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SEA ICE STUDIES ON MCMURDO SOUND DURING DEEP FREEZE 62

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
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DURING DEEP FREEZE 62

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by

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ABSTRACT

A study of thickness, density, and salinity of various ages of sea ice on McMurdo Sound, Antarctica was conducted during the summer season of Deep Freeze 62. During the sampling period, the 1- and 3-year ice decreased in thickness about 3 feet on the bottom; no loss occurred in the older 30-foot thick ice. The sampling interval of 4 to 5 weeks at 3- to 5-foot depth intervals was too great to permit the development of summer trends in salinity, density and strength.

Because of the lack of knowledge on the characteristics of antarctic sea ice, further sampling of natural and flood produced ice in McMurdo Sound are planned by the Laboratory.

INTRODUCTION

Antarctica is surrounded by sea ice at least nine months of the year; in some areas, the ice may persist for several years befor moving out to sea. Aircraft operations on this ice tend to be limited in scope and time because of the unstable nature and the limited knowledge of the ice.

Numerous investigations have been conducted on the properties of arctic sea ice and the feasibility of producing stable sea ice platforms by the surface thickening technique of free flooding.[1,2,3] No similar work, however, has been done on antarctic sea ice. Preliminary to a study of ice thickening techniques for Antarctica, an investigation of some physical properties on various ages of sea ice in McMurdo Sound were made during the summer of Deep Freeze 62. The site of these investigations was in the vicinity of McMurdo Station.

Site Selection

The age of the 30-foot thick sea ice under Williams Field was known only to be at least 7 years old. The area to the east of Williams Field was covered with younger ice. Little other information was available as to the age of various areas of sea ice near McMurdo Station but from depth measurements, one area was estimated to be 3 years old and an adjacent ice area was known to be one year old. They were located about 2 miles southeast of Cape Armitage and 1/2 mile from the face of the Ross Ice Shelf. These two areas and the old ice at Williams Field were sampled at 4- to 5-week intervals between November 1961 and February 1962. At Williams Field the samples were obtained along the northern edge of the runway.

Weather

The daily maximum, minimum and average mean temperatures for the Deep Freeze 62 summer season (October-February) at Scott Base, which is located at the edge of the Ross Ice Shelf near the sampling areas, is shown in Figure 1. During the sampling period the average mean temperature, which was obtained from hourly readings, ranged from about 5 F in early November to about 25 F in early January.

SAMPLING

A lightweight sled mounted laboratory was used to test the core samples as soon as they were extracted from the ice. Three cores were taken at all sampling stations each sampling period. These were used to obtain the average salinity, density and strength at selected depths.

Equipment

Coring and test equipment was housed in a lightweight 5- by 8-foot plywood shelter mounted on a 1-ton sled. This mobile laboratory, which was moved from one sampling area to another by weasel, permitted immediate processing of all ice specimens. A 1-hp electric drill motor was used to drive the 3-inch diameter SIPRE coring auger. The drill motor was powered by a 2.5-kw generator housed in the test sled. Cores obtained with the auger were cut into specimens in a mitre box which automatically gaged the length.

Specimen volume was determined by measuring the diameter and length with dial calipers graduated in millimeters. All specimens were weighed in air on a triple beam balance graduated to tenths of a gram and the density computed to three significant figures.

Three-inch long ring tensile strength specimens were loaded to failure in a hand-operated press employing a small screw jack. A 1500-pound capacity proving ring with a maximum indicating dial measured the proving ring deflection and load.

A shearbox designed for use with 2-inch long, 3-inch diameter ice specimens demonstrated several mechanical shortcomings, the most serious of which was the method and rate of load application. This precluded the use of the shear test data obtained during Deep Freeze 62.

The salinity of all specimens was determined by using hydrometers graduated for direct salinity reading to two-tenths of a part per thousand. The temperature of the melt water from the specimen was determined with an alcohol thermometer to the nearest one-quarter degree centigrade. The readings were then converted to salinity at 15 C.

Procedure

Three cylindrical cores were taken from each age of ice within a 15-square-foot area every 30 to 35 days. The bore holes were flagged to avoid recoring in subsequent sampling. All sampling for each age of ice was taken from the same area.

In the 1- and 3-year ice, from each core, four specimens were taken at three different depths below the ice surface. In the one-year ice these sets were taken at depths of 3 to 13 inches, 36 to 46 inches, and 72 to 82 inches. In the three-year ice the sets were taken at depths of 3 to 13 inches, 60 to 70 inches, and 120 to 130 inches.

In the Williams Field ice, which averaged 360 inches thick, one core was taken through the entire ice thickness and two cores were taken to a depth of 200 inches. The sets of four specimens were taken at 3 to 13 inches, 60 to 70 inches, 120 to 130 inches and 180 to 190 inches. In the one core taken through the entire ice thickness additional sets of specimens were taken at 240 to 250 inches and 300 to 310 inches.

Of the four specimens taken at each of the various depths, two were cut in the mitre box to a length of 3 inches for the ring tensile test and two to a length of 2 inches. Each specimen was immediately measured for density.

The 3-inch specimens were made to fail in tension by applying a compressive load normal to the cylinder axis. This is the ring tensile test method recommended by Butkovitch.[4] In most test work using the ring tensile test, a small hole, concentric with the diameter and parallel with the cylinder axis, is drilled in the specimen. In these tests, the center hole was eliminated and it was assumed that there was an infinitely small hole parallel with the cylinder axis which caused the initial stress concentration and the resulting tension failure.[3] The load application rate was measured intermittently to insure that the minimum recommended rate of 7.1 psi per second was exceeded. Each broken specimen was crushed in a small, crank-type ice crusher and the strength specimen temperatures were obtained with a dial thermometer placed in the ice chips.

The crushed specimens were placed in a plastic canister with a tight fitting lid and melted for the salinity determination.

DISCUSSION

The ice thickness, salinity and density for each age of ice were obtained by sampling, and analyzed for trends with time and depth. During the sampling and testing program, certain problems were encountered and improvements made in the operation of the test equipment.

Ice Test Results

A decrease of 42 inches in thickness was observed in the one-year ice and 34 inches in the three-year ice. The major part of this loss occurred on the bottom of the ice sheet; the snow cover remained on the ice during the summer season and the ice surface beneath the snow was dry. This decrease on the bottom is attributed in part to moderate currents in the area of the younger ice; no currents have been reported under the older, thicker ice at Williams Field. However, because the amount of ice lost decreases with increasing ice sheet thickness, there may be a critical thickness at which little or no loss occurs.

Moist cores were encountered in all three ages of ice beginning about 40 inches below the ice surface in the one- and three-year old ice and about 180 inches below the ice surface in the 9-year ice. Minute brine passages were noticed in the 9-year ice at the 120-inch depth. These became more noticeable and larger at the 180-inch depth and appeared similar to the brine passages found all the way through the younger ice.

The near or above freezing air temperatures (Figure 1) and solar radiation during December and January caused the mobile laboratory temperature, on occasion, to rise as high as 50 F. Although the metal parts of the mitrebox, calipers, tensile strength test frame and other equipment were packed with ice the entire effect of the warm metal parts on the ice during testing was probably not completely eliminated.

