In Summer, the Origin of Tsushima Warm Current Water in Western Channel of the Korea Strait-1

— On the Water in Surface Layer —

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夏季 大韓海峽 西水道에 流入되는 Tsushima 暖流水의 起源 — 1

— 表層水에 對한 考察 —

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夏季 대한 해협 西水道에는 鉛直的으로 특성이 서로 다른 세개의 水塊가 존재한다. 그 중 표층수에 대하여 인접 해역의 해수 특성과 相互 비교함으로써 그 기원과 流路를 推定하였다. 그 結果, 표층수는 동지나해의 대륙붕 상에서 형성된 Kuroshio수와 중국대륙연안수의 混合水로써, 중국대륙연안수의 影響을 더 많이 받은 것으로 나타났다. 大部分의 표층수는 Kyushu Isalnd의 서쪽 해역, 경도 126°E와 127°E사이 해역과 제주도 동쪽 해역을 거쳐 流入되고, 한국연안 부근에 있는 一部 표층수는 제주도 서쪽 해역과 제주 해협을 거쳐 流入된 것으로 나타났다.

Introduction

Sverdrup et al(1942) defined that Tsushima Current was the warm current that branched off on the left-hand side of the Kuroshio and entered the Japan Sea following the western coast of Japan to the north carrying waters of high temperature and high salinity.

Among the region where Tsushima Warm Current passes, western channel of the Korea Strait (hereinafter "western channel"), containing various water masses such as Tsushima Warm Current Water, Korean Coastal Water and North Korean Cold Current Water etc(Lee et al, 1984), shows more complicated water distribution than eastern channel of the Korea Strait.

In western channel, there exists nearly homogeneous water by active convection due to strong NW'ly monsoon and drop of atmospheric temperature in winter, while waters in summer become clearly stratified due to strong solar radiation, increase of Chinese Continental Coastal Water(hereinafter "CCCW"), Korean Coastal Water and rainfall.

As to the waters in western channel in summer, Miyazaki and Abe(1960) concluded that waters, which passes western channel in summer, was classified into two layers on the basis of sigmat-t (σ_t) 25.20kg/m^3 and upper water was the oceanic surface water mixed remarkably with coastal water of the East China Sea and lower water was the Western North Pacific Central Water defined by Sverdrup et al(1942) which advanced ascending toward the north-west along the bottom of the sea valley west off the Kyushu District. On the other hand, Lim(1971) presented different report that Tsushima Current Water was compased of the surface water only and formed by the mixing of the Kuroshio Surface Water and East China Sea Water on the marginal region of the continental shelf of the East China Sea at the depth of from 100 to 200*m* Besides, Kim(1986) suggested that less saline CCCW less than 32.2‰ seemed to be intruded into western channel with the thickness of about 50 meters through the Cheju Strait.

As the above mentioned, only a few studies have been produced regarding the origin of the Tsushima Warm Current in western channel in summer. It is thought more reasonable that waters in western channel in summer would be dealt with separately as water above and below the seasonal thermocline because less saline water from Chinese Continent, which is being extended eastward in the East China Sea in summer, is covering the surface thin layer and considerably affects Tsushima Warm Current region(Inoue, 1975). Therefore, the characteristic of water masses in western channel in summer will be investigated, then the inflow path and origin of surface water will be discussed and estimated comparing with water characteristics of the neighbouring sea in this paper.

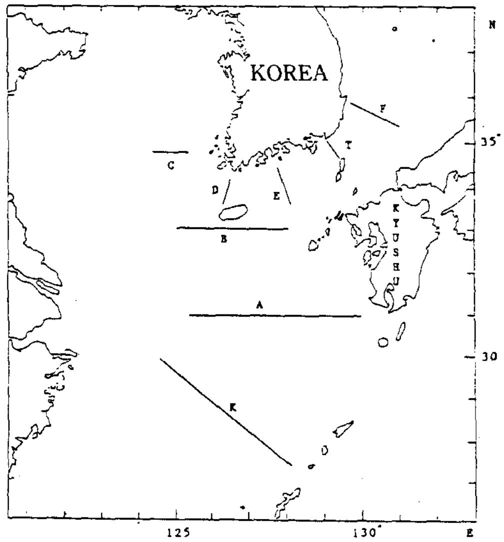

Fig. 1. Selected oceanographic lines in the studied area.

