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Oxygen isotope characteristics of seawaters in the Yellow Sea

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Abstract : Due to extremely large variation of temperature and salinity, typically as much as 20℃ in temperature seasonally, it is a difficult task to characterize and classify water masses in the Yellow Sea. We studied $^{18}O/^{16}O$, oxygen isotope characteristics, of seawaters in the area in order to provide additional constraints on the water mass analysis.

Even with large variations in salinity and temperature, isotopic composition of seawaters in summer and winter does not indicate any signficant seasonal difference, showing a simple mixing trend. The contrasting difference observed in T-S and $\delta^{18}O$-S characteristics of surface waters in summer, therefore, reflects the non-conservative nature of temperature in the area, resulted from solar heating at the sea-air interface.

The present study implies that seawaters in the area are, in essence, a mixture of two end-members; isotopically light, fresh waters from precipitation and river discharges (S = 0 ‰, $\delta^{18}O = -7 \sim -9$ ‰) and isotopically heavy, saline waters originated from the East China Sea as a Kuroshio branch (S = 34.40 ‰, $\delta^{18}O = 0.2$ ‰).

1. Introduction

The Yellow Sea is a typical epicontinental sea, surrounded by the contiguous land masses of Korea and China. With a mean depth of 44m and maximum depth of 105m, it is open to the East China Sea to the south and the Bohai Sea to the north, whose significant portion freezes during winter (GONG, 1989).

The salinity and temperature in the Yellow Sea show enormously large variations as much as 20℃ in temperature between summer and winter time and from 29 ‰ to 35 ‰ in salinity. While several water masses such as Yellow Sea (Bottom) Cold Water (YSCW), Yellow Sea Warm Current Water (YSWCW) and East China Sea Water (ECSW) have been identified as distinct water masses with persistent T-S characteristics, individual investigator often disagrees on the property limits of these waters (LIE, 1984, 1986; PARK, 1985, 1986; KIM *et al.*, 1991). Furthermore, waters along Chinese and Korean coasts were defined rather loosely, reflecting difficulties involved in classification and characterization of water masses in the area.

Oxygen isotope composition, $^{18}O/^{16}O$, of seawater is a classic example of conservative tracers applied to water mass analysis along with temperature and salinity in the ocean (CRAIG and GORDON, 1965). It is also interesting to note that the stable isotope composition is the characteristics of water molecule itself, experiencing little alteration with thermal conditions such as heating or cooling. This property, therefore, can be very powerful in water mass analysis for coastal or shelf waters, where temperature can no longer be a conservative property due to relatively small size of thermal mass (TORGENSEN, 1979).

Oxygen isotope studies have been carried out for the coastal, estuarine waters in the area (ZHANG *et al.*, 1990; WU, 1991). In this paper, we explored the possibility of utilizing this unique tracer for water mass analysis of Yellow Sea waters.

2. Materials and methods

During five oceanographic cruises carried out in the Yellow Sea from 1991 through 1993, 59 stations were occupied as shown in Fig. 1. Water temperature and salinity were measured using a

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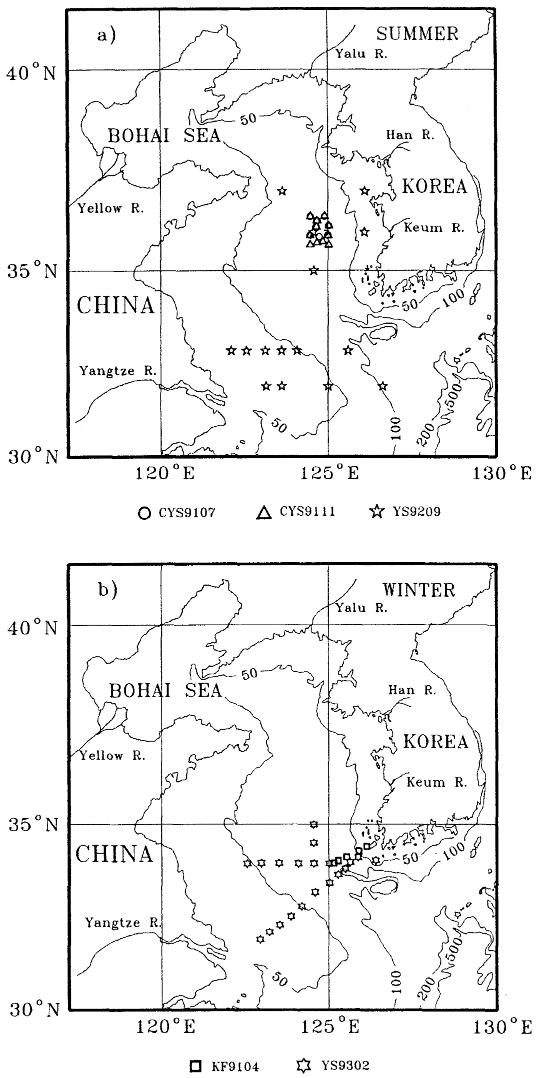

