The importance of trace metal nutrients for marine phytoplankton and bacteria along Line-P

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Outline

Trace Metals and Marine Biogeochemical Cycles

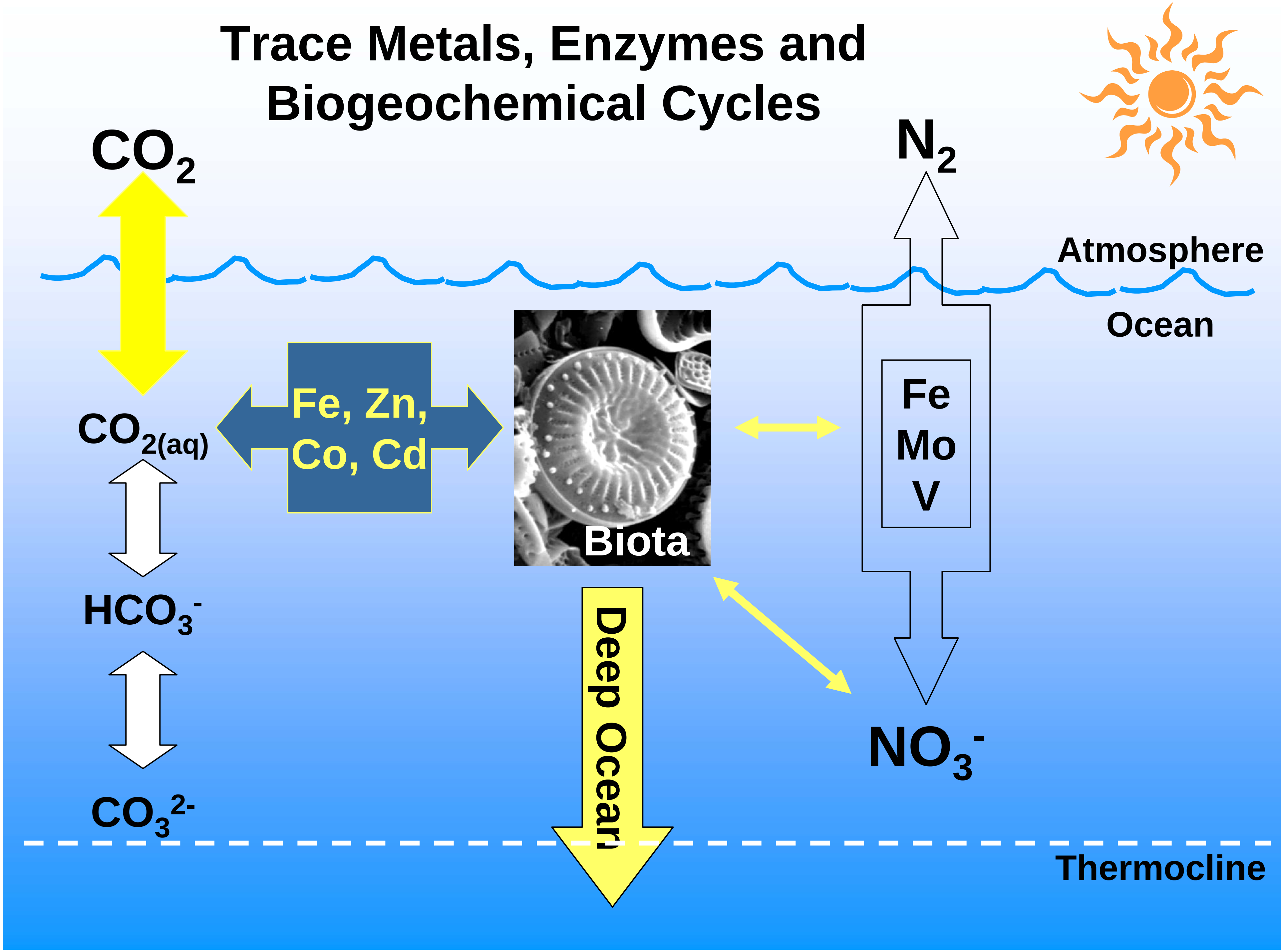
Iron and microbial production in the Gulf of Alaska

- **Dissolved Fe distributions**
- **Limitation of algal growth**
- **Fe acquisition by marine microbes**
- **Bacterial carbon use efficiencies**

The Future:

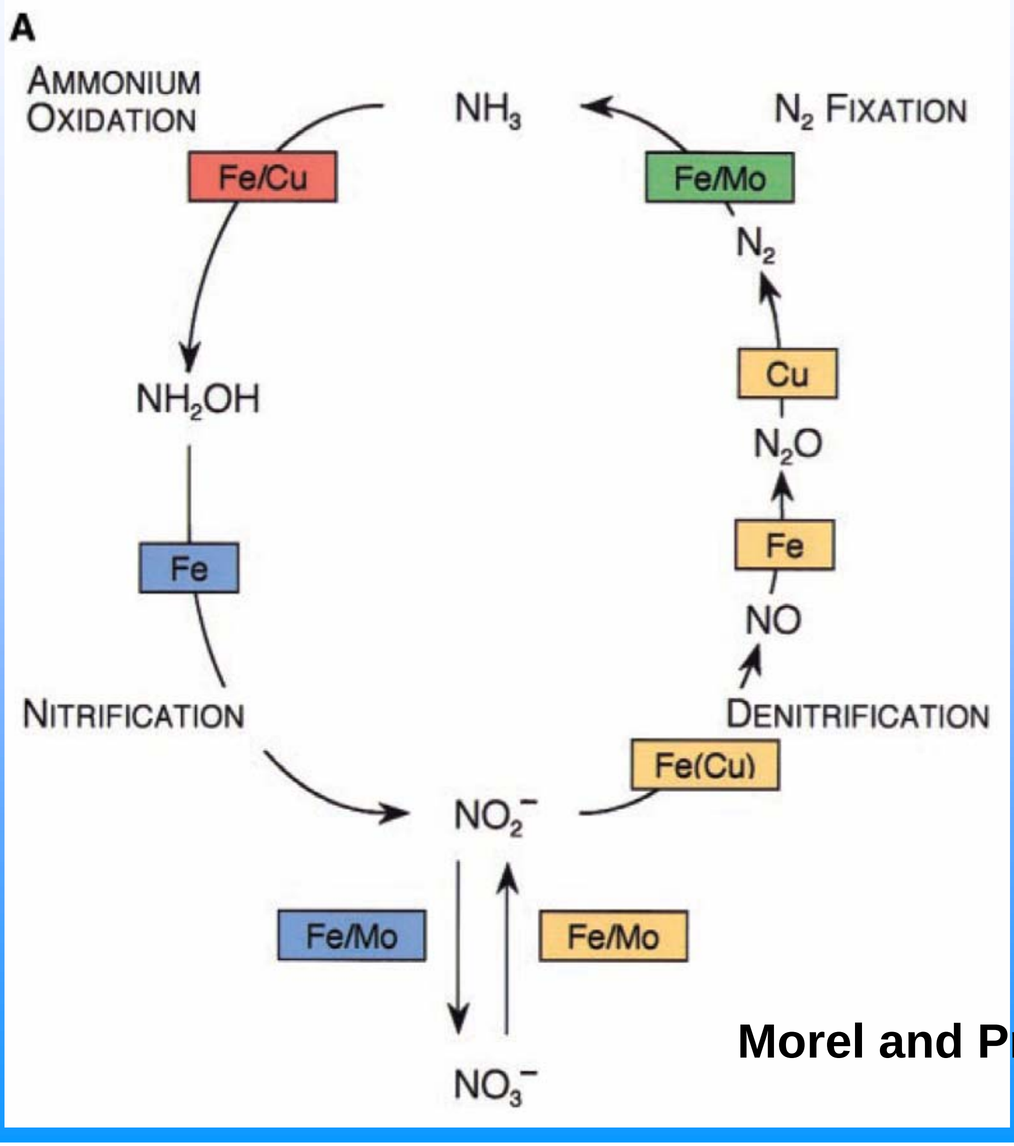
Trace Metal Interactions and Global Elemental Cycles

- **Fe limitation and Cd biogeochemistry**
- **Role of Cu in Fe uptake by eukaryotic phytoplankton**



Trace Metals, Enzymes and Biogeochemical Cycles
CO_2
N_2
Atmosphere
Ocean
$CO_{2(aq)}$
Fe, Zn, Co, Cd
Biota
Fe
Mo
V
HCO_3^-
CO_3^{2-}
Deep Ocean
NO_3^-
Thermocline

