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## Upward Transport of Nutrients and Trace Metals in the North Pacific Subarctic Ocean

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### Abstract

The vertical cross-sections of salinity, nutrients and trace metals at 37-51°N on a 180° longitude line in the North Pacific Subarctic Ocean indicated an upward transport toward the north. The diffusive and advective fluxes of nutrients and trace metals at 49° N on this line were estimated from the values of vertical advection and eddy diffusivity coefficient as physical mixing parameters. The primary production at this station was also estimated to be about 5,000  $\mu\text{M m}^{-2} \text{d}^{-1}$  or 60 mg C  $\text{m}^{-2} \text{d}^{-1}$  from the upward nitrate flux and was in the same order as that in January at Funka Bay, Japan.

### Introduction

Recent studies on several trace metals in the ocean elucidated the biogeochemical processes controlling their distributions (Bruland, 1980; Danielsson, 1980; Boyle et al., 1981; Danielsson et al., 1985; Nolting et al., 1991; and many others). It is well known that copper, nickel, cadmium and zinc are involved in marine biogeochemical cycles (Morel and Hudson, 1985). In oligotrophic surface waters of the major ocean gyres these metals and nutrients are often strongly depleted. In several studies cadmium was found to correlate strongly with phosphate (Boyle et al., 1976; Bruland, 1980; Knauer and Martin, 1981; Matsunaga and Abe, 1985), suggesting the biogeochemistry of cadmium is strongly dominated by the cycling of organic matter (Abe and Matsunaga, 1988; Abe et al., 1990).

An important step toward an understanding of the geochemistry of any trace metals in seawater is the development of sample collection and analytical procedures that provide accurate and meaningful data. The graphite furnace atomic absorption spectrophotometer (GFAAS) has been used to determine copper, nickel and cadmium in seawater, after preconcentration. The general concentration technique was mainly based on an ammonium pyrrolidine dithiocarbamate/diethylammonium diethyldithiocarbamate (APDC/DDDC) organic solvent extraction (Bruland et al., 1979; Danielsson et al., 1982), Chelex-100 ion exchange (Riley and Taylor, 1968; Bruland et al., 1979) or cobalt-APDC coprecipitation (Boyle and Edmond, 1975 and 1977).

It is well known that the North Pacific Subarctic Ocean is one major area with high primary productivity in the global ocean. Trace metals and nutrients as well

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as physical conditions are very important factors concerning any increase in primary productivity. Deep water in the North Pacific Ocean move upward with a velocity of 4–5 m/y. The vertical transport of nutrients to surface waters and the ratios of  $\text{SiO}_2/\text{PO}_4$  and  $\text{NO}_3/\text{PO}_4$  were discussed in the previous study (Matsunaga et al., 1986). In this study, we report on the distributions of copper, nickel and cadmium in the North Pacific Subarctic Ocean, with emphasis on their nutrient relations and their vertical transports to surface waters.

### Experimental

Water samples for trace metals were collected with Go-Flo samplers hung on a Kevlar line from the stations shown in Fig. 1 during the period between June to July, 1990. The samples were immediately preserved in acid-cleaned polyethylene bottles on board by the addition of conc. Ultrapur HCl (Cica-MERK) adjusting the pH to 2 in order to prevent the possible adsorption of trace metals on the walls of the bottles before analysis in the laboratory. Water samples for nutrients were collected with Niskin samplers fitted on a stainless steel conductivity-temperature-depth (CTD) rosette frame. The samples were immediately frozen to  $-20^\circ\text{C}$  on board and subsequently analyzed in the laboratory.

Copper, nickel and cadmium in the samples were determined by GFAAS after preconcentration by the cobalt-APDC coprecipitation method (Boyle and Edmond, 1975 and 1977) in a clean room. The recoveries of copper, nickel and cadmium were 87.4%, 98.5% and 82.9%, respectively. The relative standard deviations were 1.6% at the 6 nM Cu level, 2.7% at the 7 nM Ni level and 4.5% at the 0.2 nM Cd level. Nitrate, phosphate and silicate concentrations were determined by a Technicon Autoanalyzer.

