Sm-Nd method

^{147}Sm decays to ^{143}Nd by α-decay,
decay process: $^{147}\text{Sm} \rightarrow \alpha + {}^{143}\text{Nd}$

half-life =106 billion years!!

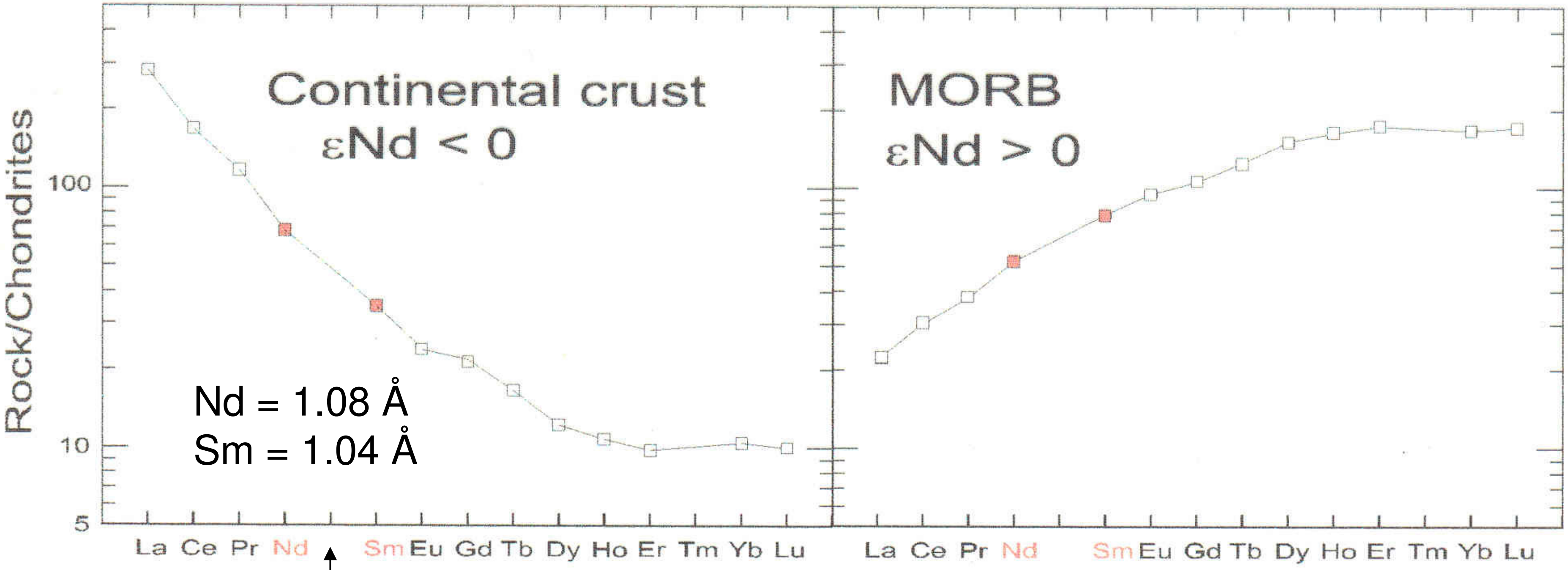
^{147}Sm=15%
4 other isotopes

^{143}Nd=12.2%
6 other isotopes

De Paolo: *Neodymium Isotope Geochemistry: an introduction*
Springer-Verlag 187pp.

A. Dickin: *Nd in the oceans*:
http://www.onafarawayday.com/Radiogenic/Ch4/Ch4-5.htm

Sm-Nd method

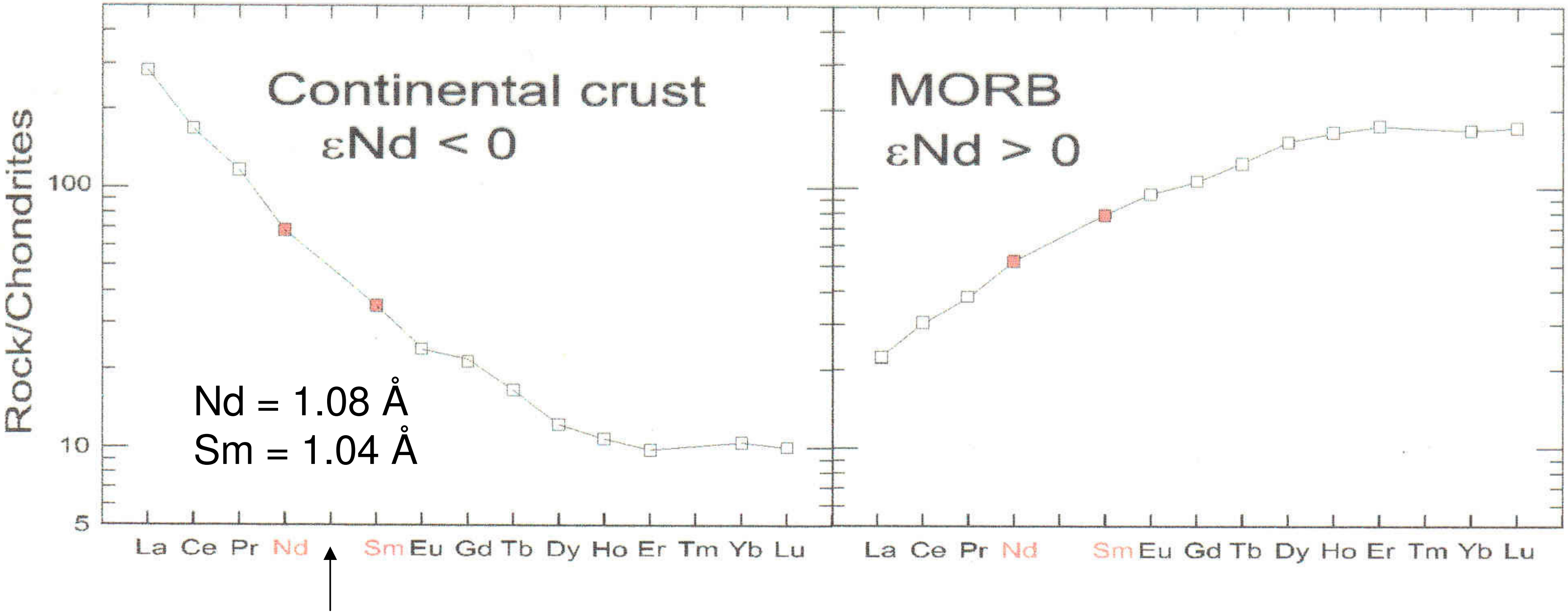


Nd = 1.08 Å
Sm = 1.04 Å

Promethium - unstable
(otherwise purification of Sm and Nd would have been more difficult)

Sm and Nd are rare earth elements
REE have 3+ charge, ionic radii decrease with increasing Z
all REE are “incompatible” (they prefer the melt), but light REE are more incompatible

Sm-Nd method

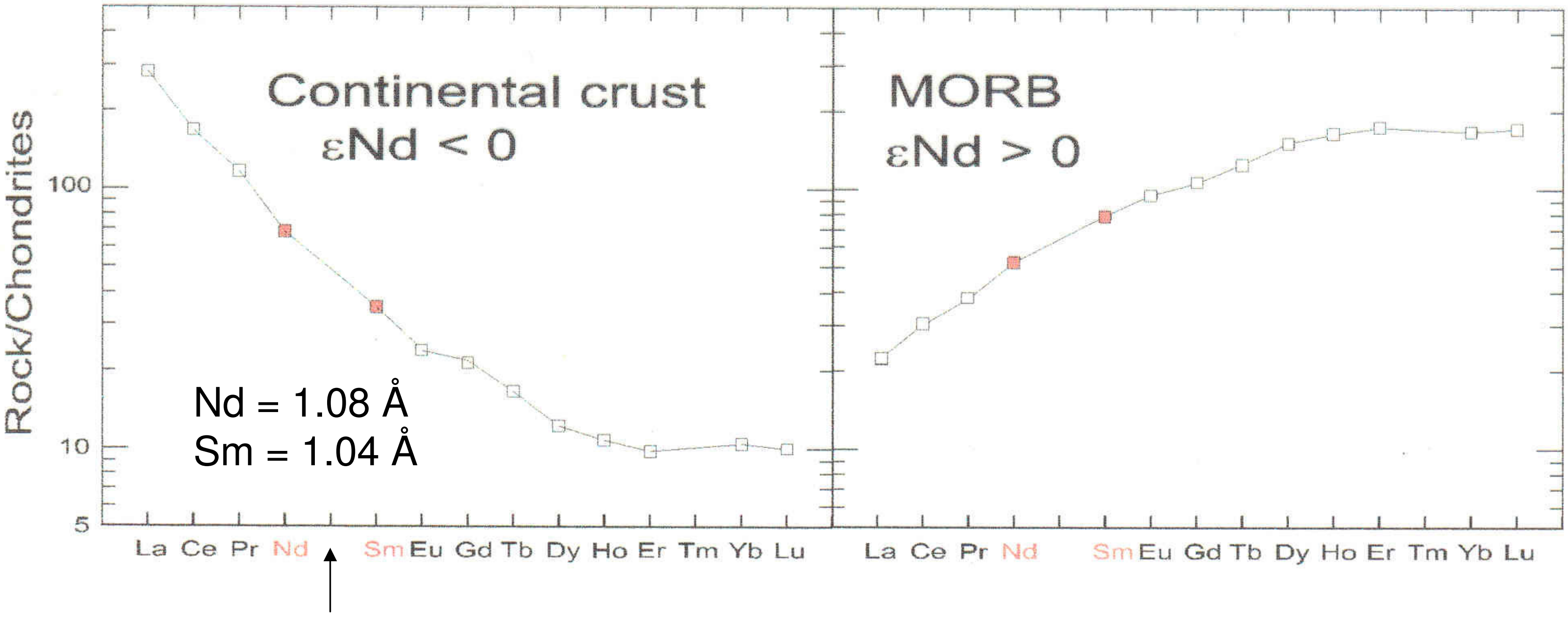


Nd = 1.08 Å
Sm = 1.04 Å

Promethium - unstable
(otherwise purification of Sm and Nd would have been more difficult)

Nd is slightly more incompatible during mantle melting than Sm
Sm parent will be enriched in “depleted” sources (i.e. MORB)
(opposite to Rb/Sr system, where parent enriched in continents)

Sm-Nd method



Promethium - unstable
(otherwise purification of Sm and Nd would have been more difficult)

High **Sm**/**Nd** rocks produce more ^{143}Nd
Low **Sm**/**Nd** rocks produce less ^{143}Nd
Although the difference is small, ^{143}Nd/^{144}Nd increases faster in the mantle than in the crust. Thus, mantle-derived rocks have higher $(^{143}\mathrm{Nd}/^{144}\mathrm{Nd})_0$ than crustal rocks.

Sm-Nd method

Sm/Nd ratios for terrestrial materials:

MORB	0.32
cont. crust	~0.2
seawater	0.211
shale	0.209
garnet	0.539

Sm-Nd method

Based on the decay:

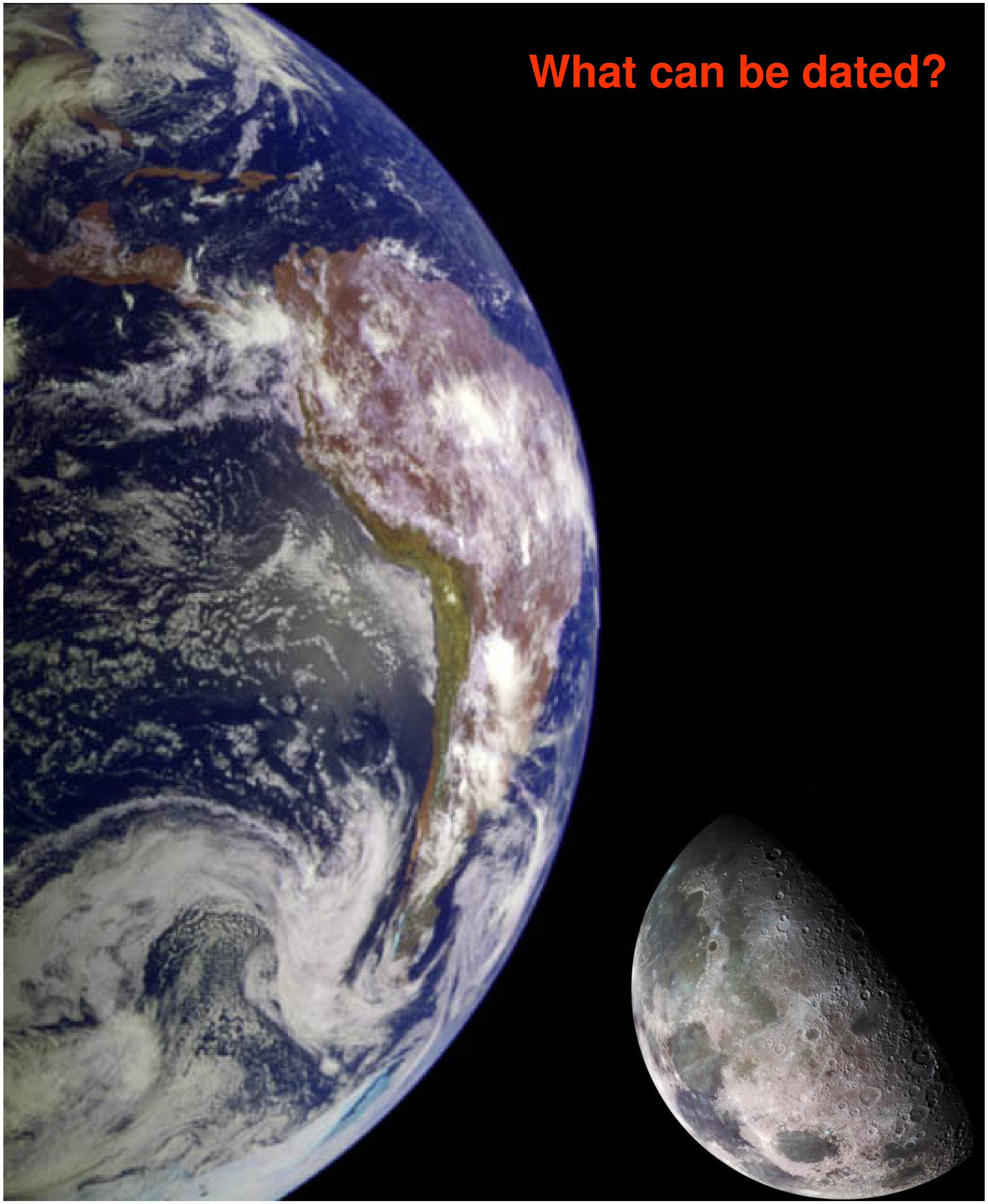
$^{147}Sm \rightarrow {}^{143}Nd$ $T_{1/2} = 106$ Ga ($\lambda = 6.54 \times 10^{-12} y^{-1}$)