Primary Metal Requirements For Microbially Mediated N Transformations



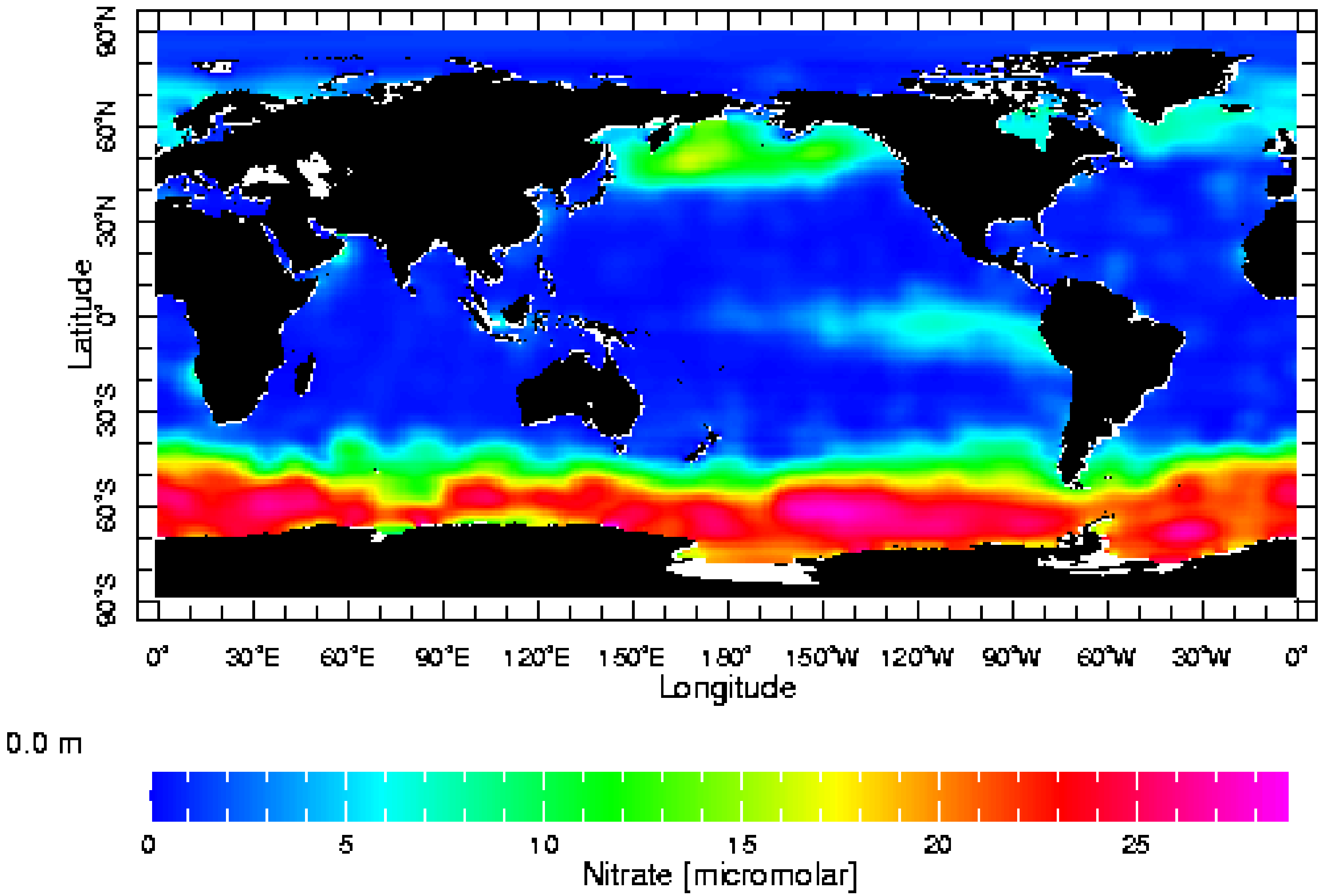
Morel and Price 2005 *Science*

Known Biochemical Functions of Selected Trace Elements in Marine Microorganisms

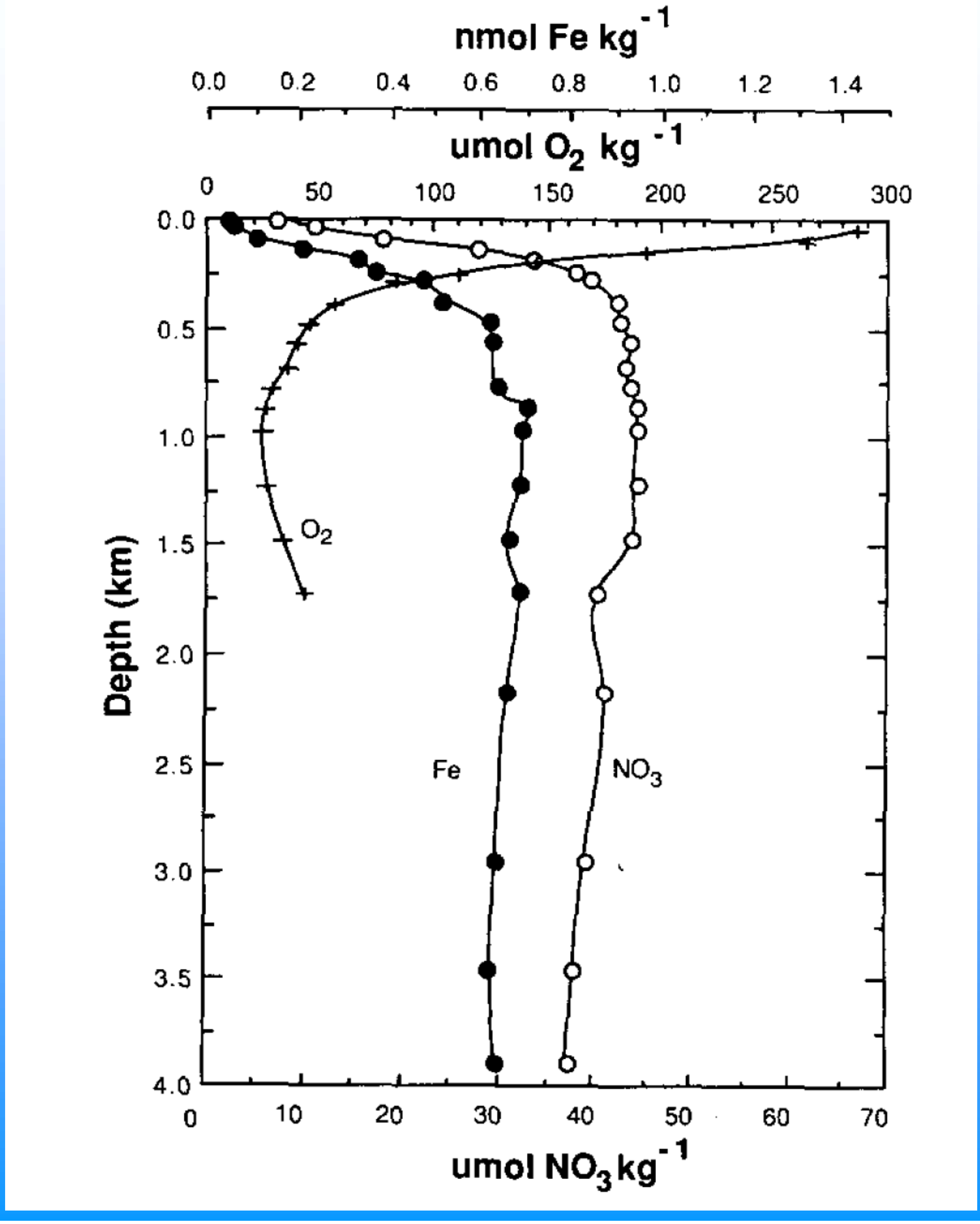
Metal	*Function*
Mn	Oxygen evolving complex of PS II
	Superoxide dismutase
Fe	FeS centers (e.g., aconitase, ferredoxin)
	Cytochromes
	Superoxide dismutase
	Nitrate reductase (assimilatory and respiratory)
	Nitrite reductase (assimilatory and respiratory)
Co	Carbonic anhydrase
Ni	Urease
Cu	Plastocyanin
	Ferrous oxidase
	Amine oxidase
Zn	Carbonic anhydrase
Cd	Carbonic anhydrase
	Alkaline phosphatase?

Morel et al. 2005 *Treatise on Geochem.*

Surface Nitrate Concentrations Showing HNLC Regions



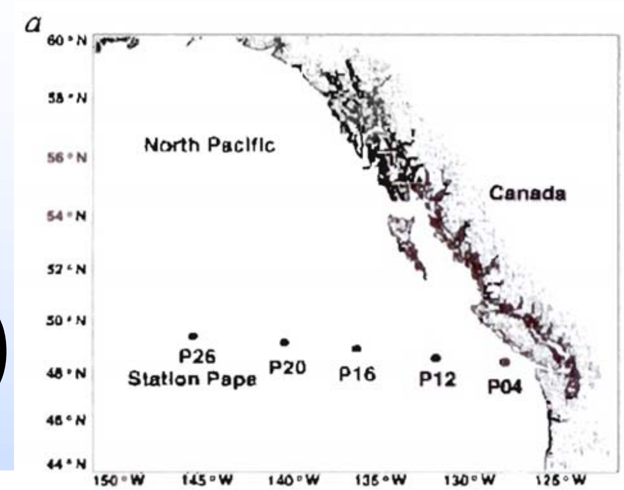
The Distribution of Dissolved Fe at OSP

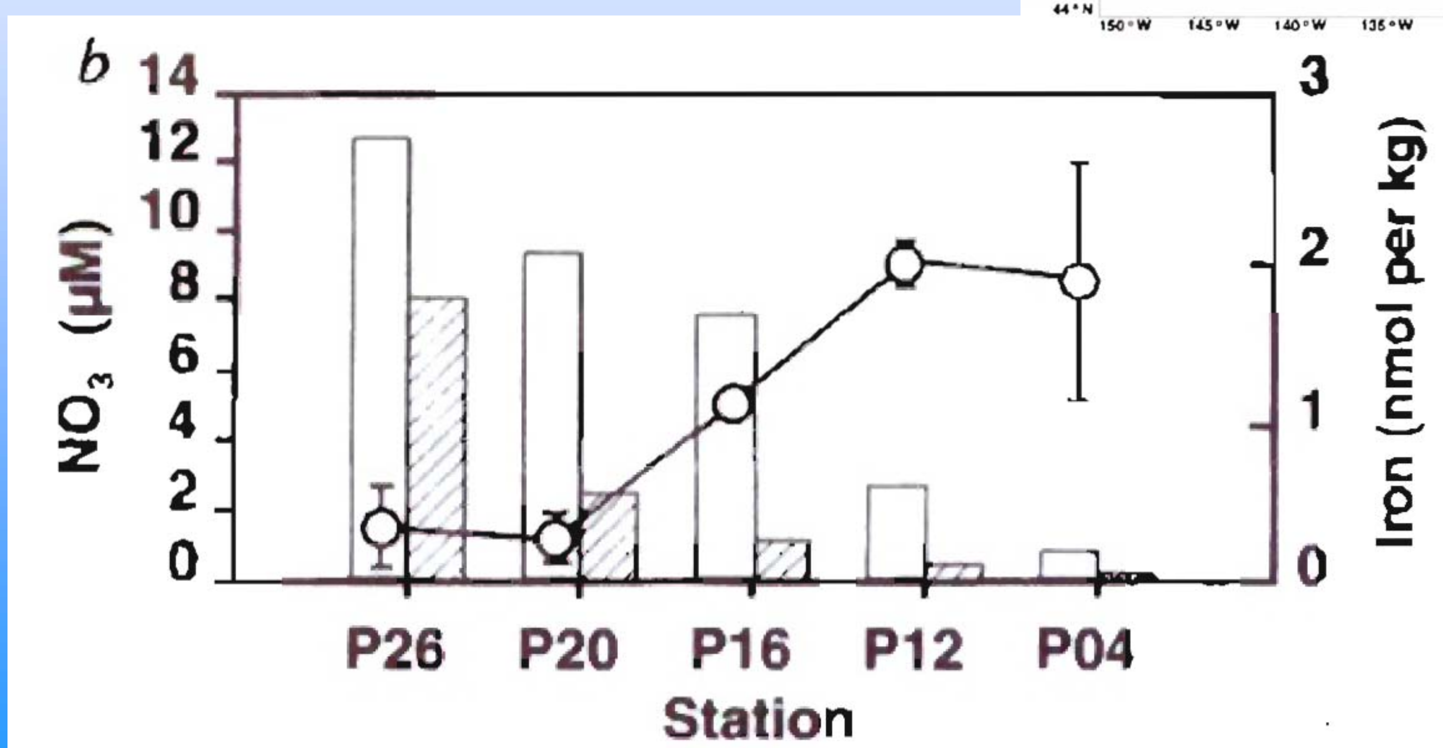


Aug. 5, 1987

Martin et al. 1989 *DSR*

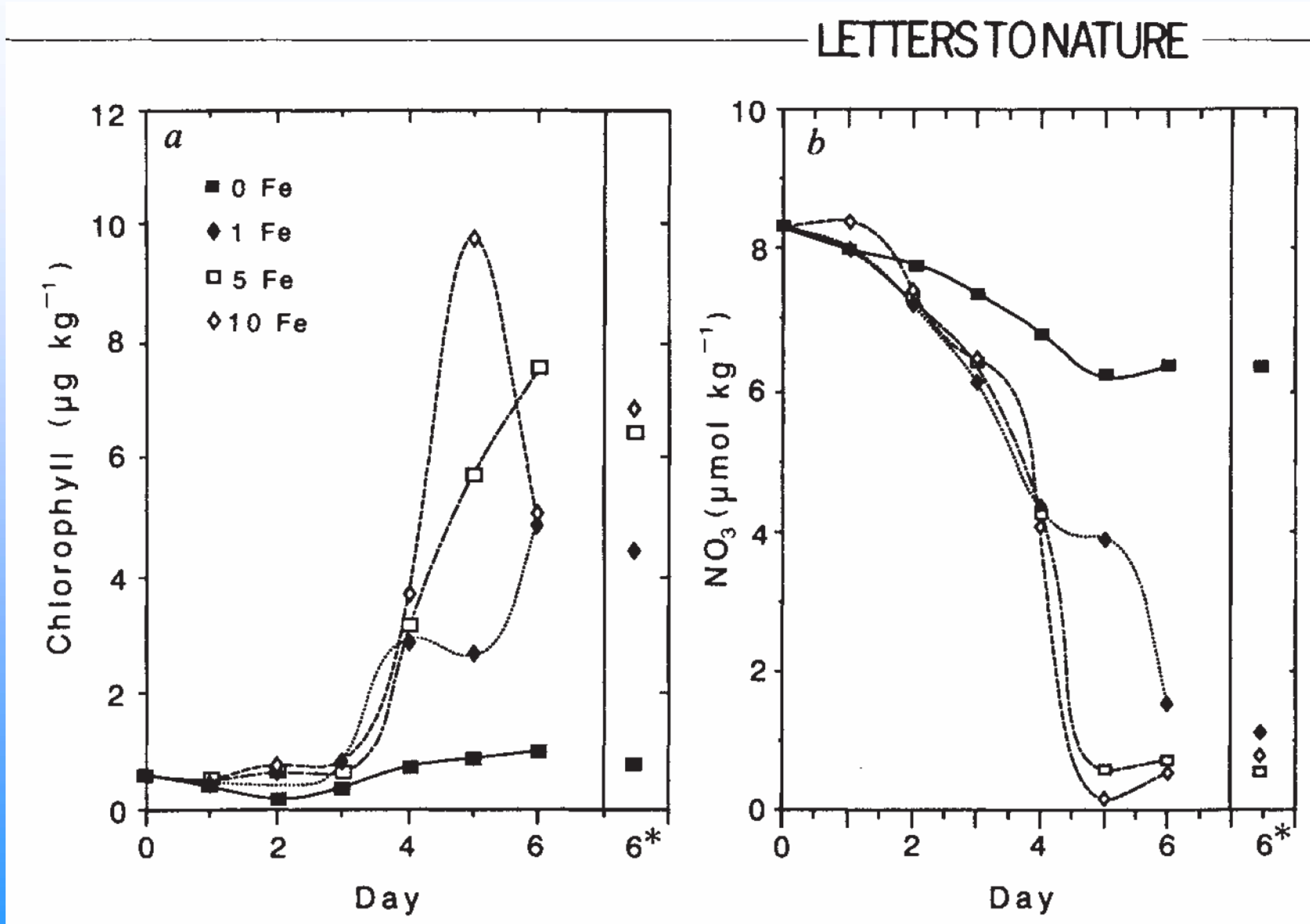
High Nutrient-Low Chlorophyll Conditions and Dissolved Fe Along Line P (Wong, Johnson)





