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THE MOVEMENT OF THE COLD WATER IN THE KOREA STRAIT

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ABSTRACT

From available data, the movement of the cold water in the Korea Strait was investigated. The cold water forms an undercurrent with a speed of 0.10 knots near Ulgi in June. Sometimes it reaches a speed of 0.35 knots. The cold water forms a sharp wedge in the western channel like a salt wedge in an estuary. The calculated volume transport of the cold water is 17,135 cubic meters per second in June. The external influences are also discussed.

INTRODUCTION

The Korea Strait is one of the most extensively surveyed areas in the world. From 1926, cross-strait oceanographic surveys have been carried out nearly every month in three or four observation lines (Fig. 1). The presence of a very cold water at the bottom of the western channel of the Korea Strait was found from these early observations and it has been studied by many hydrographers.

Though the general properties of the cold water in the Korea Strait have been described by Nisida (1927, 1955), Fukuoka (1962), and Lim and Chang (1969), conclusive descriptions were not given concerning the movement of the cold water. The objective of this study was to determine, the movement of the cold water, and to describe the exact shape of the cold water wedge in the western channel of the Korea Strait. A discussion was made concerning the factors affecting the cold water movement.

Data used in the present analysis were the same as those used by Lim and Chang (1969). Additional data of longitudinal observations were taken from the Oceanographical Chart of the Neighbouring Seas of Korea for the year of 1928 published by the Fisheries Experiment Sta-

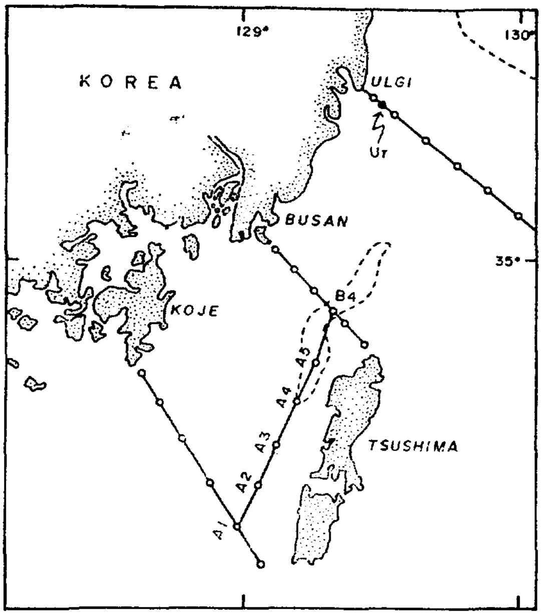

Fig. 1. Station position in the Korea Strait. Dashed lines show the 200 meter isobath.

tion of Korea. The results of current measurements were taken from Nisida (1927) and Lee(1970).

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THE COLD WATER WEDGE

The longitudinal temperature sections in the Korea Strait are shown in Fig. 2. This represents the monthly variation of vertical temperature distribution from January to October in 1928. Isotherms are crowded near 10℃ and this layer constitutes a boundary layer between the cold water and upper water. The shape of the cold water is a sharp wedge which extends to the south-western part of Tsushima. This cold water wedge is just like a salt wedge of an estuary in its shape and character (Farmar and Morgan, 1953).

The thickness of the cold water wedge south of Station A3 is 15 meters and near the tip is 5 meters. In the basin near St. B4, the thickness is 95 meters in September and in the other months it is not so thick, but generally it exceeds 50 meters (Table 1). Near Ulgi, the thickness of the cold water is 43 meters in September (Table 2). The width of the cold water at the bottom near Ulgi is about 30 miles in summer and about 20 miles in late autumn. Near Tsushima it is about 8 miles due to bottom topography. The thickness and width of the cold water both varies

