On the Bottom Water in the Western Channel in the Korea Strait－1

－ the inflow path of the bottom cold water －

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With 16 years' oceanographic data(1973~1988) of the National Fisheries Research and Development Agency and the CTD data collected by a training ship of Korea Maritime University during Nov. 6~11, 1989, the inflow path of the bottom cold water in the western channel of the Korea Strait were investigated. Temperature of the bottom water in the western channel shows the lowest in summer and large annual variation. According to the temperature distributions in the years when the bottom cold water exists in the western channel in summer, the cold water in the southwestern region of the East Sea seems to intrude into the western channel through the sea southeast 10~15 miles off Ulsan with its properties showing slight change during advection.

Introduction

The Korea Strait is a sole passage through which the Tsushima Current water is carried from the East China Sea into the East Sea (or Japan Sea). The Korea strait is divided into two channels by Tushima Island, the eastern and western channel.

The two channels are different in bottom topography and oceanographic conditions. The eastern channel has almost constant depth of 100*m* or more, while the western channel has a trough of more than 200*m* in depth extended NE-SE about 20 miles off Pusan. It was reported that maximum current velocity in summer was 80 *cm/s* in the western channel and 50 *cm/s* in the eastern channel (Miita, 1976), and the seasonal variation of current velocity in the western channel was larger than that in the eastern channel (Kawabe, 1982). In addition, in the bottom layer of the western channel did the cold water less than 10℃ exist, while it was not found in the eastern channel (Lim and Chang, 1969).

Many studies have been done on the origin of the cold water in the bottom layer of the western channel since Nishida(1927) who reported that the cold water flowed down from the East Sea toward the western channel along the bottom and reached to the southwestern part of Tsushima Island.

Lim and Chang(1969) suggested that the cold water with temperature 3~10℃ and salinity 34.0~34.3‰ originated from the East Sea and its strength of intrusion into the Pusan-Tsushima section was strongest in August. According to An(1974), the cold water in the western channel was formed by the mixing of the Japan Sea Proper Water and the Tsushima Intermediate Water.

Although many authors have studied the origin of the cold water in the western channel by analy-

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zing the temperature distribution, few were done on the inflow path of the bottom cold water of the western channel.

In this paper, the inflow path of the cold water in the western channel were investigated and discussed by analyzing water temperature, salinity and density.

Materials and Methods

16 years' oceanographic data(1973~1988) of the National Fisheries Research and Development Agency(FRDA) were used for this study. In addition, we used CTD data collected in the southern and southeastern sea of the Korea by a training ship "HANBADA" of Korea Maritime University during Nov. 6~11, 1989. The bottom topography, oceanographic lines and stations selected in the study area were drawn in Fig. 1.

Station 207-4 (34-50.2N, 129-19.5E), where FRDA have been carrying out routine survey bimonthly, was selected and the isobaths of temperature and salinity were constructed to investigate the seasonal variations of temperature and salinity against depth in the western channel.

Vertical profiles of mean temperature and salinity in summer for Line-206, 207, 208 and 209 were drawn to compare water characteristics in the western channel with those in the adjacent sea. Horizontal temperature distributions of bottom were drawn to investigate the seasonal variation of bottom temperature in the study area. The bottom temperature used here were 16 years' mean temperature of the deepest depth at oceanographic stations where FRDA made routine observations bimonthly.

To estimate the inflow path of the bottom cold water into the western channel in summer, horizontal temperature distribution along the isopycnal surface, which is based on density of 200*m* depth at St. 207-4, were introduced. In this paper, the bottom cold water is referred to as the one whose temperature is lower than 16 years' mean summer temperature and also lower than winter temperature in the same year.

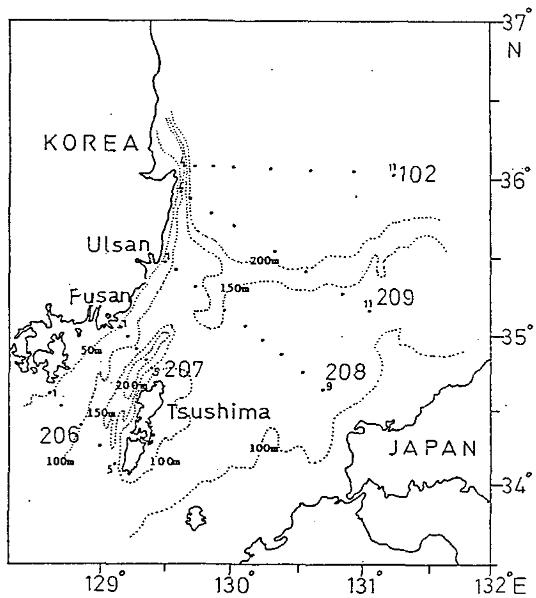


Fig. 1. Bottom topography and positions of selected oceanographic lines and stations in the study area.

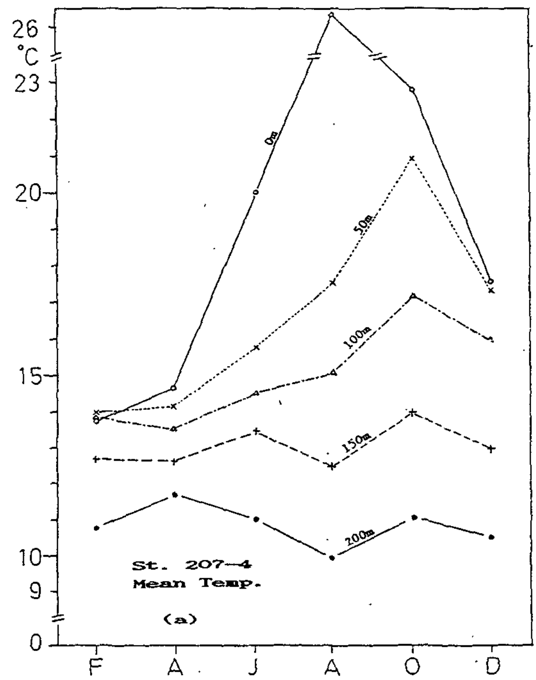
Results

Seasonal variation of mean temperature and salinity in the western channel

Fig. 2 shows the seasonal variations of mean temperature and salinity at the depths of 0, 50, 100, 150 and 200*m* at St. 207-4.

In Fig. 2(a), temperatures of 0, 50 and 100*m* depth are low in winter-spring and high in summer-autumn. The lowest surface temperature occurs in Febuary (13.74℃) and the highest in August (26.30℃). Temperature of 50 and 100*m* depth is the lowest in Febuary and April, and the highest in October, while temperature of 150 and 200*m* depth is the lowest in August (12.52℃, 9.98℃, respectively).

