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THE MOVEMENTS OF THE WATERS OFF THE SOUTH COAST OF KOREA

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ABSTRACT

The water movements in the south sea of Korea are deduced from the distributions of water properties. In summer the flow path of the Tsushima Current is deflected off from the Korean coast; between the coast and the current there exist eddies. Cyclonic eddies are particularly dominant in the southeastern area of Sorido Is. In winter, the sunken coastal water flows out along the bottom toward the southeast, and compensation is made at the surface by the coastward intrusion of off-shore waters. The so-called coastal counter-current of the area seems to be a cyclonic eddy which prevails in summer and autumn.

INTRODUCTION

In many early ocenographic studies studies of Korean waters, comparatively little emphasis was paid to the area off the south coast of Korea.

The general features of the waters off the Korean coasts were described by Nisida(1927) and Uda(1934, 1936). Recently drift-bottle experiments were carried out in the southern waters of Korea by Lee and Bong(1969), Dong (1970), and Lee (1974a). Chang(1970a) computed wind drift currents of the area and Gong (1971) studied the coastal front. Lim(1971) and Kang(1974) analyses water masses in the area.

There has been much controversy over the existence of the westward current after the first suggestion of it by Chang (1970b). From the drift-bottle experiments, Lee(1974a) concluded that there exists a westward current along the south coast of Korea in summer, which flows from Geoje Is. to Jindo Is. The results of Lee(1974a) are an affirmation of its existence. Lee reported that this current flows only in summer and autumn, and that it originates from the Tsushima Current.

However, Gong(1971) and Kang(1974) reported that a coastal water mass is located in the southern sea of Korea throughout the year, extending a considerable distance from the shore; and there exist conspicuous fronts between this coastal water and the Tsushima Current. If a westward current exists along the coast and its water is supplied from the Tsushima Current, there can be no coastal water in the southern sea of Korea. Therefore, the results of Lee(1964a) are contradictory to those of Gong(1971) and Kang(1974). Lee(1974a)also reported that in summer the Tsushima Current flows very near the Korean coast, while Gong (1971) described the coastal fronts being located far from the coast. On this point they are also contradictory to each other.

Though the use of drift-bottles is a good method for the study of surface currents, it has many weaknesses. The uncertainty of actual flow paths of bottles and the effects of winds require supplementary evidence for reliable conclusions. But Lee(1974a) did not use any subsidary data in making his conclusions.

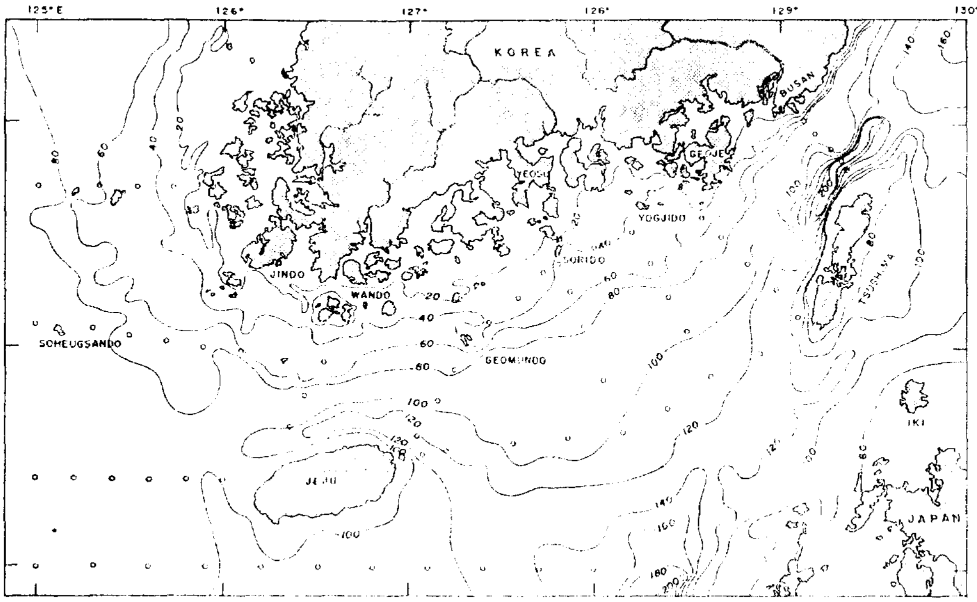

Fig. 1. Bottom topography of the area off the south and southwest coast of Korea. Open circles indicate the position of oceanographic stations. Contour interval 20 meters.

The object of this paper is to clarify the movements of waters off the south coast of Korea. Special attention is paid to whether the westward current exists or not. The circulation patterns in winter and the existence of eddies in the area are also studied.

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DATA AND METHODS

The data used in this analysis were taken from the Annual Report of Oceanographic Observations Nos. 16-23 by Fisheries Research and Development Agency of Korea(1967-1974) Since synoptic data are highly desirable in the study of coastal areas, all the data were evaluated carefully and the most pertinent were chosen.

Since there are large seasonal variations of water properties in this area (Gong 1971, Kang 1974), a proper tracer in the analysis must be carefully chosen. In this paper, a low salinity core at the 10 m layer was used to trace surface circulation. In summer extremely low salinity water spreads from the Yangtze River in the East China Sea (Uda, 1934). When this water reaches the Tsushima Current, it overrides the current and is carried away with it. This makes a narrow belt of low salinity water in the southern sea of Korea (Fig. 2). The belt represents the boundary of the Tsushima Current and thus can be used as a good tracer of the current in summer.

