Upper ocean remineralization and recycling processes, including processes in aggregates, and their impacts on dissolved trace element speciation

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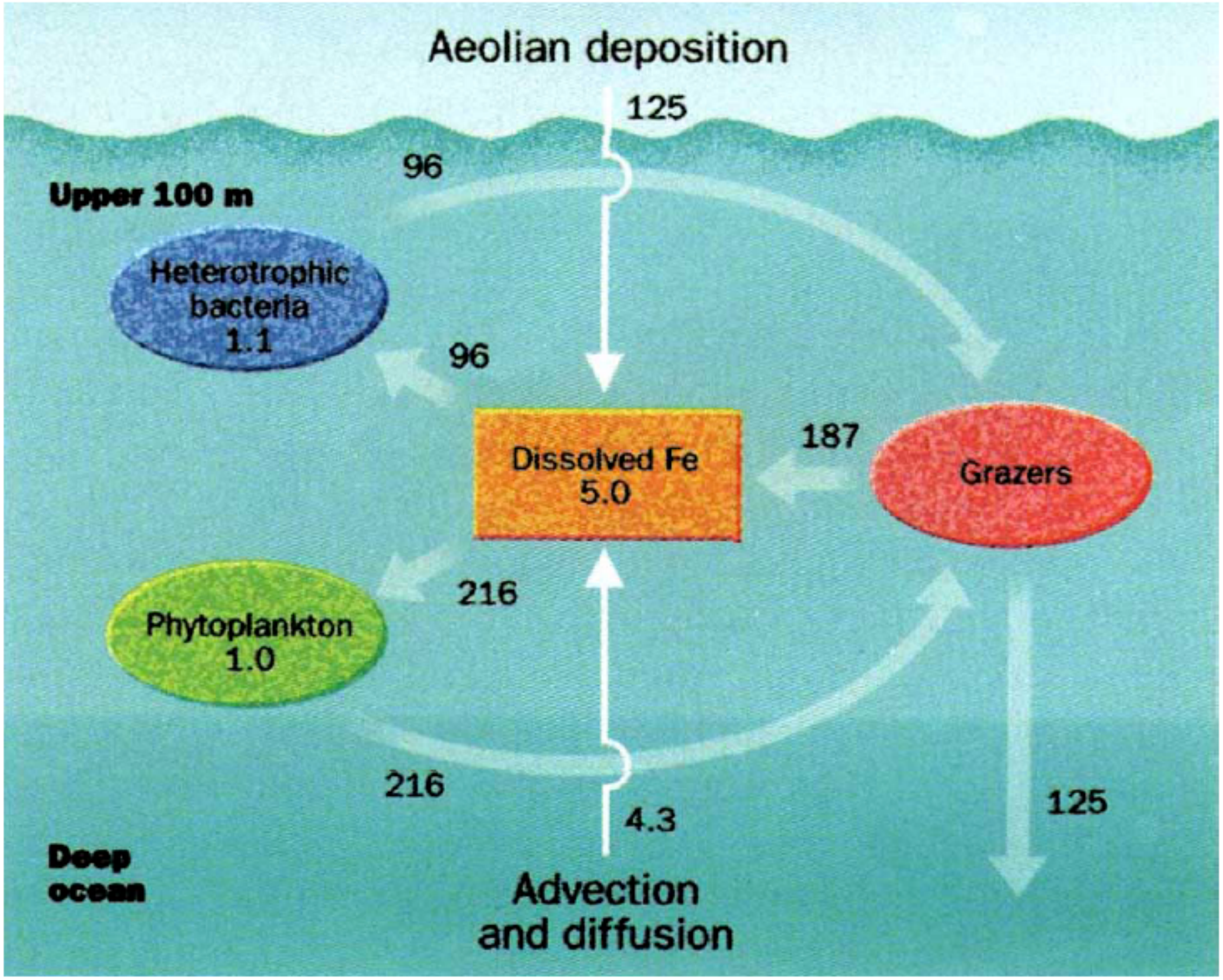
SCRIPPS INSTITUTION OF OCEANOGRAPHY

UC San Diego

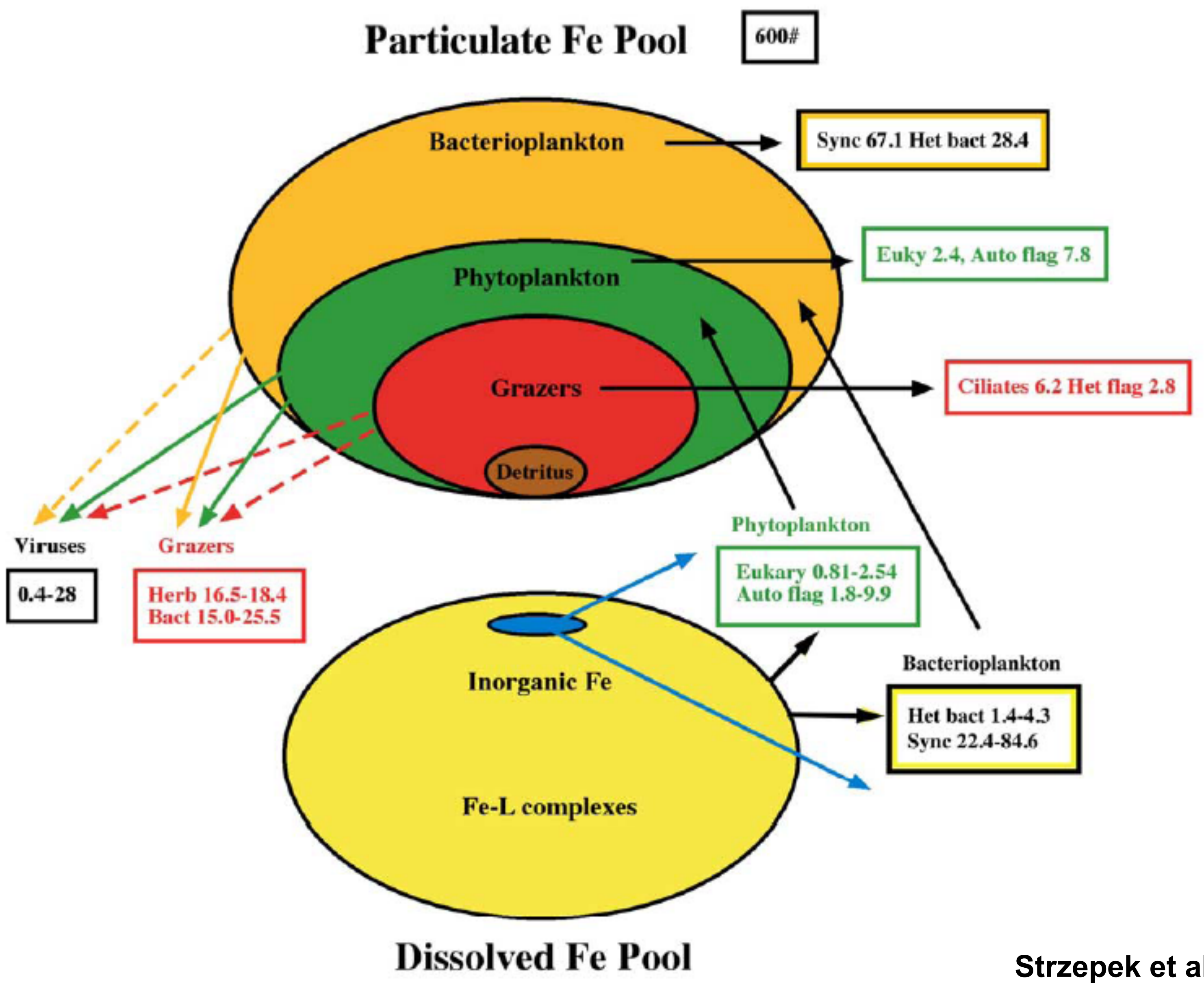
The marine "microbial ferrous wheel" - 1996



