The role of ice melting in providing available Fe to the surface water of the Bering Sea Shelf

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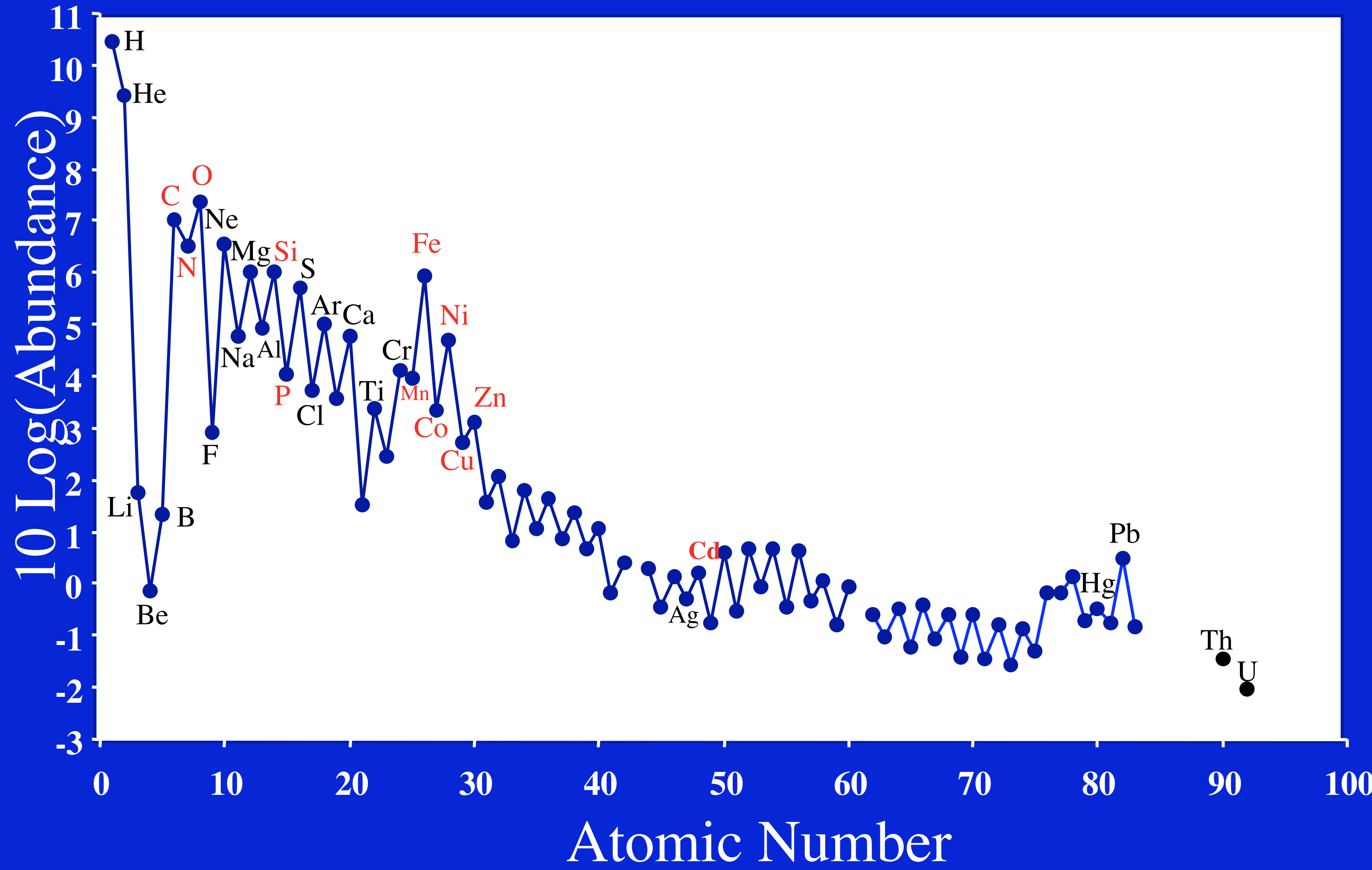
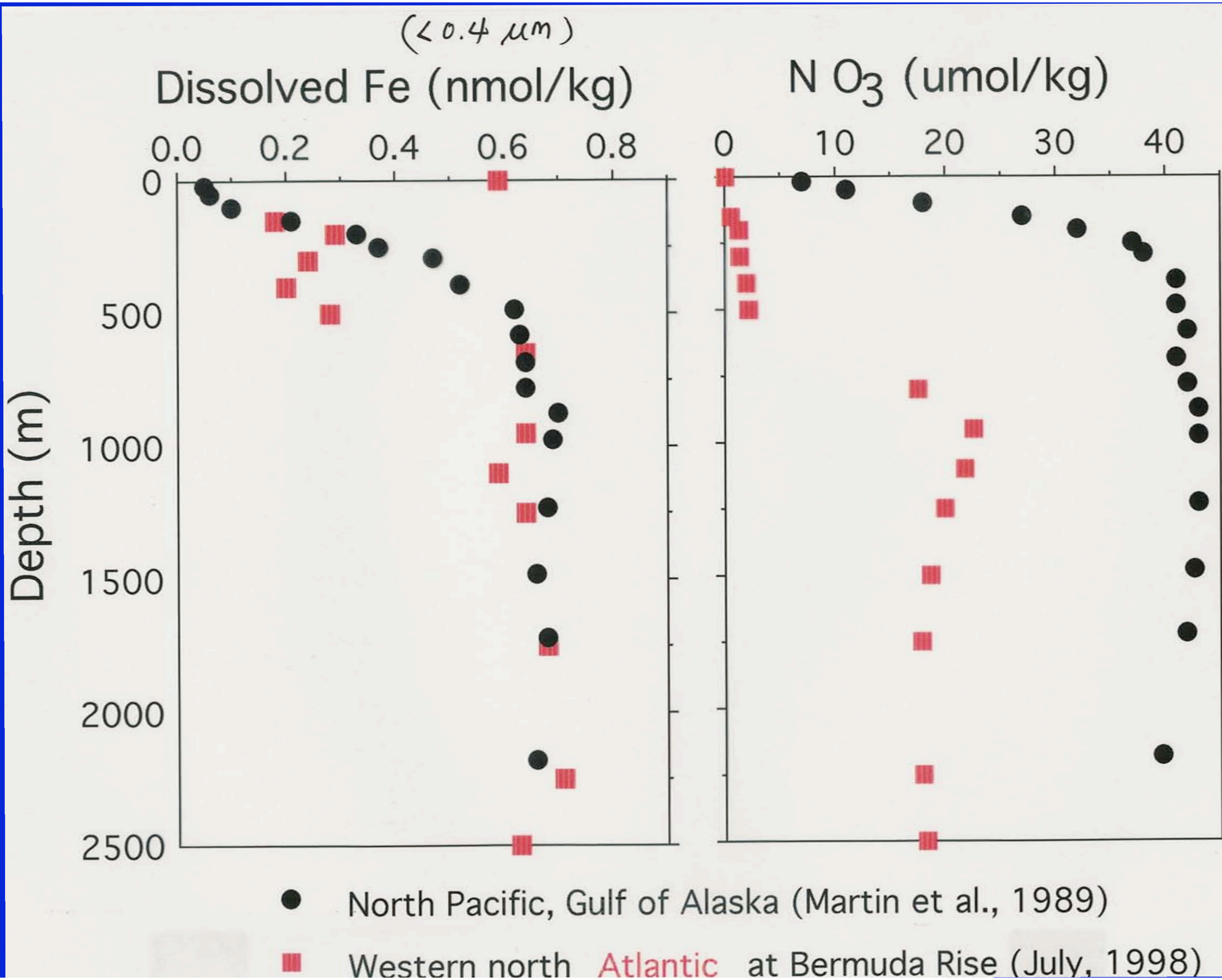
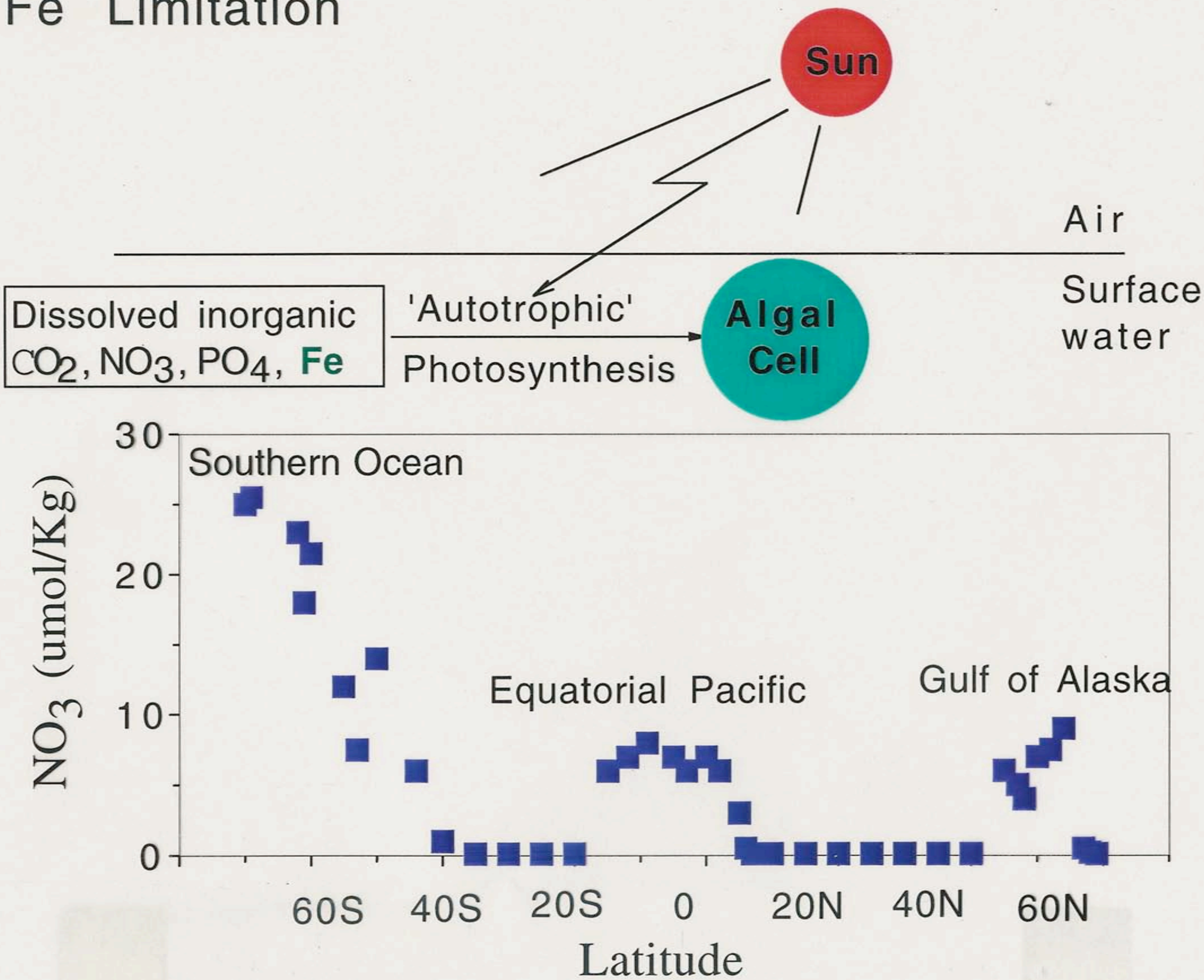
Funded by OPP: $273,000 for 3 years

Abundance of Chemical Elements




(<0.4 μm)
Dissolved Fe (nmol/kg)
0.0
0.2
0.4
0.6
0.8
N O3 (umol/kg)
0
10
20
30
40
Depth (m)
0
500
1000
1500
2000
2500
North Pacific, Gulf of Alaska (Martin et al., 1989)
Western north Atlantic at Bermuda Rise (July, 1998)

