diurnal tides predominate. A number of amphidromic systems are formed on the East Bering Shelf and in Norton Sound, due to the interference of tides propagating from various directions. As shown in the Discussion Section, various authors have different opinions as to the details of the tidal height and current distributions including the existence, shape and location of amphidromic systems. Some of the controversy can be resolved with the recently acquired data; the rest will require more observations and/or more complete models.

The remainder of this chapter is divided into three sections: A brief review of numerical models with an emphasis on the Liu and Leendertse (1978, 1979) model; next the results from observations, including empirical cotidal charts; and finally a discussion section comparing results of theoretical and field studies.

NUMERICAL MODELS

Several numerical models have been applied to the tides in the Bering Sea. They are of two basic types: vertically integrated models which simulate horizontal distributions and three-dimensional models which simulate vertical variations as well. Some of these models are still under development.

The vertically integrated models by Hastings (1976) and Sündermann (1977) superimpose uniformly spaced grids over the Bering Sea Shelf and the entire Bering Sea, respectively. Finite difference approximations to the dynamic equations with quadratic bottom friction are solved over the grids as initial value problems in time with lateral friction included to stabilize the calculation. The tides enter the models as boundary conditions along the open boundaries; time series of sea level at the open boundaries drive the motion in the interior with zero flux and no-slip conditions imposed along coasts. The imposed time series are derived from harmonic constants interpolated from observed values at islands and on coasts. After integrating the models through an initial transient, the motion can be analyzed for tides and tidal currents. Since Hastings (1976) does not take this step, we show only results of the model by Sündermann (1977), which is limited to the M_2 semidiurnal constituent (Fig. 8-2) and its consequences in time-averaged properties and higher harmonics.

A distinctly different, vertically integrated model is under development by Preisendorfer (1979), who uses Bristol Bay to illustrate a new technique. The technique involves computing the linear response of a region to a long wave of a given frequency, such as a tidal constituent, as a synthesis of responses to simple subregions. Since realistic boundary conditions were not used in the Bristol Bay example, the results of the calculation may be considered preliminary. Further work on the technique is planned (Preisendorfer, private communication).

A three-dimensional model has been developed by Leendertse and Liu (1977) and Liu and Leendertse (1978, 1979) to predict tides and wind-driven currents on the Southeast Bering Shelf for the prediction of oil spill trajectories and for risk analysis. The grid for the model (Fig. 8-3) is uniform in the horizontal dimensions but packed in the vertical dimension to allow higher resolution of the pycnocline. The dynamic variables are the horizontal and vertical velocity components, temperature, salinity, density, pressure and the energy density at subgrid scales; a passive contaminant can also be included in the model. The large-scale (resolved by the grid) variables satisfy a relatively complete set of non-linear dynamic equations averaged over each vertical layer and specialized to the extent that the hydrostatic equation is used in the vertical direction. The subgrid scale turbulence satisfies a one-equation closure model in the turbulent energy density.

Within the dynamic equations are viscous and diffusive terms. The associated viscosities and diffusivities in the horizontal direction have contributions from the large-scale motions through the local vorticity gradient. The contributions of the subgrid turbulence for each direction depend on a turbulent Richardson number which includes the local density gradient and the local subgrid energy density. The formulas for the turbulent contributions are modified from Mamayev (1958) and include empirical coefficients that are chosen to produce reasonable behavior of the turbulence in the presence of stratification. Liu (private communication) indicates that newer versions of the model under development will use a different formulation for the turbulent viscosities and diffusivities which eliminates many of the empirical coefficients.

The motion in the lowest layer is subject to bottom boundary conditions. The bottom is assumed to be impervious and insulating so that zero flux of heat, salt and water occurs through the bottom. The bottom boundary condition for momentum is a quadratic friction law in which the Chezy coefficient is adjusted to match model currents with observed currents. At the free surface, a uniform wind stress can be imposed over the region to produce wind-driven currents in addition to the tidal motion. The model is integrated as an initial value problem with predicted tide level time series specified along the open boundaries; these time series are obtained through interpolation of harmonic constants derived from bottom pressure data.

To simulate tides and tidal currents on the Southeast Bering Shelf, Liu and Leendertse (1978, 1979) chose a period, 16-18 June 1976, for which extensive observations existed, some collected specifically in support of this modelling effort. The model was run for a total of 63 hours which included an initial transient preceding the comparison period. Time series of sea level were then Fourier analyzed for composite semidaily and daily tides from which cotidal charts (Fig. 8-4) were constructed. A more detailed analysis into individual tidal constituents was not possible because of the short series length. After adjustment of model coefficients to match current data, a set of time series (Fig. 8-5) of currents and water properties were produced.

A similar, three-dimensional model is under development for Norton Sound (Liu, private communication). It includes improved equations for the subgrid-scale turbulence. The model can also impose sea ice on the water, because ice in the north Bering Shelf region can be expected to modify the tidal and wind-driven responses significantly.

OBSERVATIONS

Offshore pressure and current observations, made on the east Bering Shelf (Fig. 8-6) during 1975-1978, are a major new source of information about tidal heights and currents. These data have been analyzed* for harmonic constants and tidal current ellipses, which will be presented in this section. To these results have been added historical harmonic constants from the International Hydrographic Bureau (1966) and results of analysis of previously unpublished data from the National Ocean Survey and the U.S. Geological Survey.

* Details of the analysis procedure and results are given in the Appendix.

Tidal Observations

Empirical cotidal charts (Figs. 8-7 through 8-10) have been constructed for the four largest tidal constituents M_2, N_2, K_1, and O_1. These charts were constructed as follows: Cotidal lines were drawn by interpolation where the station spacing is relatively small compared with the spatial scales of a given tidal constituent. Elsewhere, the positions of cotidal lines were estimated either by shifting the distribution of lines from numerical models to match observed values, or by estimation with reference to hydrodynamic considerations. Like all empirical cotidal charts, these charts are somewhat subjective. On each of the cotidal charts, regions of particular uncertainty are denoted by question marks.

An example of the procedure for drawing charts can be seen from the portion of the M_2 chart (Fig. 8-7) around St. Lawrence Island. Along the northern shore of the island, M_2 harmonic constants can be found for enough stations to document the westward progression of phase without reference to models. Along the southern shore of the island there are fewer stations, and the convergence of M_2 cophase lines at Southeast Cape were drawn with references (Fig. 8-2) to the M_2 model by Sündermann (1977). The records along the northern coast of St. Lawrence Island provide harmonic constants for M_2 derived from a high water-low water analysis (see Appendix). These data are not sufficient to allow a determination of harmonic constants of other constituents; the cotidal charts of those constituent in this region are therefore more speculative than that of M_2.

The cotidal charts show the complex distribution of tidal amplitudes and phases over the eastern shelf region. Largest amplitudes for all constituents are found along the Alaskan Peninsula, interior Bristol Bay and in Kuskokwim Bay. The smallest tides are found on the outer shelf and north of St. Lawrence Island. A number of amphidromes are present; there is a semidiurnal amphidrome in Norton Sound and a virtual amphidrome at Cape Newenham, while diurnal amphidromes are found on the southeast shelf between Nunivak Island and the Pribilof Islands and west of Norton Sound. The latter diurnal amphidrome is evident only for the K_1 constituent. The situation is more ambiguous for the O_1 tide north of St. Lawrence Island, possibly because the longer wavelength of O_1 would place an amphidrome farther west of the offshore stations. The phase difference between K_1 and O_1 changes rapidly at stations in this area indicating that the structures of the two constituents are significantly different.

The S_2 tide, normally the second largest semidiurnal constituent, is unusually small throughout the Bering Sea. Typically, S_2 amplitudes range from 1 to 3 cm. The cotidal charts by Bogdanov (1961) and Bogdanov et. al. (1964) for the North Pacific Ocean show a S_2 amphidrome just south of the Aleutian Islands. Perhaps the small S_2 amplitude where tides propagate into the Bering Sea produces small S_2 amplitudes throughout the region. Since analysis of data from the Bering Sea did not produce stable S_2 harmonic constants, a cotidal chart for S_2 could not be constructed. A result of the small S_2 is that the fortnightly inequality, or semidiurnal spring-neap cycle, is much less important than the parallactic inequality due to the variation in the moon's distance from the earth. This cycle is equal to the period of the moon's orbit, 27.55 days, and is manifested in the beat of N_2 against M_2.

Tidal type may be classified (e.g. Defant, 1961) by the value of the ratios of the sums of amplitudes of principal diurnal constituents K_1 and O_1 to the principal semidiurnal constituents M_2 and S_2. Since S_2 is so small in the Bering Sea we have substituted N_2 in

$$F = \frac{K_1+O_1}{M_2+N_2} \quad .$$

Values of F less than .25 denote regular semidiurnal tides, with two high and two low waters per day of approximately the same height. The mixed, predominantly semidiurnal type has values of .25 to 1.5 and is characterized by two high and two low waters per day, but with large diurnal inequalities in heights. Mixed predominantly diurnal tides, F = 1.5 to 3.0, have only one high and low water per day when the moon is near its maximum declination. Regular diurnal tides have values of F greater than 3.0, and usually have only one high and low water per day.

In most areas of the eastern Bering Sea the tide is the mixed semidiurnal type. The regular semidiurnal type is found in the Bering Strait and in a small area near the diurnal amphidrome south of Nunivak Island. The mixed diurnal type is found along the Aleutian chain, probably near Cape Newenham and in eastern Norton Sound. Regular diurnal tides are found in the vicinity of the semidiurnal amphidrome in Norton Sound.

Examples of different tide types are shown in Fig. 8-11 which shows predicted tide curves for the month of April 1980. Station BC9, located southwest of Nunivak Island near the diurnal amphidrome, has an F value of .25 and is mainly semidiurnal. The lunar perigee is on the 14th with the largest range on about April 18 and the smallest at the beginning and end of the month. BC2 in Bristol Bay has the mixed semidiurnal type with F = .79. The inequalities are largest after maximum declination of the moon on the 7th and 20th. BC20, near St. Matthew Island, also has a mixed semidiurnal tide, F = 1.02. Note that while at BC2 the diurnal inequality is mainly in the low tide, at BC20 it is in both the high and low waters. This is because of differences in the phase relationships between the major diurnal (O_1 + K_1) tides and M_2. Finally, the regular diurnal tide type is found at LD5, located near the semidiurnal amphidrome in Norton Sound. Here F = 16.3 and the fortnightly tropic-equatorial tide cycle, caused by the declination of the moon, is evident.

Tidal Current Observations

Harmonic constants of current meter data are subject to more variability in time and space than those for pressure gages, which are generally quite stable. A variety of factors affect observed tidal current velocities, including: 1) local bathymetry and depth; 2) shear in the water column; 3) increased damping and friction in the upper layers due to ice cover. In addition, the Savonius rotor current meters used in this study were occasionally subject to errors due to; 4) wave induced mooring motion which resulted in higher recorded speeds; and 5) biological fouling of the rotor by algae growth and various types of drifting marine organisms resulting in lower recorded speeds.

To examine temporal variability, successive 29-day harmonic tide analyses were performed on all available current meter data. Analyses were performed on the east and north components of velocity. Several moorings had decreases in tidal amplitudes corresponding to times of ice cover. Generally, the semidiurnal constituents were reduced to a greater degree than the diurnal constituents; and reductions were greatest for the upper meters. Phases were also affected. Figure 8-12 shows variations in the M_2 constituents of the east component of current at station NC24 at depths of 24 meters and 40 meters for a one-year period beginning September 19, 1977 (the north component exhibited similar behavior). Ice began forming in the area of the mooring in late November and early December of 1977 (Fleet Weather Facility, 1977 and 1978) and was associated with a decrease in the M_2 amplitude at the upper meter to 18 cm/s. However, the amount of ice over the mooring and the location of the ice edge varied until February 1978 when the ice edge moved much further south. Amplitudes were lowest during February and March during the time of extensive ice cover and then increased again as the ice broke up. Amplitudes were reduced by almost 40%, from 22 cm/s in the early fall to about 14 cm/s during late winter. During summer 1978 amplitudes returned to over 20 cm/s. The effect was much less at the lower meter. Amplitudes were decreased from 15.4 to about 12.5 or less than 20%. Phases at both meters also varied. The upper meter phase decreased from 204° to 190° while at the lower meter phase increased from 201° to about 217°. This was associated with a shift in the ellipse axis orientation toward the left at the lower meter while the upper meter ellipse remained steady. The K_1 amplitudes were also reduced, although to a lesser extent than M_2. It is reasonably certain that these changes are associated with ice cover. Whether these phenomena were due more to a reduction of mooring noise resulting from wave attenuation by the ice, or to frictional effects of ice cover, remains unknown at this time. Presumably, mooring noise would increase the amplitudes of all frequencies by more or less the same amount. Also, phases wouldn't be affected. Nevertheless, mooring noise is probably an important consideration, especially during the stormy fall and spring months.

The component harmonic constants for M_2, N_2, K_1 and O_1 were converted to an ellipse representation to give amplitude H and phase G for the major axis, direction of the major axis, amplitude of the minor axis, and sense of rotation. Usually the analysis for the first 29 days of the mooring period was used, to minimize effects of fouling on the current harmonic constants. Table 8-II (Appendix) gives the results of the analyses for a representative distribution of stations. Some stations were not included because of close proximity to one or more of those listed.

Plots of ellipses for stations listed are shown in Figures 8-13 and 8-14 for the M_2 and K_1 constituents, respectively. Ellipses are centered at the station locations with lines from the center representing the constituent current vector for the time at which the equilibrium constituent passes the Greenwich meridian.

The M_2 ellipses (Fig. 8-13) exhibit clockwise rotation at most stations south of St. Lawrence Island. The exception is BC14 near the Alaska Peninsula, which has nearly rectilinear motion. Axes are generally aligned in the direction of wave propagation, although topographic constraints can modify this, as at BC18, just south of Nunivak Island. Away from the influences of land, ellipses are more nearly circular. Amplitudes are typically 15 to 30 cm/s on the open shelf, although somewhat higher speeds would be expected at the surface. In Norton Sound and near St. Lawrence Island, rotation is anti-clockwise. M_2 current speeds are small in Norton Sound.

The K_1 ellipses (Fig. 8-14) are narrower than M_2. The orientation is aligned with flow in and out of the major embayments, Bristol Bay and Norton Sound. Over the outer shelf, the rotation is clockwise but becomes generally anticlockwise in the mid-shelf region of Bristol Bay (stations BC16, BC2, BC14) and in the approaches to Norton Sound (stations LD1, LD2, NC17). Typical amplitudes over the Southeast Shelf are 10 to 20 cm/s. Largest K_1 currents are found within Norton Sound where amplitudes range from 20 to over 30 cm/s. West of Norton Sound amplitudes are very small.

Ellipses for the smaller N_2 and O_1 constituents have not been plotted. Generally they are similar to the M_2 and K_1, respectively. O_1 major axis amplitudes are 60% to 75% of K_1 in the southeastern Bering Sea and 40% to 60% in the Norton Sound region. N_2 is about 25% to 40% of M_2 throughout the Bering Sea.

DISCUSSION

Both models and observations show that the largest tides in the Bering Sea occur on the inner southeast Bering Shelf. As shown in the figures, there is general agreement that the tides propagate as free waves onto the southeast shelf from the deep basin. In the vicinity of the Alaska Peninsula, the exponential decay of amplitude northward from shore and a comparison of the tidal heights and currents at BC14 indicate that the semidiurnal and diurnal tides are Kelvin[1] waves near the peninsula. In the mid-shelf region and along the Alaska Peninsula, the semidiurnal wave is progressive in character as at BC2 where the M_2 phase difference is 12° and at BC14 where the current is nearly in phase with the tide. Conversely, the K_1 tide has a much larger standing wave component, with a phase difference of 64° at BC2 and about 40° at BC14. When the Kelvin waves propagate into the inner shelf, there is an interesting difference between the reflected waves for the two tidal species. The critical latitudes of the diurnal tides

[1] Kelvin and Sverdrup waves are long waves under the influence of the earth's rotation. In the northern hemisphere Kelvin waves propagate with the coast on the right, and amplitude decreasing exponentially away from the coast. Current motion is rectilinear (in the absence of friction). Sverdrup waves (also called Poincaré or inertial-gravity waves) have horizontal wave crests and the currents form a clockwise-rotating ellipse. Sverdrup waves can exist only where the wave period is less than the inertial period. In areas where both Kelvin and Sverdrup waves can exist, the actual wave is some combination of the two. For further discussion, the reader is referred to a text such as The Oceans (Sverdrup et al., 1942).

($\sim$30°N) lie south of the Bering Sea; diurnal tides can therefore obey only Kelvin wave dynamics on the open shelf. The reflection of each diurnal tidal constituent produces a classic amphidromic system on the southeast shelf with the amphidromic point well offshore.

The critical latitudes of the semidiurnal tides (75°N for M_2) lie north of the Bering Sea. As a result, semidiurnal tides can obey Sverdrup wave as well as Kelvin wave dynamics. The presence of a virtual amphidrome near Cape Newenham for each semidiurnal constituent suggests that a major portion (if not all) of the incident, semidiurnal Kelvin waves are dissipated or converted on reflection into Sverdrup waves. Perhaps the acute apex angle of Kvichak Bay, together with the presence of sharply protruding peninsulas, may produce an efficient conversion to semidiurnal Sverdrup waves. A large part of the semidiurnal tidal energy may also be dissipated over the extensive mud flats and shoals of the Kvichak and Nushagak Bays and Rivers. On the open shelf, the broad semidiurnal tidal ellipses have approximately 45-50° phases relative to the tidal heights in the direction of propagation. This fact, together with the offshore cophase lines being roughly parallel to the coast and widely separated, indicates that the semidiurnal tides act as a standing Sverdrup (Poincaré) wave in this region due to cooscillation in Kuskikwim Bay. Further cooscillation is evident at BC11, just southwest of Nunivak Island, where the M_2 tide actually leads that at stations farther seaward.

To the North of the Southeast Bering Shelf, the Coast Pilot published by the U.S. Department of Commerce (1964) notes that the currents in Etolin Strait between Nunivak Island and the mainland are sufficiently strong to prevent ice formation in winter. This may be due to tidal currents associated with the large differences in tidal phases between the north and south sides of Nunivak Island.

There is much less consensus about the tides in the north Bering Sea. The tides around St. Lawrence Island are particularly confusing. Harris (1904) shows the tide progressing from west to east along the south shore and then east to west along the north shore, so that all phases of the tide are found around the island. Leonov (1960) has branches of the tide progressing through the passes on the west and east sides of the island and meeting on the north side together with the tide from the Arctic Ocean and discusses areas of convergence and divergence and abrupt changes in velocity as a result of the meeting of the Pacific and Arctic tides. Conversely, the Office of Climatology and Oceanographic Analysis Division (1961) chart shows very little effect on the tide from St. Lawrence Island with a fairly smooth progression of the tide northward across the shelf and through the Bering Strait. Coachman et al. (1975) inferred the presence of an amphidrome south of St. Lawrence Island from tidal differences of stations listed in the tide tables.

According to Sündermann's (1977) charts (Fig. 8-2), cophase lines converge on Southeast Cape; and there is probably cooscillation in the bight on the south side of the island with a reversal of phase progression. This may be responsible for the large phase differences noted by Coachman et al. (1975). The tide appears to progress through the pass between Northwest Cape and Siberia and thence west to east along the north shore of St. Lawrence Island to the vicinity of Northeast Cape where it meets the wave progressing north along the Alaskan mainland. This results in a nearly 180° phase difference between the M_2 currents at LD1, near the Yukon Delta, and at LD2 near Northeast Cape. That is, current is northerly at LD1 when it is southerly at LD2. Station NC17, between these two stations, is in a transition zone; most motion is cross-channel.

Coachman et al. (1975) discussed measurements made at a current meter mooring 90 km south of the Bering Strait. Tidal currents were mainly semidiurnal with amplitudes of 1 to 12 cm/s and the current ellipse orientation was generally NE/SW to N/S. In the Bering Strait, Ratmanoff (1937) and Fleming and Heggarty (1966) did not find noticeable tidal currents while Bloom (1964) and Coachman and Aagaard (1966) found that tidal currents modulated the net northward flow.

Semidiurnal currents are especially small in Norton Sound south of Nome, for example at stations NC14 and NC20. These stations are located in an antinode one-half wavelength from the head of the bay. Generally, semidiurnal tides and tidal currents are small throughout the Norton Sound and Bering Strait region. This may result from frictional dissipation across the broad Bering Sea shelf and Kelvin wave dynamics (i.e., the Norton Sound amphidrome and small amplitudes to the west of a northward progressing wave).

The diurnal tides appear to be simpler than the semidiurnal tides because they are restricted to Kelvin waves dynamics and have longer wavelengths. Tidal height-tidal current phase relationships indicate predominately standing wave characteristics in southeast Bering Sea and Norton Sound, although between St. Lawrence Island and the Alaskan mainland the tide is more progressive. Thus the diurnal tide in the deep western Bering Sea basin cooscillates with Bristol Bay and Norton Sound. Currents are highest in Norton Sound because of the shallower depth, even though the diurnal tides are higher at the head of Bristol Bay. Between St. Lawrence Island and the Bering Strait, the diurnal tides virtually disappear, again due to Kelvin wave dynamics and dissipation.

While there is good agreement between the models and the observations on the major features of the tides of the eastern Bering Sea shelf, there are some differences. For instance, the M_2 cotidal chart of Sündermann (1977) has systematically higher amplitudes and later phases than the observations on the southeast shelf, but lower amplitudes in Kvichak Bay. Also, the actual amphidrome in Norton Sound appears to be further ashore. These differences may be due to the coarse grid (75 km) and high horizontal eddy viscosity (10^9 cm^2/s) used in the model.

It is more difficult to evaluate the Liu and Leendertse model (Figs. 8-3 through 8-5), since many of the observations were used for boundary conditions and for tuning empirical parameters. The model and observations are therefore not independent. The cotidal charts (Fig. 8-4) present composite tides based on a Fourier analysis of 50 hours of computed data; therefore the cotidal charts represent sums of constituents within each species, with an arbitrary composite phase rather than one referred to Greenwich. For these reasons, no attempt will be made here to quantitatively assess the accuracy of this model.

APPENDIX

Moorings usually consisted of one or two Aanderaa RCM-4 current meters on a taut wire, with the upper current meter located at a depth of about 20 m, just below the subsurface float; the deeper one was below the pycnocline, about 10 m above the bottom. In the Norton Sound area where depths are generally less than 30 m, moorings contained only one meter. The Aanderaa TG2 or TG3 pressure gage, if present, was located either in a well within the anchor or was attached to acoustic release, just above the anchor. Pressure gage resolution is claimed by the manufacturer to be better than 0.5 cm. Individual moorings were in place for periods of up to one year, with observations of some locations spanning as much as three years.

Data were processed by methods similar to those described in Charnell and Krancus (1976). No correction was made for atmospheric pressure in the pressure gage data. In Aanderaa current meters, the recorded speed is an average over the data interval (15, 20, 30, 40 or 60 minutes), while direction is essentially instantaneous. To remove the phase difference between speed and direction, speeds at times T_n and T_{n+1} were averaged to give the speed corresponding to the direction at T_n prior to converting to east and north components of velocity. The data were low-pass filtered to remove "noise" (i.e. energy at frequencies >0.5 cycle/hr) and resampled at hourly intervals. A second-order polynomial was then used to interpolate to even hours.

The Munk-Cartwright response method (Munk and Cartwright, 1966) was used for tidal height analysis using procedures based on those suggested by Cartwright et al. (1969). The pressure record from Station BC20 was selected as a reference for all other stations because of its length (300 days), location (near the center of the study area), and because the tide there is thought to be representative of that entering the shelf from the deep basin of the Bering Sea. The tide potential was used as a reference for the BC20 pressure record, using weights of 0, ±2, ±4 days for the diurnal and semidiurnal bands. For the other stations the reference series was a complex prediction based on the sixteen largest diurnal and semidiurnal harmonic constituents derived from the BC20 analysis using weights of 0, ±2 days.

Results of high and low water analyses for many locations in the Bering Sea were obtained from the National Ocean Survey. High and low water analysis gives the mean tide range and Greenwich high and low water lunitidal intervals HWI and LWI. According to Schureman (1958), if the tide is semidiurnal, the M_2 amplitude can be estimated by multiplying the mean range by 0.47. The phase may be found by:

$$M_2^\circ = \tfrac{1}{2}(\mathrm{HWI} + \mathrm{LWI}) \times 28.984 + 90^\circ.$$

For current meter data, a 29 day harmonic analysis based on Schureman (1958) was used. Constituents O_1, K_1, N_2, M_2 and S_2 are derived directly, and other constituents are inferred from these based on equilibrium relationships. The harmonic method was used for currents rather than the response method because uncertainties in data quality and seasonal variations obviated the use of the slightly more accurate response method.

The results of these analyses are given in Table 8-I (for pressure gages, the six major constituents) and Table 8-II (for current meter data, the four major constituents in an ellipse representation). Harmonic constant amplitudes H are cm sec^{-1} for currents and mbar for pressure gage data. For this region, 1 mbar equals $1.007 \pm .003$ cm of sea water. Phases are referred to Greenwich.

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FIGURE CAPTIONS

FIG. 8-1. Bathymetric chart of the Bering Sea.

FIG. 8-2. Charts of (a) co-amplitude (cm), (b) co-phase (Greenwich lag in degrees), and (c) tidal current ellipses (cm/sec; radial line within each ellipse represents the tidal velocity at Greenwich transit) from the vertically integrated model by Sündermann (1977) of the M_2 tide in the Bering Sea. For the finite-difference model: the grid size is 75 km; the time step is 223.5 s; the bottom drag coefficient is 0.003; and the lateral viscosity is 10^9 cm^2/s. The numbers appearing in boxes are observed values. (Reproduced with permission from J. Sündermann, 1977, Deutsche Hydrographische Zeitschrift, 91-101, Figures 3, 4, 5).

FIG. 8-3. (a) The horizontal grid and (b) a section showing the vertical grid of the three dimensional, turbulent energy model of the southeastern Bering Shelf by Liu and Leendertse (1978, 1979). The horizontal grid spacing is 21.82 km; the vertical spacing in this 15-layer model is variable to allow high resolution in the pycnocline. The time step for the model is 180 s, and the Chezy coefficient of bottom drag is 700 $(cm/s)^{1/2}$. (Reproduced with permission from S. K. Liu and J. J. Leendertse, 1979).

FIG. 8-4. Theoretical cotidal charts (amplitudes in cm, phases in degrees relative to the start of the simulation) for (a) the composite diurnal tide and (b) the composite semidiurnal tide obtained from the three-dimensional, turbulent energy model by Liu and Leendertse (1978) of the Southeastern Bering shelf. (Reproduced with permission from S. K. Liu and J. J. Leendertse, ibid.)

FIG. 8-5. Time series at Station BC-15 (57° 36N, 162° 45M) from the three-dimensional, turbulent energy model by Liu and Leendertse (1978) for (a) sea-level displacement, (b) current speed and (c) current direction during the period 0000 GMT 16 June 1976 through 1400 GMT 18 June 1976. (Reproduced with permission from S. K. Liu and J. J. Leendertse, ibid.)

FIG. 8-6. Locations of stations used in construction of cotidal and tidal current ellipse charts. Historic stations with names had harmonic constants available; those without names were used to estimate M_2 from high and low water analysis.

FIG. 8-7. M_2 cotidal chart based on the new observations. Dots represent locations of stations used in construction of the chart. Solid lines are cophase lines referred to Greenwich. Dashed lines are coamplitude, in centimeters. Areas of major uncertainty are denoted by question marks.

FIG. 8-8. Same as 8-7 but for N_2.

FIG. 8-9. Same as 8-7 but for K_1.

FIG. 8-10. Same as 8-7 but for O_1.

FIG. 8-11. Predicted tides for the month of April 1980 for selected stations, illustrating tidal types found in the Bering Sea. Predictions used M_2, N_2, S_2, K_1, O_1 and P_1.

FIG. 8-12. Variations in the M_2 constituent of the east component of current at station NC24 for a one-year period beginning September 1977. Upper meter was at a depth of 24 m (19 m for the last two months). Lower meter depth was 40 m.

FIG. 8-13. M_2 current ellipses for stations listed in Table 8-II. For stations with records from two depths the ellipse for the deeper meter is plotted. Ellipses are centered on station location; line from center indicates constituent current vector when the M_2 Greenwich equilibrium phase angle is 0°. Arrows indicate sense of rotation.

FIG. 8-14. Same as 8-13 but for K_1.

TABLE CAPTIONS

Table 8-I. Results of response analyses for the new pressure gage observations. Amplitude H are in mbar of pressure. 1 mbar equals 1.007 ± .003 cm of sea water in the Bering Sea. Phases G are referred to Greenwich.

Table 8-II. Results of 29 day harmonic analyses for selected current meter records, in ellipse representation. Amplitudes H are cm/s, phases G are referred to Greenwich, and direction D of major axis is compass degrees. C refers to clockwise rotation, A to anticlockwise. To obtain phase and direction of minor axis, add 90° to major axis direction; then add 90° to major axis phase if rotation is clockwise, or subtract 90° if anticlockwise.

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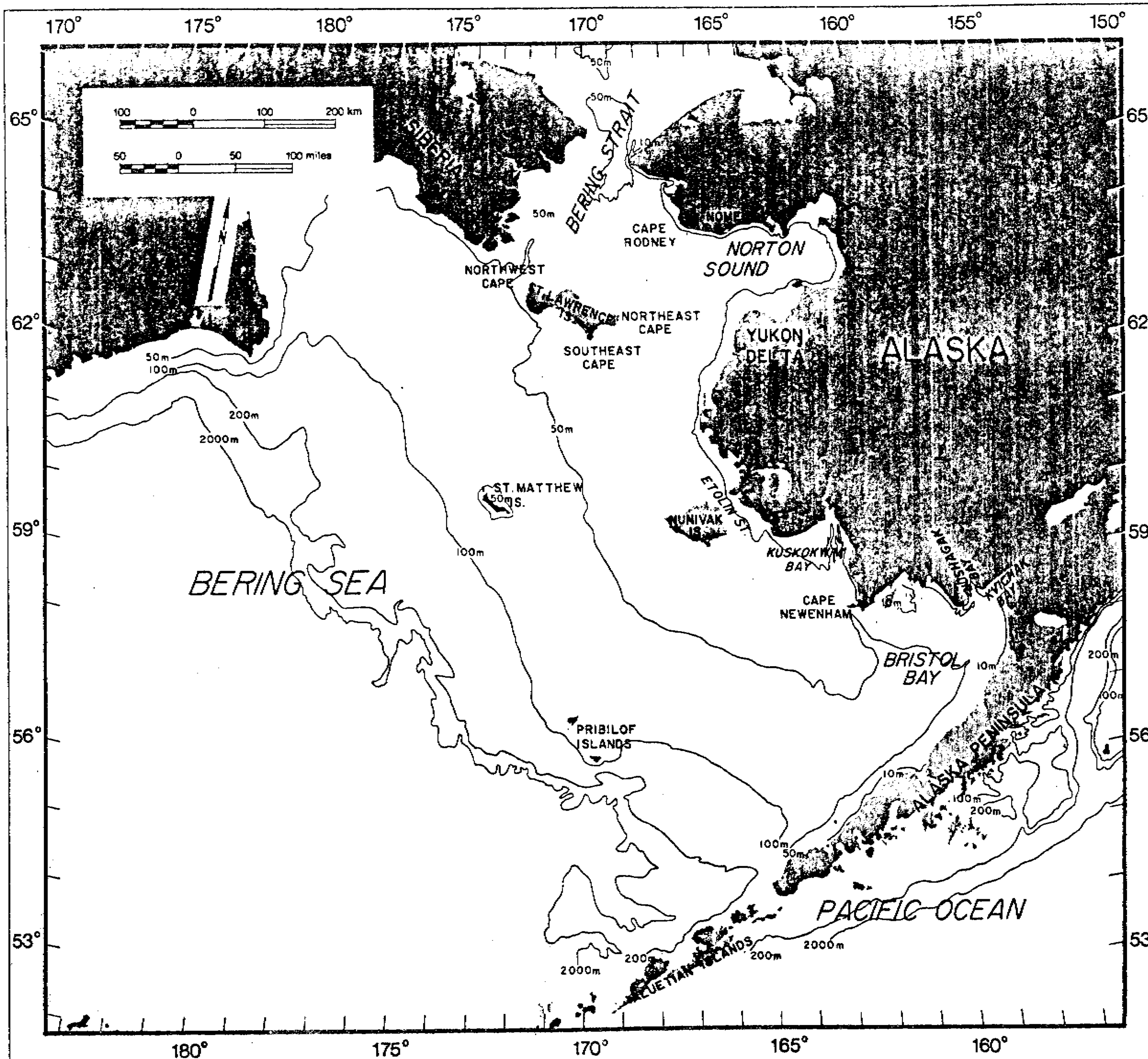
TABLE I

STATION	LAT, N		LONG, W		O1		P1		K1		N2		M2		S2		START DATE		LENGTH DAYS
					H	G	H	G	H	G	M	G	H	G	H	G	Yr	JD	
BC20	60	26	171	05	9.8	310	5.8	323	18.1	326	6.9	121	20.5	171	2.2	249	77	260	300
BC3	55	01	165	10	26.4	304	13.3	317	40.9	319	15.8	40	41.9	89	3.2	2	76	077	73
BC13B	55	30	165	49	23.8	311	11.4	322	34.4	325	13.2	52	35.5	106	1.8	327	76	158	114
BC13D	55	47	165	23	23.0	312	11.0	324	33.4	327	15.0	56	39.0	109	1.4	314	77	252	131
BC10	57	17	169	33	17.3	319	8.2	330	24.9	333	8.7	77	24.9	131	1.5	266	76	153	101
BC4	58	37	168	14	6.3	305	3.9	300	12.4	303	11.1	98	33.4	151	1.8	252	75	250	58
FX2	58	32	167	56	4.0	286	1.8	284	8.9	288	11.8	104	33.8	158	1.9	251	78	200	64
BC9	59	13	167	42	2.4	220	3.1	253	9.7	258	12.4	108	36.7	164	2.0	246	76	269	230
BC11	59	42	167	15	10.6	165	6.0	204	18.3	207	11.9	98	35.9	155	2.8	224	76	154	102
BC21	60	23	169	11	7.4	271	5.3	294	16.6	297	10.1	136	30.9	189	2.9	265	77	260	246
BC7	55	42	163	01	31.3	318	16.0	332	49.0	335	24.5	81	71.4	134	1.4	45	76	080	70
BC2	57	04	163	22	19.0	358	9.3	11	28.3	13	14.7	102	45.2	157	0.5	343	76	151	200
BC15	57	39	162	42	21.7	25	9.9	45	29.9	48	11.1	116	36.2	168	1.3	257	77	257	129
LD1	62	30	166	07	17.9	286	10.3	319	31.7	324	13.2	274	46.1	328	6.8	49	78	204	54
NC17	62	53	167	05	10.7	303	6.2	336	19.0	341	7.4	274	25.6	330	3.0	121	77	263	293
NC18	63	09	168	23	4.4	339	2.9	351	8.9	356	4.7	272	22.4	324	2.6	59	76	245	120
LD2	63	13	168	35	4.6	338	2.6	356	8.1	359	6.2	261	26.6	319	5.3	58	78	203	54
LD4	64	47	166	50	2.3	75	1.1	218	4.2	222	2.3	47	4.9	138	0.6	324	78	205	55
NC10	65	45	168	27	0.5	228	0.6	277	2.7	296	2.5	147	12.0	213	3.5	284	77	202	26
GEOPROBE	64	00	165	30	9.5	23	4.8	66	14.0	71	4.4	349	13.0	44	2.5	131	77	189	60
LD5	64	08	163	00	16.9	60	10.4	106	32.1	110	1.0	186	2.0	233	0.2	277	78	206	41
UNALAK-LEET	65	53	160	47	24.0	55	13.9	102	42.9	108	5.2	164	17.3	222	3.0	326	77	220	95

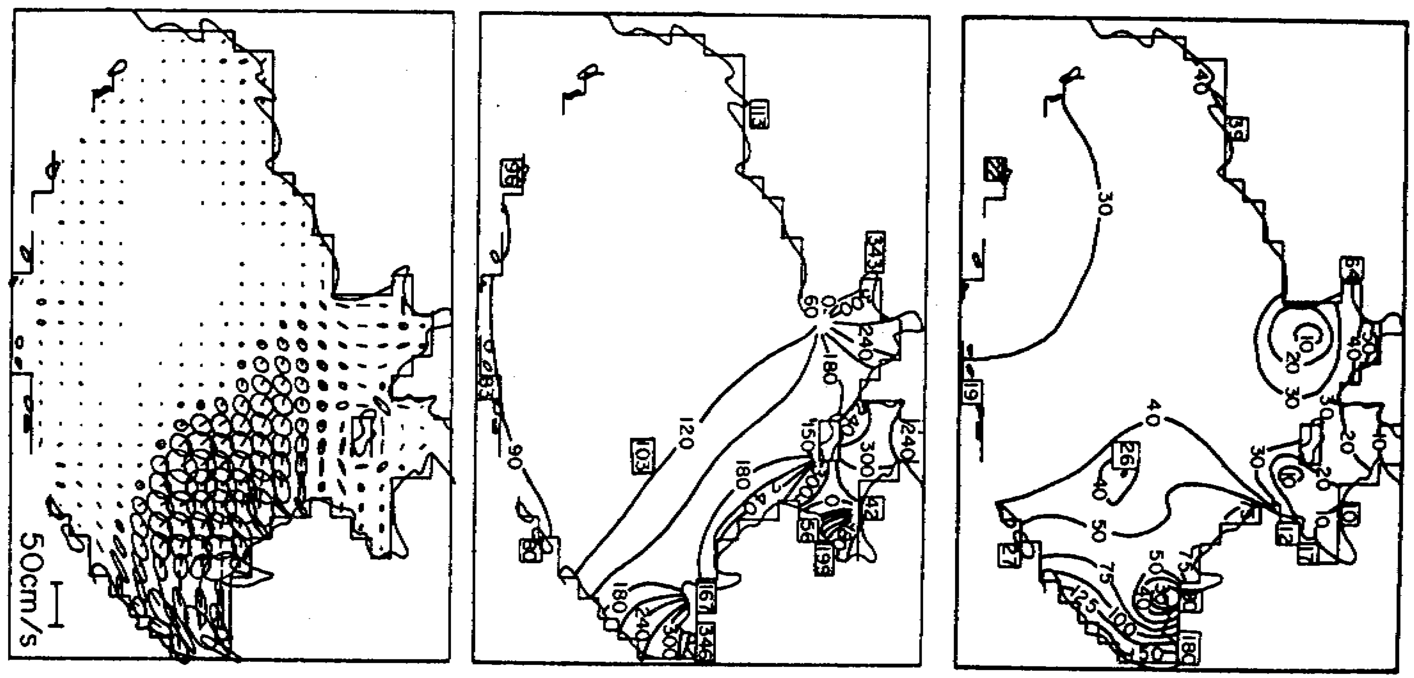
TABLE II

Station	Depth	Meter Depth	Lat N		Lon W		Start YR	Date JD	O1 major H	O1 major G	O1 D	O1 min H	O1 R	K1 major H	K1 major G	K1 D	K1 min H	K1 R	N2 major H	N2 major G	N2 D	N2 min H	N2 R	M2 major H	M2 major G	M2 D	M2 min H	M2 R
BC3	114	20	55	02	165	10	76	150	7.9	245	52	1.7	C	9.8	279	57	1.0	C	6.5	26	37	1.8	C	26.4	71	38	7.6	C
BC3	114	100	55	02	165	10	76	150	7.8	265	52	1.2	C	10.4	281	48	2.1	C	4.9	11	50	0.6	C	21.0	61	47	4.4	C
BC13B	115	100	55	30	165	49	76	158	5.6	272	71	2.2	C	8.0	289	68	2.8	C	5.3	3	50	2.2	C	18.9	67	54	9.6	C
BC17	104	96	56	34	167	34	76	266	6.5	312	109	1.8	C	9.1	326	105	4.3	C	6.4	27	61	4.0	C	15.9	81	53	10.5	C
BC4	51	30	58	37	168	14	75	251	7.4	330	140	3.1	C	11.7	350	133	6.2	C	9.6	45	49	7.2	C	27.3	118	50	22.2	C
BC4	51	47	58	37	168	14	75	251	7.3	331	128	2.6	C	10.9	0	131	4.8	C	4.9	28	46	3.3	C	20.2	107	51	15.1	C
BC9	41	33	59	12	167	43	77	133	8.5	332	130	0.9	C	13.0	359	134	2.8	C	7.0	60	47	5.1	C	18.7	120	51	14.6	C
BC18	31	20	59	40	167	07	77	132	12.7	333	113	0.6	A	20.5	356	116	0.1	A	6.3	130	109	4.8	C	21.2	186	103	13.8	C
BC16	50	37	57	59	165	16	77	123	7.7	308	102	1.3	A	11.4	328	108	1.5	A	6.8	69	69	5.8	C	20.8	101	52	15.1	C
BC2	65	50	57	04	163	22	75	310	8.6	292	77	1.1	A	14.1	309	81	1.6	A	5.9	76	81	2.9	C	20.4	145	80	12.1	C
BC14	51	20	56	03	161	50	76	152	13.5	292	68	0.5	A	21.7	312	70	0.5	A	12.2	98	69	0.1	A	35.4	159	67	0.7	C
BC20	64	51	60	26	171	05	78	202	4.5	186	340	2.4	C	6.7	214	353	4.5	C	4.5	68	68	2.7	C	13.7	136	61	9.5	C
BC21	42	20	60	24	169	10	78	202	8.0	188	352	2.4	C	12.5	219	0	4.6	C	8.0	86	68	3.0	C	28.6	150	63	17.1	C
BC21	42	32	60	24	169	10	78	202	7.9	187	351	2.9	C	11.6	221	353	4.1	C	6.9	87	61	2.5	C	21.1	139	64	9.6	C
NC24	48	19	61	48	170	26	78	203	3.4	212	358	2.7	C	5.5	263	35	4.4	C	6.4	144	86	3.7	C	21.1	206	92	12.5	C
NC24	48	39	61	48	170	26	78	203	2.9	189	335	2.7	C	4.6	274	33	3.9	C	4.1	120	103	1.3	C	14.1	191	103	6.1	C
LD1	14	10	62	30	166	07	78	204	10.9	261	19	0.2	C	19.8	290	34	1.2	A	5.9	268	28	3.3	A	17.5	56	298	12.8	A
NC17	26	17	62	53	167	05	78	165	8.8	271	39	0.1	A	12.8	310	41	1.7	A	4.6	348	305	1.0	A	12.1	48	301	2.3	A
LD2	28	24	63	13	168	35	78	203	4.5	220	20	0.3	C	7.5	29	11	0.7	C	4.5	12	201	1.7	A	15.4	310	211	8.5	A
LD3	37	33	64	00	168	00	78	204	1.9	342	63	0.1	C	4.0	24	73	1.7	C	1.3	39	301	1.1	A	4.9	78	322	3.5	A
LD4	20	16	64	47	166	50	78	205	3.9	144	294	1.6	C	7.5	222	309	0.9	C	2.7	358	17	0.4	C	6.8	74	356	4.0	A
NC20	19	5	64	00	165	29	77	189	18.5	315	70	3.0	C	33.0	22	70	5.7	C	2.0	244	126	0.5	A	7.5	303	155	0.9	A
NC14	32	21	64	22	165	22	76	234	14.5	327	93	0.4	C	27.7	27	94	0.9	C	1.9	167	90	0.5	C	3.3	182	85	0.5	C
LD5	27	20	64	08	163	00	78	206	9.3	335	66	1.7	A	22.7	25	67	4.8	A	3.0	167	0	2.4	A	8.0	244	331	6.7	A



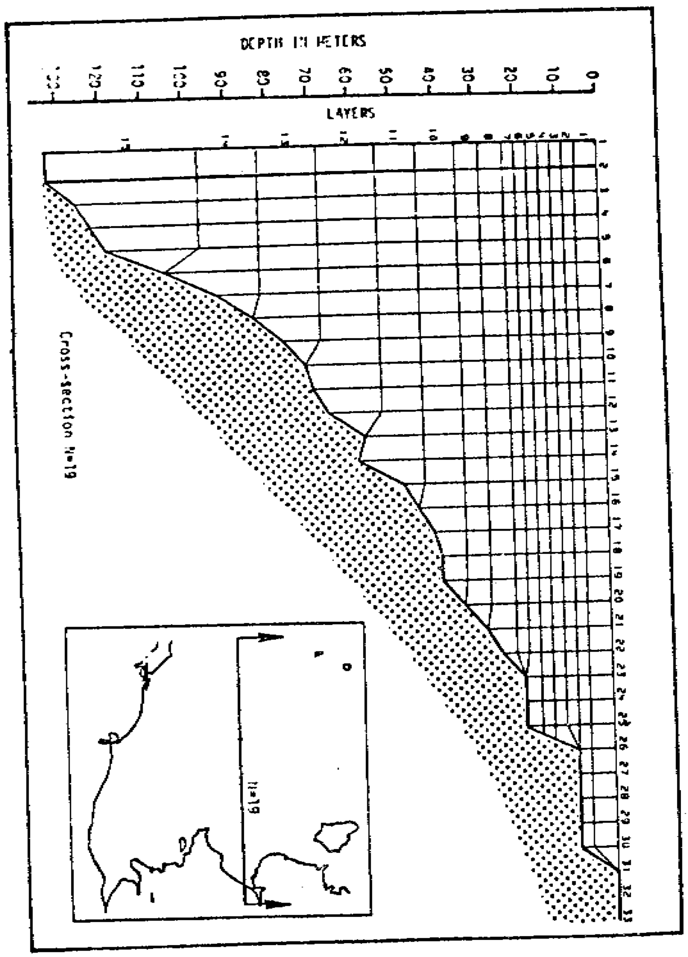
SIBERIA
BERING STRAIT
NOME
CAPE RODNEY
NORTON SOUND
NORTHWEST CAPE
ST. LAWRENCE IS.
NORTHEAST CAPE
SOUTHEAST CAPE
YUKON DELTA
ALASKA
ST. MATTHEW IS.
NUNIVAK IS.
ETOLIN ST.
KUSKOKWIM BAY
CAPE NEWENHAM
BRISTOL BAY
BERING SEA
PRIBILOF ISLANDS
ALASKA PENINSULA
PACIFIC OCEAN
ALEUTIAN ISLANDS
100 0 100 200 km
50 0 50 100 miles
50m
100m
200m
2000m
10m

Fig. 1



A B C

Fig. 2



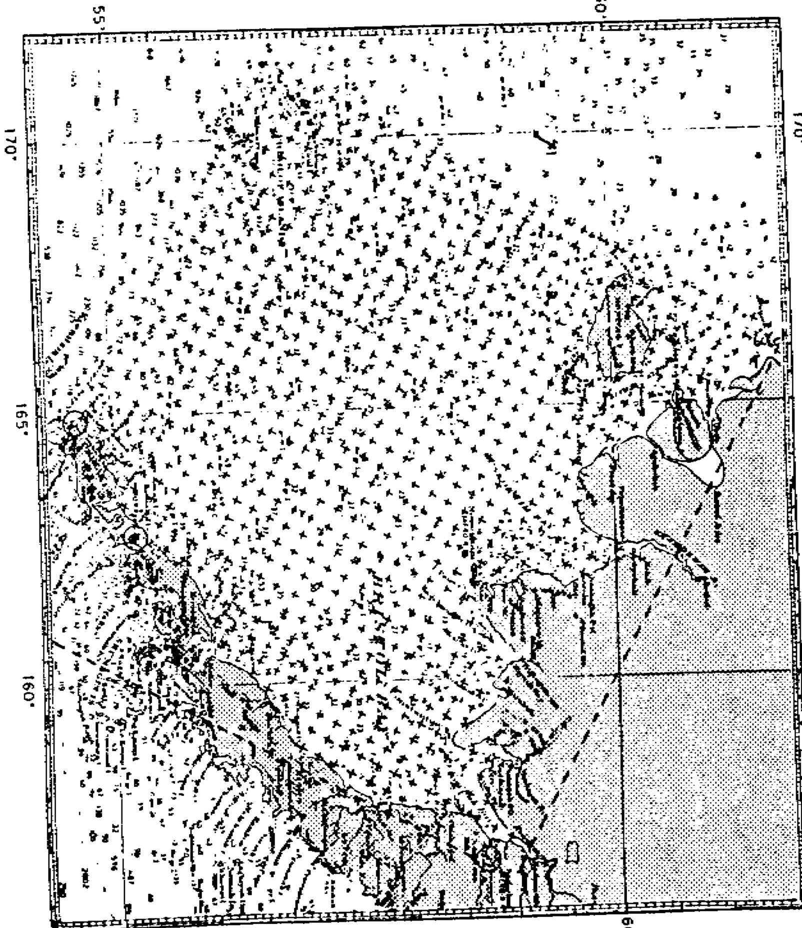


Fig. 3

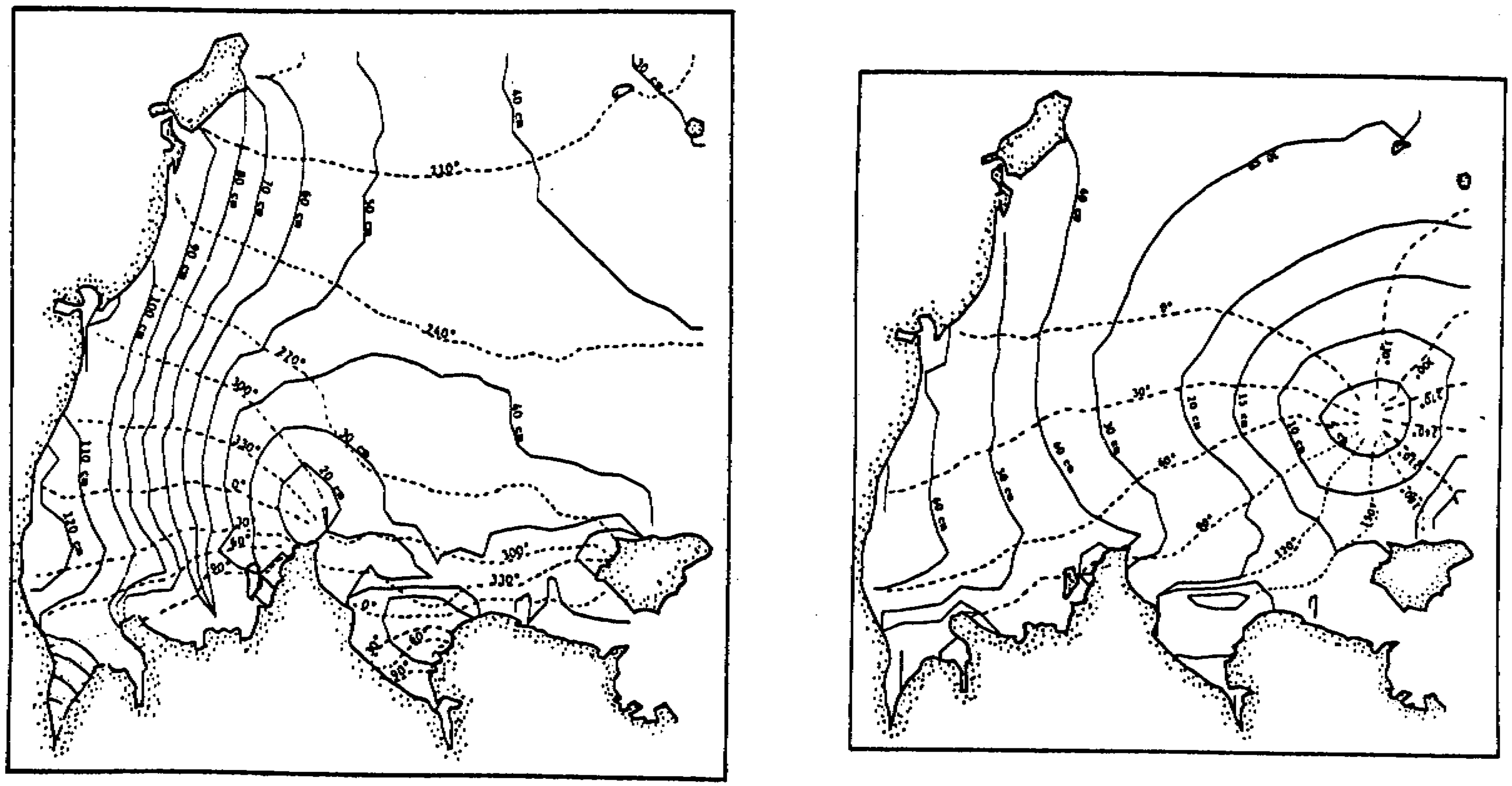

330°
240°
210°
300°
330°
0°
30°
60°
90°
40 cm
50 cm
60 cm
70 cm
80 cm
100 cm
110 cm
30 cm
20 cm
30°
60°
90°
120°
150°

Fig. 4

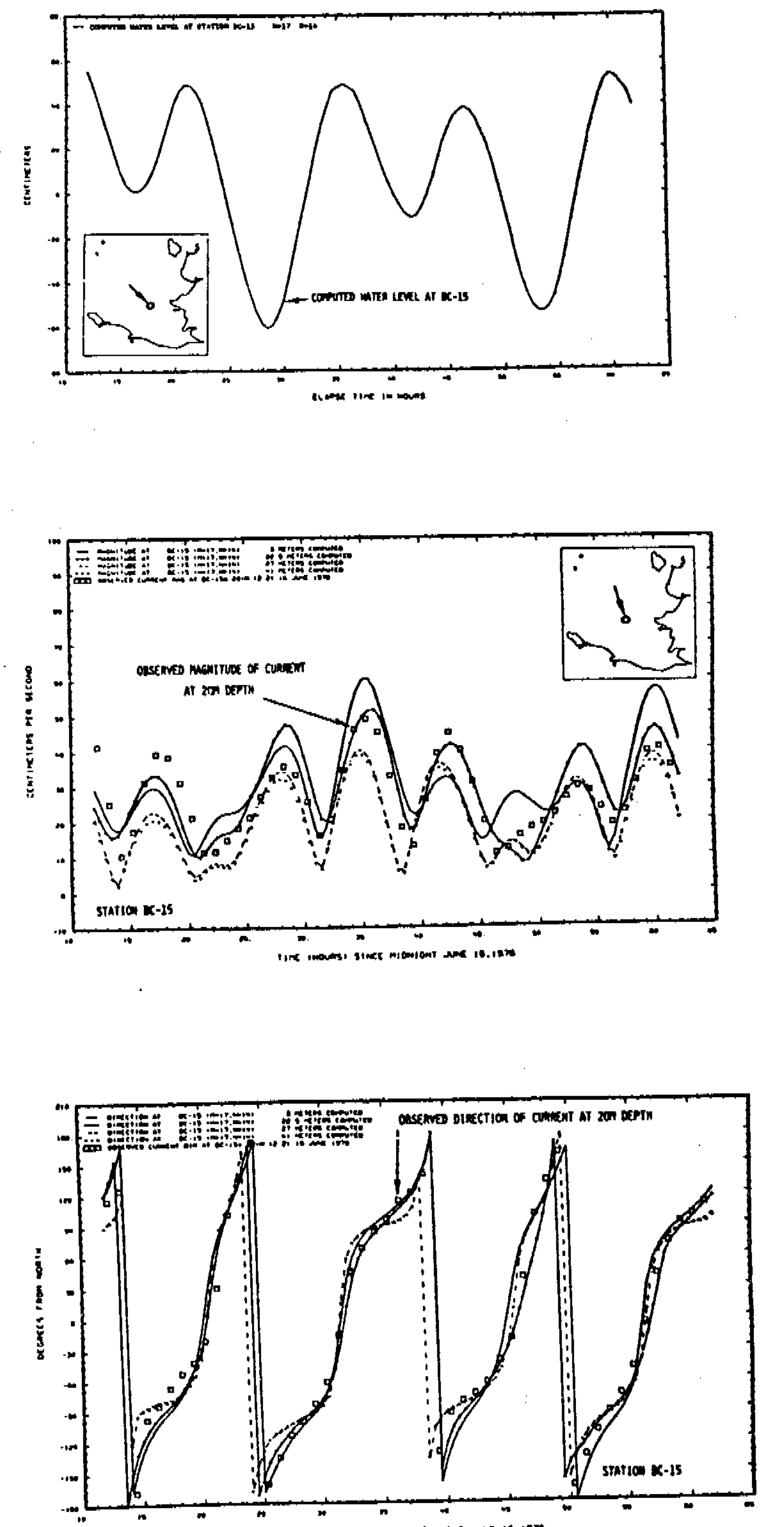

CENTIMETERS
COMPUTED WATER LEVEL AT BC-15
ELAPSE TIME IN HOURS
CENTIMETERS PER SECOND
OBSERVED MAGNITUDE OF CURRENT
AT 20M DEPTH
STATION BC-15
TIME (HOURS) SINCE MIDNIGHT JUNE 16,1976
DEGREES FROM NORTH
OBSERVED DIRECTION OF CURRENT AT 20M DEPTH
STATION BC-15
TIME (HOURS) SINCE MIDNIGHT JUNE 16,1976

Fig. 5

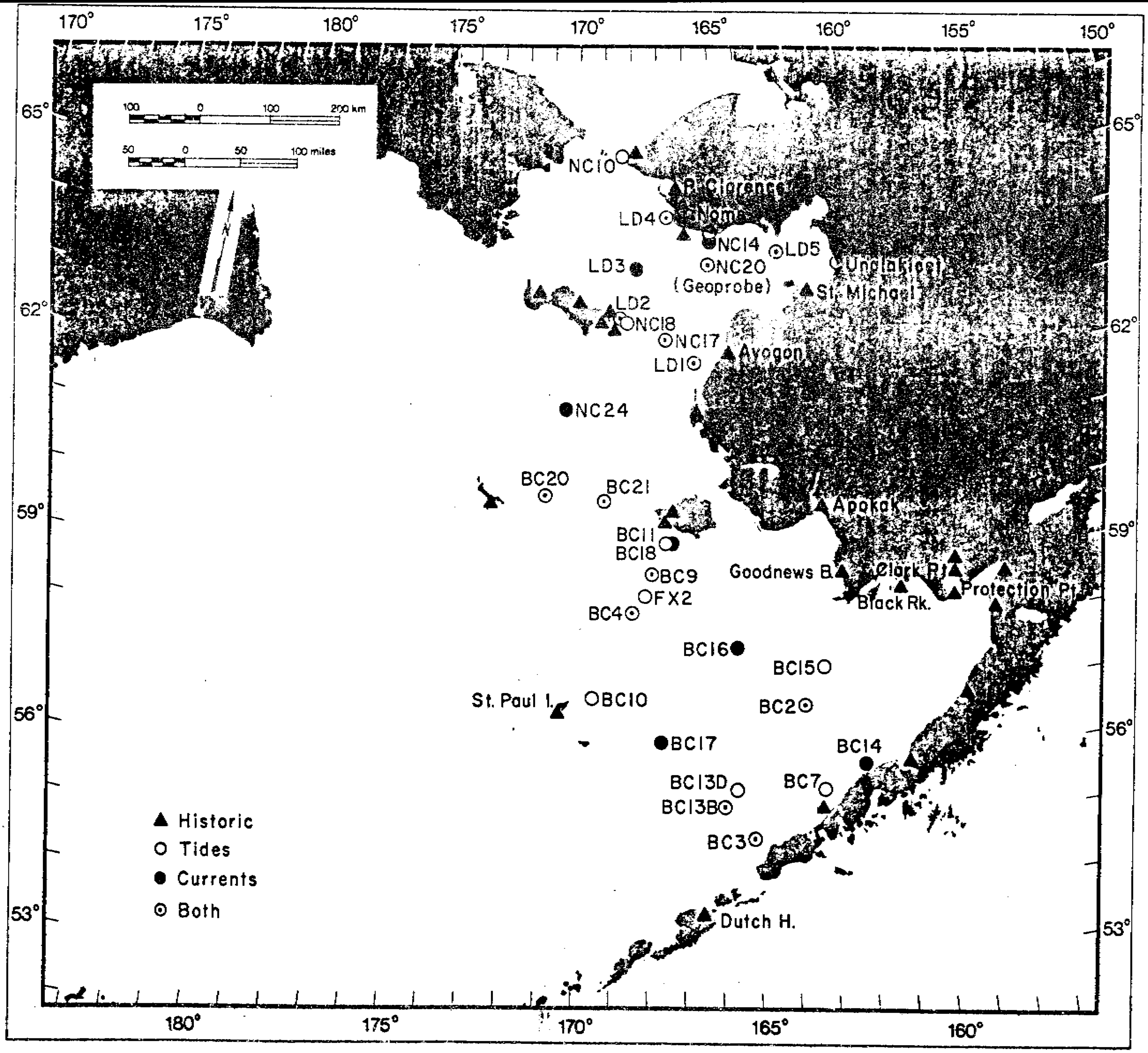

170°
175°
180°
175°
170°
165°
160°
155°
150°
65°
62°
59°
56°
53°
100 0 100 200 km
50 0 50 100 miles
NC10
P. Clarence
LD4
Nome
NC14
LD5
LD3
NC20
(Geoprobe)
St. Michael
LD2
NC18
NC17
Avogon
LD1
NC24
BC20
BC21
Apokak
BC11
BC18
BC9
Goodnews B.
Clark Pt.
Black Rk.
Protection Pt.
FX2
BC4
BC16
BC15
St. Paul I.
BC10
BC2
BC17
BC14
BC13D
BC7
BC13B
BC3
Dutch H.
Historic
Tides
Currents
Both
180°
175°
170°
165°
160°

Fig. 6

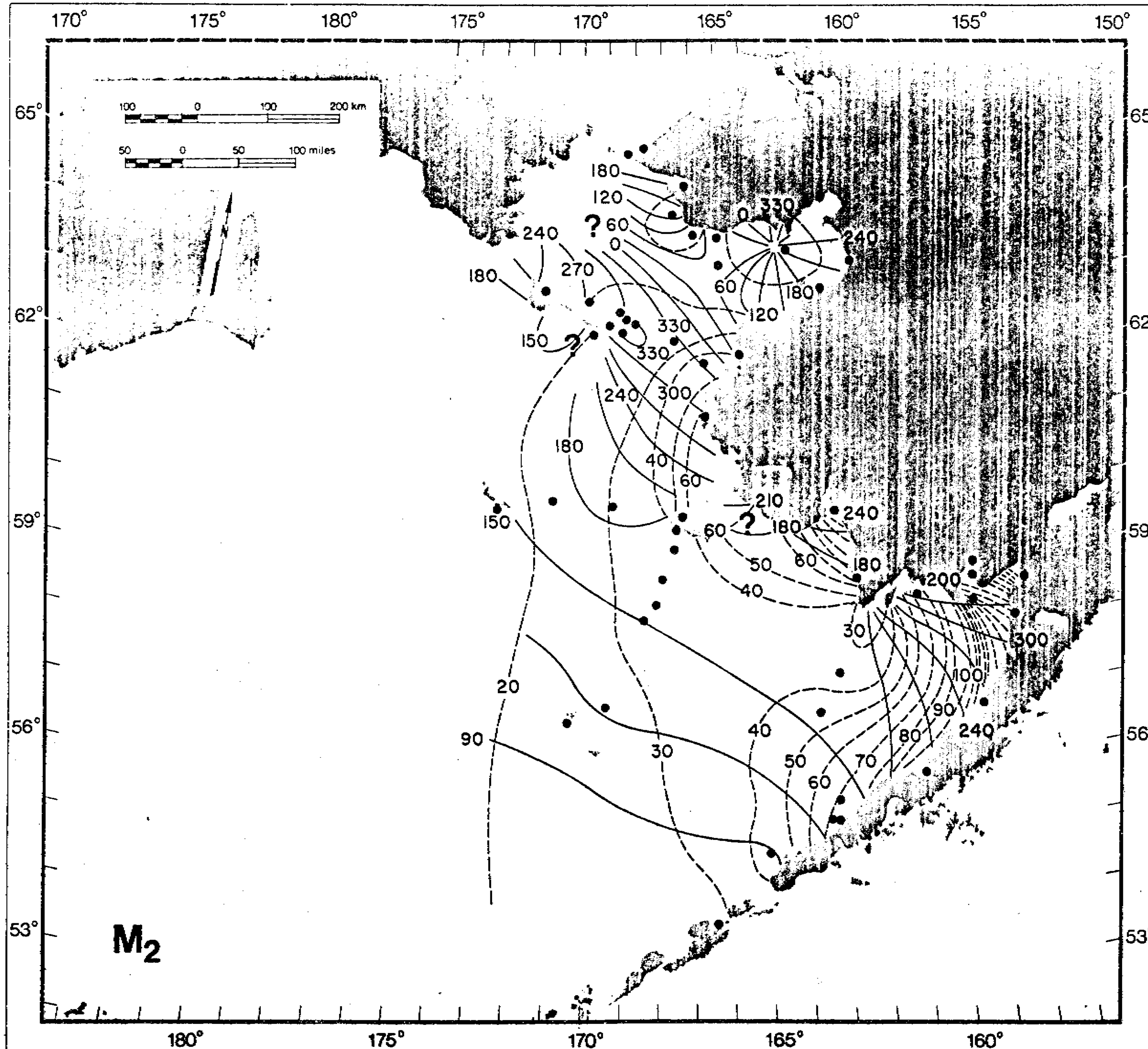

M2
100 0 100 200 km
50 0 50 100 miles
170° 175° 180° 175° 170° 165° 160° 155° 150°
65° 62° 59° 56° 53°
180° 175° 170° 165° 160°

Fig. 7

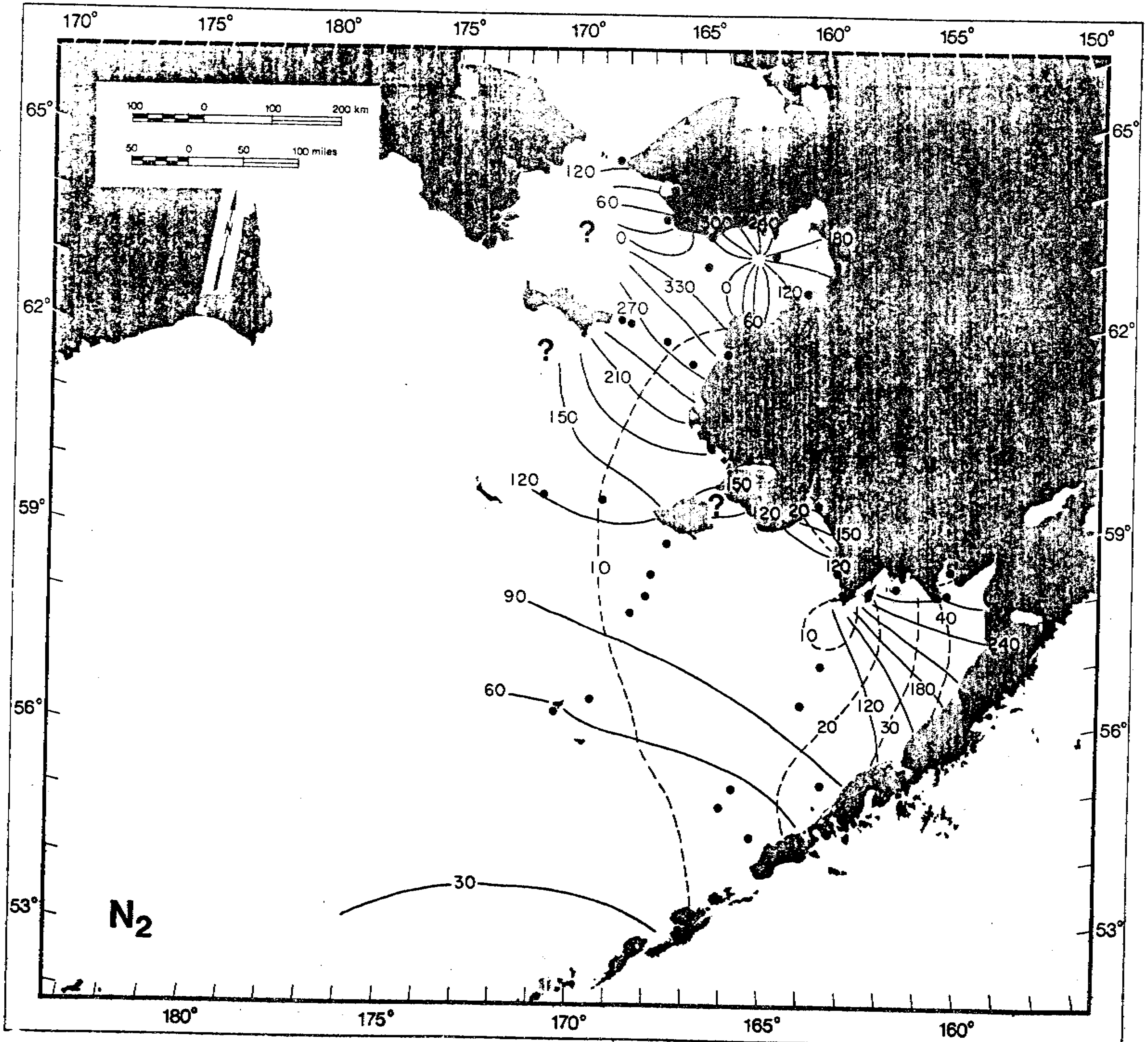
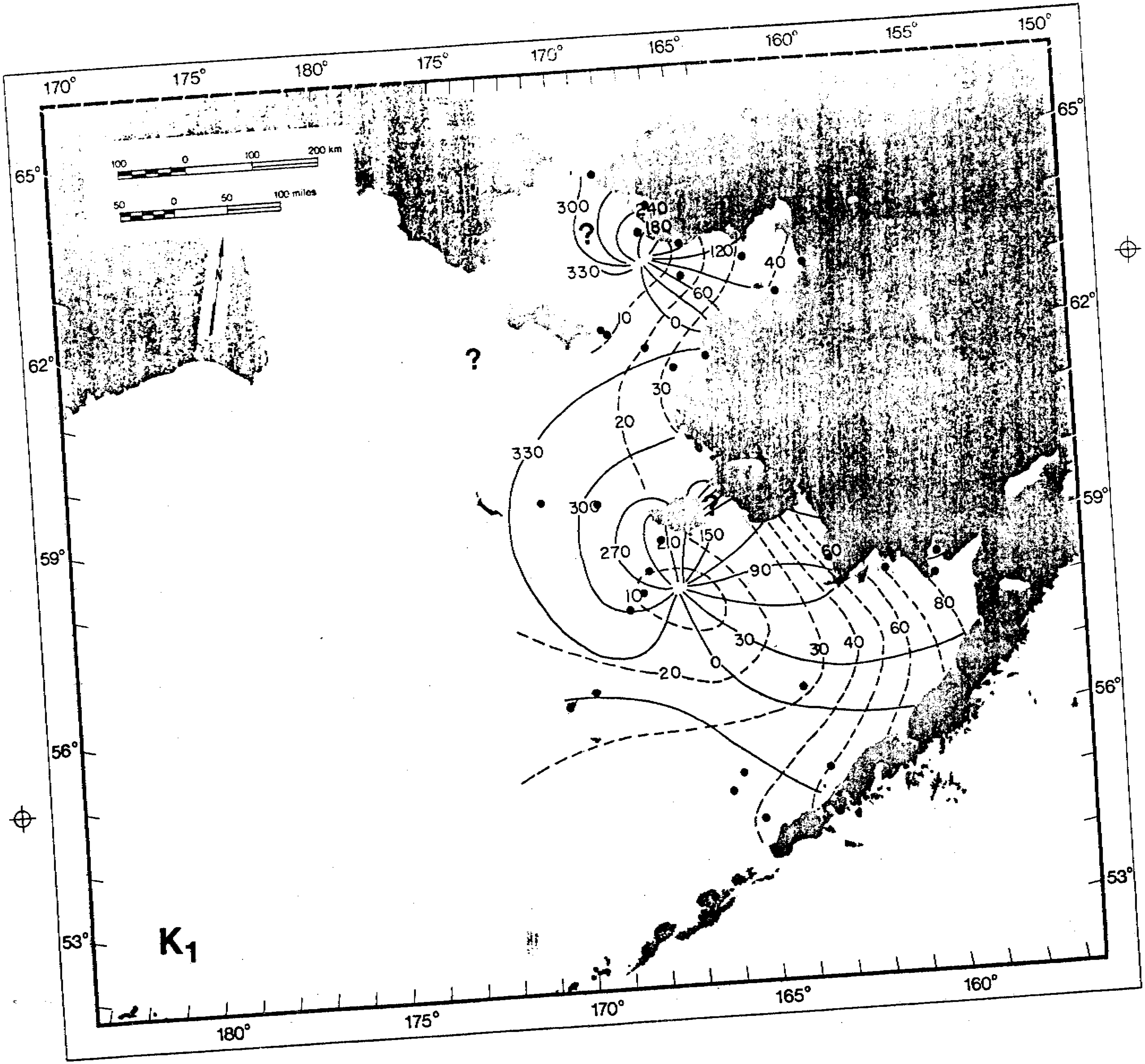

N2
100 0 100 200 km
50 0 50 100 miles
170° 175° 180° 175° 170° 165° 160° 155° 150°
65° 62° 59° 56° 53°
180° 175° 170° 165° 160°
120
60
0
330
270
210
150
120
90
60
30
10
20
40
180
240
?

Fig. 8


K1
100 0 100 200 km
50 0 50 100 miles
N
170° 175° 180° 175° 170° 165° 160° 155° 150°
65° 62° 59° 56° 53°
180° 175° 170° 165° 160°
300
240
180
120
40
330
60
10
0
?
?
30
20
330
300
270
210
150
60
90
10
80
60
30
40
30
0
20

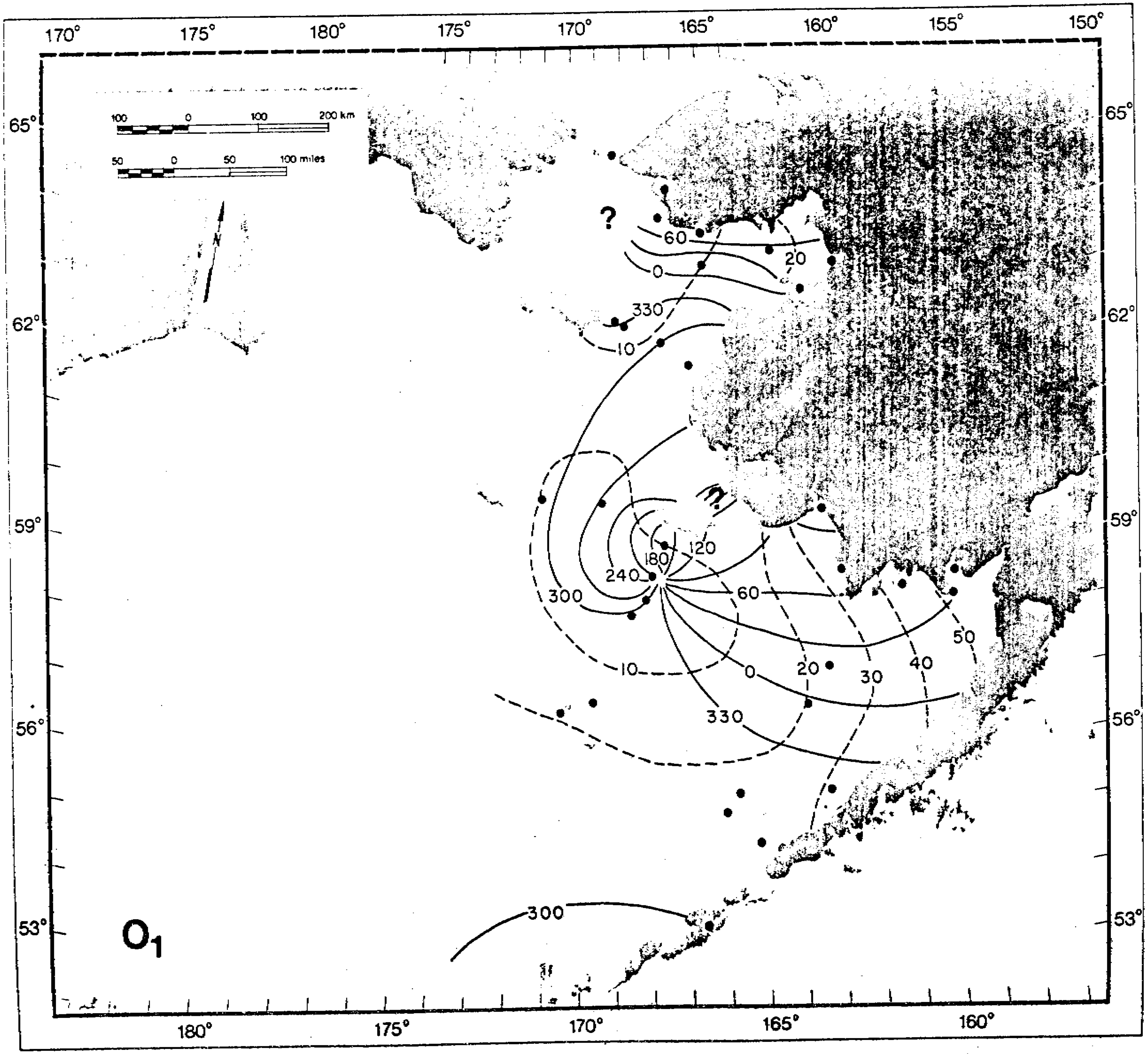
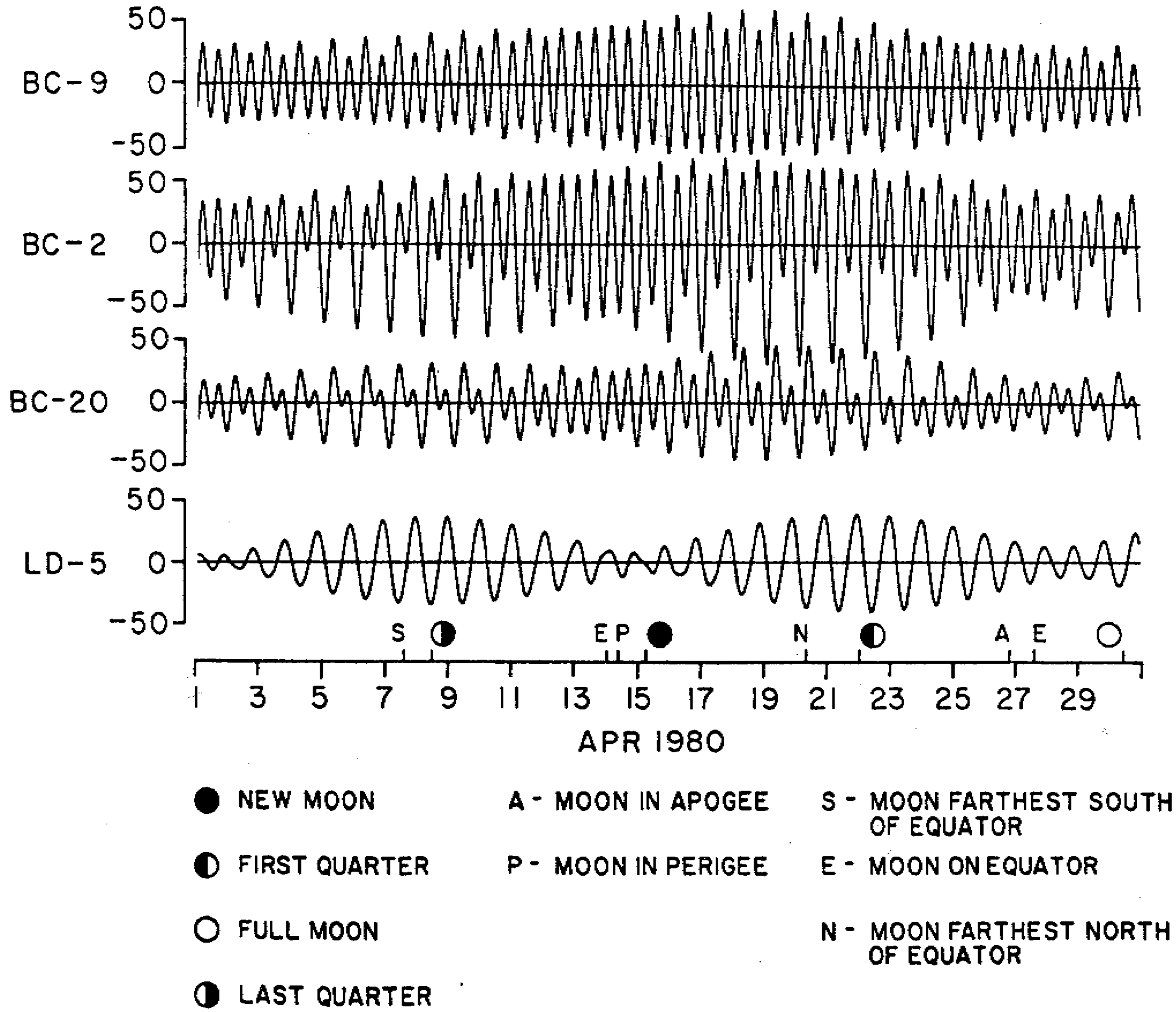

170°
175°
180°
175°
170°
165°
160°
155°
150°
65°
62°
59°
56°
53°
100 0 100 200 km
50 0 50 100 miles
N
?
60
20
0
330
10
120
180
240
300
60
50
40
30
20
0
10
330
300
O1

Fig. 10



BC-9
BC-2
BC-20
LD-5
50
0
-50
S
E P
N
A E
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
APR 1980
NEW MOON
FIRST QUARTER
FULL MOON
LAST QUARTER
A - MOON IN APOGEE
P - MOON IN PERIGEE
S - MOON FARTHEST SOUTH OF EQUATOR
E - MOON ON EQUATOR
N - MOON FARTHEST NORTH OF EQUATOR

Fig. 11

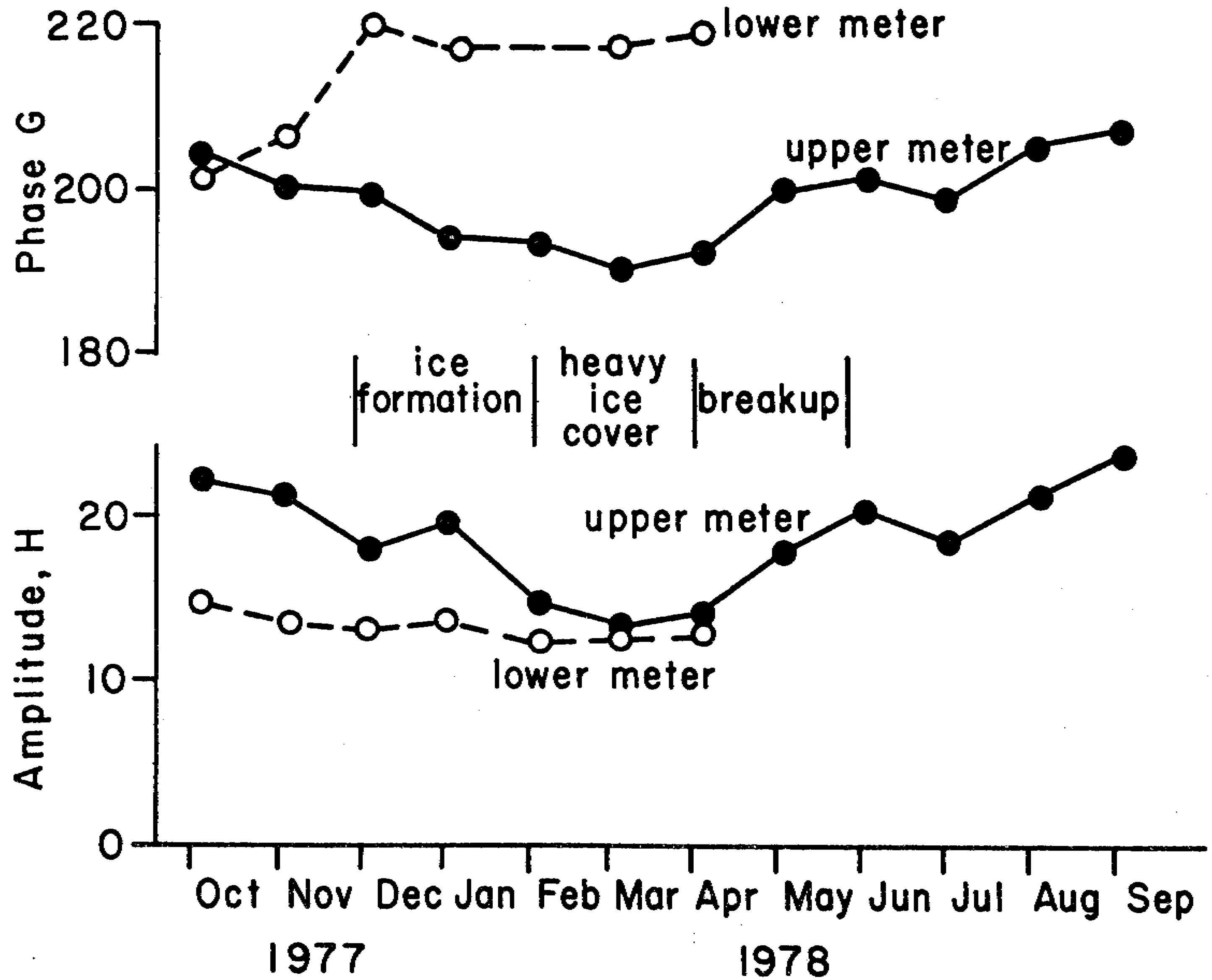
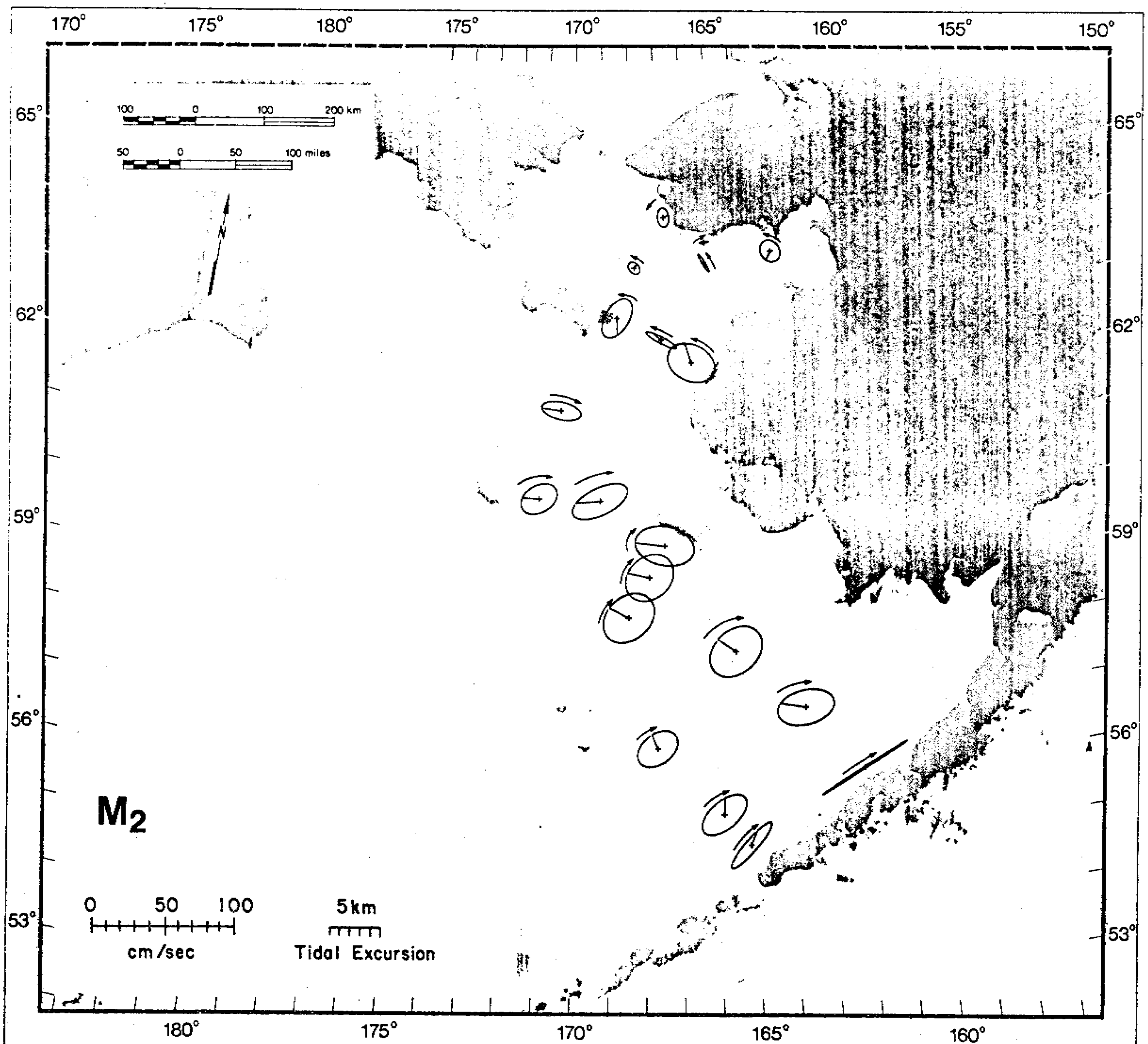
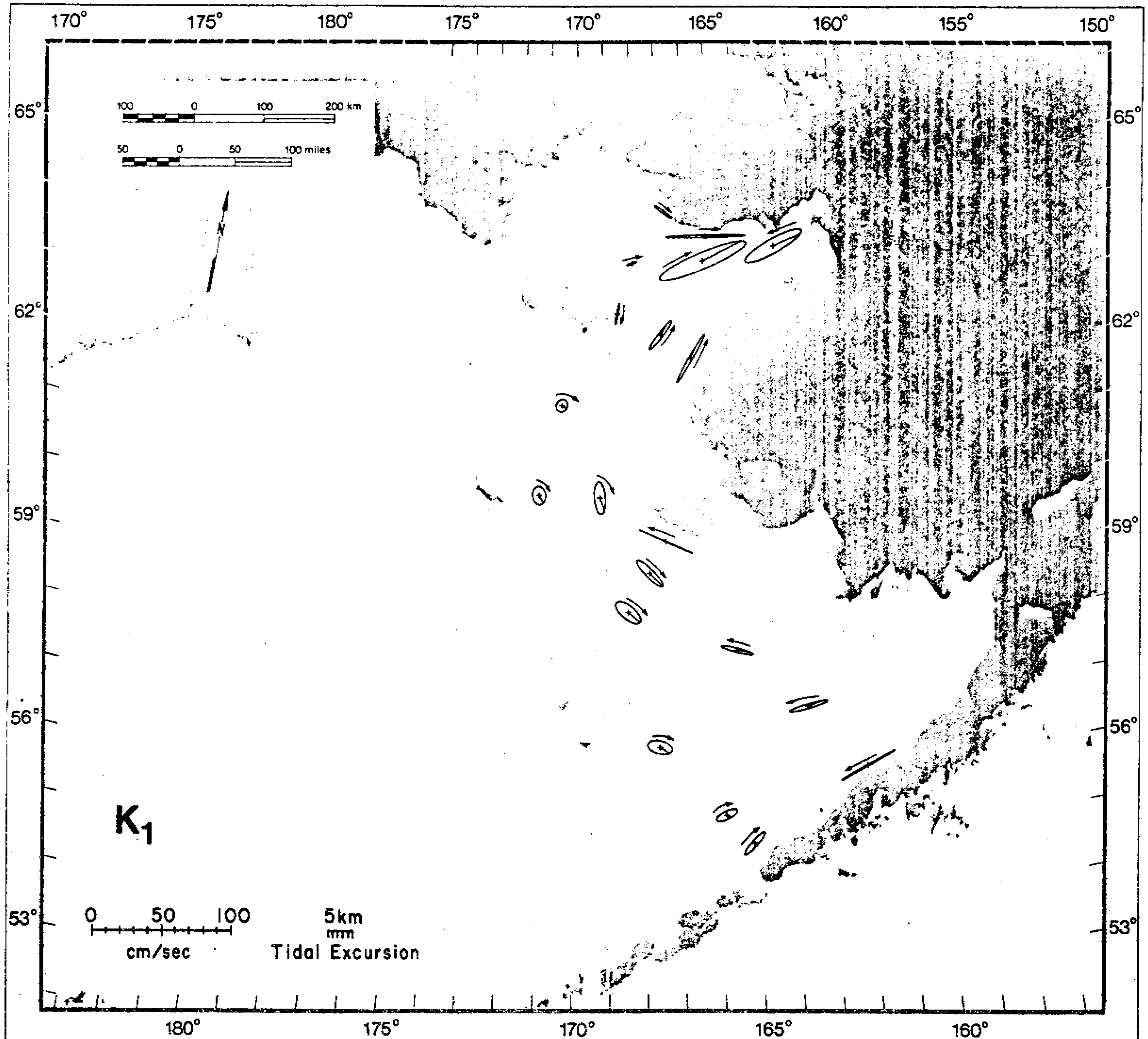

220
200
180
Phase G
lower meter
upper meter
ice formation
heavy ice cover
breakup
20
10
0
Amplitude, H
upper meter
lower meter
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
1977
1978

Fig. 12



170° 175° 180° 175° 170° 165° 160° 155° 150°
65° 62° 59° 56° 53°
100 0 100 200 km
50 0 50 100 miles
M2
0 50 100
cm/sec
5km
Tidal Excursion
180° 175° 170° 165° 160°

Fig. 13



K_1
0 50 100
cm/sec
5km
Tidal Excursion
100 0 100 200 km
50 0 50 100 miles
N
170° 175° 180° 175° 170° 165° 160° 155° 150°
180° 175° 170° 165° 160°
65° 62° 59° 56° 53°

Fig. 14

G. CHAPTER 6. CIRCULATION AND HYDROGRAPHY OF NORTON SOUND

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ABSTRACT

Norton Sound was two-layered vertically in temperature and salinity during summer, the eastern portion being more strongly layered than the western. Weak cyclonic mean flow in the eastern upper layer was not reflected in the lower layer, which was nearly stagnant and contained remnant cold, saline water formed locally during winter. Maintenance of this extreme layering in the eastern sound despite shallow depths (∿15 m) was due to buoyancy input, as solar heating and freshwater, sufficient to offset vertical mixing generated by tidal currents. In the western sound, coupled northerly upper and lower layer flows reflected a northward net flow over the shelf west of the sound. At times a strong baroclinic coastal flow occurred off Nome, and the central western sound was a locus for vertical mixing due to impingement of currents upon a shoal area. During winter, the sound approached vertical homogeneity due to vertical convection consequent to cooling and ice formation. Though it was possible to define mean flows, the currents were dominated by events which reflected regional wind and atmospheric pressure patterns in an as-yet-uncertain fashion. Such flow events may exert a primary control over such features as the Yukon River plume, which was never observed to enter the eastern sound even though the upper layer salinity there suggests that Yukon water may have entered the sound prior to our observations.

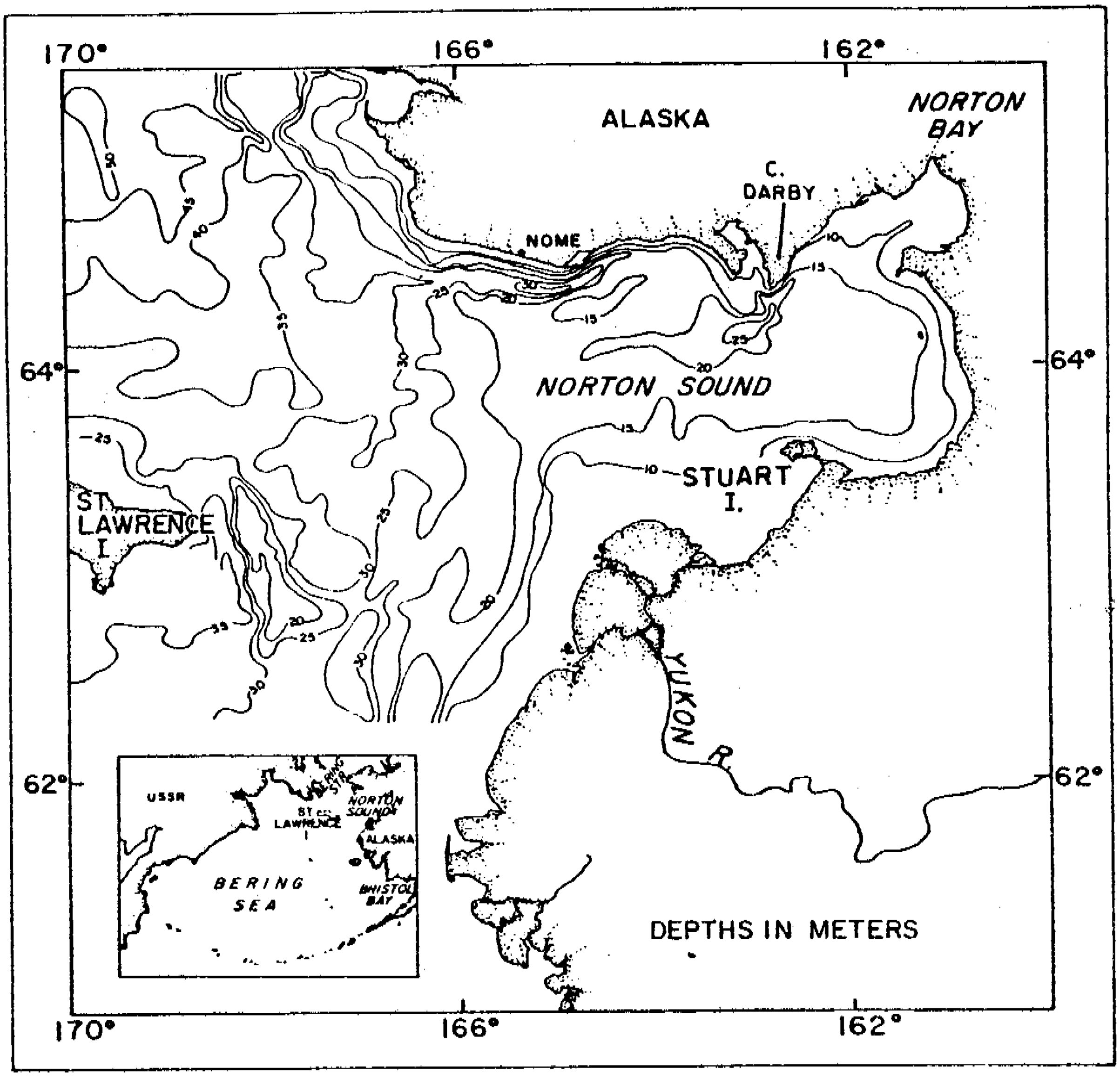
INTRODUCTION

Observations of temperature, salinity and currents have been obtained from Norton Sound, Alaska as part of an investigation of transport processes on the Alaskan continental shelves. The general physical oceanographic conditions within Norton Sound, as deduced from observations obtained between 1976-1978, are addressed in this paper. Since analyses of the observations are still ongoing, this should be considered as an interim, working document rather than a set of firm, final conclusions.

Physical Setting

Norton Sound is a shallow, high-latitude embayment extending eastward from the northern Bering Sea and forming an indentation in the central west coast of Alaska (Fig. 6-1). Its east-west length is about 220 km, and its width about 150 km. Depths vary from less than 10 m in the southern portion to more than 30 m in a trough-like feature which trends east-west in the nearshore region just south of Nome; overall depth in the sound is about 20m. Two promontories indent the sound about two-thirds of the way toward its eastern end, Cape Darby from the north and Stuart Island from the south (Fig. 6-1).

Norton Sound is located in a geographical region of extreme seasonal variability. During the approximately June-September summer the sound is ice-free and air temperatures are well above freezing. The waters are exposed to a 24-hour daylight though not necessarily direct sunlight during part of this period, and



170°
166°
162°
ALASKA
NORTON BAY
C. DARBY
NOME
64°
NORTON SOUND
STUART I.
ST. LAWRENCE I.
YUKON R.
62°
USSR
BERING STR.
NORTON SOUND
ST. LAWRENCE I
ALASKA
BERING SEA
BRISTOL BAY
DEPTHS IN METERS

generally light and variable winds. By November, air temperatures drop well below freezing and ice formation has normally commenced along the northern shore, with first ice typically forming on the surface in Norton Bay at the northeast corner of the sound. Ice growth continues southward until, by mid-December, the entire sound is more or less covered. This ice cover, which usually persists until April or May, consists primarily of loose pack 0.5-1.0 m thick except for shore-fast ice in near-shore regions and for some distance offshore in the region of the Yukon River delta. Direct observations of the ice cover are limited, and much information on its distribution and extent has been obtained through use of satellite data (Muench and Ahlnäs 1976; Ahlnäs and Wendler 1979).

During winter the ice cover would be expected to markedly reduce air-sea exchange of heat, moisture and momentum. This would ameliorate effects on the water of low air temperatures and winter storms.

Oceanographic Background

Our existing knowledge of northern Bering Sea circulation prior to the present series of studies was summarized by Coachman et al. (1975). The regional circulation is dominated by a northward net water transport of about 1.5 x 10^6 m^3 sec^{-1} over the shelf between Norton Sound and Siberia. More recently Muench et al. (1978) have reported, based upon near-bottom recorded current measurements, northward net flow southeast of St. Lawrence

Island and in Bering Strait from October 1975 through April 1977. They also noted that the currents were characterized by north-south flow events having speeds of 50-100 cm sec^{-1}, large relative to mean flow speed of about 15 cm sec^{-1}. These flow events had time scales of several days, or the same durations as meteorological events. Spatial variability of the northward flow and its interaction with the waters of Norton Sound remain uncertain.

Prior to this study, little oceanographic information was available from Norton Sound itself. Bottom sediment distributions within the sound suggest that mean circulation is cyclonic and penetrates to the easternmost sound (Drake et al. 1980), but flow rates have not been estimated. Cyclonic flow in western Norton Sound was depicted qualitatively in the compilation by Hughes et al. (1974) and mentioned as a probability by Coachman et al. (1975).

The Yukon River enters the Bering Sea in the southwest corner of Norton Sound (Fig. 6-1). A minor portion of its discharge is directly into the southern sound, while the remainder enters the Bering Sea along the coast farther west. Both the volume and the pathway of Yukon water which enters the sound remain uncertain. River flow can be as high as about 3×10^4 m^3 sec^{-1}, as gauged at Pilot Station some 60 km above the river mouth. Most of the annual river input occurs between about April and November, and flow is an order of magnitude greater during mid-summer than during mid-winter.

FIELD PROGRAM

Oceanographic data were obtained from Norton Sound during 1976-1978. Temperature and salinity data were acquired from vessels during summer 1976, 1977 and 1978 and through the ice from a helicopter during winter 1978. The periods of these cruises are summarized in Table 6-I. Twenty-four hour time series current observations were obtained from anchor stations during summer 1976, and instantaneous current profiles were obtained from anchor stations during summer 1977. Ancillary data obtained during summer 1977 included vertical profiles of transmissivity.

In addition to shipboard data, current data were obtained using taut-wire moorings during both winter and summer periods. Statistics for these moorings are summarized in Table 6-II.

Summer temperature and salinity data were obtained using a Plessey conductivity/temperature/depth (CTD) profiling unit with calibration samples on each cast. Winter data were obtained with a Plessey Model 9400 profiling unit operating through the ice from a helicopter. Temperature and salinity data are accurate to within 0.02°C and 0.02°/₀₀, respectively.

Currents were observed on the taut-wire moorings with Aanderaa Model RCM-4 current meters. Our discussion addresses the non-tidal, low frequency flow components, as tides are treated elsewhere in the volume (Chapter 8). In order to remove tidal and higher frequency components, the records were processed according to Charnell and Krancus (1976) and run through a 35-hour low-pass filter.

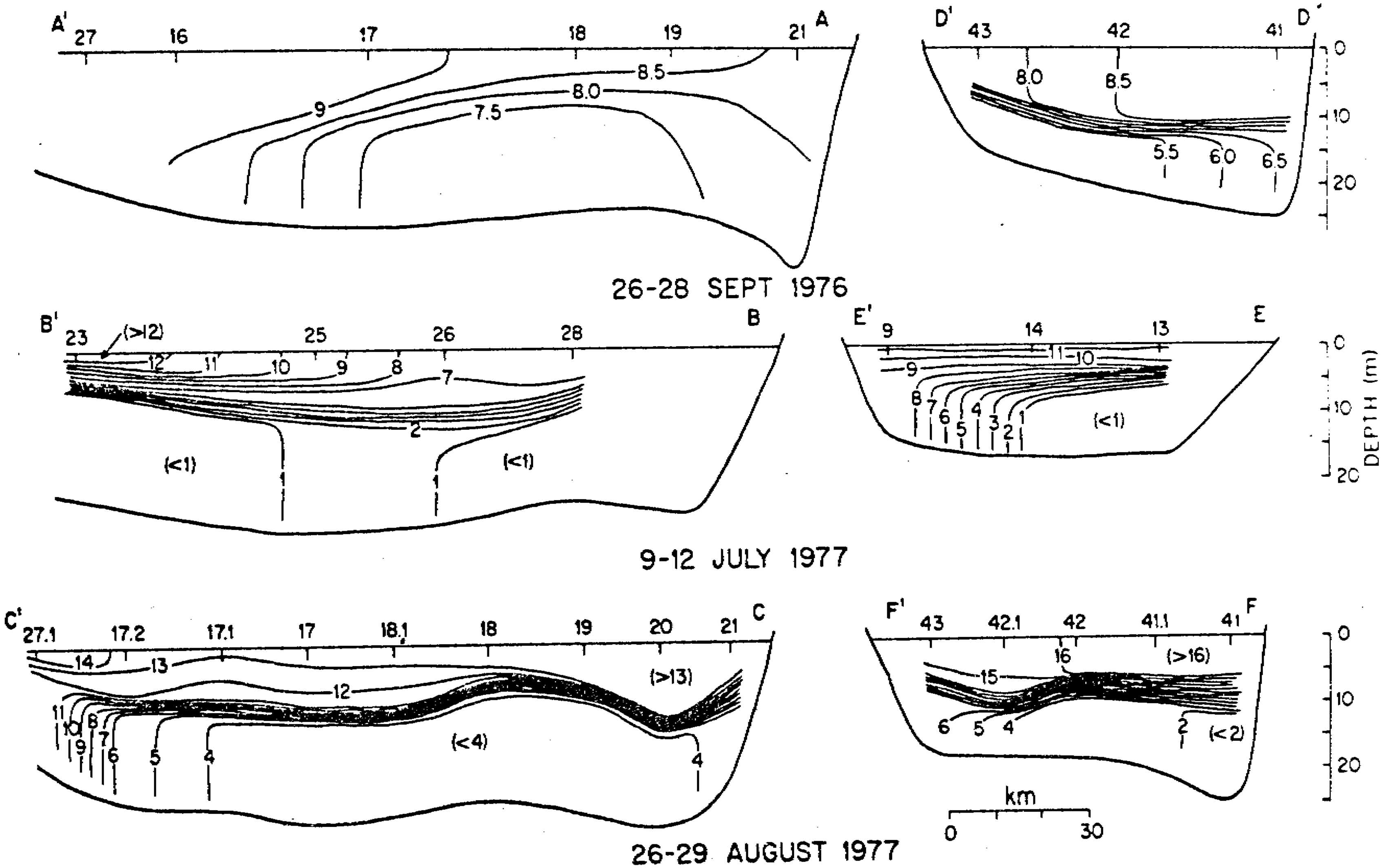
Anchored time-series stations were obtained using an Aanderaa current meter modified to operate through a deck read out unit. Speed and direction were measured hourly at 5 m intervals through the water column. Hourly CTD casts were also made at the time-series stations. Instantaneous current profiles were obtained using a Hydro Products current meter. Observations were not taken when the vessel exhibited yawing motions, easily discernable by rapid variations in heading.

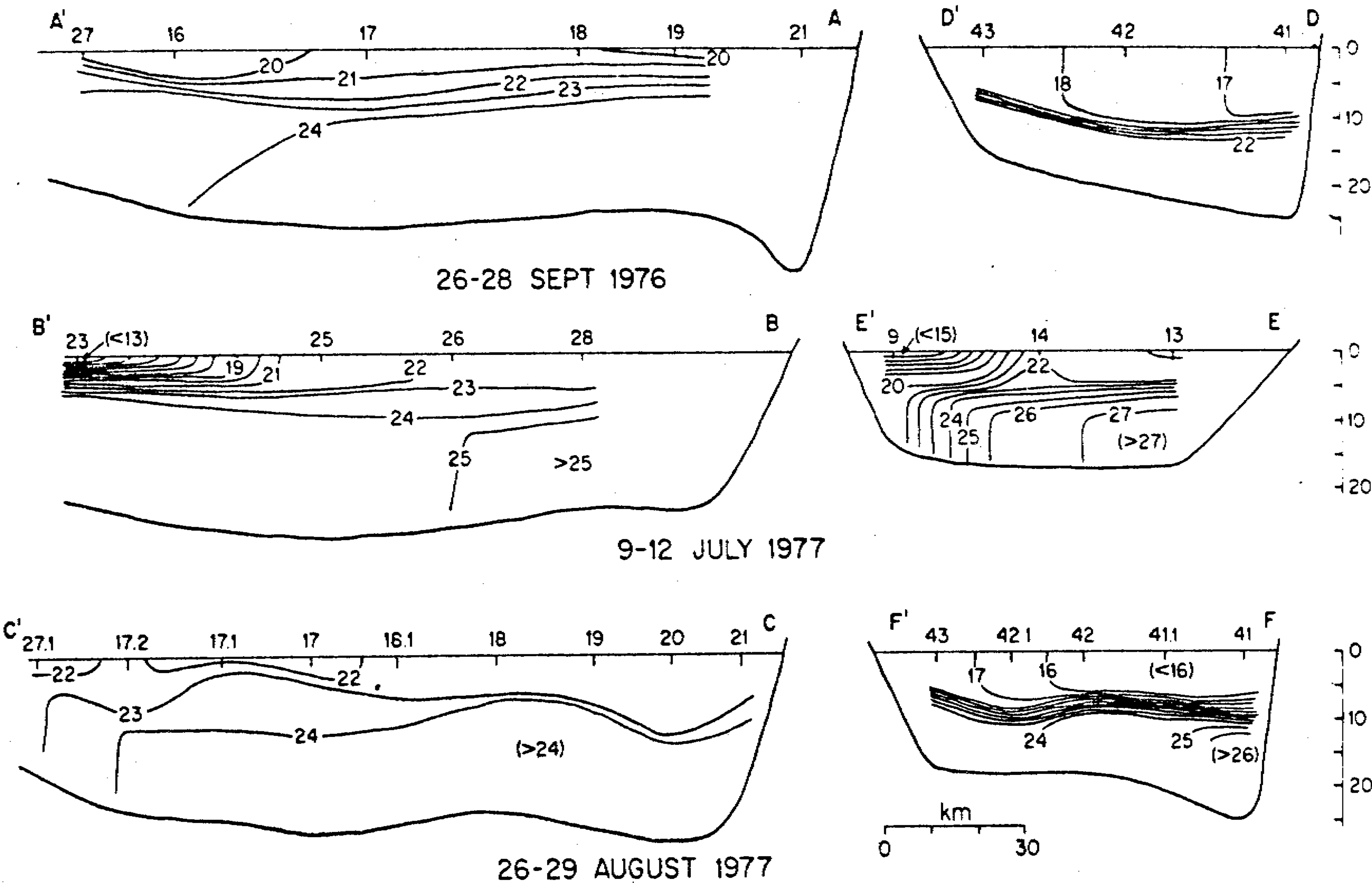
In addition to the water column observations, wind speed and direction and air temperature were obtained from shipboard and were also recorded at the nearby weather station at Nome.