rates in nmol Fe m^{-2} d^{-2}; standing stocks in μmol Fe m^{-2}

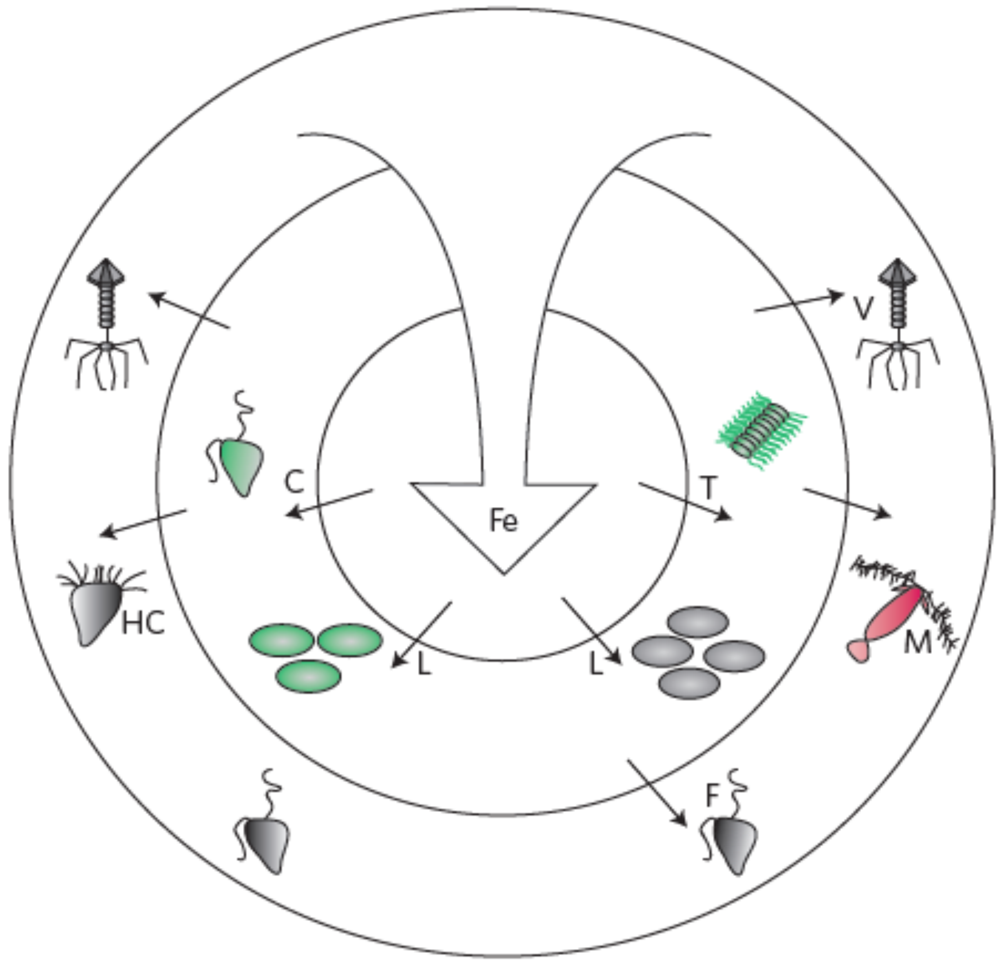
Kirchman N&V on Tortell et al., *Nature* 1996

Spinning the "ferrous wheel" – FeCycle, 2005



Strzepek et al., GBC 2005

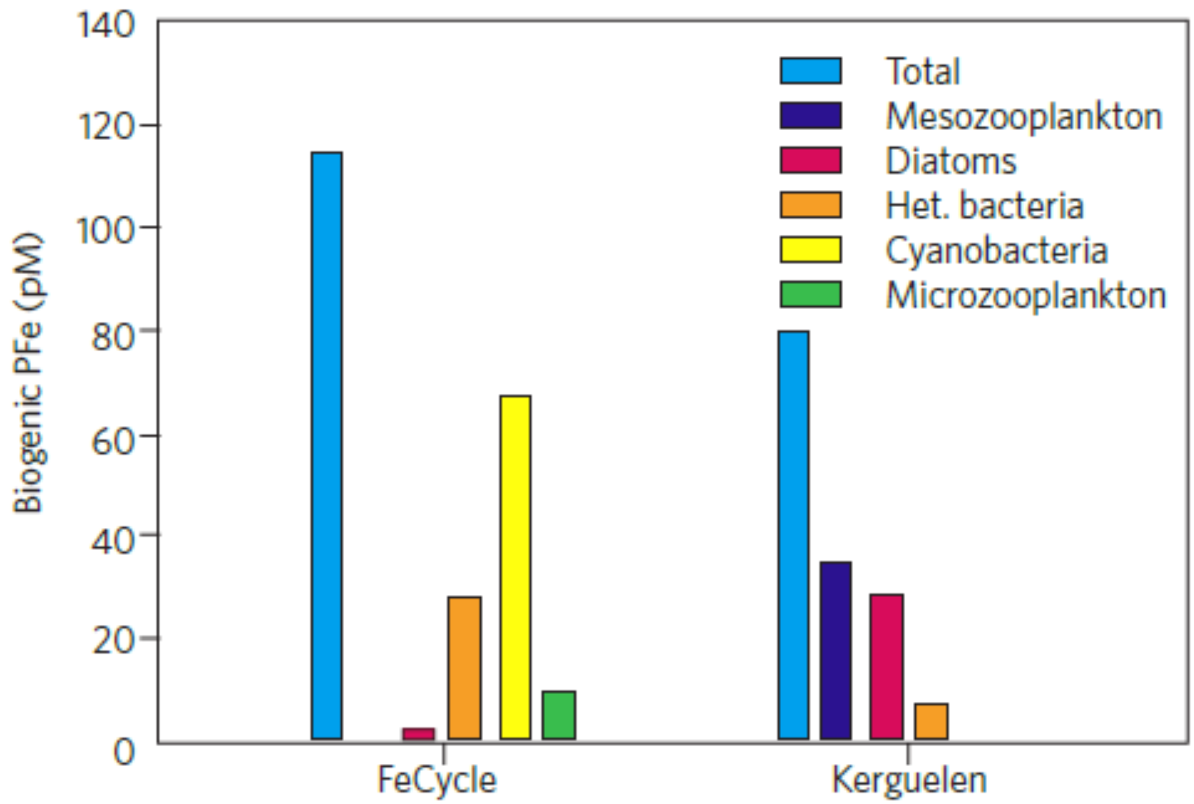
Ferrous wheel – current concept



***f*e ratio = new iron/(new + regenerated iron)**

Boyd & Ellwood, *Nature Geoscience* 2010

Uniformity in biotic iron pool across contrasting ecosystems



Boyd & Ellwood, *Nature Geoscience* 2010

AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE

10.1002/2014GB005014

Why are biotic iron pools uniform across high- and low-iron pelagic ecosystems?