Average density and salinity values at the different depths for each age of ice are shown in Figures 2, 3, 4 and 5. The average salinity and density for the total ice thickness of each ice age during the summer season are shown in Figure 6. The data from which these values were obtained are listed in the Appendix. The density of all ice varied with depth and time. In the Williams Field ice large numbers of closed air bubbles, nearly spherical in shape, varying in size from pin point to nearly 1 cm in diameter were observed in the top 20 inches. These air bubbles undoubtedly explain the low surface density and the small change in density between mid-December and early February in the top foot of this older ice. About 60 inches below the surface, no air bubbles or brine pockets were visible; it was in this region that the ice density increased.

In general, there was little or no salinity change with time in any of the three ages of ice except in the top foot of 1-year old ice (Figure 2). In this ice the average salinity of 8 ppt in late November and December decreased to 4.5 ppt by early February. At that time the salinity in this foot of ice approached that of the 3-year old ice.

The average of the summer salinity and density for the total ice thickness is shown in Figure 7; the averages for the top foot and the 5- to 6-foot level for each ice age are plotted in Figure 8. The average salinity and density curves for the total ice thickness show a general decrease with age. The density in the top foot makes a concave curve with a large decrease for the older, Williams Field ice as compared to a convex curve at the 5- to 6-foot depth. On the other hand, salinity shows a decrease from 7 ppt to near 0 ppt in the top foot as compared to a fairly stable condition at the 5- to 6-foot level.

During the warm weather in late December and January, plastic deformation of the ring tensile strength specimens occurred before failure of the specimen. This deformation consisted of a flattening of the curved surface in contact with the bearing plates. Failure consisted of many roughly parallel fractures and might be described as a crushing or mashing action rather than the more normal primary fracture in a single plane. The fragments of the broken specimens, 5/8 to 7/8 inch wide adhered to each other when removed from the test frame. Since the ring tensile test assumes that the plastic properties of the ice are overshadowed by the elastic properties, only the results of the colder, November and early December tests are shown in Figure 9. They indicate a fairly uniform strength with depth at that time.

Test Equipment Problems

Prior to the Deep Freeze 62 ice studies, nearly all of the ice sampling performed by this Laboratory was in ice less than 10 feet thick. Sampling of the 30-foot thick ice at Williams Field during early January and February required some changes in drilling technique and minor modification of equipment.

The one-horsepower electric drill motor used to turn the SIPRE coring auger had sufficient torque to drive the auger to its full depth near the surface. As the bore hole became deeper, the drive motor stalled progressively sooner and the core length obtained became shorter. Near the bottom of the 30-foot hole, core sections 12 to 15 inches long were the maximum attainable. Whipping in the drill shaft extensions increased with depth with a resultant loss of torque at the auger. It was found that some of the whipping, particularly that transmitted to the drive motor could be eliminated if each of the two operators stood with the side of one foot against the drill shaft.

Considerable difficulty was experienced in withdrawing the auger from the hole at depths below 15 feet. At this depth the ice cuttings became wet with brine draining from the ice. The wet cuttings formed a seal around the auger and a vacuum developed below the auger as it was raised. The two operators could not pull the auger to the surface until the vacuum was broken, often a difficult task. The technique used was to raise the auger as far as possible against the vacuum, generally 10 to 12 inches and hold it for 30 or 40 seconds. During this time the moisture in the ice chips drained out and the seal lost its effectiveness.

Raising and lowering the auger in the hole became very difficult as the drill shaft and operator's gloves became wet with brine water. The slipperiness of the shaft was overcome by applying a thin adhesive-backed, non-slip floor covering material to all of the auger shaft extensions. This material provided an excellent grip but represented a hazard in that gloves or clothing brushed against the rotating shaft would grab and be pulled into it. Danger from this can be reduced if the operators remain aware of the hazard.

It was also found that the drill motor switch-locking pin could accidently become engaged. Since the locking pin is not used it should be removed for safety.

The warm air temperatures during the middle and latter portion of the test period caused some problems in the processing of ice cores. After removal of the cores, the required test specimens were cut to length on a slightly modified carpenter's miter-saw. The 10-tooth per inch blade produced a good smooth cut but the fine teeth became loaded with soft ice very quickly and the cutting action stopped. To eliminate this, two 1- by 2-inch pieces of a stiff bristled scrub brush were attached to the front edge of the saw table so that the teeth were brushed clean with each stroke. This problem might also be eliminated by using a slightly coarser toothed saw when loading of the regular saw teeth occurs.

Discarded pieces of ice were kept in the mitre saw when not in use to keep the work surfaces as cold as possible. Even so, some melting of the specimens occurred from contact with the metal saw table. Covering these metal surfaces with a thin, poor heat-conducting board would insulate the ice from the relatively large mass of the saw table and frame.

FINDINGS

The Deep Freeze 62 summer studies on three ages of sea ice in McMurdo Sound showed that:

1. The 1- and 3-year old ice decreased in thickness on the bottom; the thicker Williams Field ice had no loss. Stability of the older thicker ice was dependent upon either a critical thickness, a variation in currents in the Sound, or both.

2. Ice sampling at 5-week time intervals and at 3- to 5-foot depth intervals was not sufficient to determine summer trends in ice density, salinity and strength in Antarctica.

3. Modifications to the coring and processing equipment are necessary for greater ease in sampling during the summer months.

FUTURE PLANS

In the past several years, much scientific information has been accumulated in the antarctic. However, there is still a considerable lack of knowledge on the characteristics of sea ice as contrasted to the present knowledge of sea ice in the arctic. For proper evaluation of the general characteristics of polar sea ice much more detailed information is needed from the antarctic. This knowledge is not only needed for its scientific value but also for improving methods and techniques for utilizing sea ice as aircraft runways, ship docks, roadways and floating platforms.

The Laboratory plans to continue its investigation of the multi-age sea ice in McMurdo Sound; however, the scope and length of this investigation will be dependent upon other Laboratory commitments in Antarctica. During Deep Freeze 63 it is planned to make a study of newly formed sea ice and ice upto one-year old in McMurdo Sound using a 10- to 14-day time interval between sampling periods and examining the ice at one-foot or less depth intervals.

The results of the Deep Freeze 63 study will be used as a basis for developing a broader-based study of multi-aged sea ice in McMurdo Sound. Eventually it is also planned to conduct small scale, ice thickening studies in the same area.

REFERENCES

1. U. S. Naval Civil Engineering Laboratory. Technical Report, R-185, Point Barrow Trials - FY 1959; Investigations on Thickened Sea Ice, by J. E. Dykins and A. I. Funai. Port Hueneme, California. 23 April 1962.

2. U. S. Naval Civil Engineering Laboratory. Technical Report, R-218, Point Barrow Trials - FY 1960; Free Flooded and Ice-Aggregate-Fill, by J. E. Dykins, N. S. Stehle and K. O. Gray. Port Hueneme, California. 23 November 1962.

3. U. S. Naval Civil Engineering Laboratory. Technical Report, R-189, Sea Ice Engineering, Summary Report - Project Ice Way, by W. D. Kingery, D. W. Klick, J. E. Dykins, et al. Port Hueneme, California. 25 September 1962.

4. Snow, Ice and Permafrost Research Establishment. Technical Report 57, Recommended Standards for Small-Scale Ice Strength Tests, by T. R. Butkovitch. Wilmette, Illinois. November 1958.

Appendix

Density, Salinity and Ring Tensile Strength Data

The data from which the points shown on Figures 2 through 9 were obtained are listed in Tables I, II and III.