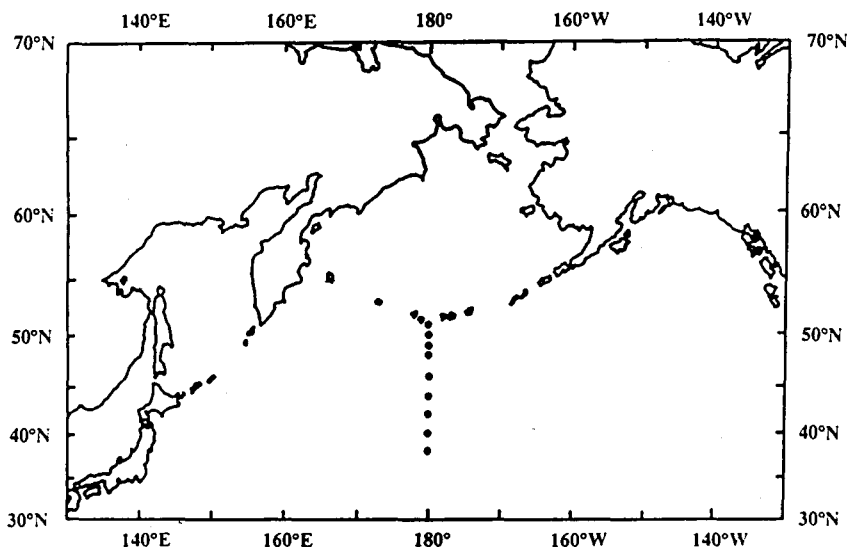


Fig. 1. Sampling stations.

### Results and discussion

The vertical cross-sections of salinity, nitrate, phosphate and silicate at 37–51°N on the 180° longitude line are as shown in Figs. 2–5, respectively. The salinity and nutrient profiles indicate an upward flow toward the north. At 49°N on this line, the nutrient concentrations at surface water (100 m depth) are 25  $\mu\text{M}$  nitrate, 1.5  $\mu\text{M}$  phosphate and 40  $\mu\text{M}$  silicate, which are nearly the same as those at deeper waters (500 m depth) at 37°N, meaning that the nutrients in deep waters are transported to the surface layers as the final arrival point of the deep water circulation. These vertical sections are very similar to those reported by Matsunaga et al. (1986).

The vertical sections of copper, nickel and cadmium on this line are also shown in Figs. 6–8, respectively. Nickel and cadmium as well as nutrients are vertically transported to surface waters. However, it is a little difficult to interpret the vertical transport from the copper section (Fig. 6) because of the low concentration.

We estimated the diffusive and advective fluxes of nutrients and trace metals at 49°N on this line by using the vertical advection ( $0.01 \text{ m d}^{-1}$ ) and eddy diffusivity coefficient ( $5 \text{ m}^2 \text{ d}^{-1}$ ) as the physical mixing parameters, which were used to calculate the iron and nutrient fluxes at an oligotrophic northeast Pacific station by Martin et al. (1989). The calculated nutrient and trace metal fluxes are presented in Table 1.

Recently, it has been reported that primary production is limited by iron since the dissolved iron concentration is almost zero at an euphotic zone in the north-east subarctic Pacific (Gulf of Alaska), Antarctic and equatorial Pacific Oceans (Martin and Fitzwater, 1988; Martin et al., 1989, 1990a, 1990b, 1991; Price et al., 1991). In these oceanic areas, the supply of macronutrients such as nitrate and phosphate and the resultant iron requirement can exceed the iron supplying rate by either vertical

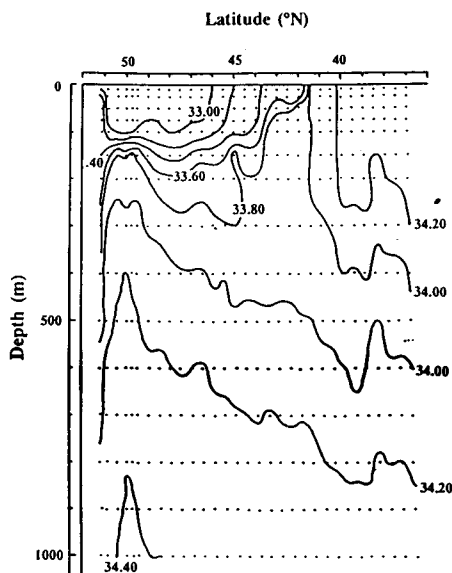


Fig. 2. Vertical section of salinity on the 180° longitude line.

