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The oceanographic toolbox for the collection of sinking and suspended marine particles

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ABSTRACT

Marine particles play a central role in controlling the transport, cycling, and inventories of many major elements and trace elements and isotopes throughout the oceans. Studies seeking to elucidate the biogeochemical roles of marine particles often require reliable ways to collect them from the ocean. Here, we review the oceanographic toolbox of techniques and instrumentation that are employed to collect both suspended and sinking particles. With these tools, it is possible to determine both the concentrations and vertical fluxes of important elements and individual particle types. We describe the various methods for quantifying the concentrations of particulate matter with in situ pumps, towed sampling devices, bottle collectors, and large volume capture devices. The uses of various types of flux collection platforms are discussed including surface tethered, neutrally buoyant, and bottom moored devices. We address the issues of sediment trap collection biases and the apparent inconsistencies that can arise due to differences in the temporal and spatial scales sampled by the various methodologies. Special attention is given to collection considerations made for the analysis of trace metals and isotopes, as these methodologies are of high importance to the ongoing GEOTRACES program which seeks to identify the processes and quantify fluxes that control the distributions of key trace elements and isotopes in the ocean. With the emergence of new particle collection methodologies and the continued reliance on traditional collection methods, it is imperative that we combine these multiple approaches in ways that will help improve their accuracy and precision while enhancing their utility in advancing understanding of the biogeochemical and ecological roles of marine particles.

Introduction

Marine particles (Fig. 1) play a critical biogeochemical role in determining the distribution and concentration of carbon, nutrients, and many trace elements and isotopes (TEIs) throughout the oceans. They serve as a vehicle for transporting material both vertically and horizontally throughout the oceans and act as oases of chemical and biological activity. For these reasons, the careful study and physical collection of particles is an important component of any oceanographic investigation attempting to identify the processes and quantify the fluxes that control the oceanic distributions of the elements.

Particle concentrations, compositions, and basic dynamics are crucial parameters for understanding the scavenging and removal of particle-reactive TEIs. Particles can be direct sources of TEIs to the water column at ocean interfaces (e.g., the atmospheric deposition of mineral dust, or the input of sedimentary material from the ocean margins) as well as agents for their removal, by

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providing surfaces for the adsorption and subsequent removal of particle-reactive TEIs. Indeed, particles are central to the internal cycling of many TEIs via processes of active biological uptake and remineralization (Morel et al., 2003), passive scavenging and desorption (Bacon and Anderson, 1982), and transformations of particles between the suspended and sinking classes through processes of aggregation and disaggregation (Clegg and Whitfield, 1990; Nozaki et al., 1987). Total and acid-leachable concentrations of TEIs can provide information about the source and scavenged fractions, respectively (Landing and Bruland, 1987). The degree of particle reactivity of a trace element or isotope can be assessed by calculating partition coefficients, which describe the equilibrium partitioning between dissolved and particulate phases (Chase et al., 2002). The controls on the scavenging behaviors of many TEIs are not well understood, however, and are thought to be a function of total particle concentration and/or particle phases such as $CaCO_3$, opal, particulate organic matter, and lithogenic material (Chase and Anderson, 2004; Chase et al., 2002; Luo and Ku, 2004). All of these metrics of the role of particles in TEI cycling require the physical collection of particles followed by laboratory-based measurements.

Direct measurements of particle fluxes are also important for several reasons. For all particle reactive and/or bioactive TEIs, their association with sinking particles and flux to depth determines their residence time in the surface ocean and recycling within the subsurface waters. These processes also set up the gradient in surface to deep-water concentration profiles. It is therefore imperative that we measure the downward fluxes of carbon, nitrogen, phosphorous, silicon, and the key TEIs in order to quantify the amount of material that is transported to different depth horizons by the ocean's biological pump. These elemental fluxes are necessary to constrain models ranging from mechanistic simulations of particle dynamics to global biogeochemical simulations (Honeyman and Santschi, 1988; Jackson and Burd, 2002, 2015; Schlitzer, 2002, 2004; Yamanaka and Tajika, 1996). In addition to constraints on the quantity of material sinking through the water column, the collection of sinking material can provide insights into the processes and mechanisms that control the flux of particles to depth.