Table I. Density, Salinity and Ring Tensile Strength Data for One-Year Old Ice.

	Density (g/cc)			Salinity (ppt)			Ring Tensile Strength (kg/cm^2)		
core no.	1	2	3	1	2	3	1	2	3
depth (in)				23 November					
0-3	0.906	0.897	0.910	7.5	8.2	9.3	15.01	- -	15.75
3-6	0.906	0.920	0.915	9.4	8.5	-	- -	14.99	- -
6-9	0.871	0.919	0.913	7.6	7.8	6.2	14.63	- -	15.37
9-12	0.911	0.912	0.918	6.5	7.5	-	- -	15.15	- -
36-39	0.922	0.924	0.923	5.8	5.9	5.1	14.96	15.61	15.26
39-42	0.918	0.914	0.925	4.0	5.2	-	- -	- -	- -
42-45	0.920	0.916	0.924	3.7	3.7	4.9	14.55	15.18	15.61
45-48	0.919	0.913	0.925	4.0	3.7	-	- -	- -	- -
72-75	0.922	0.922	0.920	4.0	4.1	5.1	14.53	14.82	14.42
75-77	0.912	0.920	0.918	4.5	-	-	- -	- -	- -
77-80	0.907	0.916	0.930	4.7	4.3	4.6	14.12	14.77	15.01
80-83	0.920	-	0.925	5.0	-	-	- -	- -	- -
				December					
	22	26	26	22	26	26			
3-6	0.901	0.870	0.860	8.6	7.6	7.1			
6-8	0.900	0.905	0.914	-	-	-			
8-11	0.909	0.911	0.912	8.4	8.1	7.5			
11-13	0.909	0.905	0.909	-	-	-			
36-39	0.923	0.924	0.925	5.6	5.2	4.2			
39-41	0.932	0.922	0.930	-	-	-			
41-44	0.928*	0.922	0.926	4.2*	4.2	5.4			
44-46	0.928**	0.925	0.921	-	-	-			
72-75	0.920	0.920	0.925	5.8	4.5	5.9			
75-77	0.919	0.920	0.924	-	-	-			
77-80	0.917	0.922	0.921	5.1	4.5	4.4			
80-82	0.898	0.918	0.922	-	-	-			
				1 February					
3-6	0.921	0.906	0.898	4.9	5.0	4.7			
6-8	0.917	0.917	0.895	-	-	-			
8-11	0.884	0.928	0.894	3.7	5.4	5.5			
11-13	0.919	0.908	0.878	-	-	-			
36-39	0.928	0.924	0.930	4.8	4.4	5.4			
39-41	0.929	0.927	0.927	-	-	-			
41-44	0.923	0.923	0.915	3.2	3.6	3.7			
44-46	0.928	0.925	0.913	-	-	-			

* sample taken at 44-47 inches
** sample taken at 47-49 inches

Table II. Density, Salinity and Ring Tensile Strength Data for Three-Year Old Ice.

	Density (g/cc)			Salinity (ppt)			Ring Tensile Strength (kg/cm^2)		
core no.	1	2	3	1	2	3	1	2	3
depth (in)				December					
	5	6	6	5	6	6	5	6	6
3-6	0.874	0.877	0.856	3.0	3.3	4.3	15.01	14.80	15.40
6-8	0.912	0.909	0.911	-	-	-	- -	- -	- -
8-11	0.915	0.915	0.919	1.8	2.8	3.4	14.42	15.21	14.99
11-13	0.908	0.914	0.919	-	-	-	- -	- -	- -
60-63	0.916	0.921	0.912	3.6	7.0	4.0	14.91	14.85	14.58
63-65	0.917	0.921	0.903	-	-	-	- -	- -	- -
65-68	0.908	0.914	0.914	2.8	6.0	4.3	15.07	15.56	14.99
68-70	0.920	0.904	0.913	-	-	-	- -	- -	- -
123-126	0.927*	0.918	0.913	4.2*	3.3	4.7	14.66*	15.04	15.23
126-128	0.920*	0.915	0.926	-	-	-	- -	- -	- -
128-131	0.917*	0.913	0.928	3.8*	4.9	3.0	14.58*	15.12	15.12
131-133	0.918*	0.913	0.930	-	-	-	- -	- -	- -
			6 January						
3-6	0.905	0.919	0.917	4.0	3.8	3.4			
6-8	0.911	0.926	0.919	-	-	-			
8-11	0.923	0.917	0.917	2.8	2.8	2.5			
11-13	0.921	0.917	0.921	-	-	-			
60-63	0.917	0.912	0.914	9.4	4.0	3.7			
63-65	0.926	0.917	0.915	-	-	-			
65-68	0.928	0.906	0.917	8.0	3.2	3.3			
68-70	- -	0.912	0.916	-	-	-			
120-123	0.930	0.916	0.925	3.8	3.0	4.3			
123-125	0.928	0.922	0.930	-	-	-			
125-128	0.920	0.909	0.923	6.2	4.4	2.9			
128-130	0.915	0.906	0.922	-	-	-			
			1 February						
3-6	0.945	0.911	0.915	3.6	3.5	3.6			
6-8	0.915	0.911	0.917	-	-	-			
8-11	0.944	0.920	0.912	3.3	2.8	2.9			
11-13	0.916	0.919	0.913	-	-	-			
60-63	0.904	0.900	0.910	-	5.6	7.1			
63-65	0.904	0.906	0.894	5.5	-	-			
65-68	0.906	0.908	0.908	-	5.8	6.2			
68-70	0.920	0.920	0.893	4.0	-	-			
106-109	0.923	0.920	0.924	3.1	2.9	3.6			
109-112	0.917	0.921	0.925	2.8	3.0	2.6			

* samples taken at 123-126, 126-128, 128-131, 131-133, respectively

Table III. Density and Salinity Data for Williams Field Ice of Indeterminate Age.

	Density (g/cc)			Salinity (ppt)			Density (g/cc)			Salinity (ppt)		
core no.	1	2	3	1	2	3	1	2	3	1	2	3
depth (in)	Dec. 26	Jan. 5	5	Dec. 26	Jan. 5	5	3 February					
3-6	0.889	0.876	0.859	0	0	0	0.904	0.889	0.868	0	0	0
6-8	0.898	0.896	0.870	-	-	-	0.902	0.857	0.870	-	-	-
8-11	0.883	0.886	0.877	0	0	0	0.904	0.867	0.893	0	0	0.2
11-13	0.883	0.895	0.886	-	-	-	0.873	0.892	0.876	-	-	-
60-63	0.918	0.926	0.922	4.1	3.6	3.2	0.910	0.902	0.914	0	2.8	2.2
63-65	0.918	0.922	0.916	-	-	-	0.912	0.907	0.916	-	-	-
65-68	0.916	0.920	0.920	3.9	3.6	3.4	0.911	0.917	0.920	3.0	3.0	3.1
68-70	0.918	0.917	0.914	-	-	-	0.912	0.917	0.919	-	-	-
120-123	0.922	0.913	0.922	3.3	3.0	3.2	0.915	0.923	0.911	3.3	3.1	3.2
123-125	0.921	0.924	0.923	-	-	-	0.912	0.916	0.916	-	-	-
125-128	0.919	0.916	0.916	3.2	2.7	2.9	0.912	0.914	0.912	2.9	2.8	2.7
128-130	0.918	0.915	0.923	-	-	-	0.913	0.924	0.920	-	-	-
180-183	0.916	0.920	0.921	3.3	3.6	2.8	0.911	0.912	0.912	2.8	3.5	2.5
183-185	0.916	0.907	0.923	-	-	-	0.909	0.906	0.915	-	-	-
185-188	0.908	0.925	0.922	4.6	3.6	3.1	0.916	0.913	0.920	2.4	3.0	3.0
188-190	0.915	0.920	0.925	-	-	-	0.918	0.898	0.925	-	-	-
240-243			0.928			2.9	0.918			2.1		
243-245			0.920			-	0.921			-		
245-248			0.924			3.4	0.914			1.8		
248-250			0.927			-	0.919			-		
300-303			0.925			3.2	0.913			2.4		
303-305			0.930			-	0.920			-		
305-308			0.926			3.5	0.920			2.2		
308-310			- -			-	0.914			-		

