The Texture and fabric of the second year sea ice cover at Mould Bay, Prince Patrick Island, NWT, April 1983

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RÉSUMÉ

Les auteurs ont étudié l'évolution du profil de l'épaisseur de glace et de neige d'une couverture de glace de mer à Mould Bay (7 km de large), pendant sa première et sa deuxième année. Ce document fait état de cette évolution et des observations notées sur les changements qui se sont opérés au niveau des propriétés physiques, chimiques (salinité) et de la microstructure de la glace. Il présente également des détails sur la structure des bulles d'air ou de gaz emprisonnées dans la glace de deux ans et celle de l'interface entre la vieille glace et la nouvelle glace sous-jacente.

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INTRODUCTION

Mould Bay, an Atmospheric Environment Service upper air and weather station located at 76°N, 119°20'W, provides one of the few sites for a long term continuous study on the aging process of sea ice as it relates to remote sensing. Once the first year (FY) fast-ice cover has formed, there is a good chance the ice might stay in the bay for a number of years before it is driven out by winds into Crozier Channel during the summer period. Measurements of the physical, chemical, microwave and mechanical properties were carried out in October 1981, June-July 1982 and April 1983. The initial ice cover formed during the fall of 1981 after all the old ice had left the bay. During the summer of 1982 the ice melted only partially, becoming by definition second year (SY) ice as the new ice growth season started in September 1982. During April 1983 a multidisciplinary, international research team revisited the site as in previous seasons to document the properties of SY ice. In the intervening periods, when no research teams were stationed at Mould Bay, members of the AES weather station carried out routine observations on the ice. Published results have concentrated on the microwave properties (1,2), the summer conditions (3) and mechanical properties (4,5). As in previous years, an east-west line with 10 stations was established across the bay and the ice properties measured at each station. The AES weather station was used as the base camp where a field facility based in trailers contained a cold room kept at a temperature of -15±5°C and a heated laboratory. Ice samples collected in the bay were analyzed in the field with selected samples shipped to the National Research Council of Canada (NRC) for detailed analysis. This paper discusses in a general way the changes which took place in the physical, chemical and structural properties during the aging process from October 1981 to April 1983 as well as the SY ice at station 9.

GENERAL OBSERVATIONS OF THE ICE COVER CHARACTERISTICS

During the study period 1-27 October 1981, the FY ice cover grew from 0.24 to 0.54m in thickness. Salinity profiles were consistent with earlier results published in the literature (6). As seen in Figure 1 the ice cover had reached a maximum thickness of 2.17m and a snow cover of 0.65m. By mid July of 1982 the thickness of the ice cover had diminished to 1.38m, primarily by surface ablation and to a lesser extent by bottom melt. The minimum average thickness of 0.7m was reached around 1 September. The salinity by mid July had decreased to a value of less than 3ppt throughout the ice cover as compared to greater than 4.4ppt at the end of April 1982. At the end of June, ponding on the surface had increased to 90% and decreased shortly thereafter to less than 50% (3). The effect of the ablation and drainage caused the surface to become undulated with a relief of 0.3m. Shore leads formed along both the east and west coasts of the bay, however the ice cover remained stationary in the bay. Ice growth during year two (Figure 1) plus the addition of the SY ice gave a total ice thickness of 1.75m at the beginning of the new experimental period (31 March - 10 May 1983) and a snow depth of 0.4m.

ICE COVER CHARACTERISTICS 1983

Figure 2 shows the ice thickness profile across the bay for the 5th of April 1983. The second year ice was located between stations 2 and 9 with a refrozen lead near station 7. The thickness of the second year ice varied between a minimum of 0.17m at station 2 and a maximum of 0.90m at station 5. The maximum underlying new ice growth had a thickness of 2.06m at station 7 and a minimum of 1.35m at station 5. The shore leads consisted entirely of first year ice with the maximum thickness of 2.5m at station 10 which coincided with an absence of snow. The snow varied between 0.1 to 0.6m over the remainder of the stations. The SY ice cover was completely desalinated as shown in Figure 3 for station 9. The FY had an average bulk salinity of 4.4±0.3ppt while the underlying new ice growth had an average bulk salinity of 3.7±0.7ppt. The FY ice was opaque and had a layer of frazil at the surface. The average density of the SY cover was 913±5 kg/m^3 while the average density of FY ice was 902±15 kg/m^3 (Figure 3).

The ice fabric was columnar grained through the entire ice cover (Figure 3) with an anisotropic fabric and texture. The mean c-axis of the crystals was in the horizontal plane and observed to be parallel (±10°) to the N-S axis of the bay which coincides with the direction of the tidal current. Other investigators have observed a similar alignment of the c-axis in areas affected by shore currents (6).

