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Some Important Summer Oceanogaphic Phenomena in the East China Sea

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夏季 東支那海의 重要한 海洋學的 現象들

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Abstract: In this paper, the most important oceanographic phenomena of the summer season in the East China Sea are reviewed. The hydrographic conditions in the suface layer above the seasonal thermocline are under great influence from solar heating, fresh water runoff mainly from the Yangtze River, and summer wind fields. In the lower layer below the thermocline, several distinct water masses e.g. the Kuroshio surface water, the Western North Pacific Central Water and the Yellow Sea Bottom Cold Water are intruded in response to the adjustment of the field of mass to the various dynamical processes. The frontal mixing between the intruded Yellow Sea Bottom Cold Water and the Western North Pacific Central Water takes place in the bottom layer over the continental shelf south off Cheju Is. This mixed water probably has mush influence on the water properties of the intermediate and bottom layer around Cheju Is. and the south coast of Korea.

要約: 하계 동지나해에서 가장 중요한 해양학적 현상들을 재검토하였다. 계절적 수온약층 상부 표층수는 태양가열과 주로 양자강으로 부터의 담수의 유입 그리고 하계 계절풍에 의해 지대한 영향을 받고 있다. 수온약층 하부층에는 여러가지 해양 역학적 작용에 대한 질량장의 조정에 의해서 몇가지 분명히 구별되는 수괴들 즉 쿠로시오 표층수, 서북태평양 중앙수, 황해저층 냉수등이 잠입되고 있다.

잠입된 황해저층 냉수와 서북 태평양 중앙수와의 전선역 혼합이 제주 남방 대륙붕상의 저층에서 일어난다. 이 혼합수는 제주 주변과 한국 남해안 중저층의 해수 특성에 커다란 영향을 미칠 것으로 보인다.

INTRODUCTION

Summer hydrographic conditions in the East China Sea are strongly influenced by the transport of different water masses such as warm and saline Kuroshio, low-salinity East China Sea coastal waters and Yellow Sea Bottom Cold Water etc. Dynamical proceses and hydrographic conditions over the continental shelf show charactericstics of a two-layer ocean: Extensive precipitation, river runoff and solar heating produce a well stratified water column with a warm and low salinity surface layer. The surface circulation is under great influence of monsoon winds which are mainly southerly throughout the summer season.

The corresponding Ekman transport over the continental shelf is mainly eastward (Choi, 1982; Yuan et al., 1982) which can be a main cause of the eastward advection of diluted china coastal waters. While the water characteristics in the lower layer of the thermocline are well protected from the surface effects by strong seasonal thermocline. The water properties there seem to be adjusted to various dynamical factors

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such as the intensity of the Kuroshio, wind stress and bottom friction induced cross-shore circulation, thermo-haline circulation and frontal mixing etc.

Since the early sixties abundant hydrographic data in the East China Sea have been collected mainly by Japanese oceanographers who have motivated many hydrographic studies (Miyazaki and Abe, 1960; Kato, 1969; Lim, 1971; Nakao, 1977; Sawara and Hanzawa, 1979). Though some important oceanographic phenomena have been revealed from the previous works, there sometimes appears differing interpretations between authors about the same phenomena. Moreover, the frontal mixing which occurs in the bottom layer over the south shelf off Cheju Island has not been studied to any extent, but is critical in obtaining a better understanding of the environmental conditions of the South Sea of Korea including Cheju Is.

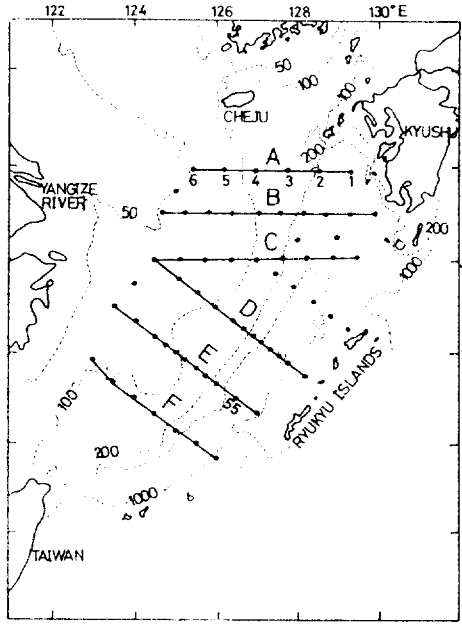


Fig. 1. Hydrographic stations of Chofu Maru in the East China Sea from 12 July to 13 August 1977.

