17 Vertical Particle Flux in the Western Pacific Below the North Equatorial Current and the Equatorial Counter Current

STEPHAN KEMPE AND HEIKO KNAACK

17.1 INTRODUCTION

In the open ocean, the vertical particle flux is largely determined by the primary productivity of the euphotic zone. Primary productivity in turn is a function of nutrient concentration. Areas low in nutrients should therefore coincide with areas of low vertical particle flux and low sedimentation rates.

In order to test this hypothesis, we deployed two sediment trap moorings in an area where the surface waters are known to have extremely low nutrient concentration; i.e., the western Pacific (e.g., King, 1954).

17.2 MATERIALS AND METHODS

Both systems consisted of two Mark VI time-series sediment traps (13 cups) (Honjo and Doherty, 1988), Benthos buoyancy balls and a Benthos acoustic release. One of the systems was deployed in the West Caroline Basin where the Equatorial Counter Current originates (ECC-System, Table 17.1; Figure 17.1). The second system was deployed in the Philippine Basin in a region where the North Equatorial Current terminates (NEC-System). This location is situated west of the near-by Palau-Kyushu Ridge. The sampling cups were filled with a NaCl-saturated solution to keep the cup fluid from convecting out during the collection phase. Furthermore, the cups were poisoned with $HgCl_2$ to avoid bacterial respirative consumption of the collected material.

The samples were wet-sieved through a 1 mm sieve and the fraction < 1 mm was filtered through pre-weighted 0.4 µm pore-size Nuclepore filters. Filters and sediment were dried at 40°C and their weight was determined. All data refer to

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Table 17.1 General information on deployments

System	ECC	NEC
Location		
Latitude	5°00.60'N	12°01.00'N
Longitude	138°49.81'E	134°17.16'E
Water depth	4130 m	5300 m
Upper trap	1130 m / ECC-T	1200 m / NEC-T
Lower trap	3130 m / ECC-B	4300 m / NEC-B
Deployment date	November 1988	
Cruise	R/V *Sonne* 59B	
Recovery date	July 1990	
Cruise	R/V *Sonne* 69B	
Collection interval	11/21/88–12/16/89	
Interval per cup	30 days	
Preservation	$NaCl/HgCl_2$	$NaCl/HgCl_2$

the < 1 mm fraction. Due to the very small size of all samples, the material could only be analyzed for major components. In order to determine how much of the collected material had gone into lysis, cup waters were analyzed for dissolved constituents as well. The amounts recovered from the dissolved phase were added to the particulate phase retained on the filters in order to calculate the total vertical flux. The samples were analyzed for total carbon and total nitrogen content by high temperature combustion (Carlo Erba CHN Analyzer) and for SiO_2 and phosphorus content by photometry. Carbonate was measured with a Carmhograph and the resulting inorganic carbon concentration was subtracted from the total carbon content to obtain organic carbon concentrations. In case of samples ECC-T12, ECC-B1, ECC-B12, ECC-B13, NEC-T6, NEC-T11, NEC-T12 not enough material for carbonate determination was available and carbonate was measured by acidifying samples and measuring organic carbon in the CHN analyzer. Carbonate was then calculated as the difference between total and organic carbon. Recalculating these data allows determination of the composition of the samples with regard to $CaCO_3$, organic matter (1.8 x C_{org}), opal (SiO_2 x 0.4 H_2O; Mortlock and Froelich, 1989) and lithogenics.

17.3 DISCUSSION OF RESULTS

All measured concentrations are listed in Tables 17.2–17.5. The recorded flux rates were very low at both stations. The averages amounted to 4.75 and 7.52 mg m^{-2} d^{-1} in case of the NEC-T and NEC-B traps and to 18.04 and 11.18 mg m^{-2} d^{-1} in case of the ECC-T and ECC-B traps, respectively. Fluxes between 45 and 20 mg m^{-2} d^{-1} were encountered in November/December 1988 and April/

