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

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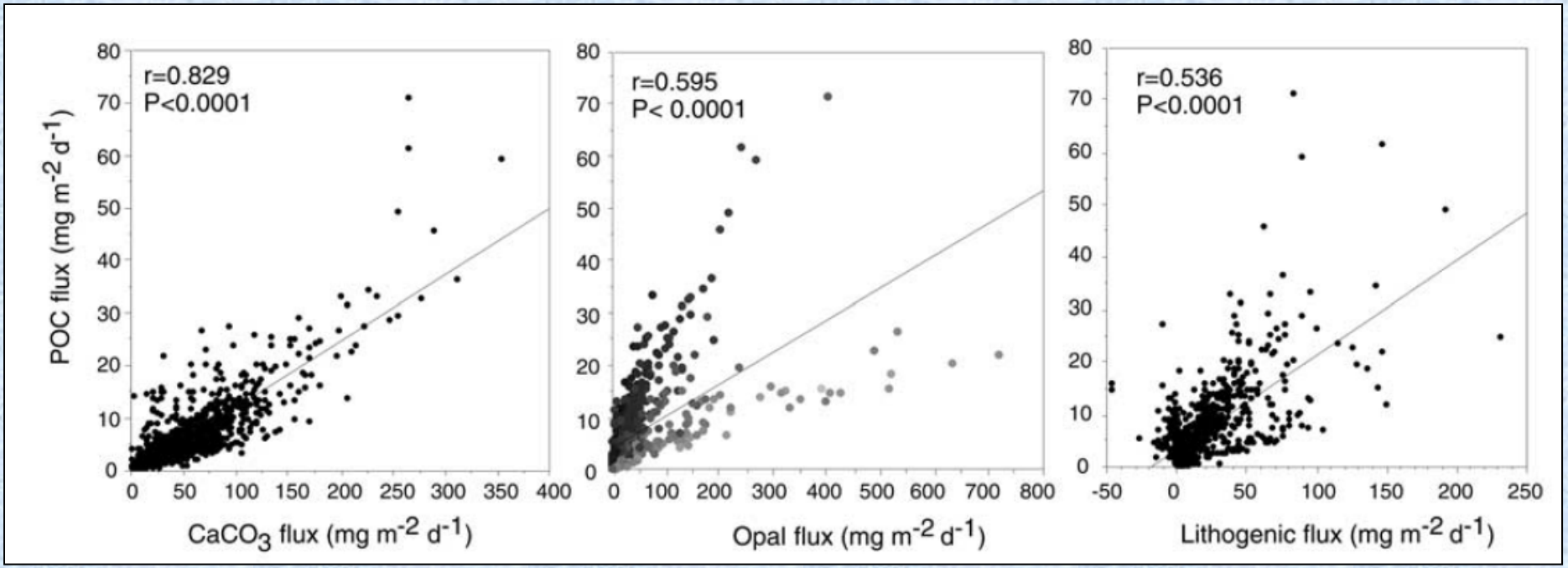
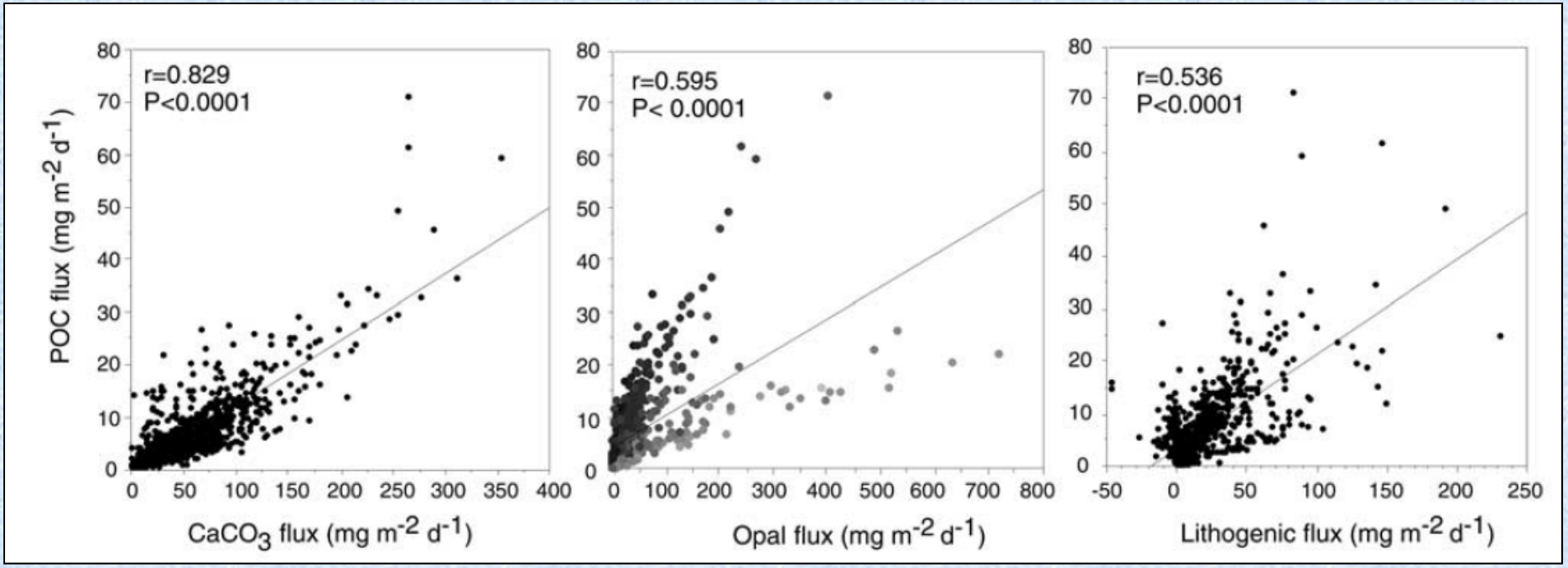
Fluxes of POC and minerals sinking into deep sea sediment traps are related

