Sediment content of nearshore fast ice - Fall 1980, Beaufort Sea, Alaska

Peter W. Barnes, Thomas E. Reiss, and Erk Reimnitz

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Menlo Park, California

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

INTRODUCTION

The sediment content of the seasonal fast ice off the north coast of Alaska has been shown to be a significant factor in the sediment transport system for fine-grained materials (Barnes et al., 1982). Sediments are believed to be incorporated during the initial freezing of the ice canopy. Sediment loads in the ice are believed to be greatest when fall storms accompany freezing (Barnes et al., 1982).A sampling program was carried out to provide a comparison of the sediment load carried by the fast ice in a season of minimal storms (1980) with 1977 when major wind and wave events are known to have occurred during freezeup (Barnes et al., 1982) (Fig. 1). We outline the results of this sampling effort in this report.

SETTING

The details of the ice regime and the history of sediment studies in the ice canopy have been outlined by Barnes and others, 1982, and will not be presented here. The unique aspects of shelf ice distribution in the fall of 1980 when the ice sampled for this report formed, are 10-20 km of open water over the inner shelf, moderate northeasterly coastal winds, and a brief freeze-up occurring over a 5-7-day period, followed by continued moderate wind events.

METHODS

The area of study extends from Cape Halkett on the west to Flaxman Island on the east (Fig. 1). Samples from the eastern half of the study area extend out to, but do not include, the stamukhi zone or the pack ice seaward of the stamukhi zone. Samples taken from the western half of the study area are well within the floating fast-ice zone inshore of the stamukhi zone.

All cores were taken from the fast ice using a 5-cm coring device. Cores were taken in areas of flat-lying ice away from the small ridges and hummocks. Ridging and rafting of small ice blocks was common during freeze-up, mechanically thickening the ice canopy. Our coring program in areas away from these features represents ice thckness due to normal ice growth and does not represent ice thicknesses due to rafting and ridging. As a result our cores represent an average ice thickness less than is actually present in the fast-ice zone. As the season progresses and ice thickness increases to incorporate many of the smallest ridges and hummocks, the regional variation in the thickness of the fast ice decreases.

The methods used to obtain and analyze the cores used in this study essentially duplicated those used by Barnes et al. (1982). Cores were returned to the laboratory in the frozen state and photographed on a light table to accentuate stratigraphy. The cores were subsampled, allowed to melt, and then filtered according to the techniques of Drake et al., (1972). Salinities were determined using a temperature compensated refractioner (American Optical, 1973). Salinities were spot checked with salinometer ($\pm.01^{o}$/oo) in 7 samples (1-4^{o}/oo) and found to be within 0.5% of the refractometer.

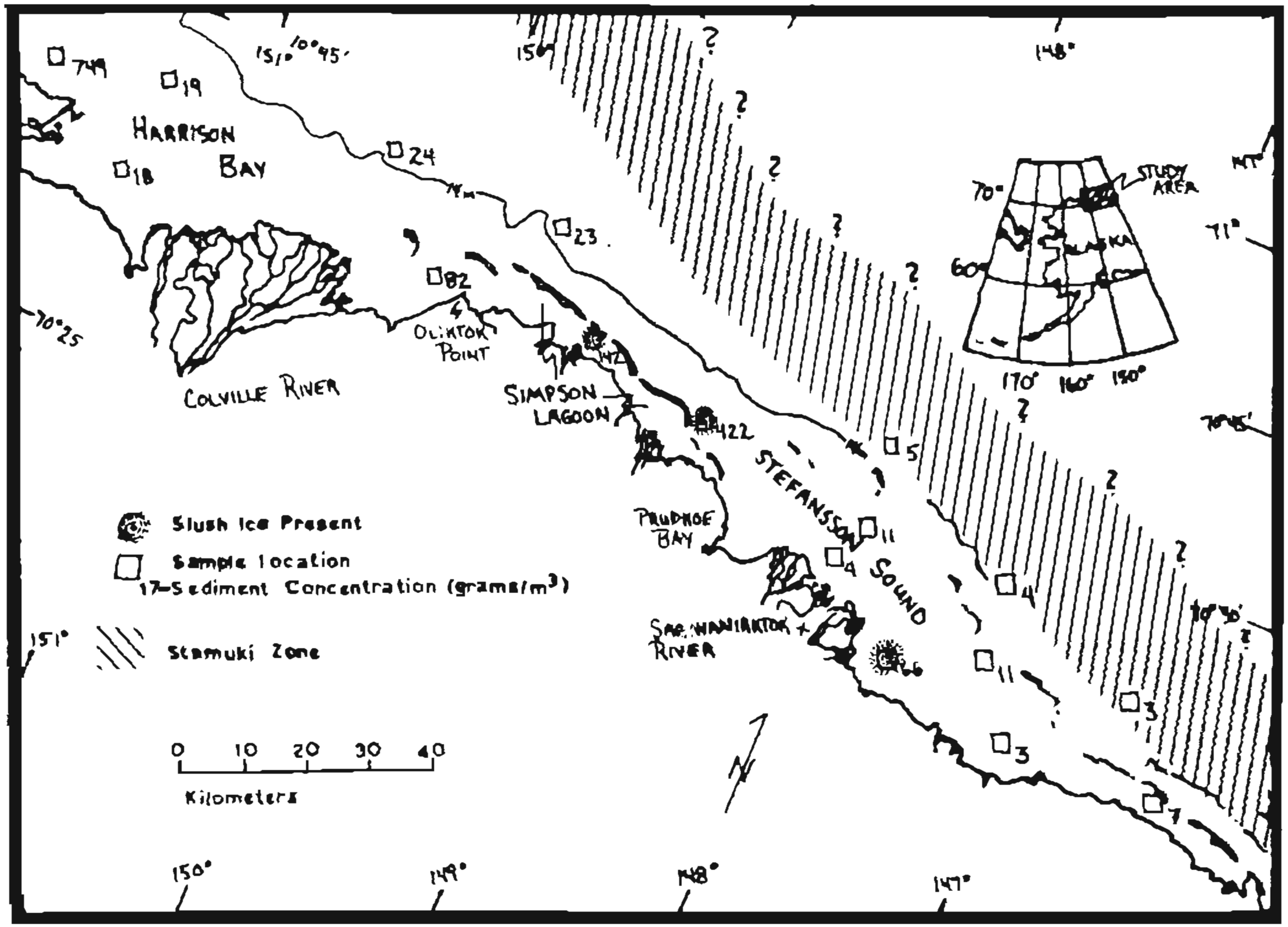

Figure 1. Sediment concentrations at ice-core sites sampled in November, 1980. Fast-ice zone is the ice area inside the stamukhi zone.