Materials and methods

Summertime data of annual report of oceanographic observations(1976~1988) and mean oceanographic charts of the adjacent seas of Korea(1986) by Fisheries Research and Development Agency of Korea and annual report of oceanographic meteorological observatons (1976~1985) by Japanese Meteorological Agency were used for this study.

Eight oceanographic lines marked in Fig. 1 were selected to compare the water characteristics in western channel in summer with those in neighbouring sea. To begin with, vertical sections of temperature, salinity, density and dissolved oxygen were drawn to investigate the water properties distribution in wetern channel in summer. Though various methods and procedures can be employed in the course of this analysis, it is assumed that the flow and mixing that take place along isanosteric surfaces are the most important to water properties distributions (Montgomery, 1937). Salinity distribution against sigma-t and water properties distribution along sigma-t 22.00kg/m^3 surface were accordingly introduced to estimate the inflow path and origin of surface water in western channel in summer.

In this analysis, all data used are average value of temperature, salinity and dissolved oxygen against the depth.

Results

1. Vertical section in western channel

Fig. 2 a~d show vertical distribution of temperature, salinity, density and oxyty in

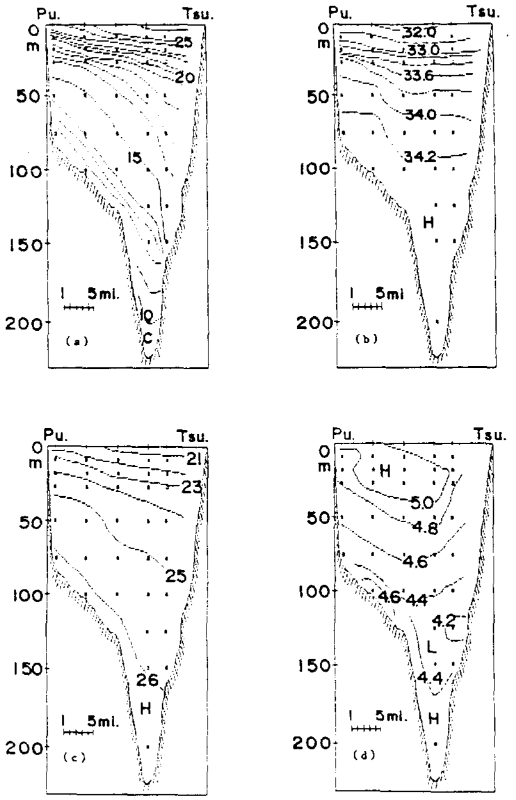

Fig. 2. Vertical sections of temperature(a), salinity(b), density(c) and oxyty(d) in western channel.
Temperature in ℃, salinity in ‰, density in kg/m^3, oxyty in ml/l and depth in meter.

western channel in summer. In Fig. 2 a, waters can be classified into three layers by two thermoclines and temperature maximum more than 25°C is seen on the surface south-east of thermal front as pointed out by Tawara and Fujiwara(1985). Temperature of surface water ranges from 19 to 26°C, that of middle water from 12 to 19°C and that of lower water less than 12°C. Since isotherm is inclined to the Tsushima Island same as Lee and Na's study(1985), temperature of Korean side shows lower than that of Tsushima Island at the same depth. Cold water less than 12°C present at bottom layer of deepest portion seems upwelled toward Korean coast along the bottom.

In Fig. 2 b, waters can be classified into two layers by halocline formed at about 10~50m and salinity minimum less than 32.0‰ exists around the surface of centeral part of the channel. Salinity of upper water varies from 32.0 to 34. 0‰ and that of lower water does from 34.0 to 34. 3‰.