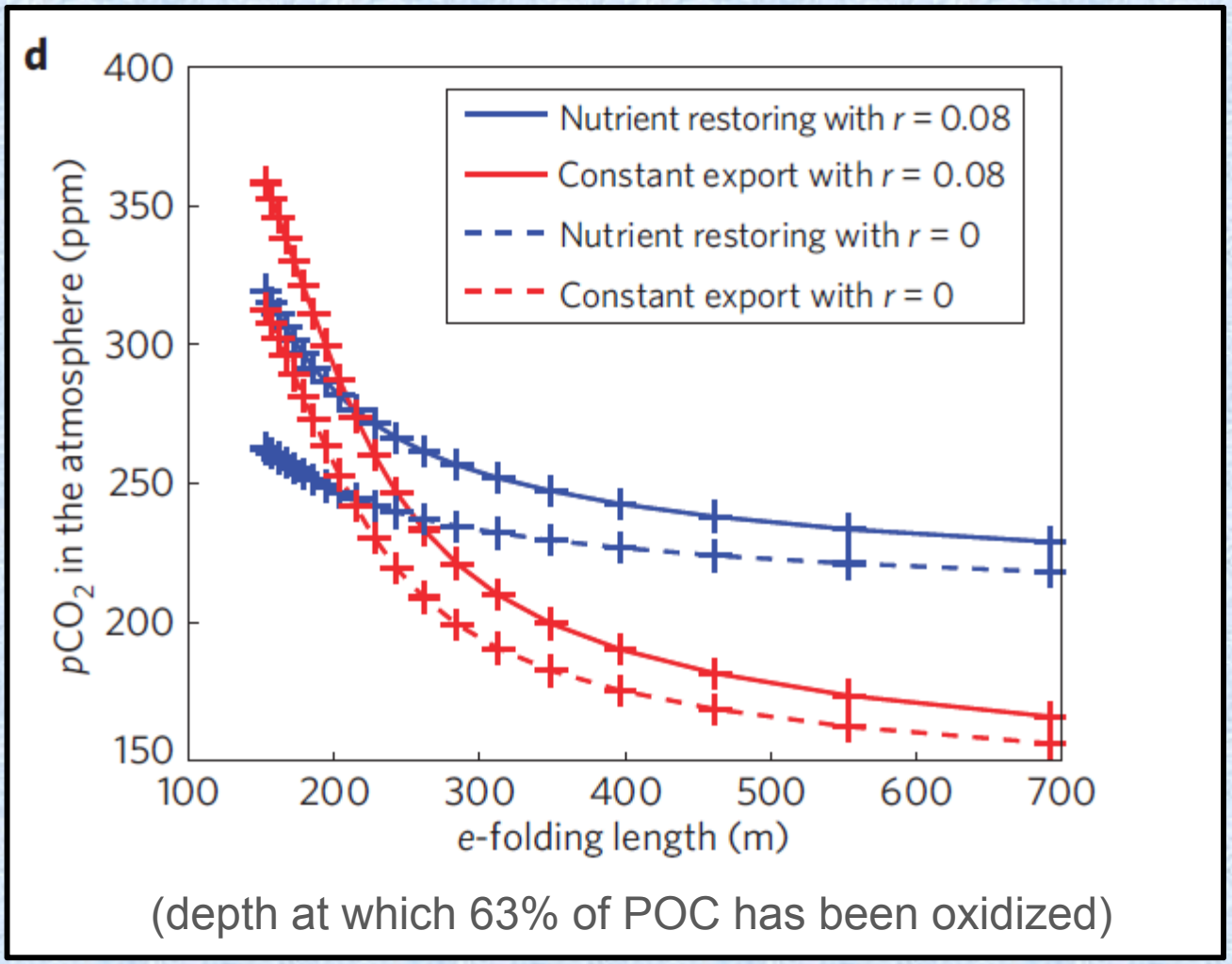


Klaas and Archer 2002



- 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



Kwon et al 2009

In the very simplest terms,
POC fluxes are controlled by the ratio of the destruction of sinking POC to its sinking speed

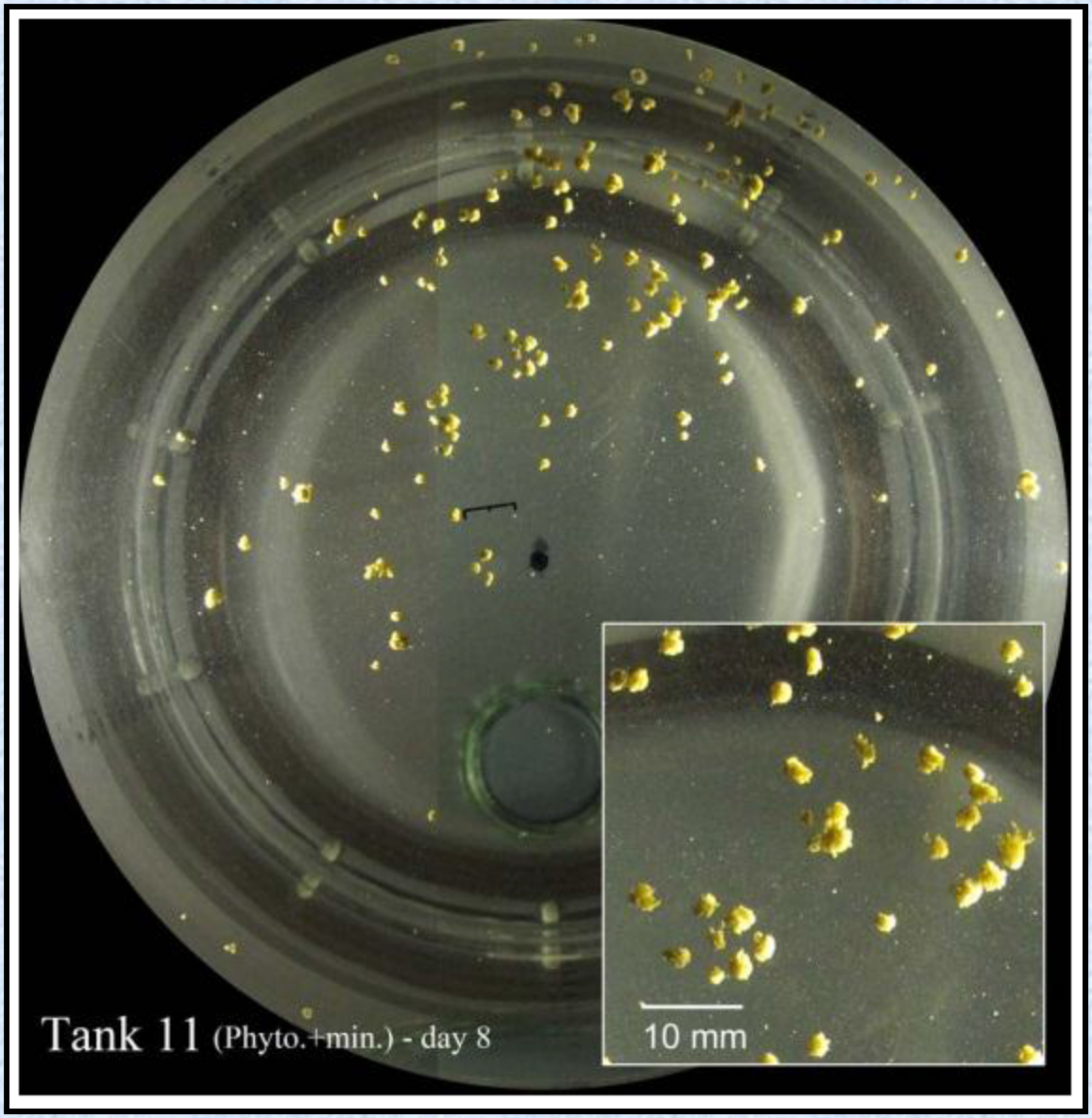
$$C_{flux_z} = (C_{flux_{z_0}})e^{-\left(\frac{D}{W}\right)z}$$

