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Characteristics of Front near the Cheju Strait in Early Winter

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Off the southwest coast of Korea, changes in hydrographic fields from stratified state of summer to a vertically homogeneous one of winter appeared to occur most actively in November. During this transitional period coincident thermal and salinity fronts are formed along the boundary between the two water masses of cold coastal water with low salinity and of the Tsushima Currrent Water. Generally frontal zone lies where the bottom depth is about 70-90m except for the central region of the Cheju Strait in which the influence of the Tsushima Current is weak. Result of the drift bottle experiment in November 1980 supports the existence of the westward coastal current.

Introduction

Physical conditions of the Yellow Sea are quite different from those of the southern sea of Korea. While the influence of strong tidal current is important in the former region, fluctuations of the Tsushima Current dominate the environment of the latter. Both regions also have the characteristic water masses respectively and they are interconnected through the Cheju Strait. Therefore various water masses including the Tsushima Current Water, the Korean Coastal Water, the East China Sea Water and the Yellow Sea Bottom Cold Water are expected to be under the complicated lateral interaction around the Cheju Island.

Kang (1974) studied the seasonal variation of the water masses in the southern sea of Korea. Lim (1973) studied the movements of water masses off the south coast by means of hydrographic data. Gong (1971) investigated the general characteristics of fronts and their relation to the fishing ground in the southern sea. Since then any remarkable research on the front off the south coast has not followed. Moreover, the distribution and interaction of water masses near the Cheju Island have not been explored carefully. According to the previous works, the vertical distributions of temperature and salinity show rather stable stratification in October, but in December, such stratification is destroyed so that the typical winter conditions prevail. Therefore the environment in November can be regarded transitional from the stratified state in late fall to the homogeneous one in winter. The cooling process due to the excessive heat loss and its influence on the alteration of the hydrographic field during this transitional period should be known in order to understand the frontal dynamics in winter. However, unfortunately, there are few observations in November because most routine surveys have been conducted in the even months. Accordingly, the November-data were used in describing the hydrographical conditions and its variability around the Cheju Island.

Data

From 16 November to 3 December 1977, hydrographic survey covering 72 stations was conducted around the Cheju Island (Fig. 1). Line S in Fig. 1 represents the hydrographic stations of the Korea Strait-East China Sea-Yellow Sea Remote Sensing Experiment (KEYRSEX-80). During this experiment the drift bottles were released at three points in the coastal area of the southern sea(Fig. 11). At each station, 300 bottles were released.

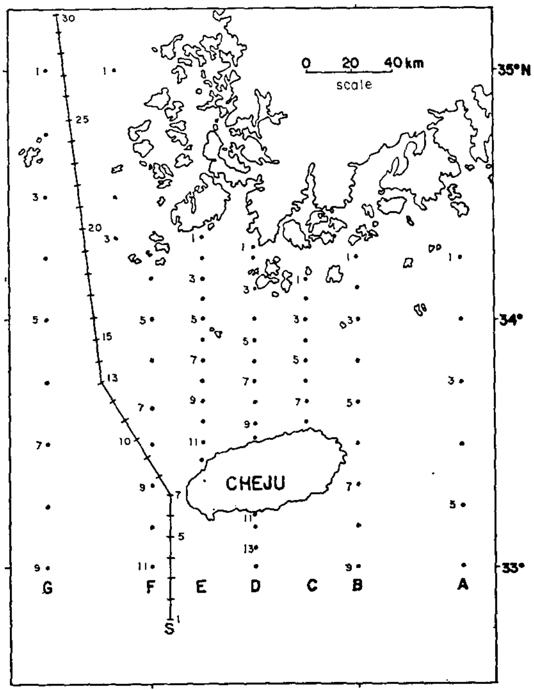

Fig. 1. Study area in the southwest sea of Korea. Shown are the 72 stations in 1977 and the cruise track with 30 stations in 1980.

Results and Discussion

Cooling processes during late fall cause both of coastal water and warm offshore water to decrease in temperature and induce an active vertical mixing. In the coastal regions, in addition to the heat loss and wind effect, strong tidal current also plays a significant role in vertical mixing of the fresher shelf water. With the continuous supply of warm and haline water from the Tsushima Current which is also nearly homogeneous, a pronounced front in the form of a vertical wall develops in the boundary region between the two water masses.