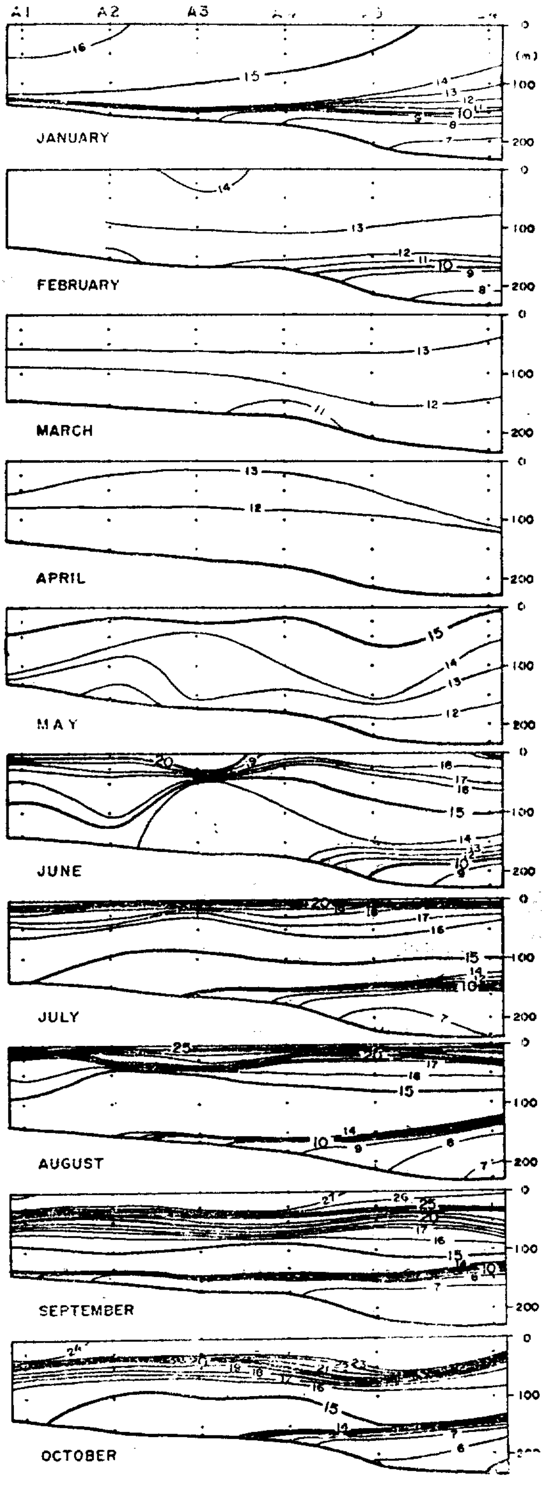

Fig. 2. Vertical temperature distributions in a longitudinal section in the Korea Strait in 1928.

during the year and shows maximum value in summer and autum.

Table 1. Thickness of the cold water wedge in the Korea Strait from 1928 to 1930 (Thickness in meters)

Year	Month	Station					
		A1	A2	A3	A4	A5	B4
1928	Jan.	5	10	15	30	60	80
	Feb.					40	60
	June					10	50
	July			5	20	60	75
	Aug.				25	55	90
	Sept.		15	15	23	65	95
	Oct.				20	55	85
1929	Jan.						40
	Apr.						30
	Dec.					20	50
1930	Jan.		5	10	20	65	58
	July						40

Table 2. Monthly variations of mean slope of the boundary layer and properties of the cold water near Ulgi in the Korea Strait

Month	Slope (*m/km*)	Thickness of Cold Water (*m*)	Width (mile)	Bottom Temperature (°C)
Jan.	1.51	20	17	7.15
Feb.	1.78	10	18	9.03
May	0.97	8	30	8.28
June	1.68	18	20	4.71
July	1.94	36	23	3.93
Aug.	2.21	37	30	4.92
Sept.	2.16	43	30	5.29
Oct.	2.16	33	30	5.78
Nov.	1.78	30	23	4.54
Dec.	1.73	24	20	7.16

The location of the tip of the cold water wedge varies monthly (Fig. 2). In January, 1928, the cold water wedge extended to St. A1. The influence of the cold water became weak in February and from March it disappeared completely in the vicinity of Tsushima. In June, it appeared at St. B4 again and from July it flowed out southward along the bottom of deep basin basin near Tsushima. It reached St. A3. In September, the thickness of the cold water became 15 meters at St A4. As is apparent in Fig. 2, the location of the southern tip varies depending upon the intensity of the western side of Tsushima.

The boundary layer between the cold water and the upper waters slopes downward to the east. Monthly variation of the slope of the boundary layer varies from 0.97m/km to 2.21 m/km (Table 2). The highest value appears in August and the lowest in May. From August to October, the slope is generally steep and afterwards it decreases.

Table 3 shows the mixing ratio of the cold water with the Tsushima Current water in the longitudinal section in 1928. Calculations were made according to Lim and Chang(1969). The cold water lost half of its properties of the Japan Sea Porper Water at St. B4 and the tip of the

Table 3. Mixing ratio of the cold water with the Tsushima Current water at the bottom of the Korea Strait in 1928. Numbers are percentage of the Japan Sea water contained in the cold water

Month	Station					
	A1	A2	A3	A4	A5	B4
Jan.	32	34	36	47	51	57
Feb.					43	50
June					32	42
July			31	42	55	50
Aug.				39	47	56
Sept.	30	50	52	52	57	60
Oct.				43	60	66

water contained only about 30 percent of the original Japan Sea water.