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

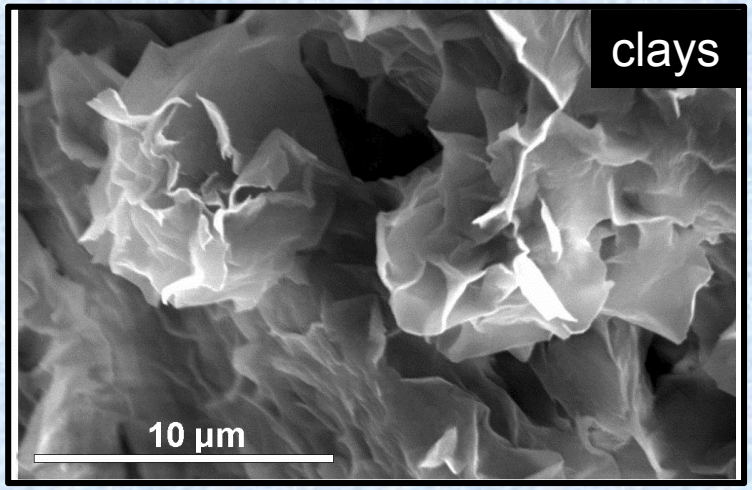
The aggregates that form look generally like this

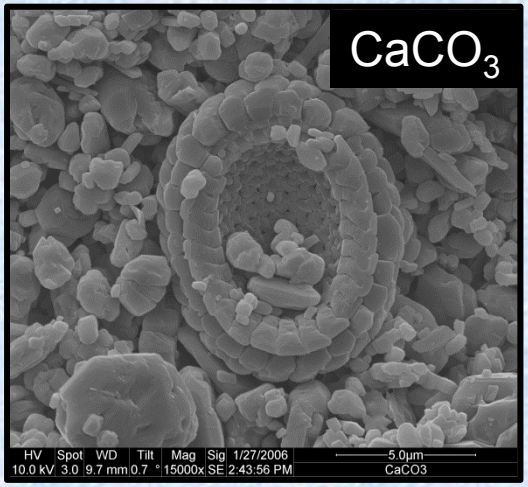


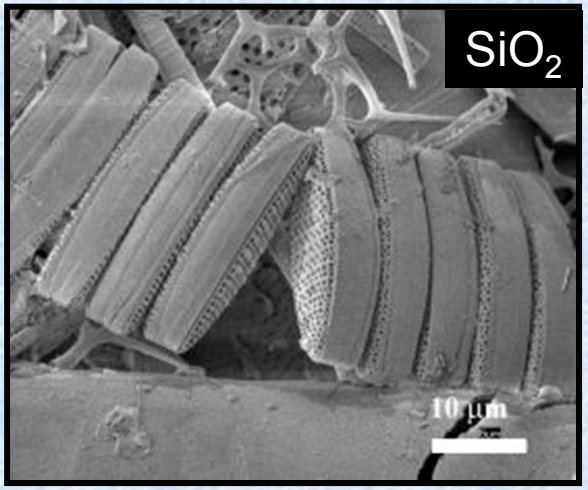
Laurenceau et al in prep

Do minerals act as ballast?

What happens when minerals are incorporated into aggregates?