In Fig.2 d, high oxyty layer more than 5.0ml/l is seen at the depth of about 10~30m, then the oxyty gradually decreases with the increase of depth and oxyty minimum layer less than 4.4ml/l appears at about 100~170m, especially lowest oxyty core(less than 4.2ml/l) exists around 125m of Tsushima Island. Below oxyty minimum layer, oxyty bocomes to gradually increase to 4 6ml/l at the bottom.

All oceanographic data of 205 and 206-line in summer by Fisheries Research and Development Agency of Korea during 13 years(1975~1987) were plotted in a T-S diagram(Fig.3), which showed no heavier water than sigma-t 26.00kg/m^3 in Korea Southern Sea.

From the above results, it might be recognized that waters in western channel in summer can be distiguished such as surface, middle and lower water, among which lower water would not be carried from the south. Since sigma-t 22.00kg/m^3

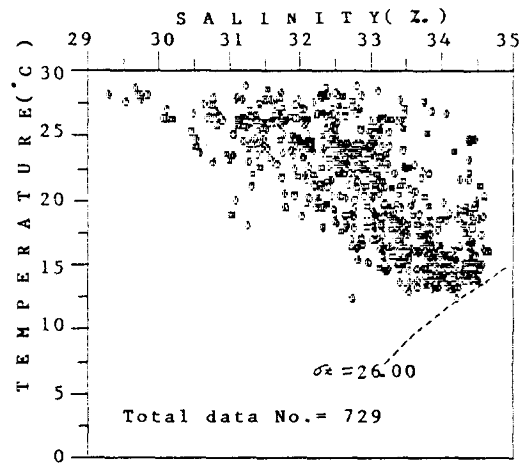

Fig. 3. T-S diagram for 205 and 206-line in summer during 13 years(1975-1987).

is distributed across right below the sea surface of western channel(Fig.2c), it is taken no matter to choose sigma-t 22.00kg/m^3 in analyzing surface water.