$$\boxed{\frac{^{143}Nd}{^{144}Nd} = \left(\frac{^{143}Nd}{^{144}Nd}\right)_0 + \frac{^{147}Sm}{^{144}Nd}(e^{\lambda t} - 1)}$$

virtually same equation as for Rb/Sr system

Sm-Nd method is useful in Ca-bearing rocks because REE substitute for Ca and garnet (high Sm/Nd ratio)

Sm-Nd method relatively resistant to alteration

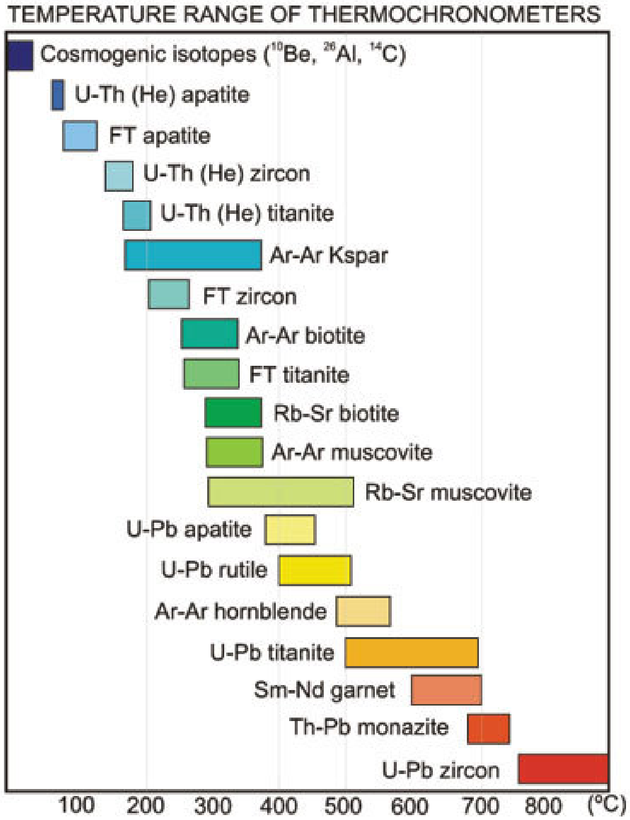


What can be dated?

Meteorites, i.e. basaltic achondrites

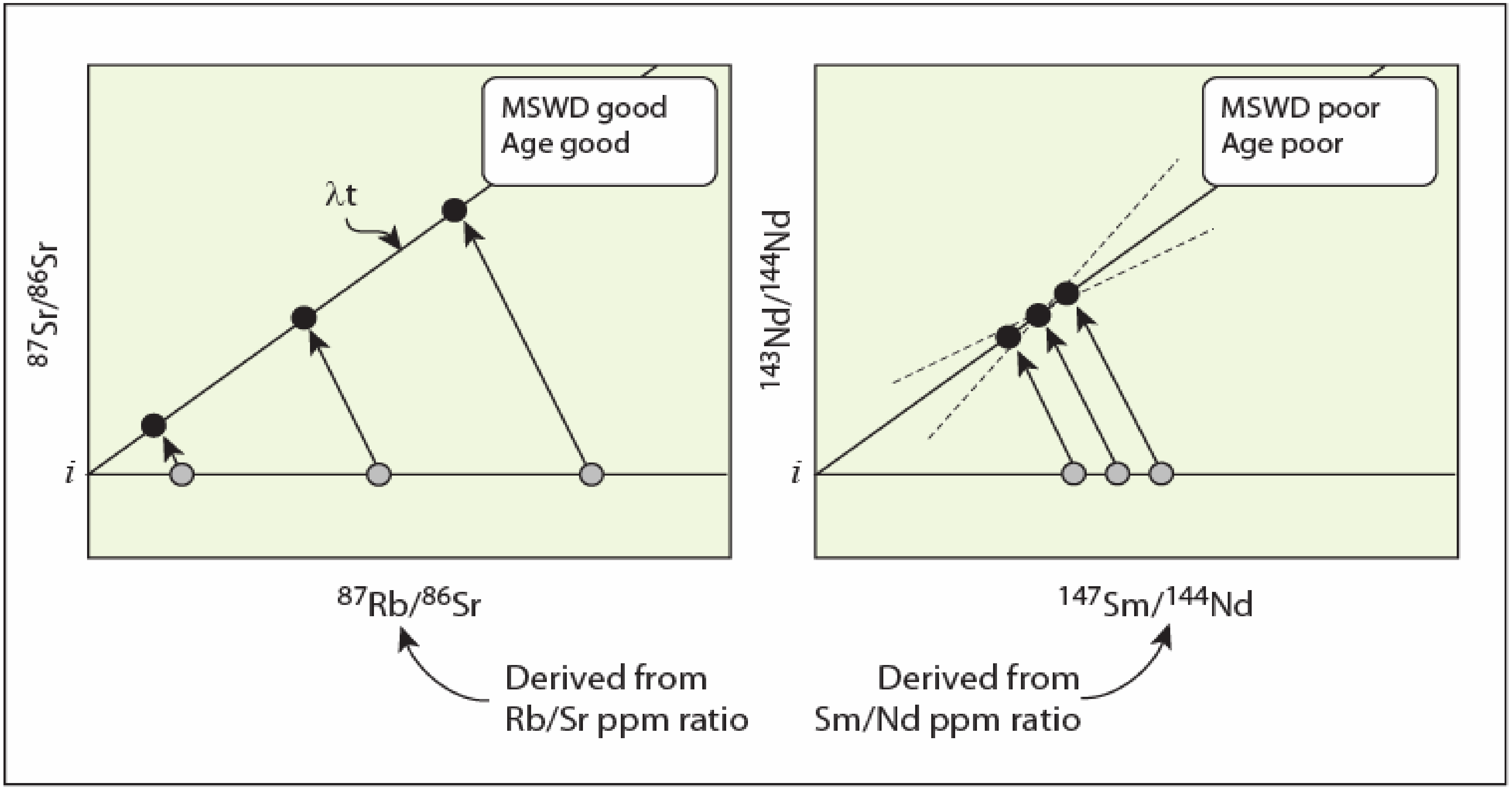
Very old rocks from moon and Earth

Garnet-bearing metamorphic rocks



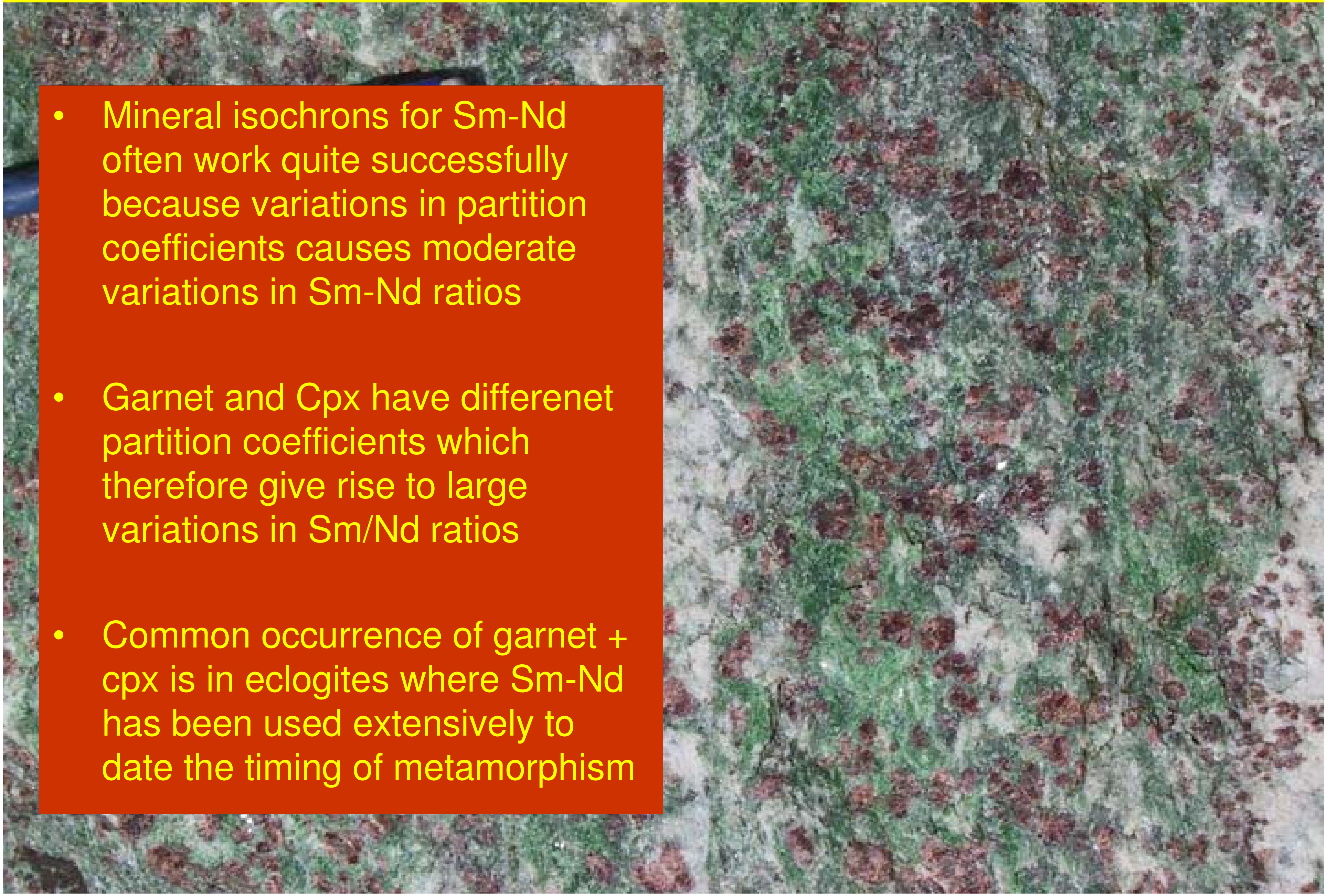
TEMPERATURE RANGE OF THERMOCHRONOMETERS

Sm-Nd method



Large variations in Sm/Nd ratios in natural rocks are rare
Therefore difficulty in obtaining a wide range of Sm/Nd ratios from a single rock body
Combined with greater technical demands of Nd-isotope work has limited applications

