mCDR using clay minerals

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- Known: clay minerals constitute over 50% of the continental mineral dust
- Depending on their composition clay minerals can provide Si, Al, Fe, Mn, P,.. to the sea-surface

  - Today..
  - Clay minerals recruit the microbial circuit and the biological pump
    - ✓ Organoclay floc formation mediated by heterotrophic bacteria
    - ✓ Floc ingestion by zooplankton. Fecal Pellets are denser and settle much faster than control
  - Depth of remineralization is expected to increase

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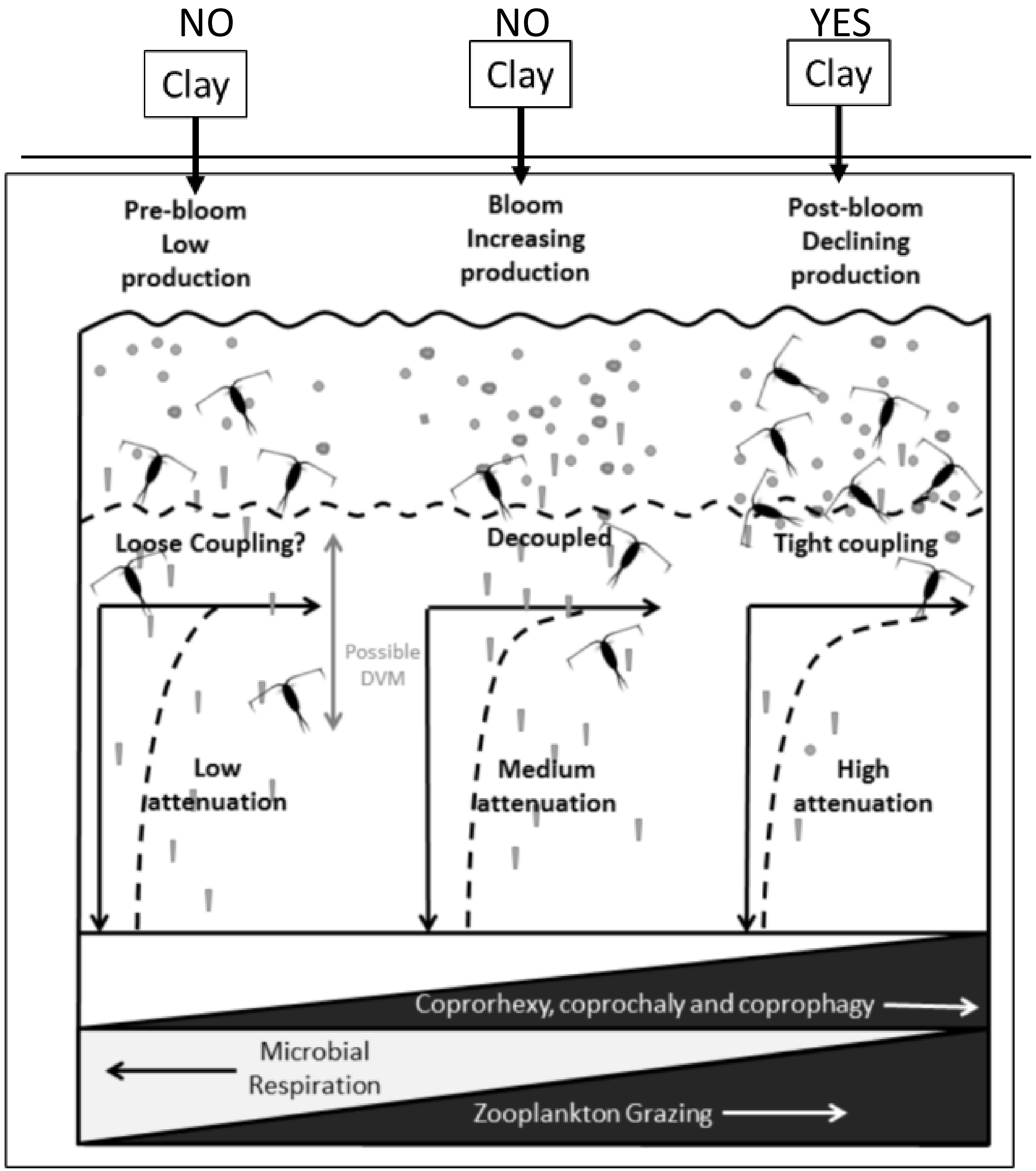
October 16, 2023



Big picture

Concoction of clay minerals when sprinkled at the end of a phytoplankton bloom.

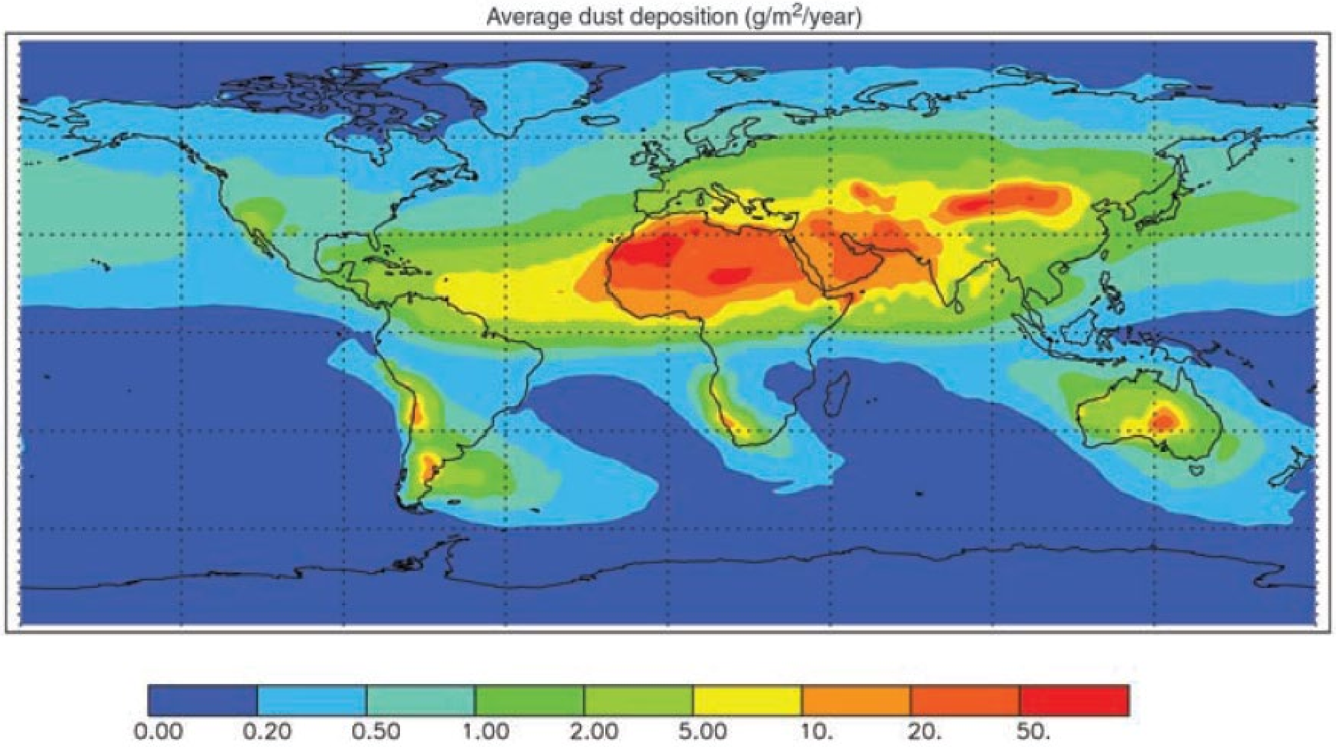
→ Increase in the depth of POC flux attenuation.