In Fig. 2(b), salinities of 0, 50 and 100*m* depth are high in winter-spring and low in summer-autumn. The surface salinity is maximum in April (34.55‰) and minimum in August (31.98‰). Salinities of 50 and 100*m* depth are the highest in Febuary and April, and the lowest in October. Salinity below 150*m* depth is almost homogeneous throughout the year as the differences between the



maximum and minimum salinity at 150 and 200*m* depth are 0.11‰ and 0.13‰, respectively.

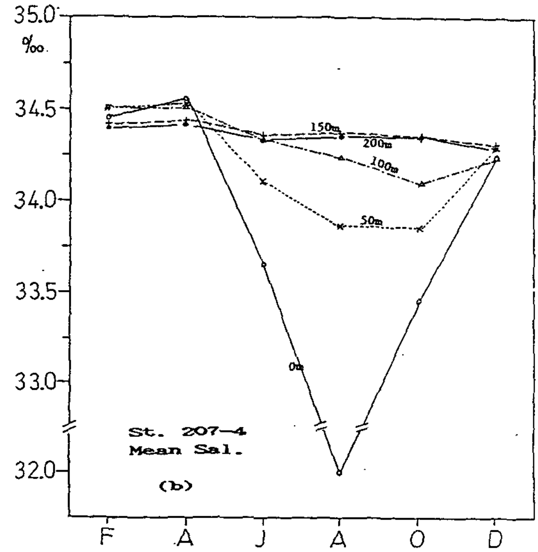


Fig. 2. Seasonal variation of mean temperature(a) and salinity(b) at St. 207－4 during 16 years(1973～1988).

Distribution of mean temperature and salinity in summer

T-S diagrams, in which all oceanographic data in summer during 16 years (1973～1988) were plotted, were drawn for Line-206, 207, 208 and 209 (Fig. 3, a-d).

Each diagram shows the common fearture in which less dense water fan-shaped is scattering toward the low salinity at the water type of about 14℃ and 34.3‰. Denser water than this water type is found at Line-207, 208 and 209 except Line-206.

In vertical profiles of the mean temperature in summer (Fig. 4), the isotherms are inclined toward off-shore from Korean coast and the warm water more than 24℃ is occupied in the surface layer above the seasonal thermocline (about 20～23℃) formed at 10～50*m* depth at all lines. However, another thermocline (about 10～12℃), which is not found at Line-206, is formed in the bottom layer at Line-207, 208 and at 100～150*m* depth of Line-209. The temperature (13～19℃) between two thermoclines at these 3 lines is similar with that of water below the seasonal thermocline at Line-206. Temperatures of the cold water under the lower thermocline at 3 lines are 2～7℃ at Line-209, 7～10℃ at Line-208 and 10～12℃ at Line-207.

Fig. 5 shows the standard deviation of temperature in summer. In Fig. 5(a), the standard deviation is large around the seasonal thermoclines, below which it is decreasing with depth. Fig. 5(b) shows that the standard deviation between two thermocline is less than 2.0℃ and increases gradually with depth, and then becomes relatively large near the bottom as 3.0℃ or more. The standard deveiations of Line-208 and 209 are considerably large around the lower thermocline which lies near the bottom at Line-208 and 75～125*m* depth at Line-209 (Fig. 5-c,d).

In Fig. 6, which shows vertical profiles of mean salinity in summer, the halocline is formed at 10～50*m* depth at all lines and the water above the halocline is more saline northward. Below the halocline, salinity at Line-206 continues to increase with depth until bottom, while salinity at Line-207, 208 increases only to the depth of 75～100*m* depth, and

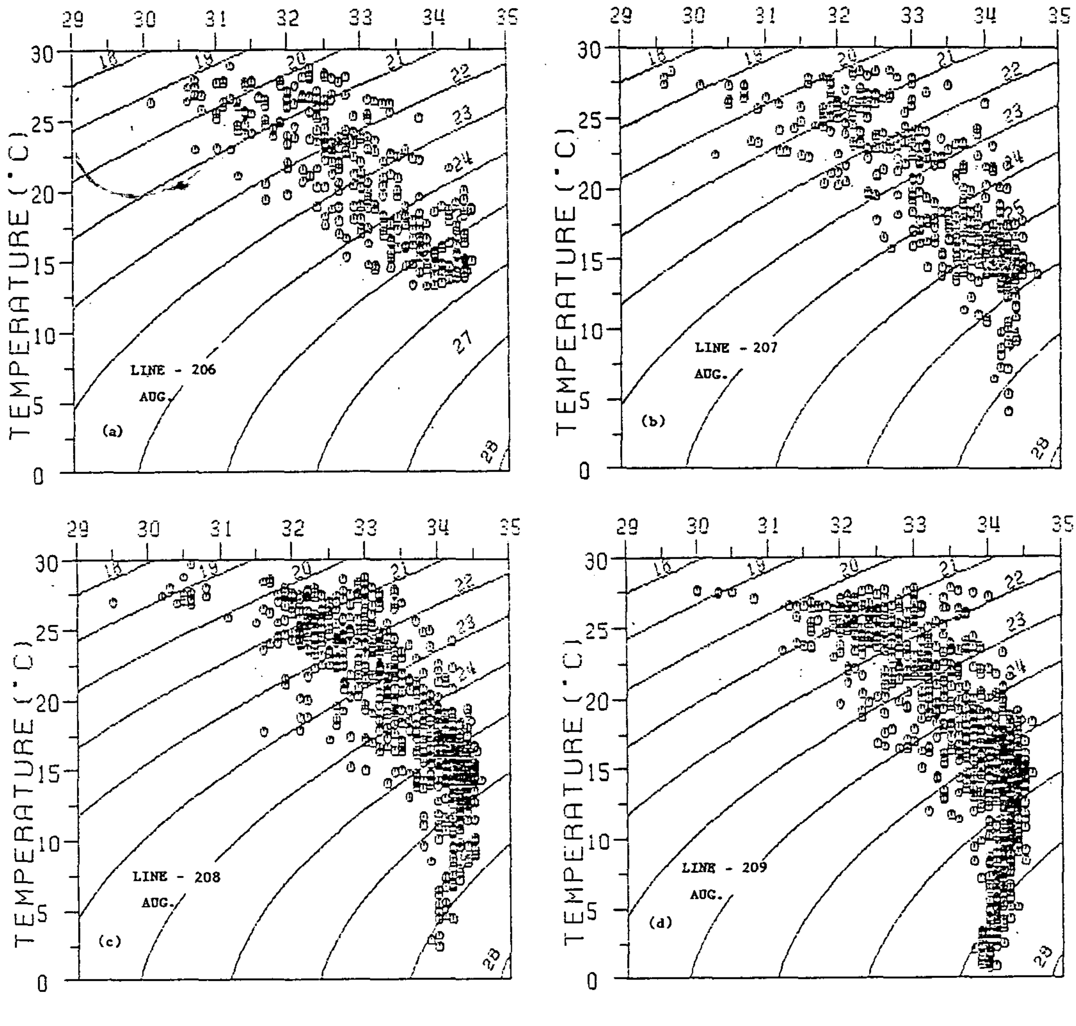


Fig. 3. T-S diagrams for Line-206(a), 207(b), 208(c) and 209(d) in summer during 16 years(1973~1988).

