Transfer of particles into the deep Atlantic and the global ocean: importance of nutrient supply and ballast production

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Introduction

A central goal of JGOFS was to understand the physicochemical and biological conditions that control the regional variations of particle fluxes and the strength of the biological pump which may drawdown oceanic CO_2. Biogenic silica (BSi) or opal production and export, mostly provided by diatoms, is crucial for the organic carbon export fluxes and the carbon rain ratio of settling particles as also demonstrated by the OPALEO group. BSi production and flux obviously show a strong dependency on the supply of dissolved silicate ('silicate pump', Dugdale et al., 1995). Armstrong et al. (2002) emphasized that ballast minerals largely determine deep-water fluxes rather than primary production changes in the surface layer. The study by Francois et al. (2002) showed that bathypelagic carbon fluxes are largely determined by carbonate. Surprisingly, other potential ballast minerals such as lithogenic particles and biogenic opal do not significantly affect the 'transfer efficiency' of organic carbon. Here, we study the above mentioned hypothesis using a large sediment trap particle flux and surface sediment data set.

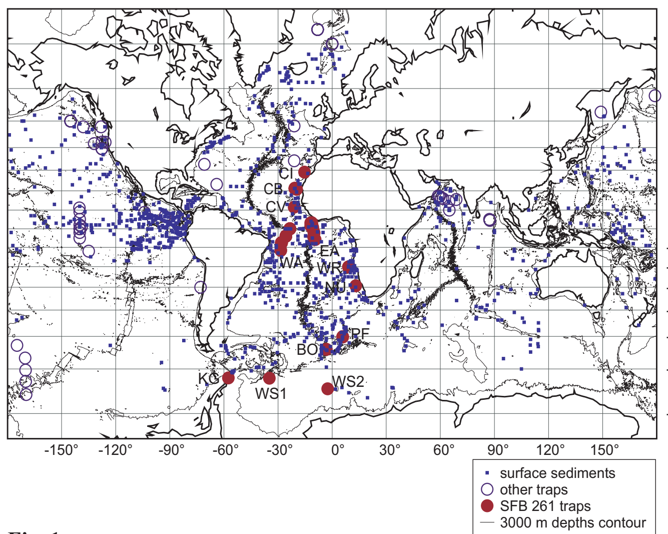

Fig. 1.
Location of the sediment trap sites (SFB 261 traps in the Atlantic, other sites: modified data set from Ragueneau et al., 2000; Honjo et al., 2000) and the surface sediments (0-5 cm core depth, 200-4500m water depth).

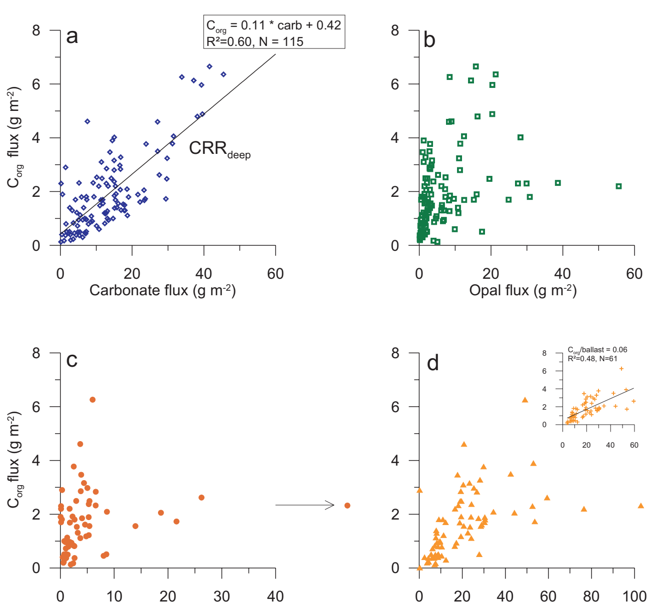

Fig. 3.
Relationships between different annual bulk flux components (a: carbonate, b: opal, c: lithogenic, d: ballast (=total flux - 1.87*C_{org} flux)) and organic carbon fluxes in the world ocean (Fig. 1, modified data set from Ragueneau et al., 2000; Honjo et al., 2000). The mean global carbon rain ratio (C_{org}/$C_{carbonate}$) to the deep ocean was ca. 1 (a), the mean global C_{org}:ballast flux ratio was 0.06 in the lower range of fluxes (insert in d).

