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臺灣東北部黑潮與東海交界鋒面之海洋化學研究

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CHEMICAL HYDROGRAPHY ACROSS THE EAST CHINA SEA–KUROSHIO FRONTAL REGION, NORTHEAST OF TAIWAN

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and CHEN-TUNG A. CHEN[3]

ABSTRACT

The hydrography across the frontal region between the East China Sea and the Okinawa Trough north-east of Taiwan is governed mainly by mixing across the front and topographically induced upwelling of the altered Kuroshio water from about 300 m in the Okinawa Trough during the periodic shelf-ward migration of the Kuroshio. At the most landward station in the East China Sea, the surface water, with a salinity and temperature of 33.4 psu and 28.7°C respectively, was about 0.7 psu fresher and 0.9°C cooler than that in the Okinawa Trough. Its concentration of silicate, being about 2 μM, was about twice of that in the Okinawa Trough. The contrasts in the concentrations of nitrate, phosphate, oxygen and pH at the sea surface were not conspicuous. Nitrate and phosphate were ubiquitously low. The upwelled altered Kuroshio water, with a salinity of 34.43 psu and a temperature of about 13°C, was much cooler. It was also characterized by its high concentrations of nutrients and NO (14, 0.8, 17 and 195 μM in nitrate, phosphate, silicate and NO repectively), low concentration of oxygen (160 μM) and low pH (7.9). This upwelled water is potentially a major source of nutrients to the East China Sea. The deep water in the Okinawa Trough at temperatures below 13°C did not participate in cross shelf mixing and its chemical properties were significantly different from those at comparable depths in the waters south of the Okinawa Island chain.

INTRODUCTION

Material exchange across the frontal region between a western boundary current and the adjacent shelf waters can have a major effect on the composition of the shelf waters. The influence of the Gulf Stream on the chemical, physical and biological characteristics of the South Atlantic Bight has been studied extensively for a number of decades (Atkinson and Menzel, 1985). Althougn the exchange processes are temporally and spatially variable (Atkinson *et al.*, 1983; Blanton and Atkinson, 1983) so that closely spaced and repeated sampling are essential for quantifying these processes and such a data-base is seldom vailable, much have already been learned from this system. It has been concluded, for example, that a large fraction of the supply of nutrients to the South Atlantic Bight is provided by the intrusion of deep Gulf Stream water onto the shelf by topographically-induced upwelling at the shelf edge (Blanton *et al.*, 1981; Hofmann *et al.*, 1981; Atkinson, 1985) and by exchanges via frontal eddies (Lee *et al.*, 1981). Although the effects of these processes on the geochemical budget of other elements in the shelf waters are less well documented, there is no reason to expect that the exchanges are confined to nutrient elements alone. In fact, the distributions of alkalinity in such areas have been shown to be affected by the same

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physical processes (Chen *et al.*, 1985; Wong, 1988).

The Kuroshio the corresponding western boundary current in the Pacifiic, is a major conduit for the transport of heat, salt and other associated material from the Equatorial Pacific to the Northern Pacific. During this journey, it squeezes througs the passage over a ridge between Taiwan and the Yonakunijma Island and enters the Okinawa Trough. There, because of topographic restrictions, the northward flowing current has to turn eastward and skirt along the seaward edge of the East China Sea before if re-enters the Pacific Ocean south of Japan through the Tokara Strait. Thus, as in the case of the South Atlantic Bignt and tne Gulf Stream, the Kuroshio may interact with the East China Sea in a similar fashion and impact upon the biogeochemical budget of the East China Sea. The physical characteristics of the forntal zone between the Kuroshio and the East China Sea northeast of Taiwan has been studied for some time (Yin, 1937; Chu, 1976; Fan, 1980: Liu, 1983; Liu and Pai, 1987) although data with the appropriate spatial and temporal spacing for studying the exchange processes in the region are still unavailable. Systematic data on the corresponding chemical signatures in the region are even more sparse (Liu and Pai, 1987; Chen, 1988; Liu *et al.*, 1988). In this paper, we shall report a set of closely spaced and systematic data on the chemical hydrography in this region during the Summer of 1988.

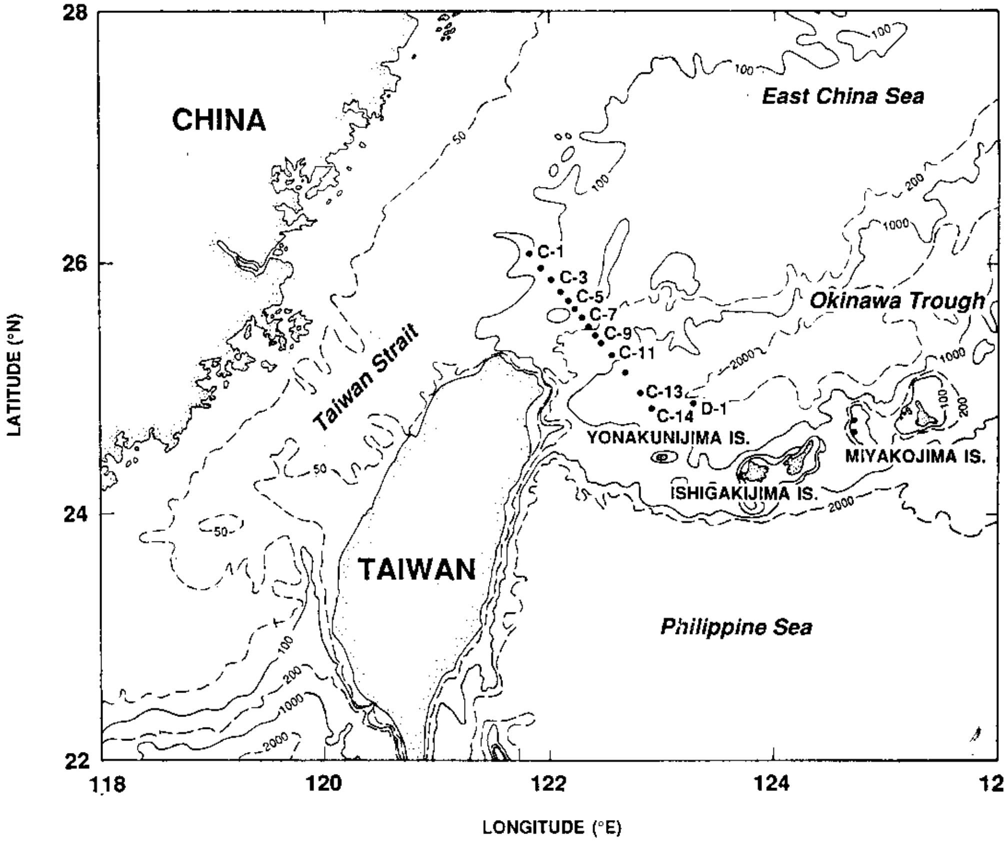

Fig. 1. The locations of the stations.

EXPERIMENTAL

Fifteen stations were occupied during cruise KECS-2 (Kuroshio-East China Sea Study 2) by R/V Ocean Researcher I on September 19 to 21, 1988 (Fig. 1). Fourteen of them were along a transect, transect C, normal to the 200-m isobath at the shelf break of the East China Sea. Stations C-1 to C-7 were located on the shelf in the East China Sea with depths of about 100 the 200 m. Stations C-12 to C-14 and D-1 were located in the Okinawa Trough. The water depth at the deepest station exceeded 1400 m. The locations of the sampling stations were chosen to study the fine scale features at the shelf break. Station C-4 to C-10 were at the vicinity of the shelf break and they were 10 Km apart. The others stations along the transect were 20 Km apart. This is the most closly spaced sampling scheme attempted in this region. The profiles of temperature, salinity and total fluorescence were measured by *in situ* sensors. Discrete samples were obtained for the determination of dissolved oxygen, phosphate, nitrate, silicate and pH onboard ship. Oxygen was measured by the Winkler titrimetric method (Carpenter, 1965) with a precision of about +0.5%. Phosphate was determined by the molybdenum blue method (Murphy and Riley, 1962). Silicate was measured by the silicomolybdenum blue method (Fanning and Pilson, 1973). Nitrate was determined by reducing nitrate to nitrite and then determining the nitrite formed by the azo dye method (Strickland and Parsons, 1972) using a flow injection analyer. pH was measured with a glass electrode/calomel electrode pair in a constant temperature bath.

RESULTS AND DISCUSSION

Salinity, temperature and sigma-t

The T-S curves of selected stations across the shelf and in the Okinawa Trough are shown in Fig. 2. Station D-1 and C-14, being located in the Okinawa Trough, and Station C-1, being closest to the mainland on the shelf in the East China Sea, may be considered as the end-members in the mixing of shelf water with Kuroshio water in this study. The broad salinity maximum between 34.8 and 34.85 psu, 19.5 to 24.5°C and 75 to 200 m at Station C-14 and D-1 represented the core of the Kuroshio. Within this broad maximum, there were actually two maxima suggesting further complexity in defining the core of the Kuroshio water. At shallower depths, the Kuroshio water mixed with the warmer and fresher surface water. At greater depths, temperature was linearly related to salinity down the broad salinity minimum between 34.3 and 34.35 psu, at 7.5°C at 450 to 550 m. This mixing line represented the mixing of Kuroshio water with the deep water in the Oksnawa Trough OTDW). All the T-S curves converged towards a common point at a sigma-t of 26 ppt at 34.5 psu and 13°C at about 250 to 350 m. At higher temperatures and shallower depths, the T-S curves fanned out systematically. At each isopycnal, salinity increased systematically from Station C-1 to Station D-1 reflecting the effects ef cross shelf mixing along isopycnal surfaces. Below 13°C, the T-S relationship were identical at all stations indicating that these deeper waters did not participate in the cross-shelf mixing between the East China Sea and the Kuroshio. Its composition was only affected by vertical mixing between Kuroshio water and the OTDW. The bottom water in the Okinawa Trough was represented as a salinity maximum in the T-S curves with temperatures below 5°C and salinities above 34.34 psu. While waters with sigma-t above

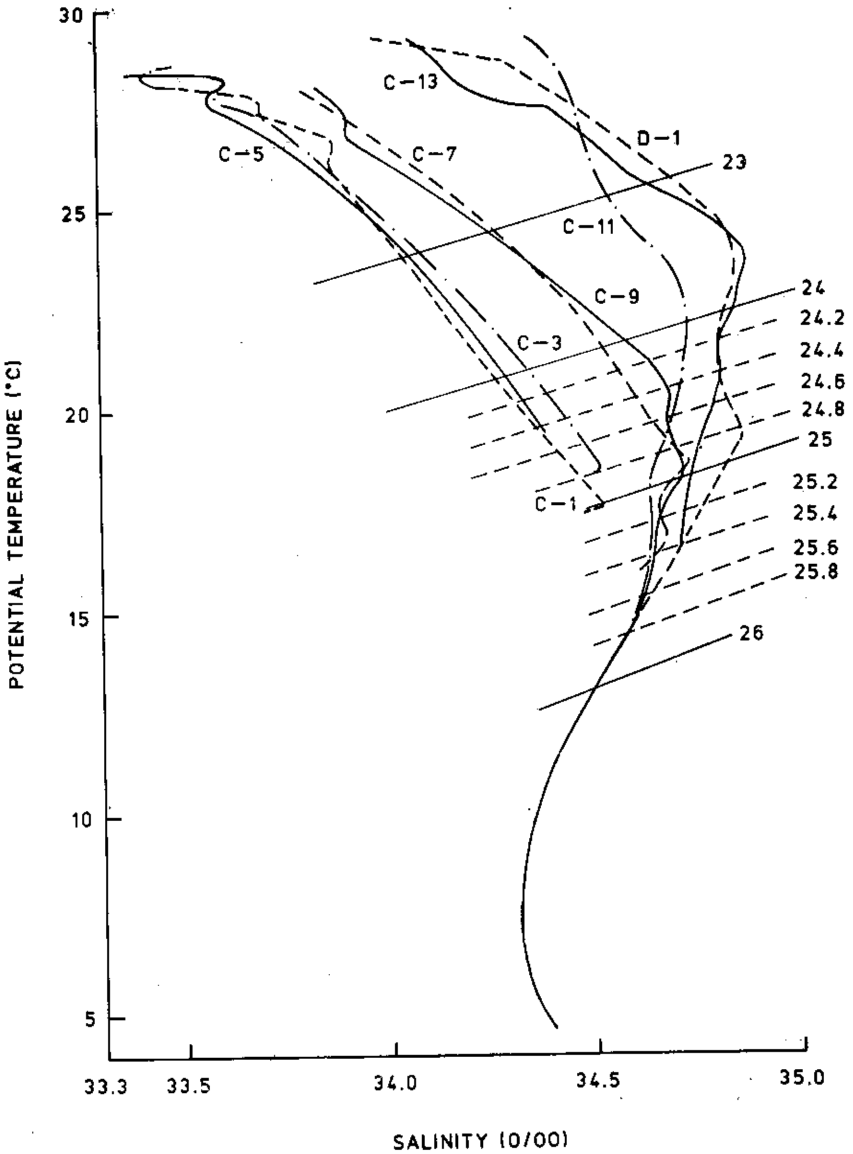

Fig. 2. The relationship between temperature and salinity in the study area.