Fig. 2 shows the horizontal distributions of temperature and salinity at the sea surface. Since it had taken 18 days to cover the whole stations, Fig. 2 can hardly be considered as a result of simultaneous observation. Nevertheless, the coastal water with temperature lower than 16°C and salinity less than 33.4‰ is distinguished from

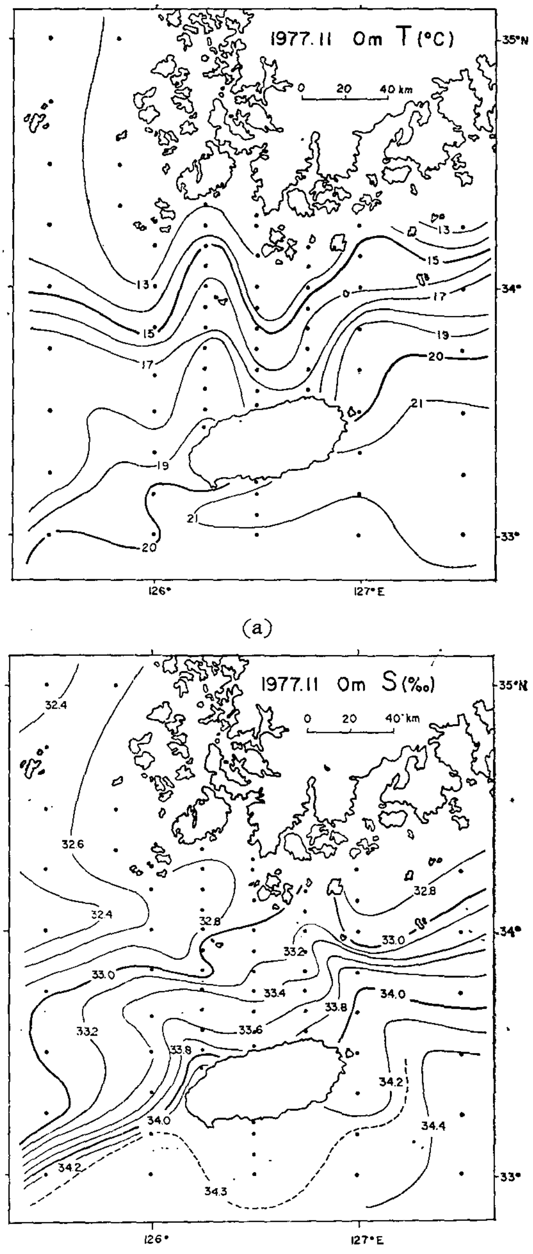

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Fig. 2. Horizontal distributions of temperature and salinity at sea surface 16 Nov.—3 Dec. 1977.

