Introduction to U-Th and ^{14}C dating

Hong-Wei Chiang (姜宏偉)

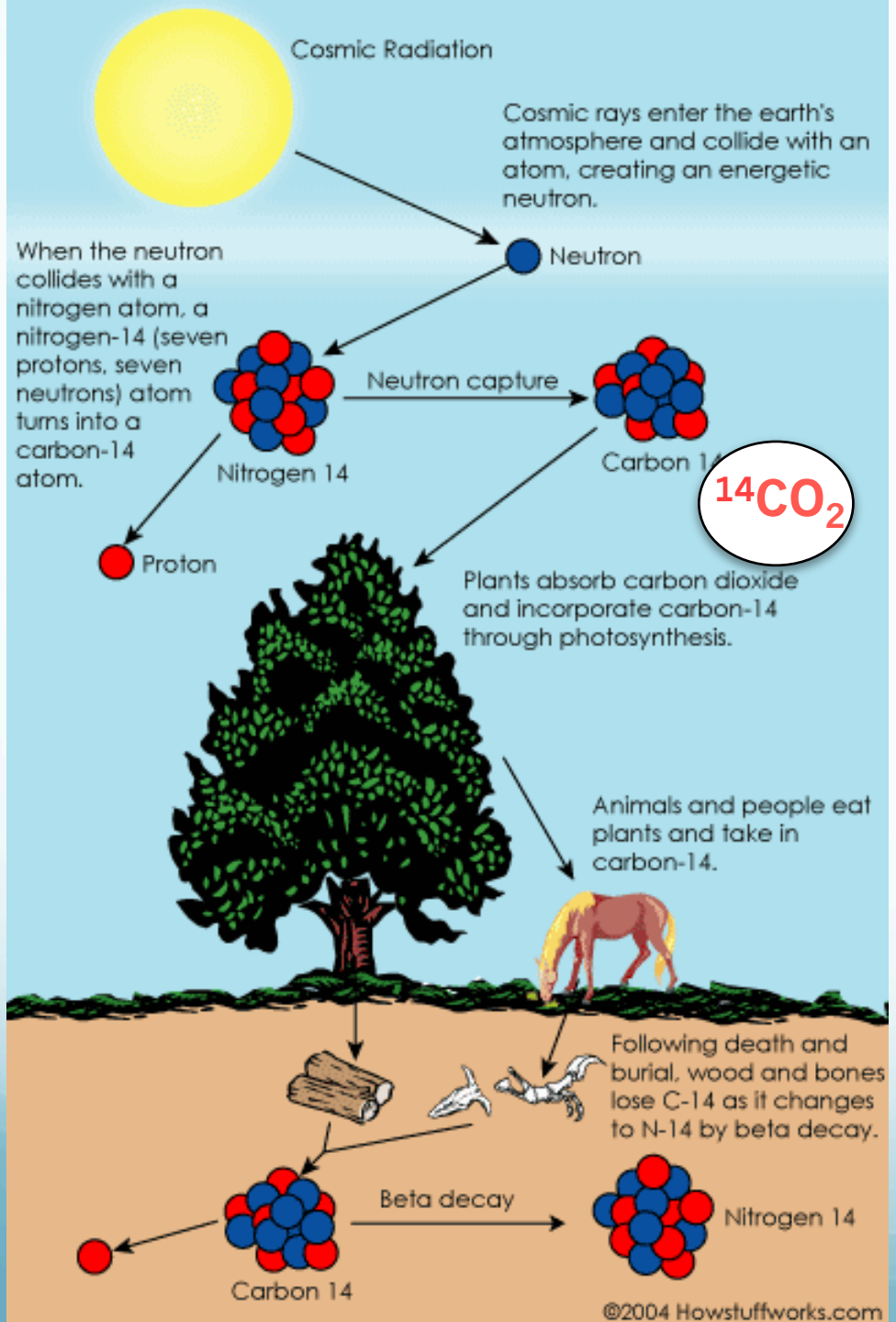
National Taiwan University

NCU 2016.12.30

Professor Willard F. Libby of the University of Chicago received the Nobel Prize in Chemistry in 1960:

"for his method to use Carbon-14 for age determinations in archaeology, geology, geophysics, and other branches of science."

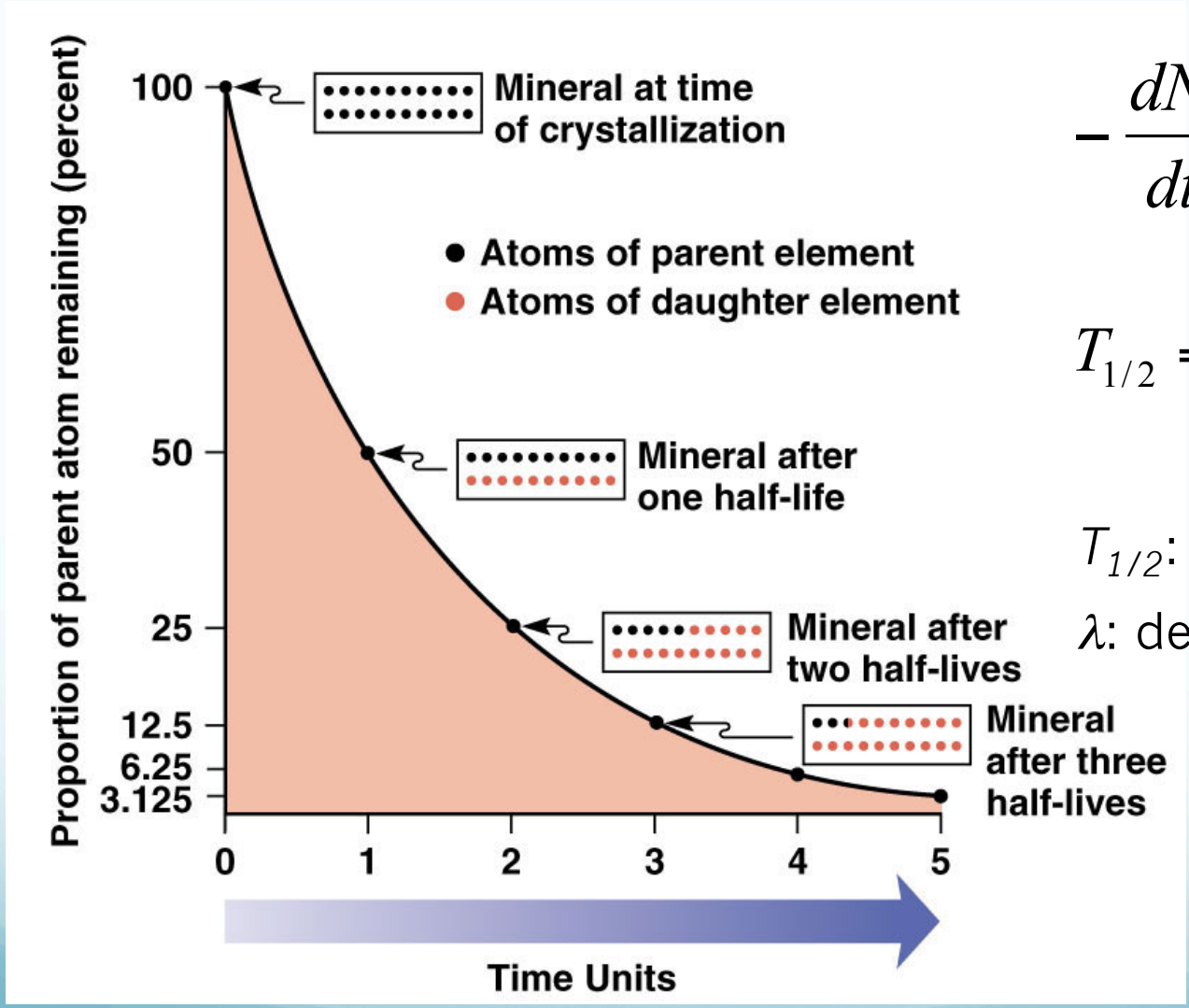
- Basic concept
  - Physical and chemical details
  - Principles
- Dating considerations
  - Atmospheric variation
  - Isotopic fractionation
  - Reservoir effects
  - Contamination
- Calibration
  - Terrestrial ^{14}C archives
  - Marine ^{14}C archives



$$^{14}N_7 + ^{1}n_0 = ^{14}C_6 + ^{1}H_1$$

$$^{14}C_6 = ^{14}N_7 + \beta^-$$

Geometric Radioactive Decay



$$-\frac{dN}{dt} = \lambda N$$

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

$T_{1/2}$: half-life (**5730** yrs)

λ: decay constant

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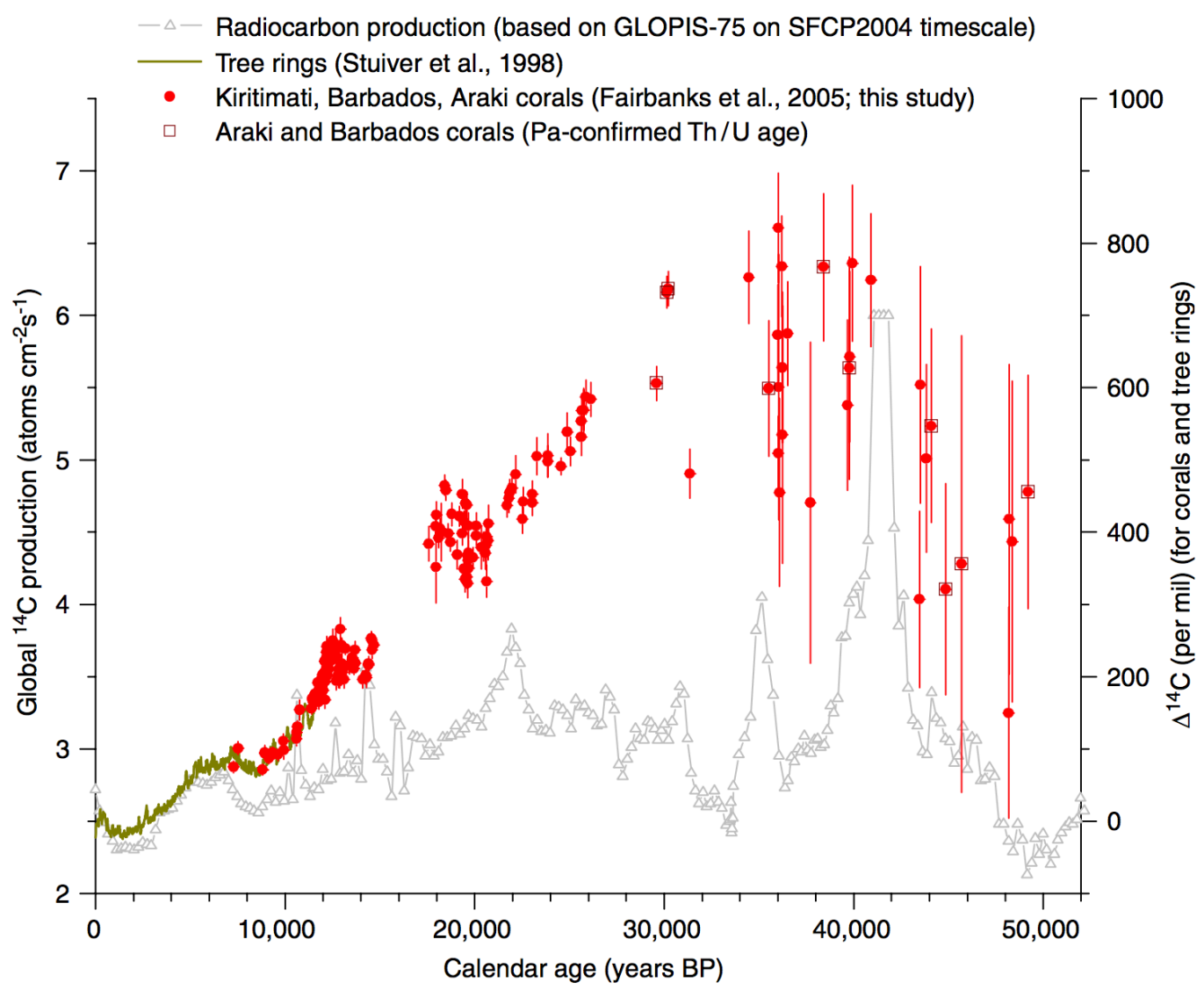
Atmospheric variation

