Utilizing clay minerals to remove atmospheric CO_2

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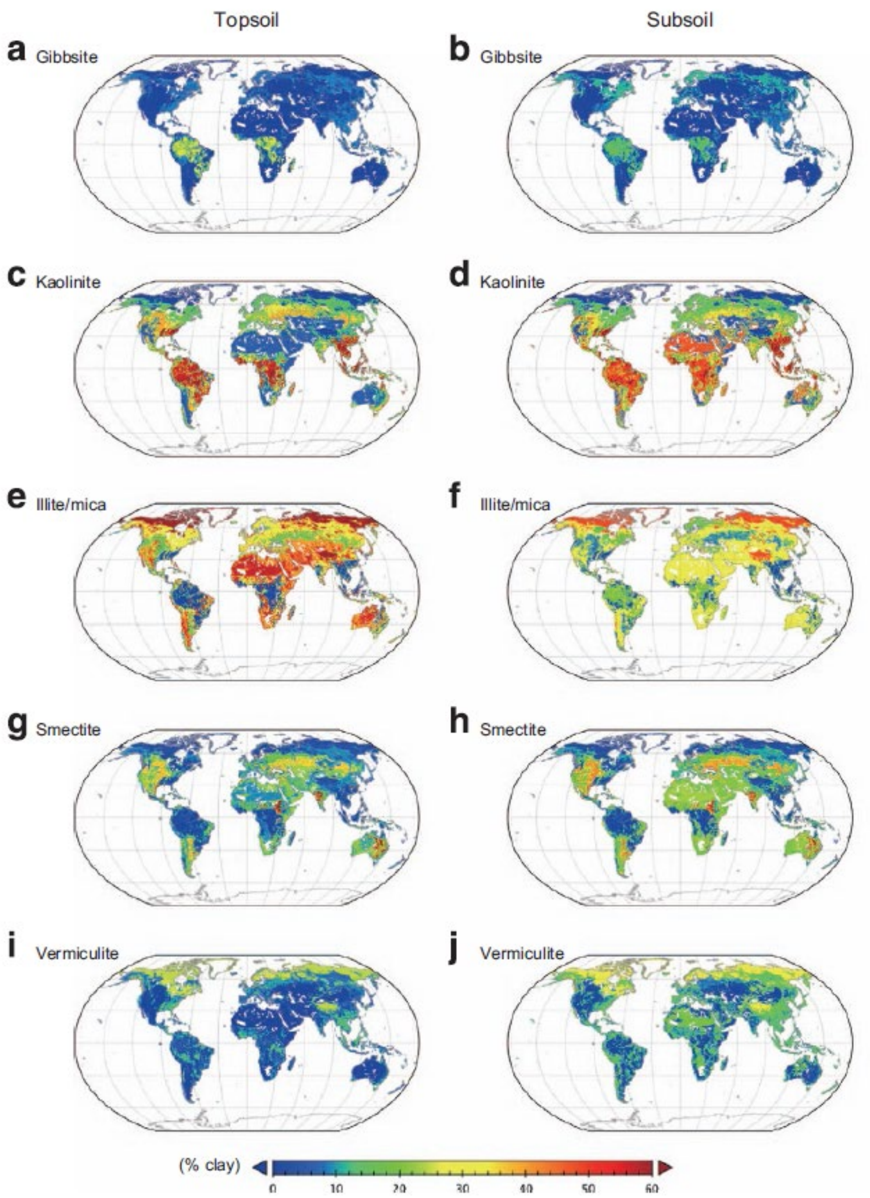
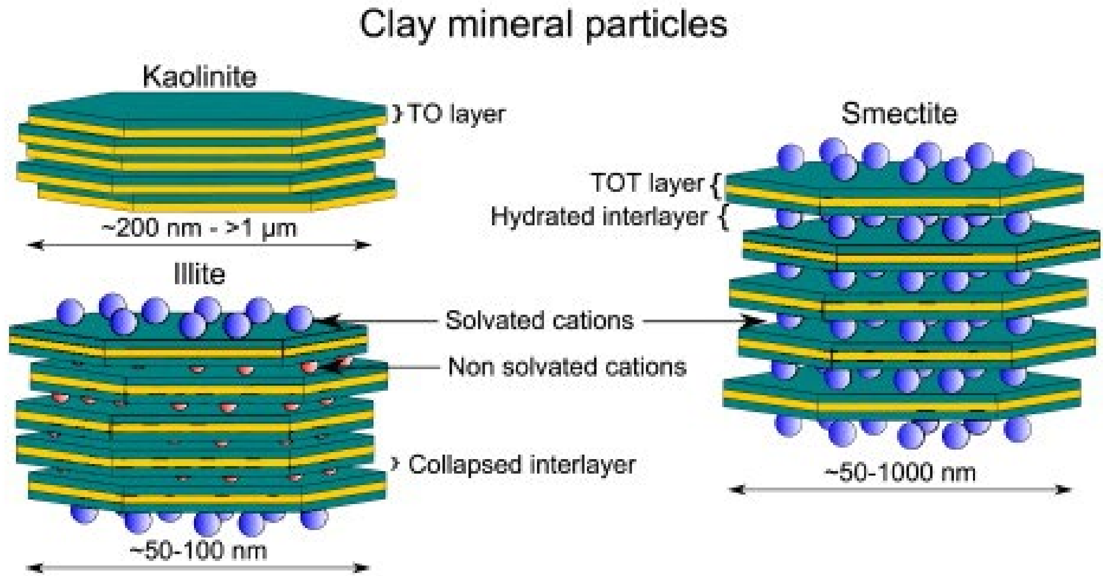
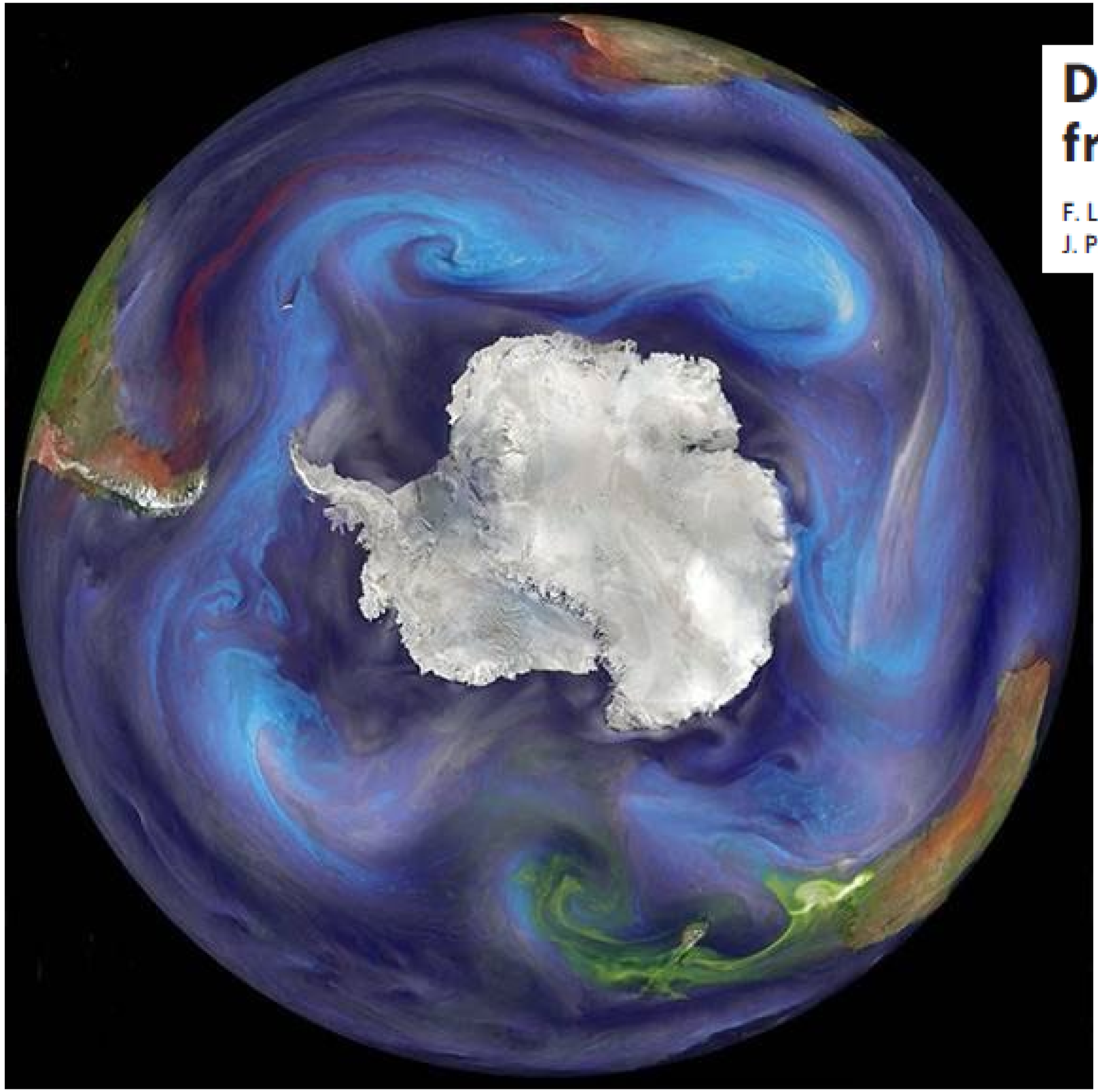
- Clays can be customized and amended to deliver elements to the sea-surface (e.g., Si, Al, Fe, Mn, P,..)
- Clays can help recruit the microbial circuit and the biological pump to remove atmospheric CO2
- Depth of remineralization is expected to increase