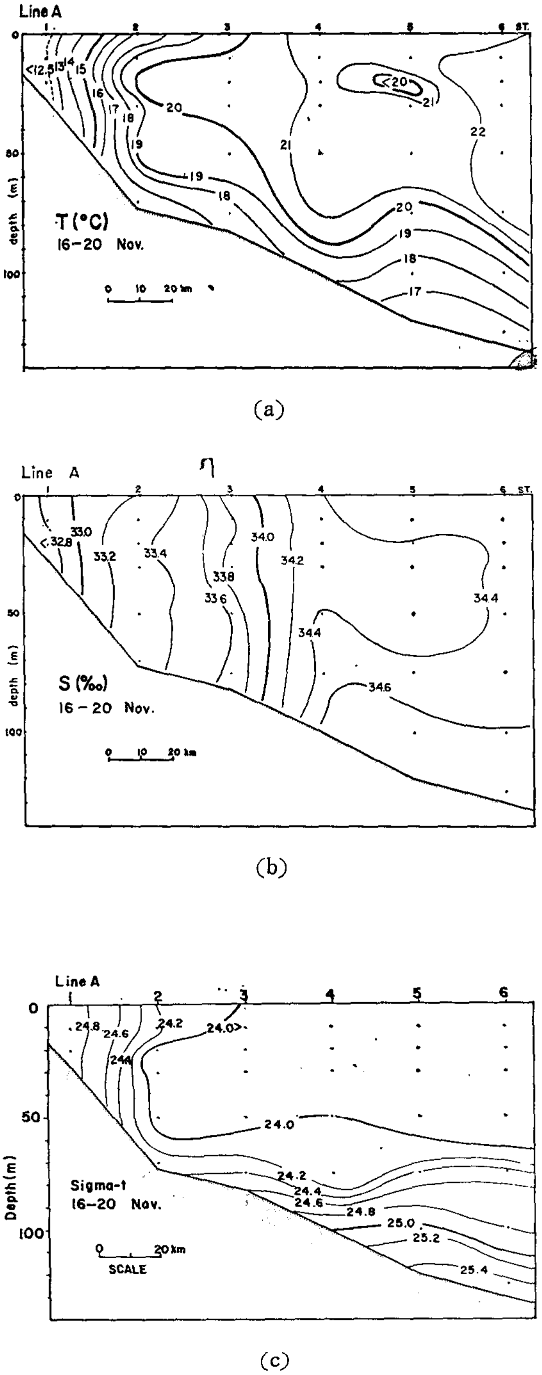

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Fig. 3. Vertical distributions of temperature, salinity and density at Line A.

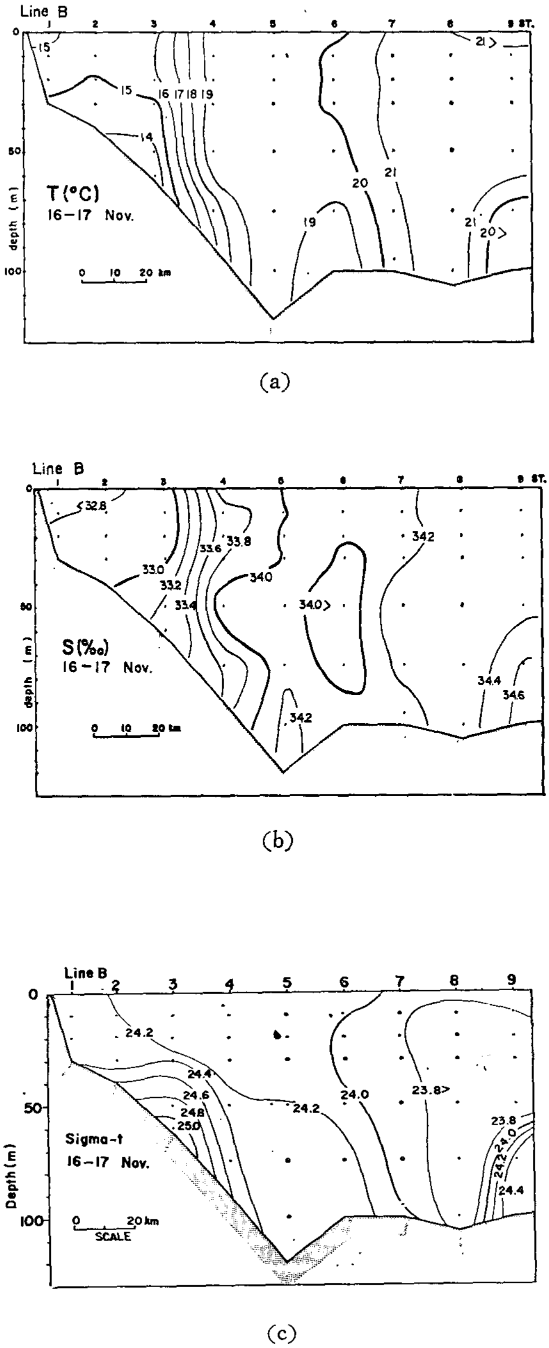

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Fig. 4. Vertical distributions of temperature, salinity and density at Line B.

the warmer (> 18°C) and more haline (> 33.8‰) offshore water. Eastward intrusion of the fresher water (less than 32.6‰) off the southwest coast is noticeable.

