Fine-Scale Observation on Salinity Stratification in an Ice Hole during Melting Season of Antarctic Sea Ice[1]

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融氷期の南極海氷上のアイスホールで観測された塩分成層の微細構造[1]

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要旨: 第 25 次南極地域観測隊の海洋生物環境調査の一環として，昭和基地付近の定着氷上の 1 定点（観測用アイスホール）において海水温度と塩分の季節変化を 1984 年 3 月より 1985 年 1 月まで観測した．その結果，夏季の上層海水中に水温・塩分の成層状態が認められた．この融氷期におけるアイスホール内の水温・塩分成層の微細構造を明らかにするため 1985 年 1 月に深度層 5-10 cm 間隔の精密観測を実施したところ，海面下 120 cm から 150 cm 間に，塩分が 3.33 から 27.88‰ まで変化する顕著な塩分躍層が観測された．この塩分躍層は海氷直下とほぼ同水準に位置したのでアイスホール周辺の海氷直下は著しい低塩分にさらされていると推定された．このような状況は融氷期の底なしパドルやクラックの周辺にも存在すると考えられ，そこでは海氷下面のアイス・アルジーが低塩分環境により生理学的な影響を受けているものと推定された．

Abstract: Observation on the seasonal variation of temperature and salinity of seawater was carried out through an ice hole at a station near Syowa Station as part of the 25th Japanese Antarctic Research Expedition. During the period from March 1984 to January 1985, temperature salinity stratification was observed only in summer in the upper layers of the seawater. In order to clarify the microstructure of the stratification, fine-scale observations on temperature and salinity profiles were conducted through the ice hole with the use of the CSTD monitor at the depth intervals from 5 to 10 cm on January 6, 1985. The results revealed that an intensified halocline occurred at the depth between 120 and 150 cm, where salinity changed considerably from 3.33 to 27.88‰. This observed halocline is supposed to exist in the underlying seawater immediately below sea ice around the ice hole. Such a condition may naturally occur in the area of paddles with thawing holes and cracks. Ice algae inhabiting the undersurface of ice may be physiologically affected by the extremely low salinity of the underlying seawater.

1. Introduction

In the Antarctic sea ice region, salinity of underlying seawater is strongly affected by the freezing and melting of ice because salt is generally rejected by the freezing of seawater while low saline water is supplied during the process of ice melting (MAYKUT,

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1985). Thus the growth of sea ice as well as melting have remarkable interactions with the underlying seawater. Variation in salinity then contributes to the vertical movement of seawater under ice through the change of density structure. Although density of seawater is a function of salinity and temperature, density of underlying seawater is mainly affected by salinity because the variation of seawater temperature immediately below ice is not so different from the freezing point of seawater. Consequently, vertical circulation prevails under ice during the growth of sea ice, while vertical stratification is formed during the melting of sea ice.

Ice algal assemblages attached to the undersurface of sea ice are directly exposed to the environmental variations of the underlying seawater. Hence, the change of salinity of the underlying seawater is supposed to influence the physiological conditions of ice algae (HORNER, 1985). Ice algae inhabit not only at the undersurface of ice but also in brine pockets entrapped in sea ice where salinity is generally higher than the salinity of ambient seawater. Accordingly, ice algae are exposed to a wide range of salinity variation compared with marine phytoplankton. With regard to the effect of low salinity on physiology of ice algae, PALMISANO and SULLIVAN (1985) pointed out that changes in salinity could have a profound effect not only on ice algal photosynthetic rate but also on cell viability and that individual species may respond in different ways depending on whether they are euryhaline or stenohaline. It was also pointed out by HOSHIAI (1981) that the solar radiation and the stability of the undersurface of sea ice were the principal factors which governed the ice algal proliferation.

There are many studies dealing with ice algae, but a relatively few observations have been made of underlying seawater with which ice algae attaching to undersurface of ice have contact. WATANABE and SATOH (1987) made an intensive study on the seasonal variation of ice algal standing crop in the same area during the 24th Japanese Antarctic Research Expedition (JARE-24) in the preceding year of the present observation, in which they discussed salinity at a depth between 2–2.5 m as an environmental condition.

