Radiocarbon

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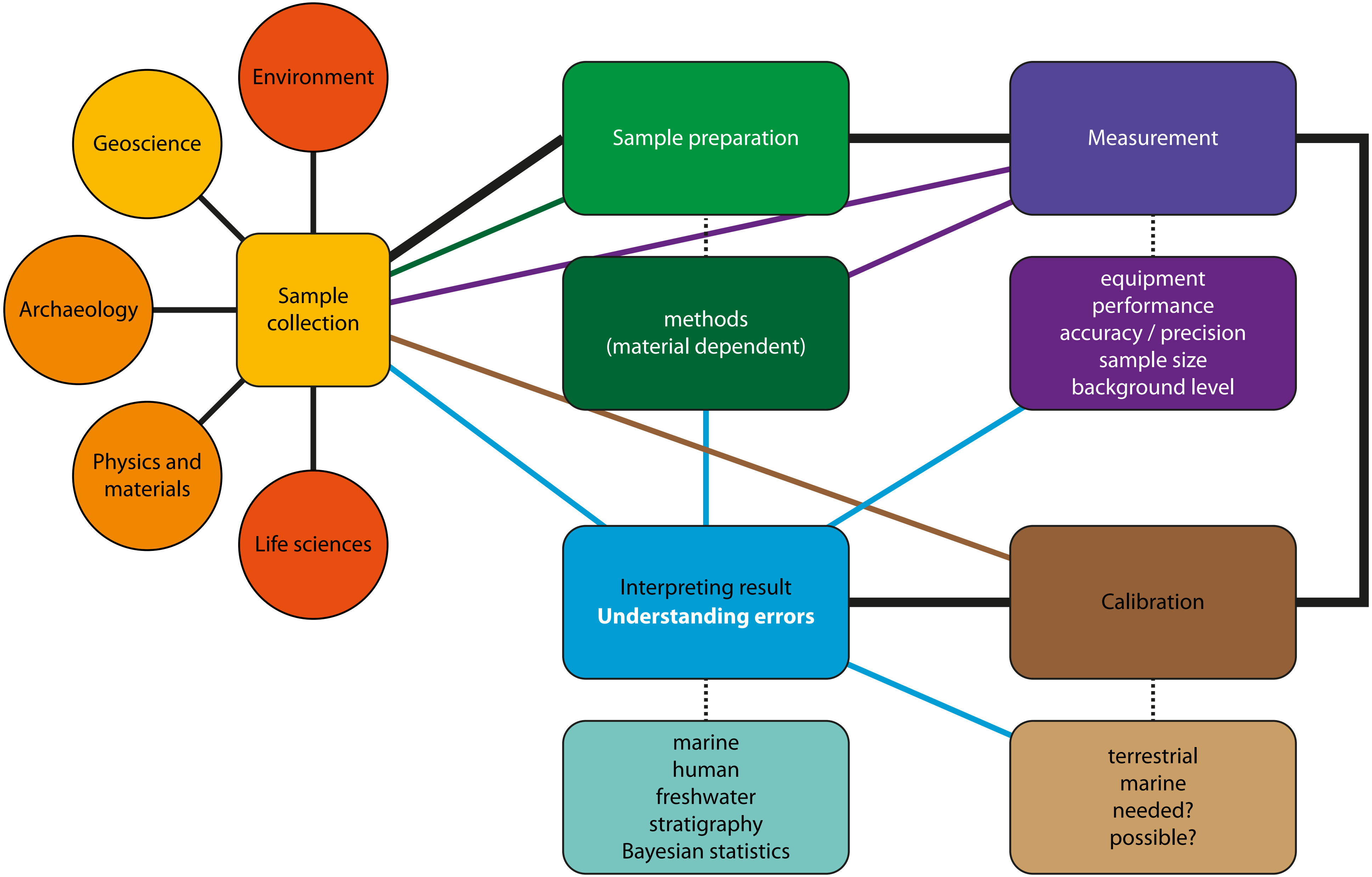
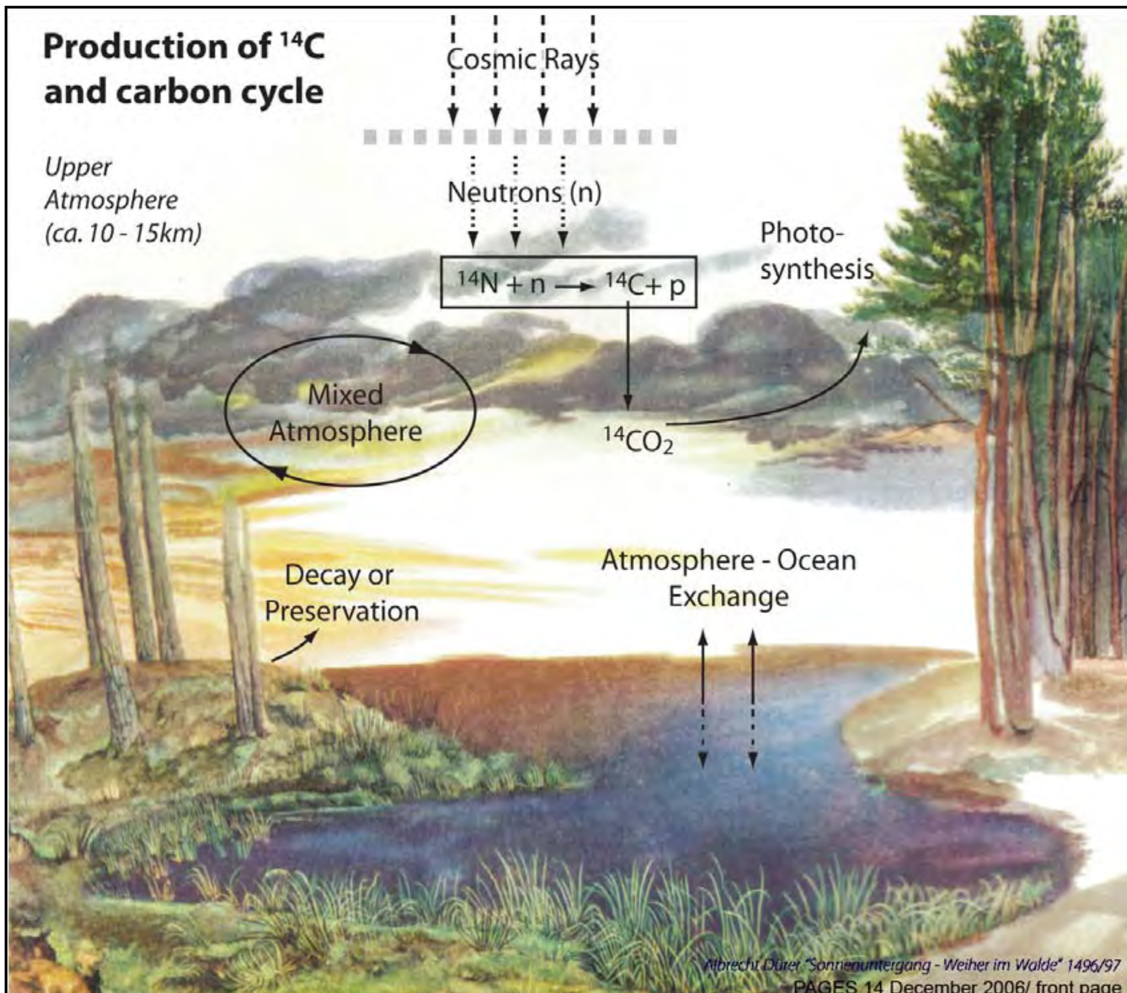
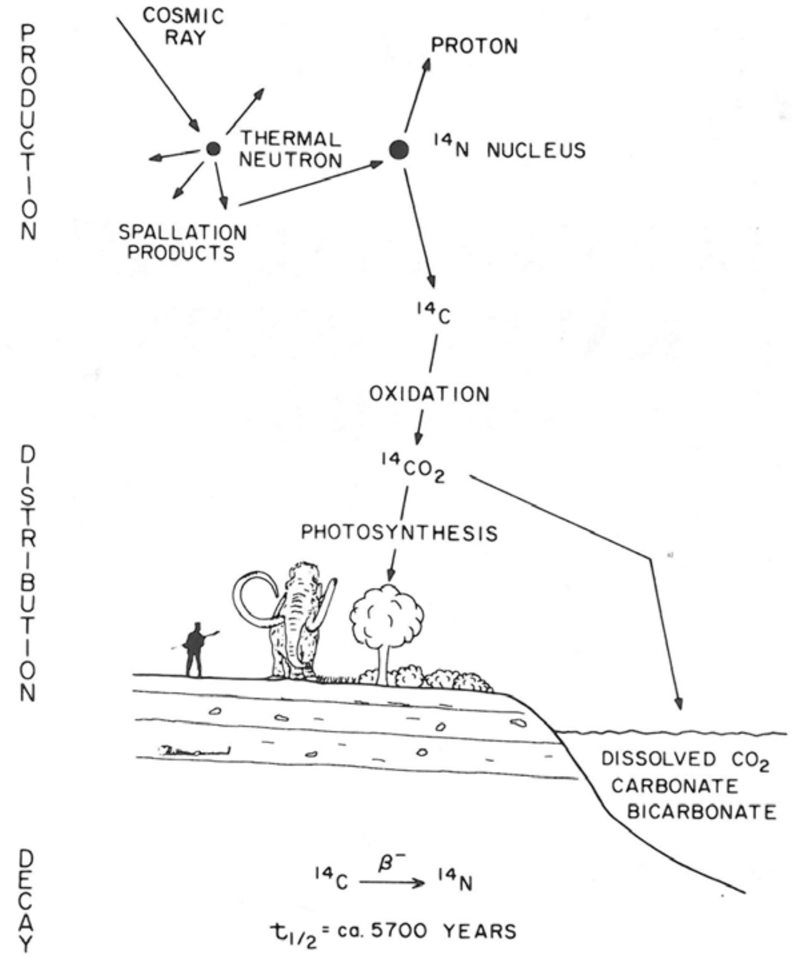
Basic principle - overview



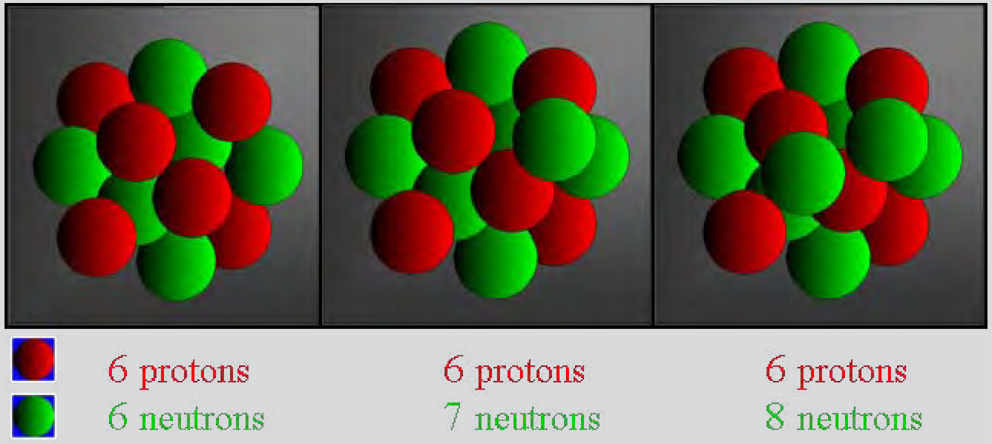
Production and cycling of radiocarbon





re 1.1 Basis of radiocarbon method: production, distribution and decay of ^{14}C. [After or (1985b).]

Basic technique / Dating principle



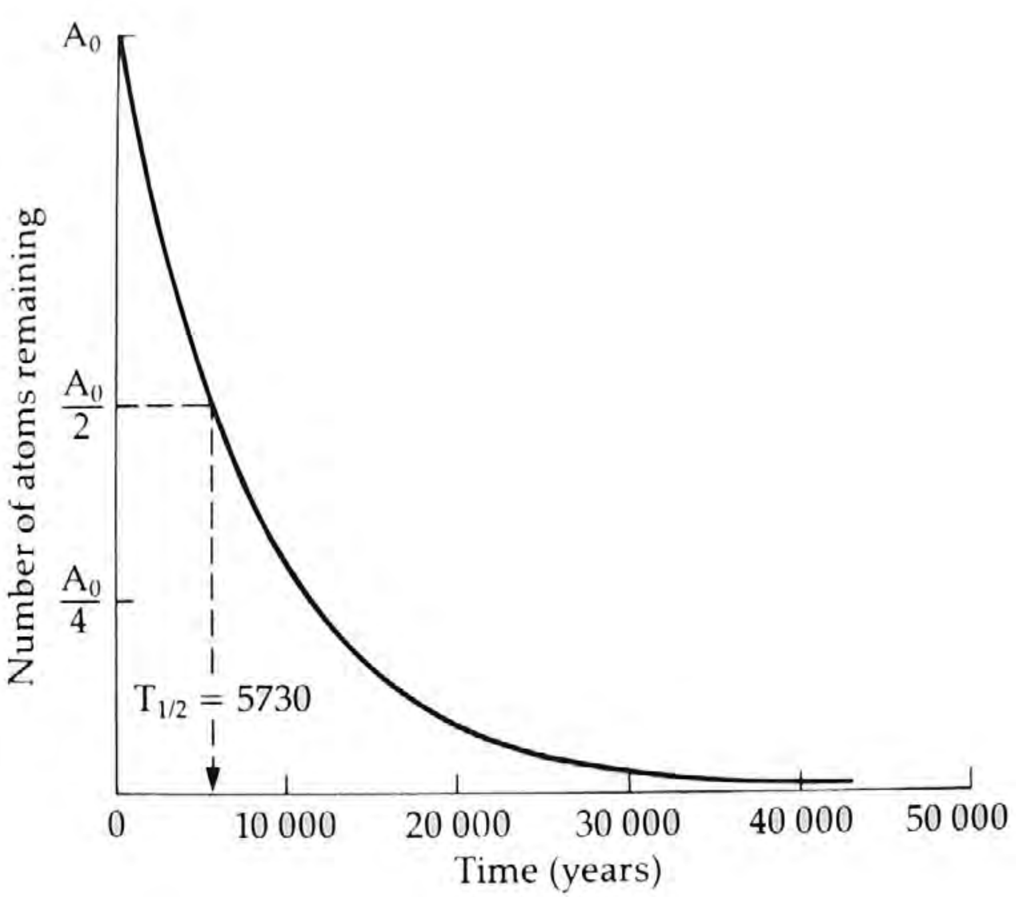
Libby: Nobel prize (1960) "for his method to use carbon-14 for age determination in archaeology, geology, geophysics and other branches of science"

Radioactive decay:

$$A = A_0 \cdot e^{-\frac{t}{\tau}}$$

$$t = -\tau \cdot \ln\left(\frac{A}{A_0}\right)$$

Measure $^{14}C / ^{12}C$ (if A_0 ≈constant)



