Seasonal Variations in Water Structure under Fast Ice near Syowa Station, Antarctica, in 1976

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1976年南極昭和基地周辺海域における定着氷下の海洋構造の季節変化

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要旨： 均質な水が，定着氷の厚さが最大になった 9 月上旬に，オングル海峡の表層 400 m の所で観測された．定着氷は 5 月上旬の約 1 m から 9 月上旬の約 2 m まで生長した．5 月には，氷の下の海洋構造は塩分成層していたが，この氷生長期間中のブライン排出によって生じた塩対流が，この均質水を形成した．表層水の平均塩分量も，氷生長期間中のこの対流過程によって，33.93‰ から 34.10‰ まで増加した．一方ラングホブデでは，氷河舌の流入によって定着氷上にしばしば割れ目が生じ，冬期でさえ水面が大気にさらされた．そのため定着氷の生長だけでなくその水面の急激な凍結によるブライン排出によって，中層に最大塩分量 35.03‰ の高塩分水が形成された．オングル海峡の 400 m 以深やラングホブデの 200 m 以深の海水の塩分量が春から著しく減少した．その頃，両海域の表層水の塩分量はともにむしろ増加傾向を示したので，これら中・底層水の塩分量低下の原因は，低塩分水が，それらの層に移流してきたためと解釈される．この低塩分水の源は，宗谷海岸沖の表層水か，大陸沿岸部の融解水のたぶん氷河の底からの流出のいずれかであろう．冬の氷生長によるブライン排出によって形成された高塩分水が，大陸棚上にある海盆にたまっているという現象は夏には観測されなかったが，それは春からの低塩分水の移流によって希釈されたためと解釈される．

***Abstract*:** Formation of homogeneous water was observed in the surface layer above a depth of 400 m in the Ongul Strait in early September of 1976 when fast ice had the maximum thickness. This water was produced from stratified water as a result of haline convection induced by the exclusion of brine during the growth of fast ice from 1 m in thickness in May to about 2 m in early September. The salinity of surface water in this strait also increased from 33.93‰ to 34.10‰ by the convection process during the ice growth. Meanwhile in the Hovdebukta, water with the maximum salinity of 35.03‰ was observed at 300 m. The formation of the saline water is probably due to the exclusion of brine by the rapid freezing of sea water in cracks as well as by the gradual growth of fast ice. With the beginning of the spring a marked decrease was seen in salinity of bottom water in the Ongul Strait and of intermediate and bottom waters in the Hovdebukta despite a rather increasing salinity of surface water in both areas. It can be explained only by the advection of less saline water into the deeper layers in both

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areas. The saline water produced by the exclusion of brine was expected to remain near the bottom of glacial troughs until summer, but it was not observed there in summer. An interpretation is given that the saline water disappeared as a result of the advection of less saline water off the Sôya Coast and/or the inflow of fresh water produced in the coast of the continent, probably from the bottom of glaciers from spring onward.

1. Introduction

Although the formation of Antarctic Bottom Water is not yet fully understood, it is now widely believed from the works of BRENNECKE (1921) and MOSBY (1934) that surface freezing over the antarctic continental shelves is the primary mean of its formation. Brine exclusion on account of ice formation brings about an increase in salinity and a decrease in temperature of surface water. On the basis of Brennecke's data FOSTER (1972) suggested that haline convection carries the brine excluded from sea ice into an isothermal surface layer in the Weddell Sea. He also suggested that this convection process can increase the salinity of the entire water column in shallow shelf regions.

To examine the contributions of brine exclusion to an increase in salinity of the entire shelf-water column, oceanographic observations should be made in winter, when freezing is most active, at fixed stations over the continental shelf. However,

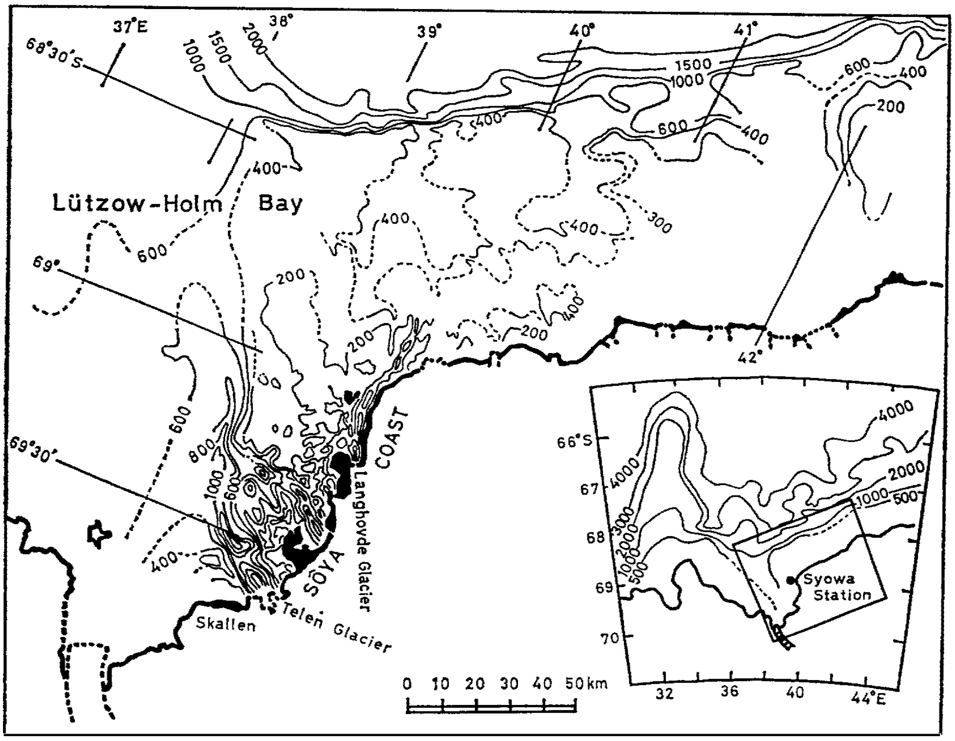

Fig. 1. Bathymetry of Lützow-Holm Bay.

such observations have not been made except those in the McMurdo Sound (TRESSLER and OMMUNDSEN, 1962; NEAL and CREW, 1976).

Oceanographic observations were made near Syowa Station (69°S, 39.5°E) in Lützow-Holm Bay from May to December in 1976 by the present author, member of the 17th Japanese Antarctic Research Expedition. The continental shelf shown in Fig. 1 has the mean width of about 60 km and the mean depth of about 300 m. Near the Sôya Coast there are several glacial troughs and narrow channels with the depth of about 600–800 m (FUJIWARA, 1971). The purposes of the observations were to examine whether the salinity of the entire shelf-water column increases as a result of haline convection due to brine exclusion and, if so, whether water with a relatively high salinity which has sunk in winter remain near the bottom of troughs and depressions until summer.

2. Oceanographic Stations

Oceanographic stations were selected in three areas as shown in Fig. 2: the Ongul Strait (A, B and C), the Hovdebukta (Langhovde Glacier inlet) (D, E, F and G) and off the Sôya Coast (K, L, M and N), most of which were located in the glacial troughs

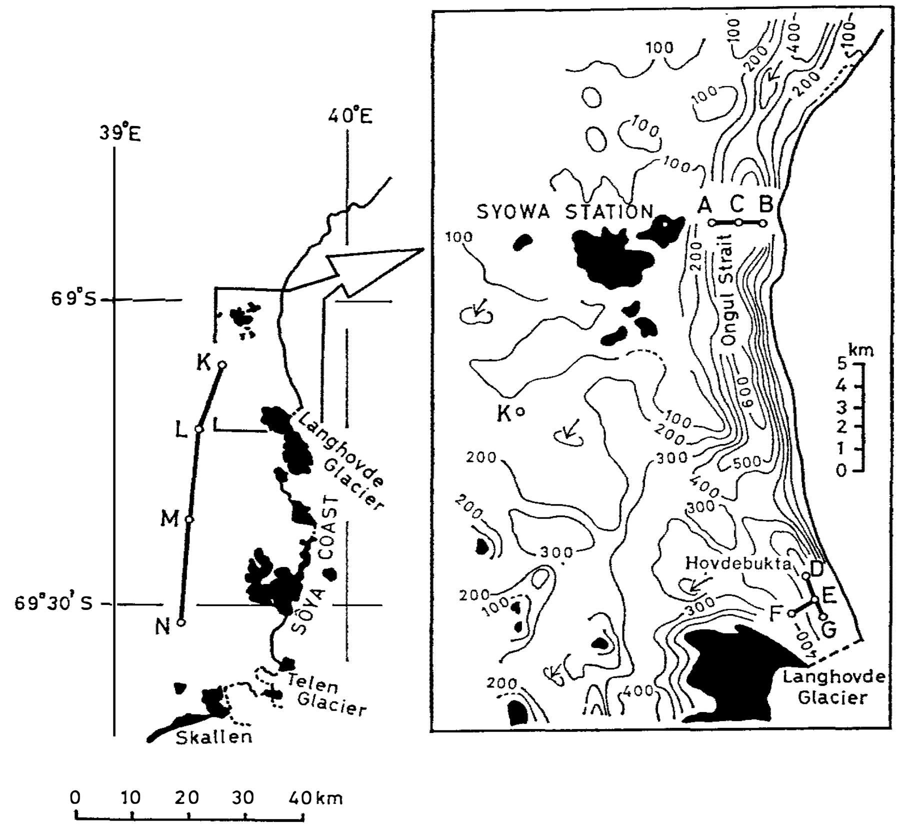

Fig. 2. Locations of oceanographic stations near Syowa Station.