During the course of JARE-25 we made a series of routine oceanographic observations at three fixed stations (Stn. 1–3) near Syowa Station from February 1984 through January 1985 (MATSUDA *et al.*, 1987a). In this paper, we present the results of a finescale observation on the microstructure of salinity temperature profiles as well as density profile obtained in an ice hole at one station (Stn. 2). The possible influence of low salinity on the ice algae is also discussed. This research is part of the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) program.

2. Methods

Ten sets of field observations on the vertical temperature and salinity profiles beneath sea ice were conducted at the ice hole of Stn. 2 in the Kita-no-ura Cove off East Ongul Island in Lützow-Holm Bay (Fig. 1) from March 16, 1984 to January 6, 1985. For measurements of salinity and temperature profiles, an *in situ* CSTD monitor (FIC Model AFC-III) was used in which digital values of temperature and salinity were recorded at intervals of one meter depth.

During each observation, the CSTD monitor was submerged into an ice hole maintained at the station, approximate size of which was one square meter. There-

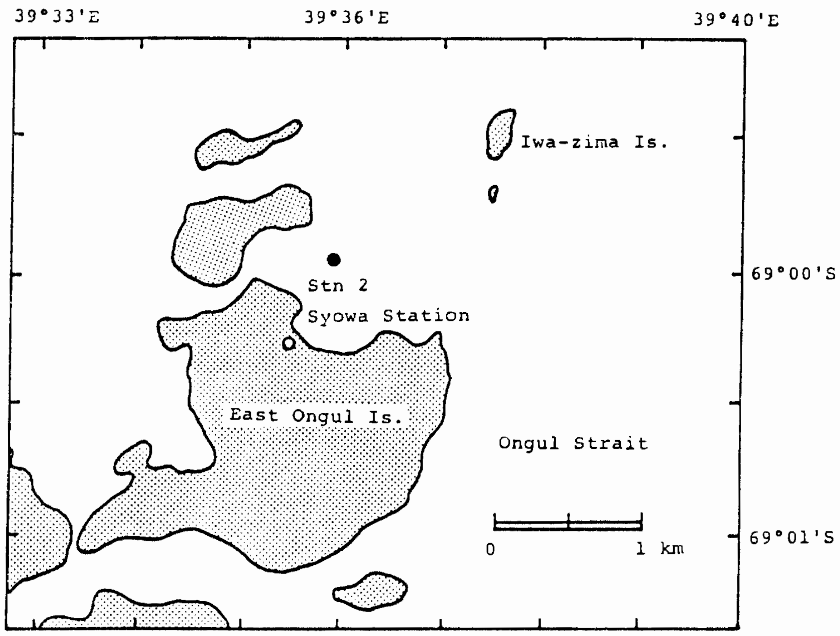

Fig. 1. Location of an ice hole (Stn. 2) where temperature and salinity of seawater were observed.

fore, the surface of seawater observed in this study indicates the surface of seawater in the ice hole. The general oceanographic and ice condition and the date of each observation were already reported (MATSUDA *et al.*, 1987a). Density of seawater is expressed in terms of sigma-t calculated from temperature and salinity.

To clarify the microstructure of salinity temperature profiles during the season of ice melting, data were also collected at 5 to 10 cm depth intervals in the ice hole on January 6. During the observation an extra care was taken not to disturb the water column.

3. Results and Discussion

Seasonal variations of salinity and temperature are presented in Figs. 2 and 3, respectively. The minimum seawater temperature observed was −1.92°C in September and the maximum was in March 1984 and January 1985. Temperature was vertically uniform from April to December, although a thermal stratification was observed in March 1984 and January 1985, particularly in the upper layers of the seawater. Vertical distributions of salinity were almost uniform from June through December. However, more or less stratified distributions of salinity were found in March, April, 1984 and in January 1985 particularly above 5 meter depth. From these results, it can be concluded that the steepest gradient of both temperature and salinity is found near the surface in January followed by a gradient in March. A similar trend was also observed in the vertical density gradient. Although the results of these routine observations at intervals of one meter depth followed a general trend of seasonal variations, those data were not enough to make clear the microstructure of the stratification in the ice hole.