Basic technique / Dating principle

Radioactive decay:

$$A = A_0 \cdot e^{-\frac{t}{\tau}}$$

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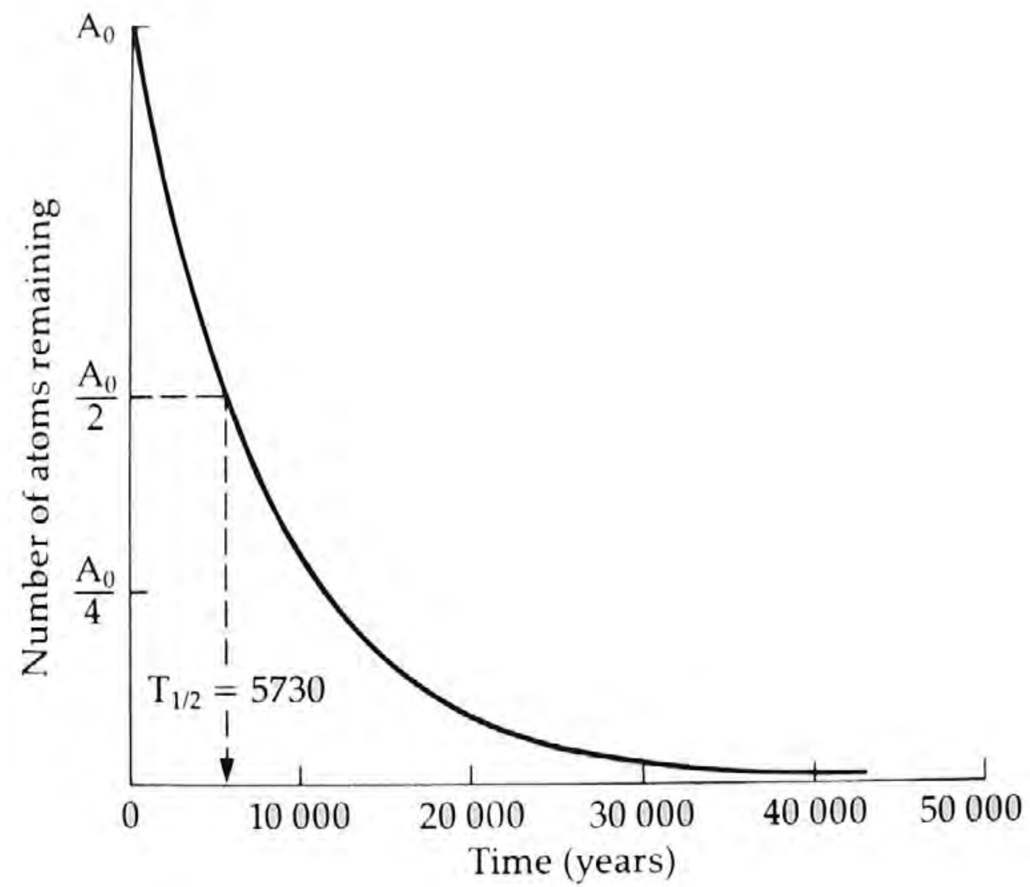


Measure $^{14}C/^{12}C$ (if A_0 ≈constant)

Assumptions:

- ^{14}C activiteten in each part of the global carbon reservoir (atmo-sphere, ocean, biosphere) has re-mained constant over time
- Complete and rapid mixing of ^{14}C
- no alteration of ^{12}C, ^{13}C, ^{14}C since death
- half life is accurately know

Målinger...

$$^{14}_{6}C \rightarrow ^{14}_{7}N + e^{-} + \bar{\nu}$$

Detecting the beta decay

- gas proportional counting
- liquid scintilation

Counting atoms using accelerator mass spectrometry (AMS)

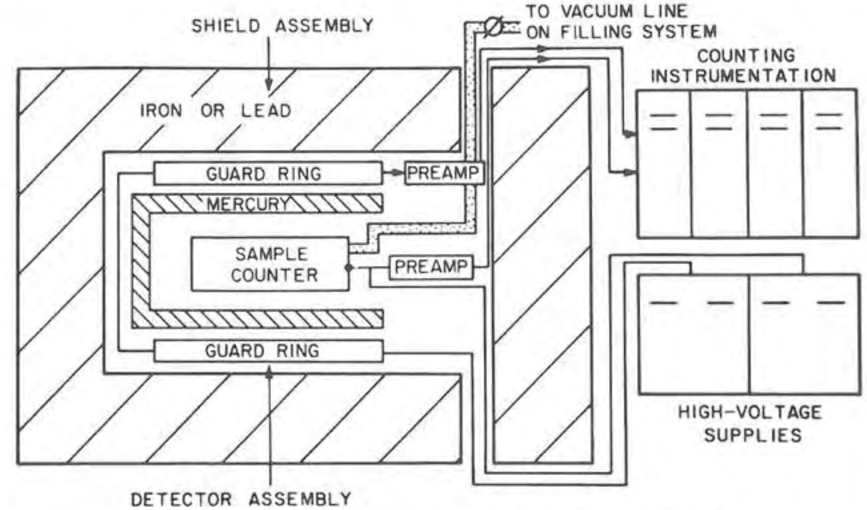


Figure 4.4 Components of a gas decay counting system.

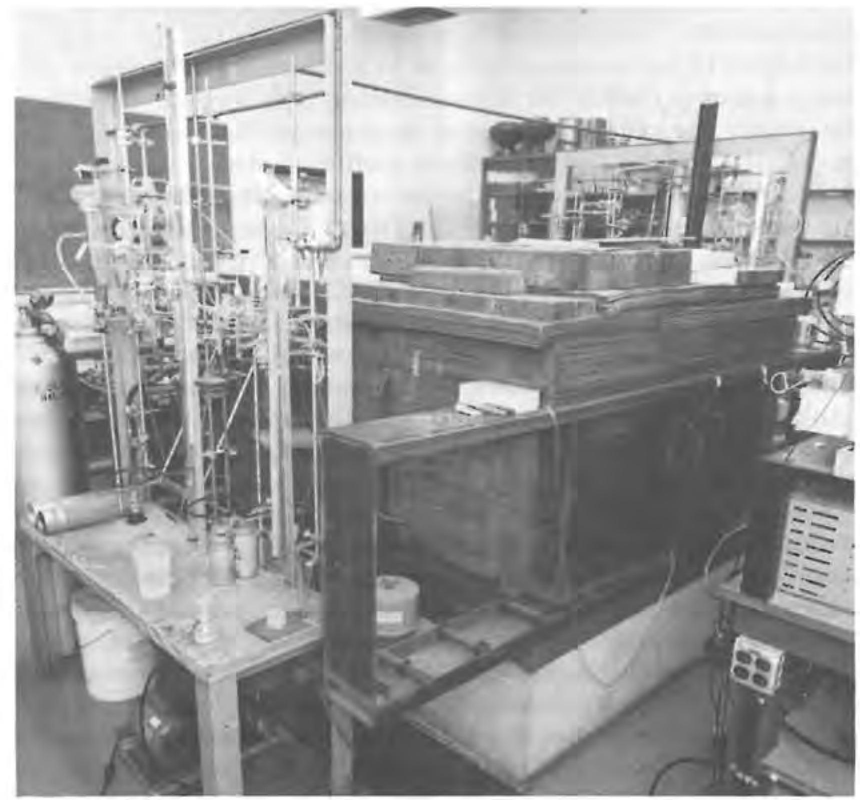
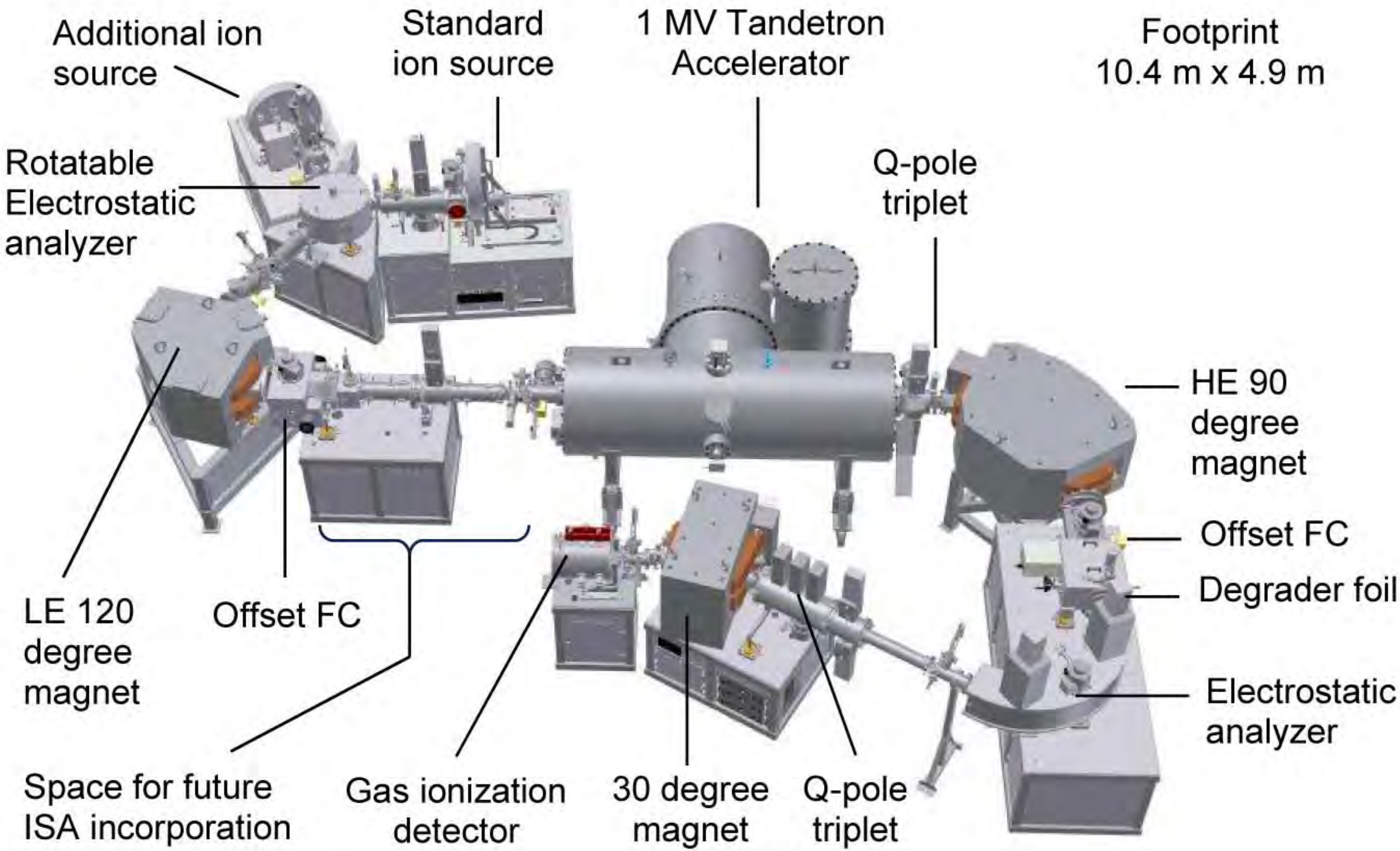


Figure 4.5 Shield assembly for a gas counting system. (Photograph courtesy of H. E. Suess and L. D. Ford, University of California, San Diego.)

^{14}C dating using AMS:

Small samples	(0.02) 0.2 – 1 mg (research!)
Capacity	>1000 pr. year
Measuring time	0.5 – 2 hours
^{14}C precision	0.3% or ± 25 years (research!)
Range	40 – 50.000 years


Additional ion source
Standard ion source
1 MV Tandetron Accelerator
Footprint 10.4 m x 4.9 m
Rotatable Electrostatic analyzer
Q-pole triplet
HE 90 degree magnet
Offset FC
Degrader foil
Electrostatic analyzer
LE 120 degree magnet
Offset FC
Space for future ISA incorporation
Gas ionization detector
30 degree magnet
Q-pole triplet

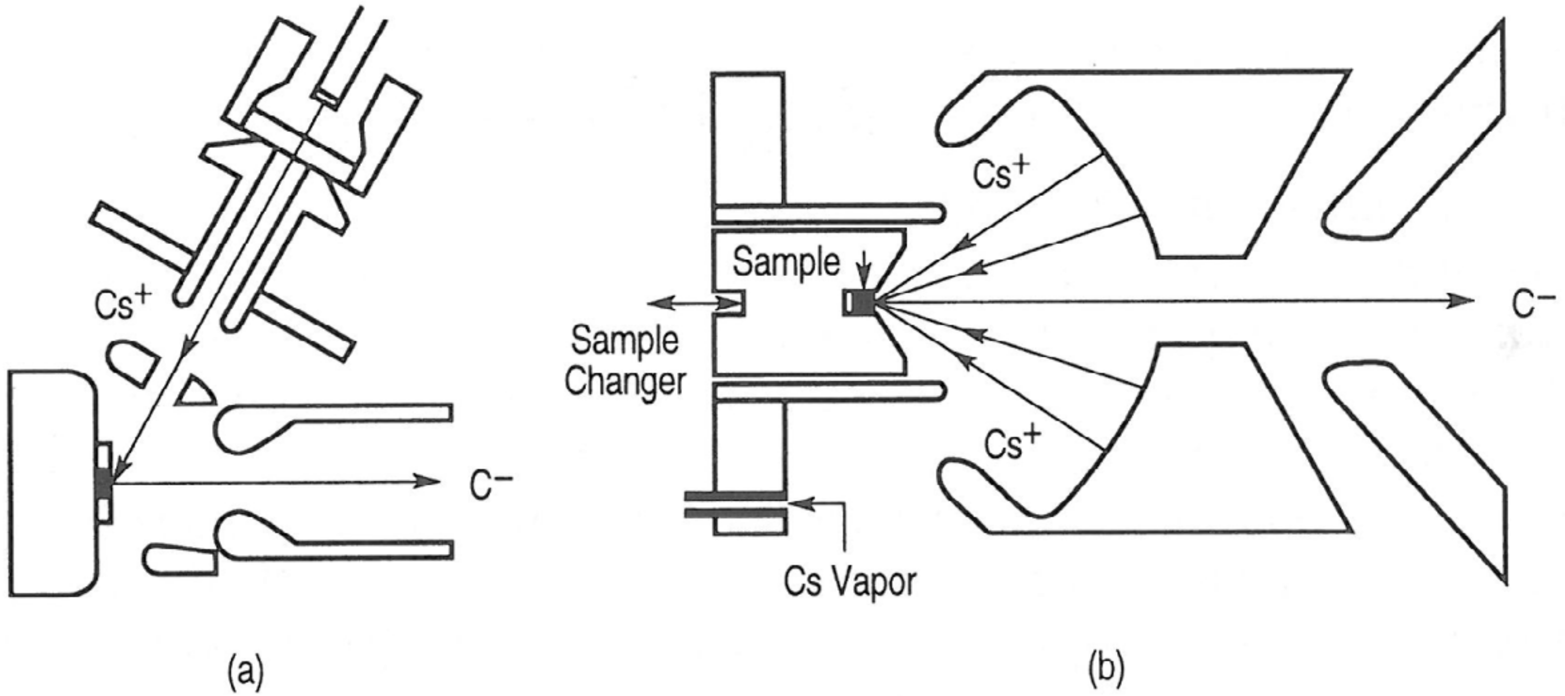
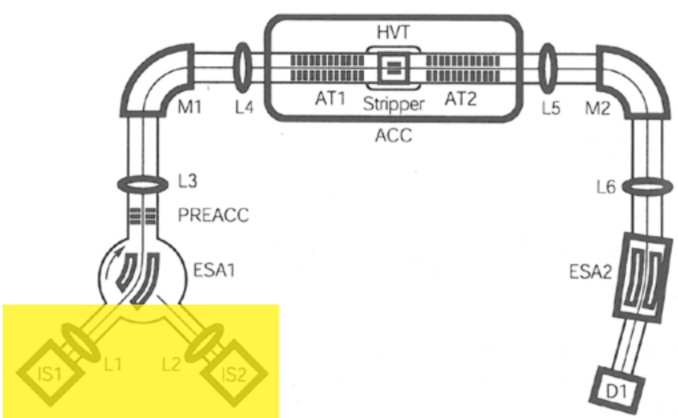


Figure 3.2 Ion source geometries: (a) focused Cs source, and (b) high-intensity source.