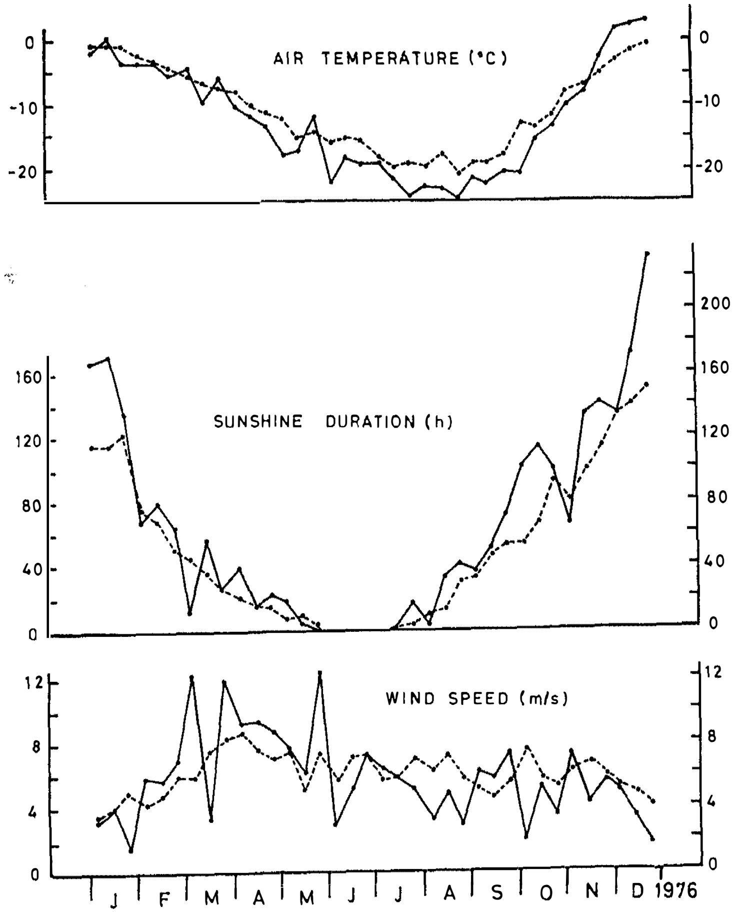

Fig. 3. Mean 10-day meteorological elements at Syowa Station in 1976. Broken line are the average values for the last 19 years.

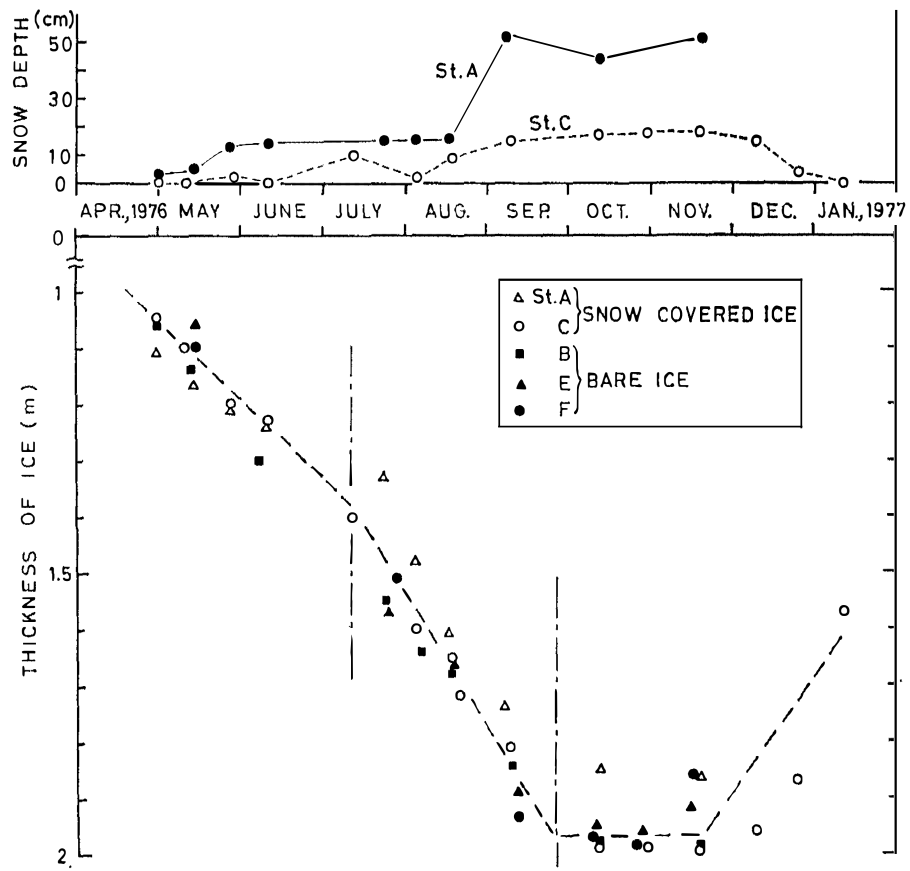

Fig. 4. Seasonal variations in thickness of fast ice at Sts. A, B, C, E and F (lower part) and in snow depth at Sts. A and C (upper part).

and the narrow channels.

In the first two areas oceanographic observations were made several times from May to December in 1976, while in the last area only once in October. Figure 3 shows air temperature, sunshine duration and wind speed at Syowa Station in 1976. The weather in this year had lower air temperature, longer sunshine duration and smaller wind speed than the averaged values for the last nineteen years. The first two areas were covered with fast ice about 1 m in thickness in May when the observations started. The thickness increased during the winter and the maximum attained to about 2 m in September as shown in Fig. 4. The growth rate from May to July was 0.52 cm/day; it increased to 0.75 cm/day in August and September. Ice stopped growing in mid-September; since the beginning of late November the thickness decreased with the progress of melting due to solar radiation. In the Hovdebukta and at St. B in the Ongul Strait there was no snow on the ice surface, bare ice persistently occupying the areas during the observation period.

3. Observation Methods

A caravan of three units mounted on sledges was used for the observations on the ice field; the caravan consisted of one hydrographic laboratory, one electric generator and one living hut as shown in Fig. 5. The laboratory had a 75 cm square hole in a deck to fit over an ice hole and was equipped with an electric winch with a 1000 m-long stainless steel cable (Fig. 6), a heater and a rack of Nansen bottles; room temperature was kept at about 15°C. A 5 kVA generator was used to operate the winch and an electric core drill was used to open an ice hole 30 cm in diameter.

Measurements were made of vertical temperature and salinity profiles using the standard Nansen bottles and the paired reversing thermometers in a low temperature range (−2 to 10°C). Observation depths were 5, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 500 and 600 m. Surface water was not measured since it was warmed by the

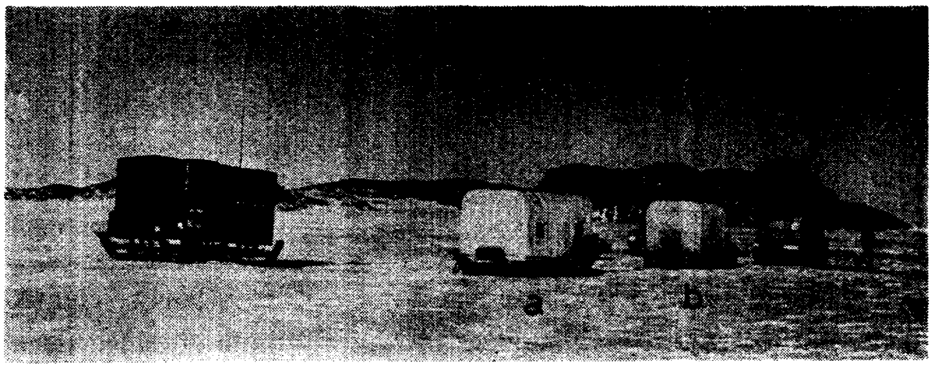

Fig. 5. Caravan for oceanographic observations on the fast ice field. (a) Hydrographic laboratory, (b) Generator.