Natural dust circulating in the atmosphere is mainly made of clay minerals derived from soils



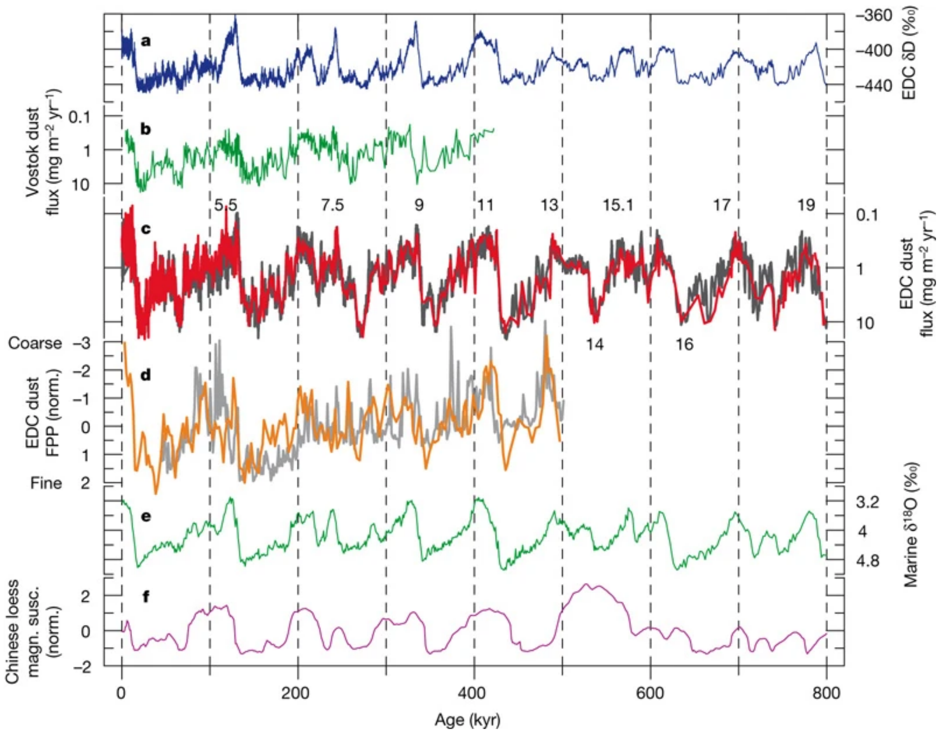


Ito & Wagai (2017) Nature



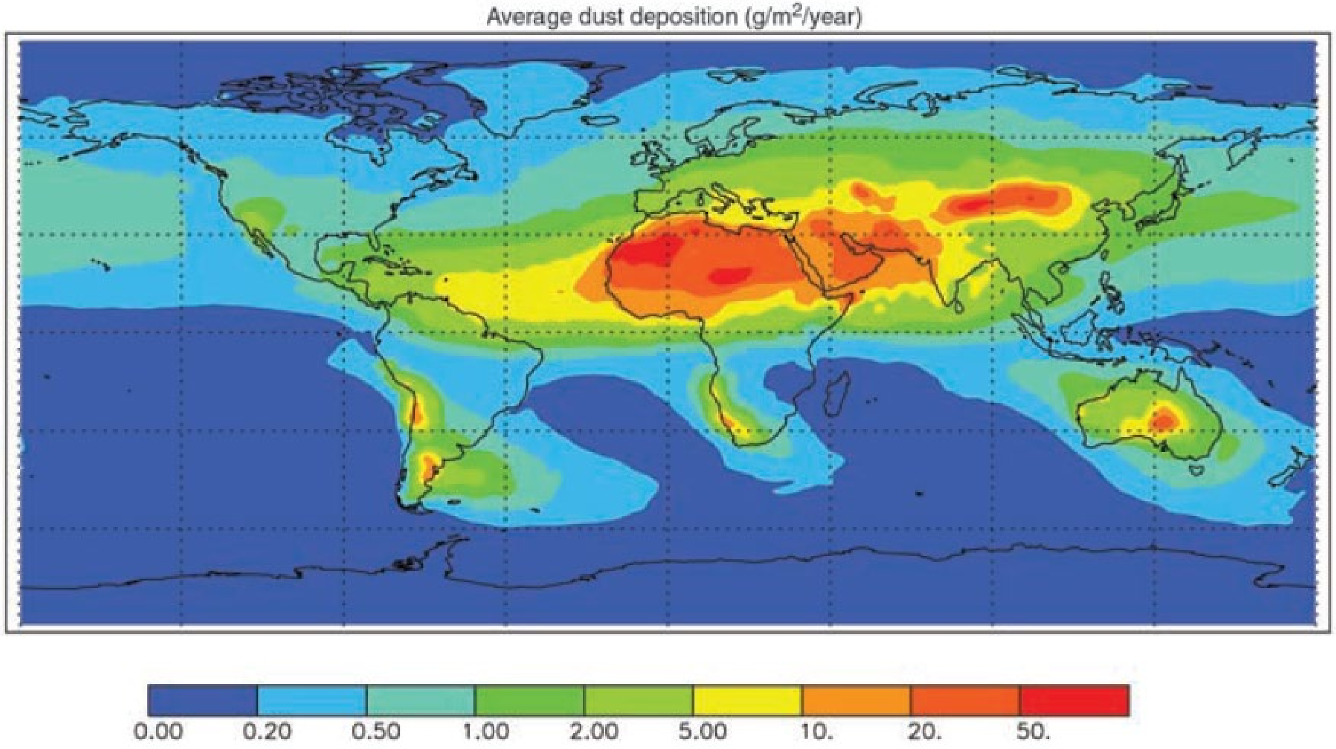
Dust–climate couplings over the past 800,000 years from the EPICA Dome C ice core