Mass	Molecule
12	^{12}C
13	^{12}CH, ^{13}C
14	$^{12}CH_2$, ^{13}CH, ^{14}C

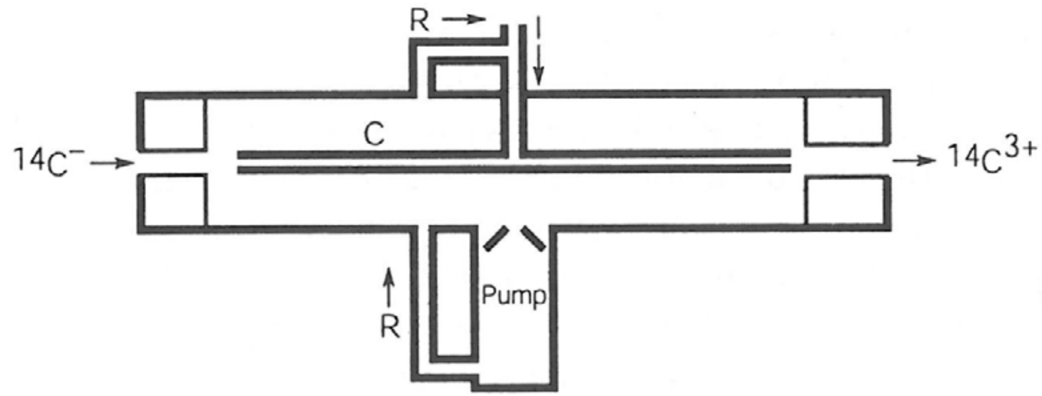
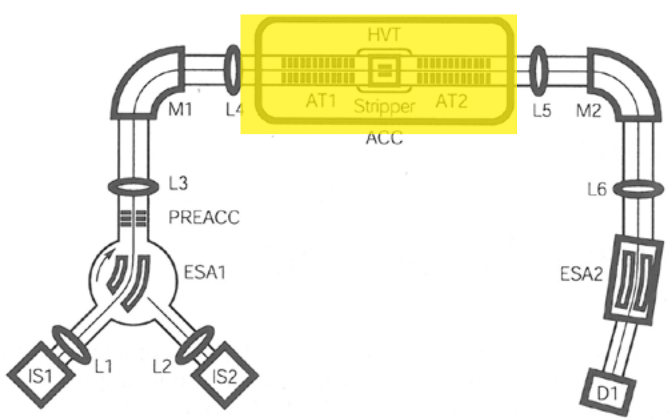
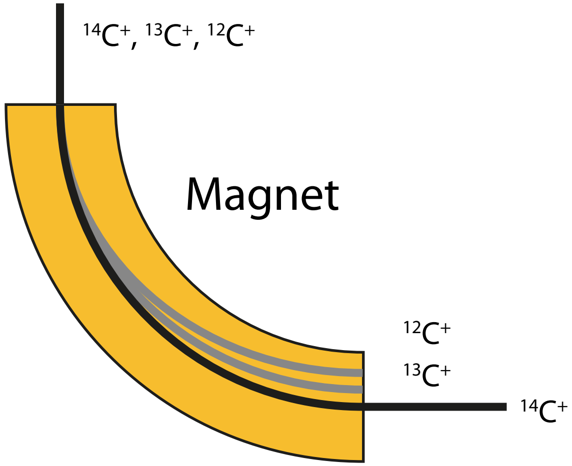


Figure 3.4 Schematic illustration of a gas stripper system in the terminal of a tandem accelerator with recycling of the stripper gas. The incoming negative ion (shown for example as $^{14}C^-$) is stripped of four electrons as it passes through the gas canal (C), emerging at the exit as a $^{14}C^{3+}$ ion for further acceleration. The gas is fed into the canal by a controlled needle valve, removed by a turbo pump, and recirculated (R) back into the stripper canal. (From Bonani, G. et al., *Nucl. Instrum. Methods Phys. Res.*, B52, 338, 1990. With permission.)



$$^{12}CH_2^- \rightarrow {}^{12}C^+ + 4e^- + 2H^+$$

$$^{13}CH^- \rightarrow {}^{13}C^+ + 3e^- + H^+$$

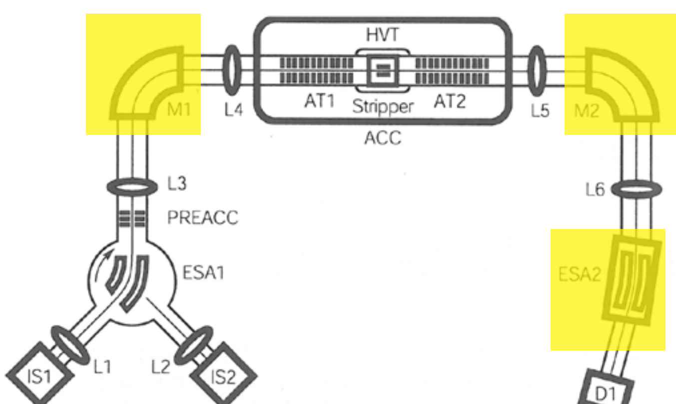


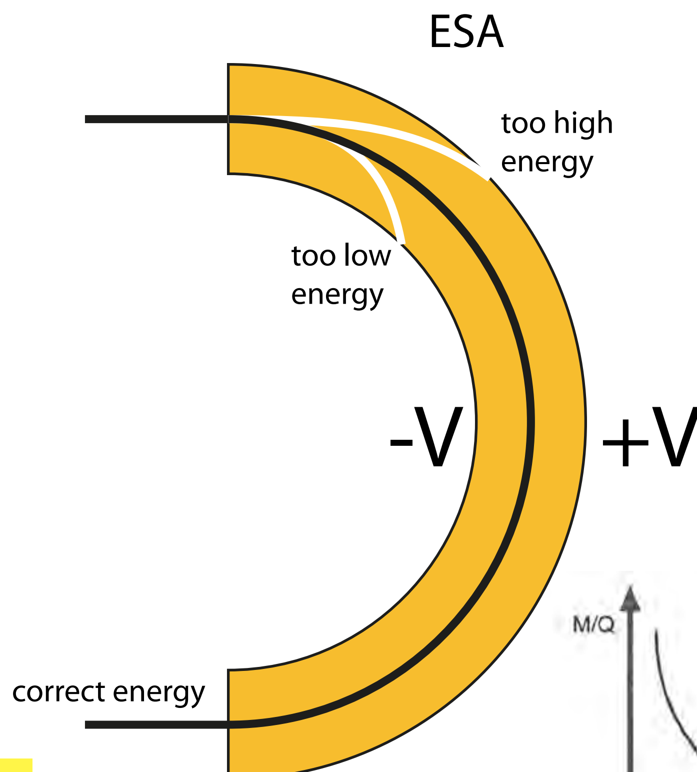
Mass filter:

$$F = m \cdot a$$

$$m\frac{v^2}{r} = q \cdot B \cdot v$$

$$B \cdot r \propto \frac{\sqrt{m \cdot E}}{q}$$





Energy filter:

$$F = m \cdot a$$

$$m\frac{v^2}{r} = q \cdot \epsilon = q\frac{V}{d}$$

$$\frac{Vr}{2d} \propto \frac{E}{q}$$

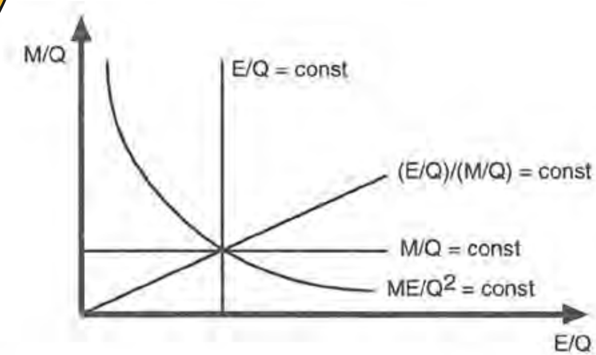


Figure 3.5 Loci of values of M/Q vs. E/Q determined by different beam line analyzers. Ions with equal E/Q ratios will be transmitted identically by an electrostatic analyzer, those with equal ME/Q² by a magnetic analyzer, and those with equal (E/Q) and (M/Q) by a velocity (or Wien) filter. Combinations of analyzers can be used to dramatically reduce background events. In order for an ion to pass all analyzers, it must have values of E, M, and Q which are determined by the intersection point of all analyzer loci.

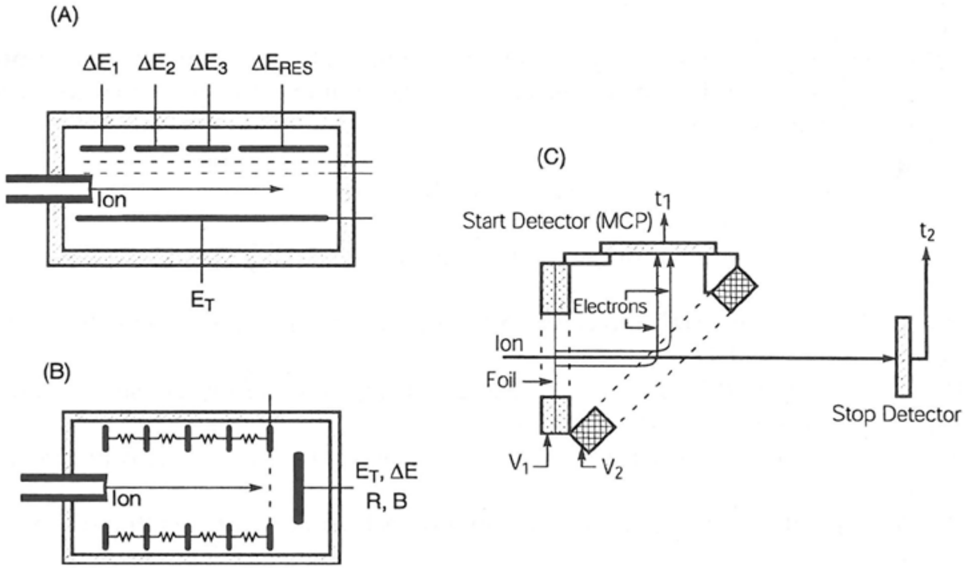


Figure 3.7 Schematic drawings of ion detectors used in AMS: (A) multi-anode gas ionization detector (see Fifield et al., 1987, and Knies and Elmore, 1994b, for details); (B) a Bragg detector; and (C) start and stop detector setup used to determine the time-of-flight ($t_2 - t_1$) for each ion. Dashed lines

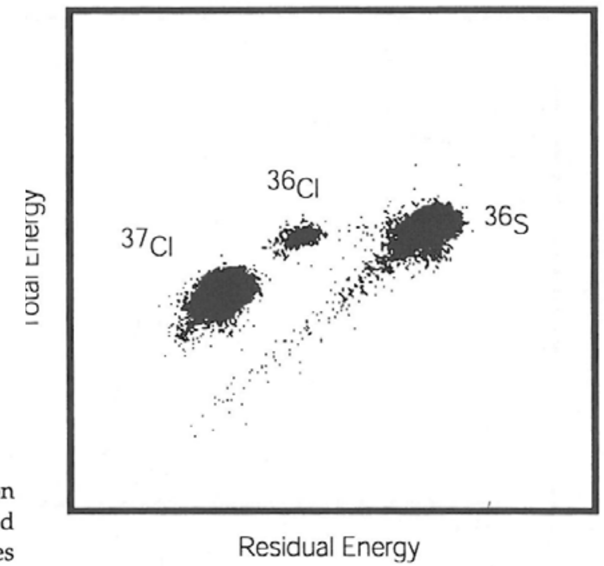
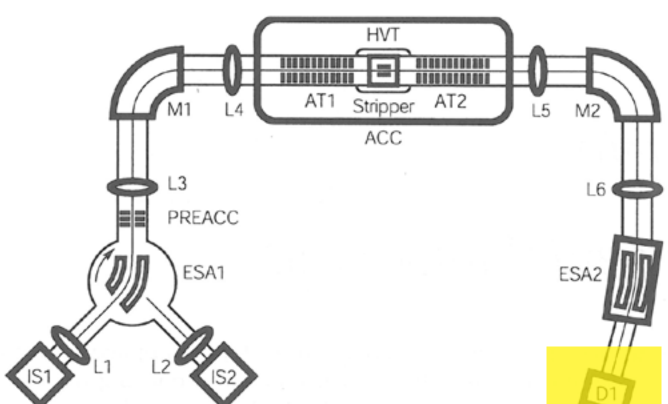


Figure 3.8 Identification of ^{37}Cl, ^{36}Cl, and ^{36}S ions at 130 MeV using the residual energy (last anode plate) and total energy parameters measured with a gas ionization detector. Correlated energy degraded events associated with the ^{37}Cl and ^{36}S peaks (at <0.1% of peak intensity) are observed. (From Ophel, T.R. et al., *Nucl. Instrum. Methods Phys. Res.*, A272, 734, 1988. With permission.)



