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ON THE ORIGIN OF THE TSUSHIMA CURRENT WATER

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ABSTRACT

The origin of the Tsushima Current water was investigated with a discussion on the western North Pacific Central Water. The Tsushima Current water is formed by the mixing of the Kuroshio surface water and the East China Sea water. The area where the mixing takes place remarkably is found to be the marginal region of the continental shelf of the East China Sea at the depth from 100 to 200 meters.

INTRODUCTION

It is generally believed that the Tsushima Current is a branch of the Kuroshio and its waters are mainly from the Kuroshio Current. Suda and Hidaka (1932) reported that the salinity maximum layer of the Tsushima Current originates from that of the Kuroshio. But Miyazaki and Abe (1960) made another conclusion on the origin of the Tsushima Current water. According to them, the water which passes the eastern channel of the Korea Strait is the oceanic surface water mixed slightly with the coastal water of the East China Sea and the one which passes the western channel is composed of the oceanic surface water mixed remarkably with the coastal water of the East China Sea and the North Pacific Central Water indicated by Sverdrup *et al.* (1942). The Central Water advances ascending toward the northwest along the bottom of the sea valley west off the Kyushu district and flows into the Japan Sea.

However, there are several points in their conclusion which raise questions. They described that the Central Water flows only in the western channel of the Korea Strait. If it is true, how can this water supply the vast quantity of Tsushima Current water in the Japan Sea? In order to supply enough water for the Current, the speed of the Central Water must be very high. There has been no such evidence that the bottom layer of the Tsushima Current is faster than the upper layer. Secondly, the Central Water does not advance in winter. From December to May, the water in the Korea Strait is nearly homogeneous. They could not explain why there is no Central Water advance in winter. They also couldn't explain what makes the Central Water ascend along the bottom of the Korea Strait.

Lim and Chang (1969) pointed out that in the Korea Strait the intruded cold water from the Japan Sea can be represented in a T-S diagram as a straight line, whose relation is the same as that of the Central Water.

In this paper, a discussion was made on whether the North Pacific Central Water flows into the Japan Sea or not. And an analysis was made of the origin of the Tsushima Current water and its place of formation by use of the recent oceanographic data.

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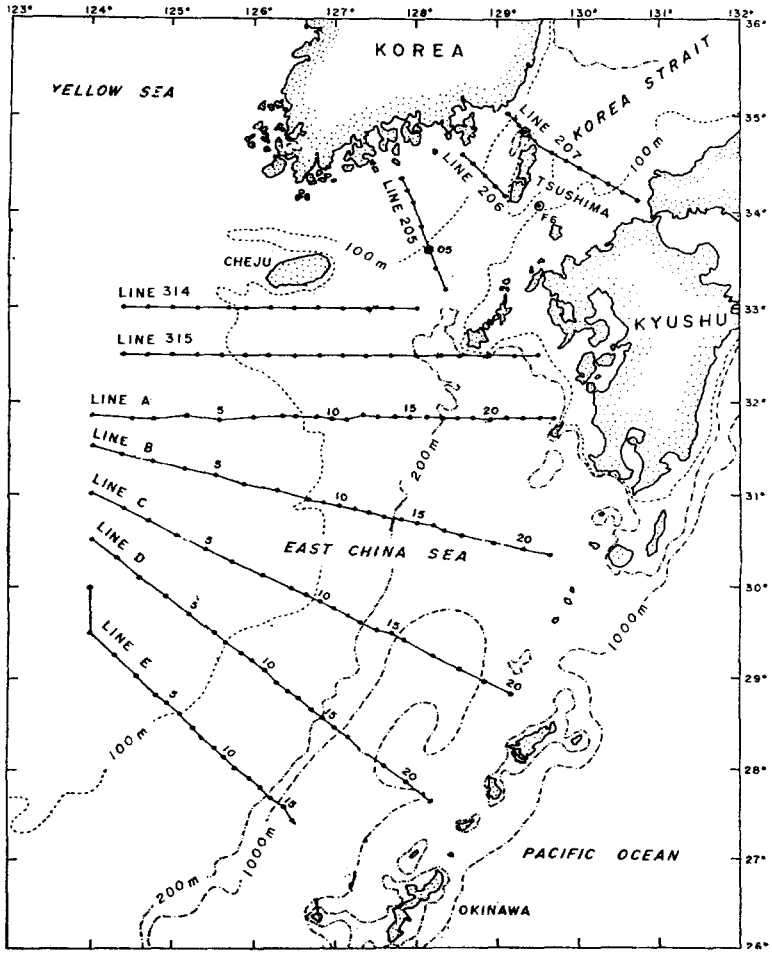

Fig. 1. Bottom topography and position of oceanographic stations in the East China Sea.