then almost homogeneous below this depth (Fig. 6-b,c). Distribution of salinity at Line-209 (Fig. 6-d) is quite different from that of the other 3 lines. There is a salinity maximum in the middle layer between two thermoclines. Salinity on-Korean shore is a little lower than that off-shore in the bottom layer of Line-208 and in the salinity maximum layer of Line-209.

The standard deviation of salinity in summer (Fig. 7) represents different pattern from that of temperature (Fig. 5). The standard deviation is large near the surface and decreases with depth, and becomes relatively small near the bottom at all lines.

Distribution of temperature in November, 1989

To investiagate the existence of cold water in the bottom layer of the western channel in autumn and compare temperature distribution in autumn with that in summer, we collected CTD data mdade in southern and southeastern sea of Korea by a training ship of Korea Maritime University during Nov. 6~11, 1989. The locations of 20 stations selected were drawn in Fig. 8(a).

In Fig. 8(b)-(f), which show vertical profiles of temperature for 5 lines, the thick warm layer more than 20℃ exists 15~20 miles off Korean coast and the upper weak thermocline is formed about 50*m*

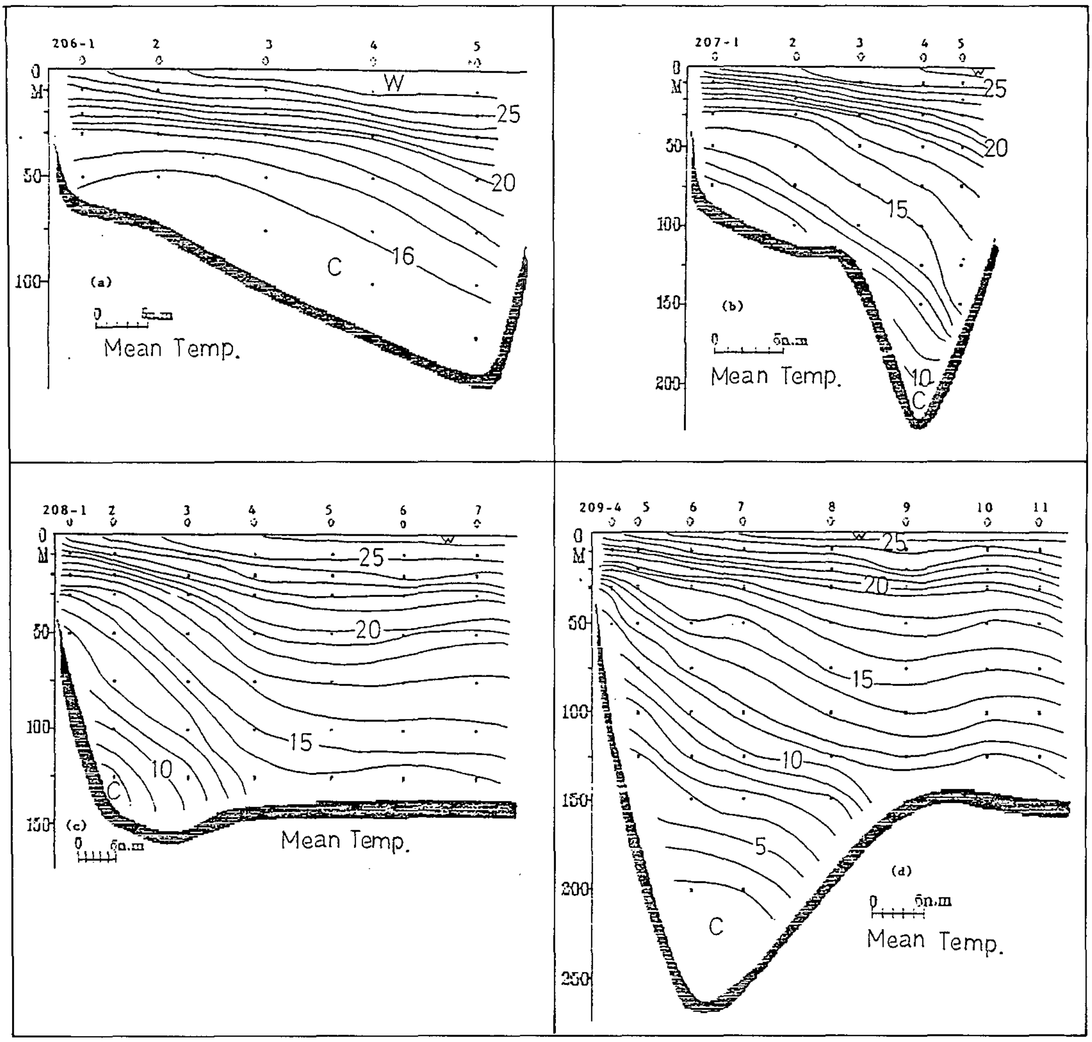


Fig. 4. Vertical section of mean temperature for Line-206(a), 207(b), 208(c) and 209(d) in summer.

depth at all lines. The lower strong thermocline, however, is fromed at 100～150*m* depth of Line-A through D, where warm water of 15～21℃ is occupied above the lower thermocline and the cold water of 5～10℃, which is not found at Line-E, exists below and temperature in the bottom layer becomes warmer southward.

Bottom temperature and temperature along isopycnal surface

Fig. 9 shows the seasonal variations of mean bottom temperature during 16 years (1973～1988) in the study area.

Extension of the isotherms toward the western channel is not clearly seen is Febuary (Fig. 9-a), but the tips of isotherms between 5℃ and 10℃ becomes close to the Korean coast from April and the tongue-shaped isotherms extend to the western channel in April through December. Bottom temperature in the trough of the western channel and southeastern sea of Korea near Ulsan shows seasonal variation.