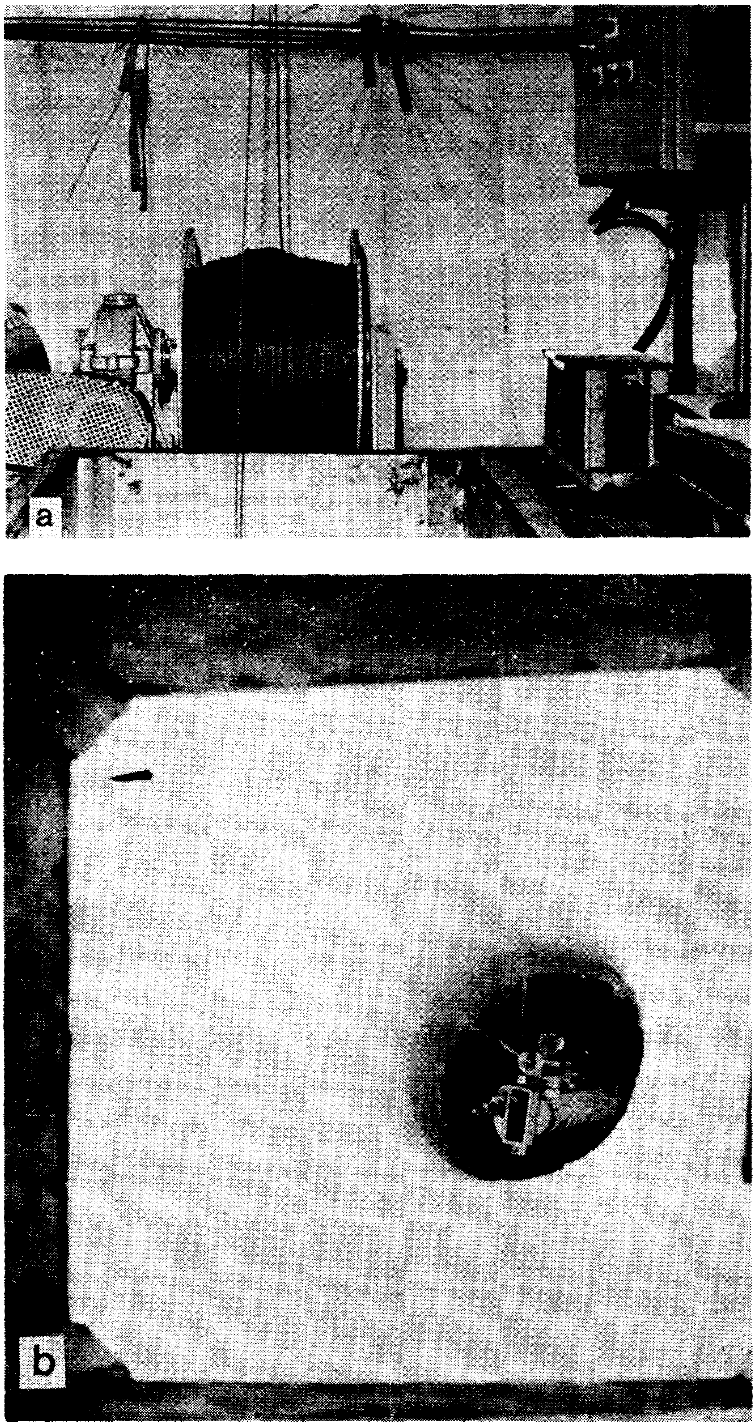

Fig. 6. Inside of hydrographic laboratory. (a) Winch, (b) ice hole.

room air. For the last two depth, the thermometric depth was calculated from the readings of the unprotected thermometers. A water sample obtained from a Nansen bottle was put in a gasket-sealed 100 m*l* glass bottle; all samples were brought to Syowa Station and titrated with silver nitrate for the measurement of salinity. Accuracies of temperature and salinity were $\pm 0.05°C$ and $\pm 0.02‰$, respectively.

Using a vane type current meter (TS current-meter, type V-2, made by the Tsurumi Seiki Co., Japan), current speed and direction at 5 m intervals were measured from the undersurface of the ice cover to a depth of 50 m.

4. Results

The oceanographic locations and all the data obtained from the observations are given in Tables 1 and 2, respectively.

Figure 7 shows seasonal variations of temperature and salinity at St. C located immediately over the depression in the Ongul Strait. The distributions of temperature and salinity have remarkable differences between winter and summer seasons. Figure 8 shows cross sections of temperature and salinity distributions in the Ongul Strait at three characteristic times when ice is growing (a), the growth nearly stopped (b) and the ice is melting (c).

Figure 9 shows the seasonal variations at St. E immediately over the glacial trough of the Hovdebukta. The distributions changed remarkably during the period from winter to summer also in this area. The characteristic cross sections are shown in Fig. 10.

Spatial distributions of water with relatively low salinity which appeared in a bottom layer of the Ongul Strait (Fig. 8c) and in an intermediate layer of the Hovdebukta (Fig. 10b) were examined only once in October at eight stations in the Hovdebukta (D, E, F and G) and off the Sôya Coast (K, L, M and N). The cross sections in the areas are shown in Figs. 11 and 12, respectively.

The results of current speeds obtained at St. C are shown in Fig. 13. A weak northward current was observed at a depth of 50 m from October on.

Seasonal variations in water structures in the Ongul Strait and the Hovdebukta are described by using these figures.

In the Ongul Strait, as shown in Fig. 7b, the salinity profile was already stratified in May when the observations started. Surface water less than 33.5‰ in salinity seems to be a remnant of the layer diluted by melting of ice in summer. From May to July, the salinity of the water column above 200 m gradually increased and the water temperature lowered with the progress of ice growth. The stratified structure disappeared on July 11 and two homogeneous water masses with salinities of 33.65‰ and 33.93‰ were observed above and below a relatively strong halocline at a depth of 50 m. In particular the latter extended from 50 m to 300 m in depth. The salinities of both homogeneous water masses further increased during the period from late July to early September when the growth rate of ice was relatively high as shown in Fig. 4. As the upper water mass increased its salinity at a relatively high rate, the seasonal halo-

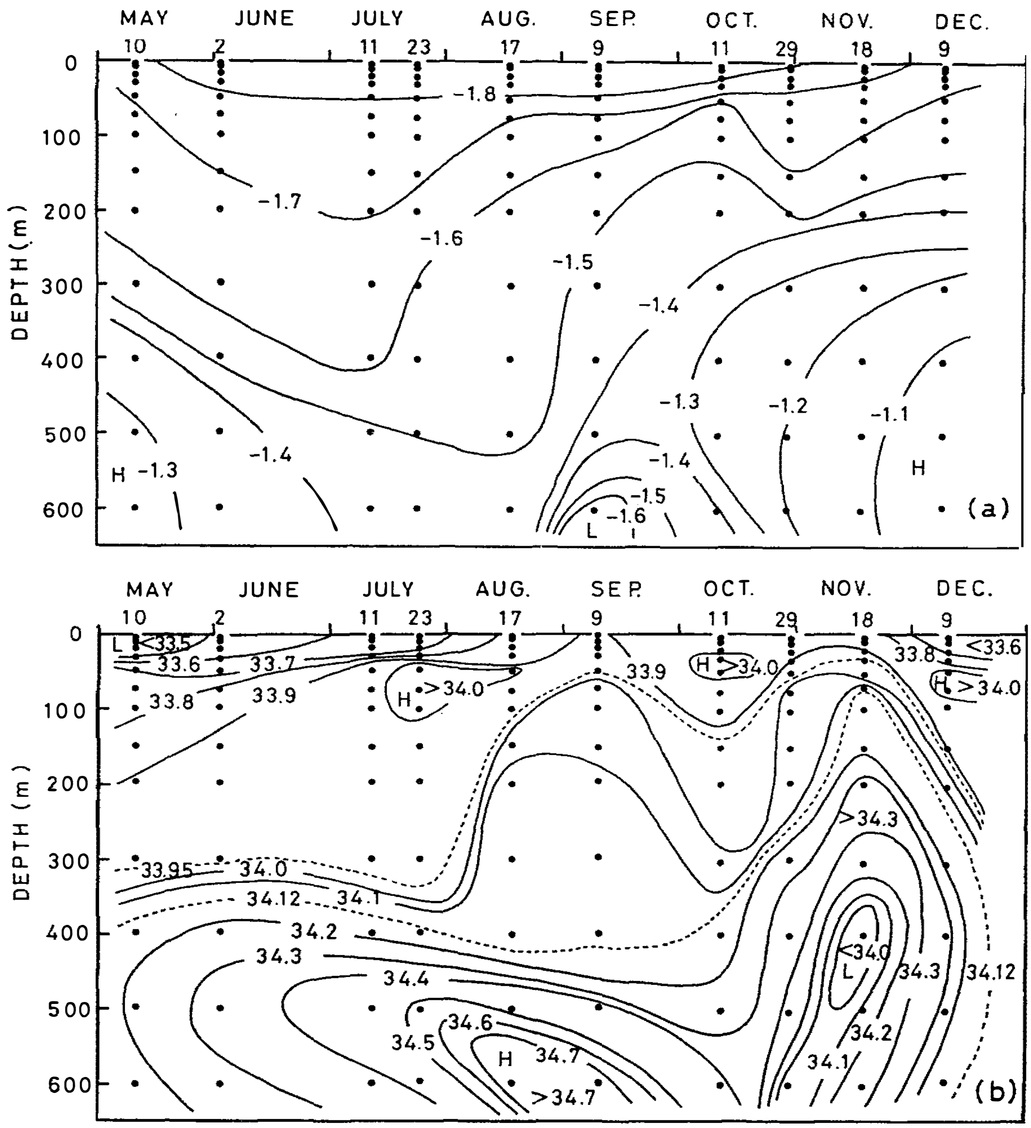

Fig. 7. Seasonal variations in temperature (a) and salinity (b) at St. C in the Ongul Strait.

cline disappeared in early August and one homogeneous water mass was newly observed in early September. This homogeneous water within 0.2‰ in the salinity difference reached a depth of 400 m as shown in Fig. 8b.

