Environmental Assessment of the Alaskan Continental Shelf

Volume 4

Principal Investigators' Reports
October–December 1976

VOLUME 1. RECEPTORS (BIOTA):
MARINE MAMMALS; MARINE BIRDS; MICROBIOLOGY

VOLUME 2. RECEPTORS (BIOTA):
FISH; PLANKTON; BENTHOS; LITTORAL

VOLUME 3. EFFECTS; CONTAMINANT BASELINES; TRANSPORT

VOLUME 4. HAZARDS; DATA MANAGEMENT

Environmental Assessment of the Alaskan Continental Shelf

October-December 1976 quarterly reports from Principal Investigators participating in a multi-year program of environmental assessment related to petroleum development of the Alaskan Continental Shelf. The program is directed by the National Oceanic and Atmospheric Administration under funding from and for use by the Bureau of Land Management.

ENVIRONMENTAL RESEARCH LABORATORIES
Boulder, Colorado
February 1977

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VOLUME 4

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HAZARDS

HAZARDS

*Indicates Final Report

HAZARDS

HAZARDS

GEOLOGICAL SURVEY
Conservation Division
Office of the Area Geologist
Anchorage, Alaska 99510
P.O. Box 259

NO. 77-1 January 21,1977

PUBLIC NOTICE

RELEASE OF HIGH RESOLUTION GEOPHYSICAL DATA

LOWER COOK INLET, ALASKA

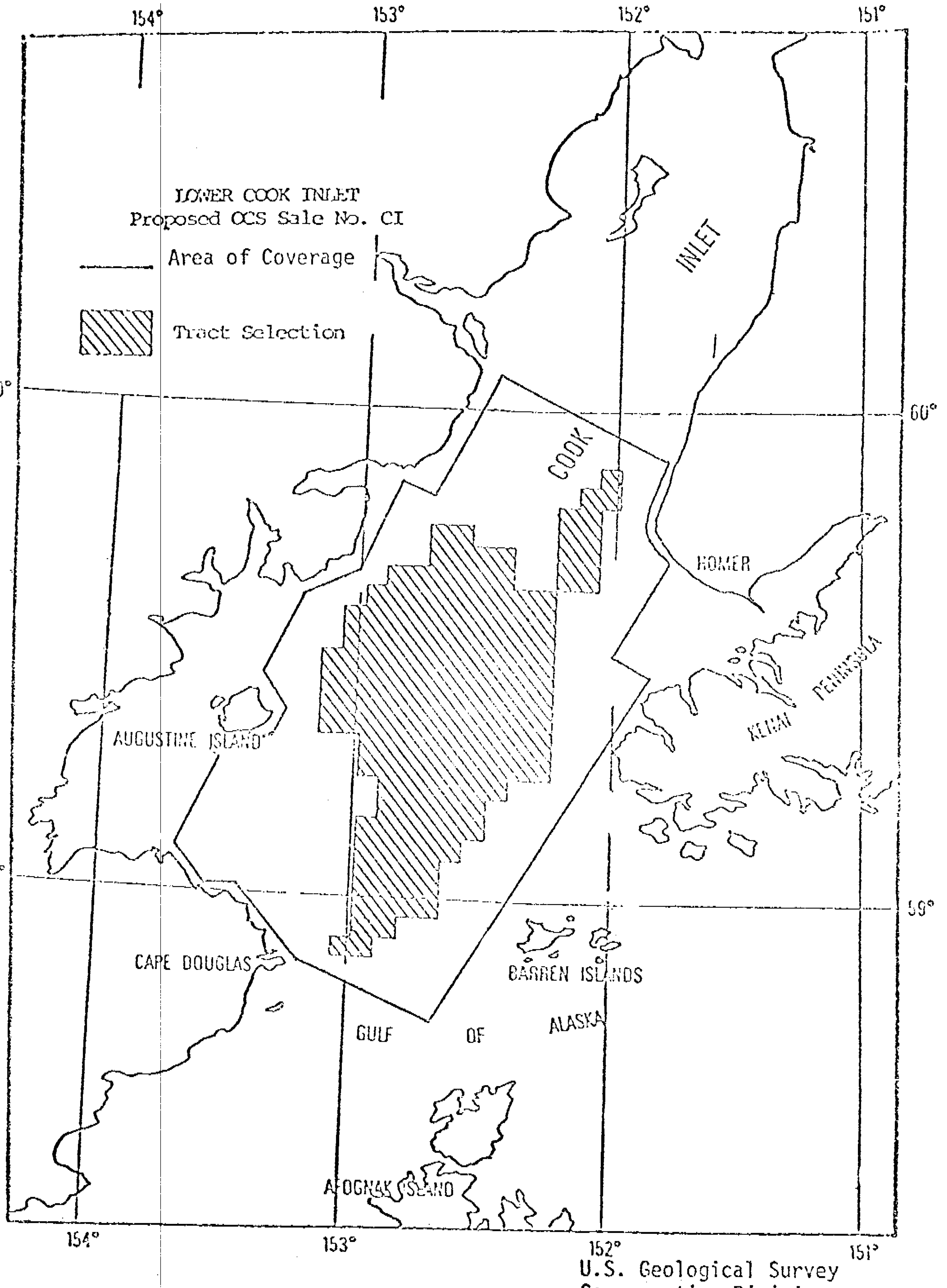
The U.S. Geological Survey is releasing for public use approximately 3,123 kilometers of nonproprietary high resolution geophysical data covering the area recently selected for leasing on the lower Cook Inlet, Alaska, Outer Continential Shelf. The data were acquired by the Geological Survey in the area shown on the attached index map. Reproducible vellum transparencies of sparker and 3.5 kHz profiles and 16 mm positive and negative microfilms of dual side scan sonar records are available for inspection in Suite109, 800 "A" St., Anchorage, Alaska 99501. Paper and sepia prints may be obtained through local copying firms for the cost of reproduction.

The following types of data are available for various specific areas:

1. Postplot fix-point location base maps at 1:96.000 scale (4 maps).
2. Half-scale profiles of the following geophysical data:
    a. 1,023 kilometers of 1.0 kilojoule sparker.
    b. 3,123 kilometers of 3.5 kHz subbottom profiler (primarily useful as bathymetric indicator).
    c. 2,817 kilometers of dual side scan sonar records (full-scale reproductions are of lower quality).

R.H. McMullin
Area Geologist

Attachment



U.S. Geological Survey
Conservation Division
Alaska Area

No. 77-1, Attachment A

LAMONT-DOHERTY GEOLOGICAL OBSERVATORY
OF COLUMBIA UNIVERSITY

PALISADES, NEW YORK

SEISMOTECTONIC ANALYSIS OF THE SEISMIC AND VOLCANIC HAZARDS IN THE PRIBILOF ISLANDS-EASTERN ALEUTIAN ISLANDS REGION OF THE BERING SEA

Quarterly Report R.U. 16

October 1976

J. N. Davies, R. Bilham, J. Beavan
L. House, P. Lelyveld, K. H. Jacob

Prepared for the

National Oceanic and Atmospheric Administration

under Contract No. 03-5-022-70

RU #16

QUARTERLY REPORT RESEARCH UNIT 16

I. Task Objectives. Lamont-Doherty Geological Observatory is carrying out a seismotectonic research program partially funded through NOAA contract number 03-5-022-70, entitled "Seismotectonic Analysis of the Seismic and Volcanic Hazards in the Pribilof Islands - Eastern Aleutian Islands Region of the Bering Sea". This work is divided into three portions: 1) the operation of a 16 station telemetered seismic network in the Shumagin seismic gap to obtain data with which to study the Benioff zone seismicity which may help predict the next major earthquake in the gap, to study the crustal seismicity which may help to delineate active faults and to obtain focal mechanisms which will help to understand the stress systems which cause these earthquakes; 2) the operation of a linear array of tide gauges transverse to the Aleutain Arc which will help measure the magnitude of the tectonic strain accumulating in this gap region prior to the next major earthquake; and 3) the operation of single seismic stations on Pavlof, Akutan, and Makushin volcanoes to monitor their activity and the operation of a single station on St. Paul Island to monitor the low level seismic activity on the north end of the St. George basin.

During this summer we were primarily engaged in the field work necessary to maintain this extensive instrumentation network. To the extent possible we have also continued to process the data collected this last winter and this spring. The bulk of this report is in the form of appendices which summarize this summer's work.

II. Field and Laboratory Activities.

A. Helicopter and Field Trip Schedules

1. Lamont personnel were in the field from June 10, 1976 through September 15, 1976. We worked with the NOAA Jet Ranger helicopter on June 14, 1976 and July 9-17, 1976. See Appendix I for details.

B. Scientific Party

NAME	AFFILIATION	ROLE	DATES (in Aleutians)
Dr. John Davies	L-DGO	Chief Scientist	June 10 - August 12
Mr. Leigh House	L-DGO	Student/Assistant	June 10 - July 17
Mr. Laszlo Skinta	L-DGO	Electronic Tech.	July 7 - September 15
Mr. Phil Lelyveld	L-DGO	Field Assistant	July 7 - July 22
Dr. David Stone	U. Alaska	Field Assistant	July 9 - July 17
Ms. Mary Matthews	L-DGO	Field Assistant	July 16 - August 6
Dr. Roger Bilham	L-DGO	Chief Scientist	August 2 - September 3
Dr. John Beavan	L-DGO	Field Assistant	August 2 - September 3

C. Methods

1. Seismic field work - see Appendix I
2. Tide gauge work - see Appendix II
3. Seismic data analysis - see Appendix III
4. Level line measurements - see Appendix IV
5. Strong motion accelerograph installation - see Appendix V

D. Sample localities - see Appendices I and II

E. Data analyzed

1. Seismic data - see Appendix III

2. Level line data - see Appendix IV

F. Milestone Chart and Data Submission Schedules

1. The milestone chart given in the renewal proposal was as follows:

Jan. - Apr.: Analyze seismic data and prepare papers

May: Prepare for field work

June - Aug.: Field work

Sept. - Oct.: Analyze geodetic and strong motion data

Nov.: Prepare annual report

Dec.: AGU and vacation

This schedule reflects the logical sequence of data collection, analysis and publication imposed by a heavy summer field program. The only major slip in this schedule for this year is that a paper, prepared last spring, is only now in the second draft stage.

A major addition to this work, which is being funded by ERDA, is a seismic search for a magma chamber under Pavlof volcano. A 12 station, VHF telemetered array of seismic stations was installed on the flanks of Pavlof this summer. The data are recorded on 3 tape recorders at the Port Moller White Alice Site and are mailed to Lamont each 10 days.

The system is working quite well and initial data reduction is under way. We have already recorded at least one eruptive sequence. This portable system will be available to concentrate on areas of special interest, e.g. specific faults, aftershock zones, other volcanoes, land portions of OBS arrays, etc.

2. Our data submission schedule calls for quarterly reports of the hypocenter data collected and is essentially up to date. We have produced maps and cross-sections which were scheduled to be produced on a six month basis. These are included in Appendix III to this report and soon will be published in a more polished catalogue format. The catalogue will be submitted to NOAA to satisfy the map and cross-section data analysis requirement. We will try to produce these maps and cross-sections on a six-month basis as called for in the schedule; however, due to the inevitable loss of data in the spring (after the winter ravaging of our telemetry system and before repairs are possible) a yearly schedule may make more sense. Due to its lower priority and low data rate we have not yet made any analysis of the volcanic activity as monitored by the three stations on Pavlof, Akutan and Makushin volcanoes.

III. Results. See Appendices I-V

IV. Preliminary interpretation of results - none with this report. Plan a meeting with Page/Lahr and Pulpan/Kienle at Fall AGU meeting to discuss joint map of Alaska Peninsula - Gulf of Alaska hypocenters.

V. After the initial survey with regional (land based) networks I recommend that areas of special interest be studied in detail with portable land arrays and OBS units. The accuracy necessary to associate earthquakes with a specific fault can only be obtained if the fault is contained within or is very close to the array of seismic stations used to locate the earthquakes.

VI. Estimate of funds expended - see Appendix VI.

This appendix is a copy of the monthly account summary for September 1976 produced by our accounting office at Lamont. It may not reflect the final postings (assignment to line items) and should be regarded as preliminary.

APPENDIX I

Lamont-Doherty Geological Observatory | *Palisades, N.Y. 10964*
of Columbia University

Cable: LAMONTGEO
Palisades New York State
TWX-710-576-2653

Telephone: Code 914, Elmwood 9-2900

27 September 1976

Mr. Dick Moody
Juneau Project Office
NOAA/OCSEP
Box 1808
Juneau, Alaska 99802

Dear Dick:

Please find enclosed field report entitled "Helicopter Operations in Support of Research Unit Sixteen - June and July 1976". As I've indicated the field program went quite well this summer. My thanks to you and your staff. There were a number of near misses, however, mostly having to do with the establishment of the fuel caches. That was somewhat understandable given that it was the first time around, but I hope we can have them in place sooner next year. Also, there were a couple of problems which came up which required returning to a station several weeks later. I was able to make use of the ERDA chartered helicopter for some of these stations, but, in general, it would be desirable to be able to schedule follow-up helicopter support to polish off the remaining work 3 to 4 weeks after the main effort. Perhaps this isn't possible but I'd appreciate it if you would give it some consideration.

Thanks again.

Best regards,

Dr. John N. Davies
Principal Investigator
Research Unit Sixteen

JND:ma

Helicopter Operations in Support of Research Unit Sixteen
June - July 1976

Introduction.

The NOAA Outer-Continental Shelf Energy Program has provided support for seismological studies by Lamont-Doherty Geological Observatory of Columbia University through a contract entitled "Seismotectonic Analysis of the Seismic and Volcanic Hazards in the Pribilof Islands - Eastern Aleutian Islands region of the Bering Sea". The contract number is 03-5-022-70. A significant portion of NOAA's support for this project is logistical, in the form of helicopter support for the maintenance of the remote seismic stations. This report describes that helicopter support for June and July 1976.

Summary of Helicopter Operations.

This summer the helicopter, a Bell 206 B Jet Ranger piloted by Don Winters, was (excepting the Dutch Harbor area) land-based rather than ship based as it was during the 1975 field program. This allowed more flexibility in scheduling the flights to the remote stations. This flexibility allowed us to make optimum use of the good weather afforded us and resulted in a significant improvement in the number of stations serviced per

TABLE 1

Summary of Helicopter Operations in Support of RU#16

June and July 1976

STATION	CODE	TASK
DUTCH HARBOR 14 June 1976		
Akutan volcano	AKV	Repaired and changed batteries
Makushin valley	MKV	Repaired and changed batteries
SAND POINT 9 - 13 July 1976		
Pavlof volcano	PVV	Changed batteries
West Unga	WUN	Removed (moved to Zachery Bay)
Zachary Bay	ZKB	Installed new station
San Diego Bay	SGB	Repaired and changed batteries
Ivanof Bay	IVF	Repaired and changed batteries
Big Koniuji Is.	BKJ	Repaired and changed batteries
Squaw Harbor	SQH	Repaired and changed batteries
Nagai Island	NGI	Repaired and changed batteries
Chernabura Is.	CNB	Changed batteries
COLD BAY 14 - 16 July 1976		
False Pass	FPS	Repaired and changed batteries
Sanak Is.	SNK	Repaired and changed batteries
Dolgoi Is.	DOL	Repaired and changed batteries
Deer Is.	DRR	Replaced electronics and changed batteries
Baldy Mtn.	BAL	Attempted repair and changed batteries
Balck Hills	BLH	Weathered out
SAND POINT 17 July 1976		
Port Moller	PMA	Adjusted transmitter at White Alice Site
Herendeen Bay	HNB	Repaired and changed batteries
Balboa Bay	BBB	Attempted repair and changed batteries

day: 2/day this year vs. 1.5/day in 1975.

The stations serviced and the bases of operation are given in Table I. The station locations are shown on the three maps, Figure 1-3. These maps show the stations serviced from each of the three logistic bases used this summer: Dutch Harbor, Cold Bay and Sand Point.

The Akutan volcano and Makushin valley stations were serviced from the Dutch Harbor airport. The helicopter was based on the NOAA ship Surveyor. The seismic personnel were based at the Dutch Harbor Fish and Game Office. The remainder of the stations were serviced from the Sand Point airport or the Cold Bay airport with both helicopter and seismic crew based at the village of Sand Point or the U.S. Air Force Base, respectively. Fuel caches were utilized at Sand Point and Port Moller and additional fuel was bought at Cold Bay.

On a typical day when weather permitted servicing the remote stations, two seismic personnel with tools, batteries and water were dispatched to station A. If logistics and weather permitted the people were left at station A, while the helicopter returned, refueled and took another party to station B. The group from A was then retrieved and returned to base, re-outfitted and taken to C. Using this leap-frogging technique (and many variations, depending upon the conditions) we were able to service as many as five stations on a good day.

Table II lists the seismic personnel involved in this project. The NOAA pilot and mechanic worked very well under

TABLE II

NAME	EMPLOYED BY	DATES
Dr. John Davies	L-DGO	14 June - 17 July
Mr. Leigh House	L-DGO	14 June - 16 July
Mr. Laszlo Skinta	L-DGO	9 July - 17 July
Mr. Phil Lelyveld	L-DGO	10 July - 17 July
Dr. David Stone	U. Alaska	10 July - 16 July
Ms. Mary Matthews	L-DGO	16 July - 17 July

the somewhat primative conditions. They understood the need to work hard when the weather allowed and put in some long days for which we are quite appreciative. Don Winters again showed much skill and appropriate caution in dealing with the marginal flying conditions presented by the Aleutian weather and remote island terrain. Both he and his mechanic, Gary Mitchell, were a pleasure to work with.

In conclusion, we were able to work at 19 out of 20 stations, for a logistical completion rate of 95%. We successfully completed work at 17 of the 20 stations for an overall completion rate of 85%. Those stations which were not visited (BLH) or not completed (BAL and BBB) were successfully serviced later in the summer so that eventually 100% of the projected task was accomplished. If future operations go as well as this one we would be quite satisfied. The flexibility due to the land-based logistics contributed significantly to the successful completion of this field program.

Figure 1. DUTCH HARBOR

Sectional Aeronautical Chart
Scale: 1:500,000
Pub. by: Coast and Geodetic Survey

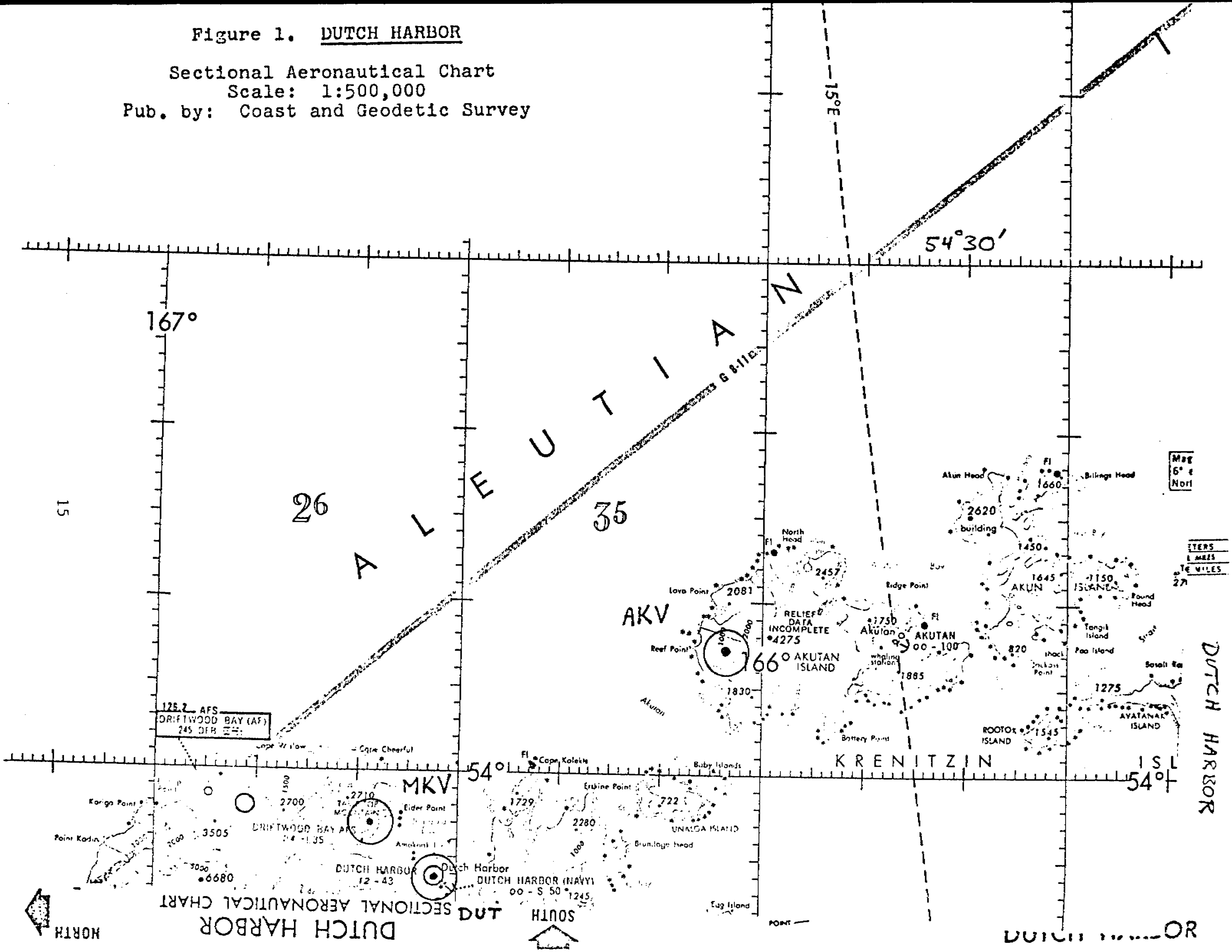


Figure 2. COLD BAY (Cold Bay)

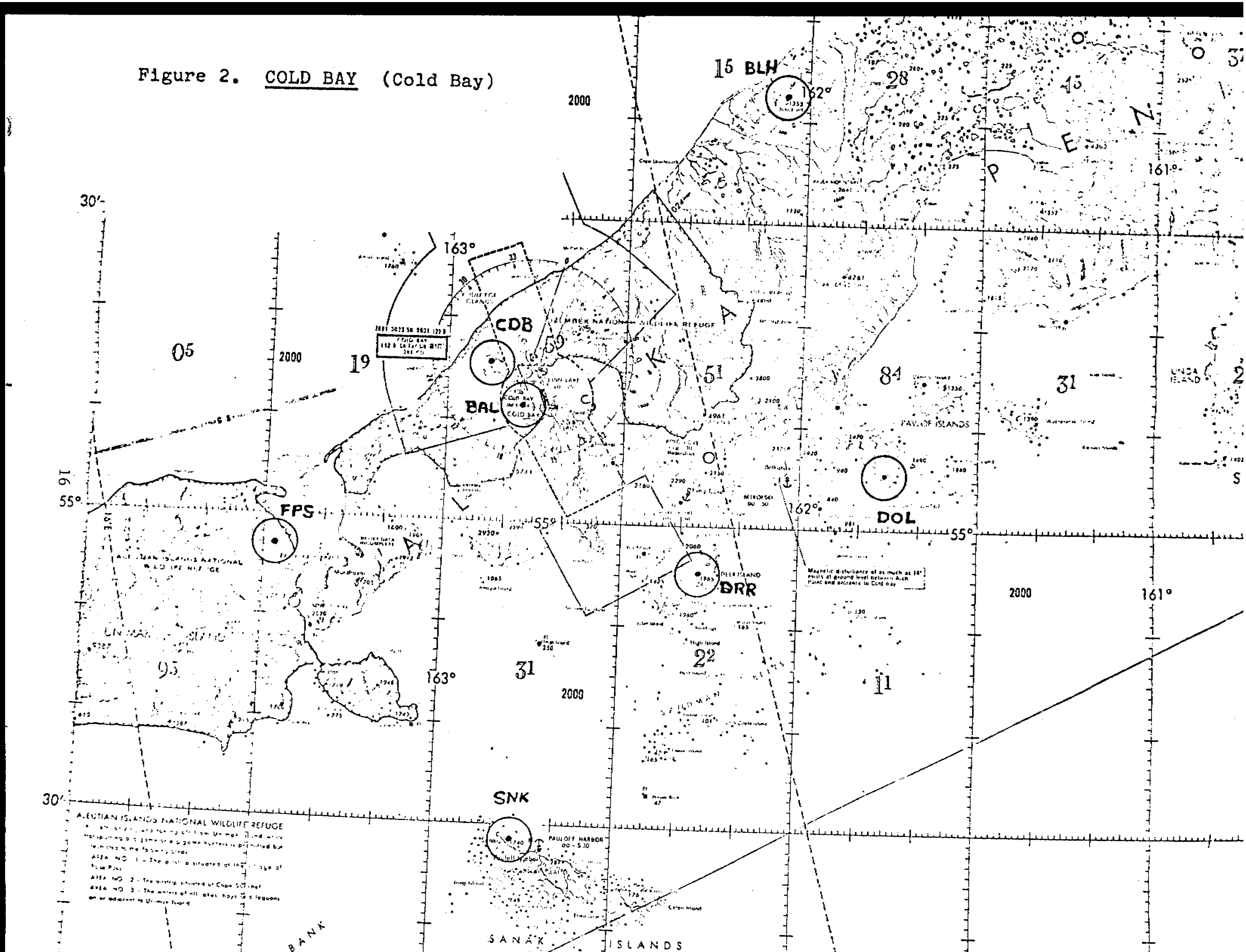
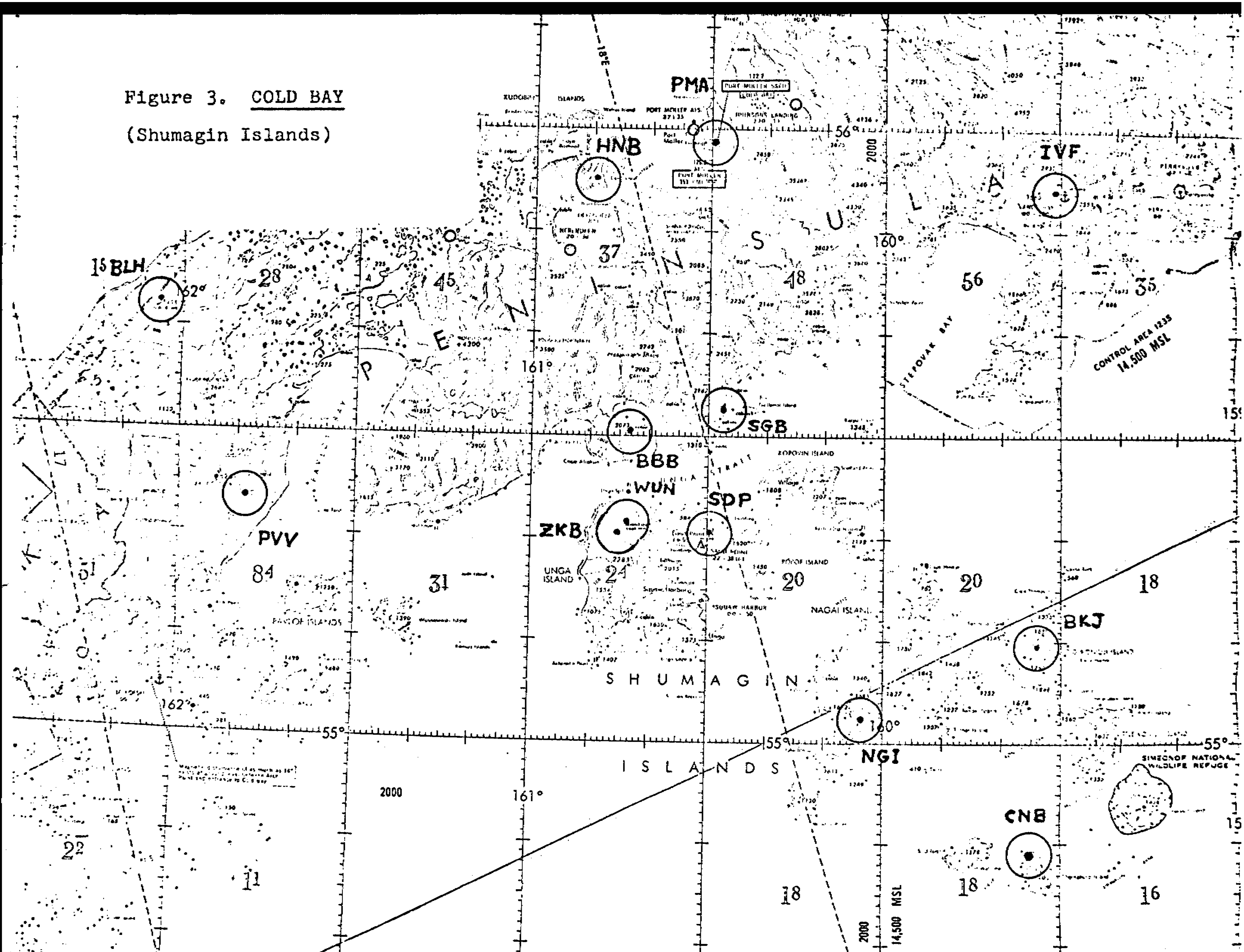


Figure 3. COLD BAY

(Shumagin Islands)



A SEISMOTECTONIC ANALYSIS OF THE SEISMIC AND VOLCANIC HAZARDS IN THE PRIBILOF ISLANDS - EASTERN ALEUTIAN ISLANDS REGION OF THE BERING SEA

NOAA Contract NOAA 03-5-022-70

Crustal Deformation Studies in the Shumagin Islands

Field Report - August 1976

John Beavan

Roger Bilham

TABLE OF CONTENTS

FIGURES

Introduction

This report describes the installation of five sea-level monitors in the Shumagin Islands, Alaska. The monitors have a resolution of 1 mm and are intended to detect crustal deformation associated with the Aleutian trench, by measurement of changes in mean sea-level at widely separated points.

The instrument is described in detail by Bilham (1976). It consists basically of a standpipe connected to the sea by an inlet tube, with a capillary in the inlet tube acting as a low pass filter to reduce the tidal amplitudes. A wire attached to a float in the standpipe passes over a pulley connected to a potentiometer, and the rotation of the potentiometer is detected electronically and recorded by a measurement package which runs for a year on several 'D' cells. The principal effort in installation is the burial of the standpipe and the entry tube. The level detection system or recording unit can be replaced on an existing standpipe in a matter of minutes. This makes replacement of defective units, or addition of improved units, a very easy matter.

The intended distribution of instruments is a linear array stretching from the Alaskan Peninsula toward the Aleutian trench, the southernmost island being some 120 km from the mainland (and 100 km from the trench axis). The array can be considered as a very long baseline tiltmeter, or as a long levelling line.

In this report we first describe the operation of the two prototype instruments of August 1975, then detail the design improvements that have been made during the year. We briefly describe the new August 1976 installations, and examine possible remaining problems and further proposed improvements in the instrument. In the appendix we give full details of each of the present installations.

The report also describes the strain experiment which was initiated in August 1975.

1. Prototype Installations, 1975

1.1 Eagle Harbor, Nagai Island (EGH)

The instrument was installed on 28 August 1975 and ran perfectly until 28 November 1975, a total of three months data (see Fig. 1). The instrument continued to operate until 22 February 1976 with the amplitude of the tide steadily reducing; thereafter it ran intermittently until mid-May. From mid-May, a constant signal was recorded until the paper ran out in early July. The instrument was visited in mid-July and a temporary repair attempted. It was visited again 27 August 1976, when the instrument head was exchanged for an updated version (see para. 2), the capillary system was replaced with a new version (para. 2) and the inlet tube was re-buried (and pinned) beneath the gravel beach (see Appendix for details of present installation).

It is important to note that the electronics and recording part of the system ran perfectly throughout the year. The failure was due to one (or perhaps both) of two causes:

(1) The first severe frosts of the 1975/76 winter occurred at the end of November and it is possible that the water in parts of the inlet tube or capillary started to freeze, thus reducing the amplitude of the tide.

(2) Air leakage into the pipe will eventually cause the

syphon to fail, and failure will be preceded by a decrease in the amplitude of the tide (see para. 4). The problem of leakage has been largely overcome in this year's instruments by the redesign of the capillary system (see para. 2), but the exsolution of bubbles from aerated sea water may still present difficulties.

1.2 Pirate Cove, Popof Island (PRC)

The instrument was installed on 24 August 1975. The record was recovered during July 1976, and at that time the instrument head had been damaged by some form of heavy blow. The record showed the water level falling (with a tide superimposed) with an abrupt failure on 2 September 1975. This failure was either due to the damage to the instrument head, or due to the stand-pipe not being buried deeply enough, so that the water drained out of it at some low tide (the damage to the head occurring at some later date).

We first installed a new instrument head and capillary on the existing standpipe (9 August 1976), but this drained of water on 14 August 1976. We therefore dug a completely new installation at Pirate Cove, only the entry tube remaining the same as in 1975.

2. Improvements Made to the System 1975/76

2.1 Capillary system

The capillary system has been improved by removing all the bypass valves and taps of the prototype. The capillaries have been installed in a water environment so that any leaks which do occur will suck water rather than air into the system (see Fig. 2).

2.2 Entry tube

The entry tubes in the 1975 prototypes consisted of five 100' lengths of tubing joined together. This was unsatisfactory as any joints above sea level are possible leakage points. The 1976 systems use a continuous 500' length of tube.

2.3 Time marks

The new instrument heads apply twelve hour offset time marks lasting ∿ 20 minutes, using a reed-relay and a magnet attached to the hour hand of an electric clock. Time marks were not present on the prototypes.

2.4 Absolute level reference

If slippage occurs of the wire around the pulley, this will appear as a change in sea level. Such eventuality has been guarded aginst this year by putting a paint mark on the wire, and on the pulley adjacent to it. It is intended to improve this system, as described in para. 4.

3. New Installations

Three completely new instruments were installed as well as the re-installation of PRC and the updating of EGH. One of these was on Popof Island and two on Simeonof Island, (Fig. 3). A continuously recording microbarograph was also installed on Simeonof Island.

We first attempted to install an instrument in a sandy beach on Unga Island by pumping water under high pressure into the sand to fluidise it, then sinking the standpipe into the fluidised sand (quicksand). We were easily able to insert a 1" copper pipe to a depth of 6-8' using this technique. However, our pumping facilities and our plumbing were inadequate to deliver sufficient water to sink the standpipe by this method. The method does appear to have promise, given adequate pumping facilities and a sandy beach free of stone layers.

The tide gauge at Sand Point, Popof Island (SDP) was installed with the aid of a backhoe which was available locally. This is unquestionably the easiest way to install these instruments; the complete installation took less than a day.

The holes for the two instruments on Simeonof Island (SMH-Simeonof Harbor and SMW - Simeonof West) were dug to a depth of between 8' and 9' using pick and shovel, and a bucket to remove the water which invariably drains into the hole below a depth of about six feet.

Brass levelling pins were mounted on solid rock near each of the five installations, and the upper platform of the recording package related to them using a geodetic level (see Fig. A1). The measurement is necessary to monitor the stability of the standpipe as a function of time.

4. Possible Problems and Proposed Improvements

4.1 Ice

Icing up will presumably stop the water flow, and hence temporarily stop the instruments from working. There seems no reason why the instruments should not continue to operate after the thaw; the electronics of the EGH instrument operated throughout the 1975/76 winter.

4.2 Air

The accumulation of air in the inlet tube and the capillary will eventually break the syphon and cause failure of the instrument. On this year's instruments there is no way for air to enter the tube except by exsolution from the sea water; this mechanism is possible as the water near the top of the syphon can be at as low a pressure as 0.5 atmospheres at a very low tide.

Provided the syphon remains unbroken, the presence of an air bubble does not seriously affect its operation.

Improvements proposed

4.3 Absolute level reference

1) We propose to replace the present wire and pulley with a fine chain and pulley to eliminate possible slippage.

2) We intend to measure the depth of water in the stand-pipe tube at each visit and relate this both to the recorded instantaneous chart value and to the local bench mark(s). This will give an absolute level for the data span recorded. If for any reason the data are interrupted, the value can then be related to a similar value obtained at a different time. The water depth measurement will be made by utilising the electrical contact between a plumb-bob electrode and the water surface (Fig. 4).

4.4 Timing and electronics

We propose to change the present timing and switching system which used two electric clocks, to an all electronic system using a crystal clock. We also intend to add an auxiliary signal output suitable for telemetry or for satellite relay.

4.5 Air

We propose to experiment with a system similar to that sketched in Fig. 5 for solving the problem of air bubbles accumulating in the entry tube.

5. Present and Future Layout of Array

Fig. 3 shows the present layout of the array. We hope eventually to operate at least two and preferably three instruments on the mainland and on each of the three islands (Popof, Nagai and Simeonof) leading toward the trench.

We are operating a recording microbarograph on Simeonof and we hope to install others; at least one at Sand Point on Popof Island. We intend to use differential pressure variation across the array of tide gauges to eliminate some of the atmospherically introduced variations in sea level.

6. Strain Experiment

Two invar-wire strainmeters were installed on Popof Island in August 1975. The strainmeter experiment had the following aims: (a) Two instruments were to be installed with sufficient long-term stability to identify changes of tectonic rate. The stability obtained by the instruments during the 3 weeks of operation was deemed sufficient to identify transient strain events (> 10^{-9} per hour) but not sufficient to study longer period strains (< 10^{-7} week).

(b) The instruments were to be installed inland on the island so that the nearest coastline was no closer than 10 km. In response to the local sea tides, the strains inland would then contain information on the local elasticity to a depth of approximately 3 km. Dilantancy theory predicts that changes in elasticity should occur prior to seismicity. The body tide, being much smaller than the local tide was not expected to be useful for this study. Thus, the experiment required temporal stability of the local load tide and of instrument calibration. Unfortunately, it was difficult to install the strainmeters inland on any of the islands due to the absence of roads. A pilot study was therefore initiated at Sand Point 800 m from the nearest coast, the furthest we could operate a backhoe from the sea.

It was our intention this year to record the two strainmeters and the new SDP sea level monitor digitally on a Memodyne cassette recorder situated at Sand Point. The signals were to be transmitted to the recorder by land line using a V/F converter at the transmitting end, and an F/V converter at the receiving end.

However, there were several problems with the strainmeter installations which, in addition to the difficulties mentioned above, led us to abandon the experiment:

1. Both instruments were found with their tensioning units flooded to a depth of about a centimeter. There were several tide marks below the present water level which showed that the water had leaked in, in three or four distinct phases. These were presumably when the ground above was saturated after the thaw, or after heavy storms, giving a pressure head of about six feet of water on the instrument housing.

   Considerable corrosion had resulted due to the brass and aluminum construction of the tensioning unit. The invar wire was completely uncorroded, and we feel that an all stainless steel tensioning unit would stand a considerably larger chance of survival in hostile environments.

2. The cable from the remote instrument to the recording package was found cut. From the record it appeared that the cut occurred at the time the trench was filled, some two weeks after the meters began operating. The record from the local strainmeter failed at the same time.

3. The air supply tube for the air-cells had not been opened at the time of filling the trench. This would have led to failure after about two months due to lack of air.

7. Acknowledgments

We wish to thank the following, who all provided valuable assistance before or during the field trip:

Martin Berry, Dick Plumb, Chuck Griffey, Connie Griffey, Bob Cochran, Bill Eubanks, Glen Woodworth, Oliver Felton, Hazel Read, Tom Howlett, Lazlo Skinta, Joan Leone.

8. References

Bilham, Roger, 1976. A sea-level recorder for tectonic studies, Geophys. J. R. astr. Soc., in press.

9. Appendix. Detailed Description of Sea-level Monitoring Sites

1. SDP Sand Point, Popof Island

Installed:

15 August 1976.

Standpipe buried ∿ 9'6", at a point about 2'-3' above high water. Special head installed with V/F converter for transmission of signal by land line.

Checked:

31 August 1976.

Perfect operation. Water level in standpipe had increased about 50 cm since installation. Tidal range ∿ 3 cm on chart. Record removed, and the instrument head was exchanged for a standard type (the head removed from PRC on 29 August). No significant air bubbles near capillary, so the tube was not bled. Clock set to give time marks at 00.00 and 12.00 GMT.

Levelling:

Two bench marks were installed on the rock at the SW end of the beach on 28 August 1976 (see Fig. A1). Bench mark 1 is a few feet above high water mark, and BM 2 is further inland and higher up on a small ledge.

The levelling was done in light rain on 31 August, using one 0.5 cm invar stave and the parallel-plate micrometer attachment.

	Centre		Upper Stadia		Lower Stadia	
Shot to tide gauge	45662 45661	15512 15511	47908	17765	43423	13266
Shot to BM1	42580 42579	12432 12431	45776	15624	39387	09240
Shot to BM1 with tripod in new position	44256	14103	47471	17319	41036	10888
Shot to BM2 (only upper stadia was visible)					30731 30730	00580 00579

The instrument is thus 308.3 $\pm$ 0.3 mm below BM1. The height of BM2 is uncertain without further measurements.

2. PRC Pirate Cove, Popof Island

Installed:

24 August 1975

Water level decreasing until standpipe emptied on 2 September 1975.

Re-installed:

9 August 1976

New instrument head and new capillary system added to existing standpipe. Water level decreasing until standpipe emptied on 14 August 1976.

Re-installed:

29 August 1976

New hole dug closer to high water mark and new instrument head added. Capillary system as 9 August. The bottom of the standpipe is 35 cm lower than in the 1975 installation. The standpipe was surrounded with stout timbers buried to a depth of several feet as a protection during storms.

Clock not set correctly.

Note that the entry tube remains as in 1975 installation. This consists of five 100' lengths of tube joined together. However, the beach shelves steeply enough that all, excepting perhaps one, of the joints are always below sea-level; thus there is probably not a leakage problem due to these joints.

Checked:

1 September 1976

Water level decreasing slowly. Reset clock to give time marks at 00.00 and 12.00 GMT.

Levelling:

A bench mark was installed in 1975 on a large rock east of the instrument. The mark is about 4' above high water. Levelling was done with the 1 cm stave and without the parallel plate micrometer.

	Centre	Upper Stadia	Lower Stadia
Sight to tide gauge	0474 0474	0508	0442
Sight to bench mark	0324 0323	0408	0237

Thus instrument is 152 ± 1 mm below the bench mark.

3. <u>EGH Eagle Harbor, Nagai Island</u>

Installed:

28 August 1975

Entry tube buried perfunctorily due to lack of time.

28 Aug. - 28 Nov.	ran perfectly
28 Nov. - 22 Feb. 76	amplitude reducing
22 Feb. - 3 Mar.	stuck at a constant value
3 Mar. - 11 Apr.	small amplitude

intermittent poor signal for a month or so thereafter.

early July paper ran out

mid July visited, record recovered.

Checked:

27 August 1976

Capillary system broken.

Installed new instrument head and new capillary system.

Buried inlet tube below beach. Note that this tube consists of five 100' lengths of pipe joined. Several of the joints are above sea-level at low tide, so this might present a leakage problem.

Clock set to GMT.

Levelling:

Two bench marks were installed on solid rock SE of the instrument. They were installed and measured on the same day, before the cement had fully set. Levelling was done with a 1 cm stave and without the parallel plate micrometer.

	Centre	Upper Stadia	Lower Stadia
Sight to instrument	1095 mm 1093 1093	1151 1152	1035 1034
Sight to BM1 (under-water at high tide)	2824 2826 2821	2900 2901	2743 2742
Sight to BM2	1725 1726 1728 1727	1871 1870	1584 1582

Hence instrument is 1729 ± 2 mm above BM1

1095 ± 2 mm above BM2

4. <u>SMH Simeonof Harbor, Simeonof Island</u>

Installed:

20 August 1976

Hole dug to a depth ∿ 8'6", at a point about 1' above high water. Standpipe surrounded by buried timbers as storm protection. Clock set to GMT

Checked:

24 August 1976

Marked pulley and wire with orange paint to check for slipping.

Checked:

25 August 1976

Sucked several inches of air out of system. Water level still falling, but levelling out.

Levelling:

Three bench marks installed 25 August 1976 on rock W of the instrument. They were measured while the cement was still slightly damp. All bench marks under water at high tide. Levelling done with 1 cm stave and without parallel plate micrometer in a wind of about Force 5.

	Centre	Upper Stadia	Lower Stadia
Sight to	1230 mm	1316	1147
instrument	1230	1317	1147
49° magnetic	1230	1316	1146
from tripod			
Sight to BM1	3216	3330	3103
131° magnet-	3220	3336	3105
ic from	3218	3332	3102
tripod	3217	3330	3104
Sight to BM2	2863	2926	2795
169° magnet-	2860	2925	2793
ic	2859	2926	2794
Sight to BM3	3204	3395	3015
197° magnet-	3204	3394	3015
ic			

Thus instrument is 1988 ± 3 mm above BM1
1630 ± 3 mm above BM2
1974 ± 2 mm above BM3

5. SMW Simeonof West, Simeonof Island

Installed:

21/23 August 1976

Standpipe buried ∿ 9' at a point about 2' above high water. Surrounded by timbers for storm protection. Clock set to

GMT. Orange paint marker on pulley and wire, to check for slippage.

Checked:

25 August 1976

Water level in standpipe rising slowly. No significant bubbles in inlet tube.

Levelling:

Levelling pin installed 23 August and measured while still damp. Rather distant from instrument (280 m). Levelling done with 1 cm stave, and without parallel plate micrometer.

Levelling from pin to instrument

Backsight			Foresight		
Centre	Upper	Lower	Centre	Upper	Lower
949 mm	1294	601	1538	1793	1282
949			1539	1794	1283
1491	1695	1287	2028	2322	1732
1491			2028	2322	1731
2411	2539	2283	1265	1431	1102
2411			1267	1431	1102
			1267		

Thus instrument is 18 $\pm$ 4 mm above bench mark.

6. Microbarograph, Simeonof Island

The microbarograph is installed in the upstairs room of Glen Woodworth's house at Simeonof Harbor.

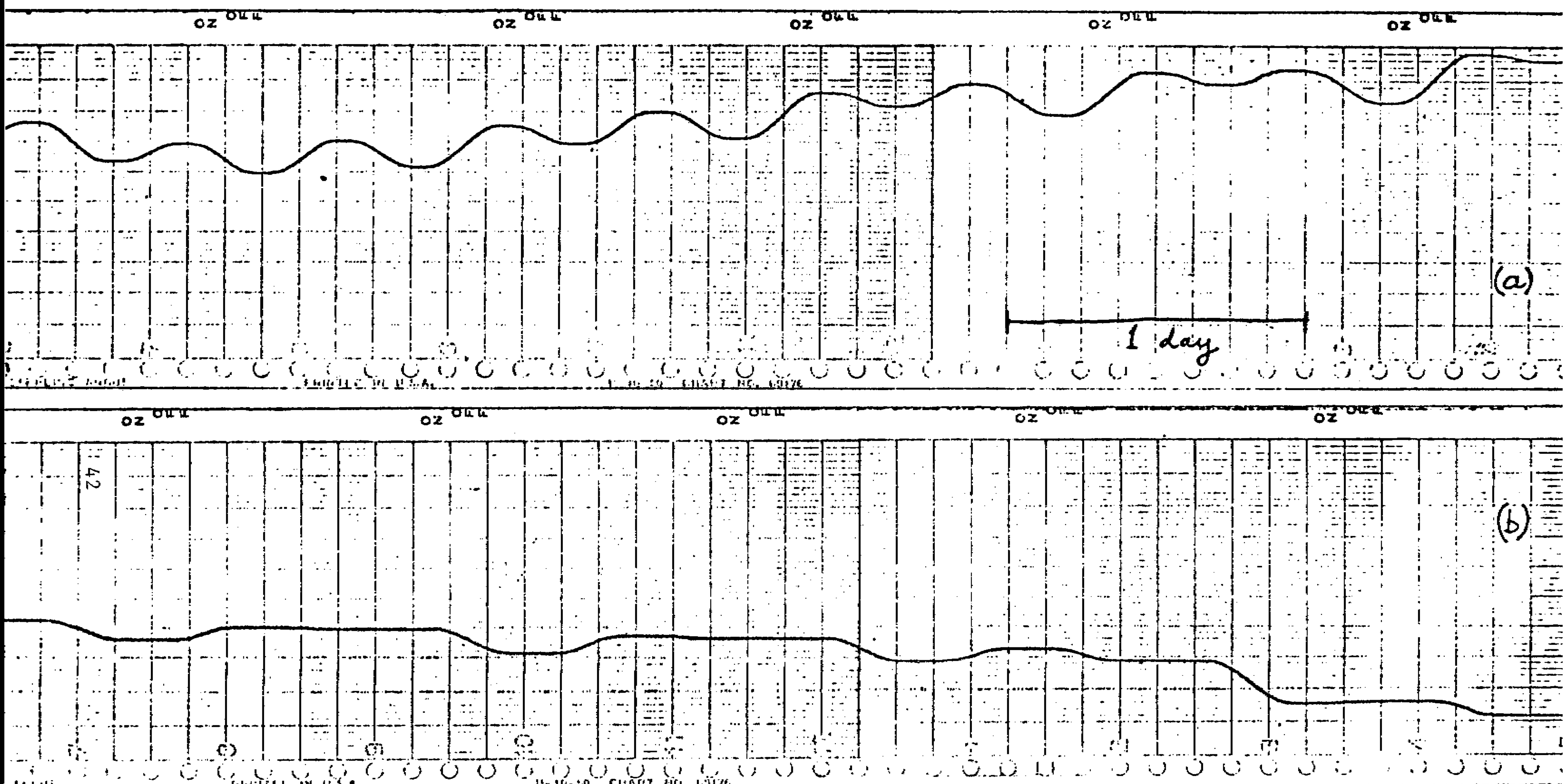


Figure 1. Data from Eagle Harbor prototype.
(a) shows typical record when the instrument was running perfectly. (b) shows record from February 1976 when the instrument was working poorly due to icing-up and/or syphon failure.

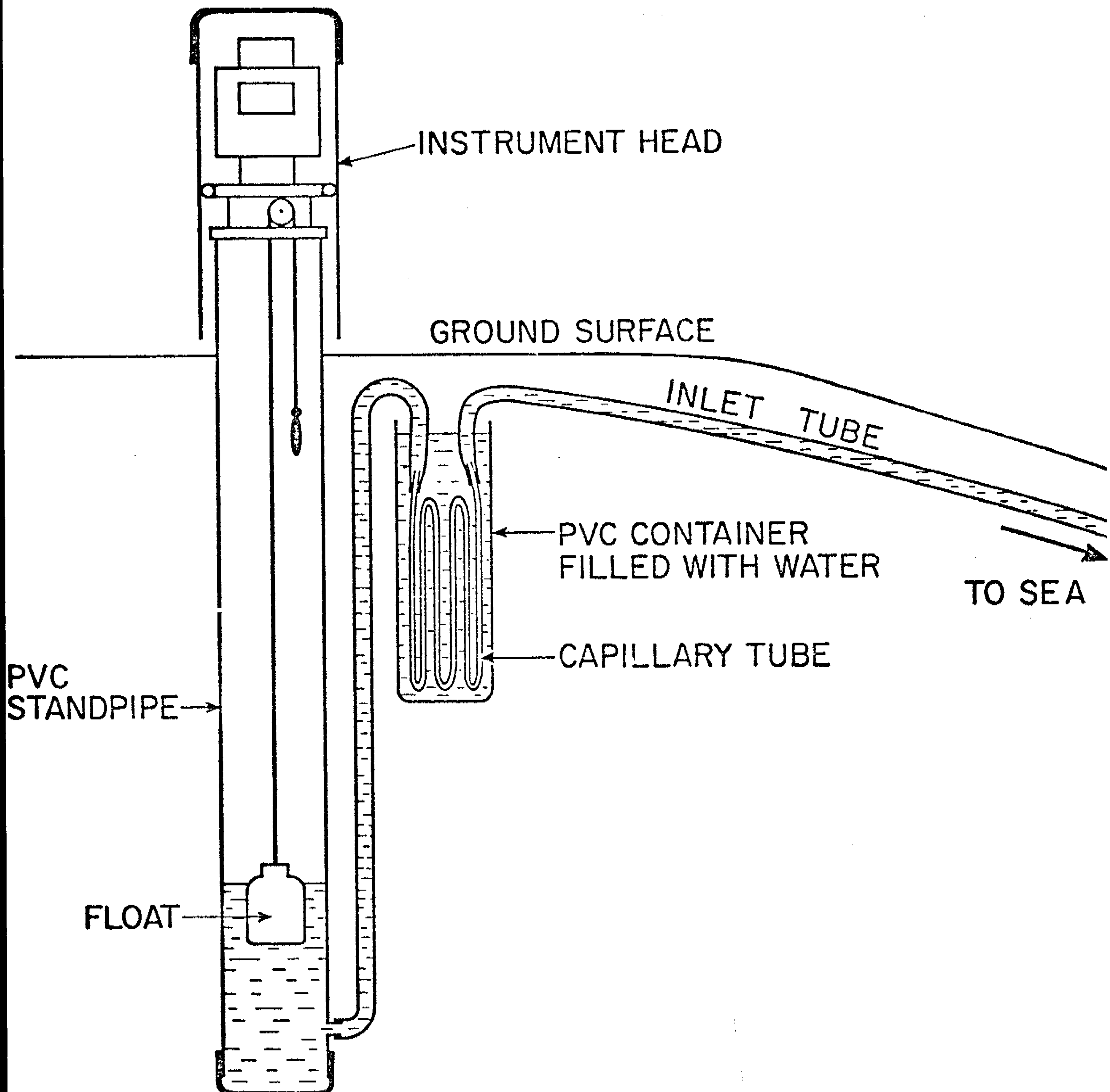


Figure 2. This shows the installation method used for the 1976 sea level monitors. Note particularly the capillary system; all joins near the top of the syphon are permanently under water so that air cannot leak into the syphon.

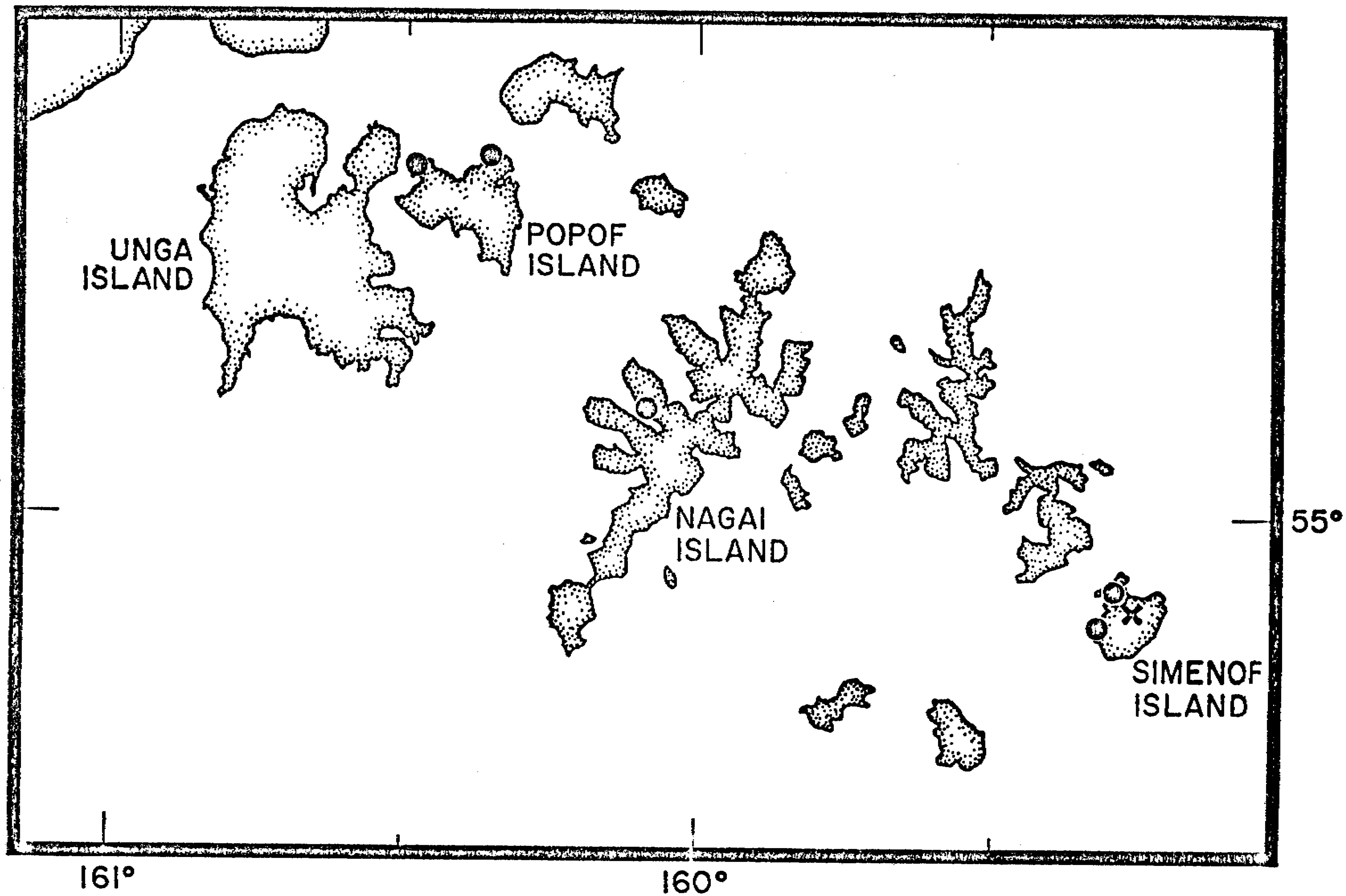


Figure 3. Present sea level monitor sites are shown by solid circles. The present microbarograph site is shown by a diagonal cross.

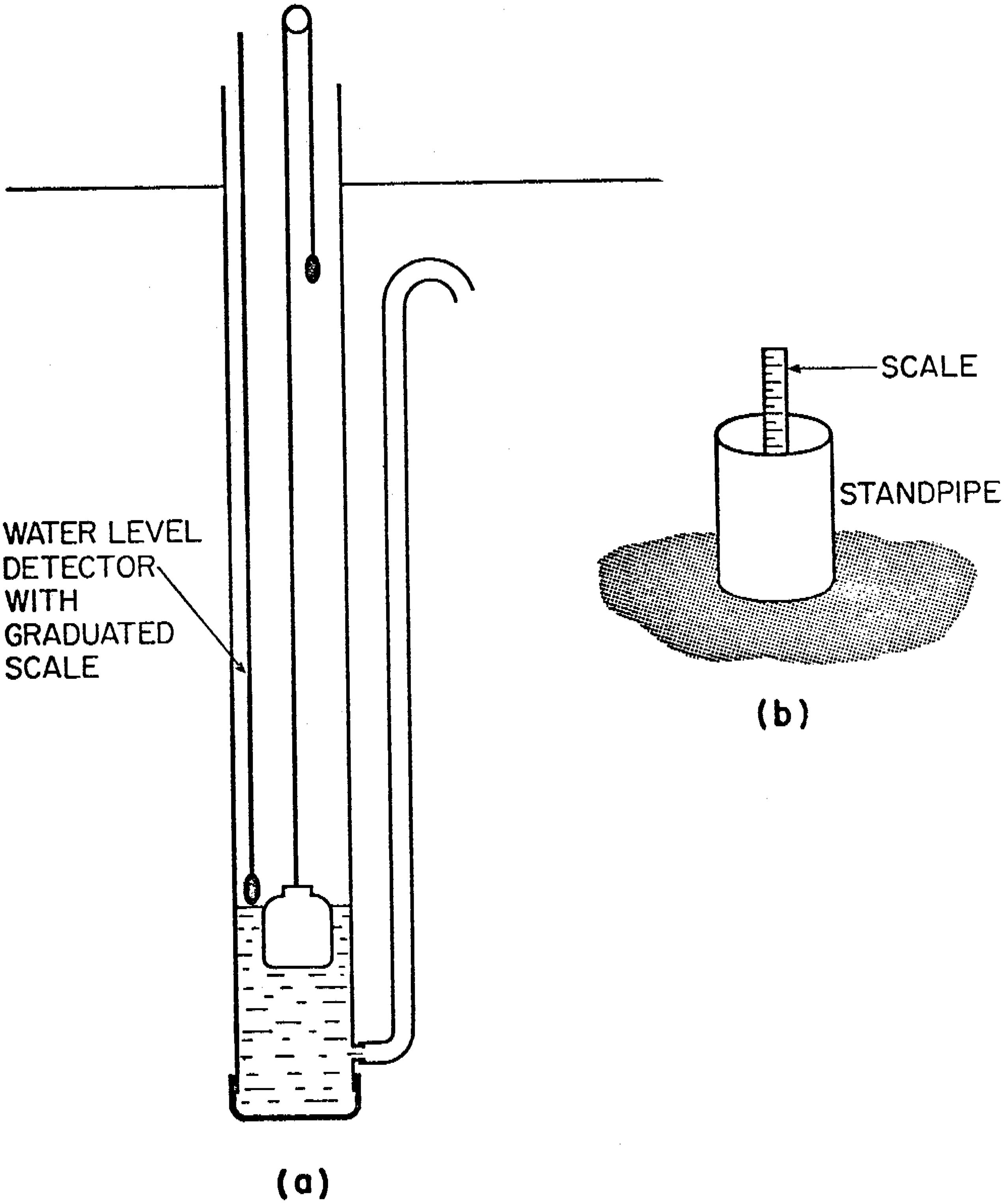


Figure 4. Schematic diagram showing proposed method for measuring absolute water level. (a) shows a cross-section while (b) shows a view from the ground surface.

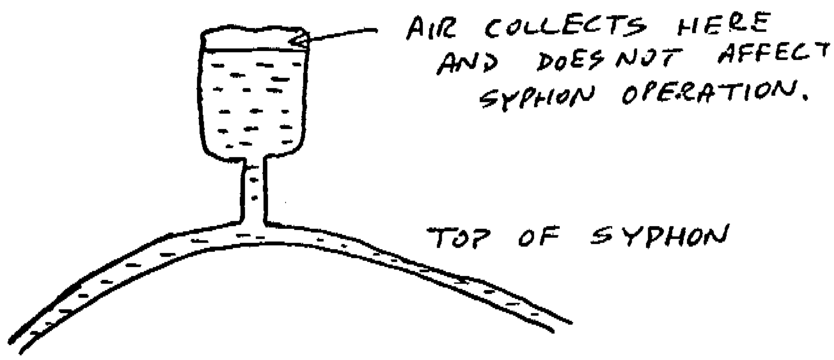


Figure 5. Sketch of possible system for preventing air bubble accumulation at the top of the syphon.

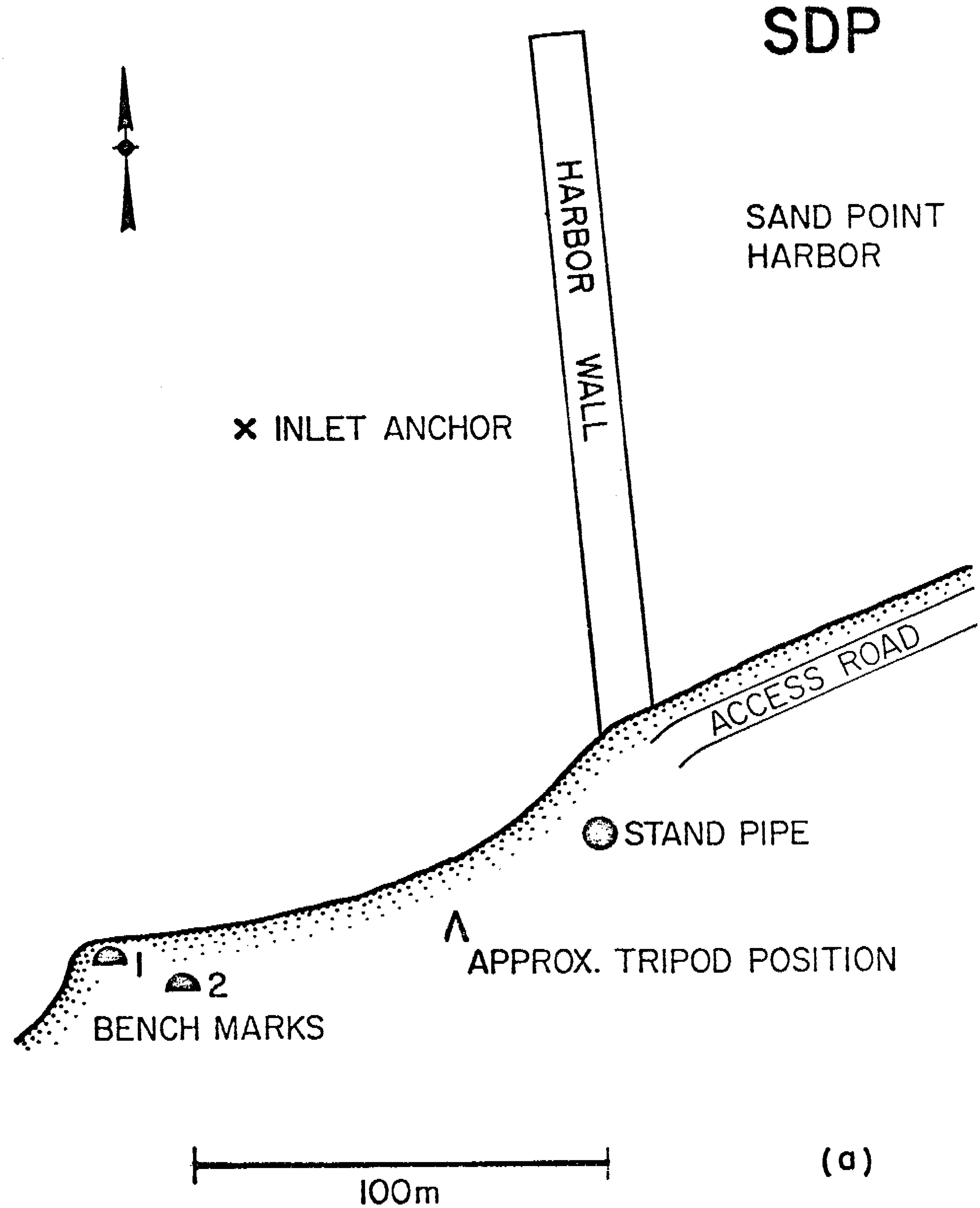
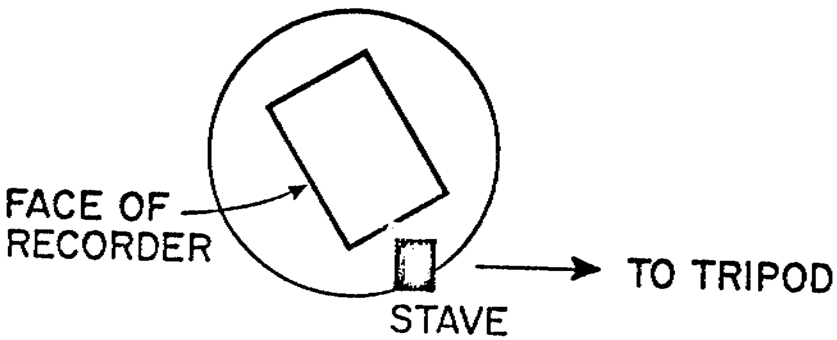
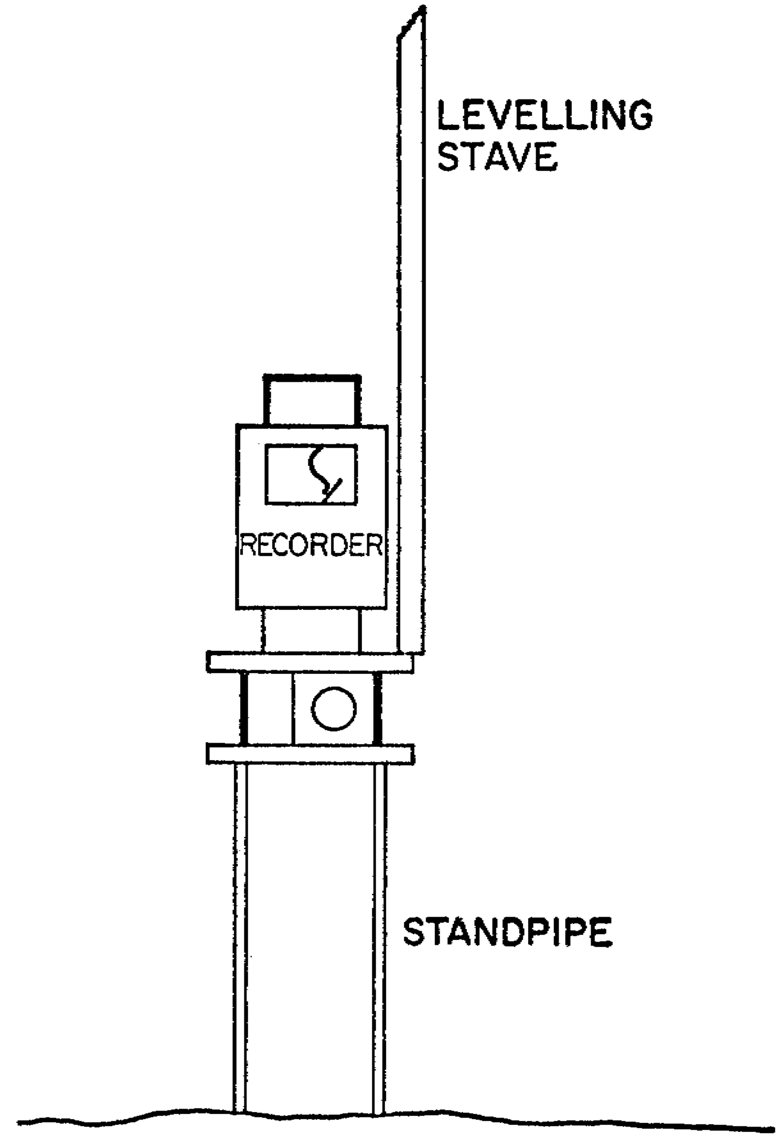


Figure A1 (a) Approximate plan of the Sand Point sea level monitor.



(b)



(c)

Figure A1 (b) shows a plan view of the position of the stave used when levelling to SDP. An accurate knowledge of the stave position is required at this installation because the standpipe is slightly tilted.
(c) shows a side view of the stave position. This base level was used for levelling to all the instruments.

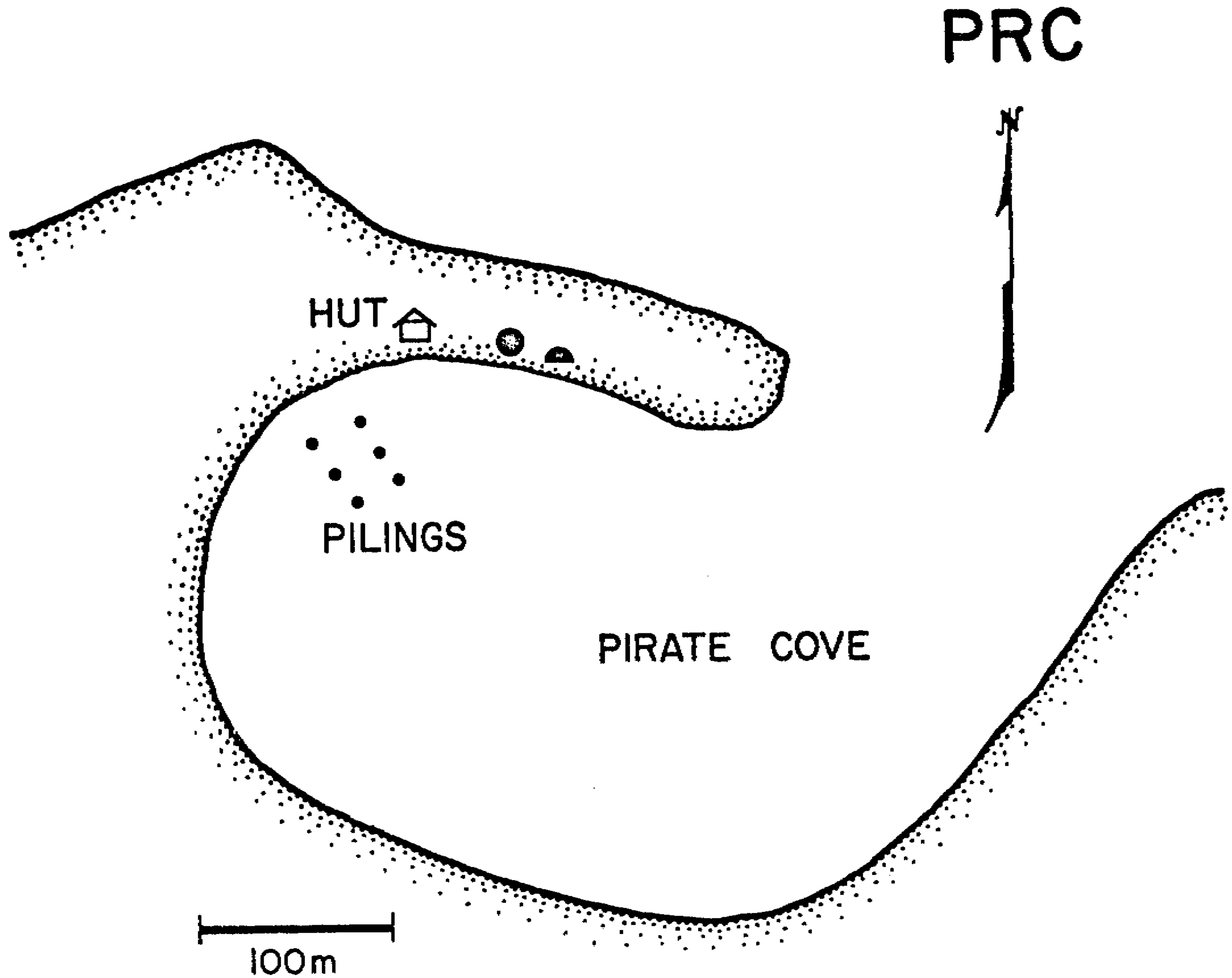


Figure A2 Approximate plan of the Pirate Cove sea level monitor. Symbols are as in Fig. A1(a).

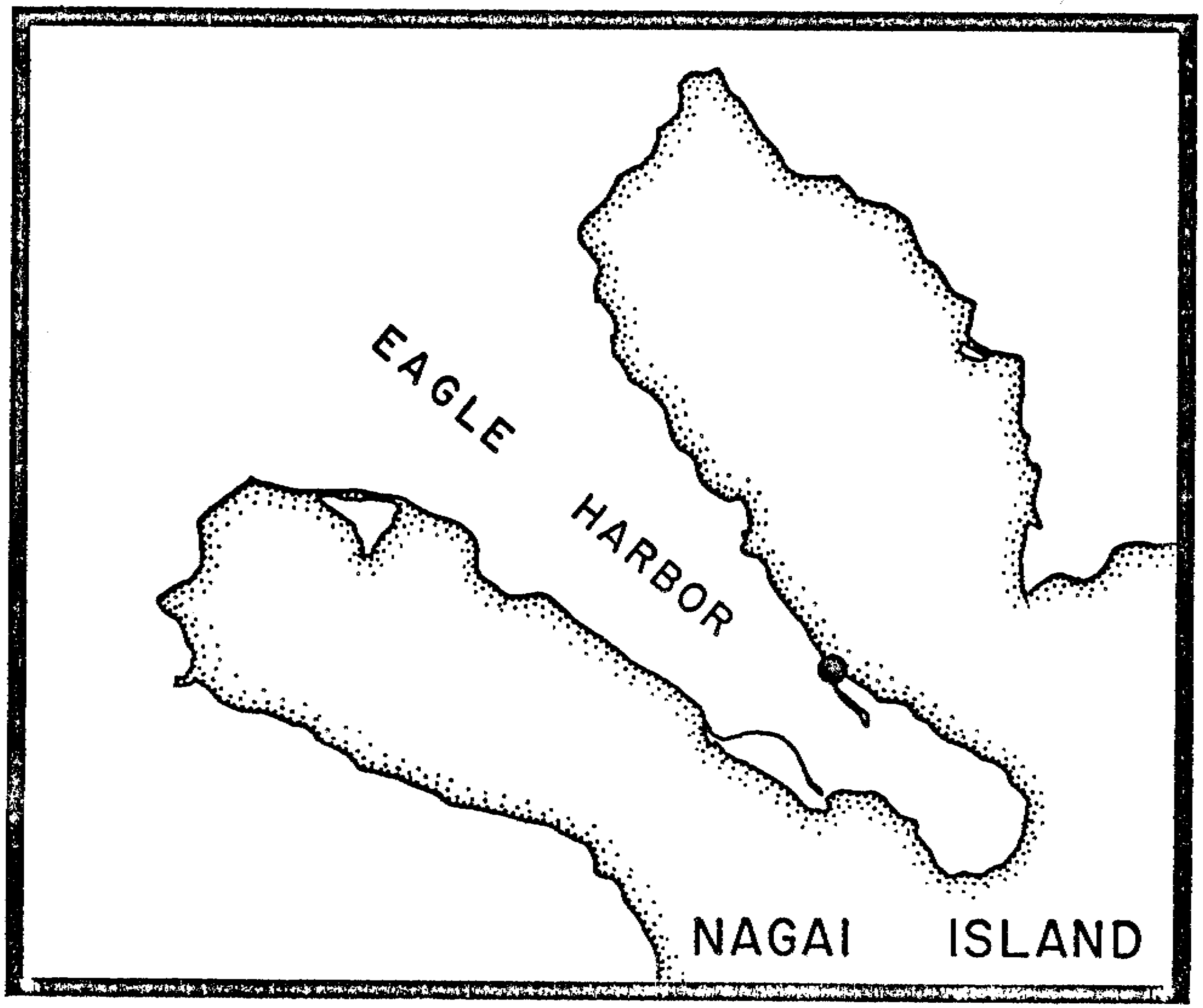


Figure A3 (a) shows the location of sea level monitor EGH in Eagle Harbor, Nagai Island.

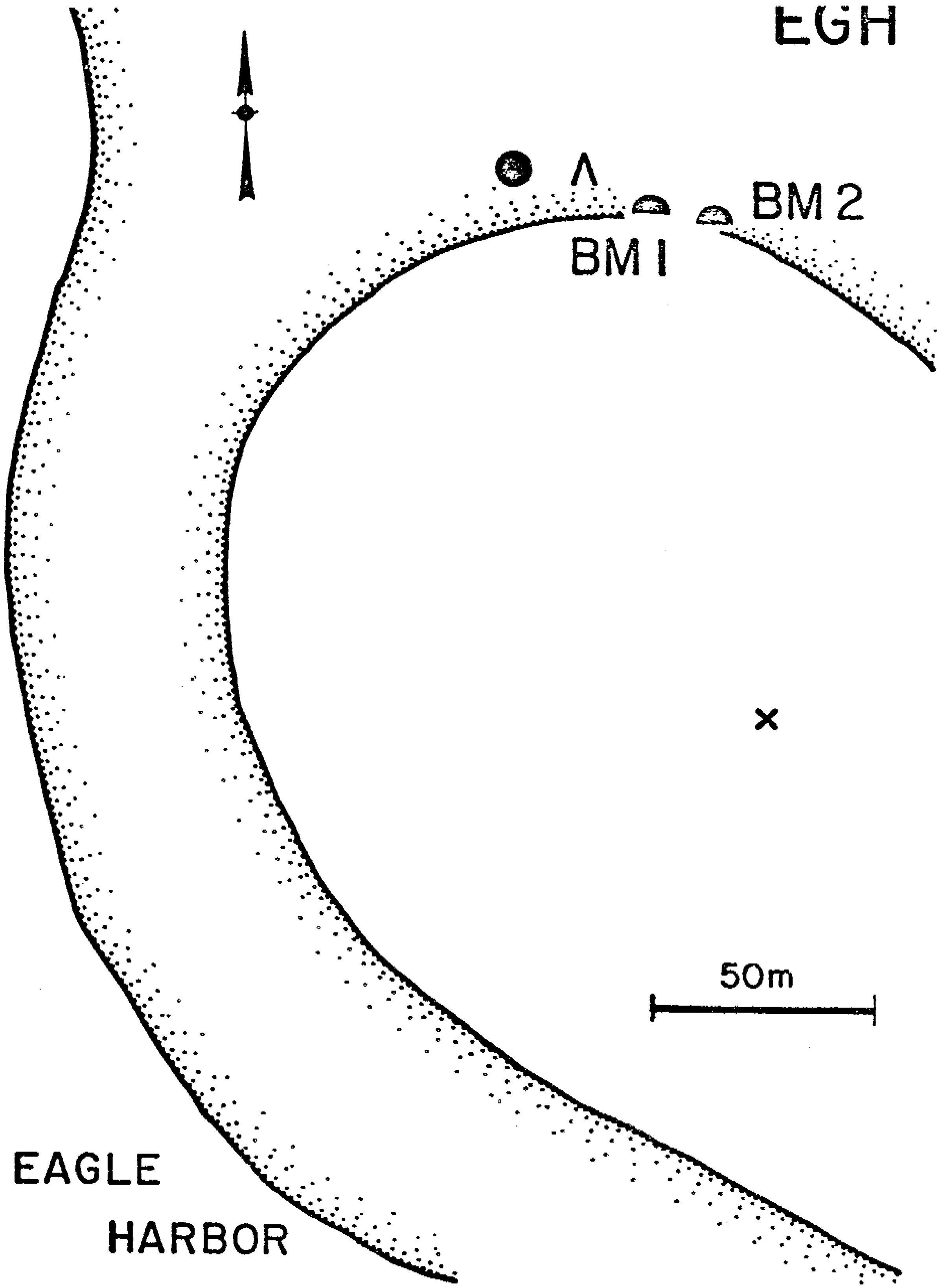


Figure A3 (b) Approximate plan of Eagle Harbor sea level monitor. Symbols are as in Fig. A1(a).

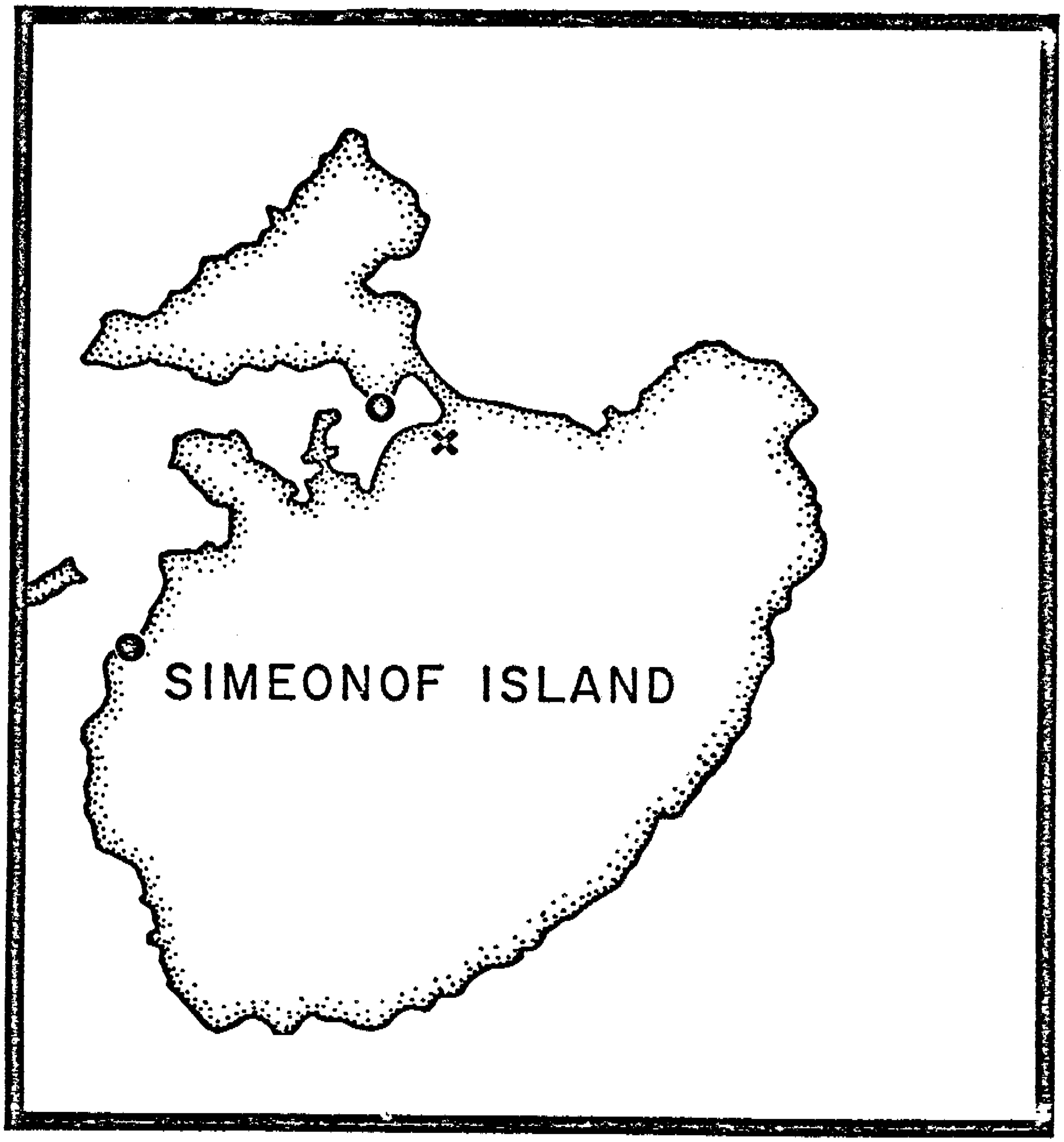


Figure A4 (a) shows the location of sea level monitors SMH and SMW (solid dots), and of the microbarograph (cross) on Simeonof Island.

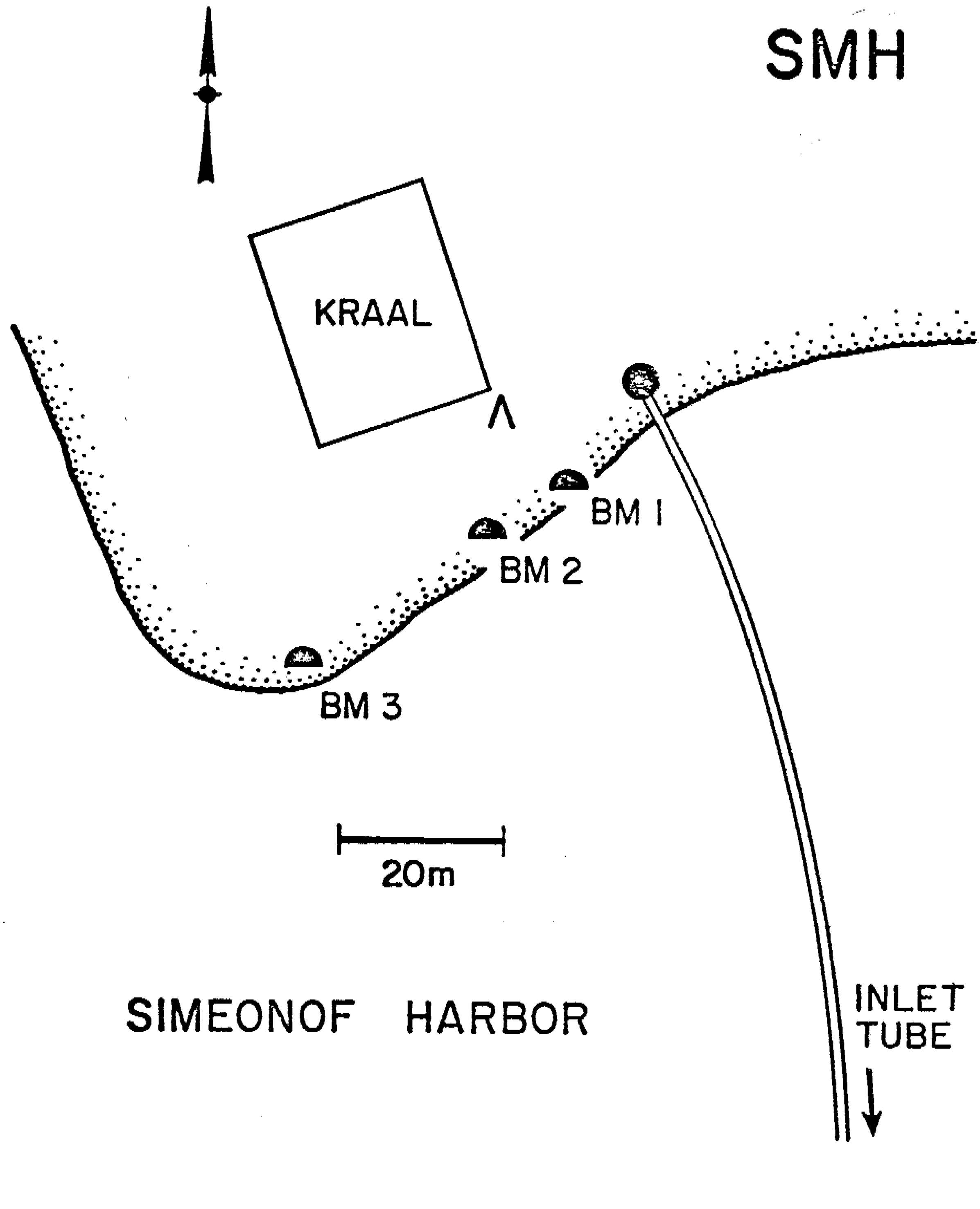


Figure A4 (b) Approximate plan of Simeonof Harbor sea level monitor. Symbols as in Fig. A1(a).

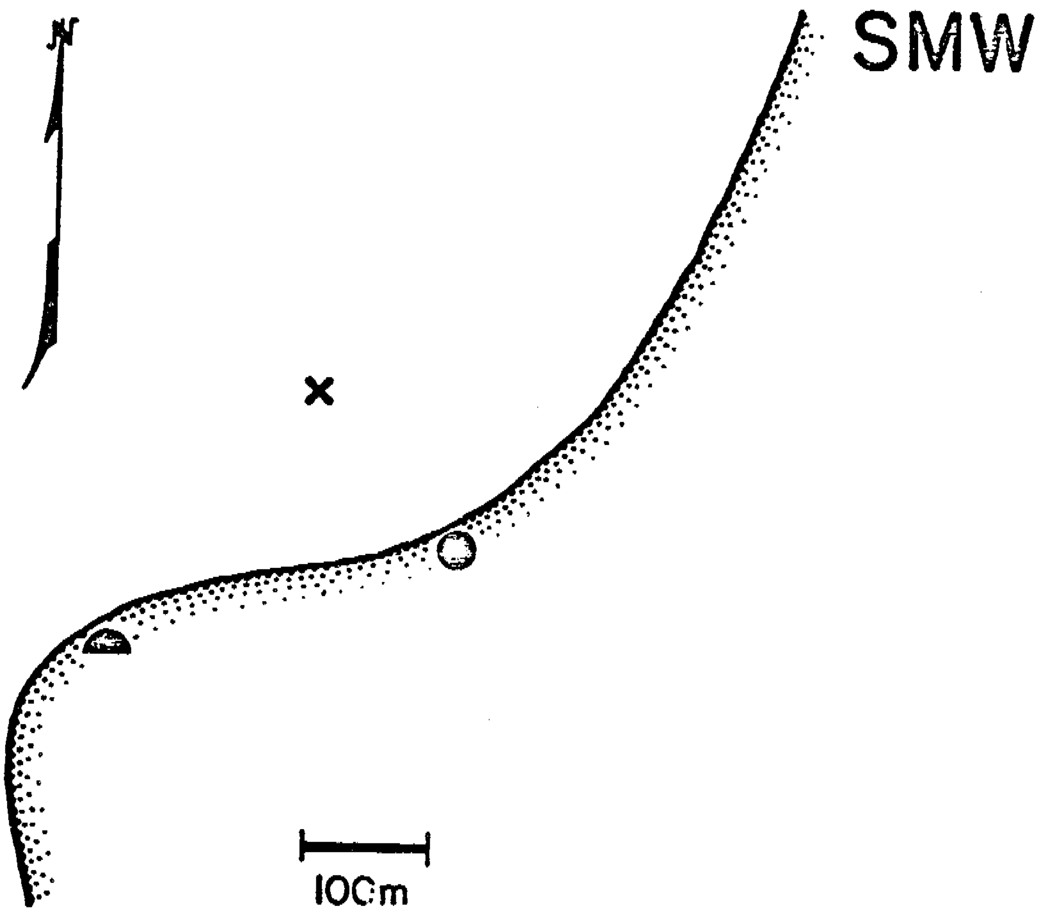


Figure A5 Approximate plan of Simeonof West sea level monitor. Symbols as in Fig. A1(a).

APPENDIX III

SHUMAGIN ISLANDS SEISMICITY JULY 1973 - JUNE 1976

The following figures show all of the highest quality hypocenter locations obtained from the Shumagin Islands seismic network for the period July 1973 through June 1976. The first three figures show in map and cross-sectional view the data for the above entire period. The remaining figures are replots of this data for yearly and quarterly intervals.

On all of the maps epicenters are marked by numbers which give the depth-to-focus in kilometers. Though hard to read in tnese Xerox reproductions, the stations are marked by their designator codes. The dashed boxes labeled "W", "C" and "E" show respectively the surface projection of the volumes used to select events for the western, central and eastern hypocenter cross-sections. All distances and depths in the cross-sections are in kilometers.

FIGURE CAPTIONS

Figure 1: Shumagin Islands seismicity, July 1973 through June 1976. Epicenters are marked by numbers which represent the depth to focus in kilometers. The dashed boxes labeled "W", "C" and "E" show respectively the locations of the western, central and eastern hypocenter cross-sections given in following figures.

Figure 2: Eastern and central hypocenter cross-sections, July 1973 through June 1976. Section locations are shown in Figure 1. Depths and distances are in kilometers.

Figure 3: Western hypocenter cross-section, July 1973 through June 1976. Section location is shown in Figure 1. Depths and distances are in kilometers.

Figure 4: Shumagin Islands seismicity, July 1973 through June 1974. Epicenters are marked by numbers which represent the depth to focus in kilometers. The dashed boxes labeled "W", "C" and "E" show, respectively, the locations of the western, central and eastern hypocenter cross-sections given in following figures.

Figure 5: Eastern and central hypocenter cross-sections, July 1973 through June 1974. Section locations are shown in Figure 1. Depths and distances are in kilometers.

Figure 6: Western hypocenter cross-section, July 1973 through June 1974. Section location is shown in Figure 1. Depths and distances are in kilometers.

Figure 7: Eastern hypocenter cross-sections by quarter for July 1973 through June 1974. Depths and distances in kilometers.

Figure 8: Central hypocenter cross-sections by quarter for July 1973 through June 1974. Depths and distances in kilometers.

Figure 9: Western hypocenter cross-sections by quarter for July 1973 through June 1974. Depths and distances in kilometers.

Figure 10: Shumagin Islands seismicity, July 1974 through June 1975. Epicenters are marked by numbers which represent the depth to focus in kilometers. The dashed boxes labeled "W", "C" and "E" show respectively the locations of the western, central and eastern hypocenter cross-sections given in following figures.

Figure 11: Eastern and central hypocenter cross-sections, July 1974 through June 1975. Section locations are shown in Figure 1. Depths and distances are in kilometers.

Figure 12: Western hypocenter cross-section, July 1974 through June 1975. Section location is shown in Figure 1. Depths and distances are in kilometers.

Figure 13: Eastern hypocenter cross-sections by quarter for July 1974 through June 1975. Depths and distances in kilometers.

Figure 14: Central hypocenter cross-sections by quarter for July 1974 through June 1975. Depths and distances in kilometers.

Figure 15: Western hypocenter cross-sections by quarter for July 1974 through June 1975. Depths and distances in kilometers.

Figure 16: Shumagin Islands seismicity, July 1975 through June 1976. Epicenters are marked by numbers which represent the depth to focus in kilometers. The dashed boxes labeled "W", "C" and "E" show respectively the locations of the western, central and eastern hypocenter cross-sections given in following figures.

Figure 17: Eastern and central hypocenter cross-sections, July 1975 through June 1976. Section locations are shown in Figure 1. Depths and distances are in kilometers.

Figure 18: Western hypocenter cross-section, July 1975 through June 1976. Section location is shown in Figure 1. Depths and distances are in kilometers.

Figure 19: Eastern hypocenter cross-sections by quarter for July 1975 through June 1976. Depths and distances in kilometers.

Figure 20: Central hypocenter cross-sections by quarter for July 1975 through June 1976. Depths and distances in kilometers.

Figure 21: Western hypocenter cross-sections by quarter for July 1975 through June 1976. Depths and distances in kilometers.