DATA

Oceanographic data of the East China Sea observed by the research vessels of the Japan Meteorological Agency in October, 1968 were used for the analysis (The Results of Marine Meteorological and Oceanographical Observations, No. 44). Also CSK oceanographic data in the southern waters of Korea in the summer of 1968 were used (Annual Data Report of the Fisheries Research and Development Agency of Korea, No. 18). Data observed by the Imperial Fisheries Experimental Station of Japan and its branch stations in 1932~1941 were also utilized to find the difference between water masses in the eastern and western channel of the Korea Strait (Semi-annual Report of Oceanographic Investigation, Nos. 59-69). Only the summer data were used because there formed nearly homogeneous water in winter, and it is difficult to distinguish water mass during the season. In the analysis, only temperature and salinity data were utilized.

RESULTS AND DISCUSSION

The Advance of the Western North Pacific Central Water

Several water masses which appear in the East China Sea and in the Japan Sea are shown in Fig. 2. There is a peculiar difference between T-S curves of the eastern and western channel of the Korea Strait. In the eastern channel, only the surface water is found in the T-S diagram, but in the western channel another different water exists below the surface water. The T-S points of this water cluster along the line which connects roughly the point 15°C, 34.5‰ and the point 0°C, 34.0‰. This T-S relationship does not change from June to November. From its continuance and similarity of T-S relationship, Miyazaki and Abe (1960) concluded this water under σ_t 25.2 line to be the western North Pacific Central Water defined by Sverdrup *et al.* (1942). The Central Water is situated in depths from

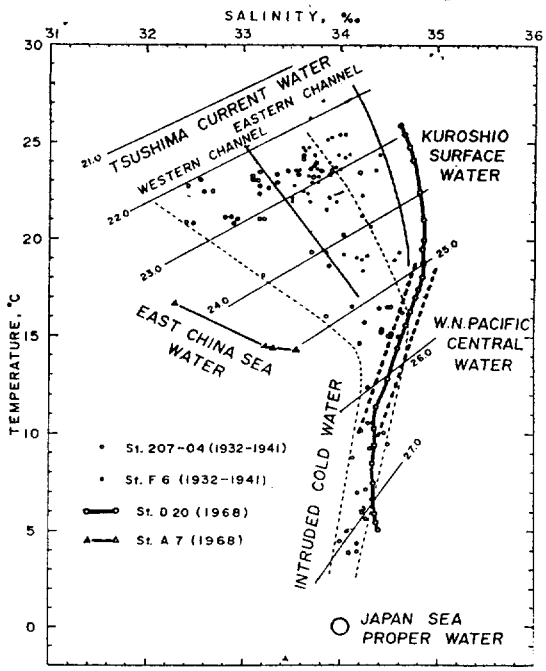

Fig. 2. Principal water masses in the East China Sea in October.

400 to 800 meters in the Kuroshio region.

According to Lim and Chang (1969), a very cold water flows out from Japan Sea in summer along the bottom in the western channel of the Korea Strait. This water is mixed with upper water when flowing out. The T-S curves of this cold water is represented as a straight line which connects the Tsushima Current Middle Water with the Japan Sea. Proper Water in a T-S diagram. The T-S relationship of this water is same as that of the Central Water. Hence, the T-S points which Miyazaki and Abe (1960) concluded to be the Central Water are the points of this water. It seems that they took this cold water for the Central Water.

For the additional evidence, bottom temperatures of St. 205-5 were plotted (Fig. 3). Station 205-05 is located in the path of the Tsushima Current, but there passes no water cooler than 13°C during summer and autumn when the Central Water is believed to flow strongly.

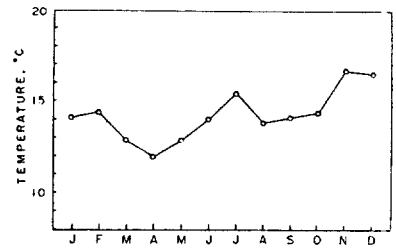

Fig. 3. Monthly variation of bottom temperature at St. 205-05. Values are lowest ones occurred during 8 years from 1960 to 1967.

This discrepancy might have been arisen by the method of analysis. They used the method proposed by Sverdrup *et al.* (1942), which admits a straight line in a T-S diagram as a water mass while others adopt it as a result of mixing two different water masses. The straight line in the T-S diagram of the Korea Strait is not an original water mass, but a result of mixing.