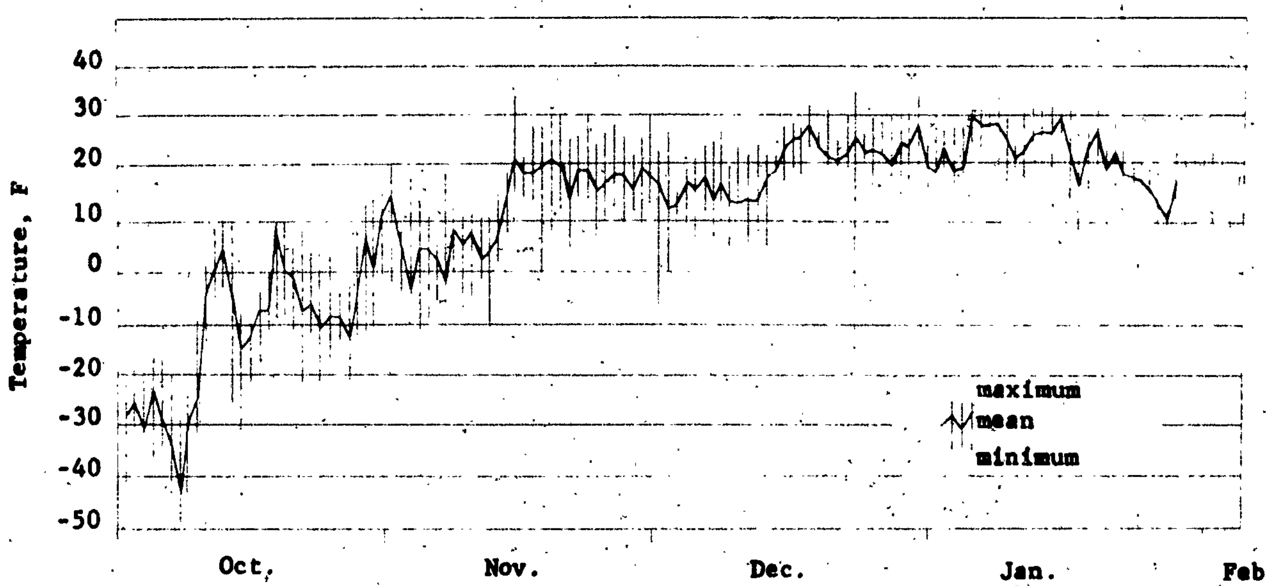


Figure 1. Daily Temperature at Scott Base, Antarctica.

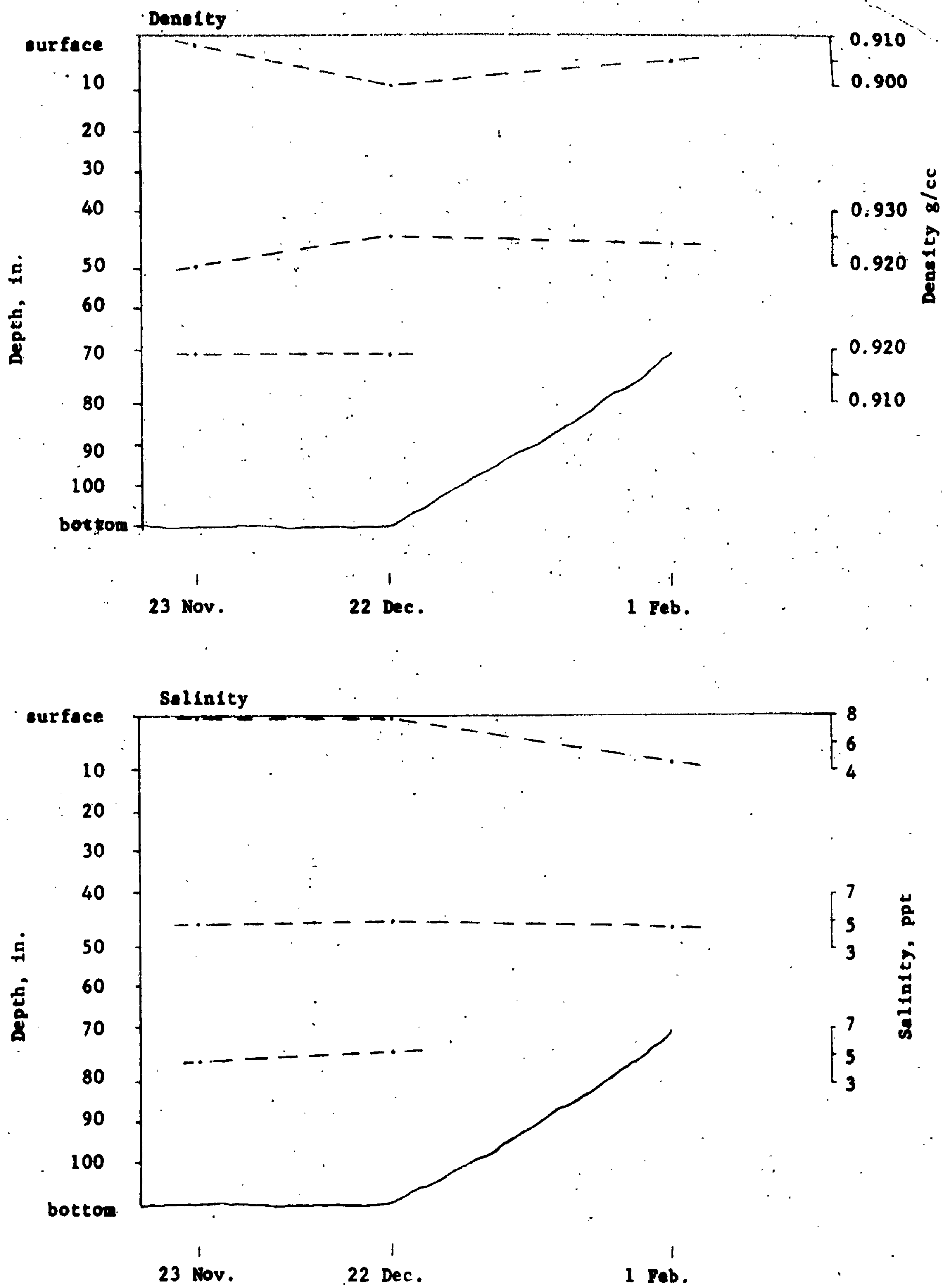


Figure 2. Average density and salinity of one-year old ice.