Fig. 10 shows year-to-year fluctuations of both summer and winter temperature at 200*m* depth of St. 207-4 during 16 years (1973～1988) and dotted line denotes the mean summer temperature.

Difference between the maximum (14.37℃ in su-

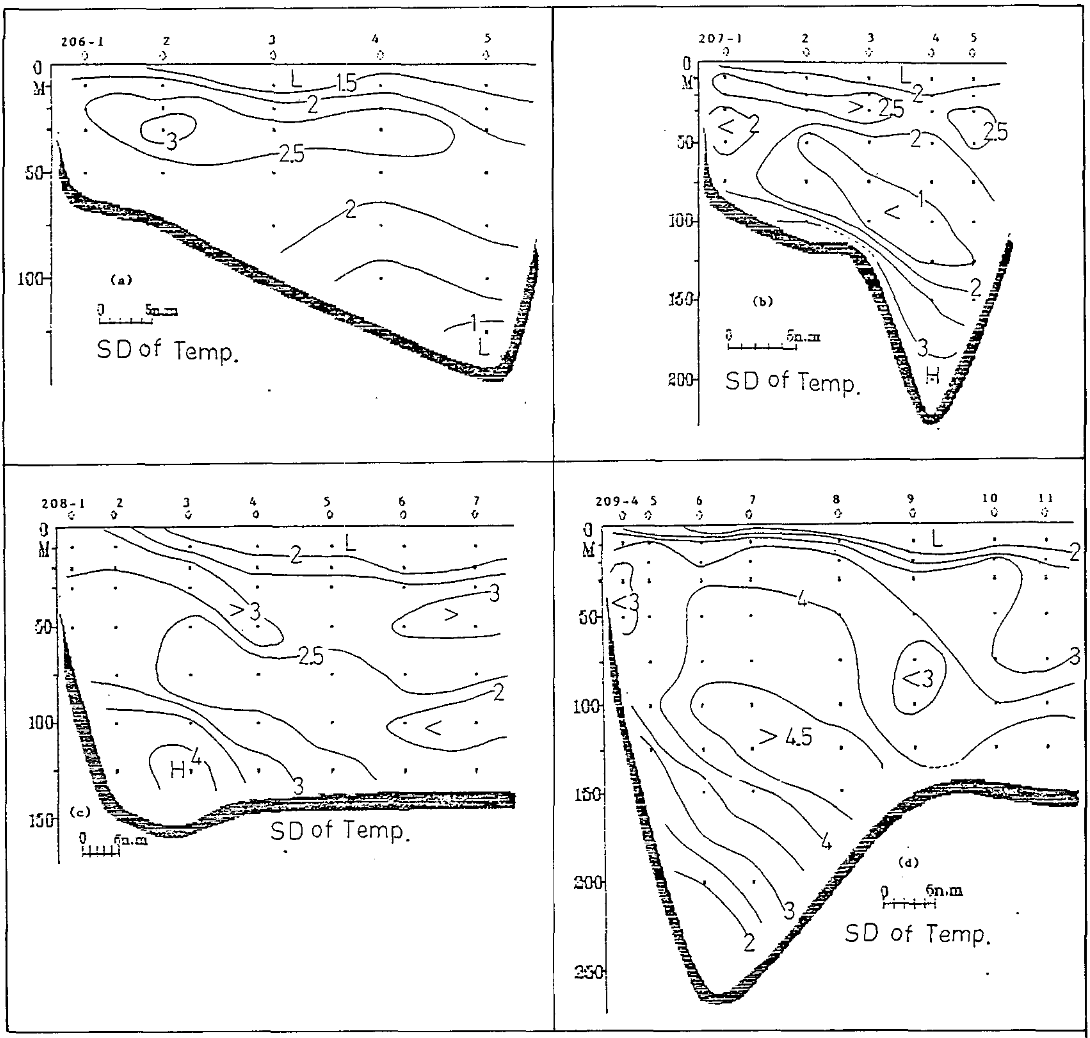


Fig. 5. Standard deviation of temperature for Line-206(a), 207(b), 208(c) and 209(d) in summer.

mmer in 1974, 13.98℃ in winter in 1978) and minimum temperatures (4.11℃ *in summer in 1986*, 6.33 ℃ in winter in 1985) is 10.26℃ in summer and 7.65 ℃ in winter. Year-to-year fluctuation is larger in summer than in winter and the years when the bottom cold water exists in the western channel are 1981, 1982, 1984 and 1986.

Since it is assumed that water flow most possibly takes place along the surface of constant sigma-t (Pickard and Emery, 1982), temperature distributions along the isopycnal surface (Fig. 11) were drawn to investigate the moving path of cold water in the study area.

Fig. 11(a)−(e) show horizontal distribution of the mean summer temperature (1973~1988) and *temperature in summer in* 1981, 1982, 1984 *and* 1986 along the isopycnal surface, which are based on density at 200*m* depth of St. 207-4, and Fig. 12 (f) shows temperature in November, 1989 along the isopycnal surface which is based on density at 150*m* depth of St. D-4.

As shown in Fig. 11, the cold water, in general, extends southwestward to the western channel from the southwestern region of the East Sea. On the horizontal distribution of the mean temperature (Fig. 11-a), the cold water of 10℃ or less extends to the western channel. In 1981, 1982, 1984 and 1986, tongue-shaped isotherms of 4~8℃ also ex-