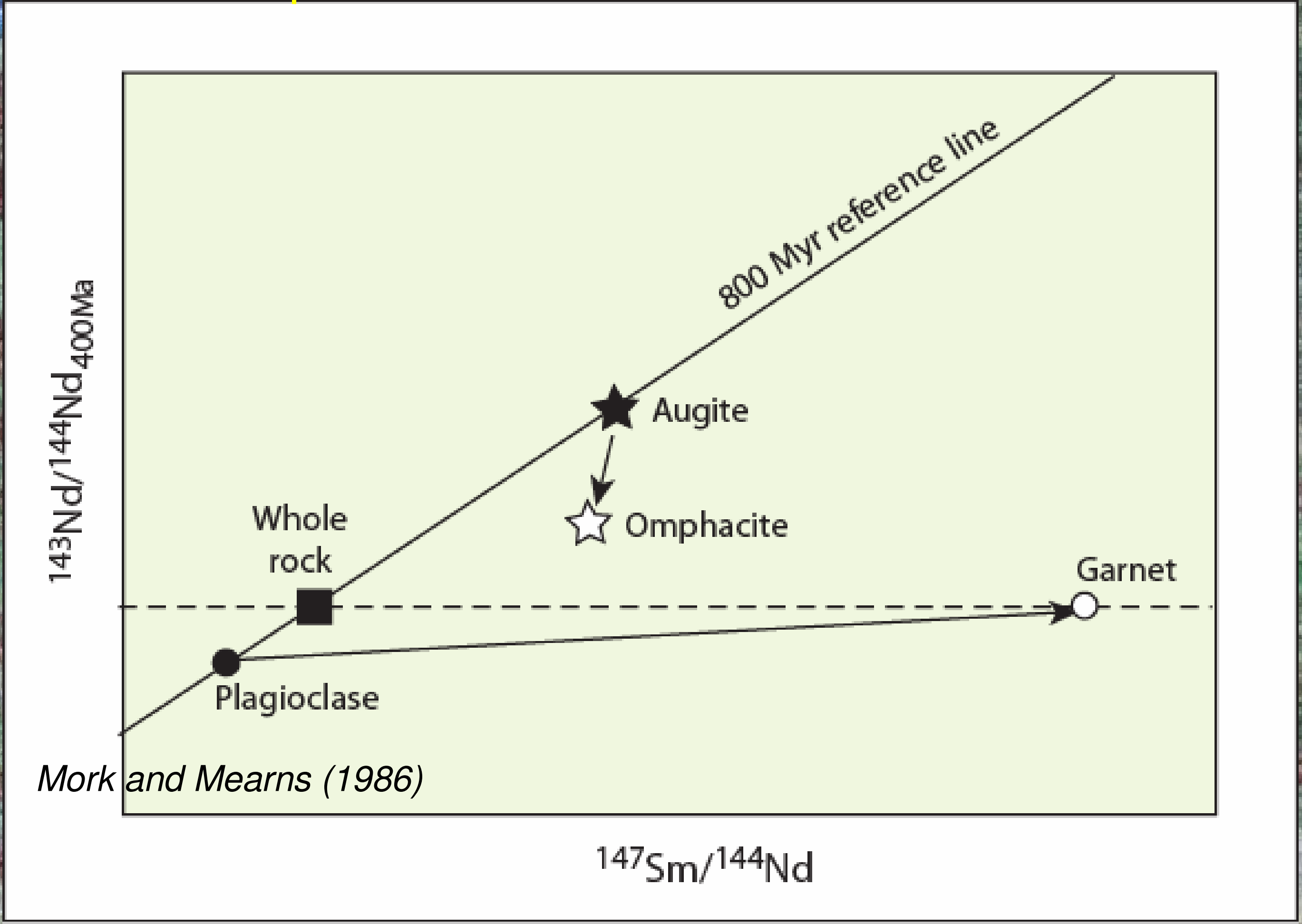
Applications



- Mineral isochrons for Sm-Nd often work quite successfully because variations in partition coefficients causes moderate variations in Sm-Nd ratios
- Garnet and Cpx have differenet partition coefficients which therefore give rise to large variations in Sm/Nd ratios
- Common occurrence of garnet + cpx is in eclogites where Sm-Nd has been used extensively to date the timing of metamorphism

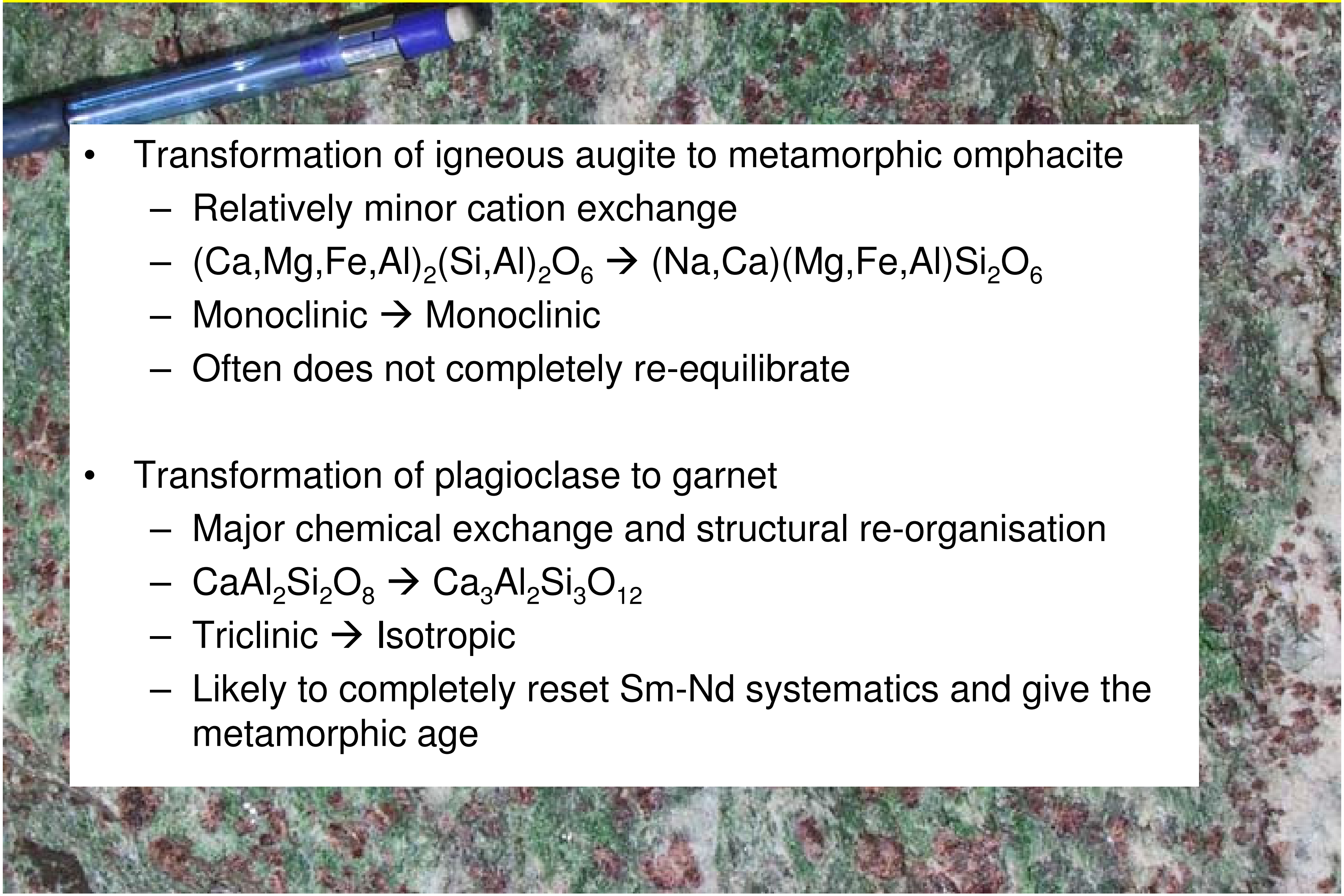
Sm-Nd remobilisation and re-equilibration

Sm-Nd as REE are relatively immobile and may therefore not fully re-equilibrate during metamorphism



Mork and Mearns (1986)

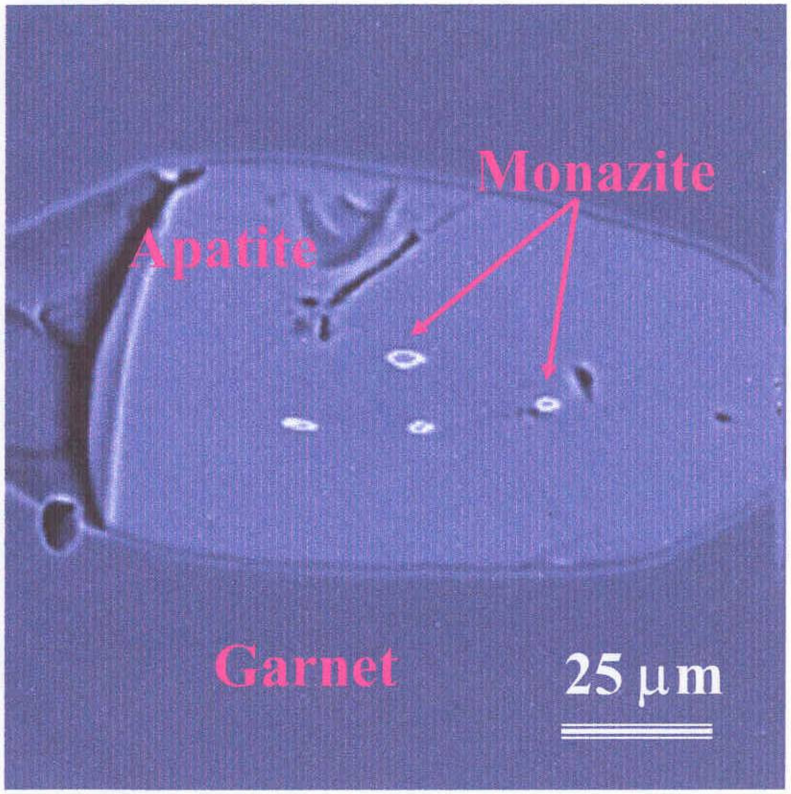
Mineral transformation

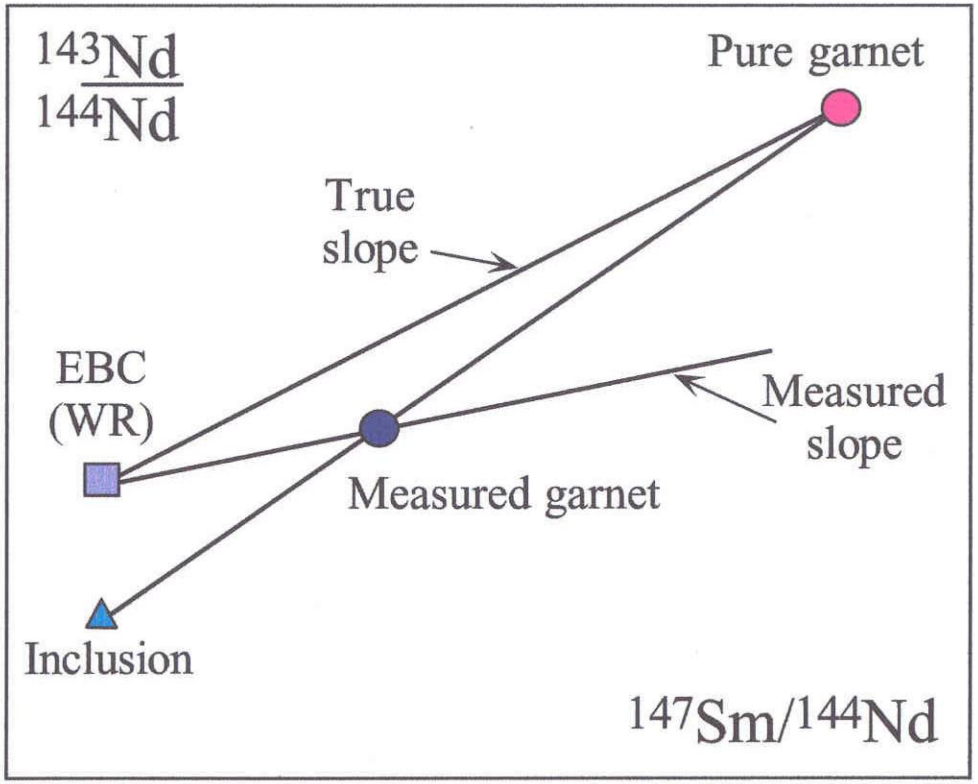


- Transformation of igneous augite to metamorphic omphacite
  - Relatively minor cation exchange
  - $(Ca,Mg,Fe,Al)_2(Si,Al)_2O_6 \rightarrow (Na,Ca)(Mg,Fe,Al)Si_2O_6$
  - Monoclinic → Monoclinic
  - Often does not completely re-equilibrate

- Transformation of plagioclase to garnet
  - Major chemical exchange and structural re-organisation
  - $CaAl_2Si_2O_8 \rightarrow Ca_3Al_2Si_3O_{12}$
  - Triclinic → Isotropic
  - Likely to completely reset Sm-Nd systematics and give the metamorphic age

