# CHLOROFLUOROCARBONS AS CIRCULATION AND VENTILATION TRACERS IN THE EAST (JAPAN) SEA

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## Introduction

Dissolved chlorofluorocarbons (CFCs) in the East (Japan) Sea were measured during summer 1999 on R/V Roger Revelle (HNRO-7) and R/V Prof. Khromov (KH36) to study circulation and ventilation in the East (Japan) Sea. CFCs were measured onboard the R/V Roger Revelle, and about 100 duplicate seawater samples were stored in the flame-sealed glass ampoules for post-cruise comparison with the *in situ* analysis results. All seawater samples for CFC analysis in KH36 expedition were collected using the flame-sealed glass ampoules. Approximately 1400 water samples have been analyzed for dissolved CFC, and the stored-sample CFC measurements are still ongoing. The locations of CTD casts and sampling for CFCs are shown in Figure 1.

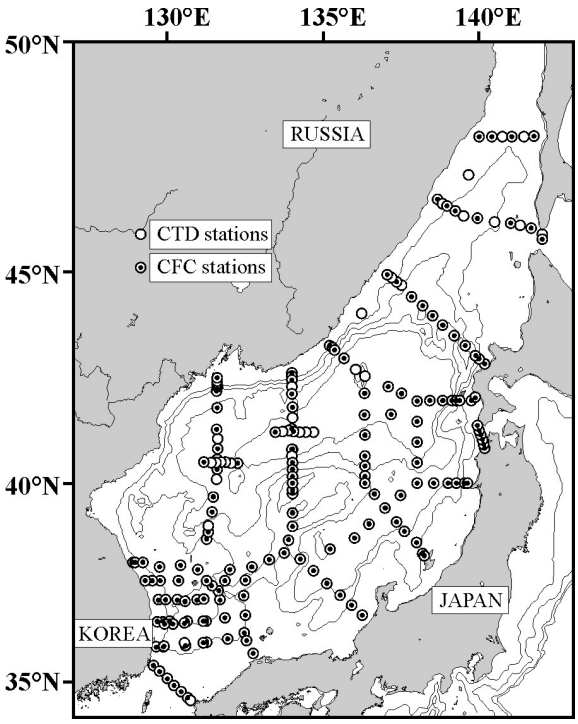


*Fig. 1. Station locations of CTD casts and sampling for CFCs in Hahnaro-7 (R/V "Roger Revelle") and KH-36 (R/V "Prof. Khromov") expeditions in the East (Japan) Sea during summer 1999*

The salinity-minimum "East Sea Intermediate Water (ESIW)" originates from the winter mixed layer north of the subpolar front and it spreads southward to the Ulleung Basin with high oxygen concentration (Kim & Chung, 1984). It's characteristics and distribution have been mainly studied in the Ulleung Basin (Shin, *et al.*, 1998), and there are only a few basin-scale studies (Senjyu, 1999). The ventilation of adiabatic bottom water below about 2500 m (BW) has been inferred from potential temperature and oxygen concentration gradients in the order of the Japan Basin, Ulleung Basin and Yamato Basin (Gamo, *et al.*, 1986).

We report here that the CFC-maximum layer centered at potential density of ~27.25 was widely distributed both in Ulleung and Yamato Basins south of the subpolar front in summer 1999. We also report that CFC distributions in BW show remarkable anti-correlation with that of dissolved oxygen and potential temperature, and show even higher CFC concentrations in the Yamato Basin than in the eastern Japan Basin. Several anticyclonic eddies observed north of the subpolar front seem to play important role in mixing the CFC tracer signals to deep waters below ~1500 m.

## Ventilation Patterns of Intermediate and Deep Waters from CFC Distributions

Vertical profiles of CFC concentrations exhibit a maximum (CFC-11: 4.6 pmol/kg) approximately along the layer of potential density 27.25, and monotonically decreasing concentrations with increasing depth below this layer (Fig. 2). The CFC tracer signals, of which cold surface water concentrations only became significant after 1950s (CFC-11 & CFC-12) or mid-1960s (CFC-113), were found throughout the water column indicating active vertical mixing. The CFC-12 tracer age was estimated to be near zero at surface and ~25 yrs at 500 m with a steep gradient between them. The tracer age increases more gradually with increase of depth below this layer to ~45 yrs at 2500 m layer, and stays rather invariable at ~45 yrs below 2500 m.

The thickest CFC-maximum layer, 700-800 m thick, was located along the main SW-NE axis of the Japan Basin, and it was associated with anticyclonic eddies. Anticyclonic eddies seem to play an important role in ventilating deep waters below ~1500 m (Takematsu, *et al.*, 1999).

The CFC maximum layer is widely distributed both to the north and south of the subpolar front below the seasonally warmed surface layer and local mixed layer depths, respectively. It is apparent that a tongue of the CFC-maximum water spreads southward from its source region to the north of the subpolar front into the Ulleung Basin as far south as to the Korea Strait area. This feature is less significant in the Yamato Basin along the Japanese coast due to the influence of warm, saline Tsushima current.

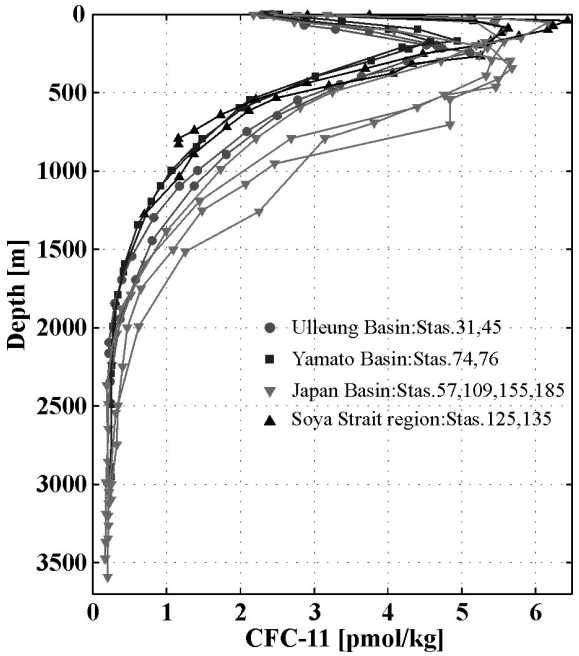


*Fig. 2. CFC-11 in the East (Japan) Sea, 1999 Summer*

Over most of the water column, the CFC concentrations are higher in the Ulleung and Japan Basins than in the Yamato Basin. However, the CFC concentrations are higher in the BW of the Yamato Basin below ~2400 m than in the Ulleung and Japan Basins. Within the Japan Basin, the BW CFC concentrations are highest adjacent to the boundary and lowest in the interior of the eastern portion of the basin, suggesting that the boundary region is more well-ventilated (Min, 1999). These BW CFC distributions are opposite to the distributions of dissolved oxygen and potential temperature. These unexpected findings can be explained by more active vertical mixing of cold, high-oxygen and low-CFC BW with oxygen-minimum and higher CFC-content waters above along the basin boundaries.

## Changes of CFC Concentrations Between 1995 and 1999

The measured CFC concentrations are compared the CFC data obtained in spring 1995 (Riser, *et al.*, 1999) and in summer 1996 (Min, 1999). In general, there has been small increase in CFC concentrations in the upper 1500 m waters between 1995 and 1999, reflecting the slower atmospheric CFC increase in recent decade. However, there was significant increase in CFC concentrations below 2000 m depth after 1996 with no significant change in the tracer age field. Further study is needed to understand the cause of rapid CFC increase in deep water.

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