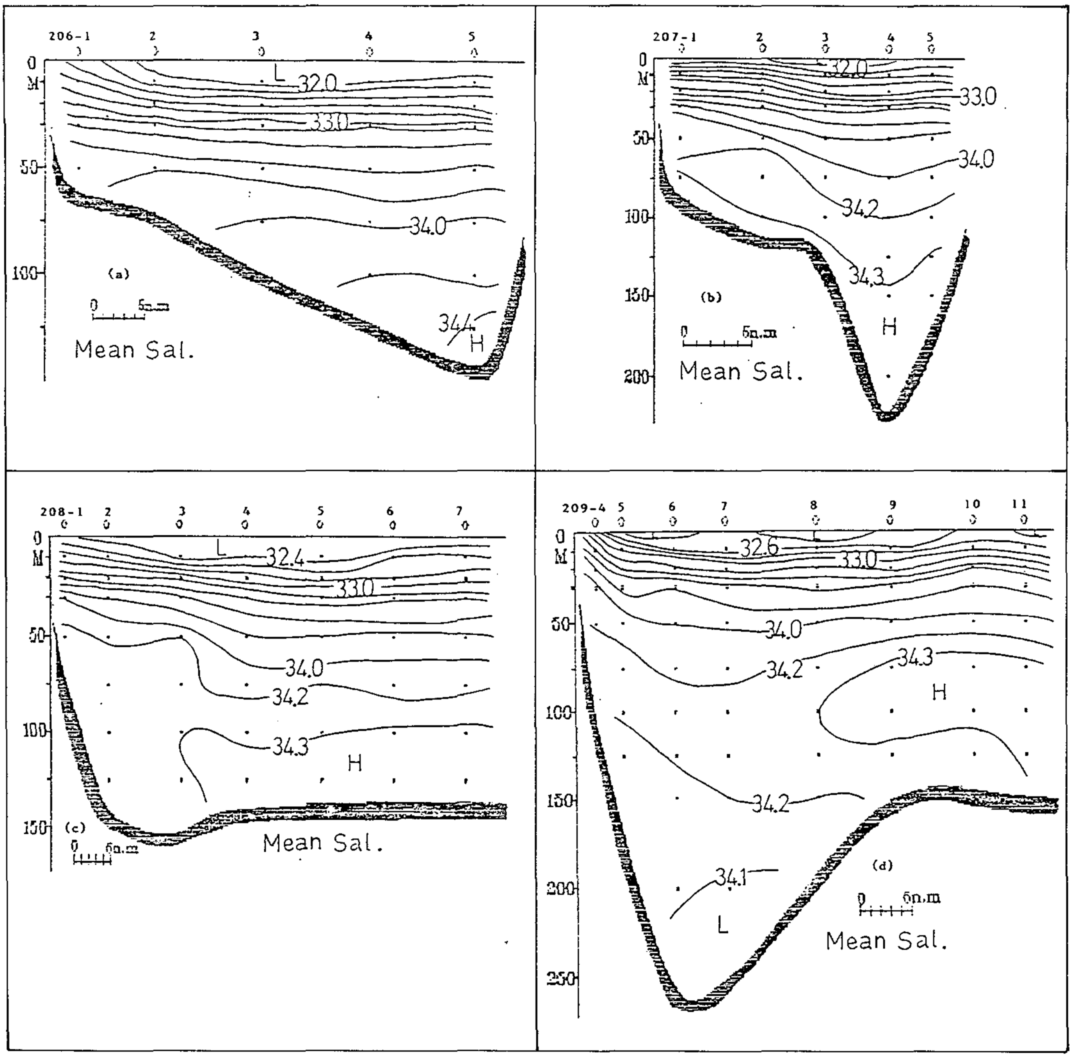


Fig. 6. Vertical section of mean salinity for Line-206(a), 207(b), 208(c) and 209(d) in summer.

tend southwestward toward the western channel from southwestern part of the East Sea, and temperature becomes higher southward with the axis of the tip of isotherms lying about 10～15 miles off Ulsan(Fig. 11, b-e). On the temperature distribution in November, 1989(Fig. 11-f), isotherms of less than 10℃ about 15 miles off the southeastern coast of Korea extend southwestward down to the middle portion between Line-C(Line-207) and Line-E(Line-206) approximately.

Discussions and Conclusion

Characteristics of the bottom cold water in the western channel

There are cold water masses around Korea such as Yellow Sea Bottom Water, East China Sea Central Bottom Water and Japan Sea Proper Water. These three water masses seem to be formed in winter by the atmospheric influence. Yellow Sea Bottom Cold Water (less than 10℃, 32.0～32.5‰) is known to be formed by remaining in the bottom layer of Yellow Sea central part until summer with little change in properties after its descent in winter by surface cooling (Nakao, 1977). East China