F. Lambert[1,2], B. Delmonte[3], J. R. Petit[4], M. Bigler[1,5], P. R. Kaufmann[1,2], M. A. Hutterli[6], T. F. Stocker[1,2], U. Ruth[7], J. P. Steffensen[5] & V. Maggi[3]

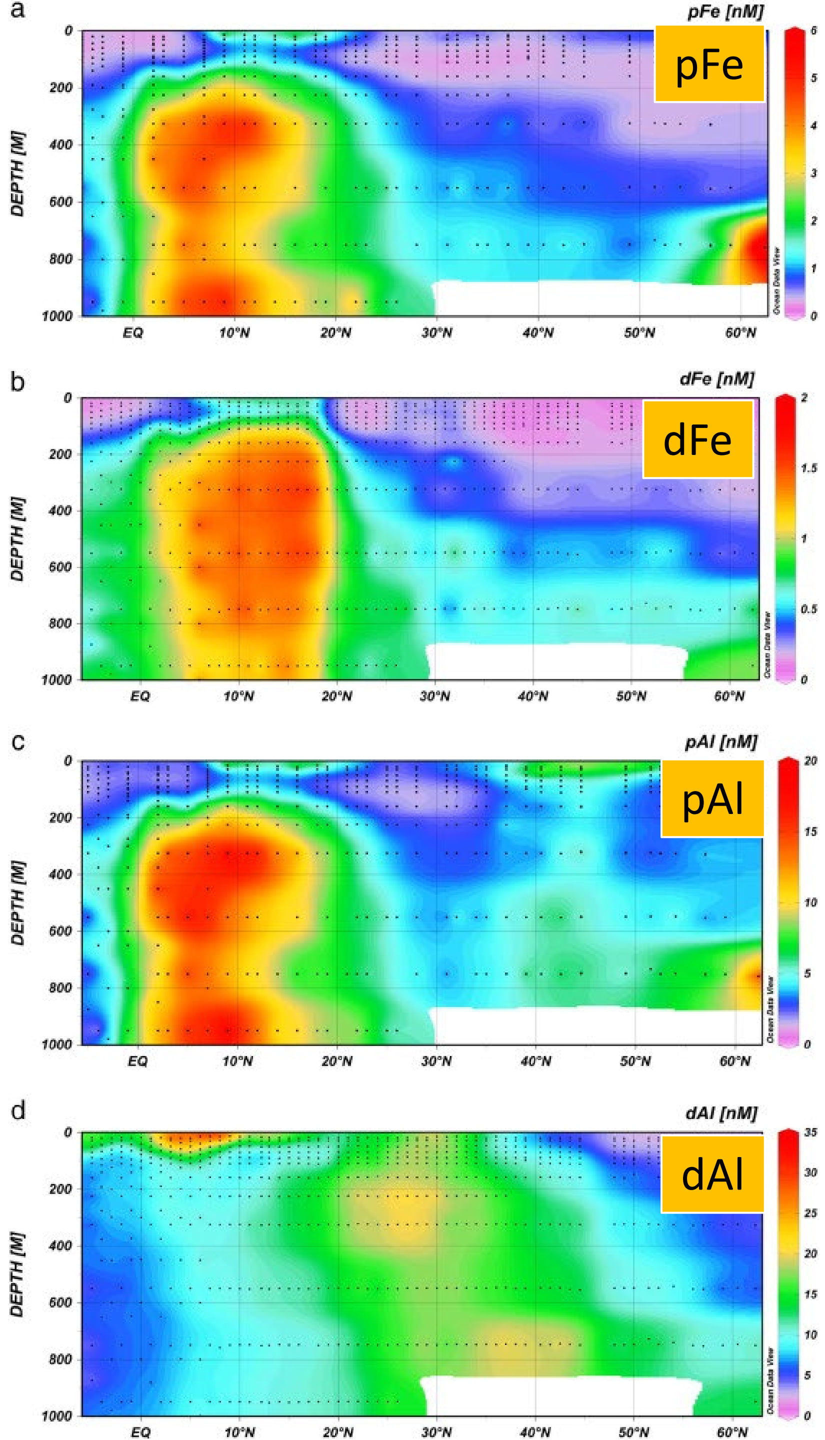


Transport of dust (red) from southern South America eastward over the Subantarctic Atlantic Ocean on Dec. 30, 2006. (William Putnam and Arlindo da Silva, NASA/Goddard Space Flight Center.