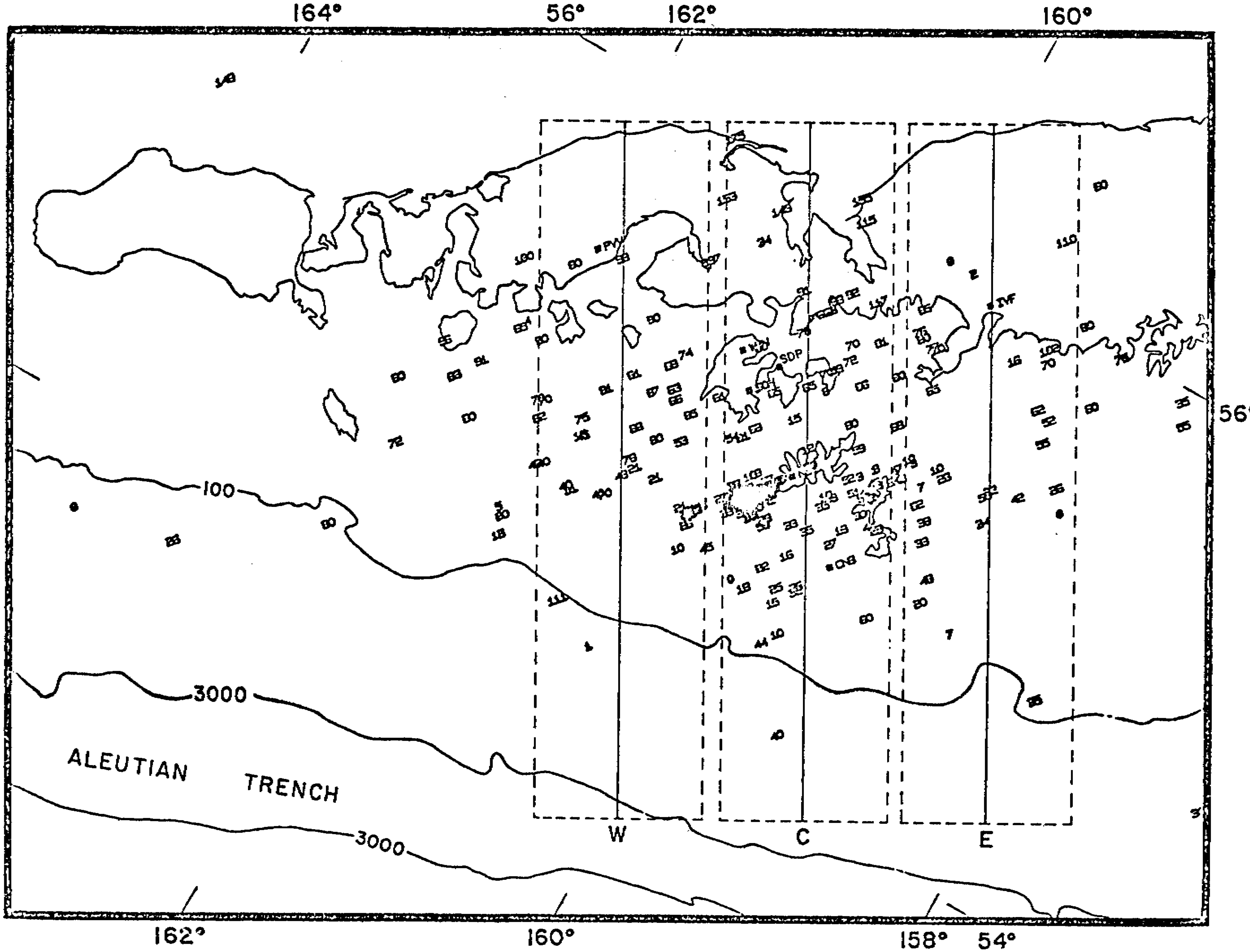

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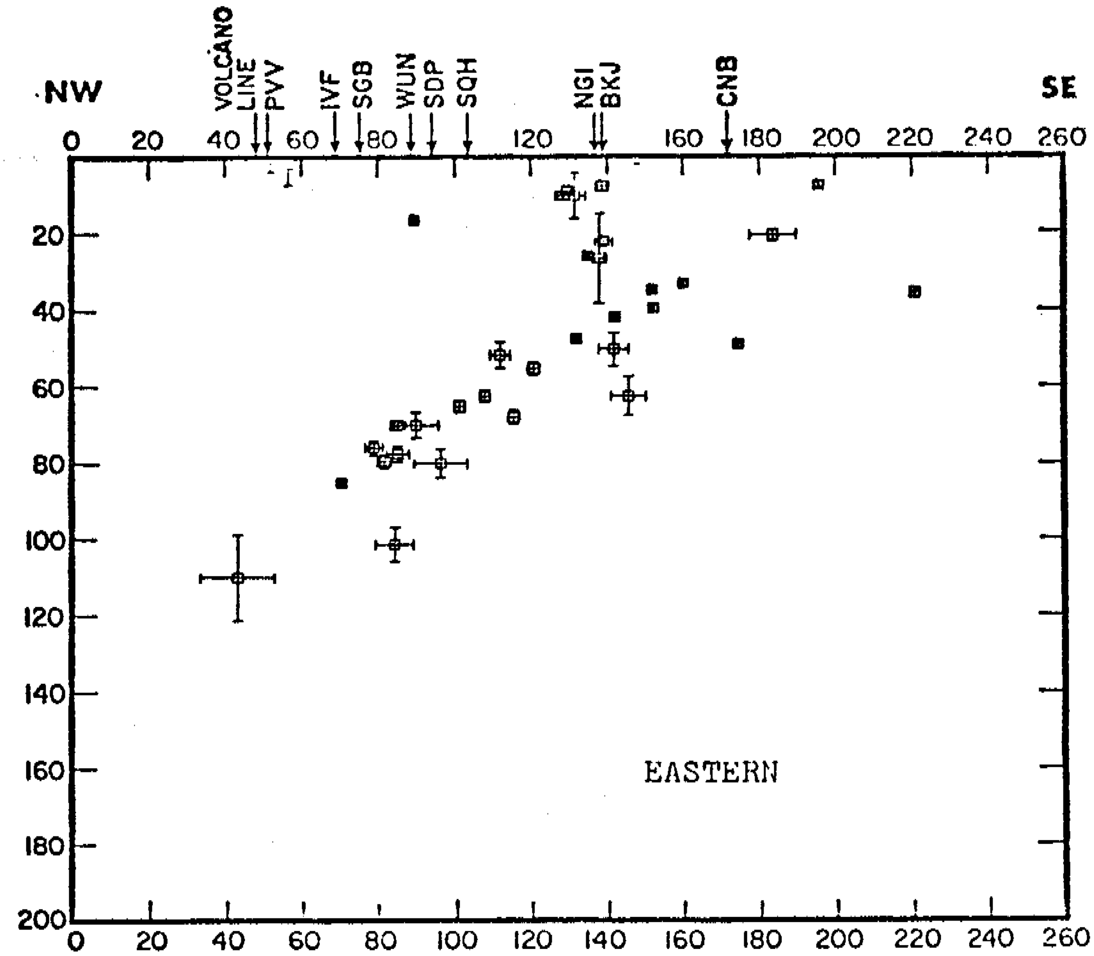
Figure 1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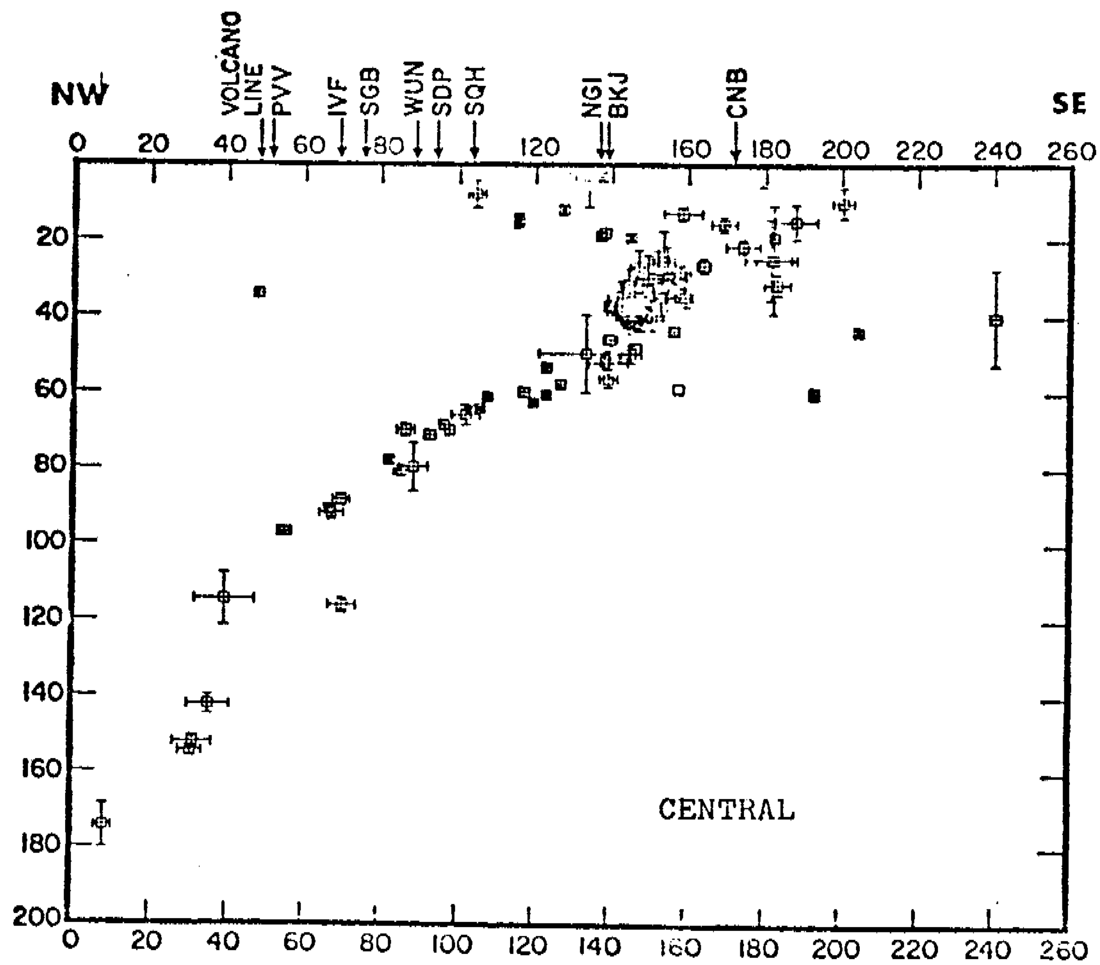
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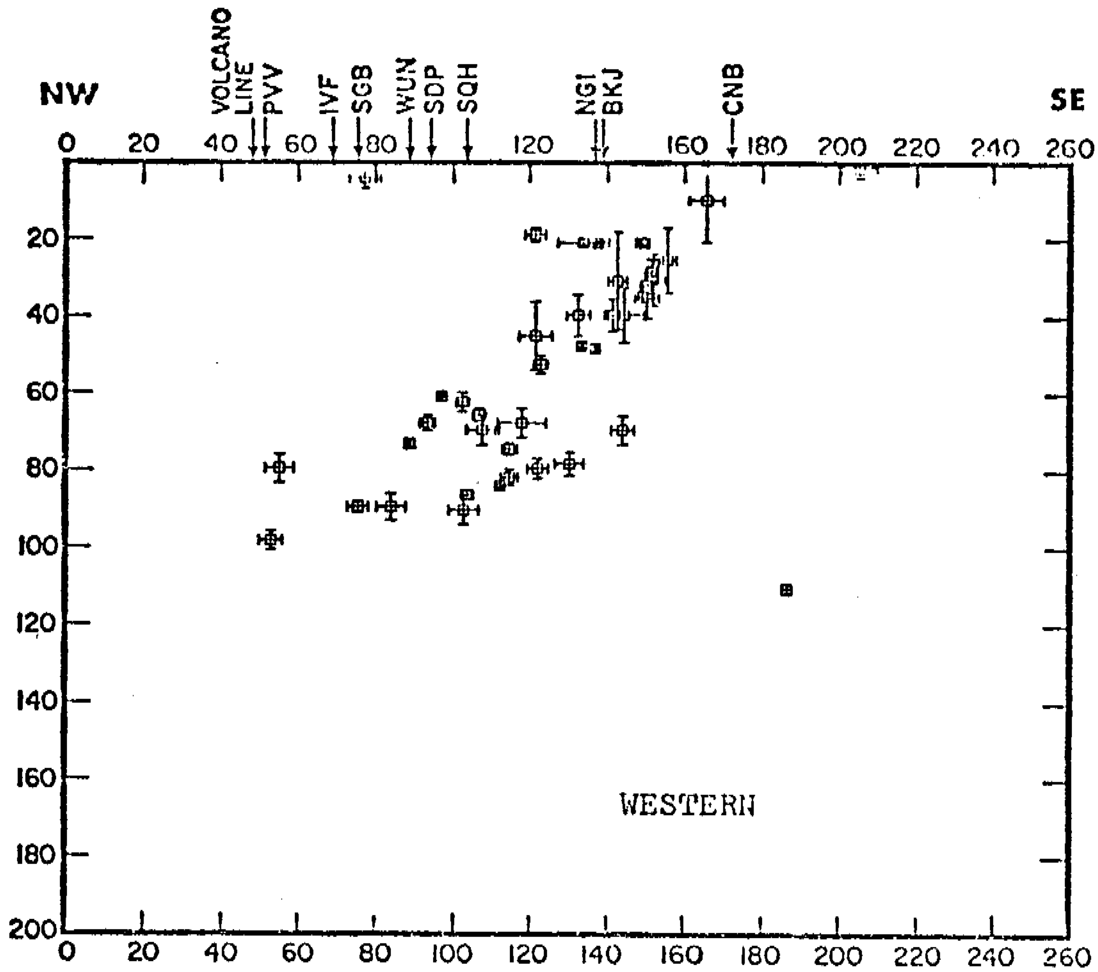

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Figure 3

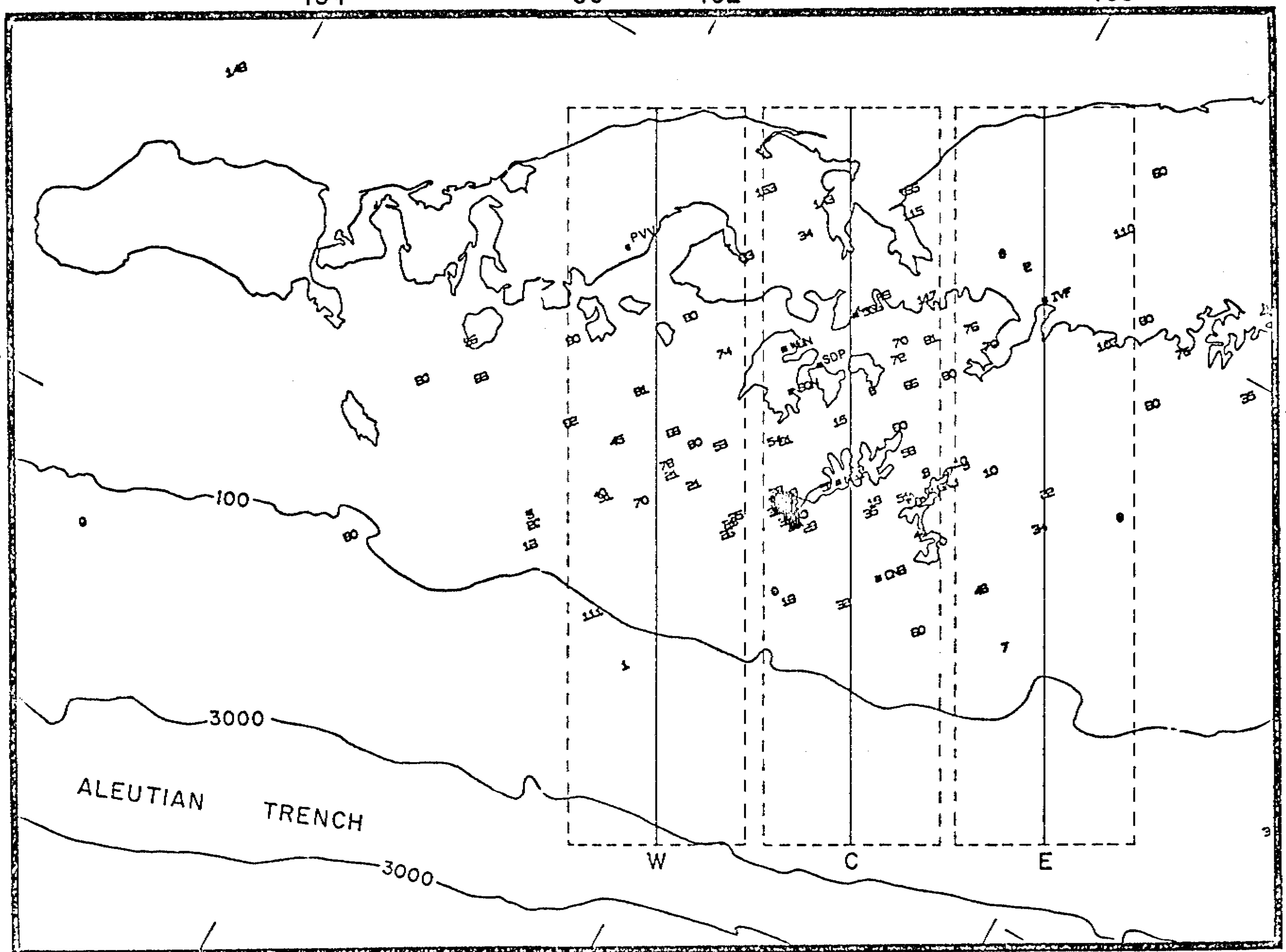

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Figure 4

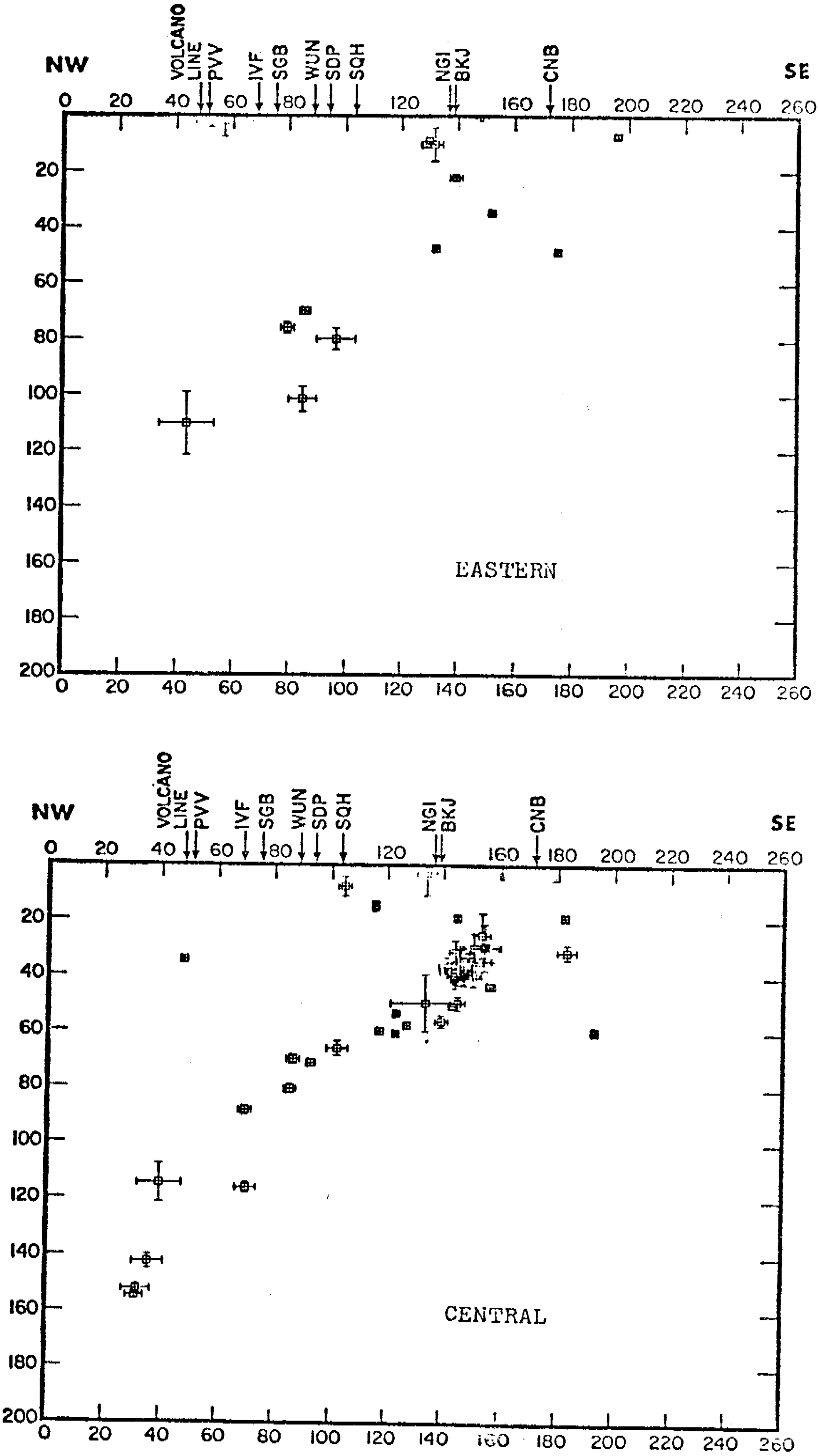

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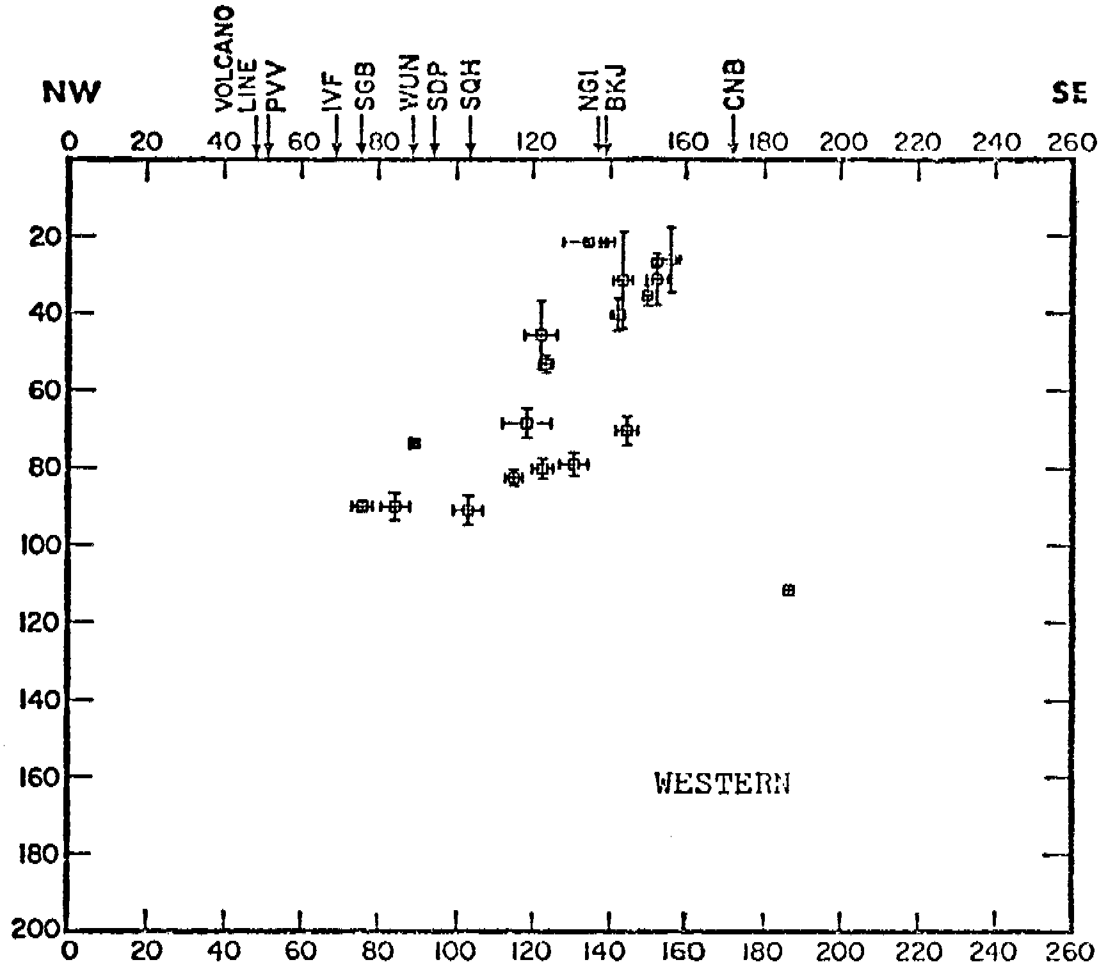
Figure 5



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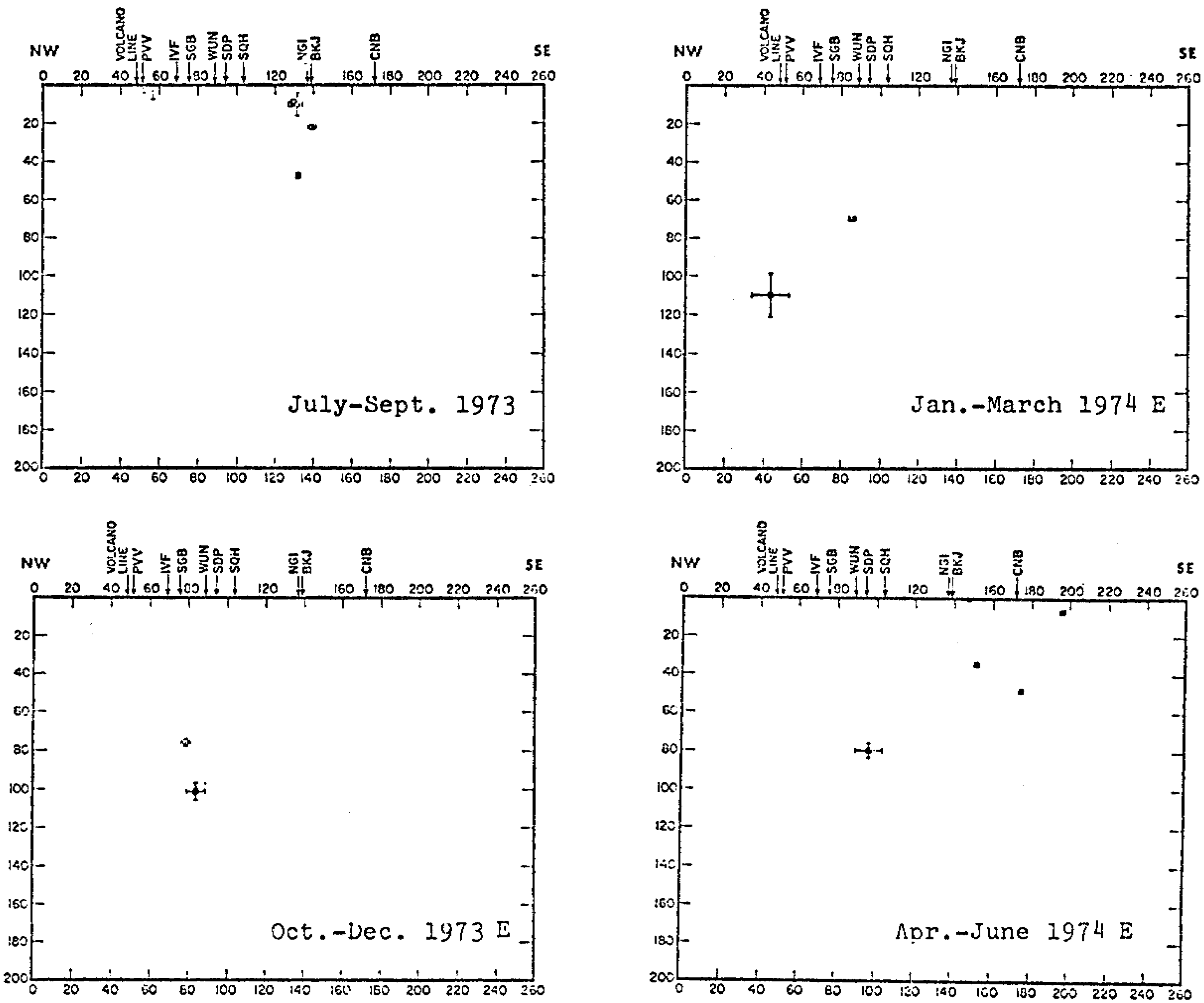
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Figure 7

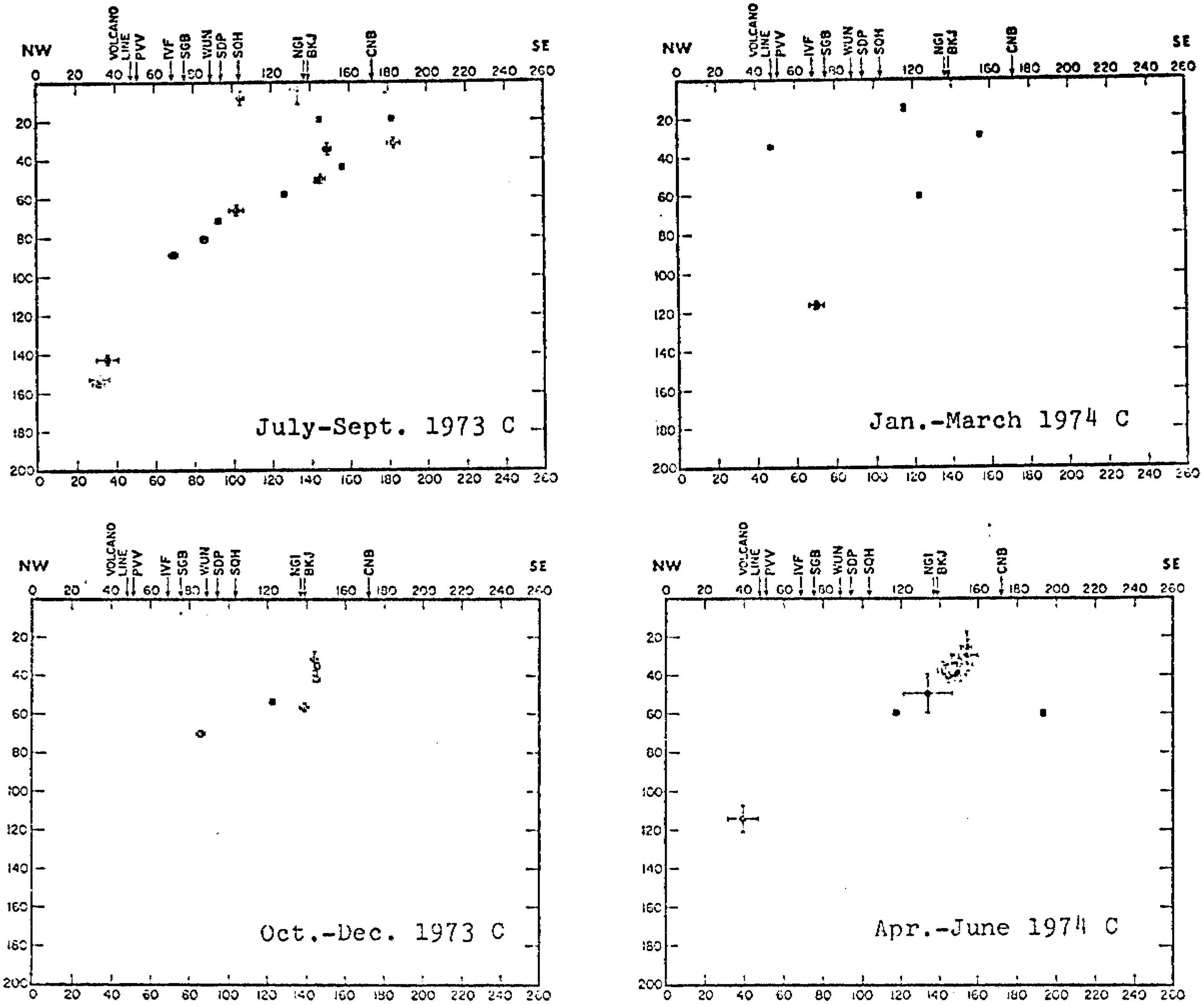
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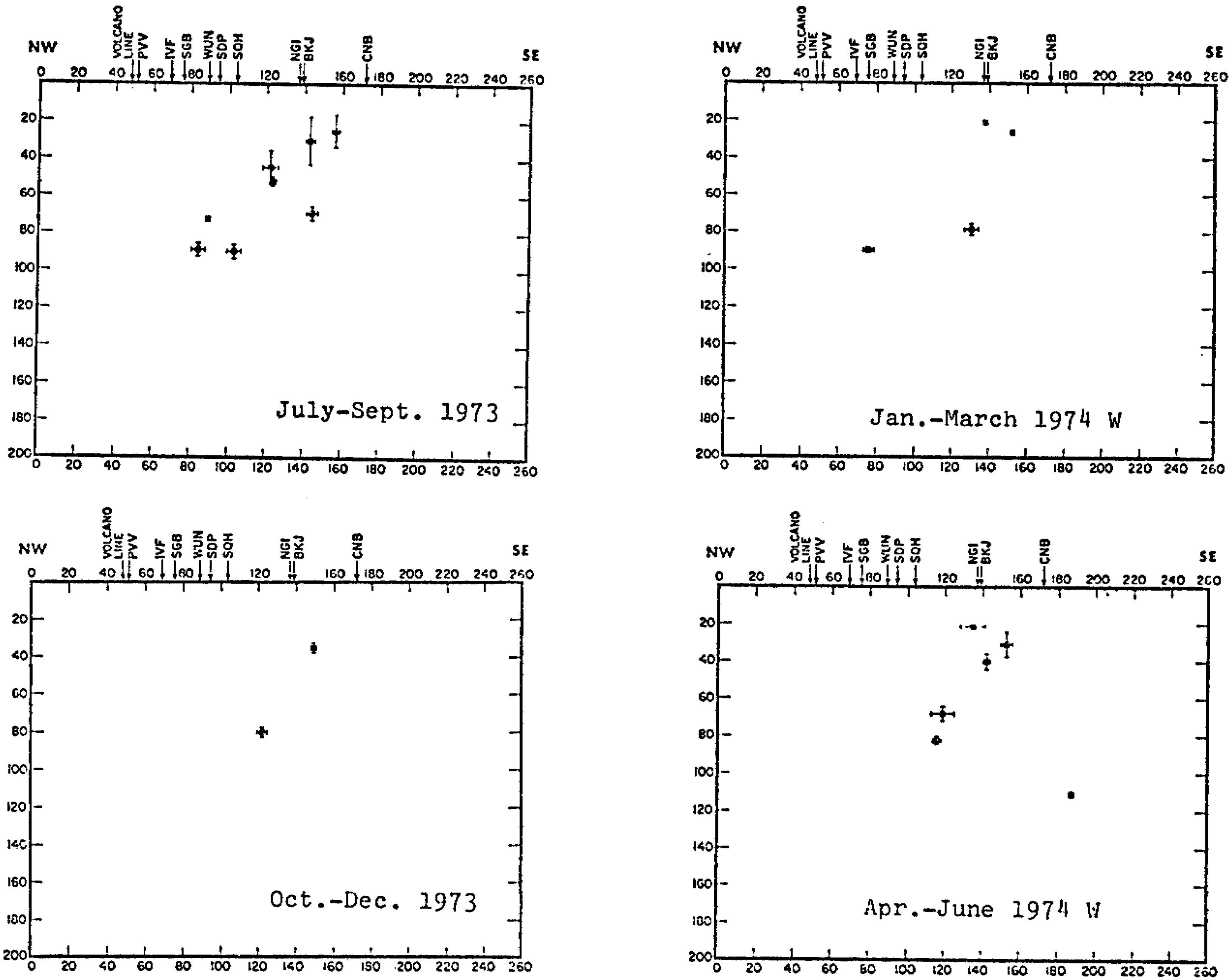
Figure 8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Apr.-June 1974 W

Figure 9

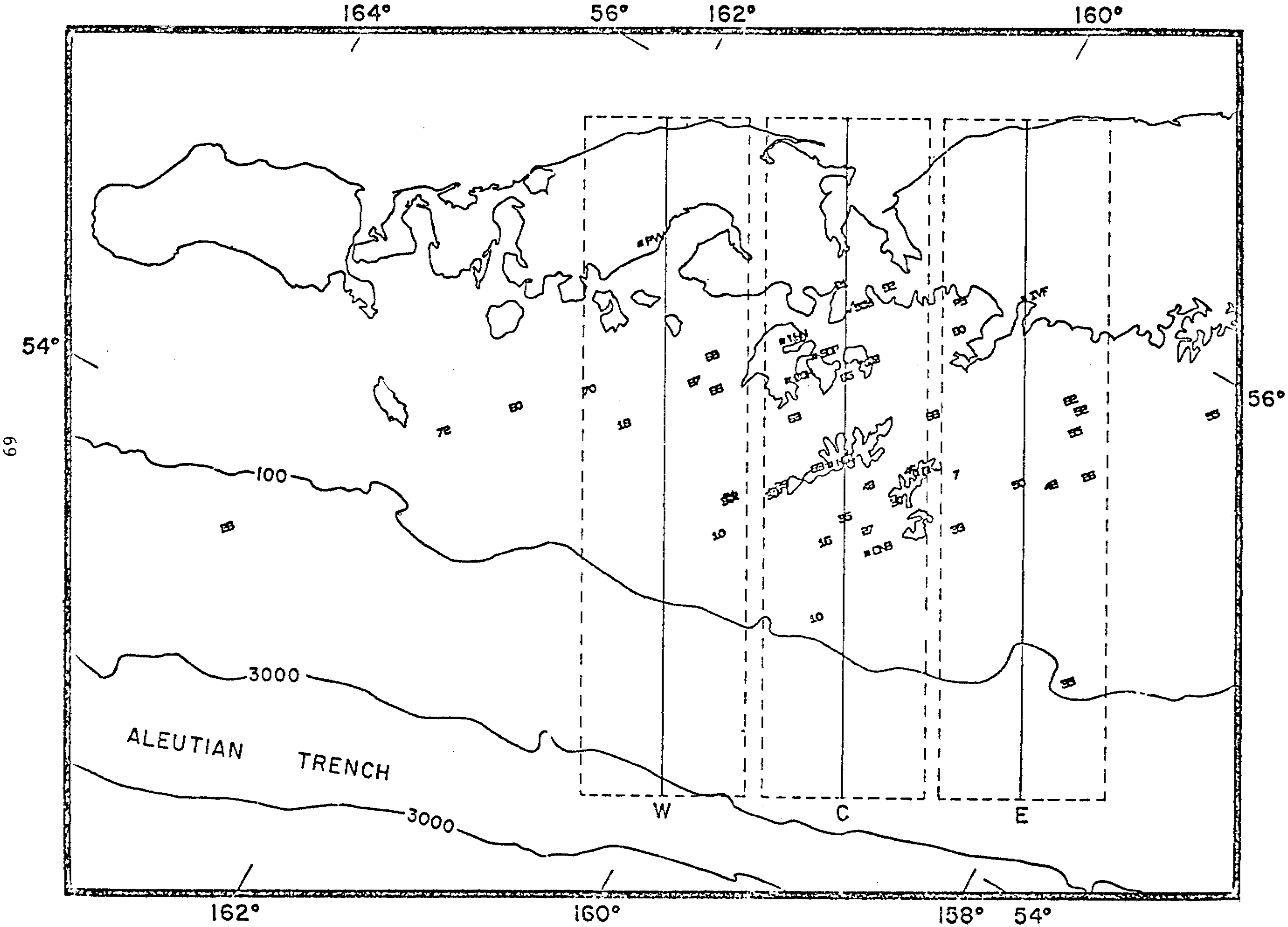
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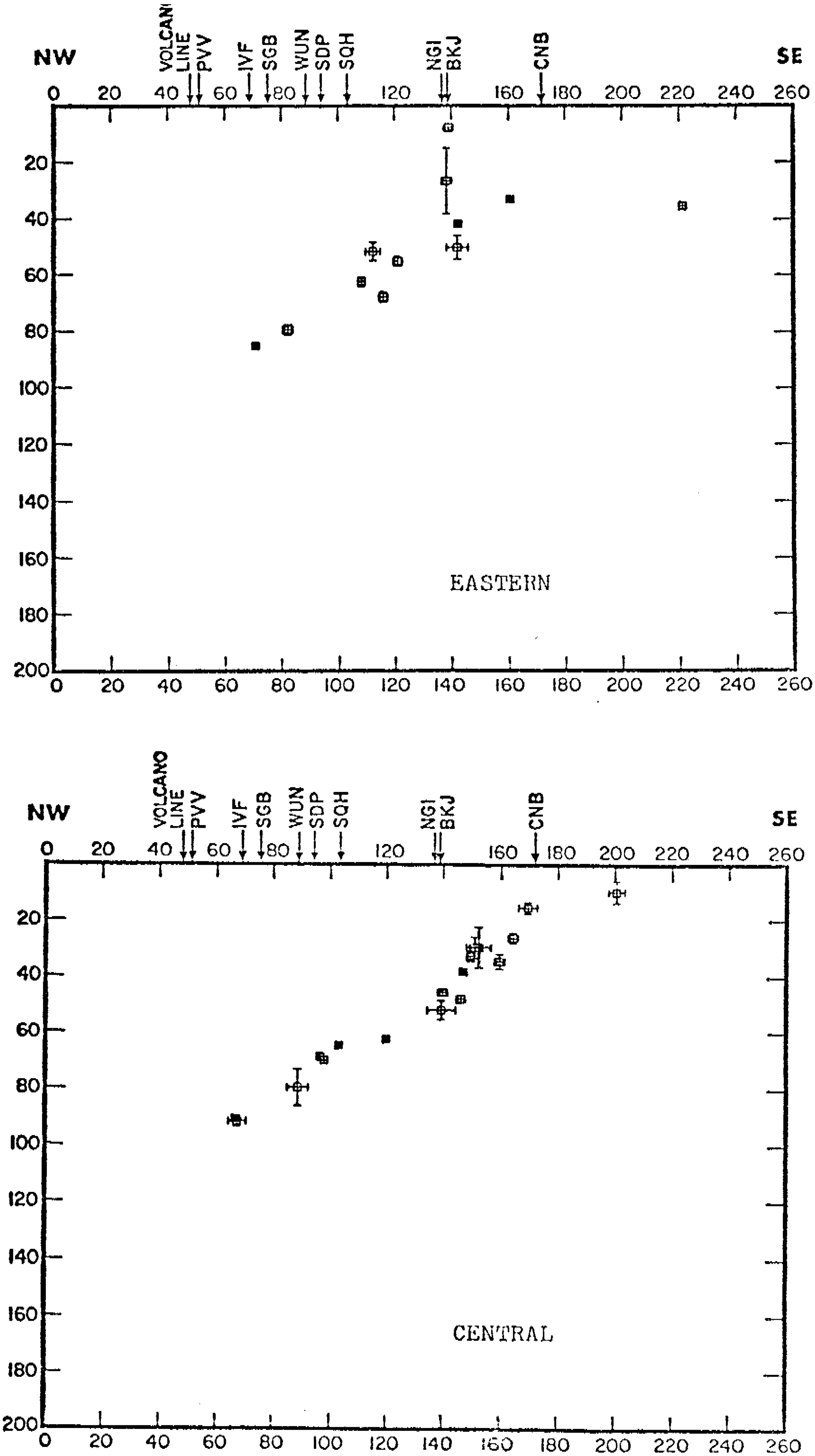
Figure 10



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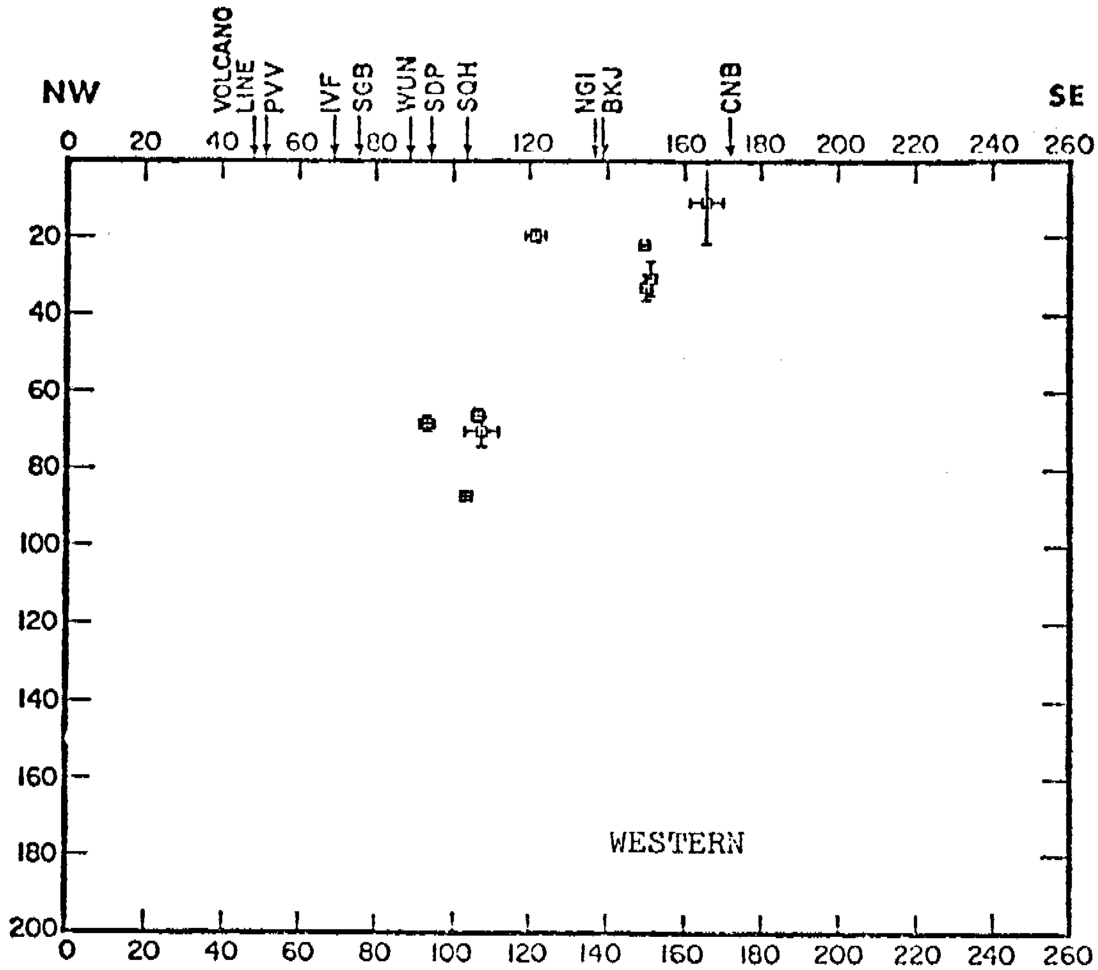
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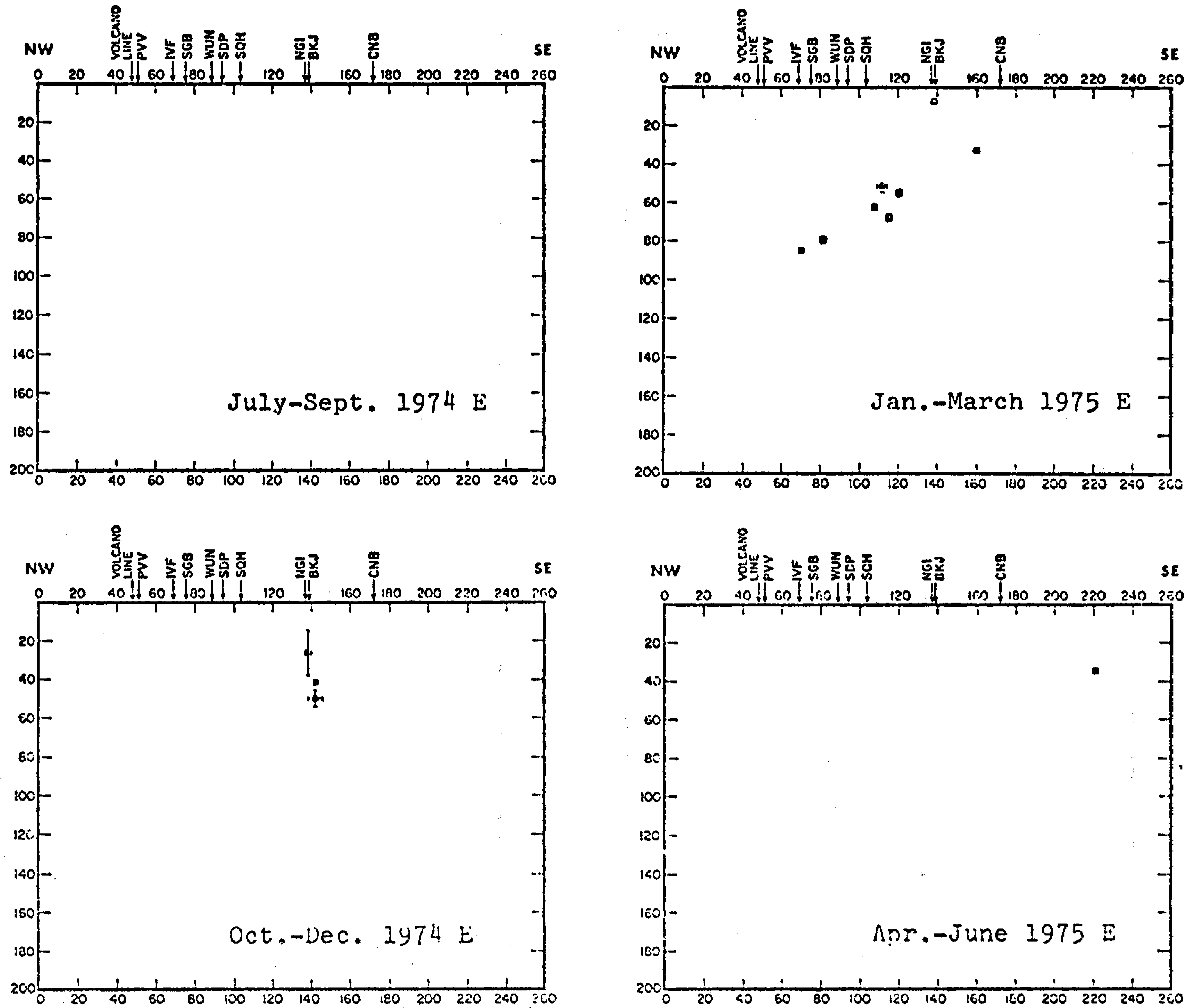
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Figure 13

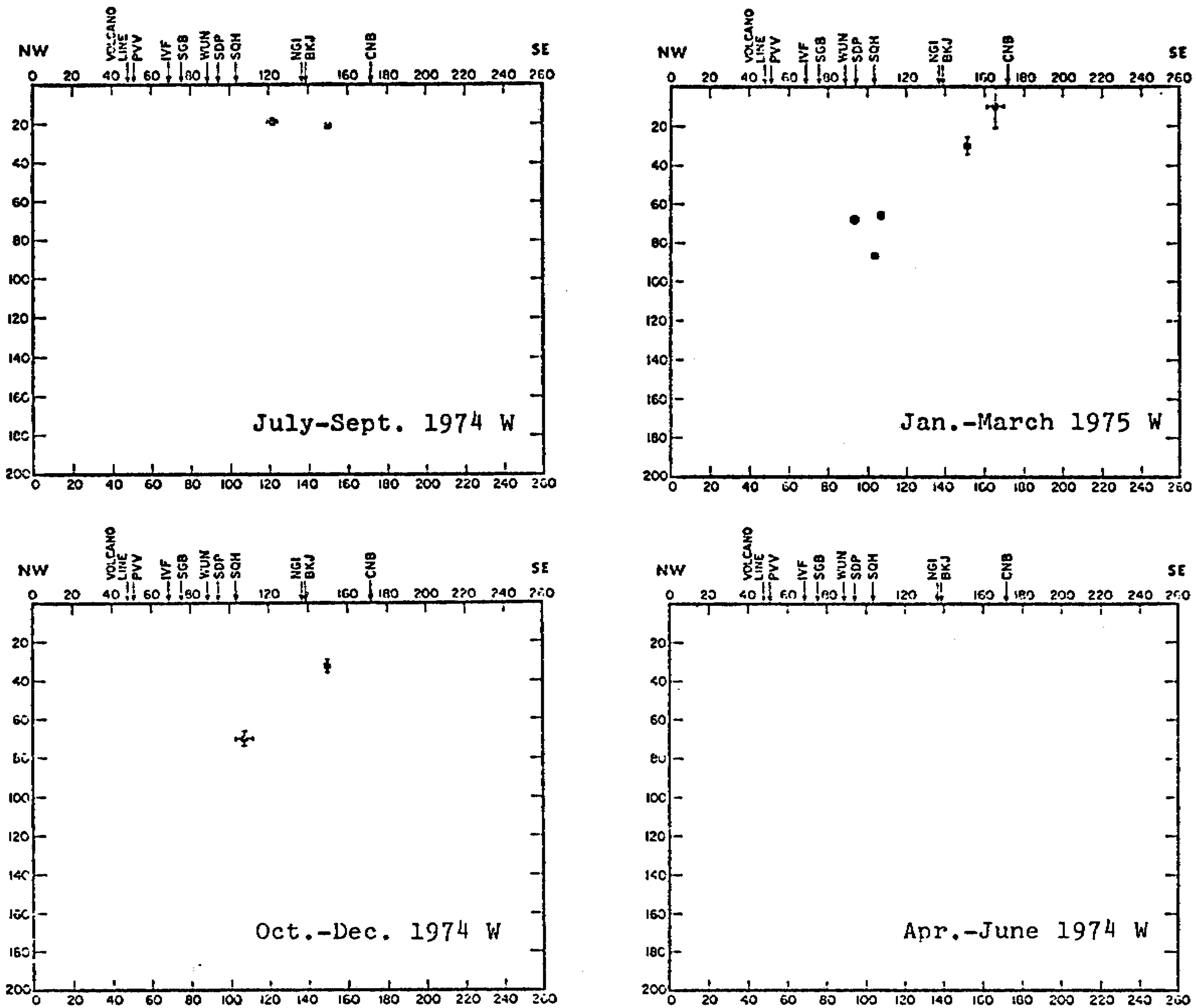
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Figure 15

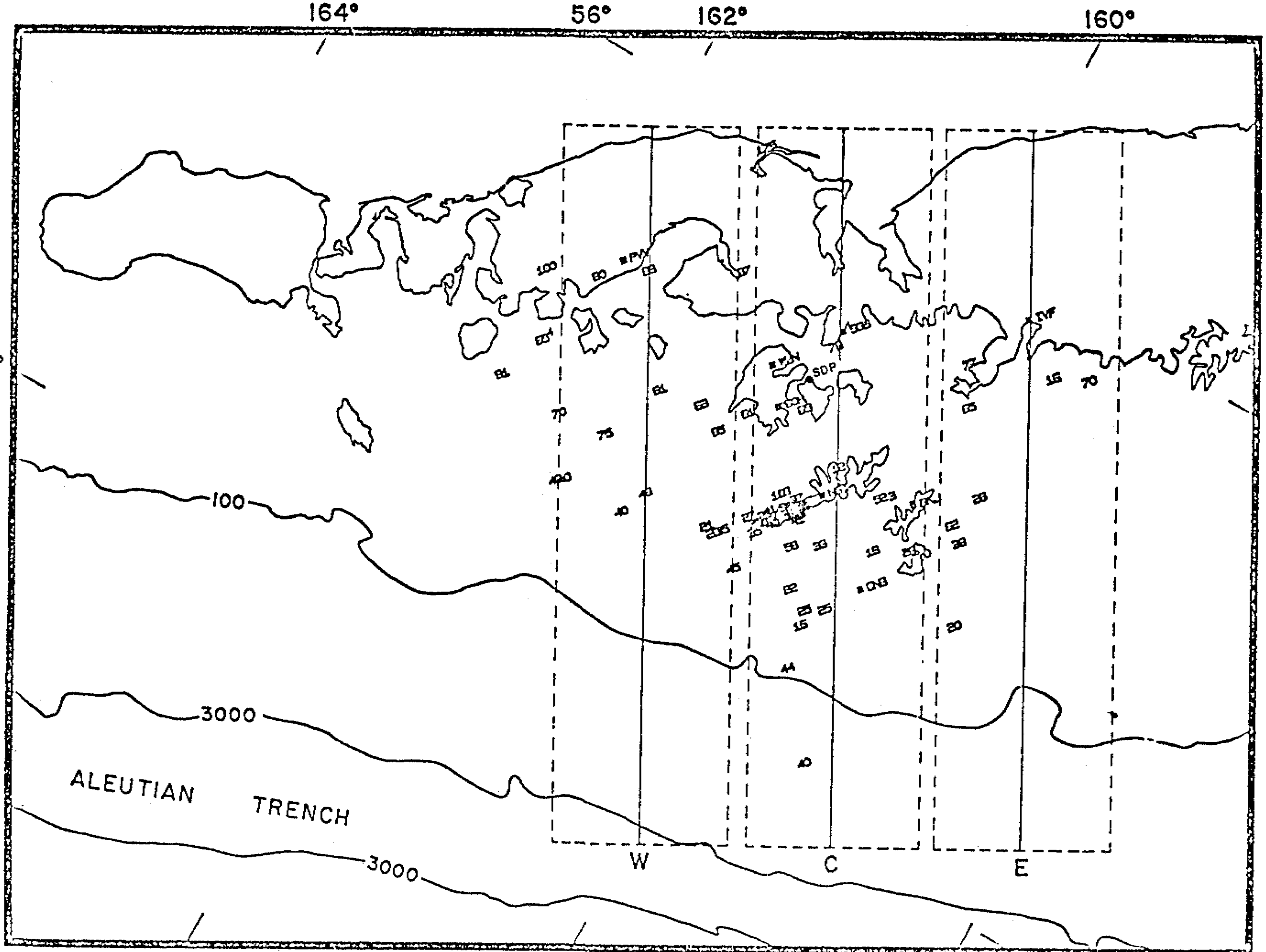
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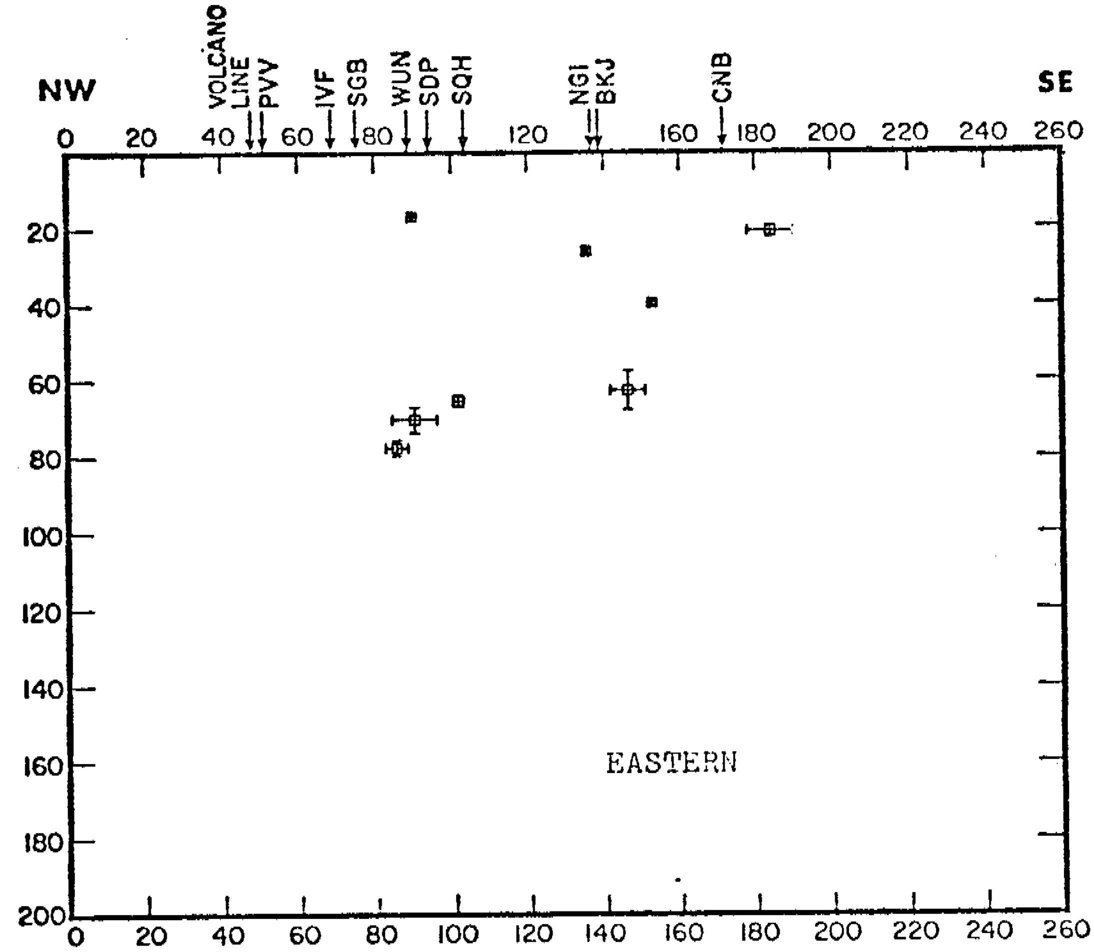
Figure 16



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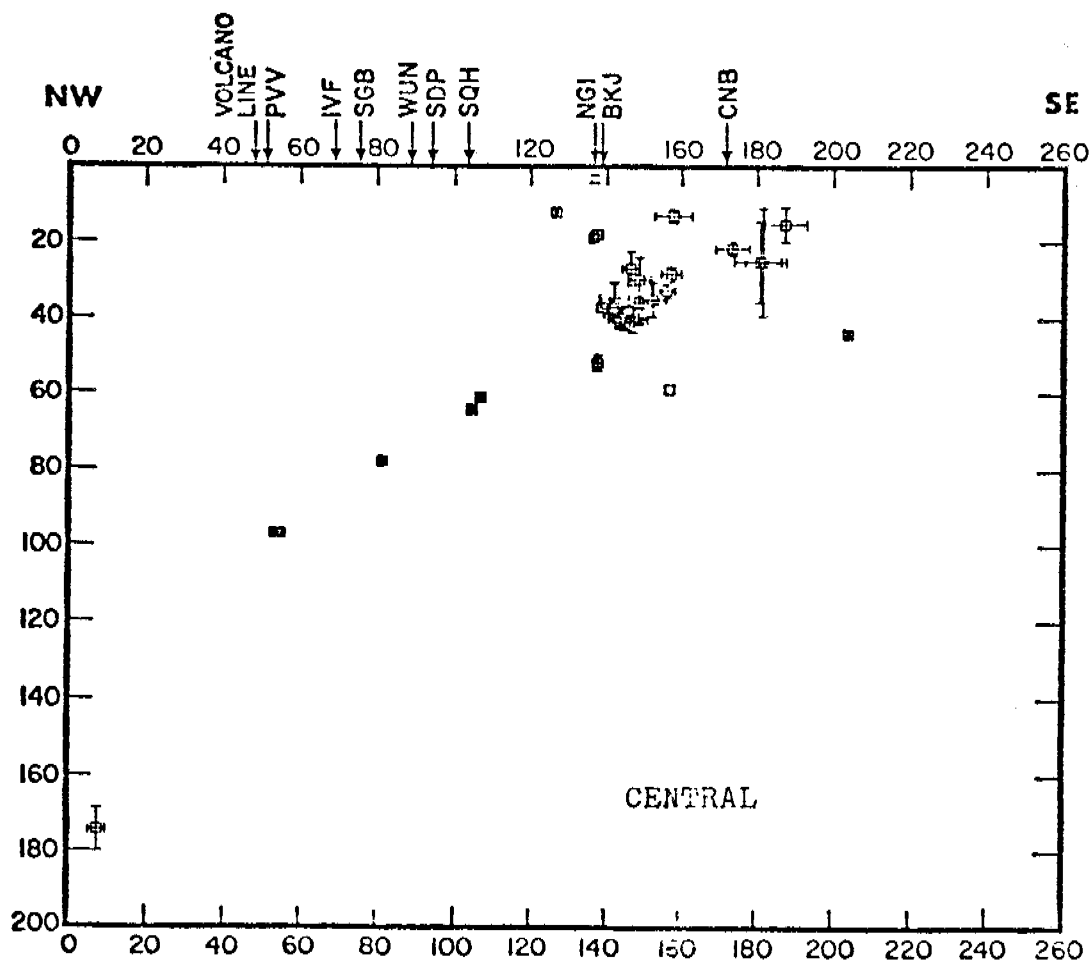

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Figure 17

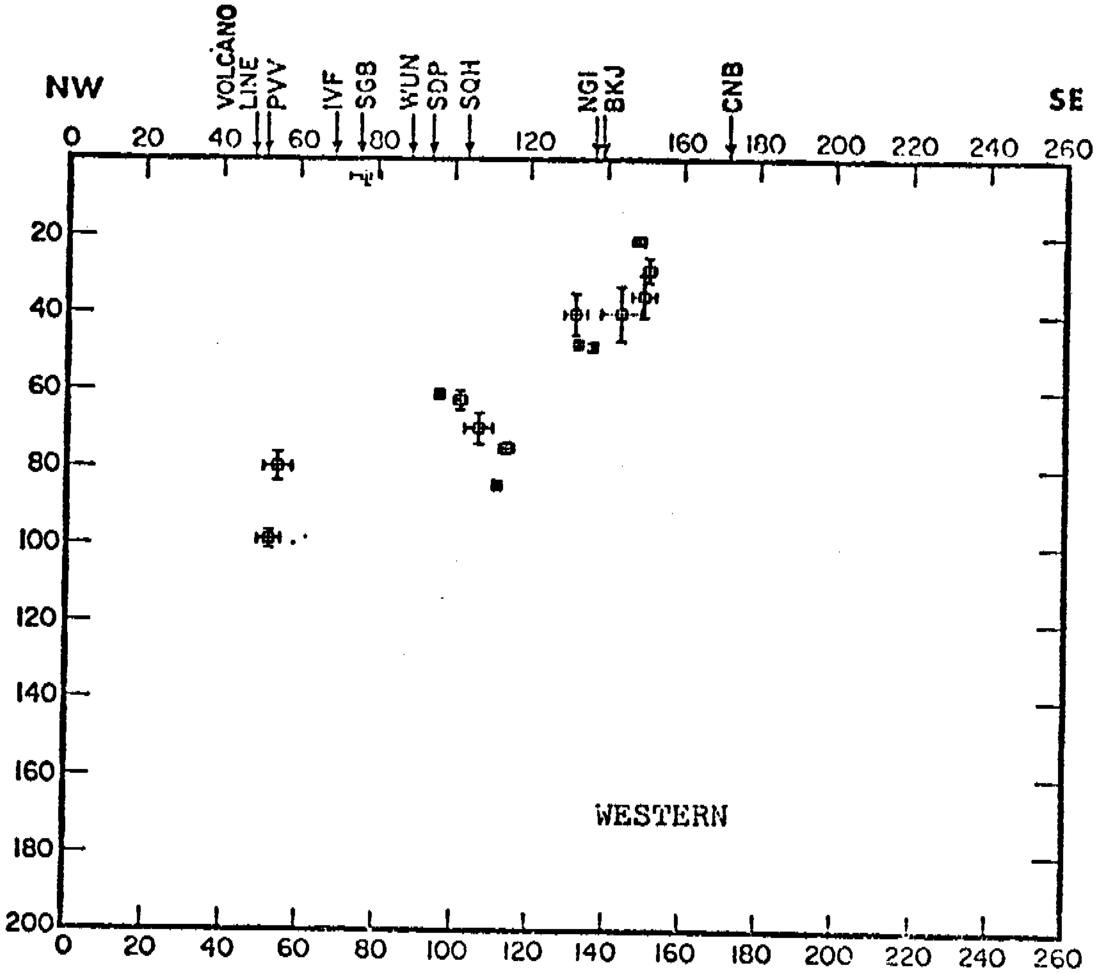
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Figure 18

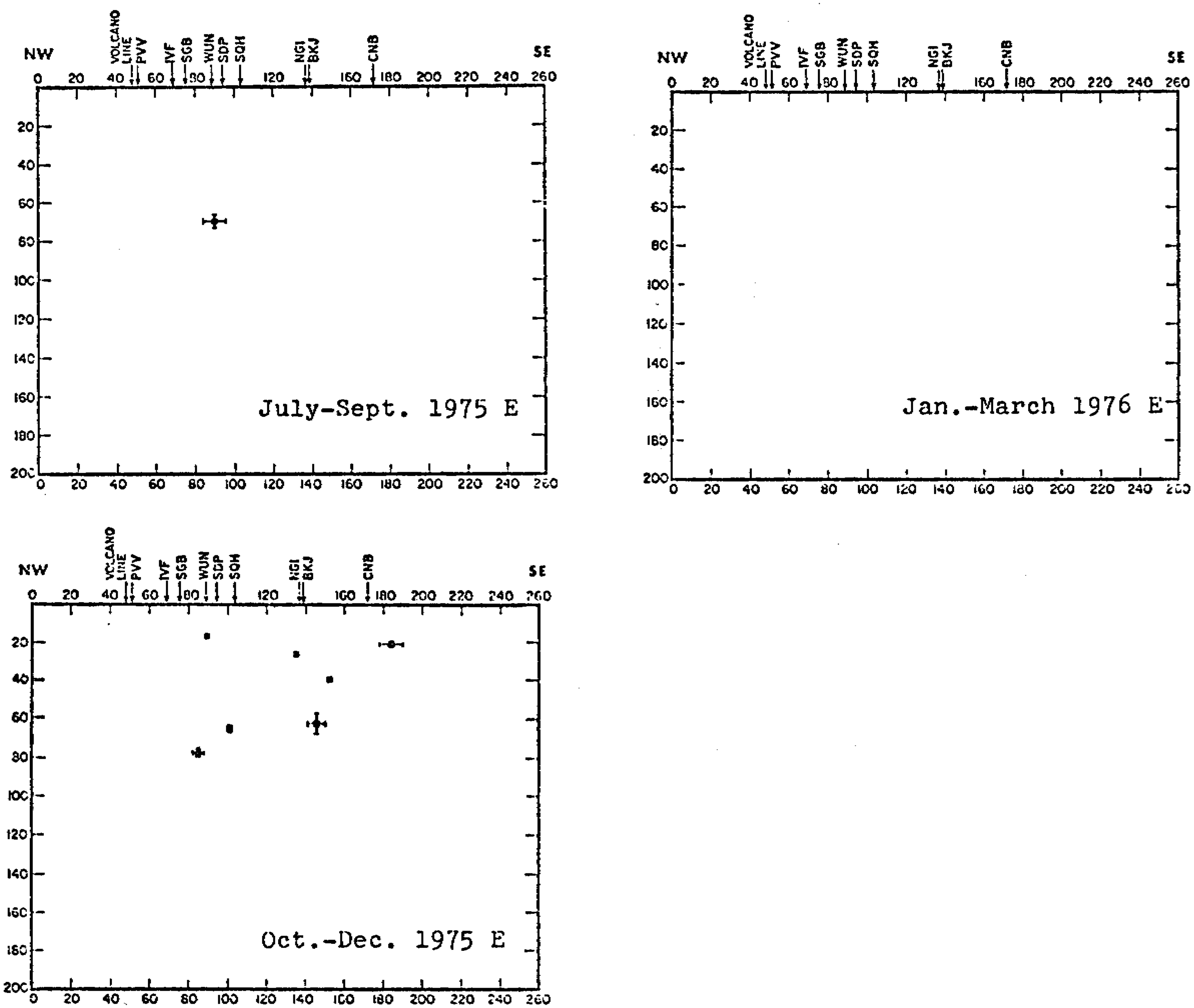
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Figure 19

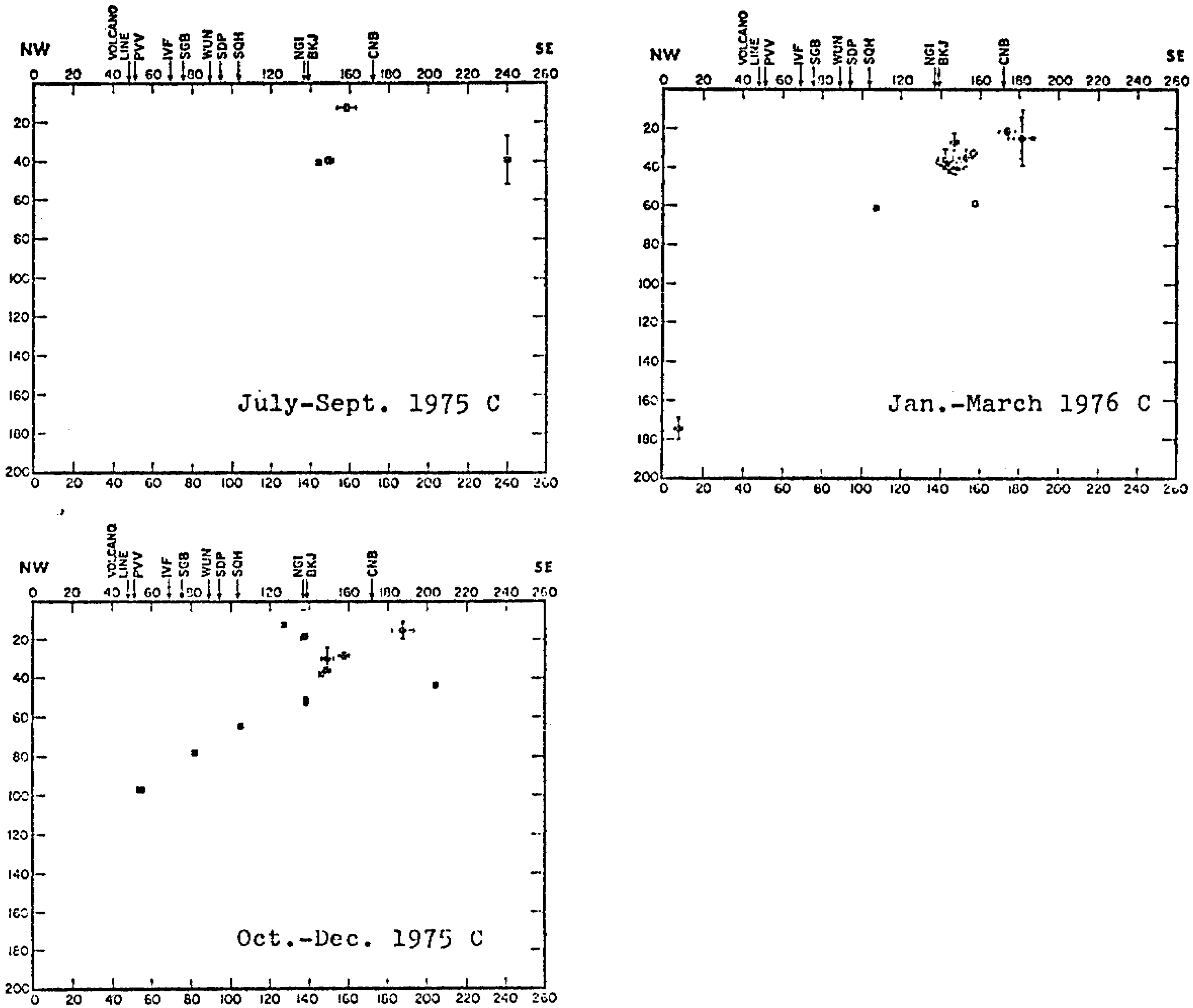
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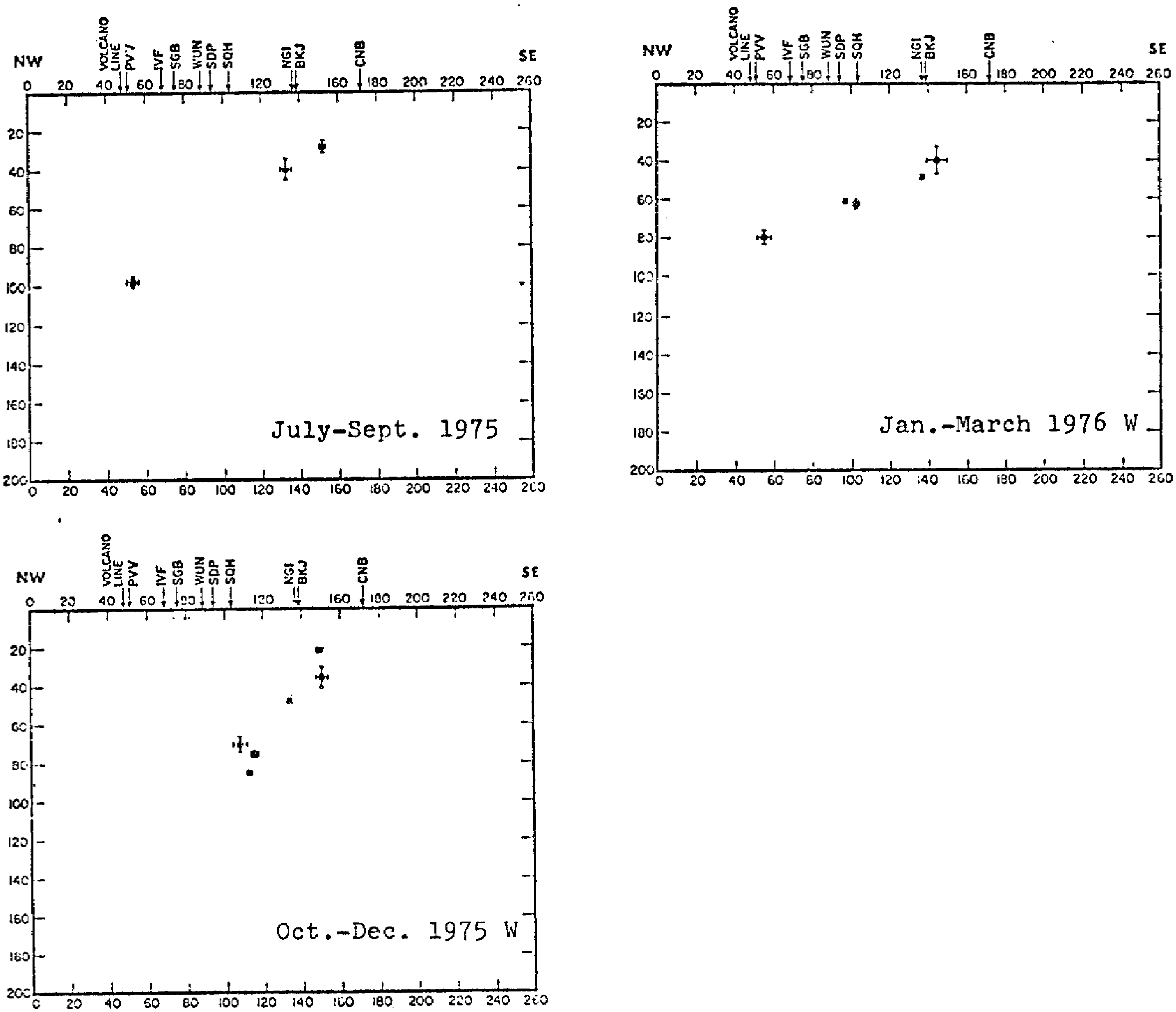
Figure 20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BKJ
CNB
0 20 40 60 80 100 120 140 160 180 200 220 240 260
20 40 60 80 100 120 140 160 180 200
July-Sept. 1975
Jan.-March 1976 W
Oct.-Dec. 1975 W

Figure 21

APPENDIX IV

LEVEL LINE MEASUREMENTS FOR THE SAND POINT LEVEL LINE

A one kilometer north-south level-line on Popof Island has been surveyed annually from 1972 to 1976. The line extends south from the central brass cap of the four-arm Sand Point dry tilt figure to a brass cap on the east side of the airport road. Three additional brass caps, installed near the southern end of the survey line during the 1976 field season, will be used in future surveys as a check on the southern brass cap's stability.

The 1972, '74, '75, and '76 field groups surveyed in both directions. Since only one reading was taken at each turning point of the 1974 survey, there is more uncertainty in this survey data than in the other bidirectional surveys. The 1973 field group surveyed the line once, from north to south.

The results of these surveys are plotted in Figure 1. The RMS error associated with a least square fitted straight line implies that tilting, if any, is less than 30 microradians per year.

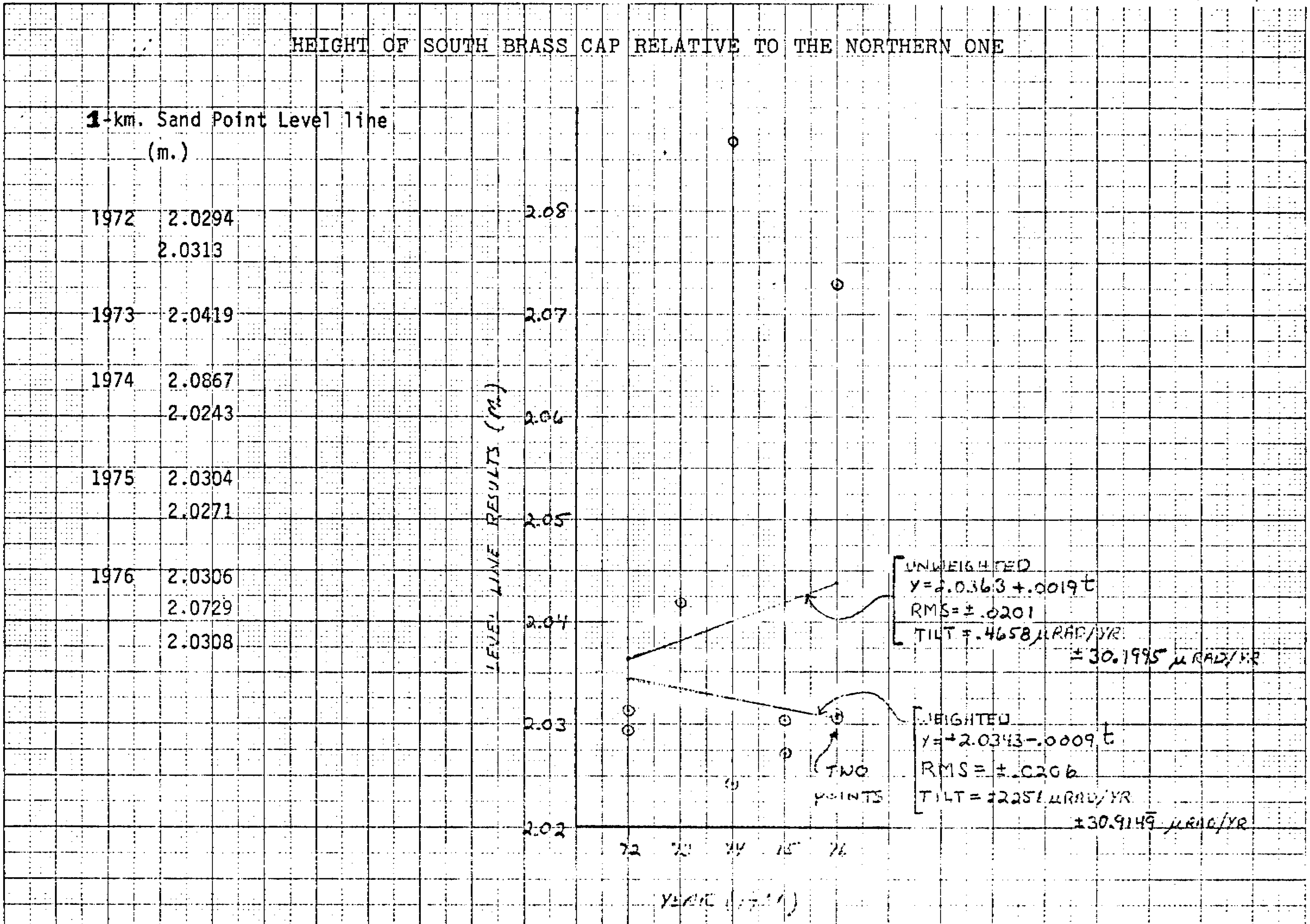

Figure 1: Sand Point level line results 1972-1976. Weights assigned were the inverse of the average difference (in cm) between a height and the others for that year. The average weight was used for 1973.

APPENDIX V

Strong Motion Accelerographs in the Shumagin Gap

During the summer 1976 field season two new Strong Motion Accelerographs were installed on the Alaskan Peninsula/eastern Aleutians. These new installations, in Port Moller (PMA in Figure 1) and Cape Sarichef (CPS) bring to five the number of SMA's currently operated in the eastern Aleutian/western Alaska Peninsula area. The others are at Sand Point (SDP), Cold Bay (CDB) and Dutch Harbor (DUT). Four of the five (except CDB) are operated by Lamont-Doherty Geological Observatory. The Cold Bay SMA is maintained by the USGS's Seismic Engineering Branch. A short description of each installation follows:

Sand Point: The instrument is located in the seismograph vault, which is a small concrete and wood frame structure. The location is 55°20.32'N and 100°29.92'W. The vault is on bedrock, which is Tertiary volcanic breccia.

Dutch Harbor: The instrument is in a small concrete vault, probably on bedrock, which is Quaternary basalt. The vault is behind the airport tower building, and is located at 53°53.87'N and 166°31.82'W.

Cape Sarichef: The instrument here is on the first floor of the two-story building of the Coast Guard Loran Site and Lighthouse. The building sits on volcanic ash of undetermined thickness. The coordinates are 54°35.84'N and 164°54.91'W.

Port Moller: The instrument here is at the White Alice Communications Site (WACS) on the first floor of a four-story building. The coordinates are 55°58.67'N and 160°29.29'W. The building sits on glacial outwash of unknown depth.

Cold Bay: The site here is the first floor of the two-story FAA building at the Cold Bay Airport. This building is also on glacial outwash. The coordinates are 55.21°N and 162.71°W.

These SMA's operate unattended and are normally visited once a year for calibration and record retrieval. The instruments record only when triggered by a local earthquake. We have obtained records of three earthquakes from the SMA at Sand Point (see Figures 2 - 4). Two of these earthquakes triggered the instrument on the P-wave and were identified as M_b = 5.7 and 6.0 earthquakes on April 6, 1974. The third earthquake apparantly triggered the SMA on the S-phase and was identified as the earthquake of July 25, 1975, M_b = 5.7. This earthquake was farther from the instrument than were the two previous earthquakes.

The five Strong Motion Accelerographs currently being operated in this area provide good coverage of the Shumagin Islands seismic gap and should allow us to obtain at least one record for any earthquake larger than M_b = 6.0 occurring in this area.

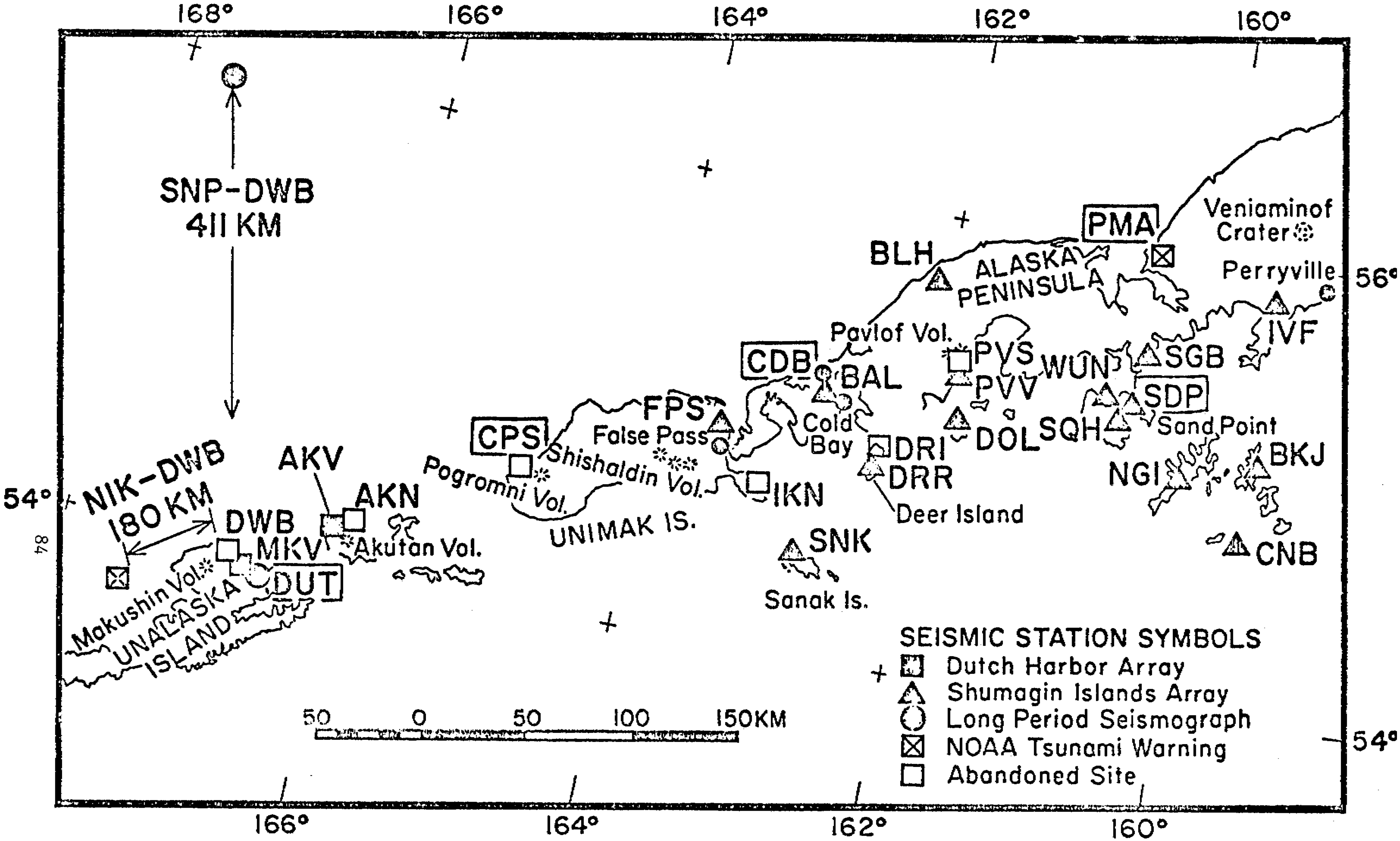

Figure 1: Map of eastern Aleutian-western Alaska Peninsula area showing Strong Motion Accelerograph (SMA) locations (names within boxes) in relation to the other seismograph instruments currently being operated.

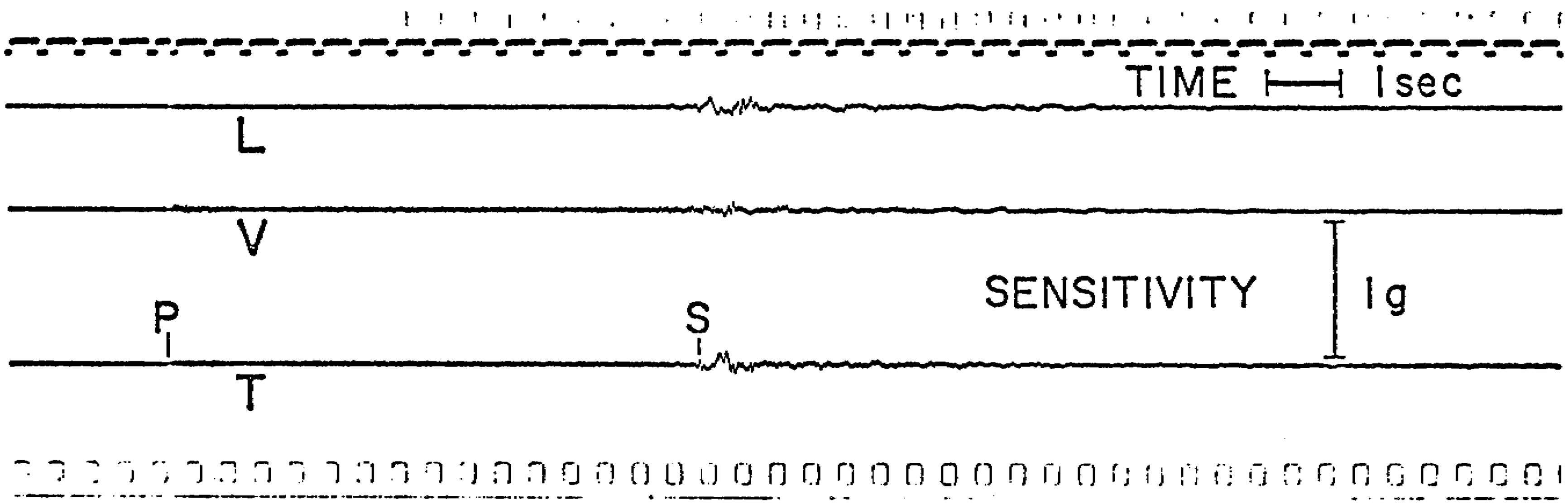

Figure 2: Accelerogram from Sand Point SMA-1. Record from earthquake of 0153 April 6, 1974: epicenter, 54°52.06'N and 160°17.49'W; depth, 37 km; magnitude, 5.7 m_b GS; maximum zero-to-peak horizontal acceleration, L 0.07g, T 0.09g, distance to hypocenter, 64 km. Earthquake parameters are from the L-DGO Shumagin Islands network.

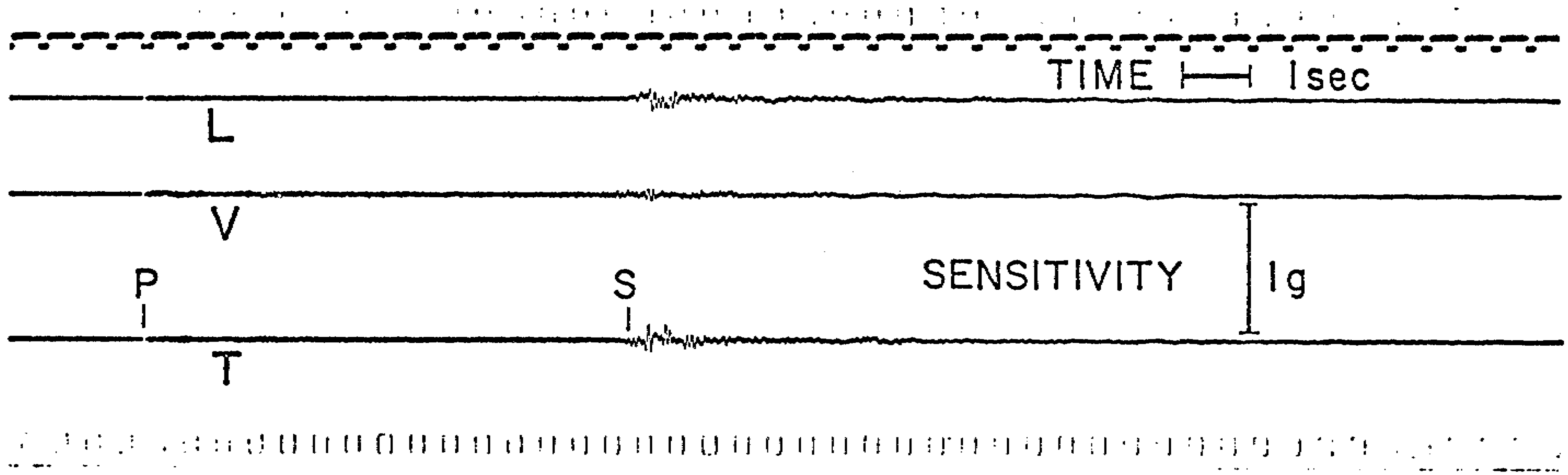

Figure 3: **Accelerogram from Sand Point SMA-1.** Record from earthquake of 0356 April 6, 1974: epicenter, 54°54.33'N and 160°17.71'W' depth, 40 km; magnitude, 6.0 m_b GS; maximum zero-to-peak horizontal acceleration, L 0.10g, T 0.12g; distance to hypocenter, 65 km. Earthquake parameters are from the L-DGO Shumagin Islands network.

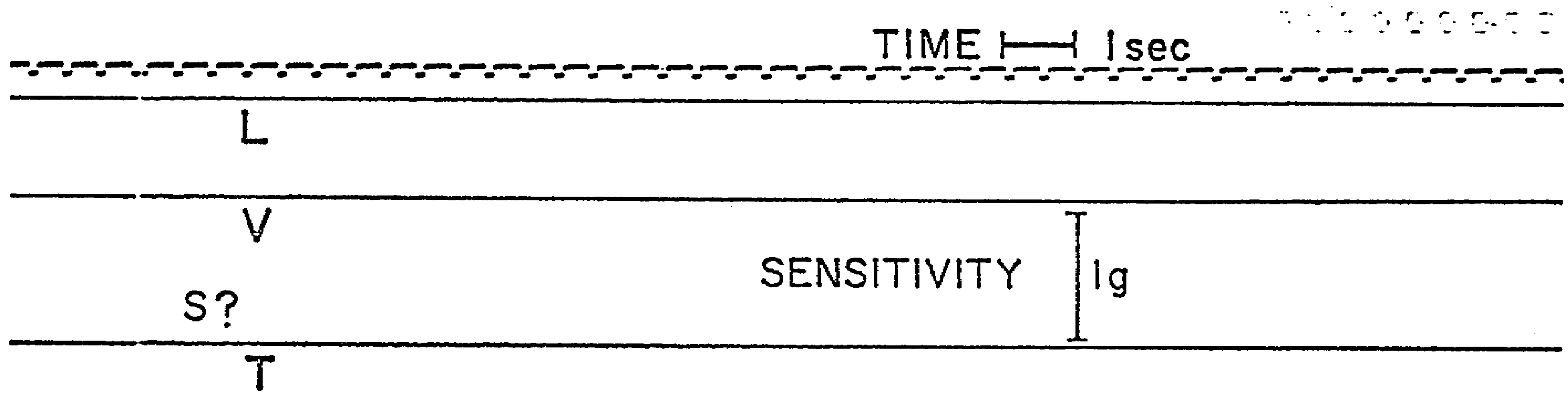

Figure 4: Accelerogram from Sand Point SMA-1. Record from earthquake of 1040 July 25, 1975: epicenter 54.9°N and 160.4°W; depth, 56 km; magnitude, 5.7 m_b GS; maximum zero-to-peak horizontal acceleration, T 0.02g; distance to hypocenter, 76 km. Earthquake parameters are from the WWSSN.

Contract No. NOAA 03-5-022-70 c/c 26321

For month ended September 30, 1976

Total Funded 125,020.00

Expiration Date 9/30/76

Project Supervisor Dr. John Davies
Dr. Klaus Jacob

LAMONT-DOHERTY GEOLOGICAL OBSERVATORY
PALISADES, NEW YORK 10964

ACCOUNT SUMMARY

59% S&W 7/1/75

Ms. E. Wellmon
Dr. R. Bilham

CUMULATIVE

ITEM	BUDGET	EXPENDITURES	COMMITTED OR ENCUMBERED	BALANCE BAL. OVERDRAFT O.D.
—PERMANENT EQUIPMENT	39,560.00	27,547.06		12,012.94 BAL
—MAT. SERVICES AND SUPPLIES	6,302.00	19,380.27		13,078.27 O.D
—PUBLICATION COST	600.00			600.00 BAL
—SERVICES - OTHER		2,226.26		2,226.26 O.D
—COMMUNICATIONS AND SHIPPING	6,000.00	5,787.86		212.14 BAL
—TRAVEL - DOMESTIC	9,960.00	9,064.56		895.44 BAL
—TRAVEL - FOREIGN				
—INSURANCE		12.00		12.00 O.D
—RENTAL - EQUIP. - SPACE	1,574.00	1,113.00		461.00 BAL
—COMPUTER USAGE	1,000.00	1,531.83		531.83 O.D
—SALARIES AND WAGES	34,382.00	30,041.70	4,436.00	95.70 O.D
—FRINGE BENEFITS	5,531.00	5,250.00	865.00	584.00 O.D
—OVERHEAD - I.C.A.	20,111.00	17,724.73	2,617.00	230.73 O.D
TOTALS	125,020.00	119,679.27	7,918.00	2,577.27 O.

7th Quarterly Progress Report
for quarter ending
31 December, 1976
Research Unit - 59

COASTAL MORPHOLOGY AND SEDIMENTATION

Miles O. Hayes - Principal Investigator
Christopher H. Ruby - Co-investigator
Coastal Research Division
University of South Carolina
Columbia, S. C. 29208

Contract No. 03-5-022-82

Project 1. Shoreline of the Northern Gulf of Alaska (Hinchinbrook Island to Dry Bay)

Project 2. Shoreline of Kotzebue Sound (Cape Prince of Wales to Point Hope)

I. Task Objectives

The major emphasis of this project falls under Task D-Y, which is to: evaluate present rates of change in coastal morphology, with particular emphasis on rates and patterns of man-induced changes, and locate areas where coastal morphology is likely to be changed by man's activities and evaluate the effect of these changes, if any. The relative susceptibility of different coastal areas will be evaluated.

Project 1. Shoreline of Northern Gulf of Alaska (Hinchinbrook Island to Dry Bay.)

a) Field and Laboratory Activities

No field work has been carried out on this project during October - December 1976. Final laboratory analysis of sediment samples has been completed. Computer synthesis and data analysis of the sediment samples has also been completed. At this time, our main emphasis is placed on the completion of our final report (expected publication date, March 1, 1977). In addition, we are having our computer programs modified to be compatible with the NODC data bank formats.

b) Results (General)

A three-day meeting with Michael Crane of NODC has resulted in the development of a new program format, which is compatible to our beach profile data. As a result, our beach profiles measured in the Northern Gulf of Alaska (106 profiles) and also in Kotzebue Sound (89 profiles) will be available for magnetic tape storage and retrieval by March 30, 1976; provided there are no problems with the format at NODC. We are presently modifying our "in house" programs to be totally compatible with the program developed for NODC. In addition, we are modifying our "in house" sedimentological analysis programs to comply with NODC formats already in existence. This modification and submission of our sedimentological data is expected to be complete by March 30, 1976.

The Coastal Research Division field teams have completed two detailed field projects at the Metula oil spill site in the Strait of Magellan, Chile, (40,000 tons deposited in the coastal zone), and the Urquiola spill site in La Coruña, Spain (~ 25,000 tons deposited in the coastal zone). Both of these projects are funded by NSF. The synthesis of the data collected is presently under way, and a preliminary ranking of coastal geomorphological type areas and their relative susceptibility to oil pollution and oil longevity once contaminated has been completed (see below). This ranking will be used to construct an impact map for the Northern Gulf of Alaska.

Finally, the study area has been expanded to include the area between Hinchinbrook Island and Cape Yakataga. The oil spill susceptibility maps, as well as geomorphologic and sedimentologic data, will be expanded to include this additional stretch of shoreline.

POTENTIAL OIL SPILL IMPACTS

Introduction

The probability of oil spills occurring on the shorelines of either the Northern Gulf of Alaska or the Kotzebue Sound area increases daily as exploration continues. Development of suspected oil reserves in these areas will inevitably result in some amount of oil pollution. Further, potential large spills from tanker accidents and platform blowouts could seriously affect large areas of coastline, changing sedimentation patterns, biota habitat conditions, and biotic productivity.

The behavior of spilled oil in an arctic or subarctic environment may vary widely from that described for more temperate regions. Evaporation losses are slower, and biodegradation rates are reduced. Robertson et al., (1972) estimated that biodegradation rates at $0^{o}C$ to be 10% of the rates at $25^{o}C$. Oil on ice is extremely difficult to clean up. Isakson et al., (1975, p. 6-27) stated that the only feasible method of dealing with oil spills on ice is burning. In many areas, however, this type of treatment is inadvisable. In addition, the Gulf of Alaska is subject to violent storm activity which is likely to coincide with accidental spills. These storms can eliminate the possibility of a quick response to the spill. The remote nature of this area, as well as Kotzebue Sound, make clean-up efforts extremely difficult and expensive.

Case Studies

Introduction. - It is possible to make some general predictions of oil spill behavior in the study area, based on previous experiences of our research group with two major oil spills, the Metula spill in the Strait of Magellan and the Urquiola spill in northwest Spain, plus documentation in the literature. Oil spills do occur with some regularity, and, in some instances, their effects have been devastating. A listing of some of the major oil spills that have occurred in recent years is given in Table 1 (compiled by Erich Gundlach).

The Metula spill. - The VLCC Metula ran aground on 9 August 1974 while navigating through the eastern passage of the Strait of Magellan (Fig. 1). Over the next month, 53,000 tons of oil leaked from the ship, and 40,000 tons washed onto the nearby shores (Hann, 1974). Because of the remoteness of the area and questionable legal responsibility for the accident, no attempt was made to control or clean up any of the spreading oil. We were able to visit the spill site during August 1975 and found that oil coverage was still excessive in many of the coastal environments that were originally affected (Fig. 2), including beach face and low-tide terrace portions of gravel and sand beaches, tidal flats, marsh areas, and tidal channels (Hayes and Gundlach, 1975; Hayes et al, 1976). Because of the great similarity of the area to the coasts of New England and Alaska, a full study was sponsored by NSF-RANN the following January - March. A total of 66 zonal stations were set up and profiled to determine the overall distribution and perseverence of the oil, as well as the overall geomorphic units present in the affected area. Sixteen stations were

TABLE 1. MAJOR OIL SPILLS

OIL SPILL	DATE	OIL TYPE & AMOUNT (SHORT TONS)	AFFECTED COASTLINE	CONTROL/TREATMENT COSTS	CONTROL/TREATMENT METHODS
Torrey Canyon 7 miles N/E of Isles of Scilly, S/W England	March 1967	Type: Kuwait Crude 2% Bunker C 117,000 tons total 18,000 tons reached British coastline	180 km in Britain 320 km in France Sandy Beaches Rocky Shores Estuaries	$1 million	Detergents Chalk Heavy Machinery Manual Labor
Metula Strait of Magellan, Chile	August 1974	Type: Saudi Arabian Crude 3% Bunker C 53,000 tons total 40,000 tons on coastline	150 km Sand & Gravel Beaches Estuaries Marshes/Tidal Flats	No clean-up or control activities	
Mizushima Refinery Shorebased tank, Inland Sea, Japan	Dec. 1974	Type: Bunker C 46,686 tons 20-40,000 tons on coastline	Rocky Shores Sandy Beaches	Over $100 million	Dispersants Heavy Machinery Booms and pumps Manual Labor
Urquiola La Coruña, Spain	May 1976	Type: Persian Gulf Crude 2% Bunker C 110,000 tons total 25-30,000 ashore	215 km Sandy Beaches Rocky Shores Estuaries Marshes/Tidal Flats	?	Dispersants Booms and Pumps Heavy Machinery Manual Labor
Jakob Maersk Porto, Portugal	Jan. 1975	Type: Iranian Crude 2% Bunker C 80,000 tons total 15-20,000 tons ashore	Sandy Beaches Rocky Shores Shore Facilities	?	Dispersants Booms Heavy Machinery Manual Labor
Santa Barbara Blowout Santa Barbara Channel, Calif.	Jan. - May 1969	California Crude 12,320-124,190 tons total	Rocky Shores Sandy Beaches	?	Detergents Sand Blasters Hydro-blasters Heavy Machinery Manual Labor
Arrow Chedabucto Bay, Nova Scotia	February 1970	Bunker C 18,220 tons total	150-190 miles Sandy Beaches Gravel Beaches Rocky Shores	?	Mechanical Removal Manual Labor
Tamano Portland, Me.	July 1972	No. 6 Fuel Oil 380 tons total 114-138 tons ashore	46 miles affected Sandy Beaches Rocky Shores Marshes/Tidal Flats	?	Mechanical Removal Adsorbants Booms Manual Labor
F.L. Hayes Long Island Sound, Conn.	March 1972	No. 2 Fuel Oil 304 tons total Minor amounts ashore	Rocky Shores Sandy Beaches	?	Booms Adsorbants Manual Labor

selected as representative areas and studied in much greater detail. Trenches were analyzed to determine oil distribution beneath the present beach surface (Fig. 3), and plan-view oil distribution maps were superimposed on our physiographic maps for each locality (Fig. 4).

The distribution of oil within the affected environments assumed many forms. On the beaches, oil was usually preserved at the upper high-tide swash areas and on the low-tide terrace (Fig. 5). In the middle beach face zone, the beach was either swept clean of oil by the waves, or the oil was buried by newly-

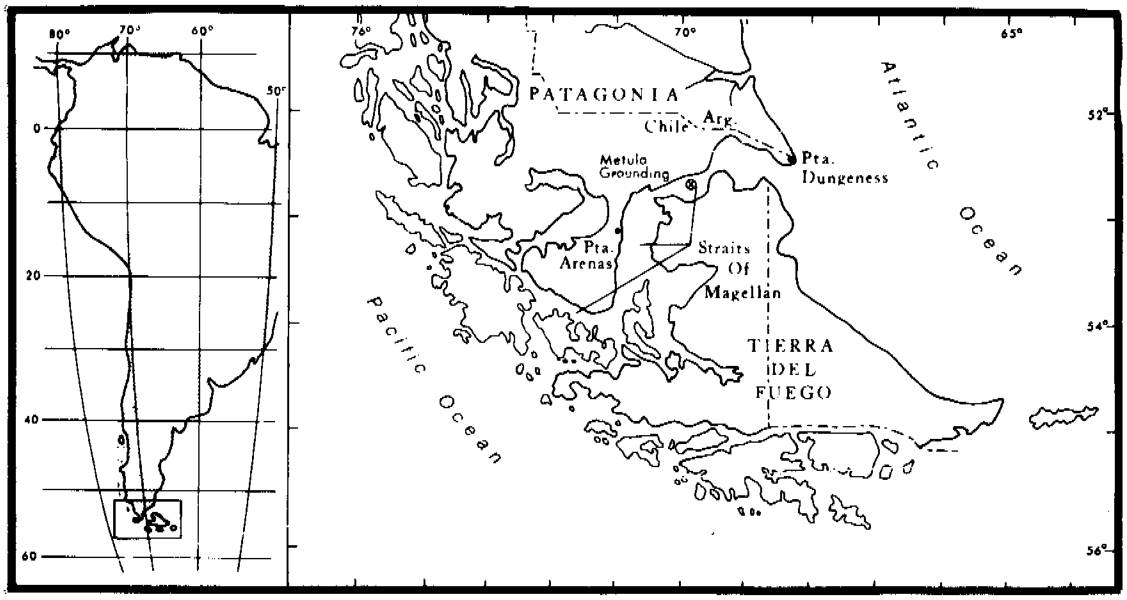

Figure 1. Location of the Metula grounding on 12 August 1974. 40,000 tons of Saudia Arabian crude were spread over 150 km of shoreline (Hann, 1974).

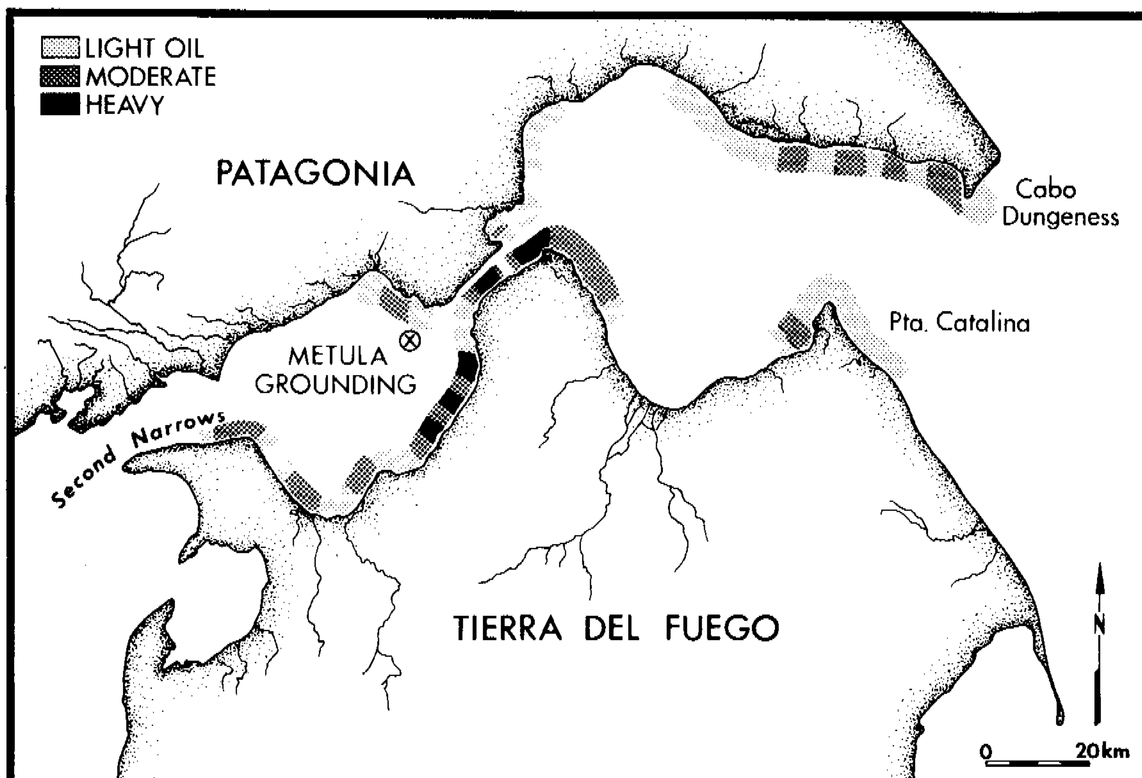

Figure 2. Distribution of oil spilled by the supertanker Metula in August and September 1974. Sand and gravel beaches, tidal flats, low-tide terraces and marshes were heavily affected. Map based on study conducted by the Coastal Research Division in January-March 1976.

deposited sediment. The sheltered tidal flats and salt marshes were the most severely-affected zones. Gravel areas were also highly affected, being especially susceptible to penetration by the oil.

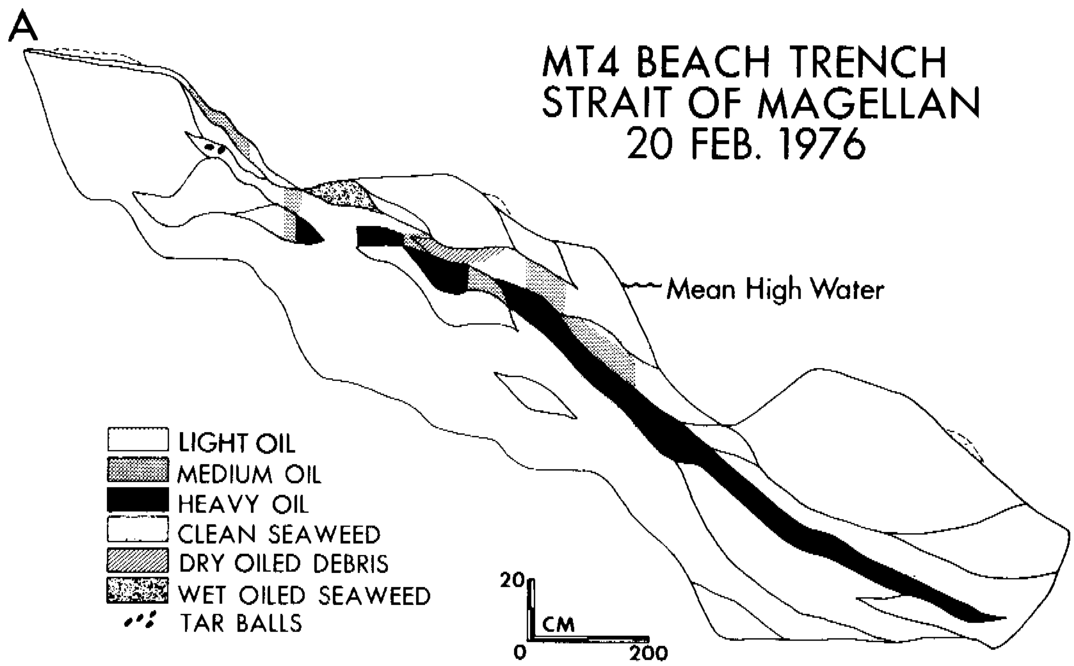

Figure 3. Oil in beach sediments at <u>Metula</u> oil spill site. Cross section of trench through beach. Oil occurred in layers to depths of 50 cm beneath the surface on the date the trench was dug (20 February 1976), 18 months after the spill.

The <u>Metula</u> oil spill site is similar in many ways to our study areas in Alaska. Alaskan beaches are often exact duplicates of those studied in Chile. Sediment sizes and compositions are similar. There are also numerous similarities in the dynamics of the two areas. In addition, they show similar geologic histories (glaciated), although the Alaskan areas are still undergoing active glaciation.

<u>The Urquiola spill</u>. - At 8:00 a.m., 12 May 1976, the supertanker <u>Urquiola</u> ran aground at the entrance to La Coruña Harbor in northwestern Spain. The ship exploded in the early afternoon. Part of its cargo of 110,000 tons of crude oil burned, but approximately 25-30,000 tons washed into the coastal environment. After nine days, the oil was dispersed over 60 km of shoreline.

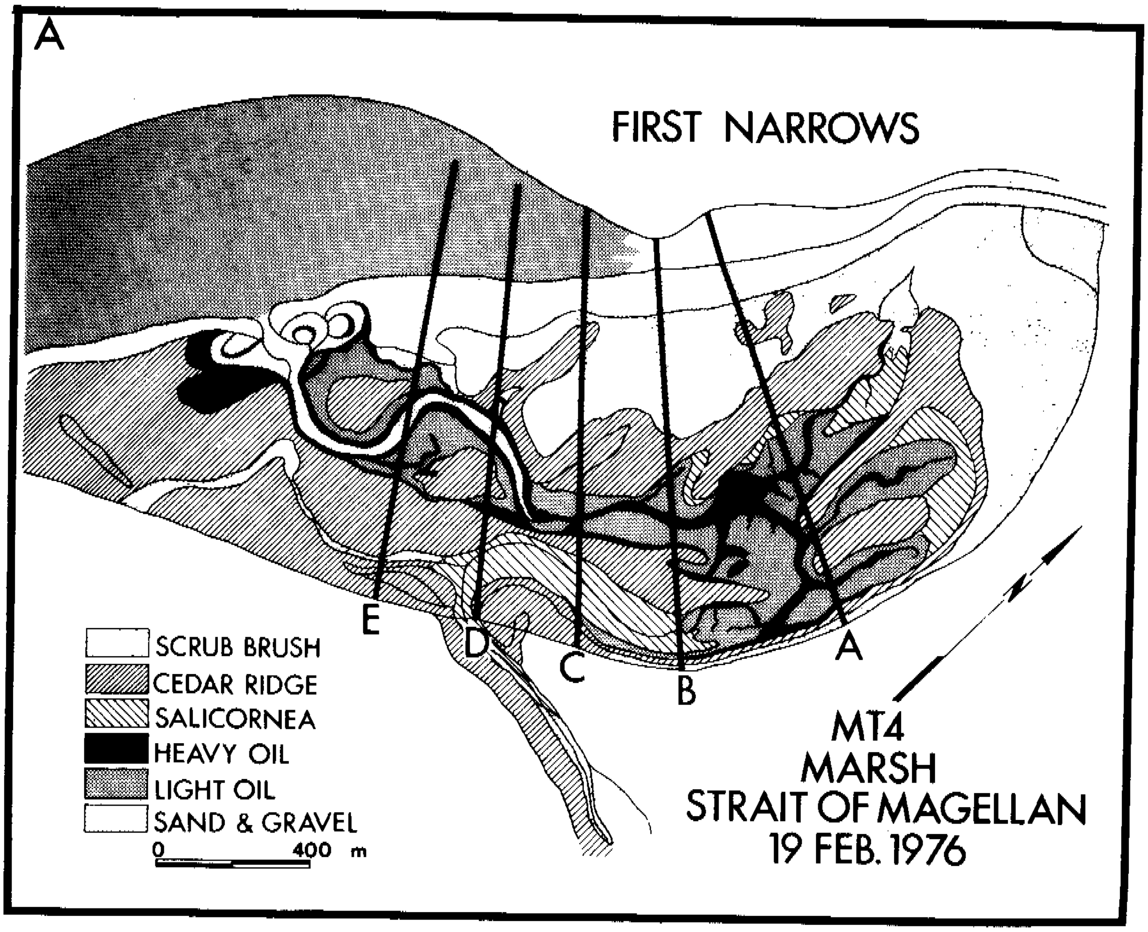

Figure 4. Plan view of oil distribution on 19 February 1976, in small tidal estuary (East Estuary) at Metula oil spill site. Note increased concentration of oil along the minor levees of the main channel.

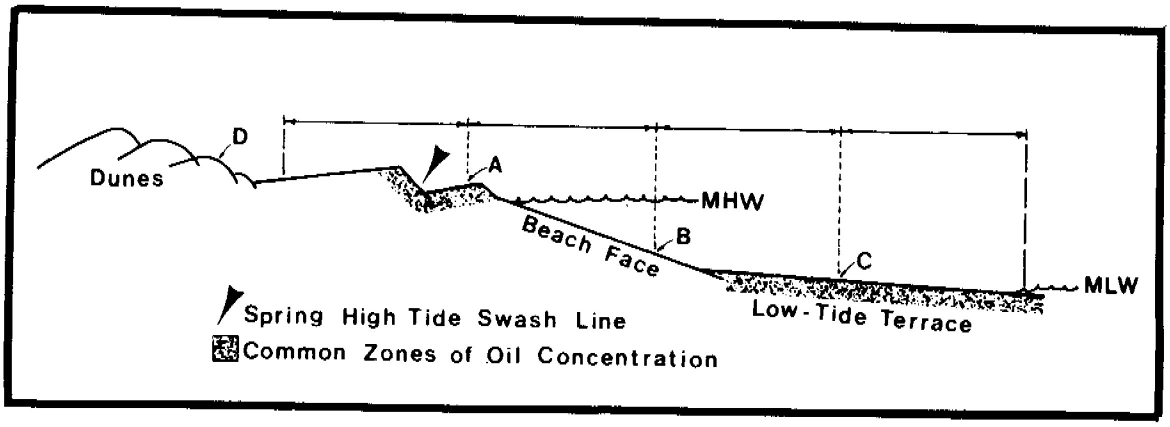

Figure 5. Typical beach profile of the Metula oil spill site, showing the zones of maximum oil concentration one year after the spill.

At the end of 30 days, a total of 215 km of coastline was affected.

A preliminary study of the Urquiola spill was carried out by the principal investigator and 6 associates immediately after the spill, from 17 May through 10 June 1976. Many different coastal environments were affected by the oil, including open ocean beaches, rocky cliffs, protected beaches, tidal flats, and marshes. The Urquiola site also shows some similarities to Alaskan study areas in that it is predominantly a ria shoreline. This study provided us with the opportunity to actually see a large mass of oil come onshore and observe its behavior through time.

Environmental Susceptibility

On the basis of the two case studies cited above, plus careful study of the literature, a scale of environmental susceptibility to oil spill impacts has been derived. This scale relates primarily to the longevity of

Table 7. Chemical and physical characteristics of original and residual Bunker C oils extracted from sediments collected in Chedabucto Bay 3½ years after the Arrow spill (From Rashid, 1974).

Characteristics	Bunker C oil Original[a]	Bunker C oil Stored sample	Low energy coast	Moderate energy coast	High energy coast
Hydrocarbons (%)					
Saturated	--	26	25	23	18
Aromatic	--	25	24	24	16
Total hydrocarbons	73.1	51	49	47	34
Ratio of saturate to aromatic	--	1.04	1.04	0.96	1.12
Non-hydrocarbons (%)					
Asphaltenes	16.3	20	22	23	22
Resins and NSOs	10.6	29	29	30	44
Total of non-hydrocarbons					
Hydrocarbons/ non-hydrocarbons	2.72	1.04	0.96	0.88	0.52
Physical properties					
Specific gravity	0.950	0.963	0.9953	0.9765	0.9823
Viscosity (cP)	--	19.584	28.600	1210.000	3640.000

[a] Task Force Operation Oil Report, 1970

oil in each environment. The subleties of chemical weathering of the oil within each environment have not yet been studied in enough detail to be incorporated into the susceptibility scale. Results of a preliminary study by Rashid (1974) are given in Table 7. He concluded that chemical weathering processes are more active on high energy coasts than on low energy coasts, although the details of his environmental classification are rather obscure. Also, although biodegradation rates are thought to be slower in cold temperatures, little documentation exists to verify that notion.

Coastal environments are listed and discussed below in order of increasing susceptibility to oil spills:

1. Straight, rocky headlands:

   Most areas of this type are exposed to maximum wave energy. Waves reflect off the rocky scarps with great force, readily dispersing the oil. In fact, waves reflecting off the scarps at high tide tend to generate a surficial return flow that keeps the oil off the rocks (observed in Spain). There are a number of similar areas in the Northern Gulf of Alaska.

2. Eroding wave-cut platforms:

   These areas are also swept clean by wave erosion. All of the areas of this type at the Metula spill site had been cleaned of oil after one year. The rate of removal of the oil would be a function of the wave climate. In general, no clean-up procedures are needed for this type of coast.

3. Flat, fine-grained sandy beaches:

   Beaches of this type are generally flat and hard-packed. Oil that is emplaced on such beaches will not penetrate the fine sand. Instead, it usually forms a thin layer on the surface that can be readily scraped off by a motorized elevated scraper or some other type of road machinery. Furthermore, these types of beaches change slowly, so burial of oil by new deposition would take place at a slow rate. The Copper River Delta barriers are good examples of this type of environment.

4. Steeper, medium- to coarse-grained sandy beaches:

   On these beaches, the depth of penetration would be greater than for the fine-grained beaches (though still only a few centimeters), and rates of burial of the oil would be greatly increased. Based on earlier studies by our group in numerous localities, it is possible for oil to be buried as much as 50-100 cm within a period of a few days on beaches of this class. In this type of situation, removal of the oil becomes a serious problem, inasmuch as it would be necessary to destroy the beach in order to remove the oil. This was a common problem encountered during the clean-up of the Arrow spill in Chedabucto Bay, Nova Scotia (Owens and Rashid, 1976). Another problem is that burial of the oil preserves it for release at a later date when the beach erodes as part of the natural beach cycle, thus assuring long-term pollution of the environment. Long stretches of shoreline in the Gulf of Alaska fall into this category.

5. Impermeable muddy tidal flats (exposed to winds and currents):

   One of the major surprises of the study of the Metula site was the discovery that oil did not readily stick to the surfaces of mud flats. Also, penetration into the sediments was essentially non-existent. Therefore, if an oiled tidal flat is subject to winds and some currents, the oil will tend to be eventually removed, although not at the rapid rate encountered on exposed beaches.

6. Mixed sand and gravel beaches:

   On beaches of this type, the oil may penetrate several centimeters, and rates of burial are quite high (a few days in Spain). Most of the beaches of both the Metula site and the Gulf of Alaska are of this type. The longevity of the oil at the Metula site, particularly on the low-tide terraces and berm top areas, attests to the high susceptibility of these beaches to long-term oil spill damage.

7. Gravel beaches:

Pure gravel beaches have large penetration depths (up to 45 cm in Spain). Furthermore, rapid burial is also possible. A heavily-oiled gravel beach would be impossible to clean up without completely removing the gravel. Alaskan beaches downdrift of Sitkagi Bluffs and near rock headlands are composed of pure gravel and will behave similarly.

8. Sheltered rocky headlands:

Our experience in Spain indicates that oil tends to stick to rough rocky surfaces. In the absence of abrasion by wave action, oil could remain on such areas for years, with only chemical and biological processes left to degrade it.

9. Protected estuarine tidal flats:

Once oil reaches a backwater, protected estuarine tidal flat, chemical and biogenic processes must degrade the oil if it is to be removed. Much of the area behind the Copper River Delta barrier islands fall into this class.

10. Protected estuarine salt marshes:

In sheltered estuaries, oil from a spill may have long-term deleterious effects. We observed oil from the *Metula* on the salt marshes of East Estuary, on the south shore of the Strait of Magellan, that had shown essentially no change in 1½ years. We predict a life span of at least 10 years for that oil. Marshes fringe much of the tidal flat areas on the Copper River Delta.

Project 2. Shorelines of Kotzebue Sound (Cape Price of Wales to Point Hope)

a) Field and Laboratory Activities

No field work has been carried out on this project during October - December 1976. Laboratory analysis is under way on the sediment samples collected (220). Computer synthesis will begin after lab studies are completed. Computer synthesis of our beach profiles in Kotzebue Sound (70) will be completed in approximately one month. A more detailed geomorphic breakdown of the shoreline has been completed, and an oil spill susceptibility map is presently under construction.

b) Results

As indicated in "Results" section under Project 1, we have developed a new format for magnetic tape storage of beach profile data. This program and format, assuming it is accepted by NODC, will be added to their data storage system. Sediment data obtained for the Kotzebue Sound samples will be analyzed, using the program modified for the Gulf of Alaska samples. This will reduce magnetic tape data submission time by approximately 3 months.

A more detailed geomorphic breakdown of the coastline of the study area has been completed. It is based on three primary subclasses:

1. Erosional shorelines.
2. Depositional shorelines.
3. Neutral or stable shorelines.

This method of classification is considered to be superior to a simple morphologic classification in that it contains a morphologic classification as sub-classes under the broader primary classifications of erosion vs. deposition. This new method will be integrated into base maps to be submitted at the end of the next quarter.

