(slightly more than..) 25 years of marine geochemistry

Why the geochemical approach essential in oceanography

Catherine Jeandel
CNRS, LEGOS, Toulouse

Major questions in oceanography

- Quantifying the circulation
- Quantifying the flux and fate of the elements: sources, sink and internal cycling

Fate of the chemical species?
Which tracer for what?

Outline

- 4 tracers across 4 main temporal steps

« and the winners..» are

- ➢ ^{14}C : the mixing rate of the oceans
- ➢ $^{234}U/^{230}Th$: D-P exchange & settling velocities of the particles
- ➢ Nd isotopes : D-P exchange, origin of waters & elements
- ➢ Fe and isotopes: speciation and quantification of the sources

- The 4 temporal steps

GEOSECS legacy — 70s-80s

Clean lab, mass spect. WOCE&JGOFS — 90s

GEOTRACES — 2000-20s

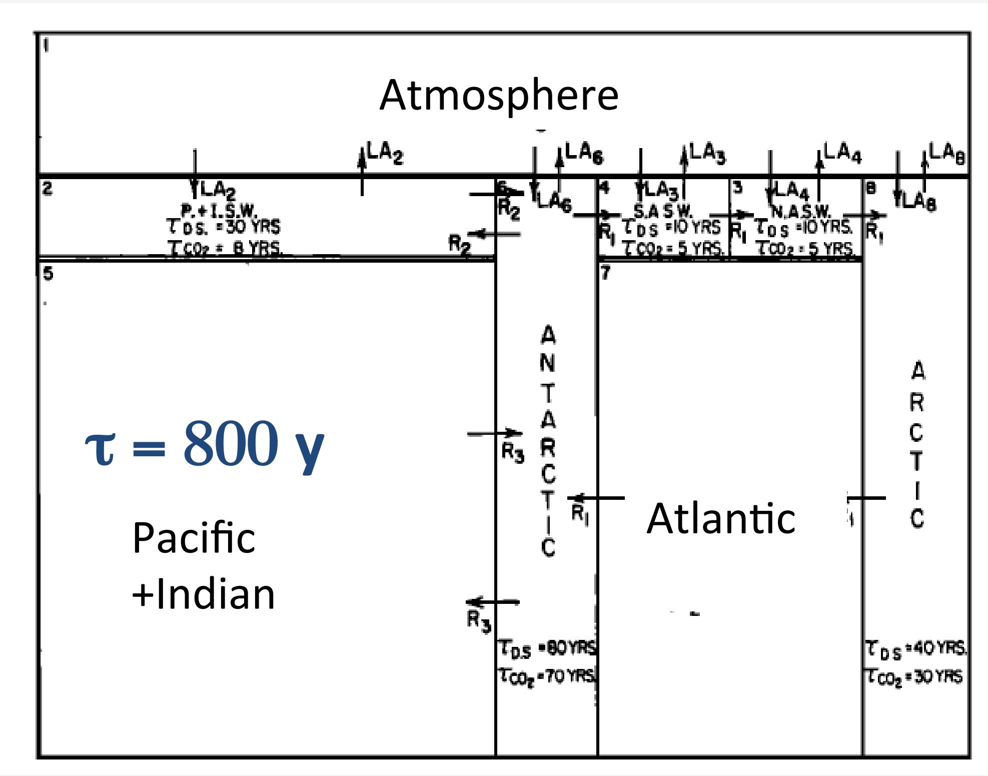
Futurs — ....s

^{14}C (radioactive, $T_{1/2}$= 5700 y)

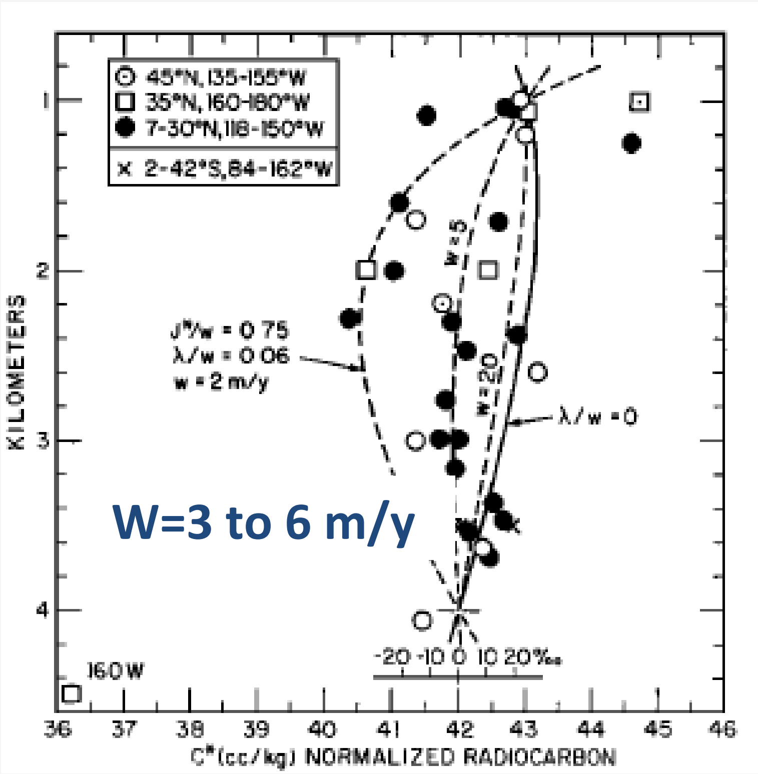
GEOSECS legacy

70s-80s

- Chronometer of the deep waters
- Beta counting: more than 400l, long counting times
- First deep water residence time and ventilation rates



First box model to calculate deep water residence time (Broecker et al. 1960)



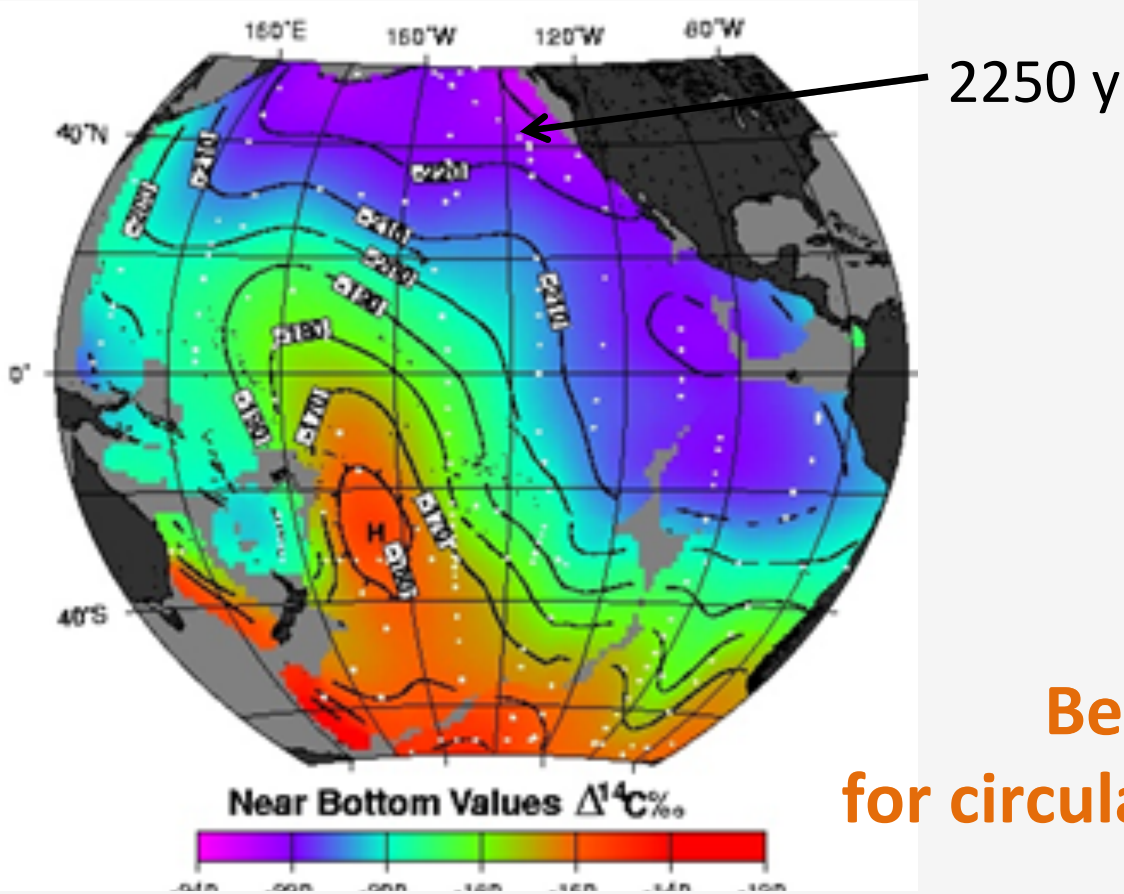
Pacific advection-diffusion ^{14}C model (Craig et al, 1969)

^{14}C

Clean lab, mass spect.
WOCE&JGOFS

90s

- Change of scale: mass spec, few liters, high resolution
- WOCE : sections and maps, ages of all water masses



Schlosser et al, 2001

Beautiful tracer for circulation quantification

^{14}C

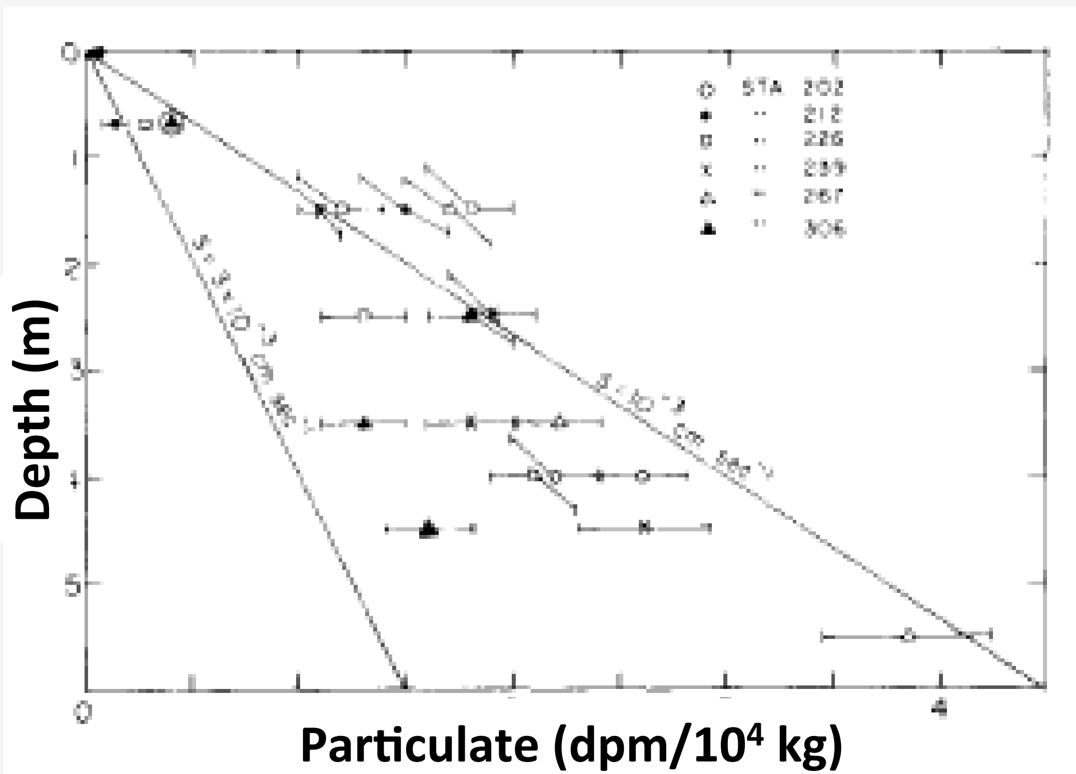
- Ancillary parameter
- Highly recommended