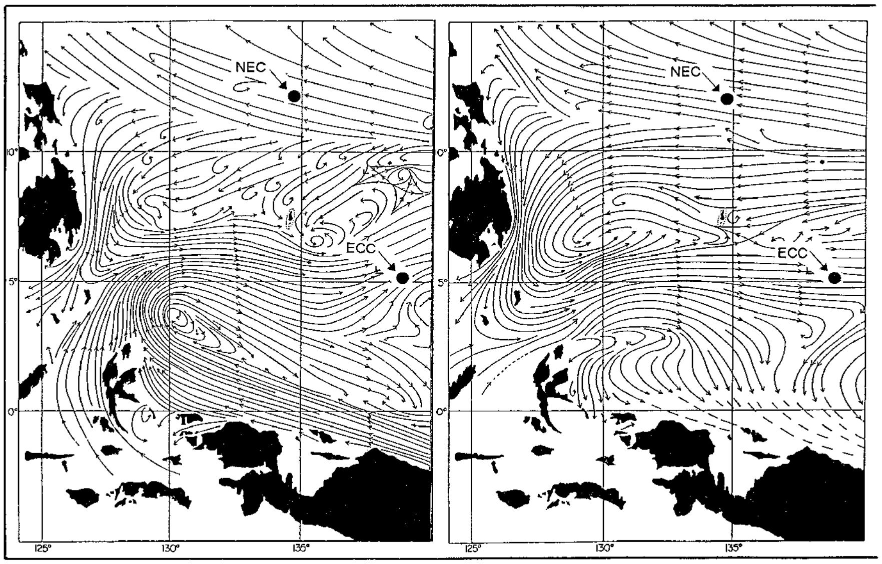

Figure 17.1 The equatorial currents of the western Pacific Ocean (left northern summer, right northern winter) and the positions of sediment traps (NEC = North Equatorial Current; ECC = Equatorial Counter Current) (Kendall, 1970; after Schott, 1939).

May to June/July 1989 in the ECC-T trap and only once (May/June) 1989 in the ECC-B trap (Figure 17.2). In the NEC traps individual fluxes rarely exceeded 10 mg m^{-2} d^{-1} (Figure 17.3).

Total fluxes showed a pronounced seasonality at the ECC location in the West Caroline Basin. Fluxes showed the highest values in late spring and early summer (mid-April to mid-July) with a maximum of 43.3 mg m^{-2} d^{-1} (mid-April to mid-June, ECC-T). Intermediate fluxes occurred in winter and early spring (mid-November to mid-April) in the upper trap and in late winter to late spring in the lower trap (mid-February to mid-April).Low fluxes occurred in late summer to early winter (mid-July to mid-December).

In contrast to this, the NEC traps from the Philippine Basin did not record any pronounced seasonality in vertical particle flux except for a period of lower than average flux in late autumn and early winter (mid-September to mid-December). The absolute minimum flux, 0.72 mg m^{-2} d^{-1}, was recorded in mid-October to mid-November.

The seasonal differences in vertical particle flux in the West Caroline Basin most probably arise from seasonal changes in wind and current direction. During the northern summer with a normal trade wind, part of the ECC arises from a current flowing NW along the northern coast of New Guinea probably advecting higher loads of nutrients than during NW-monsoon winter conditions when the

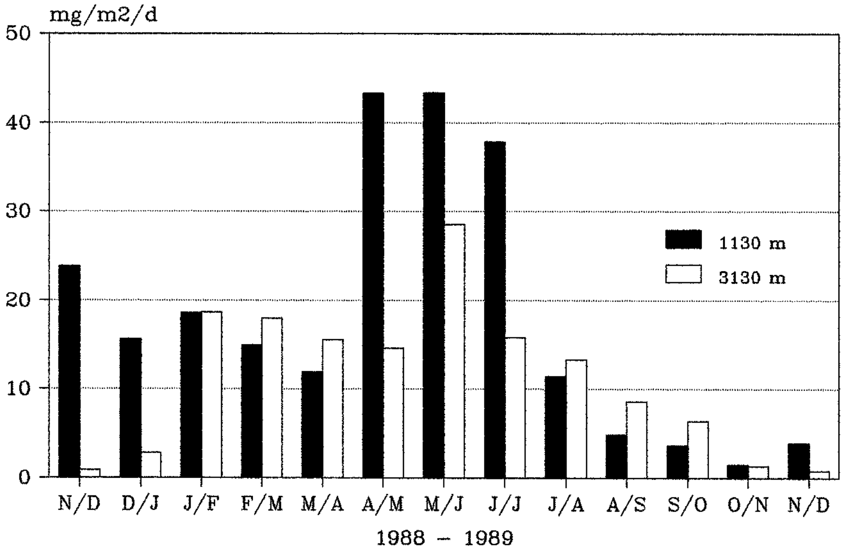

Figure 17.2 Total particle flux (< 1 mm) at station ECC (Western Caroline Basin) November-December 1988 / November-December 1989.

