frontiers | Frontiers in Earth Science

TYPE Editorial
PUBLISHED 09 September 2022
DOI 10.3389/feart.2022.1020065

# Editorial: The oceanic particle flux and its cycling within the deep water column

Maureen H Conte[1,2]*, Rut Pedrosa Pàmies[2], Makio Honda[3] and Gerhard J. Herndl[4]

[1]Bermuda Institute of Ocean Sciences, Saint Georges, Bermuda, [2]Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA, United States, [3]Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan, [4]Department of Functional and Evolutionary Ecology, University of Vienna, Vienna, Austria

Check for updates

OPEN ACCESS

EDITED AND REVIEWED BY
Timothy Ian Eglinton,
ETH Zürich, Switzerland

*CORRESPONDENCE
Maureen H Conte,
mconte@mbl.edu

SPECIALTY SECTION
This article was submitted to Biogeoscience,
a section of the journal
Frontiers in Earth Science

RECEIVED 15 August 2022
ACCEPTED 25 August 2022
PUBLISHED 09 September 2022

CITATION
Conte MH, Pedrosa Pàmies R, Honda M and Herndl GJ (2022), Editorial: The oceanic particle flux and its cycling within the deep water column.
*Front. Earth Sci.* 10:1020065.
doi: 10.3389/feart.2022.1020065

COPYRIGHT
© 2022 Conte, Pedrosa Pàmies, Honda and Herndl. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

KEYWORDS

**particle flux, deep ocean, marine particles, ocean biogeochemistry, carbon cycling, marine chemistry**

Editorial on the Research Topic
The oceanic particle flux and its cycling within the deep water column

The oceanic particle flux transfers energy and material from the surface through the water column to the seafloor. (See review by Conte (2019) and references therein). The particle flux fuels life below the sunlit photic zone, exerts a major control on the global cycling of carbon and particle-associated elements, and also plays a major role in long-term carbon sequestration. In this Research Topic we present a collection of articles that provide a broad overview of current research on the interlinked processes controlling the magnitude and composition of the oceanic particle flux, and its cycling and depth attenuation within the deep water column.

Several articles focus on physical processes that influence seasonal and nonseasonal variability in particle flux generation in surface waters and particle export flux to depth. Shih et al. and Tan et al. examine how atmospheric and mesoscale eddy forcing influence euphotic zone nutrient supply, primary production and, in turn, particulate organic carbon (POC) export flux in the northern South China Sea (SCS). Tan et al. show that during the northeast monsoon, a deep mixed-layer depth and surface cooling, together with cyclonic eddy forcing, promote a strong winter flux peak. Conversely, an anticyclonic eddy in spring suppressed nutrient upwelling and primary production, decreasing summer fluxes. In autumn, aerosol optical depth in the SCS increases due to higher dust transport, suggesting that mineral ballasting of sinking particles varies seasonally. Shih et al. find that nutrient upwelling within cold eddies in the SCS fuels growth of large centric diatoms and dinoflagellates, increasing POC export. Conversely, downwelling within warm eddies intensifies stratification and reduces the nutrient supply, favoring small phytoplankton species and reducing POC export. Zúñiga et al. combine sediment trap observations in the Southern Ocean with a data-assimilative model to investigate how physical forcing of diatom ecology drives silicon vs. carbon sequestration efficiencies and nutrient stoichiometry in the flux. They report on an anomalous sea-ice episode that induced (*via* re-stratification due to sea-ice melt) a massive, rapidly sinking bloom of *Corethron pennatum*, which greatly increased the biogenic silica to organic carbon export ratio.

Lopez et al. compare the seasonality of the POC export flux with deep water total organic carbon (TOC) concentrations in the northeast Pacific Ocean, a highly productive region of extreme seasonality. They find that deep (>1,000 m depth) TOC concentrations correlate with the POC export flux, and that this export also contributes to the dissolved organic carbon pool. Similar rates of TOC net accumulation and removal within deep waters indicates efficient remineralization of the seasonally exported carbon.