The salinity of the surface water above 400 m increased from 33.93‰ in May to 34.10‰ in September with the progress of ice growth during the winter. The salinity of bottom water below 400 m also increased during the ice growth, its maximum attaining to 34.83‰ in mid-August as shown in Fig. 7b.

Meanwhile throughout the Hovdebukta in winter, the salinity of water was relatively higher than that in the Ongul Strait as shown in Figs. 7b and 9b. In particular, intermediate water at 300 m had the maximum salinity of 35.03‰ on August

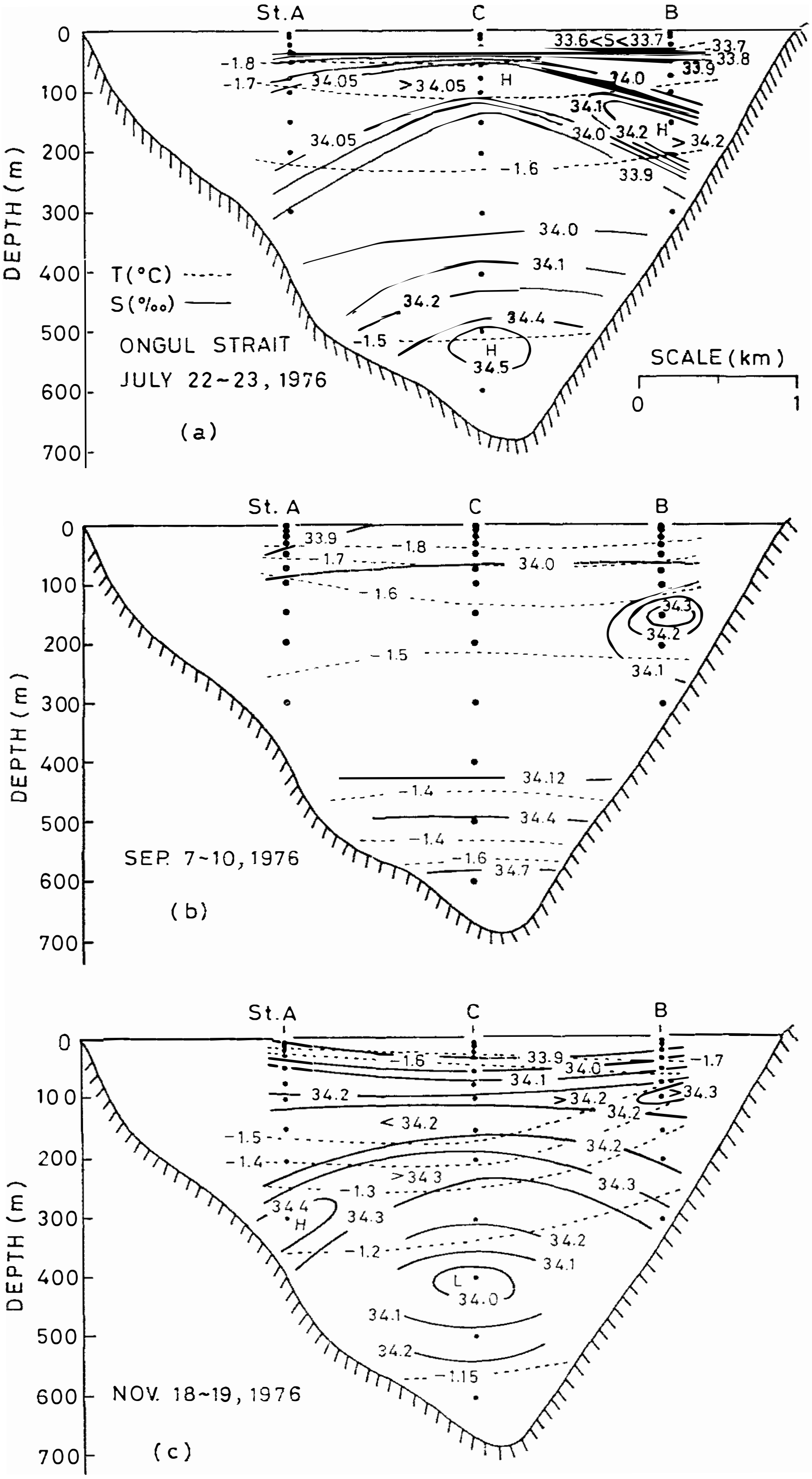

Fig. 8. *Temperature and salinity distributions in a cross section of the Ongul Strait in July (a), September (b) and November (c).*

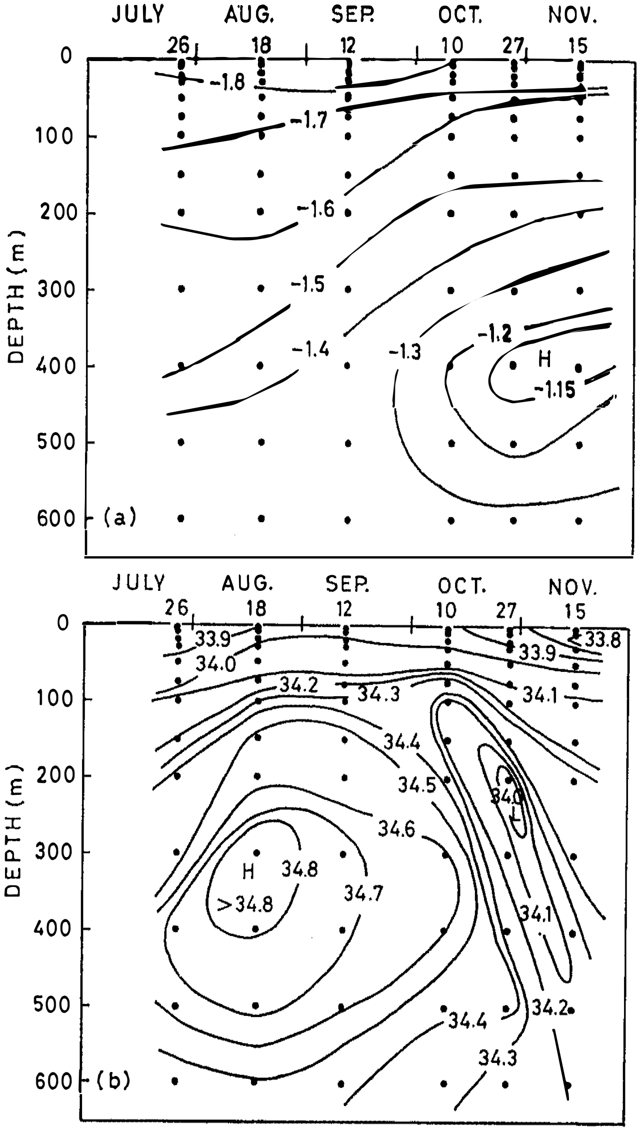

Fig. 9. Seasonal variations in temperature (a) and salinity (b) at St. E in the Hovdebukta.

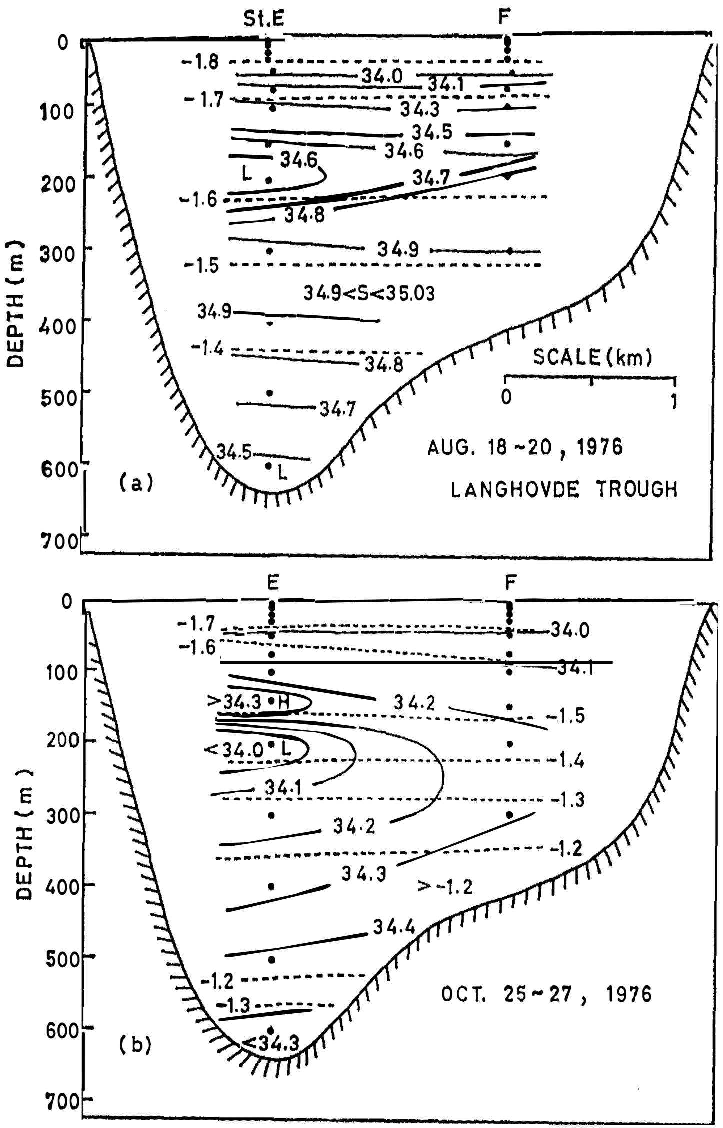

Fig. 10. Temperature and salinity distributions in a cross section of the Hovdebukta in August (a) and October (b).

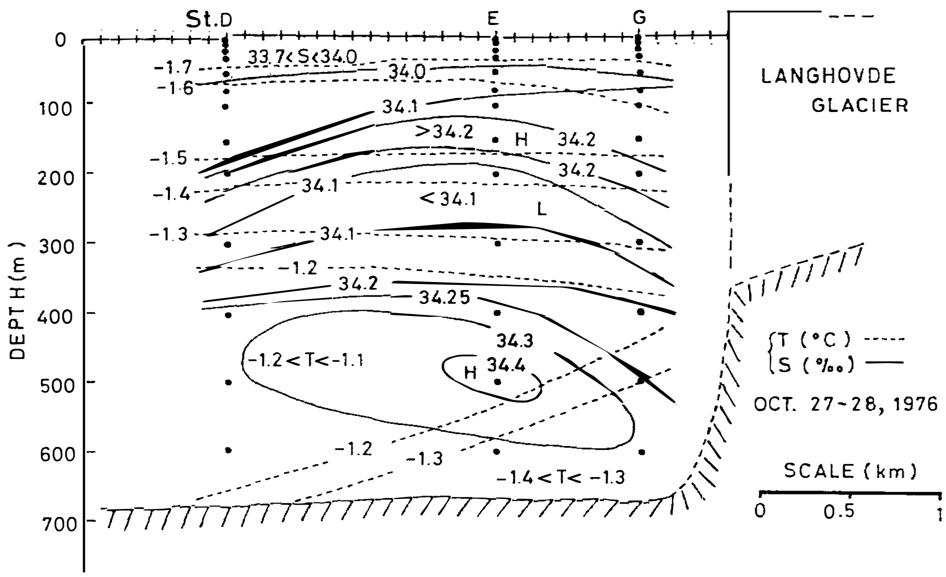

Fig. 11. Temperature and salinity distributions in a cross section of the Hovdebukta (D, E and G) in October.

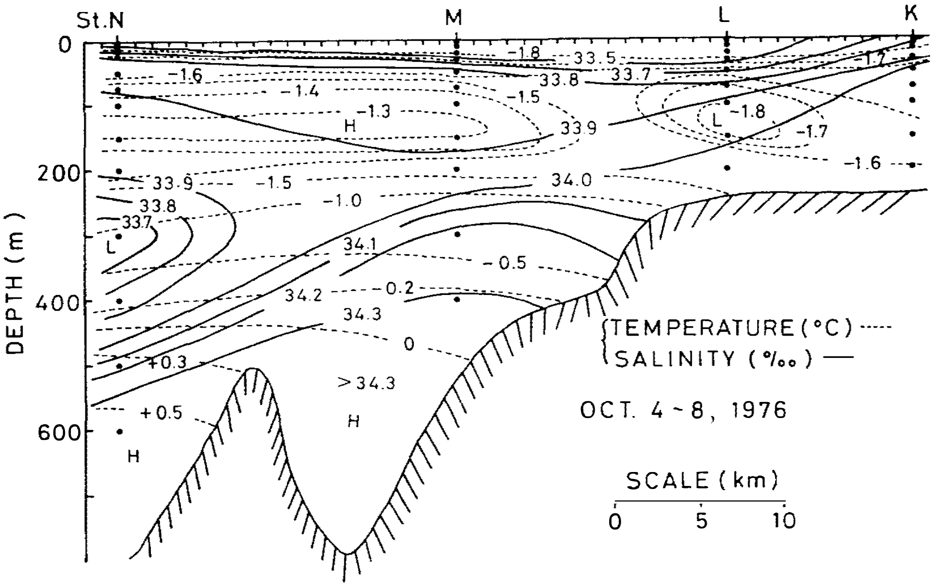

Fig. 12. Temperature and salinity distributions in a cross section off the Sôya Coast in October.

18, which was much higher than that of Antarctic Bottom Water (about 34.7‰).

Both the saline waters which were observed in the bottom layer of the Ongul Strait and in the intermediate layer of the Hovdebukta in winter decreased in salinity from spring on as shown in Figs. 7b and 9b. As the result of the continuous decrease, less saline water masses as shown in Figs. 8c and 10b appeared in both the areas. The less saline water was observed also off the Sôya Coast as shown in Fig. 12.

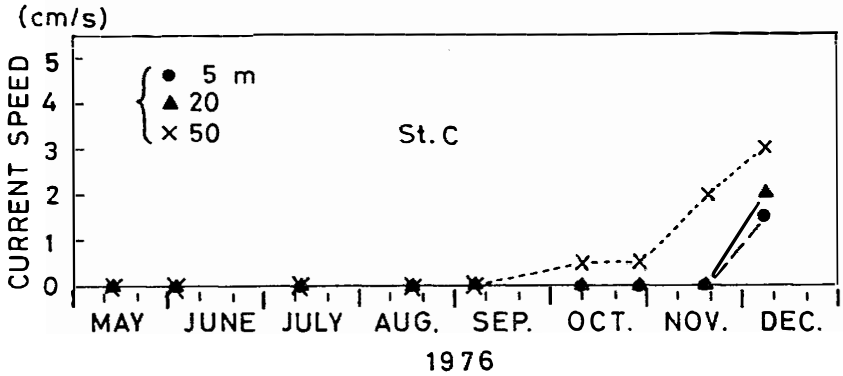

Fig. 13. Results of current speed measurements at St. C.

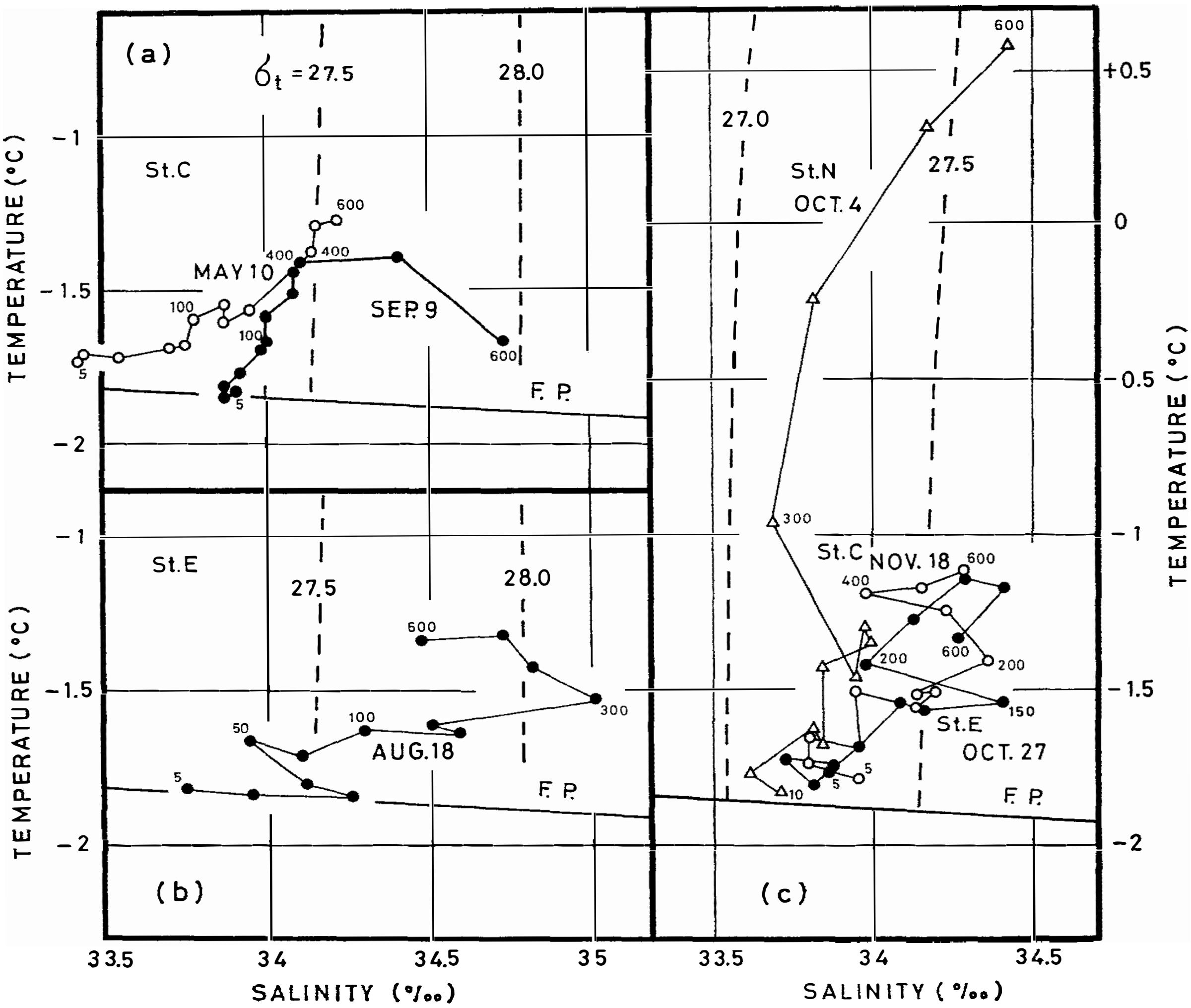

Fig. 14. Temperature-salinity diagrams. (a) St. C on May 10 (open circles) and on September 9 (solid circles). (b) St. E on August 18. (c) St. C on November 18 (open circles), St. E on October 27 (solid circles) and St. N on October 4 (triangles).

From the observation results, several oceanographic features as shown in Fig. 14 were obtained near Syowa Station. The first is the formation of homogeneous water mass above 400 m at St. C in the Ongul Strait on September 9 (Fig. 14a). The second is the appearance of highly saline waters in a bottom layer at St. C on September 9 and an intermediate layer at St. E in the Hovdebukta on August 18 (Figs. 14a and 14b). The last feature is the disappearance of the saline waters and the appearance of intermediate waters with relatively low salinity in three areas in October or November (Fig. 14c).

5. Discussion

As described in the previous section, the salinity of the upper water mass above 400 m in the Ongul Strait increased with the progress of ice growth and the water structure changed from stratification to homogeneity. This change, which is clearly shown in Fig. 14a, implies that haline convection was induced by the exclusion of brine during the ice growth and the salinity of the upper water mass increased mainly through the convection process. The maximum thickness of the convection layer, therefore, should be about 400 m in early September. For the bottom water it remains unknown as yet whether the salinity increase is caused by the brine excluded from the ice which penetrated through the convection layer and reached the bottom layer or by the surrounding saline water which made advection there.

Meanwhile in the Hovdebukta, relatively saline water as shown in Fig. 14b was observed in the intermediate layer from 300 m to 400 m in mid-August. What is the cause of production of such saline water? Bare ice persistently occupies this area during the observation period. Part of it near the coast is continuously compressed by seaward movement of the Langhovde Glacier, thus bringing about a fracture zone hundreds of metres in width in the compressed bare ice area (over there and in the right-hand side of the picture of Fig. 15) and exposing water which appears in cracks even in winter. The water is subjected to rapid freezing in winter. Brine exclusion from sea ice is actually accelerated with increasing growth rate of the ice (WAKATSUCHI, 1977, 1980). The cause which produces the saline intermediate water, therefore, probably depends on brine exclusion not only by the gradual growth of fast ice but also by the rapid freezing of water in the cracks.

As clearly shown in Fig. 14b, at St. E an unstable condition in density was observed on August 18, giving the maximum salinity of 35.03‰ at 300 m. Therefore, the salinity of the underlying bottom water was expected to increase by mixing with the saline intermediate water when observed afterwards. As shown in Fig. 16a, however, the salinity of the bottom water as well as that of the intermediate water decreased after August. To give an interpretation on this phenomenon, the advection of less saline

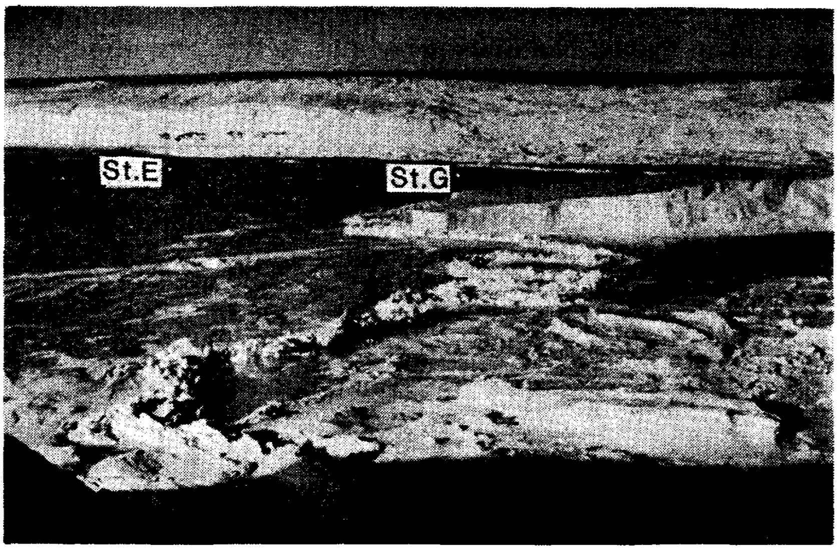

Fig. 15. Photograph showing the margin of the Langhovde Glacier in the Hovdebukta.

water into the bottom layer will be needed at least.

The salinity decrease of the bottom water began also in the Ongul Strait from early September on. Furthermore, the salinity of the surface water above 400 m did not decrease but rather increased then. The results obtained, which disclosed that the salinity of the surface water does not decrease and that of deeper water only decreases, can be explained only by the advection of less saline water into the deeper layer. A marked decrease in salinity of the bottom waters in the Ongul Strait and the Hovdebukta continued until November as shown in Fig. 16. These observation results suggest, therefore, that less saline water continued to penetrate into the bottom layers in both the areas during the period.

In the Ongul Strait, as shown in Fig. 13, a weak northward current was observed at 50 m from October on when the salinity of the bottom water was decreasing. Unfortunately, the limited cable length of the current meter did not allow measurements deeper than 50 m. However, when a stainless cable with Nansen bottles was lowered to the deepest level (600 m), the cable strongly inclined northward. The salinity decrease of the bottom water in the Ongul Strait began some period later than that in the Hovdebukta as shown in Fig. 16.

From the above two observation results, that is, the presence of northward current in the Ongul Strait and a time lag on the start of the salinity decrease between the both areas, it will be suggested that at least there was no penetration of less saline water from the north into the bottom layer of the Ongul Strait.