Particle concentrations (C) and fluxes (F) are linked by the sinking rate (w), $F = C * w$ (e.g., Bishop et al., 1987). However, this sinking rate is difficult to determine independently for all particles classes, sizes and chemical compositions, and is known to vary

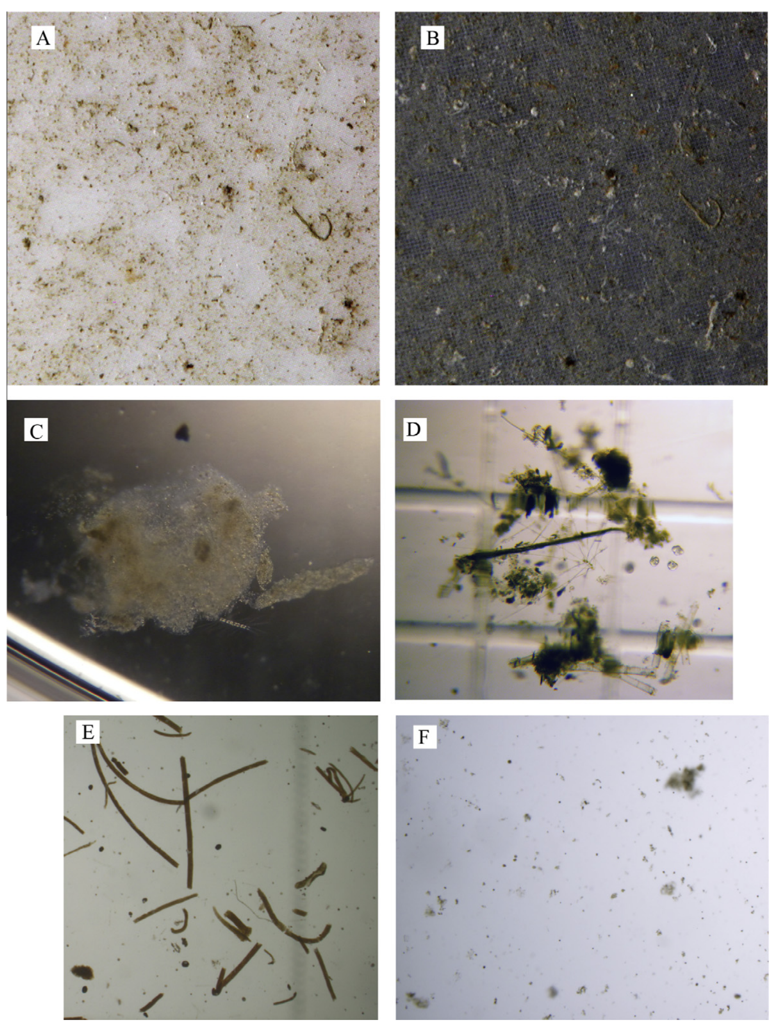

Fig. 1. Images of various particle collections obtained from large volume in situ pumps and polyacrylamide gel sediment traps. Panels A and B show samples from the Multiple Unit Large Volume in-situ Filtration System (MULVFS) on 51-μm mesh filters against white (A) and black (B) backgrounds to highlight the dark and light aggregates, respectively. Samples A and B are from 138 m in the Subantarctic Pacific (from Lam and Bishop, 2007). Panels C and D show examples of large sinking particles collected using the Marine Snow Catcher, (C) a marine snow aggregate from 57 m in the Norwegian Sea (70°N) and (D) a phytodetrital aggregate (whole diatom cells are visible) from 95 m in the South Indian Ocean (55°S). Panels E and F show particle collections from polyacrylamide gel samples of sinking particles from (E) the west Antarctic Peninsula at 50 m and (F) the Sargasso Sea at 150 m.