Some Cosmogenic Radionuclides
(formed by cosmic ray interactions)

Parent	Half-Life Years
^{14}C	**5,730**
^{10}Be	**1.6 million**
^{26}Al	**710,000**
^{36}Cl	**300,000**
^{129}I	**160,000**

Inventory of Extinct Radionuclides

Parent	Daughter	Decay Mode	Half-Life Myr
^{146}Sm	**^{142}Nd**	**Alpha**	**103**
^{244}Pu	Various	Fission	82
^{129}I	^{129}Xe	Beta	16
^{247}Cm	^{235}U	3α, 2β	15.6
^{182}Hf	**^{182}W**	**2β**	**9.0**
^{107}Pd	^{107}Ag	Beta	6.5
^{53}Mn	**^{53}Cr**	**Beta**	**3.7**
^{60}Fe	^{60}Ni	2β	1.5
^{26}Al	**^{26}Mg**	**Beta**	**0.7**
^{41}Ca	^{41}K	Beta	0.1

Inventory of Living Radionuclides

Parent	Daughter	Decay Mode	Half-Life Billion yr
^{87}Rb	^{87}Sr	Beta –	49.44
^{147}Sm	^{143}Nd	Alpha	106.0
^{176}Lu	^{176}Hf	Beta–	37.1
^{187}Re	^{187}Os	Beta	41.6
^{190}Pt	^{186}Os	Alpha	469
^{232}Th	^{208}Pb		14.01
^{235}U	^{207}Pb		0.7038
^{238}U	^{206}Pb		4.468

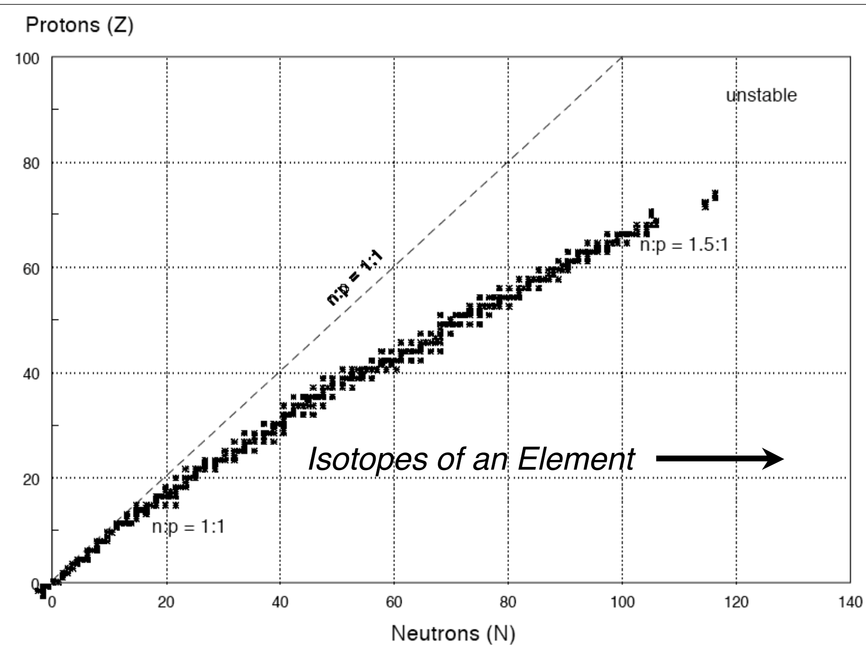
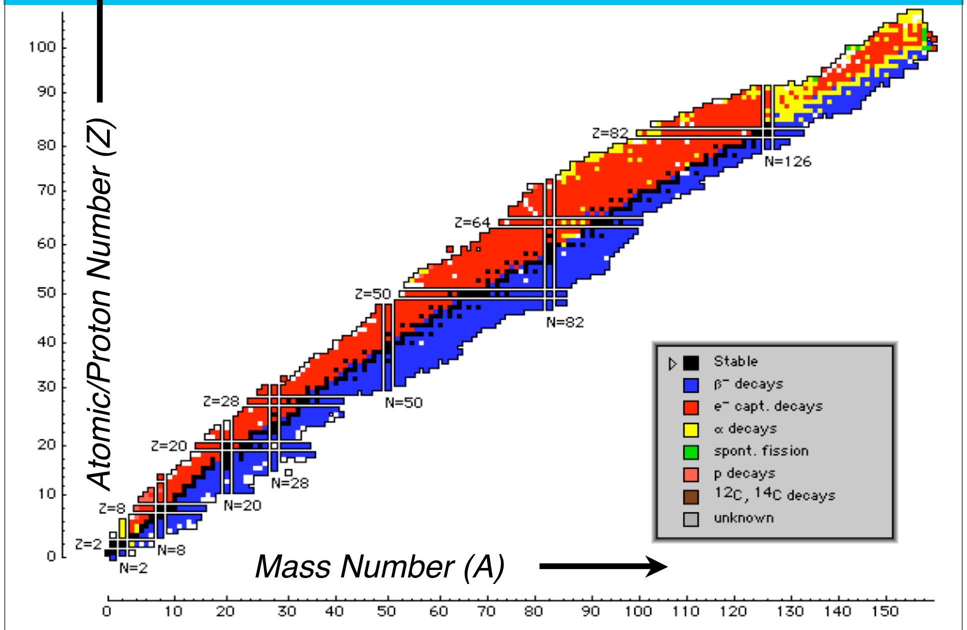