- 25-fold increase in glacial dust flux over all eight glacial periods
- strengthening of South American dust sources, plus a longer lifetime for atmospheric dust particles in the upper troposphere resulting from a reduced hydrological cycle during the ice ages.



Jickells et al. (2005) Science



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Barrett et al. (2012)

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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*]

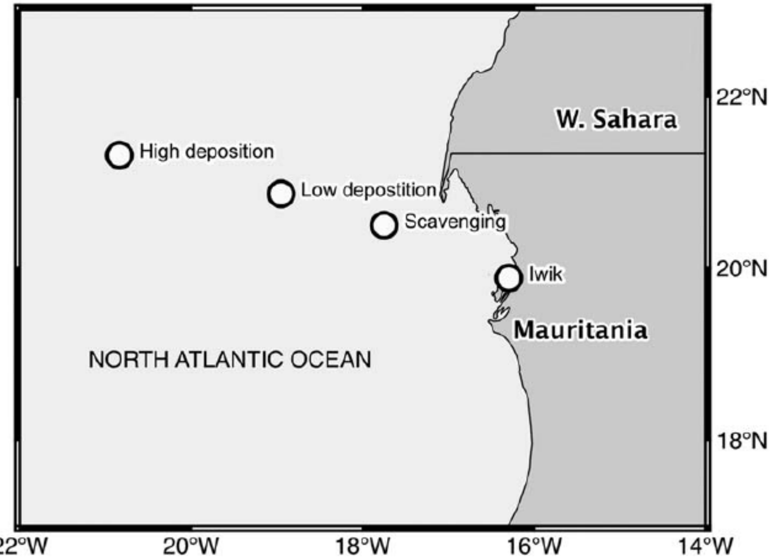
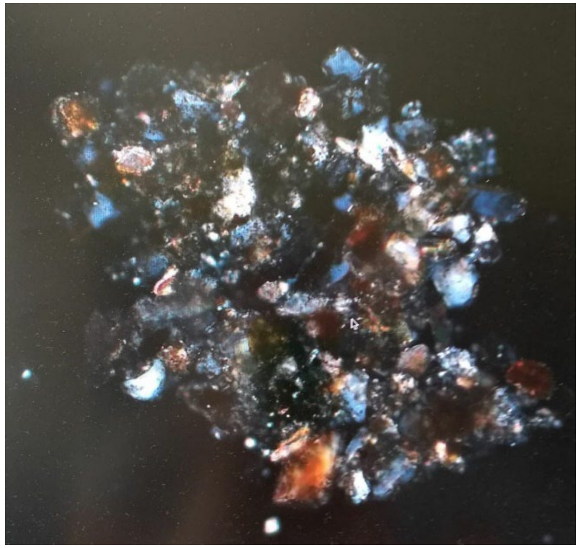


Table 1. Equivalent spherical diameter (ESD), number of formed aggregates per liter, total aggregated volume and sinking velocity for the high deposition, low deposition and scavenging experiments. Average ± SD.

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



Saharan dust particles "glued together" in marine snow. Total width of snow particle: 800µm.
Image credits: Helga van der Jagt, AWI / MARUM, Germany