→ deeper burial of the carbon fixed by phytoplankton.

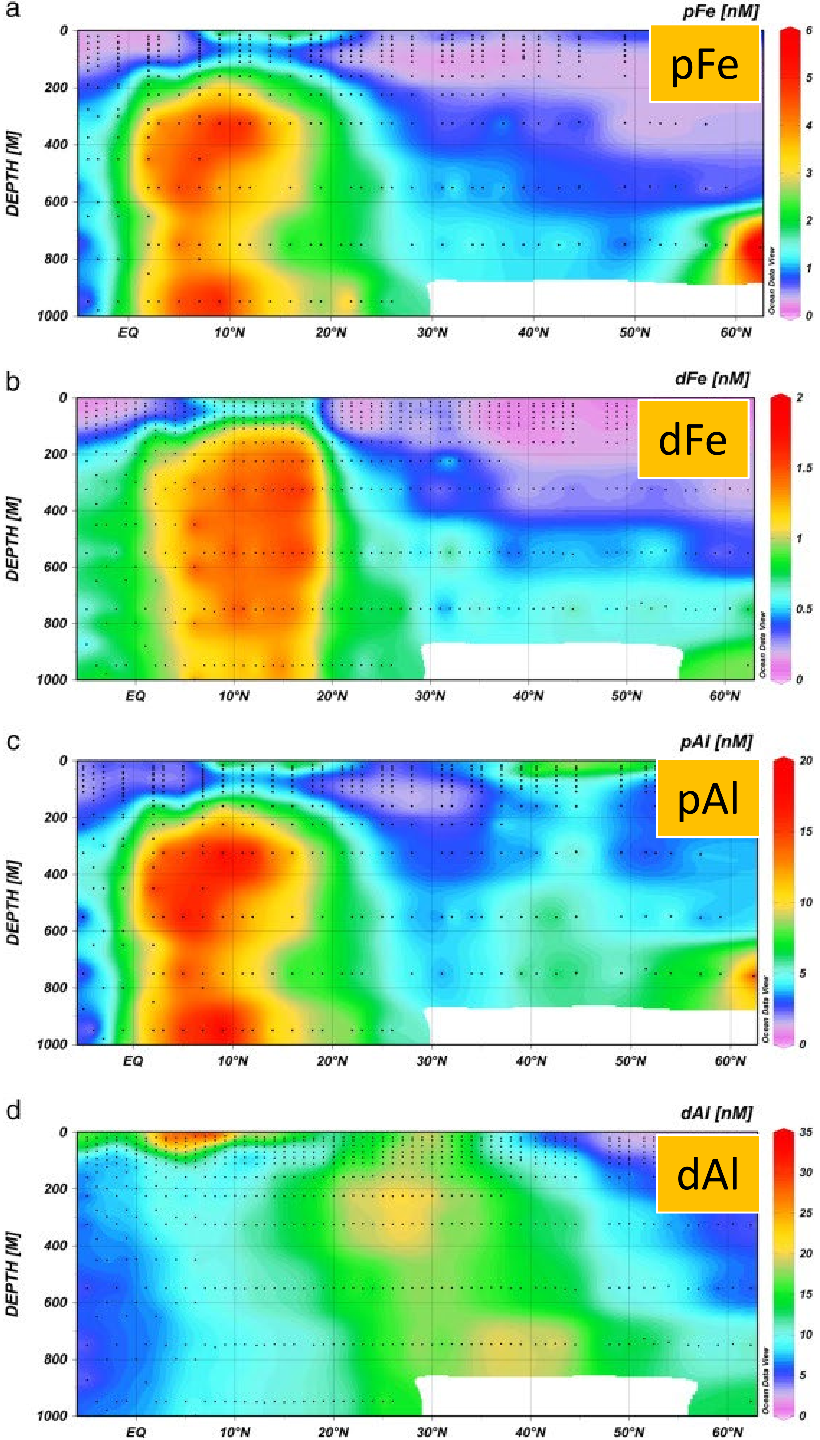
We can potentially *customize* deep burial of carbon at the end of a bloom!!!

Figure from Belcher (2016) to show bloom progression in the Scotia Sea modified as an example to show the time when clay deposition would make maximum impact.

Saharan dust provides the bulk of particulate and dissolved Fe and Al to the equatorial-north Atlantic



Jickells et al. (2005) Science



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Barrett et al. (2012)

LIMNOLOGY and OCEANOGRAPHY

ASLO

Limnol. Oceanogr. 63, 2018, 1386–1394

doi: 10.1002/lno.10779

The ballasting effect of Saharan dust deposition on aggregate dynamics and carbon export: Aggregation, settling, and scavenging potential of marine snow

Helga van der Jagt[1,2] Carmen Friese,[2] Jan-Berend W. Stuut[2,3] Gerhard Fischer,[2,4] Morten H. Iversen[1,2*]

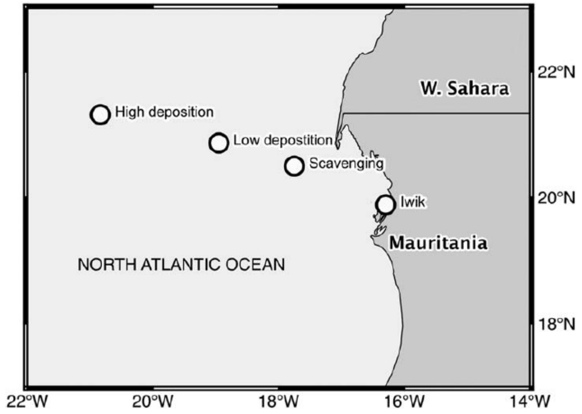


Fig. 1. Overview of the locations of the high dust deposition, low dust deposition, and scavenging experiment, and dust collection location Iwik.

