The multiple roles of dust in ocean biogeochemistry

Christoph Völker

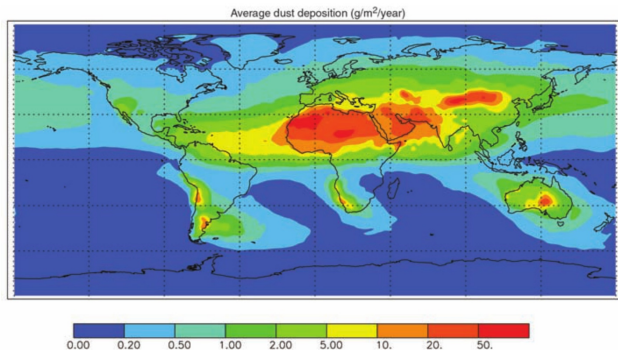Alfred Wegener Institut für Polar- und Meeresforschung

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AWI

DUST AS NUTRIENT INPUT

Average dust deposition (g/m²/year)


| 0.00 | 0.20 | 0.50 | 1.00 | 2.00 | 5.00 | 10. | 20. | 50. |

(Jickells et al., 2005)

- dust deposition brings in N (largely anthropogenic), P (lithogenic), Fe (lithogenic, combustion aerosols), other trace elements
- globally, the input is minor compared to internal recycling for elements with long residence time, such as N and P
- for elements with short residence time, such as Fe, it is important

IRON IS PARTICLE REACTIVE
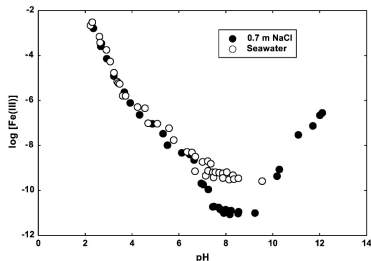
(Liu and Millero, 2002)
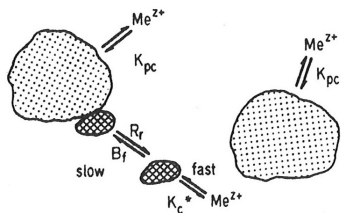

(Honeyman and Santschi, 1989)

iron in oxic seawater is mostly Fe(III)

solubility of inorganic Fe(III) is extremely low:
< 0.1 nmol kg^{-1} at typical ocean pH

$\rightarrow$ iron is lost much faster from the ocean than nitrogen or phosphorus

loss proceeds via *scavenging* on particle surfaces, accelerated by aggregation of small colloids

DUST AND IRON
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DUST IN THE ATLANTIC
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EFFECT ON dFe
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CONCLUSIONS
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CONSEQUENCE OF THE SHORT RESIDENCE TIME OF FE
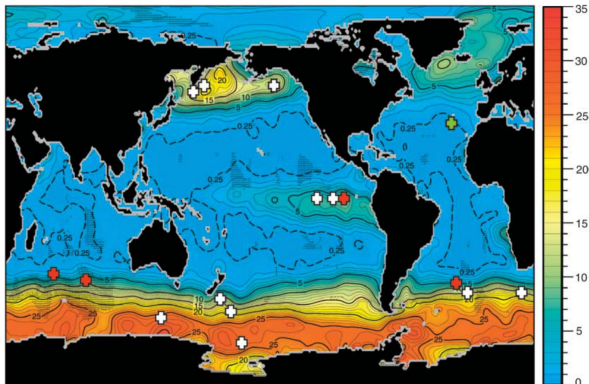
(Boyd et al., 2007)

• High-Nutrient-Low-Chlorophyll regions: despite enough nitrate and phosphate little net primary production
• what is missing is iron; crosses mark *iron fertilization* studies

FE-BINDING LIGANDS AS NATURES REMEDY

**Phaeophytin
(porphyrin)**

**Desferrioxamine
(hydroxamate)**
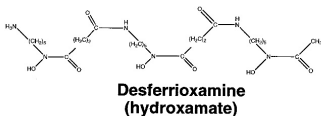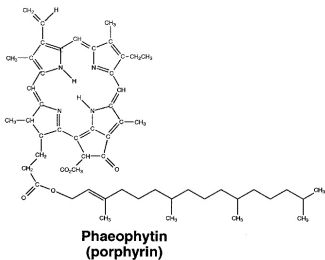
Witter et al., 2000

- typically, ≫90% of dissolved Fe is bound to organic ligands
- binding of iron to organics prevents rapid scavenging
- two main types of ligands: degradation products, such as porphyrins, and siderophores, produced by bacteria under iron stress
- production / degradation pathways probably as varied as ligand origins