24.8 were absent at Stations C-3 to C-5, they could be found at stations further in-shelf or off-shelf.

As is common in a number of other continental shelves, fresh water is added to the shelf via rivers, primarily from the Yangtze and the Huangho in the case of the East China Sea, resulting in fresher water on the shelf and more saline water further off-shelf. Thus, while the salinity in the surface waters at Stations C-1 to C-5 was about 33.4 psu, in the Okinawa Trough at Stations C-11 to C-14, the salinity was about 34.1 psu (Fig. 3). A salinity front was observed between Stations C-5 and C-10 where the salinity increased from 33.4 to 33.8‰ from Stations C-5 to C-7, stayed relatively constant between Stations C-7 to C-9 and then

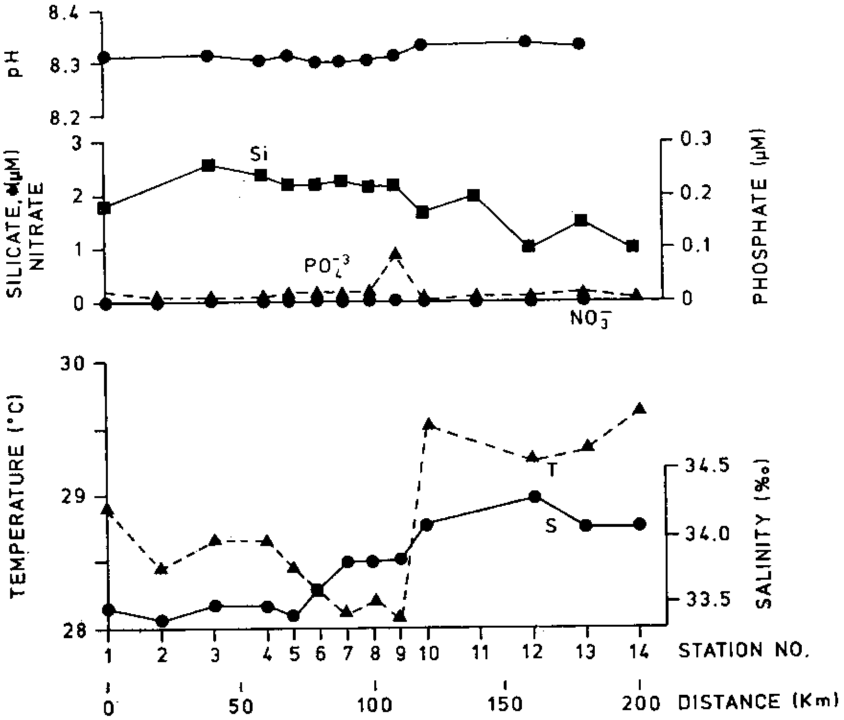

Fig. 3. The distribution of temperature, salinity, the nutrients and pH in the surface water along transect C.

jumped abruptly to 34.1‰ at Station C-10. As a first approximation, the distribution of salinity along transect C (Fig. 4) resembled that of an estuary. A prism of fresher surface water with salinities below 34‰ was found between Station C-1 and C-5 in the East China Sea. It reached as deep as 80 m at Station C-3. Eventually, the isohalines outcropped to the surface further off-shelf. This body of water was underlain by the self-ward intrusion of the more saline off-shelf water, resulting in a salinity front that can be detected as a surface expression between Stations C-5 to C-10 (Fig. 3). Superimposed on this pattern was the subsurface influence of the Kuroshio which as represented as a layer of warm saline water, with a maximum salinity exceeding 34.8 psu, centered around 110 m at Station C-13 and C-14, and sandwiched between less saline water at shallower and greater depths. This layer of saline water could be traced by the 34.6 psu -isohaline from Station C-14 in the Okinawa Trough to Station C-6 in the East China Sea where it ended abruptly as a sub-surface salinity front. The tilting of the isohalines at 34.6 and 34.7 psu in the lower portion of the Kuroshio towards shallower depths at the shelf edge from about 200 m at Station C-14 to 100 m at Station 8 was indicative of a topographically induced upwelling. Thus, the upwelled water was an altered Kuroshio water, a mixture of Kuroshio water and the deeper and slightly fresher OTDW. The stations along this transect may then be subdivided into three groups: Stations C-1 to C-5 were on the shelf where the least modified shelf water was found, Stations C-6 to C-10 were in a transition zone where the effect of upwelling was evident and Stations C-11 to C-14 were in the Okinawa Trough where the Kuroshio was found. The prism of bottom water at

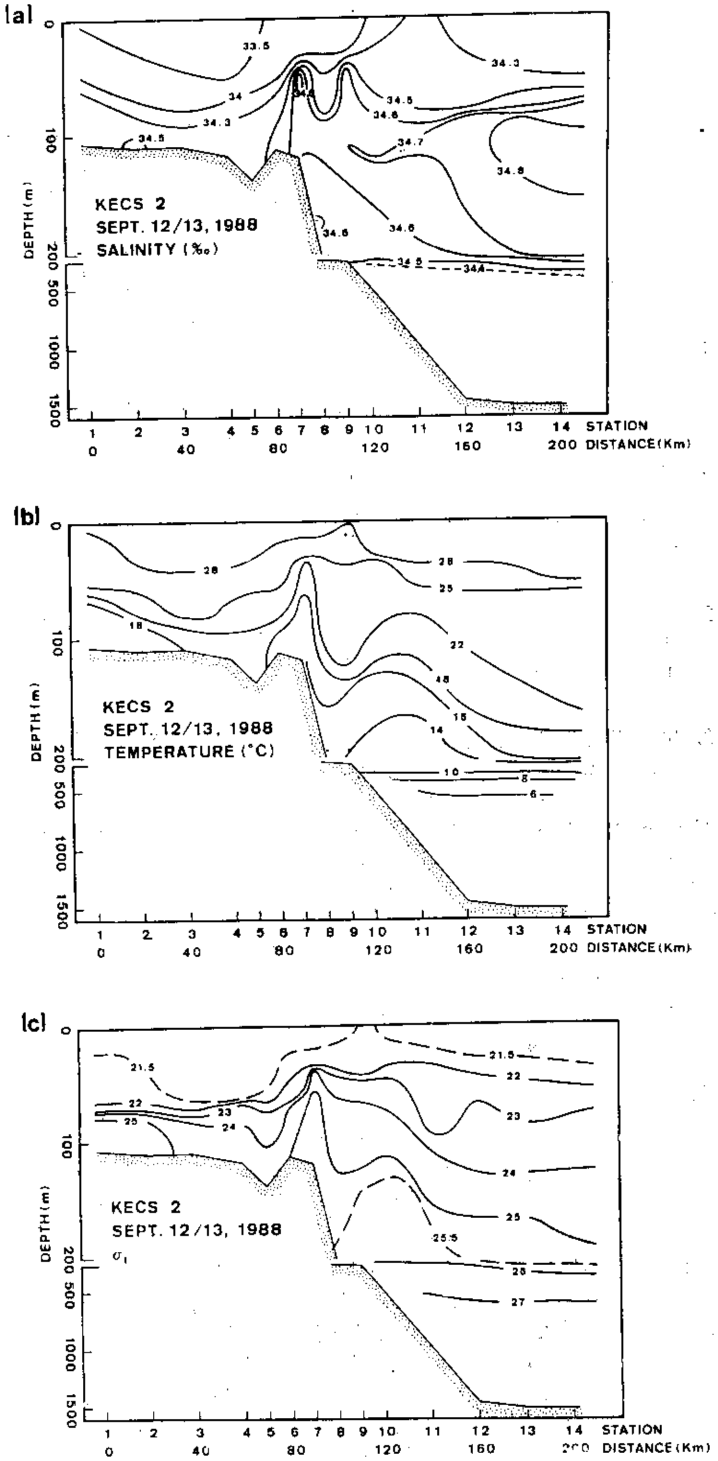

Fig. 4. The distribution of (a) salinity, (b) temperature and (c) sigma-t along transect C.

Stations C-1 and C-2 with sigma-t above 24.8 was also characterized by higher salinity. Since more saline water could only be found futher off-shelf, this water was probably off-shelf water which had found its way onto the shelf as an eddy, as a filament or as a separate branch of the upwelled water In the upper portion of the Kuroshio water, between 50 and 80 m at Stations C-6 to C-10, the shelf-ward edge of the isohalines at 34.5 and 34.6 psu exhibited a double-humped structure. The exact cause of this fine-scale structure is unknown. It may be caused by the formation of eddies or filaments at the shelf-ward edge of the shelf-ward migrating water or by episodes of consecutive in-shelf and off-shelf meandering of the Kuroshio.

The temperature of the surface water in the shelf was about 28.7°C. It was about 0.9°C lower than that in the Okinawa Trough (Fig. 3). The upwelled water at Stations C-5 to C-10 formed a pool of cold surface water with temperature depressed to 28.0°C. In the sub-surface waters, the upwelling of the altered Kuroshio water was represented as tilting isotherms between 16 and 22°C resulting in a temperature front between Stations C-6 and C-8 were temperature decreased by about 6°C in 20 Km (Fig. 4). The double-humped structure was also evident in these isotherms between Stations C-7 and C-13. The 22°C isotherm was at 160 m at Sation C-14. It rose to 70 m at Station C-11, dropped to 130 m at Station 9 and rose again to 30 m at Station C-7 before it dropped off to 60 to 90 m further in-shelf. These humps had dimensions of a few tens of kilometers and are suggestive of complex mixing processes at the frontal region as described previously. These fine scale hydrographic features have not been resported in previous studies since they can be detected only with the closely spaced sampling scheme as utilized in this study. The other parcel of off-shels water at the bottom at Stations C-1 to C-3 appeared as an isolated prism of cold water on the shelf as defined by the 18°C-isotherm.

The tilting of the isopycnals towards shallower depths at the shelf break, which is indicative of upwelling, was clearly evident from a sigma-t of 23 to a sigma-t to 26 (Fig. 4). Since the sigma-t at the core of the Kuroshio was about 24. this suggests that the source of the upwelled water was not pure Kuroshio water alone. A double-humped structure in the isopycnals was also observed between Stations C-6 and C-13. The sigma-t of the bottom water at Stations C-1 and C-2 exceeded 25 and was more characteristic of the off-shelf altered Kuroshio water than the shelf waters proyer.

Oxygen, phosphate, nitrate, silicate, pH and NO

The upwelling at the shelf edge, the double-humped structure of this sub-surface upwelled water at the vicinity of the shelf break and the occurrence of another parcel of off-shelf upwelled water at the bottom of Stations C-1 were also evident from the distributions of oxygen, phosphate, nitrate, silicate and pH (Fig. 5 and 6.)The upwelling altered Kuroshio water was characterized by a low concentrations of oxygen and low pH, between 160 to 175 μM and 8.0 to 8.2, and high concentrations of phosphate, nitrate and silicate, between 0.4 to 1.0, 5 to 16 and 5 to 20 μM respectively. In constrast, the core of the Kuroshio at 110 m at Station 14 was relatively poor in phosphate, nitrate and silicate with concentrations of 0.13, 2.1 and 1.9 μM. These concentrations were similar to those in the shallow waters on the shelf proper. Thus. while the direct transport of Kuroshio water to the shelf would have minimal effect on the nutrient budget in the East China Sea, topographically induced upwelling of altered Kuroshio water from greater

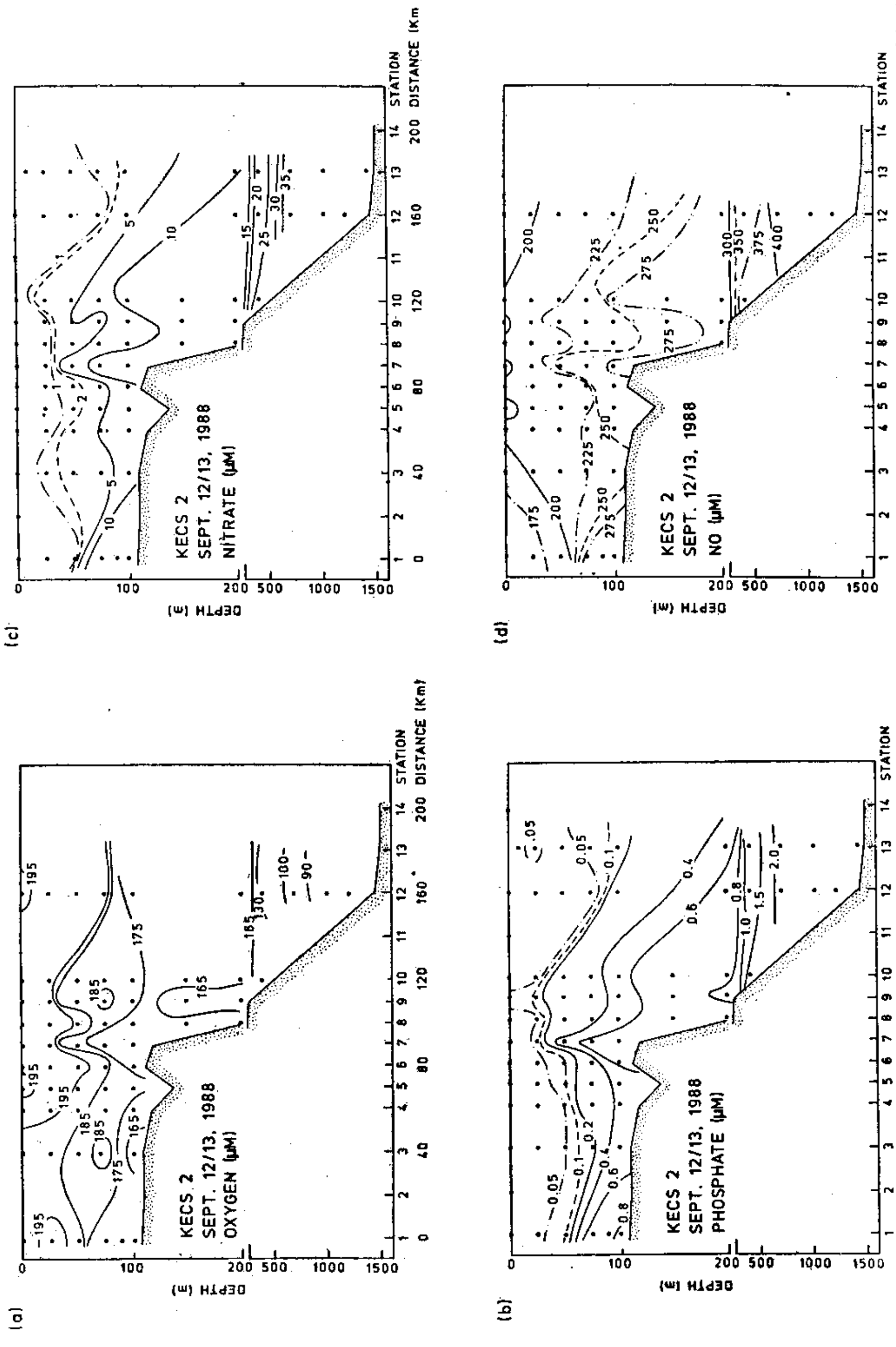

Fig. 5. The distribution of (a) oxygen, (b) phosphate, (c) nitrate and (d) NO along transect C.

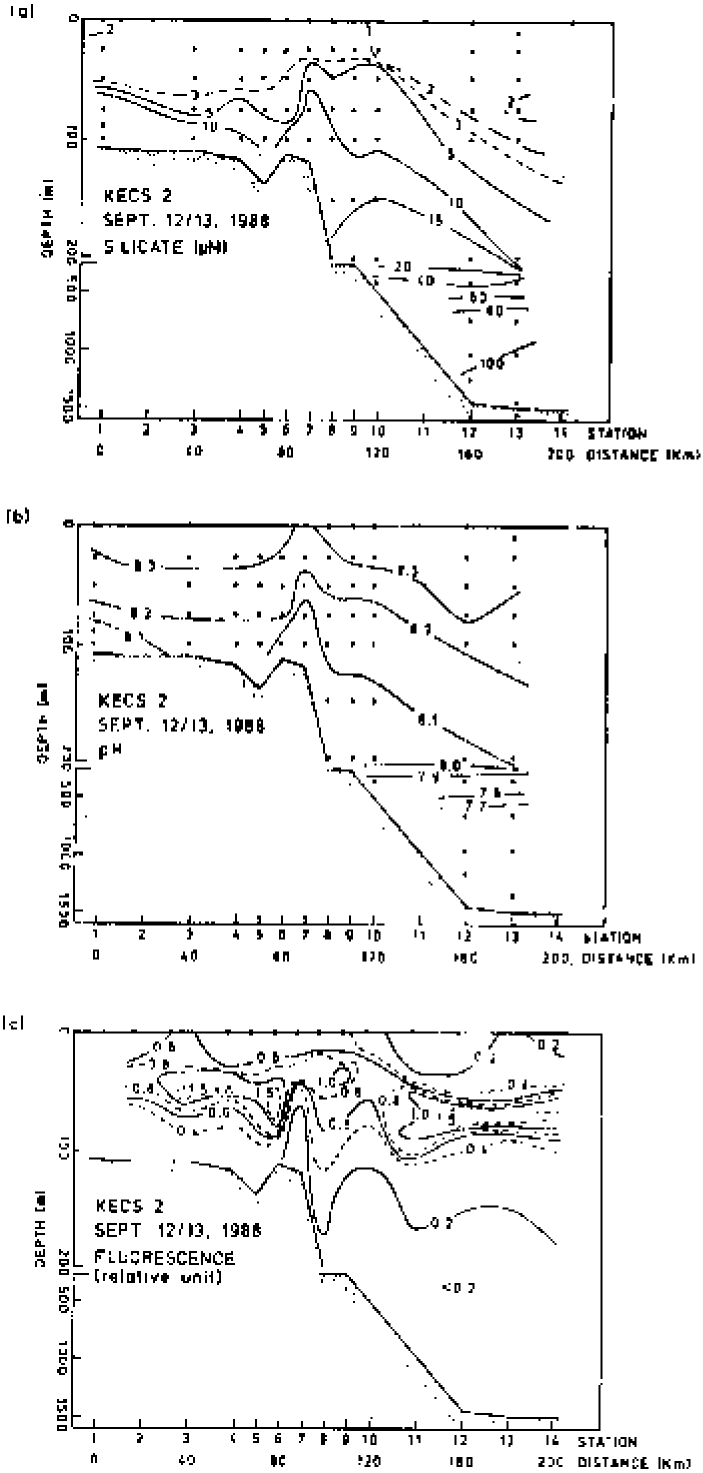

Fig. 6. The distribution of (a) silicate, (b) pH and (c) total fluorescence along transect C.

degths is potentially a major source of nutrient to the East China Sea. As in the upwelled water, the bottom water at Stations C-1 was also relatively low in oxygen (>175 μM) and pH (>8.1), and high in phosphate, nitrate and silicate (>0.6, 10 and 10 μM respectively).

The concentrations of phosphate and nitrate in the surface waters on the shelf were similar to those in the Okinawa Trough, being around the detection limit in both cases, However, the concentration of silicate in the surface water of the shelf was higher than those in the Okinawa Through by about a factor of two (Fig. 3). This may be a reflection of the influence of the input of river water, which is well known for its elevated concentrations of silicate relative to surface seawater (Moore *et al.*, 1986), on the chemical composition of the shelf water.

In the Okinawa Trough, the concentrations of nitrate, phosphate and silicate increased monotonically with depth while that of oxygen decreased in the same fashion. pH also decreased monotonically with depth. A nutrient maximum and an oxygen minimum zone were not found even at 1400 m at Station C-14 although such features were found routinely at about 1000 m in the Philippine Sea south of the Okinawa Island chain (Yamamoto and Horikashi, 1979; Liu *et al.*, 1987; Pai *et al.*, 1985). This difference in the distributions of oxygen and nurients may be caused by the enhanced interactions between the bottom water and the interstitial water in a trough, where the ratio of the surface area of the sediments to the volume of water was relatively large, and the lack of direct communication between the deep water in the Okinawa Trough and those in the adjacent basins. This resulting diffusive supply of nutrients from the sediments and the removal of oxygen to the sediments may be large enough to play a prominent role it regulating the composition of the deep and bottom water in the basin.

Broecker (1974) suggested that NO can be used as a conservative tracer for water masses. NO is defined as:

$$NO=[O_2]+9[NO_3]$$

where $[O_2]$ and $[NO_3]$ are the concentrations of oxyen and nitrate in μM so that NO is also in μM. In such a combination, the non-conservatiove effects of the concommitant utilization of oxygen and the regeneration of nitrate may offset each other resulting in a conservative parameter for tacing water masses. The distribution of NO in transect C is shown in Fig. 5. The major hydrographic features observed in the distribution of temperature and salinity were also evident in the distribution of NO. The surface waters in the shelf was characterized by the lowest concentration (>175 μM). The surface waters further off-shelf had higher values. NO increased with depth in the Okinawa Trough. The concentration of NO in the upwelled water was about 250 to 300 μM. In the deep Okinawa Trough, the concentration of NO was about 420 μM.

Total fluorescence

The upwelled water at the shelf edge between Stations C-7 and C-10 could be identified as a plume of water with low fluorescence that was injected shelf-ward towards the surface (Fig. 6). The double-humped structure of the upwelled water at the shelf edge was again evident. The upwelled water, although low in fluorescence, was nutrient rich. This suggests that other factors, aside from the availability of nutrients, were controlling the amount of phytoplankton biomass in this water, The need for the development of physiological adaptation before phytoplankton can support an increased rate of growth in nutrient-rich upwelled water has been suggested in other studies (Jones *et al.*, 1983; MacIssac *et al.*, 1985). similar processes may be operating here. The pool of highly saline and nutrient-rich water at the bottom of Stations C-1 to C-3 was also characteized by low fluorescence, which was characteristic of deeper off-shelf water. A sub-surface layer of water with high fluorescence was found on the shelf and in the Okinawa Trough at the two sices of the upwelled water at about 60 to 80 m. This layer of water was found at the top or just above the nutricline where the concentrations of nutrients were still quite low. It was situated at slightly shallower depths on the shelf. Although the total fluorescence at the fluorescence-maximum in the shelf waters and in the Okinawa Trouugh were similar, the fluorescence might not have been caused by the same kinds of organisms.

Relationships among the chemical hyrographic parameters

The stoichiometric model of Redfield *et al.* (1963) suggests that the concentration of nitrate in the ocean should be linearly and directly related to that of phosphate since the distributions of these two elements are governed by their coupled biological uptake or regeneration, In this region, in general, the concentration of nitrate increased with increasing concentration of phosphate (Fig. 7). In estimating the linear relationships between nitrate and phosphate, the data points were subdivided into three groups: C-1 to C-5 on the shelf in the East China Sea, C-6 to C-10 in the transition zohe where upwellng occurred and C-11 to C-14 plus D-1 in the Okinawa Trough. Thus, in the Okinawa Trough,

$$[NO_3]=17.8\ [PO_4]-0.3 \qquad r=1.00.$$

where $[PO_4]$ is the concentration of phosphate in μM. At Statiohs C-1 to C-5,

$$[NO_3]=14.2\ [PO_4]+0.5 \qquad r=0.96.$$

The N:P ratio in the East China Sea seemed to be somewhat different from that observed in the Okinawa Trough. However, a carefal examination of the data points shows that, at Stations C-1 to C-5, although the correlation coefficient is quite high, a linear model may not represent the data well. The data points with the highest and lowest concentrations of nitrate tended to deviate from the linear relationship most. This deviation from the stoichiometric model indicates that the coupled uptake and regeneration of nutrients were not the only processes that affect the concentrations of nutrients in the East China Sea. At low concentrations, the concentration of nitrate dropped to undetectable levels while there were still detectable amounts of phosphate. Thus, nitrate became limiting so that the N:P ratio was controlled by their relative availability rather than the uptake or regeneration of nutrients and the stoichiometrid model broke down. The data points with the highest concentrations of nitrate and phosphate were found in the cottom water of Station C-1. The properties of this water were more similar to those further off-shelf than those of the surrounding water on the shelf proper as discussed previously. Thus, the N:P ratio might be controlled by the composition of the source waters and the stoichiometric model would not be applicable to such a situation (Chen *et al.*, 1982, 1986; Takahashi 1985; Minster and Boulahdid, 1987; boulahdid and Minster, 1989). If these data points are eliminated, the remaining data points can be described by a linear relationship well and the equation becomes

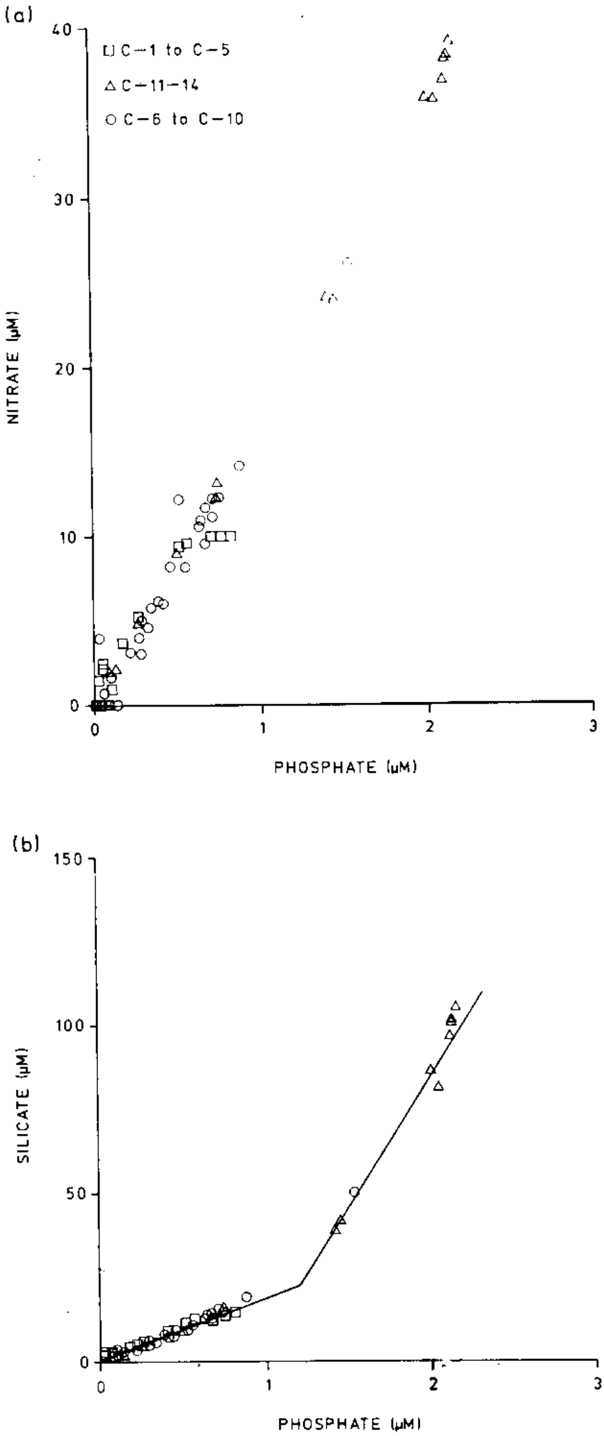

Fig. 7. The relationship between (a) nitrate and phosphate, and (b) silicate and phosphate. □—Stations C-1 to C-5; ○—Stations C-6 to C-10; △—Stations C-11 to C-14.

$[NO_3]=16.8\ [PO_4]+0.8$ $r=0.97$.

This equation is similar to the one observed in the Okinawa Trough. In the transition zone at Stations C-6 to C-10,

$[NO_3]=17.0\ [PO_4]-0.3$ $r=0.98$,

As in the nitrate-phosphate relationships in the other two groups of stations, the intercept of this line was also small. The N:P ratio was intermediate between those of the shelf and the Okinawa Trougt. These N:P ratios in the waters in the East China Sea and the Okinawa Trough were similar to the value of 16:1 proposed in the stoichiometric model (Redfield *et al.*, 1963).

The relationship between silicate and phosphate can be represented by two linear lines with an inflexion point at a phosphate concentration of about 1.2 μM (Fig. 7) where the corresponding depth and temperature were about 300 m and 12°C. In the Okinawa Trough,

$[Si]=18.4\ [PO_4]+0.6$ $r=0.99$ when $[PO_4]>1.2\,\mu M$, and
$[Si]=82.8\ [PO_4]-78.6$ $r=0.98$ when $[PO_4]>1.2\,\mu M$.

where [Si] is the concentration of dissolved silicate in μM. In the shelf and in the transition zone, the concentrations of phosphate rarely exceeded 1.2 μM and, respectively,

$[Si]=16.9\ [PO_4]+1.9$ $r=0.99$ and
$[Si]=18.8\ [PO_4]+1.0$ $r=0.99$.

Thus, in the shallower waters where the concentrtion of phospate was below 1.2 μM, the Si: P ratio increased slightly from 16.9:1 in the shelf to 18.41:1 in the Okinawa Trough. Although both phosphate and silicate have been classified as nutrient element elements, their biogeochemical properties are markedly different. While phosphorus is associated perimaril with the soft tissues of the organisms, silicon is found mostly in the skeletal parts of siliceous organism. Thus, their biological uptake and regeneration should not be closely coupled to each other and they sould not obey the stoichiometoic model. The observed simple linear relationships may thus either be fortuitous or be controlled by other processes, such as mixing, instead. If the relationships were controlled by mixing, the inflexion point may represent the upwelled altered Kuroshio water which mixes with the shallower, silicate-poor, phosphate-poor shelf water and the deeper, silicate rich, phosphate-rich OTDW.

The relationship between nitrate, phosphate, silicate, NO and temperature also fell on two linear lines with an inflexion point at abound 11 to 13°C (Fig. 8). Thus, adove 12°C, the relationships in the shelf, the transition zone and the Okinawa Trough were, respectively,

$[NO_3]=25.5-0.88\,T$ $r=0.98$,
$[PO_4]=1.69-0.59\,T$ $r=0.97$,
$[Si]=30.54-1.00\,T$ $r=0.97$, and
$[NO]=401.4-7.347\,T$ $r=0.92$ in the shelf;
$[NO_3]=25.2-0.89\,T$ $r=0.95$,
$[PO_4]=1.49-0.052\,T$ $r=0.97$,
$[Si]=28.89-0.97\,T$ $r=0.95$. and
$[NO]=352.2-5.374\,T$ $r=0.91$ in the transition zone; and
$[NO_3]=23.9-0.85\,T$ $r=0.95$,
$[PO_4]=1.32-0.46\,T$ $r=0.95$,
$[Si]=24.15+0.82\,T$ $r=0.91$, and
$[NO]=369.6-6.216\,T$ $r=0.95$ in the Okinawa Trough

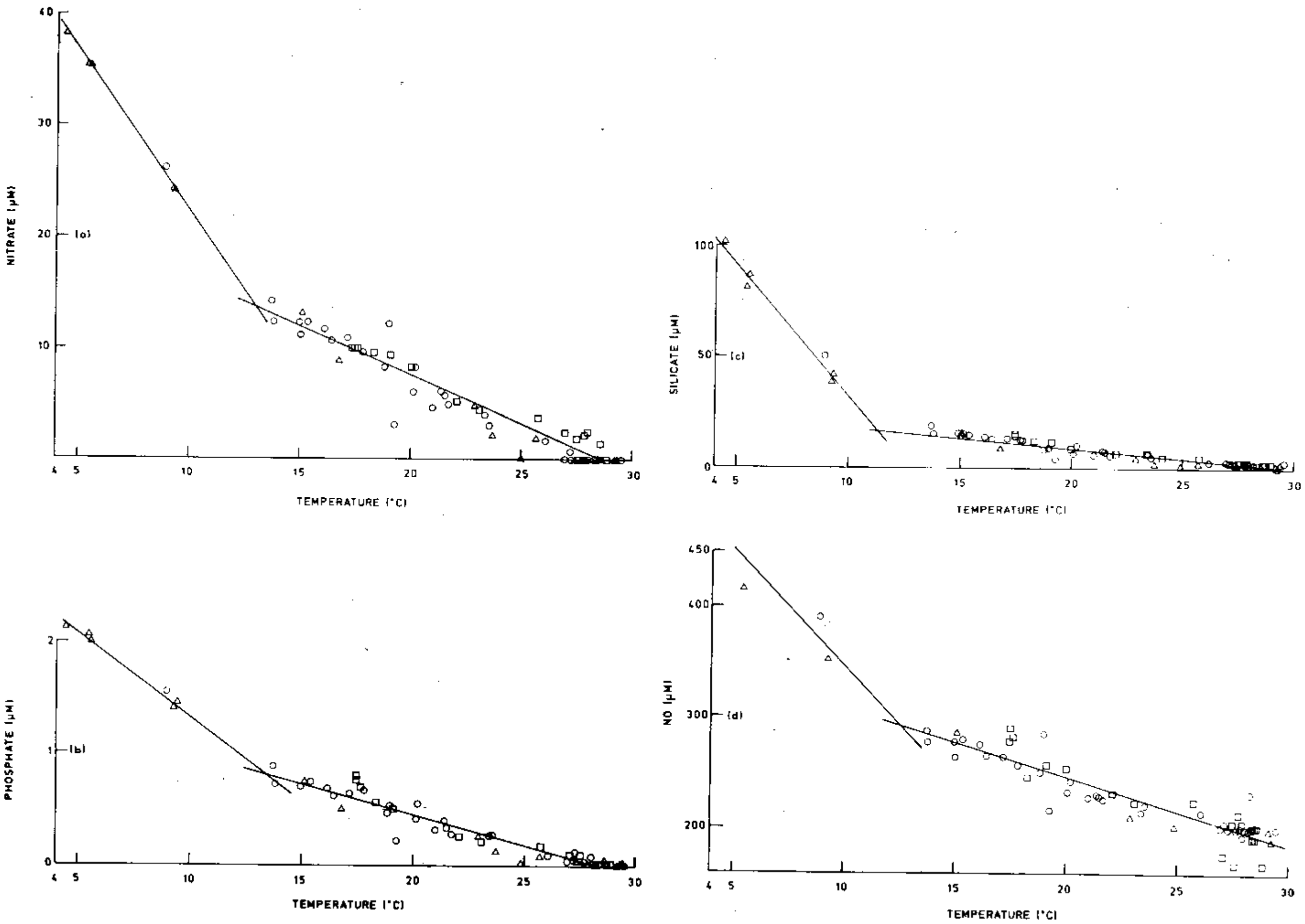

Fig. 8. The relationship between (a) nitrate and temperature, (b) phosphate and temperature, (c) silicate and temperature and (d) NO and temperature. The symbols are defined in Fig. 7.

where T is temperature in°C. In many cases, there seems to be a systematic change in these relationships form the shelf to the transitional zone to the Okinawa Trough. The changes are small, on the order of at most 15%, in both the slope and the intercept. These linear relationships suggest that the dominating processes governing the compoiition of the water in the region is through the mixing of cold, nutrient-rich deeper water with the warm, nutrient-poor surface waters. If these linear relationships can be verified as in the South Atlantic Bight (Dunstan and Atkinson, 1976; Lee *et al.*, 1981; Atkinson *et al.*, 1982, 1983; Lee and Atkinson, 1983), temperature may be a convenient indicatior for estimaing exchanges of nutrients between these waters (Chen, 1986). Below 12°C, in the Okinawa Trough,

$$[NO_3]=51.4-2.93\,T \qquad r=1.00,$$
$$[PO_4]=2.83-0.150\,T \qquad r=1.00, \text{ and}$$
$$[Si]=149.89-11.8\,T \qquad r=0.99.$$

The points of intersection of these nutrient-temperature relationships above and below 12°C occur at 12.6 to 13.2°C for nitrate, 12.5 to 14.5°C for phosphate, and 11.1 to 11.5°C for silicate. These temperatures are similar to that of 13°C at which the T-S relationships at all stations merged to a common point. Although there are only a few data points for the deep water, these results are similar to those found by Liu *et al.* (1988). If this point of intersection represents the source of the upwelling water, then, the upwelled water, initially at a temperaure of about 13°C, contained about 14 μM of nitrate, 0.8 μM of phosphate and 17 μM of silicate. The corresponding concentrations of oxygen, NO, pH and salinity were 160 μM, 195 μM, 7.9 and 34.43°‰. Some form of this altered Kuroshio water is added to the East China Sea where its nutrients are stripped off to undetectable levels in nitrate and phosphate and to about 2 μM for silicate. Thus, it may be a significant source of nutrients of the East China Sea.

CONCLUSIONS

The boundary between the East China Sea and the Okinawa Trough northeast of Taiwan was clearly defined by a large contrast in temperature and salinity across the frontal region at the sea surface. Among the nutrients, oxygen and pH, only silicate could provide an indication of this front. The concentration of silicate in the surface waters in the shelf was about twice of that in the Okinawa Trough. Aside from mixing across this frontal region, the distribution of temperatue, salinity, oxygen, phosphate, nitrate, silicate, NO, pH and total fluorescence also suggested the occurrence of topographically induced upwellihg of altered Kuroshio water at the shelf break probably as a result of the periodical meandering and shelf-ward migration of the Kuroshio. While the Kuroshio was centered at about 110 m and it was relatively impoverished in nutrient, the source of the upwelled water came from about 300 m and it had the following characteris tids: temperature—13°C, salinity—34.43° psu, nitrate—14 μM, phosphate—0.8 μM, silicate—17 μM, oxygen—160 μM, NO—195 μM and pH 7.9. In contrast, the concentrations of nitrate and phosphate in the water of the shelf were undetctable while that of silicate was about 2 μM. Thus, upwelling of altered Kuroshio water is potentially a significant source of nutrient to the East China Sea.

The concentrations of the nutrients were linearly related to temperature above about 13°C. As a result, it may be possible to estimate the exchange of nutrients between the East China Sea and the Kuroshio in the Okinawa Trough from the corresponding heat exchanges.

The deep water in the Okinawa Trough at temperatures below 13°C below about 300 m did not participate in cross-shelf mixing. Furthermore, it is cut off from the deep water in the Phillipine Sea south of the Okinawa Island chain. As a result, the chemical characteristics of these deep water were significantly different from each other.

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臺灣東北部黑潮與東海交界鋒面之海洋化學研究

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摘要

本研究係探討臺灣東北部黑潮與東海陸棚交界處鋒面的水文和化學結構。由一次橫斷鋒面航次的資料顯示，此地區海洋化學特性的變化，主要受控於黑潮因地形變化引起的湧升流和穿透鋒面的混合作用。本研究測得九月時靠東海內側表層水團平均溫度爲 28.7°C，鹽度爲 33.4 psu，若與沖繩海槽的黑潮表層水比較，溫鹽各低了 0.9°C 和 0.7 psu，差異十分明顯。表面水含矽酸鹽濃度在鋒面兩側差異很大，但硝酸鹽及磷酸鹽濃度均極低，和溶氧量一樣看不出差別。黑潮造成湧升的水團特性，可由其高鹽 (34.3 psu)，低溫 (13°C)，高營養鹽 (硝酸鹽磷酸鹽和矽酸鹽分別爲 14, 0.8 和 17 μM)，高 NO 値 (195 μM)，低溶氧量 (160 μM) 和低 pH (7.9) 等指標辨別之。至於沖繩海槽深部的水團 (溫度低於 13°C 者) 並未參與本地區的混合作用，且與琉球島弧外的同深度水團截然不同。