THE MOVEMENT OF THE COLD WATER

There are few measurements of the current in the western channel of the Korea Strait. Fig. 3 shows a result of current observation made in June, 1925 at St. Ur 4 miles off Ulgi. The velocity and direction are values of the resultant current observed for 25 hours. Surface water flows northeasterly with a speed of 1.46 knots and at 50 meters the speed is 1.23 knots. However, the current at 35 meters shows an opposite diretion and remarkable decrease in its speed. The speed is 0.10 knot and its direction of flow 216°. The temperature of the 50 meter layer is 14.3 °C, while that of 85 meter layer is 6.3°C. The difference is more than 7°C. From this, it is easily recognizable that the water at the bottom is the cold water which originates from the Japan Sea. Hence, it is evident that the cold water forms an undercurrent with a speed of 0.10 knots near Ulgi in June.

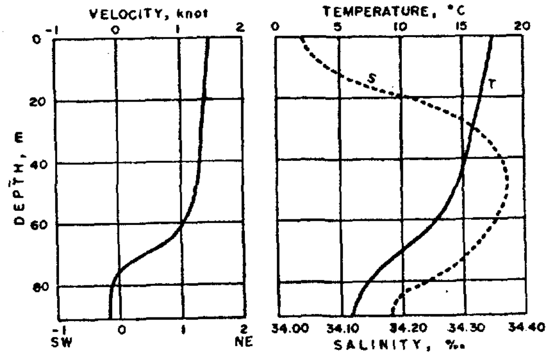

Fig. 3. Vertical distribution of current speed, temperature and salinity at St. Ur in June, 1925.

In Table 4, the results of current observations show the southwesterly current in the Korea Strait. The current near Ulgi in August, 1926 reveals a strong southwesterly flow from the surface to the bottom. The speed at 5 meters is 0.22 knots and at 50 and 85 meters 0.35 and

Table 4. Results of current observations in the western channel of the Korea Strait

Station	Date of Observation	Depth (*m*)	Current Direction (o)	Current Velocity (knot)	Mean Temperature (°C)	Mean Salinity (‰)	Source
Ur	June 13-14, 1925	5	27	1.46	17.2	34.05	Nisida(1927)
		50	21	1.23	14.2	34.47	
		85	216	0.10	6.3	34.19	
Ur	Aug. 21-22, 1926	5	615	0.22	16.2	33.76	Nisida(1927)
		50	59	0.35	4.2	34.28	
		85	196	0.30	3.5	34.38	
Ur*	Aug. 22-23, 1927	5	133	0.32	19.1	32.59	Report of Annual Hydrog. Obs. (1933)
		50	174	0.31	8.5	34.31	
		100	45	0.05	4.3	34.18	
B4	Aug. 26-28, 1968	5	52	0.91	27.41	—	Lee(1970)
		20	67	0.85	24.85	33.29	
		50	156	0.49	18.83	34.36	
		150	145	0.58	11.34	—	

* one mile east of Station Ur.

0.30 respectively. The influence of the colp water reaches even up to the 50 meter layer, showing the temperature of 4.2°C. This phenomenon can be explained as being the surface water deflection from the Korean coast (Lim and Chang, 1969). The results of current measurement in August, 1927 also show the same trend. But there is no flow at the bottom in 1927. The southward undercurrent was also observed at 50 and 150 meters of St. B4 in August, 1968(Lee, 1970). Temperature and salinity values observed at this time do not show the cold water's presence in these layers. It is not certain whether the cold water influenced this current or not.

From these results, it can be seen that the cold water forms an undercurrent with a speed ranging from 0.10 to 0.30 knots.

Using the speed of the undercurrent in June, 1925, the volume transport of the cold water into the Korea Strait was calculated. It was 17,135 cubic meters per second. The depth and width of the cold water for computation was determined from average values of temperature and salinity in the Ulgi-Kawazirimisaki section.

DISCUSSION

The movement of the cold water was described as an "intrusion" by Nisida(1927) and Fukuoka(1962). Recently Lim and Chang(1969) described it as an undercurrent which flows out from the Japan Sea along the bottom toward Tsushima. In Fig. 3, the cold water shows a velocity of 0.10 knots toward the Korea Strait near Ulgi in June, 1925. This velocity of the cold water seems to be the normal speed of the undercurrent in the area because the distribution of temperature and salinity shows the average pattern of the area and its stratification is also a typical one. When the cold water is abnormally strong, there exists even stronger southwesterly flow of the cold water from surface to bottom with a speed of 0.35 knots. These results conclusively show that the cold water forms an undercurrent in the Ulgi area.