OBSERVATIONS

Stratigraphy

The cores and samples taken from the fast ice in 1978 had a regional stratigraphic similarity (Barnes et al., 1982) which was not found in the cores taken in this study. As in 1978, the surface 5-10 cm of most 1980 ice cores appeared less sediment-laden than the underlying sections of the cores. Below this surface layer the general character was highly variable some cores being extremely sediment laden and others essentially sediment-free. The location of the sediment-laden zones varied from upper and middle parts of the cores to the very base of the cores where new ice was still being formed (see appendix). Salinities of cores decreased with depth in core. One core of the Sagavanirktok River was taken in fresh-water ice (Core #10 and possibly #13).

Sediment Concentrations

Sediment concentrations from individual ice core segments varied from less than 3 mg/l to a high value of 2127 mg/l (see appendix). In order to compute the quantity of sediment in the fast ice, the segment concentrations in each core segment were normalized to a value for the entire ice thickness (core length) at each sample site. When this was done the sediment concentration values ranged from 3 g/m^3 to 749 g/m^3 (Table I) over core lengths of 35-55 cm (Note: 1 mg/l = 1 g/m^3). The areal distribution of sediment suggests higher concentrations inshore on northeast-facing coasts (Fig. 1). Lowest values occur both inshore - as off the Sagavanirktok delta - and offshore in the vicinity of the stamukhi zone north and east of Prudhoe Bay.

While drilling at 3 inshore sampling sites, a sediment-laden soft (slushy) ice mass of unknown thickness was encountered below the core (Fig. 1). The concentration and amount of sediment in this ice mass is not known.

Sediment Textures

Binocular-microscope investigation of filtered sediment indicates that silt- and clay-sized particles were responsible for the vast bulk of sediments in the cores. When sand-sized material was present it often was in the form of fibrous organic matter rather than mineral grains. The core with the largest sand fraction (estimated at about 10 percent of total sediment by weight) was observed in the core from Simpson Lagoon (Fig. 1; Appendix Core #8).

Weather during freeze-up

During the fall of 1980, freeze-up - that period when the sea goes from ice-free to essentially ice-covered - occurred between the 20th and 24th of September (E. Reimnitz, personal commun.). During this time abundant quantities of frazil ice were present along the outer coasts of the islands and were noted to be accumulating against coastal promontories such as Oliktok Point, the bend in Long Island, and in the vicinity of artificial islands in Stefansson Sound.

Table I - Summary of Ice Core Characteristics

Core	Average Sediment Concentration (gm/m^3)	Core Length (cm)	Salinity ($\pm 2^o$/oo)	Notes
2	749	37.5	2 - 4^o/oo	
3	19.4	35.5	2 - 4^o/oo	
4	18.1	42.0	0 - 4^o/oo	
5	24.0	47.5	2 - 6^o/oo	
6	82.2	39.0	2 - 3^o/oo	
7	22.8	51.0	2 - 4^o/oo	
8	141.8	55.0	0 - 2^o/oo	
9	421.6	54.0	0 - 4^o/oo	
10	3.5	46.0	0^o/oo	fresh water
11	5.4	53.0	1 - 4^o/oo	
12	10.5	41.0	2 - 3^o/oo	
13	66.1	53.5	0^o/oo	fresh water(?)
14	3.6	44.5	0 - 2^o/oo	
15	10.8	39.0	0 - 4^o/oo	
16	3.3	37.5	0 - 5^o/oo	
17	3.2	41.5	1 - 4^o/oo	
18	7.2	38.5	2 - 5^o/oo	
Average	97.8	44.5		

Coastal wind speed noted at the weather station at Barter Island 100-200 km to the east of the study area were low-velocity northeasterlies 2-4 m/sec prior to freeze-up rising to about average winds of 9 m/sec during the first part of freeze-up followed by lower velocity westerlies at the end of freeze-up (Fig. 2)

DISCUSSION

When compared to observations of the 1977-78 ice canopy, sediment concentrations in the 1980-81 are about an order of magnitude lower (Table II, Barnes et al., 1982). We attribute these lower values to the less intense wind and wave regime durng the fall of 1980 and the fact that the entire freeze-up process occurred over a shorter period of time, thereby preventing any extensive reworking and resuspension of sediments in the presence of frazil ice.