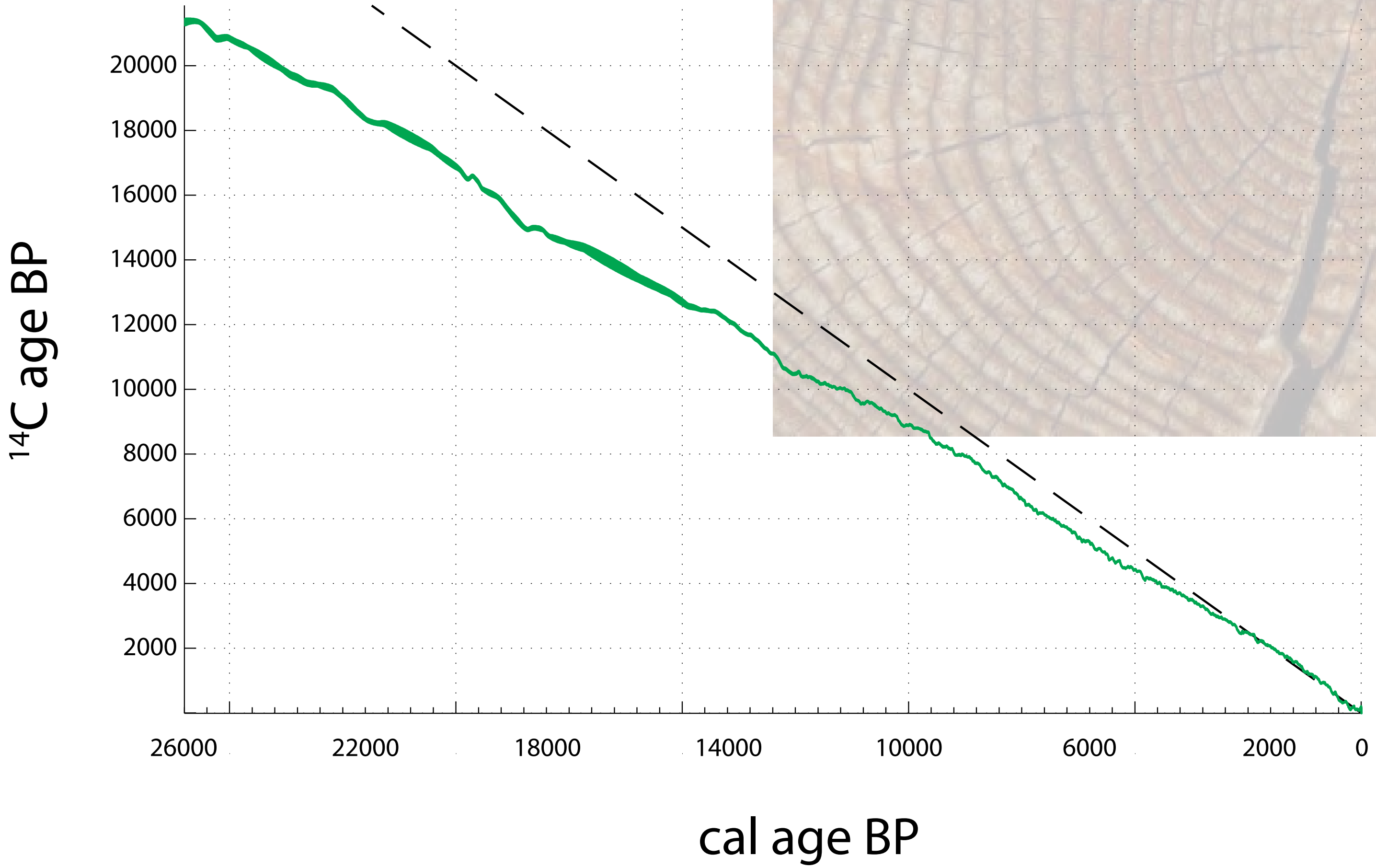
Calibration

from ^{14}C years to calendar years

Radiocarbon chronology

Dendro-chronology

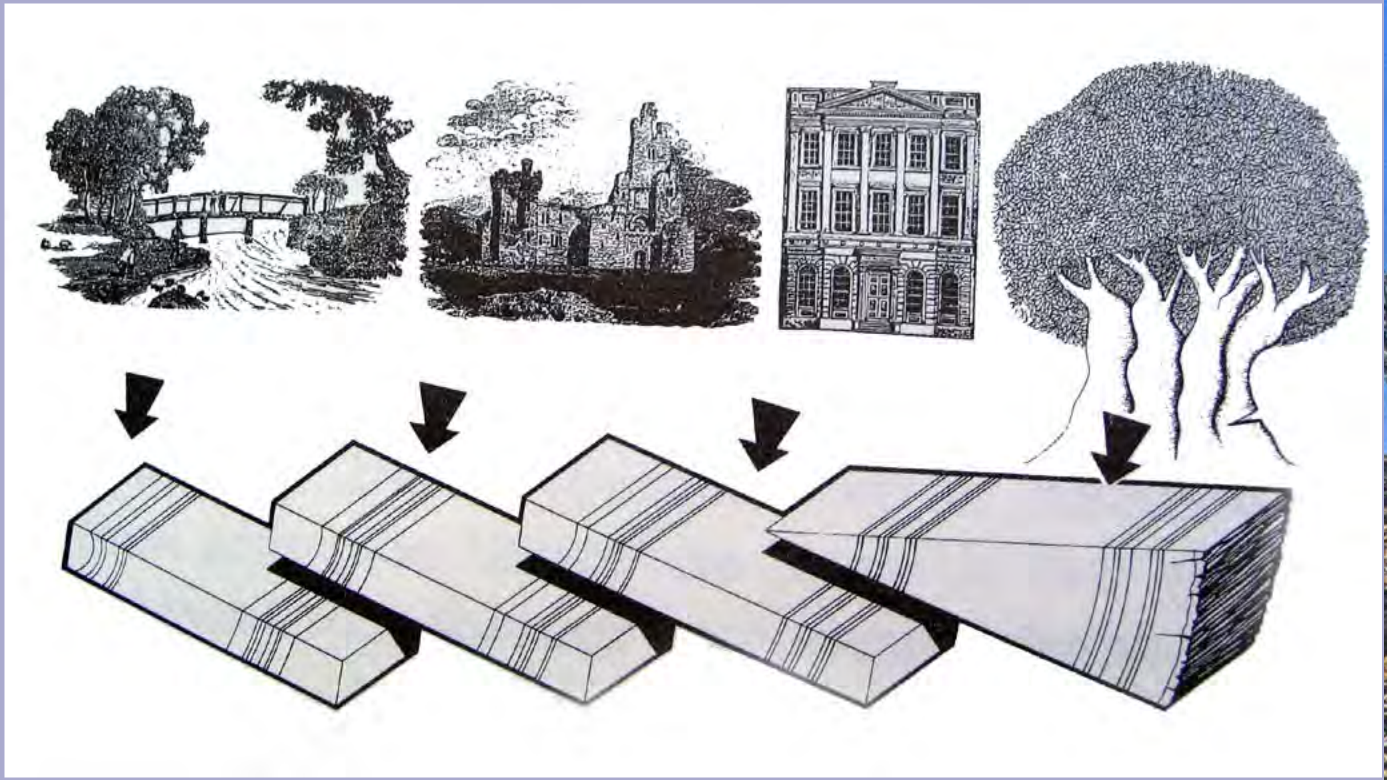
Past atmospheric ^{14}C levels



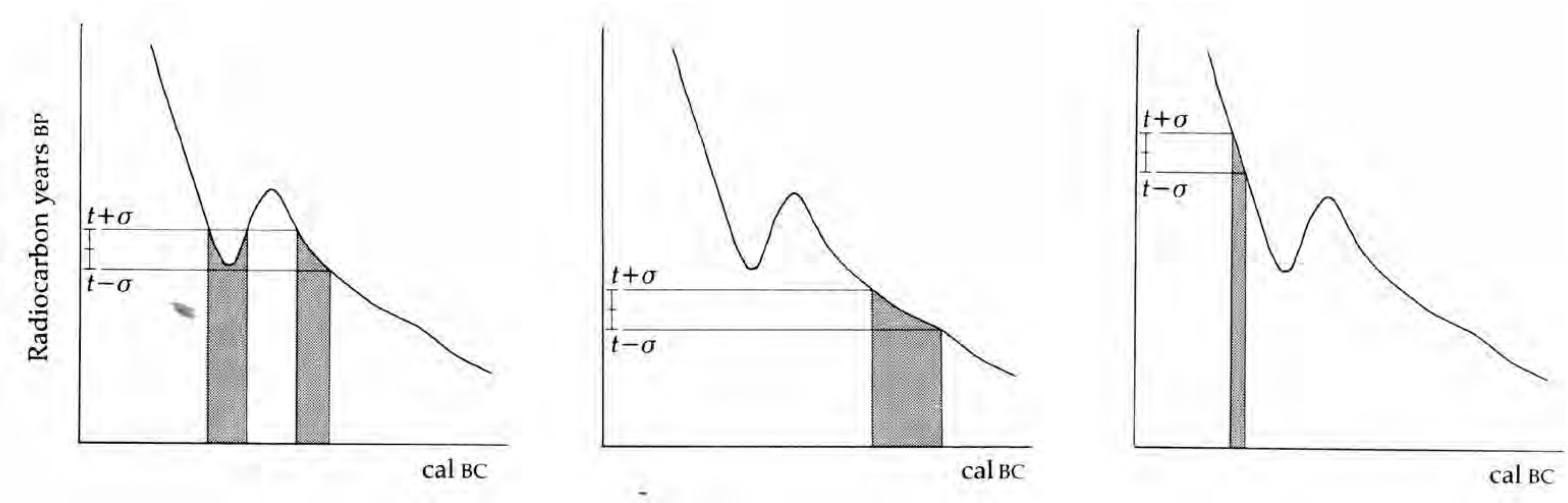
Calibration:
Sample must be in carbon equilibrium with atmosphere

Reimer, P. J., M. G. L. Baillie, et al (2004). "IntCal04 terrestrial radiocarbon age calibration, 0-26 cal kyr BP." Radiocarbon 46(3): 1029-1058.

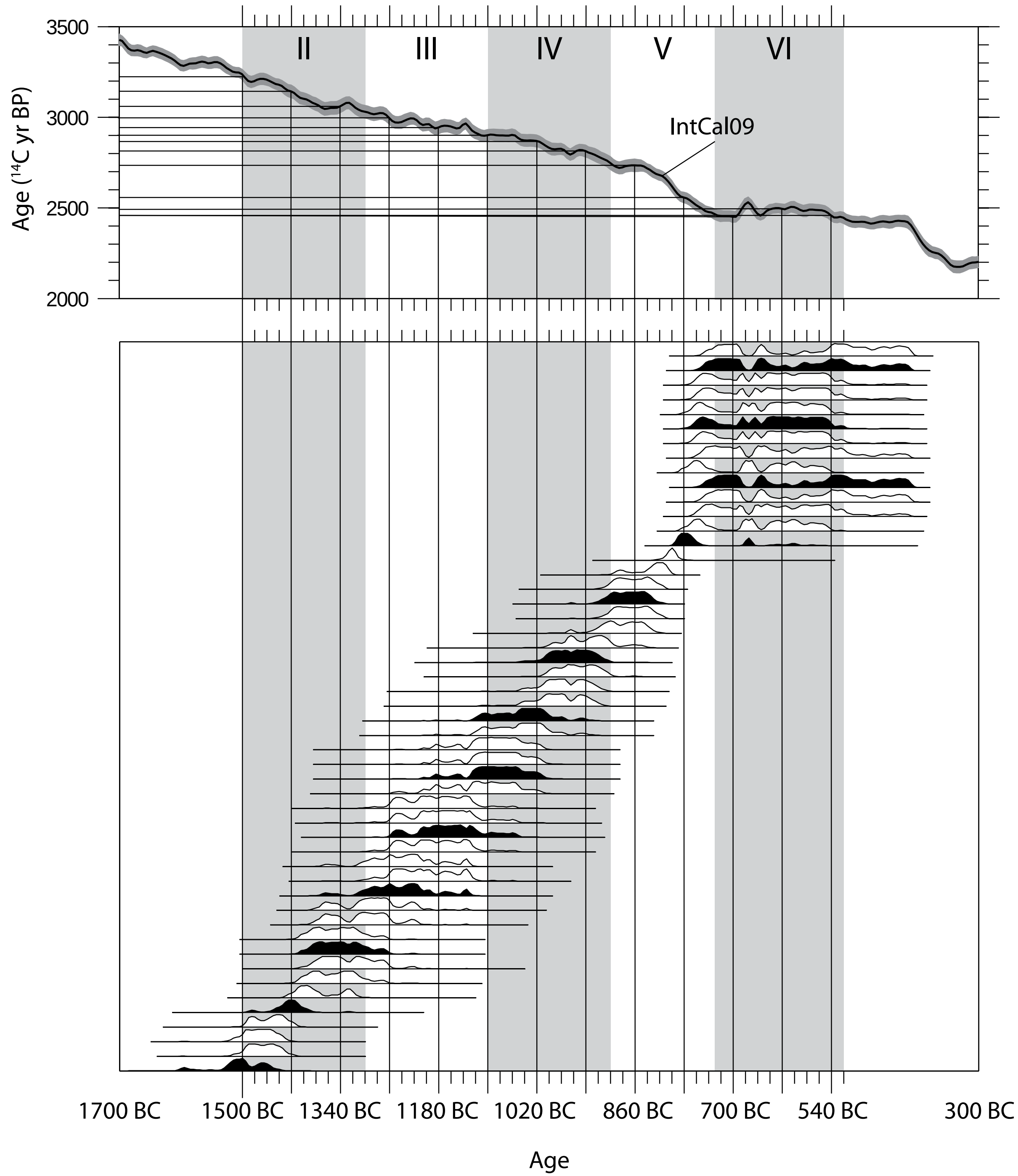
The radiocarbon calibration curve

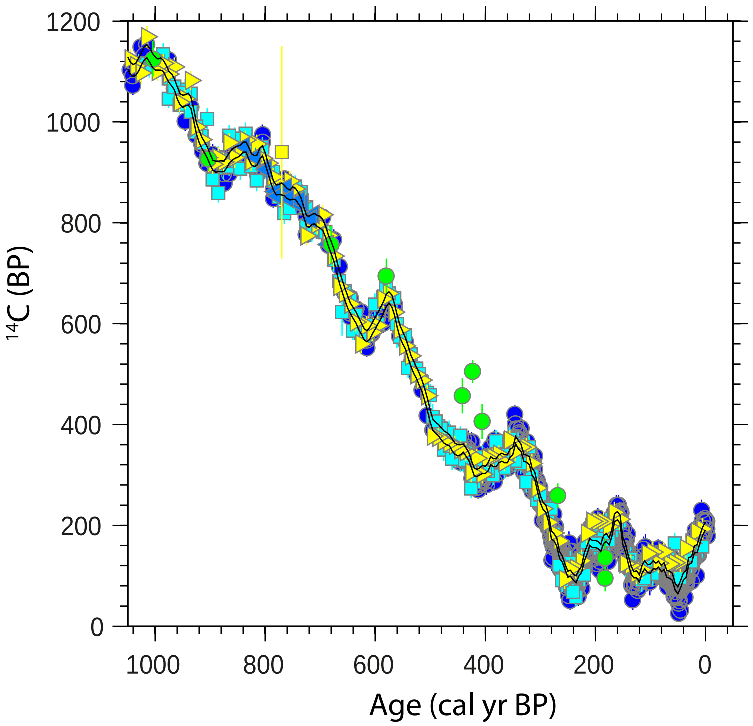


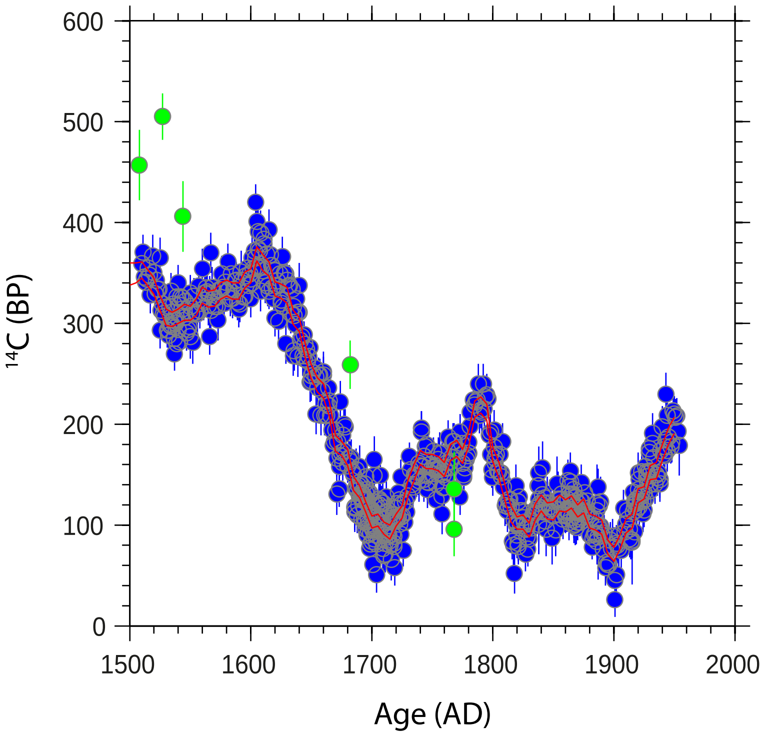
How to convert a ^{14}C date into a calender date