Fe Limitation



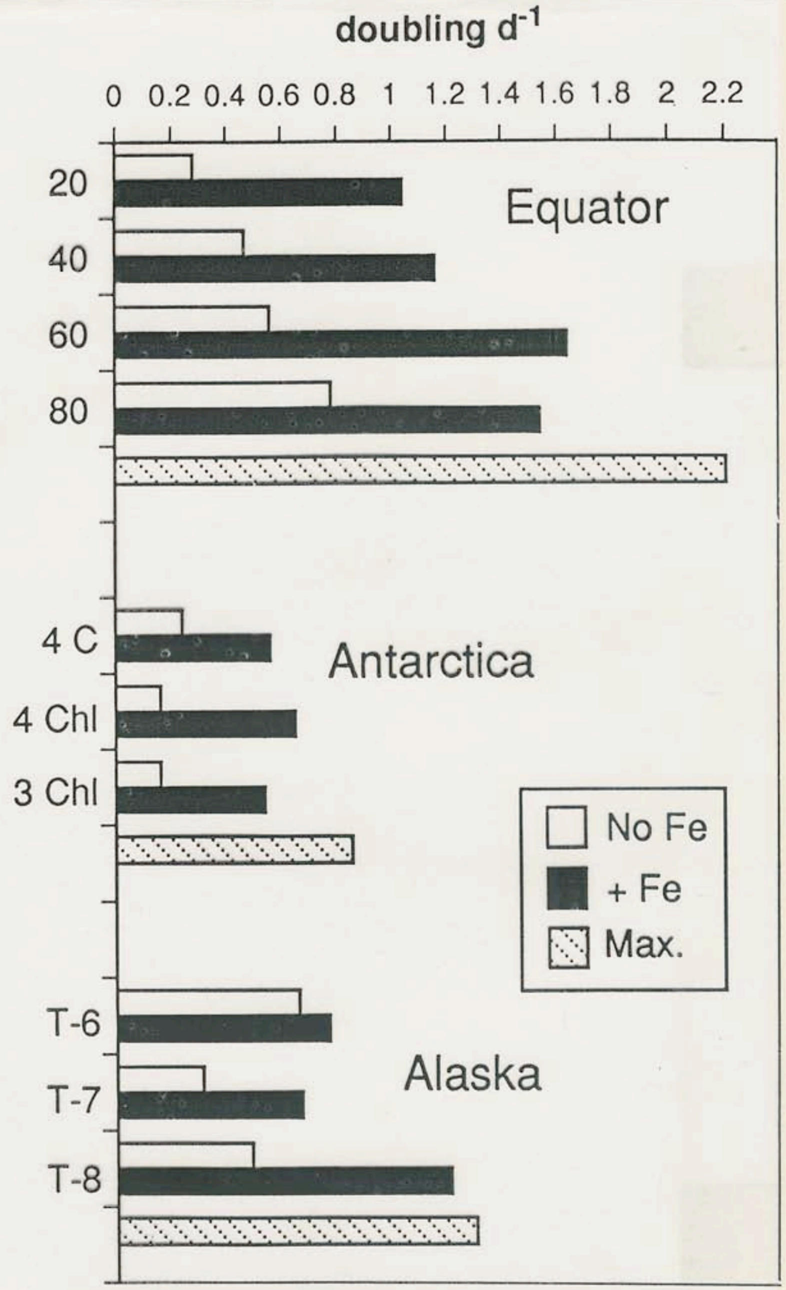
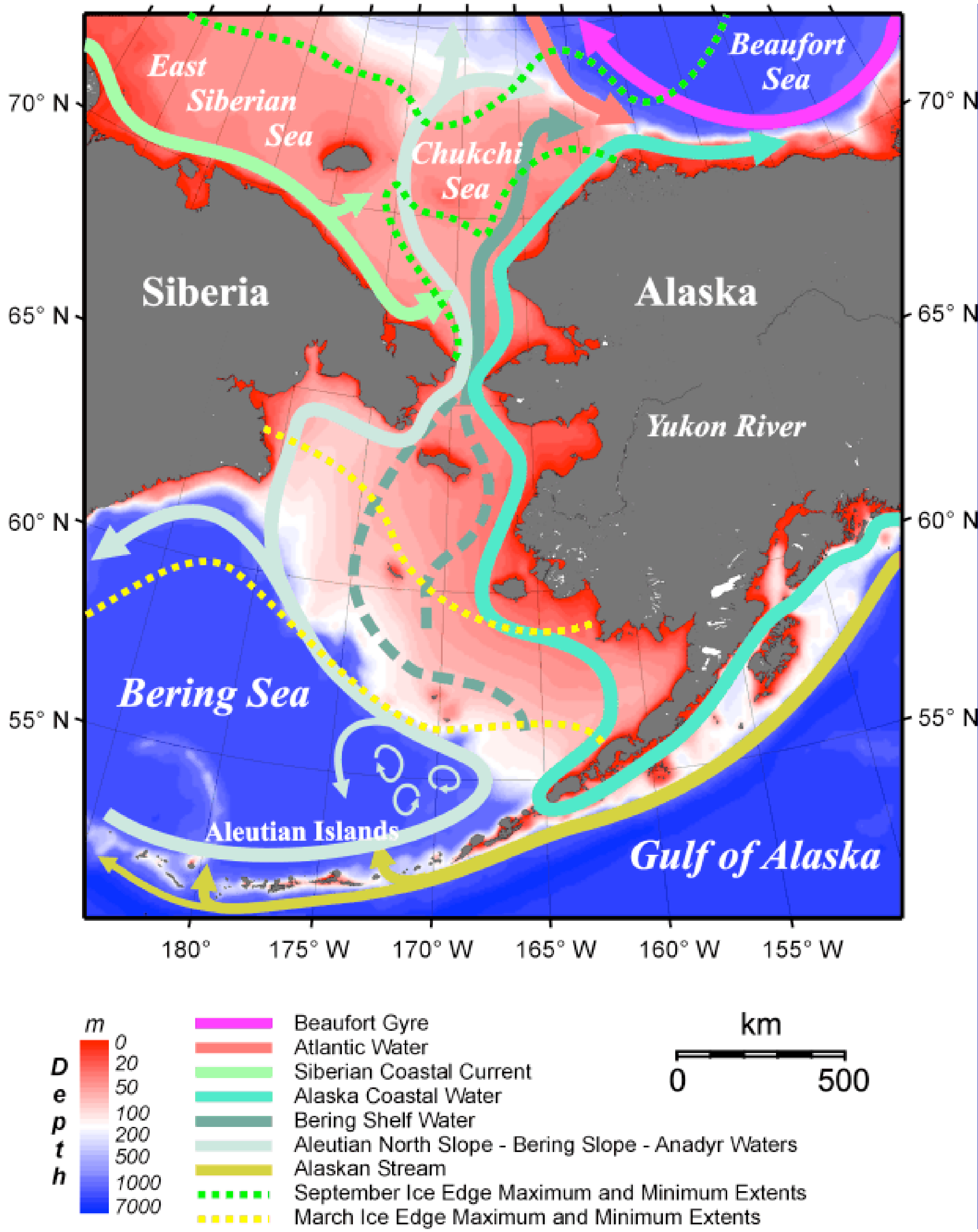


Fig. 2: Comparisons of the rates at which phytoplankton double each day with and without added iron.

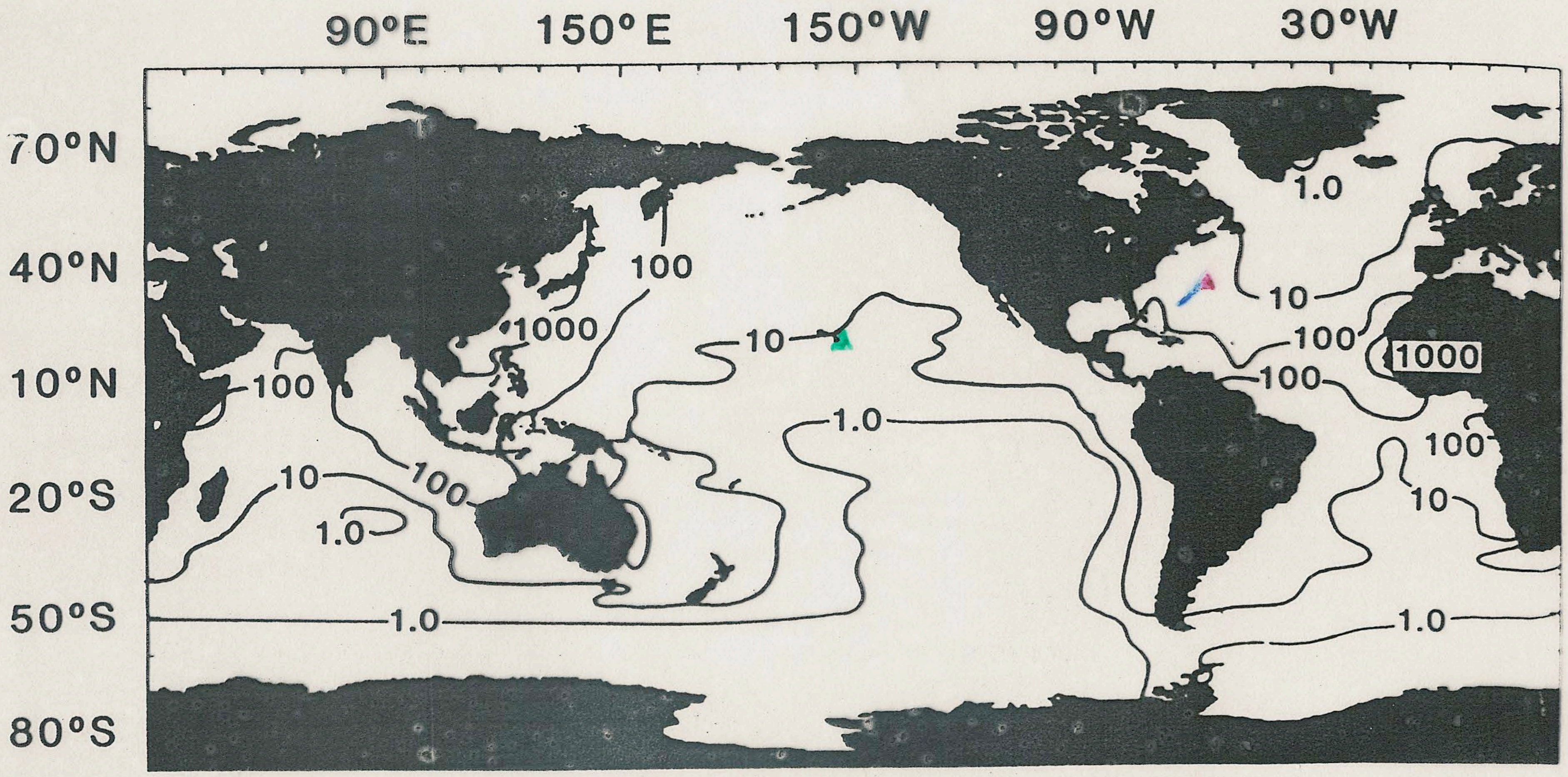


High quality Fe data are needed to understand the demand for and the supply of Fe in the Bering Sea Shelf.

Fe sources

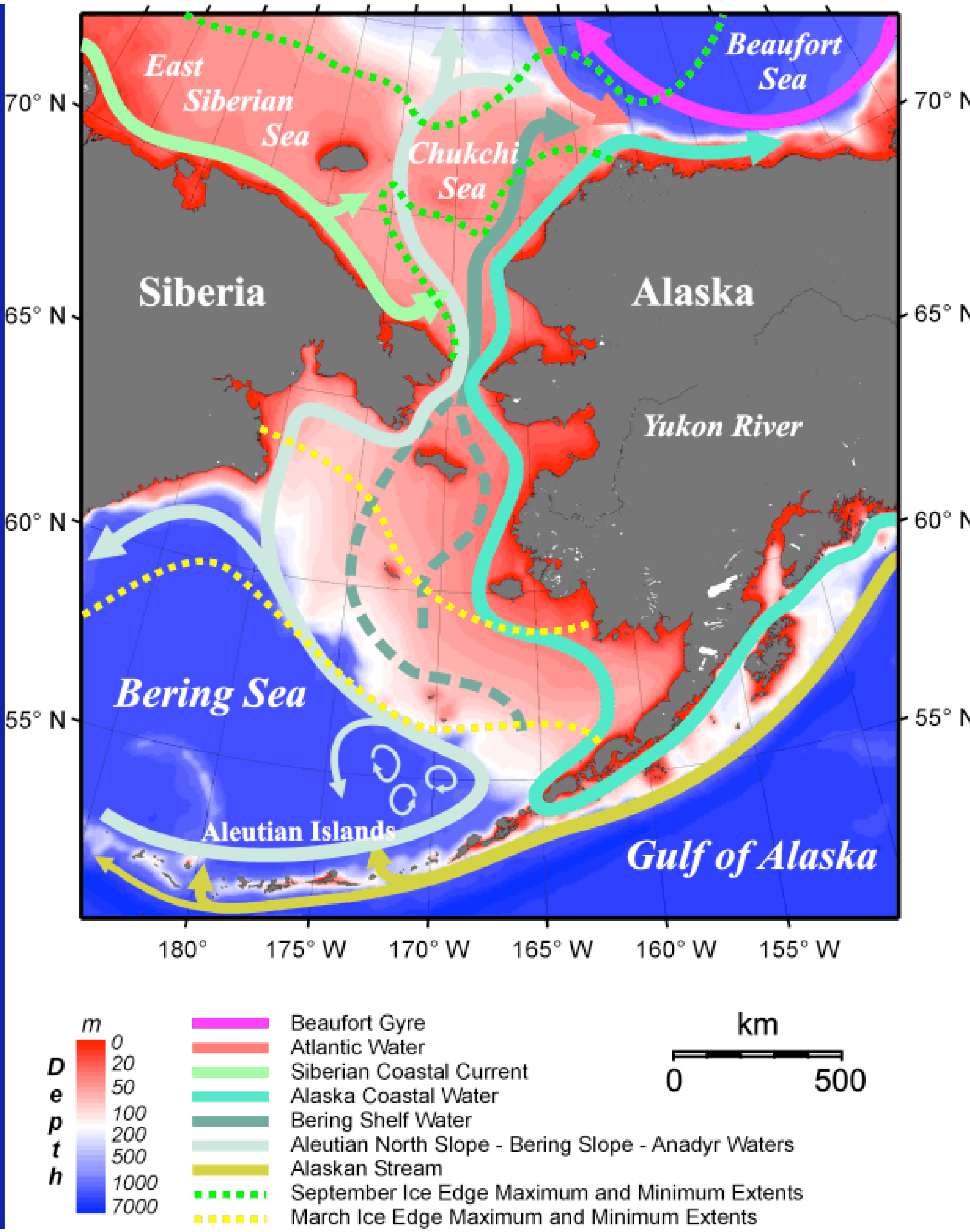
- Yukon river runoff
- Fresh water in the Alaska Coastal Current
- Shelf bottom sediment
- Eolian Fe input from Asian arid region and Aleutian volcanoes

Duce and Tindale (1991)