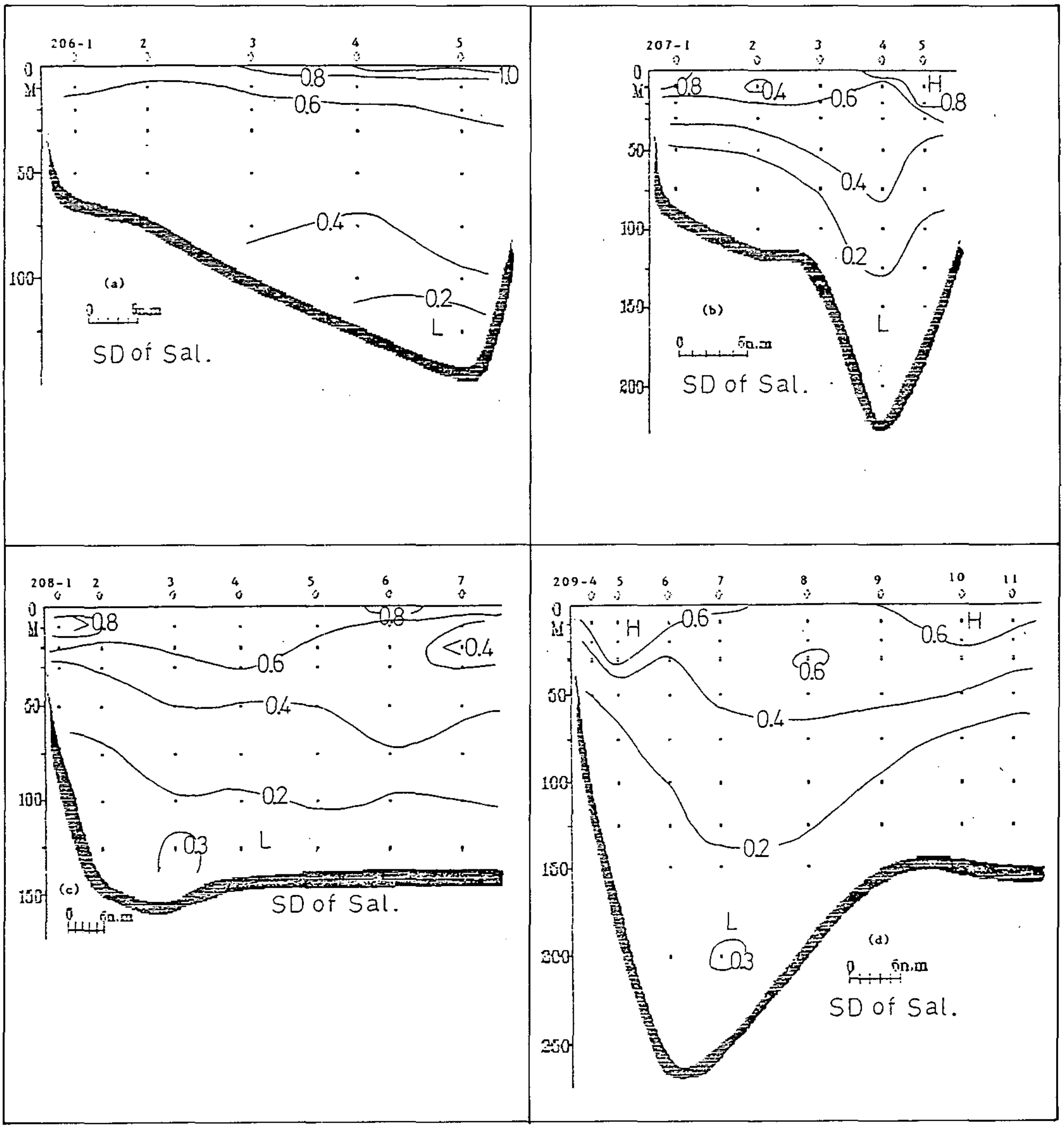


Fig. 7. Standard deviation of salinity for Line-206(a), 207(b), 208(c) and 209(d) in summer.

Sea Central Bottom Water (12~15℃, 33.5~34.5‰) proposed by Fukase (1975) is known to be formed in the area south of Cheju Island in the same manner as Yellow Sea Bottom Cold Water. Japan Sea Proper Water (0.0~0.5℃, 34.0~34.1‰), occupying about 90% of the East Sea (Yasui et al, 1967), is also known to be originated from the surface water of nothern part of the East Sea which is sinking in winter by surface cooling. The cold water in the western channel in summer, however, seems not to be formed in winter because bottom temperature in summer is lower than that in winter (Fig. 2-a).

Comparing the mean temperature and salinity distribution of the western channel with those of the adjacent sea in the study area (Fig. 4 and 6), the water in the western channel (Line-207) may be divided into 3 water masses by two thermoclines in summer as suggested by Lim and Chang (1969). The bottom water(10~12℃, 34.3‰) of

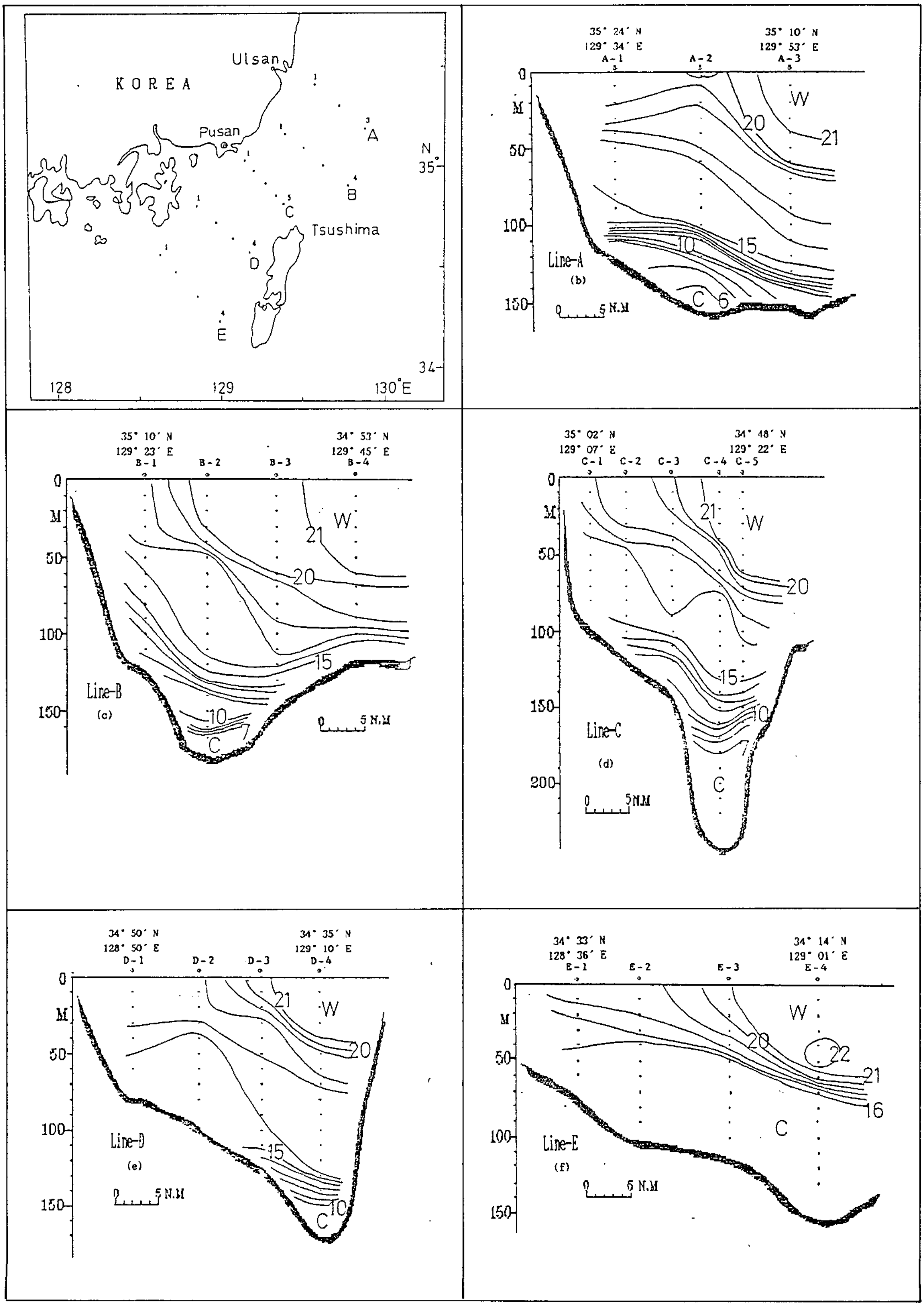


Fig. 8. Location(a) of CTD observation made and vertical section of temperature for Line-A(b), B(c), C(d), D(e) and E(f) in November, 1989.