Recommendations for Future Research

The alterations of the coastal zone due to freeze-up and break-up of coastal ice in the Kotzebue Sound area are poorly understood. A detailed study of the shoreline during active break-up would answer many of the questions regarding:

1. breakdown of fast ice contact.

2. sediment interaction.

3. ice movement related to nearshore coastal processes.

4. modification to permafrost following ice-out and response of beach sediments

5. ice-melt effects on upper beach face, and

6. delineation of nearshore subtidal ice effects.

In addition, a detailed study should follow the same guidelines for the freeze-up in the fall.

These studies would provide answers to many of the questions regarding ice effects on the nearshore and beach zones. These answers are necessary for a complete understanding of the dynamics in Kotzebue Sound. Further, a complete evaluation of the coastal zone under task D-Y necessitates an understanding of the ice effects. Knowledge of ice movement and sediment interaction is needed in order to delineate the possible movement of spilled oil in the Sound as well as potential impact of oil contamination on the beaches. In the "Results" section of Project 1, an oil spill impact susceptibility ranking system was enumerated. This ranking was developed primarily for ice free areas. Necessary modification could be made to this scheme, after an ice study in Kotzebue Sound, resulting in a more complete picture of potential oil spill problems. Efficient and effective clean-up of the most fragile environments will, to a great degree, depend on the presence or absence of ice and its interaction with the beach zone.

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QUARTERLY REPORT

Contract # 03-5-022-67 TA 6
Research Unit #87
Reporting Period: 1 October 1976 - 30 December 1976
Number of Pages: 2

THE INTERACTION OF OIL WITH SEA ICE IN THE BEAUFORT SEA

Seelye Martin

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23 December 1976

14 December 1976

I. Task Objectives: To understand the small scale interaction of petroleum and sea ice in the Beaufort Sea. Our eventual air is to predict how an oil spill or well blow-out would interact with the mobile pack ice of the Arctic Ocean.

II. Field or Laboratory Activities:

During the past quarter, we have not done any field work. Our efforts have gone into the design and construction of our field equipment in preparation for our March 1977 traverse.

In the laboratory, because our cold rooms were being serviced during the period 1 October - 1 December, we have also spent most of the quarter in the re-designing and rebuilding of our apparatus. Specifically, we have rebuilt our paddle so that it will generate larger waves, and added a wedge-shaped beach so that we will be able to grow a field of ellipsoidal-shaped pancakes. Now that the cold rooms are operable, we have run two calibration experiments with fresh water on the growth of pancake ice in a wave field. Beginning in January, we plan to grow pancakes in sea water, then measure the areal extent of a crude oil spill within this field.

III. Estimate of Funds Expended:

As of this date, we are about 20% expended.

QUARTERLY REPORT

R.U. #88: Dynamics of Near-Shore Ice
P.O.: 01-5-022-1651
Reporting Period: October 1976-December 1976
Number of Pages: 7

DYNAMICS OF NEAR - SHORE ICE

Principal Investigators: A. Kovacs and W. F. Weeks

Cold Regions Research and Engineering Laboratory

Hanover, New Hampshire 03755

20 December 1976

I. Task Objectives

1. Narwhal Island

a. Collect quantitative information on the movements (velocities, directions, accelerations, and deformation rates) of the nearshore pack ice and the fast ice along the southern coast of the Beaufort Sea.

b. Make observations on major ice deformation features that occur near the edge of the fast/pack ice boundary.

c. Utilize an air-borne radar system for measuring variations in the thickness of sea ice.

d. Document the nature of the internal crystal structure of the fast ice in the vicinity of Narwhal Island.

2. Bering Strait

Complete arrangements leading to the installation of an ice monitoring radar system at the Bering Straits.

3. Remote Sensing

Obtain further laser profiles over the near-coastal sea ice.

II. Field and/or Laboratory Activities

1. Narwhal Island

During the time period 29 October - 1 November, Tucker and Weeks visited Narwhal Island and surveyed in 8 markers on the surrounding fast ice. The markers will be resurveyed in the spring to obtain net motion of the fast ice during the winter. The radar towers were found to be in excellent shape. However, the camp had been vandalized and a number of house-keeping items stolen (stove, cooking equipment, mattresses). Arrangements were made with the program office for items that will be required in the spring.

The majority of the effort was devoted to analyzing the 1976 data. Project personnel during the period were A. Gow, A. Kovacs, S. J. Mock, W. B. Tucker and W. F. Weeks.

2. Bering Strait

The Raytheon X-band radar unit was finally delivered to CRREL in late November. The unit has now been set-up and is operating successfully (there were a number of minor problems with initial adjustment). We are now in progress of installing the camera system. As soon as this is completed the unit will be shipped to Tin City. We anticipate that we will install it during mid-January. Project personnel were M. Frank and W. F. Weeks.

3. Remote Sensing

The 4th set of laser flights which was scheduled for late October is being flown as this report is being prepared (10 December 1976). M. Frank is also assisting the University of Kansas staff in completing a X-band SLAR flight. We are currently in process of analyzing the previous laser records. Project personnel are M. Frank and N. Fungcharon.

III. Results (DB indicates available in data bank)

1. Published reports

a) Kovacs, A. (1976) Grounded ice in the fast ice zone along the Beaufort Sea coast of Alaska. CRREL Report 76-32, 21 pp (DB)

b) Kovacs, A. and Gow, A. J. (1976) Some characteristics of grounded floebergs near Prudhoe Bay, Alaska. CRREL Report 76-34, 10 pp (DB)

2. Reports Completed and In Press

   a) Weeks, W. F., Kovacs, A., Mock, S. H., Tucker, W. B., Hibler, W. D. and Gow, A. H. (1977) Studies of the movement of coastal sea ice near Prudhoe Bay, Alaska. Journal of Glaciology, Vol. 19, No. 81 (DB, available in xerox copy only).

   b) Kovacs, A. (1977) Sea ice thickness profiling and under-ice oil entrapment. Offshore Technology Conference (DB, available in xerox copy only).

   c) Schwarz, J. and Weeks, W. F. (1977) Engineering properties of sea ice. Journal of Glaciology, Vol. 19, No. 81 (DB, available in xerox copy only).

3. Reports in Preparation

   a) Gow, A. J. and Weeks, W. F. (1977) The internal structure of fast ice, near Narwhal Island, Beaufort Sea, Alaska. CRREL Report

   b) Sodhi, D. S. (1977) A study of ice arching and pack ice drift. CRREL Report

   c) Weeks, W. F. Tucker, W. B., Frank, M. and Fungcharon, N. (1977) Characteristics of the near-shore ice of the Chukchi and Beaufort Seas as determined via remote sensing. CRREL Report

   d) Kovacs, A. (1977) The origin of rock debris found on sea ice north of Narwhal Island, Alaska. CRREL Report

   e) Weeks, W. F., Kovacs, A. Mock, S.H., Tucker, W. B., Hibler, W. D. and Gow, A. H. (1977). Motion of coastal sea ice near Narwhal Island, Alaska. CRREL Report (an expanded version of the Journal of Glaciology paper giving a thorough discussion of the results and complete documentation of the data).

IV. Interpretation of Results

1. Narwhal Island

a) Laser observations of fast ice motion at sites close to Narwhal Island show long term changes in the distance to targets located on the ice that are believed to be primarily the result of the thermal expansion of the sea ice. The main ice motion was outward normal to the coast (in the least-constrained direction). The maximum movement was approximately 1 m with short term changes of 30cm.

b) Radar observations of fast ice sites further off-shore from the barrier islands do not permit the study of small motions (as do the laser records) because of insufficient measurement resolution. However, these records show many larger events with the standard deviation of the motion measured parallel to the coast increasing systematically with distance off-shore reaching a value of ±6.6 m at 31 km. The ice motions show short term displacements of as much as 12 m at the sites furthest from the coast. The observations also show systematic changes in line length (up to 6 m over a distance of 30 km) that are believed to be the result of thermal expansion of the ice. Correlations between the wind and the ice movement are only appreciable for movements normal to the coast.

c) Radar targets located within the pack ice showed large short term movements (up to 2.7 km) but negligible net motion along the coast. There was no significant correlation between the motion of the pack and the local wind suggesting the models for predicting coastal ice movement in the Beaufort Sea during the March-June time period can only succeed if they are handled as part of a regional model which incorporates the lateral transfer of stress through the pack ice.

d) Off-shore from Narwhal and Cross Islands the fast ice-pack ice boundary was usually located (during March-May 1976) in 30 to 35 m of water as opposed to 18 m of water where the boundary has been observed at sites further west along the Alaskan coast.

e) The large grounded multiyear shear ridge formations that were studied along Beaufort Sea coast in the Harrison Bay/Prudhoe Bay area must be considered as formidable obstacles in the development of off-shore operations in this region. In the design of off-shore drilling sturctures significant consideration must be given to not only the forces which can develop when these formations are pushed against the structures, but also to the potential for ice piling up and over riding them. The inner edges of the multiyear shear ridge formations studied north of Cross Island were found to be as high as 12.5 m and to be grounded along the ∿15 m depth contour. This depth is significantly less than the ∿19 m contour previously considered to be the water depth at which grounded shear ridges begin to form. The grounded ice formations studied formed in the fall of 1974 and remained through August 1976. However, they were not present in November 1976.

f. The dual antenna impulse radar system was highly effective in determining the thickness of both first-year and multiyear sea ice from the air. Good agreement was achieved between calculated and observed ice thicknesses and representative cross-sections of both ice types were obtained. These cross sections reveal characteristic undulating bottom relief in both ice types which could trap significant amounts of oil as the result of an under-ice spill. Preliminary estimates of the entrapped volume of oil are 0.03 m^3 of oil per square meter of ice area for first year ice and 0.3 m^3 of oil per square meter for multiyear ice.

g) Our observations coupled with published U.S. and Russian results suggest that very large areas (tens of kilometers) of sea ice have sufficiently similar c-axes orientations to act as a large single crystal. If this proves to be the case off-shore structures may have to be designed for "hard-fail" ice strengths which are 2 to 6 times the strength values normally used.

h) Although there have been many studies of the engineering properties of sea ice, there still is considerable uncertainty concerning the appropriate values to use in offshore design. This comment is particularly ture of the mechanical properties where both the basic experimental measurements and their interpretation are not well resolved.

V Estimate of Funds Expended

At the time this report was prepared we still had not received funding (although we have been notified that 25% of our FY77 funding has been authorized). We find it difficult to expend what we do not have.

STUDIES OF THE MOVEMENT OF COASTAL SEA ICE NEAR PRUDHOE BAY, ALASKA

By

W.F. Weeks, A. Kovacs, S.J. Mock
W.B. Tucker, W.D. Hibler and A.J. Gow

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Hanover, New Hampshire 03755, U.S.A.

Abstract: During March-May 1976, a combination of laser and radar ranging systems were used to study the motion of both the fast ice and the pack ice near Narwhal and Cross Islands, two barrier islands located 16 and 21 km offshore in the vicinity of Prudhoe Bay, Alaska. Laser measurements of targets on the fast ice near Narwhal Island indicate small net displacements of approximately 1 m over the period of study (71 days) with short-term displacements of up to 40 cm occurring over 3-day periods. The main motion was outward normal to the coast and was believed to be the result of thermal expansion of the ice. The radar records of fast ice sites further offshore show a systematic increase in the standard deviation of the displacements as measured parallel to the coast, reaching a value of $\pm$ 6.6 m at 31 km. The farthest fast ice sites show short-term displacements of up to 12 m. There are also trends in the records that are believed to be the result of the general warming of the fast ice with time.

Radar targets located on the pack ice showed large short-term displacements (up to 2.7 km) but negligible net ice drift along the

coast. There was no significant correlation between the movement of the pack and the local wind, suggesting that coastal ice prediction models can only succeed if handled as part of a regional model which incorporates stress transfer through the pack. The apparent fast ice - pack ice boundary in the study area was located in 30 to 35 m of water.

INTRODUCTION

Considerable effort has been expended in the last few years to collect information that will advance our understanding of the drift and deformation of pack ice. In planning such studies a deliberate effort is usually made to establish the study area far enough from the coast so that the boundary effects associated with the coast can (presumably) be ignored. This is undoubtedly a wise policy in that the effects of land and its associated fast ice are believed to be complex and are certainly poorly understood. Yet in many applied problems it is just this boundary area over the continental shelf between the fast ice and the offshore pack that is of interest. This is particularly true in petroleum exploration in the Arctic where many regions of the continental shelf are believed to have high potential for significant production of oil and/or gas.

To develop such areas in a rational manner requires a solid foundation of geophysical knowledge of the major hazards that will be encountered. In the Arctic offshore these hazards are largely due to the presence of sea ice in one form or another. It is reasonable to assume that offshore development will gradually start at "easy" protected sites within the fast ice zone. In fact this has already occurred with the successful exploratory drilling operations that have been undertaken from artificial gravel islands constructed in shallow water ($<$ 8 meters) in Mackenzie Bay in the western Canadian Arctic. As confidence is gained operations will gradually move into deeper water within the winter fast ice zone and ultimately into the seasonal pack ice zone itself.

Similar developments are expected to occur off the North Slope of Alaska inasmuch as a lease sale in the Beaufort Sea is anticipated in the near future. The present study attempts to acquire some of the geophysical information (i.e. quantitative data on the movement of both the near-shore pack ice and the fast ice) necessary for rational decision making relative to such developmental activities and specifically to delineate some of the hazards that the environment poses to the safety of petroleum exploration and development operations.

LOCALE

The present study was based at a small camp located on Narwhal Island (see Fig. 1). Additional instrumentation was sited on Cross Island located 19 km to the northwest. These two islands were selected for a number of reasons. First, the geological structures trapping the oil in the Prudhoe Bay field are known to extend out to sea near the study area. Any information gained in the Narwhal Island operation would have immediate applicability to the coming lease sale. The two islands are representative examples of a large number of similar barrier islands that occur along the coast of the North Slope between Harrison Bay and Demarcation Point. A "sheltered" lagoonal fast ice environment exists between these barrier islands and the mainland, while north of the islands a narrow belt of fast ice extends to the southern edge of the near-shore pack ice. Cross and Narwhal Islands are the outermost of the barrier islands and as such they are closest to the pack ice/fast ice

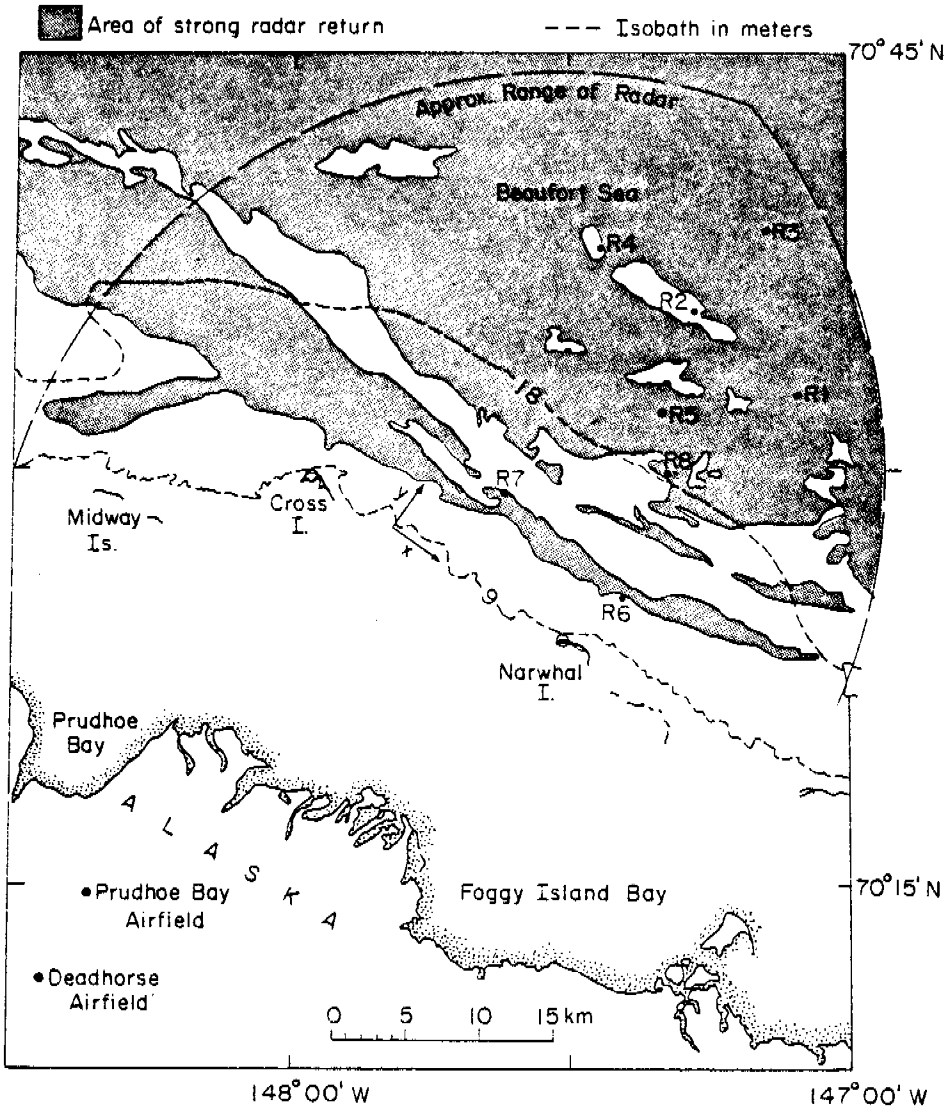

Figure 1. Map of the Narwhal and Cross Island area showing the location of the radar transponder sites, the orientation of the x, y coordinate system used in the ice movement study, the 9 and 18 m isobaths, the approximate range of the radar system (taking 37 km as the maximum effective range from a master unit), and the areas of strong X-band radar return as seen by SLAR.

boundary. This is important in that it is very desirable to observe ice motion some distance into the pack ice. If the base stations had not been located on these outermost islands, we would not have been able to obtain suitable observations on the movement of the pack inasmuch as in 1976 the fast ice - pack ice boundary proved to be located much farther from shore than anticipated.

A general impression of the ice morphology in the study area can be gained from examining Figure 1 on which we have plotted the regions of strong radar return as observed by X-band SLAR imagery obtained by an aircraft overflight on 11 May 1976. The strengths of X-Band radar returns from sea ice are almost entirely a function of the roughness of the upper ice surface. As indicated, a low-return area of essentially undeformed fast ice extends from the coast to a few kilometers north of the barrier islands. At the time of our study this ice was approximately 215 cm thick. The other principal area of undeformed ice is the elongated low-return feature that trends NW-SE and runs between radar transponders R7 and R8. This is a large refrozen lead that was active until mid-December 1975 as ascertained from infrared imagery from the DMSP satellite. The areas of high radar return are comprised of ice that was primarily deformed when it was quite thin (< 30 cm) plus a few small multiyear floes. Again, during the time of the study, this ice was roughly 2 m thick. At the time the SLAR image was obtained, all the ice on which radar transponders were sited was fast.

The water between Narwhal and Cross Islands and the mainland is shallow, with a maximum depth of 7.6 m. Most of the area is less than 6.7 m deep and there are several shoals. North of the islands water depth increases rapidly, reaching 10 m within a distance of less than 1 km. Beyond this the increase in depth is more gradual, with the 20 m depth contour paralleling the islands roughly 11 km farther offshore.

TECHNIQUES

The best system to use to study ice movement depends on the sort of motion to be measured. Unfortunately, very little information was available on the movement of either fast ice or near-shore ice along the north coast of Alaska, particularly for the March-June time period. Coachman and Barnes (1961) reported that mean net long-term winter ice drift rates in the seasonal pack ice zone in the southern Beaufort Sea were on the order of 2.1 to 2.6 km/day. The general drift direction was east to west parallel to the coast. Short-term exceptions to the general drift direction can, however, readily be found by examining the tracks of past drift stations (Polar Research Board, 1976). Whatever the drift direction, the main problem anticipated with the remote pack ice measurement sites was "keeping" them within range of the onshore tracking units which commonly require line-of-sight contact.

Even less information was available about the motion of the fast ice along the North Slope of Alaska. The published observations closest to those proposed by the present study were taken by Cooper (1975) on the fast ice in Kugmallit Bay, north of Tuktoyaktuk, Canada (located on the northeast side of the Mackenzie Delta). Working in a reasonably protected locale, Cooper observed ice displacements of up to 17 m between January and March 1969. These movements were presumed to be due to the thermal expansion of the ice cover associated with the general warming trend during the time period of the study. It was not known whether the ice movements were gradual or sharp, intermittent or continuous. Because the fast ice north of Narwhal Island was believed to be more exposed to the pressure exerted by the pack than at Kugmallit Bay, we anticipated ice displacements of a similar or greater magnitude.

To study the above problem a combination of ranging systems was used. Near Narwhal Island a He Ne laser ranging system with a range of 12 km was used because it had the high resolution required to study the small displacements that were expected. Also the ranges were small enough that severe restrictions due to unfavorable atmospheric conditions were not anticipated. The nominal accuracy of the system is ± 5 mm ± 2 ppm. Eleven targets were used with the farthest target located approximately 7 km from the laser. Readings were taken twice a day when possible. Blowing snow, fog and severe atmospheric refraction made it impossible to obtain readings on a number of occasions.

For sites located in the pack ice (and far from Narwhal or Cross Islands) a radar transponder tracking system was used that measures distances by using the relatively constant velocity characteristics of X-band (9.4 GHz) energy. The system is therefore not limited by blowing snow, ice fog, or darkness. The base stations or master units were located on Cross and Narwhal Islands, separated by a distance of 19,774 m. The masters transmitted in sequence a coded series of pulses to activate each remote transponder. Once the proper code corresponding to a given transponder was received, the transponder returned a like series of pulses to the master, establishing an RF link. The time required for the RF energy to make the round trip, less any delays, was converted into a distance. To achieve accuracy and stability each reported distance was based on the average of 100 individual readings selected by digital filtering. A set of readings was taken every 4 hours and was comprised of five separate distance determinations from each master station to each remote site. The system was anticipated to have an accuracy of ± 2.5 m or better and a resolution of ± 0.5 m. Inasmuch as the distance between the two masters was known, the location of the remote transponders was also known (three sides of a triangle).

The effective line-of-sight range of the unit was 80 km. However, the effective range drops significantly because of the curvature of the earth and pressure ridges which act as transmission obstacles. The range required for this operation depended upon the distance to the fast ice - pack ice boundary from the islands as it was necessary to monitor targets some distance within the pack. As the location of the boundary was unknown, we assumed that it would be at a water depth of 18 m as the boundary had characteristically been observed at approximately this depth at a number of sites farther west along the Beaufort Sea coast (Stringer, 1974). Considering that the 18 m isobath was located between 12 and 13 km NE of the line between Narwhal and Cross Islands, a 30 km range was the minimum that could be contemplated and still have a reasonable area within which a transponder could be reached by both masters. A 40 km range was finally chosen which would allow data to be collected within an "arch-shaped" area located NE of the 18 m isobath (the base of the arch was almost 60 km wide and the peak was 26 km north of the 18 m isobath). To achieve this range, 45.7 m (150 ft) towers were constructed on both Narwhal and Cross Islands and the outermost transponders were placed on 11 m (36 ft) towers.

Because the wind was believed to be the main environmental factor affecting the motion of both the fast and pack ice, meteorological observations were made at Narwal Island. Information collected included wind speed and direction (measured at 10 m), barometric pressure and air temperature.

ANALYSIS

Laser Stations. The array of laser stations, shown in Figure 2, was operated for varying time periods during the experiment. In all cases the data are simply the ranges from Narwhal Island to the laser

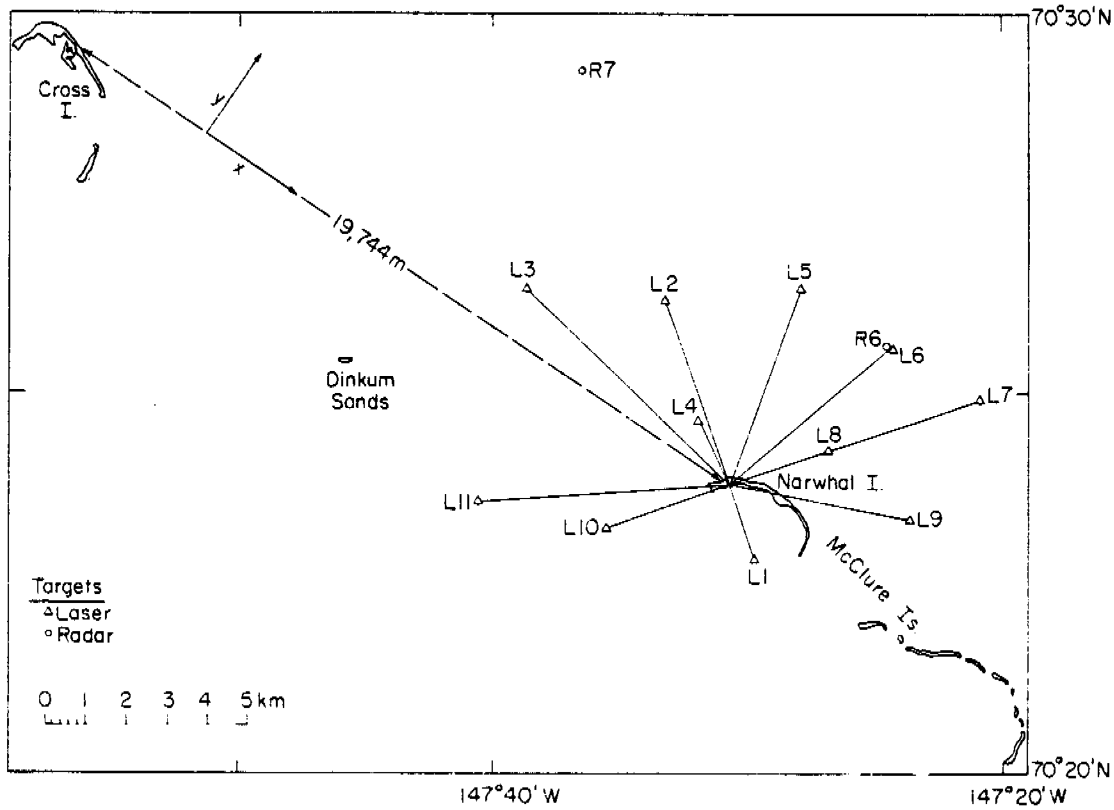

Figure 2. Map showing the location of the laser targets located around Narwhal Island and the orientation of the x, y coordinate system used in the ice movement study.

targets. Later, in discussing the radar ranging results, we will use the cartesian coordinate system oriented as indicated in Figures 1 and 2 with the line between Cross and Narwhal Islands serving as the positive abscissa. Because the abscissa is approximately parallel to the coast and to the 18 m isobath, positive y displacements are offshore while negative y displacements are onshore. Considering the locations of the laser targets in terms of this coordinate system it is clear that some laser stations primarily measure y components of the motion while others measure x components. Figure 3 shows the motions measured at the five laser stations (L1, L2, L3, L4 and L6) which operated over the longest time period.

Station L1, which was located on the "sheltered" lagoonal fast ice, showed virtually no detectable movement. Station L3, which primarily measured the x component of motion, showed a very slight increase in distance as a function of time. We consider this to be the result of the thermal expansion of the ice with increasing ice temperature. This thermal effect increases as the lines to the laser targets become more aligned with the y direction (i.e. in the sequence L3, L4, L2, L6) which is the direction of least physical constraint. A strain ellipse based on these data would have its major axis aligned parallel to y. Although L6 shows a major thermal effect, it is not a simple record and shows displacements which are clearly not thermal.

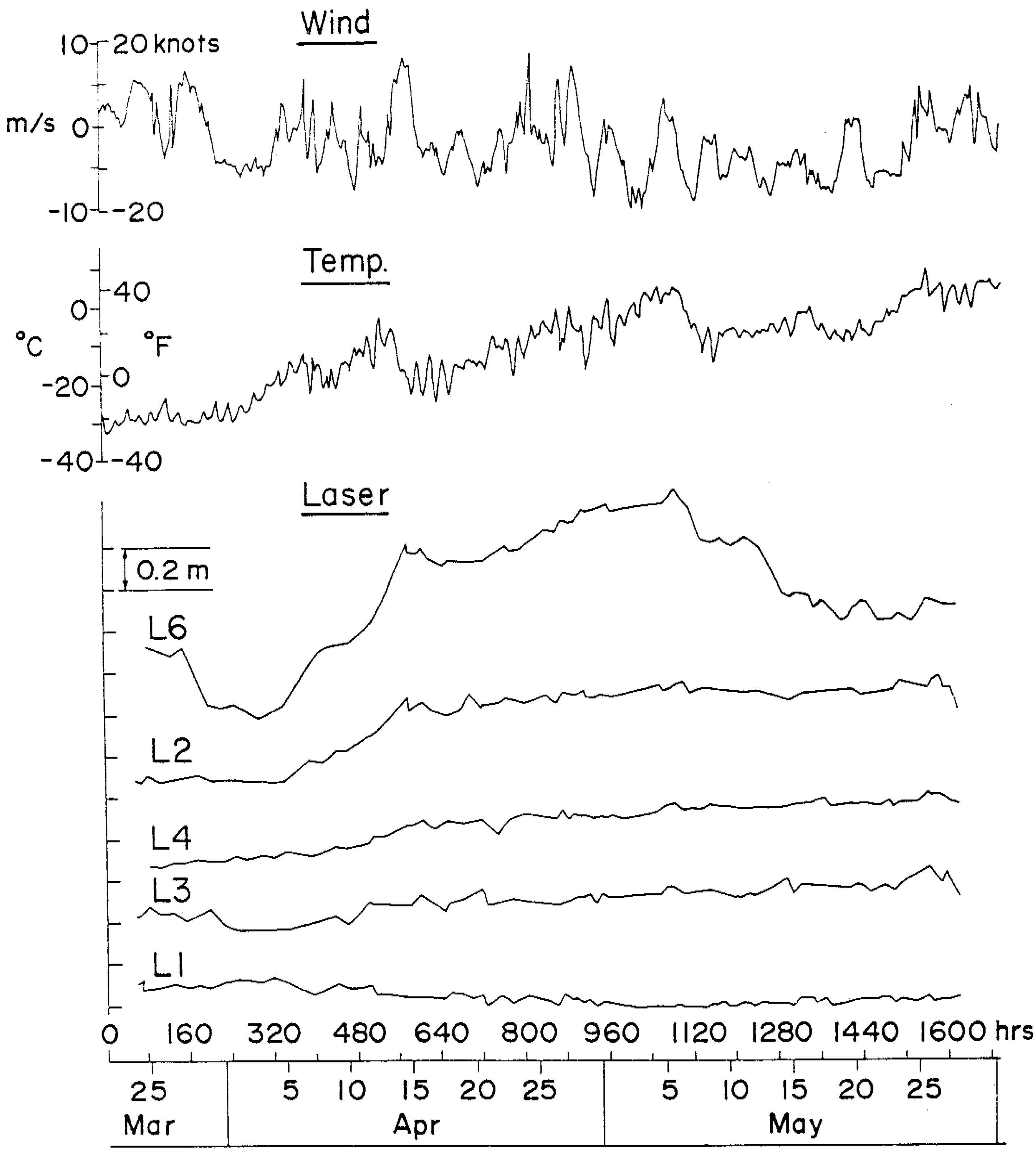

Figure 3. Relative distances between laser targets and the control station on Narwhal Island, air temperature and the y component of the wind.

Regardless of the causes of the ice displacements, Figure 3 is believed to be indicative of the scale of motion that can be expected in a reasonably protected fast ice environment during the early spring (in this case approximately 1 m over a 30 day period).

Radar Transponder Stations. The locations of the eight radar transponder sites are shown in Figure 1. Two stations were located south of and six stations north of the 18 m isobath which, as mentioned earlier, was expected to be near the pack ice/fast ice boundary. We anticipated that soon after our experiment was started gradual breakup of the ice would place one after another transponder in the westward-drifting pack until only R6 and perhaps R7 remained in the fast ice with the fast ice boundary paralleling the large refrozen lead. These two radar sites would then supplement the information provided by the laser targets, particularly during periods of poor visibility. The movements of the six other radar transponders would characterize the behavior of the near-shore pack ice.

To develop a time series of ranges from the Narwhal and Cross Island master sites to the different transponders, each individual set of five readings was averaged to give a single value representative of a given transponder at a given time. There are occasional gaps in all the time series for a variety of reasons, chief of which were polar bear attack and loss of propane from the thermoelectric generators. With the exception of stations R6 and R8 these data gaps were sufficiently short that linear interpolation could be used to estimate the missing values.

The data were then translated into the cartesian coordinate system described earlier. This same convention is used for the x and y components of wind.

Cursory inspection of the ice motion data showed that the anticipated sequence of events relating to the location of the fast ice/pack ice boundary did not occur. When the transponders were installed, all sites proved to be within the fast ice. Roughly 15 days later stations R2 and R3 became part of the pack because of the development of a wide flaw lead that initially ran just offshore of Stations R1 and R4 and onshore of Station R2. After two weeks of drift, showing movements of hundreds of meters, stations R2 and R3 again became part of the fast ice and remained as such until the measurements were terminated.

Fast Ice Stations. In discussing the behavior of the fast ice radar transponder stations, analysis will be confined to stations R1, R4, R5 and R7 because extensive temporal gaps exist in the data from stations R6 and R8, rendering them less useful. The data set consists of 427 x and y coordinates for each station taken at 4 hour intervals over a period of 71 days. The apparent ice movements as recorded by the transponder system consist of two components, real movements and system fluctuations. In turn, the system fluctuations include short and long term systematic thermal effects and random noise while real ice movement includes long-term thermal effects, wind-induced movement, random movement and perhaps current-driven movement. To obtain an understanding of the limitations placed on the radar data by instrumental noise, a transponder was placed on Narwhal Island (providing a constant distance) and ranges were obtained to it from Cross Island. This record is shown as part of Figure 5 with the temperature trend removed (as the instrument becomes warmer, it reports slightly shorter distances). The detrended record has a standard deviation of ± 0.45 m. In the following we will be conservative and only consider deviations of > 2 m from the trend of the data to be signal instead of noise.

Table I summarizes some statistical parameters calculated from the radar time series. The general negative slopes of the distance vs. time plots are believed to be the result of the decrease in the apparent distance measured with increasing instrument temperature (there was a steady rise in ambient temperature during the study period (see Figure 3 or 6)). Station R7 appears to be an exception in this regard.

Table I. Statistical information on fast ice stations as determined by the radar transponder system.

Station	Mean Distance (m)		Variance (m^2)		Slope of the regression line as f(time); m/hr	
	$\bar{x}$	$\bar{y}$	s_x^2	s_y^2	b_x	b_y
1	23610.9	22628.3	17.43	5.44	-3.83×10^{-3}	-2.35×10^{-3}
4	7448.1	23433.7	5.49	8.00	-3.60×10^{-3}	-4.25×10^{-3}
5	16714.5	16503.8	4.57	6.58	-3.73×10^{-3}	-4.56×10^{-3}
7	11151.0	6318.1	0.39	6.69	$+4.68 \times 10^{-4}$	-2.85×10^{-3}

Figure 4 shows the power spectra of the x and y coordinates for Station R1. Each spectrum shows a large peak at 24 hours and a lesser

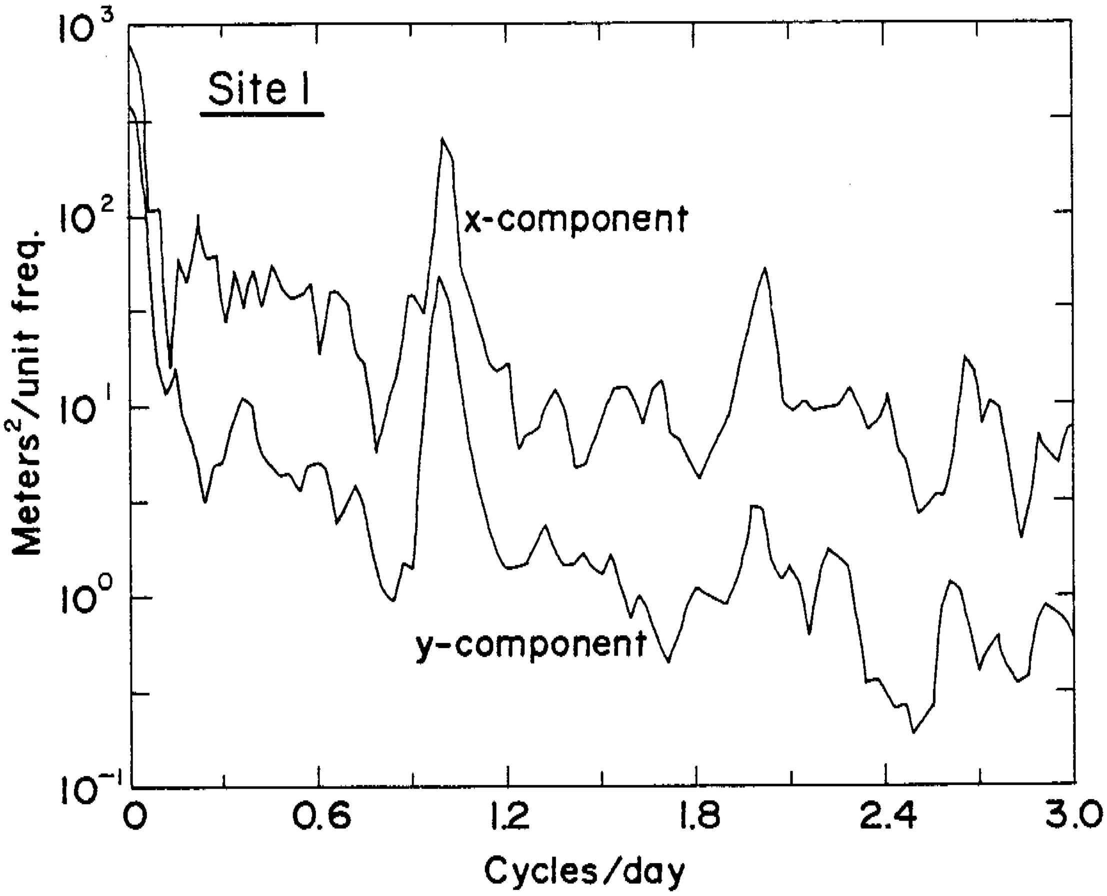

Figure 4. Power spectra of the x and y components of the observed ice movements at Station R1.

peak at 12 hours. The 24 hour peak, which occurs in the spectra of all the fast ice stations, is believed to be the result of the response of the measurement system to diurnal temperature changes. The 12 hour peak is now believed to be the result of some other contributing factor such as the tidal cycle because it does not follow the 24-hr oscillation exactly either in phase or in amplitude and is not present on the power spectrum obtained from the measurements of the fixed distance record between Cross and Narwhal Islands.

Figures 5 and 6 show the x and y components of motion for the fast ice stations as well as the x and y components of the wind as recorded at Narwhal Island. Air temperature is also presented in Figure 6. Note that although the time axis is plotted on the same scale used in presenting the laser data, the displacement is now in increments of 3.0 m as opposed to 0.2 m. The displacement data as shown have been detrended and band pass filtered to remove the 24 hour cycle. The 12 hour cycle, which is not strong in most records, has not been removed. Consider first the x component of motion shown in Figure 5. Clearly there is no striking correlation with the x component of the wind. There also do not appear to be any striking similarities between the records from the different stations. Although the correlation coefficients shown in Table II are uniformly low, the correlation coefficients that are underlined are significant at the 1% level.

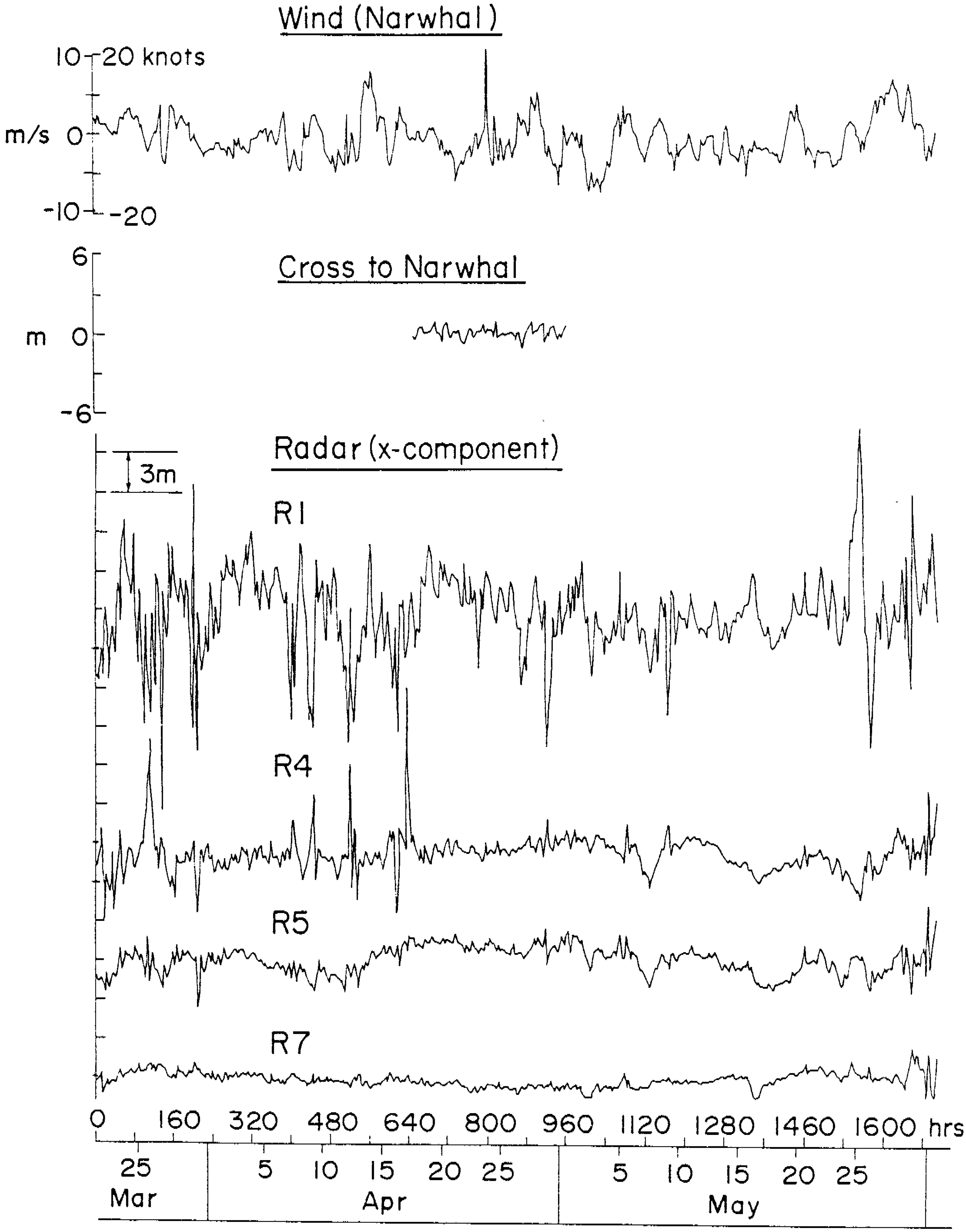

Figure 5. x component of ice movements as determined by the radar system, the x component of the wind, and the radar record of a fixed distance between Cross and Narwhal Islands.

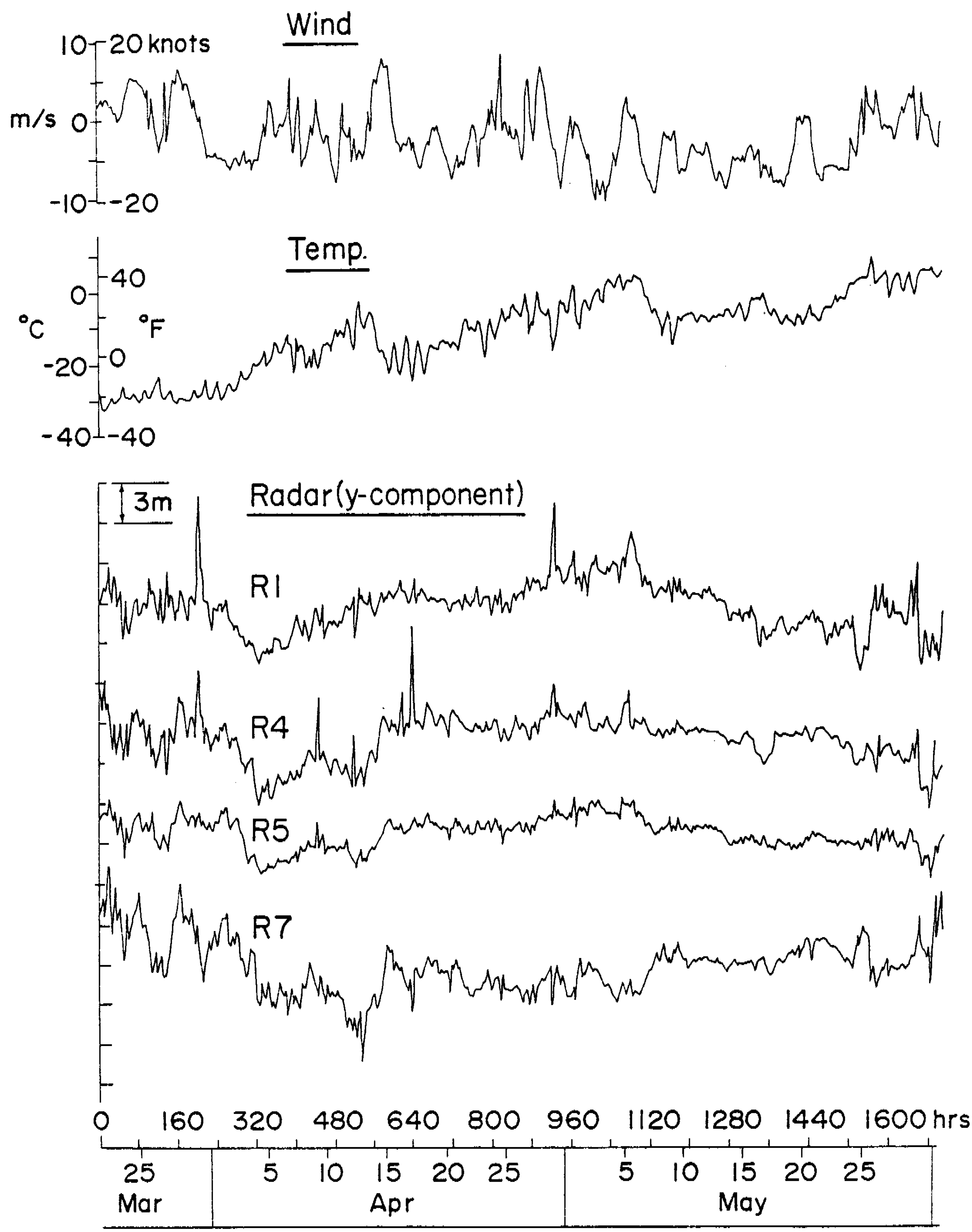

Figure 6. y component of ice movements as determined by the radar system, the y component of the wind, and the air temperature.

Table II. Correlation coefficients between the ice motion as determined by the radar transponder system and the wind. Values underscored are significant at the 0.01 level.

x-Component

Station	1	4	5	7
1	1.00	-<u>0.235</u>	+<u>0.396</u>	+0.061
4		1.00	+<u>0.382</u>	-0.005
5			1.00	-<u>0.145</u>
7				1.00
X comp. wind	+0.046	+0.028	+0.037	+<u>0.184</u>

y-Component

Station	1	4	5	7
1	1.00	+<u>0.663</u>	+<u>0.776</u>	-<u>0.132</u>
4		1.00	+<u>0.804</u>	+<u>0.260</u>
5			1.00	+<u>0.279</u>
7				1.00
Y comp. wind	+0.053	+0.002	+0.031	+<u>0.150</u>

Two different types of motion are discernible in Figures 5 and 6: long period movements occurring over periods of days and short period movements occuring over periods of less than 4 hours. The y components of the ice movements have a much higher correlation with each other than do the x components. However, despite these high internal correlations there is no significant correlation with the wind except for station R7. This station is closer to Narwhal Island than the other stations with complete position records and therefore the higher correlation was not unexpected. The generally low correlations were, however, disappointing. It is our impression that many times during this study, sharp meteorological gradients existed normal to the coastline.

When the plots of the y components are compared with the temperature data it can be seen that in the central portion of the study period the general increase in the values of y follows the general rise in temperature. This is believed to be due to the thermal expansion of the ice cover as was observed in the laser measurements. It should be noted that this trend is opposite in sense to the system's response to the temperature rise. The observed expansion is on the order of 6 m at a range of up to 30 km over a time period of weeks. During the latter part of the radar records there is a reversal of this trend as the distance to the transponders decreases. This is also believed to be the result of the gradual warming of the ice cover inasmuch as the sign of the coefficient of thermal expansion changes from negative (expansion on warming) to positive (contraction on warming) as the ice temperature rises above roughly -8°C (Anderson, 1960). This effect is not nearly so pronounced in the shorter laser lines although there is also a general stop to the expansion in those data.

A particularly interesting aspect of the radar data is the sharp elastic-like events that occur at a number of places in the records. By this we mean that when an event occurs it is of short duration, with the ice rapidly returning to roughly its position prior to the excursion.

As we discussed earlier the smaller fluctuations in measured distances (less than ± 0.5 m) are probably noise. However, we believe that the large deviations (> 2 m) from the trend of the data are definitely real. The records contain one event with a 12 m displacement and several with 9 m displacements. Figure 7 shows that the standard deviation of the x component of the ice displacement increases sharply as the reporting station becomes further offshore. In this figure we have included the S_x values calculated from Stations R2 and R3 for the time periods that they were part of the fast ice. The y component of the displacement does not show a similar trend; the standard deviation remains approximately constant with a value of 2.5 m.

Pack Ice Stations. The x and y components of the observed displacements for Stations 1 and 3 are shown in Figure 8 along with the y component of the wind. During much of the period both stations were part of the fast ice and showed movements similar to the other fast ice stations. (These fast ice movements are obscured in Figure 8 because the compressed scale.) However, during a 3 week period in April major ice movements did occur. The overall correlation of these observed displacements with the local wind was not significant. It should be noted that the major positive ice motion occurred near the end of a period of maximum positive winds and also that the major negative ice motion occurred during a maximum in the onshore winds. However during other periods of almost equally strong winds, no permanent displacement

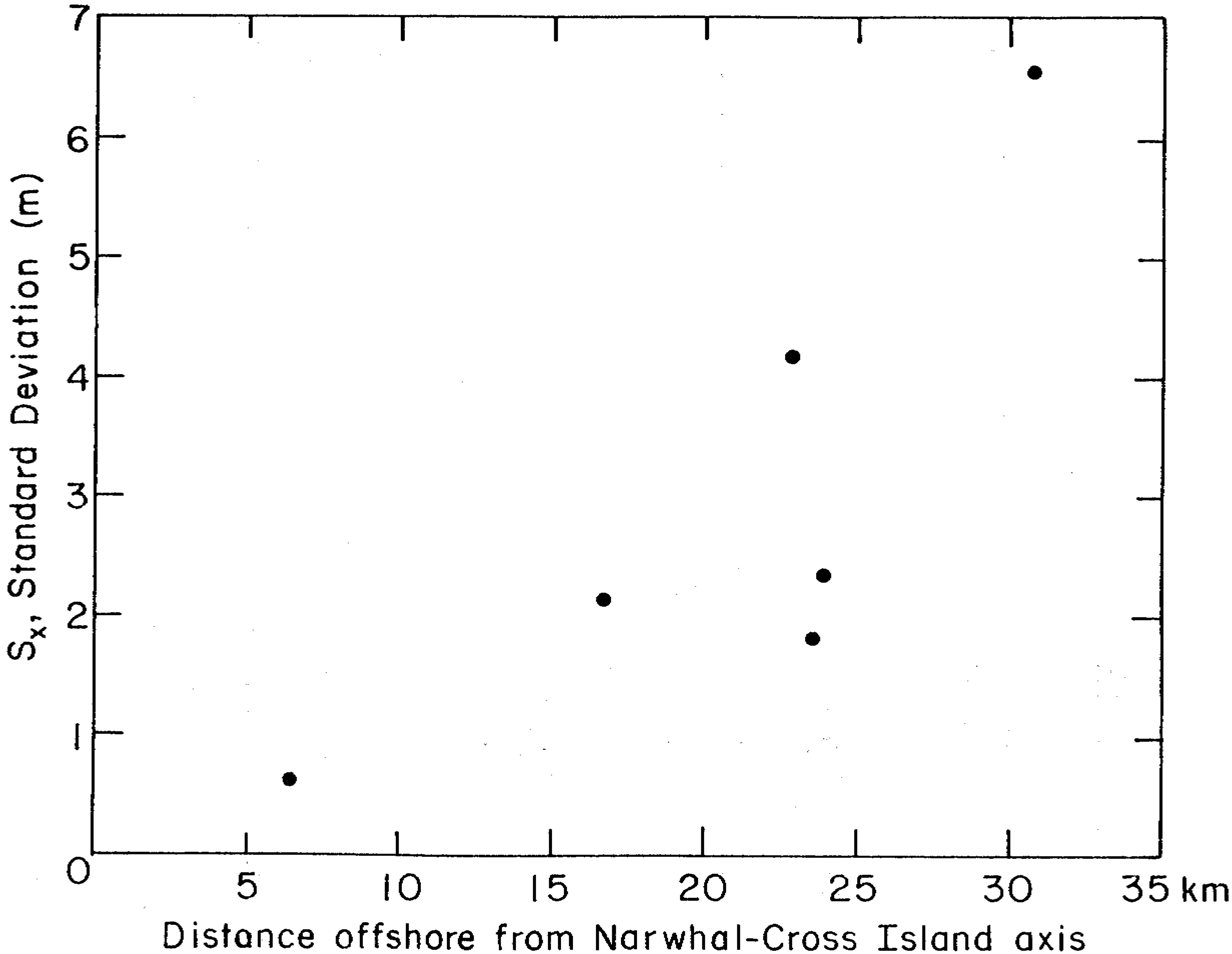

Figure 7. Standard deviation of the x component of the ice movement versus the distance of the measurement site offshore from the Cross-Narwhal Island axis.

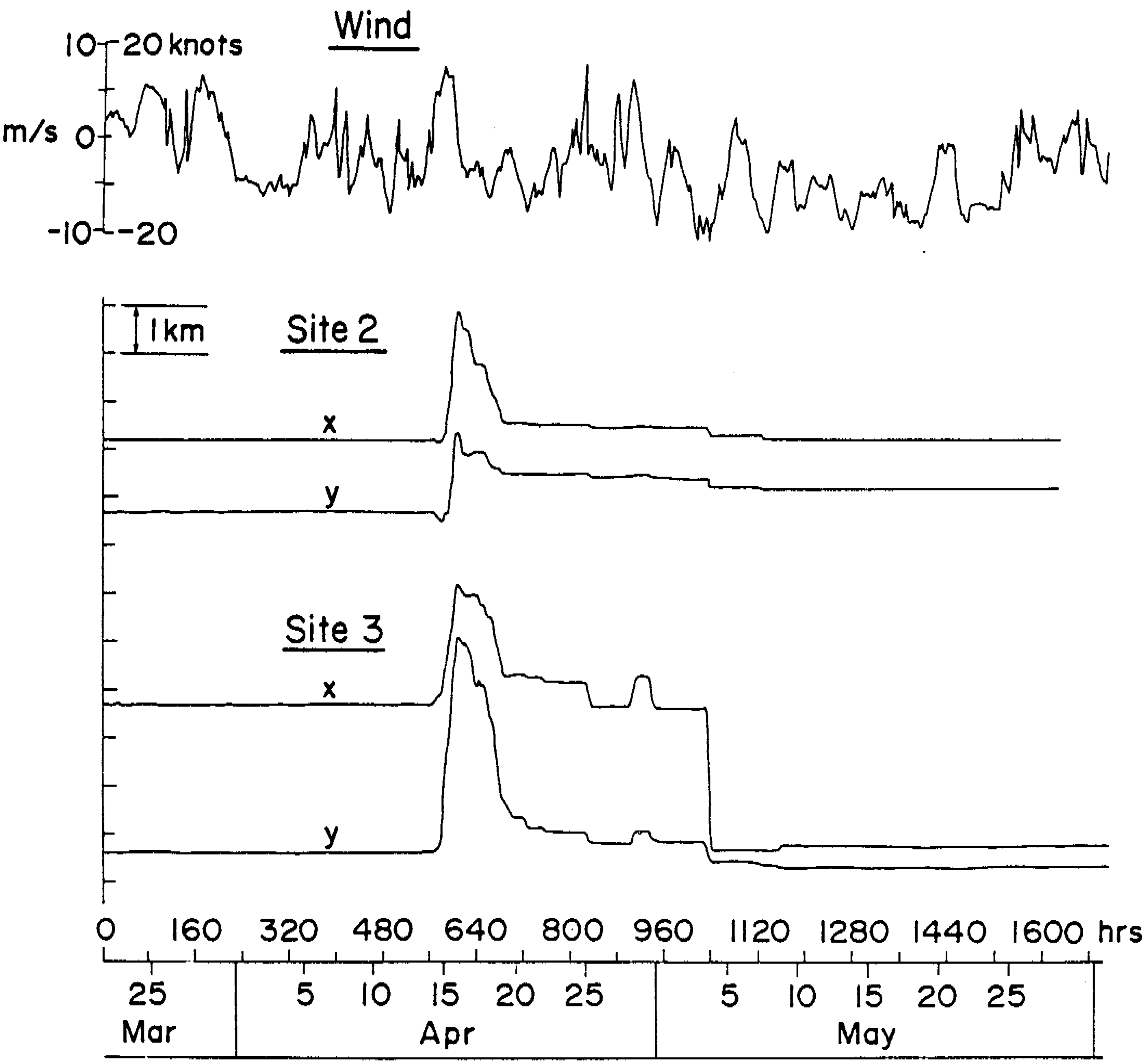

Figure 8. x and y components of the movement of Stations R1 and R3 and the y component of the wind.

occurred. This suggests that no adequate model for predicting the movement of the near-shore pack ice can afford to neglect the lateral transfer of stress through the ice. Therefore, local models can only succeed if handled as part of a regional model. This comment is particularly applicable to the time period covered by this study when the general ice conditions in the Beaufort Sea were very tight and maximum lateral transfer of stress was to be expected.

Surprisingly the net ice drift during the period of study was negligible (we did not have to relocate a single tower). It was also interesting how Stations 1 and 3 started out as part of the fast ice, transferred to the pack, and then returned to the fast ice cover.

Finally, at no time during the study did the location of the fast ice/pack ice boundary correspond even approximately to the location of the 18 m isobath. The boundary was usually located over water that was 30 m or more deep.

CONCLUSIONS

Laser observations of the movement of fast ice at sites close to Narwhal Island show long-term changes in the distance to targets located on the ice that are believed to be primarily the result of the thermal expansion of the sea ice. The main displacements were outward normal to the coast (in the least constrained direction). The maximum net displacement was approximately 1 m with short-term changes of up to 40 cm occurring over 3 day periods.

Radar transponder records of the movement of fast ice sites located farther offshore from the barrier islands do not permit the study of such small motions because of noise in the measurement system. However, these records show many large displacements, with the standard deviation measured parallel to the coast increasing systematically with distance offshore, reaching a value of $\pm$ 6.6 m at 31 km. Short-term ice displacements of as much as 12 m occur at the sites farthest from the coast. The observations also show systematic changes in line length (up to 6 m over a distance of 30 km) that are also believed to be the result of thermal expansion of the ice. Correlations between the wind and the ice movement are only appreciable for movements normal to the coast.

Radar targets located within the pack ice show large short-term movements (up to 2.7 km) but negligible net displacement along the coast. There was no significant correlation between the movement of the pack and the local wind, suggesting that models for predicting coastal ice conditions can only succeed if they are handled as part of a regional model which incorporates the lateral transfer of stress through the pack ice.

Offshore from Narwhal and Cross Islands the fast ice/pack ice boundary was usually located (during March-May 1976) in 30 to 35 m of water as opposed to 18 m of water where it has commonly been observed at sites farther west along the Alaskan coast.

We stress that the results presented here are based on observations during only a 3 month period (March-May) in the spring of 1976. We caution against the generalization of these results to other times or locales.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Figure

1. Map of the Narwhal and Cross Island area showing the location of the radar transponder sites, the orientation of the x, y coordinate system used in the ice movement study, the 9 and 18 m isobaths, the approximate range of the radar system (taking 37 km as the maximum effective range from a master unit), and the areas of strong X-band radar return as seen by SLAR.

2. Map showing the location of the laser targets located around Narwhal Island and the orientation of the x, y coordinate system used in the ice movement study.

3. Relative distances between laser targets and the control station on Narwhal Island, air temperature and the y component of the wind.

4. Power spectra of the x and y components of the observed ice movements at Station R1.

5. x component of ice movements as determined by the radar system, the x component of the wind, and the radar record of a fixed distance between Cross and Narwhal Islands.

6. y component of ice movements as determined by the radar system, the y component of the wind, and the air temperature.

7. Standard deviation of the x component of the ice movement versus the distance of the measurement site offshore from the Cross -Narwhal Island axis.

8. x and y components of the movement of Stations R1 and R3 and the y component of the wind.

ENGINEERING PROPERTIES OF SEA ICE

By

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Abstract: As the continental shelves of the Arctic become important as source areas for the oil and minerals required by human society, sea ice becomes an increasing challenge to engineers. The present paper starts with a consideration of the different fields of engineering which require information on sea ice, with the tasks ranging from the design of ice breaking ships to arctic drilling platforms to man-made ice islands. Then the structure of sea ice is described as it influences the observed variations in physical properties. Next the status of our knowledge of the physical properties important to engineering is reviewed. Properties discussed include mechanical properties (compressive, tensile, shear and flexural strengths; dynamic and static elastic moduli; and Poisson's ratio); friction and adhesion; thermal properties (specific and latent heats, thermal conductivity and diffusivity, and density); and finally electromagnetic properties (dielectric constants and loss, resistivity). Particular attention is given to parameters such as temperature, strain rate, brine volume, and loading direction as they affect property variations. Gaps, contradictions in the data, and inadequacies in testing

techniques are pointed out. Finally suggestions are made for future research, especially for more basic laboratory studies designed to provide the data base upon which further theoretical developments as well as field studies can be built.

INTRODUCTION

Although descriptions of sea ice as an oceanographic oddity date from the time of Christ (Zukriegel, 1935), the first serious study of it as an engineering material was undertaken in the 1890's by Russian investigators in conjunction with cruises of the icebreaker Ermak (Makarov, 1901; Krylov, 1901). The purpose of these studies was to provide basic information needed to improve the capability of shipping to transit the ice covered waters that commonly occur along so much of the Russian coast. During the 1920's and 30's, similar studies were made by other Russian scientists (Arnol'd-Aliab'ev, 1925, 1939; Weinberg and others, 1940) although the overall level of activity was low. By the Second World War, some data were available on most of the engineering properties of sea ice although both the quantity and the quality of much of the information left something to be desired. Perhaps more important, a paper had been published (Tsurikov, 1940) suggesting that the variations in the strength of sea ice could be analyzed starting from models based on the internal structural arrangement of the liquid and gaseous inclusions in the ice. An excellent summary of the Russian work carried out prior to about 1940 can be found in Zubov (1945).

Following the Second World War, a variety of national groups showed interest in obtaining improved engineering information on sea ice. Russian activity continued at an accelerated pace associated with increased shipping activity along the North Sea Route and the establishment of the Severnyi Polus drifting stations in the Arctic Ocean. Finnish and Japanese investigators started to consider problems caused by the presence of pack ice in the Baltic and Okhotsk Seas while Canadians and Americans became involved in a variety of problems associated with sea and air resupply in the Arctic. This interest resulted in a number of programs that systematically attempted to enlarge our data base of engineering information, particularly concerning the mechanical properties of sea ice.

At the same time, a theory was developed (Anderson and Weeks, 1958; Assur, 1958) that explained many of the observed variations in the physical properties of sea ice in terms of more realistic models of the actual geometry of the brine and gaseous inclusions than were used by Tsurikov (1940, 1947a, b). As in earlier studies, many of the test procedures left much to be desired. Even so, the data and the theory were found to be in reasonable agreement. This is important in that the theory showed that most of the large observed variations in the mechanical properties of sea ice were produced by changes in the volume of voids, both liquid and gaseous, in the ice. At least in first-year ice most voids are filled with brine, the volume of which is specified uniquely by the salinity and temperature of the ice. These two parameters are not difficult to measure, even under field conditions. Once they are determined, one can use them to obtain a brine volume and then by comparison with sets of tests on the parameter of interest, obtain a good estimate of its value in the field situation. In retrospect, research on the engineering properties of sea ice during this time period could be characterized as leisurely in that adequate time was usually available for reasonably thorough experiments and analysis. Also, the engineering problems that were being considered were modest: expanded navigation during the summer and longer air resupply capabilities during the winter via sea ice runways. In addition, the stations that required such support were small, rarely involving more than a few hundred persons.

This ended in 1967 with the oil strike at Prudhoe Bay, followed by the discovery of gas in the Mackenzie Bay area, and in 1969-70 by the cruises of the tanker Manhattan. The economic potential of the Arctic became generally recognized and development started at a rapid pace. Similar activities were also occurring in the coastal areas of the Soviet Arctic. The engineering problems that were now being posed were much more difficult; for example, year-round navigation on the margins of, and perhaps across, the Arctic Ocean; offshore drilling and oil and gas production from both coastal and deep water sites on the Arctic Continental Shelf; the long-term use of both natural and artificially thickened sea ice to support very large loads; and the installation of pipelines between islands in the Canadian Archipelago. The solutions of these types of problems require a thorough knowledge of the engineering properties of sea ice coupled with information on the geophysical characteristics of the ice cover. For instance, once we know how to calculate the forces a multi-year pressure ridge can exert on an offshore structure, we must consider the probabilities of encountering ridges of different sizes, with the final design being a judicious compromise between the value of development, the cost of construction, and the risk and environmental consequences of structural failure.

If the 1946-66 period of sea ice research was "leisurely," the 1967-present period might best be described as "pandemonium." Once developmental activities started it took only a short time to exhaust our basic research bank account concerning sea ice. What disturbs us most is that, at the present, the pressures of providing the day by day sea ice information required for operational problems have become so severe that little effort and even less funding is being devoted to improving our basic understanding of sea ice as a material.

In the present paper, we will first describe the structure of sea ice as it relates to models of the variation in its engineering properties. Then the current status of our knowledge of the more important engineering properties will be reviewed with emphasis on updating more detailed earlier discussions (Weeks and Assur, 1967, 1969), leading the reader to important references, and appraising the adequacy of the data. Finally, a number of suggestions will be made concerning research needs.

EFFECT OF SEA ICE STRUCTURE

Structurally undeformed first-year sea ice is very similar to a cast ingot. Its uppermost zone (the initial skim) is produced by the formation of the initial ice layer across the sea surface. This layer may vary from a few millimeters to 20 cm in thickness depending on the sea state at the time the ice cover forms. The layer below this can be referred to as the transition zone, in that a preferred growth orientation develops in the crystals. Although these upper two layers are quite interesting from a crystal growth point of view, they are usually very thin (the base of the transition zone is commonly less than 30 cm below the upper surface of the ice sheet) and do not need to be considered for most engineering purposes.

During the melt season, the upper two layers commonly ablate away, causing multiyear ice to be essentially completely composed of ice of the third zone. This so-called columnar zone ice characteristically has a strong preferred growth fabric with the crystals elongated vertically parallel to the direction of heat flow and the c-axes of the crystals oriented almost perfectly in the horizontal plane. This results in the basal planes of the ice crystals being oriented in a near vertical direction. The geometric selection that occurs, as crystals with their c-axis oriented close to horizontal cut out other less fortunately oriented crystals, causes a gradual increase in grain size with depth, at least in the upper portion of the ice sheet. In fact the very limited number of measurements of grain size (Weeks and Assur, 1967) suggests a linear increase in mean crystal diameter with depth, with the rate of increase independent of the grain size present at the base of the transition zone. Because the crystals become large relative to methods for sampling them, adequate descriptions of grain size variations are only available for the top 60 cm of first-year ice. Limited observations of the lower portions of 2 m thick ice show large areas (at least 1 m in diameter) that have roughly co-linear c-axis orientations (Peyton, 1966). Although the degree of co-linearity is not sufficient for such areas to be considered as single crystals (Gow and Weeks, unpublished results), the degree of orientation would clearly result in large variations in physical characteristics such as ice strength with changes in the direction of loading. In fact in the old sea ice that was incorporated in the Ice Island ARLIS II, Smith (1964) reported areas of co-linear c-axes that are as large as 10 m on a side, and recent studies of the anisotropy of the electrical characteristics of first-year ice have suggested that these domains may be very large (Campbell and Orange, 1974).

Each individual crystal of sea ice is subdivided into a number of ice platelets that are joined together to make a sort of quasi-hexagonal network as viewed in the horizontal plane. It is within this network that most of the entrapped brine present in the sea ice is believed to be located. Figure 1 presents a schematic view of a cross-section of first year sea ice. Also shown are several sketches made from thin sections showing both the individual crystals and the ice platelets, and a close-up of the brine pockets located between the platelets. The width of the platelets a_o, the so-called plate spacing, varies systematically with the ice growth velocity. Observations in metals suggest a functional relationship of the general form

$$a_o v^{1/2} = c$$

where v is the growth velocity and c is a constant. Limited observations on a_o variations in NaCl ice (Lofgren and Weeks, 1969) suggest that the power of v may actually be a function of v. In any case, the slower the ice grows, the wider the ice platelets, resulting, in most situations, in a_o increasing with increasing depth in the ice sheet. Other aspects of the geometry of these platelets or of the details of the geometry of the brine layers, channels and pockets have received only cursory examination. It is, however, reasonable to expect that they will also prove to be a function of the ice growth velocity.

One other aspect of the sea ice substructure should be mentioned here. As the brine initially trapped between the ice platelets drains down and out of the ice sheet, it moves through structural features within the ice that have been referred to as brine drainage channels. These channels can be thought of as tubular river systems in which the tributaries are arranged with cylindrical symmetry around the main drainage channels. In first-year ice, such channels do not appear to reach above the base of the transition zone, presumably indicating that a certain volume of ice is required as a source of brine before a channel can form (or be identified). Near the bottom of thick annual sea ice, drainage channels with a diameter of approximately 1 cm appear to occur on a horizontal spacing of 15 to 20 cm. The presence of drainage channels is also schematically indicated in Figure 1.

Although all aspects of the structure of sea ice should influence its physical properties, at the present only the substructure associated with the presence of the ice platelets has been considered; all the salt is taken as entrapped in channels, layers, and pockets (or at very low temperatures as crystals of solid salt) between these plates. A drawing showing this idealization as developed by Assur (1958) is given as Figure 2. It is also assumed that the failure planes within each ice crystal will largely coincide with the planes along which the salt is concentrated. This assumption is borne out by a limited number of observations of the geometry of actual failure surfaces in natural sea ice (Anderson and Weeks, 1958; Tabata, 1960). The reason for this coincidence is that the salt inclusions reduce the effective cross-sectional area of ice-to-ice bonding between the plates, causing the interplate boundaries to be planes of weakness. Therefore it is reasonable to suppose that variations in the failure strength σ_f of sea ice can be expressed in the general form

$$\frac{\sigma_f}{\sigma_o} = 1 - \psi$$

where ψ is the plane porosity (the relative reduction in the area of the failure surface caused by the presence of gaseous and liquid inclusions)

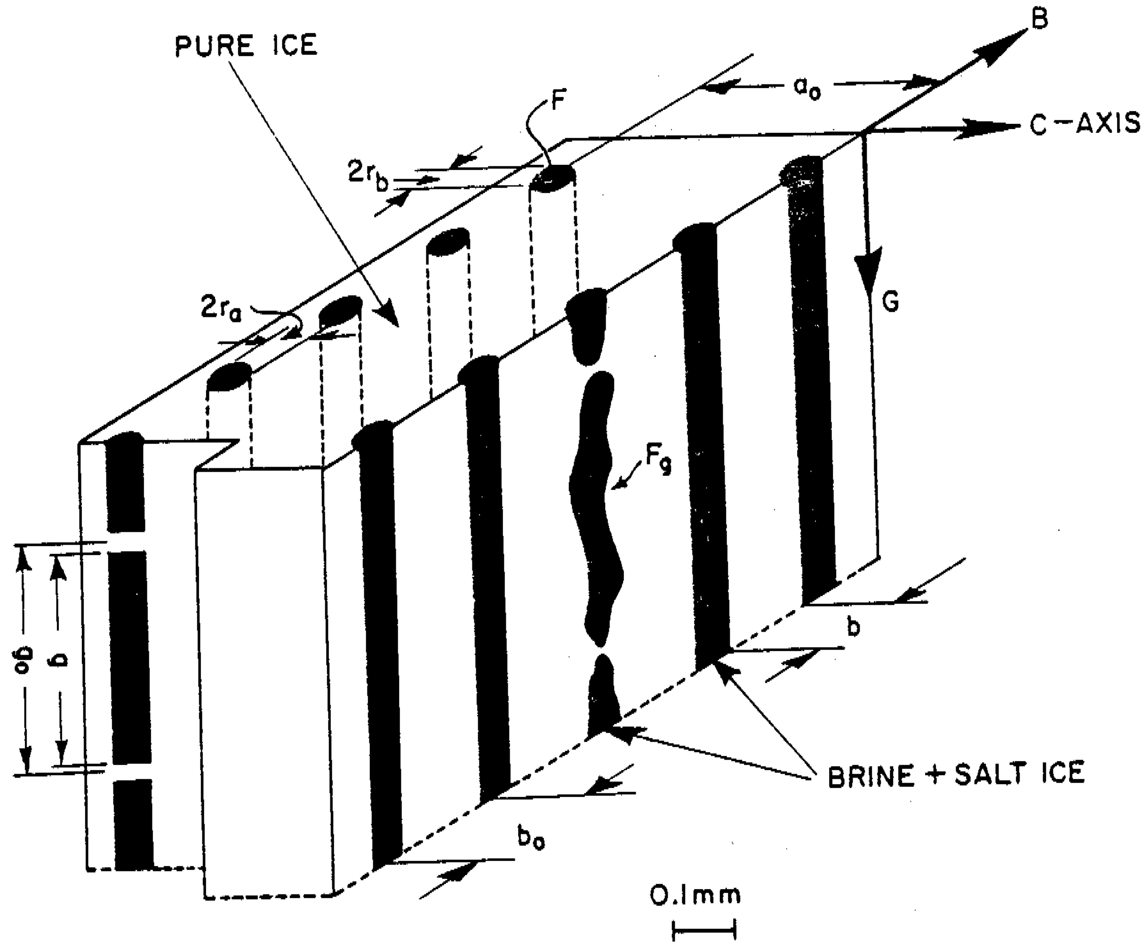

Figure 2. Idealized diagram showing the shape of the brine inclusions in sea ice and parameters used to describe them (Assur, 1958).

and σ_o is the so-called basic strength of sea ice (the strength of an imaginary material containing no brine or air but still possessing the sea ice substructure). The critical value of ψ along the failure plane is

$$\psi = f(\nu) = f(\nu_a + \nu_b)$$

where ν, ν_a, and ν_b are respectively the volumes of void, or the porosity, of air and of brine. It then only remains to express ψ in terms of ν via a model for the geometry of the inclusions. This has been done by Assur (1958), Anderson and Weeks (1958), and Anderson (1958a, 1960). Details on these treatments can be found in Weeks and Assur (1967, 1969) and need not concern us here. The results of the analysis give an equation of the general form

$$\frac{\sigma_f}{\sigma_o} = 1 - c\nu^k$$

where c and k are constants, the values of which depend upon how the geometry of the fluid inclusions varies with changes in ν. Models that have been considered include ones in which the brine pockets remain a constant width (k = 1) or show geometric similarity in a horizontal plane (k = 1/2) or in space (k = 2/3). In fact the detailed petrographic observations necessary to indicate which model most closely approximates reality are lacking. However, most recent authors have satisfactorily used k = 1/2 to correlate changes in σ_f with changes in ν and we will also present available data in this form. On such plots the value of

σ_o is given by the intercept of the linear extension of the least-squares straight line through the data with the σ_f axis.

As will be discussed later, similar variations in many other physical properties of sea ice are also caused by changes in ν. It is upon this dependence that the estimation of the engineering properties of sea ice is usually based. Design values are usually extreme values which are difficult to measure in the field because they occur so rarely. However, if the value of ν associated with the extremes can be estimated, then one can simply determine the value of the physical property of interest from its measured or extrapolated dependence upon ν. In fact, this is not too difficult to do because the salinity of sea ice changes rather systematically with ice thickness and age. Attempts to present these types of correlations for both average salinities and salinity profiles can be found in Weeks and Assur (1967, 1969), Cox and Weeks (1974), and Tsurikov (1976). This compositional information can then be combined with representative ice temperatures, which can be estimated from information in Peschanskii (1967), Maykut and Untersteiner (1969), and Maykut (1976).

For instance, if we are interested in the tensile strength and elastic modulus profiles for 0.2, 0.8 and 3.0 m thick ice in the Arctic Basin on roughly 1 May, we would expect values similar to the profiles shown in Figure 3. Here we have converted the estimated salinity and ice temperature profiles to a brine volume profile via the empirical relation developed by Frankenstein and Garner (1967) from the brine

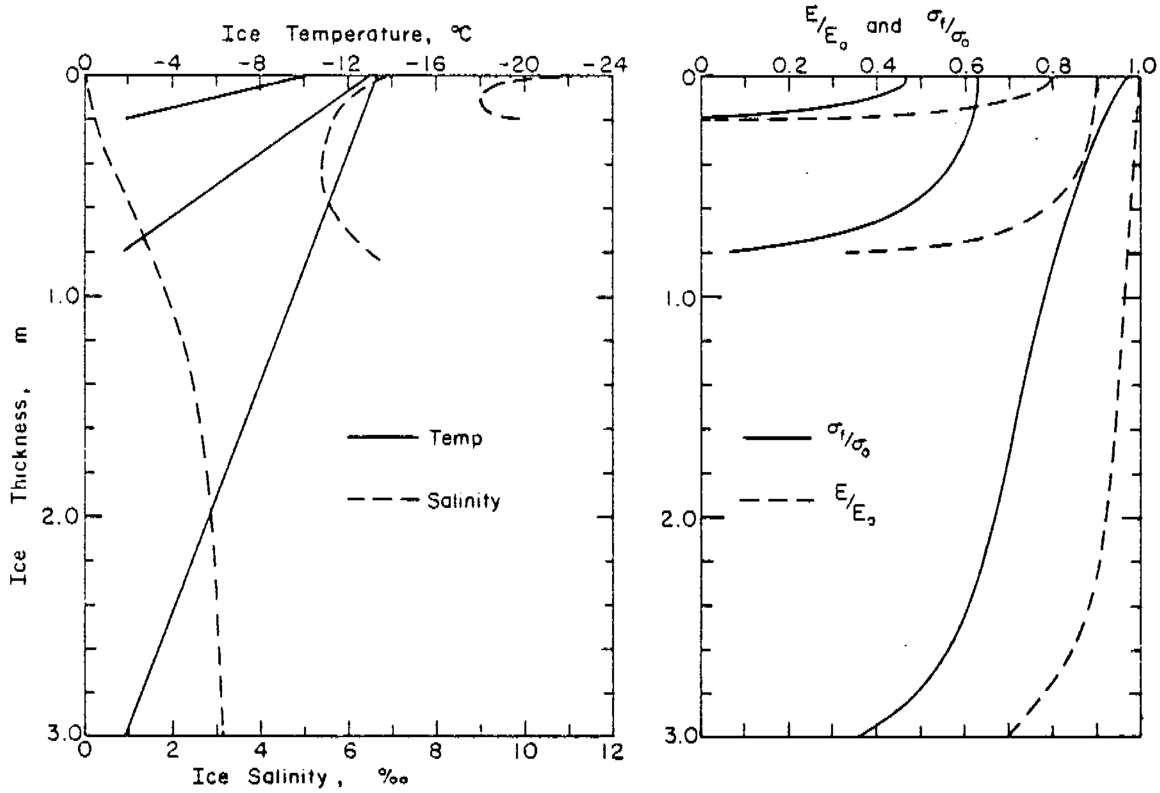

Figure 3. Representative sea ice temperature, salinity, E/E and σ_f/σ_o profiles for 0.2, 0.8, and 3.0 m thick Arctic sea ice on about 1 May. To convert σ_f/σ_o to σ_f and E/E_o to E multiply by 10.3 x 10^5 N/m^2 and by 10^{10} N/m^2 respectively based on the flexural strength determinations of Dykins (1971) and the elastic modulus measurements of Langleben and Pounder (1963).

volume tables for standard sea ice worked out by Assur (1958). In doing this, we have not taken account of the volume of gas entrapped within the ice although for first-year ice this volume is usually believed to be small relative to the brine volume. This may not be true for multi-year ice. In converting from brine volume profiles to σ_f/σ_o and E/E_o profiles, the equations suggested by Dykins (1971) and by Langleben and Pounder (1963) for flexural strength and dynamically determined elastic modulus were used. As will be discussed later, the problems in preparing such profiles are primarily caused by uncertainties in the values of the engineering parameters of interest near the melting point (large ν) and at temperatures lower than -23°C (presence of significant amounts of solid salt in the ice). Once adequate physical property profiles have been obtained, either by the methods that we have described or by direct measurement, methods for deducing proper composite characteristics for the ice can be applied (Assur, 1967; Weeks and Assur, 1967).

ENGINEERING PROPERTIES OF SEA ICE

There are, of course, a large number of material characteristics of sea ice that can legitimately be considered of engineering interest. Fortunately, in most problems one needs to be concerned with only a sm ll number of these. We can discern what these properties are by listing first some of the more important applied areas of concern, then a few more specific problems in each of these areas, and finally the engineering properties of sea ice required to resolve these problems. This is done in Table I. Although this table does not attempt to provide an inclusive list of problems, it is clear that certain engineering properties of sea ice would occur over and over in any such list that is prepared. These are the mechanical properties as they relate to both short-term and long-term loading and to ultimate failure of the ice, the frictional properties which must be considered when ice bonds to or moves relative to either an engineering structure or to itself, and the thermal properties which are essential to any problem in which ice growth or the change in temperature of the ice is important. Finally there are the electromagnetic properties of the ice which must be understood to obtain maximum benefit from the application of current remote sensing technology to sea ice. It is these techniques that will provide the requisite descriptions of areas of pack ice that should be available before sound engineering calculations can start.

MECHANICAL PROPERTIES

Although sea ice is the main engineering concern in the development of arctic navigation and offshore technology its mechanical properties have been investigated far less than those of freshwater ice. In fact, in the last four symposia dealing with the engineering aspects of ice in which 250 papers were presented, only 10 dealt with the mechanical properties of sea ice. One reason for this situation is that properties such as failure strength, elasticity, plasticity, stress-strain behavior,

TABLE I. DATA REQUIRMENTS FOR SELECTED PROBLEMS IN SEA ICE ENGINEERING

General Problem Areas	Specific Problems	Sea Ice Characteristics Required: Mechanical	Friction and Adhesion	Thermal	Electro-magnetic
1. Ships transiting sea ice	a) Ice resistance during breaking	x	x	x	
	b) Impact loads on hull plates	x	x		
	c) Forces exerted by converging ice	x	x		
	d) Ice reconnaissance			x	x
	e) Ice forecasting	x	x	x	
2. Design of offshore structures for Arctic sites	a) Ice forces on structures	x	x	x	
	b) Estimation of ice pile-ups	x	x	x	
	c) Abrasion of structural elements	x	x	x	
	d) Ice erosion of gravel islands	x	x		
	e) Remote sensing of ice thick-ness			x	x
	f) Reconstruction of ice dynamics from past meteorological data	x	x	x	
3. Large loads on ice sheets	a) Calculation of short term failure	x	x		
	b) Calculaton of long term creep	x	x	x	
	c) Remote sensing of ice thickness			x	x
4. Ice scoring of the sea floor	a) Forces exerted by grounded ice features	x		x	
	b) Ice reconnaissance			x	x
	c) Reconstruction of ice dynamics from past meteorological data	x	x	x	

and the fracture modes under various load conditions are presumably complicated by the presence of brine inclusions which do not occur in relatively pure freshwater ice. Also frozen lakes are readily accessible from many locations while studies of sea ice invariably involve considerable logistic effort and expense.

Even though some work has been done on each of the mechanical properties the evaluation and comparison of results is, at best, difficult, since the methods of testing commonly differ from one investigator to another. This lack of standardization has proven to be such a problem that the International Association for Hydraulic Research (IAHR) has formed a Task-Committee on "Standardizing Testing Methods for Ice." We will refer to their first report (IAHR, 1975) several times in the following discussion.

STRENGTH

General Conditions

Proper procedures for testing sea ice strength require the recording of the following subsidiary information:

a) ice type (specified according to some general classification)

b) ice temperature, salinity and gas content

c) size and orientation of ice crystals

d) sample dimensions and load direction

e) history of the ice sample including its location in the ice sheet

f) strain rate

g) end condition of the sample (nature of the interface between the ice and the loading platens)

h) failure mode

Collecting all these data is both time consuming and laborious. This may be another reason why the number of investigations on sea ice strength is extremely small. Only rarely do available results satisfy all these requirements for basic information.

In reviewing the various mechanical properties of sea ice we will try to both identify the gaps in existing knowledge and suggest ways in which the present situation can be improved.

Compressive Strength

a) Testing Procedures

In the conventional uniaxial compression test, axial force is applied to the ends of a specimen through steel platens that make direct contact with the test specimen. Friction between platen and specimen produces radial restraint, so that there is commonly a triaxial state of stress near the end planes. The triaxial field is significant over an axial distance from the end planes of about one specimen radius. Interposition of highly compliant sheets (elastic or plastic) between the platens and the specimen often changes the sign of radial end forces, but does not eliminate the triaxial stress state. On a different scale, irregularities in the specimen end planes also create localized stress perturbations, and in brittle material these commonly initiate microcracks that lead to premature failure of the specimen.

Most attempts to overcome all these difficulties have been unsuccessful. Therefore the usual procedure has been to use a specimen that is long enough to provide a midsection that is reasonably free from end-effect stress perturbations.

The IAHR Standardization Task-Committee has suggested a new method for performing field tests of ice in compression by using low modulus urethane which is laterally confined by an aluminum cylinder to prevent radial deformation. This method has been tested and found to be satisfactory in the sense of providing a uniaxial state of stress throughout the specimen. For more information see either the Task-Committee report (IAHR, 1975) or Haynes and Mellor (1977). However, as of the present this method has not been utilized in studies of sea ice.

b) Load Direction

The earliest simple compression tests on cylinders of sea ice were carried out by Butkovich (1956, 1959) who obtained strength values ranging from 76×10^5 N/m^2 at -5°C to roughly 120×10^5 N/m^2 at -16°C from vertical cores. Average values on horizontal cores in the same temperature range varied from 21×10^5 to 42×10^5 N/m^2. A similar strong orientation dependence was found by Peyton (1966) who ran tests on a large number of samples of different sea ice petrographic types at various orientations and stress rates (Figure 4). The ice Peyton used characteristically had grain sizes larger than the diameter of his specimens. Therefore, his samples were essentially single crystals with their c-axes oriented parallel to the plane of the ice sheet. In Figure 4 the loading angle notation is as follows: the first number gives the angle between the axis of the test cylinder and the vertical, while the second number gives the angle between the sample and the c-axis of the single ice crystal being tested. Note that the ratio of the strength obtained from vertical cores to that obtained from horizontal cores is about 3 to 1 which is in agreement with the results of Butkovich (1959).

In contrast to these findings are results of compressive strength tests carried out by Schwarz (1970) on saline ice from the western part of the Baltic Sea. The salinity of this ice was 2.7 o/oo due to the high rate of freezing (12 cm in 36 hours). As shown in Figure 5, the strength was about 20% higher when the ice was compressed in the horizontal rather than in the vertical direction. Because similar results in respect to the effect of the direction of load on the compressive strength have reportedly been obtained in proprietary studies sponsored by oil companies, the whole matter needs to be reconsidered. In further studies the failure mode and the strain conditions in the three principal directions of deformation as well as the structure of the ice should be investigated in order to remove some of the ambiguity in explaining the results.

It has been argued in explaining Peyton's and Butkovich's results that the grain boundaries and the basal planes of individual crystals,

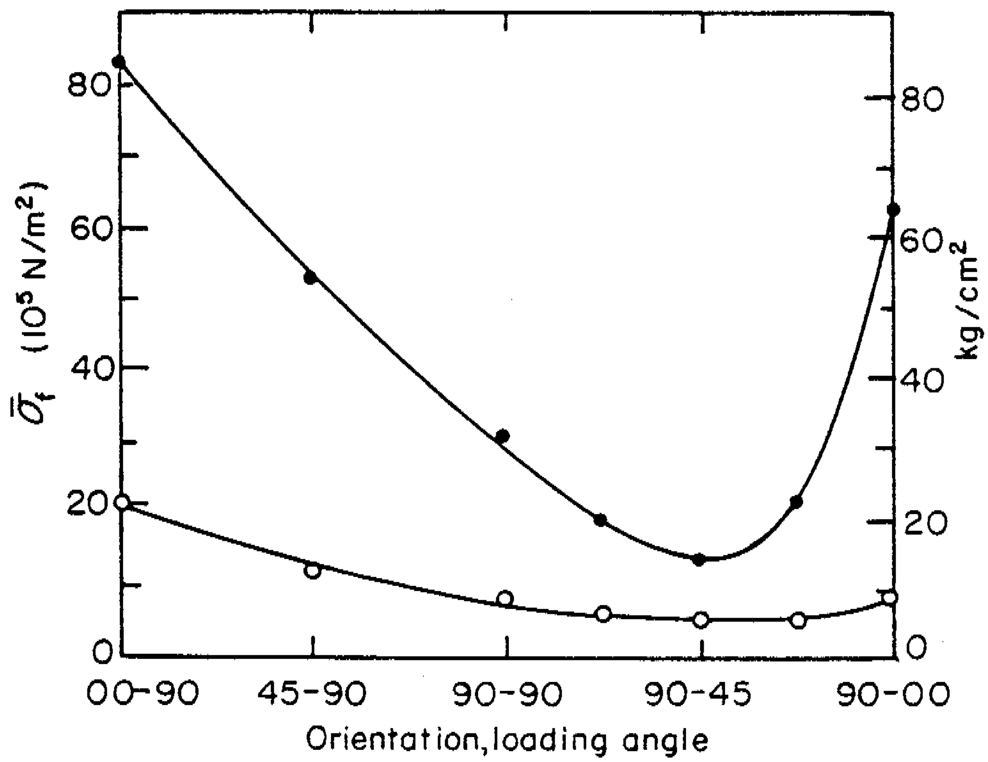

Figure 4. Average failure strength in compression (solid circles) and in direct tension (open circles) versus sample orientation: bottom ice, -10°C (Peyton, 1966). For orientation notation see text.

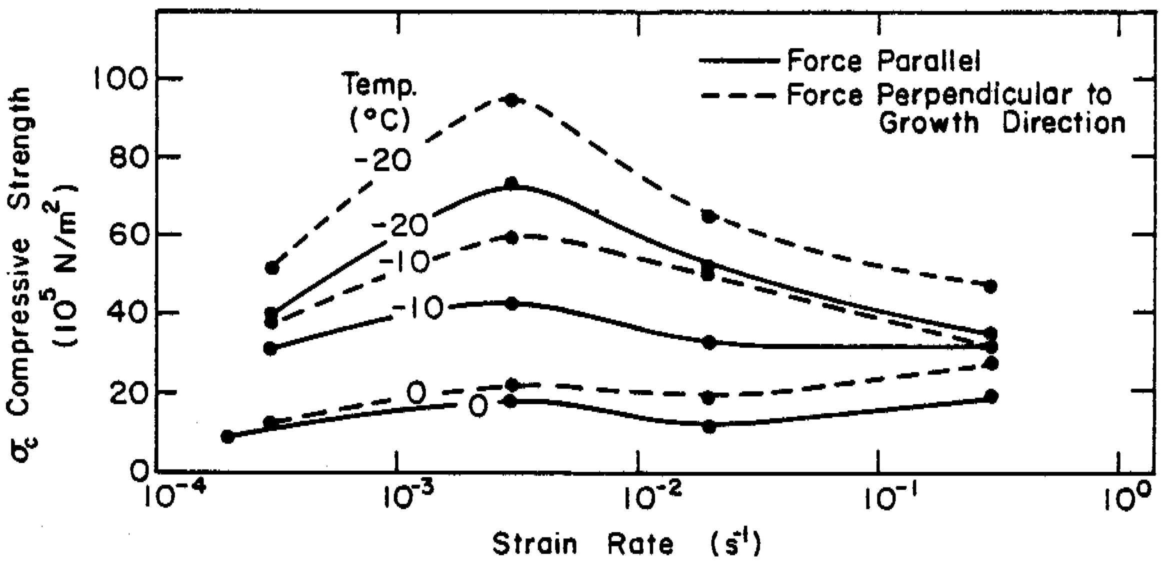

Figure 5. Compressive strength of Baltic Sea ice as a function of strain rate, ice temperature, and orientation of the force (Schwarz, 1970).

which are the planes where the brine pockets are located, are oriented so the specimen will fail easier when loaded perpendicular to the direction of growth. Other arguments can be formulated to explain Schwarz's results: sea ice fails most easily in tension by separation of the ice crystals along their long axis. This is what has been observed to happen in the uniaxial state of stress when a sample is loaded parallel to the direction of growth (which is also the direction of the long axes of the crystals) and subsequently fails by tensile strain perpendicular to the direction of load (Wu and others, 1976).

c) Brine Volume

Peyton's results on the variation of the compressive strength of sea ice with changes in the brine volume are shown in Figure 6. Here σ_R is a strength index (the measured compressive strength corrected for variations in the rate of application of the stress; $\sigma_R \equiv \sigma_c/\dot{\sigma}^b$ where σ_c is the compressive strength, $\dot{\sigma}$ is the rate of stress application and b is an experimental constant equal to 0.22). Different interpretations can be placed on these data as indicated by the solid and dashed lines. The solid line suggested by Weeks and Assur (1967) is

$$\sigma_R = 16.5 \cdot 10^5 \left(1- \sqrt{\frac{\nu_b}{0.275}}\right) \mathrm{N/m^2}$$

where σ_R was defined as mentioned and ν_b is the absolute value of the brine volume. This relation holds only at $\nu_b \leq 0.25$. At higher values of ν_b, σ_R is assumed to be constant independent of ν_b in agree-

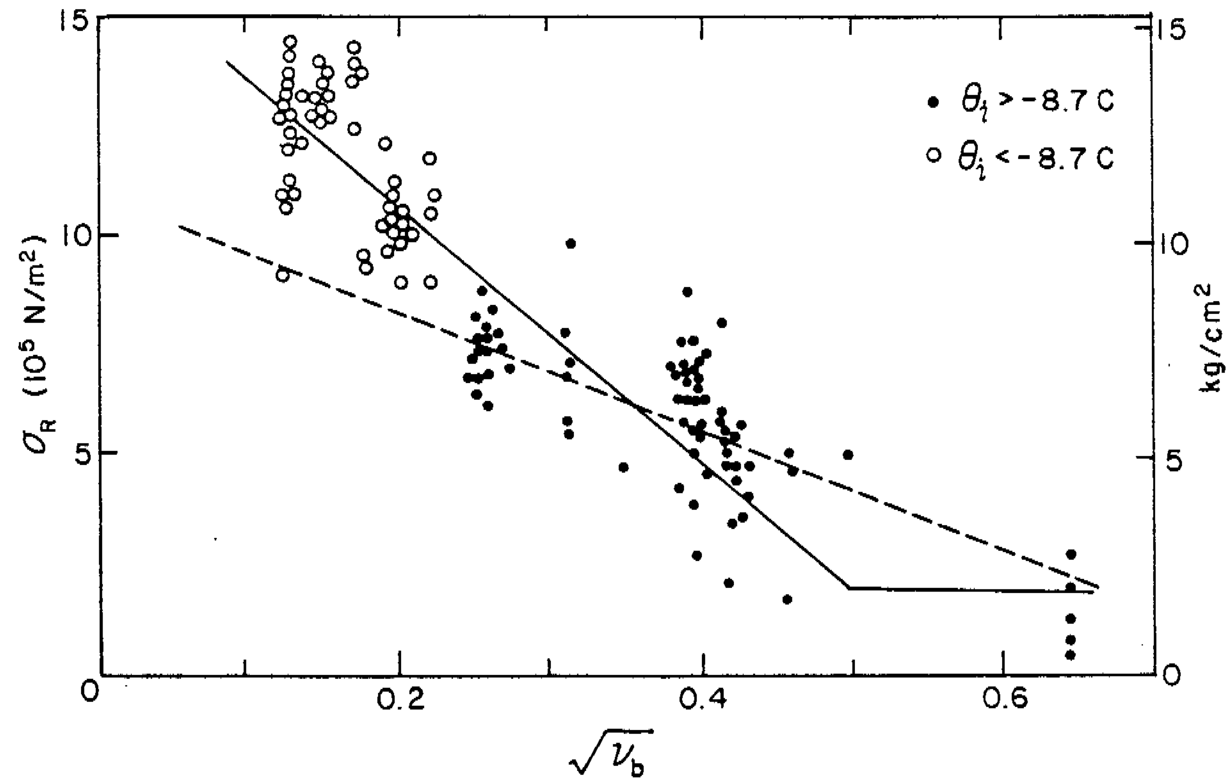

Figure 6. σ_R from compression tests versus square root of the brine volume (Peyton, 1966). For the difference between the solid and dashed lines see discussion in text.

ment with similar observations in in-situ cantilever beam tests, shear tests and ring tensile tests. The dashed line suggested by Peyton (1966) will be discussed later. The significant feature in these results is that both sets of investigators felt that σ_R could be adequately expressed as a function of the square root of the brine volume.

d) Temperature

The effect of temperature on the compressive strength has only been considered in connection with the brine volume. Peyton found the ice strength obtained at temperatures below -8.7°C to be significantly greater than extrapolated values based only on tests from warmer ice (see the dashed line in Figure 6). This was explained by the fact that at -8.7°C $Na_2SO_4 \cdot 10H_2O$ starts to precipitate. This solid salt was suggested to strengthen the ice in a manner similar to steel in concrete. Tests of Schwarz (1970) lend some support to this explanation since his investigation on saline ice from the Baltic Sea shows a relatively steeper increase of the strength between -10 and -20°C compared with equivalent tests on freshwater ice (Figure 7). The results are hardly conclusive.

e) Strain Rate

From compressive strength tests on freshwater ice we know that ice has a failure strength maximum at a certain strain rate. In this respect Peyton found contradictory results for sea ice from different locations. For sea ice from Point Barrow the strength increased with the stress

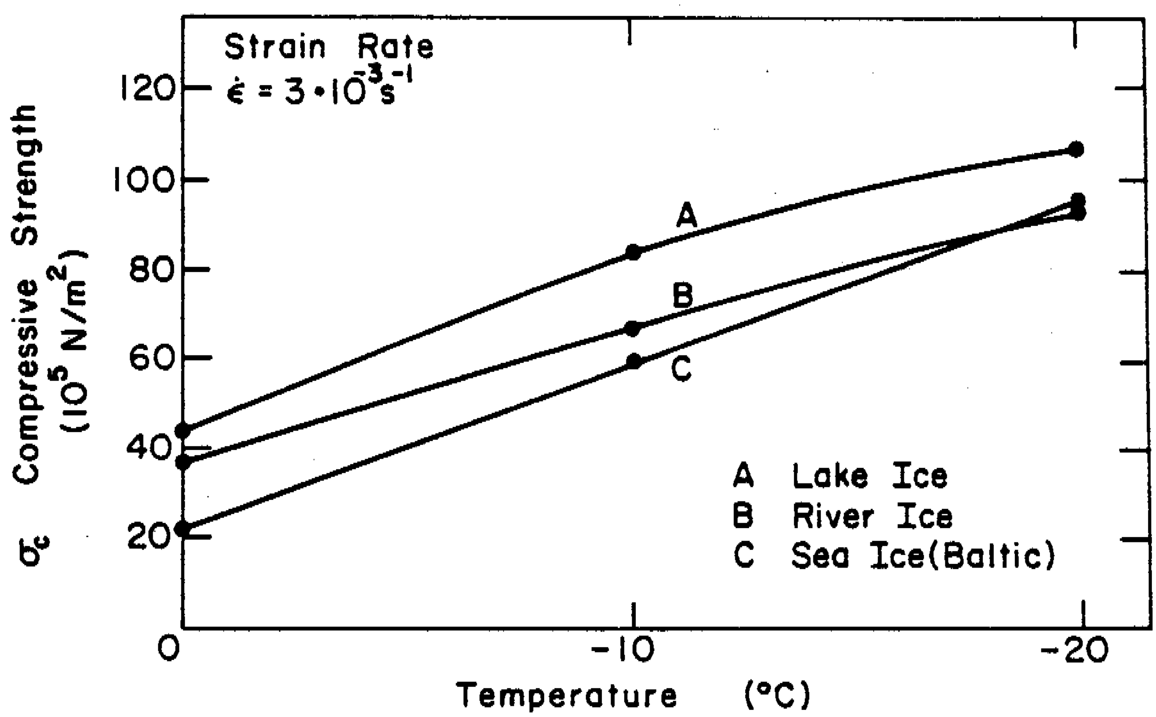

Figure 7. Compressive strength of Baltic ice and freshwater ice as a function of temperature (Schwarz, 1970). Load applied perpendicular to the growth direction.

rate while for sea ice from Cook Inlet the strength decreased when tested at the same loading rates.

In spite of these non-conclusive results Peyton expected the failure strength to have a maximum at a certain stress rate. This assumption was confirmed by Schwarz (1970) who investigated the strength of saline ice from the Baltic Sea in respect to different strain rates and temperatures. The results given in Figure 5 clearly indicate a maximum failure strength at a strain rate of about 10^{-3} s^{-1} which is associated with the transition between creep-ductile and brittle failure. The same phenomenon has been found in compression tests of freshwater ice (Carter (1972), Korzhavin (1962), Wu and others (1976) and Schwarz (1970)). There is still discussion as to whether or not the compressive strength decreases at higher strain rates. Carter (1972) explains the decrease of strength at higher strain rates by energy considerations. He shows that the stress concentrations occurring at the tips of cracks are reduced by plastic deformation. Therefore at high strain rates there is less time for plastic deformation and as a result the strength decreases. Hawkes and Mellor (1972) believe the decrease is a result of poor experimental methods. With the new testing method suggested by the IAHR Standardization Task-Committee and also with the improvements in available testing machines it should be possible to establish reliable results on such relationships. Furthermore, ice temperature should not be overlooked as an important parameter in connection with the strain rate. This has, as yet, not been investigated for sea ice, but from testing freshwater ice (Carter, 1972; Wu and others, 1976) we know that the relation between strength and strain rate is temperature dependent. Due to the correlation between temperature and the brine volume of the ice, the strain rate effect will also be a function of the brine volume.

f) Size Effect

Investigations on freshwater ice have shown that the compressive strength increases if the ratio of crystal size to sample size exceeds a certain value. This so called "size effect" has not, as yet, been investigated for sea ice. Due to the substructure of the crystals and the possibility of easy crack propagation across the crystals on planes of impurities it is very likely that the size effect will not occur in sea ice. This, of course, needs to be proven.

g) Conclusions

The controversial results and the gaps of knowledge on the uniaxial compressive strength of sea ice should be a challenge for further intensive studies on this subject. In order to be able to make both qualitative and quantitative comparisions of the results of different investigators it is suggested that the recommendations for testing ice in compression of the IAHR Standardization Task-Committee be carefully considered in designing any such studies.

Tensile Strength

Uniaxial tensile strength can only be determined unambiguously through direct tension tests. Any substitute for direct testing methods such as ring tensile, brazil, or beam tests induces complicated stress states within the sample which require assumptions relative to the stress-strain relationship before strength values can be calculated from the test results.

The most comprehensive work on the tensile strength of sea ice has been carried out by Dykins (1970) and has also been summarized by Katona and Vaudrey (1973). The ice investigated was frozen from sea water in a laboratory tank to simulate freezing conditions in nature. The salinity within the ice was 1 to 2 o/oo (brackish ice) and 8 to 9 o/oo (sea ice). By varying the temperature, a wide range of brine volumes was investigated. The tests were carried out on dumbbell specimens which were attached to the testing machine by gripping heads. A similar method in which the ice was frozen to the metal end cups has been used by Hawkes and Mellor (1972). Both methods provide a fairly accurate uniaxial state of stress as photoelastic observations by Vaudrey (personal communication) have shown. These procedures have therefore been recommended for such tests by the IAHR Standardization Task-Committee.

Dykins' (1970) results have shown a very strong difference in the tensile strength depending on the direction of load: the ice was two to three times stronger when the tension was applied in the vertical direction than in the horizonta (Figure 8). This result supports the compression test results on sea ice of Schwarz (Figure 5), since compression applied in the vertical direction induces tensile strain in the lateral direction.

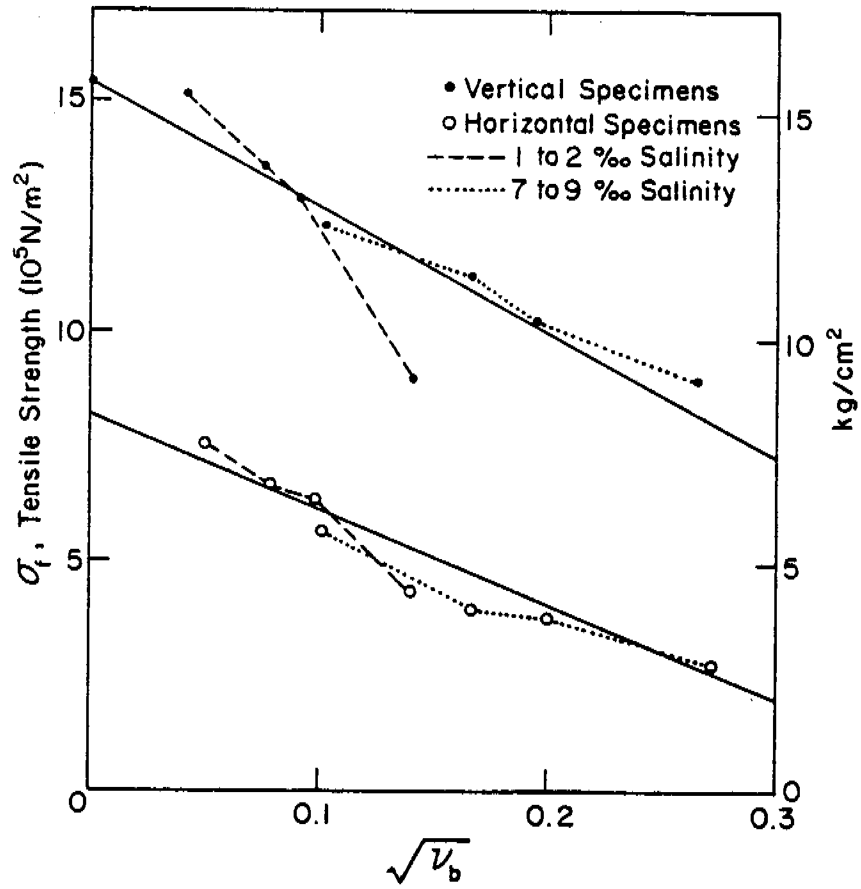

Figure 8. Tensile strength of sea ice versus the square root of the brine volume (Dykins, 1970).

Figure 8 shows that the tensile strength, in the vertical as well as horizontal loading direction, can be adequately expressed as a function of the square root of the brine volume, similar to the case for compressive strength. The equations derived from the two curves of Figure 8 are:

$$\sigma_t \text{ (vertical)} = 15.4 \cdot 10^5 \left(1-\sqrt{\frac{\nu_b}{0.311}}\right) \text{ N/m}^2$$

$$\sigma_t \text{ (horizontal)} = 8.2 \cdot 10^5 \left(1-\sqrt{\frac{\nu_b}{0.142}}\right) \text{ N/m}^2$$

Dykins stated that the tensile strength was not appreciably dependent on the crystal size. Since the ratio of dumbbell diameter to crystal diameter was as low as 5, the so called size effect should have shown up if it is present in sea ice. These results indicate that the substructure of a sea ice crystal works like the grain boundaries in freshwater ice in respect to easy crack propagation.

Limited studies on the effect of stress rates on the tensile strength show strength to be insensitive to stress rates ranging from $\dot{\sigma} = 1 \cdot 10^3$ to $\dot{\sigma} = 1.8 \cdot 10^5$ N/m^2·s. A similar result was found by Hawkes and Mellor (1972) in tensile tests on fine grained freshwater ice. However, for stress rates greater than $1.8 \cdot 10^5$ N/m^{2}s, Dykins (1970) observed that the tensile strength decreased by 52% of the initial value. This result can be explained by the higher number of stress concentrations within sea ice in the form of brine pockets and air bubbles which become more effective at higher stress or strain rates.

Even though the tensile strength tests of Dykins were carried out well, more testing of the tensile strength is necessary to confirm his results and to answer remaining questions such as the strain effect in relation to the brine volume, the precipitation of solid salts and their influence on the tensile strength, and the failure mode at various strain rates. Further testing should also be expanded to include tensile strength behavior under three dimensional stress states.

Flexural Strength

The flexural strength is not a basic material property but only an index strength. It is normally obtained by two different test methods: simply supported beam tests or cantilever beam tests. The cantilever beam tests have an advantage in that they can be easily carried out in the field, thereby avoiding major brine drainage.

As Gow (1977) has shown in a paper presented earlier at this conference, cantilever beam tests on freshwater ice provide a flexural strength which is up to 50% less than the flexural strength obtained from simply supported beams. Gow suggests that this difference is the result of stress concentrations occurring at the butt ends of the beams. In sea ice such significant differences in strength have not been reported; on the contrary, it has been stated (Frankenstein, 1968) that the results obtained by these two testing methods vary only slightly. This characteristic of sea ice is probably due to its more plastic behavior which relieves the stress concentrations and results in higher strengths.

The flexural strength of cantilever beams has usually been calculated by

$$\sigma_f = \frac{6\,P\ell}{b\,h^2}$$

where

P = failure load

ℓ = length

b = width, and

h = beam thickness

This equation assumes that the deformation is elastic and the material is both isotropic and homogeneous. Sea ice, however, is an anisotropic material with a non-linear stress distribution over the beam depth. Hutter (1973) has developed an equation which considers these conditions; its application, however, is difficult, because it requires the establishment of a stress distribution according to the temperature and salinity gradient. Therefore, for practical uses and for the purpose of obtaining some index strength the given equation may be sufficient.

On the other hand we should not forget that, by using the equation based on the elastic theory, certain controversial results have been reported, for example by Lavrov (1971), for beams of different dimensions. It is very likely that these and other peculiar results of ice tests are due to incorrect assumptions with regards to the material properties.

If, for practical reasons, we continue to use equations based on the elastic theory for calculating the flexural strength, then more testing is necessary to elucidate the size effect and to standardize the testing methods, i.e. beam preparation, loading conditions, etc.

Many investigators have determined values for the flexural strength of sea ice. The relation between brine content and flexural strength as determined from <u>in-situ</u> cantilever beam tests is particularly consistent, as shown in the investigations of Weeks and Anderson (1958), Brown (1963), and Butkovich (1956) (Figure 9). From Figure 9, the following equation has been obtained:

$$\sigma_f = 7.5 \cdot 10^5 \left(1-\sqrt{\frac{\nu_b}{0.202}}\right) \quad N/m^2$$

for $\sqrt{\nu_b} < 0.33$. These results indicate that the flexural strength remains roughly constant at brine volume $\sqrt{\nu_b} > 0.33$. However, this constancy of strength was not obtained by Schwarz (1975) in his investigation of high salinity ice produced for model studies.

The most recent and extensive work on flexural strength was done by Dykins (1971) who tested large in-situ beams with ice thicknesses of up to 2.4 m. His test results (see Figure 10) are well described by the equation

$$\sigma_f = 10.3 \cdot 10^5 \left(1-\sqrt{\frac{\nu_b}{0.209}}\right) \quad N/m^2$$

A comparison of the results of Figure 9 and Figure 10 shows that both curves have similar slopes as well as zero brine volume intercepts.