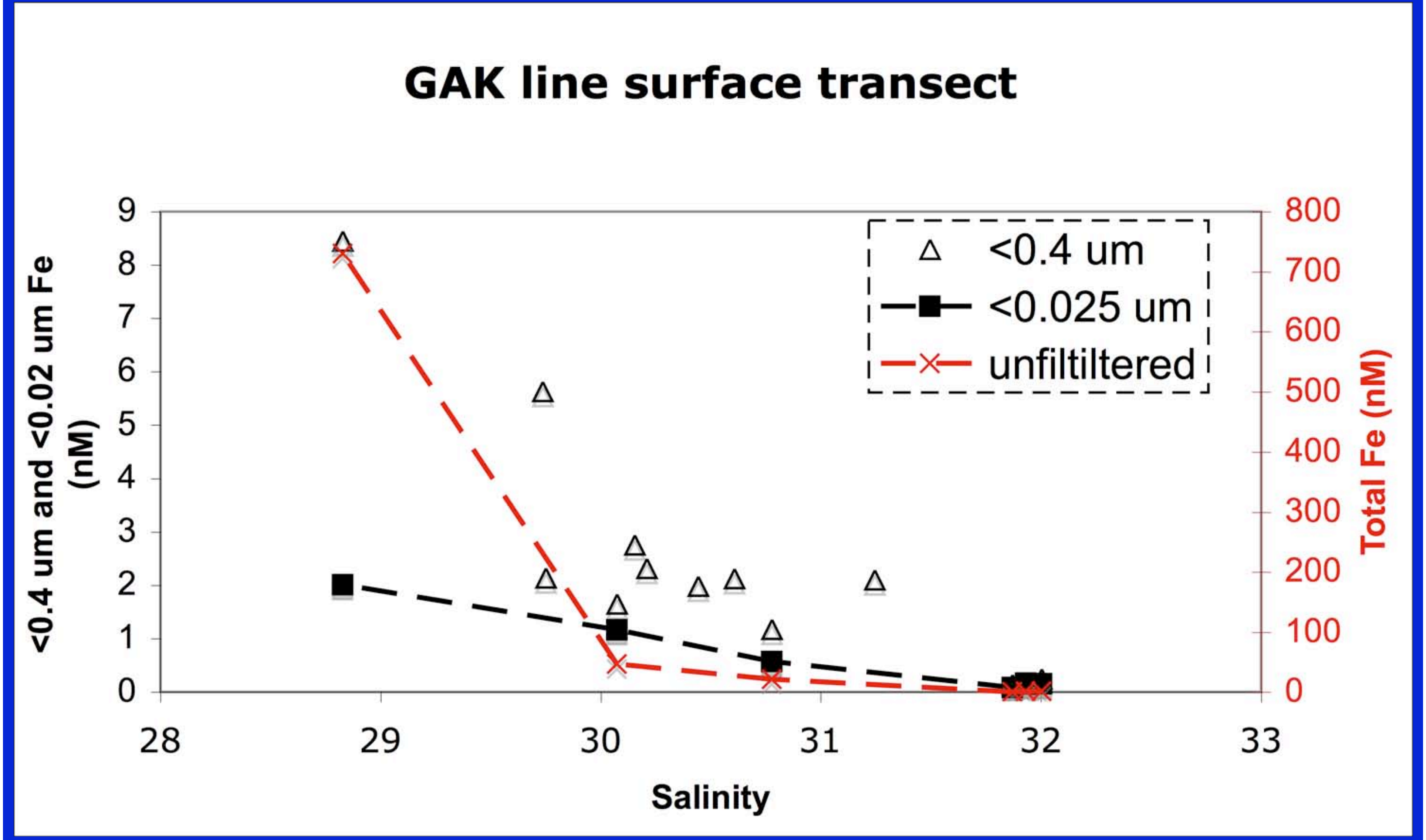


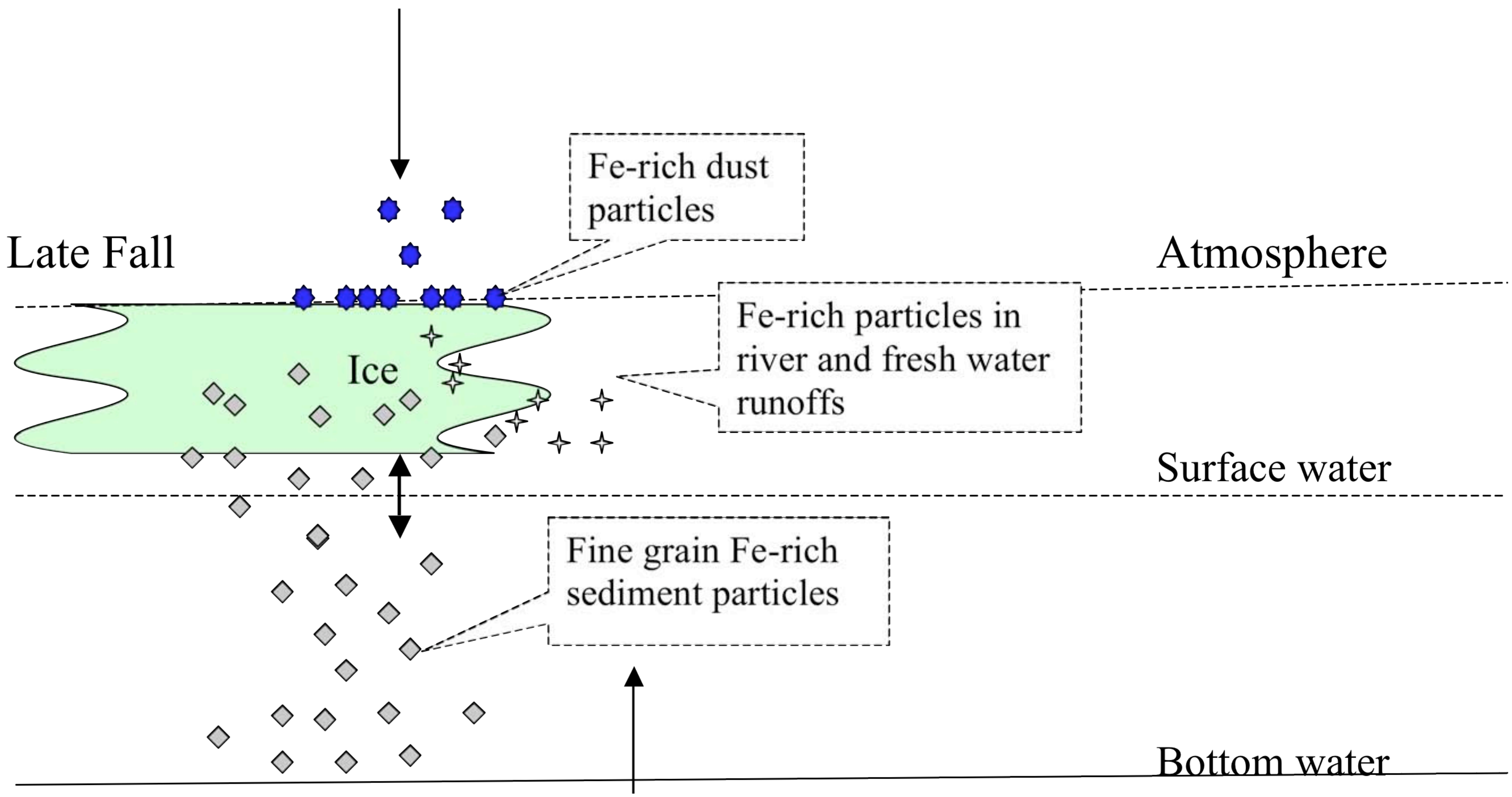
IRON FLUX $(mg\ m^{-2} yr^{-1})$

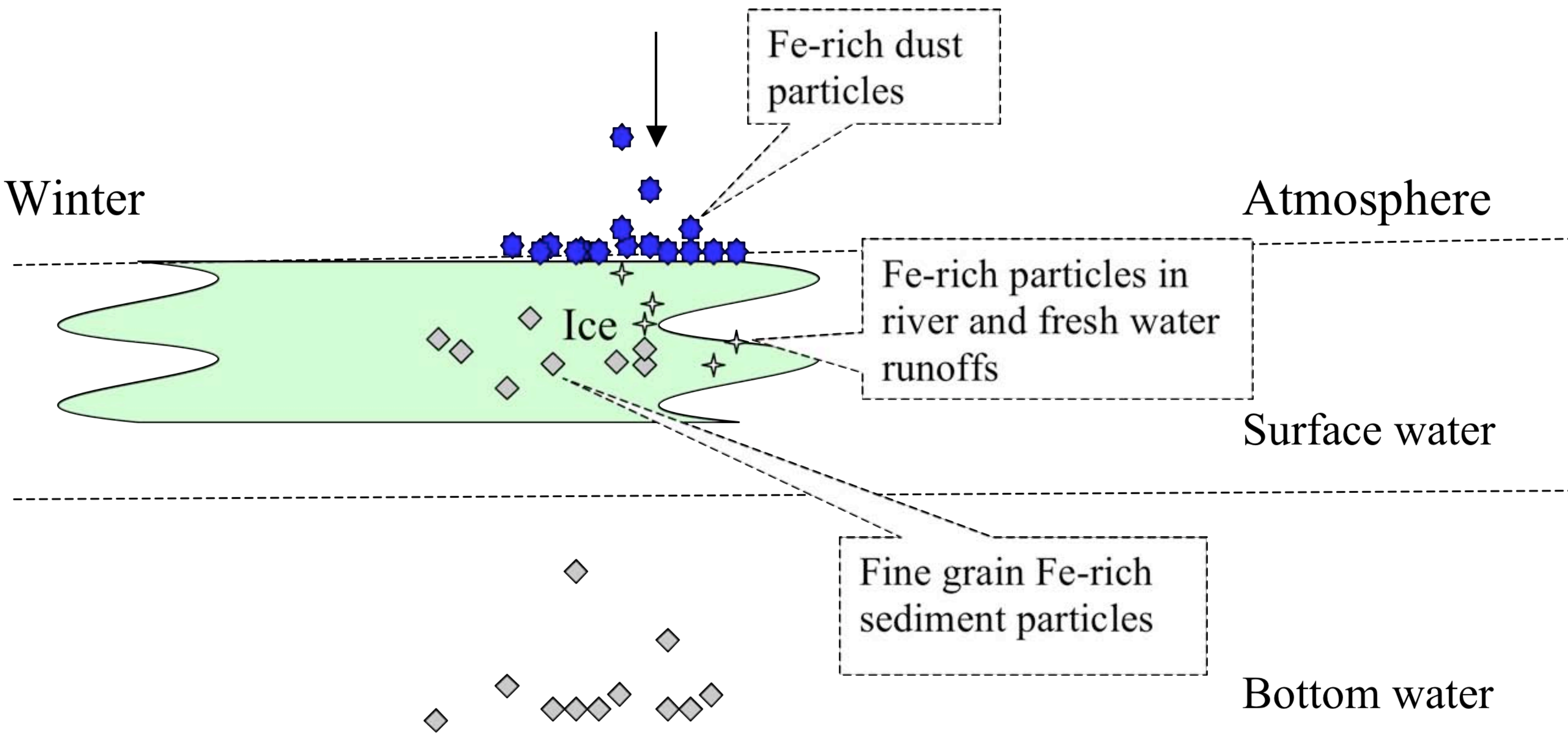
Fig. 8. Calculated flux of total (particulate plus dissolved) Fe from the atmosphere to the ocean (adapted from Donaghay et al. 1991).

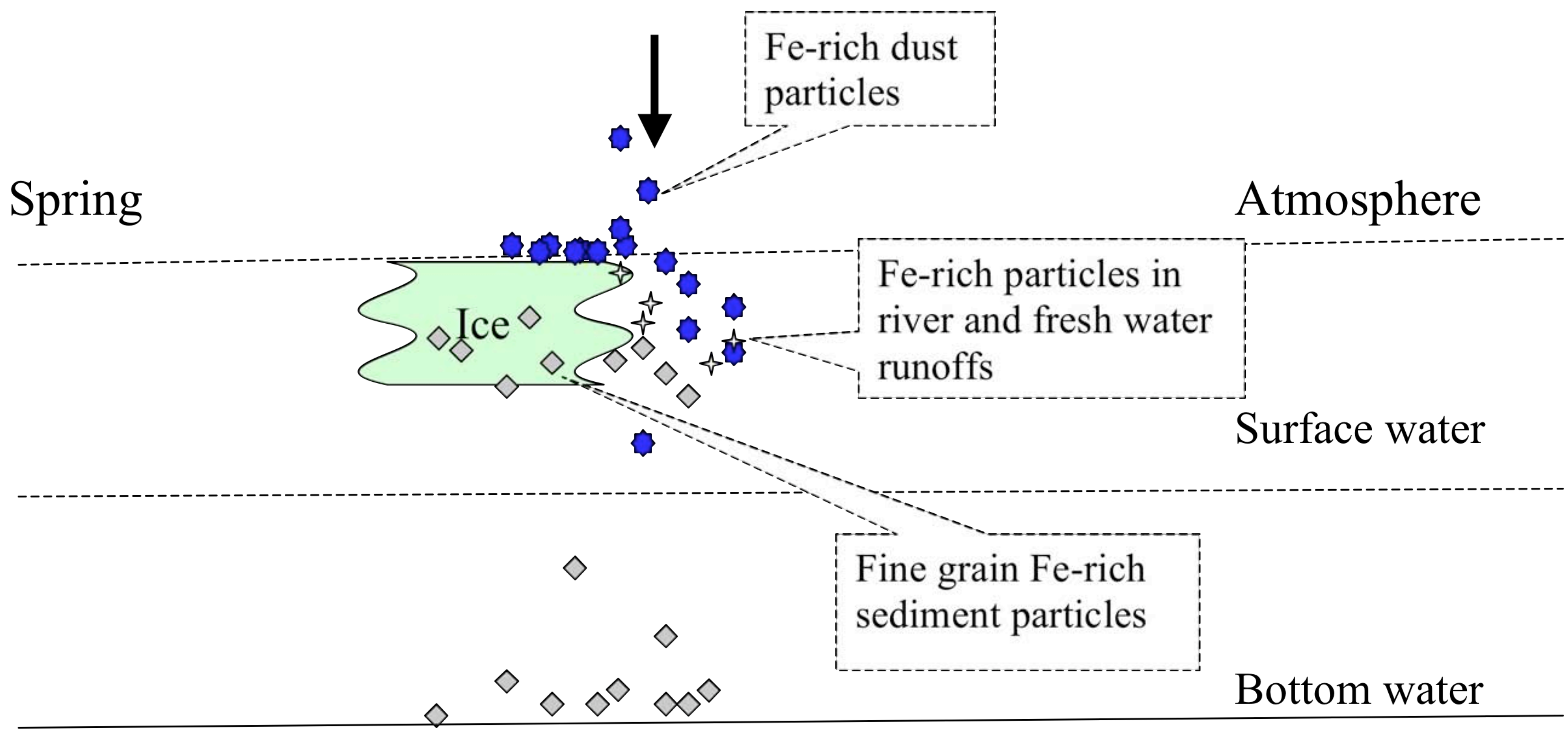


East Siberian Sea
Chukchi Sea
Beaufort Sea
Siberia
Alaska
Yukon River
Bering Sea
Aleutian Islands
Gulf of Alaska
70° N
65° N
60° N
55° N
180°
175° W
170° W
165° W
160° W
155° W
m
Depth
0
20
50
100
200
500
1000
7000
Beaufort Gyre
Atlantic Water
Siberian Coastal Current
Alaska Coastal Water
Bering Shelf Water
Aleutian North Slope - Bering Slope - Anadyr Waters
Alaskan Stream
September Ice Edge Maximum and Minimum Extents
March Ice Edge Maximum and Minimum Extents
km
0
500

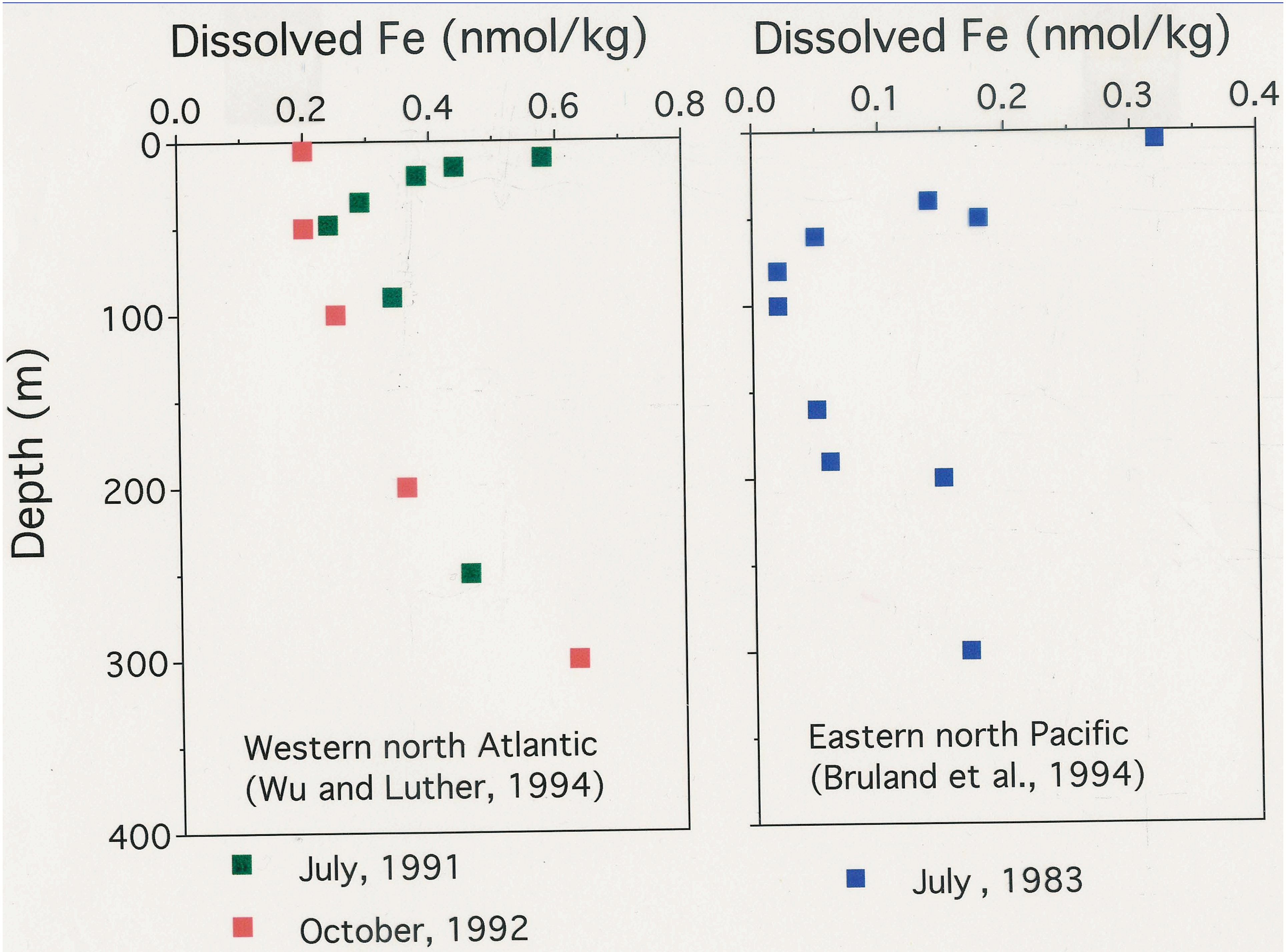

GAK line surface transect
<0.4 um and <0.02 um Fe (nM)
Total Fe (nM)
Salinity
<0.4 um
<0.025 um
unfiltiltered
9
8
7
6
5
4
3
2
1
0
800
700
600
500
400
300
200
100
0
28
29
30
31
32
33