OBSERVATIONS

Distribution of Density, Temperature and Salinity

Norton Sound is characterized during summer by two layers separated by a strong pycnocline. The upper layer is warmer and of lower salinity, hence less dense than, the lower layer. This layering was more pronounced and consistent in its characteristics during 1976 and 1977 (Figs. 6-2 and 6-3) than in 1978 (University of Washington data not shown). During 1976 and 1977 temperature and density differences between the layers were greater in the eastern than in the western sound. A near-surface lens of warm (> 12°C), low-density (< 13 sigma-t units) water in the southwestern sound was especially pronounced in July 1977 (station 23), and indicated the presence there of Yukon River water which is


A' 27 16 17 18 19 21 A
9
8.5
8.0
7.5
D' 43 42 41 D
8.0
8.5
5.5
6.0
6.5
26-28 SEPT 1976
B' 23 (>12) 25 26 28 B
12 11 10 9 8 7
2
(<1)
1
(<1)
E' 9 14 13 E
11 10
9
8 7 6 5 4 3 2 1
(<1)
DEPTH (m)
0 10 20
9-12 JULY 1977
C' 27.1 17.2 17.1 17 18.1 18 19 20 21 C
14 13
12
(>13)
11 10 9 8 7 6 5 4
(<4)
4
F' 43 42.1 42 41.1 41 F
16 (>16)
15
6 5 4
2 (<2)
km
0 30
26-29 AUGUST 1977

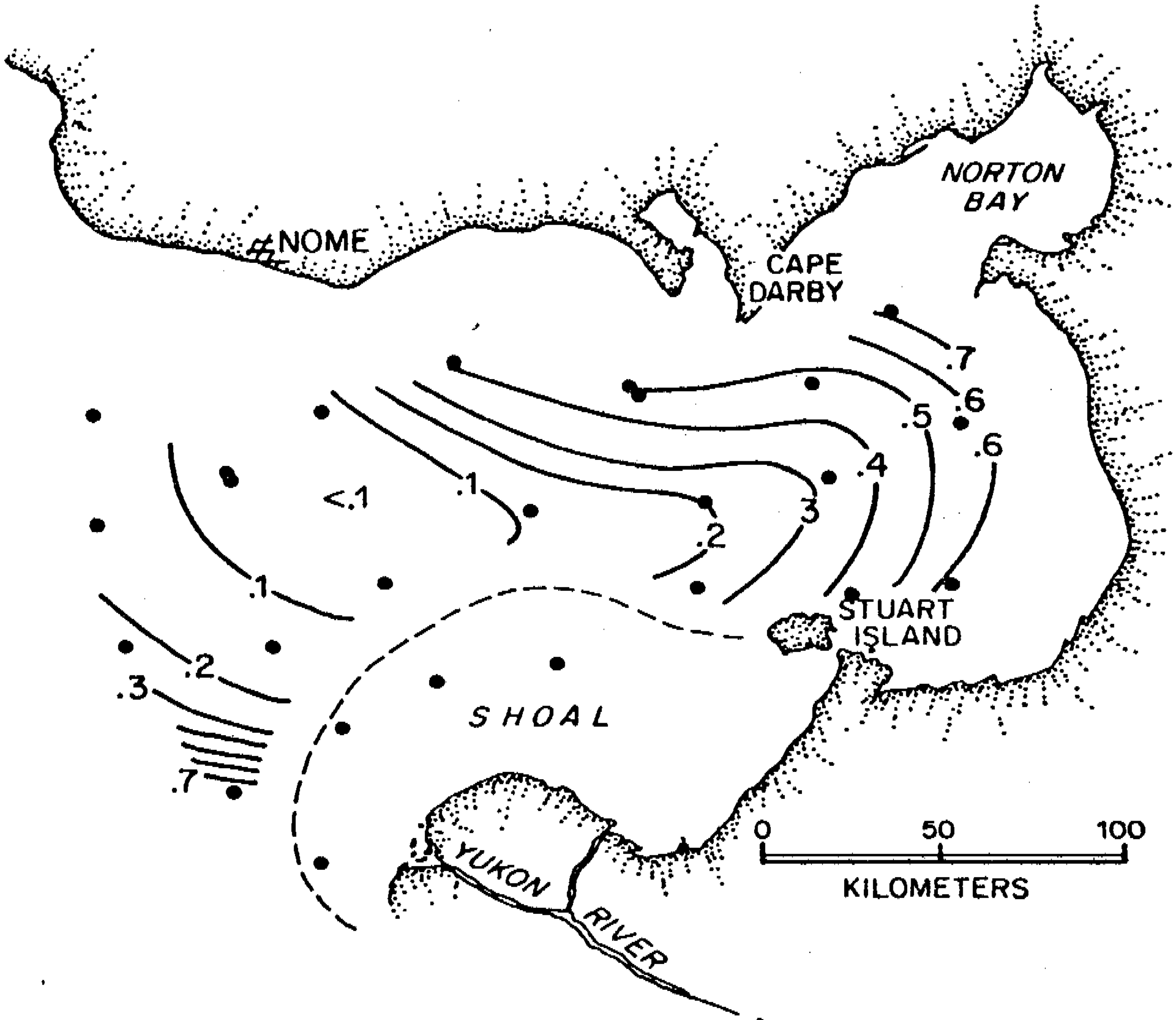

A' 27 16 17 18 19 21 A
20 21 22 23 24
26-28 SEPT 1976
D' 43 42 41 D
18 17 22
B' 23 (<13) 25 26 28 B
19 21 22 23 24 25 >25
9-12 JULY 1977
E' 9 (<15) 14 13 E
22 20 24 25 26 27 (>27)
DEPTH (m)
C' 27.1 17.2 17.1 17 16.1 18 19 20 21 C
22 22 23 24 (>24)
26-29 AUGUST 1977
F' 43 42.1 42 41.1 41 F
17 16 (<16) 24 25 (>26)
km
0 30

3

characterized by low salinity and corresponding low density. Concurrent temperature increases and density decreases with time during July-August 1977 were evident in both layers. The data in summer 1978 were insufficient to define spatial variations, but were adequate to detect higher bottom layer temperatures in the eastern sound (∿7°C, as opposed to 1-2°C during 1976 and 1977) than during the previous two seasons. Bottom layer salinities were also lower in the eastern sound in 1978 than during 1976 or 1977 (about 32°C/∘∘, as compared to 34°/∘∘).

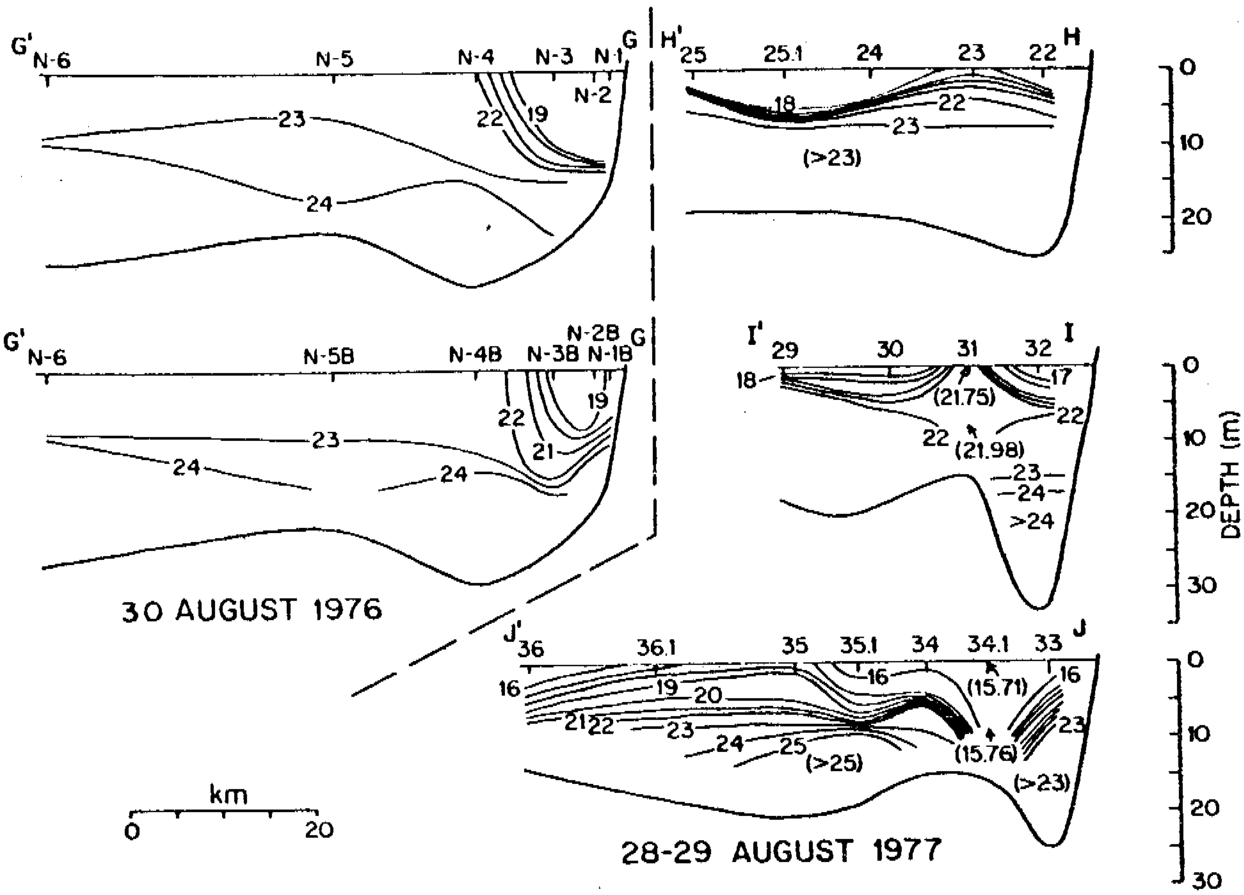
The tendency for increased stratification in the eastern as compared to the western sound is exemplified by vertically averaged density gradients for July 1977 (Fig. 6-4). The single large, isolated value off the Yukon River was due to elevated near-surface temperatures. A pronounced region of minimum stratification was present in the central western sound. Closely spaced stations obtained through this region in August 1977 defined vertical density structure through the area of minimum stratification (Fig. 6-5). This feature coincided with a shallow rise (depths <20 m) in the bottom southeast of Nome (Fig. 6-1).

Though there was considerable year-year variation in detail, several features of the horizontal temperature and salinity distributions persisted. The surface and near-bottom temperature and salinity distributions adequately represent the upper and lower layers, respectively, and are used to depict these features (Figs. 6-6 and 6-7). The upper layer was dominated by an eastward-trending high salinity, low temperature tonguelike feature which



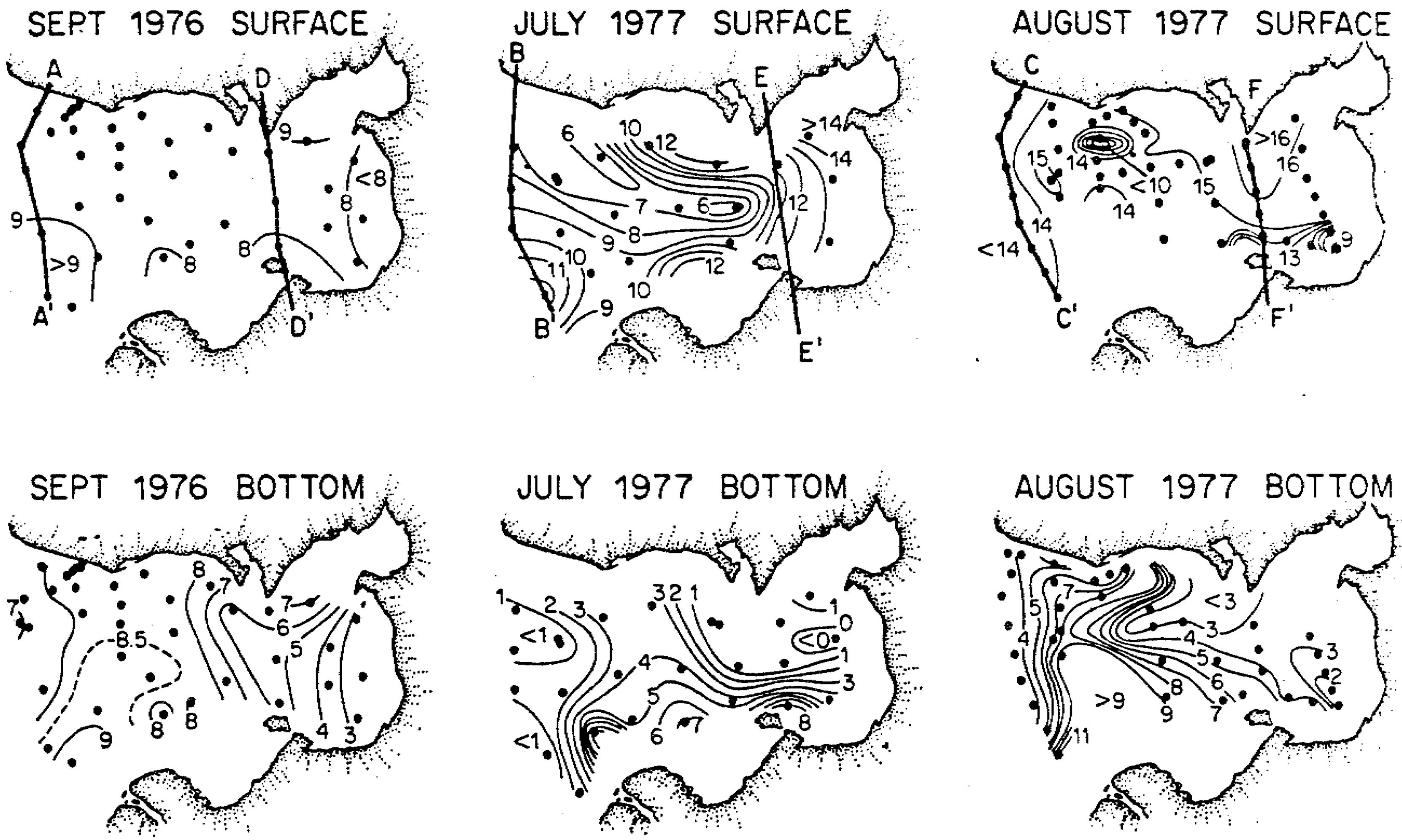
NORTON
BAY
NOME
CAPE
DARBY
.7
.6
.5
.6
.4
<.1
.1
3
.2
.1
STUART
ISLAND
.2
.3
.7
SHOAL
0
50
100
KILOMETERS
YUKON
RIVER

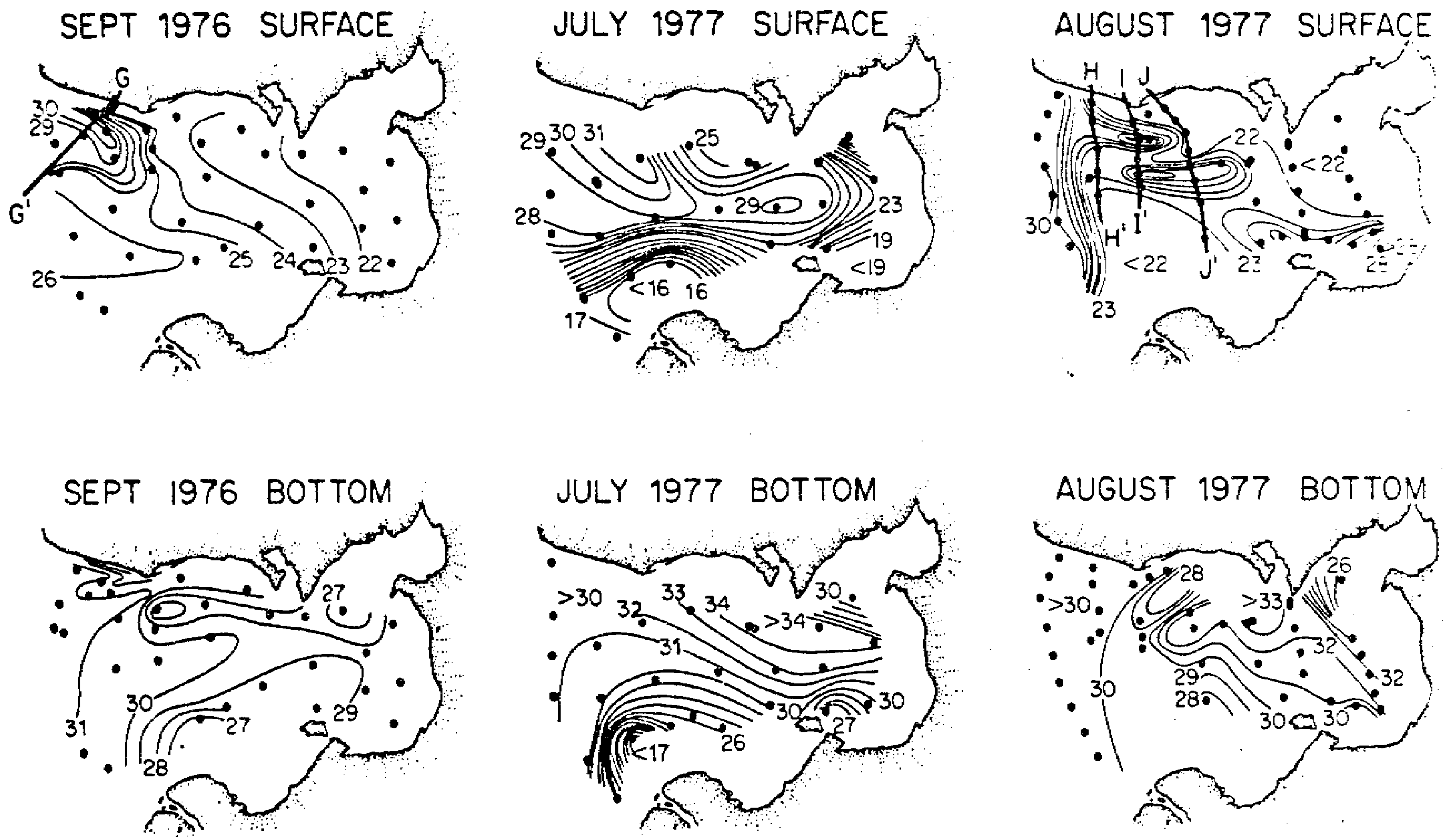
4



G'
N-6
N-5
N-4
N-3
N-1
G
N-2
23
24
22
19
H'
25
25.1
24
23
22
H
18
22
23
(>23)
0
10
20
G'
N-6
N-5B
N-4B
N-3B
N-2B
N-1B
G
22
19
21
23
24
24
30 AUGUST 1976
I'
29
30
31
32
I
18
17
(21.75)
22
22
(21.98)
23
24
>24
0
10
20
30
DEPTH (m)
J'
36
36.1
35
35.1
34
34.1
33
J
16
19
20
16
(15.71)
16
21
22
23
24
25
(>25)
(15.76)
23
(>23)
0
10
20
30
km
0
20
28-29 AUGUST 1977

5


SEPT 1976 SURFACE
A
A'
D
D'
9
>9
8
<8
JULY 1977 SURFACE
B
B'
E
E'
6
7
8
9
10
11
12
>14
14
AUGUST 1977 SURFACE
C
C'
F
F'
<14
14
15
<10
>16
16
13
9
SEPT 1976 BOTTOM
7
8
8.5
9
6
5
4
3
JULY 1977 BOTTOM
1
2
3
<1
4
5
6
7
8
<0
0
AUGUST 1977 BOTTOM
<3
>9
11
2


SEPT 1976 SURFACE
G
G'
30
29
26
25
24
23
22
JULY 1977 SURFACE
29
30
31
25
28
29
23
19
<19
<16
16
17
AUGUST 1977 SURFACE
H
I
J
H'
I'
J'
22
<22
30
<22
23
23
SEPT 1976 BOTTOM
27
30
31
27
28
29
JULY 1977 BOTTOM
>30
32
33
34
>34
30
31
30
30
27
26
<17
AUGUST 1977 BOTTOM
28
>33
26
>30
32
32
29
28
30
30
30

originated in the northwestern portion of the sound. This feature was best defined in July 1977, and by August it extended east-southeastward the full length of the sound but was patchy in nature. In September 1976 the tongue was restricted to the region just off Nome, and in 1978 the data were inadequate to detect its presence or absence. Generally, lower salinity, warmer water lay north and south of the tongue. The lowest salinities which were observed occurred off the Yukon River in July 1977. This may have been a sampling artifact, as measurements were obtained closer to shore at that time than during other cruises and probably penetrated farther into the Yukon River plume. The maximum observed temperatures (>16°C) occurred in the northeastern sound during August 1977. The horizontal range of temperatures within the upper layer during September 1976 was only about 1°C, in sharp contrast to stronger gradients observed in the 1977 summer data.

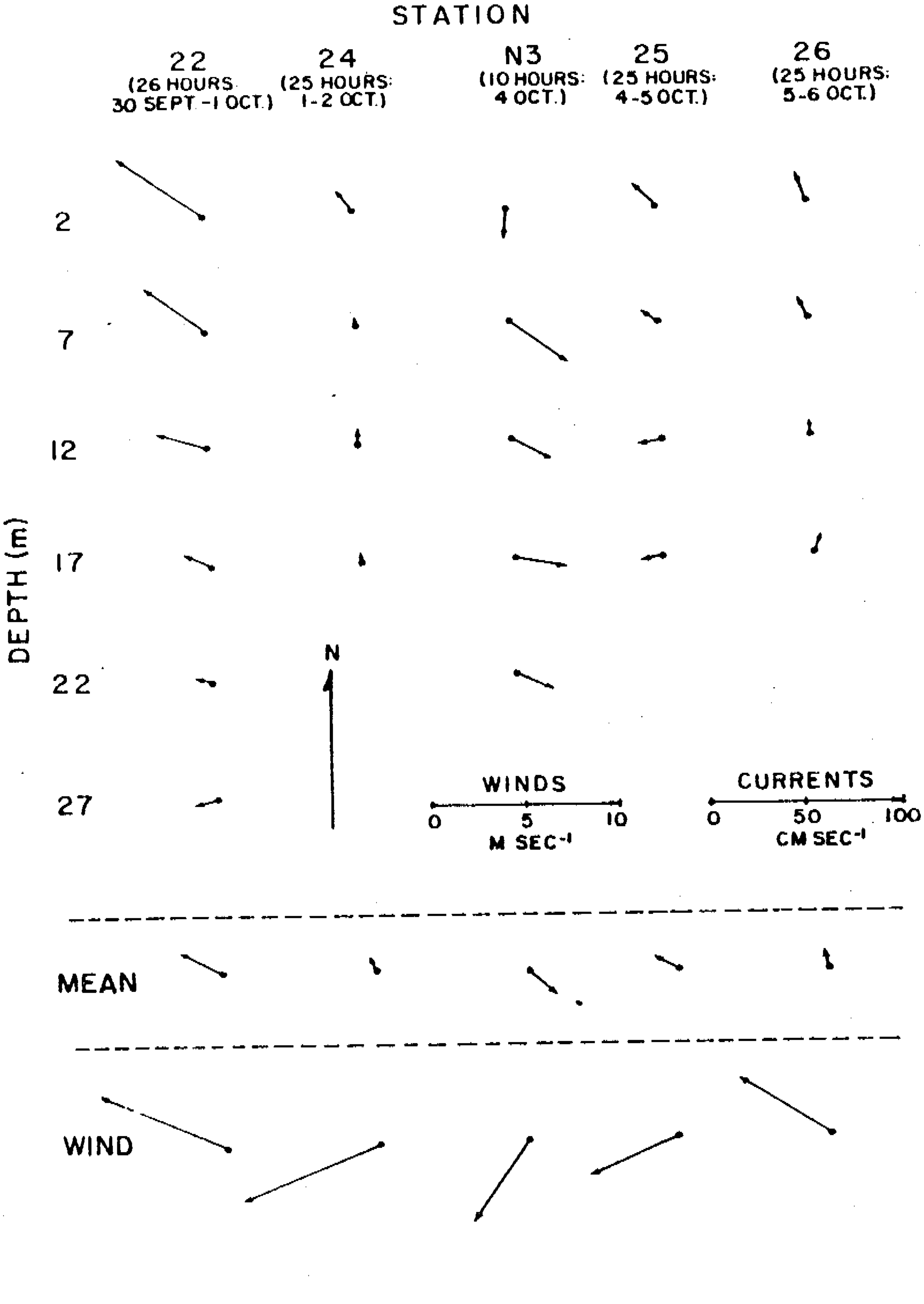
The lower layer in the eastern and northeastern sound was characterized during summer 1976 and 1977 by particularly cold, saline water. The coldest (<0°C), most saline (>34°/₀₀) water observed was present in July 1977, whereas by August temperatures had increased to 2-3°C, salinities had decreased to 32-33°/₀₀ and the locus of maximum salinity had shifted somewhat westward. As for the surface layers, bottom layer salinities were lowest off the Yukon River mouth.

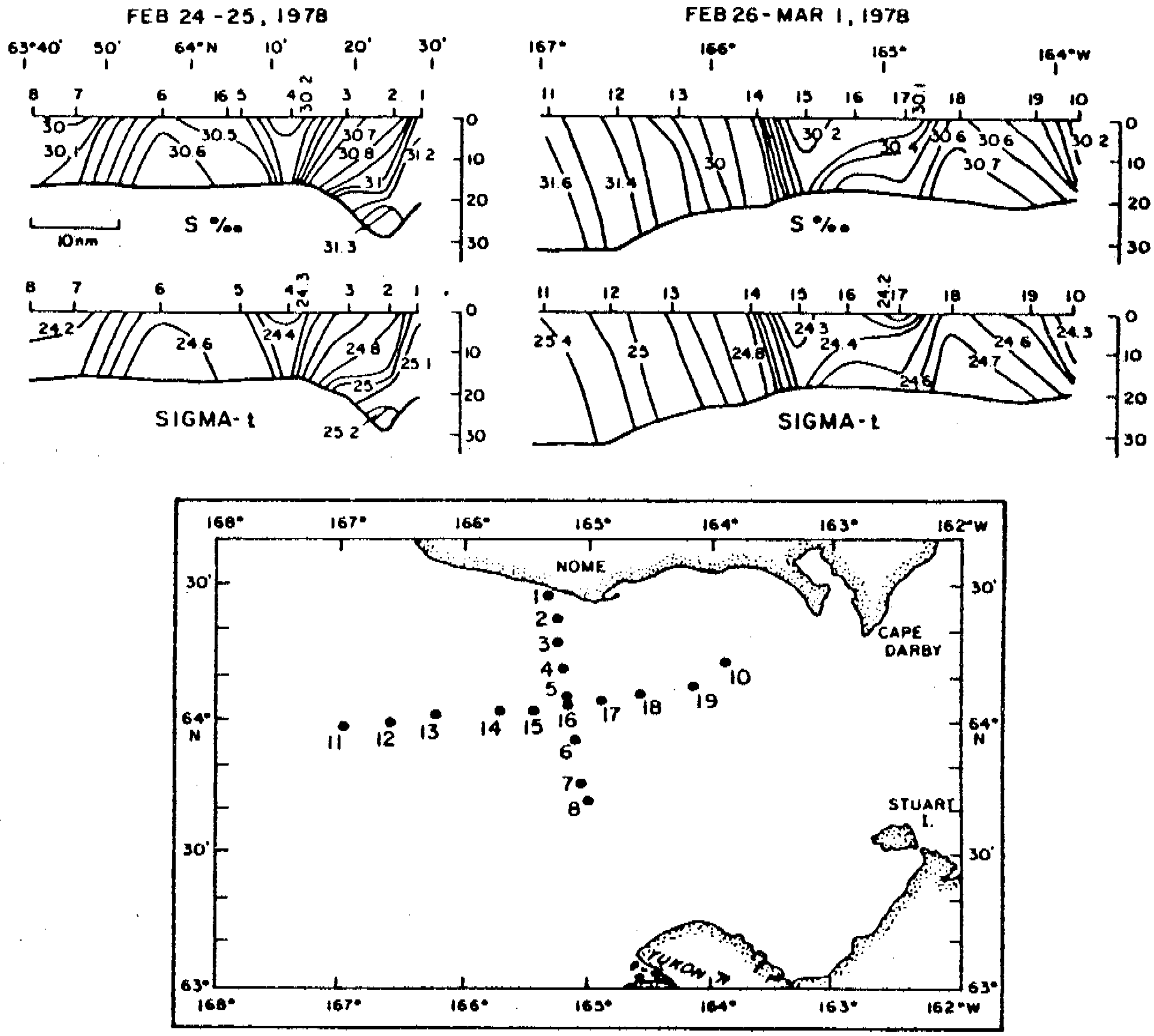
A band of relatively low salinity (22-23°/₀₀) water paralleled the northern coast of the sound in September 1976 and August 1977 and appeared to be a westerly extension of warm, low salinity water then occupying the upper layer in the northeastern sound. Station coverage during July 1977 and in 1978 was inadequate to determine whether or not the feature was present. Horizontal salinity gradients were stronger in both layers during 1977 than in 1976.

Other temperature-salinity features were evident only part of the time, but nevertheless can contribute to our understanding. In September 1976, temperature on the σ_{τ} = 21 surface showed two tongues (Fig. 6-8): a warm (8.5-9.0°C) easterly-directed tongue in the southern sound and a colder (7.0-8.5°C) tongue extending westward in the northern part, neither of which was evident in summer 1977. Though distributions on isopycnal surfaces in shallow water such as this, particularly near the top of the pycnocline, must be interpreted with caution, the distribution shown here agrees generally with the concept of a cyclonic circulation as discussed below. In September 1976 the near-bottom salinity distribution revealed two tongues of relatively high salinity water (>31°/₀₀) penetrating the sound from the west roughly coincident with the two troughs in bottom topography south of Nome (Fig. 6-7). These features were not evident during summer 1977. A westward baroclinic coastal flow was present off Nome during August 1976 (Fig. 6-5), and was also reflected in the time-series current observations at station 22 (Fig. 6-9). The same region during 1977 appeared to be the site of vertical mixing 10-15 km offshore rather than of such a baroclinic current.

Winter observations were obtained in February 1978, and the temperature and salinity distributions at that time are summarized

8


STATION
22
(26 HOURS
30 SEPT.-1 OCT.)
24
(25 HOURS:
1-2 OCT.)
N3
(10 HOURS:
4 OCT.)
25
(25 HOURS:
4-5 OCT.)
26
(25 HOURS:
5-6 OCT.)
DEPTH (m)
2
7
12
17
22
27
N
WINDS
0
5
10
M SEC-1
CURRENTS
0
50
100
CM SEC-1
MEAN
WIND


FEB 24 - 25, 1978
FEB 26 - MAR 1, 1978
63°40'
50'
64°N
10'
20'
30'
167°
166°
165°
164°W
S ‰
10nm
SIGMA-t
DEPTH (m)
NOME
CAPE DARBY
STUART I.
YUKON
168°
167°
166°
165°
164°
163°
162°W
30'
64° N
63°

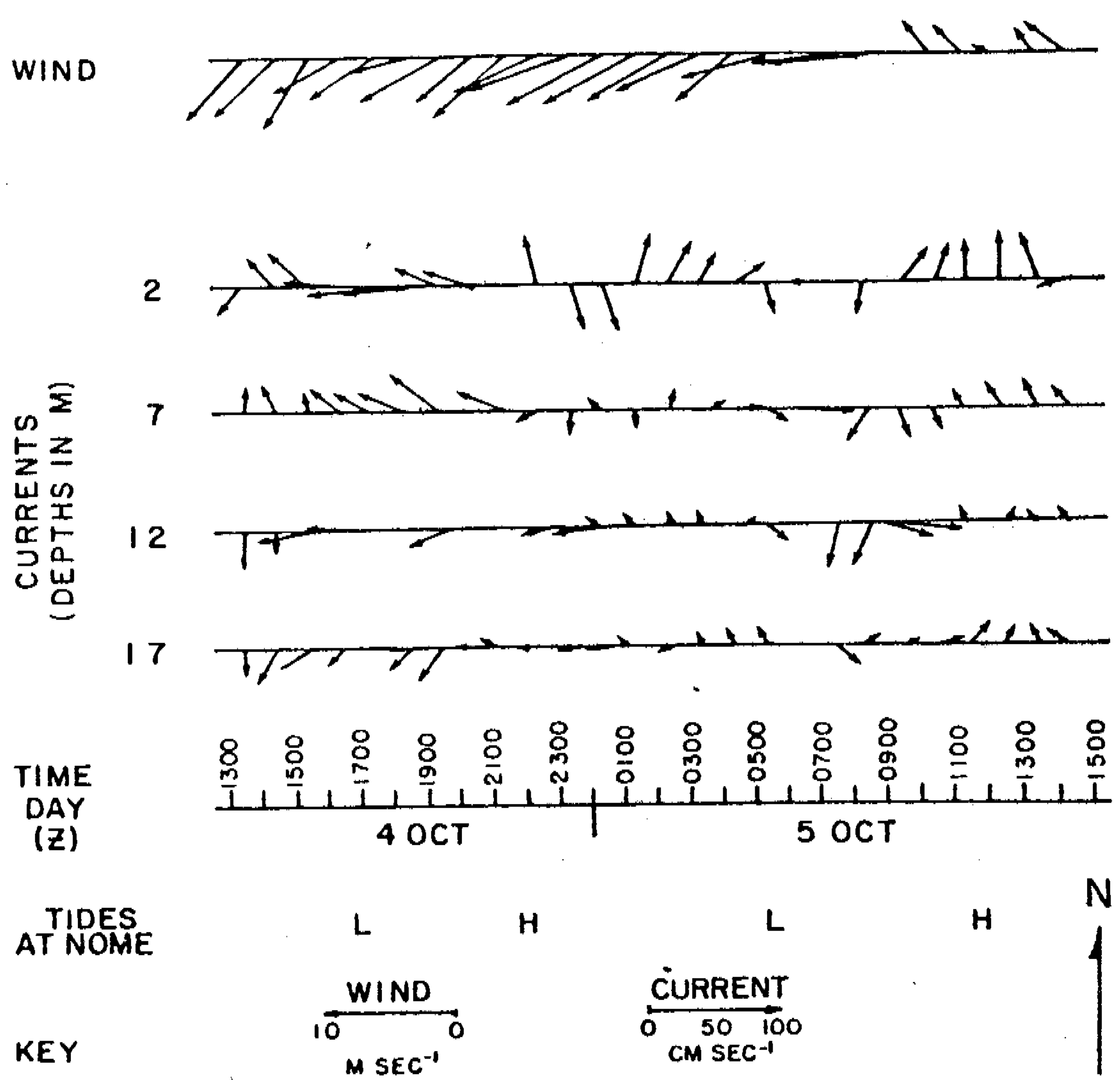
on vertical sections in Fig. 6-10. The entire water column was at the freezing point, or about -1.6°C. Density differences were due to salinity differences, and were small with overall variations being less than 1 sigma-t unit. Observations did not extend into the eastern portion of the sound because that region was ice-free during the field work, therefore conditions there remain uncertain but were probably similar to those observed in the western sound. The western sound was characterized by weak horizontal and vertical density gradients. Density was about 0.2-0.3 lower in the eastern than in the western portion, and lower by about the same amount near the bottom than near the surface. The two-layered structure which was present during summer had disappeared, its place having been taken by more or less uniform and weak vertical density stratification. Convective cooling and ice formation had created vertically uniform temperatures at the freezing point, but some vertical salinity, hence density, stratification remained.

CURRENT OBSERVATIONS

Current measurements were obtained from taut-wire moorings, as time-series from anchored vessels and as instantaneous vertical profiles from anchored vessels. Statistics of the taut-wire mooring current measurements are given in Table 6-II.

Five time-series current profiles were obtained at anchor stations along a transect south of Nome during summer 1976 (Fig. 6-14). While these were of too short duration to use in estimating mean flow, four of the five (22, 24, 25 and 26) were long enough to allow averaging out of the tidal signal. Moreover, they provide the only vertical distributions of current obtained in the region south of Nome. They are summarized as vector-averaged currents at each depth and presented along with vector-averaged winds observed from the anchored vessel (Fig. 6-9). The highest speeds observed were about 50 cm sec^{-1} and occurred near the surface at Station 22. Speeds decreased with increasing depth at that location to about 10 cm sec^{-1} near the bottom, and direction rotated from northwesterly near the surface to west-southwesterly near the bottom. Mean speeds at stations 24, 25 and 26 were highest, 12-18 cm sec^{-1} near the surface and had decreased to about 5 cm sec^{-1} near the bottom. Flow directions at these locations were in the northwest quadrant throughout the water column. Short-term fluctuations, having time scales of a few hours, were superposed upon the mean flow at each location (Fig. 6-11). The surface wind was considerably steadier with time than the currents.

Two 44-day and one 14-day record were obtained from taut-wire moorings in summer 1977 (Table 6-II and Fig. 6-14). An additional 45-day record, LD-5, was obtained during summer 1978 from nearly the same location as NC-21 off Cape Darby. Near-bottom records from this location during both summers indicated flows of order 1 cm sec^{-1} or less. The summer 1977 near-surface record at the same location was truncated due to instrument malfunction, but indicated northwesterly flows of 10-15 cm sec^{-1}. The summer 1977 near-surface record from NC-20 in the central western sound indicated north-northwesterly flow at 10-15 cm sec^{-1}.


WIND
CURRENTS (DEPTHS IN M)
2
7
12
17
TIME DAY (Z)
1300
1500
1700
1900
2100
2300
0100
0300
0500
0700
0900
1100
1300
1500
4 OCT
5 OCT
TIDES AT NOME
L
H
L
H
N
KEY
WIND
10
0
M SEC⁻¹
CURRENT
0
50
100
CM SEC⁻¹

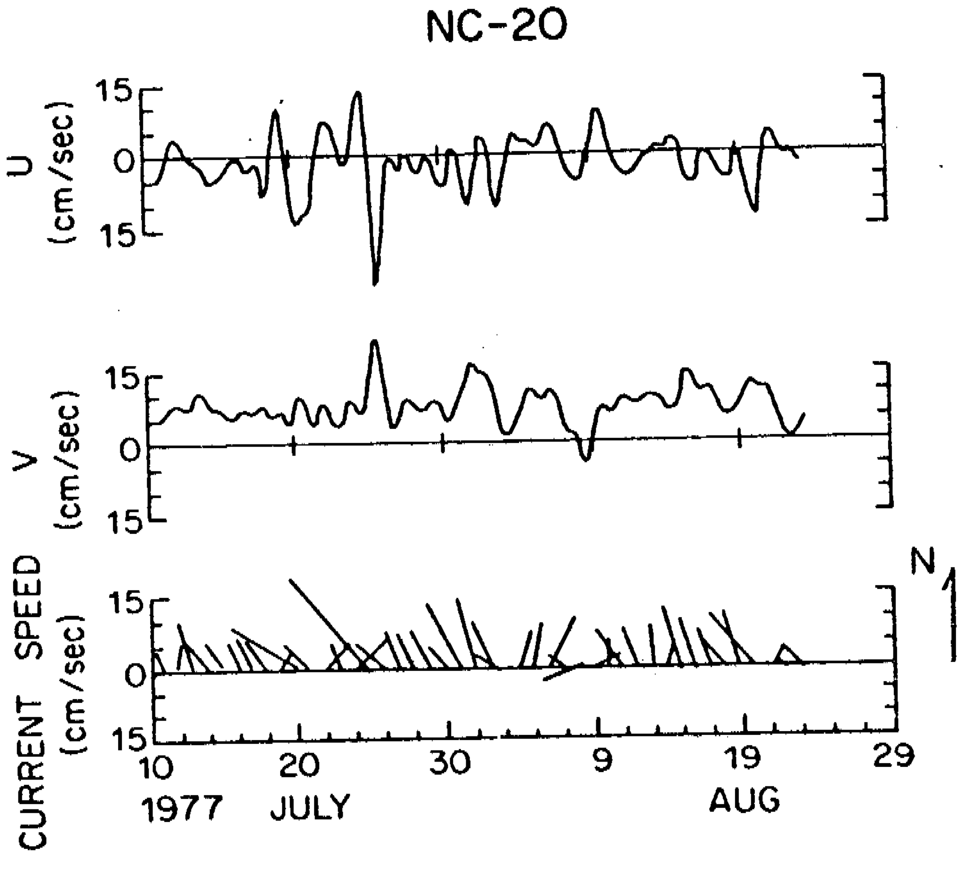
11

Overwinter records were obtained from moorings NC-14 and NC-15 in the western sound. These were both near bottom and bracketed the period from late summer to mid or late winter 1977. They indicate a mean current which was northerly in the central sound and northwesterly along the northern shore, with speeds of about 5 cm sec^{-1}.

All of the moored current records revealed non-tidal speed fluctuations which were large relative to mean flow speeds and had time scales of several days (Fig. 6-12), including occasional flow reversals.

DISCUSSION

Winter hydrographic observations obtained through the ice have established that Norton Sound becomes vertically well-mixed during winter. This is common in high-latitude regions, and is a consequence of vertical thermohaline convection due to surface cooling and ice formation. Observations during three summers reveal that well-mixed structure gives way to a regime which is strongly two-layered in temperature and salinity, hence, also in density. Such a layered structure is generally typical of shallow oceanic regimes subject to tidal and wind mixing and buoyancy input. The upper layer is a consequence of the combined effects of wind mixing, freshwater input and solar warming, while the lower layer acquires vertical homogeneity through turbulence generated by currents at the bottom. Persistence of this structure


NC-20
U (cm/sec)
15
0
15
V (cm/sec)
15
0
15
CURRENT SPEED (cm/sec)
15
0
15
N
10
20
30
9
19
29
1977
JULY
AUG

12

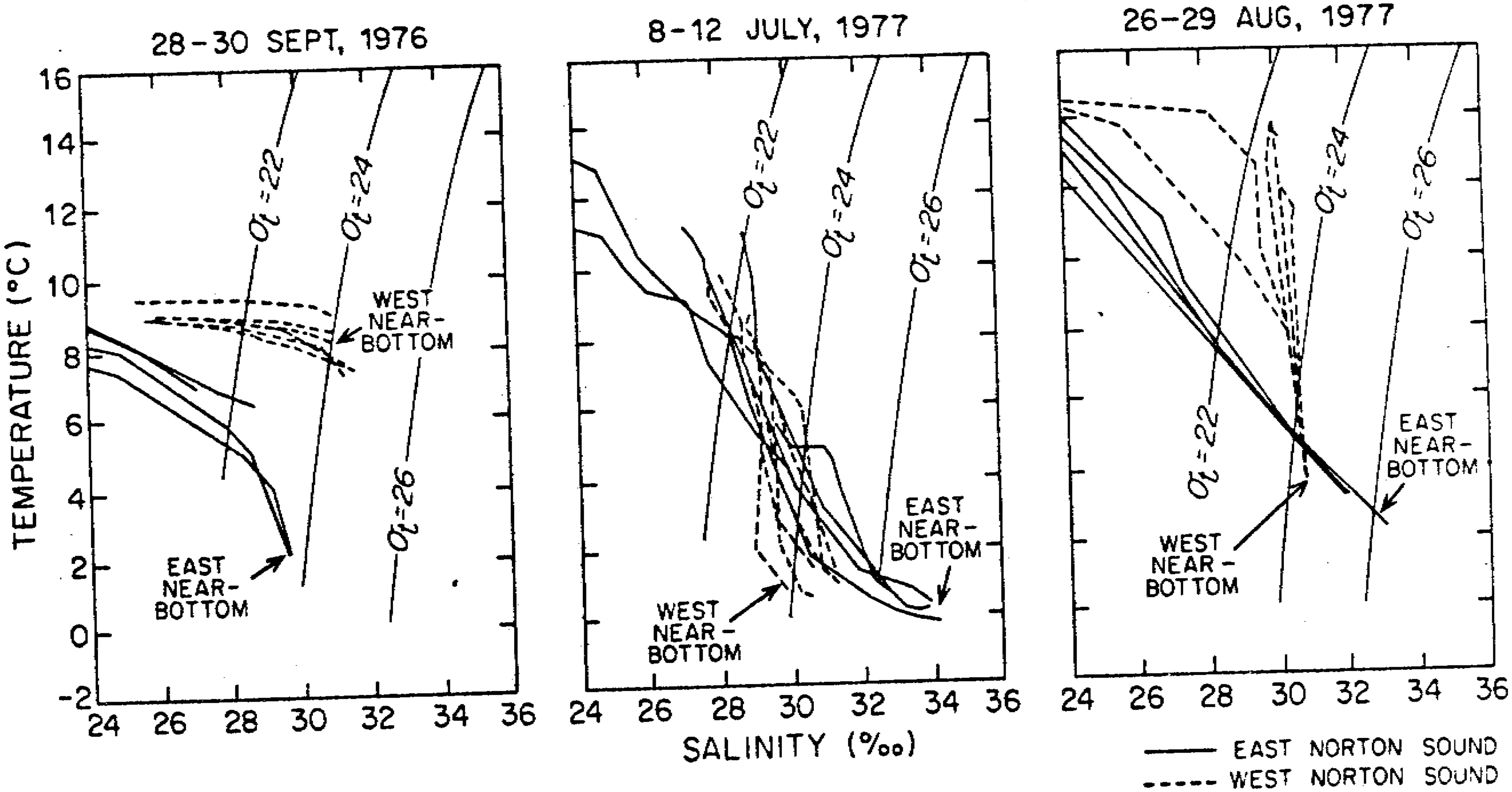
in Norton Sound for several months each summer suggests that the time rate of change is small and that a small horizontal advection is balanced by other processes. The strong pycnocline between upper and lower layers inhibits vertical exchange of heat and salt. Our discussion examines these premises.

Circulation

Horizontal property distributions tend to reflect circulation processes. During winter there was little horizontal variability; in summer the upper layer had its lowest temperatures and highest salinities in the central western part of the sound. Elsewhere in the upper layer temperature and salinity distributions, particularly in September-October 1976 and August 1977, indicate water mass continuity between the easternmost sound and a near-coastal band farther west along the northern coast. This structure suggests that a baroclinic coastal flow was transporting water from the eastern sound westward along the northern coast. This was substantiated both by subsurface density observations (Fig. 6-5) and current observations from station 22 (Fig. 6-9). The baroclinic feature was not present off Nome in August 1977, and hydrographic data obtained during July 1977 were inadequate to detect its presence or absence. Upper layer current observations farther east off Cape Darby during July 1977 indicate that a westerly mean flow paralleled the coastline but was superposed upon a highly variable flow which included reversals. We conclude that westerly flow along the northern coast is a usual feature but may vary in intensity and extent. It was more pronounced and uniform during October 1976 than during August 1977.

Lower layer temperature and salinity distributions differed from those in the upper layer, which suggests that advective processes were different in the two layers (Fig. 6-13). Temperature was lower and salinity higher in the eastern lower layer than in its western part. This was most apparent in July 1977, less so in August 1977 and least obvious in Seotember-October 1976. Deep temperatures in the eastern sound increased during summer, while salinity decreased; during July-Auqust 1977 the record from a current meter (NC-21) moored in the eastern lower laver indicated that these changes were nearly linear with time. The cold (<0°C), saline (>34°/₀₀) deep water present in the eastern sound during summer 1976 and 1977 cannot have originated on the shelf to the west because water there was too warm and of too low a salinity except during September 1976. This deep water can only have been a remnant from the preceding winter convective layer, with elevated salinities resulting from salt exclusion as ice was formed. Observations during summer 1978 were sufficient to establish that this was not the case at that time as temperatures and salinities were similar in both the eastern and western lower layers.

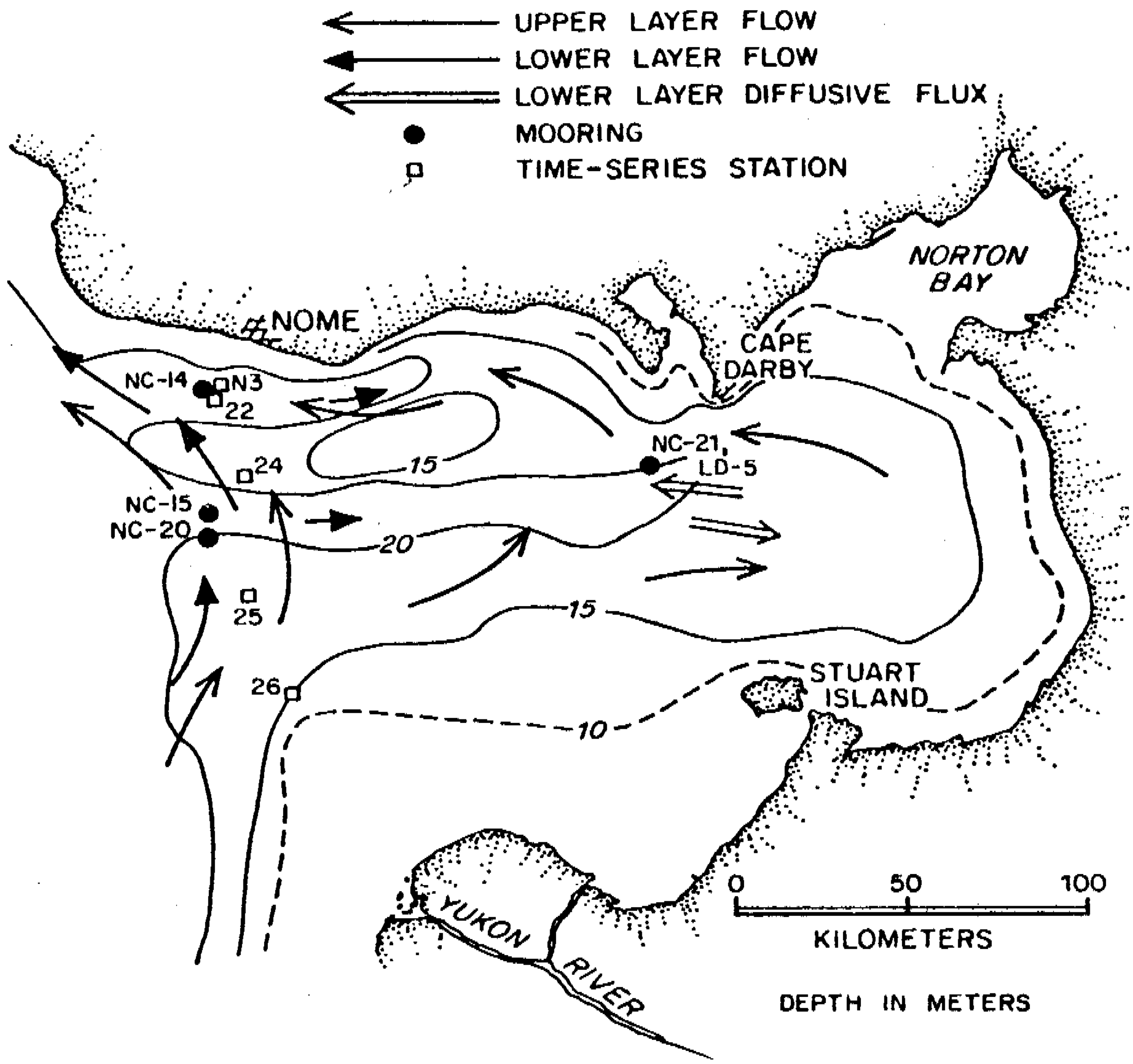
Sluggish circulation in the lower layer of the eastern sound was substantiated by observations. An advection rate along the lower boundary of the upper-lower layer interface can be estimated for September 1976 usinq temperature and salinity observations if we assume that the tongue-like low-temperature protrusion from



28-30 SEPT, 1976
8-12 JULY, 1977
26-29 AUG, 1977
TEMPERATURE (°C)
SALINITY (‰)
$\sigma_t = 22$
$\sigma_t = 24$
$\sigma_t = 26$
WEST NEAR-BOTTOM
EAST NEAR-BOTTOM
EAST NORTON SOUND
WEST NORTON SOUND

the eastern sound (Fig. 6-8) reflected a steady-state balance between horizontal advection and lateral diffusion. A horizontal length scale of 100 km, applied to the empirical findings of Okubo and Ozmidov (1970) yields a lateral eddy conductivity of order 10^6 cm^2 sec^{-1}. Application of the graphical method described by Proudman (1953) to the geometry of the "tongue" leads then to estimates of a westward advection rate of less than 1 cm sec^{-1} along its axis. During July-August 1977 the observed lower layer current speed at NC-21 off Cape Darby was 0.13 cm sec^{-1}, a comparable value. During summer 1978 a near-bottom mooring at the same location (LD-5) showed a net flow of less than 1 cm sec^{-1} to the northwest, again, in agreement. The cause of this sluggish circulation in the eastern lower layer is uncertain, and is probably due primarily to the extreme layering which could decouple the lower layer from upper layer motions. It does not appear that basin configuration plays a major role, though the promontory extending from the southern shore and formed by Stuart Island may be sufficient to deflect to the north whatever easterly flow exists along that shore, preventing it from entering the eastern sound. There exists, however, no sill between these promontories which might prevent interchange of deeper waters, and there are no observations to directly support this hypothesis. The case for decoupling of motions at the horizontal interface between upper and lower layers will be examined in more detail below.

While upper and lower layer circulation appeared decoupled in the eastern sound, time-series observations obtained from the vessel during September and October 1976 did not reveal such decoupling in the western sound. Rather, there was a monotonic decrease in current speed, along with a slight rotation of flow direction, with increasing depth (Fig. 6-9). The four stations having records of adequte length to allow at least a crude attempt at averaging out the tidal signal (stations 22, 24, 25 and 26) all indicated northwesterly surface flow which became westerly near the bottom. This was in rough agreement with the moored current record from July-August 1977 (NC-20) which indicated a northwesterly near-surface flow in the same region, with an overwinter record at NC-15 which showed northerly flow, and with a near-bottom record off Nome which indicated a weaker westerly flow during September 1976-March 1977. These current observations suggest that western sound circulation was dominated by flow which penetrated only slightly eastward into the sound and was driven primarily by the northward flow over the shelf between Norton Sound and St. Lawrence Island (Fig. 6-14). Low-frequency (of order 2 days and longer) current fluctuations observed at all of the moorings NC-14, NC-15, NC-20, NC-21 and LD-5 were a major characteristic of the flow and suggest that the cyclonic circulation driven by northward regional flow may penetrate eastward into the sound to varying extents and may at times form a cyclonic loop within the western sound. Occurrence of Northwesterly flow fluctuations at NC-21 off Cape Darby suggests that at least the upper layer of the eastern sound responds to fluctuations in the western portion, though a coherency analysis of near-surface current records from


UPPER LAYER FLOW
LOWER LAYER FLOW
LOWER LAYER DIFFUSIVE FLUX
MOORING
TIME-SERIES STATION
NOME
NORTON BAY
CAPE DARBY
NC-14
N3
22
24
NC-15
NC-20
NC-21
LD-5
25
26
15
20
15
10
STUART ISLAND
YUKON RIVER
0 50 100
KILOMETERS
DEPTH IN METERS

14

stations NC-20 and NC-21 did not reveal a significant coherency between currents at the two locations. Penetration of flow eastward to Stuart Island would require, by continuity, increased westward flow off Cape Darby. That remnant water was not present in the lower layer in summer 1978 suggests, also, that advection had occurred in the eastern lower layer prior to our observations. Therefore, it appears that at times eastward flow may penetrate into the eastern sound.

The role of northward flow on the Bering Sea shelf in inducing a circulation within Norton Sound is uncertain. A probable mechanism invokes the high-latitude tendency for conservation of potential vorticity to constrain streamlines to parallel isobaths. The northward regional flow would tend to follow bottom contours into the sound and contribute to a cyclonic circulation there. The potential vorticity argument requires, however, that friction be neglected, an assumption of debatable validity in view of the shallow depths in the sound. Regardless of cause, easterly flow entering the sound along its southern shore, curving cyclonically to the north, would then be deflected to the west at the northern coast to satisfy volume continuity constraints.

Subtidal flow pulses observed in the time-series current records are a dominant feature of regional flow. Their cause is uncertain, though the shallow depths and broad horizontal extent of the regional shelf suggest that winds and atmospheric pressure events would play major roles. Coachman <u>et al</u>. (1975) have suggested that flow through Bering Strait is characterized by pulsations that depend upon north-south atmospheric pressure differences across the Strait. A detailed analysis of this problem is beyond the scope of this chapter, and is treated elsewhere in this book (Chapter 7).

Maintenance of layering

The extremely sluggish circulation, and consequent isolation of the lower layer in the eastern sound during summer 1976 and 1977, is of particular interest because of its basic scientific implications and because similar conditions may also exist in other high latitude bodies of water subject to similar conditions, for example, Kotzebue Sound (Kinder, et al. 1978). Retention of temperature and salinity characteristics by this water for 4-5 months in a total water depth of about 20 m and despite wind and tidal mixing and insolation suggests: 1) horizontal advection of bottom water into the eastern sound was negligible; 2) insolation, particularly significant during early summer because of long daylight hours, had been unable to penetrate the bottom layer sufficiently to cause appreciable warming; and 3) vertical mixing through the pycnocline was extremely small through the summer. Of these possibilities, the first has been shown by temperature, salinity and current observations to be the case. The second may be examined summarily in light of observations of transmissivity obtained using a beam transmissometer in the eastern sound during summer 1977. In the northeastern sound off Norton Bay, transmissivity was of order 10%. Transmissivities were somewhat higher farther south, but were still too small to allow appreciable penetration of solar radiation below the upper layer. Transmissivities in the lower layer were uniformly of order 10% throughout the eastern sound. The net result was to effectively prevent solar radiation from penetrating to the lower layer.

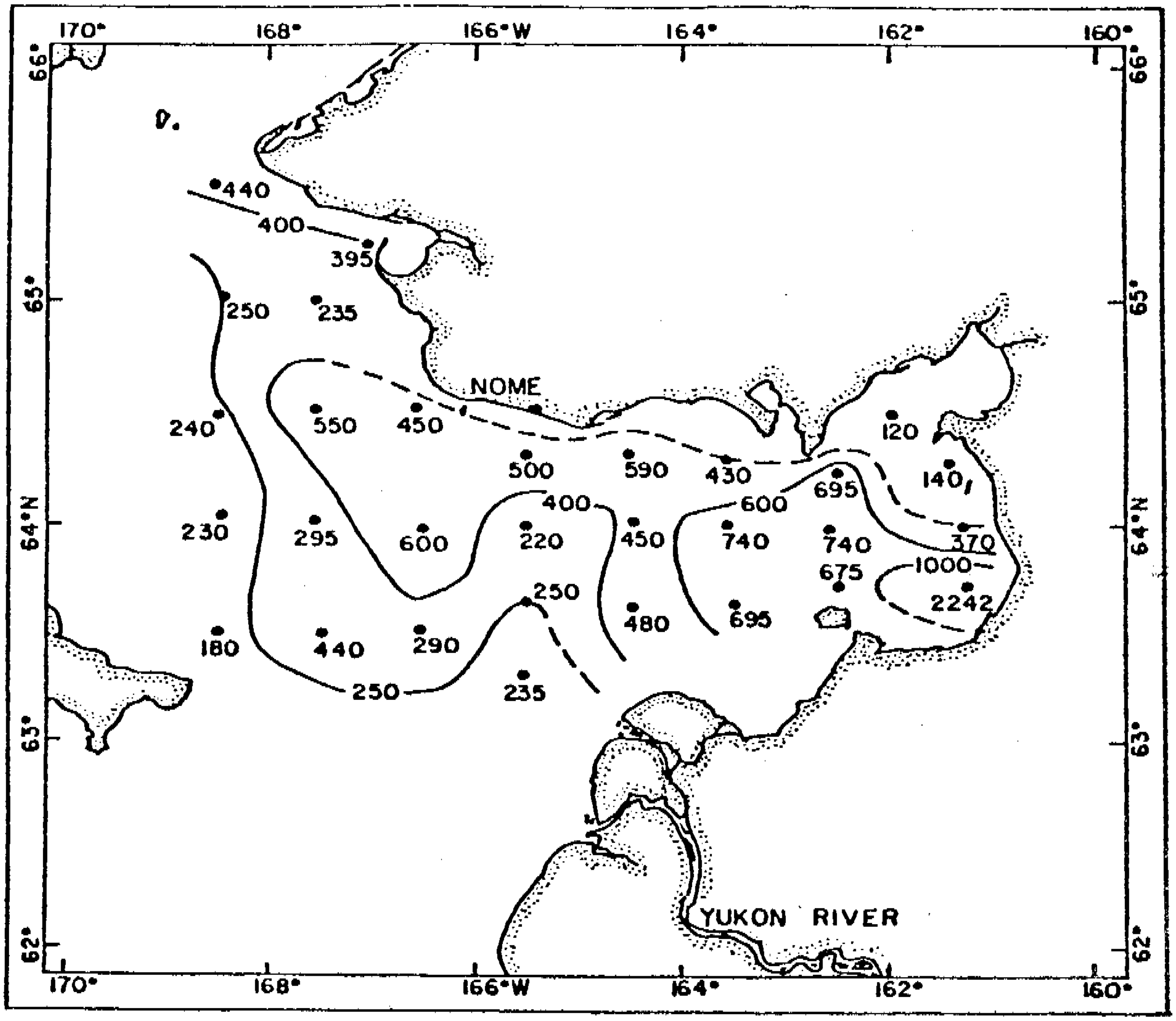
The extreme layering in the eastern sound can be examined in terms of maintenance of the horizontal interface between layers. This interface is characterized by high vertical gradients; as high as 4°C m^{-1} in temperature and 1.5°/₀₀ m^{-1} in salinity, with a corresponding Väisälä frequency of about 0.1 sec^{-1}. Using the upper and lower layer current observations obtained from mooring NC-21 off Cape Darby, in conjunction with estimated mean vertical density distributions obtained at the beginning and end of the mooring period, a bulk interfacial Froude Number of about 10^{-1} can be estimated. This value suggests that little exchange due to turbulent mixing occurs across the interface. We may estimate a vertical mixing coefficient through the interface using a simple conservation of heat argument. Assume 1) that bottom water temperature at the end of each winter was near-freezing (∿1.7°C), as borne out by the winter 1978 observations, 2) that upper layer temperature had reached 8°C by early August following a linear increase with time from early May when the ice first melted, and 3) that advective sources and sinks of heat can be neglected so that heat entering the lower layer all passes through the interface. The computed vertical mixing coefficient through the pycnocline was of order 10^{-2} cm^{-2} sec^{-1} for both summer 1976 and 1977. These values are small compared with those computed for other oceanic regions, but are reasonable for the extremely strong stratification observed.

Buoyancy input into the eastern sound appears to be critical to maintenance of the two-layered structure there. Comparison of our data with those presented by Coachman et al. (1975) from the Bering Strait suggest that the vertical density structure in the western sound is continuous with that on the Bering Sea shelf to the west. The enhanced summer 1976 and 1977 layering in the eastern sound can be accounted for by additional dilution of the upper layer by local freshwater input and solar insolation. Assuming an initial salinity of 30°/₀₀ (see Fig. 6-10), about 10^6 m^3 of freshwater are required for the observed dilution. This can be roughly accounted fo. using a mean annual runoff of 30 cm extrapolated from Nome over a watershed area of about 2.5 x 10^5 km^2. The Yukon River is a second source of freshwater input, and during midsummer runoff of order 10^4 m^3 sec^{-1} could supply water sufficient to effect the observed dilution in about 10 days if the water were all to flow into the eastern sound. This amount of freshwater input is equivalent to a buoyancy input of about 10^{-4}W m^{-2}. Assuming an input from solar insolation of 0.2 ly min^{-1} yields a buoyancy input to the upper layer of the same order, therefore both insolation and freshwater input are important to the buoyancy input. This compares with a bottom tidal dissipation of about 200 x 10^{-4}W m^{-2} computed using the same method as Schumacher et al. (1979). In other shallow shelf regions, 1-2% of the tidal dissipation is sufficient to vertically mix the water column. Our estimates suggest that buoyancy input to eastern Norton Sound is sufficiently high that tidal dissipation is inadequate to vertically mix the water column. We conclude that persistence of this extreme layering in the eastern sound is due to the roles of freshwater input and solar insolation in generating sufficient buoyancy to overcome tidal mixing. Low net advection in the lower layer is then due to decoupling from the upper layer across the sharp interface maintained by buoyant forces.

Hydrocarbon Observations

September 1976 observations of dissolved hydrocarbons provide additional evidence in support of our proposed general horizontal circulation scheme for Norton Sound. Though the observations included other hydrocarbons, we consider here distributions only of methane, ethane and propane. Most methane found in shallow shelf waters arises from biochemical reactions occurring in anoxic near-surface sediments. A prominent local source of methane may be used as a short-term water mass tracer, since it appears to be quasi-conservative over time and space scales such as we are dealing with in Norton Sound.

The near-bottom methane distribution in Norton Sound suggests a dominant source (2,242 $n\ell \ell^{-1}$) at the eastern end of the basin, with a sluggish, ill-defined northwesterly drift (Fig. 6-15). Methane-deficient water (250 $n\ell\ \ell^{-1}$) was apparently entering from the south near the Yukon River delta with relatively little transport eastward along the southern coast. The high methane



170°
168°
166°W
164°
162°
160°
66°
65°
64°N
63°
62°
D.
440
400
395
250
235
NOME
240
550
450
500
590
430
120
695
140
230
295
600
400
220
450
600
740
740
370
675
1000
2242
250
180
440
290
480
695
250
235
YUKON RIVER

15

concentration in the southeast corner of the sound suggests either an increased source at that location, an extremely sluggish circulation, or a combination of these.

Coincident with the methane observations, a near-bottom plume of ethane and propane-rich water was located about 40 km south of Nome near station 24 (Cline and Holmes, 1977). The hydrocarbons appeared to originate from a point source and drift northward toward Nome then northwest along the coast, in agreement with the circulation scheme deduced above.

The Yukon River Plume

The fate of Yukon River water remains problematic, though it seems likely that it is dominated by flow events rather than mean flow. The temperature-salinity and hydrocarbon observations obtained during summer 1976 and 1977 yielded no evidence of Yukon River water being advected eastward into the eastern sound. Rather, it appeared that Stuart Island might have contributed to blocking the easterly flow along the southern coast (Figs. 6-5 and 6-6). It is of course feasible that sporadic flow of Yukon water had occurred earlier during either or both seasons, and that the observed upper layer dilution was due in part to remnants of past Yukon water inflows. This may have been the case prior to July 1977, when particularly low ($<19^{\circ}/_{\circ\circ}$) near-surface salinities were observed in the eastern sound (Fig. 6-7). The limited observations which indicated that the eastern basin had flushed out in summer 1978, resulting in deep layer temperatures and salinities similar to those in the outer part of the sound, strengthens the supposition that appreciable eastward flow events may occur. The summer 1978 data were not however adequate to determine whether or not Yukon-diluted waters were in fact continuous between the eastern and western sound. Yukon River origin for bottom sediments in the eastern sound suggests that Yukon water can enter there (Drake et al. 1980). The pulse-like events observed in the current records suggest, moreover, that water motion in the sound particularly in the form of easterly migrations in the cyclonic flow, may be adequate to cause such additions. We have, however, no direct supporting evidence of such flow. R. Feely (PMEL unpublished data) has observed in summer 1979 data a narrow coastal band of low-salinity surface water along the southern coast, which may be eastward-flowing Yukon water. However, no flow rates are available.

SUMMARY

Observations obtained from Norton Sound indicate that in summer the regime was strongly two-layered in both temperature and salinity. The eastern and western sound were effectively separated into two distinct flow regimes at a line roughly coincident with the constriction formed by Cape Darby on the north and Stuart Island on the south. The eastern sound was more strongly layered than the western, and upper and lower layer flows were decoupled. The surface layer exhibited a weak tendency for cyclonic flow, which was reflected both in the hydrographic observations and in moored current records. The eastern lower layer exhibited a

near-zone mean flow allowing remnant cold, saline water from the previous winters' convective regimes to retain its identity in both 1976 and 1977 despite the shallow depth of the eastern basin. Sluggish lower layer circulation was borne out by near-bottom moored measurements south of Cape Darby. Absence of the remnant water in summer 1978 suggested either that a flow event had flushed out the eastern basin or that less cold, saline water was produced in 1977-78.

Short-term time-series measurements in the western sound suggest that the upper and lower layers were not decoupled as in the eastern sound. These observations, in conjunction with moored current records and dissolved hydrocarbon distributions, support the concept of a northerly flow in the westernmost sound. Extent of this flow eastward into the sound may vary; it was apparently more intense in 1976, as evidenced by a strong westerly coastal current off Nome, than during 1977 when such a coastal feature was not observed. Fluctuations large relative to the mean flows, having time scales of several days, were observed at all moorings and suggest that instantaneous flow patterns in the sound may vary considerably.

The central western sound was a locus for vertical mixing as currents, primarily tidal, impinged upon a relatively shoal area. This was the only area where a breakdown in vertical layering was observed. We hypothesize that the relatively deep channels bracketing the shoal allowed occasional eastward flow of deeper, saline water that was then mixed upward leading to the observed higher local surface salinities.

At no time did we see flow of the Yukon River plume into eastern Norton Sound. It remains uncertain where the Yukon water goes: it appears likely that pulse-like flow events such as those observed at the current mooring sites may intermittently transport Yukon water into the eastern sound, or conversely, westward completely out of the sound. It may be entrained into the general northward flow west of the sound. Disposition of the Yukon River plume must be considered an appreciable regional problem.

The near-bottom water in the eastern sound presents an interesting case. It is highly unusual, if not necessarily unique, for water at these depths (about 15 m) to retain its temperature-salinity identity for several months without undergoing vertical mixing due to winds or tides or sufficient lateral advection or diffusion to alter its heat or salt content appreciably. Maintenance of this regime is due to a large buoyancy input, in the form of insolation and freshwater addition, to the upper layer.

ACKNOWLEDGEMENTS

This study was supported in part by the Bureau of Land Management through interagency agreement with the National Oceanic and Atmospheric Administration, under which a multi-year program responding to needs of petroleum development of the Alaskan continental shelf is managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Office. We are indebted to Dr. L. K. Coachman for suggestions in preparation of the manuscript, and to the anonymous reviewers who provided suggestions for improving it.

The work could not have been carried out without the cooperation of officers and crew of R/V's *Discoverer*, *Surveyor* and *Sea Sounder*.

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1979 A structural front over the continental shelf of the eastern Bering Sea. J. Phys. Oceanog., 9: 79-87.

TABLE 6-I

Summary of Cruises to Norton Sound

Vessel	Cruise ID	Dates	No. of Stations
Discoverer	RP4-D1-76B Leg V	26 Sept - 9 Oct 1976	33
Sea Sounder	None	8-12 July 1977	26
Surveyor	RP4-SU-77B Leg IV	11 Aug - 2 Sept 1977	55
Discoverer	RP4-D1-78B Leg I	10 July - 3 Aug 1978	56
Discoverer	RP4-D1-78B Leg 3	10-29 Sept 1978	46
NOAA UH-1H	W-29	17 Feb - 5 March 1978	37

TABLE 6-II

Norton Sound taut-wire mooring summary

Mooring	Bottom D (m)	Meter D (m)	Mooring Time Period	Useable Record L (days)	Latitude (°N)	Longitude (°W)	Vector Mean Speed	Vector Mean Dir
NC-14	32	22	8/21/76 - 6/25/77	309	64°21.6'	165°21.6'	2.2 cm sec^{-1}	073°T
NC-15	19	15	8/21/76 - 1/30/77	131	64°06.5'	165°17.7'	5.9 cm sec^{-1}	018°T
NC-20	19	6	7/8/77 - 8/25/77	48	63°59.7'	165°29.4'	7.8 cm sec^{-1}	340°T
"	"	14	7/8/77 - 8/25/77	None	"	"	malfunctioned	
NC-21	25	6	7/9/77 - 7/22/77	∿13	64°08.2'	163°15.2'	malfunctioned *	
"	"	20	7/9/77 - 8/26/77	48	"	"	0.1 cm sec^{-1}	198°
NC-22	16	8	7/9/77 - lost	None	63°41.0'	163°00.1'	not recovered	
LD-5	27	20	7/25/78 - 9/4/78	42	64°08.3'	163°00.2'	0.8 cm sec^{-1}	309°

* Record became increasingly error-ridden with time, so no mean is presented here, however, early part of record was useful for comparison purposes.

FIGURE LEGENDS

Figure 1. Geographical location and bathymetry of the Norton Sound region.

Figure 2. Vertical distributions of temperature along selected north-south sections across Norton Sound at three different times. Section locations are shown on Figure 6.

Figure 3. Vertical distributions of density (σ_t) along selected north-south sections across Norton Sound at three different times. Section locations are shown on Figure 6.

Figure 4. Horizontal distribution of the mean vertical density gradient in sigma-t units/m for the upper 15 m of the water column during July 1977, obtained by vertically averaging, from the surface to 15 m, gradients computed for 1-m increments. Dotted line defining shoal area is schematic only.

Figure 5. Vertical distributions of density (σ_t) along selected sections normal to the coastline of northern Norton Sound at two different times. Section G-G^1 was occupied twice in rapid succession on the same day. Section locations are shown on Figure 7.

Figure 6. Horizontal distribution of upper and lower layer temperatures in Norton Sound at three different times. Location of sections in Figures 2 and 3 are indicated.

Figure 7. Horizontal distribution of upper and lower layer salinity in Norton Sound at three different times. Locations of sections in Figure 5 are indicated.

Figure 8. Distribution of temperature (0°C) on σ_t = 21 in September 1976.

Figure 9. Vector-averaged currents and surface winds at the five time-series stations in western Norton Sound during September and October 1976. Mean current vectors are depth averaged. Station locations are shown on Figure 14.

Figure 10. Vertical distribution of salinity and density (σ_t) along two sections during winter 1978.

Figure 11. Hourly surface winds and currents at time-series station 25 in western Norton Sound during October 1976, illustrating short-term fluctuations.

Figure 12. Low-pass filtered currents at 5-m depth at station NC-20 in Norton Sound, summer 1977; u and v are east and north components, respectively. Mooring locations are indicated on Figure 14.

Figure 13. Temperature-salinity curves from selected stations in eastern and western Norton Sound during summers 1976 and 1977. Temperature and salinities were in fact continuous from east to west across the sound, but stations from the central sound have been omitted in the interest of clarity.

Figure 14. Schematic representation of circulation and mixing in Norton Sound based on the summer 1976 and 1977 hydrographic and current data. Locations of time-series current and CTD stations occupied in September and October 1976, and taut-wire current moorings, are shown.

Figure 15. Distribution of dissolved methane 5 m above the bottom, September 1976, in $n\ell\ \ell^{-1}$.

H. The following abstract represents work conducted primarily during PROBES.

From: ECOLOGICAL PROCESSES IN COASTAL AND MARINE SYSTEMS
Edited by Robert J. Livingston
(Plenum Publishing Corporation, 1979): 437-466

ECOLOGICAL SIGNIFICANCE OF FRONTS IN THE SOUTHEASTERN BERING SEA

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Abstract

A series of three fronts divides the continental shelf of the southeastern Bering Sea into two interfrontal zones which contain different food webs. Large stocks of birds, mammals, and pelagic fish, primarily walleye pollock, occur in the outer shelf zone between the 200 meter isobath and the middle front near the 100 meter isobath. Large stocks of benthic infauna, demersal fish, and crabs occur in the middle shelf zone between the middle front and the inner front at the 50 meter isobath. Very low cross-shelf advection and the presence of the middle front which acts as a diffusion barrier restrict large oceanic herbivores to the outer shelf zone. Large diatoms are not graced by the small coastal herbivores which inhabit the middle shelf aone, resulting in an accumulation of phytoplankton biomass which settles to the benthos.

V. Cooperation

We are cooperating with other research units as follows:

289 (Royer) Satellite imagery usefully delineates the structural front and the seasonal ice cover.

435 (Leendertse) We provide hydrographic, current and pressure data. Together we attempt to understand the tidal regime.

217 (Hansen) We are trying to understand the deep eddy, initially revealed by drifters, and to compare current meter and drifter records where appropriate.

206 (Vallier and Gardner) We are exchanging thoughts and data on the St. George Basin regime.

83 (Hunt) We are attempting to relate the bird distribution to the structural front near the Pribilof Islands.

367 (Reynolds) We are exchanging ideas and data on the effects of local meteorology on the oceanography.

Coordination will be continued with RU 541 and PROBES (Coachman and Tripp), RU 435 (Leendertse and Liu) and other investigators in the proposed Transport Processes Experiment: J. Overland, E. Baker, R. Atlas, J. Cline, R. Griffiths, R. Morita and D. Cacchione.

VI. Publications

The following list of publications was compiled 15 March 1980. It does not include manuscripts "in press" such as the Bering Sea: Oceanography and Resources and others.

1. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Kinder, T.H., 1977. HYDROGRAPHIC STRUCTURE OVER THE CONTINENTAL SHELF NEAR BRISTOL BAY, ALASKA, JUNE 1976; Univ. Washington Dept. of Oceanography Technical Report (M77-3): 61 pp.

RU # : 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	Bristol Bay, St. George	17, 24
RESEARCH AREA:	Oceanography	30

2. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Coachman, L.K. and R.L. Charnell, 1977. FINESTRUCTURE IN OUTER BRISTOL BAY, ALASKA; Deep-Sea Res. 24(10): 869-889.

RU # 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	St. George, non-site	24, 25
RESEARCH AREA:	Oceanography	30

3. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Coachman, L.K. and R.L. Charnell, 1979. LATERAL WATER MASS INTERACTIONS - A CASE STUDY, BRISTOL BAY, ALASKA; J. Phys. Oceanogr. 9(2): 278-287.

RU #: 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	St. George, non-site	24, 25
RESEARCH AREA:	Oceanogr.	30

Reviewer's Name J. D. Schumacher

Affiliation PMEL/Coastal Physics

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1. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Charnell, R.L. and G.A. Krancus, 1976. A PROCESSING SYSTEM FOR AANDERAA CURRENT METER DATA; NOAA Technical Memo ERL PMEL-6: 50 pp.

RU # : 141/549/138

	CODE WORD(S)	CODE NUMBER(S)
REGION:	NA	14
LEASE AREA:	NA	45
RESEARCH AREA:	Other: data processing	43

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2. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Kinder, T.H., J.D. Schumacher, R.B. Tripp and D. Pashinski, 1977. THE PHYSICAL OCEANOGRAPHY OF KOTZEBUE SOUND, ALASKA DURING LATE SUMMER, 1976; Univ. Washington Dept. of Oceanography Technical Report (M77-99): 84 pp.

RU # : 550/541

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Arctic	6
LEASE AREA:	Chukchi Sea	18
RESEARCH AREA:	Oceanogr.	30

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3. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Aagaard, K. 1979. POLAR OCEANOGRAPH I: ARCTIC OCEAN; Reviews of Geophys and Space Phys. 1767): 1576-1578.

RU #: 550/541

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Arctic/Bering	9
LEASE AREA:	NA	45
RESEARCH AREA:	Oceangr.	30

Reviewer's Name J. D. Schumacher

Affiliation PMEL/Coastal Physics

1. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Schumacher, J.D. and L.K. Coachman, 1976. BRISTOL BAY, OCEANOGRAPHIC PROCESSES (B-BOP); In Envir. Assessment of the Alaskan Cont. Shelf, Annual Reports, Vol 2: 213-248.

RU # : 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering Sea	7
LEASE AREA:	St. George, Bristol Bay	24, 17
RESEARCH AREA:	Oceanogr.	30

2. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Schumacher, J.D., R.L. Charnell and L.K. Coachman, 1977. BRISTOL BAY OCEANOGRAPHIC PROCESSES (B-BOP); In Envir. Assessment of the Alaskan Cont. Shelf, Annual Reports, Vol XIV. Transport: 407-472.

RU # : 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering Sea	7
LEASE AREA:	St. George, Bristol Bay	24, 17
RESEARCH AREA:	Oceanogr.	30

3. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Coachman, L.K. T.H. Kinder, J.D. Schumacher and R.L. Charnell, 1978. BRISTOL BAY OCEANOGRAPHIC PROCESSES, (B-BOP); In Envir. Assessment of the Alaskan Cont. shelf, Annual Reports, Vol IX Transport: 327-574.

RU # 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	St. George, Bristol Bay	24, 17
RESEARCH AREA:	Oceanogr.	30

Reviewer's Name J. D. Schumacher

Affiliation PMEL/Coastal Physics

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1. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Schumacher, J.D., T.H. Kinder, D.J. Pashinski and R.L. Charnell, 1979. A STRUCTURAL FRONT OVER THE CONTINENTAL SHELF OF THE EASTERN BERING SEA; J. Phys. Oceanogr. 9(1): 79-87.

RU # : 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	Bristol Bay, non-site	17, 25
RESEARCH AREA:	Oceanogr.	30

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2. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Reed, R.K., 1978. HEAT BUDGET IN THE EASTERN BERING SEA. J. Geophys Res. 83; 5613-5619

RU # : 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	non-site	25
RESEARCH AREA:	Oceanogr.	30

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3. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Muench, R.D. and R.L. Charnell, 1977. OBSERVATIONS OF MEDIUM SCALE FEATURES ALONG THE SEASONAL ICE EDGE IN THE BERING SEA; J. Phys. Oceanogr. 7(4): 602-606

RU #: 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	non-site	25
RESEARCH AREA:	Ice physics	29

Reviewer's Name J. D. Schumacher

Affiliation PMEL/Coastal Physics

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1. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Pearson, C.A., G.A. Krancus and R.L. Charnell, 1978. R2D2: AN INTERACTIVE GRAPHICS PROGRAM FOR RAPID RETRIEVAL AND DISPLAY OF OCEANOGRAPHIC DATA; In: Proc. Second Working conference on oceanographic data systems, C.D. Tollios Ed., Woods Hole: 318-329

RU # : 549/138/550

	CODE WORD(S)	CODE NUMBER(S)
REGION:	All regions	13
LEASE AREA:	NA	45
RESEARCH AREA:	Other: data storage, display and analysis	43

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2. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Kinder, T.H., J.D. Schumacher, R.B. Tripp and J.C. Haslett, 1978. THE EVOLUTION OF HYDROGRAPHIC STRUCTURE OVER THE CONTINENTAL SHELF NEAR BRISTOL BAY, ALASKA, DURING SUMMER 1976; UNIV. WASHINGTON DEPT. OF OCEANOGRAPHY TECHNICAL REPORT (M78-16): 72 pp.

RU # 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	St. George, Bristol Bay	24, 17
RESEARCH AREA:	Oceanogr.	30

---

3. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Kinder, T.H. and L.K. Coachman, 1978. THE FRONT OVERLAYING THE CONTINENTAL SLOPE OF THE EASTERN BERING SEA: J. Geophys. Res. 83; 4551-4560.

RU #: 141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering	7
LEASE AREA:	St. George	24
RESEARCH AREA:	Oceanogr.	30

NEW CITATIONS

Reviewer's Name J. D. Schumacher

Affiliation PMEL/Coastal Physics

1. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Krancus, G.A., C.A. Pearson and R.C. Charnell, 1978. A ONE-PASS PROCESSING SYSTEM FOR AANDERAA CURRENT METER DATA. In: Proc. Second Working Conference on oceanographic data systems, C.D. Tollios, Ed, Woods Hole: 96-111.

RU # : 138/141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	All regions	13
LEASE AREA:	NA	45
RESEARCH AREA:	Other: data processing	43

2. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

McLain, P.D., 1978. A MICROPROCESSOR-BASED TRANSCRIBER. In: Proc. Second Working Conference on oceanographic data systems, C.D. Tollios, Ed. Woods Hole: 384-390.

RU # : 138/141/549

	CODE WORD(S)	CODE NUMBER(S)
REGION:	All regions	13
LEASE AREA:	NA	45
RESEARCH AREA:	Other: data processing	43

3. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

RU #:

	CODE WORD(S)	CODE NUMBER(S)
REGION:		
LEASE AREA:		
RESEARCH AREA:		

NEW CITATIONS

Reviewer's Name J. D. Schumacher

Affiliation PMEL/Coastal Physics

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1. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Coachman, L.K., R.L. Charnell, J.D. Schumacher, K. Aagaard, and R.D. Muench, 1977. NORTON SOUND/CHUKCHI SEA OCEANOGRAPHIC PROCESSES (N-COP); In Envir. Assessment of the Alaskan Cont. Shelf, Vol. XV. Transport: 579-673.

RU # : 550/541

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering/Arctic	9
LEASE AREA:	Chuckchi Sea	18
RESEARCH AREA:	Oceanogr.	30

---

2. CITATION: (INCLUDING TITLE, DATE, PLACE OF PUBLICATION)

Schumacher, J.D., R.D. Muench, T.H. Kinder, L.K. Coachman, R.L. Charnell and K. Aagaard, 1978. NORTON SOUND/CHUKCHI SEA OCEANOGRAPHIC PROCESSES (N-COP); In Eviron. Assessment of the Alaskan Cont. Shelf. Vol X Transport: 860-928.

RU # : 550/541

	CODE WORD(S)	CODE NUMBER(S)
REGION:	Bering/Arctic	9
LEASE AREA:	Chukchi Sea	18
RESEARCH AREA:	Oceanogr.	30

VII. Needs for Further Study

We believe that the continued study of Bristol Bay should emphasize analysis of data already obtained, and selected field work directed at specific objectives. The remaining tasks to be undertaken include:

1. Characterization of flow in the vicinity of Unimak Pass.
2. An understanding of transport processes in the north Aleutian lease area.
3. Field work in the Navarin lease area. A several year long field program, commencing in FY-81, could yield knowledge regarding advective and diffusive processes over this shelf lease area. Such a program would be an extension of our present understanding of oceanographic processes over the southeastern Bering Sea shelf.

We note that item 1 is already underway and 2 is proposed.

VIII. Conclusions

Field work in the Bristol Bay region has yielded more complete understanding of the physical oceanography. This understanding is reflected in Section IV of this report (present status), in previous reports, and in the publications listed in Section VI.

Major elements include:

1. the shelf exhibits low mean flow, kinetic energy is tidally dominated, and the velocity field in summer separates into three distinct domains: coastal, middle shelf and outer shelf;

2. the hydrographic structure in summer also separates into three distinct domains;

3. melting ice in winter can re-establish vertical structure locally in the middle shelf domain;

4. finestructure is ubiquitous in the outer shelf domain, and is evidence of lateral water mass interaction;

5. the middle shelf and coastal domains are separated by a structural front which results from a varying balance between buoyancy input and tidal mixing;

6. a similar front exists near the Pribilof Islands and has biological implications;

7. during summer, tidal currents show anomalous diminution at some locations while tidal heights do not, reflecting instrument fouling;

8. observed reduction of tidal currents (<25%) and heights during winter is likely related to the presence of ice;

9. flow over the deep basin is spatially and temporally complex with occurrences of current rings and eddies;

10. the heat balance over the central shelf during summer primarily involves atmospheric exchange;

11. certain ice-edge features are associated with the wind; and,

12. low frequency (less than diurnal) flow is episodic or quasi-periodic.

Annual Report

R.U. 562: OIL POOLING UNDER SEA ICE

Report Period: 1 April 1979 - 31 March 1980

Principal Investigator: A. Kovacs

Associate Investigators: R.M. Morey
D. Cundy

Prepared for the BLM-NOAA Arctic Outer
Continental Shelf Environmental Assessment Program

United States Army Corps of Engineers
Cold Regions Research and Engineering Laboratory
Hanover, N.H. U.S.A.

I. Summary

The objectives of R.U. 562 are to determine the cause of and variation of the significant relief which exists under fast ice, to estimate the quantity of oil which could pool up in the under-ice depressions should a sea bed oil release occur, and to use impulse radar to investigate sea ice thickness and electromagnetic phenomena.

II. Introduction

Our investigations are concerned with understanding the morphology of the significant relief which exists under first-year sea ice. Our studies are directed toward obtaining ice thickness profile information which can be used to determine the cause of the under-ice relief and determining the amount of oil which could be expected to pool up in this under-ice relief should an oil release occur. To obtain ice thickness profile information we have used radio echo sounding equipment and direct drill hole measurement techniques. From the ice thickness profile information both cross section profiles of ice thickness and contour maps of the under-ice relief have been constructed, and an assessment of the quantity of oil which could pool up in and under the ice depressions was made.

Our studies also were directed toward understanding the electromagnetic properties of sea ice in the radio frequency range. These studies increase our ability to interpret the radar profile information. They also provide insight into the cause of sea ice anisotropy and the potential for determining under-ice current orientation from an airborne platform, which would indicate the direction oil might move under sea ice.

We have also studied the use of radio echo sounding for detecting fresh water under lakes, as source of fresh water will be essential for offshore development.

III. Current State of Knowledge

The data collected during this program have significantly increased our knowledge of under-ice relief and the quantity of oil which this relief could contain if oil were released under first-year sea ice. Data on the electromagnetic properties and anisotropy of sea ice have contributed to our knowledge of ice forces and offshore current alignment. A list of papers containing the results of this program appears in section V below.

IV. Study Area

Sea ice studies have been made in the area of Prudhoe Bay, Steffanson Sound north of Prudhoe Bay, southwest and south of Narwhal Island, and west of Tigvariak Island. Our studies related to detecting water under North Slope lakes were made in the general area of Deadhorse and on Teshekpuk Lake.

V. Results

The results of our studies are documented in the following reports:

1. Published reports (DB indicates logged in the OCS Data Bank)

a) Kovacs, A. (1977) Sea ice thickness profiling and under ice oil entrapment, Offshore Technology Conference Paper OTC 29-49 (DB).

b) Kovacs, A. and R.M. Morey (1978) Radar anisotropy of sea ice due to preferred azimuthal orientations of the horizontal c-axes of ice crystals, J. Geophys. Res., vol. 83, no. C12 (DB).

c) Kovacs, A. (1970) Remote detection of water under ice covered lakes on the North Slope of Alaska, Arctic, vol. 31, no. 4 (DB).

d) Kovacs, A. (1978) Sea ice thickness profiles and ice bottom contour relief maps, data report for the BLM/NOAA data bank (DB).

e) Kovacs, A. and R.M. Morey (1979) Remote detection of a fresh-water pool off the Sagavanirktok River Delta, Alaska, Arctic, vol. 32, no. 2 (DB).

f) Kovacs, A. and R.M. Morey (1979) Anisotropic properties of sea ice in the 50-150 MHz range, J. Geophys. Res., vol. 84, no. C9 (DB).

g) Kovacs, A. (1979) Oil pooling under sea ice, NOAA/BLM Annual Reports of Principal Investigators (DB).

2. Reports in press

a) Kovacs, A. and R.M. Morey (1980) Investigations of sea ice anisotropy, electromagnetic properties, strength and under ice current orientation, J. Geophys. Res. Paper also presented at the Workshop on Remote Estimation of Sea Ice Thickness, Memorial Univ. of Newfoundland (DB).

3. Reports in preparation

a) Kovacs, A. et al. Oil pooling potential under sea ice.

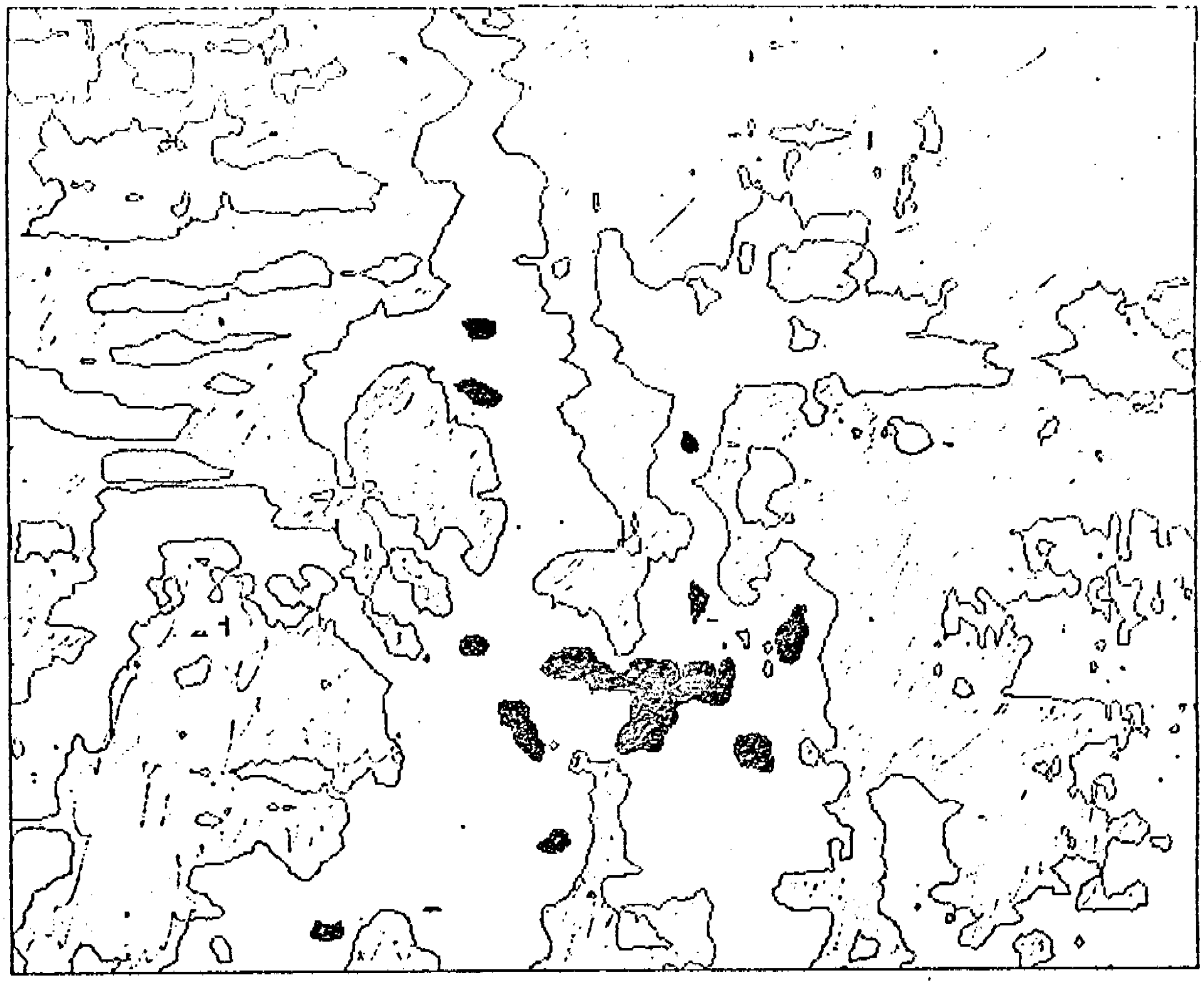
VI. Discussion

Field studies were again undertaken in the area of Prudhoe Bay in March. These studies included the profiling of sea ice thickness at three sites: east of Narwhal Island, near the Boulder Patch dive hole 11, and near the Exxon ice island location. Further studies of the electromagnetic properties of sea ice were also performed.

VII. Conclusions

The profile information collected to date has revealed the strong effect of snow cover variation and therefore its insulating effect on sea ice growth. Thin snow cover with less surface relief variation results in less under-ice relief and lower pocket storage capacity. At an ice location south of Narwhal Island in 1977 we found that the under-ice relief had an oil pooling potential of 27,000 m^3/km^2. Our 1978 studies near Tigvariak Island showed that the ice bottom at the study site had an oil storage potential of 31,000 m^3/km^2, while at a snow-free site north of Reindeer Island the ice bottom was relatively flat and had a storage capacity of about 10,000 m^3/km^2.

The profile information collected in the spring of 1979 near the Prudhoe Bay west dock on ice that had undergone deformation during fall freeze-up (ice rubble surface as a result) had a rougher subsurface relief. An area about 180 m square was plowed free of ice blocks and snow. Ice thickness over an area 127 x 160 m was then profiled along lines spaced about 1.6 m apart. The data have been reduced to provide an under-ice contour map and cross sections of the ice relief. Data analysis revealed a mean ice thickness of 1.89 m and a pocket area above the mean thickness of 60,000 m^3/km^2. This value may be slightly reduced by the probability that some cavities will be isolated by rims of deeper ice and oil moving along the ice bottom will not spill into them. Eleven small areas where this may occur are shown in the following figure.



CONTOUR INTERVAL = 1.90 METERS

The above figure gives the 1.9-m contour interval for the profiled area. We assume that the oil will flow along this interval. The light shaded areas are shallower than 1.9 m. The 11 dark areas are also shallower than 1.9 m but are isolated by surrounding ice of greater depth.

Our electromagnetic property investigations of sea ice show that sea ice having a bottom structure in which the horizontal c-axes of the ice crystal platelets are aligned is an effective polarizer of transverse electromagnetic waves. It was found that the preferred crystal c-axis orientation appears to be the same as the under-ice current orientation. Our studies have also revealed that it is possible to detect this orientation using linear polarized antennas, not only from the ice surface but also from the air. This gives rise to the possibility of detecting under-ice current orientation in remote areas from an aircraft.

VIII. Need for further study

Information needs to be acquired on multi-year sea ice thickness, as this ice failing against an offshore structure will represent one of the larger forces that such structures will have to resist. At this time there is a lack of ice thickness information on multi-year ice as well as on the under-ice relief of multi-year ice floes which would allow a determination of oil pooling potential under this ice type.

Further studies need to be made on the electromagnetic characteristics of sea ice of different thicknesses and brine volumes. This information is needed to extend our understanding and use of radio echo sounding for profiling sea ice thickness from the surface and from the air, for determining sea ice strength from the radio echo data, and for detecting under-ice current directions.

IX. Summary of January-March Quarter

Laboratory work included data analysis and report writing as well as preparing for the spring field program. The spring field program started in mid-March and terminated in mid-April.

Annual Report
March 1979 - March 1980
Research Unit 567

THE TRANSPORT AND BEHAVIOR OF OIL SPILLED IN AND UNDER SEA ICE

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March 27, 1980

Table of Contents

Annual Report

I. Summary of Objectives

The objective of this work is to write twelve scenarios to describe the fate of oil spilled under the sea ice cover near Prudhoe Bay, Alaska. The twelve scenarios will encompass two times of year for the oil spill, spring and fall, together with spills occurring in three ice conditions; shorefast smooth, shorefast rough and deformed moving pack ice, as well as two lengths of a blowout, a five day and a ninety day.

A second objective of the proposed work is to determine whether ice containing oil from the Prudhoe area which has been transported to the Chukchi Sea can pass through the Bering Strait into the Bering Sea. This objective will be studied utilizing a sea ice dynamics model for the ice cover in the Chukchi Sea north of the Bering Strait.

II. Introduction

A. General Nature and Scope of Study

The twelve oil spill scenarios will draw on data and findings from last year's work in this Research Unit, which was presented in the Annual Report entitled "Beaufort and Chukchi Sea Ice Motions - Part I Pack Ice Trajectory" and "Part II Onset of Large Scale Chukchi Sea Ice Breakout," and the work will draw on the findings of other research units. ARCTEC, Inc. working under Research Unit 568 is conducting laboratory experiments to determine how oil spreads under sea ice and how oil is incorporated into the ice. CRREL is conducting work under Research Unit 562 which consists of field studies to determine the ice thickness profile, and therefore the bottom contour relief which will entrap oil. The findings of these two Research Units will form important input into the scenario preparation. Also the data from oceanographic findings and reconnaissance studies which have been a part of OCSEAP will be used in the scenario preparation.

The reporting of the oil spill scenarios will be accomplished in two separate reports. The first report will develop the background material needed for the oil spill scenarios. This report will include oceanographic and climitalogical data such as currents, tides, winds and ice growth data. Also the report will discuss properties of crude oil and mechanisms of blowout together with the interaction of oil with the sea ice cover in terms of a spreading model. The second report will consist of the twelve scenarios drawing together the information in the first report.

Results from the first year's work in this Research Unit indicated that ice which entrapped oil in Prudhoe Bay could be transported to the Chukchi Sea within one season. Once this is determined, it is important to then determine whether this ice containing oil could escape the Chukchi Sea through the Bering Strait. To this end a sea ice dynamics model calculation is being carried out under this Research Unit this year. The sea ice model will be an elastic ideally plastic model which account for the sea ice properties and consider loadings of winds and sea currents. These calculations will involve a parameter study varying the magnitude of winds and the strength of the sea ice cover. The oceanographic driving forces will be taken to be consistent with the ocean current as measured by Aagaard. In last year's work on this Research Unit, it was concluded that sea ice breaks out from the Chukchi to the Bering Sea when the normally northward ocean currents through the straits reverse, and a southernly flow is produced. Having studied the current data of Aagaard, it was determined that these events occur several times a year when an ice cover is present and the measurements from February 4, 1977, will be used in the actual study case. This work will be presented in a separate report.

B. Specific Objectives

The objectives of this Research Unit are to produce twelve oil spill scenarios and a report on the breakout of sea ice from the Chukchi to the Bering Seas.

C. Relevance to Problems of Petroleum Development

Studies of the possible fate of oil spilled in the Prudhoe Bay area can provide for a more environmentally safe exploration and development of possible offshore oil.

III. Current State of Knowledge

Past oil spill scenarios for the Arctic have been qualitative in that they have described what might happen given the rather sketchy bits of information available. It is the intent of this work to bring together the results from OCSEAP to quantify the inputs and subsequent conclusions for oil spill scenarios.

IV. Study Area: Beaufort and Chukchi Seas

V. Sources, Methods and Rationale of Data Collection

Data collection was not part of this Research Unit.

VI. Results

The results of the sea ice trajectory work were presented in last year's Annual Report. The oil spill scenarios and Chukchi Sea breakout results for this year's work will be reported in the final report for this Research Unit to be delivered in October 1980.

VII. Discussion

When the results of this Research Unit and Research Units 562 and 568 have been completed, the data necessary for constructing oil spill scenarios for the Prudhoe Bay area will have been amassed. Therefore not only the twelve that are reported but any other scenarios for that geographic region will be possible from the data developed.

VIII. Conclusions

Although the work on this research task has not been completed, it is possible to draw some tentative conclusions about oil spills in the Prudhoe area. It appears that under the rather low ocean current regimes that occur in the Prudhoe area in winter that oil spilled under the sea ice cover will not spread indefinitely but will be entrapped in the bottom sea ice topography and subsequently incorporated into the ice cover. It would appear that even large oil spills will cover regions of only tens of kilometers in diameter as compared to the large areas covered in open ocean spills. The winter ice cover of the Prudhoe area will provide for oil spill containment. Also it appears that the oil spilled during the winter within the Barrier Islands will be released from the ice as it melts in place during the next melt season in June and July. However for oil spilled outside the Barrier Islands and in particular outside the fast ice zone that the oiled ice could be transported to the Chukchi Sea and subsequently released during melt seasons.

IX. Need For Further Study

The work on this Research Unit has clearly indicated that oil spill scenarios for upcoming lease sales should be developed with adequate lead time to the lease sale such that the results can be considered. It is clear from the work on this and other Research Units that the local ocean current and ice conditions are important factors in the spreading and transportation of oil spilled in ice covered waters. Therefore scenarios should be tailored to each individual lease area. Also because the development of these scenarios require the data of many investigators, it is important to begin the work on scenario development early enough that any data gaps that do exist could be filled in to complete the scenarios prior to lease sales. Therefore it is felt that scenario preparation for other lease areas should be considered and commenced in a timely manner as dictated by the target lease sale dates.

The research work of the last few years has gone a long way toward providing a rational view of how oil can spread under sea ice. However there has been no field work utilizing oil whether it be petroleum or vegetable to verify that these spreading mechanisms work under real ocean current regimes and ice conditions. Therefore it is deemed extremely important that a controlled oil spill be conducted to study these spreading and entrapment mechanisms.

X. Summary of Forth Quarter Operation

A. Ship or Laboratory Activities

1-5 No activities in this Research Unit.

6 Milestone Chart

All work and reports are on or ahead of schedule.

B. Problems Encountered/Recommended Changes

None

C. Estimate of Funds Expended

Its estimated that expenditures on this year's contract through March 31, 1980, will be $80,000, leaving $70,000 to complete the task.

ANNUAL REPORT

Contract: 03-78-B01-62
Research Unit 568
Reporting Period: 1 April 1979 - 31 March 1980
Number of Pages: 11

THE TRANSPORT AND BEHAVIOR OF OIL SPILLED IN AND UNDER SEA ICE

PHASE II OF PHYSICAL PROCESSES

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31 March 1980

1. Summary of Objectives, Conclusions, and Implications with Respect to OCS Oil and Gas Development

The objective of this project has been to study the mechanisms of oil transport beneath an ice cover. The oil-ice interaction results of this project can be combined with a modification of the AIDJEX ice motion simulation to predict the long-term trajectory and disposition of oil spilled in the ice infested waters of the Arctic. Potential spill impact zones can then be identified and appropriate environmental safeguards can be implemented. Additionally the most promising oil spill clean-up procedures can be identified if a more precise knowledge of the oil-ice interaction is available.

The major preliminary conclusions and implications drawn from this year's work relative to OCS oil and gas development are as follows:

1. Wake regions behind ice roughness do not exhibit significant containment potential in the long term.

2. Cavities in the ice have the potential to at least partially contain oil even for free stream velocities exceeding the flushing velocities of frontal slicks.

3. The actual containment volume for any cavity is a function of the free stream flow rather than the cavity volume.

2. Introduction

2.1 General Nature and Scope of Study - The purpose of the present study is to examine how oil from a spill will interact with the sea ice of the Beaufort and Chukchi Seas. The scope of the Phase II effort includes the level of oil containment possible behind major under-ice obstructions and the containment potential of meso-scale obstructions which would be found under rough (but not ridged) ice. The work was performed in an ice covered laboratory flume. The results of these oil-ice interaction studies will be incorporated into a modification of the AIDJEX model of ice dynamics to provide a means for predicting the ultimate fate of oil spilled in ice infested waters.

2.2 Specific Objectives - As the problem was being formulated, the direction of the research was shifted from determining the limiting extreme conditions for containment to also include intermediate levels of containment and environmental conditions. This shift in emphasis was made based on recent under-ice current measurements which suggest that the higher current velocity states exist for only short periods of time. Therefore, it is of major importance to also understand the intermediate levels of containment. Specific questions to be answered by this year's work are as follows:

1. How much oil can be trapped in the wake region of a roughness element? How does the containment change for various oil viscosities, oil densities, and current speeds?

2. How much oil can be trapped between multiple roughness forms? What current speeds cause flushing of the trapped oil? How does containment vary with current speed? What spacing is sufficient for roughness to cease acting as a cavity?

3. What is the long term stability of the containment of oil in wakes and cavities? Does non-steady flow affect the containment of oil?

2.3 Relevance to Problems of Petroleum Development - The continuing energy crisis, particularly the shortages of oil and natural gas, indicate that the petroleum reserves already found and expected to be found in the Alaskan offshore region will be developed in a timely manner. This increased petroleum industry activity related to the exploration, development, production, and transportation of Alaskan offshore oil and gas will increase the potential for accidental spills of oil in the region. The results of the present research will provide predictions of the extent of under-ice spreading of an offshore oil spill or blowout. In addition, when incorporated into the AIDJEX ice dynamics model, the likely long-term trajectory and fate of oil spilled in ice-infested waters can be predicted. Such predictions can be used to evaluate the possible impact of oil spills upon biological systems, and to aid in the selection of protective measures and the potentially most effective spill response method.

3. Current State of Knowledge

Some research has been done on the behavior of stratified fluids in the lee of hills for meteorological application. Baines [1] sites work which examines two dimensional and three dimensional behavior of stratified winds around hills. Additionally, the flow pattern by a single fluid in wakes has been examined experimentally, and attempts at obtaining analytical solutions have been made [2]. The flow behavior of a single fluid in a cavity has also been looked at in some detail [3]. The only known study which addresses trapping of an immiscible fluid in a cavity is an abbreviated test done by Moir and Lau [4] who attempted to model the trapping of oil between two simulated ice ridges. These studies provide the basis for developing a theory on the behavior of oil trapped beneath rough ice. As with the Phase I effort of this project, other concepts of oil containment are adapted from open water boom theory.

4. Study Area

Horizontal oil transport tests were performed in ARCTEC's glass walled Ice Flume. Fresh water ice was grown by a patented cryogenic process on the surface of a 50 cm depth of water in the flume. With the pump running at full capacity, oil behavior for mean currents up to 30 cm/sec could be observed through the glass walls of the flume.

5. Sources, Methods, and Rationale of Data Collection

Data for this project comes from studies made on the horizontal transport of oil performed in ARCTEC's Ice Flume. These data include direct measurements of slick dimensions, speed, shape, ice properties and roughness, and current speed. Measurements of the under-ice spreading and containment of oil are best made in the controlled environment of an ice flume. This eliminates the danger of creating a hazardous spill while in the process of studying one. It also allows for the level of detail in observations and measurement needed for a fundamental study which is not possible in the field.

6. Results

This study addresses the potential trapping of oil in cavities and roughness wakes beneath an ice cover. The behavior of the trapped oil in both cases, although different, appears to be related in terms of the physical mechanisms involved. Since the testing portion of this year's work was only started in late January 1980 and an analysis of the test results is just getting underway, a heuristic discussion on the behavior of the oil will be presented. A draft final report covering the entire two phase program is scheduled for preparation in the next quarter.

6.1 Wake Trapping - In infinite water depth, the wake behind a thin flat "fence" has been observed to extend seventeen times the fence height downstream [2]. Since the wake was assumed to be a region of stagnant or reverse flow, it appeared that, based on the Phase I test results, the wake formed by ice roughness had the potential of trapping oil downstream to perhaps seventeen times the roughness height. Preliminary tests in this phase of the program using dye traces and velocity profiles of the flow behind a triangular roughness form indicated that in the limited water depth of the flume, the wake was only eight times the roughness height. Tests with oil added resulted in trapping of the oil in the wake to a distance not exceeding four times the barrier height, and with a thickness that was only approximately the static equilibrium thickness.