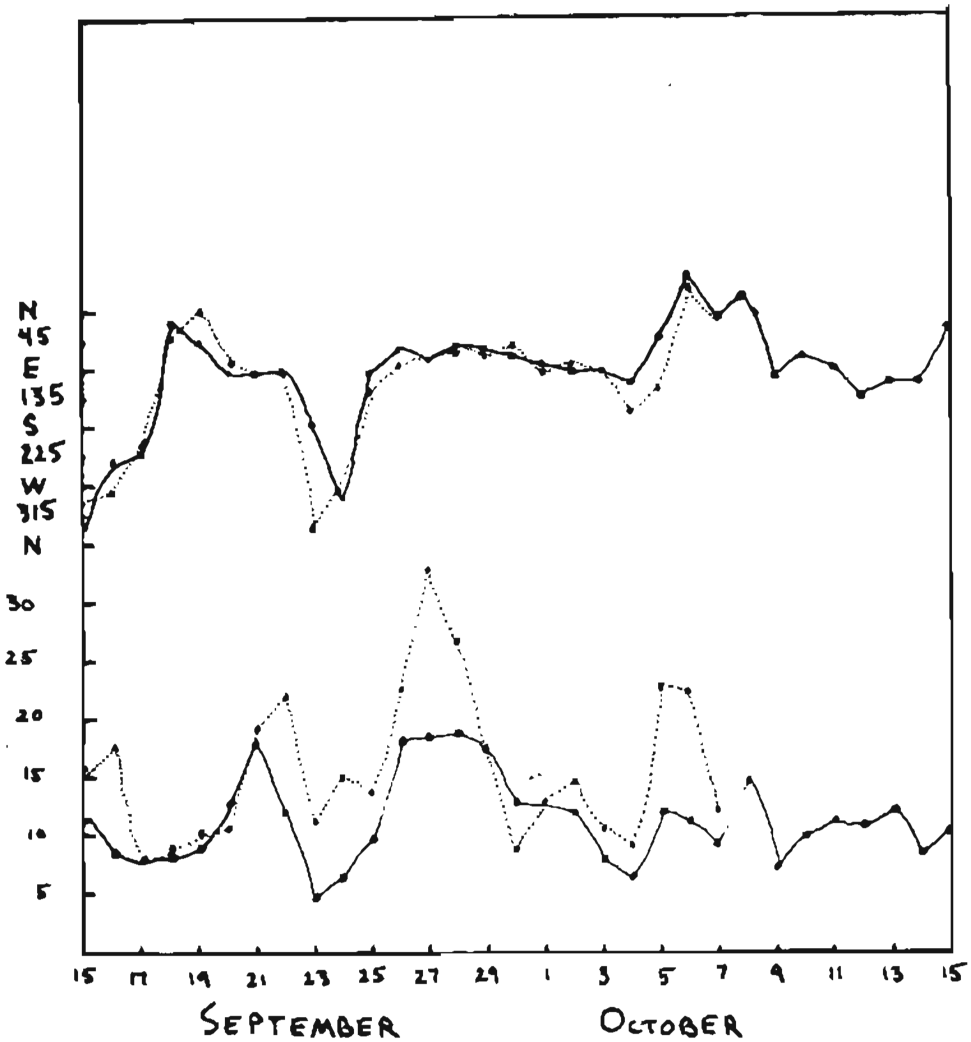

Figure 2. Coastal wind speed and wind direction during and subsequent to freeze-up, fall, 1980.

Based on observations in this study we believe that the mechanism suggested by Barnes et al. (1982) is basically valid. Their mechanism for incorporating sediments into the fast-ice canopy calls for suspension of frazil ice and sediment to be created during freeze-up. Extensive areas of open water in conjunction with fall storms allow waves to build up, resulting in more intensive sediment resuspension. In 1977 open-water areas were more extensive and waves were larger than in 1980 which resulted in a larger quantity of sediments in the 1978-79 ice canopy (Barnes et al., 1982). A lingering freeze-up with prolonged periods of frazil generation, would enhance the quantity of sediments incorporated in the fast ice.

The locations where sediment-laden ice would accumulate are believed to be controlled by wind and ice drift history during and immediately following freeze-up (Barnes et al., 1982). Under uniform wind directions we would expect that accumulations of sediment and ice slush would occur on the windward side of promontories and obstructions. The data of the present report support this idea in that the prevailing northeasterlies (Fig. 2) resulted in accumulations in the southwestern part of Harrison Bay and on the windward side of Long Island (Fig. 1). Ice accumulations were also noted by us in 1980 on the windward site. We believe that the wind events during and subsequent to the freeze-up allowed the transport and redistribution of sediment-laden ice and no apparent wind pattern was preserved.

Table II - Sediment in Ice Canopy

Ice Canopy Fall, 1980	No. of cores	Average Sediment Concentration (g/m^3) (range)	Average core length (m)	Area (km^2)	Weight of sediment in ice canopy (t.)
Harrison Bay	4	203 (18-749)	0.41	2140	1.78×10^5
Stefansson Sound	7	75 (3-422)	0.44	1300	0.43×10^5
Simpson Lagoon	2	112 (82-142)	0.47	146	0.08×10^5
Study Area	17	97.8	0.445	9300	4.05×10^5
Ice Canopy Winter, 1977-78					
Fast Ice	18	122	1.59	11,400	28.0×10^5
Simpson Lagoon	3	480	1.58	146	1.11×10^5

The data also support earlier observations that the sediments incorporated in the fast-ice canopy are primarily well sorted silt and clay fractions(Barnes et al., 1982). The sorting of fine-grained materials is believed to be related to 3 factors. First, the probability is higher that fine-grained materials will remain in turbulent suspension for longer periods due to their slower settling velocity and therefore silts and clays would be more readily available for inclusion in the ice canopy. Secondly, turbulent energy will decrease when waves are damped as frazil ice masses become larger and larger against promontories and obstructions. The decreasing turbulence allows material to settle out; the first being coarse-grained, thus fine-grained materials are most likely to be included in the congealing frazil masses. Lastly, it is likely that frazil ice in a shallow turbulent water column impacts the bottom eroding seabed materials and preferentially driving the more easily suspended fine-grained materials into suspension.

The stratigraphy of the cores very generally repeats that observed in the 1978 cores. The upper 5 to 10 cm parts of the cores are reasonably sediment free. Sediment content increases irregularly with depth. In some cases the increasing of sediment-rich zones extends to the bottom of the cores (see appendix) as if all of the sediment-laden ice had not as yet been icorporated in the thin ice canopy (Reimnitz and Dunton, 1979) In support of the above hypothesis, at three of these sites where sediments extended to the bottom of the core we encountered sediment-laden frazil ice at the bottom of the drill hole (Fig. 1 and appendix).

CONCLUSIONS

Ice-core sampling of the fast-ice canopy in the fall of 1980 showed the widespread presence of sediment-laden ice. However, sediment concentrations were an order of magnitude less than determined for the ice canopy of 1978. The difference in load is related to a relatively rapid and storm-free freeze-up, which resulted in reduced quantities of frazil ice and sediment. The lack of major storms and the presence of an ice cover on much of the inner shelf reduced sediment concentrations. The sediments present in 1980-81 were concentrated inshore, at coastal promontories, and in shallow lagoons. These are the locations where downdrift accumulations of frazil ice were most likely to occur under the prevailing northeasterlies.