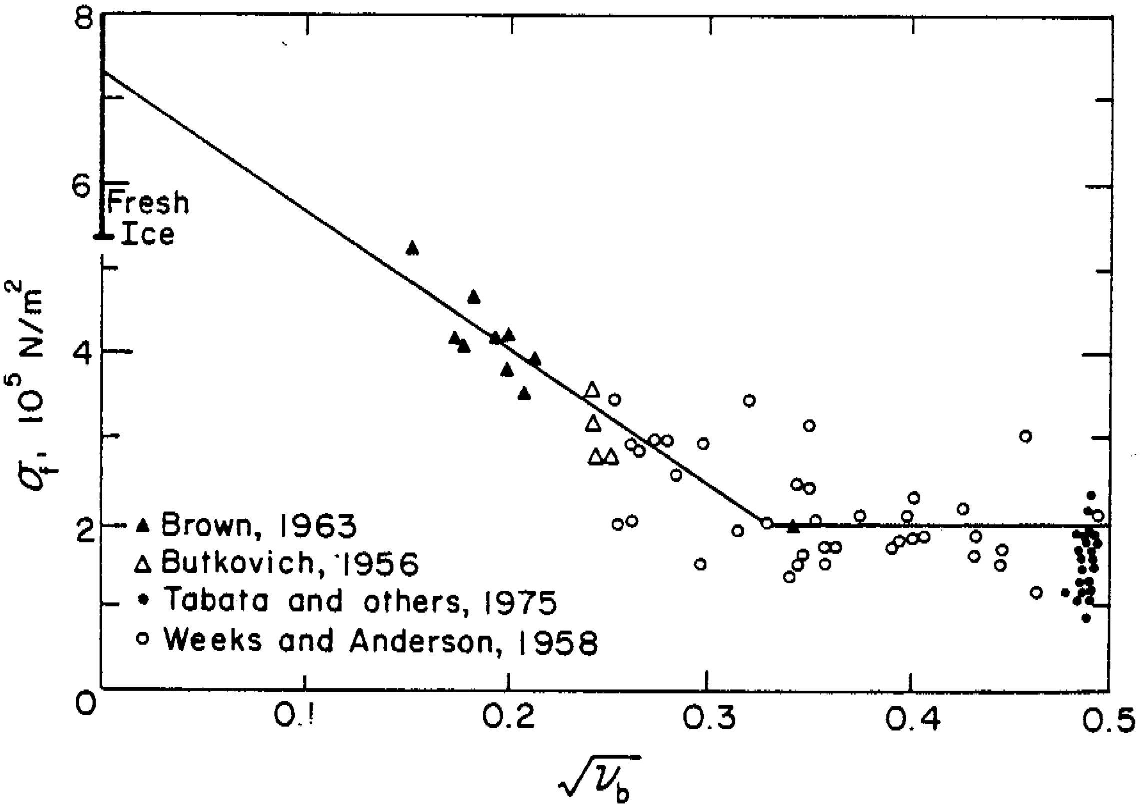

Figure 9. Flexural strength measured by in-situ cantilever beam tests versus square root of the brine volume.

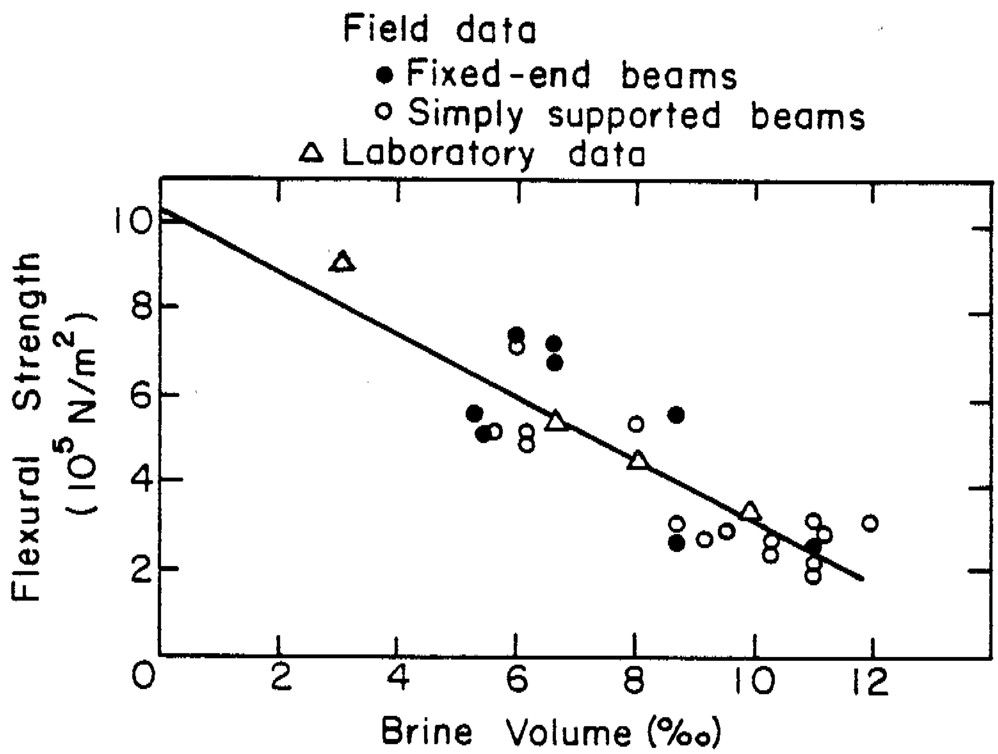

Figure 10. Flexural Strength as measured by fixed-end and simply supported beams versus brine volume (Dykins, 1971).

This strongly suggests that external stress concentrations at the sharp corner of the butt of the cantilever are quite small for sea ice as has been suggested by Frankenstein (1968).

Strength tests with different stress or strain rates have shown quite contradictory results. Tabata and others (1967) have tested cantilever beams of sea ice - even recently in the Gulf of Bothnia (1975) - at stress rates up to about $3 \cdot 10^5$ N/m^2 s. They found a considerable increase of the flexural strength of sea ice with increasing stress rates. However, if the inertial force associated with the displacement of the water during rapidly performed tests is eliminated (Mataanen, 1975), the flexural strength of sea ice is almost independent of the stress rate.

Even though the flexural strength is not a basic material property, it is relatively easy to obtain, and therefore it is commonly used as an indicator of the strength of ice. Our present knowledge of the flexural behavior of sea ice, however, is not sufficient for reproducible and consistent results. Questions such as the size effect, the failure mechanism, and the shear involvement in the failure of beams remain unresolved.

Shear Strength

Only a small number of shear strength tests have been carried out and reported. In fact, many tests described as shear are actually the result of mixed mode failures as in punch tests. Indeed, it is extremely difficult to obtain pure shear strengths. The best sets of shear test data available are those of Paige and Lee (1967) and of Dykins (1971). Paige and Lee's (1967) results show similar trends with brine volume changes (Figure 11) as do in-situ cantilever beam tests (Figure 10). Also the absolute value of the shear strength is in the range of observed flexural and tensile strengths (tension applied parallel to the growth direction). Dykins (1971) found the shear strength of sea ice to be not appreciably affected by different crystal orientations. This indicates again that not only are grain boundaries and the basal planes of ice crystals lines of easy slip but that the same is also true of planes within the substructure where brine pockets and imperfections are lined up.

Even though the few results available indicate a strong dependency of the shear strength on the load or strain rate, this effect can not yet be quantified. This is an area requiring more thorough investigations.

Some contradictory results have been reported by Katona and Vaudrey (1973) on the effect of temperature on shear strength. On one hand shear strength increased significantly in a similar fashion to other strength results when the temperature was lowered from -2 to -10°C. On the other hand the shear strength was lower at -10°C than at -4°C and greater at -20°C than at -27°C. This last result is probably incorrect but it is mentioned here in order to show the gaps and to stimulate

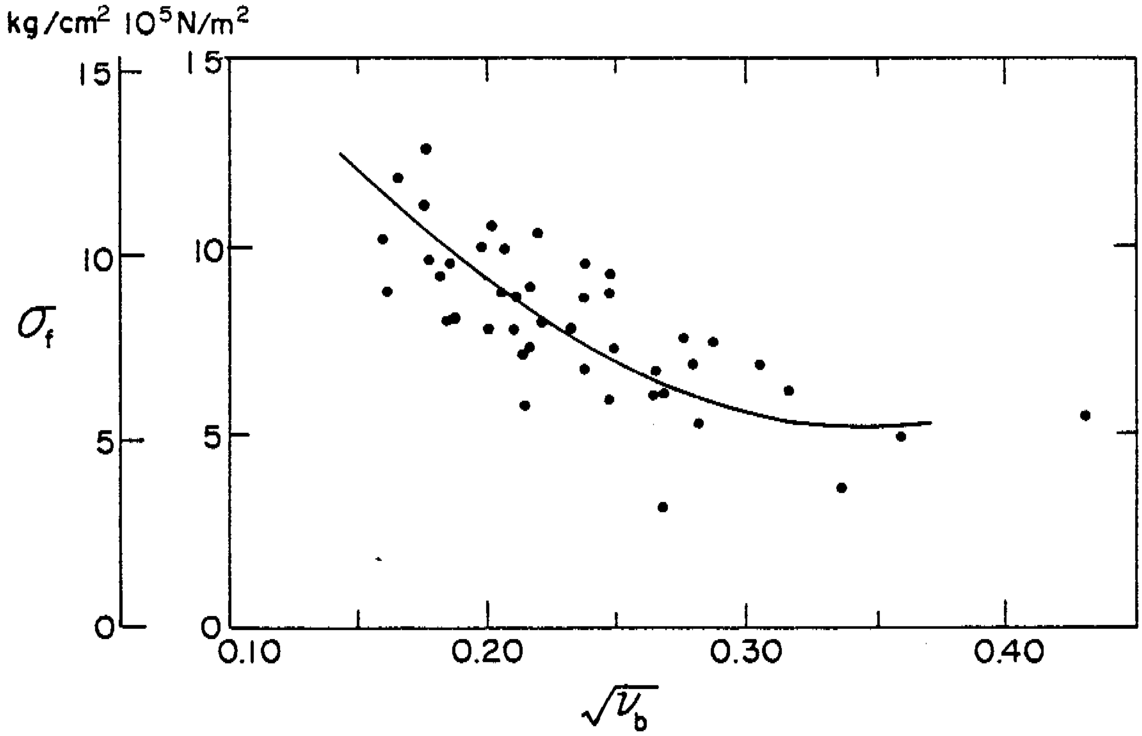

Figure 11. Shear strength as a function of the square root of brine volume (Paige and Lee, 1967).

further investigations, especially on shear strength, which has been widely disregarded in the past.

Suggestions for Further Study

Although our knowledge of the relationships between the various strength properties of sea ice and its brine volume is fairly satisfactory, additional studies at high brine volumes would be most useful. In addition, uncertainties remain regarding the effect on strength of the strain or stress rate, of the sample size, of the loading direction in relation to the crystal orientation, and of the crystallization of solid salts. Also the behavior of sea ice under two and three dimensional stress states has not been investigated even though such stress states actually occur in many applied problems.

ELASTIC MODULUS

There has not, as yet, been an adequate theoretical treatment of the variation in the elastic modulus of sea ice with brine volume and crystal orientation that is based on a realistic model of the arrangement of inclusions in sea ice. Even so, current experimental observations are in general agreement with theoretical predictions for materials with a random distribution of pores in that the variation in E with the volume fraction of pores is to a good approximation linear in the porosity range 0 to 10% (Coble and Kingery, 1956; Buch and Goldschmidt, 1970) which is the range in which sea ice has primarily been studied.

Dynamic Measurements

By dynamic measurements of the elastic modulus E we refer to values determined by either the rate of propagation of vibrations in the ice or by exciting natural (resonant) frequencies of different types of vibrations. The displacements in such measurements are extremely small and, for many purposes, anelastic effects can be neglected. Therefore, dynamic measurements of E tend to be quite reproducible when compared with E values determined from typical mechanical tests.

In-situ seismic determinations of E for natural sea ice are reviewed by Weeks and Assur (1967). More recent results are reported by Kohnen (1972). E was found to vary from 1.7 to $5.7 \cdot 10^9$ N/m^2 when measured by flexural waves and 1.7 to $9.1 \cdot 10^9$ N/m^2 when determined by *in-situ* body wave velocities. The E values, when measured on similar ice, are invariably larger when determined by body waves. This is reasonable inasmuch as the flexural wave velocity is controlled by the overall properties of the ice sheet while the body wave velocity is controlled by the high velocity channel in the usually colder and stiffer upper portion of the ice. Pronounced changes in E are noted throughout the year with high values occurring in winter (cold, low brine volumes) and low values in the summer (warm, high brine volumes). Detailed studies of the relation between E and brine volume have been made by Anderson (1958b) and Brown and Howick (1958). Both test series show a pure ice intercept at zero brine volume of 9 to $10 \cdot 10^9$ N/m^2 and a pronounced decrease in E as ν_b increases. The results of Anderson are shown in Figure 12.

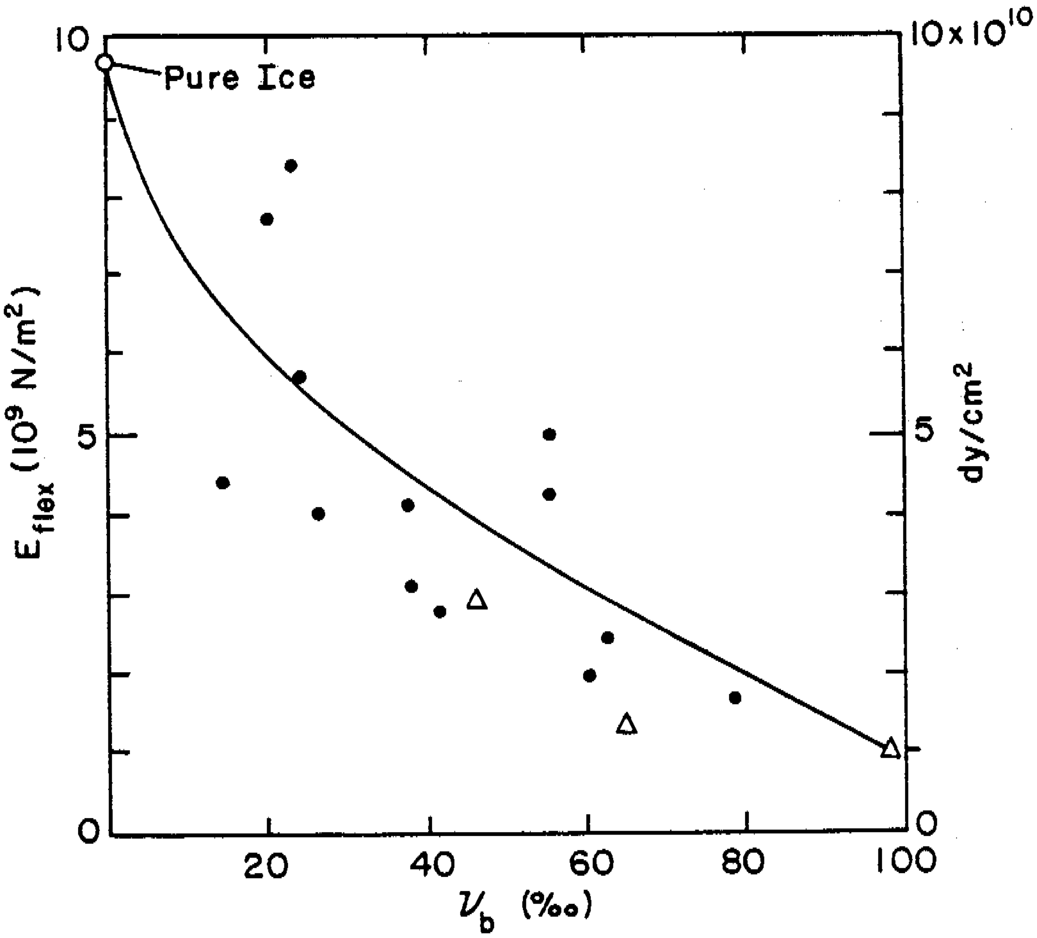

Figure 12. Elastic modulus of sea ice as determined by seismic techniques versus brine volume (Anderson, 1958b). The three triangular points are the results of static tests performed by Dykins (1971).

The remainder of the dynamic determinations of E were made on small specimens which were removed from the ice sheet. A representative series of tests performed by Langleben and Pounder (1963) is shown in Figure 13. E values at zero brine volume are characteristically found to be 9 to $10 \cdot 10^9$ N/m^2, in good agreement with the seismic determinations. The decrease in E with increasing ν_b appears to be linear within the brine volume range studied. Recent studies suggest that at ν_b values greater than 0.1 the value of E decreases more slowly, becoming a weak function of ν_b at ν_b values in excess of 0.15 (Slesarenko and Frolov, 1972). This is in general agreement with theoretical predictions (Coble and Kingery, 1956; Hashin, 1970). However, in these predictions appreciable deviations from a linear relation do not occur until porosity values become larger than 0.2.

Static Measurements

Static measurements of E are much more variable and difficult to interpret than are dynamic measurements because of the viscoelastic behavior of ice when subjected to significant stresses for finite time periods. Nevertheless static measurements are extremely important as they are required in the consideration of problems such as ice forces on structures and vessels and bearing capacity calculations.

The most extensive study of the static modulus of sea ice is by Dykins (1971) who utilized small beams in bending. His stress-strain curves, which were obtained at stress rates of $2.6 \cdot 10^5$ N/m^2 s were

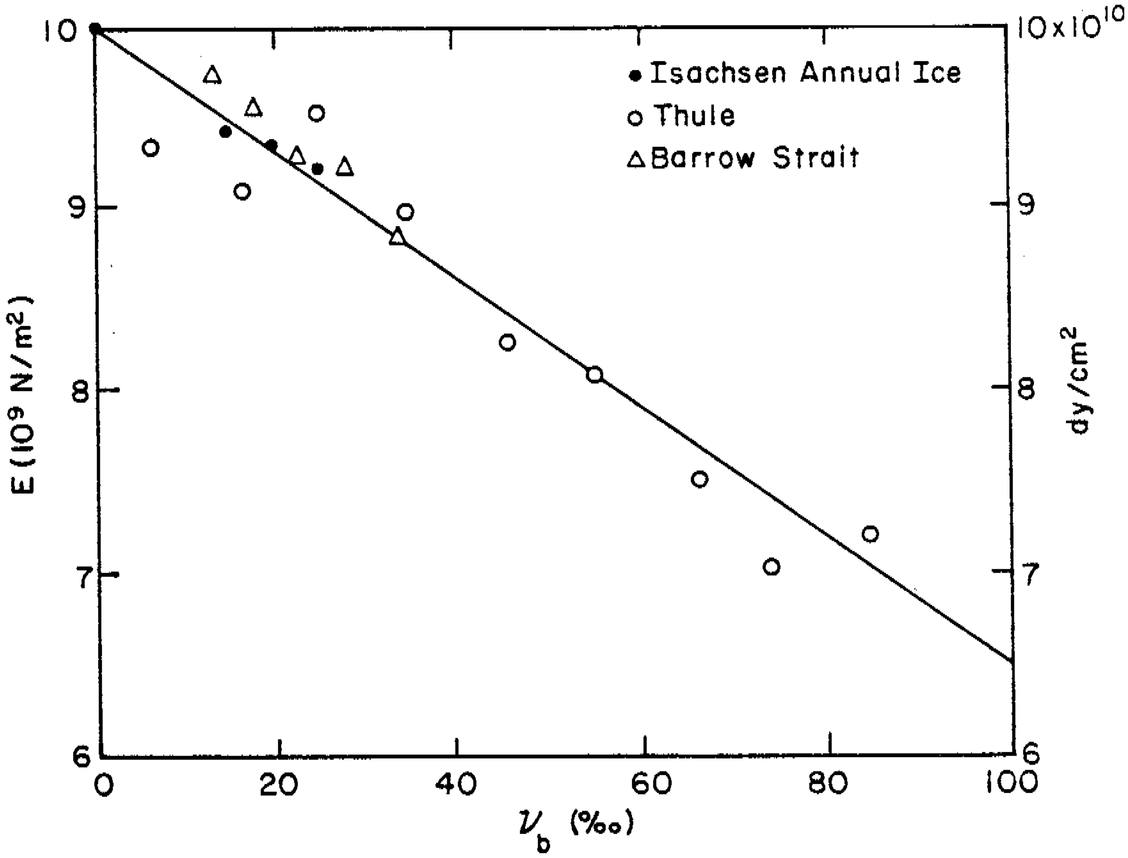

Figure 13. Elastic modulus of cold arctic sea ice as determined by small specimen tests versus brine volume (Langleben and Pounder, 1963).

quite linear. The plots of E versus temperature are suggestive of discontinuities at the temperatures where $Na_2SO_4 \cdot 10H_2O$ and $NaCl \cdot 2H_2O$ precipitate (-8.7 and -22.8°C respectively). However, testing is not sufficiently detailed to clearly establish this effect. When E was plotted vs ν_b, the values indicated by the triangles in Figure 12 were obtained. It is encouraging to note that the values obtained by static measurements are in general agreement with the "seismic" values obtained by Anderson.

In 1967 Weeks and Assur proposed, in connection with the formulation of a physical model of sea ice, the following relationships between the elastic modulus E, the flexural strength σ_f, and the brine volume ν_b:

$$\frac{\sigma_f}{\sigma_o} = (1 - \sqrt{\nu_b})^2$$

$$\frac{E}{E_o} = (1 - \nu_b)^4$$

By combining both equations we obtain

$$\frac{\sigma_f}{\sigma_o} = (1 - \sqrt{1 - (E/E_o)^{1/4}}\,)^2$$

Laboratory tests on the flexural strength and elasticity of saline ice as determined in flexure have been carried out by Schwarz (1975). The results plotted in Figure 14 support the theoretically developed relationship between E, σ_f and ν_b. These results are quite important

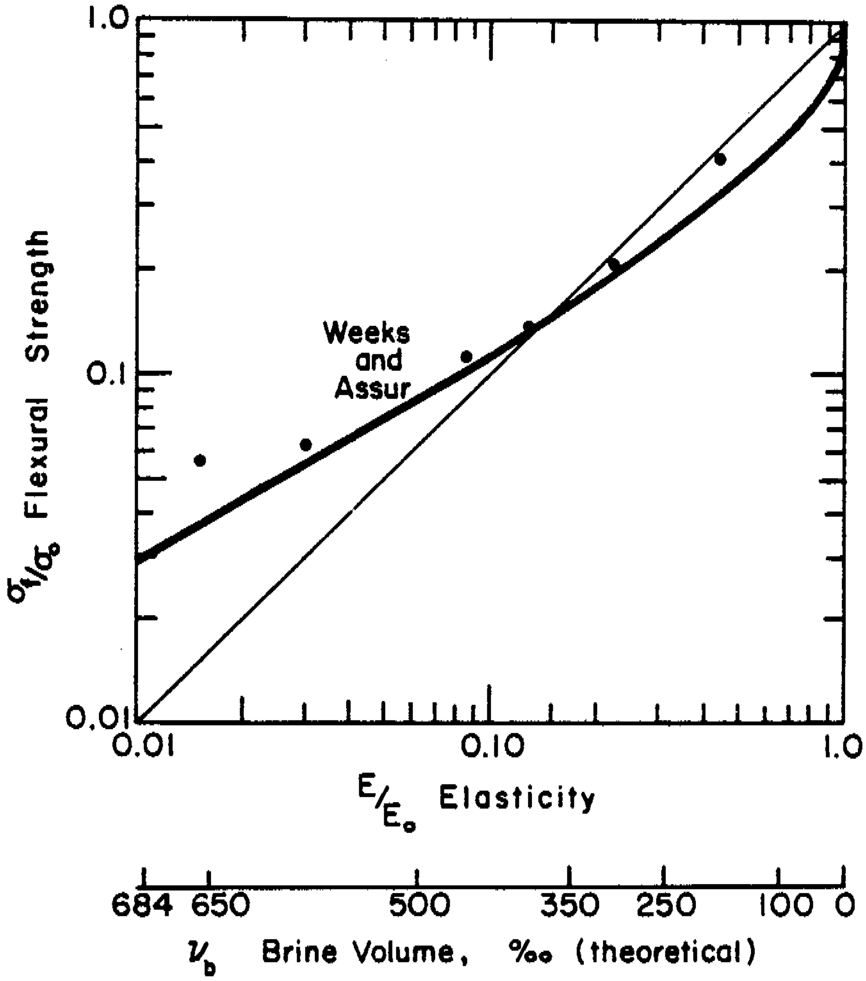

Figure 14. Normalized strength versus normalized elastic modulus for saline model ice (Schwarz, 1975).

to investigators working on the physical modeling of ice problems in which it is desirable to keep the ratio E/σ the same in both the model ice and the natural ice. As indicated in Figure 14, for high brine contents the elasticity of saline ice is too small compared with its strength. Current measurements of the E/σ ratio of natural sea ice give values varying between 2000 and 5000 as determined in flexure and tension to as low as 330 as determined in compression (Schwarz, 1975; Johnson, 1972).

Poisson's Ratio

In discussing Poisson's ratio, i.e. the ratio between the strain in two directions perpendicular to each other, it is important to distinguish between the dynamic and the static methods. The only data presently bearing on the variation of Poisson's ratio μ with sea ice structure and state are those of Lin'kov (1958) based on in-situ seismic observations at Cape Schmidt, Siberia. From these observations, Weeks and Assur (1967) proposed a formula which expresses μ as an extremely weak function of ice temperature. Presumably, the prime functional relation will prove to be between μ and $\sqrt{\nu_b}$. The value of μ would also be expected to vary with the structural orientation of the ice and the loading conditions (assuming that the ice is to a large extent permeable). Inasmuch as studies of other materials indicate that μ shows only slight changes (< 10%) over porosity ranges of up to 30% (Buch and Goldschmidt, 1970), for most engineering purposes μ can be considered constant with a value of 1/3. Also a detailed examination of the theoretical effects of the vertical variation of μ through a floating ice sheet on the mechanical response of the sheet (Hutter, 1975) has indicated that for most real problems it is not necessary to consider the variation of μ.

Although the above may be true for elastic deformation, it is quite important to know the ratio of the strain in different directions if the ice deforms viscoelastically or plastically. Static measurements of the strain ratio have been carried out by Hirayama and others (1974) by freezing strain gages along the three principal strain directions into a fresh ice cover in front of a vertical pile. As long as the ice deformation remained elastic, Poisson's ratio was 0.3. But when the ice was deformed plastically the ratio $\varepsilon_z:\varepsilon_x$ (z = vertical direction, x = direction of advance, y lateral direction) increased to about 0.8 due to the lateral confinement of the ice cover ($\varepsilon_y \simeq 0$). This caused the ice cover to fail by cleavage as a result of tensile strain in the z-direction. Similar investigations on the strain ratio in different directions are desirable for sea ice in respect to stress state, temperature, salinity and loading rate.

FRICTION AND ADHESION

The frictional and adhesive characteristics of sea ice are extremely important in a wide variety of applied problems. For instance, current thinking on the physics of icebreaking by ships suggests that in continuous mode icebreaking the dominant aspect of the ice resistance is related to forces associated with the buoyancy of the ice (Lewis and

Edwards, 1971). These include the frictional forces between the broken ice and the hull (forces associated with the initial breaking of the ice appear to be comparatively small). Also, as we have discussed earlier, current testing indicates that ice forces measured during studies of ice and piles are as much as 50% higher if the ice is allowed to bond to the pile (Croasdale, 1974). In fact, ice-ice and ice-metal friction and ice-metal adhesion are components of a proper analysis of almost every problem concerned with the differential motion of sea ice and structures. Therefore, the paucity of information on this subject is rather surprising.

Table II summarizes the currently available data. There obviously is considerable scatter and the data are of use only for providing rough estimates. It is recommended that anyone using these data study the details of how the different data sets were obtained before applying them to specific problems. Some general conclusions can, however, be drawn from the tests. These are: static friction coefficients are appreciably larger than dynamic coefficients, reaching values of up to 0.7, and are also relatively independent of surface pressure; dynamic coefficients first decrease rapidly with increasing surface pressure up to values of roughly 5000 N/m^2; at higher surface pressures coefficients are generally constant, with values varying between 0.04 and 0.11, dynamic coefficients are practically independent of velocity (even on wet ice), dry snow increases sliding friction to about four times the

Table II. Friction Coefficients

Investigator	Friction Coefficient Static	Friction Coefficient Kinetic	Test Material	Test Temperature (°C)
Arnol'd-Aliab'ev (1938)	.15-.25	.10-.20	sea ice - stainless steel	-
	.30-.35	.20	sea ice - painted steel	-
Jansson (1956)	.25	.10-0.15	sea ice - steel	-
	.25	.20	"polar" ice - steel	-
Milano (1962)	.3-.5	.1-.2		-
Ryvlin and Petrov (1965)	.15-.20		sea ice - rusted steel	0
	.03-.04		sea ice - wet smooth steel	0
Enkvist (1972)			brackish ice- (0.9°/oo)	-5
		.025-.045	smooth steel	
		.11	rough steel	
			snow-	
		.09-.19	smooth steel	
		.31	rough steel	
			wet snow-	
		.03-.10	smooth steel	
		.14	rough steel	
Finke (1972)		.045-.065	sea ice - steel	-4.5
Airaksinen (1974)	.4-.7	.07-.25	sea ice - steel	-
Grothues-Spork (1974)	.3-.5	.12-.23	sea ice - steel cone	-7

value for dry ice; and wet snow produces essentially the same values as dry snowless ice.

There do not appear to be any detailed studies of the adhesion of sea ice to surfaces. This is not too surprising in that if the adhesion of pure ice to clean surfaces is difficult to understand then the adhesion of sea ice to dirty surfaces can hardly be a readily tractable problem. It is reasonable to assume that the adhesive strength will prove to be highly dependent on the brine volume in the ice, although preliminary attempts to obtain a correlation with ice salinity have shown that the relation is not simple (Ryvlin and Petrov, 1965). Additional work on this subject is badly needed.

THERMAL PROPERTIES

From an engineering point of view our knowledge of the thermal characteristics of sea ice is in a fairly developed state. The classic reference on this subject is Malmgren (1927). However his studies have recently been expanded by several different authors, specifically Anderson (1960), Schwerdtfeger (1963) and Ono (1966, 1967, 1968). Here, by the thermal properties of sea ice we particularly refer to the parameters composing the thermal diffusivity term in the diffusion equation, i.e. the specific heat, the thermal conductivity, and the density. However we will also discuss the latent heat and the heat required to melt sea ice that is initially at an arbitrary temperature. All of these terms show fairly complex dependence on both the temperature and the composition while the thermal conductivity also requires information on the geometric distribution of all the components.

Specific Heat

The specific heat of sea ice depends primarily upon the amount of water changing state during a temperature change as well as on the specific heats of pure water, ice and solid salts making up the sea ice. The pertinent equations can be found in either Schwerdtfeger (1963) or Ono (1967). Both authors tabulate calculated values of the specific heat in the salinity and temperature ranges of 0 to 10 o/oo, -2 to 23°C (Schwerdtfeger, 1963) and 0 to 11 o/oo, -0.1 to 8.0°C (Ono, 1967, 1968). Slightly different constants were used producing slightly different specific heats, with Ono's values usually being lower than Schwerdtfeger's (the maximum difference of 4.4% occurs at high salinities and temperatures). Schwerdtfeger's values have recently been compared against the results of a series of determinations of the specific heat of artificial sea ice performed by Dixit and Pounder (1975). The agreement was very good (within 4.5%), with the experimental value commonly being slightly larger than the theoretical. An earlier comparative study using specific heats of real sea ice on the drifting station Severnyi Polus -4 vs theoretical values as calculated by Malmgren can be found in Nazintsev (1959).

Latent Heat

In pure materials the latent heat is a well defined parameter implying a release or absorption of heat at the constant temperature specified by the particular phase change involved. In sea ice such a "discontinuous" process does not occur and the heat input (or output) is associated with a continuous change in sample temperature. Nevertheless the amount of pure ice formed from a unit mass of sea ice at the freezing temperature can be ascertained and the heat associated with this ice calculated. Values of this "latent heat" for ice salinities of up to 8 o/oo are calculated by Schwerdtfeger (1963). Perhaps more important are the values of heat required to completely melt isolated specimens of sea ice. Calculated values of this parameter can be found in Schwerdtfeger (1963) and in Ono (1968). A particularly useful parameter is the amount of heat required to change the temperature of 1 g of sea ice from one arbitrary temperature to another. Nomographs allowing this quantity to be rapidly determined are given by Untersteiner (1964) and by Ono (1968).

Thermal Conductivity

The thermal conductivity k of sea ice is a particularly interesting property in that it is dependent on the geometric arrangement of the phases involved as well as their relative volumes and conductivities. Sea ice of course is a mixture of ice, brine and air, and, at temperatures below -8.2°C, solid crystals of salt. Anderson (1958a, 1960) calculated k for several different geometries of ice and brine: parallel layers of brine and ice with conductivity measured a) normal to the layers, and b) parallel to the layers, and c) parallel brine cylinders spaced according to thin section measurements with conductivity measured parallel to the axes of the cylinders and d) spherical brine pockets. Options b) and c), which are the most realistic, gave very similar results. However, Anderson did not consider the presence of gas in the sea ice. This important factor was included in the calculations of Schwerdtfeger (1963) and Ono (1968) but in slightly different ways. Schwerdtfeger considered the gas phase to be uniformly distributed in spherical inclusions within the ice only and then included the brine as a series of vertical cylinders aligned parallel to the direction of heat flow. Ono considered the air bubbles to be uniformly dispersed in both the ice and the brine, with the brine being arranged in layers oriented parallel to the direction of heat flow. Ono's results, which are based on a slightly more realistic model, are preferable, although either set of values should be adequate for most purposes.

Both Schwerdtfeger's and Ono's calculations only go down to -8°C (just before the first solid salt, $Na_2SO_4 \cdot 10H_2O$, crystallizes out of the brine). Calculations of the values of k at lower temperatures have not been carried out because thermal conductivities of the different hydrated solid salts are not available. Fortunately this is not a major problem inasmuch as at temperatures of -8°C the k of air-free sea ice, which rarely would have a salinity of more than 10 o/oo, is within roughly 1% of the k of air-free pure ice, with the difference decreasing as the temperature drops.

Comparisons between the calculated values of k and values measured from natural sea ice have been made by several different authors, notably Schwerdtfeger (1963), Lewis (1967) and Weller (1968). In all cases good agreement was obtained. This was particularly true in the study by Lewis, which is the most extensive comparative investigation yet published.

We feel that the shortcomings in any such comparisons are not with the details of how k is calculated but with the fact that only rarely is the volume of gas entrapped in the ice measured precisely enough (it is rarely measured at all) to allow really first class comparisons to be made between theoretical and observed values. Although this might not prove to be a major problem in the first year ice upon which these published comparisons have been made, there is every reason to believe that gas measurements would be essential to any comparative study using multiyear ice. It is also reasonable to assume that the processes of brine migration within the ice sheet should result in the vertical transfer of appreciable amounts of heat. The effects of such processes on altering the observed values of k have not, to our knowledge, been seriously examined.

Density

Information on the variation of the theoretical density of gas-free sea ice can be found in Malmgren (1927), Zubov (1945) and Anderson (1960), with values ranging from 920 to 950 kg/m^3 depending on the temperature and salinity of the ice. Because of gas entrapped in natural sea ice, real densities are invariably lower than these calculated values. Calculations of sea ice density incorporating the effects of gas inclusions are given by Schwerdtfeger (1963) and Ono (1968). As Schwerdtfeger points out, in density as in thermal conductivity, there are two interesting asymptotic tendencies in that at temperatures near the melting point the values of these parameters are largely controlled by the amount of liquid brine present while at low temperatures it is the volume of entrapped air that is the important factor.

In first-year ice, densities of 910 to 920 kg/m^3 are common, although values as low as 840 kg/m^3 have been observed during the early part of melt season (Weeks and Lee, 1958). Detailed ice profile information collected on the 1971 and 1972 AIDJEX stations gave average multiyear ice densities of 910 and 915 kg/m^3 (Hibler and others, 1972; Ackley and others, 1974). The data collected in 1972 indicated that the higher the freeboard of the ice (multiyear), the lower the average ice density as given by the empirical equation

$$\rho = -194f + 974$$

where ρ, the ice density, is in kg/m^3 and f, the freeboard is in meters. For most purposes, unless detailed information on the actual density of a specific piece of sea ice is required (which would probably require direct field measurements), a value of 910 kg/m^3 should serve as a reasonable estimate.

Thermal Diffusivity

The parameter that actually enters the differential equation for heat transfer in an isotropic medium is the thermal diffusivity $K \equiv k/\rho c$ where k is the thermal conductivity, ρ is the density and c is the specific heat. The temperature dependence of K is more than the temperature dependence of the three parameters that compose it in that as temperature increases, k decreases while both ρ and c increase. A graph showing the calculated variation in K in the temperature range 0 to -8°C and the salinity range 0 to 12 o/oo is given by Ono (1968). Comparisons between observed and calculated values of K have been made by both Weller (1968) and Ono (1968) with rough agreement. One striking result of Weller's study was the obvious importance of the effect of direct radiation on determining the temperature in such a transparent medium as sea ice. If it becomes necessary to take the absorption of short-wave radiation into account, observed values for the extinction coefficient fortunately show general agreement: 0.013 cm^{-1} (Bunt, 1960); 0.011 cm^{-1} (Thomas, 1963), 0.013 cm^{-1} (Untersteiner, 1961) and 0.012 cm^{-1} (Weller, 1968).

ELECTROMAGNETIC PROPERTIES

The variations in the electromagnetic properties of sea ice are both complex and poorly understood and have only recently been studied in detail. As we mentioned earlier these properties are of prime importance in remote sensing where a thorough understanding of the interactions between electromagnetic radiation and sea ice is desirable for both interpreting field observations and designing new instruments.

Many of the electrical measurements on sea ice have been performed on "artificial" samples that were prepared in the laboratory. Therefore it is interesting to start our discussion with observations on the DC resistivity of sea ice, a parameter that is commonly measured in the field on natural ice sheets using a Wenner array of electrodes. McNeill and Hoekstra (1973) and Kohnen (in press) obtained resistivity values of between 40 and 120 Ω m on representative first year ice when small electrode spacings were used. Smaller values (6 to 32 Ω m) were observed by Fujino (1960) but the ice that he studied was thinner, warmer and more saline. As the electrode spacings increased, the resistivity values dropped rapidly, approaching a value of 0.4 Ω m, which is the resistivity of cold sea water. As might be expected, attempts to determine ice thickness via the use of such data have been unsuccessful. The difficulty is that the models used in the analysis assume not only that we are dealing with a layered system (which, of course, we are) but also that the individual layers are electrically homogeneous. That this last assumption is far from the case can be seen in Figure 15, which presents resistivity values determined at 18 kHz by McNeill and Hoekstra (1973) on cores from both first- and multiyear ice. The first-year ice values vary from 65 Ω m at the upper surface to roughly 3 Ω m near the bottom at 1.40 m and are in reasonable agreement with the DC resistivities. Multiyear ice shows much larger variations (over three powers of ten)

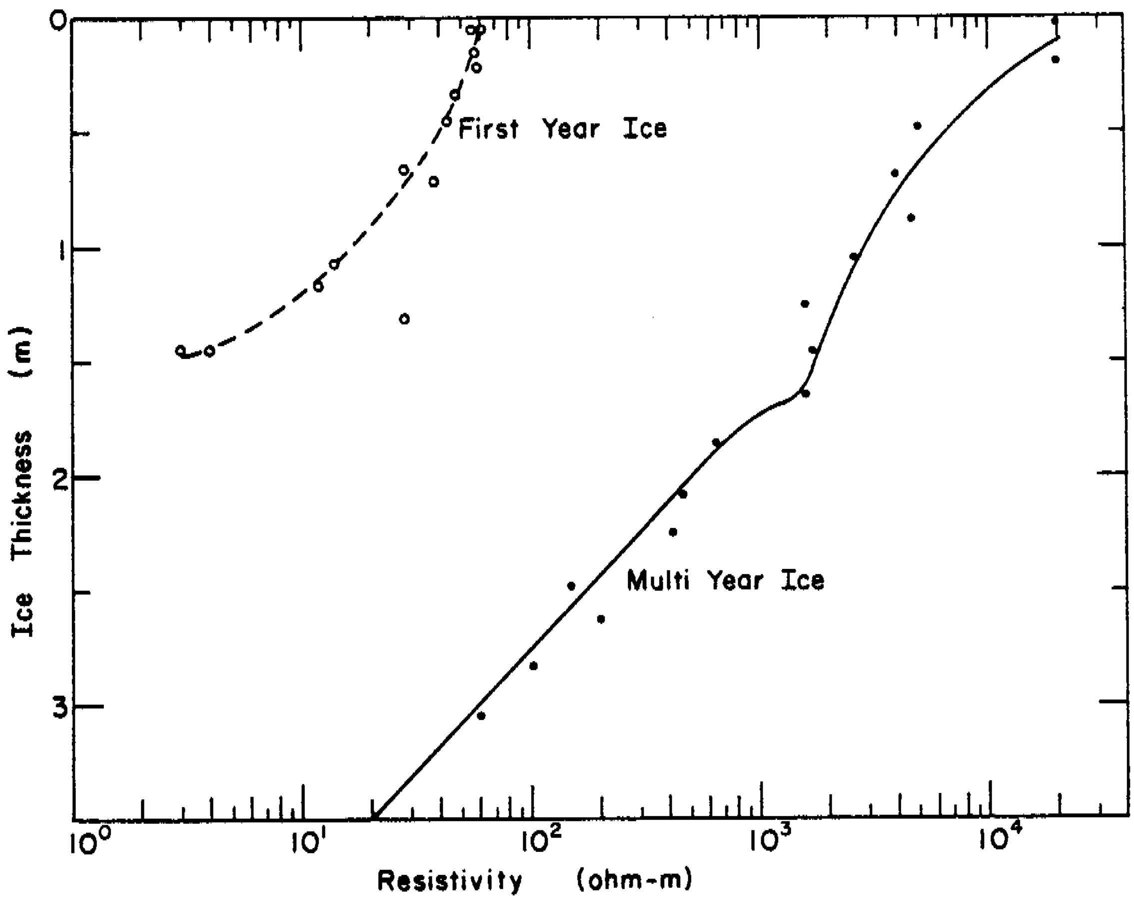

Figure 15. Vertical resistivity profiles of typical first year and multi-year sea ice measured at 18.6 kHz (McNeill and Hoekstra, 1973).

with values of 20,000 Ω m for the cold, low-salinity surface ice and 20 Ω m for the warmer, more saline ice at the bottom of the sheet. The break in the multiyear resistivity profile corresponds to a break in the salinity profile caused by the presence in the lower portion of the ice sheet of more saline ice formed during the latest ice growth season. Temperature and salinity profiles can be found in the original paper.

One rather surprising result of both the resistivity studies of McNeill and Hoekstra and of Kohnen is that when the electrode array was moved from site to site on the ice, using a fixed electrode spacing and a similar lateral shift for each move, the apparent resistivity showed large fluctuations of a factor of 4 (see Figure 16), even though the first year ice in both areas was specifically selected for its apparent lateral homogeneity and each measurement integrates over a considerable volume of ice. These are rather sobering results because if such variations prove to be commonplace in otherwise laterally uniform sea ice, they obviously must be considered in the development of remote sensing systems designed to measure ice characteristics. These resistivity fluctuations must at least in part be due to erratic salinity variations. It has been known for some time (Weeks and Lee, 1962) that there are significant random lateral variations in salinity measured at identical depths in the ice. Even so, resistivity variations of such magnitude are surprising. Variations from multiyear ice would be expected to be even larger.

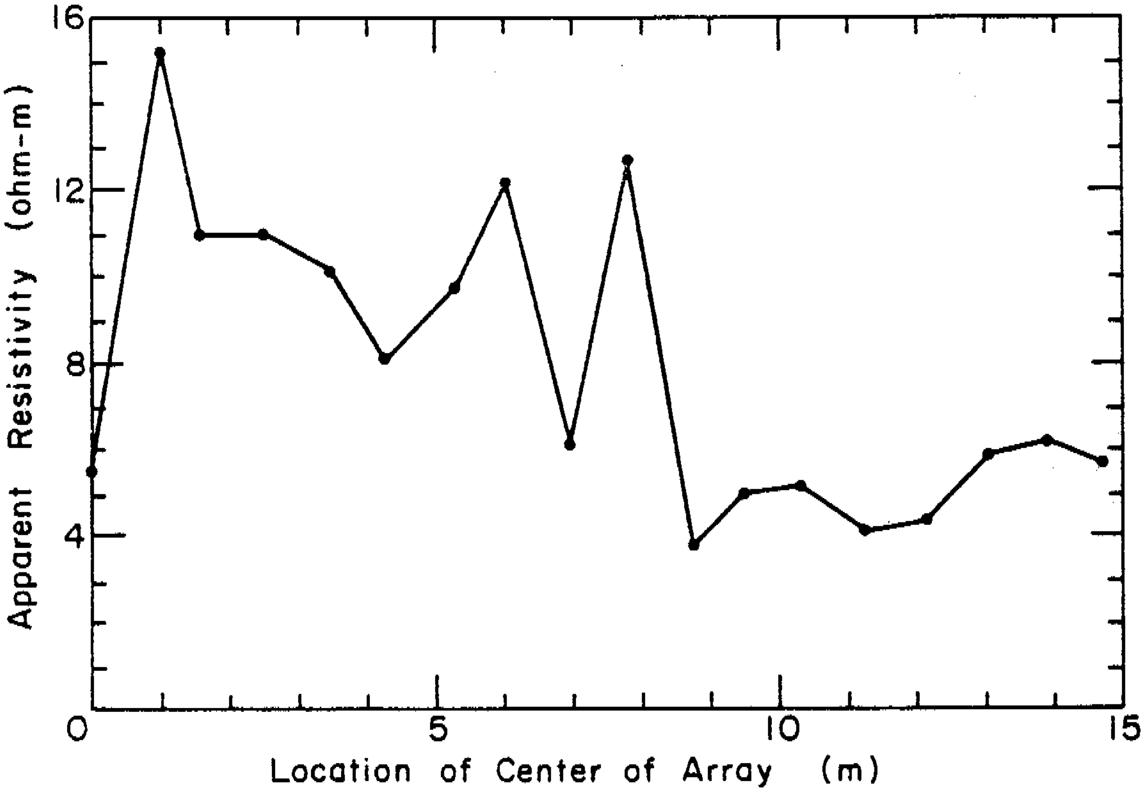

Figure 16. The apparent resistivity of first year ice of uniform thickness determined in a linear traverse with a Wenner array having an electrode spacing of 0.92 m (McNeill and Hoekstra, 1973).

Studies of the dielectric characteristics of sea ice that cover a wide range of frequencies below 100 MHz and/or temperatures are those of Wentworth and Cohn (1964), 0.1 to 30 MHz, -5 to -40°C; Fujino (1967a, 1967b), 100 Hz to 50 kHz, -5 to -70°C; Addison (1969), 20 Hz to 100 MHz, -12.5 to -35°C; and Addison (1975), 1 kHz, -25 to -150°C. The studies of the temperature dependence of the dielectric constant, particularly that by Addison (1975) have proven to be quite informative in that the temperatures at which the various solid salts crystallize from the brine can be identified. Also the data indicate the presence of brine within the ice down to much lower temperatures (-70 to -75°C) than suggested by earlier studies. Finally although there is evidence for fluoride doping in the ice phase of sea ice, there appears to be no strong reason for postulating substitutional chloride.

The measurements of the frequency dependence can be considered in three parts (Fig. 17). In the low frequency range both the real and imaginary parts of the dielectric constant (ε' and ε'') show very large values (10^4 to 10^7), with ε'' values being larger than ε' up to at least 1 MHz. The loss tangent ($\tan \delta$) is usually near 10 indicating that sea ice is a rather lossy material in this range. As frequency increases the values of ε' decrease almost inversely up to 1 MHz. Addison (1970) suggests that in this frequency range the observed electrical properties are principally controlled by the migration of ions in the irregular interconnected brine channels that link the electrodes. The experimental observations (Fujino, 1967a, b) suggest that at low temperatures

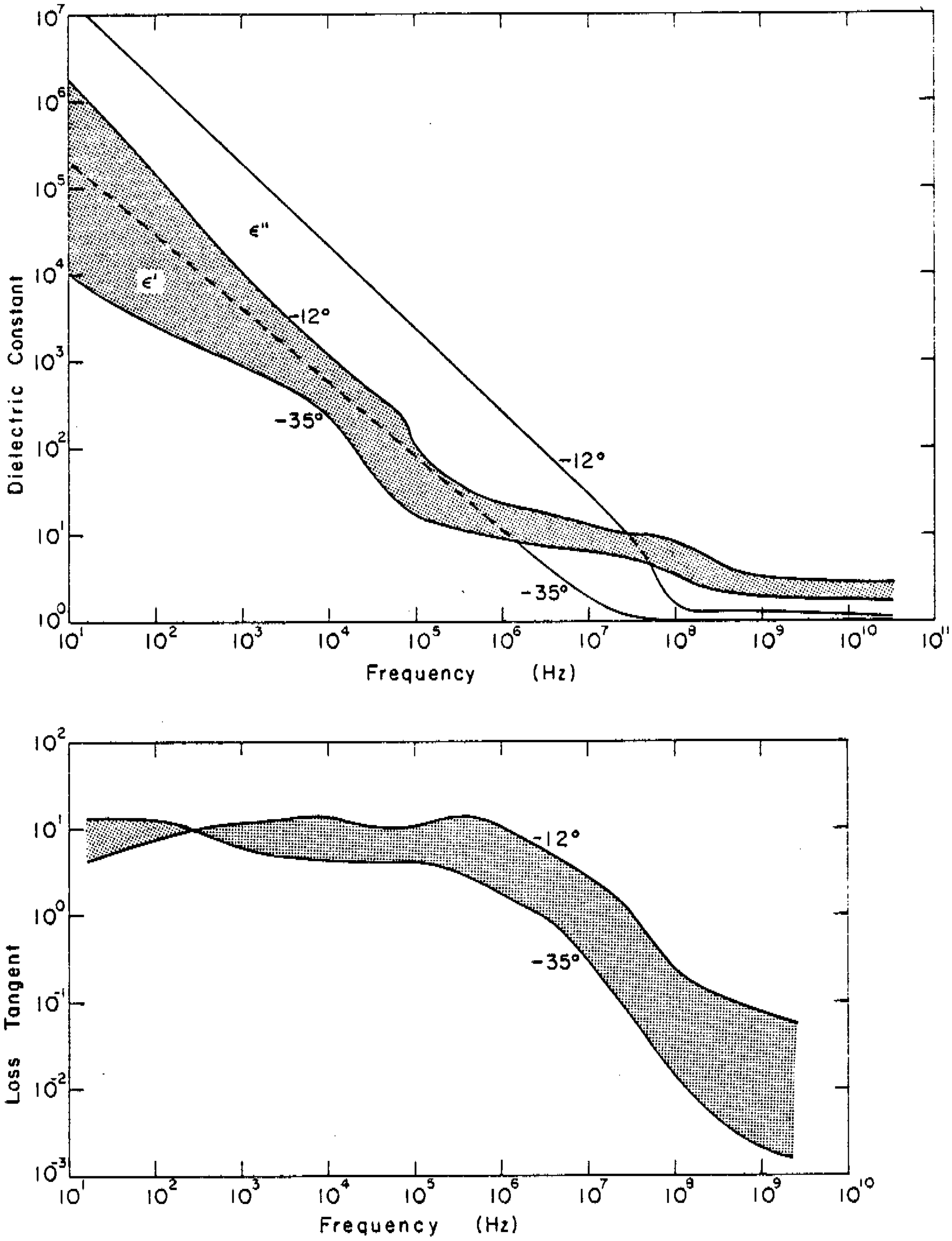

Figure 17. Schematic diagram showing the variation in the real (ε') and imaginary (ε'') components of the dielectric constant and the loss tangent (tan δ) as a function of frequency; based primarily on results of Addison (1969) and Vant (1976).

when the brine channels are no longer inter-connected, this mechanism becomes ineffective.

In the mid-frequency range (10 to 100 kHz), curves of ε' versus temperature show a downward concavity and two maxima are observed in many of the tan δ curves. The suggested but tentative explanation is Debye dispersion of the ice protons with a somewhat shortened relaxation time. Similar reduced relaxation times have been observed in fluoride-doped ices.

At frequencies above 1 MHz the curves for ε' flatten out and the ε'' curves also decrease less rapidly (above 10 MHz). There is also a gradual decrease in tan δ from 1 MHz to 10 MHz where it usually has values near or below 1. The dispersion in this range is believed to be the result of interfacial polarization arising from the presence of brine inclusions. As such, it should be possible to model the variations in ε in terms of a mixed dielectric model based on the volume of brine present in the ice. That this would be a profitable approach was shown by Weeks (1968), who took the Wentworth and Cohn data at 3 MHz, grouped the values according to structural ice type (normal sea ice, frozen slush) and plotted ε' versus ν_b. The result was two straight lines with distinctly different slopes.

The dielectric properties of sea ice at higher frequencies have been studied by Hoekstra and Cappillino (1971), 0.1 to 24 GHz; Sackinger and Byrd (1972), 26 to 40 GHz; Vant and others (1974), 10 and 35 GHz; and Vant (1976), 100 MHz to 40 GHz. Values of ε' and ε'' range between

2.5 and 6.0 and 0.0 and 1.9 respectively. In correlating their data Hoekstra and Cappillino used, with considerable success over a wide range of brine volumes, a dielectric mixing formula proposed by DeLoor (1956). The relation was

$$\varepsilon_s' = \varepsilon_i' \, (1 - 3\,\nu_b)$$

where ε_s' and ε_i' are the real dielectric constants of sea ice and pure ice respectively and ν_b is the relative volume of brine. The actual values obtained by Hoekstra and Cappillino are suspect because the structure of the artificial sea ice that they produced by flash freezing was probably not similar to the structure of natural sea ice. The model assumes that the brine inclusions are spherical. Vant and others (1974) also used this relation to correlate their data and obtained good results for frazil sea ice (correlation coefficient $r = 0.81$) and for columnar sea ice ($r = 0.90$). For multiyear ice the correlation was lower ($r = 0.57$). They also used another model based on Wiener's dielectric mixing formula which gave a higher correlation ($r = 0.723$) for multiyear ice and slightly lower correlations ($r = 0.76$ and 0.85) for frazil and columnar ice. This work has recently been greatly expanded by Vant (1976), who has also successfully used empirical dielectric mixing equations to predict the dielectric behavior of sea ice at any of the several frequencies he studied. He has also attempted to develop a general theoretical model that works over a wide frequency range. At the present time the theoretical and observed values are in reasonable agreement for first year ice. The fact that results for multiyear ice show less than good agreement is believed to be the result of large variations in the amount of entrapped gas in the ice as well as of the very low overall salinities characteristic of such ice. A detailed discussion of Vant's results is beyond the scope of this paper. However, his results are particularly encouraging in that the dielectric loss of sea ice at 1 GHz is a factor of 5 less than initially reported by Hoekstra and Cappillino. Figure 18 shows the trends of the frequency dependence of both the attenuation (dielectric loss) in db/m and the attenuation distance (skin depth) in meters for first-year sea ice based on the experimental results of Addison (1969) and Vant (1976). This figure is very informative in explaining the difficulty in developing an operational system for remotely determining sea ice thickness: at low frequencies the penetration is good (low attenuation) but the resolution is poor (the wave length $\lambda \gg$ ice thickness h) while at high frequencies the resolution is good ($h \gg \lambda$) but the penetration is negligible. The figure suggests that the best compromise, between these two conflicting requirements would be found in the frequency range between 10 MHz and 1 GHz. In fact the Geophysical Survey Systems Inc. VHF impulse radar system which has proven to be effective in profiling sea ice (Campbell and Orange, 1974; Kovacs, in press) has a center frequency in this range (100 MHz).

Finally we would like to note that Campbell and Orange (1974) while using the above mentioned pulsed radar system to measure the thickness

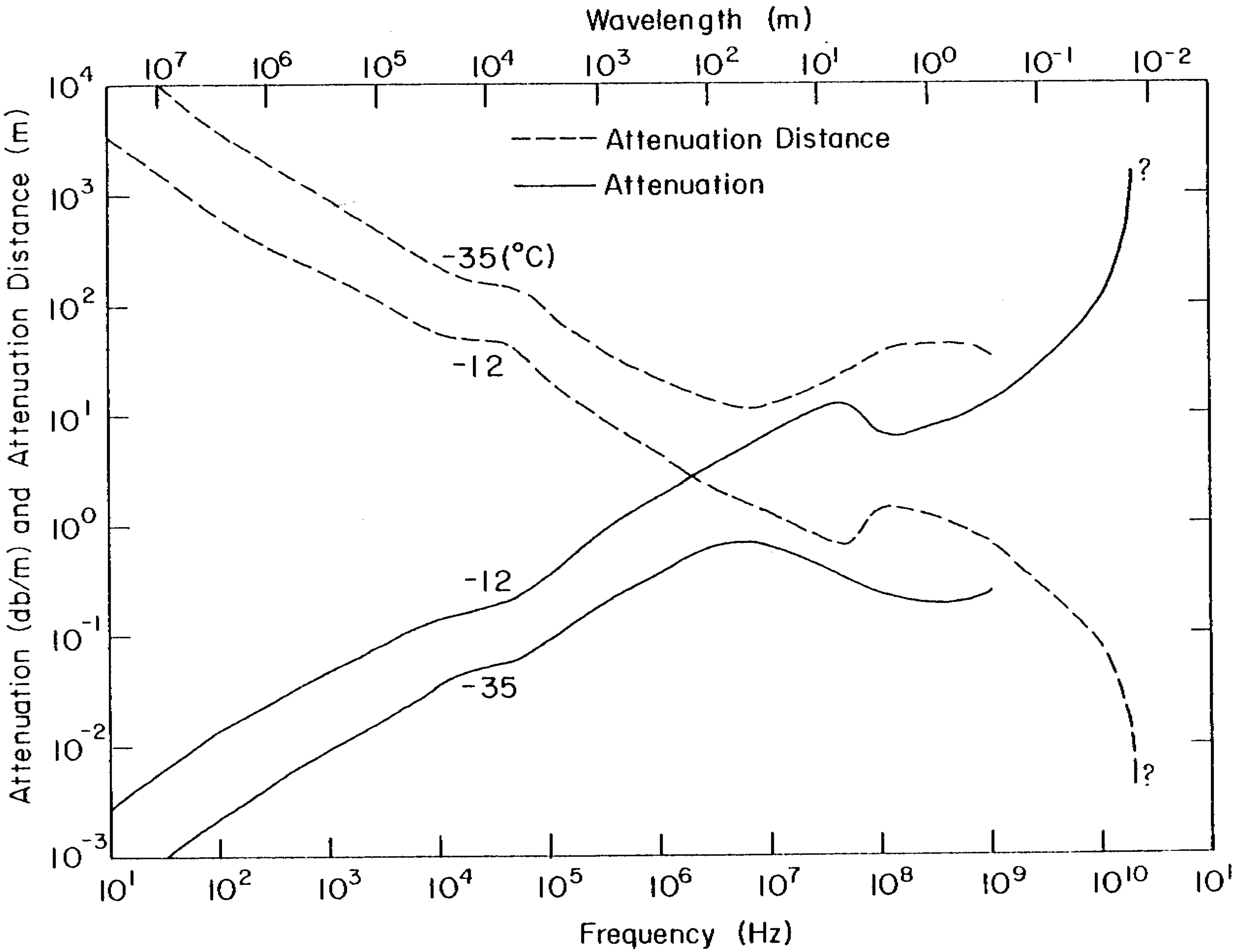

Figure 18: Diagram showing the trends of the frequency dependence of the attenuation and the attenuation distance for electromagnetic radiation penetrating first-year sea ice; based primarily on the results of Addison (1969) and Vant (1976).

of sea ice, noted a marked change in the amplitude of the return from a vertically polarized signal when the antenna was rotated. This anisotropy has been observed in both first-year and multiyear ice, with all first-year ice showing the effect and some showing it very strongly. Similar but less pronounced results were observed on multiyear ice. The effect was not noted on freshwater ice. In some fast ice areas the orientation of the maximum return remained roughly constant over distances of the order of kilometers. In other areas, characterized by obviously rotated ice plates, marked changes in the orientation of the maximum occurred over distances of meters. It has been tentatively suggested that these effects are the result of a highly preferred crystal orientation in the lower portion of the ice sheet, and the one check that was made suggests that the maximum return is received when the output field is oriented roughly parallel to the c-axis direction (normal to the platy substructure). These experiments and their interpretation are hardly, as yet, conclusive. Nevertheless, if they are correct they will provide a link between the observations mentioned in the first portion of this review, detailing the increasing evidence for the existence of large domains of ice crystals with similar c-axis orientations in the lower portions of thicker (> 1 m) fast ice, and the fact, noted several times in our discussion of mechanical properties, that changes in crystal orientation correspond to large differences in observed strength.

CONCLUSIONS

In this paper we have attempted to provide an introductory assessment of what is known about the engineering properties of sea ice by discussing its mechanical, thermal, and electrical properties. We have not quoted all the pertinent references but we have to the best of our knowledge mentioned all the major studies relating to this highly specialized field of study. Works that we have missed should be readily locatable via the bibliographies in the referenced material. Because of space limitations we have been unable to adequately discuss differences in experimental results as related to differences in measurement techniques. We caution the reader against using any of the experimental values quoted here without thoroughly investigating the techniques used in making the measurements. In discussing the available results, we have tried to stress gaps and inconsistencies in the data base. Specific obvious examples are the conflicting results on whether both E and σ_f go to zero at high values of $\nu(>0.3)$ or have values that are essentially independent of ν_b. This is particularly important inasmuch as the lower portion of every piece of sea ice contains ice that has brine volumes in or near this range. Also important is the effect of variations in strain or stress rate, of sample size, of the loading direction in relation to the crystal orientation, and of the precipitation of solid salts within the ice.

There is clearly much to be done. However, we feel that if proper standardization of testing techniques is followed by combined laboratory and (when necessary) field testing, we should be able to resolve many of the remaining problem areas within a reasonable period of time. Writing this review has helped clarify many of these problem areas for us. We hope that it will serve as a similar aid to the reader. We anticipate that significant advances will be made in our understanding of the engineering properties of sea ice within the next few years. It is certainly essential that such advances be made if the engineering problems associated with increased offshore activities over the Arctic continental shelves are to be analyzed using good quality data as opposed to "informed guesses."

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FIGURE CAPTIONS

Figure

1. Schematic drawing showing several different aspects of the structure of first year sea ice.

2. Idealized diagram showing the shape of the brine inclusions in sea ice and parameters used to describe them (Assur, 1958).

3. Representative sea ice temperature, salinity, E/E_o and σ_f/σ_1 profiles for 0.2, 0.8, and 3.0 m thick Arctic sea ice on about 1 May. To convert σ_f/σ_o to σ_f and E/E_o to E multiply by 10.3×10^5 N/m^2 and by 10^{10} N/m^2 respectively based on the flexural strength determinations of Dykins (1971) and the elastic modulus measurements of Langleben and Pounder (1963).

4. Average failure strength in compression (solid circles) and in direct tension (open circles) versus sample orientation: bottom ice, -10°C (Peyton, 1966). For orientation notation see text.

5. Compressive strength of Baltic Sea ice as a function of strain rate, ice temperature, and orientation of the force (Schwarz, 1970).

6. σ_B from compression tests versus square root of the brine volume (Peyton, 1966). For the difference between the solid and dashed lines see discussion in text.

7. Compressive strength of Baltic ice and freshwater ice as a function of temperature (Schwarz, 1970). Load applied perpendicular to the growth direction.

8. Tensile strength of sea ice versus the square root of the brine volume (Dykins, 1970).

9. Flexural strength measured by in-situ cantilever beam tests versus square root of the brine volume.

10. Flexural strength as measured by fixed-end and simply supported beams versus brine volume (Dykins, 1971).

11. Shear strength as a function of the square root of brine volume (Paige and Lee, 1967).

LIST OF TABLES

QUARTERLY REPORT

Contract: 03-50-022-67, No. 5
Research Unit: 98
Reporting Period: 1 Oct - 31 Dec 1976
Number of Pages: 4

DYNAMICS OF NEAR SHORE ICE
(Data Buoys)

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1 January 1977

I. Task Objectives

The University of Washington, under Task Order No. 5 of NOAA Contract 03-5-022-67, as amended, agreed to deploy 20 ice buoys to gather data on ice movement and oceanographic and atmospheric conditions in the near-shore areas of the Beaufort and Chukchi Seas of the Arctic Ocean and assist with the development of six additional buoys for later deployment. The buoy developments were to be accomplished in conjunction with field work being conducted by the Arctic Ice Dynamics Joint Experiment (AIDJEX). Three types of buoys were developed and produced for the task under contracts from the NOAA Environmental Research Laboratory monitored by the NOAA Data Buoy Office (NDBO). Fourteen of the buoys are designed to be dropped by parachute from aircraft and report position through the Random Access Measuring System (RAMS) of the NIMBUS-6 satellite. Two additional buoys of this type have been modified to include a pressure sensor. All 16 of these buoys and the six future buoys are produced by Polar Research Laboratory, Inc., (PRL) of Santa Barbara, California. The other four buoys are of a more complex design and are instrumented with atmospheric pressure and temperature sensors, current meters at 3 and 30 meters under the ice, and a RAMS platform to provide position. Again, all data are transmitted through the NIMBUS-6 satellite. These buoys were developed and produced by the Applied Physics Laboratory, University of Washington. Data from the buoys are placed in the AIDJEX Data Bank after receipt from NASA.

II. Field and Laboratory Activities

A. Field trip schedule

None.

B. Scientific party

None.

C. Methods

1. All buoys mentioned in this report are sampled by the Random Access Measurement System on board Nimbus VI. Position is determined 6-12 times per day.

D. Sample localities

No new deployments.

E. Data collected or analyzed

1. A total of five buoys were tracked during the quarter, the movement of which corresponds to ice drift. No barometric pressure or ocean current data were obtained. The buoys with these sensors having quit.

2. All buoys ceased operation, generally early in the quarter.

3. The major effort has been to assemble all the data taken through the first three quarters.

III. Results

1. The Met-Ocean buoys lasted 301, 323, and 332 days as compared with a planned life of 365 days. The mean life of the air-drop buoys was 187 days, the median 180 days, the minimum 80, the maximum 328. Two-thirds were within 50 days of 180; four buoys were unusually short-lived; one unusually long. The mean of the other thirteen was 199 days, two-thirds quitting within 30 days of this number. Position data are available for all the drift occurring in the first three quarters.

   A data report is in progress and will be submitted in February 1977 with buoy data through September 1976.

2. Two of the air-drop buoys produced barometric pressure time series of six months each. Compensation for temperature fluctuations was achieved

by *in situ* calibration with respect to the U.S. Weather Service station at Pt. Barrow. The pressures may be considered to be good to 0.5 millibar, the synoptic pressures having been obtained from a polynomial fit to the irregularly-spaced observations. The Met-Ocean buoy pressures have a resolution of 1.5 millibars and have been corrected for clock errors. Synoptic time series of 332 days and 127 days are available. Ocean current data are available for the same time periods, beginning in early November 1975.

IV. Preliminary Interpretation of the Results

1. The air-drop buoys have lived up to expectations and have greatly increased the amount of data available for analysis. There has also been a lot of technical information generated about surface sitting buoys on sea ice which will be valuable for future work. The Met-Ocean buoys have been troubled by various problems, frequently related to electronic design oversights, but have still produced useful ocean current and barometric pressure data for the expected duration.
2. Plans are being made to incorporate the buoy data into a run of the AIDJEX sea ice model. The model will use data from January 25 to February 1976. During this period a shear zone developed which separated the OCS buoys.
3. Ice conditions in the Beaufort Sea continue to differ remarkably from the previous year, with new ice forming in a 150-200 mile wide expanse between the edge of the pack ice and shore.

V. Problems Encountered and Recommended Changes

An attempt to recover a Met-Ocean buoy had to be cancelled when the buoy failed shortly before the recovery was to be made. It would be prudent to plan for such recoveries farther in advance so that better advantage might be taken of each opportunity.

VI. Estimate of Funds Expended

As of 31 December 1976, actual expenditures under this contract totaled $88,414.31. The estimated obligations not yet expended under this contract were about $12,000.

Quarterly Report

Contract #03-5-022-56
Research Unit #99
Task Order #6
Reporting Period 10/1 - 12/31/76
Number of Pages 3

THE ENVIRONMENTAL GEOLOGY AND GEOMORPHOLOGY OF THE GULF OF ALASKA COASTAL PLAIN AND THE COASTAL ZONE OF KOTZEBUE SOUND

Dr. P. Jan Cannon
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January 1, 1977

I. Task Objectives of Gulf of Alaska Project

A. To produce three maps of the coastal plain section of the Gulf of Alaska.

B. To produce a report on the application of radar imagery to the environmental geologic mapping of coastal zones.

C. To construct an annotated mosaic of the area from radar imagery.

D. To indicate the effects (beneficial and adverse) that oil and gas development might have in relation to the geologic setting.

Task Objectives of Kotzebue Sound Project

A. To produce three maps, with explanations, which will display certain baseline data necessary for an environmental assessment of the regions. The maps will be constructed from various types of remote sensing data.

B. To produce a report on the unique geologic setting of Kobuk Delta indicating the possible effects (beneficial and adverse) of petroleum related development in the area.

C. Direct the acquisition of remote sensing data of the area for Cannon, Hayes and other investigators.

D. Construct a mosaic of the area of sequential LANDSAT data for Cannon, Hayes and other investigators.

E. Construct an annotated mosaic of the area from SLAR imagery.

II. Activities

Completed final report for Gulf of Alaska Coastal Plain.

Mosaic of radar imagery of Kotzebue Sound area constructed. Color and black and white photography of Kotzebue Sound was received and reviewed. Made search of data files at the Eros Data Center in Sioux Falls, S. D., for up dated radar and LANDSAT imagery. Plans were made to undertake field work in Kotzebue Sound during winter.

III. Results

Many elevated shorelines can be seen on the radar imagery. These are potential archeological sites as well as indicators of geomorphic changes.

IV. Preliminary Interpretation of Results

The tectonic uplift has occurred in pulses and may well account for the changes in sediment transport in the Sound.

V. Problems Encountered/Recommended Changes

Deep winter radar imagery is needed of the area in order to determine the effects of sea ice.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 6 R.U. NUMBER: 99

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[1].

REFERENCE

Cannon, Dr. Jan P. Application of Radar Imagery to Outer Continental Shelf Studies in the Gulf of Alaska. Manuscript, 18 pp.

NOTE: [1] Data management plan was submitted to NOAA in draft form on October 9, 1975 and University of Alaska approval given on November 20, 1975. We await formal approval from NOAA.

CRREL

Contract no. - 01-50-22-2313
Research Unit no. - 105
Reporting period - Oct - Dec 1976
Number of pages - 3

Quarterly Report
to

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Arctic Projects Office
Fairbanks, Alaska

DELINEATION AND ENGINEERING CHARACTERISTICS OF PERMAFROST BENEATH THE BEAUFORT SEA

Principal Investigator:
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Associate Investigators:
R. Berg
J. Brown
S. Blouin
E. Chamberlain
A. Iskandar
H. Ueda

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

I. TASK OBJECTIVES

The emphasis of the program is on quantifying the engineering characteristics of permafrost beneath the Beaufort Sea, and determining their relation to temperature, sediment type, ice content and chemical composition. These data will be used in conjunction with those from the marine and subsea permafrost projects listed below to develop a map portraying the occurrence and depth of permafrost under the Beaufort Sea. The drilling program will provide subsurface samples and control for the other programs. It is also designed to test drilling, sampling, and in situ measurement techniques in this offshore environmental setting where material types and ice conditions make acquisition of undisturbed samples extremely difficult.

Our activities are currently coordinated with the following OCS Beaufort Sea projects:

Research Unit #204: Offshore permafrost studies, Beaufort Sea - David M. Hopkins, U.S. Geological Survey.

Research Unit #205: Marine environmental problems in the ice-covered Beaufort Sea Shelf and coastal regions - Peter Barnes and Erk Reimnitz, U.S. Geological Survey.

Research Unit #253: Offshore permafrost drilling, boundary conditions, properties, processes and models - T.E. Osterkamp and William D. Harrison, University of Alaska.

Research Unit #271: Beaufort seacoast permafrost studies - James C. Rogers, University of Alaska.

Research Unit #407: A study of Beaufort Sea coastal erosion, northern Alaska - Robert Lewellen, Littleton, Colorado.

II. FIELD OR LABORATORY ACTIVITIES

A. Ship or field trip schedule: No field activity during reporting period.

B. Scientific party: See A.

C. Methods: See previous progress reports.

D. Sample localities: See previous reports.

E. Data collected or analyzed: See previous reports and section III.

III. RESULTS AND DISCUSSION

A. Drilling

CRREL Special Report 76-12 entitled "Operational Report - 1976 USACRREL-USGS Subsea Permafrost Program, Beaufort Sea, Alaska," was published and initial distribution made. The report contains details of the drilling mobilization, equipment used, logs of cores, problems encountered, and cost information. Requests for additional distribution should be made to USACRREL or directly to Paul Sellmann. Numerous meetings and phone discussions with Robert Lewellen, USGS, and University of Alaska staff continued as a follow up on 1976 activities and in planning 1977 activities.

B. Engineering properties

All laboratory tests for determination of strength and index properties were completed. The results of this work have been incorporated into a draft report covering the determinations made in the field and in the laboratory and include data on: triaxial compressive strength, static and impact cone penetration resistance, and index properties (grain size, density, specific gravity, moisture and organic content, temperature, and liquid and plastic limits). In addition, results of permeability, consolidation, and thermal conductivity tests on selected samples are presented. One of the most interesting results is from the consolidation tests which indicate that the fine-grained marine sediments in PB-2 are highly over-consolidated. Over-consolidation was only observed in this hole. The geological and engineering implications of this condition are discussed in the draft report which will be available next quarter.

C. Chemical analyses

Additional analyses of the PB-2 core were performed on samples possessing very low moisture contents. Twenty milliliters of deionized water were added to 40-60 grams of moist sediment, shaken for one hour, and supernatant obtained by centrifugation. Specific conductance calculated to the original moisture ranged from 31 to 57 mmhos/cm at 25°C. Samples from 4.6 and 7.8 meter depth below the sea bed in PB-2 were extracted with chloroform to determine the presence and concentrations of the hydrocarbons. Preliminary analyses indicated the presence of paraffinic hydrocarbons and possibly elemental sulfur. A draft of a cooperative manuscript entitled "Chemistry of interstitial water from subsea permafrost at Prudhoe Bay" was initiated for consideration at the 1978 Third International Permafrost Conference.

D. Soviet literature

A list of references on Soviet subsea permafrost was received from the U.S.S.R. and is being cross-checked against our earlier compilation. The review of this Soviet literature is being coordinated with a new INSTAAR project under Dr. Vigdorchik.

IV. PRELIMINARY INTERPRETATION OF RESULTS

See previous reports and section III.

V. PROBLEMS ENCOUNTERED/RECOMMENDED CHANGES

Uncertainties concerning FY77 funding are beginning to impact on plans for calendar year 1977.

VI. ESTIMATE OF FUNDS EXPENDED

All previous OCS funds have been expended and work continues at a minimal level in the absence of a NOAA transfer of FY77 funds.

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QUARTERLY REPORT, OCT. 1-DEC. 31, 1976

R.U. 204

OFFSHORE PERMAFROST STUDIES, BEAUFORT SEA

I. Abstract of highlights of quarter's accomplishments.

Pebbles in the pebbly mud in borehole PB-2 represent the chert facies of Rodeick (1975) and are of local origin. The sediment is not a glaciomarine deposit.

Surficial pebbly sand in borehole PB-2 represents the dolomite facies of Rodeick (1975) and provides the earliest stratigraphic record of a nearby barrier island. These coarse surficial sediments possibly may represent the eroded "stump" of a barrier-island chain that was subsequently driven shoreward to the present site of Reindeer Island.

II. Task objectives: D-9

III. Field and laboratory activities

A. No field trips or cruises

B. Scientific party

D. M. Hopkins, geologist and principal investigator
R. E. Lewellen, logistics and drilling operations
A. H. Lachenbruch, geothermal studies
Peter Barnes, core radiography
Kris McDougall, identification of microfauna
Louie Marincovich, identification of fossil mollusks
R. E. Nelson, palynology, paleoclimatic estimates

C. Methods of analysis

Analysis of geothermal data; radiography of drill cores; identification of fossil remains in order to interpret former water depths and temperatures and former air temperatures; study of lithology of pebbles washed from cores.

D. Sample localities

Shown on previous reports.

E. Data collected or analyzed

1. Washed 37 microfossil samples from 1976 boreholes and 47 samples from University of Alaska 1975 boreholes (Osterkamp and Harrison, 1976).

2. Completed identifications for 65 foraminiferal faunas from the 1976 boreholes. Identification of University of Alaska 1975 material still in progress.

3. Prepared and identified mollusks from 18 samples from 1975 boreholes. Report in progress.

4. Completed core radiography. Report in progress.

5. Examined pebble lithology for samples from marine section of PB-2. Results reported in Section IV-V.

6. Work is being completed on reduction of temperature data from PB-1, PB-2, and PB-3, on calculation of pre-drilling temperature, and on development of a preliminary thermal model for permafrost conditions on- and offshore in the Prudhoe Bay area. Report in progess.

7. Began a synthesis of paleoclimatic data in order to estimate mean annual air temperatures for the interval 24,000-14,000 years ago in the Kotzebue and Prudhoe Bay areas, in order to provide basic data for geothermal modeling. Report in progress.

IV and V. Results and interpretation

Pebbles from the late Wisconsinan-Holocene marine section encountered in the upper 8.5 m of borehole PB-2 were examined by Craig Rodeick. Rodeick's examination resulted in a reinterpretation of the nature of pebbly silt in the lower part of the late Wisconsin-Holocene marine section, provided evidence bearing on the history of barrier island development in the Prudhoe Bay area, and suggested a possible cause for the overconsolidation of clay and silt in cores from PB-2.

Rodeick (1975) distinguished two suites of pebbles, a chert facies and a dolomite facies, in bottom samples and beach sediments from the Beaufort Sea. The chert facies is characterized by an abundance of chert and limestone pebbles and consists mostly of material introduced directly or indirectly by local rivers draining from the Brooks Range. Chert-facies gravel comprises the Sagavanirktok River delta and the beaches and barrier bars to the west along the Beaufort Sea coast. The dolomite facies is characterized by an abundance of dolomite and red granite pebbles and consists mostly of clasts ultimately derived from the Canadian Shield. Dolomite-facies rocks evidently were rafted into the Beaufort Sea region by glacial icebergs during one or more episodes of Pleistocene continental glaciation. Dolomite-facies boulders are common in the Pleistocene Gubik Formation, growing increasingly abundant eastward. Dolomite-facies pebbles redeposited from the Gubik Formation predominate in the gravel of the barrier-island chain that extends westward from Brownlow Point to Reindeer Island.

Borehole PB-2, sited in water 12 m deep on the open continental shelf 3 km outside Reindeer Island, passed through 15 cm of pebbly sand, 4 m of stiff marine clay, and then 4.5 m of pebbly mud originally interpreted as glaciomarine (Hopkins, 1976). Rodeick's examination showed, however, that the pebbles in the pebbly mud consist mostly of local, chert-facies rocks with only a minor component of dolomite-facies rocks of Canadian origin. Chert-facies pebbles are also present, though less abundant, in the stiff clay, but the surficial pebbly sand consists of dolomite-facies pebbles.

The predominance of chert-facies pebbles in the pebbly mud and stiff clay indicates that these sediments are not glaciomarine and also indicates that the Brownlow Point-Reindeer Island barrier chain was not present nearby at the time of sedimentation. Pebbles in the marine pebbly mud and stiff clay seem to have been ice-rafted from a nearby mainland beach. The surficial pebbly sand, with its predominance of dolomite-facies pebbles, evidently signals the first appearance near site PB-2 of barrier islands constructed by longshore drift of materials brought from Brownlow Point and the coast further east. The pebbly sand itself may be derived by ice-rafting from the nearby beach of Reindeer Island, or it may actually represent the stump of a barrier island that was subsequently driven shoreward to the present site of Reindeer Island.

P. Sellmann and E. Chamberlain note that clay and silt in cores from PB-2 is overconsolidated (R.U. #205, quarterly report, Oct.-Dec., 1976), probably as a result of having undergone a cycle of freezing and thawing. They suggest two alternate scenarios that might account for the freezing and subsequent thawing of the marine section: (1) Site PB-2 may have been subaerially exposed and the marine sediments frozen during a negative oscillation of sea level about 10,000 years ago; or (2) Site PB-2 might once have been occupied by a barrier island, beneath which equilibrium permafrost would have formed and then thawed again when the island migrated away. The pebble lithologies in the marine section of borehole PB-2 is supportive of a scenario involving migration of a barrier bar. If this scenario can be demonstrated to be correct, it may be possible to predict the distribution offshore of overconsolidated clays based on the lithology of the coarse fractions of bottom samples.

VII. Estimate of funds expended to date: $33,000

VIII. References cited:

Rodeick, C. A., 1975, The origin, distribution, and distributional history of gravel deposits on the Beaufort Sea continental shelf, Alaska: California State Univ., San Jose, M.S. thesis, 87 p.

Hopkins, D. M., 1976, Offshore permafrost studies, Beaufort Sea: Natl. Oceanic and Atmospheric Adm., Environmental Assessment of the Alaskan Continental Shelf; Principal Investigator's Repts., July-Sept., 1976, v. 4, p. 109-121.

Osterkamp, T. E., and Harrison, W. D., 1976, Subsea permafrost at Prudhoe Bay, Alaska; drilling report: Univ. Alaska Geophys. Inst., Sea Grant Rept. 76-5.

RU. # 205
Peter Barnes - P.I.
Quarterly Report
October 1, 1976

Quarterly Report

Contract #RK6-6074
Research Unit #205
Reporting Period -
July-1976 - Sept.-1976
Pages 3
5 Attachments

Marine environmental problems in the ice covered Beaufort Sea shelf and coastal regions

Principal Investigators:

Peter Barnes
Erk Reimnitz
David Drake

U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA94025

1 October 1976

Quarterly Report

I. Task Objectives

The primary goal of this project is to study the nature, distribution, stability and thickness of Holocene sediments and their relationship to sources, dispersal mechanisms and bottom processes. Emphasis is placed on processes that are unique to the arctic environment, where ice plays a dominant role. Ice deforms and stirs bottom sediments, controls and modifies bathymetry, permits conductive heat transfer, inhibits the free discharge of river waters during the spring and transports sediments by rafting and bulldozing. Using sediment profiling, sampling, diving, underwater TV and photography, thermoprobes, and oceanographic sensors we hope to achieve the following specific objectives:

A. A definition of the character, source and physical composition of bottom materials including permafrost where present.

B. An understanding of the present sediment transport regime, elucidating the influence of ice, rivers, currents and waves.

C. An understanding of the Pleistocene and Holocene geologic record for use in interpreting the stability of the present day marine geologic setting of arctic Alaska.

II. Field or Laboratory Activities

A. Ship and Field Trip Schedule, July 8 - September 24, 1976
USGS R/V KARLUK
ERA hèlicopter-NOAA charter

B. Scientific field party: P. Barnes, E. Reimnitz, L. Toimil, T. Barnett, R. Patrick, G. Smith, D. Maurer

C. Scientific laboratory group:

Peter Barnes	Project Chief	U.S. Geological Survey Office of Marine Geology
Erk Reimnitz	Principal Investigator	" " "
David Drake	" "	" " "
Larry Toimil	Co-Investigator	" " "
John Melchoir	Assistant	" " "
Greg Smith	"	" " "
Dennis Mann	"	" " "

D. Methods

1) Field - collection of a variety of geologic information from the inner shelf off northern Alaska between Cape Halkett and Flaxman Island. This includes: vibrocore samples, underwater TV observations, diving observations, bathymetry, sediment profiles, side scan sonar sonographs, bottom photographs, temperature, salinity and transmissivity measurements, water samples for suspended particulate matter, bottom samples for interstitial salinities, current measurements.

E. Sample Localities

See attachment A for the location of operations through August 19, 1976. (Four Sheets)

F. Data Collected or analyzed

See Attachments A and B for location and types of data collected thru August 19, 1976.

G. Milestone Chart - Data Submission - No change

III. Results

A. Track line charts and station locations for the R/V Karluk 8 July through 19 August 1976. (Attachment A)

B. Temperature, salinity, and transmissivity measurements R/V KARLUK 8 July through 19 August, 1976. (Attachment B)

Temperature and salinity were measured using a Beckman RS5-3 conductivity cell modified for arctic use. Light transmission was measured using a 10 cm beam path length Hydroproducts transmissometer. The accuracy of these systems is believed to be as follows:

Temperature	$\pm$ 0.5°C
Conductivity	$\pm$ 0.5 millimhos/cm
Salinity	$\pm$ 0.5^{o}/oo
Transmissivity	$\pm$ 2%

IV. Preliminary interpration of results

A. Preliminary field report of activities summer, 1976
(See Attachment C)

B. Morphologic changes in the coastline and bathymetry between Prudhoe Bay and Stump Island (See Attachment D)

C. Rates of ice gouging and sediment reworking, Beaufort Sea, Alaska. Abstract submitted to annual meeting of SEAM, AAPG. (See Attachment E)

V. Problems encountered - recommended changes - none.

VI. Estimate of funds expended

NOAA·BLM 9,189$ USGS 17,899$

B

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Date	Time	Water Depth	Sample Depth	Conductivity	Salinity	Temp.	Transmissivity	Suspend. Sediment Sample		Remarks
7/24	1000		Surface	—	2.9‰	4.8°C	61%			[illegible] #1
	1400				2.1	9.4				
	1410				1.9	10.0				
	1420				1.8	10.1				
	1430				1.3	10.7				
	1440				1.4	10.3				
	1450				1.4	10.0				
	1500				1.9	9.6				End Line 1/Start Line 2
	1510				1.4	9.8				
	1520				1.7	9.7				
	1530				1.4	9.5				
	~~1540~~									
	1550				2.0	8.7				
	1600				2.0	8.9				
	1610				1.8	9.0				End line 2/Start line 3
	1630				1.8	9.0				
	1640				2.1	7.7				
	1700				2.6	6.9				

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Date	Time	Water Depth	Sample Depth	Conductivity	‰ Salinity	°C Temp.	% Transmissivity	Suspend. Sediment Sample		Remarks
7/24	1710		Surface	—	2.1	6.7	—			
	1725			—	[illegible].3	4.2	—			End line 3
7/30	1435		Surface	13.4	13.4	4.5	62			Start line 1 @ 1435
	1445			13.3	12.7	5.7	66			
	1455			13.0	12.4	5.7	66			
	1505			13.2	12.5	5.6	66			
	1515			11.5	11.0	5.2	66			
	1525			11.5	11.1	5.3	66			
	1535			11.5	11.1	5.2	66			
	1545			11.8	11.4	5.2	65			[illegible]
	1605			12.0	11.5	5.8	65			
	1615			12.3	11.8	6.3	65			
	1625			11.9	11.6	[illegible]	66			
	1635			12.0	[illegible]	6.5	[illegible]			
	1645			[illegible]	[illegible]	6.8	66			
	[illegible]			11.7	[illegible]	6.0	[illegible]			
	[illegible]			11.5	[illegible]	6.2	[illegible]			
	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]			
	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]			

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Date	Time	Water Depth	Sample Depth	Conduct-ivity	‰ Salinity	°C Temp.	% Transmi-ssivity	Suspend. Sediment Sample		Remarks
7/30	1745		surface	11.3	10.8	5.7	66			
	1745			11.5	11.2	6.1	66			
	1755			12.1	11.2	6.4	67			
	1805			11.8	11.2	6.3	67			
	1815			12.1	11.5	5.9	66			
	1825			12.0	11.5	5.6	67			
	1835			11.8	11.3	5.7	67			cleaned window on transmissometer
	1845			11.9	11.5	5.2	73			
	1855			10.9	10.3	6.2	73			
	1905			10.9	10.3	6.0	73			
	1915			11.4	10.8	5.8	73			
	1925			12.1	11.5	5.7	72			
	1935			13.3	12.7	5.6	73			End line 17 @ 1940
7/31	1045		surface	10.2	10.6	2.7	74			Start line 18 @ 1035
	1055			10.1	10.3	3.3	74			
	1105			11.0	10.9	4.5	74			
	1115			10.8	10.7	4.1	74			
	1125			11.4	11.1	5.4	73			
	1135			10.9	10.5	5.0	73			

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Date	Time	Water Depth	Sample Depth	Conduct-ivity	‰ Salinity	°C Temp.	% Transmi-ssivity	Suspend. Sediment Sample	Water Sample	Remarks
7/31	1145		Surface	10.9	10.9	4.6	73			
	1155			11.0	10.6	6.3	73			End line 18 @ 1200
	1655			11.6	11.4	4.0	67			Start line 19 @ 1644
	1705			12.4	11.7	6.1	67			
	1715			10.6	9.2	9.1	50			← River water ?
										End line 19 @ 1723
8/02	0735		surface	9.7	8.0	10.9	37			Start line 20 @ 1724
	0745			10.0	8.3	9.7	39		X	
	0755			10.1	8.6	9.4	42			
	0805			9.9	8.6	8.7	42			
	0815			10.0	8.6	8.8	39			
	0826			10.2	9.0	7.5	45			
	0835			9.5	9.0	9.4	40			
	0845			10.3	8.8	9.6	37		X	
	0855			10.2	8.5	10.2	35			
	0905			11.0	9.5	9.3	41			
	0915			[illegible]	9.2	9.3	42			
	0925			[illegible]	9.1	9.8	42			
	[illegible]			[illegible]	[illegible]	9.4	44			
	[illegible]			[illegible]	[illegible]	[illegible]	42			

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Date	Time	Water Depth	Sample Depth	Conductivity	‰ Salinity	°C Temp.	Transmissivity	Suspend. Sediment Sample	[illegible]	Remarks
8/02	0955		surface	10.7	9.5	8.0	42		X	
	1005			11.1	9.6	9.5	41			[illegible]
	1015			10.9	8.5	12.0	32			[illegible]
	1025			11.0	9.0	11.2	25			
	1035			11.1	9.2	10.3	34			
	1045			11.7	9.8	10.0	57			
	1055			12.3	10.3	10.0	36		X	
	1105			13.0	11.1	10.0	23			
	1116			14.0	11.8	10.4	29			
	1125			13.8	11.5	10.3	28			
	1136			13.6	11.5	10.4	27			
	1145			14.2	11.7	11.1	21		X	
	1155			14.0	11.4	11.6	20			[illegible]
	1205			14.4	11.8	11.6	25			
	1215			12.5	10.6	10.0	42			
	1225			11.3	9.7	9.0	55			
	1235			11.3	9.8	8.9	56			
	1245			11.0	9.6	8.4	59		X	
	1255			10.4	9.3	7.6	60			
	1305			10.1	9.2	6.9	61			

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Date	Time	Water Depth	Sample Depth	Conductivity	‰ Salinity	°C Temp.	% Transmissivity	Suspend. Sediment Sample	Water Sample	Remarks
8/02	1315		Surface	10.3	9.2	6.6	63			
	1325			10.2	9.3	7.1	63			
	1335			10.6	9.2	10.5	—			transmissometer out
	1345			11.6	10.0	9.5			X	
	1355			11.7	9.9	9.8				
	1405			12.3	10.3	10.4				
	1415			12.7	10.2	10.2				
	1426			12.0	10.5	10.5				
	1435			13.2	11.0	10.9				
	1440			13.1	10.4	10.8			X	
	1445			12.3	10.3	10.5				[illegible]
	1525			9.5	8.4	7.9				
	1535			10.3	9.3	7.1				
	1545			[illegible]	[illegible]	6.5				
	1555			[illegible]	9.0	6.2				
	[illegible]			[illegible]	[illegible]	8.2				
	[illegible]			[illegible]	9.3	[illegible]				
	[illegible]			[illegible]	9.5	[illegible]				
	[illegible]			[illegible]	[illegible]	[illegible]				
	[illegible]			[illegible]	[illegible]	[illegible]				

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Date	Time	Water Depth	Sample Depth	Conductivity	Salinity	Temp.	Transmissivity	Suspend. Sediment Sample	Water Sample	Remarks
8/02	1150		Surface	6.2	6.5	2.3				
	1140			[illegible]	6.2	2.7				
	1250			[illegible]	6.0	2.6				
	1255			6.0	6.0	2.6				
	1305			5.5	6.0	2.6				
	1315			[illegible]	6.0	2.1	68			End line 22
8/03	1305		Surface	10.6	9.2	9.6	37			Start line 23
	1315			10.5	8.9	9.7	30			
	1325			9.9	8.9	8.0	36			
	1335			9.6	9.0	6.4	35			
	1345			9.8	9.3	5.2	61		X	
	1355			9.6	9.4	4.5	68			
	1405			9.7	9.4	4.8	69			
	1415			8.5	8.6	3.5	73			
	1425			8.6	8.8	3.0	73			End line 23
	1435			9.6	8.7	2.9	74			Start line 24
	1445			8.2	8.3	3.0	74			
	1455			8.7	8.7	4.0	69			
	1505			[illegible]	9.7	4.2	67			

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Date	Time	Water Depth	Sample Depth	Conductivity	‰ Salinity	°C Temp.	Transmissivity	Suspend. Sediment Sample	Water Sample	Remarks
8/03	1525		Surface	9.9	8.6	4.9	60			
	1535			9.8	8.4	5.2	59		X	
	1545			9.9	8.4	5.9	56			
	1555			9.7	8.5	7.0	55			
	1605			9.7	8.5	8.0	54			
	1615			9.7	8.5	8.3	54			
	1625			9.5	8.1	8.9	55			
	1645			9.5	8.1	9.5	52			
	1655			9.6	8.0	9.9	49			
	1705			[illegible]	7.8	10.0	44			
	1715			9.1	7.6	9.8	42			
	1725			8.5	7.4	8.3	44			
	1735			8.0	7.2	6.9	45			
	1745			6.32	[illegible]	7.2	64		X	End line 24 Start line 25
	1755			6.3	[illegible]	7.2	63			
	1805			6.2	[illegible]	7.2	[illegible]			
	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]			
	[illegible]			[illegible]	[illegible]	7.1	[illegible]			
	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]			
	[illegible]									

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Date	Time	Water Depth	Sample Depth	Conductivity	% Salinity	°C Temp.	Transmissivity	Suspend. Sediment Sample	[illegible]	Remarks
8/04	1105		Surface	6.1	6.5	1.8	[illegible]			Start Line 26 @ 1055
	1115			6.5	6.9	[illegible]	74			
	1125			6.6	6.9	1.7	71			
	1145			7.0	7.3	1.9	75		X	End Line 26/Start 27
	1155			7.1	7.5	1.9	71			
	1205			6.8	7.2	1.5	72			
	1215			6.6	7.0	1.5	73			End Line 27/Start 28
	1335			6.9	7.3	1.7	72			
	1345			7.3	7.7	1.9	73			
	1355			7.1	7.5	1.6	73			
	1405			7.4	7.7	2.2	70			
	1425			7.1	7.5	1.5	70			
	1435			6.9	7.3	1.5	70			
	1445			6.9	7.2	1.5	70			
	1505			7.4	7.6	2.2	72			
	1515			8.2	8.1	3.8	69			
	1525			9.6	8.4	4.9	71			
	1535			8.5	8.2	4.9	72			
	1545			8.6	8.3	5.0	70			
	1555			8.9	8.4	5.9	62			

1976

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Date	Time	Water Depth	Sample Depth	Conductivity	% Salinity	°C Temp.	% Transmissivity	Suspend. Sediment Sample		Remarks
8/04	1605		Surface	9.0	8.3	6.3	55			
	1615			8.3	8.5	7.5	45			
	1625			9.8	8.7	8.3	24			
	1635			10.2	8.6	9.4	16			

1976

Date	Time	Water Depth	Sample Depth	Conduct-ivity	Salinity	Temp.	Transmi-ssivity	Suspend. Sediment Sample		Remarks
8/0[illegible]	1645		Surface	[illegible]	8.6	10.1	12			
	1655			[illegible]	8.4	10.5	13			
	1705			9.7	8.0	11.0	22			
	1715			9.7	7.9	11.2	18			End line 28 @ 1725
8/0[illegible]	1330		Surface	7.7	6.9	10.4	—			Start line 29 @ [illegible]
	1340			10.1	8.6	9.6	—			
	1350			12.0	10.6	7.7	—			
	1358			12.9	12.1	6.6	—			
	1408			12.3	11.3	6.9	—			
	1420			12.1	11.4	6.1	68			
	1430			10.7	10.8	3.3	74			
	1444			11.9	11.9	4.0	71			
	1510			10.3	9.7	6.0	63			
	1610			10.6	9.8	7.0	55			End line 29
8/07	1402		Surface	8.6	8.4	3.9	—			Start line 30 @ 1405
	1410			8.9	8.7	4.4	—			
	1415			8.9	8.7	4.4	—			
	1420			8.9	8.7	4.3	—			

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Date	Time	Water Depth	Sample Depth	Conduct-ivity	‰ Salinity	°C Temp.	% Transmi-ssivity	Suspend. Sediment Sample	Water Sample	Remarks
8/07	1425		Surface	9.1	8.9	4.5				Out line 30
	1430			9.2	8.8	4.7				
	1435			9.2	9.0	4.8				
	1440			9.4	9.0	5.5				
	1445			9.1	8.8	4.8				
	1450			9.1	8.7	4.8				
	1454			9.3	8.9	5.2				
	1500			9.8	9.1	6.6			X	
	1507			10.1	9.3	6.7				
	1510			10.6	9.2	6.1				
	1515			9.9	9.2	6.7				
	1520			9.8	8.6	8.4				[illegible]
	1530			10.3	9.2	6.7				repaired [illegible]
	1700			9.7	8.6	8.1				
	1705			[illegible]	7.7	8.4				
	1710			[illegible]	6.1	5.6				
	1715			[illegible]	6.1	5.4				
	1720			[illegible]	6.6	9.0				
	1725			[illegible]	7.6	5.5				
	[illegible]			[illegible]	[illegible]	9.5				[illegible]

1976 Date	Time	Water Depth	Sample Depth	Conductivity	‰ Salinity	°C Temp.	% Transmissivity	Suspend. Sediment Sample	Water Sample	Remarks
8/09	1935		Surface	0.4	0.4	11.0	—			
	1940			1.3	1.2	10.0				
	1945			1.0	1.2	9.8				
	1950			0.7	0.6	10.9				End line 30
8/10	0825			17.8	18.7	3.4				Start line 31 @ 0825
	0830			17.7	18.7	3.3				
	0835			17.6	18.5	3.3				
	0845			17.7	18.3	3.8				
	0900			15.5	15.9	4.4				
	0910			17.3	17.8	4.1				
	0920			18.3	19.1	3.8				
	0930			19.0	20.0	3.4				
	0940			19.1	20.5	3.1				
	0950			19.1	20.7	2.5				
	1000			19.3	21.2	2.3				
	1010			19.3	21.7	1.6			X	
	1020			18.2	20.2	2.0				
	1030			18.2	20.1	1.5				
	1040			17.7	19.3	1.8				
	1050			17.3	19.2	2.1				

1976 Date	Time	Water Depth	Sample Depth	Conductivity	‰ Salinity	°C Temp.	% Transmissivity	Suspend. Sediment Sample	Water Sample	Remarks
8/10	1100		Surface	17.1	18.7	1.8	—		X	
	1110			17.1	18.8	2.1	—			
	1120			16.6	18.0	1.6	—			End line 31
	1420			23.4	26.3	2.8	78		X	Start line 32 @ 1416
	1430			25.3	29.3	1.0	76 (?)			transmissometer was bouncing
	1450			25.6	30.3	1.3	—			
	1500			24.5	28.1	1.5	79			
	1510			23.6	26.7	2.4	78			
	1520			23.3	26.1	2.2	78		X	
	1530			22.5	25.5	2.1	82			
	1540			22.2	25.2	1.9	82			
	1550			22.6	25.5	2.6	82			
	1600			22.3	24.5	2.4	81			
	1610			21.8	24.2	[illegible]	83			
	1620			21.5	22.8	3.4	80		X	
	1630			20.5	21.9	3.8	79			
	1640			21.0	22.2	3.1	81			
	1650			18.1	19.9	4.1	80			
	1700			17.3	[illegible]	3.6	[illegible]			
	1710			[illegible]	[illegible]	[illegible]	83			

Date	Time	Water Depth	Sample Depth	Conduct-ivity	‰ Salinity	°C Temp.	Transmis-ssivity	Suspend. Sediment Sample	[illegible] Sample	Remarks
8/10	1720		Surface	15.2	[illegible]	3.5	83		X	
|	1730		|	14.1	14.7	3.4	83			
|	1740		|	13.3	13.7	3.2	83			[illegible] 32 @ 1745

REPORT OF FIELD ACTIVITIES: SUMMER 1976

The first part of the summer-open water-activities in the Beaufort Sea were completed from the R/V KARLUK, during July and August, under the direction of Peter Barnes and are reported on here. The first half of July was spent in Prudhoe Bay with the mundane job of preparing the KARLUK for the summer season. The hydraulic system was completely rebuilt, a new and stronger mast and boom were installed and the damage from last winters break-in and burglary was repaired. Two 50 foot towers for navigation beacons were installed; one on the eastern Cottle Island bench mark and the other at Tolaktovut Point on the Colville delta. We anticipate leaving these towers installed for the winter. They could be made available for other OCS projects.

On 24 July the ice in Prudhoe Bay had cleared sufficiently that a seismic refraction survey for sub-sea permafrost utilizing three 40 in^3 air guns and a 24-channel recording system was begun under the direction of James Rogers of the University of Alaska. Several lines were run inside Prudhoe Bay, including two transects over the permafrost drill hole in the northern part of the bay and two transects onto the beach (attachment A). Ice precluded operations outside Prudhoe Bay and the refraction equipment was offloaded on 29 July.

Subsequently, instrument moorings implanted in the fall of 1975 off Prudhoe Bay and in the channel between Egg Island and Long Island were recovered. The instrument package outside the entrance channel to

Prudhoe Bay had moved onshore in a southerly direction about 200 meters. Furthermore, it was badly damaged either by ice during the winter or from the barge unloading activities of late last fall. The instruments in the Egg Island channel were also recovered damaged, although not as severely. The 300 meter grapling line on the Egg Island implant was heavily covered with grasses and small twigs suggesting significant organic input from the nearby Kuparuk River during the early June flooding. Although damaged, both instruments had completely utilized their tapes which are presently being processed at NOAA/PMEL. Hopefully, they were damaged after their recording cycle. The least damaged meter was repaired and implanted with a nephlometer and tide gauge in 5 meters of water off of the Sagavanirktok River on July 31 (Attachment A).

Detailed bathymetry in the vicinity of the west dock and the entrance channel to Prudhoe Bay were taken to establish if changes have occurred since the U.S. Coast and Geodetic Survey of 1950 and to serve as a baseline for further changes. Precision range-range navigation system was used along with a fathometer which could be read to the nearest 0.1 meter. The preliminary interpretations from this survey are appended as Attachment D. Operations during the first week in August included about 200 km of sediment profiling coupled with bathymetry, surficial temperature,salinity and transmissivity, spot current measurements and side scanning sonar data. Two track lines were run in Stefansson Sound essentially completing our coverage there. The remainder of the profiling was concentrated in western Harrison Bay where our previous data had been sparse. It is apparent from this data that the near surficial geological conditions in western Harrison Bay differ from those to the east. Most significant is that subbottom records suggest that there is much less gravel in the sediments. In addition, "tundra" capped ice was studied in the vicinity of a former island just east of Cape Halkett. The location of the former island was indicated by grounded ice concentrations and a 1 meter shoal.

The survey test lines established off Thetis and Spy Islands in 1973 and rerun in 1975 were reoccupied again this year. This years records indicated considerable ice gouge activity during the winter and spring. Ice observations during the spring and summer indicated that the stamukhi zone is poorly developed in the Olitok area during the winter of 1975-76. The absence of numerous large winter ice features coupled with evidence of ice gouging is puzzling.

On the 12th of August Erk Reimnitz and Larry Toimil joined the KARLUK for vibro-coring work. The corer was assembled at the Prudhoe Bay camp and onloaded. After successful testing at the dock and in the central part of Prudhoe Bay a sampling transect was run from Stump Island offshore and across the Reindeer Island shoal (Attachment A). In addition, the boulder patch south of Narwhal Island and the two meter bench off the Sagavanirktok River were cored. Operations were then moved to Harrison Bay where a transect of cores was obtained from the one meter contour to 18 meters depth, 26 km seaward off the central delta. A short section across the western delta front platform obtained 3 more core samples.

Data from the rate of penetration of the hammer driven corer almost always indicated a sharp decrease at approximately one meter below the sea floor suggesting an increase in sediment strength. These data will be of significance when offshore structures are built. No ice or ice bonded sediments were recovered at any of our coring sites.

Studies during the second part of the summer activities from the KARLUK are being directed by Erk Reimnitz and Larry Toimil. Their efforts will include (a) the study of areas of outcrop by diving and TV observation; (b) plowing an artificial ice gouge which can be monitored for changes in coming years; (c) studying changes in bathymetry and coastal configuration north of Pingok Island; and (d) to recover and reimplant current meters for the winter season off the Colville Delta and in Stefansson Sound.

PRELIMINARY DRAFT

Bathymetric and Shoreline Changes Northwestern Prudhoe Bay, Alaska

By: Peter Barnes and Greg Smith

Introduction

The coastal environment in the vicinity of Prudhoe Bay (Fig. 1) is presently being vigorously utilized by petroleum activities. In particular the freight movement from barges onshore has used the Prudhoe Bay channel for 8 years. In 1975 a new causeway and dock were built just outside the channel. During the winter of 1976 this causeway was extended. The availability of detailed 1950 coastlines and nearshore bathymetry from U.S. Coast and Geodetic Survey provides a baseline to assess natural and man-related changes in the coastline and bathymetry.

During July and August of 1976 the R/V KARLUK ran a series of sounding lines in the Prudhoe Bay entrance channel and in the vicinity of the new causeway just to the west of the channel. These data coupled with 1970 U.S. Geological Survey orthophotos, allow us to compare changes in bathymetry and coastal configuration since the 1950 survey.

During the 1976 survey, depths were read to the nearest 0.1 foot, but were uncorrected for tidal or sea level differences (normal tidal range 0.5 ft.). Navigational control was achieved using a range-range system giving a position accuracy within 10 m, considering the system error and errors in locating the shore stations. Thus, a detailed comparison of the absolute depth values of the 1976 survey with the 1950 survey is inappropriate. However, the changes in position and form are probably real.

Results

Prudhoe Bay Channel

A comparison of 1976 and 1950 bathymetry is presented in Figures

2 and 3. The most apparent changes which have occurred in the 26 year interval are the relative depth and location of the channel. Within the interval, the axis of the deepest part of the channel has shifted shoreward 50 to 175 m and the greatest onshore movement occurred near the midpoint in the channel. In addition to the onshore movement, the channel is displaced seaward and the shallows on either side of the channel have prograded seaward as evidenced by displacement to the northwest of the 1976 4-foot contour relative to the 1950 contour.

Depth of the channel axis is 1 to 1.5 feet greater in 1976 than in the 1950 data. The 1976 fathograms also show occasional holes or deeper channels, up to 8 feet in depth. Apparently these deep holes are related to seasonal changes in the maximum depth of the channel. The 2-foot shoal in the central section of the channel has remained unchanged since the 1950 survey.

Personnel of the tug and barge operations report that the channel seems to become more difficult to traverse as the open water season progresses (July to September) due to shoaling. During the 1976 season with the KARLUK we noted that in late July and early August we could transit the channel easily with a draft of 4 feet, while in late September, even lightly loaded (3.5 foot draft), we had to grind along the bottom over much of the central portion of the channel.

Causeway and Vicinity

To facilitate the offloading of supply barges, Atlantic Richfield Company constructed a gravel fill causeway in 1975 between the Prudhoe Bay Channel and Stump Island (Fig. 2). As initially constructed the causeway extended 1.3 km from the coast. Subsequently the causeway was extended

1.5 km. in a northwesterly direction during the winter of 1976 to facilitate offloading of barges stranded during the 1975 sealift (Fig. 2).

A comparison of the 1950 and 1976 bathymetry shows a number of marked changes in bathymetry in the vicinity of the causeway. The 6, 7, 8 and 9 foot contours on the east side of the causeway are displaced shoreward. At the dogleg in the causeway, sheet piling and weighted barrels are being used to retard and prevent erosion on the eastern side. Further inshore Alaska Department of Fish and Game personnel experienced inundation of their fish trap due to longshore transport of gravel (T. Bendock, Pers. comm.). To the east, the contours midway between the causeway and the entrance channel have apparently been displaced seaward since 1950.

Along the northeast side of the causeway extension of our fathograms indicate a very irregular and disturbed bottom with depths of 3 to 15 feet. Field observations suggest that in part these features are due to dredging operations during causeway construction and completion. Furthermore, the aerial photographs show that the intense tug and barge activity in October, 1975 during freeze-up occurred along a corridor just to the northeast of the causeway extension. Propellor wash during this period could have created cut and fill structures.

Stump Island Area

Data from the 1950 survey did not cover much of the inshore area southwest of the causeway and across the entrance to Gwydyr Bay, thus changes cannot be evaluated. Our data shows a channel in excess of 5 feet deep along the mainland side of the channel between Stump Island and the coast. This channel shoals to the east and probably shoals to the west in Gwydyr Bay as we know this end of the bay is impassable to a vessel of 4-foot draft.

The eastern tip of Stump Island has moved approximately 275 meters to the northeast of its 1950 location. The 1976 location from our studies and the 1970 location of the island terminus from U.S. Geological Survey orthophoto maps are essentially the same indicating that the changes occurred prior to 1970 and that this end of the island has been essentially stationary since 1970. Our bathymetric survey crossed a shoal of less than 2 feet somewhere east of the present end of the island at a position which coincides with the 1950 location of Stump Island (Figs. 2 and 3).

Stump Island has undergone dramatic changes in shape and position during the twenty-year interval. The Island has moved onshore (southwest) 75-100 meters while both ends have extended in a northeasterly direction. In effect, this has changed the shape from lunate to almost linear. In addition, the area of the island has increased about 120,000 square meters between 1950 and 1970.

Considering the earlier work on the movement of islands and spits on the Arctic Coast (Short, 1973, RU#205 annual report) the onshore movement of Stump Island is to be expected. However, the earlier reports and our unpublished data show that these islands typically migrate in a westerly direction as exhibited by the westward extension of Stump Island. The enlargement and offshore movement of the eastern spit is unique. The easternmost island in a long chain of islands extending more than 50 kilometers to the west, perhaps the funneling of water from the occasionally westerly storm down the lagoon between the islands and the mainland has operated to maintain the eastern extremity of Stump Island.

Coastal Erosion

A comparison of the 1950 and 1970 coastlines shows erosional changes on the mainland coast and a marked change in the configuration of Stump Island (Fig. 4). The Arctic Coast in this area is characterized by 1-

to 3-meter high tundra bluffs which display abundant evidence of slumping due to thermokarst erosion. The northeast-facing coasts east of Gwydyr Bay have been eroded up to 65 meters. The most pronounced erosion occurs at Point McIntyre. From here eastward the coast is uniformly eroded from 10 to 20 meters. Rates of erosion calculated for the 20-year interval range up to more than 3 meters per year, but average about a meter per year. Within Gwydyr Bay erosion has been restricted to the coastal promintory west of Point McIntyre. On this point maximum coastal retreat of 50 meters was measured.

The coastal retreat reflects the pattern of dominant winds and waves. On the exposed coast east of Point McIntyre, erosion is noted all along the coast while within the protected environment of Gwydyr Bay only the coastal promintory exposed to the considerable fetch of westerly and northeasterly waves has marked erosion. It is interesting to note erosion even in the region of coast somewhat protected by the Gull Island shoal. Coastal retreat in the lee of the new causeway will probably decrease.

Discussion

The predominant winds and waves during the open water season on the Arctic Coast are from the northeast. Elsewhere along the coast this has resulted in longshore drift to the west as seen in the westward movement or extension of insular spits on many of the coastal islands (Short, 1973, RU#205 annual report). Furthermore, the eastern parts of these same islands show erosion. The rare late summer and fall storms usually are accompanied by westerly winds and a significant rise in sea level (up to 3 meters in 1970).

Coastal erosion along the north coast of Alaska is a result of permafrost degradation of the low tundra bluffs. Rates of erosion are commonly around

1 meter per year. Greatest erosion occurs on headlands and the eastern end of the islands (Short, 1973, Lewellen, 1976), where rates of 10 to 40 meters per year have been reported.

