What can we learn from natural iron sources ?

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Thanks to the KEOPS and CROZEX teams

What can we learn from natural iron fertilization ?

NEWS

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Only mother nature knows how to fertilize the ocean

Web site Nature, Q. Schiermeier

?

Natural iron fertilization : what is it?

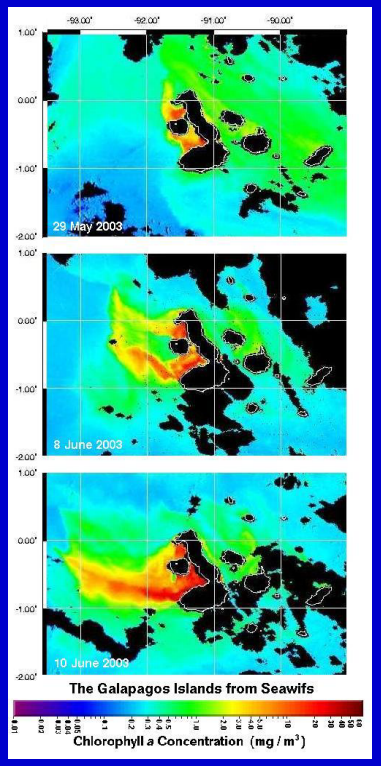
Two criteria :

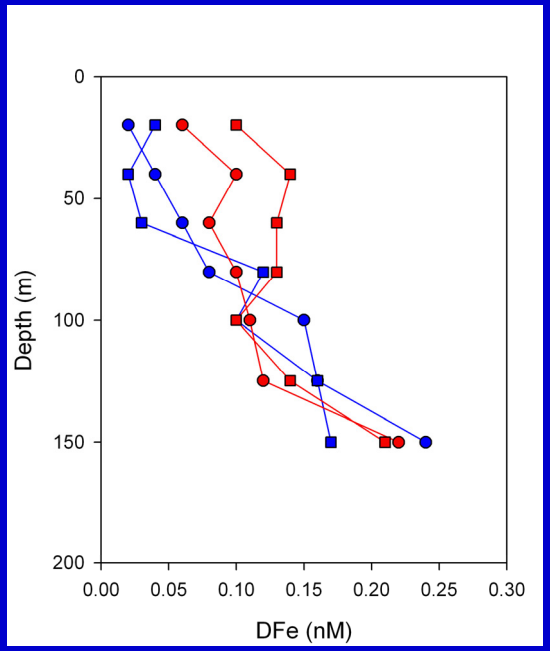
enhanced supply of iron (field data) and enhanced biological activity

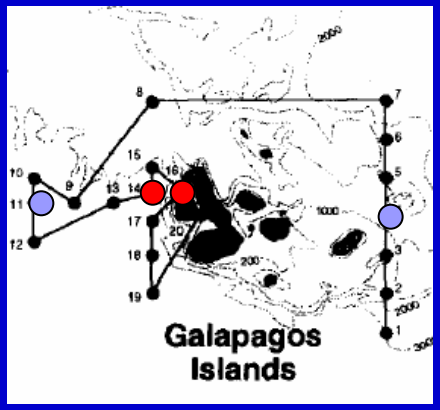
compared to the background of the region

Is natural iron fertilization a common process in the ocean ?

"….In conjunction with this research a study will be made of the HNLC water west of the Galapagos Islands. This area is of interest since it appears to represent a natural enrichment experiment."
Summary of the NSF proposal, J. Martin 1992.

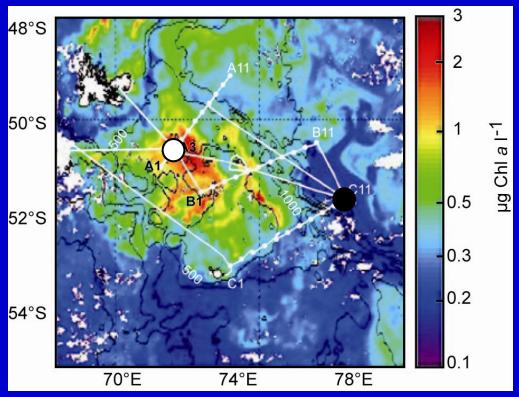




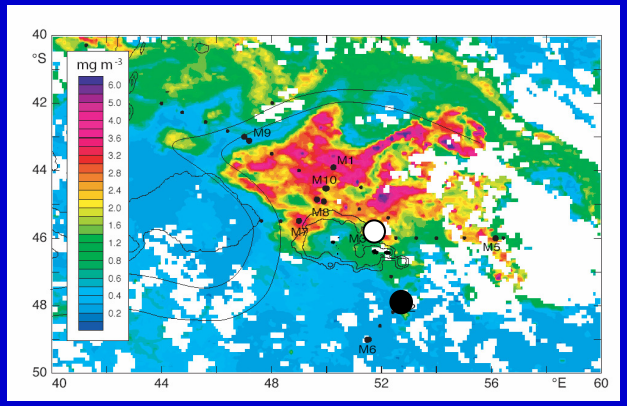


Gordon et al. 1998

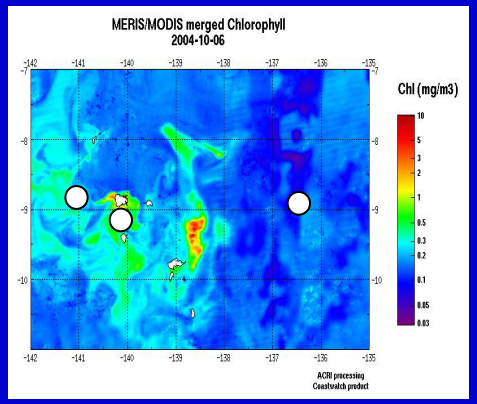
Kerguelen I.

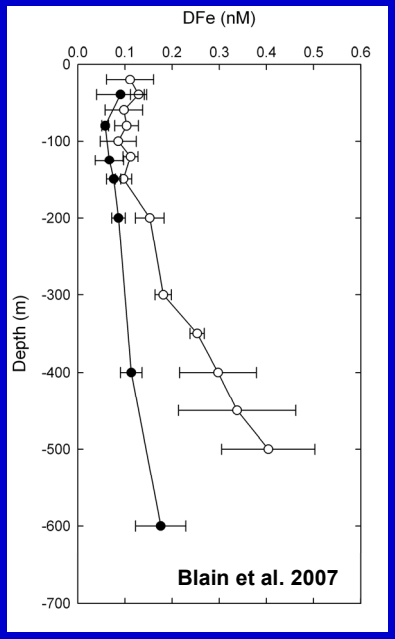


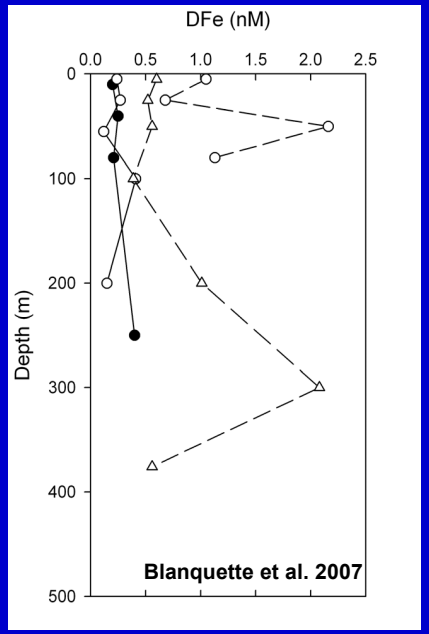
Crozet I.

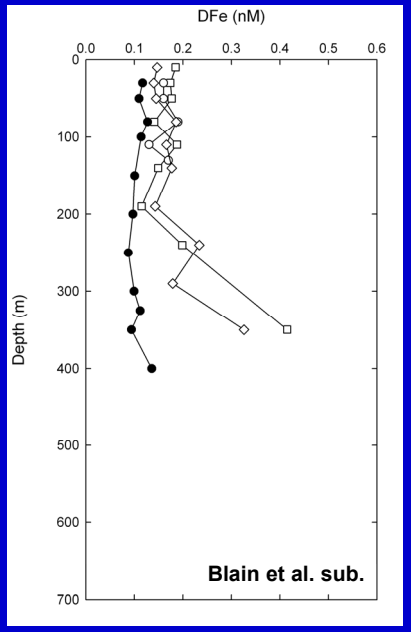


Marquesas I.