Because our interest is concentrated in the cross-frontal structure, the cross sections are examined in detail. Fig. 3 shows the T and S sections of the front east of the Cheju Strait. Thermal front with strong temperature gradient is located near the St. 2. On the whole, temperature inversion prevails to the subsurface layer of 10-30*m* depth. Unstable stratification caused by the density inversion is particularly outstanding near the front. Continuous overturning is expected. Salinity gradient is not so strong. Both of the shelf water and the offshore water are fairly homogeneous in the vertical and temperature as well as salinity increase from 12.5°C and 32.8‰ near shore to about 20°C and 33.6‰ in the Tsushima Current region. Although the temperature and salinity gradients have a tendency to minimize the density contrast through a compensating effect on density (Mooers *et al.*, 1978), sigma-t decreases offshore from about 24.8 near shore to 24.0 south of the front (Fig. 3-c). Compensating effect by salinity would be insufficient to overcome the temperature contrast. Because the coastal cold water has a relatively greater density it would sink and spread as a bottom water. This cold water region corresponds to the source area of the heavy bottom water as Lim(1976) suggested.

In the sections of Line B the thermal and salintiy fronts coincide apparently between St. 3 and St. 4(Fig. 4). Here, the compensating effect of temperature and salinity on density appears efficient.

In the central regions of the Cheju Strait, any strong front with sharp gradients of T and S does not appear because the influence of the Tsushima Current is weak. For example, cross sections of the Line D(Fig. 5) show no distinct front. There is a temperature inversion near the Cheju Island but it does not produce a density inversion. Cold (< 13.0°C) and fresher (< 33.0‰) water off the northern coast in the Cheju Strait represents the coastal water mass. Complex distribution of salinity seems to imply the active mixing of the coastal water off the southwest coast of Korea, East China Sea Water and Tsushima Current Water entering the strait.

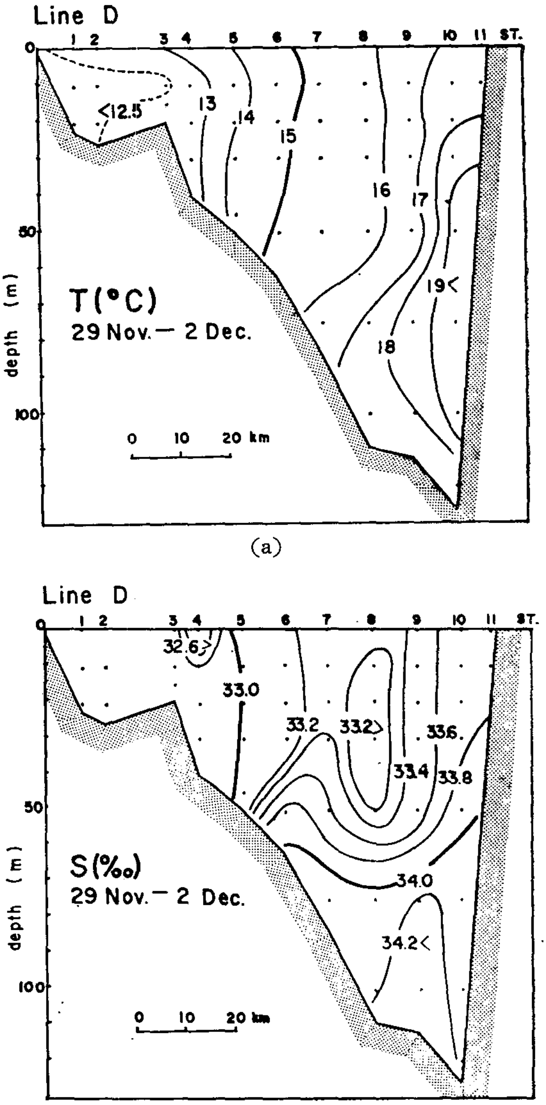

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Fig. 5. Vertical distributions of temperature and salinity at Line D.