The variation in wake length between what was expected and what was observed can be explained in two ways. Figure 1, given by Pande et al., [5] shows how the length of the wake of a flat fence is affected by water depth. In our experiments, the ratio of the fence height to water depth was in the range of 0.20 to 0.25. According to Figure 1, the wake length should then be of the order of eight to nine times the fence height, which it was. From this we might argue that in deep water the length of the wake trapped oil would also increase proportional to the increase in wake length. Additionally, the shape of the fence affects the wake length. The velocity defect in the wake is given by:

$$\frac{U_\infty - u}{U_\infty} = \frac{C_D \eta}{\beta x}$$

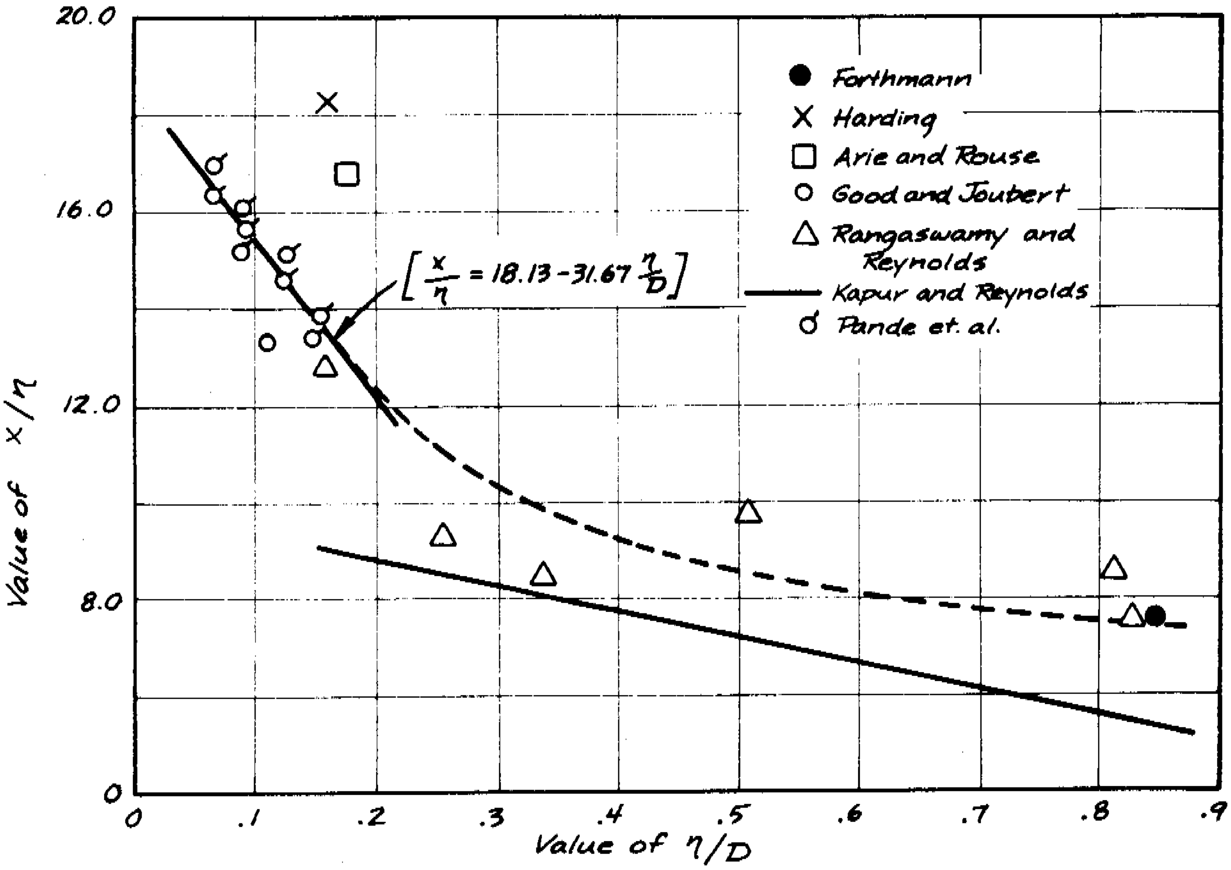

Figure 1. Variation of Wake Length with Roughness Height

where u is the local defect velocity, U_∞ is the free stream velocity, η is the roughness height, C_D is the drag coefficient for that shape, x is the distance downstream, and β is a constant empirically equal to 0.11 for wakes and jets [6]. Where the flow reattaches, $u = 0$. The drag coefficient for a flat plate equals 2.0. The ratio of roughness height to wake length, (x/n), can then be computed for the flat plate case to be equal to 18 at the reattachment point, which generally agrees with observations.

For a triangular shape $C_D = 1.55$, therefore the wake behind a triangular roughness would be reduced to 14 times the roughness height. This defect relation allows the computation of the wake length for any shape. By making a proportional argument, recognizing the effect of water depth and roughness shape, the length of a trapped oil slick in the wake of a triangular shaped ice roughness in deep water would be predicted to reach seven times the roughness height.

The major conclusion that can be made with regard to the trapping of oil in the wake of ice roughness is that the actual contained volume is relatively small in the short term (minutes to hours), and likely nil in the long term. In the short term, the thickness of the contained slick is nearly the static equilibrium thickness, and its length is considerably less than the total length of the separated zone. Additionally, the flow in the wake was found to be much more dynamic, erratic, and turbulent than originally believed. This makes the long term stability of any contained oil questionable. Based on the results of these tests, it is likely that in the long term virtually all of the contained oil would be flushed out of the wake region by the forceful, highly variable and fluctuating flow in the wake region.

6.2 Cavity Trapping - Shown in Figure 2 is a generalized description of oil trapped in the cavity formed by ice roughness. Two zones are indicated, a vortex zone and a shear zone. The vortex zone is the result of turbulent eddies being shed from the tip of the ice roughness resulting in a highly agitated and unstable region having a reverse mean flow. An offset develops in the location of the oil-water interface as a result of this vortex shedding region. Further downstream the flow smooths out and the shape of the interface becomes dominated by the shear applied by the free stream. This region is analogous to the shear region observed in slicks trapped upstream of an oil boom.

The location of the interface in the vortex zone appears to be controlled primarily by the free stream velocity and the density of the oil. As the velocity increases the offset of the interface increases. Preliminary analysis of the data suggests that the offset can be predicted by a Froude number relation:

$$\varepsilon = 1.8 \Delta g U_w^2$$

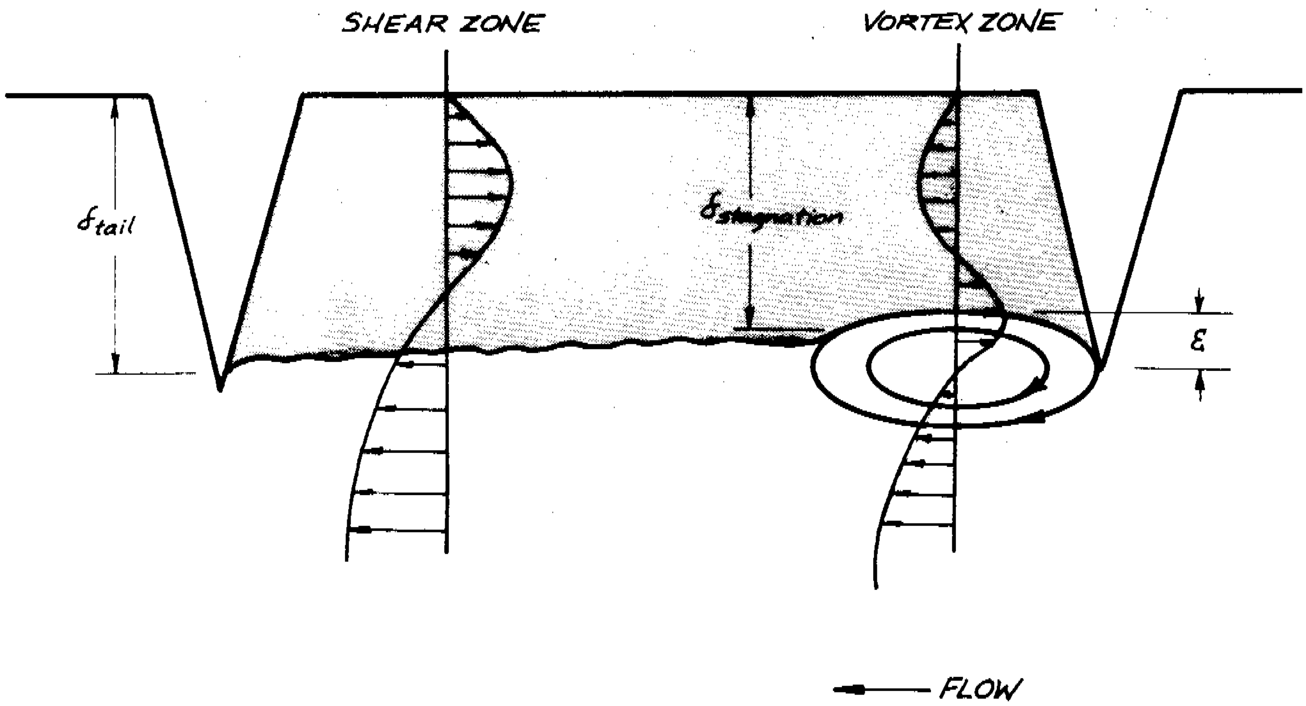

Figure 2. Generalized Description of Oil Contained in an Ice Roughness Cavity under the Influence of a Current

where ε is the offset, Δ is the density difference ratio = $(\rho_w-\rho_o)/\rho_w$, and U_w is the free stream velocity. The range of validity of this relation remains to be established; however, it appears reasonable until the offset becomes comparable with the cavity depth, causing the free stream flow to "feel" the ice cover in the cavity directly.

The length of the vortex zone remains largely undefined. Cursory inspection of the data suggests that the ratio of the offset to the zone length might be a constant, similar to the definition of a wake. However, this conclusion is highly speculative at this time.

The shear zone develops downstream of the vortex zone. As with frontal trapping, the shape of the interface in this region is parabolic in deep water. The interface is described by the relation:

$$\delta^2_{tail} - \delta^2_{stagnation} = \frac{2\tau_s}{\Delta\rho_w g} \quad ,$$

where δ_{tail} is the thickness at the downstream end of the cavity, $\delta_{stagnation}$ is the thickness behind the vortex zone, τ_s is the interfacial shear, and $\Delta\rho_w$ is the density difference. The location of the interface is controlled by the offset that formed in the vortex zone. The origin of the upstream end of the shear zone appears to occur at half of the offset of the vortex zone. For a cavity initially completely filled with oil, as velocity increases the interface stays attached at the downstream tip of the barrier, leaking small quantities of oil until the offset in the vortex zone has reached a point where it is no longer possible to support a parabolic shaped interface. A large quantity of oil is then flushed until a parabolic shape can be re-established. The result is a reposition of the interface further up into the cavity. This behavior is suggested in Figure 3. The process will continue with increasing velocity until separation between the vortex zone and the shear zone occurs, transforming a cavity into two independent ice fences forming their own frontal slicks and wakes. Complete flushing of the cavity can be expected when, as with frontal trapping, the velocity increases to the point at which a Kelvin-Helmholtz instability occurs.

6.3 References

1. Baines, P., "Observations of Stratified Flow Past Three-Dimensional Barriers," JGR Vol. 84, No. C-12, December 20, 1979, pp. 7834-7838.

2. Lin, A., and L. Landweber, "On the Solution of the Lavrentier Wake Model and Its Cascade," JFM Vol. 79, Pt. 4, 1977, pp. 801-823.

3. Pan, F., and A. Acrivos, "Steady Flows in Rectangular Cavities," JFM Vol. 28, 1967, pp. 643-655.

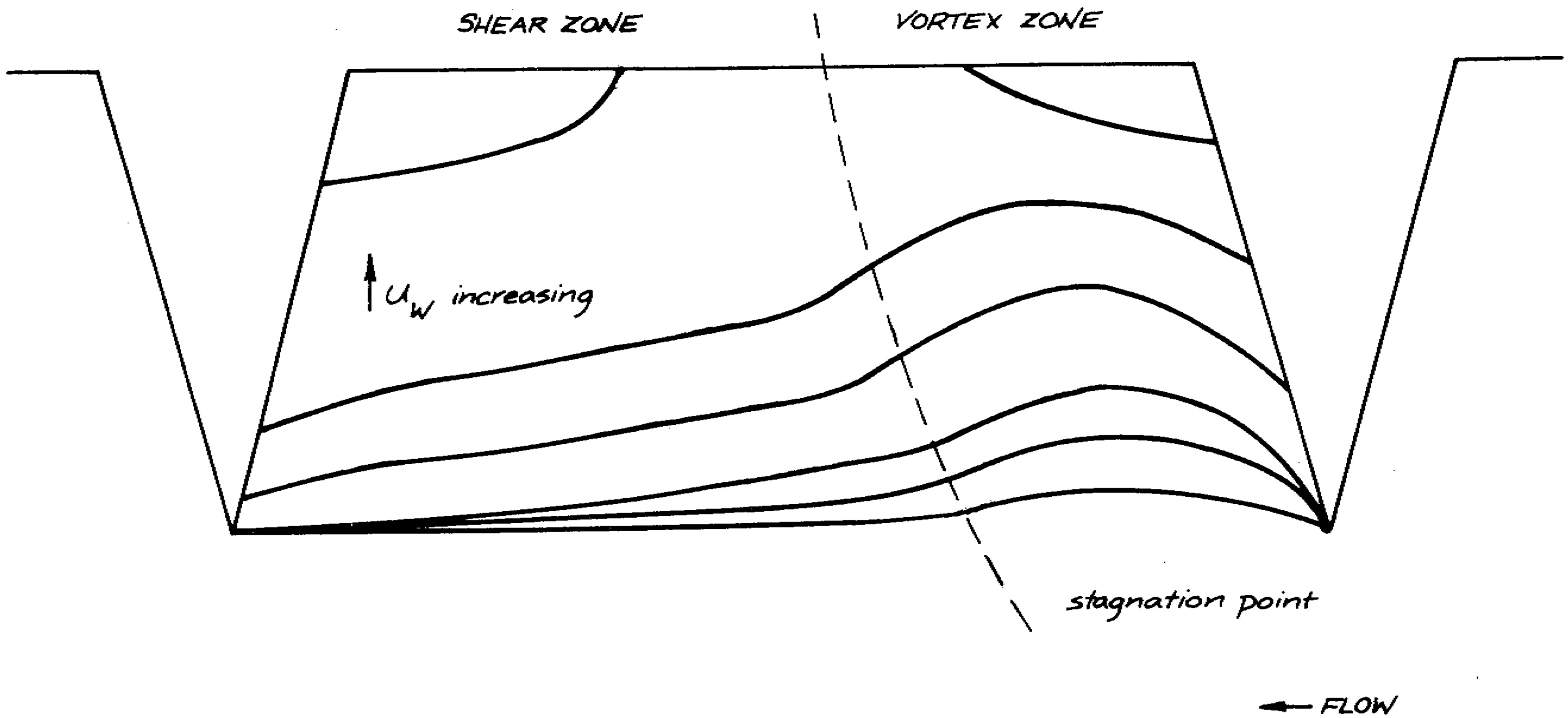

Figure 3. Schematic Representation of the Shift in Oil-Water Interface Position Within a Cavity as a Function of Increasing Current

4. Moir, J., and Y. Lau, "Some Observations of Oil Slick Containment by Simulated Ice Ridge Keels," for the Frozen Sea Research Group, Victoria, B.C., Hydraulics Division, C.C.I.W., March 1975.

5. Pande, P., R. Prakash, and M. Agarwal, "Flow Past Fence in Turbulent Boundary Layer," ASCE HY1, January 1980, pp. 191-207.

6. Jirka, G., G. Abraham, D. Harleman, "An Assessment of Techniques for Hydrothermal Prediction," R. M. Parsons Laboratory for Water Resources and Hydrodynamics, M.I.T., Report No. 203, July 1975.

7. Discussion

The amount of oil that can be trapped in the short term in the wake of an ice roughness is small in comparison to that observed in frontal trapping of oil, although frontal trapping is limited to current speeds below some critical value whereas wake trapping is not. Proportional extensions of slick length to deep water is probably reasonable, although unproven. In the long term it is likely that there will be no significant containment of oil in wake regions; all of the oil will be flushed out by the highly dynamic reversing flow in the wake.

The definition of a cavity according to length or depth appears to depend strongly on the free stream current, which, in turn, defines the size of the vortex zone. Real cavities whose length are less than or equal to the vortex zone length will have oil-water interfaces at the offset caused by the vortex shedding. Cavities which exceed the vortex zone in length will have interface positions controlled both by the vortex and the length over which the shear stress can act. Given a long enough cavity, the shear determined interface will always extend to the tip of the downstream roughness provided Kelvin-Helmholtz instability does not occur.

8. Conclusions

The examination of the transport of spilled oil beneath rough ice has revealed these preliminary conclusions:

1. For short time periods, wakes can trap oil in a two dimensional sense to a distance of half of the wake length, but only to the equilibrium thickness of the oil. The long term stability of any contained slick is judged unlikely.

2. The shape of the obstacle affects the wake length.

3. Cavities can be divided into two regions; a vortex dominated region and a shear dominated region which are defined by the flow and not by the cavity itself.

4. An offset develops in the position of the oil-water interface in the vortex zone which can be predicted by $\varepsilon = 1.8gU_w^2$.

5. The shape of the shear zone interface is parabolic and its origin can be taken at one half of the offset established by the vortex zone.

6. Cavities appear to be able to contain or partially contain oil for free stream velocities exceeding flushing velocity levels for frontal containment.

9. Needs for Further Study

Developing an understanding of oil containment by cavities is pushing the state-of-the-art for flow behavior of immiscible fluids. The preceding heuristic comments are based on limited data with two oils. In order to say with confidence that the offset theory is valid, tests should be made over a broader range of density, in cavities having large variability in depth and length, and in cavities defined by various roughness shapes.

In this particular test series, two questions remain unanswered. First, what actually is the length relation for the vortex zone? Present data are insufficient to do much more than speculate on the relation based on observations with wakes. Second, what is the range of validity for prediction of the vortex zone offset; i.e., is there a minimum oil thickness beyond which the flow "feels" the ice and behaves differently? These questions must be answered before an approximation can be made with any degree of confidence on the containment volume of cavities for given flow conditions and oil properties.

A final consideration is that the results are still two dimensional. Although directly applicable in many instances, they should still be verified by larger three dimensional tests and field tests.

10. Summary of Third Quarter Operations

A. Ship or Laboratory Activities

1. Ship or Field Trip Schedule

   None

2. Scientific Party

   None

3. Methods

   Laboratory data was gathered during this quarter, analyzed, compared against existing theories, and new relations developed to describe observed behavior.

4. Sample Localities

   Not Applicable

5. Data Collected or Analyzed

   Not Applicable

B. Problems Encountered

None

C. Estimate of Funds Expended

As of 31 March 1980, it is estimated that approximately $152,000 will have been expended for the work of Task 1. It is estimated that the work will be completed on budget.

Volume VII

DATA MANAGEMENT

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Volume VII - Data Management

ANNUAL REPORT

Contract # 03-5-022-55
Research Unit #267
Reporting Period:
April 1, 1979 to
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OPERATION OF AN ALASKAN FACILITY FOR APPLICATIONS OF REMOTE-SENSING DATA TO OCS STUDIES

Albert E. Belon
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April 1, 1980

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OPERATION OF AN ALASKAN FACILITY

FOR APPLICATIONS OF REMOTE-SENSING DATA TO OCS STUDIES

1979/80 Annual Report

Principal Investigator: Albert E. Belon
Affiliation: Geophysical Institute, University of Alaska
Contract: NOAA # 03-5-022-55
Research Unit: # 267
Reporting Period: April 1, 1979 - March 31, 1980

I - SUMMARY OF OBJECTIVES

The primary objective of the project is to assemble available remote-sensing data of the Alaskan outer continental shelf and to assist OCS investigators in the analysis and interpretation of these data to provide a comprehensive assessment of the development and decay of fast ice, coastal geomorphology and ecology, sediment plumes and offshore suspended sediment patterns along the Alaskan coast from Yakutat to Demarcation Bay.

Four complementary approaches are used to achieve this objective. They are: 1) the operation of a remote-sensing data library which acquires, catalogs and disseminates satellite and aircraft remote-sensing data; 2) the operation and maintenance of remote-sensing data processing facilities; 3) the development of photographic and computer techniques for processing remote sensing data; and 4) consultation and assistance to OCS investigators in data processing and interpretation.

Thus, the project has primarily a support role for other OCS projects, and in itself does not usually generate disciplinary conclusions and implications with respect to OCS oil and gas development. Such results will be generated by the various disciplinary OCS projects, most of which are users of remote-sensing data and services provided by our project. At this time at least fourteen OCS projects are utilizing remote-sensing data routinely, seven (RU #205, 530, 250, 88, 289, 519, and 265) almost exclusively. In addition, the availability of near-real-time remote-sensing data (NOAA and DMSP satellites) and delayed repetitive data (Landsat and aircraft) provides a continuous monitoring of environmental conditions along the Alaskan continental shelf for research and logistic support of the OCSEAP Program.

II - INTRODUCTION

A. General Nature and Scope of Study

The outer continental shelf of Alaska is so vast and so varied that conventional techniques, by themselves, are unlikely to provide the detailed and comprehensive assessment of its environmental characteristics which is required before the development of its resources is allowed to proceed during the next few years. The utilization of remote-sensing techniques, in conjunction with conventional techniques, provides a solution to this dilemma for many disciplinary investigations. Basically the approach involves the combined analysis of ground-based (or sea-based), aircraft and satellite data by a technique known as multistage sampling. In this technique, detailed data acquired over relatively small areas by ground surveys or sea cruises are correlated with aerial and space photographs of the same areas. Then the satellite data, which extend over a much larger area and provide repetitive coverage, are used to extrapolate and update the results of the three-way correlations to the entire satellite photograph. Thus, maximum advantage is taken of the synoptic and repetitive view of the satellite to minimize the coverage and frequency of data which have to be obtained by conventional means.

B. Specific Objectives

The principal objective of the project is to make remote-sensing data, processing facilities and interpretation techniques available to the OCS investigators so that the promising applications and cost effectiveness of remote-sensing techniques can be incorporated in their disciplinary investigations. The specific objectives of the project are: 1) the acquisition, cataloging and dissemination of existing remote-sensing data obtained by aircraft and satellites over the Alaskan outer continental shelf, 2) the operation and maintenance of University of Alaska facilities for the photographic, optical and digital processing of remote-sensing data, 3) the development of photographic, optical and computer techniques for processing remote-sensing data for OCS purposes and 4) the active interaction of the project with OCS users of remote-sensing data, including consultation and assistance in disciplinary applications, data processing and data interpretation.

C. Relevance to Problems of Petroleum Development

The acquisition of remote-sensing data, especially satellite data, has proved to be a cost-effective method of monitoring the environment on a synoptic scale. Meteorological satellites have been used for over a decade to study weather patterns and as an aid to weather forecasting. The earth resources satellite program, initiated in 1972, offers a similar promise to provide, at a higher ground resolution, synoptic information and eventually forecasts of environmental conditions which are vital to petroleum development on the continental shelf. For instance the morphology and dynamics of sea-ice which are relevant to navigation and construction of offshore structures, the patterns of sediment transport and sea-surface circulation which will aid to forecast trajectories of potential oil spills and impact on fisheries, the nature of ecosystems in the near-shore regions which can be changed by human activity, are among the critical development-related environmental parameters which can be studied, in conjunction with appropriate field measurements, and eventually routinely monitored by remote-sensing.

III - CURRENT STATE OF KNOWLEDGE

The utilization of remote-sensing techniques in environmental surveys and resource inventories has made great strides during the last few years with the development of advanced instruments carried by aircraft and satellites. The early meteorological satellites had a ground resolution of a few miles and a broad-band spectral response which made them well-suited to meteorological studies and forecasting but inadequate for environmental surveys. The ground resolution of the sensors has been gradually much improved over the years and thermal sensors were added for cloud and sea temperature measurements, but generally the relatively low ground and spectral resolution of the meteorological satellites is a limitation for environmental surveys.

The initiation of a series of Earth Resources Technology Satellites (now renamed Landsat) in July 1972 was intended to fill the need for synoptic and repetitive surveys of environmental conditions on the land and the near-shore sea. With a ground resolution of about 80 meters and sensitivity in four visible spectral bands, Landsat-1 and 2, have fulfilled that promise beyond all expectations. Landsat 3 was launched on March 5, 1978 and is acquiring MSS data in all four spectral bands as well as RBV data which provides higher ground resolution (40 meters) than either of the first two satellites. Unfortunately the thermal spectral band on Landsat 3 never worked properly and very little useful data was acquired from it.

The development of techniques for analyzing and interpreting Landsat have proceeded at an even more rapid pace than the satellite hardware. While in 1972 much of the Landsat data interpretation was done by visual photointerpretation, the last four years have seen major developments in photographic, optical and, in particular, digital techniques for processing and interpreting the Landsat data. Some of these techniques, applicable to OCS studies, will be discussed in section V and VI of this report.

Through the impetus provided by the national commitment to satellite observations of the earth, the aircraft remote-sensing program has also made great strides in the last few years. While in the early 1960's airborne platforms were mostly used for aerial photography, the late 1960's saw the development of advanced multispectral scanners, thermal scanners, side-looking radars and microwave radiometers, partly for the testing of future satellite hardware and partly because the airborne observations serve for middle-altitude observations between ground and satellite measurements as part of the multistage sampling technique. Two philosophies are apparent in the airborne remote-sensing program: the first, exemplified by the NASA program as well as several universities and industrial agencies, involves relatively large aircraft and sophisticated instrumentation which produce vast quantities of data usually applied to intensive, non-repetitive surveys of relatively small areas. The second approach uses airborne remote-sensing in a truly supporting role for ground-based or satellite measurements. The aircraft are smaller and the instrumentation usually consists of proven, simpler instruments such as aerial cameras, single-band thermal scanners, and single wavelength side-looking radars which usually generate data only in photographic format. The costs of data acquisition and data processing, while they are not small, are sufficiently low that the approach is often used for repetitive surveys of relatively large areas. In our opinion the second approach fulfills best the needs of the NOAA/OCSEAP program and we have been working very closely with the NOAA Arctic Project Office toward the implementation of such a remote-sensing program.

IV - STUDY AREA

The study area for the project includes the entire continental shelf of Alaska, except for the southeastern Alaska panhandle. This area includes the Beaufort, Chukchi and Bering Seas and the Gulf of Alaska shelves and coastal zone. Temporal coverage is year-round, although the data coverage from November 1 to February 15 is limited owing to the very low solar illumination prevailing at high latitudes during winter.

V - SOURCES, METHODS AND RATIONALE OF DATA COLLECTION

A remote-sensing data library and processing facility was established in 1972 on the Fairbanks campus of the University of Alaska as a result of a NASA-funded program entitled "An interdisciplinary feasibility study of the applications of ERTS-1 data to a survey of the Alaskan environment". This experimental program, which covered ten environmental disciplines and involved eight research institutes and academic departments of the University, terminated in 1974, but the facility which it established proved to be so useful to the statewide university and government agencies that it has continued to operate on a minimal basis with partial funding from a NASA grant and a USGS/EROS contract. In view of the large potential demand of the OCS program on these facilities, a proposal was submitted to NOAA in March 1975 for partial funding of the facility for OCS purposes. This proposal resulted in a contract from NOAA on June 12, 1975, and the work performed since that time is the basis for the present report.

As a result of the NASA-funded program, the remote-sensing data library had total cloud-free and repetitive coverage of Alaska by the ERTS - now renamed Landsat - satellite from the date of launch (July 29, 1972) to May 1974 (about 30,000 data products), 60 rolls of imagery acquired by NASA aircraft (NP3 and U-2) some of which includes coverage of the Beaufort Sea, Cook Inlet and Prince William Sound, and substantial facilities for photographic, optical and digital processing of these data. Through a NOAA-funded pilot project, which studied applications of NOAA satellite data in meteorology, hydrology, and oceanography, the remote-sensing data library also had nearly complete coverage of Alaska by the NOAA satellites since February 1974.

A. Remote-Sensing Data Acquired for the OCS Program

1) Landsat data

At the initiation of the project we performed searches of the EROS Data Center (EDC) data bank for Landsat and aircraft remote-sensing data obtained over the four areas of interest to the OCSEAP program. From the several thousand scenes so identified, we selected the scenes which we did not have in our files and which had satisfactory quality and 30% or less cloud cover. As a result of this search 566 Landsat scenes (2830 data products) were ordered from the EROS Data Center in the following data formats:

- -70mm positive transparencies of multispectral scanner (MSS) spectral bands 4, 5 and 7
- -70mm negative transparencies of MSS spectral band 5
- -9-1/2 inch print of MSS spectral band 6

During the first four years of the project, 2,806 additional cloud free scenes were acquired by the satellite and purchased from EDC.

After March 31, 1977, the EDC price for Landsat products having increased by an average of 166%, we reduced our routine purchase of selected Landsat scenes to two formats:

- -70mm positive transparency of MSS, spectral band 5
- -9 1/2 inch print of MSS, spectral band 7

Other formats are ordered on a case-by-case basis and at the request of individual OCS investigators. During the past year, 556 scenes were added to our files.

2) NOAA satellite data

With the termination of a NOAA pilot project, sponsored by NOAA/NESS, in October 1975, our acquisition of NOAA satellite scenes stopped after having accumulated 1320 images since February 1974. Following an interim arrangement with the National Weather Service, which turned out to be inconvenient for both parties, funding was provided by OCSEAP, starting on 1 February 1976, to purchase NOAA satellite imagery directly from the NOAA/NESS Satellite Data Acquisition Facility at Fairbanks. Under this purchase order we are receiving two NOAA scenes daily from the Bering Sea pass of the satellite (covering the Beaufort, Chukchi and Bering Seas) and one scene daily from the interior Alaska pass (covering the Gulf of Alaska) in both the visible and infrared spectral bands (6 images daily except in winter) for a total of 1,103 images received during the reporting period.

In addition we have made arrangements with the NOAA/NESS facility to save digital tapes of the thermal infrared data, upon request and for the cost of tape replacement, for scenes which are especially cloud-free or of high interest to OCS investigators. These tapes allow the precise mapping of sea-surface temperatures at locations and at times of special interest to OCS investigators.

3) USGS/OCS aircraft remote-sensing data

In November 1975, we started receiving the remote-sensing data acquired by USGS aircraft, under a NOAA/OCS contract, along the Alaskan arctic coast since July 1975.

These data consist of six 250 ft. rolls of black and white aerial photography and 42 strips of side-looking radar imagery. This program terminated in December 1975.

4) NASA aircraft remote-sensing data

Over the last few years the NASA Earth Resources Aircraft Program has flown several missions over preselected test sites within Alaska. The program is directed primarily at testing a variety of remote-sensing instruments and techniques and to support NASA-sponsored investigations. However, black and white and color-infrared aerial photography were obtained on most missions and in particular during the May 1967, July 1972, June 1974, and October 1976 missions which include flights over portions of the Alaskan coast and coastal waters. We have acquired copies of these data from NASA.

The U-2 imagery of the Beaufort Sea obtained in June 1974 is of particular interest to OCS investigators because it was obtained during the sea-ice break-up period, it covers a large area (20x20 mi.) in a single frame with good ground resolution (10 ft.), and nearly concurrent Landsat data are available. Similarly, the U-2 imagery of the northern Gulf of Alaska and Prince-Williams Sound, acquired in October 1976, is of excellent quality.

During June 1977, the U-2 aircraft once again acquired photography over Alaska. New flight lines, mostly in the Prudhoe Bay area, using a 6" and 12" focal length lens were flown and copies of the data are included in our files.

In 1978 several state and federal agencies combined efforts to obtain high altitude aerial photographic coverage of the whole State of Alaska. This imagery is being acquired by NASA over a three-year period which commenced in summer 1978. Approximately sixty percent of the state was satisfactorily covered in the first two years' efforts. Two cameras are being used with focal length lenses of 6" and 12" resulting in black and white coverage at 1:120K scale and color infrared coverage at 1:60,000 scale. Coastal areas covered include Point Hope to Cape Espenberg, Kodiak Island, most of the Beaufort coast, all of Southeast Alaska, and most of the coastal areas from Seldovia to Glacier Bay. All of this imagery is in our files and available to OCSEAP investigators for use at the library or copies may be ordered for their individual use.

5) NOS aircraft remote-sensing data

In spring 1976 we learned that the National Ocean Survey's (NOS) Buffalo aircraft was scheduled to obtain aerial photographic coverage of Shelikof Strait during summer 1976. Knowing that this area is frequently covered by clouds, we requested NOS to acquire aerial photography of other areas of the Alaskan coastal zone on a non-interference basis with their primary mission. NOS agreed to do so for the cost of the raw film. As a result 1316 frames of color aerial photography were acquired, covering the entire coast from the Yukon delta to Cape Lisburne and several isolated areas in the Gulf of Alaska.

During July 1977 the NOS aircraft flew additional flight lines on the Chukchi and Beaufort coasts extending our coverage eastward to the mouth of the Kogu River, in Harrison Bay. This medium scale photography is of excellent quality and has been used heavily by OCS investigators.

6) Army aircraft remote-sensing data

With the termination of the USGS/OCS remote-sensing data acquisition program in December 1975, an important need developed for all-weather remote-sensing coverage of the Beaufort and Chukchi coasts during critical periods (end of winter and end of summer). We worked closely with the OCSEAP Arctic Project Office and with a major user (Dr. Cannon, RU #99) in investigating various options culminating in a contractual arrangement with the U. S. Army remote-sensing group at Ft. Huachuca, Arizona.

Under this contract an Army Mohawk aircraft equipped with an all-weather side-looking radar (SLAR) flew two missions in Alaska in May and August 1976 resulting in complete SLAR coverage (51 flights) of the Beaufort and Chukchi shelves during the critical periods. These data have been heavily used, particularly by OCSEAP RU #88 (Weeks) and RU #99 (Cannon). An April 1977 SLAR mission was flown which resulted in spring sea-ice coverage of the Chukchi and Beaufort coastlines as far east as Camden Bay. During the 1978-79 ice season four flights were made along the Beaufort coast. Additionally, NASA/Lewis Research Center flew several SLAR flights in the Bering and Beaufort Seas in March 1979 and these data are on file in our library.

During this reporting period arrangements were made by NOAA/BLM and USA/CRREL to obtain SLAR missions along the Beaufort and Bering coasts on a regular basis. The imagery is obtained by an Army Mohawk OV-1B and to-date data has been received for the Beaufort area on February 13 and the Bering Sea on February 20, 1980. The film is copied in the Geophysical Institute photo lab, transparencies made as well as several copies of prints for distribution. The original imagery is then returned to the Army and a copy is retained in our file.

7) Near-real-time satellite imagery

Near-real-time satellite imagery is now available to OCS investigators through the Remote-Sensing Library. Air Force weather satellite imagery (DMSP) is received at Elmendorf Air Force Base near Anchorage and shipped on a regular basis to the Geophysical Institute. Also, Landsat quick-look data from selected scenes is received from Canadian sources two or three days after acquisition. These new data products are made possible through a State-funded project to evaluate the utility of near-real-time satellite imagery to Alaskan problems. OCS has made extensive use of these data, primarily to determine sea-ice conditions.

8) Preparation and distribution of remote-sensing data catalogs

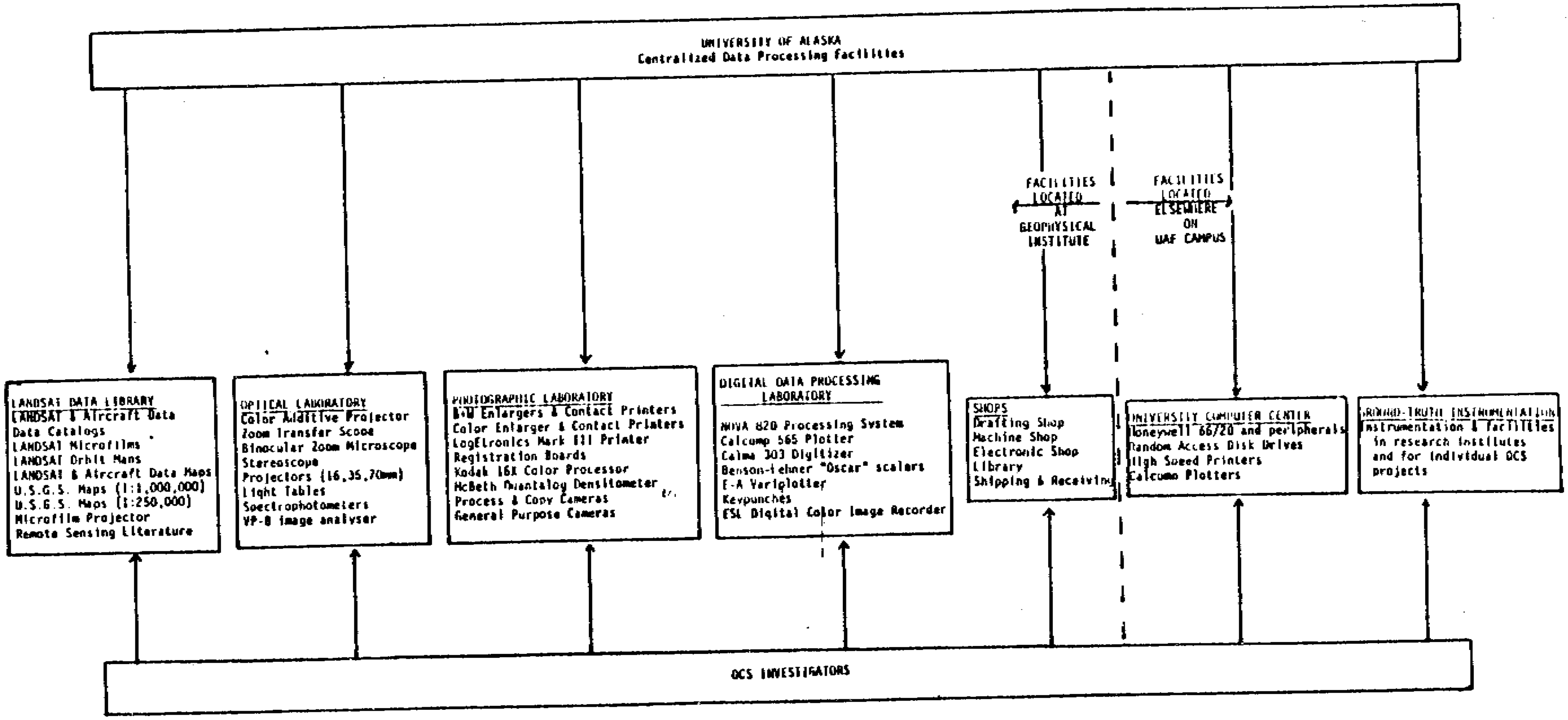
All the remote-sensing data available in our files for the Alaskan continental shelf have been indexed and plotted on maps. Catalogs summarizing the availability of these data and providing instructions for selecting and ordering data have been prepared and distributed to all OCS investigators as appendices to the series of Arctic Project Bulletins (Nos. 6, 9, 10, 12, 14, 17, 22 and 28). In addition we have developed a file of catalogs and photo indices of aerial photography obtained by federal, state and industrial agencies in Alaska, and we attempt to stay informed on plans for future aircraft photographic missions.

B. Remote-Sensing Data Processing Facilities and Techniques

The facilities and equipment commonly used for remote-sensing data processing are listed in Figure 1. Most of this equipment is not devoted exclusively to remote-sensing data processing but arrangements have been made to support the needs of the OCS investigators on a time-share and work-order basis, and to take into account the needs of the OCS program in any planned modifications or expansions.

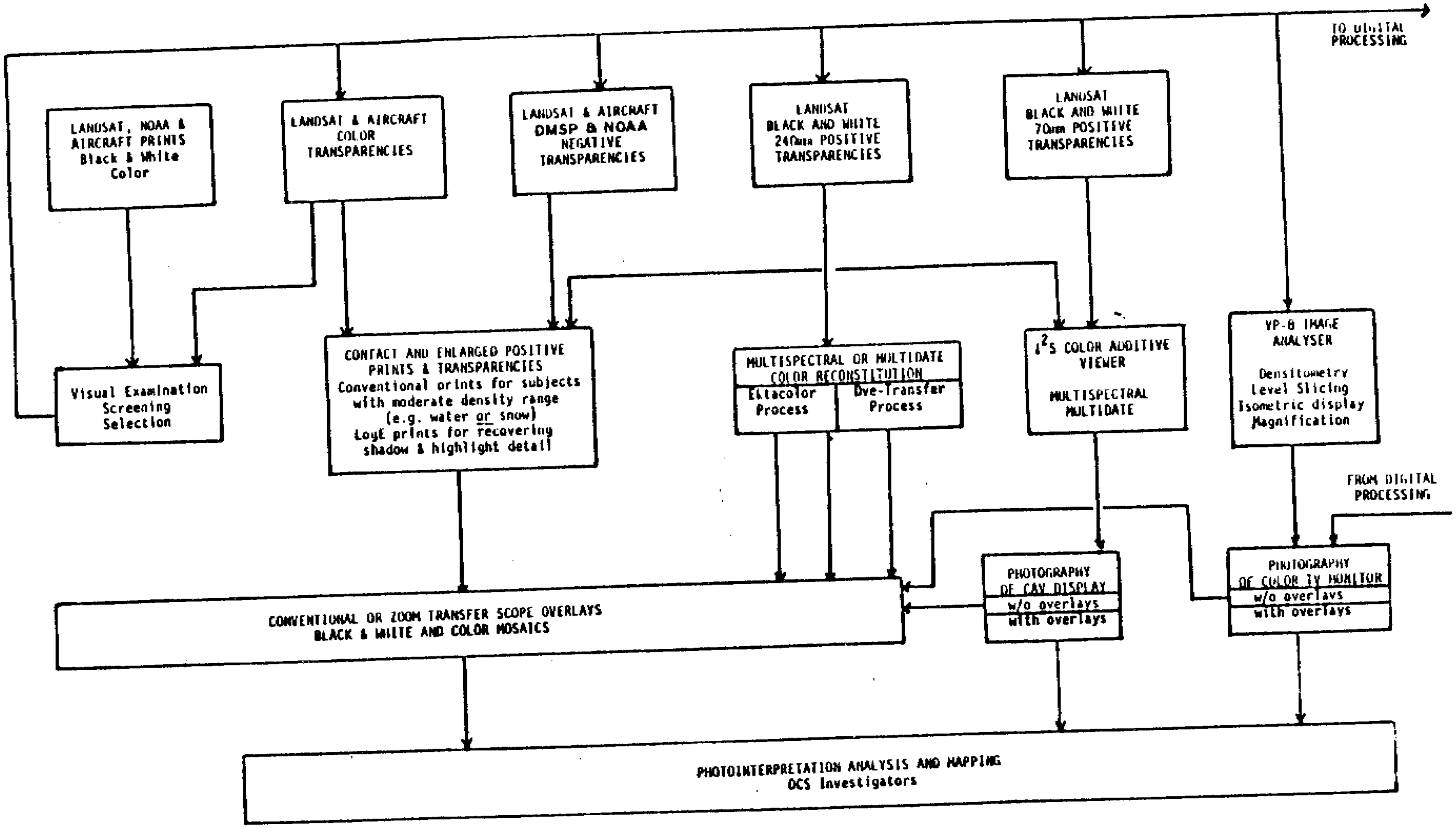
The optical and photographic processing techniques developed for the remote-sensing program are described in the flow diagram of Figure 2.

Photographic processing probably needs no further explanation. The full range photographic laboratory of the Geophysical Institute is well adapted to the generation of custom, as distinct from production run, photographic products. However, the available equipment limits photographic enlargements to 16x20" maximum size from 8x10" originals. Electronically dodged prints or transparencies are produced by contact printing only.



Centralized Data Processing Facilities

Figure 1



Optical and Photographic Processing

Figure 2

Optical processing revolves around the use of specialized equipment such as the multiformat photo-interpretation station, the zoom transfer scope, the color additive viewer and the VP-8 image analyzer in addition to conventional light tables, stereoscopes and a binocular zoom magnifier.

Multiformat Photo Interpretation Station - Analysis of aerial imagery in roll form is a cumbersome task and is likely to damage the original material even with careful handling if one uses ordinary reel holders and a light table. With stereo coverage, it is impossible to achieve stereo viewing with the frames appearing on the roll format unless one uses the photo interpretation machine. It can accommodate either 5-inch or 9-inch film formats and the film transport adjusts to permit stereo viewing with varying amounts of forward lap between frames. The viewing turret includes zoom binoculars with up to 5X magnification.

Zoom Transfer Scope - The time-consuming process of transferring information from images to maps is made considerably easier by the use of the zoom transfer scope. This table-top instrument allows the operator to view simultaneously both an image and a map of the same area. Simple controls allow the matching of differences in scales (up to 14X) and provide other optical corrections so that the image and the map appear superimposed. ~~In~~ particular a unique one-directional stretch capability (up to 2X) allows the matching of computer print-out "images" to a map or photograph.

Color Additive Viewer/projector/tracer - This instrument is primarily intended for the false-color recomposition of Landsat images from 70mm black and white transparencies and tracing information contained on these images at scales of 1:1,000,000 and 1:500,000. However it has proved to be very useful also for superimposing and color-coding Landsat images acquired on different dates and looking for change or movement and for viewing any other enlarged image on 70mm film format.

VP-8 Image Analysis System - The VP-8 image analysis system provides an electronic means of quantizing information contained in a photograph when the sought information can be expressed in terms of density ranges. It consists of:

- a light table having uniform brightness and a working surface of 15x22 inches
- a vidicon camera which transforms the photographic (transmittance) data to electrical signals
- an electronic image analyser which quantizes and formats the vidicon signals
- a CRT oscilloscope
- a color television monitor as an output device

The capabilities of the VP-8 image analysis system include:

- -density level slicing. This feature allows lines of uniform density on the input image to be displayed as contours. These contours form the boundaries of density bands which are displayed as up to 8 color bands on the color television monitor. The base density levels and the density range of the bands are individually as well as collectively variable. An example and illustration of the density slicing technique applied to coastal sedimentation studies was provided in the OCSEAP Arctic Project Bulletin No. 7, Appendix C, "Environmental Assessment of Resource Development in the Alaskan Coastal Zone based on Landsat Imagery" by A. E. Belon, et al, University of Alaska.

- -single scan line display. Any single horizontal scan line of the vidicon camera can be selected for display on the CRT oscilloscope by positioning a horizontal cross-hair on the image. This display of a single scan line is effectively a microdensitometer trace.

- -digital read-out of point densities, selected by adjustable cursors or of total area of the image having a given (color-coded) density range. For instance the VP-8 image analysis system is well adapted to the area measurement of sea-ice, newly refrozen ice, and open water in any area of the Beaufort Sea imaged by Landsat.

- -3-D display. This mode of operation allows a three-dimensional presentation where the X and Y coordinates of the original image are displayed in isometric projection and intensity information is shown as a vertical deflection. Subtle features of the image which are often lost on level-sliced displays, become obvious in 3-D displays.

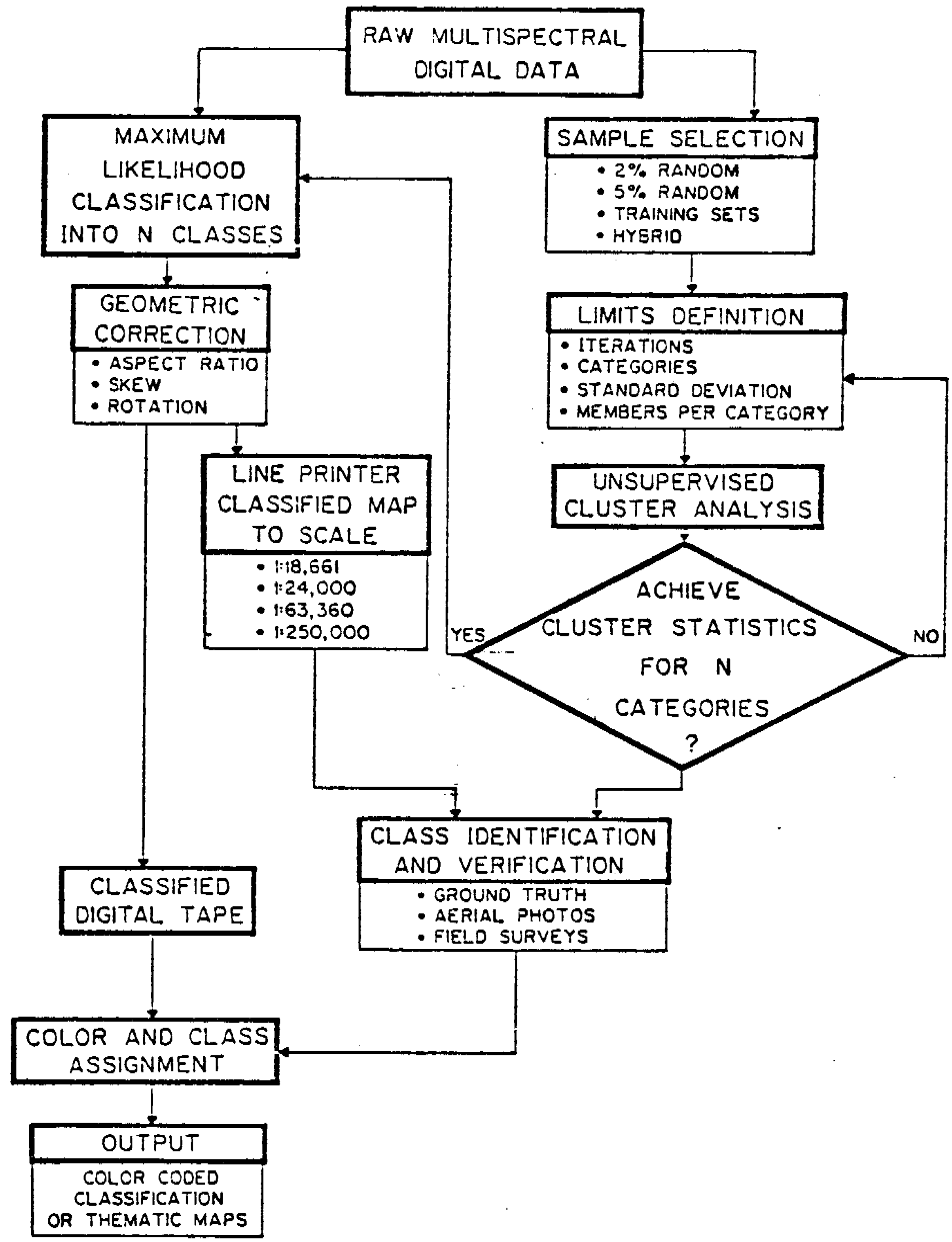
- -5X magnification. This feature allows the expansion of a small part of the image on the 3-D display to full screen size.

The digital data processing equipment available to the OCS investigators include the main University computer, a Honeywell model 66/20 with 1 M bytes of core memory, which has a remote time-share terminal at the Geophysical Institute, a NOVA 820 data preprocessing computer as well as conventional line printers, plotters and digitizers. Most remote-sensing imagery in digital format is reformatted, classified or otherwise processed on offline computing systems. An overall flow diagram of digital processing of Landsat imagery is illustrated in figure 3 and discussed later in this report. Once the digital data have been processed, they are displayed on line printer maps or the digital image film recorder.

Digital Color Image Recorder - It often is necessary to reconstitute an image from the processed digital data in order to convey information in the most suitable form to the human mind. Also, if one deals with multi-spectral data it is impossible to convey the density of information required without the use of color. A digital image recorder with the capability of reconstituting color products was procured and installed in 1976 using State of Alaska funds appropriated to the University of Alaska Geophysical Institute. Basically it is a rotating-drum film recorder which produces four simultaneous standard images on film up to 8x10" in size. Density resolution is 255 levels of gray, and spatial resolution is 500 lines per inch. Recording rate is 1.5 lines per second. Any combination of the four negatives so produced can be registered and printed with suitable filters to produce a reconstituted color negative which can be processed and enlarged photographically.

Remote-Sensing Data Interpretation Techniques - The basic techniques for remote-sensing data reduction and interpretation are described in flow diagram format in figure 2 (optical and photographic data processing) and figure 3 (digital data processing). The techniques for visual photointerpretation, as applied to sea-ice mapping; for density slicing, as applied to sea-surface suspended sediment mapping and transport; and for digital data processing, as applied to ecosystem thematic mapping, are described in the OCSEAP Arctic Project Bulletin No. 7, in particular its Appendix C "Environmental Assessment of Resource Development in the Alaskan Coastal Zone based on Landsat Imagery" by A. E. Belon, J. M. Miller and W. J. Stringer.

Variations of these techniques offer considerable promise of effective applications to OCS studies, but are too numerous and varied to be discussed in detail here. Usually they are developed in cooperation with individual OCS investigators for application to a specific project. Therefore we refer to the reports of other OCS investigators for detailed descriptions of applications of remote-sensing data to disciplinary studies.



FLOW CHART FOR GENERATING ECOSYSTEM MAPS

Figure 3 Digital Processing of Landsat Imagery

Flow chart of the unsupervised classification algorithms used for generating ecosystem maps of the Alaskan coastal zone from Landsat digital imagery.

C. Consultation and Assistance to OCS Investigators

This activity may be subdivided into two parts: general assistance to all OCS investigators provided through the Arctic Project Bulletins, program planning and negotiations and meetings/workshops; and individual assistance through consultation, training sessions on the use of remote-sensing data and equipment, and cooperative data analyses.

1. General Assistance

In order to familiarize OCS investigators with the available remote-sensing data, processing equipment, and interpretation techniques, we prepared seven substantial reports which were included as appendices to the OCSEAP Arctic Project Bulletins Nos. 6, 7, 9, 10, 12, 14, 17, 22 and 28 and distributed to all OCS investigators active in studies of the Beaufort, Chukchi and Bering Seas and the Gulf of Alaska.

The appendix to Arctic Project Bulletin No. 6 described the operation of the remote-sensing data library, provided catalogs of Landsat and aircraft data available in our files and provided instructions to OCS investigators on the selection and ordering of these data.

The appendix to Arctic Project Bulletin No. 7 described the facilities and techniques available for analyzing remote-sensing data and included a scientific report in which these facilities and techniques were used to analyse and interpret remote-sensing data in three representative investigations of the Alaskan continental shelf: sea-surface circulation and sediment transport in the Alaskan coastal waters, studies of sea-ice morphology and dynamics in the near-shore Beaufort Sea, and mapping of terrestrial ecosystems along the Alaskan coastal zone.

The appendix to Arctic Project Bulletin No. 9 provided a cumulative catalog of all available OCS remote-sensing data including Landsat and NOAA satellite data, USGS/OCS aircraft data and NASA aircraft data.

Arctic Project Bulletin No. 10 provided a catalog of the SLAR (Side-looking radar) imagery obtained by the Army Mohawk remote-sensing aircraft in May 1976.

The Appendix to Arctic Project Bulletin No. 12 provided an updated catalog of satellite and aircraft remote-sensing data acquired since the issuance of the cumulative catalog of Bulletin No. 9.

Arctic Project Bulletin No. 14 provided a catalog of the SLAR imagery obtained in May 1977 by the Army-Mohawk aircraft.

Arctic Project Special Bulletin No. 17 provided an updated catalog of satellite and aircraft remote sensing data acquired through the spring and summer field season of 1977.

Arctic Project Special Bulletin No. 22 provided an updated catalog of Landsat and NOAA imagery acquired through the spring and summer field season of 1978.

Arctic Project Special Bulletin No. 28 provided an updated catalog of Landsat and NOAA imagery as well as Side-Looking Airborne Radar and high-altitude aerial photography acquired through winter 1978 and all of 1979.

Although the existing remote-sensing data base is very useful in supporting OCS disciplinary projects, there is also a vital need for an airborne remote-sensing data acquisition program dedicated to OCS purposes. To this end we have worked very closely with the NOAA Arctic Project Office in attempting to implement such a program. We participated in several meetings at the Geophysical Institute and one at Barrow in an attempt to set the USGS/OCS airborne remote-sensing data acquisition program on the right course, and took over responsibility for cataloguing, reproducing and disseminating these data. When this program failed and was terminated in January 1976, we studied alternatives and recommended several options to NOAA, one of which was a contractual arrangement with the U. S. Army remote-sensing squadron at Ft. Huachuca, Arizona. This recommendation was implemented, and two missions of the Army Mohawk remote-sensing aircraft were conducted in May and August 1976, resulting in high quality SLAR imagery of the Beaufort, Chukchi and Gulf of Alaska shelves at critical period. Another mission was conducted in April 1977. In parallel with these activities we have negotiated with NASA for the acquisition of high altitude (U-2, 65,000 ft.) aerial photography of the entire Alaskan coastal zone. This program was approved by NASA at no cost (so far) to NOAA/OCSEAP. The first attempt to acquire the requested data, in June 1975, failed because of prevailing heavy cloud cover during the 3 weeks the U-2 aircraft was in Alaska. A second attempt, unfortunately delayed until October 1976, was partially successful and acquired high quality aerial photography of the Gulf of Alaska and Prince Williams Sound. Due to excessive cloud cover very little usable U-2 imagery was acquired from the June 1977 mission; however, two flight lines in the Prudhoe Bay area were of good quality. We also participated in successful negotiations with the National Ocean Survey for acquisition of color aerial photography of the Bering and Chukchi Sea coasts during a previously scheduled mission of their Buffalo aircraft to Alaska in summer 1976.

Excellent medium altitude photography was acquired from the Yukon delta to Cape Lisburne, as well as isolated areas of the Gulf of Alaska coast. In summer 1977 NOS again flew several flight lines, extending from Cape Sabine on the Chukchi Sea coast to Cape Halkett on the Beaufort Sea. This imagery is of excellent quality and is archived here for OCS investigators' use.

While the OCSEAP Arctic Project Office and our project have been fairly successful in negotiating remote-sensing data acquisition by other agencies on an irregular basis, such arrangements are not wholly satisfactory on a long-term basis because the type and format of the data vary from one mission to another and the frequency of data acquisition is insufficient to provide timely observations and good statistical information on coastal zone conditions and processes. For this reason we worked with the Arctic Project Office on a plan which would utilize a Naval Arctic Research Laboratory (NARL) C-117 aircraft, remote-sensing equipment available from several sources, and local processing of the data to provide more frequent and more relevant data on a consistent format.

OCSEAP agreed with this plan and contracted with NARL for the airborne data acquisition program and with our project (RU 267) for the processing of the data. The Cold Regions Research Laboratories (CRREL) provided a Motorola side-looking radar and a laser profilometer, as well as a qualified engineer, to NARL, and we located and secured four aerial cameras for installation in the aircraft which was subsequently modified and committed to a remote-sensing program by NARL. Our project also acquired wide-film processing and printing equipment and constructed a photographic laboratory for processing of the data acquired by the NARL aircraft. Unfortunately, the NARL data acquisition program failed after acquiring very little SLAR data, and it was terminated by OCSEAP in the spring of 1978.

The most recent attempt to acquire SLAR data on regular basis is based on a contract, through CRREL, to the local (Ft. Wainwright) Army Mohawk squadron which obtained well-equipped, new model, remote-sensing Mohawk aircraft in early 1978. A trial mission was flown at our request in September 1978 as a training army mission. The resultant SLAR data of the Beaufort Sea coast proved to be of sufficiently good quality that formal arrangements were made for identical flight lines to be flown on a monthly basis during winter 1978/79. Good quality SLAR data have been received for December 1978, January, February and March 1979, and February 1980. They provide for the first time excellent coverage of Beaufort sea-ice morphology and dynamics during the important mid-winter period when other remote-sensing data are not available owing to the absence of daylight.

2. Individual Assistance

Individual assistance to OCS investigators involves consultations on the applicability of remote-sensing data to specific studies, data selection and ordering, preparation and supervision of work orders for custom photographic products and data processing, training in the use of remote-sensing data processing equipment and techniques, development of data analysis plans and sometimes participation in or performance of data analysis and interpretation.

This individual assistance has stabilized over the past year as requests become more site specific and detailed in nature. 36 OCS investigators utilized our facilities during the past year, most of them for several hours, and some of them repeatedly. In addition, numerous contacts occurred by mail or telephone correspondence. Therefore, it is not possible to describe in detail these individual activities but their scope is illustrated by listing the user projects: RU's numbers 562, 526, 265, 205, 530, 460, 250, 88, 537, 230, 196, 289, 529, 87, 248, 519, 253. Of these about twelve are using remote sensing data routinely and seven of them (RU no. 205, 530, 250, 88, 289, 519, and 265) almost exclusively. The principal applications are sea-ice morphology and dynamics, coastal geomorphology and geologic hazards, sea-surface circulation and sedimentation, sea-mammals habitat and herd habitat mapping. A partial list of users and their needs is included as Appendix A of this report.

VI - RESULTS

The results of the project so far can be separated into two categories: the operational results (establishment of a remote-sensing data facility) and the research results (disciplinary applications of remote-sensing data to OCS studies).

A. <u>Establishment of a Remote-sensing Facility for OCS Studies</u>

The principal result of the project, as specified in the work statement of the contract, is that there now exists at the University of Alaska an operational facility for applications of remote-sensing data to OCS studies. This facility and its functions have been described in detail in the previous section of the report. Briefly it consists of:

1) A remote-sensing data library which routinely acquires catalogs and disseminates information on Landsat and NOAA satellite imagery and aircraft imagery of the Alaskan continental shelf.

2) A remote-sensing data processing laboratory which provides specialized instrumentation for the photographic reproduction and optical or digital analysis of remote-sensing data of various types and formats.

3) A team of specialists that generates and develops techniques of remote-sensing data analysis and interpretation which appear to be particularly well-suited for OCS studies.

4) A staff that is continually available to OCS investigators for consultation and assistance in searching for, processing and interpreting remote-sensing data for their disciplinary investigations.

As a result of the establishment of the remote-sensing facility established by our project, about fourteen OCS projects are routinely using remote-sensing data, seven of them almost exclusively, and many more OCS investigators are occasional users of remote-sensing data.

B. Disciplinary Results of the Applications of Remote-Sensing Data to OCS Studies

In general, the results of applications of remote-sensing data to OCS studies will be contained in the annual reports of the individual projects and need not be repeated here. However as part of our function to develop techniques of remote-sensing data analysis and interpretation, we did prepare a scientific report entitled "Environmental Assessment of Resource Development in the Alaskan Coastal Zone based on Landsat Imagery" which illustrates the applications of Landsat data to three important aspects of the OCSEAP program: studies of sea-surface circulation and sediment transport in Alaskan coastal waters, studies of sea-ice morphology and dynamics in the near-shore Beaufort Sea, and mapping of terrestrial ecosystems in the Alaskan coastal zone. This report was presented at the NASA Earth Resources Symposium, Houston, Texas, June 1975 where it was acclaimed as one of the best presentations. It was also distributed to OCS investigators as part of Arctic Project Bulletin No. 7 and is now out of print due to heavy demand in spite of the fact that 250 copies were made.

A report produced by RU's 267 and 258, was released in September 1978 by the OCSEAP Arctic Project Office. The report incorporates part of the RU 267 annual report for 1977 and an article by RU's 267 and 258 in Arctic Project Bulletin No. 20 to illustrate, by means of historical Landsat imagery and sea ice morphology maps, the seasonal sequence of sea ice and sea-surface conditions from fall freeze-up to summer breakup in the 1979 Beaufort lease sale area.

C. Results of Cooperative Investigations

1. Beaufort Coast Sediment Transport

Landsat scenes of the Beaufort Sea coastal area have long been known to show great amounts of sediment transport. Naidu (RU 529) has pointed out that summertime Landsat scenes show mid-summer coastal suspended sediment arises from wave action on exposed headlands and shoals. Previously it was thought that coastal rivers were the sources of suspended material during this time as well as in spring when they are known to provide transport for great amounts of material. In fact, summertime scenes showed plumes of relatively clear water eminating from the mouths of coastal rivers into turbid coastal waters.

The Landsat data alone is only qualitative--showing sources and transport vectors of turbid water. During this past year a joint effort was initiated between this research unit and RU 529 to quantify the levels of suspended sediment observed on the Landsat scenes. This effort had two aspects: first, this research unit investigated methods of assigning quantitative grey level values to the observed sediment plumes, and second, RU 529 prepared to obtain sediment samples simultaneously with satellite overpasses.

The first effort was carried out with some degree of success. In order to assess the technique deemed most likely to produce useful results, Landsat scene 2915-20483 was digitally processed by means of an IDIMS image interpretation system. Figure C.1 shows the portion of this scene containing Prudhoe Bay. On this figure, continuous grey levels appearing on the Landsat image have been dividied into discrete step density levels. This process clearly delineates the patterns of suspended sediment density and would allow quantitative assessments of volumes to be made when on-site measurements are available.

In addition to aiding quantitative analyses, this process shows more clearly the sources and distribution patterns of

FIGURE C.1. Processed Landsat image showing sediment transport in near shore Beaufort Sea areas.

This figure was not included in this report as its quality was not suitable for reproduction.

suspended sediment than an unprocessed Landsat image. For instance, on figure C.1 suspended sediment can clearly be seen to arise from the Sagavanirktok River prodelta and not from the river channels. Further, the sediment plume can be seen traveling to the west in response to wind-driven currents. Another source of suspended sediment can be seen on the exposed, western side of Prudhoe Bay and continuing even beyond to the eastern side of the ARCO west dock. Another interesting feature is the zone of relatively unturbid water on the lee side of the west dock.

The second phase of this joint effort was to collect sediment samples in the study area simultaneously with Landsat imagery in the study area during the summer of 1979. Unfortunately, clouds prevented the acquisition of the required imagery. Hopefully this effort will be more successful during summer, 1980.

2. Sea Ice Mapping Activities

This research unit has taken over the files and some follow-up activities of RU 258 (Near Shore Ice Morphology). These activities have included:

a) Coordinating preparation of the section of the Bering Sea Synthesis effort dealing with sea ice. Because our remote sensing activities have played such a large part in Bering Sea ice studies, we have performed the role of coordinating this effort. In addition, we have prepared two chapters for this section, one dealing with Bering Sea near shore ice conditions, and the other describing Bering Sea near shore ice hazards and pollutant transport problems arising from these near shore ice conditions.

b) Coordinating preparation of materials to be used by RU 516 (Vigdorchik) in preparing computer-generated ice maps of the Beaufort Coastal areas. RU 516 is using computer mapping techniques to compile site-specific information concerning hazardous conditions in the Beaufort Lease Sale areas arising from a wide variety of causes. One of the chief sources of hazards arises from sea ice activity. This research unit has supplied RU 516 with maps derived from Landsat images at 1:500,000 scale showing the locations of leads, fast ice, ridges and polynyes. The results of this work have been reported in the current annual report of RU 516.

3. Training Activities

This research unit participated in a week-long training program on remote sensing conducted for Outer Continental Shelf resource managers held in Corpus Christi, Texas during February, 1980. Course attendees included representatives from nationwide BLM OCS offices including several representatives from the Alaskan office. The course material included the physical and historical basis for remote sensing, sensors and systems, films and related passband filters, image interpretation principles, ground data calibration and digital image interpretation techniques.

This research unit presented two lectures: one on the use of remote sensing techniques to study Beaufort Coastal sea ice, river over ice flooding, and turbidity mapping, and the other describing environmental geologic mapping, and landcover mapping on the Seward Peninsula.

VII & VIII - DISCUSSION AND CONCLUSIONS

The principal objective of the contract, as specified in its work statement, has been achieved: a facility for applications of remote-sensing data to outer continental shelf studies has been established at the University of Alaska and is now fully operational.

The remote-sensing data library has acquired all available cloud-free remote-sensing imagery of the Alaskan continental shelf, catalogued it and provided information on its availability to all OCS investigators through the series of Arctic Project Bulletins.

Existing instrumentation for analyzing remote-sensing data has been consolidated into a data processing laboratory and techniques for its use have been developed with particular emphasis on the needs of the OCSEAP program. New instrumentation is being acquired and new analytical techniques are continually being developed from this contract and other funding sources.

The staff of the project is interacting with a number of OCS investigators, providing consultation and assistance in all aspects of remote-sensing applications from data searches and ordering to advanced analyses of the data in photographic and digital format. We have also worked very closely with the OCSEAP Arctic Project Office in designing an interim remote-sensing data acquisition program using contract and aircraft missions by other agencies.

At this time about fourteen OCS projects are using remote-sensing data and processing facilities routinely, some of them almost exclusively of other research activities, and many more OCS investigators are occasional users of remote-sensing data. As the focus of OCSEAP changes from synoptic studies to the leasing process, requests have become more detailed and site specific. Studies of processes and potential impacts on individual areas rely heavily on historical remote sensing data and detailed interpretations on a case by case basis. It is important to collect and archive available coverage as well as assist in the acquisition of more detailed imagery of key areas.

It is clear from the foregoing discussions and from consultations with OCS investigators, regarding their study plans for the next year, that there will be a continuing need for the research support that our project provides. We intend to submit a continuation proposal to NOAA for this purpose.

IX - SUMMARY OF FOURTH QUARTER OPERATIONS

This quaterly report covers the period January 1 to March 31, 1980.

A. Laboratory Activities During the Reporting Period

1. Operation of the Remote-Sensing Data Library

We continue to search continuously for new Landsat imagery of the Alaskan coastal zone entered into the EROS Data Center (EDC) data base. During this reporting period 84 new scenes have been received at a total cost of $1,322.

We continued to receive three daily scenes from NOAA satellite for a total of 328 scenes at a cost of $2,801. Again, owing to the low solar illumination during January and February, images in the visible spectral band were not acquired by the satellite for the first six weeks, but the thermal IR images which depend on emitted, rather than reflected radiation, were received throughout the reporting period.

Under a State-funded project we are receiving Air Force weather satellite imagery (DMSP) on a fairly regular basis. During this reporting period 48 scenes were received in a variety of data products.

Side-looking Airborne Radar (SLAR) imagery of the Beaufort coastline from Oliktok to Prudhoe Bay was obtained February 13 and of the Bering Sea, Bering Straits area on February 20, 1980. Copies are available in our files.

2. Consultation and Assistance to OCS Investigators

Seven OCS investigators requested our assistance in searching for, obtaining or analyzing remote-sensing data. Some visitors to our facility are not formal OCSEAP investigators but their activities are OCSEAP-related and they are mentioned here. Users (OCS and non-OCS) this quarter included:

Stu Rawlinson (RU 530 Cannon) placed a large order for historical aerial photography of the Cap Halkett, Harrison Bay area.

Erk Reimnitz, RU 205, asked for a search for Landsat data from 1978 and 1979 which covered the Stamukhi Shoal. He also was interested in any DMSP or NOAA imagery which showed water overflows after freeze-up on the Colville River. Two images were chosen to send to him along with several Landsat images.

Don Schell, RU 537, ordered copies of 1979 high altitude aerial photographs of the Colville River delta.

Curt Wallace (RU 250, Shapiro) has worked many hours looking through NOAA transparencies of ice features in the Bering and Chukchi Seas.

Brendan Kelly (RU 248, Fay) looked through the latest NOAA and Landsat images of the Bering Sea.

Thomas Kozo, RU 519, requested a search for historical Landsat and NOAA imagery of the Beaufort Sea from early spring through late fall of 1979. A search was made and imagery was ordered for him. After receipt of the data he called again to request daily coverage for two periods when unusual ice movement seemed to occur.

Mitchell Taylor, University of Minnesota, has been involved in a project monitoring polar bears in the Beaufort and Chukchi Seas using radio collars to help identify their denning areas and movements through the winter months. The concern is that off-shore drilling in certain areas may interfere with their natural habitat and prevent denning. He is currently stationed at Barrow and has made arrangements to have NOAA imagery sent to him on a weekly basis until May 31. We are also furnishing imagery to Fred Sorensen, U.S.F.&W.S. in Anchorage for this same project.

Dick Sellers, Alaska Dept. of Fish and Game, asked for a search for the oldest possible aerial photographs of Susitna flatas and Redoubt Bay. A search was made and an order placed for him.

Edward Earle, Shell Development Co., ordered imagery of the Cross Island area.

Dirk Derksen, U.S. Fish & Wildlife Service, queried for the latest imagery of Cape Halkett area.

Robert Lewellen, Lewellen Arctic Research, Colorado, ordered copies of SLAR imagery for Cross-Narwhal Island.

Thomas Rothe, U. S. Fish & Wildlife Service, ordered aerial photography of various gravel sites along the Beaufort Coast.

Terry Ralston, EXXON Production Research Co., Houston, browsed through our files and ordered several Landsat images and aerial photographs.

Dennis Ward, Department of Environmental Conservation, used National Ocean Survey photography to select possible locations for a new dumpt site for Barrow.

Dave Norton, OCSEAP Arctic Project Office, borrowed sequential Landsat images which showed early spring along the Colville River.

Bill Dehn, Sea Ice Consultants, asked for a search for all imagery showing ice features in the six lease areas in the Chukchi and Bering Seas. A detailed search for imagery was made for him and he responded with a very large purchase order to cover the cost of acquiring the imagery for his files.

B. Estimates of Funds Expended

$191,400

APPENDIX A

FIRST TO THIRD QUARTER USER ACTIVITY

APPENDIX A

FIRST TO THIRD QUARTER USER ACTIVITY

In addition to those users mentioned in our summary of fourth quarter operations, the following persons utilized our facilities during the previous nine months of the 1979-80 reporting period, either as OCSEAP investigators or in OCSEAP-related activities:

Jan Cannon, RU 530, continues to keep watch for current Landsat imagery by browsing through our files and utilizing our catalog. He also looked through all 1979 aerial photography and SLAR of the Beaufort Sea area.

Peter Barnes, RU 205, looked through all of the Summer 1979 aerial photography obtained of the barrier islands in the Beaufort Sea and ordered copies of many frames. He also requested that we ask NASA to obtain repeat coverage next summer of Cross and Narwhal Island to monitor changes that may have occurred as a result of a major storm in October 1979. This request has been made but at this time it does not look favorable as far as NASA obtaining it and we are looking into other possible sources.

Alan Springer, RU 460, searched for a variety of dates of NOAA imagery and had copies of it made in our photo department.

Lew Shapiro, RU 250, checked out a frame of aerial photography and had a slide made for use in a presentation he was making.

Juergen Kienle, RU 251, ordered several Landsat images of the Alaska Peninsula area.

Austin Kovacs, RU 88, looked at 1979 aerial photographs of the barrier islands along the Beaufort Sea coast and ordered copies of several frames.

Don Schell, RU 537, borrowed a Landsat image from our files to use at a conference he attended in Canada. He also ordered it for his own use and looked at and ordered several aerial photographs of the Colville River delta.

Glenn Seaman (RU 230, Burns) asked for the most recent coverage of Kotzebue Sound to determine ice conditions before leaving for field work there. We were able to supply him with DMSP for the previous day. He also studied historical data to correlate ice conditions and the bowhead whales' arrival in Kotzebue Sound.

Curt Wallace (RU 248, Shapiro) reviewed all of the historical NOAA data to complete records he has made for Shapiro's project.

Austin Kovacs, RU 88, looked through SLAR imagery obtained in April 1980 and received a set of the imagery for his use.

Dr. Naidu, RU 529, ordered imagery of the Oliktok area and also asked for the dates on which Landsat II and III would be covering that area in summer 1979. A schedule or orbit dates was given to him.

Frank Fay, RU 248, asked for DMSP imagery or NOAA imagery for use as a navigational aid in the Bering Sea. Imagery acquired on the day of departure was copied and given to him.

Erk Reimnitz, RU 205, ordered SLAR imagery of the Beaufort Sea to observe ice conditions prior to and after a severe storm which occurred in March. He also asked that in the future we extend the SLAR coverage to better cover his area of interest. We passed this request along to the flight coordinator and will remind him of it when the next season approaches.

Seelye Martin, RU 87, asked for Landsat imagery to support his work during the 1978 and 1979 seasons for the Bering and Chukchi Seas. Imagery for the 1978 season has been ordered for him and as soon as the 1979 imagery becomes available it will be ordered.

Alan Springer, RU 460, inquired about the feasibility of determining the seasonal variation of sea-surface temperature in the near-shore Chukchi Sea over the last five years from satellite imagery. He suspects that a recent change in sea-surface temperature has affected migratory bird populations in that area.

John Burns, RU 230, ordered several Landsat images to use in his OCSEAP report.

Kristina Ahlnas, RU 289, Royer) continued to check through NOAA and DMSP imagery on a weekly basis.

Dr. Naidu, RU 529, asked for a search for imagery of his area of interest for dates which would coincide with his field measurements. He also obtained imagery to use on a poster display at the 30th AAAS Conference.

Seeley Martin, RU 87, asked for a search for historical and current data on given dates in the Bering Sea. A search was made and some NOAA and Landsat imagery were sent to him.

Teri McClung (RU 248, Shapiro) spent several days using the color additive viewer, color filters and film chips of radar imagery to enhance the movement of ice floes off the Barrow coast.

Glenn Seaman (RU 230, Burns) browsed through DMSP and NOAA data of the Point Lay area before leaving for field work in that area.

George Divoky, RU 196, browsed through the latest imagery available and ordered several images. He habitually stops at the remote-sensing library when passing through Fairbanks to keep up-to-date on current imagery.

Fred Sorensen, U.S.F. & W.S. asked us to again watch for good NOAA imagery of the Beaufort Sea area and send him one print per week. This is to aid in the study of polar bear migration and denning habits he is conducting.

Dan Foley, Shell Oil Company, Houston, asked for a search of Landsat imagery for a broad area in the Chukchi Sea. A listing was made and sent to him and he is selecting those scenes he wishes to order.

Doug Woodley, University of Washington, Institute of Environmental Studies, asked about the availability of satellite imagery along the Arctic coast during a four-month period in 1976 to compare with OCSEAP data he has obtained. A listing of available imagery was sent to him along with ordering information. He responded with a letter stating his intent to visit our facility on his next trip to Fairbanks and make his selection of imagery at that time.

Dave Agerton, Shell Development Company, Houston, ordered several years' imagery which showed open leads in the ice structure of the December 1979 lease sale area in the Beaufort Sea. Earlier he had ordered SLAR and other imagery of the lease area.

Ron Reimer, FLOW Industries, Seattle, called and asked for DMSP imagery of the Bering Straits to Barrow area for several days in early April when rapid ice movement was occurring. Copies of the imagery were made and sent to him.

Mike Pollen, Environmental Services Ltd., studied U-2 photographs of Prudhoe Bay to pinpoint sewage lagoons as part of an EPA study he is involved with. This aerial photography was available to him because of the OCSEA Program.

Todd Butler, Mobil E & P Services, ordered all available SLAR imagery of the Beaufort lease area.

Gil Springer, BLM/Alaska OCS Office in Anchorage, ordered aerial photos of the Reindeer Islands to Dinkum Sands in the Beaufort Sea. After receiving the first set of photographs he reordered five additional sets for use in reports and for distribution.

John Carnahan, a private consultant from Anchorage, is conducting a study of historical sites in the Beaufort Sea island groups for the North Slope Borough and asked for assistance in ordering imagery. Aerial photographs of Cross, Tigvariak and Flaxman Islands were ordered and sent to him.

Bill Dehn, Sea Ice Consultants, asked for an estimate of Landsat imagery available for the Beaufort Lease area for 1975 to present. An estimate was given and he responded with a purchase order.

Bruce Webster, ice forecaster for the National Weather Service, borrrowed a few frames of NOAA imagery for reproduction purposes.

Joe Miller and Bob Britch, Northern Technical Services in Anchorage, asked for all available Landsat imagery showing break-up and freeze-up conditions at Prudhoe Bay. After learning of the availability of DMSP imagery they asked for copies of it on a weekly basis retroactive to April 1. We will also order all Landsat imagery from April to June as it becomes available in the data base.

Brad Halter, GMCC-NOAA, has a project involving CO_2 in sea ice and visited the library to see what data are available which might be useful for this project.

Allen Tolcotte, DNR, Division of Technical Services, ordered copies of the latest Landsat imagery and aerial photography available for the Prudhoe Bay area.

Arne Hanson, NARL, spent considerable time during this reporting period looking through DMSP and NOAA imagery of ice in the Beaufort Sea and ordered a large number of prints which were made for him in our photo lab.

Jay Brueggeman, PMEL, Seattle, called and asked for climatological data for Barrow and Barter Island from 1973 to the present. Copies of these data were sent him.

Robert Lewellen, Lewellen Arctic Research, looked through available SLAR imagery of the Beaufort Sea and ordered copies of 1978 and 1979 data.

Carlton Ray, John Hopkins University, queried as to the availability of an accurate overlay giving geographic coordinates for NOAA Tiros N imagery.

Richard Neve, UA/Institute of Marine Science, looked at Landsat and NOAA imagery to study the pack ice in Cook Inlet and ordered copies of the imagery.

Allen Milne, Naval Postgraduate School, Monterey, asked for a search for good NOAA imagery of the Amundsen Gulf-Beaufort Sea area from 1974 to the present. A search was made and a large order for imagery was placed. Additionally, we will order copies of clear imagery as it becomes available.

Jim Riehle, D.G.D.S. Anchorage, queried for aerial photography of Dinkum Sands. High altitude aerial photographs were obtained July 15, 1979 over this area and copies of the imagery were ordered by him.

ANNUAL REPORT

Contract 03-5-022-56
Research Unit #350
Reporting Period 4/1/79-3/31/80
Number of Pages 37

ALASKA OCS PROGRAM COORDINATION

Donald H. Rosenberg
OCS Coordination Office
University of Alaska

March 31, 1980

I. Summary of Objectives

This project provides for coordination of all NOAA/OCS Task Orders within the University of Alaska. It provides for a coordination and related support staff and services necessary to conduct the scientific program of OCS. This is accomplished by being a focal point for all contract, data management, and logistics coordination.

II. Introduction

Not applicable

III. Current State of Knowledge

Not applicable

IV. Study Area

Not applicable

V. Sources, Methods, Rationale of Data Collection

Not applicable

VI. Results

A. Scientific and Contract Monitoring

During the reporting period this office has exercised monitoring authority over the Task Orders listed in Table 1. As noted on this table, certain tasks have been completed during the reporting period and final reports have been submitted.

The monitoring effort of this office is limited to the following: the evaluation of the scientific effort relative to the work statements to insure contractual compliance, the coordination of proposal submission, logistic requirements, and data submission. In the last case, Data Management Plans are formulated and submitted through this office, as are the resulting Data Submission Schedules and formatted, taped data. All reports are also submitted through this office.

In the past year, the proposals tabulated in Table II were submitted to NOAA for OCS work.

Contact with the Juneau, Arctic Project and Boulder OCS offices was maintained to insure that progress in the scientific programs pursued by University of Alaska principal investigators is consistent with NOAA/OCS program needs and that any problems that arise are solved in a timely manner.

The staff of this office and their duties relative to OCS are outlined in Table III.

B. Data Management

Data Management Plans were formulated and kept up-to-date by this office as needed.

Formats for submitting data on magnetic tape have been received for all data which will be so submitted.

C. Data Submissions

During the past year contract 03-5-022-56 investigators have submitted through this office batches of data which were checked for format, entered onto the computer, transferred to tape and submitted to NOAA/OCS. See Table IV for a listing of these data submissions.

D. Travel Coordination

Funds were provided through this Task Order to allow for travel of management, staff and principal investigators under this contract to meetings requested by NOAA/OCS. These funds were used to attend synthesis and coordination meetings as well as meetings requested by the Project Offices between principal investigators and their Trackers. This is summarized on Table V.

E. Logistics Coordination

Coordination of logistics requirements in the pursuit of tasks assigned to this contract was carried out through this office in the past year. We attempt to act as a pipeline for changes requested in project instructions as well as in the submission of Chief Scientists Reports and ROSCOP II forms where appropriate.

VII. Discussion

Not applicable

VIII. Conclusions

Not applicable

IX. Needs for Further Study

Not applicable

X. Summary of Fourth Quarter Operations

A. Ship or Laboratory Activities

Not applicable

B. Results

See results section above and Tables

C. Problems Encountered

There have been some major problems with time delays both in getting proposals funded with new monies, and in getting approval for transferring to new categories money already in the University.

We are glad to have come to an agreement concerning the voucher specimen policy. However, there was more than a two month time lag before fund transfer approval left the Juneau Project Office. This was disturbing, since there was an urgency to get started on these voucher specimen projects before key personnel, who were originally involved in the research, moved on.

In addition, we have often received word in conversation that proposal funding approval would imminently leave the Juneau Project Office, only to have this verbal approval rescinded later. Such inability to predict time lapses before receiving contract modifications for funding may cause us to stop all work on a given research project in the future, while the Principal Investigator waits for new monies.

Table I

University of Alaska OCS Projects

Contract 03-5-022-56

Task Order	R.U.#	Project Title	Principal Investigator
1*	427	Bering Sea Ice-Edge Ecosystem Studies	Vera Alexander R. T. Cooney
2	350	Alaskan OCS Program Coordination	Donald H. Rosenberg
5	275	Hydrocarbons: Natural Distribution and Dynamics on the Alaskan Outer Continental Shelf	David G. Shaw
7	278	Microbial Release of Soluble Trace Metals from Oil-Impacted Sediments	Robert J. Barsdate
8	194	Morbidity and Mortality of Marine Mammals	Francis H. Fay
12	162	Natural Distribution of Trace Heavy Metals and Environmental Background in Three Alaskan Shelf Areas	David C. Burrell
15	5	The Distribution, Abundance, Diversity and Productivity of Benthic Organisms in the Bering Sea	Howard M. Feder
19	289	Mesoscale Currents and Water Masses in the Gulf of Alaska	Thomas C. Royer
23	351	Logistics & R/V Acona	Dolly Dieter
24	370	Administrative Support NODC/EDS	Linda Dwight
32	537	Nutrient Dynamics and Primary Production in Alaska Beaufort Sea Coastal Waters	D. M. Schell
33	529	Sediment Characteristics, Stability, and Origin of the Barrier Island-Lagoon Complex, North Arctic Alaska	A. S. Naidu
34	530	The Environmental Geology and Geomorphology of the Barrier Island-Lagoon System Along the Beaufort Sea Coastal Plain from Prudhoe Bay to the Colville River	P. Jan Cannon

* Final reports for these projects have been submitted and the Task Order work completed.

TABLE II

Proposals Submitted to NOAA/OCS for Contract 03-5-022-56
4/1/79 - 3/31/80

Submission Date	Proposal No.	Title	Principal Investigator	Cost Proposal
6/18/79	80-1	Alaska OCS Program Coordination	Rosenberg	$38,087[1]
9/6/79	80-1	Amendment 1	Rosenberg	7,690
9/24/79	80-1	Amendment 2	Rosenberg	13,880[1]
7/27/79	80-2	Species Accounts: Red and Northern Phalaropes RU# 441	Schamel, Tracy	13,658
7/27/79	80-3	Environmental Geology and Geomorphology of the Barrier Island-Lagoon System Along the Beaufort Sea Coastal Plain	Cannon	25,287[1]
7/27/79	80-4	Sources, Transport Pathways, Depositional Sites and Dynamics of Sediments in the Lagoon and Adjacent Shallow Marine Region, Northern Arctic Alaska	Naidu	70,255[1]
10/2/79	80-4	Amendment	Naidu	8,240[1]
7/27/79	80-5	Nutrient Dynamics and Trophic System Energetics in Nearshore Beaufort Sea Waters	Schell	98,264[1]
10/4/79	80-6	Distribution, Abundance, Community Structure, and Trophic Relationships of the Benthos of the Northeastern Gulf of Alaska from Yakutat Bay to Cross Sound	Feder	122,714[2]
8/17/79	80-7	Circulation and Water Masses in the Gulf of Alaska	Royer	168,040

TABLE II (continued)

Submission Date	Proposal No.	Title	Principal Investigator	Cost Proposal
1/3/80	80-7	Revision	Royer	$ 60,836
8/17/79	80-8	Voucher Specimens for Bering Sea Phytoplankton	Alexander	5,095
8/24/79	80-9	Distribution, Abundance, Community Structure and Trophic Relationships of the Nearshore Benthos of the Kodiak Shelf and NEGOA	Feder	24,141
9/6/79	80-10	Morbidity and Mortality of Marine Mammals	Fay	72,133[3]
9/11/79	80-11	Administrative and Technical Support for the OCSEAP Data Processing Center and the NODC/OSCEAP Representative	Hickok	34,481
	80-11	The Anchorage OCSEAP Data Processing Center	Dwight	163,322[4]
11/21/79	80-12	Distribution, Abundance, and Community Structure of the Infaunal Benthos from the Northeastern Bering Sea and the Chukchi Sea	Feder	25,000[1]
11/28/79	80-13	(replacement for 80-9)	Feder	11,202
11/14/79	80-14	Carbon Isotope Studies in Chukchi Sea Waters	Schell	7,502[1]
12/3/79	80-15	Observation of Marine Mammals and Birds During Winter Icebreaker Cruise, Northern Bering and Chukchi Seas	Fay	22,973[1]
1/21/80	80-16	Voucher Specimens for Benthos (R.U. #s 5,281, 502, 517)	Feder	29,281
1/21/80	80-17	Voucher Specimens for Zooplankton (R.U. #s 426, 427)	Cooney	15,549

TABLE II (continued)

Submission Date	Proposal No.	Title	Principal Investigator	Cost Proposal
2/8/80	80-18	Coastal Oceanography of Northeastern Gulf of Alaska	Royer, Colonell	153,638

[1]Fully funded

[2]$45,000 funded

[3]$59,087 funded

[4]$165,424 funded

TABLE III

University of Alaska OCS Project

Management Staff

Position	Percent Effort	Name
Coordinator[1]	0%	Donald H. Rosenberg
Data Manager[1]	33%	Raymond S. Hadley
Data Manager[1]	100%	Sue Keller
Typist[2]	Approximately 10%	Carol Brown

Note: 1 Funded directly from project

2 Funded from overhead

TABLE IV

Submitted Data Batches

File I.D.	File Type	Cruise/Field Operation	Submission Date
Task Order 5			
LCI7-8	044	Lower Cook Inlet 05/04/77-11/16/77	08/13/79
DSHW01	044	Discoverer 05/02/78-05/02/78	
SURV	044	Surveyor 05/04/78-05/17/78	08/13/79
Task Order 15			
FED01	032	Surveyor 11/05/77-11/16/77	07/02/79
FED02	032	Surveyor 03/27/78-04/01/78	07/02/79
FED03	032	Miller Freeman 05/10/78-05/16/78	07/02/79
FED04	032	Miller Freeman 06/07/78-06/14/78	07/02/79
FED05	032	Miller Freeman 07/13/78-07/22/78	07/02/79
FED06	032	Miller Freeman 08/13/78-08/20/78	07/02/79
MIL01	032	Miller Freeman 03/22/78-03/24/78	07/02/79
MIL02	032	Miller Freeman 06/22/78-07/09/78	07/02/79
IZ478	032	Commando/Yankee Clipper 04/11/78-04/15/78	07/02/79
IZ578	032	Commando/Yankee Clipper 05/11/78-05/14/78	07/02/79
IZ678	032	Commando/Yankee Clipper 06/09/78-06/13/78	07/02/79

File I.D.	File Type	Cruise/Field Operation	Submission Date
IZ778	032	Commando/Yankee Clipper 07/09/78-07/13/78	07/02/79
IZ878	032	Commando/Yankee Clipper 08/09/78-08/12/78	07/02/79
IZ1178	032	Commando/Yankee Clipper 11/14/78-11/16/78	07/02/79
KL478	032	Commando/Yankee Clipper 04/19/78-04/21/78	07/02/79
KL678	032	Commando/Yankee Clipper 06/18/78-06/23/78	07/02/79
KL778	032	Commando/Yankee Clipper 07/18/78-07/21/78	07/02/79
KL878	032	Commando/Yankee Clipper 08/19/78-08/22/78	07/02/79
KL1178	032	Commando/Yankee Clipper 11/14/78-11/16/78	07/02/79
Task Order 19			
266IMS	022	Acona 09/17/78-09/30/78	05/02/79
264IMS	022	Acona 07/31/78-08/12/78	05/02/79
274IMS	022	Acona 04/03/79-04/09/79	05/16/79
271IMS	022	Acona 02/01/79-02/17/79	05/16/79
CM0042	015	Montague Strait 04/24/78-09/21/78	06/05/79
CM0043	015	Montague Strait 04/24/78-09/21/78	06/05/79
SU8IMS	022	Surveyor 02/09/79-02/21/79	07/02/79

File I.D.	File Type	Cruise/Field Operation	Submission Date
277IMS	022	Acona 05/11/79-05/17/79	07/02/79
282IMS	022	Acona 07/24/79-07/28/79	12/04/79
Task Order 32			
DUMB01	029	Dease 03/30/77-03/31/77	07/02/79
DUMB02	029	Elson Lagoon 05/23/77-05/23/77	07/02/79
DUMB03	029	Simpson Lagoon 04/04/78-07/29/78	07/02/79
Task Order 33			
GLA77N	073	Glacier 08/21/77-09/03/77	08/13/79
GLA77	061	Glacier 08/21/77-09/03/77	03/24/80
SL877S	061	Simpson Lagoon 08/03/77-08/14/77	03/24/80
UGNURA	061	Ugnuravik River 08/07/77	03/24/80

TABLE V

OCS Travel from Fairbanks, Alaska April 1, 1979-March 31, 1980

Person Traveling	Destination	Reason for Travel	Dates	Cost
P.J. Cannon	Seattle, WA	OCS Workshop	04/22-04/25/79	$294.86
H. Feder	Kodiak, AK Anchorage, AK	OCS Kodiak Synthesis Meeting EPA Project Conference	05/14-05/20/79	405.86
S. Jewett	Kodiak, AK	OCS Kodiak Synthesis Meeting	05/07-05/16/79	158.48
H. Pulpan	Kodiak, AK	OCS Kodiak Synthesis Meeting	05/14-05/17/79	328.64
R. Hadley	Seward, AK	OCS Voucher Specimen Policy Consultation	08/30/79	210.65
H. Stockholm	Juneau, AK	OCS Synthesis Reports Consultation	09/27-09/28/79	368.00
T. Royer	Seattle, WA	OCS Kodiak Synthesis Meeting	10/02-10/05/79	476.01
D. Burrell	Anchorage, AK	Bering Sea Symposium	01/15-01/16/80	218.20
T. Royer	Anchorage, AK	Lease Sale 55 Consultation with BLM and NOAA on DEIS. OCS Briefing	12/06/79	152.00
S. Keller	Juneau, AK	OCSEAP Meeting	01/08-01/10/80	429.00
R. Hadley	Juneau, AK	OCSEAP Meeting	01/08-01/11/80	492.00
T. Royer	Winthrop, WA	OCS NWGOA Physical Oceanography Synthesis Meeting	02/03-02/07/80	642.00

Summary of 4th Quarter Operations

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 2

PRINCIPAL INVESTIGATOR: Mr. Donald H. Rosenberg

No environmental data are to be taken by this task order as indicated in the Data Management Plan. A schedule of submission is therefore not applicable.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 5 R.U. NUMBER: 275

PRINCIPAL INVESTIGATOR: Dr. D. G. Shaw

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches refer to data as identified in the data management plan.

Cruise/Field Operation	Collection Dates		Estimated Submission Dates			
	From	To	Batch 1	2	3	
Discoverer	8/29	9/2/78	7/31/80	7/31/80		
Alumiak	8/3	9/2/78	7/31/80			

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 8 R.U. NUMBER: 194

PRINCIPAL INVESTIGATOR: Dr. F. H. Fay

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches refer to data as identified in the data management plan.

Cruise/Field Operation	Collection Dates		Estimated Submission Dates			
	From	To	Batch 1			
Data as yet to be submitted:						
Surveyor	4/9	5/4/79				Histological Data*
St. Lawrence	6/17	7/4/79	8/31/80			
Round Island (Bristol Bay)	8/17	9/2/79	8/31/80			

* Specimen data will be reported separately in tabular format.

Data Batch 1 = Stranding information.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 12 R.U. NUMBER: 162

PRINCIPAL INVESTIGATOR: Dr. D. C. Burrell

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches are identified as foot notes.

Cruise/Field Operation	Collection Dates		Estimated Submission Dates		
	From	To	Batch 1	2	3
Shore	5/4	5/17/77		Submitted	Submitted
Acona	6/21	6/26/77		Submitted	Submitted
Discoverer	5/25	6/ 5/77			Submitted
Acona 246	7/25	7/30/77	Submitted		
Volna	7/77	8/77	Submitted		
Surveyor	3/15	5/2/77			Submitted
Surveyor	11/3	11/17/77		Submitted	Submitted
Acona 254	11/20	12/ 4/77		Submitted	
Surveyor	3/27	3/31/78			Submitted
Acona 260	4/22	4/26/78		Submitted	
Discoverer	5/4	5/17/78	Submitted	Submitted	
Northwind		8/18/78	Submitted		
Acona 267	10/10/78	10/19/78		Submitted	

Data Batch 1 = Trace elements in water column.
2 = Trace elements in sediment or sediment extracts.
3 = Trace elements in biota.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 15 R.U. NUMBER: 5

PRINCIPAL INVESTIGATOR: Dr. H. M. Feder

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches refer to data as identified in the data management plan.

Cruise/Field Operation	Collection Dates		Estimated Submission Dates			
	From	To	Batch 1 032	2 032	3 032	4 123
LCI						
Surveyor	11/04	11/16/77		Submitted		08/31/80
Surveyor	03/27	04/02/78		Submitted		08/31/80
Surveyor	08/13	08/22/78		Submitted		08/31/80
Miller Freeman	05/08	05/16/78		Submitted		08/31/80
Miller Freeman	06/06	06/16/78		Submitted		08/31/80
Miller Freeman	07/12	07/22/78		Submitted		08/31/80
Kodiak						
Miller Freeman	03/21	03/24/78		Submitted		08/31/80
Yankee Clipper/Commando	04/08	04/21/78		Submitted		08/31/80
Scuba	05/04	10/30/78				08/31/80

Data Batch 1 = Grab data, File Type 032
2 = Trawl data, File Type 032
3 = Pipe dredge data, File Type 032
4 = Feeding data, File Type 123.

PRINCIPAL INVESTIGATOR: Dr. H. M. Feder

Cruise/Field Operation	Collection Dates		Estimated Submission Dates			
	From	To	Batch 1	2	3	4
			032	032	032	123
Kodiak (continued)						
Yankee Clipper/Commando	05/01	05/22/78		Submitted		08/31/80
Yankee Clipper/Commando	06/08	06/21/78		Submitted		08/31/80
Miller Freeman	06/19	07/09/78		Submitted	08/31/80	08/31/80
Yankee Clipper/Commando	07/09	07/21/78		Submitted		08/31/80
Yankee Clipper/Commando	08/08	08/23/78		Submitted		08/31/80
Yankee Clipper/Commando	11/04	11/17/78		Submitted		08/31/80
Miller Freeman	02/09	03/11/79		06/30/80	06/30/80*	06/30/80
NEGOA						
Searcher	07/27	08/08/78		08/31/80		08/31/80
Commando	03/05	03/19/79		08/31/80		08/31/80
Miller Freeman	11/05	11/26/79	06/30/80	06/30/80	06/30/80*	08/31/80

*Semi quantitative or qualitative data. The format used will depend on the nature of the data.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 19 R.U. NUMBER: 289

PRINCIPAL INVESTIGATOR: Dr. T. C. Royer

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches refer to data as identified in the data management plan.

Cruise/Field Operation	Collection Dates		Estimated Submission Dates			
	From	To	Batch 1	2	3	
Hinchinbrook	9/17/78	2/16/79		5/31/80		
Montague Strait	9/19/78	2/13/79		5/31/80	5/31/80	
Montague Strait	2/13/79	9/6/79		5/31/80		
Acona 286	9/4/79	9/11/79	5/31/80			

Data Batch 1 = STD/CTD
2 = Current meter
3 = Pressure gauge.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 23 R.U. NUMBER: 351

PRINCIPAL INVESTIGATOR: Ms. E. R. Dieter

No environmental data are to be taken by this task order as indicated in the Data Management Plan. A schedule of submission is therefore not applicable.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 24 R.U. NUMBER: 370

PRINCIPAL INVESTIGATOR: Linda Dwight

No environmental data are to be taken by this task order as indicated in the Data Management Plan. A schedule of submission is therefore not applicable.

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 32 R.U. NUMBER: 537

PRINCIPAL INVESTIGATOR: Dr. D. M. Schell

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches refer to data as identified in the data management plan

Cruise/Field Operation	Collection Dates		Estimated Submission Dates		
	From	To	Batch 1		
Simpson Lagoon Stefansson Sound	11/78		05/31/80		
Smith Bay Dease Inlet, Elson Lagoon	11/78		05/31/80		
Prudhoe Bay	11/79		05/31/80		

Data Batch 1 = nutrients, File Type 029.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 33 R.U. NUMBER: 529

PRINCIPAL INVESTIGATOR: Dr. A. S. Naidu

Submission dates are estimated only and will be updated, if necessary, each quarter. Data batches refer to data as identified in the data management plan

Cruise/Field Operation	Collection Dates		Estimated Submission Dates			
	From	To	Batch 1	2	3	4
Archived Samples				8/31/80	Submitted	8/31/80
Simpson Lagoon	8/77		Submitted	8/31/80	Submitted	Submitted
Barrier Islands	8/77			8/31/80		
Glacier	8/21/77	9/6/77	Submitted		Submitted	Submitted
Summer 1979 Field Season	7/20/79	9/12/79	9/30/80			

Data Batch 1 = Sediment size analysis, File Type 073

2 = Heavy minerals, Tabular form

3 = Clay minerals, Tabular form

4 = Heavy metals, File Type 061

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 34 R.U. NUMBER: 530

PRINCIPAL INVESTIGATOR: Dr. P. Jan Cannon

No environmental data are to be taken by this task order as indicated in the Data Management Plan. A schedule of submission is therefore not applicable.

Fiscal Report

Contract : 03-5-022-56

Task Order: #2

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$ 9,757.86	$232,705.72
Travel	1,357.46	45,204.68
Other	473.49	327.845.20
Equipment	0.	0.
Staff Benefits	1,601.66	41,250.43
Overhead	5,649.81	124,245.18
Total Billed	18,840.28	771,251.21
Total Award		844,004.00
Total Unbilled		72,742.79

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #5

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$ 5,539.44	$412,846.32
Travel	422.89	19,962.19
Other	1,466.37	167,485.79
Equipment	0.	136,664.12
Staff Benefits	1,128.96	68,066.66
Overhead	3,207.35	216,250.88
Total Billed	11,765.01	1,021,275.94
Total Award		1,154,543.00
Total Unbilled		133,267.06

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #8

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$4,238.97	$182,245.41
Travel	0.	22,996.63
Other	1,828.03	29,296.76
Equipment	0.	0.
Staff Benefits	794.53	32,540.98
Overhead	2,454.37	97,274.09
Total Billed	9,285.90	364,353.87
Total Award		435,642.00
Total Unbilled		71,288.13

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #12

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries	$ 0.	$312,075.44
Travel	0.	23,728.01
Other	1,448.00	247,281.14
Equipment	0.	52,947.44
Staff Benefits	0.	51,438.68
Overhead	0.	167,023.68
Total Billed	1,448.00	854,494.39
Total Award		880,717.00
Total Unbilled		26,222.61

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #15

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$17,540.12	$370,845.38
Travel	899.15	25,917.89
Other	10,899.74	327,598.74
Equipment	39.90	11,260.40
Staff Benefits	3,734.44	64,411.70
Overhead	8,904.49	192,552.78
Total Billed	42,017.85	992,586.89
Total Award		1,038,436.00
Total Unbilled		45,849.11

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #19

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$1,688.16	$361,850.26
Travel	110.90	22,648.20
Other	1,907.28	149,531.99
Equipment	0.	44,434.62
Staff Benefits	342.02	62,333.05
Overhead	977.45	189,890.42
Total Billed	5,025.81	830,688.54
Total Award		911,044.00
Total Unbilled		80,355.46

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #23

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$ 873.15	$113,845.71
Travel	382.76	11,083.33
Other	809.73	551,543.70
Equipment	0.	0.
Staff Benefits	192.96	19,562.41
Overhead	505.55	60,643.66
Total Billed	2,764.16	756,678.81
Total Award		886,396.00
Total Unbilled		129,717.19

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #24

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$7,558.09	$139,797.24
Travel	0.	0.
Other	3,831.43	95,401.07
Equipment	236.00	9,221.25
Staff Benefits	1,670.33	27,588.41
Overhead	4,376.14	74,908.50
Total Billed	17,671.99	346,916.47
Total Award		515,678.00
Total Unbilled		168,761.53

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #32

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$5,164.17	$81,294.21
Travel	1,966.07	9,531.85
Other	1,086.51	12,455.09
Equipment	0.	7,569.49
Staff Benefits	888.22	13,418.91
Overhead	2,990.06	44,583.98
Total Billed	12,095.03	168,853.53
Total Award		262,213.00
Total Unbilled		93,359.47

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #33

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$1,541.45	$55,524.70
Travel	464.34	5,875.84
Other	597.14	44,561.16
Equipment	0.	16,567.90
Staff Benefits	0.	7,485.29
Overhead	892.51	29,573.81
Total Billed	3,495.44	159,588.70
Total Award		183,299.00
Total Unbilled		23,710.30

These data are taken from University of Alaska vouchers submitted prior to the above date.

Fiscal Report

Contract: 03-5-022-56

Task Order: #34

Date: March 31, 1980

Category	Billed this Quarter	Cumulative Billed
Salaries and Wages	$1,299.20	$44,371.62
Travel	0.	9,764.37
Other	622.94	6,356.22
Equipment	0.	6,669.32
Staff Benefits	0.	2,673.16
Overhead	752.24	23,678.69
Total Billed	$2,674.38	93,513.38
Total Award		105,875.00
Total Unbilled		12,361.62

These data are taken from University of Alaska vouchers submitted prior to the above date.

ANNUAL REPORT

Contract #03-5-022-56
Research Unit #351
Task Order 23
Reporting Period 04/01/79-03/31/80
Number of Pages-5

MARINE LOGISTICS SUPPORT

Ms. E. R. Dieter
Institute of Marine Science
University of Alaska
Fairbanks, Alaska 99701

March 31, 1980

I. Summary of Objectives

This project provides logistics and vessel time support for portions of the NOAA program. Provided is technician support for all of the sea-going projects funded through the University of Alaska contract. Required ship time for the R/V Acona has also been funded and monitored through this project.

II. Introduction

Not applicable.

III. Current State of Knowledge

Not applicable.

IV. Study Area

Not applicable.

V. Sources, Methods, and Rationale of Data Collection

Not applicable.

VI. Results

A. Logistics Travel

Research and vessel support travel has been provided in this project for the transportation of support personnel handling logistics.

B. R/V Acona

During the reporting period the R/V Acona sailed in support of NOAA/OCS cruises as follows:

04/03/79-04/09/79	Gulf of Alaska	Royer(RU#289)
05/10/79-05/17/79	Gulf of Alaska	Royer
07/23/79-07/28/79	Gulf of Alaska	Royer
09/04/79-09/11/79	Gulf of Alaska	Royer

VII. Discussion

Not applicable.

VIII. Conclusions

Not applicable.

IX. Needs for Further Study

Not applicable.

X. Summary of Fourth Quarter Operations

A. Ship or Laboratory Activities

There was no vessel support for OCS during the last quarter.

B. Results

None.

C. Problems

None.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: March 31, 1980

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 23 R.U. NUMBER: 351

PRINCIPAL INVESTIGATOR: Ms. E. R. Dieter

No environmental data are to be taken by this task order as indicated in the Data Management Plan. A schedule of submission is therefore not applicable.

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A N N U A L R E P O R T

1 April 1979 - 31 March 1980

RU 362

OCSEAP DATA BASE MANAGEMENT SUPPORT

John J. Audet

NODC OCSEAP Data Coordinator

31 March 1980

RU497: SUPPLEMENT TO THE ANNUAL REPORT FOR RU362

Significant Accomplishments

Several important events occurred during the reporting period. OCSEAP requests were completed, new staff were recruited, new equipment was ordered and delivered, and office activities were monitored. Meetings with OCSEAP staff and investigators were instrumental in resolving problems and developing new data products or services. Computer programming requirements were initiated and monitored.

1. Monitored data processing activity to ensure timely delivery of digital data to the NODC.

2. Recommended new equipment to develop graphic data products.

3. Assisted BLM and NODC in fishery data products in the St. George and Norton Basins. Included a site visit to the NODC to review interim products.

4. Attended the OCSEAP data management meetings during the reporting period.

5. Assisted investigators in defining their needs in design of digital data products - Mr. Arneson for FT040 data products; Rita Horner for taxonomic code products; and C. Broad in Taxonomic category products.

6. Drafted reports, memoranda, and other documents at the request of OCSEAP staff. Monthly reports were distributed to OCSEAP staff as required.

7. Submitted three quarterly reports.

8. Initiated lease of 3741 workstation with telecommunications feature through the NODC procedures. Installation is expected by June 1980.

9. Discussed taxonomic code conversion service with the NODC and arranged for funding with the University of Alaska's Arctic Environmental Information and Data Services (AEIDC) for this task. NODC is the sponsor.

10. Assisted the Anchorage Data Processing Facility staff in resolving errors in the digital code file.

11. Drafted 123 original pieces of correspondence during the reporting period.

CONTENTS

I. INTRODUCTION

In contrast to the annual report format suggested for OCSEAP investigators, this report for RU 362 is presented in terms of primary data management tasks - data processing, data format development and support, data inventories and catalogs, requests, and product development. A summary of the fourth quarter activities (January - March, 1980) is incorporated in the report.

II. DATA PROCESSING

A. Digital Data Received

The majority of digital data sets received during the past year have been biological data which is similar to the previous two years' trend. Submissions to NODC for this past year have declined from the previous year in all data categories from a total of over 500 to slightly less than 400 data sets. The submission of selected file types through AEIDC and the Data Projects Group at URI accounts for several hundred data sets that otherwise would be included in data sets received by the Data Center. The quarterly distribution of data received is shown in Table 1.

Table 1. OCSEAP Data Received from April 1979 through March 1980

	Apr - Jun 79	Jul - Sep 79	Oct - Dec 79	Jan - Mar 80	Total This Year	Total Last Year	Total To Date
Biological	37	39	50	160	286	414	1285
Physical	26	10	0	43	79	97	366
Chemical	3	4	0	10	17	6	44
Geological*	2	6	0	2	10	15	52
Totals	68	59	50	215	392	532	1747

* Includes OCSEAP epicenter and analog data submissions

Totals will not agree exactly with last year's totals due to resubmissions and in some cases, deleted data sets, which initially are counted as received, but are not counted in 'finaled' data sets.

B. ROSCOPS Received

A total of 91 ROSCOPs were received during the past year with the total to date for OCSEAP surveys now 778.

C. Data Reports

No further status reports will be included for receipt of OCSEAP data reports and other non-digital information. Only four data reports were received from Project Offices during the past year; no further entries will be made in the NODC version of the OCSEAP tracking system as the final version has been distributed. It is anticipated that this type of information will be maintained through the automated comprehensive bibliography or the new tracking system being developed by the Boulder staff.

D. Processing Activities

Processing this past year has been concentrated on assembling all data for each file type on one or more magnetic tapes to permit convenient, efficient conversion from the IBM system to the new UNIVAC system this June. As a result, comprehensive uniform checking of all data, regardless of date of receipt, has been completed for nearly all file types for data received through 1979 through the efforts of Chris Noe and his staff. A summary of the status of data sets through February, 1980 is shown in Table 2. A more detailed list by file types is included as Appendix A.

Table 2. OCSEAP File Type Status thru February, 1980

	Received	Finaled	In Processing	In Hold
Biological	1245	1058	100	97
Fishes	268	230	5	33
Plankton, etc.	343	297	37	9
Birds	326	253	18	55
Mammals	318	278	40	0
Physical	326	279	11	36
Chemical	44	13	22	9
Geological*	9	5	1	3
Totals	1634	1355 (83%)	134 (8%)	145 (9%)

* Includes only OCSEAP file types

The number of data sets 'in hold' has been reduced significantly through the assistance of the Project Offices and the AEIDC and the Univ. of Rhode Island groups, combined with improved data submissions by most investigators. Through the pre-processing efforts of the AEIDC staff and the Data Projects Group at URI, much of the data now being received by the Data Center is encountering less key entry errors and tape characteristics and use of data formats are nearly all compatible with NODC's system.

Two on-going processing activities that will eventually resolve major processing and data product problems are being carried out under the direction of the Anchorage liaison officer at AEIDC. A 'conversion file' for clarifying 'pre-Alaska' taxonomic code problems has been established so that NODC will be receiving only acceptable codes for those data passing through the AEIDC facility. The second activity is an intensive review of a major portion of the biological data received to date by NODC to identify further problems and in the case of fish resource data to determine the proper schemes for converting these data to the new file type 123 - Fish and Shellfish Resource Assessment. The potential for more reliable and useful data products is realized as these data are converted to FTP 123.

Check run results have been forwarded over the past year to 24 investigators for 310 data sets involving 17 different file types. A total of 165 magnetic tapes and diskettes of originator's data were returned to investigators following final processing of their data. Check runs now routinely include annotated station location plots.

The progress for final processing of digital data, which includes conversion of Alaska codes to the NODC taxonomic codes where necessary, continues to increase each year. This is due in most part to a significant editing effort by Data Preparation Division personnel and an improved response record by investigators to clear up data problems identified during data checking. Table 3 summarizes this progress over the past four years.

Table 3. Comparison of Final Processing of OCSEAP Data for the Past Four Years

Year	Data Sets Finaled/Received	Percent of Total
1976-77	91/645	14%
1977-78	434/1030	42%
1978-79	983/1507	65%
1979-80	1355*/1634	83%

* This total includes some data sets that are being more intensively reviewed by the AEIDC staff.