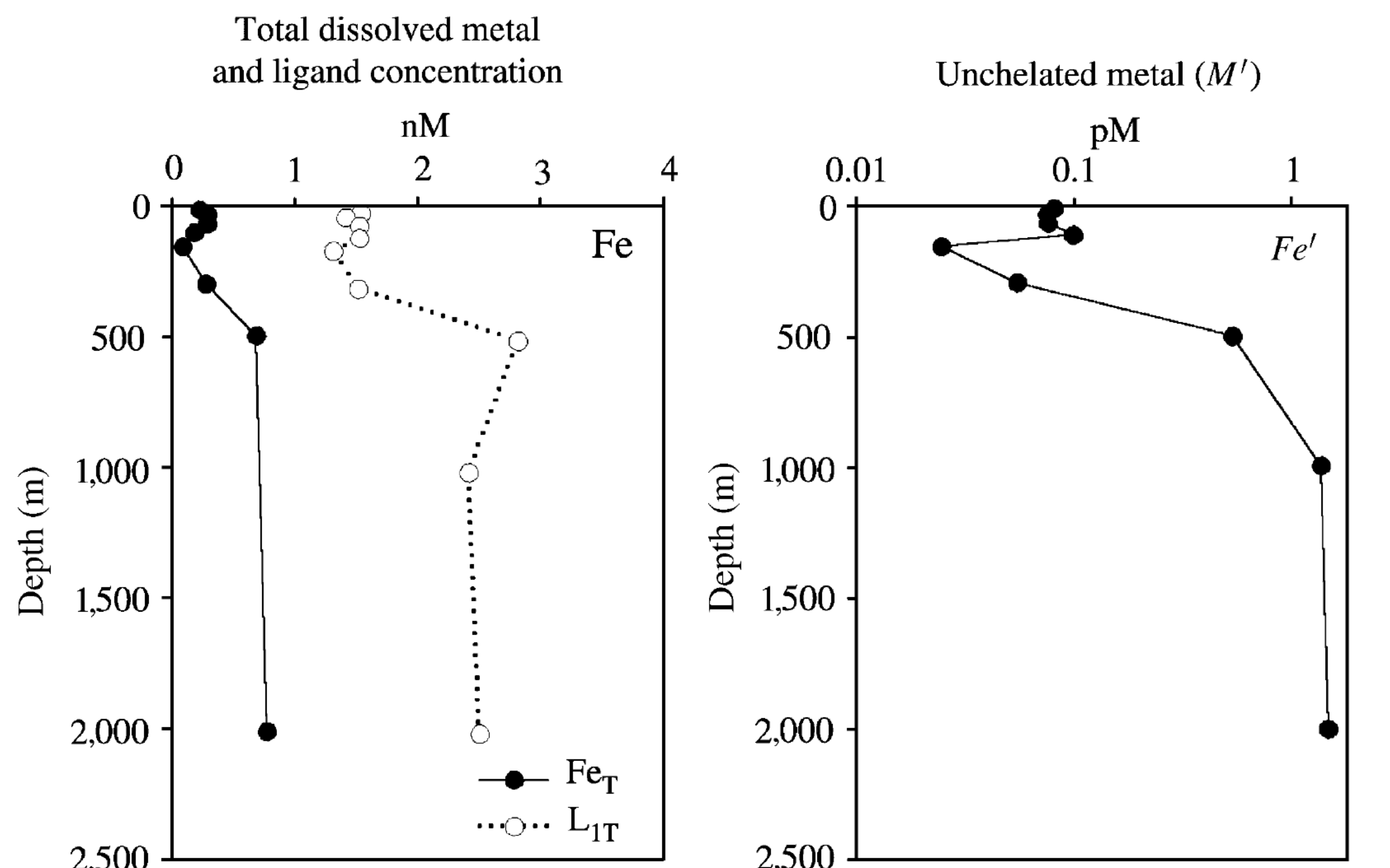
LaRoche et al. 1996 *Nature*

Fe Limits Algal Growth in Shipboard Incubation Studies at OSP



Martin and Fitzwater 1988 *Nature*

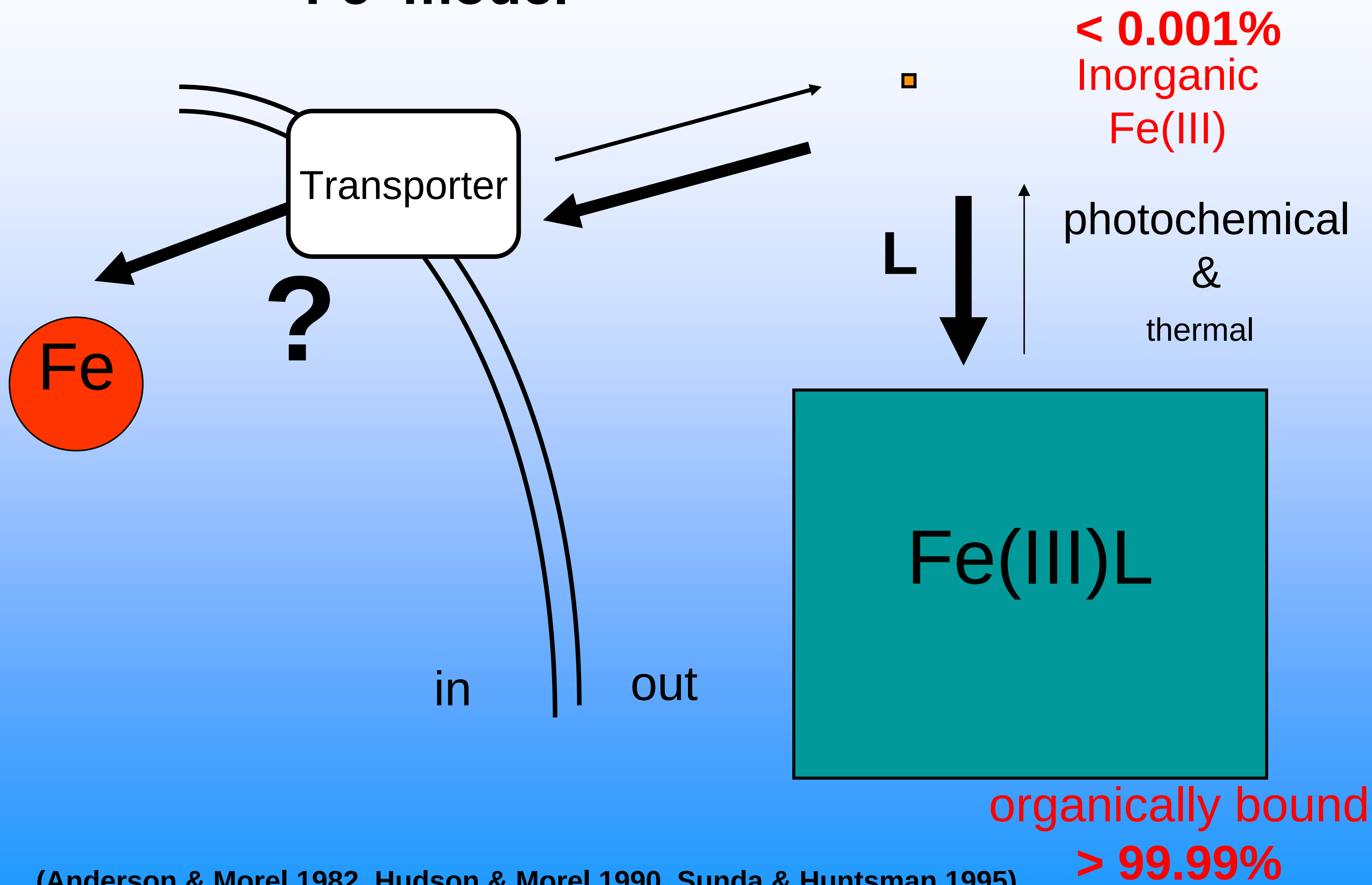
Organic Complexation of Dissolved Fe



after Rue and Bruland 1995 *Marine Chemistry*

Fe acquisition by phytoplankton
Fe’ model

Seawater Fe chemistry with strong L



(Anderson & Morel 1982, Hudson & Morel 1990, Sunda & Huntsman 1995)

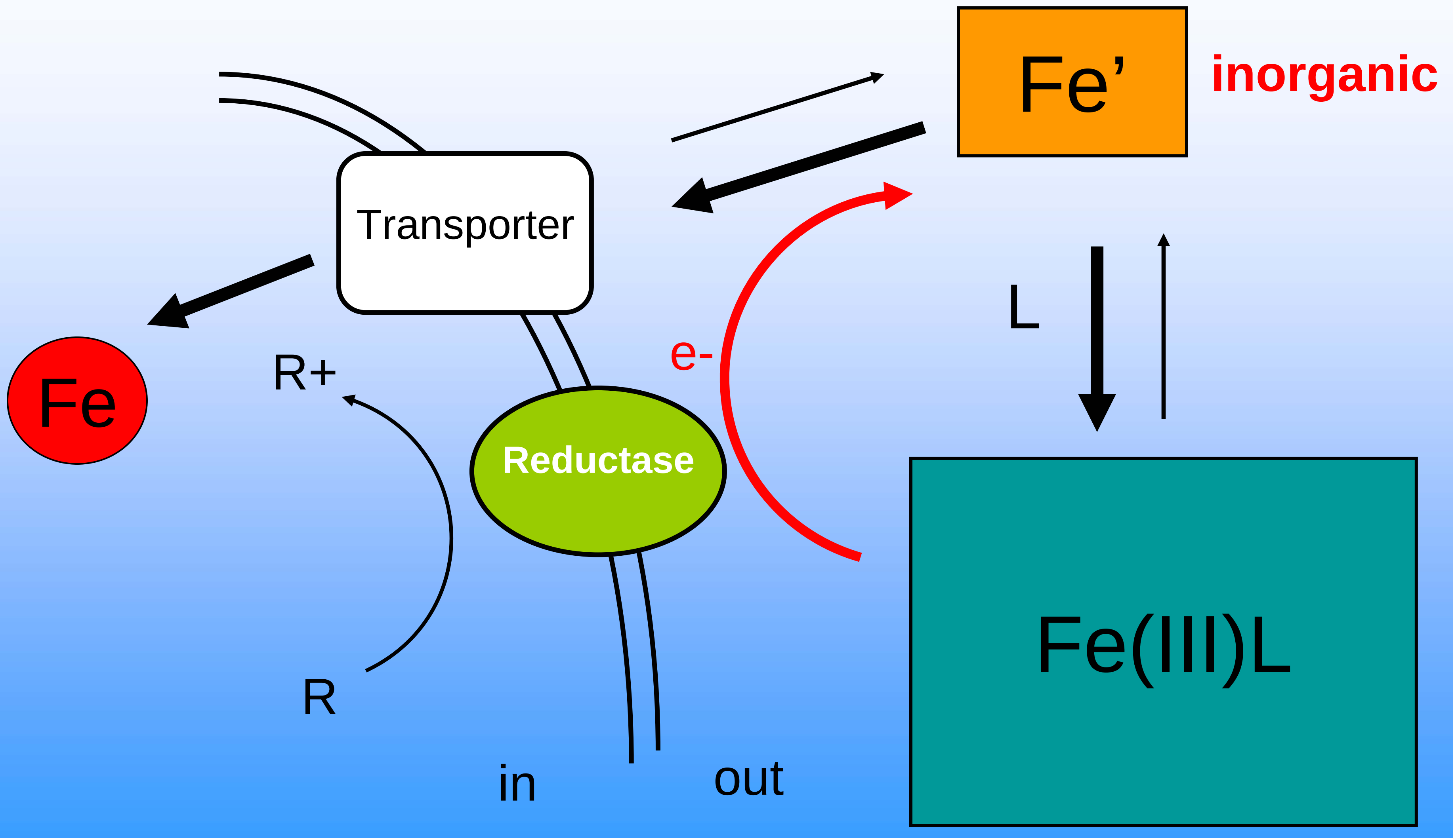
Utilization of Organically Complexed Fe by Marine Microbes and Fe-light Co-limitation