REFERENCES

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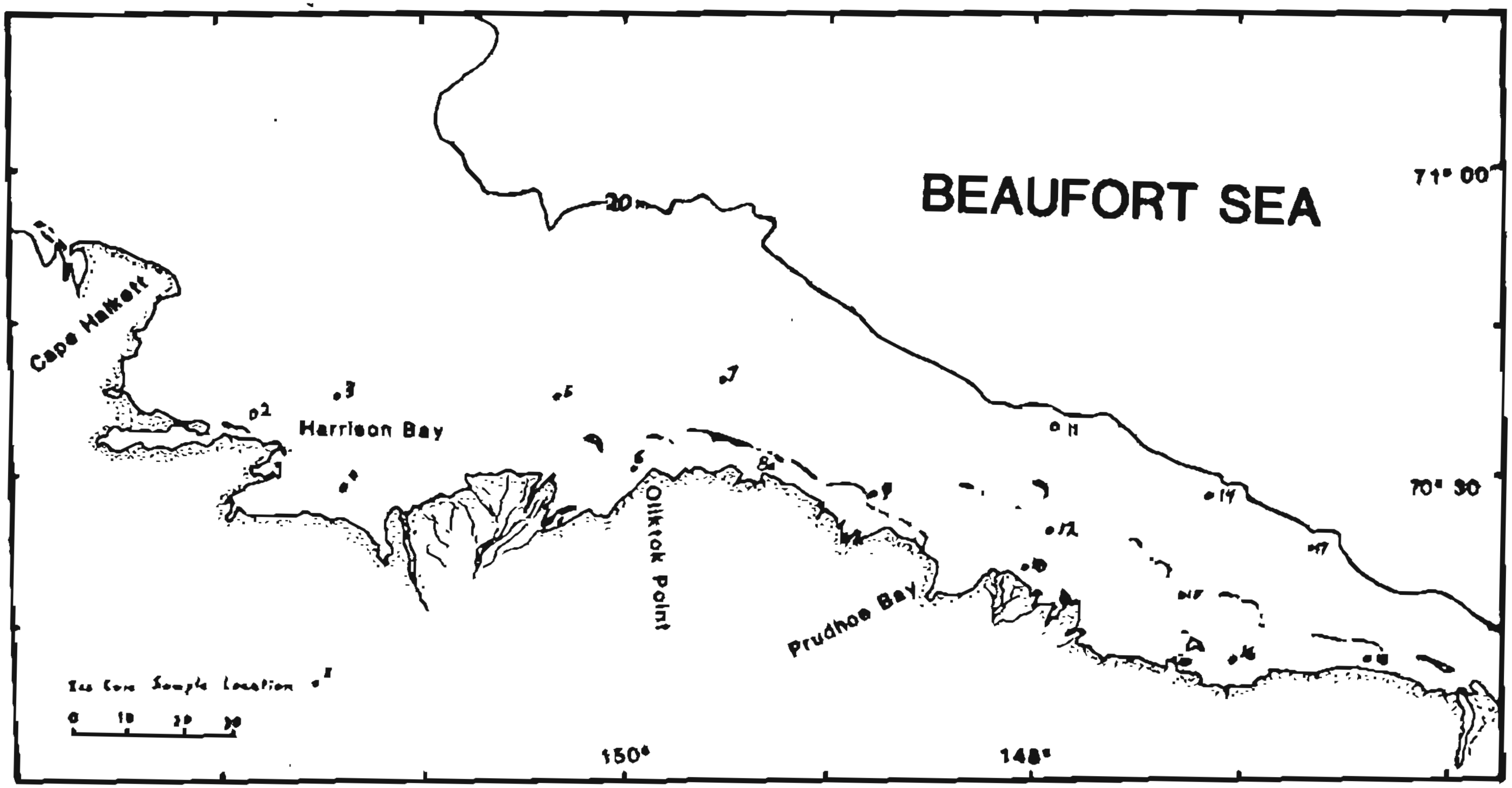
Barnes, P. W., Reimnitz, Erk, and Fox, Dennis, 1982, Ice-rafting of fine-grained sediment, a sorting and transport mechanism, Beaufort Sea, Alaska: Journal of Sedimentary Petrology, v. 52, no. 2 (in press).

Drake, D. E., Kolpack, R. L., and Fischer, P. J., 1972, Sedimentary transport on the Santa Barbara-Oxnard Shelf, Santa Barbara Channel, California; in: Swift, D. P., Duane, D. B., and Pilkey, O. H. Eds., Shelf Sediment Transport: Process and Pattern, Stroudsburg, Pennsylvania, Dowden Hutchinson, and Ross, p. 307-332.