The purpose of this study is to highlight the most important hydrographic phenomena encountered every summer season in the East China Sea. Special attention was paid to the mixing of the intruded Yellow Sea Bottom Cold Water with the ascended Western North Pacific Central Water in the lower layer over the shelf south off Cheju Is.

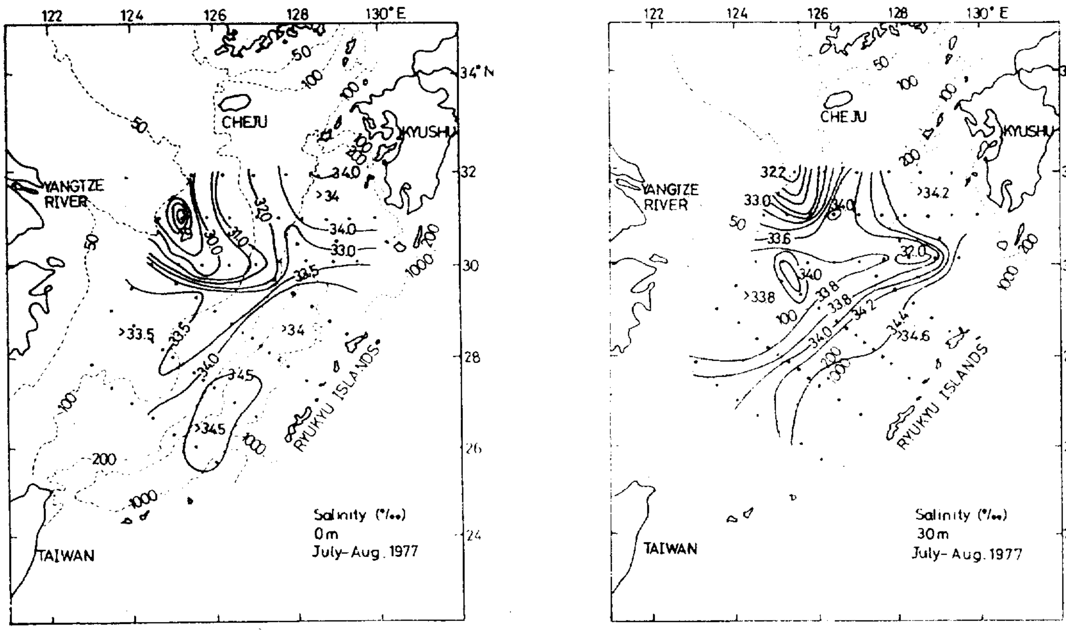


Fig. 2. Spatial distributions of salinity at the sea surface and 30m depth during July-August 1977.

Hydrographic data used in this study are those collected from the R.V. Chofu Maru of Nagasaki Marine Observatory, Japan Meteorological Agency from 12 July to 13 August 1977 in the East China Sea (JODC, 1979). Fig. 1 shows the hydrographic stations of the Chofu Maru.

EASTWARD EXTENSION OF THE YANGTZE OUTFLOW

Solar heating and fresh water runoff from the summer monsoon rains govern the surface hydrographic regime over the continental shelf of the East China Sea. The warm and low salinity surface waters float above the underling heavier waters due to a buoyancy effect and find their way to the direction of the surface circulation. The spatial distial distributions of salininity at depths of 0 and 30m (Fig. 2) demonstrate obviously the tongue-like eastward extension of diluted coastal waters along the latitude 30°N. The eastward extension of the Yangtze outflow across the continental shelf is consistent with the numerical model of Yuan et al. (1982; Fig.

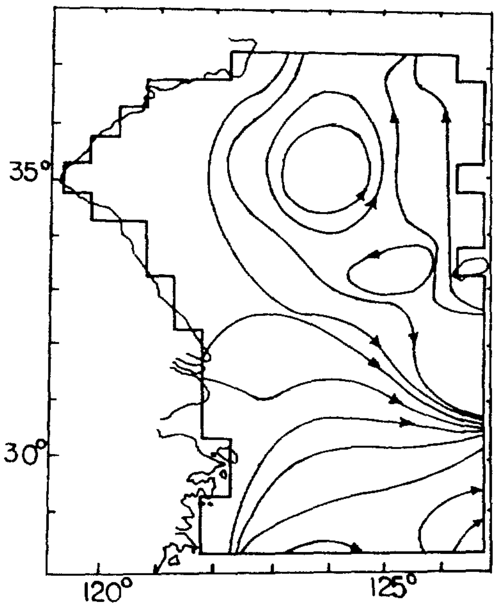


Fig. 3. Summer circulation accompanying a steady SW wind of 6m/sec. From Yuan et al. (1982).