Radiocarbon calibration

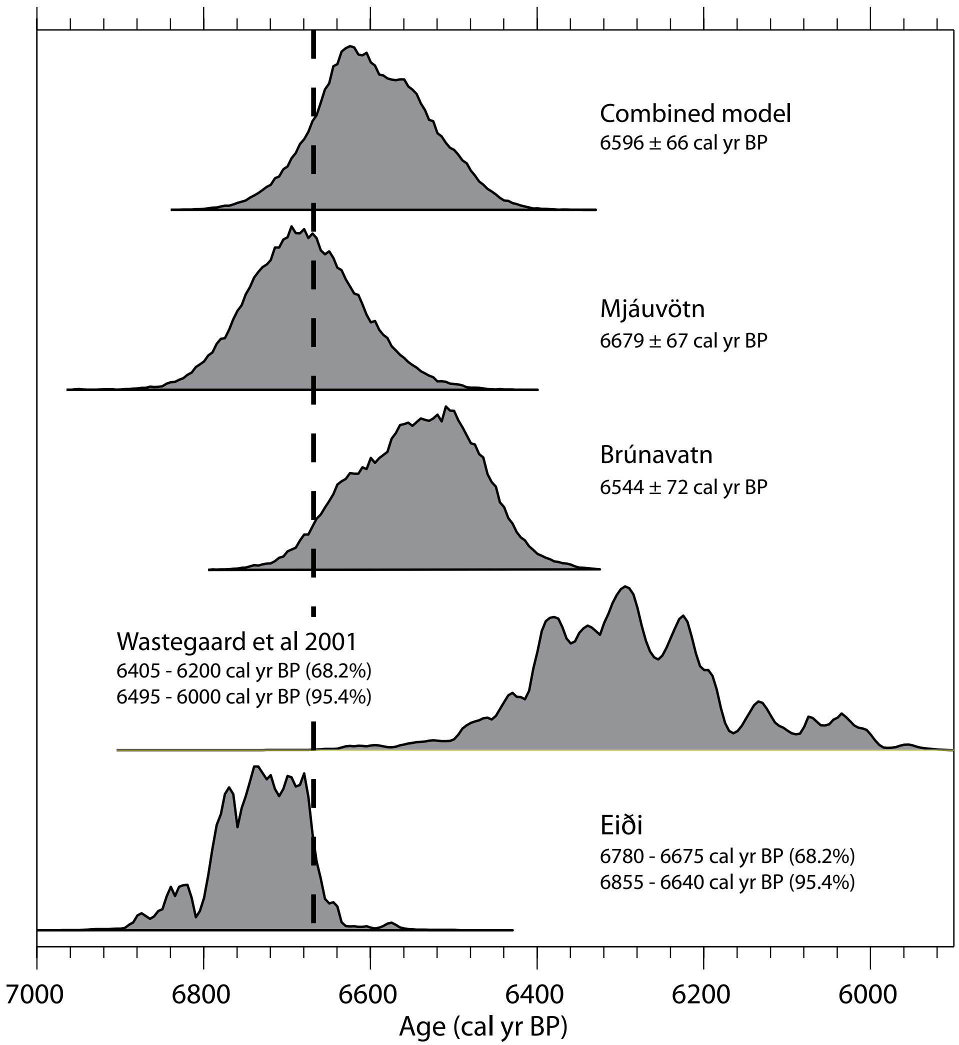


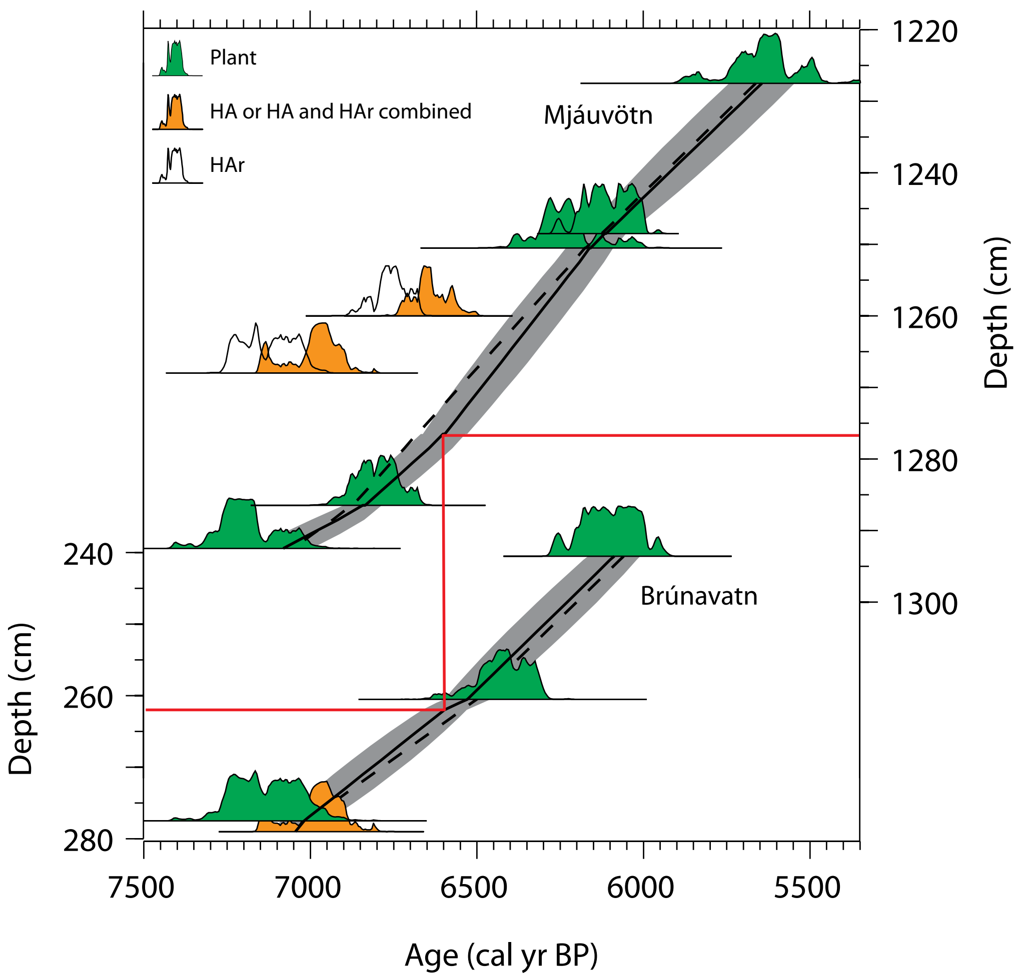




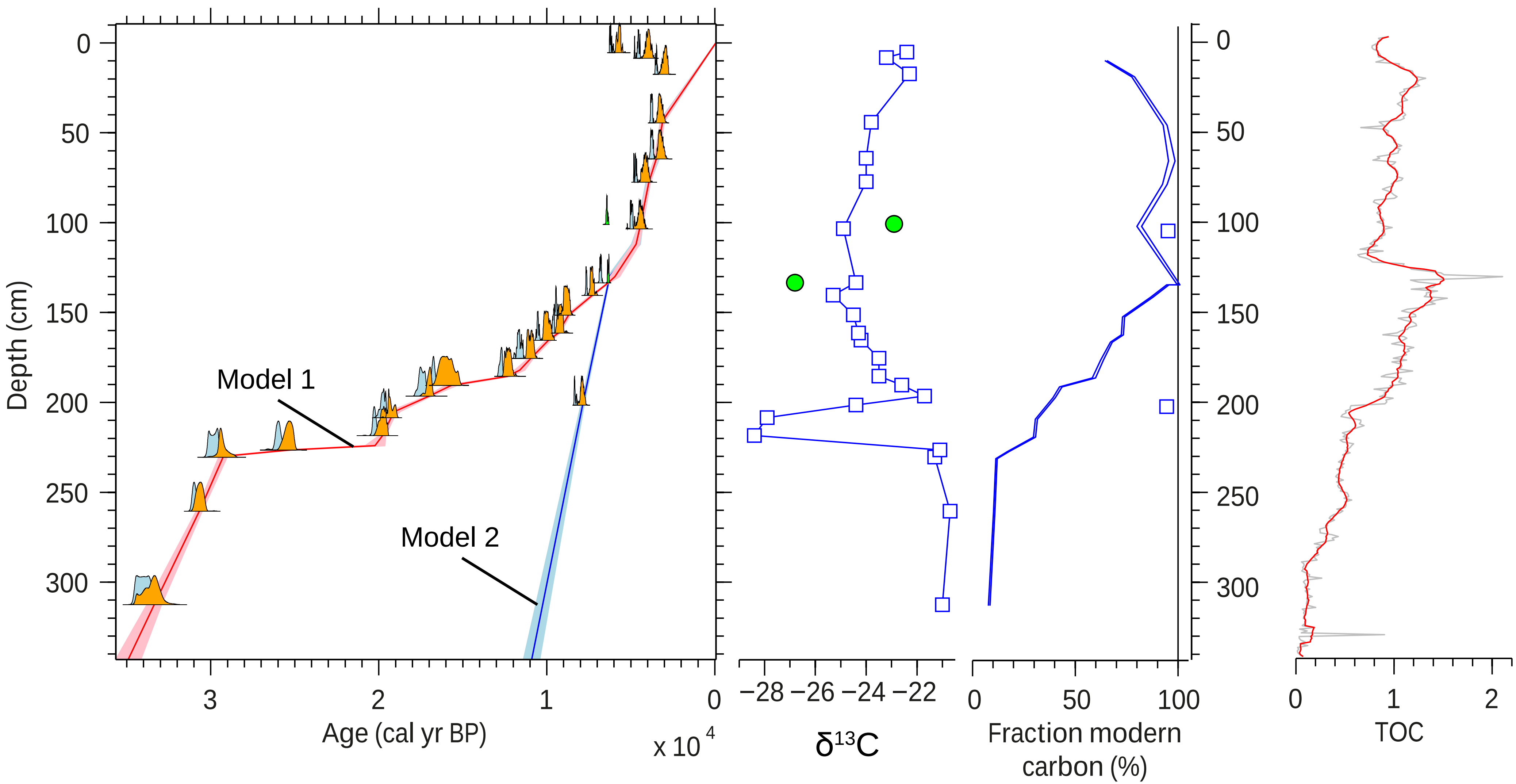
Suess effect - annual data (can the 11 yr solar cycle be observed?)

Linked age models

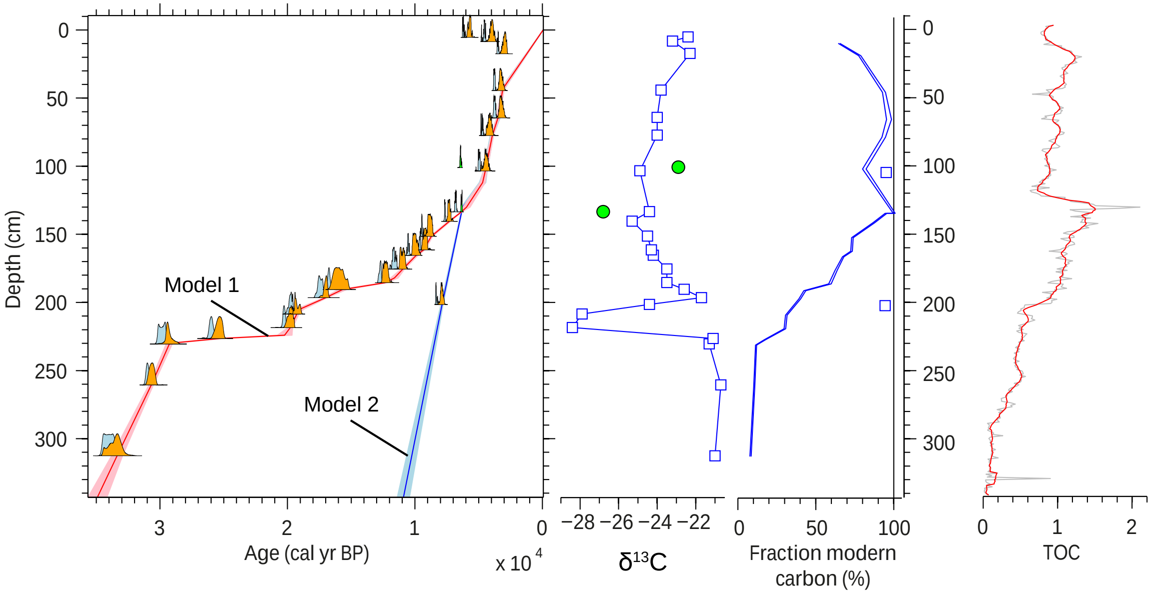




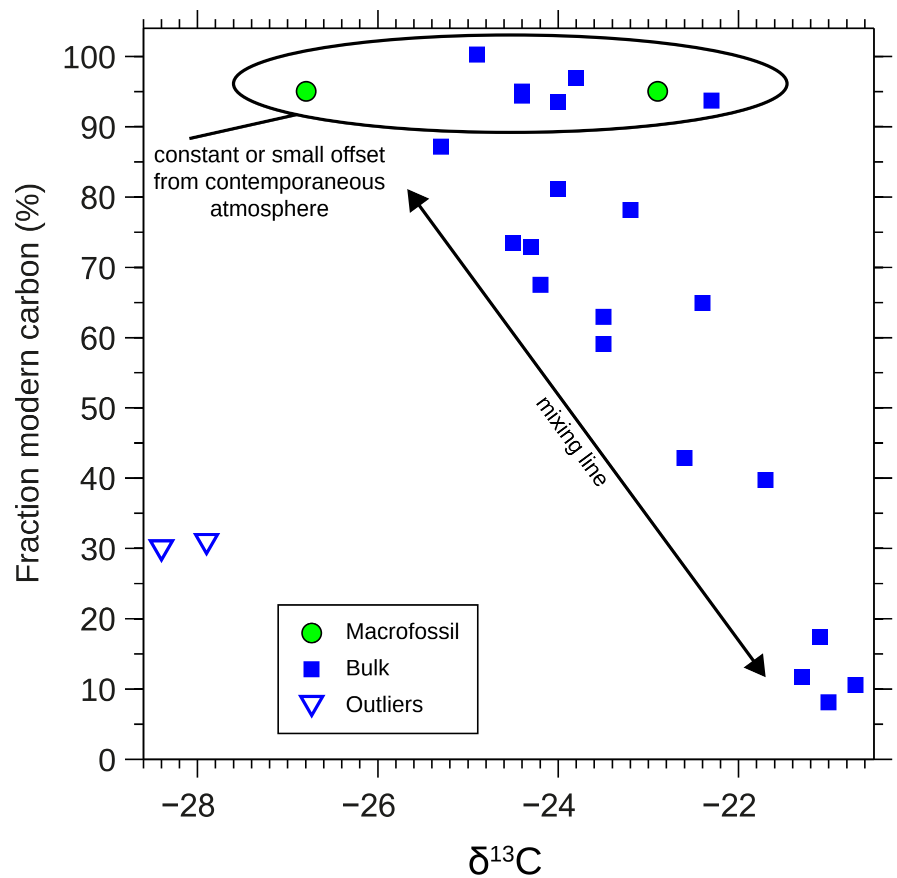
A complicated chronology - but can we provide explanations?



Mixing between two reservoirs



local glacier acitivity



Radiocarbon and the ocean....

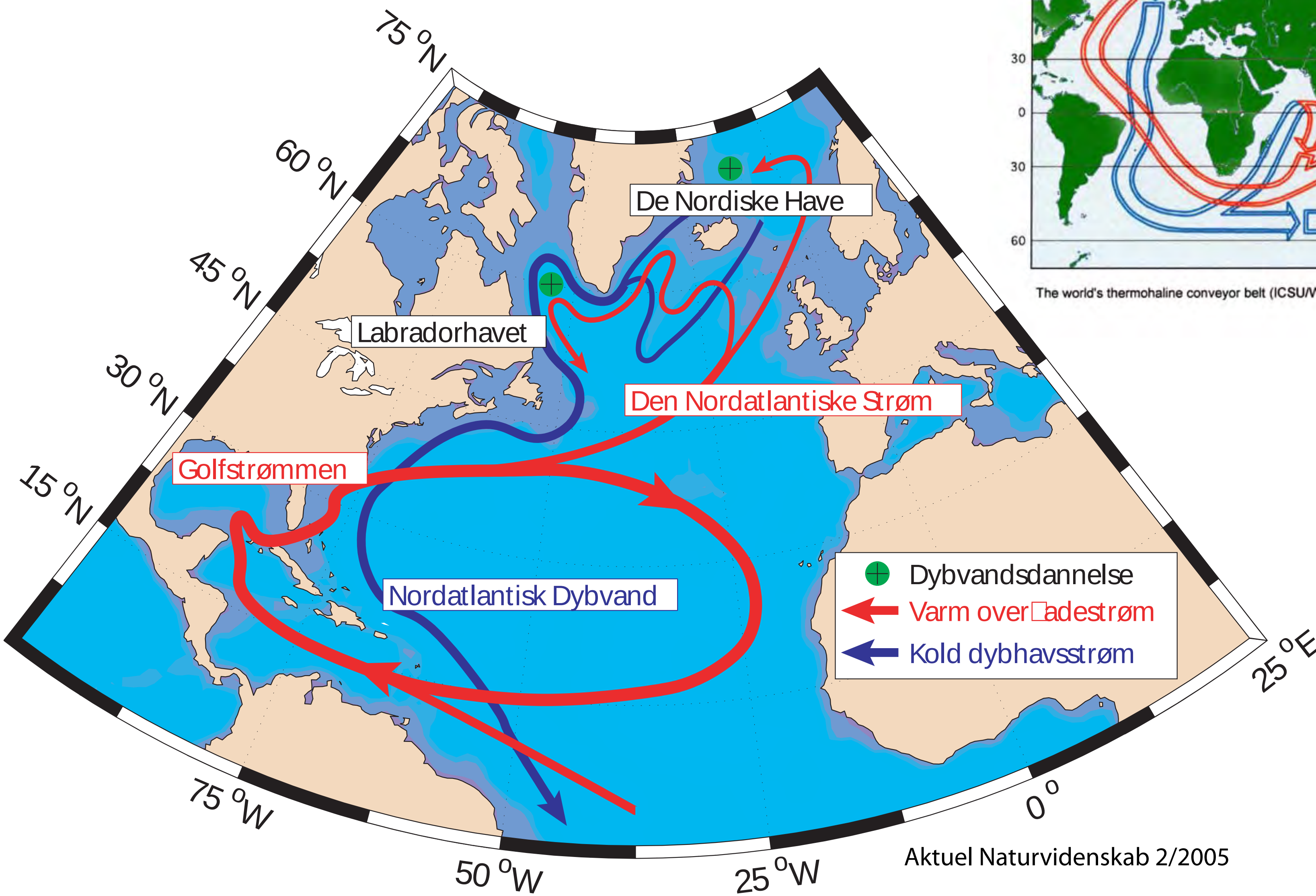
Ocean circulation

Surface: ^{14}C exchange with atmosphere

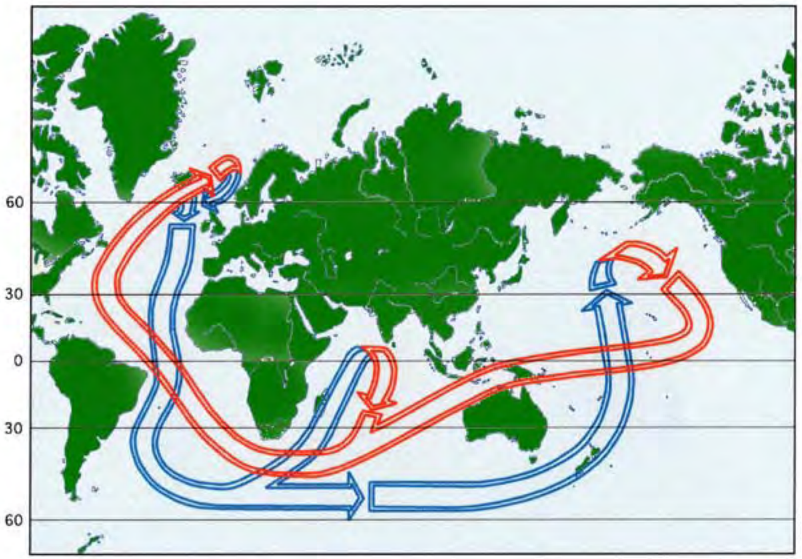
age~400 years

Deep ocean: no ^{14}C exchange with atmosphere

age>400 years, deep ocean can be very 'old'

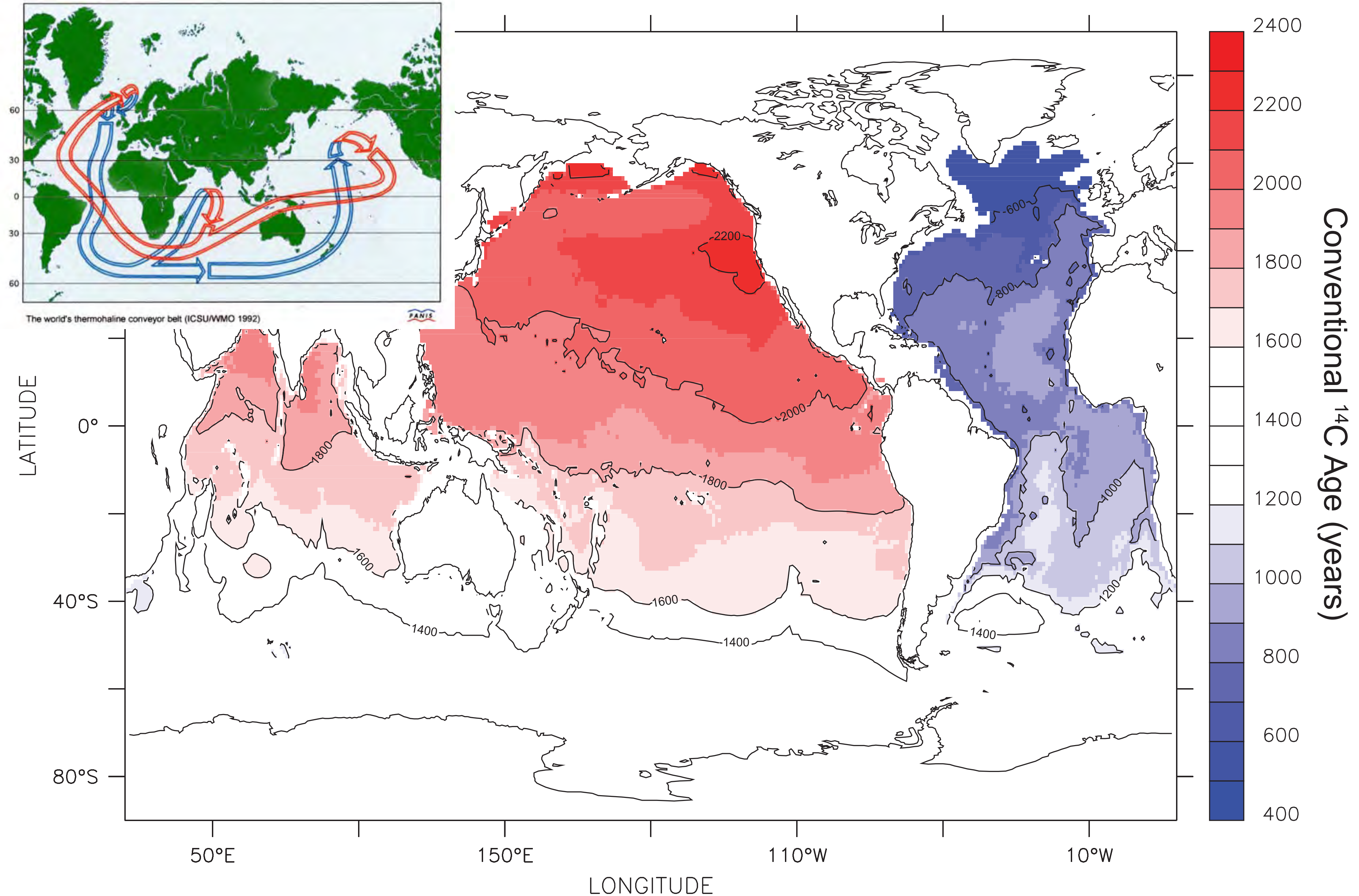


Aktuel Naturvidenskab 2/2005



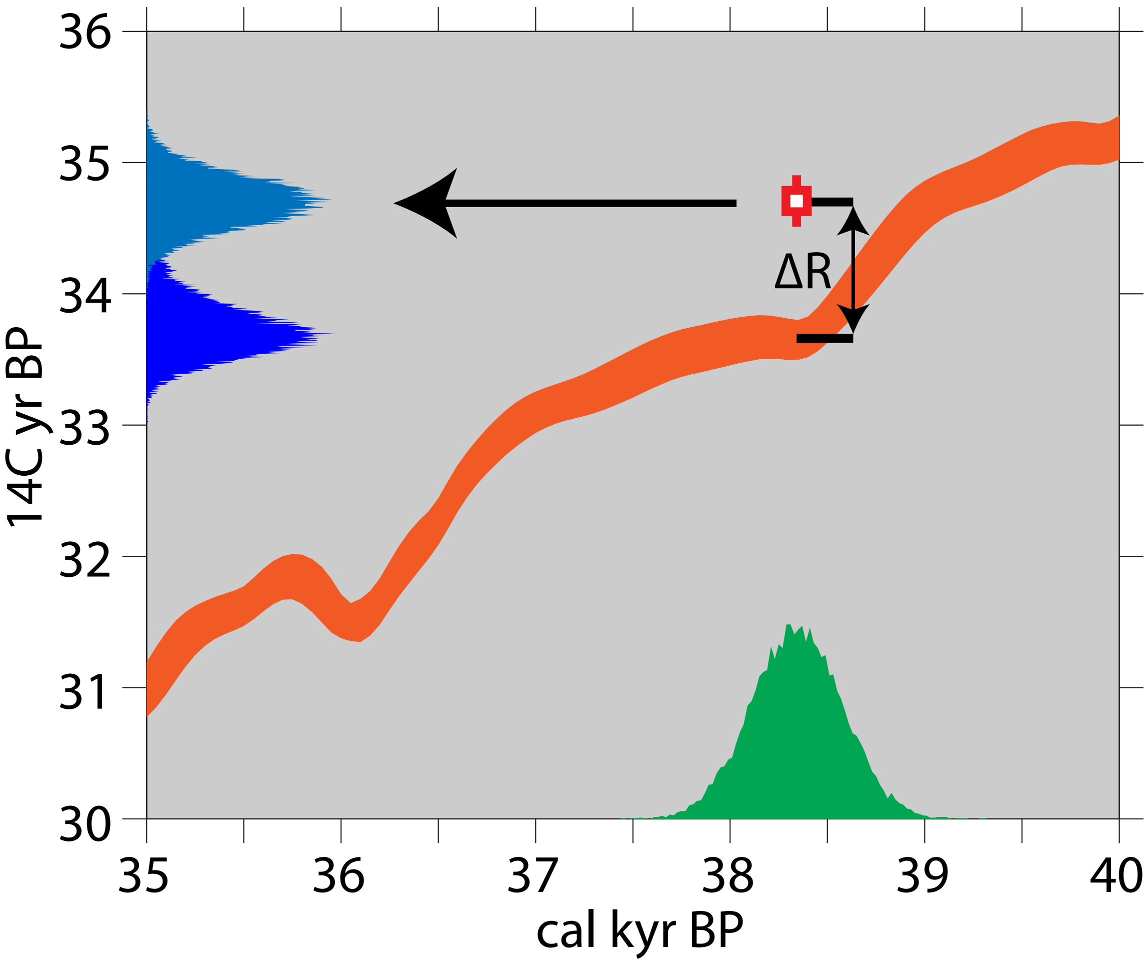
The world's thermohaline conveyor belt (ICSU/WMO 1992)

Deep ocean ^{14}C ages (>1500 m)



Matsumoto, K., 2007. Journal of Geophysical Research-Oceans, 112(C9): DOI: 10.1029/2007JC004095.

Calculating reservoir ages



Requires knowledge on **calendar** age

- use ‘atmospheric’ ^{14}C samples
- use tephro-chronology
- use tie-points (*under the assumption of synchronicity*)

Reservoir age **R**

- deviation from **atmospheric** curve

Local reservoir **ΔR**

- deviation from **marine** curve

Marine chronology

www.radiocarbon.org/IntCal04

Global model ocean ~400 years older than contemporaneous atmosphere

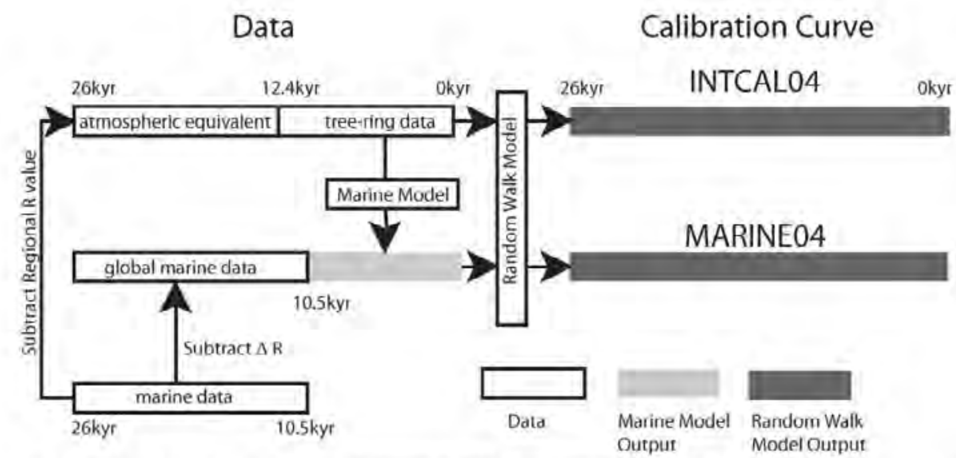
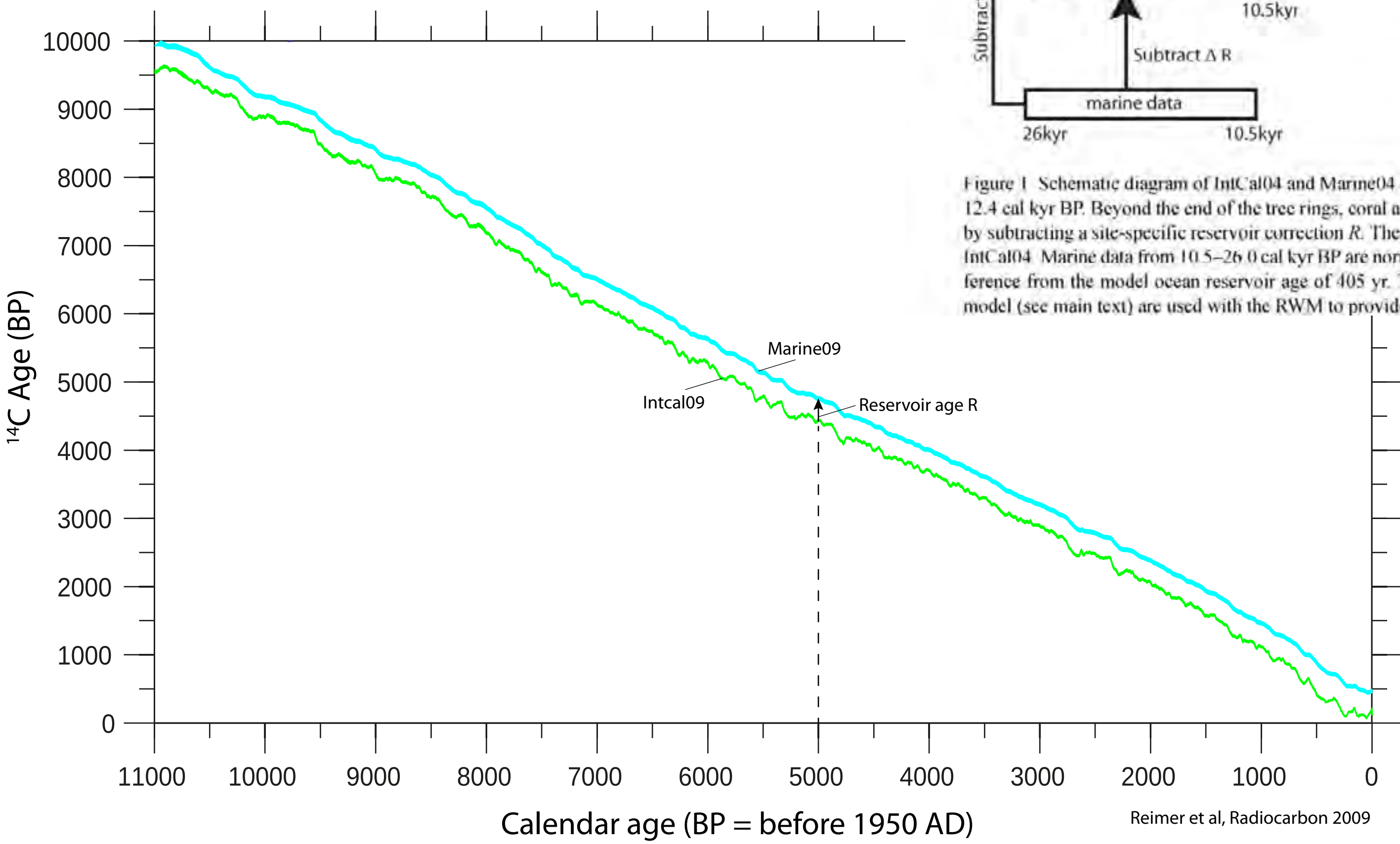
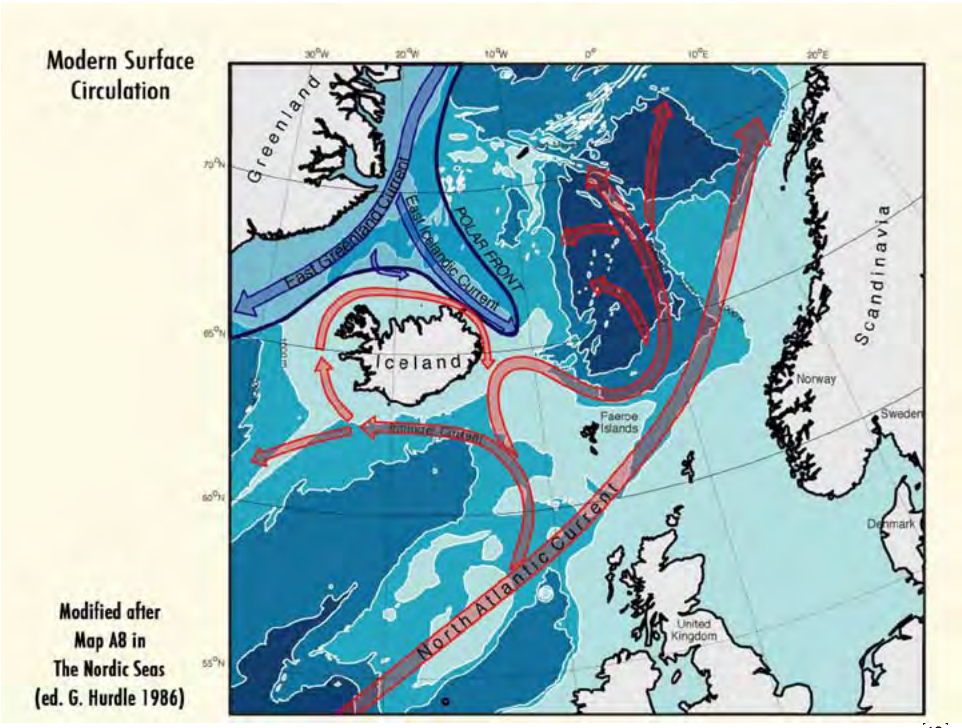