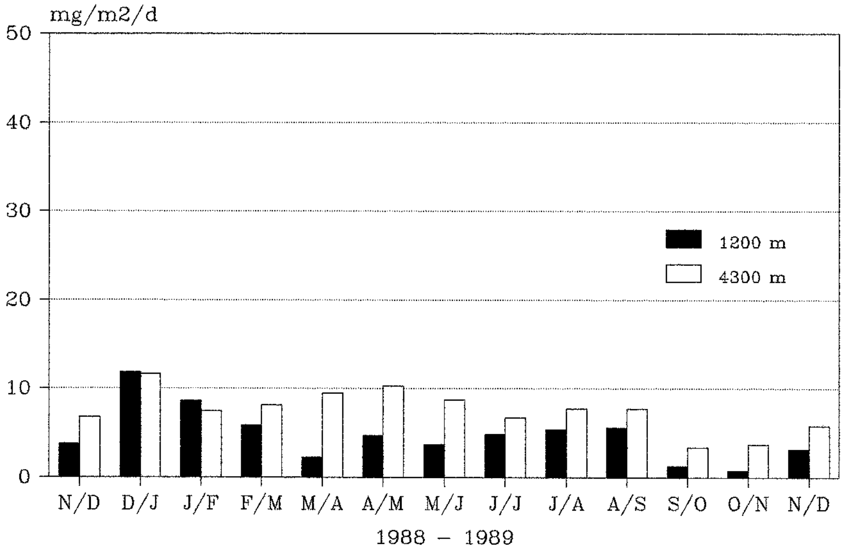

Figure 17.3 Total particle flux (< 1 mm) at station NEC (Philippine Basin) November-December 1988 / November-December 1989.

ECC is almost entirely composed of rerouted NEC water (Figure 17.1). Such a seasonality is not observed in the Philippine Basin. The NEC is stable throughout the year. It does, however, intensify in winter, thereby advecting nutrient impoverished water faster across the Pacific than in summer and giving less opportunity for nutrients to mix into the euphotic zone. Overall, the western terminus of the NEC apparently is one of the least productive regions of the entire ocean.

Because the 13-cup sediment trap was programmed to collect settling particles once every month, the November/December flux interval was sampled twice. In the case of the NEC trap, the recorded fluxes in the repeated interval were similar. This was also true for the deeper ECC trap, but not for the shallower ECC trap. There, a six times larger flux was recorded in 1988 than in 1989, suggesting that the change to more nutrient-rich conditions in surface waters occurred much earlier in 1988 than in 1989. Interannual variations such as these are rather common in particle flux records (e.g., Deuser et al., 1981; Izdar et al., 1987; this volume, Chapters 9, 14, 15).

Due to the large distance the water masses above the trap positions have traveled since last encountering coastal waters, lithogenic material comprises less than 10% of the vertical particle flux (Figure 17.4). The overwhelming mass of the material intercepted is biogenic. Only the lower NEC trap had a higher lithogenic component of ca. 20%. This may be attributed to the vicinity of the Palau-Kyushu Ridge. There, deep-sea currents could remobilize sediments rich in lithogenics and material inert to dissolution. This admixture of resuspended sediment may also explain why the total flux rate in the lower trap was significantly higher than the flux rate in the upper trap at this position.

Calcium carbonate was the single most important constituent of particles recovered at both stations. It reached annual means of 50–70% of the total flux. Investigation by SEM showed that coccolithophorids, foraminifers, pteropods and cysts of dinoflagellates (in decreasing order of significance) were the principle source of $CaCO_3$.

Biogenic opal is derived from diatoms, radiolaria and silicoflagellates (in decreasing order of importance) and contributed 14% (ECC-T) and 9% (NEC-T) to the material intercepted by the upper traps and 17% to the material of the lower traps. Variation in composition between cups was more pronounced in the ECC material than in the NEC samples, but clear correlations among concentration changes of parameters were missing.