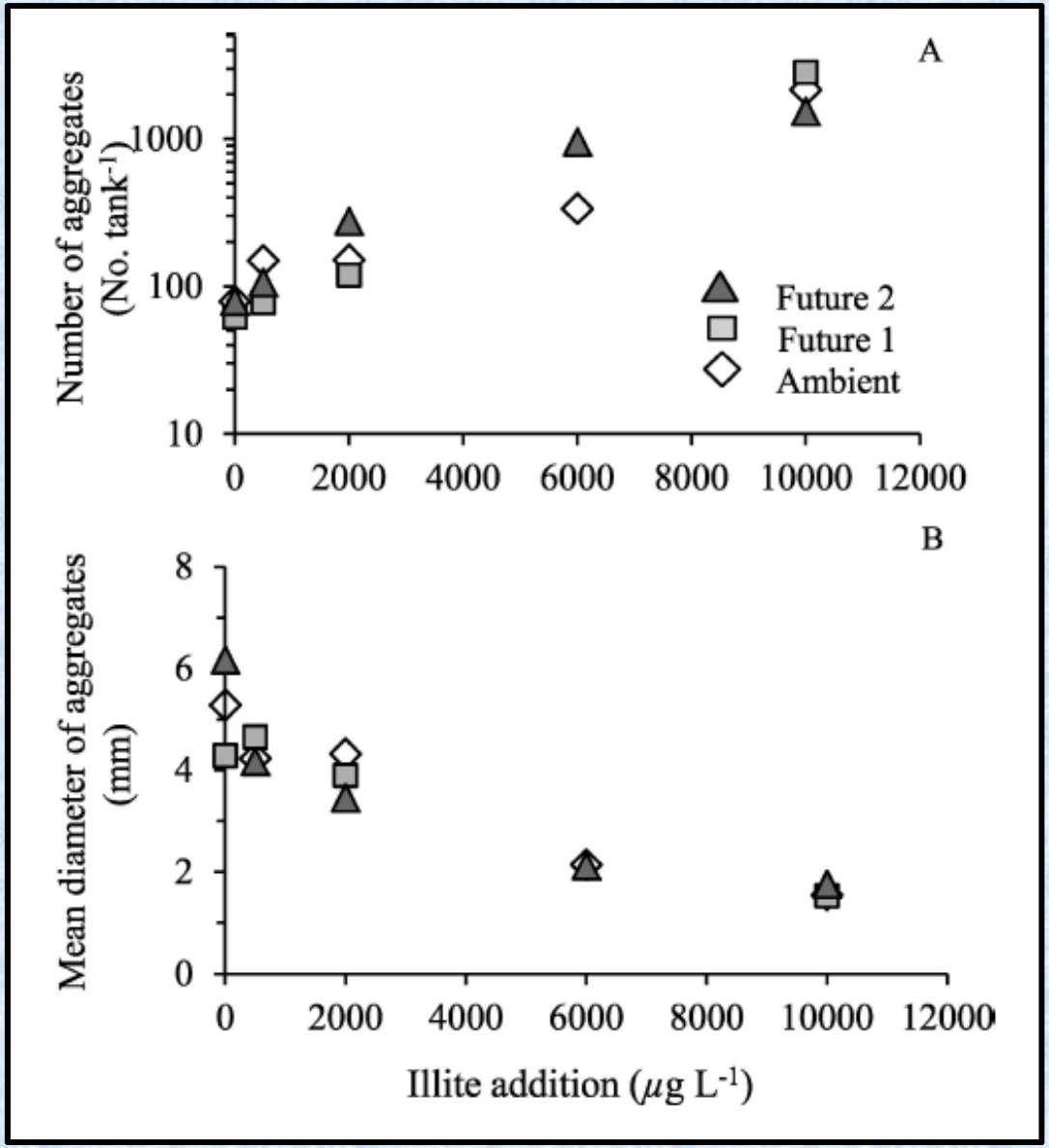


~2.8 g cm^{-3} ~2.8 g cm^{-3} ~2.6 g cm^{-3}

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

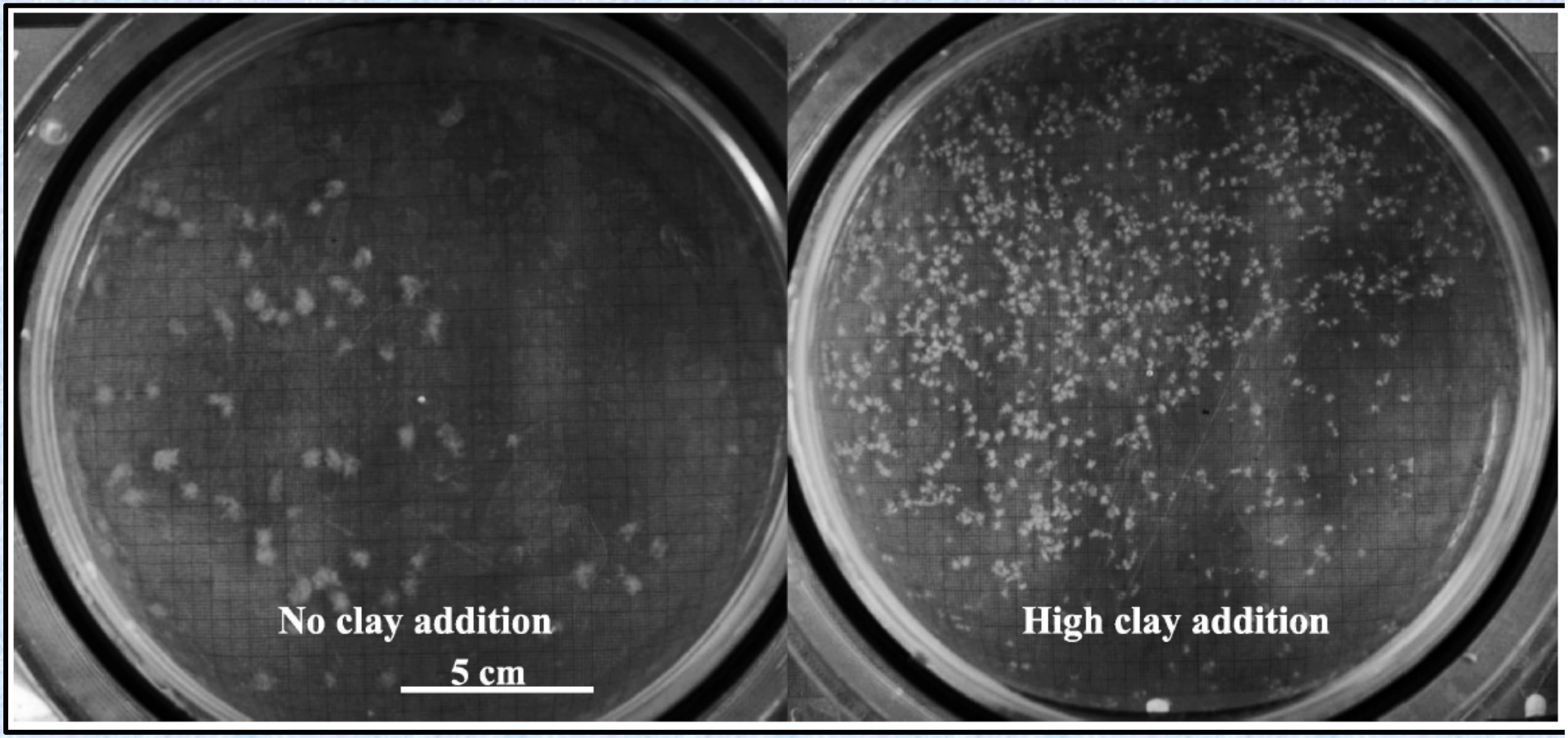
photo credits: U. Passow, I. Grigorov, &
Images of Clay Archive of the Mineralogical Society of Great Britain & Ireland

Minerals result in more, smaller aggregates



Passow et al 2014

Minerals result in more, smaller aggregates



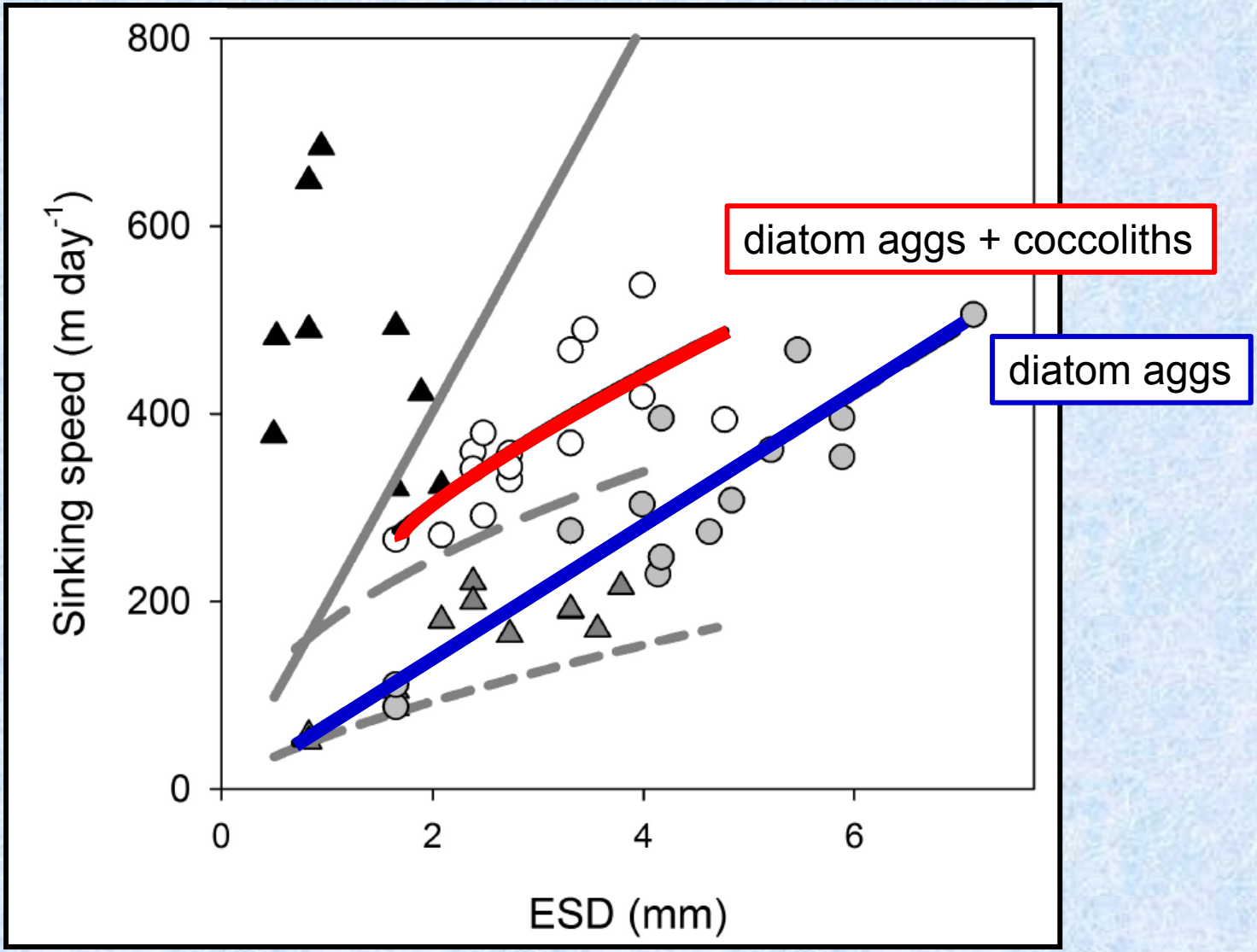
Passow et al 2014

$$W = (2g\,\Delta\rho\,V/\rho_f C_D A)^{0.5}$$

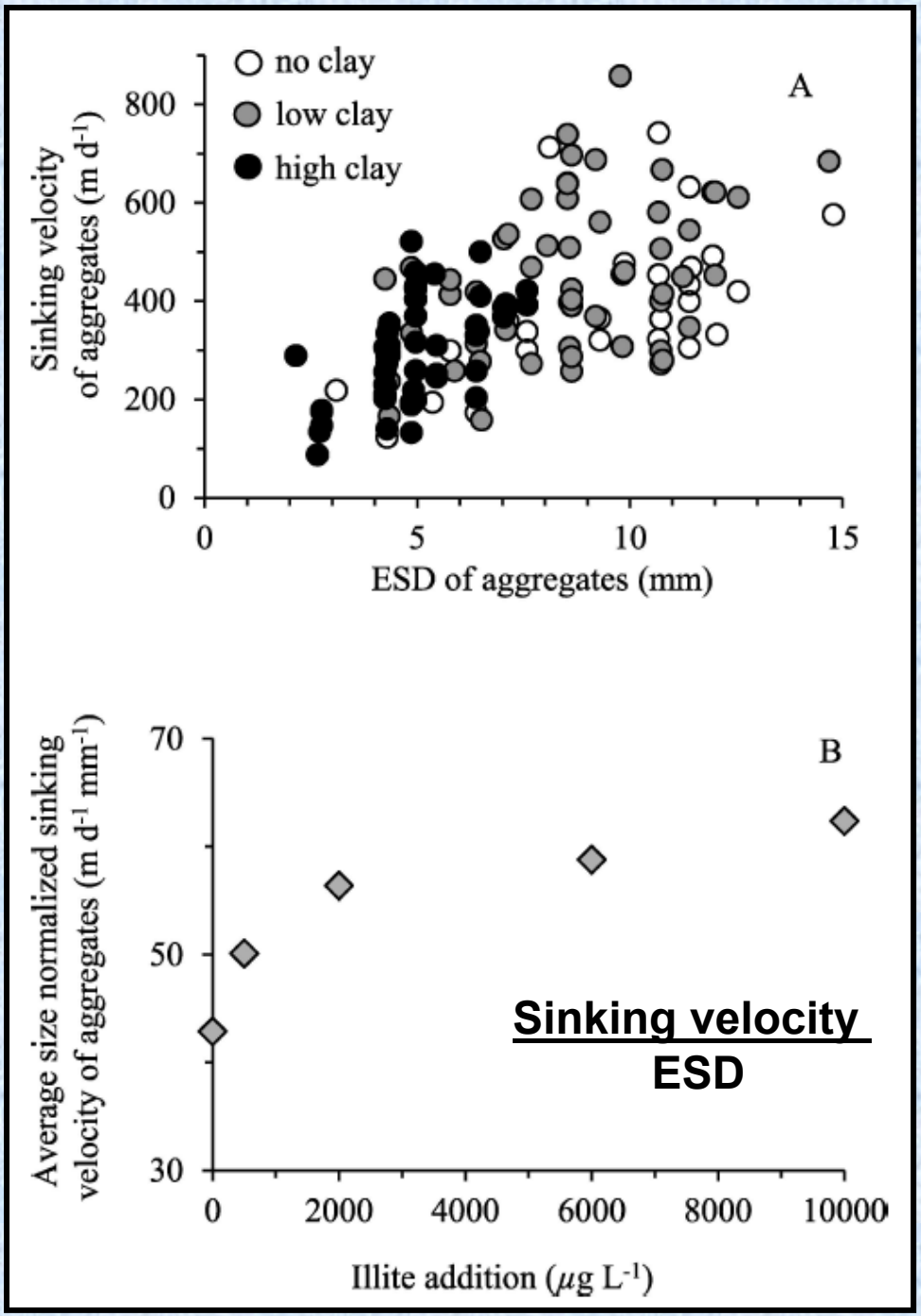
To make an aggregate sink faster

- 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 (ρf)
- decrease the drag (C_D)

Despite driving a decrease in ESD, minerals increase sinking speeds

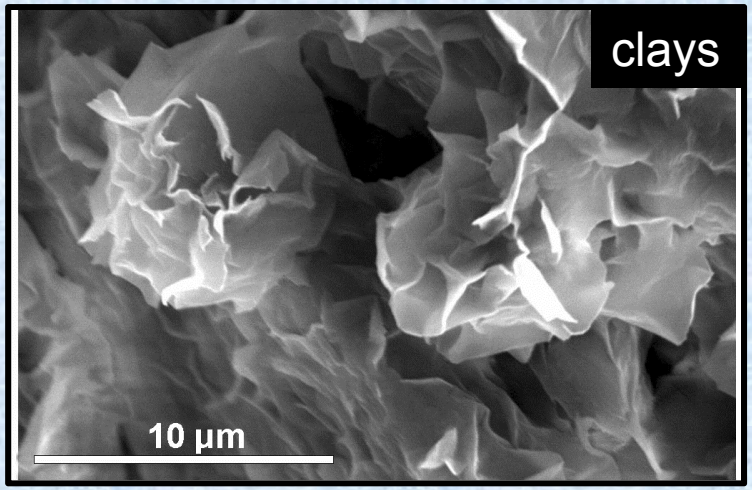


Schmidt et al 2014

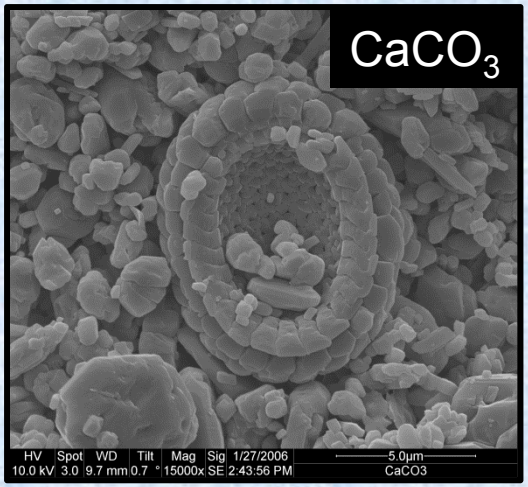


Passow et al 2014

Do minerals act as ballast?



~2.8 g cm^{-3}



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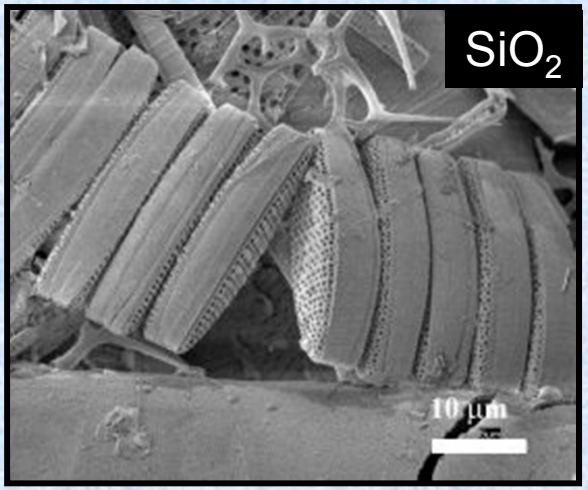


~2.6 g cm^{-3}

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 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

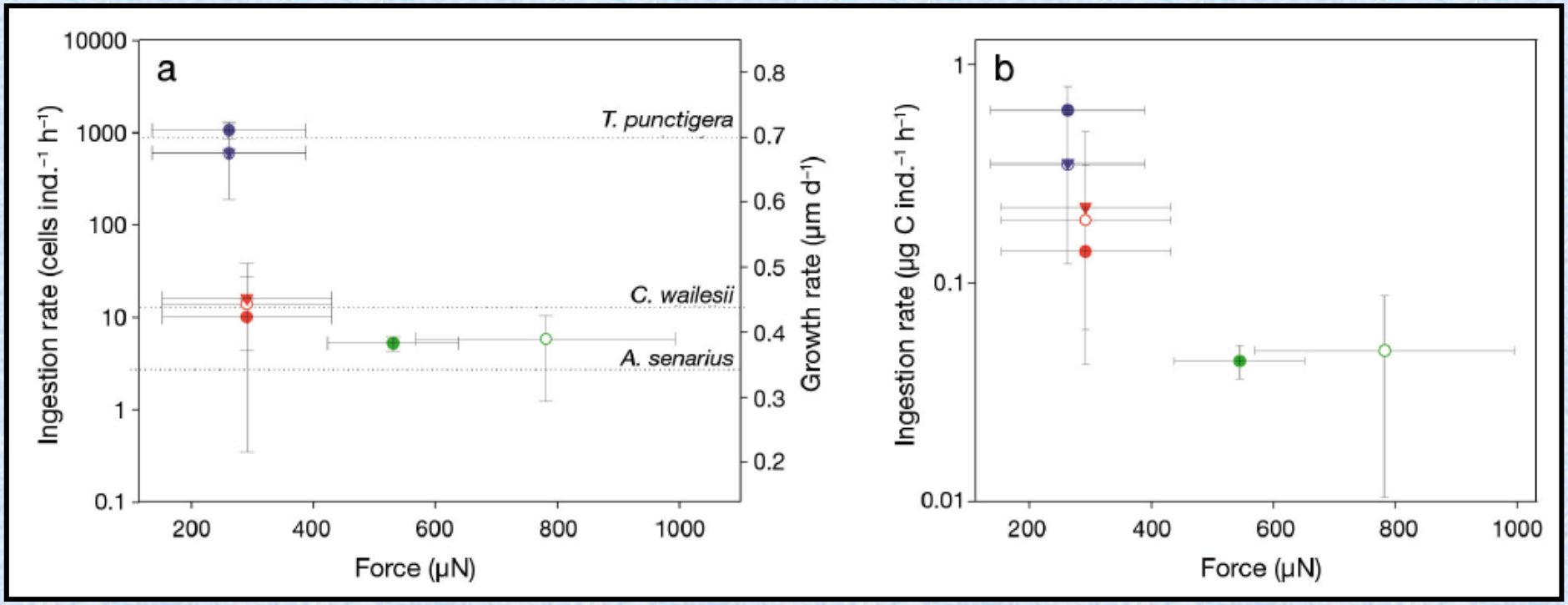
Liu H., Zhu F., Chen M.

(2013 talk at ASLO)

EFFECT OF DIATOM SILICA CONTENT ON COPEPOD GRAZING, GROWTH AND REPRODUCTION

http://www.sgmeet.com/aslo/neworleans2013/viewabstract2.asp?AbstractID=12085

Stronger frustules inhibit ingestion by copepods



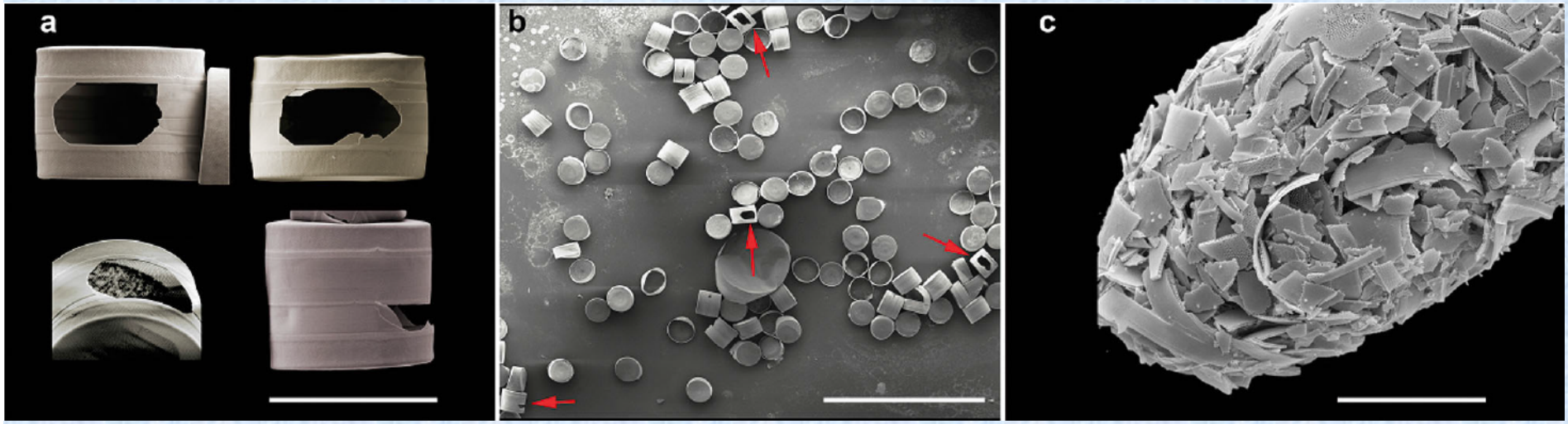
Copepods:
filled circles = *Acartia clausi*
unfilled circles = *Temora longicornis*
solid inversted triangle = *Centropages hamatus*

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

Dotted lines: growth rates of the diatoms

Friedrichs et al., 2013

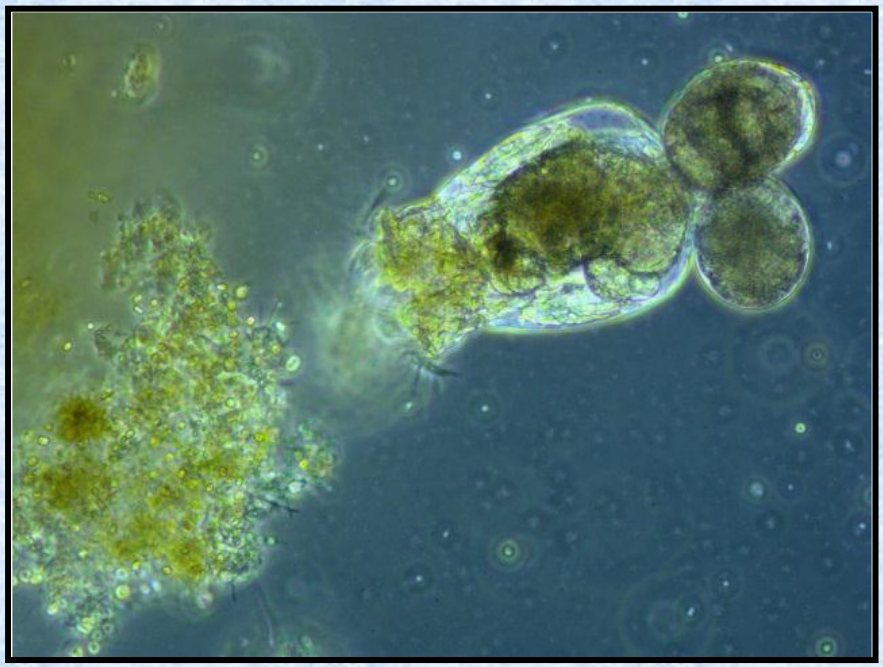
What copepods must do to eat diatoms



150 µm 1000 µm 25 µm

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 rotifer *Brachionus* feeding on a diatom aggregate

The resulting ammonium excretion rates:

1.3 mg L^{-1} $CaCO_3$

0.1 µg N mg^{-1} rotifer h^{-1}

no $CaCO_3$

0.3 µg N mg^{-1} rotifer h^{-1}

Le Moigne et al., 2013

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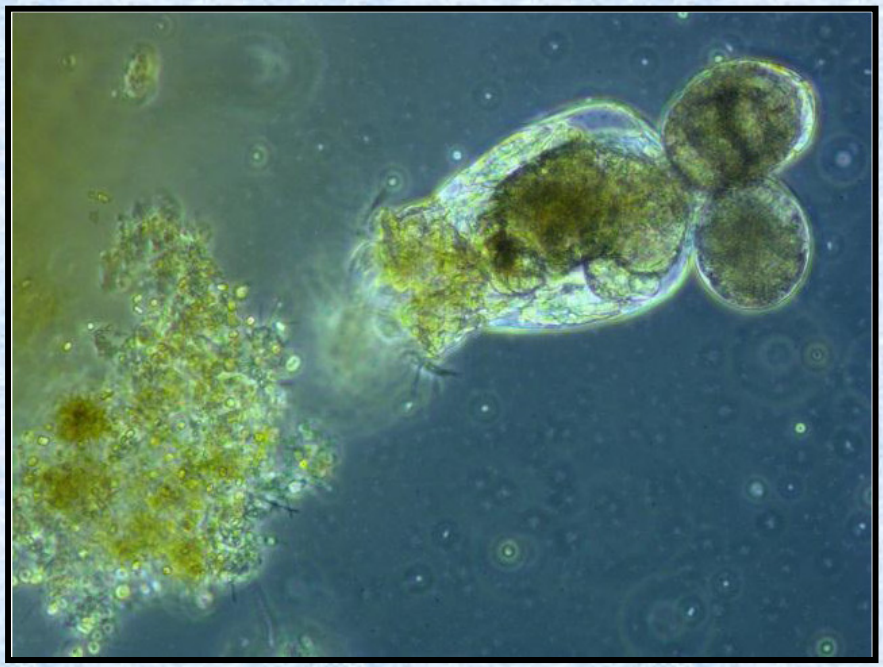


The rotifer *Brachionus* feeding on a diatom aggregate

The resulting phosphate excretion rates:

1.3 mg L^{-1} $CaCO_3$

0.09 µg P mg^{-1} rotifer h^{-1}

no $CaCO_3$

0.14 µg 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

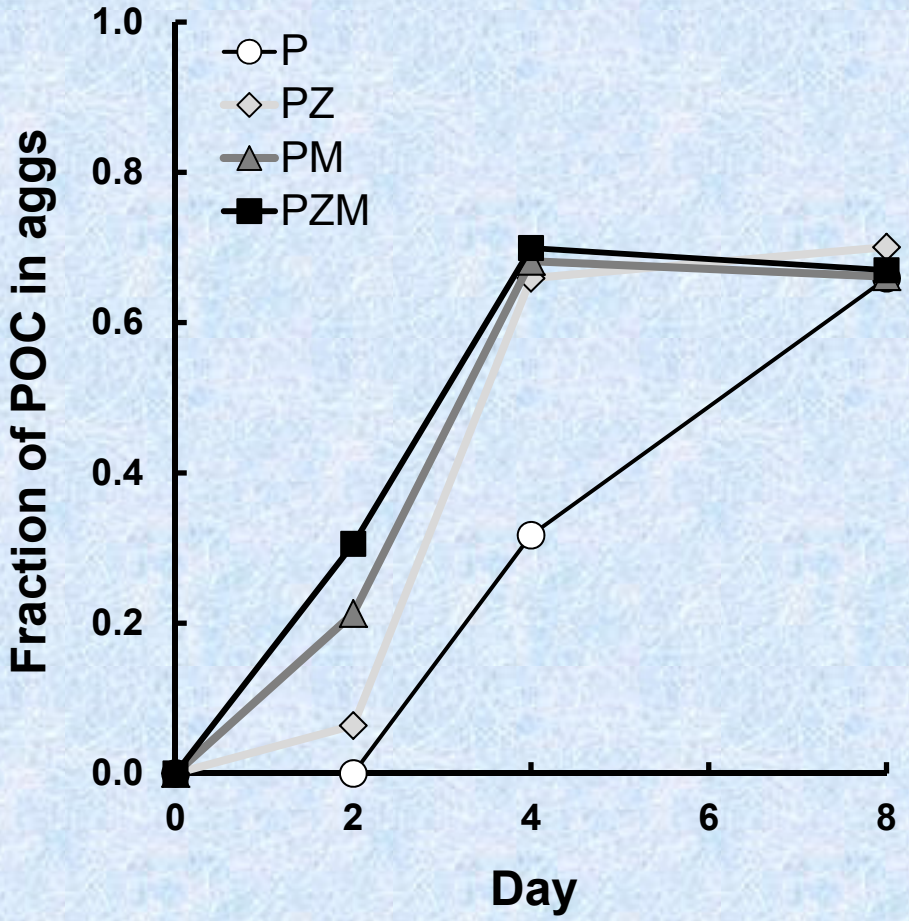
Do minerals promote aggregation?

- 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).

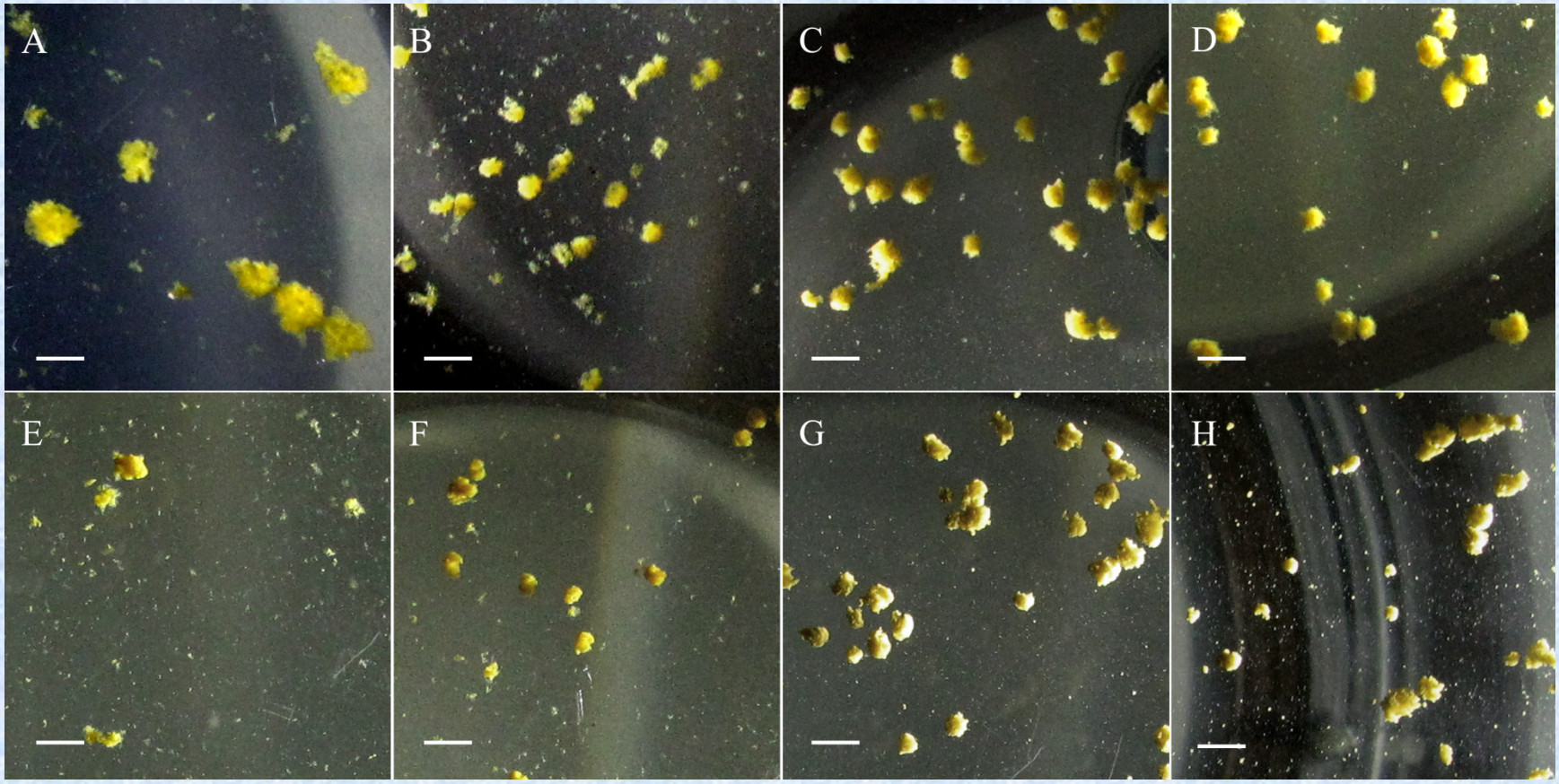
Phyto + Zoo + Min
faster than
Phyto + Min
faster than
Phyto + Zoo
faster than
Phyto



But, ultimately, equivalent amounts of POC aggregated.

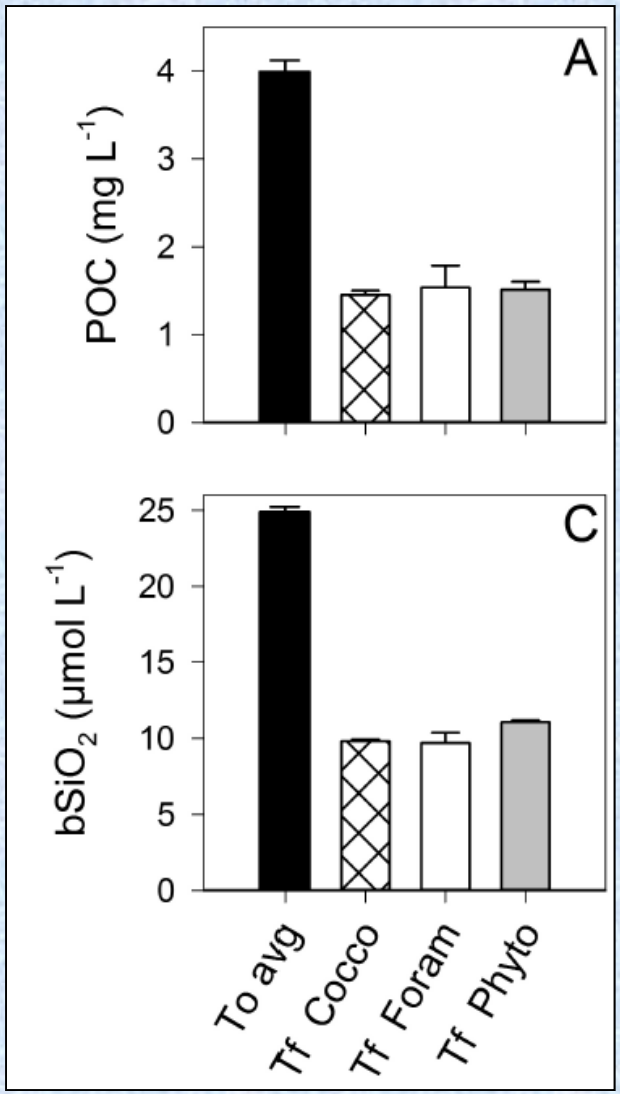
Le Moigne et al., 2013

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