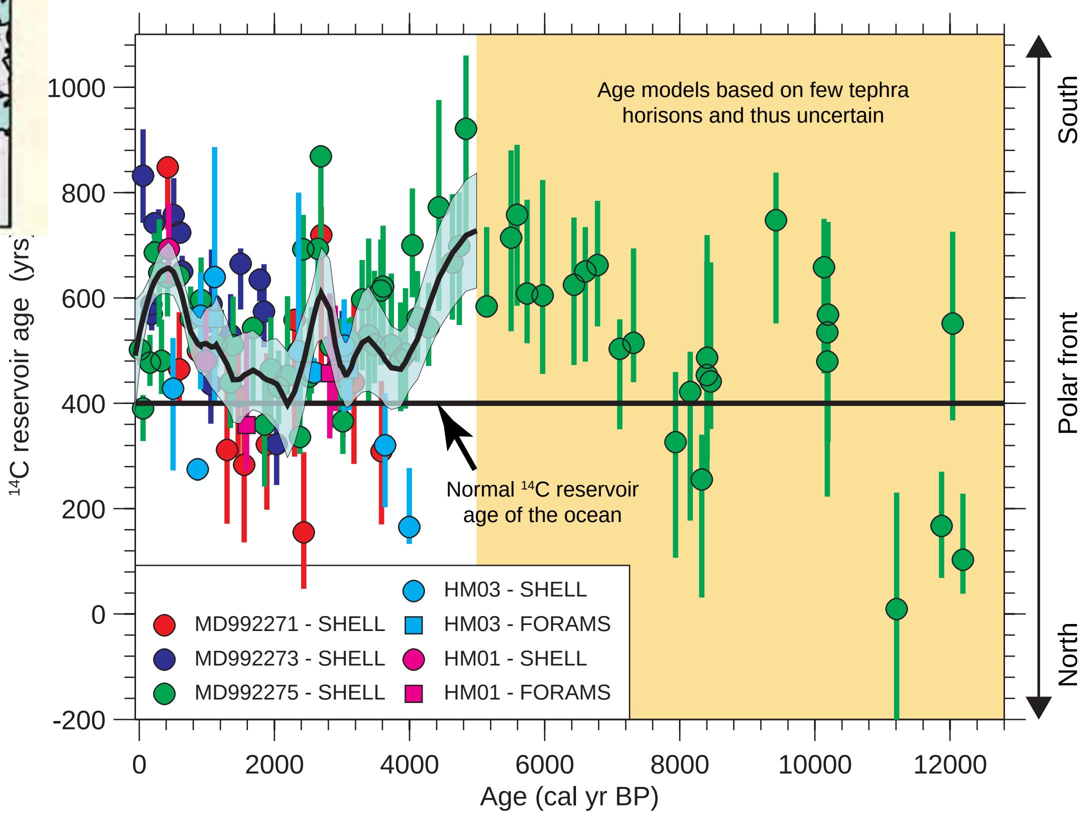
Figure 1 Schematic diagram of IntCal04 and Marine04 calibration data set construction. Tree-ring data extend from 0 to 12.4 cal kyr BP. Beyond the end of the tree rings, coral and foraminifera data are converted to the atmospheric equivalent by subtracting a site-specific reservoir correction *R*. These data are input into the random walk model (RWM) to produce IntCal04. Marine data from 10.5–26.0 cal kyr BP are normalized to the "global" ocean by subtracting ΔR, the regional difference from the model ocean reservoir age of 405 yr. The "global" marine data and the output from the box diffusion model (see main text) are used with the RWM to provide our estimate of the global marine calibration curve Marine04.



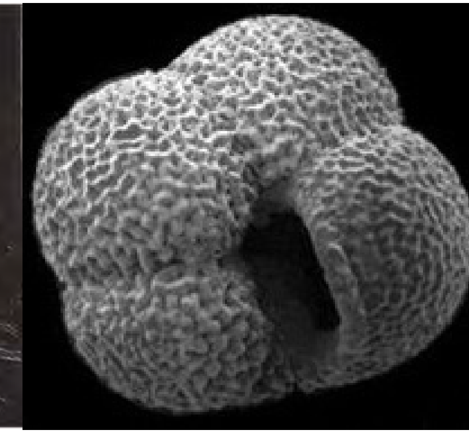
Reimer et al, Radiocarbon 2009

Holocene ^{14}C variability linked to changes in position of polar front





How do we it?



$$Ca^{2+} + CO_3^{2-} \Rightarrow CaCO_3$$

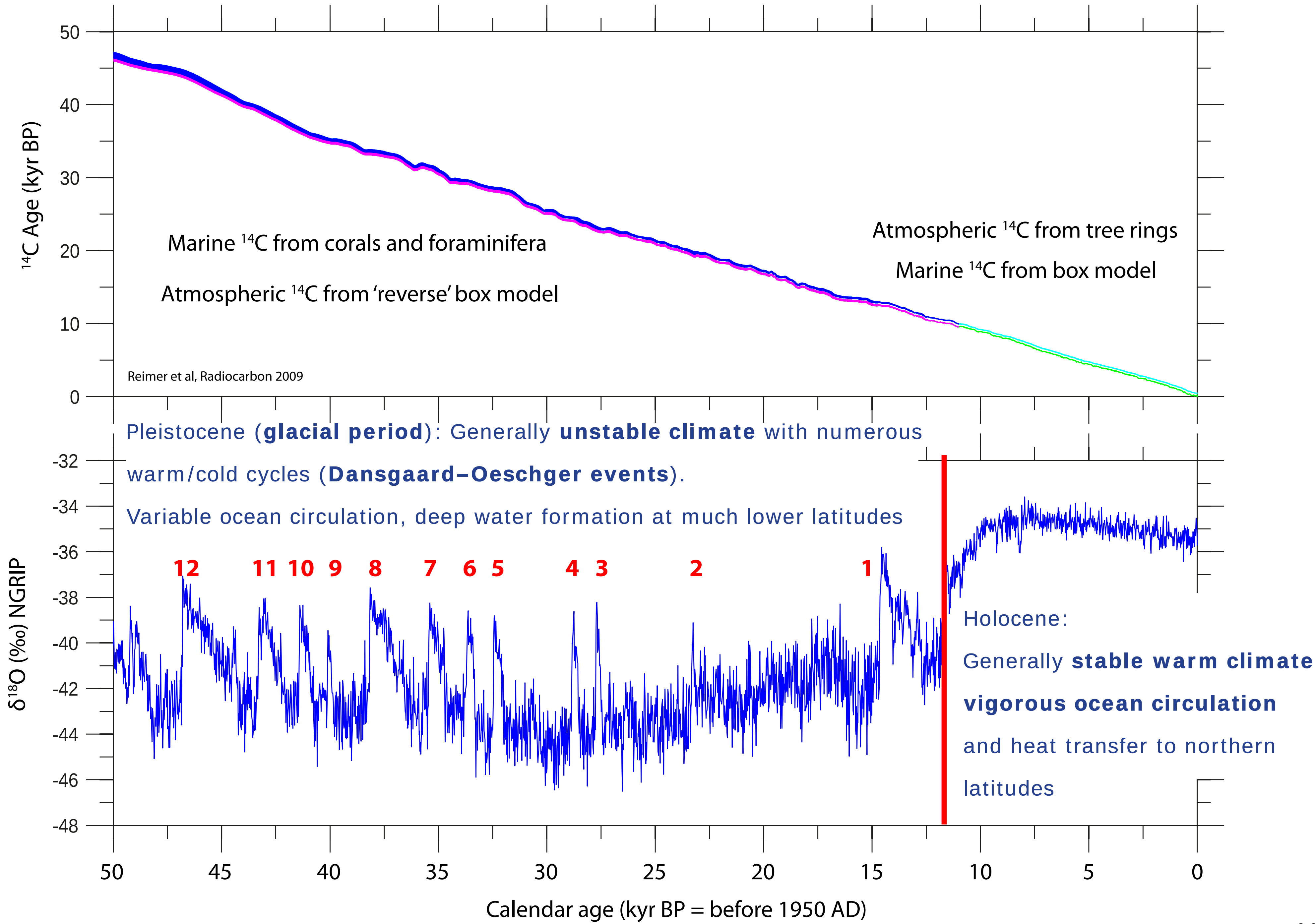
Shells and foraminifera calcify in equilibrium with dissolve ocean bicarbonate

proxy for ocean ^{14}C (**age**), $\delta^{13}C$ (**production / stratification**) and $\delta^{18}O$ (**salinity / temperature**)

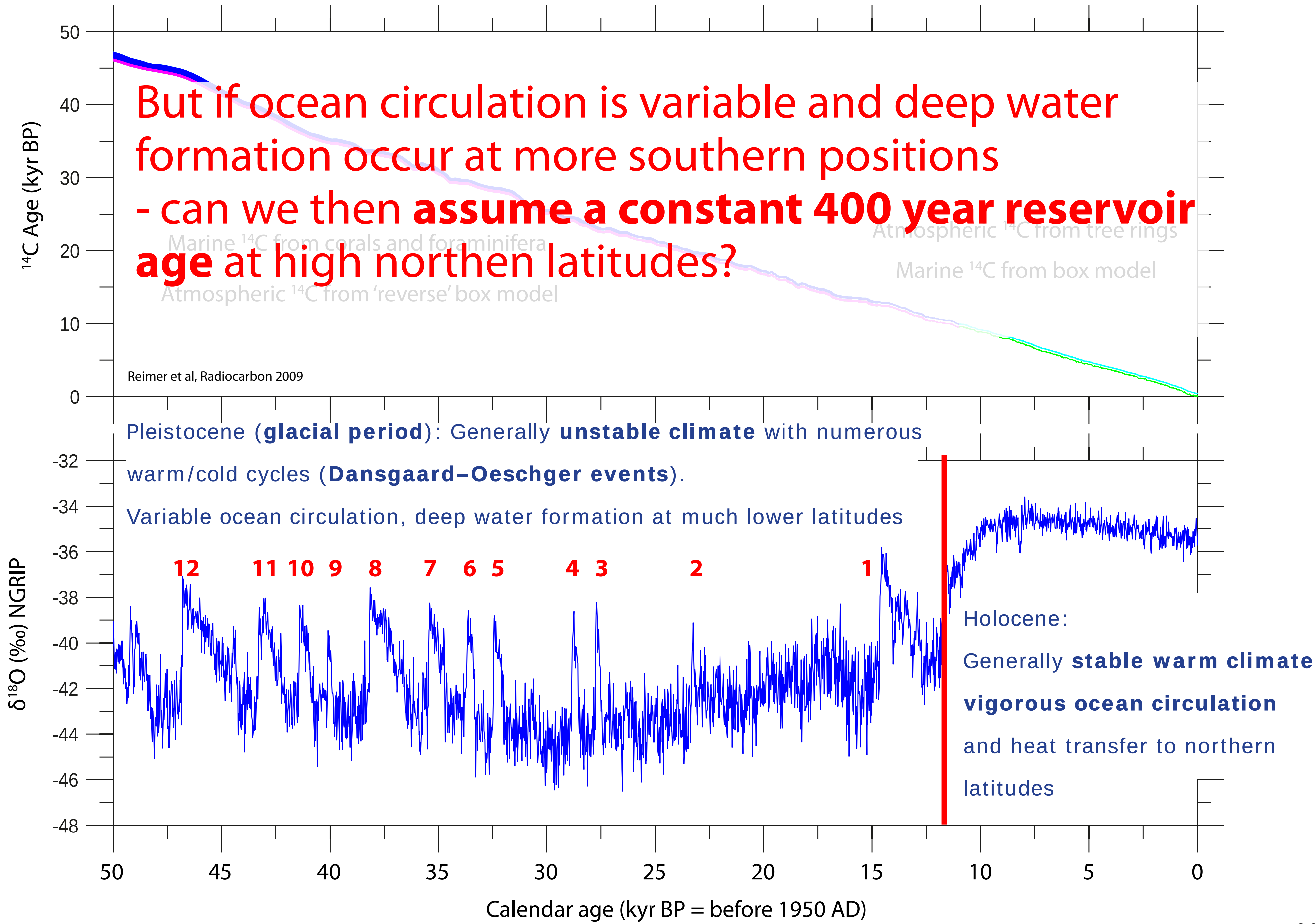
Planktic species provides information on **surface ocean** conditions (*100 - 200 metres*)

Benthic species provides information on **deep ocean** conditions (*few hundreds meters to kilom-eters*)

Going beyond the Holocene (last 11k)



Going beyond the Holocene (last 11k)



But if ocean circulation is variable and deep water formation occur at more southern positions - can we then **assume a constant 400 year reservoir age** at high northen latitudes?

Pleistocene (**glacial period**): Generally **unstable climate** with numerous warm/cold cycles (**Dansgaard–Oeschger events**).