2. Salinity distribution against sigma-t

Fig.4 which show salinity distribution against

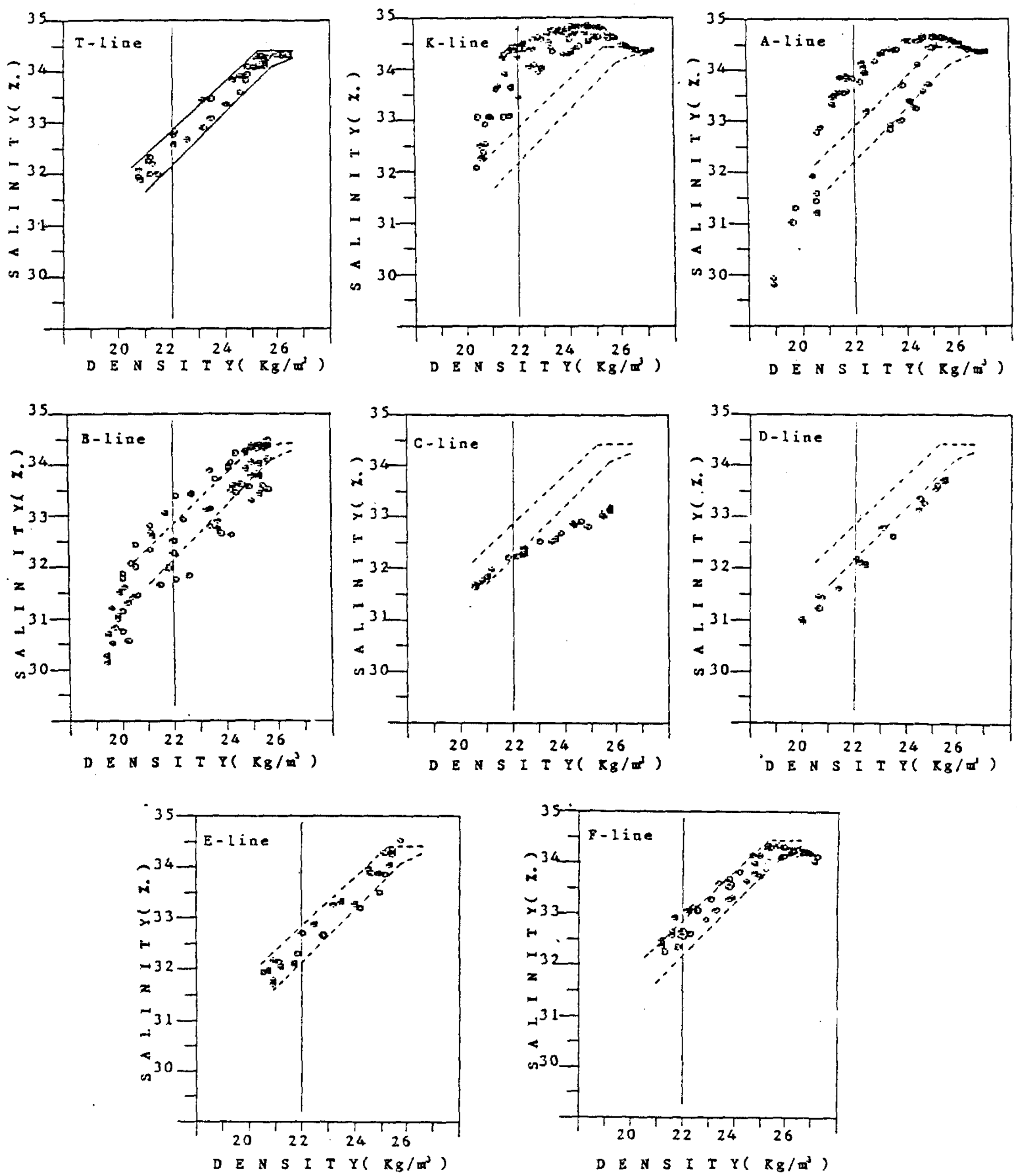

Fig. 4. Salinity distribution against sigma-t at 8 lines. Thick and dotted lines indicate approximate range of salinity distribution in western channel.

sigma-t at 8 selected lines were constructed to inspect the mixing process of water masses in the studied area. Thick and dotted lines shown in the figure indicate approximate range of salinity distribution in western channel.

Salinity of western channel against signa-t 22.00kg/m^3 ranges from 32.1 to 32.8‰. Only saline water(33.4~34.5‰) is distributed in the middle of the East China Sea(K-line). Those saline water, however, can be recognized to be gradually diluted by the influence of CCCW as going north(A and B-line), at the same time less saline water(less than 32.0‰) is distributed in the northern part of the East China Sea. In C and D-line, salinity against sigma-t 22.00kg/m^3 (about 32.0‰) shows slightly lower than that of western challel, while salinity distribution in E and F-line shows almost same as that of western channel.

3. Water characteristics at the sea surface in summer

Fig. 5 a~c show temperature, salinity and density at the sea surface in summer. Isotherm

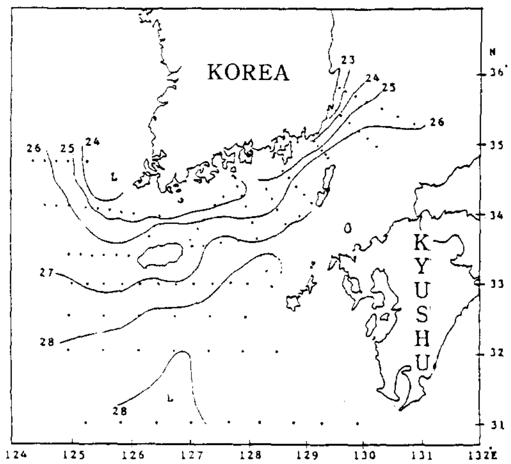

Fig. 5 a. Temperature(°C) at sea surface in summer.