The Origin of The Tsushima Current Water

From the above discussion, it seems evident

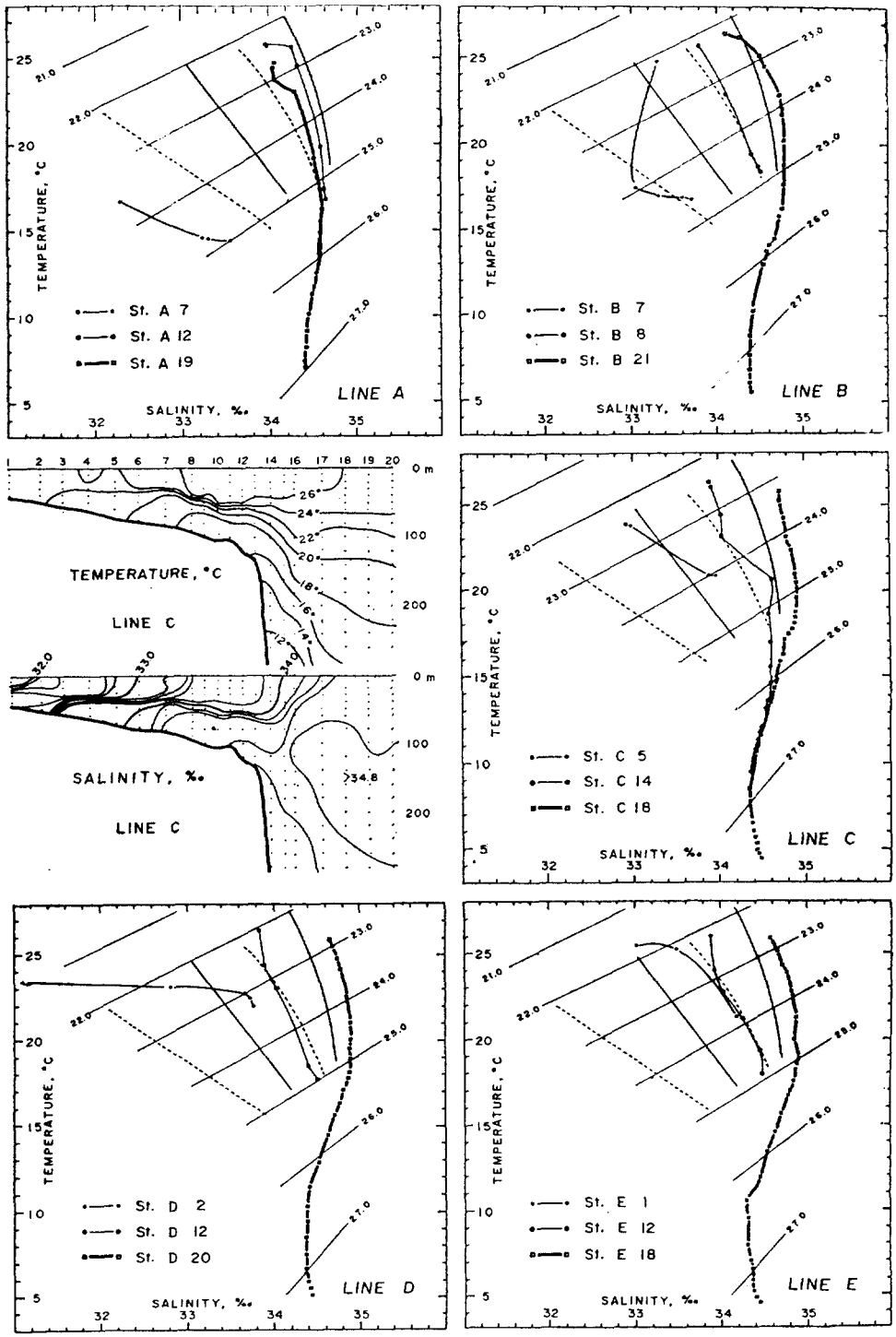

Fig. 4. T-S curves of the East China Sea in October, 1968. Vertical distributions of temperature and salinity of Line C was inserted at the center.

that the Tsushima Current water is composed of the surface water only. There are slight difference between the Tsushima Current waters in the eastern and western channel of the Korea Strait; the water which passes the eastern channel is slightly warm and more saline. But their T-S relationship is nearly parallel in the T-S diagram. The surface waters show a considerable seasonal fluctuation (Nan-niti and Fujiki, 1967); in summer this water is heated by the sun and surface salinity goes down because of rainfall and fresh water inflow from the continents. In summer, therefore, there appears very light water in the surface layer. On the other hand, the water becomes nearly homogeneous in winter owing to strong stirring by the wind and surface cooling.