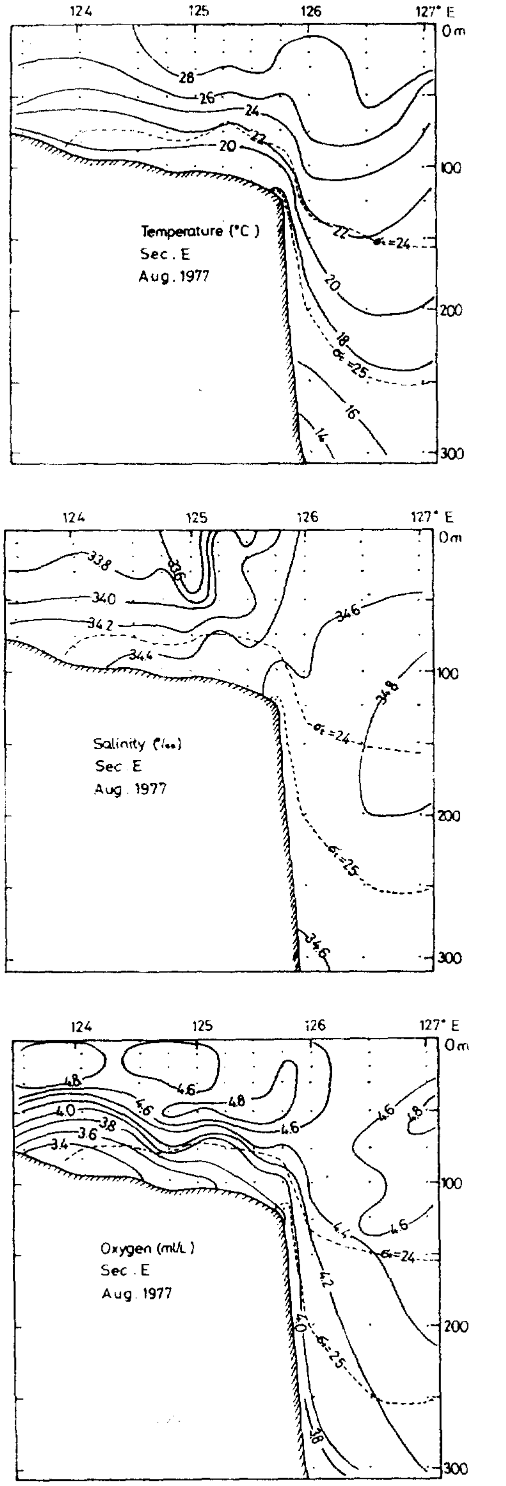
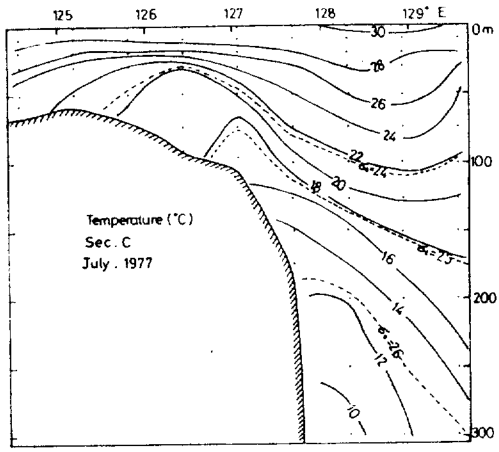


Fig. 4-A. Vertical sections of temperature, salinity and dissolved oxygen content along E line during July-August 1977.



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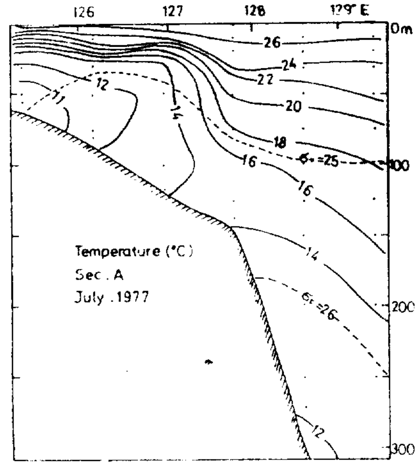