The study of Pedrosa-Pàmies et al. in the eastern Mediterranean Sea underscores the importance of atmospheric forcing in deep ocean carbon sequestration. Using lipid biomarkers to partition marine, terrestrial and anthropogenic particle flux sources, they show that extreme weather and dust deposition events trigger significant episodic flux pulses to the deep Mediterranean Sea.

Honda and Weber and Bianchi focus on carbon transfer efficiency through the water column. Honda compares POC fluxes at subarctic-eutrophic and subtropical-oligotrophic sites in the western Pacific. Although primary production and mesopelagic fluxes were similar at both sites, the deep (5,000 m) POC flux was 2–3 times higher at the subarctic-eutrophic site despite its much larger zooplankton carbon demand. Honda suggests that carbon transfer efficiencies may be higher in subarctic regions due to greater mineral ballasting and armoring of opal-rich particles and lower remineralization rates within subarctic mesopelagic waters due to colder water temperatures and lower dissolved oxygen concentrations.

Weber and Bianchi also report the influence of dissolved oxygen concentration on carbon transfer efficiency. They find that oxygen minimum zones (OMZs) of the Eastern Tropical Pacific and Arabian Sea have much lower mesopelagic carbon flux attenuation than surrounding waters and sequester carbon twice as efficiently. They suggest three mechanisms are responsible: decreased remineralization at the transition from aerobic to anaerobic respiration, exclusion of zooplankton-mediated particle disaggregation, and reduced diffusive supply of oxidants (oxygen and nitrate). Because each mechanism uniquely alters particle size distributions, particle optical profiling could help distinguish between them.

Chaikalis et al. combine particle optical profiling with traditional biochemical measurements to better elucidate particle cycling processes. They find that particle optical and biogenic properties in the Mediterranean Sea covary among water masses and that both are lower in the eastern than in the western Mediterranean Sea, consistent with stable isotopic evidence for different particle pools in the two sub-basins. POC concentration was positively correlated with beam attenuation and negatively correlated with particle median diameter, indicating that particles are primarily biogenic and small particles are especially POC-rich. Particle aggregation in deep waters was indicated by low particle size distribution slopes and increasing particle mean diameter with depth.

Thomson et al. focus on particle remineralization within the water column, specifically the extracellular phosphatases (phosphomonoesterase, MEA and phosphodiesterase, DEA) that hydrolyze and release phosphorus from particles. They find that in subantarctic waters DEA and MEA are equally important in organic phosphorus hydrolysis, both in surface waters and at mesopelagic depths. Variations in the MEA:DEA ratio suggest variability in availability and/or utilization of P-monoester and P-diester pools. The observed negative correlation of the MEA:DEA ratio to phosphate and the positive correlation to the inorganic N:P ratio, suggesting that the relative importance of DEA vs. MEA is linked to inorganic phosphorus availability and N:P stoichiometry.

Two articles evidence the importance of lateral advection on deep particle fluxes in regions having high spatial gradients. Aristegui et al. studied epipelagic and mesopelagic microbial respiration along two zonal transects extending from the northwest African coastal upwelling to open ocean waters. Except at the coastal upwelling site, mesopelagic respiration exceeded satellite-derived net primary production (NPP), with the imbalance increasing offshore. They show that in offshore waters mesopelagic respiration is supported by lateral advection of suspended POC from coastal upwelling areas, either *via* deep circulation and/or mesoscale eddy transport. Kim et al. find that ~40% of the deep mass flux in the central basin of the East Sea/Japan Sea is resuspended lithogenic material. Radiocarbon data and excess Mn concentration show that the lithogenic flux at 500 m depth has a shallower source region than that at 2,000 m depth. Mesoscale eddies are suggested to transport material from the Korea Strait and/or western basin shelf and upper slope to the site.