U/Th story: first profiles

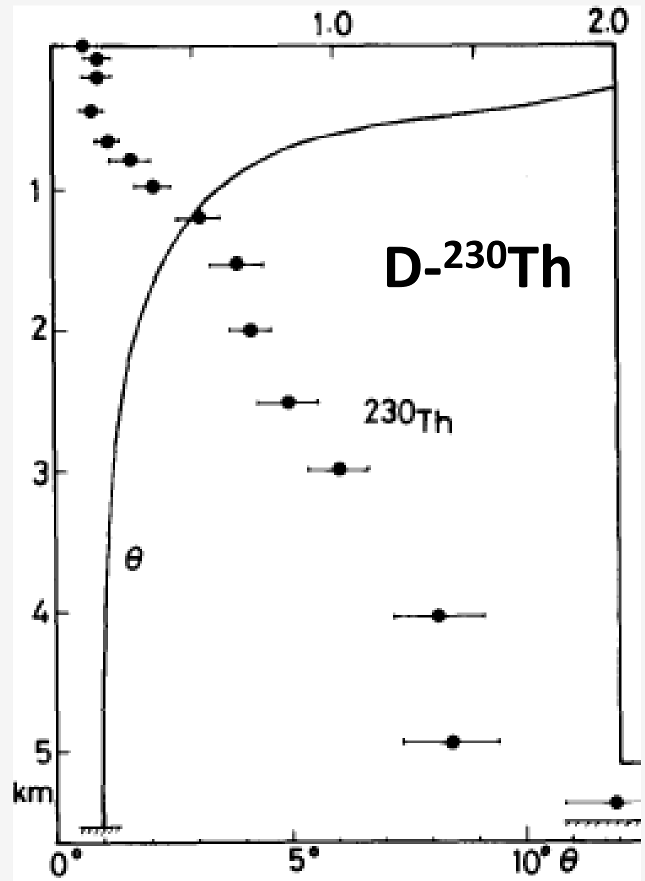
GEOSECS legacy

70s-80s

- Developed and measured during GEOSECS
- Tons of water, first in situ pumps



Krishnaswami et al, 1976

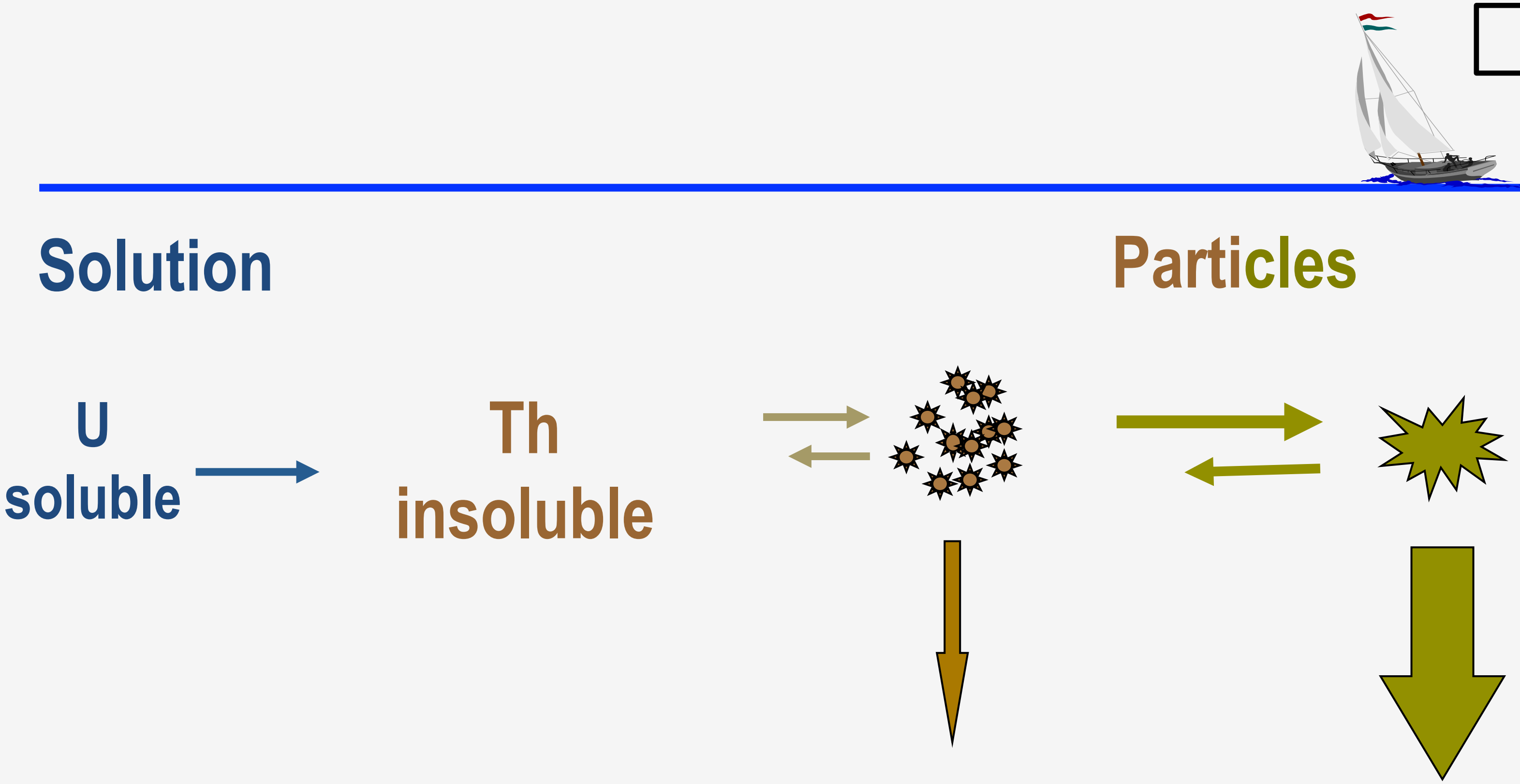


Nozaki et al, 1981

U/Th: the mechanism

GEOSECS legacy

70s-80s

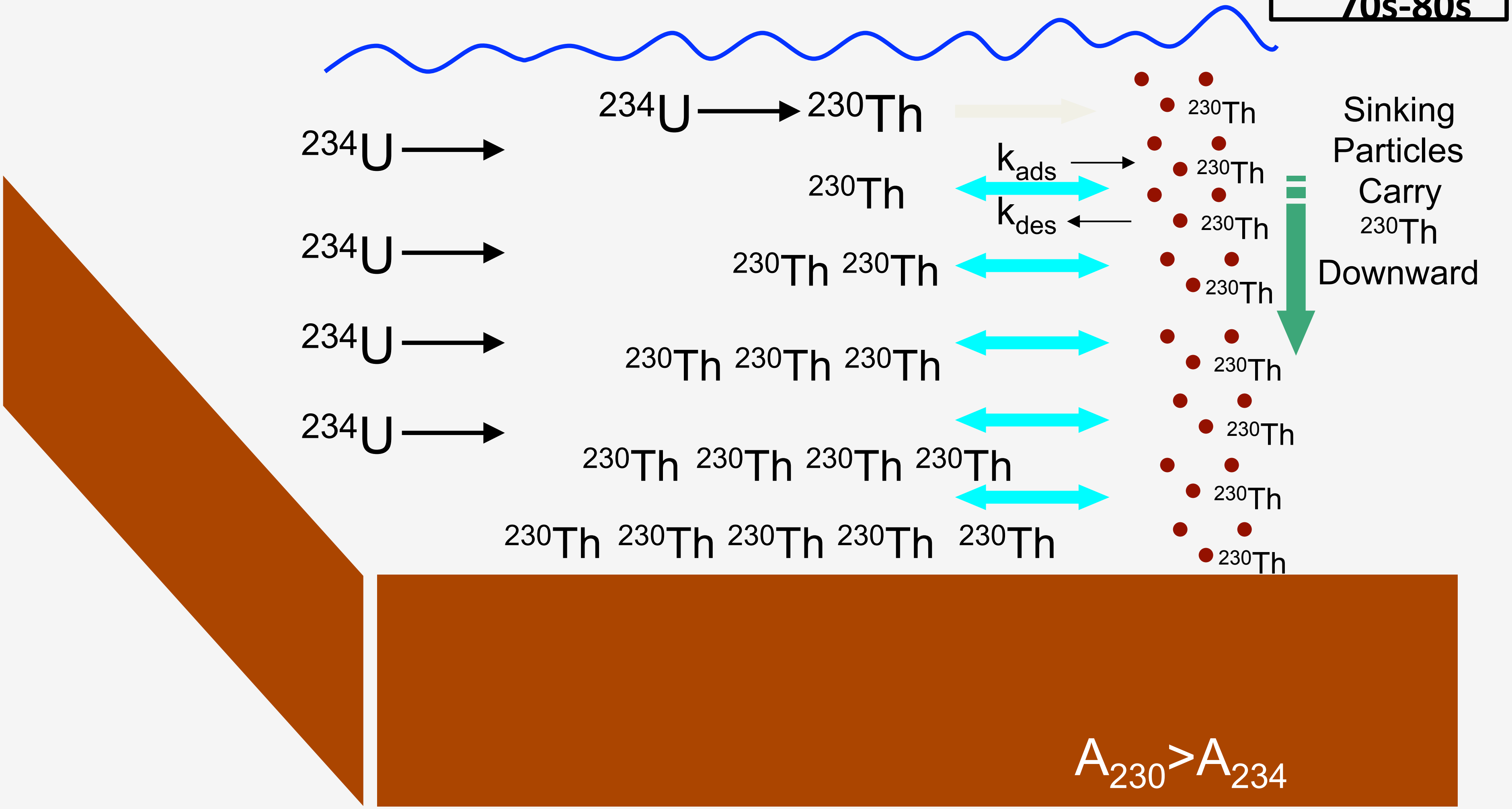


^{230}Th, $T_{1/2}$ 75 000y: deep processes

What is observed and hypothesized?