Fig. 2 shows that T-S curves of the Tsushima Current lie between the Kuroshio surface water and the East China Sea water. From this, it is seen that the Tsushima Current water is formed by mixing between these water masses. Mixing processes are mainly lateral mixing (Miyazaki and Abe, 1960; Kato, 1969).

In order to find the water mass distribution in the East China Sea, T-S curves are plotted (Fig. 4). In Line E, the Kuroshio water is seen in the right side as a thick curve. The two other curves show that the properties of the Kuroshio water are slightly changed owing to the increase of distance from the flowing area of the Kuroshio. In this Line there does not appear distinctive East China Sea water. In Line D, there appears a water which is influenced by the East China Sea water. Vertical temperature and salinity distribution in Line C shows the spreading of the surface water from the East China Sea and influence of Kuroshio surface water on the bottom water of the continental shelf. T-S curves of Line C also show the changed Kuroshio water. In Line B, there begins to appear the unaffected East China Sea water. Also the surface water of Kuroshio is changed slightly; a low salinity value appeared

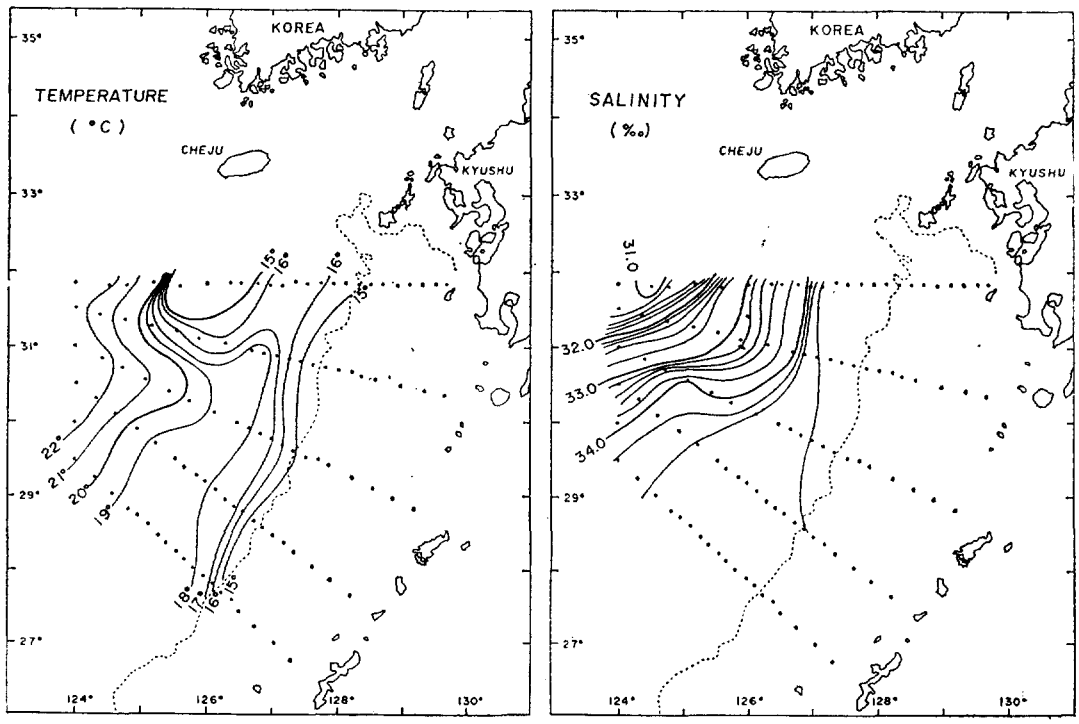

Fig. 5. Horizontal distribution of bottom temperature and salinity in the East China Sea in October, 1968.

at the surface. In Line A, there is no original Kuroshio surface water. The surface water is greatly changed by mixing with the East China Sea water. On the left side of the T-S diagram of Line A there appears an original East China Sea coastal water.

From Fig. 4, it is seen that the mixing between the Kuroshio water and the East China water takes place in the marginal region of the continental shelf. Tsushima Current flows in the transition area between the Kuroshio and the East China Sea water and its water is originated by the mixing of these waters. It does not seem to occur that the salinity maximum layer of the Tsushima Current is directly derived from that layer of the Kuroshio, as reported by Suda and Hidaka(1932).

The influence of the Kuroshio on the water over the continental shelf is shown in the horizontal distribution of temperature and salinity of the bottom layer (Fig. 5). Isotherm lines are running parallel with the continental margin. At the center of the East China Sea, there exists a very warm water heated by the sun. Also south of Cheju Island, there appears a very cool water of 15°C which is a part of the Yellow Sea Cold Water. The salinity distribution also shows that high salinity water of 34.0‰ is dispersed deeply in the continental shelf. This is in agreement with the results of Kato (1969).