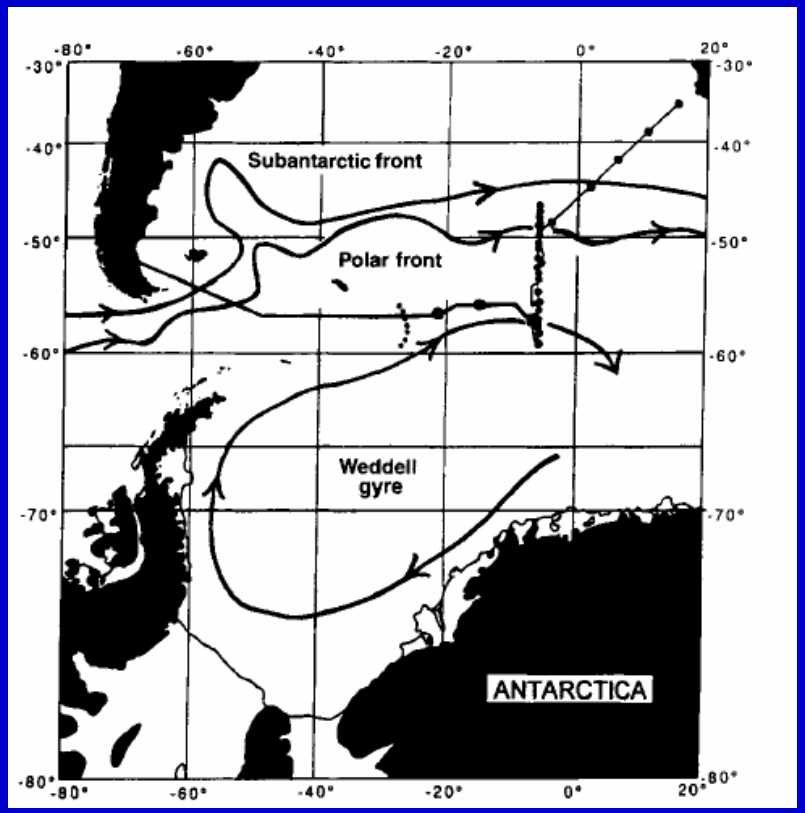


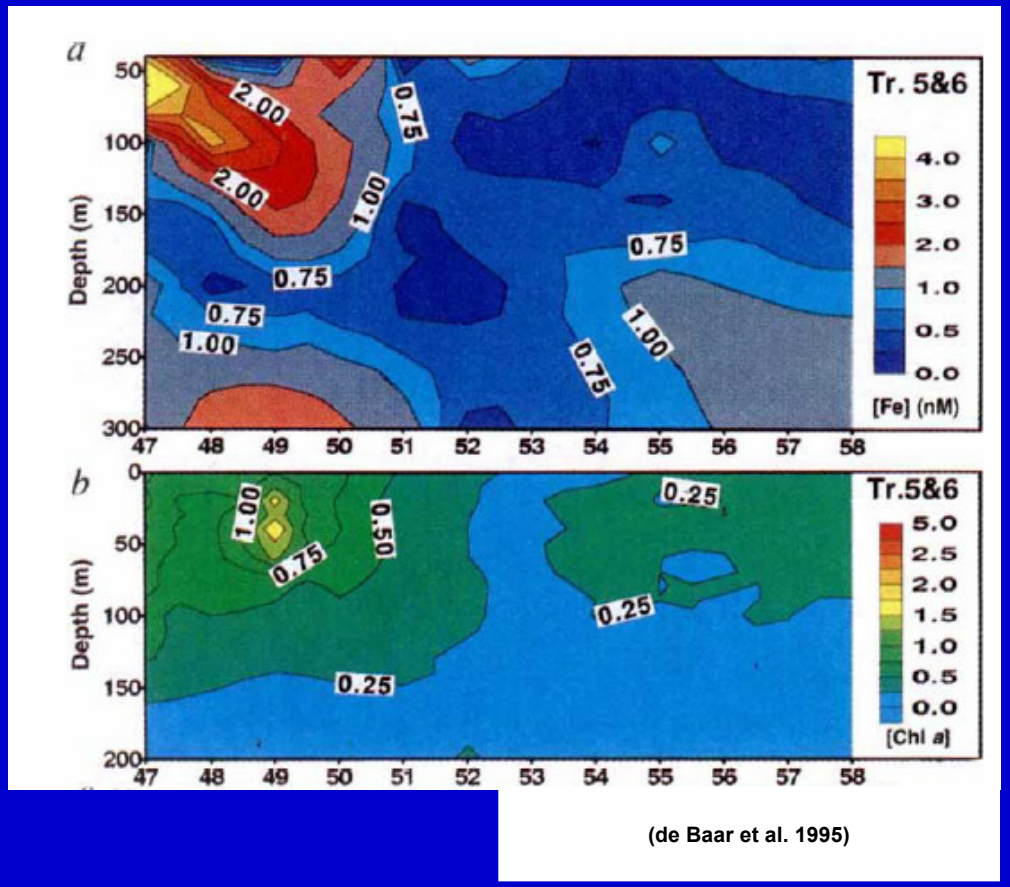






Polar Front in the Atlantic Southern Ocean

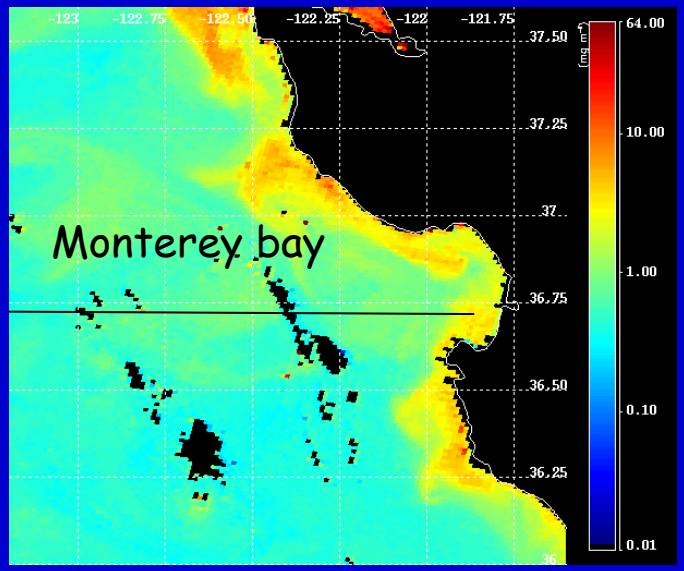


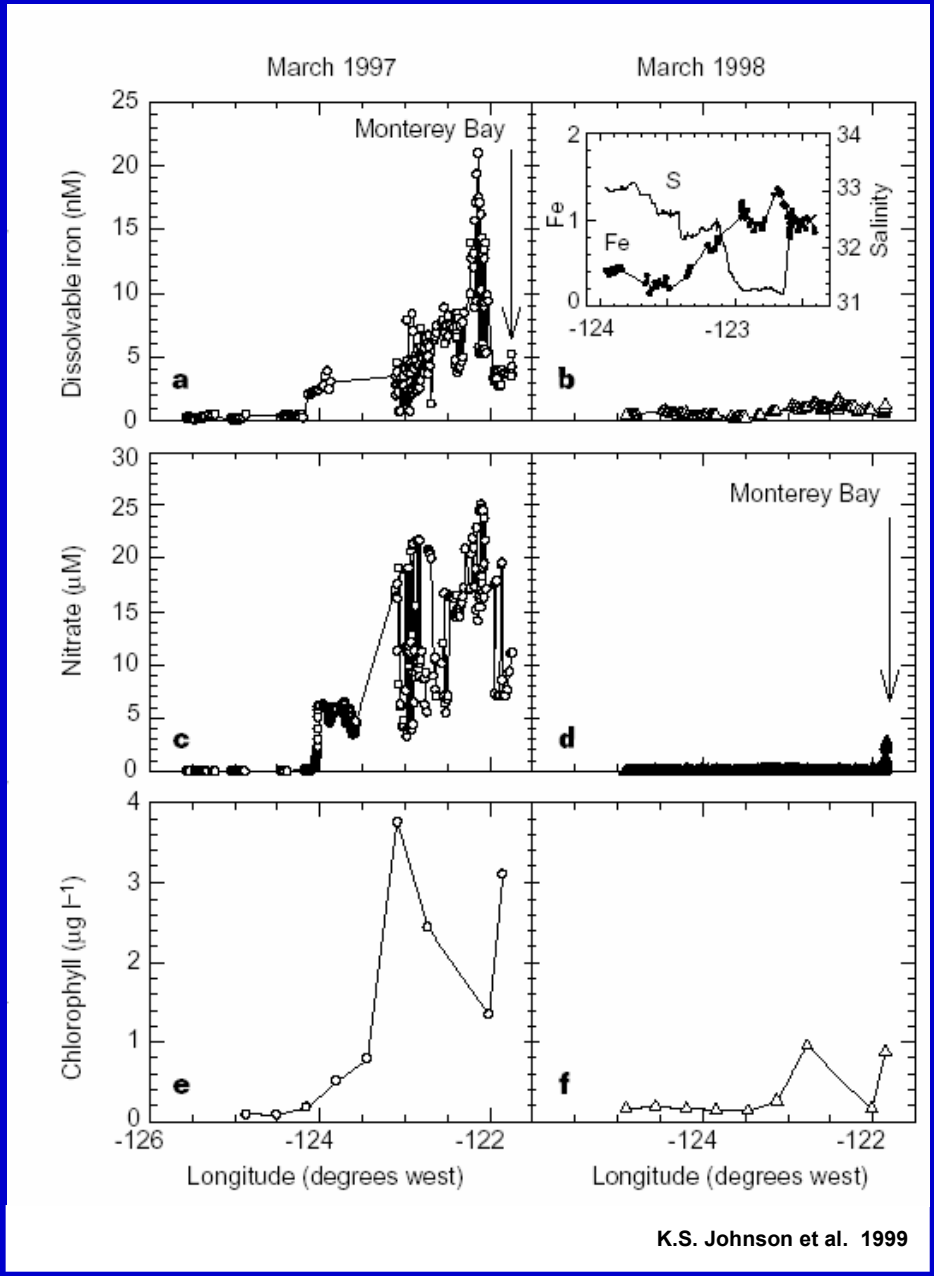


(de Baar et al. 1995)

