The Geritol Solution

Class 22, Tu 18 November 2008

EEOS630

Slide 1 The Geritol Solution

NOTES:

Final exam & upcoming classes

- Final exam will be 3-h closed book, but with essay questions provided in advance
  - **There is no set date for the final, so I'll have Angeliki send you emails to fix a time for the 3-h in class final. Copies of old final exams will be on Vista/Blackboard**
  - **Arnab at Lowell and Christina at Amherst: when date is set, arrange for your advisor or other faculty member to proctor the exam**
- **Outer continental shelf oil effects will be due on with 1 week left in semester. I have a set of the latest analyses being sent to me on CD by Dr. James Blake. This is a very 'hot' and current topic.**
- **This Thursday's class will be an introduction to zooplankton & grazing by Dr. Juanita Urban-Rich**

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Slide 2 Final exam & upcoming classes

NOTES:

Why no phytoplankton bloom in the Subarctic Pacific?

- **Parsons et al. (1966): the Major Grazer hypothesis**
- **Evans & Parslow's (1985) Micrograzer Hypothesis**
- **Martin's Iron Hypothesis**
- **Ecumenical Iron hypothesis**
- **Also consider**
  - **Light limitation (Nelson & Smith** 1991, Mitchell)
  - Zinc limitation

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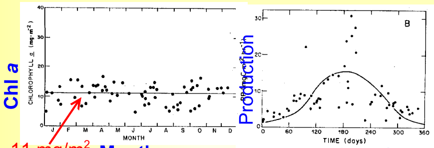
Slide 3 Why no phytoplankton bloom in the Subarctic Pacific?

NOTES:

No bloom at Station P in the Subarctic Pacific

Chl *a* and production from Frost (1987)



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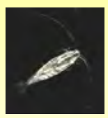
Slide 4 No bloom at Station P in the Subarctic Pacific

NOTES:

The 'Major Grazer' hypothesis

Macrozooplankton grazing keeps bloom in check

- Major grazer Hypothesis
  - Heinrich (1957)
  - Beklemishev (1957)
  - McAllister (1960)
  - Parsons et al. (1966)
  - Fulton (1973)
- *Neocalanus plumchrus* & *N. cristatus*:
  - Horsefly-sized calanoids
  - Keep blooms in check due to unique life history

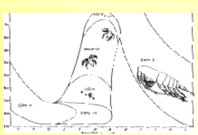


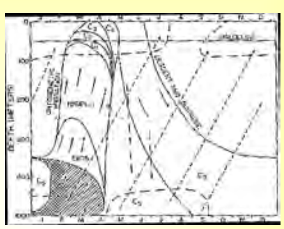
Slide 5 The 'Major Grazer' hypothesis

NOTES:

Neocalanus life history

Different from North Atlantic *Calanus finmarchicus*, *Calanus pacificus* & *Pseudocalanus*: reproduce at depth, CIII stages feeding on bloom





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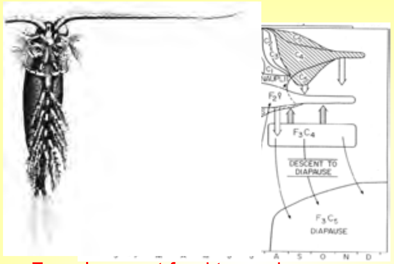
Slide 6 Neocalanus life history

NOTES:

N. Atlantic *Calanus* life history

***Calanus finmarchicus*: the N. Atlantic dominant**



Females must feed to produce eggs:
20-30 d lag

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Slide 7 N. Atlantic Calanus life history

NOTES:

The micrograzer hypothesis: ciliates

Evans & Parslow's (1985) model

In the critical depth concept, a shallowing of the mixed layer is not necessary to initiate a spring bloom. Blooms can occur, or not, even if the mixed layer remains constant seasonally. If the winter mixed layer is deep, a bloom is often the result. If shallow, grazing can keep the bloom in check.