III. REQUESTS

The highest percentage of data requests this past year was from OCSEAP investigators as shown in Table 4. The number of OCSEAP management requests increased significantly (from 15 to 29) and several large BLM requests were completed in contrast to the previous year's work for BLM.

Requestor	Data Type	Apr-Jun 79	Jul-Sep 79	Oct-Dec 79	Jan-Mar 80	Total	Total Previous Year
BLM	OCSEAP	2	2	2	0	6	0
	Archival	0	0	0	0	0	0
OCSEAP offices*	OCSEAP	7	8	3	6	24	35
	Archival	1	1	0	0	2	5
OCSEAP PIs	OCSEAP	10	13	6	6	35	27
	Archival	0	3	2	2	7	11
Non-OCSEAP Requestors	OCSEAP	5	5	3	2	15	13
	Archival	NA	NA	NA	NA	-	-

Requestor	Data Type	Apr-Jun 79	Jul-Sep 79	Oct-Dec 79	Jan-Mar 80	Total	Total Previous Year
OCSEAP Management	NA	6	11	6	6	29	15
Totals		31	43	22	22	118	106

* Includes AEIDC and URI groups

The major requests completed during the past year are briefly described below in Table 5. More details of these and other requests are available in Quarterly and Monthly Reports.

Table 5. Major Requests (April 79 - March 80)

Date Completed	Requestor	Type of Request
5/79	Arneson (ADF&G) (RU 003)	Station location plots - bird habitat studies.
6/79	Wesnousky (Lamont-Doherty) (RU 016)	Magnetic tape of hypocenter data (NGSDC).
6/79	SAI (Boulder) (RU 468)	Grided base maps for specific areas (NGSDC).
6/79	Arbegast (BLM)	Inventories and species lists - Yakutat lease area.
6/79	Ingraham (NMFS)	Bering Sea OCSEAP STD inventory.
6/79	Ramsdell (Col. of Atlantic) (RU 237)	Coding and format use of Marine Bird Colony format (FTP 135).
7/79	Arbegast (BLM)	Selected fish and benthic plots - Yakutat.
7/79	Blackburn (ADF&G) (RU 486)	Fish school sighting plots for Bering Sea.
7/79	Waldron (NMFS) (RU 380)	Listings of selected ichthyoplankton.
8/79	Crane (Anchorage) (RU 370)	Two tapes of all fish resource data (File Type 023).
8/79	Beck (Imarpik)	Herring spawning inventory plots.
8/79	Hansen (U. Alaska)	Magnetic tape of NODC map package.
8/79	OCSEAP Offices	NODC parameter ranges - all file types.

Date Completed	Requestor	Type of Request
8/79	Pearson (PMEL) (RU 541)	Punched card deck of NODC map package.
9/79	Feder (U. Alaska) (RU 502)	Magnetic tape - selected fish species for Bering/Norton.
9/79	Guzman (U. Calgary) (RU 239)	Inventory - bird, fish, plankton and phy. ocean . data.
9/79	Marelli (Calif. Acad. Sci.) (RU 563)	Taxonomic summary for voucher specimens.
9/79	Cava (JPO)	Formatted output listings - selected file types.
10/79	Guzman (U. Calgary) (RU 239)	Monthly surface temp. and salinity contour charts - Bering/NEGOA.
10/79	Miller (U. Alaska) (RU 253)	Bottom temperature plots - Norton/ Chukchi.
10/79	Hunt (U. Calif-Irvine) (RU 083)	Clarification of zooplankton density plots.
10/79	Arbegast (BLM)	Summary plots for selected fish and benthic species - St. Geo/Norton.
10/79	Ordzie (URI) (RU 527)	Selected marine bird data sets - (FTP 033).
10/79	Peason (PMEL) (RU 541)	Magnetic tape of selected STD data sets.
11/79	Lippincott (SAI-La Jolla)	Magnetic tape of selected intertidal data (FTP 030).
11/79	Sonntag (NMFS) (RU 67)	NODC map package documentation.
11/79	OCSEAP Office (Boulder)	Format layout inventory with current dates.
12/79	Wyrtki (U. Hawaii)	OCSEAP Data Catalogs and users guide.
1/80	Reimer (Flow Reseach) (RU 567)	Current meter time series plots - Beaufort/Chukchi.
1/80	Braham (NMFS) (RU 67)	Formatted output and tape - selected whale species sightings.

Date Completed	Requestor	Type of Request
1/80	Guzman (U. Calgary) (RU 239)	Station lists and contour plots of temperature and salinity.
1/80	Windus (URI) (RU 527)	Magnetic tape copy of selected marine bird data sets (FTP 033).
2/80	Reimer (Flow Research) (RU 567)	Transport plots for Beaufort Sea.
2/80	Schumacher (PMEL) (RU 541)	Magnetic tape copy of selected STD/CTD data sets.
2/80	Guzman (U. Calgary) (RU 239)	Plots of selected shearwater sightings - NEGOA/Bering areas.
2/80	Mathisen (Cont. Shelf Inst.)	OCSEAP Catalogs and NODC inventory information.
3/80	Cava (JPO)	Data listings and summaries for recent zooplankton data submissions (FTP 024)
3/80	Conners (Bodega bay, CA) (RU 172)	Magnetic tape copy of all bird census data (FTP 034).
3/80	SAI (Boulder) (RU 468)	Selected bathymetric contour products (NGSDC).
3/80	Crane (Anchorage) (RU 370)	Magnetic tape copy of OCSEAP PI phone/address file.
3/80	Windus (URI) (RU 527)	Magnetic tape copy of selected marine bird data sets (FTP 033).

IV. FORMAT DEVELOPMENT

A. Data Format and Code Activities

The distribution of the automated version of formats and codes was completed in August 1979 for all OCSEAP investigators and OCSEAP management. The distribution involved approximately 150 formats to over 70 individuals. A list of all formats used by OCSEAP investigators and their current dates is included as Appendix B.

New format activities for the year were as follows:

File Type 031 - Marine Bird Specimen - updated in October, 1979 - distributed to investigators at the January 1980 Bodega Bay marine bird meeting.

File Type 123 - Fish and Shellfish Resource Assessment - completed and distributed in September 1979.

File Type 127 - Marine Animal Sighting and Census - final draft distributed in September 1979.

File Type 135 - Marine Bird Colony II - final version distributed in October 1979 - new modifications now incorporated and available for distribution to potential users of the format.

File Type 144 - Toxic Substances - draft version distributed in November 1979 - final to be distributed in April 1980.

Because of limited format and code modifications, only one 'FACT" sheet was distributed this past year, in July 1979. A second 'FACT' sheet is being prepared at this time for distribution before the end of April, 1980. Requests for modifications are provided to the investigator prior to any formal distribution of the additions or changes.

B. Taxonomic Codes

The NODC taxonomic code file continues to be updated and copies of the updated file or related information periodically forwarded to AEIDC and the University of Rhode Island to keep their files current.

Data submissions with 'pre-Alaska' unofficial taxonomic codes are gradually being corrected through the efforts of the AEIDC staff and the NODC marine biology group. For the remaining data sets still being submitted in Alaskan codes, the AEIDC and URI groups are converting the codes prior to submission to NODC.

The use of 'species group' codes was discussed once more at the recent Bodega Bay marine bird meeting. A review of data sets for determining the frequency of use and potential need for new codes is underway by NODC and the Data Projects Group. A final decision on new codes is pending.

C. Chemical Codes

The Chemical Abstract Service chemical code file has been adapted for use with the new Toxic Substance format (FTP 144). A large variety of chemical compounds and other substances may be reported using this 9-character code. An alpha character assigned by NODC precedes the code to separate organics and inorganics, as well as non-chemical substances. This file and related chemical compound files may be accessed through computer terminal systems such as Lockheed or SDC or the EPA/NIH Chemical Information System. This capability provides a convenient means for many investigators to readily obtain codes and proper names for substances that may not be included in the subset of codes distributed with the toxic substance format.

V. INVENTORIES AND CATALOGS

A. Data Tracking System

The final version of the Data Tracking System was distributed in February 1980 to OCSEAP, BLM and NOAA personnel. This version included all updates received from the Project and Program Offices through January 1980. A restructured copy of the tracking system file is being prepared on magnetic tape for conversion to the OCSEAP/OMPA version of the tracking system being developed in Boulder.

B. OCSEAP Catalogs

Part 1 - Revised-of the OCSEAP Data Catalog has been completed and submitted to NOAA printing in March 1980.

Part 2 - Revised-was completed and distributed to over 300 individuals in August 1979.

Part 3 - Data Formats and Codes - was distributed as subsets to relevant OCSEAP investigators in August 1979.

Part 4 - Data Product Examples-is nearly completed in draft form. All figures and texts have been received and reviewed by contributors to the Catalog. The status of the major steps for completing the Catalog are as follows:

92 of 95 - draft plots completed.
78 of 95 - final plots completed (15 of these need photo reduction).
105 of 109- texts including section introductions have been completed in draft form.

VI. PRODUCT DEVELOPMENT

A major development of the past year was the implementation of annotated station location plots by the Applications Design Branch. Plots now routinely accompany other data checking and summary information sent to investigators and project offices for their review.

A request flow using a BLM data request was developed working with Mike Crane to better indicate to BLM and the Project Offices the time frame required to complete most routine but complex data requests (plots of selected species for specific time periods, areas, data types, etc).

The conversion of the SAI biostatistics package for use with OCSEAP formats has been delayed until the UNIVAC system is operational at NODC. It was determined to be too expensive and time-consuming to resolve conversion problems for this package for the IBM system as it will soon be replaced.

A product which separates census data for marine birds and mammals or chemical concentration levels into categories (1-10, 10-100, 100-500, etc.) was completed and products provided to an OCSEAP investigator for selected bird species. A similar product is available as a symbol plot instead of numbers representing each category.

A general plot product was developed to summarize observations, such as counts of marine birds or weight per catch on specified grids from 6' areas to one-degree areas or greater. A large number of BLM graphics were provided using this product.

The STD/CTD data in file type 022 was adapted to a number of 'standard' NODC graphic presentations, including horizontal array summaries, stability index profiles, excedence diagrams and multiple-depth histograms.

Very few (less than 20%) of the product evaluation forms concerning completeness or usefulness of a product have been returned from requestors. An OCSEAP evaluation form accompanies each product request with an addressed return envelope. Some simple requests, such as inventory plots, may only include the NODC evaluation check list that accompanies each transmittal form. Many of these transmittals are returned with the responses ranging from 'partially satisfactory' to 'exactly what was needed'.

The lack of feed-back for the more complex products makes it difficult to improve or correct a particular product for future distribution. Although some improvements are made to products by Data Center personnel, it would be most helpful to obtain more evaluations of products by the users.

VII. SUMMARY OF FOURTH QUARTER ACTIVITIES (January - March, 1980)

Digital Data Received

A total of 213 data sets were received this quarter for the following file types:

015 - Current Meters	- 40
022 - STD/CTD Data	- 1
024 - Zooplankton	- 1
025 - Mammal Specimens	- 4
027 - Mammal Sightings	- 140
030 - Intertidal Data	- 2
033 - Marine Bird Sightings	- 13
044 - Hydrocarbons II	- 10
101 - Wind Data	- 2
	213

Data Reports

No further data report activity.

ROSCOPS

A total of 23 ROSCOPs were received, all in February for a total to date of 778.

Data Processing

A total of 95 data sets were final processed, 50 tapes and diskettes of originator data were returned to investigators, and 55 check runs were forwarded to Project Office and investigators for review.

All file type 030 data received to date at NODC was assembled on a magnetic tape and forwarded, with accompanying documentation, to Mike Crane's office for further review.

Data Requests

The major requests for this quarter are noted in the 'Request' section of the annual report. Other requests received and/or completed during the quarter are as follows:

- Copies of format layouts sent to Linda Hass.

- Information on World Data Base II provided to Mark Freberts-hauser at IRIS, Tiburon, California.

- Draft copies of the revised Part 1 Catalog plots forwarded to Hal Petersen for the Bering area and to Francesca Cava for the Norton area.

- Several non-NODC formatted NEGOA data sets (current meter and STD) were returned to Sharon Wright for potential resubmission as FTP 015 and 022 - data had been submitted in 1974.

- Supplied Data Projects Group with updated list of taxonomy for birds.

- Searched OCSEAP files for oxygen and carbon dioxide data as requested by World Data Center A for oceanography.

Format Development

The final versions of the Marine Animal Sighting and Census (FTP 127) and Toxic Substances (FTP 144) were completed and will be distributed during April. A 'FACT' sheet also is being completed for distribution before the end of April.

Taxonomic Codes

A 'conversion file' has been established by Mike Crane's staff to help convert 'pre-Alaska' and unacceptable taxonomic codes to the proper NODC codes prior to submission to the Data Center.

Inventories and Catalogs

The final distribution of the NODC version of the OCSEAP Data Tracking System was completed in February.

Part 1 of the OCSEAP Data Catalog is in printing and Part 4 is in a draft stage as discussed in the annual report Catalog section.

Data Products

New products included a generalized display for indicating census, concentration or other groupings, either with representative numbers or proportional symbols.

Additional zooplankton concentrations have been completed for those data sets submitted without concentrations but with adequate gear code and sample interval data to compute volumes which subsequently permit concentration values to be determined.

Adminstrative

Hal Petersen and Bill Johnson have been added to the EDIS liaison CONFER system.

Updates to the 'ISM' Action items were submitted to Cheryl Brower via CONFER.

Technical justification for the NODC IBM 3741 work station was submitted to NODC management.

Meetings during the quarter are included in Appendix C with other trips and meetings of the past year.

VIII. ADMINISTRATIVE

The replacement of the current IBM computer system with a new UNIVAC system appears to be about to take place by June. The impact to OCSEAP, although somewhat uncertain at this time, will certainly mean delays in most data processing and data product activities. Some of the work, such as preliminary inventories, distribution lists, and data format files have been or are being considered for conversion to other systems such as NODC's mini-computer, System 1022 in Waltham, or the NIH facility to minimize the impact of the conversion.

A list of the major meetings and briefings involving RU 362 personnel is included as Appendix C. An updated milestone chart is attached as Appendix D.

The financial summary for the first half of FY 80 is summarized below. Data management activities are pretty much on schedule and consequently funds are being expended close to the work statement plans. The total OCSEAP budget for RU 362 is $381.2 excluding $41.0K transferred to NGSDC but including $33.2 for Wayne Fischer.

Salaries and benefits	$120.8K
Travel	$ 5.5K
Supplies, etc.	$ 7.7K
Computer	$ 43.8K
Totals	$177.8K

Although it is difficult to identify expenditures for specific tasks, the following estimates have been determined for the major tasks within RU 362.

	Labor	Computer
Processing and Validation	$ 32K	$24K
Requests and Products	$ 29K	$16K
Management Support	$ 60K	$ 4K
Totals	$121K	$44K

IX. PROBLEMS

Timely response to many of the more complex requests continues to be a major problem. Available personnel and computer time at NODC has been severly restricted due to computer conversion efforts which are now impacting on all phases of the Data Center operations. More importantly, problems with the scientific content of much of the OCSEAP data continues to be uncovered as specific products are prepared. Missing critical parameters, such as counts or concentrations of species, areas or lengths of surveys and coding of taxonomic data to a lesser level than required (six digit family level vs. 10 or 12 digit species levels) are some of the more obvious problems that have prevented or delayed completion of many products.

The management of format updates and code additions, a continuing problem, has improved significantly, primarily due to the implementation of automated format and code files which provides an easier and more efficient means of distributing multiple copies of individual formats and code groups.

Over the past few years, a disproportionate amount of NODC labor and computer costs has been placed on marine bird data management, from formats to processing to products. The result has been that other areas such as fisheries or marine chemistry have suffered in terms of intensive data processing and improved products. More emphasis will be placed on these other areas in the future.

The illegal use of taxonomic codes and the continuing use of Alaskan codes well past the Project-approved deadline of a year ago is gradually being resolved, but only through the increased efforts of Mike Crane's staff and the transfer of funds from NODC to his group for this work.

Finally, it is not certain what the impact of the organizational changes underway within OCSEAP will be on NODC and future data management support. Planning for support in FY 81 and 82 is dependent somewhat on determining where OCSEAP fits within OMPA, 95-273 and NOAA's marine pollution program. Will our task be coordinated from personnel in Rockville or Juneau or Boulder? To summarize, it is not clear from which direction NODC will receive guidance (and funding) in the next FY.

X. GOALS (Next Quarter)

- Distribute Part 1 - Revised-of the Catalog.

- Complete typing and figure assembly of Part 4 of the Catalog and submit to NOAA printing.

- Distribute 'FACT' sheet to OCSEAP management and investigators.

- Distribute new formats for Marine Animal Sighting and Census (FTP 127) and Toxic Substances (FTP 144).

- Continue to update the NODC Taxonomic Code file as required.

- Provide updates of 'crunch tapes' as available to the AEIDC office.

Appendix A

OCSEAP File Type Status for Data Received through February, 1980

File Type	Received	Finaled	In Processing	In Hold	Comments
013	8	6	2	0	
015	117	83	1	33	Unreadable tapes
017	20	19	0	1	
021	12	11	1	0	
022	94	84	8	2	
023*	183	152	3	28	All data to be converted to 123.
024	72	49	22	1	
025	81	41	40	0	
026	34	34	0	0	
027	203	203	0	0	
028	68	58	5	5	
029	170	162	5	3	
030*	30	28	2	0	
031	No data received to date				
032*	32	27	0	5	
033	217	199	18	0	
034	10	10	0	0	
035	58	3	0	55	All data to be combined on one tape.
037	8	8	0	0	
040	33	33	0	0	
043	11	2	0	9	Data checks sent to PI for review.
044	6	0	6	0	
056	87	87	0	0	
057	15	0	15	0	
061	15	0	15	0	
063	1	1	0	0	
072	1	0	0	1	
073	8	5	1	2	
101	8	6	2	0	
123	No data received in this format to date - see 023.				
124	3	0	3	0	
135	No data received to date.				
Totals	1634	1355	134	145	

* Data being intensively reviewed by Crane's Anchorage Office.

Appendix B.

Current Formats for OCSEAP Investigators

File Type		Current Date
013	Fish Pathology	3/5/79
015	Current Meters	3/30/79
017	Pressure Gauges	7/1/76
021	Trace Metals	12/27/79
022	STD/CTD	3/30/79
025	Marine Mammal Specimen	9/11/78
026	Marine Mammal Sighting II	1/19/77
027	Marine Mammal Sighting I	5/24/77
028	Phytoplankton	12/8/78
029	Primary Productivity	7/7/78
030	Intertidal Data	3/13/78
031	Marine Bird Specimen	12/27/79
032	Benthic Organisms	2/11/77
033	Marine Bird Census (Ship/Aircraft)	1/18/78
034	Marine Bird Census (Land)	6/29/77
037	Marine Birds - Feeding Flock	1/11/77
038	Migratory Bird Sea Watch	7/7/78
040	Marine Bird Habitat	1/21/77
043	Hydrocarbon I	11/9/77
044	Hydrocarbon II	3/5/79
056	Lagrangian Currents	1/5/77
057	Herring Spawning	12/8/78
061	Trace Elements	9/9/77
063	Marine Invertebrate Pathology	3/5/79
072	Beach Profiles	3/10/77
073	Grain Size Analysis	2/7/77
101	Wind Data	8/23/76
123	Fish/Shellfish Resource Assessment	9/4/79
124	Zooplankton	11/6/78
127	Marine Animal Sighting and Census	2/25/80
135	Marine Bird Colony II	4/1/80
144	Toxic Substances	Final Draft

Appendix C.

Major Meetings Attended (April 79 - March 80)

1979

April	- Fischer/Brower at NODC to discuss product development and graphic applications.
May	- BLM-Anchorage briefed on NODC data validation and product development capabilities.
May	- NODC 'Format Policy' meeting held with NODC management (policy never implemented).
June	- Visit to URI to discuss data entry problems and format logic with Data Projects Group.
June	- Fischer presented 'ISM' structure to NODC management.
July	- Meeting in Boulder to discuss future NODC and NGSDC tasks for OCSEAP.
July	- Annual OCSEAP Data Management meeting - held on Univ. Alaska campus in Fairbanks.
September	- Briefed Dr. Potter on OCSEAP objectives and accomplishments for NODC/NGSDC.
October	- Visit by Mike Crane to NODC to resolve variety of OCSEAP items, particularly BLM data requests, data checking compatibility and contributions to Part 4 of the Catalog.
November	- Visit to URI to discuss data entry, OCSEAP data inventories and contributions to Part 4 of the Catalog.

1980

January	- Meeting at Bodega Bay Laboratory to discuss data entry and data products for marine bird investigators.
January	- Visit by Brower to NODC to review draft of Part 4 of the Catalog.
February	- Meeting at NODC with Fischer and Haas to discuss OCSEAP/OMPA data management.
March	- Visit by Fischer and Brower to NODC to discuss OCSEAP and OMPA activities.

March - Meeting at NODC with Hal Petersen and Chris Noe to discuss and resolve transfer of OCSEAP Data Tracking file to the system being developed at Boulder.

MILESTONE CHART (Revised)

Appendix D

0 - Planned Completion Date

X - Actual Completion Date

RU # 362 PI: John J. Audet, Jr.

Major Milestones: Reporting, data management and other significant contractual requirements; periods of field work; workshops; etc.

MAJOR MILESTONES	1979 O	N	D	1980 J	F	M	A	M	J	J	A	S	O	N	D
Data Catalog (I) *-Station plots by area			0				X								
Data Catalog (II) *-Data source listing by area						Ø					0				
Data Catalog (III) -Formats/Codes				Ø			0								
Data Catalog (IV) -Sample Data Products			Ø						0						
*All updates/revisions to the catalog are dependent on the quantity of new data submitted.															
Quarterly Status Reports (courtesy copies of NODC monthly reports included)	X			X			0			0			0		
Attendance at workshops and data synthesis meetings (as scheduled)															

Future status reports will include only NODC file type summaries - not the data tracking system.

ANNUAL REPORT

RU Contract No.
370 03-5-022-56

Reporting Period - 1 April 1979
through 31 March 1980

35 Pages

OCSEAP Alaskan Data Processing Facility

Michael L. Crane

Linda Perry Dwight

31 March 1980

OCSEAP ANNUAL REPORT

Contents

I. Introduction

The Outer Continental Shelf Environmental Assessment Program (OCSEAP) has a special responsibility to the future users by making available the fundamental environmental data collected during the lifetime of the program. To meet this need, the OCSEA Program established a digital data base at the NOAA Environmental Data and Information Service (EDIS). The arrangement with EDIS encompasses data base service, data management support, and technical data processing.

In order to implement the data management responsibility, OCSEAP has contracted the University of Alaska's Arctic Environmental Information and Data Center (AEIDC) and EDIS to jointly execute professional data management activities. In partial fulfillment of these commitments, AEIDC and the EDIS Alaskan Liaison Officer have established a facility providing project management support, digital data base support, and originator support. This report summarizes the major accomplishments of the facility from 1 April 1979 to 31 March 1980.

II. Significant Accomplishments

The most important activities have been programming development, data checking, data editing, creation and maintenance of automated files, and data management support. Significant accomplishments during the reporting period are listed below. Details are contained in the monthly reports and special reports on data management.

1. Computer programs have been developed in three categories.

   A. Checking - 61 programs
   B. Utility - 22 programs
   C. Analysis for file type/formats or data type - FT040 (Marine Bird Habitat), FT028 (Phytoplankton Species), FT030 (Intertidal) - 14 programs

2. Preprocessing of FT023 (Fish Resource Assessment) data has been completed for data submitted by Jim Blackburn.

   A. For RU512 created record type 6 and edited record type 7. These records were merged with the catch records.
   B. For RU552 processing of the record type 7 records.

3. Taxonomic code checking in FT033 (Marine Bird Sightings), FT124 (Zooplankton), FT028 (Phytoplankton Species), FT038 (Migratory Bird Sea Watch), and FT040 (Marine Bird Habitat) has been executed during this fiscal year.

4. Full-service processing in FT027 (Marine Mammal Sighting) for RU243, Don Calkins. The beluga whale surveys were processed in Anchorage by the following actions:

   A. Develop coding forms (November)
   B. Keyentry (January)
   C. Checking (February)
   D. Edit (February)
   E. Final processing (February)
   F. From Scratch to delivery - less than 90 days! (See Section III for details.)

5. Determine illegal taxonomic code (pre-Alaskan code) as direct management support - Feder, Ronholdt, and Harris. (See Section III for details.)

6. Review and update master records in digital code file - joint project with Mr. Robert Gelfeld of NODC. (See Section III for details.)

7. Developed fishery taxonomic table for BLM data requests - instrumental in timely delivery of fishery data products from NODC. (See Section III for details.)

8. Processed all FT040 as a joint project between Mr. Arneson (RU003) and Anchorage Data Processing Facility.

9. Created bird analysis products in FT040 for Mr. Arneson. (Details noted in Section III and examples in the appendix.)

10. Implemented word processing communications between Anchorage and Fairbanks, using IBM OS/6 word processing equipment.

11. Received 51 requests from OCSEAP staff, investigators, and users. (Section III outlines these requests.)

12. Received 362 data sets from April 1979 to April 1980.

13. Forwarded 120 data sets to the NODC or to the University of Rhode Island group.

14. Three quarterly reports were submitted to the OCSEA Program.

15. Computer graphics capability for information display has begun using an H-P2647A graphics terminal. The figures in this report were generated by this terminal and plotter.

16. Several taxonomic codes were negotiated between the investigators and the NODC.

17. Special management files were maintained, such as the "Parameter Checklist." Reports were generated from this file. (Section III describes one special report.)

18. FT031 (Marine Bird Specimen and Feeding Studies) preprocessing completed for Gerry Sanger, RU341. Several thousand edits were made to these data.

19. Computer programs were documented; the utility programs and the analysis programs have been completed; the "file type" check programs will be written next. (See Section VII for more details.)

20. Camera-ready examples for the Data Catalog (Part IV) have been generated and delivered to Mr. Audet.

21. R. Horner, RU359, requested TFILE listings for voucher specimen documentation. TFILE lists the file and adds the taxonomic name to the right of each taxonomic record. Taxonomic listings for FT024 and FT028 were generated. (See Section III.)

22. Mr. D. Roseneau, RU460, requested and received a predator/prey listing for Common and Thick-billed murres. (See Section III for details.)

23. TAXCAT28 for Rita Horner, RU359, was developed. This program computes density values by taxonomic category and merges values by depth. (See appendix for an example.)

III. Summary of Requests and Important Events

The OCSEA Program has requested support in three areas. Data checking of digital data, principal investigator assistance, and project management assistance have been offered by the Anchorage staff. Several of the significant accomplishments are important items and require further description in this section. Fifty-one requests were received during the reporting period.

OCSEAP REQUESTS

1.	Cava	Parameter Checklist updates
2.	Johnson	LGL tax codes for Harvie
3.	Roseneau	Predator/Prey
4.	Cava	Review pre-Alaskan tax codes (RU174/175)
5.	Arneson	Develop and execute data products in FT040
6.	Arbegast/Audet	Develop Fishery tax code table for lease areas
7.	Johnson	Create management review programs

OCSEAP Requests (continued)

8.	R. Horner	Develop tax code compression program
9.	Calkins	Keyentry FT027 data
10.	Cava	Send tax codes to Mintel
11.	Audet	Send examples for data catalog, Part IV
12.	Blackburn	Create new record type 6 records for data in FT023
13.	Cava	Review tax code for RU424
14.	R. Horner	Tax code listing of data in FT024 (Zooplankton)
15.	R. Hadley	Isolate illegal tax codes in FT032 (Benthic Organisms) data
16.	Smith/Cava	TFILE on FT023 data
17.	McAlister	Edit new values in FT025 (Marine Mammal Specimen) for RU229 and RU243
18.	Blackburn	Preprocess FT023 data for RU552
19.	Windus	Send tape of tax code master file
20.	Johnson	Incorporate NODC summary input to Parameter Checklist
21.	Murphy	Send TEKTRONIX 4051 to Seattle
22.	Cava	Site visit to Kodiak to see Blackburn
23.	Audet	Contact R. Hadley about taxonomic code error
24.	Walter	Met data from oil rigs monthly
25.	Cava	Review tax codes for RU058
26.	Cava	Review tax codes for RU239
27.	Audet	Parameter Checklist on unlined paper
28.	Johnson/Cava	Bring copies of Parameter Checklist file
29.	Murphy	Deliver World Data Base II to USFWS
30.	Boettcher	Send tax code listing

OCSEAP Requests (continued)

31.	Walter	Locate new met data in LCI for July 1978
32.	Cava	Run Parameter Checklist for continuing RUs in FY80
33.	Johnson	Update and run the Parameter Checklist for Arctic RUs for FY80
34.	Johnson	Draft a joint letter to James Keniston, RU006
35.	Johnson	Draft a joint letter to Brian Harvie, RU467
36.	Fischer	Draft response to letter dated 16 May
37.	Johnson	Letter to Brian Harvie on FT123 (Fish/Shellfish Resource Assessment) format changes
38.	Swanner	Send 023 check runs for FT023, LCOOK2, LCOOK3 from Dennis Lees, RU417
39.	Swanner	Send TC-ANY and TFILE output for FT030, LCOOK2, and LCOOK3 from Dennis Lees, RU417
40.	Johnson	Execute a station sort on FT034 Connors, RU172 File ID 77062; run TC-ANY and TFILE on sort; bring to Fairbanks
41.	Cava	Copy of data products section from FGGE publication
42.	Cava	Run EX032 for all subarctic data sets in FT032; also MXMN032 if time permits
43.	Swope	Update the FT025 data file for histopathology measurements for RU229 and RU243
44.	Johnson	Send budget to Fischer - draft report
45.	Harvie	Send tapes of taxonomic codes and OCSEAP digital codes
46.	Johnson	Check Connors RU172 data for FT034
47.	Swanner	Review check programs for FT027/RU417, Lees
48.	Meyer	Find 1920's publication on fisheries data
49.	Lees	Correct LCOOK2, LCOOK3 data errors
50.	Cava via Hauwert	Update Parameter Checklist
51.	Gould	Code sort

The important events this year are noted in brief summary form below. Future data analysis and support will branch from the foundation of computer programs and master files maintained by the Anchorage staff. The items included data processing tasks, review of taxonomic codes, data analysis products, and BLM products support. The items span a broad range and include new advances. Principal investigators, OCSEAP staff, and the data base staff have benefited from these events.

FT027 Processing

From item number 4 in Section II, the processing of beluga whale data was completed this year. Direct, full-service processing in file type 027 was executed for data from Mr. Don Calkins, RU243. The development went as follows:

November 1979 - coding forms were designed.
January 1980 - coding forms were received and key entered.
February 1980 - data checked, edited, final processed, and forwarded to NODC.

All processing, from start to finish, was accomplished in less than 90 days! The check programs were developed for the MESA Puget Sound Project, and the OCESA Program was the first user of these checking programs.

Illegal Taxonomic Codes

The following item is mentioned in Section II, Number 5.

Taxonomic codes are still surfacing which are illegal Alaska codes or pre-Alaska codes. To date, three investigators have submitted data with codes in pre-Alaska form: Lael Ronholt, RU174; Colin Harris, RU424; and Howard Feder, RU005. Codes in pre-Alaska form are now being linked by taxonomic name to a NODC taxonomic code with the use of a separate conversion tax file. Only after the link has been established can the codes be converted to NODC codes.

Digital Code File

From item number 6 in Section II, the Digital Code file was updated. In order to check the Digital Code file, a joint project with Mr. Robert Gelfeld of NODC was undertaken. A current listing of the NODC version of the Digital Codes from Mr. Gelfeld was compared to the formats. The program CDLIST isolated each code for the various formats. All discrepancies were annotated. An updated Digital Code file was sent to Mr. Gelfeld.

BLM Fishery Taxonomic Table

The following item is mentioned in Section II, Number 7.

A product was requested by BLM for fishery data products in the St. George lease area and the Norton lease area. A Crustacea taxonomic list and a fin fish taxonomic list was received from BLM. The combined lists were used to generate a special file of taxonomic information related specifically to the BLM lease areas. The taxonomic name, NODC tax file common name or BLM common name (noted with an asterisk), Alaska code number, and NODC code number were listed. Eight lease areas were listed to the left of the taxonomic entry. An "X" was placed under the lease area number to mark that species' occurrence. Two products are available: the total lease area list or a list of each lease area. Examples of the products are included in the appendix.

Bird Analysis Products - FT040

The following item is mentioned in Section II, Number 9.

Analysis products for RU003 have been created and altered to reflect Mr. Arneson's needs. Sections of the Alaskan coast now constitute the breakdown for analysis instead of stations, and the taxonomic variations are reduced to eighteen categories of species groups rather than individual species. The number of different programs used in the analysis procedure has been reduced from the original four to three: TAXCAT40, SVDEN040, and STAT040. The original programs TAXCAT40 and CATNAME were combined to meet the need of a decrease in processing time.

The original data are copied on disks and internally labeled by section blocks or files. Each section is handled as a distinct unit. The different taxonomic entries are reduced to eighteen categories with the use of the program TAXCAT40. The program TAXCAT40 merges each taxonomic record into its appropriate species category within each station. The species individual taxonomic code is changed to a new code representing the associated species category, the "number of individual" field is increased, and the taxonomic category name is written alongside. TAXCAT40 recognizes files within the source disk and maintains separate files on the receiving disk.

Mr. Arneson requested the original measurements converted to normalized values for analysis. The first "normalization" was converting from number of individuals to the areal density of birds. The records from the merging process were converted by the program SVDEN040. The disk of merged taxonomic codes is then run through the program SVDEN040. Density records are created. Those stations which were a linear measurement are converted, by multiplying by a constant, to an areal measurement. Multiple files are recognized and maintained onto the receiving disk.

The program SVDEN040 computes the density using the area value computed from those stations with bird sightings. The area value of a station with no birds sighted is not taken into account for the density computation. To include the stations with zero birds sighted in the area value, an alternate program was written entitled CNDEN40. The program CNDEN40 computes density with an area value of all stations within a section, irregardless of bird sightings.

The product generated from the density disk is a summary table of the eighteen possible taxonomic categories for each section. That table is generated by STAT040. All like species category taxonomic records from within a section are combined, resulting in one record for each species category. These are then listed in taxonomic order with the corresponding number of individuals, average density, category name, and number of records. A space to type in an explanatory title is provided at the beginning of each section table, and a grand total figure for the fields "number of individuals," "average density," and "number of records" follows each section table. This is stored on a receiving disk and then printed.

Examples are included in the appendix.

SUMxxx

From Section II, item number 17, the SUMxxx programs were designed to produce an exception report of fields committed to be entered by each individual PI. The programs access the Parameter Checklist file to extract the PI's committed status for each field. The program then takes an inventory of each file--accumulating the total number of exceptions and the number of exceptions for each field. The exception report contains each field description, the commitment status indicator, and the number of exceptions for that field. Also, the grand total of exceptions found within the file is printed at the beginning of the report. The option to print each record containing an exception also exists.

Voucher Specimens

From item number 21, computer programs were executed to list taxonomic information. Rita Horner requested the tax code listings for her voucher specimens in FT024 (FT124) and FT028. A printed listing of the entire file with taxonomic names was delivered to Dr. Horner.

Predator/Prey Products

The following item is mentioned in Section II, Number 22.

The program PL031 was created to fill a request by Mr. David G. Roseneau of LGL Alaska for Common murre and Thick-billed murre stomach analysis. Mr. Roseneau's request for listings of both Murre species encompassed all of Jerry Sanger's (RU341) FT031 data.

Using PL031, the desired predator tax codes are selected. Each predator code selected is printed as a taxonomic code number followed by the taxonomic name. The predator code is followed by its associated prey information. The prey information associated with each selected predator code is listed as the prey tax code, number of entries, and the taxonomic name. Totals for each predator are placed at the end of the prey list--the number of unique prey and the total number of prey. PL031 is presently only applicable to file type 031. With this program, it is possible to isolate a predator and its prey within a file of numerous predators and their prey. A product example is included in the appendix.

IV. Problems

A. Conversion of FT023 to FT123 requires PI assistance. Many PI's are no longer funded by OCSEAP.

B. The BLM staff may require assistance which impacts data checking.

C. Conversion of pre-Alaskan taxonomic codes requires new master files, new computer programs, and new operating procedures. NODC is funding this task.

D. WANG Laboratories is delinquent in sending a firm and final quotation on the WANG 2200 upgrade.

E. With all the reorganizations in OMPA/OCSEAP, who is in charge of data management?

V. Computer Programs

The cornerstone of the data processing activities is computer programming. Computer programs have been written in WANG BASIC2 language. Sixty-one new checking programs were written, installed, and tested during this reporting period. Twenty-two utility programs were created, and fourteen analysis programs were developed. A list of these OCSEAP checking programs and utility programs is noted below.

NEW OCSEAP PROGRAMS

April 1979 to Present

MXMN031
MXMN032
MXMN023
CD040
SD040
SD025
SD023
SD031
SD032
CFILE040
SL032
SL031
TXE031
CFILE030
CD030
EX030
STAT040
START(030)
ID030
TC030
TFILE030

DEN040
PTAX040
SVTAX040
SL023
EX024
EX028
CFILE024
CD024
CD124
EX124
SVDEN040
SUM
SUM032
CAT030
TAXCAT30
CNDEN040
CFILE123
CD123
BL123
START(123)

TC123
TFILE123
CAT-ARR
TAXCAT40
CATNAME
CAT028
TAXCAT28
PL031
SUM023
ID123
BL030
TX030
PFILE(030)
SD030
EX123
TXE123
PFILE(123)
RX023
SUM030
SUM031
PFILE(023)

NEW UTILITY PROGRAMS

April 1979 to Present

TAXTEST
RASEARCH
WRTSEQ
TAXZERO
REFORM
SL-ANY
SL-ALL

STASQ
RTSQ
EDIT
SEARCH
AQUADI
QUADI2
PCBLANK

INITZ
MAKEFILE
COUNTCD
TX-SPL
TC-MANY
NUMCHECK
PREPFILE

The checking program status to date is noted in the following table.

OCSEAP DATA CHECK PROGRAMS

Name	FT023	FT025	FT030	FT031	FT032	FT123
START	X	X	X	X	X	X
IDxxx	X	X	X	X	X	X
TCxxx	X	X	X	X	X	X
TFILExxx	X	X	X	X	X	X
TXExxx	X	X	X	X	X	–
TXxxx	X	X	X	X	X	NA
PCxxx	?	X	NA	X	NA	–
SQxxx	X	X	X	X	X	–
RAxxx	X	X	–	X	X	–
BLxxx	X	X	X	X	X	X
RLxxx	–	X	–	–	–	–
CFILExxx	X	X	X	X	X	X
CDxxx	X	X	X	X	X	X
SLxxx	X	X	–	X	X	–
SDxxx	X	X	X	X	X	–
SUMxxx	X	X	X	X	X	–
EXxxx	X	X	X	X	X	X
MXMNxxx	X	–	–	X	X	–
RXxxx	X	NA	NA	NA	NA	NA
PFILE	X	X	X	X	X	X

Legend

X = completed
? = format design problems
– = to be developed
NA = not applicable

VI. Data Processing Summary

Using the utility and checking programs developed to date, the Anchorage Data Processing Facility staff has expanded the data processing scope. New data types were assigned for preprocessing and checking. The NODC has compiled all data sets in FT023, Fishery Resource Assessment, and FT030, Intertidal Biology, and forwarded these data on crunch tapes. Principal investigators have used the professional expertise in expediting data submissions to the NODC data base. The processing tasks are the foundation upon which all future data products will be developed.

The table below notes the data processing milestones and status of data in Anchorage during the reporting period. The preprocessing for fisheries data in FT023 was a significant activity but does not appear in the statistics. Data edits for bird specimen data in FT031 was also important but does not appear in the "Processed" column.

OCSEAP DATA PROCESSING SUMMARY

1979/1980

	Received	Processed	Forwarded	Data in Processing
FT023	210	0*	0*	212
FT024/124	36	3	3	0
FT025	20	40	40	0
FT027	17	17	17	0
FT028	62	5	5	0
FT029	5	5	5	0
FT030	31	0	0	31
FT031	75	0	0	75
FT032	21	0	0	44
FT033	15	15	15	0
FT038/034	1	2	2	0
FT040	0	33	33	0
TOTAL	493	120	120	362

*Does not include extensive preprocessing of RU552 and RU512 data.

PROCESSING ACTION BREAKDOWN

Total Data Sets	=	Total PI Have Action	+	Total Short-Term (Anchorage)	+	Total Long-Term (Anchorage)
362		97		84		181

PROCESSING CATEGORIES

	In Hold	Active	Long
FT023	0	31	181
FT030	0	31	0
FT031	74	1	0
FT032	23	21	0

Figure 1 graphically displays the data processing activity (excluding FT023) during the reporting period. The file types are noted along the x axis and number of data sets along the y axis. Four categories are displayed. Figure 2 breaks down the data "to be processed" by file type. Figure 3 notes the response needed to final process the data in Anchorage now. Twenty-seven percent require action by principal investigators. Figure 4 displays the processing to be completed by file type. "In hold" category notes the data sets which require PI action.

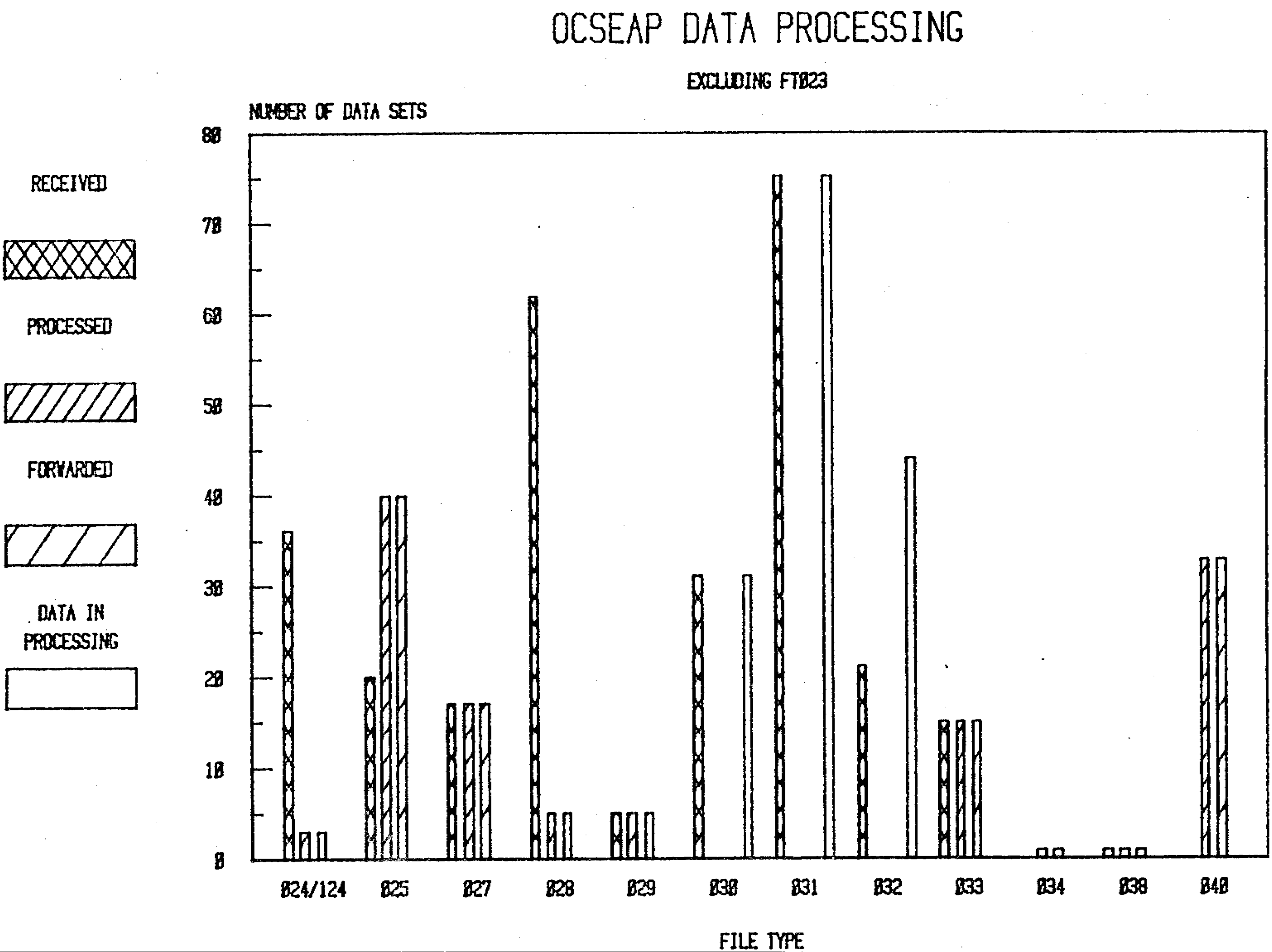
OCSEAP DATA PROCESSING
EXCLUDING FT023
NUMBER OF DATA SETS
RECEIVED
PROCESSED
FORWARDED
DATA IN PROCESSING
0
10
20
30
40
50
60
70
80
024/124
025
027
028
029
030
031
032
033
034
038
040
FILE TYPE

Figure 1

OCSEAP DATA IN PROCESSING
1979/1980

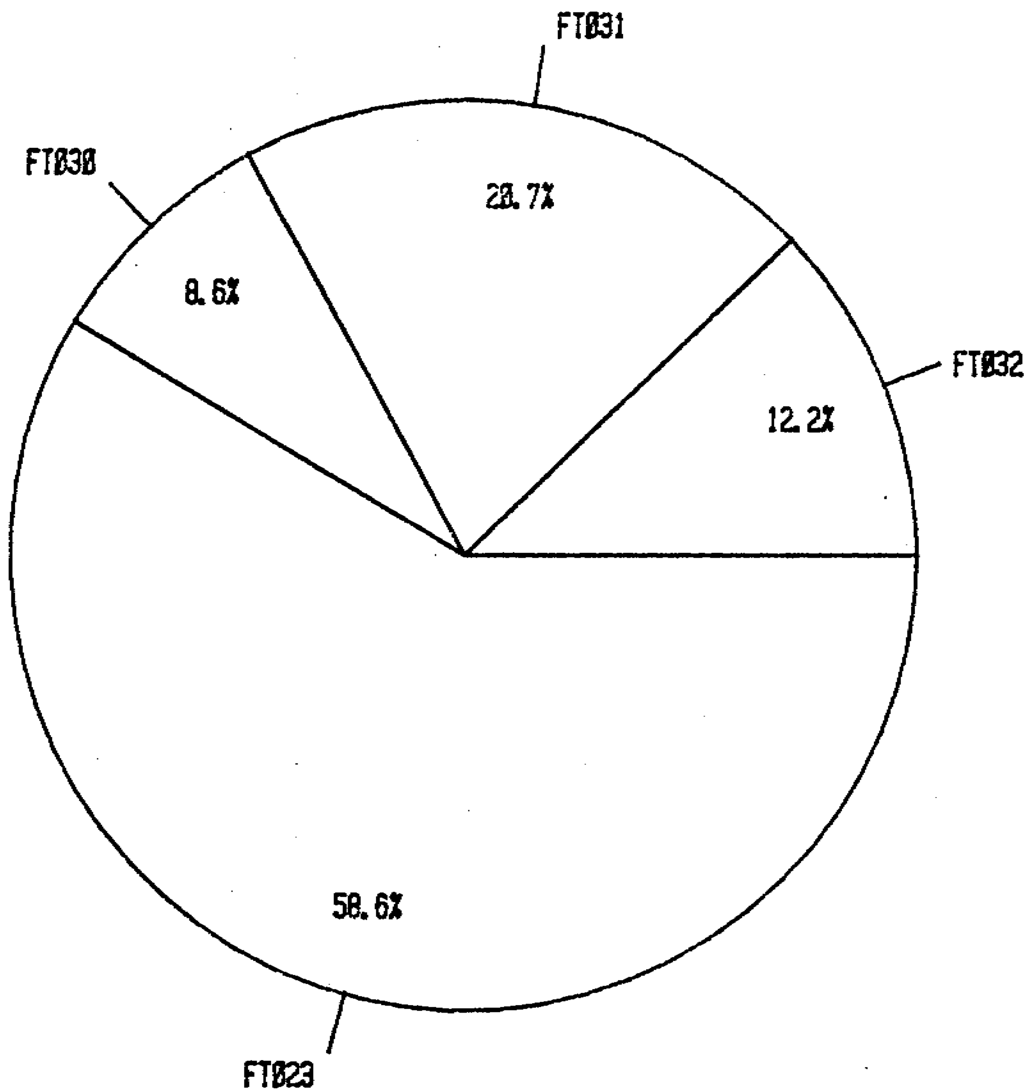

Figure 2

PROCESSING ACTION BREAKDOWN

1979/1980

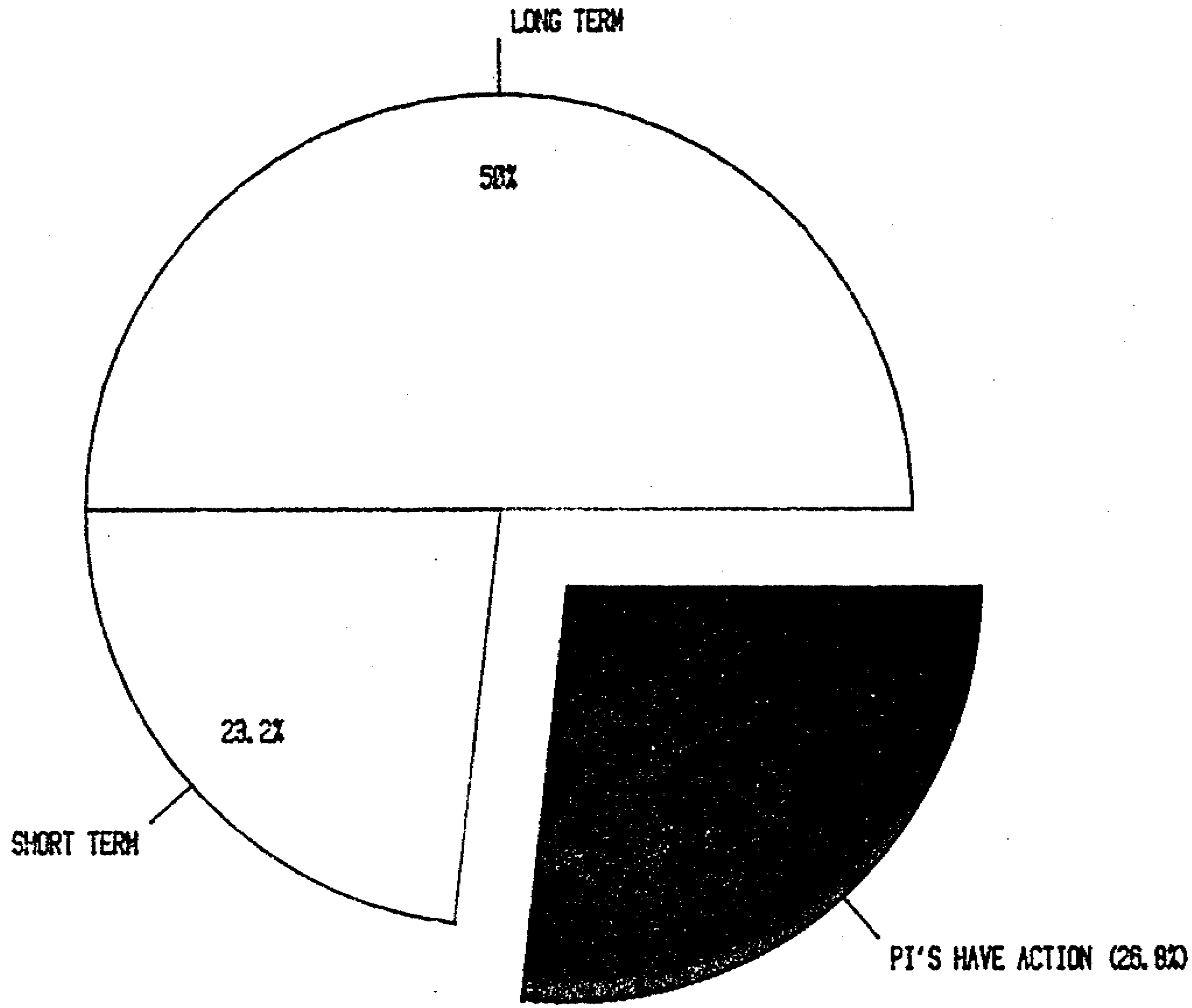

Figure 3

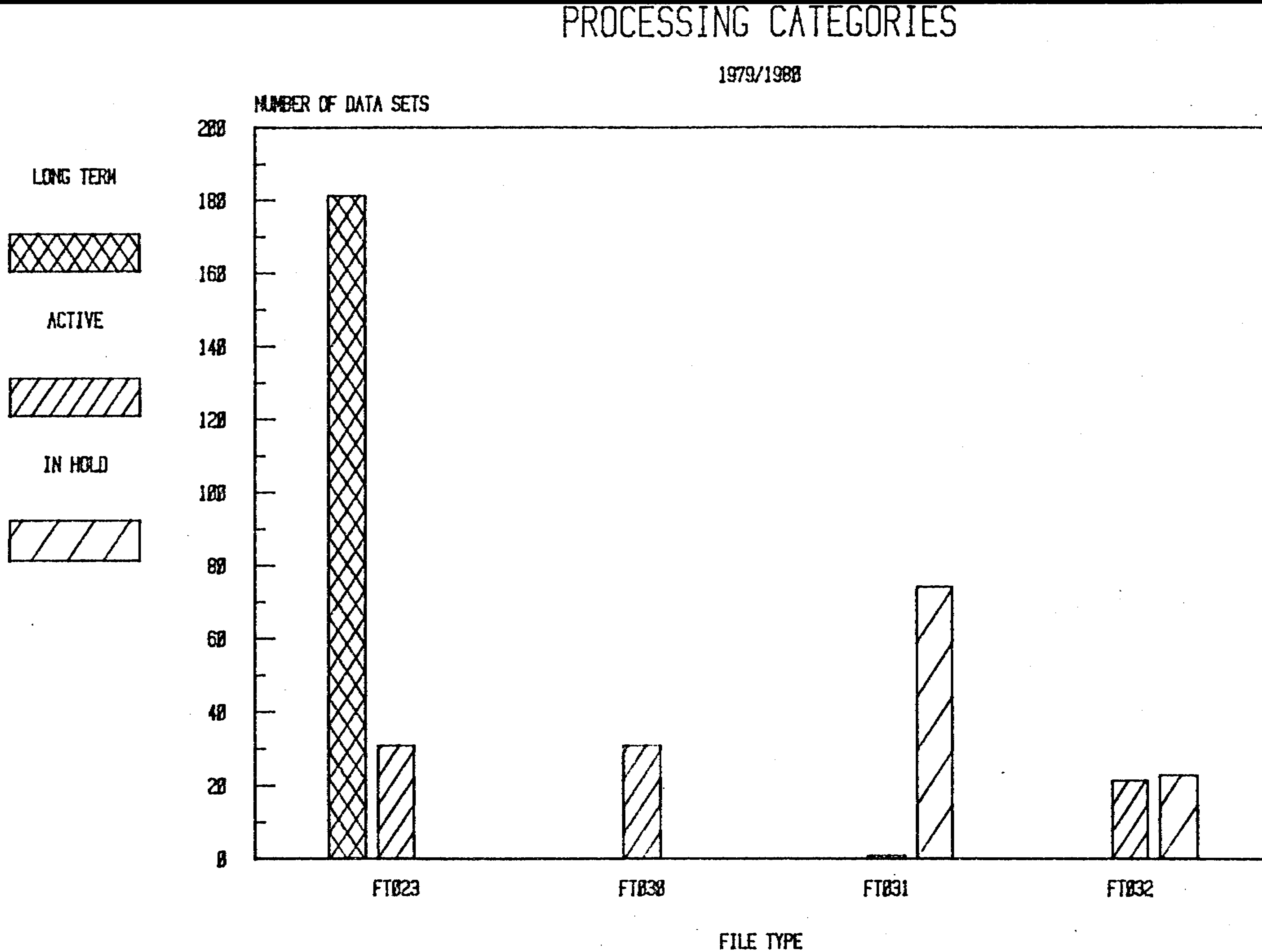
PROCESSING CATEGORIES
1979/1980
NUMBER OF DATA SETS
200
180
160
140
120
100
80
60
40
20
0
LONG TERM
ACTIVE
IN HOLD
FT023
FT030
FT031
FT032
FILE TYPE

Figure 4

Figure 5 summarizes the activity in data processing for the reporting period. Figure 6 displays the data sets received during this year. Figure 7 examines the data received excluding the fishery data (which is placed in the long-term processing category). OCSEAP management should realize that many types of data are processed in Anchorage. Taxonomic codes can be checked and converted, if necessary, for all biological file types.

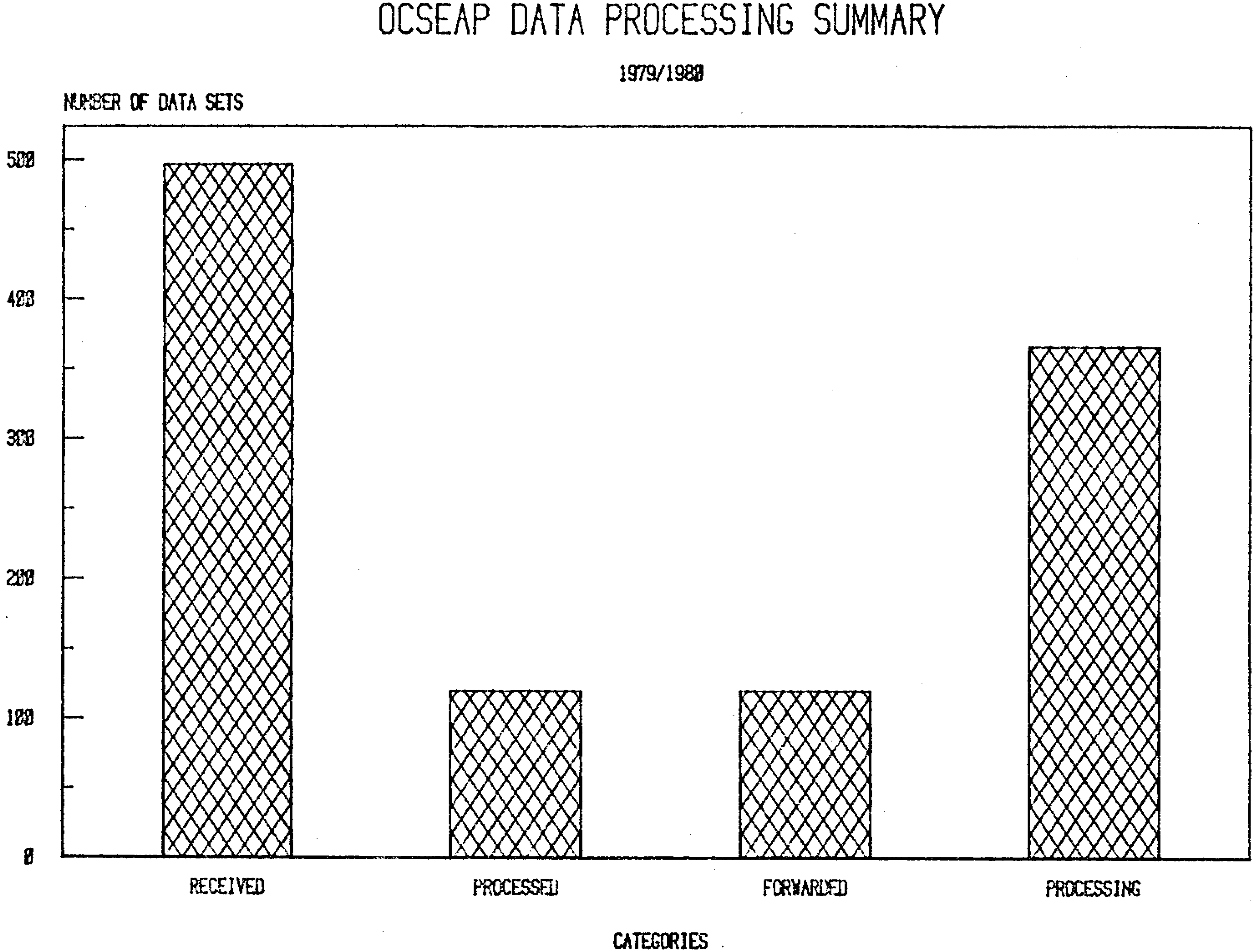
OCSEAP DATA PROCESSING SUMMARY
1979/1980
NUMBER OF DATA SETS
500
400
300
200
100
0
RECEIVED
PROCESSED
FORWARDED
PROCESSING
CATEGORIES

Figure 5

OCSEAP DATA RECEIVED

1979/1980

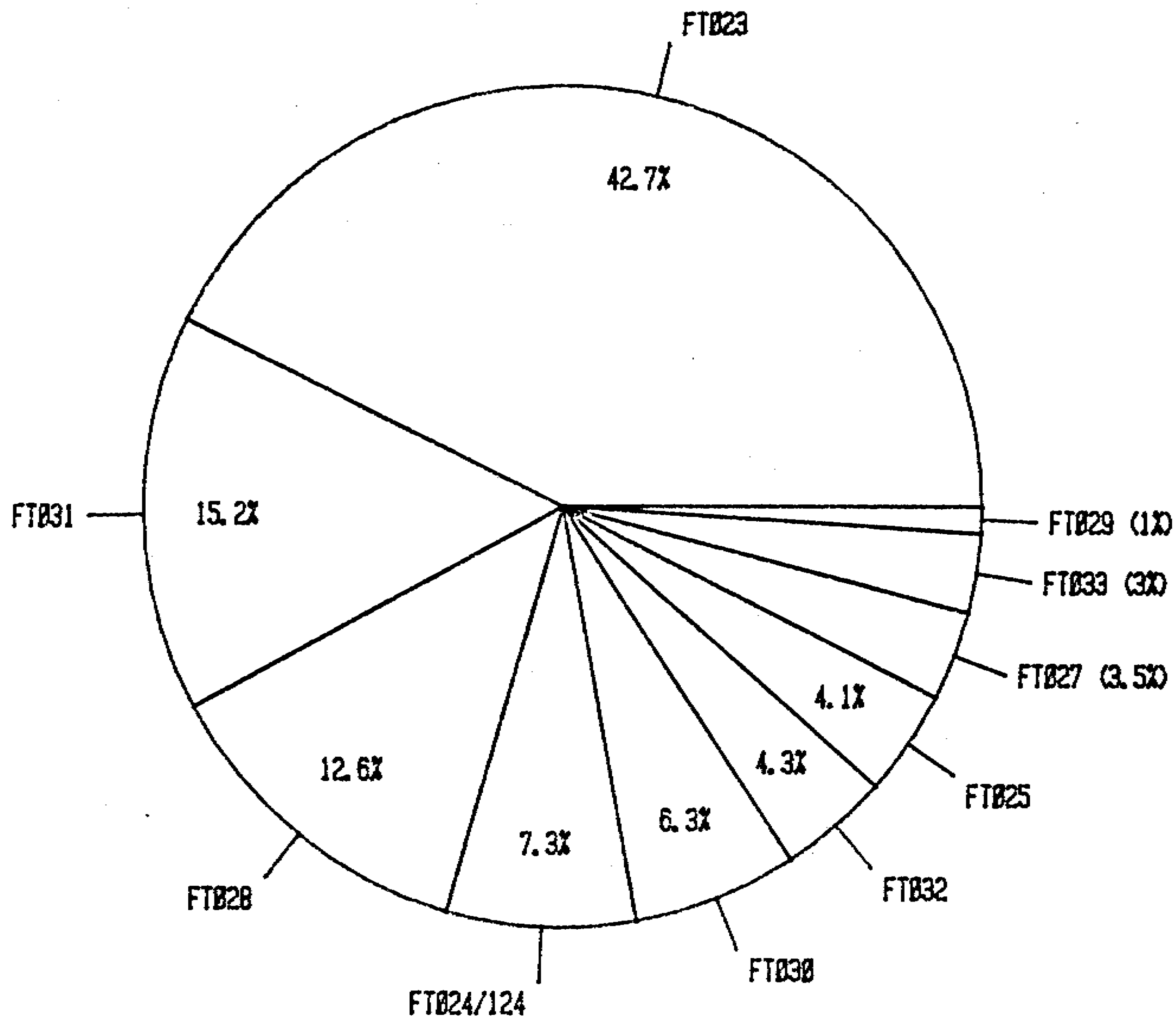

Figure 6

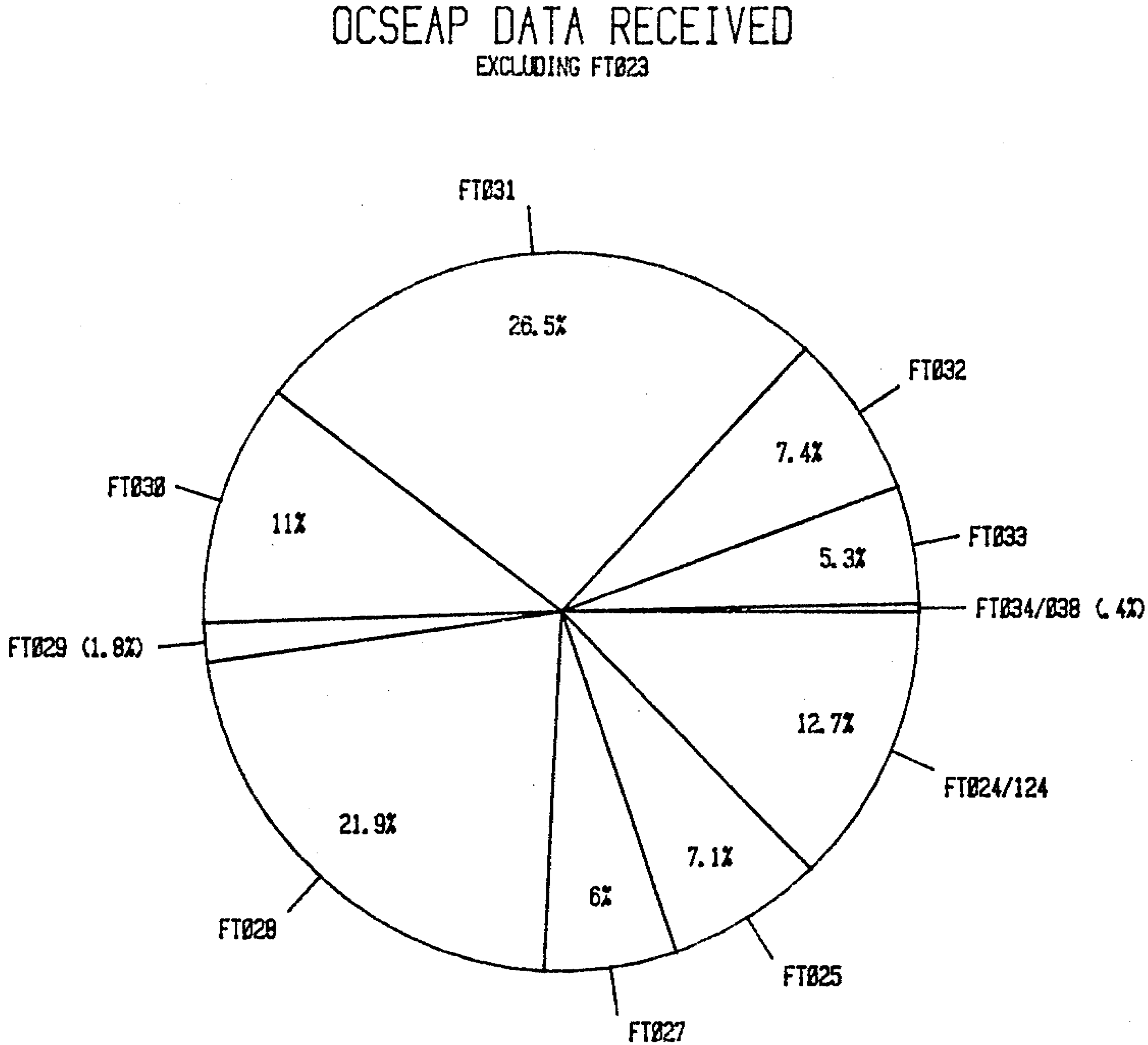
OCSEAP DATA RECEIVED
EXCLUDING FT023
FT031
26.5%
FT032
7.4%
FT033
5.3%
FT034/038 (.4%)
12.7%
FT024/124
7.1%
FT025
6%
FT027
21.9%
FT028
FT029 (1.8%)
11%
FT030

Figure 7

VII. Computer Program Documentation

The utility programs and the checking programs for file type 031 have been documented to date. The remaining checking programs will be completed this fiscal year. This task is an important part of computer program development. Future users may require a detailed description of the logic implicit in the program. Several OCSEAP action items in the past have emphasized documented products and services. The computer documentation is an integral part of this product annotation.

In the last year, an extensive effort to document all existing computer programs and related operating procedures was initiated. The documentation is designed to accomplish three purposes, which are as follows:

1. Provide the end user with a detailed description of each available computer product and the program logic used to obtain each computer product
2. Provide the computer operator with all information necessary to successfully execute each program
3. Provide the programmers with an indepth explanation of each program's logic, variable assignments, and sub-routine functions. This facilitates timely updates and revisions.

All computer programs have been divided into the three following categories:

1. Utility programs
2. Analysis programs
3. Check programs

The utility programs were designed to do generalized data checking and manipulation, internal file maintenance, internal record keeping, and data editing. The analysis programs were primarily developed for Mr. Arneson of RU003 to help with his bird data analysis. The check programs are specialized data checking programs designed specifically for each file type.

The program documentation is formatted as follows:

1. A brief description of the purpose of the program
2. A detailed description of the program logic
3. An explanation of all variable assignments
4. An explanation of each subroutine and its function

All utility programs and analysis programs have been documented. The check program documentation is a continuing task, with 18 of 132 programs documented.

Our Hewlett-Packard 2647A graphics terminal has been installed as of February. All graphic displays included in this report were produced by the graphics terminal using a menu-driven program called "Multiplot."

VIII. Milestone Chart

A. Staff recruitment - 2 April 1980 - data control clerk
B. New FT123 check programs will be written and installed in June 1980 and September 1980.
C. Computer graphic display programs will be developed from April 1980 to March 1981.
D. Taxonomic conversion file will be developed with funds from NODC and be operational by May 1980.
E. Data processing for biological file types will continue throughout the next reporting period.
F. New BLM taxonomic files will be developed for birds and mammals (three weeks after receipt of information).
G. Parameter Checklist will be updated in August through October 1980.
H. OS/6 telecommunication will be implemented in April 1980.
I. Digital code file will be maintained routinely during the next reporting period.
J. Histographic programs will be written for the WANG 2200.
K. Data products for Rita Horner, Ron Smith, and others will be delivered in FY80.

IX. Appendix

TOTAL LEASE AREA & LIST

	TAXONOMIC NAME	AK CODE	NODC CODE	57	60	70	71	75	83	85	55
06	PANDALUS BOREALIS *(PINK SHRIMP)	5333040101	6179180101		X	X		X	X		)
07	PANDALUS GONIURUS *(HUMPY SHRIMP)	5333040102	6179180102		X	X		X	X		
09	PANDALUS PLATYCEROS *(SPOT SHRIMP)	5333040105	6179180105		X	X		X	X		
10	PANDALUS HYPSINOTUS *(COONSTRIPE SHRIMP)	5333040106	6179180106		X	X		X	X		
11	PANDALOPSIS DISPAR *(SIDESTRIPE SHRIMP)	5333040204	6179180204		X	X		X	X		
12	PARALITHODES CAMTSCHATICA *(KING CRAB)	5333120701	6183080701	X	X	X		X	X	X	
13	CHIONOECETES OPILIO *(TANNER CRAB OPILIO)	5333170301	6187010301	X	X	X		X	X	X	
14	CHIONOECETES BAIRDI *(TANNER CRAB BAIRDI)	5333170302	6187010302	X	X	X		X	X	X	)
16	CANCER MAGISTER *(DUNGENESS CRAB)	5333180104	6188030104		X	X		X			)
17	CLUPEA HARENGUS PALLASI (PACIFIC HERRING)	7903010201	874701020101	X		X		X	X	X	)
18	ONCORHYNCHUS GORBUSCHA (PINK SALMON)	7904010201	8755010201			X		X	X		)
19	ONCORHYNCHUS KETA (CHUM SALMON)	7904010202	8755010202			X		X	X		)
20	ONCORHYNCHUS KISUTCH (COHO SALMON)	7904010203	8755010203			X		X	X		)
21	ONCORHYNCHUS NERKA (SOCKEYE SALMON)	7904010205	8755010205			X		X	X		)
22	ONCORHYNCHUS TSHAWYTSCHA (CHINOOK SALMON)	7904010206	8755010206			X		X	X		)
23	MALLOTUS VILLOSUS (CAPELIN)	7904020201	8755030201	X		X		X	X	X	
24	ARCTOGADUS GLACIALIS (POLAR COD)	7909020102	8791030102	X		X	X	X	X	X	
25	BOREOGADUS SAIDA (ARCTIC COD)	7909020201	8791030201	X		X	X	X	X	X	
26	ELEGINUS GRACILIS (SAFFRON COD)	7909020301	8791030301	X		X	X	X	X	X	
:01	GADUS MACROCEPHALUS (PACIFIC COD)	7909020401	8791030401	X		X	X	X	X	X	
:02	MICROGADUS PROXIMUS (PACIFIC TOMCOD)	7909020601	8791030601	X		X	X	X	X	X	
:03	THERAGRA CHALCOGRAMMA (WALLEYE POLLOCK)	7909020701	8791030701	X		X	X	X	X	X	)
:04	MERLUCCIUS PRODUCTUS (PACIFIC HAKE)	7909020501	8791040102	X		X	X	X	X	X	)
:05	SEBASTES	79150101	88260101	X	X	X	X	X	X	X	
:06	SEBASTES ALUTUS (PACIFIC OCEAN PERCH)	7915010102	8826010102			X		X	X		)
:07	PLEUROGRAMMUS MONOPTERYGIUS (ATKA MACKEREL)	7915020301	8827010501	X		X		X	X		
:08	ANOPLOPOMA FIMBRIA (SABLEFISH)	7915030101	8827020101	X		X		X	X	X	)
:09	ATHERESTHES STOMIAS (ARROWTOOTH FLOUNDER)	7917020102	8857040102	X		X	X	X	X	X	)
:10	EOPSETTA JORDANI (PETRALE SOLE)	7917020401	8857040401	X		X	X	X	X	X	
:11	GLYPTOCEPHALUS ZACHIRUS (REX SOLE)	7917020501	8857040501	X		X	X	X	X	X	
:12	LIMANDA ASPERA (YELLOWFIN SOLE)	7917021001	8857040901	X		X	X	X	X	X	)
:13	LIOPSETTA GLACIALIS (ARCTIC FLOUNDER)	7917021101	8857041001	X		X	X	X	X	X	
:14	PLATICHTHYS STELLATUS (STARRY FLOUNDER)	7917021501	8857041401	X		X	X	X	X	X	
:15	HIPPOGLOSSUS STENOLEPIS (PACIFIC HALIBUT)	7917020701	8857041901	X		X	X	X	X	X	)

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	TAXONOMIC NAME	AK CODE	NODC CODE
0112	PARALITHODES CAMTSCHATICA	5333120701	6183080701
0113	CHIONOECETES OPILIO	5333170301	6187010301
0114	CHIONOECETES BAIRDI	5333170302	6187010302
0115	CHIONOECETES ANGULATUS	5333170303	6187010303
0117	CLUPEA HARENGUS PALLASI (PACIFIC HERRING)	7903010201	874701020101
0123	MALLOTUS VILLOSUS (CAPELIN)	7904020201	8755030201
0124	ARCTOGADUS GLACIALIS (POLAR COD)	7909020102	8791030102
0125	BOREOGADUS SAIDA (ARCTIC COD)	7909020201	8791030201
0126	ELEGINUS GRACILIS (SAFFRON COD)	7909020301	8791030301
0201	GADUS MACROCEPHALUS (PACIFIC COD)	7909020401	8791030401
0202	MICROGADUS PROXIMUS (PACIFIC TOMCOD)	7909020601	8791030601
0203	THERAGRA CHALCOGRAMMA (WALLEYE POLLOCK)	7909020701	8791030701
0204	MERLUCCIUS PRODUCTUS (PACIFIC HAKE)	7909020501	8791040102
0205	SEBASTES	79150101	88260101
0207	PLEUROGRAMMUS MONOPTERYGIUS (ATKA MACKEREL)	7915020301	8827010501
0208	ANOPLOPOMA FIMBRIA (SABLEFISH)	7915030101	8827020101
0209	ATHERESTHES STOMIAS (ARROWTOOTH FLOUNDER)	7917020102	8857040102
0210	EOPSETTA JORDANI (PETRALE SOLE)	7917020401	8857040401
0211	GLYPTOCEPHALUS ZACHIRUS (REX SOLE)	7917020501	8857040501
0212	LIMANDA ASPERA (YELLOWFIN SOLE)	7917021001	8857040901
0213	LIOPSETTA GLACIALIS (ARCTIC FLOUNDER)	7917021101	8857041001
0214	PLATICHTHYS STELLATUS (STARRY FLOUNDER)	7917021501	8857041401
0215	HIPPOGLOSSUS STENOLEPIS (PACIFIC HALIBUT)	7917020701	8857041901

LCI SPRING SEC.1 ORIG. DATA PAGE 1

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....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....

0101 040FG76051L  10604202N1512000W7605031939   53116    A51480 30516N
0102 040FG76052L  10          72       9929+18 2       03 8          4-
0103 040FG76054L  10    19128020113            173A320               Q        1    MEGU
0104 040FG76054L  10    29112010301           2073A320                        4    CAGO
0105 040FG76055L  10    1OBSERVERS WERE D. ERIKSON AND W. BALLARD
0106 040FG76055L  10    2PLATFORM TYPE: BEAVER ON FLOATS FOR COUNT UNITS
0107 040FG76055L  10    3FOR ENTIRE SURVEY
0108 040FG76051L  20603433N1511301W7605031933   63108    A51480 30516N
0109 040FG76052L  20          72       9929+13 2       03 8          4-
0110 040FG76054L  20    19128020113           1973A320                        1    MEGU
0111 040FG76054L  20    29128020113           90734301                        4    MEGU
0112 040FG76054L  20    3912802         03   300734301                        6    GULL
0113 040FG76054L  20    4912802         03     573A320                        1    GULL
0114 040FG76054L  20    59128020108            173A320                        1    HEGU
0115 040FG76054L  20    69112010301           3573A320                        1    CAGO
0116 040FG76054L  20    79112010910           40737303                        1    GWTE
0117 040FG76054L  20    89112010907            2737303                        1    PINT
0118 040FG76054L  20    99126           01    65737303                        5    SMSH
0119 040FG76054L  20    109108010101           173A301                        1    RNGR
0120 040FG76054L  20    1191100401      02     173A301                        1    SMCO
0121 040FG76054L  20    129128020113          237B7301                        8    MEGU
0122 040FG76054L  20    139128020103         3237B7301                        6    GWGU
0123 040FG76054L  20    149112010907           57BA320                        1    PINT
0124 040FG76051L  40602735N1511700W7605031918   53161    A51480 30500N
0125 040FG76052L  40          72       9929+13 2       03 8          4-
0126 040FG76054L  40    19112011303            273A301                        1    SUSC
0201 040FG76054L  40    29112010301            473A320                        1    CAGO
0202 040FG76054L  40    39112010907            573A303                        1    PINT
0203 040FG76054L  40    49128020103            1734301                        1    GWGU
0204 040FG76054L  40    591120118              873A301                        1    SCOT
0205 040FG76051L  50602246N1512000W7605031908   33 35    A51480 305 4N
0206 040FG76052L  50          72       9929+18 2       03 8          4-
0207 040FG76054L  50    19128020108            3734301                        1    HEGU
0208 040FG76054L  50    2912802         03     3734301                        1    GULL
0209 040FG76054L  50    39128020113            4734301                        1    MEGU
0210 040FG76051L  30603201N1511303W7605031927   63     121E51480 30534N
0211 040FG76052L  30          72       9929+13 2       03 8          4-
0212 040FG76054L  30    19128020103           25AB7301                        9    GWGU
0213 040FG76054L  30    29128020113           35AB7301                        1    MEGU
0214 040FG76054L  30    3912802         03     2AB7320                        1    GULL
0215 040FG76054L  30    49112012101            18BA303                        1    COME
0216 040FG76054L  30    59112010907            43BA303                        1    PINT
0217 040FG76054L  30    69112010901            68BA303                        1    MALL
0218 040FG76054L  30    791120112       01     4AFA303                        1    GOLD
0219 040FG76054L  30    891120109            600AB7803                        5    DABB
0220 040FG76054L  30    9911201         02     158B7801                        1    DUCK
0221 040FG76054L  30    109112010601         435AB7801                        9    SNGO
0222 040FG76054L  30    119112010601         923AB7803                        9    SNGO
0223 040FG76054L  30    129120010102          45AB7803                        2    SHCR
0224 040FG76054L  30    139128020108           3AF7803                        1    MEGU
0225 040FG76054L  30    149112010301          548B7803                        5    CAGO
0226 040FG76054L  30    159113021002           1AF5320               Q        1    BAEA
0301 040FG76054L  30    169113021101           18B7820                        1    MAHA
0302 040FG76051L  4A602215N1511725W7605031911   32       63E51480 305 4N
0303 040FG76052L  4A          72       9929+13 2       03 8          4-
0304 040FG76054L  4A    191120102             27AB7501                        1    SWAN
0305 040FG76054L  4A    29112010910           75AFA301                        3    GWTE
0306 040FG76054L  4A    39120010102          140AB7803                        9    SHCR
0307 040FG76054L  4A    49112010907          2628BA303                        4    PINT
0308 040FG76054L  4A    59112010901          2348BA303                        4    MALL
0309 040FG76054L  4A    691120111       01    92ABA301                        5    SCAU
0310 040FG76054L  4A    791120121              1ABA303                        1    MERC
0311 040FG76054L  4A    891120103             308B7803                        8    DABB
0312 040FG76054L  4A    9911201         02    228B7801                        4    DUCK
0313 040FG76054L  4A    109112010601         270AB7803                        4    SNGO
0314 040FG76054L  4A    119112010301          59AB7503                        5    CAGO
0315 040FG76054L  4A    129128020103          22AB3301                        4    GWGU
0316 040FG76054L  4A    139128020113           1AB5301                        1    MEGU
0317 040FG76054L  4A    14912802        03   3108B7801                        6    GULL
0318 040FG76054L  4A    159107010103           28BA301                        1    ARLO
0319 040FG76054L  4A    169126          01    608B7503                        9    SMSH
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LCI SPRING SEC.3 ORIG. DATA PAGE 1

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....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....
0602 040FG76051L 120594256N1514846W7505032048   92161    A51480 30513N
0603 040FG76052L 120             72       9929+13 2        03 8            4+
0604 040FG76054L 120    19112011304          1473A301                                1     BLSC
0605 040FG76054L 120    29112011301           173A301                                1     OLDS
0606 040FG76054L 120    39129010302          3473A301                                1     PICU
0607 040FG76054L 120    49128020113          6973B301                                1     MEGU
0608 040FG76054L 120    591070101             873A301                                1     LOON
0609 040FG76054L 120    691120113             573A301                                1     SCOT
0610 040FG76054L 120    79112011803          9073A301                                4     SUSC
0611 040FG76054L 120    89112011502          1373A301                                1     WWSC
0612 040FG76054L 120    99112011401          1473A303                                1     HARL
0613 040FG76054L 120   109107010101           773A301                                1     COLO
0614 040FG76054L 120   1191080101             173A301                                1     GREB
0615 040FG76054L 120   1291290103             173A301                                1     MURR
0616 040FG76054L 120   13912901        03     673A302                                1     MULE
0617 040FG76054L 120   14912901        01     173A301                                1     SMAL
0618 040FG76054L 120   159110040102           2736301                                1     DCCO
0619 040FG76054L 120   1691100401      02     2736301                                1     SMCO
0620 040FG76054L 120   17911201        04     573A301                                1     SEDU
0621 040FG76054L 120   189112011601           873A301                                1     STEI
0622 040FG76054L 120   1991120117             873A301                                1     EIDE
0623 040FG76054L 120   2091100401      02     173A320                                1     SMCO
0624 040FG76054L 120   219128020103           573B301                                1     GWGU
0625 040FG76054L 120   229105010102           173A302                                1     HOGR
0626 040FG76054L 120   239128020113           273A320                                1     MEGU
0701 040FG76054L 120   24912802        03    1073A301                                1     GULL
0702 040FG76051L 130593331N1512324W7505032057   33191    A51480 30512N
0703 040FG76052L 130             72       9929+13 2        03 8            4+
0704 040FG76054L 130    191100401             8731100                                1     CORM
0705 040FG76054L 130    2912802        03    39731100                                B     GULL
0706 040FG76054L 130    39112011401          1173A303                                1     HARL
0707 040FG76054L 130    491120113            2073A301                                4     SCOT
0708 040FG76054L 130    5911201        04     473A301                                1     SEDU
0709 040FG76054L 130    69128020103          26731100                                B     GWGU
0710 040FG76054L 130    79112011701          4373A301                                B     COEI
0711 040FG76054L 130    89112012102           373A301                                1     RBME
0712 040FG76054L 130    99112011303         13773A301                                6     SUSC
0713 040FG76054L 130   109112011304          2373A301                                1     BLSC
0714 040FG76054L 130   1191290103             373A301                                1     MURR
0715 040FG76054L 130   129128020113           2731100                                1     MEGU
0716 040FG76054L 130   139107010101           1731100                                1     COLO
0717 040FG76054L 130   149112011301          27731100                                B     OLDS
0718 040FG76054L 130   15912901        01     173A300                                1     SMAL
0719 040FG76054L 130   1691080101             173A300                                1     GREB
0720 040FG76055L 130    1COUNT UNITS 13 AND 14 COMBINED.
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LCI SPRING SECT01 CAT-MERGE PAGE 1

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     ....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....

0101 040FG76051L  10604202N1512000W7605031939   53116     A51480 30516N
0102 040FG76052L  10         72       9929+18 2      03 8          4-
0103 040FG76055L  10     1OBSERVERS WERE D. ERIKSON AND W. BALLARD
0104 040FG76055L  10     2PLATFORM TYPE: BEAVER ON FLOATS FOR COUNT UNITS
0105 040FG76055L  10     3FOR ENTIRE SURVEY
0106 140FG76054L  10      91120102           20                  SWANS & GEESE
0107 140FG76054L  10      91280101            1                  JAEGER & GULL
0108 040FG76051L  20603433N1511901W7605031933   63108     A51480 30516N
0109 040FG76052L  20         72       9929+18 2      03 8          4-
0110 140FG76054L  20      91080101            1                  GREBES
0111 140FG76054L  20      91100401            1                  CORMORANTS
0112 140FG76054L  20      91120102           35                  SWANS & GEESE
0113 140FG76054L  20      91120109           47                  DABBLERS
0114 140FG76054L  20      9127030103         65                  SHOREBIRDS
0115 140FG76054L  20      91280101         1271                  JAEGER & GULL
0116 040FG76051L  40602735N1511700W7605031918   93161     A51480 30500N
0117 040FG76052L  40         72       9929+18 2      03 8          4-
0118 140FG76054L  40      91120102            4                  SWANS & GEESE
0119 140FG76054L  40      91120109            5                  DABBLERS
0120 140FG76054L  40      9112011301         10                  SEADUCKS
0121 140FG76054L  40      91280101            1                  JAEGER & GULL
0122 040FG76051L  50602246N1512000W7605031908   33 35     A51480 305 4N
0123 040FG76052L  50         72       9929+18 2      03 8          4-
0124 140FG76054L  50      91280101           10                  JAEGER & GULL
0125 040FG76051L  30603201N1511303W7605031927   63      121E51480 30534N
0126 040FG76052L  30         72       9929+18 2      03 8          4-
0201 140FG76054L  30      91120102         1412                  SWANS & GEESE
0202 140FG76054L  30      91120109          610                  DABBLERS
0203 140FG76054L  30      9112011101          4                  DIVERS
0204 140FG76054L  30      91120121            1                  MERGANSERS
0205 140FG76054L  30      9113                2                  RAPTORS
0206 140FG76054L  30      9120010102         45                  CRANES
0207 140FG76054L  30      91280101           65                  JAEGER & GULL
0208 140FG76054L  30      91584602           15                  OTHER BIRDS
0209 040FG76051L  4A602215N1511725W7605031911   32       63E51480 305 4N
0210 040FG76052L  4A         72       9929+18 2      03 8          4-
0211 140FG76054L  4A      91070101            2                  LOONS
0212 140FG76054L  4A      91120102          356                  SWANS & GEESE
0213 140FG76054L  4A      91120109          651                  DABBLERS
0214 140FG76054L  4A      9112011101         92                  DIVERS
0215 140FG76054L  4A      91120121            1                  MERGANSERS
0216 140FG76054L  4A      9120010102        148                  CRANES
0217 140FG76054L  4A      9127030103         60                  SHOREBIRDS
0218 140FG76054L  4A      91280101          333                  JAEGER & GULL
0219 140FG76054L  4A      91584602           22                  OTHER BIRDS
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LCI SPRING SEC.3 CAT MERGE PAGE 1

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     ....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....

0101 040FG76051L 120594256N1514846W7605032048   92161     A51480 30513N
0102 040FG76052L 120         72       9929+18 2      03 8          4+
0103 140FG76054L 120      91070101           15                  LOONS
0104 140FG76054L 120      91080101            2                  GREBES
0105 140FG76054L 120      91100401            5                  CORMORANTS
0106 140FG76054L 120      9112011301        164                  SEADUCKS
0107 140FG76054L 120      91280101           86                  JAEGER & GULL
0108 140FG76054L 120      912901             42                  ALCIDS
0109 040FG76051L 130593831N1513324W7605032057   83191     A51480 30512N
0110 040FG76052L 130         72       9929+18 2      03 8          4+
0111 040FG76055L 130     1COUNT UNITS 13 AND 14 COMBINED.
0112 140FG76054L 130      91070101            1                  LOONS
0113 140FG76054L 130      91080101            1                  GREBES
0114 140FG76054L 130      91100401            8                  CORMORANTS
0115 140FG76054L 130      9112011301        270                  SEADUCKS
0116 140FG76054L 130      91120121            3                  MERGANSERS
0117 140FG76054L 130      91280101           67                  JAEGER & GULL
0118 140FG76054L 130      912901              4                  ALCIDS
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STATION NO.		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS	NEW RT	ST	KILOMETERS
L 10	SECTION #1	21	2.4464	2	8	A	4.2 SQ
L 20		1420	59.2258	6	8	A	3.9 SQ
L 40		20	0.3393	4	8	A	5.9 SQ
L 50		10	7.7220	1	8	A	1.2 SQ
L 30		2154	22.2520	8	7	E	12.1 SQ
L 4A		1665	29.3650	9	7	E	6.3 SQ
		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS			
		5290	27.1209	30			
L 60	SECTION #2	12	2.1913	1	8	A	5.4 SQ
L 70		202	5.5937	4	8	A	9.0 SQ
L 90		84	22.2575	3	8	A	1.2 SQ
L 100		2759	60.1336	7	8	A	6.5 SQ
L 110		136	4.0303	8	8	A	4.2 SQ
		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS			
		3193	23.5898	23			
L 120	SECTION #3	314	8.7851	6	8	A	5.9 SQ
L 130		354	7.1559	7	8	A	7.0 SQ
		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS			
		668	7.3079	13			
L 150	SECTION #4	2484	96.4585	8	8	A	3.2 SQ
L 160		3228	74.5306	7	8	A	6.1 SQ
L 170		3150	185.0763	5	8	A	3.4 SQ
L 190		1519	77.7538	8	8	A	2.4 SQ
L 19A		38	1.7466	6	8	A	3.6 SQ
L 200		33	11.1486	2	8	A	1.4 SQ
L 210		308	30.1605	4	8	A	2.5 SQ
L 220		495	19.7030	7	8	A	3.5 SQ
L 230		371	20.3801	6	8	A	3.0 SQ
L 240		468	18.2520	9	8	A	2.8 SQ
L 250		89	2.1553	9	8	A	4.5 SQ
L 260		3	0.5813	1	8	A	4.4 SQ
L 270		102	3.1906	8	8	A	3.9 SQ
L 28A		968	45.1071	10	8	A	2.1 SQ
L 180		5614	22.3665	10	7	E	25.1 SQ
L 20A		253	70.2777	6	7	E	0.6 SQ
		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS			
		19123	43.0320	106			
L 280	SECTION #5	565	65.8201	4	8	A	2.1 SQ
L 290		53	4.3394	5	8	A	2.1 SQ
L 29A		31	9.9742	6	8	A	0.5 SQ
L 29B		98	7.5772	5	8	A	2.5 SQ
L 29C		153	32.0553	3	8	A	1.5 SQ
L 30A		228	2.7883	10	8	A	8.1 SQ
L 310		173	2.3032	10	8	A	7.5 SQ
L 320		171	2.7282	11	8	A	5.6 SQ
L 32A		7	4.7297	1	8	A	1.4 SQ
L 33B		11	29.7297	2	8	A	0.1 SQ
L 330		33	2.0503	3	8	A	5.3 SQ
L 33D		42	35.4729	2	8	A	0.5 SQ
L 33E		70	34.3980	5	8	A	0.4 SQ
L 340		100	3.3366	9	8	A	3.3 SQ
L 350		290	29.5767	5	8	A	1.9 SQ
L 360		572	56.2162	5	8	A	2.0 SQ

LCI SPRING SEC-1 DENSITY PAGE

.....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....*....

0101	140FG76058L	10	91120102	20	4.660	SWANS & CEESE
0102	140FG76058L	10	91280101	1	.233	JAEGER & GULL
0103	140FG76058L	20	91080101	1	.250	GREBES
0104	140FG76058L	20	91100401	1	.250	CORMORANTS
0105	140FG76058L	20	91120102	35	8.759	SWANS & GEESE
0106	140FG76058L	20	91120109	47	11.762	DABBLERS
0107	140FG76058L	20	9127030103	65	16.266	SHOREBIRDS
0108	140FG76058L	20	91280101	1271	318.068	JAEGER & GULL
0109	140FG76058L	40	91120102	4	.671	SWANS & GEESE
0110	140FG76058L	40	91120109	5	.839	DABBLERS
0111	140FG76058L	40	9112011301	10	1.679	SEADUCKS
0112	140FG76058L	40	91280101	1	.168	JAEGER & GULL
0113	140FG76058L	50	91280101	10	7.722	JAEGER & GULL
0114	140FG76057L	30	91120102	1412	116.694	SWANS & GEESE
0115	140FG76057L	30	91120109	610	50.413	DABBLERS
0116	140FG76057L	30	9112011101	4	.331	DIVERS
0117	140FG76057L	30	91120121	1	.083	MERGANSERS
0118	140FG76057L	30	9113	2	.165	RAPTORS
0119	140FG76057L	30	9120010102	45	3.719	CRANES
0120	140FG76057L	30	91280101	65	5.372	JAEGER & GULL
0121	140FG76057L	30	91584602	15	1.240	OTHER BIRDS
0122	140FG76057L	4A	91070101	2	.317	LOONS
0123	140FG76057L	4A	91120102	356	56.508	SWANS & GEESE
0124	140FG76057L	4A	91120109	651	103.333	DABBLERS
0125	140FG76057L	4A	9112011101	92	14.603	DIVERS
0126	140FG76057L	4A	91120121	1	.159	MERGANSERS
0201	140FG76057L	4A	9120010102	148	23.492	CRANES
0202	140FG76057L	4A	9127030103	60	9.524	SHOREBIRDS
0203	140FG76057L	4A	91280101	333	52.857	JAEGER & GULL
0204	140FG76057L	4A	91584602	22	3.492	OTHER BIRDS

LCI SPRING SEC-3 DENSITY PAGE

....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....*....

0101	140FG76058L	120	91070101	15	2.518	LOONS
0102	140FG76058L	120	91080101	2	.336	GREBES
0103	140FG76058L	120	91100401	5	.839	CORMORANTS
0104	140FG76058L	120	9112011301	164	27.531	SEADUCKS
0105	140FG76058L	120	91280101	86	14.437	JAEGER & GULL
0106	140FG76058L	120	912901	42	7.051	ALCIDS
0107	140FG76058L	130	91070101	1	.142	LOONS
0108	140FG76058L	130	91080101	1	.142	GREBES
0109	140FG76058L	130	91100401	8	1.132	CORMORANTS
0110	140FG76058L	130	9112011301	270	38.206	SEADUCKS
0111	140FG76058L	130	91120121	3	.425	MERGANSERS
0112	140FG76058L	130	91280101	67	9.481	JAEGER & GULL
0113	140FG76058L	130	912901	4	.566	ALCIDS

LCI SEC.1-SCNDENDENSITY 040 PAGE 1

STATION NO.		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS	CONSTANT USED 34.0
L 10		21	0.3088	2	
L 20		1420	6.9607	6	
L 40	SECTION	20	0.1470	4	
L 50	#1	10	0.2941	1	
L 30		2154	7.9191	8	
L 4A		1665	5.4411	9	
GRAND TOTALS		5290	5.1862	30	

STATION NO.		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS	CONSTANT USED 34.0
L 60		12	0.3529	1	
L 70	SECTION	202	1.4852	4	
L 90	#2	84	0.8235	3	
L 100		2759	11.5924	7	
L 110		136	0.5000	8	
GRAND TOTALS		3193	4.0831	23	

STATION NO.		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS	CONSTANT USED 13.1
L 120	SECTION	314	3.9949	6	
L 130	#3	354	3.8604	7	
GRAND TOTALS		668	3.9224	13	

STATION NO.		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS	CONSTANT USED 73.1
L 150		2484	4.2476	8	
L 160		3228	6.3083	7	
L 170		3150	8.6183	5	
L 190		1519	2.5974	8	
L 19A	SECTION	38	0.0866	6	
L 200		33	0.2257	2	
L 210	#4	308	1.0533	4	
L 220		495	0.9673	7	
L 230		371	0.8458	6	
L 240		468	0.7113	9	
L 250		89	0.1352	9	
L 260		3	0.0410	1	
L 270		102	0.1744	8	
L 28A		968	1.3242	10	
L 180		5614	7.6798	10	
L 20A		253	0.5768	6	
GRAND TOTALS		19123	2.4679	106	

STATION NO.		TOTAL INDIVIDUALS	AVERAGE DENSITY	NO. RECORDS	CONSTANT USED 78.0
L 280		565	1.8108	4	
L 290		53	0.1353	5	
L 29A		31	0.0662	6	
L 29B		98	0.2512	5	
L 29C		153	0.6538	3	
L 30A		228	0.2923	10	
L 310		173	0.2217	10	
L 320	SECTION	171	0.1993	11	
L 32A	#5	7	0.0897	1	
L 33B		11	0.0705	2	
L 330		33	0.1410	3	
L 33D		42	0.2692	2	
L 33E		70	0.1794	5	
L 340		100	0.1424	9	
L 350		290	0.7435	5	
L 360		572	1.4666	5	

LCI SPR. SEC.1 CONSTANT DEN. PAGE

....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....*....9

0101	140FG76050L	10	91120102	20	.588	SWANS & GEESE
0102	140FG76050L	10	91280101	1	.029	JAEGER & GULL
0103	140FG76050L	20	91080101	1	.029	GREBES
0104	140FG76050L	20	91100401	1	.029	CORMORANTS
0105	140FG76050L	20	91120102	35	1.029	SWANS & GEESE
0106	140FG76050L	20	91120109	47	1.382	DABBLERS
0107	140FG76050L	20	9127030103	65	1.912	SHOREBIRDS
0108	140FG76050L	20	91280101	1271	37.382	JAEGER & GULL
0109	140FG76050L	40	91120102	4	.118	SWANS & GEESE
0110	140FG76050L	40	91120109	5	.147	DABBLERS
0111	140FG76050L	40	9112011301	10	.294	SEADUCKS
0112	140FG76050L	40	91280101	1	.029	JAEGER & GULL
0113	140FG76050L	50	91280101	10	.294	JAEGER & GULL
0114	140FG76050L	30	91120102	1412	41.529	SWANS & GEESE
0115	140FG76050L	30	91120109	610	17.941	DABBLERS
0116	140FG76050L	30	9112011101	4	.118	DIVERS
0117	140FG76050L	30	91120121	1	.029	MERGANSERS
0118	140FG76050L	30	9113	2	.059	RAPTORS
0119	140FG76050L	30	9120010102	45	1.324	CRANES
0120	140FG76050L	30	91280101	65	1.912	JAEGER & GULL
0121	140FG76050L	30	91584602	15	.441	OTHER BIRDS
0122	140FG76050L	4A	91070101	2	.059	LOONS
0123	140FG76050L	4A	91120102	356	10.471	SWANS & GEESE
0124	140FG76050L	4A	91120109	651	19.147	DABBLERS
0125	140FG76050L	4A	9112011101	92	2.706	DIVERS
0126	140FG76050L	4A	91120121	1	.029	MERGANSERS
0201	140FG76050L	4A	9120010102	148	4.353	CRANES
0202	140FG76050L	4A	9127030103	60	1.765	SHOREBIRDS
0203	140FG76050L	4A	91280101	333	9.794	JAEGER & GULL
0204	140FG76050L	4A	91584602	22	.647	OTHER BIRDS

LCI SPR. SEC.3 CONSTANT DEN. PAGE

....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....*....9

0101	140FG76050L	120	91070101	15	1.145	LOONS
0102	140FG76050L	120	91080101	2	.153	GREBES
0103	140FG76050L	120	91100401	5	.382	CORMORANTS
0104	140FG76050L	120	9112011301	164	12.519	SEADUCKS
0105	140FG76050L	120	91280101	86	6.565	JAEGER & GULL
0106	140FG76050L	120	912901	42	3.206	ALCIDS
0107	140FG76050L	130	91070101	1	.076	LOONS
0108	140FG76050L	130	91080101	1	.076	GREBES
0109	140FG76050L	130	91100401	8	.611	CORMORANTS
0110	140FG76050L	130	9112011301	270	20.611	SEADUCKS
0111	140FG76050L	130	91120121	3	.229	MERGANSERS
0112	140FG76050L	130	91280101	67	5.115	JAEGER & GULL
0113	140FG76050L	130	912901	4	.305	ALCIDS

....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8....*....9....

LOWER COOK INLET, SPRING, SECTION #1, SUMMARY OF ALL SPECIES CATEGORIES PRESENT.

		SEQ#	CATEGORY #	# BIRD	AVG DENSITY	CATEGORY NAME	# RECORDS
040	9	1	91070101	2	.317	LOONS	1
040	9	2	91080101	1	.250	GREBES	1
040	9	3	91100401	1	.250	CORMORANTS	1
040	9	4	91120102	1827	37.458	SWANS & GEESE	5
040	9	5	91120109	1313	41.587	DABBLERS	4
040	9	6	9112011101	96	7.467	DIVERS	2
040	9	7	9112011301	10	1.679	SEADUCKS	1
040	9	8	91120121	2	.121	MERGANSERS	2
040	9	9	9113	2	.165	RAPTORS	1
040	9	10	9120010102	193	13.606	CRANES	2
040	9	11	9127030103	125	12.895	SHOREBIRDS	2
040	9	12	91280101	1681	64.070	JAEGER & GULL	6
040	9	13	91584602	37	2.366	OTHER BIRDS	2
	GRAND TOTALS			5290	27.120		30

LOWER COOK INLET, SPRING, SECTION #2, SUMMARY OF ALL SPECIES CATEGORIES PRESENT.

		SEQ#	CATEGORY #	# BIRD	AVG DENSITY	CATEGORY NAME	# RECORDS
040	9	14	91070101	2	.516	LOONS	2
040	9	15	91080101	1	.153	GREBES	1
040	9	16	91100401	1	.237	CORMORANTS	1
040	9	17	91120102	39	2.197	SWANS & GEESE	3
040	9	18	9112011101	27	4.123	DIVERS	1
040	9	19	9112011301	2664	106.527	SEADUCKS	4
040	9	20	91120121	3	.711	MERGANSERS	1
040	9	21	9120010102	2	.222	CRANES	1
040	9	22	91280101	323	17.020	JAEGER & GULL	5
040	9	23	912901	17	1.340	ALCIDS	2
040	9	24	91584602	114	8.957	OTHER BIRDS	2
	GRAND TOTALS			3193	23.689		23

LOWER COOK INLET, SPRING, SECTION #3, SUMMARY OF ALL SPECIES CATEGORIES PRESENT.

		SEQ#	CATEGORY #	# BIRD	AVG DENSITY	CATEGORY NAME	# RECORDS
040	9	25	91070101	16	1.330	LOONS	2
040	9	26	91080101	3	.239	GREBES	2
040	9	27	91100401	13	.986	CORMORANTS	2
040	9	28	9112011301	434	32.869	SEADUCKS	2
040	9	29	91120121	3	.425	MERGANSERS	1
040	9	30	91280101	153	11.959	JAEGER & GULL	2
040	9	31	912901	46	3.809	ALCIDS	2
	GRAND TOTALS			668	7.908		13

LOWER COOK INLET, SPRING, SECTION #4, SUMMARY OF ALL SPECIES CATEGORIES PRESENT.

		SEQ#	CATEGORY #	# BIRD	AVG DENSITY	CATEGORY NAME	# RECORDS
040	9	32	91070101	7	.429	LOONS	4
040	9	33	91080101	14	1.076	GREBES	4
040	9	34	91100401	21	.694	CORMORANTS	8
040	9	35	91120102	1034	96.839	SWANS & GEESE	3
040	9	36	91120109	658	10.442	DABBLERS	10
040	9	37	9112011101	3557	77.049	DIVERS	13
040	9	38	9112011301	5536	93.415	SEADUCKS	15
040	9	39	91120121	356	13.422	MERGANSERS	10
040	9	40	9113	3	.273	RAPTORS	2
040	9	41	9127030103	5214	70.225	SHOREBIRDS	8
040	9	42	91280101	2425	74.690	JAEGER & GULL	13
040	9	43	912901	44	3.283	ALCIDS	5
040	9	44	9158450601	65	6.207	CORVIDS	4
040	9	45	91584602	189	6.181	OTHER BIRDS	7
	GRAND TOTALS			19123	43.032		106

SPECIAL PREDATOR PREY RELATION P

L031

PREDATOR 9129010301 URIA AALGE (COMMON MURRE) NO. OF TIMES 2

PREY TAX CODE	NO. OF ENTRIES	NAME
28	1	PTEROPHYTA
500124	2	NEREIDAE
5707	2	THEUTHIDIDA OEGOPSIDA
61	5	ARTHROPODA MANDIBULATA CRUSTACEA
61530101	1	ACANTHOMYSIS
6153011507	11	NEOMYSIS RAYII
6169	1	PERACARIDA AMPHIPODA GAMMARIDEA
616921	1	GAMMARIDAE
61693403	1	ANONYX
61740209	3	SPECIES GROUP##THYSANOESSA
6174020902	4	THYSANOESSA INERMIS
6174020906	2	THYSANOESSA RASCHII HOM.1
6175	1	EUCARIDA DECAPODA(ARTHROPODA)
6179	3	EUCARIDA DECAPODA PLEOCYEMATA CARIDEA
61791604	1	EUALUS
617918	3	PANDALIDAE
61791801	2	PANDALUS
6179180101	6	PANDALUS BOREALIS
6179180102	1	PANDALUS GONIURUS
61792201	1	SPECIES GROUP##CRANGON
6179220107	3	CRANGON FRANCISCORUM
62	1	INSECTA I
874701020101	1	CLUPEA HARENGUS PALLASI (PACIFIC HERRING)
875503	11	OSMERIDAE (SMELTS)
87550302	1	MALLOTUS
8755030201	57	MALLOTUS VILLOSUS (CAPELIN)
879103	34	SPECIES GROUP##GADIDAE (CODFISHES AND HAKES)
8791030401	1	GADUS MACROCEPHALUS (PACIFIC COD)
8791030601	2	MICROGADUS PROXIMUS (PACIFIC TOMCOD)
8791030701	27	THERAGRA CHALCOGRAMMA (WALLEYE POLLOCK)
879999	46	SPECIES GROUP###GNATHOSTOMATA I
8840010201	5	TRICHODON TRICHODON (PACIFIC SANDFISH)
884212	1	STICHAEIDAE (PRICKLEBACKS)
8842120902	2	LUMPENUS SAGITTA (SNAKE PRICKLEBACK)
8842120903	3	LUMPENUS MACULATUS
8845010101	29	AMMODYTES HEXAPTERUS (PACIFIC SAND LANCE)
885704	1	PLEURONECTIDAE (RIGHTEYE FLOUNDER)

UMBER UNIQUE PREY 37 NUMBER OF PREY 277

PREDATOR 9129010302 URIA LOMVIA (THICK-BILLED MURRE) NO. OF TIMES 6

PREY TAX CODE	NO. OF ENTRIES	NAME
500124	1	NEREIDAE
51	1	GASTROPODA
57	29	CEPHALOPODA
61	1	ARTHROPODA MANDIBULATA CRUSTACEA
6113	1	COPEPODA CALANOIDA
6169	1	PERACARIDA AMPHIPODA GAMMARIDEA
617001	1	HYPERIIDAE
6170011002	4	PARATHEMISTO LIBELLULA HOM.1
6170011003	2	PARATHEMISTO PACIFICA
617402	1	SPECIES GROUP##EUPHAUSIIDAE
6174020902	3	THYSANOESSA INERMIS
6175	1	EUCARIDA DECAPODA(ARTHROPODA)
6179180102	2	PANDALUS GONIURUS
61792201	1	SPECIES GROUP##CRANGON
8755030201	3	MALLOTUS VILLOSUS (CAPELIN)
879103	6	SPECIES GROUP##GADIDAE (CODFISHES AND HAKES)
8791030201	1	BOREOGADUS SAIDA (ARCTIC COD)
8791030701	3	THERAGRA CHALCOGRAMMA (WALLEYE POLLOCK)
879999	7	SPECIES GROUP###GNATHOSTOMATA I
8845010101	4	AMMODYTES HEXAPTERUS (PACIFIC SAND LANCE)

UMBER UNIQUE PREY 20 NUMBER OF PREY 73

TOTAL PREY 350

....*....1....*....2....*....3....*....4....*....5..8....*....9....*..