Maldonado and Price 1999 *DSR*

- Eukaryotic reduction of FeL at cell surface allows access to strong organic Fe complexes
- Physiological response of marine microbes to Fe limitation

New model of Fe acquisition by marine phytoplankton…

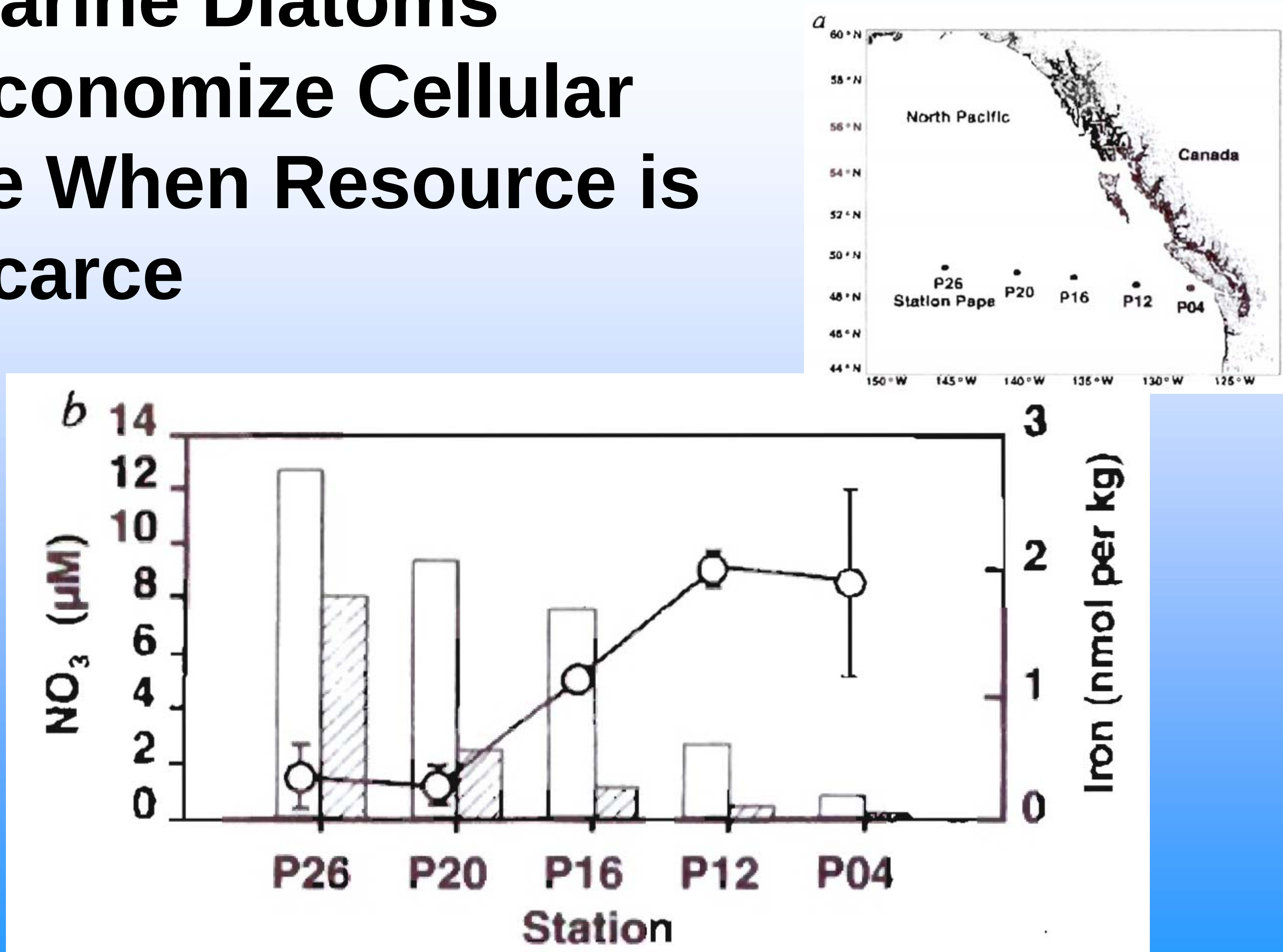
Revised Model for Fe Acquisition by Fe-limited eukaryotic phytoplankton



HIGH-AFFINITY Fe Transport System

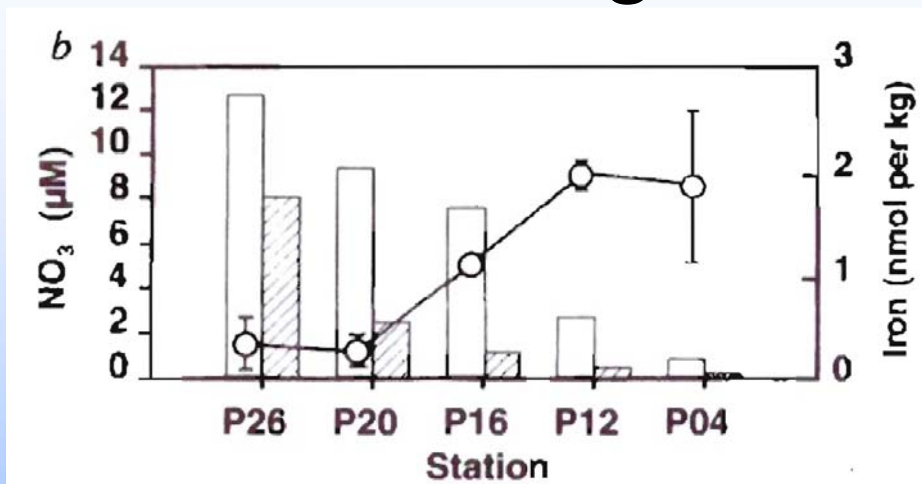
Organically bound

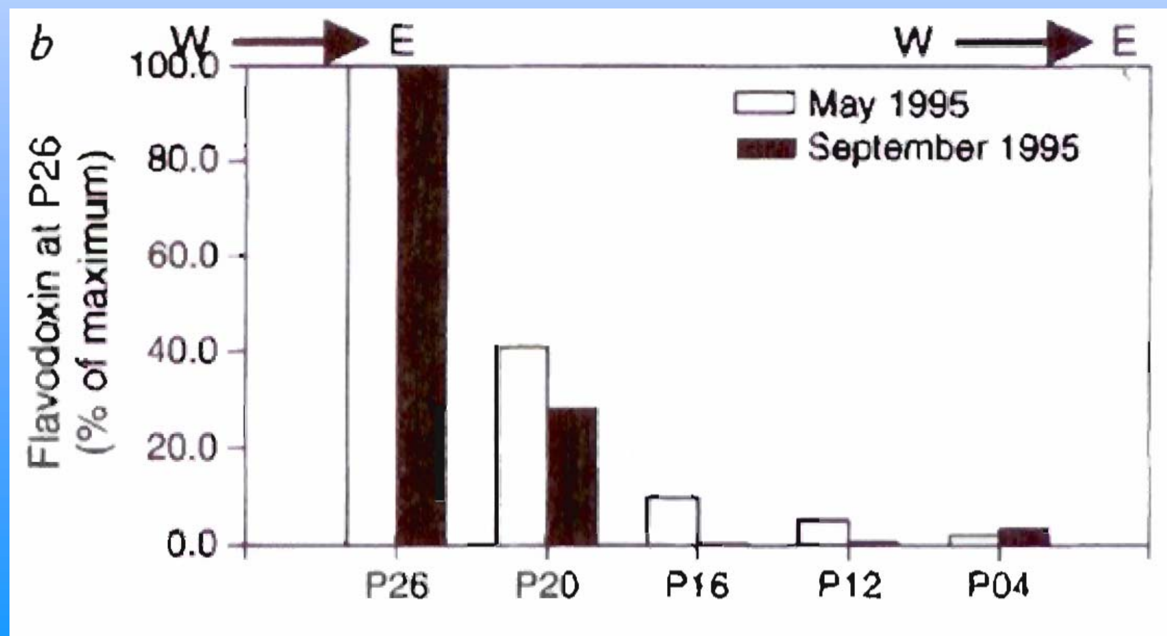
Marine Diatoms Economize Cellular Fe When Resource is Scarce



LaRoche et al. 1996 *Nature*

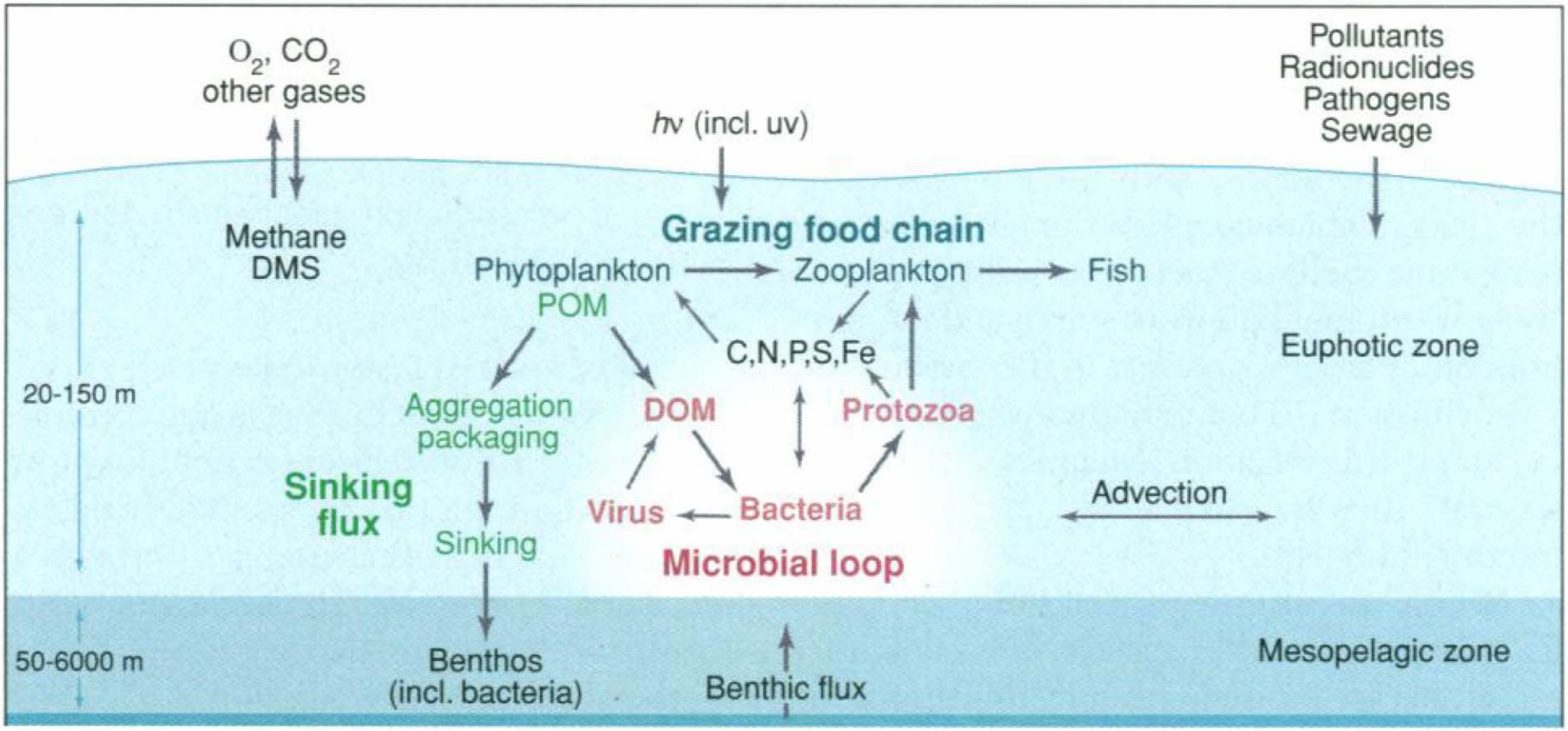
Substitution of Flavodoxin for Ferredoxin in Diatoms Along Line P