Yamaoka et al. present a particle flux study at an oligotrophic site in the subtropical northwest Pacific. Very low vertical flux attenuation suggests that remineralization mainly occurs near the sediment interface in this region. Fluxes reflect lithogenic inputs, carbonate production, biogenic carbon incorporation and scavenging, with >85% of Mn, Co, Ni, Cu, Zn, Cd, and Pb fluxes attributable to scavenging. They speculate that blooms fueled by nitrogen fixation or typhoon activity induce late summer fluxes.

Xu et al. use ultrahigh resolution mass spectrometry to unravel the particle chemistry relevant to Fe scavenging. Their study shows that particles play an important role in controlling the distribution and flux of Fe and particle-reactive radionuclides having similar chemistry (e.g., thorium). They find that potential iron-carrying moieties comprise ~14% of identifiable molecules in particles and appear to be incorporated via ion complexation, hydrophobic interaction, and/or interlayered “occlusion.” Molecular features and depth compositional changes suggest that surface photochemical reactions produce precursors that are subsequently modified during particle cycling. A notable finding is the presence of hydroxamate-like moieties in particles, the key functionality of strong iron-binding in dissolved ligands.

Martinez-Ruiz et al. present a study of authigenic barite distributions in the Pacific, Atlantic and Indian Oceans. They find that barite is mainly associated with organic aggregates and extracellular polymeric substances and is universally most abundant at mesopelagic depths of intense organic matter remineralization, regardless of barite saturation state. Their study provides strong evidence that microbially mediated organo-accumulation of barium in decaying particles leads to saturated microenvironments and nucleation sites promoting barite precipitation, and supports experimental studies that show barium binds to phosphate groups on cell surfaces and within the extracellular polymeric substances of microbial biofilms.

Two final articles synthesize multidecadal particle flux time series in contrasting oceanographic regions. These studies demonstrate the immense value of long time-series to elucidate the overarching role of climate drivers on the oceanic particle flux. Wynn-Edwards et al. present a 20-years particle flux record at the subantarctic Australian Southern Ocean Time Series site (SOTS, 47°S, 142°E, 4,600 m water depth). They show that the subantarctic Southern Ocean is a significant carbon sink despite its high-nutrient, low chlorophyll characteristics. The carbonate counter-pump is estimated to reduce carbon sequestration by ~8%. Fluxes, dominated by carbonate (>60%), opal (~10%) and organic matter, vary seasonally with an early spring peak (October/November) and a smaller late summer peak (January/February). However, the annually-averaged flux is relatively constant year to year and shows no temporal trend. Flux variability exceeds variability in satellite-estimated net primary production (NPP), providing additional evidence that processes independent of NPP significantly modulate surface flux export and vertical transport efficiencies. The SOTS time-series provides an important baseline in a region predicted to experience large future climate perturbations.

Fischer et al. present an 18-years particle flux record at the oligotrophic ESTOC site (29°N, 15.5°W, ~3,600 m water depth) in the eastern subtropical Atlantic, and compare fluxes at ESTOC with those at a mesotrophic site further south. At ESTOC, fluxes at 1,000 m depth record oligotrophic conditions of overlying waters whereas deep (3,000 m) fluxes also record advective influences of the coastal Cape Ghir filament. At ESTOC, increases in spring biogenic flux and particle compositional changes correlate with North Atlantic Oscillation variability. Fluxes further south show no North Atlantic Oscillation correlation, indicating that coastal upwelling systems along the African margin respond differently to basin-scale climate forcing depending on location.

## Author contributions

Topic coeditor MC was the lead author of this editorial. Topic coeditors RP, MH and GH reviewed and contributed to the editorial content.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## Reference

Conte, M. H. (2019). "Oceanic particle flux," in *Encyclopedia of ocean sciences*. Editors J. Kirk Cochran, J. Henry Bokuniewicz, and L. Yager Patricia. 3rd Ed. (Oxford: Elsevier), 4, 192–200. doi:10.1016/b978-0-12-409548-9.11481-2