

Shelf edge exchange processes of radionuclides in the East China Sea

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Abstract: Two naturally occurring radionuclides, ^{228}Ra and ^{210}Pb are very useful in the study of shelf-edge exchange processes at the ocean margins. ^{228}Ra can be used to determine the residence time of water on the continental shelf and ^{210}Pb can be used as a tracer of particle-reactive heavy metals in the water. Particular application of these nuclides to the East China and Yellow Seas yielded the shelf water residence time of 2.3 years with respect to exchange with the Kuroshio water and the ^{210}Pb scavenging residence times of ~ 2 months on the shelf and ~ 7 months in the Kuroshio surface water.

Introduction

The East Asian land-ocean boundary region probably has a significant influence on the global environment, yet detailed studies have been few. One of the unique features of this region is the existence of a series of marginal seas including the Bering Sea, Sea of Okhotsk, Sea of Japan, the East China, and South China Sea, all of which have isolated basins deeper than 3000 meters. Therefore, materials transported from the land to the sea must be modified in this marginal region before entering to the open ocean. I describe here the exchange of water and radionuclides between the shelf water of the East China Sea and the Kuroshio Current.

The East China and the Yellow seas (Fig.1) are largely occupied by the continental shelf shallower than 200 meters. The water on the shelf has the salinities of lower than 33 PSU due to fresh water discharge from land largely through the Yangtze and Yellow rivers. A sharp front is formed along the shelf edge between the shelf water and a branch of the Kuroshio Current which flows offshore northward and enters the Japan Sea through the Tsushima Straits. The Tsushima Current, which flows along the Japanese Island and passes the Tsugaru and Soya

straits to enter the Pacific, is believed to be formed by mixing the shelf water of East China Sea and the Kuroshio. Therefore, it is a major pathway by which materials are transported from East Asian continental shelf to the North Pacific.

Two natural radionuclides in the U/Th decay series are supplied to the coastal/shelf region via two distinctly different pathways. One is ^{228}Ra with a half-life of 5.75 years and supplied by diffusion from underlying sediments to the water, after its production from ^{232}Th in sediments (MOORE, 1969). Some ^{228}Ra is also transported by rivers, but it is believed that the desorption of Ra from river suspended particles is a predominant source compared to the input in dissolved form. Because of these inputs of ^{228}Ra , the shelf water contains high ^{228}Ra concentration compared to the open ocean surface water, and the ^{228}Ra is transported from the coastal regions to the offshore by lateral mixing.

The other nuclide is ^{210}Pb with a half-life of 22.3 years which is a daughter product of atmospheric ^{222}Rn , and enters to the ocean surface by dry and wet precipitation. Because of this atmospheric input, ^{210}Pb is normally present in excess relative to the in-situ production from ^{226}Ra in the surface waters and serves as a useful indicator of terrestrial materials transported through the atmosphere (NOZAKI *et al.*, 1976). This is in contrast to ^{228}Ra which is a good indicator of