Detailed analysis of the transition zone between SY and the new ice growth shows a rapid increase in salinity from 0 to 3.7ppt over a short distance of 0.05m. As shown in Figure 4, the interface was marked by a high concentration of small circular bubbles. The bubbles within the fabric were predominantly circular in shape and located at the subgrain boundaries. Eighty two per cent of the bubbles had diameters of less than 0.001m. Tables 1 and 2 represent the results of the bubble analysis as a function of depth.

DISCUSSION

The most striking observations were the events associated with the transition zone between SY ice and the new ice growth. Specifically these events were the sharp increase in salinity, the continual columnar growth, the preservation of the fabric, and an increase in substructure across the boundary. It is proposed that the desalination of the SY ice occurred predominantly by gravity drainage during the melt season and that the aging processes did not affect the fabric. The bulk FY ice properties were very similar to the new ice growth underneath the SY ice cover, and was classified as FY ice as shown in Figures 1 and 2.

If one projects the aging process to a third year, depending on how much surface melt takes place, one can end up with either third year ice which is by definition multi-year ice or with a new SY ice if the total thickness of the previous SY melts away. The properties of these two ice types in the third year would be different as would the two SY ice types as compared from the second to the third year.

It is clear that the aging process is a very complex process which depends particularly on the amount of ablation and how it affects the near surface properties of the ice. These changes in the aging process are clearly observable in the 90 GHz passive microwave data collected with the Naval Research Laboratory P-3 aircraft in the Mould Bay region in 1981 (1). The spread of emissivity for old ice varies between 0.68 to 0.85. This high variation in emissivity makes it very difficult to select the proper value for inclusion in sea ice algorithms to determine the fraction of old ice present.

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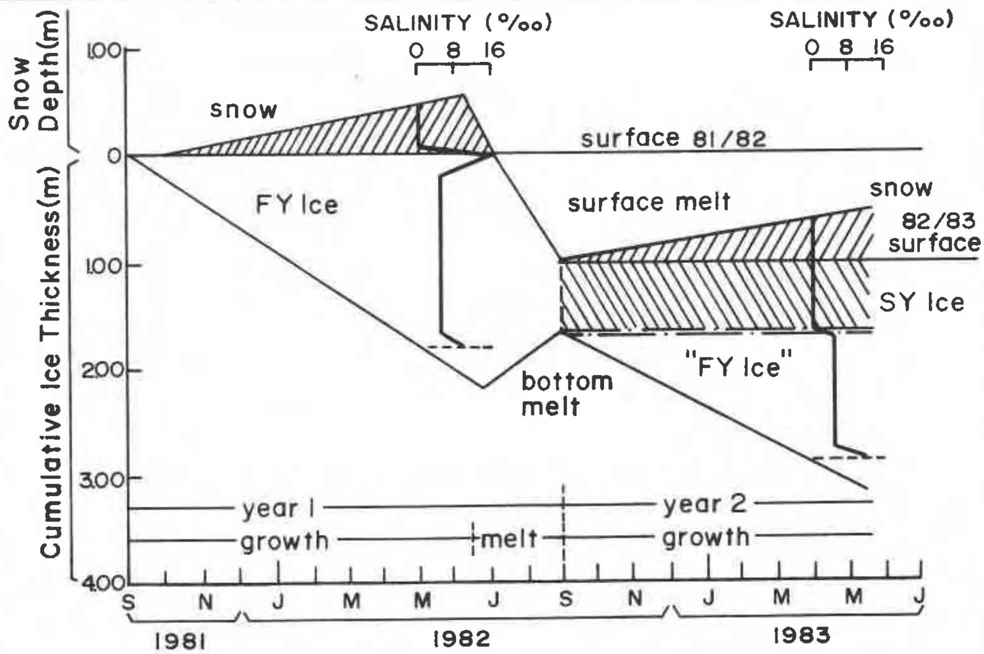

FIGURE 1. SCHEMATIC DIAGRAM OF THE AGING PROCESS OF THE SEA ICE AT MOULD BAY, NWT OCTOBER 1981 TO MAY 1983. NOTE THAT IN NATURE THE SURFACES OF THE ICE COVER ARE AT THE SAME ELEVATION. MOULD BAY IS A DEEP WATER (200m) INLET 30km LONG AND 7km WIDE. IT ENTERS INTO CROZIER CHANNEL AT ITS SOUTH END.