Table 1. Equivalent spherical diameter (ESD), number of formed aggregates per liter, total aggregated volume and sinking velocity for the high deposition, low deposition and scavenging experiments. Average ± SD.

Experiment		ESD (mm)	Total agg. (# L^{-1})	Total agg. vol. (mm^3 L^{-1})	Sinking velocity (m d^{-1})
High deposition	Control	0.52 ± 0.30	5.04 ± 3.71	0.79 ± 0.48	133 ± 108
	Dust	0.62 ± 0.51	16.87 ± 9.21	8.98 ± 3.11	430 ± 280
Low deposition	Control	1.45 ± 0.78	4.35 ± 2.84	3.43 ± 4.47	42 ± 23
	Dust	0.75 ± 0.61	23.04 ± 6.60	71.88 ± 22.81	109 ± 42
Scavenging	Control	1.29 ± 0.85	6.09 ± 3.14	17.10 ± 5.64	319 ± 210
	Dust	1.40 ± 0.80	5.51 ± 3.05	17.21 ± 6.81	403 ± 280

“carbon export to the deep ocean in regions with high dust deposition is strongly controlled by dust input to the surface ocean”

nature geoscience

ARTICLES

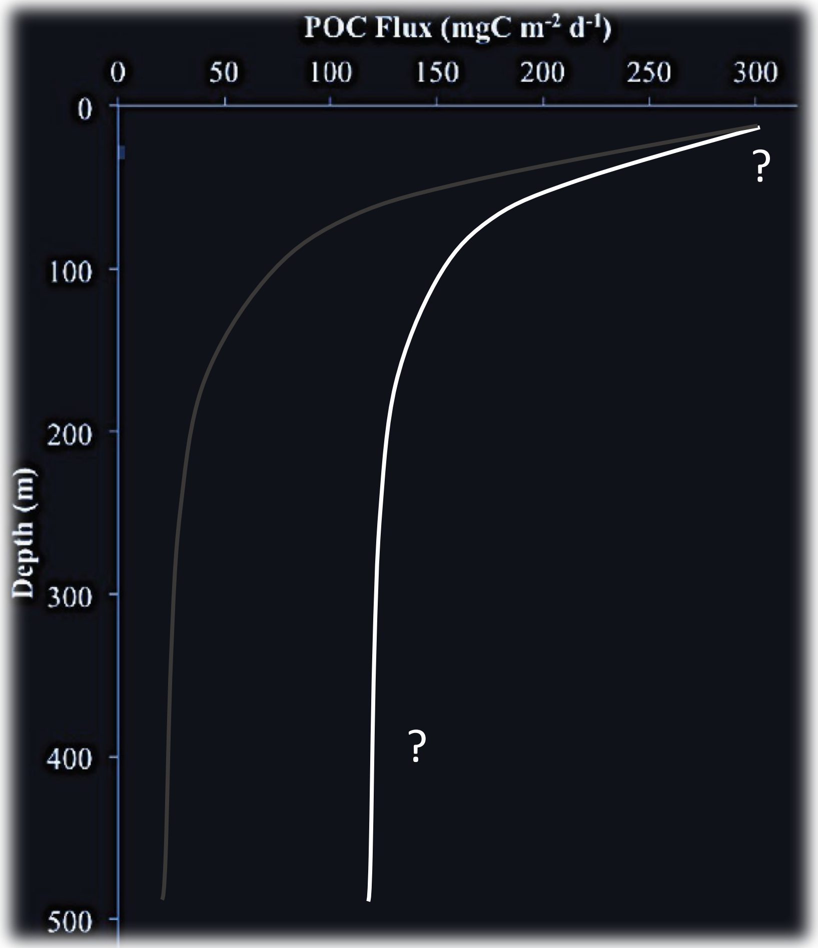
PUBLISHED ONLINE: 27 FEBRUARY 2017 | DOI: 10.1038/NGEO2899

Carbon sequestration in the deep Atlantic enhanced by Saharan dust

Katsiaryna Pabortsava[1*], Richard S. Lampitt[1], Jeff Benson[1], Christian Crowe[1], Robert McLachlan[1], Frédéric A. C. Le Moigne[2], C. Mark Moore[3], Corinne Pebody[1], Paul Provost[1], Andrew P. Rees[4], Gavin H. Tilstone[4] and E. Malcolm S. Woodward[4]

“Dust deposition increases carbon sequestration in the North Atlantic through the fertilization of the N2-fixing community in surface waters and mineral ballasting of sinking particles”

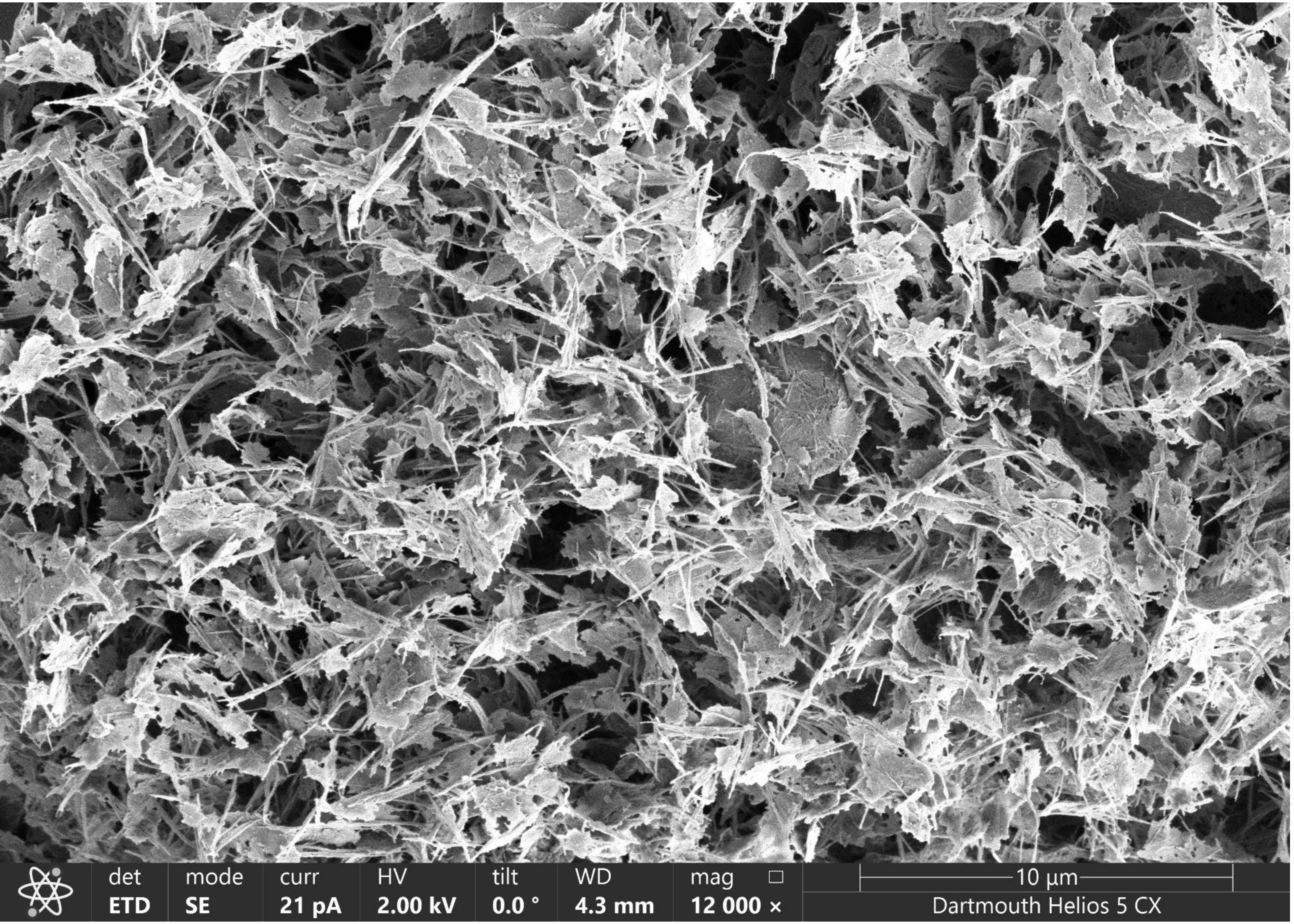
On the way to hack the Martin Curve!
(a rough sketch)



