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The effect of suspended particle composition on particle area-to-mass ratios in coastal waters

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HIGHLIGHTS

- The hypothesis that the area-to-mass ratio of organic mass is twice that of mineral mass is tested.
- The hypothesis could not be rejected.
- Particle composition may not correlate with particle size or packing geometry within aggregates.

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ABSTRACT

Measurements of particle area, organic suspended mass, and mineral suspended mass were collected at 9 sites on the west and south coasts of Great Britain. Multiple linear regression of particle area on organic suspended mass and mineral suspended mass was used to estimate the area-to-mass ratios of organic and mineral matter. Statistically, the null hypothesis that the organic area-to-mass ratio was 2 times the mineral ratio could not be rejected. Failure to reject this hypothesis may indicate that component particle composition is not correlated with the packing geometry of aggregated particles or the size of component particles that comprise the aggregates. Alternatively, correlations between particle parameters may exist, but they offset one another, thereby producing an organic area-to-mass ratio that is not significantly different from two times the mineral area-to-mass ratio.

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Introduction

The application of optical sensors to the characterization of marine particle suspensions was advanced fundamentally in the late 1960s when it was demonstrated that scattering and attenuation of light are linearly correlated to the total suspended particle projected area (Beardsley et al., 1970). As a result, to a first approximation, scattering and attenuation of light in particle suspensions can be converted into particle volume or mass concentration, because volume and mass concentrations are linearly related to area concentration (Pak and Zaneveld, 1977). On the basis of this argument, optical instruments were used in the 1970s and 1980s to investigate particle processes in diverse environments, including, among others, shelf benthic nepheloid layers (Pak and Zaneveld, 1977), open-ocean basins (Plank et al., 1973), various ocean fronts (Zaneveld and Pak, 1979), shelf and slope internal nepheloid layers (Pak et al., 1980), coastal bays (Kitchen et al., 1982), nepheloid layers on the continental rise (Spinrad et al., 1983), and in river plumes (Pak et al., 1984).

Estimates of particle concentration from these various pioneering studies were attended by the caveat that the conversion from optical to particle properties depended on size, shape, structure and refractive index of particles, which were known to vary (e.g., Kitchen et al., 1982). Despite this concern, reasonable relationships between suspended particle volume and optical attenuation continued to emerge (Spinrad et al., 1983), a result that captured the attention of sedimentologists seeking automated, in situ methods for estimating suspended sediment mass concentration (e.g., Baker and Lavelle, 1984). The problem posed by variable conversion coefficients from optical properties to sediment mass, however, remained. The search for sources of variability in conversion coefficients is the topic of this manuscript.

The coefficients required to convert scattering or attenuation coefficients into mass concentration vary over an order of magnitude (Baker and Lavelle, 1984; Bowers et al., 2009; Hill et al., 2011), compromising the accuracy of optical scattering and attenuation sensors for estimating sediment mass concentration. The conversion coefficients vary because the projected-area-to-mass ratios of suspended particles vary. Baker and Lavelle (1984) showed quantitatively that the projected-area-to-mass ratio for solid spheres varies as the inverse of the product of particle density and diameter. Because particle size is variable in marine waters, size has long been suspected of causing the majority of variability in the area-to-mass ratio of particles (Baker and Lavelle, 1984; Wiberg et al., 1994; Fugate and Friedrichs, 2002; Downing, 2006). Recent work has shown, however, that size only accounts for a small fraction of the observed variability in the conversion from optical attenuation or scattering to suspended mass (Bowers et al., 2009; Hill et al., 2011; Neukermans et al., 2012). The explanation is that suspended solids are in aggregates for which particle mass varies approximately with particle area, which is linearly correlated with optical attenuation and scattering cross sections for particles that are large relative to the wavelength of light (Bowers et al., 2009; Hill et al., 2011; Neukermans et al., 2012; Boss et al., 2009; Slade et al., 2011).

Increasingly, attention is being focused on the effect of particle density on the projected-area-to-mass ratio of suspended particles (Bowers et al., 2009; Neukermans et al., 2012; Babin et al., 2003; Braithwaite et al., 2010). Aggregate density depends primarily on three parameters: component particle density, component particle size and aggregate packing geometry (Khelifa and Hill, 2006; Maggi, 2007, 2013). Component particle density depends on the composition of component particles, with mineral particles having densities that are generally twice as large as organic particle densities (cf. Babin et al., 2003). Presently, the extent to which component particle composition is correlated with component particle size and aggregate packing geometry is not known. Aggregate packing geometry is estimated from observations of particle size and settling velocity (Khelifa and Hill, 2006; Maggi, 2007, 2013), but because of the difficulty in collecting individual aggregates, most studies of this sort do not measure either component particle size or composition. The lack of direct data necessitates the use of indirect methods for exploring the extent of correlation between component particle composition, component particle size, and aggregate geometry.

Maggi (2013) explored possible correlations in the three particle parameters by dividing published size-settling velocity data into different compositional groups and then fitting the data to a model that estimated aggregate packing geometry, component particle size and component particle density. His

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