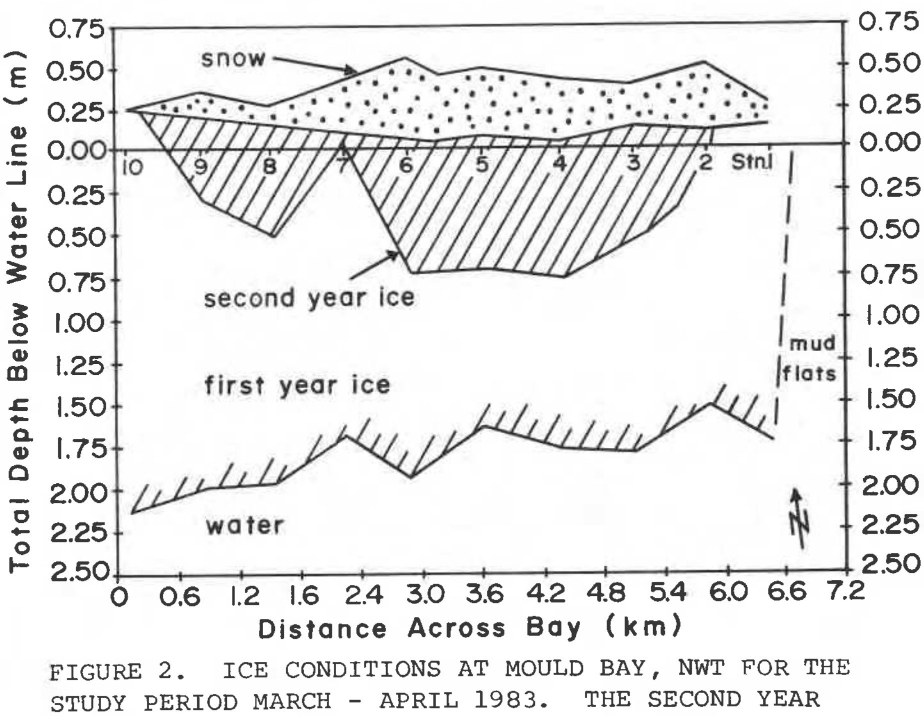

FIGURE 2. ICE CONDITIONS AT MOULD BAY, NWT FOR THE STUDY PERIOD MARCH - APRIL 1983. THE SECOND YEAR ICE REMAINED ESSENTIALLY INTACT IN THE CENTRE OF THE BAY. STATION 1 WAS LOCATED IN THE FORESHORE FLATS.

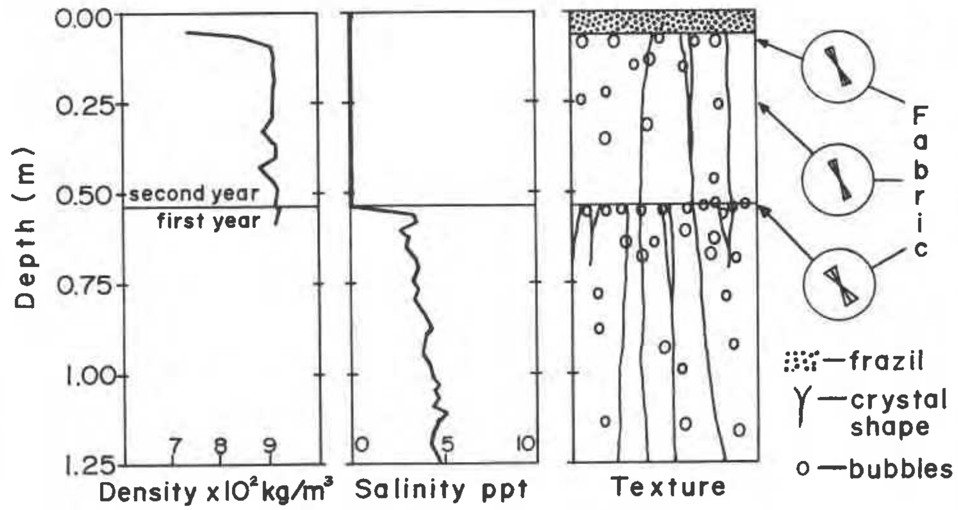

FIGURE 3. VERTICAL DENSITY, SALINITY AND TEXTURE PROFILE FOR SECOND YEAR SEA ICE AT STATION 9, MOULD BAY, APRIL 1983. THE NEW ICE GROWTH CONTINUED THE OVERLYING ORTHOTROPHIC TEXTURE AND FABRIC. NO CHANGE IN DENSITY WAS OBSERVED BETWEEN THE SECOND YEAR AND FIRST YEAR ICE. THE DATA WERE BASED ON OVER 40 SAMPLES COLLECTED FROM THE SECOND YEAR ICE STATIONS.