The temperature and salinity profiles on January 6, 1985 elucidated the microstructure of temperature and salinity distributions from the surface to 5 m depth (Fig. 4). Between 1.2 and 1.5 m depths the temperature and salinity gradients were steep so that this layer can be regarded as the discontinuous layer. Temperature above this layer was almost 0°C while below the layer it was lower than −1.5°C. Salinity above the layer was lower than 5‰ while it was always higher than 30‰ below the layer.

Since a decrease of seawater temperature and an increase of salinity contribute to the increase in density of seawater, the stratified temperature and salinity indicate a strong density stratification. Vertical distribution of seawater density in terms of sigma-t showed almost exactly the same profile as that of salinity. In the distribution, a steep density gradient (pycnocline) was found between 1.2 m and 1.6 m depths.

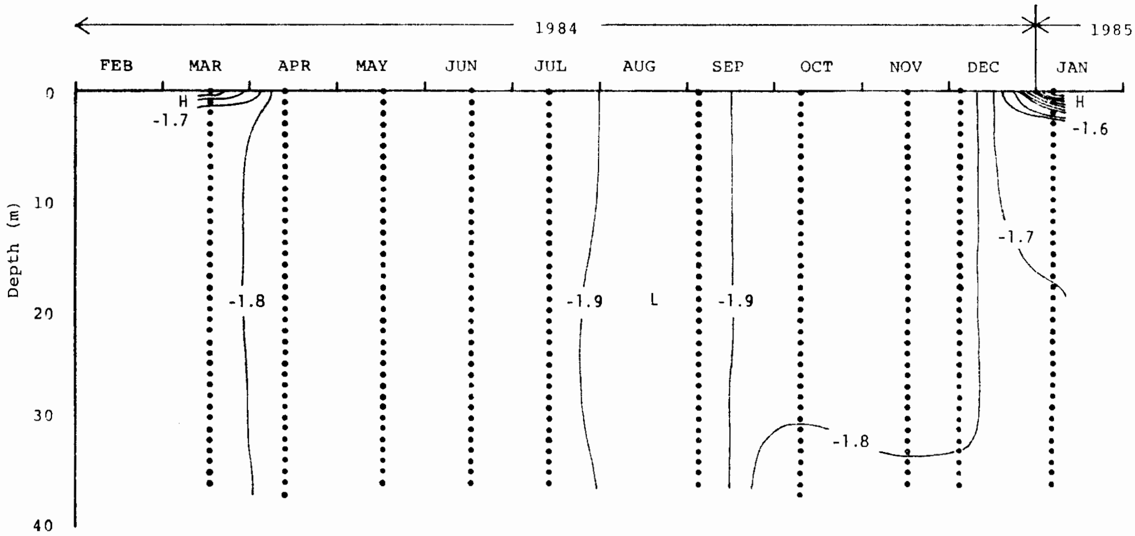

Fig. 2. Seasonal variation in seawater temperature (°C) under ice observed at Stn. 2 near Syowa Station, Antarctica. H and L indicate higher and lower temperature regimes than the surrounding water, respectively. Dots denote depth at which data were recorded.

