The effects of minerals on the aggregation, sinking, and destruction of POC

Christina De La Rocha
Université de Bretagne Occidentale
Fluxes of POC and minerals sinking into deep sea sediment traps are related.

Klaas and Archer 2002
• Which flux drives which?

• To what extent do ballast minerals enable the export of POC out of the surface ocean?

• If minerals do increase the export of POC via sinking, is it by adding ballast, protecting against destruction, or influencing aggregation?
We ask because even minor change in the depth of export has a large effect on atmospheric CO$_2$.

(depth at which 63% of POC has been oxidized)
In the very simplest terms, POC fluxes are controlled by the ratio of the destruction of sinking POC to its sinking speed

\[ C_{f\text{lux}z} = (C_{f\text{lux}z_0}) e^{-\left(\frac{D}{W}\right)z} \]
Can minerals increase POC sinking fluxes by

- adding ballast thereby
  - increasing sinking speeds

- protecting sinking POC from
  - oxidation back to CO$_2$
  - decomposition into DOC
  - destruction into more slowly sinking or non-sinking particles

- influencing aggregation by
  - triggering aggregation at lower concentrations of POC
  - increasing the speed at which POC aggregates
  - driving more of the available POC into aggregates
Forming aggregates in rolling tanks on roller tables
The aggregates that form look generally like this.
Do minerals act as ballast? What happens when minerals are incorporated into aggregates?

clays: ~2.8 g cm\(^{-3}\)
CaCO\(_3\): ~2.8 g cm\(^{-3}\)
SiO\(_2\): ~2.6 g cm\(^{-3}\)

compared to density of typical cytoplasm of ~1.06 g cm\(^{-3}\)

photo credits: U. Passow, I. Grigorov, & Images of Clay Archive of the Mineralogical Society of Great Britain & Ireland
Minerals result in more, smaller aggregates
Minerals result in more, smaller aggregates

Passow et al 2014
To make an aggregate sink faster

- increase its volume \((V)\)
- decrease its area \((A)\) facing the sinking direction
- increase its density in excess \((\Delta \rho)\) of the density of the fluid \((\rho_f)\)
- decrease the drag \((C_D)\)

\[
W = \left(2g\, \Delta \rho \, V / \rho_f \, C_D \, A\right)^{0.5}
\]
Despite driving a decrease in ESD, minerals increase sinking speeds
Sinking velocity

Passow et al 2014
Do minerals act as ballast?

~2.8 g cm\(^{-3}\)  ~2.8 g cm\(^{-3}\)  ~2.6 g cm\(^{-3}\)

Yes, but their effect on sinking speed depends also on the changes they induce in aggregate size, shape, and porosity.

photo credits: U. Passow, I. Grigorov, & Images of Clay Archive of the Mineralogical Society of Great Britain & Ireland
Do minerals protect POC?

• from being
  – oxidized back to $\text{CO}_2$
  – converted to non-sinking forms
  • POC not in aggregates
  • DOC

Suspended minerals hinder feeding by *Daphnia* in freshwater systems. Perhaps minerals also interfere with zooplankton grazing in the ocean.
Recent work suggests that diatom silica inhibits grazing, growth, and reproduction of copepods.

Liu H., Zhu F., Chen M. (2013 talk at ASLO)
EFFECT OF DIATOM SILICA CONTENT ON COPEPOD GRAZING, GROWTH AND REPRODUCTION

Stronger frustules inhibit ingestion by copepods

Copepods:
- filled circles = *Acartia clausi*
- unfilled circles = *Temora longicornis*
- solid inverted triangle = *Centropages hamatus*

Diatoms:
- blue = *Thalassiosira punctigera*
- red = *Coscinodiscus wailesii*
- green = *Actinoptychus senarius*

Dotted lines: growth rates of the diatoms

Friedrichs et al., 2013
What copepods must do to eat diatoms

Size and biomechanic properties of diatom frustules influence food uptake by copepods
L. Friedrichs, M. Hörnig, L. Schulze, A. Bertram, S. Jansen, C. Hamm
MEPS 481: 41–51, 2013
We put rotifers into rolling tanks with and without coccoliths and let diatom aggregates form. The resulting ammonium excretion rates:

1.3 mg L\(^{-1}\) CaCO\(_3\)  
0.1 \(\mu\)g N mg\(^{-1}\) rotifer h\(^{-1}\)

no CaCO\(_3\)  
0.3 \(\mu\)g N mg\(^{-1}\) rotifer h\(^{-1}\)

The rotifer *Brachionus* feeding on a diatom aggregate

Le Moigne et al., 2013
We put rotifers into rolling tanks with and without coccoliths and let diatom aggregates form. The resulting phosphate excretion rates:

- **1.3 mg L$^{-1}$ CaCO$_3$**
- **0.09 $\mu$g P mg$^{-1}$ rotifer h$^{-1}$**

The added minerals decrease grazing efficiency by being a physical barrier to feeding or by acting as a diluent.

Le Moigne et al., 2013
Do minerals protect POC?

• from being
  – oxidized back to $CO_2$
  – converted to non-sinking forms
    • POC not in aggregates
    • DOC

Yes, by decreasing the grazing efficiency, growth, and reproduction of microzooplankton and mesozooplankton
Do minerals promote aggregation?

- Do minerals:
  - affect the speed of aggregation
  - increase the amount of available POC incorporated into aggregates
Minerals may increase speed of aggregation by increasing frequency of collisions

Diatom aggregates formed faster in rolling tanks with added coccoliths and/or rotifers (microzooplankton).

- **Phyto + Zoo + Min** faster than
- **Phyto + Min** faster than
- **Phyto + Zoo** faster than
- **Phyto**

But, ultimately, equivalent amounts of POC aggregated.

Le Moigne et al., 2013
This occurred despite there being very different sizes and numbers of aggregates in the different treatments.

Laurenceau et al in prep
We also saw equivalent incorporation of POC into aggregates at the end of a 48-hr experiment with and without CaCO$_3$.

Concentrations of suspended (A) POC and (C) bSiO$_2$, at the beginning of the experiment (To) and at the end of the experiment (Tf).

Phyto tanks contained only diatom cultures and fecal pellets. Cocco and Foram tanks also contained 4.6 mg L$^{-1}$ of CaCO$_3$ in the relevant form.

Schmidt et al., 2014
Do minerals promote aggregation?

• Minerals:
  – may increase the speed of aggregation
  – but in a closed system they do not increase the amount of available POC incorporated into aggregates
Conclusions

• Minerals increase aggregate sinking velocities by adding excess density
  – but their exact effect depends also on the changes they induce in aggregate size, shape, and porosity

• Minerals protect POC in aggregates
  – by decreasing the grazing efficiency of zooplankton

• Minerals may increase the speed of aggregation
  – but in a closed system they do not increase the amount of available POC incorporated into aggregates