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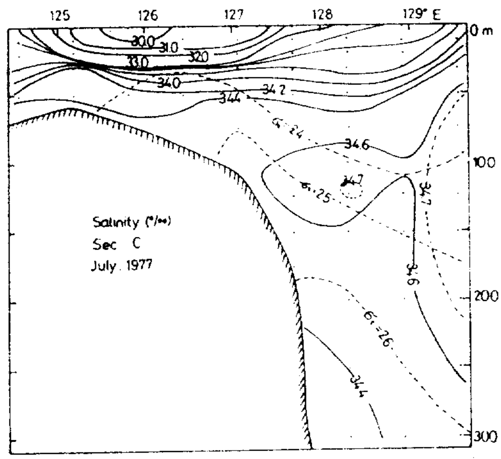

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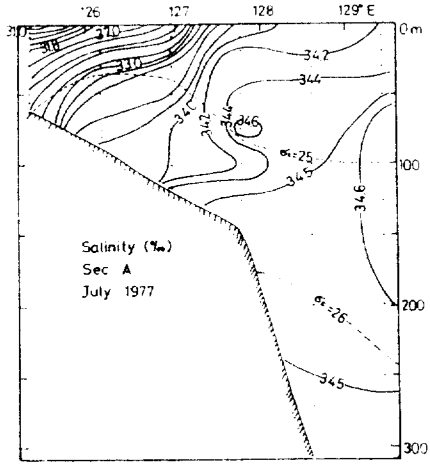

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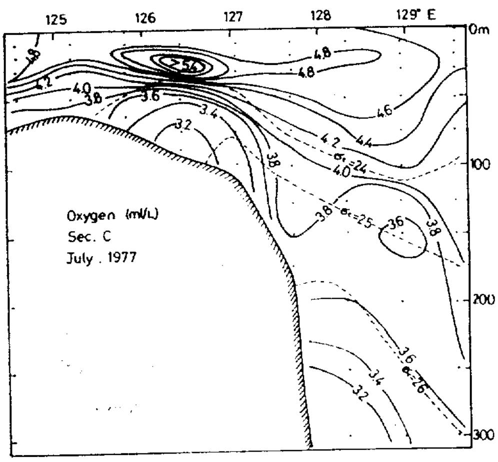

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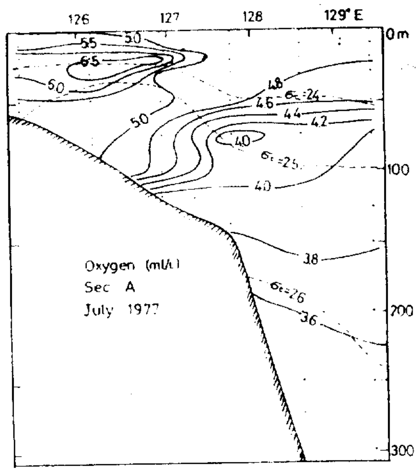

4-C-3

Fig. 4-B. As in Fig. 4-A, except for along C line.

Fig. 4-C. As in Fig. 4-A, except for along A line.

3). According to them, the turning of the Yangtze outflow to the east is due to combined effects of mainly southeasterly summer wind field, topography, and baroclinicity.

INTRUSION OF THE KUROSHIO SURFACE WATER (KSW) IN THE BOTTOM LAYER OVER THE CONTINENTAL SHELF

The intrusion of the KSW over the continental shelf is clearly shown in the vertical distribution of T,S,O_2 in the bottom layer of sections C and E (Figs. 4A and 4B). The high salinity water ($34.4<S<34.6‰$) below depths from 50 to 70m is dispersed deeply into the shelf especially in the section C where the Yangtze outflow in the surface layer reveals its maximum eastward extention. The horizontal distribution of salinity at 50m (Fig. 5) shows a noticeabe tongue-like intrusion of the KSW toward a sea valley east off the Yangtze River mouth. This seems to be essentially the result of the hydrodynamic balance between the east ward Ekman transport of the Yangtze outflow in the surface layer and the compensating westward

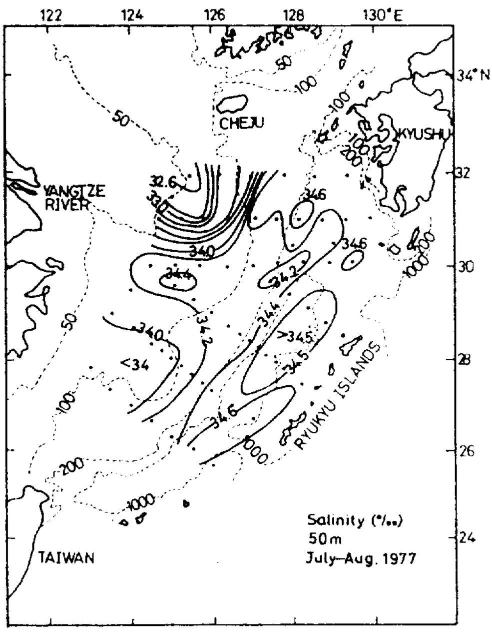

Fig. 5. Spatial distribution of salinity at 50m depth during July-August 1977.

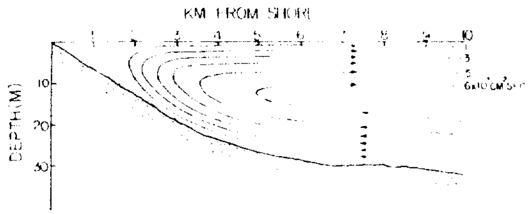

Fig. 6. Transport streamlines in a cross-shore transect accompanying steady longshore wind of 5m/sec in the south coast of Long Island. From Csanady (1982).

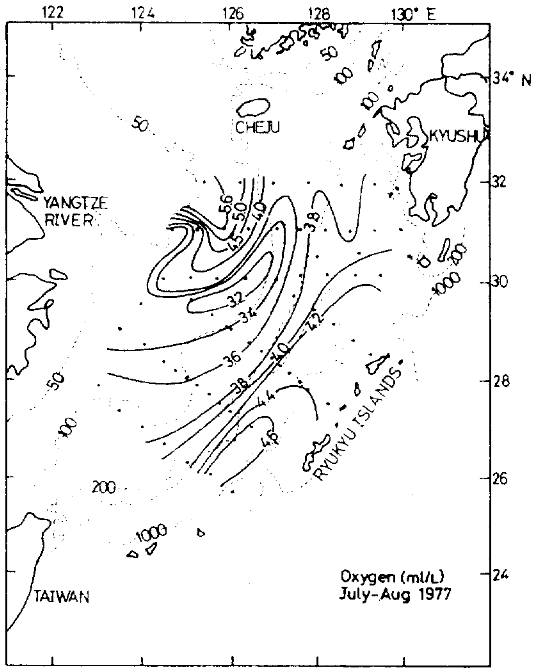

Fig. 7. Spatial distribution of oxygen content at the level of maximum salinity during July-August 1977.

intrusion of the KSW through the bottom layer. The analogous cross-shore circulation in a homogeneous fluid has been clearly demonstrated by Csanady (1982; Fig. 6) in his analytical model of flow controlled by bottom friction. The most striking feature of the distribution of oxygen content over the continental shelf is the isolated patch of waters within which the oxygen content is exceedingly small $O_2<3.4$ ml/L) along the frontal boundary of the intruded Yellow Sea Bottom Cold Water (Fig. 7). Nakao(1977) attributed these oxygen poor waters to the northward intrusion of the central Warm Water in the East China Sea separated from the Kuroshio around the northern part of Taiwan. However the shape of the spatial distribution of oxygen content does not show any evidence for the northward advection of the oxygen poor waters originating from the south. Instead, it is rather plausible at this state to relate this phenomena to high concentrations of organic matters and nutrients derived from the land primarily by the Yangtze outflow. A great biological productivity of the region due to the ascending of the nutrientrich lower waters over the continental shelf (Kato, 1964) can also be postulated as an another possible cause of the regional low-oxygen content.

In fact, the great consumptions of the dissolved oxygen by biochemical activities in the bottom layer for the disintegration of the abundant organic matters fallen from the productive surface layer, might be imagined. More convincing evidence for the real cause of the oxygen poor waters has to be found by a precise and well planned oceanographic survey of the area in the future.

ASCENDING OF THE WESTERN NORTH PACIFIC CENTRAL WATER (WNPCW)

The Kuroshio main current in the East China Sea flows to the northeast along the continental slope west of the Ryukyu trench with maximum speeds ranging from 1.5 to 3.0 knots and turns slowly to the east at approximately 29.5°N and 129°E to exit to the Pacific through the Tokara Strait (Inoue, 1974). The steep inclination of isopycnals, isotherms and iso-oxygen curves across the continental slope of the section E (Fig. 4A) is essentially the result of a geostrophic adjustment of the field of mass to the field of the strong current. It is known that in the intermediate layer of the Western North

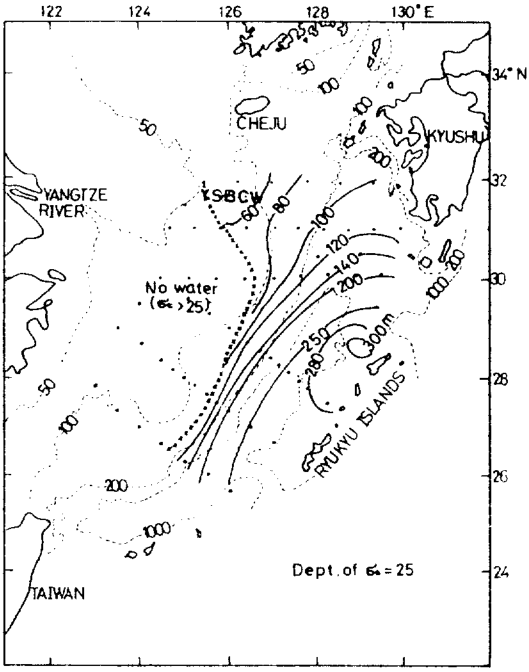

Fig. 8. Spatial distribution of the depth (in meters) of isopycnal $\sigma_t=25$ during July-August 1977.

Pacific there exists a well defined Central Water, WNPCW, characterized by an average salinity between 34.2 and 34.8‰ and a temperature between 10 and 18°C (Sverdrup et al., 1954). According to this T-S range, the density of the WNPCW can be deduced to have a Sigma-t value between 25.1 and 26.4. Therefore the isopycnals $\sigma_t=25$ and isotherms T=18°C with a salinity between 34.5 and 34.8‰ can be regarded as an approximate boundary between the KSW and the underling WNPCW (Fig. 4A, 4B, and 4C). In order to illustrate the ascending of the WNPCW, spatial distribution of the depth of isopycnal $\sigma_t=25$ is prepared (Fig. 8). In the Kuroshio main current region the WNPCW is found below depths from 200 to 300m and the core of 300m seems to correspond to the center of the clockwise turning of the Kuroshio around the northern part of Tokara Is. While, along the continental edge west of the Kuroshio main current region as well as over the continental shelf west off Kyushu, the WN-

PCW ascends up to depths from 80 to 100m. The accumulation of warm and less dense surface water into greater depths in the center of the rotation and the ascending of the cold and more dense WNPCW in the outer region of the center can be resonably explained by a geostrophic adjustment of the field of mass to the anticyclonically turning Kuoshio before making its exit to the Pacific.

Additional evidence for ascending of the WNPCW can be given by the fact that the oxygen poor water (O_2<4 ml/L) situated below 300m in the Kuroshio main current region (see oxygen section E) ascends to 100m in the west off Kyushu (see oxygen sections A and C). The existence of the WNPCW in the lower layer over the continental shelf west off Kyushu is cousistent with the results of Miyazaki and Abe (1960).

TONGUE-LIKE INTRUSION OF THE YELLOW SEA BOTTOM COLD WATER (YSBCW) AND MIXING WITH THE WNPCW

The YSBCW is the cold water mass formed during the winter season by severe cooling processes in the Yellow Sea and stagnates under the seasonal thermocline in the deeper area, moving south. The southern limit of the water passes between Cheju and the Yangtze Bank to reach around 30°N in a tongue-like shape (Inoue, 1974). The southward intrusion of the YSBCW during the summer of 1977 is clearly demonstrated by water of extremly low temperature (T<12°C), low salinity (S<33.5‰) and high content of dissolved oxygen (O_2> 5ml/L) (Figs. 4C, 9 and 10). The presence of maximum oxygen (O_2> 6ml/L) inside strong thermocline is a common phenomena in the YSBCW region in the East China Sea (Nakao, 1977; Kim et al., 1982; see also Figs. 10 and 11). Hence, the intruded YSBCW can be traced with the aid of the horizontal distribution of maxi-

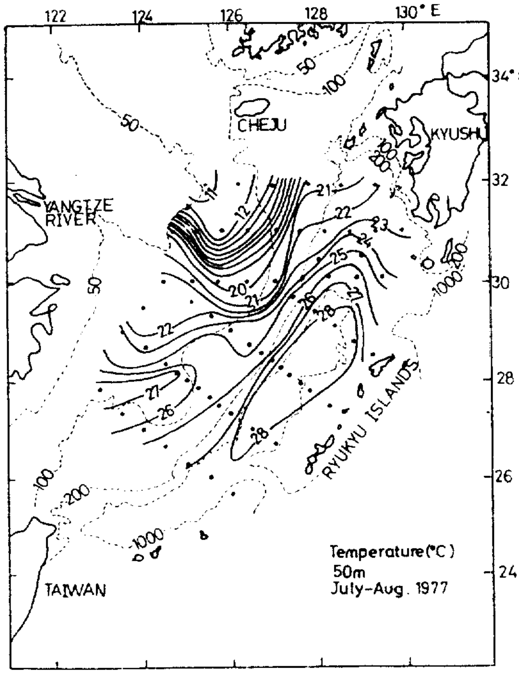

Fig. 9. Spatial distribution of temperature at 50m depth during July-August 1977.