The recorded dominance of $CaCO_3$ versus opal fits into the picture of global oceanic particle flux composition. In general, arctic regions have sinking particles composed of less than 5% $CaCO_3$ but 80–90% opal (this volume, Chapter 7). Towards the tropics $CaCO_3$ increases to more than 50% of the sinking material and opal decreases to less than 20% (e.g., Wefer et al., 1982; Honjo et al., 1982; Noriki and Tsunogai, 1986; Ittekkot et al., 1991; this volume, Chapters 7, 14, 15). Flux rates (4.5–7 mg m^{-2} d^{-1}) and composition (ca. 70% $CaCO_3$, 9% opal, 8%

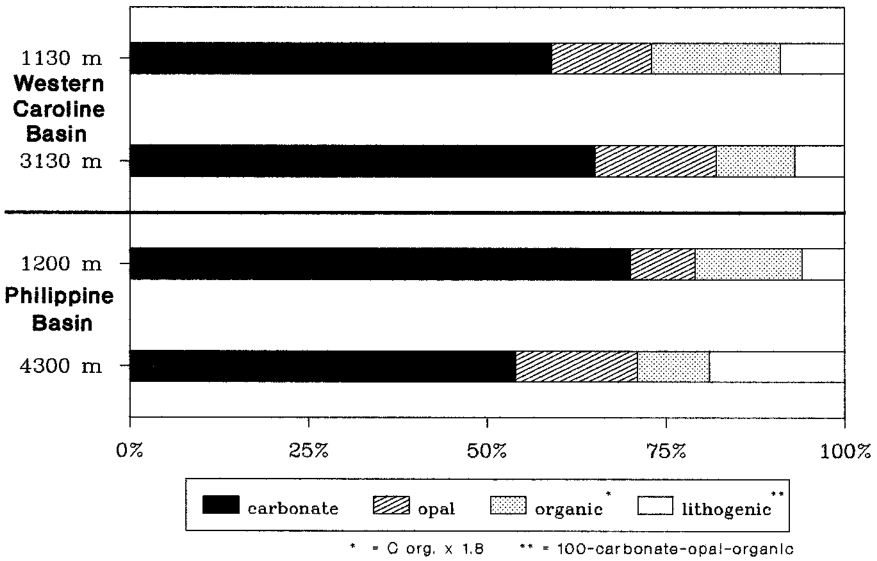

Figure 17.4 Comparison of average percentage composition of top and bottom traps from station ECC (upper two bars) and NEC (lower two bars).

C_{org}) of the NEC-T trap material were almost identical to measurements reported by Honjo (1980) from a position 15°N, 151°W. Even though this position is 7000 km away from our NEC-position, both traps sampled the North Equatorial Current and therefore have similar conditions of primary productivity and for the formation of sinking particles.

The contribution of organic carbon to the total flux varied from 4% to 18% (organic matter 7% to 33%) but was below 10% for most of the samples. At both stations the lower traps collected significantly less (ca. 3%) organic carbon than the upper traps (Figure 17.4). This is in accordance with progressive bacterial respiration of fresh organic matter settling slowly to the seafloor. The C/N (weight) ratio amounted to 8.9 in the NEC and to 9.0 in the ECC; i.e., the organic material at both stations is probably of similar composition. C/N/P ratios did not show considerable difference between the upper and the lower traps. This indicates that most of the easily remineralized phosphate-bearing organic compounds had been consumed before the settling particles reach the upper traps at a depth of 1000 m. Further degradation of organic matter during settling towards the deep traps must therefore have resulted in rather constant releases of C, N and P to maintain the observed constancy in the C/N/P ratios.

Both opal and phosphorus bearing organic matter proved to be highly soluble in the cup waters. 20–35% of the total opal was found to have dissolved and 50% to 70% of the phosphorus. These measurements illustrate that total fluxes are minimal values at best if only the particulate matter present in the cups is analyzed. Even if the dissolved phase is analyzed in addition, flux values are likely to be significantly lower compared to the composition of the material which originally sank into the cup. Partial exchange of the cup waters with ambient seawater during the collection period might extract an appreciable amount of opal and phosphorus.

17.4 ACKNOWLEDGMENTS

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