- Clay interacting with heterotrophic bacteria → production of sticky polymers (TEPs)
- Rapid formation of biofilms → organo-clay complexes → flocs
- Flocs remove dissolved carbon, bacteria, dying/dead phytoplankton
- Transfer to higher trophic level
- Zooplankton (*Calanus finmarchicus*) ingest clay-leaden flocs → fecal pellets with much higher settling rates would be released by the animals at ~100 m depth (Diel migration)

=> Organoclay flocs and fecal pellets with clay are likely to be remineralized at a greater depth than those with no clay

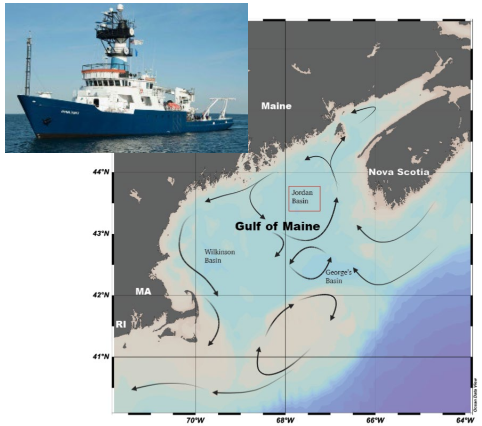
A mixture of palygorskite (fibrous)--$Mg_5Si_8O_{20}(OH)_2(OH_2)_4 \cdot 4H_2O$ and nontronite (flakes)--$[Si_{6.98}\ Al_{0.95}Fe_{0.07}][Al_{0.36}\ Fe_{3.61}\ Mg_{0.04}]O_{20}(OH)_4$

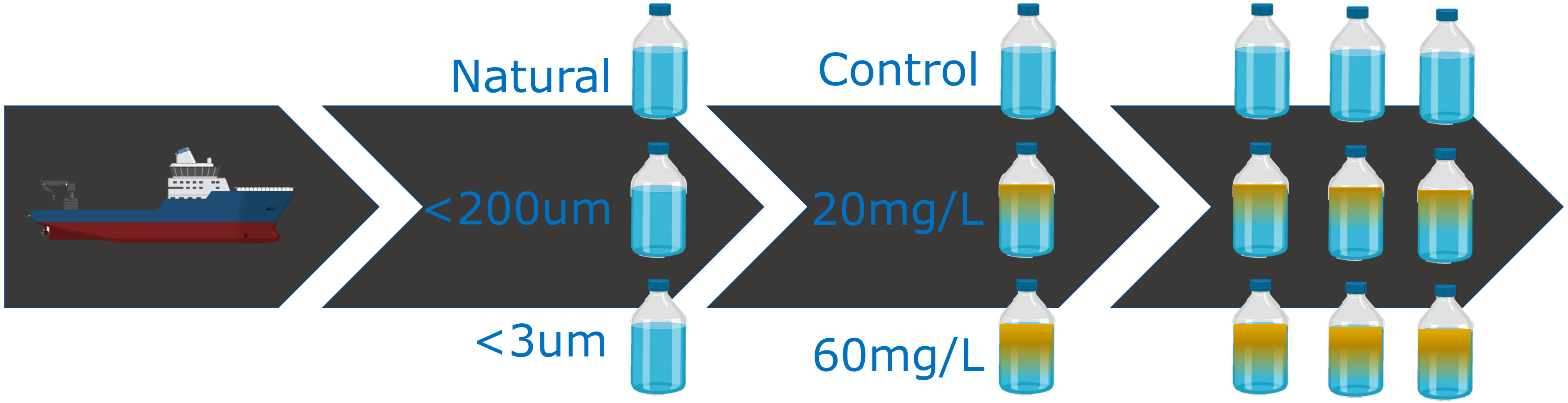


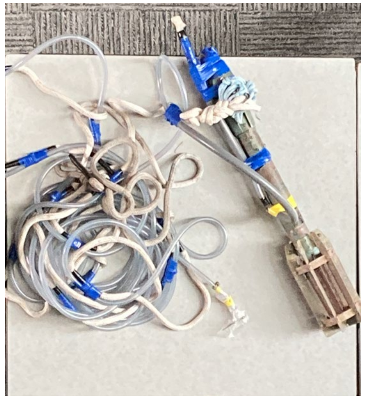
- Uniform deposition of just 1 mg of clay per m^2 to sea surface would result in a sea surface microlayer having a density of ~10,000 clay grains per µL.
- 1 µL of seawater in a bloom contains about 500-3000 heterotrophs, along with 10,000 viruses, and less than 100 of each of picocyanobacteria, protists, and algae.
- Strong interaction is expected between clay-DOC-heterotrophic bacteria and plankton