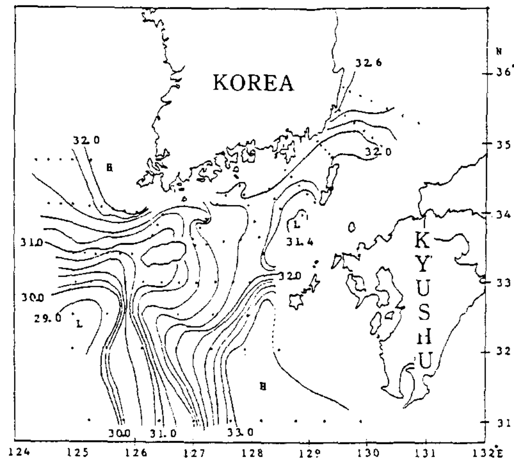

Fig. 5 b. Salinity(‰) at sea surface in summer.

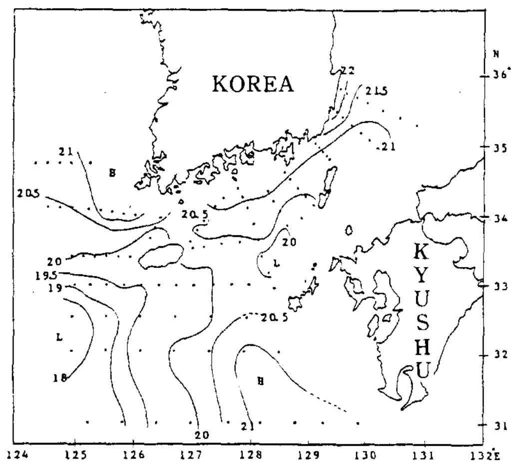

Fig. 5 c. Density(kg/m^3) at sea surface in summer.

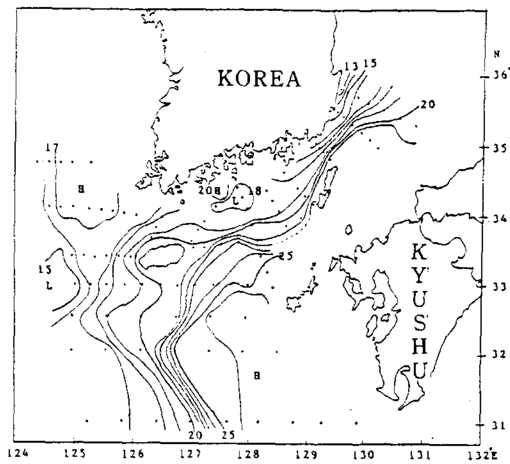

Fig. 5 d. Temperature(°C) at the depth of 30m in summer.

runs nearly parallel to Korean coast and thermal front is found, though not conspicuous, at western channel and Korea south-eastern coast. Surface temperature of western channel ranges from 23.9 to 26.4°*C* and that of the East China Sea(more than 27°*C*)is relatively warm(Fig. 5a). As pointed out by Uda(1934) and Beardsley et al(1983), less saline water present south-west off Cheju Islands seems to extend north-eastward toward Cheju Island and Cheju Strait like plume -shape with the increase of Changjiang river water, also less saline water extended eastward seems mixing with more saline water west off Kyushu Island. Surface salinity of western channel ranges from 31.8 to 32.0‰ and surface salinity along Korea coast(32.0~32.6‰) shows more saline than that of off-shore(Fig.5b). Density at Chju Strait and west of 127°~30′E meridian in the East China Sea is less than 20.50kg/m^3 due to warm and less saline water, while waters in western channel and Korea south-eastern sea become denser(more than 20.50 kg/m^3) due to relatively low temperature and saline water(Fig.5c). Fig.5d shows the temperature at 30m, thermal front at this depth become conspicuous along about 127°E meridian in the East China Sea, line between Cheju and Goto Island and in western channel. Horizontal gradient of western channel is revealed about 0.2°*C*/*mile*.