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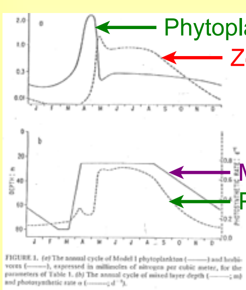
Slide 8 The micrograzer hypothesis: ciliates

NOTES:

Blooms with constant mixed layers

Evans & Parslow (1985), Figures 2 & 3



Phytoplankton biomass
Zooplankton biomass
Mixed-layer depth
Photosynthetic rate

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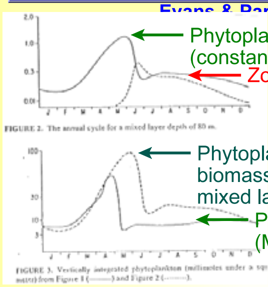
Slide 9 Blooms with constant mixed layers

NOTES:

Protozoan grazing & winter standing stocks the key!

Evans & Parslow's (1985)



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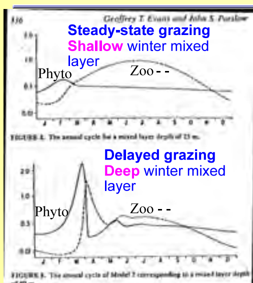
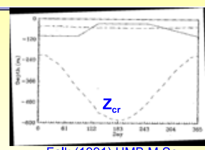
Slide 10 Protozoan grazing & winter standing stocks the key!

NOTES:

Permanent halocline is one key to the lack of spring bloom in the N. Pacific





Falk (1991) UMB M.Sc

- Permanent halocline & lack of dust leads to Fe limitation
- Critical depth> halocline
  - Micrograzers active in winter

Slide 11 Permanent halocline is one key to the lack of spring bloom in the N. Pacific

NOTES:

Evans & Parslow's (1985) micrograzer hypothesis

- North Pacific blooms are kept in check by protozoan grazing
- The permanent halocline in the North Pacific (relatively high rainfall relative to evaporation) results in a permanent surface mixed layer and higher winter-time production than the N. Atlantic
- Protozoan grazer standing stocks remain high during the winter and can keep spring phytoplankton production in check

Slide 12 Evans & Parslow's (1985) micrograzer hypothesis

NOTES:

Problems with the “naive” micrograzer hypothesis

- Why are there spring and fall blooms in areas like MA Bay, where the critical depth usually always exceeds the bottom depth?
- What controls diatom production, a group that owes much of its evolutionary success to its resistance to microzooplankton grazing?

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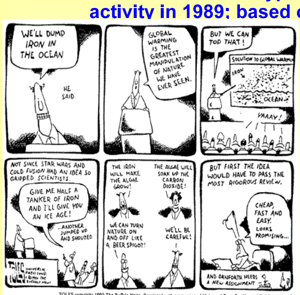
Slide 13 Problems with the “naive” micrograzer hypothesis

NOTES:

Martin’s Geritol solution

The late John Martin’s hypothesis created a frenzy of activity in 1989; based on a talk at WHOI



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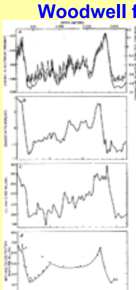
Slide 14 Martin’s Geritol solution

NOTES:

The Greenhouse effect & Fe

Woodwell figures. Fe dust increased during ice ages



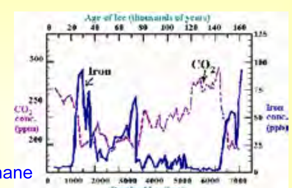
Deuterium ≈ Temp

^{18}O

CO_2

Methane

0 150,000



0 7,000

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Slide 15 The Greenhouse effect & Fe

NOTES:

Roles of Fe in plant metabolism

Geider & LaRoche (1994)

- Cytochrome oxidase
- Fe-superoxidize dismutase
- Catalase
- Peroxidase
- Ferrodoxin (needed for N_2 fixation)
- Nitrate reductase, nitrite reductase
- Glutamate synthetase
- Others

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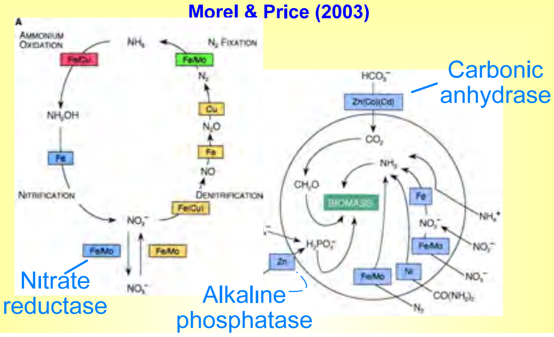
Slide 16 Roles of Fe in plant metabolism