Natural Community Experiment

RV Endeavor – Gulf of Maine







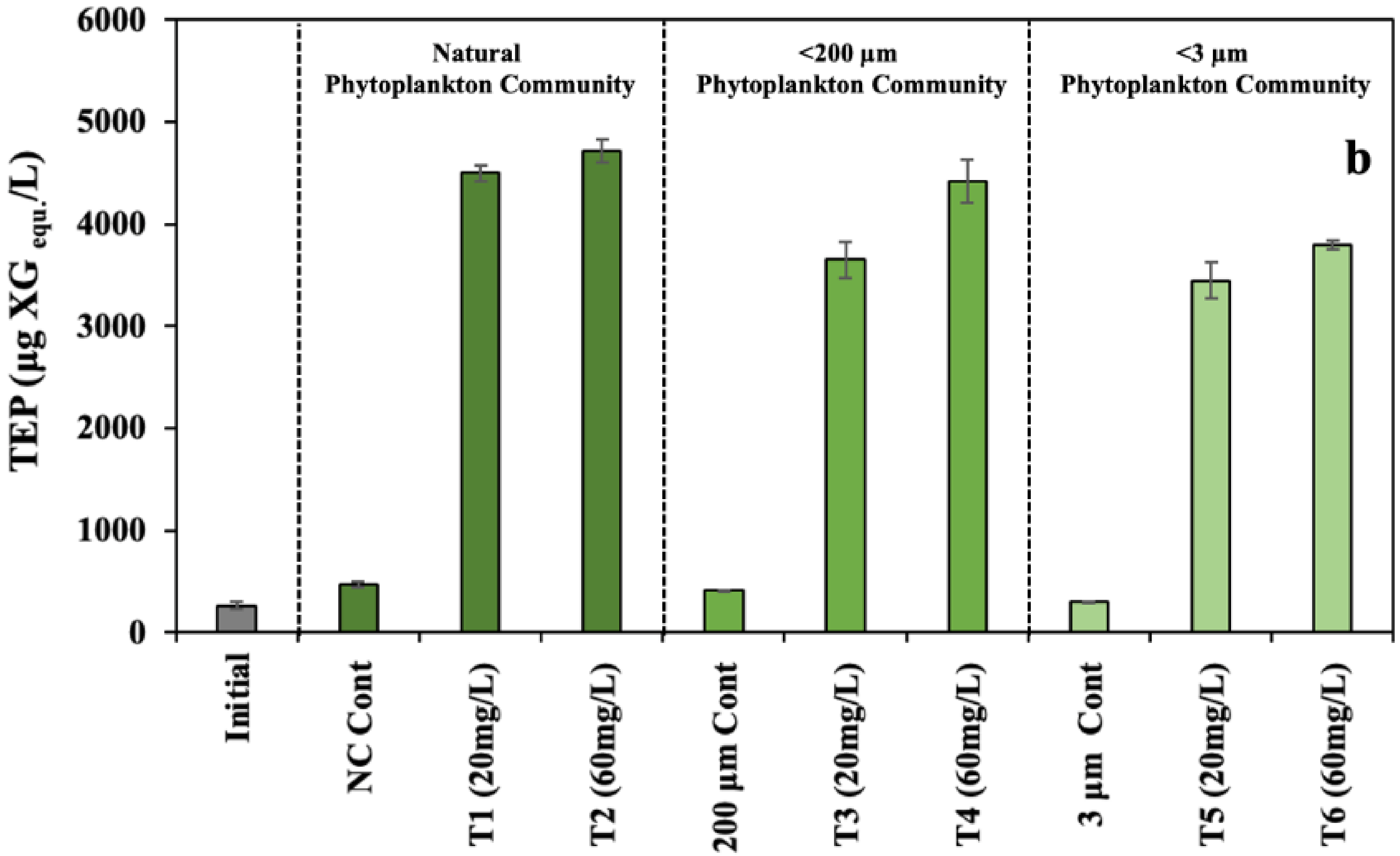
Geofish (Bruland)