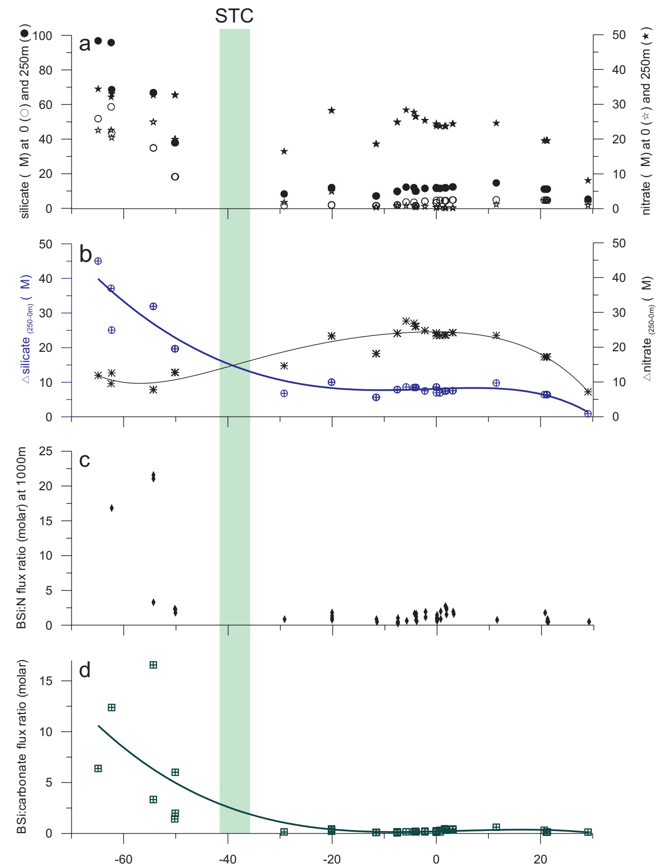

Fig. 2.
Latitudinal distribution of major nutrients at the surface and in subsurface waters (a) and differences in nutrients (Levitus et al., 1994) between both depths (b) at the Atlantic trapping sites (Fig. 1). The mean annual BSi:$N_{(1000m)}$ molar ratio of sinking particles (c) and the molar BSi:carbonate flux ratios (d) show a distinct decrease from south to north in accordance with silicate (250-0m) (STC=Subtropical Convergence).

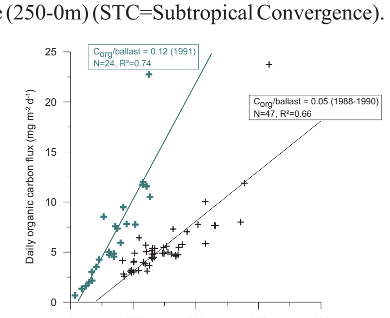

Fig. 4.
Variable correlations between daily total ballast (=total flux - 1.87*C_{org} flux) and organic carbon fluxes off NW Africa (site CB, Fig. 1). Note the high correlation in 1991 during a strong coccolithophorid bloom (Müller and Fischer, 2001) when the carbonate-C_{org} correlation was also most significant.

Summary and Conclusions

1. BSi/opal fluxes are strongly dependent upon the silicate supply.
   Variable annual BSi:C_{org} ratios (0.05-3, mol/mol) mirror the flow path of the conveyor.

2. Annual opal:carbonate fluxes increase exponentially above a Si:$N_{(250m)}$ nutrient threshold value of ca. 1.7.
   Surface sediment data provide a higher threshold (2-2.5) though data scatter is large.

3. Carbonate fluxes correlate well with organic carbon fluxes suggesting a strong ballasting effect on the 'transfer efficiency' of C_{org} to greater depths. Ballast fluxes and organic carbon fluxes also show a positive linear relationship showing a global mean C_{org}:ballast ratio of 0.06.

4. Off NW Africa (high dust supply), lithogenic particles may also serve as the important particle carriers. We obtained variable positive linear relationships between the daily total ballast/lithogenic and organic carbon fluxes. During a strong coccolithophorid bloom in 1991, the carbonate-C_{org}-correlation was most significant, stressing the importance of carbonate particles for the efficient C_{org} transfer to depth.