Coastal upwelling

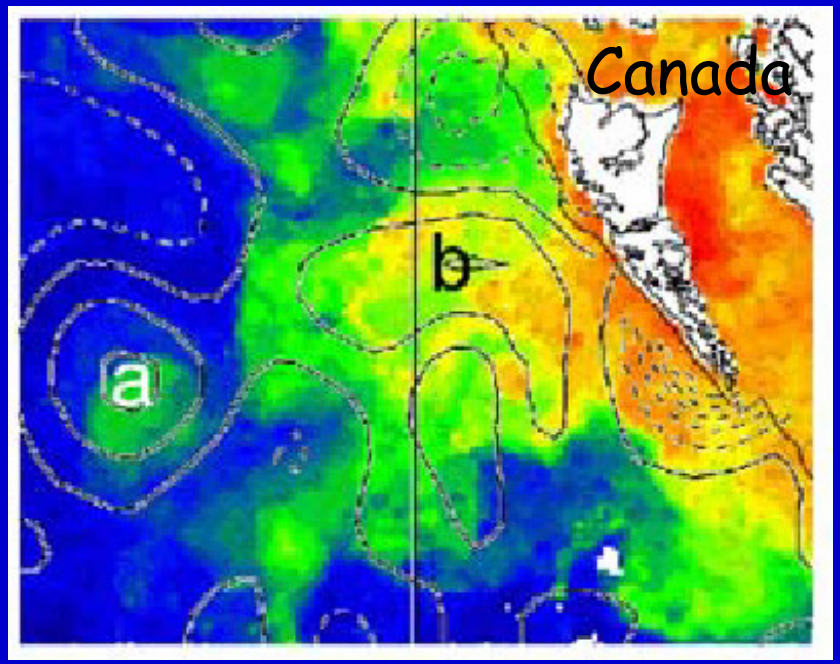
Californian upwelling

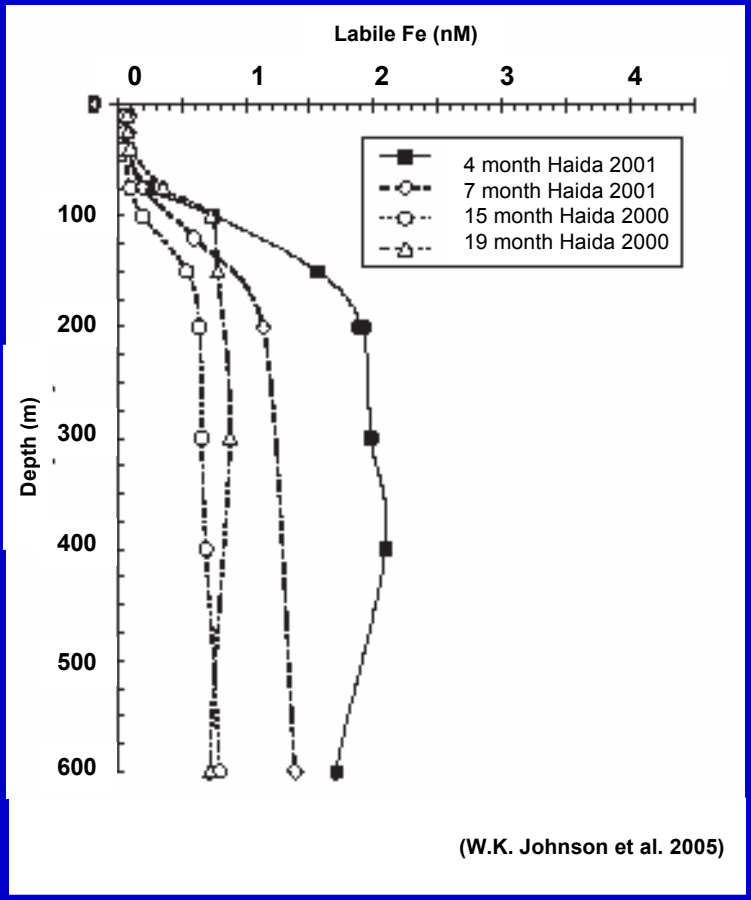




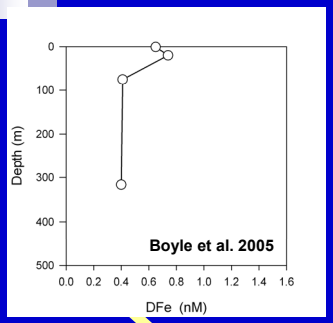
K.S. Johnson et al. 1999

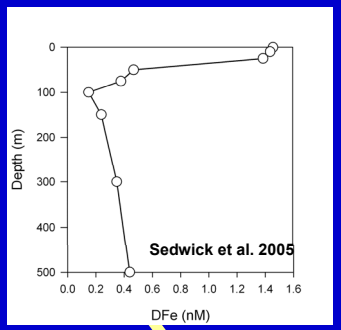
Anticyclonic mesoscale Haida eddies in the eastern North Pacific Ocean