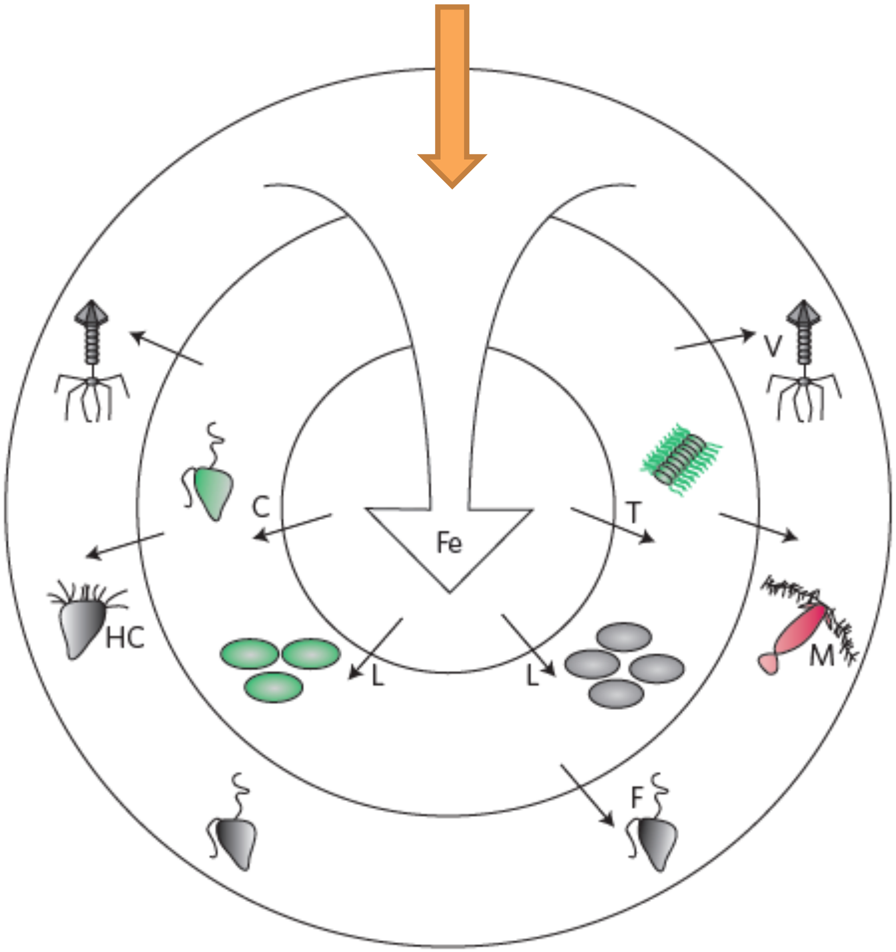
P. W. Boyd[1,2], R. F. Strzepek[3,4], M. J. Ellwood[5], D. A. Hutchins[6], S. D. Nodder[7], B. S. Twining[8], and S. W. Wilhelm[9]

Table 1. Summary of the Community Composition of Microbes, Phytoplankton, and Grazers Across the Five Study Sites Featured[a]

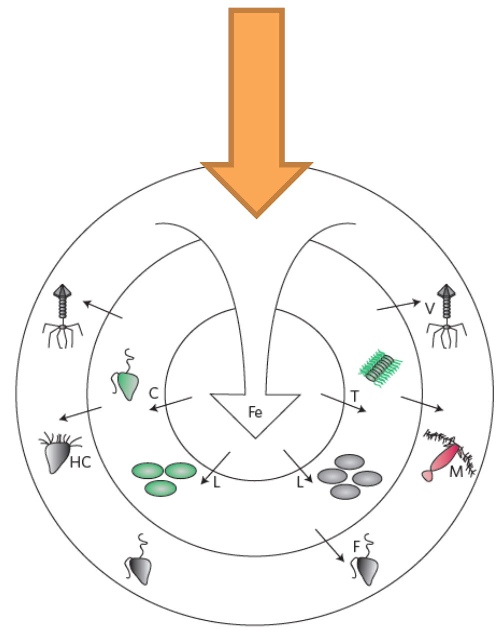
Site	Characteristics	Cyanobacteria	Auto-flags	Diatoms	Microzoo	Mesozoo
FeCycle[b]	Subantarctic HNLC	Prokaryotic (*Synecho.*)	Mixed comm. (low abundances)	Low abundances, mixed comm.	Mixed comm.	Calanoid and neocalanoid copepods
FeCycle II[c]	Subtropical high iron	Prokaryotic (*Synecho.*)	Mixed comm. (low abundances)	*Asterionellopis* bloom	Mixed comm.	Mainly calanoid copepods
SOIREE HNLC[d]	Polar HNLC	Eukaryotic	Mixed comm. (low abundances)	Low abundances, mixed comm.	Mixed comm.	Mainly calanoid copepods
SOIREE high iron[d]	Polar high iron	Eukaryotic	Mixed comm. (high abundances)	*Fragiliariopsis* bloom	Mixed comm.	Mainly calanoid copepods
KEOPS[e]	Island wake high iron	Pro and Euk's (low abundances)	Mixed comm. (low abundances)	*Chaetoceros* bloom	Mixed comm.	Mixed community (including euphausiids)

Boyd et al. GBC 2015

"…..quotas and iron recycling efficiencies together set biotic iron pools. Hence, site-specific differences in iron recycling efficiencies (which provide 20–50% and 90% of total iron supply in high- and low-iron waters, respectively) help offset the differences in new iron inputs between low- and high-iron sites."



HNLC – Fe recycling 90%, low *fe*



Fe fertilized regions – Fe recycling 20-50%, higher *fe*

Boyd et al. GBC 2015

Biogeosciences, 12, 4421–4445, 2015
www.biogeosciences.net/12/4421/2015/
doi:10.5194/bg-12-4421-2015