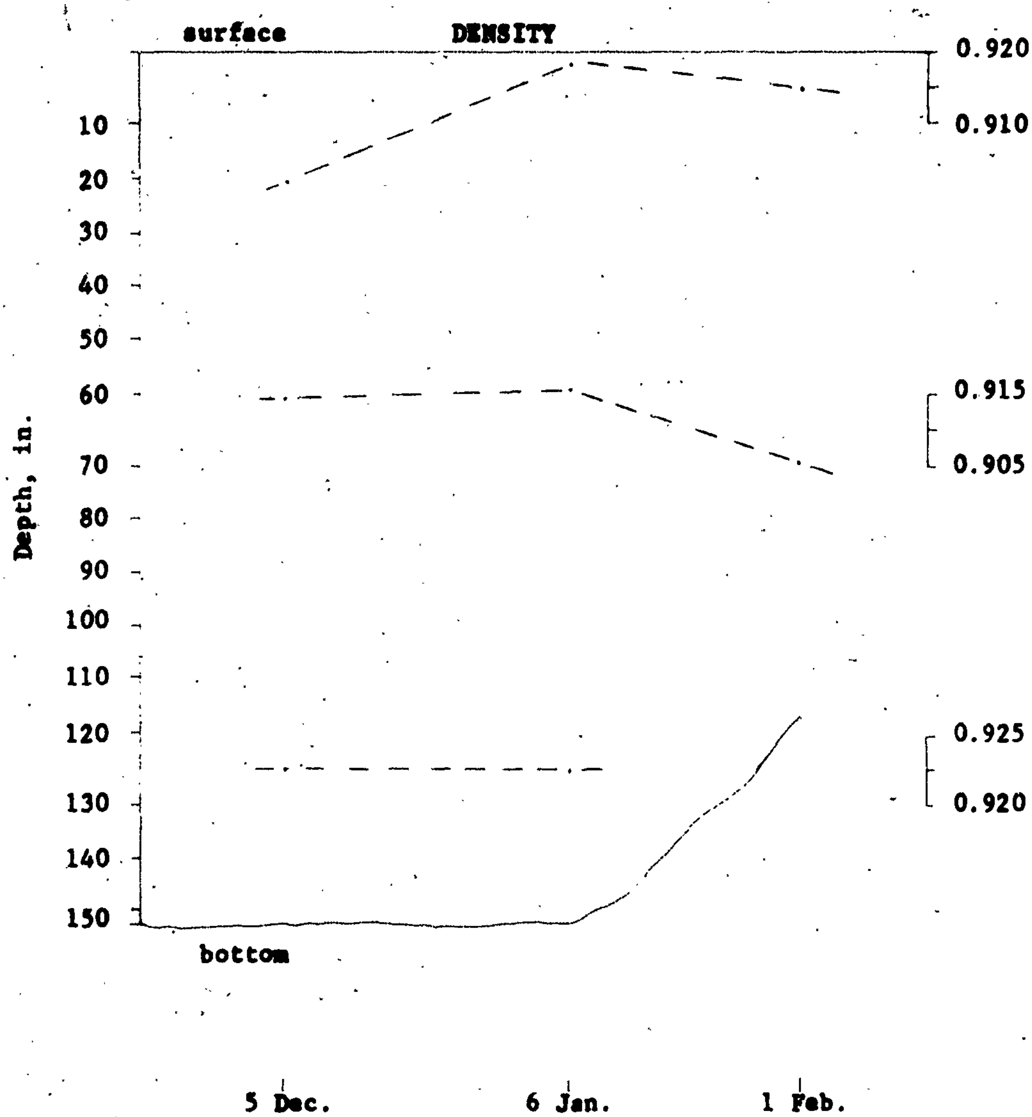


Figure 3. Density of 3-year old ice.