GEOSECS legacy

70s-80s

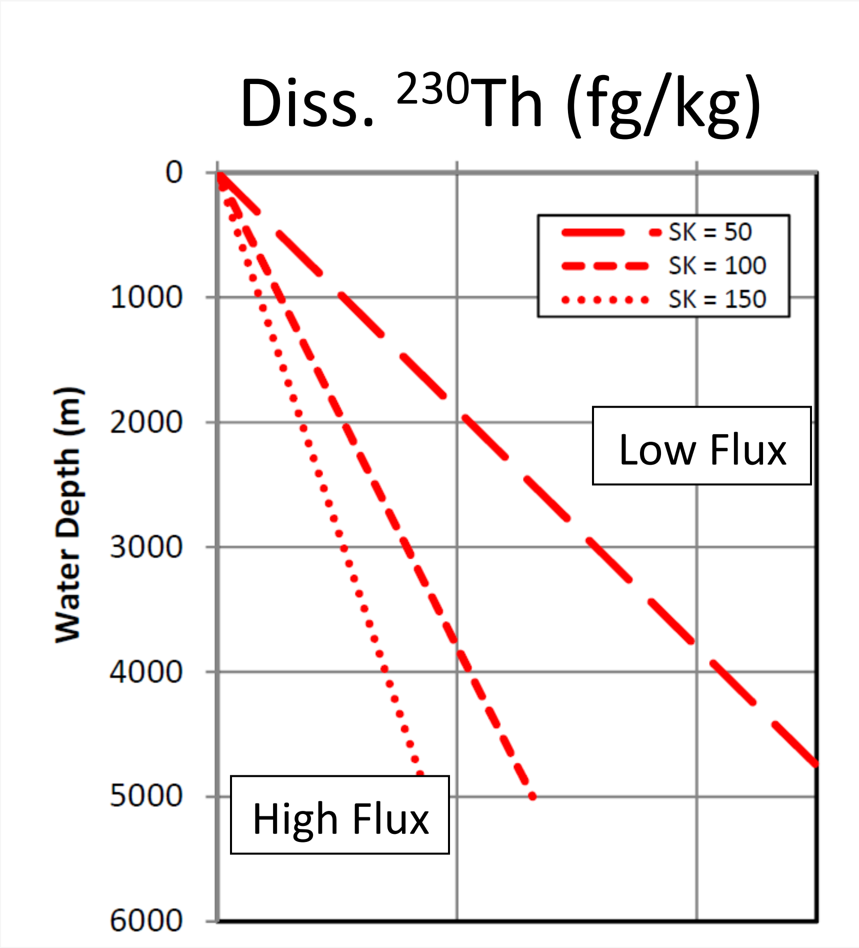


Courtesy of Bob Anderson

Linearity of solid and dissolved ^{230}Th Reversible scavenging

GEOSECS legacy

70s-80s



$$Th_d = \frac{Pz}{SK}$$

$K = k_{ads}/k_{des}$

$$\mathrm{Th_p} = \frac{Pz}{S}$$

Bacon and Anderson 1982, *JGR*

$$P = 0.5\, fg\, kg^{-1} yr^{-1}$$
$$\mathrm{S} \approx 1000\, m\, yr^{-1}$$
$$K \approx 0.2$$

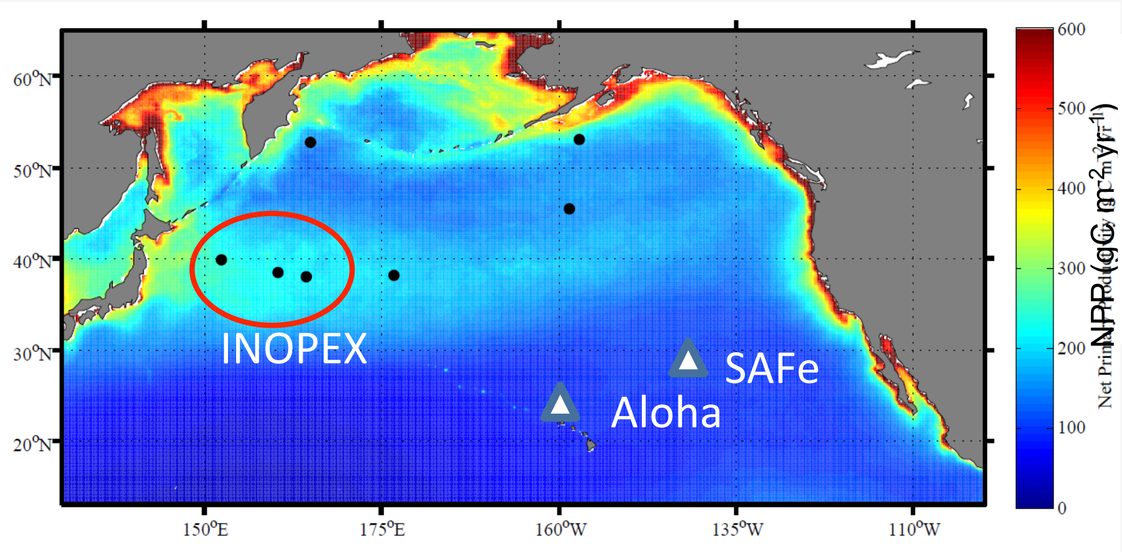
P is production due to U decay
S is sinking rate of particles
K is solid-solution distribution coefficient

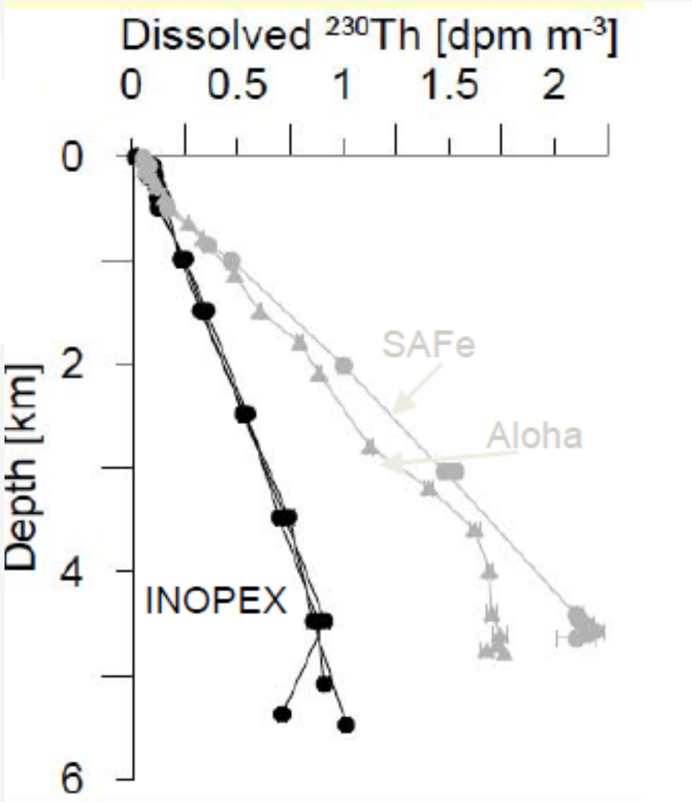
Courtesy of Bob Anderson

1D reversible scavenging model is working in quite areas

Clean lab, mass spect. WOCE&JGOFS

90s



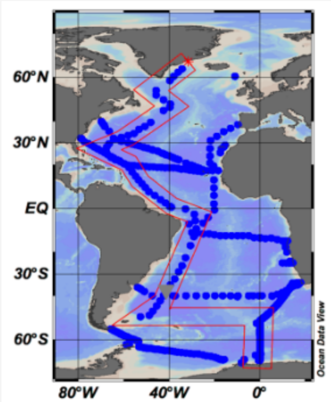


Higher particle flux (K) in NW Pacific lowers ^{230}Th Concentration.

Hayes et al., EPSL 2013

Aloha data from Roy-Barman et al., 1996

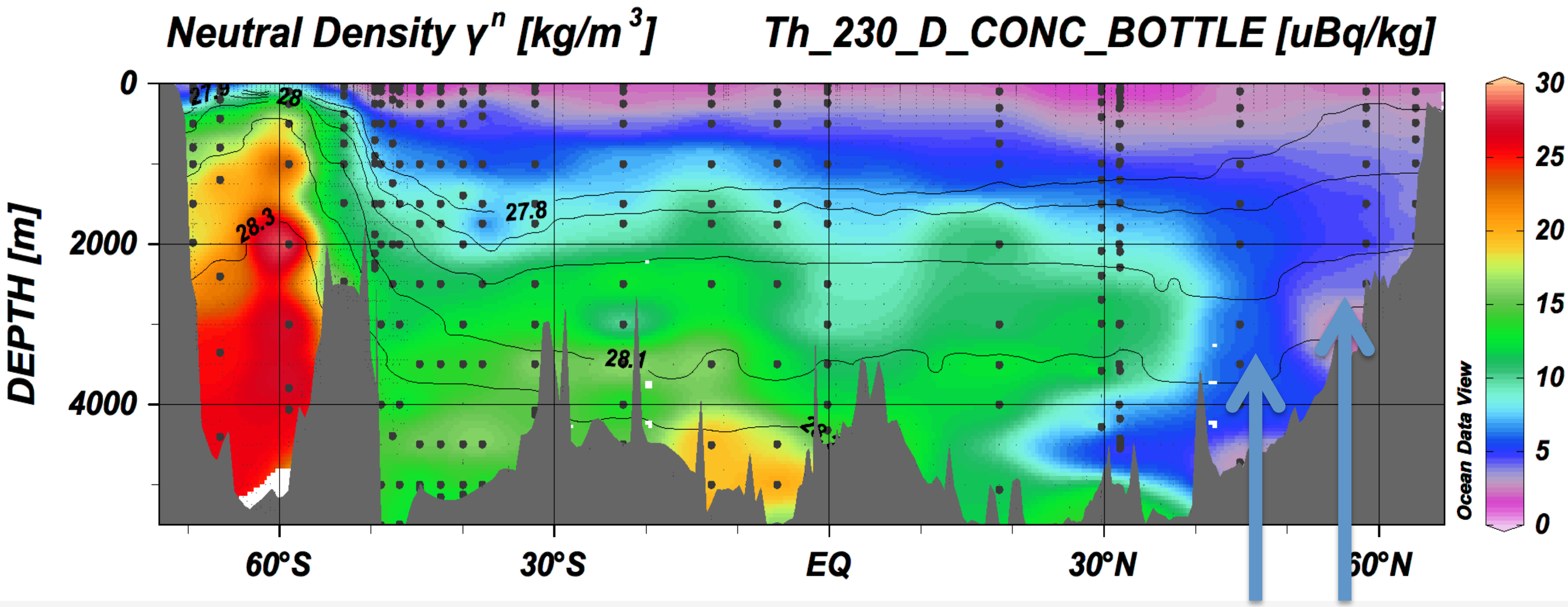
Beautiful tracer: P-D processes and particle dynamics