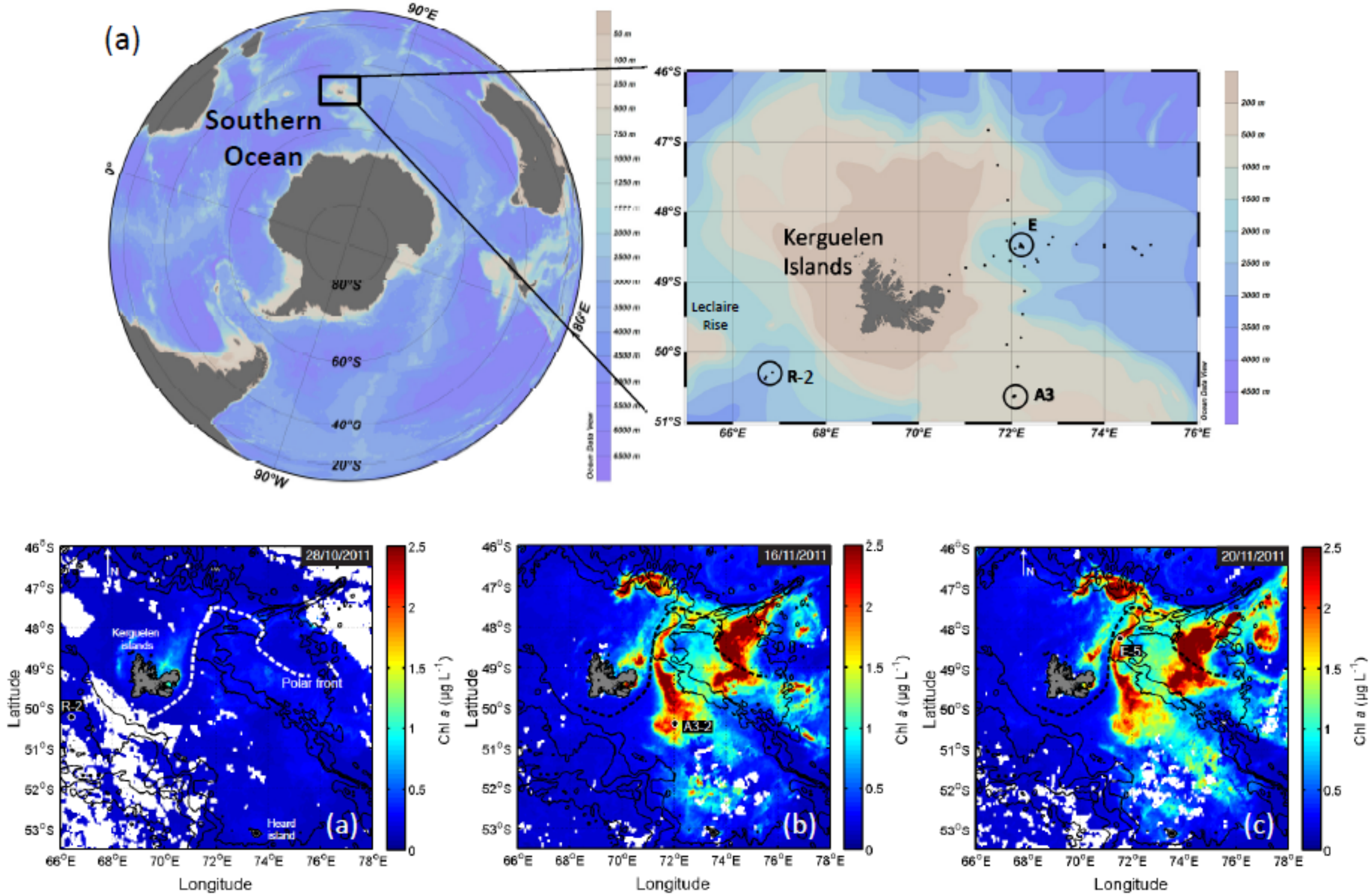
Biogeosciences Open Access

Iron budgets for three distinct biogeochemical sites around the Kerguelen Archipelago (Southern Ocean) during the natural fertilisation study, KEOPS-2

A. R. Bowie[1,2,3], P. van der Merwe[1], F. Quéroué[1,2,3], T. Trull[1,4], M. Fourquez[2,5], F. Planchon[3], G. Sarthou[3], F. Chever[3,a], A. T. Townsend[6], I. Obernosterer[5], J.-B. Sallée[7,8,9], and S. Blain[5]

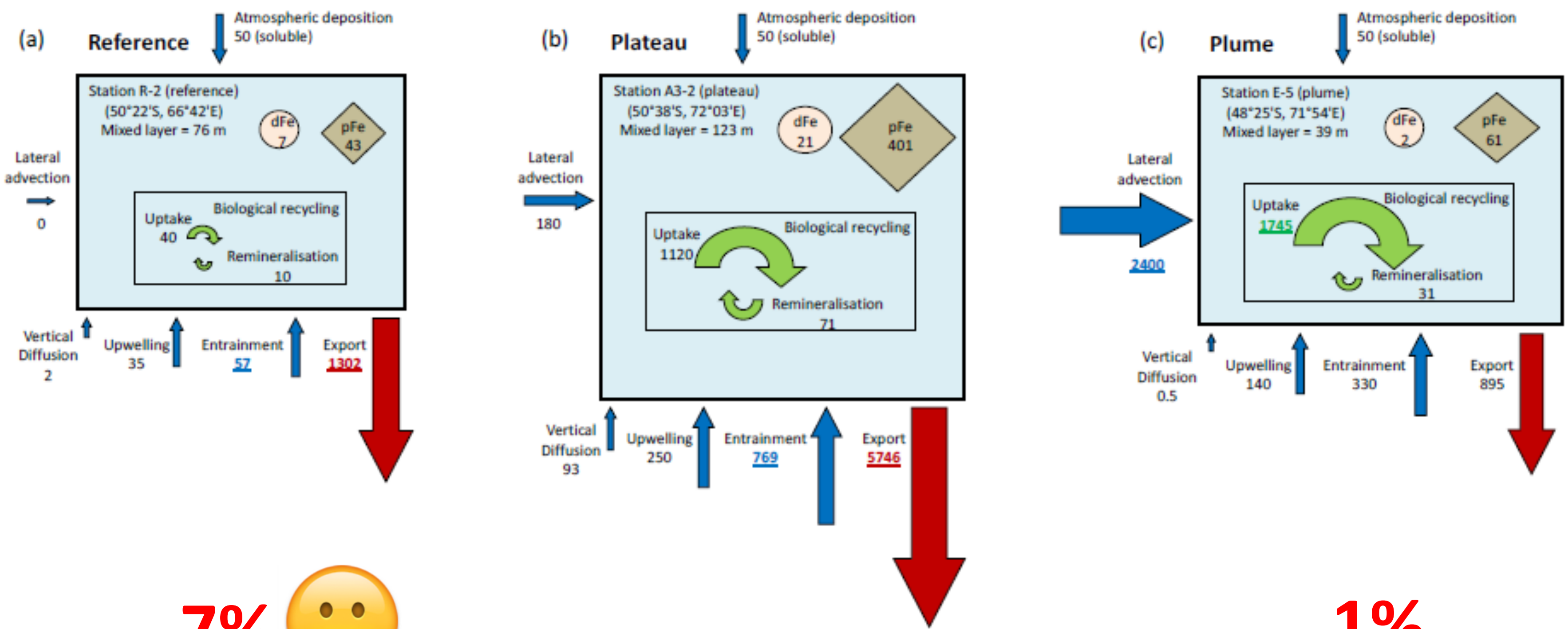
Bowie et al. BG 2015

KEOPS-2 study area



Bowie et al. BG 2015

Fe budgets for three KEOPS-2 sites



7% 5% 1%

Recycled iron vs new iron supply

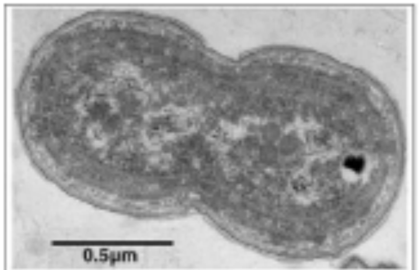
Bowie et al. BG 2015

How important is Fe recycling, really?

KEOPS-2 biogeochemical Fe budgets indicate Fe supply from recycling was relatively minor component at all sites - contrast to earlier findings from other Fe process studies in the Southern Ocean.

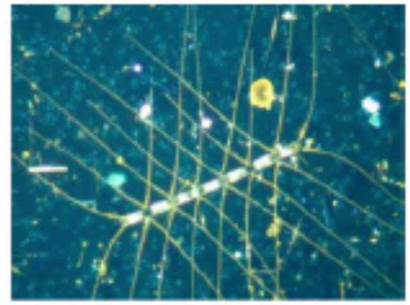
???

Cyanobacteria vs diatoms in the ferrous wheel – no contest?