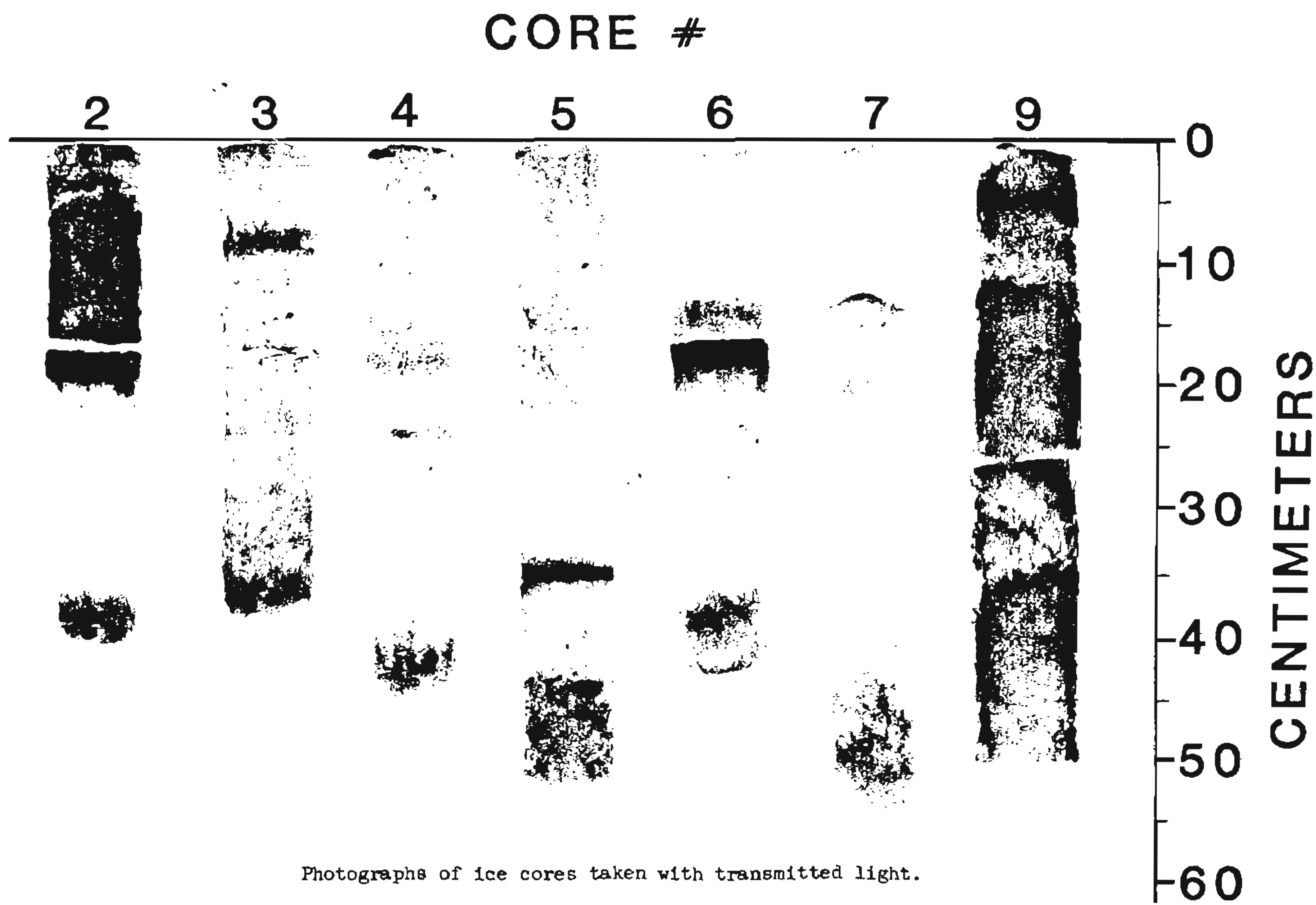
Reimnitz, Erk, and Dunton, K.H., 1979, Diving observations on the soft-ice layer under the fast ice at DS-11 in Stefansson Sound boulder patch: Environmental Assessment of the Alaskan Continental Shelf, Annual Reports of Principal Investigators, March, 1979, NOAA/OCSEAP, Boulder, Colo., v. 9, p. 210-230

APPENDIX

Contains location map and core descriptions, stratigraphic sketches and photographs. Sketches and descriptions were made from the study of the cores on a light table which enhanced internal detail. The cores were also photographed with transmitted light.



Locations of cores taken in November, 1980 along the north coast of Alaska. Numbers refer to cores in following descriptions.



Photographs of ice cores taken with transmitted light.

Note - No photograph taken of core #8.

Core Number 2

Core Description

0-14 cm - gradually increasing sediment content with opaque ice at 0-2 cm and maximum sediment zone at 10-14 cm.

14-18 cm - intermediate amount of sediments with a jagged interface with clear ice at 18 cm.

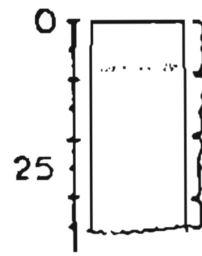
18-27.4 cm - clear ice

Sediment Concentration: grams	grams/m³ of ice	Ice Salinity °/oo
255.5	730	4
755.1	2,127	4
8.5	12.7	2

Core Number 3

Core Description

0-35.5 cm - sediment-free core except for approximately 1-cm band at 8 cm of very light sediment. Translucent ice throughout.



Sediment Concentration: grams	grams/m³ of ice	Ice Salinity °/oo
13.2	35.1	4
4.8	12.8	2
3.5	9.4	3
3.1	23	2

Core Number 4

Core Description

0-1 cm - Several pieces of 1-2-cm-long detritus.

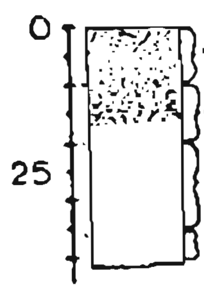
0-4.5 cm - Lightly sedimented section, obscured boundary with clean ice at 4.5 cm.

4.5-17 cm - Translucent ice at 4.5 cm gradually increasing sedimente to an abrupt interface at 17 cm.

17-20 cm - Clear ice.

20-37 cm - Clear ice.

34-42 cm - Soft ice.



Sediment Concentration: grams	grams/m³ of ice	Ice Salinity °/oo
10.3	27.1	1
12.8	33.6	2
3.1	5.0	2
1.8	11.5	0

Core Number 5

Core Description

0-18 cm - Translucent ice-no layering or inclusions.

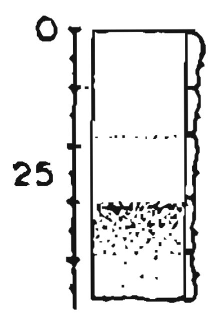
18-19 cm - Very faint sediment line - smooth boundaries.

19-20 cm - Relatively cleaner ice.

30-31 cm - Sediment layer - abrupt boundary at 30 cm - gradually decreasing sediments into next section. Uneven bottom boundary.

31-38.5 cm - Gradually decreasing sediment content - no inclusions.

38.5-47.5 cm - Dark plates.



Sediment Concentration: grams	grams/m³ of ice	Ice Salinity °/oo
3.0	10.4	6
3.6	12.0	4
8.4	19.2	3
18.0	47.4	2
8.2	26.3	2

Core Description

0-6 cm - Translucent ice with 3 distinct layers of patchy, cloudy ice. Maximum sediment concentrations are at 0-2 cm and 5-6 cm.

6-10.5 cm - Clear ice, no layering or inclusions.

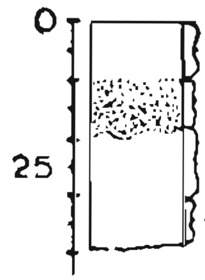
10.5-14 cm - Sediment-laden ice

14-19 cm - Maximum sediment concentration in core, uneven boundary at 19 cm.