4. Horizontal distribution along sigma-t 22.00kg/m^3 surface

Fig.6a~b which show temperature and salinity along signa-t 22.00kg/m^3 surface were constructed to estimate the inflow path of surface water of western channel in summer.

The 23~24°*C* waters are distributed in the sea between 126°E and 127°E west off Kyushu Island approximately, east off near-Cheju Island and most of western channel, while 22~23°*C* waters are distributed along 126°E meridian in the East

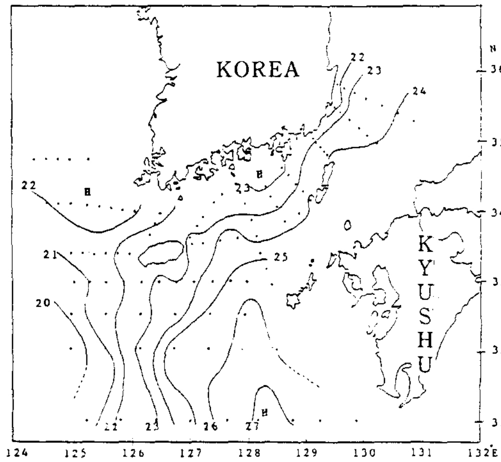

Fig. 6 a. Temperature(℃) where sigma-t equals 22.00(kg/m^3).

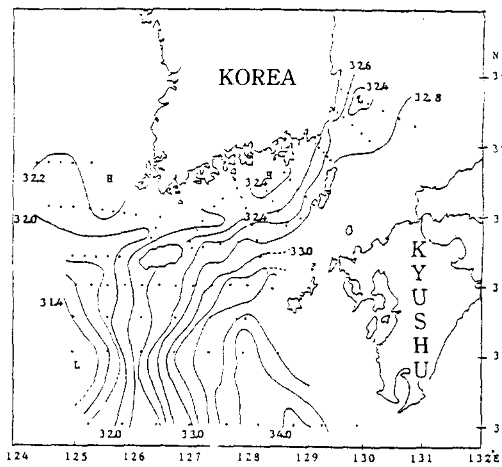

Fig. 6 b. Salinity(‰) where sigma-t equals 22.00(kg/m^3).

China Sea, west off Cheju Island, Cheju Strait and near-Korean coast of western channel in Fig. 6b.

In Fig.6b, less saline water(less than 32.2‰) influenced by Changjiang river(Lie, 1986) seems extended to the south off Sori Island approximately 32.4~32.8‰ water and 32.2~32.4‰ water are distributed in almost same manner as 23~24°*C* and 22~23°*C* waters in Fig. 6a respectively.

Discussions and Cconclusions

1. Characteristics of water masses in western channel

According to Fig.2 and Fig.3, waters in western channel in summer can be classified as three water masses such as surface water, middle water and lower water. Surface water is characterized by warm and less saline water(19 ~26℃, 32.0~34.0‰), middle water by relatively saline and low oxyty water(34.0~34.3‰, less than 4.4ml/l) and lower water by cold water(less than 12℃). Surface and middle water can be taken as Tsushima Warm Current Water, while lower water might be taken to be intruded from the Japan Sea as suggested by Lim and Chang(1969).

2. The origin and inflow path of surface water

It can be seen that saline Kuroshio Water in the middle of the East China Sea gradually decreases mixing with less saline CCCW extended eastward as going up north, and salinity distribution of Korea Southern Sea seems almost same as that of western channel in Fig.4 and Fig.6. With these changes of salinity distribution, surface water of western channel may be taken to form by the mixing of the Kuroshio Water and CCCW same as Lim' study(1971).