GEOTRACES IDP 2014: high resolution ^{230}Th data

2000-20s

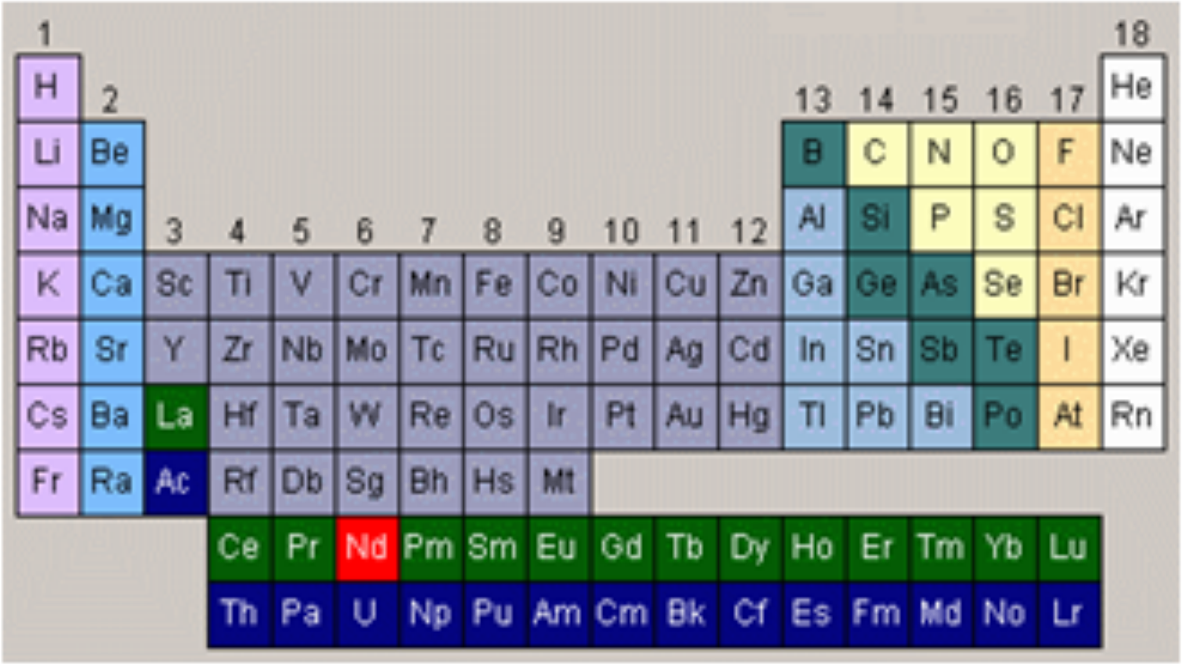
Hayes & Anderson, 2015



Depleted dissolved ^{230}Th in the North Atlantic
is reflecting enhanced scavenging in the nepheloids
Barely the ventilation

Nd isotope story

NEODYMIUM ???



$^{147}\mathrm{Sm} \Rightarrow {}^{143}\mathrm{Nd} + \alpha + Q$

$T_{1/2} = 10^{11}$ yr

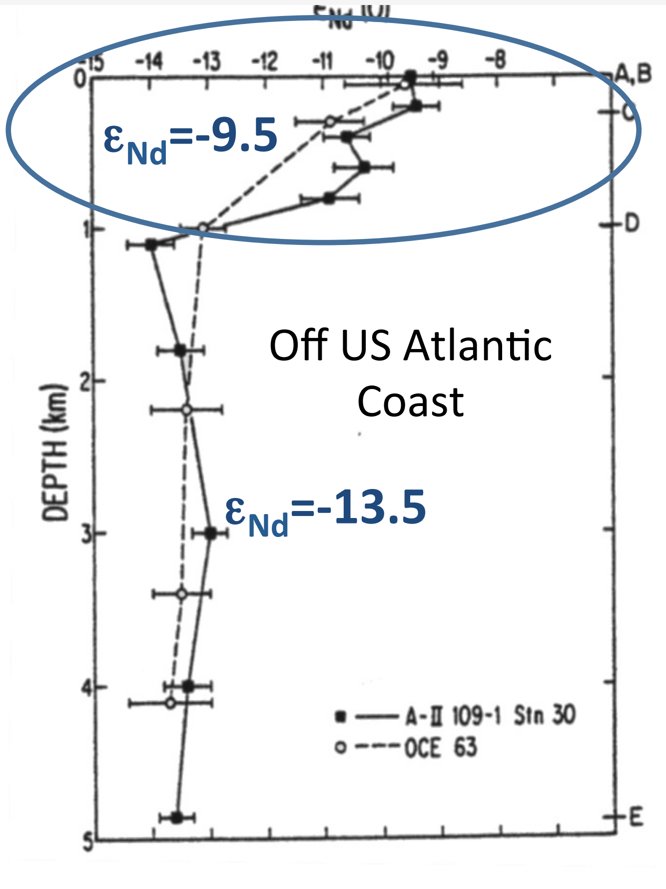
$$\varepsilon_{Nd} = \left(\frac{\left(\frac{^{143}Nd}{^{144}Nd}\right)_{SAMPLE}}{\left(\frac{^{143}Nd}{^{144}Nd}\right)_{CHUR}} - 1 \right) \times 10^{4}$$

Nd isotopes are stable

Nd isotope story

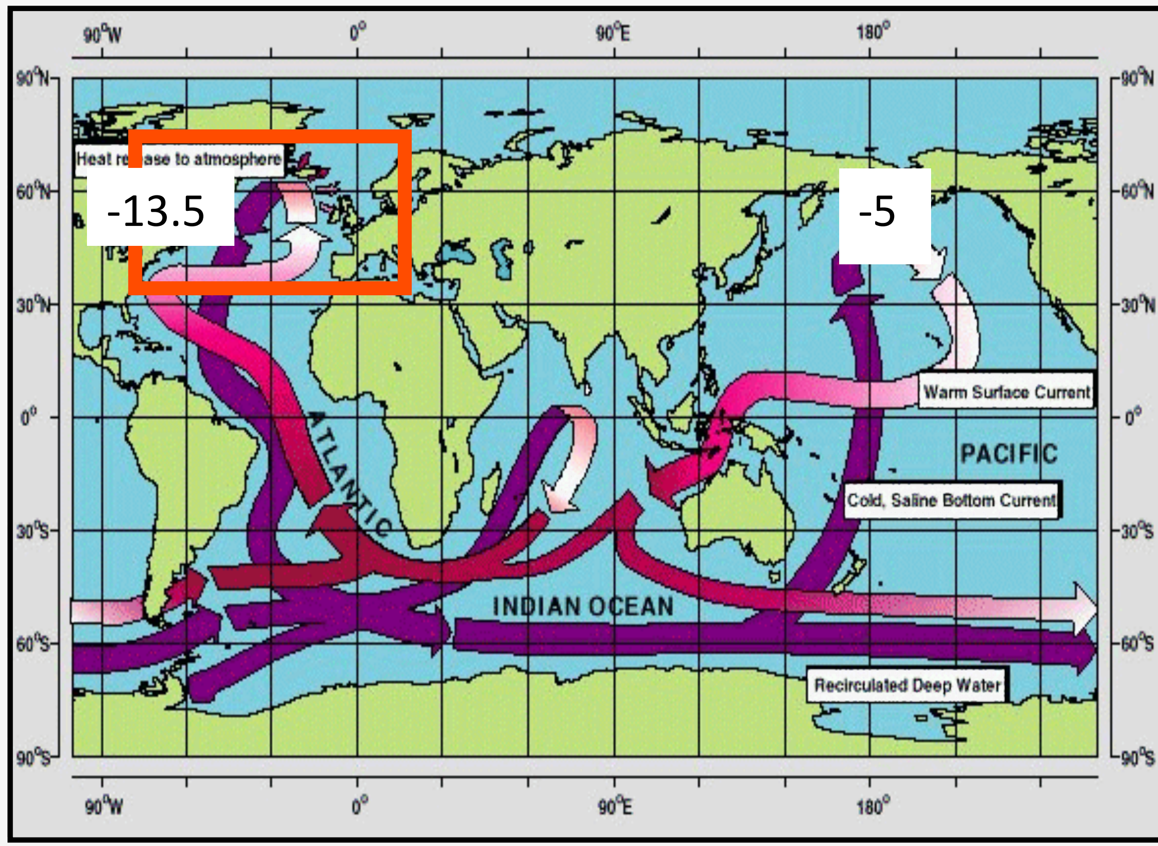
GEOSECS legacy

70s-80s



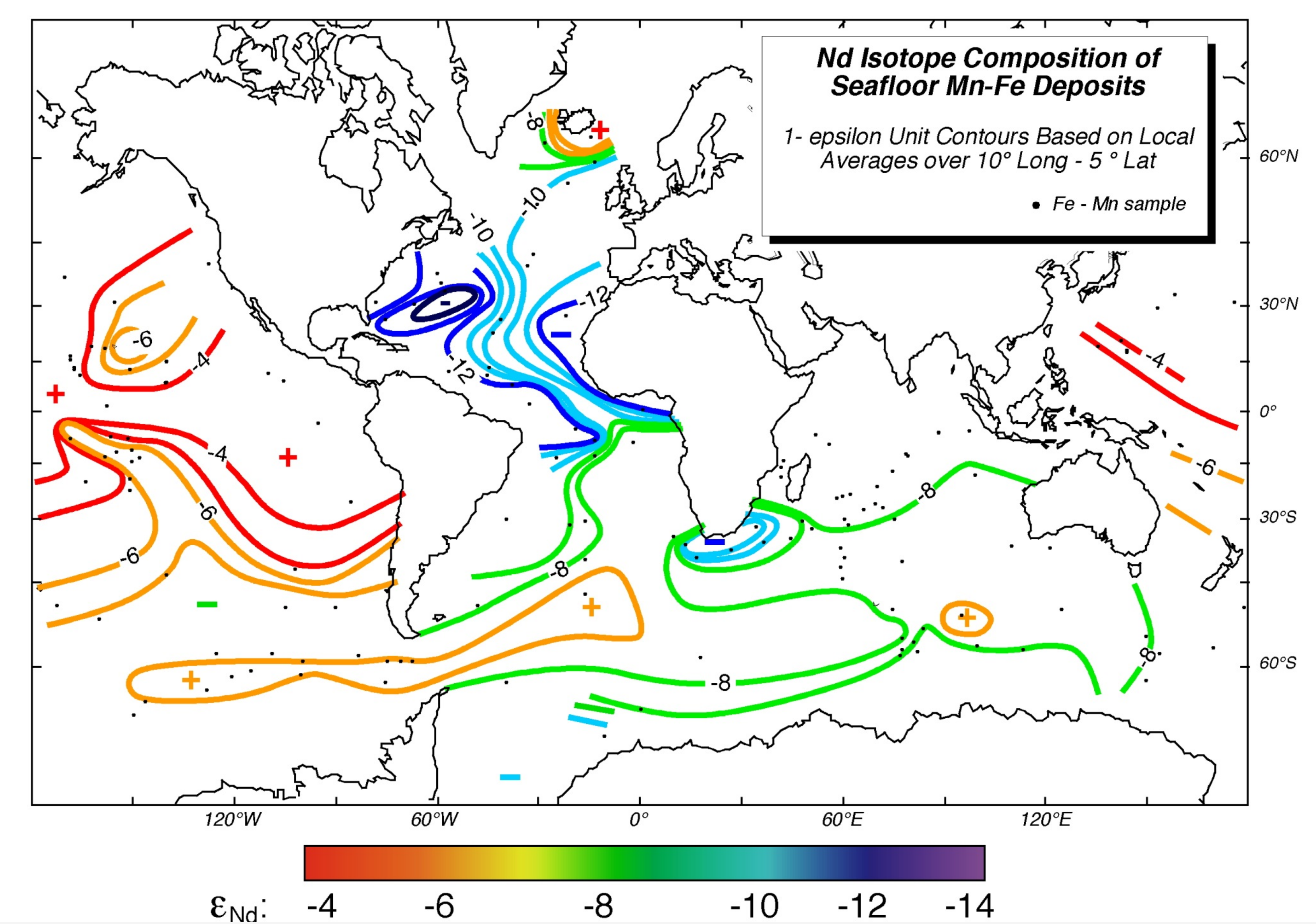
Piepgras and Wasserburg, 1987

?