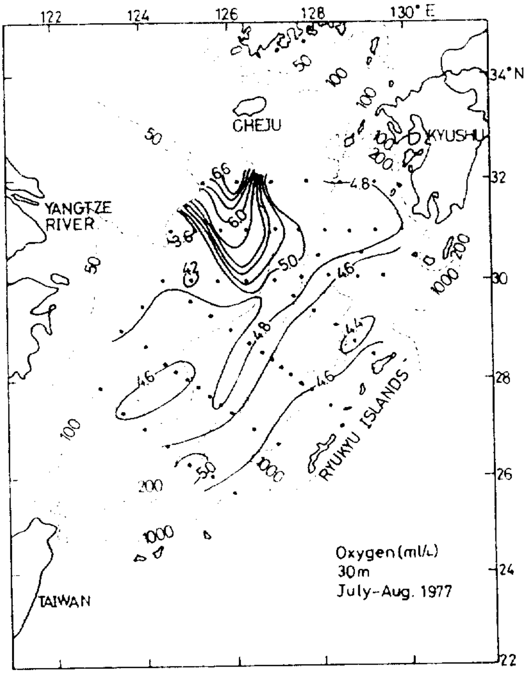

Fig. 10. Spatial distribution of oxygen content at 30m depth during July-August 1977.

mum dissolved oxygen (Nakao, 1977). The supersaturation of dissolved oxygen of this kind seems to be related to some biological effects such as a great concentratin of phytoplanktons in a strong thermocline (Seminar, 1979).

In order to delineate precisely the influence of the YSBCW, the cross-frontal structure of section A is examined in detail (Fig. 4C). Four water masses are distinguishable there: To the west of 127°E the YSECW outlined by the isotherm 12°C occupies the bottom layer below 40m depth and above it is situated the warm and low-salinity East China Sea Surface Water (ECSSW: tentatively called). To the east of 127°30′E and above the isopycnal $\sigma_t=25$, the KSW affected a little by the ECSSW occupies the surface layer and below it the WNPCW. The steep horizontal gradients of T, S and O_2 between 126°30′ and 127°30′E seems to imply an intense frontal mixing of the intruded YSBCW with surrounding waters. For a clear demonstration of the frontal mixing, T-S and T-O_2 diagrams in the section A with representative T-S and T-O_2 curves in the Kuroshio main current region (St. 55 in the section E) are prepared (Fig. 11). The close superposition of T-S and T-O_2 curves below depths from 80 to 100m at Sts. 2 and 3 with those below 250m at St. 55 supports once again the ascending of the WNPCW. The intense lateral mixing between the intruded YSBCW and the WNPCW appears well below 50m depth at Sts. 4 and 5 by a gradual approch of T-S and T-O_2 points of the YSBCW toward those of the WNPCW. The increase in temperature and salinity and the decrease in oxygen content with increasing depth in the lower layer below 50m at Sts. 4 and 5 are essentially the result of the mixing of the YSBCW with the WNPCW. The mixed water having intermediate properties between the intruded YSBCW and the WNPCW can be characterized by the water of 13< T<16°C, 33.5 <S<34.5‰ and 4<O_2<5ml/L below depths from 50 to 80m in the south off Cheju Is.. This mixed water probably has much influence on the hydrographic conditions of the intermediate and bottom layer waters around Cheju Is. as well as the south coast of Korea as the water