LaRoche et al. 1996 *Nature*

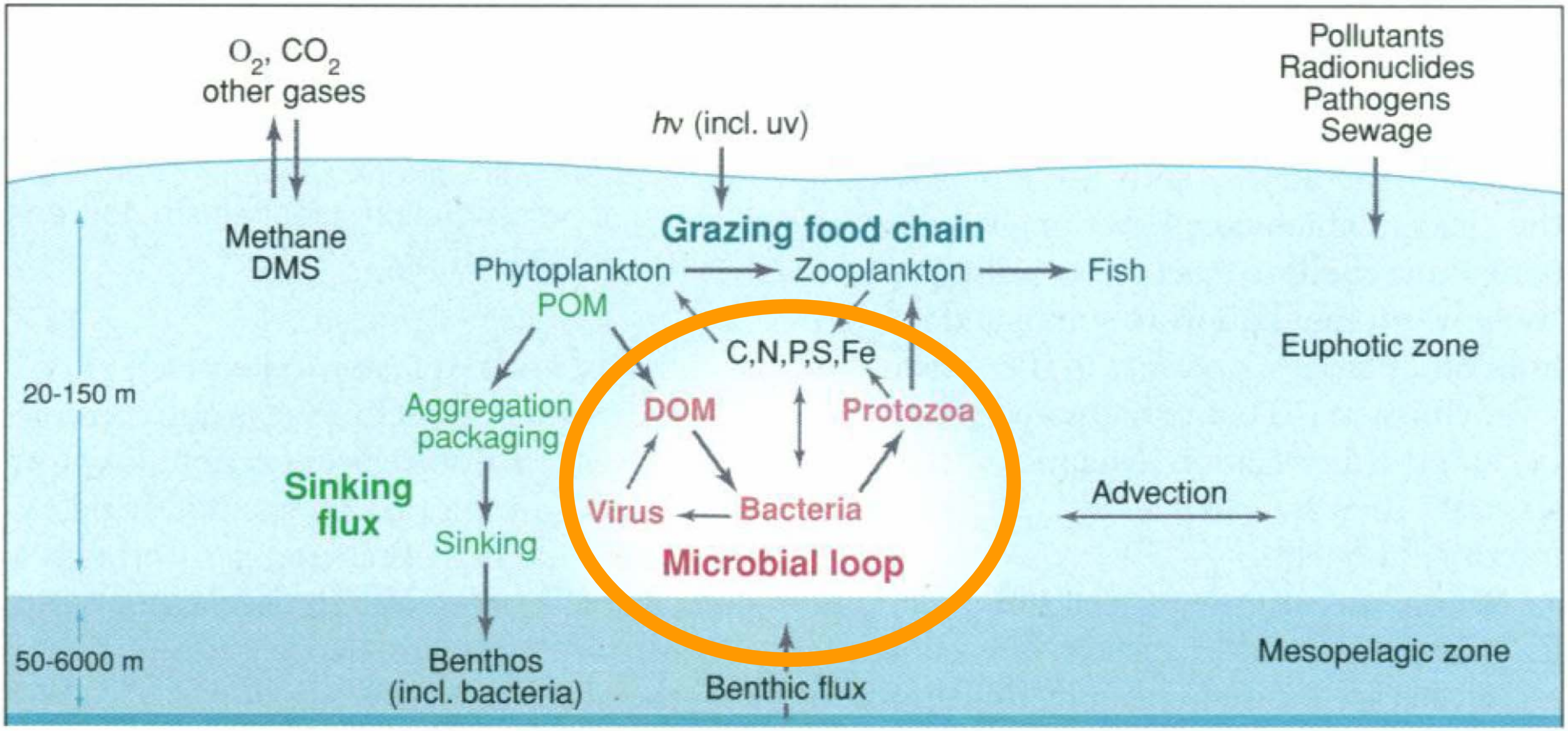
Fe Requirements and Physiology of Heterotrophic Marine Bacteria



The microbial loop: classical version. Modern view of the pelagic food web, emphasizing the microbial loop as a major path for organic matter flux. Competition between the three main flux paths—grazing food chain, microbial loop, and sinking—significantly affects oceanic carbon cycle and productivity. DOM, dissolved organic matter; DMS, dimethylsulfide.

Azam 1998 *Science*

Fe Requirements and Physiology of Heterotrophic Marine Bacteria



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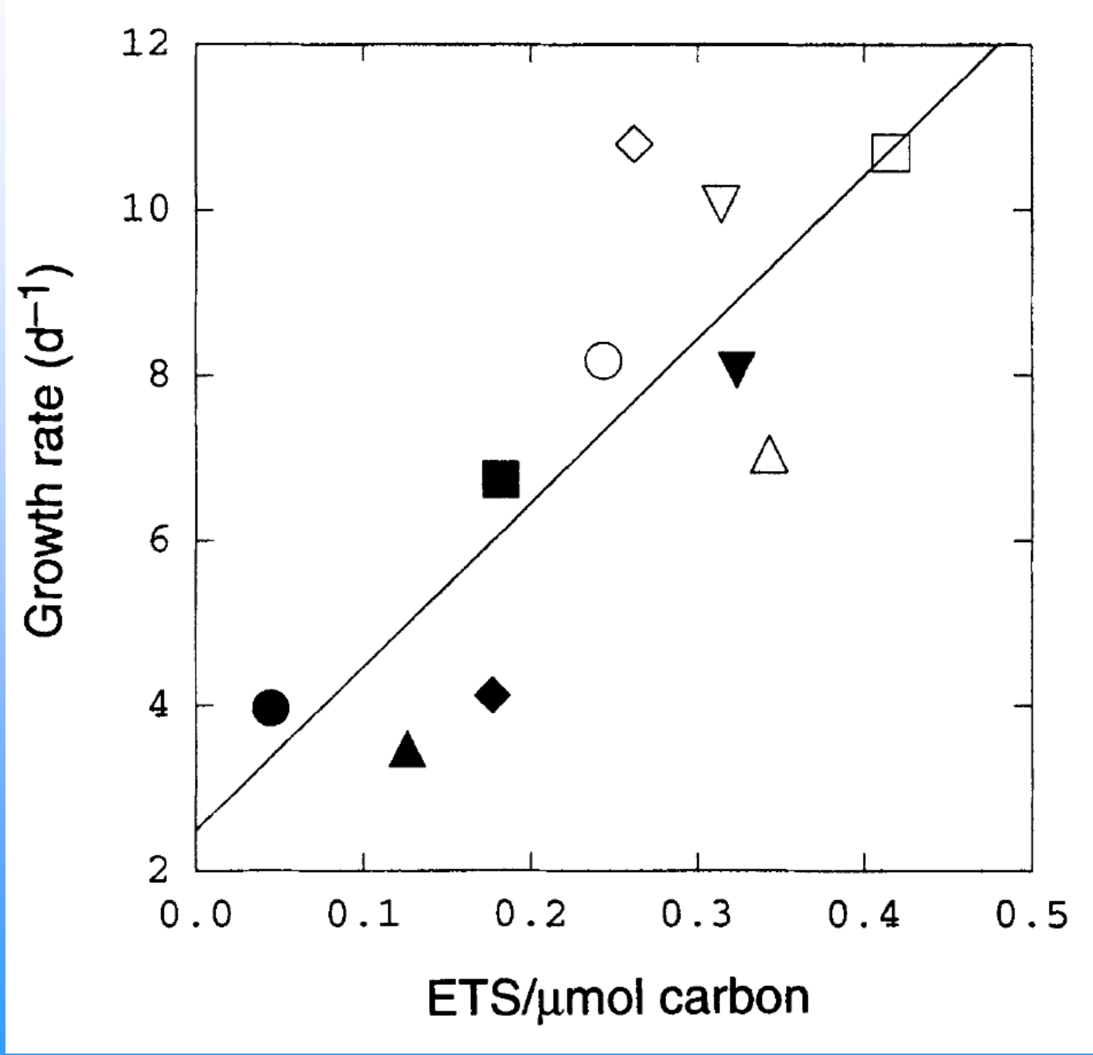
Azam 1998 *Science*

Fe Requirements and Physiology of Heterotrophic Marine Bacteria at OSP

Tortell, Maldonado and Price 1996 *Nature*

1. **Heterotrophic bacteria have higher Fe:C than eukaryotic phytoplankton**
2. **Constitute ~50% of total biogenic Fe**
3. **Account for 20-45% of Fe uptake**

Bacterial ETS Activity and Carbon Use Efficiencies Affected By Fe-Limitation



Tortell, Maldonado and Price 1996 *Nature*

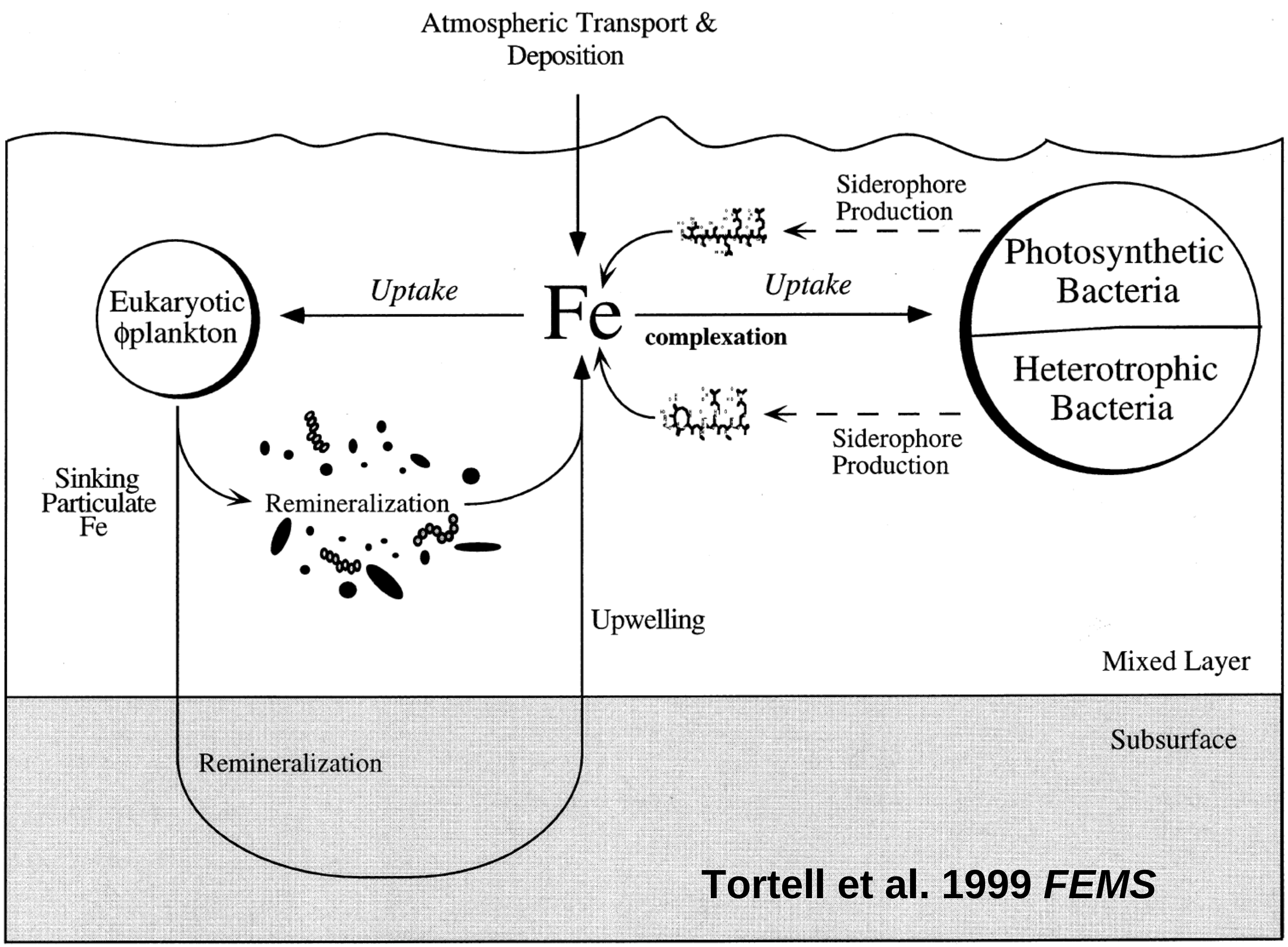
Fe Requirements and Physiology of Heterotrophic Marine Bacteria at OSP

Tortell, Maldonado and Price 1996 *Nature*

4. **Bacterial Fe quotas in the field imply Fe-limitation**
5. **Fe-limited cultures have lower ETS activity, growth rates and C use efficiencies**

In Fe-limited ecosystems heterotrophic bacteria may respire more organic carbon reducing the amount available to higher trophic levels.

Fe Biogeochemistry in Surface Waters of HNLC Areas



Tortell et al. 1999 *FEMS*

Trace Metal – Biota Interactions

1. There is a reciprocal relationship
   – Trace metal distributions and availability affect the microbial community structure
   – Microbes can alter the chemical speciation and distribution of trace metals

2. The biogeochemical cycles of C, N and P (Si) can be modulated by trace metals

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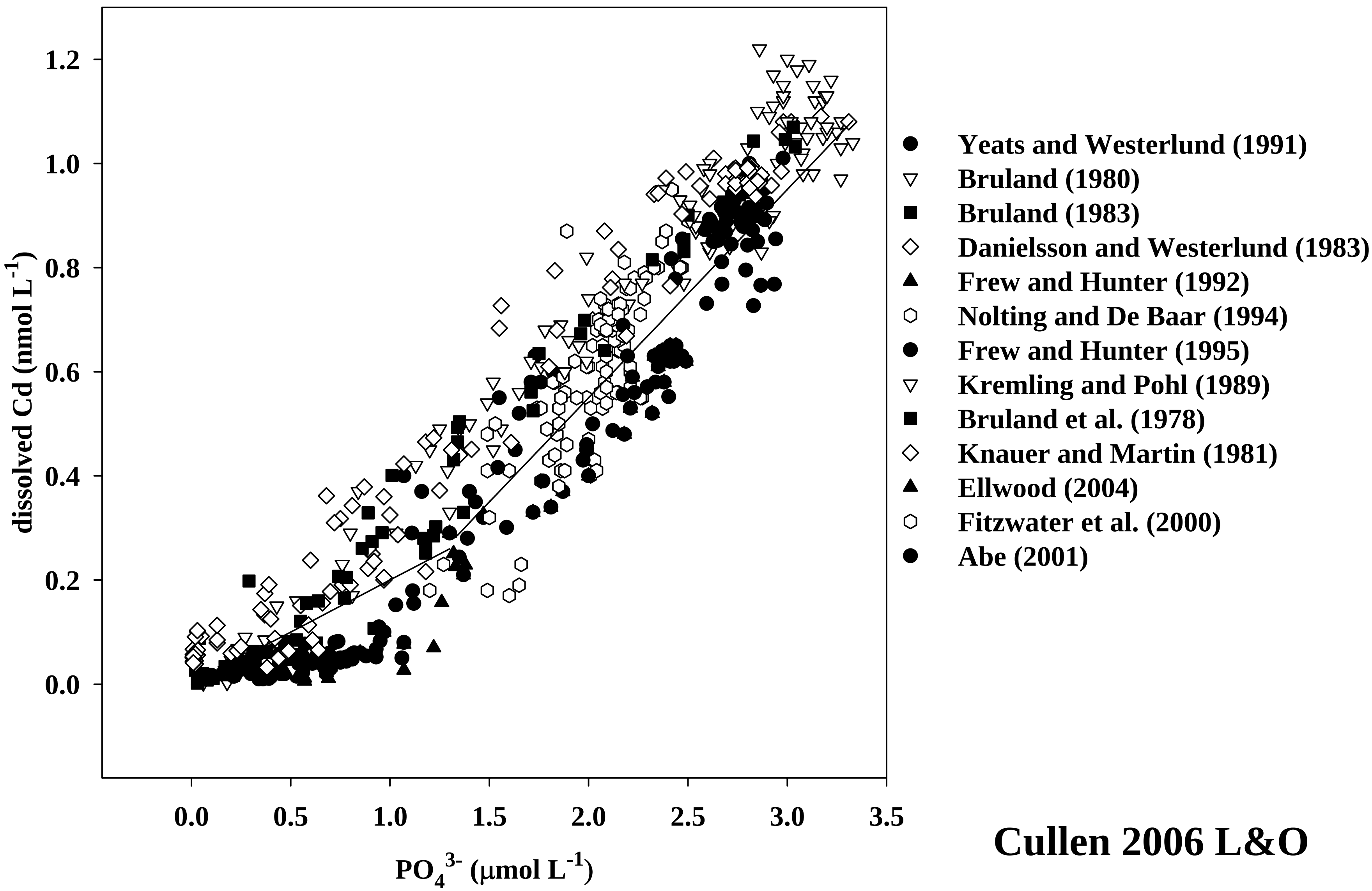
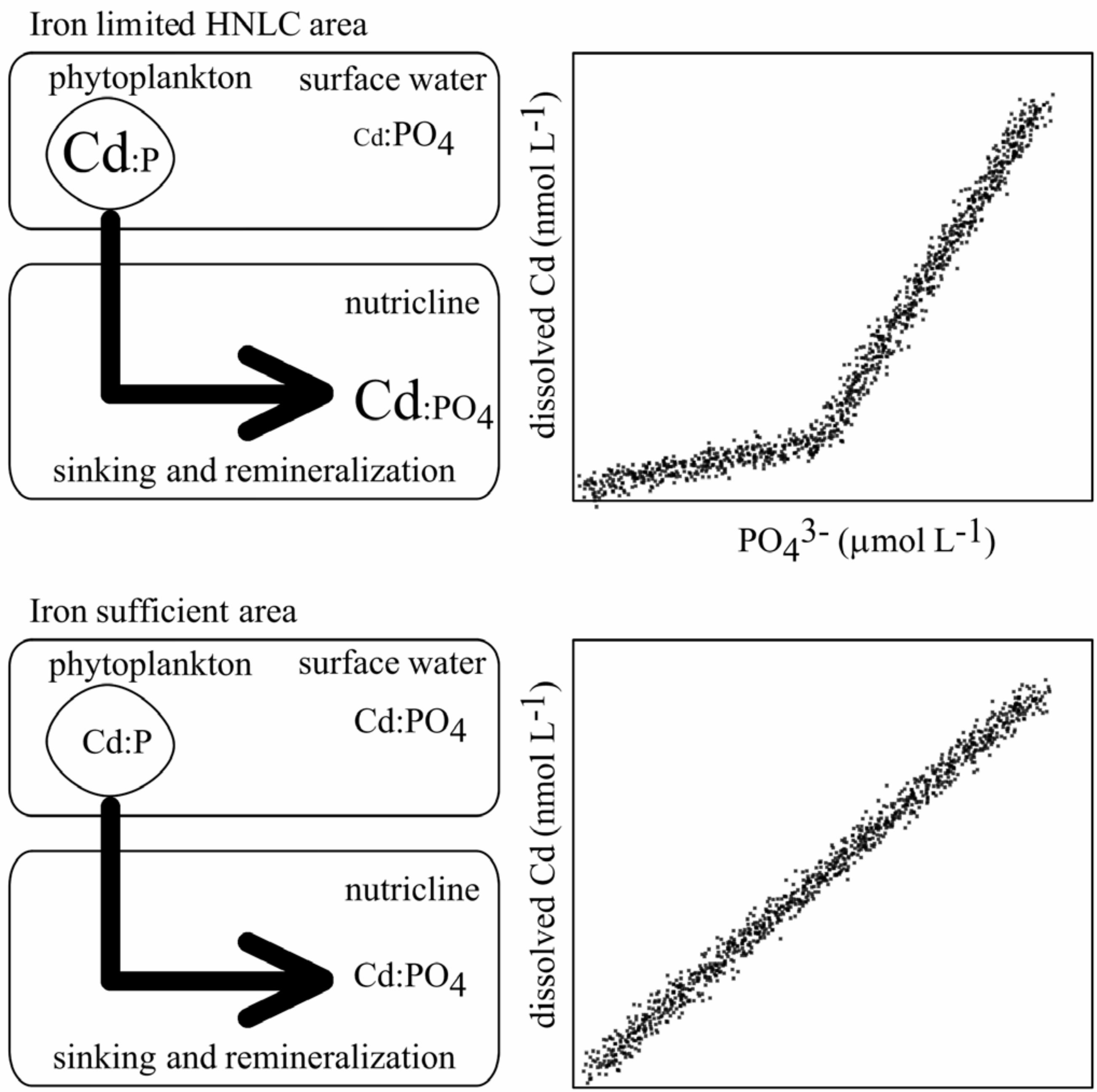
Global Dissolved Cadmium Versus Phosphate Relationship