Prudhoe Bay Channel

The onshore movement of the channel axis is probably a result of the coastal retreat and the southwestward extension of the Gull Island shoal under the influence of of the dominating northeasterly winds and waves. Apparently, however, the channel has moved more than the coastline has retreated. Furthermore, there is an apparent shoaling of the channel during the open water season. One possible explanation for these changes is apparent when the entire yearly cycle of events is considered. During the fall and early winter when the sea ice canopy is growing in thickness, tidal and barometric changes in sea level must move in and out of Prudhoe Bay through smaller and smaller cross sections. Ultimately, when Gull Island shoal and the openings between Gull Island and Heald Point are sealed off by bottom fast ice, the only opening remaining for the flow of water is the entrance channel. Data taken from channel cross sections by drilling through the ice in May and June, show that the channel may be hydraulically maintained all year below the ice (RU#205 July quarterly report). The shallowest section of the channel in this survey was 5.5 feet. Thus each spring the channel could be scoured to a depth somewhat near the thickness of the seasonal ice cover (about 6 feet).

During the open-water season, the prevailing northeasterly winds and waves would tend to move sediments from the Gull Island shoal into the channel, which would explain the shoaling noted by the tug and barge operators and the shallower depth of the August 1950 Survey of the Coast and Geodetic Survey. Our 1976 survey was accomplished in late July right after the ice had cleared and would explain why we observed a deeper channel.

The southwesterly extension of the Gull Island Shoal is further evidence that sediments are moving onshore. With the onset of freezeup, channel scour would be initiated with the newly infilled sediments being the most susceptible to erosion.

Conclusions

1. The Prudhoe Bay channel is migrating shoreward at 1-2 meters per year and possibly experiences seasonal infilling and erosion which results in open season variations in channel depth.
2. Coastal retreat under the influence of the northeast winds averages 1-2 meters per year but may LOCALLY BE ~~average~~ more than 3 meters.
3. The construction of the causeway and the attendant ship traffic is affecting the bathymetry in the immediate vicinity, although it is too soon to see any established trends.
4. Stump Island has moved onshore and has undergone an apparently episodic change resulting in an increase in size and change in shape.
5. The nearshore environments in this area are influenced by long and short term changes in coastal configuration, bathymetry and island morphology which are and will continue to be influenced by man's activities.

References Cited

Lewellen, R., 1970, Permafrost erosion along the Beaufort Sea Coast, Published by the author, Denver, Colorado, 25 p. Short, A.D., 1973,

Short, A.D., 1973, Beach dynamics and nearshore morphology of the Alaskan Arctic Coast, Unpublished Ph.D. dissertation., Louisiana State Univ. Baton Rouge, La., 140 p.

Figure Captions

Figure 1. Physiographic diagram of the North Slope of Alaska and Canada showing the location of the study area of this report. View is from the north.

Figure 2. Bathymetric contours from the 1950 survey east of Stump Island. U.S. Coast and Geodetic Survey smooth sheet 7857. Contours at one foot increments. Scale 1:20,000.

Figure 3. Bathymetric contours from the 1976 U.S. Geological Survey KARLUK data. The inner causeway segment was constructed in spring 1975 and the outer segment in the winter of 1975-76. Contours at one foot increments. Scale 1:20,000.

Figure 4. Coastal erosion and Stump Island re-configuration from 1970 and 1950 data from U.S. Coast and Geodetic Survey smooth sheet 7857. 1970 data from U.S. Geological Survey Orthophoto map, Beechy Point B-3 NW. Scale 1:20,000. The coastal retreat and changes in island morphology from 1950 to 1970 are shown as solid blue.

Rates of ice gouging and sediment reworking, Beaufort Sea, Alaska

by

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ABSTRACT

Repetitive side-scan sonar and precision bathymetric surveys over a 4-year period, in the Beaufort Sea at 6-12 m depth, have demonstrated changes in micro relief due to ice gouging. Surveys were made in 1973, 1975, and 1976. Gouges postdating the 1973 and 1975 surveys could be distinguished by the superposition of gouges and by the crispness of the gouge flanks. Using the cross-sectional relief of a gouge as measured on fathograms, it is conservatively estimated that 0.65 km of a 10-km segment of trackline was gouged between 1973 and 1975 (33 m/km/yr). Preliminary measurements on the 1976 records indicate a similar rate of ice gouging (45 m/km/yr). Assuming that no area is gouged more than once, the bottom in the entire area of the survey would be reworked by ice in 20 to 30 years. The estimated gouging rates are conservative because they include neither the very small gouges nor the gouge flanks, and because the actual area of the bottom disturbed by a blunt ice keel is probably much greater than the measured width of the gouge. With an average gouge incision of 3 m and inner-shelf sedimentation rates of less than 1 m/1,000 yr, surficial sediments will be reworked several times before being buried deep enough to escape the action of ice. Seaward of the study area in the stamukhi zone, where ice activity is most intense, rates and intensities of ice gouging are expected to be greater. This study has important implications for the study of ancient high-latitude geologic environments as well as for the planning and design of offshore installations.

QUARTERLY REPORT

Contract #RK6-6074
Research Unit #205
Reporting Period -
October 1976 -
December 1976

Marine environmental problems in the ice covered Beaufort Sea shelf and coastal regions

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David Drake

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1 January 1977

Quarterly Report

I. Task Objectives

The primary goal of this project is to study the nature, distribution, stability and thickness of Holocene sediments and their relationship to sources, dispersal mechanisms and bottom processes. Emphasis is placed on processes that are unique to the arctic environment, where ice usually plays a dominant role. Ice deforms and stirs bottom sediments, controls and modifies bathymetry, permits conductive heat transfer, inhibits the free discharge of river waters during the spring and transports sediments by rafting and bulldozing. Using sediment profiling, core sampling, diving, underwater TV and photography, thermoprobes, oceanographic sensors, along with aerial and spacecraft imagery, we hope to achieve the following specific objectives:

A. A definition of the character, source and physical composition of bottom materials including permafrost where present.

B. An understanding of the present sediment transport regime, elucidating the influence of ice, rivers, currents and waves.

C. An understanding of the Pleistocene and Holocene geologic record for use in interpreting the stability of the present day geologic setting.

II. Field of Laboratory Activities:

A. No field activities this quarter

B. Scientific Laboratory Group:

Peter Barnes	Project Chief - Geologist	U.S. Geological Survey, Office of Marine Geology
Erk Reimnitz	Principal Investigator-Geologist	" "
David Drake	" " "	" "
Larry Toimil	Co-Investigator-Geologist	" "
Doug Maurer	Physical Science Technician	" "
Dennis Mann	" " "	" "

C. Methods:

Included in section on results below.

D. Sample localities:

Included in section on results below. Additional sample localities will be detailed in future reports as the data is presented from those sites.

E. Data collected or analyzed;

a) 25 vibrocores have been opened, described, radiographed, photographed, sampled, and impregnated with resins.

b) Suspended sediment samples have been filtered and weighed, and detailed examination of the filtrates is underway.

c) Engineering properties in the form of shear vane measurements, core penetration rates and diving observations have been compiled for 1971-1976 data.

d) Interstitial salinities have been compiled for surface and near surface sediments over much of the shelf from 1972 and 1976 samples.

e) Current meter data, water level data, and turbidity information from three sites on the inner shelf have been processed at NOAA/PMEL and Oregon State University.

F. Milestone Chart - Data Submission -

No change.

III. Results - See Next Section

IV. Preliminary interpretation of results.

Attachment A; Reconaissance Survey of Kogru River

Attachment B; Engineering properties of Beaufort Shelf sediments

Attachment C; Near bottom currents on the inner shelf

Attachment D; Species list of Shelled Fauna of the Chukchi Sea.

Some observations on surficial suspended sediments, Beaufort Sea

Surface water samples for suspended sediment analyses were obtained during July-September 1976 from the USGS R/V KARLUK. Seventy-eight samples were taken between Stockton Islands and Cape Halkett in a coastal belt extending about 15 kilometers offshore. Concentrations of total suspended matter ranged from a high of 75 mg/liter in western Harrison Bay to lows of 0.1 mg/liter in Prudhoe Bay and near the Stockton Islands. In general, the low values occurred later in the field season and in the eastern portion of the area. Preliminary analyses indicate that westward drift of surface water is predominant in Harrison Bay and the bulk of the suspended matter is present within 5 km of the shore. These data would tend to suggest that any suspended polutants resulting from petroleum development would remain in close proximity to the coast and would normally be displaced in a westerly direction.

Further analyses are underway. It is anticipated that comparison of these data with data collected in March 1976(subice) and in previous years will substantially increase our understanding of nearshore circulation and sediment transport pathways in Beaufort Sea.

V. Problems Encountered - None.

VI. Estimate of funds expended.

NOAA/OCS Funds - $ 1,079

USGS Funds - 12,331

Attachment A Reconaissance Survey of Kogru River

During the middle of September, 1976, the R/V KARLUK made a reconaissance survey of the navigable parts of Kogru River in southwestern Harrison Bay (Fig. A-1). During this survey the following systems were operated: a) Uniboom subbottom seismic profiler using 300 joules of power, b) Raytheon subbottom profiler, c) Raytheon and Simrad fathometer, d) E.G.& G. side-scanning sonar, e) salinity and temperature sensor, and f) transmissometer.

Navigational control is based on radar ranges to favorably located promontories along the embayment, giving sharp returns. Position inaccuracies may range to as much as 50 m, but generally are less.

The purpose of this survey was severalfold:

1) Not previously charted, Kogru River, if found deep enough may serve as a protected harbor for small craft and barges bringing supplies to the North Slope.

2) Kogru River extends for a considerable distance into the coastal plain. It therefore provides the opportunity to compare coastal plain geology, seen in seismic profiles, to continental shelf geology.

3) Offshore seismic profiles in southwestern Harrison Bay show a very pronounced change in character of the Quaternary Gubic Formation underlying the shelf. Kogru River seismic data would help in defining this boundary.

4) Previous workers have speculated that the irregular embayment of Kogru River represents a series of coastal plain lakes, breached by erosion and now connected with the ocean. This survey may shed further light on this hypothesis, and may enable us to identify similar lake deposits on the open shelf.

5) Seismic profiles extending through lake deposits and the intervening recently eroded coastal plain deposits may show corresponding undulating reflectors representing the upper surface of high velocity ice bonded sediments.

Some initial interpretations of data, and results are listed below.

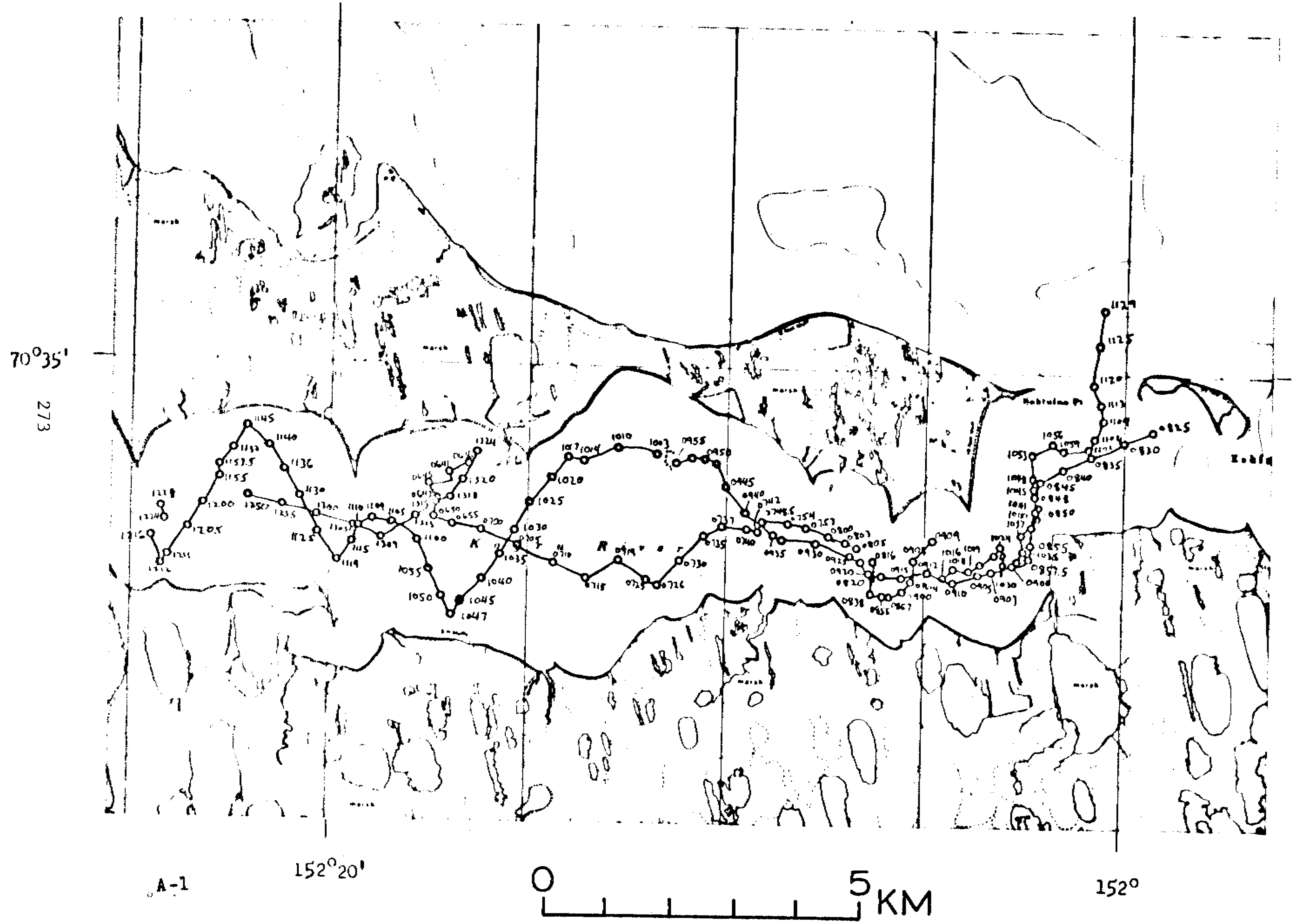
1) Depth contours at 1/2 m contour interval are shown in Figure A-2. With a normal sea level a minimum depth of 1.5 m can be carried for about 15 km into the coastal plain. Several broad basins of 2.5 and 3 m water depth occur in the western part of the surveyed area. Therefore vessels of the

types entering Prudhoe Bay can operate and find shelter in Kogru River, making it a useful access route to the Naval Petroleum Reserve.

2) The lake bottoms of the surrounding coastal plain lie at considerably higher elevations than the bottom of Kogru River. The above hypothesis concerning the origin of this embayment therefore can be rejected.

3) The seismic records obtained are excellent, and further analysis may provide clues to the true origin of the embayment. The geology of the Gubic Formation exposed in bluffs surrounding Kogru River, and seen in subbottom profiles, similar to that underlying southwestern Harrison Bay, is very different from that underlying the shelf eastward. The nature of the boundary, and differences in Quaternary depositional environment await further analysis.

4) Kogru River, lacking streams supplying fresh water, really is an embayment connected with the open ocean. During the time of the survey, surface water salinity, temperature, and transmissivity were as shown in Figure A-3. These measurements were made during a 4 hour period, and for all practical purposes may be considered synchronous. From the mouth over a distance of about 15 km landward, the salinity gradually decreased from 27 ppm to 15 ppm. The water temperature along the same transect increased from 1.3°C to 2°C, and the percentage of light transmissivity (10 cm light path) increased from about 40 to about 60. Going inland, the Kogru River water thus becomes fresher, warmer, and clearer. During September, therefore, the sediment source for the embayment seems to be Harrison Bay and the Colville River.



A-1

Attachment B Some Mass Physical Properties of Shelf Sediments

So far, almost no data on mass physical properties of shelf sediments in the Alaskan Beaufort Sea has been published. This type of data however, is important for several reasons. Kovacs and Mellor (1974) in: "The Coast and Shelf of the Beaufort Sea" have attempted to calculate the driving forces on grounded ice producing gouges on the sea floor. Such calculations require knowledge of the mechanical properties of surface sediments encountered. Also industry contemplating dredging and other offshore construction projects have often requested this type of data.

For these reasons we have compiled pertinent information obtained in previous operations, and from our field effort during the last summer. The data included in this attachment is listed without an attempt to interpret the results.

Shear Strength Values from Bottom Samples

During bottom sampling operations of the past, shear strength values of relatively undisturbed samples have been measured aboard ship with a simple hand held shear-vane (Dill and Moore, A diver-held vane-shear apparatus, Mar. Geol. v. 3 p. 323-327). The results, along with information on location, water depth, sampler type, and sediment type have been compiled in tables B-1a and B-1b. The station locations are shown in Figure B-1.

In Situ Shear Strength Values Obtained by Divers

A few *in situ* shear-vane measurements, using the same hand held instrument, were obtained during diving operations in 1972. A number of additional measurements were made in the same way during summer 1976 diving operations. On a number of dives more than one reading was taken. This was done particularly in ice gouged areas where differences are to be expected between flat, undisturbed bottom, gouge flanks, and gouge floors. Also, the maximum reading (peak) observed just prior to shearing of the sediment, and the reading during shearing (residual) were recorded. All these values, along with information on station location, water depth, depth below sea floor, bottom type, sediment type, etc. are presented in Table 2-A and 2-B. Station locations are shown in Figure B-1.

Although care was taken by the divers to increase torque slowly and evenly to obtain reliable readings, currents and other factors did not allow them to do so in all cases. The *in situ* shear strength values still are considered to be the most accurate ones presently available. It should be noted shear-vane readings obtained in sandy and especially gravelly sediments do not represent the true shear strength of the sediment due to sediment dilation and other factors.

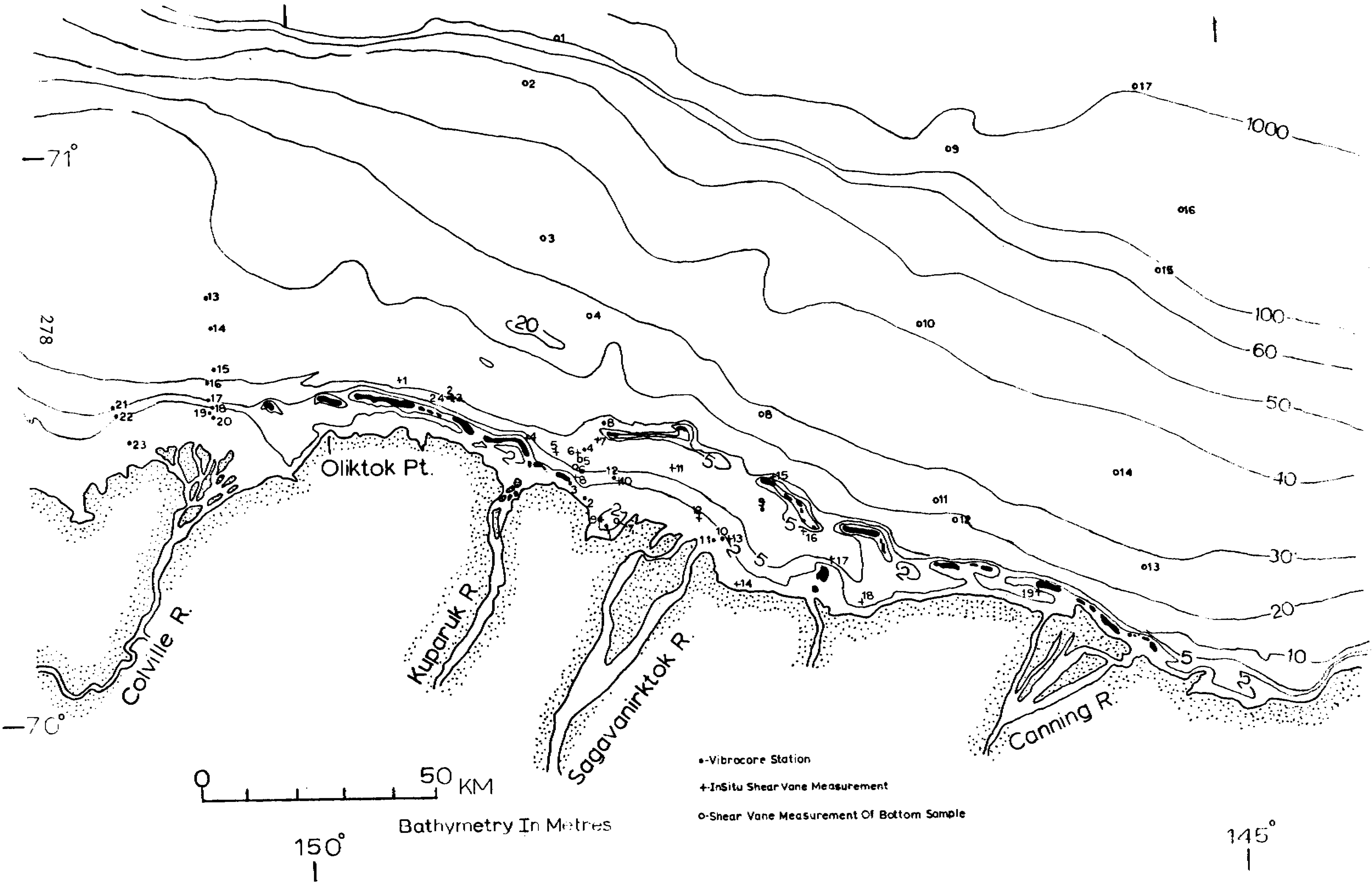
Penetration Rates of Vibrocore Barrels

Twentyfour vibrocore samples were obtained during the summer of 1976, with core length of up to 1.80 m. The rates of penetration were recorded for most stations. These rates provide some measure of the soil properties in different environments of the inner shelf. In several instances divers using a shear vane measured *in situ* shear strength of surface sediments near vibrocore stations (Fig. B-1).

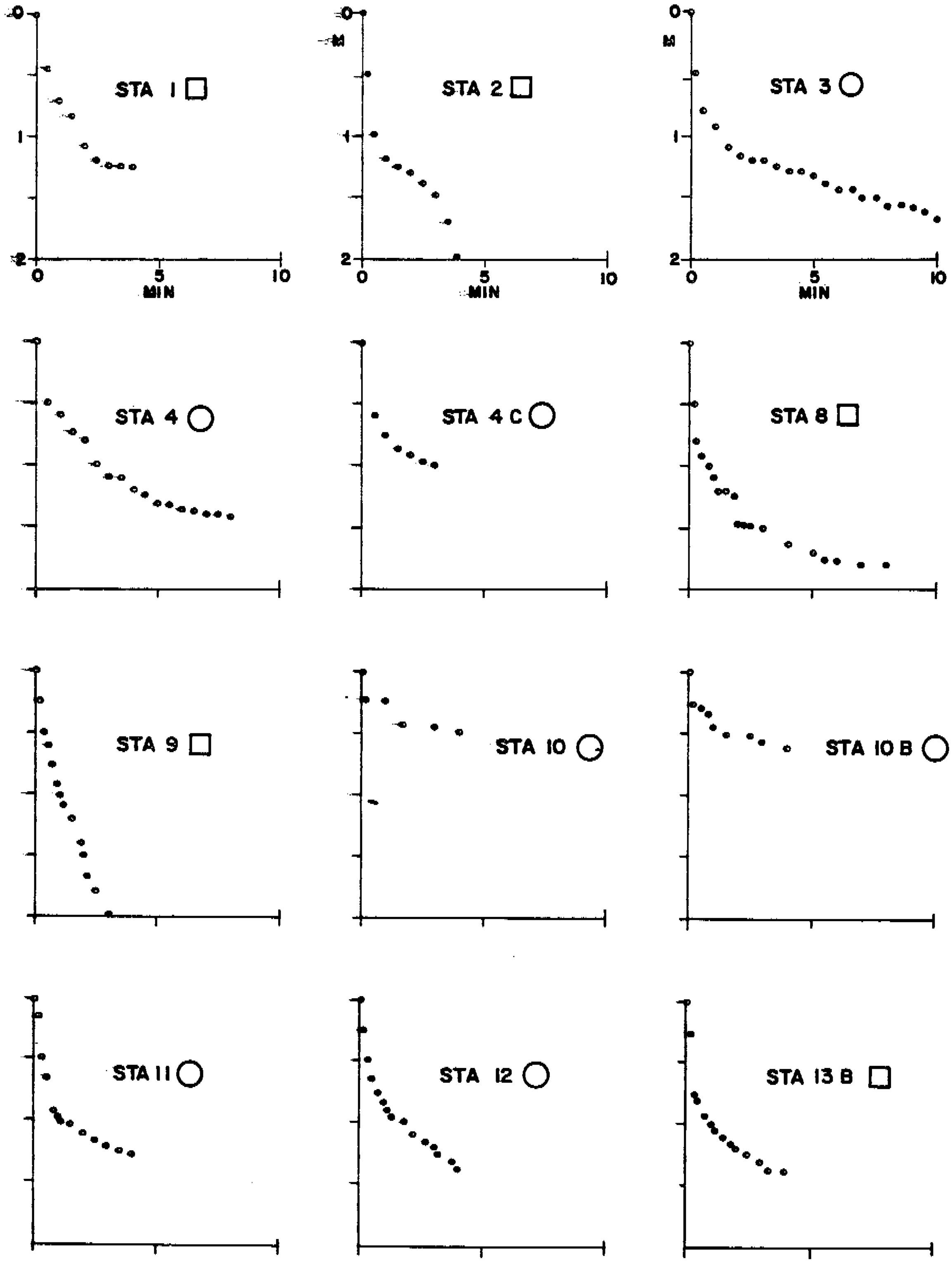
The vibrocorer used is driven by two electric motors producing a combined driving force of 700 Kg at a rate of 2,840 impulses/min. We used square steel barrels and tubular fiberglass barrels. Steel barrels propagate the pulse more efficiently to the core nose than do fiberglass barrels. With the penetration rates, shown in Figure B-2, the barrel type used at each station is identified. Station locations and water depths are liisted in Table B-3.

Only preliminary core studies are completed, and we therefore did not include sediment descriptions with the penetration rates. However, comparing sediment characteristics in the penetrated section with penetration rates, we feel fairly certain that cores 19 and 20 from the Colville Delta were stopped at the top of the underlying ice bonded sediments.

Fig. B-1



1000
100
60
50
40
30
20
10
5
2
20
Oliktok Pt.
Colville R.
Kuparuk R.
Sagavanirktok R.
Canning R.
—71°
—70°
150°
145°
0
50 KM
Bathymetry In Metres
•-Vibrocore Station
+-InSitu Shear Vane Measurement
o-Shear Vane Measurement Of Bottom Sample



STA 1
STA 2
STA 3
STA 4
STA 4 C
STA 8
STA 9
STA 10
STA 10 B
STA 11
STA 12
STA 13 B
0
1
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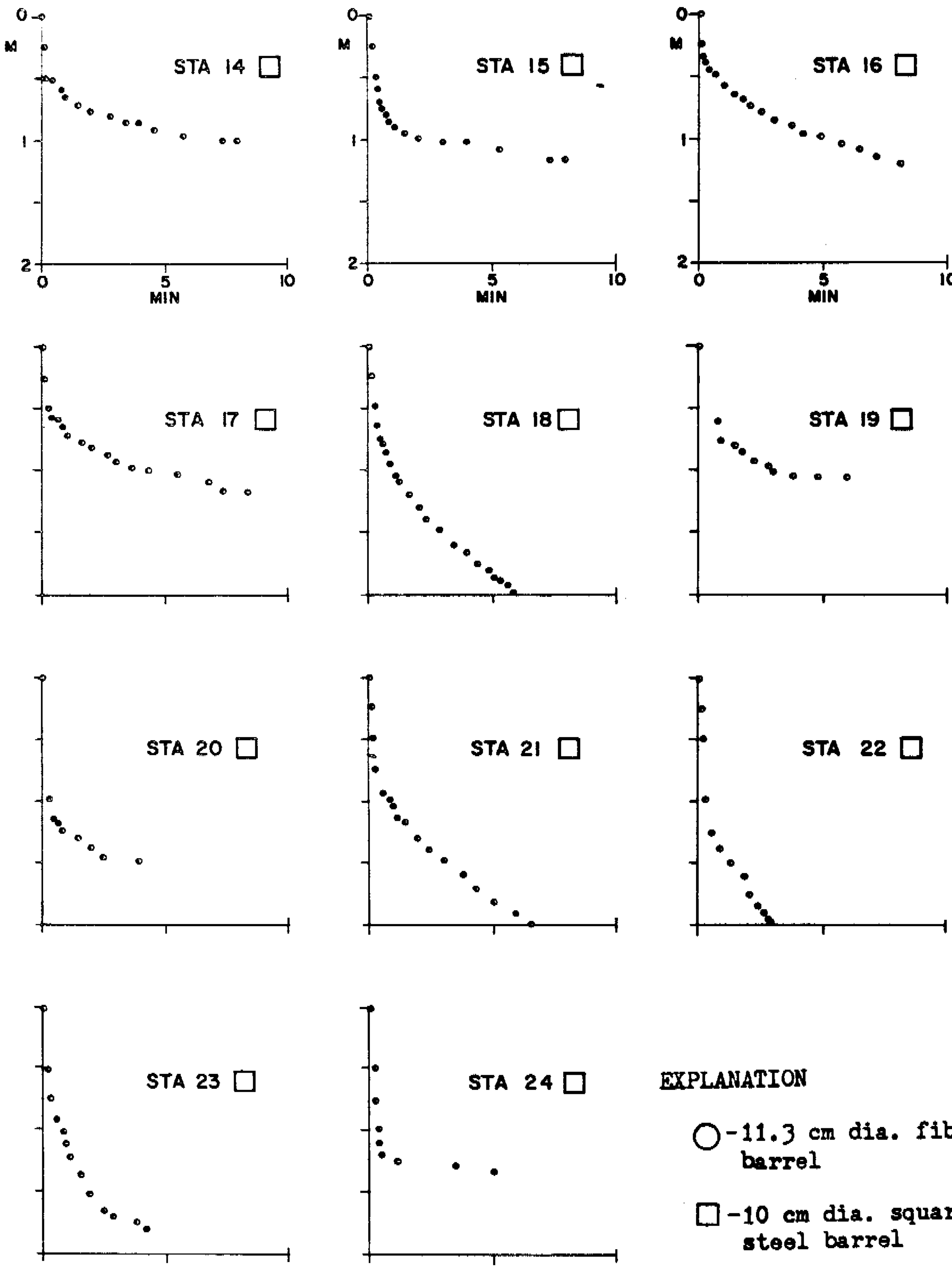
M
0
5
10
MIN

Fig. B2 Contd



EXPLANATION

○ -11.3 cm dia. fiberglas barrel

□ -10 cm dia. square steel barrel

Table B-1a

SHEAR STRENGTH VALUES FROM SAMPLES

o.s - off scale
PSI - pounds per square inch
KN/M^2 - Kilo Newtons per square meter

Station Number	Location	Water Depth (m)	Shear Strength Peak PSI (KN/M^2)	Shear Strength Residual PSI (KN/M^2)	Depth of Measurement below sediment surface in centimeters	Sample type	Sediment description
1	71°10.3'N 148°34.5'W	30.7	0 0.32(2.21)	- -	2 5	Van Veen Grab	Soft mud Stiff mud
2	71°06.0'N 148°43.2'W	43	0.21(1.45) 1.33(9.17)	- -	2 5	Van Veen Grab	Pebbly, sandy, mud Gravelly Mud
3	70°49.7'N 148°40.1'W	33	0.21(1.45) 2.0(3.79)	- -	2 5	Van Veen Grab	Soft, fine-grained sandy mud Stiff, fine-grained sandy mud
4	70°41.6'N 148°25.3'W	27	0.10(0.69) 1.11(7.05)	- -	2 5	Van Veen Grab	Soft, Fine-grained Mud Gravelly mud
5	70°26.05'N 148°29.26'W	7	1.11-1.33 (7.65-9.17)	0.1 - 0.21 (0.09-1.45)	6	Undisrupted snapper sample	Brown/grey, medium-grained silty sand w/worm tubes
6	70°25.25'N 148°30.15'W	6.5	1.11	0.1 - 0.21 (0.69-1.45)	2	Undisrupted snapper sample	Brown/grey medium-grained silty sand w/worm tubes
7	70°18.92'N 148°20.3'W	3.3	o.s.	0.88-1.11 (6.07-7.65)	8	Gravity core	Dark grey silty clay
8	70°30.4'N 147°30.9'W	26	<0.10(<0.60) 0.71(4.90)	- -	2 5	Van Veen Grab	Fine-grained sandy mud Stiff medium to coarse-grained sandy mud
9	70°22.4'N 146°27.5'W	364	0 0.38(2.62) 0.66(4.55)	- - -	2 5 5 - 10	Van Veen Grab	Soft, brown mud Stiff, grey mud Stiff, grey mud
10	70°39.2'N 146°38.7'W	47	0.44(3.03)	-	2	Van Veen Grab	Muddy sand
11	70°20.4'N 146°35.1'W	26	0 o.s.	- -	2 5	Van Veen Grab	Soft, fine-grained sandy mud Stiff, coarse-grained sandy mud

o.s - off scale
PSI = pounds per square inch
KN/M^2 - Kilo Newtons per square meter

SHEAR STRENGTH VALUES FROM SAMPLES

Station Number	Location	Water Depth (m)	Shear Strength Peak PSI(KN/M^2)	Shear Strength Residual PSI(KN/M^2)	Depth of Measurement below sediment surface in centimeters	Sample Type	Sediment description
12	70°19.5'N 146°29.0'W	17	2 2	- -	2 5	Van Veen Grab	Stiff, grey clay
13	70°12.6'N 145°29.0'W	25	0.88(6.07) 1.33(9.17) 2.0 (13.79)	- - -	2 5 5 - 10	Van Veen Grab	Soft, muddy sand Stiff, gravelly mud Muddy sand
14	70°22.9'N 145°37.3'W	37	0.10(0.69) 2.22(15.31)	- -	2 5	Van Veen Grab	Sandy, gravelly, mud w/coarse, 20 cm diameter rocks Stiff, sandy, gravelly, mud
15	70°49.0'N 145°13.1'W	102	0.21(1.45) 0.76(5.24)	- -	2 5	Van Veen Grab	Pebbly mud Mud
16	70°50.0'N 145°13.1'W	331	0.44(3.03) 0.76(5.24)	- -	2 5	Van Veen Grab	Soft mud
17	70°04.4'N 145°26.0'W	1155	0 1.33(9.17) o.s.	- - -	2 5 5 - 10	Van Veen Grab	Pebbly mud Grey mud Stiff Clay

IN SITU SHEAR STRENGTH VALUES

o.s - off scale
* - average of several readings
PSI = pounds per square inch
KN/M² = Kilo Newtons per square meter

Dive Station Number	Location	Water Depth (m)	Shear Strength Peak PSI(KN/M²)	Shear Strength Residual PSI(KN/M²)	Depth of Measurement below sediment surface in centimeters	Bottom description at point of measurement	Sediment description	Comments
1	70°35.6'N 149°27.1'W	12	1.55(0.60) 2.55(17.58)	0.34(2.34) 0.55(3.79)	5 10	Bioturbated flat bottom	Bioturbated mud	Soft to 10 cm stiffer below
2	70°33.2'N 149°11.0'W	11.5	1.38(9.52)	0.69(4.76)	2	Seaward foot of major shoal, between gouges	Muddy Sand	
3	70°33.12'N 149°11.5'W	5	0.23 (1.59)	0.11(.76)	2	Flat bottom on major shoal	Clean, medium-grained sand w/clam fragments	Intensely gouged
4	70°28.4'N 148°47.2'W	4.5	0.34(2.34)	0.34(2.34)	2	Undisturbed sediment near gouge	Muddy sand	Trough of gouge impenetrable with veins
			0.69(4.76)	0.46(3.17	15	Flat bottom near gouge flank	Sandy, muddy gravel	
5	70°26.9'N 148°37.5'W	6.4	o.s. o.s.	1.03(7.10) o.s.	2 15	Flat bottom	Gray, cohesive mud Very stiff, muddy, sandy gravel with some shells	
6	70°26.9'N 148°30.5'W	8.5	0-0.34 (0-2.34)	0-0.34 (0-2.34)	2	Floor of gouge	Very soft surficial sediment underlain by fairly stiff layer	
			o.s.	0.69(4.76)	2	Flat bottom		
			1.03(7.10)	0.57(3.93	2	Flat bottom		
7	70°28.1'N 148°24.0'W	8.5	1.03(7.10)	0.46(3.17)	2	Floor of gouge	Mud	Stiff boundary at 2.5cm depth covered by fairly soft mud mud w/numerous clams
			0.69(4.76)	0.34(2.34)	2	Gouge trough		
			0.69(4.76)	0.46(3.17)	2	Gouge flank		
			0-0.34*(0-2.34)	0-0.34*(0-2.34)	2	Gouge flank		
			0.69(4.76)	0.23(1.59	2	Flat bottom		
			o.s.	o.s.	5	Flat bottom		
8	70°24.2'N 148°31.5'W	3.0	1.03(7.10) 0.69(4.76)	0.86(5.93) 0.46(3.17)	2 15	Flat bottom	Fine, muddy sand	

IN SITU SHEAR STRENGTH VALUES:

o.s - off scale
PSI - pounds per square inch
KN/M^2 - Kilo Newtons per square meter

Dive Station Number	Location	Water Depth (m)	Shear Strength Peak PSI(KN/M^2)	Shear Strength Residual PSI(KN/M^2)	Depth of Measurement below sediment surface in centimeters	Bottom description at point of measurement	Sediment description	Comments
9	70°19.8'N 148°23.5'W	2.5	0.54(3.72)	0.44(3.03)	8	Flat bottom	Fine, muddy sand	
10	70°24.0'N 148°17.3'W	3.1	1.15(7.93	1.03(7.10)	2	Flat bottom.	Slightly muddy medium-fine grained sand.	
			o.s.	o.s.	15			
11	70°24.9'N 148°01.0'W	7.0	o.s.	o.s.	2	Rippled flat bottom	Muddy sand	Ripples of 15 cm. wavelength
12	70°19.5'N 147°51.5'W	2.5	o.s.	o.s.	2	Flat bottom with ripples	Muddy sand	Ripples are 15-20 cm wavelength - 1-2 cm high
			o.s.	o.s.	3	Flat bottom with ripples	Very stiff mud	
13	70°17.2'N 147°42.8'W	3.0	1.09(7.52)	0.69(4.76)	2	Ripple field-flat bottom	Muddy, sandy	Ripples of 20 cm wave-length. 203 cm height. Old, weathered gouges creating broad bottom undulations
			o.s.	o.s.	15	Ripple field-flat bottom	Muddy sand	
			0.69(4.76)	0.46(3.17)	2	Exposed underlying gravel on flat bottom	Angular, pea-size gravel	
14	70°12.8'N 147°41.0'W	1.6	1.15(7.93)	0.92(6.34)	6.5	Flat bottom	Highly muddy, medium grade sand	
15	70°23.8'N 147°28.7'W	1.5	0.69(4.76)	0.46(3.17)	2	Flat bottom,	Sand	
			<0.34(<2.34)	<0.34(<2.34)	2	Gouged flank and floor	Sand	
			1.38(9.52	-	2	Flat bottom	Mud	
			1.03(7.10)	0.71(4.90)	2	Flat bottom	Muddy sand	
			1.03(7.10)	0.71(4.90)	10		Pea-size gravel	
16	70°18.2'N 147°18.7'W	6	0.34(2.34)	0	2	High ground covered by worm tubes	Soft mud	Hummocky relief related to distribution of worm tube patches
			o.s.	o.s.	2	Depression between worm tube patches	Muddy sand	
17	70°14.7'N 147°10.5'W	5.5	o.s.	1.09(7.52)	2	Flat bottom	Sandy mud	Dive site is marked by exposure of firm gravel in depressions
18	70°10.3'N 147°01.0'W	4.5	o.s.	o.s.	2	Flat bottom with decayed ripple train	Sandy mud	Burrowing activity
19	70°10.8'N	2.5	o.s.	1.15(7.93)	2	Slightly undulating bottom	Sandy mud	Small scale relief from bioturbation

Table B-3

VIBRO CORE STATIONS

Station Number	Location	Water Depth (m)	Station Number	Location	Water Depth (m)
1	70°19.0'N 148°22.0'W	3	15	70°37.0'N 150°27.0'W	12.4
2	70°22.3'N 148°28.4'W	1.7	16	70°36.3'N 150°28.2'W	11.5
3	70°24.0'N 148°33.2'W	1.5	17	70°34.0'N 150°28.2'W	8.5
4	70°27.3'N 148°28.2'W	6.5	18	70°33.3'N 150°27.9'W	3.3
8	70°29.8'N 148°20.8'W	8	19	70°33.6'N 150°28.1'W	2
9	70°20.1'N 147°31.1'W	6.5	20	70°32.7'N 150°27.5'W	1.5
10	70°17.1'N 147°44.3'W	2.7	21	70°33.8'N 151°01.0'W	4
11	70°17.7'N 147°47.0'W	1	22	70°32.5'N 150°59.6'W	0.6
12	70°24.1'N 148°18.5'W	3	23	70°29.5'N 150°55.9'W	1
13	70°44.8'N 150°28.1'W	19	24	70°33.2'N 149°11.2'W	17.5
14	70°41.5'N 150°27.2'W	15			

Attachment C Preliminary Observations of Near Bottom Currents on the Inner Shelf

The coastal oceanography and especially the coastal current of inner Beaufort Sea shelf are poorly known. In the Fall of 1975 the R/V KARLUK installed two current meter arrays in the Prudhoe Bay area (Figure C-1). One was placed in Egg Island channel and the other outside of Prudhoe Bay channel. These recorded for two months and were recovered in July, 1976. Both meters were damaged during the winter. The least damaged instrument was repaired and placed near the bottom off the delta of the Sagvaniriktok River (Figure C-1) in late July 1976 and recovered in September. Our aim during these studies was to determine near bottom current velocities and directions for estimating paths and rates of sediment transport, erosion and deposition. In particular we were interested in observing the effects of the ice cover on diminishing the effect of wind stress and concurrently increasing the tidal flow through restrictions created by ice growth.

The Aanderaa RCM-4 current meters used in this study recorded temperature and salinity in addition to current speed and direction. Data indicated that the speed sensor on the Egg Island meter was not functioning. Without this knowledge the meter was subsequently placed off the Sagvaniriktok Delta. Thus the speed data from this mooring must also be suspect although speed data was recorded. The speed sensor on the Prudhoe Bay meter operated for 20 days before being damaged and no further data were gathered. All other sensors appeared to function normally. Mooring particulars are given in Table C-1.

Egg Island Channel: (Instrument #1756-1)

Currents in the channel were consistently flowing out of the lagoon to the northwest throughout the period of record (Fig. C-2). Ice growth started shortly after the meter was moored and the record shows a continuous "draining" of the lagoonal waters along the bottom in response to ice growth.

Prudhoe Bay entrance: (Instrument #1757-1)

The progressive vector diagram for this mooring (Fig. C-3) covers essentially the same time period as that for Egg Island channel. Flow is aligned in the same dominant northwest-southeast direction, however there were several current reversals. The overall transport, as indicated by the brief record, is also to the northwest out of the bay. Although tidal components are present in the printout data, the circulation during freezeup at the mouth of the bay is dominated by other events of longer duration.

Table C-1

1756-1	Egg Island Entrance Channel 70°26.45'N; 148°46.40'W Water Depth 5 meters - meter 1 m off bottom Start 1958 Hr. local September 9, 1975 End 0512 Hr. local November 19, 1975 10 minute recording interval
1757-1	Northwest of Prudhoe Bay channel 70°23.73'N; 148°29.50'W Water Depth 3.2 meters - meter 1 m off bottom Start 1752 Hr. local September 9, 1975 End 0152 Hr. November 19, 1975 10 minute recording interval
1756-2	Northwest of Sgvaniriktok Delta 70°23.95'N; 148°01.40'W Water depth 5.5 meters - meter 1 m off bottom Start 1605 Hr. local July 31, 1976 End 1400 local September 22, 1976 10 minute recording interval

Sagvaniriktok Delta front: (Instrument #1756-2)

Currents appear to be dominated by easterly offshore movement and westerly alongshore drift (Fig. C-4). Just prior to mooring this meter, a Bendix-Q-15 deck readout current meter measured currents at 1.5 meters of 1.2 knots (60cm/s) at 085°T and at 0.5 meter off the bottom of 0.8 knots (40 cm/s) at 110°T. Initial records from the Aanderaa meter indicate currents of 25 cm/s at about 075°T. The velocities used for plotting the progressive vector diagram (Fig. C-4) were incorrectly computed, thus the horizontal and vertical scales are incorrect although the form of the diagram is correct.

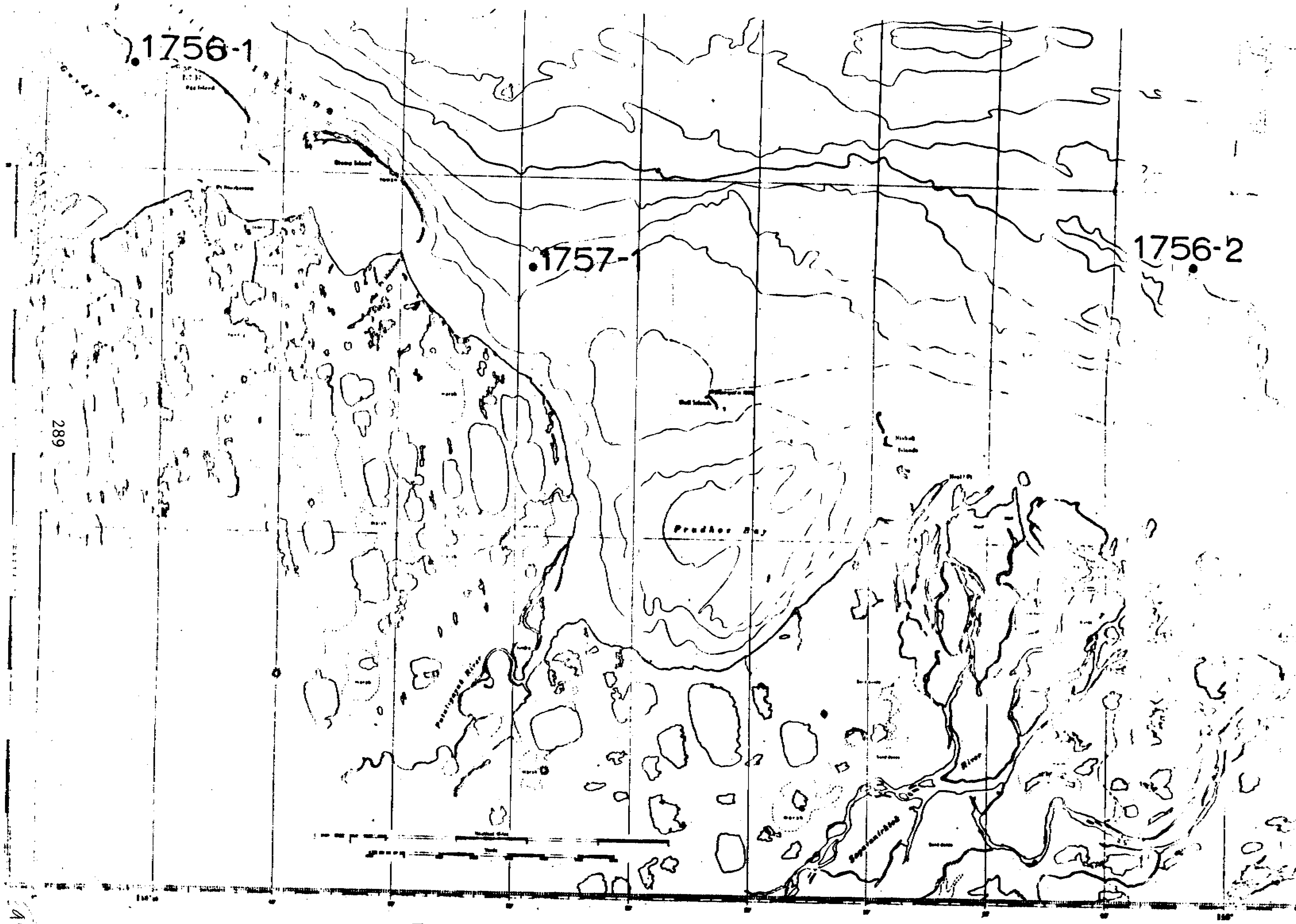


Fig. C-1

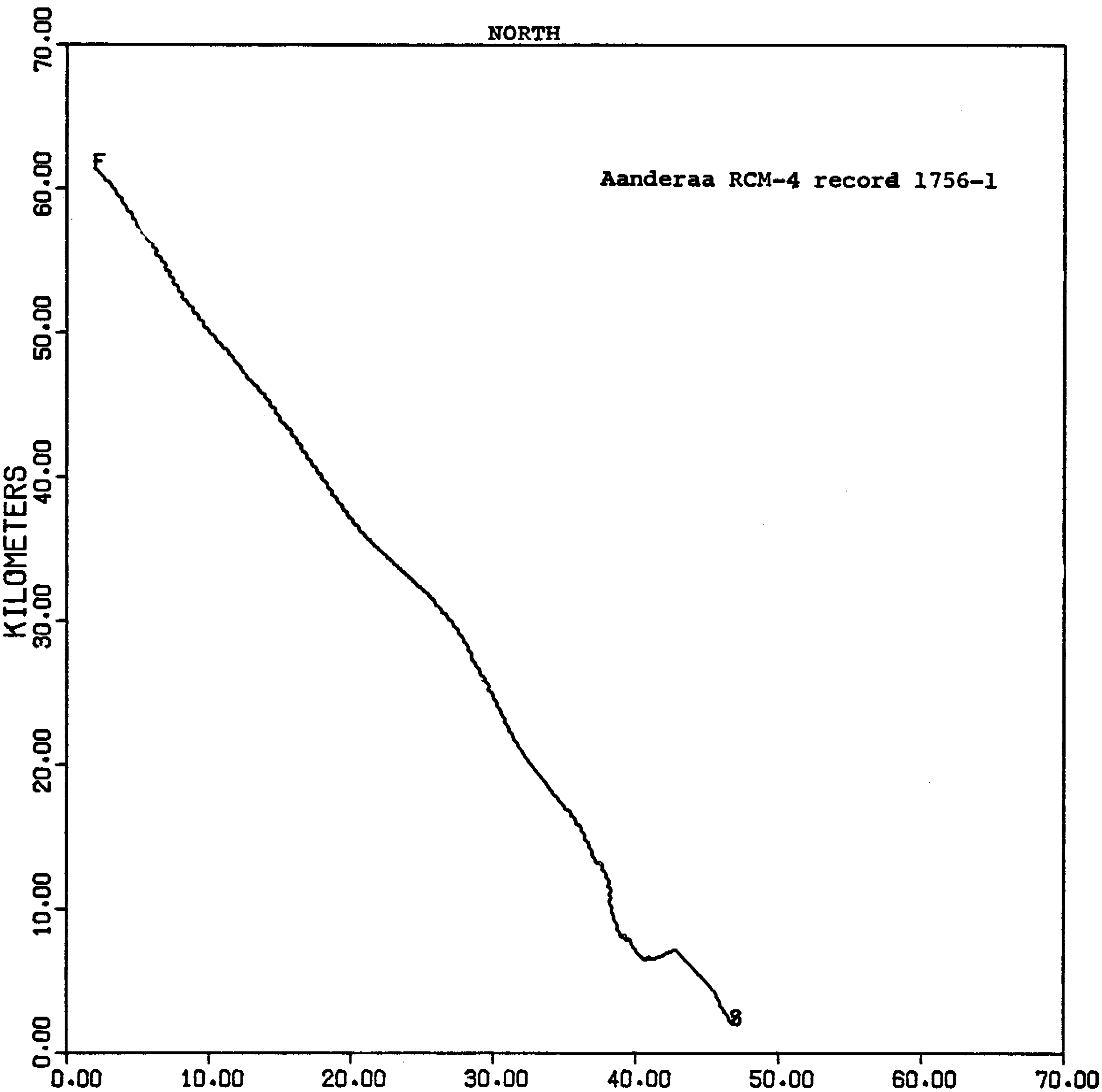


Figure C-2. Progressive vector diagram, Egg Island Channel Fall 1975

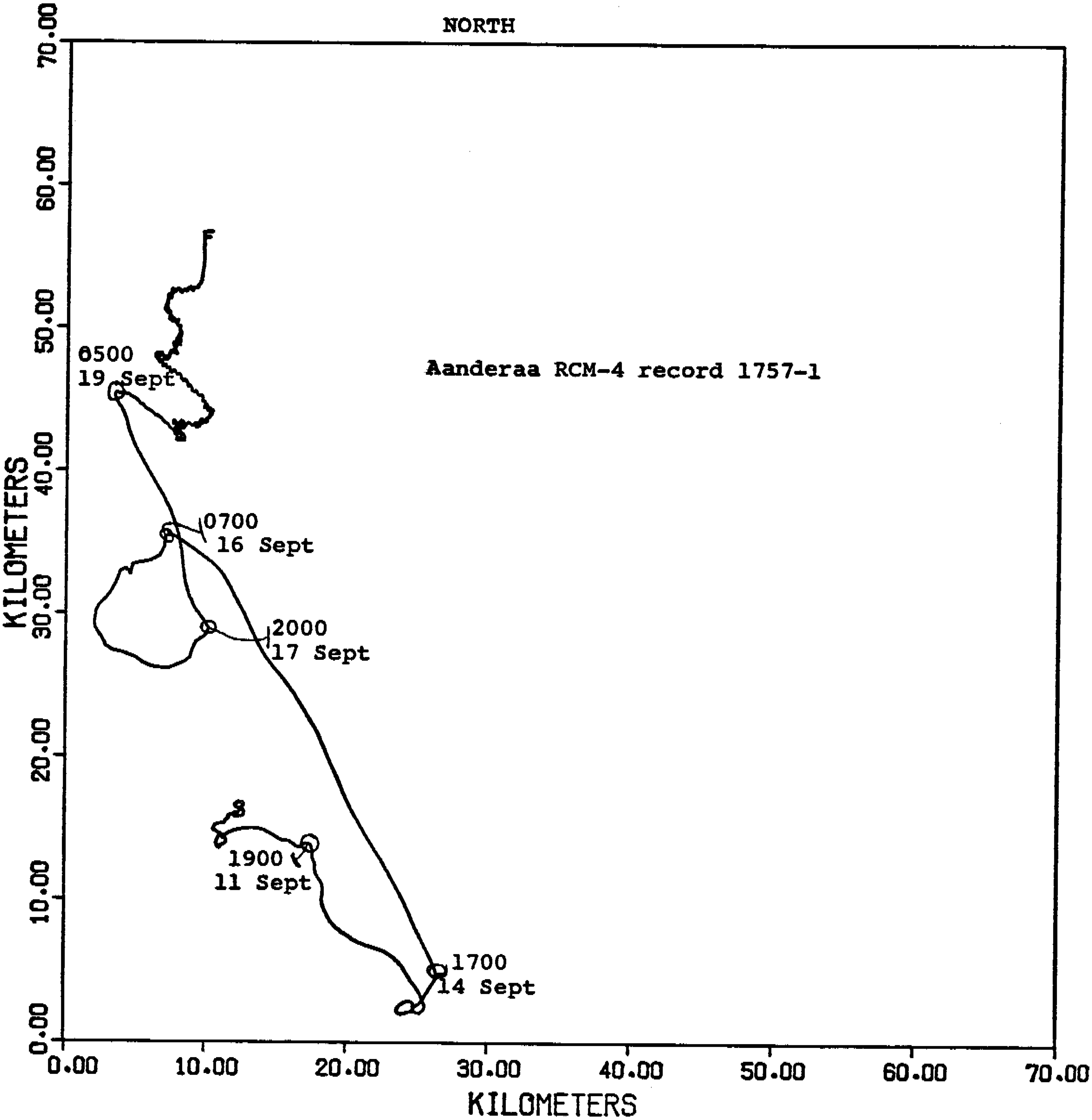
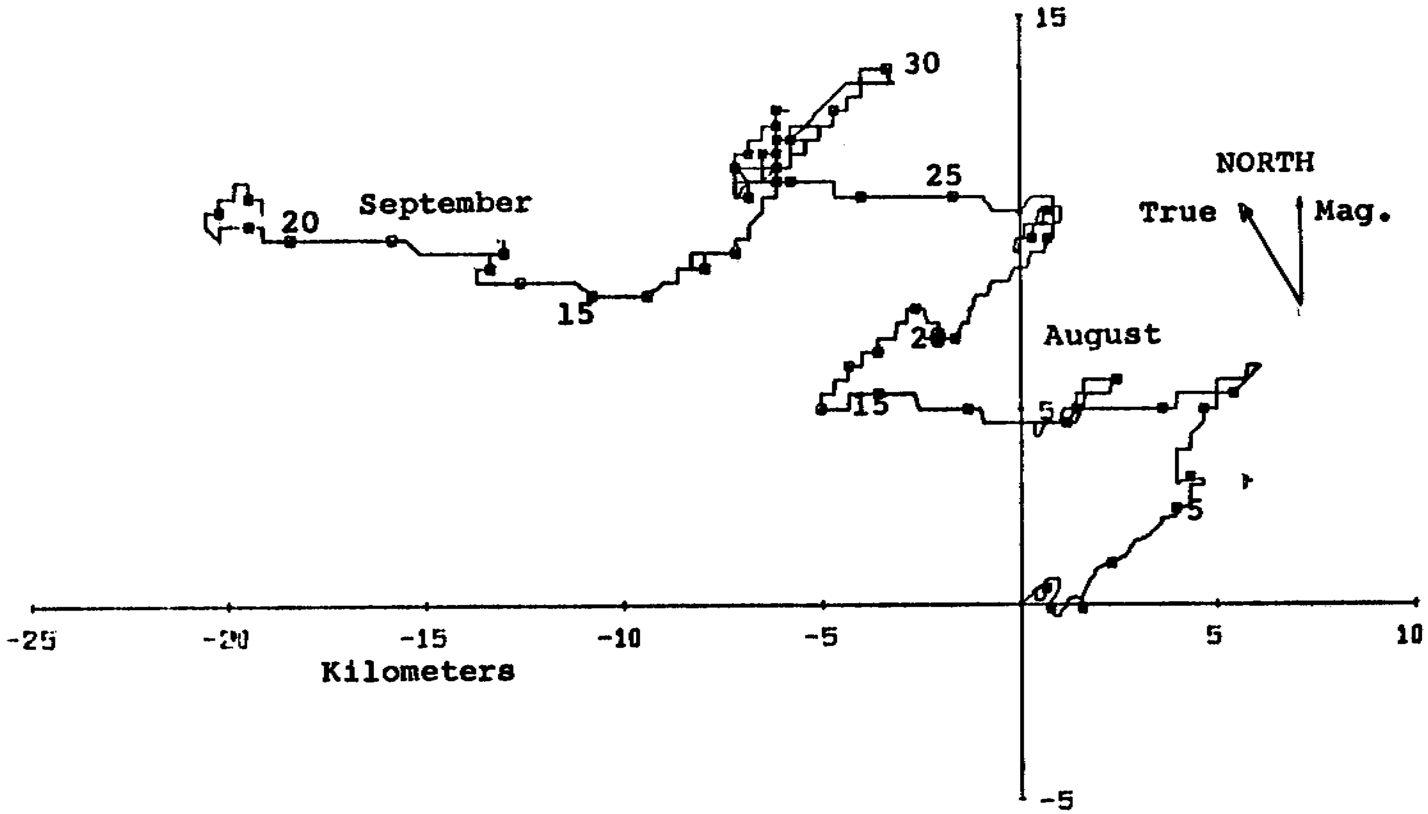


Figure C-3. Progressive vector diagram, Northwest of Prudhoe Bay. Fall, 1975. Water depth 3.2m.



HOURLY VALUES FROM 1756-2

Figure C-4. Progressive vector diagram, off Sagavanirktok River Delta, Summer, 1976. Note; vector lengths incorrect.

Attachment D Preliminary species list of shelled fauna - Chukchi Sea

Sediment samples collected in the Chukchi Sea by the U.S.Geological Survey on the 1974 curise of the U.S.C.G.C. Burton Island were examined for benthic faunal data. Purpose of the study is to describe the benthic shelled fauna of the eastern Chukchi Sea, to delineate the communities they form, and to examine environmental parameters that may control the distribution of the communities which could be preserved in the geologic record.

Faunal material was separated from the Van Veen grab samples, sorted into generic classifications, identified to species, and counted for each sample location. Identification was conducted using the available literature on Arctic benthos and by corresponding with benthic ecologists and taxonomic specialists. The counts were put on computer cards and will be run through a Q-mode factor analysis to determine communities. This will form the basis for a future report. 103 Van Veen grabs were examined and the following number of species were recognized; 45 Pelecypods, 32 Gastropods, 1 Brachiopod, 1 Foraminifera, 5 Echinoderms, and 1 Polychete. Table D-1 is a preliminary list of the species identified from the samples.

Table D-1

PELECYPODA

Astarte montagui

Astarte montagui var. striata

Astarte montagui var. warhami

Astarte borealis

Astarte bennettii

Asthenotharus adamsi

Axinopsida orbiculata

Clinocardium ciliatum

Clinocardium californiense

Cyclocardia crassidens

Cyclocardia crebicostata

Chalamys pseudoislandica

Hiatella artica

Liocyma fluctuosa

Lyonsia arenosa

Macoma calcarea

Macoma moesta

Macoma lipara

Macoma brota

Montacuta planata

Mya truncata

Mya elegans

Mya pseudoarenaria

PELEYCPODA cont.-

Mya japonica

Musculus corregatus

Musculus niger

Musculus discors

Musculus discors var, laevigatus

Leda radiata

Leda minuta

Leda perdula

Nucula tenuis

Panomya artica

Periploma sp.

Pandorella glacialis

Pseudopythina compressa

Serripes greenlandicus

Yoldia myalis

Yoldia scissuratus

Yoldia hyperborea

GASTROPODA

Acmaea testudinalis

Beringus beringi

Boreotrophon clathratus

Boreotrophon clathratus var. gunneri

Boreotrophon trunctus

GASTROPODA cont.-

Boreotrophon pacificas

Buccinum glaciale

Buccinum glaciale var. morchianum

Buccinum polare

Buccinum undulatum var. striatum

Buccinum tenue

Coralliophila sp.

Cylichna alba

Cylichna occulata

Crepidula grandis

Epitonium greenlandicum

Lepeta caeca

Margarites frigidus

Margarites costalis

Margaritopsis probiloffensis

Natica clausa

Neptunea middendorfana

Oenopota elegans

Oenopota tenuicostata

Piliscus commodus

Puncturella noachina

Plifuscus kroyeri

Ptychatractus occidentalis

Polinices palladus

Tachyrynchus erosus

Tachyrynchus reticulatum

POLYCHETE

Pectinaria granulata

And various worms and worm tubes.

FORAMINIFERA

Elphidium subiricum

BRACHIOPODA

Hemithiris psittacea

CRUSTACEANS

Balanus rostratus alaskensis

Balanus crenatus

ECHINODERMATA

Echinarachinus parma

Strongyocentrotus drobachiensis

Psolus phantopus

Psolus fabricii

Myrotrochus rinki

And various species of Astroidea and Ehinoidea

QUARTERLY REPORT

Contract: #RK 6-6074
Research Unit: 206
Reporting period: Sixth Quarter
Number of pages: 3

FAULTING AND SLOPE INSTABILITY IN THE SAINT GEORGE BASIN AREA, SOUTHERN BERING SEA

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October, 1976

QUARTERLY REPORT RU #206

I. Task Objectives

Research objectives are to outline and document problems related to seafloor instability of the St. George Basin and adjacent outer Beringian shelf, Southern Bering Sea.

II. Field and Laboratory Activities

We just completed 43 days of work at sea aboard the U.S.G.S. vessel R.V. SEA SOUNDER. Leg 1: Aug. 2 thru Aug. 20; Leg 2: Aug 22 thru Sept. 14. This cruise is designated S76-4.

The Scientific Party included:

T. Vallier, USGS Co-Chief Scientist
J. Gardner, USGS Co-Chief Scientist
A. Kaneps, Scripps Institution of Oceanography, Sedimentologist
W. Dean, U.S.G.S./Denver, Inorganic geochemist
B. Ruppel, USGS/Seattle, Geophysicist
K. Kvenvolden, USGS, Organic Geochemist
F. Cook, Univ. Calif. Santa Cruz, benthonic foraminifera
E. Stanley, Univ. Calif. Davis, Radiolaria
A. Budai, Calif. State Univ. Fresno, Sedimentologist
S. Johnson, Univ. Washington, Physical Science Technician (PST)
R. Garlow, USGS, Navigator
R. Brady, USGS, PST
D. Klise, USGS, PST
S. Davenport, Univ. Calif. Santa Crúz, PST
S. Lewis, Univ. Calif. Santa Cruz, PST
K. Glikman, Calif. State Univ. San Francisco, PST
G. Tanner, USGS, Electronics technician
H. Hill, USGS, Electronics technician
M. Underwood, USGS, PST
G. Redden, USGS, PST
J. Cudnohufsky, USGS, PST

The field methods used can be divided into two basic disciplines; geophysics and geology. Our geophysical methods include 3.5 KHz (3 kw source) 2.5 KHz (4-plate uniboom source), 60 to 125 HZ (60 KJ sparker source), gravity, magnetics, and side-scan sonar. Geologic data was collected using gravity and piston coring, Van Veen sampling, dredging, and 35 mm bottom photography. Additional data were taken by expendable bathythermographs and thermosalmograph.

Our navigation was by integrated Loran C and satellite which gave accuracies typically better than ± 200 m.

Tracklines and sampling stations are shown on figures 1 & 2. The types and amounts of data collected on S76-4 are outlined in Table 1.

TABLE 1

DATA COLLECTED ON CRUISE S76-4

3.5 KHz	4388 nautical miles (n.m.)
2.5 KHz	3161 n.m.
60-125 Hz	3661 n.m.
Gravity	4388 n.m.
Magnetics	2509 n.m.
Side-scan sonar	82 n.m.
Gravity cores	96
Piston cores	8
Piston core trigger weights	3
Van Veen samples	27
Expendable bathythermographs	67
Bottom camera stations	3
Thermosalinograph	3500 n.m.
Number of Stations	85

III. Results

Our data is just arriving at the writing of this report; consequently, no analyses have yet been performed.

IV. Preliminary interpretation of results not applicable at this time.

V. We encountered no problems in the field.

VI. Estimate of funds expended : All funds expended.

QUARTERLY REPORT

Contract:	RK 6-6074
Research Unit:	206
Reporting Period:	10/1/76-12/31/76
Number of Pages:	1

FAULTING AND SLOPE INSTABILITY IN THE SAINT GEORGE BASIN AREA, SOUTHERN BERING SEA

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Menlo Park, California 94025

January, 1977

QUARTERLY REPORT RU #206

I. Task Objectives

Research objectives are to outline and document problems related to sea floor instability of the St. George Basin area and adjacent outer continental shelf and upper continental slope of the southern Bering Sea.

II. Field and Laboratory Activities

A. Ship or Field Trip Schedule: None

B. Scientific Party: None

C. Methods: We currently are analyzing geophysical records to determine areas of faulting and slope instability and are processing sediments for grain size analyses.

D. Sample Localities: Please refer to our quarterly report of October, 1976.

E. Data Collected or Analyzed: Please refer to our quarterly report of October, 1976 for miles of trackline. We have nearly completed the laboratory work of processing 200 sediment samples for grain size analyses (sieving, settling tube, and hydrophotometer methods). We also have studied about 2500 nautical miles of 3.5 KHz, and 60 to 125 Hz records.

F. Milestone Chart: Map of faulting and slumps should be available by April 1, 1977. Map of grain size distribution should be available by June 1, 1977.

II. Results

Data are currently being analyzed and a full discussion of results is premature.

IV. Preliminary Interpretation of Results

These are numerous small scale (1 - 2 m offset) subsurface faults and a small number of faults that show surface (~1 m) offsets. Faults seem to be distributed about evenly over the St. George Basin. Because of the small scale offsets of most faults and the approximately 50 km line spacing, we are unable to map the continuations of the faults with confidence or to match the faults between tracklines.

V. Problems Encountered

None.

VI. Estimate of Funds Expended

During this quarter, only U.S.G.S. funds were expended; no BLM/NOAA funds have yet been received.

4th Quarter Report

1 April - 30 June 1976

TITLE: Earthquake Activity and Ground Shaking in and along the Eastern Gulf of Alaska

RESEARCH UNIT: 210

PRINCIPAL INVESTIGATORS: John C. Lahr
Robert A. Page

I. Objectives

A. Basic Objective

The objective of this research is to evaluate the hazards associated with earthquake activity in the Gulf of Alaska and adjacent onshore areas that pose a threat to the safety of petroleum exploration and development.

B. Field Objectives

The primary objective of the 1976 field operations is to improve the reliability and performance of the network stations in the Gulf of Alaska vicinity. Again, as happened during the 1974-75 winter, most of the stations in the area were rendered useless due to damage from wind, ice, and snow burial during the 1975-76 winter. This situation was expected after the extensive damage we encountered during the 1975 field season. In 1975 we were not prepared to make major modifications, so our efforts were limited to repairing the stations without necessarily strengthening them against the hostile environment. According to the National Weather Service (NWS) a record snowfall of 34 feet was observed at the Yakutat station for the 1975-76 season. Heavy snows fell all along the coast last winter and during a reconnaissance trip in late March 1976 it was observed that most of the stations were buried in snow at least to the top of the antennas (~9 ft).

A second objective of this year's field activities is to modify the station distribution in order to have better azimuthal coverage of sites of relatively high microearthquake activity around Icy Bay.

II. Field and Laboratory Activities

A. Field Trip Schedule

The 1976 field season schedule is based on the availability of a

USGS contract helicopter used jointly by the Branch of Alaskan Geology, the Branch of Environmental Geology and us. In order to accomodate a previously determined ship schedule, we were allocated two blocks of helicopter time before and after shipboard operations. The first interval scheduled was from 20 May to 2 June and the second was from 21 July to 9 August. A last minute delay in the availability of the contract helicopter necessitated the use of a charter helicopter for 10 days before the contract aircraft was available on 30 May.

The basic plan which was followed this season was to begin field work in the Yakutat area and progress westward as station repair and maintenance was accomplished. Three bases of operation were used: Yakutat, the Gulf Timer Company lumber camp at Icy Bay, and Cordova. Weather conditions and station accessibility (primarily whether or not a station was completely buried by snow during the May service period) required a rather flexible schedule. Those stations which were not completely serviced during the May period will be finished in August.

Ten days before helicopter operations were scheduled to begin personnel from California went to Anchorage to pack various tools and equipment stored there and to ship the material to Yakutat. During July western stations in the USGS network will be serviced and recording equipment located at Palmer, Alaska will be serviced.

B. Field Party

John Lahr, Geophysicist, Project Chief, 19 May - 5 June

Michael Blackford, Geophysicist, 11 May - 5 June

Clearthur Lee, Electronics Technician, 17 May - 3 July

Eric Fuglestad, Geological Field Assistant, 14 May - 30 June

Richard Brown, Electronics Technician, 20 May - 25 May

Eric Fuglestad and Richard Brown are both USGS employees stationed in Anchorage. Eric is available for summer field work and occasionally during the remainder of the year since he is a student. Richard Brown, who works for the USGS Water Resources Division, spent a week at Yakutat in order to familiarize himself with our electronic equipment. We may call on him to make emergency repairs to vital, accessible network components during the winter months.

C. Data Processing

The present processing stream is initiated by scanning 16 mm multi-channel films which contain records of seismic signals from a suite of stations in the study area. Earthquakes which are recorded by eastern Gulf of Alaska stations are found by this process and are noted to be timed on a scan form for each day. Using the scan form as a guide, up to four 16 mm films per earthquake are processed manually by the operator of a combination projector and X-Y digitizer. Output from the digitizer in the form of punched cards contains relative arrival times observed for the various traces on the films as well as sufficient data, punched by the operator, to identify the channels, to relate the timing picks to universal time, to determine the magnitude, and to indicate the quality of the timing picks. These cards are then processed by a computer program which generates the actual phase data which is then used in the hypocenter location program.

III. Results

Maps and tabulations of earthquakes located in July 1975 through June 1976 will be included with the 5th Quarter Report.

5th Quarter Report

1 July - 30 September 1976

TITLE: Earthquake Activity and Ground Shaking in and along the Eastern Gulf of Alaska

RESEARCH UNIT: 210

PRINCIPAL INVESTIGATORS: John C. Lahr

Robert A. Page

I. Objectives

The objective of this research is to evaluate the hazards associated with earthquake activity in the Gulf of Alaska and adjacent onshore areas that pose a threat to the safety of petroleum exploration and development.

II. Field and Laboratory Activities

A. Seismic Network Changes

Figure 1 summarizes changes made to that portion of the USGS network funded by OCSEP in the Gulf of Alaska vicinity during the 1976 field season. The changes are tabulated below.

STATION	ACTION
Peninsula (PNL)	Horizontal seismometers installed
Nunatak (NTK)	Removed
Disenchantment Bay (DSB)	Removed; moved to Bancas Point
Bancas Point (BCS)	Installed
Guyot (GYO)	Installed
Riou (RIU)	Installed
Yakataga (YKG)	Reactivated
Martin River (MRN)	Closed
Goodwin (GWN)	Removed; moved to Sherman Glacier
Sherman Glacier (SGA)	Installed
Sunshine Point (SSP)	Horizontal seismometers removed

Note that two additional stations were installed near Icy Bay in order to improve coverage in this area which has been the source of many earthquakes over the past year.

B. Field Party

Michael Blackford, Geophysicist, 26 July - 26 August

Clearthur Lee, Electronics Technician, 29 July - 10 September

Eric Fuglestad, Geological Field Assistant, 1 July - 15 September

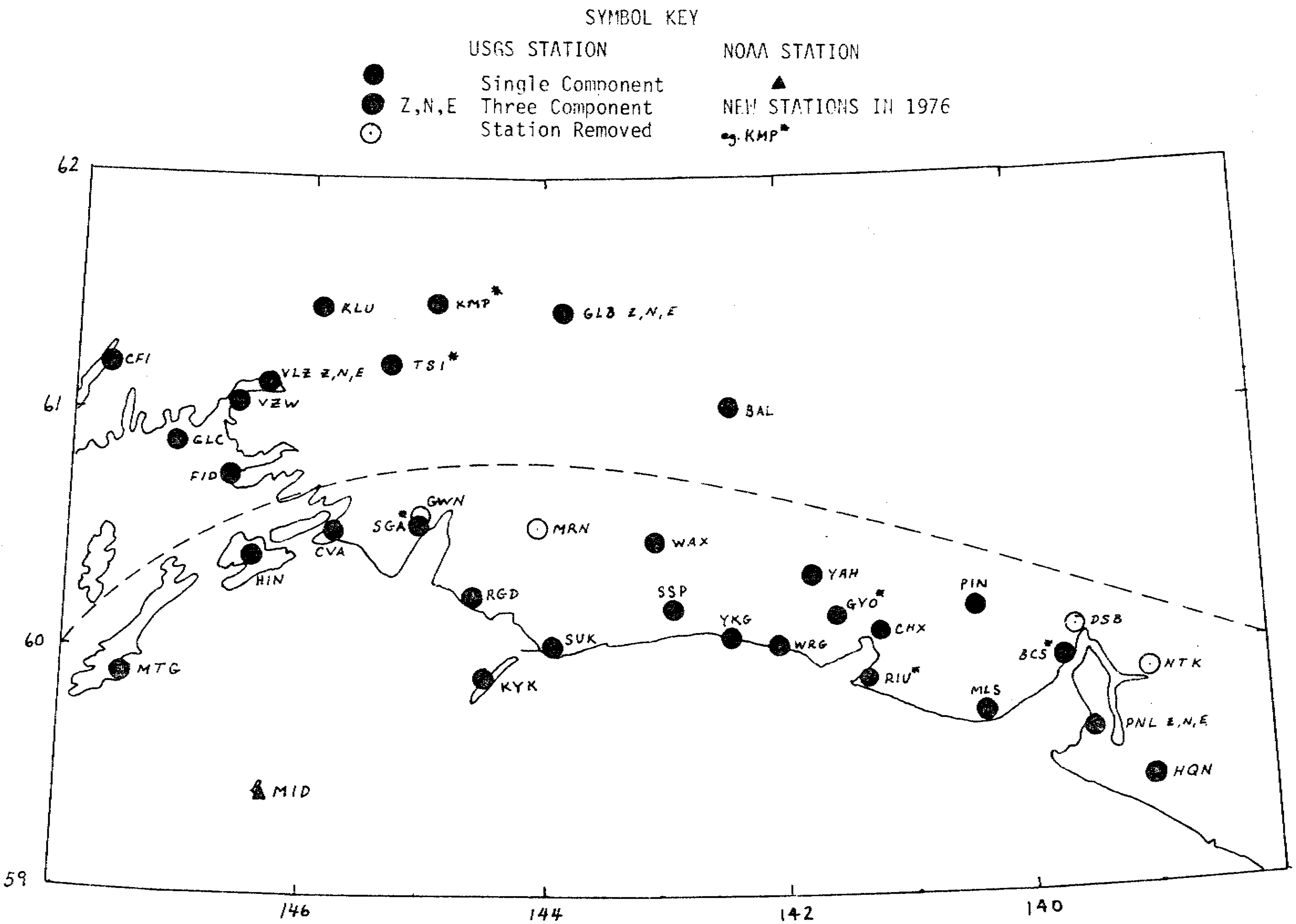


Figure 1. Seismic stations located in the Eastern Gulf of Alaska region. Stations south of the dashed line are supported by OCSEP.

C. Notes on station maintenance

A major weak point in the typical seismic station set-up observed during the 1975 field season was the antenna system. When stations were installed in 1974 along the Gulf of Alaska coast, construction methods were used that had proven to be quite durable in the Cook Inlet vicinity. The marked differences in the amount and density of the snow as well as other climatic factors were underestimated. Antennas and masts were severely bent and there was ample evidence that the antenna systems had been subjected to very large vertical stresses. Eighth-inch thick steel guy rings were folded over their support bolts on the masts. In some instances the mast had been driven into the ground several inches after the 1/4-inch bolt which attached it to a base plate had sheared.

The preferred solution to this problem which was implemented where ever possible was to raise the antenna above the level of the accumulating snow. At 6 stations, BCS, MLS, RIU, WRG, SSP, and SGA, antennas are attached to masts which are strapped to trees with stainless steel bands at least 15 feet above the ground. At those stations along the coast where antenna systems have collapsed during the previous winters and where trees were not available, the 1 1/4 inch diameter thin-wall steel masts (electrical conduit) were replaced with 2 inch diameter thick-wall steel masts (water pipe). On the new masts antennas are now higher than before.

At several stations where icing is believed to be a problem, Yagi antennas were replaced with log-periodic antennas. Yagi antennas are severely detuned when the air dielectric between the elements is replaced by ice.

Another serious problem with the existing seismic stations has been the stability of the center frequency of the voltage-controlled oscillators (VCOs). The VCOs were replaced at all stations with units that had undergone a temperature stability test. VCO center frequency instability still remains a serious problem, however, and the seismic amplifier/VCO electronics will be replaced next year with units that have automatic gain-range amplifiers, amplifier calibrators, and crystal-stabilized VCOs.

The mercury power cells, which have been used in the past, were replaced with lithium cells which provide greater voltage stability with respect to temperature than do the mercury cells. The lithium cells apparently do require some initial aging because VCOs installed in May were off several 10's of cycles in August and had to be adjusted.

In addition to modifications of the seismic stations, changes in the methods of transmitting data to communication sites were also made. Some of these changes have been necessary because over the last few years RCA Alascom has been phasing out the older troposcatter communication system with a satellite system. This year satellite earth stations went into operation at Cordova and Yakutat. The troposcatter station at Yakutat was closed and the stations at Cape Yakataga and Boswell Bay were reduced to two-man sites. Unless there is significant development along the Gulf of Alaska coast the stations may be reduced to unmanned status and then be serviced out of Cordova. The closure of the Yakutat troposcatter station made it necessary to relocate our receivers at a site near the new satellite station. Through an agreement with the Federal Aviation Administration (FAA) we have moved our receivers to an FAA facility about 1/4 mile from the satellite station.

We installed 3 broadband antennas near the top of a 195 foot tall tower and placed the receivers in an existing waterproof housing near the base of the tower. The signals from the six receivers are multiplexed at the FAA facility and transmitted via VHF radio to the satellite station.

The number of stations being relayed through the Ragged Mountain (RGD) station has been reduced from 5 to 2. RGD has proven to be a troublesome station that is difficult to maintain, even in the summer, because of persistent fog or low ceilings which make access limited at best. Kayak Island (KYK) station is now received at Boswell Bay directly. Goodwin (GWN) was removed and replaced by Sherman Glacier (SGA) which transmits to Boswell Bay. Martin River (MRN) was closed. RGD now repeats only Waxell Ridge (WAX) and Suckling Hills (SUK).

In anticipation of the reversion of the RCA communication sites at Boswell Bay and Cape Yakataga to unmanned status, waterproof housings for our receiving equipment were fabricated. One of the housings was installed at Boswell Bay but the other housing was stored in Anchorage when it was determined that these communication sites would remain manned for another year. These housings will enable us to locate our equipment in a place that is accessible without having to arrange for the RCA technician to come along also. This will allow us greater flexibility and presumably greater speed in correcting receiver problems at these sites when they become unmanned.

III. Results

Maps and tabulations of preliminary earthquake locations along the Eastern Gulf of Alaska for July 1975 through June 1976 are in the Appendix.

IV. Milestone Chart and Data Submission Schedules

The following milestone summary reflects updates to information contained in the Annual Report for 1 July 1975 to 31 March 1976, dated 12 April 1976, as well as information contained in the Technical Proposal for the period 1 October 1976 through 30 September 1977:

April - September, 1976 (refer to Annual Report: IX., A, 3 and 4; and C, 2 and 3)

The milestones referred to were essentially accomplished with slight adjustments in the dates indicated. Only 3 stations were installed in the vicinity of Icy Bay instead of 4 when it was determined in the field that no site on the west side of Icy Bay could both transmit to Cape Yakataga and act as a repeater for GYO and RIU as well as the existing station WRG. WRG which was scheduled to be removed was repaired instead and made the repeater for GYO and RIU.

October 1976 - September 1977 (refer to Technical Proposal: XVI)

Since this text comprises the 5th Quarterly Report the completion date has slipped. Calibration of a local magnitude scale has been tied to the successful operation of the 1 inch tape recorder since both our data and the calibrated data of the NWS Palmer Observatory are now available on the tape. Processing of all data in the same manner should allow for a direct comparison of the Palmer data, as a standard, to our data. The first tapes sent to us from Palmer were not usable for the magnitude calibration because of gross irregularities in the tape recorder system. A revised milestone chart follows:

Milestone	Comp. Date
Complete lab tests of new amp./VCO	Nov., 1976
Order OBS system components	Dec., 1976
6th Quarter Report, October - December 1976	Jan., 1977

Order new amp./VCO components	Jan., 1977
Laboratory tests of OBS system	Jan., 1977
Automate data scan process	Feb., 1977
Meet with Kienle/Pulpan and Davies to discuss annual report	Feb., 1977
Test OBS system in Santa Barbara Channel	Mar., 1977
Calibration of a local magnitude scale	Apr., 1977
Annual Report, April 1976 - March 1977	Apr., 1977
Complete plans for field season	Apr., 1977
Field Program in Alaska	June - Sept., 1977
Deploy OBS systems	June, 1977
8th Quater Report, April - June 1977	July, 1977
Service and repair seismic stations	July - Aug., 1977
Remove OBS systems	Aug. - Sept., 1977
9th Quarter Report July - Sept. 1977	Oct., 1977

Appendix

Preliminary earthquake locations along the Eastern Gulf of Alaska for the period July 1975 through June 1976

This appendix lists origin times, focal coordinates, magnitudes, and related parameters for earthquakes which occurred in the eastern Gulf of Alaska region. The following data are given for each event:

(1) Origin time in Greenwich Civil Time (GCT): date, hour (HR), minute (MN), and second (SEC). To convert to Alaska Standard Time (AST) subtract ten hours.

(2) Epicenter in degrees and minutes of north latitude (LAT N) and west longitude (LONG W).

(3) DEPTH, depth of focus in kilometers.

(4) MAG, magnitude of the earthquake.

(5) NP, number of P arrivals used in locating earthquake.

(6) NS, number of S arrivals used in locating earthquake.

(7) GAP, largest azimuthal separation in degrees between stations.

(8) D3, epicentral distance in kilometers to the third closest station to the epicenter.

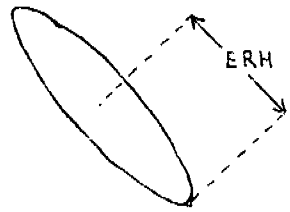
(9) RMS, root-mean-square error in seconds of the traveltime residuals:

$$RMS = \sqrt{\sum_i (R^2_{Pi} + R^2_{Si}) / (NP + NS)}$$

where R_{Pi} and R_{Si} are the observed minus the computed arrival times of P and S waves respectively at the i-th station.

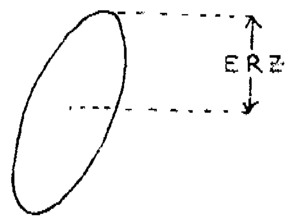
(10) ERH, largest horizontal deviation in kilometers from the hypocenter within the one-standard-deviation confidence ellipsoid. This quantity is a measure of the epicentral precision for an event. An upper limit of 99 km is placed on ERH.

Projection of ellipsoid
onto horizontal plane:



(11) ERZ largest vertical deviation in kilometers from the hypocenter within the one-standard-deviation confidence ellipsoid. This quantity is a measure of the depth precision for an event. An upper limit of 99 km is placed on ERZ.

Projection of ellipsoid
onto vertical plane:



(12) Q, quality of the hypocenter. This index is a measure of the precision of the hypocenter and is calculated from ERH and ERZ as follows:

Q	ERH	ERZ
A	$\leq$ 2.5	$\leq$ 2.5
B	$\leq$ 5.0	$\leq$ 5.0
C	$\leq$ 10.0	$\leq$ 10.0
D	$\geq$ 10.0	$\geq$ 10.0

This quality symbol is used to denote each earthquake on epicenter maps.

All earthquakes were located using the following horizontally layered velocity model:

Layer	Depth to Top (km)	P velocity (km/sec)
1	0.	6.0
2	20.	7.0
3	32	8.2

This model was selected ad hoc and is considered a reasonable model but not necessarily the optimum model for this region. Further modifications and refinements to the model will undoubtedly take place in the future as more data are gathered.

Whenever possible S-phase arrivals are used in addition to P-phase arrivals. The S-phase velocity is assumed to equal (P-velocity)/1.78 in each layer of the velocity model.

Magnitudes are determined from the signal duration or the maximum trace amplitude, or from both parameters. Eaton and others (1970) approximate the Richter local magnitude, whose definition is tied to maximum trace amplitudes recorded on standard horizontal Wood-Anderson torsion seismographs, by an amplitude magnitude based on maximum trace amplitudes recorded on high-gain, high-frequency vertical seismographs such as those operated in the Alaskan network. The amplitude magnitude XMAG used in this catalog is based on the work of Eaton and his co-workers and is given by the expression (Lee and Lahr, 1972)

$$XMAG = \log_{10} A - B_1 + B_2 \log_{10} D^2 \qquad (1)$$

where A is the equivalent maximum trace amplitude in millimeters on a standard Wood-Anderson seismograph, D is the hypocentral distance in kilometers, and B_1 and B_2 are constants. Differences in the frequency response of the two seismograph systems are accounted for in calculating A; however, it is assumed that there is no systematic difference between the maximum horizontal ground motion and the maximum vertical motion. The terms $-B_1 + B_2 \log_{10} D^2$ approximate Richter's $-\log_{10} A_0$ function (Richter, 1958, p. 342), which expresses the trace amplitude for a zero-magnitude as a function of epicentral distance. For small local earthquakes in central California, $B_1 = 0.15$ and $B_2 = 0.80$ for $\Delta = 1$ to 200 km and $B_1 = 3.38$ and $B_2 = 1.50$ for $\Delta =$ 200 to 600 km.

For small, shallow earthquakes in central California, Lee and others (1972) express the duration magnitude FMAG at a given station by the relation

$$\mathrm{FMAG} = -0.87 + 2.00 \log_{10} \tau + 0.0035\,\Delta \qquad (2)$$

where τ is the signal duration in seconds from the P-wave onset to the point where the peak-to-peak trace amplitude on the Geotech Model 6585 film viewer falls below 1 cm,and Δ is the epicentral distance in kilometers.

Comparison of XMAG and FMAG estimates from equations (1) and (2) for 77 Alaskan shocks in the depth range 0 to 150 km and in the magnitude range 1.5 to 3.5 reveals a systematic linear decrease of FMAG relative to XMAG with increasing focal depth. To remove this discrepancy, a linear dependence on depth is added to the expression for FMAG as follows:

$$\mathrm{FMAG} = -1\ 1.15 + 2.0 \log_{10} \tau + 0.007z + 0.0035\Delta \qquad (3)$$

where z is the focal depth in kilometers. Incorporating the depth term in the calculation of FMAG, the average and standard deviations between XMAG and FMAG for the 77 events are 0.02 and 0.29 respectively.

The magnitude assigned to each earthquake in this catalog is the mean of the average XMAG and FMAG (equation 3) estimates obtained for USGS stations. For shocks larger than about magnitude 3.0, XMAG cannot be determined because the maximum trace amplitudes are off-scale or the traces are too faint to read. For many shocks smaller than about magnitude 2.0, the trace amplitude drops below 1 cm peak-to-peak between the P and S arrivals and FMAG is not determined.

Many of the earthquakes recorded by the stations occur outside of the network, so it is difficult to establish good depth control for these events. The procedure for locating these earthquakes is to first fix the depth and determine the optimal epicentral location, and then allow the depth to vary. Frequently, little or no improvement to the solution is found when the depth is allowed to vary. The result is that the depths of the final hypocentral solutions are biased toward the initial trial depth, which may not reflect the true depth of the earthquakes. The trial depth used for the earthquakes occurring in the third and fourth quarters of 1975 was 10 km, but for the first and second quarters of 1976 it was changed to 15 km.

References

Eaton, J. P., M. E. O'Neill, and J. N. Murdock (1970). Aftershocks of the 1966 Parkfield-Cholame, California, earthquake: a detailed study, Bull. Seism. Soc. Am. 60, 1151-1197.

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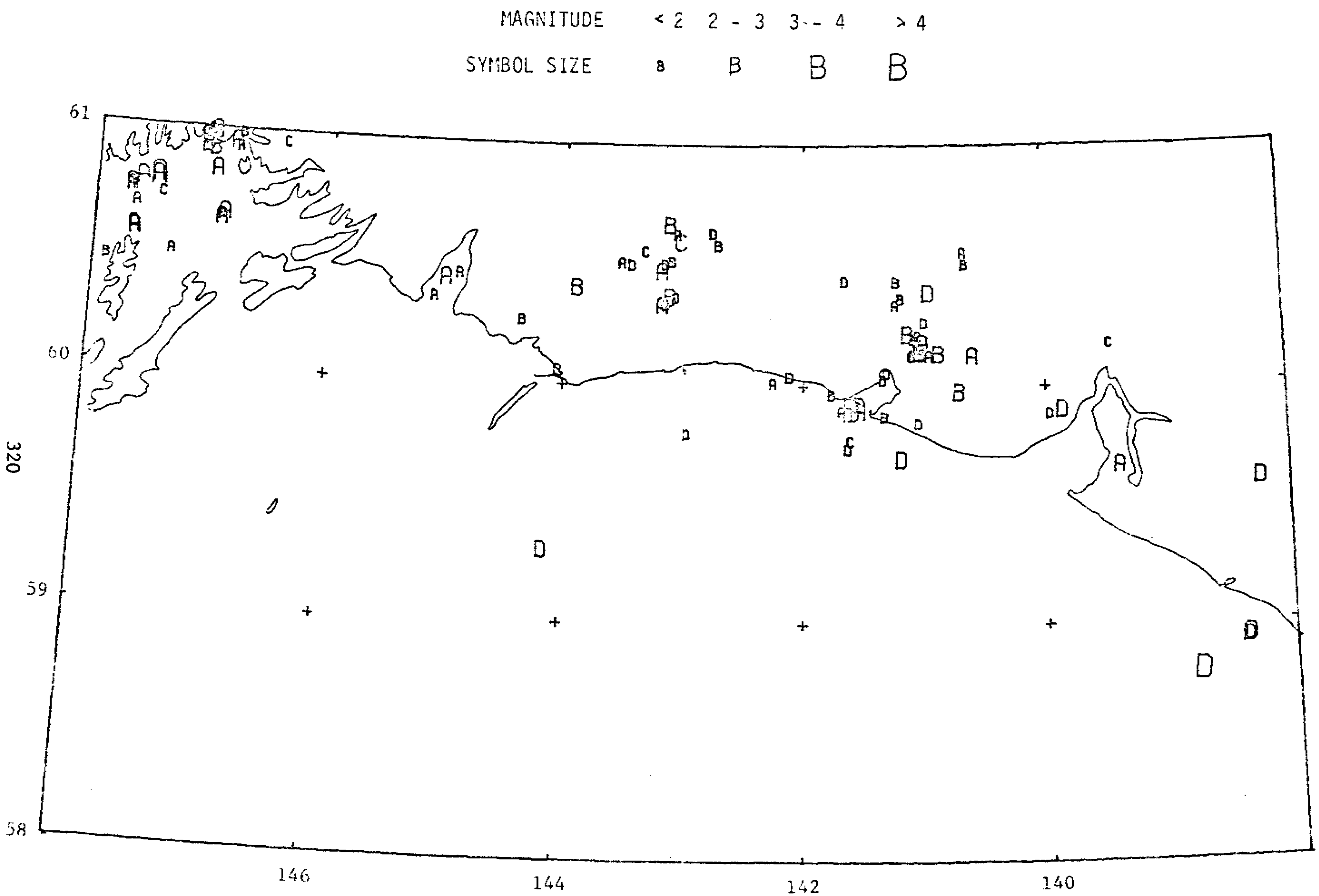
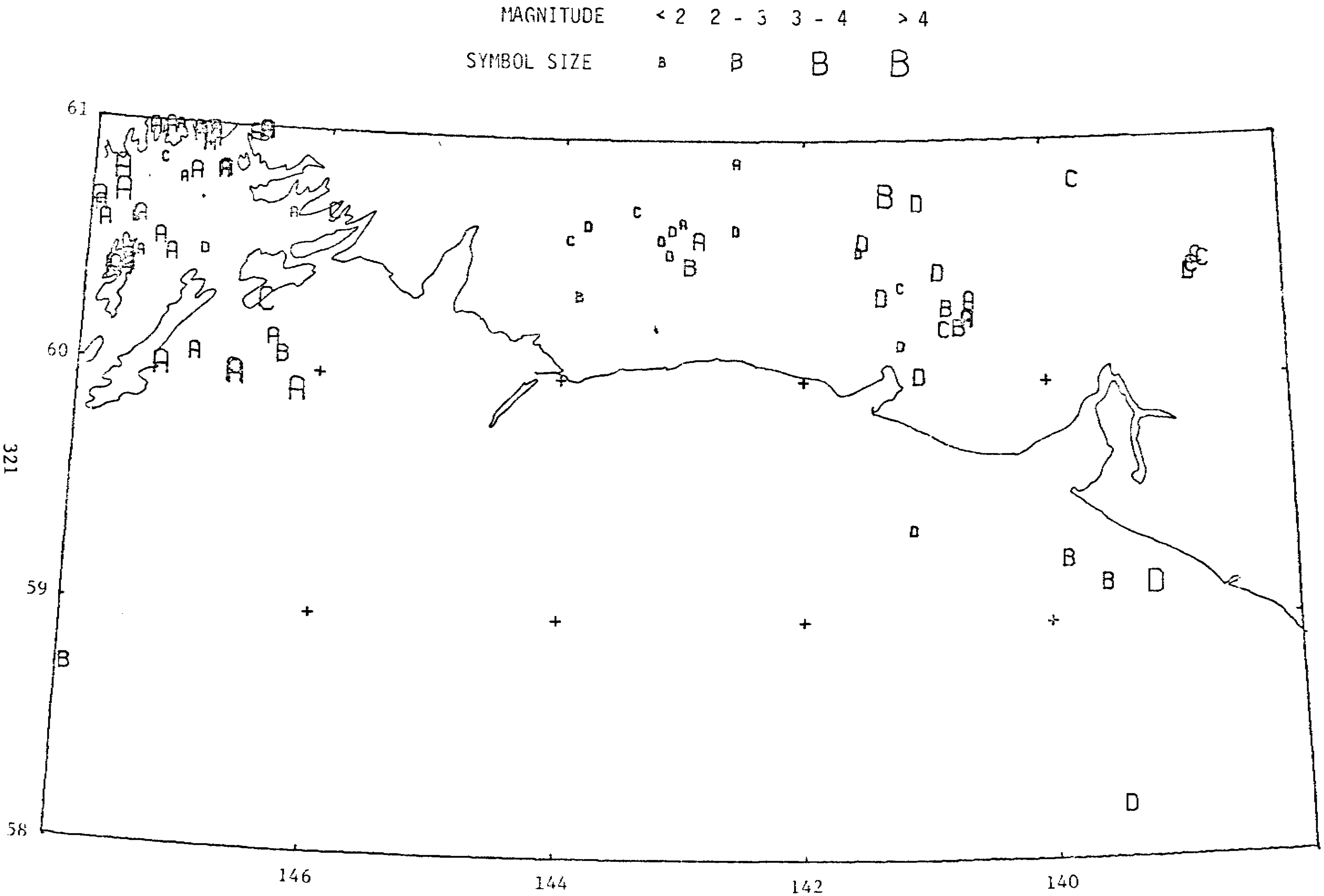


EASTERN GULF OF ALASKA SEISMICITY

3rd QUARTER 1975

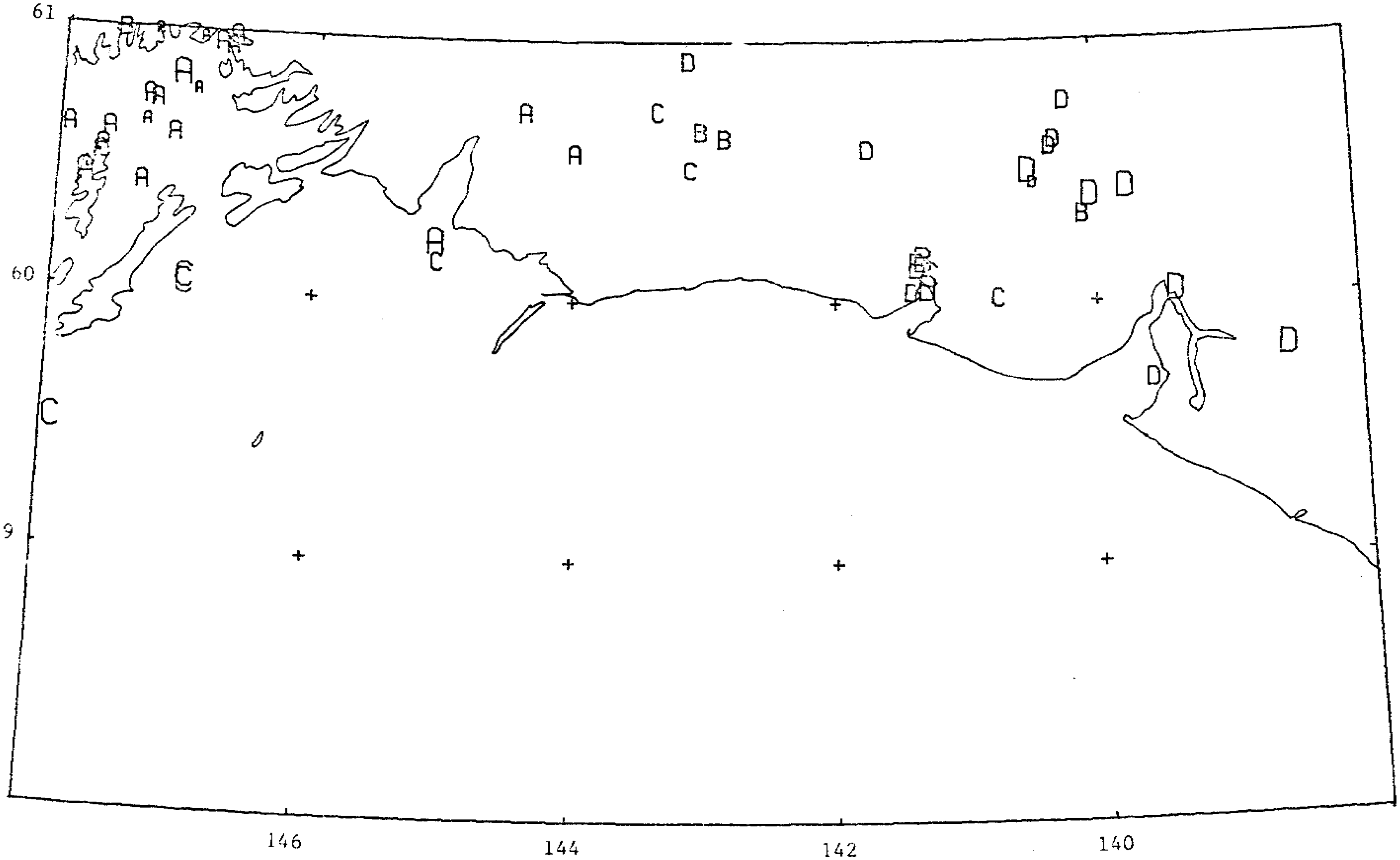


EASTERN GULF OF ALASKA SEISMICITY

4th QUARTER 1975

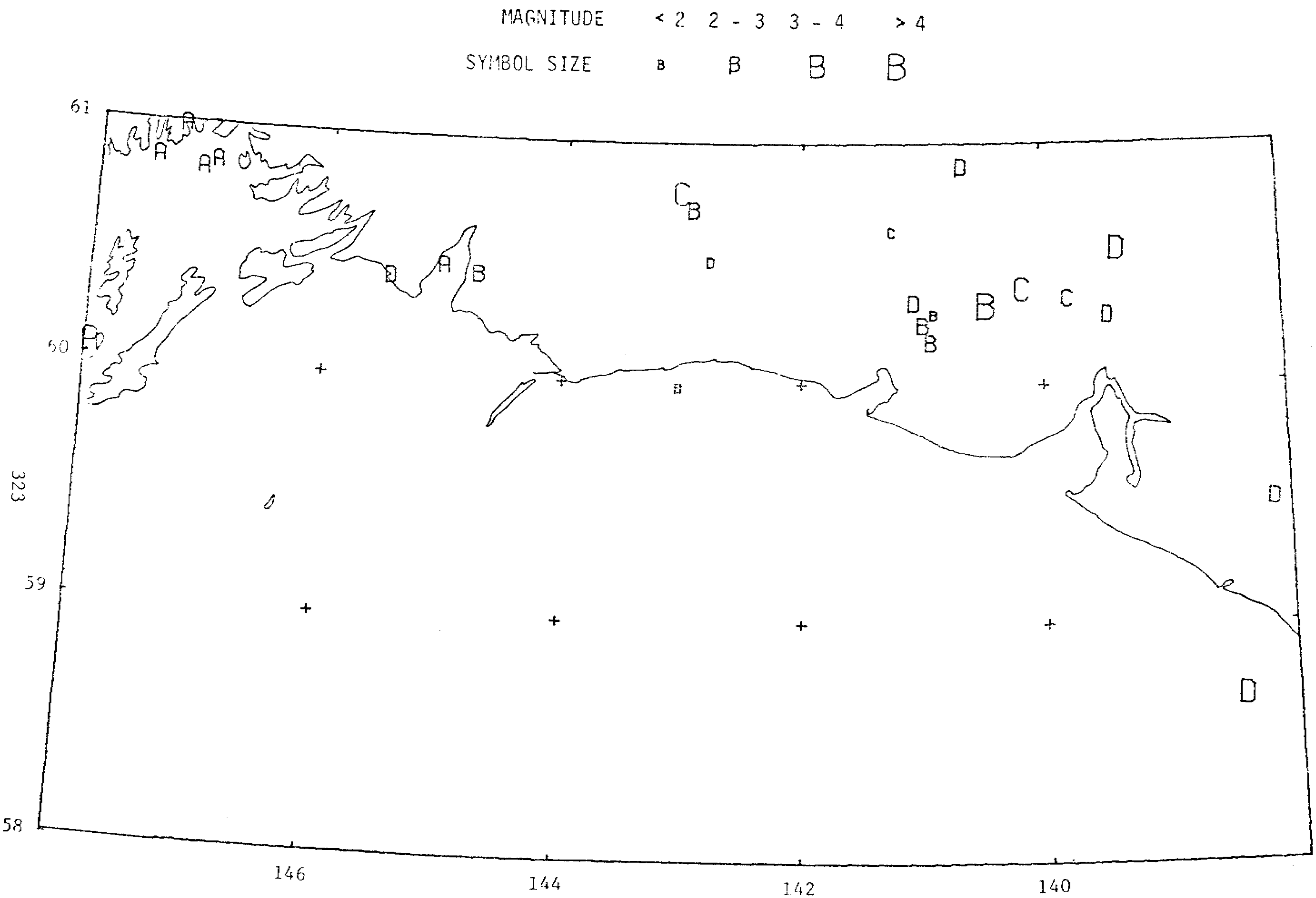
MAGNITUDE <2 2 - 3 3 - 4 >4

SYMBOL SIZE B B B B



EASTERN GULF OF ALASKA SEISMICITY

1st QUARTER 1976



EASTERN GULF OF ALASKA SEISMICITY

2nd QUARTER 1976

EASTERN GULF OF ALASKA EARTHQUAKES

1975	ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
JUL 3	10	30	5.6	59	50.5	141	2.8	10.0	1.5	3	3	225	95	.52	15.5	25.3	D
3	16	53	12.2	60	12.2	141	3.2	8.8	1.8	5	2	160	110	.12	5.1	3.7	C
3	17	6	2.7	60	11.6	141	4.3	9.1	.9	3	1	185	111	.12	23.9	22.5	D
3	17	9	22.2	60	11.6	141	5.2	10.0	1.1	3	1	184	111	.09	39.3	33.5	D
5	18	26	26.7	61	39.2	146	35.0	20.6	2.2	14	7	86	44	.56	1.3	2.6	B
6	10	1	23.3	59	35.6	138	14.0	.0	2.2	3	2	344	214	.03	45.1	11.6	D
8	9	0	33.8	60	26.0	141	39.4	18.6	1.6	4	2	153	77	.30	16.5	6.8	D
8	17	41	23.7	61	14.8	140	42.4	1.5	1.8	4	2	263	133	.38	4.2	8.7	C
11	12	51	1.4	59	52.8	139	57.5	20.1	1.8	3	2	188	113	.76	27.2	25.0	D
12	12	31	21.0	59	53.7	139	51.2	32.0	2.3	5	3	151	73	.30	37.9	57.6	D
13	10	8	22.7	60	8.5	141	2.4	2.1	2.4	5	3	156	123	.38	1.2	2.9	B
13	10	12	16.8	60	8.1	141	1.8	2.6	2.2	5	3	155	124	.43	1.3	2.9	B
13	10	52	40.2	60	8.4	141	1.6	0.0	2.6	8	3	156	123	.46	1.4	1.2	A
13	10	55	43.5	60	1.4	141	20.3	4.2	1.8	3	1	224	126	.25	26.2	41.3	D
13	11	0	15.7	60	3.0	141	18.6	5.1	1.6	3	2	221	124	.12	13.4	16.2	D
15	0	59	6.9	60	23.2	140	57.3	28.5	2.2	3	1	179	118	0.00	17.6	12.9	D
19	13	28	52.9	60	55.7	147	5.0	15.1	2.2	8	5	162	46	.38	3.9	1.7	B
19	17	28	45.0	60	7.2	141	6.3	4.9	1.5	4	3	151	123	.52	5.1	5.7	C
19	23	10	47.6	60	44.8	147	42.0	13.3	1.5	8	7	108	71	.67	1.3	1.6	A
20	10	35	16.3	60	38.7	146	56.0	11.3	1.5	13	8	147	66	.65	1.0	1.4	A
21	11	50	37.7	60	40.4	147	39.2	19.7	1.7	11	6	81	57	.50	1.4	1.2	A
21	19	2	24.5	60	46.8	147	36.8	18.9	2.1	9	6	89	46	.30	.9	1.0	A
23	19	58	6.7	60	38.1	142	45.7	.5	.6	3	3	202	78	.05	3.1	99.0	D
24	0	45	11.6	60	21.6	141	11.4	14.9	1.7	5	3	167	93	.33	3.6	4.3	B
24	13	35	53.6	60	37.9	146	55.2	19.9	2.5	14	5	109	57	.42	1.3	1.8	A
24	15	8	5.4	60	15.7	144	21.4	14.2	1.8	9	6	174	85	.60	3.6	2.2	B
26	1	33	30.7	60	25.8	141	13.8	16.3	.4	5	3	172	91	.28	2.9	3.2	B
26	3	33	32.7	60	57.4	146	24.1	34.8	1.6	4	2	296	20	.76	7.1	4.6	C
26	12	59	30.0	60	33.2	140	40.0	16.1	.7	3	5	204	106	.27	2.4	2.5	A
27	4	2	15.9	60	39.2	146	53.7	19.9	2.2	17	9	104	54	.40	1.3	1.9	A
30	9	6	30.0	60	44.1	147	42.4	19.1	1.4	9	6	88	67	.23	1.5	1.4	A
30	17	56	24.2	60	15.8	140	59.6	10.0	1.2	3	0	167	114	0.00	70.3	69.7	D
30	18	39	53.0	60	44.8	147	41.7	19.6	2.2	9	6	90	66	.29	1.7	1.4	A
31	8	53	55.0	58	55.9	138	23.3	2.9	2.2	3	1	338	137	.15	16.9	18.2	D
31	12	4	42.8	60	57.8	147	5.3	16.8	2.4	14	8	108	43	.44	1.3	1.2	A
31	16	5	49.1	60	59.0	146	47.0	1.6	1.4	11	4	94	29	.57	1.2	2.6	B
AUG 1	5	12	13.7	58	56.5	138	22.0	10.0	2.4	2	1	348	136	0.00	97.2	19.8	D
1	5	54	41.3	59	41.5	141	10.9	34.0	2.1	2	2	273	101	.51	28.6	94.9	D
6	0	52	24.3	60	55.0	147	1.0	20.0	2.6	15	8	130	44	.46	1.2	3.0	B
6	10	28	6.4	60	58.2	147	.1	22.4	1.4	5	5	124	40	.15	1.7	4.8	B
6	13	31	37.2	58	47.7	138	45.5	0.0	3.1	7	0	182	134	.71	6.4	27.4	D
11	20	41	37.9	59	18.2	144	8.4	4.7	2.7	5	0	189	232	.26	45.1	88.2	D
13	10	1	29.3	60	43.0	147	26.3	13.4	1.5	5	6	197	76	.35	5.7	3.4	C
16	5	37	52.6	60	30.1	140	39.1	2.1	1.7	5	2	198	116	.56	3.9	4.6	B
20	23	51	7.0	60	22.2	143	6.9	.1	2.5	9	7	151	190	.53	3.9	2.7	B