Synechococcus

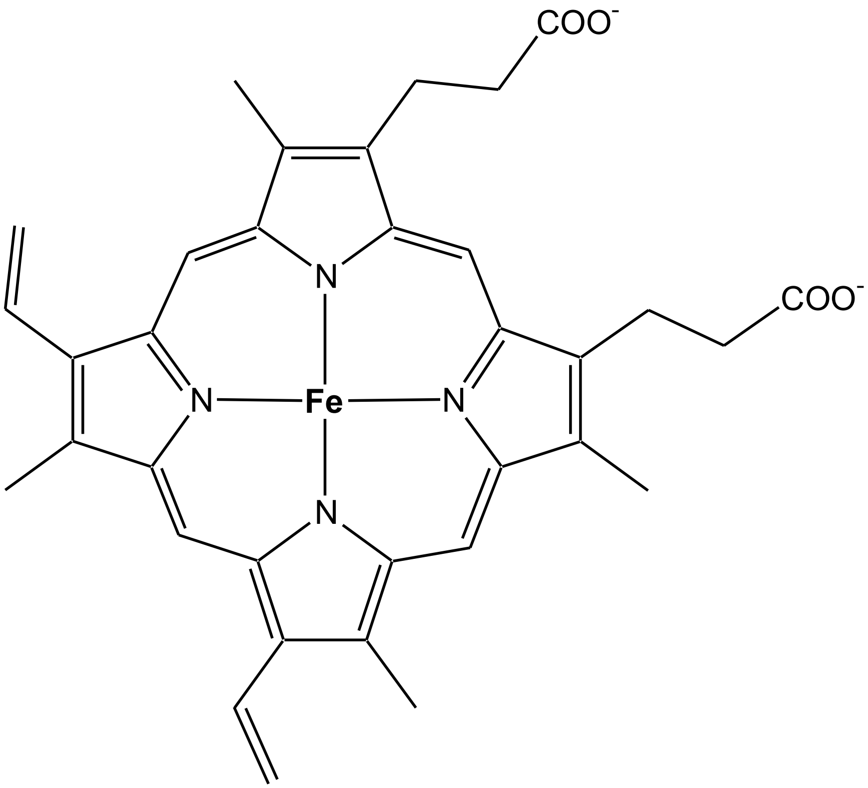
High surface area:volume ratio
High affinity for DFe
High cellular Fe requirements
High dissolved Fe requirements
Low Fe use efficiency?
“steady-state biomass”
Major contributor to biogenic Fe pool
Fate – mainly grazing (h to d)
Fe readily mobilised (h to d)
Major part of the Ferrous Wheel
Minor algal contributor to export



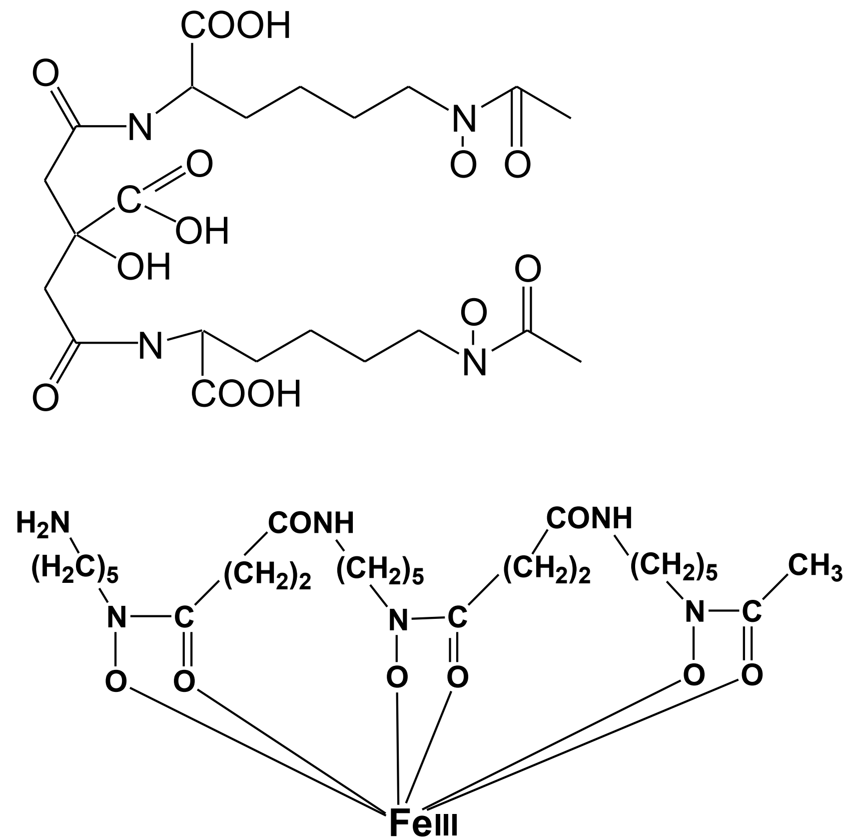
Low surface area:volume ratio
Low affinity for DFe
Low cellular Fe requirements
Low dissolved Fe requirements
High Fe use efficiency?
“non steady-state biomass”
Minor contributor to biogenic Fe pool
Fate – mainly export (d)
Fe retained intracellularly (d)
Minor part of the Ferrous Wheel
Major algal contributor to export

Boyd et al. GBC 2015

How bacteria act to short-circuit diatom Fe export and keep the ferrous wheel spinning



Heme



Siderophores

Heme as a component of the biogenic Fe pool

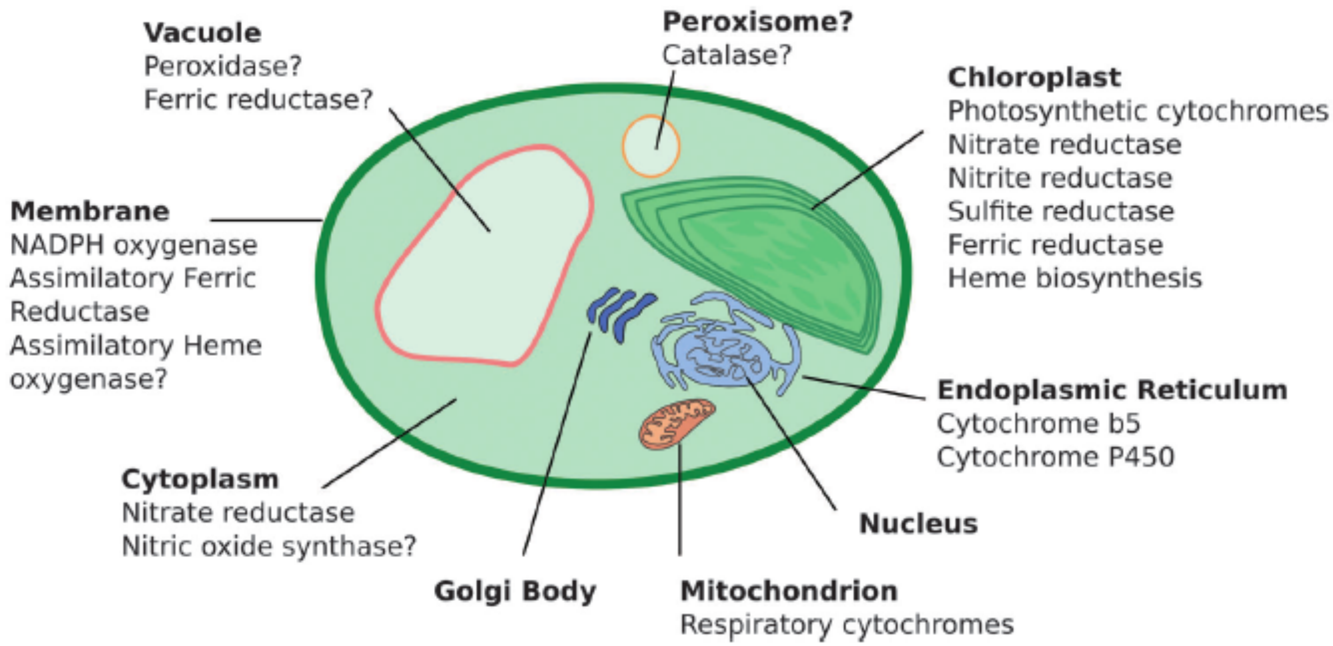
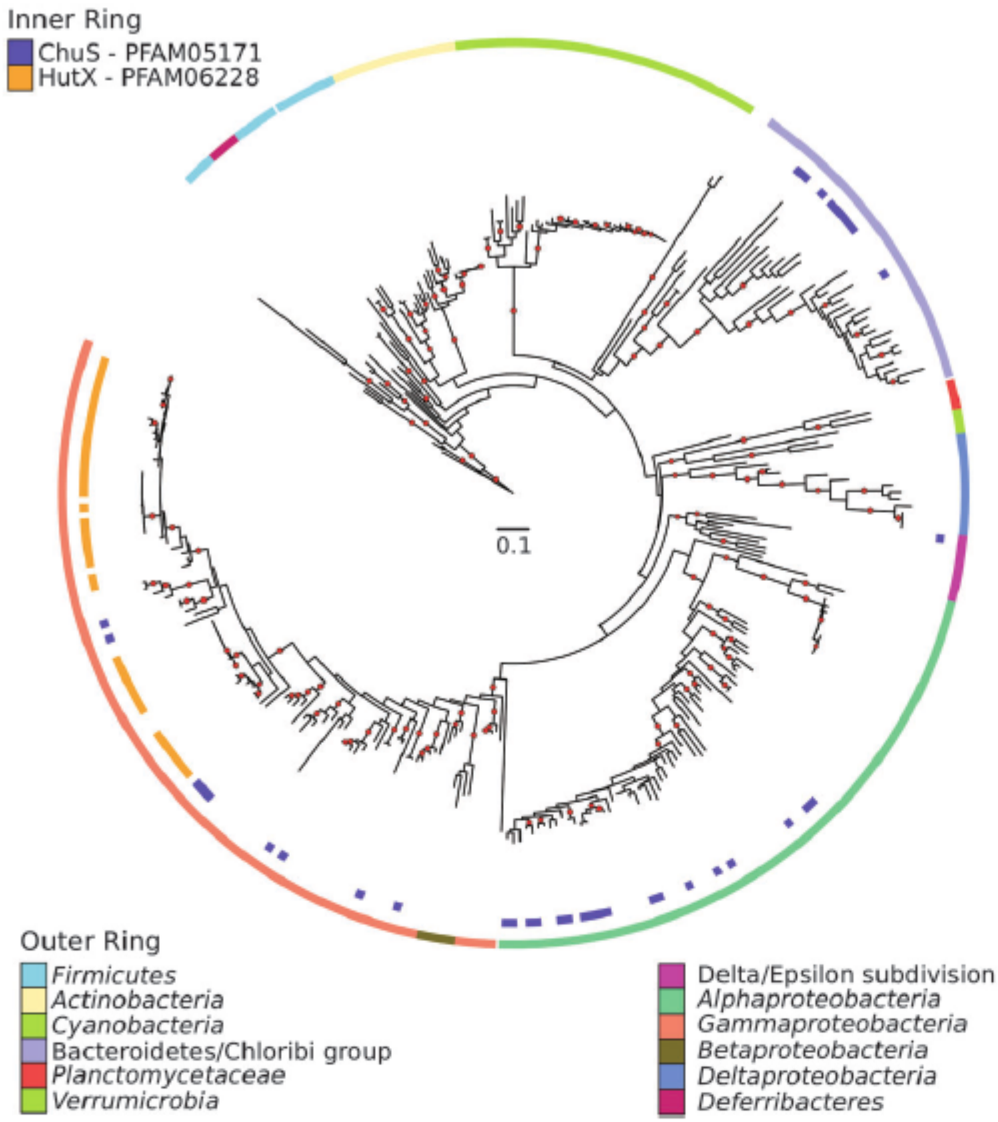