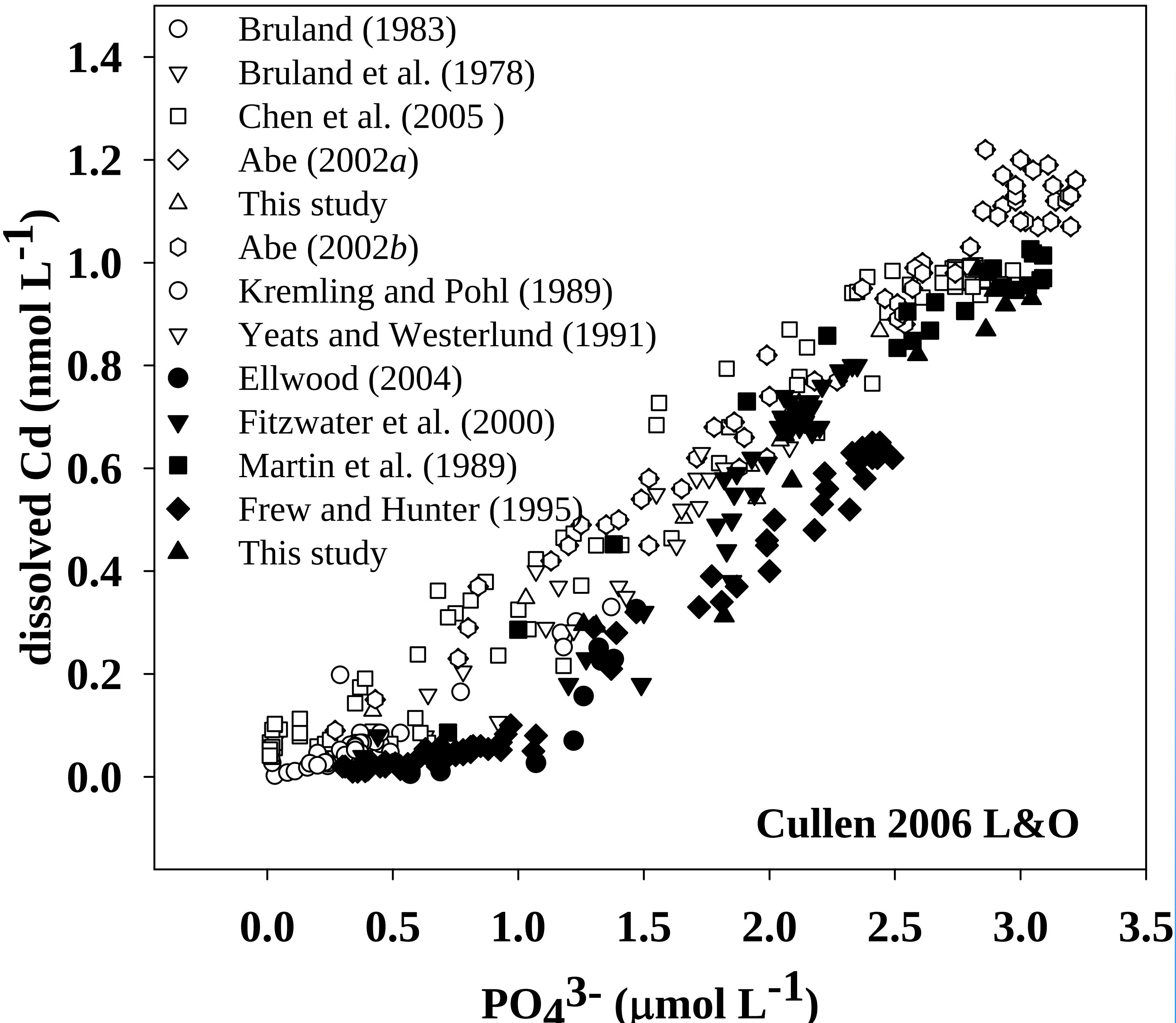
Cullen 2006 L&O

The Effect of Fe Bioavailability on the Cd:P Composition of Phytoplankton

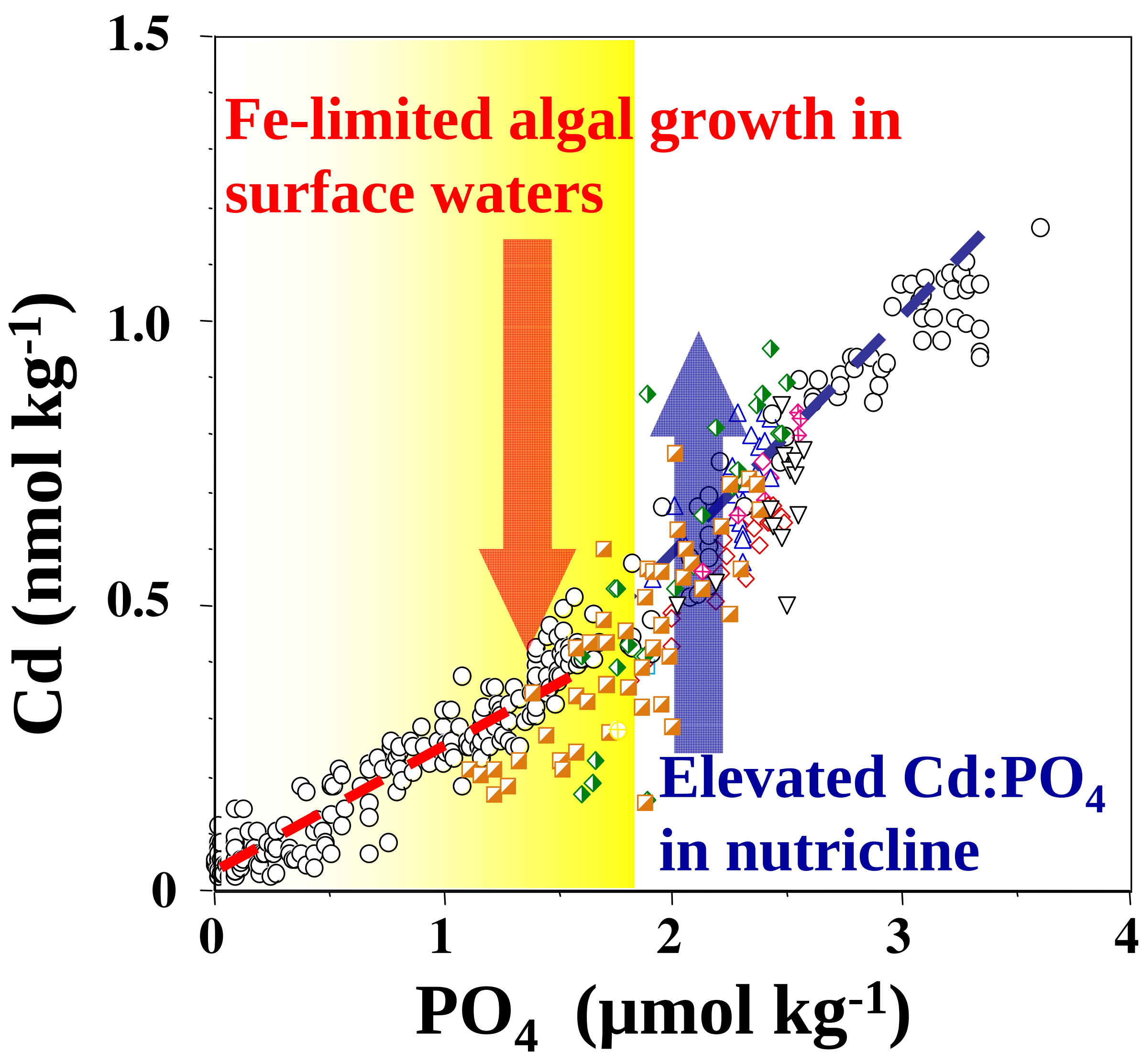


Cullen 2006 L&O

Dissolved Cd:PO_4 Lower in HNLC Fe-Limited System

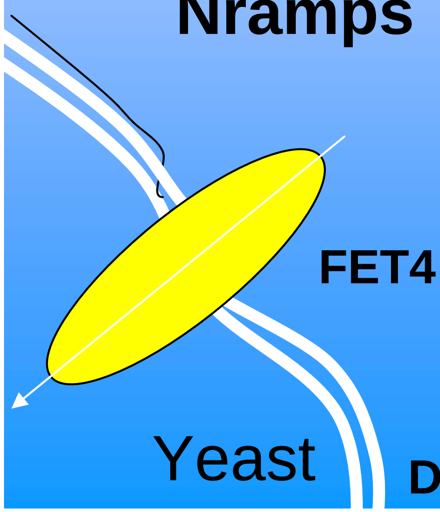


An Fe link to the Cd:PO_4 kink?

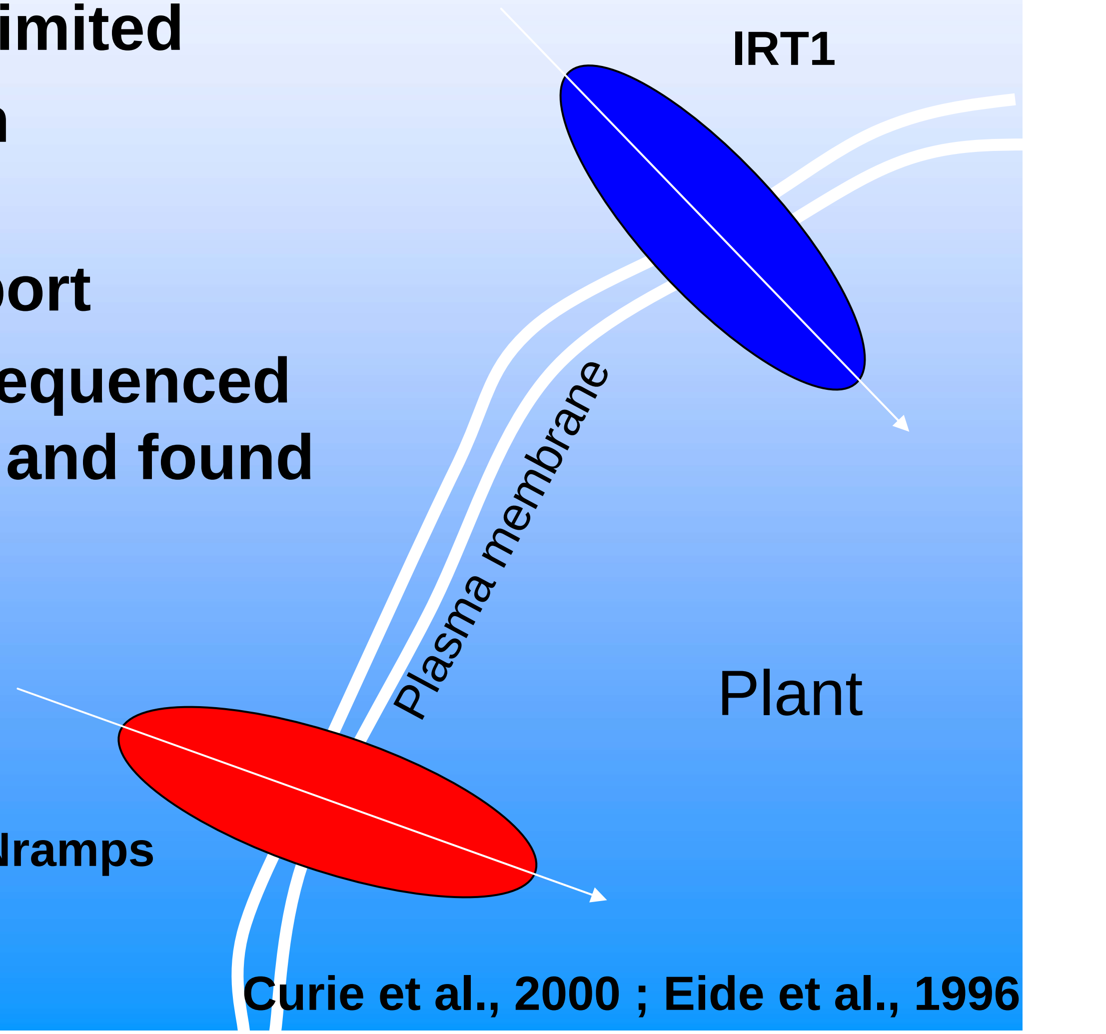


Mechanism: Non-specific Fe Transporter (Lane and Maldonado, UBC)

- **Up-regulated under Fe-limited**
- **Fe deficient plants often accumulate Cd**
- **Cd inhibits Fe (II) transport**
- **Searched the recently sequenced *T. pseudonana* genome and found Nramps**