According to Defant(1961), in the case of a cyclonic vortex with the upper layer rotating more rapidly, the heavier water accumulates around the axis of rotation while the lighter top layer is forced to the outside. In the case of an anticyclonic vortex with the top layer rotating more rapidly, an accumulation of the lighter water masses occurs around the rotational axis. The author's conclusion that on eddy exists is based on these criteria.

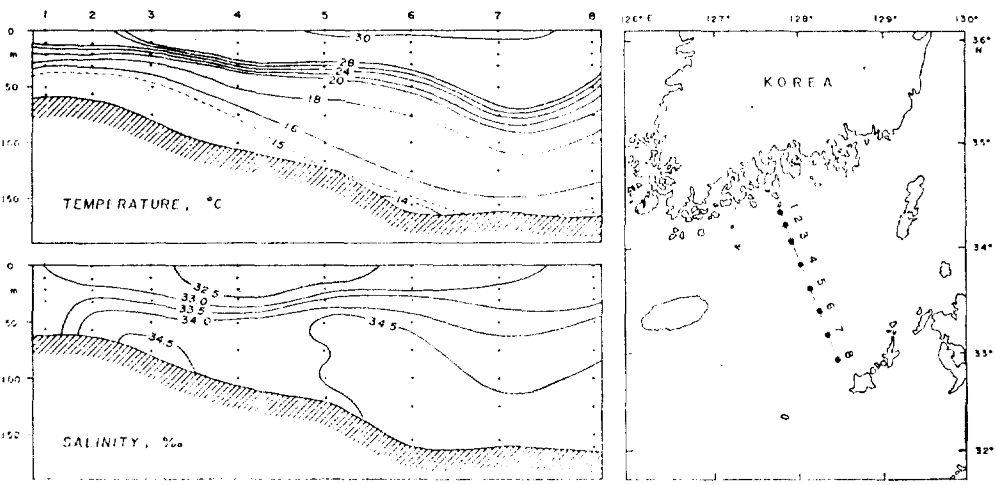

Fig. 2. Distribution of temperature and salinity in a section (Sorido Is.-Goto Retto, August 1967). Shaded area in the salinity section represents the the belt of low salinity water.

TRAJECTORY OF THE LOW SALINITY WATER

An illustration is made in Fig. 3 of the relationship between the temperature distribution and the position of the belt of low salinity water at the 10 m layer in summer in the southern sea of Korea.

In August, 1969, a water mass with temperatures under 21°C extends off shore from the coast between Geoje Is. and Sorido Is. The isotherms of between 22° and 28°C are converged around this water. The belt of low salinity water is locatde southward of the 25°C isotherm and runs parallel with the converged isotherms. These features indicate that the trajectory of this low salinity water can be used as a tracer of the Tsushima Current. Since this low salinity water is located at the tip of the Tsushima Current, it is evident that the current flows about 30 miles off the Korean coast at this time. In the western channel of the Korea Strait, the belt is located about 30 miles southward off Geoje Is., which indicates that the main stream of the Tsushima Current passes very near Tsushima Is.

In September, 1969, the isotherms of 21°-27°C are also converged and are parallel to the belt of low salinity water of this time. About 25 miles southward of Sorido Is. there exists a body of isolated cool water with temperatures under 19°C, the shape of which is an ellipse. The low salinity water belt partially surrounds this isolated cool water.

In July, 1970, a mass of cool water under 21°C is also seen about 20 miles southeastward of Sorido Is. The convergence of isotherms is also seen southward of the isolated cool water. And the belt of low salinity is located southward of the 25°C isotherm. Near Busan cool water under 18°C is seen, which seems to originate from the cold water mass of the Korea Strait (Lim and Chang, 1969).

In August, 1971, an intrusion of warmer water is seen south of Sorido Is. and to the east of this warmer water a colder mass with an elliptical shape protrudes southwestward. The belt of low salinity water is located southward of the 26°C isotherm.

In August, 1972, there also exists an isolated cool water body under 22°C southward of