Changed ^{14}C production over time

Suess effect

Bomb pulse

Changed ^{14}C production over time

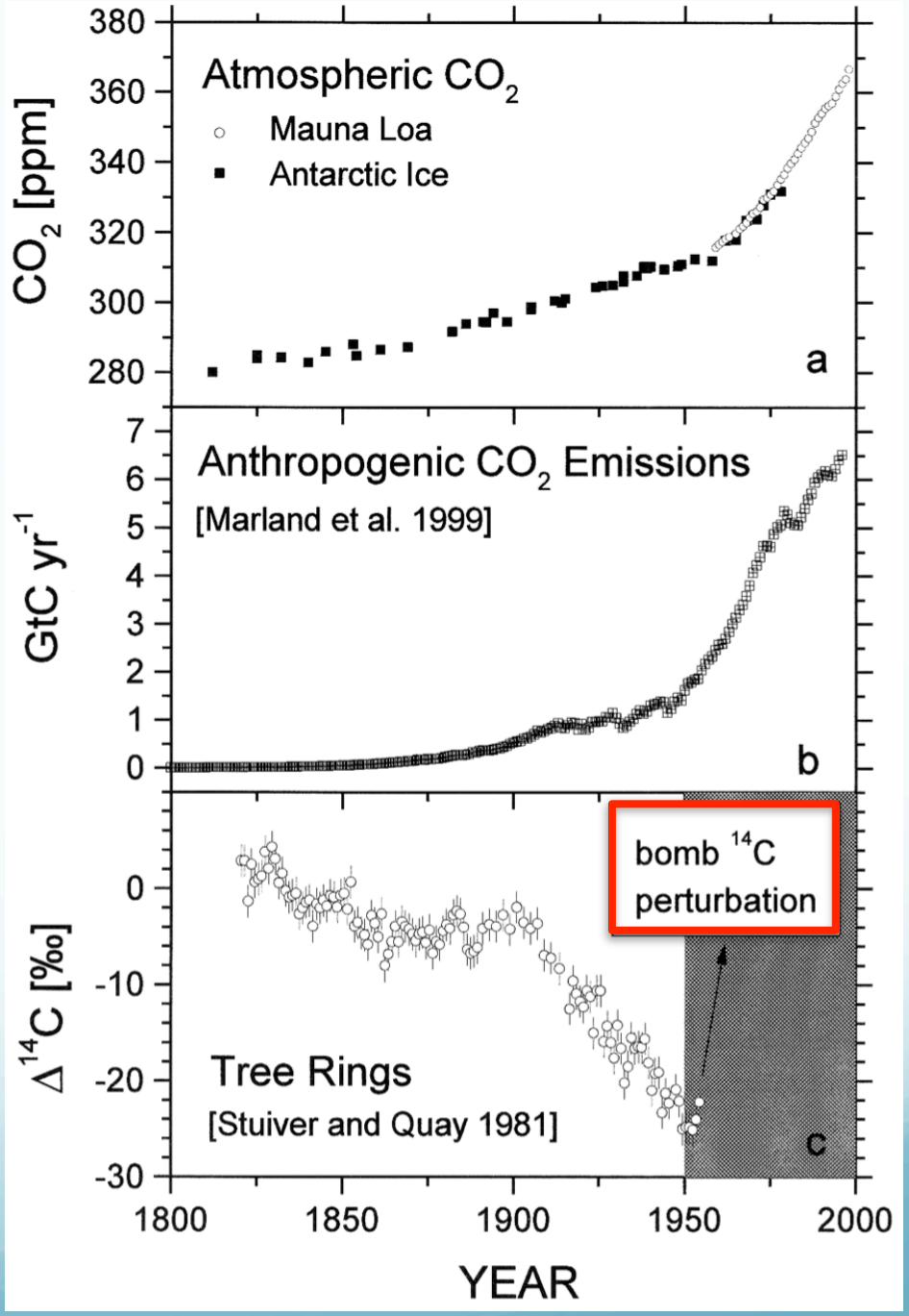


(Chiu et al., 2007)

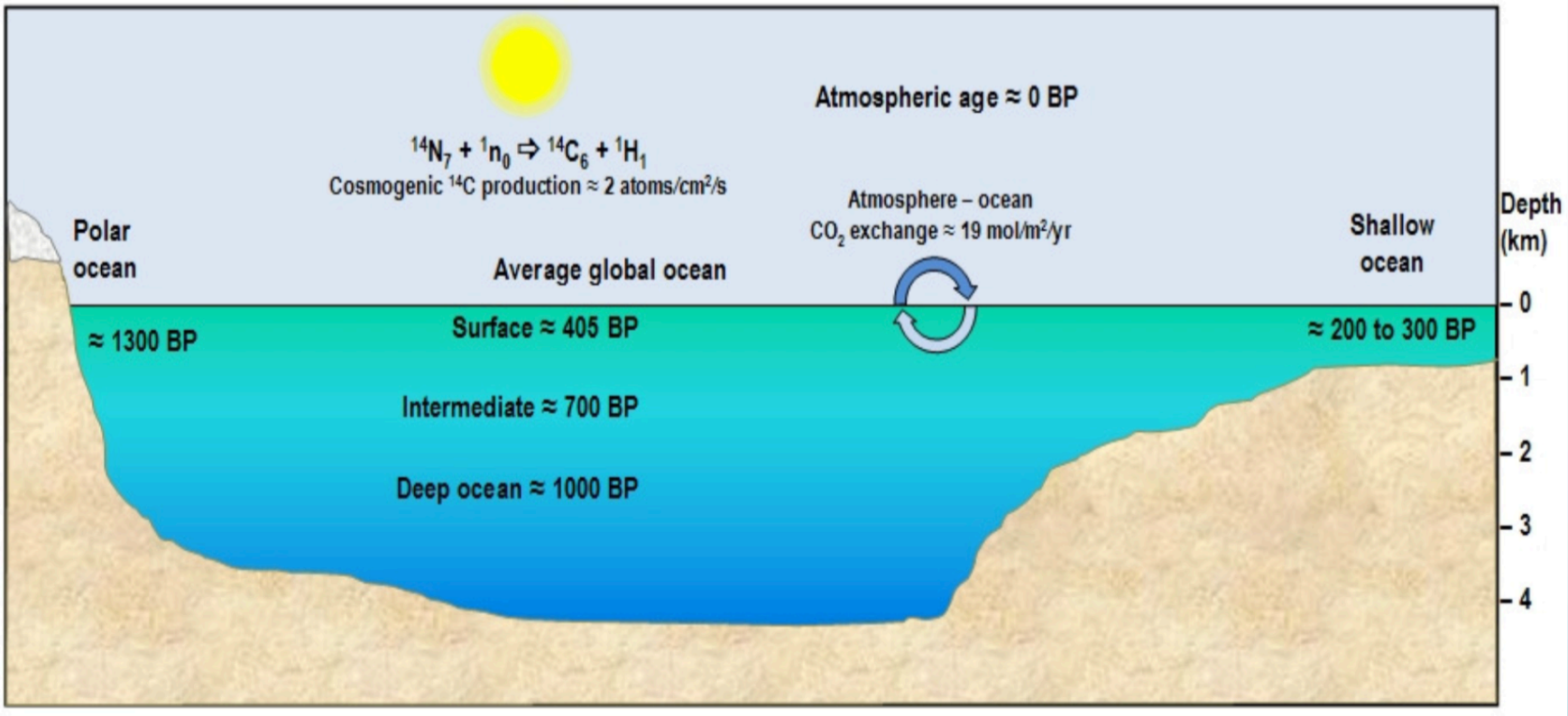
Suess effect

A change in the ratio of carbon isotopes (^{13}C and ^{14}C) in the atmosphere due to the admixture of large amounts of fossil-fuel derived CO_2.

(Levin and Hesshaimer, 2000)



Reservoir effects



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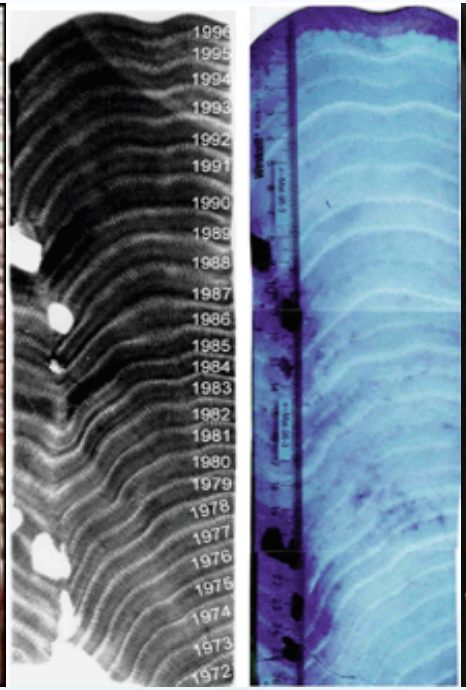
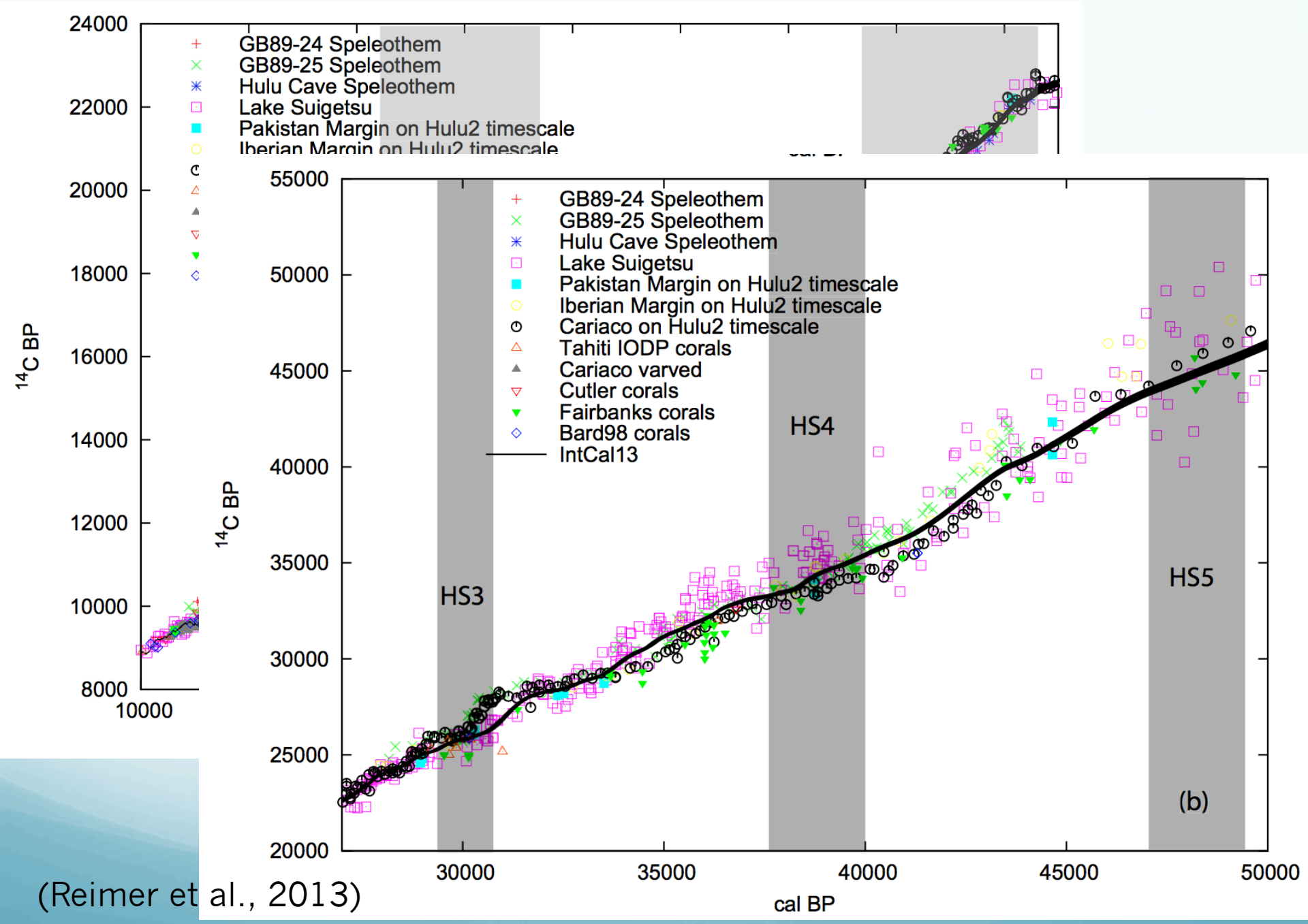
Tree