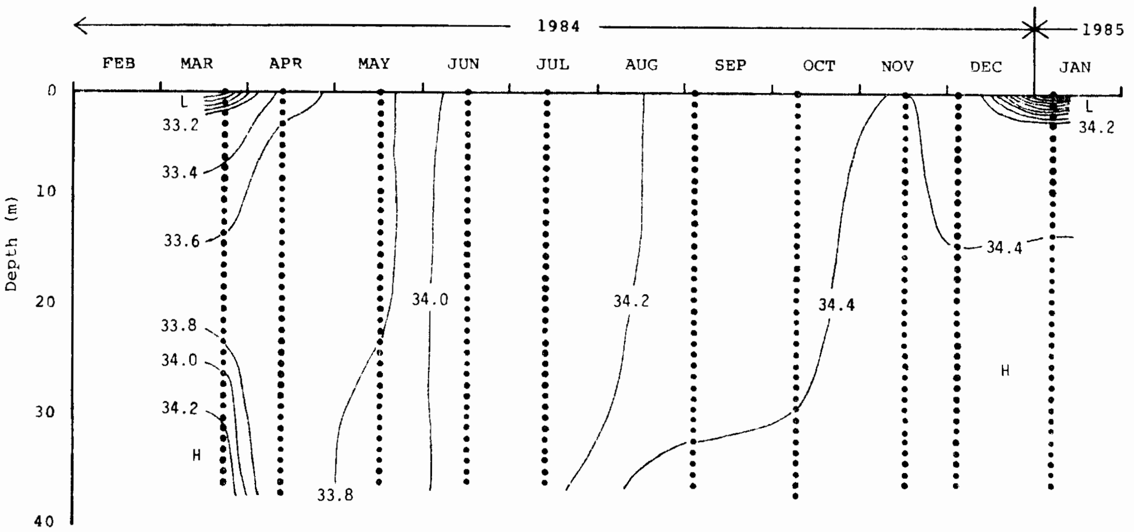

Fig. 3. Seasonal variation in salinity (‰) of seawater under ice observed at Stn. 2 near Syowa Station, Antarctica. H and L indicate higher and lower salinity regimes than the surrounding water, respectively. Dots as Fig. 2.