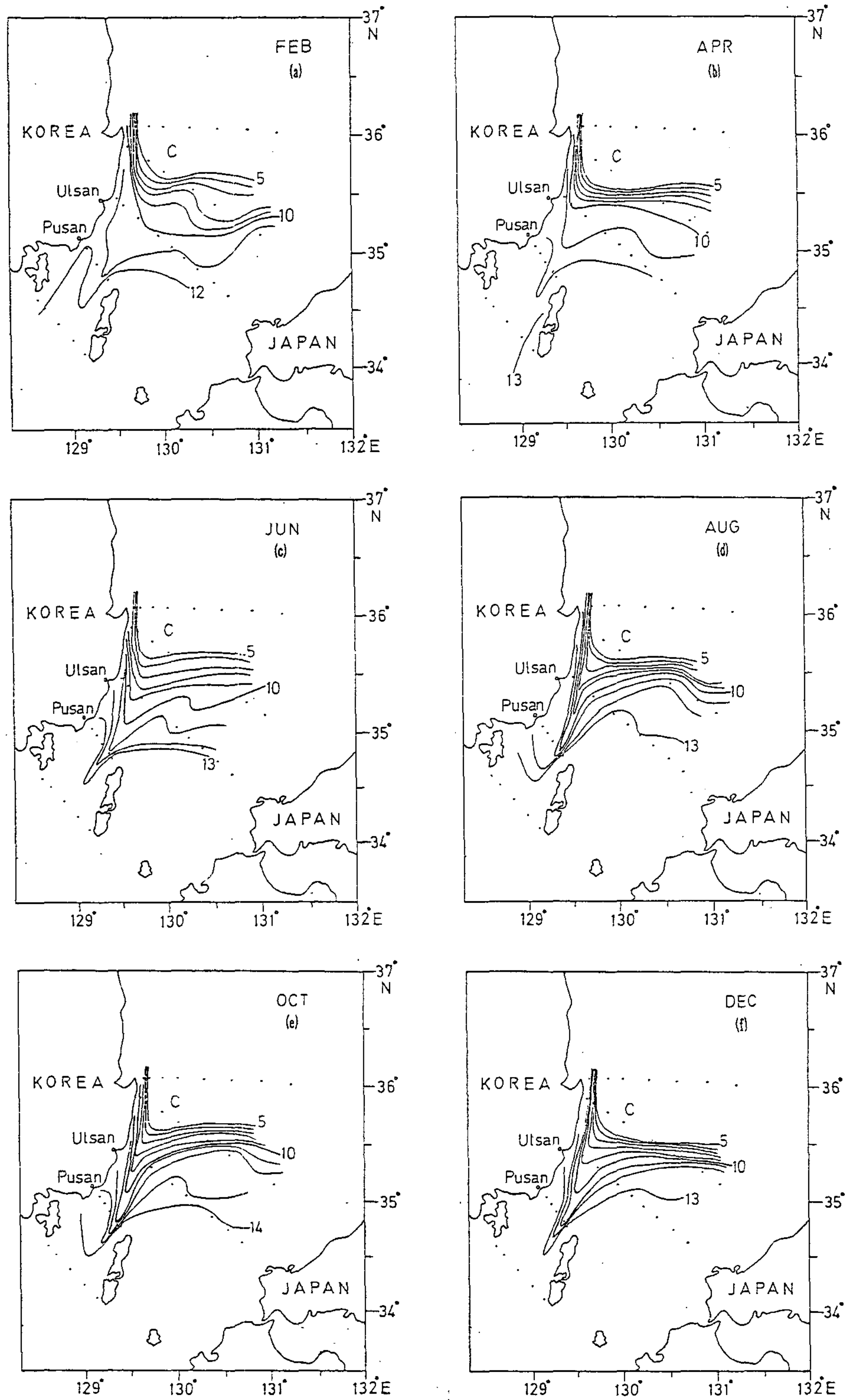


Fig. 9. Horizontal distribution of mean bottom temperature bimonthly.

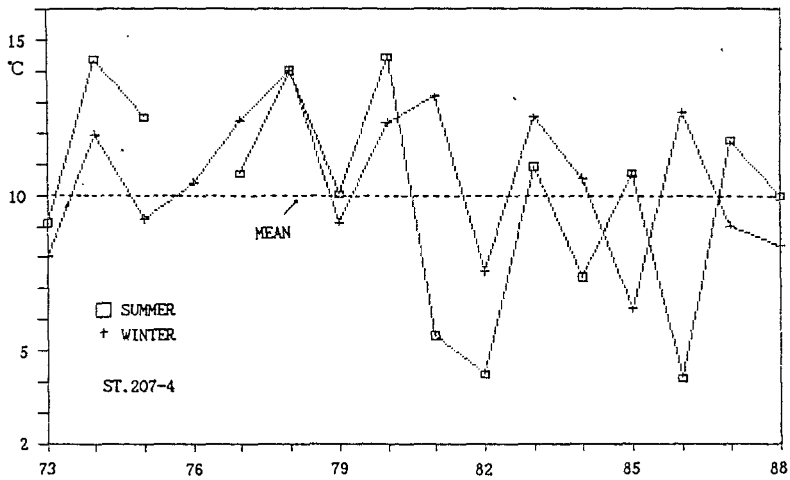


Fig. 10. Year-to-year variation of temperature at 200*m*(195*m* in winter in 1982) depth of St. 207-4 in Febuary and August. Dotted line denotes mean summer temperature during 16 years(1973～1988).

three water masses, which is not found at Line-206, represents warmer and more saline than that of Line-208 and 209.

The bottom cold water in the western channel in summer characterized with 4.11～7.37℃(Fig. 10) shows warmer than the Japan Sea Proper Water, but colder than the Tsushima Current Core Water (14～17℃; Yi, 1983).

Since the cold water less than 10℃ does not appear at Line-206(Fig. 3-a and Fig. 4-a) in summer and the bottom temperature at southern sea of Kórea(St. 205-5 of FRDA; Lim, 1971) are more than 10℃ throughout the year, It is thought that the bottom cold water in the western channel in summer may be influenced by the advection of cold water from north.

Inflow path of the cold water mass into the western channel

On the temperature distribution along the isopycnal surface in summer, the tongue-shaped isotherms of 10℃(Fig. 11-a) and 4～8℃(Fig. 11, b-e) extends to the western channel from the southwestern region of the East Sea. The axis of isotherm tips is located nearly parallel to the southeastern coast of Korea lying about 10～15 miles southeast off Ulsan and temperature becomes warmer southward. On the temperature distribution in November, 1989(Fig. 11-f), isotherms of 10℃ or less about 15 miles off the southeastern coast of Korea also extend to the western channel.

It is thought from temperature distribution along isopycnal surfaces that the cold water in the southwestern region of the East Sea is intruded into the western channel through the sea 10～15 miles southeast off Ulsan and its properties change gradually during advection.