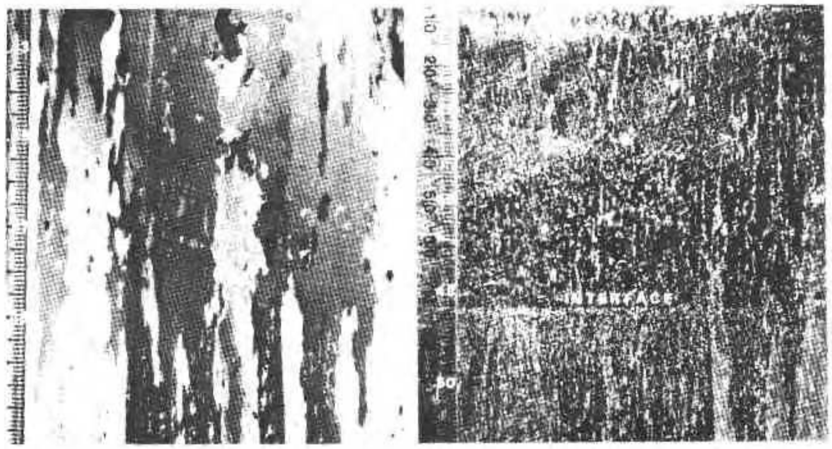

FIGURE 4. ABOVE, CLOSE-UP VIEW OF THE VERTICAL THIN SECTION CONTAINING THE SECOND YEAR-FIRST YEAR ICE INTERFACE. THE PHOTOS ARE OF THE SAME THIN SECTION PHOTOGRAPHED UNDER CROSS POLARIZED LIGHT (LEFT) AND SCATTERED LIGHT (RIGHT).

DEPTH (CM) OF HORIZONTAL THIN SECTION	BUBBLE COUNT AREA (CM^2)	NUMBER OF BUBBLES			AVERAGE BUBBLE DENSITY $/M^3$ ($X10^{-4}$)	MEAN HORIZONTAL DIMENSION (MM)	
		CIRCULAR %	ELLIPTICAL %	TOTAL NO.		CIRCULAR (Ø)	ELLIPTICAL (Major Axis)
0.62	60	73.4	26.6	1048	1.81 ± 7.9	1.15 ± 0.47	1.07 ± 0.39
3.0	35	61.3	38.7	1303	37.2 ± 21.8	0.99 ± 0.84	1.45 ± 1.19
3.8	30	63.4	36.5	363	12.1 ± 7.5	0.33 ± 0.23	1.02 ± 1.05
5.9	30	68.0	32.0	297	9.9 ± 3.8	0.69 ± 0.29	0.94 ± 0.44
8.0	30	70.0	30.0	269	8.9 ± 2.8	0.64 ± 0.27	0.81 ± 0.33
10.1	30	57.8	40.2	418	13.9 ± 4.1	0.69 ± 0.26	1.04 ± 0.37
12.1	25	59.8	40.2	246	9.8 ± 3.2	0.64 ± 0.26	0.98 ± 0.39
14.5	25	58.8	41.2	123	4.9 ± 2.3	0.52 ± 0.20	0.75 ± 0.27
15.1	30	85.2	14.8	239	8.8 ± 3.4	0.62 ± 0.35	1.26 ± 0.79

TABLE 1. ABOVE, SECOND YEAR ICE BUBBLE CHARACTERISTICS. THE BUBBLES WERE ANALYZED IN THE HORIZONTAL PLANE FROM HORIZONTAL THIN SECTIONS. 83% OF THE BUBBLES HAD DIAMETERS OF LESS THAN 1MM. THE MEAN BUBBLE DIMENSION FOR CIRCULAR BUBBLES WAS 0.69± 0.2MM AND 1.04± 0.2MM FOR ELLIPTICAL BUBBLES.

RANGE OF VERTICAL DEPTH (CM)	TOTAL NUMBER OF BUBBLES	MEAN VERTICAL DIMENSION (MM)
0 to 1	29	5.5 ± 0.94
1 - 2	102	5.0 ± 0.96
2 - 3	36	4.2 ± 0.45
3 - 4	9	3.0 ± 0.26
4 - 5	37	4.6 ± 0.54
5 - 6	26	9.1 ± 1.19
6 - 7	56	5.1 ± 0.93
7 - 8	43	5.7 ± 0.87
9 - 10	55	4.0 ± 1.90
10 - 12	78	6.6 ± 3.92
12 - 13	170	0.66 ± 7.34
13 - 14	122	0.27 ± 0.56
14 - 15	119	0.36 ± 0.46

TABLE 2. LEFT, SECOND YEAR ICE BUBBLE DIMENSIONS IN THE VERTICAL PLANE BASED ON VERTICAL THIN SECTIONS. THE BUBBLES CONSISTED OF VERTICAL TRAILS LESS THAN 7MM LONG.