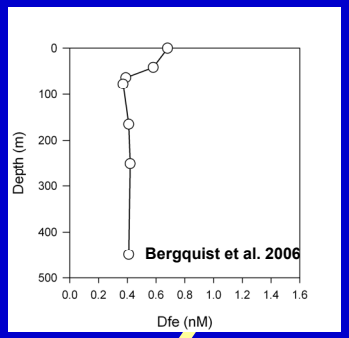


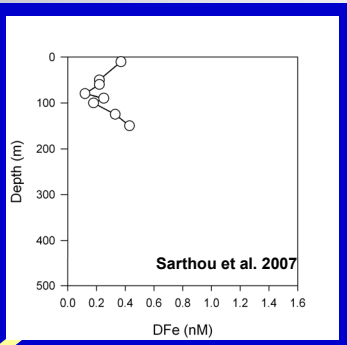


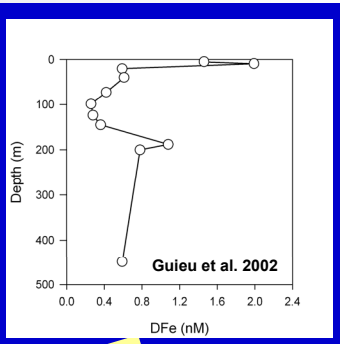
Oligotrophic gyres

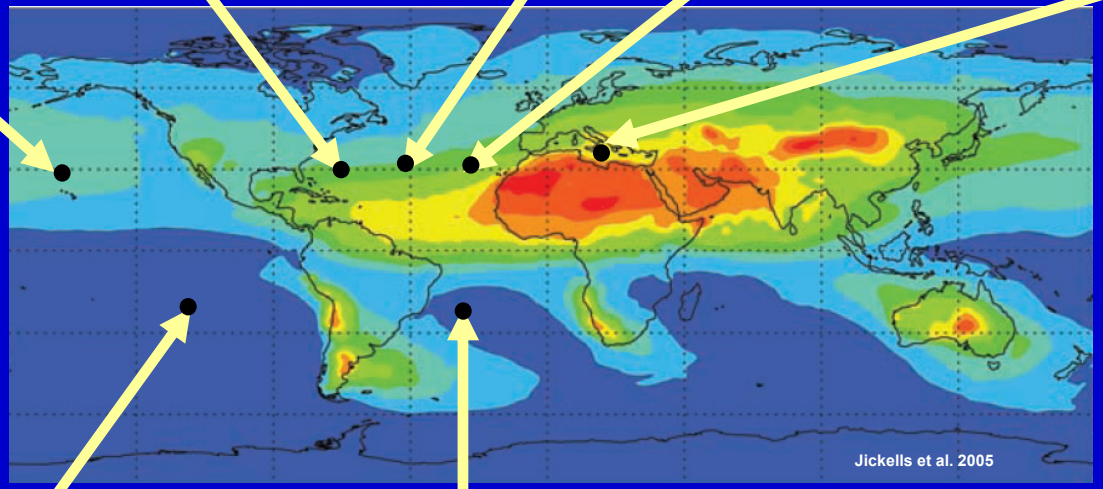


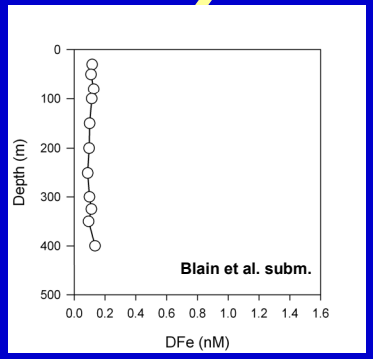


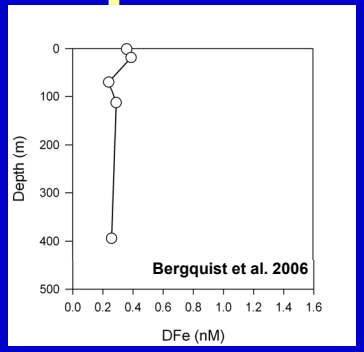




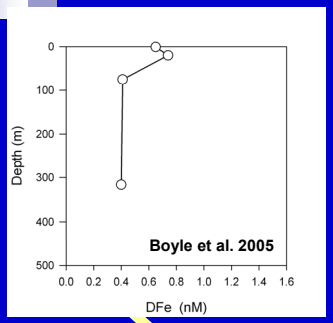


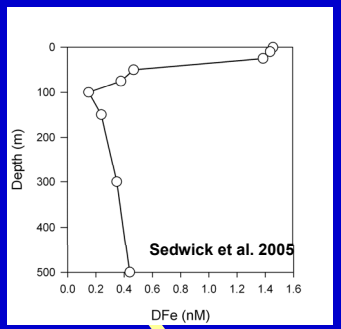


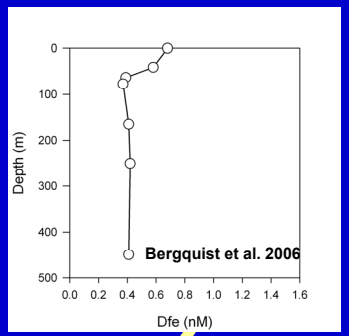


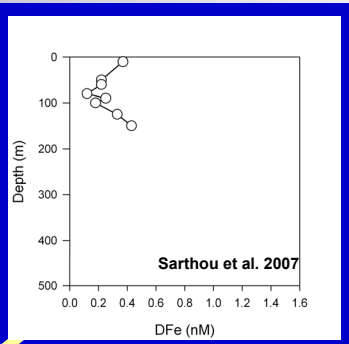


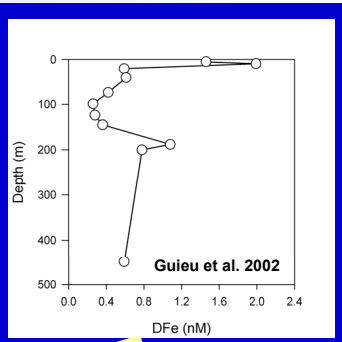
Oligotrophic gyres