19-32 cm -Translucent ice, no layering or inclusions.

32-39.25 cm - Soft, white, opaque ice - crystals prevalent.

CORE NUMBER 6



Sediment Concentration grams	grams/m³ of ice	Ice Salinity °/oo
2.0	5.5	2
105.7	341.0	3
2.9	5.9	2
3.1	14.0	2

Core Description

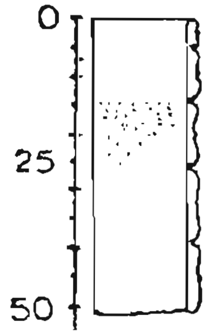
0-15 cm - Translucent cloudy ice - air bubbles - cleaner ice at bottom of section.

15-26 cm - Sediment layer - denser at 15 cm, gradually decreasing concentrations to a non-distinct boundary at 26 cm.

26-38 cm - Clear ice - no inclusions.

38-51 cm - White ice crystals, air bubbles, inclusions.

CORE NUMBER 7



Sediment Concentration grams	grams/m³ of ice	Ice Salinity °/oo
4.7	19.4	4
3.2	14.4	3
18.0	40.9	2
6.6	14.4	3
8.0	19.6	2

Core Description

0-10 cm - Dirty ice - some sediment inclusions.

10-18.4 cm - Very dirty ice - sediment inclusions.

18.4-26.5 cm - Dirty ice - increasing in sediment concentration towards the bottom - many sediment inclusions.

26.5-28 cm - Diagonal sediment band

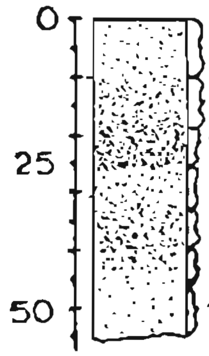
28-33 cm - Diagonal sediment band

28-33 cm - Dirty ice - no sediment inclusions.

33-47 cm - Dirty ice - sediment inclusions.

44-55 cm - Translucent ice, large crystals.

CORE NUMBER 8



Sediment Concentration grams	grams/m³ of ice	Ice Salinity °/oo
21.0	56.8	0
86.3	274.0	2
48.6	160.4	0
32.4	118.1	2
52.2	193.4	2
26.6	101.1	0
21.7	90.0	0

Core Description

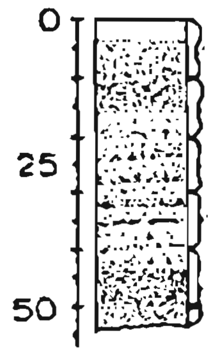
0-3 cm - "Clean" ice.

3-9 cm - Dirty ice, abrupt contact - irregular surface at 5 cm.

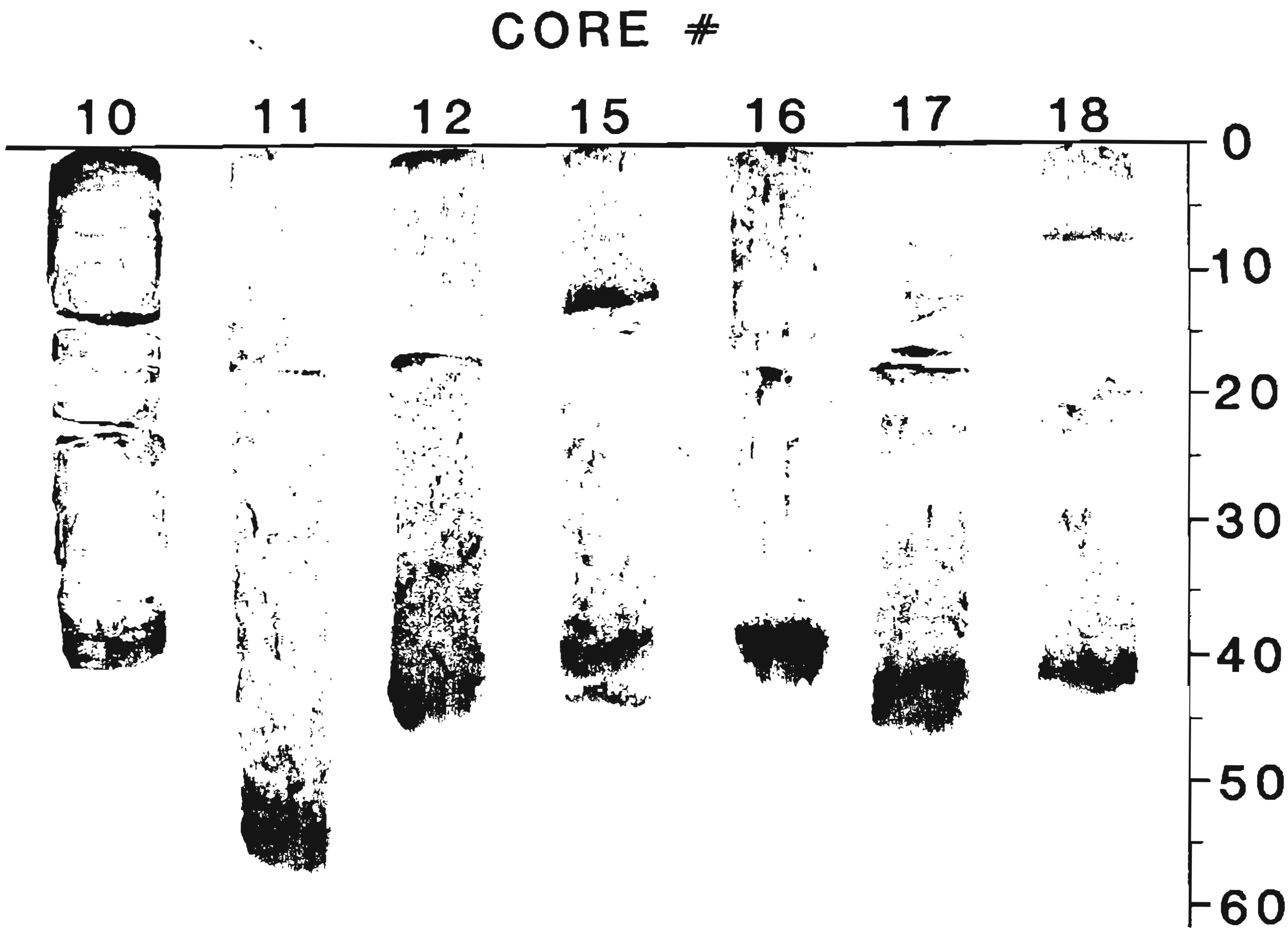
9-16 cm - Increasing sediment content.

16-44 cm - Abrupt but ragged contact with clearer ice at 16 cm with faint turbidity bands at 28-34 cm.

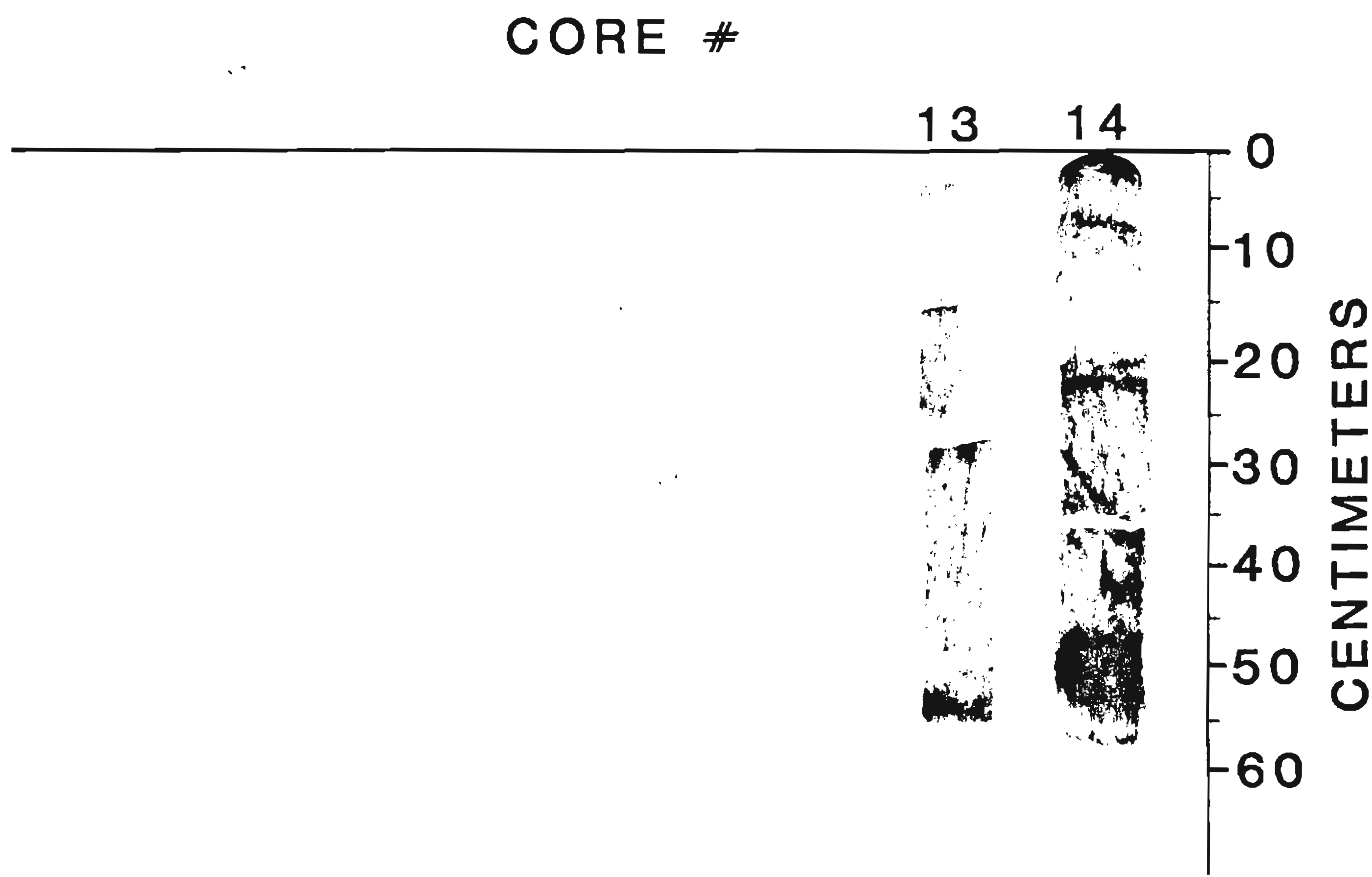
CORE NUMBER 9



Sediment Concentration grams	grams/m³ of ice	Ice Salinity °/oo
132	348	4
199	463	3
147	365	2
142	380	1
232	540	1
40	399	0



Photographs of ice cores taken with transmitted light.

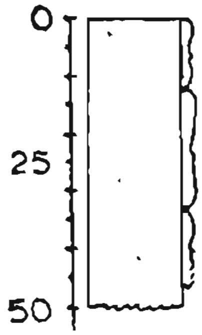


Photographs of ice cores taken with transmitted light.

CORE NUMBER 10

Core Description

0-46 cm - Clear ice - freshwater ice?



Sediment Concentration: grams	Sediment Concentration: grams/m^3 of ice	Ice Salinity ‰
2.8	5.9	0
2.4	2.8	0
0.7	1.9	0

CORE NUMBER 11

Core Description

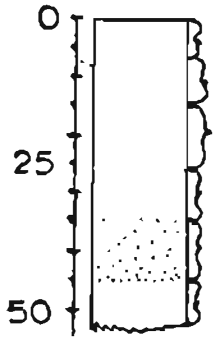
0-7.5 cm - Translucent ice.

7.5-15.5 cm - Verv clear (transparent) ice.

15.5-35 cm - Translucent ice.

35-46 cm - Gradually increasing sediment contact - cloudy-opaque.

46-53 cm - Ice crystals - uneven boundary surfaces.