There are several factors to lower the salinity, that is, precipitation, meltwater of sea ice, oceanic water and meltwater produced in the coastal area of the continent. The precipitation does not take place in the areas and the meltwater of sea ice cannot

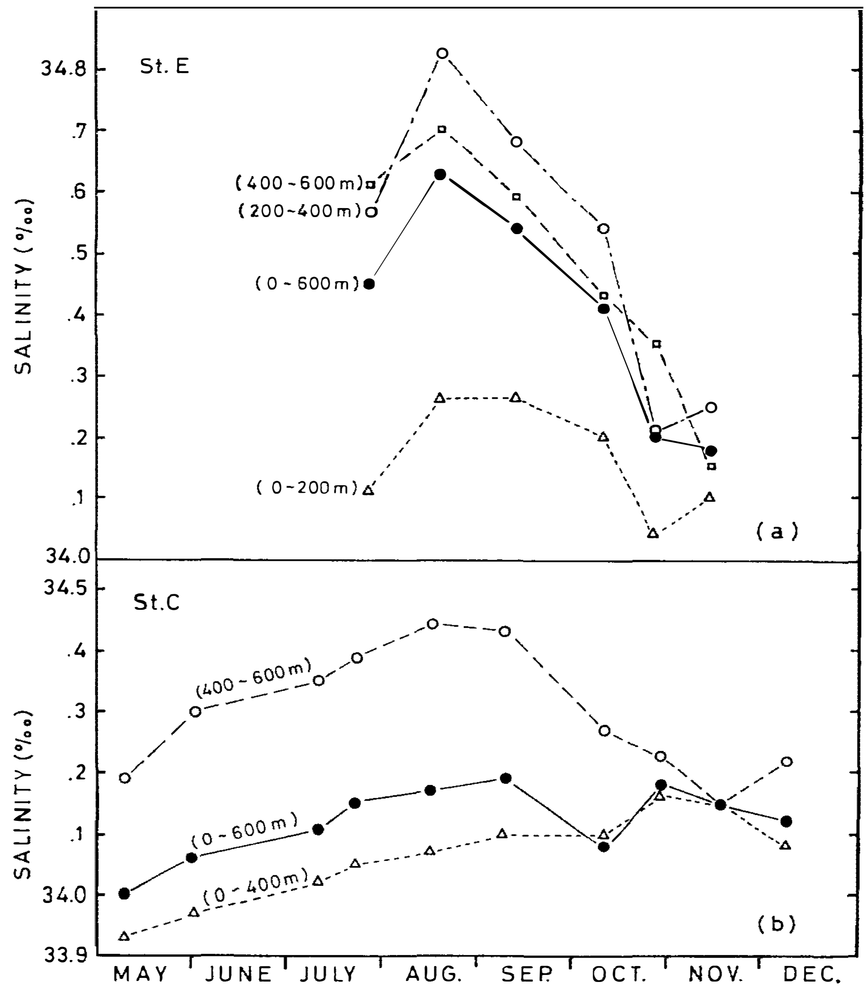

Fig. 16. Seasonal variations in mean salinity of water columns at Sts. E (a) and C (b).

penetrate into the deeper layer since its density is far less than that of the underlying water. As shown in Figs. 8c, 10b, 11 and 12, less saline water is present entirely over the three areas. The water extends in the bottom layer cored at a depth of 400 m in the Ongul Strait and the intermediate layer from about 200 m to about 400 m in the Hovdebukta. Meanwhile off the Sôya Coast the salinity of the water in the layer from about 500 m at St. N to about 50 m at St. K on October 4–8 was less than 34.0‰, which is the minimum salinity of samples of the less saline water observed in the Ongul Strait and the Hovdebukta.

Although the spatial distribution of less saline water does not give a clue to its source, the water in the Ongul Strait and the Hovdebukta is probably due to the advection of less saline water off the Sôya Coast and/or the inflow of meltwater produced in the coast of the continent from the bottom of glaciers. This advection may cause an instability as a result of the presence of dense water layers over light water layers in three areas as shown in Fig. 14c.

Saline intermediate water was observed in the Hovdebukta in winter. The formation of the saline water is probably due to the remarkable exclusion of brine from ice. The water was expected to remain near the bottom of the glacial troughs until summer, but it was not observed in the summer. Its disappearance may have resulted from the advection of the less saline water off the Sôya Coast and/or the inflow of the meltwater, probably from the bottom of the Langhovde Glacier.

6. Concluding Remarks

Seasonal variations in water structure near Syowa Station were observed. Vertical haline convection was induced by brine exclusion due to ice formation during the winter. This was verified by a change in water structure in the upper layer above a depth of 400 m in the Ongul Strait from stratification in May to homogeneity in early September. The convection process due to brine exclusion brought about an increase in salinity of water columns in both the Ongul Strait and the Hovdebukta. Water in the intermediate layer of the Hovdebukta had the maximum salinity of 35.03‰ in mid-August. The formation of this water seems to depend on brine exclusion not only by the gradual growth of fast ice but also by the rapid freezing of sea water in cracks exposed to the atmosphere even in winter.

Salinity of bottom water in the Ongul Strait and intermediate and bottom waters in the Hovdebukta decreased remarkably in spring after reaching maximum in August. The salinity decrease of the waters is probably due to the advection of less saline water into the deeper layers.

The saline water produced by brine exclusion in winter was expected to remain near the bottom of the glacial troughs and the depressions until summer, but the water was not observed in summer. The disappearance of saline waters near Syowa Station might have resulted from the advection of less saline water off the Sôya Coast and/or the inflow of fresh water produced in the coast of the continent, probably from the bottom of glaciers from spring on.

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Table 1. Oceanographic locations.

Station	Latitudes (S)	Longitude (E)
A	69° 0′28″	39°38′06″
B	69° 0′28″	39°41′10″
C	69° 0′28″	39°39′51″
D	69° 9′00″	39°44′14″
E	69° 9′47″	39°45′07″
F	69°10′06″	39°43′22″
G	69°10′16″	39°45′49″
K	69° 6′38″	39°27′09″
L	69°12′47″	39°21′01″
M	69°21′38″	39°19′16″
N	69°31′53″	39°17′05″

Table 2. Oceanographic data, 1976 (Interpolated values of temperature and salinity at standard depths).

	Station A					
Date	July 22		August 16		September 7	
Local time (=GMT+3 h)	1400–1600		1730–1930		1230–1430	
Ice thickness (cm)	133		161		174	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.84	33.71	−1.81	33.75	−1.81	33.80
10	−1.84	33.64	−1.82	33.85	−1.80	33.84
20	−1.83	33.62	−1.82	33.71	−1.80	33.82
30	−1.94	33.66	−1.80	33.69	−1.82	33.87
50	−1.91	33.91	−1.72	33.98	−1.70	33.93
75	−1.73	34.00	−1.70	33.98	−1.64	33.93
100	−1.66	34.11	−1.68	34.04	−1.58	34.02
150	−1.64	34.02	−1.64	34.02	−1.56	34.07
200	−1.60	34.11	−1.60	34.02	−1.59	34.07
300	−1.54	33.89	−1.51	34.11	−1.47	34.13

Table 2 (continued).

	Station A				Station B	
Date	October 12		November 19		July 23	
Local time (=GMT+3h)	1200–1330		1300–1430		2100–2300	
Ice thickness (cm)	185		186.5		155	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.83	33.69	−1.76	33.84	−1.84	33.64
10	−1.81	33.78	−1.73	33.96	−1.84	33.55
20	−1.74	33.66	−1.60	33.89	−1.82	33.62
30	−1.75	33.66	−1.57	33.96	−1.82	33.66
50	−1.55	33.78	−1.51	34.16	−1.72	33.93
75	−1.55	33.96	−1.48	34.00	−1.73	33.95
100	−1.47	33.85	−1.49	34.23	−1.63	33.98
150	−1.49	34.00	−1.53	34.16	−1.63	34.23
200	−1.53	34.16	−1.41	34.16	−1.58	34.23
300	−1.35	34.36	−1.22	34.45	−1.54	33.95

	Station B					
Date	August 17		September 10		October 11	
Local time (=GMT+3h)	2100–2330		1130–1300		1130–1330	
Ice thickness (cm)	168		184.5		198	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.86	33.73	−1.84	33.90	−1.84	33.84
10	−1.84	33.73	−1.85	33.89	−1.81	33.71
20	−1.81	33.71	−1.83	33.89	−1.80	33.95
30	−1.86	33.77	−1.77	33.87	−1.82	33.90
50	−1.81	33.97	−1.72	33.94	−1.65	33.85
75	−1.83	34.00	−1.68	34.04	−1.59	34.02
100	−1.66	34.25	−1.61	34.07	−1.53	34.04
150	−1.66	34.49	−1.58	34.33	−1.48	34.23
200	−1.58	34.31	−1.56	34.18	−1.43	34.04
300	−1.51	34.18	−1.44	34.13	−1.32	34.09

Table 2 (continued).

	Station B		Station F			
Date	November 18		August 20		September 12	
Local time (=GMT+3 h)	1100–1400		1130–1400		1700–1800	
Ice thickness (cm)	198.5		172		193.5	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.74	34.04	−1.80	34.18	−1.83	34.07
10	−1.71	33.69	−1.85	34.04	−1.93	34.00
20	−1.68	33.69	−1.84	34.23	−1.83	33.98
30	−1.74	34.05	−1.87	33.82	−1.80	33.96
50	−1.62	33.93	−1.73	33.98	−1.76	34.02
75	−1.52	34.23	−1.73	34.13	−1.66	34.18
100	−1.42	34.32	−1.64	34.27	−1.65	34.43
150	−1.36	34.14	−1.55	34.56	−1.53	34.29
200	−1.21	34.14	−1.62	34.87	−1.59	34.54
300	−1.19	34.32	−1.51	34.90	−1.42	34.69

	Station F					
Date	October 9		October 25		November 16	
Local time (=GMT+3h)	1930–2200		1600–1800		1630–1830	
Ice thickness (cm)	197		198.5		186	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.82	33.87	−1.80	33.71	−1.74	33.93
10	−1.80	33.98	−1.78	33.85	−1.73	33.84
20	−1.79	33.69	−1.76	33.69	−1.72	33.95
30	−1.83	33.84	−1.81	33.89	−1.71	33.80
50	−1.62	33.85	−1.63	34.02	−1.54	34.02
75	−1.61	34.07	−1.63	34.09	−1.58	34.16
100	−1.54	34.34	−1.46	34.11	−1.49	34.18
150	−1.51	34.22	−1.54	34.16	−1.51	34.23
200	−1.49	34.11	−1.43	34.27	−1.41	34.22
300	−1.35	34.22	−1.28	34.28	−1.22	34.18

Table 2 (continued).