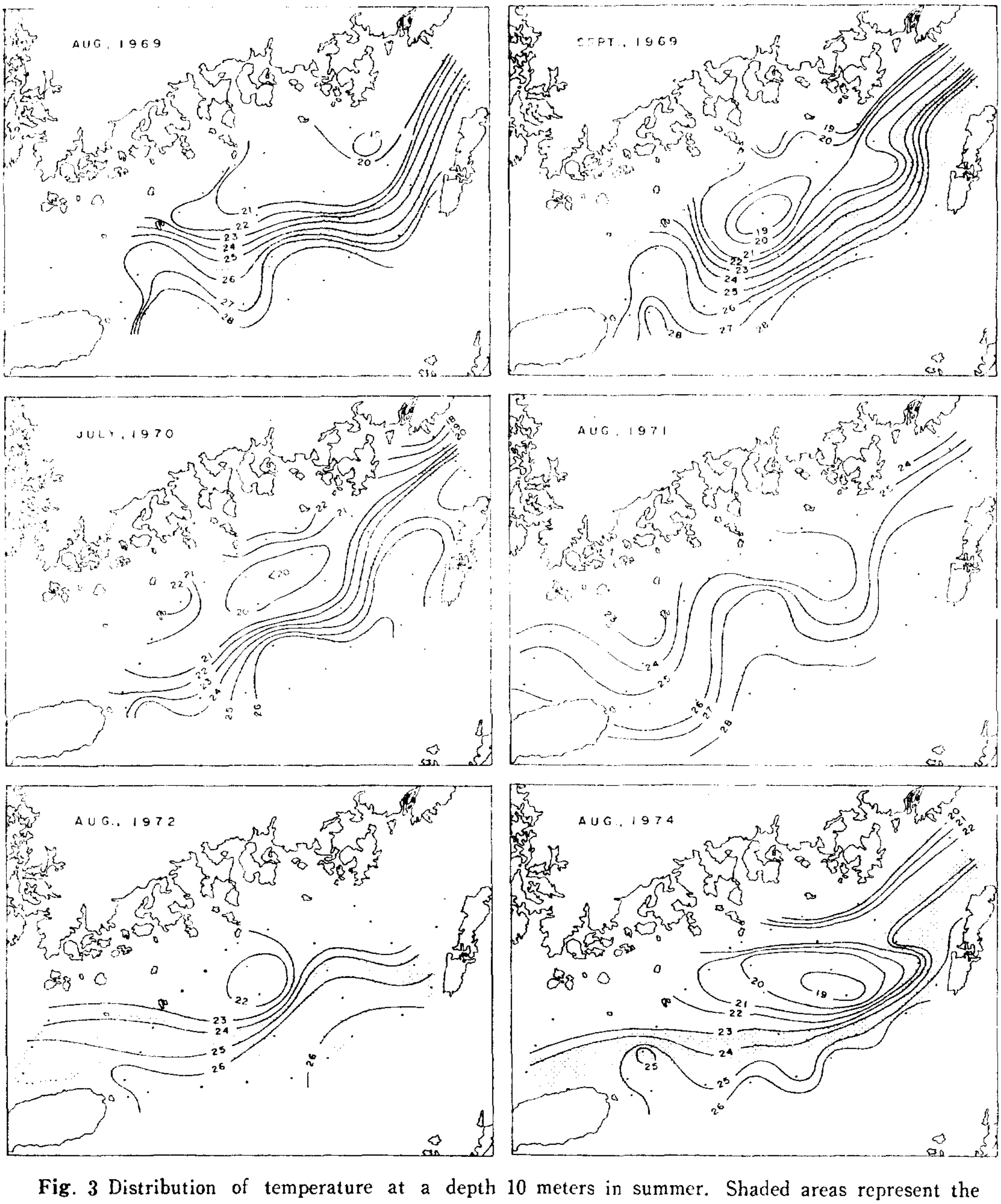

Fig. 3 Distribution of temperature at a depth 10 meters in summer. Shaded areas represent the belt of low salinity water.

Sorido Is. and the low salinity belt runs parallel with the 24°C isotherm in the south.

In August, 1974, cool water under 19°C is located about 35 miles southeastward of Sorido Is. This cool water occupies a very wide area. The low salinity belt which is located southward of the 23°C isotherm partially surrounds this water.

From Fig. 3, it is found that in summer there are three flow patterns of the Tsushima of the Tsushima Current in the area: an elliptical type surrounding the cool coastal water as in September 1969, July 1970, August 1972, and August 1974; an elongated concave type as in August

1969; and a sinuous type as in August 1971. The type occurring most frequently in the area is the elliptical kind, and the least frequently occurring is the sinuous type.

It is known that the Tsushima Current is strongest in summer and weakest in winter (Hidaka and Suzuki 1950, Miyazaki 1952). Lee (1974a) concluded that the Tsushima Current flows much nearer the Korean south coast in summer than in winter. However, in Fig. 3, it can not be found that the belt of low salinity water which shows an actual trajectory of the Tsushima Current has ever been located near the south coast of Korea. It is always located at least 30 miles offshore. The position of the belt is very near Tsushima Is., which indicates that the current flows near the island. Lee's conclusion that it approaches the Korean coast in summer seems unreasonable. The closest approach of the belt to the Korean coast occurs in August 1971. However, this approach results from the meandering of the belt. It is also apparent that the Tsushima Current does not sweep the Geoje coast strongly, as has been supposed by many. Lee (1974a) described the so-called coastal counter-current as branching out from the Tsushima Current. If so, the belt of low salinity water must be situated very near the Korean coast parallel to the shore. No such distribution is ever seen in Fig. 3. From the figure it is apparent that the Tsushima Current water is not carried westward along the south coast of Korea in summer. Though Lim (1975) reported that there are intrusions