ε_{Nd} = Thermohaline circulation tracer?

ε_{Nd} variations imprinted in the sediments

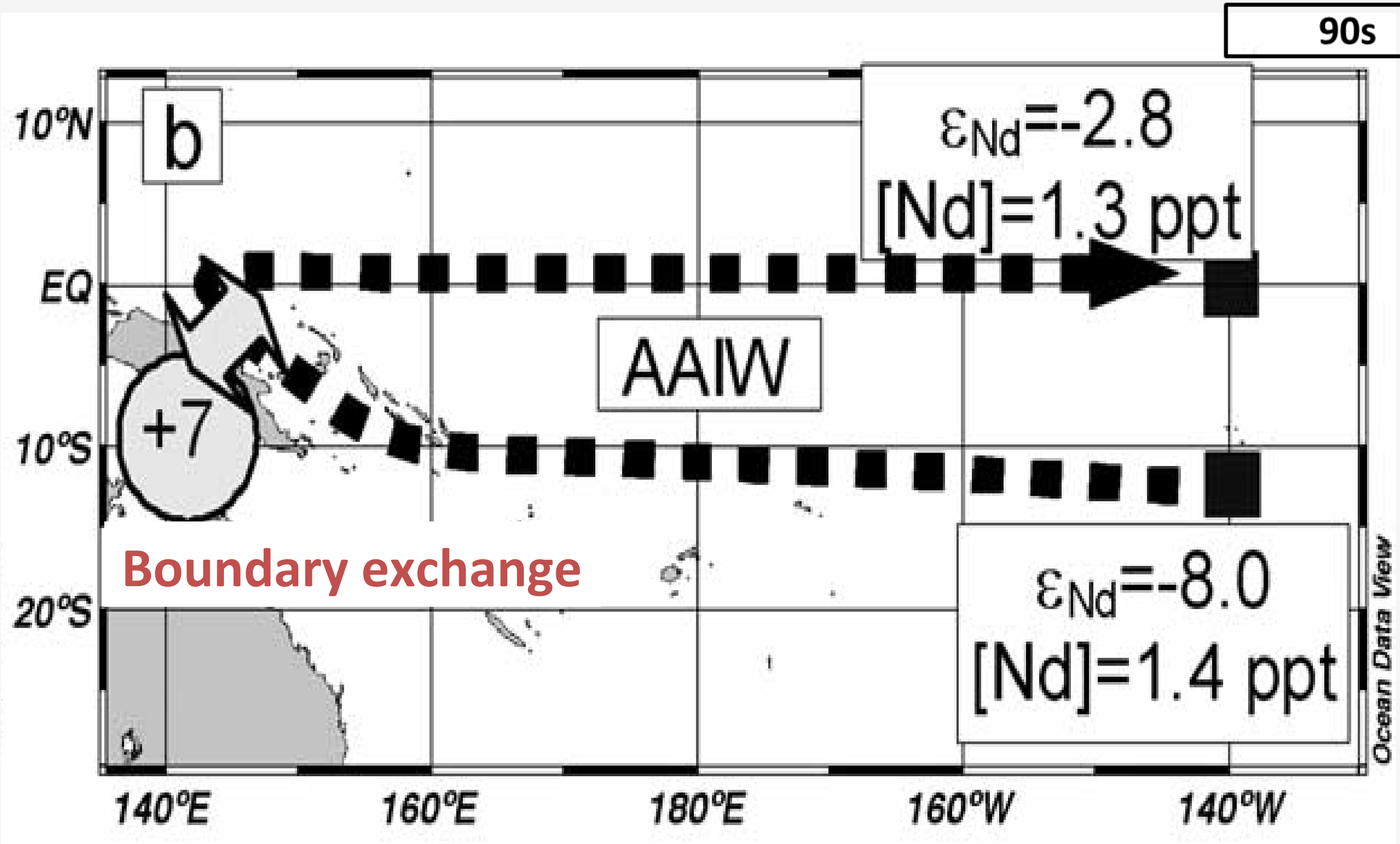


Goldstein and Hemming,2003

Nd parameters: Data from the Pacific

Clean lab, mass spect. WOCE&JGOFS

90s



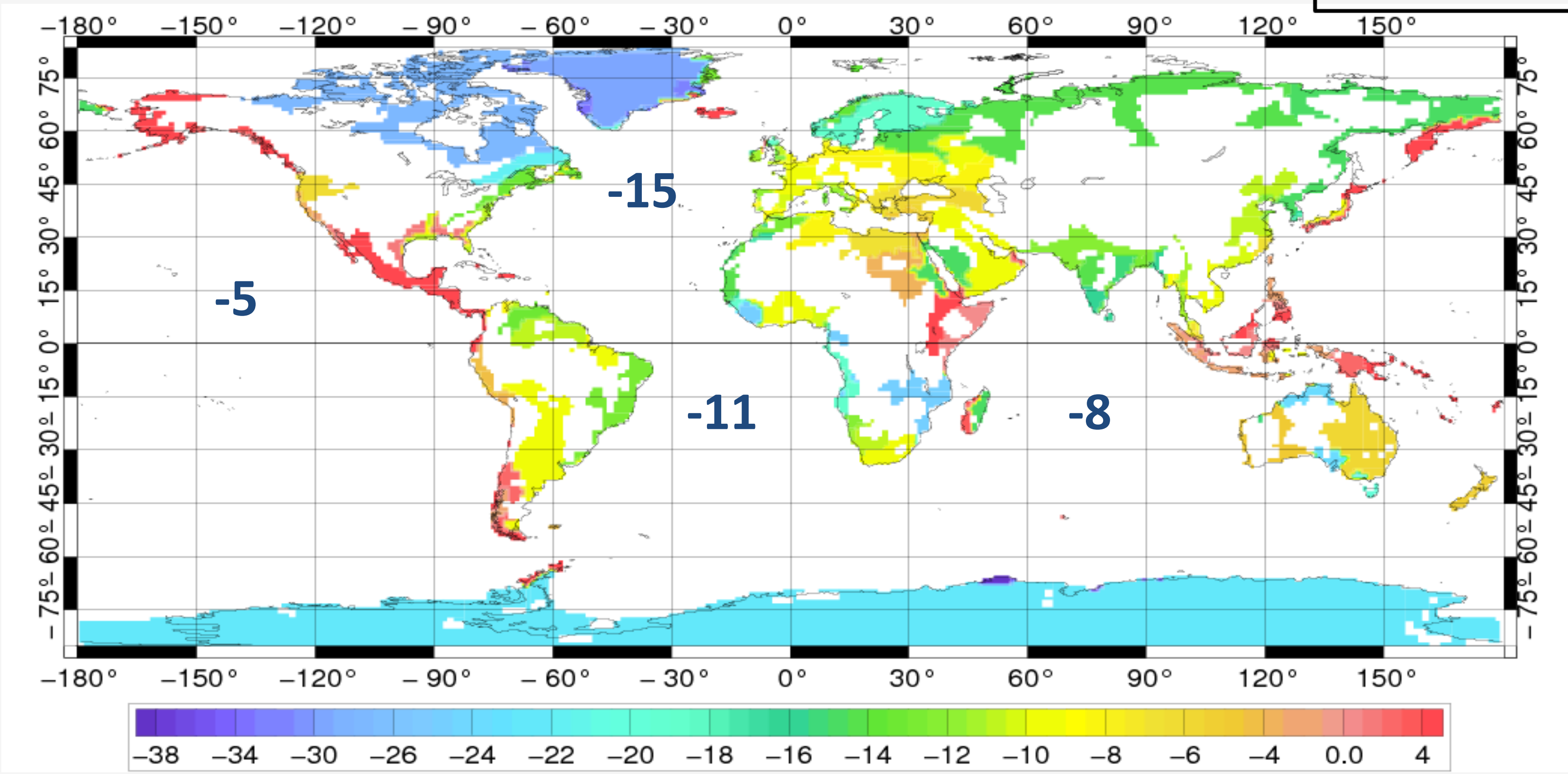
Lacan & Jeandel, 2001; 2005

Nd isotopic composition changes while Nd concentration remains the same

Heterogeneous distribution of ε_{Nd}

Clean lab, mass spect. WOCE&JGOFS

90s



Jeandel et al, 2007

$$-50 \leq \varepsilon_{Nd} \leq +10$$

Old continent

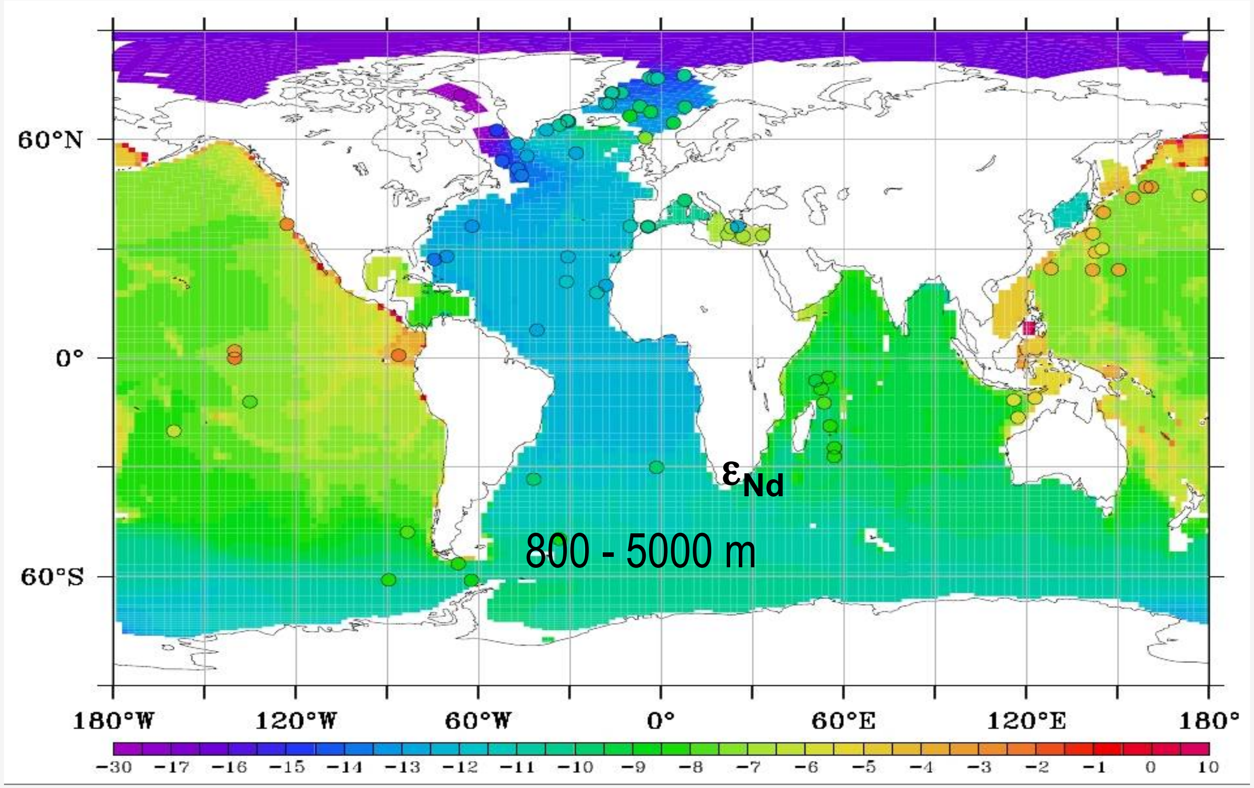
Young volcanic

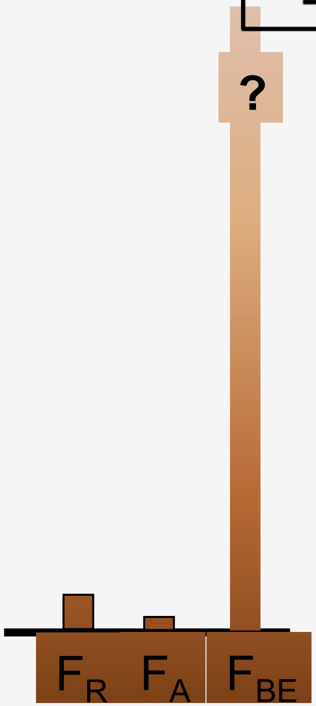
What is controlling the ε_{Nd} gradient ?

Coupling OGCM and Nd cycle *(Arsouze, 2008; 2009)*

GEOTRACES

2000-20s





- BE is **THE** major source term (>95% of the total : 1.1 10^{10} g(Nd)/an).
- Dust and dissolved river inputs significant in the Atlantic surface waters.
- Reversible scavenging: reconciliate the Nd and ε_{Nd} with depth and along the thermohaline

Nd: a beautiful tracer of sources; Warn us on the roles of the margins;
Boundary Exchange quantified

Iron: an essential micro-nutrient

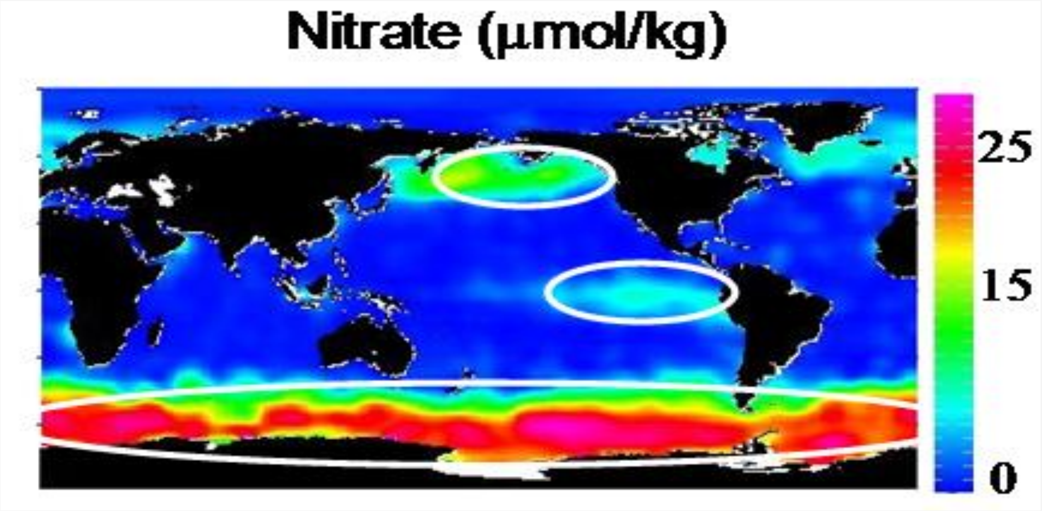
Clean lab, mass spect. WOCE&JGOFS

90s

- ✓ Electron carrier→ photosynthesis, respiration
- ✓ Enzyme cofactor → Nitrogen assimilation

- ➢ Continental crust : 5.6%
- ➢ Surface of the ocean: 0.000 000 005%

Fe could limit primary production in ~1/2 of the ocean *(Moore et al 2001)*



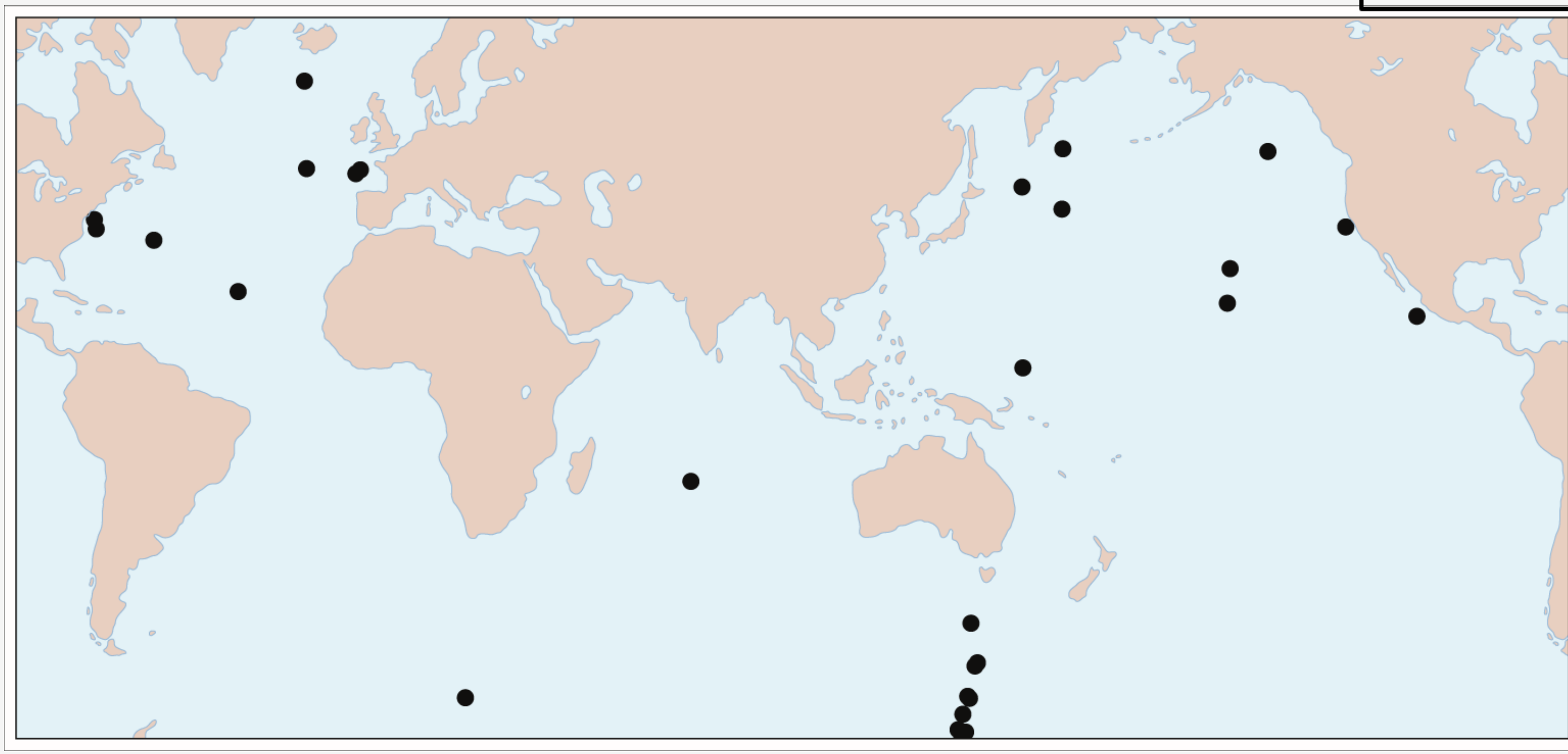
Variations of iron inputs to the ocean

Climate Variations

2003: Stations with Fe concentrations at depth

Clean lab, mass spect. WOCE&JGOFS

90s



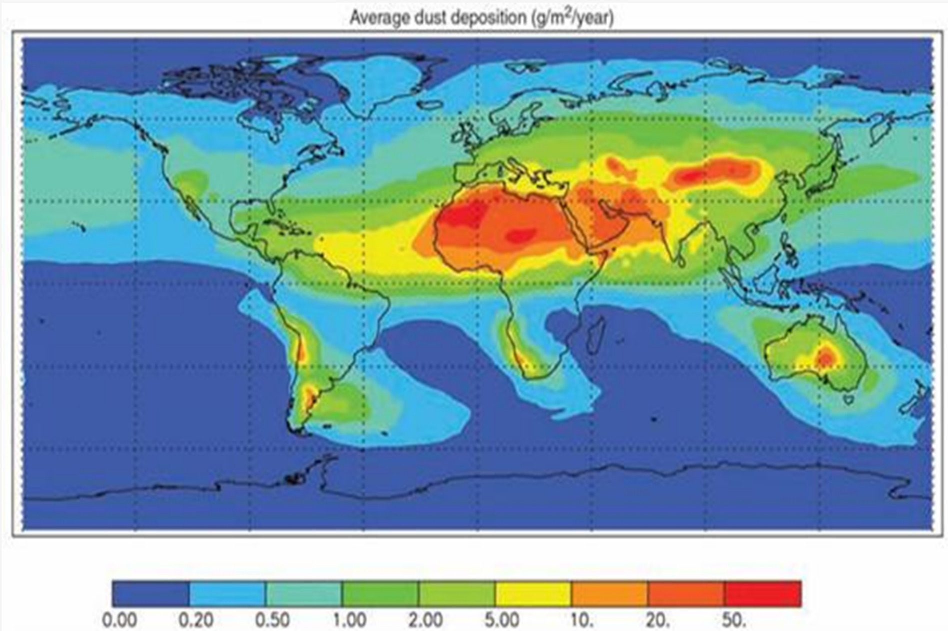
P. Parekh (MIT)

Paucity of information about deep Fe distribution limits understanding of upwelling supply and internal cycling.

Main DFe sources? Early 2000

Clean lab, mass spect. WOCE&JGOFS

90s



Dust?

Jickells et al, 2005

The flux of iron from continental shelf sediments: A missing source for global budgets

Virginia A. Elrod,[1] William M. Berelson,[2] Kenneth H. Coale,[3] and Kenneth S. Johnson[1]

Received 9 April 2004; accepted 20 May 2004; published 18 June 2004.

Reducing Sediments?

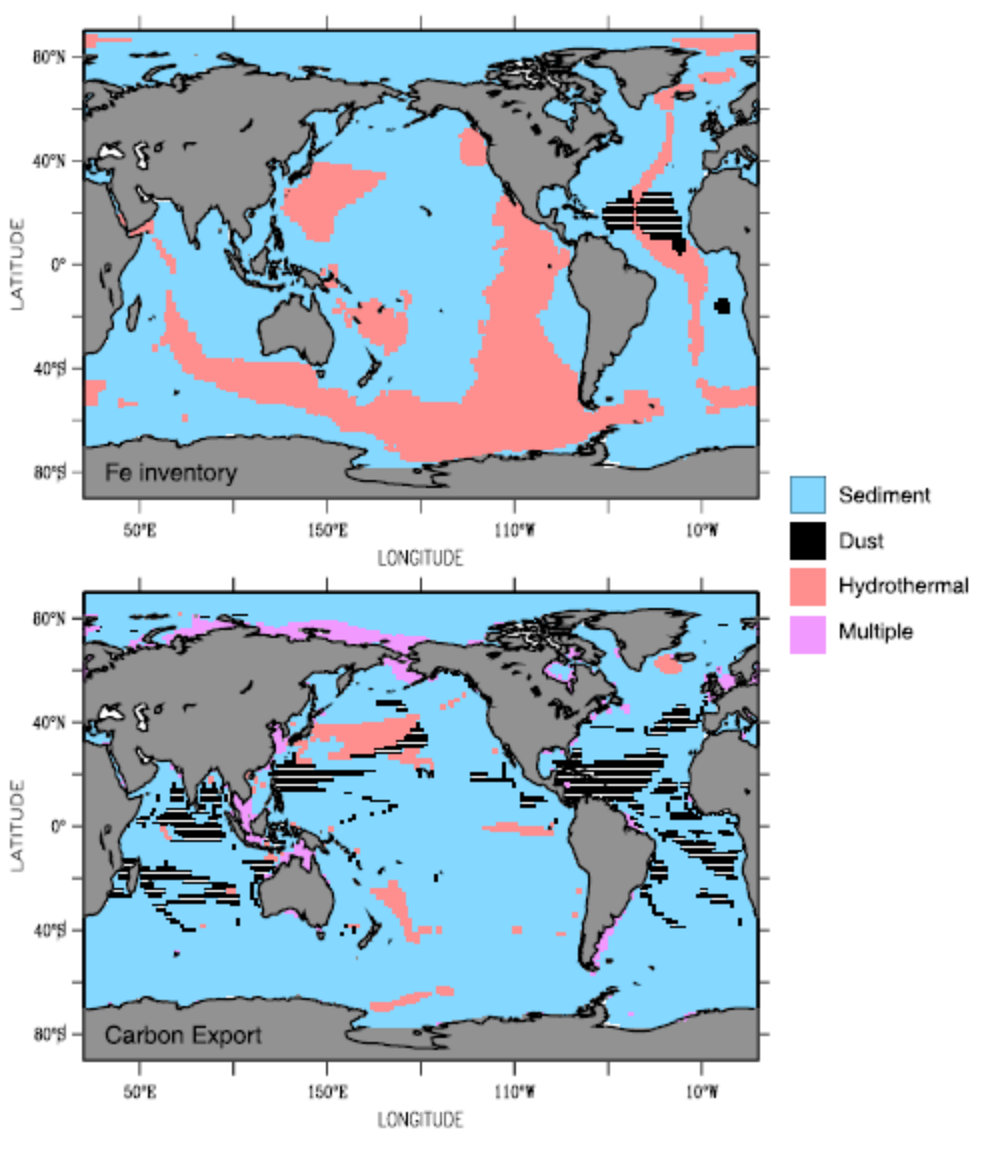
Elrod et al, 2004

Others?

http://www.egeotraces.org/scenes/
Atlantic_Fe_D_CONC_BOTTLE_large.html

Role of the sediments confirmed by modelling

2000-20s



On the DFe inventory

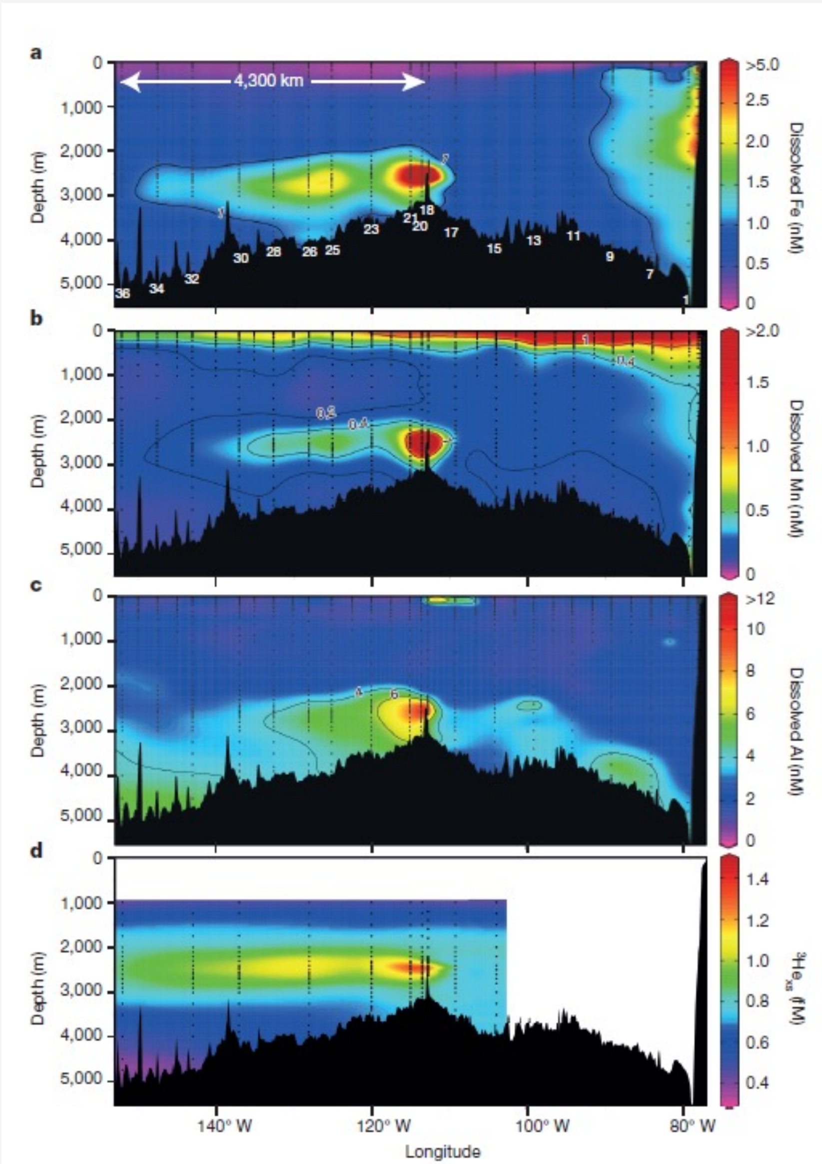
On the carbon export

Tagliabue et al, 2014

Unexpected hydrothermal inputs
(EPZT GEOTRACES cruise)

GEOTRACES

2000-20s

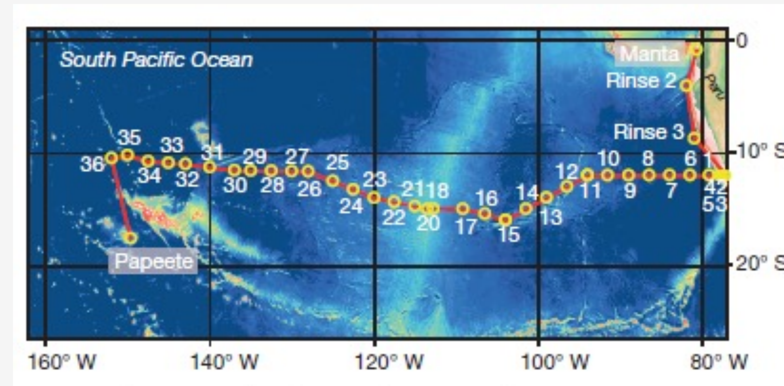


DFe

DMn

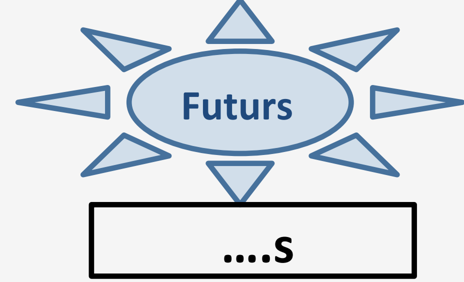
DAl

^{3}He



Resing et al, Nature
July 2015

Futurs



- Contrasted distributions (ex dZn&dFe)
- Land-ocean exchange processes (ex REE, Nd&Ra)
- Quantifying all the sources (SGD; sediment release)
- Quantifying the internal cycling&exits
- Refining paleo-proxies

What was (almost) not discussed...

- Carbonate chemistry
- Carbon cycle and flux
- Particles in the Ocean

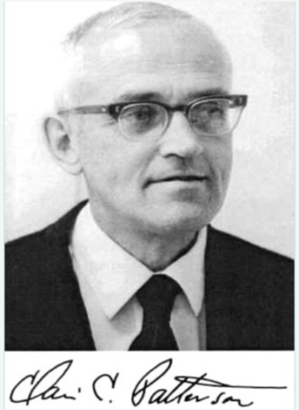
  (except when needed...)