Late Fall
Atmosphere
Fe-rich dust particles
Fe-rich particles in river and fresh water runoffs
Ice
Surface water
Fine grain Fe-rich sediment particles
Bottom water


Fe-rich dust
particles
Winter
Atmosphere
Ice
Fe-rich particles in
river and fresh water
runoffs
Surface water
Fine grain Fe-rich
sediment particles
Bottom water



Fe-rich dust particles
Spring
Atmosphere
Fe-rich particles in river and fresh water runoffs
Ice
Surface water
Fine grain Fe-rich sediment particles
Bottom water


Dissolved Fe (nmol/kg)
0.0
0.2
0.4
0.6
0.8
Dissolved Fe (nmol/kg)
0.0
0.1
0.2
0.3
0.4
0
100
200
300
400
Depth (m)
Western north Atlantic
(Wu and Luther, 1994)
Eastern north Pacific
(Bruland et al., 1994)
July, 1991
October, 1992
July , 1983

Early cold-water algal blooms (in March and April) in the Bering Sea were frequently observed to occur along the ice edge as the sea ice retreated (McRoy and Goering, 1974; Alexander and Niebauer, 1981; Niebauer, 1981; Hunt et al., 2002). Fe input from melting sea ice may help sustain this algal bloom by relieving Fe limitation.

Questions

- How do ice melting, coastal fresh water discharge and water column stratification influence surface water Fe distribution?
- How is Fe removed from the surface water compared to macronutrients N, P and Si?
- How do these Fe input and removal processes influence the timing and magnitude of algal bloom and algal species composition in the shelf and shelf break waters?

Hypothesis

Melting ice is a significant source of Fe for biological growth in the stratified Bering Sea shelf during spring. The initial algal growth in spring depletes available Fe in the winter-mixed surface water, resulting in a Fe limitation on algal growth. The input of available Fe from melting ice relieves this Fe limitation and supports a high level of dissolved Fe in the stratified shelf surface water for subsequent algal growth when macronutrients are transported inshore from Fe-poor nutrient-rich waters of the Aleutian basin.

Objectives

- To determine if Fe in the water immediately beneath sea ice cover is depleted before macronutrients by algal growth in the absence of available Fe input from melting sea ice.
- To quantify the Fe flux from melting ice and to understand if sea ice is an important source of available Fe to the stratified shelf surface water that affects early spring algal bloom around the ice edge.
- To understand if the input of Fe from melting sea ice results in a persistent excess of Fe in the stratified ice-free shelf surface water that influences late warm-water bloom on the shelf.

Task #1

Determine the concentration of soluble, colloidal and particulate Fe and Fe-binding dissolved organic ligands, and macronutrients in surface water immediately beneath the winter ice cover and perform on-deck bottle incubation experiments using these waters to determine if algae growth at enhanced sun irradiance depletes Fe before it depletes macronutrients.

Task # 2

Determine the concentration of soluble, colloidal and particulate Fe in ice cores, water in leads between the ice floes, and snow and melt water pools on the top of ice sheets, and low salinity water at the interface between the bottom of the ice cover and the water column where most of the melting water is expected to accumulate.

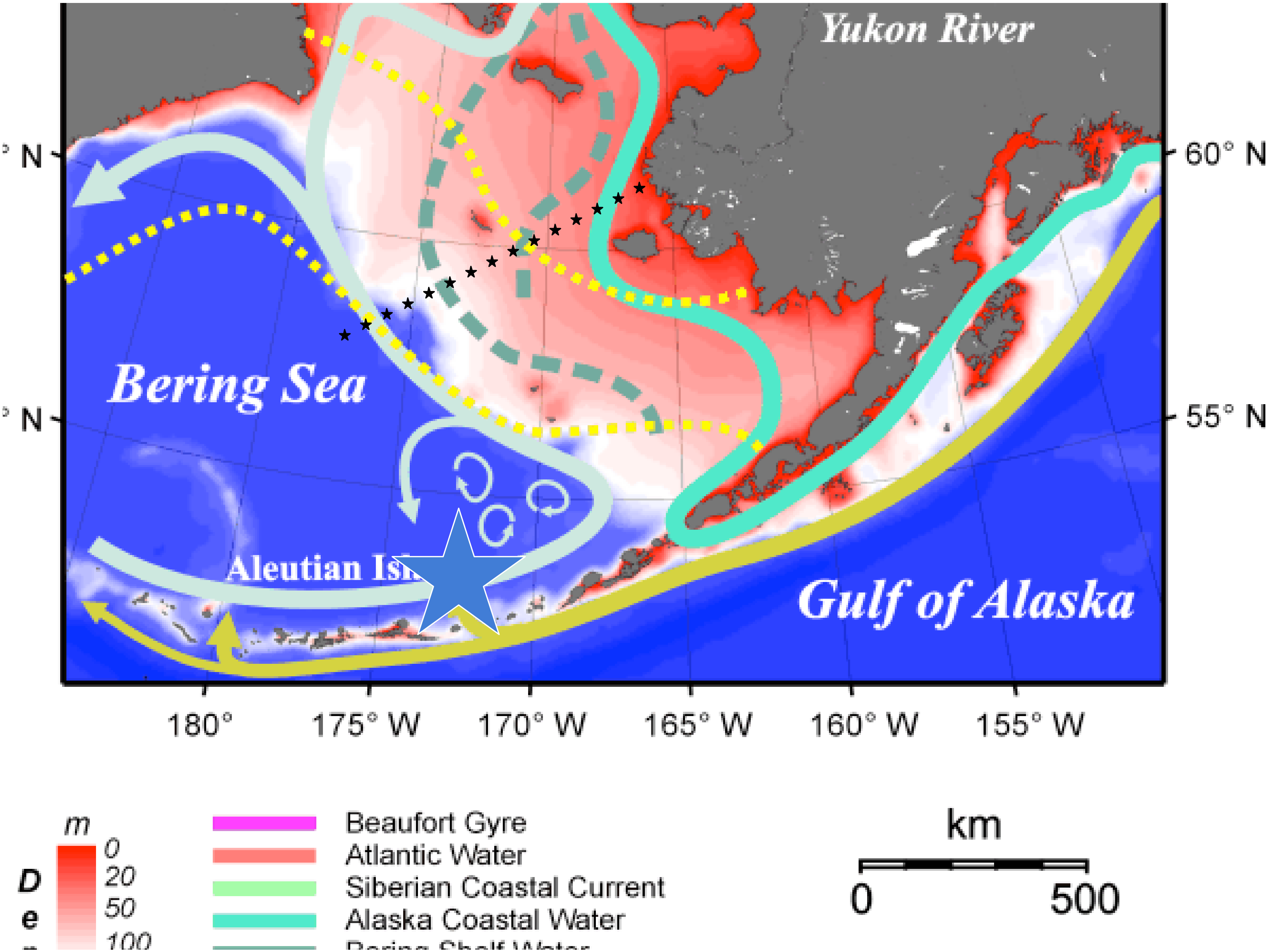
Task # 3

Determine the temporal variation of dissolved, colloidal and particulate Fe and dissolved Fe-binding organic ligand concentrations in the waters around the ice edge during ice sheet retreats (gradients as a function of distance southward from the ice edge) and the surface waters after the ice melting period.

Field plan

- Sample along a transect from outer basin to the mouth of Yukon river during the early Spring (before ice melting), mid-Spring (when ice start to melt) and late Spring (after significant ice melting).

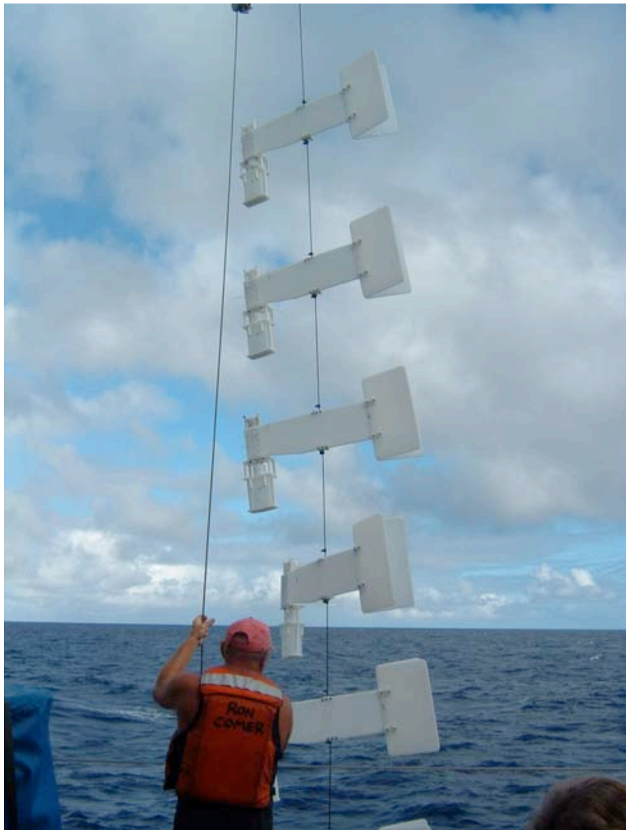
- The early Spring transect will focus on ice cores and the seawater immediately beneath the ice cover, whereas the mid Spring and late Spring cruises will focus on vertical profile samples around the ice edge and in the ice free waters.



Yukon River
Bering Sea
Aleutian Isl
Gulf of Alaska
60° N
55° N
N
N
180°
175° W
170° W
165° W
160° W
155° W
m
0
20
50
100
D
e
Beaufort Gyre
Atlantic Water
Siberian Coastal Current
Alaska Coastal Water
km
0
500