Coral



Speleothem

Sediments



(Reimer et al., 2013)

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  - Decay chains
  - Secular equilibrium and uranium-series dating
  - The ^{230}Th age equation
- Test of dating assumptions
  - Initial mineralogy and petrology
  - Initial $^{230}Th/^{238}U$
  - Initial $^{234}U/^{238}U$
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- Sources of error in age
  - Error in measurement of isotope ratios
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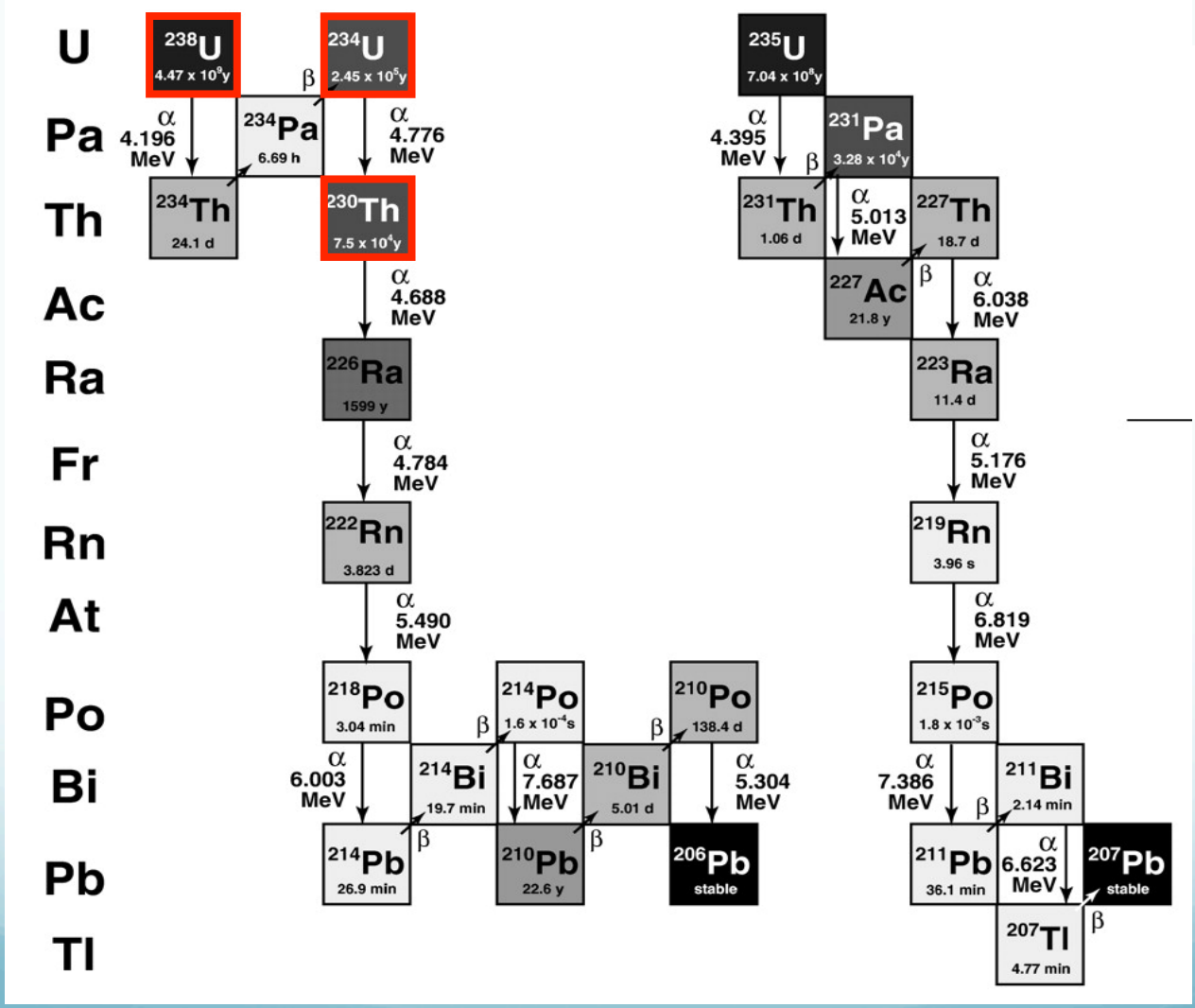
Schematic drawing of the ^{238}U and ^{235}U decay chains



$^{238}U \rightarrow ^{234}U \rightarrow ^{230}Th \rightarrow \rightarrow \rightarrow \ldots \rightarrow ^{206}Pb$

4.47 E9 y 2.45 E5 y 7.57 E4 y stable

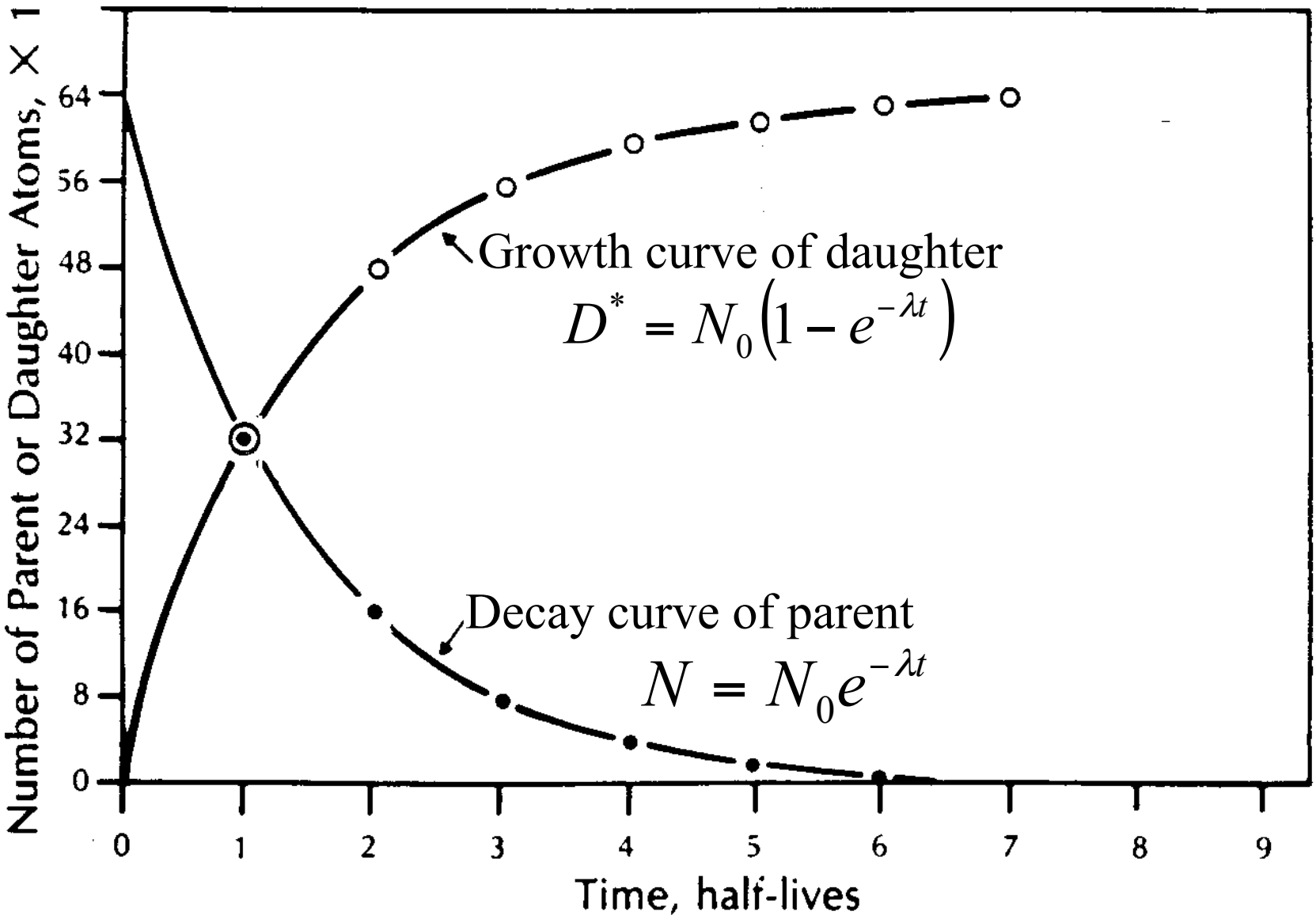
$^{235}U \rightarrow ^{231}Th \rightarrow ^{231}Pa \rightarrow \rightarrow \rightarrow \ldots \rightarrow ^{207}Pb$