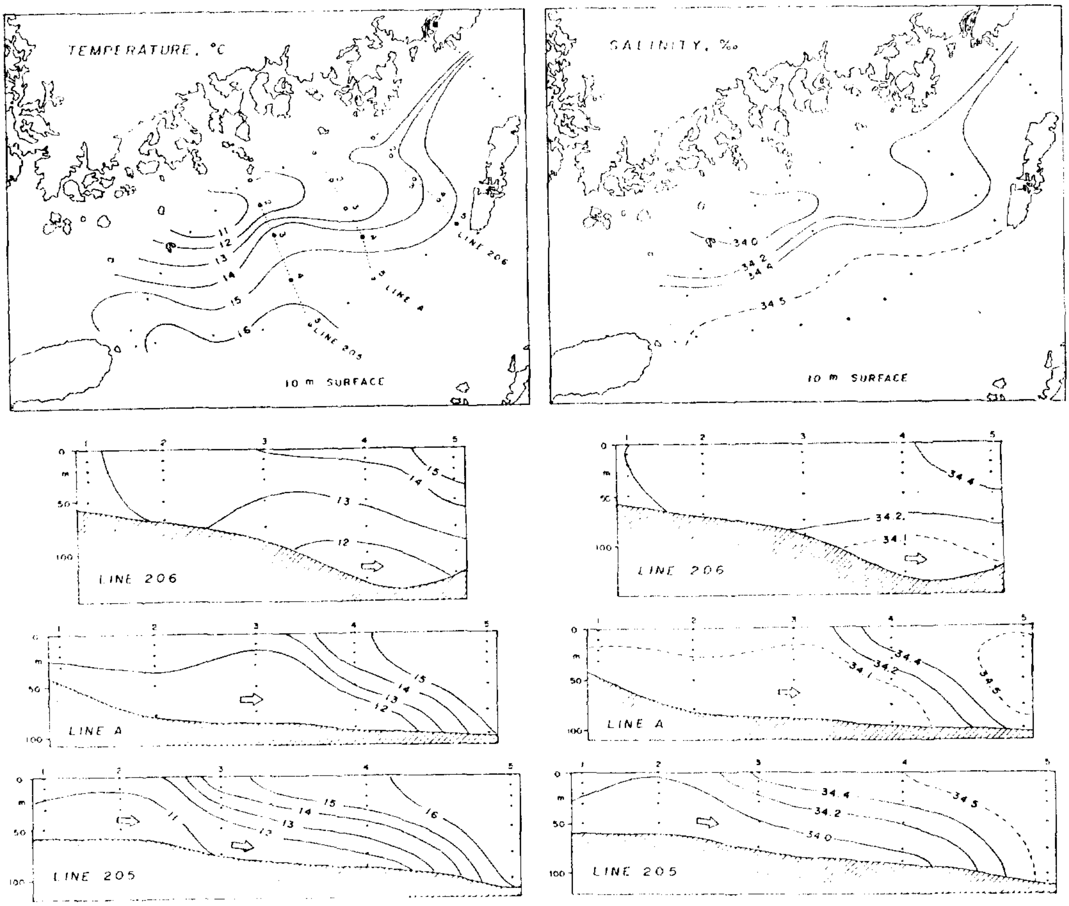

Fig. 4. Horizontal and vertcal distribution of temperature and salinity (August, 1971).

of off-shore water into the coastal area north of Yogjido Is., they occur very rarely, and they seem to be due to eddies, not to currents.

EDDIES

In order to see whether the isolated cool waters shown in Fig. 3 are related to eddies, horizontal and vertical distribution of properties in August 1971 is represented in Fig.4.

Horizontal distributions of temperature and salinity reveal very similar characteristics to each other. The warm water with temperatures over 27°C near Sorido Is. is low in salinity content (under 31‰.), and the cool water located northeastward of this is high in salinity. The waters off the south coast of Korea have increasing salinity with depth. Therefore, the area with higher salinity represents the influence of the deeper water while the low salinity area is related to the accumulation of surface water. These features are seen in the vertical profiles of temperature and salinity in Fig.4. In the profile of Line A, an upwelling trend of lower water is clearly seen around Sts. 2 and 3 (open arrow). The accumulation of surface water is shown around St.3 in Line 205 (thick arrow). These coincide well with the model of Defant (1961). Around Sts. 2 and 3 of Line A, a cyclonic eddy is formed and an anticyclonic eddy is established around Sts. 3 and 4 of Line 205. The isolated cool waters shown in Fig.