In Fig.7, all average salinity of the East China Sea and western channel used for this study were plotted in a salinity-density diagram. Two thick curves represent approximate Kuroshio Water and CCCW, and salinity distribution range of western channel was also drawn in same diagram by dotted line. By the mixing ratio aong sigma-t 22.00kg/m^3, surface water of western channel is supposed to be composed of about 50 ~70% of CCCW and the rest of Kuroshio Water.

In Fig.4 and Fig.6, Tsushima Warm Current

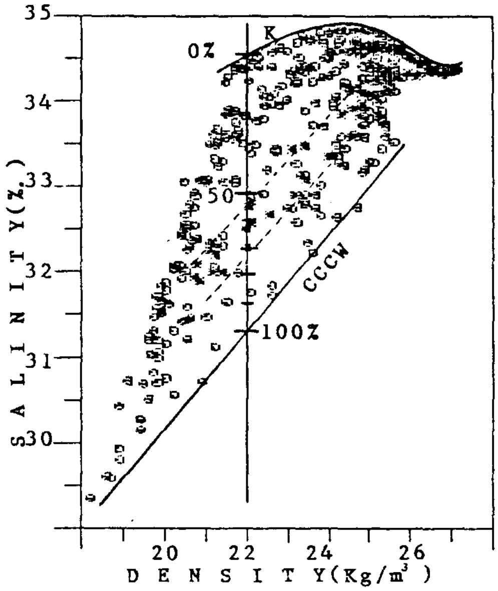

Fig. 7. Salinity-density distribution for East China Sea(o) and western channel(∗)in summer. 2 curves indicate Kuroshio(K) Chinese Continental Coastal Water(CCCW).

Water, which forms on the continental shelf at the depth of about 100~150m, seems flowing north in the sea between about 126°E and 127°E west off Kyushu Island toward Cheju Island, then most of that water seems intruded into western chaneel through east off near-Cheju Island and a part of that water seems intruded into near-Korean shore of western channel through west off Cheju Island and Cheju Strait along the left-hand side of thermal front in Fig.5(d) like schematic representation of flowing path of Tsushima Warm Current at surface layer in Fig. 8.

In summer, Tsushima Warm Current Water present in western channel can be classified as warm and less saline surface water and relatively saline and low oxyty middle water. Surface water is formed on the continental shelf in the East China Sea by the mixing of the Kuroshio Water and CCCW, and seems more influenced by CCCW. Most of surface water seems intruded through the sea between about 126°E and 127°E west off Kyushu Island and east

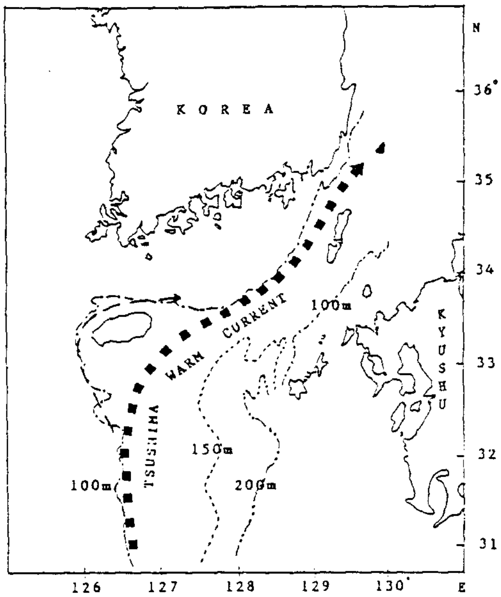

Fig. 8. Schematic representation of flowing path of Tsushima Warm Current at the surface layer in summer. Thick arrow indicates main path and thin arrow does path of a part of Tsushima Warm Current.

off near-Cheju Island, and a part of surface water near-Korean coast seems intruded through west off Cheju Island and Cheju Strait.

Since this paper deals with surface water only in western channe, it is taken not sufficient to estimate the origin of Tsushima Warm Current Water. Accordingly middle water present in western channel as well as waters in eastern channel will be planned to analyze.

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