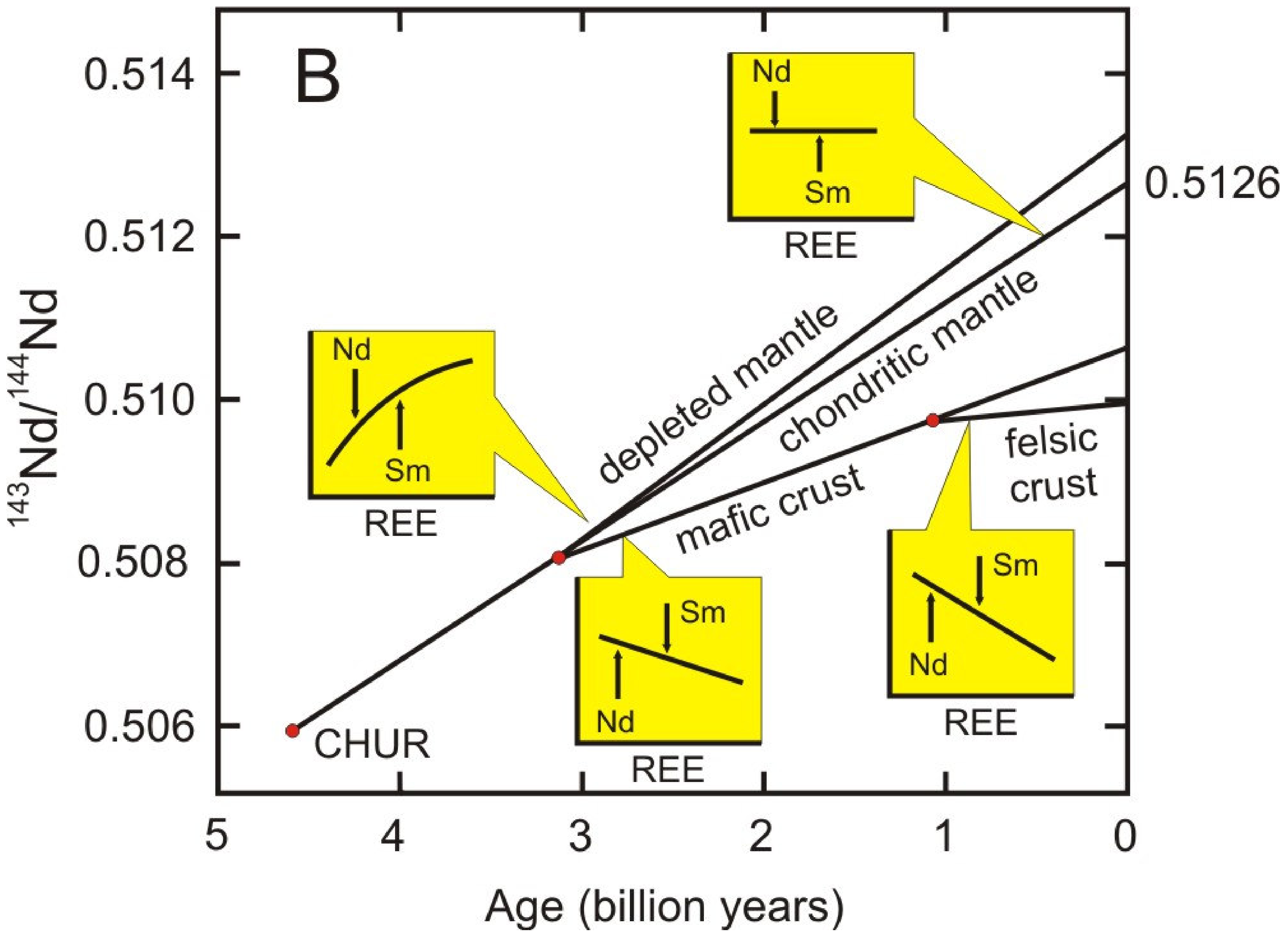
Effect of LREE-rich inclusions on garnet dating



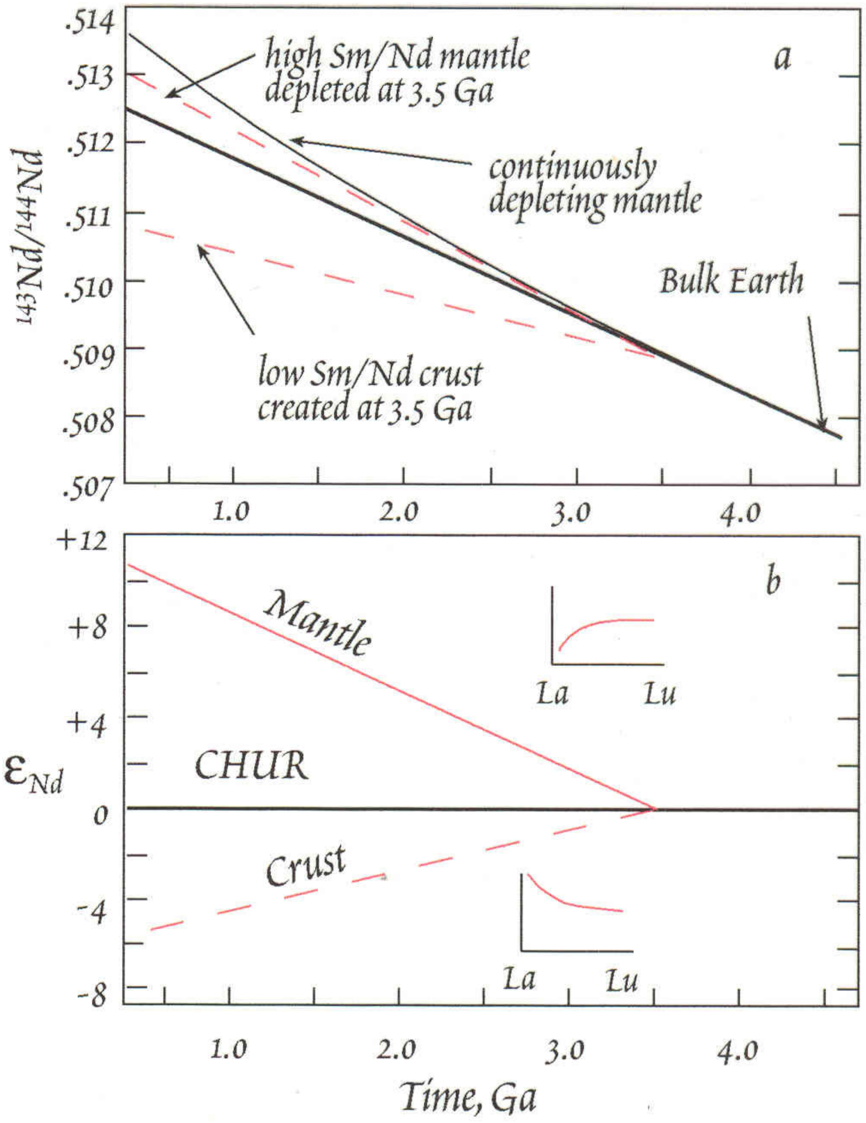


Price et al. (2000) Chem.Geol. 168

The evolution of Nd isotopes with time in the mantle, the continental crust and the bulk Earth (CHUR)



The evolution of Nd isotopes with time in the mantle, the continental crust and the bulk Earth (CHUR)



$$\varepsilon_{Nd,CHUR} = \left[\frac{\left({}^{143}Nd/{}^{144}Nd\right)_{sample}}{\left({}^{143}Nd/{}^{144}Nd\right)_{CHUR}} - 1\right] \times 10^{4}$$

Epsilon notation

$$\varepsilon_{Nd,CHUR} = \left[\frac{\left({}^{143}Nd \big/ {}^{144}Nd \right)_{sample}}{\left({}^{143}Nd \big/ {}^{144}Nd \right)_{CHUR}} - 1 \right] \times 10^{4}$$

The mantle has a higher ^{147}Sm/^{144}Nd ratio than CHUR, so the mantle has been evolving values of ^{143}Nd/^{144}Nd greater than CHUR with time, so **$\varepsilon_{Nd,CHUR} > 1$ for mantle**. The crust has a lower ^{147}Sm/^{144}Nd ratio than CHUR, so the crust has been evolving values of ^{143}Nd/^{144}Nd less than CHUR with time, so **$\varepsilon_{Nd,CHUR} < 1$ for crust**.

Nd model ages

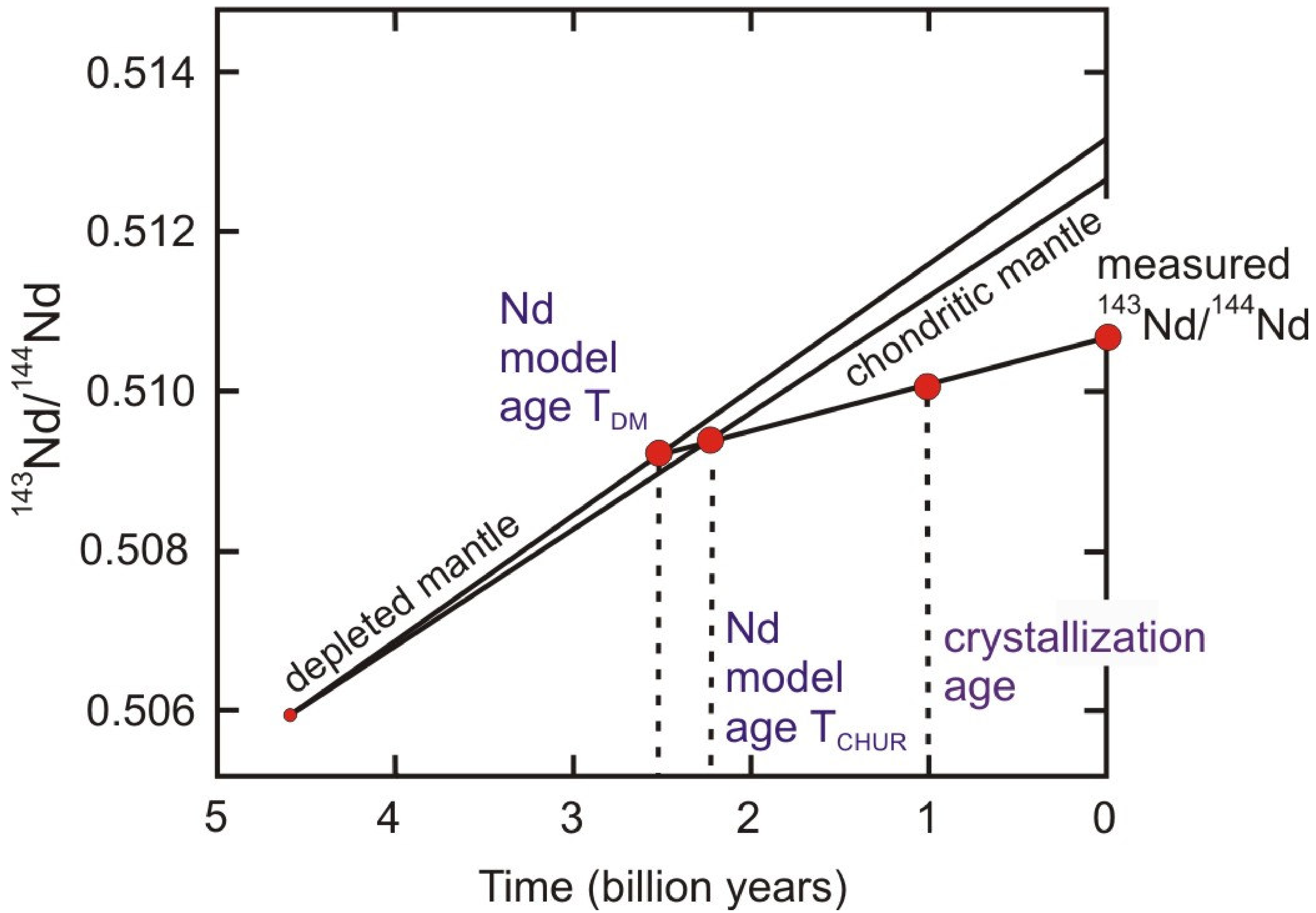
Model age - a measure of the length of time a sample has been separated from the mantle from which it was originally derived.

Model ages can be calculated for an individual rock from a single pair of Sm-Nd isotopic ratios.

The basis of all such model ages is an assumption about the isotopic composition of the mantle source region from which the samples were originally derived.

Care must be exercised in their interpretation.