Fig. 6 show the sections of Line F just west of the Cheju Island. Three water masses are distinguishable; coastal water off the southwest coast of Korea lower than 14°C and 33.2‰,

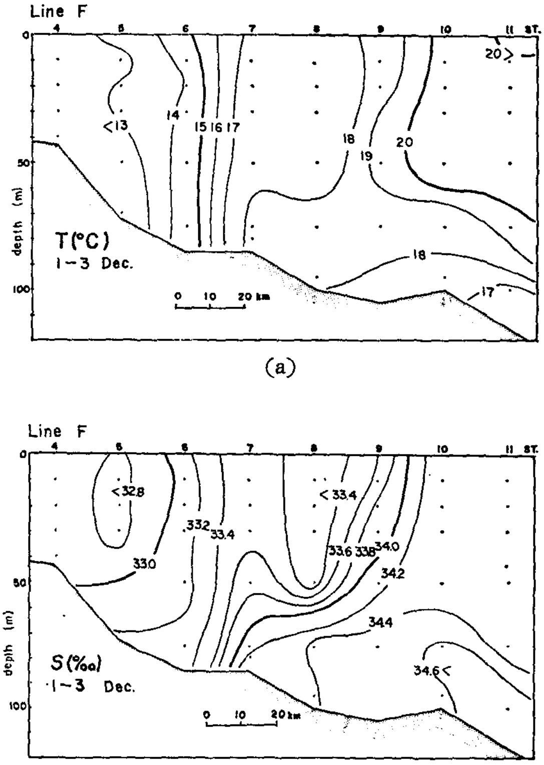

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Fig. 6. Vertical distributions of temperature and salinity at Line F.

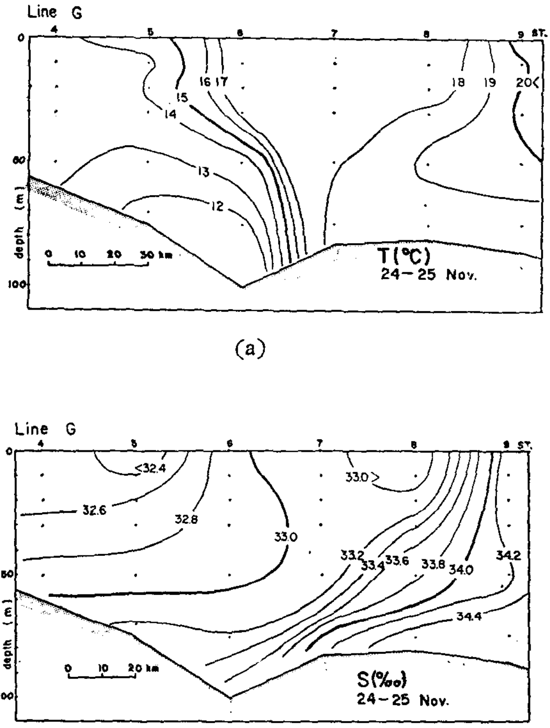

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Fig. 7. Vertical distributions of temperature and salinity at Line G.

Tsushima Current Water greater than 19°C and 34.0‰, and East China Sea Water in the intermediate region. More distinct separation of these water masses is possible along the Line G (Fig. 7). Cold bottom water (<12.0°C) near the St. 5 and St. 6 is believed to be an extension of the Yellow Sea Bottom Cold Water. The East China Sea Water occupies greater portion (from St. 6 to St. 8) than the case of Line F.

Results of the hydrographic observations conducted twice along the Line S during the KEYRSEX-80 show the evoletion of front. During the first cruise (Fig. 8) on 22-23 November, considerable stratification of salinity, and of temperature north of the St 10. But the result of the second cruise on 5-6 December (Fig. 9) reveals a radical alteration in T and S distributions.

Coincident fronts of T and S are developed near the St. 10 in December. Salinity minimum band just north of the front and the interleaving of cold fresher water at 20-70*m* dept hnear the St. 7 are the characteristic features. These water masses of low salinity are not likely to originate from the Korean coastal water but from the East China Sea Water because they are far from the Korean Coast. This salinity minimum bands extending to the Korea Strait were observed during the KEYRSEX-80 (Huh *et al.*, 1982), whereas the previous sections in 1977 did not show such phenomena. On the whole, stratifications of T and S during the first cruise disappeared in about two weeks due to the vertical winter mixing. Therefore it can be concluded that the substantial change in frontal structure is completed in November.

Fig. 10, a satellite imagery on 17 Nov. 1980

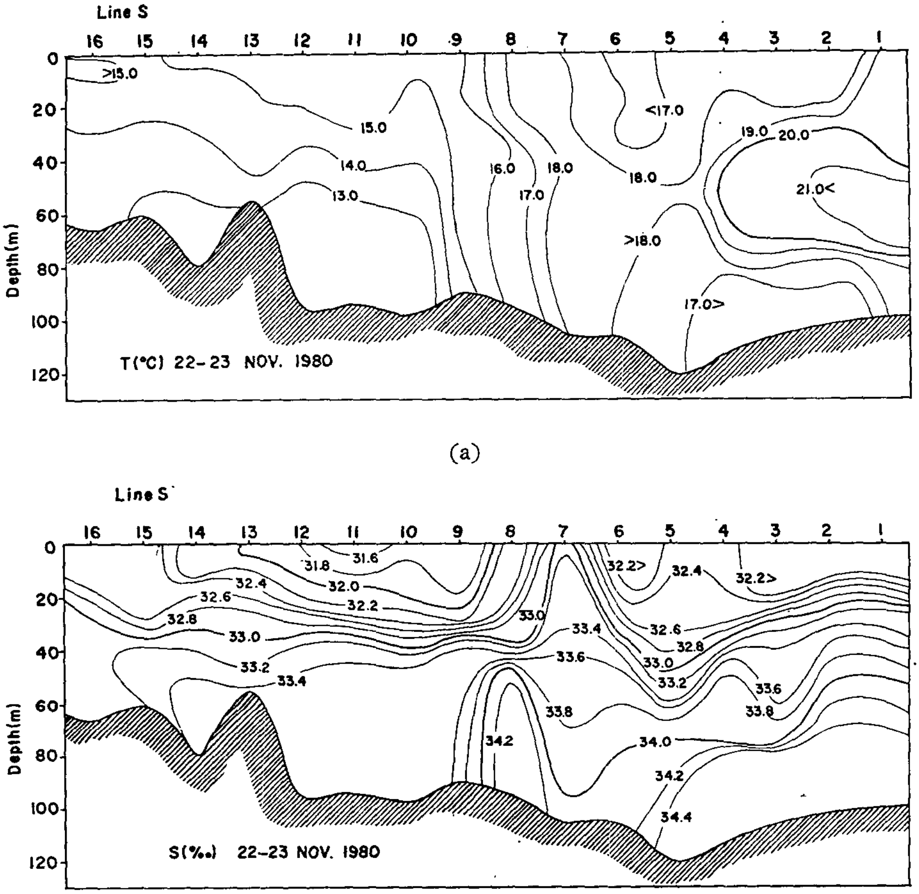

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Fig. 8. Vertical distributions of temperature and salinity at Line S during the first cruise in Nov. 1980.

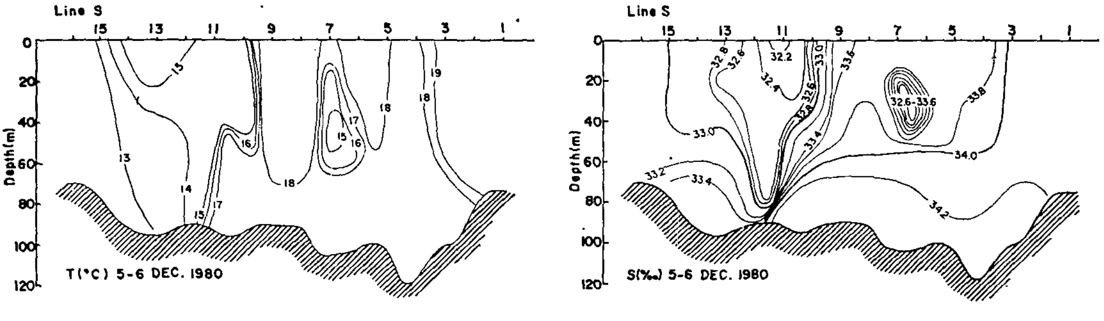

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Fig. 9. Vertical distributions of temperature and salinity at Line S during the second cruise in Nov. 1980.