Bloom Sampling at ~1 m

24 hr acclimatization in water bath

Clay slurry

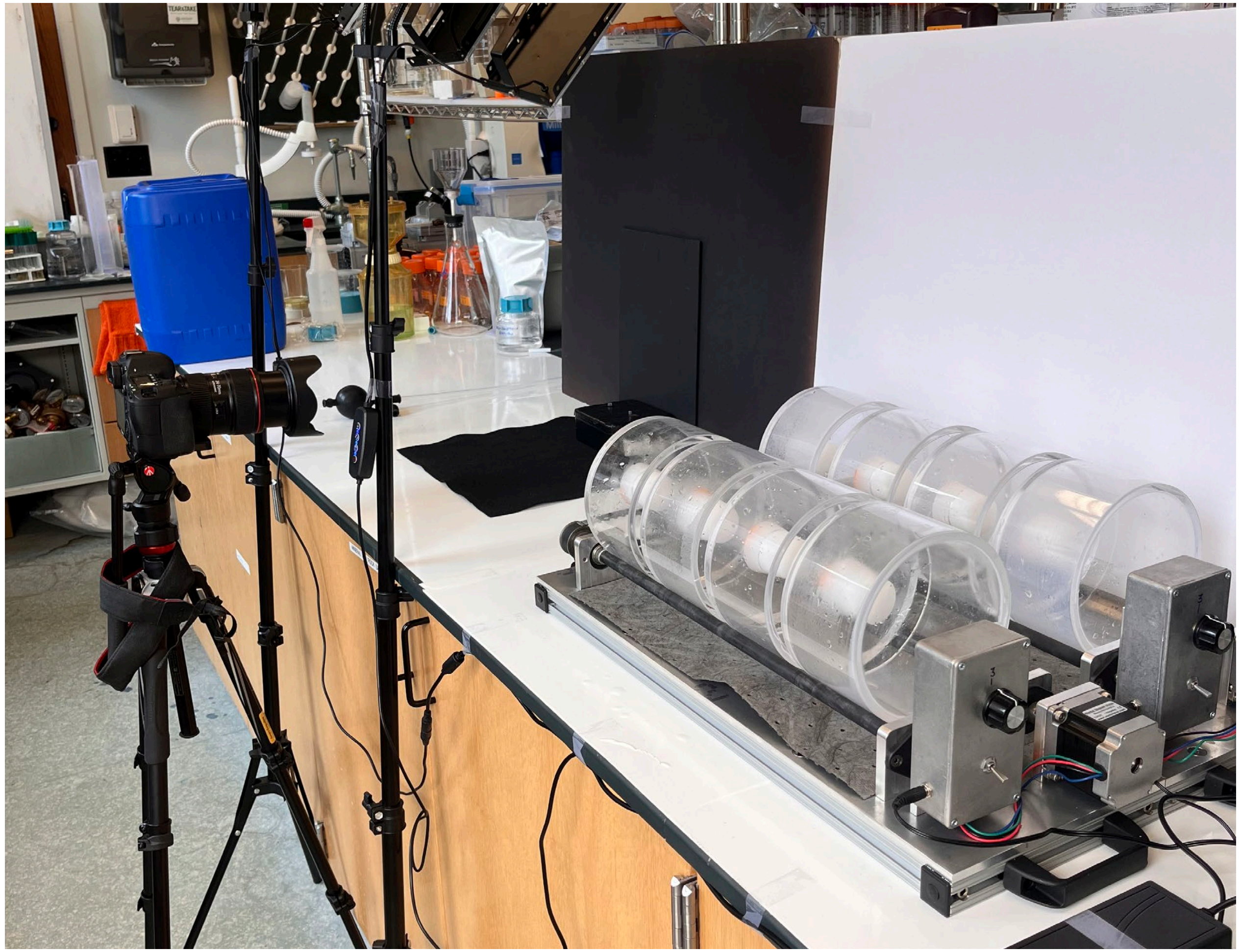
72 hr incubation



16S rRNA sequencing → Heterotrophic bacteria belonging to α-Proteobacteria and Flavobacteria

Sharma et al. (2023) ASLO

Roller tanks at Dartmouth*

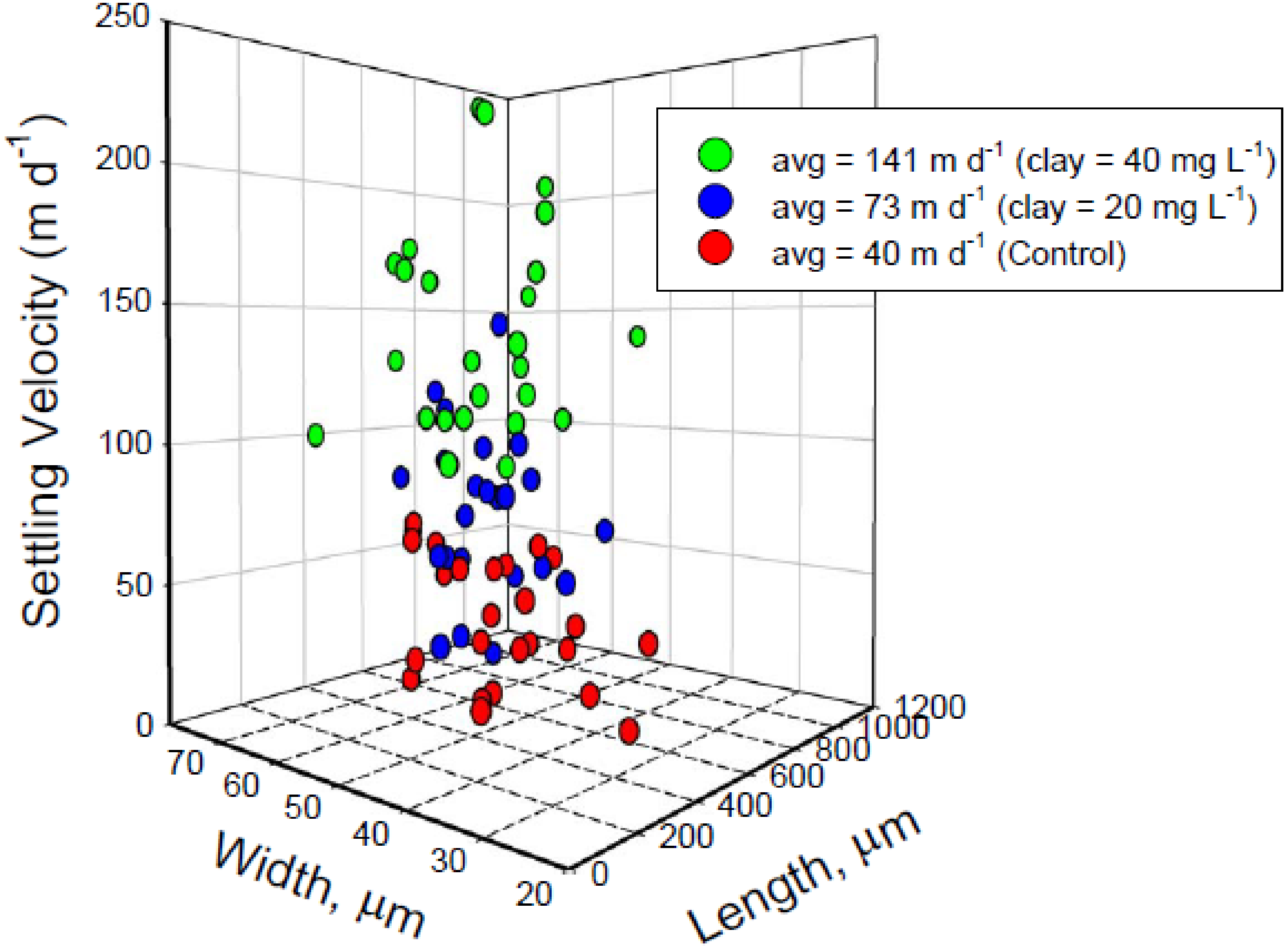


Interaction of clay with bacteria leads to the production of sticky transparent exopolymer particles → flocs

*based on design by Prof. Iversen, Zentrum für Marine Umweltwissenschaften, Bremen. Germany.


Adult female with food

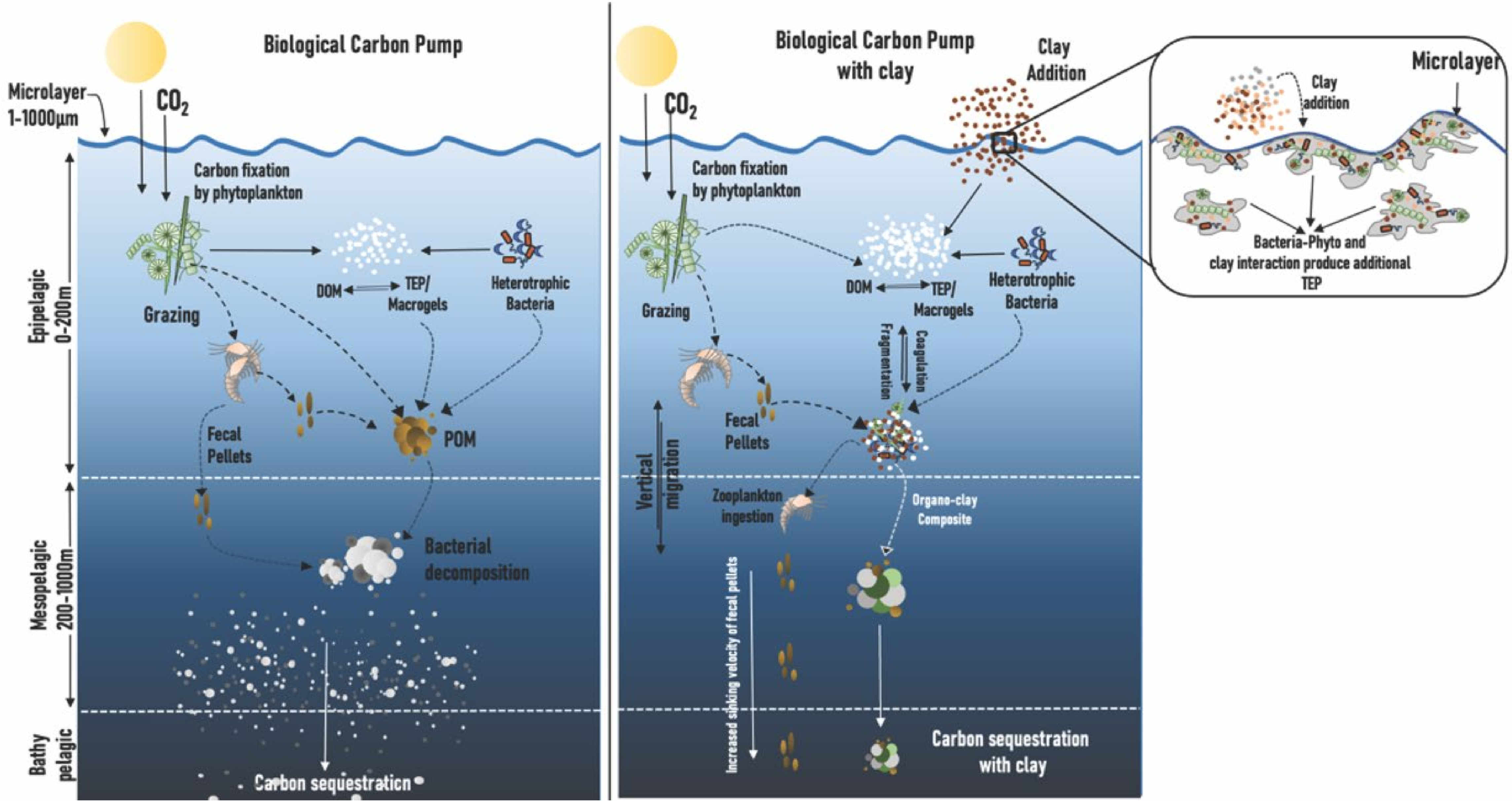

Fecal Pellets



Calanus finmarchicus Fecal Pellet Settling velocity

An increase in the relative density of fecal pellets when the zooplankton ingest flocs with clay

Desai et al. (2023) OSM (David Fields Lab, Bigelow)



Biological Carbon Pump
Microlayer
1-1000µm
CO_2
Carbon fixation
by phytoplankton
DOM
TEP/
Macrogels
Heterotrophic
Bacteria
Grazing
Fecal
Pellets
POM
Bacterial
decomposition
Carbon sequestration
Epipelagic
0-200m
Mesopelagic
200-1000m
Bathy
pelagic
Biological Carbon Pump
with clay
Clay
Addition
CO_2
Carbon fixation
by phytoplankton
DOM
TEP/
Macrogels
Heterotrophic
Bacteria
Grazing
Fragmentation
Coagulation
Fecal
Pellets
Vertical
migration
Zooplankton
ingestion
Organo-clay
Composite
Increased sinking velocity of fecal pellets
Carbon sequestration
with clay
Microlayer
Clay
addition
Bacteria-Phyto and
clay interaction produce additional
TEP

Observations

Clay addition augmented the TEP production

Heterotrophic bacteria produce TEP

FLOCs: Organo-clay composites

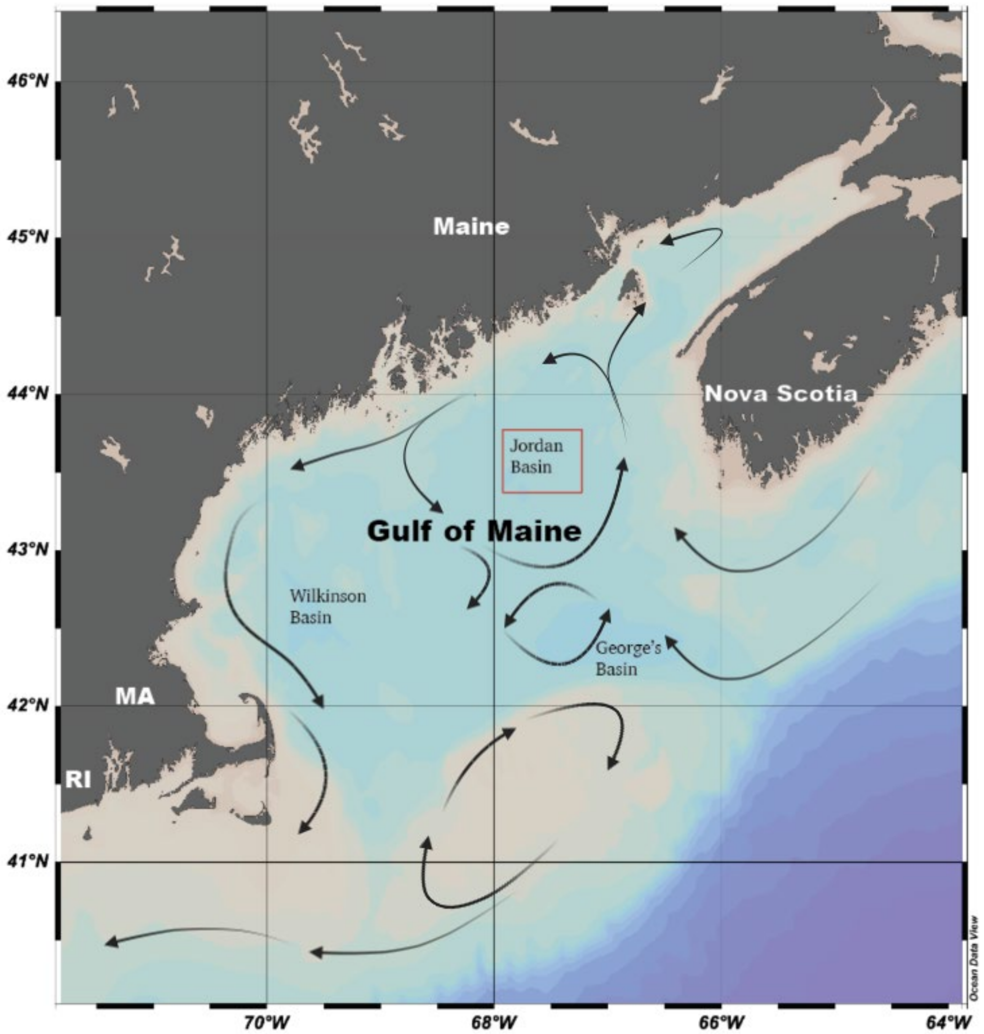
TEP increase and dinoflagellate removal

Silica released from clay promoted the growth of diatoms

Clay-treated flocs fed to zooplankton: increase in the sinking velocity of fecal pellets

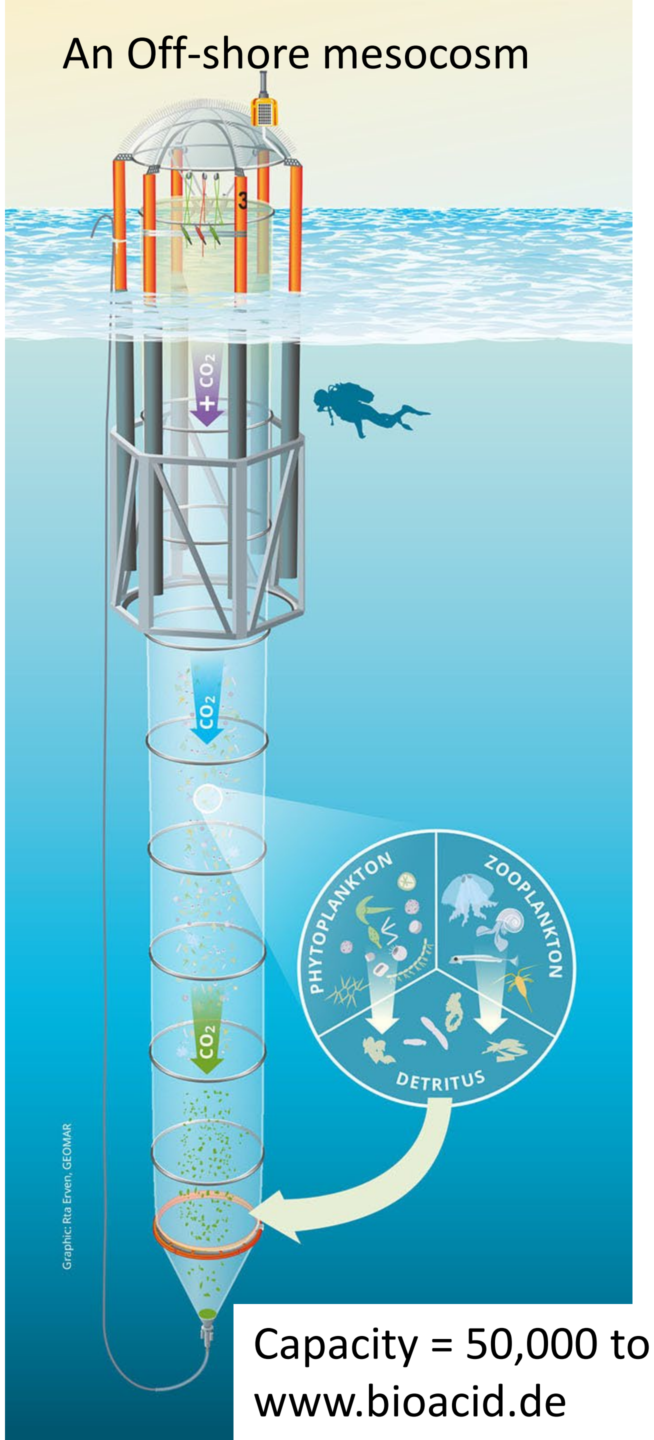
Next steps: Fall phytoplankton bloom, Gulf of Maine

R/V Endeavor



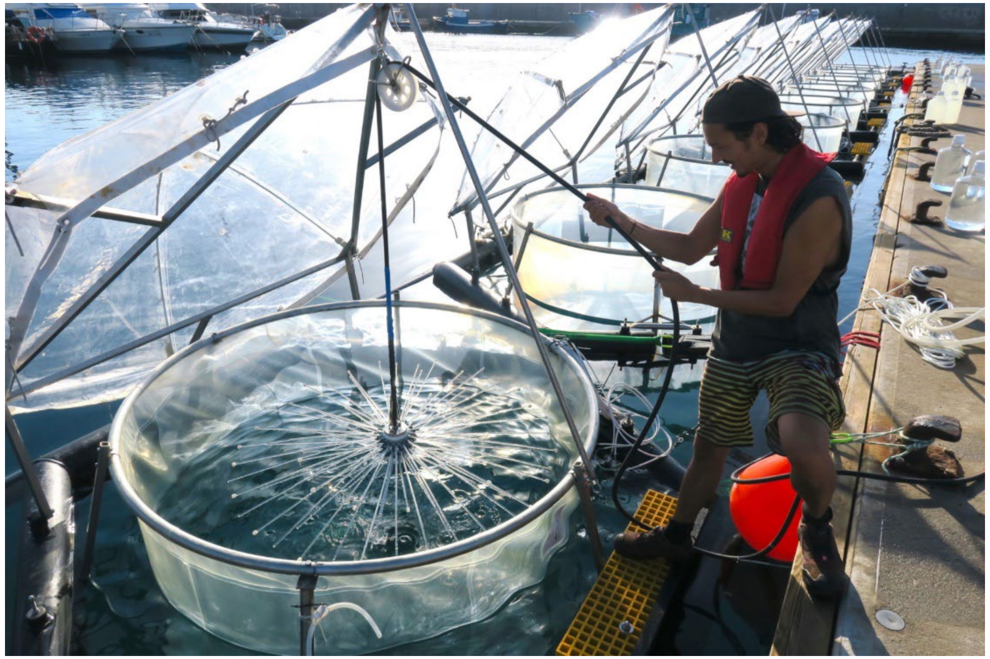
Plus lab experiments to evaluate a) if clay-bacteria-phytoplankton interaction generates GHGs, b) if nutrients, such as Fe, are released by zooplankton upon ingestion of clay→ positive feedback

An Off-shore mesocosm



Capacity = 50,000 to 80,000 L
www.bioacid.de

Next steps: on-shore mesocosms (Prof. Ulf Riebesell, GEOMAR Helmholtz Centre for Ocean Research, Kiel). Phytoplankton bloom in late Feb'24 (Kiel Fjord)—evaluate CDR efficiency of clay



Capacity ~8000 L

Photos from Ulf Riebesell

Mesocosm experiments

a) Evaluate TEP production, floc generation and transport in a different ecosystem
b) Observe changes in the ecosystem
c) Gauge carbon removal efficiency