# ATMOSPHERIC AND OCEANIC CONTROLS OF DUST INPUT
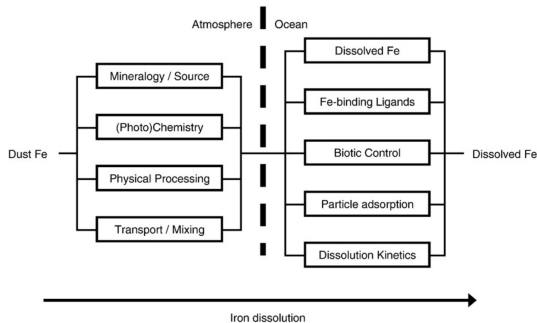
conceptual model for processes affecting solubility of dust-deposited iron (Baker and Croot, 2010)

Fraction of Fe in dust that dissolves varies from 0.1% to >10 %
Which processes in atmosphere/ocean determine this?

$\rightarrow$ some process understanding, but more need for exchange between atmospheric/oceanic communities!

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DUST IN THE ATLANTIC
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EFFECT ON DFE
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CONCLUSIONS
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OTHER SOURCES OF IRON
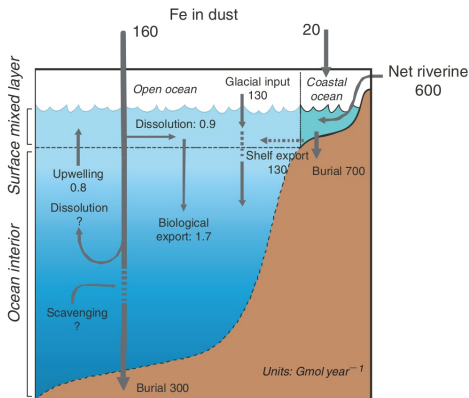
(Hunter, 2007)

besides lithogenic dust, there are also other sources of iron:
• rivers
• sediment diagenesis
• hydrothermalism
• cosmic dust . . .

but for all of them, most of the iron is lost as particles close to the source.

quantification of different iron sources is ongoing, large uncertainties so far!

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TROPICAL ATLANTIC: DOMINATED BY DUST
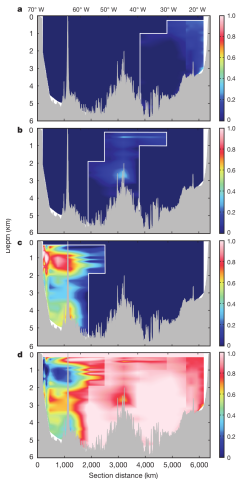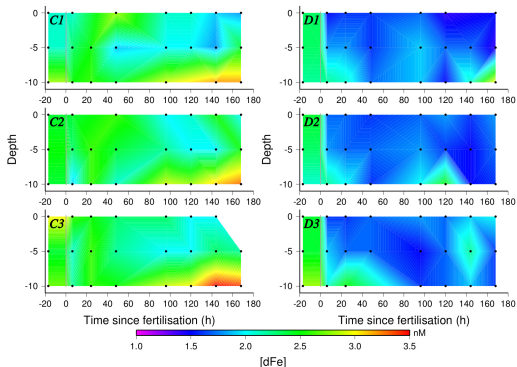

(Conway et al, 2014)

relative role of the different iron sources along a section across the subtropical/tropical Atlantic estimated from isotopic composition of dissolved iron

• sediment diagenesis
• hydrothermalism
• suspended sediment particles
• saharan dust

$\rightarrow$ in the tropical and subtropical Atlantic, dust dominates as source of iron
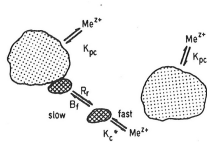
BUT: DUST ALSO SCAVENGES DISSOLVED IRON

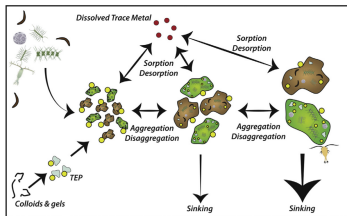colloidal pumping
mechanism (Honeyman
& Santschi 1989)

dissolved iron decreases after dust addition in mesocosms;
dust can act as dFe sink (Wagener et al. 2010)

is that important in the open Atlantic, where often biogenic particles
dominate?
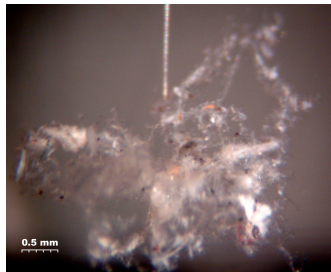needs understanding & modelling of particle dynamics!

PARTICLE DYNAMICS

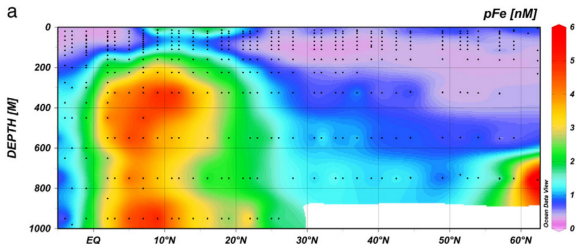

aggregation processes (Jackson and Burd 2015)

typical marine aggregate (Iversen, pers. comm.)