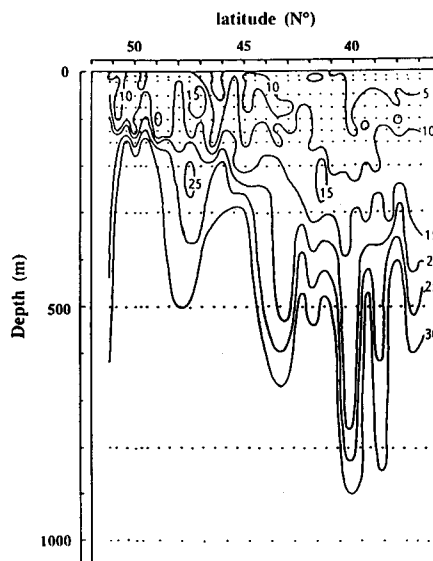


Fig. 3. Vertical section of nitrate ( $\mu\text{M}$ ) on the 180° longitude line.

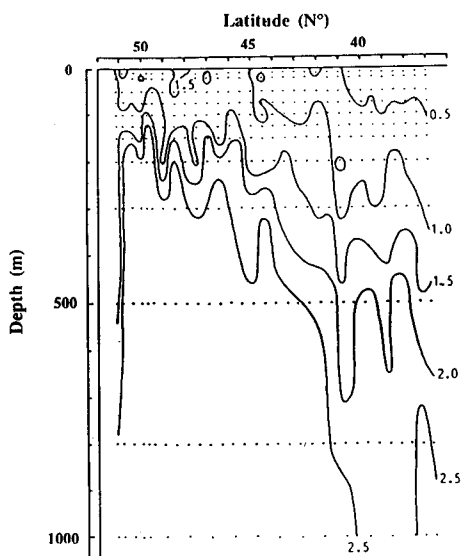


Fig. 4. Vertical section of phosphate ( $\mu\text{M}$ ) on the  $180^\circ$  longitude line.

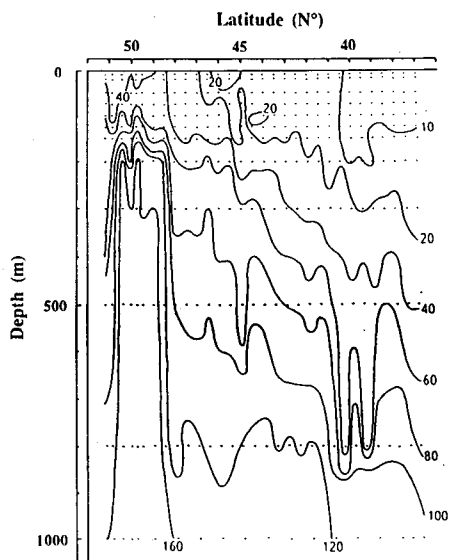


Fig. 5. Vertical section of silicate ( $\mu\text{M}$ ) on the  $180^\circ$  longitude line.

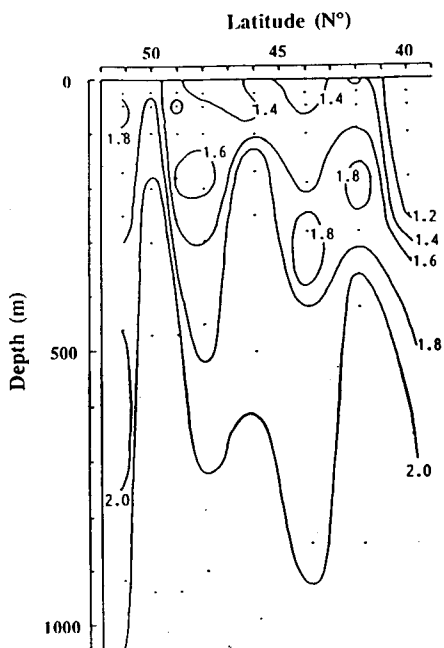


Fig. 6. Vertical section of copper (nM) on the  $180^\circ$  longitude line.