Nd model ages



Nd model ages

$$\left(\frac{^{143}Nd}{^{144}Nd}\right)_{sample} = \left(\frac{^{143}Nd}{^{144}Nd}\right)_{initial} + \left(\frac{^{147}Sm}{^{144}Nd}\right)_{sample} \times (e^{\lambda t} - 1)$$

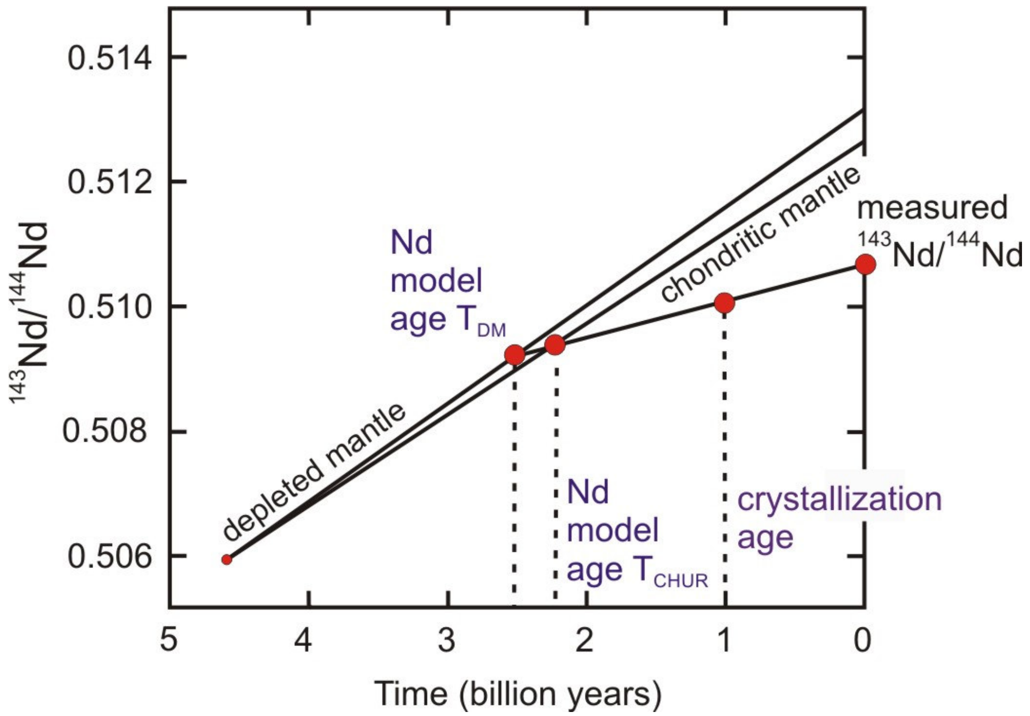
$$\left(\frac{^{143}Nd}{^{144}Nd}\right)_{CHUR} = \left(\frac{^{143}Nd}{^{144}Nd}\right)_{initial} + \left(\frac{^{147}Sm}{^{144}Nd}\right)_{CHUR} \times (e^{\lambda t} - 1)$$

$$\left(\frac{^{143}Nd}{^{144}Nd}\right)_{sample} - \left(\frac{^{143}Nd}{^{144}Nd}\right)_{CHUR} = \left[\left(\frac{^{147}Sm}{^{144}Nd}\right)_{sample} - \left(\frac{^{147}Sm}{^{144}Nd}\right)_{CHUR}\right] \times (e^{\lambda t} - 1)$$

$$(e^{\lambda t} - 1) = \left(\frac{(^{143}Nd/^{144}Nd)_{sample} - (^{143}Nd/^{144}Nd)_{CHUR}}{(^{147}Sm/^{144}Nd)_{sample} - (^{147}Sm/^{144}Nd)_{CHUR}}\right)$$

$$T_{CHUR} = \frac{1}{\lambda} \ln\left(\frac{(^{143}Nd/^{144}Nd)_{sample} - (^{143}Nd/^{144}Nd)_{CHUR}}{(^{147}Sm/^{144}Nd)_{sample} - (^{147}Sm/^{144}Nd)_{CHUR}} + 1\right)$$

Nd model ages

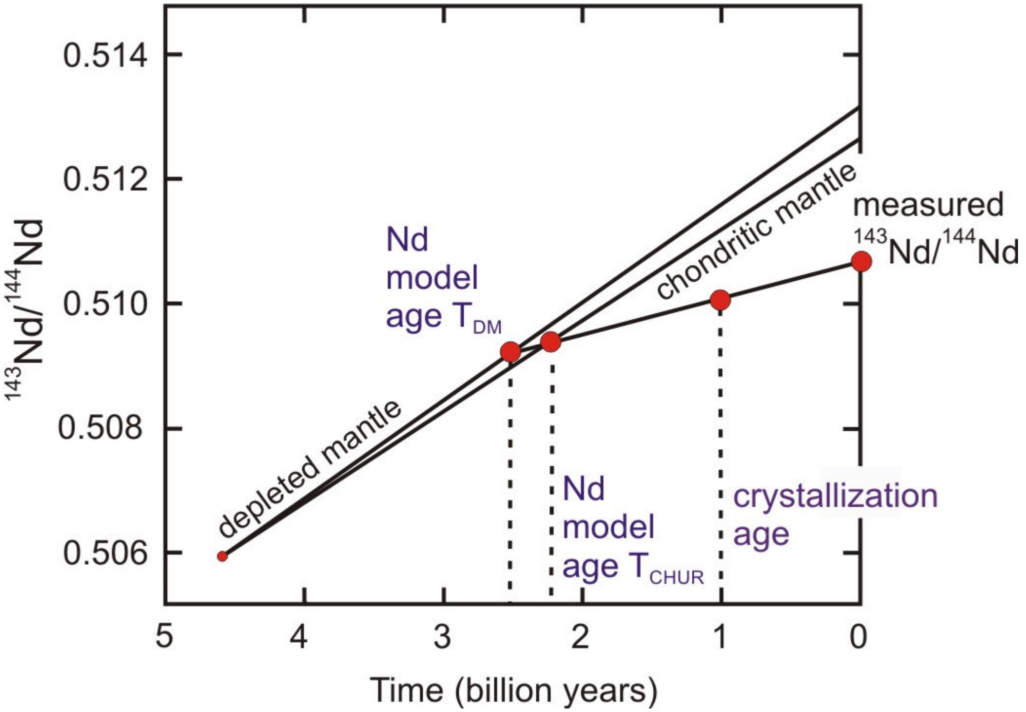


A model age calculated relative to CHUR or DM is the time in the past at which the sample suite separated from the given mantle reservoir and acquired a different Sm/Nd ratio.

$$T_{CHUR}^{Nd} = \frac{1}{\lambda} \ln\left[\frac{(^{143}Nd/^{144}Nd)_{sample,today} - (^{143}Nd/^{144}Nd)_{CHUR,today}}{(^{147}Sm/^{144}Nd)_{sample,today} - (^{147}Sm/^{144}Nd)_{CHUR,today}} + 1 \right]$$

$$T_{DM}^{Nd} = \frac{1}{\lambda} \ln\left[\frac{(^{143}Nd/^{144}Nd)_{sample,today} - (^{143}Nd/^{144}Nd)_{DM,today}}{(^{147}Sm/^{144}Nd)_{sample,today} - (^{147}Sm/^{144}Nd)_{DM,today}} + 1 \right]$$

Nd model ages

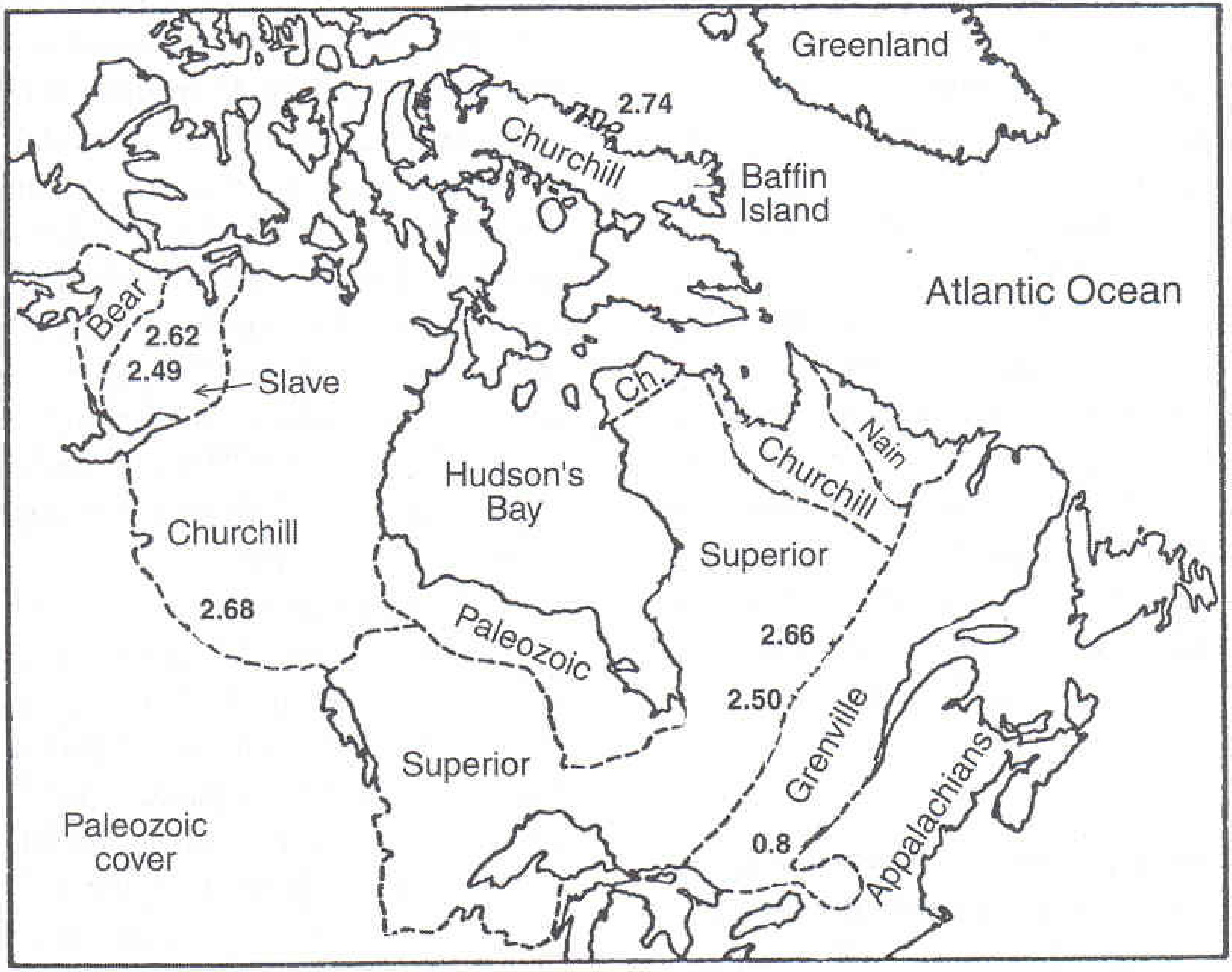


It is also the time at which the sample had the same $^{143}Nd/^{144}Nd$ ratio as CHUR or DM.

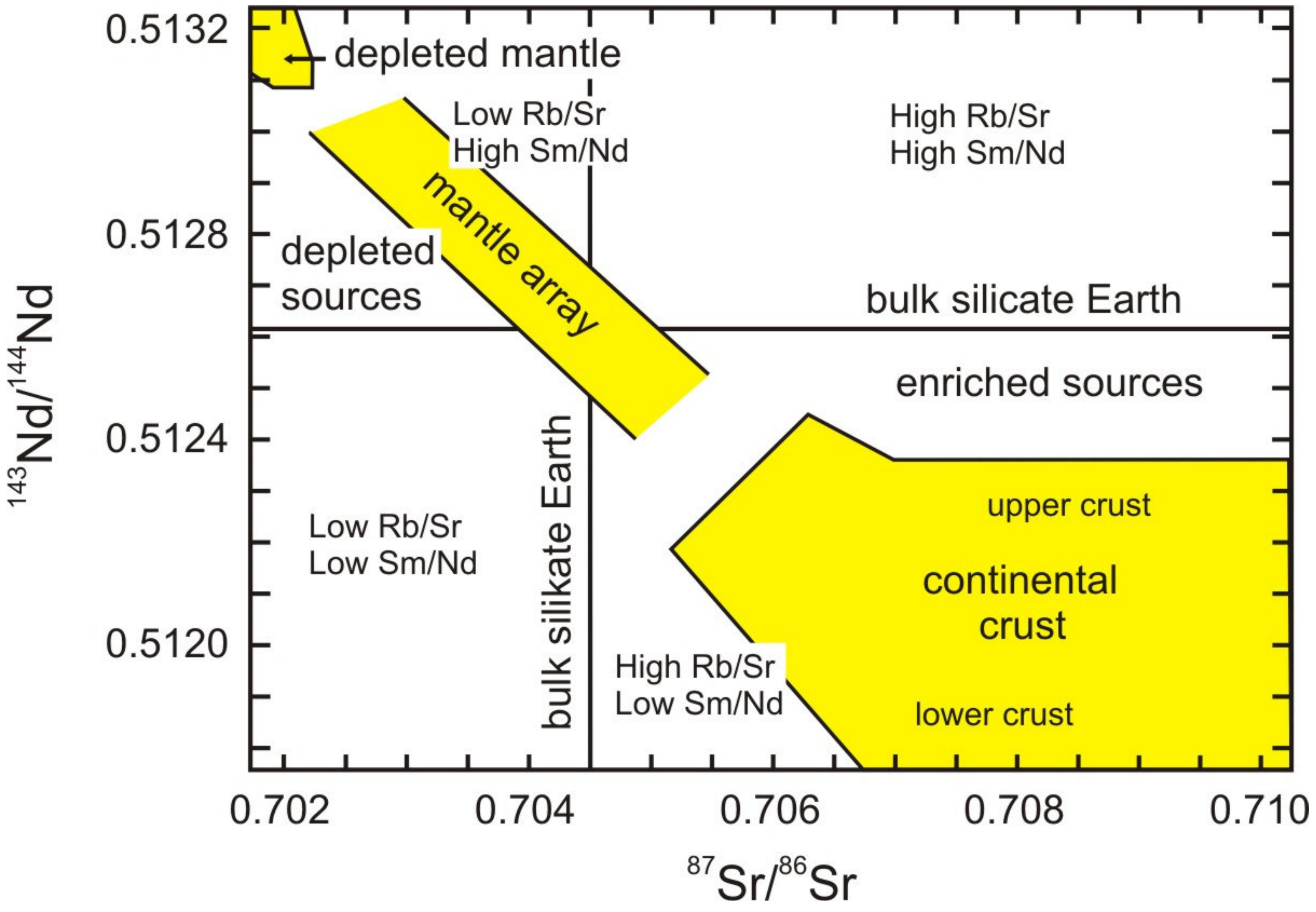
$$T_{CHUR}^{Nd} = \frac{1}{\lambda} \ln \left[\frac{(^{143}Nd/^{144}Nd)_{sample,today} - (^{143}Nd/^{144}Nd)_{CHUR,today}}{(^{147}Sm/^{144}Nd)_{sample,today} - (^{147}Sm/^{144}Nd)_{CHUR,today}} + 1 \right]$$

$$T_{DM}^{Nd} = \frac{1}{\lambda} \ln \left[\frac{(^{143}Nd/^{144}Nd)_{sample,today} - (^{143}Nd/^{144}Nd)_{DM,today}}{(^{147}Sm/^{144}Nd)_{sample,today} - (^{147}Sm/^{144}Nd)_{DM,today}} + 1 \right]$$