- dust brings in mostly micrometer-sized particles
- these hardly sink on their own
- sinking dominated by larger, mixed organic/inorganic aggregates

LITHOGENIC MATERIAL IN THE ATLANTIC

particulate Fe along section A16N (Barrett et al. 2012)

much new information on lithogenic particles from A16N and US
Geotraces Atlantic Zonal Transect (Barrett at al. 2012, 2015, Lam et al.
2015, Ohnemus et al. 2015)

• increased pFe under dust plume
• high pFe at the surface, mimimum around 100m depth, then again increase
• deep lithogenic particle concentration dominated by small particles
• large fraction of lithogenics highest around 100 m depth, higher towards African
coast

indicates dynamic aggregation / disaggregation cycle

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MODEL SETUP

global biogeochemical model REcoM including the iron cycle (Hauck et al. 2013, Völker and Tagliabue 2015)
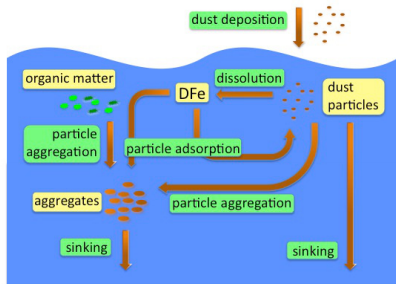
added model for lithogenic particles with two size classes (fine dust and faster-sinking aggregates)

quadratic aggregation and linear disaggregation of particles

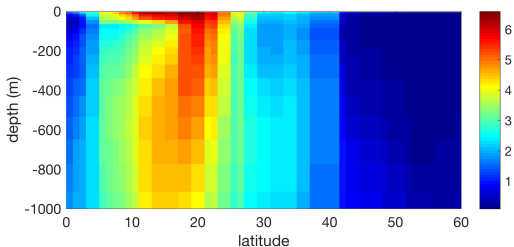lithogenic particles included as additional scavenging agents for dissolved iron

scavenging proportional to particle concentration

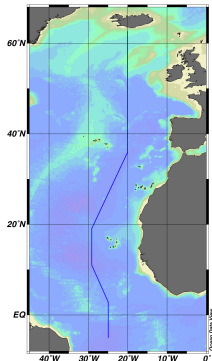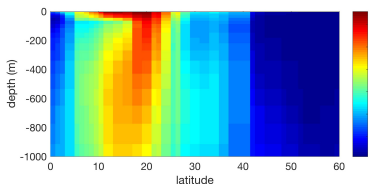rate equal for organic and lithogenic particles

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MODELLED VS. OBSERVED PARTICULATE FE
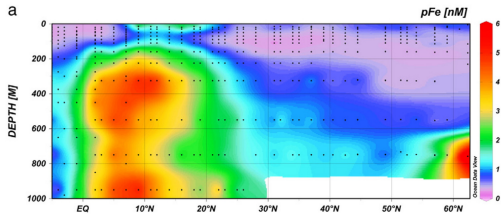
particulate Fe along section A16N (Barrett et al. 2012)

modelled particulate Fe (nM) along section A16N

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## MODELLED VS. OBSERVED PFE

modelled pFe (nM) along A16N
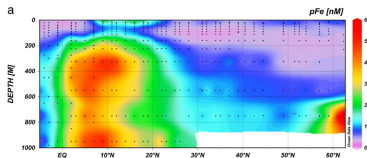
obs'd pFe along A16N (Barrett et al. 2012)

some agreement, but also some disagreement:
+ pFe concentration in the right order of magnitude
+ minimum in particle concentration around 100m depth
+ size-class distribution consistent with Ohnemus et al. (2015)
− surface pFe concentration somewhat high → aggregation rate?
− deep pFe maximum too deep → variable disaggregation?
− deep pFe maximum too far north → dust deposition?
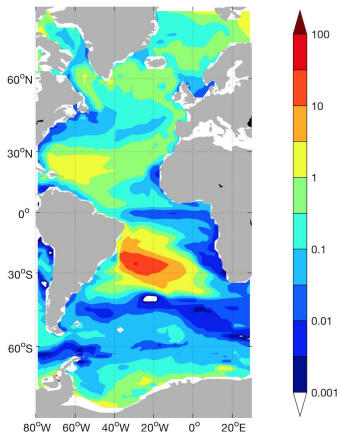− shelf-derived nepheloid layers absent