Table 1 Range of values reported for biogenic iron and heme *b* in the Southern Ocean

Region	Biogenic iron (pM)	Heme *b* (pM)	Size fraction	Method/ref.
SE New Zealand (46.24 S, 178.72 E)	40–310		>0.2 μm	Oxalate wash[a] [108]
S Australia (46–60 S, 139–140 E)	100–380		>0.2 μm	Oxalate wash[b] [112]
Scotia Sea (52–60 S, 38–45 E)		0.6–21	>0.7 μm	Heme *b* direct determination[100]

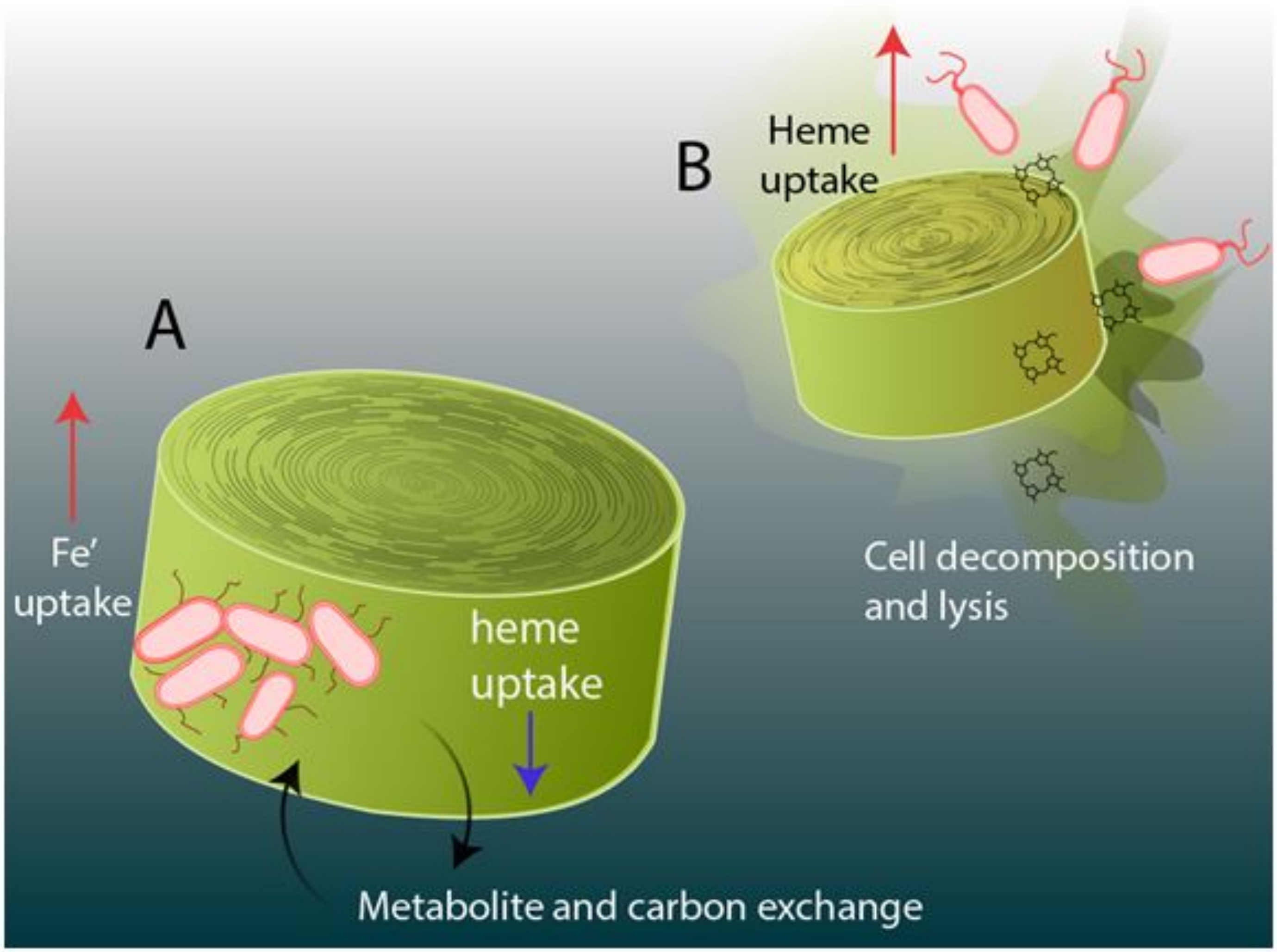
Hogle et al. Metallomics 2014

Genes for heme uptake widespread in marine bacteria



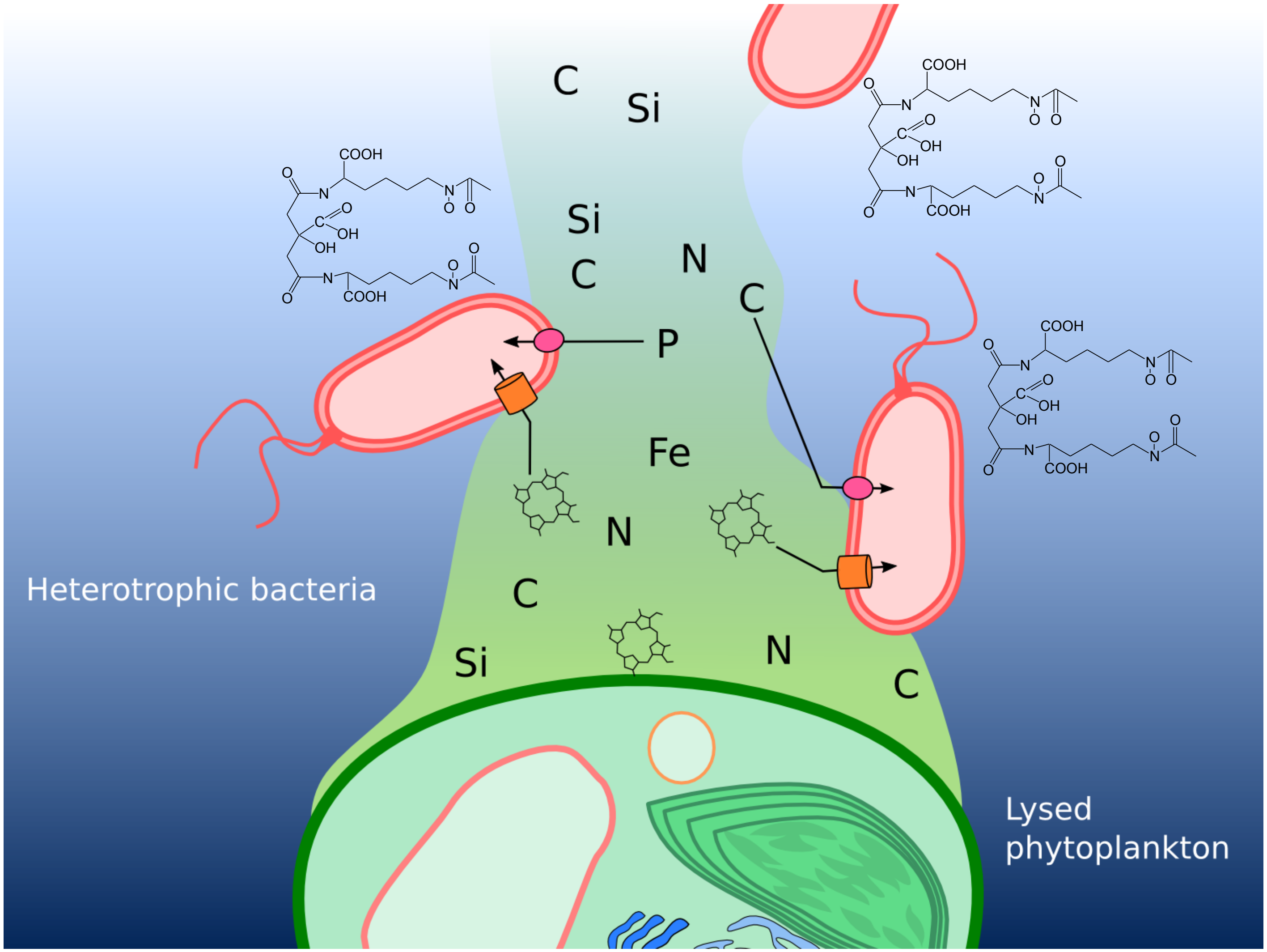
Hogle et al. Metallomics 2014

Algal-bacteria interactions facilitate Fe recycling via heme uptake

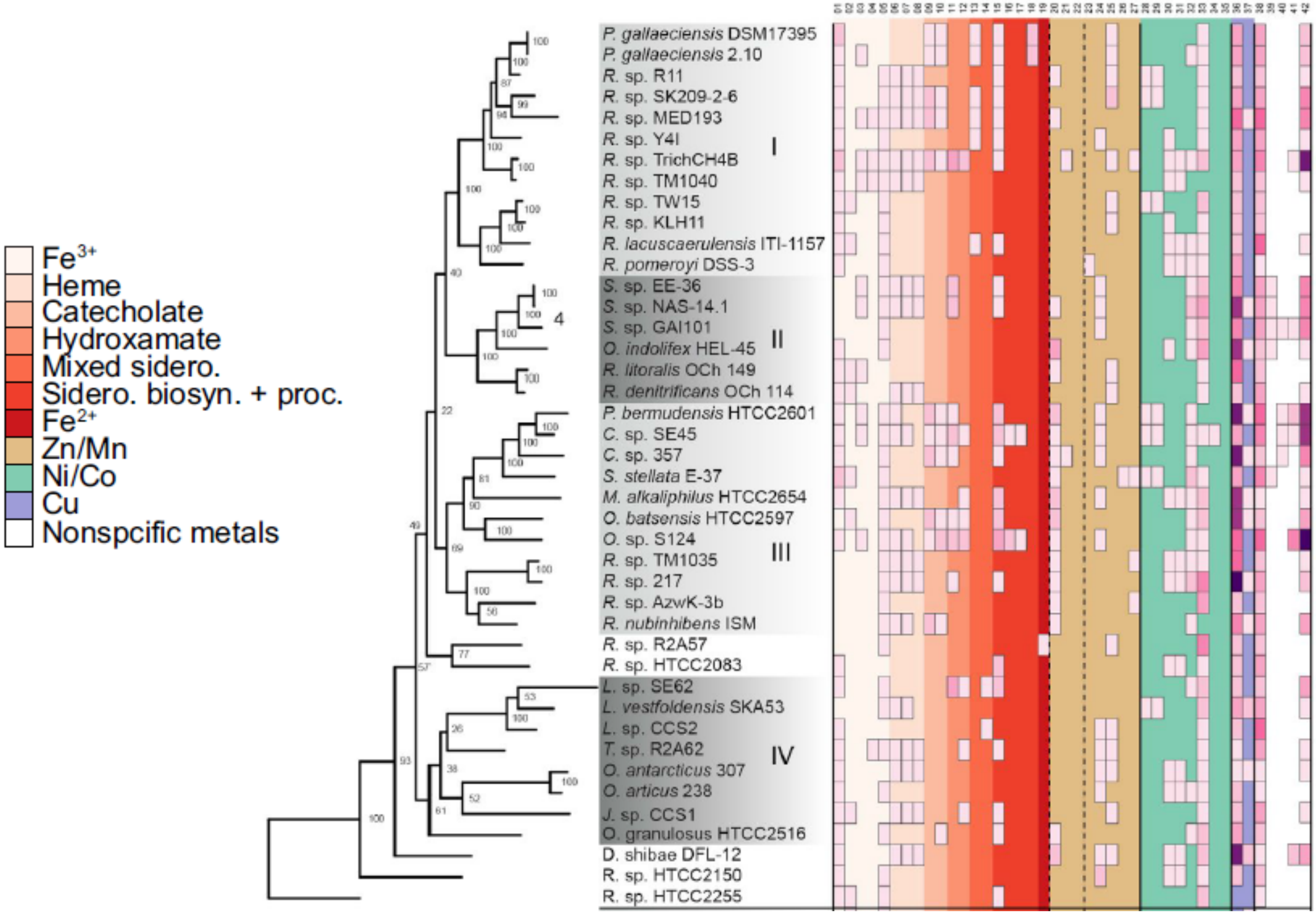


Hogle et al. in review

Algal-associated bacteria utilize a variety of organic iron acquisition strategies