On the horizontal distribution of the mean bottom temperature(Fig. 9), the cold water may flow into the western channel throughout the year from the southwestern part of the East Sea with its temperature varying in season, and these distributions suggest that the intrusion of the cold water into the western channel is probably stronger in summer-autumn than in winter-spring. With reference to the surface velocity in the western channel, the strength of the cold water intrusion into the western channel may be related to the surface velocity, which is strong in summer-autumn and weak in winter-spring (Miita, 1976; Yi, 1970).

In Fig. 5(b)－(c), it is thought that the appearance of the bottom cold water in the western channel(Line-207) and southeastern sea of Korea near Ulsan(between St. 208-2 and 208-4) in summer shows large year-to-year variation because of the

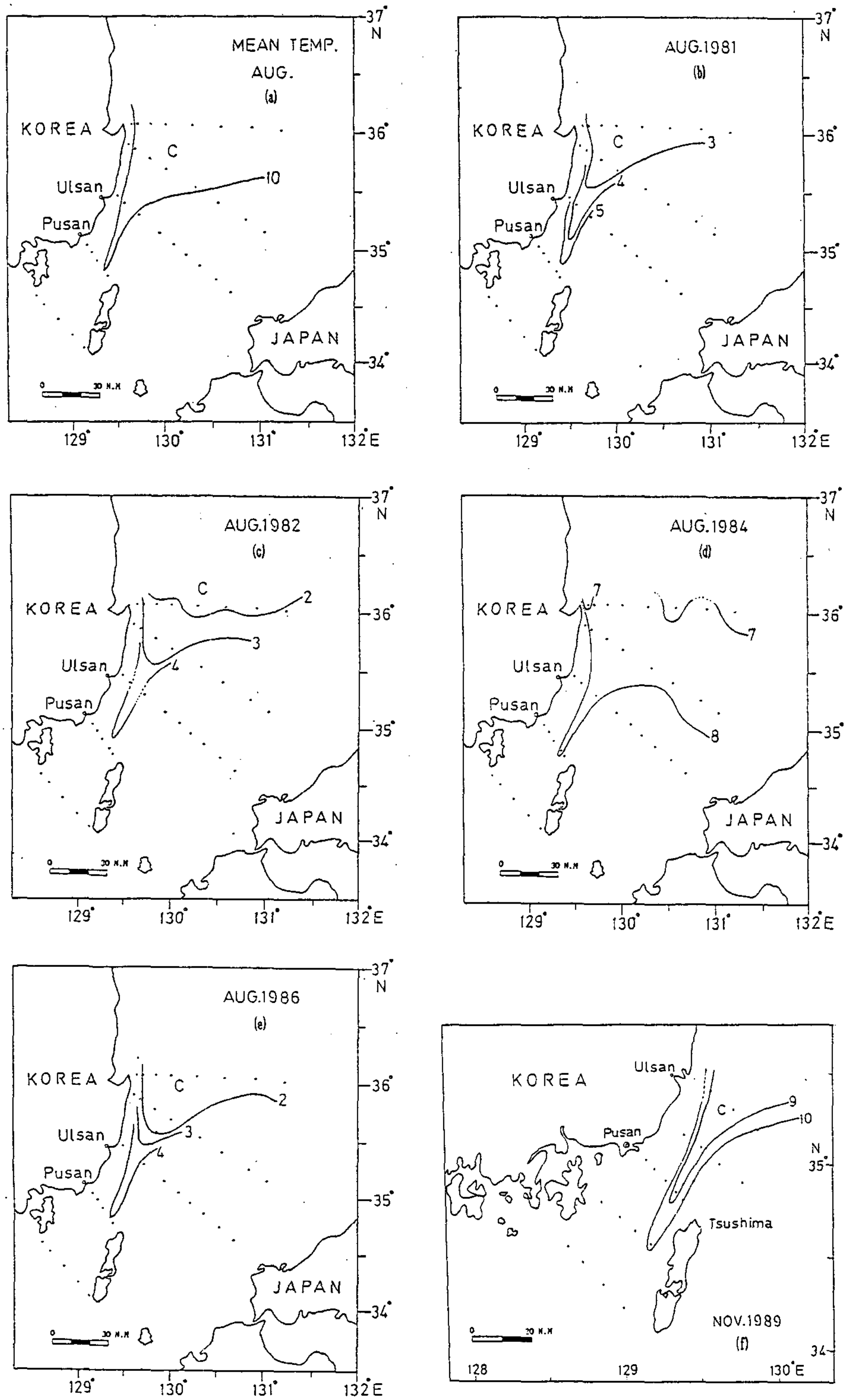


Fig. 11. Mean summer temperature along σ_t 26.43 surface(a) during 16 years(1973~1988). Temperature along σ_t 27.08(b), 27.23(c), 26.76(d) and 27.27(e) surface in summer in 1981, 1982, 1984 and 1986 respectively and along σ_t 26.59 surface(f) in November, 1989.

relatively large standard deviation(more than 3.0 ℃). At Line-209, the standard deviation(Fig. 5-d) in the bottom layer shows relatively small, while considerably large in the lower thermocline of about 100*m* depth(more than 4.5℃). This suggests that significant annual variation of the location of the thermocline between upper warm water and lower cold water may occur in this area.

In this paper, the inflow path of the bottom cold water in the western channel of the Korea Strait was investigated by using 16 years' oceanographic data(1973～1988) of FRDA and the CTD data collected by a training ship of the Korea Maritime University in the southern and southeastern sea of Korea during November 6～11, 1989.

The bottom cold water in the western channel seems to be intruded in through the sea 10～15 miles off southesast off Ulsan from the southwestern region of the East Sea. For further study on the mechanism of the southward flow of the cold water into the western channel from the southwest region of the East Sea, the oceanographic conditions of the East Sea as well as the western channel need to be analyzed.

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대한해협 서수도의 저층수에 대한 연구-1

-저층 냉수의 유입 경로-

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국립수산진흥원의 16개년(1973~1988)의 해양 관측 자료와 1989년 11월 6~11일 동안 한국해양대학 실습선으로 관측한 *CTD* 자료를 사용하여 대한해협 서수도에 존재하는 저층 냉수의 유입 경로를 조사하였다.

대한해협 서수도의 저층 수온은 하계에 가장 낮으며, 해에 따라 변동이 큰 것으로 나타났다. 하계 대한해협 서수도에 저층 냉수가 존재하였던 해의 수온 분포에 의하면, 동해 남서부 해역에 있는 냉수가 울산 남동쪽 10~15마일 떨어진 해역을 거쳐 대한해협 서수도에 유입되며, 이 냉수는 이류하는 동안 그 특성이 다소 변하는 것으로 나타났다.