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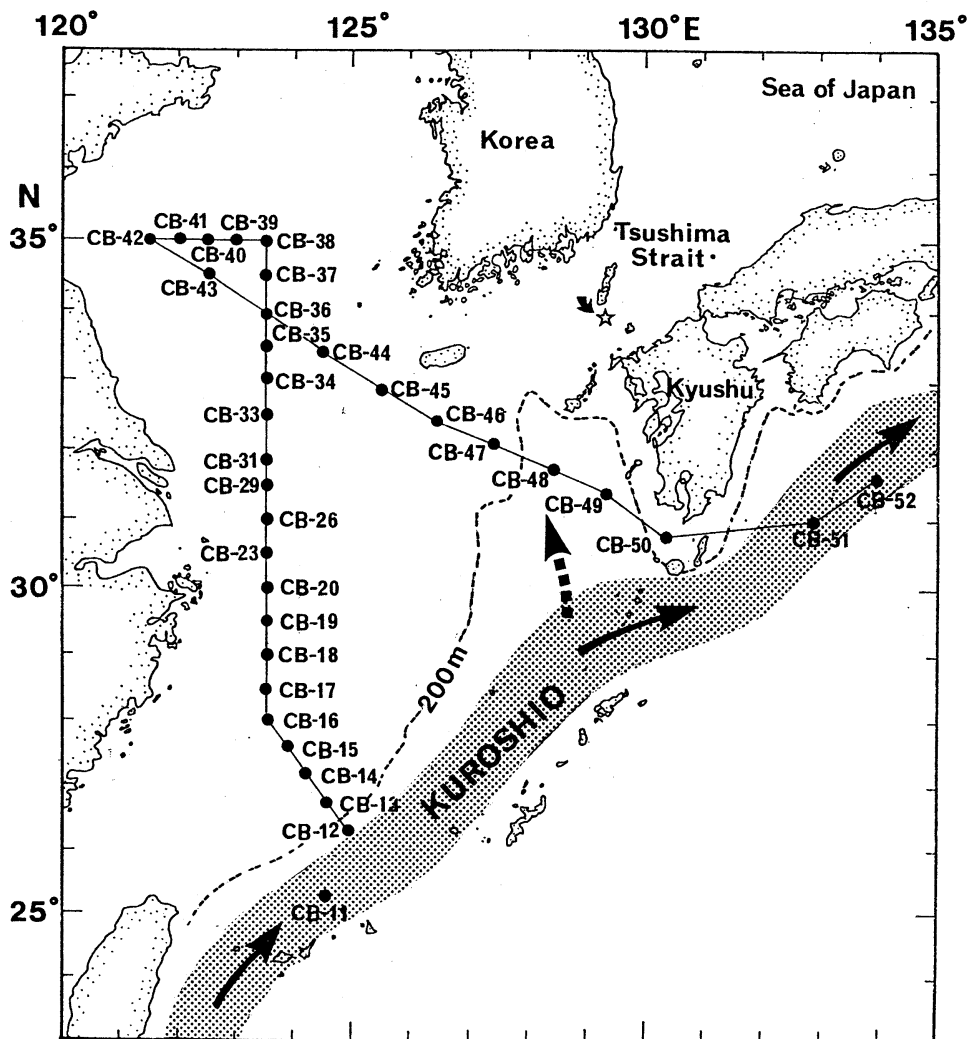


Fig. 1. Station locations of the Corona Borealis Expedition at which the surface water was sampled for radium isotope assay. The star indicates the location where Okubo's measurements are available for the Tsushima Current water.

coastally and fluviially derived substan-ces.

^{210}Pb is also particle-reactive and removed from the surface water more rapidly in the high particle flux regime of coastal waters than in the low particle flux regime of the open ocean. This would result that the concentration of ^{210}Pb is higher in the open ocean and decreases toward the coast, unlike that of ^{228}Ra which is high on the shelf and low in the open ocean. Thus, investigation of the comparative behavior of these two

nuclides should help us to understand the exchange processes at the nearshore/offshore mixing zone.

Methods and Results

Fig.1 shows the station locations where the surface water was sampled. These stations were occupied by the Corona Borealis expedition of R.V. Hakuho-Marui, in 1987. The Yangtze river influences are the strongest at the station around CB-31 as indicated