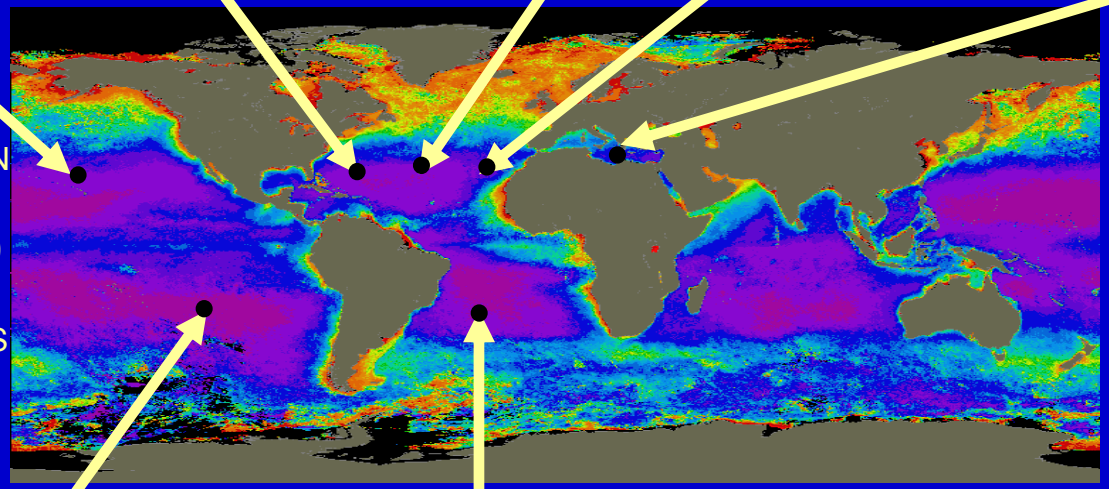


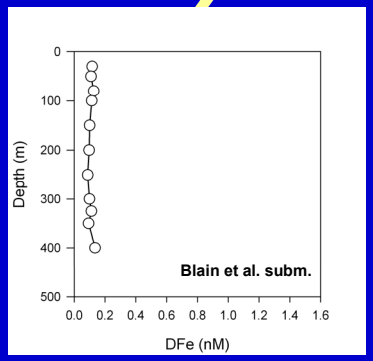


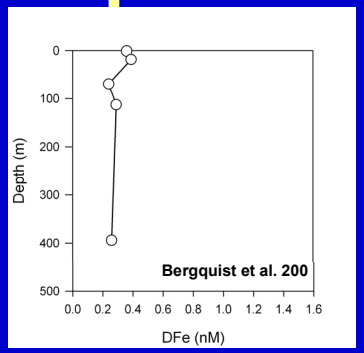




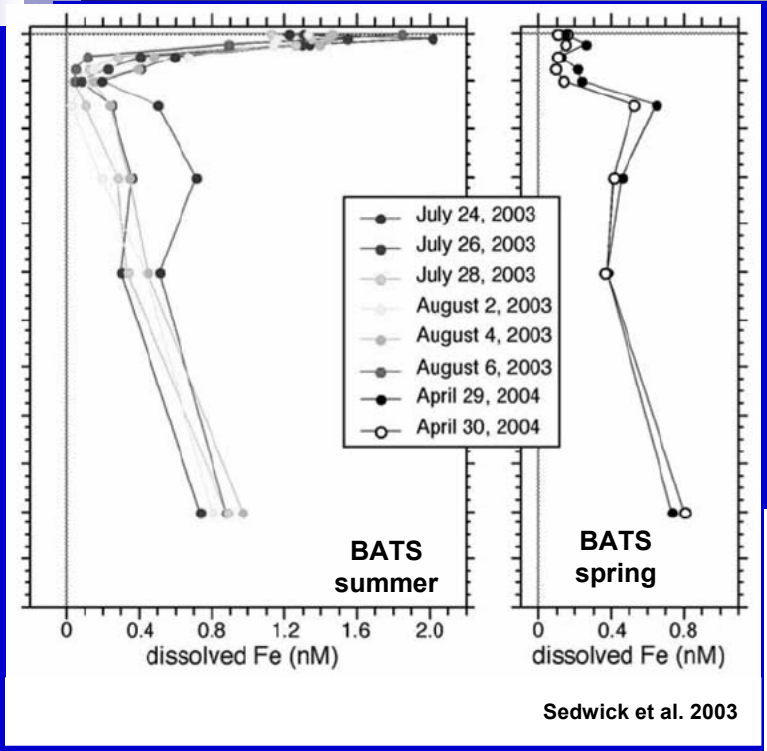




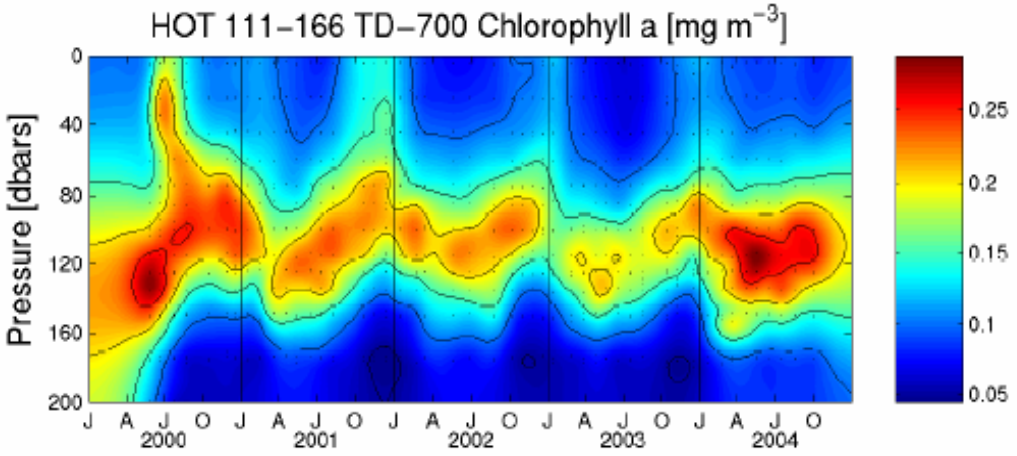




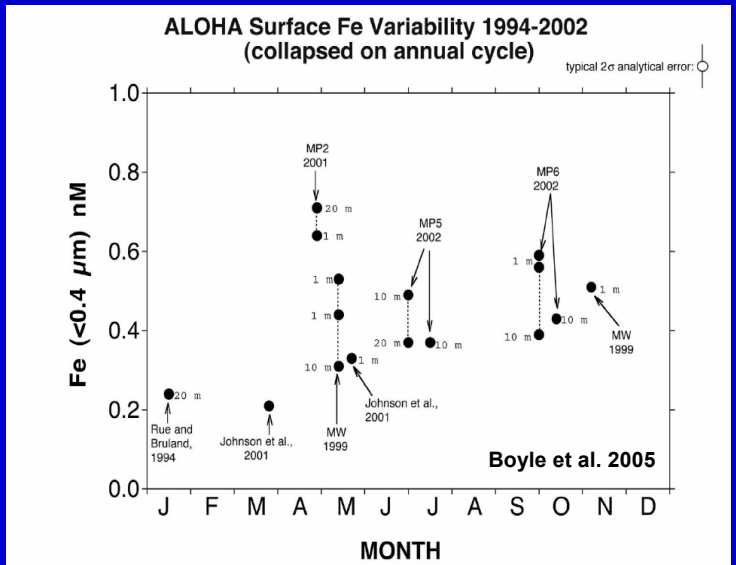
Oligotrophic gyres



Sedwick et al. 2003

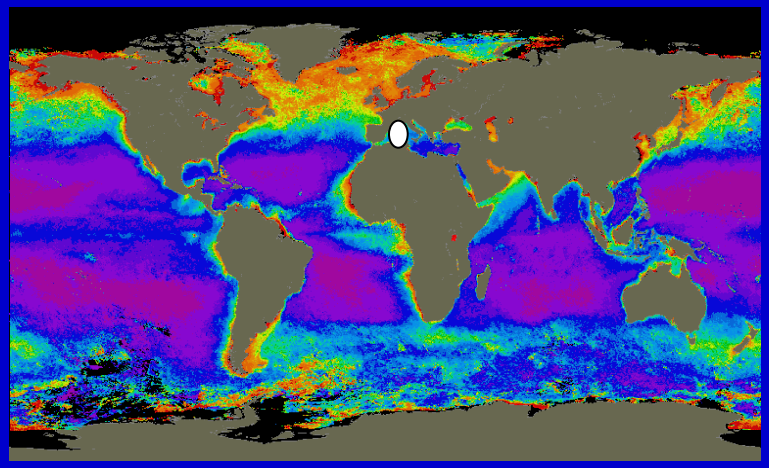


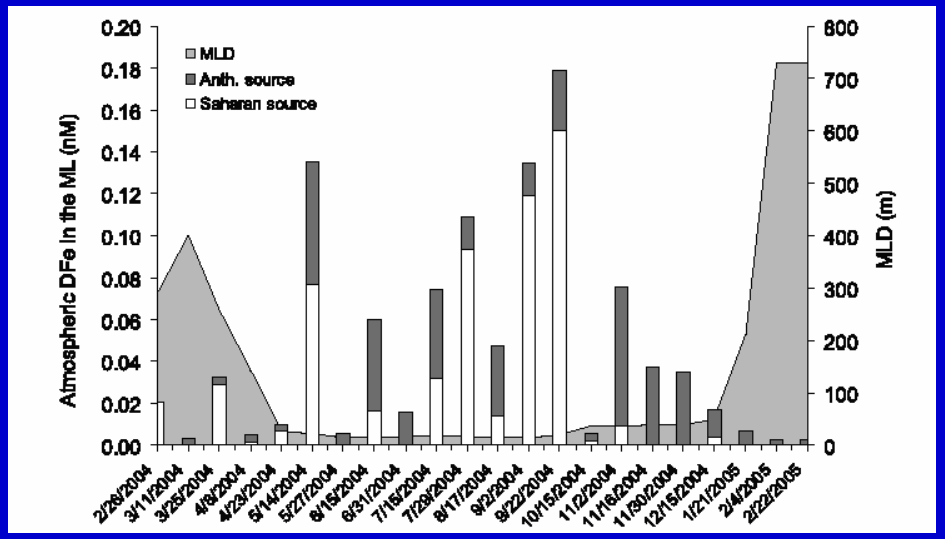
Annual report 2004

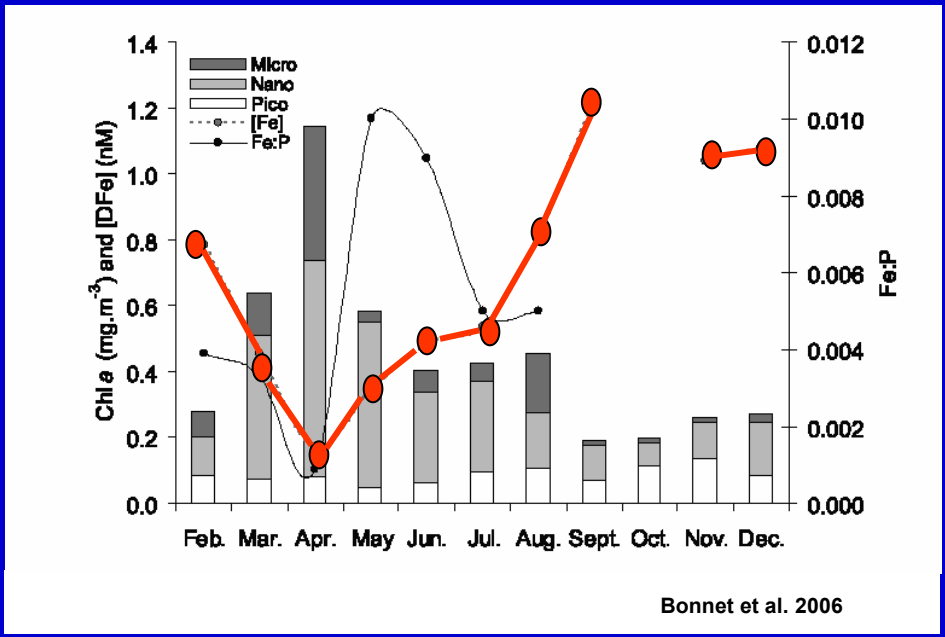


Oligotrophic gyres

At DYFAMED site
(Med. Sea between Nice and corsica)