EASTERN GULF OF ALASKA EARTHQUAKES

1975		ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
AUG	21	3	29	23.1	58	44.6	137	12.5	4.2	2.6	2	1	360	190	.23	99.0	7.0	D
	22	8	19	20.9	60	37.7	143	3.6	1.0	1.6	15	7	136	78	1.05	1.2	1.8	A
	22	10	[illegible]9	21.1	60	20.2	143	9.1	7.9	1.7	7	4	125	52	.53	1.9	2.6	B
	22	20	42	15.6	60	20.6	143	9.9	6.5	1.5	7	4	124	51	.56	1.9	3.2	B
	22	21	27	31.7	60	35.9	143	1.6	.2	2.1	9	4	135	54	.71	2.0	7.7	C
	23	5	26	13.8	60	20.2	143	10.5	1.3	2.4	16	9	127	51	.71	1.4	1.7	A
	24	10	57	39.0	59	53.7	141	40.6	10.0	1.3	8	8	198	52	.55	2.2	1.8	A
	24	23	33	27.9	60	.9	142	15.1	19.0	1.6	8	6	197	59	.54	2.2	1.0	A
	25	10	28	29.5	60	28.9	147	20.0	20.0	1.9	16	11	169	48	.43	1.2	1.3	A
	26	4	46	44.6	60	10.1	139	27.3	10.1	.5	4	2	258	56	.09	8.0	4.3	C
	26	6	23	32.2	60	7.5	140	57.2	14.4	1.8	9	5	132	51	.60	2.4	1.2	A
	26	23	44	26.9	60	57.5	147	3.3	23.6	2.8	26	4	42	39	.50	.8	1.1	A
	29	3	50	5.3	60	49.8	146	58.9	15.7	2.0	14	9	58	34	.73	1.0	1.0	A
	29	4	5	1.6	60	26.6	147	52.7	17.9	1.5	15	9	113	76	.56	1.0	3.0	B
	30	12	11	47.6	58	46.5	135	48.5	34.9	2.7	5	3	353	257	.74	25.8	99.0	D
	31	6	54	8.8	60	30.1	143	26.6	1.3	1.4	3	2	282	94	.58	5.8	99.0	D
	31	15	31	40.2	60	30.3	143	9.4	3.8	1.4	5	4	144	74	.42	1.4	15.9	D
SEP	1	11	39	4.9	60	55.7	146	48.2	22.9	1.5	15	11	86	30	.95	.8	1.0	A
	2	6	38	24.2	59	57.7	141	45.8	14.4	1.5	4	4	228	45	.33	2.6	3.5	B
	2	6	51	5.0	60	57.1	146	50.0	21.8	2.3	19	9	45	30	.53	.7	1.2	A
	2	14	21	29.8	60	2.1	142	6.4	.1	.7	2	2	360	103	8.32	99.0	94.6	D
	3	20	12	41.9	59	58.4	140	42.2	.4	2.1	9	3	148	39	.58	2.9	2.4	B
	4	14	5	37.9	60	26.0	145	.1	17.4	2.2	12	4	134	56	.34	2.1	1.3	A
	4	19	12	41.9	60	7.5	140	35.5	16.5	2.2	10	3	143	47	1.34	2.2	1.4	A
	5	8	17	17.9	60	21.0	145	6.0	16.1	1.1	12	6	158	64	.57	2.1	1.4	A
	6	12	29	44.7	59	54.7	141	32.3	13.6	1.5	7	4	223	52	.43	3.4	1.6	B
	6	13	4	45.5	60	34.2	147	39.6	18.8	2.1	18	6	90	49	.46	.9	.9	A
	6	17	57	43.8	59	54.7	141	32.1	13.6	1.3	6	6	244	52	.51	2.3	1.4	A
	7	1	17	.1	60	20.1	141	14.2	15.7	1.7	6	4	154	55	.22	2.0	1.9	A
	7	19	10	55.7	60	12.7	141	8.1	8.2	2.1	7	3	178	90	.60	3.2	1.6	B
	7	19	53	30.6	60	10.8	141	.7	10.9	2.0	7	3	140	45	.71	2.1	1.8	A
	8	23	19	7.4	61	36.6	146	26.7	15.8	3.6	31	1	92	53	4.84	.9	.9	A
	9	4	17	23.6	60	59.6	147	3.3	23.5	1.2	10	8	109	41	.56	1.4	1.6	A
	9	8	48	3.1	60	27.1	144	53.4	10.0	1.2	9	8	176	89	.67	2.2	1.6	A
	9	14	22	46.5	60	58.3	146	59.9	25.3	.9	7	7	160	38	.38	1.4	1.9	A
	9	18	45	59.0	60	35.1	142	43.0	.3	1.5	5	4	116	59	.52	1.3	2.6	B
	10	2	36	33.3	61	4.8	146	15.6	3.5	.4	5	1	190	16	.11	2.6	4.0	B
	10	22	36	51.9	60	30.9	143	6.1	2.7	1.3	4	3	222	110	.25	2.7	2.4	B
	11	21	18	45.2	60	7.9	140	52.4	9.1	2.4	9	2	133	55	.64	2.3	2.6	B
	16	22	22	44.4	59	52.3	141	19.7	29.7	1.6	3	3	267	59	.05	4.2	4.9	B
	18	8	17	49.3	61	3.3	146	49.4	10.2	1.4	11	1	124	28	.40	2.3	2.3	A
	19	3	29	21.3	61	.9	147	5.4	23.1	1.9	11	9	135	41	.59	1.3	1.5	A
	19	11	1	28.8	60	59.5	147	.5	23.0	2.3	14	7	77	38	.52	1.1	1.5	A
	20	23	45	59.2	60	34.0	147	38.9	18.8	2.7	19	2	62	50	.39	.9	.9	A
	23	13	46	31.2	59	39.6	139	22.9	9.8	2.3	9	3	156	47	.52	2.1	1.6	A

EASTERN GULF OF ALASKA EARTHQUAKES (CONTINUED)

1975	ORIGIN HR	TIME MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
SEP 23	20	47	58.0	60	7.8	141	5.4	6.9	1.9	7	3	129	47	.82	1.8	1.5	A
24	7	44	49.2	60	28.6	143	10.6	4.2	2.7	13	6	123	77	.46	1.0	1.3	A
24	14	12	34.0	59	54.1	141	35.5	16.3	3.0	10	1	190	52	.37	2.9	1.6	B
24	14	17	52.0	59	54.3	141	32.2	13.8	3.6	18	0	161	52	1.47	1.8	1.2	A
24	14	26	36.9	59	44.0	141	37.8	13.7	1.8	3	1	264	87	.24	5.8	41.3	D
24	14	54	26.7	60	3.6	144	2.9	24.3	1.7	2	2	312	144	.07	48.3	86.4	D
24	23	4	6.9	59	46.0	141	36.7	6.5	1.2	4	1	237	84	.02	3.7	7.5	C
25	0	52	20.9	60	30.5	143	31.4	10.0	1.8	10	7	143	99	3.48	1.6	2.3	A
27	5	9	40.3	60	47.5	147	28.6	29.9	3.6	21	2	67	46	.29	1.0	1.1	A
27	12	19	47.6	60	33.4	143	19.9	68.6	1.7	4	3	195	76	1.51	3.6	5.1	C
28	23	7	55.7	60	47.3	147	28.8	28.8	2.5	13	4	106	59	.28	1.3	1.4	A
30	0	9	12.7	60	40.1	143	7.1	.1	2.0	5	3	139	83	.39	1.2	3.7	B
30	0	25	39.5	60	24.2	143	53.8	81.7	2.3	5	2	148	110	1.73	2.8	4.4	B
30	1	16	43.0	59	47.8	142	58.0	32.0	1.5	4	1	284	142	1.87	14.7	28.7	D
30	16	55	2.9	60	22.1	143	4.1	20.0	1.4	3	2	168	84	1.63	2.2	25.0	D

EASTERN GULF OF ALASKA EARTHQUAKES

1975	ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
OCT 2	17	38	20.7	61	47.7	146	29.9	30.9	2.5	14	3	79	75	.46	1.3	1.3	A
2	18	4	6.2	60	25.7	147	38.5	23.1	2.0	16	5	79	60	.37	.9	1.7	A
3	8	30	23.6	60	20.9	143	51.5	42.8	1.0	4	4	160	113	.95	4.1	4.9	B
5	15	26	58.6	61	33.5	146	30.3	33.6	2.6	19	7	76	58	.52	.8	.8	A
5	17	28	29.7	61	35.2	146	14.9	36.5	2.6	16	9	93	60	.42	.9	.9	A
5	20	7	14.4	61	33.7	146	30.1	33.0	2.6	19	8	79	59	.49	.8	.8	A
7	10	2	58.0	58	13.2	139	25.7	4.2	2.2	2	2	354	207	.07	19.3	25.0	D
7	15	58	56.2	60	20.3	140	37.1	38.9	2.5	11	5	167	41	4.54	2.0	1.2	A
7	18	55	1.2	61	53.6	147	27.0	41.5	3.4	28	5	89	70	.55	.9	2.2	A
8	1	40	16.1	60	46.5	141	18.3	.2	3.0	20	6	189	91	.58	1.5	2.9	B
10	7	20	28.9	60	49.0	146	54.0	29.9	2.2	18	9	57	47	.46	.9	.9	A
11	2	30	10.2	58	43.8	147	55.3	23.3	2.6	20	1	228	212	.33	4.7	2.6	B
11	12	9	16.9	61	1.6	147	14.3	29.4	2.1	13	6	103	50	.25	1.2	1.2	A
13	14	18	40.1	60	29.0	147	.9	.3	1.5	7	5	221	81	.28	2.5	99.0	D
13	15	55	21.2	60	59.7	147	18.1	32.5	1.3	13	7	84	54	.24	1.3	1.0	A
14	6	8	56.0	61	56.5	147	49.9	39.9	3.3	23	3	86	62	.45	1.0	2.4	A
14	15	36	19.6	60	59.1	147	22.6	33.5	2.6	19	4	72	54	.17	1.1	.9	A
16	23	9	26.8	60	3.5	147	2.5	24.4	2.7	24	4	193	93	.38	1.7	1.2	A
17	14	57	32.1	61	25.5	146	50.7	37.3	2.6	17	3	64	51	.26	1.0	.9	A
17	15	57	21.0	60	49.5	146	52.8	31.6	2.4	20	4	123	40	.45	1.3	.8	A
19	6	59	27.1	59	15.1	139	51.2	26.9	2.6	9	4	268	93	.40	3.3	2.7	B
19	14	14	1.2	60	24.4	147	38.3	28.0	2.3	16	10	81	63	.36	.9	1.5	A
19	23	48	16.6	60	58.1	146	59.6	33.6	2.5	24	6	44	40	.24	.8	.7	A
21	1	16	27.6	61	20.4	147	12.4	33.3	3.7	26	2	54	52	.34	.8	.8	A
21	10	14	52.0	60	46.5	147	13.8	23.4	1.9	15	10	66	54	.48	.9	1.5	A
21	18	38	58.4	60	34.8	143	56.9	2.5	1.8	6	3	145	62	.49	1.6	8.2	C
22	12	53	19.2	60	39.5	143	.3	0.0	1.9	12	4	78	55	1.01	.9	1.2	A
22	13	44	6.3	60	15.6	140	38.7	21.4	2.5	12	8	156	62	.64	1.9	1.6	A
22	18	23	40.2	60	57.9	147	2.2	33.3	2.2	17	10	73	41	.27	.8	.7	A
23	12	3	3.5	60	13.5	140	42.7	12.1	2.0	9	4	149	59	.45	2.1	3.8	B
25	15	27	1.2	59	22.5	141	6.3	10.0	1.6	2	2	329	130	1.80	10.9	98.6	D
25	20	23	35.4	60	21.0	141	20.9	.5	2.0	10	4	142	51	.35	1.5	99.0	D
27	5	19	23.0	60	38.5	143	48.0	2.5	1.8	4	3	197	63	.76	2.6	38.0	D
27	12	20	52.4	60	18.3	140	48.4	18.0	2.2	8	1	173	71	.19	3.1	2.8	B
28	7	35	1.8	61	56.5	147	37.4	29.3	3.2	25	4	165	74	.71	1.2	.9	A
29	6	51	31.3	59	8.6	139	9.2	20.0	3.3	7	1	295	106	.71	17.9	4.8	D
30	4	2	52.9	59	9.0	139	32.2	35.4	2.6	9	6	302	113	.54	3.0	1.4	B
30	23	48	47.1	60	48.4	147	7.7	27.4	2.1	15	10	111	54	.43	1.0	1.1	A
31	17	22	51.3	60	58.5	147	7.9	30.7	2.4	17	8	80	43	.33	1.1	1.0	A
NOV 1	17	3	59.9	60	42.3	147	43.6	26.0	3.3	25	4	98	53	.35	1.1	1.2	A
1	23	11	4.8	60	31.6	143	6.9	2.5	1.7	6	5	181	71	.35	2.0	47.5	D
2	1	2	52.5	61	30.0	146	35.8	29.8	2.5	12	4	139	72	.40	1.4	1.1	A
3	1	4	2.7	60	54.8	142	33.6	10.0	1.8	14	8	291	203	6.55	2.2	1.3	A
3	16	25	37.3	60	37.8	143	5.8	18.9	1.7	3	3	146	80	.02	2.3	12.3	D
4	1	19	29.8	60	23.2	141	11.7	17.0	1.9	4	2	214	61	.43	5.7	9.7	C

EASTERN GULF OF ALASKA EARTHQUAKES

1975		ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
NOV	4	10	17	7.8	61	27.1	146	41.1	30.4	2.1	16	11	129	65	.51	1.1	1.1	A
	4	14	31	22.8	60	23.4	147	45.5	19.7	2.1	10	7	162	81	.37	1.6	8.3	C
	5	1	14	41.8	60	34.7	141	30.1	5.0	2.2	9	1	170	67	.43	1.7	18.2	D
	5	1	18	11.9	60	32.2	141	32.2	14.7	1.2	4	2	163	71	.25	6.5	14.5	D
	5	7	54	46.0	60	13.1	140	50.0	72.5	2.8	7	2	155	63	1.52	4.6	9.5	C
	5	10	13	36.2	60	8.8	141	11.6	15.8	1.8	3	1	154	52	.83	12.4	11.3	D
	6	11	9	43.0	60	40.2	145	57.0	170.3	2.9	7	2	164	43	1.67	5.4	6.2	C
	7	12	35	30.7	61	15.1	147	22.1	33.4	1.9	15	7	82	61	.26	1.0	1.1	A
	8	13	18	38.5	60	29.7	138	42.6	.6	2.6	9	3	254	117	.68	5.8	6.6	C
	8	13	42	49.0	60	29.0	138	39.5	4.2	2.6	9	3	255	116	.76	7.3	5.0	C
	8	13	46	5.1	60	27.4	138	45.0	1.2	2.9	9	3	252	112	.71	6.0	7.5	C
	8	23	12	3.4	60	37.8	142	34.1	2.5	1.3	4	3	139	80	.32	1.9	66.4	D
	9	0	37	10.0	60	25.7	138	46.3	.5	2.5	7	4	251	164	.49	3.4	10.8	D
	9	2	17	44.1	61	.4	147	46.7	29.8	2.1	15	8	102	40	.31	1.0	1.2	A
	11	4	46	56.6	60	42.4	143	23.8	24.0	1.4	3	1	304	186	0.00	7.7	7.0	C
	12	13	12	21.4	61	3.6	147	12.1	32.4	2.4	17	8	81	48	.58	.9	.9	A
	12	22	47	29.6	60	58.7	147	30.7	36.0	2.6	19	6	102	47	.37	1.0	.7	A
	13	23	24	44.8	60	35.2	143	11.2	5.0	1.9	5	2	184	88	.26	2.6	44.7	D
	15	1	5	1.6	60	35.6	147	36.6	11.5	1.7	10	4	116	66	1.16	1.0	3.2	B
	17	1	1	24.4	60	1.2	141	2.6	.4	2.6	6	4	193	55	1.09	2.5	42.2	D
	18	15	51	47.4	60	39.5	146	17.4	33.0	1.8	13	8	89	32	.62	1.1	.8	A
	19	14	59	48.9	60	57.7	147	7.5	30.1	2.2	14	3	86	42	.19	1.3	1.3	A
	20	10	41	22.9	60	44.5	141	2.4	16.8	2.1	4	4	211	84	.40	4.6	15.1	D
	22	10	13	31.8	59	58.8	146	41.0	30.5	3.0	21	3	111	82	.38	1.1	1.0	A
	22	16	45	18.4	59	59.2	146	42.2	29.4	3.6	23	3	98	66	.40	.9	.9	A
	23	2	37	55.3	61	17.3	146	48.1	33.2	2.3	16	7	109	53	.24	1.0	.9	A
	23	21	54	51.4	60	27.4	147	32.9	19.5	1.8	16	8	95	58	.40	.9	2.1	A
	24	3	50	27.9	60	35.4	142	52.1	27.0	2.1	4	4	154	57	.14	1.9	2.0	A
	25	14	6	58.7	60	16.1	140	37.9	23.9	2.8	8	5	180	82	.89	1.9	1.8	A
	25	14	32	41.4	60	27.7	147	17.1	25.4	2.8	29	5	61	55	.50	.8	.9	A
	26	7	55	21.0	60	28.7	142	56.7	41.0	2.4	9	7	100	59	4.33	1.4	4.1	B
	28	13	37	52.2	60	58.8	146	38.8	23.1	2.0	12	6	113	27	.51	1.4	1.6	A
	28	22	8	51.3	61	3.5	147	.4	21.0	1.9	13	9	87	43	.35	1.1	1.7	A
	29	11	52	16.2	61	23.0	146	53.4	40.2	2.4	10	5	165	55	.20	1.5	7.8	C
	29	16	21	53.0	61	9.0	147	16.5	13.1	1.9	11	4	105	54	.29	1.1	6.0	C
	30	8	54	25.8	60	22.9	147	39.6	26.3	2.5	15	6	202	65	.40	2.3	2.0	A
DEC	2	13	54	26.3	60	50.0	139	43.7	1.2	2.4	4	3	244	161	.35	4.0	5.8	C
	3	11	37	15.0	61	9.4	147	16.1	9.7	2.2	11	3	106	53	.51	1.2	8.2	C
	3	17	11	21.0	61	2.9	147	23.6	33.5	2.8	23	4	65	55	4.23	1.3	1.1	A
	3	17	54	33.9	61	11.2	147	3.7	20.0	2.4	11	4	121	58	2.55	1.5	2.2	A
	3	22	53	52.7	61	9.7	147	11.3	20.0	2.2	12	6	99	49	2.12	1.2	2.4	A
	3	23	40	35.7	61	15.7	146	45.0	20.0	2.0	15	5	78	55	1.56	1.3	2.5	B
	5	7	44	36.6	61	44.4	146	-5.2	10.0	1.5	6	3	192	109	6.23	4.6	55.5	D
	5	11	57	17.6	61	28.2	146	17.8	10.0	1.9	6	4	145	68	2.64	2.0	15.2	D
	7	11	14	45.4	61	13.4	143	32.4	7.5	2.0	4	2	139	68	.04	2.1	14.8	D

EASTERN GULF OF ALASKA EARTHQUAKES

1975	ORIGIN HR	TIME MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
DEC 7	12	30	38.8	60	35.2	147	52.6	26.9	2.2	24	9	88	67	.40	.9	1.5	A
7	12	44	42.5	61	13.3	143	32.2	3.0	1.5	3	1	139	68	.02	4.0	66.0	D
8	9	56	18.5	60	56.8	146	59.8	28.3	2.2	16	7	82	39	.26	1.0	1.2	A
9	11	0	53.1	59	50.6	135	58.8	0.0	4.0	5	0	324	240	.60	67.7	90.8	D
9	13	4	34.3	59	55.5	146	10.5	26.5	3.4	24	4	103	73	.44	1.0	.9	A
9	23	11	6.8	61	2.9	146	33.2	24.1	2.5	19	5	64	33	.34	1.0	1.4	A
10	8	24	6.3	61	2.5	146	34.4	23.4	2.1	16	7	98	33	.36	1.1	2.1	A
10	14	1	4.6	60	51.0	147	24.6	4.2	1.7	15	3	114	50	3.83	1.2	9.8	C
11	19	51	57.5	60	31.6	147	23.5	20.0	2.3	19	6	78	56	3.52	1.0	1.3	B
11	21	4	5.1	61	1.6	147	11.7	27.8	2.5	18	6	55	48	.23	1.2	1.7	A
12	3	39	59.7	60	59.7	146	32.5	25.3	2.3	18	3	70	31	.29	1.2	1.7	A
12	3	48	49.2	60	59.6	146	33.6	24.3	2.7	19	0	71	66	.40	1.2	1.2	A
12	3	56	40.9	61	.2	146	32.4	25.0	2.2	17	3	68	67	.30	1.2	1.6	A
12	4	2	41.7	60	59.4	146	33.5	24.5	2.2	14	4	71	66	.33	1.2	1.6	A
12	18	29	52.3	60	48.0	147	45.1	28.8	3.0	26	3	75	43	.36	1.0	1.0	A
14	9	50	.3	60	55.6	147	2.4	29.4	2.1	20	6	80	42	.30	1.2	.8	A
15	2	13	13.4	60	27.3	140	52.4	10.0	2.0	4	3	186	103	.45	8.8	47.6	D
15	6	42	36.3	59	40.6	137	21.3	2.7	2.6	5	3	328	169	.41	5.5	38.7	D
17	23	20	13.8	61	3.4	147	16.4	43.5	2.0	10	8	79	55	3.69	1.4	2.9	B
18	13	21	26.2	61	8.7	147	14.2	24.2	1.8	16	6	75	51	1.36	.9	2.0	A
20	8	14	11.1	61	28.0	146	36.3	31.3	3.3	18	2	73	69	.33	.9	1.0	A
20	14	0	1.3	61	28.9	146	34.7	31.0	3.0	20	3	75	71	.44	.9	1.0	A
21	19	9	47.5	60	39.9	147	56.0	26.4	3.7	27	0	139	58	.37	1.0	1.0	A
22	3	33	4.8	61	28.6	146	20.8	47.4	2.7	14	5	95	71	1.58	1.3	4.1	B
22	14	54	33.7	59	60.0	147	18.6	23.7	3.8	17	1	135	95	.32	1.2	1.6	A
23	6	30	34.0	60	23.0	147	46.7	27.9	3.3	21	5	88	68	.35	.8	1.2	A
23	14	34	5.8	60	8.4	146	23.8	17.3	2.2	16	5	224	68	.63	2.1	1.3	A
23	15	48	48.0	60	17.5	146	28.1	4.2	3.1	13	1	224	75	1.76	2.4	6.1	C
24	9	37	39.8	60	4.2	146	18.8	18.1	2.5	7	3	230	101	.36	3.0	1.8	B
24	14	25	21.4	62	40.6	147	56.7	38.5	4.7	18	1	235	199	.33	5.6	25.0	D
25	17	26	28.9	61	.2	146	32.2	24.9	2.7	19	4	61	32	.34	.9	1.2	A
26	5	9	55.3	61	10.3	147	13.1	13.3	2.2	12	4	85	51	.31	.9	3.4	B
27	0	36	30.9	62	23.0	147	39.8	4.2	3.5	26	5	214	84	12.77	1.6	2.2	A
27	1	31	51.7	62	4.1	147	42.5	32.5	3.8	28	2	180	80	.60	1.4	.8	A
29	9	56	25.5	60	38.6	147	55.4	23.4	2.6	10	5	163	65	.46	2.0	2.5	A
30	11	26	37.0	60	36.8	147	34.2	28.4	2.8	15	5	168	62	.55	1.4	1.1	A

EASTERN GULF OF ALASKA EARTHQUAKES

1976	ORIGIN HR	TIME MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
JAN 2	3	30	39.1	60	56.0	143	7.6	20.8	2.5	3	1	307	85	1.39	2.7	20.4	D
4	18	25	34.3	61	.6	146	31.8	16.5	1.8	10	4	119	67	.52	3.4	2.5	B
5	22	56	38.8	60	39.7	143	1.7	2.6	2.8	8	3	86	56	.76	1.2	2.9	B
8	4	26	58.7	61	.6	146	34.9	15.0	2.2	14	7	91	30	.52	1.3	1.1	A
8	10	27	8.7	60	44.9	147	19.0	15.2	2.4	15	5	134	57	.44	1.7	1.1	A
9	19	42	13.4	60	37.5	147	55.3	14.0	2.5	18	6	155	66	.35	1.5	1.3	A
14	5	43	48.5	60	43.9	144	22.9	12.6	2.5	16	4	66	78	.57	.8	1.3	A
14	14	20	4.0	61	.9	147	4.3	25.0	2.2	14	7	83	42	.56	1.2	1.2	A
14	19	51	7.1	60	13.8	145	3.3	7.2	3.3	21	2	115	67	.48	1.9	1.5	A
15	0	0	9.3	60	8.9	145	2.8	8.3	2.2	4	3	233	121	.13	8.0	3.7	C
15	6	27	41.6	61	.9	147	.6	25.0	1.9	12	7	113	39	.65	1.5	1.2	A
15	12	5	12.0	60	36.5	147	6.3	15.0	2.4	18	4	139	65	.52	1.6	1.3	A
17	14	20	23.2	60	59.5	146	40.2	15.1	2.0	11	4	92	30	.41	1.6	1.6	A
17	22	51	18.0	61	29.8	146	38.4	17.7	2.5	13	5	72	71	.35	1.1	1.3	A
19	22	52	49.5	61	23.5	145	28.2	16.0	2.9	15	4	112	89	.39	1.2	1.9	A
20	15	40	23.1	60	8.4	141	21.5	.4	3.6	11	2	210	114	.73	4.2	3.4	B
22	4	42	39.9	60	26.3	147	46.7	14.8	3.2	20	4	171	83	.42	1.6	2.1	A
26	23	34	15.1	60	44.3	143	21.9	4.0	2.1	11	3	106	82	.53	2.8	6.1	C
27	21	6	5.1	60	30.7	143	6.4	6.2	2.2	5	2	182	79	.22	2.1	7.0	C
28	0	27	6.2	60	46.7	146	56.9	14.7	1.9	10	4	145	46	.38	1.8	1.0	A
29	1	36	3.3	61	1.2	147	11.5	15.0	2.4	15	4	80	48	.48	1.3	1.2	A
29	8	18	53.3	60	50.2	147	4.4	20.3	3.2	16	3	124	48	.36	1.4	1.9	A
FEB 1	22	29	57.9	61	31.2	146	26.1	18.1	2.5	11	4	82	67	.43	1.1	1.3	A
7	13	58	1.3	59	41.4	139	35.2	15.0	2.2	4	1	169	214	.34	88.8	34.0	D
9	6	7	22.3	61	21.7	146	51.1	18.4	2.5	13	5	63	58	.31	1.0	1.5	A
10	7	37	11.7	60	6.4	141	15.7	15.0	3.9	14	1	148	153	.65	5.3	4.8	C
10	8	36	31.0	60	35.7	140	19.4	2.4	2.9	3	2	211	211	.10	19.2	3.6	D
10	9	0	44.5	60	37.3	140	17.5	3.0	2.4	3	2	213	211	.12	16.1	3.7	D
10	16	53	58.0	60	44.3	147	15.2	15.0	2.3	14	6	135	85	.46	1.4	1.5	A
10	17	28	10.1	60	59.9	147	16.7	20.8	1.9	9	4	107	78	.35	1.6	2.0	A
10	23	1	22.3	60	30.2	140	29.7	4.9	3.2	4	2	202	148	.18	11.6	4.3	D
11	1	44	39.8	60	9.9	141	18.9	3.8	3.0	5	3	192	158	.82	3.7	2.2	B
11	5	20	38.6	61	9.4	147	16.5	12.4	2.0	9	6	82	69	.55	1.2	1.6	A
12	18	41	25.0	60	34.2	143	59.7	.4	2.8	11	3	155	98	.51	1.8	2.4	A
12	20	21	36.4	61	1.0	146	39.6	13.1	2.3	11	5	101	72	.58	1.4	1.2	A
12	23	13	57.2	61	2.0	147	.7	25.0	2.3	9	6	86	88	.60	1.3	1.4	A
14	5	16	42.2	60	35.2	141	44.6	11.3	2.5	4	2	174	147	.21	18.6	5.8	D
14	16	14	17.4	60	.9	140	44.8	20.8	2.6	5	1	184	144	.52	7.4	5.8	C
14	16	16	7.3	60	19.8	140	5.1	9.2	2.5	4	4	203	146	.72	4.4	3.7	B
15	21	16	3.6	59	48.2	138	33.1	15.6	3.4	4	0	262	250	.13	67.8	72.3	D
16	10	52	13.5	61	37.2	146	17.2	25.0	2.5	11	3	92	64	.39	1.2	1.9	A
16	21	10	20.2	61	18.8	147	5.9	21.8	2.3	15	6	56	59	.34	1.1	1.8	A
19	21	43	27.4	61	20.7	147	12.1	16.6	2.4	12	5	59	59	.31	.9	1.1	A
20	5	26	7.5	60	56.8	146	41.9	20.8	2.3	12	6	107	29	.57	1.3	1.3	A
22	0	19	49.3	60	31.4	147	39.9	10.7	2.9	15	5	156	83	.44	1.3	1.2	A

EASTERN GULF OF ALASKA EARTHQUAKES (CONTINUED)

1976		ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
FEB	22	8	0	8.6	60	32.8	147	38.9	16.2	2.3	12	7	154	83	.34	1.4	1.6	A
	22	16	4	54.9	60	3.5	141	16.8	.0	3.0	3	1	202	207	.24	14.2	7.5	D
	22	18	31	19.3	61	23.5	147	22.5	14.1	2.2	12	5	86	69	.40	1.1	1.2	A
	22	22	43	37.7	59	29.7	147	54.2	19.4	3.6	14	3	213	137	.51	6.0	8.0	C
	25	9	22	40.7	60	2.4	141	24.6	23.3	2.5	5	2	205	157	.34	10.1	6.0	D
	29	13	15	58.5	61	35.7	146	21.1	25.0	3.1	15	5	88	61	.56	1.1	1.8	A
	29	17	37	58.2	60	25.9	139	44.5	15.0	3.0	4	2	260	248	1.05	57.3	60.7	D
MAR	1	14	38	11.8	60	37.1	147	36.3	11.9	2.1	11	5	146	82	.39	2.3	2.3	A
	2	20	36	27.5	60	25.0	147	20.2	15.0	2.6	15	5	100	90	.46	1.7	1.7	A
	3	18	39	4.1	60	46.2	140	12.5	2.3	2.4	3	2	222	208	1.43	15.1	4.0	D
	6	4	59	44.9	57	48.3	139	30.3	9.2	3.6	3	1	325	398	.06	99.0	99.0	D
	6	18	33	55.4	60	57.8	146	46.7	25.0	2.4	13	5	107	73	.60	1.4	1.3	A
	9	13	16	3.7	61	1.2	146	31.7	12.9	2.6	13	8	97	68	.80	1.4	1.2	A
	9	13	26	57.3	61	22.6	146	46.4	16.5	1.8	12	7	117	59	.41	1.1	1.2	A
	11	6	8	54.8	60	58.5	145	55.2	20.8	1.9	10	6	94	80	.60	1.5	1.4	A
	13	1	0	41.0	61	13.3	145	57.7	6.3	2.6	13	8	125	100	.34	1.3	1.4	A
	14	5	56	35.2	61	23.3	147	1.2	15.7	2.1	11	8	106	56	.44	1.2	1.3	A
	15	5	26	27.9	61	24.0	141	15.4	16.0	2.7	3	1	180	137	.12	17.4	9.5	D
	15	21	41	.6	61	9.7	147	19.9	4.8	1.7	8	7	81	66	.50	.9	1.8	A
	16	1	26	22.6	60	39.0	147	19.7	15.0	1.7	10	8	145	87	.58	1.5	1.6	A
	18	16	47	40.1	61	23.1	147	17.2	25.0	2.1	10	6	91	59	.40	1.2	1.9	A
	19	0	24	17.3	60	59.6	147	32.5	3.3	2.0	12	5	112	67	.56	1.0	2.8	B
	19	3	2	40.5	61	18.6	146	50.4	17.0	2.6	10	4	121	48	.23	1.9	2.1	A
	19	5	37	42.5	61	2.5	146	45.6	15.0	1.7	13	9	90	25	.57	1.2	1.2	A
	20	0	29	30.5	61	14.4	146	58.3	10.9	1.8	12	8	98	69	.52	1.0	1.3	A
	20	16	55	25.5	60	24.3	140	1.0	9.2	3.0	3	2	247	236	.56	67.8	72.6	D
	21	1	56	31.5	60	1.8	139	23.1	15.0	3.2	4	0	211	198	.13	69.4	70.7	D
	23	9	13	23.4	61	11.1	147	17.5	.9	1.8	12	9	83	67	.45	.9	1.9	A
	26	3	46	21.4	60	38.1	142	50.7	15.4	2.4	3	3	217	155	.13	3.7	3.5	B
	27	0	58	41.0	61	38.3	144	57.2	22.8	2.6	11	8	161	83	.45	1.8	2.6	B
	29	20	6	17.0	60	2.1	146	58.2	24.9	3.5	12	5	207	138	.55	3.7	8.6	C
	29	20	36	46.7	60	3.3	146	58.0	15.7	3.1	18	4	203	138	.42	3.4	5.7	C

EASTERN GULF OF ALASKA EARTHQUAKES

1976	ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
APR 2	20	51	55.0	61	18.2	146	47.2	15.3	3.0	20	8	81	95	.35	1.3	2.1	A
9	23	48	47.6	60	21.4	139	47.4	19.8	2.8	5	3	258	159	.69	7.2	2.4	C
12	14	29	1.3	60	20.4	141	4.1	15.0	2.1	4	0	168	104	.34	91.0	39.3	D
15	14	49	12.6	60	30.3	142	46.9	15.0	1.8	4	2	250	163	.51	70.5	69.5	D
20	13	39	31.0	61	34.1	146	29.5	25.0	3.1	13	6	80	53	.57	1.1	1.7	A
20	14	27	19.7	60	19.5	140	27.8	15.0	4.3	12	1	211	113	.57	2.0	3.4	B
20	14	38	37.8	60	23.6	140	9.9	14.7	3.3	9	3	229	139	.62	9.7	2.8	C
20	14	51	11.8	60	33.9	139	21.7	15.0	3.2	6	3	274	260	.66	63.0	61.2	D
22	17	23	24.1	60	47.6	143	2.0	10.4	3.1	10	2	134	84	1.03	4.4	5.1	C
24	16	46	45.9	60	54.7	140	39.9	3.8	2.9	10	3	234	159	1.57	15.5	3.4	D
27	4	27	8.4	58	41.3	138	25.6	20.8	3.4	3	2	355	429	.37	99.0	85.1	D
29	5	30	21.6	60	17.3	139	27.1	15.0	2.8	4	3	275	269	.53	70.0	70.1	D
MAY 2	14	27	50.3	60	24.7	145	28.1	22.7	2.1	3	3	246	146	.34	11.8	12.0	D
11	16	46	17.0	61	27.4	146	50.8	25.0	4.1	21	4	81	81	.53	1.4	2.2	A
15	17	39	47.8	61	36.8	146	33.4	19.1	3.6	17	2	147	58	.38	1.4	2.0	A
20	6	7	39.4	61	46.1	146	57.9	25.0	3.5	17	6	118	72	.74	1.4	1.7	A
23	17	30	10.0	61	17.8	146	54.5	25.0	3.5	19	4	83	84	.37	1.2	1.7	A
24	4	3	22.6	60	51.2	147	30.7	12.8	2.3	13	8	122	80	.43	1.1	1.4	A
25	10	28	49.1	61	2.1	147	10.1	16.8	2.3	17	12	105	89	.39	1.0	1.6	A
26	12	46	23.5	61	31.1	146	32.3	17.1	2.3	16	15	77	55	.50	.9	.9	A
26	16	24	8.8	60	50.9	146	59.9	15.8	2.3	17	11	122	76	.46	1.1	1.3	A
28	9	36	1.6	61	25.5	146	44.8	20.0	2.3	17	11	74	82	.47	1.0	2.0	A
29	5	7	36.3	61	4.9	146	27.5	19.7	2.5	14	8	89	96	.62	1.4	.9	A
29	5	21	9.0	61	3.1	146	31.3	16.6	2.1	12	9	105	97	.56	1.2	1.0	A
29	13	8	29.9	60	49.1	147	6.9	9.7	2.3	12	9	126	98	.30	1.2	1.3	A
30	2	1	11.5	60	59.6	147	17.7	17.2	2.7	20	6	109	94	.34	1.1	1.7	A
31	18	32	56.8	60	26.0	144	44.1	3.3	2.6	9	8	247	117	.48	2.5	1.4	B
JUN 1	14	7	26.2	61	18.0	146	47.5	19.7	2.4	13	6	81	66	.38	1.1	1.4	A
1	19	29	10.7	59	30.3	138	7.7	10.2	2.5	3	2	335	136	.24	13.4	4.0	D
6	22	1	27.6	62	19.5	147	19.8	25.0	3.7	26	4	82	78	.52	1.6	2.1	A
8	17	50	50.5	60	3.3	147	57.2	7.4	3.7	21	8	141	108	.39	1.4	1.5	A
21	23	30	28.6	60	28.0	145	1.1	14.9	2.6	11	7	113	91	.50	1.8	1.6	A
25	23	45	16.8	60	14.7	140	59.6	4.6	2.3	9	4	161	44	.36	2.1	3.1	B
28	10	5	47.2	60	38.2	141	15.4	17.8	1.7	5	3	269	82	.25	5.3	4.8	C
29	0	5	27.6	60	10.3	140	55.7	2.1	2.8	7	3	157	63	.35	2.0	2.5	B
29	11	20	42.2	60	43.5	142	55.5	.0	2.2	5	3	146	93	.24	4.7	2.5	B
29	16	38	51.3	60	17.2	140	54.1	15.0	1.8	5	3	197	47	.17	3.1	2.7	B
29	21	27	39.6	59	58.8	143	2.2	16.6	2.2	7	5	163	84	.44	2.7	1.7	B

Quarterly Report - R.U. 216/212

Oct. 1976 - Jan. 1977

FAULTING AND INSTABILITY AND EROSION AND DEPOSITION OF SHELF SEDIMENTS, EASTERN GULF OF ALASKA

P. I. Paul R. Carlson
Bruce F. Molnia
U.S. Geological Survey
Menlo Park, California 94025

I. Task Objectives:

B-10 - Determine the types and characteristics of bottom sediments.

D-2 - Determine the types and extent of natural seafloor stability. Compile maps indicating relative susceptibility to instability hazards.

D-6 - Determine and map the distribution, mode of faulting, age of most recent movement, and magnitude of offset for major faults.

II. Field or laboratory activities:

A. Ship or Field Trip Schedule

1. Jan. 15 - Feb. 3, 1977; U.S. Coast Guard vessel.
2. Jan. 17 - Jan. 24, 1977; n.e. Gulf of Alaska winter beach observations.

B. Scientific Party

1. William Levy, U.S.G.S., sedimentologist
2. Bruce Molnia, U.S.G.S., marine geologist

C. Methods - Field sampling or lab. analyses

1. Collected grab samples of seafloor sediments whenever possible, between Dixon Entrance and Yakutat Bay.

2. One week (Jan. 1977) field program (N.P.S. partially funded) on the beach between Cape Fairweather and Lituya Bay, n.e. Gulf of Alaska. Beach profiles were measured and beach samples were collected to provide information about beach changes and sediment sources and sinks.

3. Progress continues on analyses of mineralogy and physical characteristics of sediment samples from the n.e. Gulf of Alaska OCS. These data are being reduced and maps of sediment distribution, mean phi size, sorting, and percentages of gravel, sand, silt and clay will be completed this spring. Seismic interpretations also are being incorporated in these maps.

III. Results-Meetings-Cruise Plans

Results of our studies were presented at the NOAA-BLM sponsored meeting in Anchorage, Jan. 11-13, 1977.

Papers are being prepared for presentation at the following meetings:

Geol. Soc. Am., Cordilleran Section, April, 1977
Offshore Technology Meeting, May, 1977
Am. Assoc. Petroleum Geologists, June, 1977

Plans are being formulated to participate in several cruises in the Gulf of Alaska this field season. The cruises are:

(1) NOAA Discoverer, March 1977;
(2) U.S.G.S. R/V Growler, April-June, 1977;
(3) U.S.G.S. R/V Sea Sounder, May, 1977 and Sept., 1977;
(4) U.S.G.S. R/V Lee, June, 1977

IV. Preliminary Interpretation - Samples and records being analyzed.

V. Problems - too frequent reporting dates.

VI. Estimate funds expended - 10%.

RU# 251

NO REPORT WAS RECEIVED

GEOPHYSICAL INSTITUTE
C. T. ELVEY BUILDING
UNIVERSITY OF ALASKA
FAIRBANKS, ALASKA 99701

QUARTERLY REPORT

October 31, 1976 - December 31, 1976

Title: (i) Delineation of most probable areas for subsea permafrost in the Chukchi Sea from existing data

(ii) Subsea permafrost: probing, thermal regime and data analysis

Principal investigators:

T. E. Osterkamp and W. D. Harrison
Geophysical Institute
University of Alaska
Fairbanks, Alaska 99701

Research unit: #253

Task objectives: D9

Field or laboratory studies:

No field work was done this quarter.

Theoretical studies of salt and heat transport in subsea permafrost are progressing, largely with Sea Grant and NSF support.

Studies of the possible existence of permafrost beneath the Chukchi Sea, using existing data and simple theory, have been carried out, and a report "Permafrost beneath the Chukchi Sea - Preliminary report" is attached.

Results: See attached report.

Preliminary interpretation: See attached report.

Problems encountered:

Funds for the work described in the attached report ($12,000) have been spent, although to incorporate all the existing data would require more work. We were surprised at the large amount of relevant data that exists.

Funds expended to date:

$12,000 for attached report, plus about $15,000 for probing, thermal regime and data analysis.

PERMAFROST BENEATH THE CHUKCHI SEA - PRELIMINARY REPORT

W. D. Harrison, P. D. Miller, and T. E. Osterkamp
Geophysical Institute, University of Alaska
Fairbanks, Alaska 99701

I. Introduction

The purpose of this project is to survey relevant existing data as a first step in assessing the possible existence of permafrost beneath the Chukchi Sea. The information surveyed so far includes sea bed temperature, sea ice cover, bathymetry, and although only superficially, sea level history, geologic setting, and seismic data. Some simple calculations of the rate of growth and decay of permafrost beneath the Chukchi Sea shelf, in response to periods of emergence and submergence, have also been performed. All this is discussed in Sections II to V; a summary is given in Section VI.

This report is only a preliminary working paper, both because of its somewhat superficial and still incomplete nature, and because it does not contain input from other relevant ongoing OCS projects. However, it is produced now, as laid out in our original plan for the study of subsea permafrost in the Chukchi Sea, in order to aid communication with other workers, and to help us in our choice of sites for field work that is to be carried out in the near future.

Much of the work here has been focused on the southeastern Chukchi Sea, because it includes the Hope Basin proposed oil lease sale area.

II. Bathymetry, setting, and sea level history

The Chukchi Sea is shallow. Most of the sea bed, from Bering Strait to the shelf break at about latitude 73°N, is a featureless plain, 45 to 55 m deep. The water is somewhat shallower in the southeastern Chukchi Sea, an area of particular interest because it is a proposed oil lease area. Excluding the near-shore areas, the major relief features are Herald Shoal, Hope Seavalley, and Cape Prince of Wales Shoal (Creager and McManus, 1967; U. S. Coast and Geodetic Survey Chart No. 9402). (See Figures 1, 2, and 3.)

Some information on the geology of the Chukchi Sea is available (for example, Hopkins, 1959; Moore, 1964; Creager and McManus, 1967; Holmes and others, 1968; Grantz and others, 1970; Grantz and others, 1971; Johnson and Breslau, 1971; Grantz and others, 1972; Grantz and others, 1974). Of particular interest to the subsea permafrost problem is the nature of the material 10's to 100's of meters below the sea bed; shallow material is probably ice free, except in very shallow water, judging from experience in the Beaufort Sea (for example, Hunter and others, 1976; Rogers and others, 1975; Osterkamp and Harrison, 1976). No deep drilling data in the Chukchi Sea exist. However, seismic studies lend some support to a suggestion that the featureless bottom topography, at least in the southern Chukchi Sea, is due largely to deposition of sediments probably of Tertiary age and younger. At several sites studied in the southern Chukchi Sea (Figure 3), 200-700 m of material, probably unconsolidated because of a seismic velocity of only 2 km s^{-1} or less, underlies a thin veneer of holocene sediments. Below this material is a strong reflector, and the velocity below it seems to be about 4 km s^{-1}.

The seismic data have not been examined for information about permafrost. But based on work by Hunter and others (1976), and by Rogers and others (1975), it seems unlikely that the 200-700 m of 2 km s^{-1} material could be ice bonded, at least continuously, because the velocity is probably at least 0.5 km s^{-1} too low.

In near-shore areas, the sediment cover may be entirely different. In the Ogotoruk Creek area, near Cape Thompson for example, it is thin or even absent (Scholl and Sainsbury, 1966; see also AEIDC, 1975, Plates 2 and 3).

The sea level history of the Chukchi Sea is of interest in connection with subsea permafrost because of the growth of permafrost during periods of land emergence. The sea level history is described by Hopkins (1973) (Figure 4). Over the time of most importance to subsea permafrost, periods of emergence and submergence are probably largely associated with eustatic changes in sea level, rather than tectonic effects. About 20,000 years ago essentially the entire present Chukchi Sea, to the shelf break, was emergent.

III. Sea bed temperatures and sea ice cover

Water temperature data from the Chukchi Sea have been collected as a step toward the estimation of mean annual sea bed temperature, an important subsea permafrost boundary condition. Data have been obtained from the National Oceanographic Center files, which are not complete, and elsewhere. Not all the data available have yet been incorporated in our compilation. More information on the data sources is given in the separate reference list for temperature data. Water temperature measurements have been assumed to characterize the sea bed if they were made within 10 m of it. As an aid in estimating mean annual sea bed temperatures, ice cover data (AEIDC, 1975) were used to estimate the fractional ice cover in each half month period. These data are given in Table 1.

The mean annual sea bed temperature distribution must be complex. For example, it is known that temperatures tend to be warm near the

Alaska coast because of a north setting current of warm water from the Bering Sea. At the same time, the data are very limited, and are restricted to the summer months. We have therefore attempted to compute only large scale means over areas bounded east and west by 1° intervals of longitude, and north and south by 30' of latitude.

As a first step, the mean monthly summer temperatures have been computed in these areas. These are given in Table 2, along with the number of measurements upon which the means are based. Although insufficient data exist for yearly mean temperatures to be calculated, some limits can probably be set with the help of the ice cover data in Table 1. An example is the area bounded by 66° on the north and 169° on the west (Bering Strait) for which four months of data, from July to October, is available. To obtain a lower limit to the yearly mean temperature, we might assume that the freezing temperature of sea water, about -1.7°C applies for the other months. This gives 0.2°C as a lower limit to the mean annual temperature; evidently the mean temperature is positive.

One possible way to estimate the monthly means for months of partial ice cover is to assume a monthly mean T_m given by

$$T_m = f_m T_f + (1-f_m)\overline{T}$$

where f_m is the fractional ice cover for the month, T_f is the freezing point, and $\overline{T}$ is the mean annual temperature. Also

$$\overline{T} = \frac{1}{12} \{\Sigma\ T_i + \Sigma\ T_m\}$$

where the first sum is over the months for which temperature data are available, and the second is over the other months. These equations can be combined and solved for $\overline{T}$:

$$\overline{T} = \frac{\Sigma\, T_i + T_f\, \Sigma\, f_m}{12 - \Sigma(1-f_m)} \tag{1}$$

The approach may be reasonable because the shallow Chukchi Sea is said to reach the freezing point at all depths during winter (Garrison and Becker, 1976). Applying equation (1) to the area bonded by 66° on the north, and 169° on the west, for which the lower limit 0.2°C for the mean annual temperature was found in the previous paragraph, one finds an estimated mean annual temperature of 1.1°C.

The results of this approach are given in Table 3 and in Figures 5 and 6, which also indicate the number of months for which temperature data are available. In assessing these results, it should be borne in mind that equation (1) tends to underestimate mean temperature if data from the summer months are incomplete. In fact, if no temperature data are available, the estimated mean temperature is just the freezing temperature. For example, the means estimated for squares bounded by 67°30'N and 167°W and by 67°30'N and 168°W are -0.7°C and 0.4°C respectively. The difference is artificial, and is because only August data are available for the former, while data for three summer months are available for the latter; the August temperatures, 3.5°C and 3.2°C respectively, are similar. Taking this effect into account, it seems fairly realistic to say that mean sea bed temperatures are positive at least in the Alaska sector of the southern Chukchi Sea, say south of Cape Lisburne.

Some year round temperature data from near-shore areas are available. At Wales, on Bering Strait, the yearly mean temperature was 1.1°C during both 1954 and 1955. The measurements were made in 3.0 m of water about 365 m from shore, which is in the fast ice zone; additional measurements made farther out indicate that these are not representative of large scale oceanographic conditions (Bloom, 1956). The mean temperature off the mouth of Ogotoruk Creek, just south of Cape Thompson, has been estimated to be about 0.75°C (Lachenbruch, 1966). Extrapolation of data given by Brewer (1958) from a borehole 119 m offshore near Barrow, where the water depth is about 5 m, suggests a mean annual temperature of roughly -0.6°C there. This site is also in the fast ice zone and is probably not characteristic of large scale oceanographic conditions. Other near-shore temperature data from Barrow exist (Wilimovsky, 1953, 1954; Brewer, 1975).

IV. Thermal models

Some preliminary work on the application of thermal models to the southeastern Chukchi Sea permafrost regime has been done. This work applies only to areas some kilometers from shore, and therefore not subject to complications arising from very shallow water and the nearby presence of land. Two limiting cases have been considered, those of very high and of very low water content in the subsea materials. The discussion of Section II, which indicates that the material is probably unconsolidated, indicates that the former of these cases is the more likely to apply.

In the high H_2O case, Figure 7 shows the response of permafrost to the sea level history suggested by Hopkins (1973) at a location where the present water depth is 45 m, which is characteristic of large areas of the Chukchi Sea. As it stands, the model predicts that at the 45 m water depth, the last of the permafrost disappeared about 4000 years ago. Details are given in Appendix A. Because the assumptions are many, this model does not exclude the present existence of permafrost beneath water this deep, although it may be worth noting that several of the assumptions, such as the absence of salt, tend to artificially favor the survival of permafrost. Figure 8 shows the permafrost response at a location where the water depth is 15 m; the possibility of survival of permafrost to the present time seems fairly good. In order to maintain perspective, it is well to keep in mind the bathymetry of Figures 1, 2, and 3 as well as the possibility that sedimentation, particularly on the north side of the Seward Peninsula, may have modified the depth distribution on a time scale comparable with that associated with changes in sea level.

The case of very low H_2O content in the subsea materials is considered in Appendix B. In this case, it seems that present day subsea temperatures would be positive at all except very shallow depths in the southeastern Chukchi Sea.

V. Near-shore areas

The subsea permafrost regime is likely to be most complicated in near-shore regions. Some of the problems are listed below, but a detailed discussion is postponed until results of ongoing projects are available.

(i) The near-shore regime is influenced by the nearby presence of land (Lachenbruch, 1957), say within 1 or 2 km from shore.

(ii) The near-shore regime depends sensitively upon shoreline history. This history is the focus of an ongoing OCS study by Hopkins.

(iii) In shallow water (less than about 2 m), the regime may be very senstive to the details of the water depth distribution (Osterkamp and Harrison, 1976, for example). We have compiled some of this information.

(iv) Oceanographic conditions, including the existence of shorefast ice, are different near shore, and not well studied. We have compiled some data on the distribution of shorefast ice. (See also last paragraph of Section III.)

There seems to be no doubt that permafrost will be found in near-shore areas, but it should be noted that based on experience in the Beaufort Sea (see OCS reports by Rogers and by Sellman and others; Osterkamp and Harrison, 1976; Hunter and others, 1976, for example), any ice-bearing permafrost is probably overlain by a thawed layer except in very shallow water (less than 2 m deep).

We hope that OCS supported projects by Hopkins (shoreline history, as noted earlier), by Rogers (seismic studies), and by us (temperature studies), together with NSF and Sea Grant supported projects to improve our understanding of physical processes, can be synthesized to give a better idea of the near-shore permafrost règime (and possibly of the regime in deeper water also) within a year or so. However, it should be realized that only a few of the actual details of this regime are likely to be determined by these modest projects.

VI. Summary

Part of a body of existing data relevant to the possible presence of permafrost beneath the Chukchi Sea has been surveyed, and some simple calculations have been performed. Most of the work so far has been concentrated on the southeastern Chukchi Sea. The most important results are as follows: Permafrost must have formed over essentially the entire present Chukchi Sea shelf when it was exposed during the times of the Wisconsin and earlier glaciations. However, seismic studies at several sites in the southern Chukchi Sea (Figure 3) seem to indicate the presence of unconsolidated, and therefore ice-unbonded sediments there to depths of at least 200 to 700 m at present. A simple calculation (for which the assumptions cannot be justified) may lend some support to the absence now of ice-bonded sediments beneath the southeastern Chukchi Sea, at least where the present water depth is of the order 45 m (see Figures 1, 2, and 3). Subsea permafrost should be widespread in near-shore areas. However, any ice-bearing material is probably overlain by a thawed layer except under very shallow water (less than about 2 m deep). The present mean annual sea bed temperature in the southeastern Chuckchi Sea appears to be positive.

Appendix A. Evolution of subsea permafrost when H_2O content is high

The evolution of subsea permafrost in materials whose H_2O content is high is simply illustrated under three assumptions:

(1) The H_2O content is high enough so that the latent heat per unit volume is much greater than the sensible heat, so that temperature varies linearly with depth between phase boundaries. (For the numerical values used, this assumption is reasonable, considering the other uncertainties.)

(2) The presence of salt can be ignored, so that phase boundaries are at 0°C. (In fine grained soils, particle surface effects are also ignored.) As pointed out by Harrison and Osterkamp (1976), salt is probably often the key to the problem, at least when the sea bed temperature is negative. In the south-eastern Chukchi Sea, the mean annual temperatures seem to be positive, but the errors associated with the assumption will still be serious.

(3) The heat transported by pore fluid motion is negligible. It has been shown by Harrison and Osterkamp (in preparation) that this may often be true.

(4) Near-shore areas are excluded.

The following notation is used:

Y' = depth from sea bed to top of permafrost

Y = depth from sea bed to bottom of permafrost

t = time

h = latent heat per unit volume

$\Delta T'$ = sea bed temperature during periods of submergence

ΔT = sea bed temperature during periods of emergence

G = geothermal heat flux

K_t = thermal conductivity of unfrozen material

K_f = thermal conductivity of frozen material

$Y_\infty = \frac{K_f \Delta T}{G}$ = equilibrium thickness of permafrost during emergence

$t_c = \frac{hY_\infty}{G}$ = a time constant describing the approach to this thickness

$t_c' = \frac{hY_\infty^2}{K_t \Delta T'}$ = a time constant describing the melting of the permafrost from the top during periods of submergence

$Y'^* = \frac{Y'}{Y_\infty}$ = dimensionless Y'

$Y^* = \frac{Y}{Y_\infty}$ = dimensionless Y

Under the assumptions noted above, all the theory that is needed for solution of the problem is the Stefan boundary condition: the velocity of a phase boundary is proportional to the heat flux into the boundary, and inversely proportional to the latent heat per unit volume.

Several different situations need to be considered:

(1) If the permafrost is freezing downward from the sea bed and there is no other frozen layer at greater depth, its evolution is described by

$$\frac{dY}{dt} = \frac{K_f \Delta T}{h} \frac{1}{Y} - \frac{G}{h} ,$$

or in dimensionless form by

$$\frac{dY^*}{d(t/t_c)} = \frac{1}{Y^*} -1$$

for which the solution is

$$Y^* = f^{-1}[(t/t_c) + f(Y^* \text{ at } t=0)]$$

where

$$f(u) \equiv -\ln(1-u) - u.$$

(2) If the permafrost is freezing downward from the sea bed, and there is another frozen layer at greater depth, so that no goethermal heat enters the upper layer, the evolution of the upper layer is described by

$$\frac{dY}{dt} = \frac{K_f \Delta T}{h} \frac{1}{Y}$$

or in dimensionless form by

$$\frac{dY^*}{d(t/t_c)} = \frac{1}{Y^*}$$

for which the solution is

$$Y^* = \sqrt{\frac{2t}{t_c}}$$

where $Y^* = 0$ at $t = 0$.

(3) If the permafrost is thawing downward from the sea bed

$$\frac{dY'}{dt} = \frac{K_t \Delta T'}{h} \frac{1}{Y'}$$

or

$$\frac{dY'^*}{d(t/t_c')} = \frac{1}{Y'^*}$$

for which the solution is

$$Y'^* = \sqrt{\frac{2t}{t_c'}}$$

where $Y'^* = 0$ at $t = 0$.

(4) If the bottom of the permafrost is being thawed by geothermal heat, and there is a thawed layer below the sea bed so that no heat from above reaches the bottom

$$\frac{dY}{dt} = - \frac{G}{h}$$

or

$$\frac{dY^*}{d(t/t_c)} = -1$$

for which the solution is

$$\Delta Y^* = -\frac{t}{t_c}$$

where ΔY^* is the change in Y^* in time t.

Cases (2) and (4) are actually special cases of (1). These four cases are sufficient for calculation of the permafrost evolution.

Numerical values of thermal properties for the Chukchi Sea are unknown, but it may be reasonable to use values characteristic of Prudhoe Bay, where the subsea material is unconsolidated, as also seems likely in the southern Chukchi Sea (Section II). The volumetric ice content is about 40% and $h \simeq 1.34 \times 10^8$ J m^{-3}, $G \simeq 1.84 \times 10^6$ J m^{-2} a^{-1}, $K_f \simeq 10.3 \times 10^7$ J m^{-1} a^{-1} deg^{-1}, $K_t \simeq 6.2 \times 10^7$ J m^{-1} a^{-1} deg^{-1} (Gold and Lachenbruch, 1973; Osterkamp and Harrison, 1976). If the temperature during emergence is similar to what it has been recently on land near Cape Thompson (Lachenbruch and others, 1966), $\Delta T \simeq 7°C$, and if the temperature during submergence is also similar to its present value, ΔT is roughly 1°C in the southeastern Chukchi Sea (Section III). It then follows that

$$Y_\infty \simeq 392 \text{ m}, \ t_c = 28{,}500 \text{ a}, \ t_c' = 332{,}000 \text{ a}.$$

The four cases are then summarized as follows:

	Emergent (Freezing)	Submerged (Thawing)
Top	$Y'^* = \sqrt{\frac{2t}{t_c}}$	$Y'^* = \sqrt{\frac{2t}{t_c'}}$
	$= \sqrt{\frac{t}{14,300}}$	$= \sqrt{\frac{t}{166,000}}$
Bottom	$Y^* = f^{-1}\ [t/t_c + f(Y^* \text{ at } t = 0)]$	$\Delta Y^* = -\frac{t}{t_c}$
	$= f^{-1}\ [\frac{t}{28,500} + f(Y^* \text{ at } t = 0)]$	$= -\frac{t}{28,500}$

These can be used to calculate the permafrost configuration as a function of time, using the sea level history of Hopkins (1973) at a location defined by the present water depth. The results for a depth of 45 m are shown in Figure 7. According to this simple model, the permafrost would have vanished about 4000 years ago, surviving longest at a depth of about 100 m. The results for a water depth of 15 m are shown in Figure 8. Permafrost would still exist at this water depth.

Appendix B. Evolution of subsea permafrost when H_2O content is low

The evolution of subsea permafrost in materials whose H_2O content is low, in the sense that latent heat is much less than sensible heat per unit volume, is easily studied by the principles of heat conduction. The results do not apply to near-shore areas, which are complicated by shallow water and the nearby presence of land.

Suppose that the boundary temperature (sea bed or emergent land surface) is initially T_o, and that the temperature gradient due to geothermal heat flow is g. Then the initial temperature distribution is

$$T = T_o + gy$$

where y is depth below the sea bed. If the boundary temperature is suddenly changed to T_1 at time t_1, and to T_2 at time t_2, the subsea temperature distribution at time $t > t_2$ is given by

$$T = T_o + gy + (T_1 - T_o) \operatorname{erfc} \frac{y}{\sqrt{4\kappa(t-t_1)}} + (T_2 - T_1) \operatorname{erfc} \frac{y}{\sqrt{4\kappa(t-t_2)}}, \qquad \text{(B1)}$$

where κ is the thermal diffusivity. Although this is easily generalized to any time-dependent temperature boundary condition, it is adequate for this calculation in its present form.

It is reasonable to use numerical values characteristic of Cape Thompson (Lachenbruch and others, 1966): $g \simeq 2.2 \times 10^{-2}$ deg m^{-1}, $\kappa \simeq 40\ m^2\ a^{-1}$, and the temperature during periods of emergence $\simeq -7°C$. During periods of submergence, a temperature of roughly 1°C is reasonable for the southeastern Chukchi Sea (Section III). At a present water depth of 45 m, Hopkins' (1973) sea level history then gives $t < -24{,}000$ a, $T = +1.0°C$; $-24{,}000 < t < -15{,}000$, $T = -7.0$; $t > -15{,}000$, $T = +1.0$. For these numerical values, and for depths ≤ 1000 m, equation (2) gives approximately

$$T \simeq 1 + 2.1 \times 10^{-2}\, y$$

for the present temperature distribution. This can be compared with the steady state value of

$$T = 1 + 2.2 \times 10^{-2}\, y$$

appropriate for a +1.0°C sea bed temperature. No permafrost should remain where present water depth is 45 m. Although the numerical values used in the calculation assume a submergent history prior to 25,000 years ago, the conclusion that no permafrost should remain is unchanged if an emergent history prior to 25,000 years is assumed; only the slope of the present near surface temperature distribution would be changed somewhat.

The results are rather similar for a location where the present water depth is 15 m. No permafrost would be present, but the temperature gradient at the sea bed would be only about 60% of its steady state value.

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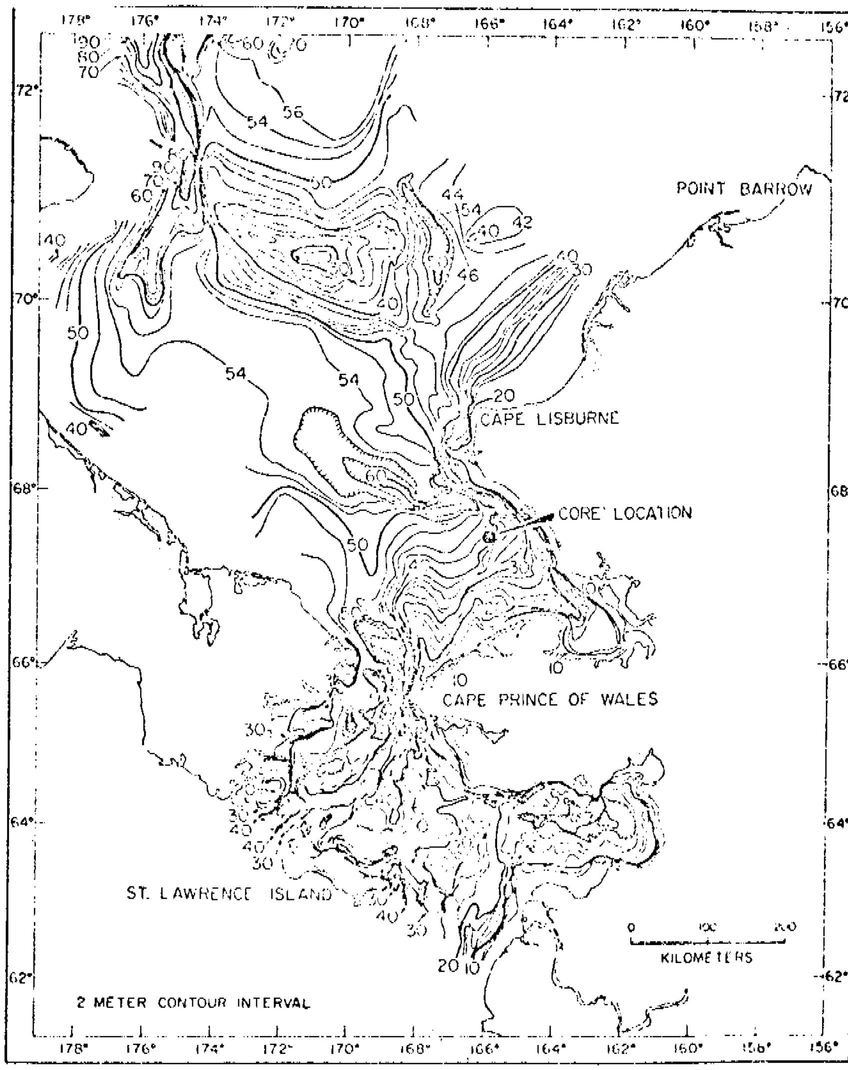

Figure 1. Bathymetry of the Chukchi Sea (contours in meters) (Creager and McManus, 1967).

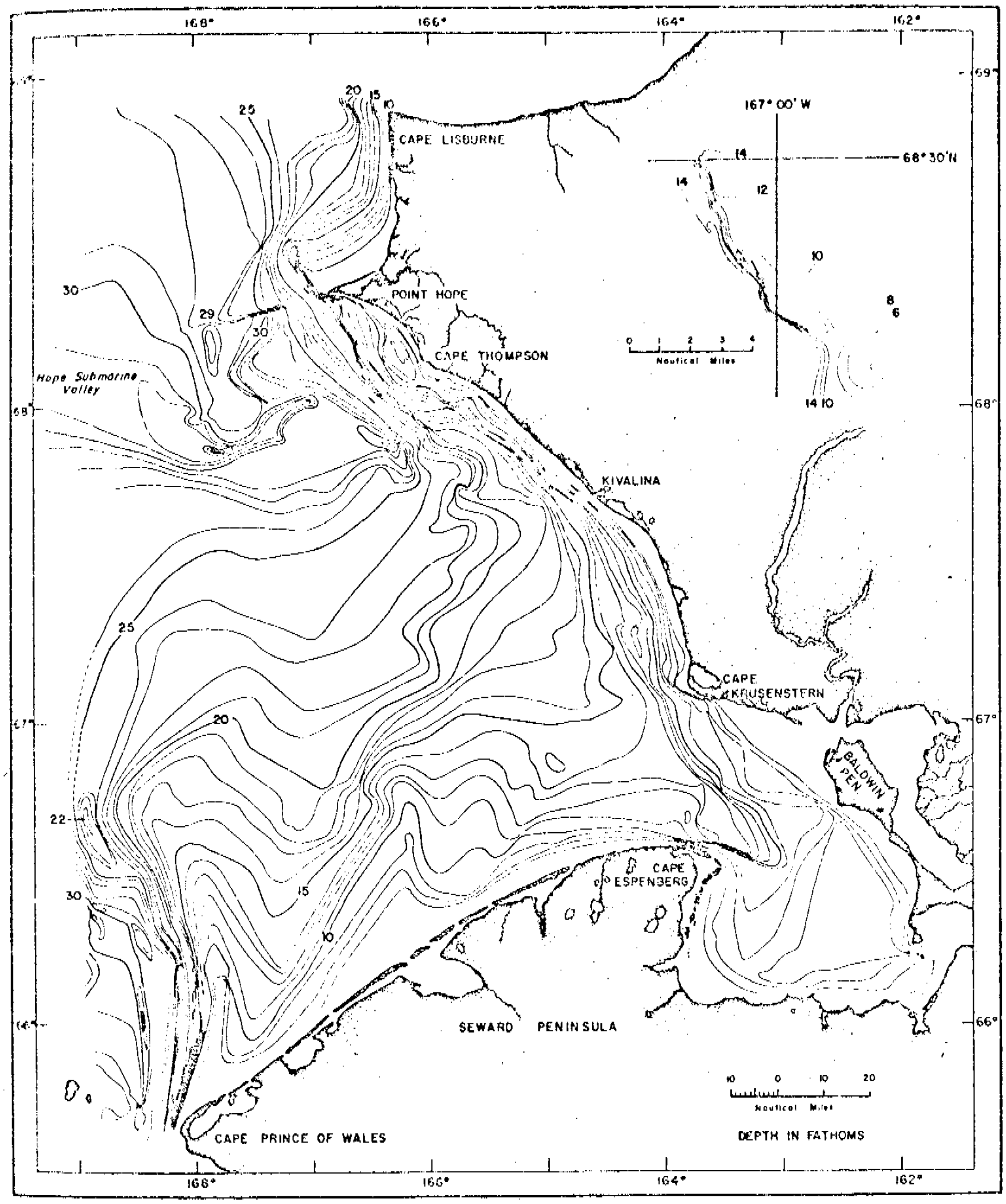

Figure 2. Bathymetry of the southeastern Chukchi Sea (contours in fathoms) (Creager and McManus, 1966).

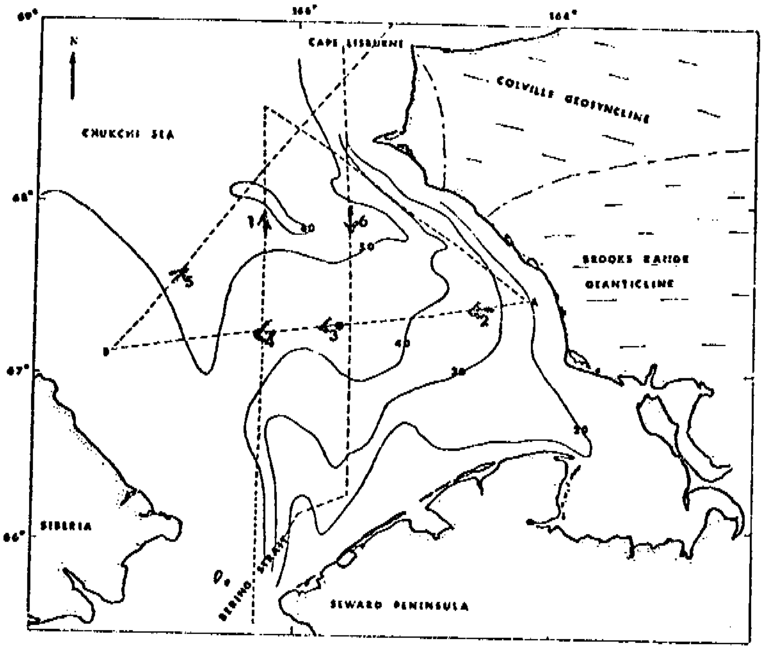

Figure 3. Locations of seismic sites (denoted by numbers 1 to 6) and bathymetry of the southeastern Chukchi Sea (contours in meters) (Johnson and Breslau, 1971).

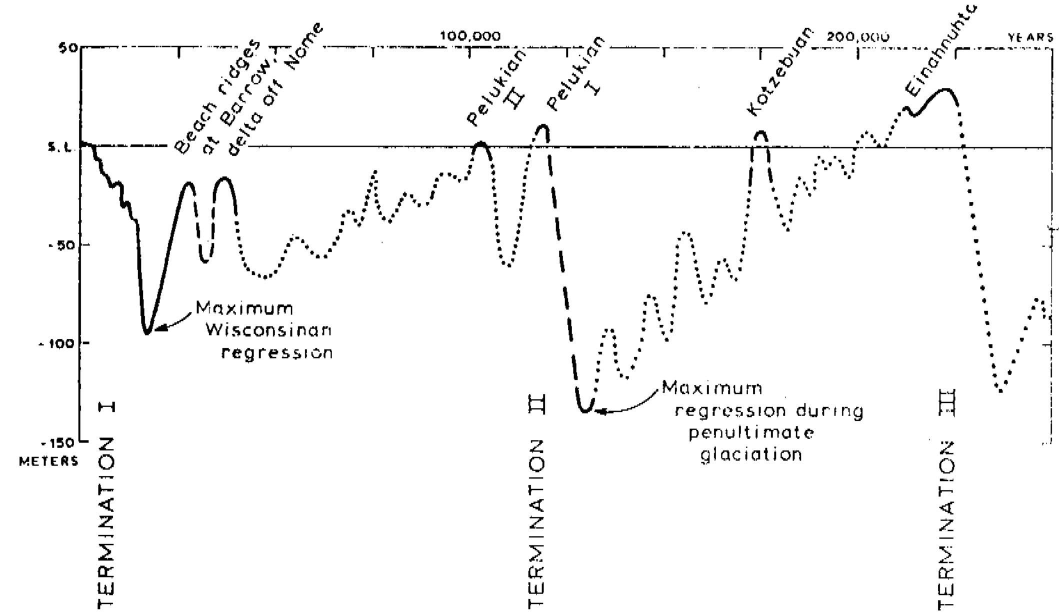

Figure 4. Sea level history for the Chukchi Sea (Hopkins, 1973).

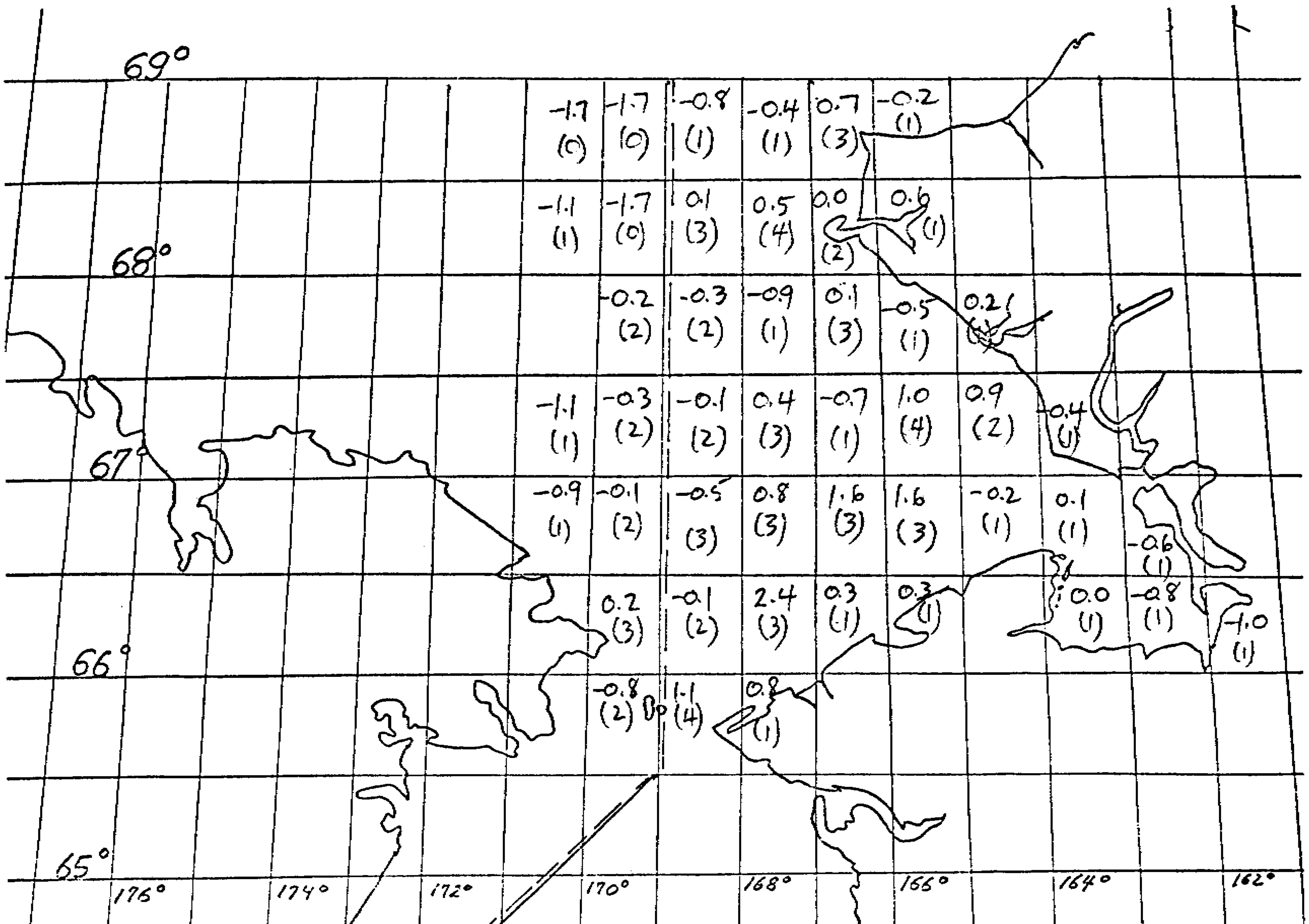

Figure 5. Estimated mean annual temperature, in °C, in the southern Chukchi Sea. The number of months of available data is given in parentheses

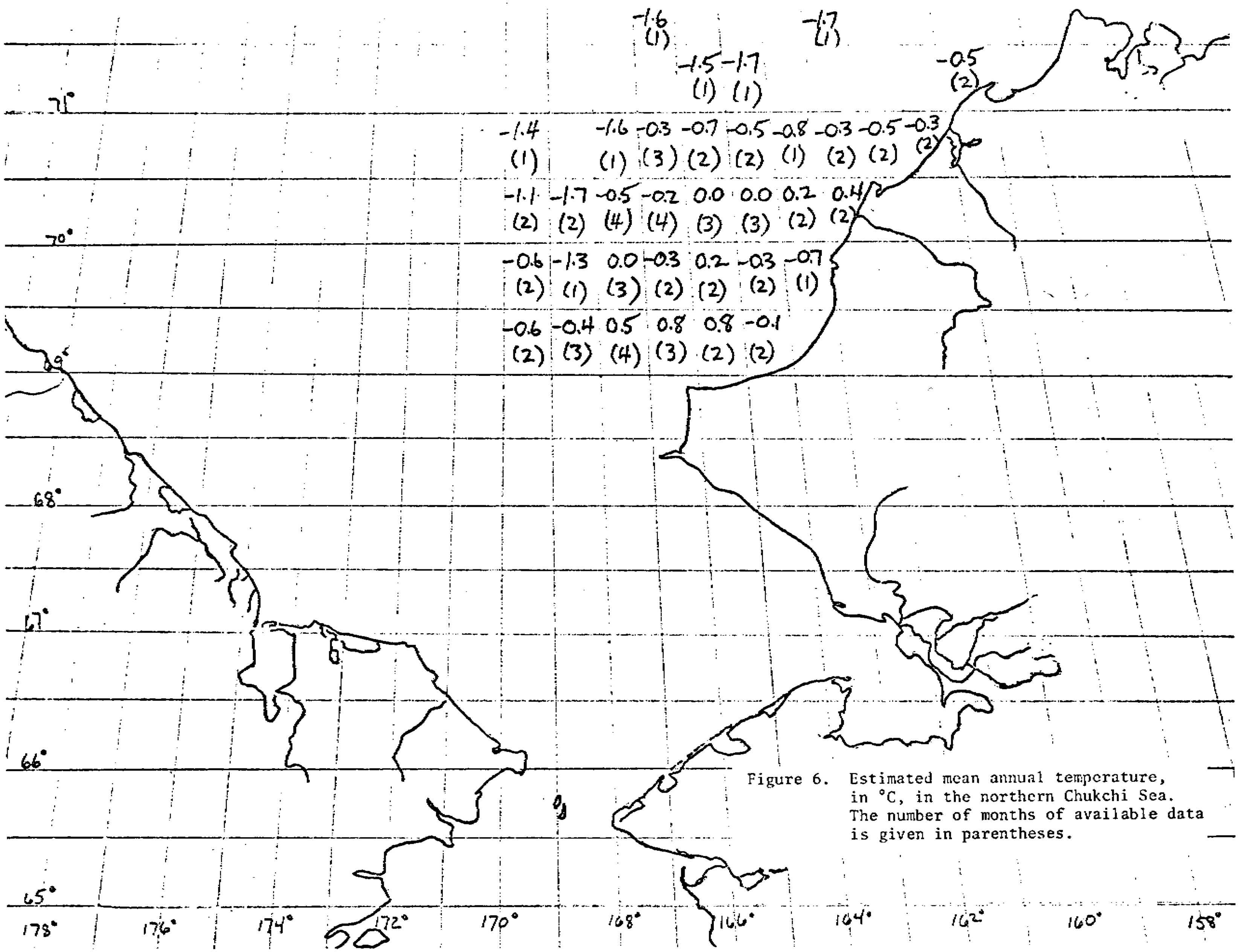

Figure 6. Estimated mean annual temperature, in °C, in the northern Chukchi Sea. The number of months of available data is given in parentheses.

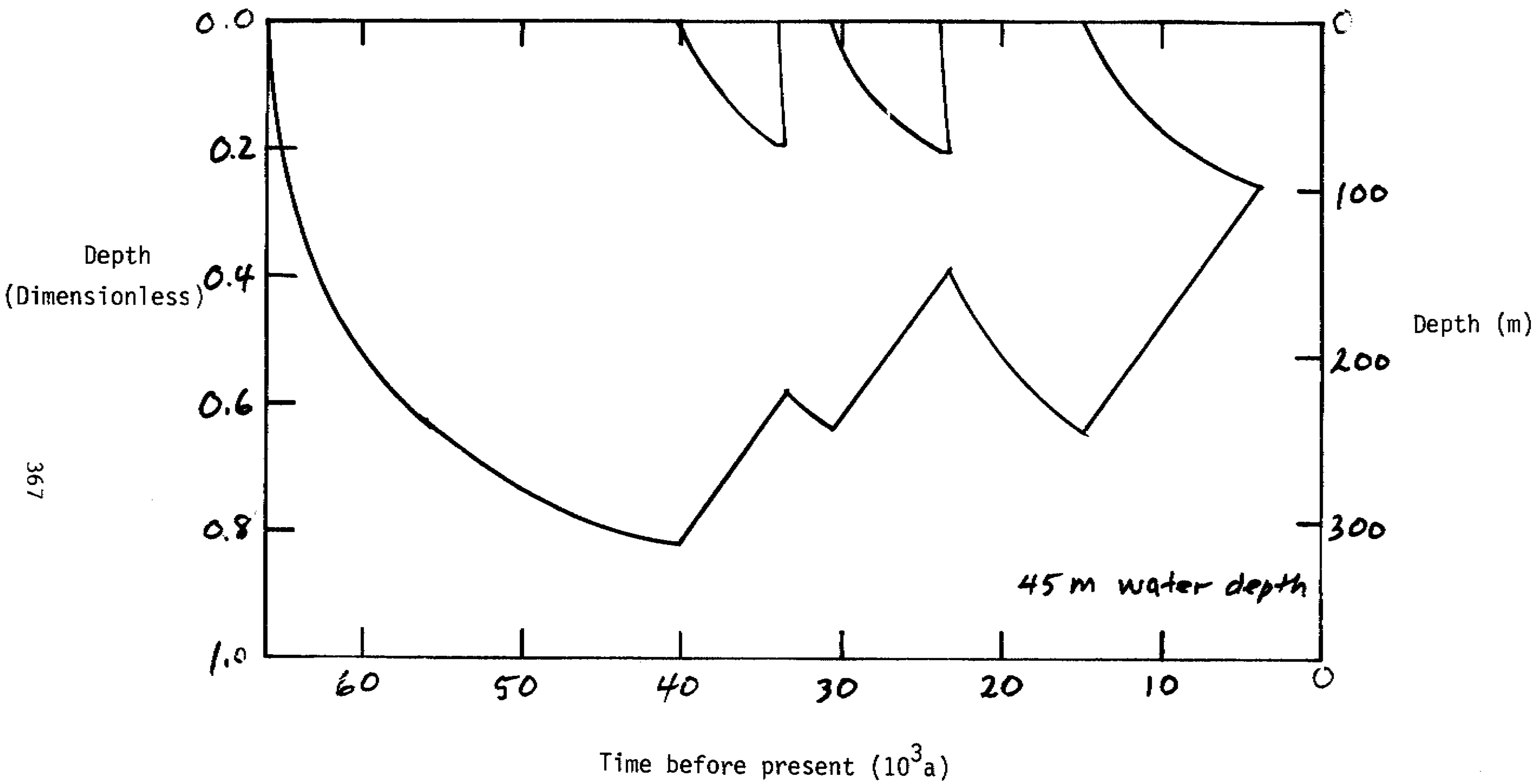

Figure 7. Depth to top and bottom of permafrost in ice-rich material, as calculated from a simple model described in the text, at a location where the present water depth is 45 m. The dimensionless depth is the ratio of the depth to the depth that would be attained by the permafrost after a very long period of emergence.

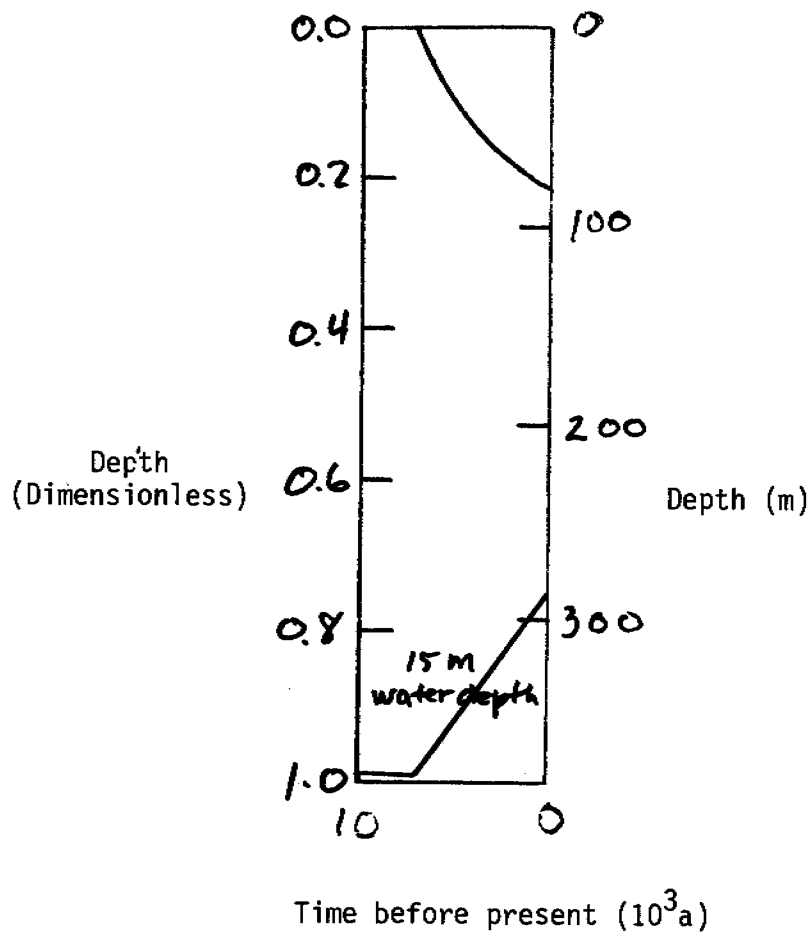

Figure 8. Depth to top and bottom of permafrost in ice-rich material, as calculated from a simple model described in the text, at a location where the present water depth is 15 m. The dimensionless depth is the ratio of the depth to the depth that would be attained by the permafrost after a very long period of emergence.

Table 1.

Ice cover data in areas bounded by 1° of longitude and 30' of latitude. The boundaries of the areas are given in the first two columns. Percent ice cover in each half monthly period is given in the other columns. Parts I and II of the table are for the southern and northern Chukchi Sea respectively, as defined by latitude 69°N.

PART I

N Boundary	W Boundary	J		F		M		A		M		J		J		A		S		O		N		D	
66°	168°	60	80	60	80	80	60	80	40	40	40	20	10	0	0	0	0	0	0	0	0	20	40	60	40
66°	169°	60	60	80	80	80	60	60	40	40	40	10	10	0	0	0	0	0	0	0	0	40	40	60	40
66°	170°	100	40	80	80	80	60	60	40	40	20	10	0	0	0	0	0	0	0	0	0	60	20	(60)	(60)
66°30'	162°	100	100	60	80	80	80	100	80	60	60	40	20	10	0	0	0	0	0	20	20	40	40	(60)	(60)
66°30'	163°	100	100	60	80	0	0	100	80	60	60	40	20	10	0	0	0	0	0	20	20	40	40	(60)	(60)
67°	163°	100	100	60	80	80	80	100	80	60	60	40	20	10	0	0	0	0	0	20	20	40	40	(60)	(60)
66°30'	164°	100	100	60	80	80	80	100	80	60	60	40	20	10	0	0	0	0	0	20	20	40	20	(60)	(60)
67°	164°	100	100	60	80	80	80	100	80	60	60	40	20	10	0	0	0	0	0	20	20	40	20	(60)	(60)
67°	165°	100	100	60	60	80	80	100	80	40	60	40	20	10	0	0	0	0	0	0	20	20	20	(60)	(60)
66°30'	166°	100	100	60	60	80	80	80	60	40	60	40	20	10	0	0	0	0	0	0	0	20	40	(60)	(60)
67°	166°	100	100	60	60	80	80	80	60	40	60	40	20	10	0	0	0	0	0	0	0	20	40	(60)	(60)
66°30'	167°	100	100	60	60	80	80	80	60	40	60	20	10	0	0	0	0	0	0	0	0	20	40	40	60
67°	167°	100	100	60	60	80	80	80	60	40	60	20	10	0	0	0	0	0	0	0	0	20	40	40	60
66°30'	168°	60	80	60	80	80	80	80	60	40	40	20	10	0	0	0	0	0	0	0	0	20	40	40	60
67°	168°	60	80	60	80	80	80	80	60	40	40	20	10	0	0	0	0	0	0	0	0	20	40	40	60
66°30'	169°	60	60	60	80	80	80	80	60	40	40	20	10	0	0	0	0	0	0	0	0	40	40	40	60
67°	169°	60	60	60	80	80	80	80	60	40	40	20	10	0	0	0	0	0	0	0	0	40	40	40	60

N Boundary	W Boundary	J		F		M		A		M		J		J		A		S		O		N		D	
66°30'	170°	100	100	60	80	80	40	60	40	40	20	10	0	0	0	0	0	0	0	0	0	60	20	40	40
67°	170°	100	100	60	80	80	40	60	40	40	20	10	0	0	0	0	0	0	0	0	0	60	20	40	60
67°	170°40'	100	100	60	80	80	40	60	40	40	20	10	0	0	0	0	0	0	0	0	0	60	20	40	(60)
67°30'	164°	100	100	60	80	80	80	100	80	40	40	40	10	10	0	0	0	0	0	0	0	40	60	(100)	(100)
67°30'	165°	100	100	60	80	80	80	80	60	40	20	20	10	10	0	0	0	0	0	0	0	20	60	(100)	(100)
68°	165°	100	100	60	80	80	80	80	60	40	20	20	10	10	0	0	0	0	0	0	0	20	60	(100)	(100)
67°30'	166°	100	100	60	60	80	80	60	60	40	20	20	10	10	0	0	0	0	0	0	0	20	60	(100)	(100)
68°	166°	100	100	60	60	80	80	60	60	40	20	20	10	10	0	0	0	0	0	0	0	20	60	(100)	(100)
67°30'	167°	100	80	60	60	80	80	80	40	40	20	20	10	10	0	0	0	0	0	0	0	20	40	40	(100)
68°	167°	100	80	60	60	80	80	60	40	40	20	20	10	10	0	0	0	0	0	0	0	20	40	40	(100)
67°30'	168°	100	60	60	60	80	60	80	40	40	20	20	10	0	0	0	0	0	0	0	0	50	70	40	(100)
68°	168°	100	60	60	80	80	60	80	40	40	20	20	10	10	0	0	0	0	0	0	0	50	70	40	(100)
67°30'	169°	100	60	60	80	80	60	80	40	40	20	20	10	0	0	0	0	0	0	0	0	60	60	40	(100)
68°	169°	100	60	60	80	80	60	80	40	40	20	20	10	10	0	0	0	0	0	0	0	60	60	40	(100)
67°30'	170°	100	60	60	80	80	40	80	40	40	20	20	10	0	0	0	0	0	0	0	0	(40)	60	(100)	(100)
68°	170°	100	60	60	80	80	60	80	40	40	20	20	10	10	0	0	0	0	0	0	0	(40)	60	(100)	(100)
67°30'	170°40'	100	80	80	80	80	60	80	(60)	20	20	20	10	0	10	0	0	0	0	0	0	(40)	(40)	(100)	(100)
68°30'	166°	100	60	60	60	80	80	60	40	40	20	20	10	10	0	0	0	0	0	0	0	20	40	40	(100)
69°	166°	100	60	60	60	80	80	80	60	40	60	20	10	10	0	0	0	0	0	0	20	20	40	60	(100)
68°30'	167°	100	60	60	80	80	80	60	40	40	20	20	10	10	0	0	0	0	0	0	20	20	40	40	(100)

N Boundary	W Boundary	J		F		M		A		M		J		J		A		S		O		N		D	
69°	167°	100	60	80	100	80	80	60	60	40	20	20	10	10	0	0	0	0	0	0	20	20	40	40	(100)
68°30'	168°	100	60	80	100	80	60	80	40	40	20	40	10	10	0	0	0	0	0	0	20	20	40	40	(100)
69°	168°	100	60	80	100	80	60	80	60	40	20	40	10	10	0	0	0	0	0	0	20	20	40	40	(100)
68°30'	169°	100	80	80	100	80	60	60	40	40	20	40	10	10	0	0	0	0	0	0	0	(40)	40	40	(100)
69°	169°	100	80	80	100	80	60	60	60	40	20	40	10	20	10	0	0	0	0	0	0	(40)	40	40	(100)
68°30'	170°	100	80	100	100	80	60	(80)	(60)	20	20	40	10	10	10	0	0	0	0	0	0	(40)	40	(40)	(100)
69°	170°	100	80	100	100	80	60	(80)	(60)	20	40	40	10	40	10	0	0	0	0	0	0	(40)	(40)	(40)	(100)
68°30'	170°40'	100	80	100	100	80	60	(80)	(60)	10	20	40	10	(10)	10	0	0	0	0	0	0	(40)	40	(40)	(100)
69°	170°40'	100	80	100	100	80	60	(80)	(60)	10	40	40	10	(10)	10	0	0	0	0	0	0	(40)	40	(40)	(100)

PART II

N Boundary	W Boundary	J		F		M		A		M		J		J		A		S		O		N		D	
71°	161°	(100)	(100)	80	60	80	80	80	60	60	40	60	60	30	20	10	10	10	20	40	40	60	60	(100)	(100)
71°	162°	(100)	(100)	80	60	80	80	80	60	40	40	60	60	20	10	10	20	10	40	40	20	60	60	(100)	(100)
71°	163°	(100)	(100)	80	80	80	(100)	80	60	20	20	60	40	20	10	10	20	10	40	40	20	60	60	(100)	(100)
70°30'	163°	(100)	(100)	80	80	80	(100)	80	60	60	20	60	40	20	10	10	20	10	0	20	10	60	60	(100)	(100)
71°	164°	(100)	(100)	80	80	80	(100)	80	80	20	20	60	20	20	10	10	20	20	40	20	10	40	60	(100)	(100)
70°31'	164°	(100)	(100)	80	80	80	(100)	80	80	40	20	60	20	20	10	10	20	10	40	10	10	40	60	(100)	(100)
71°	165°	(100)	(100)	80	100	(100)	(100)	80	80	40	20	40	20	20	10	20	20	10	10	10	10	40	80	100	(100)
70°30'	165°	(100)	(100)	80	100	(100)	(100)	80	80	40	20	40	20	20	10	0	20	20	10	20	10	40	80	100	(100)
71°	166°	(100)	(100)	80	100	(100)	(100)	80	80	40	20	20	20	20	20	10	20	10	10	20	10	20	80	100	(100)
70°30'	166°	(100)	(100)	80	100	(100)	(100)	80	80	40	20	20	20	20	10	0	20	10	10	10	10	20	80	100	(100)
71°	167°	(100)	(100)	80	100	(100)	(100)	80	80	60	20	20	40	20	20	10	10	(10)	(10)	20	(10)	20	60	100	(100)
70°30'	167°	(100)	(100)	80	100	(100)	(100)	80	80	40	20	20	40	20	20	0	10	(10)	0	10	(10)	20	60	100	(100)
71°	168°	(100)	(100)	80	100	(100)	(100)	80	80	60	40	40	20	40	20	10	10	(10)	0	0	(10)	40	60	100	(100)
70°30'	168°	(100)	(100)	80	100	(100)	(100)	80	80	40	40	40	20	40	20	10	10	(10)	0	0	(10)	40	60	100	(100)
70°31'	169°	(100)	(100)	100	100	(100)	(100)	80	80	40	40	60	20	60	10	10	10	10	0	0	(10)	60	60	(100)	(100)
71°	170°	(100)	100	100	100	(100)	(100)	80	80	40	60	(60)	20	40	10	10	10	(10)	0	0	(10)	60	(60)	(100)	(100)
70°30'	170°	(100)	100	100	100	(100)	(100)	80	80	40	60	(60)	20	60	10	10	0	(10)	0	0	(10)	60	(60)	(100)	(100)
72°	163°	(100)	(100)	80	100	(100)	(100)	100	100	80	(60)	60	60	60	40	10	20	10	10	20	20	40	60	100	(100)
71°30'	166°	(100)	(100)	100	100	(100)	(100)	100	100	(100)	(100)	80	(80)	60	40	10	20	10	10	20	20	40	60	100	(100)
72°	167°	(100)	(100)	100	100	(100)	(100)	100	100	(100)	(100)	80	(80)	60	40	10	20	10	10	20	20	60	60	100	(100)

N Boundary	W Boundary	J		F		M		A		M		J		J		A		S		O		N		D	
72°30'	165°	(100)	(100)	100	100	(100)	(100)	100	100	(100)	(100)	80	(80)	60	60	20	40	20	20	40	40	60	80	100	(100)
72°	160°	(100)	(100)	80	60	80	80	80	60	40	60	60	60	40	20	10	10	10	10	40	40	60	60	(100)	(100)
71°	160°	(100)	60	80	80	80	80	80	60	40	40	60	60	40	20	10	10	10	10	40	40	60	60	(100)	(100)
70°	164°	(100)	(100)	60	80	80	80	80	80	40	80	40	40	20	10	0	0	10	0	10	10	40	80	(100)	(100)
70°	165°	(100)	(100)	60	80	80	80	100	80	60	40	20	20	20	10	0	10	10	0	10	10	20	80	80	(100)
69°30'	165°	(100)	(100)	60	80	80	80	100	80	60	60	20	20	20	10	0	10	10	0	10	10	20	80	80	(100)
70°	166°	(100)	40	60	100	80	80	80	80	10	20	20	20	20	10	0	10	10	0	10	10	20	80	80	(100)
69°30'	166°	(100)	40	60	100	80	80	80	60	10	20	20	20	20	10	0	10	10	0	10	20	20	80	60	(100)
70°	167°	(100)	40	80	100	80	80	80	80	10	20	20	20	20	20	0	0	10	0	10	10	20	60	80	(100)
69°30'	167°	(100)	60	80	100	80	80	80	60	10	20	20	20	20	10	0	0	10	0	10	10	20	60	60	(100)
70°	168°	(100)	60	80	100	80	80	80	80	10	40	40	20	40	10	0	0	10	0	10	10	20	60	80	(100)
69°30'	168°	(100)	60	80	100	80	80	80	80	10	20	40	20	40	10	0	0	0	0	10	10	20	60	60	(100)
70°	169°	(100)	60	80	100	80	80	80	80	10	40	60	20	60	10	0	0	0	0	0	10	40	(60)	(100)	(100)
69°30'	169°	(100)	60	80	100	80	80	80	80	10	40	40	20	60	10	0	0	0	0	0	10	40	(60)	(80)	(100)
70°	170°	(100)	80	100	100	80	80	80	80	20	40	60	20	60	10	10	0	0	0	0	0	60	(60)	(100)	(100)
69°30'	170°	(100)	80	100	100	80	80	80	80	10	40	60	10	60	10	0	0	10	0	10	10	40	80	(100)	(100)

Table 2.

Estimated monthly mean temperatures, as compiled from actual temperature measurements, in areas bounded by 1° of longitude and 30' of latitude. The boundaries of the areas are given in the first two columns. Pairs of numbers are listed. The first is the mean in °C; the second (in parentheses) is the number of measurements upon which it is based. Parts I and II of the table are for the southern and northern Chukchi Sea respectively, as defined by latitude 69°N.

PART I

N Boundary	W Boundary	J	F	M	A	M	J	J	A	S	O	N	D
66°	168°								11.2 (3)				
66°	169°							4.0 (2)	2.9 (24)	4.4 (9)	4.5 (7)		
66°	170°								1.0 (5)		0.9 (1)		
66°30'	162°								3.1 (8)				
67°	163°								5.8 (6)				
66°30'	163°								4.4 (17)				
67°	164°								9.7 (19)				
66°30'	164°								9.4 (12)				
67°	165°								7.1 (1)				
67°	166°							7.6 (1)	8.9 (13)		4.2 (2)		
66°30'	166°								10.0 (1)				
67°	167°								7.2 (16)	7.7 (1)	5.1 (1)		
66°30'	167°								9.4 (2)				
67°	168°							3.3 (1)	6.7 (16)		3.4 (1)		
66°30'	168°								10.5 (15)	8.5 (1)	5.7 (3)		
67°	169°							3.4 (1)	4.4 (13)		3.3 (1)		
66°30'	169°								3.5 (22)		3.2 (4)		
67°	170°								3.7 (3)		2.8 (1)		

N Boundary	W Boundary	J	F	M	A	M	J	J	A	S	O	N	D
66°30'	170°							3.2 (1)	3.3 (1)		1.8 (2)		
67°	170°40'							2.4 (2)					
67°30'	164°								7.2 (67)				
68°	165°								10.0 (10)				
67°30'	165°								8.1 (22)	6.7 (1)			
68°	166°								5.2 (93)				
67°30'	166°						0.1 (5)		5.9 (15)	6.8 (1)	3.8 (3)		
68°	167°						0.3 (3)		4.1 (50)	3.0 (2)			
67°30'	167°								3.5 (13)				
68°	168°								3.0 (19)				
67°30'	168°								3.2 (15)	4.1 (1)	3.3 (1)		
68°	169°								3.5 (4)	2.6 (2)			
67°30'	169°								3.1 (9)		4.0 (2)		
68°	170°								3.3 (1)		3.3 (1)		
67°30'	170°								3.1 (4)		2.8 (1)		
67°30'	170°40'								1.8 (1)				
69°	166°								6.9 (2)				
68°30'	166°								10.2 (2)				
69°	167°							2.6 (2)	6.8 (8)			-1.8 (1)	
68°30'	167°								8.0 (23)	7.3 (1)			
69°	168°								6.0 (14)				

N Boundary	W Boundary	J	F	M	A	M	J	J	A	S	O	N	D
68°30'	168°							1.4 (1)	5.4 (17)	3.2 (1)	1.7 (1)		
69°	169°								3.7 (10)				
68°30'	169°								2.7 (6)	3.1 (1)	2.9 (1)		
69°	170°							--	--	--			
68°30'	170°							--	--	--			
69°	178°40'							--	--				
68°30'	170°40'										1.7 (2)		

PART II

N Boundary	W Boundary	J	F	M	A	M	J	J	A	S	O	N	D
71°	161°								3.4 (24)	5.1 (3)			
71°	162								2.8 (2)	4.0 (2)			
71°	163°								3.4 (1)	4.5 (2)			
70°30'	163°								6.6 (4)	6.8 (1)			
71°	164°									4.4 (1)			
70°30'	164°								4.6 (10)	6.8 (17)			
71°	165°								1.2 (12)	5.2 (4)			
70°30'	165°								3.7 (5)	6.5 (11)	0.4 (1)		
71°	166°								1.2 (19)	3.6 (1)			
70°30'	166°								-0.9 (1)	4.2 (6)	6.4 (6)		
71°	167°								2.1 (16)	3.3 (1)	1.8 (1)		
70°30'	167°							-0.3 (1)	3.2 (9)	2.3 (1)	2.7 (1)		
71°	168°								-0.7 (10)				
70°30'	168°							-0.9 (1)	0.6 (9)	2.8 (1)	2.2 (1)		
70°30'	169°								-1.5 (7)	-1.7 (1)			
71°	170°									0.8 (1)			
70°30'	170°								3.6 (1)	-1.5 (1)			
71°	170°40'							-1.2 (1)					
72°	163°								-1.8 (1)				
71°30'	166°							0.2 (1)					

N Boundary	W Boundary	J	F	M	A	M	J	J	A	S	O	N	D
72°	167°								-1.2 (1)				
72°30'	165°								-1.8 (8)				
72°	160°								--				
71°	160°								4.9 (12)	1.8 (1)			
70°	164°								5.2 (5)				
70°	165°								3.2 (4)	4.1 (2)			
69°30'	165°								2.4 (5)	7.1 (1)			
70°	166°								2.6 (8)	7.1 (4)			
69°30'	166°								6.4 (7)	7.1 (1)			
70°	167°								2.4 (19)	4.4 (4)			
69°30'	167°							2.6 (6)	5.8 (18)	6.5 (1)			
70°	168°							0.9 (5)	3.9 (4)	3.8 (2)			
69°30'	168°							2.1 (8)	5.0 (9)	4.8 (1)		0.2 (2)	
70°	169°								1.1 (5)				
69°30'	169°							1.1 (1)	1.4 (1)		3.2 (1)		
70°	170°								1.9 (2)	4.1 (1)			
69°30'	170°								3.0 (2)	2.7 (1)			

Table 3.

Estimated mean annual temperatures in areas bounded by 1° of longitude and 30' of latitude. The north and west boundaries of each area are given. The number of months for which temperature data exist is given in parentheses. Parts I and II of the table are for the southern and northern Chukchi Sea respectively, as defined by latitude 69°N.

PART I.

N Boundary	W Boundary	Mean Annual Temp. (°C)	Number of Months of Data
66°	168°	0.8	(1)
66°	169°	1.1	(4)
66°	170°	-0.8	(2)
66°30'	162°	-1.0	(1)
67°	163°	-0.6	(1)
66°30'	163°	-0.8	(1)
67°	164°	0.1	(1)
66°30'	164°	0.0	(1)
67°	165°	-0.2	(1)
67°	166°	1.6	(3)
66°30'	166°	0.3	(1)
67°	167°	1.6	(3)
66°30'	167°	0.3	(1)
67°	168°	0.8	(3)
66°30'	168°	2.4	(3)
67°	169	-0.5	(3)
66°30'	169°	-0.1	(2)
67°	170°	-0.1	(2)
66°30'	170°	0.2	(3)
67°	170°40'	-0.9	(1)
67°30'	164°	-0.4	(1)
68°	165°	0.2	(1)
67°30'	165°	0.9	(2)
68°	166°	-0.5	(1)
67°30'	166°	1.0	(4)
68°	167°	0.1	(3)
67°30'	167°	-0.7	(1)
68°	168°	-0.9	(1)
67°30'	168°	0.4	(3)
68°	169°	-0.3	(2)
67°30'	169°	-0.1	(2)
68°	170°	-0.2	(2)
67°30'	170°	-0.3	(2)
67°30'	170°40'	-1.1	(1)
69°	166°	-0.2	(1)
68°30'	166°	0.6	(1)
69°	167°	0.7	(3)
68°30'	167°	0.0	(2)
69°	168°	-0.4	(1)
68°30'	168°	0.5	(4)
69°	169°	-0.8	(1)
68°30'	169°	0.1	(3)
69°	170°	-1.7	(0)
68°30'	170°	-1.7	(0)
69°	170°40'	-1.7	(0)
68°30'	170°40'	-1.1	(1)

PART II.

N Boundary	W Boundary	Mean Annual Temp. (°C)	Number of Months of Data
71°	161°	-0.3	(2)
71°	162°	-0.5	(2)
71°	163°	-0.3	(2)
70°30'	163°	0.4	(2)
71°	164°	-0.8	(1)
70°30'	164°	0.2	(2)
71°	165°	-0.5	(2)
70°30'	165°	0.0	(3)
71°	166°	-0.7	(2)
70°30'	166°	0.0	(3)
71°	167°	-0.3	(3)
70°30'	167°	-0.2	(4)
71°	168°	-1.6	(1)
70°30'	168°	-0.54	(4)
70°30'	169°	-1.7	(2)
71°	170°	-1.4	(1)
70°30'	170°	-1.1	(2)
72°	163°	-1.7	(1)
71°30'	166°	-1.5	(1)
72°	167°	-1.6	(1)
72°30'	165°	-1.7	(1)
72°	160°	-1.7	(0)
71°	160°	-0.5	(2)
70°	164°	-0.7	(1)
70°	165°	-0.3	(2)
69°30'	165°	-0.1	(2)
70°	166°	0.2	(2)
69°30'	166°	0.8	(2)
70°	167°	-0.3	(2)
69°30'	167°	0.8	(3)
70°	168°	0.0	(3)
69°30'	168	0.5	(4)
70°	169°	-1.3	(1)
69°30'	169°	-0.4	(3)
70°	170°	-0.6	(2)
69°30'	170°	-0.6	(2)

QUARTERLY REPORT

CONTRACT #03-5-022-55

RESEARCH UNIT #271

REPORT PERIOD: QUARTER ENDING DECEMBER 31

BEAUFORT SEACOAST PERMAFROST STUDIES

JAMES C. ROGERS

GEOPHYSICAL INSTITUTE

UNIVERSITY OF ALASKA 99501

907-272-5522 X225

I. Task Objectives - See previous reports.

II. No field work was done this quarter.

III. Analysis of data continues. Preliminary results: High velocity subbottom refractors judged to be permafrost have been observed at all four locations sampled on the edge of Prudhoe Bay. In the center of the bay, no refractors have been located, indicating either the absence of permafrost or permafrost existing below the depth capability of the equipment. Investigation of this question continues.

Frozen material velocities were observed in the sparsely-vegetated areas on Cross Island. No frozen material was observed on Reindeer Island. In both cases, a hammer seismograph with a depth capability of perhaps ten meters was used.

IV. See III.

V. Additional work is required in Prudhoe Bay to determine the permafrost surface roughness and contours. Further work is also required to determine the influence of the Sag river on the sub-bottom permafrost distribution.

VI. Funds spent to date approximately $85,000.

Quarterly Report

Contract #03-5-022-56
Research Unit #291
Task Order #3
Reporting Period 10/1 -12/31/76
Number of Pages 8

BENTHOS - SEDIMENTARY SUBSTRATE INTERACTIONS

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January 1, 1977

I. Task Objectives

A computer print-out of macrobenthos data for 29 stations has been received and analysed. From the 443 taxons listed, 90 occur at 2.5 percent by weight (or more) at one or more stations. These 90 taxa will be correlated with grain size characteristics.

II. Field Activities

None

Laboratory Activities

Tabulation of benthos species has been done for the 29 stations available. The data were submitted to M. Crane, E.D.S. No additional sediment samples have been received for grain size analysis.

III. Results

None

IV. Problems Encountered

At the outset of this project, it was assumed that benthos data would be available for each station and sampling period. This apparently will not be so, due to cost. Comparing benthos data with grain size data (see enclosed Table) shows that 9 of 29 have both sets of data currently available for the same station and sampling day. As it is much more costly to generate benthos data, an attempt may be made to secure funds necessary for grain size analyses to be made for the remaining 20 stations, unless corresponding benthos data are made available in the very near future.