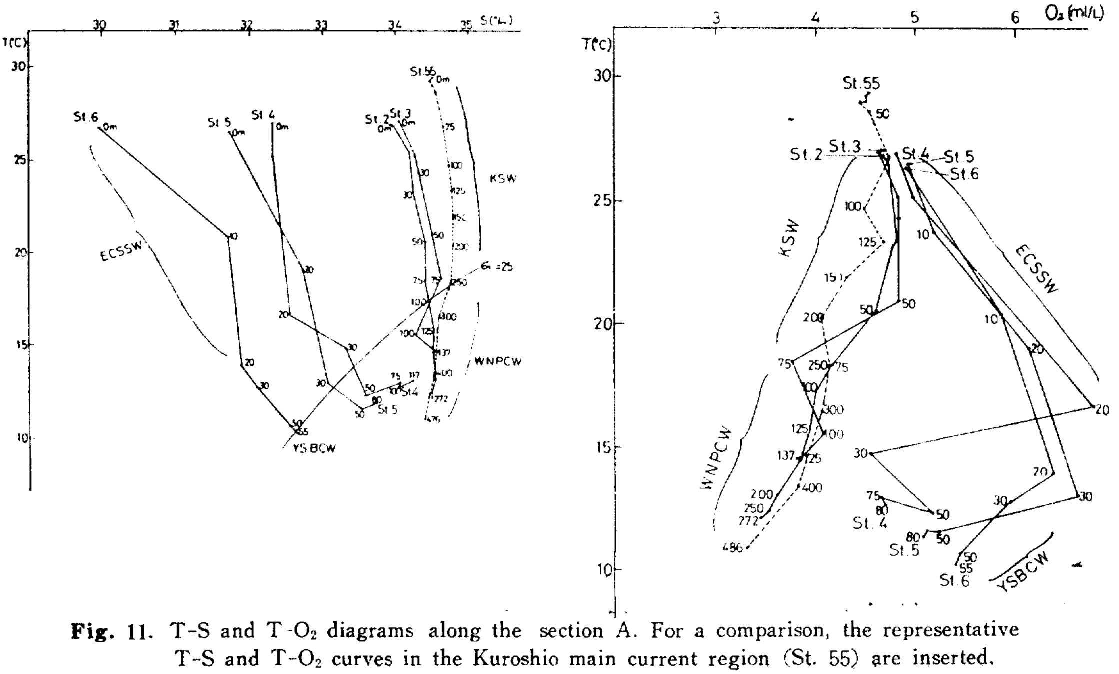

Fig. 11. T-S and T-O_2 diagrams along the section A. For a comparison, the representative T-S and T-O_2 curves in the Kuroshio main current region (St. 55) are inserted.

advances to the north with the Tsushima Current. The Tsushima Current Middle Water in the western channel of the Korea Strait, which Lim (1971) indicated that this water mixed with the Japan Sea Cold Water, seems to coincide with this mixed water. Hence, Lim's conclusion that the WNPCW does not flow in the Japan Sea through the Korea Strait seems to be unreasonable.

CONCLUSIONS

Summer hydrographic conditions and dynamical processes over the continental shelf in the East China Sea show characteristics of a two-layer ocean. Solar heating and fresh water runoff especially from the Yangtze River produce the warm and low-salinity surface waters above the strong thermocline and this diluted ECSSW extends far eastward due to the effects of the southeasterly summer monsoons. In the lower-layer below the thermocline appears the westward intrusion of the KSW over the continental shelf, which seems to be the result of the hydrodynamic compensation against the eastward Ekman transport of the Yangtze outflow in the surface layer.

The isolated oxygen minimum waters around the frontal boundary of the intruded YSBCW seems to be related to a great biological productivity of the region due to the inflow of the abundant organic matters and nutrients by the Yangtze discharge and the ascending of nutrient-rich lower waters over the continental shelf. The WNPCW characterized by waters of $10<T<18°C$, $34.2<S<34.8‰$, $25.1<\sigma_t<26.4$, $O_2<4ml/L$ found below depths from 200 to 300m in the Kuroshio main current region, ascends up to depths from 80 to 100m along the continental edge west of the Ryukyu Trench as well as over the continental shelf west off Kyushu. The ascending of the cold, dense and low oxygen content WNPCW in the outer region of the Kuroshio main flow is essentially the result of a geostrophic adjustment of the field of mass to the anticyclonically turning Kuroshio in the north of Tokara Is..

The tongue-like intrusion of the YSBCW in the bottom layer over the shelf south off Cheju Is. can be detected by low temperature ($T<12°C$), low salinity ($S<33.5‰$) and high oxygen content ($O_2>5ml/L$). The maximum oxygen content ($O_2>6ml/L$) found commonly inside the thermocline just above the intruded YSBCW may be related to a great concentration of phytoplanktons in a strong thermocline. The frontal mixing between the intruded YSBCW and the WNPCW takes place in the bottom layer over the shelf south off Cheju Is. between 126.5 and 127.5°E. The mixed water characterized by $13<T<16°C$, $33.5<34.5‰$ and $4<O_2<5ml/L$ will probably has much influence on the water properties of the intermediate and bottom layer aroued Cheju Is. as well as the south coast of Korea.

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