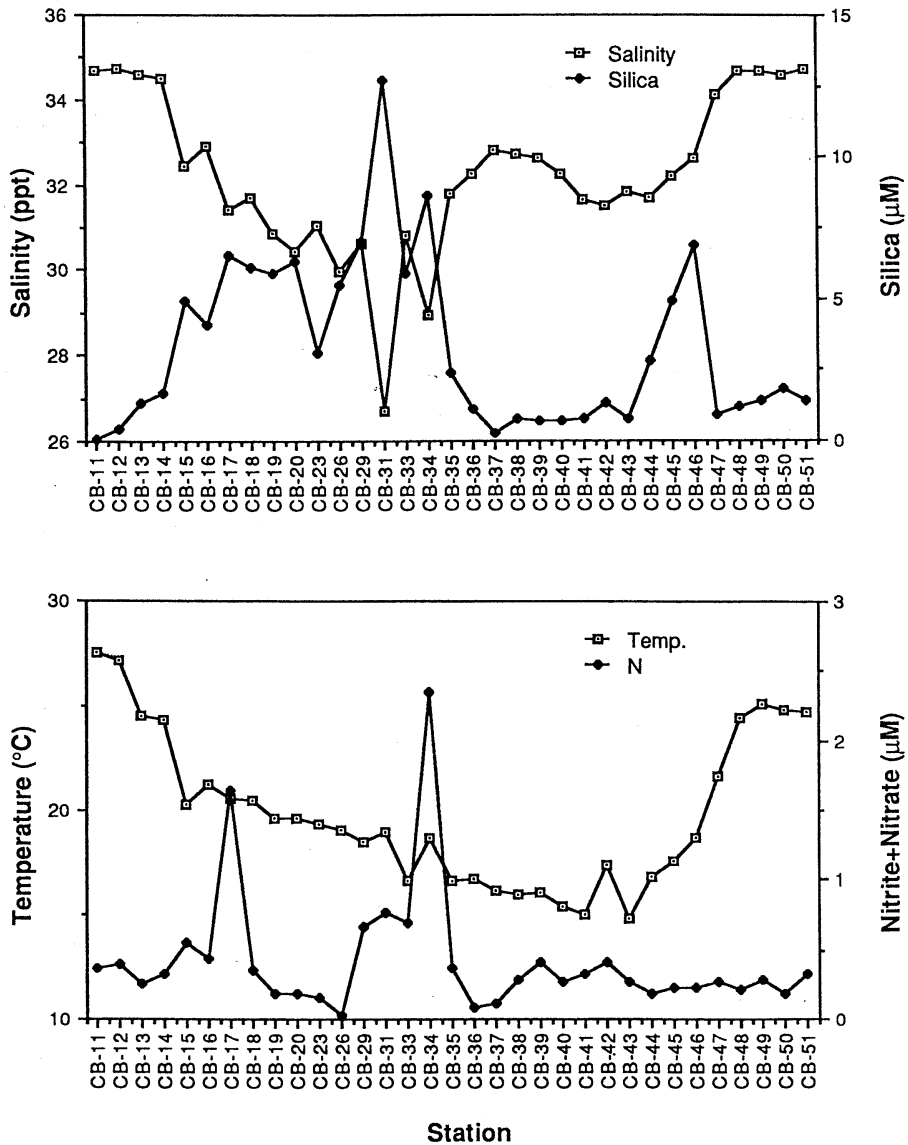


Fig. 2. The results of temperature, salinity, dissolved silica and inorganic nitrogen (nitrate+nitrite). See Fig. 1 for the station locations.

by the salinity decrease down to 26.5 PSU and the high dissolved Si concentration (Fig.2). ^{226}Ra and ^{228}Ra were analyzed by γ -spectrometry according to the method of YAMADA and NOZAKI (1984) using 250 l of seawater. ^{210}Pb and ^{210}Po were analyzed on the separate aliquots (3 l each) of water samples following the methods of NOZAKI *et al.*

(1990).

The results of Ra isotopes (Fig.3) show that, as expected, ^{228}Ra concentration is very high on the shelf and the highest in the Yellow Sea, but very low in the Kuroshio Current. ^{226}Ra shows similar tendency, but because of its relatively long half-life of 1600 years, the variation is smaller than