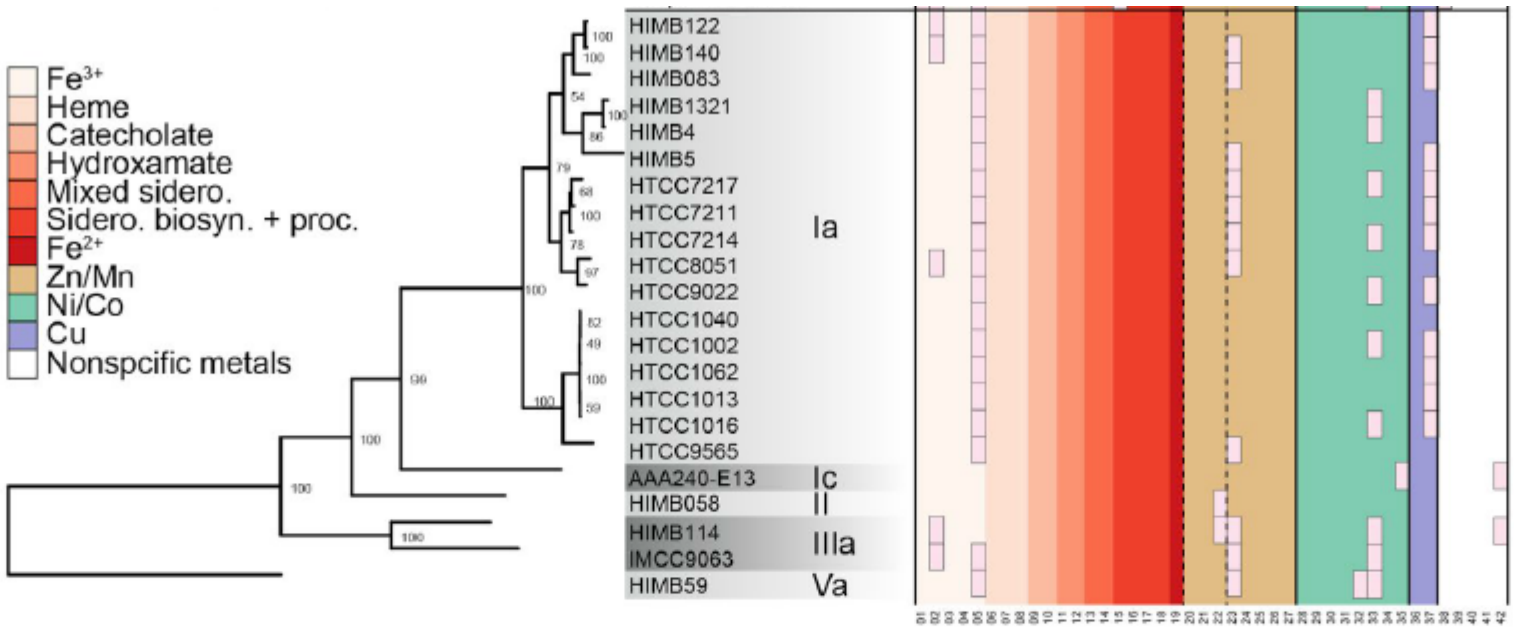


Algal-associated *Roseobacters* have diverse metal uptake capabilities



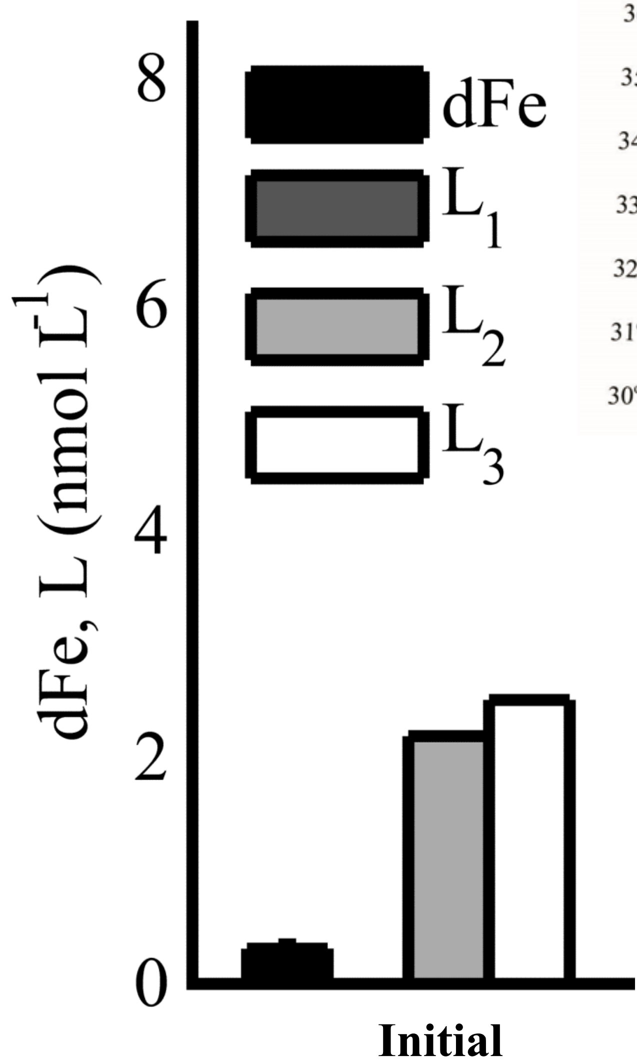
Hogle et al., AEM 2016

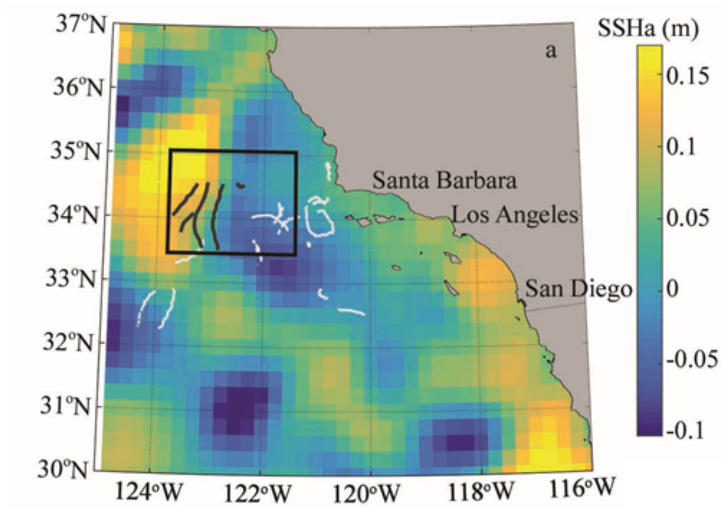
Free-living SAR11 strains have much lower versatility in metal transport systems



Hogle et al., AEM 2016

Evidence for a pulse of strong ligands produced at bloom decline in deckboard grow-out





Closing thoughts

Our understanding of Fe recycling mechanisms has continued to expand over the past two decades. Need to catch up for other metals.

May need to re-examine our assumptions about Fe recycling efficiency in different regimes, or improve methods to constrain.

Diatoms may be a bigger part of the ferrous wheel than previously appreciated, due to the metal recycling capabilities of algal-associated bacteria.

The relative importance of different metal recycling pathways likely feeds back into oceanic food webs via impacts on metal speciation and bioavailability.

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