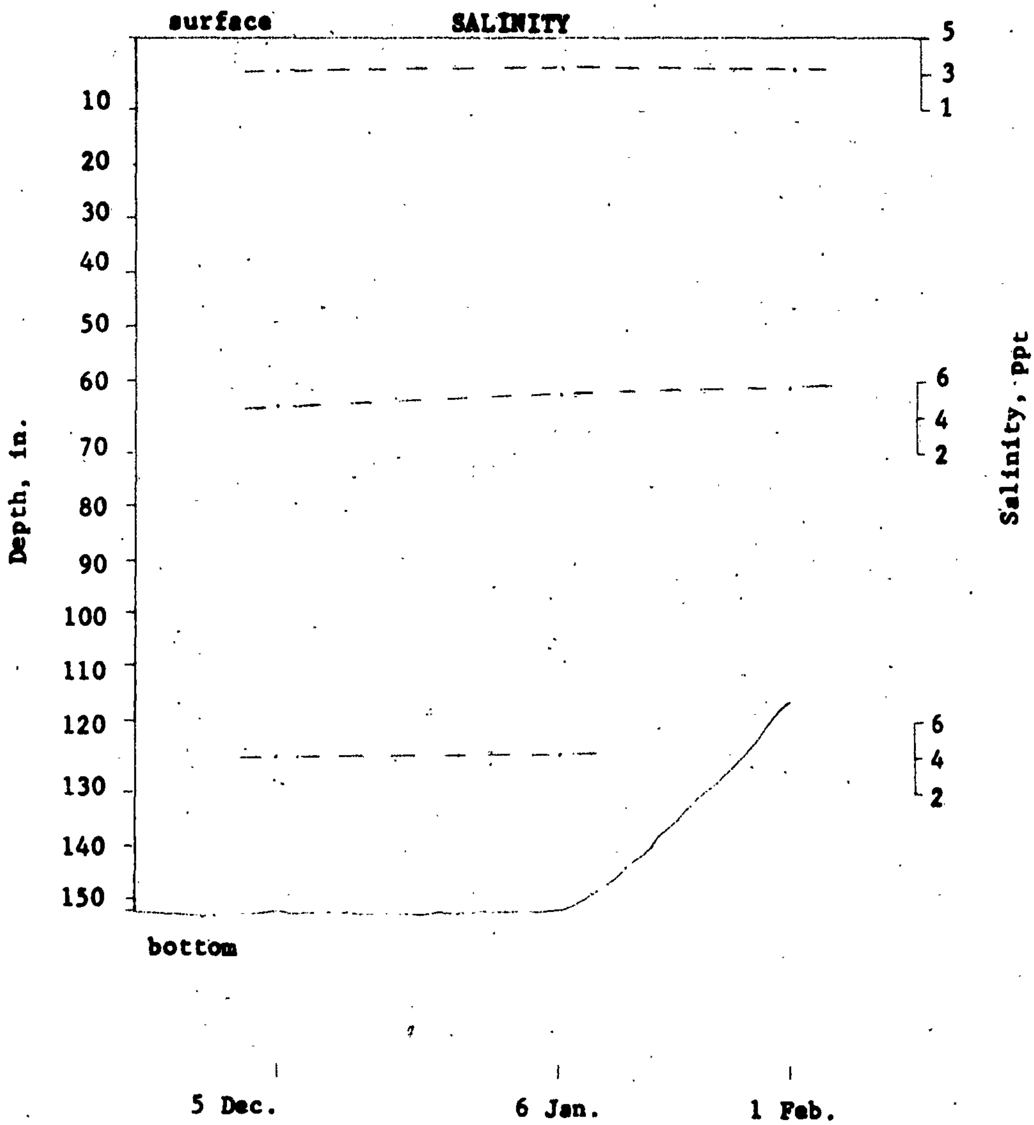
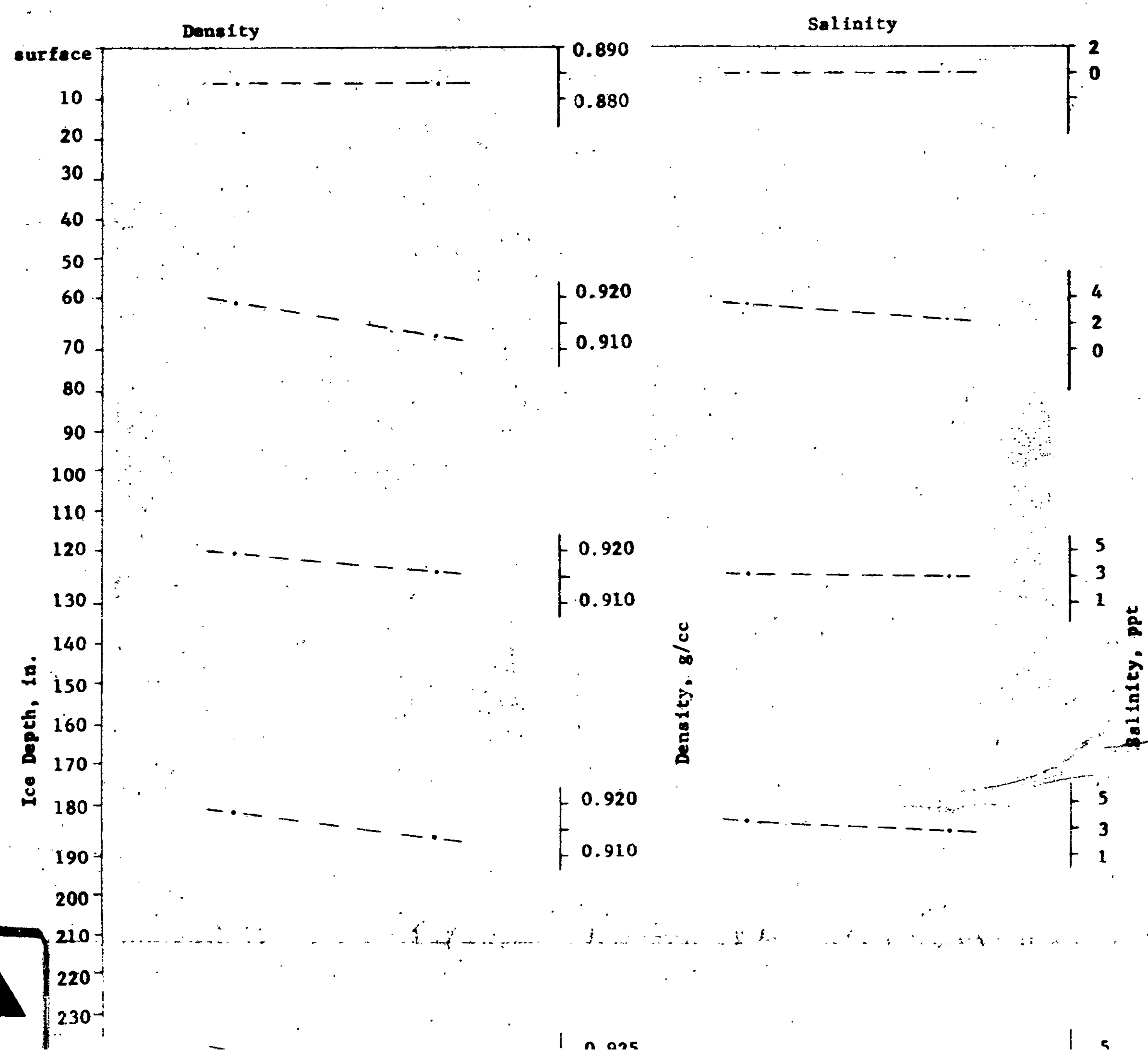


Figure 4. Salinity of 3-year old ice.


Density
Salinity
surface
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
Ice Depth, in.
0.890
0.880
0.920
0.910
0.920
0.910
0.920
0.910
Density, g/cc
2
0
4
2
0
5
3
1
5
3
1
Salinity, ppt

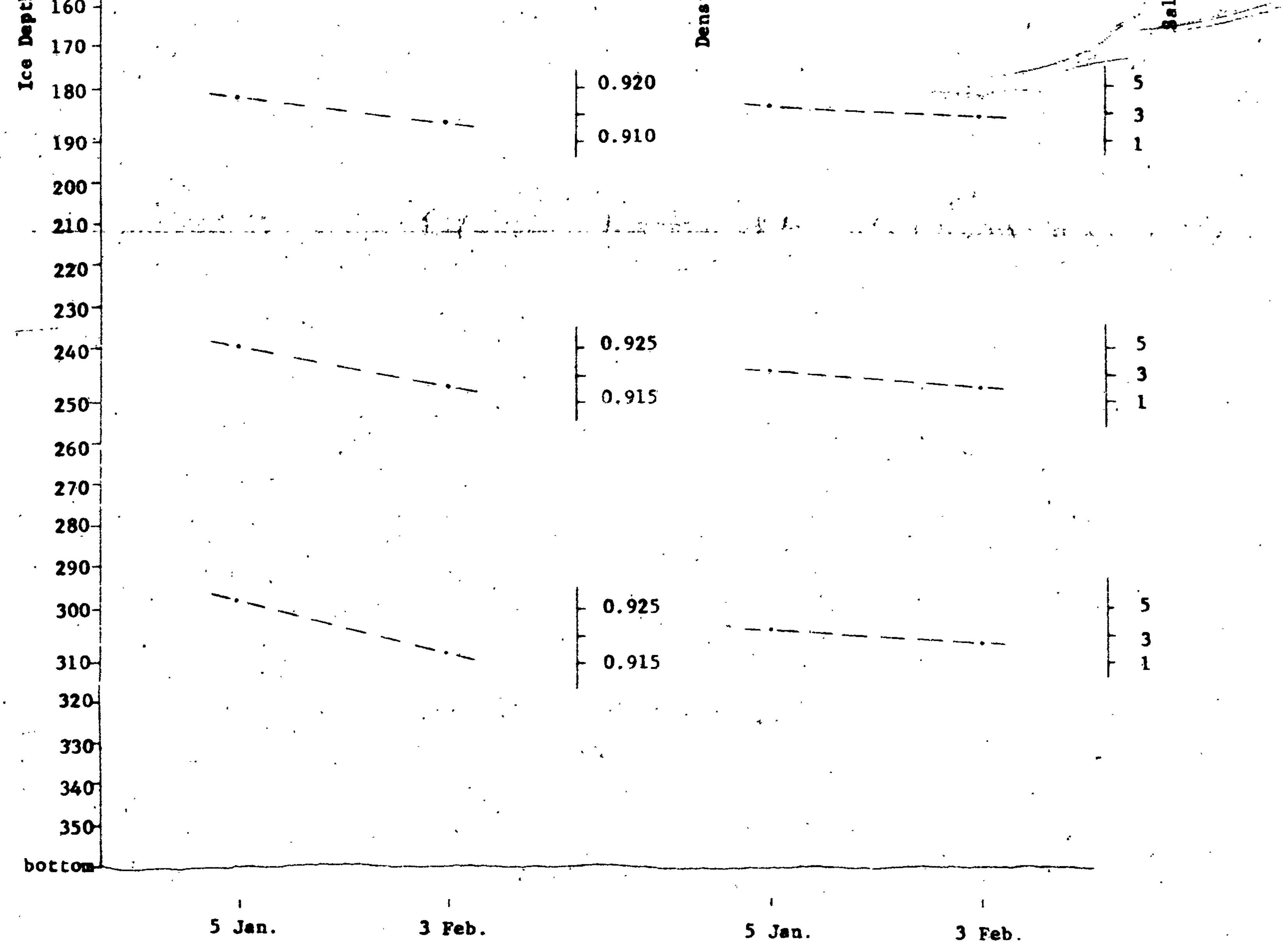


Figure 5. Density and salinity of Williams Field ice.