FIGURE 1. Neutron:Proton Ratios for Stable Nuclides

Chart of the Nuclides

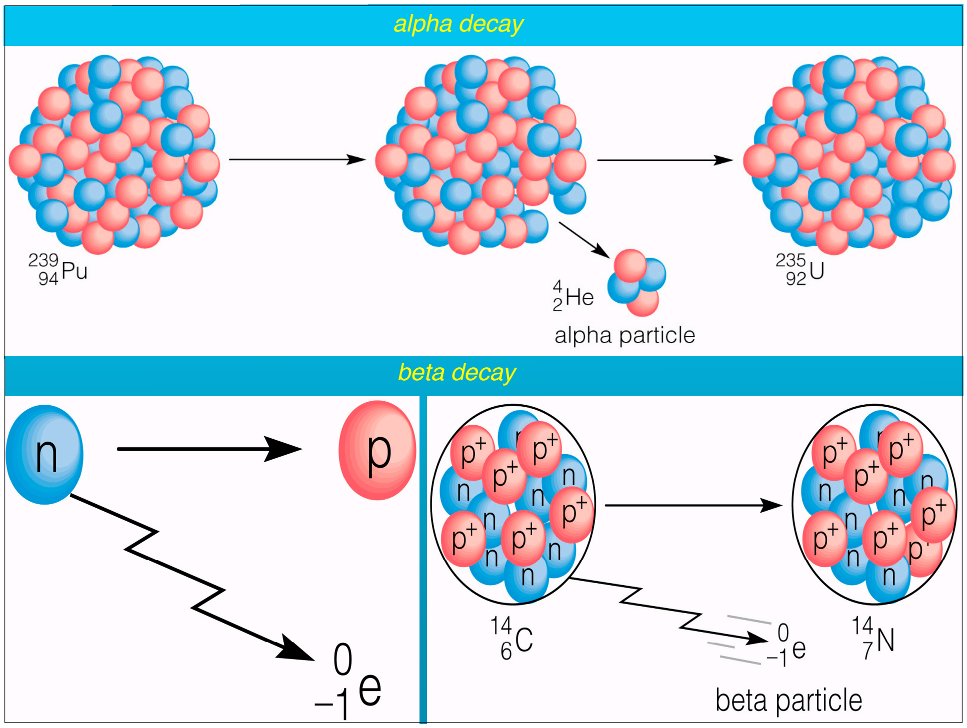


Section from the Chart of the Nuclides

Atomic/Proton Number (Z) ↑

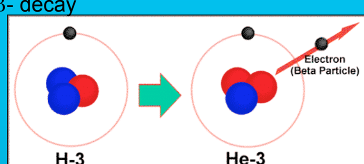
^{85}Y 2.68 H ε: 100.00%	^{86}Y 14.74 H ε: 100.00%	^{87}Y 79.8 H ε: 100.00%	^{88}Y 106.626 D ε: 100.00%	^{89}Y STABLE 100%
^{84}Sr STABLE 0.56%	^{85}Sr 64.84 D ε: 100.00%	^{86}Sr STABLE 9.86%	^{87}Sr STABLE 7.00%	^{88}Sr STABLE 82.58%
^{83}Rb 86.2 D ε: 100.00%	^{84}Rb 33.1 D ε: 96.20% β-: 3.80%	^{85}Rb STABLE 72.17%	^{86}Rb 18.642 D β-: 99.99% ε: 5.2E-3%	^{87}Rb 4.81E+10 Y 27.83% β-: 100.00%
^{82}Kr STABLE 11.58%	^{83}Kr STABLE 11.49%	^{84}Kr STABLE 57.00%	^{85}Kr 3916.8 D β-: 100.00%	^{86}Kr STABLE 17.30%

Mass Number (A) →



β decay - three types

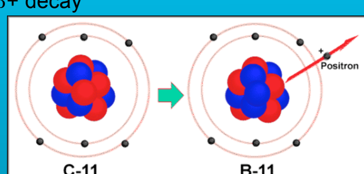
1) β- decay



$$^{3}_{1}H \xrightarrow{\beta} {}^{3}_{2}He + e^{-} + \bar{\upsilon}_e$$

- converts one neutron into a proton and electron
- no change of A, but different element
- release of anti-neutrino (no charge, no mass)

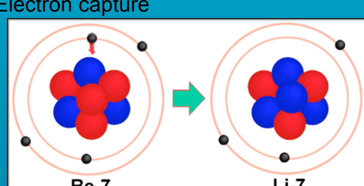
2) β+ decay



$$^{11}_{6}C \xrightarrow{\beta^{+}} {}^{11}_{5}B + e^{+} + \upsilon_e$$

- converts one proton into a neutron and electron
- no change of A, but different element
- release of neutrino