https://www.nioz.nl/en/blog/dust/ballasting-potential-of-saharan-dust

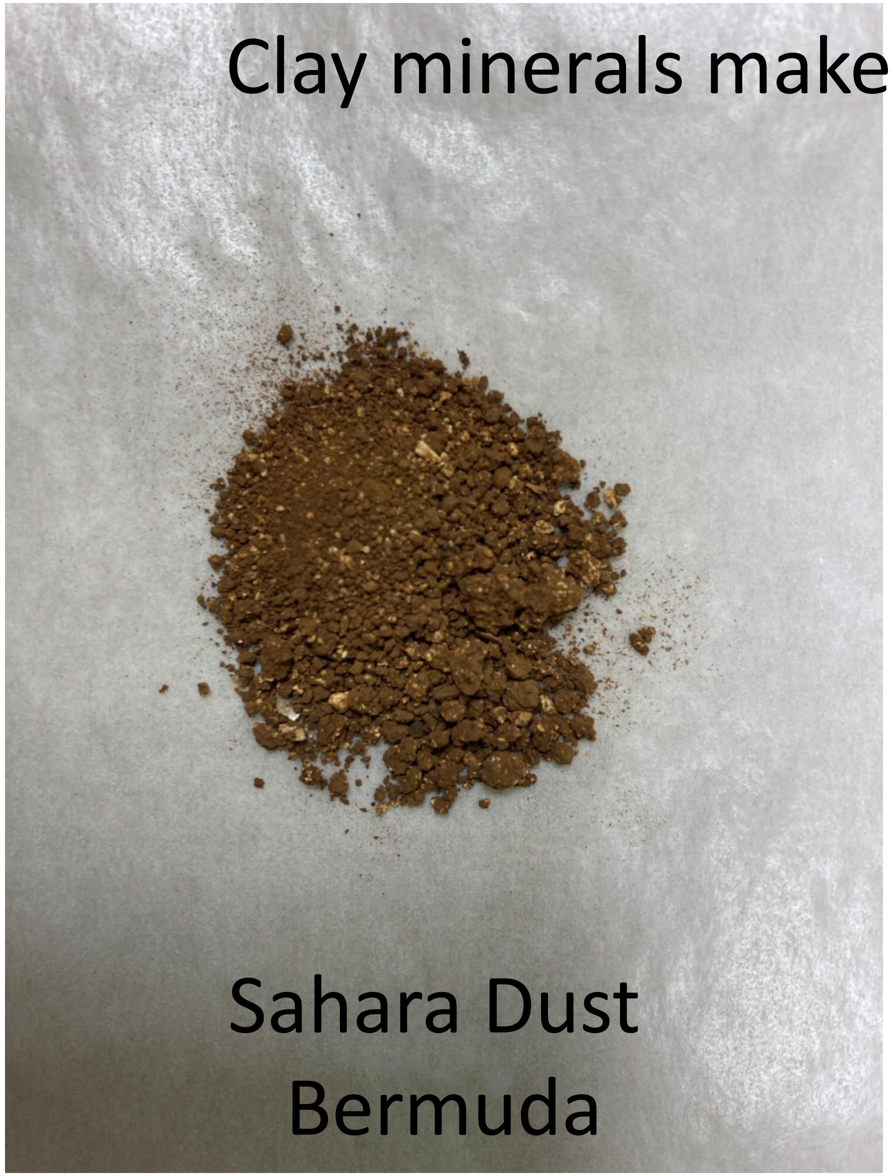
nature geoscience ARTICLES
PUBLISHED ONLINE: 27 FEBRUARY 2017 | DOI: 10.1038/NGEO2899

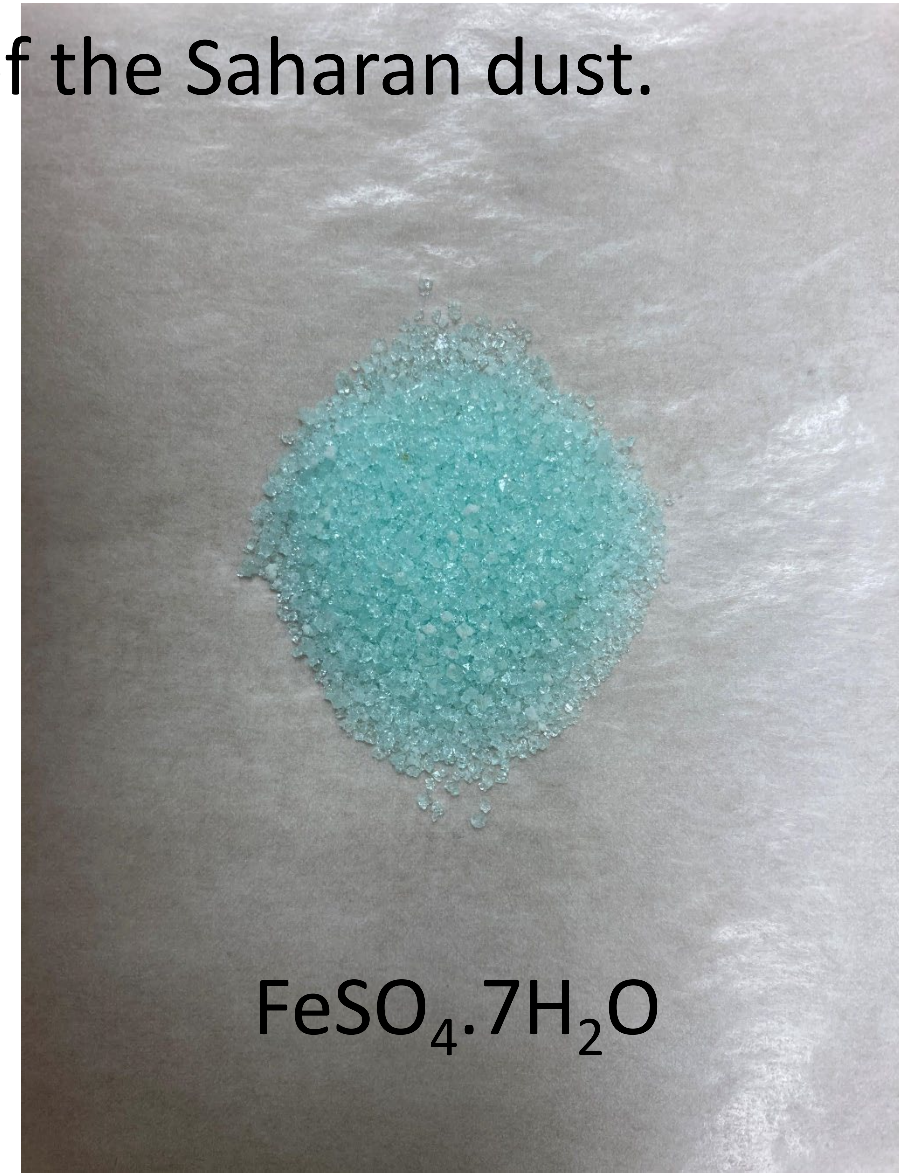
Carbon sequestration in the deep Atlantic enhanced by Saharan dust