	Station L		Station C			
Date	October 7		May 10		June 2	
Local time (=GMT+3 h)	1600–1730		1200–1700		1300–1800	
Ice thickness (cm)	225		110		121	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.86	33.62	−1.73	33.42	−1.79	33.50
10	−1.89	33.49	−1.71	33.44	−1.79	33.50
20	−1.83	33.42	−1.71	33.44	−1.80	33.50
30	−1.83	33.42	−1.72	33.55	−1.77	33.66
50	−1.51	33.69	−1.69	33.71	−1.78	33.66
75	−1.70	33.80	−1.68	33.76	−1.73	33.88
100	−1.79	33.98	−1.60	33.78	−1.63	33.78
150	−1.80	33.96	−1.55	33.88	−1.65	33.90
200	−1.53	34.04	−1.60	33.88	−1.65	33.90
300			−1.56	33.95	−1.65	33.93
400			−1.38	34.15	−1.54	34.24
500			−1.28	34.23	−1.35	34.38
600			−1.30	34.16	−1.35	34.22

	Station C					
Date	July 11		July 23		August 17	
Local time (=GMT+3h)	1500–2000		1100–1300		1200–1700	
Ice thickness (cm)	140		148		165	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.83	33.62	−1.84	33.64	−1.84	33.84
10	−2.07	33.77	−1.84	33.64	−1.84	33.80
20	−1.80	33.62	−1.83	33.65	−1.85	33.80
30	−1.83	33.72	−1.82	33.75	−1.83	33.80
50	−1.79	33.93	−1.76	34.07	−1.73	34.00
75	−1.67	33.93	−1.70	34.07	−1.70	33.95
100	−1.69	33.98	−1.69	34.07	−1.61	33.93
150	−1.65	33.88	−1.68	33.95	−1.59	34.03
200	−1.66	33.95	−1.64	33.95	−1.56	34.10
300	−1.59	33.93	−1.52	33.95	−1.47	34.10
400	−1.62	34.20	−1.52	34.13	−1.48	34.00
500	−1.49	34.40	−1.49	34.52	−1.50	34.47
600	−1.44	34.39	−1.46	34.41	−1.48	34.83

Table 2 (continued).

	Station C					
Date	September 9		October 11		October 29	
Local time (=GMT+3 h)	1330–1530		1730–2130		1130–1530	
Ice thickness (cm)	188		199		199	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.83	33.93	−1.81	33.84	−1.82	33.84
10	−1.85	33.89	−1.80	33.84	−1.79	33.91
20	−1.82	33.89	−1.78	33.80	−1.74	33.80
30	−1.82	33.89	−1.78	34.00	−1.77	33.89
50	−1.77	33.94	−1.60	34.04	−1.60	33.84
75	−1.69	34.00	−1.51	33.80	−1.55	34.05
100	−1.66	34.02	−1.51	33.80	−1.52	34.09
150	−1.57	34.02	−1.48	33.95	−1.59	34.04
200	−1.51	34.10	−1.48	33.95	−1.50	33.95
300	−1.43	34.10	−1.37	34.00	−1.29	34.27
400	−1.41	34.12	−1.23	34.18	−1.21	34.47
500	−1.39	34.42	−1.24	34.23	−1.18	34.25
600	−1.66	34.75	−1.40	34.44	−1.18	34.07

	Station C				Station E	
Date	November 18		December 9		July 26	
Local time (=GMT+3 h)	1630–1900		1000–1300		2130–2330	
Ice thickness (cm)	199.5		196		157	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.79	33.96	−1.53	33.75	−1.85	33.55
10	−1.75	33.80	−1.65	33.55	−1.84	33.64
20	−1.66	33.80	−1.67	33.55	−1.84	33.89
30	−1.69	33.96	−1.68	33.78	−1.76	33.87
50	−1.51	33.95	−1.54	34.00	−1.74	33.95
75	−1.56	34.14	−1.55	34.09	−1.71	33.95
100	−1.51	34.20	−1.56	33.82	−1.70	34.13
150	−1.52	34.14	−1.50	33.85	−1.64	34.20
200	−1.41	34.36	−1.40	34.02	−1.62	34.43
300	−1.23	34.23	−1.20	34.16	−1.54	34.43
400	−1.19	33.98	−1.08	34.34	−1.50	34.74
500	−1.17	34.16	−1.04	34.20	−1.33	34.63
600	−1.12	34.29	−1.04	34.14	−1.33	34.43

Table 2 (continued).

	Station E					
Date	August 18		September 12		October 10	
Local time (=GMT+3 h)	1900–2300		1030–1330		1200–1600	
Ice thickness (cm)	166		189		195	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.83	33.76	−1.83	33.98	−1.80	34.04
10	−1.85	33.96	−1.84	33.95	−1.79	34.00
20	−1.85	34.27	−1.79	34.11	−1.76	33.78
30	−1.81	34.13	−1.83	34.02	−1.77	34.02
50	−1.67	33.95	−1.73	34.00	−1.65	34.02
75	−1.72	34.11	−1.66	34.20	−1.61	34.38
100	−1.64	34.31	−1.64	34.34	−1.54	34.20
150	−1.65	34.61	−1.61	34.54	−1.51	34.20
200	−1.63	34.52	−1.57	34.49	−1.48	34.36
300	−1.54	35.03	−1.42	34.76	−1.34	34.63
400	−1.44	34.83	−1.37	34.71	−1.19	34.61
500	−1.33	34.74	−1.37	34.61	−1.24	34.40
600	−1.35	34.49	−1.35	34.41	−1.33	34.32

	Station E				Station D	
Date	October 27		November 15		October 28	
Local time (=GMT+3 h)	1900–2200		1400–1730		1400–1700	
Ice thickness (cm)	196		192		188	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.77	33.87	−1.72	33.96	−1.76	34.07
10	−1.75	33.89	−1.72	33.76	−1.76	33.80
20	−1.73	33.73	−1.71	33.66	−1.80	33.80
30	−1.81	33.82	−1.72	33.80	−1.79	33.73
50	−1.61	34.04	−1.53	33.98	−1.64	33.87
75	−1.54	34.09	−1.57	34.11	−1.53	34.13
100	−1.57	34.16	−1.50	34.14	−1.50	34.02
150	−1.54	34.41	−1.51	34.14	−1.54	34.00
200	−1.42	33.98	−1.39	34.34	−1.44	34.23
300	−1.27	34.13	−1.24	34.32	−1.28	34.07
400	−1.14	34.29	−1.13	34.20	−1.15	34.29
500	−1.17	34.41	−1.23	34.11	−1.19	34.29
600	−1.33	34.27	−1.33	34.20	−1.14	34.23

Table 2 (continued).

	Station G		Station N		Station M	
Date	October 27		October 4		October 6	
Local time (=GMT+3h)	1100–1400		1400–1800		1800–2030	
Ice thickness (cm)	191.5		277		231	
Depth (m)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)	Temperature (°C)	Salinity (‰)
5	−1.79	33.93	−1.83	32.83	−1.85	33.44
10	−1.78	34.11	−1.83	33.71	−1.87	33.42
20	−1.73	33.73	−1.77	33.62	−1.83	33.40
30	−1.82	33.66	−1.65	33.80	−1.68	33.53
50	−1.61	33.91	−1.68	33.84	−1.63	33.82
75	−1.63	34.11	−1.43	33.84	−1.41	33.75
100	−1.59	34.14	−1.35	34.00	−1.34	33.73
150	−1.55	34.13	−1.30	33.98	−1.30	33.78
200	−1.44	34.23	−1.46	33.95	−1.53	33.95
300	−1.31	34.09	−0.96	33.69	−0.68	34.22
400	−1.19	34.23	−0.24	33.82	−0.18	34.34
500	−1.30	34.25	+0.32	34.18		
600	−1.33	34.29	+0.59	34.43		

	Station K	
Date	October 8	
Local time (=GMT+3h)	1700–1830	
Ice thickness (cm)	284	
Depth (m)	Temperature (°C)	Salinity (‰)
5	−1.80	33.78
10	−1.83	33.84
20	−1.78	33.82
30	−1.70	33.82
50	−1.57	34.04
75	−1.56	34.04
100	−1.56	34.04
150	−1.62	34.13
200	−1.60	34.05