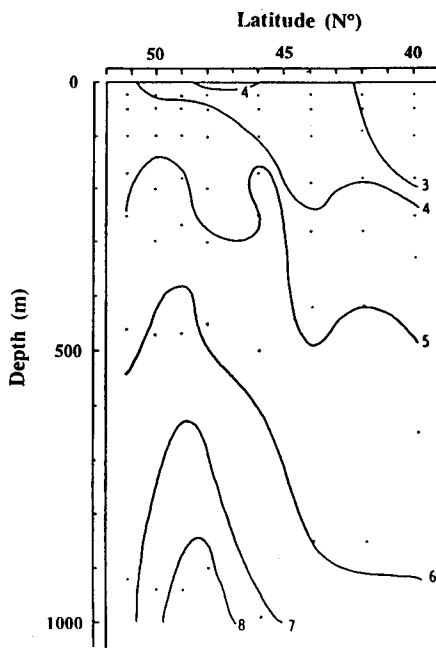


Fig. 7. Vertical section of nickel (nM) on the  $180^\circ$  longitude line.

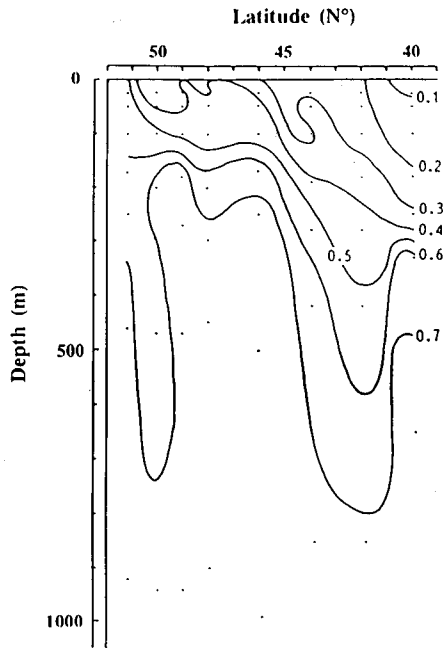


Fig. 8. Vertical section of cadmium (nM) on the 180° longitude line

mixing or from atmospheric deposition (Bruland et al., 1991). For example, the dissolved (0.45  $\mu\text{m}$  filterable) iron concentration at the euphotic zone in the Gulf of Alaska is nearly zero in nitrate-rich (10  $\mu\text{M}$ ) because of low atmospheric iron inputs, indicating that iron is a biolimiting nutrient. On the other hand, their concentrations at 49°N on the 180° line are high (ca. 2 nM iron and 10  $\mu\text{M}$  nitrate). The detailed results for iron will be reported elsewhere. The primary production at this station was estimated to be about 5,000  $\mu\text{M m}^{-2} \text{d}^{-1}$  or 60 mg C  $\text{m}^{-2} \text{d}^{-1}$  from the upward flux of nitrate (Table 1). This low primary production is in the same order as that in January at Funka Bay, Japan (Maita and Yanada, 1978).

Table 1. Diffusive and advective fluxes of nutrients and trace metals at 49°N on the 180° longitude line in the North Pacific Ocean.

nutrients or trace metals	Diffusive	Advective
	$\mu\text{M m}^2 \text{d}^{-1}$ (nutrients) or $\text{nM m}^2 \text{d}^{-1}$ (trace metals)	
NO <sub>3</sub>	400	320
PO <sub>4</sub>	16	26
Cd	8	7
Ni	33	6
Cu	6	20

### Acknowledgements

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