Sampling requirements

- Ice core sampling will take 4 hrs at each station and requires the use of cold room at Healy for processing the core.
- Water column sampling will be carried out by using a clean underway pumping system for surface water in the ice-free regions and using pole sampling method for surface water and MITESS/ATE vane sampler for subsurface water in the icy waters which takes ~2 hours at each station and requires the use of hydrowire.
- On-deck incubation does not require additional ship-time except that (~3 hours) needed to collect 50 L samples for incubation using Teflon-coated Go-Flo bottles.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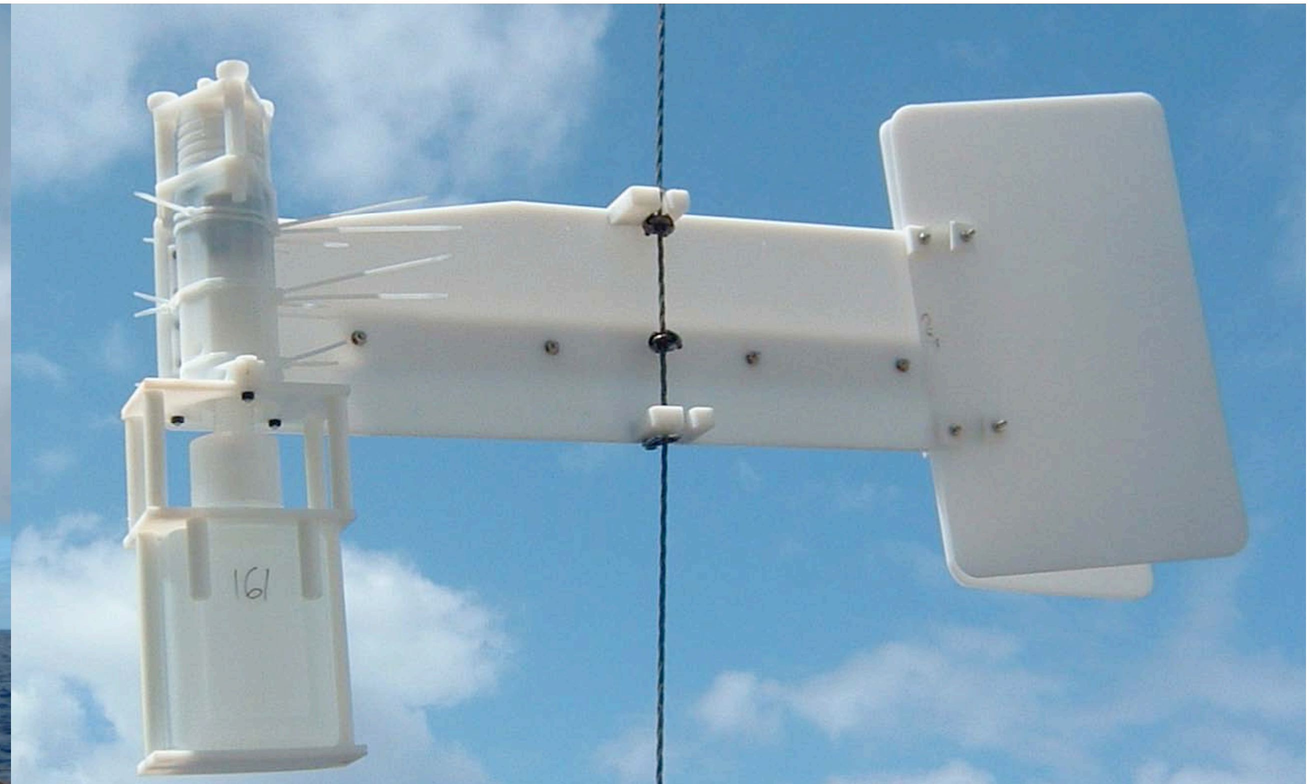
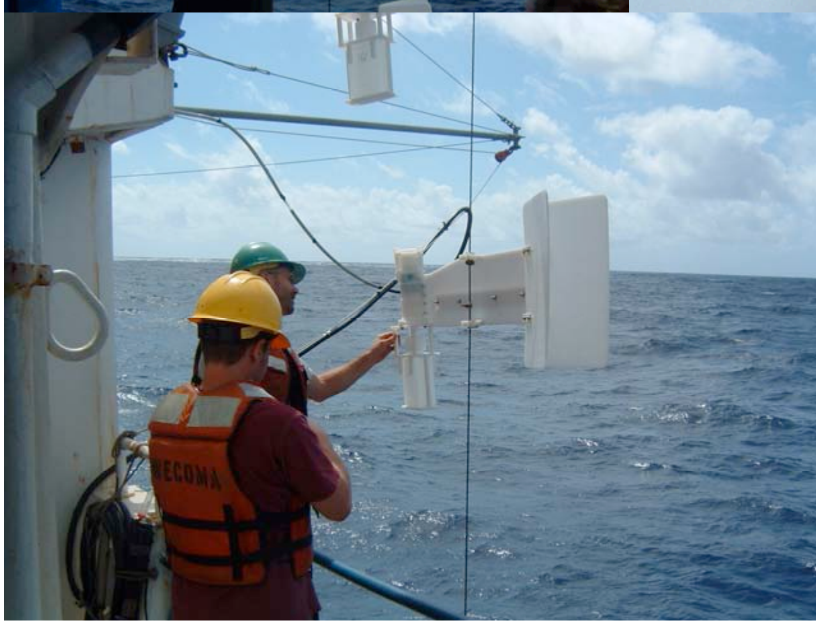
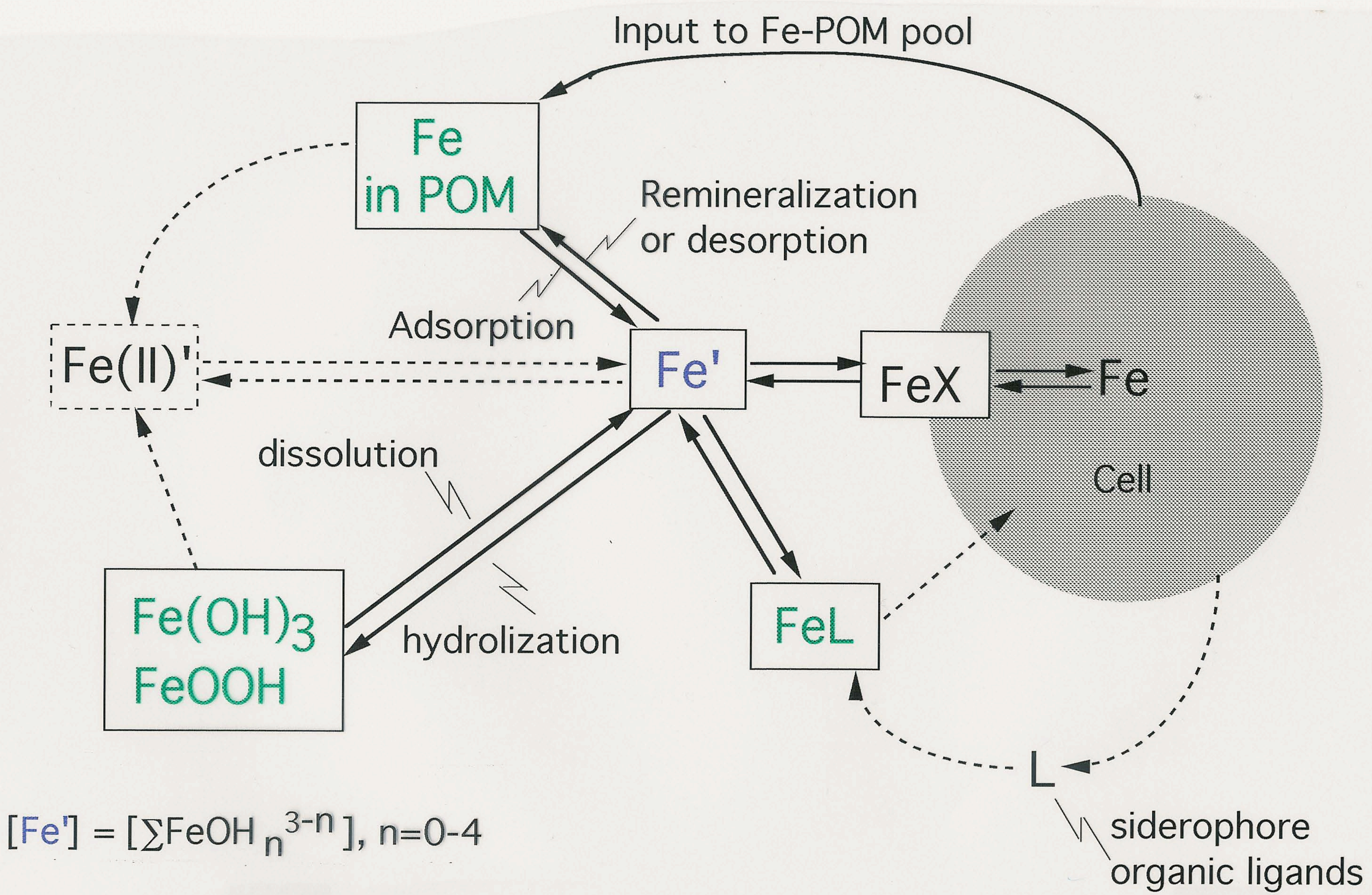
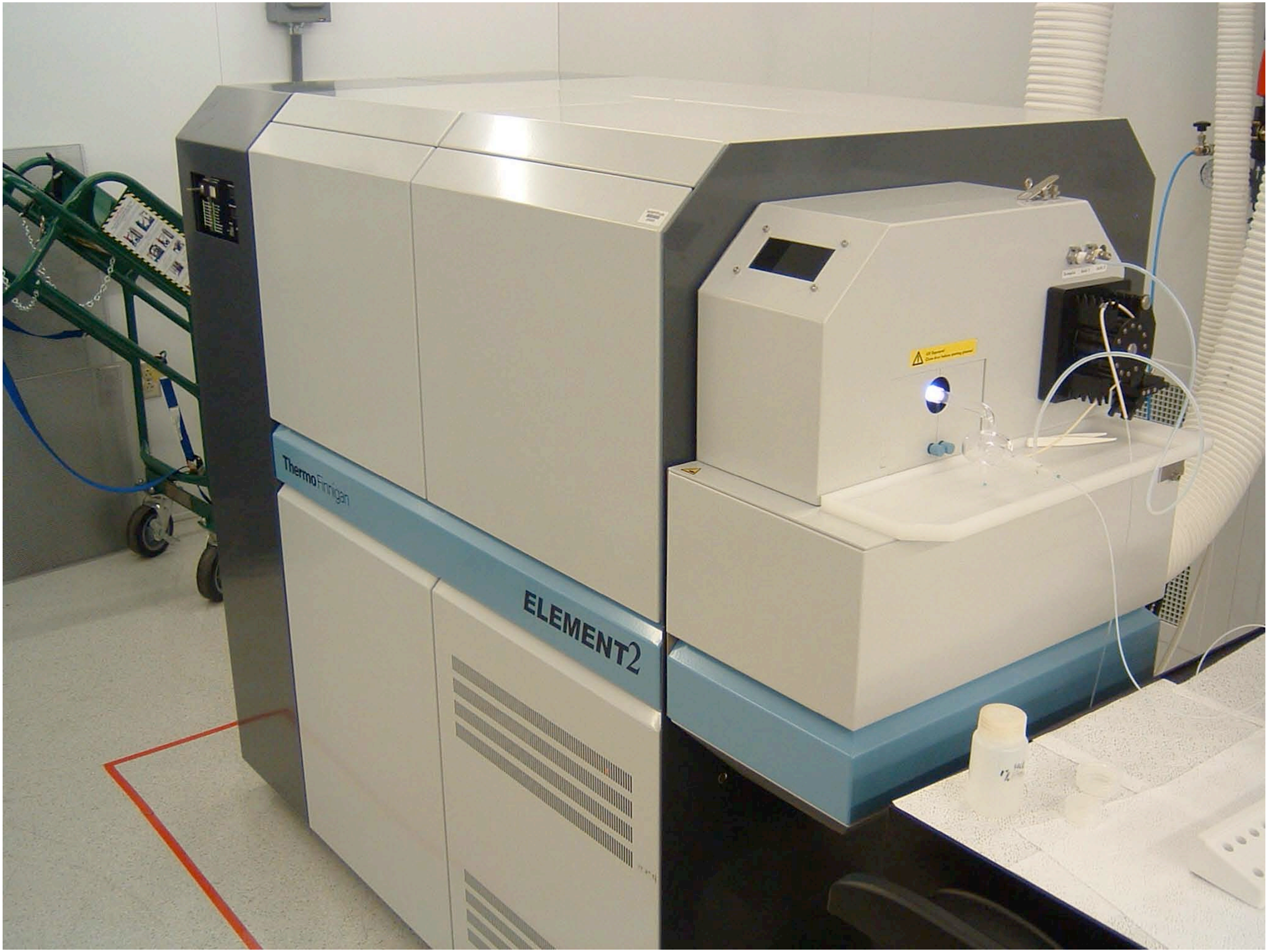
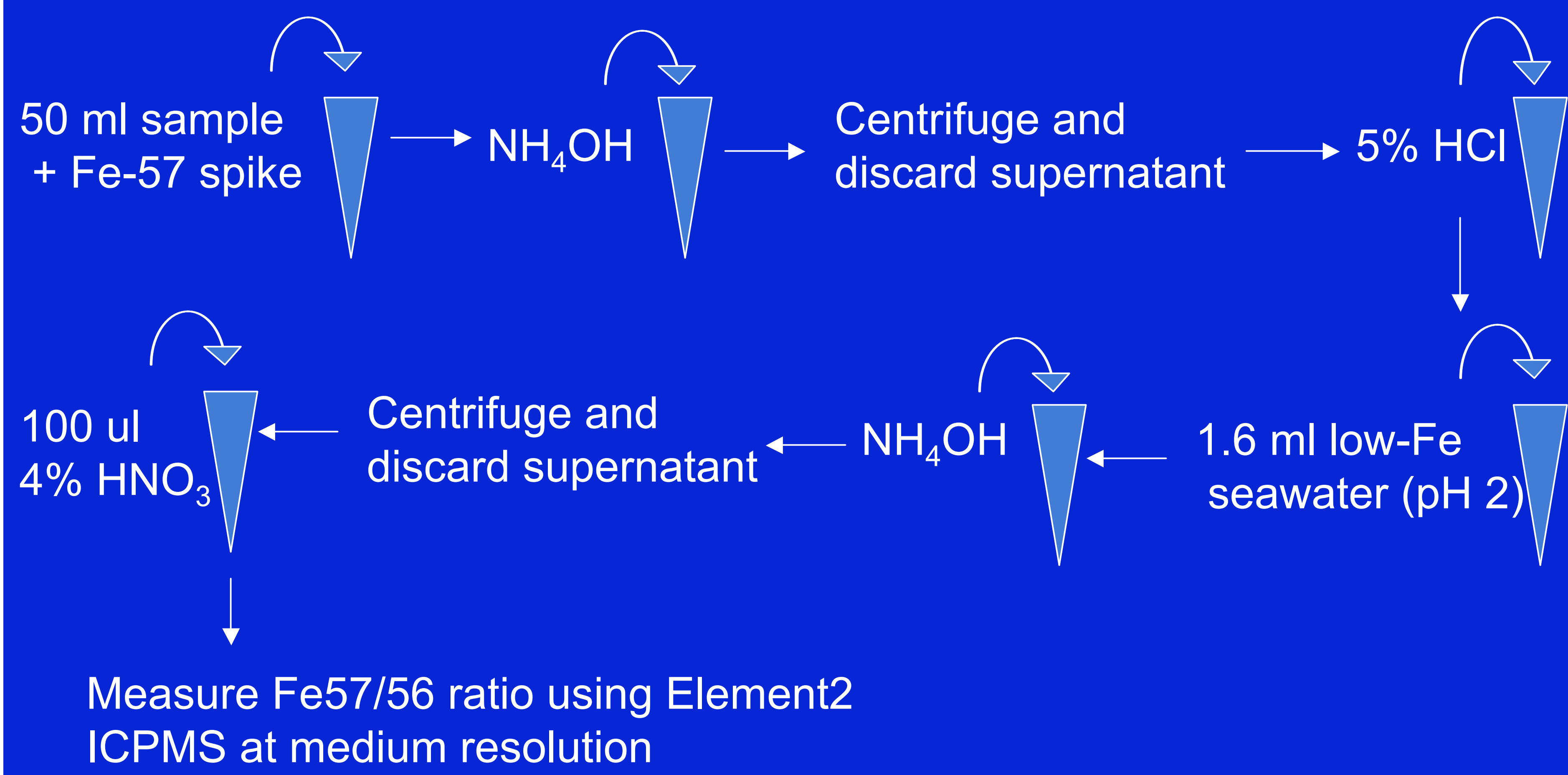
COMER

161


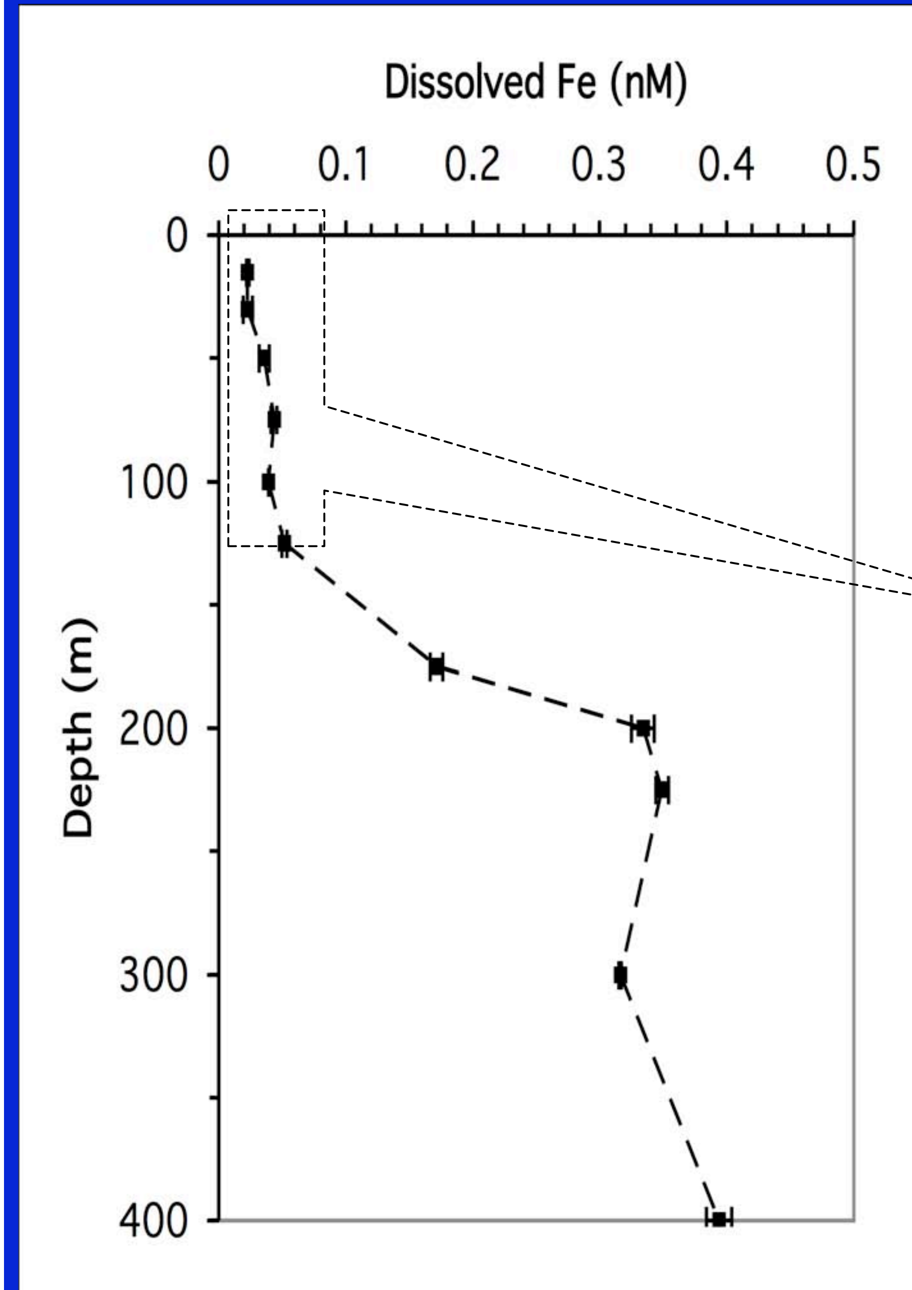


Input to Fe-POM pool
Fe
in POM
Remineralization
or desorption
Adsorption
Fe(II)'
Fe'
FeX
Fe
Cell
dissolution
hydrolization
Fe(OH)3
FeOOH
FeL
L
siderophore
organic ligands
[Fe'] = [∑FeOH n 3-n], n=0-4