Variable ocean circulation, deep water formation at much lower latitudes

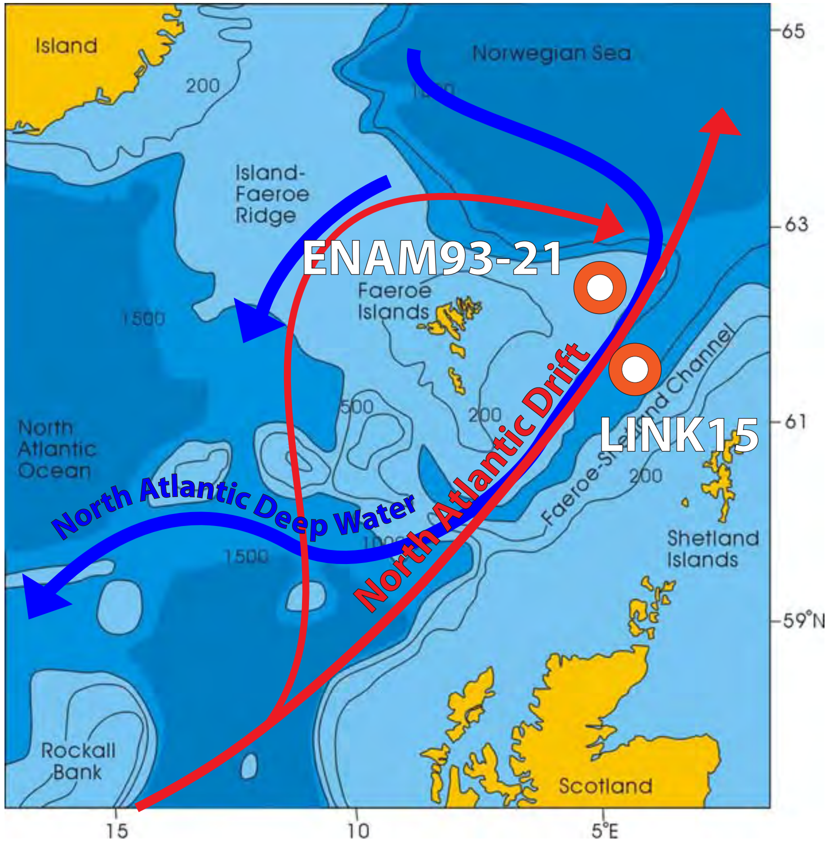
Holocene:

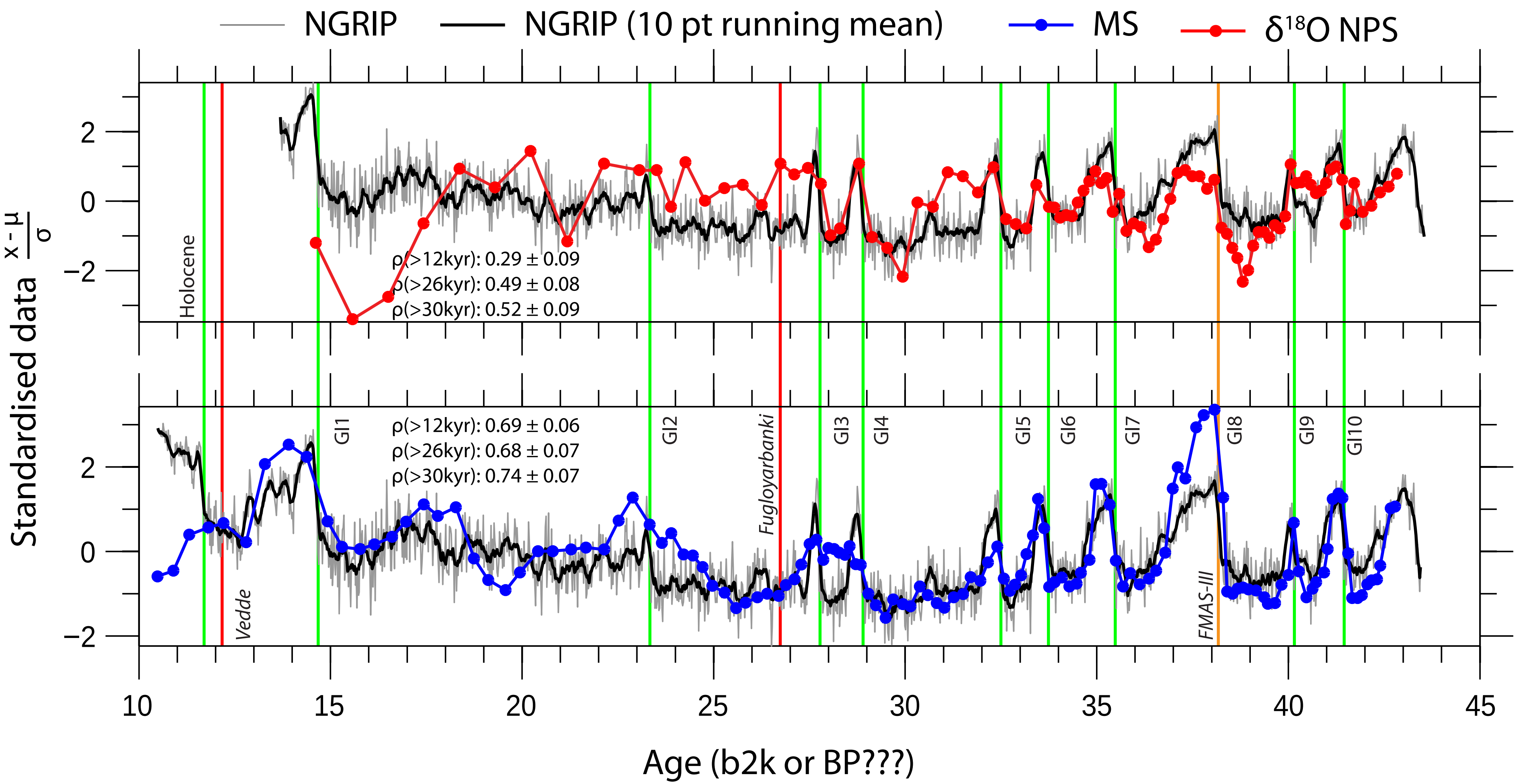
Generally **stable warm climate**

vigorous ocean circulation

and heat transfer to northern latitudes

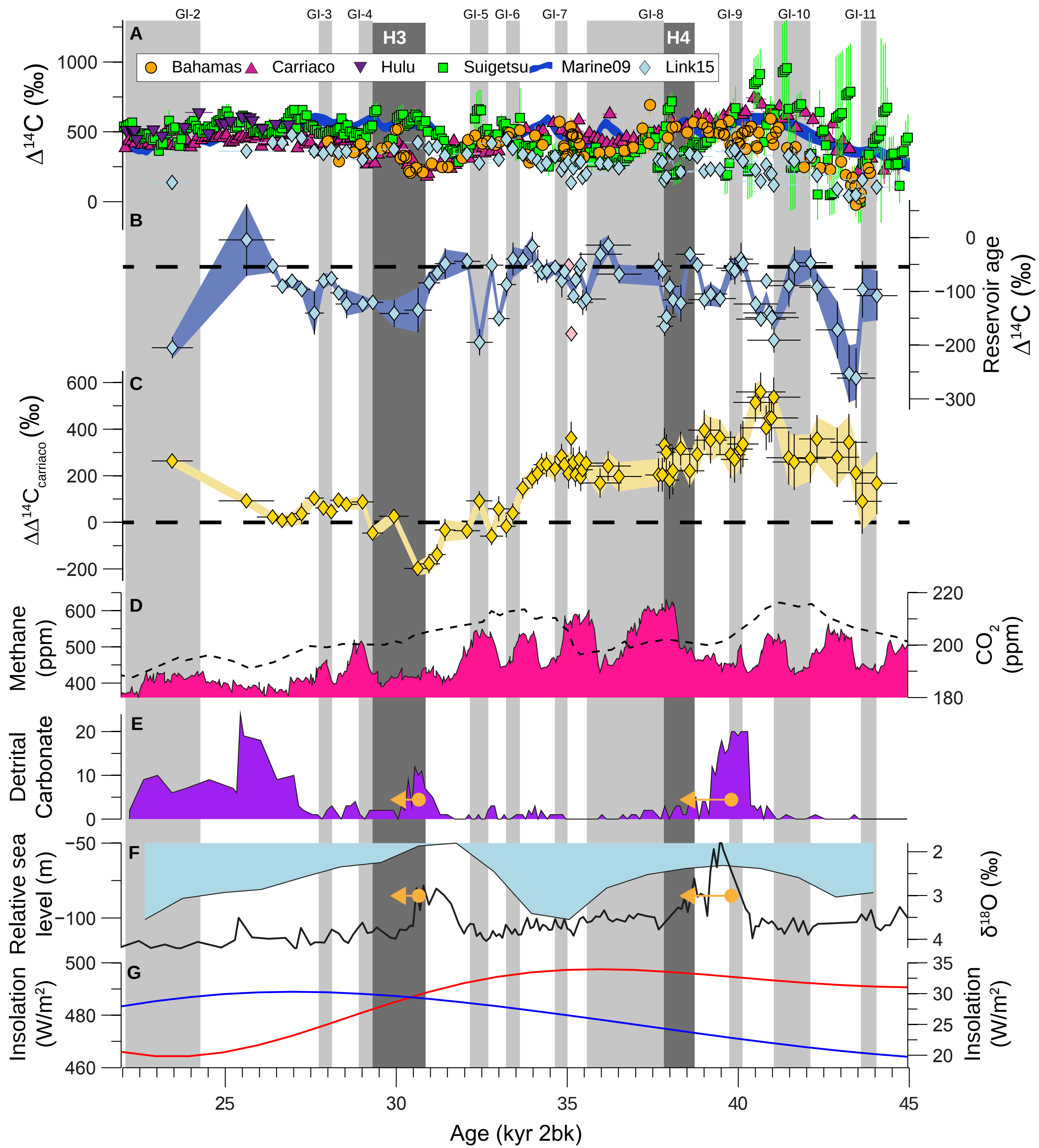
LINK15 - reservoir age variability 30 - 40 cal kyr BP



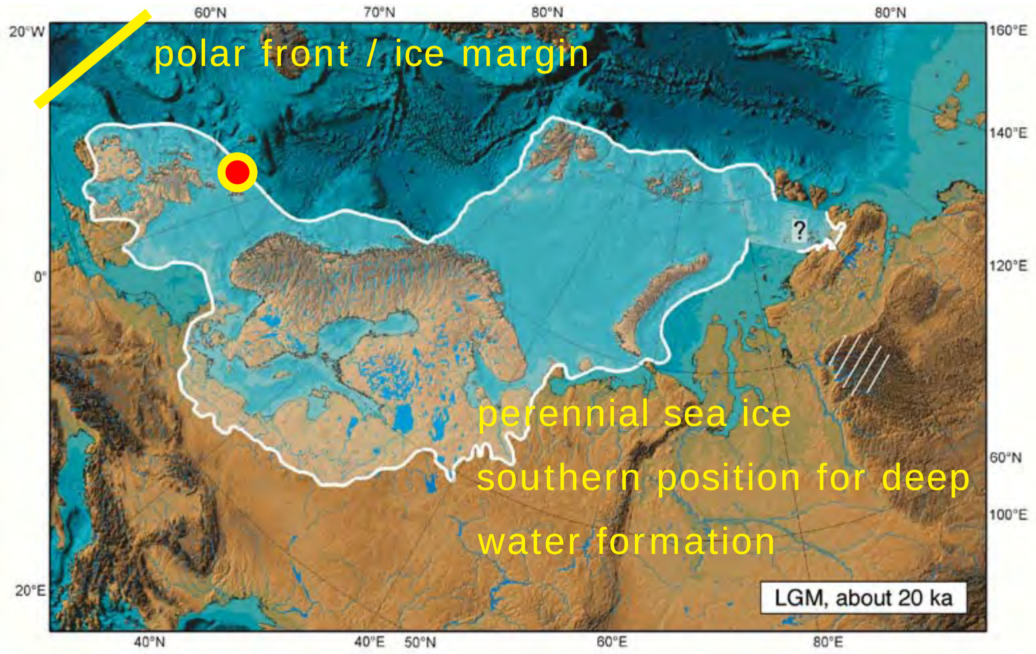


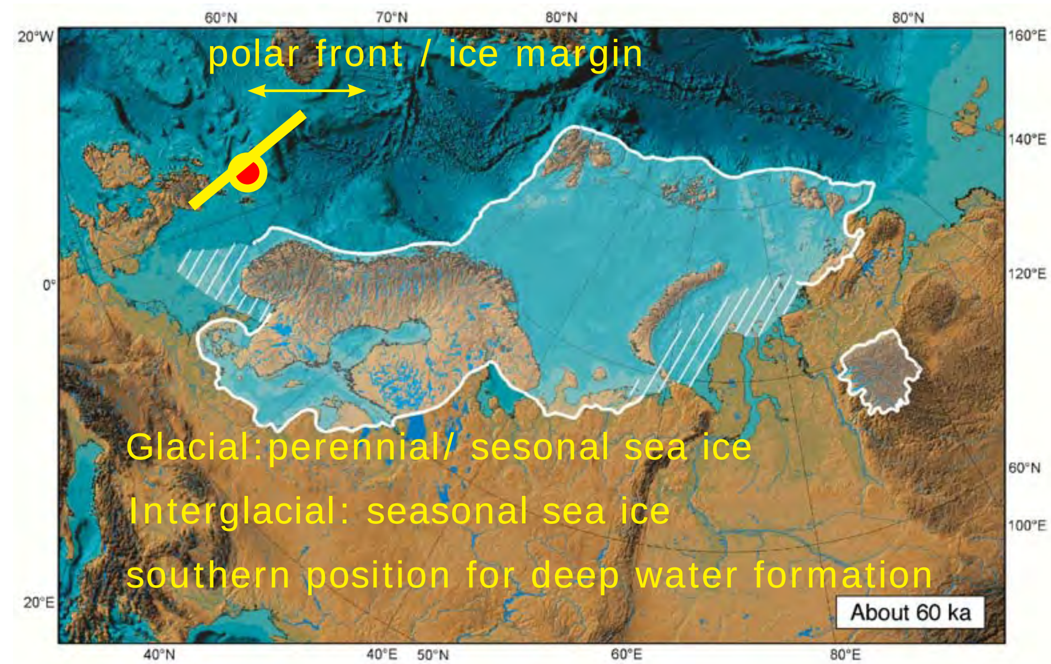
NGRIP
NGRIP (10 pt running mean)
MS
δ18O NPS
Standardised data $\frac{x - \mu}{\sigma}$
Holocene
ρ(>12kyr): 0.29 ± 0.09
ρ(>26kyr): 0.49 ± 0.08
ρ(>30kyr): 0.52 ± 0.09
ρ(>12kyr): 0.69 ± 0.06
ρ(>26kyr): 0.68 ± 0.07
ρ(>30kyr): 0.74 ± 0.07
GI1
GI2
Fugloyarbanki
GI3
GI4
GI5
GI6
GI7
GI8
GI9
GI10
Vedde
FMAS-III
Age (b2k or BP???)

Significant change in R (up to R=2000 ^{14}C years)

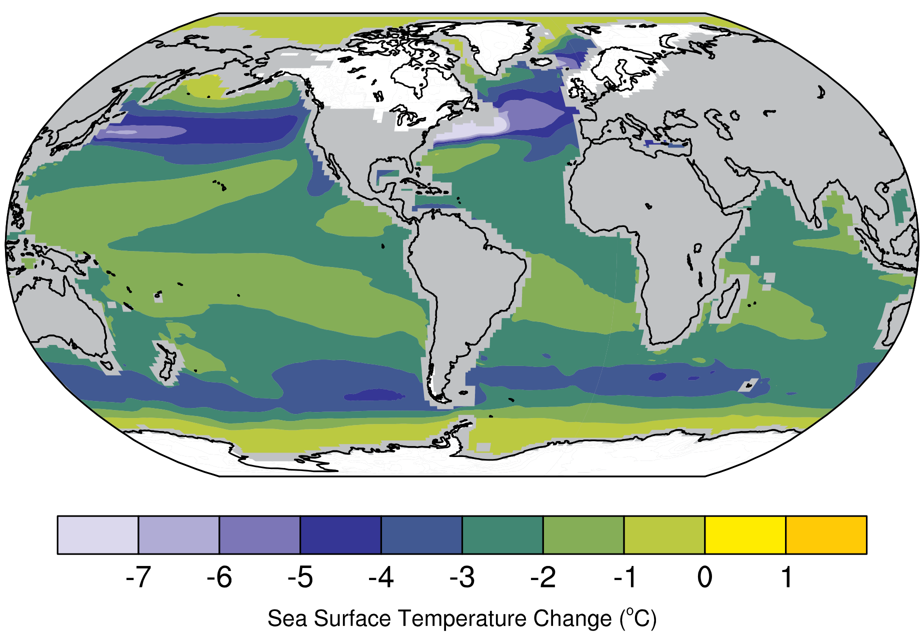


Why the difference at LGM?





QRS 23 2004, APEX/ QUEENS



IPCC fig 6.7 (modified)

Position of the polar front associated with sea ice coverage


Tak for Jeres opmærksomhed