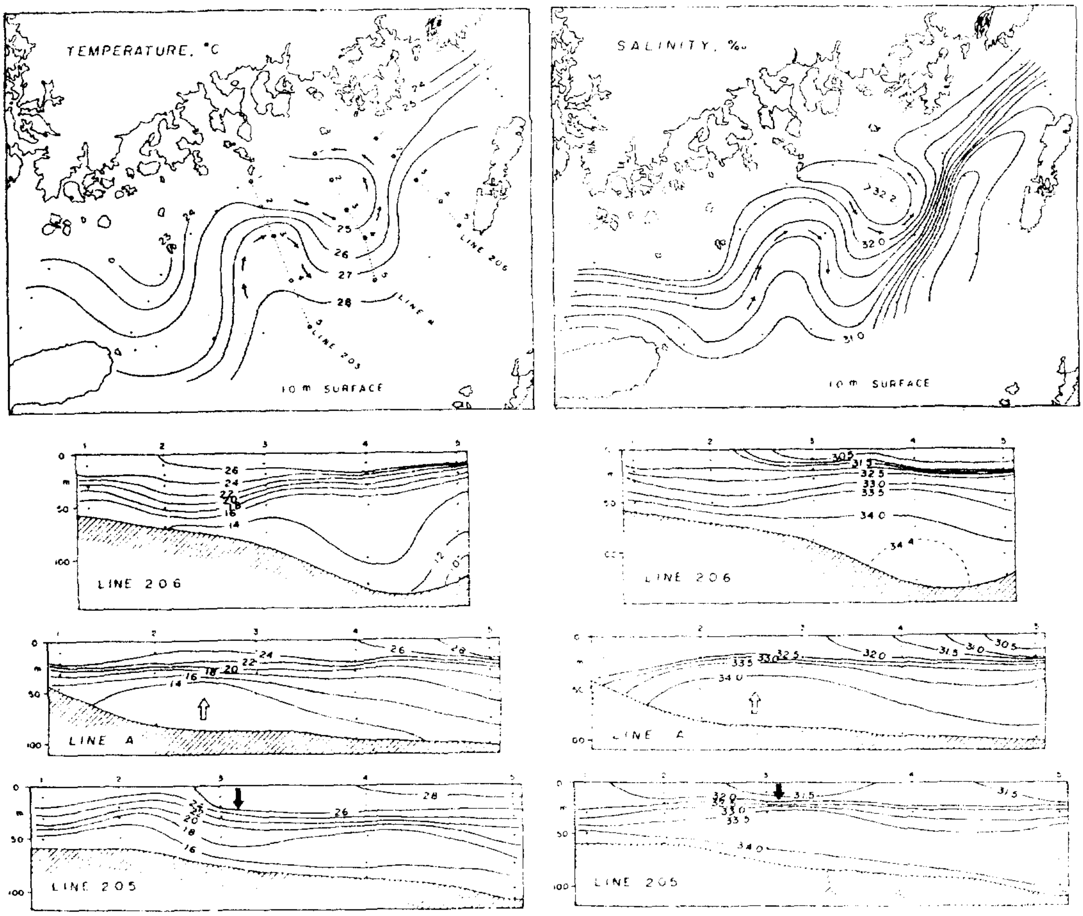

Fig. 5. Distribution of temperatvre at a depth of 10 meters.

3 are easily recognized to be associated with eddies from their respective property distributions.

The location of frequent eddy formation is mainly the southeastern area off Sorido Is., though shows large annual variations. In Sepember 1969 and August 1974 when the extraordinary cool waters appear, cyclonic eddies are located southeastward of Sorido Is. The shape of of eddies is an ellipse and from their very low temperatures, it is seen that they are very intense. In July 1970 and August 1972 the existence of eddies is not so apparent, but there do exist waters with temperatures lower than those of the surrounding water by 4°or 5°C. This is a good indication that eddies prevail in the southern waters of Korea.

Sometimes it is difficult to ascertain the position of eddy axis in this area. In August 1969, colder and warmer waters are located side by side with a boundary of a nearly straight line.

In order to show the seasonal change of eddy formation, horizontal distributions of temperatures at 10m depth in October are represented in Fig. 5. The low salinity water in the East China Sea disappears in autumn and loses its value as a good tracer of currents. From October surface water is cooled rapidly, particularly in the southeastern area off Sorido. In Fig. 5, much cooler water extends southeastward from Sorido Is. in a tongue-like shape in October 1970. The over-all trend in 1973 and 1974 is the same as that of 1970. A body of warmer water creeps westward into the coastal area along the south coast between Geoje Is. and Yeosu. The Tsushima Current is particularly deflected offshore in October of 1973 and 1974, and its axis is located near Tsushima Is. In

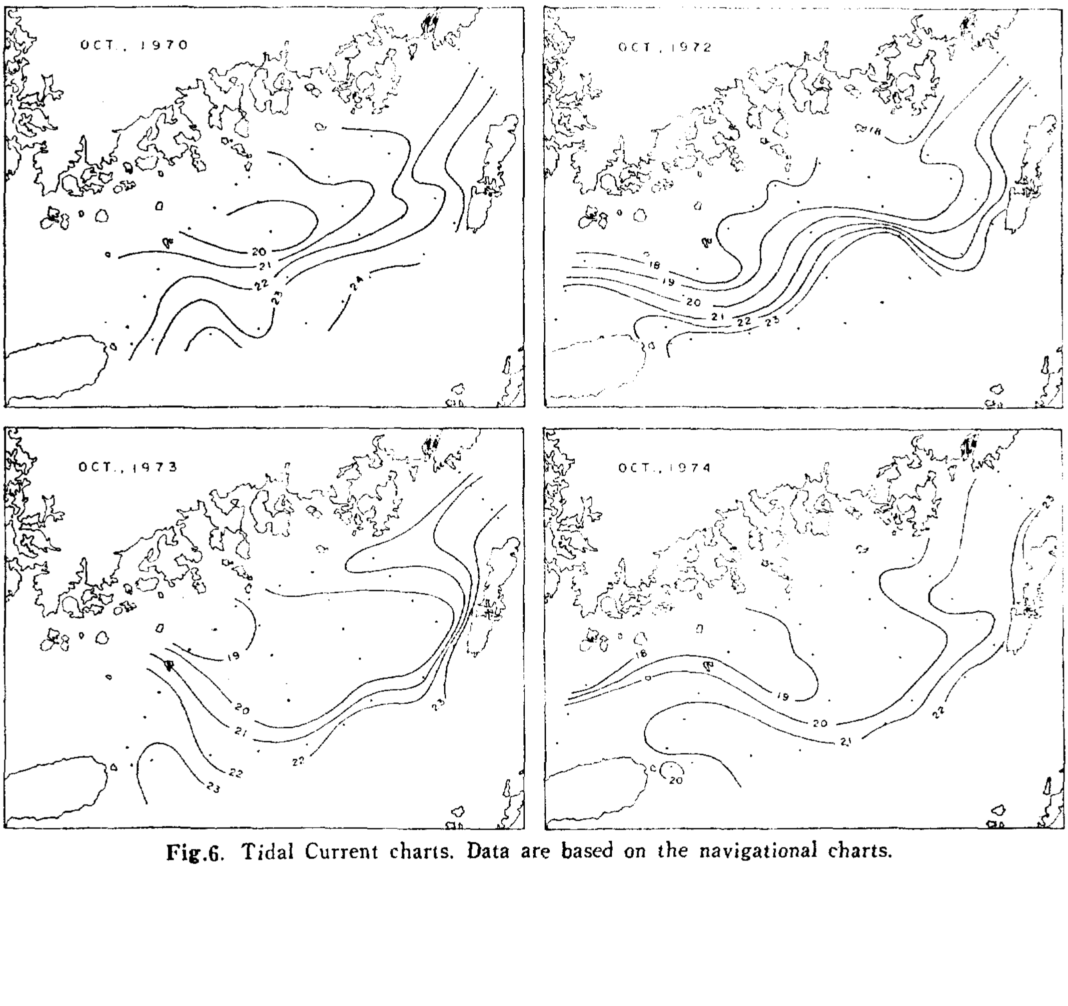

Fig.6. Tidal Current charts. Data are based on the navigational charts.

1972, warm water with temperatures over 23°C intrudes the coastal area concavely, the type of which appears most frequently in winter. From this it is concluded that in autumn eddies are still present in this area.

Lee(1974a) reported many recoveries of drift-bottles along the south coast of Korea in summer, particularly along the coast between Geoje and Sorido Islands. This drift of the bottles seems to be due to the prevailing eddies in this area. Annual variation of drift-bottle recovery (Lee and Bong 1969, Dong 1970, Lee 1974a) seems to be related to the variation of eddies.

Tidal current charts of the area may be of help in understanding the eddy formation mechanism in the waters off the south coast of Korea. Fig. 5 is prepared by use of the

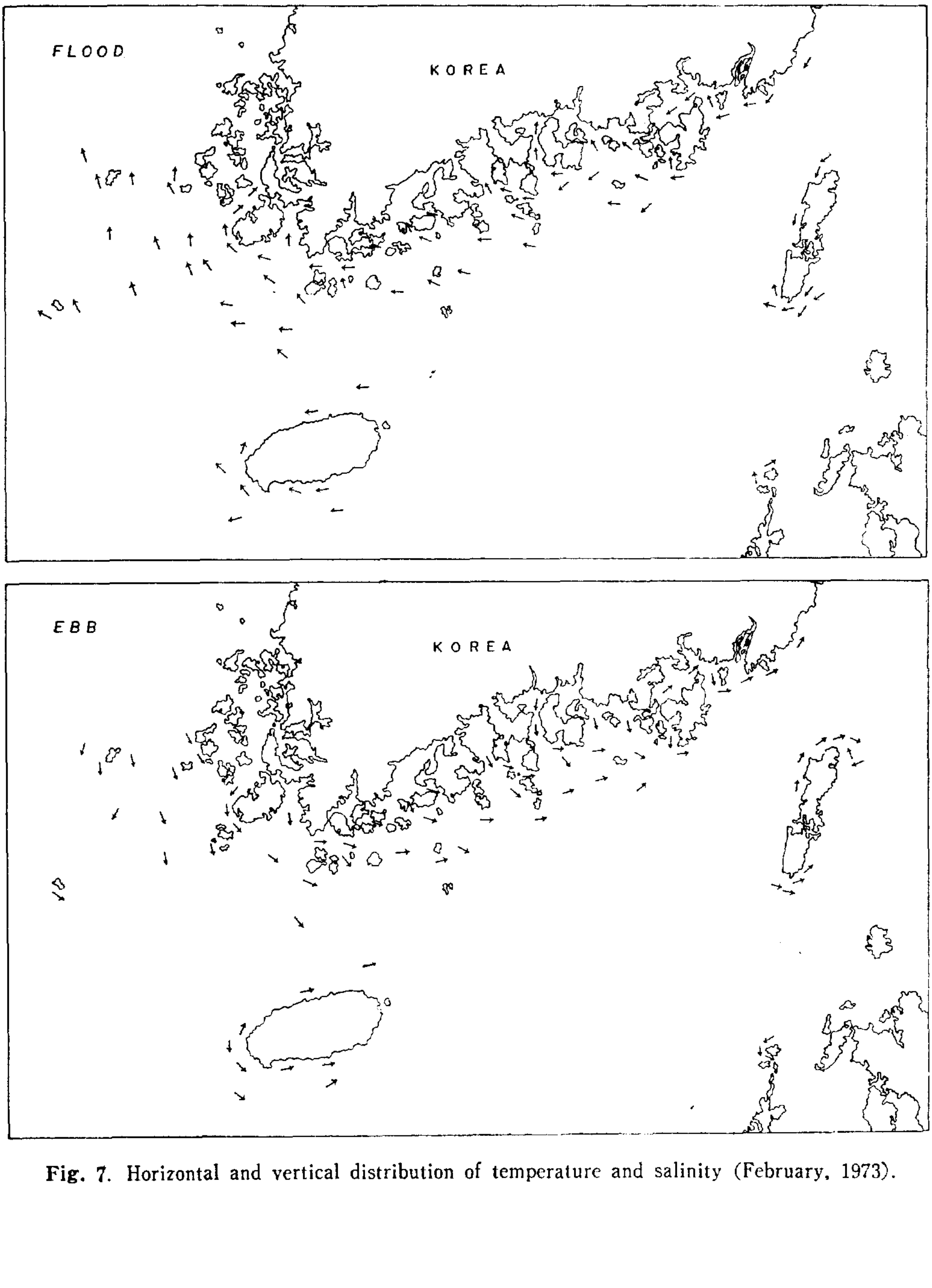

Fig. 7. Horizontal and vertical distribution of temperature and salinity (February, 1973).

data on the navigational charts. Generally the flood current flows westward and the ebb current eastward in this area, and semidiurnal tide is dominant. In ebb tide, the Tsushima Current is accelerated by the tidal current of the same direction, while in flood tide the opposite occurs. Since the current is usually fast in its main stream, the accelerasion and deceleration of the ocean current speed by tidal current is not equal in the entire area. In flood tide, in the coastal region where the Tsushima Current is not so strong, the tidal current overcomes the ocean current and actually flows westward. Meanwhile, in the off-shore area, the ocean current is so strong in its axis as to overcome the tidal current and actually flows eastward. Therefore there is westward flow in the near-shore area and eastward flow in the offshore area. This phenomenon of opposite currents in the southern sea of Korea has early been reported by Nisida (1927). It seems that between these opposite currents eddies form, very often the cyclonic eddies. Thus eddy formation seems to be closely connected with the Tsushima Current.

SINKING AND SPREADING OF THE COASTAL WATER IN WINTER

In winter both temperature and salinity can be used as a tracer of water movement. In Fig. 7, horizontal sections show that cold water with temperatures under 11°C and salinities under 34.0‰ is situated in the coastal area between Sorido Is. and Geomundo Is., and extends southeast toward Tsushima Is. in a tongue-like shape. Warm water over 14°C intrudes broadly into the area south of Sorido Is. Another warm water mass is seen to flow westward along the coast of Geoje Is. toward Sorido Is.

Vertical profiles also show that cold water under 11°C near Sts. 1 and 2 of Line 205 flows out toward the south along the bottom, and in the upper layer warm water over 14°C flows in toward the coast. In Line A the trend is the same. In Line 206, cold water under 12°C is located at the deepest place of the section, which seems to be related to the sinking coastal water.

From the figure then, it is seen that in winter the coastal water sinks near Sorido Is. and flows out along the bottom toward off shore. This water is replenished by the off-shore water in the surface layer.

These phenomena are much more clearly represented in Fig. 8. In March 1970, at the surface layer very cold waters under 8°C extend outward from the coasts between Sorido Is. and Geomundo Is., and between Sorido Is. and Yogjido Is. From the south of Sorido Is. warm water over 12°C approaches the island. And the isotherms between 8° and 12°C are located near the coast, which shows that the fronts are situated there. The cold water between Yogjido Is. and Geomundo Is. is stretched out toward Tsushima Is. The same trend is seen in the bottom temperature distribution of Fig. 8.

In February 1971, off-shore water with temperatures influences the water very near the coast and at the bottom layer, sunken cold water spreads out off the coast in two branches, toward the east and the south. A warm water mass flows in toward Yogjido Is. A sunken cold water mass between Sorido Is. and Geomundo Is. is also seen stretched southeasterly, in February 1973.

From this it is evident that the excessively cooled coastal water sinks near the south coast of Korea in winter and flows off the coast along the bottom. When flowing out, it does not form a narrow belt but rather spreads broadly. The usual direction of flow is southeastward

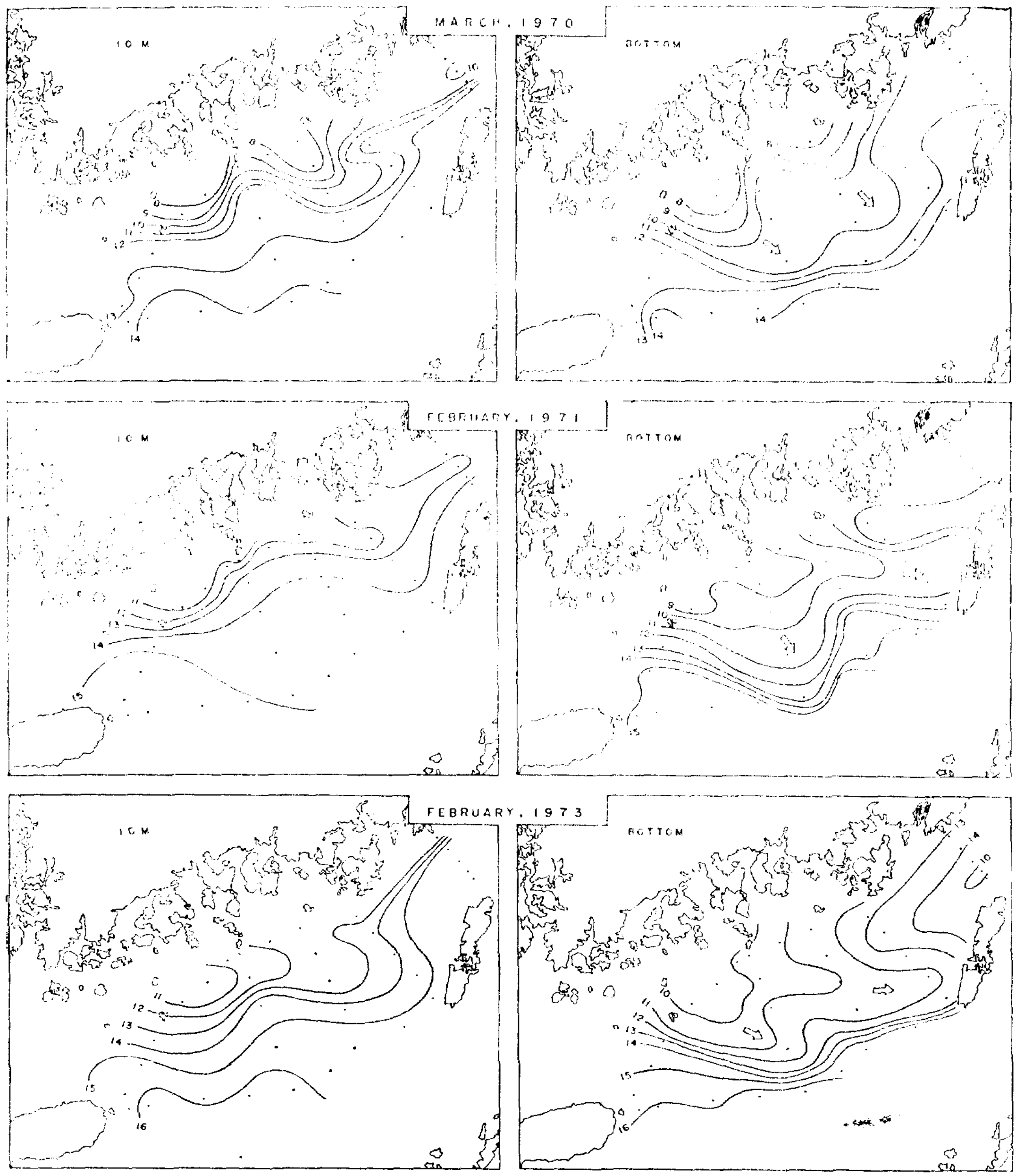

Fig. 8. Distribution of temperature at a depth of 10 meters and at bottom.