Thermo Finnigan
ELEMENT2

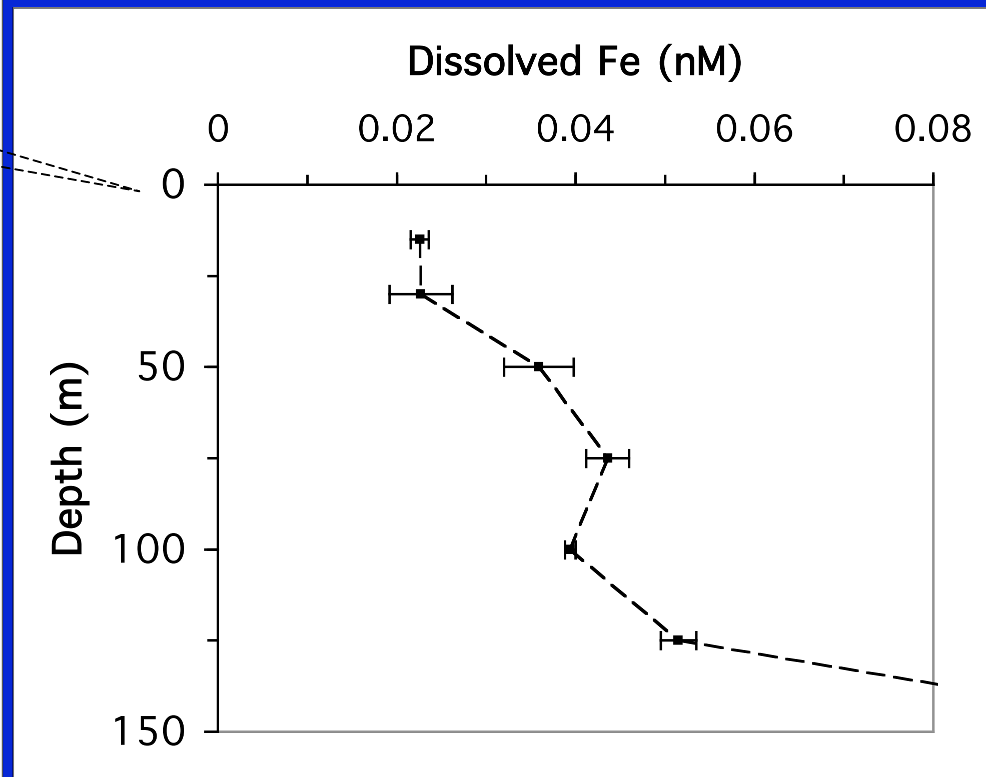
The New procedure:

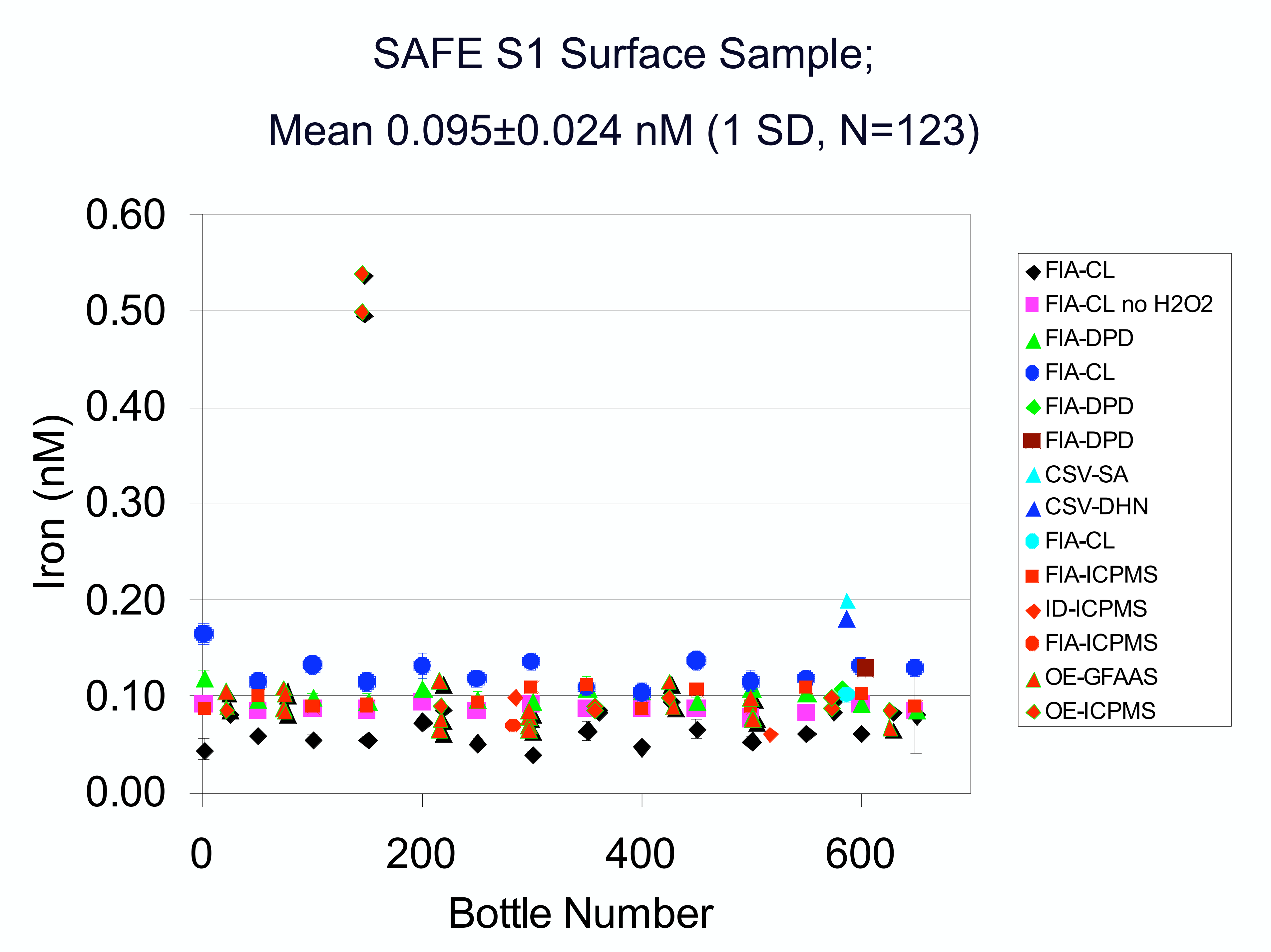
The 500 fold preconcentration procedure includes a double precipitation step:



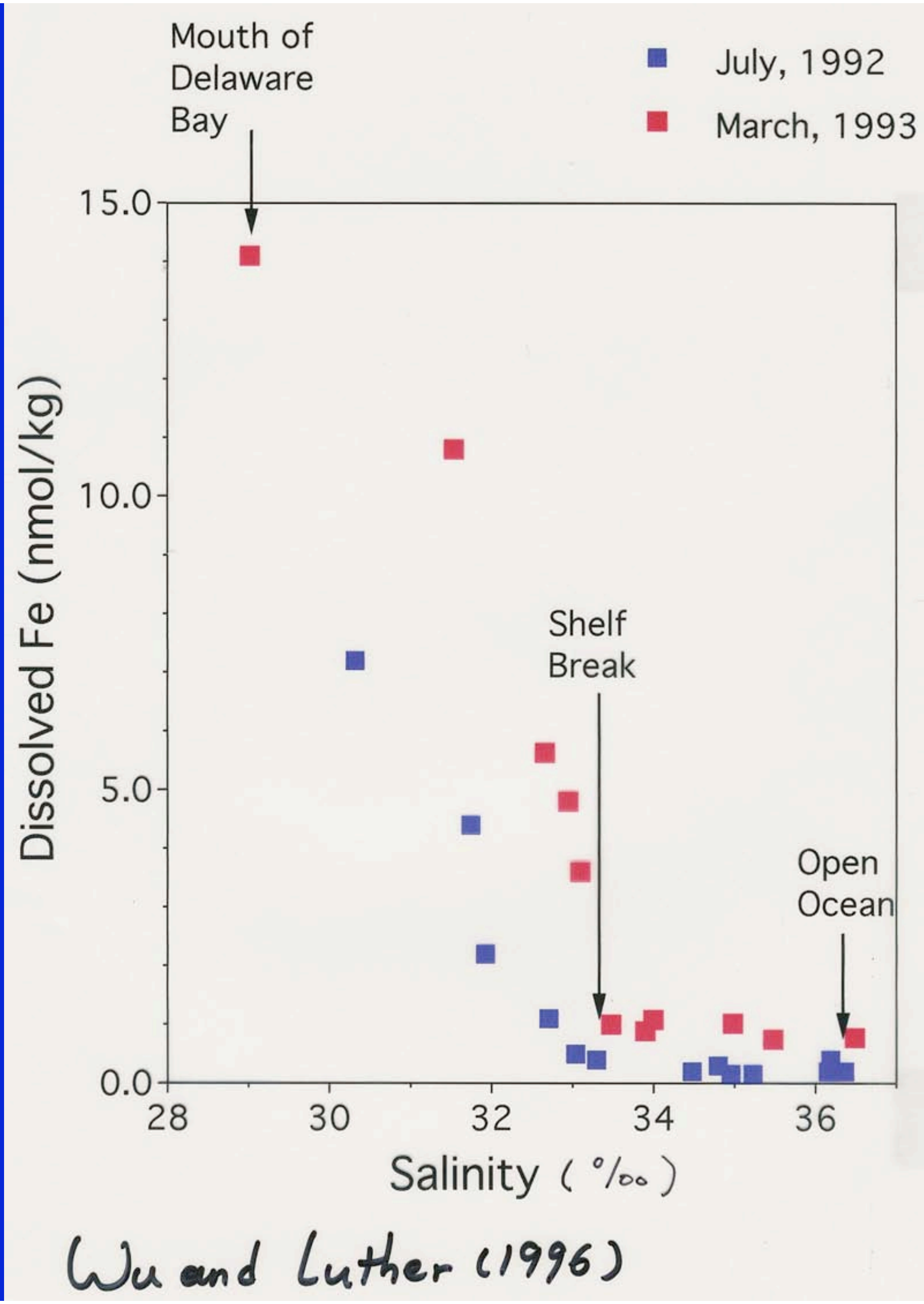


Seawater samples were collected in the Equatorial Pacific (0°N, 158°W) in April 2005 and determined by the 1.6 ml method (below 150 m) and the 50 ml method (above 150 m).





SAFE S1 Surface Sample;
Mean 0.095±0.024 nM (1 SD, N=123)
Iron (nM)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
200
400
600
Bottle Number
FIA-CL
FIA-CL no H2O2
FIA-DPD
FIA-CL
FIA-DPD
FIA-DPD
CSV-SA
CSV-DHN
FIA-CL
FIA-ICPMS
ID-ICPMS
FIA-ICPMS
OE-GFAAS
OE-ICPMS

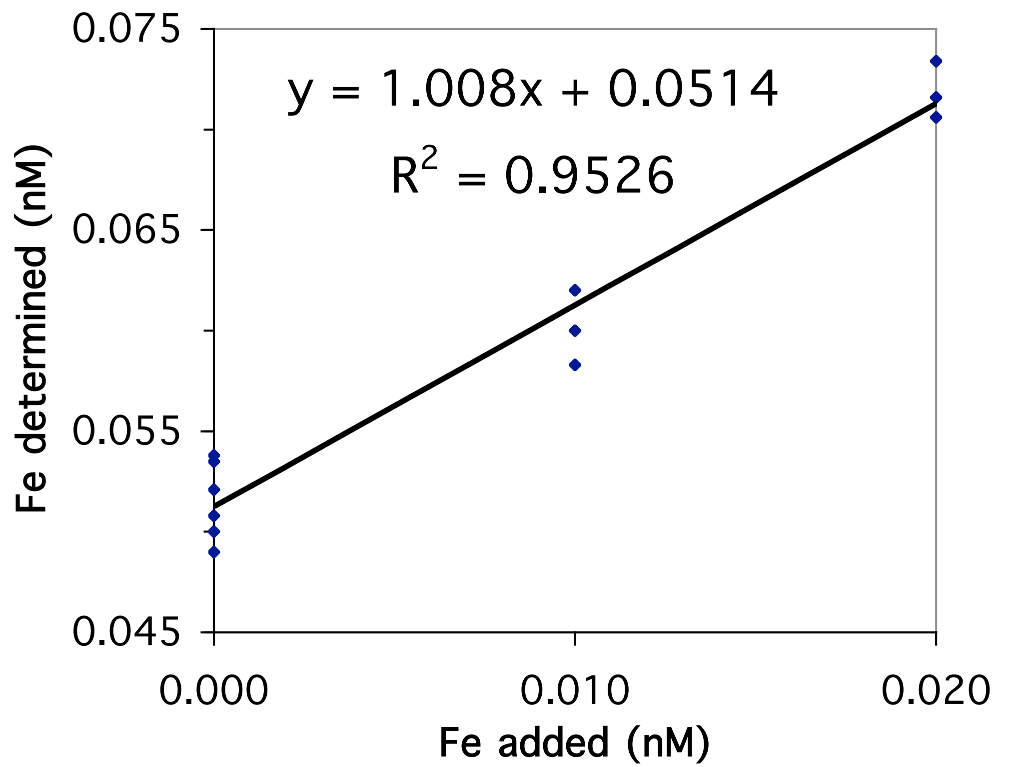


Mouth of
Delaware
Bay
July, 1992
March, 1993
15.0
10.0
5.0
0.0
Dissolved Fe (nmol/kg)
Shelf
Break
Open
Ocean
28
30
32
34
36
Salinity (‰)
Wu and Luther (1996)