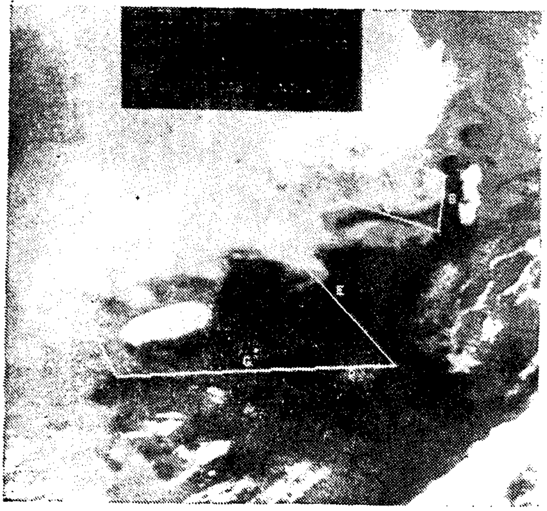

Fig. 10. IR imagery, 17 Nov. 1980. Darker tones and lighter tones depict warmer and colder regions respectively.

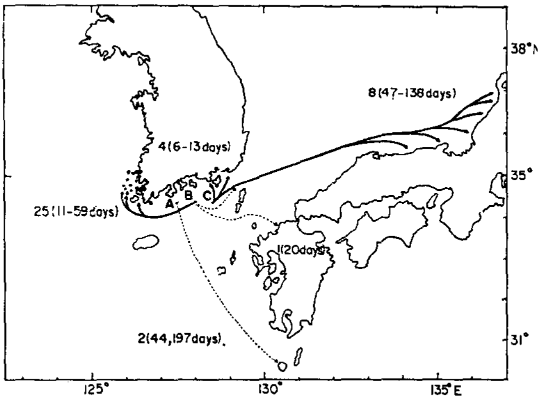

Fig. 11. Result of the drift bottle experiment in Nov. 1980.

shows the position of frontal zone and the temperature contrast. Folding of front and eddies seem to suggest rather strong velocity shear near the Tsushima Current. If the whole water masses off the sonth coast moved eastward with the Tsushima Current, velocity shear and deformation of frontal zone would be greatly reduced. Result of the drift bottle experiment carried out in the coastal region north of the front in November 1980 supports the existence of the westward coastal counter current as proposed by Chang (1970) and Lee (1974). Among 300 bottles released at St. B, 25 ones were recovered in the soutwest coast of Korea in about two months. But almost all the bottles released at St. A were not recovered. A detailed observation of current is necessary to confirm the westward movement of coastal water.

Reviewing the all sections, fronts appear to occur where the bottom depth is 70-90 *m* except for the central region of the Cheju Strait where the Tsushima Current is weak. Satellite imagery also suggest that the position of front would be related to the bottom topography. Frontogenesis in winter is probably more susceptible to bottom topography than in summer because the barotropic effect is dominant in the vertically homogeneous condition. Even though the tidal front models by Pingree and Griffiths (1978), Simpson *et al.*, (1978) and Simpson and Bowers (1981) are suitable for the summer environment off the west-south coast of Korea where the tidal current is strong, it would be interesting to examine the effect of tidal energy dissipation and water depth on the winter front.

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초겨울 제주해협 근해에서 형성되는 전선의 특성

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한국 남서해 연안에서 여름에 발달했던 성층이 겨울철에 접어들면서 파괴되어 수직적으로 균일한 수온분포를 갖게 되는데 이러한 변화가 11월에 가장 활발하게 일어나는 것으로 나타났다.

이 변절기에 차고 염분이 낮은 연안 수괴가 대마난류와 접한 경계에 전선이 거의 수직으로 발달하며, 대마난류의 세력이 약한 제주해협의 중앙부를 제외하고는 수심 70∼90 *m* 의 해역에서 수온전선과 염분전선의 위치는 일치하였다.

1980년 11월에 남해연안 중앙부에서 투하한 해류병이 주로 완도 근해에서 회수된 결과는 전선의 연안쪽에 있는 수괴가 서쪽으로 이동하는 남해연안반류의 존재를 뒷받침 해 주었다.