BERING SEA

STATION NUMBER	SAMPLING DATE IN 1975	N. LAT.	W. LONG.	WATER DEPTH, m	RAW SAMPLE	SIZE ANALYSIS	MACROBENTHOS DATA
1	22 or 24 September	55^{o} 18'	163^{o} 19'	50	1	no	no
2					no	no	no
3	8 June	56^{o} 17.4'	161^{o} 02.3'	52	no	yes	no
3A	17 October	56^{o} 02'	160^{o} 41'	14	yes	no	no
4					no	no	no
5	8 June	57^{o} 20.5'	158^{o} 50.0'	48	no	yes	yes
6	10 May	57^{o} 43'	159^{o} 05'	52	yes	no	no
	19 May			71	yes	no	no
	8 June			45	yes	no	no
	6 October	57^{o} 43.4'	159^{o} 05.4'	48	no	yes	no
7	8 June	58^{o} 58'	158^{o} 15.7'	35	no	yes	yes
8	8 June			23.7	yes	no	no
	5 October	57^{o} 16'	159^{o} 31'	25	yes	no	no
	6 October	57^{o} 17'	159^{o} 31.7'	22	no	yes	no
9	20 May				yes	no	no
	9 June	57^{o} 54.8'	160^{o} 08.5'	53	no	yes	yes
10	10 May	57^{o} 19.5'	161^{o} 05.8'	65	yes	no	no
	20 May				yes	no	no
	9 June	57^{o} 19.5'	161^{o} 05.8'		no	yes	no
11	9 June	56^{o} 45.4'	161^{o} 59.7'	71	no	yes	no
12	15 September	56^{o} 08'	162^{o} 56'		yes	no	no
13	6 June			87	yes	no	no
13	7 June				no	no	no
13A	1 September	55^{o} 05'	164^{o} 43'	84	yes	no	no
13B	1 September	55^{o} 05.5'	164^{o} 47'	100	yes	no	no
13	2 September	55^{o} 05.5'	164^{o} 47.0'	102	no	yes	no
13	16 September	55^{o} 33'	163^{o} 49'	84	yes	no	no

BERING SEA
(continued)

STATION NUMBER	SAMPLING DATE IN 1975	N. LAT.	W. LONG.	WATER DEPTH, m	RAW SAMPLE	SIZE ANALYSIS	MACROBENTHOS DATA
14	7 June	54° 38.7'	165° 25.3'	163	no	yes	yes
14A	22 September	54° 53'	165° 04'		yes	no	no
14A	22 September	54° 53'	165° 04'	95	yes	no	no
14C	22 September	54° 53'	165° 43'	140	yes	no	no
15	29 May	54° 18'	167° 38'		no	no	yes
16	28 May	54° 53'	166° 44'		no	no	yes
	2 September	54° 52'	166° 48'	197	yes	no	no
	2 September	54° 53.1'	165° 48.0'	198	no	yes	no
16A	3 September	54° 51.7'	167° 26.6'	476	yes	no	no
17	28 May	55° 28'	165° 50.0'		no	no	yes
	2 September	55° 28.2'	165° 49.2'	124	no	yes	no
18	28 May	56° 05'	164° 55'		no	no	yes
	15 September	56° 06'	164° 54'	93	yes	no	no
19	10 June	56° 40.0'	163° 57.6'	77	no	yes	no
	14 September	56° 38'	163° 51'	79	yes	no	no
20	4 October	57° 15'	163° 05'	54	yes	yes	no
21	10 June			47	yes	no	no
	4 October	57° 32'	162° 40'	50	yes	no	no
	5 October	57° 32.1'	162° 40.0'	48	no	yes	no
22	10 June	57° 50'	162° 10'		no	no	yes
	7 October	57° 50'	162° 11'	50	yes	no	no
	7 October	57° 50'	162° 10'	46	no	yes	no
23	6 October	58° 20'	161° 21'	31	yes	no	no
	6 October	58° 20'	161° 21'	33	yes	no	no
	7 October	58° 20'	161° 21.1'	33	no	yes	no
24	22 May	57° 27.3'	167° 26.40'		no	no	yes
	10 June			47.5	yes	no	no
	8 October	58° 46.1'	162° 30.3'	48	no	yes	no

BERING SEA
(continued)

STATION NUMBER	SAMPLING DATE IN 1975	N. LAT.	W. LONG.	WATER DEPTH, m	RAW SAMPLE	SIZE ANALYSIS	MACROBENTHOS DATA
25	11 June	58° 19.0'	163° 13.0'		yes	no	yes
	8 October	58° 19.7'	163° 13.0'	33	no	yes	no
26	11 June			51	yes	no	no
	4 October	57° 44.4'	164° 14.4'	51	no	yes	no
27	23 May				yes	no	no
	11 June	57° 40.1'	164° 16.3'	53	no	yes	no
	4 October	57° 40.0'	164° 23.0'	50	yes	yes	no
28	11 June	57° 09.9'	165° 04.3'	70	no	yes	no
	24 September	57° 10.0'	165° 04.0'	75	yes	no	no
29	22 May			73	yes	no	no
	28 May	56° 35.0'	165° 54.0'		no	no	yes
	31 August	56° 32.0'	165° 54.0'	84	yes	no	no
	1 September	56° 36.2'	165° 54.0'	84	no	yes	no
30	27 May	55° 59.0'	165° 57.0'		no	no	yes
31	6 June	55° 21.9'	167° 46.5'	166	no	yes	no
32	23 May	57° 47.0'	167° 43.0'		no	yes	yes
33	23 May				yes	yes	no
34	5 June	55° 52.8'	168° 44.1'	150	no	yes	no
35	24 May	58° 51.0'	169° 17.0'	68	yes	yes	yes
36	24 May				yes	yes	no
	27 May	56° 30.0'	167° 56.0'		no	no	yes
37	25 May	58° 41.0'	169° 17.2'		yes	no	yes
	16 June			75	yes	no	no
	31 August	57° 05.0'	167° 00.0'	73	yes	no	no
	1 September	57° 05.9'	167° 00.1'	77	no	yes	no

BERING SEA
(continued)

STATION NUMBER	SAMPLING DATE IN 1975	N. LAT.	W. LONG.	WATER DEPTH, m	RAW SAMPLE	SIZE ANALYSIS	MACROBENTHOS DATA
38	12 June	57° 40.0'	166° 05.9'	66	yes	yes	no
39	25 May	58° 28.5'	169° 18.2'		yes	no	yes
	12 June	58° 02.7'	165° 29.8'	52	no	yes	no
40	12 June	58° 08.5'	165° 17.4'	47	no	yes	no
41	25 May	58° 20.0'	169° 19.0'		yes	no	yes
	12 June	58° 47.0'	164° 14.3'	33	yes	no	yes
	8 October	58° 45.8'	164° 12.2'	35	no	yes	no
42	25 May	58° 25.0'	169° 23.0'		no	no	yes
	12 June			22	yes	no	no
	8 October	59° 16.0'	165° 20.0'	23	yes	yes	no
43	25 May				yes	no	no
	27 August	58° 42.5'	166° 16.3'	40	no	yes	no
	27 August	59° 42.0'	166° 13.0'	40	yes	no	no
44	13 June	58° 26.0'	166° 43.0'	47	no	yes	no
	13 June	58° 26.0'	166° 43.0'	47	no	yes	no
45	26 May				yes	no	no
	12 June			62	yes	no	no
	13 June	58° 10.0'	167° 10.0'		no	no	yes
	14 October	58° 09.8'	167° 10.7'	62	no	yes	no
	14 October	58° 09.8'	167° 10.7'	62	no	yes	no
46	16 June			72	yes	no	no
	19 August	57° 34.8'	168° 07.0'	75	no	yes	no
	19 August	57° 34.0'	168° 05.0'	69	yes	no	no
47	18 August	56° 59.0'	169° 01.0'	84	no	yes	no
48	4 June	56° 19.1'	169° 42.0'	155	no	yes	no
49	4 June	56° 29.6'	169° 56.7'	105	no	yes	yes
	4 June	56° 24.6'	169° 56.7'	105	no	yes	no

BERING SEA
(continued)

STATION NUMBER	SAMPLING DATE IN 1975	N. LAT.	W. LONG.	WATER DEPTH, m	RAW SAMPLE	SIZE ANALYSIS	MACROBENTHOS DATA
50	4 June	59° 06.9'	170° 23.6'	135	no	no	no
51					no	no	no
52					no	no	no
53	26 May	57° 49.0'	169° 38.0'		no	no	yes
54	4 June	56° 58.2°	170° 58.8'	110	no	yes	no
55	20 August	57° 31.0'	170° 00.0'	73	no	yes	no
56	15 June			71	yes	no	no
	30 August	58° 36.0'	168° 13.0'	75	yes	no	no
	31 August	58° 05.0'	169° 02.0'	75	no	yes	no
	31 August	58° 05.0'	169° 02.0'	75	no	yes	no
57	13 June	58° 37.2'	168° 13.0'	53	no	yes	yes
	29 August	58° 36.0'	168° 12.8'	55	yes	yes	no
58	28 May			84	yes	no	no
	13 June			44	yes	no	no
	28 August	58° 49.0'	168° 56.0'	25	yes	no	no
	29 August	58° 49.2'	168° 57.1'	46	no	yes	no
59	13 June			38	yes	no	no
	25 August	59° 11.7'	167° 16.2'	38	no	yes(2)	no
	25 August	59° 12.0'	167° 15.0'	19	yes	no	no
60	13 June	59° 43.0'	166° 24.0'	29	no	yes	yes
	24 August	59° 44.0'	169° 27.0'	12	yes	no	no
	25 August	59° 44.0'	166° 27.5'	27	no	yes	no
61	13 June			29	yes	no	no
	27 August	59° 39.0'	168° 22.0'	22	yes	no	no
	28 August	59° 39.0'	168° 21.8'	38	no	yes	no
62	14 June	59° 05.9'	169° 15.1'	55	no	yes(2)	no
	28 August	59° 04.8'	169° 14.2'	55	yes	yes	no

BERING SEA
(continued)

STATION NUMBER	SAMPLING DATE IN 1975	N. LAT.	W. LONG.	WATER DEPTH, m	RAW SAMPLE	SIZE ANALYSIS	MACROBENTHOS DATA
63	14 June			73	yes	no	no
	30 August	58° 33.4'	170° 10.0'	75	yes	yes	no
64	14 June			90	yes	no	no
	20 August	58° 01.0'	171° 08.5'	93	yes	yes	no
65	15 June	57° 24.7'	172° 05.5'	109	no	yes	no
66	15 June	56° 44.2'	173° 11.5'	141	no	yes(2)	no
67	15 June				no	no	no
68	15 June	57° 29.7'	173° 05.2'	135	no	yes	no
69	15 June	57° 56.5'	173° 05.2'	114	no	yes	no
70	21 August	58° 29.0'	172° 13.0'	106	no	yes(2)	no
71	21 August	59° 03.9'	171° 10.8'	82	yes	yes	no
72	24 August	59° 33.9'	170° 19.0'	68	no	yes	no
73	23 August	60° 02.4'	169° 29.2'	48	no	yes	no
82	22 August	60° 32.9'	170° 29.9'	60	no	yes(2)	no
83	23 August	60° 02.0'	171° 26.0'	73	no	yes	no
92	22 August	60° 28.5'	172° 27.0'	57	no	yes	no

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 3 R.U. NUMBER: 291

PRINCIPAL INVESTIGATOR: Dr. C. M. Hoskin

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[1]		
	From	To	Batch 1		
Discoverer Leg I #808	5/15/75	5/30/75	Submitted		
Discoverer Leg II #808	6/2/75	6/19/75	Submitted		
Miller Freeman	8/16/75	10/20/75	Submitted		

All data for FY '76 have been submitted.

Note: [1] Estimated submission dates are contingent upon final approval of data management plan submitted in draft form Oct. 9, 1975 and University of Alaska approved form Nov. 10, 1975, to NOAA.

1st Quarter Report
OCSEAP RU#327

Shallow faulting, bottom instability, and movements of sediments in lower Cook Inlet and western Gulf of Alaska

Principal investigators: Monty A. Hampton
Arnold H. Bouma
U.S. Geological Survey
Menlo Park, California

I. Task objectives
Assessment of the environmental geologic hazards of lower Cook Inlet and the western Gulf of Alaska; in particular the identification and mapping of active surface faults and areas of sediment instability.

II. Field or Laboratory Activities
During the past quarter we have concentrated our efforts on analyzing data from lower Cook Inlet, due to the announced lease sale in February, 1977. We made available microfilms of our seismic records as part of U.S. Geological Survey Open-File Report 76-848 (Appendix A). Measurements were made from our sparker records of the thickness of Quaternary sediments in the lower Inlet, and a generalized isopach map was constructed (Appendix B). A map of the faults in lower Cook Inlet also was prepared (Appendix C), as a revision of the preliminary map that was included in our U.S. Geological Survey Open-File Report 76-695. Finally, a study was made of the bedforms observed on our bottom television, side-scan sonar, and high-resolution seismic records in lower Cook Inlet (Appendix D).

III. Results
See Appendix A,B,C,D.

IV. Preliminary interpretation of results
See Appendix A,B,C,D.

V. Problems encountered/recommended changes
None

VI. Estimate of funds expended
Only USGS funds expended; no BLM/NOAA funds received.

APPENDIX A

U.S. Geological Survey Open-File Report 76-848

"Seismic profiles of lower Cook Inlet and Kodiak Shelf, R/V SEA SOUNDER, June - July 1976"

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Seismic profiles of Lower Cook Inlet and Kodiak Shelf, R/V SEA SOUNDER, June-July 1976

by

Monty A. Hampton and Arnold H. Bouma

OPEN-FILE REPORT

76-848

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

Menlo Park, California

November, 1976

INTRODUCTION

From June 18 until July 30, 1976, the Pacific-Arctic Branch of the U.S. Geological Survey conducted an environmental geologic cruise in lower Cook Inlet and on the Kodiak shelf (Fig. 1). Sparker, uniboom and 3.5 kHz seismic records were acquired along approximately 6500 kilometers of track line (Plates 1 and 2). In addition, side scan sonar surveys, bottom television observations and 154 sampling stations were made (Bouma and Hampton, 1976).

This report accompanies the seismic records that are publicly available on microfilm. It includes two track-line maps (Plates 1 and 2) at a scale 1:500,000 and two shot-point maps (Plates 3 and 4) at the same scale. This report also includes examples of the navigational data sheets as they were made during the survey and which are included on the microfilm, some remarks on the navigational accuracy, and an explanation of notations made on the seismic records. Details on the equipment, location and textural data of samples, shipboard interpretations of the sparker records, and some notations on the geology of both areas are given in Open-File Report 76-695 (Bouma and Hampton, 1976).

Microfilm prints of the seismic records and the shipboard logs are available from:

U.S. Geological Survey
Alaska Technical Data Unit
345 Middlefield Road
Menlo Park, California 94025
Telephone (415) 323-8111, ext. 2342

National Geophysical and Solar Terrestrial
Data Center
EDS/NOAA
Boulder, Colorado 80302

NAVIGATION

Two independent navigational systems were used by the scientific party. One system was a Magnavox integrated satellite-Loran C system that automatically recorded the data on magnetic tape, as well as typing it out on a keyboard printer. The other system was a Motorala Mini-Ranger unit that recorded the data on paper tape at 7-1/2 minute intervals.

Mini-Ranger positions were plotted manually on a 1:5000,000 scale chart at intervals of 15 minutes. In addition, all acceptable satellite positions were plotted. For easy reference a shot-point number was given to each 15-minute position. All satellite positions are shown on the enclosed position maps (Plates 3 and 4) as triangles with the time of fix. Mini-Ranger positions are presented as dots or as squares with shot-point numbers and occasionally with a time (GMT) indication. If a line started prior to an even 15-minute interval, shot-point number 0 was used to mark the position of the start of the line. In addition to the routine plots, the locations of major course changes were also plotted (see also trackline maps, Plates 1 and 2).

The Mini-Ranger was the primary navigational system, as the Loran C coverage in this region was inadequate. In most instances the Mini-Ranger locations were of high quality when the ship moved inside the range of the system's transponders. The maximum line-of-sight range for the Mini-Ranger was 80 nautical miles, but many stations on shore did not have sufficient elevation to obtain such a range. Consequently, some navigational weaknesses were encountered near the Kodiak shelf break. Technical problems occasionally occurred, forcing us to make use of direct bearings and radar.

SEISMIC SYSTEMS

A total of 2419 nm (4499 km) of sparker data, 2552 nm (4746 km) of uniboom data, and 3524 nm (6555 km) of 3.5 kHz high resolution data was recorded in Cook Inlet and on the Kodiak shelf. The combination of shallow water and sandy-gravelly bottom in many places resulted in little subbottom penetration and many strong multiples.

Examples and annotations, as can be found on the microfilm, are given in this report. Shot-point numbers are used throughout and occasionally the Julian Day and the time in GMT are listed. Stamps are given for beginning and end of line (see enclosed samples) as well as for beginning and end of roll of recording paper.

OTHER DATA

Open-file report 76-695 (Bouma and Hampton, 1976) lists the cruise itinerary, nannofossil ages of dart and gravity cores from Kodiak shelf and the position, lithology and some textural and color data from the samples collected at 154 stations. That report contains 9 maps (1:500,000) showing tracklines, shipboard analysis and interpretation of sparker data, location of faults, slumps and wavy bedforms, and shipboard microscopic analysis of surficial sediments. Besides containing information on instrumentation and procedures, some preliminary notes on both areas are given.

Background information on lower Cook Inlet with several references is given in open-file report 75-429 (Magoon and others), and on the Kodiak shelf in open-file report 76-325 (von Huene and others).

NOTES TO FIGURES

Attached are a number of figures displaying examples from the microfilms. Figure 2 shows the stamp used to indicate start or end of a roll of record paper, and a stamp employed to give the start or end of a trackline. The start/end of roll stamp gives archive information on the first four lines and a notation of start or end of roll. The four bottom lines show the type of data collected, Julian Day (JD), time in GMT, trackline number, and type of recorder employed. The lower stamp also gives the Julian Day, time in GMT, trackline number, the ship's course (CSE), speed (SPD) in knots, scale on the record in meters, type of data collected (values), and beginning or end of line.

Figures 3 and 4 give examples of 3.5 kHz high-resoltuion subbottom records, which commonly do show little more than bathymetry when dealing with shallow water depth and hard bottom (Fig. 3). Figure 4 shows good subbottom in reflectors in a 3.5 kHz record, in the area below the scarp. The main reason for penetration is the fine-grained nature of the overlying material.

Both 3.5 kHz examples show the "white" zone above the bottom which is due to the use of the Raytheon Correlation Echo Signal Processor (CESP) unit. The notations along the margin of the record indicate time in GMT, occasionally the Julian Day and the water depth in meters, and the shotpoint number encircled at 15 minute intervals.

Figures 5 and 6 present a low and a high quality uniboom record, respectively. Notations on the records are similar to those on the 3.5 kHz records. Hard bottom material, shallow water and a profiling speed of about 6 knots often prevents good subbottom information (Fig. 5). However, when slowing down to 4 knots or less for side-scan sonar surveys, a considerable improvement in record quality can be obtained. For example, figure 6 shows good quality uniboom records over a field of sand waves in Cook Inlet, shot at a speed of 4 knots. Foreset bedding can be seen internally within the sand waves. A strong reflector occurs immediately below the troughs of the sand waves, and an angular unconformity can be detected at about 0.15 sec below the water surface.

Sparker records are displayed in figures 7 and 8. Little, if any, subbottom information can be obtained in very shallow water due to the closely spaced multiples. As the multiples become separated, the subbottom reflectors can be distinguished, often even below the first and second multiples. Notations on the records are identical to the ones described above.

Figure 9 gives an example of the navigation log used on board the R/V Sea Sounder. The columns Julian Day, GMT time, Line Number (letter or number), and Station Number are self-explanatory. The column "Comments" uses several abbreviations: Sat 19 = satellite number 19, SP 9 = shotpoint 9, EOL = end of line, SOL = start of line, and MNR = Mini-Ranger. The "Fix Quality" column gives good (G), fair (F) or poor (P) for the quality of the navigational fix.

The column "Fix Type" uses abbreviations for: CCS = course change, S = satellite, DRC = dead reckoning course, MNR = Mini-Ranger. The other columns for New Course, New Speed, Longitude and Latitude follow known rules.

Very little use was made of the remaining columns except for writing down Mini-Ranger distances and shore-based transponder numbers.

Enclosed in a pocket in the back of this report are four maps on 1:500,000 scale. Plates 1 and 2 give the trackline positions and numbers for lower Cook Inlet and the Kodiak shelf, respectively. The numbering generally is not in any temporal or spatial sequence, as we deviated from the original preplots. In addition to using numbers for tracklines, some letters were used in the beginning of the cruise.

Plates 3 and 4 cover the same areas as Plates 1 and 2 and present the navigational plots. Solid dots or open circles are used for the 15-minute positions and the shotpoint number is given next to the fix. In a few cases the shotpoints have been connected to avoid confusion. Satellite positions are given by open triangles together with the GMT time of the fix. The normal fixes often have a full-hour time notation to facilitate realizing the correspondence between satellite and other types of fixes.

REFERENCES

Bouma, A. H. and Hampton, M. A., 1976, Preliminary report on the surface and shallow subsurface geology of lower Cook Inlet and Kodiak Shelf, Alaska: U.S. Geol. Survey Open-File Report 76-695.

Magoon, L. B., Hampton, M. A., Sable, E. G., Smith, R. A. and Chmelik, F. B., 1975, Hydrocarbon-potential, geologic hazards, and the technology, time-frame and infrastructure for exploration and development of the lower Cook Inlet, Alaska, a preliminary assessment: U.S. Geol. Survey Open-File Report 75-549.

Von Huene, R., Bouma, A., Moore, G., Hampton, M., Smith, R. and Dolton, G., 1976, A summary of petroleum potential, environmental geology, and the technology, time frame, and infrastructure for exploration and development of the western Gulf of Alaska: U.S. Geol. Survey Open-File Report 76-325.

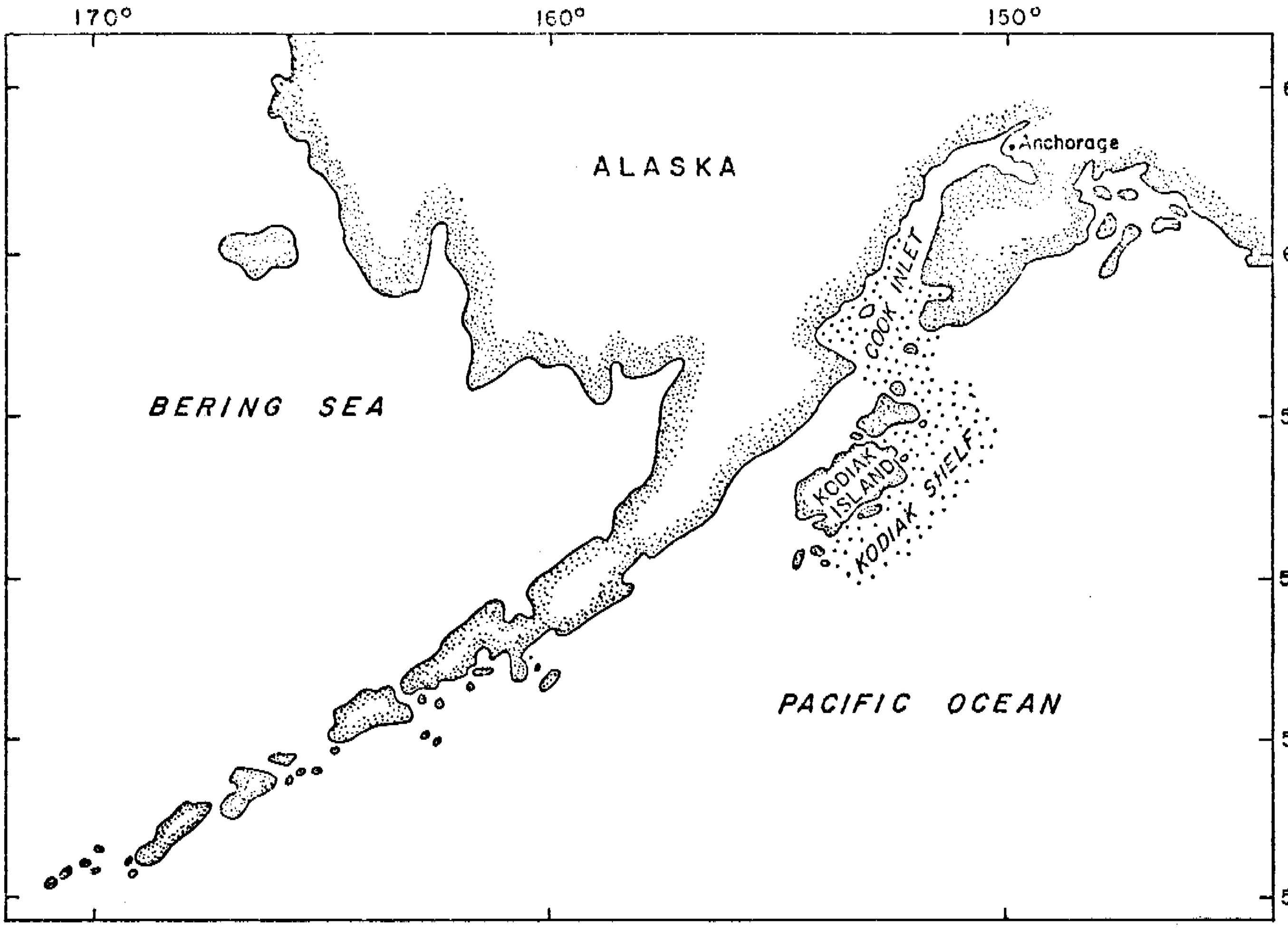


Figure 1.- Generalized location map of the study area

U.S.G.S. SHIP SEA SOUNDER START ROLL ☒

CHF. SCI BOUMA/HAMPTON END ROLL ☐

LOCATOR SEA 2 . 76 . WG
(I.D.) (YR.) (AREA)

ARCHIVE # SCAR . 7
(DATA CODE) (ROLL #)

DATA TYPE 90 KJ SPARKER

START JD 191 TIME 0224 Z LINE 81

END JD 195 TIME 0148 Z LINE 92

RECORDER # & TYPE RAYTHEON

START/END OF ROLL

JD 202 TIME 2321 Z LINE 184

CSE 021 SPD 5.4 SCALE 0.187m

VALUES UNIBOOM

☐ START LINE ☒ END LINE ☐ ROUTINE ☐ OTHER

START/END OF LINE

FIGURE 2. - EXAMPLES OF START/END OF ROLL AND START/ END OF LINE ANNOTATIONS AS USED ABOARD THE R/V SEA SOUNDER.

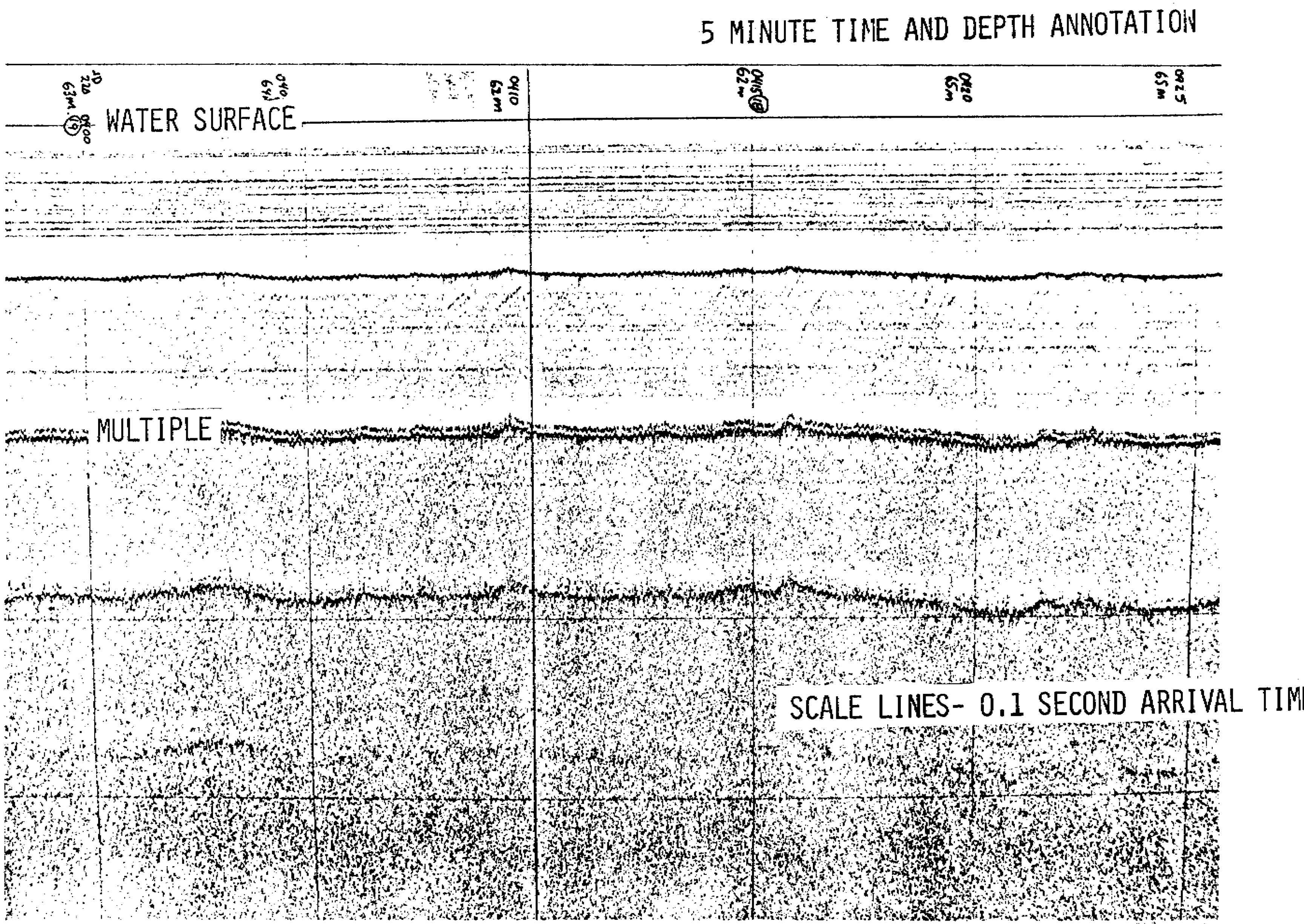


FIGURE 3.- EXAMPLE OF 3.5 KILOHERTZ BATHYMETRY RECORD.

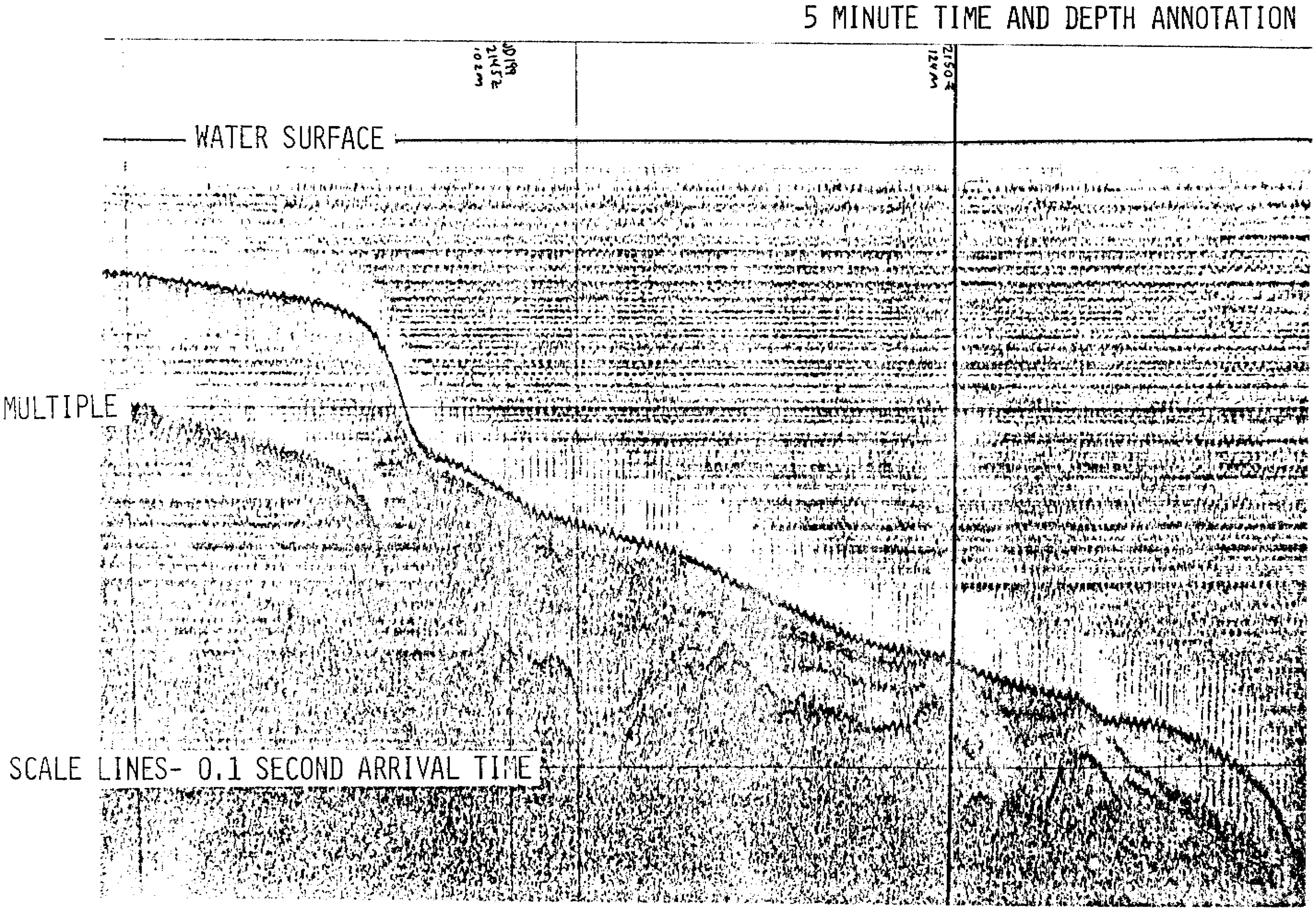


FIGURE 4.- EXAMPLE OF 3.5 KILOHERTZ BATHYMETRY SYSTEM SHOWING SUBBOTTOM STRUCTURE.

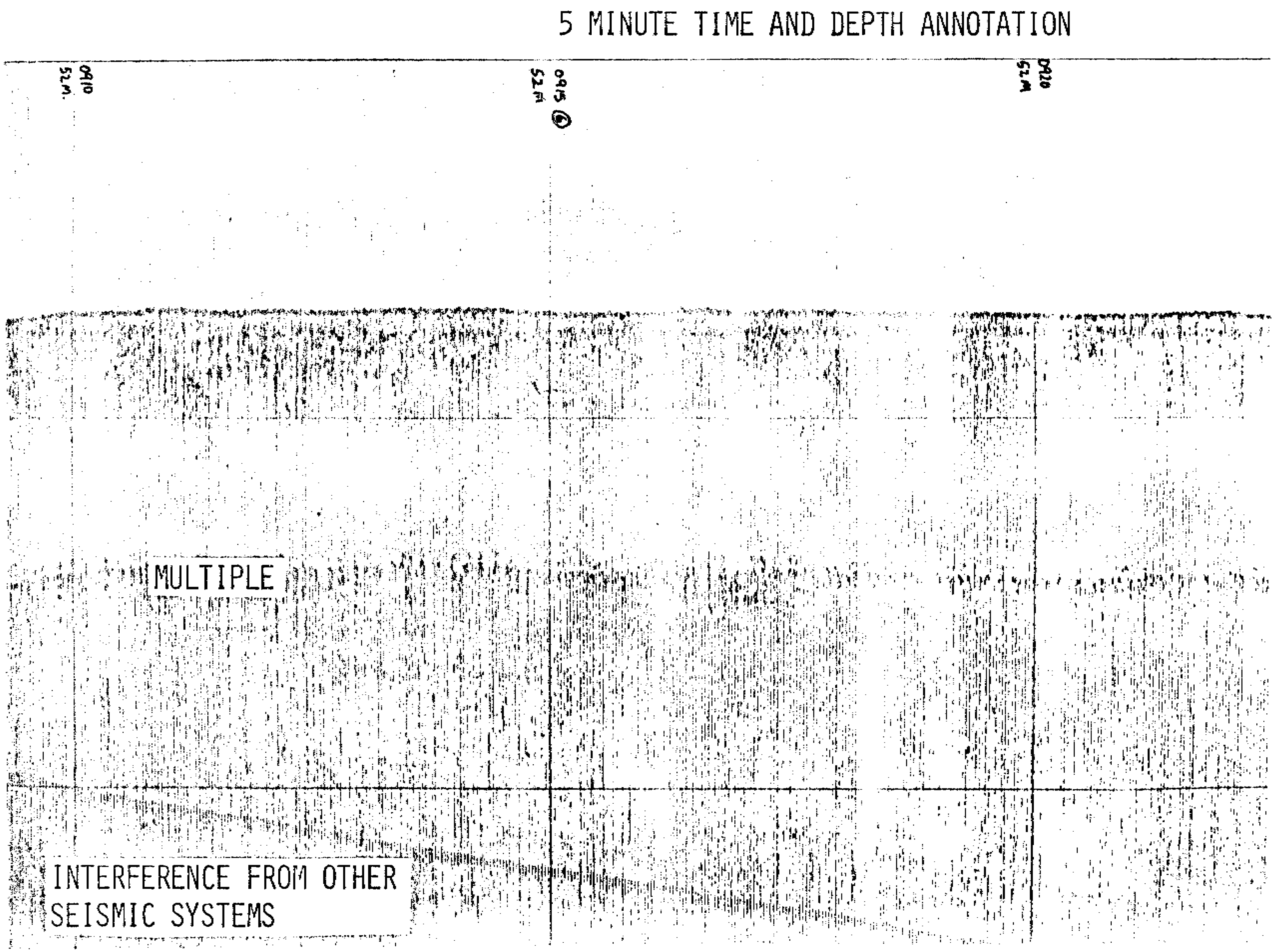


FIGURE 5. - EXAMPLE OF LOW-QUALITY UNIBOOM RECORD SHOWING ONLY BATHYMETRY DUE TO EXTREMELY HARD BOTTOM CONDITIONS WHICH DO NOT ALLOW PENETRATION OF ENERGY.

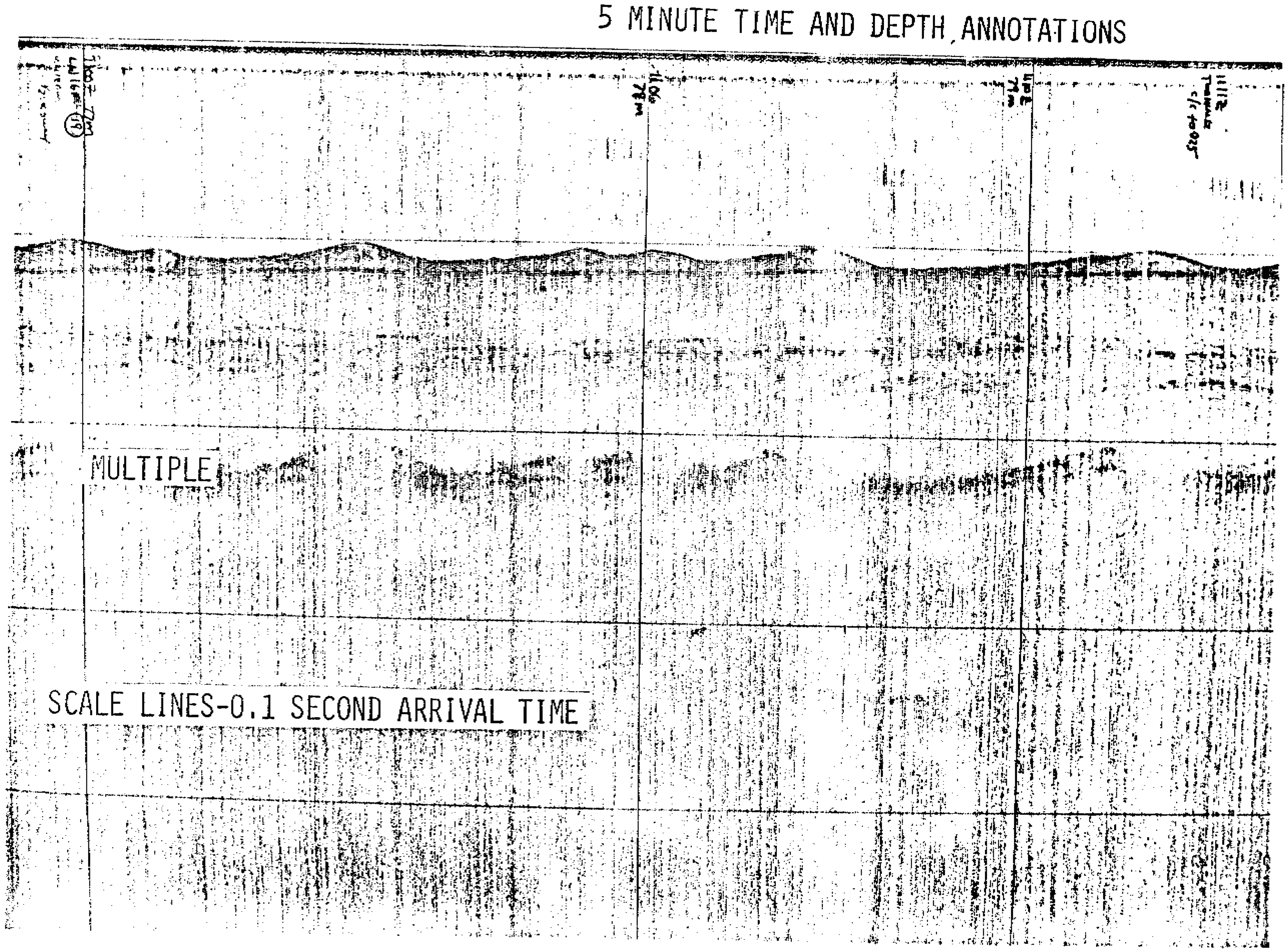


FIGURE 6.- EXAMPLE OF HIGH-QUALITY UNIBOOM RECORD SHOWING SUBBOTTOM STRUCTURE.

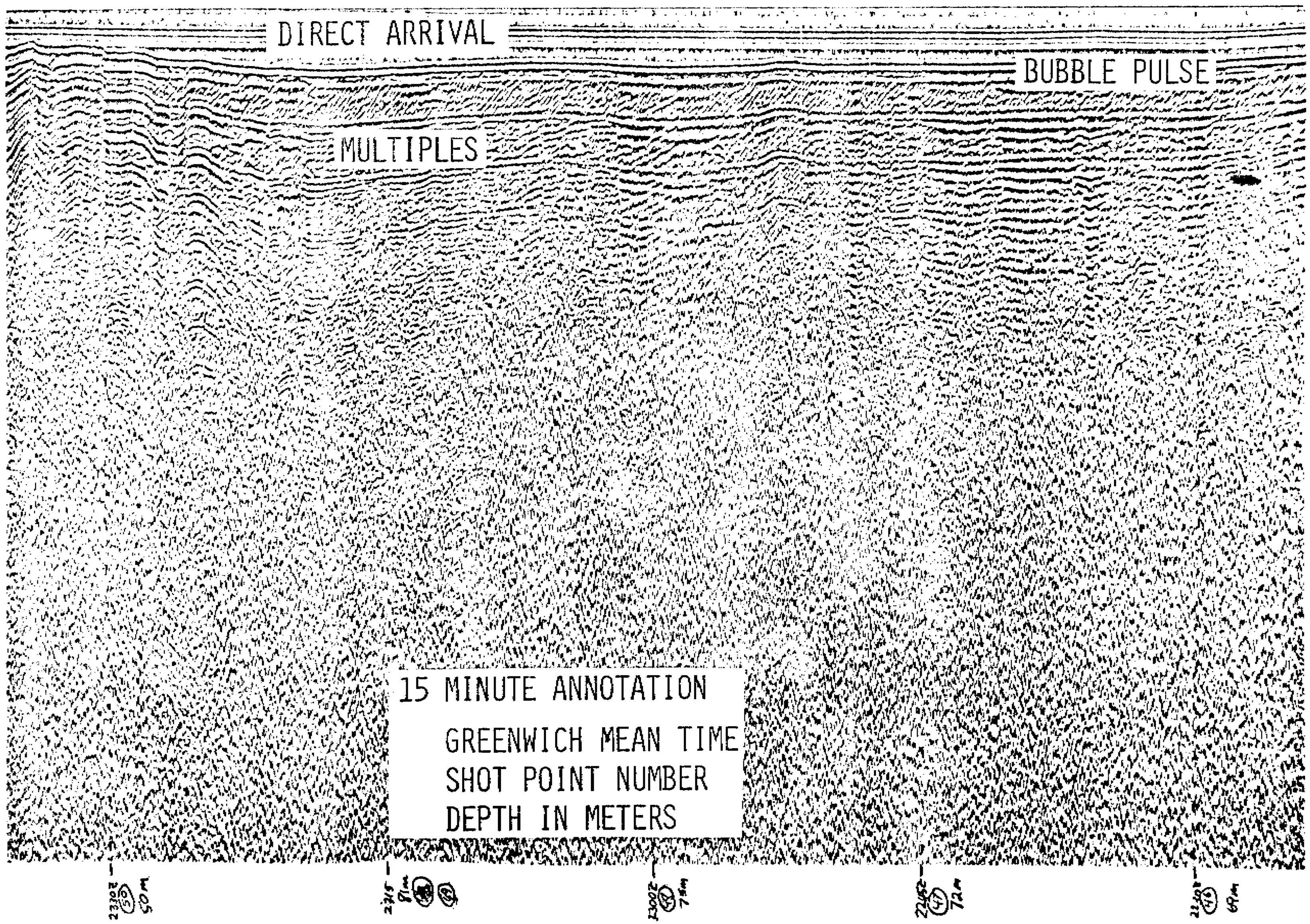


FIGURE 7. - EXAMPLE OF LOW-QUALITY 30 KILOJOULE SPARKER RECORD. EXTREMELY SHALLOW WATER CAUSES MULTIPLE REFLECTIONS TO BE VERY CLOSELY SPACED, OBSCURING SUBBOTTOM STRUCTURE.

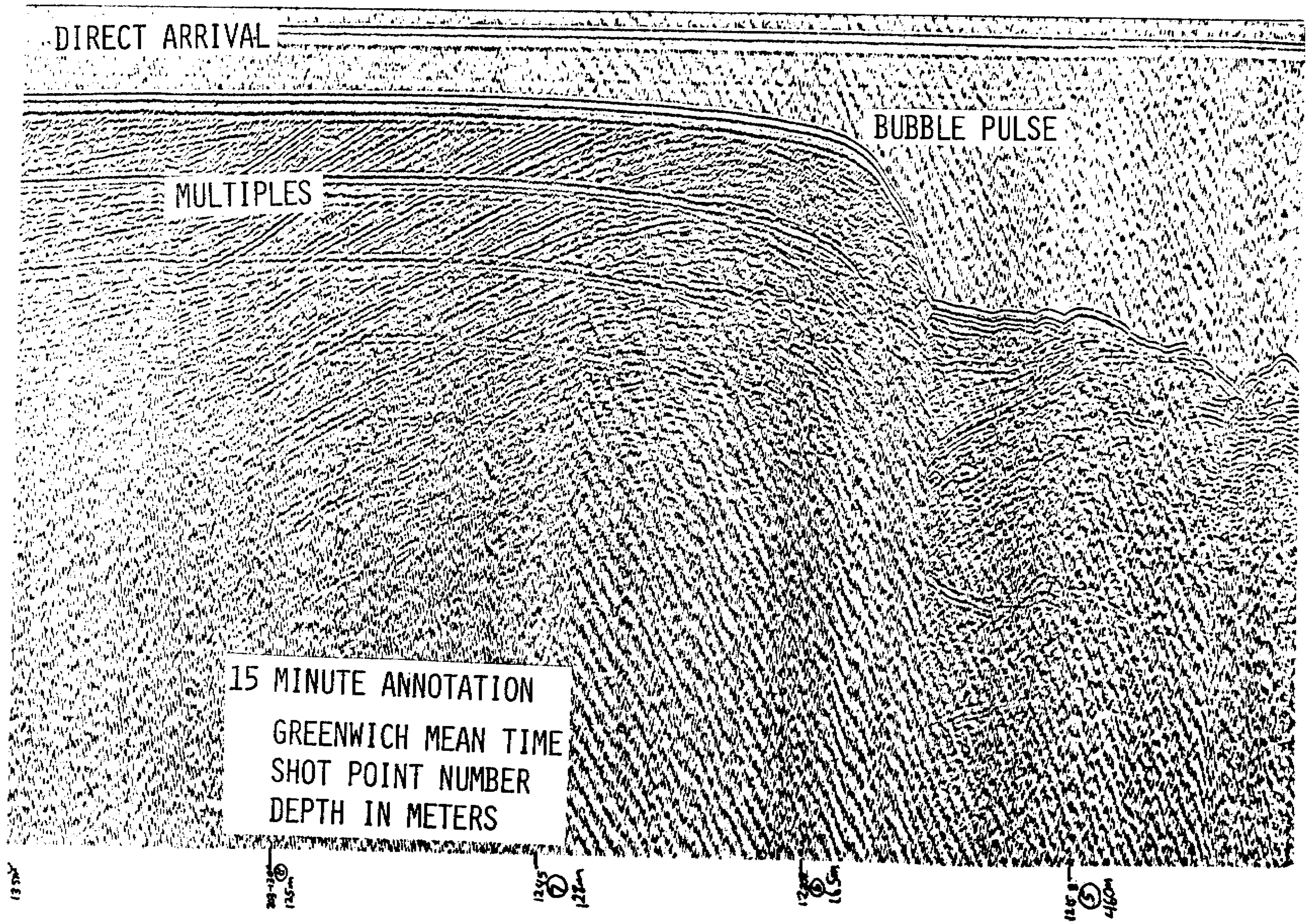


FIGURE 8.- HIGH-QUALITY 30 KILOJOULE SPARKER RECORD SHOWING APPROXIMATELY TWO SECONDS PENETRATION.

U.S.G.S. [N]AVIGATION LOG

2/75

Cruise Locator SEA 2 -76 -WG (ID. YR AREA)

Ship R/V SEA SOUNDER Chief Scientist BOUMA/HAMPTON

Affiliation U.S.G.S.

Page 25 of ____

Day	GMT HR MN	Line No	Comments	Fix Quality	Fix Type	New Course	New Speed	Lat DEG	Lat Minutes	Lon DEG	Lon Minutes	STA #	Distance	Reading	STA #
175	[illegible]	1	OFF STATION	f	CCS	099	0.0	+[illegible]	16.24	-153	32.12	← MINI RANGER →			
	2320		SAT 19	G	S				16.01		30.82				
	[illegible]		SP 9	f	DRC	235	10.6		15.23		34.25				
	[illegible]		SAT 13	G	S				13.62		36.11				
	[illegible]		SP 10	f	DRC	236	10.6		13.39		37.38				
176	[illegible]		SP 11	f	DRC	[illegible]	10.9		[illegible]		40.86				
	[illegible]		SP 12 ONSTATION	f	CCS	270	0.7		11.38		43.99				
	[illegible]		ON BOTTOM	f	DRC	287	0.3		10.69		44.09				
	[illegible]	2	EOL 2 OFFSTATIO	f	CCS	260	0.1		11.69		44.10				
	0100	TO 3	EN ROUTE LINE 3	f	DRC	316	6.7		13.82		48.95				
	[illegible]			f	DRC	329	10.1		15.73		51.35				
	[illegible]		SAT 13	G	S				[illegible]		50.86				
	[illegible]			f	DRC	003	3.0		16.40		52.71				
	[illegible]	3	SOL 3 SP 0	f	CCS	123	5.1		16.76		50.77				
	[illegible]		SP 1	f	DRC	125	6.8		16.63		50.40				
	[illegible]		SP 2	f	DRC	127	6.5		15.68		47.81				
	[illegible]		MNR FIXP USE DRC	G	MNR				15.00		46.85	3	68.83	56.68	4
	[illegible]		SP 3	f	DRC	121	6.2		14.87		45.46				
	0225			G	MNR				14.10		44.80	3	68.18	55.78	4
	[illegible]		SP 4	f	DRC	119	6.3		14.16		42.14				
	[illegible]			G	MNR				13.60		43.00	3	67.59	54.93	4
	[illegible]			G	MNR				13.10		41.60	3	67.18	54.10	4
	[illegible]		SP 5	f	DRC	120	6.3		[illegible]		40.13				
	[illegible]			G	MNR				12.50		38.50	3	66.45	53.14	4
	[illegible]		SP 6 MNR OUT	f	DRC	118	6.3		12.54		37.45				
	[illegible]		SP 7	f	DRC	121	6.3		11.76		34.81				
	0330		SP 8	f	DRC	120	6.9		10.84		32.19				
	[illegible]		SP 9	f	DRC	123	6.4		10.13		29.61				
	0400		MNR ON-FIXES A	G	MNR							3	63.26	48.28	4
	[illegible]		SP 10	f	DRC	119	6.0		09.39		27.02				
	[illegible]			G	MNR							3	62.81	47.37	4
	[illegible]		SAT 12	G	S				08.15		26.24				

FIGURE 9. EXAMPLE OF U.S.G.S. NAVIGATION LOG AS USED ON BOARD R/V SEA SOUNDER.

APPENDIX B

Thickness Measurements and Generalized Isopach Map, Lower Cook Inlet

THICKNESS MEASUREMENTS AND GENERALIZED ISOPACH MAP OF QUATERNARY SEDIMENTS - LOWER COOK INLET

Explanatory notes

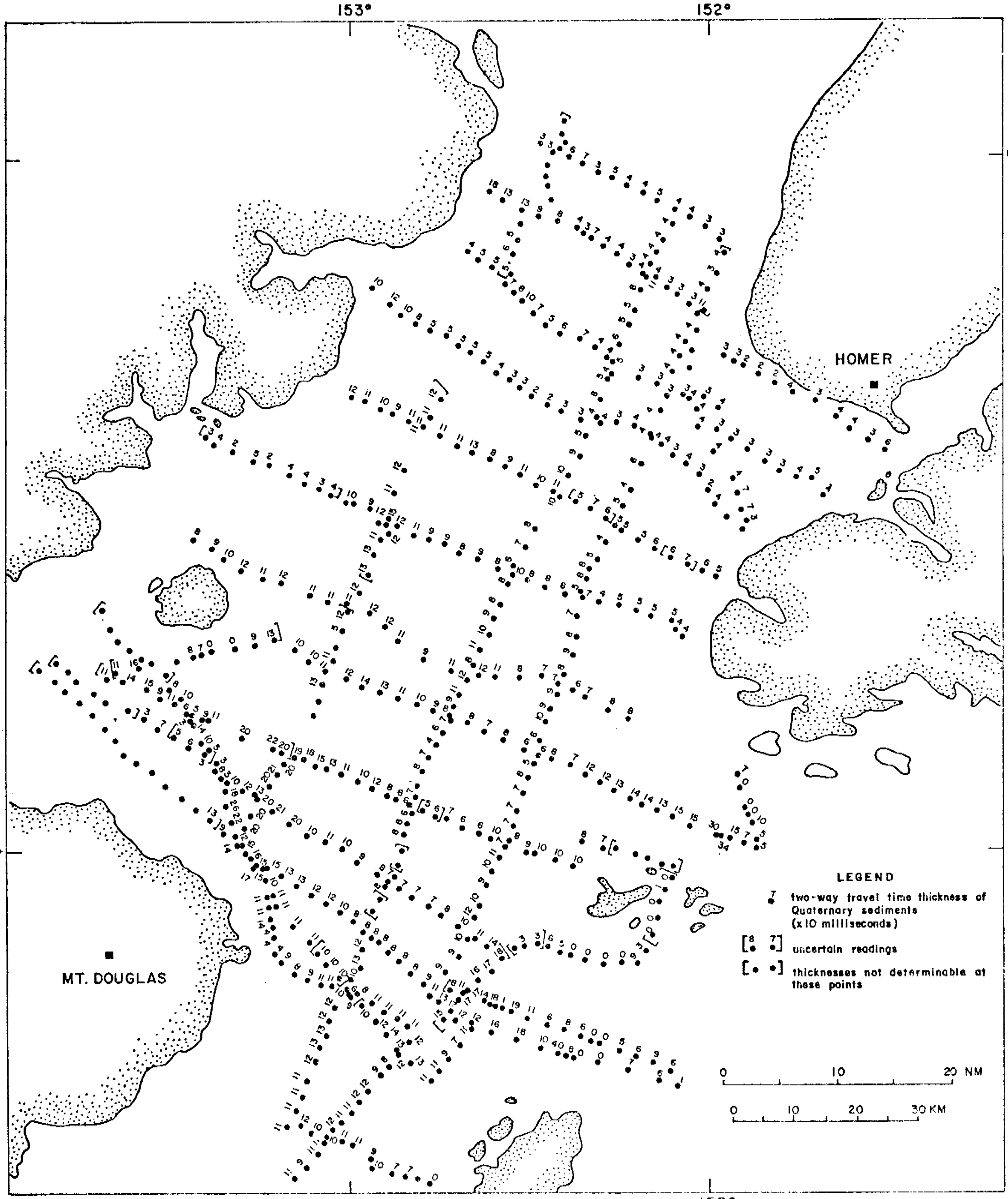
The thickness measurements were made directly on sparker seismic reflection records shot in the summer, 1976 aboard the R/V SEA SOUNDER. A track-line map is included in Appendix A. High-resolution uniboom and 3.5 kHz records collected during the 1976 cruise rarely show penetration to the base of the Quaternary sediments. On the sparker records, measurements were made routinely at the positions of 15-minute shot points.

Thicknesses were measured from the sea floor down to an angular unconformity that shows up distinctly on most of the records. Several thickness measurements were uncertain or indeterminable because of poor-quality records, shallow penetration, or the occurrence of the unconformity within the bubble pulse or a sea-bottom multiple. Where readings of 'zero' thickness were recorded, the unconformity apparently rises to the sea floor and controls the sea floor geometry. Variations in the thickness of Quaternary sediments throughout lower Cook Inlet reflect a combination of variations in the elevations of the unconformity surface and of the sea floor.

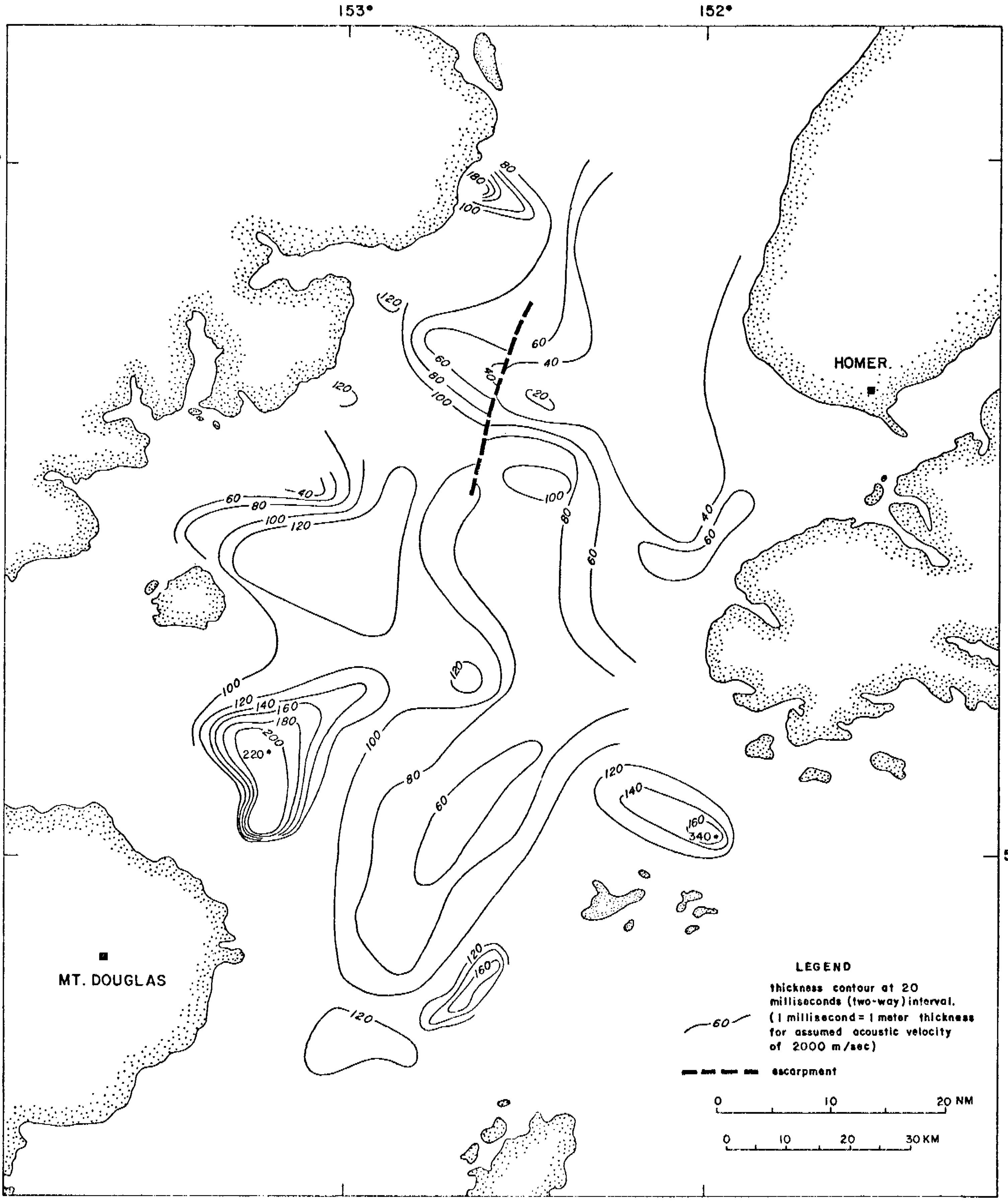
In making the following maps, the assumption was made that the deformed rocks below the unconformity are of Tertiary age, judging from the on-land geology, and that the generally flat-lying sediments above the unconformity are primary and reworked glacially derived sediments deposited during Pleistocene and later time. Conceivably, though, some of these sediments could be of upper Tertiary age.

The thickness measurements were contoured only generally. Many thickness variations greater than the contour interval were ignored because they involve only two measurements. Consequently, many small basins and highs exist that do not show on the map. The areas south of Augustine Island and surrounding the Barren Islands are especially complex, and major portions of these areas were not contoured.

The escarpment shown on the isopach map appears clearly on several records. Apparently, it is erosional, rather than fault-controlled.



THICKNESS MEASUREMENTS OF QUATERNARY SEDIMENTS
LOWER COOK INLET



GENERALIZED ISOPACH MAP OF QUATERNARY SEDIMENTS
LOWER COOK INLET

APPENDIX C

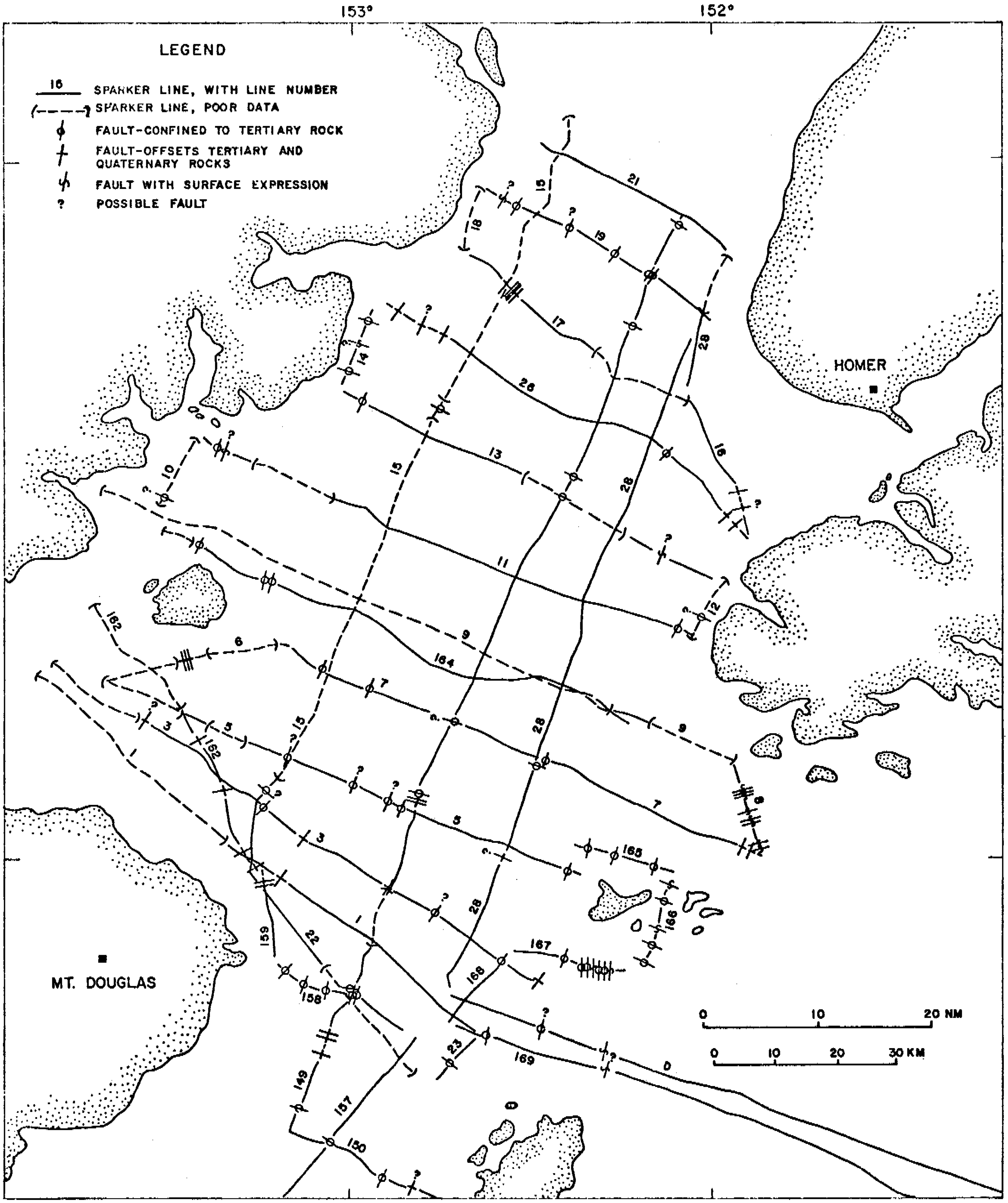
Faults in Lower Cook Inlet

FAULTS IN LOWER COOK INLET
Explanatory notes

This map of faults in lower Cook Inlet is a revision of a preliminary map prepared from shipboard interpretations and presented in U.S. Geological Survey Open-File Report 76-695. Fewer faults appear on the revised map, partly because of a more conservative approach to interpretation, but the pattern of faulting is similar to that on the original map.

Faults are divided into three categories. Faults confined to Tertiary rocks are those that offset the deformed rocks below a distinct angular unconformity, but do not offset the unconformity itself. The unconformity surface is assumed to have been eroded during Pleistocene low stands of sea level. Faults that offset Tertiary and Quaternary rocks project through the unconformity and show visible offset of it. Faults with surface expression are self-explanatory. Note that the symbols on the map are oriented perpendicular to track lines and have no implications as to the actual trend of the faults.

As also shown on the preliminary map, faults appear to be more abundant south of a line through Augustine Island and Seldovia than north of it. This line marks the approximate position of the Augustine-Seldovia Arch, a deep-seated anticline that is transverse to the predominant trend of folding, which is parallel to the length of the inlet. Faults are especially abundant near Augustine Island and the Barren Islands. Faults are most scarce in the central part of the inlet, north of the Augustine-Seldovia Arch. Faults apparently are of such short extent, in general, that correlations between track lines cannot be made.



FAULTS IN LOWER COOK INLET

APPENDIX D

Sand Waves and Other Bedforms in Lower Cook Inlet, Alaska

SAND WAVES AND OTHER BEDFORMS IN LOWER COOK INLET, ALASKA

by

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To be submitted to:

Marine Geotechnology

SAND WAVES AND OTHER BEDFORMS IN LOWER COOK INLET, ALASKA

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ABSTRACT

Lower Cook Inlet in Alaska has high tidal currents that average 3-4 knots and normally reach a peak of 6-8 knots. The bottom has an average depth of about 60-70 m in the central part of the inlet and deepens toward the south. Several types of bedforms, such as sand waves, dunes, ripples, sand ribbons, and lag deposits form a microtopography on the otherwise smooth seafloor. Each bedform type covers a small field, normally a few hundred to a few thousand meters wide and usually several kilometers long parallel to the tidal flow. High-resolution seismic systems, side-scan sonar and bottom television were used to study these bedforms. Large sand waves with wavelengths over 300 m and wave heights up to 10 m were observed. Fields of ebb- or flood-oriented asymmetric bedforms commonly grade into more symmetrical shapes. Several orders of smaller sand waves and dunes cover the flanks of the very large bedforms. Normally the crest directions of both size groups are parallel, but deviations of up to 90° have been observed; local deviations may occur where smaller forms approach the crests of the larger sand waves.

Bottom television observations revealed active bedload transport in a northerly direction on crests and midflanks of southward asymmetric large sand waves, but not in their troughs. Movement of bedload occurs in the form of small ripples. Although the asymmetry of the large bedforms suggests that migration has taken place in the ebb or flood directions, the very low surface angles (2.5° - 8°) of these bedforms do not indicate regular movements. The large bedforms are probably relict features or migrate only under severe conditions, whereas active sand transport by ripples and smaller sand waves and dunes moves bedload

back and forth with the tides. An understanding of such movements is essential in determining design criteria for offshore installations and in benthic-faunal studies.

INTRODUCTION

Bedforms of various kinds and sizes are abundant in lower Cook Inlet, Alaska. Each type seems to cover only a relatively small area ranging from a few hundred to a few thousand meters measured across the inlet, perpendicular to the main current directions. The lengths of bedform fields, measured parallel to the axis of the inlet, are usually several kilometers. Except for the individual height of any one bedform, there is not always a notable change in water depth between one field and the next. Little is known about the general current regime in Cook Inlet throughout the seasons, and nothing is published on the details of water movements. Shipboard observations, however, indicate that the movement is very complex. Continuous measurements of surface salinity and temperature, and the navigation difficulties encountered in traversing the inlet do not provide information on the interaction between water and bottom but do indicate complex circulation motions. High tidal ranges and swift currents dominate the physical regime, and we observed interaction with the seafloor with a bottom television camera.

Sampling revealed that sand and gravel are the two major textural components in the open waters of lower Cook Inlet, and although the samples indicate textural pattern changes over small distances, no special sampling efforts were made with regard to the different bedforms.

A 30- to 60-kilojoule sparker and two high-resolution seismic profiling systems--3.5 kHz and uniboom--were employed for 15 days during June and July 1976 for environmental geologic surveys on board the R/V Sea Sounder. Most of the tracklines were made across the inlet with lengths between 40 and 100 km. Three tie lines were run in a longitudinal direction, and in five locations, small "search patterns" were conducted. A total of about 2,800 km of trackline revealed several areas with bedforms at least 4 m high (Figure 1). On the basis of the results of the high-resolution seismic profiling, about 120 km of side-scan sonar profiles were made and seven bottom television sites examined, revealing additional types of bedforms (Bouma and Hampton, 1976; Hampton and Bouma, 1976).

Instrument problems prevented us from using bottom television and side-scan at the same time. Although the small area of coverage of the bottom television is beyond the resolution of the sonographs (side-scan sonar), the two employed in conjunction with one another provided supplementary information. The swift currents made it impossible to scan the bottom continuously by television and consequently it was necessary to have the television sled rest on the bottom and to make observations only during the period contact was maintained. On-bottom time ranged from 1 to 40 seconds before the ship's drift caused drag on the sled. The television observations provided important information on the small bedforms, grain sizes, and directions of transport.

LOCATION AND PHYSICAL OCEANOGRAPHIC ASPECTS

Lower Cook Inlet is the south half of the large inlet connecting Anchorage with the Pacific Ocean (Figure 1). Pacific waters, moving as part of the Alaskan Current along the Kenai Peninsula in a counter-clockwise motion, enter lower Cook Inlet primarily through Kennedy Entrance and to a lesser extent through Stevenson Entrance (Figure 1).

The water moves northward toward Anchorage over a distance of 300 km. Lower Cook Inlet has a trapezoidal shape and becomes upper Cook Inlet at the Forelands. Flood waters move along the eastern shore in lower Cook Inlet, cross over at the Forelands, and make a few major eddies such as around Kalgin Island. Ebb flows generally follow the opposite shores (Figure 1) and join the Pacific after having traveled through Shelikof Strait (Alaska OCS Office, 1976). Drift card and drogue studies by Wennekens et al. (1975) showed an intricate drift pattern up and down lower Cook Inlet with a net transport of surface water from Kachemak Bay to the west.

The mean semidiurnal tide ranges from 4.2 m at the mouth of the inlet to 9 m at Anchorage, and there is a 4 1/2 hour tidal lag between these points. Surface current velocities normally do not exceed 6.5 knots (335 cm/s) in lower Cook Inlet, and according to Wagner et al. (1969) the mean maximum velocities are on the order of 3.8 knots (196 cm/s). These strong tidal currents, combined with the Coriolis effect and the geometry of the inlet produce considerable cross-current turbulence throughout the entire water column during both ebb and flood tides (Burrell and Hood, 1967). However, occasional local deviations, such as 8-9 knots directly off Anchor Point and 12 knots in the Forelands, have been reported from vessels.

Winds in excess of 100 knots have been reported during Chinook winds (intense westerly winds) that funnel through mountain passes west of Kamishak Bay, and resulting waves in excess of 6 m have been measured. Sea ice observations are scanty but ice can be severe especially on the western side. No reports of grounded ice in open water are known.

TYPES OF OBSERVED BEDFORMS

Of the wide variety of current-generated bedforms, only a limited number have been observed in lower Cook Inlet with sufficient detail to warrant discussion. Because there is a gap in resolution between underwater photography and television on the one hand and side-scan sonar and seismic high resolution profiling on the other, it is not possible to integrate all observations. Bottom television is restricted to surficial morphology of small-scale structures within a viewing area of about 40 by 70 cm and to type and direction of grain motion. Bathymetric and high-resolution seismic profiling normally are severely hindered by the pitching and rolling motions of the vessel, which make it difficult to distinguish false shapes due to ship motion from natural bedforms of similar size. Sonographs cannot resolve features and shapes smaller than about 50-100 cm long.

We observed current ripples, sand waves, dunes, sand ribbons, and lag deposits on the sea floor. These bedforms are all current-related and are formed by tidal currents in Cook Inlet.

Ripples are small bedforms generated by currents, or waves. They are seldom higher than 5 cm with wavelengths up to 20 cm. Externally they can be simple in shape or have complicated shapes and elevations of crests and troughs (Allen, 1968; Reineck and Singh, 1973; Southard, 1975). We observed several types of current ripples on the large bedforms during bottom television sessions, most of them undergoing active movement. No oscillatory wave ripples could be identified.

Sand waves are large current-generated bedforms with a ripple shape. Their spacing or wavelength ranges from a few meters to several hundreds of meters, and their heights from tens of centimeters to more than 10 meters. They reveal a strong asymmetry, and have rather straight crests and nearly constant elevations of crests and troughs. The height-to-wavelength ratio usually is more than 1:20. They are formed by moderately strong currents in sediments coarser than 0.1-0.2 mm, (Stride, 1970; Terwindt, 1971; McCave, 1971; Southard, 1975). Figures 2-7 show several types of sand waves ranging from large to giant and a minor diversity in crest shapes. The strong asymmetry is apparent on the sonographs.

Dunes or megaripples (Southard, 1975) are another form of large rippled bedforms. Their wavelength ranges from 1 m to a few tens of meters, their wave heights from a few tens of centimeters to a few meters. Their three-dimensional shapes show substantial variation in the elevation of crests and troughs. Their height-to-length ratio typically is less than 1:20. For any given depth and grain size, dunes are formed in stronger currents than sand waves and in sand coarser than 0.1-0.2 mm. None of the records obtained show any fields with dunes only but most of the areas with smaller sand waves contain some complex forms that can be interpreted as dunes (Figures 4,6 and 7).

Sand ribbons can vary from ribbonlike trains of straight-crested waves perpendicular to the current to continuous parallel ribbons found in the troughs of very large sand waves (Kenyon, 1970). The latter type is the most common one and seems to form under surface velocities around 1 m/s over a gravelly substratum with insufficient sand to cover the entire area. The length-to-width ratio of the ribbons generally is more than 40:1 and according to Kenyon, they are probably less than 1 m thick. Bifurcation of sand ribbons is normal. Many sand ribbons in lower Cook Inlet show trains of sand waves and dunes covering their surfaces (Figure 7).

Lag deposits are concentrations of coarser material such as boulders, gravel, shells, shell debris, clay pebbles or plant fragments. They are either eroded from a substratum by removal of finer components or are the result of selective transport-deposition. Lag deposits have been observed by television in the small troughs of ripples located within the troughs of large sand waves, and they have been observed on sonographs of the near-flat areas of lower Cook Inlet (Figure 8). The first type of lag deposits are pebbles, shells, or organic remains ranging in size from several millimeters to a few centimeters. The ones observed on side-scan are of boulder size when they appear as a uniform dark color (Figure 7).

In addition, we observed active benthic growth, such as sea anemones and corals, with the bottom television, on the boundary between Kachemak Bay and the open waters of lower Cook Inlet (just west of location of Figure 5; see Figure 1).

DISCUSSION ON THE OBSERVED BEDFORMS

Figure 1 shows the locations at which wavy bedforms were observed during the 1976 summer survey utilizing 3.5 kHz and uniboom as high resolution seismic tools. Although about 2,800 km of trackline was run in lower Cook Inlet, the distance between lines was too great to ascertain the distribution of large rippled forms. Side-scan sonar is a particularly valuable tool for studies of these bedform types, especially when combined with high-resolution seismic profiling for the information is complementary and provides a strong basis for interpretation.

The segment of 3.5 kHz record depicted in Figure 2 shows a number of large asymmetrical sand waves located in the middle of lower Cook Inlet. The direction of this profile is nearly parallel to the axis of the inlet and the asymmetry of the bedforms shows ebb dominance of transport at that location. No two of the bedforms are alike in shape and size. This profile was made during a bottom television survey. Because we attempted to keep the TV lowering wire vertical during this particular run, the ship's displacement over this area was about equal to the local current velocity, which was about 1.3 - 1.5 knots in a northerly (flood) direction. The angles of the stoss and lee sides of these sand waves are very low (Figure 2), much less than the angle of repose of the material, which normally is between 24^{o} and 34^{o}, depending on grain size, composition, and angularity (Ludwick, 1972). Little spikes on the record are interpreted as smaller bedforms, since vertical motion of the vessel was insignificant. This is confirmed on a sonograph made very close to the location of this record.

Bottom television observations show large quantities of coarse to very coarse sand moving over straight-crested, north-northeast aligned ripples. The estimated velocity of sand transport within the television area is about 14 cm/s at the crest of the largest sand wave at time 1500. The flow detaches from the bottom as soon as it passes the crest, and bedload movement over the north-dipping side of the bedform decreases rapidly to about 2-6 cm/s in this coarse-very coarse sand until about time 1505, where reattachment of the current to the bottom causes higher velocities (10-12 cm/s, coarse sand, direction to north). Grain velocities in the troughs are low again, estimated at 1-2 cm/s in a north-northwest direction just before time mark 1507. The picture shows indistinct ripples in coarse-medium sand with some shell fragments and plant remains. A grain velocity of about 30 cm/s was estimated on the next crest at time 1508.

The observations on these sand waves indicate that bedload is transported in small ripples. The duration of observation was too short to give any information on possible migration of the large sand waves. Ebb currents may move these sand bodies in a southerly direction and flood currents, which are presumably weak at this location, may transport only minor quantities of sand. It is also possible that the large sand waves are relict structures that undergo minor modifications during tides. A third possibility is that major movements occur only during very strong currents that are generated once or twice a year.

Figure 3 shows a large bedform with a spacing of about 400 m and height of about 7 m on a uniboom record and a sonograph. The seismic record reveals the low undulation with small (about 1 m high) rippled bedforms on top. The flat subbottom reflector at a depth of about 110 m may represent older gravelly deposits over which these sand bodies move. Since the uniboom transducers/receivers are built into the hull of the vessel and the side-scan fish is towed several hundred meters behind, the time marks on both recorders do not represent the same parts of the bottom. Crests C_1 and C_2 on the uniboom record are also indicated on the sonograph. These crest orientations are about east-west, nearly parallel to the axis of the entrance. The smaller superimposed sand waves, with wavelengths between 12 and 25 m, show various orientations, some of them nearly normal to the large ones. The smaller sand waves on the east side of the large bedform are flood oriented, whereas those on the west side of C_1 and C_2 show an ebb dominance. It is possible that these very large undulating bedforms move very little or not at all and that the sand waves on their flanks are the principal active bedforms. If such is the case, these large bedforms may be similar to the sand ridges as described from the North Sea (Houbolt, 1968 Reineck and Singh, 1973).

Smaller large sand waves, with wavelengths varying between 75 and 175 m, are depicted in Figure 4. Their asymmetry indicates a net ebb transport. The uniboom record suggests (Figure 6) that a total blanket of about 7 m of sand migrates over a flat shallow substratum. Smaller sand waves with wavelengths averaging 10 m, and whose asymmetry indicates flood-directed transport, are superimposed on the larger ones.

Figure 5 shows slightly sinuous sand waves with wavelengths averaging 18 m. The uniboom record indicates water depths of 27-28 m with a very slightly undulating bottom and rather continuous parallel reflectors in the upper 5-7 m, underlain by more hyperbolic reflectors that may indicate glacial deposits. The sand waves depicted on the sonograph are similar to the ones given in Figure 3; their heights are very small. The asymmetry indicates a northward migration direction. Several sand waves of this size class have been observed in lower Cook Inlet. Their crest shapes vary from slightly sinuous to a complicated form to such a degree that they may be classified as dunes.

The transition from a rather smooth surface to a field with bedforms that are observable on a seismic record is shown in Figure 6. The crest of the sand wave at point A on the uniboom record is indicated on the sonograph. Its crest orientation is N. 24°W. The other crests (B,C and D) are barely discernable on the sonograph. The smaller sand waves are roughly parallel to the large ones and have wavelengths that range from 6 to 11 m, except in the area between points E and F where the wavelengths average 13 m. The uniboom record indicates a westward asymmetry of the large bedforms, but the sonograph shows a northeasterly transport for the smaller sand waves. The uniboom record shows a group of reflections with a total thickness of about 4-6 m under the large bedforms surfacing in an easterly direction. We have observed similar trends elsewhere in this area where subbottom reflectors come to the surface, changing the rippled bedforms to gravelly lag deposits.

Sand ribbons observed in lower Cook Inlet range widely in size (Figure 7). The narrowest sand ribbons are less than 10 m wide, the widest is as much as 300 m. Bifurcation of the ribbons is common. Topographically, these features are too low to be observed on a uniboom or 3.5 kHz record. The lighter colored ribbons, when over 100 m wide, normally contain sand waves and dunes. The dark colored ribbons probably represent gravelly deposits or other types of lag deposits (Kenyon, 1970; Belderson et al., 1972). The orientation of these sand ribbons on Figure 7 is N.8°E.; sand waves within the wide ribbon indicate a net north transport direction.

A sand field with some boulders is shown in Figure 8. Small sand waves on the lower flanks of a physiographic high are replaced by barchans on the upper flanks and crest. The uniboom record shows a certain bottom roughness where barchans occur. Seismic reflection data indicate that the surficial deposits on the flanks are lapped against a core of older sediments that are exposed on the crest of the high. Although not supported by samples, the interpretation of a gravel-boulder substratum cropping out in certain areas is useful in explaining the surficial sediment types, and it shows reasonable agreement with findings from the North Sea (Belderson 46 al., 1972). Two distinct boulders with sand tails are visible on the upper part of the sonograph (Figure 8) at points K and L.

CONCLUSIONS

Of the four parameters--current velocity, water depth, grain size, and type of bedform--it is obvious that for lower Cook Inlet all but the water depth have to be considered. Sampling and bottom television show a general coarsening northward through Cook Inlet (Bouma and Hampton, 1976) and local variations in sand size and gravel content are due to different bedforms and to variations over one single bedform (Figure 2). Sonographs and high resolution seismic profiles, together with the above-mentioned observations, indicate that a possible Pleistocene substratum of gravel and coarser material underlies the rippled bedforms and that it reaches the surface in sand-ribbon and boulder fields. This is similar to the North Sea.

High-resolution seismic records show that the very large sand waves have smaller ones on their flanks, some parallel to the crests of the large ones (Figure 4), and others at large angles to each other. The large bedform presented in Figure 3 is parallel to the current and thus may be similar to the sand ridges reported from the North Sea (Houbolt, 1968) but conclusive evidence is lacking.

One of the most critical questions to geotechnical and constructional engineers is the stability of the larger bedforms. Most of the North Sea sand ridges have not moved measurably during the last three centuries. However, most of the bedforms we are dealing with in lower Cook Inlet are sand waves with crests more or less perpendicular to the flow direction. In addition, the sonographs in Figures 4 and 6 show smaller sand waves with a northward asymmetry (flood direction) on larger sand waves that reveal ebb dominance. This implies that bedload transport occurs during both flood and ebb at those locations. However, the ebb flow seems to move more material. According to

Colby (1964), sediment transport rates for coarse sand are greater than 10 kg/m/s in water depths of 50 m and surface velocities over 200 cm/s. In addition, Colby (1964) and Harms and Fahnestock (1965) show a significant increase in transport power with a decrease in water temperature. Water depth, flow velocities and water temperature have such values that transitional flow conditions should be expected with plane bed conditions rather than with three-dimensional bedforms. However, any net transport can only be confirmed by long-term observations.

Although the actual size of the very large bedforms may not form an important threat to pilings of offshore structures, the turbulence and detachment of flow can induce vibrations. If the resonance in different pilings varies, damaging stresses can occur in horizontal beam connections. Scouring normally is not considered important if pilings are set deep enough into underlying formations. Scouring does, however, present a threat to trenching and pipelines.

A major shift of sand bodies will influence the development of infauna. Since this is a natural phenomenon, it can be expected that only rapidly developing types of infauna may use such substrata unless certain areas such as boulder fields and troughs of large bedforms undergo little change. The boundary area between Kachemak Bay and lower Cook Inlet, with its well-developed benthic growth, may be a rather stable area.

FIGURES

Figure 1. Lower and part of upper Cook Inlet, Alaska with generalized surface circulation pattern, location of large bedforms observed on seismic reflection records, and locations of Figures 2-8. Base map and circulation from Alaska OCS Office (1976) graphic No. 4.

Figure 2. Section of 3.5 kHz high-resolution seismic profile showing large sand waves. On top are times in GMT and depth in meters, on the bottom is the horizontal scale. The true angles have been computed and values of three slopes are indicated. Vertical exaggeration is approximately 23x. Location: middle of lower Cook Inlet (see Figure 1).

Figure 3. High resolution seismic profile (uniboom) and corresponding sonograph over part of large bedforms. C_1 and C_2: crests of the large bedforms. D: condensation drops. Wavy lines on sonographs near 85m are reflections from water surface.

Figure 4. Uniboom record and sonograph of medium large sand waves with smaller ones superimposed. Letters indicate corresponding crests between seismic record and sonograph.

Figure 5. Uniboom record and sonograph of very slightly undulating field of medium-sized sand waves (compare to Figure 3).

Figure 6. Uniboom record and sonograph of a rather smooth area with smaller sand waves changing to a field with larger bedforms. Letters on record and sonograph indicate points of correspondence.

Figure 7. Uniboom record and sonograph of sand ribbons. Letters refer to corresponding locations.

Figure 8. Uniboom record and sonograph of a physiographic high with a lag deposit on its top consisting of boulders on presumably a sandy gravel. X and Y are locations where the side-scan fish was raised.

A and B are points of correspondence.

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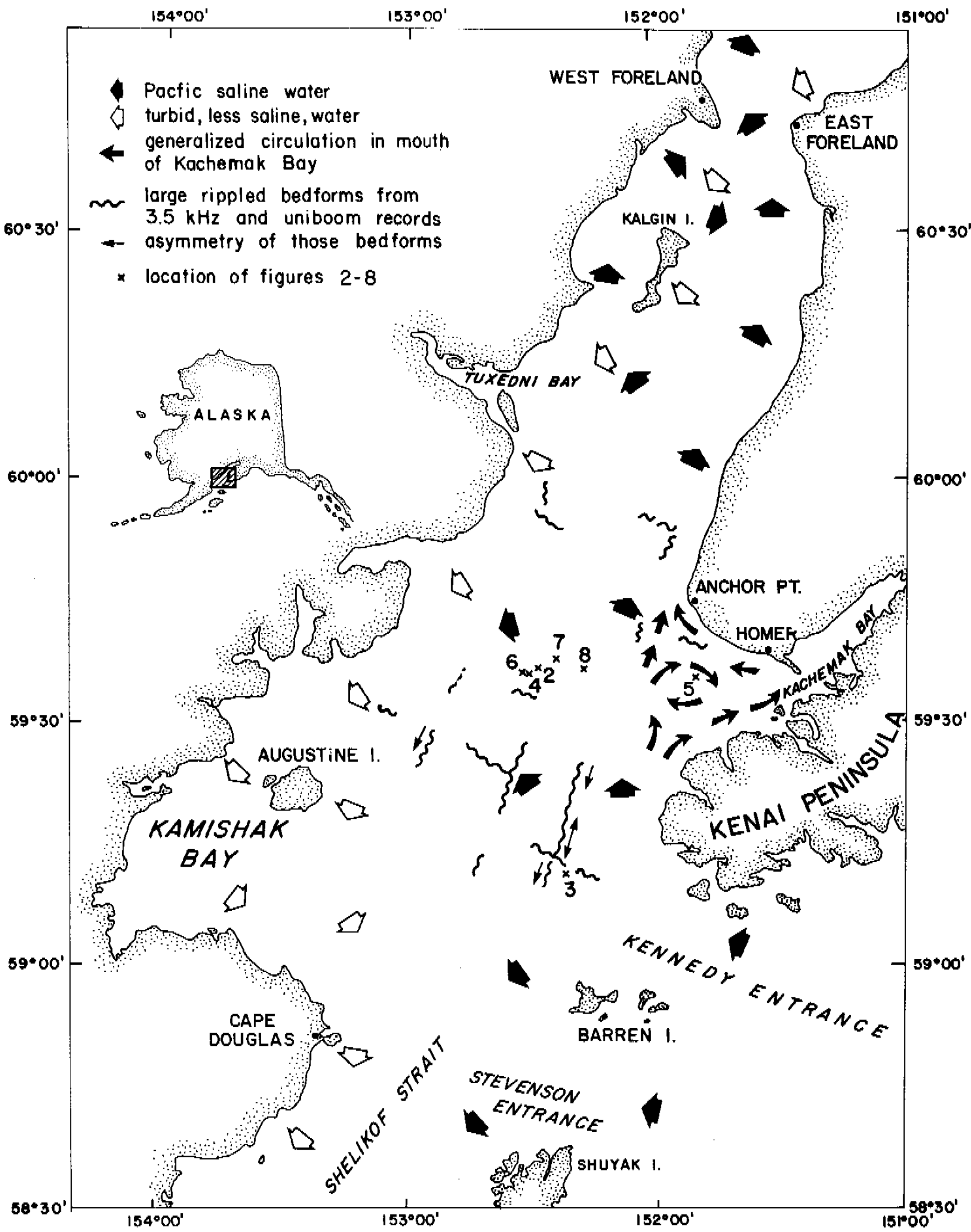
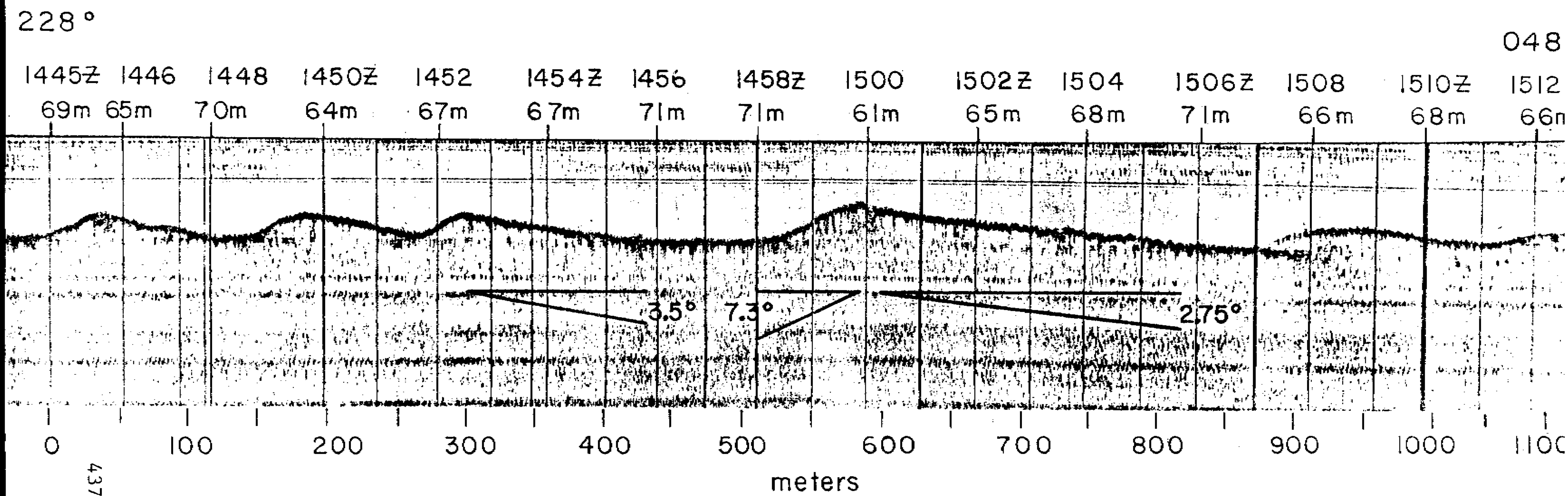

Pacfic saline water
turbid, less saline, water
generalized circulation in mouth of Kachemak Bay
large rippled bedforms from 3.5 kHz and uniboom records
asymmetry of those bedforms
location of figures 2-8
WEST FORELAND
EAST FORELAND
KALGIN I.
TUXEDNI BAY
ALASKA
ANCHOR PT.
HOMER
KACHEMAK BAY
KENAI PENINSULA
AUGUSTINE I.
KAMISHAK BAY
KENNEDY ENTRANCE
CAPE DOUGLAS
BARREN I.
STEVENSON ENTRANCE
SHELIKOF STRAIT
SHUYAK I.
154°00'
153°00'
152°00'
151°00'
60°30'
60°00'
59°30'
59°00'
58°30'

Figure 1


228°
048
1445Z 1446 1448 1450Z 1452 1454Z 1456 1458Z 1500 1502Z 1504 1506Z 1508 1510Z 1512
69m 65m 70m 64m 67m 67m 71m 71m 61m 65m 68m 71m 66m 68m 66m
3.5°
7.3°
2.75°
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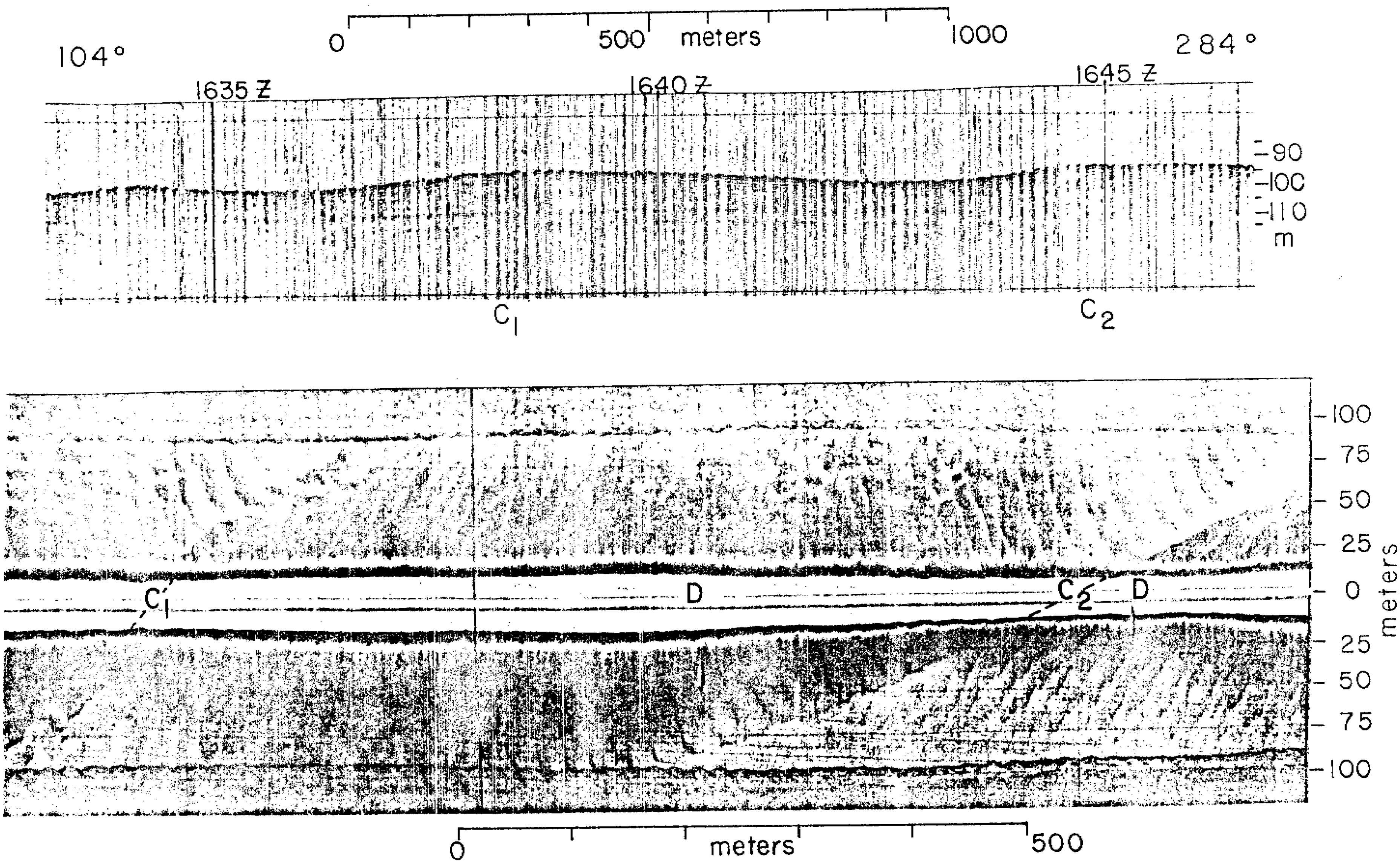
meters

Figure 2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104°
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1635 Z
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meters
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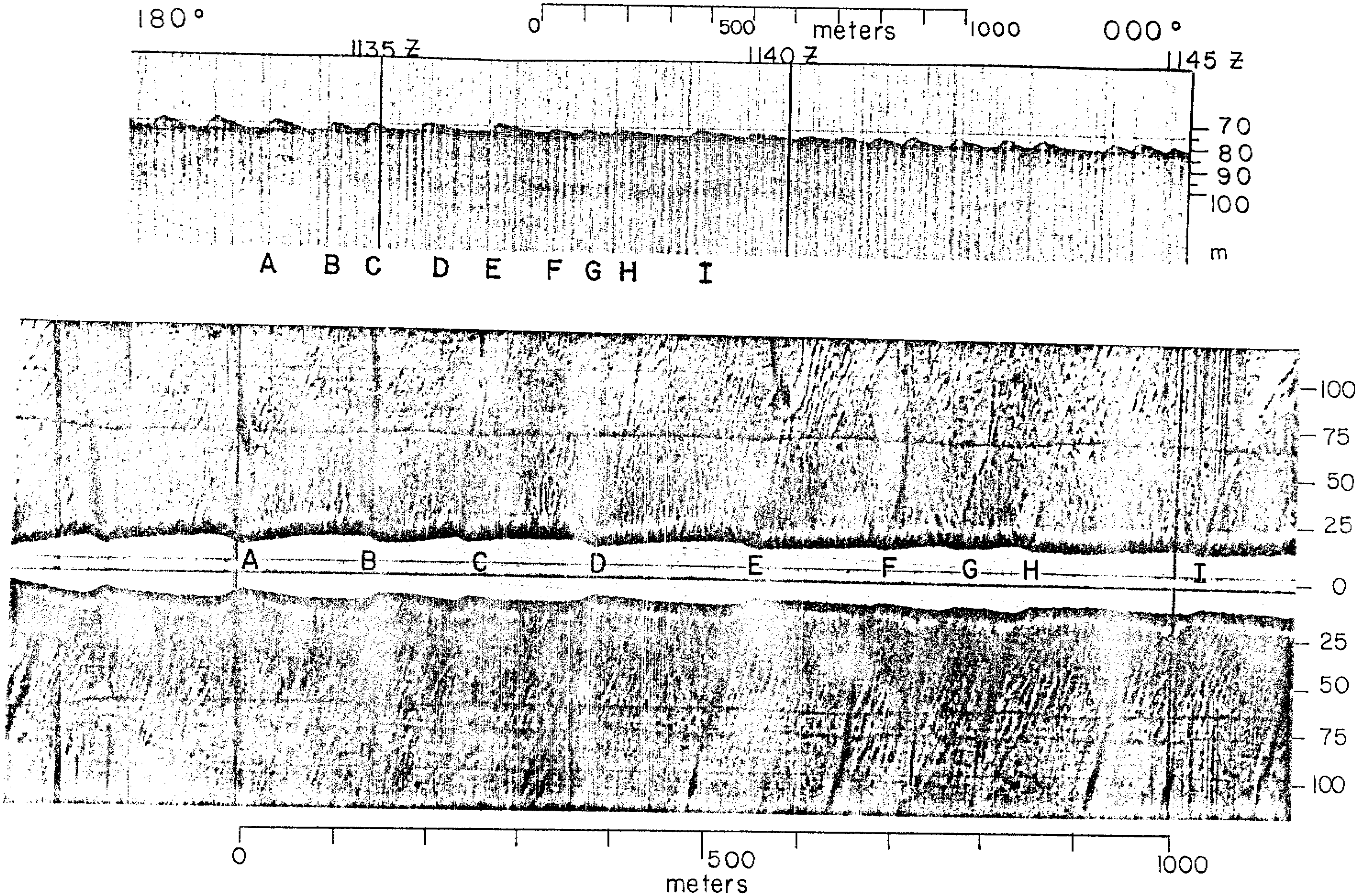
Figure 3


180°
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meters
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1135 Z
1140 Z
1145 Z
70
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90
100
m
A B C D E F G H I
100
75
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meters
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100
A B C D E F G H I
0
500
meters
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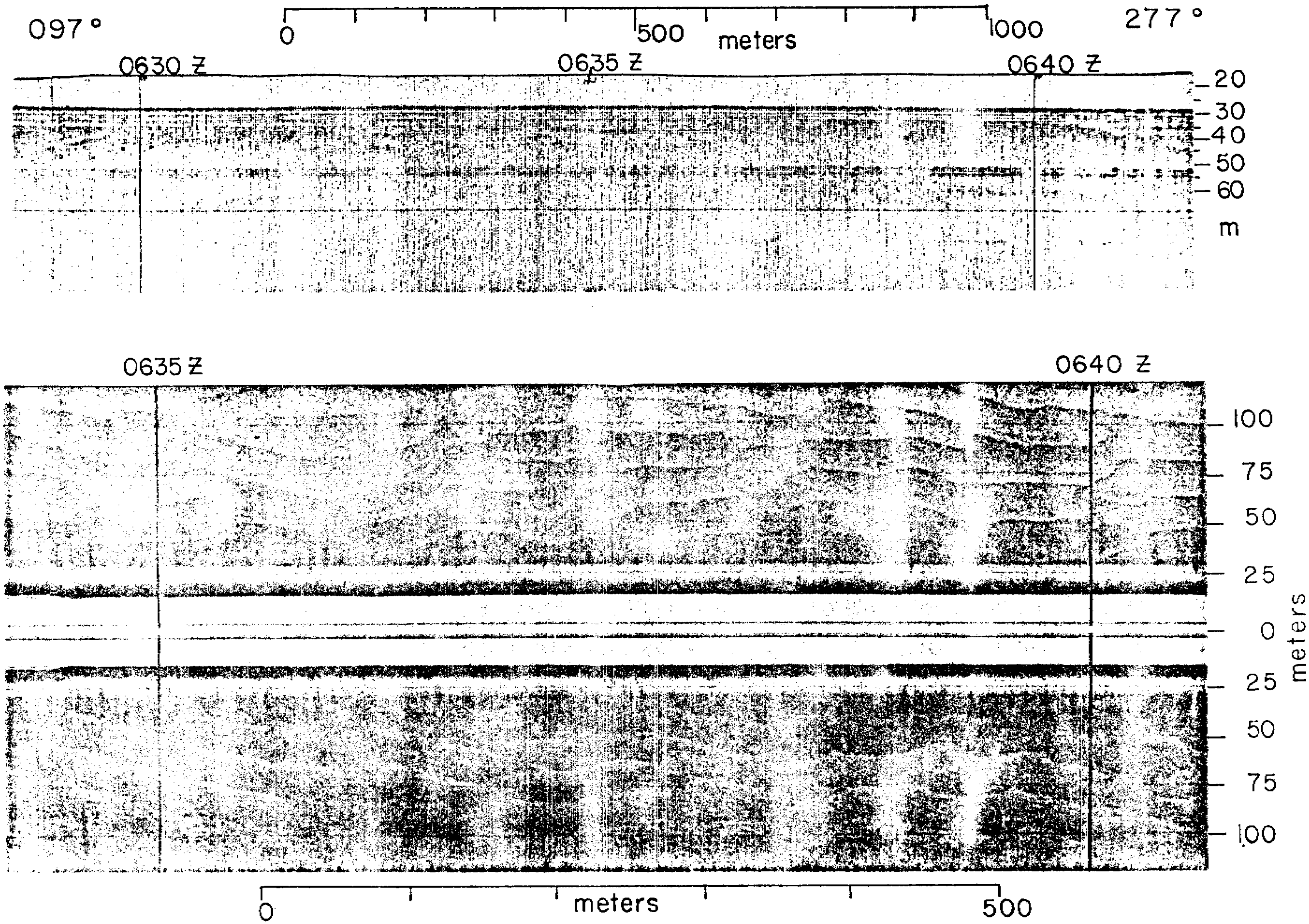
Figure 4


097°
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0640 Z
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meters
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meters
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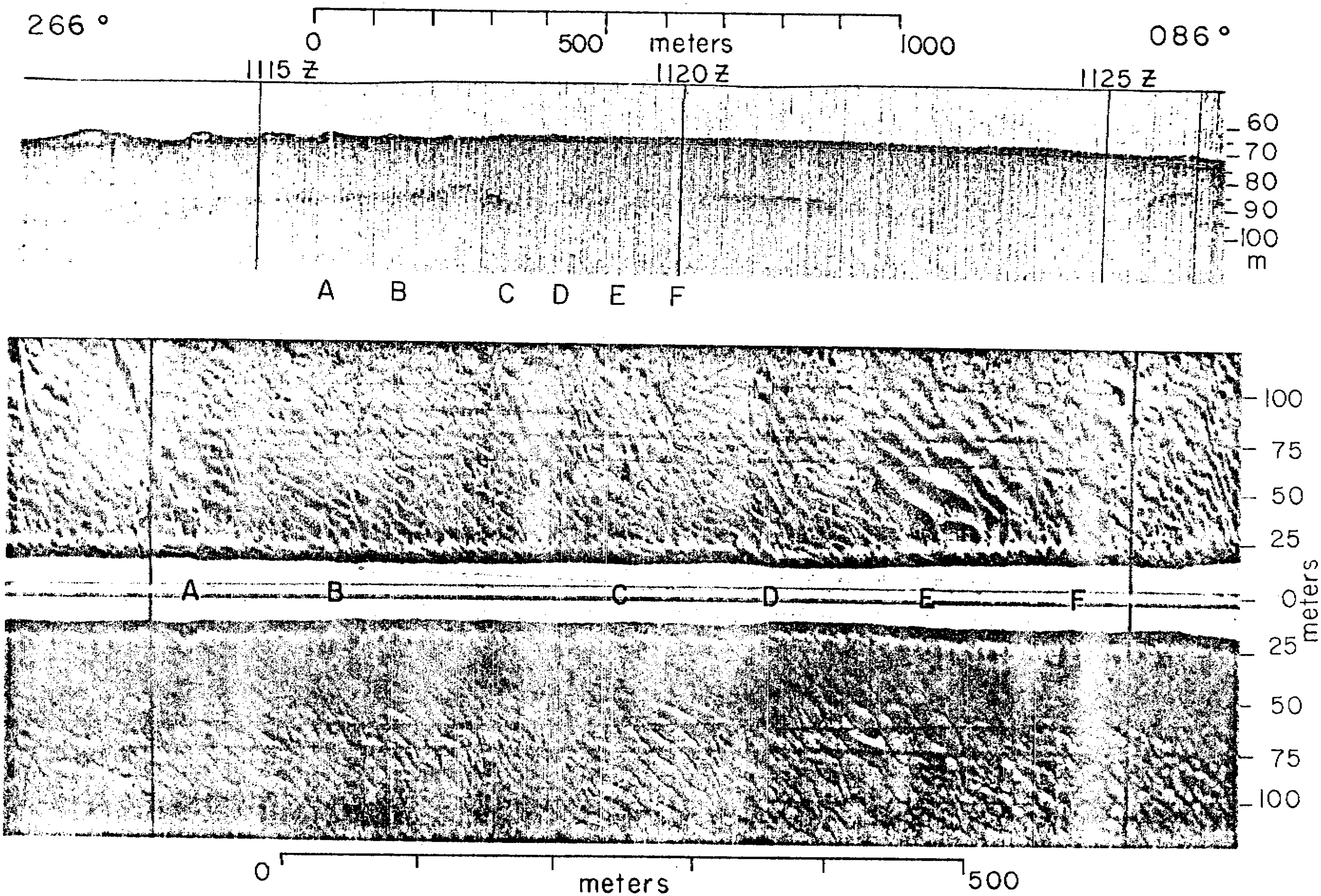
Figure 5


266 °
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500
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1000
086 °
1115 Z
1120 Z
1125 Z
60
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80
90
100
m
A
B
C
D
E
F
100
75
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meters
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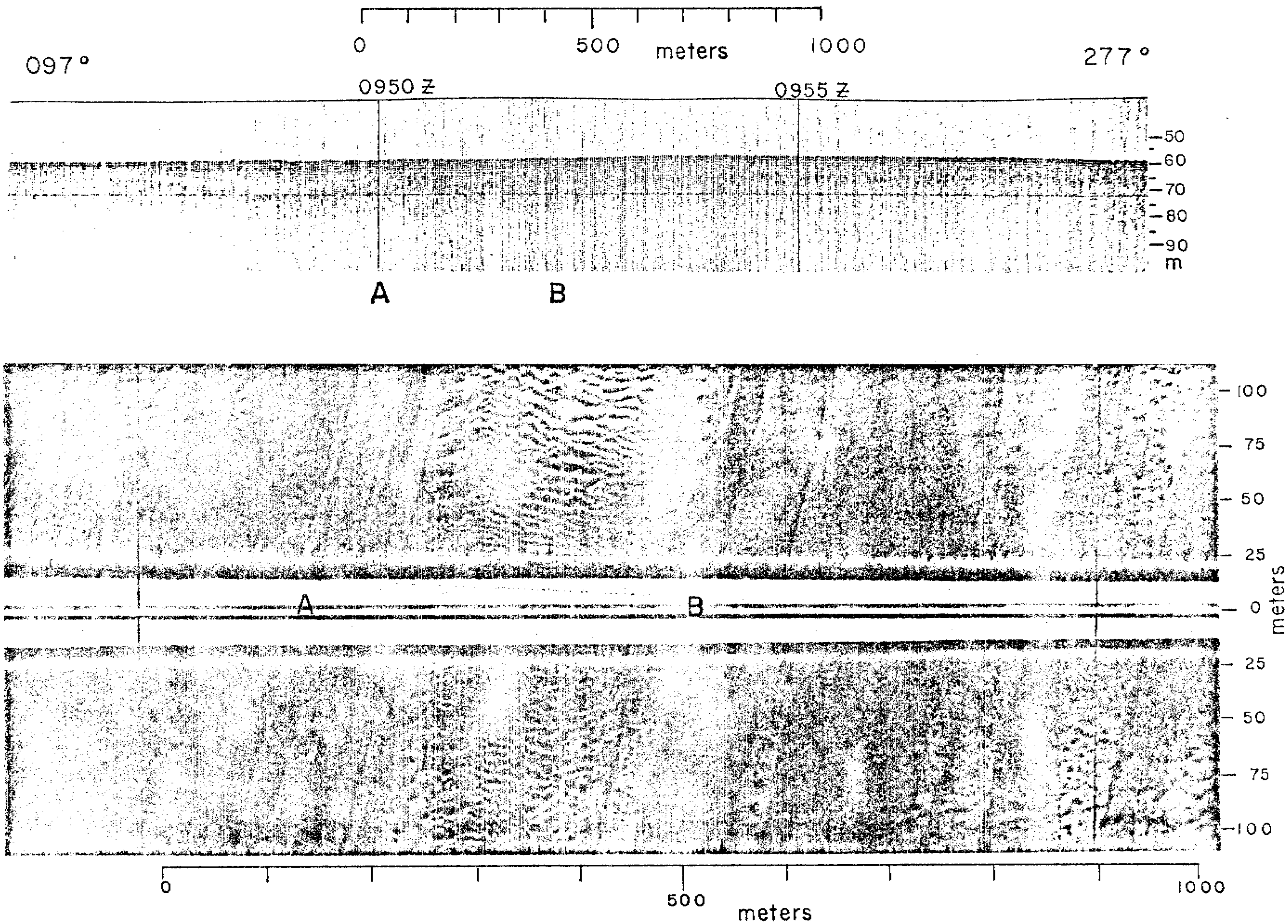
meters
500

Figure 6



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meters
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0950 Z
0955 Z
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meters
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100
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B
0
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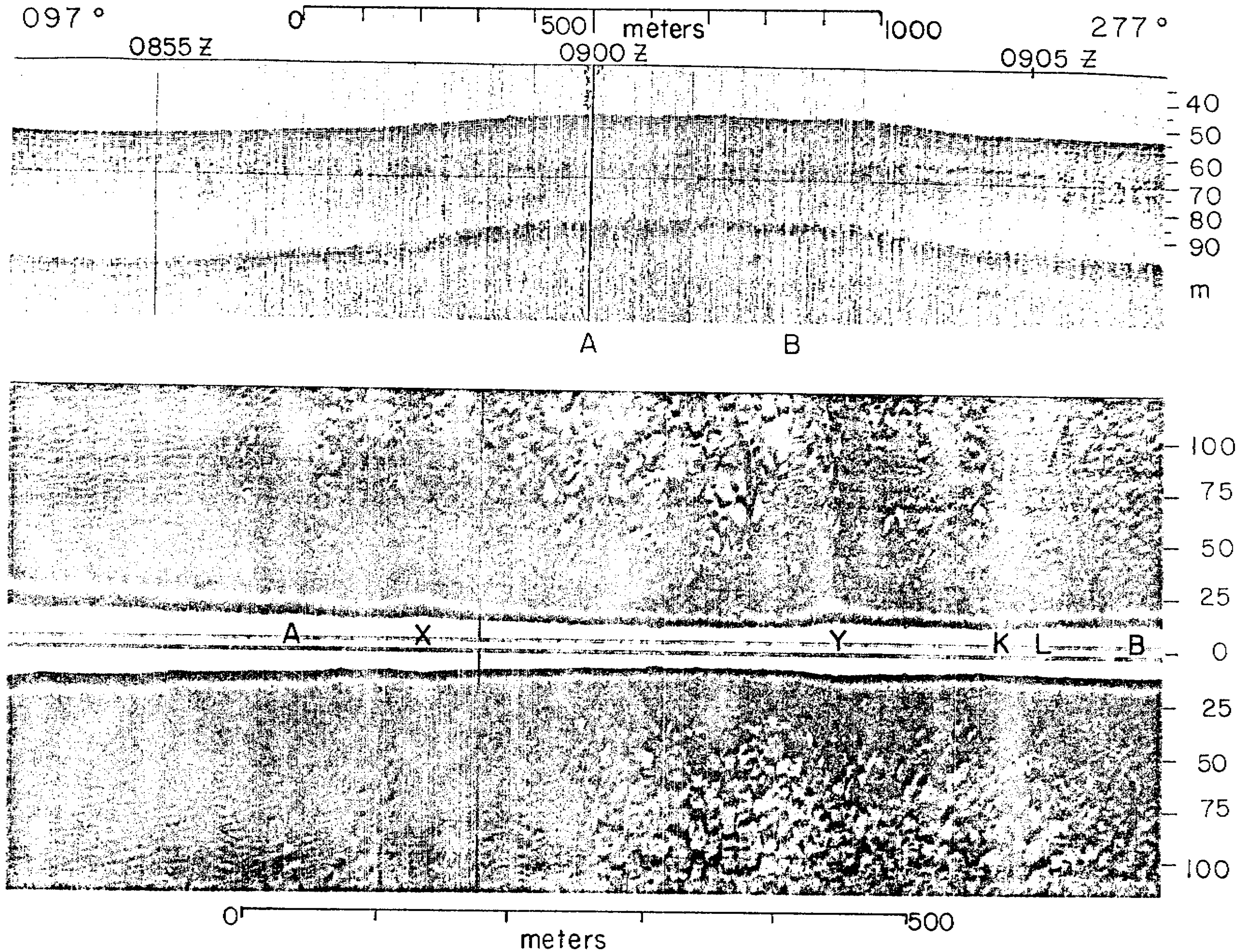
meters
1000

Figure 7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0855 Z
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0905 Z
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75
100
meters
A
X
Y
K
L
B
0
meters
500

Figure 8

RU# 352

NO REPORT RECEIVED

Supplemental reference:

Meyers, H., Brazee, R.J., Coffman, J.L. and Lessig, S.R. October 1976. An Analysis of Intensities and Recurrence Rates In and Near Alaska. National Geophysics and Solar-Terrestrial Data Center, Boulder, Colorado NOAA Tech. Memo EDS-NGSDC-3, 101 pp.