Dix et al., 1997

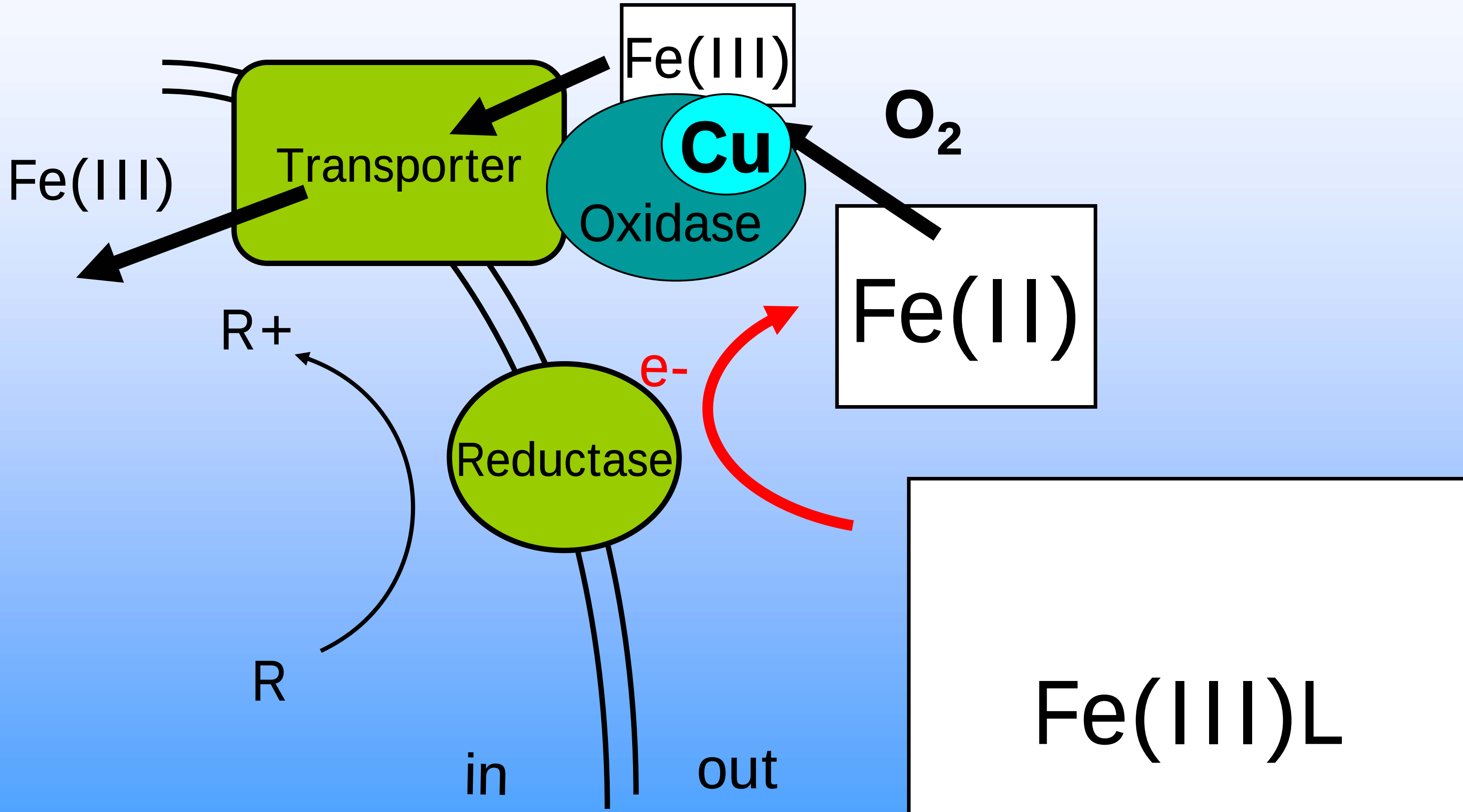


Curie et al., 2000 ; Eide et al., 1996

The role of Cu in the high-affinity Fe transport system of marine diatoms (Maldonado et al. in press *L&O*)

- **Investigations historically (even just 5 years ago) have focused on toxic effects that shape microbial community structure (Barber and Ryther 1969, Moffett et al.)**
- **Granger and Ward 2002 *L&O* …Cu limitation and N_2O production by denitrifiers**
- **What physiological processes are affected by Cu limitation in marine diatoms?**

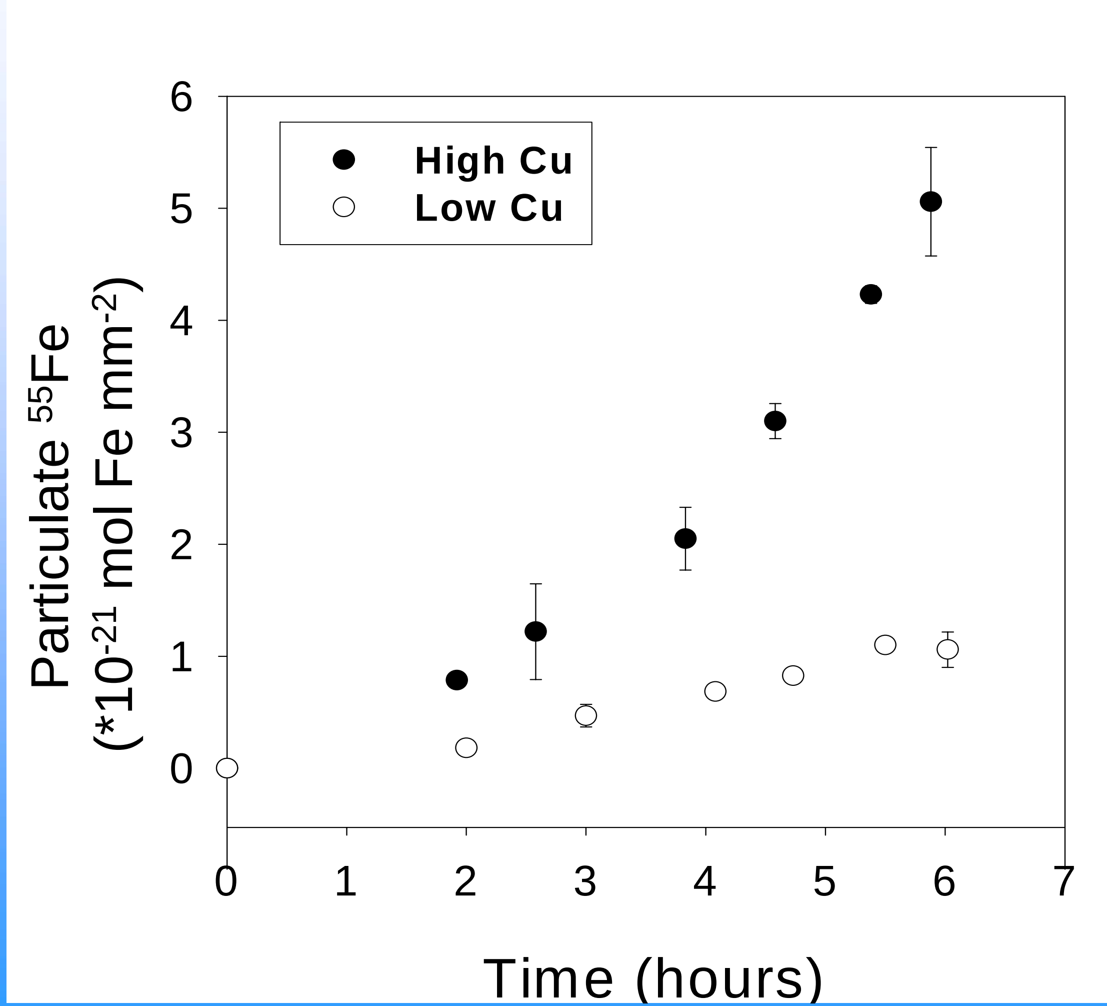
Mechanism of Fe acquisition by *Fe-limited* marine diatoms



$4Fe^{2+} + O_2 + 4H^+ = 4Fe^{3+} + \mathbf{2H_2O}$

$4Fe^{2+} + 4H^+ + O_2 = 4Fe^{3+} + \mathbf{H_2O_2}$

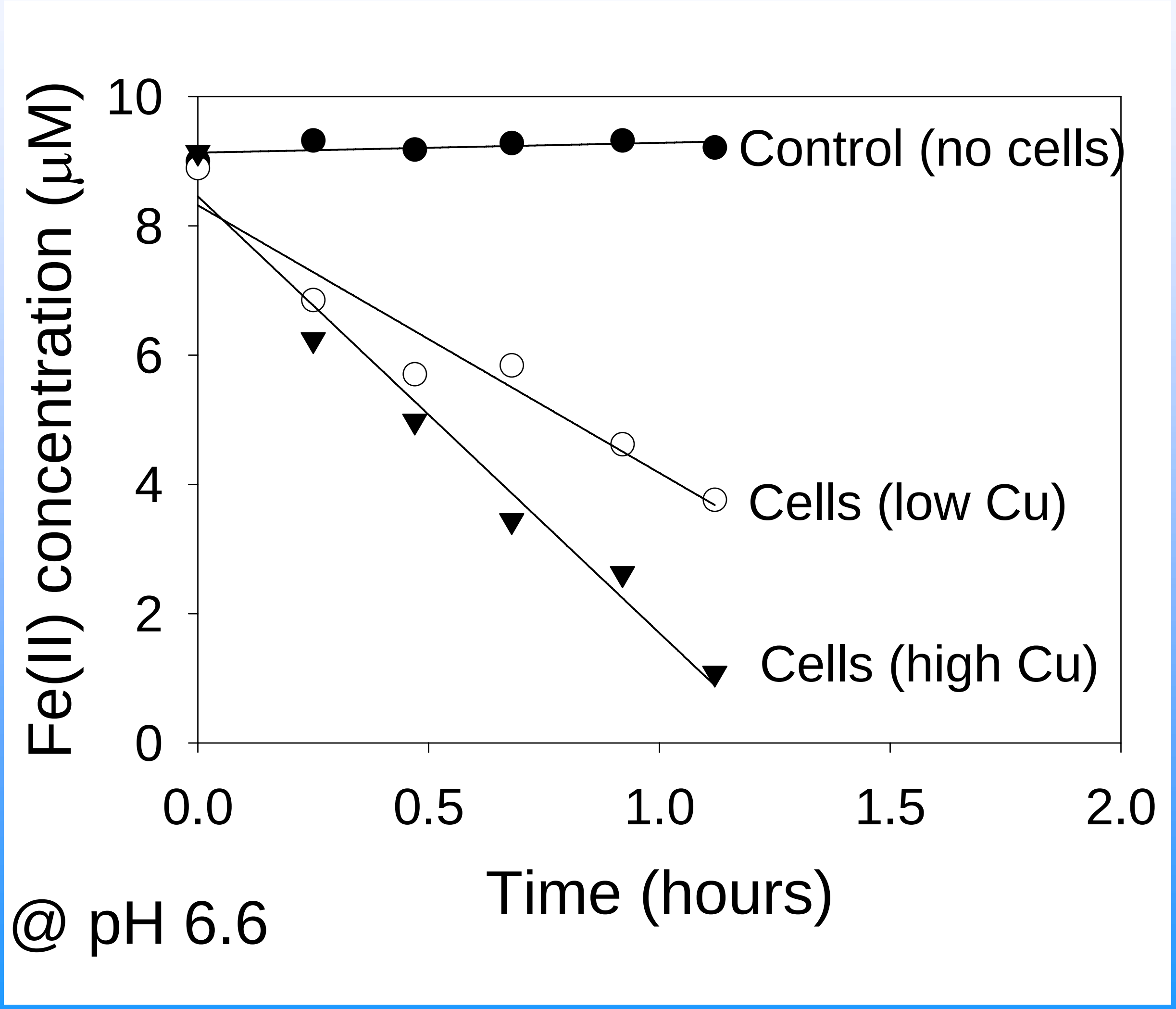
Effect of Cu-limitation on Fe transport by Fe-limited *Thalassiosira oceanica*



6 fold difference in Fe uptake rates

100 nM Fe : 1 µM siderophore (DFB)

Effects of Cu addition on Fe(II) oxidation by Fe-Cu-limited *T. oceanica*



Where do we go from here?

- **We are poised to develop more mechanistic understandings of the cellular level processes that can affect basin scale distribution of trace elements and CNPSi biogeochemical cycling**

- **The subarctic Pacific is an ideal natural laboratory and the Line P program has proven the ideal platform to probe metal – biota interactions**