Since lateral mixing occurs between the water masses in this area, a salinity distribution on an isopycnic surface ($\sigma_t=23.0$) was prepared (Fig. 6). Iso-haline lines are running parallel with the continental margin and high salinity isohalines are located in the vicinity of Kyushu. This illustrates that in the Kyushu side the mixing is slight compared with the western side.

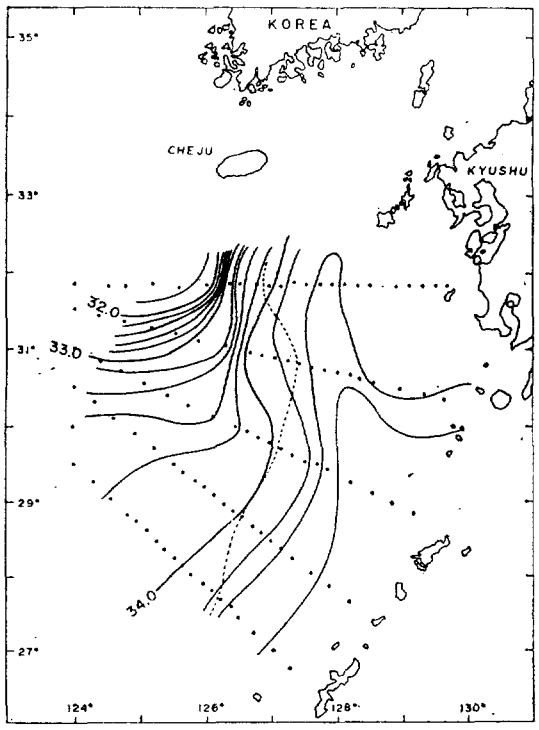

Fig. 6. Salinity distribution on the σ_t 23.0 surface. Dotted line indicates the boundary of σ_t 25.2 water. On the left side of the line, water heavier than 25.2 does not exist.

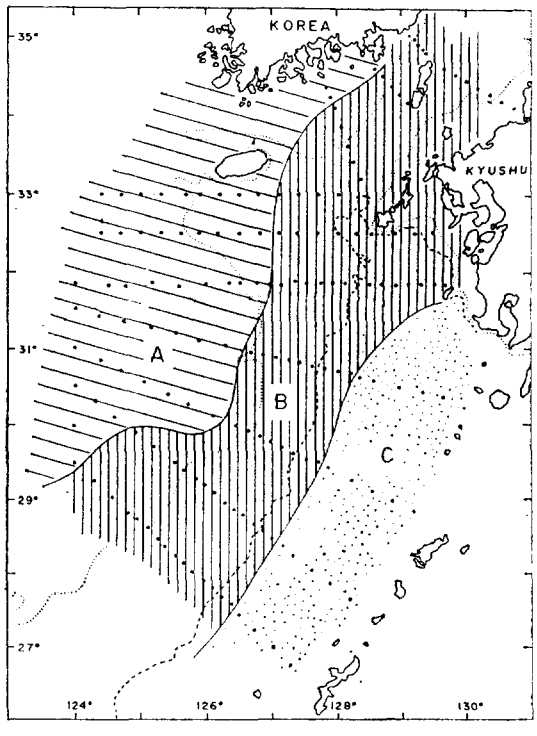

Fig. 7. Water mass distribution in the East China Sea in summer and autumn of 1968. A: East China Sea water, B: Tsushima Current water, C: Kuroshio water.

Using T-S curves and distribution of temperature and salinity, a graph of water mass distribution in the East China Sea was prepared (Fig. 7). Near Cheju Island and west of the 100 meter iso bath, the East China Sea water is situated. Between the 100 meter isobath and the 200 meter isobath exists the Tsushima Current water and slightly off the continental margin the pure Kuroshio water is located. This is in good agreement with the results of the drift bottle experiment by Uda(1950).

CONCLUSION

Miyazaki and Abe (1960)'s conlcusion concerning the North Pacific Central Water advance toward the Korea Strait was discussed. The water which they pointed out to be the North Pacific Central Water in the Korea Strait seems to be the intruded cold water which flows out from the Japan Sea and mixes with upper water. It is concluded that the western North Pacific Central Water does not flow into the Japan Sea through the Korea Strait.

The Tsushima Current water is formed by mixing between the Kuroshio Surface water and the East China Sea water. The place of formation is in the marginal region of the continental shelf at depths from 100 to 200 meters. In the formation of the water, lateral mixing is dominant.

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