0101	0280809771	17119	N15759 W7708020225+09	102	
0102	1280809776	1	05007020901	291000	CHAETOCEROS
0103	1280809776	1	05007031001	124000	NITZSCHIA
0104	1280809776	1	05018888888	50000	MICROFLAGELLATES
0105	1280809776	1	0501204	6000	DINOPHYCEAE
0106	1280809776	1	10007020901	185000	CHAETOCEROS
0107	1280809776	1	10007031001	104000	NITZSCHIA
0108	1280809776	1	10018888888	55000	MICROFLAGELLATES
0109	1280809776	1	1001204	2000	DINOPHYCEAE
0110	1280809776	1	15007020901	362000	CHAETOCEROS
0111	1280809776	1	15007031001	80000	NITZSCHIA
0112	1280809776	1	15018888888	54000	MICROFLAGELLATES
0113	1280809776	1	1501204	4000	DINOPHYCEAE
0114	1280809776	1	20007020901	1517000	CHAETOCEROS
0115	1280809776	1	20007031001	202000	NITZSCHIA
0116	1280809776	1	20018888888	102000	MICROFLAGELLATES
0117	1280809776	1	2001204	12000	DINOPHYCEAE
0118	1280809776	1	25007020901	2532000	CHAETOCEROS
0119	1280809776	1	25007031001	284000	NITZSCHIA
0120	1280809776	1	25018888888	59000	MICROFLAGELLATES
0121	1280809776	1	2501204	23000	DINOPHYCEAE
0122	1280809776	1	30007020901	2900000	CHAETOCEROS
0123	1280809776	1	30007031001	166000	NITZSCHIA
0124	1280809776	1	30018888888	104000	MICROFLAGELLATES
0125	1280809776	1	3001204	28000	DINOPHYCEAE
0126	1280809776	1	45007020901	7866000	CHAETOCEROS
0201	1280809776	1	45007031001	396000	NITZSCHIA
0202	1280809776	1	45018888888	111000	MICROFLAGELLATES
0203	1280809776	1	4501204	17000	DINOPHYCEAE
0204	0280809771	27122	N16004 W7708021615+09	48	
0205	1280809776	2	00007020901	1456000	CHAETOCEROS
0206	1280809776	2	00007031001	28000	NITZSCHIA
0207	1280809776	2	00018888888	174000	MICROFLAGELLATES
0208	1280809776	2	0001204	6000	DINOPHYCEAE
0209	1280809776	2	07007020901	1902400	CHAETOCEROS
0210	1280809776	2	07007031001	48000	NITZSCHIA
0211	1280809776	2	07018888888	86400	MICROFLAGELLATES
0212	1280809776	2	0701204	6400	DINOPHYCEAE
0213	1280809776	2	11007020901	2400000	CHAETOCEROS
0214	1280809776	2	11007031001	59200	NITZSCHIA
0215	1280809776	2	11018888888	110400	MICROFLAGELLATES
0216	1280809776	2	1101204	6400	DINOPHYCEAE
0217	1280809776	2	22007020901	644800	CHAETOCEROS
0218	1280809776	2	22007031001	91200	NITZSCHIA
0219	1280809776	2	22018888888	145600	MICROFLAGELLATES
0220	1280809776	2	2201204	11200	DINOPHYCEAE
0221	1280809776	2	27007020901	2238400	CHAETOCEROS
0222	1280809776	2	27007031001	507200	NITZSCHIA
0223	1280809776	2	27018888888	110400	MICROFLAGELLATES
0224	1280809776	2	2701204	3200	DINOPHYCEAE
0225	1280809776	2	35007020901	1171200	CHAETOCEROS
0226	1280809776	2	35007031001	971200	NITZSCHIA
0301	1280809776	2	35018888888	14400	MICROFLAGELLATES
0302	1280809776	2	3501204	22400	DINOPHYCEAE
0303	1280809776	2	45007020901	2147200	CHAETOCEROS
0304	1280809776	2	45007031001	1204800	NITZSCHIA
0305	1280809776	2	45018888888	209600	MICROFLAGELLATES
0306	1280809776	2	4501204	6400	DINOPHYCEAE
0307	0280809771	37124	N16200 W7708031430+09	46	
0308	1280809776	3	00007020901	408000	CHAETOCEROS
0309	1280809776	3	00007031001	202000	NITZSCHIA
0310	1280809776	3	00018888888	260000	MICROFLAGELLATES
0311	1280809776	3	04007020901	299200	CHAETOCEROS
0312	1280809776	3	04007031001	136000	NITZSCHIA
0313	1280809776	3	04018888888	144000	MICROFLAGELLATES
0314	1280809776	3	0401204	3200	DINOPHYCEAE
0315	1280809776	3	08007020901	265600	CHAETOCEROS

Annual Report
April, 1979 - March, 1980
RU 516
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A COMPUTERIZED ENVIRONMENTAL MAPPING SYSTEM FOR THE SYNTHESIS AND INTEGRATION OF INTERDISCIPLINARY INFORMATION IN THE BEAUFORT SEA

PART II (SEA ICE SUBSYSTEM): COMPUTERIZED PREDICTION SYSTEM FOR SEA ICE AS AN ENVIRONMENTAL HAZARD

VOLUME 1

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William J. Stringer and Hannah Pavlik

Based on W.J. Stringer's data

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OBJECTIVES

The objectives of the work are to summarize and evaluate the environmental hazards for OCS development posed by sea ice in the Beaufort Sea. Our synthesis mapping system, which was helpful in the delineation of submarine permafrost as an environmental hazard, are used to generate a series of source, derived, interpretive and composite maps addressing sea ice hazards. Source maps include data on sea ice distribution, location of leads, cracks, ridges, polynyas and flows and other variables for the different seasons during the years 1973-77. Derived' maps generate secondary information such as the orientation, dimensions and density of ice ridges, leads, cracks, polynyas and other characterisitics. Derived" and Interpretive maps show the intensity of each ice phenomen development and density of the ice motion features as a result of multivariable evaluation. Composite maps will show the sensitivity of various OCS development activities to sea ice features; for example, the sensitivity of gravel causeways, elevated pipelines, grounded barges and ice island structures to ice movement. The final product will be a candidate area map showing areas where sea ice is likely to cause problems for OCS development. This map will assign probability values to hazard areas in the Beaufort Sea.

Creation of the data bank and analysis of the existing sea ice data, collected mostly by W.J. Stringer (1978) and from the other OCSEAP sources using computerized methods, are the major part of the program. Secondary data in the form of maps are generated to help with the multidisciplinary evaluations. The sea ice data are organized as a sea ice subsystem of our environmental hazard mapping system. The last one is a mechanism for the synthesis and integration of interdisciplinary information in which the sea ice is one of the major components.

The next step is to include into this system not only other hazards but the biological data (biological subsystem); for instance, on marine mammals (bowhead whales and other), their ways of migration, habitats and so on. Only through the comprehensive computerized analysis of all components of the environment in the Beaufort Sea can we define the sensitivity of the wild marine life to the events which take place due to OCS oil and gas development.

And this is only a way for defining optimum strategies to minimize the conflicts between the energy resource development and preservation of the ecosystem and human activities in the lease areas and all over the Alaskan Shelf.

RESULTS

The assessment of the sea ice hazards in quantitative terms in the Beaufort Sea, particularly in the lease area, is a major goal of our analysis of the sea ice subsystem of the computerized environmental mapping system.

During April, 1979 - March, 1980, a great deal of the ice morphology data has been digitized and placed into the computeriezed data bank which includes all the data on sea water, submarine permafrost and sea bottom topography and geology. Fifty-seven source and derived maps have also been produced during this period. These are three generations of maps in the scale 1:250,000 (for the lease area) and 1:1,000,000 (for the whole Beaufort Sea). They are included into the "Atlas" as Volume 2 of this report. The comprehensive analysis of them will be done in the final report together with the maps of other generations (interpretive, composite and candidate).

In the preparation of this annual report, the following people took part: Principal Investigator, M. Vigdorchik; W.J. Stringer; Research Assistant, H. Pvalik (from July, 1979); Graphic Artist, J. Adams; and Computer Programmer, B. Schollar. D. Nappier and CU student C. Bruce also worked during January-March, 1980, digitizing the data.

INTRODUCTION

In order to determine where future development should take place, land use planners need to assess whether various human and industrial activities can be supported by the environment. Though much environmental data in the Beaufort Sea has already been collected, it has not always been put into a format which can be easily used to identify land use potentials. The computerized synthesis mapping system presented in this report is an easy-to-use tool for analyzing complex environmental relationships in a quantitative way. It is particularly useful for the environmental assessment of regions involved in the development of petroleum resources on the north slope and shelf of Alaska.

The synthesis mapping procedure has many advantages, which include:

- It assembles and organizes existing data from several disciplines.
- It provides a quantitative method of evaluating the sensitivity and interdependence of various components of the environment.
- It defines the response of the environment to industrial development and ecological disturbance.
- It describes the restrictions that environmental hazards place on various industrial activities.
- It provides a systematic approach to a comprehensive land use plan for any region.
- It produces a series of land capability maps that are useful to planners and decision makers.

It is our contention that conflicts between industrial development (especially of energy resources), preservation of the ecosystems and human activities can be minimized. Conflicts arise in situations where no integrated method of keeping all components of the environment in balance exists. Systems involving computerized synthesis mapping are necessary for defining optimum strategies for the integrated development of the environment.

The organization of large-scale environmental investigations into a computerized framework has many distinct advantages. Computerized data management systems are useful not only for the easy storage and monitoring of environmental information, but particularly for generating new secondary data that can lead to the quantitative evaluation of multidisciplinary problems. For land users needs, such evaluations must be presented in the form of computer generated environmental maps (source, derived, interpretive and composite maps). Usually, the information needed for analyzing an environmental problem by this method consists of:

1. mappable data; that is, geographically dispersed data in map form;
2. decision logic showing how "source" data is organized into "derived" product; and
3. analytical procedures and computer techniques for evaluating the results of the analysis.

The analysis generally consists of the quantitative assessment of all existing data, and it yields conclusions that are stated in terms of probability.

The emphasis of this work is on the evaluation of hazards associated with oil and gas exploration activities in the Beaufort Sea, Alaska, particularly with respect to the location and dynamics of the sea ice as an environmental hazard on the continental shelf.

ASSESSING THE ENVIRONMENTAL IMPACT OF SOIL AND GAS DEVELOPMENT ON THE ALASKAN OUTER CONTINENAL SHELF

History and Objectives

In May, 1974, the Bureau of Land Management (BLM) of the U.S. Department of the Interior officially requested that the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce initiate a scientific research program focused upon the environmental assessment of the Northeastern Gulf of Alaska. This request was made in antidipation of proposed oil and gas lease sales in that region scheduled for early 1976. In October of 1974, a major expansion of the environmental assessment program was requested by BLM and eight areas were proposed as additions to the Alaskan Outer Continental Shelf (OCS). An intensive planning effort including workshops, public comment and consultations with more than 300 scientists and other interested persons followed. The outcome of these activities was the formulation of an integrated Program Development Plan (PDP) wich was completed in December, 1976. The PDP bring into one interagency document the environmental study program for all proposed lease areas of the Alaskan OCS (Fig. 1). The primary objective of the Outer Continental Shelf Environmental Assessment Program (OCSEAP) is to provide timely environmental data to BLM for decisions on leasing, exploration, development and production of the petroleum reserves of the Alaskan OCS. Information about possible environmental hazards or sensitive areas must be evaluated before tracts are selected for leasing. After leasing, environmental information is needed to establish operating regulations and long-term monitoring programs which focus upon detection of possible changes in the environment resulting from development.

In order to provide BLM with necessary input to accomplish its OCS leasing responsibilities, OCSEAP conduct studies designed to obtain information of four basic types:

1. Location of critical wildlife habitats that must be protected.
2. Prediction of effects of oil and gas development (such as the direct release of toxins) on the biota.

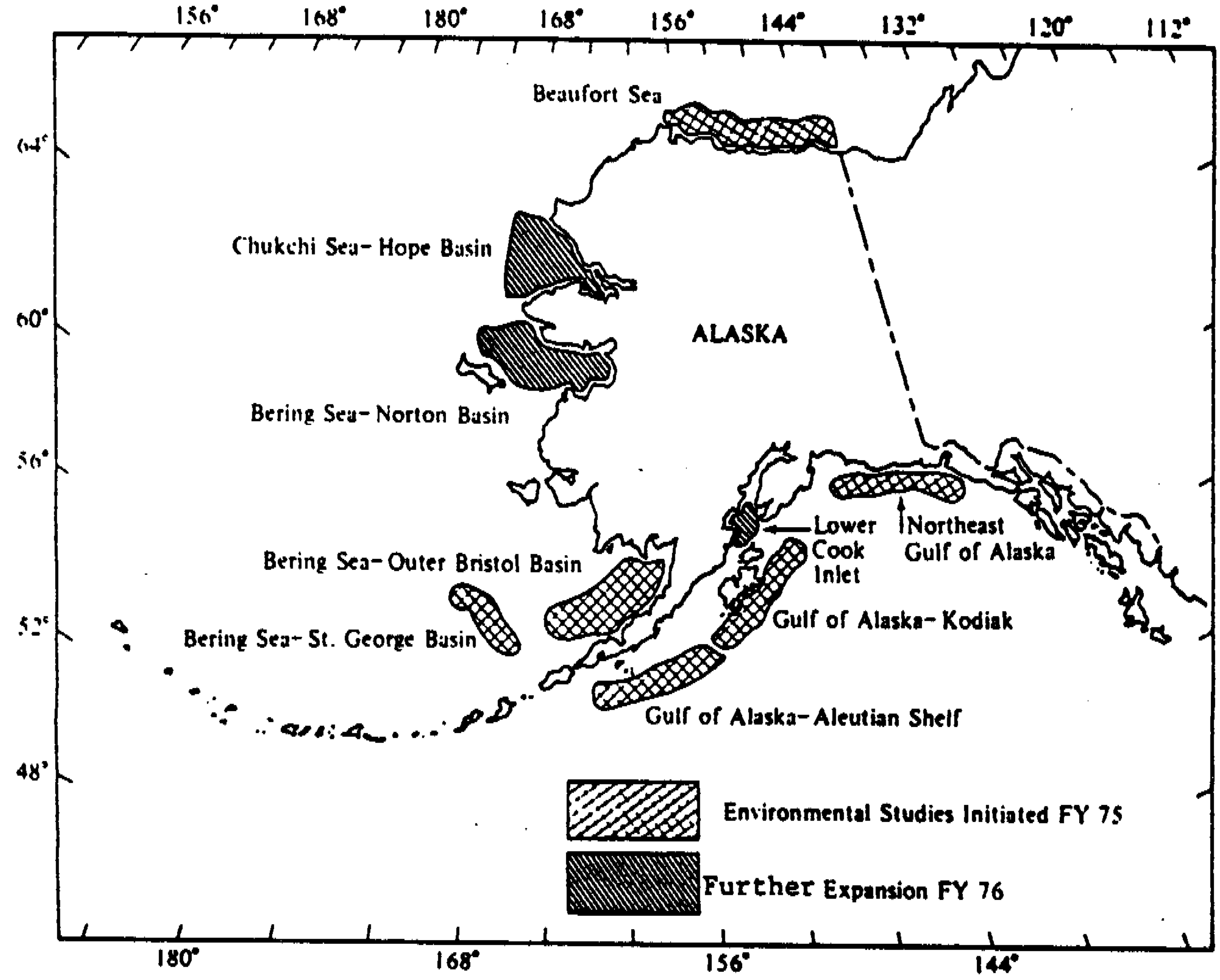


Figure 1: Map of Alaska lease areas from the Technical Development Plan, NOAA, 1978.

3. Identification and development of monitoring techniques.

4. Definition of hazards that the environment poses on man-made structures (oil rigs, pipelines, etc.) in order to mitigate the incidence of polluting accidents.

Scope of OCSEAP Studies and the OCSEAP Synthesis Effort:

A wide variety of biological and physical studies directed toward understanding the processes and relationships of the environment are conducted by OCSEAP. Indeed, OCSEAP is one of the largest geographically-focused, natural science research programs ever attempted. Since the expansion of the program in 1975, a total of $100 million in research and management funds have been spent. Besides logistical support from six NOAA research vessels (at an additional cost of $31 million), 12 other ships from the U.S. Coast Guard, U.S. Geological Survey, U.S. Navy and several universities have been used in the program. Over 1000 scientists and technical assistants have been involved in OCSEAP studies so far.

A vast amount of environmental information has been gathered on the Alaskan OCS. In 1977 alone, the OCSEAP Annual Reports took up 18 volumes, totaling over 15,000 pages. The establishment of such a data base is in itself an initial step in environmental assessment. Without reliable methods of synthesizing and integrating the multidisciplinary information into a form both understandable and useable by decision-makers, an extensive scientific data base of of limited value in terms of environmental assessment. The process of synthesis is defined as the "the putting together of parts or elements so as to form a whole." The simplicity of the definition, however, belies the complexity of applying the concept of synthesis to a research effort the size and scope of OCSEAP. Some of the more obvious problems involved in this application are: defining the nature of the whole, i.e., defining what the end product of the synthesis process should be; delineating what parts or elements should be included in the synthesis; and deciding how to put these parts or elements together so as to attain the desired end product.

OCSEAP information synthesis is an ongoing activity which occurs at various levels of data management from the unidisciplinary efforts of principal investigators working primarily with results of their own findings to complex interdisciplinary modelling which attempts to integrate environmental information in such a way as to emphasize processes and relationships. The computerized environmental synthesis mapping system described below is one strategy currently being used by OCSEAP in its continual endeavor to provide practical scientific information to decision-makers involved in the integrated management of Alaskan oil and gas resources.

GENERAL APPROACH TO SYNTHESIS MAPPING

The team of researchers involved in a synthesis mapping project generally includes representatives from several disciplines: computer science, geology, planning, hydrology, biology, sociology and economics. Initially, this group identifies the physical, biological, social, legal and economic factors affecting the development of the natural resources of a particular area and its land use planning. Public welfare and environmental impact are the issues of greatest importance. After reviewing each of these factors, the study group identifies the variables that will be gathered as base of source data. At this stage, each potential source variable is evaluated from the standpoint of cost of acquisition versus degree of importance in the overall decision-making process. The next important step is the development of a master structure diagram. This diagram identifies how the source data will be converted into secondary interpreted information and then used to produce composite maps showing the combined impact of each variable.

The master structure diagram illustrates key relationships exising among the data used in the study; it can, consequently, be viewed as describing the flow of mappable information. The layout and contents of the diagram reflect the relevant environmental issues being analyzed. Typically, the diagram is in the form of a flow chart consisting of a series of rows and columns. Rows represent variables and columns indicate the type of map analysis being employed. The source data column, for instance, contains uninterpreted data collected from base maps. Columns labelled derived data maps contain source data that has been reorganized into more meaningful categories for analysis. Interpretive data maps point out relationships between source variables. These maps are essentially interpretations of all existing data, and they form the basis of the environmental analysis. Two other types of maps are usually used in synthesis mapping:

1. a geographic base map which is used for mapping all source data at the same scale and in a common format (each data category can be mapped separately) and;
2. a grid base map which is used to reference all information for computer processing.

The grid base map consists of square or rectangular cells that represent discrete geographic areas for which data are collected. Each grid cell is indexed by a row and a column number that identify the cell's unique location on the ground. The size of the grid cells and the scale of mapping depend largely on the type of environmental assessment needed.

The data management phase of the study should be designed to provide a comprehensive framework for recording, storing and displaying mappable information that will be used later. Effective data management means that during analysis, it is possible to aggregate a number of subjective judgments into an integrated set of evaluations based on several geomorphological, geological, cartographic, geophysical, oceanographic and biological factors. The outcome is a system that provides a complete trace of the decision-making process as well as an up-to-date data pase that can be used for future environmental studies in the region.

In summary, environmental synthesis mapping system usually involves the digitization of information to be used in the environmental assessment and the preparation of the following series of maps:

1. Source Maps (one map per variable) - source maps show the distribution of major variables.
2. Derived' Maps - transform qualitative source variables into numerical data and reorganize other variables into meaningful categories for later analysis.
3. Derived" Maps - summarize the density or intensity of each variable.
4. Interpretive Maps - show relationships between source variables.
5. Composite Maps - Subdivide the study area into regions that have differing sensitivity to development and natural hazards.
6. Candidate Area Maps - assign probability values to the areas defined in the composite maps. Candidate area maps show the likelihood of social or ecological disturbance.

Synthesis maps may serve as useful tools in the application and evaluation of interdisciplinary environmental data. The synthesis mapping technique can be used in a variety of planning projects, including site selection studies for dams and power plants, highway and pipeline route selection, resource management plans, environmental impact assessments, and so on. Indeed, this basic approach can be used in any project that requires the analysis of interdisciplinary data as part of the decision-making process.

THE MASTER STRUCTURE DIAGRAM AND SUBSYSTEMS

The first stage of the environmental assessment involved detailed study of the physical and ecological characteristics of the Alaskan continental shelf. Figure 2 illustrates some typical relationships among shelf variables. After they have been studied, the environmental characteristics are then organized into a master structure diagram (Fig. 3) that describes the flow of mappable information needed for preparing a synthesis map. At this stage, the environment on the continental shelf is divided into five categories:

1. Physical environment - this includes subsea permafrost, sea ice and other hazards for which a variety of maps showing the nature of the shelf can be drawn. Subsea permafrost and sea ice form the two major subsystems in the physical environment category.
2. Chemical environment - this group of variables describes ambient contaminant levels on the shelf.
3. Biological environment - biological variables define the characteristics of biota that are sensitive to disturbance.
4. OCS development - this category supplies data on activities associated with oil drilling and transportation.
5. Population - this group of variables characterizes the effects of OCS development on native and non-native populations in the area.

Once source variables have been defined in all five categories, interpretive and composite mapping can begin. Figure 3 shows various examples of how composite maps can be used to analyze relationships between variables and give information about the sensitivity of the shelf environment. The candidate area map assigns probability values to human and ecological dangers occurring as a result of oil and gas exploration on the shelf.

The principle of defining source variables, analyzing their relationships and determining the likelihood of hazards occurring on the shelf can be applied at various levels of the study. For instance, since the physical environment of the continental shelf contains hazards associated with the presence of subsea permafrost sea ice, and other factors, subsidiary or subsystems structure diagrams can be developed to analyze each hazard in more detail.

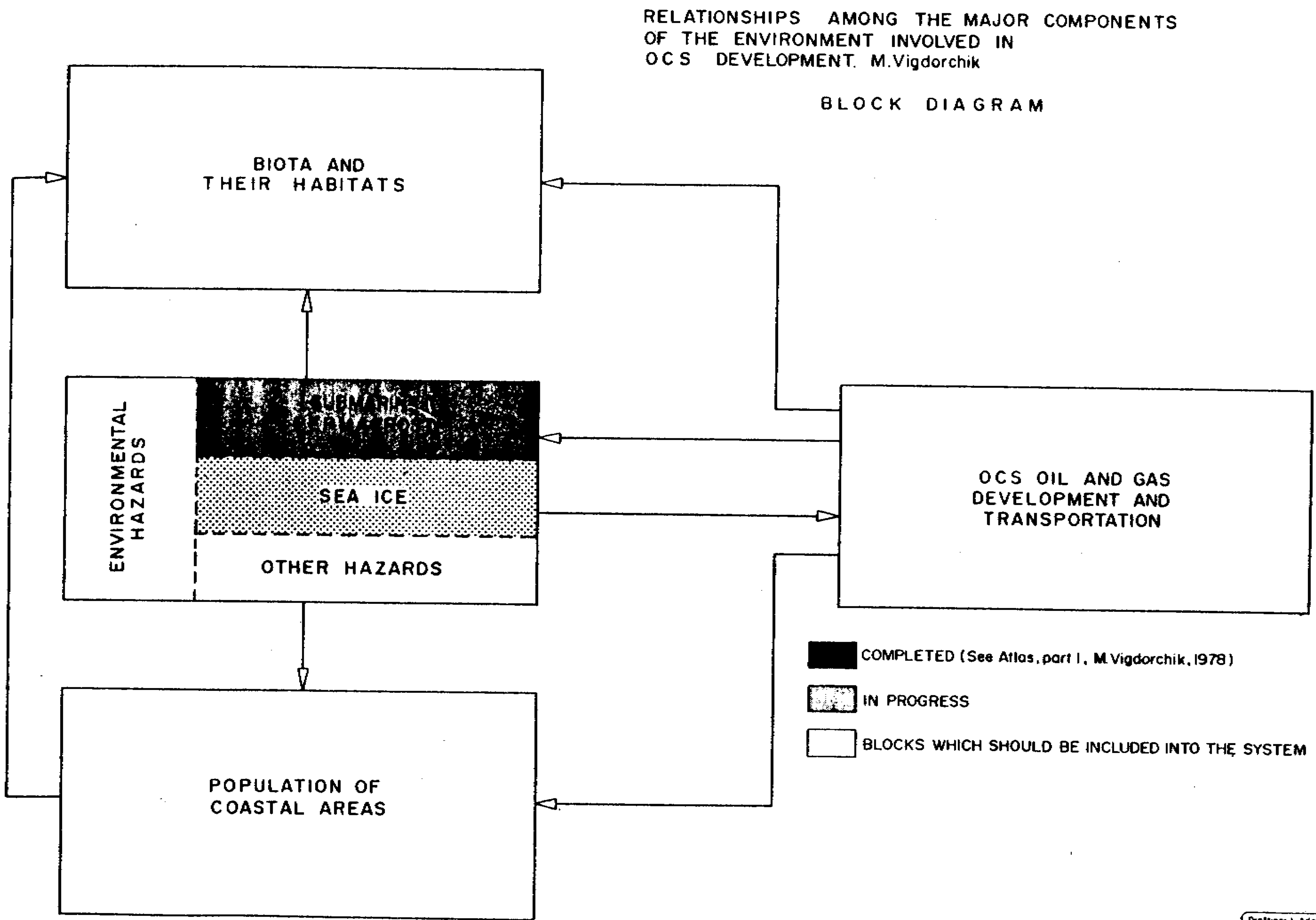

RELATIONSHIPS AMONG THE MAJOR COMPONENTS OF THE ENVIRONMENT INVOLVED IN OCS DEVELOPMENT. M.Vigdorchik
BLOCK DIAGRAM
BIOTA AND THEIR HABITATS
ENVIRONMENTAL HAZARDS
SEA ICE
OTHER HAZARDS
OCS OIL AND GAS DEVELOPMENT AND TRANSPORTATION
POPULATION OF COASTAL AREAS
COMPLETED (See Atlas, part I, M.Vigdorchik, 1978)
IN PROGRESS
BLOCKS WHICH SHOULD BE INCLUDED INTO THE SYSTEM
Drafting-J. Adams

FIGURE 2

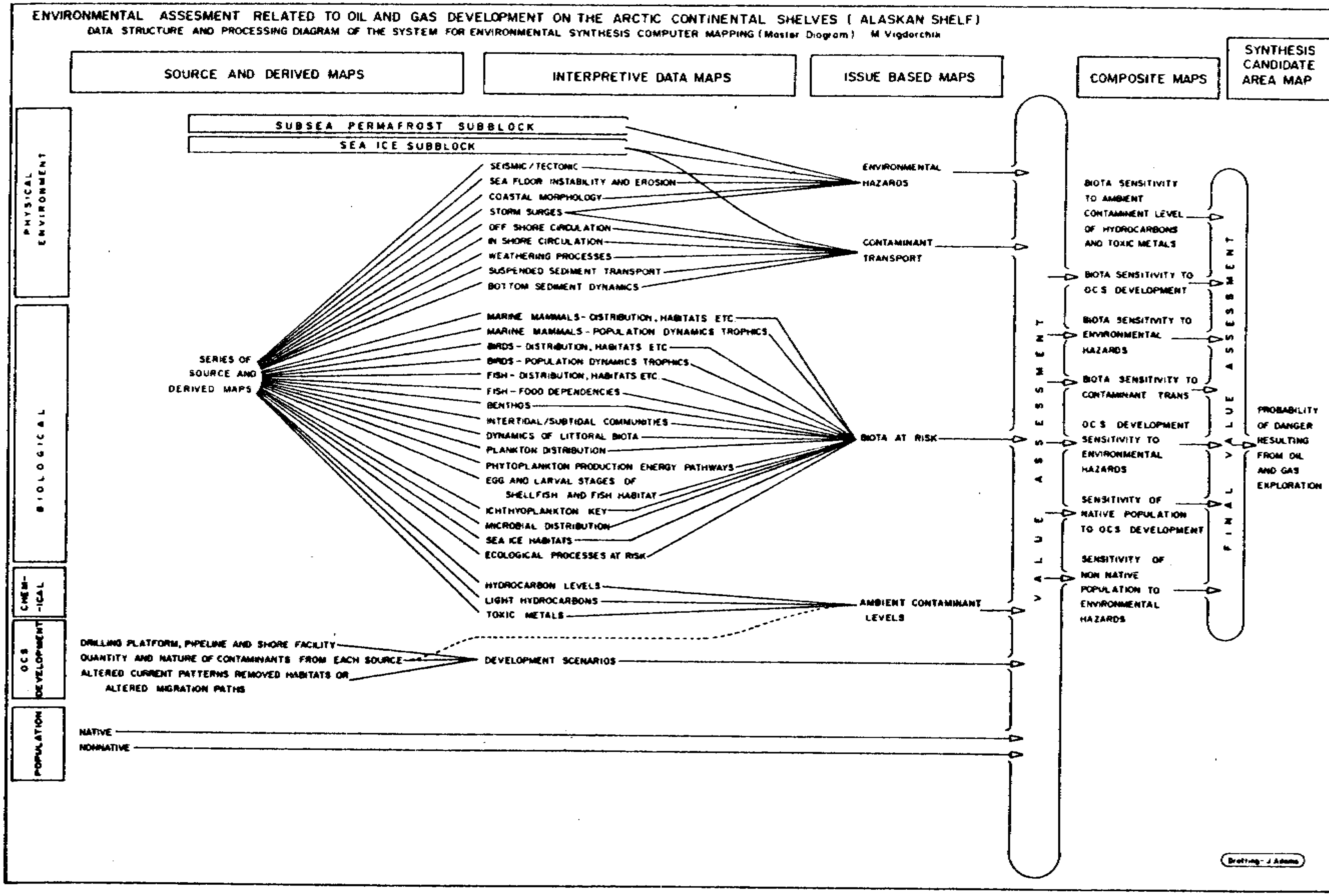


FIGURE 3: Master Structure Diagram

The study of submarine permafrost distribution and offshore ice are part of OCSEAP's interdependent biological, physical, oceanographic and geological investigations aimed at minimizing environmental damage during oil and gas exploration activities in the Arctic. Work on the permafrost subsystem of the master structure diagram shown in Figure 3 has already been completed. The results of this work have been discribed in the final report, "A Geographic Based Inforamtion Management System for Submarine Permafrost Prediction in the Beaufort and Chukchi Seas" (Vigdorchik, 1978a, b). The structural diagram of the data organization and processing of this subsystem is presented in Figure 4, in the two maps of Figures 5 and 6, and in Table 1 and 2. The results of the submarine permafrost subsystem study have included a data bank with ten source variables. These variables were finally chosed to define the location and characteristics of submarine permafrost on the continental shelf and are:

1. clay distribution of sediments on the shelf;
2. silt distribution of seidments on the shelf;
3. gravel and sand distribution of sediments on the shelf;
4. areas of sea ice - sea bottom interaction;
5. depth to the sea bottom;
6. depth of sampling'
7. summer salinity of sea water;
8. summer temperature of sea water;
9. reliability of salinity and temperature data; and
10. reliability of grain size data.

These variables were chosen in an attempt to find the most suitable combination of interdisciplinary data for permafrost prediction within the limits of what was available.

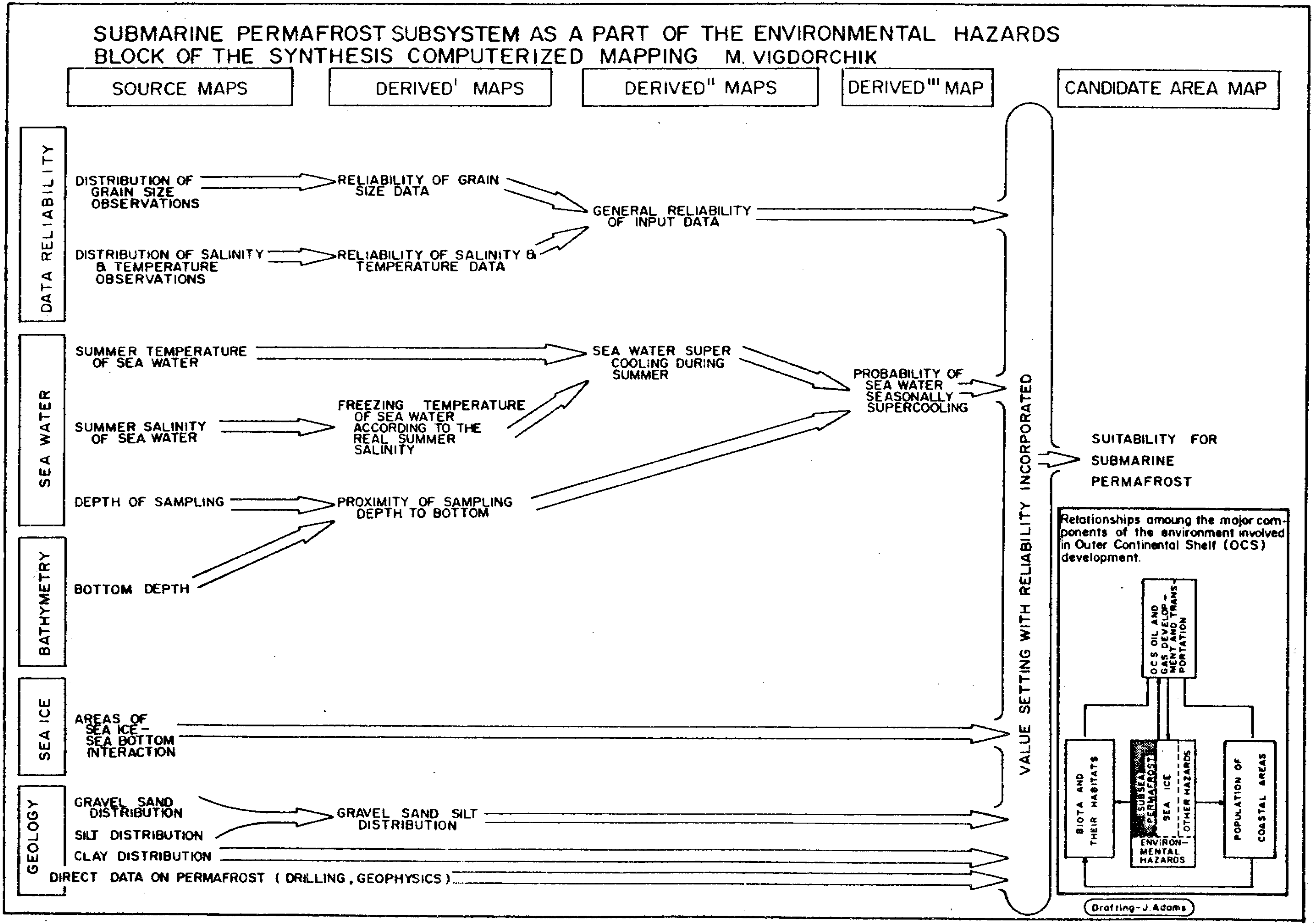

SUBMARINE PERMAFROST SUBSYSTEM AS A PART OF THE ENVIRONMENTAL HAZARDS BLOCK OF THE SYNTHESIS COMPUTERIZED MAPPING M. VIGDORCHIK
SOURCE MAPS
DERIVED' MAPS
DERIVED'' MAPS
DERIVED''' MAP
CANDIDATE AREA MAP
DATA RELIABILITY
DISTRIBUTION OF GRAIN SIZE OBSERVATIONS
RELIABILITY OF GRAIN SIZE DATA
GENERAL RELIABILITY OF INPUT DATA
DISTRIBUTION OF SALINITY & TEMPERATURE OBSERVATIONS
RELIABILITY OF SALINITY & TEMPERATURE DATA
SEA WATER
SUMMER TEMPERATURE OF SEA WATER
SEA WATER SUPER COOLING DURING SUMMER
PROBABILITY OF SEA WATER SEASONALLY SUPERCOOLING
SUMMER SALINITY OF SEA WATER
FREEZING TEMPERATURE OF SEA WATER ACCORDING TO THE REAL SUMMER SALINITY
DEPTH OF SAMPLING
PROXIMITY OF SAMPLING DEPTH TO BOTTOM
BATHYMETRY
BOTTOM DEPTH
SEA ICE
AREAS OF SEA ICE-SEA BOTTOM INTERACTION
GEOLOGY
GRAVEL SAND DISTRIBUTION
SILT DISTRIBUTION
GRAVEL SAND SILT DISTRIBUTION
CLAY DISTRIBUTION
DIRECT DATA ON PERMAFROST (DRILLING, GEOPHYSICS)
VALUE SETTING WITH RELIABILITY INCORPORATED
SUITABILITY FOR SUBMARINE PERMAFROST
Relationships amoung the major components of the environment involved in Outer Continental Shelf (OCS) development.
OCS OIL AND GAS DEVELOPMENT AND TRANSPORTATION
BIOTA AND THEIR HABITATS
SUBSEA PERMAFROST
SEA ICE
OTHER HAZARDS
ENVIRONMENTAL HAZARDS
POPULATION OF COASTAL AREAS
Drafting-J. Adams

FIGURE 4

FIGURE 5

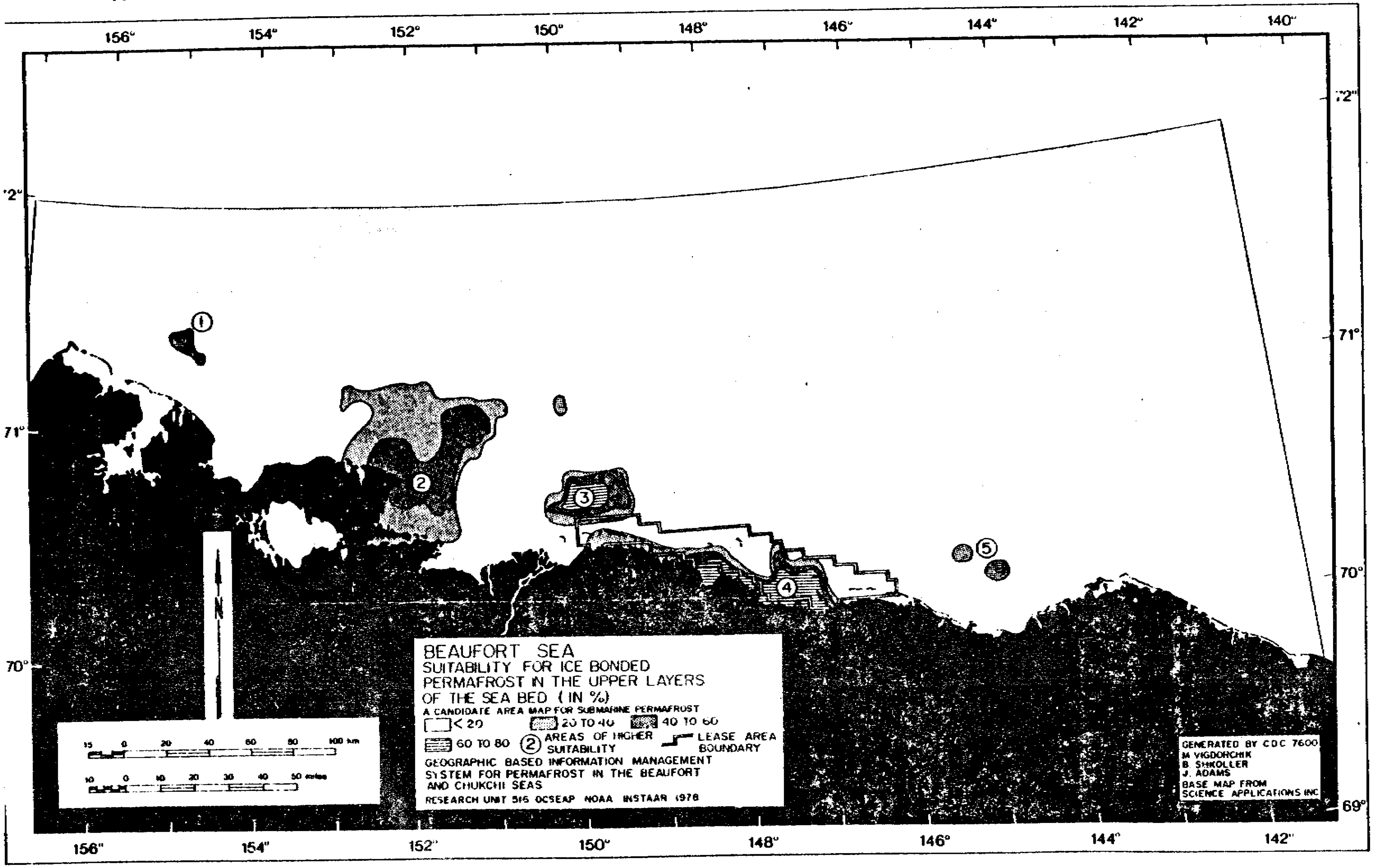
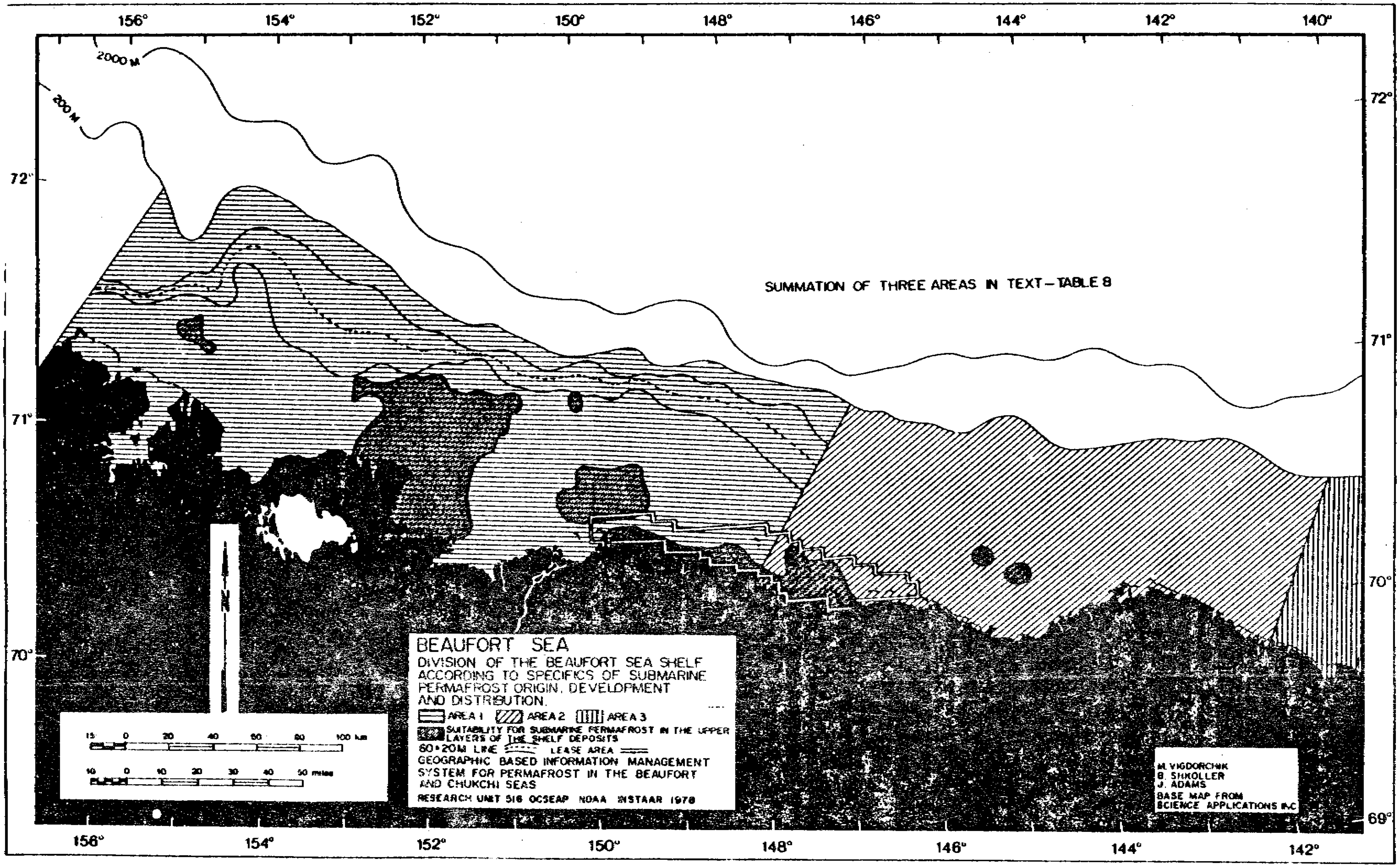

156°
154°
152°
150°
148°
146°
144°
142°
140°
72°
71°
70°
69°
BEAUFORT SEA
SUITABILITY FOR ICE BONDED
PERMAFROST IN THE UPPER LAYERS
OF THE SEA BED (IN %)
A CANDIDATE AREA MAP FOR SUBMARINE PERMAFROST
< 20
20 TO 40
40 TO 60
60 TO 80
AREAS OF HIGHER SUITABILITY
LEASE AREA BOUNDARY
GEOGRAPHIC BASED INFORMATION MANAGEMENT
SYSTEM FOR PERMAFROST IN THE BEAUFORT
AND CHUKCHI SEAS
RESEARCH UNIT 516 OCSEAP NOAA INSTAAR 1978
GENERATED BY CDC 7600
M VIGDORCHIK
B. SHKOLLER
J. ADAMS
BASE MAP FROM
SCIENCE APPLICATIONS INC
N

FIGURE 6



2000 M
200 M
SUMMATION OF THREE AREAS IN TEXT-TABLE 8
BEAUFORT SEA
DIVISION OF THE BEAUFORT SEA SHELF ACCORDING TO SPECIFICS OF SUBMARINE PERMAFROST ORIGIN, DEVELOPMENT AND DISTRIBUTION.
AREA 1
AREA 2
AREA 3
SUITABILITY FOR SUBMARINE PERMAFROST IN THE UPPER LAYERS OF THE SHELF DEPOSITS
60+20M LINE
LEASE AREA
GEOGRAPHIC BASED INFORMATION MANAGEMENT SYSTEM FOR PERMAFROST IN THE BEAUFORT AND CHUKCHI SEAS
RESEARCH UNIT 516 OCSEAP NOAA INSTAAR 1978
M. VIGDORCHIK
B. SHKOLLER
J. ADAMS
BASE MAP FROM SCIENCE APPLICATIONS INC
100 km
50 miles
156°
154°
152°
150°
148°
146°
144°
142°
140°
72°
71°
70°
69°

TABLE 1:

Division of the Beaufort Sea shelf according to the specific of the submarine permafrost origin and distribution.

Area	Sea water depth	Geological Structure	Geomorphological Structure	Extension of the area seaward
1	2	3	4	5
Western part of the shelf: Point Barrow - 148° WL	0-60 ± 20m	Colville Sincline	Continuation of the north-Alaskan flat plain. Probability of the "ancient valleys" developmant buried & half-buried & thermocarst polygonal - tetragonal forms in the different stages of thawing	70-80km
Central part of the shelf: 148° - 142° WL	0-200m	Tectonically active transitional zone, poss. boundary of Asian & American plates	Gentle plain on the complicated system of the submeridional, meridional, & latitudinal faults, blocks & dome structures	100km
Eastern part of the shelf: 142° - Mackenzie River	0-200m	Anticline	Relatively steep slope of the mountain range	85km

Table 1, continued.

	Main agents of the permafrost development	Suitability for submarine relic permafrost and its general characteristics	Suitability for submarine ice-bonded permafrost at the upper layers of the sea bed
	10	11	12
(W)	Thickness of the permafrost at the coast is relatively moderate (average 350m). Exposure of shelf was the main case of the submarine permafrost development. Ice at the depth $\leq$ 2m.	Suitable. Average thickness 100-120m. Permafr. could be met at the limits of depth first fifty to one hundred meters from the sea bed. "Taliks". Sea water depth $\leq 60 \pm 20$m.	There are several spots with higher probability for ice-bonded submarine permafrost at the upper layers of the sea bed (by 5m) at the sea water depth $\leq$35m. The spots are possible indicators of the more deep-lying body of relic permafrost. "Taliks."
(C)	Thickness of the permafrost at the coast is high -- about 600m. The cooling effect of this factor is the major one. Ice at the depth $\leq$ 2m.	Low suitability. Only at the boundary zone with the western area. Body of permafrost is the continuation of the thick coastal criogenic zone limited by first 18-22km. "Taliks." General thickness about 150-200m. Seaward less -- 50-30m. Sea water depth $\leq$ 12m.	The areas suitable for submarine ice-bonded permafrost at the upper layers of the sea bed are restricted by the first 18-22km from the shore, including barrier islands (sea water depth $\leq$ 10m). "Taliks".
(E)	Ice at the depth of $\leq$ 2m. Influence of the coastal permafrost body.	No relic permafrost. Probably permafr. limited by continuation of the coastal permafrost body, at a distance no more than 2-8km from the shore. The depth to permafrost could be 50-100m. Thickness depends on coastal permafr. Usually reduced 2-3 times. Lack of site specific data.	No areas suitable for submarine permafrost at the upper layers of the sea bed only at the limits of the 2m of sea water depth (including barrier islands).

Table 1, continued.

	Average rate of coastal retreat	Possible rate of the recent vertical movement	Possibility of exposure during Last Glaciation & how long	Time of submergence
	6	7	8	9
(W)	4.7m/year	2.2±2.0mm/year	During last glaciation 25-10,000 years ago	10,000 to present
(C)	1.6m/year	6.6±2.5mm/year	Low probability of exposure & only for small blocks at the boundary with the western part of the Beaufort shelf for a short time	>25,000 years
(E)	1m/year	10.34±3.7 mm/year	No possibility	> 25,000 years

TABLE 2: PROBABILITY OF THE SUBMARINE PERMAFROST IN THE LEASE AREAS

	PROBABILITY OF THE SUBMARINE PERMAFROST IN THE UPPER LAYERS OF THE SEA BED			
	∠20%	20-40%	40-60%	60-80%
LEASE SITE NUMBERS	1-23	24-29	95-101	112-114
	30	32-40	110	126-128
	31	57-61	111	139
	41-56	77-89	115	158
	62-76	102	116	171-175
	90-94	103	123	182-189
	104-107	108	129-131	201-208
	119-121	109	134	220-221
	125	117	135	233
	132	118	140	234
	133	122	141	
	151	124	144-149	
	152	130	153	
	163-167	131	156	
	178-181	136-138	157	
	192-200	142	159-161	
	211-219	143	168-170	
	224-232	150	176	
		154	190	
		155	209	
		162	222	
		177	235	
		191		
		210		
		223		
		236		

The following source and derived maps in the scale 1:1,000,000 have been produced and included in the "Atlas" of the computerized environmental maps of the Alaskan shalf (Part I):

Map 1	Points of observation for bottom deposits grain size.
Map 2	Reliability for the grain size data.
Map 3	Data distribution for temperature and salinity of sea water at the maximal sampling depth.
Map 4	Data reliability for temperature and salinity of sea water at the maximal sampling depth.
Map 5	Proximity of the maximal sampling depth to the botton.
Map 6	General reliability of the data.
Map 7	Sand and silt distribution.
Map 8	Silt distribution.
Map 9	Clay distribution.
Map 10	Summer temperature of the sea water at the maximal sampling depth.
Map 11	Salinity of the sea water (summer) at the maximal sampling depth.
Map 12	The freezing temperature of the sea water according to the summer salinity.
Map 13	Sea water supercooling in summer.
Map 14	Probability of the sea water seasonal supercooling.
Composite Map 15	Suitability for the ice-bonded permafrost at the upper layers of the sea bed.
Composite Map 16	Division of the Beaufort Sea shelf.

The composite mapping algorithm for combining source and derived maps into a composite map (Fig. 5) showing the probable location of submarine permafrost on the sea bed have been developed. The suitability (W) for permafrost in the given area was derived from the following parameters:

A = probability of ice-bonded permafrost;

G = percent silt-sand classes appropriate for active ice segregation'

R = general reliability of data (in percent);

R_1 = percent reliability of grain size data;

R_2 = percent reliability of sea water data;

r_1 = distance between grid point and nearest observation point for grain size date (in miles);

r_2 = distance between grid point and nearest observation point for sea water data (in miles);

Δx = horizontal distance (W-E) between adjacent grid points (in miles);

Δy = vertical distance (S-N) between adjacent grid points (in miles).

The algorithm to find W was described by $W = A.R.$ In this expression:

$A = P^*_{ij}.G$, where P^*_{ij} is the adjusted probability, and

$R = R_1 R_2$.

R_1 and R_2 were calculated in the following way:

$$R_1 = 100\% \left(1 - \frac{r_1}{5\Delta y}\right) \quad \text{and} \quad R_2 = 100\% \left(1 - \frac{r_2}{5\Delta y}\right)$$

This means that

$$W = P^*_{ij}.G\ R_1 R_2 \quad \text{or} \quad W = \frac{P_{ij}.D_{ij}.G.R_1R_2}{B_{ij}} \text{ (in \%)}$$

In this report, we are concentrating on another part of our system - sea-ice subsystem.

SEA ICE SUBSYSTEM

Description:

Ice in the Beaufort Sea, especially the nearshore ice, has been the subject of considerable study in the past years. The nearshore ice environment has been studied by Kovacs and Mellor (1974) with emphasis on the surface morphology and sea floor gouging. Reimnitz and Burnes (1978) have proposed a scheme of cross-shelf zonation and discussed the role of shoals and pack ice drift, patterns of shear lines and bottom scouring. Uncer OCSEAP, the shore-based radar studies of ice motion at Barrow have been made by Shapire (1976) and by Weeks, et al (1978), near Prudhoe Bay. The annual fast ice regimes have been characterized by Barry, et al (1979), from an analysis of LANDSAT imagery for 1973-76. Those with the most prospect for use in our system analysis of the ice conditions in the Beaufort Sea are the data and the results of the Stringer (1978) investigations of the nearshore ice morphology and subsequent identification of those features which may represent hazards to OCS oil and gas development created by ice conditions.

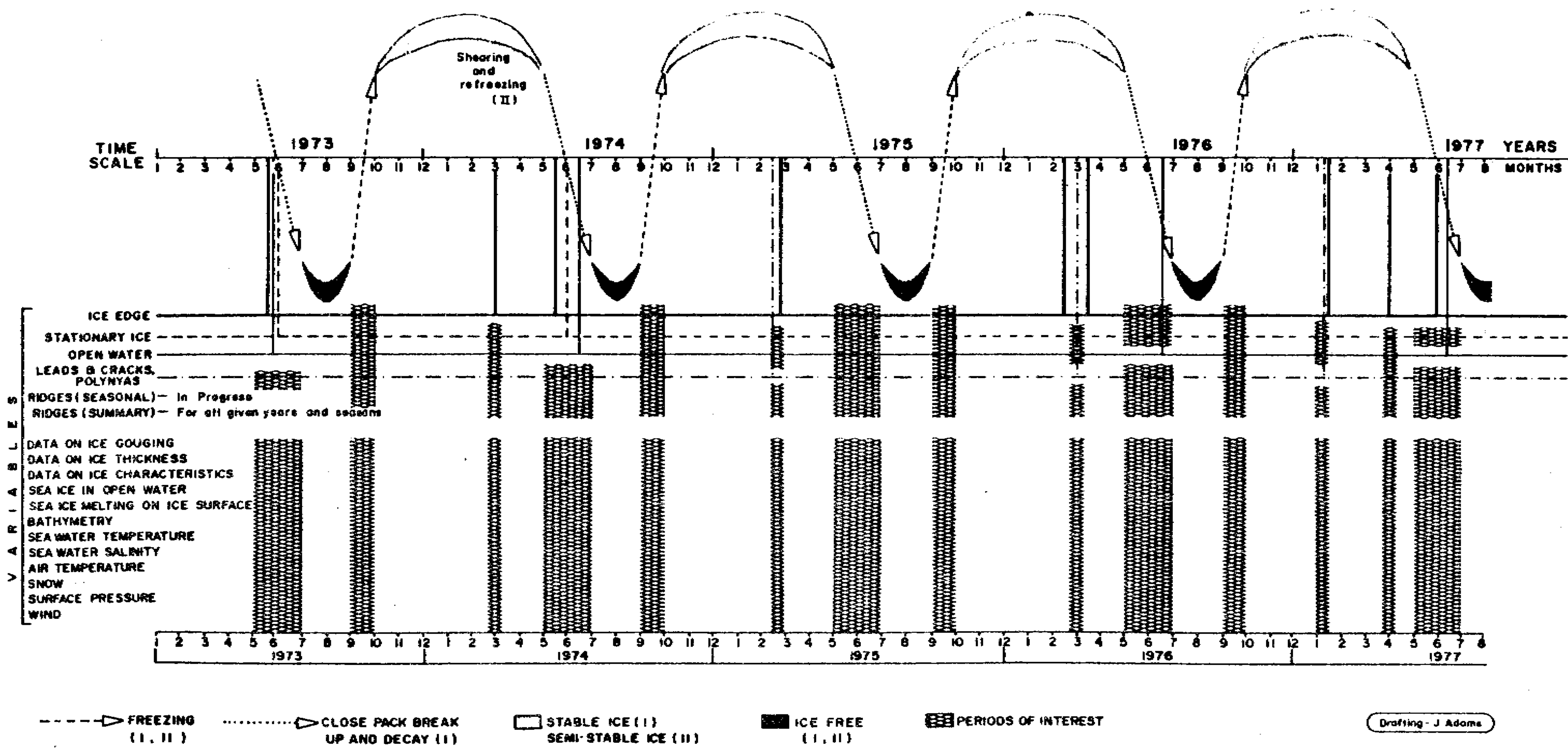
Stringer utilized LANDSAT imagery from 1973 to 1977 to map major ice features related to regional ice morphology. The regional and seasonal ice morphology patterns, together with analysis of the ice behavior, help to assess the role of ice as an environmental hazard during the different stages of oil and gas exploration, development and production. The ice hazard zones have also been described by Stringer. The assessment of these hazards, in quantitative terms, in the Beaufort Sea, particularly the lease are, is a major goal of our analysis of the sea ice subsystem. The specifics of the risk evaluation are related to the sort of activities envisioned. These activities, during the pre-lease and exploration phases (I and II), include marine transport operations with little if any ice breaking ability; ice surface transport; exploratory drilling from grounded barges sitting on the sea bottom; drilling from artificial ice and gravel islands; operations on the barrier islands; and so on. Use of the cone shaped gravity structures and floating platforms during the exploration phase has to be taken into consideration as well. During the development and production phases, the transportation of oil and gas to onshore is one of the major requirements, and the lifetime of the structures is another. Natural barrier islands could be used as production islands. Gravel islands in the shallow water, cone shaped gravity structures in the deeper water and the subsea completion without piercing structures are also part of the activity during this stage. Causeways, buried and elevated pipelines are other activities associated with the oil and gas exploration and development. The possible safety hazards to personnel performing off-shore operations include large-scale displacement of deformation of the fast ice cover; the probability of formation of large ice ridge systems which could bring immense forces to bear on offshore structures and damage thereto; and the possible oil spill with the ridk imposed to the adjacent ecosystem. The last problem is associate with the entrapment of light, water-soluble fractions of petroleum under the ice and a prolonged high concentration of these toxic agents and their transport beneath or with the ice.

Ice conditions, including the morphology, vary depending on years, seasons and geographic location. Usually, two major zones of ice in nearshore areas can be distinguished - the "fast ice zone" (the area shoreward of the 20 m isobath) with stable ice December through June and the "shear zone" extending some distance beyond the 20 m isobath. The preliminary curve showing the major patterns of the seasonal periodicity of the "fast" and "shear" ice zones development in the Beaufort Sea are shown on the scheme (Fig. 7). In this figure, we have also marked the periods of time for which the maps of some sea ice variables have been done and the periods for the further investigations. The structure diagram of the data processing in the framework of the sea ice subsystem is shown in Figure 8.

Vertically, the materials have organized into four blocks, sea ice itself, topography of the sea bottom, sea water and climatology. These blocks could be considered as the elements of the second degree in their relationship to the environmental hazards block of our general system (see the picture on left upper part of Fig. 2). The last three blocks represent the groups of variables which could be used later on during the following stages of the data processing and analysis for producing the series of composite maps to show the relationship of the sea ice features with other environmental variables. Through statistical analysis, correlation, factor and cluster analysis, we also may be able to

FIGURE 7

MAJOR SEASONAL PERIODICITY OF THE DEVELOPMENT FOR FAST (I) & SHEAR (II) ICE ZONES IN THE BEAUFORT SEA
(Preliminary curve–a framework for further investigation and dynamic modeling for each variable and the ice subsystem as a whole)
M. Vigdorchik



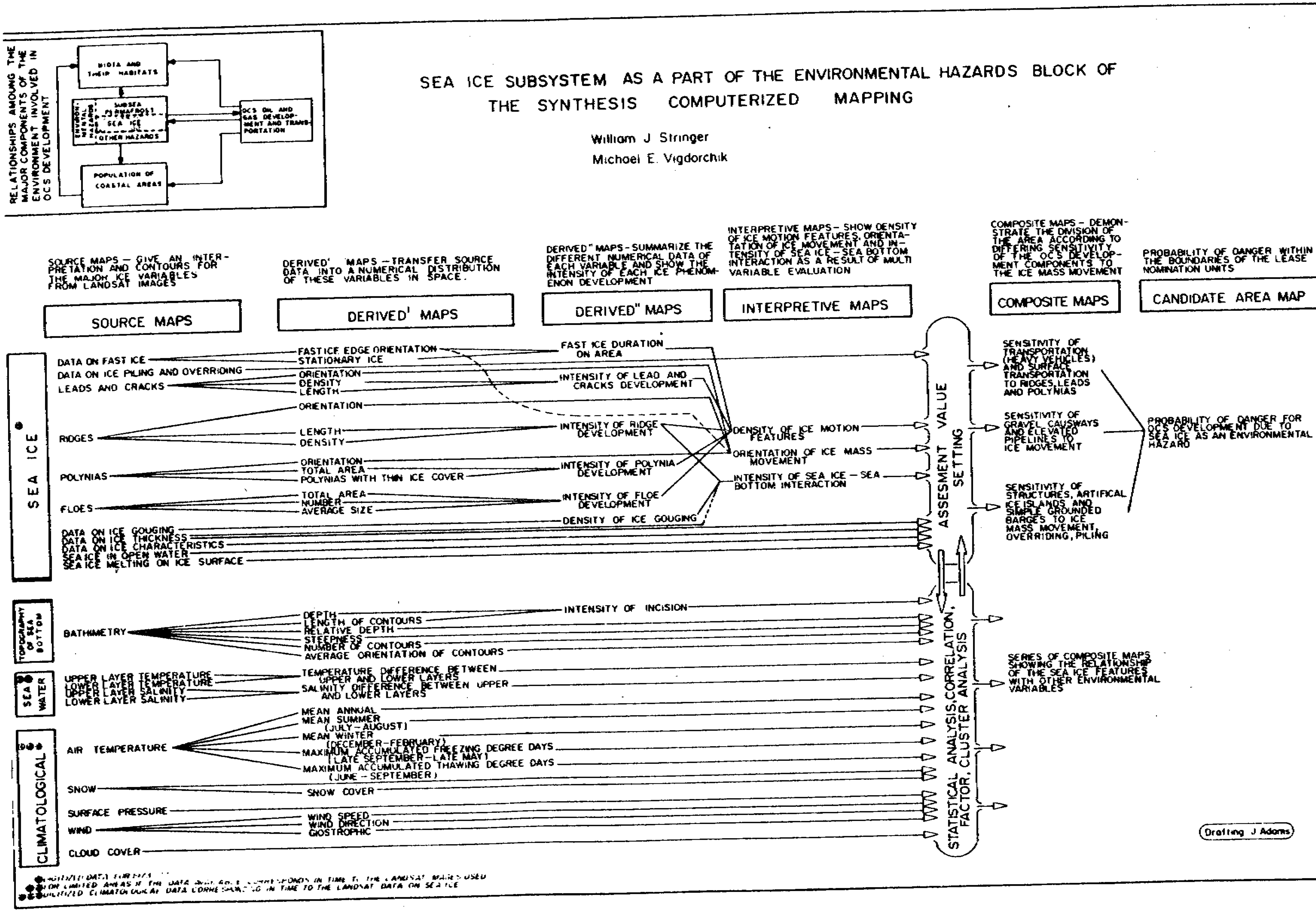

SEA ICE SUBSYSTEM AS A PART OF THE ENVIRONMENTAL HAZARDS BLOCK OF THE SYNTHESIS COMPUTERIZED MAPPING
William J Stringer
Michael E. Vigdorchik
RELATIONSHIPS AMONG THE MAJOR COMPONENTS OF THE ENVIRONMENT INVOLVED IN OCS DEVELOPMENT
BIOTA AND THEIR HABITATS
SUBSEA PERMAFROST
SEA ICE
OTHER HAZARDS
OCS OIL AND GAS DEVELOPMENT AND TRANSPORTATION
POPULATION OF COASTAL AREAS
SOURCE MAPS – GIVE AN INTERPRETATION AND CONTOURS FOR THE MAJOR ICE VARIABLES FROM LANDSAT IMAGES
DERIVED' MAPS – TRANSFER SOURCE DATA INTO A NUMERICAL DISTRIBUTION OF THESE VARIABLES IN SPACE.
DERIVED" MAPS - SUMMARIZE THE DIFFERENT NUMERICAL DATA OF EACH VARIABLE AND SHOW THE INTENSITY OF EACH ICE PHENOMENON DEVELOPMENT
INTERPRETIVE MAPS – SHOW DENSITY OF ICE MOTION FEATURES, ORIENTATION OF ICE MOVEMENT AND INTENSITY OF SEA ICE – SEA BOTTOM INTERACTION AS A RESULT OF MULTI VARIABLE EVALUATION
COMPOSITE MAPS – DEMONSTRATE THE DIVISION OF THE AREA ACCORDING TO DIFFERING SENSITIVITY OF THE OCS DEVELOPMENT COMPONENTS TO THE ICE MASS MOVEMENT
PROBABILITY OF DANGER WITHIN THE BOUNDARIES OF THE LEASE NOMINATION UNITS
SOURCE MAPS
DERIVED' MAPS
DERIVED" MAPS
INTERPRETIVE MAPS
COMPOSITE MAPS
CANDIDATE AREA MAP
SEA ICE
DATA ON FAST ICE
DATA ON ICE PILING AND OVERRIDING
LEADS AND CRACKS
RIDGES
POLYNIAS
FLOES
DATA ON ICE GOUGING
DATA ON ICE THICKNESS
DATA ON ICE CHARACTERISTICS
SEA ICE IN OPEN WATER
SEA ICE MELTING ON ICE SURFACE
FAST ICE EDGE ORIENTATION
STATIONARY ICE
ORIENTATION
DENSITY
LENGTH
ORIENTATION
LENGTH
DENSITY
ORIENTATION
TOTAL AREA
POLYNIAS WITH THIN ICE COVER
TOTAL AREA
NUMBER
AVERAGE SIZE
FAST ICE DURATION ON AREA
INTENSITY OF LEAD AND CRACKS DEVELOPMENT
INTENSITY OF RIDGE DEVELOPMENT
INTENSITY OF POLYNIA DEVELOPMENT
INTENSITY OF FLOE DEVELOPMENT
DENSITY OF ICE GOUGING
DENSITY OF ICE MOTION FEATURES
ORIENTATION OF ICE MASS MOVEMENT
INTENSITY OF SEA ICE – SEA BOTTOM INTERACTION
ASSESMENT VALUE SETTING
SENSITIVITY OF TRANSPORTATION (HEAVY VEHICLES) AND SURFACE TRANSPORTATION TO RIDGES, LEADS AND POLYNIAS
SENSITIVITY OF GRAVEL CAUSWAYS AND ELEVATED PIPELINES TO ICE MOVEMENT
SENSITIVITY OF STRUCTURES, ARTIFICAL ICE ISLANDS AND SIMPLE GROUNDED BARGES TO ICE MASS MOVEMENT, OVERRIDING, PILING
PROBABILITY OF DANGER FOR OCS DEVELOPMENT DUE TO SEA ICE AS AN ENVIRONMENTAL HAZARD
TOPOGRAPHY OF SEA BOTTOM
BATHIMETRY
DEPTH
LENGTH OF CONTOURS
RELATIVE DEPTH
STEEPNESS
NUMBER OF CONTOURS
AVERAGE ORIENTATION OF CONTOURS
INTENSITY OF INCISION
SEA WATER
UPPER LAYER TEMPERATURE
LOWER LAYER TEMPERATURE
UPPER LAYER SALINITY
LOWER LAYER SALINITY
TEMPERATURE DIFFERENCE BETWEEN UPPER AND LOWER LAYERS
SALINITY DIFFERENCE BETWEEN UPPER AND LOWER LAYERS
CLIMATOLOGICAL
AIR TEMPERATURE
MEAN ANNUAL
MEAN SUMMER (JULY – AUGUST)
MEAN WINTER (DECEMBER – FEBRUARY)
MAXIMUM ACCUMULATED FREEZING DEGREE DAYS (LATE SEPTEMBER – LATE MAY)
MAXIMUM ACCUMULATED THAWING DEGREE DAYS (JUNE – SEPTEMBER)
SNOW
SNOW COVER
SURFACE PRESSURE
WIND
WIND SPEED
WIND DIRECTION
GIOSTROPHIC
CLOUD COVER
STATISTICAL ANALYSIS, CORRELATION, FACTOR, CLUSTER ANALYSIS
SERIES OF COMPOSITE MAPS SHOWING THE RELATIONSHIP OF THE SEA ICE FEATURES WITH OTHER ENVIRONMENTAL VARIABLES
Drafting J Adams

FIGURE 8

better understand the origin, local distribution, specifics and links of the sea ice as a component of the general environmental system, with such other components as bathmetry, sea water temperature and salinity and the major climatological patterns (air temperature, snow cover, surface pressure, winds) and so on.

Horizontally, the sea ice subsystem consists of six columns. Each of these represents a new generation of maps, more and more complicated with more information based on the data combined from several previous sources. The first column defines the source maps. They give an interpretation of the LANDSAT images and the countours of the major ice variables space distribution. Source maps of the sea ice include data on fast ice, data on ice piling and overriding, leads and cracks, ridges, polynyas and flows. Data on ice gouging, ice thickness, as well as other characteristics (for instance, sea ice in open water and sea ice melt on the surface), are related to the source data and are placed in the first column. Derived' maps transfer these source materials into a numberical distribution of the sea ice variables in the Beaufort Sea. This series of maps includes ice edges, stationary ice, leads and cracks orientation, density and length, polynyas total area and orientation, and ridge characteristics. The variables related to the ridges are the same - orientation, length, density - but we compile two different sets of ridge variables. One set summarizes all the data on ridge distribution on a yearly basis (1973-77). The other (in preparation now) should give pictures of these ridge variables exactly at the periods of time, having been chosen for other variables included in the computerized mapping system. It will be done keeping in mind the role of the weekly and daily changes in the different ice patterns. It may be also possible to include in the second generation of maps the total area of flows, their number and average size.

The second column of the data structuring and processing diagram in its lower part consists of the sea depth, length of the bathymetrical contours, relative depth, steepness, number and orientation of these contours. Additionall the derived' maps include sea water temperature differences between upper and lower layers, as well as the salinity difference between upper and lower layers. Also to be considered are such climatic characteristics as mean annual, mean summer and mean winter temperatures, maximum accumulated freezing degree days for late September through late May, maximum accumulated thawing degree days for June through September, snow cover, wind speed, direction, as well as the giostrophic winds. some of the schemeatic maps of the limited areas could be produced on the basis of available data that correspond, in time, to LANDSAT images. Cloud cover would also be taken into consideration.

Derived" maps of the sea ice subsystem summarize the different numberical data of each ice variable and show the intensity of each ice phenomenon development. This thrid column of our structure diagram includes the following derived products: a map of the fast ice duration on area; a map of the intensity of lead and crack development; a map of the intensity of ridge development, the intensity of polynya development; a map of flow development intensity; and literature data on ice gouging. The third generation of the maps also includes the intensity of incision based on the bathymetry data morphometrical analysis.

The fourth column represents the interpretive maps. They show the density of ice motion features, orientation of sea ice mass movement and intensity of sea ice/sea bottom interactions as a result of multivariable evaluation.

Through the setting of assessment values, the series of composite maps presents the division of the area according to different sensitivity of the OCS development components to the ice mass movement. This fifth column of the structure diagram, or the fifth generation of maps, consists of the following composite products:

1. map of the sensitivity of the transportation (heavy vehicles) and surface transportation to ridges, leads and polynyas;
2. sensitivity of gravel causeways and elevated pipelines to ice movement; and
3. sensitivity of structures, artificial ice islands and simple grounded barges to ice mass movement, overriding and piling.

This series of composite maps show the relationship of sea ice features to the other environmental variables and give the corresponding regional area division.

The final product of the sea ice subsystem as a part of the environmental hazards block of the synthesis computerized mapping is the candidate area map, showing the probability of danger for OCS development due to sea ice as an environmental hazard within the boundaries of the lease area units and for the whole Beaufort Sea.

Maps:

This annual report includes the first series of the source and derived' maps of the following variables: edge of contiguous ices, stationary ice, open water, ridges, leads, cracks and polynyas. It includes also the two maps of the third generation: the derived" maps of the ridges development intentsity.

The following are the preliminary descriptions of all these maps which have been reduced for the text of this report (volume 1) and drawn in the scale of 1:1,000,000 and 1:250,000 in the universal transverse mercator projection (Volume 2, Atlas). Full description and analysis of the maps will be done in the final report.

The locations of the seaward edge of contiguous ice for different seasons in 1974-77 are shown in Map 1. Contiguous ice, as defined by Stringer (1978), is ice that is contiguous with the shore and continuous to the first break, whether it is the flaw lead, the edge of open ocean, or a polynya. Typically, the edge of cintiguous ice marks the boundary between pack ice and shorefast ice. Map 1 shows that the edge of fast ice is typically located quite far offshore, beyond the barrier island zone. Seasonal and annual variations in its location define a band that is approximatley 5-10 km north and south of the 20 meter isobath.

Stationary ice maps for July 1973-75 (Maps 2-4) show ice that has grounded and remaind bottom fast in the nearshore ice zone during the summer season. This ice is composed essentially of grounded ice ridges which have been swept shoreward and have remained immobile for at least two weeks prior to the dates shown on each map.

Map 2 shows the location of grounded ice for July 2 and 3, 1973. Most ice has grounded north of the barrier island beyond the 8-meter isobath in a zone stretching from Pingok Island to Point Brower west of Foggy Island Bay.

The stationary ice map for July 12-14, 1974 (Map 3) shows that maximum grounding has occurred shoreward of the 16-meter bathymetric contour and grounded ice extends well into Prudhoe Bay at this time. The zone of stationary ice reaches its maximum width north of Prudhoe Bay extending from 3-37 km from the shoreline. Foggy Island Bay, east of the Sagavanirktok River delta, is noticeably clear of grounded ice.

Stationary ice in July 6-18, 1975 (Map 4) is restricted to a small zone northeast and northwest of Cross Island. Grounding apparently appears at a depth of 6-12 meters. The remainder of the coastline and inshore areas are generally clear of grounded ice at this time.

The open water maps (Maps 5-9) show the extent of open water along the coast during June and July in 1973-77. Three nearshore regions consistently shown to be open by the middle of July are: 1. Gwydyr Bay; 2. from Heald Point eastwards to Tigvariak Island; and 3. Mikkelsen Bay. This is presumably due to breakup of the Kuparuk, Sagavanirktok and Shaviouvik Rivers respectively. The chronological increase in open water usually starts in early June near the river mouths (Map 5) and continues outward from the shore through August. The maximum extent of open water in this series of maps occurs in the period July 17-19, 1975, where breakup is well advanced and open water occupies a large portion of the shelf shoreward of the barrier islands. Areas mapped as open water show water that contains no grounded ice or water containing floes smaller than 10 kilometers in diameter (Stringer, 1978).

Six maps showing the distribution of ice ridge systems were produced for each year in the period 1973-77. These maps* show: 1. the density of ice ridges occurring in each six square mile cell of the Beaufort Sea matrix; 2. the dominant orientation of ridges in each cell; and 3. the total length of ridges occupying each cell. Ice ridge systems were mapped for the entire Beaufort Sea and also for that portion of the coast bounded by the Colville and Canning Rivers.

1973 was not a particularly heavy ice year according to Map 10 showing the density of ice ridges for that year. Ridges tended to be found adjacent to major promotories (Cape Simpson, Cape Halkett) when close to shore, otherwise they were located beyond the 10-meter bathymetry contour on the seaward side of the barrier islands. The highest density of ridges (Map 11) appeared

* Legend of each map for any given variable is common for all maps of that variable.

in the Newport Entrance channel between McClive and Stockton Islands. Maps 12 and 13 show that the dominant orientation of ridges was normal to the drift of the Pacific Gyral and prevailing winds. The greatest areas of stress in the ice, based on total length of ridges per cell, can be seen in Maps 14 and 15.

Significantly more ridges were produced in 1974 than in 1973. Map 16 shows that ridge systems were spread out fairly uniformly along the coast from east of Point Barrow to east of Demarcation Point. Ridges tended to be closer to shore than in 1973 and several prominent hummock fields developed within 10 kilometers from shore in Harrison Bay, Gwydr Bay and Camden Bay. The densest distribution of ridges occurs in a northwest trending zone 10-15 km north of Cross Island (Map 17). Again, the dominant orientation of ridges appears to be normal to the wind and ocean circulation systems (Map 18), though there is evidence of grounding in the Midway Island region (Map 19) where ridges tend to trend east-west. This region is also one of high compressional and sheer stress as shown by the total length of ice ridges calculated per cell (Maps 20 and 21).

Of the five years mapped in this study, 1975 showed the smallest distribution and density of sea ice ridges. Ridge densities were greatest far offshore between Prudhoe and Harrison Bays (Maps 22 and 23) where dominant orientation of ridge systems was again northwest to southeast (Maps 24 and 25). Map 26 shows areas of maximum ice stress based in the total length of ridges recorded per cell.

The distribution of ice ridges that occurred in 1976 is shown in Map 28. During this year, ridges developed primarily beyond the 20 meter bathymetry contour in a zone stretching across the Beaufort Sea from Boint Barrow to east of Demarcation Point. The greatest ridge density occurs offshore between Harrison and Prudhoe Bays (Map 29). The dominant orientation of ridges in each cell of the data matrix show considerably more variability than in previous years (Maps 30 and 31). The effects of pack ice motion on the total length of ice ridges (Maps 32 and 33) were also more pronounced.

Considerably more data was available for the mapping of the 1977 ice ridge system than for the four previous years. Maps 34 and 35 show that a large number of ridges in 1977 developed north of Camden Bay, 100 kilometers or more offshore. Again most ridges can be found beyond the 20 meter isobath and a pronounced hummock field can be seen north of Harrison Bay. Orientation and ridge length trends can be seen in Maps 36-37.

Maps 40-55 show the distribution of leads, cracks and polynyas in the shear zone off the Beaufort Sea during early March in 1973, 1975, 1976 and 1977. These maps summarize the density, orientation and total length of major ridge and crack systems in the shear zone and the area occupied by large polynyas. Analysis of these maps is still ongoing pending receipt of oceanographic and meteorologic data needed to access the dynamics of ice pack motion.

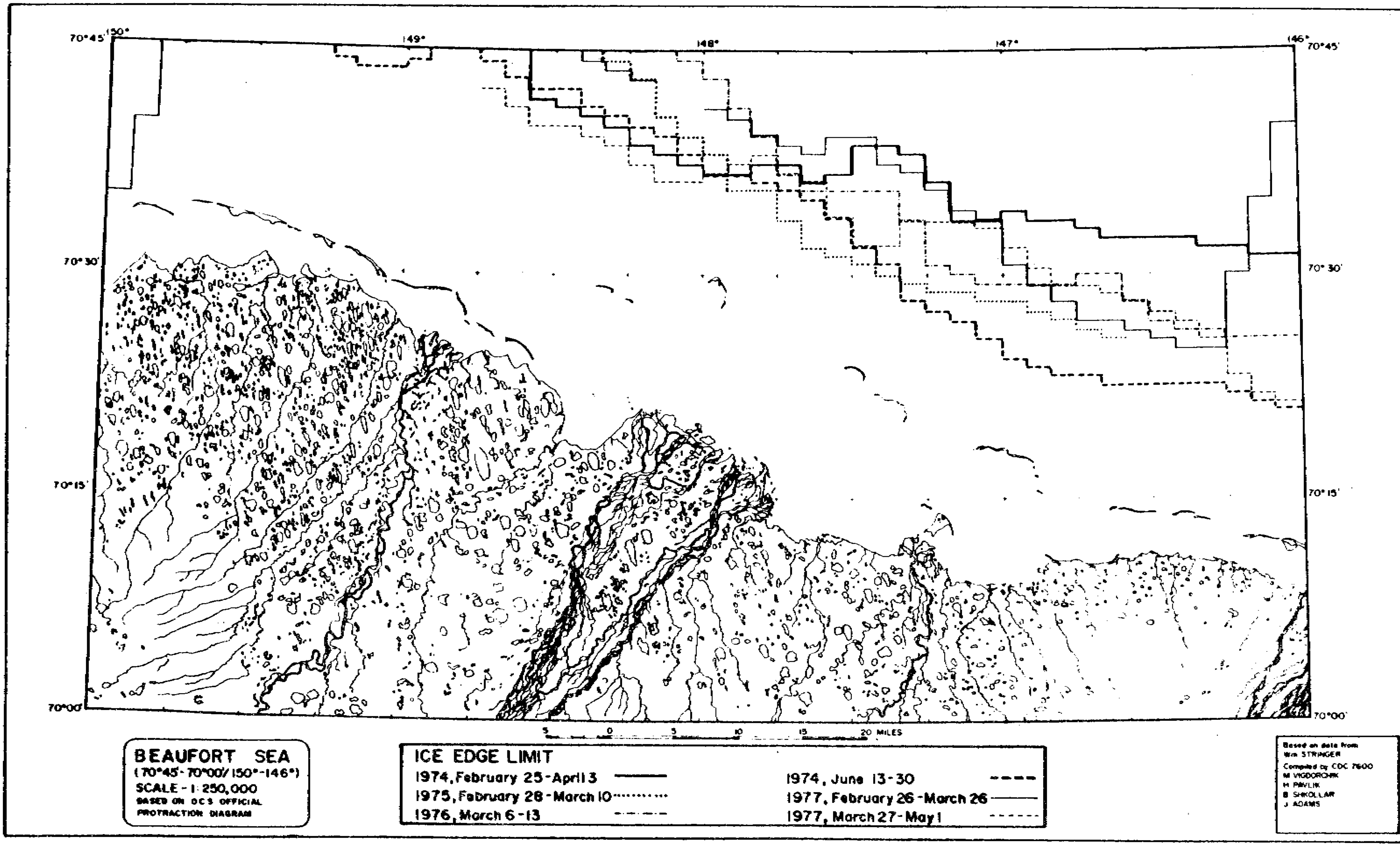
Maps of the ridge development intensity (Maps 56 and 57) are the first ones in the series of the derived" maps, which summarize the different numerical data of each ice variable and show the intensity of each ice phenomenon development in a given area. The map of the ridges development intensity included in this report have been produced for areas of both base maps (scales 1:250,000 and 1:1,000,000). To evaluate the relative intensity of the ridge development ($\mathcal{I}_R$) in these areas during 1973-77, we have decided to take into consideration the following parameters:

- l - average ridge length in each cell;
- l_{max} - maximal ridges length observed in the Beaufort Sea, during 1973-77;
- m - number of years when each given cell has been frequented by sea ice ridges development; maximal number of years in our case is five.

The simplest equation to link these parameters to our purposes is:

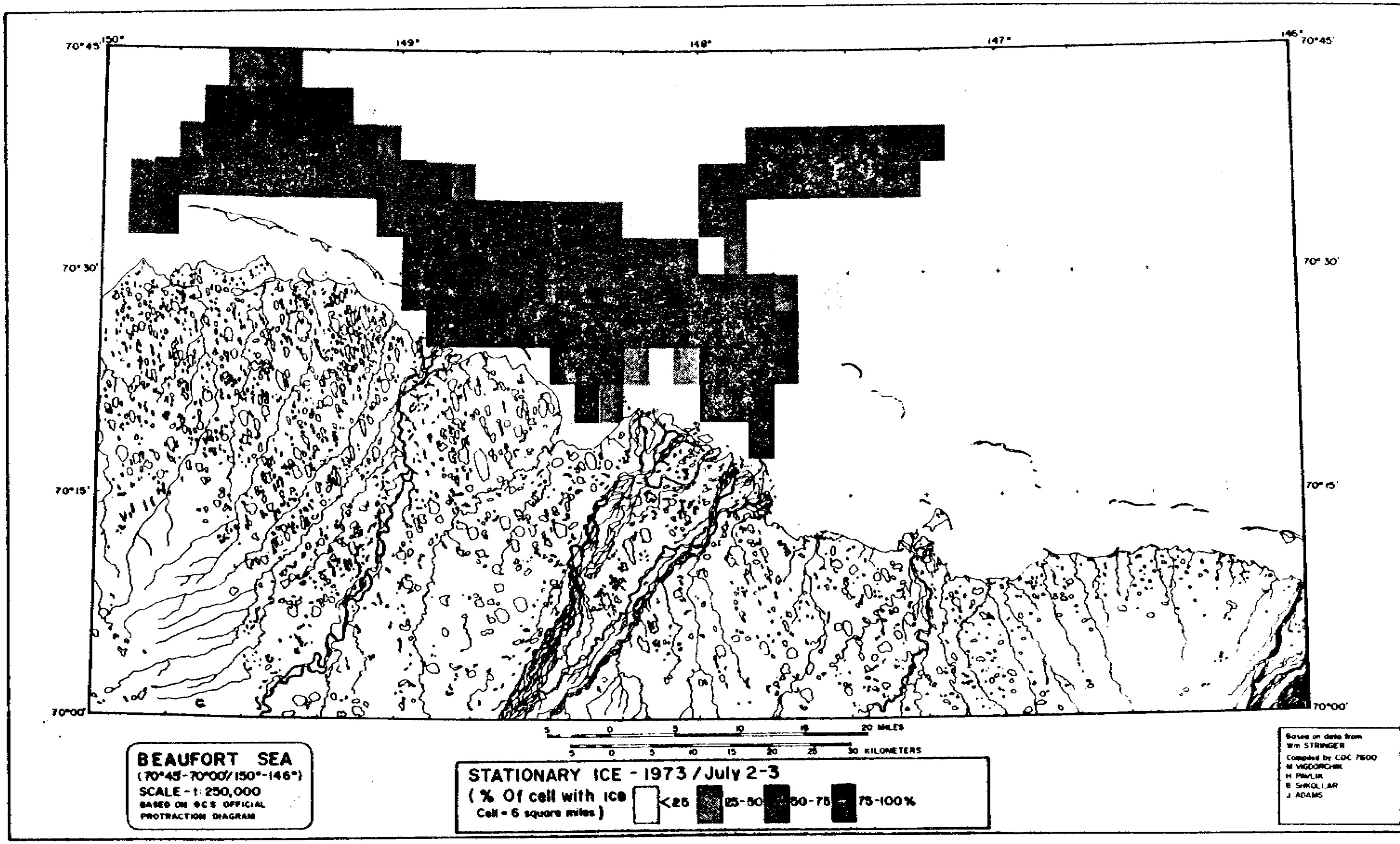
$$\mathcal{I}_R = \frac{l.m}{5l_{max}} \text{ (in \%)}$$

As could be seen, the intensity of the ridge development in the Beaufort Sea area (Maps 56 and 57) is mostly uniform. The increase in this intensity takes place in some small areas, especially in the region of $70^\circ 35/149^\circ$ and along the 147°w.l. There are some regions with no development of the ridges during 1973-77 at all. The correllation of this phenomena with other variables of the Beaufort Sea environment is now in progress.



70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O C S OFFICIAL
PROTRACTION DIAGRAM
ICE EDGE LIMIT
1974, February 25-April 3
1975, February 28-March 10
1976, March 6-13
1974, June 13-30
1977, February 26-March 26
1977, March 27-May 1
Based on data from
Wm STRINGER
Compiled by CDC 7600
M VIGDORCHIK
H PAVLIK
B SHKOLLAR
J ADAMS

MAP 1



150°
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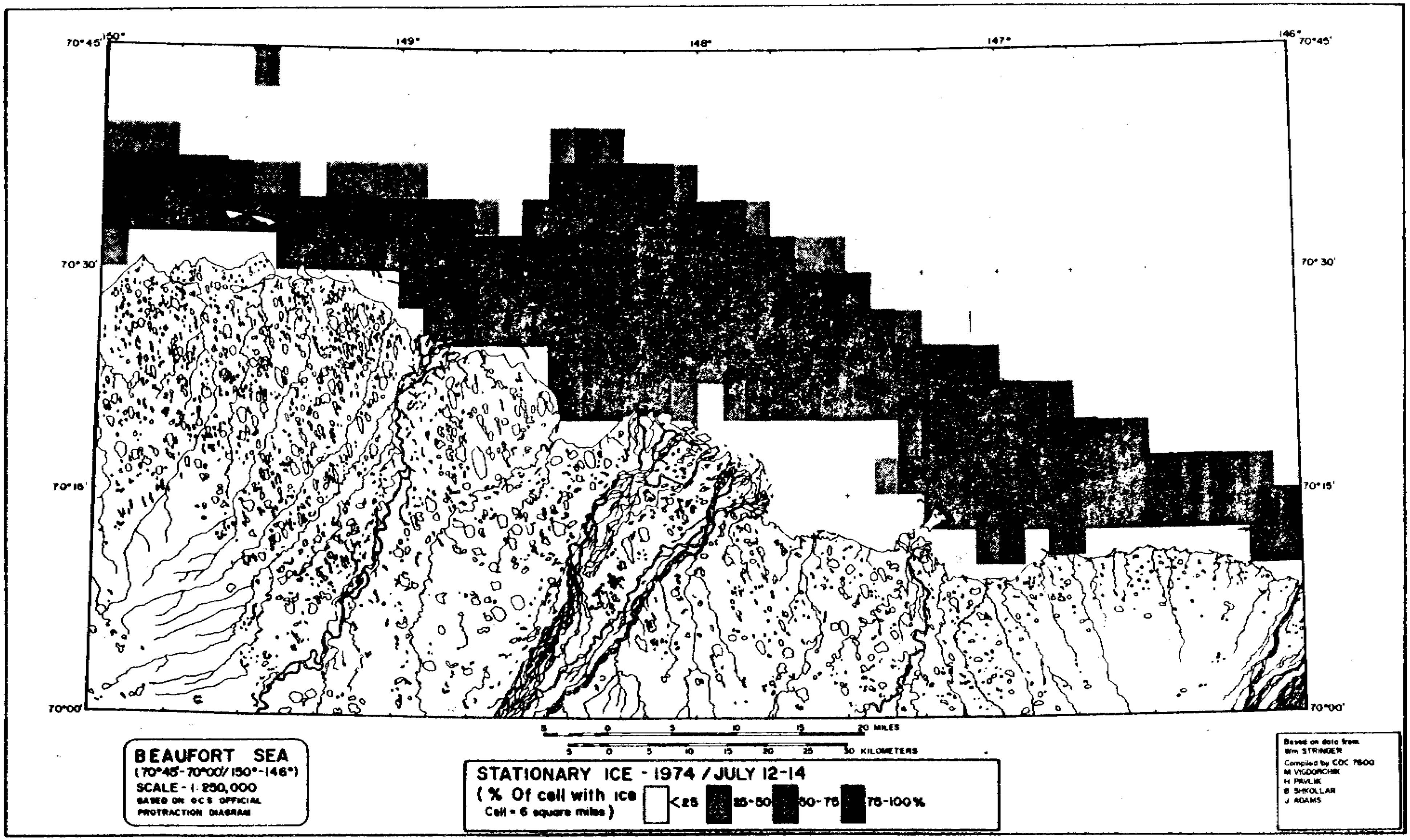
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL
PROTRACTION DIAGRAM
STATIONARY ICE - 1973 / July 2-3
(% Of cell with ice
Cell = 6 square miles)
<25
25-50
50-75
75-100%
Based on data from
Wm STRINGER
Compiled by CDC 7600
M VIGDORCHIK
H PAVLIK
B SHKOLLAR
J ADAMS

MAP 2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70°15'
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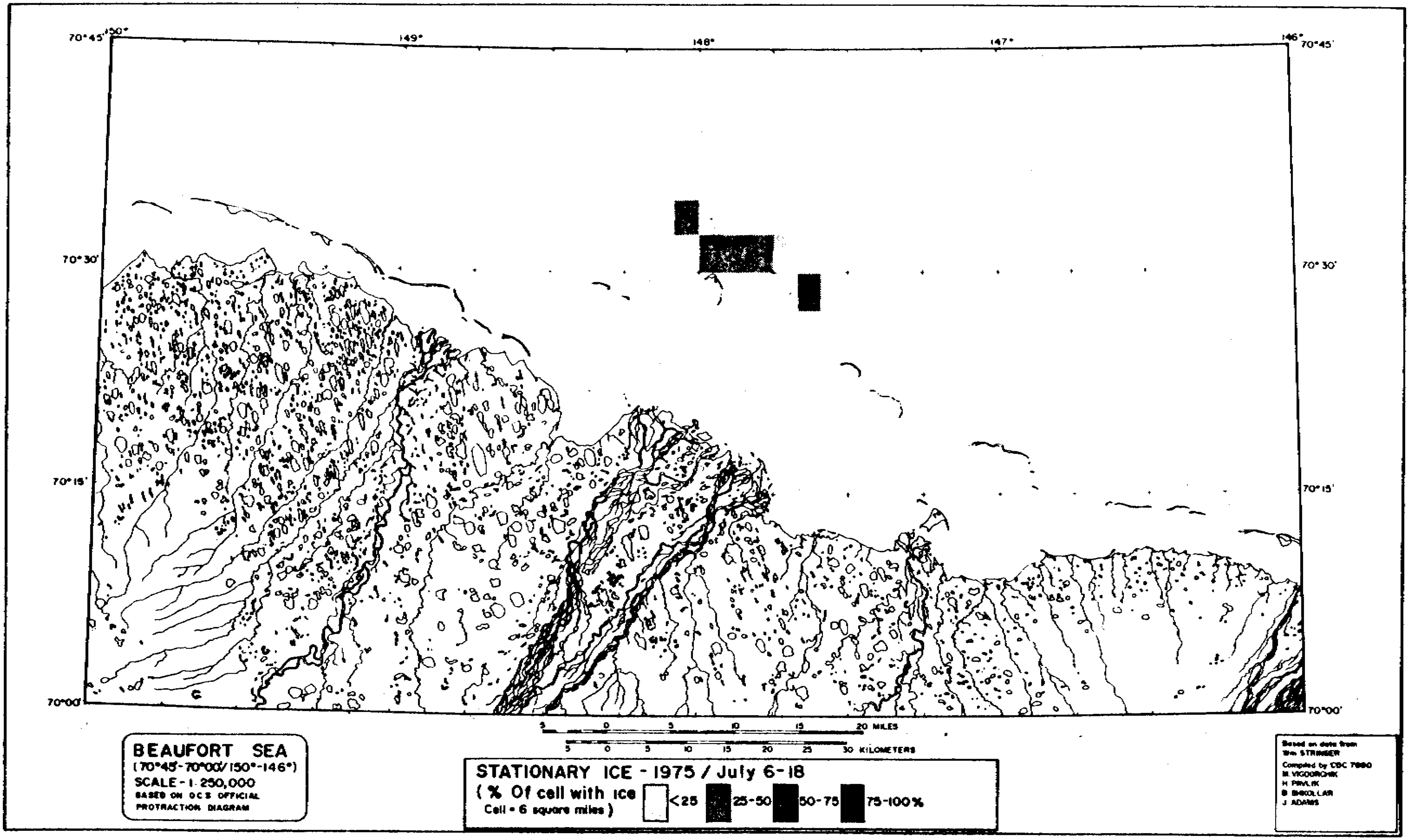
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
STATIONARY ICE - 1974 / JULY 12-14
(% Of cell with ice
Cell = 6 square miles)
<25
25-50
50-75
75-100%
Based on data from
Wm STRINGER
Compiled by CDC 7600
M VIGDORCHIK
H PAVLIK
B SHKOLLAR
J ADAMS

MAP 3


70°45'
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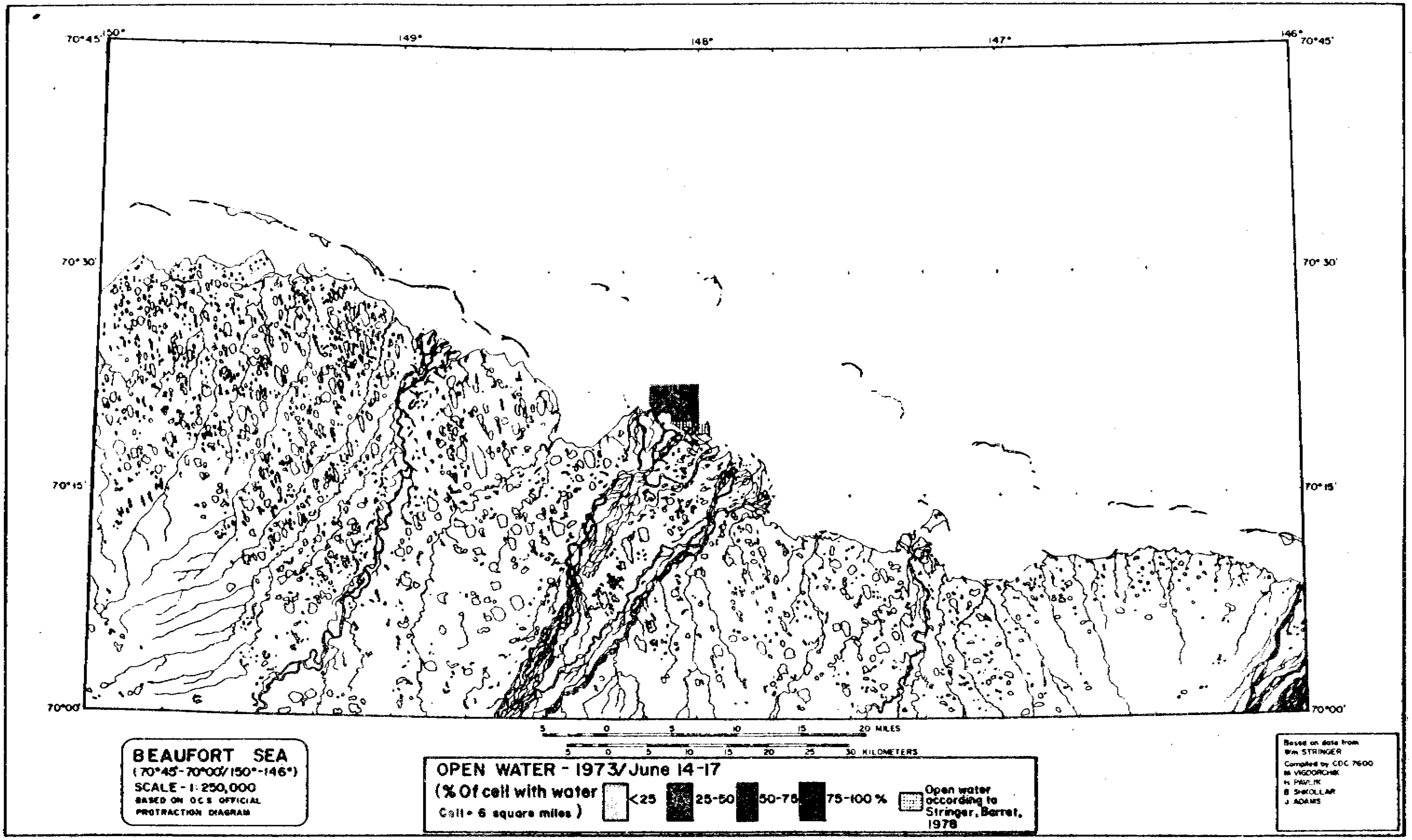
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1: 250,000
BASED ON O.C.S. OFFICIAL
PROTRACTION DIAGRAM
STATIONARY ICE - 1975 / July 6-18
(% Of cell with ice
Cell = 6 square miles)
<25
25-50
50-75
75-100%
Based on data from
J ADAMS

MAP 4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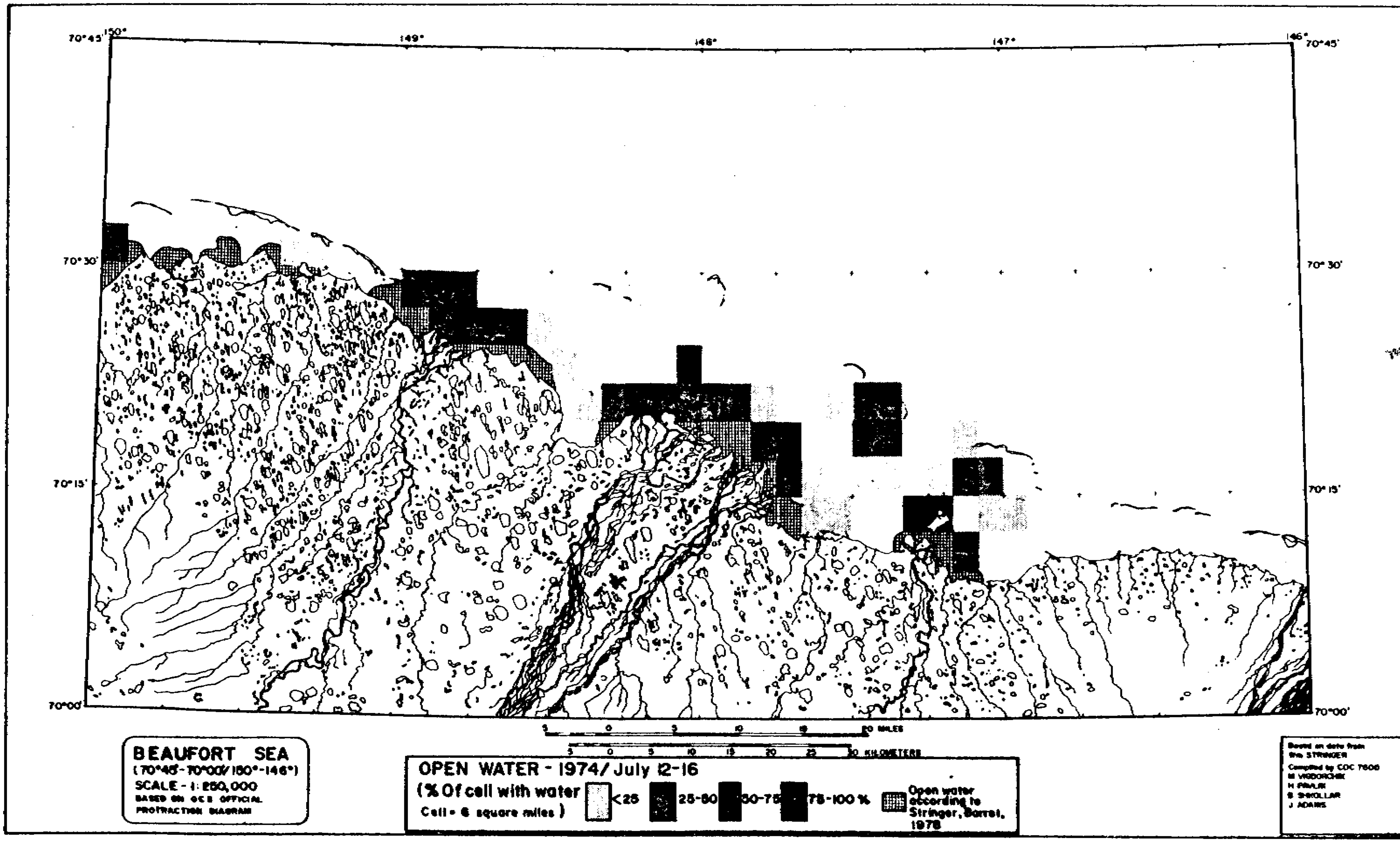
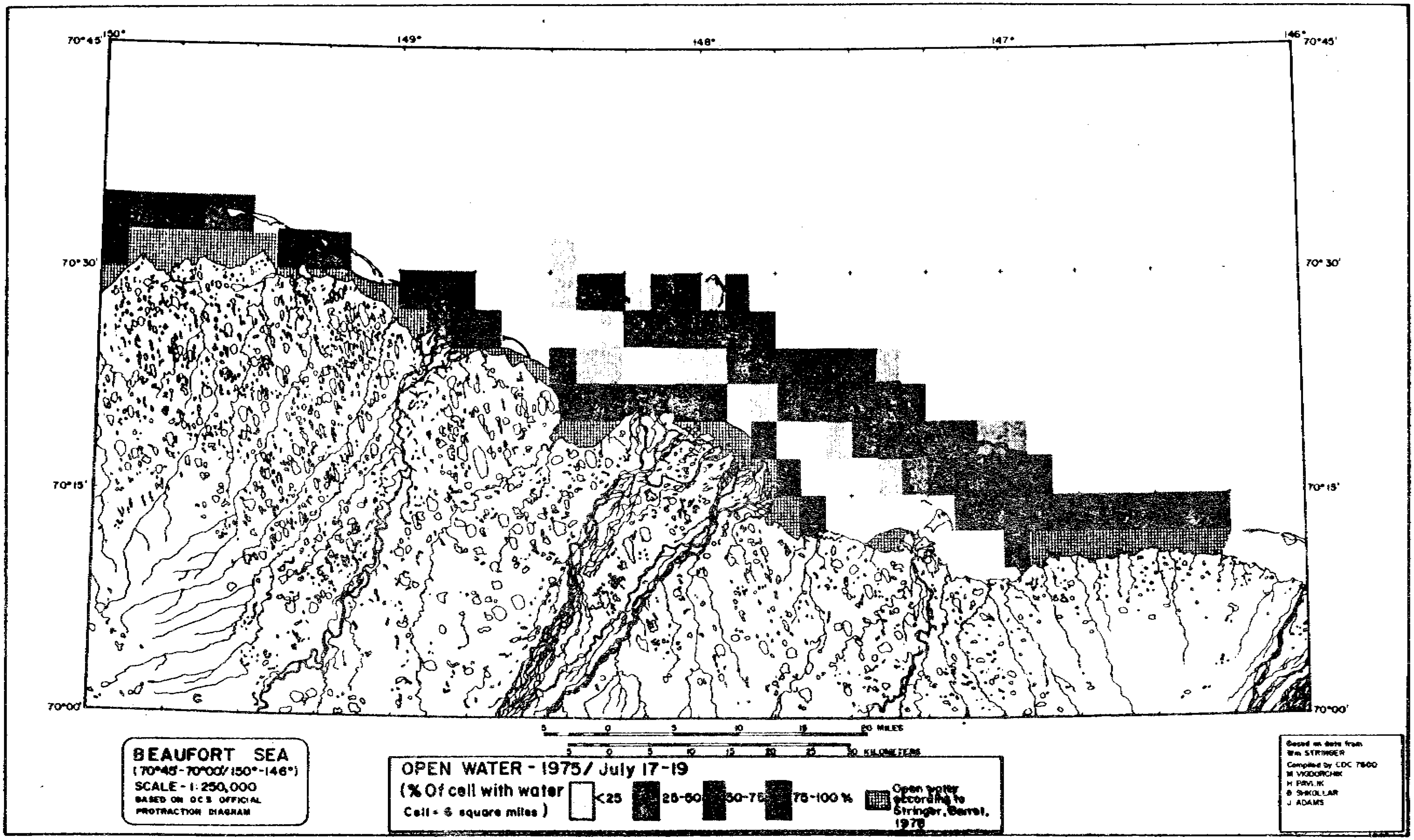
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1: 250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
OPEN WATER - 1973/June 14-17
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100 %
Open water according to Stringer, Barret, 1978
Based on data from Wm STRINGER
Compiled by CDC 7600
M VIGDORCHIK
H PAVLIK
B SHKOLLAR
J ADAMS

MAP 5

MAP 6



70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°15'
70°00'
20 MILES
30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL PROTRACTION DIAGRAM
OPEN WATER - 1974/ July 12-16
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100 %
Open water according to Stringer, Barrel, 1978
Compiled by CDC 7600
J ADAMS



70°45'
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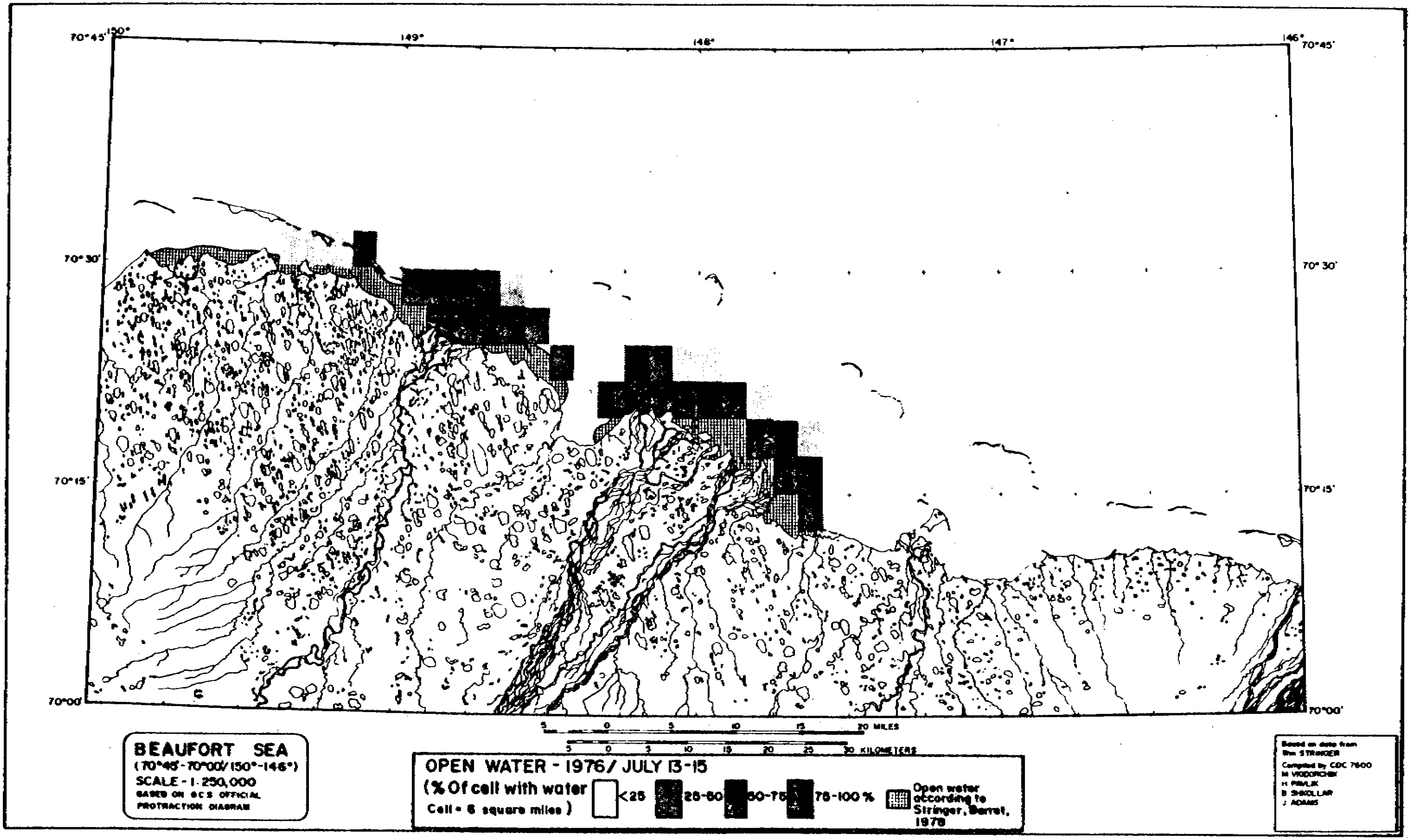
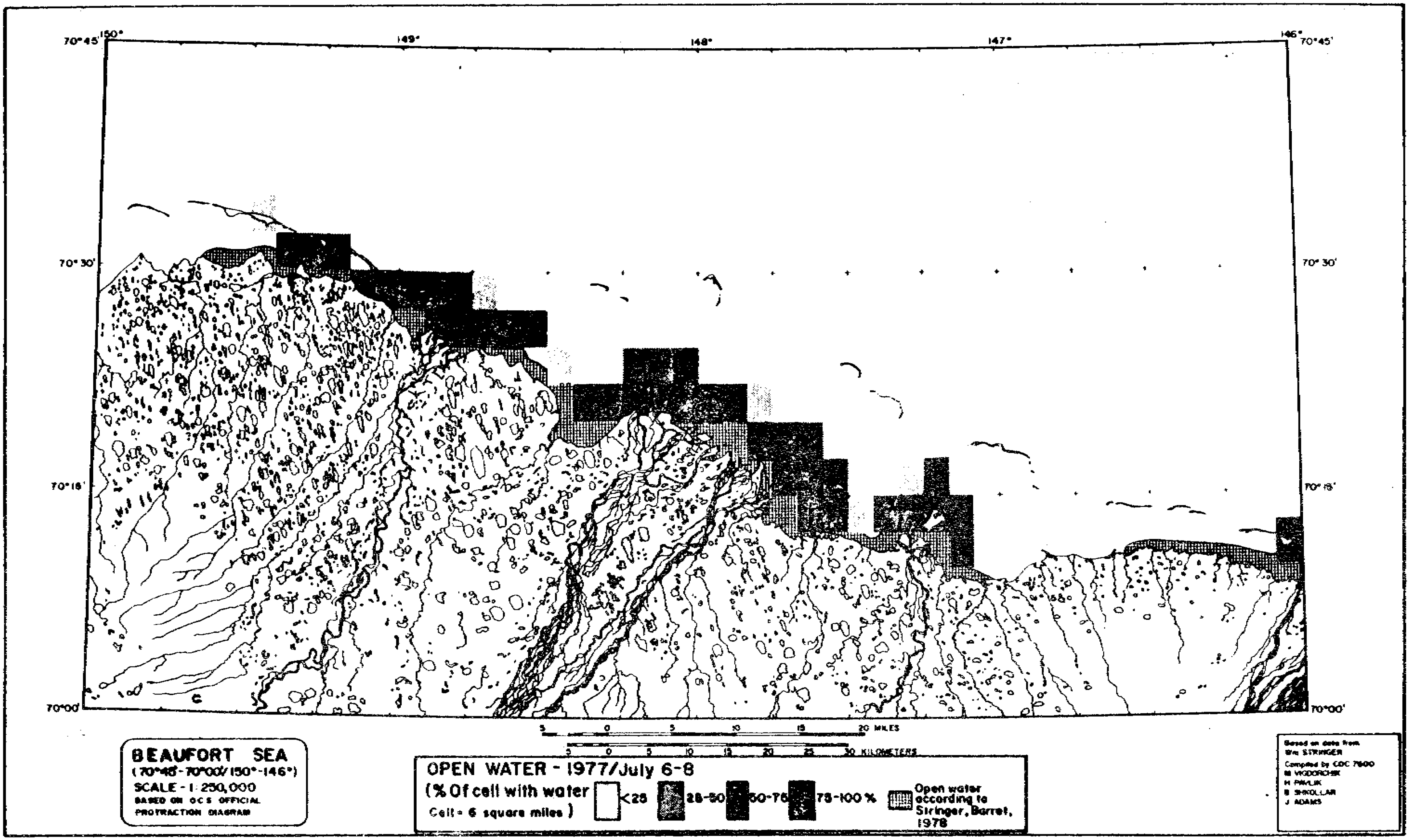
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL PROTRACTION DIAGRAM
OPEN WATER - 1975/ July 17-19
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100 %
Open water according to Stringer, Barrel, 1978
Compiled by CDC 7600
J ADAMS