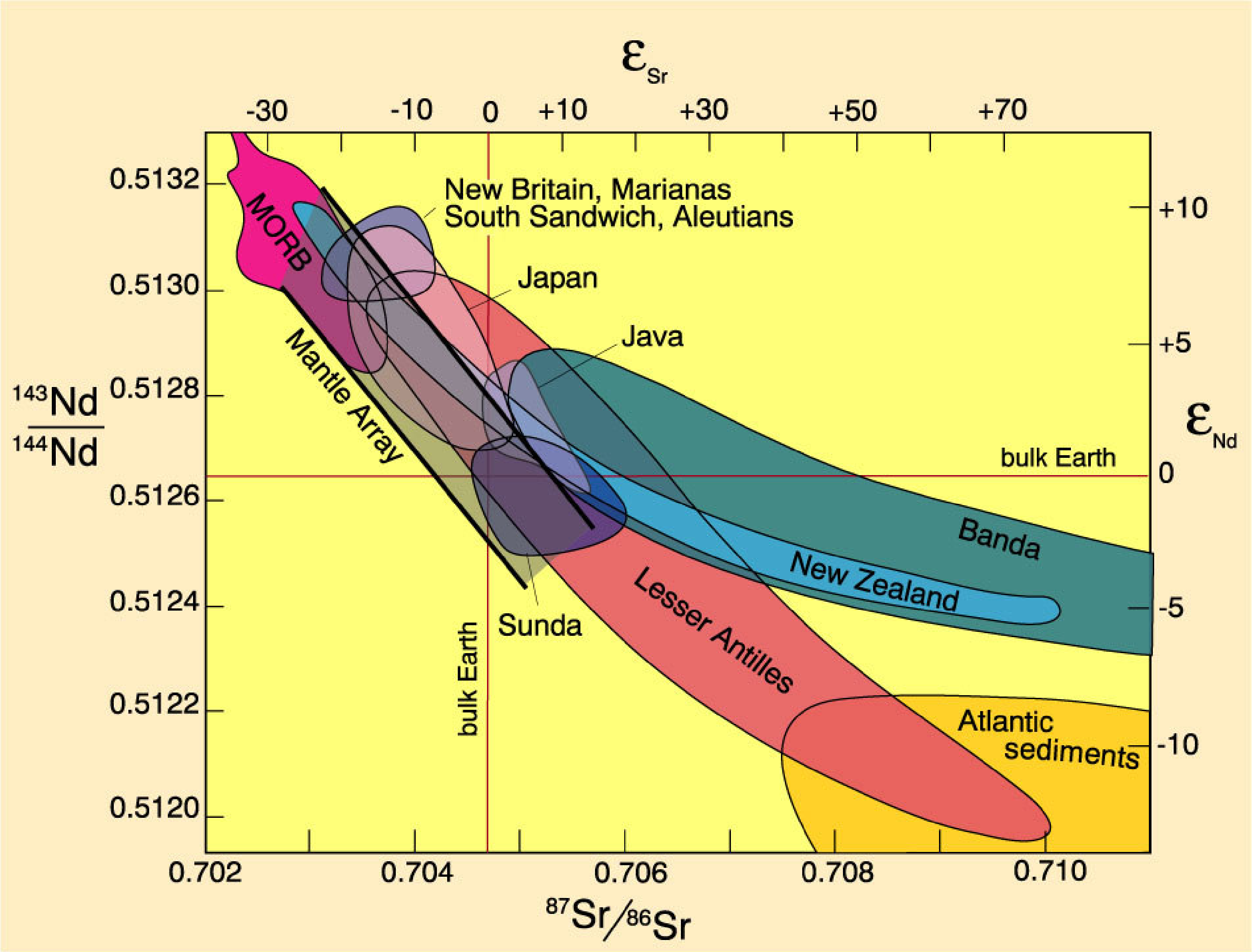
Nd model ages



Nd-Sr isotope correlation diagram

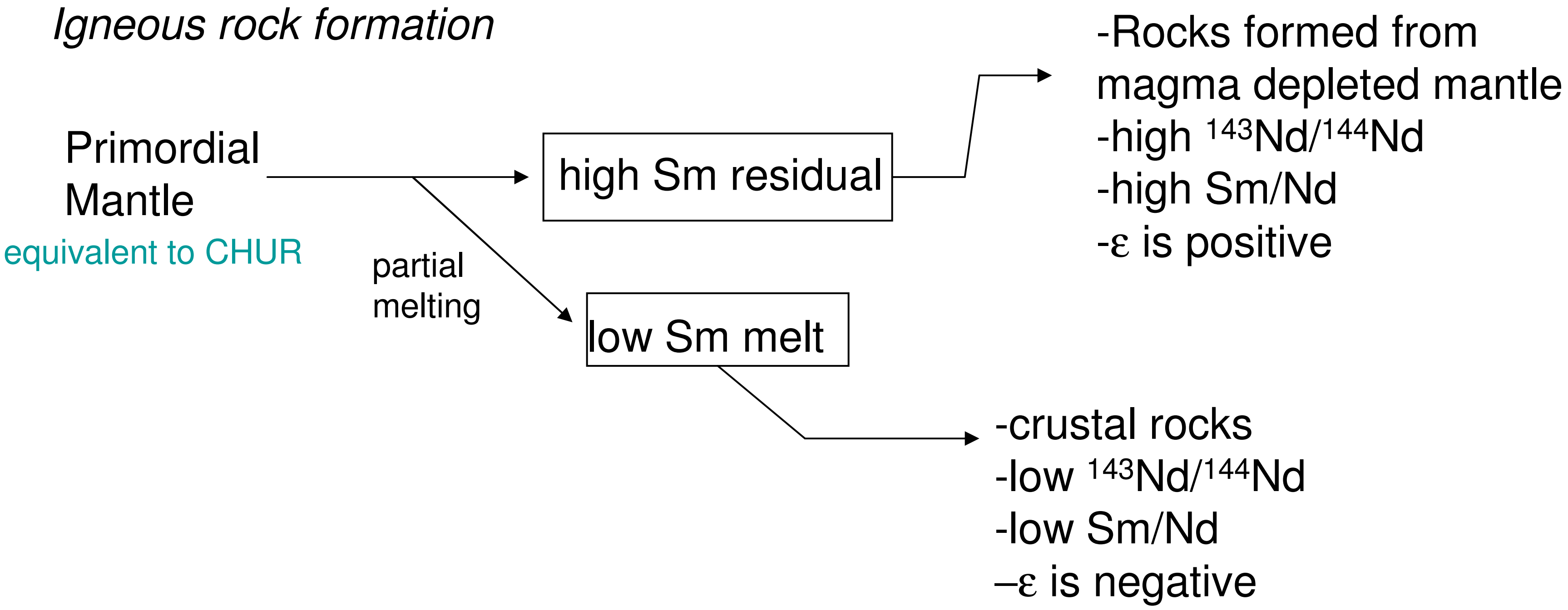


Nd-Sr isotope correlation diagram



Summary Sm-Nd

Igneous rock formation



Primordial Mantle

equivalent to CHUR

partial melting

high Sm residual

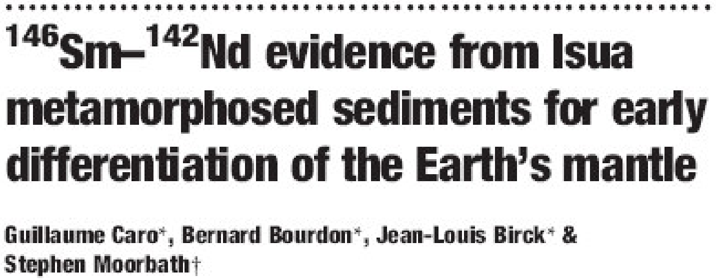
low Sm melt

-Rocks formed from magma depleted mantle
-high $^{143}Nd/^{144}Nd$
-high Sm/Nd
-ε is positive

-crustal rocks
-low $^{143}Nd/^{144}Nd$
-low Sm/Nd
–ε is negative

Same timescales as Rb-Sr and K-Ar (Ar-Ar)
More resistant to changes during metamorphism and ion exchange
Better adherence to closed system assumptions

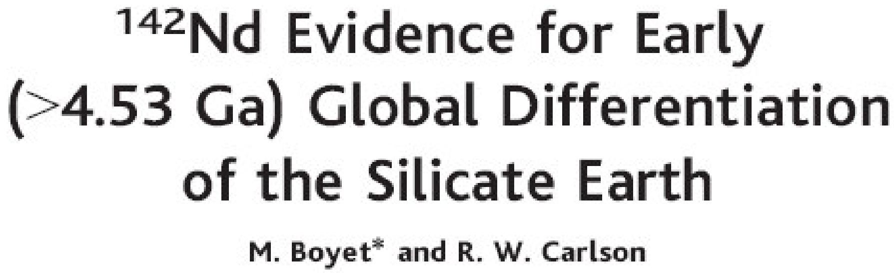
^{146}Sm-^{142}Nd chronometer



^{146}Sm–^{142}Nd evidence from Isua metamorphosed sediments for early differentiation of the Earth's mantle

Guillaume Caro*, Bernard Bourdon*, Jean-Louis Birck* & Stephen Moorbath†

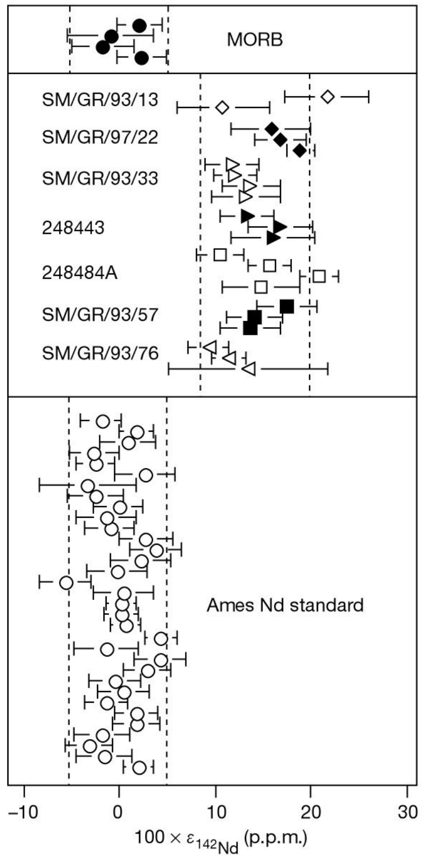
Nature 423, p428 (2003)



^{142}Nd Evidence for Early (>4.53 Ga) Global Differentiation of the Silicate Earth

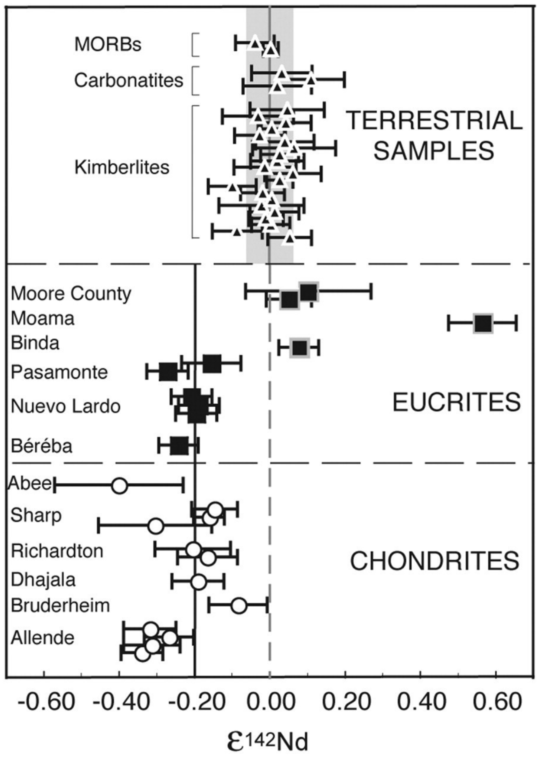
M. Boyet* and R. W. Carlson

Science 309, p576 (2005)