Jeandel, Lam, Marchal, Anderson Edits

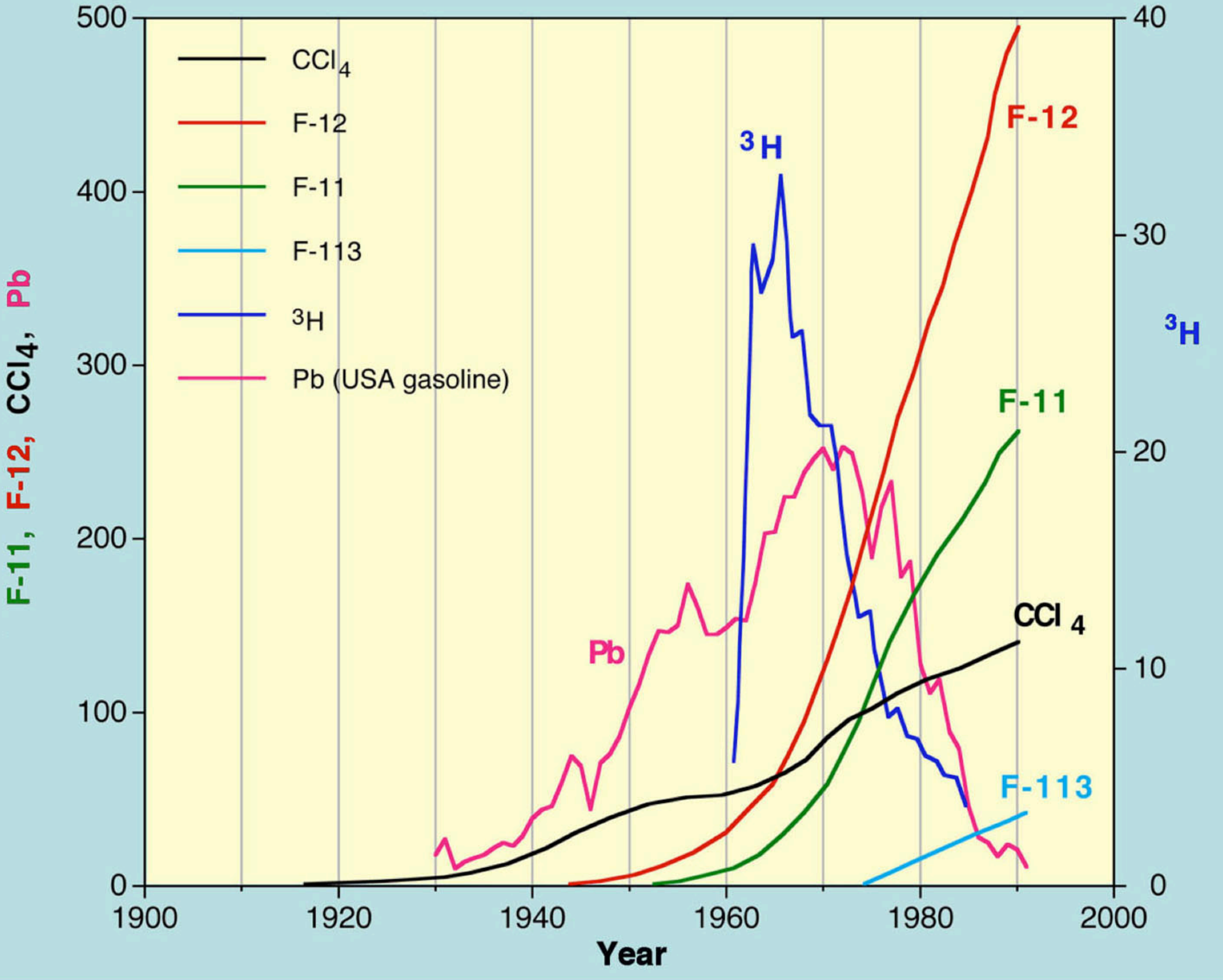

Thank you!

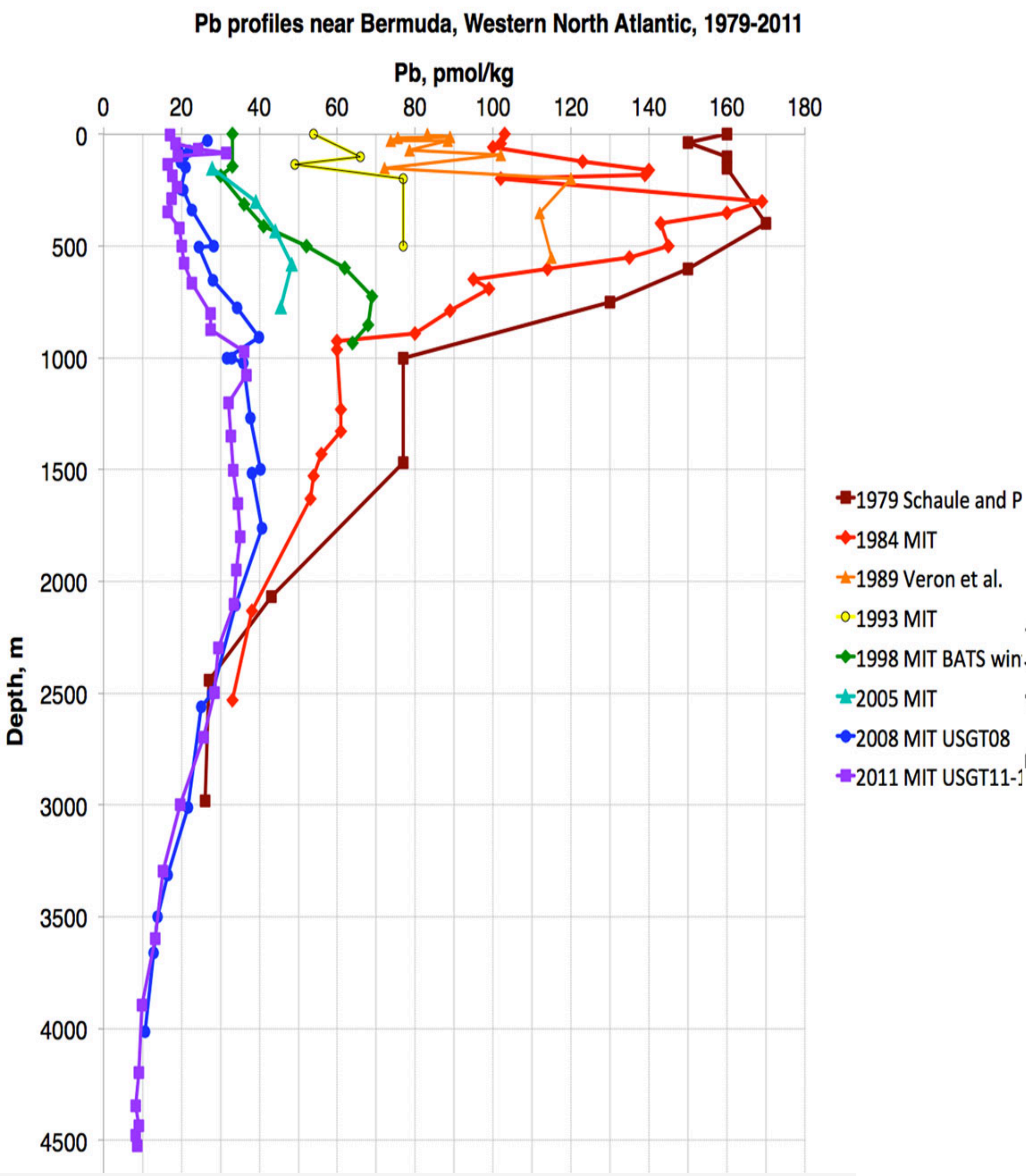
Lead and lead isotopes

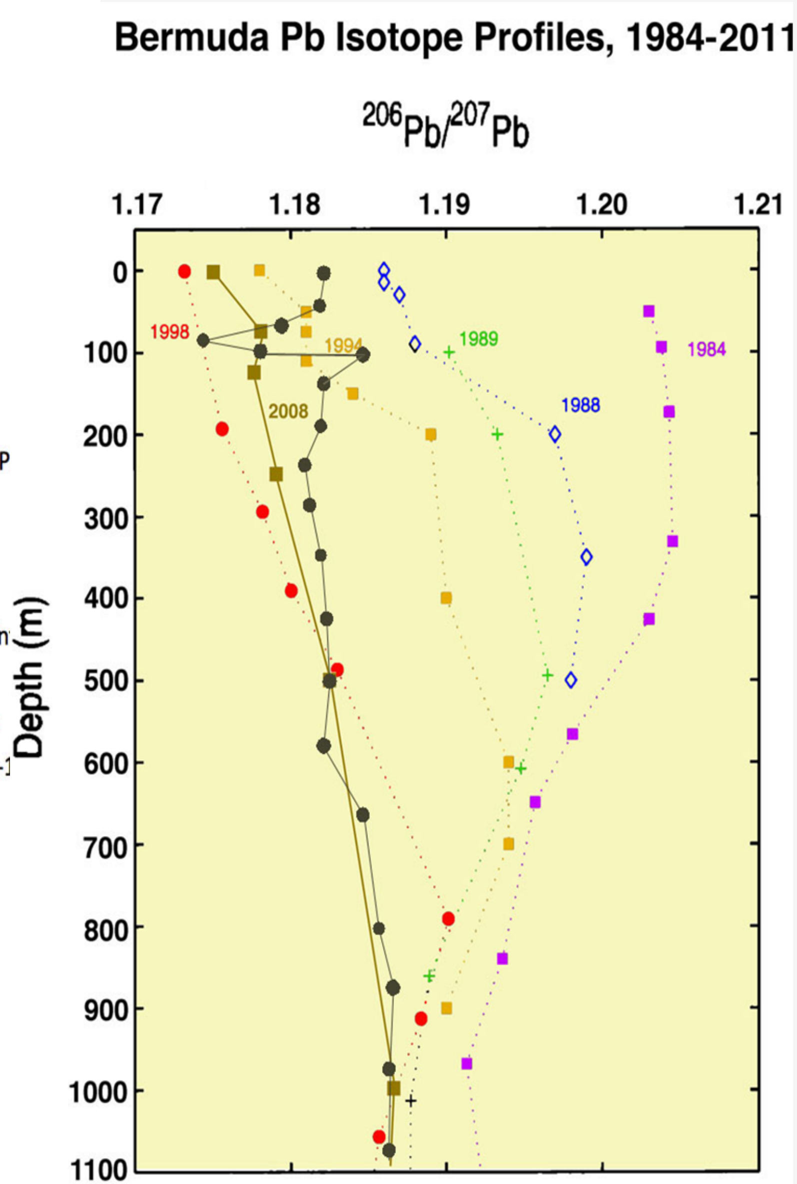
Schaule and Patterson first profiles



Transient Tracers 1900-1990







Boyle et al. (2014) Oceanography 27:69

GEOTRACES GA03: US GT10,11 North Atlantic Transect Pb