7.04 E8 y 1.063 d 3.28 E4 y stable

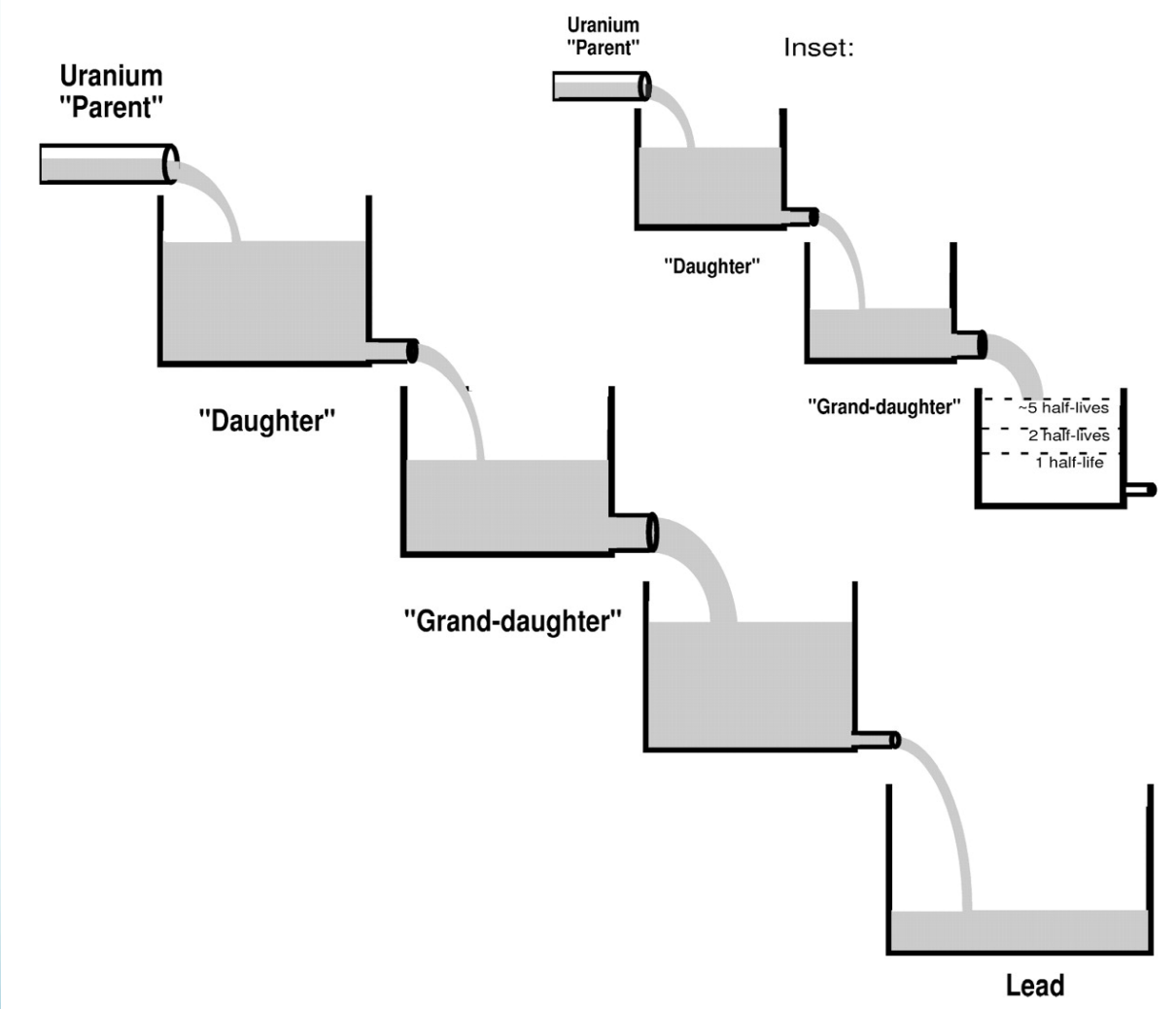
$$\frac{^{230}Th}{^{238}U} = 1 + \left(\left(\frac{^{232}Th}{^{238}U} \right) \left(\frac{^{230}Th}{^{232}Th} \right)^{0} - 1 \right) e^{-\lambda_{230} t}$$

$$+ \frac{\delta^{234}U(0)}{1000} \left(\frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}} \right) \left(1 - e^{(\lambda_{234} - \lambda_{230}) t} \right)$$

Decay curve of a radionuclide and growth curve of its stable daughter



At Secular Equilibrium $N_1\lambda_1 = N_2\lambda_2 = N_3\lambda_3$ .....



In contrast, we are using the disequilibrium of ^{238}U-^{234}U-^{230}Th.

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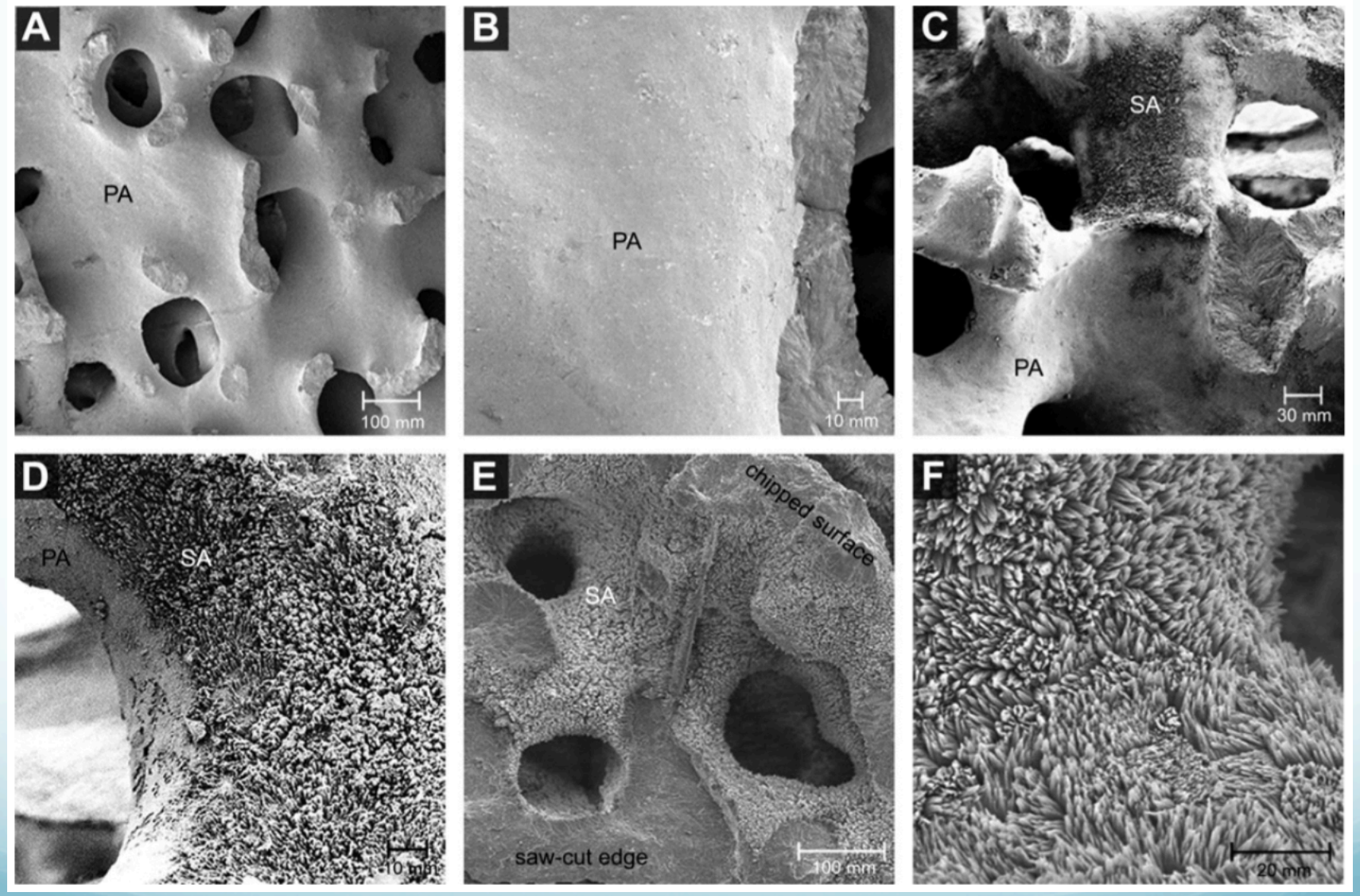
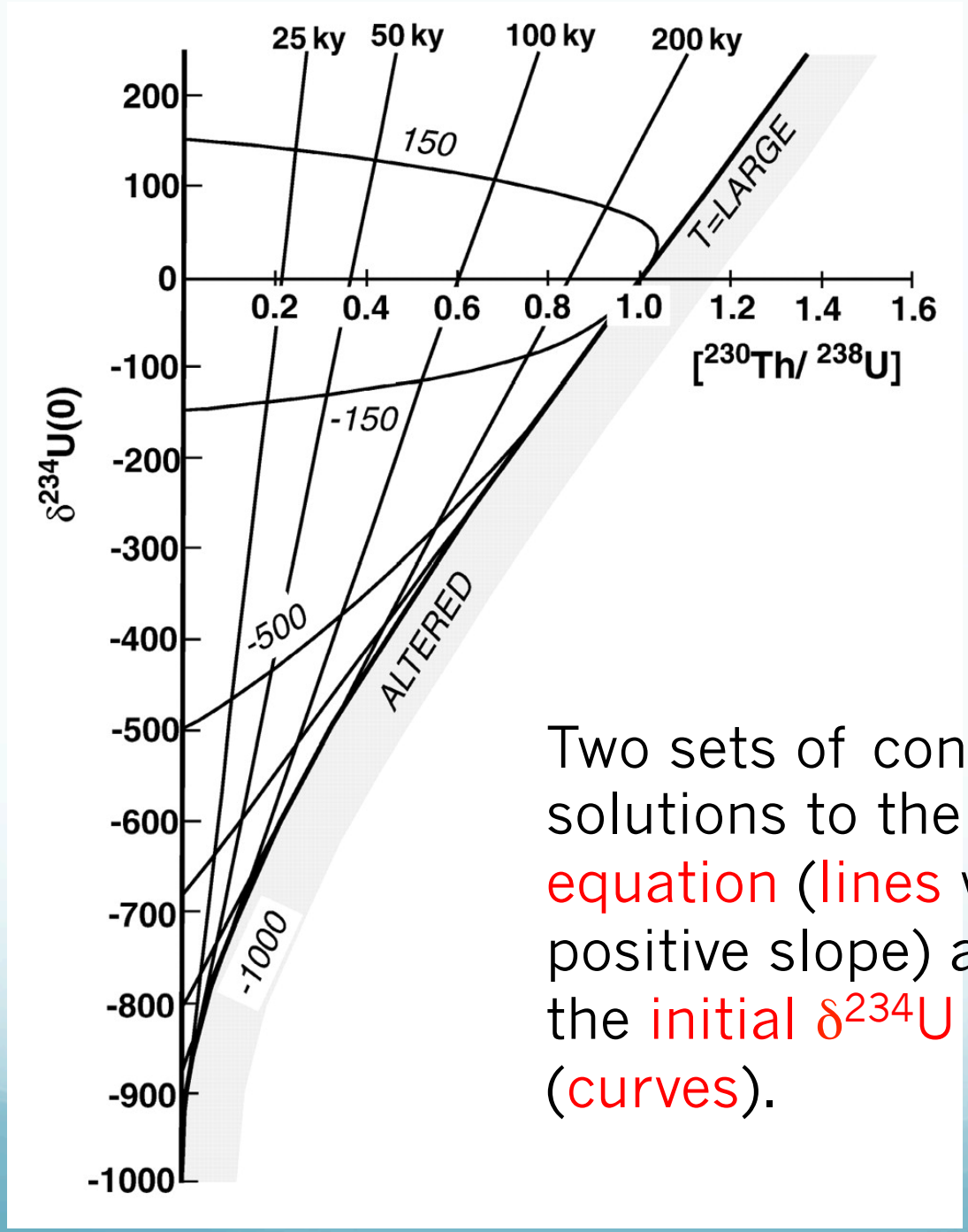
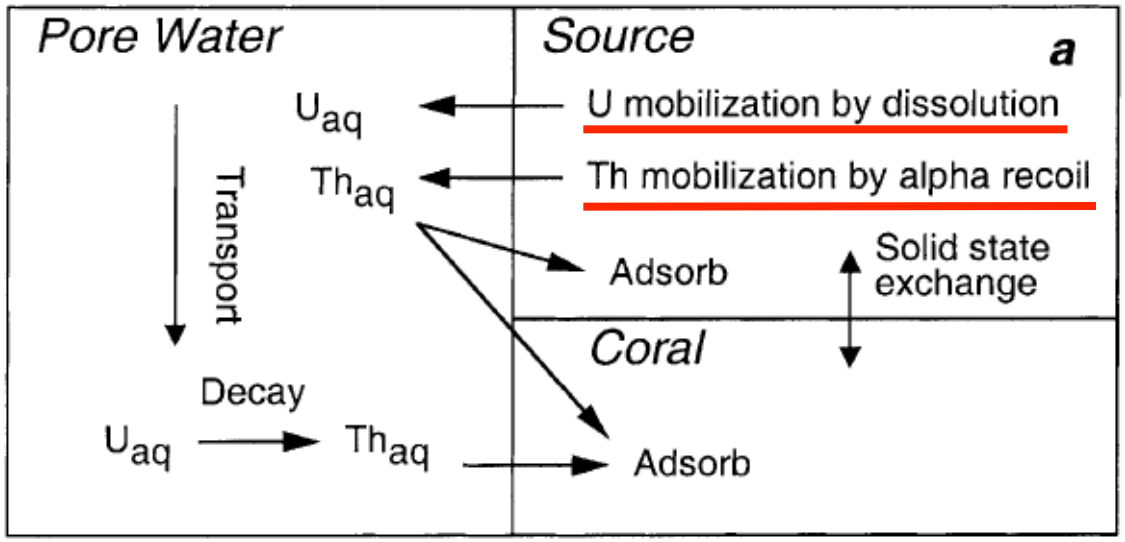
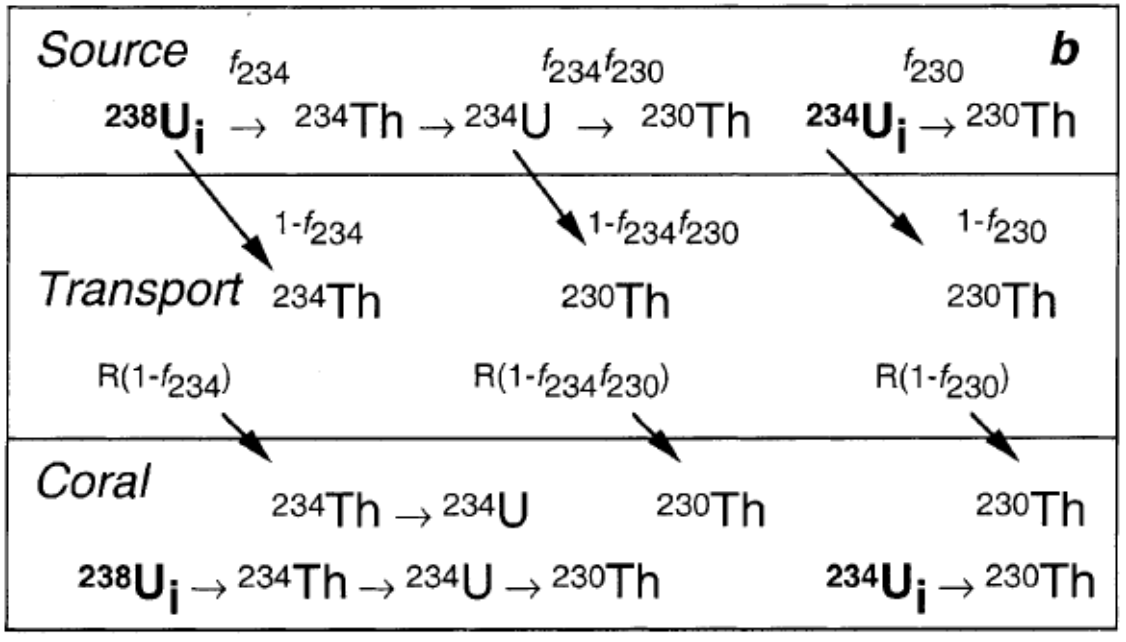


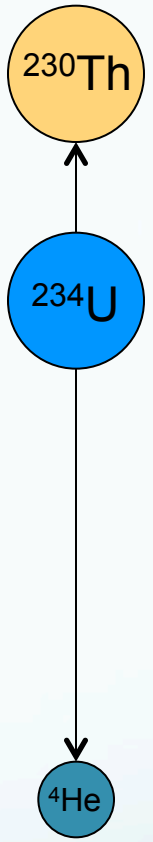
Sayani et al., 2011



Two sets of contours indicate solutions to the ^{230}Th age equation (lines with steep positive slope) and solutions to the initial δ^{234}U equation (curves).







Thompson et al., 2003

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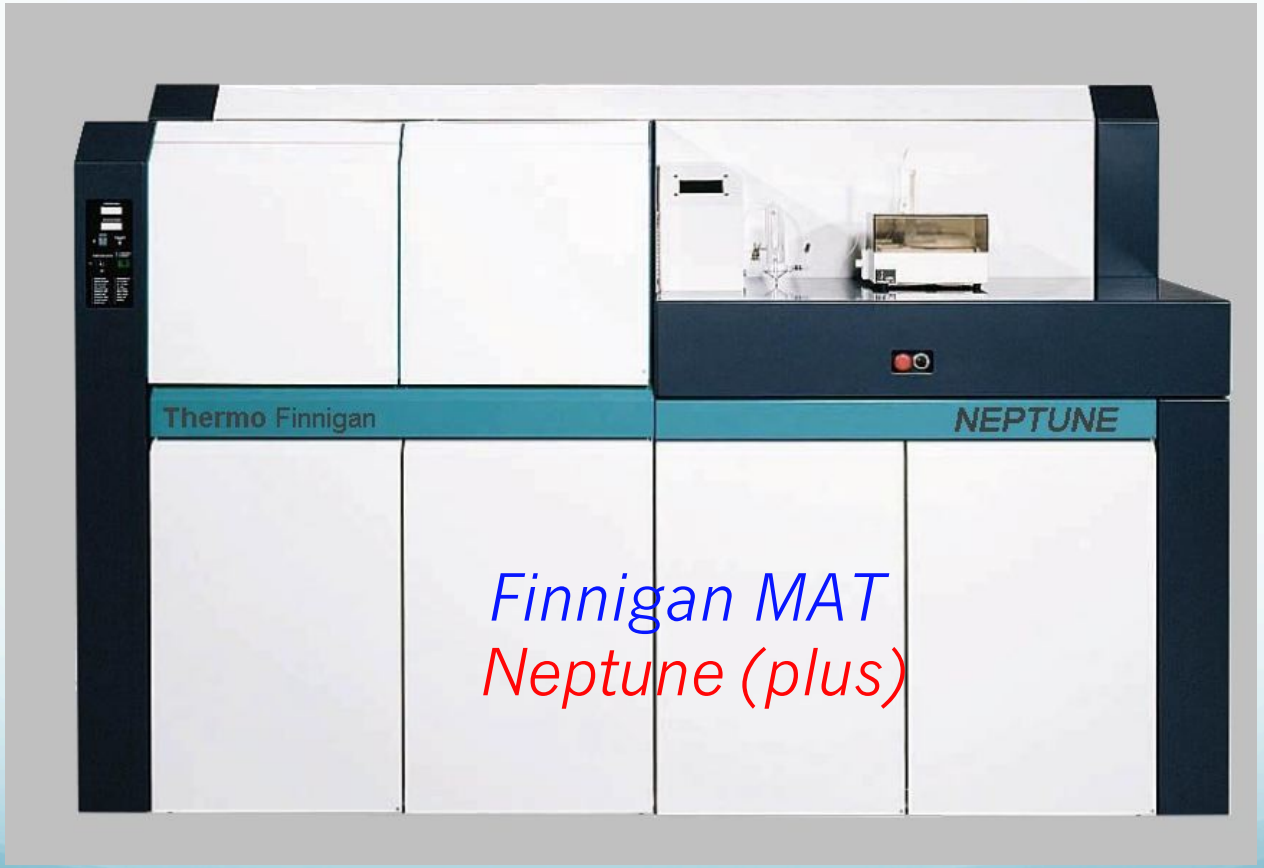
Multi-collector ICP-MS (MC-ICP-MS)

Higher efficiency of ionization and transmission due to better focusing



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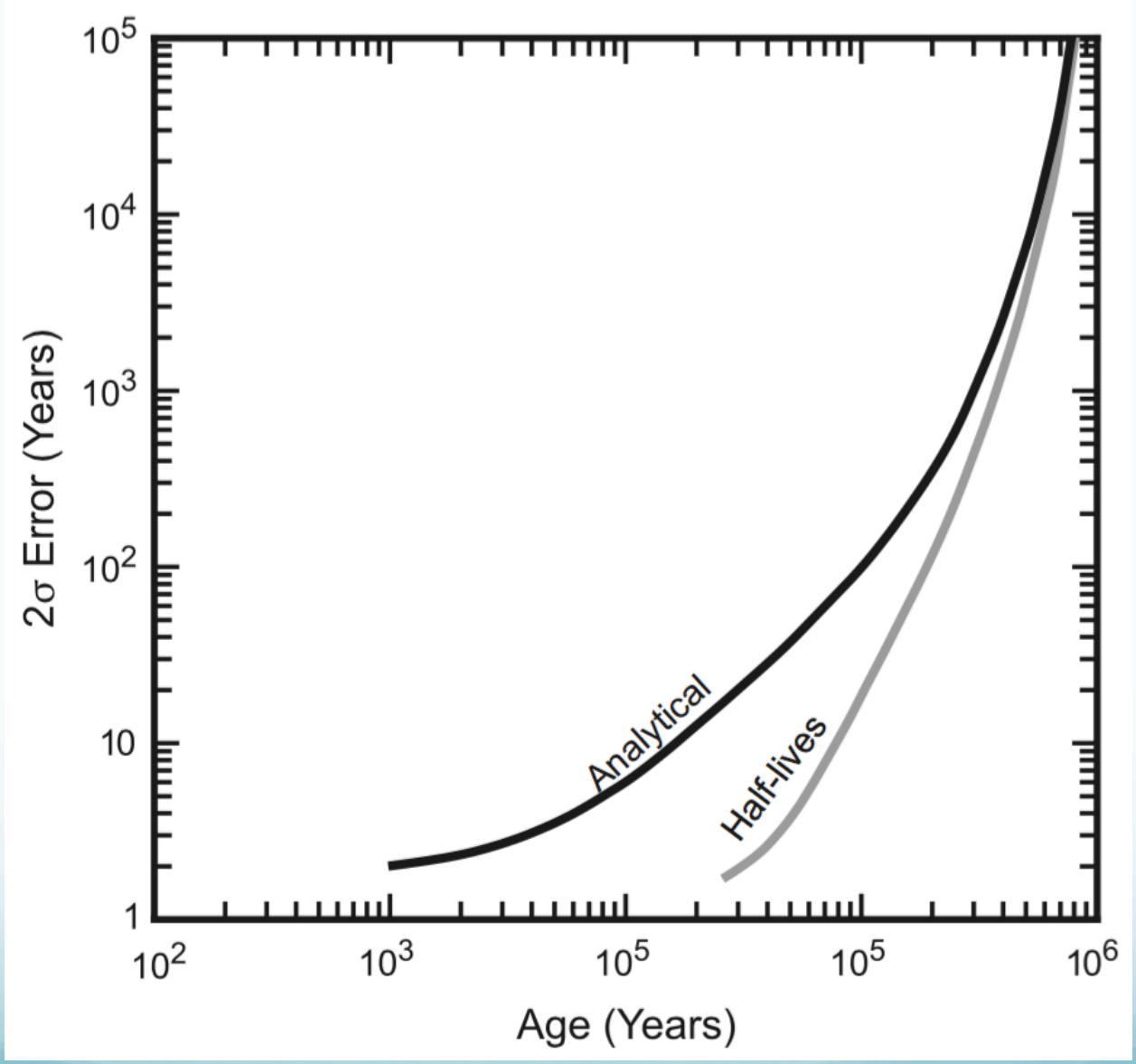

Cheng et al., 2013

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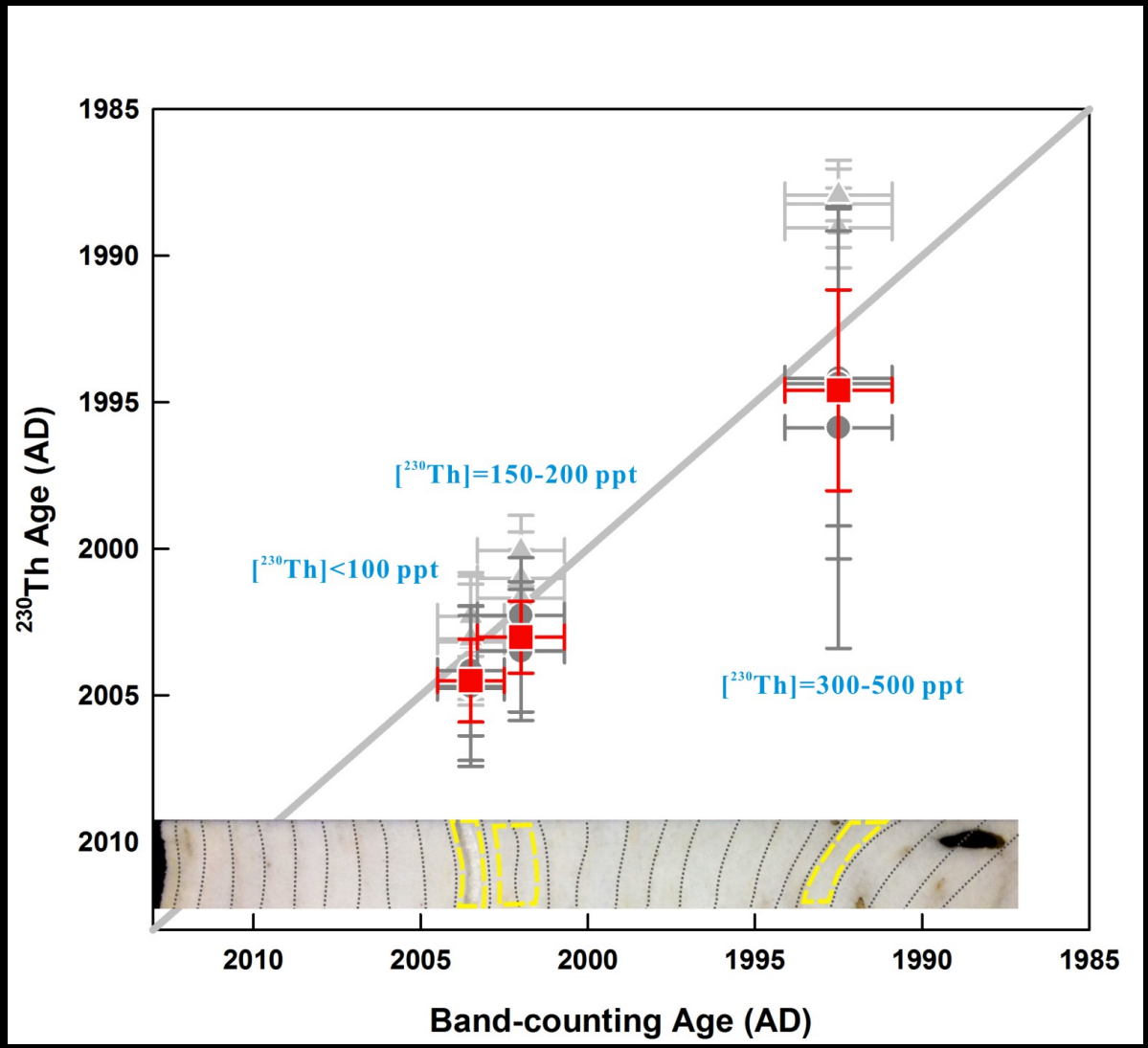
Problems

$$\frac{^{230}Th}{^{238}U} = 1 + \left(\left(\frac{^{232}Th}{^{238}U} \right) \left(\frac{^{230}Th}{^{232}Th} \right)^{0} - 1 \right) e^{-\lambda_{230} t}$$

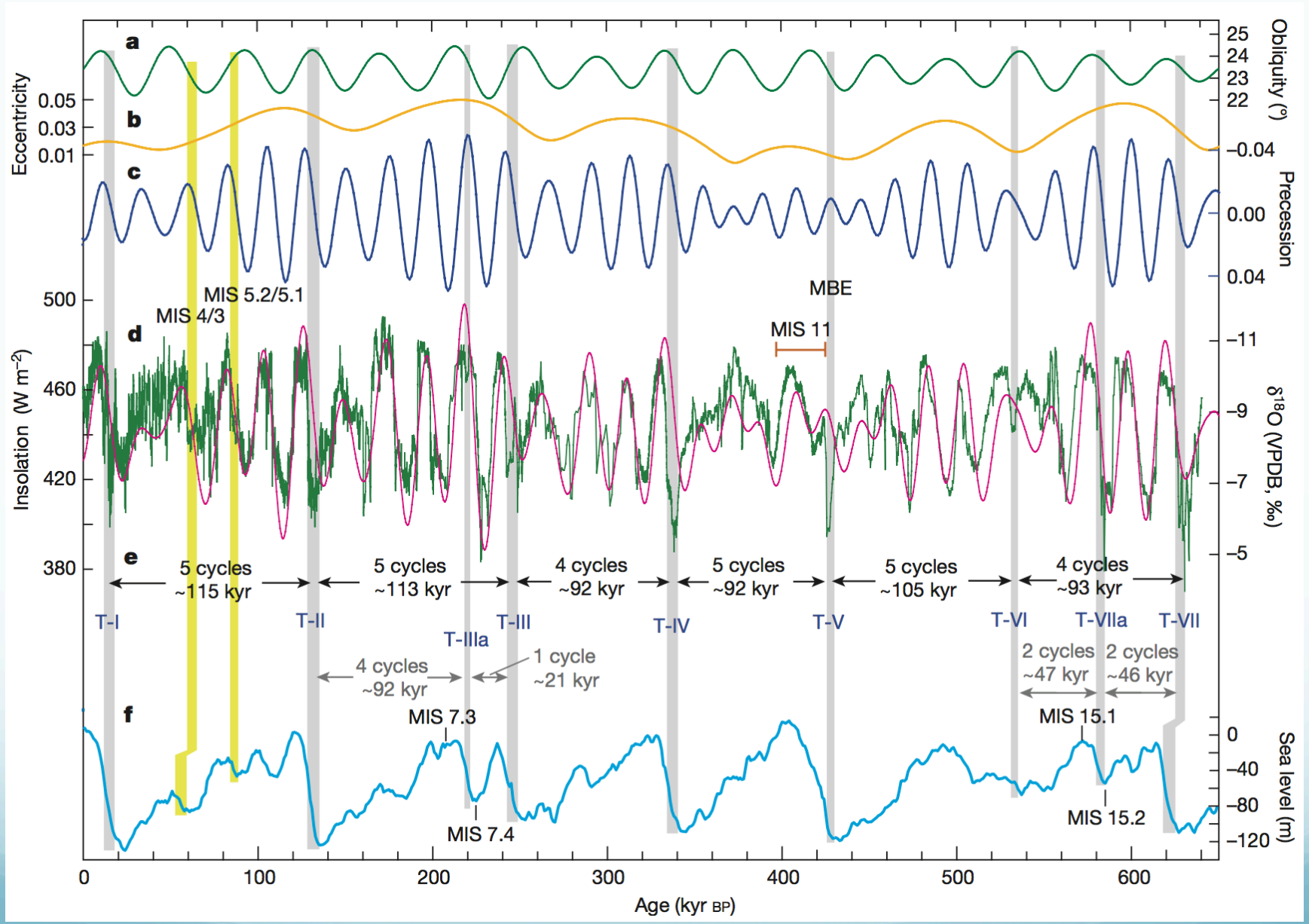
$$+ \frac{\delta^{234}U(0)}{1000} \left(\frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}} \right) \left(1 - e^{(\lambda_{234} - \lambda_{230})t} \right)$$

3.Initial ^{230}Th → 6 years

Capability of U-Th dating

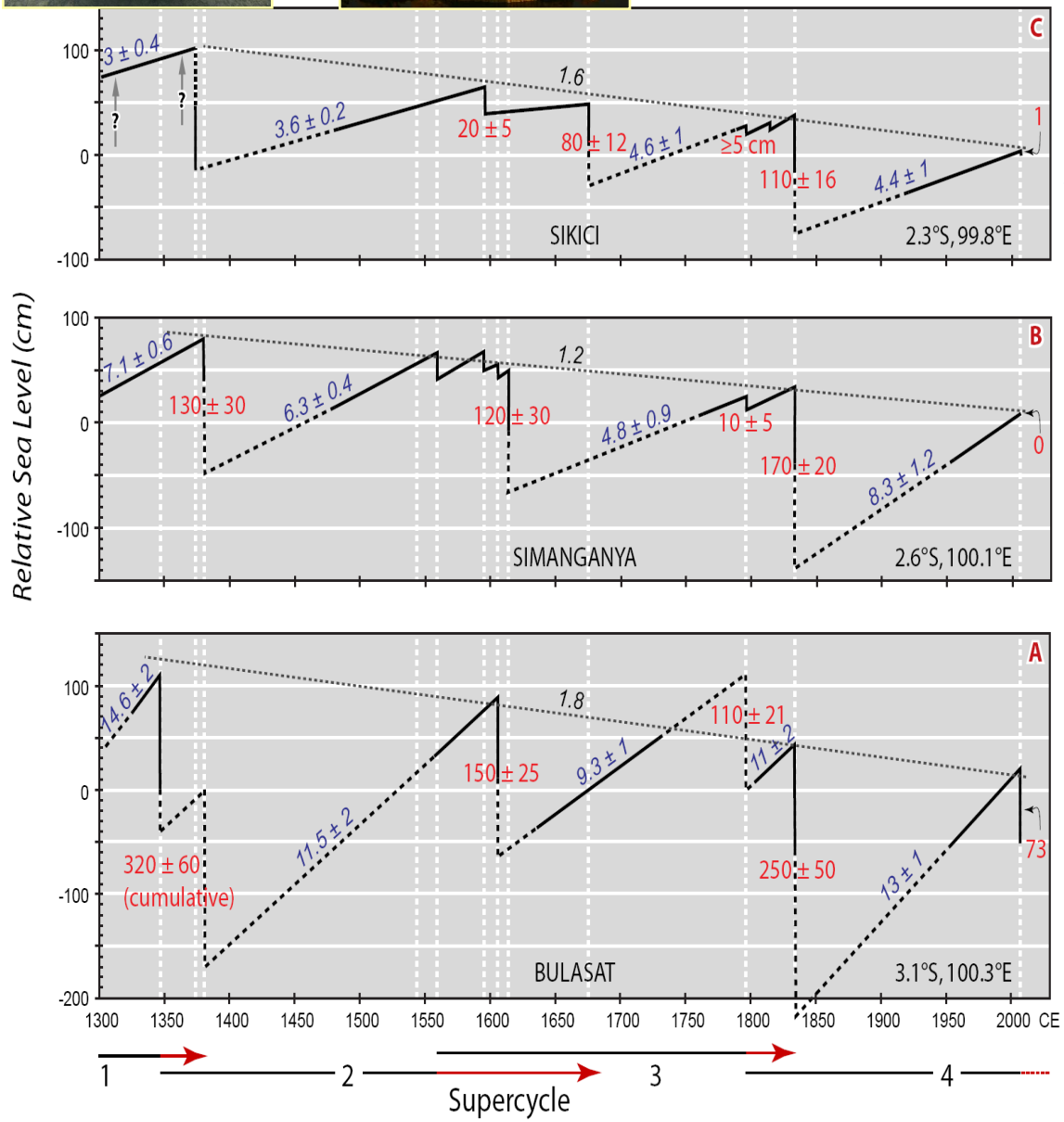


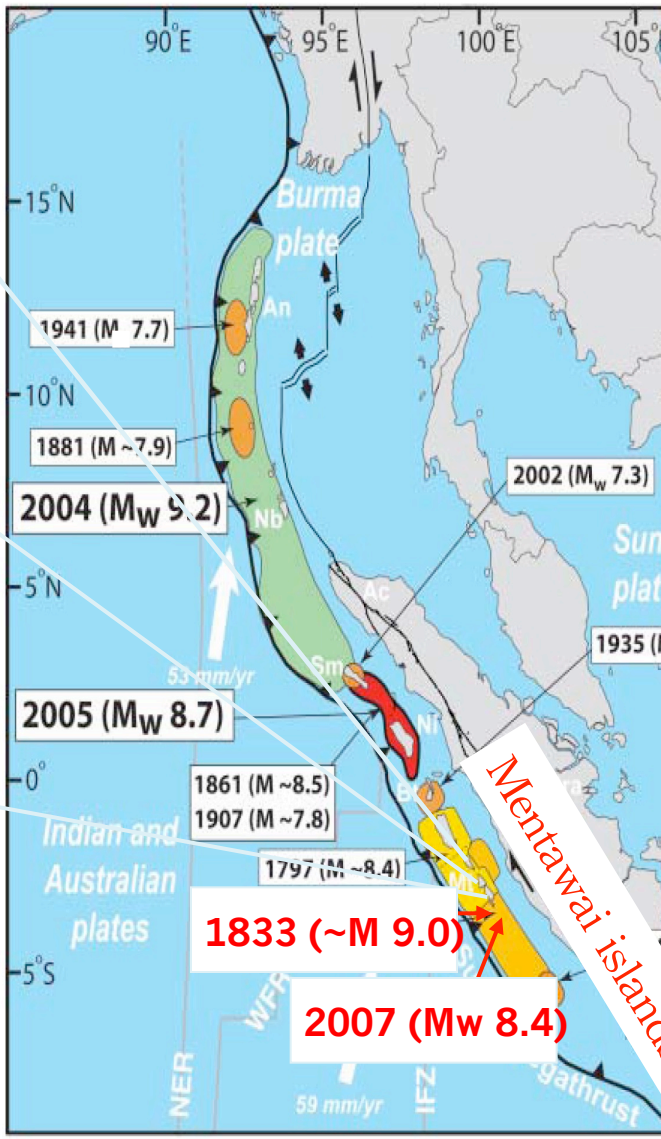
Chiang et al., in preparation



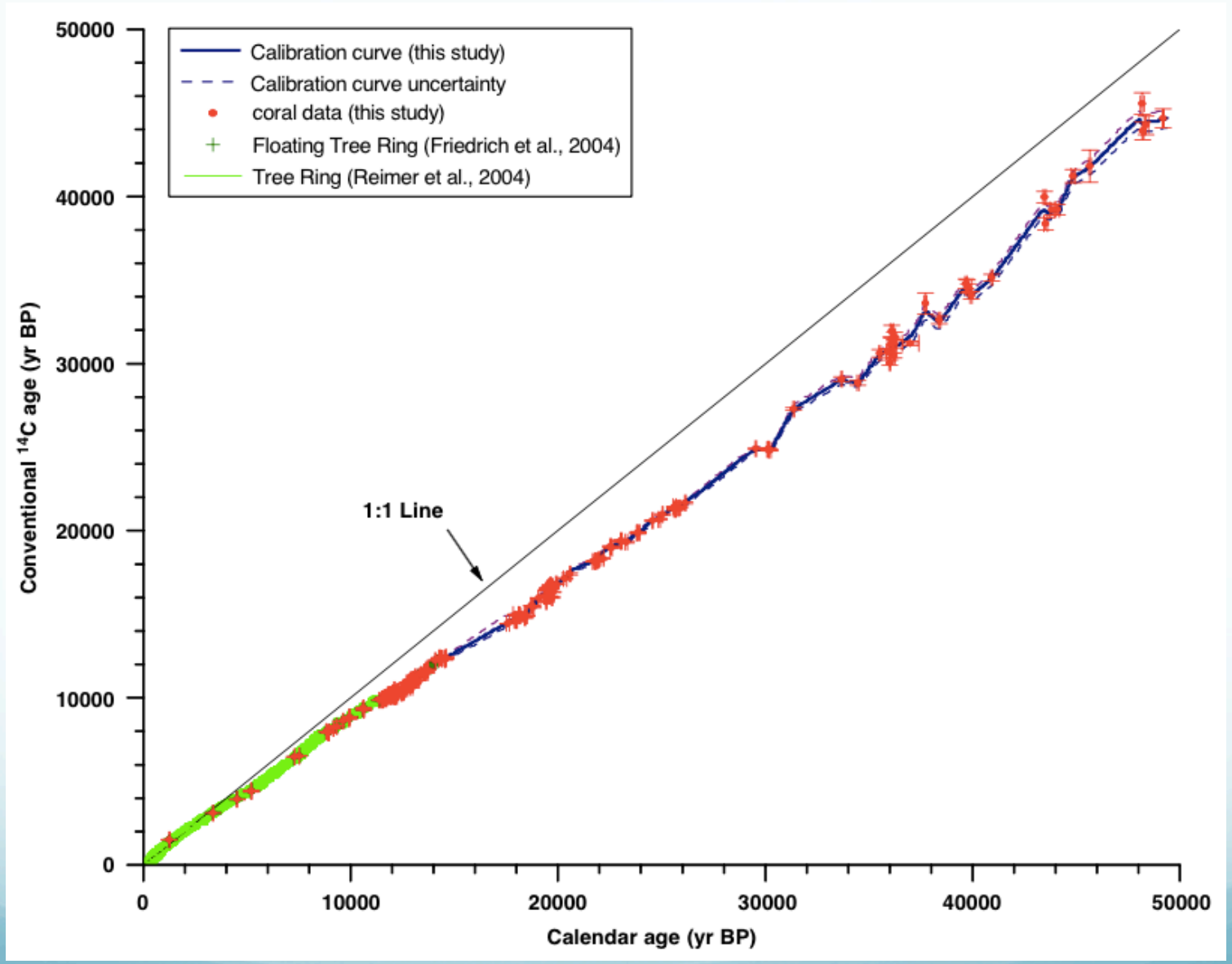
Cheng et al., 2016

200-yr supercycles of giant earthquake clusters in the Mentawai islands Sieh et al., Science, 2008