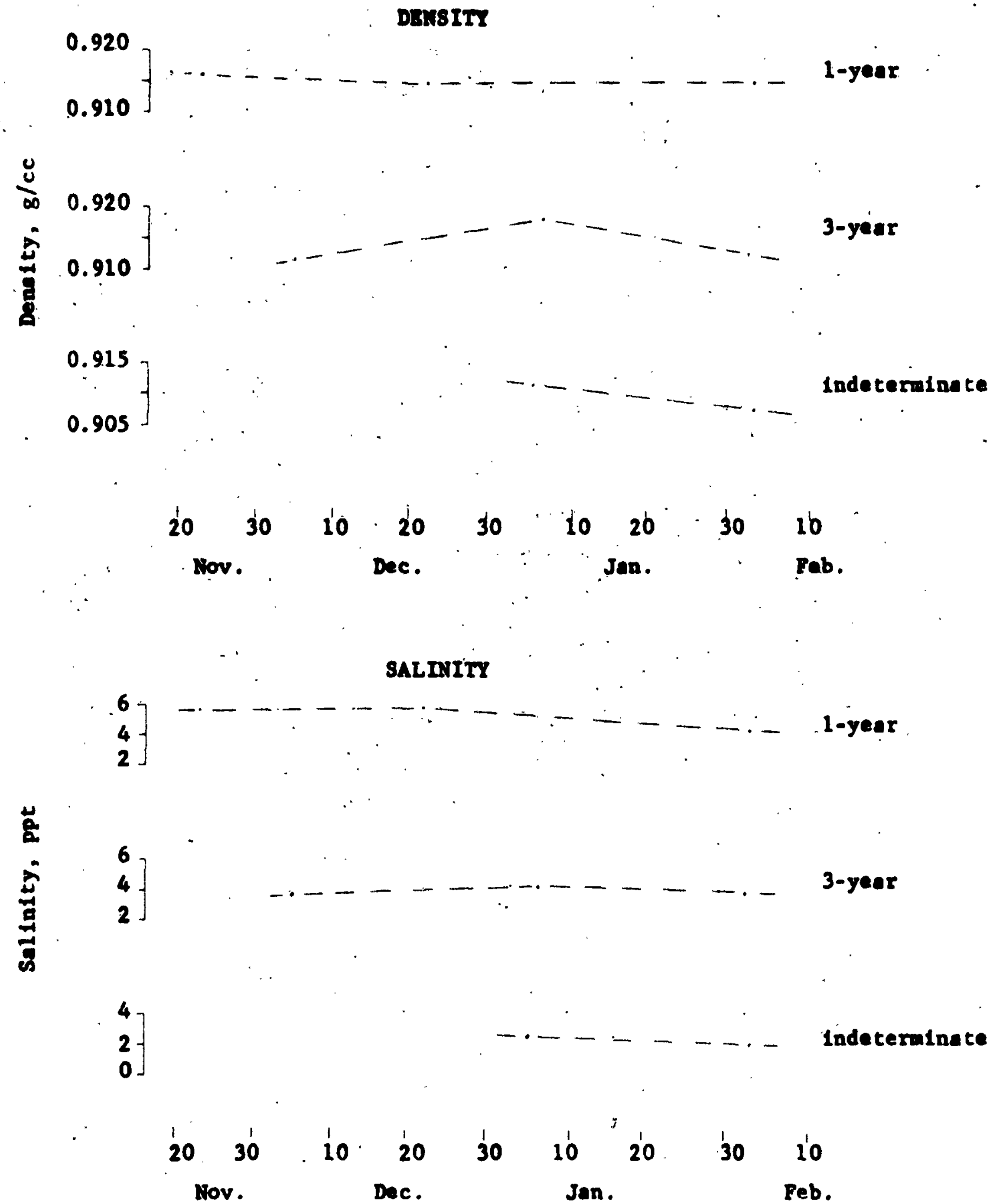


Figure 6. Average salinity and density for total ice thickness for each ice age during summer season.

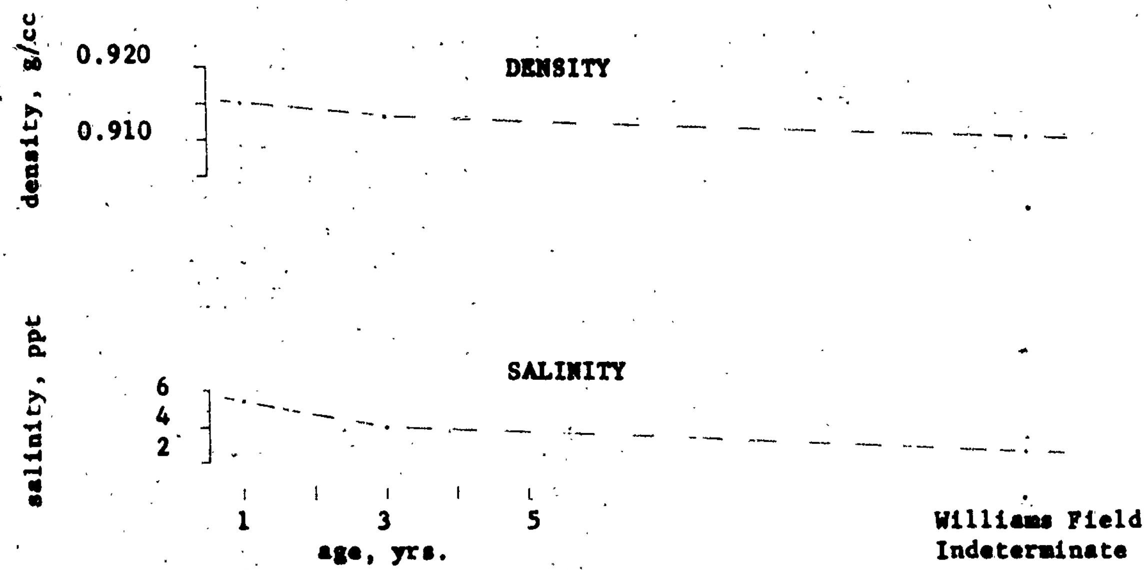


Figure 7. Average summer density and salinity for total ice thickness for 1- and 3-year ice and Williams Field ice.