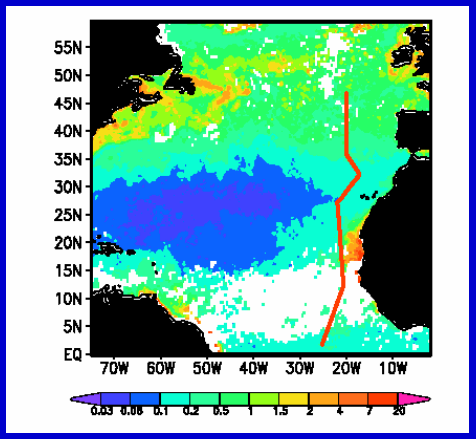


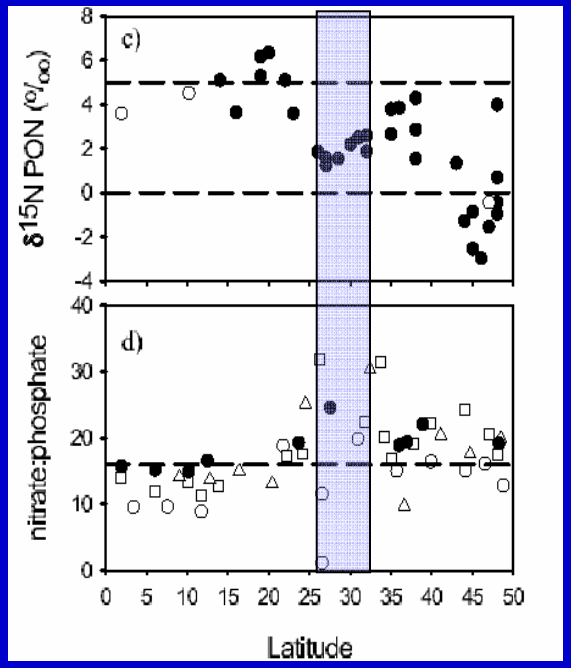


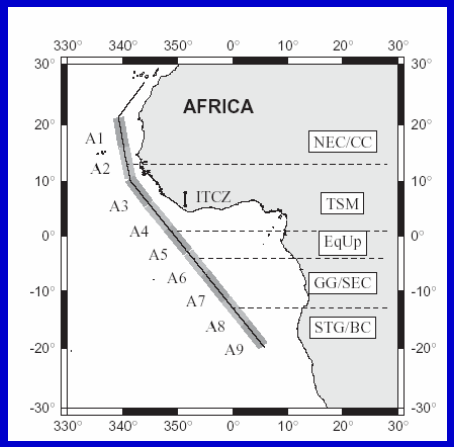


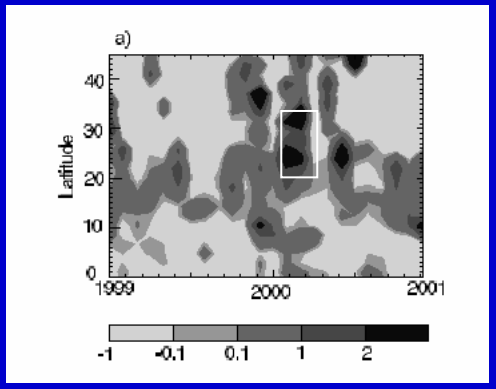
Bonnet et al. 2006

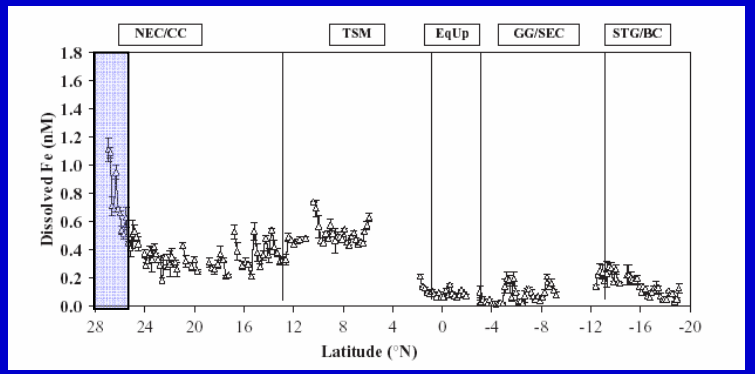
Natural iron fertilization from above and N_2 fixation











Mars 2000 — Mahaffey et al. 2003

Septembre 2000 — Sarthou et al. 2003

What are the characteristics of iron supply

to the ocean by natural processes?

How do they compare with those of purposeful additions?

Natural iron supply

What are the natural chemical forms of iron coming from below ?

Natural speciation (KEOPS)

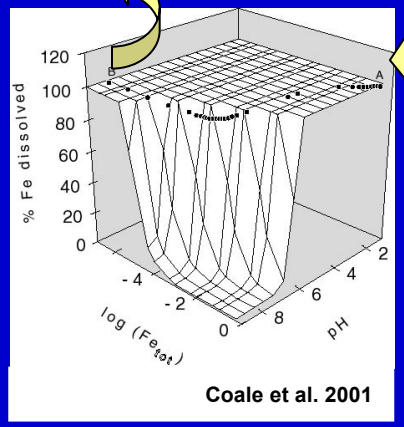
Dissolved phase dominated by organic complexation with an excess of ligands (Gueringa et al.)

Dissolution of lithogenic particulate Fe is a possible additional source.

Speciation after infusion

$Fe(II)_d$

$Fe(II)SO_4$



Coale et al. 2001

$Fe(III)_d$

inorganic colloids

Aggregation and sinking

(Wells 2003 , Nishioka et al. 2005

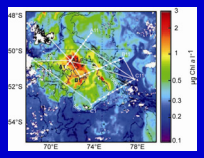
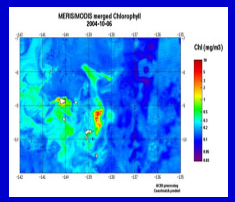
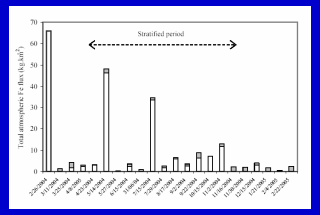
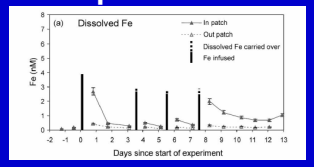
What are the natural chemical forms of iron coming from above ?

Mineral class		mineral	% in aerosol	% DFe
Clay	illite	illite	45	67.4
	kaolinite	kaolinite	7	2.3
	smectite	nontronite		
		beidellite	15	27
		montmorillonite		
feldspar		oligoclase	6	2.8
		orthoclase		
		hematite		
Iron (hydr-)oxide		goethite	4	0.5
		magnetite		


hematite

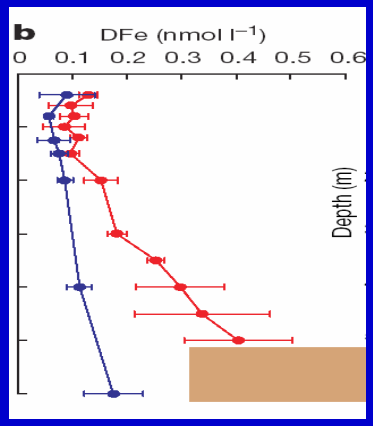
Journet et al. subm.

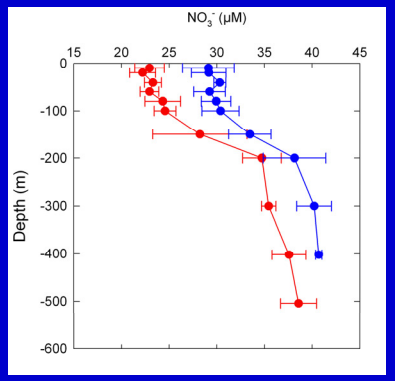
Natural iron supply

Mode of addition		Flux of DFe µmol m^{-2} d^{-1}	Flux of TFe µmol m^{-2} d^{-1}
Natural From below	more or less continuous 	< 10^{-1}	1 ?
	pulsed 		
Natural From above	pulsed 	1- 10	~10^3- 10^2
Acidic $FeSO_4$	pulsed 	10^2 10^3	~10^4

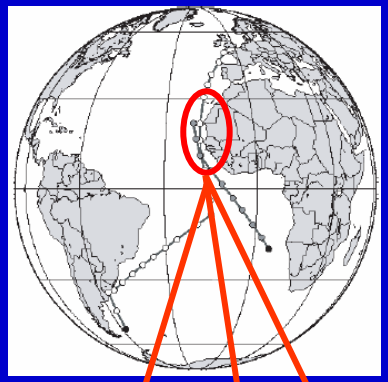
Natural iron supply

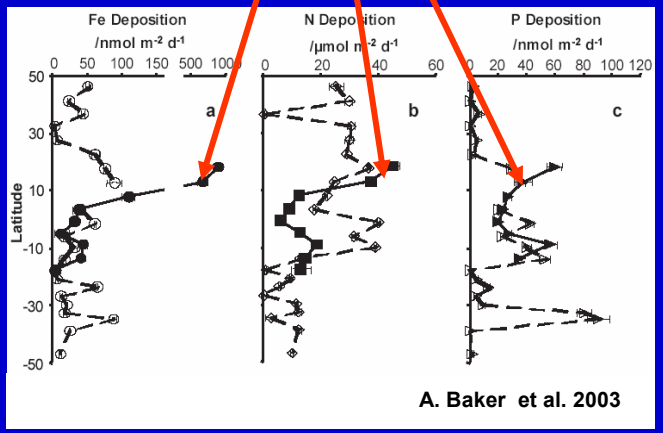
Iron is never supplied alone, macronutrients are also added.