MAP 7

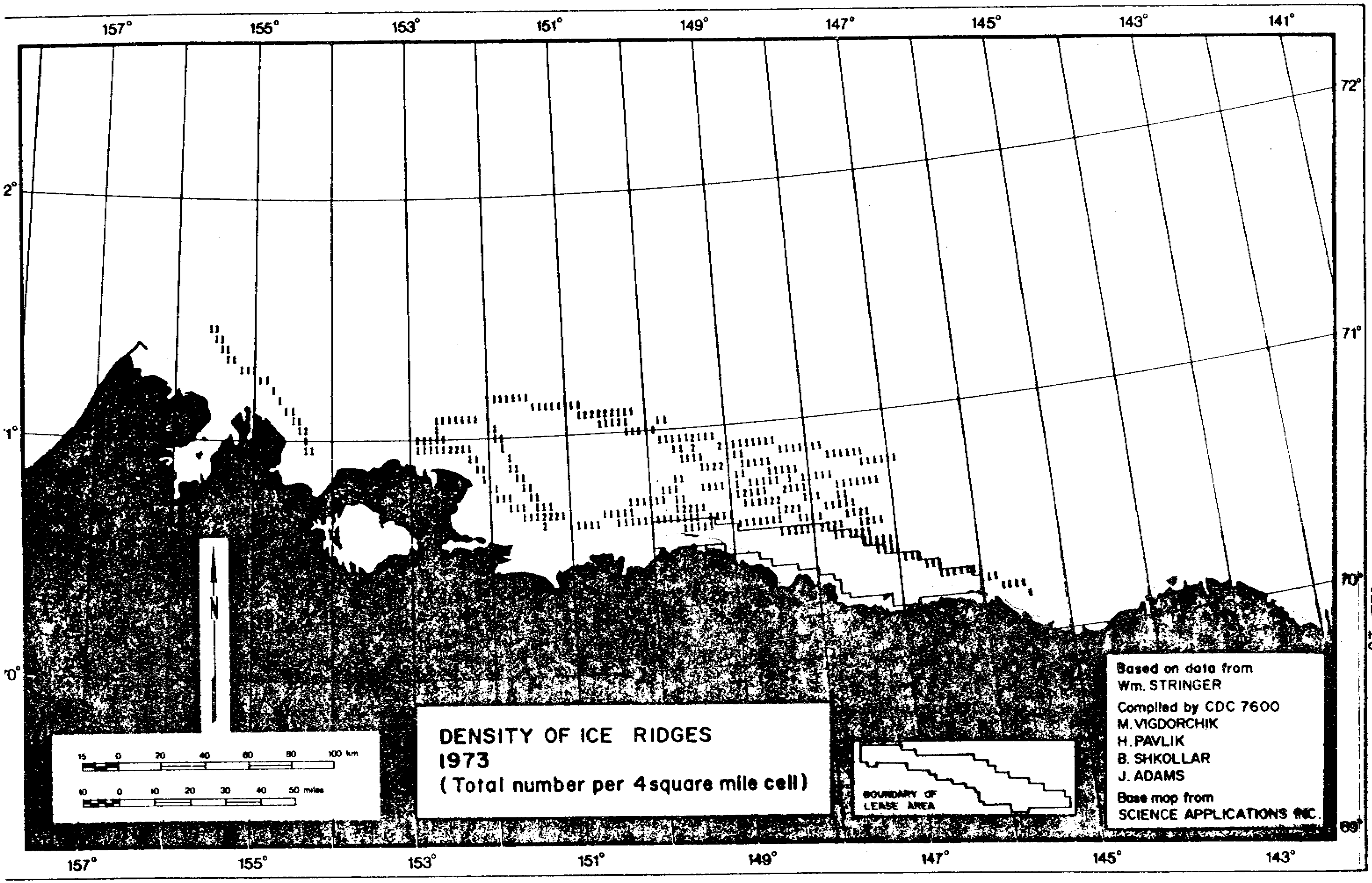


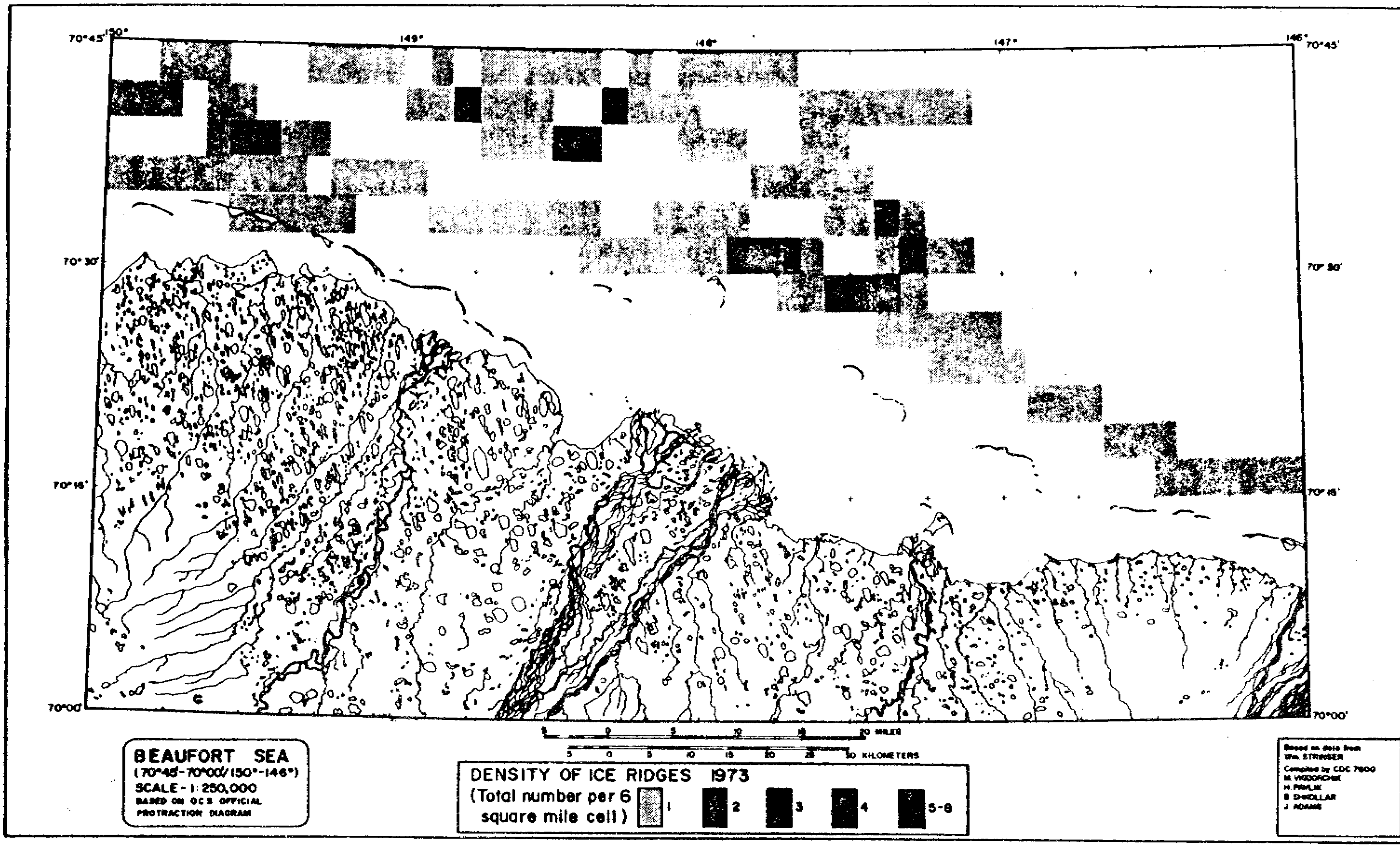
70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
OPEN WATER - 1976/ JULY 13-15
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100 %
Open water according to Stringer, Barret, 1978
Compiled by CDC 7600

MAP 8

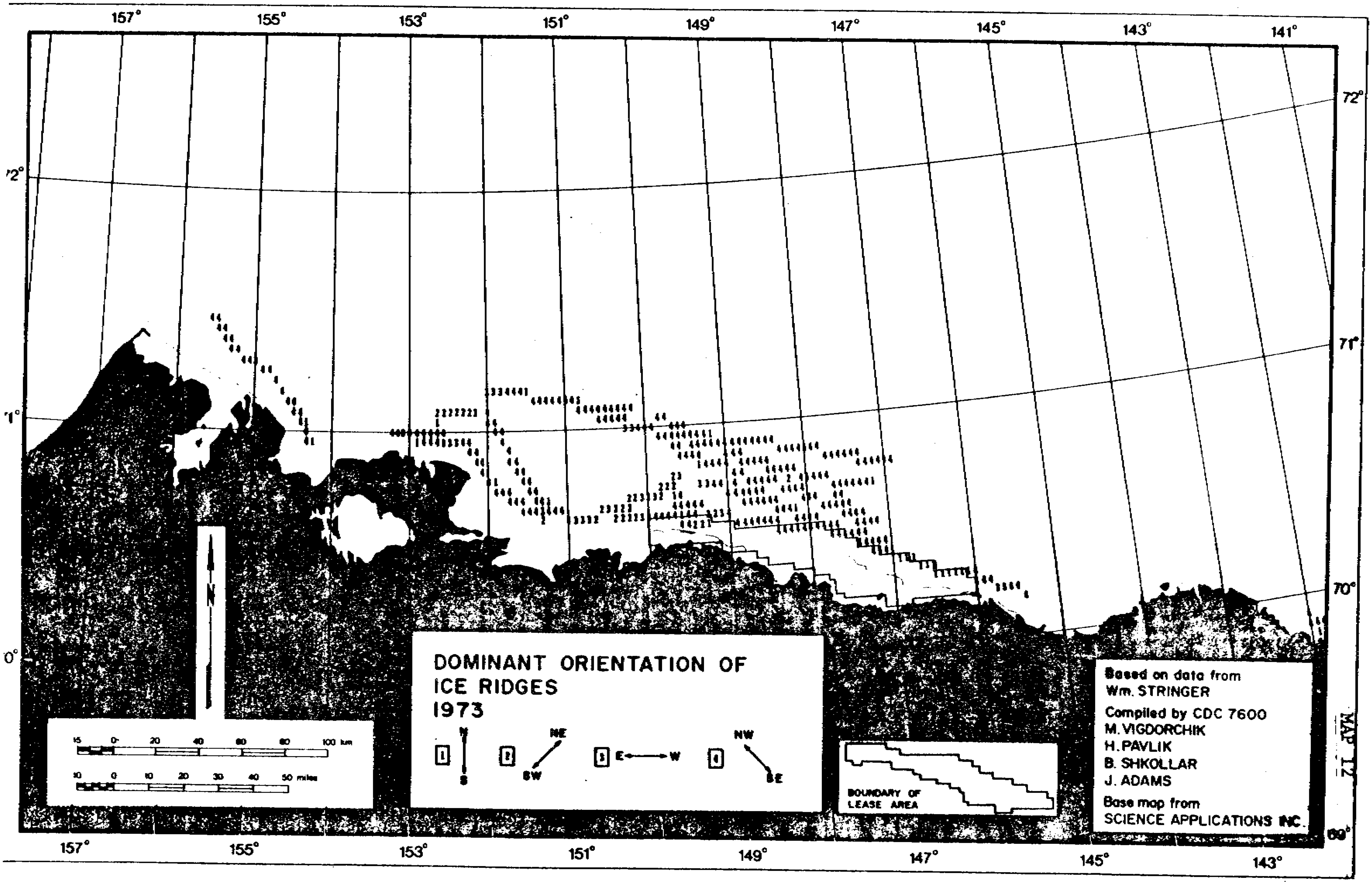

150°
149°
148°
147°
146°
70°45'
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
OPEN WATER - 1977/July 6-8
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100 %
Open water according to Stringer, Barret, 1978
Based on data from Wm STRINGER
Compiled by CDC 7600
M VIGDORCHIK
H PAVLIK
B SHKOLLAR
J ADAMS

MAP 9

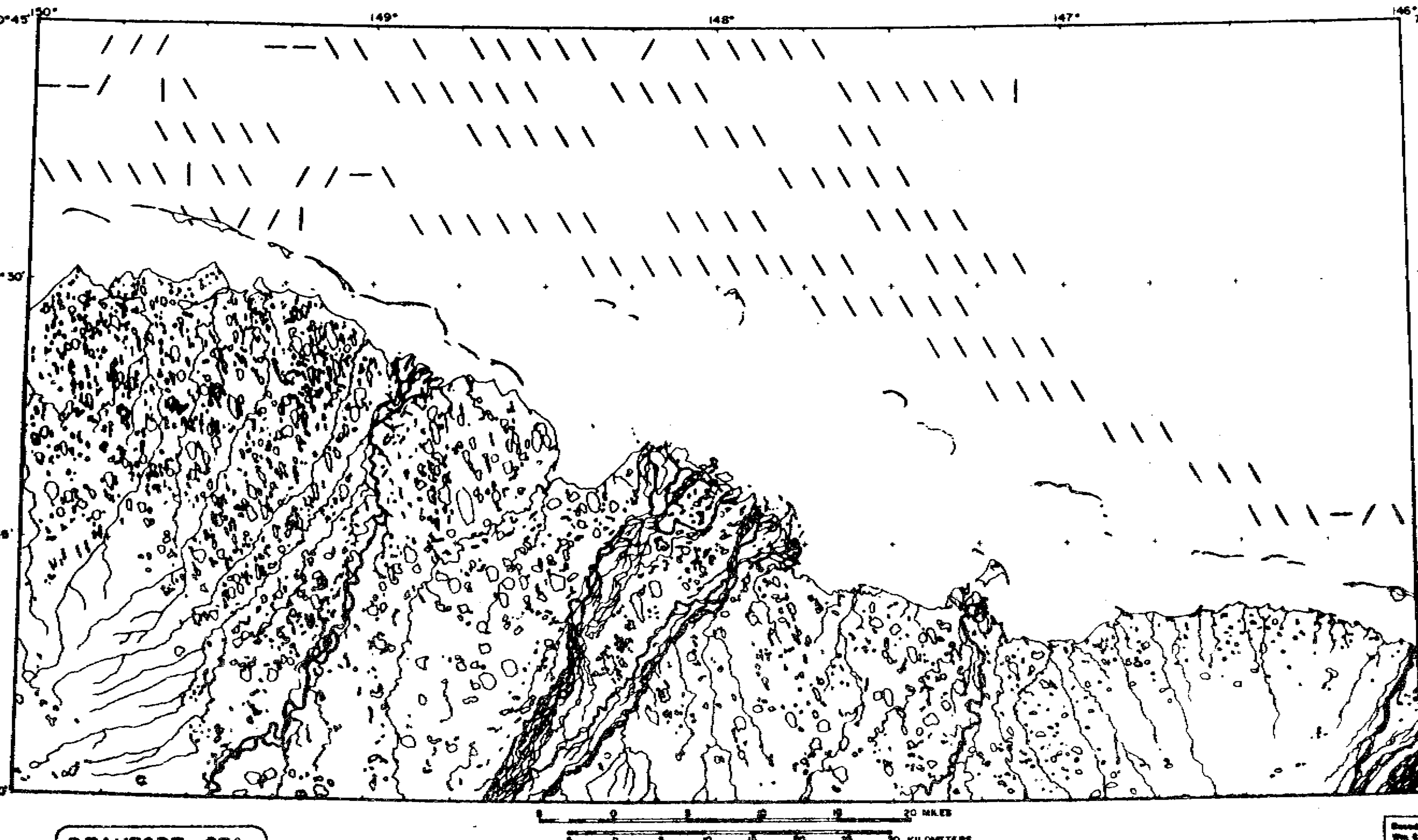

DENSITY OF ICE RIDGES
1973
(Total number per 4 square mile cell)
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
N
100 km
50 miles
157°
155°
153°
151°
149°
147°
145°
143°
141°
72°
71°
70°
69°
MAP 10


70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
MILES
KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1: 250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
DENSITY OF ICE RIDGES 1973
(Total number per 6 square mile cell)
1
2
3
4
5-8
Based on data from
Wm. STRINGER
Compiled by CDC 7600

MAP 11



DOMINANT ORIENTATION OF ICE RIDGES 1973
1 N S
2 NE SW
3 E W
4 NW SE
BOUNDARY OF LEASE AREA
Based on data from Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from SCIENCE APPLICATIONS INC.
MAP 12
0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°



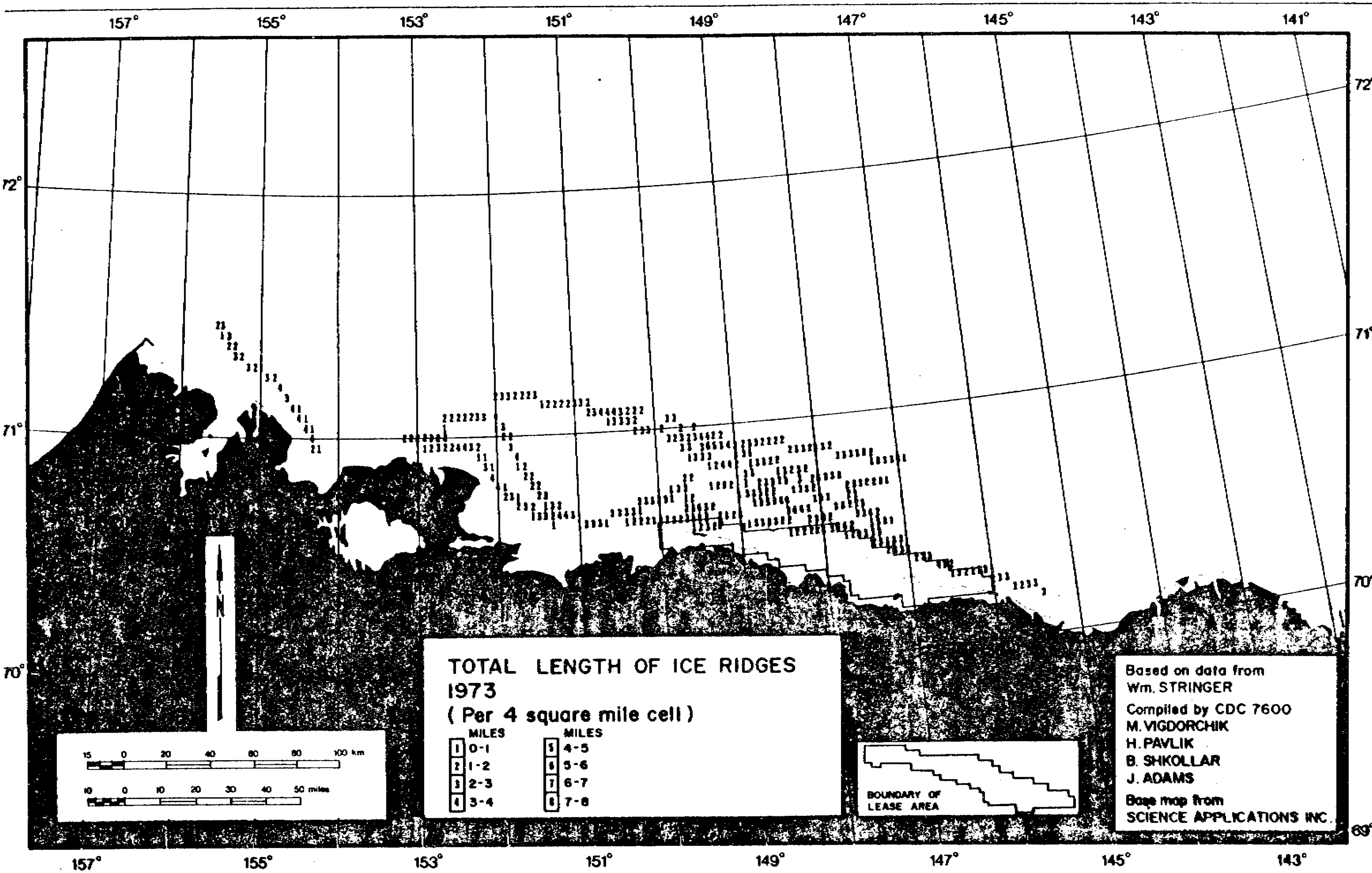
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O C S OFFICIAL PROTRACTION DIAGRAM

DOMINANT ORIENTATION OF ICE RIDGES 1973

N–S | NE–SW | W–E | NW–SE

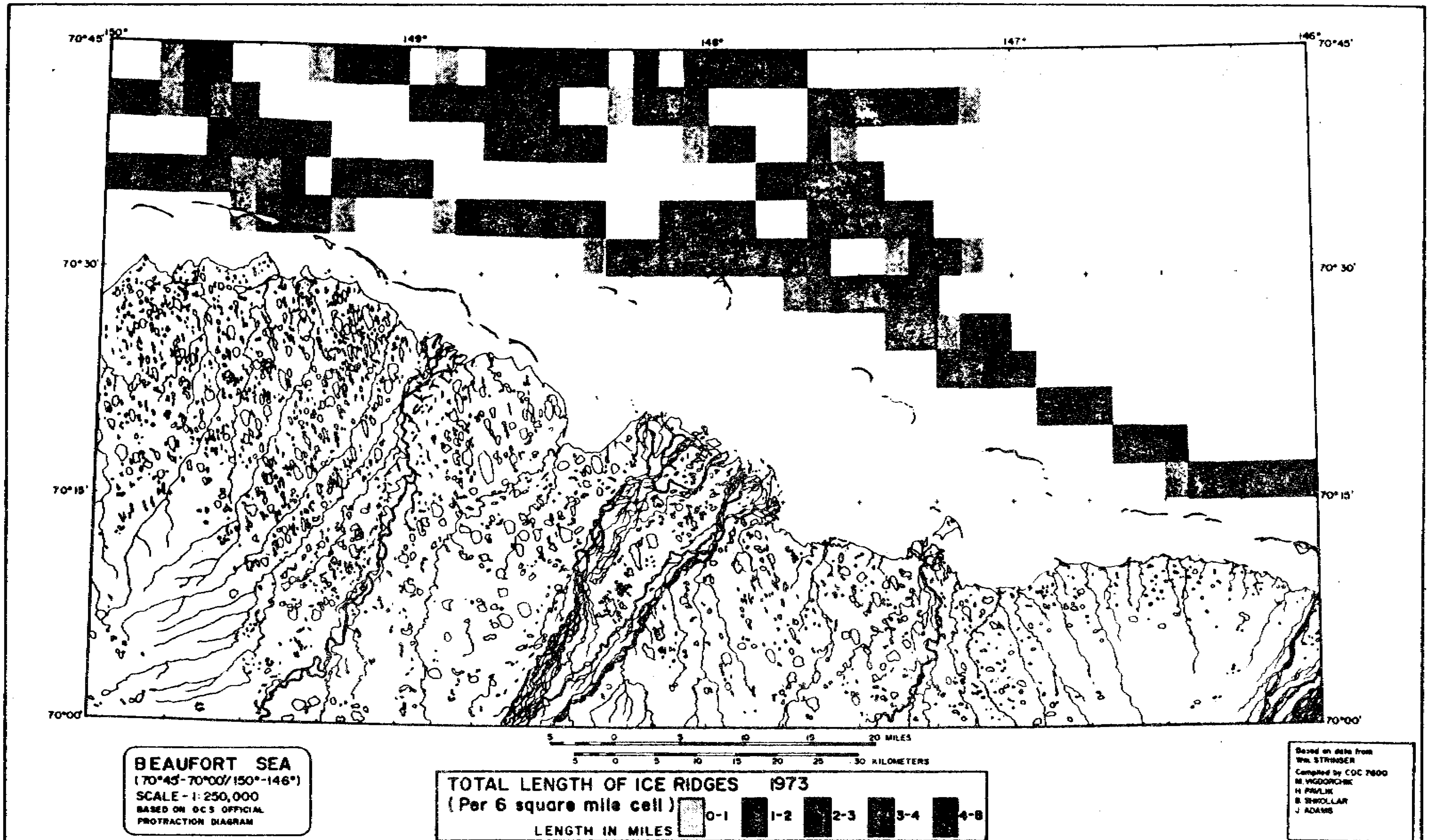
Compiled by CDC

MAP 13

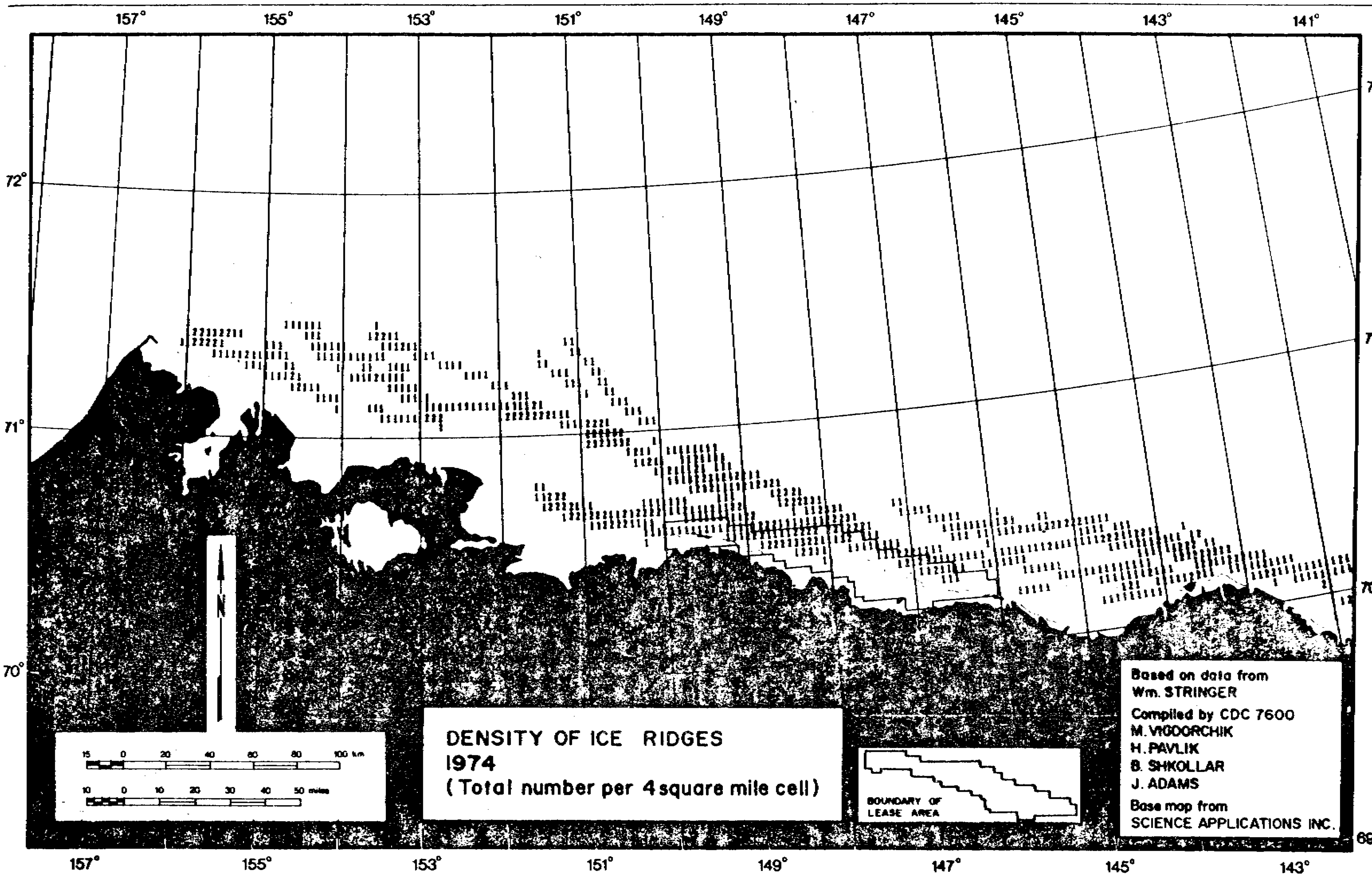


TOTAL LENGTH OF ICE RIDGES
1973
(Per 4 square mile cell)
MILES
1 0-1
2 1-2
3 2-3
4 3-4
MILES
5 4-5
6 5-6
7 6-7
8 7-8
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
N
15 0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°

MAP 14

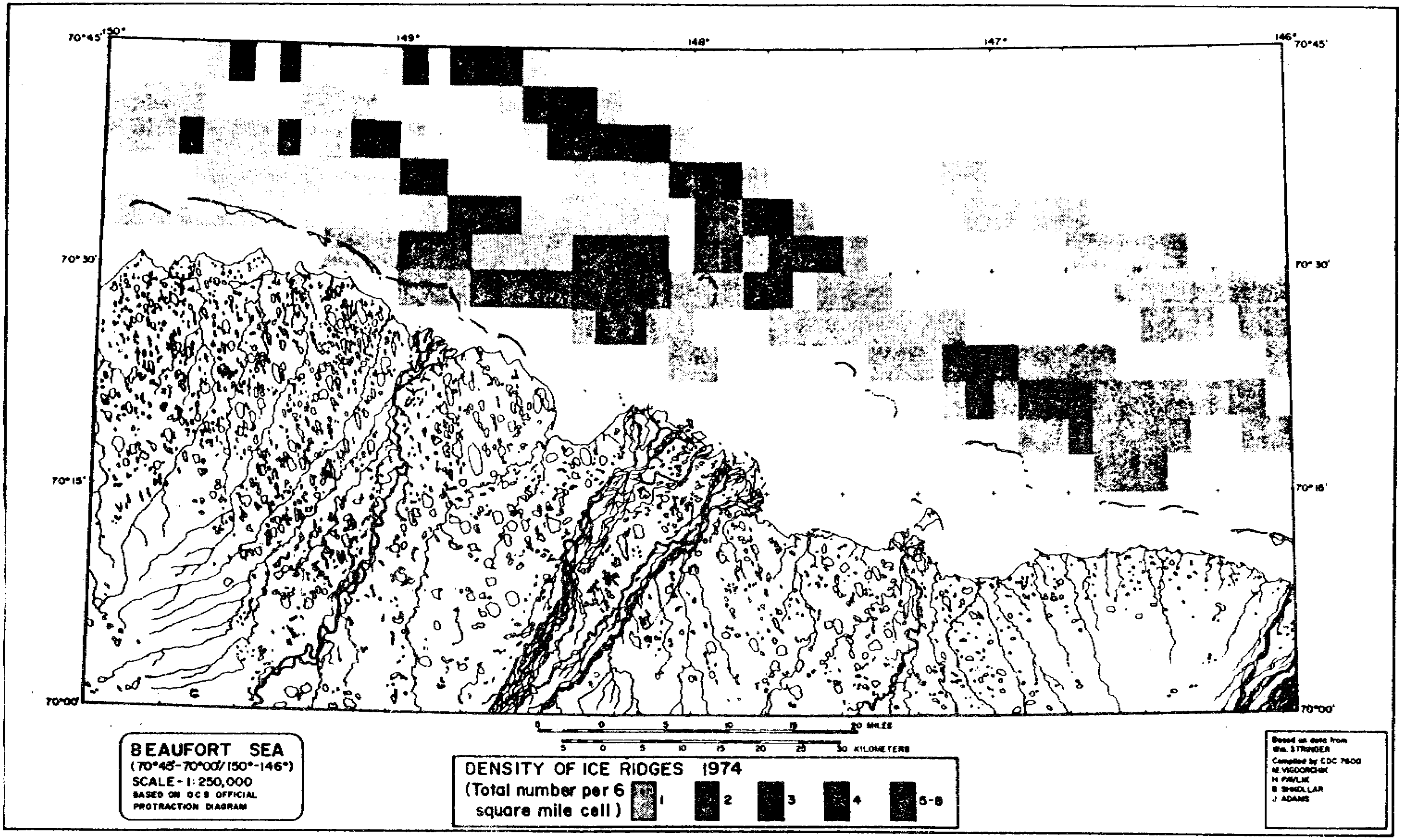

70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL
PROTRACTION DIAGRAM
TOTAL LENGTH OF ICE RIDGES 1973
(Per 6 square mile cell)
LENGTH IN MILES
0-1
1-2
2-3
3-4
4-8
Based on data from
Wm. STRINGER
Compiled by CDC 7600
J. ADAMS

MAP 15

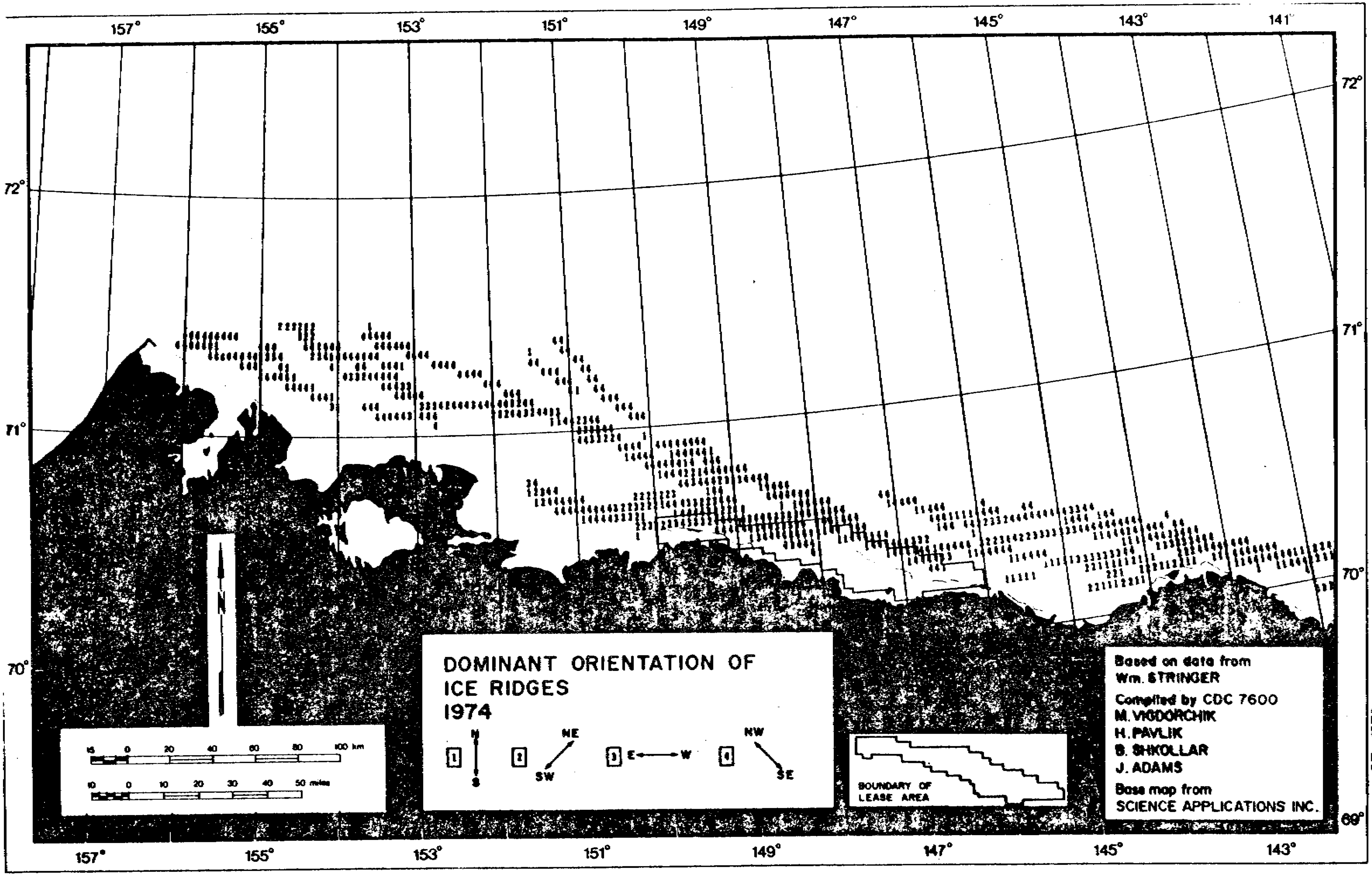

DENSITY OF ICE RIDGES
1974
(Total number per 4 square mile cell)
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
15 0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles
N
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°

MAP 16

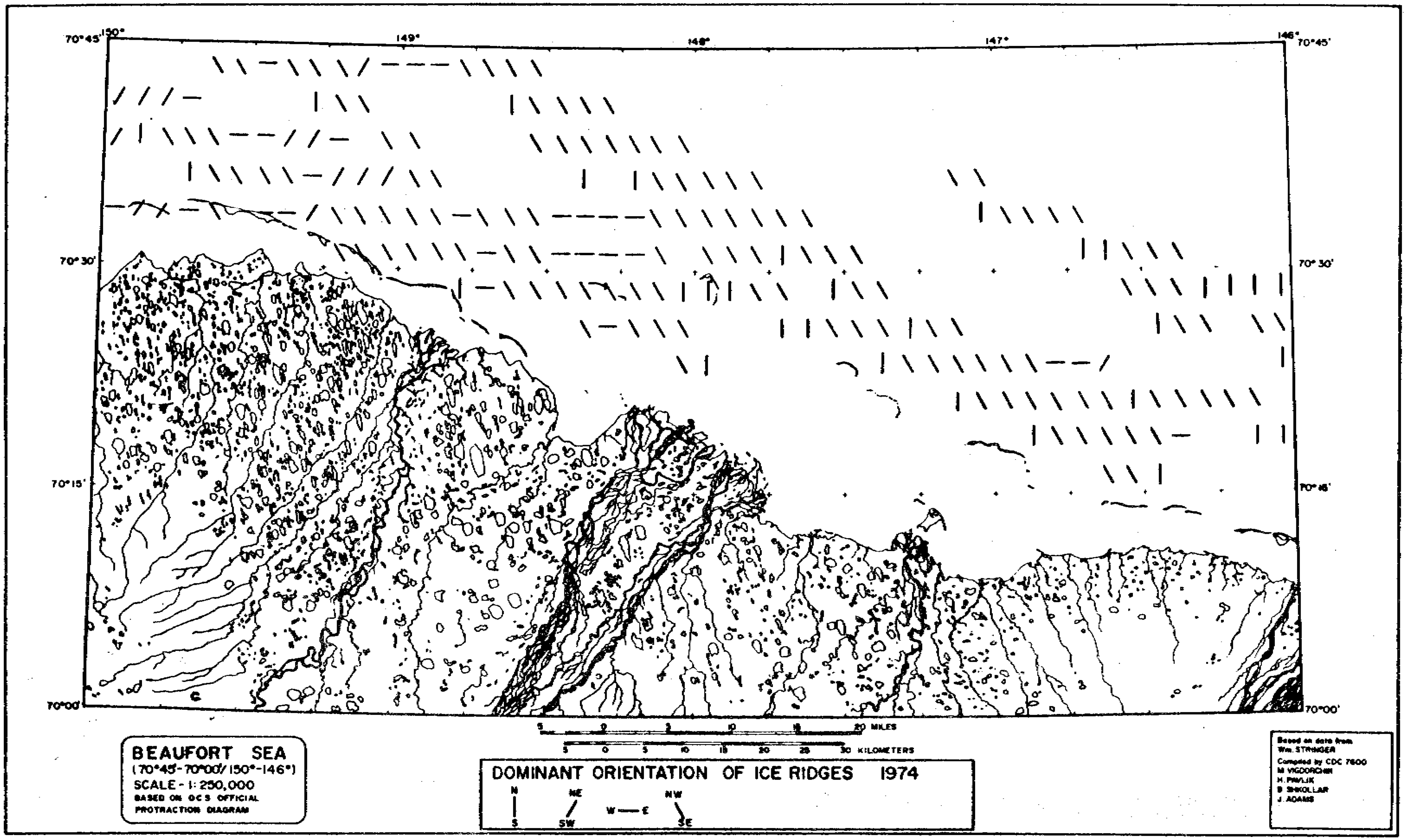
MAP 17



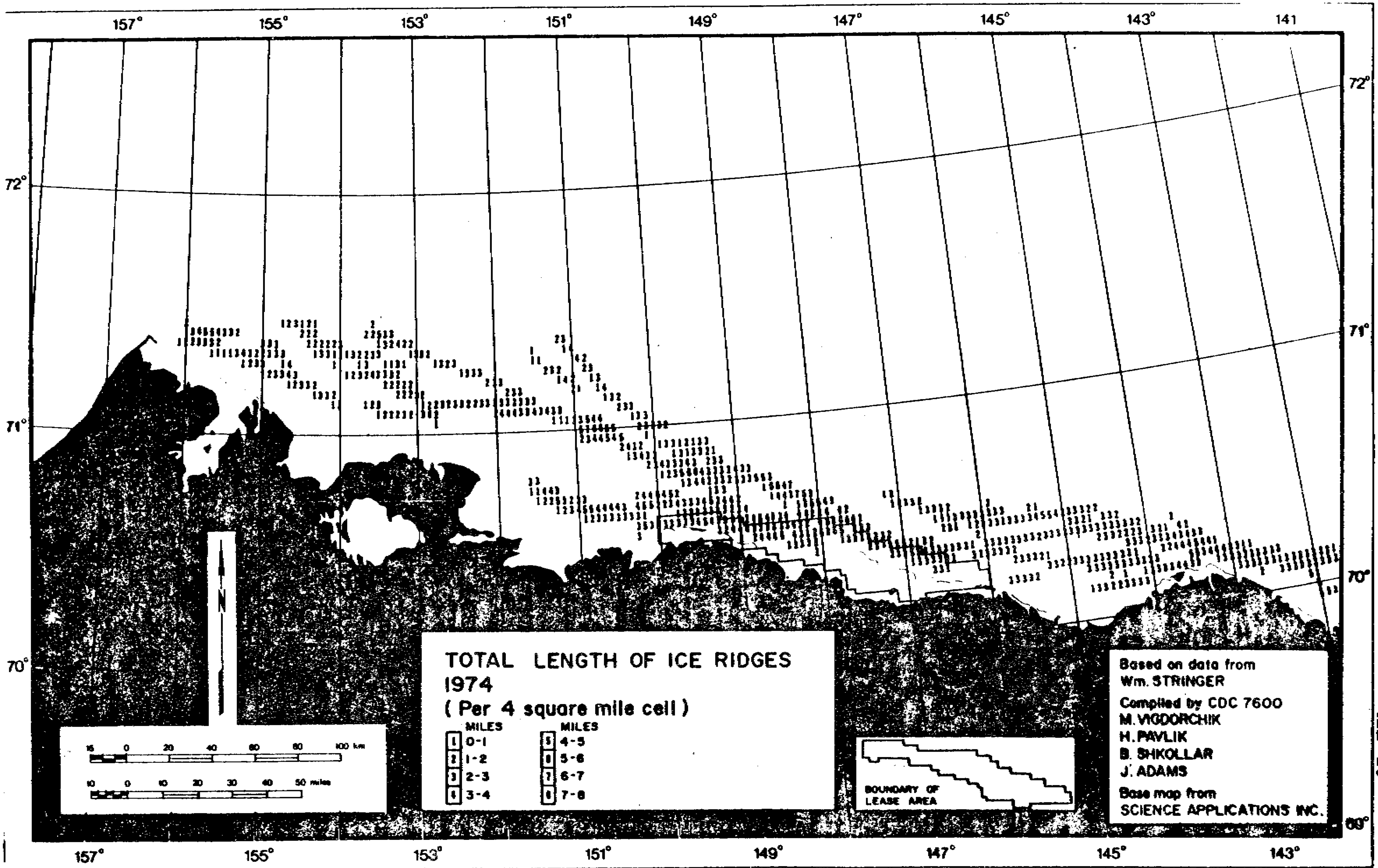
70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
DENSITY OF ICE RIDGES 1974
(Total number per 6 square mile cell)
1
2
3
4
5-8
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H PAVLIK
B SHKOLLAR
J ADAMS


DOMINANT ORIENTATION OF ICE RIDGES 1974
1 N S
2 NE SW
3 E W
4 NW SE
BOUNDARY OF LEASE AREA
Based on data from Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°
0 20 40 60 80 100 km
0 10 20 30 40 50 miles

MAP 18

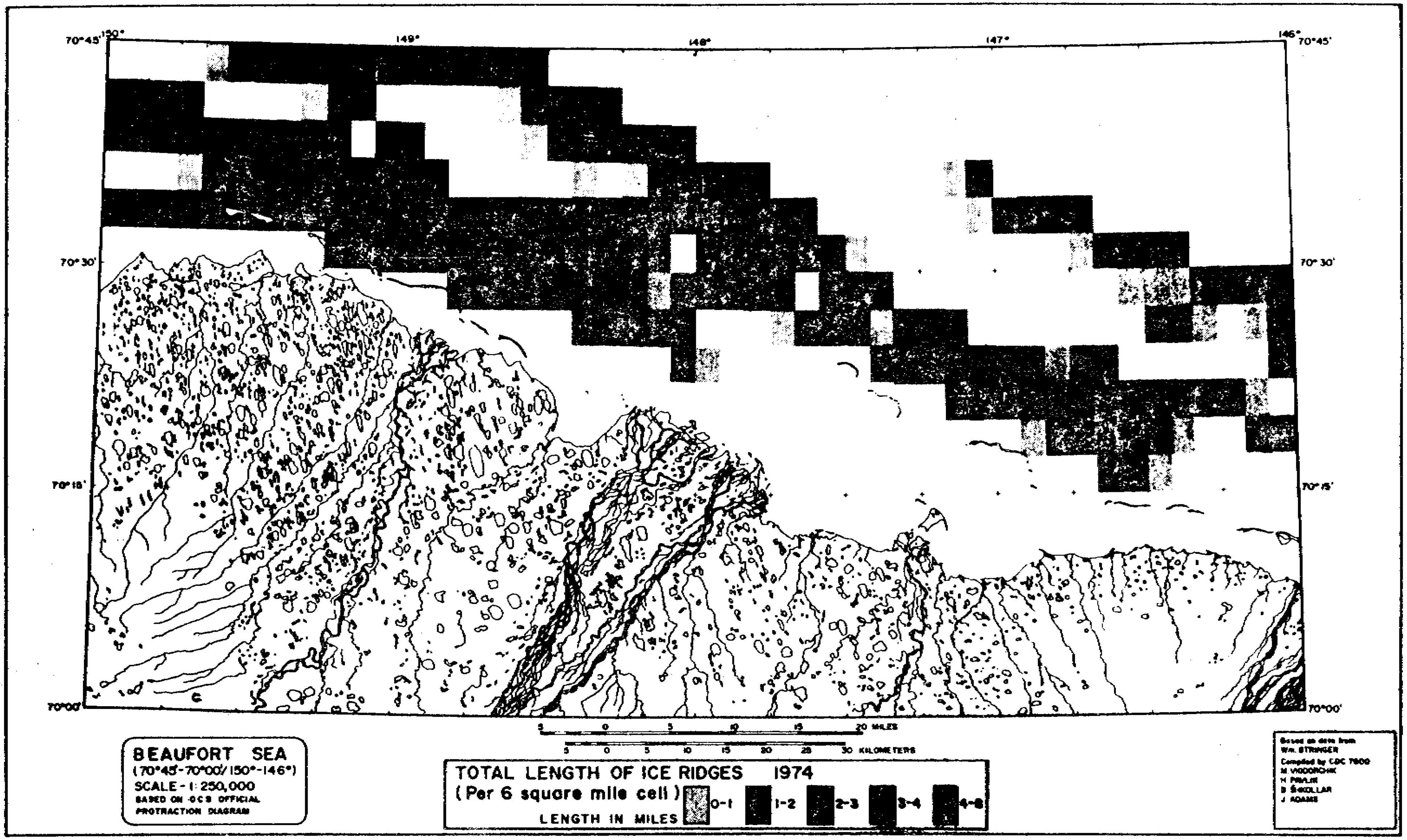

70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
DOMINANT ORIENTATION OF ICE RIDGES 1974
N
S
NE
SW
W — E
NW
SE
Based on data from Wm. STRINGER
Compiled by CDC 7600
J. ADAMS

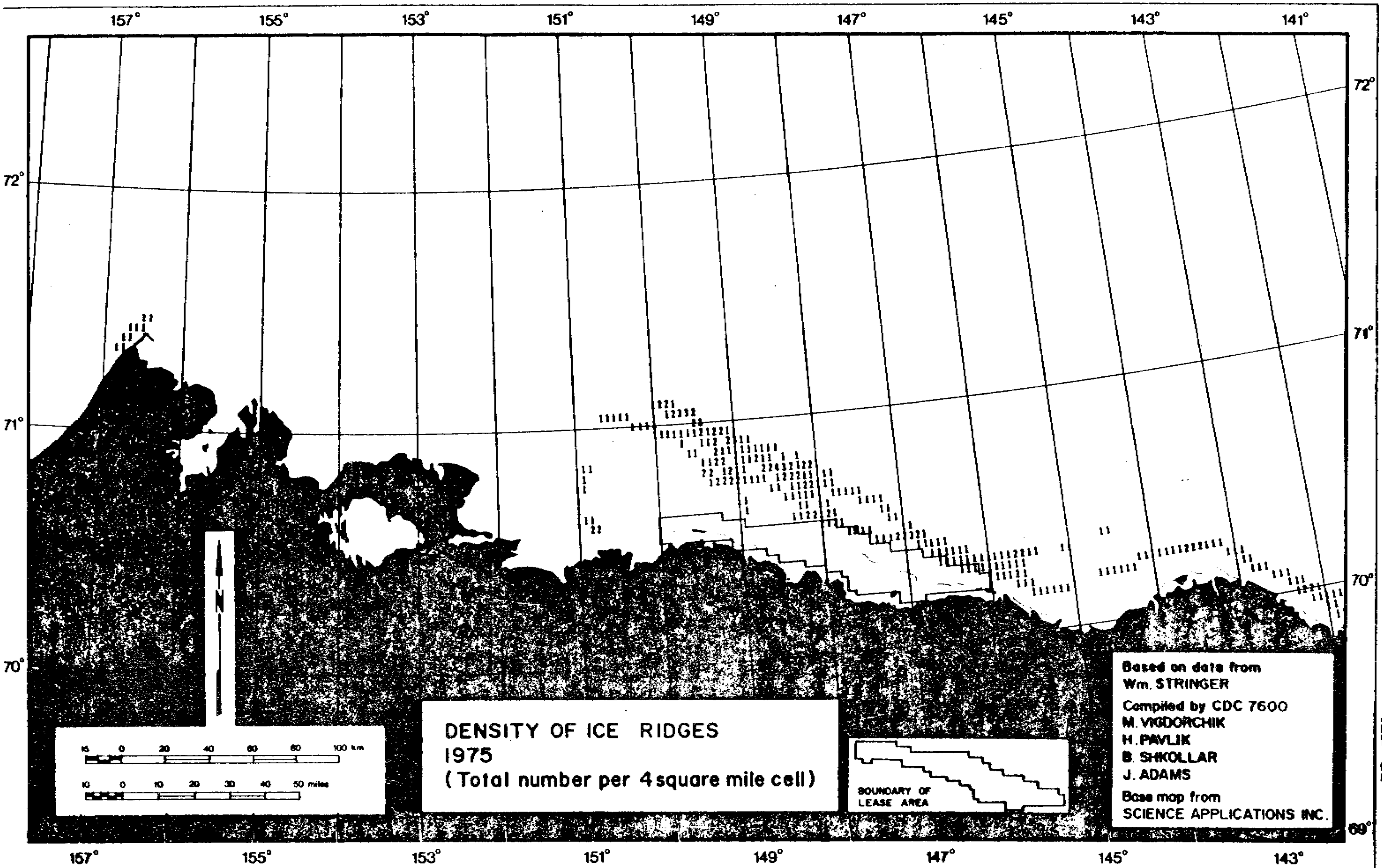
MAP 19



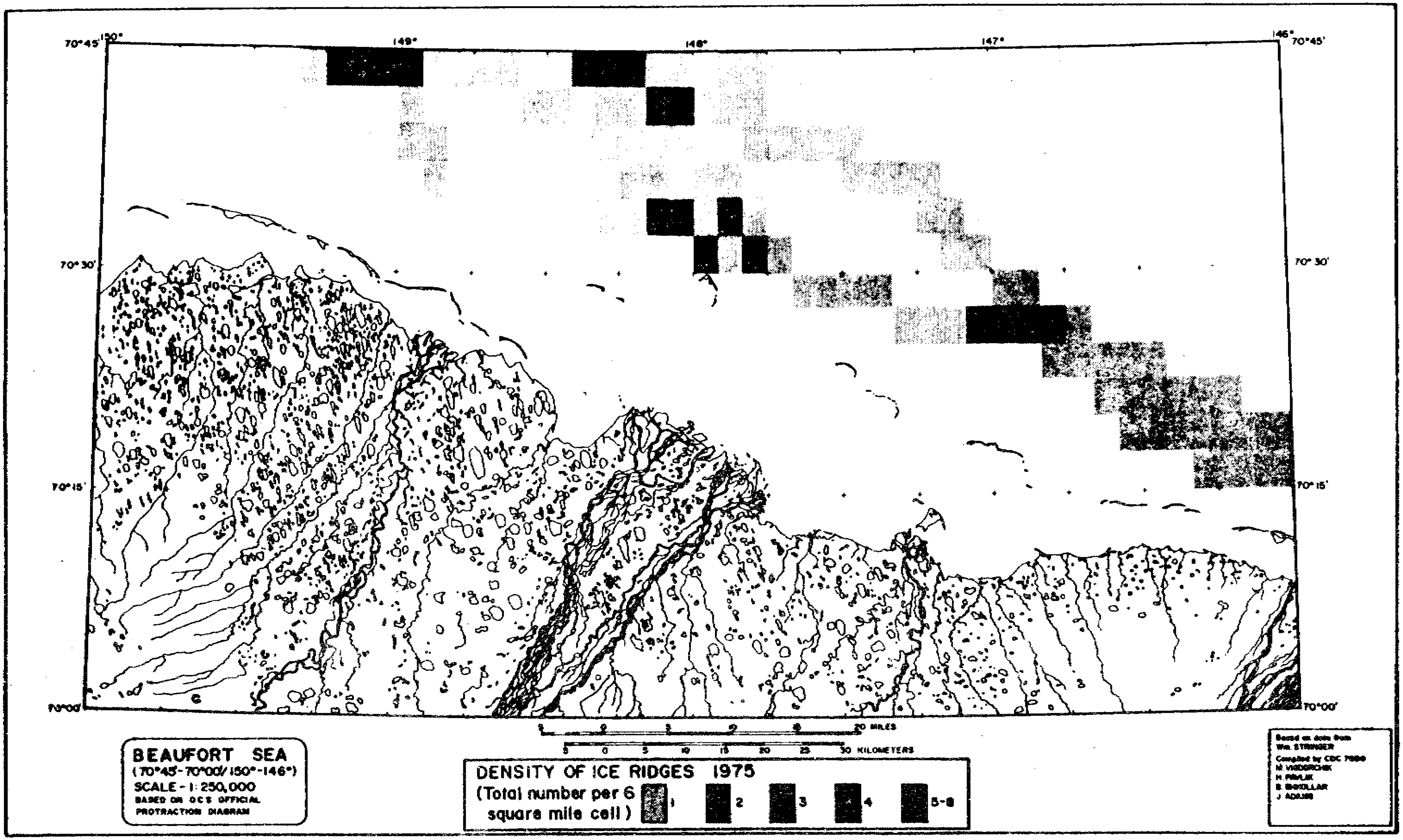
TOTAL LENGTH OF ICE RIDGES
1974
(Per 4 square mile cell)
MILES
1 0-1
2 1-2
3 2-3
4 3-4
MILES
5 4-5
6 5-6
7 6-7
8 7-8
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
N
157°
155°
153°
151°
149°
147°
145°
143°
141
72°
71°
70°
69°

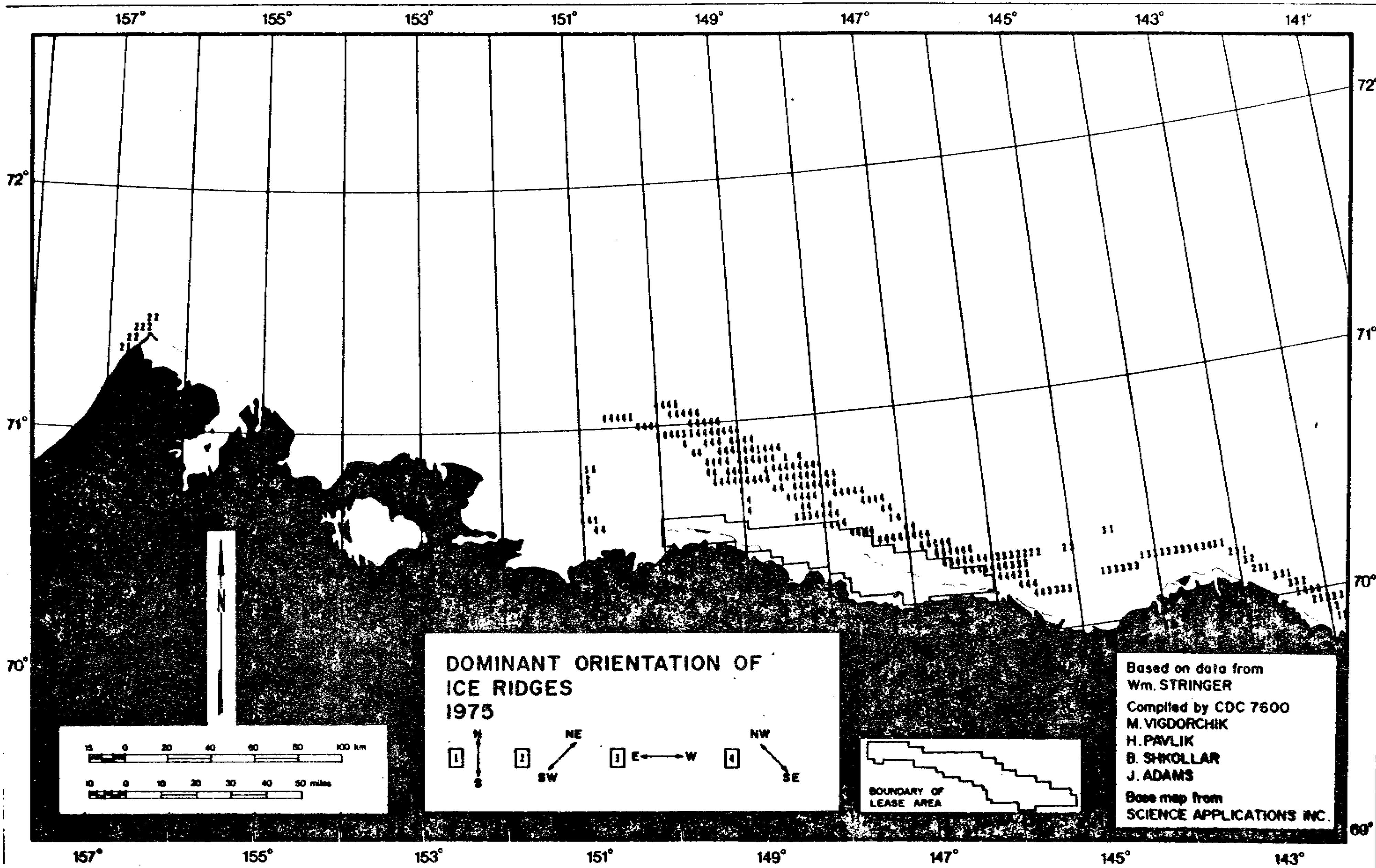
MAP 20

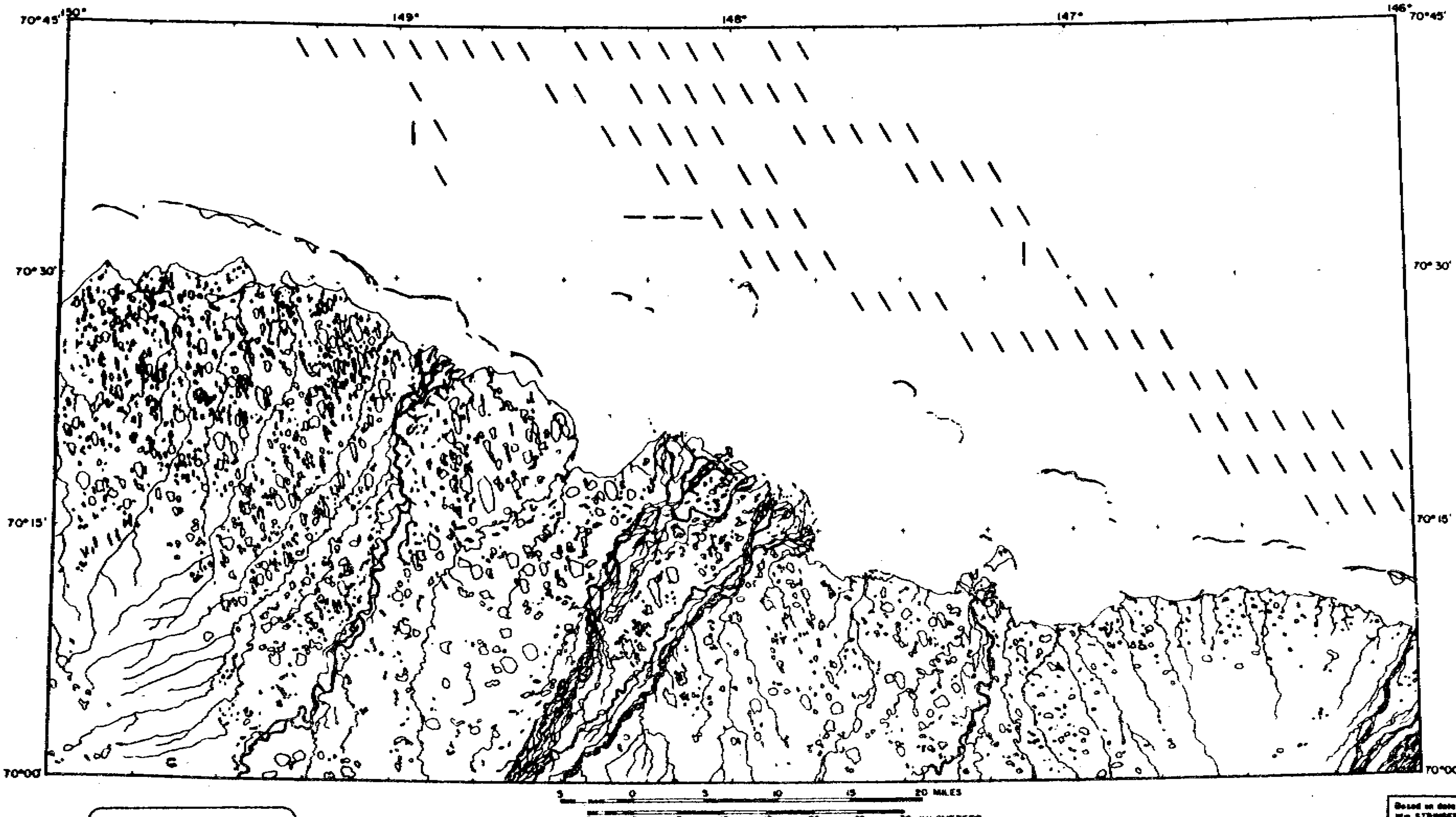

70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL PROTRACTION DIAGRAM
TOTAL LENGTH OF ICE RIDGES 1974
(Per 6 square mile cell)
LENGTH IN MILES
0-1
1-2
2-3
3-4
4-8
Based on data from
Wm. STRINGER
Compiled by CDC 7600
J ADAMS


DENSITY OF ICE RIDGES
1975
(Total number per 4 square mile cell)
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
N
100 km
50 miles
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°

MAP 22


70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1: 250,000
BASED ON O C S OFFICIAL
PROTRACTION DIAGRAM
DENSITY OF ICE RIDGES 1975
(Total number per 6 square mile cell)
1
2
3
4
5-8
Wm. STRINGER


DOMINANT ORIENTATION OF
ICE RIDGES
1975
1 N S
2 NE SW
3 E W
4 NW SE
BOUNDARY OF
LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
MAP 24
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°
15 0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles

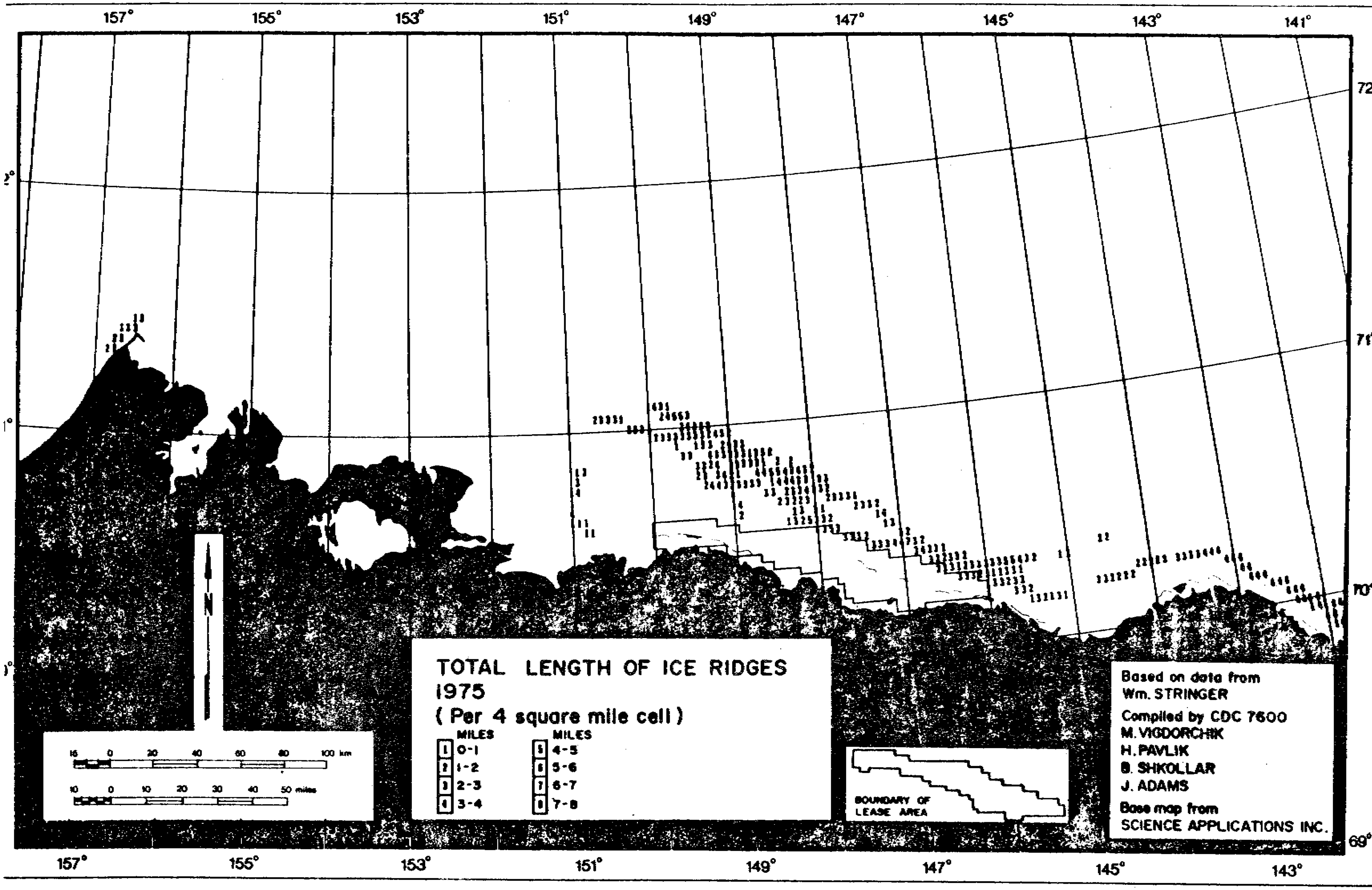


BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM

DOMINANT ORIENTATION OF ICE RIDGES 1975

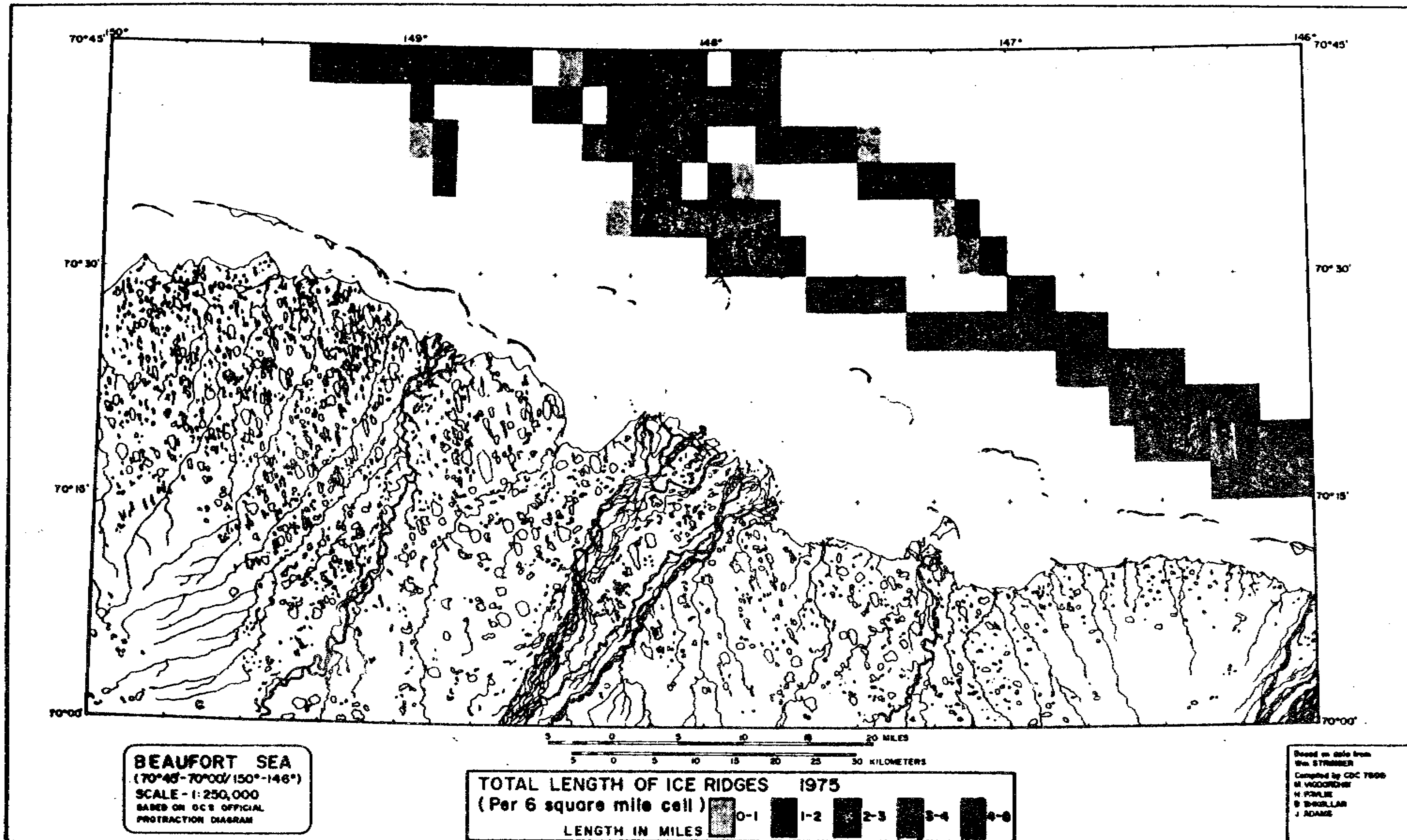
N–S NE–SW W—E NW–SE

Based on data from
Wm. STRINGER
Compiled by CDC 7600

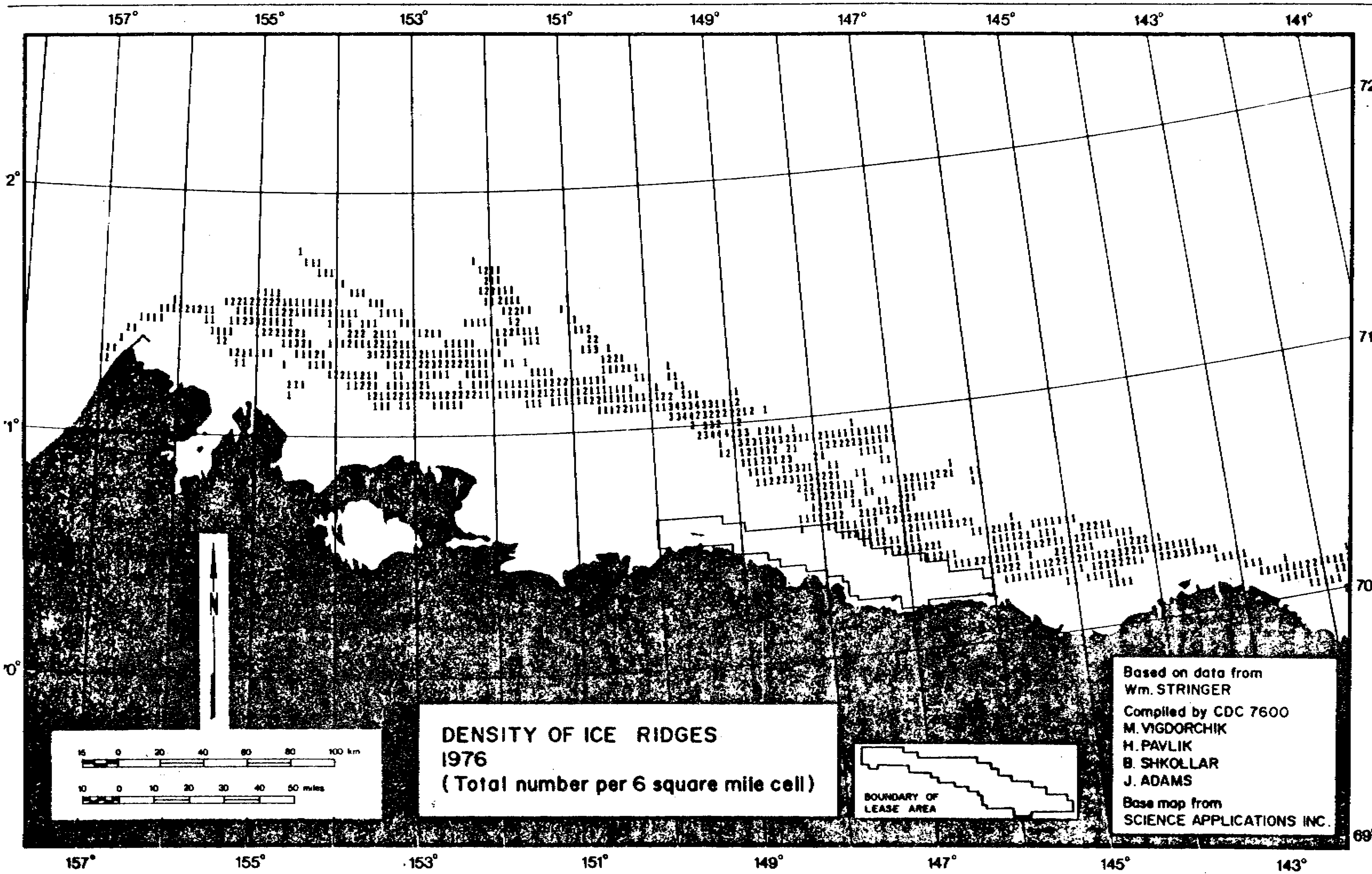


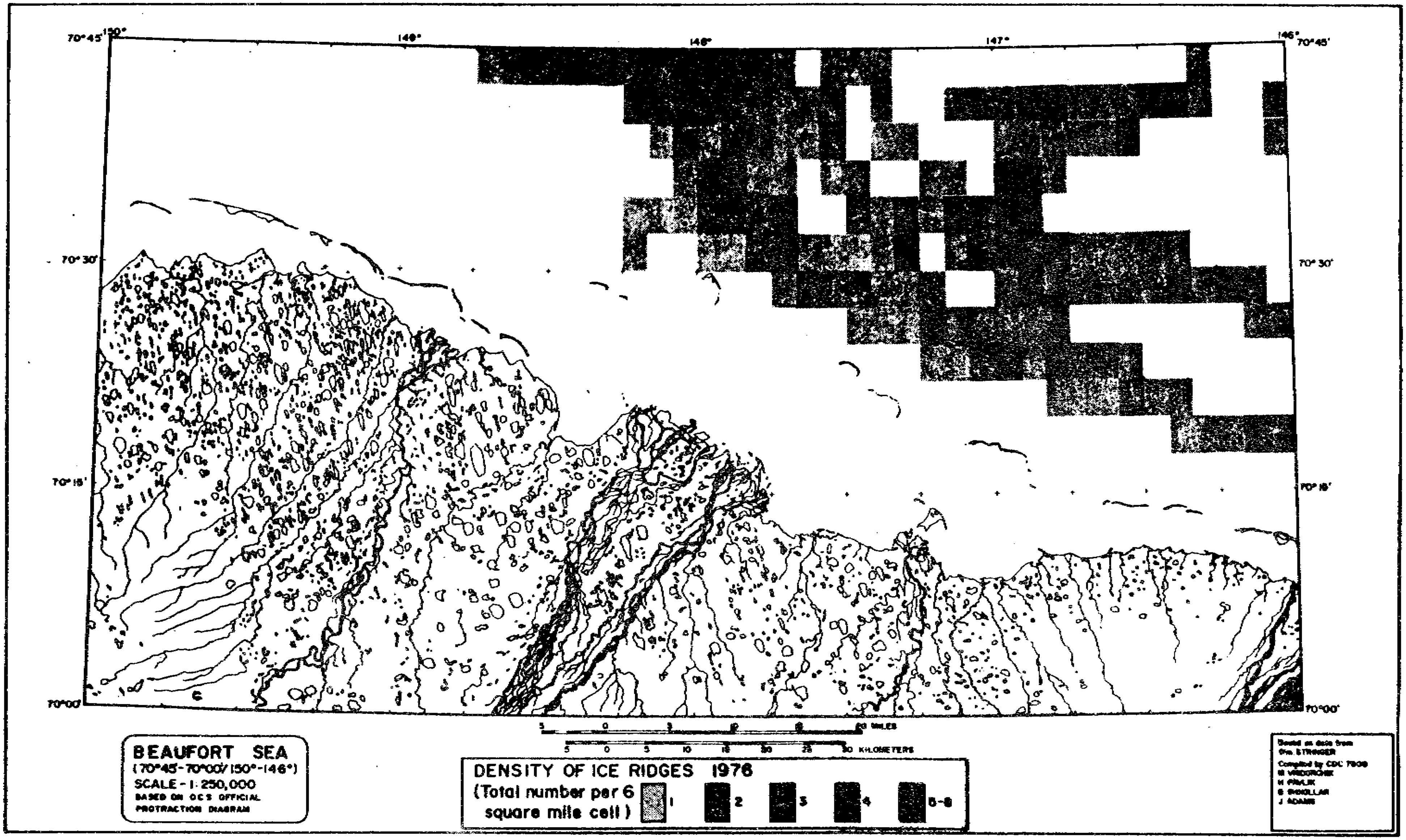
157°
155°
153°
151°
149°
147°
145°
143°
141°
72°
71°
70°
69°
N
TOTAL LENGTH OF ICE RIDGES
1975
(Per 4 square mile cell)
MILES
1 0-1
2 1-2
3 2-3
4 3-4
MILES
5 4-5
6 5-6
7 6-7
8 7-8
16 0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.

MAP 26

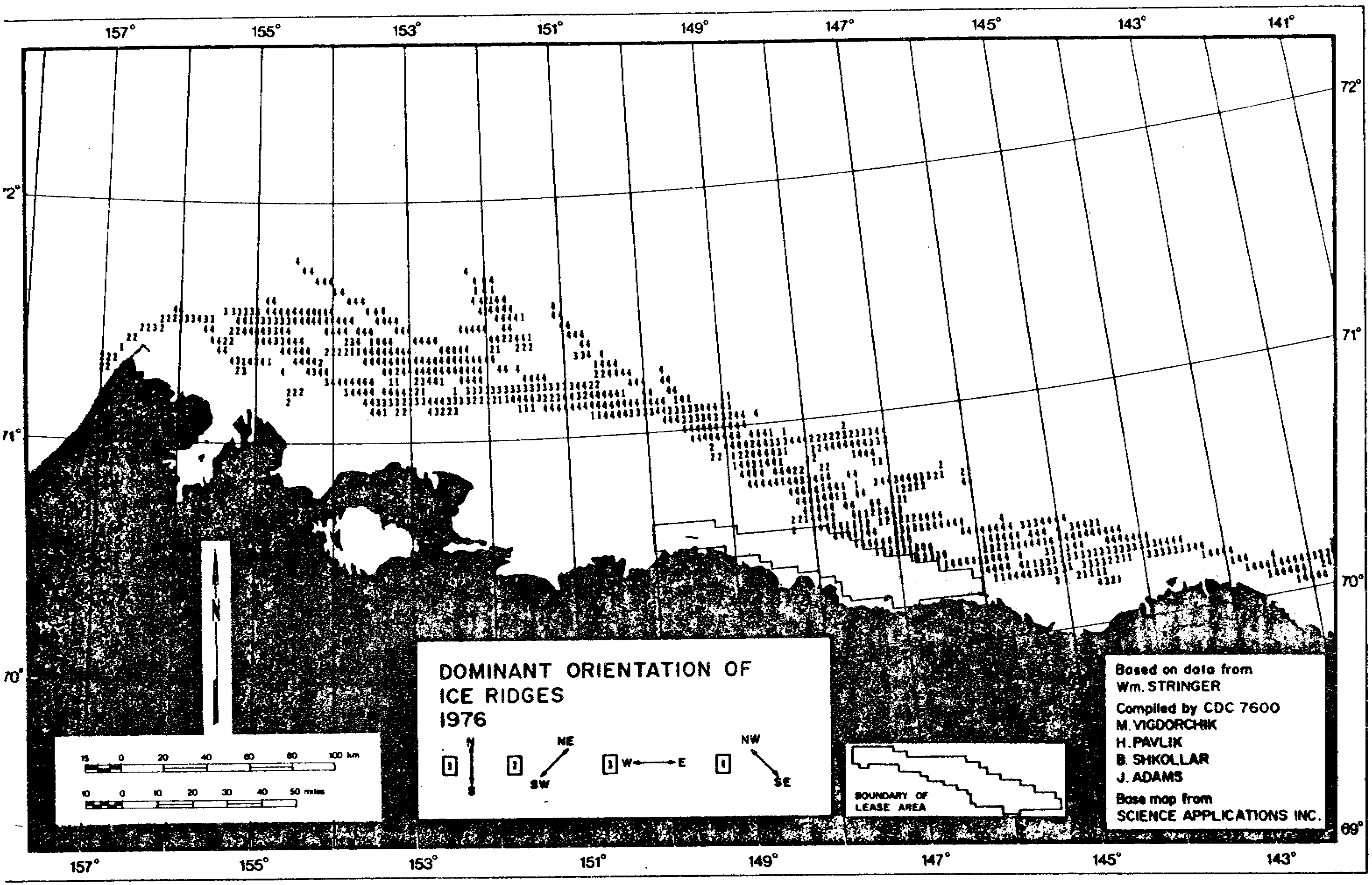

70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
TOTAL LENGTH OF ICE RIDGES 1975
(Per 6 square mile cell)
0-1
1-2
2-3
3-4
4-6
LENGTH IN MILES

MAP 27

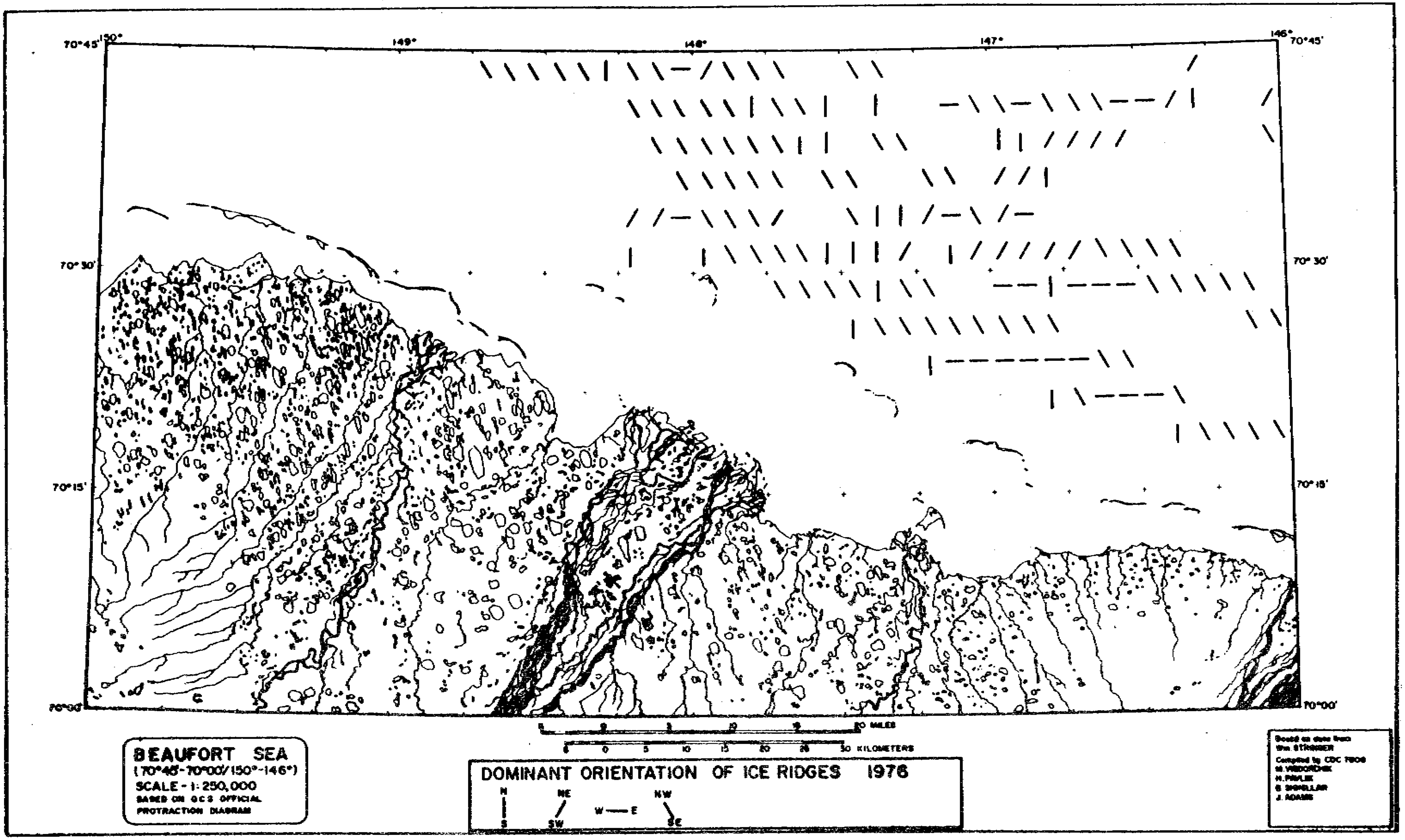

157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°
DENSITY OF ICE RIDGES
1976
(Total number per 6 square mile cell)
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
15 0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles
N
MAP 28


70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
MILES
KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
DENSITY OF ICE RIDGES 1976
(Total number per 6
square mile cell)
1
2
3
4
5-8
Compiled by CDC 7600

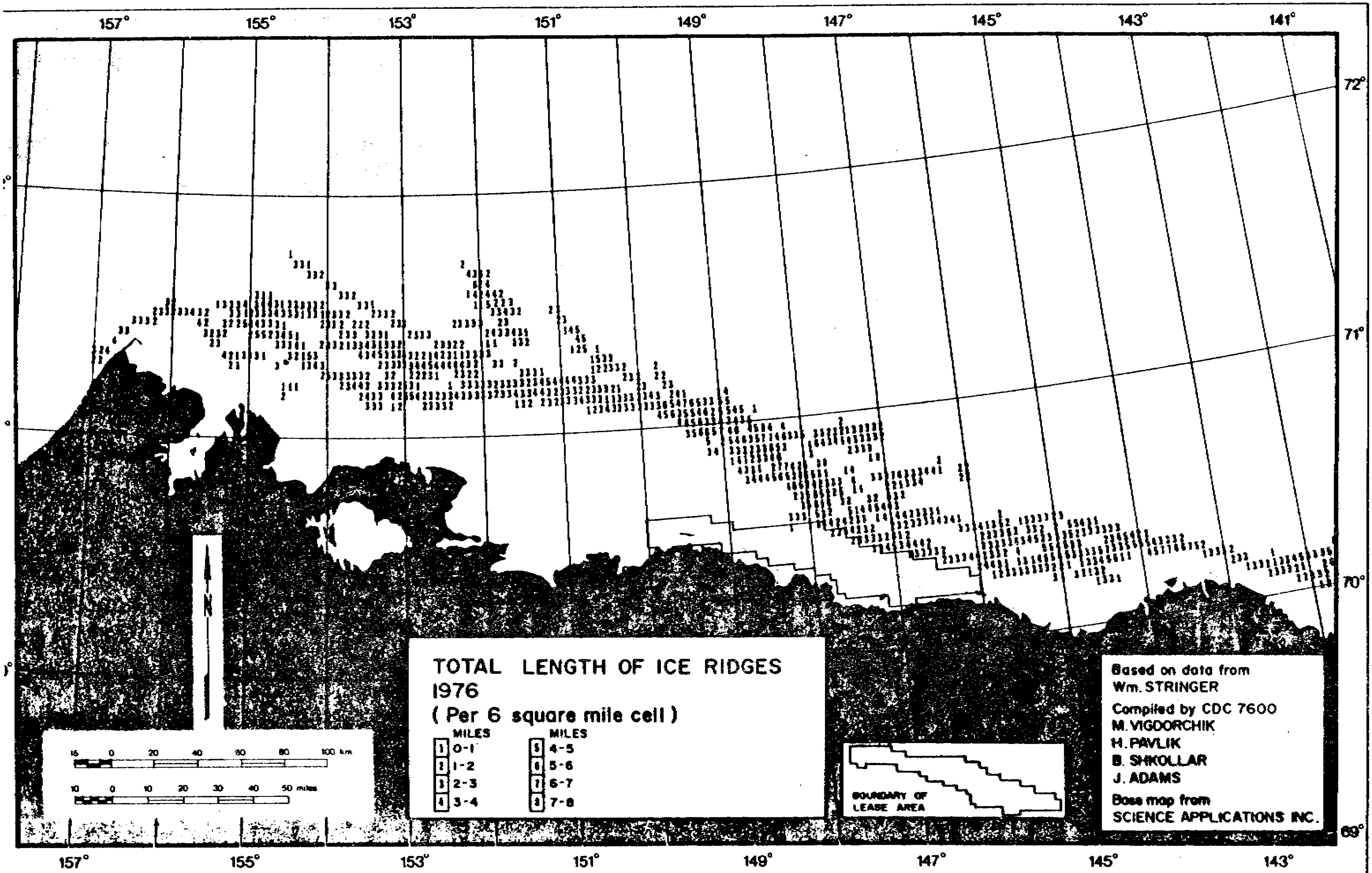
MAP 29


DOMINANT ORIENTATION OF
ICE RIDGES
1976
N
S
NE
SW
W
E
NW
SE
BOUNDARY OF
LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
100 km
50 miles
157°
155°
153°
151°
149°
147°
145°
143°
141°
72°
71°
70°
69°

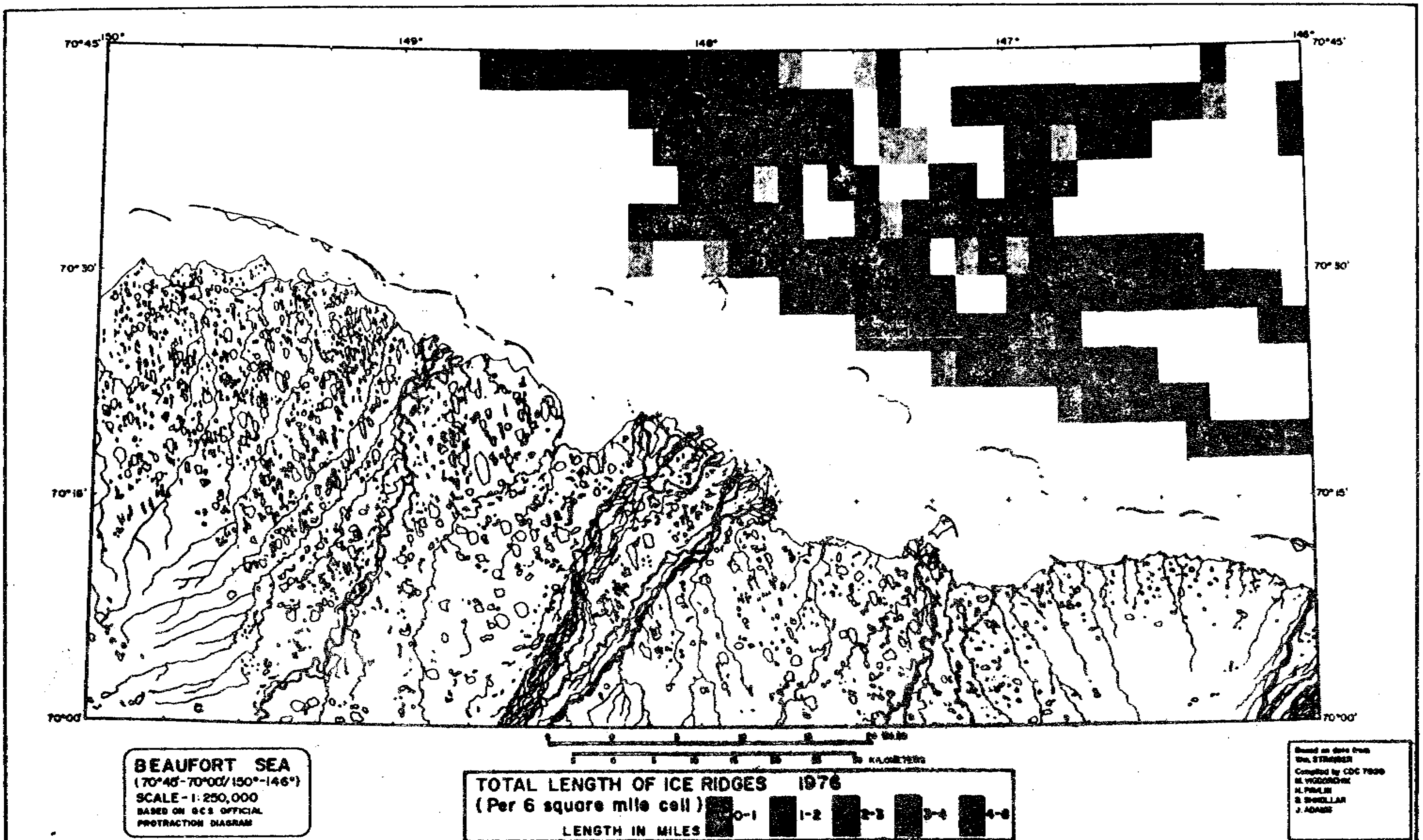
MAP 30



70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
MILES
KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1: 250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
DOMINANT ORIENTATION OF ICE RIDGES 1976
N
S
NE
SW
W — E
NW
SE
J. ADAMS

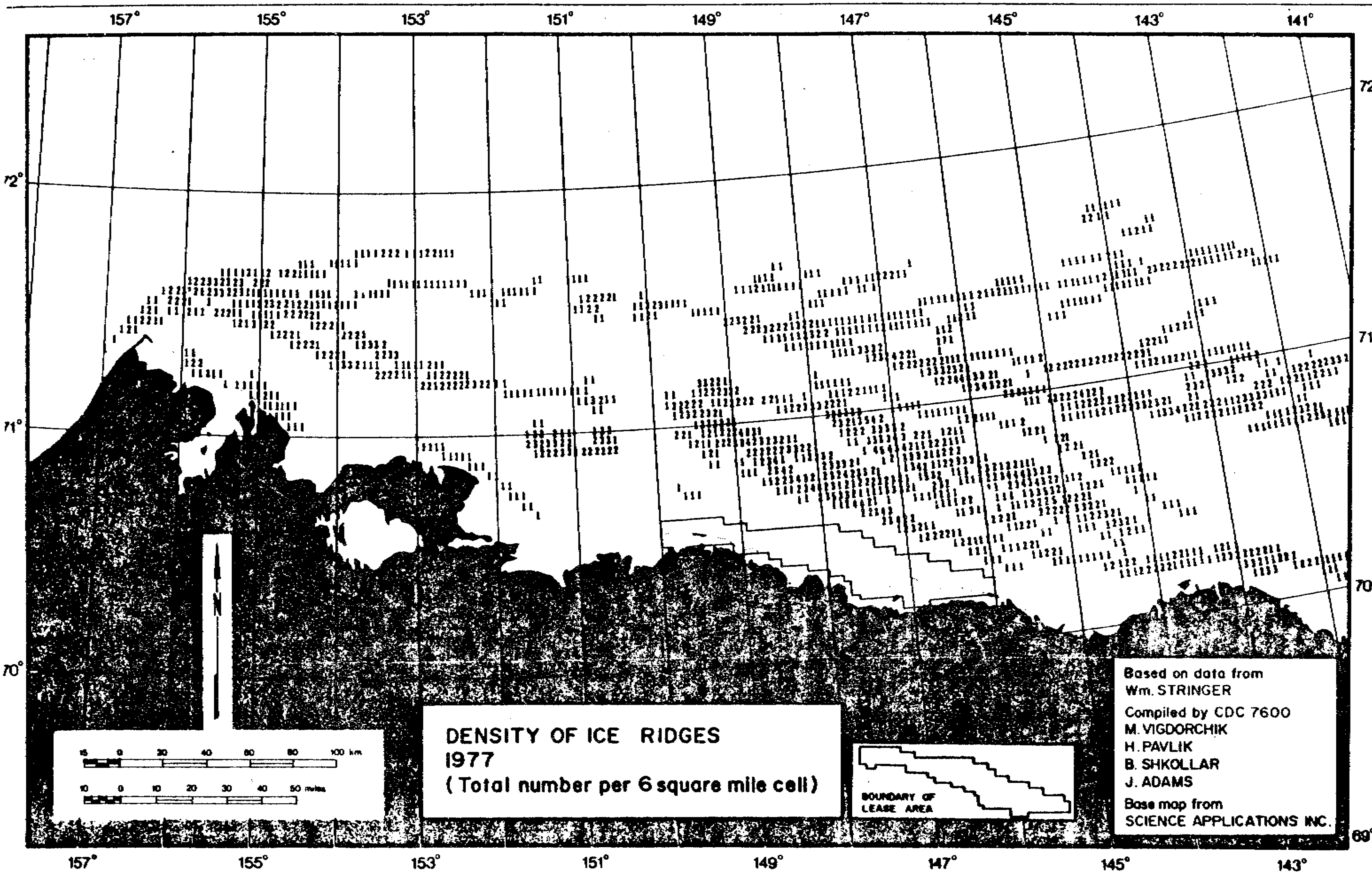

157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°
N
15 0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles
TOTAL LENGTH OF ICE RIDGES
1976
(Per 6 square mile cell)
MILES
1 0-1
2 1-2
3 2-3
4 3-4
MILES
5 4-5
6 5-6
7 6-7
8 7-8
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.