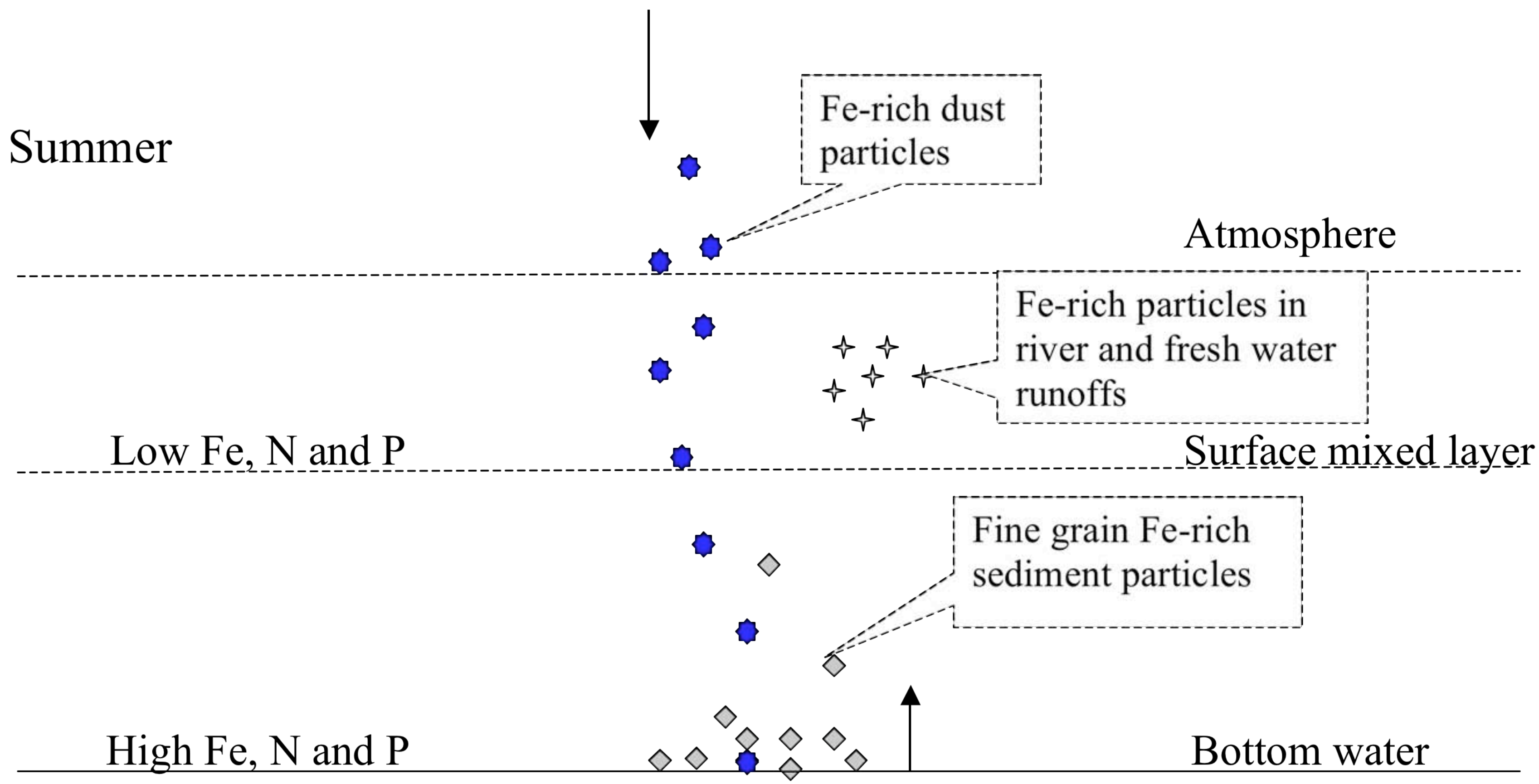
Results

The procedural blank mainly comes from reagents and thus can be determined accurately by isotope dilution.

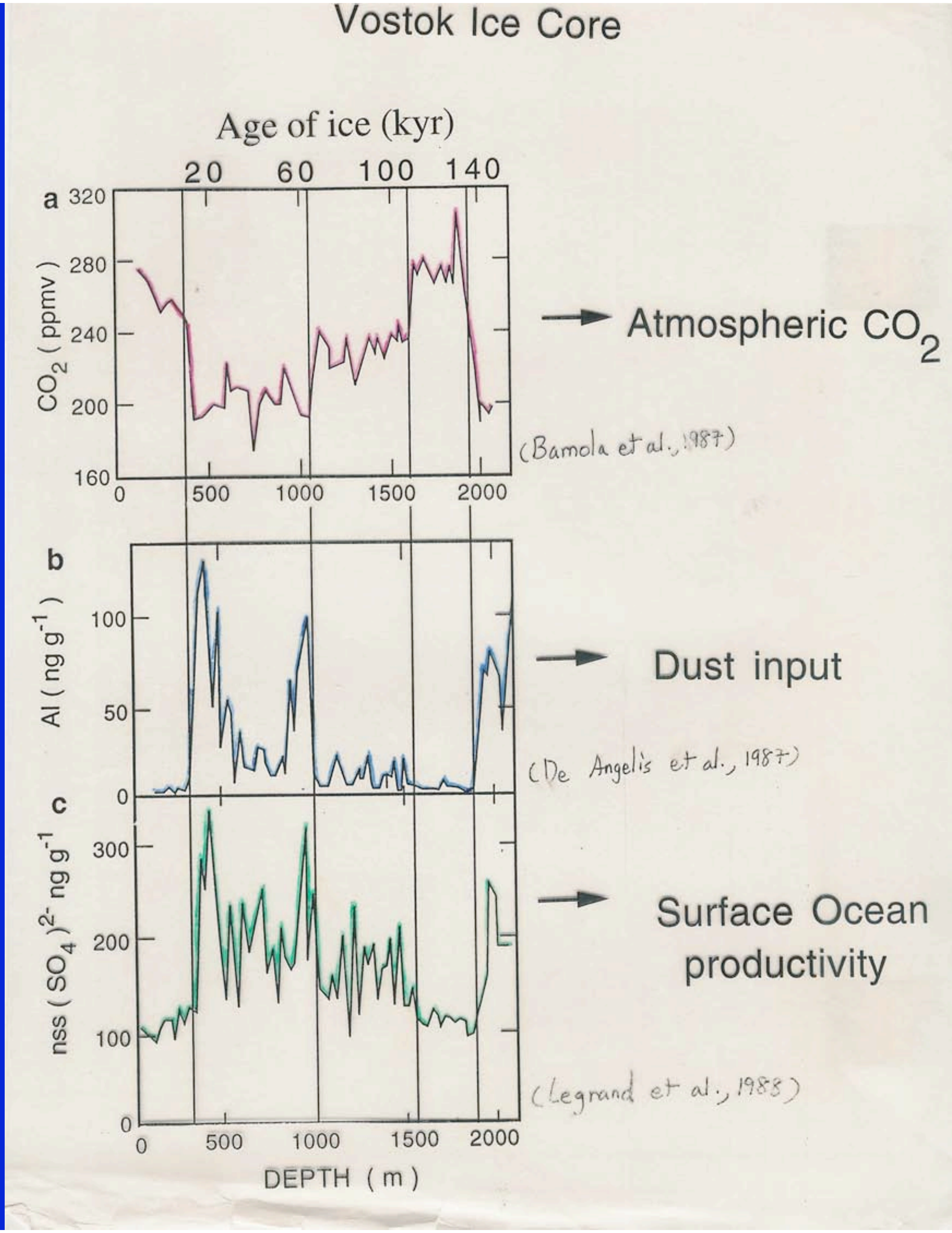
ICPMS Fe background	3 pM
5% HCl	5 pM
NH_3H_2O	2 pM
0.4 ml low-Fe seawater	1 pM
1.6 ml low-Fe seawater	4 pM
Total	15 pM



Procedural blank: 0.0150 ±0.0009 nM
Detection limit: ~0.003 nM
Precision at 0.050 nM: ~4%
Accuracy: ~0.002 nM



Summer
Fe-rich dust particles
Atmosphere
Fe-rich particles in river and fresh water runoffs
Low Fe, N and P
Surface mixed layer
Fine grain Fe-rich sediment particles
High Fe, N and P
Bottom water



Vostok Ice Core
Age of ice (kyr)
20
60
100
140
a
320
280
240
200
160
CO2 (ppmv)
0
500
1000
1500
2000
Atmospheric CO2
(Bamola et al., 1987)
b
100
50
0
Al (ng g-1)
Dust input
(De Angelis et al., 1987)
c
300
200
100
0
nss (SO4)2- ng g-1
Surface Ocean productivity
(Legrand et al., 1988)
DEPTH (m)

Intercomparison results for DOC and Dissolved Iron

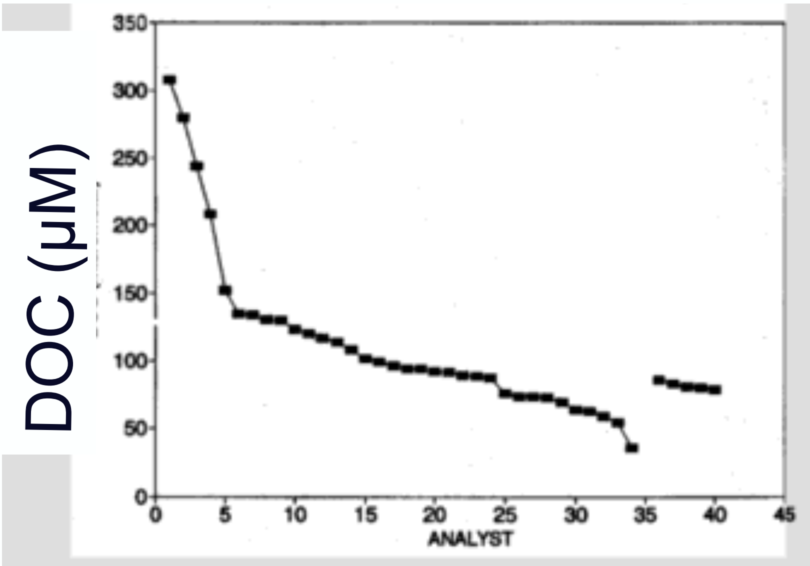
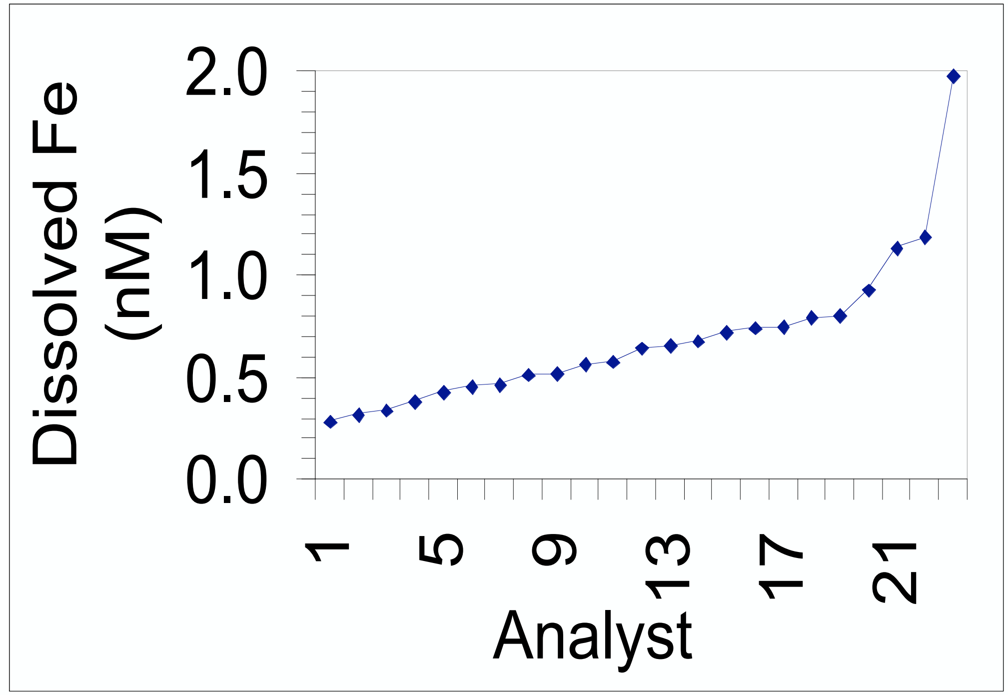


FIGURE 2.2 Example of the use of reference materials on the agreement between analysts. Analysts 1-34 represent data from all analyses of the Pacific Ocean surface sample from the Seattle Workshop (Hedges et al., 1993). These analyses were purposely performed without common reference materials or uniform blank correction in order to assess the state-of-the-art. Analysts 36-40 represent a select group of JGOFS investigators analyzing the EqPac inter-laboratory comparison sample using a common blank water and reference standard. The improvement in precision is immediately apparent.