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

Clay minerals make ~80% of the Saharan dust.





Iron Fertilization experiments

Direct addition of Fe(II) → oxidation to Fe(III) in a few minutes → FeL + ferrihydrite colloids

Fe : Biological Pump :: $: Economy

Addition of Fe overheats the biological pump.

Bounce in productivity

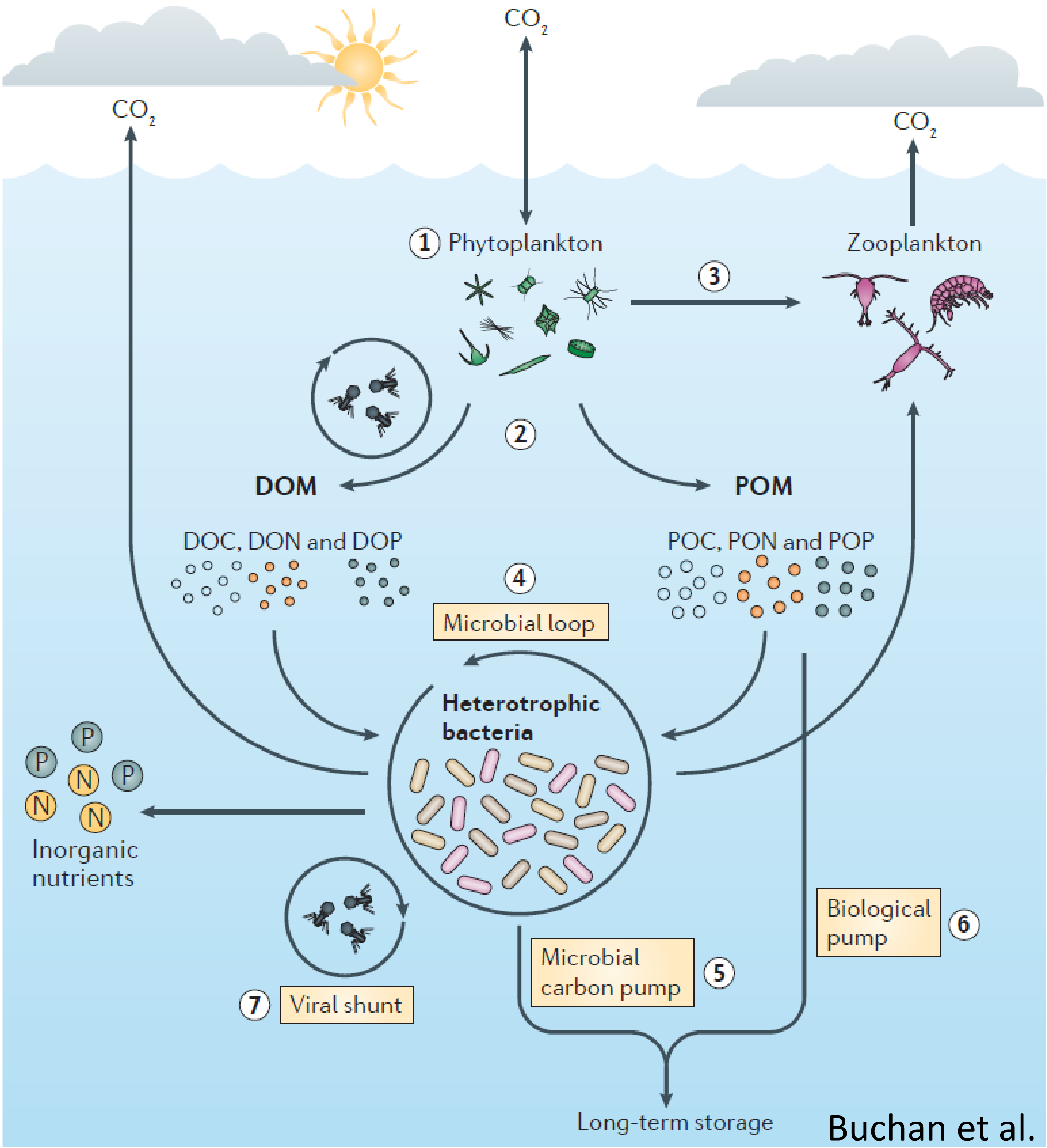
→ Changes in community structure

Phosphate depletion→ (*Pseudonitzschia* proliferation)→domoic acid

→ Extensive POC remineralization between 100m and 200 m

➔ Slow release of bioavailable Fe (and other nutrients) accompanied by ballasting of carbon