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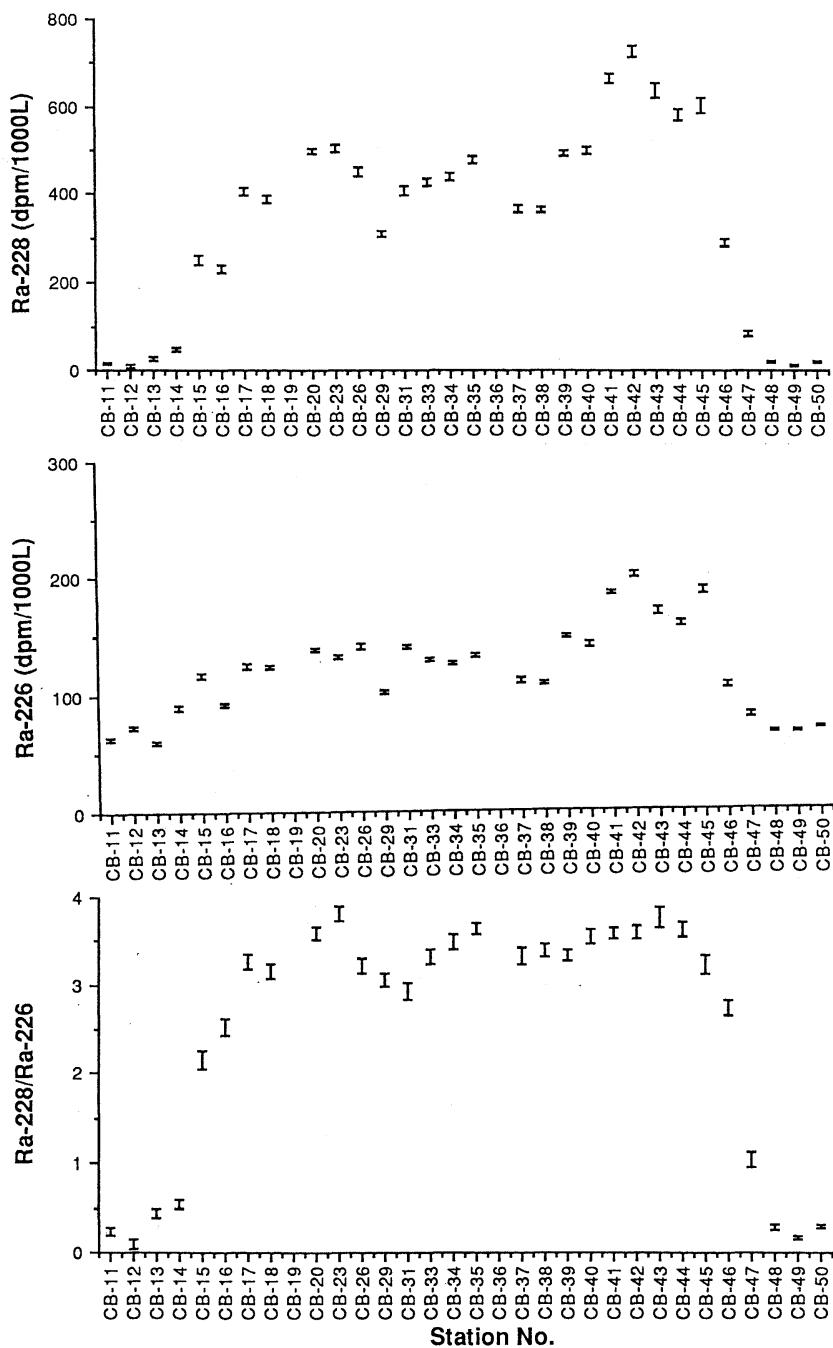


Fig. 3. The results of ^{228}Ra , ^{226}Ra and the activity ratio of $^{228}\text{Ra}/^{226}\text{Ra}$. Error bars are based on 1 sigma counting errors.