MAP 32

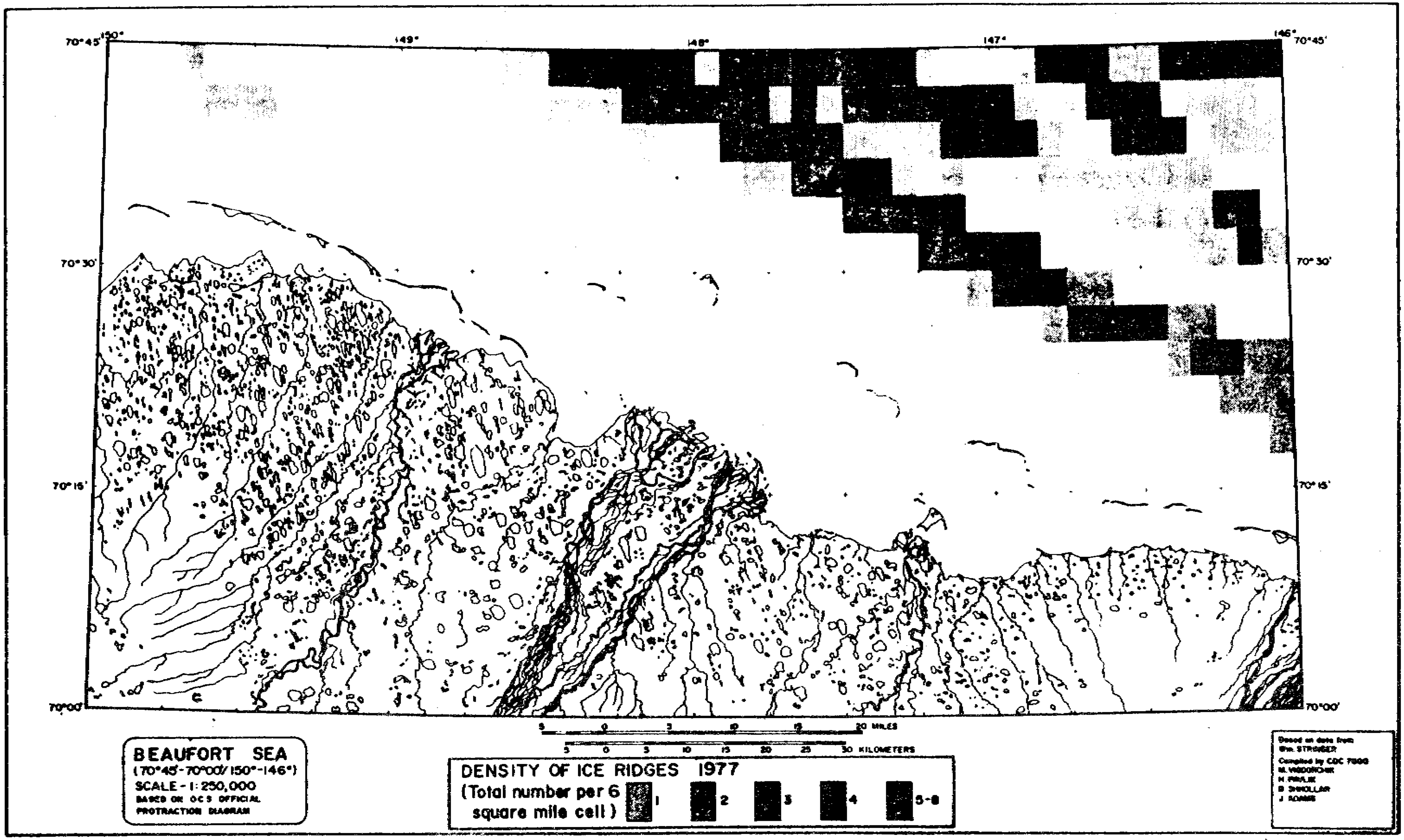


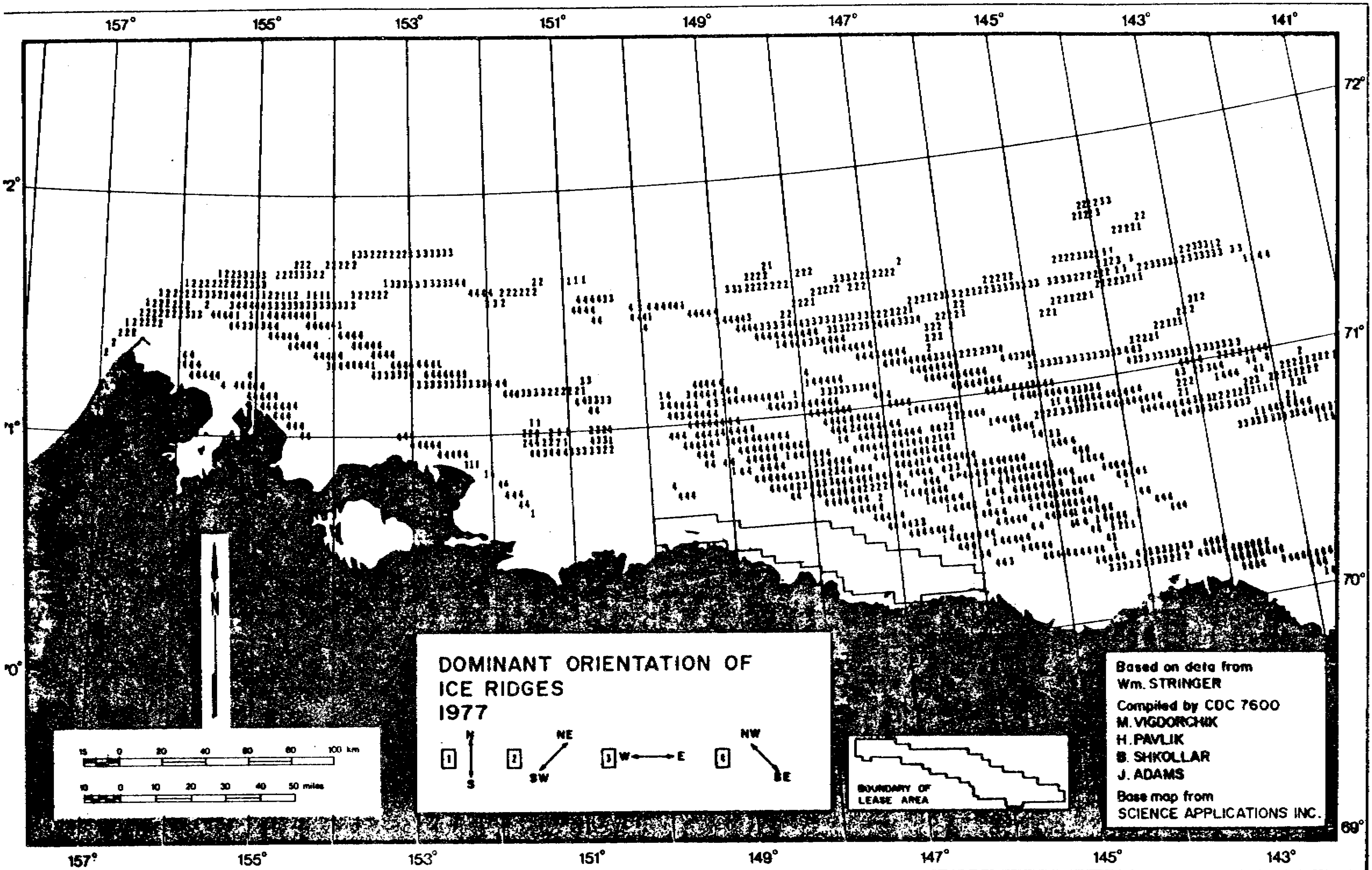
70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
MILES
KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
TOTAL LENGTH OF ICE RIDGES 1976
(Per 6 square mile cell)
LENGTH IN MILES
0-1
1-2
2-3
3-4
4-8

MAP 33

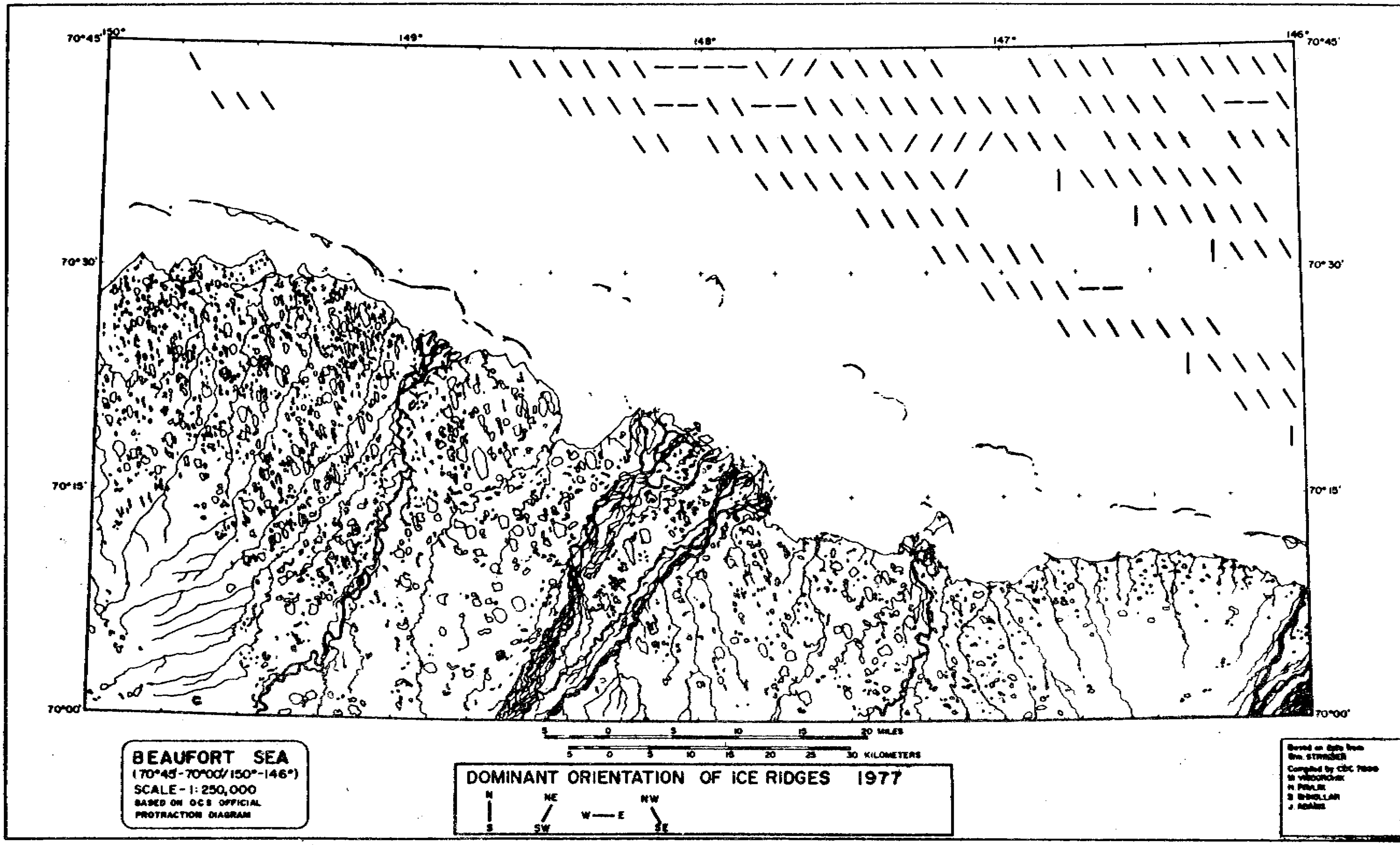

DENSITY OF ICE RIDGES
1977
(Total number per 6 square mile cell)
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°
100 km
50 miles

MAP 34

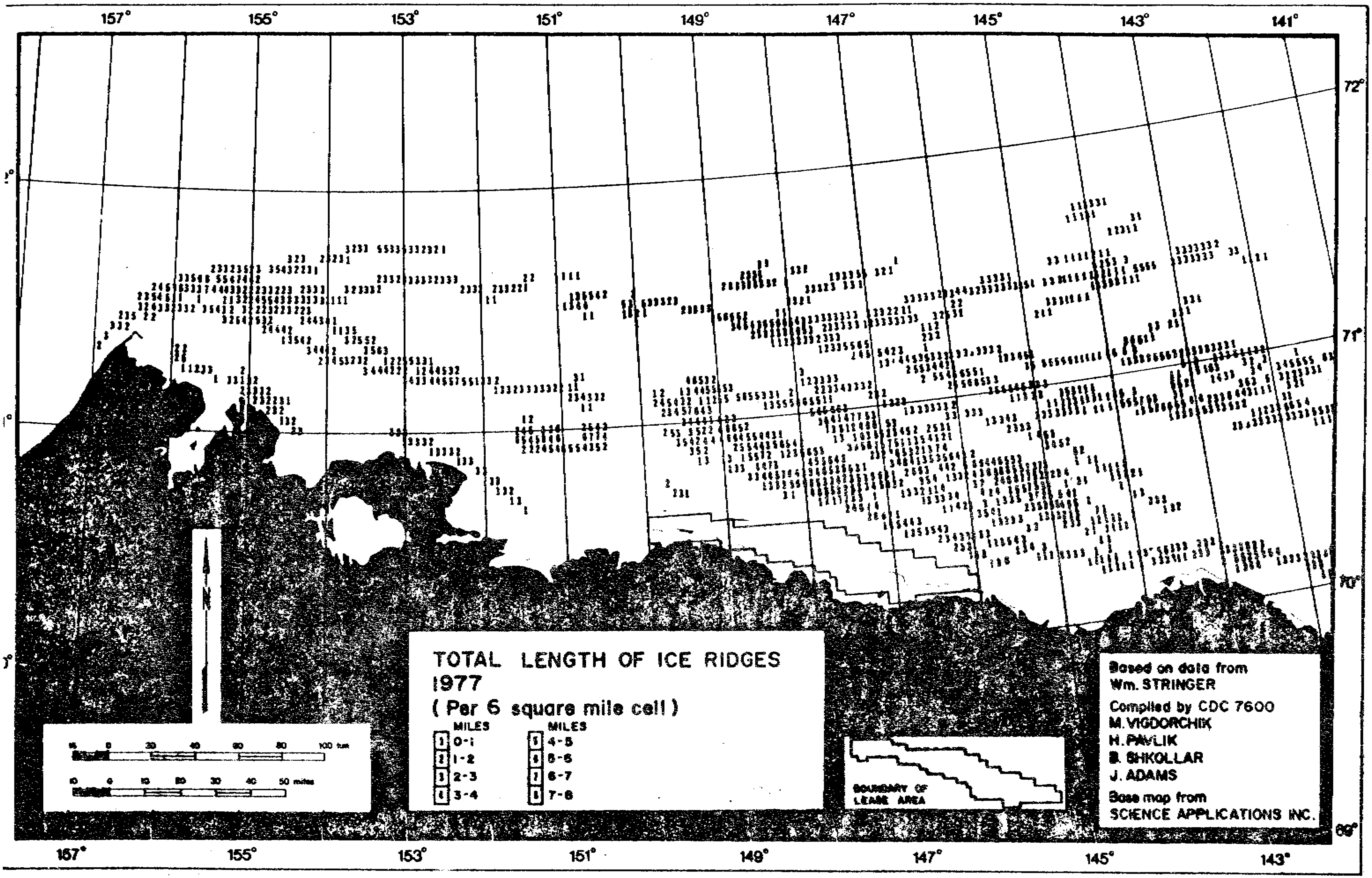

70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
DENSITY OF ICE RIDGES 1977
(Total number per 6 square mile cell)
1
2
3
4
5-8


DOMINANT ORIENTATION OF ICE RIDGES 1977
1 N S
2 NE SW
3 W E
4 NW SE
BOUNDARY OF LEASE AREA
Based on data from Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from SCIENCE APPLICATIONS INC.
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°
15 0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles

MAP 36

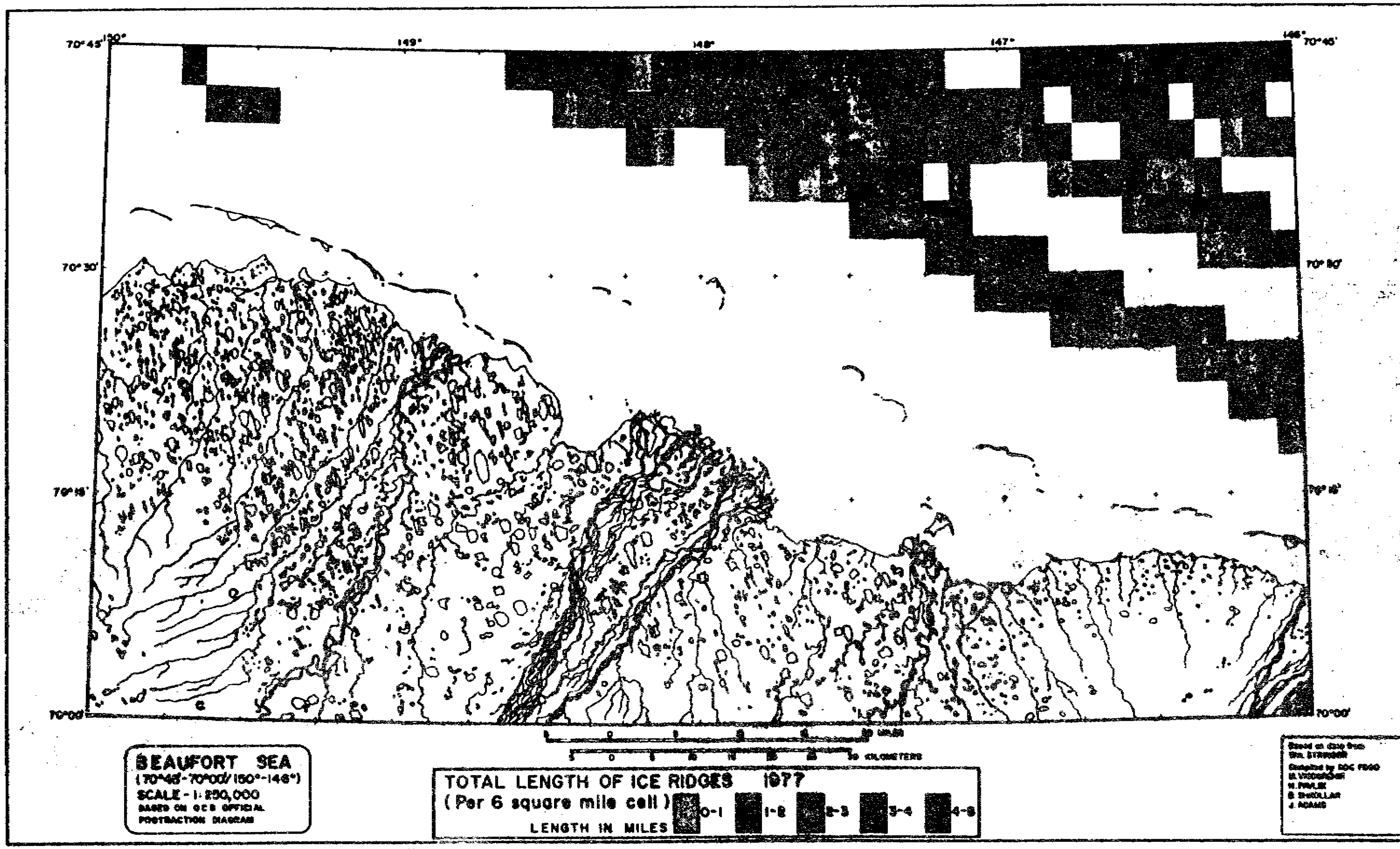

70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1: 250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
DOMINANT ORIENTATION OF ICE RIDGES 1977
N
S
NE
SW
W — E
NW
SE

MAP 37



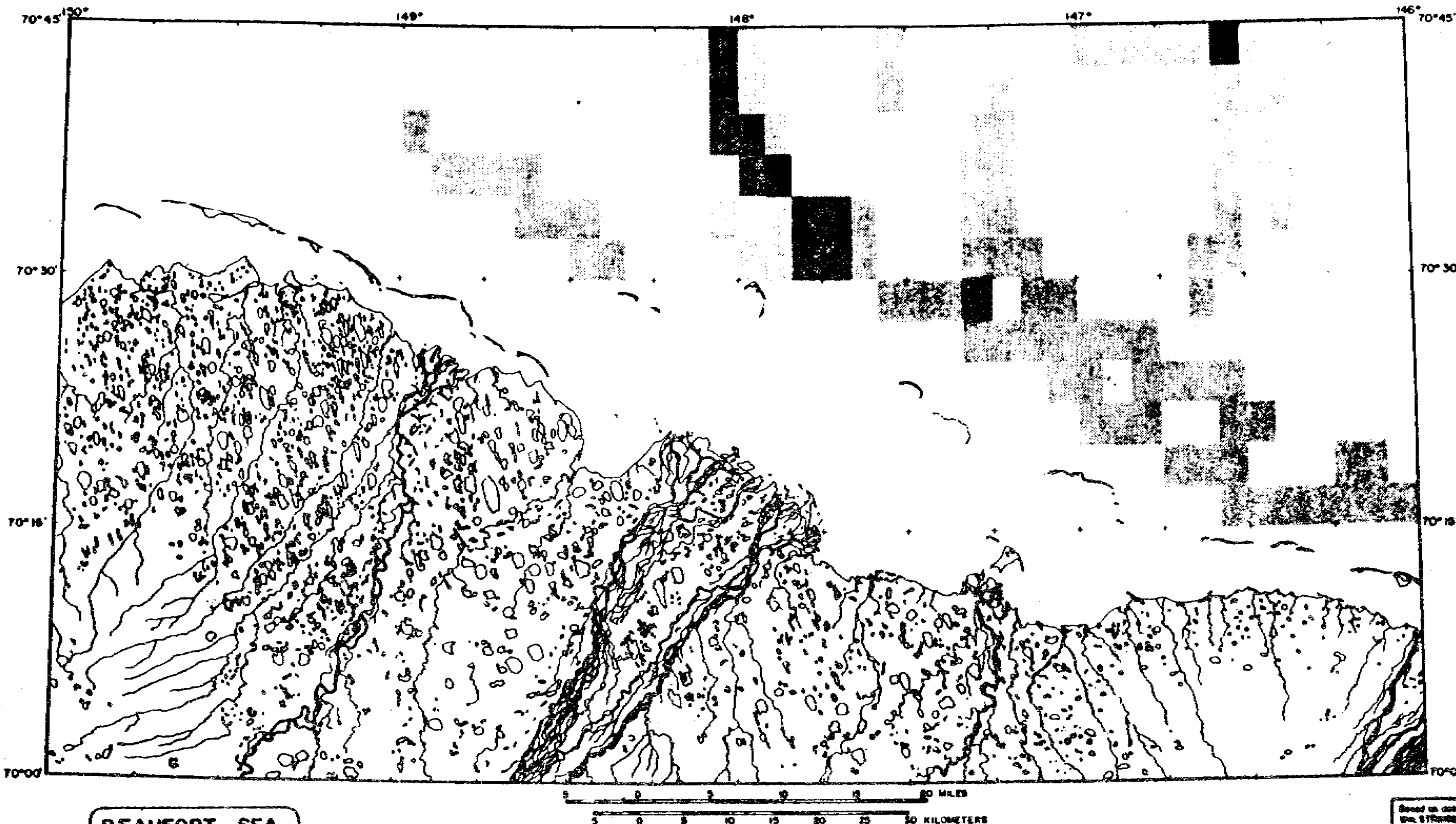
TOTAL LENGTH OF ICE RIDGES
1977
(Per 6 square mile cell)
MILES
1 0-1
2 1-2
3 2-3
4 3-4
MILES
5 4-5
6 5-6
7 6-7
8 7-8
BOUNDARY OF LEASE AREA
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
157°
155°
153°
151°
149°
147°
145°
143°
141°
72°
71°
70°
69°

MAP 38



70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
MILES
KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
TOTAL LENGTH OF ICE RIDGES 1977
(Per 6 square mile cell)
LENGTH IN MILES
0-1

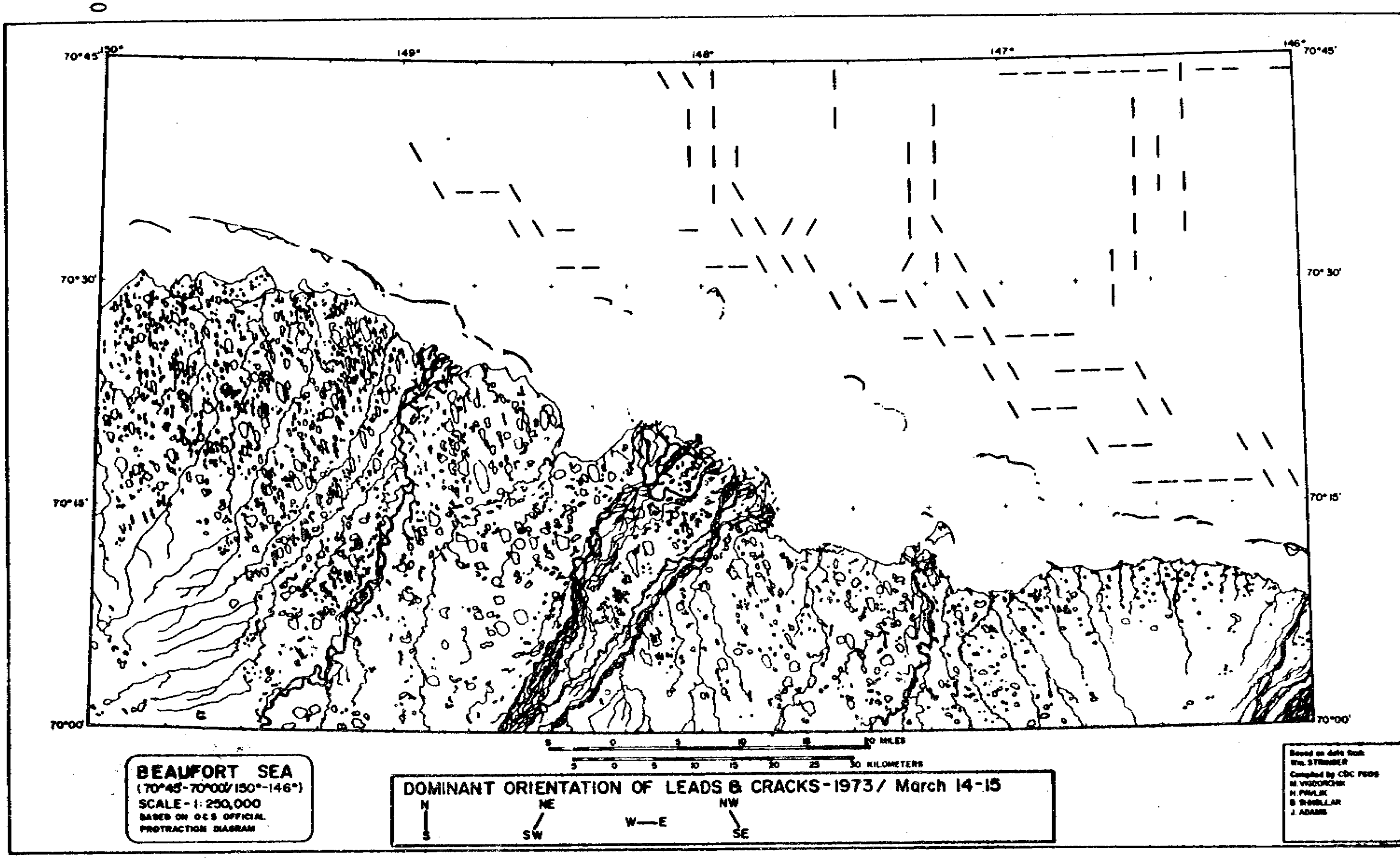
MAP 39



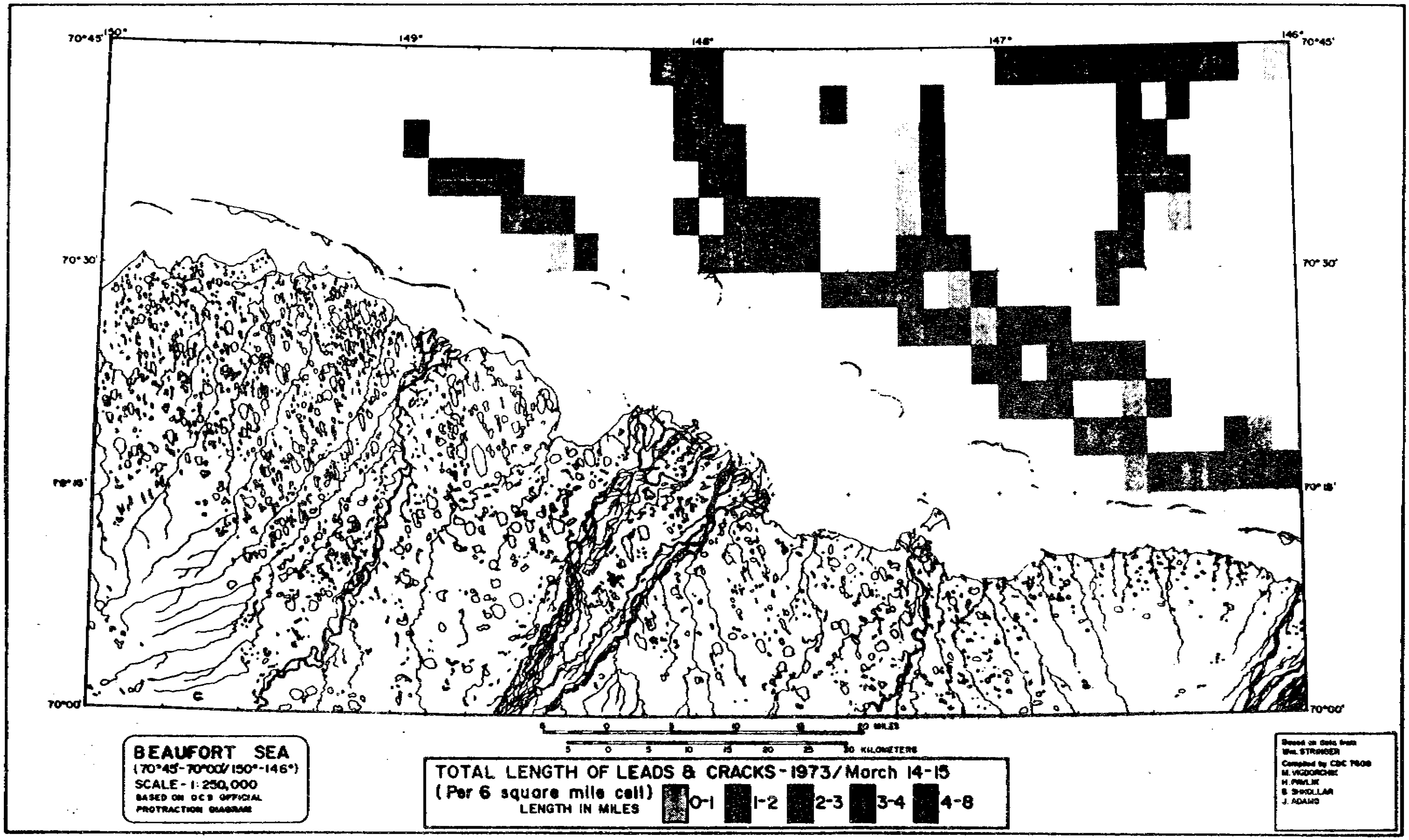
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL PROTRACTION DIAGRAM

DENSITY OF LEADS & CRACKS - 1973/ March 14-15
(Total number per 6 square mile cell) 1 2 3 4 5-8

MAP 40


70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
DOMINANT ORIENTATION OF LEADS & CRACKS - 1973 / March 14-15
N
S
NE
SW
W — E
NW
SE
J. ADAMS

MAP 41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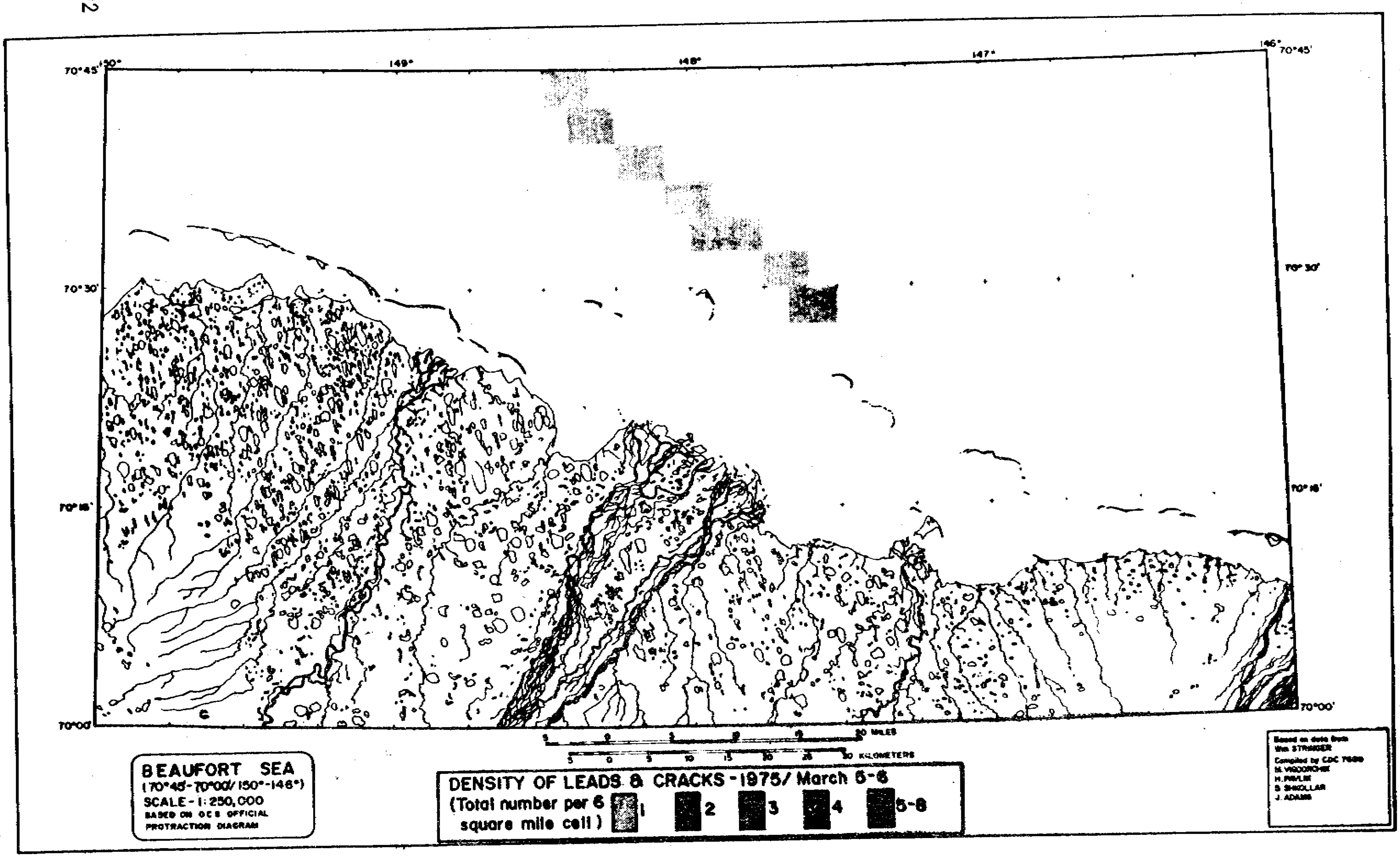
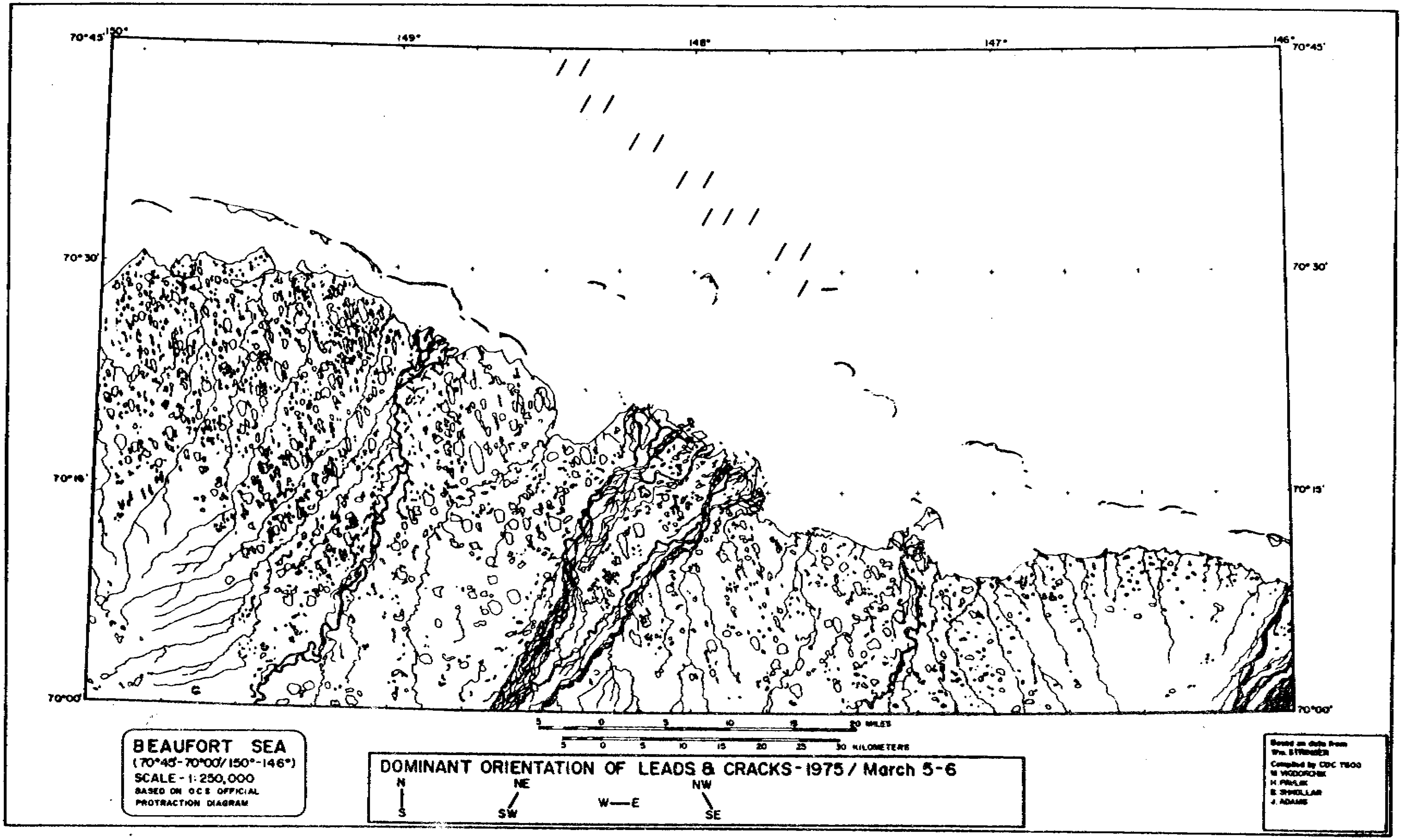
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°00'
70°00'
MILES
KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
TOTAL LENGTH OF LEADS & CRACKS - 1973/March 14-15
(Per 6 square mile cell)
LENGTH IN MILES
0-1
1-2
2-3
3-4
4-8
J. ADAMS

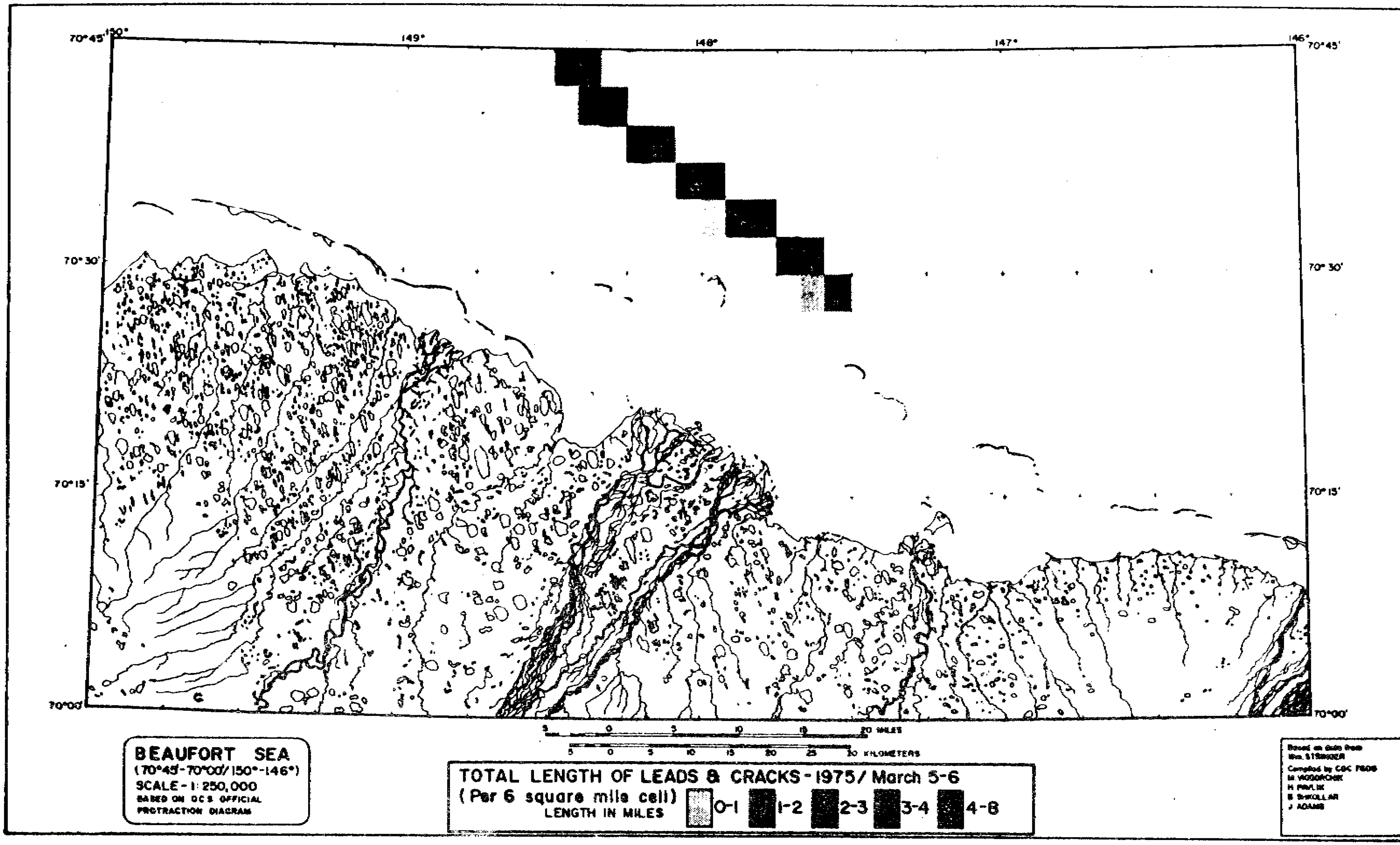
MAP 42


70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
DENSITY OF LEADS & CRACKS - 1975/ March 5-6
(Total number per 6 square mile cell)
1
2
3
4
5-8
J. ADAMS

MAP 43

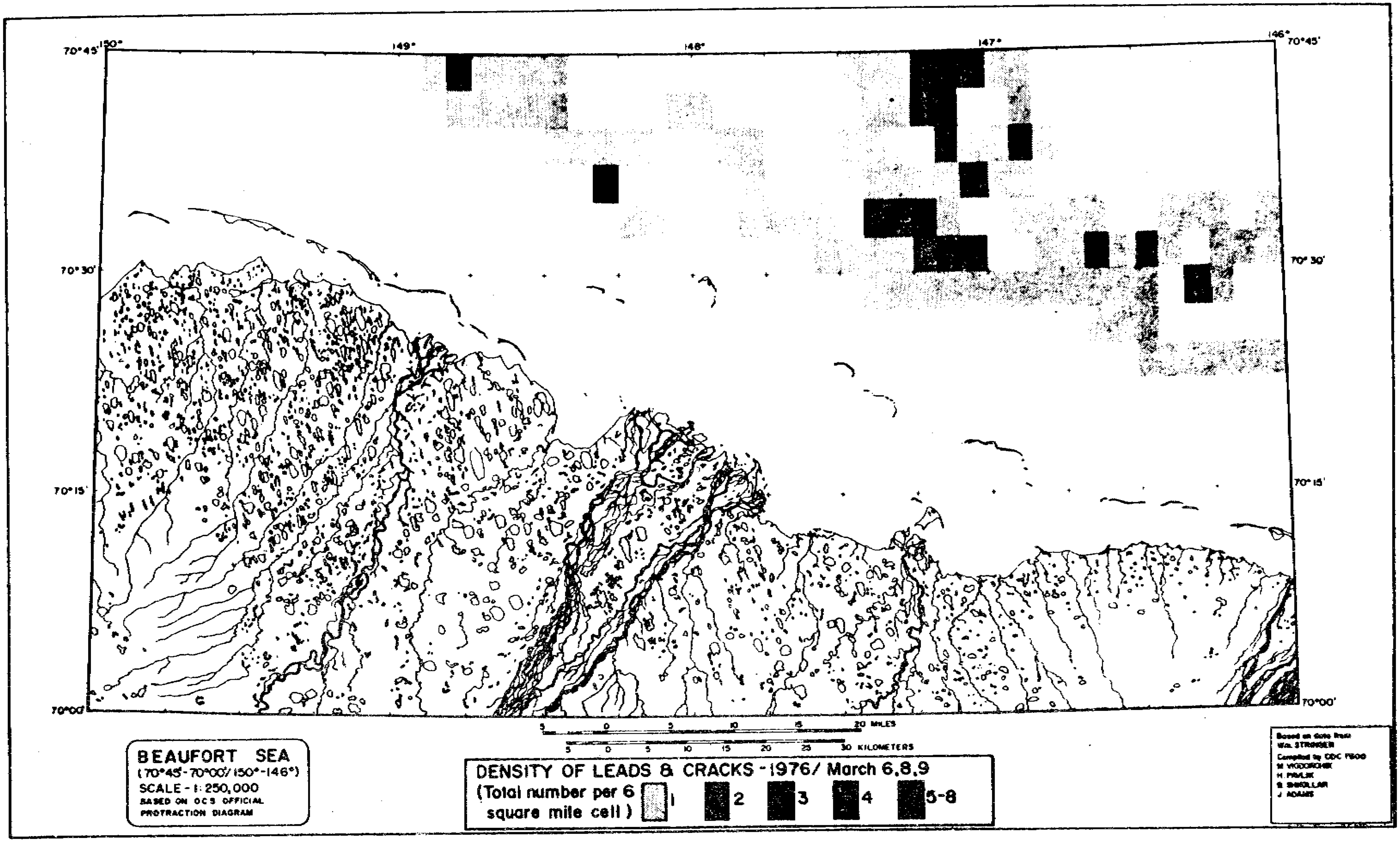

70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
DOMINANT ORIENTATION OF LEADS & CRACKS - 1975 / March 5-6
N S
NE SW
W—E
NW SE
Based on data from
J. ADAMS

MAP 44

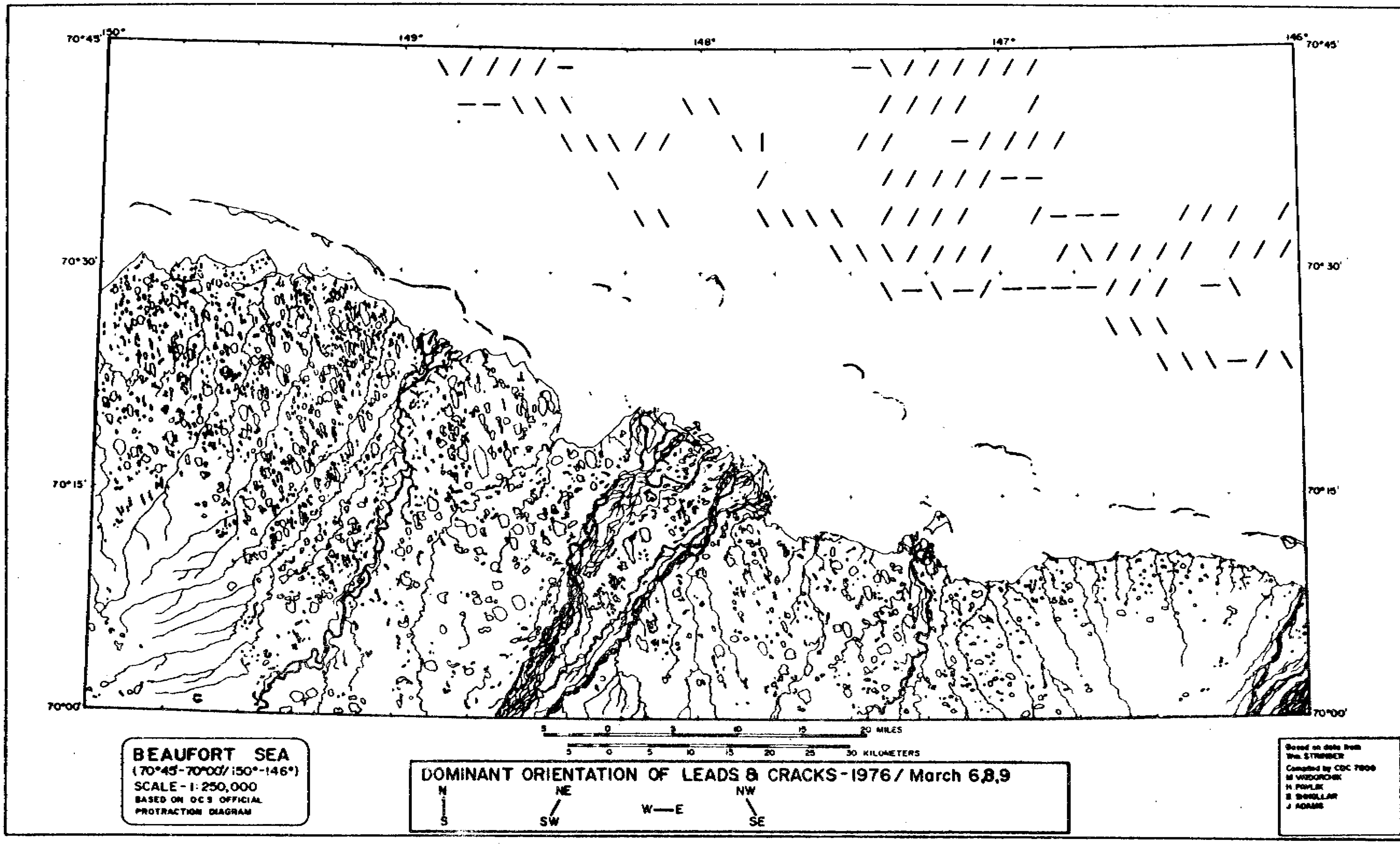


150°
149°
148°
147°
146°
70°45'
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
TOTAL LENGTH OF LEADS & CRACKS - 1975/ March 5-6
(Per 6 square mile cell)
LENGTH IN MILES
0-1
1-2
2-3
3-4
4-8
Based on data from

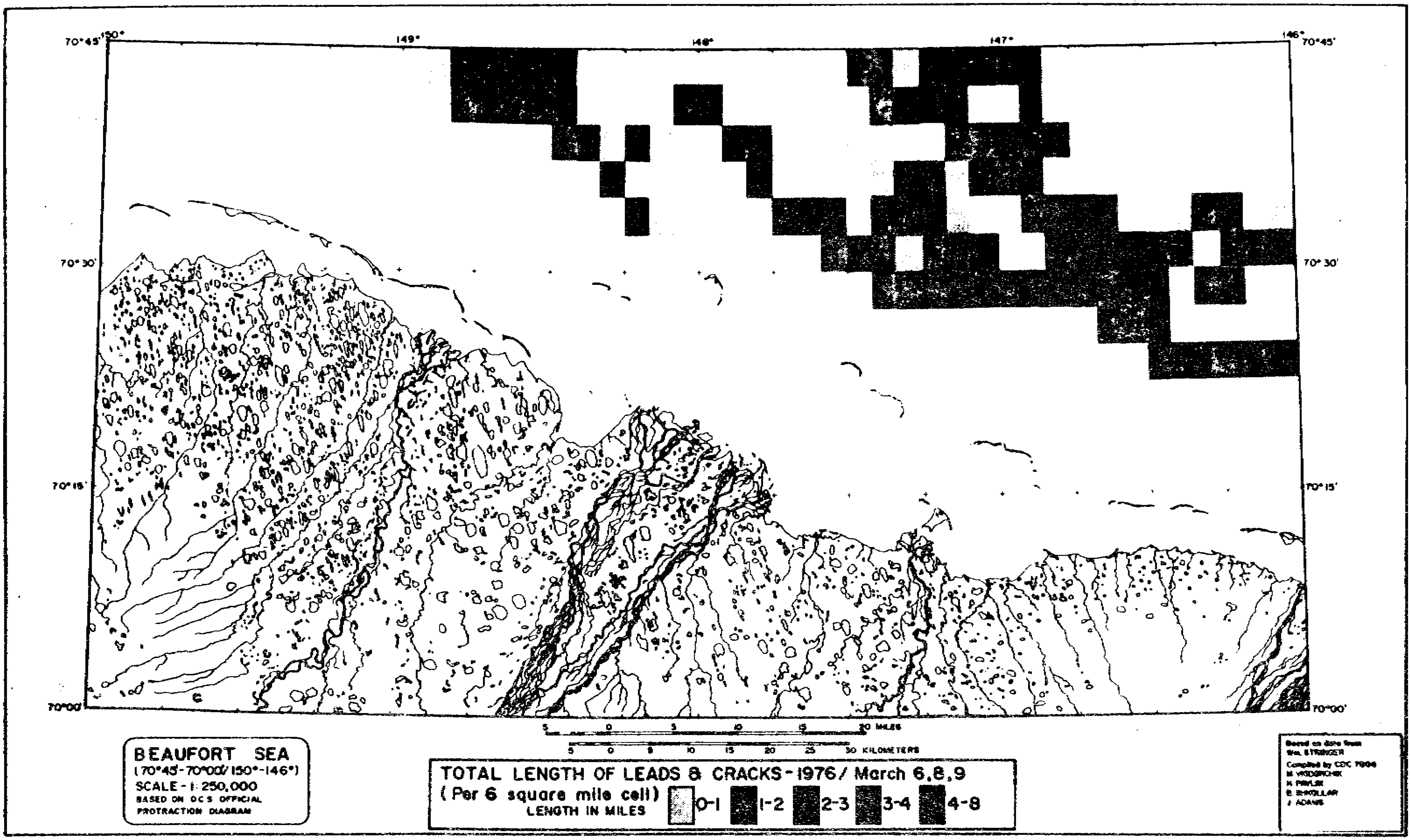
MAP 45


150°
149°
148°
147°
146°
70°45'
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL PROTRACTION DIAGRAM
DENSITY OF LEADS & CRACKS - 1976/ March 6,8,9
(Total number per 6 square mile cell)
1
2
3
4
5-8

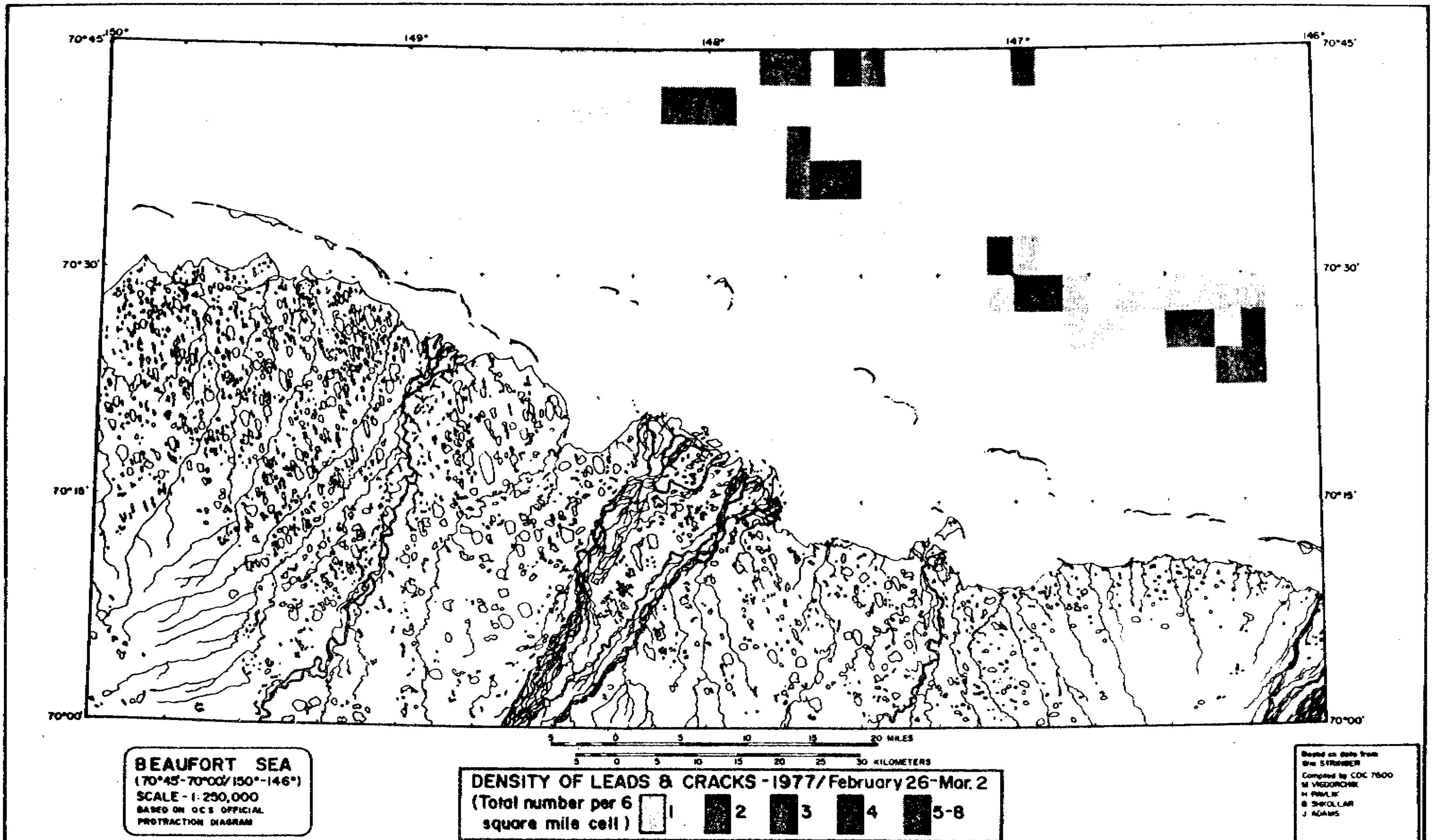
MAP 46

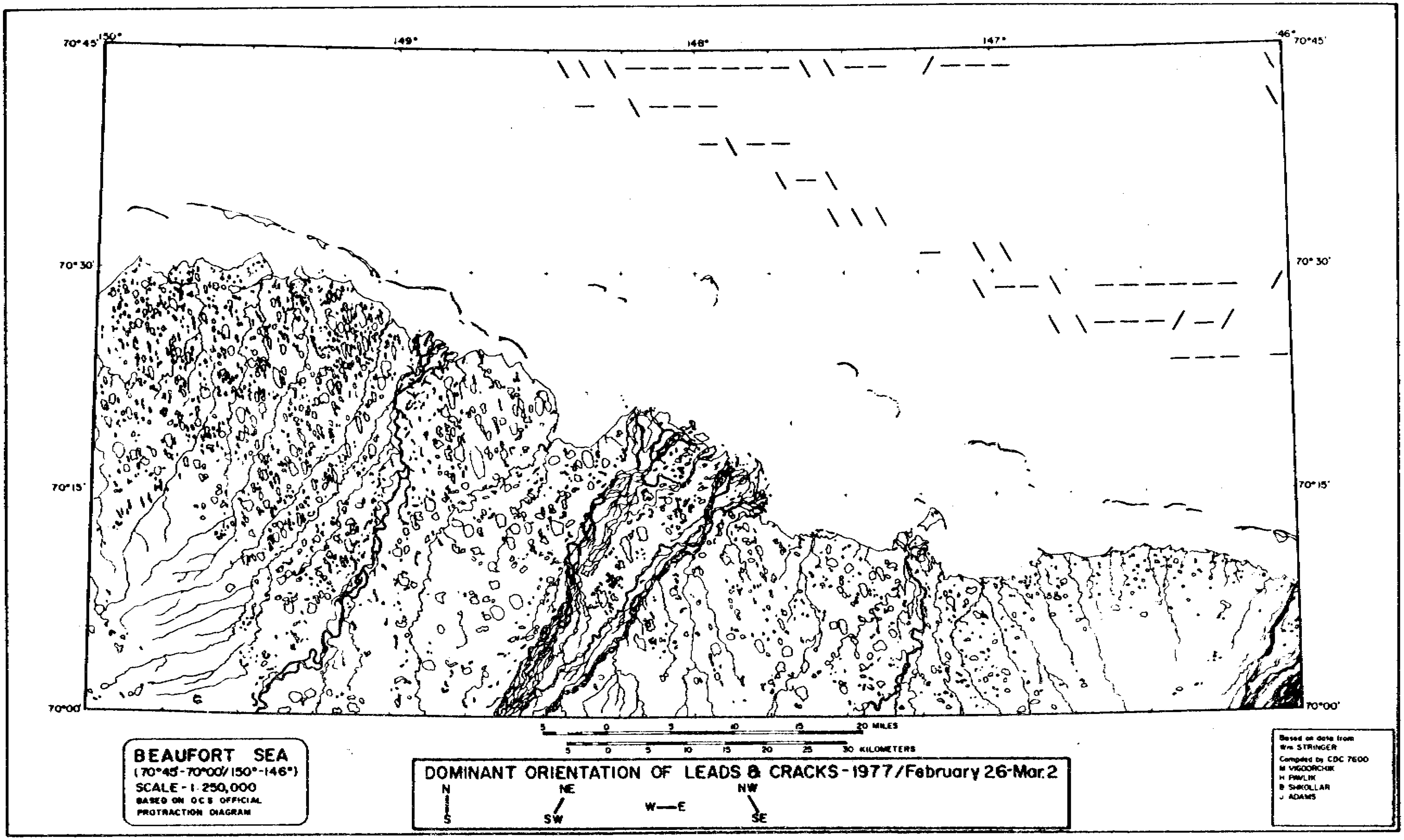

70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
DOMINANT ORIENTATION OF LEADS & CRACKS - 1976 / March 6,8,9
N
S
NE
SW
W—E
NW
SE

MAP 47

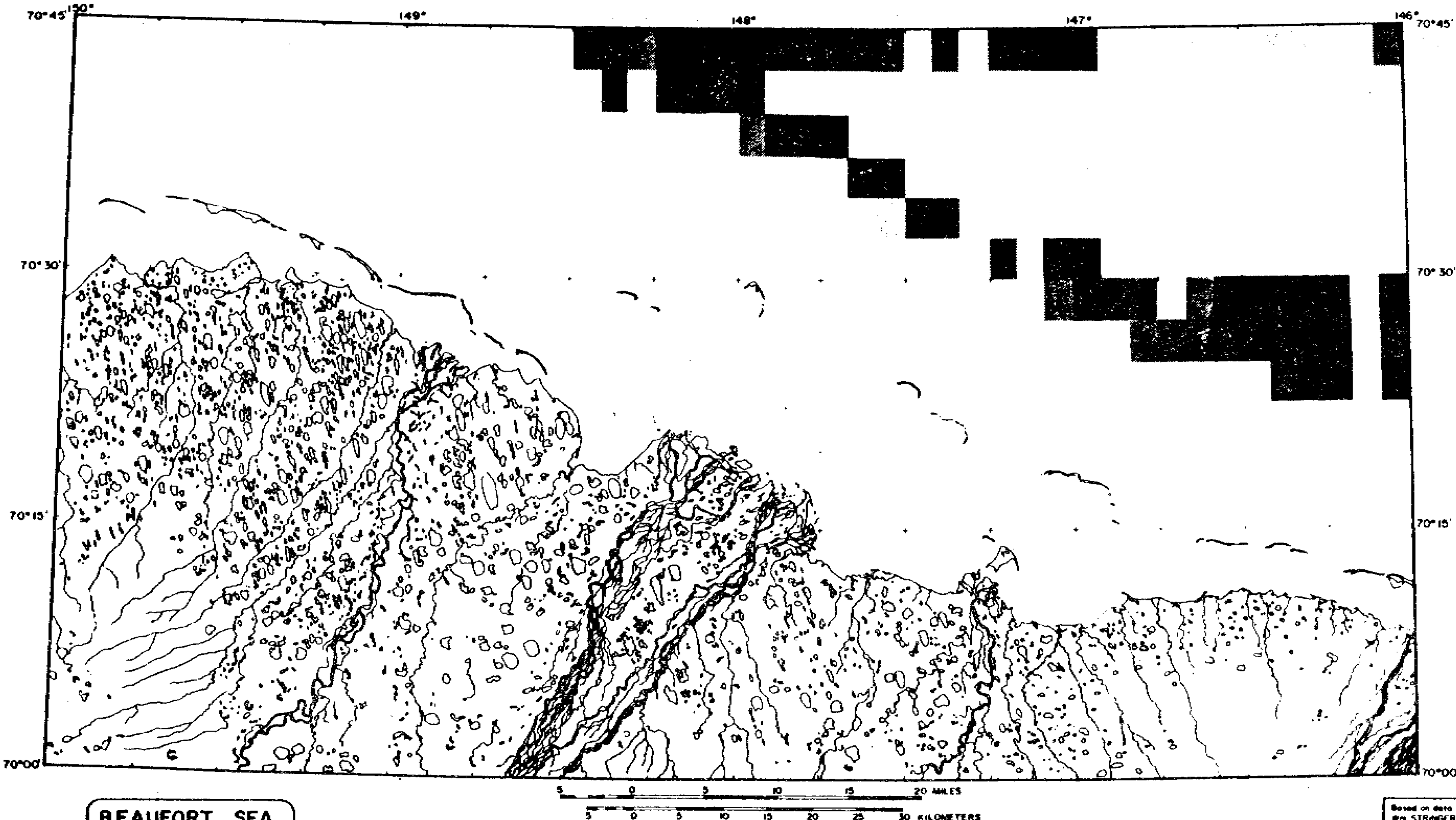

70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL
PROTRACTION DIAGRAM
TOTAL LENGTH OF LEADS & CRACKS - 1976/ March 6,8,9
(Per 6 square mile cell)
LENGTH IN MILES
0-1
1-2
2-3
3-4
4-8

MAP 48


70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL
PROTRACTION DIAGRAM
DENSITY OF LEADS & CRACKS - 1977/ February 26 - Mar. 2
(Total number per 6 square mile cell)
1
2
3
4
5-8


70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL
PROTRACTION DIAGRAM
DOMINANT ORIENTATION OF LEADS & CRACKS - 1977/February 26-Mar. 2
N
S
NE
SW
W—E
NW
SE
Based on data from
Wm STRINGER
Compiled by CDC 7600
M VIGOORCHIK
H PAWLIK
B SHKOLLAR
J ADAMS

MAP 59

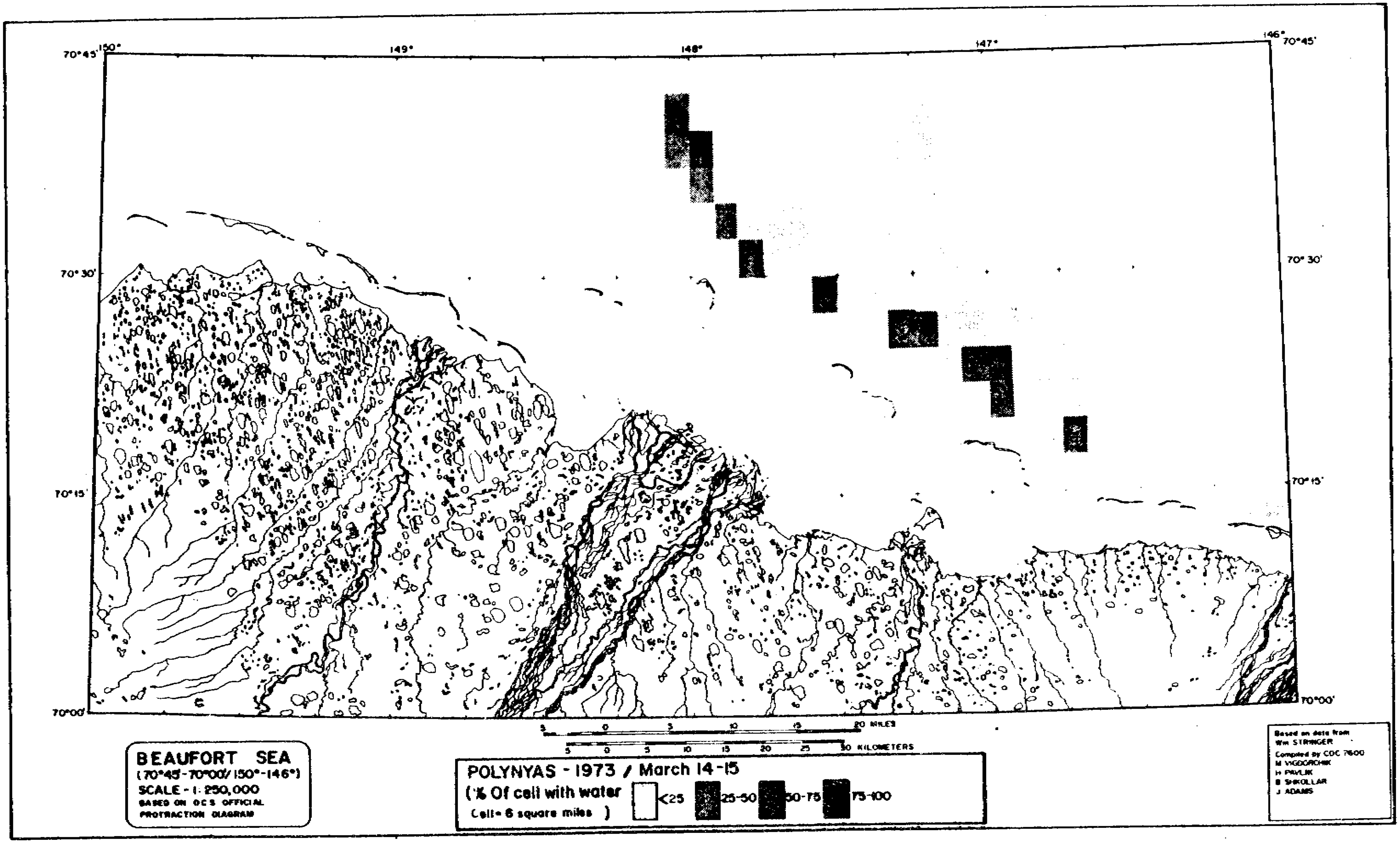


BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM

TOTAL LENGTH OF LEADS & CRACKS - 1977/Feb 26-Mar 2
(Per 6 square mile cell)
LENGTH IN MILES: 0-1, 1-2, 2-3, 3-4, 4-8

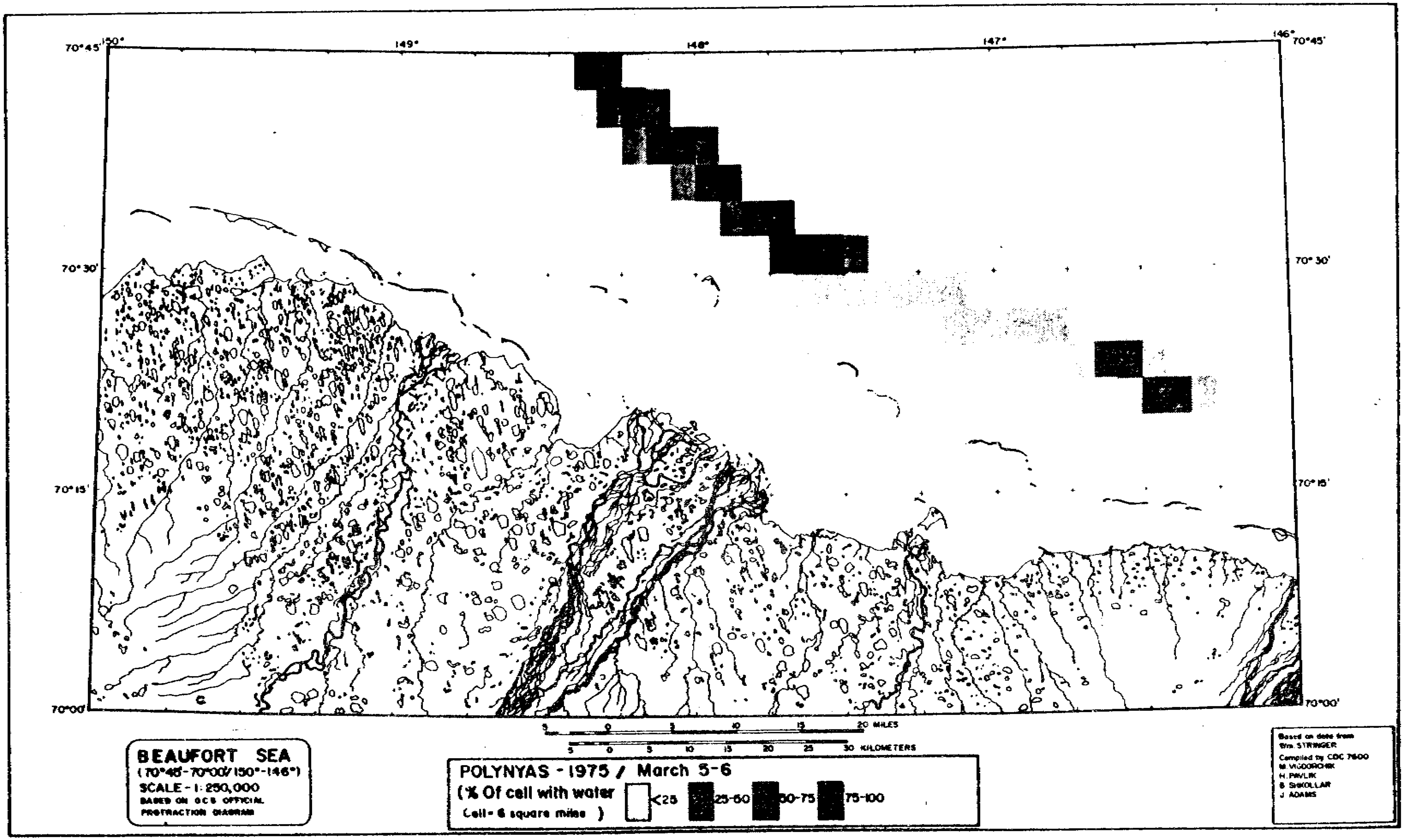
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS

MAP 51

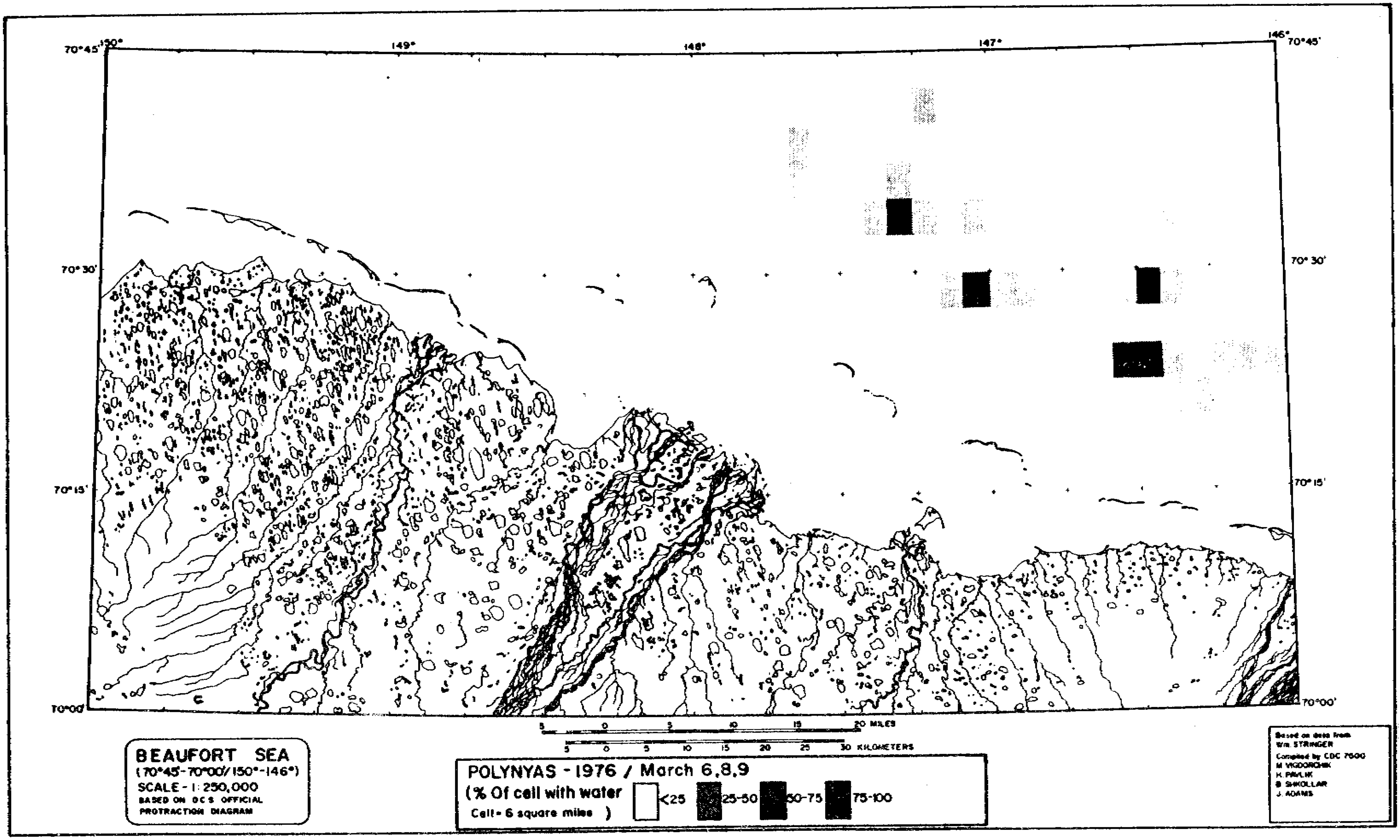


70°45'
150°
149°
148°
147°
146°
70°30'
70°15'
70°00'
20 MILES
30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1: 250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
POLYNYAS - 1973 / March 14-15
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100
Based on data from
Wm STRINGER
Compiled by CDC 7600
M VIGDORCHIK
H PAVLIK
B SHKOLLAR
J ADAMS

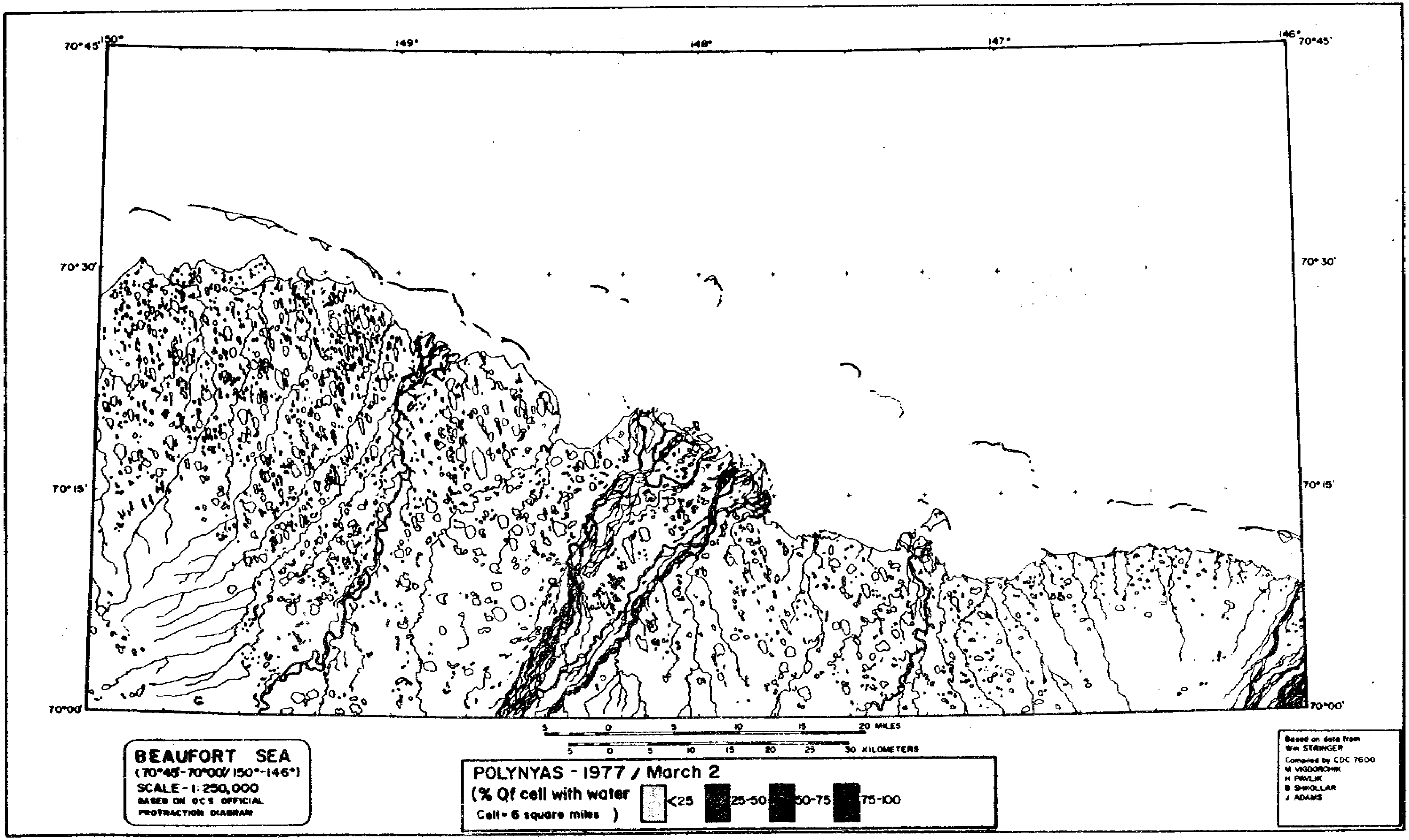
MAP 52

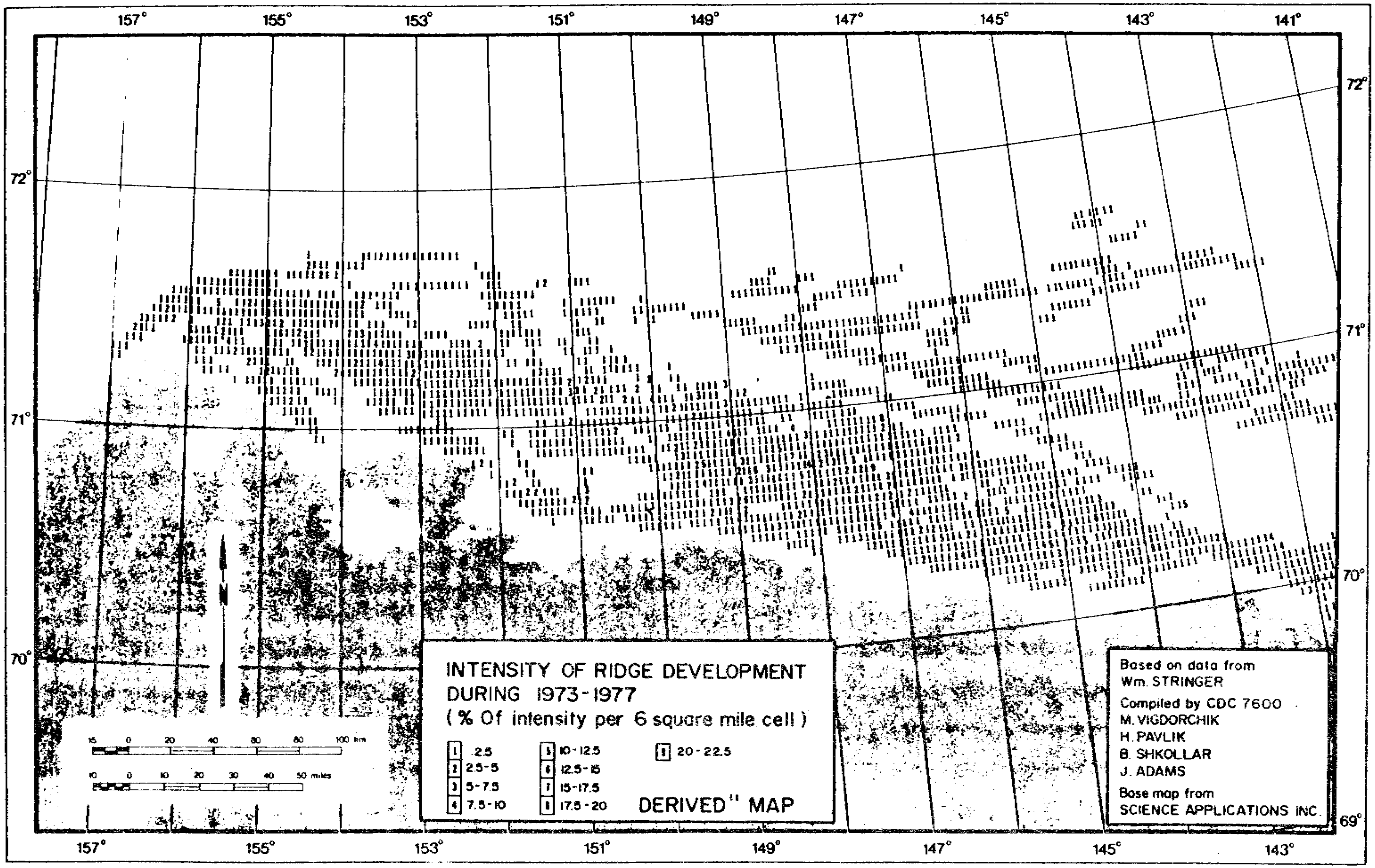

70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70° 30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1: 250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAMS
POLYNYAS - 1975 / March 5-6
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS

MAP 53

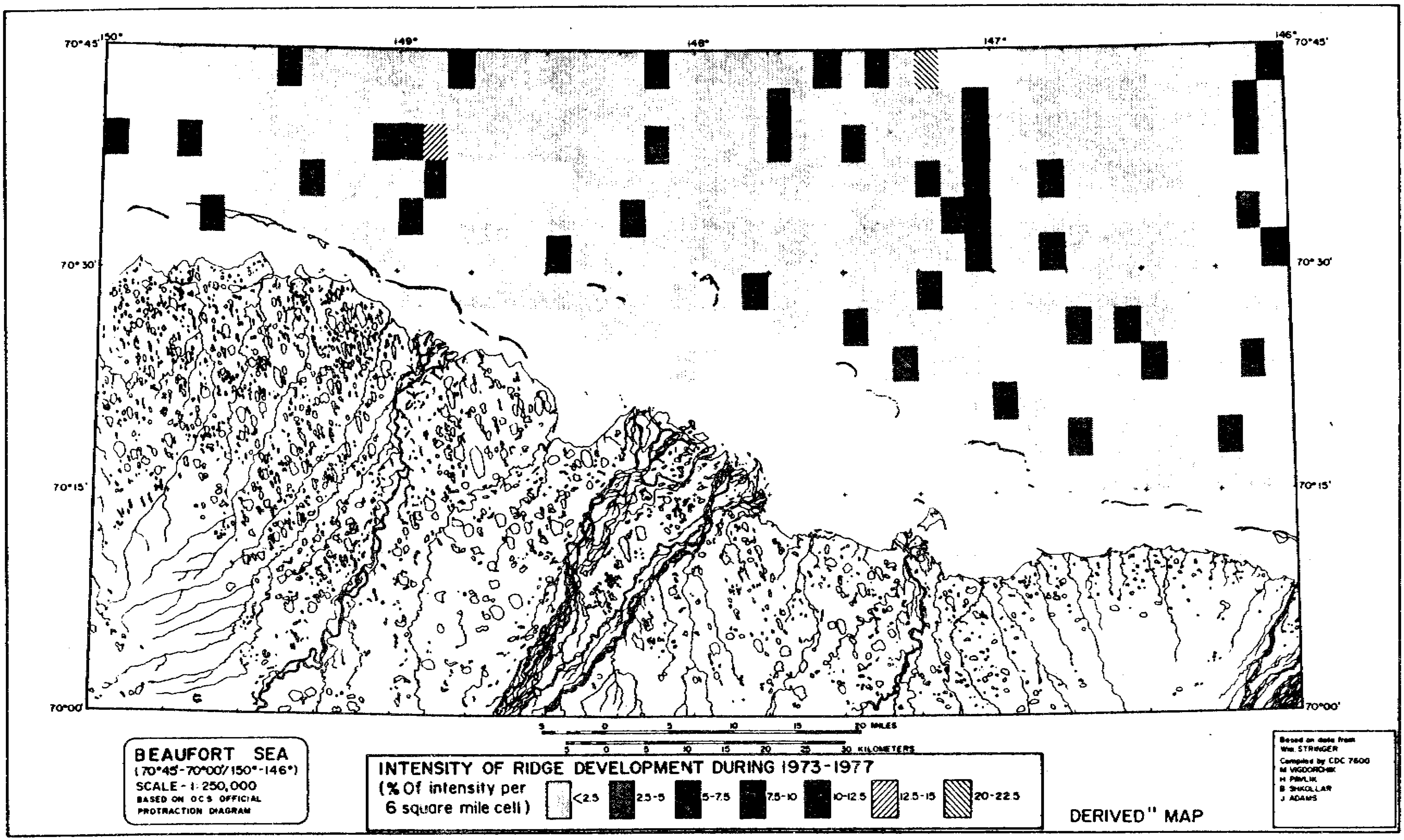

70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
POLYNYAS - 1976 / March 6,8,9
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
K. PAVLIK
B. SHKOLLAR
J. ADAMS

MAP 54


70°45'
150°
149°
148°
147°
146°
70°45'
70°30'
70°30'
70°15'
70°15'
70°00'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/ 150°-146°)
SCALE - 1: 250,000
BASED ON OCS OFFICIAL
PROTRACTION DIAGRAM
POLYNYAS - 1977 / March 2
(% Of cell with water
Cell = 6 square miles)
<25
25-50
50-75
75-100
Based on data from
Wm STRINGER
Compiled by CDC 7600
J ADAMS


INTENSITY OF RIDGE DEVELOPMENT
DURING 1973-1977
(% Of intensity per 6 square mile cell)
1 .25
2 2.5-5
3 5-7.5
4 7.5-10
5 10-12.5
6 12.5-15
7 15-17.5
8 17.5-20
9 20-22.5
"DERIVED" MAP
Based on data from
Wm. STRINGER
Compiled by CDC 7600
M. VIGDORCHIK
H. PAVLIK
B. SHKOLLAR
J. ADAMS
Base map from
SCIENCE APPLICATIONS INC.
157° 155° 153° 151° 149° 147° 145° 143° 141°
72° 71° 70° 69°
100 km
50 miles

MAP 56



150°
149°
148°
147°
146°
70°45'
70°30'
70°15'
70°00'
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS
BEAUFORT SEA
(70°45'-70°00'/150°-146°)
SCALE - 1:250,000
BASED ON O.C.S. OFFICIAL PROTRACTION DIAGRAM
INTENSITY OF RIDGE DEVELOPMENT DURING 1973-1977
(% Of intensity per 6 square mile cell)
<2.5
2.5-5
5-7.5
7.5-10
10-12.5
12.5-15
20-22.5
DERIVED" MAP
Based on data from Wm. STRINGER
Compiled by CDC 7600
M VIGDORCHIK
J ADAMS

MAP 57

PROBLEMS

The work has been oriented on the scale 1:1,000,000, for which the special base map had been provided by "Science Application, Inc." Part of the maps (ice ridge characteristics for 1973-77) have been produced in that scale.

At the beginning of February, 1980. the new map in scale 1:250,000 has been sent with a request to use it in the annual report for April, 1979 - March, 1980. Following this request, we have produced a great deal of maps in this scale on the new given base map by this deadline. One of the problems is that detailing the second series of maps could be improved; and instead of the grid cell size of about six square miles we are using now, we have to choose the smaller grid cell size (for instance, about one square mile) and spend twice the time in the process of digitizing the data. This problem is related also to the detailing of the shoreline on the continent and the islands. Another problem is the differences between the boundaries of the lease areas on the SA base map and the new base map. Without the clarification that we have asked for from the "Projects Management Office," we could not begin to compute the value of the different variables which reflect the role of the sea ice as an environmental hazard in each lease unit separately for their comparative analysis.

All these major problems are technical and will be overcome in the final report.

CONCLUSION

1. The data bank of the computerized data management system for the synthesis and integration of the interdisciplinary information in the Beaufort and Chukchi Seas has been replenished by sea ice characteristics gathered during 1973-78.

2. Fifty-six source and derived maps of sea ice features in the scale of 1:1,000,000 and 1:250,000 have been produced. These features themselves and their further evaluation in their relationships with other characteristics of the Beaufort sea environment (now in progress) are important for a quantitative assessment of the sea ice as an environmental hazard on the Alaskan Shelf.

3. Fully realizing that only through a comprehensive computerized analyis of all components of the environment in the Beaufort Sea can we define the sensitivity of the wild marine life to the evenets which take place due to OCS oil and gas development, we consider as an important step the inclusion into this system not only other hazards, but the biological data (biological subsystem); for instance on marine mammals (bowheads and others), their ways of migration, habitats and so on. Following this way, we hope to help to define optimum strategies to minimize the conflicts between the energy resource development and the preservation of the ecosystem and any human activities in the lease areas and all over the Alaskan shelf.

ANNUAL REPORT

Research Unit Number: 527
Reporting Period: 4/1/79 - 3/31/80

OCSEAP Data Processing Services

William C. Johnson II
Data Projects Group
Pastore Laboratory
University of Rhode Island
Kingston, Rhode Island 02881

Background and Objectives

The Data Projects Group (DPG) at the University of Rhode Island provides a variety of services to the OCSEA Program in general and to the Juneau Project Office (JPO) in particular. Through these auspices, services are also made available to several Research Units (RUs).

Over the lifetime of the contract, DPG has used a data management system known as the MARMAP Information System (MIS). The MIS was earlier designed and developed by DPG for the National Marine Fisheries Service. As related to this work, the MIS has provided the means to carry out batch-styled data set validations, to create and maintain a significant data base, and to retrieve those portions of the data base appropriate to any of a variety of analysis products.

A need for real-time data validation arose among the OCSEAP RUs. DPG responded to this need by developing the Interactive Data Entry and Analysis (IDEA) System. This system was described in a previous quarterly report submitted by this RU. It has significance in allowing investigators to validate field data during its initial entry into the OCSEAP/NODC formats, thereby reducing the time needed for the validation process under previously used procedures.

The coupling of the IDEA and MIS systems provides the resources necessary to efficiently carry out the primary objectives of this work, which include the orderly conveyance of validated data from investigator sites to the Program, and the provision of data analysis support to selected investigators.

Report Overview

Efforts were made in three major areas during this year, including:

- Analytical product support
- Development, enhancement and distribution of the IDEA System
- Further processing of data sets submitted to DPG

Each of the above mentioned areas will be discussed in the remainder of the report.

Analytical Product Support

This past year, the DPG has been especially active in the development and production of data analyses for the Bering Sea synthesis report and for the final report of RU083 under the auspices of JPO. The products suite includes 15 distinct products. They include: (1) File Type 033 Data Summary Table, (2) Digital Density Plot plus Block Identification Number Plot, (3) Contour Plot, (4) Star Diagram, (5) Statistical Analyses, (6) Sightings Effort Table, (7) Sightings Effort Plot, (8) Transect Catalog, (9) Graduated Symbol Plot, (10) Bird Density Histogram, (11) Density and the Variability of Distribution Summary, (12) Ratio Table of Fulmar Color Phases, (13) Mean Density: Sample Variance Ratio Table, and two products for File Type 031 data called (14) Food Analysis Table and, (15) Food Size Class Table. Products numbers 13 and 15 were developed in the last quarter of this year. Examples of these last products are included herein as Appendix I. A product compendium of the other products is available upon request from the Juneau Project Office.

An impressive volume of our analytical products were generated during the year, as demonstrated by the list below. Unless specifically requested otherwise, these analyses included data collected by RUs 083, 108, 239, and 337 over the 1975-1978 period, and which have been validated, delivered to NODC, and included in RU527's MIS data base as of 10/1/79. A complete list of these field operations can be found in Appendix II.

258	Graduated Symbol Plots of bird density data in the Bering Sea
73 (45 during last quarter)	Graduate Symbol Plots of bird density data in the area of the Pribilof Islands
90	Digital Density Plots for bird data taken in the Bering Sea
90	Statistical Analyses for data taken in the vicinity of the Pribilof Islands
74 (2 during last quarter)	File Type 031 Food Analysis Tables for the Bering Sea
48	Sightings Effort Plots for data recorded in the area of the Pribilof Islands
3	Sightings Effort Tables for the Pribilof Island area
12	Sightings Effort Plots for data taken around Kodiak Island
1	Sightings Effort Table for Bering Sea data
12	Updated Sightings Effort Plots for the Bering Sea data
3	Updated Sightings Effort Table for the Bering Sea data
1	Sightings Effort Table for data taken in the vicinity of Kodiak Island
20	Contour diagrams of bird density data in the vicinity of the Pribilof Islands
18	File Type 033 Density and Variability of Distribution Summary Tables

15	Data Summary Tables for RU83 1977 and 1978 data
9	Ratio Tables for color phases of northern fulmars
9	Bird Density Histograms, 17 bird species each, for data in the vicinity of the Pribilof Islands
8	Star Diagrams of Shearwaters in the Bering Sea
3	Food Size Class Tables
1	Table which supplemented information for the above mentioned Star Diagrams
1	Set of 15 product examples which were sent to NODC
1	Sightings Effort Table without block segmentation

A magnetic computer tape was generated for RU083 containing the validated NODC format data sets UCI478 and UCI901.

One other product was developed and made available to those RUs with TI771 mini computers. A set of 8 statistical programs were coded in the computer language BASIC. These programs include: (1) analysis of variance, (2) chi-square, (3) correlation coefficient, (4) linear regression, (5) mean variance, and standard deviation with calculation of the 95% confidence interval, (6) Spearman rank correlation, (7) stepwise regression, (8) Student's t distribution. These programs would allow an investigator to perform his/her own analyses of small data sets to test their hypotheses. This might aid in narrowing their requests for products from the DPG.

In an effort to acquaint the various RUs with the analytical product support capabilities of the DPG, a meeting was held during the last quarter in Bodega Bay, California at the Bodega Marine Laboratory. An updated product compendium was compiled during the last quarter and made available for the participants at the meeting. Each product was discussed in detail. Time during the meeting was dedicated to TI support as discussed in the next section. In all, it was agreed that the goals of the meeting were realized and that many beneficial spinoffs resulted.

Alterations and enhancements of the computer software used in product generation were made. The plotting program was changed to increase both its efficiency as well as that of the staff required to operate it. It also now generates plots using fractions of a degree as a boundaries or as grid line intervals. This significantly increases the flexability of the program, especially for plots of a small area. Programming effort was also made on a number of our analysis products to make them better suited to the needs of the principal investigator.

Development and Enhancement of the IDEA System and TI Support

During the last year the Interactive Data Entry and Analysis System (IDEAS) was developed and enhancements were made. These efforts can be catagorized into two areas; data entry programs and the support programs and procedures. So that this system can be added to and updated, a documentation manual including all current program and procedure descriptions was prepared and delivered along with a system diskette. Complete manuals are available from this RU and from JPO.

The DPG has developed TI data entry programs for File Types 031, 033, 034, and 135 during this year. In addition, programming support for these file types and also for File Type 033 through enhancements has been carried on. This support has been undertaken when principal investigators have encountered difficulty or inconvenience in data entry and subsequently brought it to our attention. Resolution of these problems has been affected through specialized programming effort. Updates have also been made to SEPRATE, CATNATE, and STAR. Appropriate updates to the IDEA documentation have accompanied these distributions. A complete listing of specific dates of release for the various versions of the data entry programs are listed in the Activity/Milestone Chart (Figure 1).

Another major accomplishment was seen in the development of a TI program which allows one to validate data which has been previously entered on a computer by means other than the TI data entry programs. This program is now being used by RU196 in the validation of File Type 033 data in preparation for analyses product generation. In order to facilitate this validation effort, data were placed on diskettes and sent to RU196. Of the 12 data sets handled to date, four were sent during the last quarter. We anticipate more data to be sent from NODC and these too will be placed on diskettes and sent to RU196.

TI support was continued throughout the year. The most noteworthy occurrences included individualized help sessions for data entry personnel at the Bodega Bay TI User Group meeting which was held in late January 1980 and the distribution of new 771 operation system and BASIC system at the same meeting. These systems had been revised and updated by TI and became available during January 1980. Direct interaction between DPG staff members and the various RU personnel proved to be a very effective means of resolving difficulties and defusing potential problems.

Data Set Processing

Before discussing the specifics of the various file types, it would be appropriate to note one code problem that was brought to our attention at the Bodega Bay meeting and since required some effort on our part. We produced a report for each of the RUs delineating how many sightings in their data that we have in the MIS data base were of unidentified alcids. Because of a code problem, these could have included auklets and puffins.

This report was generated to ascertain how great the problem was and when distributed, how difficult it would be to correct. We have been directed to await a management decision on whether or not to pursue this problem any further.

File Type 031 Data Validation

One very large data set (UCI031) was received from RU083. These data have been partially edited and were then used to generate some exploratory products despite the fact that some errors remain. These errors are being resolved now and should be completed during the next quarter.

File Type 033 Data Validation

A Field Operation Status Report for File Type 033 data is included as Appendix II to this report. Please refer to that report in conjunction with this section.

Fourteen new submissions of this file type were received this quarter bringing the year's total to 72 field operations submitted. The CODEPULLS and LOGLISTS have been generated for all of these submissions and have been mailed to the PIs. Thirty-one sets of CODEPULLS and LOGLISTS were returned to us this year, 10 of which were returned during the last quarter. All field operations for which we have corrections have been edited. Of the 51 outstanding sets of CODEPULLS and LOGLISTS, 35 are with RU337 and 16 are with RU196. Thirty-nine field operations passed their final check this year and 31 were mailed to NODC. Of the 31, 16 were sent during the last quarter. Twenty-three data sets were converted to the MIS data base. Also during the last quarter, post-submission corrections for 9 data sets were forwarded to NODC.

File Type 038 Data Validation

Validation products have been sent to RU467 and received back for the two data sets MWATCH and MWAT78. Also we received one tape, DDF and history of taxonomic code check program for RU467 called MWAT78. Editing is being carried out on these data using the returned validation products.

Financial Report

The Financial Report given in Figure 1 summarizes expenses during this quarter in terms of salaries (and indirect costs), computer expenses, supplies, travel, equipment rental, equipment purchase, and other.

Activity/Milestone Chart

The Activity/Milestone Chart shown in Figure 2 graphically displays actual and planned completion dates for past, present, and future activities.

Figure 1

OCSEAP Data Processing Services Financial Report

QUARTERLY REPORT

January 1 - March 31, 1980

OCSEAP

URI A/C 5-31730

SALARIES			$14,534.59
FRINGE BENEFITS:	19% of Salaries	$2,761.57	
	+ adjustment on 12/29 payperiod (1)	212.60	2,974.17
	TOTAL SALARIES & FRINGE BENEFITS		$17,508.76
SUPPLIES			$ 1,015.56
TRAVEL			$ 4,063.58
EQUIPMENT			$ 195.00
EQUIPMENT RENTAL			$ 4,416.70
EQUIPMENT REPAIRS & SERVICES			$ 1,340.50
COMPUTER USAGE			$ 4,868.80
OTHER (Xeroxing, postage, printing, etc.)			$ 688.88
	TOTAL DIRECT COSTS		$34,097.78
INDIRECT COSTS:	56.3% of Salaries	$8,182.97	
	+ adjustment on 12/29 payperiod (2)	266.93	8,440.90
	TOTAL DIRECT & INDIRECT COSTS		$42,547.68

(1) reported fringe benefits @ 10% and should have reported at 19%, difference is 9%.

(2) reported Indirect costs @45% and should have reported at 56.3%, difference is 11.3%.

SUBMITTED BY: Viola L. Kenyon
Fiscal Coordinator
Dept. of Chemistry
April 17, 1980

Figure 2

Activity/Milestone Chart

RU #: 527 PI: William C. Johnson II -- University of Rhode Island

	1978			1979												1980								
Major Milestones	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Procedures for validation of FWS type 038 data operational				X																				
Completion date for editing 033 data submitted prior to IDEA System			X																					
Completion date for conversion of 033 data from FWS to NODC format						X																		
Establishment of distributed data entry and processing node at RU 527									X															
Establishment of distributed data entry sites at RU 083 and RU's 196/172						X																		
Establishment of distributed data entry sites at RU 337 and RU 237								X																

(continued)

Activity/Milestone Chart

Major Milestones	1978			1979												1980								
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Preparation of data entry/validation programs for IDEA System																								
1. File Type 033 - Version 1.0						X																		
File Type 033 - Version 2.0										X														
File Type 033 - Version 3.0															X									
2. File Type 031 - Version 1.0											X													
File Type 031 - Version 2.0												X												
File Type 031 - Version 3.0												X												
File Type 031 - Version 4.0													X											
File Type 031 - Version 5.0													X											
File Type 031 - Version 6.0														X										
File Type 031 - Version 7.0																	X							
3. File Type 034 - Version 1.0												X												
File Type 034 - Version 2.0													X											
File Type 034 - Version 3.0													X											
File Type 034 - Version 4.0																	X							
4. File Type 135 - Version 1.0																X								
File Type 135 - Version 2.0																	X							

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(continued)

Activity/Milestone Chart

Major Milestones	1978			1979												1980								
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Delivery of first of four 033 analysis products to RU 083 and JPO		X																						
Delivery of evaluation samples of remaining 033 analysis products to RU 083 and JPO				X																				
Delivery of production runs of 033 analysis products to RU 083 for use in Final Report					X	-	-	-	-	-	-	-	-	-	-	-								
Production use of entire suite of 033 analysis products for Bering Sea synthesis study											X	-	-	-	-									
Developoment of additional analyses for File Type 033 data - for use in Bering Sea synthesis study												X	-	-	-									

(continued)

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Activity/Milestone Chart

Major Milestones	1978 O	N	D	1979 J	F	M	A	M	J	J	A	S	O	N	D	1980 J	F	M	A	M	J	J	A	S
Conversion of NODC version of File Type 033 data into MIS data base									X	-	-	-	-	-	-	-	-	-	-					
Preparation of IDEA system support programs									X	-	-	-	-	-	-	-	-	-	-					
Maintenance of systems and applications programs	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
Quarterly Reports	X			X			X			X			X			X			X			O		
Annual Report							X												X					
Final Report																								O

Past Contract <-------- Period ---------> | Present Contract <-------- Period -------->

O = Planned Completion Date

X = Actual Completion Date

FWS = Fish and Wildlife Service

NODC = National Oceanic Data Center

IDEA = Interactive Data Entry and Analysis

MIS = MARMAP Information System

APPENDIX I

New Analysis Products

DATE OF ISSUE: MARCH 13, 1980

SEE LAST PAGE FOR NECESSARY KEYS

OCSEAP - FILE TYPE 031 FOOD SIZE CLASS TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

UCI031

LEAST AUKLETS

SAMPLE SIZE: 157

FOOD TYPE	PREY COUNT	PERCENT <=7MM	PERCENT 7MM-15MM	PERCENT >15MM	FOOD TYPE	PREY COUNT	PERCENT <=7MM	PERCENT 7MM-15MM	PERCENT >15MM
ACANTHOCEPHALA	0	0.0	0.0	0.0	CALANUS	1172	100.0	0.0	0.0
POLYCHAETA	0	0.0	0.0	0.0	CALANUS CRISTATUS	442	81.2	18.8	0.0
NEREIDAE	0	0.0	0.0	0.0	CALANUS GLACIALIS	0	0.0	0.0	0.0
NEPHTYIDAE	0	0.0	0.0	0.0	CALANUS MARSHALLAE	507	100.0	0.0	0.0
MOLLUSCA	0	0.0	0.0	0.0	CALANUS PLUMCHRUS	186	100.0	0.0	0.0
GASTROPODA	0	0.0	0.0	0.0	LEPAS ANATIFERA	0	0.0	0.0	0.0
ACMAEIDAE	0	0.0	0.0	0.0	PERACARIDA CUMACEA	28	67.9	32.1	0.0
GASTROPODA EUTHYNEURA	0	0.0	0.0	0.0	DIASTYLIS BIDENTATA	0	0.0	0.0	0.0
LIMACINIDAE	0	0.0	0.0	0.0	PERACARIDA ISOPODA	1	0.0	100.0	0.0
LIMACINA HELICINA	85	100.0	0.0	0.0	IDOTEA OCHOTENSIS	0	0.0	0.0	0.0
POLYPLACOPHORA	0	0.0	0.0	0.0	PERACARIDA ISOPODA ASELL.	0	0.0	0.0	0.0
BIVALVIA	0	0.0	0.0	0.0	PERACARIDA AMPHIPODA	0	0.0	0.0	0.0
CEPHALOPODA	0	0.0	0.0	0.0	PERACARIDA AMPHIPODA GAM.	32	18.8	81.3	0.0
THEUTHIDIDA MYOPSIDA	0	0.0	0.0	0.0	AMPHITHOE RUBRICATOIDES	0	0.0	0.0	0.0
ANTHROPODA MANDIB. CRUST.	0	0.0	0.0	0.0	ATYLUS BRUGGENI	1	100.0	0.0	0.0
COPEPODA	0	0.0	0.0	0.0	ERICTHONIUS HUNTERI	0	0.0	0.0	0.0
CALANIDAE	8	100.0	0.0	0.0	EUSIRIDAE	0	0.0	0.0	0.0

OCSEAP - FILE TYPE 031 FOOD SIZE CLASS TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

UCI031

LEAST AUKLETS

(CONTINUED)

FOOD TYPE	PREY COUNT	PERCENT <=7MM	PERCENT 7MM-15MM	PERCENT >15MM
PAREUSIROGENES	0	0.0	0.0	0.0
GAMMARIDAE	0	0.0	0.0	0.0
MELITA DENTATA	0	0.0	0.0	0.0
ISCHYROCERUS ANGUIPES	1	0.0	100.0	0.0
JASSA PULCELLA	0	0.0	0.0	0.0
ANONYX LATICOXAE	0	0.0	0.0	0.0
PARACALLISOMA ALBERTI	0	0.0	0.0	0.0
PLEUSTIDAE	0	0.0	0.0	0.0
PARAPLEUSTES JOHANSENI	0	0.0	0.0	0.0
PLEUSTES CATAPHRACTUS	0	0.0	0.0	0.0
ORCHESTIA OCHOTENSIS	0	0.0	0.0	0.0
HYPERIIDAE	36	58.3	41.7	0.0
HYPERIONYX	1	100.0	0.0	0.0
HYPEROCHE MEDUSARUM	114	71.9	28.1	0.0
PARATHEMISTO LIBELLULA	306	49.0	42.8	8.2
PARATHEMISTO PACIFICA	9	88.9	11.1	0.0
EUCARIDA EUPHAUSIACEA	0	0.0	0.0	0.0

FOOD TYPE	PREY COUNT	PERCENT <=7MM	PERCENT 7MM-15MM	PERCENT >15MM
EUPHAUSIIDAE	16	43.8	56.3	0.0
NAMETOSCELIS	0	0.0	0.0	0.0
PSEUDEUPHAUSIA	2	0.0	100.0	0.0
THYSANOESSA	2	0.0	50.0	50.0
THYSANOESSA INERMIS	2	0.0	0.0	100.0
THYSANOESSA LONGIPES	0	0.0	0.0	0.0
THYSANOESSA RASCHII	19	10.5	10.5	78.9
THYSANOESSA SPINIFERA	5	20.0	40.0	40.0
EUCARIDA DECAP.	0	0.0	0.0	0.0
EUCARIDA DECAP. PLEO.	0	0.0	0.0	0.0
EUCARIDA DECAP. PLEO. CA.	0	0.0	0.0	0.0
LEBBEUS GROENLANDICA	0	0.0	0.0	0.0
LEBBEUS POLARIS	0	0.0	0.0	0.0
LEBBEUS GRANDIMANUS	0	0.0	0.0	0.0
CRANGONIDAE	1	100.0	0.0	0.0
ARGIS CRASSA	0	0.0	0.0	0.0
ARGIS LEVIOR	0	0.0	0.0	0.0

OCSEAP - FILE TYPE 031 FOOD SIZE CLASS TABLE

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DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

UCI031

LEAST AUKLETS

(CONTINUED)

FOOD TYPE	PREY COUNT	PERCENT <=7MM	PERCENT 7MM-15MM	PERCENT >15MM
EUCARIDA DECAP. PLEO. AN.	51	58.8	41.2	0.0
PAGURIDAE	1	100.0	0.0	0.0
LITHODIDAE	0	0.0	0.0	0.0
HAPLOGASTER	0	0.0	0.0	0.0
HAPLOGASTER GREBNITZKII	0	0.0	0.0	0.0
DERMATURUS MANDTII	0	0.0	0.0	0.0
COLLEMBOLA	0	0.0	0.0	0.0
OSTEICHTHYES	20	0.0	60.0	40.0
MALLOTUS VILLOSUS	0	0.0	0.0	0.0
EVERMANNELLIDAE	0	0.0	0.0	0.0
MYCTOPHIDAE	0	0.0	0.0	0.0
PARACANTHO. GADIF. GADOI.	0	0.0	0.0	0.0
GADIDAE	0	0.0	0.0	0.0
THERAGRA CHALCOGRAMMA	4	100.0	0.0	0.0
POLLACHIUS VIRENS	0	0.0	0.0	0.0
ZOARCIDAE	0	0.0	0.0	0.0
ACANTHOPTERYGII GASTEROS.	0	0.0	0.0	0.0
GASTEROSTEIDAE	0	0.0	0.0	0.0
HEXAGRAMMOS STELLERI	0	0.0	0.0	0.0
ACANTHO. SCORPAENIF. COT.	0	0.0	0.0	0.0
ICELIDAE	0	0.0	0.0	0.0
COTTIDAE	0	0.0	0.0	0.0
BLEPSIAS BILOBUS	0	0.0	0.0	0.0
TRIGLOPS	0	0.0	0.0	0.0
TRIGLOPS PINGELI	0	0.0	0.0	0.0
PSYCHROLUTES PARADOXUS	0	0.0	0.0	0.0
AGONIDAE	0	0.0	0.0	0.0
CYCLOPTERIDAE	0	0.0	0.0	0.0
SPHYRAENA BARRACUDA	0	0.0	0.0	0.0
TRICHODON TRICHODON	0	0.0	0.0	0.0
RONQUILUS JORDANI	0	0.0	0.0	0.0
STICHAEIDAE	0	0.0	0.0	0.0
CHIROLOPHIS POLYACTOCEPH.	0	0.0	0.0	0.0
STICHAEUS PUNCTATUS	0	0.0	0.0	0.0

OCSEAP - FILE TYPE 031 FOOD SIZE CLASS TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

UCI031

LEAST AUKLETS

(CONTINUED)

FOOD TYPE	PREY COUNT	PERCENT <=7MM	PERCENT 7MM-15MM	PERCENT >15MM
AMMODYTES HEXAPTERUS	0	0.0	0.0	0.0
ACANTHO. PLEURON. PLEURO.	0	0.0	0.0	0.0
PLEURONECTOIDAE	0	0.0	0.0	0.0
ATHERESTHES STOMIAS	0	0.0	0.0	0.0
LEPIDOPSETTA BILINEATA	0	0.0	0.0	0.0
PLATICHTHYS STELLATUS	0	0.0	0.0	0.0
TOTALS	3052	86.9	11.4	1.7

KEYS AND COLUMN HEADINGS

SAMPLE SIZE	TOTAL NUMBER OF PREDATORS FOR WHICH INDIVIDUAL PREY WERE MEASURED
FOOD TYPE	PREY SPECIES NAME
PREY COUNT	TOTAL NUMBER OF PREY SPECIES MEASURED
PERCENT<=7MM	PERCENTAGE OF PREY COUNT LESS THAN OR EQUAL TO 7MM IN LENGTH
PERCENT 7MM-15MM	PERCENTAGE OF PREY COUNT GREATER THAN 7MM AND LESS THAN OR EQUAL TO 15 MM
PERCENT>15MM	PERCENTAGE OF PREY COUNT GREATER THAN 15MM
TOTALS	THE TOTAL PREY COUNT, THE PERCENTAGE OF THE TOTAL PREY COUNT LESS THAN OR EQUAL TO 7MM, THE PERCENTAGE OF THE TOTAL PREY COUNT GREATER THAN 7MM AND LESS THAN OR EQUAL TO 15MM, AND THE PERCENTAGE OF THE TOTAL PREY COUNT GREATER THAN 15MM, RESPECTIVELY

DATE OF ISSUE: FEBRUARY 26, 1980

SEE LAST PAGE FOR NECESSARY KEYS

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
66	65 30 N	162 00 W	0.7	0.0	*****	0.0	1
333	60 00 N	159 00 W	0.0	0.0	*****	*****	1
390	58 30 N	174 00 W	0.7	0.9	0.8	1.3	4
391	58 30 N	173 00 W	0.0	0.0	*****	*****	3
392	58 30 N	172 00 W	0.0	0.0	*****	*****	3
402	58 30 N	162 00 W	2.9	14.6	0.2	5.1	3
403	58 30 N	161 00 W	0.0	0.0	*****	*****	8
404	58 30 N	160 00 W	0.0	0.0	*****	*****	12
405	58 30 N	159 00 W	0.2	0.2	1.0	1.0	6
406	58 30 N	158 00 W	0.0	0.0	*****	*****	10
407	58 30 N	157 00 W	0.0	0.0	*****	*****	8
414	58 00 N	174 00 W	0.0	0.0	*****	*****	4
415	58 00 N	173 00 W	0.4	0.2	1.9	0.5	4
416	58 00 N	172 00 W	0.0	0.0	*****	*****	1
417	58 00 N	171 00 W	1.6	3.4	0.5	2.2	19
418	58 00 N	170 00 W	0.1	0.0	1.3	0.8	13
419	58 00 N	169 00 W	0.5	0.8	0.6	1.6	10
425	58 00 N	163 00 W	3.1	0.0	*****	0.0	1
426	58 00 N	162 00 W	0.5	0.3	2.1	0.5	5
428	58 00 N	160 00 W	1.4	4.6	0.3	3.3	6

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

(CONTINUED)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
429	58 00 N	159 00 W	2.9	21.1	0.1	7.3	3
430	58 00 N	158 00 W	0.0	0.0	*****	*****	4
438	57 30 N	174 00 W	0.0	0.0	*****	*****	4
439	57 30 N	173 00 W	1.1	4.0	0.3	3.7	5
440	57 30 N	172 00 W	0.1	0.0	2.0	0.5	5
441	57 30 N	171 00 W	8.2	41.8	0.2	5.1	23
442	57 30 N	170 00 W	1.2	2.3	0.5	2.0	21
443	57 30 N	169 00 W	0.8	0.9	0.8	1.2	25
444	57 30 N	168 00 W	1.2	0.2	6.7	0.1	2
445	57 30 N	167 00 W	1.0	0.0	*****	0.0	1
446	57 30 N	166 00 W	0.0	0.0	*****	*****	2
447	57 30 N	165 00 W	2.1	3.7	0.6	1.8	3
450	57 30 N	162 00 W	2.5	7.6	0.3	3.0	5
451	57 30 N	161 00 W	1.7	0.0	*****	0.0	2
452	57 30 N	160 00 W	0.0	0.0	*****	*****	3
454	57 30 N	158 00 W	0.0	0.0	*****	*****	3
463	57 00 N	173 00 W	0.0	0.0	*****	*****	5
464	57 00 N	172 00 W	0.2	0.3	0.7	1.5	20
465	57 00 N	171 00 W	0.4	0.9	0.4	2.3	31

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

(CONTINUED)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
466	57 00 N	170 00 W	2.5	12.9	0.2	5.2	76
467	57 00 N	169 00 W	0.6	0.7	1.0	1.1	36
468	57 00 N	168 00 W	0.8	1.2	0.7	1.5	32
469	57 00 N	167 00 W	0.8	2.6	0.3	3.4	19
470	57 00 N	166 00 W	0.6	0.5	1.3	0.8	15
471	57 00 N	165 00 W	0.4	0.5	0.8	1.2	12
472	57 00 N	164 00 W	0.0	0.0	*****	*****	6
473	57 00 N	163 00 W	0.0	0.0	*****	*****	8
474	57 00 N	162 00 W	0.0	0.0	*****	*****	4
475	57 00 N	161 00 W	0.5	0.2	2.5	0.4	3
476	57 00 N	160 00 W	2.7	5.5	0.5	2.0	3
477	57 00 N	159 00 W	0.4	0.6	0.7	1.5	4
478	57 00 N	158 00 W	1.0	2.0	0.5	2.0	5
486	56 30 N	174 00 W	0.3	0.3	1.0	1.0	4
487	56 30 N	173 00 W	1.0	5.6	0.2	5.8	6
489	56 30 N	171 00 W	3.9	34.7	0.1	8.9	14
490	56 30 N	170 00 W	4.8	30.6	0.2	6.4	35
491	56 30 N	169 00 W	4.5	32.0	0.1	7.1	45
492	56 30 N	168 00 W	1.1	3.4	0.3	3.0	18

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

(CONTINUED)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
493	56 30 N	167 00 W	2.3	15.2	0.1	6.7	18
494	56 30 N	166 00 W	2.4	7.2	0.3	3.0	20
495	56 30 N	165 00 W	0.4	0.5	0.9	1.1	12
496	56 30 N	164 00 W	1.7	0.0	*****	0.0	1
497	56 30 N	163 00 W	1.1	2.1	0.6	1.8	6
498	56 30 N	162 00 W	0.3	0.1	3.0	0.3	4
500	56 30 N	160 00 W	1.3	3.1	0.4	2.4	5
501	56 30 N	159 00 W	0.0	0.0	*****	*****	2
504	56 30 N	156 00 W	0.2	0.2	0.9	1.1	9
509	56 00 N	175 00 W	0.0	0.0	*****	*****	2
513	56 00 N	171 00 W	4.2	35.8	0.1	8.6	20
514	56 00 N	170 00 W	1.0	2.4	0.4	2.5	39
515	56 00 N	169 00 W	4.4	20.2	0.2	4.6	45
516	56 00 N	168 00 W	3.7	39.1	0.1	10.6	27
517	56 00 N	167 00 W	5.0	39.9	0.1	7.9	16
518	56 00 N	166 00 W	3.0	25.3	0.1	8.5	25
519	56 00 N	165 00 W	1.1	5.0	0.2	4.5	18
520	56 00 N	164 00 W	0.4	0.2	2.2	0.5	6
521	56 00 N	163 00 W	0.9	2.2	0.4	2.5	6

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

(CONTINUED)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
522	56 00 N	162 00 W	5.7	66.7	0.1	11.6	8
524	56 00 N	160 00 W	1.8	0.2	8.3	0.1	3
526	56 00 N	158 00 W	0.4	0.8	0.5	1.8	11
527	56 00 N	157 00 W	7.5	865.1	0.0	115.3	17
528	56 00 N	156 00 W	4.4	83.8	0.1	18.9	13
533	55 30 N	175 00 W	0.0	0.0	*****	*****	1
538	55 30 N	170 00 W	1.0	2.6	0.4	2.7	14
539	55 30 N	169 00 W	1.8	3.6	0.5	2.0	17
540	55 30 N	168 00 W	1.5	5.8	0.3	3.8	33
541	55 30 N	167 00 W	2.0	13.5	0.1	6.7	29
542	55 30 N	166 00 W	0.9	2.5	0.4	2.8	16
543	55 30 N	165 00 W	0.4	0.7	0.6	1.7	17
544	55 30 N	164 00 W	0.5	0.5	1.1	0.9	17
545	55 30 N	163 00 W	1.4	6.3	0.2	4.5	32
546	55 30 N	162 00 W	0.6	1.5	0.4	2.4	6
548	55 30 N	160 00 W	0.0	0.0	*****	*****	1
549	55 30 N	159 00 W	0.3	0.4	0.7	1.4	8
550	55 30 N	158 00 W	2.2	27.9	0.1	12.9	7
551	55 30 N	157 00 W	2.6	0.2	15.6	0.1	4

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

(CONTINUED)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
552	55 30 N	156 00 W	2.6	0.0	*****	0.0	1
557	55 00 N	175 00 W	1.5	4.8	0.3	3.1	2
562	55 00 N	170 00 W	0.7	0.4	2.0	0.5	5
563	55 00 N	169 00 W	0.6	0.9	0.7	1.4	12
564	55 00 N	168 00 W	0.5	0.6	0.8	1.3	24
565	55 00 N	167 00 W	1.9	15.9	0.1	8.5	64
566	55 00 N	166 00 W	2.0	33.1	0.1	16.8	17
567	55 00 N	165 00 W	0.0	0.0	*****	*****	13
568	55 00 N	164 00 W	0.4	0.8	0.5	2.0	28
569	55 00 N	163 00 W	0.3	0.6	0.5	1.9	26
570	55 00 N	162 00 W	0.0	0.0	*****	*****	8
571	55 00 N	161 00 W	1.0	4.0	0.3	3.8	23
572	55 00 N	160 00 W	0.3	0.2	1.3	0.7	7
573	55 00 N	159 00 W	0.6	1.0	0.5	1.8	11
574	55 00 N	158 00 W	0.6	1.0	0.6	1.6	11
575	55 00 N	157 00 W	0.5	1.1	0.5	1.9	19
576	55 00 N	156 00 W	1.4	9.0	0.2	6.6	16
581	54 30 N	175 00 W	0.0	0.0	*****	*****	1
585	54 30 N	171 00 W	0.0	0.0	*****	*****	4

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

(CONTINUED)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
588	54 30 N	168 00 W	1.0	0.0	*****	0.0	2
589	54 30 N	167 00 W	0.9	0.8	1.1	0.9	13
590	54 30 N	166 00 W	0.9	1.5	0.6	1.8	18
591	54 30 N	165 00 W	0.4	0.4	1.0	1.0	14
592	54 30 N	164 00 W	0.0	0.0	*****	*****	1
593	54 30 N	163 00 W	0.5	1.5	0.3	3.3	15
594	54 30 N	162 00 W	0.1	0.1	0.9	1.1	20
595	54 30 N	161 00 W	2.0	4.7	0.4	2.4	9
596	54 30 N	160 00 W	1.2	0.7	1.7	0.6	9
597	54 30 N	159 00 W	1.0	3.1	0.3	3.2	13
598	54 30 N	158 00 W	0.8	3.5	0.2	4.3	7
599	54 30 N	157 00 W	1.7	3.2	0.5	1.9	7
600	54 30 N	156 00 W	0.0	0.0	*****	*****	1
606	54 00 N	174 00 W	0.0	0.0	*****	*****	2
607	54 00 N	173 00 W	0.0	0.0	*****	*****	1
612	54 00 N	168 00 W	1.4	0.0	*****	0.0	1
613	54 00 N	167 00 W	0.6	0.9	0.7	1.5	10
614	54 00 N	166 00 W	0.5	2.0	0.3	4.0	36
615	54 00 N	165 00 W	0.5	2.6	0.2	5.2	52

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

(CONTINUED)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
616	54 00 N	164 00 W	1.0	4.8	0.2	4.8	22
617	54 00 N	163 00 W	0.1	0.1	1.4	0.7	20
618	54 00 N	162 00 W	0.8	1.5	0.5	1.8	19
619	54 00 N	161 00 W	1.6	0.5	3.0	0.3	5
620	54 00 N	160 00 W	2.2	3.1	0.7	1.4	11
621	54 00 N	159 00 W	3.3	8.5	0.4	2.6	8
623	54 00 N	157 00 W	8.2	135.6	0.1	16.6	3
631	53 30 N	173 00 W	0.0	0.0	*****	*****	1
632	53 30 N	172 00 W	0.0	0.0	*****	*****	3
636	53 30 N	168 00 W	0.0	0.0	*****	*****	3
638	53 30 N	166 00 W	0.0	0.0	*****	*****	6
639	53 30 N	165 00 W	7.7	332.9	0.0	43.4	6
640	53 30 N	164 00 W	0.4	0.4	0.9	1.1	3
642	53 30 N	162 00 W	0.0	0.0	*****	*****	3
644	53 30 N	160 00 W	1.8	6.4	0.3	3.5	5
645	53 30 N	159 00 W	4.7	31.9	0.1	6.8	10
646	53 30 N	158 00 W	6.0	0.0	*****	0.0	1
656	53 00 N	172 00 W	0.0	0.0	*****	*****	2
657	53 00 N	171 00 W	0.0	0.0	*****	*****	1

OCSEAP - FILE TYPE 033 MEAN DENSITY VERSUS SAMPLE VARIANCE RATIO TABLE

DATA PROJECTS GROUP
PASTORE LABORATORY
UNIVERSITY OF RHODE ISLAND

BERING SEA (30' X 60' BLOCKS)

BLACK-LEGGED KITTIWAKES (MARCH - MAY)

(CONTINUED)

BLOCK	LATITUDE	LONGITUDE	MEAN	VARIANCE	M/V	V/M	TRANSECTS
658	53 00 N	170 00 W	0.0	0.0	*****	*****	6
659	53 00 N	169 00 W	0.0	0.0	*****	*****	6
660	53 00 N	168 00 W	0.1	0.1	1.3	0.8	6
661	53 00 N	167 00 W	0.0	0.0	*****	*****	8
662	53 00 N	166 00 W	0.1	0.1	1.3	0.8	7
663	53 00 N	165 00 W	0.5	1.3	0.4	2.7	8
664	53 00 N	164 00 W	0.9	2.0	0.4	2.2	13
665	53 00 N	163 00 W	0.0	0.0	*****	*****	6
666	53 00 N	162 00 W	0.0	0.0	*****	*****	4
677	52 30 N	175 00 W	0.4	0.3	1.3	0.8	2
681	52 30 N	171 00 W	0.0	0.0	*****	*****	7
682	52 30 N	170 00 W	0.0	0.0	*****	*****	22
683	52 30 N	169 00 W	0.0	0.0	*****	*****	17
684	52 30 N	168 00 W	0.2	0.4	0.6	1.8	8
700	52 00 N	176 00 W	0.0	0.0	*****	*****	8
701	52 00 N	175 00 W	0.0	0.0	*****	*****	5
702	52 00 N	174 00 W	0.0	0.0	*****	*****	2
703	52 00 N	173 00 W	0.0	0.0	*****	*****	3
704	52 00 N	172 00 W	0.2	0.2	1.3	0.8	4

COLUMN HEADING DEFINITIONS

BLOCK A UNIQUE REFERENCE NUMBER WHICH IS ASSOCIATED WITH EACH RECTANGULAR BLOCK OF AREA COVERED BY THE OUTPUT. THE BLOCK NUMBER CORRESPONDS WITH THE NUMBERS PORTRAYED ON THE BLOCK IDENTIFICATION NUMBER DISPLAY AND ASSISTS THE USER IN ASSOCIATING A PARTICULAR BLOCK WITH THE AREA IN QUESTION.