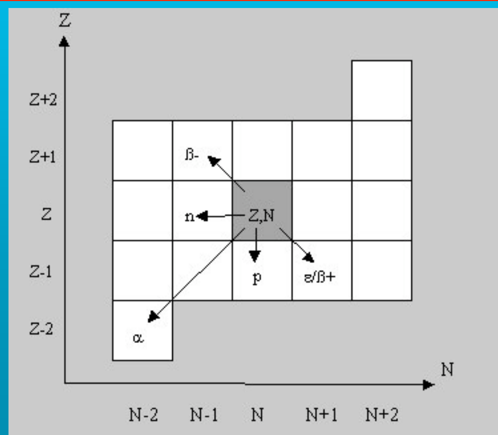
3) Electron capture

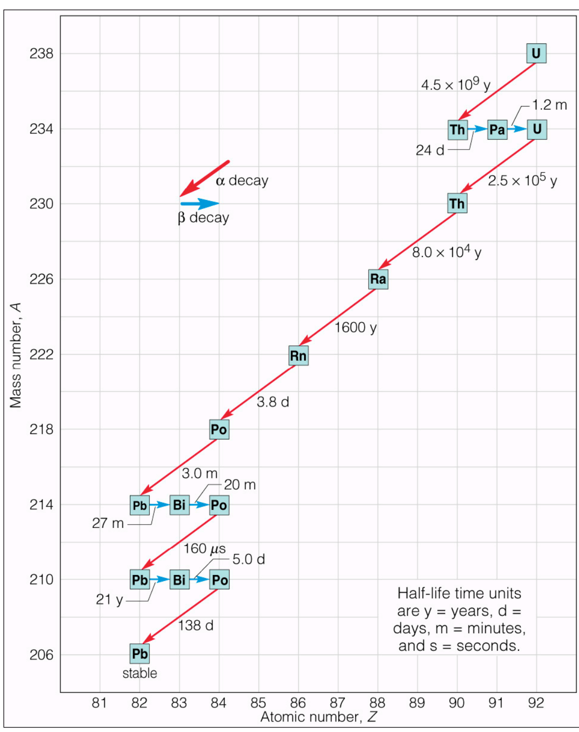


$$^{7}_{4}Be + e^{-} \xrightarrow{EC} {}^{7}_{3}B + \upsilon_e$$

Four types of radioactive decay

1) alpha (α) decay - ^{4}He nucleus (2p + 2n) ejected
2) beta (β) decay - change of nucleus charge, conserves mass
3) gamma (γ) decay - photon emission, no change in A or Z
4) spontaneous fission - for Z=92 and above, generates two smaller nuclei





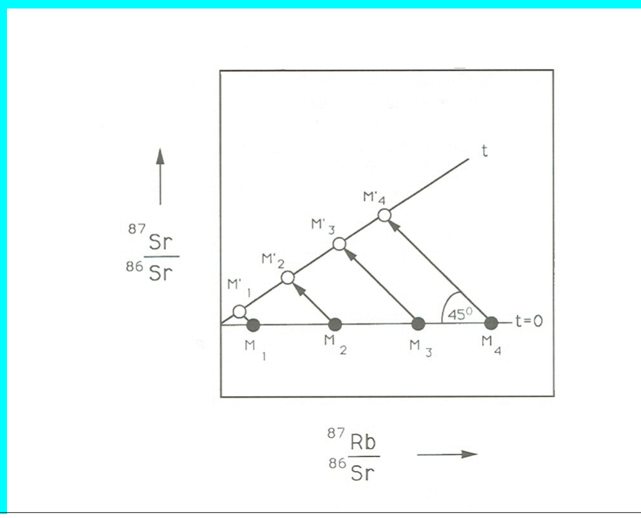
238U decay chain

8 alpha particles (α = 2 neutrons + 2 protons)

206Pb stable

But first …

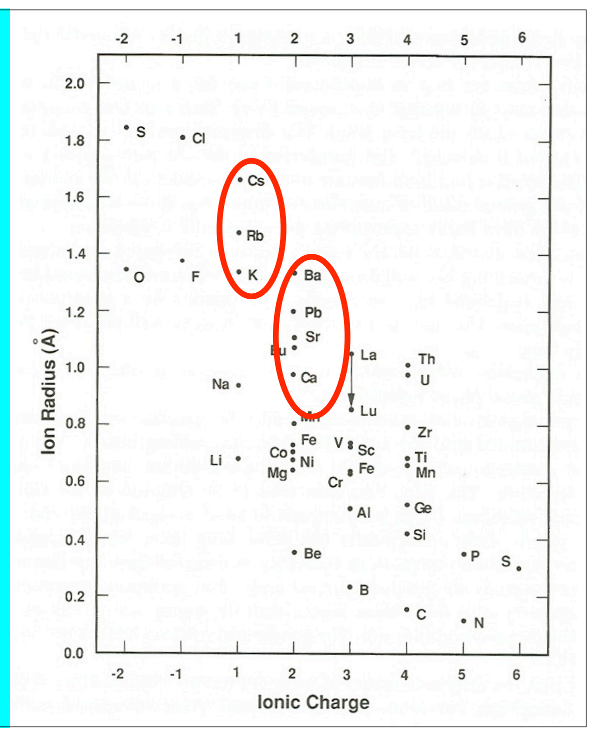
Three simple steps to using the long-lived nuclide clock:
The case of ^{87}Rb decays to ^{87}Sr (half-life = 48.8 Gyr)



Step 1:

Separate

Parent ^{87}Rb
from
Daughter ^{87}Sr

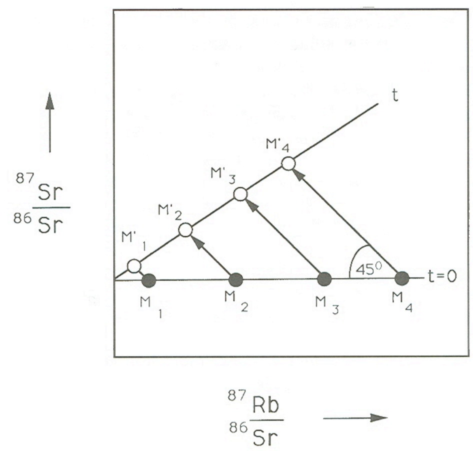


Step 2:

Close system tightly

Let ^{87}Rb decay to ^{87}Sr

(without disturbance)



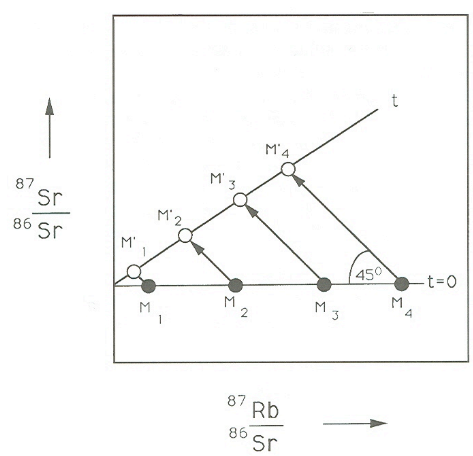
Step 3:

Observe that slope
Changes with time

Observe that where
Rb/Sr = 0 (the intercept)
No change in $^{87}Sr/^{86}Sr$

Calculate:
Slope = $(e^{\lambda t} - 1)$

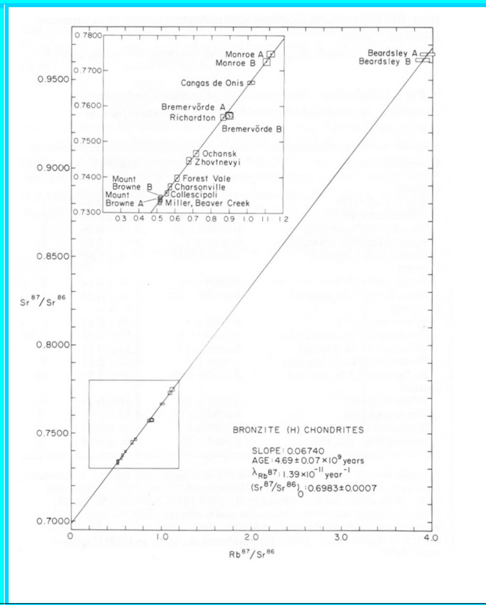
λ = decay constant
t = time since closure

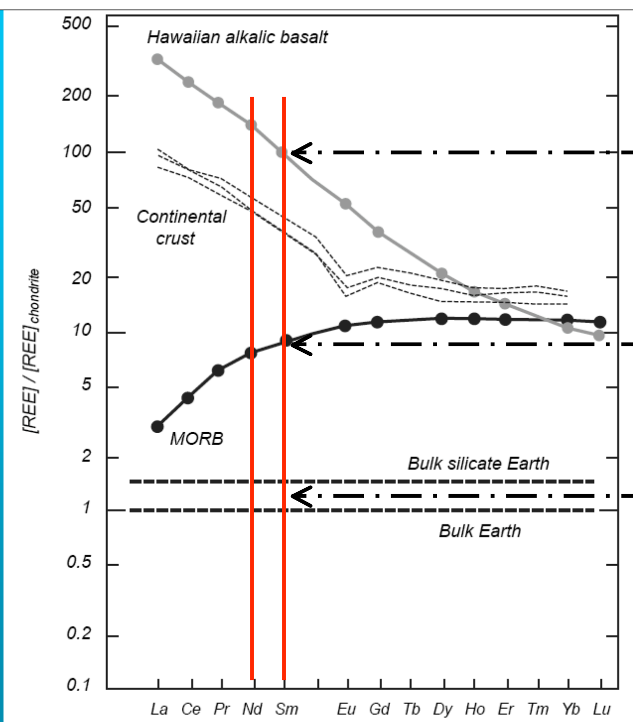


H-group chondrites

Whole-rock Rb-Sr isochron of 16 H-chondrite meteorites

=> Common formation age 4.69 ± 0.07 Ga.



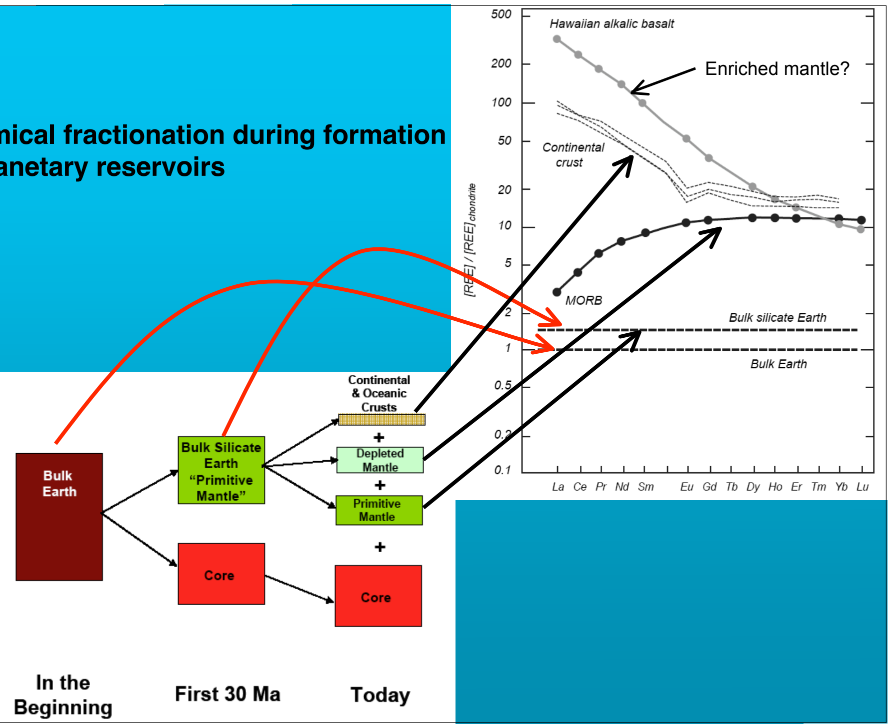


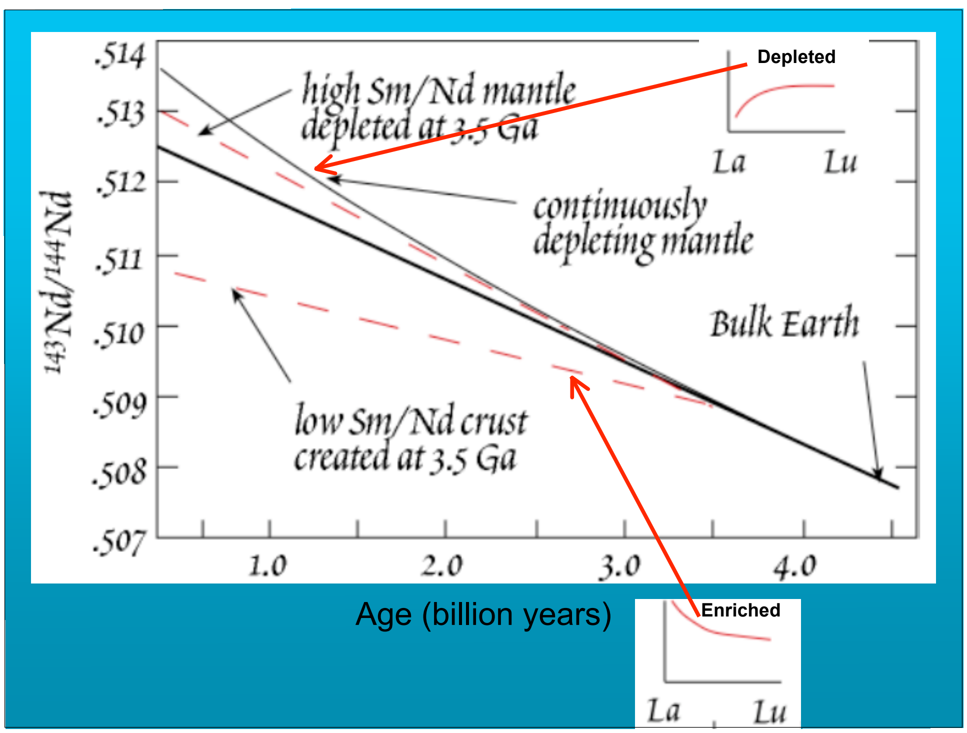
Sm/Nd Hawaii < Sm/Nd chondritic

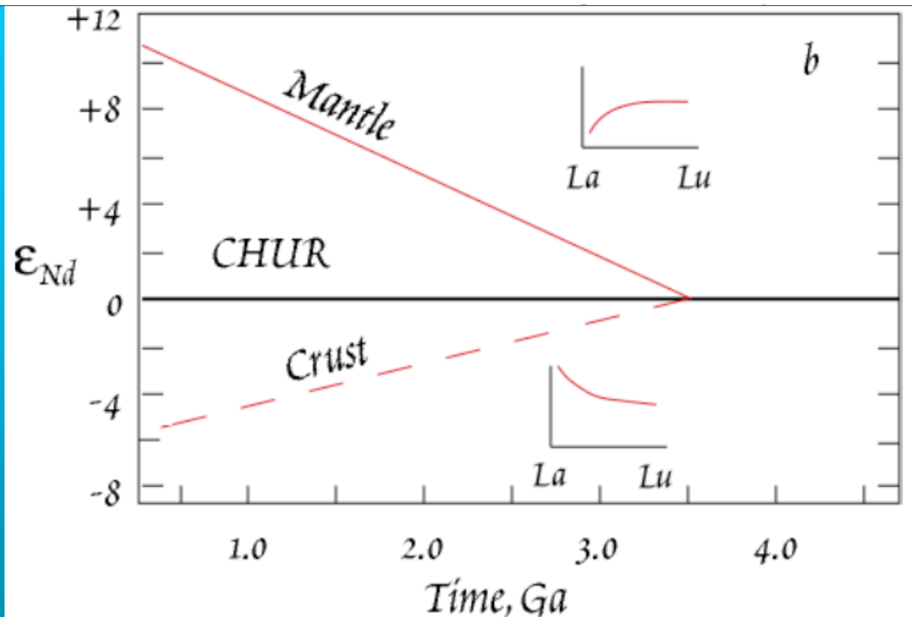
Sm/Nd MORB > Sm/Nd chondritic

Sm/Nd BE or BSE = Sm/Nd chondritic

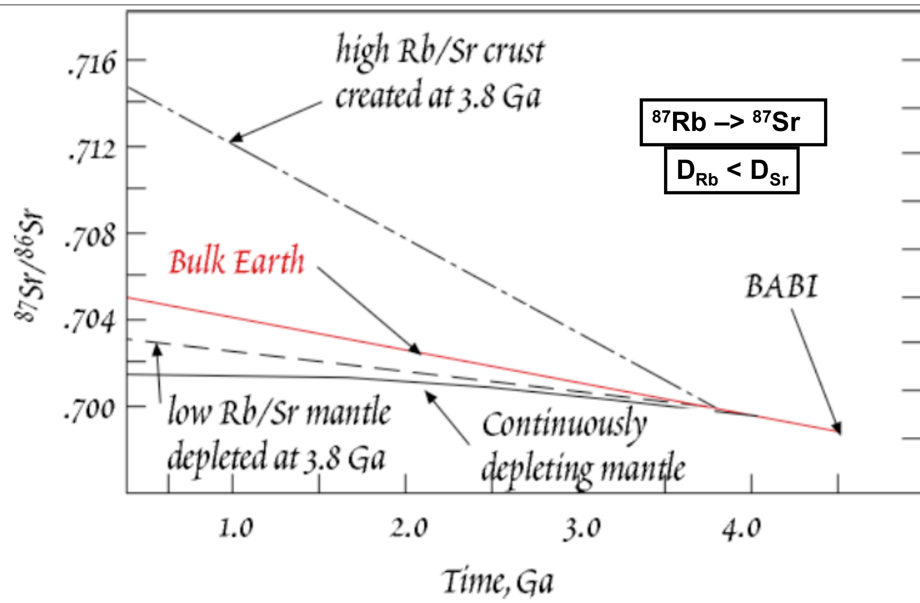
Chemical fractionation during formation of planetary reservoirs

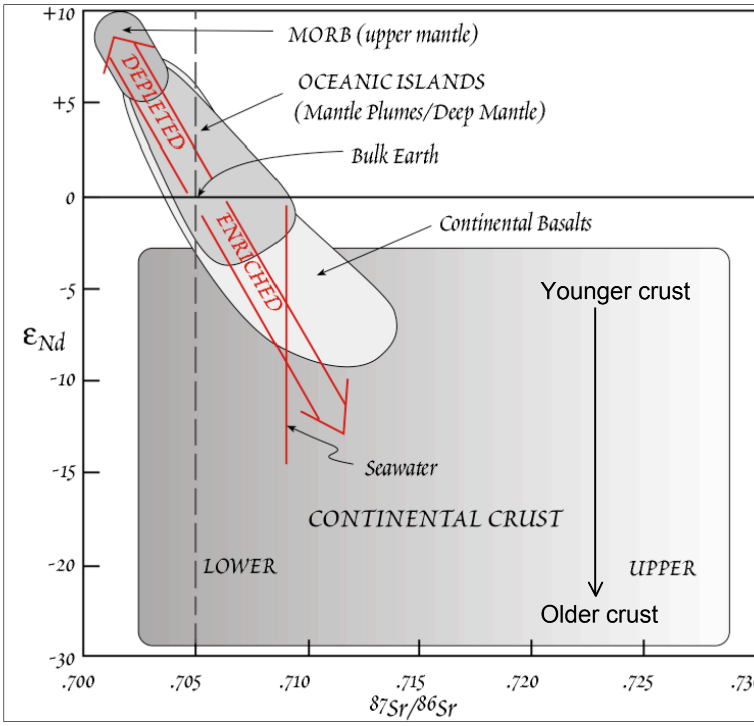


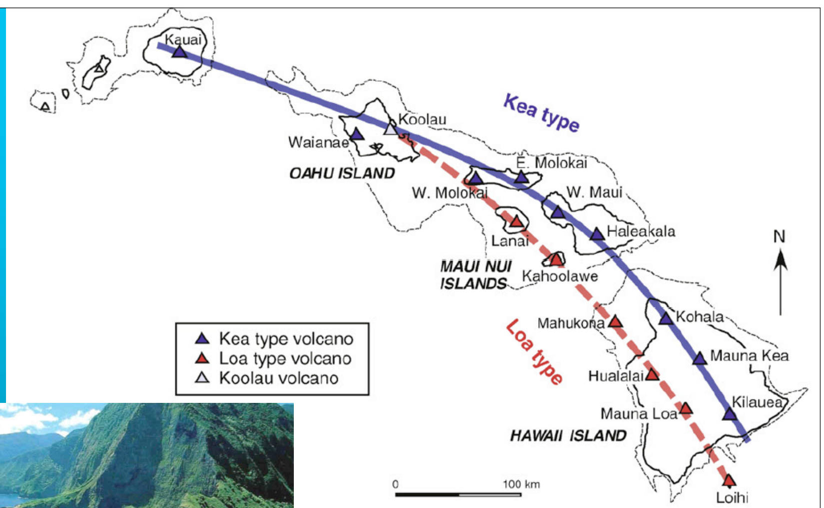


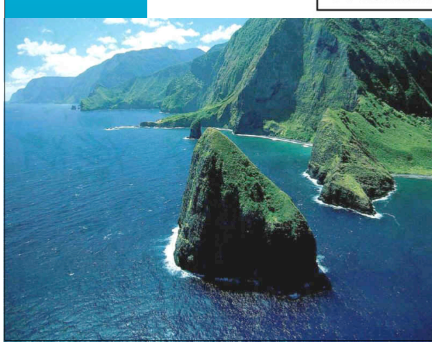


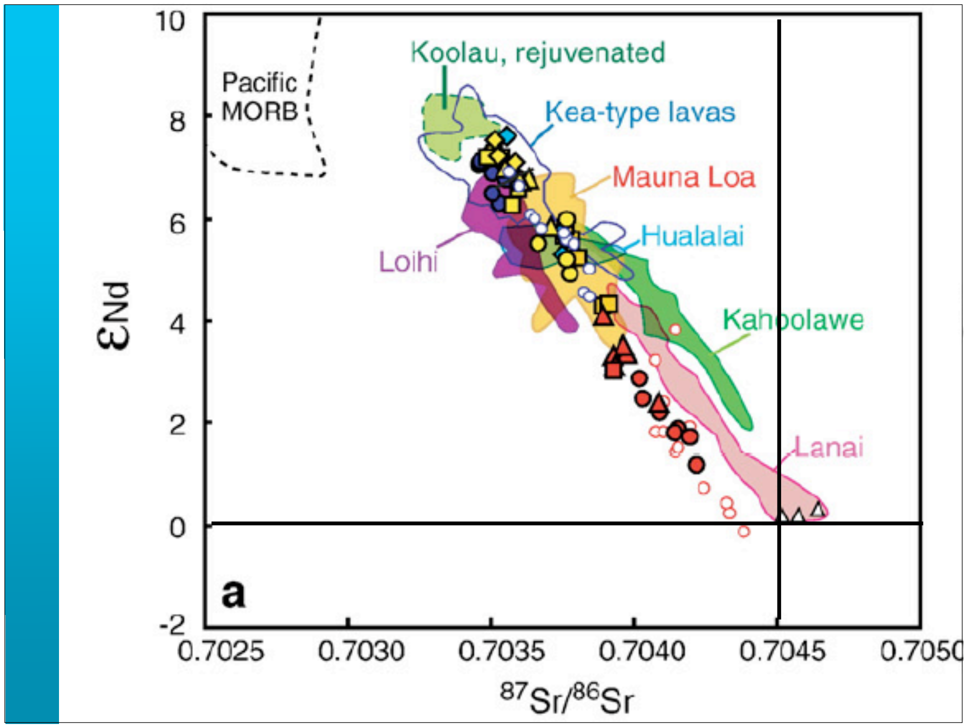
$$\varepsilon_{Nd} = \left\{ \frac{(^{143}Nd/^{144}Nd)_{Sample} - (^{143}Nd/^{144}Nd)_{CHUR}}{(^{143}Nd/^{144}Nd)_{CHUR}} \right\} \times 10{,}000$$



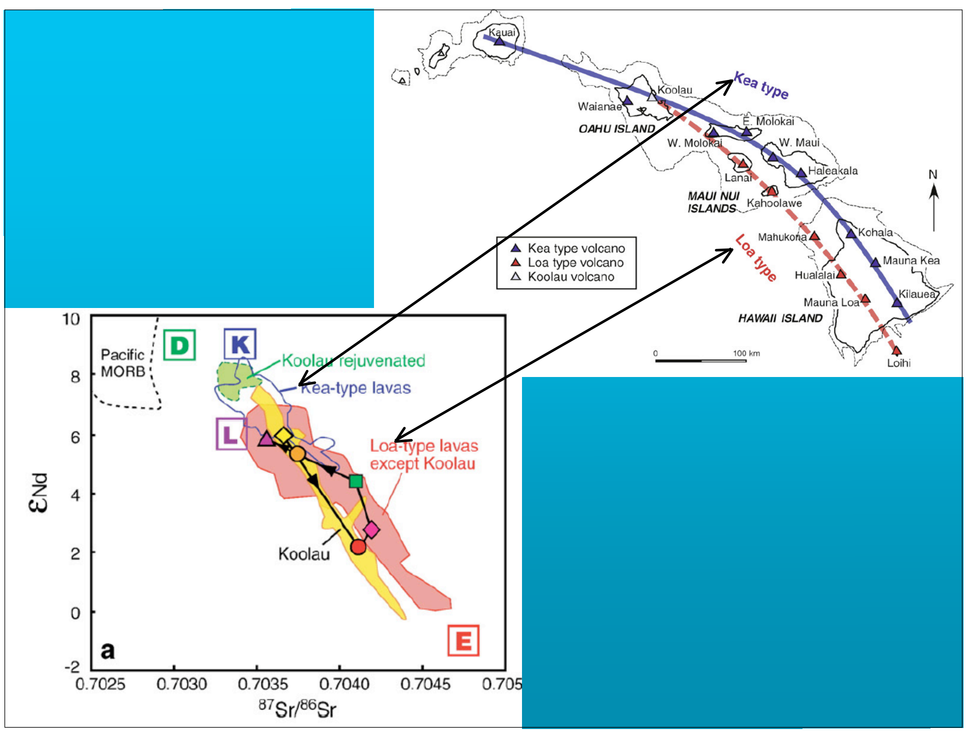

MORB (upper mantle)
OCEANIC ISLANDS
(Mantle Plumes/Deep Mantle)
Bulk Earth
DEPLETED
ENRICHED
Continental Basalts
Younger crust
Older crust
Seawater
CONTINENTAL CRUST
LOWER
UPPER
ε_{Nd}
$^{87}Sr/^{86}Sr$
+10
+5
0
-5
-10
-15
-20
-30
.700
.705
.710
.715
.720
.725
.730


Kauai
Koolau
Waianae
OAHU ISLAND
Kea type
E. Molokai
W. Molokai
W. Maui
Lanai
Haleakala
MAUI NUI ISLANDS
Kahoolawe
N
Mahukona
Kohala
Loa type
Mauna Kea
Hualalai
Kilauea
Mauna Loa
HAWAII ISLAND
Loihi
0
100 km
Kea type volcano
Loa type volcano
Koolau volcano





Pacific MORB
Koolau, rejuvenated
Kea-type lavas
Mauna Loa
Hualalai
Loihi
Kahoolawe
Lanai
a
εNd
87Sr/86Sr



Kauai
Koolau
Kea type
Waianae
OAHU ISLAND
E. Molokai
W. Molokai
W. Maui
Lanai
Haleakala
MAUI NUI ISLANDS
Kahoolawe
N
Mahukona
Kohala
Loa type
Kea type volcano
Loa type volcano
Koolau volcano
Hualalai
Mauna Kea
Mauna Loa
Kilauea
HAWAII ISLAND
Loihi
0
100 km
Pacific MORB
D
K
Koolau rejuvenated
Kea-type lavas
L
Loa-type lavas except Koolau
Koolau
a
E
εNd
87Sr/86Sr