Fig. 1. Maps showing sampling stations in the Yellow Sea. Stations with strong thermocline in summer are grouped in (a), and those with winter characteristics (thoroughly mixed vertically in water column) are grouped in (b). Isobaths in meters.

Seabird SBE-25 CTD system. Water samples were collected with 5 l Niskin bottles mounted on a Rosette sampler at standard depths; surface, 10, 20, 30, 50, 75m and near bottom.

The $^{18}O/^{16}O$ ratio of seawater was determined using Isotope Ratio Mass Spectrometer (VG ISOTECH SIRA II) equipped with an automatic H_2O/CO_2 equilibrator (Isoprep 18). The seawater was equilibrated with CO_2 gas inside the equilibrator for 6 hours at 25℃ with mild shaking and isotope ratio of the sample was determined from the observed value for CO_2 gas (EPSTEIN and MAYEDA, 1953).

The oxygen isotopic composition of seawater is compared with SMOW (Standard Mean Ocean Water), and is expressed as $\delta^{18}O$ defined as follows (CRAIG, 1961):

$$\delta^{18}O_{\text{sample}} = [\frac{(^{18}O/^{16}O)_{\text{sample}}}{(^{18}O/^{16}O)_{\text{SMOW}}} - 1] \times 1000 \ (‰).$$

Twenty samples were analyzed for each run as a batch and 2 to 4 seawater samples used for working standard were included in each batch to control the quality of the measurement. The mean $\delta^{18}O$ of the working standard used in our experiment is -0.12 ‰ $\pm$ 0.08 ‰. The precision of the measurements is $\pm$ 0.13 ‰.

3. Results and discussions

In the Yellow Sea proper with depths less than 100 m, waters are thoroughly mixed vertically in the water column in winter, while strong thermoclines with their depths up to 40 m occur in summer with mixed layers both above and below these thermoclines. Typical examples of CTD profiles representing summer and winter characteristics are shown in Fig.2. Three cruises occupied in July and November, 1991 (CYS9107 and CYS9111) and September, 1992 (YS9209) showed summer characteristics and the rest two carried out in April, 1991 (KF9104) and February, 1993 (YS9302) showed winter characteristics.

The isotopic composition of seawater samples is also shown in the figure, reflecting homogeneous nature in property distribution for each mixed layer, surface mixed layer and deep mixed layer in summer and whole water column in winter. For following discussions, data from samples at 0 and 50 m depths were chosen as representatives for each layer. Henceforth, the surface and deep waters refer to the waters at these selected depths.