NOTES:

Key uses of Fe & Zn by microbes

Morel & Price (2003)

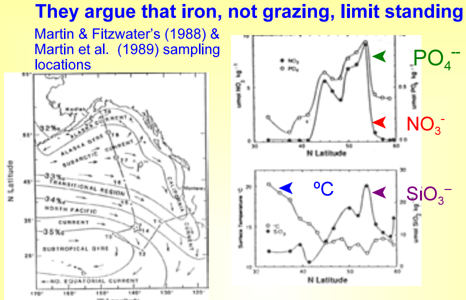


Slide 17 Key uses of Fe & Zn by microbes

NOTES:

Martin & Fitzwater's Fe hypothesis

They argue that iron, not grazing, limit standing stocks



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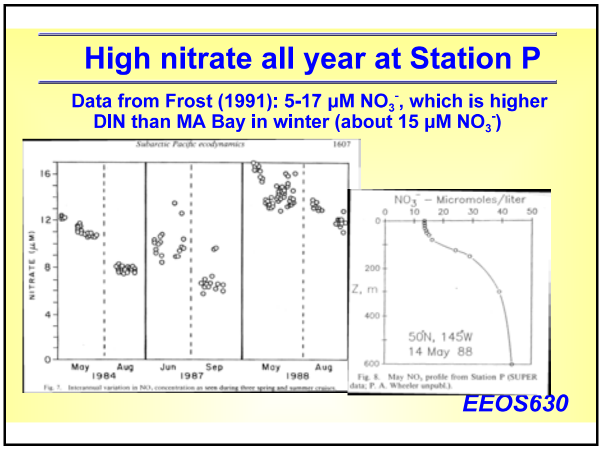
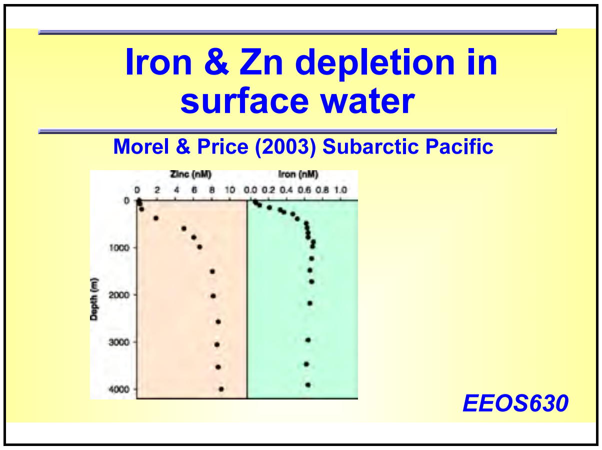
Slide 18 Martin & Fitzwater's Fe hypothesis

NOTES:



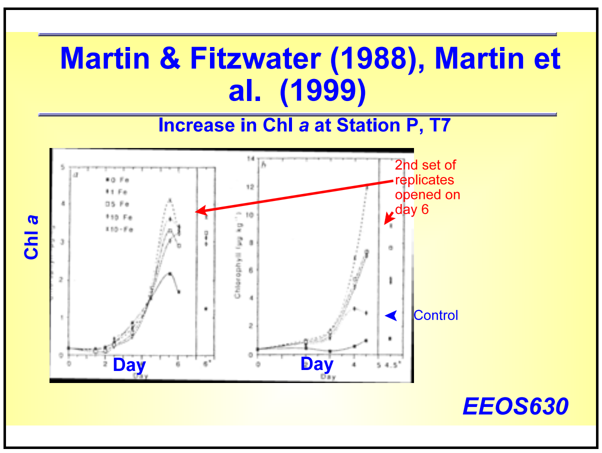
Slide 19 High nitrate all year at Station P

NOTES:



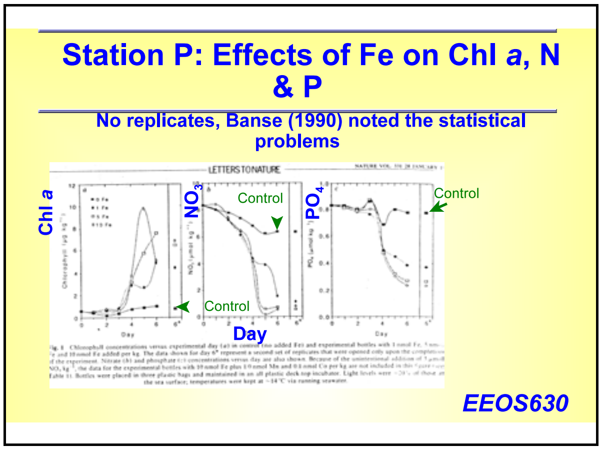
Slide 20 Iron & Zn depletion in surface water

NOTES:



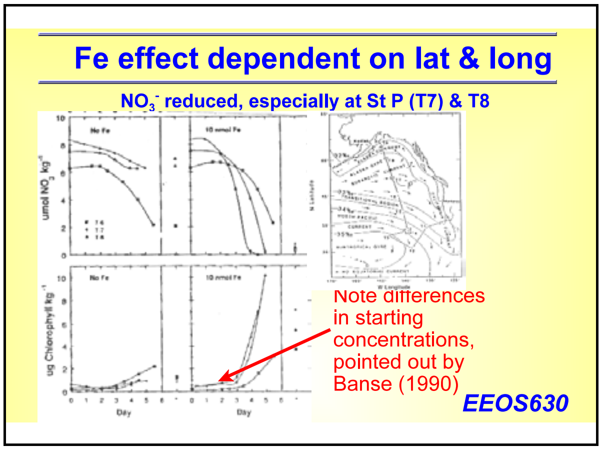
Slide 21 Martin & Fitzwater (1988), Martin et al. (1999)

NOTES:



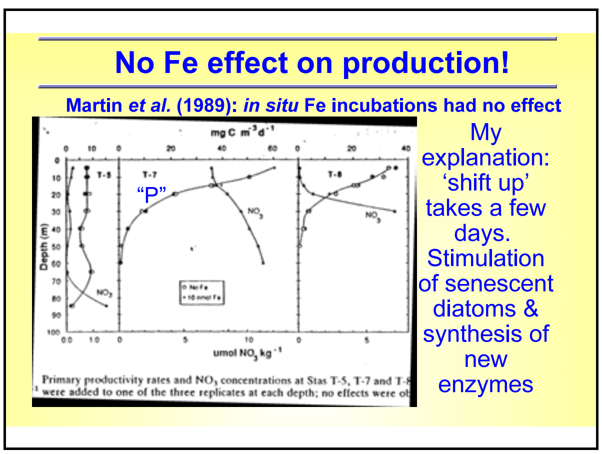
Slide 22 Station P: Effects of Fe on Chl a, N & P

NOTES:



Slide 23 Fe effect dependent on lat & long

NOTES:



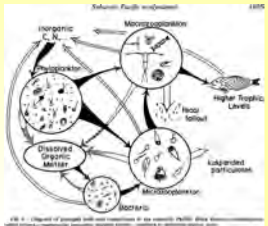
Slide 24 No Fe effect on production!

NOTES:

The ecumenical Fe hypothesis

Morel (1991) , Miller *et al.* (1991)

- Small phytoplankton (<10 µm) less affected by low Fe
  - Use NH_4^+ as primary N source
  - Outcompete diatoms for NH_4^+ and Fe due to higher Surface:Volume ratio
  - Are grazer-limited
  - Grow with high relative growth rates
- Large phytoplankton cells, especially diatoms (>10 µm) are Fe-limited
  - More likely to use NO_3^-; Nitrate reductase requires Fe;
  - Outcompeted for NH_4^+ & Fe due to low surface:volume ratios
- Fe^{2+} addition leads to stimulation of diatoms which synthesize nitrate reductase to take up NO_3^- and other key enzymes (e.g., chlorophyllase to synthesize Chl *a*



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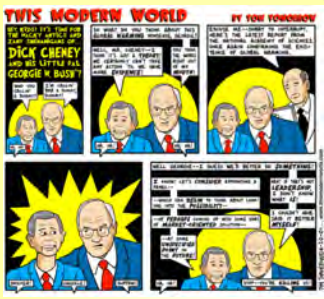
Slide 25	The ecumenical Fe hypothesis
NOTES:	

Market-oriented CO_2 solution

Carbon credits for the geritol solution



What is the geritol solution & could it work?