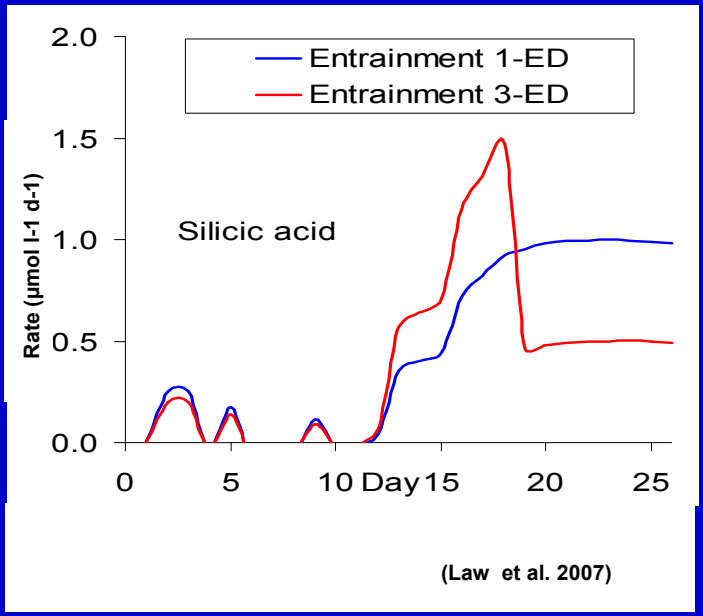
From below





From above

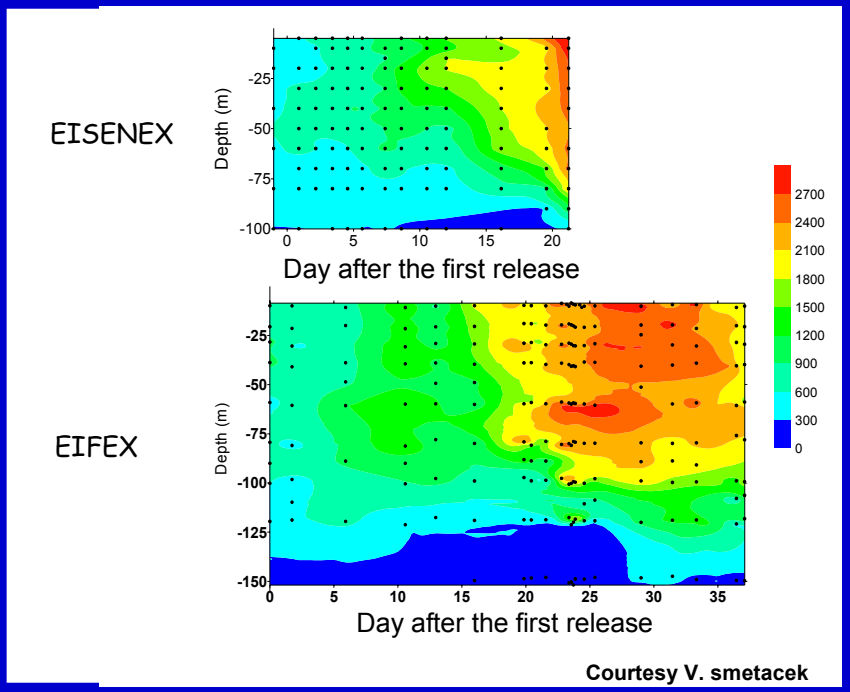
From deliberate release
Macronutrient entrainment
during SERIES



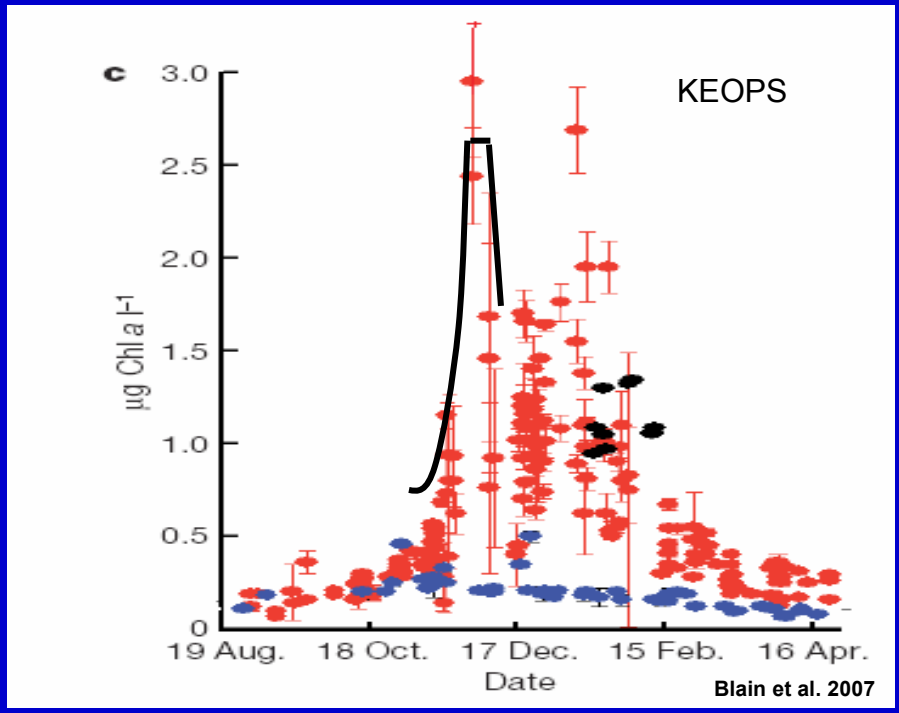
Natural iron supply

$FeSO_4$ addition is a poor imitation of the natural processes of fertilization,

but is it an important issue ? Yes it is



Courtesy V. smetacek

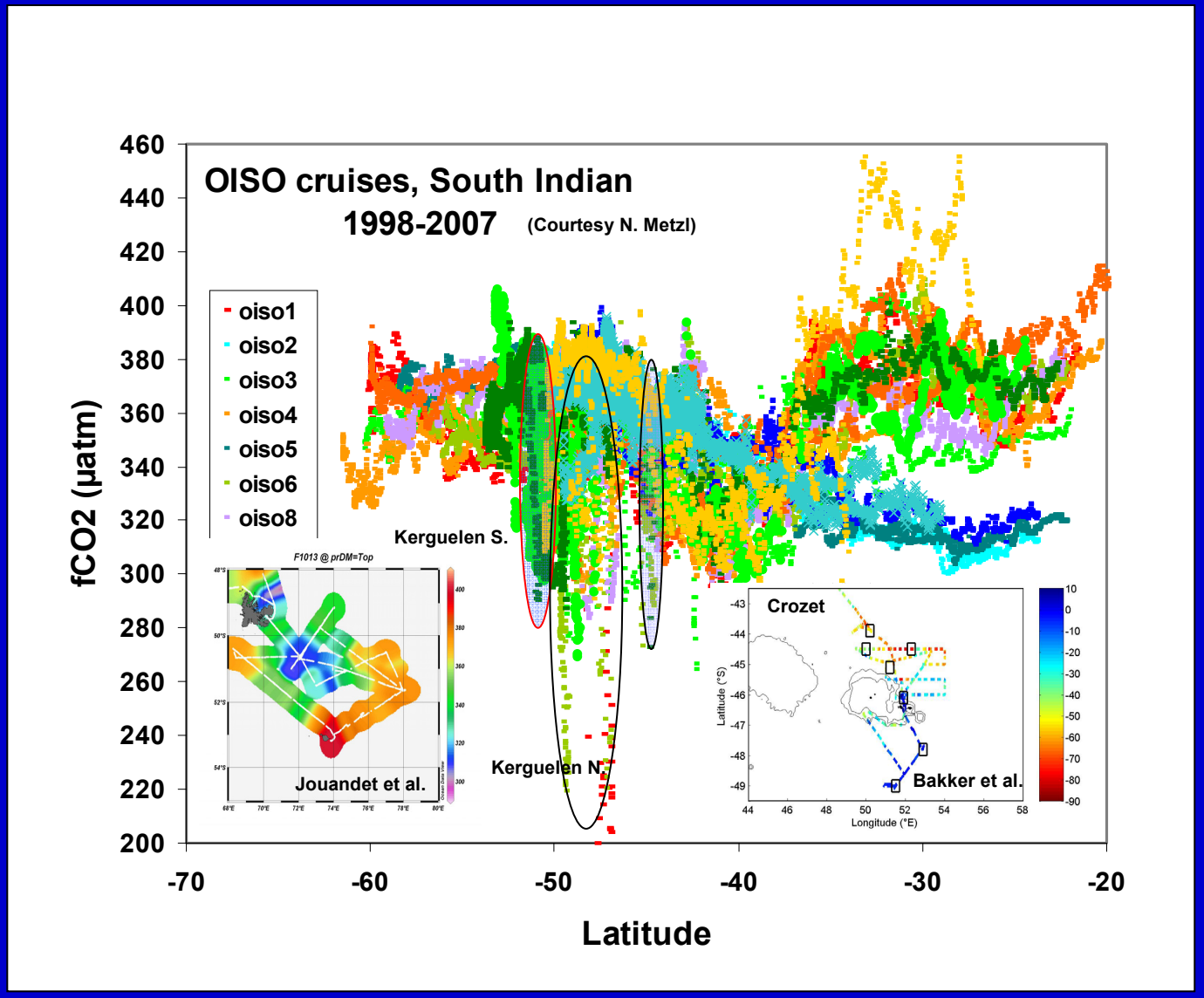


Blain et al. 2007

What can we learn from natural iron fertilization

on carbon sequestration in the ocean ?

CO_2 sink


OISO cruises, South Indian
1998-2007
(Courtesy N. Metzl)
oiso1
oiso2
oiso3
oiso4
oiso5
oiso6
oiso8
Kerguelen S.
Kerguelen N.
Crozet
Bakker et al.
Jouandet et al.
F1013 @ prDM=Top
fCO2 (µatm)
Latitude
Longitude (°E)
Latitude (°S)

Carbon export

Experiment	duration	excess of C export at 100m (mmol m^{-2} d^{-1})	excess of C export at200m (mmol m^{-2} d^{-1})	references
SOIREE	13	0	0	Charette and Buesseler,2000
EisenEx	22	0	0	Rutgers van der Loeff and Vöge 2001
SOFeX-S	27	7 ± 3	-	Buesseler et al 2005
KEOPS	~ 90	11 ± 5	14 ± 8	Savoye et al. (2007)
CROZEX	~ 90	9.4 ± 1.5		Morris et al. (2007)
EIFEX	36	13 ± 13		Savoye (unpublished)

$$\text{Efficiency} = \frac{\text{Excess of carbon export (mol)}}{\text{Excess of DFe supply (mol)}} \begin{cases} 70{,}000 \pm 40{,}000 \\ 668{,}000 \end{cases}$$ (blain et al. 2007)

Compared to 4,300 for SO exp. (de Baar et al. 2006)

Deep sequestration of C

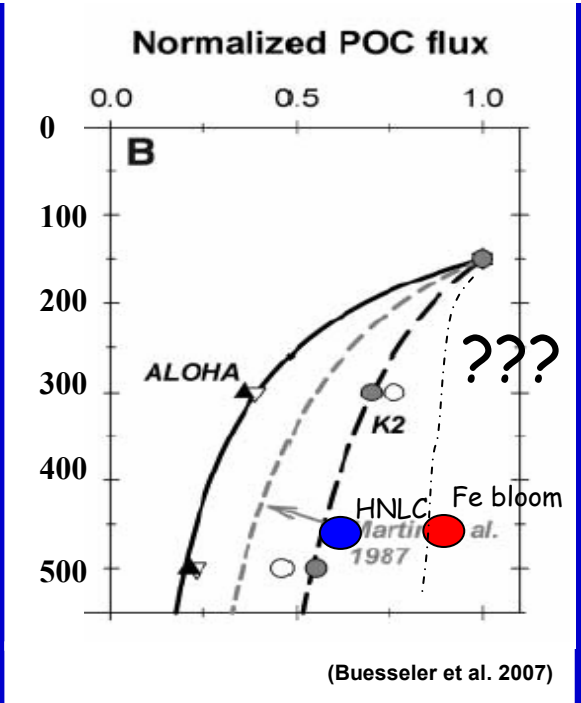
KEOPS :Fraction of the int. PP exported at 100 m was twice **lower** in the bloom than in HNLC waters

(Savoye et al. 2007)

but

KEOPS :the fraction of the Cexp that was transferred below 450 m was **higher** below the bloom than in HNLC waters

(Jacquet et al. 2007)



(Buesseler et al. 2007)

C and Fe cycles coupling

KEOPS :**No preferencial remineralization of C and Fe** in the mixed layer and also in the seasonal thermocline of the Kerguelen bloom

(Obernosterer et al. 2007, Sarthou et al. 2007)

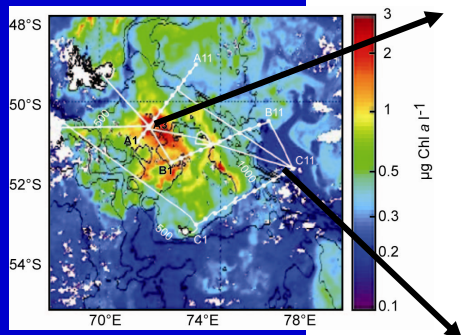
but

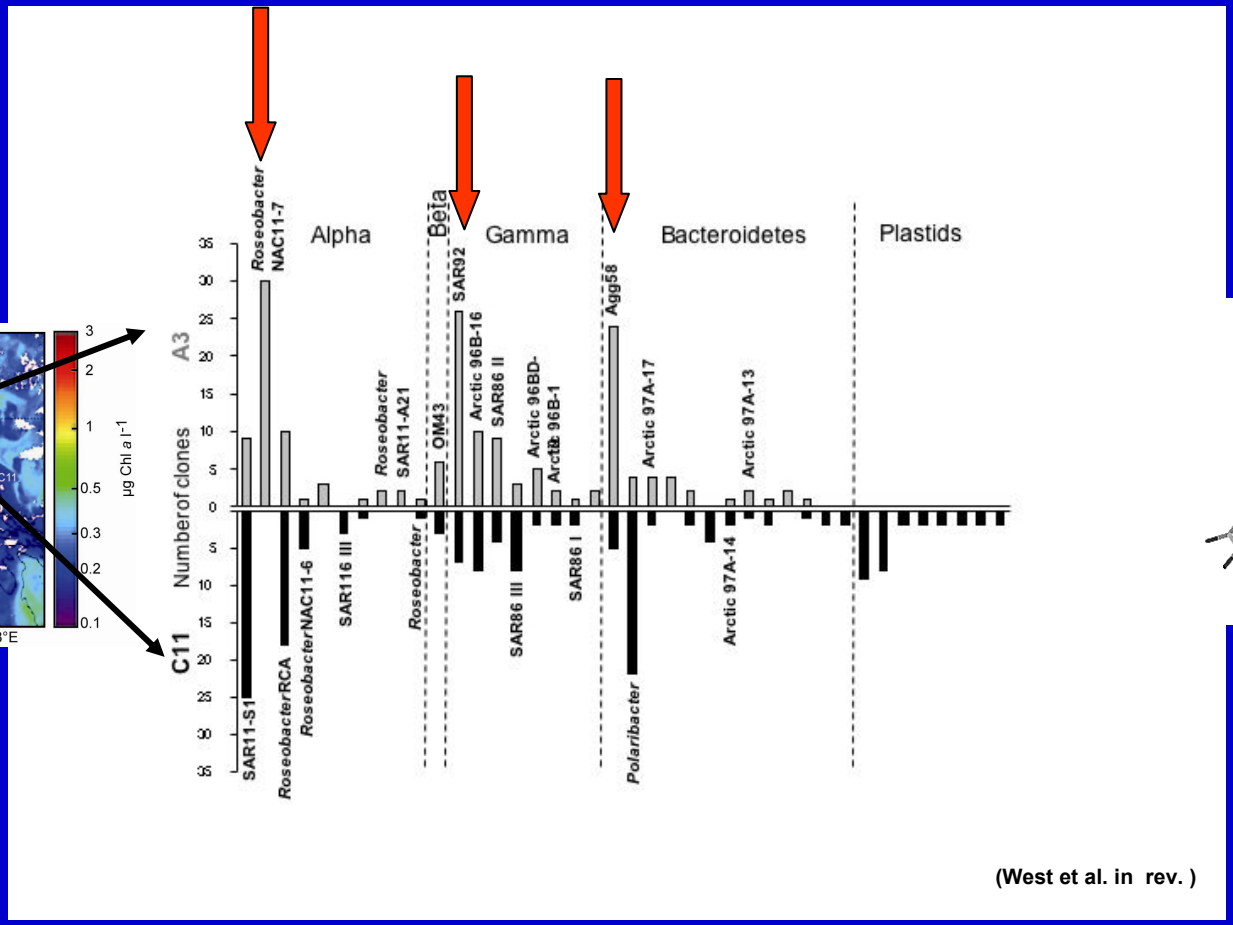
FECYCLE

During the unperturbated experiment in the subantartctic, **Preferencial remineralisation of C versus** Fe was observed below the MLD

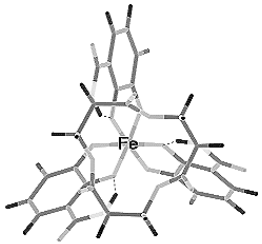
(Boyd et al. 2005, Frew et al. 2005)

Composition of the heterotrophic bacterial community





(West et al. in rev.)



Bacteria play a crucial role in coupling/decoupling C and Fe cycles in fertilized systems

- Natural iron fertilization does not only increase the rates of the biogeochemical processes but it drives a complete change of the ecosystem.

New parameterisations, new laws ?

- There is large variety of natural iron fertilized sites in the ocean with a large potential for new findings.

- The short term mesoscale iron fertilization experiment was a powerful tool for research in oceanography. The second generation of experiments should be more "subtle" to make their results more comparable with natural processes.

- The mode of iron addition, planned in large scale / commercial iron fertilization, does not imitate a natural process of fertilization.