Fig. 3 shows the T–S characteristics and $\delta^{18}O$–S characteristics of surface waters and deep waters in summer and winter. Though sampling areas for the present study were not extensive over the Yellow Sea, the T–S distribution reveals

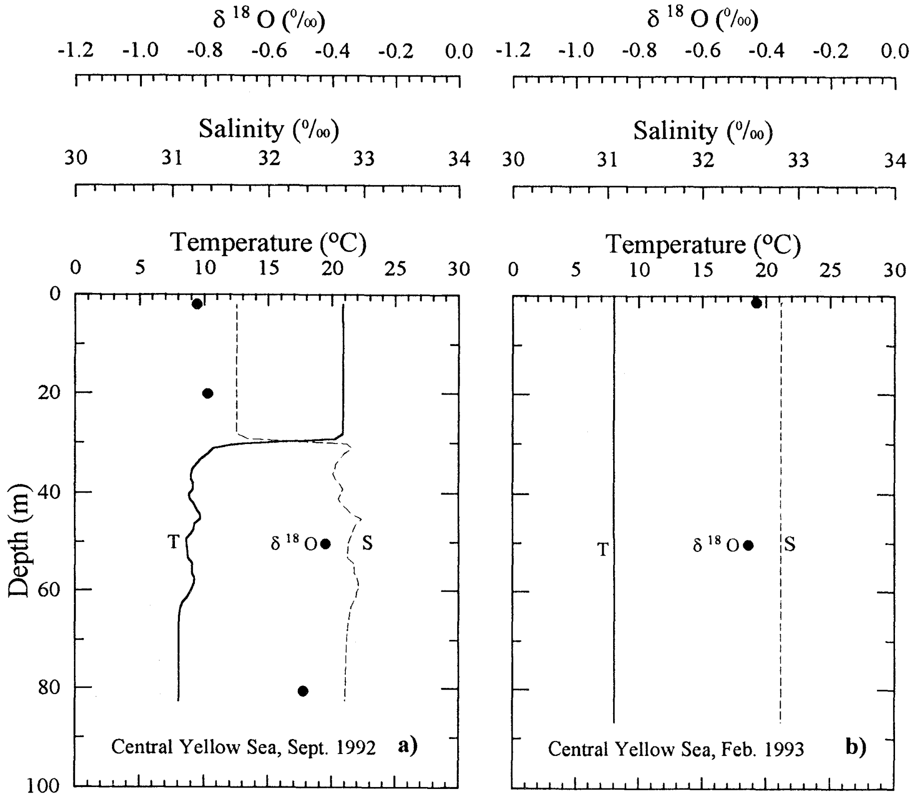

Fig. 2. Typical examples of CTD profiles representing summer characteristics (a) and winter characteristics (b) in the Central Yellow Sea. The $\delta^{18}O$ values of seawater samples are also shown in the figure reflecting homogeneous nature in each mixed layer.

major features such as YSCW, YSWCW and ECSW observed by previous investigations (NAKAO, 1977; KONDO, 1985; KIM *et al.*, 1991).

In summer as stratification occurs, a separation in T–S characteristics between surface waters and deep waters is clear. However, $\delta^{18}O$–S characteristics do not show any significant difference between surface waters and deep waters in summer and also between waters in summer and in winter. This observation, thus, strongly implies that water masses in the Yellow Sea, in essence, do not change seasonally, and that the apparent separation in T–S characteristics between surface and deep waters in summer is primarily due to solar heating at the sea-air interface resulting in very little alteration in isotopic composition.

Furthermore, as shown in Fig. 4, isotopic composition of all these waters, in general, falls on a single mixing trend between less saline and isotopically lighter waters and more saline and isotopically heavier waters, when plotted against salinity. In the figure, the isotopic compositions of Yellow River (Huanghe) estuarine waters (ZHANG *et al.*, 1990), weight-averaged precipitation collected in Korea, China and Japan (KIM and NAKAI, 1988; ROZANSKI *et al.*, 1993), and Kuroshio waters collected in the East China Sea (ONR9202) are also shown.

Major sources for fresh waters in the Yellow Sea are precipitation and discharges from major rivers in the area; the Yellow, Yalu, Han and Keum Rivers. Fresh waters discharged from the Yangtze River (Changjiang) mostly flow southward entering into the East China Sea and its direct influence on the Yellow Sea is minimal (BEARDSLEY *et al.*, 1985). The precipitation over the Yellow Sea is estimated as 4.6×10^{11} m^3/yr (LEE and KIM, 1989), about four times as large as river discharges, $\sim 1.2 \times 10^{11}$ m^3/yr

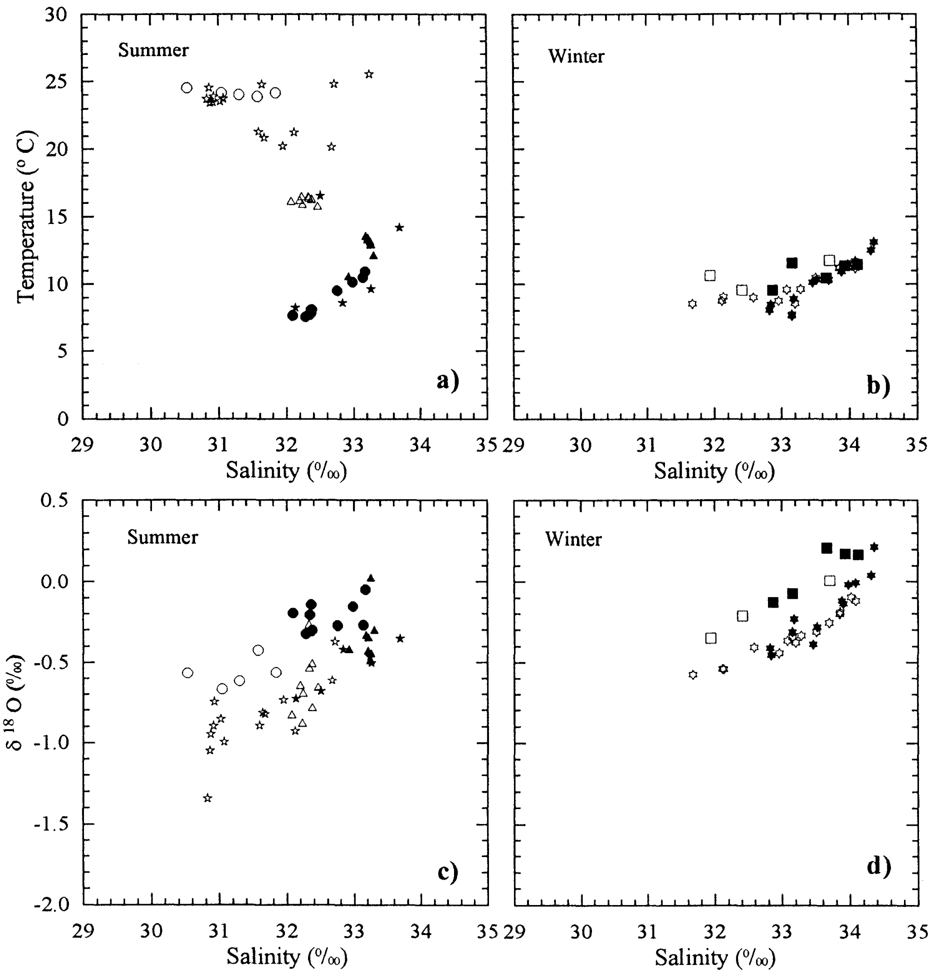

Fig. 3. T–S and δ^{18}O–S diagrams of surface waters and deep waters in summer and winter. Samples at 0 m (open symbols) and 50 m (closed symbols) depths were chosen as representatives for the surface mixed layer and the deep mixed layer, respectively. Symbols represent cruises listed in Figure 1.

(CHOUGH and KIM, 1982; MILLIMAN and MEADE, 1983; WANG and AUBERY, 1987).

The isotopic composition of precipitation in the area ranges from −6.7 to −8.8 ‰ for their weight-averaged values (KIM and NAKAI, 1988; ROZANSKI *et al.*, 1993), even with some seasonal variations, and are very comparable to riverine compositions −7.9 ～ −8.8 ‰ (ZHANG *et al.*, 1990) observed in the Yellow River. As already shown in Fig. 4, these values fit well on the extension of mixing line for the Yellow Sea waters, implying their role as one end-member for the observed mixing trend.

The most saline waters in the Yellow Sea mainly come from the East China Sea as a branch of the Kuroshio current (KONDO, 1985; PARK, 1986; KIM, 1988). The isotopic composition of Kuroshio waters collected in the East China Sea (ONR9202), shown in Fig. 4, clusters well on heavy waters with high salinity and is very comparable to values of Kuroshio waters at the northeast of Taiwan (25°10'N, 121°58.6'E), 0.2 ‰ in δ^{18}O and 34.40 ‰ in salinity. This observation reflects the role of Kuroshio waters as the other saline and isotopically heavy end-member waters in the Yellow Sea mixing trend.

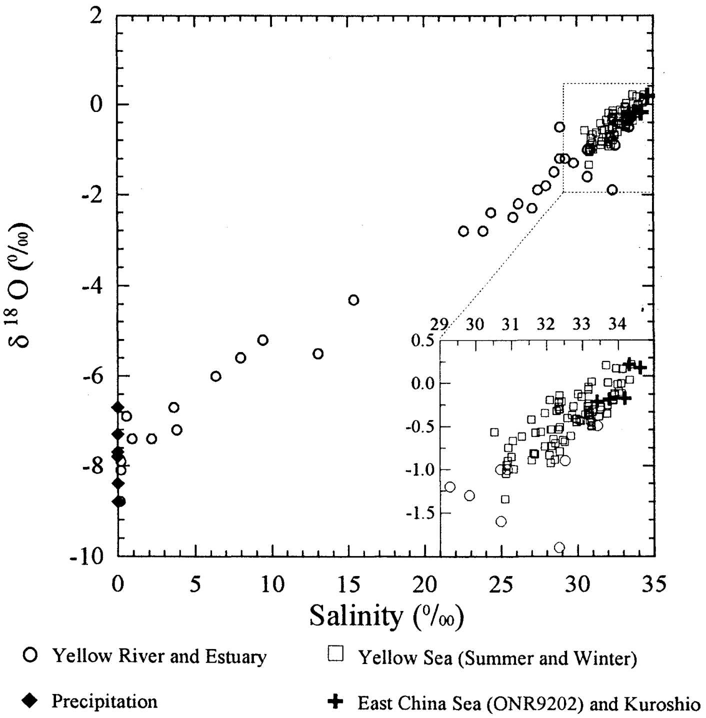

Fig. 4. A $\delta^{18}O$–S diagram of waters in the Yellow River and estuary, Yellow Sea, East China Sea (ONR9202), and precipitation in Korea, China and Japan. The data of the Yellow River estuary taken in May and August, 1985 are from ZHANG *et al.* (1990), and those of the Yellow Sea and East China Sea are obtained in this study. The precipitation data are weight-averaged from KIM and NAKAI (1988) and ROZANSKI *et al.* (1993). The diagrams of the Yellow Sea and East China Sea are redrawn also in an expanded scale.

4. Conclusion

The initial study of oxygen isotopic composition of seawaters in the Yellow Sea revealed that seawaters in the area are, in essence, a mixture of two end-members; isotopically light, fresh waters from precipitation and river discharges (S = 0 ‰, $\delta^{18}O = -7 \sim -9$ ‰) and isotopically heavy, saline waters originated from the East China Sea as a Kuroshio branch (S = 34.40 ‰, $\delta^{18}O$ = 0.2 ‰). The future studies, therefore, need to be focused on quantification of processes determining the mixing ratios in the area.

Furthermore, the contrasting difference observed in T–S and $\delta^{18}O$–S characteristics of surface waters in summer is a mere reflection of non-conservative nature of temperature in the area, resulted from solar heating at the sea-air interface; strongly implying that water mass analysis in the Yellow Sea with T–S characteristics must be exercised with caution due to their non-conservativeness. The effect of solar heating can also be confirmed and normalized by pCO_2 measurement in surface waters especially in summer and winter (WEISS *et al.*, 1982; FUSHIMI, 1987); this type of research in the area is one of the important topics to be explored in the future.

The isotopic composition of precipitation and river waters is rather loosely known at the present time, which may also be a reason for scattering of data. Further refinement is needed to apply this tracer in a more quantitative way.

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