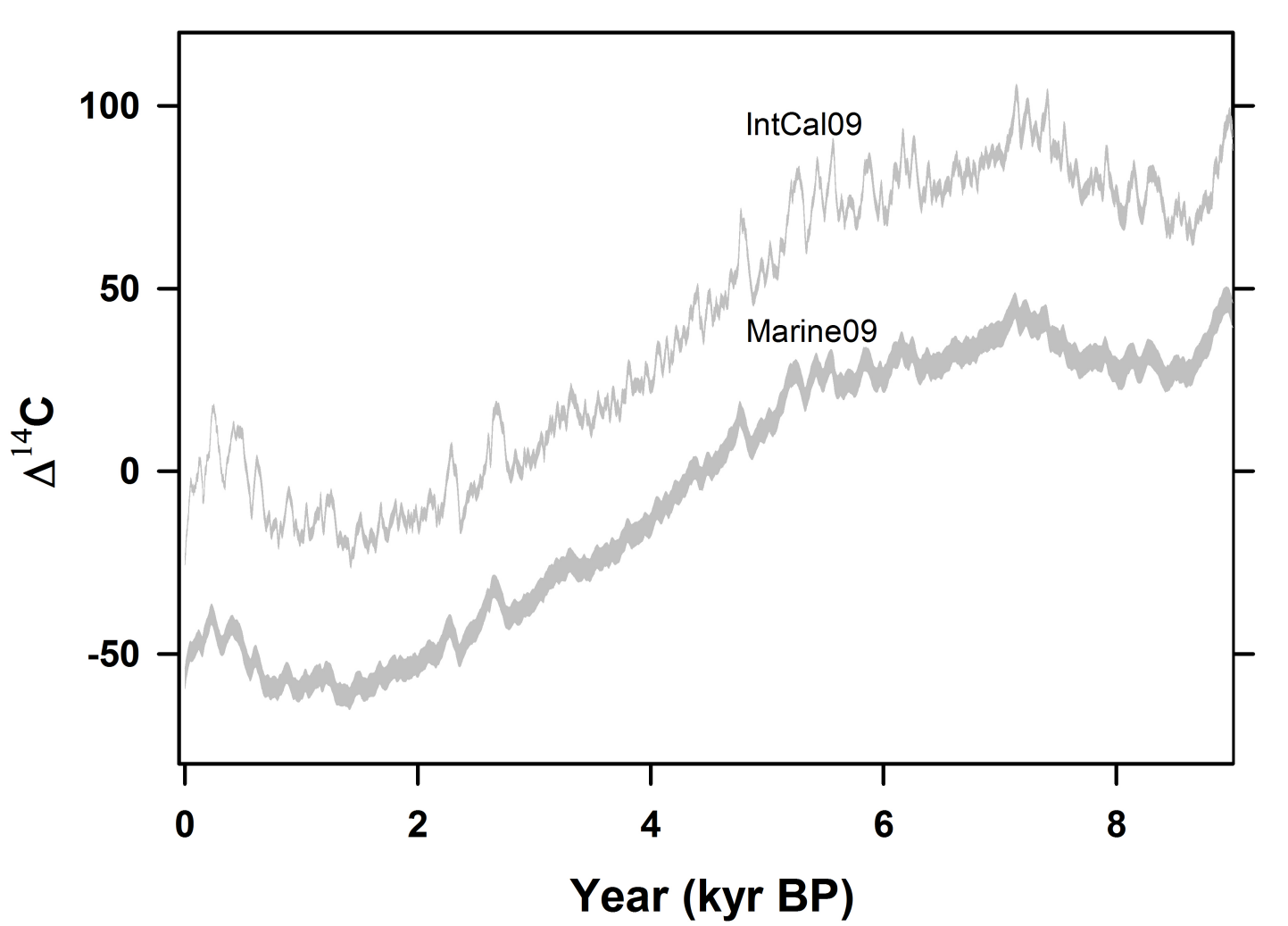




Radiocarbon calibration



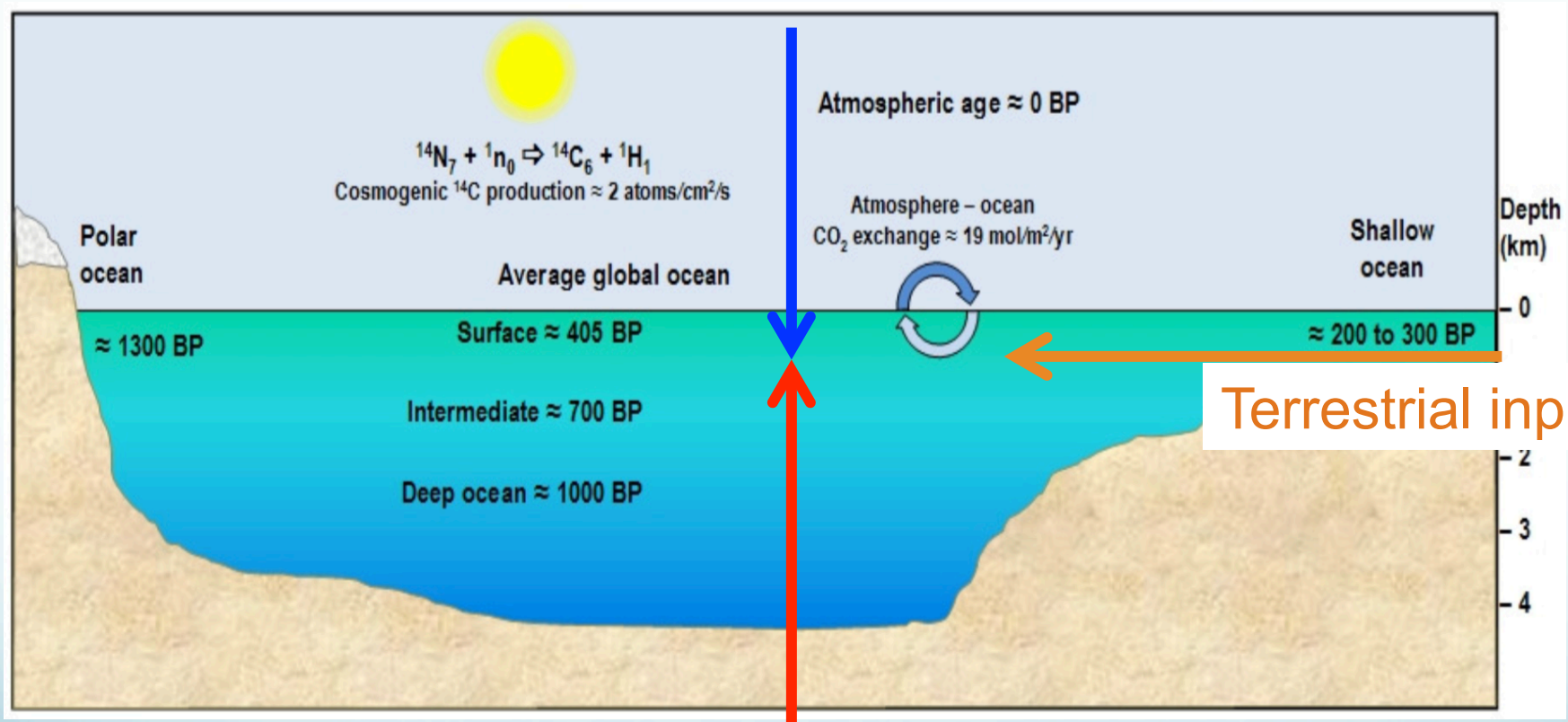
(Fairbanks et al., 2005)

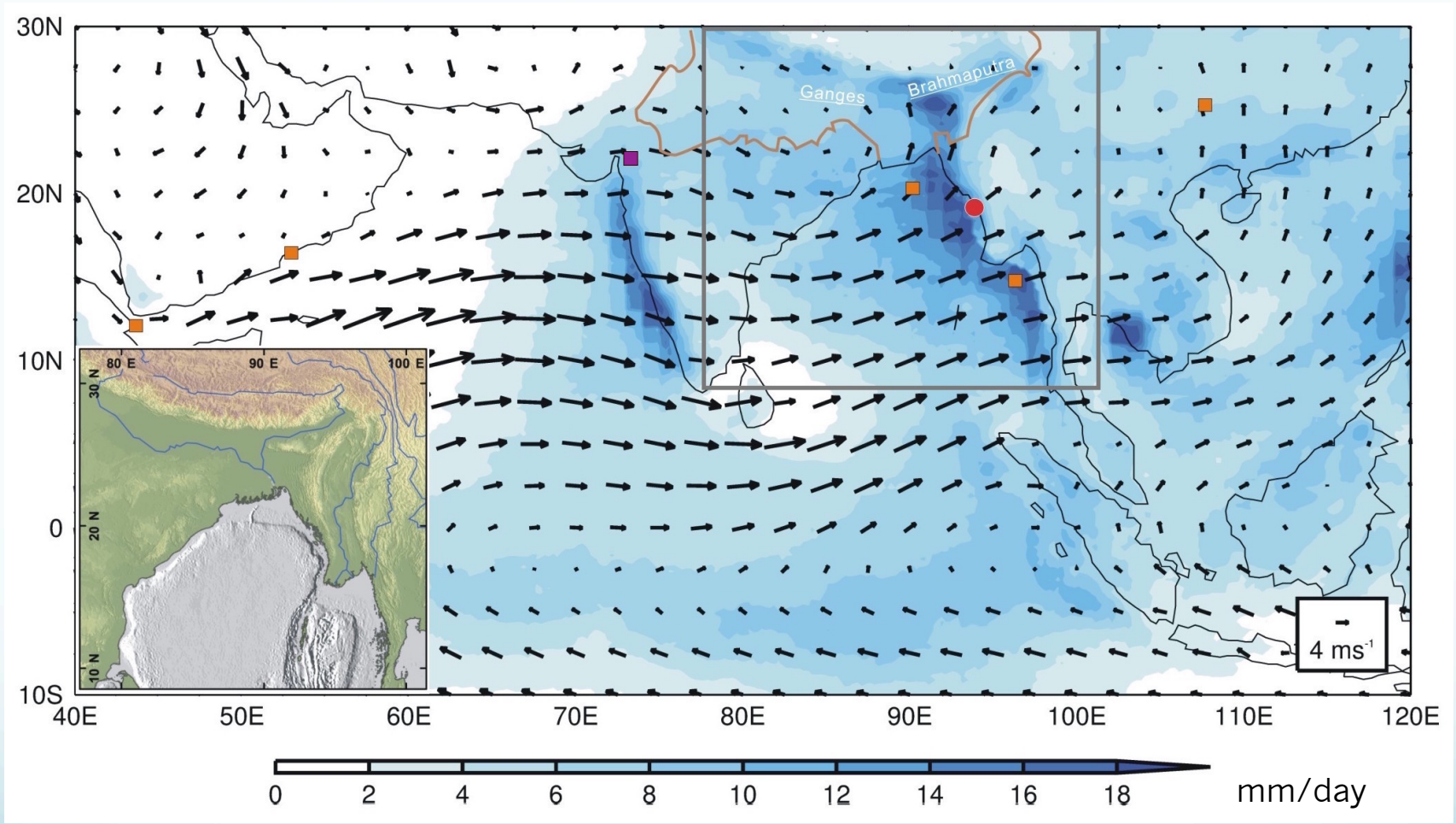


(Reimer et al., 2009)

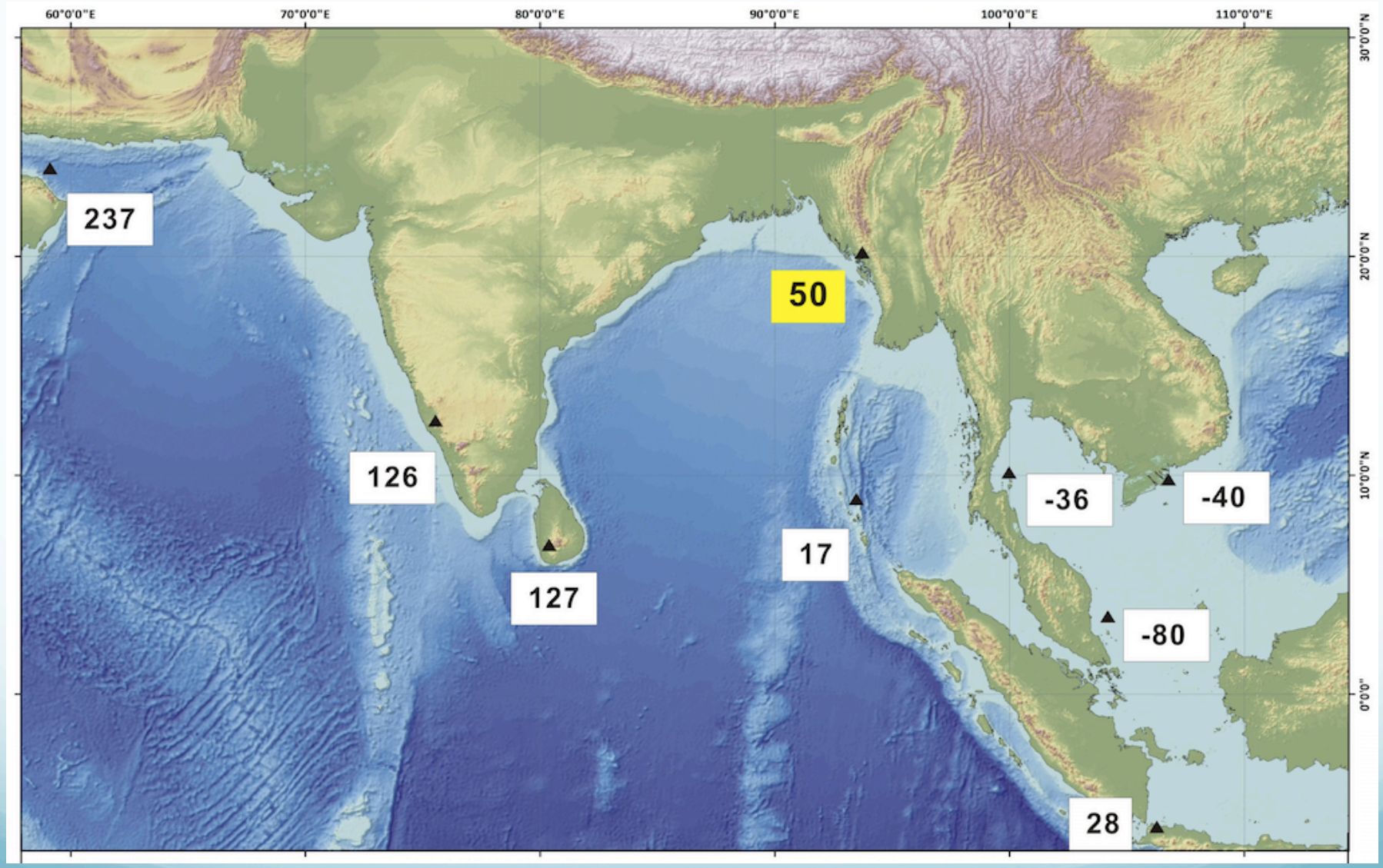
ΔR distribution in ocean

Air-Sea interaction





Chiang et al., in preparation



Chiang et al., in preparation

Take-home message:

- ^{230}Th method can date samples as young as young 10-year olds with a precision of ~1 year.
- Use of aconstant ΔR value to calibrate ^{14}C data may not be appropriate particularly in where has abundant terrigenous input.
- Time- and location-specifically regional ΔR (R) value is strongly recommended for future ^{14}C dates.

Thanks for your attention