Monthly variations of various properties of waters in the Korea Strait is represented in Fig. 4. Surface temperature shows its maximum in August and minimum in March, while the surface density reveals its minimum in August and maximum in March. From June, surface temperatures rise above average value and surface density lowers below average. It is known that in a strait the dynamic cause of currents lies in the density difference (Defant, 1961). The appearance of the cold water at St. B4 and surface density dec-

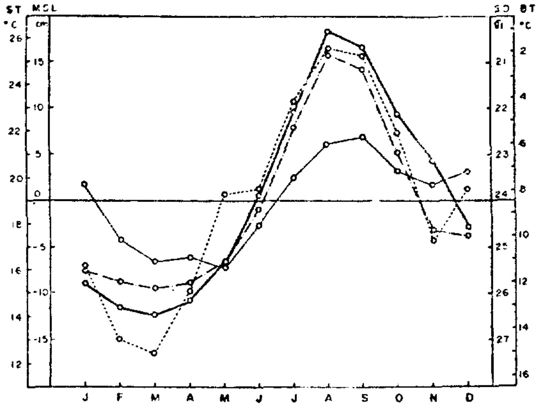

Fig. 4. Monthly variations of various properties of waters in the Korea Strait. —, surface temperature (ST); ——, bottom temperature (BT); ——·——·, surface density (SD); ············, mean sea level (MSL).

rease below σ_t 24.20 seems to be closely related. The cold water flows out when the surface density decreases below σ_t 24.20.

Variation of mean sea level at Busan shows the same trend as the surface temperature. Mean sea level is highest in summer and is closely related with density variation (Yi, 1967). The cold water flows out strongly when the mean sea level is high at Busan.

The depth of the moving path of the cold water near Ulgi is varied from 120 to 140 meters while the deepest place is 150 meters about 30 miles off Ulgi. It seems that the speed of the undercurrent is strongest near Ulgi and weakens approaching to Tsushima because the cold water slides down over the sill into the depressed basin near Tsushima, the width of the cold water in this area is about 8 miles. Approaching to the southwestern part of Tsushima, the cold water forms a wedge. In the wedge, as is evident in a salt wedge of an estuary, the velocity of the cold water is very weak (Bowden, 1967).

During flood tide the water flows southwesterly in the Korea Strait. Since the northeasterly Tsushima Current is strong near surface, the tidal current is overcome and water flows northeasterly into the Japan Sea. However, at bottom layer southwestward tidal current is very strong because the velocity of the Tsushima Current is weak. This tidal current seems to accelerate the movement of the cold water in the southwest direction.

After Suda *et al.* (1932)'s study, many attempts have been made to calculate the speed of the Tsushima Current using temperature and salinity data (Miyazaki, 1952; Yi, 1966). Hidaka and Suzuki (1950) studied the secular variation of the Tsushima Current by use of the slope of the boundary layer between the cold water and upper waters. They assumed that the velocity of the bottom layer is zero. From Fig. 3, it is evident that the cold water flows with a definite speed. Their assumption of stagnant cold water is not well-grounded. Lee (1970) also pointed out that there are discrepancies between the values observed current and computed current. Hence, it seems necessary to examine the validity of the dynamic computation method applied to the Tsushima current in the Korea Strait.

There are few studies concerning the movement of the Japan Sea Proper Water. Therefore, it is not certain whether the cold water flow in the Korea strait is closely related with it.

SUMMARY

From available data, the movement of the cold water from and its shape of wedge in the Korea Strait was investigated. The cold water forms a sharp wedge in the western channel of the Korea Strait like a salt wedge in an estuary. The location of the tip of the cold water varies monthly and its general position is in the basin west of Tsushima. The thickness of the cold water wedge is 5 meters at the tip, about 20 meters in the vicinity of Tsushima and over 50 meters at St. B4. The width of the cold water is about 30 miles near the western side of Tsushima. The slope of the boundary layer between the cold water and the

upper waters has the highest value of 2.21 m/km in Angust. The southwesterly velocity of the cold water in the Korea Strait is 0.10 knots in June. At times when the cold water reaches near the surface, the undercurrent shows a speed of 0.35 knots and from surface to bottom a southwestward flow is doninant. The calculated volume transport of the cold water was 17,135 cubic meters per second. The cold water movement is related with the decrease of surface density in the strait. Bottom topography and tide also affect the movement.

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