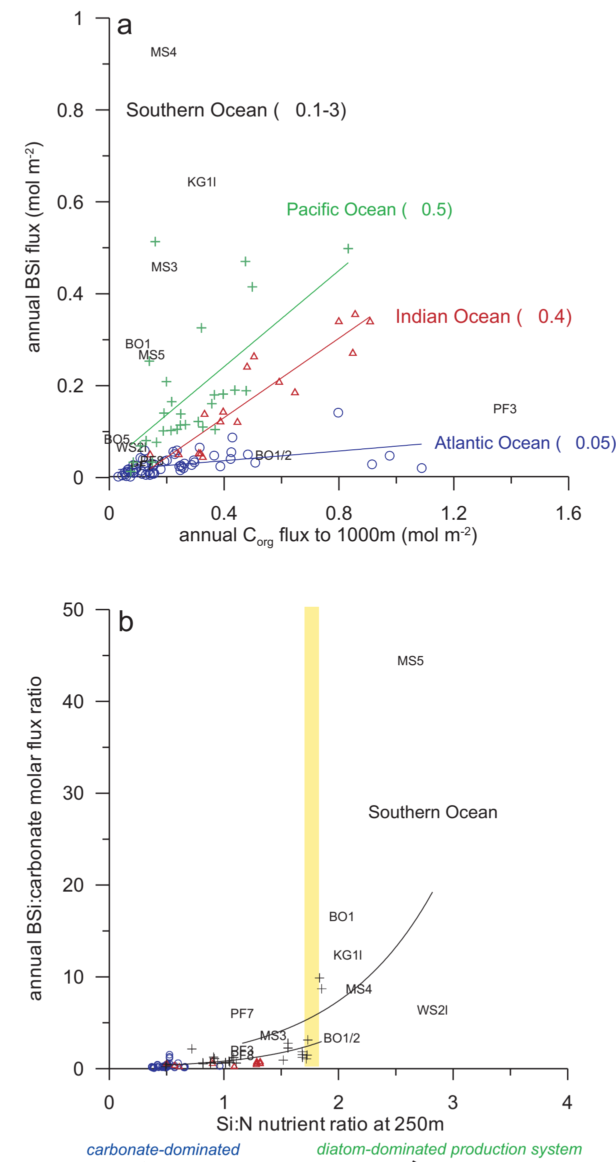

Fig. 5.
a: Global compilation of annual $C_{org(1000m)}$- fluxes versus BSi fluxes (modified data set from Ragueneau et al., 2000; Honjo et al., 2000). Note the low molar BSi:C_{org} ratios in the Atlantic and the high values in the Pacific/Southern Ocean.
b: Molar Si:N nutrient ratios of the source waters (Levitus et al., 1994) versus the annual molar BSi:carbonate flux ratios. Note the switch from carbonate to opal producers above a Si:N nutrient threshold value of 1.7 (yellow vertical bar).

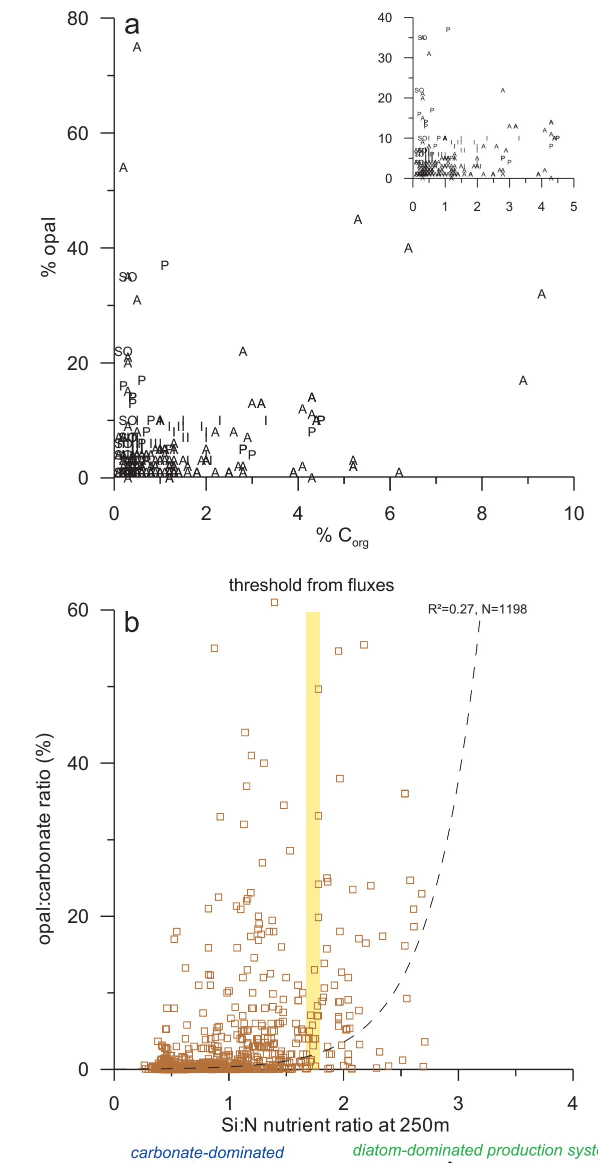

Fig. 6.
a: Global compilation of % C_{org} versus % opal from surface sediments (SO=Southern Ocean, A=Atlantic, I=Indian Ocean, P=Pacific Ocean; insert: detail of % C_{org} vs % opal). For comparison, see Fig. 5a.
b: Opal:carbonate ratios (%) from surface sediments versus the molar Si:$N_{(250m)}$ nutrient ratios. An exponential increase of the opal:carbonate ratios occurs at a nutrient Si:$N_{(250m)}$ value of 2-2.5, slightly higher compared to the threshold value derived from water column fluxes (Si:$N_{(250m)}$=1.7, yellow vertical bar from Fig. 5b).