DOC Intercomparison (Hedges et al., 1993)

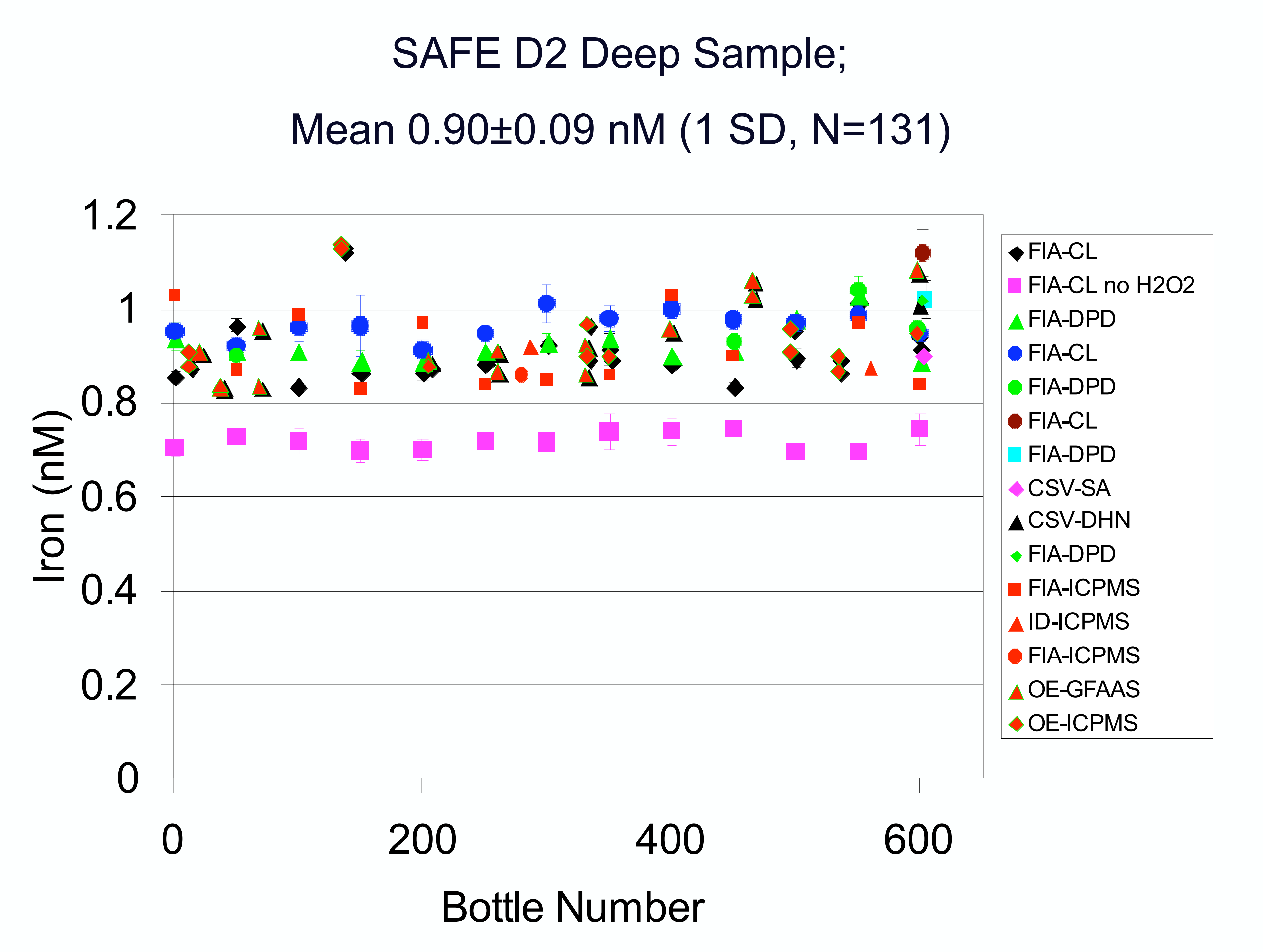
The first dissolved Fe international intercomparison in 2002 (Bowie et al., submitted) – Range (ignoring outliers) = surface to 1000 m concentration difference in Pacific Ocean

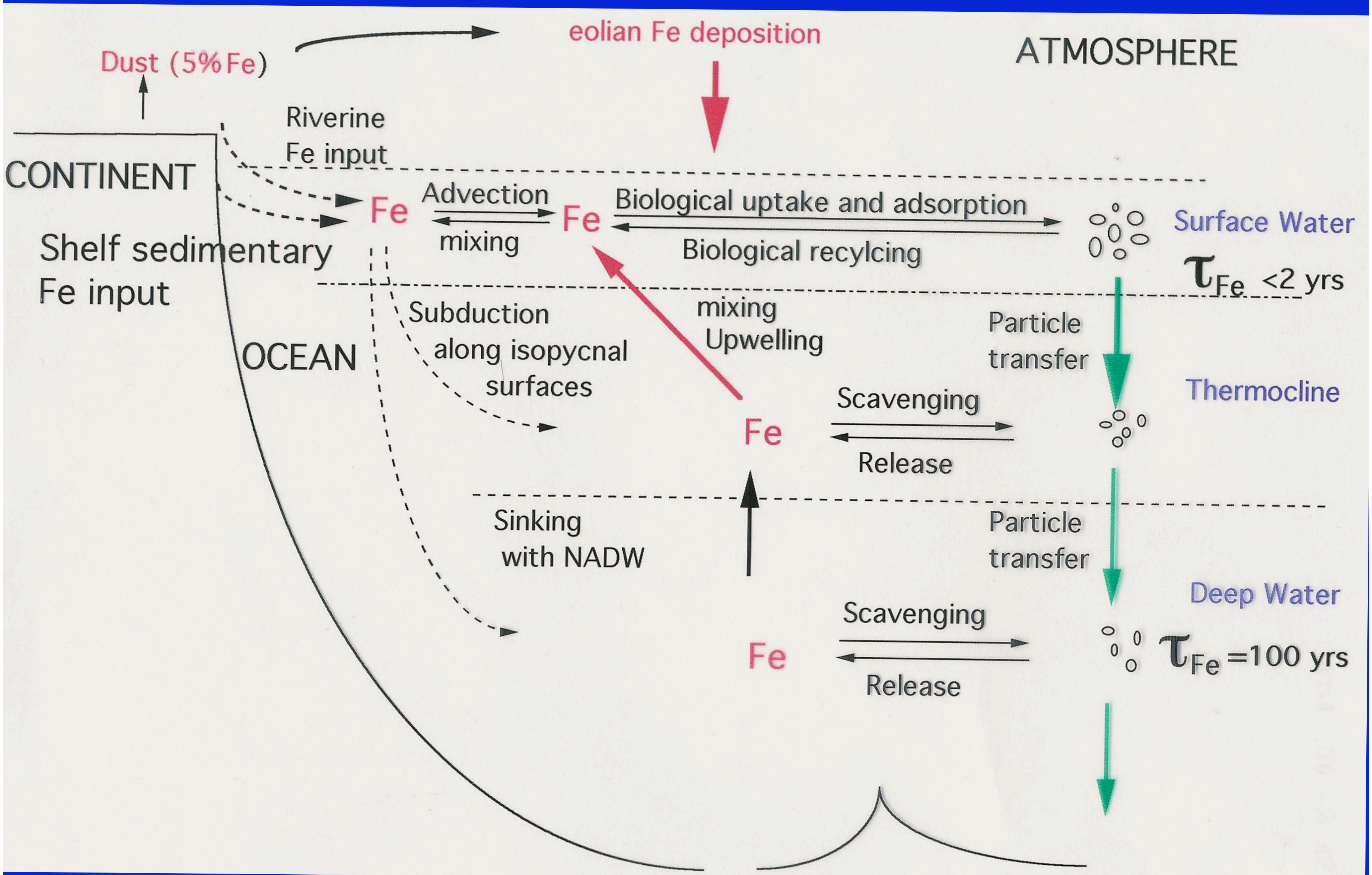
SAMPLING AND ANALYSIS OF Fe: THE SAFE IRON INTERCOMPARISON CRUISE

Oct/Nov 2004

K. Johnson	MBARI	J. Cullen	U Vic, Canada
K. Bruland	UCSC	S. van den Berg	Liverpool, UK
K. Coale	MLML	Worsfold/Achterberg	Plymouth, UK
C. Measures	UHawaii	G. Sarthou	Brest, France
E. Boyle	MIT	H. DeBaar	NIOZ, Holland
J. Moffett	WHOI	H. Obata	ORI, Tokyo
B. Landing	FSU	A. Bowie	U. Tas., Australia
Z. Chase	OSU	P. Sedwick	BBSR, Bermuda
J. Wu	UAlaska		
J. Murray	UWash		
K. Barbeau	SIO		

Selected to represent a range of analytical methods, regions, global science programs and experience.


SAFE D2 Deep Sample;
Mean 0.90±0.09 nM (1 SD, N=131)
Iron (nM)
1.2
1
0.8
0.6
0.4
0.2
0
0
200
400
600
Bottle Number
FIA-CL
FIA-CL no H2O2
FIA-DPD
FIA-CL
FIA-DPD
FIA-CL
FIA-DPD
CSV-SA
CSV-DHN
FIA-DPD
FIA-ICPMS
ID-ICPMS
FIA-ICPMS
OE-GFAAS
OE-ICPMS


Dust (5% Fe)
eolian Fe deposition
ATMOSPHERE
Riverine
Fe input
CONTINENT
Fe
Advection
mixing
Fe
Biological uptake and adsorption
Biological recylcing
Surface Water
τ_{Fe} <2 yrs
Shelf sedimentary
Fe input
Subduction
along isopycnal
surfaces
mixing
Upwelling
Particle
transfer
OCEAN
Thermocline
Scavenging
Fe
Release
Sinking
with NADW
Particle
transfer
Deep Water
Scavenging
Fe
τ_{Fe} =100 yrs
Release

Fe influences N vs. Si uptake

Study	Fe-deplete	Fe-replete
Southern Ocean (Takeda, 1998)		
plankton community	Si/N=2.3	Si/N = 0.95
	N/P = 12	N/P = 14
Chaetoceros dichaeta	Si/N = 1.9	Si/N = 0.7
Nitzschia sp.	Si/N = 2.1	Si/N = 1.2
California upwelling (Hutchins et al., 1998)		
plankton community	Si/N = 1.6	Si/N = 0.8
	Si/N = 2.7	Si/N = 1.0
	Si/N = 3.0	Si/N = 1.0

Table 1. Fe requirements for growth at a given rate under various resource supply condition

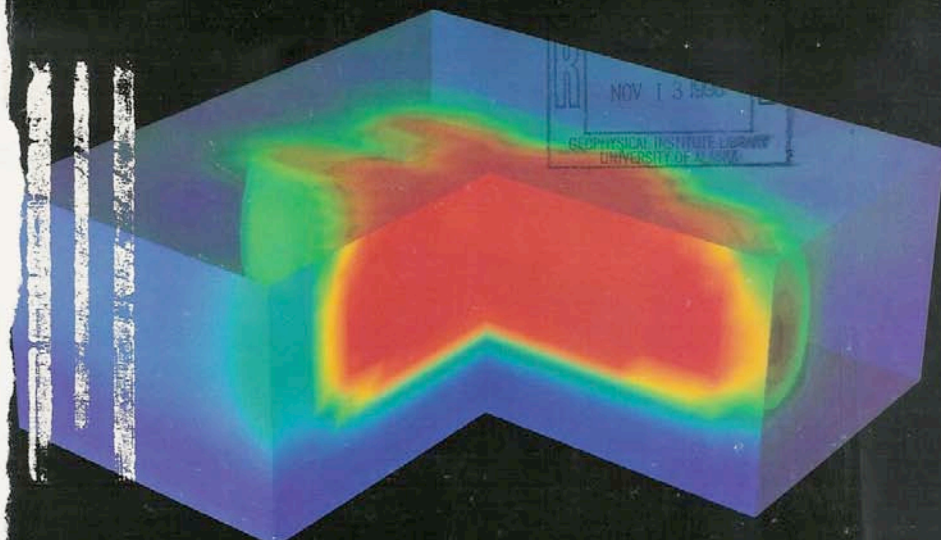
N sources	Mole Fe required in catalysts ¶ to yield a growth rate of 1 mole C assimilated per second at 20 °C
NH_4	0.8
NO_3	0.6
N_2	80

¶ Membrane-associated Fe-proteins of photosynthesis respiration, nitrate reductase, nitrite reductase and nitrogenase.

Raven (1988), New Phycol. 109, 279–287

nature

INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
Volume 383 No. 6600 10 October 1996 $10.00

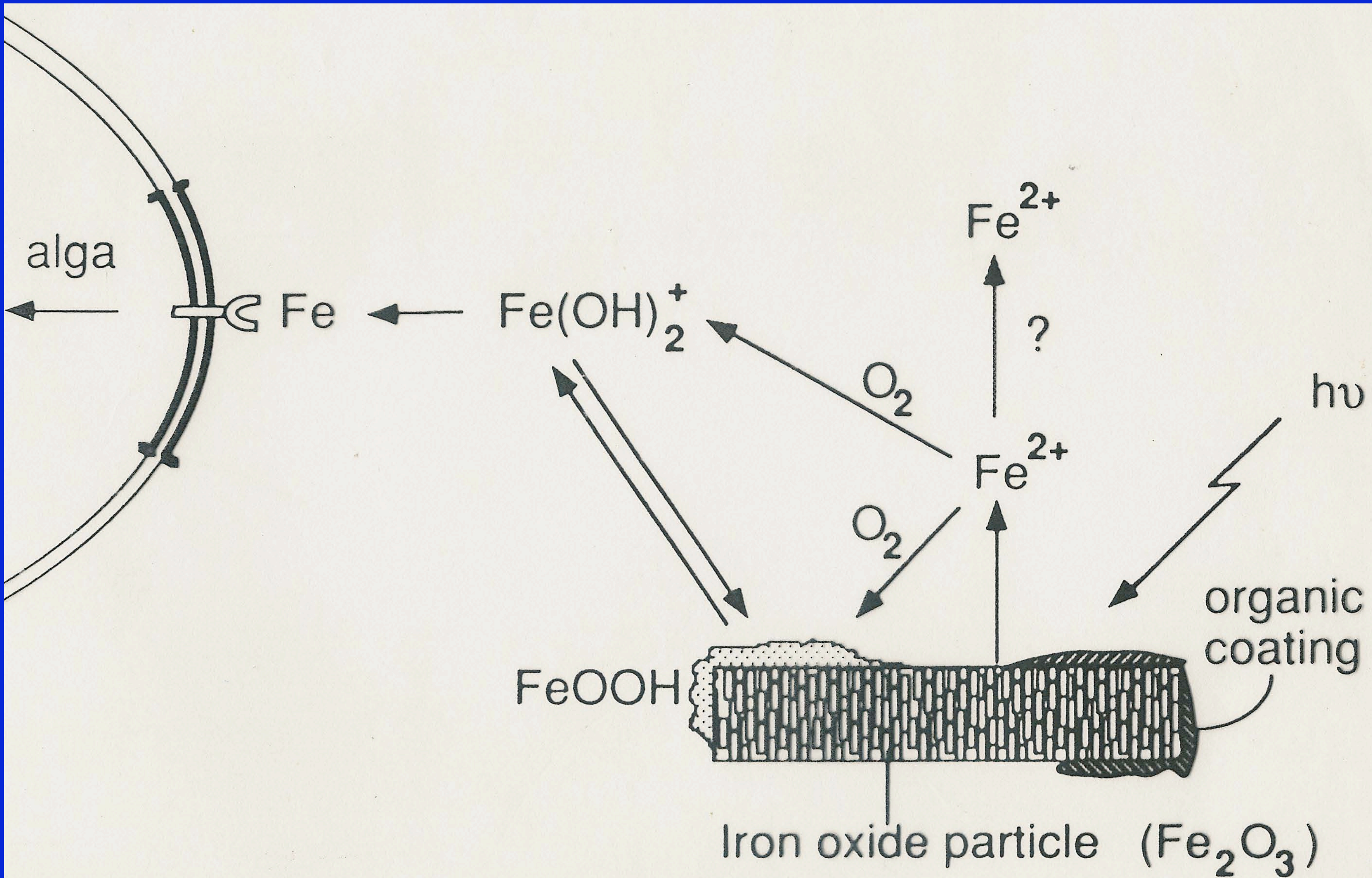


Iron fertilization in the equatorial Pacific

A tangled tale of Alzheimer's disease

Optical data storage using peptides

How birds smell danger


alga
Fe
Fe(OH)$_2^+$
Fe^{2+}
?
O_2
hυ
Fe^{2+}
O_2
organic coating
FeOOH
Iron oxide particle (Fe_2O_3)