toward Tsushima Is. The next most common path of the sunken cold water is toward the south from Sorido Is.

In winter, the existence of eddies is difficult to confirm. Sometimes there is a tongue-like protrusion of the coastal water in the surface layer from Sorido Is. toward Tsushima Is. But it does not seem probable that this forms an eddy.

Compensation of the sunken coastal water seems to be carried out partly by a westward flow along the Geoje coast at the surface, and partly by the intrusion of off-shore water toward Sorido Is.

It is known that the southern sea of Korea is under the dominant influence of the northwesterly monsoon in winter and that the Tsushima Current has its weakest speed at this time (Uda 1936, Lee 1974b). In Figs. 7 and 8, there is no indication that this prevailing wind creates a drift current. Results of drift-bottle experiments have shown many recoveries of bottles at the coast of Kyushu, Japan in winter (Uda 1936, Lee and Bong 1969, Dong 1970, Lee 1974a). From these results results Lee (1974a) concluded that the axis of the Tsushima Current passes the eastern channel of the Korea Strait in winter, and consequently the current flows far from the Korean coast. But Fig. 8 shows the closer approach of offshore water to the Korean coast, which means that the Tsushima Current water influences the coastal water much more strongly in winter. Also water exchange occurs more predominantly in winter than in summer between the coastal water and the Tsushima Current water due to sinking and compensation.

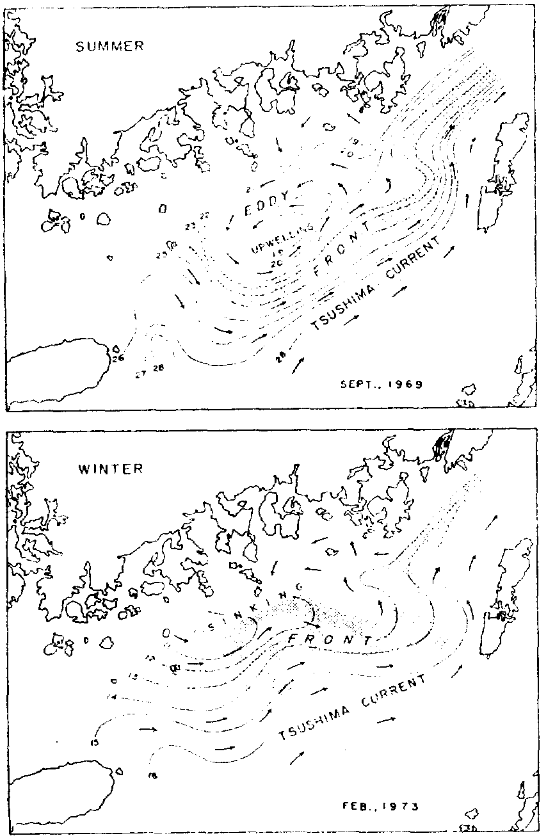

Fig. 9 Schematic representation of water movements. Contours are isotherms.

The most conspicuous sinking area is around Sorido Is. The fronts, therefore, are located very near the Korean coast in winter. Near the fronts, sinking is dominant and hence the fronts are of convergent type in winter, while in summer they are of divergent type.

In the coastal area from Geoje Is. to Yojido Is., there seems to exist a westward flow throughout the year due to eddies in summer and to compensation current in winter.

SUMMARV

By use of the oceanographic data from 1967 to 1974, the movements of the waters in the southern sea of Korea are studied.

In summer a belt of low salinity water is formed at the surface layer off the south coast of Korea. This belt can be used as a good tracer of the Tsushima Current, since it is placed at the tip of the current. The path of the Tsushima Current traced by this belt is located farther from the Korean coast in summer than in winter. It approaches the coast in winter.

In the area between the current and the south coast of Korea, there often appear eddies in summer. The most frequent place of eddy formation is southeast of Sorido Is., where cyclonic eddies are dominant. The westward flow, seems to be this cyclonic eddy. It is difficult to believe that there exists a westward current which flows continuously from Geoje Is. to Jindo Is., the water of which is supplied from the Tsushima Current. Cyclonic eddies of the area remain until autumn and vanish in winter.

In winter intense convection occurs near the Korean coast due to the excessive cooling of

the surface water, and sunken cold coastal water flows outward along the bottom. Compensation is carried out at the surface partly by the coastward approach of the Tsushima Current south of Sorido Is., and partly by the westward flow along the Geoje and Yogjido coasts. In the area from Geoje Is. to Sorido Is. a westward flow seems to be dominant throughout the year, due to eddies in summer and compensation flow in winter.

Fronts between the Tsushima Current and the coastal water are located farther off shore in summer than in winter. Fronts are of the divergent type in summer because of eddies, and of the convergent type in winter, due to sinking.

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