EFFECT ON DISSOLVED Fe
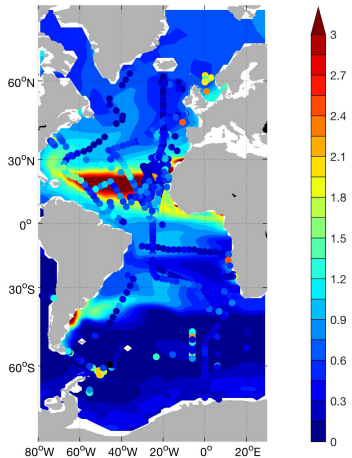
dFe with dust only as Fe source
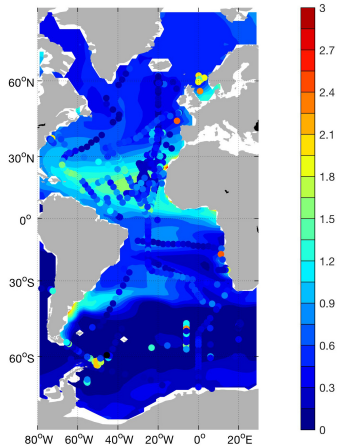
dFe with dust as Fe source and as additional scavenging

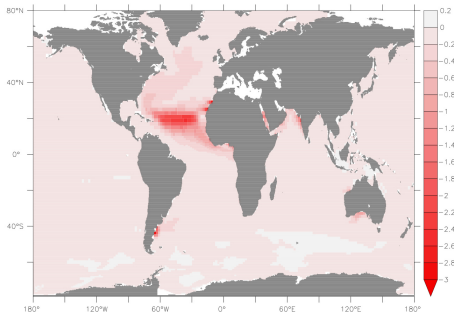# WHY THE REDUCTION? RESIDENCE TIME OF dFE

residence time (stock/total loss rate in years) of dissolved iron varies by several orders of magnitude

affected by scavenging on dust/biological particles and biological uptake

distribution of residence time agrees quite well with data-based estimates (Usher et al. 2013)

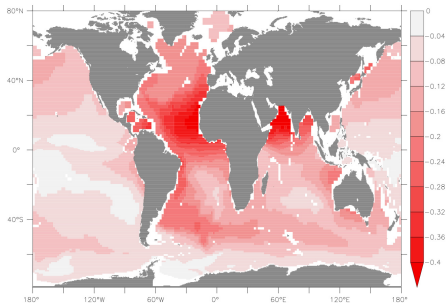# GLOBAL EFFECT AT SURFACE

surface dFe difference between a run with/without
lithogenic particles present as scavenging agent

scavenging by lithogenic
particles
• reduces surface dFe
directly in high-deposition
regions
• but hardly everywhere
else

GLOBAL EFFECT AT DEPTH

dFe difference (2000 m depth) between a run
with/without lithogenic particles

- dFe reduction more
widespread at depth
- 1st cause: lateral
transport of fine lithogenic
material
- 2nd cause: downstream
effect of localized
scavenging
- reduces deep water dFe
Atlantic – Pacific gradient

caveats: strength of effect depends on scavenging residence time, at
present highly tuned in ocean iron models (Tagliabue et al., 2016)
also affected by ligand excess (Völker and Tagliabue, 2015)

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SOME CONCLUSIONS

- dust is a major source for Fe to the ocean, especially far from land

- but relation is complicated: not only does solubility of Fe in dust vary, but dust can also scavenge iron

- lithogenic particles in the Atlantic modeled with a 2-size-class model

- both aggregation and disaggregation important, some main features of observed lithogenic particle distribution reproduced

- brings surface dFe distributions under the dust plume more in line with observations, global deep dFe distribution affected through lateral transport

- how does that affect our understanding of the role of dust in other climate states (e.g. glacial)?

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IS DUST A SOURCE OR A SINK OF DFE?
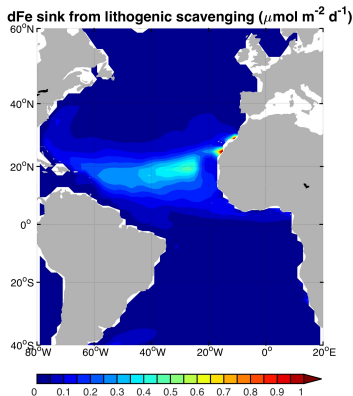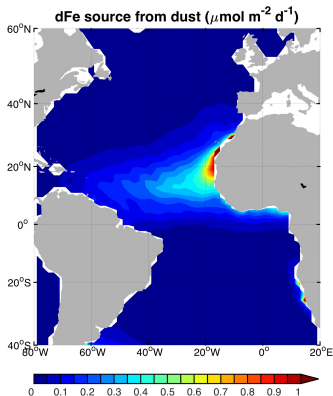
so: how much source, how much sink?
generally, dFe source stronger than vertically integrated sink; but depends somewhat where you look!