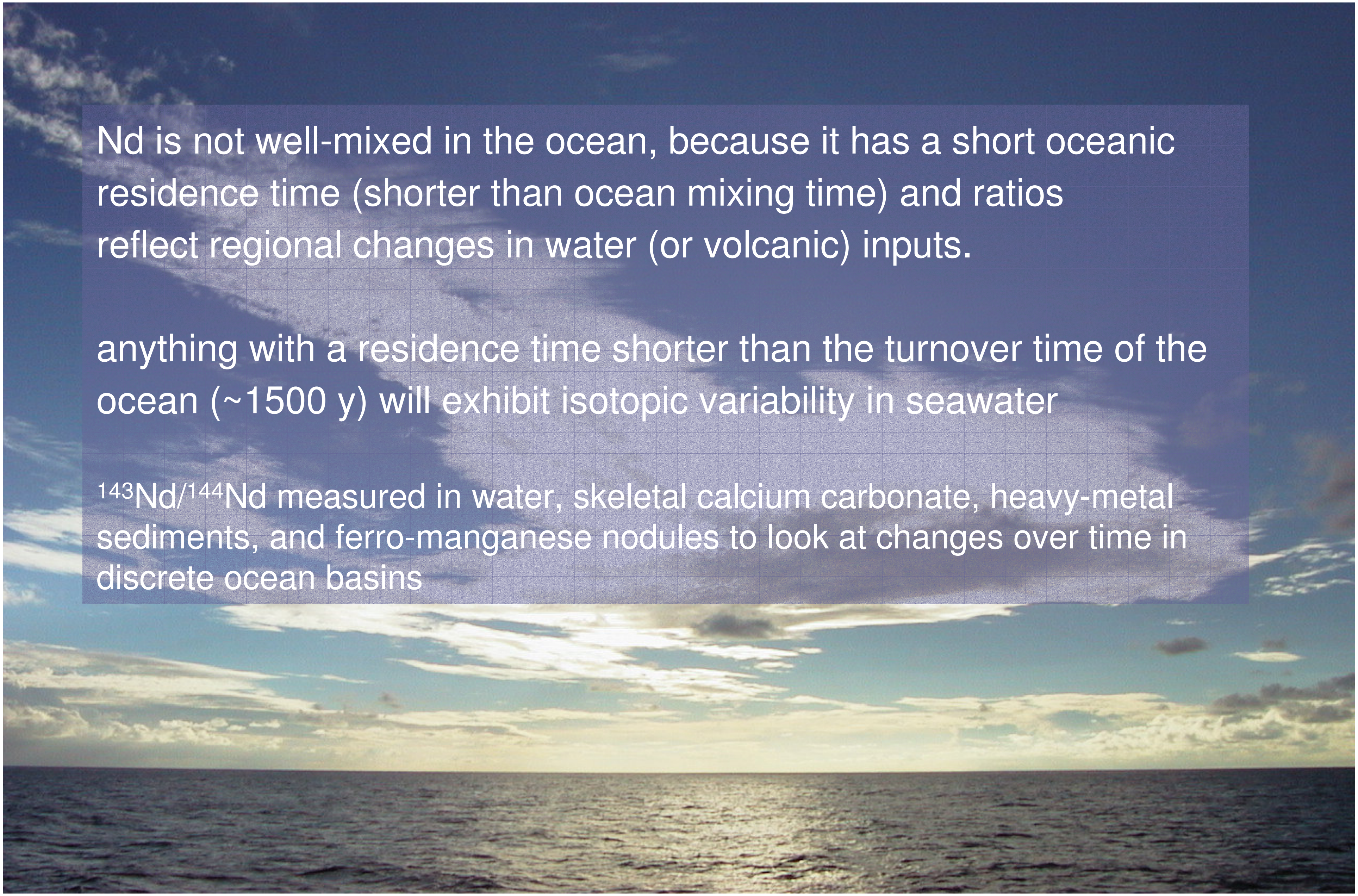


$T_{1/2}$ ^{146}Sm = 103 Ma

Extinct nuclide!



Nd in the oceans



Nd is not well-mixed in the ocean, because it has a short oceanic residence time (shorter than ocean mixing time) and ratios reflect regional changes in water (or volcanic) inputs.

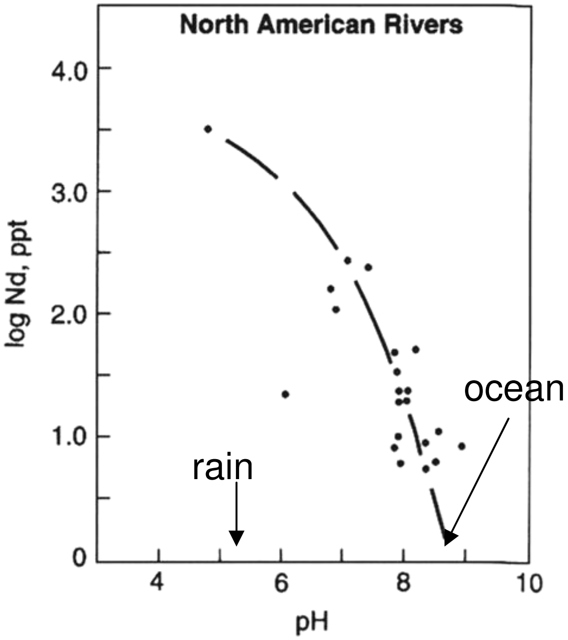
anything with a residence time shorter than the turnover time of the ocean (~1500 y) will exhibit isotopic variability in seawater

^{143}Nd/^{144}Nd measured in water, skeletal calcium carbonate, heavy-metal sediments, and ferro-manganese nodules to look at changes over time in discrete ocean basins

Nd in the oceans

Nd (and Sr) from different continental sources have isotopic signatures specific to the source rock of the watershed.

Total conc. may be changed during fluvial transport (e.g. Nd = f(pH))



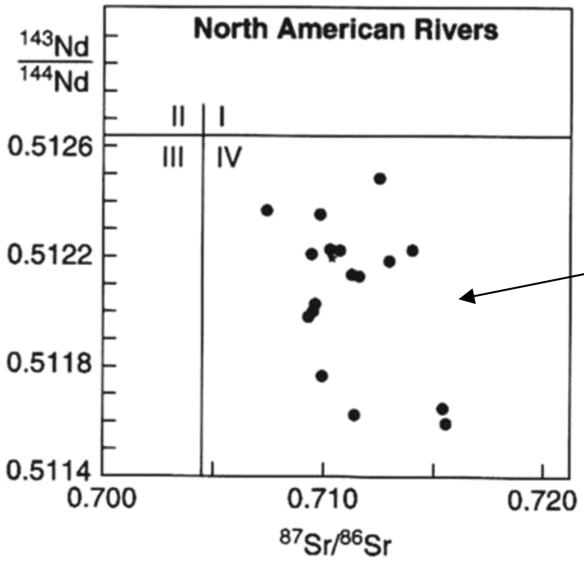
But isotopic ratios $^{143}Nd/^{144}Nd$ retained

Both Nd and Sr isotopes changed in ocean over time.

The change in $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ indicate varying contributions from different sources of water to the oceans.

Sr has long oceanic residence time and ratios reflect global changes

Nd has short oceanic residence time (shorter than ocean mixing time) and ratios reflect regional changes in water (or volcanic) inputs.



All rivers plotted drain a variety of continental crusts. Relatively low Nd ratio, relatively high Sr ratio

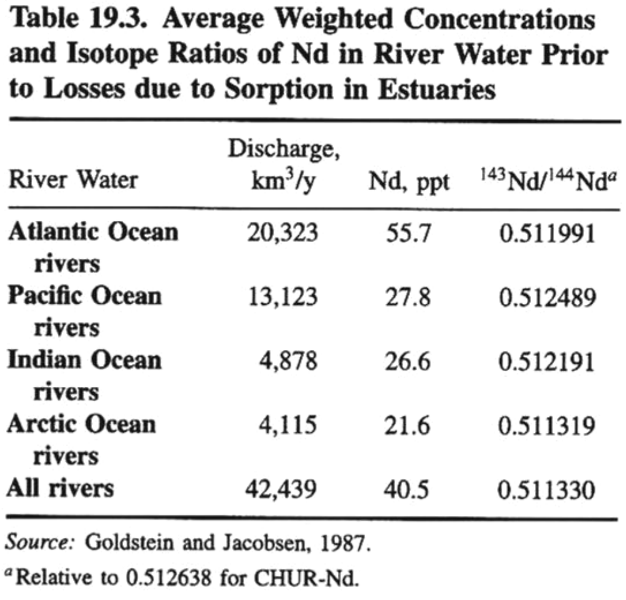


Table 19.3. Average Weighted Concentrations and Isotope Ratios of Nd in River Water Prior to Losses due to Sorption in Estuaries

River Water	Discharge, km^3/y	Nd, ppt	^{143}Nd/^{144}Nd^a
Atlantic Ocean rivers	20,323	55.7	0.511991
Pacific Ocean rivers	13,123	27.8	0.512489
Indian Ocean rivers	4,878	26.6	0.512191
Arctic Ocean rivers	4,115	21.6	0.511319
All rivers	42,439	40.5	0.511330

Source: Goldstein and Jacobsen, 1987.

[a] Relative to 0.512638 for CHUR-Nd.

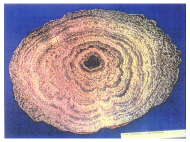
Atlantic – drains continental crust silicates (low Nd ratio)

Pacific – drains rocks that were mantle derived volcanics (high Nd ratio)

Nd in the oceans

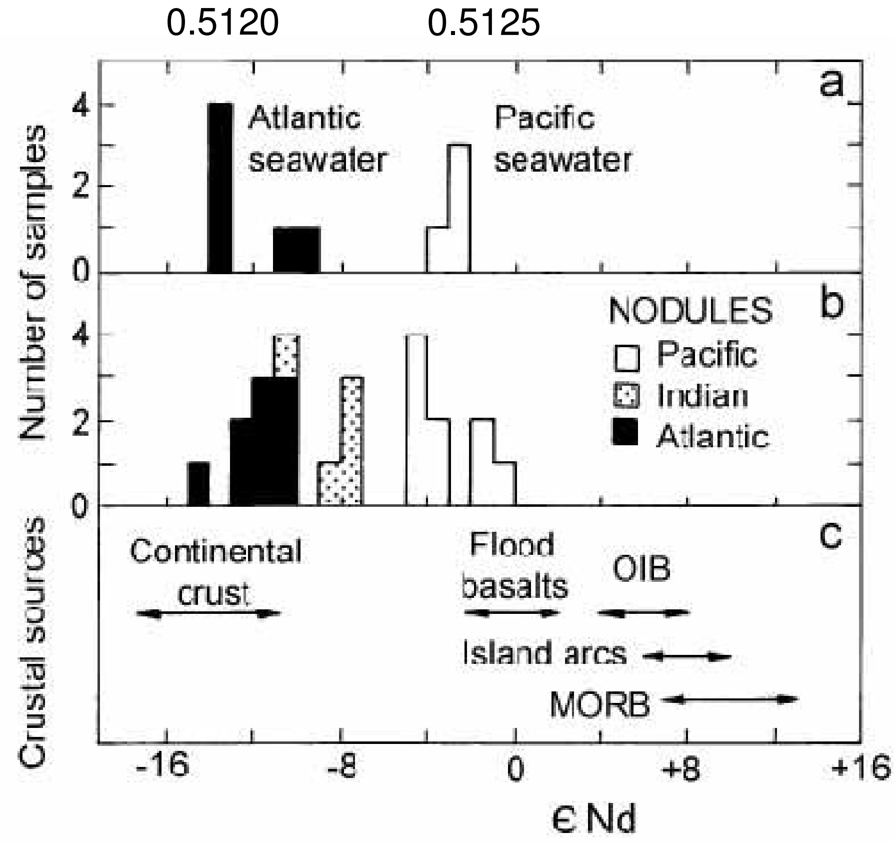
Comparison of seawater isotope compositions with sea floor Fe-Mn nodules and possible source reservoirs.