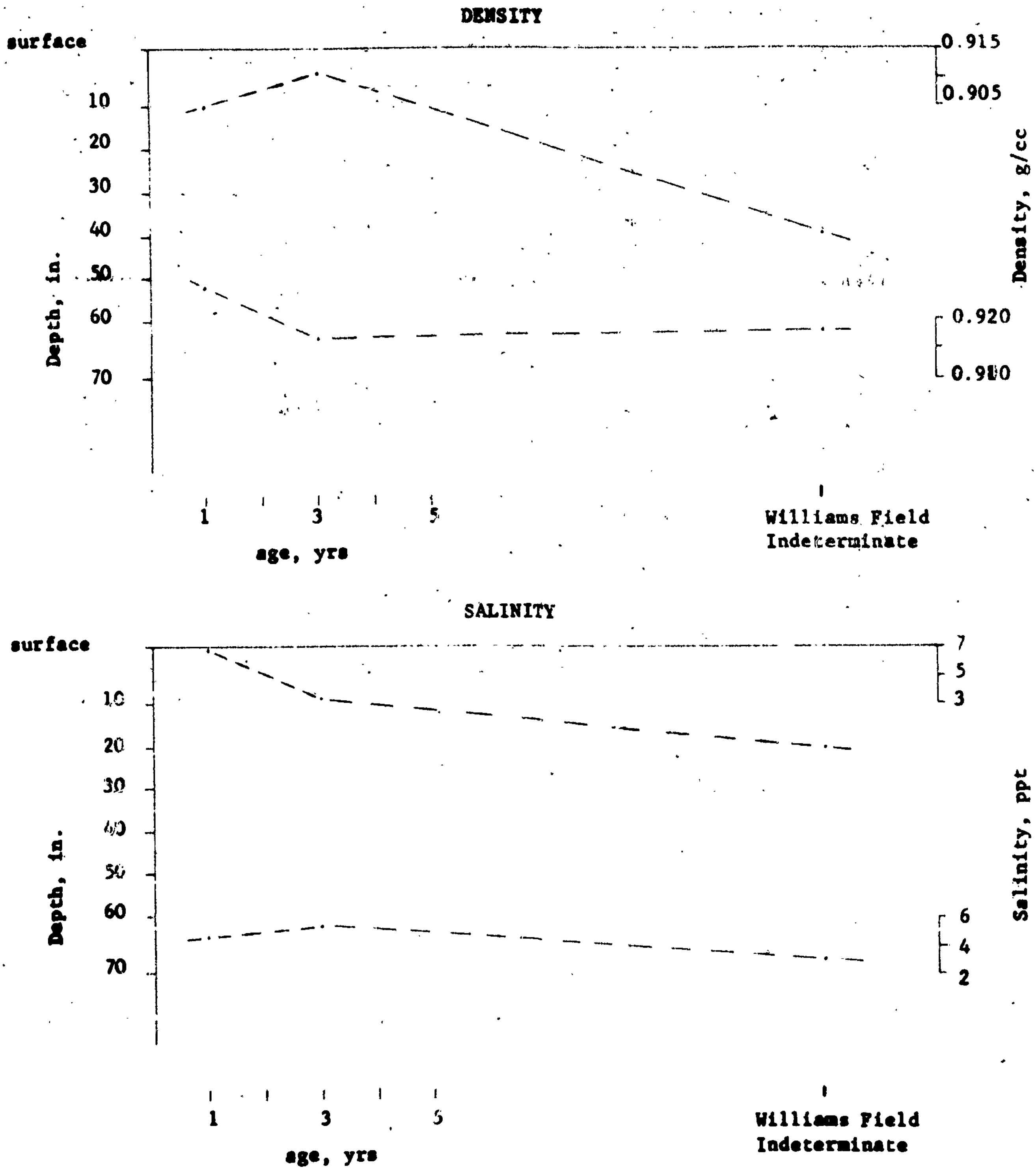


Figure 8. Average salinity and density of one- and three-year old ice and Williams Field ice at selected depths.

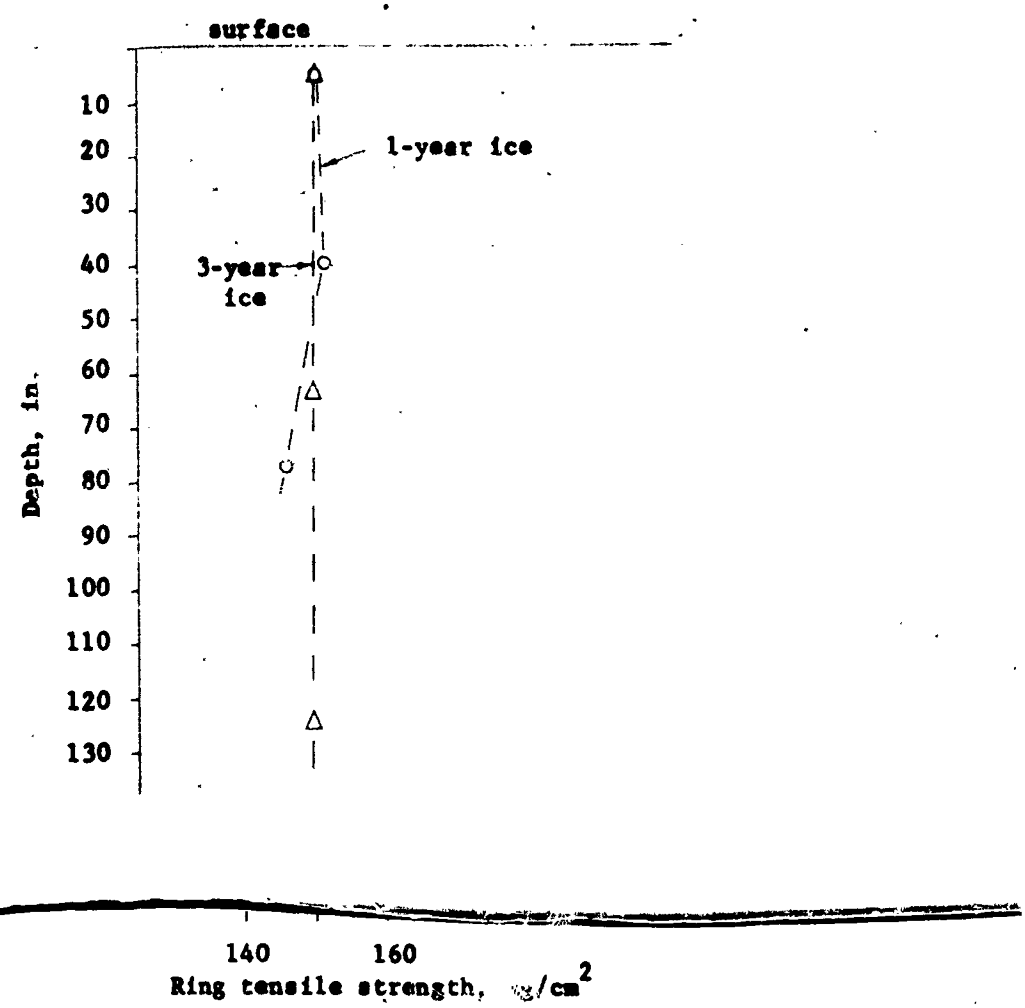


Figure 9. Average ring tensile strength for one- and three-year old ice in November.