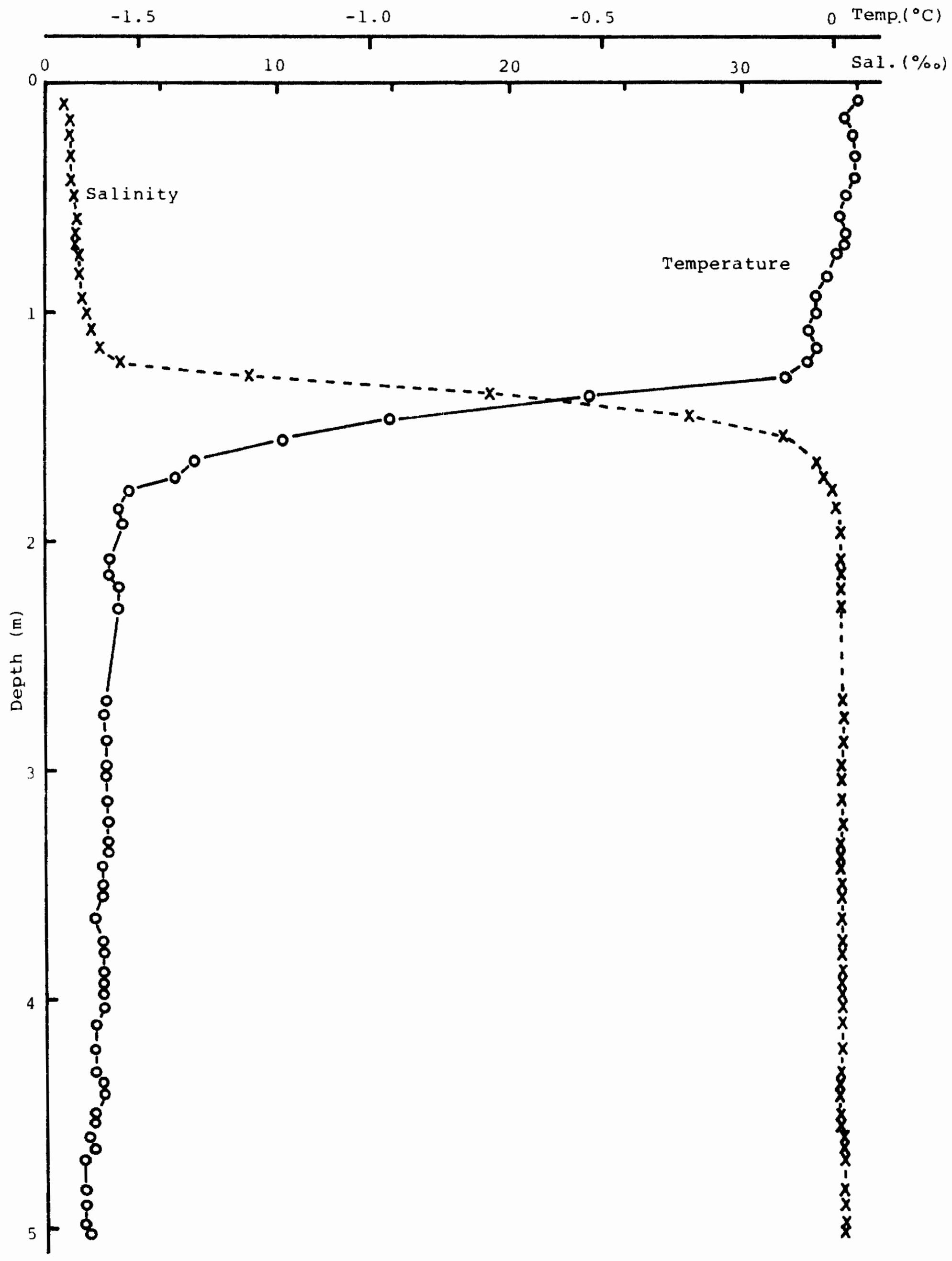

Fig. 4. Vertical distribution of seawater temperature and salinity observed at Stn. 2 on January 6, 1985. Thickness of ice was 1.4 m undersurface of which lying at an approximate depth of 1.15 m from the seawater surface.

The sigma-t values were lower than 2.0 at the depth above 1.2 m while at the depth below 1.6 m the values were higher than 26.78. Consequently, vertical sigma-t gradient in this pycnocline indicated an extremely high vertical stability of the water column. In this vertical structure, the low saline water which is almost fresh water was lying above the higher saline seawater.

As to the interpretation of the results, the possible effects of the ice hole on the temperature and salinity vertical profiles must be taken into account. The thickness of sea ice on January 6 was approximately 1.4 m although the undersurface of ice during the ice melting season was not so flat. The seawater surface of the hole was about 0.25 m below the ice surface, and from this we estimated that the location of the discontinuous layer was between 1.45 to 1.75 m below the ice surface. Since the thickness of ice was 1.4 m at that time, we estimated that a strong salinity gradient was formed in the underlying seawater just immediately beneath the ice in the vicinity of the ice hole. Therefore, the results of the present study can be applied in the interpretation of field conditions near ice holes except that low salinity water is not so thick under ice as in the observation hole in which meltwater is piled up. This condition may naturally occur in the area of paddles with holes and cracks during the ice-melting season.

From the results described above, we can conclude that the ice algal assemblages attached to the undersurface of ice in the ice hole area such as paddles and cracks were exposed to an extremely low saline environment during the ice-melting season. SULLIVAN *et al.* (1985) depicted that annual ice provides a growth substratum and refugium for a complex microbial community composed primarily of microalgae, bacteria and protozoans at least until melting occurs. Physiological effects of both low salinity on ice algae and disintegration of physical ice structure by melting are supposed to cause deterioration and mass detachment of ice algae, which in turn may enhance the sinking of ice algal flocs. A large downward flux of organic matter was observed in the same season at Stn. 3 which was located in the close vicinity of Stn. 2 in which both stations have quite similar environmental conditions (MATSUDA *et al.*, 1987b). The large downward organic flux during this season is assumed to have been caused more or less by those factors described above.

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