➔ can be accomplished by clay minerals



Buchan et al. (2017) Nat Microbiol

Marine biological pump produces

- **25 Pg of atmospheric C yr^{-1} as DOM.**
- **5-12 Pg of atmospheric C yr^{-1} as POM**

More than 90% DOM and POC is oxidized back to CO_2 in the upper 1000m.

Increasing the depth where sinking particles are respired back to CO_2 would result in increased ocean carbon sequestration (Kwon et al., 2009 Nature)

Conversion of DOM to POM can be accomplished using clay minerals that also improve POM transport efficiency

Ballasting

$$Velocity = \frac{2}{9} \cdot \frac{g}{\mu} \cdot r^2 (\Delta\rho)$$

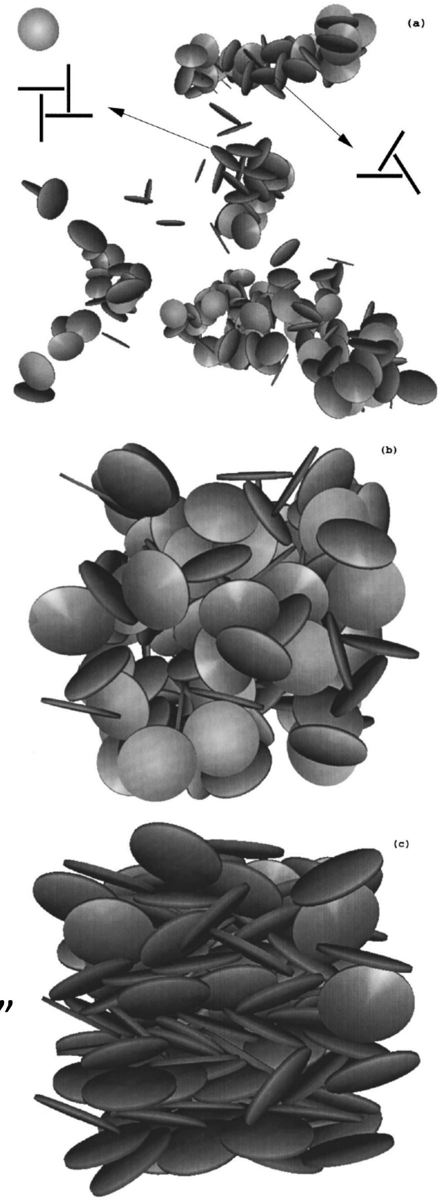
Increase in density → sinking velocity
Aggregation & increase in size → increase in sinking velocity
Protection of organic matter by clay minerals

Armstrong, 2002; Francois et al., 2002; Klass and Archer, 2002; and many other subsequent publications.

Creation of a clay mineral–DOM polymer nanocomposite drives the DOM→POM reaction forward!!

Sol

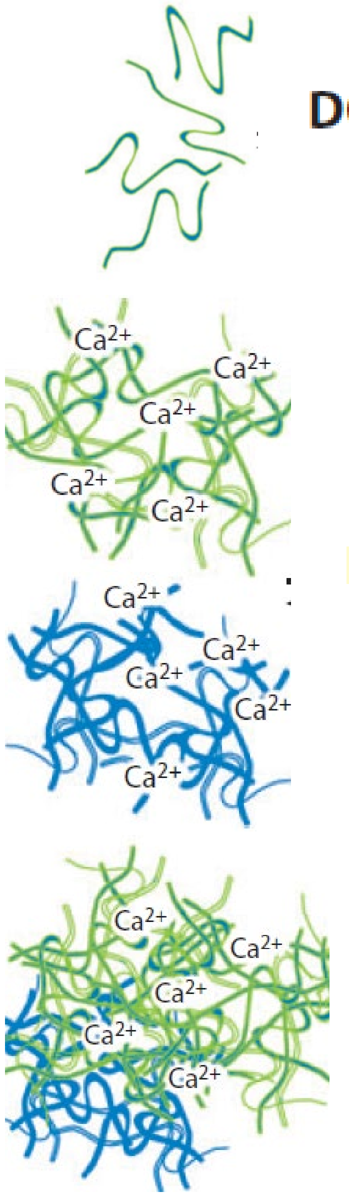
Nano-clay



"House of cards"

Gel

Dijkstra et al. (1997) Phys. Rev.



DOC polymers

Nanogels

Microgels

Verdugo (2012) Ann. Rev.

Stay tuned..there is more come!