LATITUDE THE LATITUDE OF THE SOUTHEAST CORNER OF THE BLOCK FOR WHICH INFORMATION IS DISPLAYED.

LONGITUDE THE LONGITUDE OF THE SOUTHEAST CORNER OF THE BLOCK FOR WHICH INFORMATION IS DISPLAYED.

MEAN THE MEAN DENSITY IN BIRDS PER SQUARE KILOMETER FOR ALL TRANSECTS WHICH TOOK PLACE WITHIN THE INDICATED BLOCK.

VARIANCE THE SAMPLE VARIANCE OF THE DENSITIES FOR ALL TRANSECTS WHICH TOOK PLACE WITHIN THE INDICATED BLOCK.

M/V RATIO OF MEAN DENSITY/SAMPLE VARIANCE. A SERIES OF ASTERISKS INDICATES THAT THE SAMPLE VARIANCE WAS ZERO.

V/M RATIO OF SAMPLE VARIANCE/MEAN DENSITY. A SERIES OF ASTERISKS INDICATES THAT THE MEAN DENSITY WAS ZERO.

TRANSECTS THE NUMBER OF TRANSECTS WHICH TOOK PLACE IN THE BLOCK.

APPENDIX II

Field Operations Status Report for File Type 033 Data

*** FIELD OPERATION STATUS REPORT ***

AS OF 03/31/80

THE DATA PROJECTS GROUP — OCSEAP - GULF OF ALASKA PROJECT

COLUMN HEADING DEFINITIONS:

TAPE NO -	IDENTIFYING NUMBER ASSIGNED TO THE TAPE AS IT IS RECEIVED BY RU527.
RESEARCH UNIT (RU#) -	RESEARCH UNIT NUMBER OF THE PRINCIPAL INVESTIGATOR.
DATE RECEIVED -	DATE THE TAPE WAS RECEIVED BY RU527.
FILE FORMAT -	FORMAT IN WHICH THE DATA ON THE TAPE HAVE BEEN CODED.
FIELD OPER -	NAME ASSIGNED TO THE FIELD OPERATION BY THE PRINCIPAL INVESTIGATOR.
CODEPULL/LOGLIST - MAILED	DATE THE OUTPUT FROM THE QUALITY CONTROL PROGRAMS "CODEPULL" AND "LOGLIST" WERE MAILED TO THE PRINCIPAL INVESTIGATOR FOR CORRECTIONS.
CODEPULL/LOGLIST - RETURNED	DATE THE CORRECTED OUTPUT FROM "CODEPULL" AND "LOGLIST" WERE RETURNED TO RU527.
EDITLOG COMPLETE -	DATE THE CORRECTIONS WERE MADE TO THE FIELD OP. AT RU527, THROUGH THE USE OF AN INTERACTIVE PROGRAM "EDITLOG".
FINAL CHECK -	DATE THE FIELD OP. WAS READY FOR CONVERSION OR TRANSFORMATION OCCASIONALLY ADDITIONAL PROBLEMS ARISE WHEN "CODEPULL" AND "LOGLIST" ARE RERUN AFTER EDITING. IF THESE CANNOT BE RESOLVED OVER THE TELEPHONE THE LISTINGS ARE SENT BACK TO THE PI FOR FURTHER CORRECTIONS. THIS FIELD IS NOT FILLED IN UNTIL ALL CORRECTIONS HAVE BEEN MADE.
CONVERT TO NODC -	DATE THE FIELD OP. WAS CONVERTED FROM FWS FORMAT TO NODC FORMAT. AN "NA" (NOT APPLICABLE) IS ENTERED HERE FOR FIELD OPS. RECEIVED IN NODC FORMAT.
MAIL TO NODC -	DATE THE FIELD OP. IN FINAL FORM WAS SUBMITTED TO NODC.
ENDNOTES -	REFERENCE NUMBER TO ADDITIONAL COMMENTS FOLLOWING THE TABLE.

*** FIELD OPERATION STATUS REPORT ***

AS OF 03/31/80

THE DATA PROJECTS GROUP — OCSEAP - GULF OF ALASKA PROJECT

TAPE NO	RU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	CODEPULL/LOGLIST RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
AK1	337	03/12/77	FWS	FW5004	07/12/77	08/29/77	02/15/78	02/15/78	10/06/78	10/31/78	1A,8
AK2	337	03/12/77	FWS	FW5009	07/12/77	10/06/77	01/26/78	01/30/78	09/05/78	09/18/78	1A,8
				FW5013	07/12/77	08/29/77	01/24/78	01/26/78	10/17/78	11/10/78	1A,8
				FW5018	07/12/77	08/29/77	01/30/78	02/01/78	09/02/78	10/31/78	1A,8
				FW5023	07/12/77	08/29/77	02/06/78	02/14/78	11/01/78	11/10/78	1A,8
				FW5024	07/12/77	08/29/77	02/14/78	02/15/78	11/01/78	11/10/78	1A,8
				FW5030	07/12/77	08/29/77	12/01/77	12/05/77	08/30/78	09/18/78	6,8
				FW5032	07/12/77	08/29/77	12/01/77	12/05/77	08/30/78	09/18/78	6,8
AK3	337	05/27/77	FWS	FW5008	07/14/77	09/06/77	12/09/77	12/09/77	09/07/78	09/18/78	8
				FW5016	07/14/77	09/06/77	07/25/78	07/28/78	11/15/78	11/30/78	1A,8
				FW5021	07/14/77	09/06/77	07/26/78	07/28/78	11/02/78	11/10/78	1B,8
				FW5026	07/14/77	09/06/77	01/31/78	02/01/78	11/17/78	11/30/78	8
				FW5027	07/14/77	09/06/77	02/03/78	02/06/78	09/05/78	09/18/78	8
				FW5033	07/14/77	09/06/77	07/28/78	07/31/78	11/15/78	11/30/78	1B,8
				FW5035	07/14/77	09/06/77	01/30/78	02/01/78	11/15/78	11/30/78	8
				FW6008	12/12/77	01/10/78	08/02/78	08/08/78	12/22/78	01/12/79	1B,8
				FW6027	07/14/77	09/06/77	10/24/78	10/26/78	01/02/79	01/12/79	1C,8
				FW6050	07/14/77	09/06/77	10/02/78	10/06/78	01/02/79	01/16/79	1C,8
				FW6051	07/14/77	09/06/77	10/24/78	10/27/78	01/02/79	01/16/79	1C,8
				FW6074	07/14/77	09/06/77	08/08/78	09/08/78	11/29/78	12/15/78	1B,8
				FW6083	07/14/77	09/06/77	07/21/78	07/24/78	01/02/79	01/16/79	1B,8
AK4	337	06/24/77	FWS	FW5011	08/16/77	11/01/77	10/24/78	10/27/78	11/09/78	11/30/78	1C,8
				FW5012	08/16/77	11/01/77	10/17/78	10/17/78	11/16/78	11/30/78	1C,8
				FW5020	08/16/77	11/01/77	10/31/78	11/02/78	11/09/78	11/30/78	1C,8
				FW5031	08/16/77	11/01/77	10/24/78	10/26/78	12/21/78	01/09/79	1C,8
				FW5034	08/16/77	11/01/77	04/17/78	04/19/78	09/03/78	10/31/78	8
				FW6015	08/16/77	11/01/77	04/05/78	04/18/78	09/06/78	09/18/78	8

*** FIELD OPERATION STATUS REPORT ***

AS OF 03/31/80

THE DATA PROJECTS GROUP OCSEAP - GULF OF ALASKA PROJECT

TAPE NO	RU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	CODEPULL/LOGLIST RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
AK4	337	06/24/77	FWS	FW6018	08/16/77	11/01/77	10/24/78	10/26/78	01/02/79	01/12/79	1C,8
				FW6019	08/16/77	11/01/77	12/01/78	12/14/78	12/22/78	01/12/79	1C,8
				FW6067	08/16/77	11/01/77	10/24/78	10/26/78	11/29/78	12/15/78	1C,8
				FW6068	08/16/77	11/01/77	10/24/78	10/26/78	11/29/78	12/15/78	1C,8
				FW6088	09/29/77	10/20/77	10/24/78	10/26/78	11/02/78	11/10/78	1C,8
				FW6089	08/16/77	11/01/77	07/21/78	07/24/78	11/29/78	12/15/78	1B,8
				FW6094	08/16/77	11/01/77	10/19/78	10/20/78	01/02/79	01/16/79	1C,8
AK5	337	07/01/77	FWS	FW5015	09/29/77	10/20/77	08/08/78	08/09/78	11/15/78	11/30/78	1E,8
				FW5025	09/29/77	10/20/77	07/24/78	07/26/78	12/21/78	01/09/79	1E,8
				FW6001	09/29/77	10/20/77	04/20/78	04/28/78	09/06/78	09/18/78	8
				FW6002	09/29/77	10/20/77	07/24/78	07/26/78	12/21/78	01/09/79	1E,8
				FW6007	09/29/77	10/20/77	07/24/78	07/27/78	12/22/78	01/12/79	1E,8
				FW6009	09/29/77	10/20/77	08/03/78	08/08/78	11/29/78	12/15/78	1E,8
				FW6021	10/28/77	11/30/77	07/25/78	07/26/78	12/01/78	12/15/78	1E,8
				FW6026	09/29/77	10/20/77	04/26/78	04/28/78	10/12/78	10/31/78	8
				FW6029	09/29/77	10/20/77	04/26/78	05/08/78	10/12/78	10/31/78	8
				FW6057	09/29/77	10/20/77	08/04/78	08/07/78	12/01/78	12/15/78	1E,8
				FW6064	09/29/77	10/20/77	07/21/78	07/27/78	01/03/79	01/16/79	1B,8
				FW6066	09/29/77	10/20/77	02/22/78	02/24/78	11/02/78	11/10/78	8
				FW6070	09/29/77	10/20/77	08/03/78	08/07/78	11/29/78	12/15/78	1E,8
				FW6095	09/29/77	10/20/77	08/08/78	08/09/78	01/02/79	01/16/79	1E,8
AK6	337	07/07/77	FWS	FW5014	10/21/77	11/14/77	02/17/78	02/22/78	09/05/78	09/18/78	8
				FW5022	10/21/77	11/14/77	11/09/78	11/10/78	11/10/78	11/30/78	1F,8
				FW5029	10/21/77	11/14/77	12/14/78	12/14/78	12/21/78	01/09/79	1F,8
				FW5036	10/21/77	11/14/77	06/05/78	06/07/78	11/09/78	11/30/78	8
				FW5037	10/21/77	11/14/77	06/05/78	06/07/78	11/10/78	11/30/78	8
				FW6004	10/21/77	11/14/77	12/15/78	12/18/78	12/21/78	01/09/79	1F,8
				FW6005	10/21/77	11/14/77	12/08/78	12/14/78	12/21/78	01/09/79	1F,8
				FW6010	10/21/77	11/14/77	12/08/78	12/14/78	12/21/78	01/09/79	1F,8
				FW6011	10/21/77	11/14/77	12/08/78	12/14/78	12/22/78	01/12/79	1F,8

*** FIELD OPERATION STATUS REPORT ***

AS OF 03/31/80

THE DATA PROJECTS GROUP OCSEAP - GULF OF ALASKA PROJECT

TAPE NO	RU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	CODEPULL/LOGLIST RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
AK6	337	07/07/77	FWS	FW6012	10/21/77	11/14/77	11/09/78	11/10/78	11/29/78	12/15/78	1F,8
				FW6016	10/21/77	11/14/77	12/14/78	12/14/78	12/22/78	01/12/79	1F,8
				FW6028	10/21/77	11/14/77	06/07/78	06/08/78	10/11/78	10/31/78	8
				FW6052	10/21/77	11/14/77	12/18/78	12/21/78	12/22/78	01/16/79	1F,8
				FW6077	10/21/77	11/14/77	12/15/78	12/18/78	12/22/78	01/16/79	1F,8
				FW6078	10/21/77	11/14/77	12/14/78	12/14/78	12/22/78	01/16/79	1F,8
				FW6084	10/21/77	11/14/77	11/03/78	11/08/78	11/29/78	12/15/78	1F,8
				FW6085	10/21/77	11/14/77	10/24/78	10/26/78	11/02/78	11/10/78	1F,8
				FW6092	10/21/77	11/14/77	12/14/78	12/19/78	12/22/78	01/16/79	1F,8
				FW7026	10/21/77	11/14/77	10/24/78	10/25/78	10/26/78	10/31/78	1F,8
				FW7027	10/21/77	11/14/77	06/26/78	06/27/78	09/06/78	10/31/78	8
AK7	083	07/07/77	FWS	UCI601	10/07/77	05/26/78	08/25/78	08/25/78	08/28/78	02/08/79	1G
AK8	337	07/28/77	FWS	FW5038	10/28/77	11/30/77	11/21/78	11/22/78	11/22/78	11/30/78	1F,8
				FW6013	10/28/77	11/30/77	12/21/78	12/22/78	01/05/79	01/12/79	1F,8
				FW6025	10/28/77	11/30/77	06/15/78	06/19/78	10/11/78	10/31/78	8
				FW6082	10/28/77	11/30/77	11/16/78	11/20/78	11/29/78	12/15/78	1F,8
				FW6087	10/28/77	11/30/77	11/09/78	11/10/78	11/29/78	12/15/78	1F,8
AK9	337	08/03/77	FWS	FW5003	10/28/77	11/30/77	10/02/78	10/17/78	12/21/78	01/09/79	2,1H,8
				FW5006	10/28/77	11/30/77	10/02/78	10/13/78	12/21/78	01/09/79	2,1H,8
				FW5010	10/28/77	11/30/77	10/02/78	10/13/78	11/03/78	11/10/78	2,1H,8
				FW6006	10/28/77	11/30/77	10/02/78	10/13/78	11/29/78	12/15/78	2,1H,8
				FW6014	10/28/77	11/30/77	10/02/78	10/03/78	12/22/78	01/12/79	2,1H,8
AK10	337	09/06/77	NODC	FW7032	10/07/77	11/03/77	11/22/77	11/30/77	/NA/	12/12/77	
				FW7033	10/07/77	11/03/77	11/22/77	11/30/77	/NA/	12/12/77	

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THE DATA PROJECTS GROUP | OCSEAP - GULF OF ALASKA PROJECT

TAPE NO	RU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
AK11	337	11/16/77	NODC	FW7034	11/30/77	01/04/78	01/09/78	01/10/78	/NA/	02/28/78	
				FW7035	11/30/77	01/04/78	01/06/78	01/17/78	/NA/	02/28/78	
				FW7042	11/30/77	01/04/78	01/09/78	01/16/78	/NA/	02/28/78	
				FW7046	11/30/77	01/04/78	01/09/78	01/16/78	/NA/	02/28/78	
AK12	337	01/10/78	NODC	FW7028	01/18/78	01/30/78	01/31/78	02/01/78	/NA/	02/28/78	
				FW7031	01/18/78	01/30/78	02/01/78	02/02/78	/NA/	02/28/78	
				FW7036	01/18/78	01/30/78	01/31/78	02/01/78	/NA/	02/28/78	
				FW7045	01/18/78	01/30/78	02/01/78	02/01/78	/NA/	02/28/78	
AK13	337	01/10/78	FWS	FW6086	01/18/78	01/30/78	07/26/78	07/26/78	10/26/78	11/10/78	1B,8
				FW6186	01/18/78	01/30/78	02/17/78	02/17/78	11/01/78	11/10/78	5,8
AK14	083	04/10/78	NODC	UCI602	04/14/78	04/25/78	06/02/78	06/06/78	/NA/	02/08/79	
AK15	083	06/13/78	NODC	UCI501	07/07/78	07/27/78	08/25/78	08/28/78	/NA/	02/08/79	7
				UCI701	07/07/78	07/27/78	09/05/78	09/05/78	/NA/		10
				UCI702	07/07/78	07/27/78	09/05/78	09/05/78	/NA/		10
				UCI703	07/07/78	07/27/78	08/25/78	08/28/78	/NA/	02/08/79	
				UCI704	07/07/78	07/27/78	08/25/78	08/28/78	/NA/	02/08/79	
AK16	337	09/05/78	NODC	FW6093	09/08/78	09/18/78	10/23/78	10/25/78	/NA/	10/31/78	
				FW7029	09/08/78	09/18/78	10/23/78	10/25/78	/NA/	10/31/78	
AK17	467	10/23/78	NODC	AERSR1	10/30/78	06/06/79	06/25/79	06/25/79	/NA/	07/03/79	9,12
				AERSR2	10/30/78	06/06/79	06/25/79	06/25/79	/NA/	07/03/79	9,12
				AERSR3	10/30/78	06/06/79	06/25/79	06/25/79	/NA/	07/03/79	9,12
				AERSR4	10/30/78	06/06/79	06/25/79	06/25/79	/NA/	07/03/79	9,12

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THE DATA PROJECTS GROUP — OCSEAP - GULF OF ALASKA PROJECT

TAPE NO	RU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	CODEPULL/LOGLIST RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
AK17	467	10/23/78	NODC	AERSR5	10/30/78	06/06/79	06/25/79	06/25/79	/NA/	07/03/79	9,12
				AERSR6	10/30/78	06/06/79	06/25/79	06/25/79	/NA/	07/03/79	9,12
				AERSR7	10/30/78	06/06/79	06/25/79	06/25/79	/NA/	07/03/79	9,12,14
AK18	083	12/15/78	NODC	UCI702	01/18/79	02/02/79	05/18/79	05/18/79	/NA/		11,1J
				UCI801	01/18/79	02/02/79	05/11/79	05/18/79	/NA/	06/25/79	1J
				UCI802	01/18/79	02/02/79	05/11/79	05/18/79	/NA/	06/25/79	1J
				UCI803	01/18/79	02/02/79	05/11/79	05/18/79	/NA/	06/25/79	1J
				UCI804	01/18/79	02/02/79	05/11/79	05/18/79	/NA/	06/25/79	1J
				UCI805	01/18/79	02/02/79	05/11/79	05/18/79	/NA/	06/25/79	1J
				UCI806	01/18/79	02/02/79	05/18/79	05/18/79	/NA/	06/25/79	1J
				UCI808	01/18/79	02/02/79	05/11/79	05/18/79	/NA/	06/25/79	1J
TI2	083	08/20/79	TI	UCI903	09/26/79	10/18/79	02/19/80	02/19/80	/NA/	02/21/80	
TI3	083	10/25/79	TI	UCI902	11/05/79	11/13/79	02/19/80	02/19/80	/NA/	02/21/80	
TI4	083	11/16/79	TI	UCI901	12/11/79	12/26/79	01/07/80	02/19/80	/NA/	02/21/80	
AK19	337	08/20/79	NODC	FW5007	10/01/79						
				FW5028	10/01/79						
				FW6069	10/01/79						
				FW8006	10/01/79						
				FW8007	10/01/79						
				FW8008	10/01/79						
				FW8029	10/01/79						
				FW8032	10/01/79						
				FW8100	10/01/79						
				FW9001	10/01/79						

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THE DATA PROJECTS GROUP — OCSEAP - GULF OF ALASKA PROJECT

TAPE NO	RU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	CODEPULL/LOGLIST RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
AK20	337	08/20/79	NODC	FW5038	10/01/79						15
				FW6096	10/01/79						
				FW6100	10/01/79						
				FW6200	10/01/79						
				FW6300	10/01/79						
				FW6400	10/01/79						
				FW7047	10/01/79						
				FW7050	10/01/79						
				FW7051	10/01/79						
				FW7052	10/01/79						
				FW7053	10/01/79						
				FW7054	10/01/79						
				FW8012	10/01/79						
				FW8014	10/01/79						
				FW8015	10/01/79						
				FW8016	10/01/79						
				FW8017	10/01/79						
				FW8018	10/01/79						
				FW8019	10/01/79						
				FW8023	10/01/79						
				FW8024	10/01/79						
				FW8025	10/01/79						
				FW8026	10/01/79						
				FW8027	10/01/79						
				FW8028	10/01/79						
AK21	467	09/20/79	NODC	AER801	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
				AER802	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
				AER803	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
				AER804	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
				AER805	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
				AER806	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
				AER807	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
				AER808	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	

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THE DATA PROJECTS GROUP — OCSEAP - GULF OF ALASKA PROJECT

TAPE NO	PU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	CODEPULL/LOGLIST RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
AK21	467	09/20/79	NODC	AER809	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
				AER810	10/01/79	11/16/79	02/21/80	02/21/80	/NA/	02/25/80	
OR1	108	05/25/77	NODC	W05220	10/26/77	01/03/78	05/05/78	05/17/78	/NA/	05/24/78	3B
				W05221	10/26/77	01/03/78	05/05/78	05/17/78	/NA/	05/24/78	3B
				W05310	10/26/77	01/03/78	05/08/78	05/17/78	/NA/	05/24/78	3B
				W05311	10/26/77	01/03/78	05/09/78	05/17/78	/NA/	05/24/78	
				W05325	10/26/77	01/03/78	05/10/78	05/17/78	/NA/	05/24/78	3B
				W06211	10/26/77	01/03/78	05/10/78	05/17/78	/NA/	05/24/78	3A
				W06221	10/26/77	01/03/78	05/12/78	05/17/78	/NA/	05/24/78	3A,3B
				W16140	10/26/77	01/03/78	05/12/78	05/17/78	/NA/	05/24/78	3B
				W16150	10/26/77	01/03/78	05/02/78	05/17/78	/NA/	05/24/78	3B
				W16161	10/26/77	01/03/78	05/12/78	05/17/78	/NA/	05/24/78	3A,3B
				W26140	10/26/77	01/03/78	05/05/78	05/17/78	/NA/	05/24/78	3B
				W36070	10/26/77	01/03/78	05/04/78	05/17/78	/NA/	05/24/78	3B
CN1	239	03/30/78	NODC	01UC75	04/17/78	05/08/78	05/11/78	05/15/78	/NA/	06/12/78	4
				02UC75	04/17/78	05/08/78	05/12/78	05/15/78	/NA/	06/12/78	4
				03UC75	04/17/78	05/08/78	05/15/78	05/16/78	/NA/	06/12/78	4
				01UC76	04/17/78	05/08/78	06/09/78	06/09/78	/NA/	06/12/78	4,1D
				02UC76	04/17/78	05/08/78	06/09/78	06/09/78	/NA/	06/12/78	4,1D
				03UC76	04/17/78	05/08/78	05/15/78	05/16/78	/NA/	06/12/78	4
				04UC76	04/17/78	05/08/78	06/09/78	06/09/78	/NA/	06/12/78	4,1D
				05UC76	04/17/78	05/08/78	06/09/78	06/09/78	/NA/	06/12/78	4,1D
CA1	196	07/18/78	NODC	1SR377	08/31/78						
				1SR477	08/31/78						
				1DI577	08/31/78						
CA2	196	02/06/79	NODC	1SR678	02/12/79						

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THE DATA PROJECTS GROUP — OCSEAP - GULF OF ALASKA PROJECT

TAPE NO	RU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
CA3	196	05/18/79	NODC	3AL877	06/11/79						16A
				3AL878	06/11/79						16A
				3GL877	06/11/79						16A
				1SR578	06/11/79						16A
				1SR678	06/11/79						13,16A
TI1	196	06/04/79	TI	UCI478	06/29/79	07/18/79	07/19/79	07/23/79	/NA/	08/15/79	
ND1	196	12/04/79	NODC	2GL976	01/14/80						16A
				2GL876	01/14/80						16A
				3AL876	01/14/80						16A
ND2	196	02/04/80	NODC	2GLA76	02/07/80						16B
				2BI776	02/07/80						16B
				2GL875	02/07/80						16B
SOL1	196	02/04/80	SOL	3NW878	02/07/80						16B
TI5	337	02/04/80	TI	FW9002	02/15/80	/NA/	/NA/	02/14/80	/NA/		
				FW4001	02/15/80	/NA/	/NA/	02/14/80	/NA/		
				FW5038	02/15/80	/NA/	/NA/	02/14/80	/NA/		15
TI6	237	02/04/80	TI	WD77BS	01/30/80	02/14/80	02/18/80	02/19/80	/NA/	02/25/80	
				WD78BS	01/30/80	02/14/80	02/18/80	02/19/80	/NA/	02/25/80	
				WD78CS	01/30/80	02/14/80	02/18/80	02/19/80	/NA/	02/25/80	
ND3	237	02/04/80	NODC	WD5WFS	02/20/80	/NA/	/NA/	02/19/80	/NA/	/NA/	17
				WD6OSI	02/20/80	/NA/	/NA/	02/19/80	/NA/	/NA/	17

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TAPE NO	RU#	DATE RECEIVED	FILE FORMAT	FIELD OPER	CODEPULL/LOGLIST MAILED	RETURNED	EDITLOG COMPLETE	FINAL CHECK	CONVERT TO NODC	MAIL TO NODC	END NOTES
ND3	237	02/04/80	NODC	WD6SUI	02/20/80	/NA/	/NA/	02/19/80	/NA/	/NA/	17
				WD6WPS	02/20/80	/NA/	/NA/	02/19/80	/NA/		17

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*** FIELD OPERATION STATUS REPORT ***

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ENDNOTES:

1 A CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (12/12/77), RETURNED TO RU527 (01/10/78).
B. CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (03/16/78), RETURNED TO RU527 (06/26/78).
C CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (04/26/78), RETURNED TO RU527 (07/05/78).
D. CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (05/18/78), RETURNED TO RU527 (06/08/78).
E CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (06/06/78), RETURNED TO RU527 (06/26/78).
F. CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (06/27/78), RETURNED TO RU527 (07/13/78).
G. CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (07/07/78), RETURNED TO RU527 (07/27/78).
H CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (07/21/78), RETURNED TO RU527 (07/28/78).
J. CODEPULL/LOGLIST SENT BACK TO PI FOR MORE CORRECTIONS (03/02/79), RETURNED TO RU527 (05/09/79).

2. TAPE WAS UNREADABLE, SENT BACK TO PI TO BE RE-GENERATED (08/31/77), RETURNED TO RU527 (10/21/77).

3 A UNAUTHORIZED LIGHT LEVEL AND WEATHER CODES USED BY PI, (NOT INCLUDED IN SUBMISSION TO NODC).
B. UNAUTHORIZED DISTANCE TO BIRDS ENTRY REPLACED BY OUTSIDE ZONE CODE FOR SUBMISSION TO NODC.

4 TAPE RETURNED TO PI BECAUSE SEVEN OF THE EIGHT EXPECTED FIELD OPS COULD NOT BE FOUND (01/03/78). NEW TAPE WITH EIGHT FIELD OPS. RECEIVED (03/30/78).

5. FIELD OP. FW6186 IS A CONTINUATION OF FIELD OP. FW6086 BECAUSE FW6086 NEEDED MORE THAN 999 STATIONS.

6 ONE OF FIRST FIELD OPS. CONVERTED (02/28/78). FWS AND NODC FORMATS SENT TO PI FOR REVIEW RETURNED TO RU527 FOR REVISIONS TO CONVERSION (07/07/78).

7. DATA FOR THIS FIELD OP. REPLACES THAT ORIGINALLY CODED IN FWS FORMAT AND RECEIVED ON TAPE AK7.

8. ADDITIONAL PROGRAM WAS REQUIRED TO CORRECT TRANSECT TYPE AND WIDTH FOR RU337.

9. TAPE HAD ONLY 2 OF 6 SPECIFIED FIELD OPS. RETURNED (10/12/78). NEW TAPE RECEIVED (10/23/78).

10 PROBLEMS WITH CODING OF ENVIRONMENT RECORDS DETECTED BY RU083 AFTER USUAL DATA VALIDATION COMPLETED. FURTHER CORRECTIONS NEEDED. SUBMISSION TO NODC DEFERRED.

11. ADDITIONAL DATA FOR FIELD OP. UCI702 WHICH WAS ORIGINALLY RECEIVED ON TAPE AK15.

12 CODEPULLS AND LOGLISTS WERE NOT RETURNED; INSTEAD A LETTER WITH CORRECTIONS WAS RECEIVED.

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13. DATA FOR FIELD OP. 1SR678 REPLACES THAT ORIGINALLY RECEIVED ON TAPE CA2.

14. FIELD OP. AERSR7 SPLIT OFF FROM AERSR4.

15 STATIONS 1-404 OF FIELD OP. FW5038 WERE RECEIVED WITH TAPE AK8 IN JULY, 1977.
FW5038 ON AK20 CONTAINS STATIONS 405-459 (BUT WITHOUT TAX CODES).
FW5038 ON TI5 CONTAINS CORRECTED STATIONS 405-459, WITH TAX CODES.

16 A FIELD OPS SENT TO RU196 FOR TI VALIDATION ON 01/14/80.
B. FIELD OPS SENT TO RU196 FOR TI VALIDATION ON 03/07/80.

17. FIELD OP RECEIVED FROM NODC FOR INCLUSION IN DPG DATA BASE; TI DISKETTE PLUS CODEPULL AND LOGLIST SENT TO RU237 FOR USE WITH STATISTICAL PROGRAMS.

*** FIELD OPERATION STATUS REPORT ***

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THE DATA PROJECTS GROUP — OCSEAP - GULF OF ALASKA PROJECT

SUMMARY:

TOTAL FIELD OPERATIONS RECEIVED BY RU527	209
CODEPULLS/LOGLISTS MAILED TO PI	209
CODEPULLS/LOGLISTS RETURNED TO RU527	158
TOTAL FIELD OPERATIONS BEING EDITED AT RU527	0
FIELD OPERATIONS WHICH PASSED FINAL CHECK	158
FIELD OPERATIONS CONVERTED TO NODC	81
FIELD OPERATIONS MAILED TO NODC	148

QUALITY ASSURANCE PROGRAM

FOR

TRACE PETROLEUM COMPONENT ANALYSIS

by

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Submitted as the Annual Report
for Contract #R7120826
Research Unit #557
OUTER CONTINENTAL SHELF ENVIRONMENTAL ASSESSMENT PROGRAM
Sponsored by
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Bureau of Land Management

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I. SUMMARY OF OBJECTIVES, CONCLUSIONS, AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

A. SUMMARY OF OBJECTIVES

The objectives are to coordinate and conduct an analytical quality-assurance program that compares results among Principal Investigators (PI's) within the OCSEAP program, as well as between OCSEAP and other BLM-funded investigators, and to recommend procedural modification for improved analytical techniques, particularly those dealing with polar organic compounds associated with petroleum.

B. SUMMARY OF CONCLUSIONS

1. Intercalibration. Analyses for hydrocarbons in the OCSEAP Interim Reference Material (sediment) performed by twelve analytical laboratories show improved results compared to the previous OCSEAP study conducted by the National Bureau of Standards.
2. Metabolite Research. Numerous metabolites of individual petroleum aromatic hydrocarbons (PAH) can be analyzed by high-pressure liquid chromatography (HPLC) with ultraviolet (UV) absorption and fluorescence detectors. Interferences by other xenobiotics and natural organics can be suppressed by appropriate choice of UV fluorescence excitation and emission wavelengths. Plasma desorption/chemical ionization mass spectrometry (PD/CI MS) is effective in identifying conjugated metabolites of aromatic hydrocarbons.

C. SUMMARY OF IMPLICATIONS

The developments reported herein contribute to an understanding of analytical methodology for hydrocarbons and other petroleum-related compounds in marine environmental samples.

II. INTRODUCTION

A. GENERAL NATURE AND SCOPE OF STUDY

1. Intercalibration. A quality-assurance program for chemical analyses of petroleum components among BLM/OCS environmental studies is an objective of the BLM/OCS and OCSEAP programs. The NOAA National Analytical Facility (NAF) conducts an interlaboratory calibration study among eleven PI's associated with the BLM/OCS program (Table 1). An interim reference material (IRM) prepared from an intertidal harbor sediment known to be contaminated with aliphatic and aromatic hydrocarbons was employed. NAF performed over 30 replicate analyses on 100-g portions of this reference material by four procedures typical of the state-of-the-art required for BLM/OCS environmental studies (Tables 2 and 3). When OCSEAP determined that the IRM's homogeneity was satisfactory, NAF distributed multiple 100-g portions to the laboratories participating in the intercalibration. Results returned to NAF will be evaluated by statisticians.

2. Metabolite Research. Hydrocarbon metabolizing enzymes are prevalent in marine organisms; hence it is important to have analytical procedures available to delineate the details of metabolite formation and retention, and to determine the nature of the chemical structures formed. Recent research with marine organisms exposed to aromatic hydrocarbons suggests that mixtures of aromatic hydrocarbons are converted to a complex array of metabolic products which are retained for significant periods. Several of the aromatic hydrocarbons found in petroleum are not only on EPA's priority pollutant list but are also carcinogenic.

3. Alaskan Crude Oils. The OCSEAP/BLM program desires chemical composition data on major Alaskan crude oils.

B. SPECIFIC OBJECTIVES

1. Evaluate existing methods and develop new methods to analyze hydrocarbons and petroleum-related polar compounds in environmental samples. Recommend procedural modifications and improvements to OCSEAP/BLM.

2. Distribute interim intercalibration reference materials to PI's for analysis of residual hydrocarbons.

3. Tabulate the analytical results of reference material reported by collaborating laboratories and have center (NWAFC) statisticians evaluate these results.

4. Submit data on the chemical composition of two Alaskan crude oils (Prudhoe Bay and Cook Inlet).

C. RELEVANCE TO PROBLEMS OF PETROLEUM DEVELOPMENT

1. Intercalibration. OCSEAP and BLM have regarded analyses of environmental samples for hydrocarbons as essential to their environmental studies pertaining to petroleum development on the outer continental shelf (OCS). Effective measurement of hydrocarbons in marine sediments requires standardized extraction procedures that are efficient and reproducible. Our studies that compare existing state-of-the-art methodology with new methodology address this issue. After the major procedures were interrelated statistically with the IRM within NAF's laboratory, the interlaboratory calibration could proceed. Eleven laboratories have returned analytical data for most of the selected hydrocarbons and statistical evaluation of the results is proceeding.

2. Metabolite Research. Petroleum also contains many organic compounds more polar than hydrocarbons, which may also be more toxic. Current analytical methodology to extract and analyze marine environmental samples

for trace polar organics, including metabolites, remains inadequate. Therefore, it is important to the OCS program to establish efficient, statistically-proven, ultra-sensitive analytical procedures for these compounds.

III. CURRENT STATE OF KNOWLEDGE

A. INTERCALIBRATION

Concern over oil pollution has led to considerable interest in measuring the amounts of various hydrocarbons in the marine environment [1]. A number of researchers have developed specialized procedures for analyzing hydrocarbons in marine sediments [2-8]. Because the different procedures had not been adequately assessed or interrelated [2,3], interpretation of analytical data from such analyses has been difficult, especially for individual aliphatic and aromatic hydrocarbons. To surmount this problem, it is important to compare analytical methods for hydrocarbons in marine sediments using a representative set of individual hydrocarbons. OCSEAP's intra- and interlaboratory calibration with the interim reference material addresses this point.

B. METABOLITE RESEARCH

Polycyclic aromatic hydrocarbons (PAHs) are frequently encountered in the marine environment. Sources include natural oil seeps, aerial fallout of combustion products, and spilled petroleum [9,10]. Some fish species rapidly accumulate PAHs from water and are capable of metabolizing them to various oxygenated derivatives [11]. Studies with mammals have indicated that some of these metabolites may be more toxic to the organism than the parent hydrocarbon [12]. Although several analytical procedures for the separation, identification, and quantitation of metabolites formed in PAH-dosed biological systems have been reported, each has one or more limitations. For example, separation of solvent-extracted radiolabeled metabolites by thin-layer chromatography (TLC) and quantitation of the compounds by liquid scintillation counting (LSC) have been used [11,13,14]. However, problems have been noted in the resolution of individual metabolites (e.g., 1-naphthyl sulfate, 1-naphthyl glucoside) by usual TLC procedures [15]. Moreover, quantitation by LSC is time consuming and involves the use of radioactive compounds which are costly, often difficult to obtain in pure form, and require special handling procedures [11,13,14]. Also, radio isotopes cannot easily be used in environmental field studies. To surmount these problems, we investigated the application of high-performance liquid chromatography (HPLC) to the efficient separation of aromatic hydrocarbon metabolites [13,16-18]. Note that HPLC coupled with LSC for quantitation of radiolabeled compounds still retains the disadvantages inherent in the use of radioactive materials. Also, ultraviolet (UV) absorption spectrometry may be used with HPLC for quantitation [17,18], but it is not sensitive enough for trace analysis of many hydrocarbons and their metabolites. In addition, UV absorbance is generally non-specific, so direct quantitation of metabolites from complex biological mixtures containing interfering UV absorbing compounds is not practical. Several research groups [19-23] have reported an efficient method for the determination of highly fluorescent compounds, including PAHs, using HPLC in conjuction with on-line fluorescence detection. However, only limited attention has been devoted to direct detection of compounds of low native UV fluorescence [24]. This project addresses these issues.

Mass spectrometry (MS) is one of the most powerful methods for obtaining positive identifications and structural information. However, the inherent low volatility and thermal instability of many metabolites has prevented their analysis by conventional MS techniques. Analysis of labile biological compounds by MS has generally required special equipment and techniques such as field desorption direct insertion probes, HPLC/MS interface, and chemical ionization (CI) methods. For example, field desorption mass spectrometry (FD/MS) has been used to obtain the spectra of many thermally labile or nonvolatile compounds, but FD equipment is not available in many laboratories. However, Hunt et al. [25] has used a FD probe with a modified CI mass spectrometer to obtain spectra of compounds such as creatine and guanosine without requiring an externally applied field for desorption. In another approach, three research groups have modified a conventional direct insertion probe to directly expose samples to a CI reagent gas plasma. Hansen and Munson [26] used a Teflon probe tip; Cotter [27] used a specially machined Vespel tip; and Thenot et al. [28] devised a glass tip coated with a nonpolar liquid phase such as SE-30.

C. ALASKAN CRUDE OILS

Insufficient information is available on chemical composition of the major Alaskan crude oils to be employed in OCSEAP/BLM biological studies.

IV. STUDY AREA

Cook Inlet

V. SOURCES, METHODS AND RATIONALE OF DATA COLLECTION*

Intercalibration

Techniques employed by Hilpert et al. [3], Marks and Rao [25], and Youden [26] were consulted in the interlaboratory quality-assurance program for hydrocarbons in the IRM sediment.

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* Reference to a company or product does not imply endorsement by the U.S. Department of Commerce to the exclusion of others that may be suitable.

Metabolite Research

Animal Exposure

Rainbow trout (Salmo gairdneri) (109 $\pm$ 23 g) were obtained from a local fish hatchery and maintained in flow-through, aerated aquaria supplied supplied with declorinated fresh water. Aquaria temperatures were maintained at 8°-10°C, and fish were acclimated to aquaria conditions for at least two weeks.

Fish were fed naphthalene in one of two concentrations. In the higher level of exposures, ten fish were mildly anesthetized with tricaine methanesulfonate (50 μg/L H_2O)(Sigma Chemical Co., St. Louis, Mo.). Then each fish was force-fed a gelatin capsule containing 4.0 mg naphthalene (Baker and Adamson, Morristown, N.J.) dissolved in 50 μL ethanol. This feeding was repeated after 24 hr providing a total of 8.0 mg of naphthalene (73 mg/kg body wt) to each fish. Twenty-four hours after the second feeding, bile was removed from the gall bladder of each fish. The bile was pooled for analysis and frozen at -60°C. The lower level exposure study was carried out similarly except that three fish were each force-fed a gelatin capsule containing 0.40 mg of naphthalene dissolved in 50 μL ethanol (0.1 times the higher dose). This feeding was repeated after 24 hr; thus each of three fish received 0.80 mg naphthalene (7.3 mg/kg body wt). Control fish received capsules containing ethanol only. Bile samples were collected, pooled, and frozen 24 hr after the second feeding.

Three male Swiss-Webster mice (40.3 $\pm$ 0.3 g) were each injected intraperitoneally with 3.0 mg of naphthalene (74 mg/kg body wt) dissolved in 50 μL corn oil. Eighteen hours after injection, bile was removed from the gall bladder of each mouse. Control and test bile samples were each pooled for analysis. Bile was used directly for HPLC analysis.

Apparatus and Materials

HPLC. Metabolite separations were performed with a Spectra-Physics 3500 high performance liquid chromatograph (Santa Clara, Calif.) using a 0.26 x 25 cm Perkin Elmer HC-ODS 10 μm column (Norwalk, Conn.). A Perkin-Elmer MPF-44A fluorescence spectrometer fitted with a 20 μL square, micro flow cell was used for detection and characterization. The square, cross-sectional flow cell reduces specular reflection of incident light, lowering the background signal, thus, lowering the minimum detectable amount of a substance. A 0.21 x 5-cm stainless steel precolumn was dry-packed with Vydac 37 μm reverse phase packing (The Separation's Group, Hesperia, Calif.). The precolumn was used to protect the analytical column from noneluting bile components and was replaced when operating pressures increased significantly. Samples were injected with a Rheodyne 7120 loop injecting valve (Berkeley, Calif.), using a 10-μL sample loop and a 10-μL Hamilton syringe (Reno, Nev.). Detector response was simultaneously recorded and integrated on a Hewlett-Packard 3385A recording integrator (Avondale, Pa.).

Preparative HPLC separations were performed on a Hewlett-Packard 1084B high performance liquid chromatograph (Palo Alto, Calif.), using a 0.46 x 25-cm Brownlee LiChrosorb RP-18 10-μm column (Santa Clara, Calif.). Eluted fractions were collected with a Fractomette 400 fraction collector (Buchler Instruments, Fort Lee, N.J.). Stop-flow fluorescence spectra were taken with the Perkin-Elmer MPF-44A instrument equipped with a Perkin-Elmer 2000 X-Y recorder. A Perkin-Elmer differential corrected spectra microprocessor 0.63-0184 was used to correct for the solvent Raman band.

Mass Spectrometer. Mass spectra were obtained using Finnigan 3200 mass spectrometers (Sunnvale, Calif.) equipped with electron impact (EI) and chemical ionization (CI) sources. An INCOS 2300 data system processed the MS data. A standard Finnigan solids probe was used after the probe tip was modified to improve heat conduction to the sample. First, a 2-cm length of 2 mm-o.d. glass tubing was sealed at one end and packed with 0.25-mm o.d. silver wire. Then the open end of the glass probe was inserted into the standard Finnigan solids probe so that ca. 1 cm of the glass was inside the probe and ca. 1 cm extended beyond the probe tip.

Chemicals. "ResiAnalyzed" methanol and "HPLC-Reagent" water were purchased from Baker Chemical (Pillipsburg, N.J.). Glacial acetic acid was obtained from Mallinckrodt (Paris, KY.). Solvents were prepared for HPLC by filtering through 0.5-μm pore filters (Millipore Corp., Bedford, Mass.). The standards: 1-naphthol, sodium salt of 1-naphthol-β-D-glucuronic acid, and 1-naphthyl sulfate were obtained from Sigma Chemical (St. Louis, Mo.). Naphthalene was obtained from Aldrich Chemical (Milwaukee, Wis.).

Methods

HPLC Gradient Elutions. Acetic acid/water (0.5% v/v)(Solvent A) and methanol (Solvent B) were used in a linear gradient from 5 to 95% Solvent B in 15 min, followed by 5-8 min at final conditions. Flow rate was 1.0 mL/min and HPLC oven temperature was 50°C. The column was equilibrated at 5% methanol for ca. 15 min between gradient runs.

Preparative HPLC Elutions. Samples of metabolites for MS analysis were prepared on the apparatus described above. Naphthyl glucuronide eluted in ca. 4 min in a 30-min linear gradient from 10 to 100% methanol (Solvent B). Water was used as Solvent A. Flow rate was 1.0 mL/min and oven temperature was 55°C. Fractions (0.5 mL) were collected every 30 sec. Other metabolites collected in the elution were naphthyl sulfate at 6 min and naphthol at 13 min. The glucuronide retention time changed to ca. 16 min by changing Solvent A to 0.5% v/v acetic acid/water. Fractions believed to contain metabolites were reinjected onto the analytical column (Perkin-Elmer) and verified by retention times and/or stop-flow fluorescence spectra.

HPLC Stop-flow Spectra. Sample materials can be trapped in the detector flow cell by diverting the column effluent to waste. Three ports of a six-port injector valve were used in the stop-flow system; the remaining three were sealed with nylon plugs. Flow from the column normally goes through the valve to the fluorescence detector. Turning the valve to the stop-flow position deverts the effluent to waste and traps desired HPLC peak components in the flow cell. Excitation and emission UV fluorescence spectra can then be taken.

HPLC Quantitation. Eluting the HC-ODS reverse phase column with aqueous acetic acid provides sharp peaks with little tailing. Compounds were tentatively identified from their HPLC retention times by comparison to those of known standards. Standards were added to the bile to verify the identity of certain peaks. Then, peak areas obtained from the chromatogram (as integrated by the Hewlett-Packard recording/integrator) were compared to those of chromatographed standards. Standard calibration curves were linear in the concentration ranges used in this work. Minimum detectable quantities were estimated as the amounts (ng) necessary to give a peak height two times the baseline noise of interference level based on 5 uL injections of fish bile and 2 uL injections of mouse bile: fish bile--naphthalene (13 ng), 1-naphthol (20 ng), naphthyl glucuronide (2 ng), and 1-naphthyl sulfate (5 ng), mouse bile--naphthalene (7 ng), 1-naphthol (20 ng), naphthyl glucuronide (2 ng), and 1-naphthyl sulfate (4 ng).

Chemical Ionization Mass Spectrometry (CI MS). Analysis of the commercially available sodium salt of 1-naphthyl-β-D-glucuronic acid (naphthyl glucuronide) did not yield a mass spectrum by direct plasma desorption MS.

The free acid form produced from the salt by acidification with 2N H_2SO_4 and exhaustive extraction with ethyl acetate yielded a good spectrum and therefore was used as the standard.

The naphthyl glucuronide present in biological samples was isolated by preparative HPLC as a nonvolatile salt. Because salts do not generally yield good spectra, the sample was acidified and extracted as above. However, only a poor mass spectrum could be obtained due to small amounts of the acidified sample obtained. To avoid extracting, the HPLC glucuronide salt fraction was evaporated to dryness and the methyl ester was prepared by dissolving the residue in 30 μL methanol containing 3 μL conc. hydrochloric acid. HPLC analyses showed that the reaction was complete after heating at 40°C for 2 hr. A methyl ester was prepared from the commercial naphthyl glucuronide standard in the same manner.

The glass probe tip was used as an inert support for the analyte; the tip was placed directly into the CI plasma. Ammonia was used as the reagent gas (0.5-0.9 torr). Heat was conducted by the wire to the glass tip, as the probe temperature was increased from 50° to 400°C in 90 sec. Spectra of less than 100 ng of both standard and experimental samples of naphthyl glucuronide (acid form) and of the methyl ester of naphthyl glucuronide were obtained in this manner.

Gas Chromatography/Mass Spectrometry (GC/MS). The 1-naphthol fraction collected from bile by preparative HPLC was analyzed by gas chromatography/ electron impact mass spectrometry (GC/EI MS). The naphthol was exchanged from water-methanol into methanol and the sample was injected into a Hewlett-Packard 5840 GC interfaced to the Finnigan 3200 EI MS. The GC column was a 30 m x 0.25 mm i.d. WCOT capillary column coated with SE-54 (Supelco, Inc., Bellefonte, Pa.). The injector temperature was 280°C and the column temperature was programmed at 10°C/min from 50° to 280°C. EI MS operating conditions were: electron energy, 60 eV; filament emmission current, 500 uA; and scan, 34 to 534 AMU/sec.

Alaskan Crude Oils

Analyses of Prudhoe Bay and Cook Inlet crude oils were performed according to published NAF procedures. Consult the analytical treatment of extracts in Brown et al. [8].

VI. RESULTS

Intercalibration

NAF conducts an interlaboratory quality assurance program for hydrocarbon analyses for OCSEAP/BLM using the interim reference material (IRM) prepared by OCSEAP. The OCS PI's who have returned analytical data on hydrocarbons in the IRM to this date are listed in Table 1.

Prior to release of the OCSEAP IRM to these PI's, NAF performed replicate analyses of the IRM (homogenized Duwamish River intertidal sediment) by four procedures typical of those employed by OCSEAP/BLM OCS PI's. Our results for arenes and alkanes are presented in Tables 2 and 3.

Tables 4 and 5 contain mean analytical values reported by the PI's in numerical order as per Table 1.

Metabolite Research

The HPLC chromatogram of bile from fish fed the higher level of naphthalene (73 mg/kg) is shown in Fig. 1. The parent substance (naphthalene, N), one nonconjugated metabolite (1-naphthol, NOH) and two conjugated metabolites (1-naphthyl sulfate, NSO_4; 1-naphthyl glucuronide, NG) were detected by UVF. In addition, two significant peaks of unidentified compounds were recorded at ca. 7 and 8 min. The fluorescence

Table 1. Principal Investigators participating in OCSEAP's hydrocarbon quality assurance program.

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emmission spectrum of naphthyl glucuronide from fish bile taken with the stop-flow technique is shown in Fig. 2.

The HPLC profile of bile from fish receiving the lower level of naphthalene (7.3 mg/kg) is also shown in Fig. 1. 1-Naphthyl sulfate, 1-naphthyl glucuronide and 1-naphthol were detected. Two peaks of unidentified compounds were also present; both corresponded to the unidentified peaks in the higher level chromatogram. The parent compound, naphthalene, was not detected. No attempt was made to detect 1,2-dihydrol,2-dihydroxynaphthalene (a minor metabolite in fish bile [13-15]) because it does not fluoresce well.

Table 2. Mean Concentrations of Arenes (ng/g dry wt) Found in Homogenized Duwamish River Sediment by Four Extraction Methods; $\bar{x}$ = Mean, n = Number of Analyses, RSD = Relative Standard Deviation of the Mean (100 SD/$\bar{x}$).

Aromatic Hydrocarbon	CH_2Cl_2/CH_3OH TUMBLE		CH_3OH/KOH REFLUX		SOXHLET EXTRACTION			
					Benzene/CH_3OH		CH_2Cl_2/CH_3OH	
	$\bar{x}$ (n=11)	RSD	$\bar{x}$ (n=4)	RSD	$\bar{x}$ (n=4)	RSD	$\bar{x}$ (n=4)	RSD
2-Methylnaphthalene	10 ng/g	33%	7	25%	14 ng/g	28%	11	59%
1-Methylnaphthalene	6	33	4	16	8	25	7	67
Biphenyl	2	39	1	28	9	24	2	95
2,6-Dimethylnaphthalene	8	26	5	21	9	27	6	118
2,3,5-Trimethylnaphthalene	6	58	<1	--	7	29	4	76
Fluorene	30	28	14	8	50	50	35	51
Dibenzothiophene*	28	32	20	2	50	57	51	63
Phenanthrene	330	28	180	2	610	44	370	47
Anthracene	57	26	34	7	120	50	65	49
1-Methylphenanthrene	22	24	16	8	56	38	33	48
Fluoranthene	570	23	320	3	840	40	560	41
Pyrene	760	21	280	5	1100	38	550	46
Benz[*a*]anthracene	440	23	170	3	870	71	620	31
Chrysene	270	20	200	5	530	48	370	30
Benzo[*e*]pyrene	150	26	150	5	230	31	310	38
Benzo[*a*]pyrene	170	33	180	4	410	45	300	43
Perylene	36	36	56	5	97	22	160	66

* A sulfur-substituted aromatic hydrocarbon

Table 3. Mean Concentrations of Alkanes (ng/g dry wt) Found in Homogenized Duwamish River Sediment by Four Extraction Methods; $\bar{x}$ = Mean, n = Number of Analyses, RSD = Relative Standard Deviation of the Mean (100 SD/$\bar{x}$).

n-Alkane	CH_2Cl_2/CH_3OH TUMBLE $\bar{x}$ (n=14)	RSD	CH_3OH/KOH REFLUX $\bar{x}$ (n=5)	RSD	SOXHLET EXTRACTION Benzene/CH_3OH $\bar{x}$ (n=5)	RSD	SOXHLET EXTRACTION CH_2Cl_2/CH_3OH $\bar{x}$ (n=4)	RSD
C_{13}	6 ng/g	23%	4 ng/g	17%	6 ng/g	14%	5 ng/g	32%
C_{14}	11	25	8	16	11	15	9	29
C_{15}	18	19	15	12	18	16	15	29
C_{16}	23	26	20	10	23	16	20	24
C_{17}	36	16	29	7	29	24	29	15
Pristane*	51	18	40	8	40	42	37	15
C_{18}	44	15	28	9	39	17	33	22
Phytane*	39	16	33	7	33	29	32	15
C_{19}	54	15	31	5	41	33	32	7
C_{20}	40	14	30	9	38	20	28	4
C_{21}	28	24	35	12	39	15	36	4
C_{22}	29	14	22	8	30	15	30	7
C_{23}	39	15	27	7	34	12	40	20
C_{24}	36	15	31	5	35	13	46	20
C_{25}	52	15	37	9	44	8	74	51
C_{26}	43	23	34	11	47	15	69	48
C_{27}	51	32	59	15	62	23	150	63
C_{28}	54	33	45	11	110	15	170	57
C_{29}	72	30	42	11	100	17	160	46
C_{30}	98	35	36	15	98	20	180	120
C_{31}	96	55	36	10	144	23	130	87

* A branched alkane

Table 4. Mean arenes (ng/g, dry wt) of Interim Reference Material: Duwamish River Sediment. Laboratory number as per Table 1. Arenes listed according to increasing number of rings. "-" denotes no data submitted.

Laboratory No.:	1	2	3	4		5	6	7	8			9	10			11
Data Set:				a	b				a	b	c		a	b	c	
Arene																
fluorene	-	-	24	-	-	-	-	49	35	41	210	331	-	-	-	33
dibenzothiophene*	-	22	271	14	19	-	-	-	25	27	141	462	7	15	5	32
phenanthrene	408	-	476	-	-	363	840	464	430	251	2,358	3,995	348	399	255	422
anthracene	71	-	31	-	-	80	-	117	94	69	546	780	-	-	-	97
1-methylphenanthrene	109	197	-	-	-	-	-	135	75	63	347	239	21	67	28	185
fluoranthene	638	-	749	1,016	1,250	752	1,040	811	743	515	3,435	3,808	521	681	221	799
pyrene	566	162	735	626	774	614	980	678	683	433	2,700	3,197	560	639	379	890
benz[*a*]anthracene	284	-	1,810	614	1,079	328	-	769	-	-	-	916	19	182	152	390
chrysene	453	251	603	811	795	-	960	532	-	-	-	921	0	160	109	135
benzo[*e*]pyrene	-	-	426	-	-	235	-	275	-	-	-	505	0	70	58	175
benzo[*a*]pyrene	451	-	537	-	-	303	-	295	-	-	-	716	0	-	47	202
perylene	103	-	129	-	-	80	-	74	-	-	-	193	0	-	4	70

* A sulfur-containing arene

Table 5. Mean alkanes (ng/g, dry wt) of Interim Reference Material: Duwamish River Sediment. Laboratory number as per Table 1. *n*-Alkanes listed according to carbon number. "-" denotes no data submitted.

Laboratory No.:	1	2	3	4		5	6	7	8			9	10			11
Data set:				a	b				a	b	c		a	b	c	
Alkane																
n-C_{14}	6	0	5	35	4	-	-	11	9	13	8	12	4	5	5	11
n-C_{15}	18	5	10	13	9	46	39	20	16	57	19	33	17	15	14	42
n-C_{16}	30	24	19	42	16	51	49	30	24	59	35	38	30	26	25	31
n-C_{17}	50	35	20	38	25	42	60	48	39	97	57	65	47	44	41	64
pristane	70	51	28	51	29	49	80	56	58	104	75	61	60	51	42	69
n-C_{18}	59	53	29	49	24	40	74	56	44	95	64	50	52	51	45	81
phytane	59	51	24	35	20	-	59	46	49	94	61	58	53	42	35	68
n-C_{19}	78	73	38	-	-	60	110	72	49	96	67	36	77	66	57	70
n-C_{20}	60	61	34	65	21	10	81	59	48	70	67	26	58	55	48	83
n-C_{21}	53	26	27	-	-	-	61	60	55	72	70	30	44	45	39	69
n-C_{22}	64	49	32	55	19	-	70	83	34	60	53	24	51	48	36	39
n-C_{23}	81	48	49	-	-	-	54	130	42	78	56	21	48	55	45	43
n-C_{24}	77	52	35	70	20	-	67	89	43	82	67	17	52	62	50	53
n-C_{25}	118	100	65	-	-	-	85	100	54	93	81	17	75	80	82	54
n-C_{26}	160	83	85	130	48	-	89	76	60	107	68	15	40	60	48	58
n-C_{27}	223	-	53	-	-	-	113	122	43	75	89	12	27	41	46	56
n-C_{28}	244	311	120	241	96	-	-	117	101	108	73	16	38	52	55	103
n-C_{29}	313	-	52	-	-	-	-	133	95	123	94	14	15	38	47	68
n-C_{30}	-	409	36	-	-	-	-	104	95	122	79	14	2	8	12	27
n-C_{31}	-	-	39	229	185	-	-	186	64	92	122	7	7	11	22	46

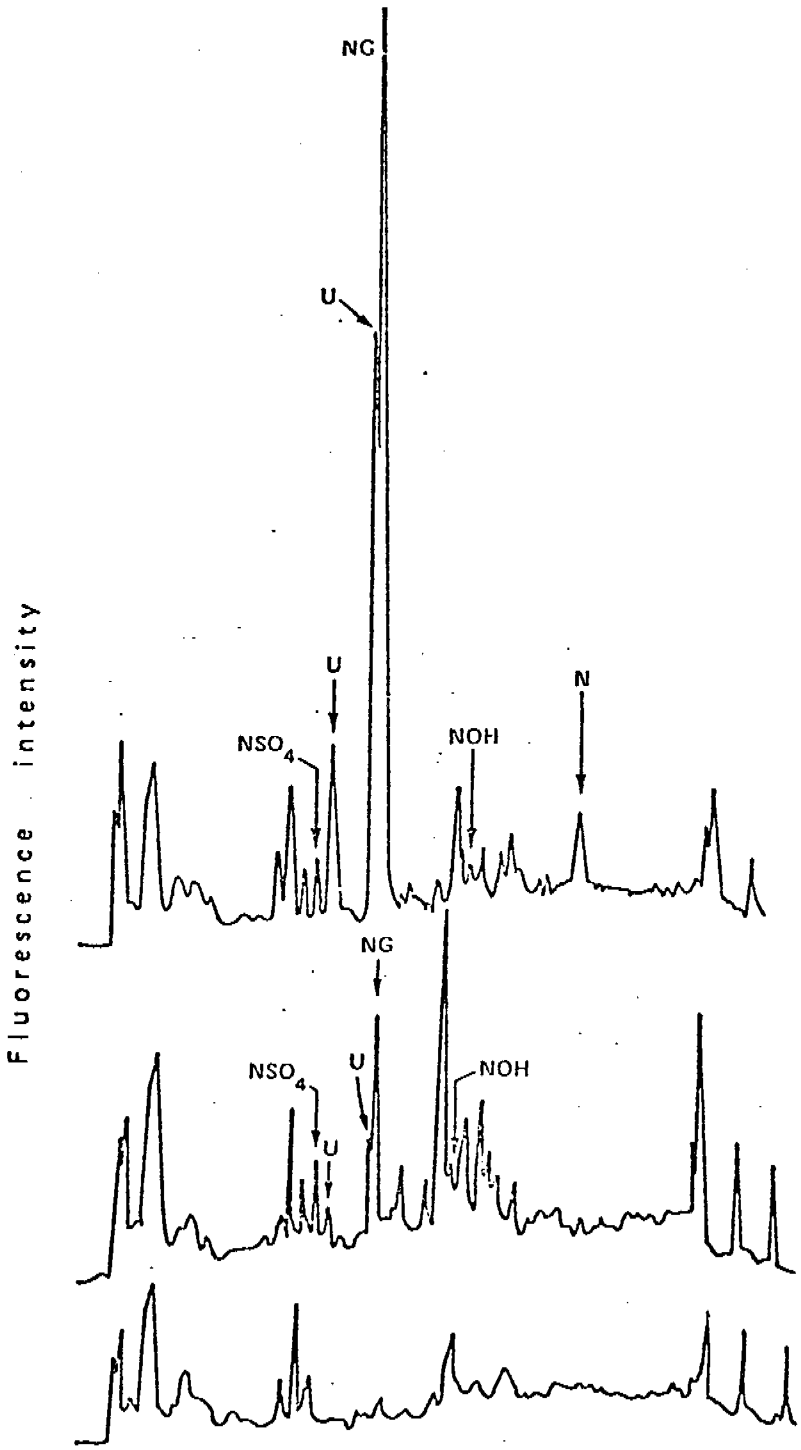

FIG. 1. HPLC profiles of naphthalene and its metabolites in the bile of rainbow trout. Fish received two force-feedings 24 hr apart. Samples of bile were taken 24 hr after the last feeding. Upper: Chromatogram of trout receiving 8.0 mg of naphthalene (73 mg/kg, higher level). Middle: Chromatogram for trout receiving 0.8 mg naphthalene (7.3 mg/kg, lower level). Lower: Chromatogram of the control bile. Detection of compounds at UVF wavelengths λ_{ex} 305 nm and λ_{em} 340 nm. See Table 6 for quantitation and notation of compounds; U=unidentified components.

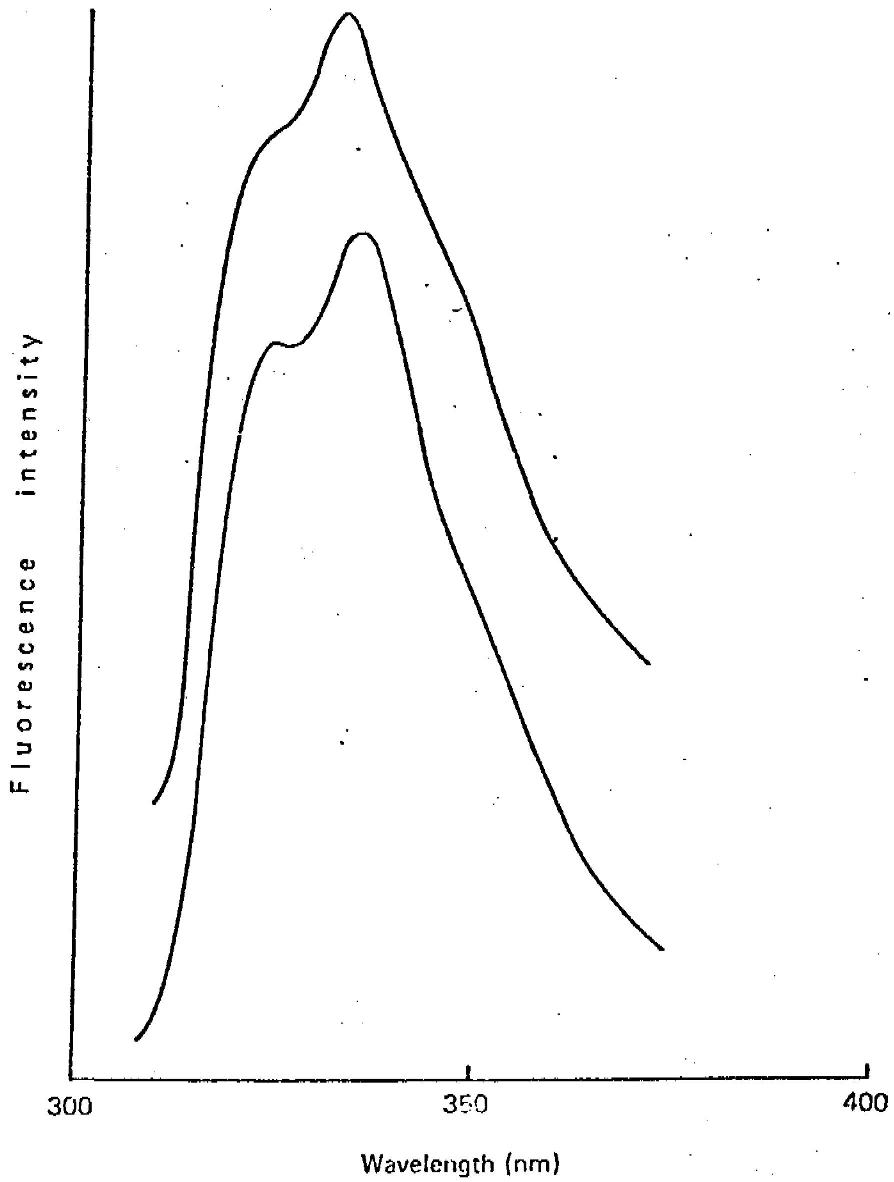

FIG. 2. Emission spectrum of naphthyl glucuronide (UVF λ_{ex} 294 nm). Upper spectrum: Naphthyl glucuronide obtained from bile of rainbow trout force-fed the higher level of naphthalene (see caption for Fig. 1). Lower spectrum: Standard of sodium salt of naphthyl glucuronide.

To show that such HPLC/fluorescence techniques may be applied to another species, bile from mice injected with naphthalene (74 mg/kg) was also analyzed (Fig. 3). Both naphthyl glucuronide and naphthyl sulfate were found; however, neither naphthol nor naphthalene was detected. Quantitations of naphthalene and metabolites in fish bile and mouse bile are presented in Table 6. The table gives averages based on three runs of each sample with the exception of the mouse bile where a limited sample allowed only two runs. The range of values represent the uncertainties found.

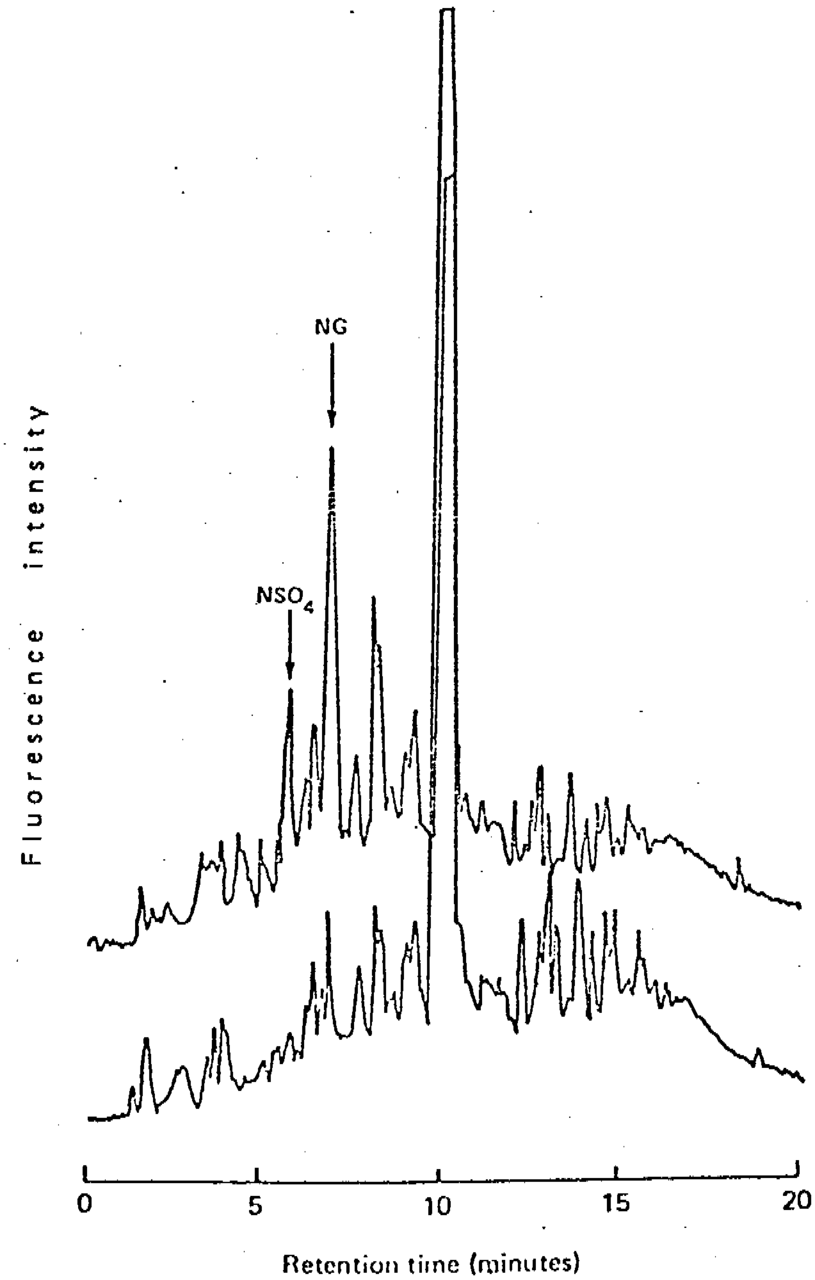

FIG. 3. HPLC profile of naphthalene and its metabolites in the bile of mice 18 hr after intraperitoneal injection with 3.0 mg of naphthalene (74 mg/kg). Lower chromatogram is of the control bile. Detection of compounds at UVF wavelengths λ_{ex} 305 nm and λ_{em} 340 nm. See Table 6 for quantitation and notation of compounds.

Table 6. Naphthalene and metabolites in bile of rainbow trout (Salmo gairderi) and mice exposed to naphthalene.

Animal Exposure to naphthalene (mg/kg)	Concentrations of compounds in ppm, wet weight:[a]			
	1-Naphthyl sulfate (NSO_4)	1-Naphthyl glucuronide (NG)	1-Naphthol (NOH)	Naphthalene (N)
Rainbow trout[b]				
73	3.6 ± 0.1	10.2 ± 0.3	18 ± 2	22 ± 2
7.3	7.4 ± 0.1	4.4 ± 0.2	23 ± 1	--[d]
Mouse[c]				
74	2.9 ± 0.1	4.0 ± 0.1	--[d]	--[d]

[a] See Experimental section for minimum detectable amount of each substance. Values are averages ± range.

[b] See Fxperimental section for force-feeding procedures.

[c] Mice were intraperitoneally injected with 3.0 mg of naphthalene. Bile was taken 18 hr after injection.

[d] Not detected. See Experimental section for the estimated minimum detectable amounts.

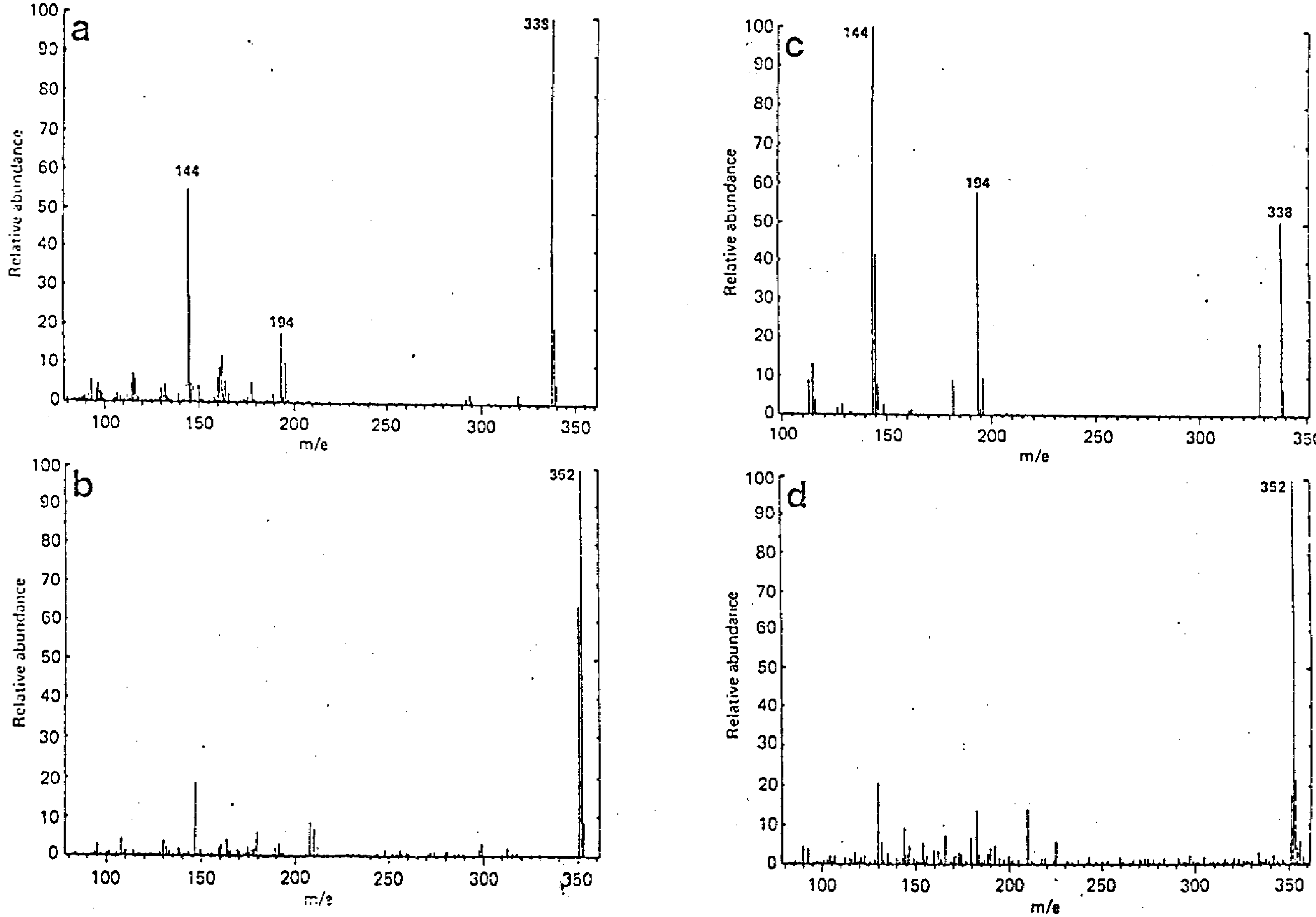

FIG. 4. (a) Mass spectrum of standard naphthyl glucuronide (acid form). (b) Mass spectrum of the methyl ester of naphthyl glucuronide formed by dissolving sodium salt of naphthyl glucuronide in methanol-HCl. (c) Mass spectrum of naphthyl glucuronide (acid form) isolated from rainbow trout bile by preparative HPLC. Fish had received the higher level dose of naphthalene (73 mg/kg). (d) Mass spectrum of methyl ester of naphthyl glucuronide prepared from naphthyl glucuronide isolated from bile of rainbow trout (73 mg/kg).

The ammonia plasma desorption/chemical ionization (PD/CI) mass spectrum of the acid form of naphthyl glucuronide standard (Fig. 4a) has a quasimolecular ion $(M + NH_4)^+$ at m/e 338. The nonvolatile sodium salt of naphthyl glucuronide standard dusted onto the solids probe gave no MS response. However, the methyl ester of the glucuronide gave a spectrum (Fig. 4b) showing a major ion $(M + NH_4)^+$ at m/e 352.

Naphthyl glucuronide, isolated from fish bile as a salt, gave no PD/CI mass spectrum. However, when the salt from the same HPLC fraction was converted to the acid form of the glucuronide and anlyzed by PD/CI MS, a poor spectrum with a quasimolecular ion $(M + NH_4)^+$ at m/e 338 was obtained (Fig. 4c). Therefore, additional fish bile was separated using preparative HPLC. A good mass spectrum of the methyl ester of the glucuronide was obtained, showing the quasimolecular ion at m/e 352 (Fig. 4d).

A spectrum of 1-naphthol from fish bile (Fig. 5) was obtained by glass capillary GC/EI-MS and positively identified by comparison to the spectrum of 1-naphthol from the MS library.

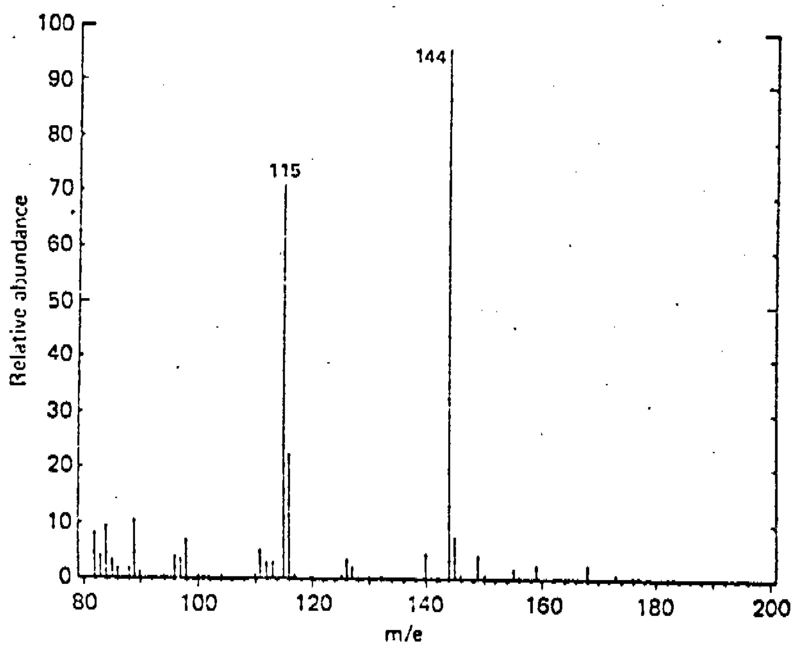

FIG. 5. Mass spectrum of 1-naphthol isolated from rainbow trout bile by preparative HPLC.

Alaskan Crude Oils

The hydrocarbon analysis of two major Alaskan crude oils from Prudhoe Bay and Cook Inlet is given in Table 7.

Table 7. Composition of aliphatic and aromatic fractions of Prudhoe Bay and Cook Inlet crude oils, determined by glass-capillary gas chromatography.

	Wt %			Wt%	
Alkane composition	Prudhoe Bay	Cook Inlet	Arene composition	Prudhoe Bay	Cook Inlet
$n-C_9$	.43	.88	Benzenes	.65	1.02
$n-C_{10}$	.33	.66	Indans	.10	.13
$n-C_{11}$	.39	.71	Naphthalenes	1.43	1.70
$n-C_{12}$	.41	.66	Biphenyls	.07	.19
$n-C_{13}$	.44	.66	Acenaphthalenes	.03	.03
$n-C_{14}$	.40	.58	Fluorenes	.14	.17
$n-C_{15}$	.38	.53	Dibenzothiophenes	.03	.23
$n-C_{16}$	.32	.46	Phenanthrenes	.47	.28
$n-C_{17}$	.31	.42	Pyrenes	.06	.02
Pristane	.21	.33	Chrysenes	.03	.02
$n-C_{18}$	.26	.34	Benzopyrenes	.002	.001
Phytane	.14	.12			
$n-C_{19}$	.28	.35	Total arenes	3.01	3.79
$n-C_{20}$	.24	.28			
$n-C_{21}$	.23	.25			
$n-C_{22}$	.23	.23			
$n-C_{23}$	.21	.22			
$n-C_{24}$	.19	.19			
$n-C_{25}$	.17	.18			
$n-C_{26}$	.15	.16			
$n-C_{27}$	.13	.14			
$n-C_{28}$	.09	.11			
$n-C_{29}$	.07	.09			
$n-C_{30}$	.07	.07			
$n-C_{31}$	.06	.07			
$n-C_{32}$	.05	.04			
Σn-Alkanes and pristane, phytane	6.19	8.73			
Unresolved chromatographed material	12.2	20.2			
Other alkanes	10.2	16.2			
Total alkanes	28.6	45.1			

VII. DISCUSSION

INTERCALIBRATION

The intercalibration study was designed to determine the adequacy of the various analytical procedures for hydrocarbons in sediment and to assess the uncertainties with which the results from the various methods and laboratories may be compared. The general scheme for determining hydrocarbons in sediment involves solvent extractions followed by adsorption chromatography to isolate the hydrocarbons. Of the twelve laboratories (including NAF) that participated in the intercalibration, nine used soxhlet solvent extraction, four used reflux/solvent extraction, two used shaker/solvent extraction, two used tumbler/solvent extraction and one used ultrasonic/solvent extraction. A variety of solvents were employed.

Because the true values of hydrocarbons in sediment can not be directly determined by state-of-the-art methods, it may not be possible to decide which method is the best. However, the statistical analyses, now in progress, should provide information on the limitations of each analytical procedure and an estimate of how each laboratory compares with the others.

Tables 2 and 3 show results of NAF's intralaboratory analyses of replicate sediment samples for alkanes and arenes by three prominent extraction methods. The hydrocarbon values by soxhlet extraction were generally the highest for both alkanes and arenes. The values by the tumble method were intermediate while those for the reflux method were lowest (see Tables 2 & 3). In our hands the Soxhlet method tended to extract a greater proportion of the higher molecular weight alkanes (C_{27} and greater) and certain of the arenes than did the tumble or reflux methods. The relative standard deviation (RSD) values for the data by the reflux method were generally the lowest; those for the tumble and the benzene/methanol Soxhlet method were intermediate. The RSD for the CH_2Cl_2/CH_3OH Soxhlet extraction were the highest in values and in the range of variation.

Any possible trends in the mean alkane and arene data (Tables 2-5) are not evident by visual examination of the data although there were wide ranges in values for the means of certain alkanes and arenes. Assessment of the results must await the statistical analyses of the data now in progress.

METABOLITE RESEARCH

There are inherent difficulties in the use of current analytical techniques in the determination of xenobiotics in natural marine systems. For example, presently used radio assay techniques are not readily applicable to such problems. Thus, a need exists for sensitive methods to analyze for non-radioactive compounds arising from petroleum pollution of marine waters. In addressing this issue we have developed a rapid method for the identification and quantitation of an individual aromatic hydrocarbon and its metabolites in biological fluids. Only minimal sample preparation is required for HPLC analysis. Body fluids can be injected directly into the HPLC. Bile was used in this study; however, the method can easily be extended to other fluids such as urine. Tissue extracts can also be analyzed, but often require complicated extraction schemes [5,7] to ensure high extraction efficiencies. The method is presently restricted to the analysis of metabolites present in tissues and body fluids of animals dosed with single or binary aromatic hydrocarbon compounds from petroleum. However, research efforts are being directed toward the development of methods for the analysis of aromatic compounds present in complex mixtures of petroleum products found in environmentally exposed marine organisms.

Naphthalene and its metabolites, compounds which exhibit low native fluorescence, were used in this study. Potentially, many of the PAHs and metabolites may be determined by this method. After separation by reverse phase HPLC, the compounds are detected by UVF. Good sensitivity and selectivity are achieved using an on-line fluorescence spectrometer equipped with a square micro flow cell. The fluorescence signal is maximized by selecting appropriate excitation and emission wavelengths for the particular PAH to be determined.

Bile is a complicated biological material and the fluorescent background varies from species to species. For accurate quantitation, interferences from fluorescent compounds eluting close to compounds of analytical interest must be minimized. Accordingly, good selectivity is achieved with a dual grating fluorescence spectrometer [29]. Although many compounds absorb radiation at the chosen excitation wavelength, very few will also strongly fluoresce at the wavelength selected for experimental compounds. Precision in quantitation is shown in Table 1.

Metabolites of aromatic hydrocarbons can be identified by three different methods. Components are tentatively identified by HPLC retention times. Additionally, a stop-flow system can trap individual components in the detector flow cell so that excitation or emission fluorescence spectra can be recorded and used to further characterize the compounds. Identities were confirmed by MS. For example, thermally stable 1-naphthol was identified by conventional GC/EI MS. In addition, the thermally labile naphthyl glucuronide and its methyl ester gave a PD/CI spectrum; the ammoniated molecular ion was the major ion. None of the probe tips discussed under III. B. could be heated sufficiently rapidly. However, we designed a wire-filled glass probe tip that allows rapid heating of the experimental sample for sensitive detection of a labile, non-volatile substance.

VIII. CONCLUSIONS

INTERCALIBRATION

Eleven participating OCS PI's have returned intercalibration anatytical data for hydrocarbons in the OCSEAP IRM (sediment). These results are being evaluated by statisticians. However, the numbers of individual hydrocarbons reported by all PI's (Tables 4 and 5) shows a substantial improvement compared to the previous OCSEAP intercalibration conducted by the National Bureau of Standards.

METABOLITE RESEARCH

We have developed a rapid, sensitive, selective method for the analysis of naphthalene, a toxic aromatic hydrocarbon in petroleum, and its metabolic products in the bile of fish (and other fauna). The low-fluorescent naphthalene and products are separated by reverse phase HPLC and detected by sensitive ultraviolet fluorescence spectrometry. In addition, a method for mass spectral analysis of thermally labile, conjugated metabolites has been developed using plasma desorption chemical ionization MS with a modified direct insertion probe tip. These integrated analytical methods have application to other aromatic hydrocarbons and metabolites with only slight modifications in technique. Future refinement of these techniques may permit the study of petroleum organics and their metabolites in samples from polluted environments.

IX. SUMMARY OF THE 4TH QUARTER

A. ACTIVITIES

The results of the interlaboratory calibration of hydrocarbons in the interim reference material (IRM) were forwarded to the statistician(s) in January when we felt we could wait no longer for "stragglers." The participating PI's are those indicated in Table 1. Dr. Brian Eadie of Great Lakes ERL visited NAF and expressed interest in joining our IRM interlaboratory calibration. We plan to include him in the intercalibration with the new Deepwater IRM sediment once homogeneity of the new IRM has been established here. Meanwhile, we have forwarded the previous Intertidal IRM to him.

The statistician has not completed his evaluation. However, it is apparent from the substantial data base that this intercalibration is much improved over the previous OCSEAP intercalibration with sediment conducted by the National Bureau of Standards.

Dr. Krahn has been heavily committed to assembling, learning and debugging the new OCSEAP HPLC system delivered last quarter. When the system functions, the retention time and peak area RSD's are outstanding (<1%, <7% resp.) even for biological samples. There has been a persistent problem in a metering pump and related software which we now believe to be corrected.

The manuscript by Krahn et al., forwarded to OCSEAP for approval last year, has been accepted for publication in the Jounal of Biochemical and Biophysical Methods.

Finally, the analyses of Prudhoe Bay and Cook Inlet crude oils were performed. Results are reported above.

B. PROBLEMS ENCOUNTERED

Delays with the statistician's data analyses due to computer failures presumably will be alleviated shortly. We have hired a student aide to assist him.

Problems with the HPLC metering pump have received our constant vigorous attention. The manufacturer appears to be doing everything possible to correct this. In our judgement, our system is still the most promising one available; although, the design of HPLC instrumentation is still in its early stages.

C. ESTIMATE OF FUNDS EXPENDED: 79K out of 135K

AUXILIARY MATERIAL

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MILESTONE CHART

0 - Planned Completion Date

● - Actual Completion Date
(to be used on quarterly updates)

RU # 557 PI: William D. MacLeod, Jr.

Major Milestones: Reporting, and other significant contractual requirements; periods of field work; workshops; etc.

	1979			1980											
MAJOR MILESTONES	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Quarterly Reports				●			●			0			0		
Annual Report							●								
AK oil composition data				●			●			0			0		
Intercalibration results				●			●								

ANNUAL REPORT
April 1, 1980

Contract no.: 03-78-B01-53

Project no.: RK 0000-R7120815

Archival of Voucher Specimens of Biological Materials Collected under the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Support

Period of Performance: May 1, 1978 - March 31, 1980
Subsequent support subject to availability of funding.

Period Covered by This Report: April 1, 1979 - March 31, 1980

Institution: California Academy of Sciences
Golden Gate Park
San Francisco, CA 94118

Principal Investigator:

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Archival of Voucher Specimens of Biological Materials Collected Under OCSEAP Support

I. Summary of Objectives, Conclusions and Implications:

The baseline data collected for the fauna and flora in the OCSEAP study area is based on extensive biological collections made by many separate research units. OCSEAP has established the California Academy of Sciences as a central repository for representative specimens from these collections. This will ensure that materials are permanently available for reference and for confirmation and upgrading of identifications made by research units. This project was initiated on 1 May 1978, and the contract awarded on 24 May 1978.

A policy for the preservation and labeling of voucher specimens was formulated in the first year of the project. A subsequent revision, for phytoplankton samples, finalized the procedures.

Several thousand lots of voucher specimens from over 16 research units have been archived. More voucher specimens are expected as projects are completed.

An under-representation of preserved Alaskan fauna in most major research collections makes most of this material unique. Combined with the very high quality of the specimens and the accompanying extensive documentation, this material comprises a very important and useful collection.

II. Introduction

A. General Nature and Scope of Study:

As outlined above, a voucher specimen repository was established so that extensive biological collections made by OCSEAP would be documented with voucher samples. A rather specific voucher policy was needed such that the quality and integrity of the biological data taken would be maximized. The fauna (or parts of it) are poorly known for the area under study. Field identifications need to be made by knowledgeable people, and by reference to actual voucher or reference specimens that can be saved and forwarded to the central repository. The essential point is that the voucher specimen be of the same species as the other specimens analyzed and discarded, even if the state of systematic knowledge permits only partial identification. If the field identifications are faulty then the usefulness of the data is much reduced. Upgrading identifications and changing scientific names as nomenclature improves will, through the years, increase the usefulness of the data in the NODC.

The California Academy of Sciences has had extensive experience as a repository of voucher specimens from the scientific community and from Federal, State, and some private agencies. The Academy collections are world-wide in composition, with especially strong representation of the flora and fauna of western North America, including Alaska. The Academy was selected as the voucher specimen repository and charged with the specific tasks outlined below.

Principal investigators will deposit representative voucher specimens with the Academy. All of the data will be coded on an IBM System 6/452 Information Processor and sent to NODC. The specimens will be maintained as a separate collection for a period of 5 years, marked distinctly, and then integrated into the main collections of the Academy.

B. Specific Objectives:

The California Academy of Sciences is responsible for:

1. Specifying preservation techniques for archival voucher specimens.

2. Coordinating the shipment of materials.

3. Establishing and maintaining a fully catalogued repository for the collections; and

4. Providing quarterly data summaries on the status and content of the collections.

C. Relevance to Problems of Petroleum Development:

Management decisions and monitoring that may be necessary to protect the OCS marine environment from damage during petroleum development are based on the accumulation of a data base. The permanent voucher specimen collection and policy, including the identification policy for field personnel, are aimed at increasing the reliability of the data collected. The voucher specimens are permanently available for reference and for confirmation and upgrading of identifications made by field personnel during the data gathering phase.

III. Current State of Knowledge:

The fauna of Alaska, while similar to that of other parts of the North Pacific, is not very well known. Identifications of certain groups of organisms are difficult because of a lack of adequate literature or prior studies. The utilization of the identification and voucher policy will increase the reliability and usefulness of the biological baseline data collected by OCSEAP.

IV. Study Area:

Voucher specimens will be received from studies conducted throughout the OCSEAP study area.

V. Sources, Methods and Rationale of Data Collection:

All specimens will be provided by the individual project principal investigators. Standard curation techniques will be used to process the incoming materials. Once each voucher specimen shipment is processed, the specimen data information will be electronically processed and transferred to NODC and the principal investigators.

VI. Results:

Eleven shipments of voucher specimens were received during the period from April 1, 1979 to March 31, 1980. Several of these shipments contained large numbers of specimen lots, and there is currently a backlog of material to process. Two shipments received prior to April 1, 1979 and 4 of the above 11 shipments have been fully processed, with one more shipment nearing completion. The remainder of the specimens have been transferred to final storage containers and are awaiting cataloging.

During the year, 2 trips to the University of Alaska were undertaken at the request of the project office. The first trip in late August, 1979, was for the express purpose of meeting with the principal investigators and seeing the material at hand in order to better estimate the expenditures involved in processing samples for projects that were already completed. In January, 1980, the Collection Manager returned to the University to initiate the packaging of specimens and data for several research units. Since that time, 1,879 specimen lots have been received from one research unit, and more shipments are expected.

The following is a summary of the material catalogued during the last year:

PRINCIPAL INVESTIGATOR:	Dr. James Blackburn
INSTITUTION:	Alaska Department of Fish and Game
RU#:	486, 552, 512
ACCESSION NUMBER:	CAS ACC.1979-III:16
LOCALITY (LEASE AREA):	Cook Inlet, Shelikof Strait
NO. OF SPECIMENS:	109

90 lots, 109 specimens of fishes.

PRINCIPAL INVESTIGATOR:	Dr. Jerry Larrance
INSTITUTION:	Pacific Marine Environmental Laboratory - NOAA
RU#:	425
ACCESSION NUMBER:	CAS ACC.1979-III:19B
LOCALITY (LEASE AREA):	Cook Inlet
NO. OF SPECIMENS:	not determinable

36 lots, 130 species of phytoplankton

PRINCIPAL INVESTIGATOR:	Dr. Ken Waldron
INSTITUTION:	NMFS Northwest and Alaska Fisheries Center
RU#:	380
ACCESSION NUMBER:	CAS ACC.1979-IV:16
LOCALITY (LEASE AREA):	Eastern Bering Sea
NO. OF SPECIMENS:	794

78 lots, 794 specimens of larval fishes and fish eggs.

PRINCIPAL INVESTIGATOR:	Dr. Kenneth Pitcher
INSTITUTION:	Alaska Department of Fish and Game
RU#:	229, 243
ACCESSION NUMBER:	CAS ACC.1979-X:2
LOCALITY (LEASE AREA):	Gulf of Alaska
NO. OF SPECIMENS:	87

 26 lots, 73 specimens of fish otoliths; 6 lots, 14 specimens of invertebrates.

PRINCIPAL INVESTIGATOR: Dr. T. Saunders English
INSTITUTION: University of Washington
RU#: 424
ACCESSION NUMBER: CAS ACC.1979-X:10B
LOCALITY (LEASE AREA): Lower Cook Inlet
NO. OF SPECIMENS: 272

50 lots, 108 specimens of larval fishes; 61 lots, 164 specimens of invertebrates.

PRINCIPAL INVESTIGATOR: Dr. Mark E. Wangerin
INSTITUTION: University of Washington
RU#: 553
ACCESSION NUMBER: CAS ACC.1979-X:23
LOCALITY (LEASE AREA): Kodiak Island; Cook Inlet
NO. OF SPECIMENS: 3,541

84 lots, 533 specimens of fishes; 207 lots, 3,008 specimens of invertebrates.

The following shipment is partially catalogued:

PRINCIPAL INVESTIGATOR: Dr. Rita A. Horner
INSTITUTION: Private Contractor
RU#: 359
ACCESSION NUMBER: CAS ACC.1979-X:15
LOCALITY (LEASE AREA): Chukchi Sea; Beaufort Sea
NO. OF SPECIMENS: not determinable

476 lots phytoplankton (234 lots catalogued); 388 lots zooplankton; 28 lots, 30 specimens of fishes; 360 lots, 1,148 specimens of invertebrates.

The following shipments have been transferred to final storage containers but not catalogued:

PRINCIPAL INVESTIGATOR: Dr. Andrew Carey
INSTITUTION: Oregon State University
RU#: 6
ACCESSION NUMBER: CAS ACC.1979-X:29
LOCALITY (LEASE AREA): Beaufort Sea
NO. OF SPECIMENS: 144

38 lots, 144 specimens of invertebrates (Class Bivalvia).

PRINCIPAL INVESTIGATOR: Dr. Charles O'Clair
INSTITUTION: Auk Bay Fisheries Laboratory - NOAA
RU#: 78, 79
ACCESSION NUMBER: CAS ACC.1979-XII:13
LOCALITY (LEASE AREA): Gulf of Alaska; Bristol Bay; Pribilof Islands (part of the St. George lease area).
NO. OF SPECIMENS: undetermined at this time

309 lots of intertidal algae, fishes and invertebrates.

PRINCIPAL INVESTIGATOR:	Dr. Murray Hayes
INSTITUTION:	NMFS Northwest and Alaska Fisheries Center
RU#:	551
ACCESSION NUMBER:	CAS ACC.1980-I:2
LOCALITY (LEASE AREA):	Gulf of Alaska
NO. OF SPECIMENS:	undetermined at this time

171 lots of larval fishes; 119 lots of invertebrates.

PRINCIPAL INVESTIGATOR:	Mr. Gerry Sanger
INSTITUTION:	U.S. Fish and Wildlife Service
RU#:	341
ACCESSION NUMBER:	CAS ACC.1980-I:15
LOCALITY (LEASE AREA):	Lower Cook Inlet
NO. OF SPECIMENS:	Approximately 387

36 lots, 70 specimens of fishes; 130 lots, 317 specimens of invertebrates.

PRINCIPAL INVESTIGATOR:	Dr. George Hunt
INSTITUTION:	University of California, Irvine
RU#:	83
ACCESSION NUMBER:	CAS ACC.1980-II:6
LOCALITY (LEASE AREA):	Pribilof Islands (part of the St. George lease area)
NO. OF SPECIMENS:	undetermined at this time

113 lots of fishes and invertebrates.

PRINCIPAL INVESTIGATOR:	Dr. Howard Feder
INSTITUTION:	University of Alaska
RU#:	5
ACCESSION NUMBER:	CAS ACC:1980-II:11
LOCALITY (LEASE AREA):	Kodiak Island; Cook Inlet; Norton Sound; Chukchi Sea; Bering Sea
NO. OF SPECIMENS:	undetermined at this time

1,879 lots of benthic invertebrates.

PRINCIPAL INVESTIGATOR:	Kathryn Frost and Lloyd Lowry
INSTITUTION:	Alaska Department of Fish and Game
RU#:	232
ACCESSION NUMBER:	CAS ACC.1980-III:14
LOCALITY (LEASE AREA):	Alaska
NO. OF SPECIMENS:	undetermined at this time

111 lots of fishes and invertebrates.

VII. Discussion:

A total of 1,260 lots were catalogued over the past year, while another 3,148 lots have been transferred to final storage containers and are awaiting further processing. The number of catalogued lots reflects the lack of material received during the period from April 1, 1979 to October 2, 1979. The high number of uncatalogued specimens results from the arrival of several large shipments within a 3 week period in October, plus the continuing shipments from the University of Alaska.

Cataloguing and data entry of each lot proceeds fairly quickly once the material has been transferred to final storage containers. The current backlog, although substantial, should pose no problems in processing.

The problem of selecting voucher specimens for completed projects by the the University of Alaska was resolved. Where material is available, representative samples are being selected. This may, in some cases, require additional funding. Where large numbers of specimens have been distributed to local or university museums, a cross reference to this material could be noted as part of the archive records.

VIII. Conclusions:

Problems of obtaining voucher specimens from completed projects have been solved. Principal investigators are now depositing their voucher specimens on a regular basis. A part time curatorial assistant has been added to the project to assist in processing backlog material.

IX. Needs for Further Study:

The voucher specimen policy and field identification procedures should be continued through the OCSEAP data gathering phase.

X. Summary of January-March Quarter:

A. Laboratory Activities:

Five shipments of voucher specimens were received during the January-March quarter. The first shipment was from Dr. Murray Hayes (RU# 551) from the National Marine Fisheries Service and consisted of 171 lots of larval fishes and fish eggs, plus 119 lots of invertebrates. The material was accessioned (CAS ACC.1980-I:2) and transferred to 75% ethanol.

The second shipment was from Mr. Gerry Sanger (RU# 341) of the U.S. Fish and Wildlife Service. It consisted of 36 lots of fishes and 130 lots of invertebrates representing the prey items of several species of marine birds. The material was accessioned (CAS ACC.1980-I:15) and placed in 75% ethanol.

Another shipment of bird prey items was received from Dr. George Hunt (RU# 83) of the University of California at Irvine. There were 113 lots of fishes and invertebrates in the shipment. The specimens were accessioned (CAS ACC.1980-II:6) and transferred to 75% ethanol.

An extremely large shipment of specimens was received from Dr. Howard Feder (RU# 5) of the University of Alaska. The initial packing and data gathering for the material was facilitated by the presence of the Collection Manager at the University during the end of January. To date, we have received 1,879 lots of benthic invertebrates and there is more material to be shipped.

All of the specimens have the same accesion number (CAS ACC.1980-II:11) and are being stored in 75% ethanol.

The last shipment was from Ms. Kathryn Frost and Mr. Lloyd Lowry from the Alaska Department of Fish and Game. The material consists of 111 lots of fishes and invertebrates, representing seal stomach contents. The specimens were accessioned (CAS ACC.1980-III:14) and transferred to 75% ethanol.

Material catalogued during the quarter was received during the previous quarter (October-December). Two shipments were processed; 291 lots from Dr. Mark Wangerin (RU# 553) and 622 lots from Dr. Rita Horner (RU# 359). There is a remainder of 242 lots from Dr. Horner's material to be catalogued, plus the material described above.

1. Ship or Field Trip Schedule: Not applicable

2. Scientific Party:

Dr. William N. Eschmeyer, Chairman and Curator, Department of Ichthyology. Principal Investigator.
Mr. Dustin Chivers, Senior Scientific Assistant, Department of Invertebrate Zoology. Invertebrate Coordinator.
Ms. Susan Gray Marelli, Collection Manager.
Mr. Scott M. Cutler, Curatorial Assistant.

Other Academy curators as needed.

3. Methods:

All of the incoming voucher specimens are curated by the procedures outlined in the the Voucher Specimen Policy. Final bottle labels and data capture are made on an IBM System 6/452 Information Processor.

D. Sample Localities:

Voucher specimens will be received from throughout the OCSEAP study area.

E. Data Collected or Analyzed:

A total of 2,559 voucher specimen lots were received during the quarter, and transferred to their final preservative and storage container. During this time, another 913 lots were catalogued. With the addition of a part time curatorial assistant, the handling of voucher specimens proceeds very smoothly.

XI. Auxiliary Material: Not applicable at this time.