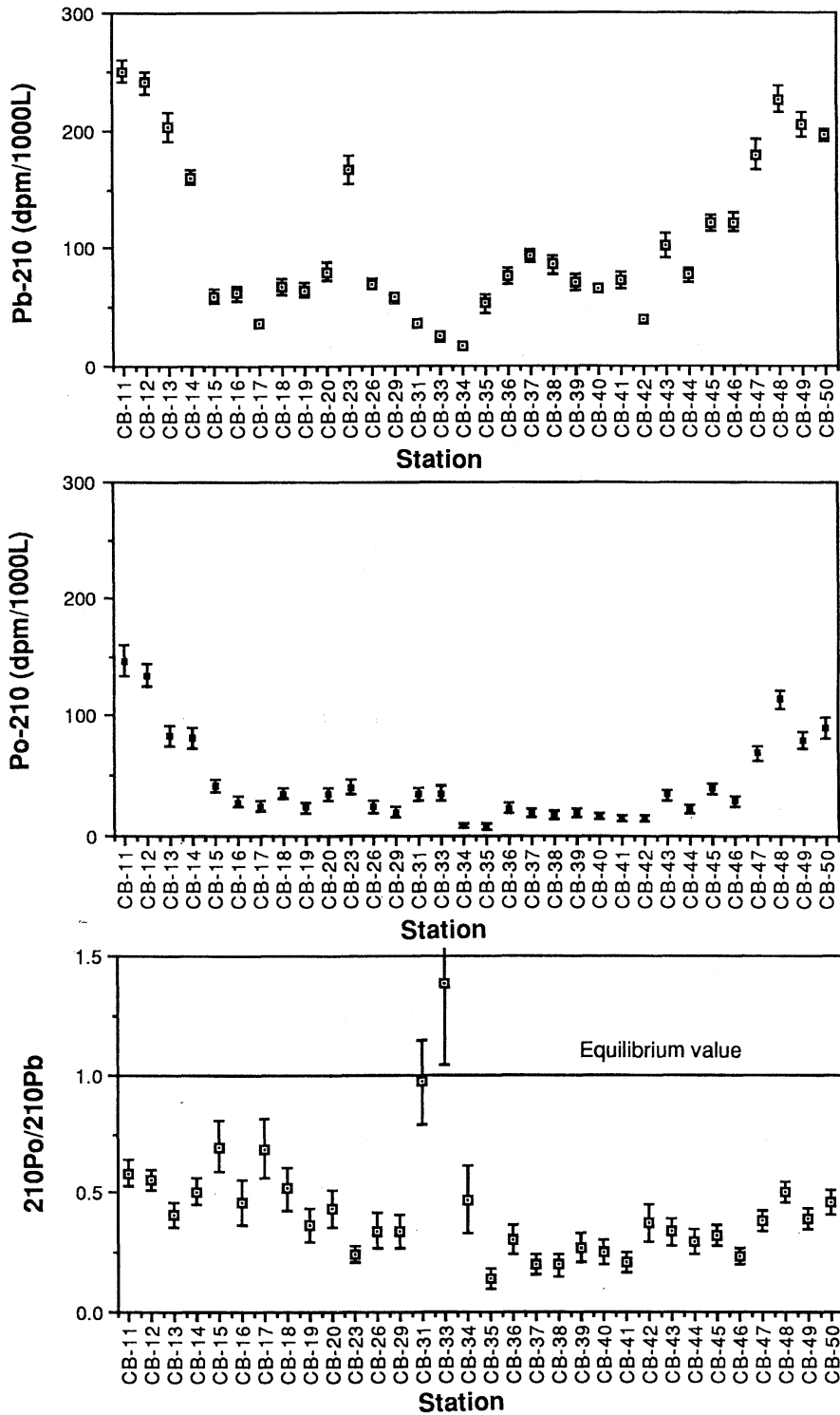


Fig. 4. The distributions of ^{210}Pb and ^{210}Po , and their activity ratio in the East China and the Yellow Seas. See Fig. 1 for the station locations.

that of ^{228}Ra . The Yangtze river influence appears to be small on the Ra distribution, which suggests that the concentrations of Ra isotopes in the river water do not significantly differ from those of the shelf waters. The activity ratio of $^{228}\text{Ra}/^{226}\text{Ra}$, is about 3.5 on the shelf and 0.2 in the Kuroshio Current.

The distribution of ^{210}Pb is contrasting to that of ^{228}Ra , showing the higher concentrations in the Kuroshio and the lower concentrations on the continental shelf (Fig.4). The same is true for ^{210}Po . The $^{210}\text{Po}/^{210}\text{Pb}$ ratio is normally less than 0.5, except for the Yangtze mouth stations, where it rises to an equilibrium value presumably due to input of old detrital materials.