Sediment Concentration: grams	Sediment Concentration: grams/m^3 of ice	Ice Salinity ‰
1.2	4.9	4
0.9	3.3	3
1.8	5.1	2
1.4	4.0	1
1.6	4.0	1
2.9	15.0	1

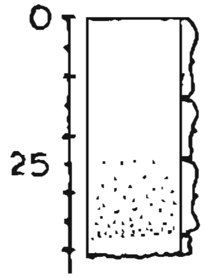
CORE NUMBER 12

Core Description

0-25 cm - Translucent ice, no visible sediments.

25-38 cm - Gradually increasing sediment content - obscured interface at 25 cm - abrupt contact at 38 cm.

38-41 cm - Distinct ice crystals arranged longitudinally.



Sediment Concentration: grams	Sediment Concentration: grams/m^3 of ice	Ice Salinity ‰
3.3	6.5	3
4.7	13.2	2
5.1	10.4	3
1.7	33.0	2

CORE NUMBER 13

Core Description

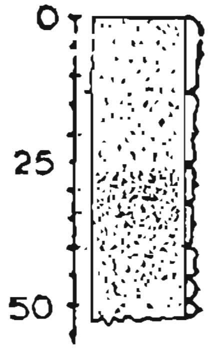
0-13.4 cm - Translucent ice, uniform light sediment distribution.

13.5-26 cm - Uniform moderate sediment distribution.

26-33.5 cm - Turbid ice-sediment inclusions throughout.

33.5-40 cm - Light sediment inclusions.

40-45 cm - Moderate quantity of sediment inclusions throughout.



Sediment Concentration: grams	Sediment Concentration: grams/m^3 of ice	Ice Salinity ‰
20.3	44.2	0
23.4	49.9	0
29.8	101.3	0
20.7	86.2	0
17.4	85.6	0
9.2	68.3	0
4.8	49.0	0

CORE NUMBER 14

Core Description

0-3 cm - Clear ice, uneven interface at 3 cm.

3-5.5 cm - Clear ice - freshwater? diagonal interface at 5 - 6 cm.

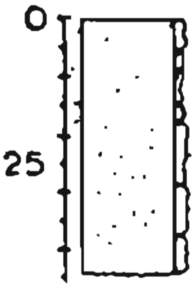
5.5-12.5 cm - Cloudy ice - no sediment. Distinct interface at 12.5 cm.

12.5-13.5 cm - Clear (Freshwater?) ice.

14.5-17.5 cm - Slightly opaque cloudy ice - abrupt interface at 17.5 cm.

17.5-37 cm - Cloudy ice with uniform sediment coloration.

37-44.5 cm - Ice crystals with many air inclusions.



Sediment Concentration		Ice Salinity
grams	grams/m^3 of ice	$^o/oo$
0.7	4.4	2
0.3	3.2	0
0.4	2.0	0
0.3	3.6	0
1.4	3.2	2
1.1	3.5	2
1.3	5.9	0

CORE NUMBER 15

Core Description

0-4 cm - Translucent ice.

4-11 cm - Increasing sediment content - no distinct inclusions.

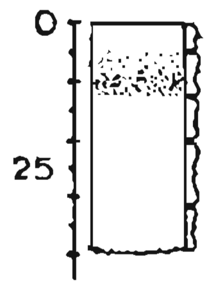
10-11 cm - Uneven band of sediment - very distinct interface at 11 cm.

11-12 cm - Translucent ice - no sediment visible.

12-20 cm - Relatively clear ice, no sediment.

20-32.5 cm - Gradually increasing sediment content.

32.5-38.8 cm - Uneven longitudinal crystals - patches ov very clear ice.



Sediment Concentration		Ice Salinity
grams	grams/m^3 of ice	$^o/oo$
0.9	6.1	4
12.6	45.2	2
1.1	3.8	2
1.5	3.2	2
0.7	4.3	0

CORE NUMBER 16

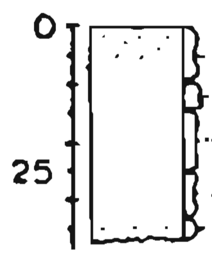
Core Description

0-9 cm - Translucent ice - no distinct sediment inclusions.

9-14.8 cm - Clearer ice.

14.8-33.5 cm - Translucent ice, sediment concentration decreases with core depth - no sediment bands or layers.

33.5-37.5 cm - Ice crystals, no sediment inclusions.



Sediment Concentration		Ice Salinity
grams	grams/m^3 of ice	$^o/oo$
2.1	6.1	5
0.6	3.3	2
0.8	2.0	0
0.4	1.4	0
0.5	4.8	2

CORE NUMBER 17

Core Description

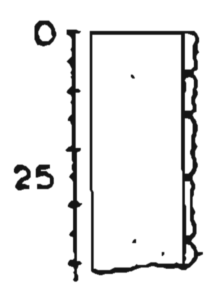
0-3.5 cm - Cloudy ice - no distinct sediment.

3.5-7 cm - Clear ice.

7-7.5 cm - Cloudy band - no distinct sediment.

7.5-10 cm - Clear ice.

10-11 cm - Cloudy ice - no distinct sediment.



Sediment Concentration		Ice Salinity
grams	grams/m^3 of ice	$^o/oo$
1.1	4.2	3
1.0	4.3	2
0.9	2.1	2
0.8	2.3	2
0.8	5.5	1

CORE NUMBER 18

Core Description

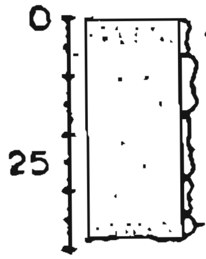
<u>0.6.5 cm</u> - Cloudy ice with sediment - no distinct sediment accumulations.

<u>6.5-7 cm</u> - Dark band - no distinct sediment.

<u>7-17.3 cm</u> - Clear ice gradually getting darker. No sediment - sharp interface at 7 cm.

<u>17.3-28.4 cm</u> - Uniformly spaced sediment bands approximately 4 cm apart. Sediment concentration - increasing towards bottom.

<u>35-38.5 cm</u> - Ice crystals - heaviest sediment concentration (darkest area).



Sediment Concentration grams	Sediment Concentration grams/m^3 of ice	Ice Salinity $^o/_{oo}$
3.9	16.2	5
2.9	6.7	2
1.6	3.8	2
1.2	4.6	2
0.8	8.9	2