QUARTERLY REPORT

Contract RK6-6074
Research Unit 429
Reporting Periods:

1 October 1976
1 January 1977

429 - Faulting, Sediment Instability, Erosion, and Deposition Hazards of the Norton Basin Sea Floor

Hans Nelson
Pacific-Arctic Branch of Marine Geology
345 Middlefield Road
Menlo Park, CA 94025

January, 1977

Oct 1 - RU 429

A one-month cruise aboard R/V SEA SOUNDER to northern Bering Sea covered 3,500 km of geophysical tracklines and collected 3.5 Khz, Uniboom, side scan sonar and 60 kilojoule sparker records. Twenty vibracores, 25 box cores, 30 Soutar Van Veen and 10 gravity core sampling stations were completed. Suspended sediment samples nephalometry data, and hydrographic measurements were collected at 176 stations. A GEOPROBE instrument was sited in the center of Norton Basin; it gathered current meter data (at four levels in the first meter above the bottom), took bottom photographs, measured light transmission, and measured wave pressures throughout the month it was on the sea floor. Sediment cores were logged for lithology, photographed, radiographed and subsampled at sea. Composition and geotechnical properties of cores also were measured at sea. Selected subsamples from cores are presently undergoing laboratory analyses for texture, mineralogy, paleontology, radiocarbon dates, lead 210 dates, C content, hydrocarbon fractions, and trace elements.

CRUISE PERSONNEL LIST

Name	Affiliation	Role
Nelson, C. Hans	USGS	Chief Scientist
Larsen, Bradley R.	USGS	Dafe Curator
Nilsen, Tor	USGS	Geologist
Field, Mike	USGS	Geologist
Howard, Jim	Uni. of Georgia	Geologist
Rowland, Robert	USGS	Geologist
Holmes, Mark	USGS	Geophysicist
Winter, Dave	U.C.L.A.	Geochemist
Sandstrom, Mark	U.C.A.A.	Geochemist
Jaffe, Louise	Univ. of Georgia	Biologist
Cacchione, Dave	USGS	Oceanographer
Drake, Dave	USGS	Oceanographer
Newby, John	Univ. of Berkeley	Engineering Geologist
Clukey, Ed	USGS	Engineering Geologist
Garlow, Rich	USGS	Navigator
Tanner, Gordon	USGS	Electronics Technician
Novak, Robert	USGS	Electronics Technician
Finley, Otis	USGS	Watch Stander
Tate, George	USGS	Watch Stander
Evans, Jim	USGS	Watch Stander
Brady, Roland	USGS	Watch Stander
Gutmacher, Chris	USGS	Watch Stander
Johnson, Janice	USGS	Watch Stander
Hirozawa, Carol	USGS	Watch Stander
Gibbons, Helen	USGS	Watch Stander

Jan 1 - RU 429

The following preliminary results have been noted from the Sept. - Oct 1976 cruise to Norton Sound. Ice gouging has been found in all areas less than 20 m. depth, but intensity of gouging is highly variable. Gouging is very intense where southward moving bergs first intersect the 18-20 m isobaths trending across the mouth of Norton Sound. Intense gouging also occurs around the shallow margin of the modern Yukon subdelta, where the outer edge of shorefast ice coincides with the counterclockwise current gyre entering the southern side of Norton Sound. The preservation state of ice gouges delimits regions of non-deposition and sites a rapid deposition, particularly around the modern Yukon subdelta. In some areas, all new and old gouges are well preserved indicating non-deposition during recent time. In others, recent gouges are truncated by superposed sediment smoothing showing rapid recent deposition. Fresh ice gouges in the nearshore portions of the sand wave fields near Pt. Clarence suggest that movement of the bedforms is intermittent and may be due mainly to periodic forcing by storm-related barotropic currents.

The sand wave fields near Pt. Clarence were found to be much more extensive than anticipated. All shoal crests out to and including the one on the lee side of King Island were covered by a wide variety of sand wave types. All flanks and troughs between the sand ridges were covered by a thin veneer of marine sandy muds underlain by pretransgressive deposits of peaty limnitic muds. Fine-grained surface muds on the flanks and troughs, but overall thin Holocene deposits, indicate that periodic intense scouring must have generally prevented Holocene deposits between sand ridges.

New geophysical profiles suggest a logical explanation for an apparent large gas seep recently discovered by Dr. Joel Cline on a NOAA cruise to Bering Sea. A high gas concentration in the water column was detected 30 km directly south of Nome and the anomaly was traced downcurrent in the water over 100 km to King Island. The seep appears to be related to up-dipping beds along the northern Norton Basin margin that are truncated by a near-surface fault. This creates a possible migration pathway for hydrocarbons to reach the sea floor.

Quarterly Report

Contract RK6-6074
Reserach Unit: 430
Reporting Period:
1 October 1976 -
31 December 1976

Bottom and Near-Bottom Sediment Dynamics in Norton Basin

David A. Cacchione
David E. Drake

Pacific-Arctic Branch of Marine Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025

January, 1977

I. Objectives:

A. Development of quantitative relationship between hydrodynamic bottom velocity shear and induced sediment entrainment for a specific site in Norton Sound.

B. Estimation of near-bottom sediment flux at various locations in Norton Sound, with particular attention to the movements of Yukon River materials.

C. Comparison of bottom sediment movements during quiescent and stormy periods at specific sites in Norton Sound.

D. Monitoring of bottom currents and light scattering/transmission (within two meters of the sea floor) to enable prediction of sediment and pollutant flux vectors at future times.

E. Measurement of subsurface and surface suspended sediment distribution in eastern Norton Basin.

II. Field and Laboratory Activities

A. October 1 - October 15: Geological investigations and recovery of Geological Processes Bottom Environmental (GEOPROBE) station in Norton Sound using R/V Sea Sounder.

B. Scientific Party: This cruise was accomplished in cooperation with Dr. Hans Nelson, U.S.G.S., who is conducting detailed geological and geophysical investigations in Norton Basin under OCSEAP research unit The shipboard personnel directly supporting the sediment dynamics work were:

Dr. David A. Cacchione, U.S.G.S.; oceanographer and cruise co-chief scientist (with H. Nelson).

Dr. David E. Drake, U.S.G.S.; geologist

Mr. George Tate, U.S.G.S.; physical science technician

Ms. Helen Gibbons, U.S.G.S.; physical science technician

Mr. Otis Finley, U.S.G.S.; physical science technician

C. Methods.

1. An instrumented, self-contained bottom tripod, the GEOPROBE station, was deployed from the R/V Sea Sounder on September 23, 1976 at 64°-00.25'N, 165°-29.10'W in 18 meters water depth in Norton Sound. The GEOPROBE station was equipped with a vertical array of four spherical electromagnetic current meters (arranged at 20 cm. to 170 cm. above the sea floor), one Bendix savonius rotor/vane type current sensor, one bottom pressure sensor, one nephelometer/transmissometer, one temperature sensor, a bottom camera and strobe system, and an electronics control and recording package. All GEOPROBE data except the photographs are recorded on a SEA DATA digital cassette recorder.

For this experiment the basic sampling interval over which most data was averaged and recorded was 30 minutes. Currents and pressure were also measured and recorded in a burst sequence once each second over a two minute interval that occurred once every 30 minutes. Pressure was also averaged and recorded over the 30 minute basic interval.

The GEOPROBE station was successfully recovered by R/V Sea Sounder using an acoustic relocation and release device (SONATECH, Inc.) on October 13, 1976.

2. A detailed geological survey of the GEOPROBE station site was carried out prior to launch and subsequent to recovery. Cores, grab samples, current measurements, and water samples were collected during this survey. Side-scan sonar and underwater television reconnaissance of the area provided detailed information on the surface character of the sea floor.

3. During the entire cruise (19 September 1976 - 15 October 1976), water samples were collected on a regular schedule from the sea surface, mid-water, and near bottom depths. Light transmission profiles, temperature, and horizontal current speed and direction were also obtained at the subsurface sampling sites. The water samples were filtered onto pre-weighed filters for future determination of suspended sediment concentrations.

D. Sample localities:

1. GEOPROBE station site: 65° - 00.3'N
165° - 29.1'W
Water depth: 18 meters.

2. GEOPROBE site survey: within a five-mile radius of the GEOPROBE station.

3. Suspended sediment samples (with light transmission, temperature, and at times, current speed and direction measurements): at various locations in Norton Basin. Sample locations available on request and to be included in the annual report.

E. Data Collection

1. GEOPROBE station data is contained on one digital cassette tape and includes:

a) current vectors at four levels of 25 cm, 50 cm, 100 cm, 150 cm above the bottom;

b) current speed at 2 meters above the bottom;

c) bottom pressure at 2 meters above the bottom;

d) bottom temperature at 2 meters above the bottom;

e) light scattering (nephelometer) and light transmission at 2 meters above the bottom.

2. GEOPROBE station photographs (100 feet of time-sequenced 35 mm pictures).

3. Suspended sediment samples (filters) for 46 subsurface stations (100 samples) that included concurrent measurements of light transmission and temperature, and selected horizontal current recordings.

4. Suspended sediment samples at 160 surface locations.

5. Twenty surface salinity samples.

F. Milestone Chart

No changes in the milestones are anticipated. We expect to have the GEOPROBE station data fully analyzed by June, 1977.

III. Results:

Data are currently being analyzed, and a complete presentation of results can not be given at this time. The complicated electronics system on the GEOPROBE tripod appears to have worked satisfactorily; the cassette tape has been transcribed onto one-half inch computer accessible tape and checked for errors. A quick look at the data indicates that all sensors except the nephelometer appear to have functioned satisfactorily. The nephelometer readings show little change from the fully off value, suggesting that the sensitivity (gain) was too low.

The GEOPROBE camera photographs have been developed and examined. There is considerable backscatter throughout the film strip, suggesting that high concentrations of suspended materials were present during the recording. The GEOPROBE compass, used to obtain tripod orientation in space, is easily discernible in the photographs, but the bottom is generally faint or obscured by the backscatter.

Post-cruise calibration and check-out of pressure and current sensors is presently underway. Current speeds measured with the Savonius rotor sensor appear reasonable.

IV. Preliminary Interpretation of Results:

Not enough of the GEOPROBE station data has been analyzed to present confident interpretations. Current speeds appear to be in the 5 - 15 cm/s range; bottom pressure records suggest that the surface tide can be easily discerned.

Generally low light transmission values and the high degree of backscatter in the photographs suggest that suspended sediment concentration remained high throughout the sample period at the GEOPROBE site. According to our preliminary examinations of the cores taken near this site, it appears that we were, in fact, located in an area dominated by sediment supplied by the Yukon River.

No severe storms occurred during the measurement period, which will thwart our investigation into storm-dominated sediment transport effects. However, we anticipate being able to derive correlations for the fluctuations in light transmission, temperature, and bottom currents.

V. Problems Encountered:

Premature activation of the GEOPROBE acoustic release device occurred shortly after launch from R/V Sea Sounder. This unexpected event necessitated recovery and re-launch of the tripod system, extending the deployment by about 4 hours. SONATECH, Inc. is presently investigating the cause of the release malfunction. We fortunately had a back-up recovery system with a second release that was used in the second deployment.

VI. Estimate of Funds Expended:

No BLM/NOAA funds have been programmed for a FY77 effort by this project--despite a successful launch and recovery of a valuable sensing system.

Quarterly Report

Contract No.
Research Unit No. 431
October 1 - December 31, 1976
One Page

Coastal Processes and Morphology the Eastern Bering Sea

Asbury H. Sallenger, Jr.
John R. Dingler
Ralph E. Hunter

U.S. Geological Survey
Menlo Park, California 94025

I. Abstract

Efforts during the past quarter have involved the reduction of data gathered during the '76' field season. This includes the reduction and plotting of beach survey data, sediment textural analyses and compilations of coastal morphological observations

II. Task Objectives

A. Categorization of coastal morphology and regional sediment characteristics of the northeast Bering Sea (Yukon River to Bering Strait).

B. Categorization of coastal morphology and regional sediment characteristics of the northern coast of the Alaska Peninsula (Kvichak Bay to Unimak Island).

C. Monitoring sediment-level variations on the beach and in the nearshore at selected locations in the northeast Bering Sea.

D. Measurement of storm surge elevations of the November 11-12, 1974 storm utilizing indirect evidence around the coast of the northeast Bering Sea.

III. Laboratory Activities

A. 87 beach surveys, 30 beach/nearshore surveys and 87 sediment samples were gathered during the '76' field season. Data reduction is approximately 70% complete. Data analyses will be complete by March and will be included in our annual report.

IV. Results

Results will be reported once data reduction is complete (April 1).

V. Problems Encountered

None

VII. Estimate of Funds Expended

approximately $5000.00 (P.S.T. salaries)

VIII. Bibliography of References

Hunter, R. E., and A. H. Sallenger, Net littoral drift directions for the eastern Bering Sea (status: Data has been compiled and maps are being drafted. Intended for publication as a U.S.G.S. Miscellaneous Field Map).

RU# 432

NO REPORT RECEIVED

QUARTERLY REPORT, OCT. 1-DEC. 31, 1976

R.U. 473

SHORELINE HISTORY AS AN AID TO PREDICTING OFFSHORE PERMAFROST CONDITIONS

D. M. Hopkins

I. Abstract of Highlights of Quarter's Accomplishments

The published description of a water well drilled at Kotzebue (Cedarstrom, 1961) indicates that relict permafrost extends beneath a Holocene beach-ridge complex to a depth of 71 m, providing basic data for predictive thermal models for offshore permafrost in the Kotzebue Sound area.

Preliminary examination of single-channel SRP records suggests that relict ice-bonded permafrost is not likely to be found in Chukchi Sea waters deeper than 30 m.

A study of coastal processes and coastal history for the area between Cape Thompson and Cape Krusenstern indicates that during the last 3,000 years the coast has prograded several kilometers at Cape Krusenstern, remained nearly stable at Cape Thompson, at the north end of Kivalina Lagoon, and at the north end of Ipavik Lagoon, and retreated about 0.5 km in most other places (Hopkins, 1977).

II. Task Objectives: D-9

III. Field and laboratory activities

A. No field trips or cruises

B. Scientific party

D. M. Hopkins: geologist and principal investigator
R. W. Hartz: physical science technician

C. Methods of analysis

Study of maps and air photographs.
Synthesis of field observations.

D. Sample localities: None

E. Data collected or analyzed

Studied rate and direction of coastal change between Cape Thompson and Sheshalik Spit (work completed and reported on here) and between Cape Beaufort and Point Barrow (work still in progress).

Examined SRP records collected by A. Grantz and S. Eittreim for possible evidence of offshore permafrost.

Conducted literature search of onshore permafrost data.

IV and V. Results and interpretation.

(1) Single-channel seismic reflection profiles collected by A. Grantz and Stephen Eittreim aboard the U.S.C.G. BURTON ISLAND were examined for evidence of subsea permafrost. If permafrost boundaries were crossed, we would have expected to see upward displacement of deep reflectors at places where the ship crossed from unfrozen subsea sediments to a sea bottom underlain by ice-bonded permafrost. In general, the records lack anomalies suggestive of the presence of ice-bonded subsea permafrost, but in water shallower than 30 m, some tracks show perturbations that may be due to the presence of ice-bonded permafrost. We conclude that permafrost is probably lacking in most parts of the Chukchi Sea deeper than 30 m but may be present in some nearshore areas beneath water depths shallower than 30 m.

(2) A test well 97 m deep drilled at Kotzebue in 1949-1950 encountered permafrost extending to a depth of 71 m (Cederstrom, 1961) (fig. 1). The ice-bonded permafrost is interrupted at a depth of 24 m by a layer 2 m thick in which gravel is saturated with highly saline brine. The well is situated on a beach-ridge complex that formed during part of the time since sea level stabilized near its present level about 4,000 years ago. The deeper brine-soaked gravel is probably beach gravel deposited about 11,000 years ago during the late Pleistocene and Holocene rise in sea level, and the overlying frozen marine clay is probably all of Holocene age.

The permafrost above the brine-soaked gravel has evidently formed in equilibrium with the present climate subsequent to the emergence of the beach-ridge complex. The permafrost below the brine-soaked gravel is largely, if not entirely relict.

Recognition that relict permafrost extends to a depth of at least 71 m beneath the Holocene beach ridges at Kotzebue should be useful in thermal modeling studies for prediction of the extent of offshore permafrost in Kotzebue Sound.

(3) A report on coastal processes and rate and direction of coastal change between Cape Thompson and Cape Krusenstern was prepared for the dual purpose of providing information for the OCSEP offshore permafrost program and for filling the needs of the National Park

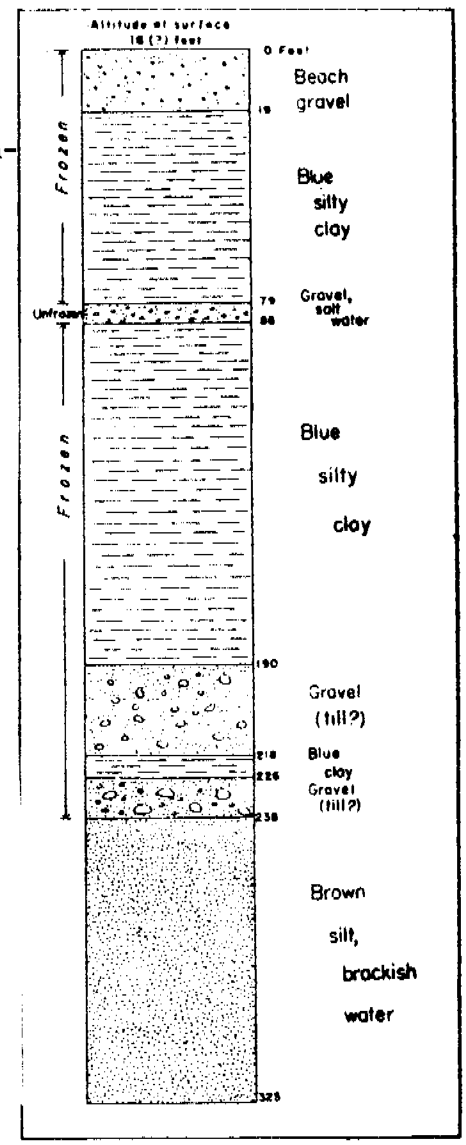

Figure 1. Log of U. S. Geological Survey test well at Kotzebue, Alaska

Service in planning the proposed Cape Krusenstern National Monument. The report which is enclosed herewith, has been issued as U.S. Geological Survey Open-File Report 77-32 (Hopkins, 1977).

A similar report on the coast between Cape Beaufort and Point Barrow is in preparation and hopefully will be ready for inclusion in the Annual Report. A similar report for southern Kotzebue Sound is planned but not yet started.

VI. Problems encountered and recommended changes.

VII. Estimate of funds expended to date: $6,500.

REFERENCES CITED

Cederstrom, D. J., 1961, Origin of salt-water lens in permafrost at Kotzebue, Alaska: U.S. Geol. Survey Bull., v. 72, p. 1427-1432.

Hopkins, D. M., 1977, Coastal processes and coastal erosion hazards to the Cape Krusenstern archaeological site: U.S. Geol. Survey Open-file Rept. 77-32. (Enclosed herewith.)

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

COASTAL PROCESSES AND COASTAL EROSIONAL HAZARDS TO THE CAPE KRUSENSTERN ARCHAEOLOGICAL SITE

By

David M. Hopkins

Open-file report
77-32

Menlo Park, California
1977

COASTAL PROCESSES AND COASTAL EROSIONAL HAZARDS TO THE CAPE KRUSENSTERN ARCHAEOLOGICAL SITE

by

David M. Hopkins
U.S. Geological Survey
Menlo Park, CA 94025

Cape Krusenstern, a sharp inflection in the coast of the Chukchi Sea forming the north portal to Kotzebue Sound (fig. 1), is a broad, accretionary beach-ridge plain which contains an exceptionally complete and well-studied record of Arctic prehistory spanning the last 4,000 years (Giddings, 1960). Cape Krusenstern National Monument is proposed to protect this important archaeological resource from inadvertent damage or destruction.

The beach-ridge plain is a depositional feature formed of sand and gravel brought by beach drift from a more northern source. Moore (1960) has suggested that the sand and gravel comprising Cape Krusenstern came predominantly from cliffs near Cape Thompson, some 100 km to the north. What would be the consequences, if the source of sediment were reduced or cut off by construction, for example, of a harbor or jetty at Kivalina?

It is the purpose of this report to examine the recent coastal history and the contemporary coastal processes between Cape Krusenstern and Cape Thompson in an effort to evaluate the possible effects at Cape Krusenstern of a disruption in the southward sediment drift. The report is based upon four days of helicopter-supported field work during the period August 3-6, 1976, supplemented by study of maps and air photos. The report was written for the use of the Alaska Task Force of the

National Park Service. Field work was carried out as part of a larger study of the proposed Monument by Robert Belous, National Park Service, and Douglas Anderson, Brown University. In undertaking this study and this report, I benefited from discussions with my Geological Survey colleagues, Ralph Hunter and Abby Sallenger.

Previous work.--Extensive archaeological excavations by J. L. Giddings and his co-workers (Giddings, 1960) have made Cape Krusenstern a major archaeological resource containing a more or less complete history of coastal occupation during the past 4,500 years. Because their maritime economy required that aboriginal Eskimo communities locate as close as possible to the beach, the individual beach ridges at Cape Krusenstern can be approximately dated by their occupation remains. Thus, the archaeological studies have also provided valuable historical information on coastal processes and the evolution of the Cape Krusenstern beach-ridge complex during the last 4,500 years.

The archaeological information from Cape Krusenstern was used by G. W. Moore in a series of pioneering papers on Arctic beach processes (Moore, 1960, 1966; Moore and Giddings, 1961; Moore and Giddings, unpub. map given here as fig. 2). In his 1960 paper, Moore showed that the beach ridges provide information about sea-level history. The oldest beach ridges are partly submerged, and sea level was at least 3 m lower than at present when they were formed. Moore went on to suggest that especially high beach ridges such as the one occupied by the Ipiutak culture about 2,000 years ago may have formed at a time when sea level was slightly higher than at present, but this idea is not generally accepted. Other workers have shown that beach ridges are formed by the onshore migration of submerged offshore bars during storm surges in which sea level is temporarily raised in response to lowered barometric pressure and strong onshore winds. Temporary rises in sea level as great as 4 meters have been recorded during storm surges along the shores of northern Bering, Chukchi, and Beaufort Seas. The accretion of a beach ridge and its ultimate height are governed by the height of sea level during the storm surge, by the intensity of wave attack, and by the volume of sediment that has accumulated nearshore. Thus, differences in the heights of individual Cape Krusenstern beach ridges do not provide a record of eustatic sea-level fluctuations, although the semi-submerged condition of the oldest beach ridges does reflect the fact that sea level was several meters lower 3,500 to 4,500 years ago.

Moore's and Giddings' unpublished map (fig. 2) shows that the accretion of beach ridges on the south side of Cape Krusenstern has been interrupted, from time to time, by short periods of erosion which are recorded by discordant relationships in which younger beach ridges truncate older ones. Erosion, when it has taken place, has resulted in removal of segments of southeast trending beach ridges north of present-day Cape Krusenstern proper, followed by accrual there of a series of south-trending beaches. Moore and Giddings (1961) suggest that the erosion and ensuing shifts in the locus of accrual of beach ridges has been the result of a series of shifts in the direction of storm winds. However, the series of erosional events followed by shifts in locus of deposition might have been caused, instead, by episodic interruptions or reductions in the sediment supply. Some of the large, rectangular lagoons (for example, Kotlik Lagoon, Imik Lagoon) look like truncated thaw lakes. Possibly the erosional episodes record occasions when the retreating coast breached large thermo-karst lakes. Southward sediment drift might then have been disrupted or substantially diminished until a spit and then a barrier bar could be built across the new embayment.

In his 1966 paper, Moore postulated that the segment of the coast between Cape Thompson and Sheshalik Spit forms a single beach-drift cell which is supplied almost exclusively by erosion of the 20 km of cliffed coast near Cape Thompson. If Moore were completely correct, then an interruption in beach drift at any point along the coast south of Cape Thompson would result, sooner or later, in erosion at Cape Krusenstern. Despite some local evidence to the contrary, Moore is probably correct in concluding that net beach drift is southward and eastward throughout the Cape Thompson-Sheshalik Spit segment of the Chukchi Sea coast. However, the system contains several important sources of sediment in addition to the cliffs near Cape Thompson.

Identification of sediment sources is aided by knowledge of the regional geology. The bedrock geology of the region from Point Hope to the Noatak River has been mapped at scale 1:250,000 by I. L. Tailleur (unpublished compilations) and summarized at scale 1:1,000,000 by Beikman and Lathram (1976). A photogeological map of the surficial geology of the Cape Krusenstern region was compiled at scale 1:250,000 by D. M. Hopkins and summarized at scale 1:2,500,000 by Coulter and others (1965).

Description of the coast between Cape Thompson and Cape Krusenstern.--Cape Krusenstern lies about 150 km southeast of Cape Thompson and about 75 km west of Sheshalik Spit (fig. 1). The coast from Cape Thompson to Cape Krusenstern describes a broad, shallow arc concave toward the Chukchi

Sea, interrupted by short, sharp convexities at Cape Thompson and Battle Rock and by broad, rounded convexities at Cape Seppings and Kivalina. Bedrock cliffs and steep gravel bluffs front the coast almost continuously through a 20-km stretch of coast from Cape Thompson to Kisimilok Mountain, and low bedrock cliffs extend along the coast for about a kilometer at Battle Rock. Bluffs a few meters high cut in silt, sand, and pebbly sand occupy a few kilometers of the coast in various places between Rabbit Creek and Krusenstern Lagoon. Elsewhere, the coast is low-lying and devoid of erosional bluffs.

Two-thirds of the coast consists of barrier bars backed by lagoons. The beaches and barrier bars generally consist of a single ridge ranging from 100 to 200 m in width. Dunes are rarely present. In many places, the rear parts of the barrier bars show wash-over channels and storm-surge deltas as well as grooves and ridges that result from ice-push. The rear parts of the beaches commonly support a halophyte flora consisting chiefly of Elymus mollis, Lathyrus maritimus, and Chrysanthemum arcticum, but areas that have not been affected by salt water for many decades support a dry-tundra matte of prostrate heaths and willow and birch shrubs, and areas that have been subjected to wash-overs within the last couple of years are nearly bare. Although all of the species comprising the halophyte flora reach their climatic limits hundreds of kilometers north of Cape Thompson, the vegetation cover on back beaches and barrier bars grows sparser, and bare area grow more extensive as one proceeds northward. This observation, coupled with the northward increase in the morphological evidence of recent wash-overs, seems to indicate that the beaches are flooded with increasing frequency as one progresses northward.

Older beach ridges are generally lacking except in the giant Cape Krusenstern complex, but a single old beach ridge extends behind the modern beach for about one kilometer along the north end of Ipiavik Lagoon, and two older ridges are present behind the modern beach for several kilometers north of the north entrance to Kivalina Lagoon (fig. 3). Examination of the well-dated Cape Krusenstern beach ridge complex shows that beach ridges in this region can be approximately dated on the basis of whether or not they are semi-submerged and according to the degree of development of the ice-wedge network. The older beach ridge along Kivalina Lagoon and the old beach ridge at Ipiavik Lagoon have ice-wedge networks indicative of an age of one to two thousand years. The younger and more seaward beach ridge along Kivalina Lagoon has a series of old house pits whose form indicates that they were built between 1400 and 1500 A.D. (Douglas Anderson, oral commun., 8/5/76).

The lagoon shores of the barrier bars commonly display their own systems of beach ridges, built partly by waves and partly by ice-push from the lagoon side. The north ends of Krusenstern, Imik, and Kotlik Lagoons are filled in by a series of broadly arcuate beach ridges. Ice-wedge development and the semi-submerged condition of the northernmost and oldest ridges in each set indicate that they were formed earlier than 3,500 and perhaps as early as 4,500 years ago. These oldest beach ridges are sharply truncated by the ocean beach, but the younger lagoon beach ridges in each set curve more sharply and become tangent to the modern barrier bar.

Sources of sediment.--The Cape Krusenstern beach-ridge complex consists largely of gravel. The sand-sized component may be derived from points as far north as Cape Thompson, but the gravel component must originate south of Kivalina, because the ocean beach in front of Kivalina Lagoon consists of sand with very few pebbles.

Large quantities of sandstone, chert, and limestone--the predominant components of the Cape Krusenstern beach sediment (Moore, 1966)--are supplied by bedrock cliffs at Cape Thompson and by bluffs cut in Pleistocene gravel and colluvium between Ogotoruk Creek and Kisimilok Mountain (fig. 1). However, the same suite of rocks is also added in several other places. Limestone is supplied by the coastal cliffs at Battle Rock and by bluffs cut in Pleistocene beach gravel and colluvium that extend a few hundred meters to the north and south. Trails of gravel can be seen extending diagonally across the beach from low bluffs cut in alluvium south of Rabbit Creek and from bluffs cut in Pelukian interglacial beach deposits north of Krusenstern Lagoon (fig. 3).

Some gravel is added to the beach from the nearby sea bottom. Moore minimized the possible importance of movement of material from shallow nearshore waters onto the beach, but I have seen clear evidence of the capacity of storm waves to erode pebble-sized particles from the nearshore bottom and to move them onshore. Abundant, large, discolored fossil mollusk shells appear after storms on the beach at Cape Krusenstern and in many places between Cape Espenberg and Shishmaref on the north coast of the Seward Peninsula (south of the area of fig. 1). The fossil mollusks include species that no longer live in the Chukchi Sea, and they differ in color from the shells of mollusks of the modern infauna with which they are mingled on the beach. The stained fossil mollusk shells are obviously derived from marine deposits of the Pelukian (last interglacial) transgression, but no Pelukian deposits are exposed above sea level in the places named. It is clear that the fossil mollusk shells have been ripped up and transported onshore from submarine outcrops of Pelukian deposits.

Gravel evidently also enters the Cape Thompson-Sheshalik Spit beach-drift system as a result of erosion at and below beach level of onshore alluvial fans, outwash deposits, and deltas. Coastal convexities at Cape Seppings and just south of Kivalina River testify to the importance of the alluvial fans of the Singoalak and Wulik Rivers as sediment sources. Although the Singoalak River is a small, short stream, Creager and McManus (1966) mapped a large area of gravel offshore near Cape Seppings, indicating that the Singoalak River fan extends seaward as a relict bottom deposit, constituting an additional potential additional source of supply. Gravel is also added by the retreat of the shore through alluvium and glacial-outwash gravel at the mouths of Agagrak, Rabbit, and Kilikmak Creeks.

Direction of coastal drift.--As Moore (1966) showed, the direction of beach drift varies from one day to another during the open season, depending upon the orientation of incoming waves relative to the coast. However, net drift over a period of years can be inferred on the basis of direction of displacement of river mouths and lagoon outlets and on the basis of direction in which submerged offshore bars diverge from the strand. Some insight can also be gained by examining the direction in which distinctive pebbles trail and the directions in which beach sediments grow finer from points of sediment input; however, the frequent temporary reversals in direction of beach drift make these indicators less definitive.

Morphological indicators, directions of drift of distinctive pebbles, and directions of fining indicate clearly that net beach drift is southward and eastward along most segments of the coast between Cape Thompson and Sheshalik Spit, but northward drift is suggested locally. During my overflights in August, 1976, morphological indicators suggested recent northward drift along short segments of the coast to the north and south of Cape Seppings and, more surprisingly, along most of the 40-km segment of coast from Ipiavik Lagoon to the northern inlet of Kivalina Lagoon (fig. 3).* The gross morphology of the coast makes Ipiavik Lagoon--at the center of the sweeping concave arc between Cape Thompson and Cape Krusenstern--an unlikely place for a divergence in the direction of coastal drift, and further work will be required before the direction of net beach drift in the Kivalina Lagoon-Ipiavik Lagoon segment can be considered to be firmly established. The question is important, because if beach drift is either northward or nearly neutral in that sector, then a perturbation of the beach drift north of Ipiavik Lagoon would have little effect upon the beach regime at Cape Krusenstern.

An indication of the amount of coastal retreat possible during a single storm is provided by thermokarst features seen at the rear of the beach south of Rabbit Creek during early August, 1976. In my experience, Arctic beaches display thermokarst collapse features only in newly formed areas in front of recently and rapidly eroded coastal bluffs. Quaternary

* After completing this report I noticed that my field maps record clear morphological evidence of westward beach drift along 6 km of coast from Tukrok Creek toward Cape Krusenstern (fig. 3). This observation seems to lend support to Moore's inference that changes in wind regime may be responsible for shifts in sites of deposition and erosion in the Cape Krusenstern beach-ridge complex.

sediments in coastal bluffs generally contain ice wedges which fill polygonal systems of frost cracks. If the bluffs are less than 5 m high, the wedges generally extend below beach level. During periods when the bluff is retreating slowly, the ice wedges thaw more rapidly than the adjoining frozen sediments. Small tundra streams develop along the ice wedges, accelerating removal of the ground ice, and the turf then collapses into the resulting trenches, creating ice-wedge pseudomorphs which may persist as recognizable features on scoured beach surfaces. During intense storms, however, the coastal bluffs may retreat quickly and in toto, leaving the roots of ice wedges to persist beneath the newly formed beach. The wedge ice then thaws out and forms polygonal collapse trenches in the beach next to the freshly exposed bluff. One may conclude that the bluff has recently retreated by an amount equal to and probably exceeding the width of the belt of collapse trenches. Based on this criterion, bluffs carved in Pleistocene sediment south of Rabbit Creek retreated at least 2 meters during a 1975 storm surge.

The amount of shoreline retreat over a longer period can be estimated by reconstructing the position of the ocean beach when the truncated beach ridges at the north ends of Krusenstern, Kotlik, and Imik Lagoons were formed. If the arcuate lagoonal beach ridges originally extended seaward with the same radius of curvature to a point where they were tangent to the barrier bar of the time, then the shoreline has retreated 500 to 600 m in the 3,500 to 4,500 years since the earliest beach ridges were formed. Retreat rates of 10 to 20 m per century are suggested. These figures seem entirely reasonable in the light of the evidence at Rabbit Creek for coastal retreat of 2 m or more during a single recent storm.

Differential erosion since sea level approached its present position, 3,500 to 4,500 years ago, has converted a former limestone hillock into the Battle Rock headland by eroding the softer Pleistocene alluvium and beach gravel 250 m landward at the southern, downdrift end of the bedrock bluffs. A small but unknown amount of coastal retreat has taken place on the headland itself, so that the total amount of coastal retreat by erosion of soft sediments south of Battle Rock must be somewhat greater than 250 m during the last 3,500-4,500 years.

We may now attempt to reconstruct the position of the shoreline 3,500 years ago (fig. 3). This moment is chosen because the rapid post-glacial rise in sea level had slowed several centuries earlier. Sea level stood only a few meters below its present position, and sufficient time can be assumed to have elapsed so that a nearly straight coast had developed as a result of truncation of headlands and construction of barrier bars across embayments.

A beach ridge bearing the remains of a 3,500-year-old settlement marks the former position of the shoreline inland from present-day Cape Krusenstern. From Krusenstern Lagoon to the north end of Ipiavik Lagoon, the shore evidently stood several hundred meters seaward of its present position. The presence of ancient beach ridges indicates that the shoreline at the north ends of Ipiavik and Kivalina Lagoons has changed very little within the last one or two thousand years, and we shall assume that in these places the position of the shore has been more or less constant for the longer period of 3,500 years. The remaining segment of the coast between Ipiavik and Kivalina stood an unknown distance seaward from the present shore.

There are too many uncertainties in our reconstruction of the position of the 3,500-year-old shoreline to justifv a quantitative comparison, but it is clear that the volume of material contributed to the beach system by coastal retreat between Kivalina and Krusenstern Lagoon is of the same order of magnitude as the quantity of material deposited in the Cape Krusenstern beach-ridge complex.

Conclusions.--Despite the anomalous evidence of northward beach drift from Ipiavik to Kivalina Lagoon, the Chukchi Sea coast between Cape Thompson and Sheshalik Spit probably constitutes a single beach-drift cell in which sediment is gradually and intermittently transported southward and eastward. The barrier bars in this system are transmission belts for sediment. If the sediment supply were disrupted, somewhere updrift, the barrier bars would retreat lagoonward synchronously with a rapid erosional retreat of the nearby low-lying mainland coast. Disruption of sediment supply updrift would not result in breaching of barrier bars and opening of lagoons to the sea.

Sediment is contributed to the Cape Thompson-Sheshalik Spit beach system in many places The contributions are probably cumulative. The northward narrowing of the barrier bars, thinning of the beach vegetation, and intensification in the frequency of inundation probably reflects beach starvation--the effects of inadequate sediment supply and consequent rapid coastal retreat in the more northern sectors. Coarse debris supplied between Cape Thompson and Kisimilok Mountain and at Cape Seppings is largely reduced to sand by the time it reaches Kivalina, and the gravel component of the Cape Krusenstern beach-ridge complex is evidently mostly derived from sources south of Kivalina. Sediment supplied during the last 3,500 years by coastal retreat between Kivalina and Krusenstern Lagoon may be equal to the quantity of sediment deposited during the last 3,500 years in the Cape Krusenstern beach-ridge complex.

Construction of a jetty or harbor between Cape Krusenstern and Ipiavik Lagoon would disrupt southward sediment drift and would eventually result in erosion at Cape Krusenstern. The response time cannot be predicted with data presently available. The extent of erosion would depend upon the duration of sediment disruption and upon the success of countermeasures such as possible attempts to pump sediment past the disrupting structure. The several episodes of erosion recorded by discordances in the beach-ridge sequence at Cape Krusenstern resulted from natural perturbations in the sediment drift that lasted for decades or possibly centuries (fig. 2); they provide a guide to the probable consequences of an artificial disruption. The narrow neck of land connecting Cape Krusenstern with the mainland coast to the north would be inundated by storm surges more frequently, and it would be displaced toward the lagoon. However, it would not be breached, and Krusenstern Lagoon would not be converted into an open embayment. The south-trending beach ridges to the north of Cape Krusenstern would be eroded and their rich archaeological record would be destroyed, but the east-trending beach ridge complex east of Cape Krusenstern would be unaffected.

The possible effects of an artificial disruption to the beach drift in the area between Ipiavik Lagoon and Kivalina cannot be evaluated without more careful study, because the direction of net beach drift is not firmly known.

Construction of a harbor or jetty at Kivalina or at some point further north would have little or no effect at Cape Krusenstern. The diminishment in sediment supply would be compensated by accelerated coastal retreat nearer to the site of the disturbance.

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Giddings, J. L., 1960, First traces of man in the Arctic: Sci. American, Nov. 1960, p. 10-19.

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FIGURE CAPTIONS

Figure 1. Index Map.

Figure 2. Beach ridge sequence at Cape Krusenstern. Numbered areas represent sequences of parallel beach ridges separated from one another by discordances which represent short erosional episodes. A profile through showing heights and ages of beach ridges and approximate duration of erosional intervals is given at the base of the figure. This figure was originally compiled by G. W. Moore and J. L. Giddings.

Figure 3. Shoreline morphology and history, Noatak Quadrangle, Alaska. Shoreline morphology of the proposed Cape Krusenstern National Monument (area enclosed by heavy lines) and surrounding areas. This is an overlay for the Noatak Quadrangle (1:250,000) (U.S. Geological Survey, 1955).

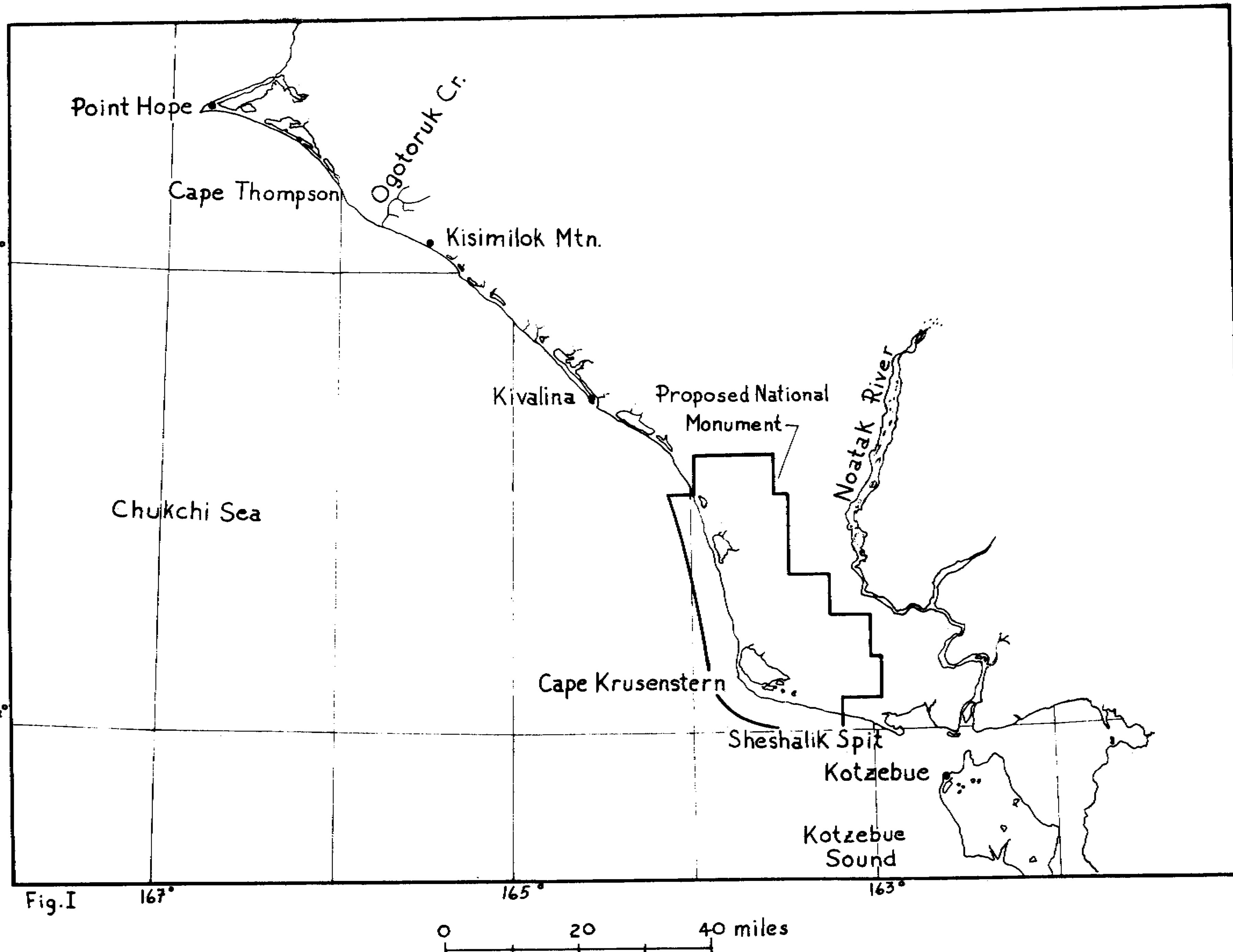
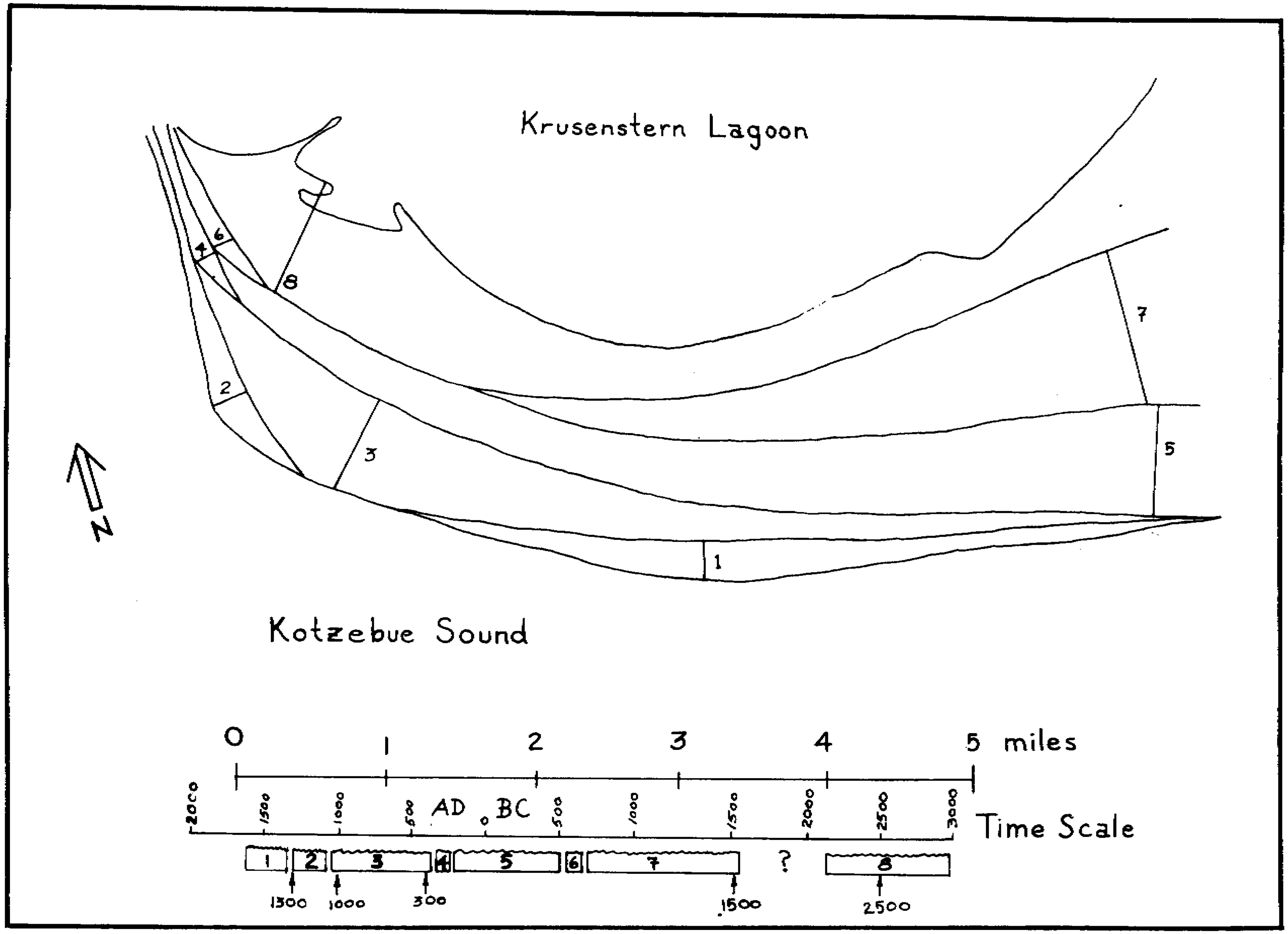

Point Hope
Ogotoruk Cr.
Cape Thompson
Kisimilok Mtn.
68°
Kivalina
Proposed National Monument
Noatak River
Chukchi Sea
Cape Krusenstern
67°
Sheshalik Spit
Kotzebue
Kotzebue Sound
167°
165°
163°
0
20
40 miles

Fig. I



Krusenstern Lagoon
Kotzebue Sound
N
1
2
3
4
5
6
7
8
0 1 2 3 4 5 miles
2000 1500 1000 500 AD 0 BC 500 1000 1500 2000 2500 3000
Time Scale
1 2 3 4 5 6 7 ? 8
1300 1000 300 1500 2500

Fig. II

SECOND QUARTERLY REPORT

PERIOD: September 1, 1976 - December 31, 1976

TITLE: Evaluation of earthquake activity around Norton and Kotzebue Sounds

PRINCIPAL INVESTIGATORS: N. N. Biswas and L. Gedney, Geophysical Institute, University of Alaska

I. TASK OBJECTIVE: To complete installation and operate a short-period seismic network to provide seismic coverage of the study area.

II. FIELD AND LABORATORY ACTIVITIES:

A. STATION INSTALLATION: The installation of all the stations except at Savoonga (SVG) on St. Lawrence Island have been completed (Figure 1). The data from this station required to be telemetered to the seismology laboratory, Geophysical Institute at Fairbanks via the RCA Satellite Communication System. However, RCA could not provide the required data telemetry link during the reporting period; it is anticipated to obtain this during February, 1977.

B. INSTRUMENTATION: The instrumental difficulties encountered at the field and recording sites, as reported in the previous progress report, have been resolved. Some improvement in the signal-to-noise ratio, particularly, for the station at Tin City (TNC) is required. How best this can be achieved is presently under investigation. Also, the signal from the remote station (REM) is intermittent in character. We hope to resolve these residual instrumental problems in another month or so.

C. DATA TELEMETRY AND RECORDING: Despite some of the field site difficulties yet remained to be solved as mentioned above, successful routine recording of data from the operating stations are continuing. Recording polarities have been checked from a recent underground nuclear explosion in Russia.

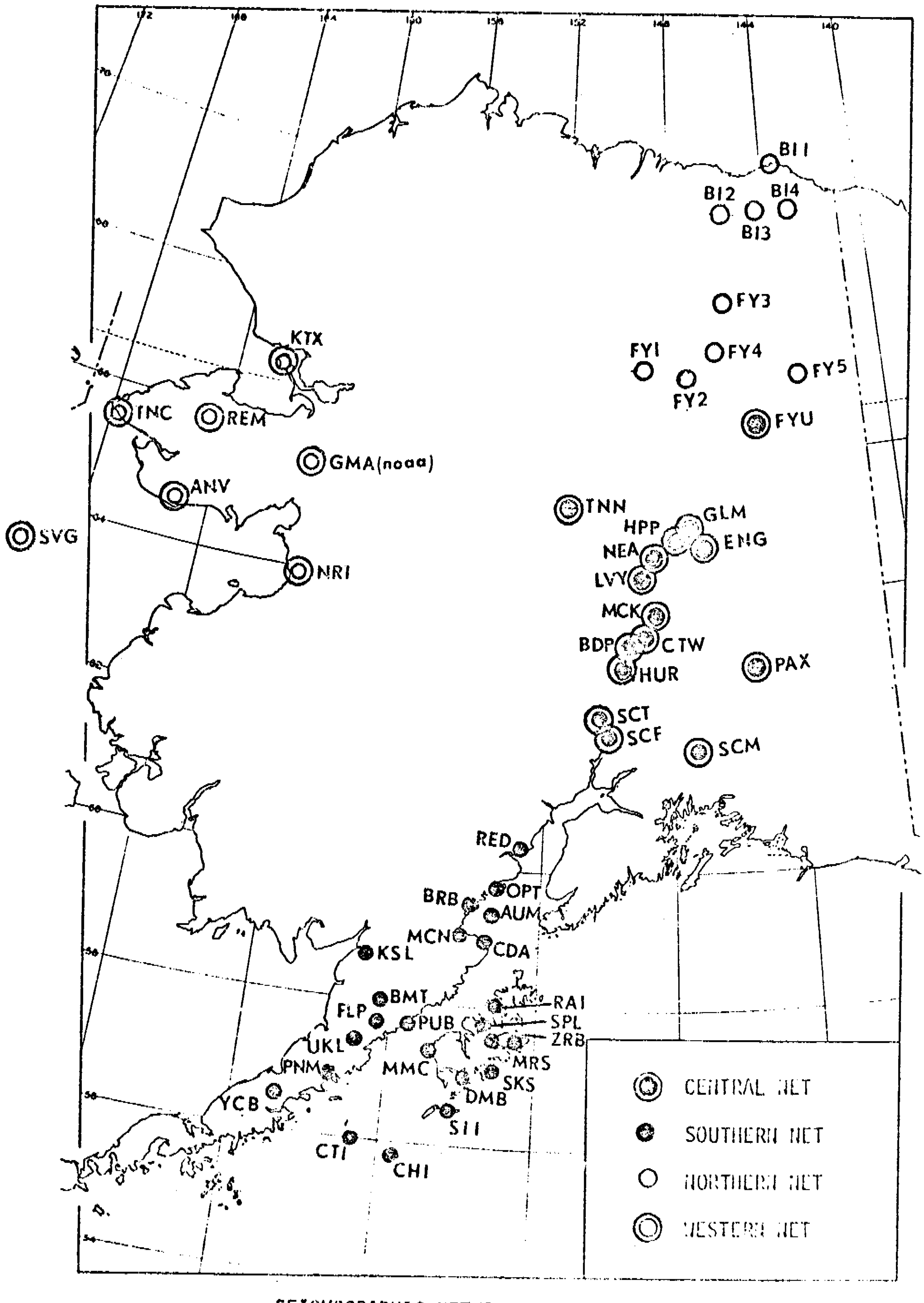
D. DATA REDUCTION: Evaluation of the system-magnification of each station are in progress. Routine scaling of data is continuing and we hope to start locating the events in the near future.

III. RESULTS: None

IV. PRELIMINARY INTERPRETATION: None

V. ESTIMATES OF THE FUND EXPENDED: $78,500.00

NOV. 1976



SEISMOGRAPHIC NETWORKS OPERATED BY THE UNIVERSITY OF ALASKA

DATA MANAGEMENT

DATA MANAGEMENT

Quarterly Report

Contract #03-5-022-56
Research Unit #350
Task Order #2
Reporting Period 10/1 - 12/31/76
Number of Pages 3

ALASKAN OCS PROGRAM COORDINATION

Mr. Donald H. Rosenberg
Alaska Sea Grant Program
University of Alaska
Fairbanks, Alaska 99701

January 1, 1977

I. Task Objectives

This project provides for coordination of all NOAA/OCS Task Orders within the University of Alaska. It provides for a coordinator and related support services necessary for the accomplishment of the scientific programs. These services include Data Management, Fiscal Management, and Logistics Coordination.

II. Field and Laboratory Activities

Not applicable

III. Results

A. Data Management

1. Data Management Plans

Data Management Plans have been approved and made contractual for the following: Contract 03-5-022-56, Task Orders #1, 2, 4, 5, 7, 9, 10, 11, and 13-26; Contract 03-5-022-55, no Task Order Management Plans have been approved by the contracting officer.

Data Management Plans have been approved by the Contract Data Manager for the following: Contract 03-5-022-56, Task Orders #3, 6, 8, 12, and 30; Contract 03-5-022-55, Task Orders #1, 2, 3, 4, 5, 6, 7, 8, 10, and 11. We await approval of these by the contracting officer.

We have submitted proposed Data Management Plans for Task Orders #27, 28, 29, Contract 03-5-022-56 and await approval.

Contract 03-5-022-55, Task Order #9 has not as yet submitted a Data Management Plan. We intend to submit same shortly.

2. Data Submitted This Quarter

Task Order #3, Sediment Size Analyses for Discoverer 808, and Miller Freeman 818 on 11/12/76.

Task Order #8, Marine Mammal Sitings for the Summer of 1976 on 10/7/76.

Task Order #14, CTD Data for Surveyor 002 on 11/1/76.

Task Order #15, Benthic Organisms Trawl Data for Miller Freeman 817 on 11/12/76.

Task Order #19, CTD Data for Moana Wave 003,004, Surveyor 814 updated and corrected on 11/1/76.

Task Order #20, Benthic Data for Discoverer 812 on October 7, 1976.

Task Order #21, Fish Food Data for "Rex Sole" on 11/10/76.

Data Submission Schedule updates for all Task Orders in Contract 03-5-022-56 are attached as requested.

B. Logistics Coordination

Coordination of logistics for OCS cruises was rendered by this office. This coordination consisted of reviewing and correcting Project Instructions and acting as a conduit between Principal Investigators and OCSEAP concerning any problems with shipboard programs.

Cruises, this quarter, in which our personnel were involved are:

Miller Freeman	Trawl Survey
Miller Freeman	Benthic Survey
Miller Freeman	CTD Survey
Moana Wave	CTD Survey

C. Contract Monitoring

The Unversity continues to have problems with regard to contractural matters. Although NOAA did notify the University which Task Orders were to be continued beyond September 30, 1976, it was not until December 28, 1976 that a contract modification was received. This contract modification did not indicate which work statements were being funded. As a result, this office is unable to determine if purchases, etc. are in accordance with our contractural obligation. Because of the terms of our contract, all equipment purchases have been held up until specific permission is received from our Contracting Officer.

IV. Problems Encountered

A. Failure of NOAA to notify the University of work statement approval is causing extra work and concern by the University.

B. Confusion in the administrative structure within NOAA causes considerable concern from Principal Investigators. Originally, they were informed by this office who their Contracting Officer Technical Representatives were. They are now being contacted by a Data Tracker. We verbally requested information on who was assigned to whom from the Juneau project office. This was never received.

C. We requested a change in the Data Management article of our contract in accordance with a request from our Data Manager. The proposal modification was submitted to the Data Manager in October 1976. No further information has been received by the University.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56   T/O NUMBER: 1   R.U. NUMBER: 159/164

PRINCIPAL INVESTIGATOR: Dr. Vera Alexander

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[1]			
	From	To	Batch 1	2	3	4
Discoverer Leg I #808	5/15/75	5/30/75	submitted	submitted	None	None
Discoverer Leg II #808	6/2/75	6/19/75	submitted	submitted	None	None
Discoverer Leg I #810	8/9/75	8/28/75	submitted	submitted	None	None
Miller Freeman #815	11/10/75	11/26/75	submitted	submitted	None	None
Surveyor Su/001/2	3/76	4/76	(a)	(a)	None	None

Note: [1] Data Management Plan and data Formats have been approved and are considered contractual.

(a) These samples will be processed; pending funding for October - December 1977, as requested by proposal submitted 9/13/76. Data submission will be made 120 days after end of processing as per contract.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

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[1]

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 3 R.U. NUMBER: 291

PRINCIPAL INVESTIGATOR: Dr. C. M. Hoskin

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[1]		
	From	To	Batch 1		
Discoverer Leg I #808	5/15/75	5/30/75	Submitted		
Discoverer Leg II #808	6/2/75	6/19/75	Submitted		
Miller Freeman	8/16/75	10/20/75	Submitted		

All data for FY '76 have been submitted.

Note: [1] Estimated submission dates are contingent upon final approval of data management plan submitted in draft form Oct. 9, 1975 and University of Alaska approved form Nov. 10, 1975, to NOAA.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 4 R.U. NUMBER: 111

PRINCIPAL INVESTIGATOR: Dr. Robert F. Carlson

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[1].

The final report is being prepared.

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 5 R.U. NUMBER: 275/276/[illegible]

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[1]		
	From	To	Batch 1	2	3
Silas Bent Leg I #811	8/31/75	9/14/75	None	submitted	submitted
Discoverer Leg III #810	9/12/75	10/3/75	None	None	submitted
Discoverer Leg IV #812	10/3/75	10/16/75	9/30/76	None	submitted
Surveyor #814	10/28/75	11/17/75	None	submitted	None
North Pacific	4/25/75	8/7/75	submitted	None	None
Contract 03-5-022-34	Last	Year	submitted	submitted	submitted
Moana Wave MW 001	2/21/76	3/5/76	None	9/30/76	9/30/76
Miller Freeman	5/17/76	6/4/76	9/30/76	None	None
Glacier	-	-	None	(a)	None
Discoverer	9/10/76	9/24/76	None	(a)	(a)
Moana Wave	10/7/76	10/16/76	None	(a)	(a)

Note: [1] Data Management plan has been approved and made contractual.

(a) Data will be processed and submitted in FY '77, contingent upon receiving funding for Fy '77.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 6 R.U. NUMBER: 99

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[1].

NOTE: [1] Data management plan was submitted to NOAA in draft form on October 9, 1975 and University of Alaska approval given on November 20, 1975. We await formal approval from NOAA.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56   T/O NUMBER: 7   R.U. NUMBER: 178

PRINCIPAL INVESTIGATOR: Dr. Robert J. Barsdate

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[1].

NOTE: [1] Data Management Plan has been approved and made contractural.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

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[1]			
	From	To	Batch 1			
Alaska Peninsula	7/23/75	7/24/75	submitted			
Kotzebue Sound	7/17/75	7/20/75	submitted			
Kotzebue Sound	7/22/75	7/24/75	submitted			
St. Lawrence Is.	8/8/75	8/22/75	submitted			
Alaska Peninsula	Summer 1976		submitted			
Kotzebue Sound	Summer 1976		submitted			

All FY '76 data have been submitted

Note: 1 Data Management Plan has been approved by M. Pelto; we await approval by the Contract Officer.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 9 R.U. NUMBER: 318

PRINCIPAL INVESTIGATOR: Dr. J. E. Morrow

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[1].

The final report is being prepared.

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 10 R.U. NUMBER: 282/301

PRINCIPAL INVESTIGATOR: Dr. H. M. Feder

Progress on this study has indicated that there is little data in a form suitable for submission using available EDS Format (Benthic Organisms). It is suggested that the following information products be accepted; (1) key word bibliography (2) distribution maps, which would be available as they are produced; however, the total applicable information available could rot be converted into this media prior to December 1976. An example of maps being produced is available for OCSEAP review.

The delay on the bibliography is due to the addition of information for the Chukchi Sea, and a backlog in keypunching information due to the loss of one operator. The bibliography is being finalized and the keypunching proofed. Computer key word indexing is expected to proceed, including a final output, in the next month.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 11 R.U. NUMBER: 215

PRINCIPAL INVESTIGATOR: Mr. George Mueller

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[1].

The final report has been submitted. This task order has been contractually completed.

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56   T/O NUMBER: 12   R.U. NUMBER: 162/163/288/293/312

PRINCIPAL INVESTIGATOR: Dr. D. C. Burrell

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[1]			
	From	To	Batch 1	2	3	4
Discoverer Leg II #808	6/2/75	6/19/75	*	*	None	*
Silas Bent Leg I #811	8/31/75	9/14/75	None	None	None	None
Discoverer Leg IV #812	10/8/75	10/16/75	*	*	None	*
Miller Freeman	8/16/75	10/20/75	None	None	Unknown	None
Discoverer Leg III #810	9/12/75	10/3/75	None	None	None	*
North Pacific	4/25/75	8/7/75	None	None	Unknown	None
Intertidal Biota		1975	None	None	Unknown	None
Discoverer #816	11/12/75	12/2/75	*	*	None	*
Contract 03-5-022-34	Last	Year	*	None	None	None
USCGC Glacier	-	-	Data batches as yet not determined			
Discoverer	9/10/76	9/24/76	Funding for analysis not provided.			

Note: [1] Data Management Plan has been approved by M. Pelto, we await approval by the Contract Officer.

Cruise/Field Operation	Collection Dates		Estimated Submission Dates[1]			
	From	To	Batch 5	6	7	8
Discoverer Leg II 808	6/2/75	6/19/75	*	None	None	None
Silas Bent Leg I 811	8/31/75	9/14/75	None	None	None	None
Discoverer Leg IV 812	10/8/75	10/16/75	*	*	None	None
Miller Freeman	8/16/75	10/20/75	None	Lost	*	*
Discoverer Leg III 810	9/12/75	10/3/75	None	*	None	None
North Pacific	4/25/75	8/7/75	None	Lost	Lost	Lost
Intertidal Biota		1975	None	None	*	*
Discoverer 816	11/23/75	12/2/75	*	None	None	None
Contract 03-5-022-34	Last	year	*	None	*	*
Glacier	8/23	9/3/76		*		

Cruise/Field Operation	Collection Dates		Estimated Submission Dates[1]			
	From	To	Batch 9	10		
Discoverer Leg II 808	6/2/75	6/19/75	*	*		
Silas Bent Leg I 811	8/31/75	9/14/75	*	*		
Discoverer Leg IV 812	10/8/75	10/16/75	9/30/76	*		
Miller Freeman	8/16/75	10/20/75	none	none		
Discoverer Leg III 810	9/12/75	10/3/75	none	none		
North Pacific	4/25/75	8/7/75	none	none		
Intertidal Biota		1975	none	none		
Discoverer 816	11/23/75	12/2/75	*	*		
Contract 03-5-022-34	Last	year	*	none		
Moana Wave	3/76	4/15/76	*	none		
Beaufort Sea Sediments			*	*		

* These data have been submitted in tabular form in the Annual and Quarterly Reports for T/O 12 including the Final report of contract 03-5-022-34.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 13 R.U. NUMBER: 156/164

PRINCIPAL INVESTIGATOR: Dr. R. T. Cooney

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[1]		
	From	To	Batch 1		
Discoverer Leg I #808	5/15/75	5/30/75	submitted		
Discoverer Leg II #808	6/2/75	6/19/75	submitted		
Discoverer Leg I #810	8/9/75	8/28/75	submitted		
Miller Freeman #815	11/10/75	11/26/75	submitted		
Contract #03-5-022-34	Last	Year	submitted		
Surveyor 001/2	3/76	4/76	submitted		
Discoverer 002	8/3/76	8/17/76	3/30/77[a]		

Notes: [1] Data Management Plan has been approved and made contractual. Format has been received and approved by all parties.

[a] Date of submission is dependent upon continuation and funding of this project in FY '77.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 14 R.U. NUMBER: 307

PRINCIPAL INVESTIGATOR: Dr. R. D. Muench

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[1]			
	From	To	Batch 1			
Acona #197	7/20/75	7/30/75	submitted			
Discoverer Leg I & II #808	5/15/75	6/19/75	submitted			
Discoverer Leg I #810	8/9/75	8/28/75	(a)			
Miller Freeman #815	11/19/75	11/26/75	submitted			
Surveyor 001/002	3/76	4/76	submitted			

All data to be submitted under this task order, for this contract have now been submitted.

NOTE: 1 Data Management Plan and Data Format have been approved and are considered contractual.

(a) Parent tapes were coded in PODAS format, tapes were submitted to F. Cava as requested.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 15 R.U. NUMBER: 5/303

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[1]			
	From	To	Batch 1	2		
Discoverer Leg I #808	5/15/75	5/30/75	*	None		
Discoverer Leg II #808	6/2/75	6/19/75	*	None		
Miller Freeman	8/16/75	10/20/75	(a)	submitted		
Miller Freeman	3/76	6/76	(a)	(a)		

Note: [1] Data Management Plan and Data Format have been approved and are considered contractual.

(a) These materials will be archived. Selected samples will be processed in FY '77, providing project is funded.

* That portion of cruise 808 grabs sorted, were submitted. The remainder will receive top priority in FY '77 providing projest is funded.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 16 R.U. NUMBER: 348

PRINCIPAL INVESTIGATOR: Dr. J. E. Morrow

No environmental data are to be taken by this task order as indicated in the Data Management Plan.[1] A schedule of submission is therefore not applicable.

The final report is being prepared.

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 18 R.U. NUMBER: 123

PRINCIPAL INVESTIGATOR: Dr. R. L. Smith

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[1].

The final report is being prepared.

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

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 From	To	Estimated Submission Dates[1] Batch 1	2	3
Acona #193	7/1/74	7/9/74	submitted	None	None
Acona #200	10/8/74	10/14/74	submitted	None	None
Acona #202	11/18/74	11/20/74	submitted	None	None
Acona #205	2/12/75	2/14/75	submitted	None	None
Acona #207	3/21/75	3/27/75	submitted	None	None
Acona #212	6/3/75	6/13/75	submitted		
Oceangrapher #805	2/1/75	2/13/75	submitted	None	None
Silas Bent #811	8/31/75	9/28/75	Submitted		
Discoverer #812	10/3/75	10/16/75	(a)		
Surveyor #814	10/28/75	11/17/75	submitted		
Discoverer #816	11/23/75	12/2/75	(b)	None	None
Station 60	6/2/74	9/10/74	None	Unknown	None
Station 64	4/28/75	5/20/75	None	Unknown	None
Station 9	Current meter, not available in field.				
Station 9	Pressure gauge, not available in field.				
Moana Wave MW 001	2/21/76	3/5/76	submitted		
Moana Wave MW 003/004	4/20/76	5/21/76	submitted		
Moana Wave MW005	9/22/76	8/1/76	(c)		
Surveyor SU 003	9/7/76	9/17/76	(c)		

Cruise/Field Operation	Collection Dates		Estimated Submission Dates[1]			
	From	To	Batch 1	2	3	
Surveyor	9/20/76	10/2/76	(c)			
Miller Freeman	11/1/76	11/19/76	(c)			
Moana Wave	10/7/76	10/16/76	(c)			

Note: [1] Data Management Plan and Data Formats have been approved and are considered contractual.

(a) Parent tapes were coded in PODAS format, tapes were submitted to F. Cava as requested.

(b) Data useless due to malfunction of shipboard data logger.

(c) Data will be processed in FY '77 contingent upon approval of and funding for extension of this project for FY '77.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 20 R.U. NUMBER: 281

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[1]		
	From	To	Batch 1	2	
Silas Bent Leg I #811	8/31/75	9/14/75	1/31/77	None	
Discoverer Leg IV #812	10/8/75	10/16/75	submitted	None	
North Pacific	4/25/75	8/7/75	None	submitted	
Discoverer #816	11/23/75	12/2/75	(b)	None	
Contract #03-5-022-34	Last	Year	submitted		
Moana Wave	3/30/76	4/15/76	submitted		
Discoverer 001	3/17/76	3/27/76	(b)		
Miller Freeman			(b)		

Note: [1] Data Management Plan and Data Formats have been approved and are considered contractual.

(a) Only samples for Kodiak area were processed and submitted as requested.

(b) Selected samples will be processed in FY '77 pending continuation and funding for this project.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 21 R.U. NUMBER: 284

PRINCIPAL INVESTIGATOR: Dr. R. L. Smith

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[1]			
	From	To	Batch 1			
North Pacific	4/25/75	8/7/75	(a)			
Miller Freeman	8/16/75	10/20/75	(a)			
Miller Freeman	3/76	6/76	(a)			

Note: [1] Data Management Plan has been approved and made contractual.

(a) Selected species will be examined, data will then be submitted pending continuation and funding of this project in FY '77.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 22 R.U. NUMBER: 285

PRINCIPAL INVESTIGATOR: Dr. J. E. Morrow

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[1].

The final report is being prepared.

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

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[1]. A schedule of submission is therefore not applicable[1].

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 24 R.U. NUMBER:

PRINCIPAL INVESTIGATOR: Mr. David M. Hickok

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[1].

NOTE: 1 Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 25 R.U. NUMBER: 347

PRINCIPAL INVESTIGATOR: Mr. James Wise

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[1].

NOTE: [1] Data Management Plan has been approved and made contractual.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 27 R. U. #441

PRINCIPAL INVESTIGATOR: Dr. P. G. Mickelson

A draft Data Management Plan has been submitted for review by the Contract Data Manager. Once agreement on the batching of data has been reached; a schedule for submission of the batches will be forthcoming. Many of the data batches are ready for formating and submission.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 28 R. U. #458

PRINCIPAL INVESTIGATORS: Dr. G. F. Shields and Mr. L. J. Peyton

A draft Data Management Plan has been submitted for review by the Contract Data Manager. Once agreement on the batching of data has been reached; a schedule for submission of the batches will be forthcoming. Many of the data batches are ready for formating and submission.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 29

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[1]			
	From	To	Batch 1	2	3	4
Big Valley 001	6/17/76	6/23/76	2/28/77[a]			
Big Valley 002	7/18/76	7/28/76	2/28/77[a]			
Big Valley 003	8/19/76	8/29/76	2/28/77[a]			

NOTE: 1 Data Management Plan submitted August 16, 1976, we await formal approval.

a Data submission is dependent on approval and funding of proposed work statement for FY '77, and reflects the Milestone dates of said proposal.

OCS COORDINATION OFFICE

University of Alaska

ENVIRONMENTAL DATA SUBMISSION SCHEDULE

DATE: December 31, 1976

CONTRACT NUMBER: 03-5-022-56 T/O NUMBER: 30 R.U. NUMBER: 502

PRINCIPAL INVESTIGATOR: O.C.S. Coordination Office/H. M. Feder
University of Alaska

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[1]		
	From	To	Batch 1		
Miller Freeman	9/1/76	10/15/76	(a)		

Note: [1] Data management plan was submitted on 8/30/76, approved by M. Pelto on 9/13/76; we await approval by the contracting officer.

(a) Raw field data was submitted at the end of the cruise. Verified and formated data will be submitted in accordance with the management plan of the FY '77 proposal (modified) providing the proposal is approved and funded.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL DATA SERVICE
A.E.I.D.C. 707 A. Street
Anchorage, Alaska 99501

RU# 362

August 2, 1976

TO: DR. A. PICCIOLO, D781

FROM: Michael L. Crane

SUBJECT: Monthly Report 1 July through 31 July 1976

SUMMARY:

1. Data Tracking System:

   Submitted 2 updates to tracking system
   Received updates & request for modifications from Juneau Project office.

2. OCSEAP DATA COORDINATION

   7 Data Sets Received and forwarded to NODC
   Resolved Tape configuration problems with IMS
   Received 5 format modifications from MODC
   Forwarded two requests for modifications to formats to EDS
   Corp of Engineers is testing tape conversion from 9 track BCD to 9 Track EBCDIC Anchorage.

3. OCSEAP LIAISON

   Discussed Code problems with Peter Jackson, Ru 486
   Discussed Keypunching contract arrangements with FM CAVA

4. EDS Services

   Jerry Imm, BLM/OCS requested current metro data for Kodiak Area. Tom Kozo, Ru 367, requested assistance with weather data. NCC will send xerox of station logs.

5. Summary

   Admin
   4 Hours time allowed for Blood donation 8 July
   24 Hours Annual 21-23 July
   8 Hours Sick

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL DATA SERVICE
Michael L. Crane
707 A. Street (AEIDC)
Anchorage, Alaska 99501

August 31, 1976

TO: Dr. A. Picciolo

FROM: Michael L. Crane

SUBJECT: Report of Activities from 1 August to 31 August 1976.

SUMMARY

I. Data Tracking System:
The initial update phase has ended and the format modifications have been incorporated. All Cruise information has been updated. Next phase will concentrate on the lease area corrections.

2. OCSEAP Data Coordination:
Three sets of data have been received from ADF&G, Anchorage for key-punching. J & J will complete all keypunching in two weeks. From OCSEAP Investigation, nine data sets were received for a total of 10 tapes and 2 boxes of cards. Received two formats or revisions this month.

3. OCSEAP Liaison:
Traveled to Juneau on 25 August to discuss data tracking system. At the request of Mauri Pelto, advised Juneau Project Office on computer-compatible office machines to be used by office personnel. Arranged for a demonstration of IBM 3741 with the Juneau Project Office.

Now sharing office facilities with OCSEAP in Anchorage office. The OCSEAP is renting space from AEIDC in ajoining office.

4. EDS Services:
Discussed EDS services with Ron Morris, NMFS in Anchorage. Data from Port of Valdez may be a archived and serviced by EDS.

Weather Data from Umiat, Oliktok and Lonely have been forwarded to Tom Kozo, RU 367.

Discussed EDS services with Galen Hansen and Mike David ADF&G. Will coordinate program develop/data exchange with ADF&G programmers.

5. Administrative:
Frank Bassett completed his summer employment on 27 August 1976.

No computer costs billed for the 4th quarter. Balance added to next quarter (total less than $20.00). ARR is now providing a xerox machine to reduce computer printouts to 8½ x 11 paper.

8 hours of sick leave 10 August 1976

10 hours annual leave 13 August 1976 8, 17 August (2)

Plan to hold Open House on 8 October 1976. Will coordinate activities with NWS in Anchorage.

Travel Plans:	Fairbanks, Alaska	1 September and 8 September 1976
	Juneau, Alaska	27 September through 29 September.

Taking two classes this fall: 1) Cobol programming
2) Information Management Systems.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL DATA SERVICE

Michael L. Crane
707 A. Street (AEIDC)
Anchorage, Alaska 99501

October 4, 1976

TO: Dr. A. Picciolo

FROM: Michael L. Crane

SUBJECT: Report of Activities from 1 September to 30 September.

Summary

1. Data Tracking System:
The system has been installed, the first distribution completed. Special products must be developed.

2. OCSEAP Data Coordination:
Fairbanks, ADF&G, solved 026 Format problem on 8-10 September.
Fairbanks, ADF&G, solved 023 Format conversion problems with ADF&G, with Geophysics Institute.
Discussed 030 with Dennis Lees, Dames and Moore in Barrow.
Discussed 033 data with George Divoky, ADF&G, Fairbanks.
Kodiak, ADF&G, disucssed 023 with Pete Jackson plus file type 057.
Anchorage, ADF&G, picked up data for keypunching from Paul Arneson, Don Calkins and Karl Schneider.
Began keypunching 033 data for USF&WS. Invoice will be forwarded to Juneau.

3.OCSEAP Liaison
Arranged for USF&WS keypunching by J&J at the request of Mauri Pelto.
Wrote memo to F. M. Cava on 035 problem with USF&WS.
Wayne Fisher in Anchorage, discussed Atlas series, data management problems and new products with BLM.
F. M. Cava visited Anchorage, suggested Data Management package of forms and instructions.

4.EDS Services
Report by Felix Favorite -- Jerry Imm, BLM forwarded to Dean Dale.
Jim Wise wanted Felix Favorite's Annual Report, John Murphy forwarded that report to him.
Forwarded request to Dennis Lees from Judy Gattlieb of BLM/OCS.
Dave Morton wanted tide tables for twenty years; Jim Audet discussed request with NOS.

5. Administration

Courses	$149.00
Books	32.95

Will forward receipts to D 781.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL DATA SERVICE

October 4, 1976

Report of Activities from 1 September to 30 September

Travel

1 September	Fairbanks
8 September	Fairbanks
17 September	Homer/Anchor Point
18, 19 September	Barrow
25--27 September	Kodiak

Travel Plans

1 October	Palmer	Open House participation
13 October	Fairbanks	
15--18 October	Juneau.	

Open House in Anchorage - October 8. Receipts for Displays materials are enclosed.

OCSEAP QUARTERLY REPORT

July - September 1976

Data Tracking System

An operational version of the Tracking System was distributed to a number of individuals, including BLM and Program and Project Office personnel on August 20, 1976.

An interim updated version was submitted to Project and Program Office personnel (Mauri Pelto and Wayne Fischer) and Mike Crane the week of September 13, 1976, which included approximately 1200 additions and corrections to the August version. A significant quantity of Project data inputs were received from the Project on September 16 (approximately 2000 additions and corrections), which will be included in the October version.

A tentative distribution list for the tracking system was confirmed during a visit to the Project Office on September 16. The distribution will include several different products - small xerox versions and larger computer lists, sorts by R.U. and by discipline and study area as well as subsets for Program Staff Scientists, Project Trackers, and NGSDC (Geology, Ice and Chemistry studies).

The present scheme for maintaining an up-to-date version of the tracking system involves receipt of mailed or telephone updates by Project and Program Office personnel, as well as information from Mike Crane, Dean Dale, and NGSDC to the central control point at NODC (D781 - Jim Audet). This information is recorded on the master copy and coded by D781 (J. Shaw) and then submitted for keypunching. Chris Noe (D782) checks the data inputs before completing an updated version. This new version is then edited by D781 and additional corrections due to keypunch errors, etc. or supplemental data are entered and a new master copy is generated. Duplicates of this new master information provide the information for the general distribution of the tracking system.

Products requested from the tracking system, consequently, may contain all current data submitted to NODC depending on the date of update and the date of request. Large quantities of information may require additional time so that some products may be completed without all current data included. The standard data tracking listing is planned for general distribution once a month with copies submitted to the Project Office on a more frequent basis.

During the past quarter it is estimated that costs for the data tracking system included $2,500 for D781, $1,000 for D782 and a small fraction of Mike Crane's time for developing, correcting and editing the different versions of the tracking system. Keypunching costs were approximately $200 and computer costs $1,000. With the addition of a new employee to assist in managing the input data, time spent by Audet and Noe is anticipated to be reduced significantly during the next quarter.

Data Products

Mike Crane and Jim Audet met with Wayne Fischer and BLM, ADF&G, AEIDC, and NMFS personnel in Anchorage. OCSEAP data products were the principal items of interest. Data processing, the data tracking system, the OCSEAP atlas series and the proposed data catalog also were discussed. OCSEAP data inventories plotted on specific scale and chart projections were indicated by BLM as an essential item for conducting their permit program in Alaska. Action is underway at NODC to prepare sample plots for their comments.

A meeting was held between Bob Stein, Jim Audet and Bob Muirhead of NOS to discuss current meter products. Program listings and other information were supplied to EDS by NOS personnel. Time constraints for the particular current meter product, however, required that the software and plots be developed within NODC (D752 and D763) rather than utilizing and converting data to the NOS programs. Future contacts with NOS concerning current meter data are anticipated.

Data Catalog

Despite several discussions concerning a proposed data catalog and its contents, form, etc., there is little specific information concerning this product. It is anticipated that both the data tracking system and plots and listings of OCSEAP data inventories, as well as information concerning data reports, will be valuable inputs to any data catalog. Assistance from Project Office trackers may be required in assigning specific names to data sets to provide some means of adequately describing each data set.

Juneau Project Summaries

Summaries were provided to Project Office Personnel for the following items:

1. Summary of OCSEAP investigators and others receiving OCSEAP formats (through 8/4/76).

2. One-page summary for each format used by OCSEAP investigators (format cover sheets).

3. Summary of OCSEAP and other project formats completed at EDS (through 8/4/76).

4. Misc. data tracking system products.

Additional OCSEAP Manpower

One of the six positions, a full-time temporary GS-6 Physical Science Technician position was established and filled to assist in data management and data processing. The employee, Joseph Shaw, was hired 10/3/76. *

Mike Crane's Activities

Mike Crane's activities concerning the data tracking system, OCSEAP data processing coordination, and liaison are described in the monthly summary reports (attached) submitted to Dr. Picciolo (D781).

Taxonomic Code

All species code data have been assembled and three-fourths of the codes have been keypunched. There has been some problem retaining personnel for keypunching the data. A subset of the data will be forwarded to EDS to check for computer capability. The estimated date for completion of processing is October 31, 1976. There is no indication that data submissions to OCSEAP are being delayed due to lack of taxonomic code information.

During this quarter, OCSEAP investigators requesting or supplying additional taxonomic information included the following:

- T. Eley - ADF&G
- T. Booth - U. Washington
- K. Frost - ADF&G
- R. Bakkala - NWFC

DATA RECEIVED

Now that the OCSEAP data tracking system is operational, details concerning specific data sets are available from that source. Data sets overdue by 90, 180, and 270 days, based on cruise plans, ROSCOP's and other cruise information, are indicated by one, two and three asteriks respectively for each data set. A summary of data sets received at EDS during this past quarter is as follows:

Data sets received this quarter - 54

Summary by lease area/file type

NEGOA	Current meters (015) - 5	Phytoplankton (028) - 1
	STD (022) - 6	Hydrocarbons (043) - 1
	Zooplankton (024) - 1	Wind Data (101) - 1
KODIAK	Current meters (015) - 1	
	STD (022) - 2	
	Fish Resource (023) - 1	

* Three additional full-time temporary employees were hired in NODC in October, 1976 to assist in data processing.

Cook Inlet	Primary Productivity (029) - 3 Benthic Organisms (032) - 1 Hydrocarbons (043) - 1
Bristol/St. George	STD (022) - 5 Zooplankton (024) - 4 Mammal Specimen (025) - 1 Mammal Sighting (026/027) - 3 Phytoplankton (028) - 3 Primary Productivity (029) - 3 Benthic Organisms (032) - 1 Birds-Land Census (034) - 1
Beaufort/ Chukchi	Zooplankton (024) - 1 Mammal Specimen (025) - 1 Phytoplankton (028) - 1 Primary Productivity (029) - 2 Benthic Organisms (032) - 2 Birds-Land Census (034) - 1 Lagrangian Currents (056) - 1

Total Data Sets Received to Date - 84

Final Processed	- 31
In Processing	- 41
Held for additional information (missing DDFs, incorrect tape specs., etc.)	- 11
Forwarded to NGSDC	- 1

DATA REPORTS

Received this quarter - 21

Distribution of Reports by Subject/Lease Area

- Sedimentation - NEGOA - 2
- Seismic/Earthquakes - Aleution/Bristol/St. George - 2
  - NEGOA - 2
  - General - 1
- Tsunamis - General - 1
- Ice/Permafrost - Beaufort - 3
- Hydrocarbons/Trace Metals - Cook - 2
- Demersal Fish/Shell Fish - Cook - 3
- Phytoplankton/Primary Productivity - Cook - 1
- Plankton/Zooplankton - Cook - 1
- Marine Mammals - Beaufort/Chukchi/Norton - 1

Total Reports Received to Date - 44

ROSCOPs

ROSCOPs received this quarter - 37
Total ROSCOPs received to date - 56

Data Requests

Most data requests continue to be for archival data held at NODC and for meteorological data held at NCC.

The requests for this quarter include:

BLM, Anchorage (Imm) - Surface currents and current meter data for Kodiak lease area (Summary data and plots of OCSEAP current meter data included in response).

OCSEAP - Juneau (Wright) - Nansen casts for Bristol Bay - (Plots at several levels for temperature produced as examples of NODC products).

Univ. Louisville (Atlas) - Nansen cast/STD for NEGOA and Bering areas.

U. Alaska - IMS (Royer) - USCG STD data for NEGOA (update of earlier data request).

NMFS (Favorite) - OCSEAP STD data (Responded with letter indicating those OCSEAP cruises (File Type 022) received at NODC to date).

Misc. requests for OCSEAP data reports and data formats.

NMFS (Alverson) - Summary of cruises submitting grain size data to NGSDC - (reply by Meyers - NGSDC).

NCC requests - Coordinated data requests John Hopkins (Patten) - Cordora Meteorology; U. Wash (Tripp) - Surface Weather Obs.; U. Alaska - IMS (Royer) - EB03/Middleton Island Weather data.

Data Format Development

New final draft formats distributed this quarter -

013 - Fish Pathology (8/25/76)
057 - Herring Spawning (8/24/76)
073 - Sediment Char. I (8/18/76) - NGSDC (Grain Size Analysis)
074 - Sediment Char. II (8/20/76) - NGSDC (Geotechnical Properties)
075 - Permafrost (8/23/76) - NGSDC
101 - Wind Data (8/25/76)
074 and 075 in final review

Format Modifications

023 - Fish Resource Assessment 7/7
024 - Zooplankton 7/7, 7/22 and 9/21
025 - Mammal Specimen 7/22
027 - Mammal Sighting I 7/22
028 - Phytoplankton Species 7/28
029 - Primary Productivity 7/22
030 - Intertidal Data 7/20

A number of verbal approvals to requests for modifications also have been completed and information forwarded to the investigator through the Project Office. Documentation and distribution to all investigators using each format will follow for the following:

013 - Fish Pathology (additions)
023 - Fish Resource Assessment (codes/crab data)
024 - Zooplankton (new field)
026 - Draft of Mammal Sighting II (new codes)
027 - Mammal Sighting ((new codes)
030 - Intertidal Data (new fields)
033/034/035 - Marine birds (new/modified codes)

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL DATA SERVICE
NATIONAL OCEANOGRAPHIC DATA CENTER
Washington, D.C. 20235

January 26, 1977 D781/JJA

TO : Dr. Herb Bruce
OCSEAP Project Manager

VIA : Robert V. Ochinero, Director, NODC
Edgar F. Law, Director, D78
Anthony R. Picciolo, Chief, D781

FROM : Jim Audet
NODC OCSEAP Data Coordinator

SUBJECT: OCSEAP Quarterly Report: October-December 1976

The attached report and enclosures summarizes EDS OCSEAP activities for R.U. 362 during the first quarter of FY-77. Submission of this report has been delayed because of NOAA/Interior Department correspondence concerning a summary report to be submitted for the period of initial FY-77 funding - October 1976 through January 1977. However, since no further information has been received from the Project or Program Office concerning a four-month summary, I am forwarding the standard three-month quarterly report.

Enclosures

cc: K. Hughes
W. Fischer
M. Crane
G. Weller

DATA RECEIVED

A summary of data sets received at EDS during this past quarter is indicated below. Details concerning specific data sets are available from the enclosures and from the data tracking system also distributed this week.

Data sets received this quarter	175
Data sets received to date	257

File Type		Format Name	Number of Data Sets	Lease Area (code) 1	2	3	4	5	6	7	8	9
013	-	Fish Pathology	2	-	-	-	1	-	1	-	1	-
015	-	Current Meter	10	8	-	1	1	-	-	-	1	-
017	-	Pressure Gauge	4	3	-	-	-	-	3	-	-	-
021	-	Trace Metals	2	1	-	1	1	-	1	-	-	-
022	-	STD Data	14	2	2	3	7	2	5	2	1	2
023	-	Fish Resource	5	3	1	2	2	1	2	-	-	-
024	-	Zooplankton	6	4	2	2	1	-	2	-	-	-
025	-	Mammal Specimen	23*	4	2	2	-	7	2	9	-	6
026	-	Mammal Sighting II	33*	28	-	28	30	5	30	1	-	4
027	-	Mammal Sighting I	24*	18	1	20	18	-	19	-	-	-
028	-	Phytoplankton	4	1	3	1	-	-	-	-	-	-
029	-	Primary Productivity	21*	10	10	11	1	-	1	-	7	-
030	-	Intertidal Data	1	1	-	-	-	-	-	-	-	-
032	-	Benthic Organisms	2	-	-	1	1	-	1	-	-	-
033	-	Marine Bird Sighting	6	5	5	5	4	-	4	-	1	-
040	-	Marine Bird Habitat	6	5	1	3	-	-	1	-	-	-
043	-	Hydrocarbons	3	1	-	1	1	-	1	1	-	1
057	-	Herring Spawning	2	-	2	2	1	-	2	-	-	-
073	-	Grain Size Analysis	2	-	-	-	1	-	1	-	-	-

				1	2	3	4	5	6	7	8	9
101	-	Wind Data	3	3	-	-	-	-	-	-	-	-
999	-	Indiv. Fish Species (Non-OCSEAP format)	2	1	-	-	1	-	1	-	-	-

*Includes multiple-file IDs varying from 7 to 28 file IDs submitted on one magnetic tape. A replacement tape for 056 data also was received (for data originally received 760927). The number of data sets in the lease area summary exceeds the totals for most file types because of more than one lease area included in a data set. The lease area code is that used in the data tracking system.

1 - NEGOA
2 - Lower Cook Inlet
3 - Kodiak
4 - St. George
5 - Beaufort Sea
6 - Bristol Bay
7 - Norton Sound
8 - Aleutians
9 - Chukchi Sea

Data sets accepted for final processing (data agrees with DDF information, tape specs, etc.)	170
Data sets held for additional information (missing DDFs, incorrect tape specs, formats, etc.)	36
Data sets returned to originator (tapes not readable)	3
Data sets forwarded to NGSDC	1
Data sets final processed	47
	257

DATA REPORTS

Reports received this quarter 40
Reports received to date 84

Subject		Total	Lease Area (code) 1	2	3	4	5	6	7	8	9	General
Physical Oceanography	-	3	3	1	2	-	-	-	-	-	-	1
Seismic/Earthquakes	-	4	3	-	1	-	-	-	1	1	-	-

		1	2	3	4	5	6	7	8	9	General
Ice/Permafrost	- 14	-	-	-	-	13	1	1	-	1	2
Trace Organics/ Metals	- 6	4	-	-	4	1	4	-	-	-	-
Hydrocarbons	- 2	2	1	1	1	1	1	1	-	1	-
Plankton	- 1	1	-	-	1	-	1	-	-	-	-
Benthic Organisms	- 1	-	-	-	-	1	-	-	-	-	-
Marine Birds	- 2	-	-	-	2	2	2	-	-	-	-
Marine Mammals	- 1	-	-	-	1	-	1	-	-	-	-
Effects	- 4	1	-	1	-	1	-	-	-	-	3
Remote Sensing	- 1	-	-	-	-	-	-	-	-	-	1
Technology Scene-rio	1	-	-	-	-	1	-	-	-	-	-

ROSCOPs

ROSCOPs received this quarter - 108
ROSCOPs received to date - 164

DATA REQUESTS

A. OCSEAP and other investigator requests

Dr. Robin Muench - PMEL
Ocean station data for Cook Inlet

Ron Weaver - Science Applications Inc.
Dr. Martin's Ice Core Data - Feb/May Field Reports

Steve Moore - Resource Management Associates
Dr. Zimmerman's Intertidal data on magnetic tape

Kathryn Frost - ADF&G, Fairbanks
Data on pollock, cod, etc. extracted from file type 023 data submitted by Dr. Pereyra (NMFS)

Univ. of Tokyo
OCSEAP STD data in the Bering Sea (part of request for all oceanographic data collected in the Bering after 1974).

Dr. Steven Pazan, Scripps Institution of Oceanography
Verbal request for OCSEAP STD data tape inventory.

Donald McCrimmon - Cornell University
Marine bird information and sample data formats.

Sam Patten, Johns Hopkins University
Plots and summaries of his FY 75-76 field data (not yet completed).

Robert Muirhead - National Ocean Survey/NOAA
Examples of OCSEAP Current meter plots, summaries and data inventory.

Dr. Taivo Laevastu - NMFS, Seattle
Copy of OCSEAP Data Tracking System - version sent to him excluded Project data management information.

Kathryn Frost - ADF&G, Fairbanks
Plots, tables and summaries of specific data sets - request being coordinated with Frost and Crane.

Dr. Tom Royer - IMS, Univ. of Alaska
Coordinate continuing request for surface meteorological data (forwarded by NCC) and USCG Nansen cast and STD data (forwarded by NODC).

Other miscellaneous requests for copies of OCSEAP data formats and NCC meteorological data completed.

B. OCSEAP Office Requests

Program Office - Boulder
- Inventory of all OCSEAP data available for Cook Inlet by file types, dates collected, etc.

Project Office - Juneau
- Selected OCSEAP data reports for Lower Cook Inlet

- List of all OCSEAP data reports for NEGOA lease area.

- Formatted data listings for seven OCSEAP data sets identified by file type and ID - listings forwarded individually to Project Office.

- Maps of selected seabird distributions for BLM - awaiting additional information from the Project Office before completing request.

C. BLM Requests

OCSEAP data inventories and data listings for selected NEGOA lease blocks - request completed in two parts, included plots, summaries and data listings for 17 data sets.

D. Taxonomic Code Requests

Carter Broad - Western Washington State
Steve Moore - Resource Management Associates
Frank Mayo - Auke Bay Fisheries Laboratory
Ralph Walotira - NMFS, Seattle

DATA TRACKING SYSTEM

Monthly distributions of the data tracking system were forwarded to NOAA and BLM personnel on October 21 and November 19, 1976. The December distribution was delayed to include all data received at NODC through December 31, 1976. New R.U. information received from Mike Crane in December, additional inputs from the Project Office received in mid-December and FY-77 budget information received from the Program Office in early January have all been included in the latest update, which is being distributed this week.

As a result of the December meeting in Boulder, future data tracking distributions will be on a quarterly basis rather than monthly except for periodic updated listings for Project Office personnel and others on request. Several modifications to the DTS input and output formats also were suggested which will be reflected in the next quarterly distribution for January-March 1977. The suggested list of changes has been distributed recently to OCSEAP personnel for comments before modification of the DTS software is begun in February.

Because of various problems in entering Project changes for the data tracking system submitted to NODC and because of time delays for Project personnel receiving up-to-date information from the DTS, it was agreed at Boulder that a) minimum modification of future Project entries will be made by NODC personnel; b) Project personnel will make an effort to limit length of DTS comments and to indicate the exact record where the comment applies; and c) Project Office personnel will consider submitting completed coding forms to NODC for processing or process their inputs on-site and submit punched card or diskette data when they have a keypunch facility available in Juneau.

A system for identification by file type of other types of data in addition to digital data in OCSEAP formats also has been developed recently; copies of the suggested numerical system have been distributed for comments before implementing for future DTS distributions.

During the past quarter, it is estimated that costs for the data tracking system included $3700 for manpower, $400 for keypunching and $500 for computer expenses.

DATA CATALOG

Little progress was made this past quarter concerning the data catalog. The file ID system mentioned in the data tracking system report will provide a framework for describing the different types of data available in a catalog. The BLM inventories and station listings will provide valuable information regarding digital data sets. Other elements of the catalog, such as procedures for requesting OCSEAP data listings and products are expected to be discussed in more detail during the next quarter.

DATA PRODUCTS

Several products including alphabetical and numerical (R.U.) lists and a P.I. phone list were generated from the data tracking system at the request of the Project and Program Offices.

Data inventories, summaries and plots for the NEGOA lease area request by BLM were completed in December. Other products included the formatted data listings forwarded to the Juneau Project Office and other items listed under 'Data Requests'.

FORMAT DEVELOPMENT

No final drafts of new formats were distributed this quarter. A number of modifications and additions to existing formats were completed. In many cases, verbal approval of changes have been relayed through the Project Office, Mike Crane, Dean Dale or Rod Combellick to the investigator requesting the change. Formal documentation and distribution to other investigators in the same disciplines will follow for most formats in the near future. In other format activity, a list of all outstanding OCSEAP format modifications was exchanged between the Project Office and NODC to clarify the status of all format modifications. A copy of all codes used with OCSEAP formats was distributed to data management personnel in EDS and OCSEAP offices.

DATA RETRIEVAL SYSTEM

As a result of BLM and other requests, it is becoming clearer to NODC personnel what the nature of NODC's retrieval system should consist of for OCSEAP. Several positive steps have been taken this quarter including:

A. Establishment of DIP (Data Inventory for Projects) which will provide rapid access to inventory information and identification of specific data tapes which have OCSEAP data in a given area or time.

B. A data scan routine for all data as they are received at NODC has been initiated to provide station location data by lease area before the data are submitted for editing and complete processing. This provides for retrieval of unedited data for specific area requests.

C. The improvement of data inventory plots and listings for each file type by lease area with unique identification of stations, dates, etc. Efforts currently are underway to complete inventories for NEGOA and Cook Inlet areas at the chart scale of the BLM EIS charts (approximately 1: 7000,000). The same chart scale is anticipated for other lease area inventory plots.

D. A preliminary scheme for summarizing current meter data (and possibly other time-series data) has been completed. Improvements to this scheme await further comments from BLM and OCSEAP personnel concerning their usefullness.

E. Retrieval of specific species information has been completed for the recent ADF&G request for pollock and cod data. Conversion of numerical codes to descriptive nomenclature as an output listing is being considered.

DATA PROCESSING

During the past quarter, data sets have been received at NODC in the following media:

A. Coding forms (e.g. - Sam Patten's data)
B. Punched cards (e.g. - Jerry Larrance data)
C. Diskettes (e.g. - Paul Arneson's data)
D. Magnetic tapes (majority of OCSEAP data)

A. Data sets on coding forms in OCSEAP formats are being keypunched by EDS either at NODC, by Mike Crane, or by a separate NOAA keypunching contract.

B. Punched card data are converted to tape either by Mike Crane or at NODC. Punched decks are retained at the location where the data are received. NODC accession numbers are assigned once the data are on magnetic tape.

C. Diskette (floppy disk) data are now being processed by NODC. After data are assigned an NODC accession number (NAPIS), they are converted by contract to magnetic tapes and returned to NODC for final processing. An additional two to three days turn-around time is required to convert the data to tape. Data are not indicated by NODC as accepted until readability of the magnetic tape data is assured.

D. A number of magnetic tapes have been received at NODC that require additional information from the Project Office, the investigator or his data processor. In all cases, verbal or written requests for this information have been initiated. It should be noted that some questions do not arise until after data sets have been accepted and data are undergoing final editing and processing.

MIKE CRANE's ACTIVITIES

Mike Crane's activities involving the data tracking system, OCSEAP data processing coordination, pre-processing activities and liaison efforts will be forwarded by Crane as a quarterly report for R.U. 497.

TAXONOMIC CODE

The new NODC taxonomic code, consisting of over 16,000 codes has been received at NODC. The program for sorting the codes into alphabetic order and subdivisions by class, order, etc. will be available by February. Currently, only listings of species codes in numeric order are available. Since a significant number of codes have changes from the Alaskan codes distributed to OCSEAP investigators, it is emphasized that, in the future, all investigators and data processors indicate what set of codes are being used. The next 'Nomenclature Code News Note' will discuss this matter and will be distributed to all relevant OCSEAP investigators.

For those species lacking codes, investigators have two options. They may obtain the appropriate codes from Dr. Mueller or NODC that will agree with the Alaskan code list or they may use the new listings for all species in a specific data set. If other codes are still needed to supplement the new codes, that information will be made available by NODC.

OTHER ACTIVITIES

Bob Stein visited with Mike Crane in Anchorage and Fairbanks to help resolve marine bird and trace element format requirements by OCSEAP investigators.

Discussions between Jim Audet and Dr. Krichevsky of NIH have resulted in establishing a system for tracking Dr. Atlas' processed microbiological data and an approach for requesting data inventories and products from the OCSEAP files residing at NIH.

A memo recommending specific actions and responsibilities by NODC concerning OCSEAP data reports and retrieval of information from these reports was distributed to Program and Project Office personnel for their comments.

Quarterly Report

Contract No: N/A
Research Unit No: 496
Reporting Period: October 1976
through December 31, 1976
Number of Pages: 2

"Maintenance of Alaskan OCSEAP
Surface Marine and Coastal Station
Data File"

Principal Investigator:

William A. Brower, Jr. (D5312)
Applied Climatology Branch
National Climatic Center
Federal Building, Room 401
Asheville, NC 28801
Comm: (704) 258-2850, x266
FTS: 672-0266

December 23, 1976

Quarterly Report

I. Task Objectives (as proposed for FY-77)

- Survey, document and maintain AMOS (Automatic Meteorological Observation Station) data files for some 10 AMOS stations operating in remote Alaskan coastal areas.

- Maintain a current geo-file of marine surface observations for the Alaskan OCS waters.

- Maintain monthly inventories of digital and manuscript data availability for the OCSEAP area.

II. Field and Laboratory Activities

NA

III. Results

- Observations for 28 stations and for the marine area have been extracted from Global Weather Central's (GWC) telecommunications digital (unedited) data file to supplement and update the Alaskan Waters Atlas Project digital data file (Research Unit No. 347). This expands the file from 49 to 77 coastal stations and from 600K to 700K marine observations. Also produced for the GWC data is a computer inventory that lists the number of observations by month-year for each of the 28 stations and MSQ (10° square) marine areas.

- An inventory of hourly and daily digital data is being prepared for all stations currently held in several tape files at NCC.

- Monthly presistence graphs have been produced for 25 coastal stations which are to provide the hours duration of and days interval between for winds $\geq$ 10 knots and $\geq$ 20 knots and for visibility <2 n. miles. These microfilm graphs have been photo processed and forwarded to AEIDC to include in the atlases.

- Extreme value analyses have been performed for the same 25 stations. These analyses provide tabular and graphical wind speed estimates for selected return periods (2, 5, 10, 50, 100, 500, 1000 years) and upper and lower limits of a 68 percent confidence band. These tables are to be forwarded to AEIDC by January for inclusion in the atlases.

2.

IV. Preliminary Interpreation of Results

See first item under III.

V. Problems Encountered

Work on RU #496 during this quarter has been purposely delayed because of priority work on RU #347 and the delay in receipt until 12 December of FY-77 OCSEAP funding to NCC. This funding reflects a reduction from \$50K to \$25K and, of this, only 25% is available until at least 1 February 1977; the task has also been modified to use the funds as needed to provide free data request services to OCSEAP PI's.

VI. Estimate of Funds Expended

As of 12/15/76, some \$2K of the \$8.3 funds available have been expended.

QUARTERLY REPORT

Research Unit 497

Reporting Period 1 October 1976
31 December 1976

Pages

Alaskan Data Processing Facility

Environmental Data Service

Edgar F. Law

31 December 1976

I. Task Objectives

To accomplish a more timely and efficient flow of data and products between the investigators and the data base and to provide a local key entry facility, reducing the backlog of unprocessed data, are the principal objectives of this research unit. A central Alaskan facility has the advantage of being close to the data collecting activities and improved communication will reduce the time in processing environmental data. Data products can be coordinated with data processing as new priorities are established by the Juneau Project Office, therefore insuring direct control over schedules of the processing of data by the OCSEA Program.

II. Laboratory and Field Activities

A. The keyentry facility, the laboratory activity, is a function of RU 370 and is reported by the University of Alaska. The role of RU 497 is to monitor the activities of the keyentry facility and advise the Juneau Project Office of the progress of the Anchorage facility. Additional duties include data control and monitoring the control activities of the facilities

B. The field activities are visits to investigators, providing assistance and support as needed. Travel itineraries are listed below and visits to OCSEAP management components at their request.

Travel - RU.497

	Dates	Location
1.	October 13, 1976	Fairbanks
2.	October 17, 1976	Juneau
3.	October 23-30, 1976	Boulder
4.	November 11, 1976	Fairbanks
5.	November 14-16, 1976	Los Angeles
6.	November 19, 1976	Fairbanks
7.	November 21-22, 1976	Juneau
8.	December 1, 1976	Fairbanks
9.	December 5, 1976 thru January 13, 1977 est.	East Coast

C. Date Received from Investigators for editing and control.

RU#	PRINCIPAL INV.	FILE TYPE	FILE ID	MEDIA	DATE RECEIVED
332	McCain	013	760327	Cards	Oct. 7, 1976
194	Fay	027	BFAY 76	9 tk tp	Oct 12, 1976
281	Feder	032	812	9 tk tp	Oct 12, 1976
332	McCain, BB	013	760327	Cards	Oct 14, 1976
425	Ruffio P.	028	760701	Cards	Oct 19, 1976
425	Ruffio	028	760515	Cards	Oct 19, 1976
307	R. Muench	022	SU2IMS	9 tk tp	Nov 2, 1976
307	R. Muench	022	SU1IMS	9 tk tp	Nov 2, 1976
289	T. Royer	022	814IMS	9 tk tp	Nov 2, 1976
289	T. Royer	022	MW3IMS	9 tk tp	Nov 2, 1976
289	T. Royer	022	MW4IMS	9 tk tp	Nov 3, 1976
284	R. Smith	023	75100	9 tk tp	Nov 12, 1976
5	H. Feder	032	00817	9 tk tp	Nov 17, 1976
291	C. Hoskin	073	761101	9 tk tp	Nov 17, 1976
291	C. Hoskin	073	761101	9 tk tp	Nov 17, 1976
332	McCain	013	760327	Cards	Nov 17, 1976
425	D. Damkaer	024	SU7501	Cards	Nov 17, 1976
068	Mercer	027	080576	9 tk tp	Nov 17, 1976
14	Braham	026	075761	9 tk tp	Nov 17, 1976
67	Braham	026	075761	9 tk tp	Nov 17, 1976
69	Braham	026	075761	9 tk tp	Nov 17, 1976
425	D. Damaker	024	SU7501	Cards	Nov 23, 1976
240	K. Schneider	027	760801	Disk	Nov 30, 1976
240	K. Schneider	027	760802	Disk	Nov 30, 1976
240	K. Schneider	027	760803	Disk	Nov 30, 1976
240	K. Schneider	027	760804	Disk	Nov 30, 1976
240	K. Schneider	027	760805	Disk	Nov 30, 1976
240	K. Schneider	027	760806	Disk	Nov 30, 1976
240	K. Schneider	027	760807	Disk	Nov 30, 1976
425	D. Damaker	024	SU7501	Cards	Nov 26, 1976
3	P. Arneson	040	FG7604	Disk	Nov 29, 1976
3	P. Arneson	040	FG7604	Disk	Nov 29, 1976
3	P. Arneson	040	FG7606	Disk	Nov 29, 1976
3	P. Arneson	040	FG7606	Disk	Nov 29, 1976
3	P. Arneson	040	FG7603	Disk	Nov 29, 1976
3	P. Arneson	040	FG7602	Disk	Nov 29, 1976
3	P. Arneson	040	FG7610	Disk	Nov 29, 1976
3	P. Arneson	040	FG7608	Disk	Nov 29, 1976

D. Data received from Investigators for keying and control.

RU #	NAME	FILE TYPE	IDENT #	BATCH	DATE RECEIVED
330	Divoky	033	2GL876	1	Dec 1, 1976
330	Divoky	033	2GL876	2	Dec 1, 1976
330	Divoky	033	2CL876		Dec 1, 1976
330	Divoky	033	3A3976		Dec 1, 1976
330	Divoky	033	2GLA76		Dec 1, 1976
330	Divoky	033	2BI776		Dec 1, 1976
83	Hunt	033	UCI501		Dec 7, 1976
330	Divoky	033	2DI976	1	Dec 1, 1976
330	Divoky	033	2DI976	2	Dec 1, 1976
330	Divoky	033	3GL976		Dec 1, 1976
337	Lensink	033	FW5011	22	Dec 14, 1976
337	Lensink	033	FW5008	23	Dec 14, 1976
337	Lensink	033	FW6083	24	Dec 14, 1976
337	Lensink	033	FW6052	25	Dec 14, 1976
337	Lensink	033	FW6019	26	Dec 14, 1976
337	Lensink	033	FW6019	27	Dec 14, 1976
337	Lensink	033	FW6057	28	Dec 14, 1976
337	Lensink	033	FW6021	29	Dec 14, 1976
337	Lensink	033	FW6008	30	Dec 14, 1976
337	Lensink	033	FW6050	30	Dec 14, 1976
337	Lensink	033	FW6051	31	Dec 14, 1976
337	Lensink	033	FW5016	32	Dec 14, 1976
337	Lensink	033	FW5016	33	Dec 14, 1976
337	Lensink	033	FW5010	34	Dec 23, 1976
337	Lensink	033	FW5012	35	Dec 23, 1976
337	Lensink	033	FW5014	36	Dec 23, 1976
337	Lensink	033	FW5015	37	Dec 23, 1976
337	Lensink	033	FW5020	39	Dec 23, 1976
337	Lensink	033	FW5021	40	Dec 23, 1976
337	Lensink	033	FW5025	41	Dec 23, 1976
337	Lensink	033	FW5026	42	Dec 23, 1976
337	Lensink	033	FW5027	43	Dec 23, 1976
337	Lensink	033	FW5029	44	Dec 23, 1976
337	Lensink	033	FW5031	45	Dec 23, 1976
337	Lensink	033	FW5033	46	Dec 23, 1976
337	Lensink	033	FW5034	47	Dec 23, 1976
337	Lensink	033	FW5035	48	Dec 23, 1976
337	Lensink	033	FW6018	49	Dec 23, 1976
337	Lensink	033	FW6068	50	Dec 23, 1976
338	Bartonek	035	FW6063	38	Dec 23, 1976

E. Data Keypunched:

RU#	NAME	FILE TYPE	IDENT #	BATCH	DATE FINISHED
330	Divoky	033	2GLA76		Dec 10, 1976
330	Divoky	033	2BI776		Dec 9, 1976
83	Hunt	033	UCI501		Dec 17, 1976
337	Lensink	033	FW5011	22	Dec 22, 1976
337	Lensink	033	FW5008	23	Dec 22, 1976
337	Lensink	033	FW6083	24	Dec 28, 1976
337	Lensink	033	FW6052	25	Dec 30, 1976

III. Results

NA

IV. Interpretation of Results

NA

V. Problems

The volume of material to be keypunched is uncertain and no firm estimates of production are available at this time.

VI. Budget

The budget is controlled by EDS, Washington and one quarter of the allocated funds have been expended.