Discussios

Based on the Ra data, it is possible to calculate the exchange rate of water across the shelf edge. One of the approaches is based on the assumption that the Tsushima Current is a mixture of the East China Sea shelf water and the Kuroshio Current. Since the flux of water passing through the Tsushima Straits is known to be $\sim 3 \times 10^6 \text{ m}^3/\text{s}$, we can estimate the flux of water leaking out of the shelf, once the mixing ratio is known. The fraction of shelf water (f) contributed to the Tsushima Current is given by

$$f = \left[\left(\frac{^{228}\text{Ra}}{^{226}\text{Ra}} \right)_T - \left(\frac{^{228}\text{Ra}}{^{226}\text{Ra}} \right)_K \right] / \left[\left(\frac{^{228}\text{Ra}}{^{226}\text{Ra}} \right)_T - \left(\frac{^{228}\text{Ra}}{^{226}\text{Ra}} \right)_K + \frac{^{226}\text{Ra}_S}{^{226}\text{Ra}_K} \left[\left(\frac{^{228}\text{Ra}}{^{226}\text{Ra}} \right)_S - \left(\frac{^{228}\text{Ra}}{^{226}\text{Ra}} \right)_T \right] \right]$$

where the subscripts, K, S and T represent the Kuroshio water, the shelf water and the Tsushima Current, respectively. Equation (1) is derived from the mass balance for Ra isotopes and is represented in terms of the $^{228}\text{Ra}/^{226}\text{Ra}$ activity ratio. Using the mean values for the $^{228}\text{Ra}/^{226}\text{Ra}$ ratio and ^{226}Ra concentrations given above and the data of OKUBO (1980) in the Tsushima Current, f turns out to be 0.2, i.e. approximately 20% of the Tsushima Current is originated from the East China Sea shelf water. Because

total volume of the East China Seashelf water is $4.5 \times 10^4 \text{ km}^3$, the mean residence time of the shelf water with respect to exchange with the Kuroshio is estimated to be 2.3 ± 0.8 years (NOZAKI *et al.*, 1989). The error assigned is based on the fluctuation of volume transport through the Tsushima Straits.

Another way of calculation is to use the Ra balance on the continental shelf and given in NOZAKI *et al.* (1991). The water on the continental shelf is assumed to be formed by mixing between freshwater derived from land and the Kuroshio surface water. Then, the mixing ratio can be calculated from the measurement of salinity. Ra in the shelf water is composed of 1) the Kuroshio component, 2) the freshwater end member and 3) excess Ra added on the shelf resulted from the combined effect of porewater diffusion, desorption from riverborne sediments and any other possible changes like the biological uptake and release and radioactive decay. This excess Ra depends upon the residence time of water on the continental shelf.

Using these assumptions and the mass balance for Ra isotopes, the water residence times can be calculated for each water. Although the values have relatively large uncertainties, they fall about 2-3 years for the East China Sea shelf and 5-6 years for the Yellow Sea (See NOZAKI *et al.*, 1991 for details). Somewhat longer residence times for the Yellow Sea waters are consistent with the general circulation pattern in which the water tends to be trapped within the inner shelf of Yellow Sea.

Now let us calculate the removal residence time of ^{210}Pb which are essentially estimated by dividing the amount of ^{210}Pb in the surface water by the atmospheric flux of $2 \text{ dpm cm}^{-2} \text{ y}^{-1}$. For ^{210}Po , the atmospheric flux is small, so that the ^{210}Po removal residence time is estimated using the ($^{210}\text{Po}/^{210}\text{Pb}$) activity ratio following the manner of NOZAKI *et al.* (1990). If we compare the calculated mean residence times of ^{210}Pb and ^{210}Po , they normally agree each other and they are ~ 7

months in the Kuroshio water and 2-3 months on the continental shelf. Exceptions are in the Yangtze river mouth stations, where Po residence times become extraordinary longer. This is probably due to the contribution of old detrital materials in the samples. Another exceptions are the consistently longer Po residence time at CB-14 to CB-18, which may be indication of Po regeneration from the bottom. Nevertheless, that the scavenging residence times of ^{210}Pb and ^{210}Po are very short compared to the water residence time with respect to exchange with the Kuroshio waters, implies that heavy metals with the reactivity similar to Pb and Po supplied from land through rivers must be deposited on the shelf sediments prior to the transport to the open ocean. Thus, the continental shelf is a repository of particle-reactive weathering materials and pollutants transported from land.

It should be noted that the arguments given here are all based upon the surface data obtained by the one-time survey. It may be possible to come up with better thoughts on the shelf-edge exchange processes of East China Sea, if data for the temporal and spatial variations were obtained. These measurements remain to be done in the future.

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