Seawater



Mn-nodules

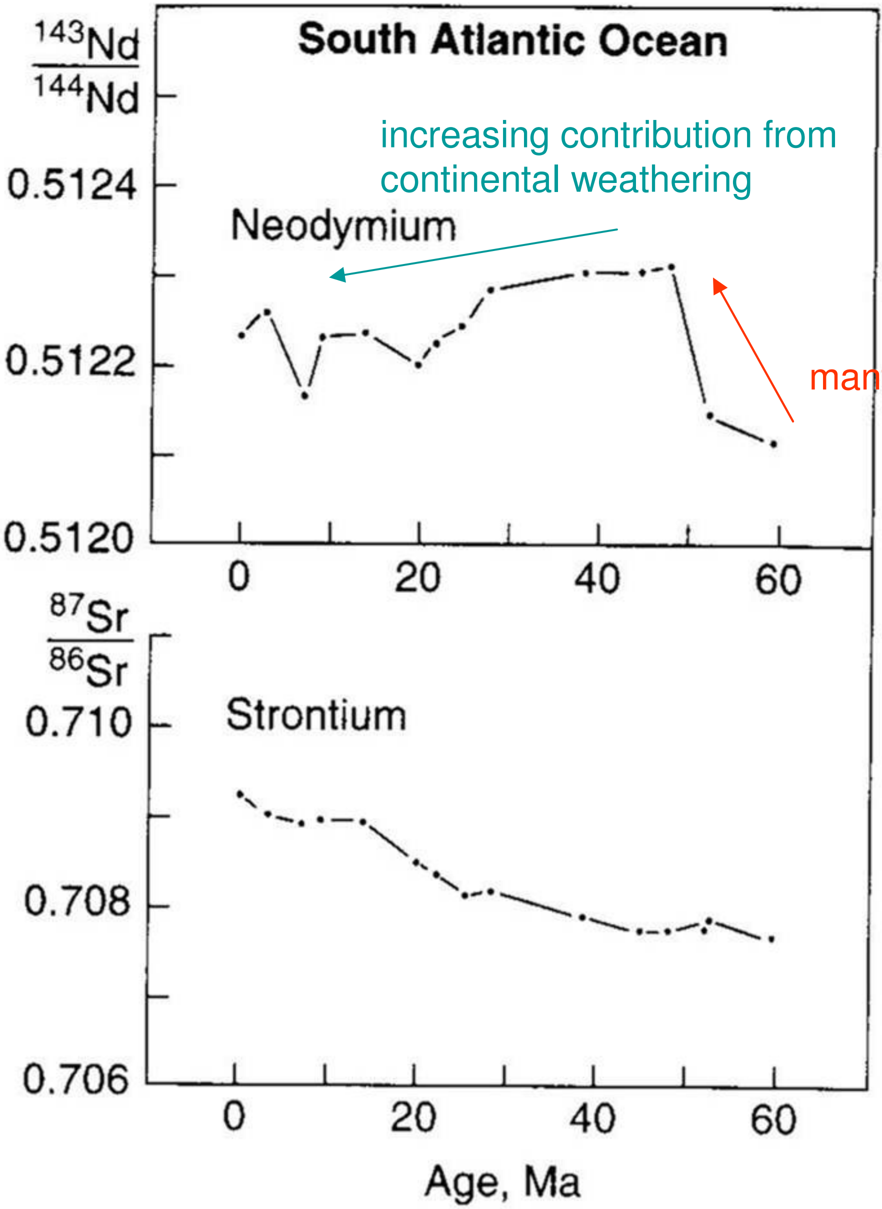
Crustal sources



Good isotopic correspondence between river discharge water, seawater, and ferro-manganese nodules

from Alan P. Dickin: http://www.onafarawayday.com/Radiogenic/

Rise of continental crust source to the Atlantic



increasing contribution from continental weathering

mantle-derived (volcanic input)

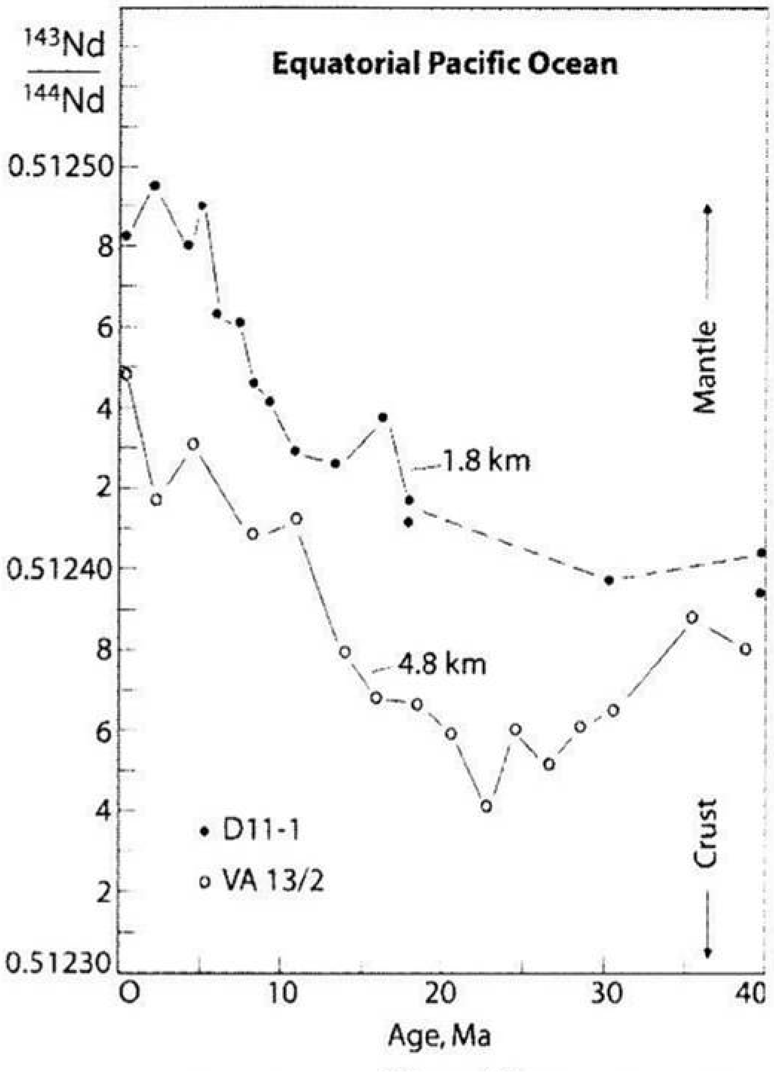
From ferromanganese oxyhydroxide coatings on the foram tests.

Show regional changes in the S. Atlantic Basin.

From foram tests $CaCO_3$

Global change

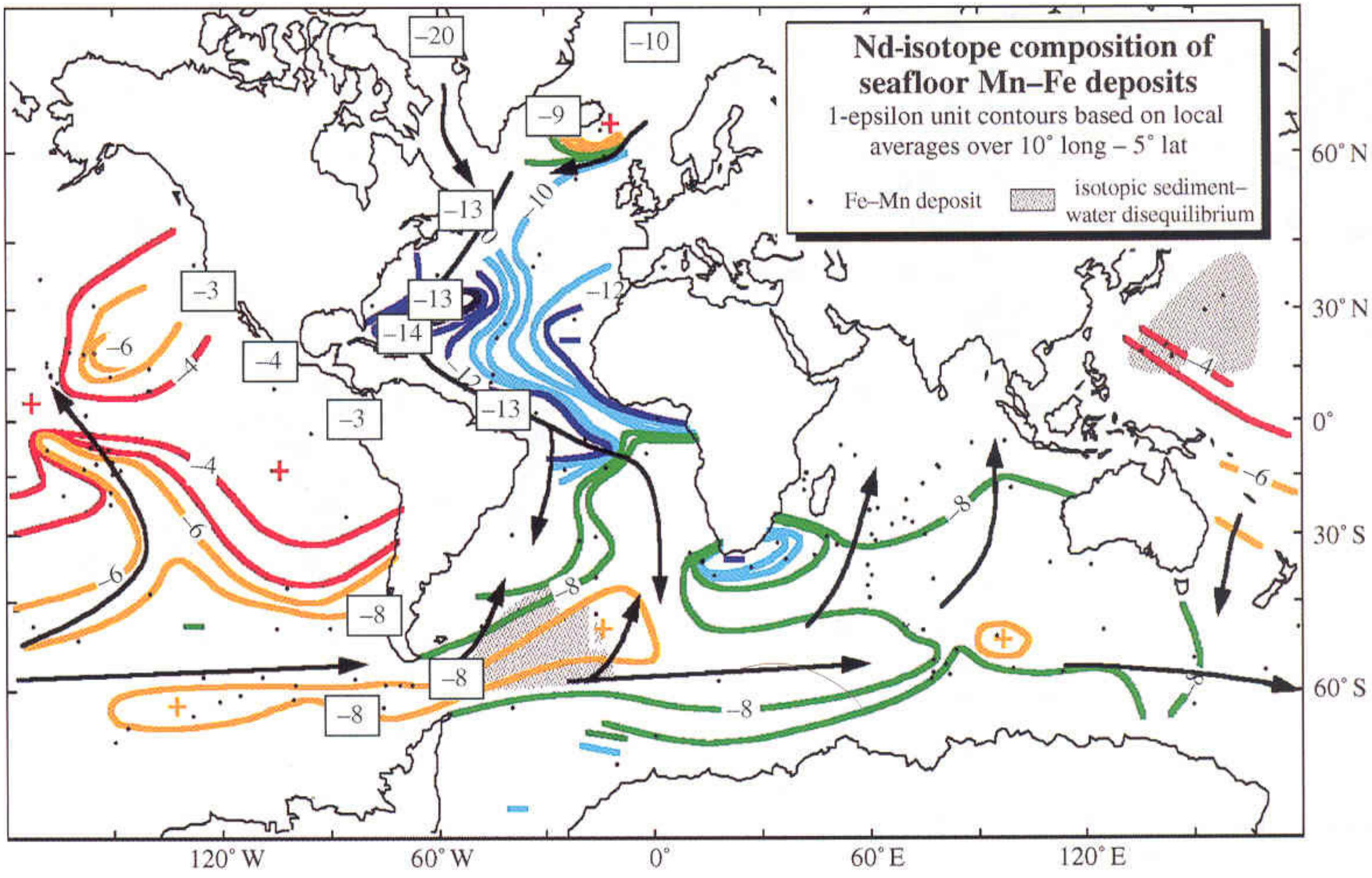
Rise of volcanic (mantle source) inputs to the Pacific



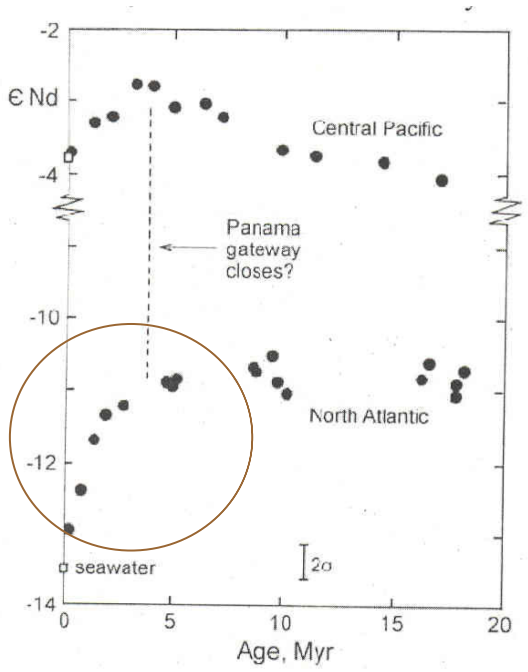
Some differences due to bottom water inputs…deep circulation.

Short residence time of Nd in the ocean relative to ocean mixing rates allows to obtain basin specific information

Nd in the oceans

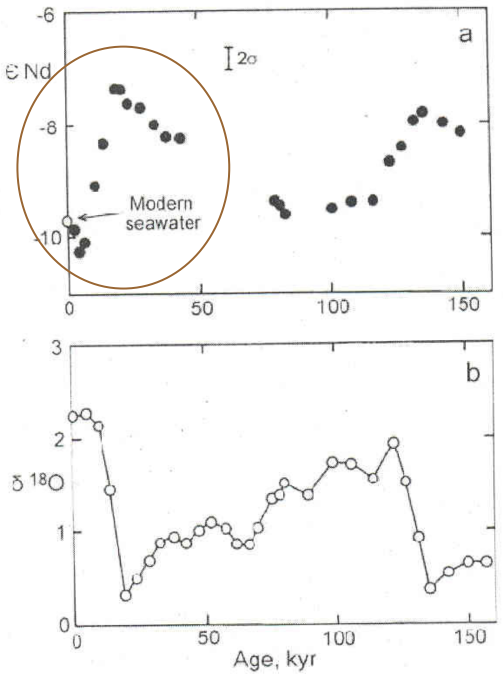


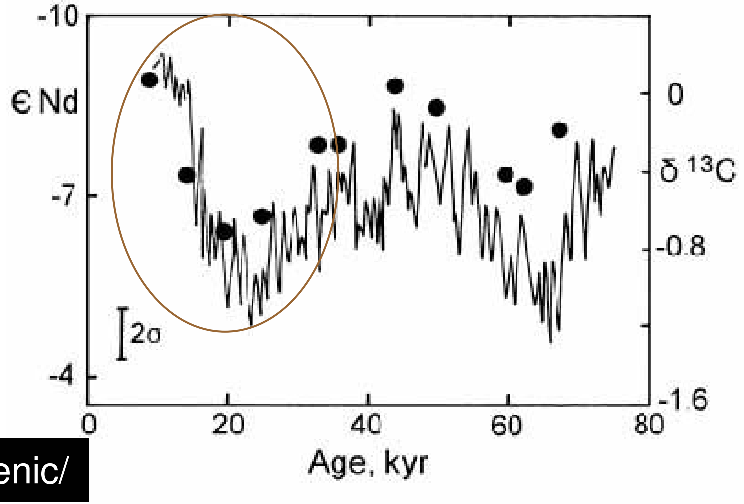
Nd in the oceans



Nd-Isotopie im Pazifik und Atlantik: *Schließung der Meerenge von Panama vor 10-3 Ma.*

Nd-(und ^{18}O)-Isotopie in Foraminiferen des Indischen Ozeans: *Hinweise auf Monsunaktivität*





Nd-Isotopie im Süd-Atlantik. Nd als Proxy (= Stellvertreter) für die Eintrag von NADW.

http://www.onafarawayday.com/Radiogenic/