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学 位 論 文 内 容 の 要 旨/Dissertation Abstract

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Biogeochemical cycles in the western North Pacific and its marginal sea: Quantitative evaluation of nutrient supply and particle export fluxes

（北西太平洋及び縁辺海における生物地球化学的サイクル：
栄養物質の供給と粒子態物質の輸出フラックスの定量評価）

The biological pump plays a crucial role in regulating the atmospheric CO_2 level by exporting particulate organic carbon (POC), which is produced by phytoplankton through photosynthetic fixation, from the euphotic layer to the deep ocean. The efficiency of this process is governed by nutrient supply to the surface, phytoplankton growth, and particulate sinking to the deep ocean. Among these factors, the primary productivity which is an essential component of the biological pump, is primarily regulated by the availability of macronutrients (such as nitrate, phosphate, and silicate) and/or micronutrients (such as iron). While the subarctic Pacific and its adjacent marginal sea (the southern Sea of Okhotsk) both exhibit high biological productivity, the biogeochemical mechanisms driving these systems remain under debate.

The subarctic Pacific is known as a high-nutrient, low-chlorophyll (HNLC) area, where macronutrient concentrations persist year-round and phytoplankton growth is primarily constrained by limited iron (Fe) availability. In this area, Fe is supplied to this area though aerosol deposition and oceanic processes. Although aerosol Fe deposition has traditionally been regarded as important, no significant relationship has ever been observed between aerosol Fe input and phytoplankton abundance. This highlights the importance of evaluating oceanic Fe supply from subsurface waters. To elucidate how the nutrient supply from subsurface waters supports the surface phytoplankton productivity in the western North Pacific, we analyzed chemical, physical, and biological data from seawater samples collected during the KH-08-2 expedition of the R/V *Hakuho Maru*. Fe and macronutrient (N, P, and Si) turbulent fluxes and their flux ratios from the intermediate layer to surface waters were calculated based on their concentrations and vertical diffusivity data set. The phytoplankton community composition in surface waters was determined through CHEMTAX analysis of high-performance liquid chromatography (HPLC)-measured pigment data. In addition,

vertical flux divergence was calculated to assess net nutrient transport. Diatom abundance exhibited significant correlation with vertical Fe and macronutrient fluxes, especially with Fe and Si fluxes, and with the Fe/N flux ratio in the study region, indicating that diatom abundance was controlled by Fe and nutrient supply from subsurface waters in summer. Flux divergence revealed that enhanced Fe and Si concentrations in the subsurface layer were supplied from North Pacific Intermediate Water in the subarctic gyre and Kuroshio–Oyashio transition area.

The southern Sea of Okhotsk also exhibits high primary production. Unlike the subarctic Pacific, this region receives substantial Fe input from the sea ice melt and East Sakhalin Current (ESC) water. These inputs provide a favorable condition for phytoplankton growth, resulting a prominent diatom bloom in early spring. Furthermore, this region is characterized by a unique topography: a board and flat continental shelf extending about 100 km offshore, which transitions into a steep continental slope. This topography setting may indicate a strong shelf pump. Collectively, these features are expected to enhance the particulate organic carbon (POC) export, although the carbon pump processes in this region have yet to be directly investigated. To evaluate the efficiency of the biological shelf pump in the southern Sea of Okhotsk, a time-series sediment trap was moored on the continental slope of the Kuril Basin and settling particle samples were collected. Additionally, bottom sediment samples were collected from the adjacent shelf. Biogenic silica (BSi), POC, lithogenic material, and calcium carbonate ($CaCO_3$) composition were quantified in both sample sets, and “the in situ” and “the external” fluxes were further divided. The temperature at 50 m depth and sea ice concentration were obtained from a moored sensor and satellite data, respectively. The in situ fluxes exhibited clear seasonality with low values in winter and high values in spring. The in situ POC and $CaCO_3$ fluxes accounted for ~60% of the integrated values, while in situ BSi was comparable to the external over the sampling period. In April, elevated POC flux coincided with increased BSi and $CaCO_3$. $CaCO_3$ was the most dominant carbon ballast. Overall, the southern Sea of Okhotsk acts as an effective carbon pump compared to other global sites.

The obtained results indicate that the nutrient flux and flux ratio from NPIW regulate diatom abundance in the western North Pacific in summer, and the southern Sea of Okhotsk functions as a significant carbon pump. These findings help understand the biogeochemical patterns in these regions and provide a framework for predicting how climate-driven changes in ocean circulation and nutrient supply may alter marine productivity and carbon storage.