Chisholm, S. W., P. G. Falkowski and J. J. Cullen. 2001. Dis-crediting ocean fertilization. Science *294*: 309-310.

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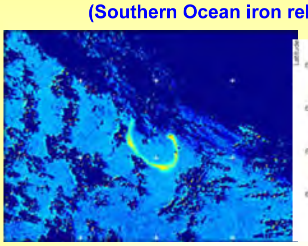
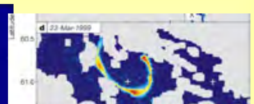
Slide 26	Market-oriented CO2 solution
NOTES:	

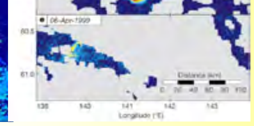
SOIREE

(Southern Ocean iron release experiment)



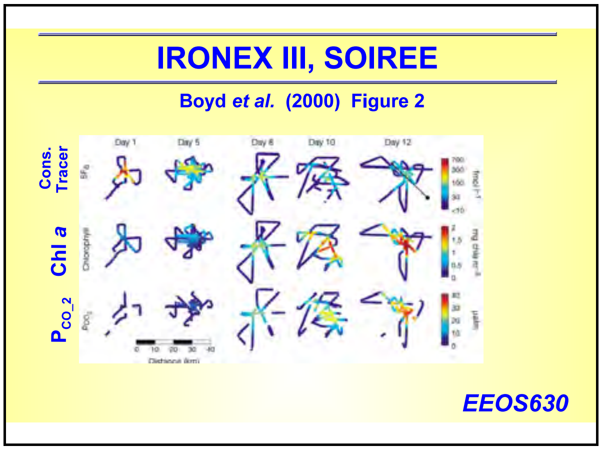
SeaWIFS Image of 100-km bloom, 30 d after Fe-II spike





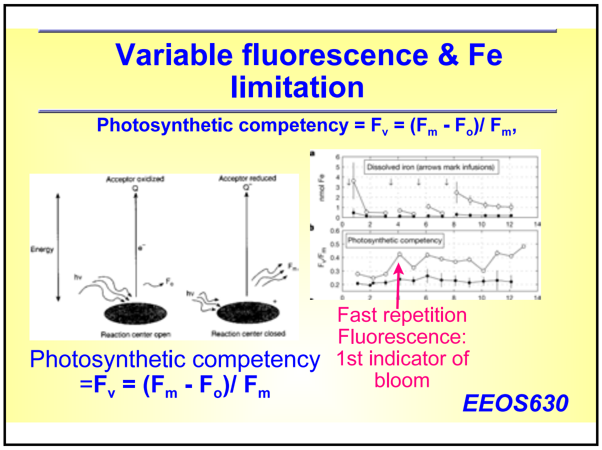
Abraham *et al.* 2000

Slide 27	SOIREE
NOTES:	



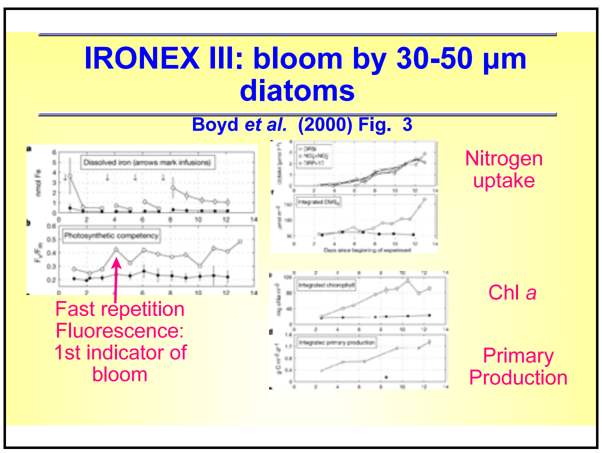
Slide 28 **IRONEX III, SOIREE**

NOTES:



Slide 29 **Variable fluorescence & Fe limitation**

NOTES:

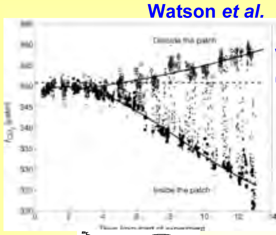


Slide 30 **IRONEX III: bloom by 30-50 µm diatoms**

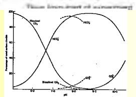
NOTES:

Fe increases CO_2 gradient

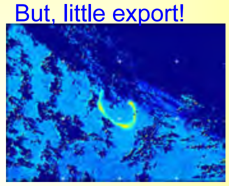
Watson *et al.* (2000): SOIREE



Warming, 0.3° C



But, little export!



Slide 31 — Fe increases CO2 gradient

NOTES:

SOIREE: major results

Confirms the 'ecumenical' iron hypothesis

- Increase in photosynthetic parameters by day 4, measured by variable fluorescence
- Increase in large chain-forming diatoms by day 5: 30-50 µm cell size
- Microzooplankton abundance quadrupled
  - Grazing only on small phytoplankton cells (< 20 µm cells)
- No evidence of macrozooplankton response
  - No increased carbon export to sediment traps
- Partial pressure of CO_2 decreased in surface ocean; this gradient would increase the atmosphere to ocean flux of CO_2

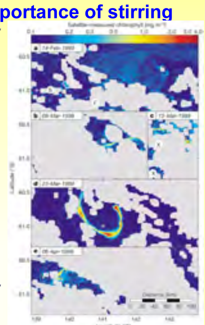
Slide 32 — SOIREE: major results

NOTES:

SOIREE

Abraham *et al.* 2000. Importance of stirring

- **150-km long bloom 6 weeks after the Fe fertiliaztion experiment**
- **23 March 1999**
  - **3 mg Chl *a* m^{-3}**
  - **In an area where SeaWiFS indicates the mean Chl *a* was 0.2 ±0.06 mg Chl *a* m^{-3} {15X increase}**
- **Stirring plays a key role**
  - **Fit growth rates of μ=0.19 d^{-1}**
  - **Loss due to horizontal diffusion=0.07 d^{-1}**
  - **Loss due to grazing = 0.01 d^{-1}**
  - **Loss due to sinking = 0.02 d^{-1}**
- **Accumulation of 600-3000 t of algal C**



Slide 33 — SOIREE

NOTES:

C:N:P:Fe Redfield ratios

C:N:P:Fe≈106:16:1:(0.003 to 0.0003)

- Lab cultures
  - Geider & LaRoche (1994)
    - Dinoflagellate (*Gymnodinium*) N:Fe ≈2000
    - Diatom N:Fe ≈ 10,000
    - *Synechococcus* (blue green) N:Fe ≈3000
  - Sunda *et al.* (1995), quoted in Fung et al. (2000)
    - Measured range N:Fe 13,000 - 116,000
      - Low productivity N:Fe ≈60,000 C:Fe 400,000
      - High productivity N:Fe ≈34,000 C:Fe 220,000
- Boyd *et al.* (2004) Gulf of Alaska bloom
  - N:Fe 5800
  - C:Fe 38,000

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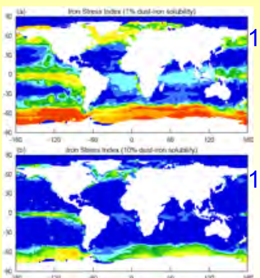
Slide 34 C:N:P:Fe Redfield ratios

NOTES:

Iron stress in the oceans

Zones where Fe:N uptake > Fe:N supply (from dust & upwelling), Fung *et al.* (2000)



1% dust-iron solubility

10% dust-iron solubility

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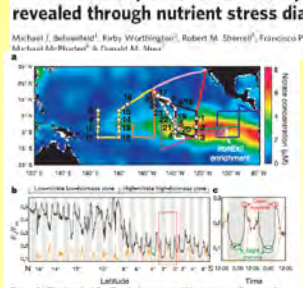
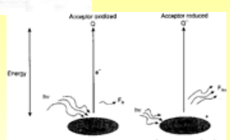
Slide 35 Iron stress in the oceans

NOTES:

Controls on tropical Pacific Ocean productivity revealed through nutrient stress diagnostics



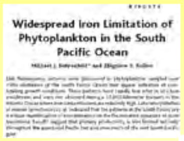


Photosynthetic competency $=F_v = (F_m - F_o)/ F_m$

Nature *442*: 1025-1028. August 2006

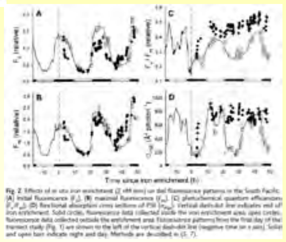
Slide 36 The ecumenical Fe hypothesis

NOTES:



Behrenfeld & Kolber (1999)

Night F_o increases relative to F_m in Fe-limited cells

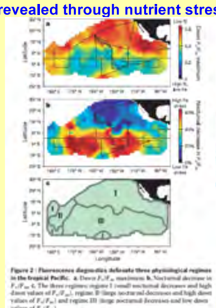


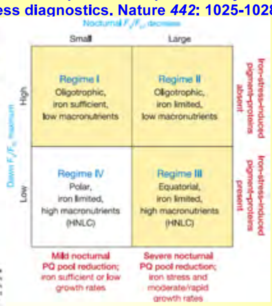
Slide 37

NOTES:

Iron-limitation zones

Behrenfeld, M. J. et al. 2006. Controls on tropical ocean productivity revealed through nutrient stress diagnostics. Nature *442*: 1025-1028.



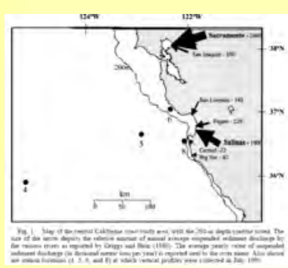


Slide 38 Iron-limitation zones

NOTES:

Does Fe limit production in the Southern California Bight?

Bruland et al. (2001) Limnol. Oceanogr



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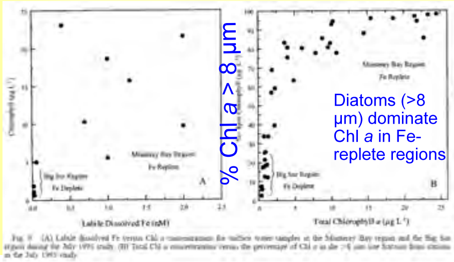
Slide 39 Does Fe limit production in the Southern California Bight?

NOTES:

Does Fe limit production in the Southern California Bight? Perhaps

Bruland et al. (2001) Limnol. Oceanogr



Slide 40 Does Fe limit production in the Southern California Bight? Perhaps

NOTES:

Problems with the Geritol solution

Not a solution for reducing atmospheric CO_2

- Fe may be the Liebigian nutrient now, but would be replaced by another, *e.g.,* Zn or Si (Leblanc *et al.* 2005)
- Increased production may not reduce the partial pressure of CO_2 sufficiently: no change in CO_2 in IronExI or IronEx II (only in SOIREE)
  - No transport of carbon to deep waters in SOIREE
- Sarmiento: bottom waters, especially in the Southern Ocean, might go anoxic
- David Archer's calcite buffering effect: increased organic matter degradation in deep ocean sediments may dissolve calcite, increasing CO_2 concentrations: Fe only sequesters DIC on the century time scale

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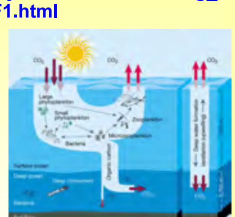
Slide 41 Problems with the Geritol solution

NOTES:

Will Fe additions work?

http://www.nature.com/nature/journal/v407/n6805/fig_tab/407685a0_F1.html

- **Short term**
  - **Fe additions must decrease the CO_2 concentrations in the ocean surface**
  - **There must be an enhanced flux to deeper water**
- **Long term**
  - **Organic material must be sequestered in sediments**
    - Archer: Sequestration in sediments unlikely long-term
  - **Fe additions to the Southern Ocean could result in bottom-water anoxia: Sarmiento's model**



Chisholm 2000 Oceanography: Stirring times in the Southern Ocean

Slide 42 Will Fe additions work?

NOTES: