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# ON THE COLD WATER MASS IN THE KOREA STRIT

*Du Byung Lim and Sun-duck Chang*

Pusan Fisheries College, Pusan, Korea

## ABSTRACT

By use of the oceanographic data from 1932 to 1941 and from 1960 to 1967, the general properties of the cold water in the Korea Strait are discussed. This water characterized with temperatures 3-10°C and salinities 34.0-34.4 ‰ originates from the Japan Sea and begins to flow out in summer along the bottom about 8 to 18 miles southeast of Ulgi in Ulsan. It usually reaches the Pusan—Tsushima section and rarely to the west of the southernmost part of Tsushima. As it flows out, it shows rising trend along the coast of Korea and sometimes upwelling occurs in the vicinity of Ulsan. It seems that the cold water forms an under current along the bottom in summer and autumn in the western channel of the Korea Strait.

## INTRODUCTION

Studies on the Tsushima Current and the oceanographical conditons of the Korea Strait were made by Uda (1934, 1936), Suda (1938), Hidaka and Suzuki (1950), Ko (1958), and Nan-niti and Fujiki (1967). The Tsushima Current carries high temperature and high salinity water to the Japan Sea through the Korea Strait and its maximum speed appears in the Korea Strait. Among two branches of the current in the strait, the western one is stronger than the eastern one in its speed (Nisida 1927, 1928, 1930). In spite of this strong current, near the coast of Korea and at the bottom of the western channel, there appears a very cold water mass every year, which does not seem to be of the Tsushima Current origin. It is known that the Tsushima Current shows the strongest flow in August and September (Miyazaki 1952, Yi 1966). However, the water temperature at the bottom of the western channel is at its minimum at this time. This phenomenon was recognized in the past. Uda (1936) described that the cold water of the Japan Sea reaches near Pusan. A brief report was made by Nisida (1955) of the general character of the cold water at the bottom of the Korea Strait. Fukuoka (1962) called this phenomenon as a southward intrusion of cold water from the Japan Sea. Chang and Uda (1968) suggested that the movement of the cold water in the Koera Strait may be an extension of an undercurrent in the Japan Sea. However, up to the present time, property, seasonal variations and movement pattern of the cold water are not clearly explained.

According to Defant (1961), there are two water bodies in the strait connecting the enclosed sea with the open ocean, which move in the opposite directions; one above the other. The stratification of the water masses in the Korea Strait and other phenomena show very similar characteristics of those of the straits which have interchange current systems. The existence of this inflow and outflow current system in the Korea Strait has not yet been clearly ascertained.

In this study, a descriptive analysis is made of the cold water mass in the bottom layer of the

Korea Strait. General Properties of the water mass are discussed. An emphasis is paid to whether the could water mass is of the same nature as an undercurrent.

The nomenclature of the strait is rather in confusion. It is generally called the Korea Strait, but some of the Japanese call it the Tsushima Strait. Some call the western channel the Korea Strait and the eastern channel the Tsushima Strait. In this paper, the Korea Strait refers to the whole strait and the western channel and eastern channel are used to represent the two branches of the Korea Strait.

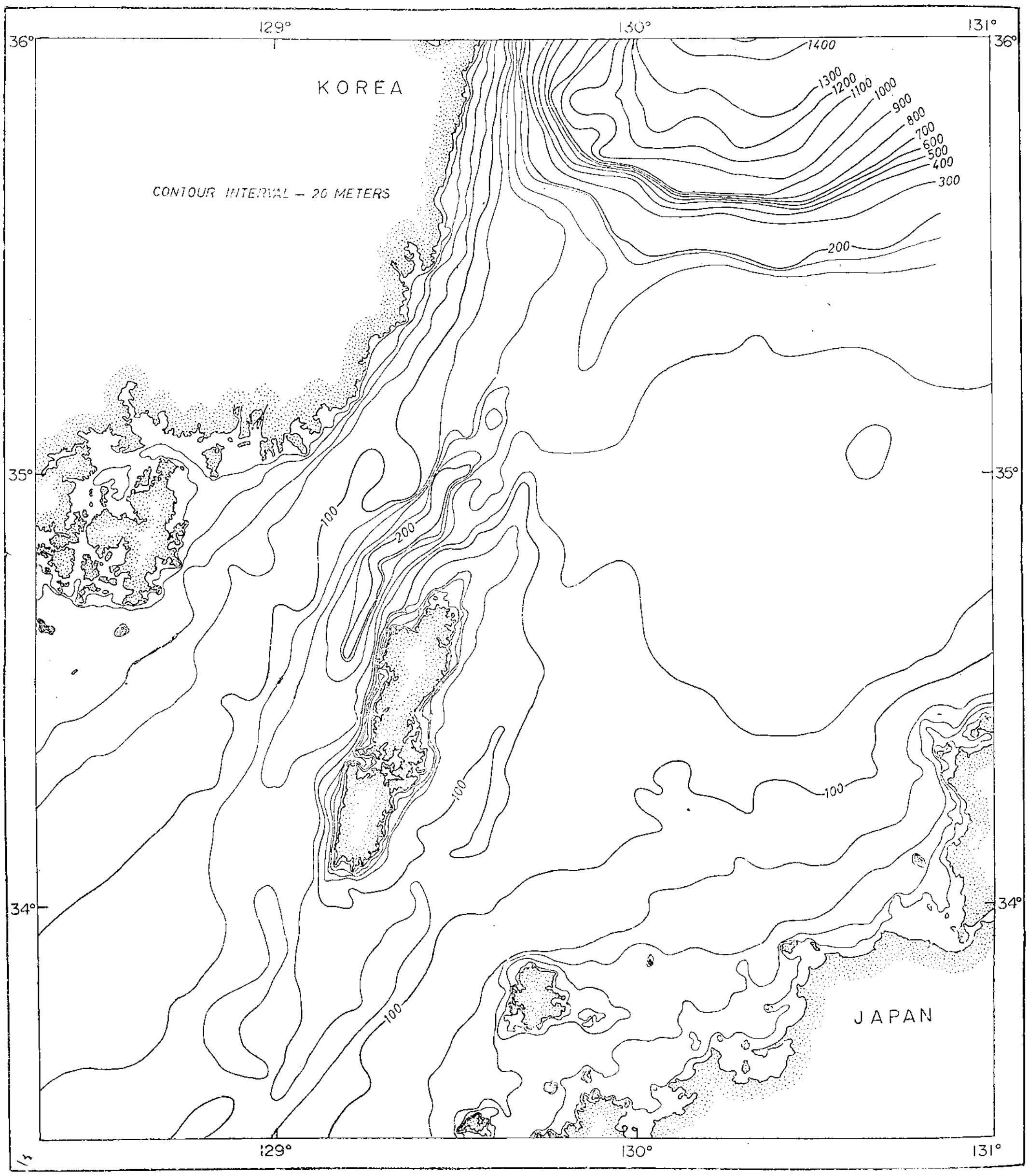


Fig. 1. Detailed bottom topography of the Korea Strait. Contours are based on soundings given on navigational chart. Depths are in meters.

## MATERIALS AND METHODS

The data used in this study are the results of oceanographic observations by the Imperial Fisheries Experimental Station of Japan and its branch stations in 1932—1945 (Semi-annual Report of Oceanographic Investigation, No. 59—69). Recent oceanographic data (1960—1967) collected by the Fisheries Research and Development Agency in Korea (Annual Report of Oceanographic Observation, No. 9—16) are also used. In order to see the seasonal variation, the former are used because observations were made every month. The latter are used for determining the southern limit of the cold water. Average values of temperature and salinity are based on the Oceanographic Handbook of the Neighbouring seas of Korea published in 1945. Only temperature and salinity are used in the analysis of water masses.

Although there are various methods proposed for the analysis of water masses by Helland-Hansen (1916), Wüst (1935), Parr (1938), Sverdrup *et al.* (1945), and Rochford (1963), each method has its own limitation. Gong (1962) analysed water masses in the western part of the Japan Sea with isentropic analysis; this method can be successfully applied where lateral mixing is predominant. Miyazaki and Abe (1960) applied the method of Sverdrup *et al.* (1942) for water masses of the Tsushima Current area, but it is inconvenient to study the origin of the water mass and its mixing process by this method.

In this paper, identification of water masses is made according to Helland-Hansen's original suggestion. In order to trace the moving path and mixing of the cold water, the core method (Wüst 1935) is used.

## RESULTS AND DISCUSSION

### Water Masses in the Korea Strait

The vertical structure of the water masses in the Korea Strait is demonstrated by the distribution of temperature and salinity along sections from Ulgi to Kawazirimisaki, Pusan via Tsushima to Hukuoka, Koje to Tsushima, and Izuhara to Hukuoka (Figs. 2—3). As the Tsushima Current flows from the southwest to the northeast, these sections meet most of the water masses of importance in this area.

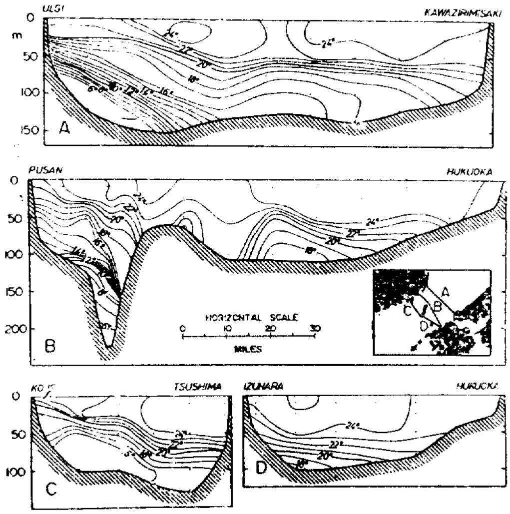


Fig. 2. Temperature distribution in vertical sections across the Korea Strait. Sections are seen from the southwest. Inserted map shows locations of the sections (October, 1933).

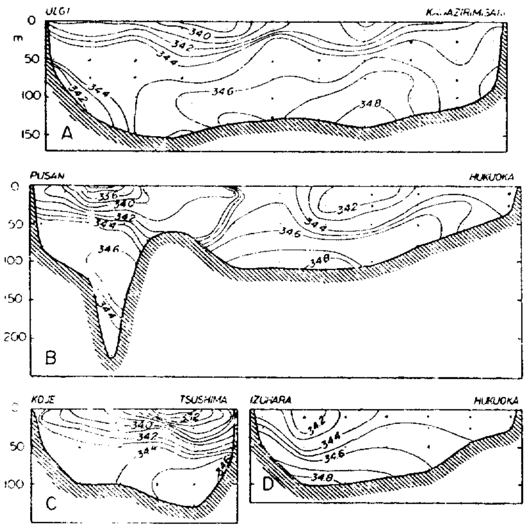


Fig. 3. Salinity distribution in vertical sections across the Korea Strait (June, 1932).

The distribution of temperaturs shows that in the eastern channel, only one discontinuity layer is recognized, while in the western part, two sharp discontinuity layers are noted in the sections from Ulgi to Kawazirimisaki and from Pusan to Hukuoka. The same characteristics of water stratifications are seen in the salinity distribution. It is easily recognized that in the western part of the Korea Strait, three different waters are situated vertically and in the eastern channel two different waters are stratified one above the other.

The temperature—salinity curves in the Korea Strait show a very simple structure (Fig. 4). As was seen from the distribution of temperature and salinity, three main water masses can be distinguished in the western channel and only two water masses can be identified in the eastern channel.

1. The Surface Water (Temperature maximum and salinity minimum)

This water is characterized by its high temperture and low salinity. It begins to appear when the sea surface is warmed and surface salinity is lowered by rainfall in June. Its temperature range is from 18° to 29° C and salinity varies from 32.0 to 34.0‰. It weakens gradually from November and disappears completely in January. The greatest depth of this water is about 50m in September. The surface water of the eastern channel has a slightly higher temperature and higher salinity than that of the western channel.

2. The Middle Water (Salinity maximum)

This water is characterized by salinity maximum (34.4-34.8‰). It is situated at near the 100 m layer in the western channel and at the bottom in the eastern channel. This core layer has considerable consistancy in its property throughout the year. Temperature at the core layer varies from 14° to 18°C. From February to May, this water occupies the whole strait and the waters of the Korea Strait are nearly homogeneous.

3. The Cold Water (Temperature minimum)

This water has minimum temperature and low salinities between 34.0-34.3‰. It is present only at the bottom layer of the western channel. Temperature ranges from 3° to 10°C and its minimum occurs in summer. From February to May this water does not appear at the bottom of the section from Pusan to Tsushima.

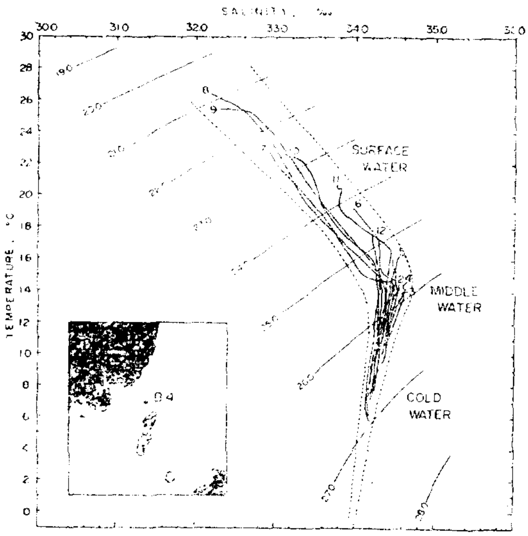


Fig. 4. Monthly T-S curves at the station B4. Temperature and salinity are values averaged using the data from 1922 to 1960 (25 years). Inserted map shows location of the station, and the numbers at the ends of T-S curves represent months.

According to Suda and Hidaka (1932), the stratification of water masses in the Tsushima Current area of the Japan Sea can be classified into the surface water, the middle water and the deep water. The middle water is a water mass of high temperature and high salinity and originates from the water in the intermediate layers of the Kuroshio off the west coast of Kyushu. But, Miyazaki and Abe (1960) made different conclusions in the identification of the water masses of the Tsushima Current. 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 other one which passes the western channel, is remarkably composed of the oceanic surface water mixed with the coastal water of the East China Sea and the western North Pacific Central Water indicated by Sverdrup *et al.* (1942).

These differences may be arisen from the methods adopted for analyses. Miyazaki and Abe used the method of Sverdrup *et al.* (1942). This method considers a straight line on a T-S diagram as a water mass, while the others methods adopt it as a result of the mixing of two water types. Hence, it is difficult to determine mixing ratio by this method. Miyazaki and Abe also failed to distinguish the cold water of the Korea Strait from the middle water represented as a straight line on a T-S diagram (Fig. 4). It seems that this method is not suitable for water mass analysis in this area.

**Origin of the Cold Water**

As the cold water is characterized by low temperatures and since it is always present at the bottom, the distribution of the bottom temperature can be used to determine the origin of the water mass. According to Uda (1934), the isotherm line of 10°C is discontinuous at the Korea Strait between the North Pacific and the Japan Sea.

Table 1. Monthly lowest temperature at 33° 36′N, 128° 10′E for 8 years (1960-1967).

| Month | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (°C) | 14.10 | 14.39 | 12.92 | 12.00 | 12.92 | 14.11 | 15.50 | 13.91 | 14.18 | 14.48 | 16.79 | 16.60 |

Bottom temperatures over the sill of the Korea Strait are above 10°C throughout the year, indicating that the water under 10°C is not carried to the Japan Sea by the Tsushima Current as shown in Table 1. The sill of the Korea Strait forms a barrier between the deep water of the Pacific and that of the Japan Sea. Under the 200 m depth in the Japan Sea, the homogeneous Japan Sea proper water (temperature 0° —1°C, salinity 34.00—34.05‰) occupies the whole basin, and its southern boundary is located at the 200 m-isobath of the Korea Strait. Since the water below 5°C may not be formed in the Korea Strait in winter, it is probable that the cold water mass is an outflow across the sill from the Japan Sea as suggested by Nisida (1955) and Chang and Uda (1968). As the cold water has temperatures above 3°C and salinities above 34.05‰, slight changes occur as it flows out.

**Seasonal Fluctuation of the Cold Water**

Characteristics of water masses in the Korea Strait show a great seasonal variation. As shown in Fig. 4, the surface water appears in June and vanishes in January of the following year. The middle water, being the core layer of the Tsushima Current, has comparatively stable consistency in its property. This water has only small variation in temperature and salinity in late winter.

The cold water shows the same kind of seasonal variation. Because it originates from the Japan Sea, it is always present at the bottom in the section from Ulgi to Kawazirimisaki throughout the year. The isopleths of temperatures at a station along the section from Pusan to Tsushima demonstrate the seasonal occurrence of the cold water (Fig. 5). As the cold water is under 10°C, the shaded area represents the time in which the cold water prevails. From June, the cold water begins to flow out across the sill and appears in the Pusan-Tsushima section. Bottom temperatures are lowered slowly and are in their minima in September, indicating that the outflow is strongest in August. The temperatures of the bottom layer begin to increase from November. In February,

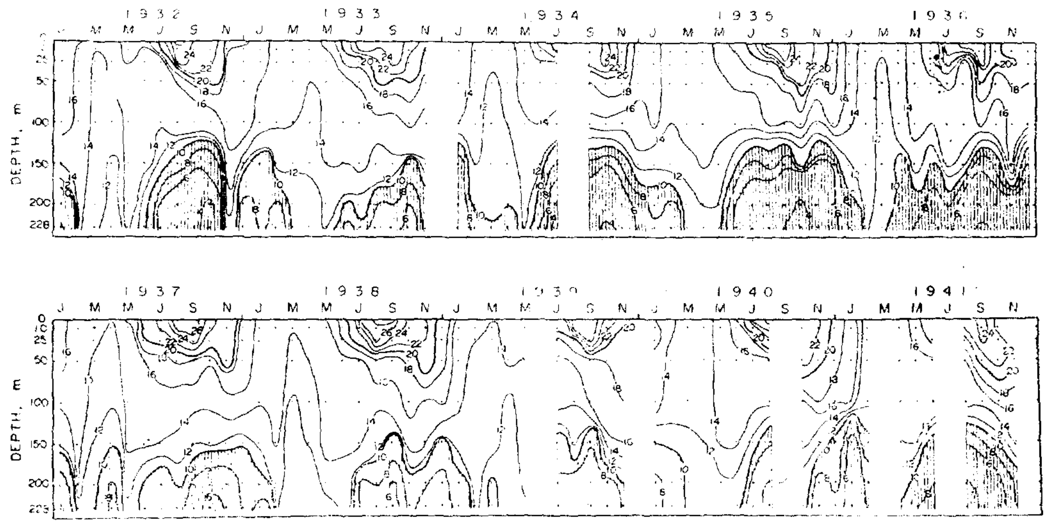


Fig. 5. Isopleths of water temperature at the station B4 (After Chang and Uda).

this water disappears and nearly homogeneous waters are formed.

But, this is a mean condition and there are remarkable yearly variations of the cold water. Sometimes this water completely disappears in a month (December, 1932) when the cold water in a normal year is still in its influence, and sometimes it appears in April (1937, 1939) when this water is supposed to be in a weak condition. Here it will be noted that the cold water is not of a stagnant nature, but swift enough to be renewed completely within a month.

### Southern Limit of the Cold Water

It is known that the bottom topography plays an important role on the current system in a strait (Defant 1961). The bottom topography of the Korea Strait shows a very irregular shape (Fig. 1). Isobath of 200 m in the Japan Sea is located near the western channel, and on the average the western channel is deeper than the eastern channel.

Moreover, in the western channel, there lies a depression deeper than 200m to the north of Tsushima, which extends northeastward. These differences in bottom topography are thought to be one of the factors causing the differences in their water masses. The cold water exists only in the western channel and its movement seems to be closely related with the bottom topography.

As shown in Fig. 2, the cold water is clearly seen in tne Ulgi-Kawazirimisaki and Pusan-Hukuoka sections; but in the Koje-Tsushima section, it can not be found. Therefore, the southern limit of the cold water is assumed to be located between these two sections. Though there are plenty of cross sectional data of the strait, none are available which covers along the strait longitudinally. Hence with the data now available, it is impossible to conclude exactly where the southern limit is. Nisida (1955) reported that the southern limit would be at the 200m isobath of the depression. Since the cold water fluctuates seasonally, the limit is considered to be changed in accordance with it.

For the past 10 years from 1932 to 1941, cross sectional observations along the Koje-Tsushima section were made only 19 times. Among these data, there is none which definitely shows the presence of the cold water in this section. But the present data show the presence of the cold water flowing far south to the west of Tsushima

(Fig. 6).

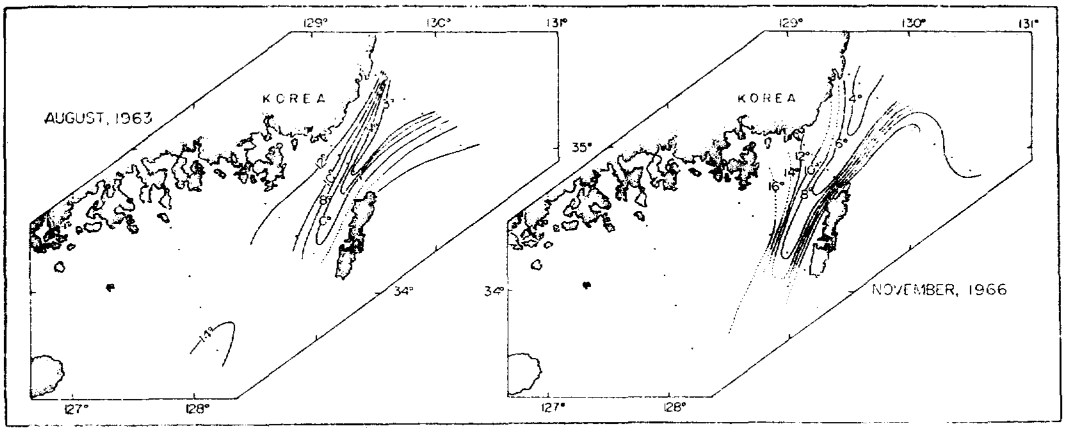


Fig. 6. Horizontal distributions of temperature in the bottom layer of the Korea Strait.

## Upwelling along the Korean Coast

As seen in the vertical temperature section from Ulgi to Kawazirimisaki the boundary layer between the cold water and upper water masses always slopes downward to the east and the cold water is pressed to the west (Figs. 2, 7). This water shows a rising trend near the coast of Korea. Generally, the thin layers of surface and middle water cover this cold water and when these thin layers of upper water are deflected offshore, cold water rises near the surface. Temperature differences between adjacent areas are more than 10°C (Fig. 7). From a review of the observation data, it is noted that the most common upwelling area is in the vicinity of Ulsan. It is rare that the cold water rises to the surface in the Pusan-Tsushima section.

## Mixing and Moving of the Cold Water

Since the cold water flows out of the Japan Sea along the bottom, the vertical mixing is predominant. In Fig. 8, Jp represents the Japan Sea proper water and O indicates the last trace of this water. The dividing of the interval between Jp and O into 100 parts allows the determination of the percentage influence of each individual component at any point. Average tem-perature and salinity show that in September the cold water at the deepest bottom of the Pusan-Tsushima section is made of about 64% of the Japan Sea proper water.

In other months, less water from the Japan Sea is contained in the cold water (Table 2). Since this is an average value, great variations are expected.

The moving paths of the cold water can be traced from bottom temperature distribution. In Fig. 9, monthly moving paths of the cold water for 10 years are represented. In July and August it passes the bottom about 8 miles east off Ulgi in Ulsan, and in September, the core is located about 18 miles off Ulgi. But in October, November and December, the core moves close to the Korean coast again. In January, the cold water flows along the bottom about 18 miles off Ulgi.

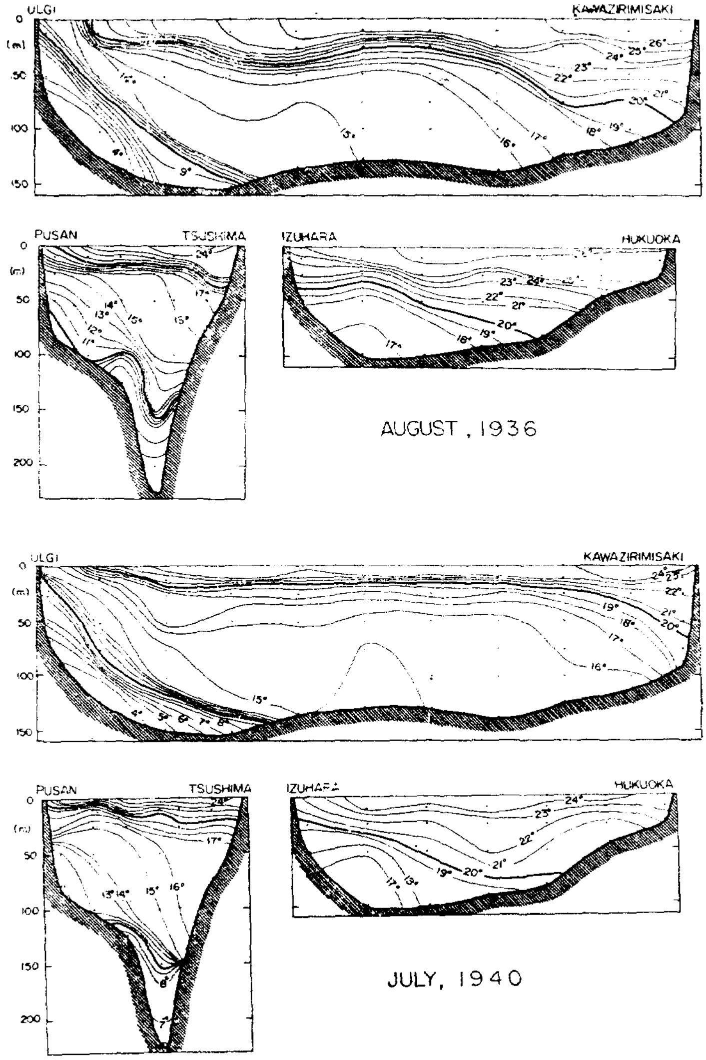


Fig. 7. Vertical temperature distributions when the upwelling occurred in the Korea Strait.

It can be seen that the general moving path of the cold water is on the bottom about 8 to 18 miles off Ulgi.

Nisida (1955) and Fukuoka (1962) explained the movement of the cold water as an intrusion of cold water into the Korea Strait. According to Nisida, the cold water flows southward across the sill from June, but outflow is obstructed by the long distance of the sill and remains at the bottom of the western channel. But careful examination of the data shows that the movement of this water can not be explained merely as an intrusion. There are several points to be noted. First, the bottom temperatures of St. B4 along the section from Pusan to Tsushima shows gradual decrease from June to September, indicating that in this time there is a continuous transport of the cold water at the bottom from the Ulgi-Kawazirimisaki section to Pusan-Tsushima section. Second, as was pointed out previously, the cold water is not of a stagnant nature, but swift enough to be renewed in a month. Thirdly, the upwelling phenom-

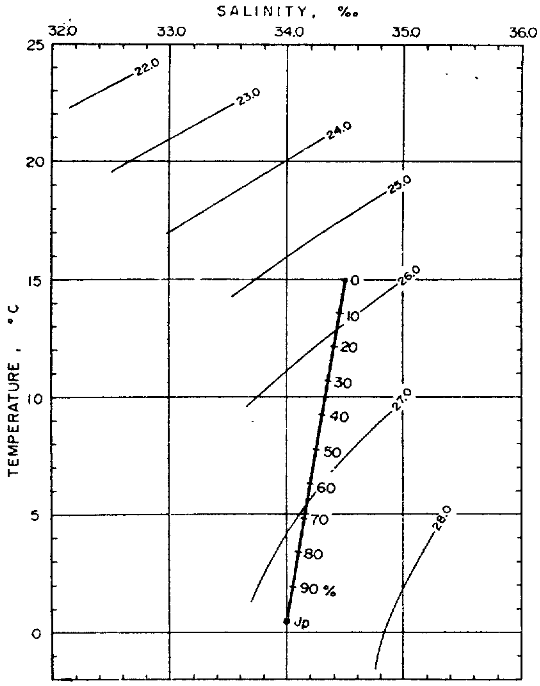


Fig. 8. Average T-S relationship for the core layer of the cold water in the Korea Strait.

enon of the cold water along the Korean coast can not be explained by intrusion because the cold water has large density. Fourthly, because of its bottom topography, it is supposed that there may exist a vortex movement at the depression in the western channel, which means a considerably intense mixing between water masses. In order to sustain an unchangeable bottom temperature, there must be continuous replenishment of the cold water.

According to Defant (1961), the characteristic feature of a strait is the interchange current system. But, the Korea Strait has somewhat different features from those straits described by Defant. The Japan Sea is not completely sorrounded by land and is connected with the open ocean through four straits. Most of the water transported by the Tsushima Current through the Korea Strait flows out into the Pacific through the Tsugaru Strait (Hata 1962). The sill of the Korea Strait is very

Table 2. Average percentage of the Japan Sea Proper Water contained in the cold water mass.

| Month | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. |
|---|---|---|---|---|---|---|---|---|
| Percentage (%) | 37 | 52 | 62 | 64 | 53 | 50 | 54 | 50 |

long and it seems difficult for the undercurrent to flow out into another ocean because of this barrier.

In spite of these features, the stratification of water masses in the western part of the Korea Strait reveals very similar characteristics to those straits which have undercurrents. Particulary, the cold water has in many points the character of an undercurrent. From June to September, this water flows continuously at the bottom from the Ulgi-Kawazirimisaki section to the Pusan-Tsushima section. As this flow is obviously of the character of a current, it seems reasonable to call it an undercurrent. This flow generally can not reach the Koje-Tsushima section and most of the water seems to be returned to the Japan Sea after mixing with upper water as shown in Fig. 10. However, sometimes this current flows far to the west of Tsushima, but it has not been confirmed whether this water flows further south (Fig. 6). Generally the area of flow seems to be confined to the west of Tsushima and it may be stated that it does not transport the water to the other ocean. From Fig. 5, it is known that this current is strongest in August and after that time the intensity decreases slowly.

The upwelling along the Korean coast can be explained if the cold water is of the character of an undercurrent. According to Defant (1961), in a strait which has interchange currents, the boundary layer between these two currents usually slopes longitudinally and transversally. The trans-

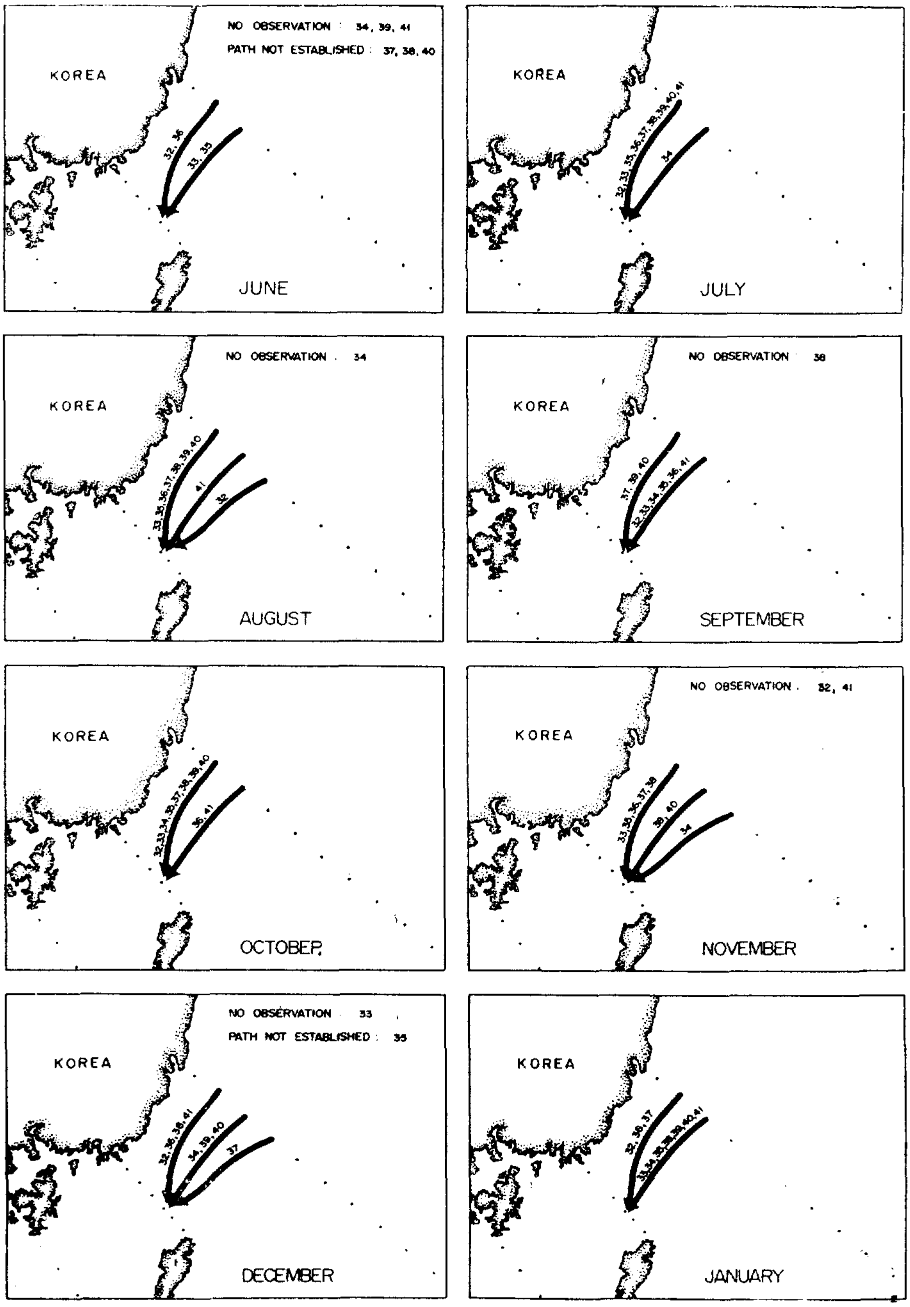


Fig. 9. Monthly moving paths of the cold water. Numbers represent years (1932-1941).

versal slope of this kind is clearly seen in Fig. 2. It is known that the faster the currents and wider the strait the greater will this slope be. For quite a large width of the strait the inclination may be so steep that in a narrow strip along the coast the heavier water moving in the opposite direction may rise to the surface and there will be a front with currents flowing in opposite directions on either side. This kind of oceanographic conditions are often met in the western channel of the Korea Strait. According to Nisida (1927, 1928, 1930), sometimes in the Korea Strait opposite directions

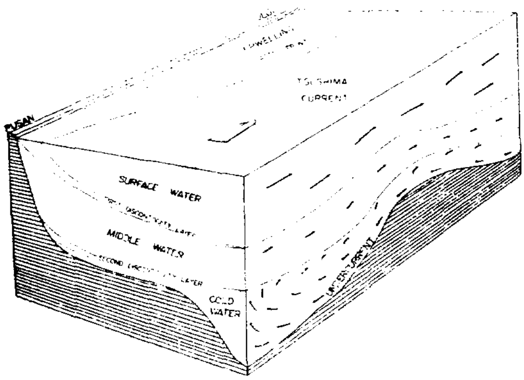


Fig. 10 Schematic representation of the currents and water masses in the western channel of the Korea Strait.

are revealed between near-shore and off-shore currents. The upwelling phenomenon and opposite currents are good indications that the cold water forms an undercurrent.

Since there are no data which cover the strait longitudinally, present knowledge on the cold water and its movement appears somewhat incomplete. Further observationsand measurements are required for the details to be clarified.

## SUMMARY

In the western channel of the Korea Strait, the surface water, the middle water and the cold water are situated vertically, while only two water masses, the surface water and the middle water, are identified in the eastern channel. The cold water is present only in the western channel and originates from the Japan Sea. This water shows large seasoal variations; it begins to appear in the Pusn-Tsushima section in June and vanishes in February. Sometimes it shows abrupt change within one month. The southern limit of the cold water is not confirmed exactly, but, sometimes it reaches to the west of Tsushima. The boundary layer between the cold water and upper waters slopes downward to the east and the cold water shows a rising trend near the coast of Korea. When the thin surface layer is deflected off-shore, this water rises to the surface. The mixing with upper waters takes place vertically and in order to detrmine the mixing ratio, the average T-S relationship was established. The path through which the cold water flows is at the bottom about 8 to 18 miles southeast off Ulgi. From these facts, it was concluded that the cold water flows as an undercurrent along the bottom from Ulgi-Kawazirimisaki section to the Pusan-Tsushima section in summer and autumn, and is strongest in August.

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