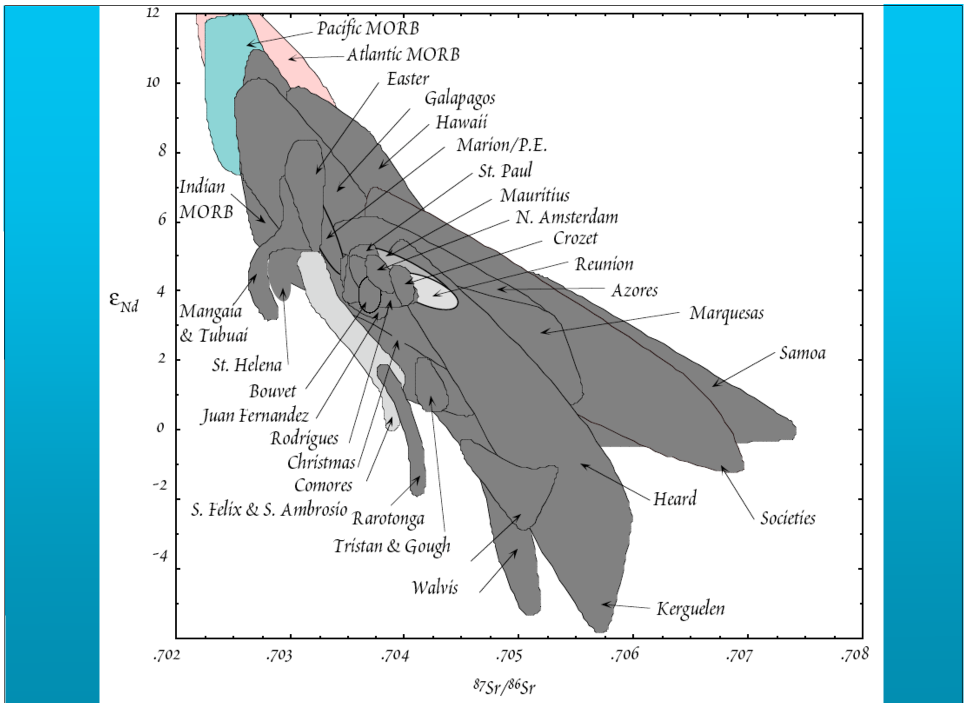
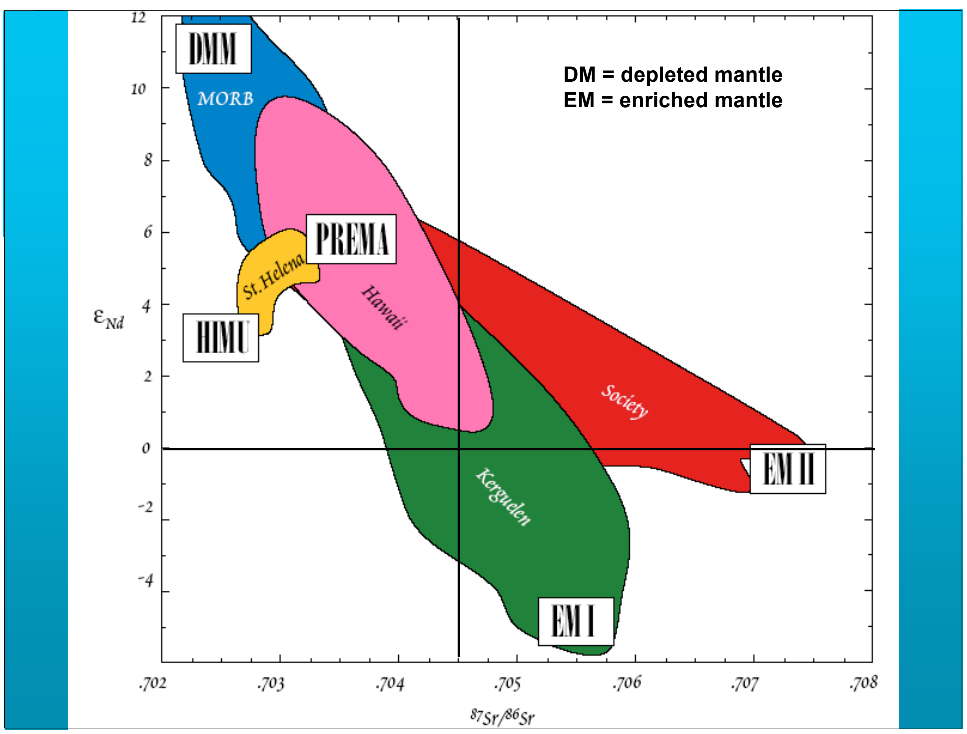
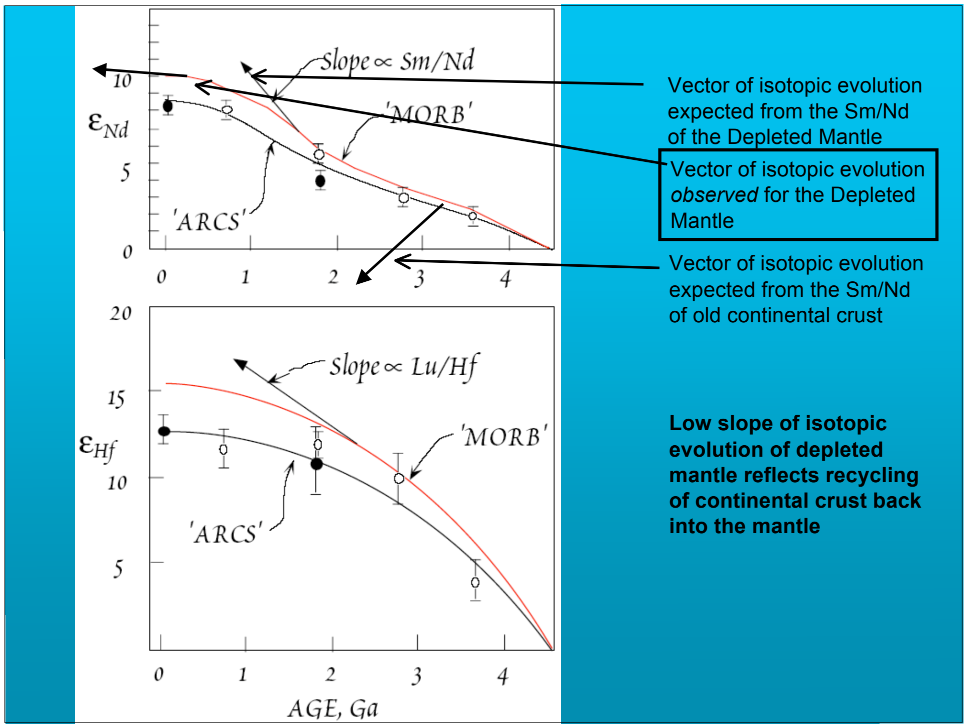
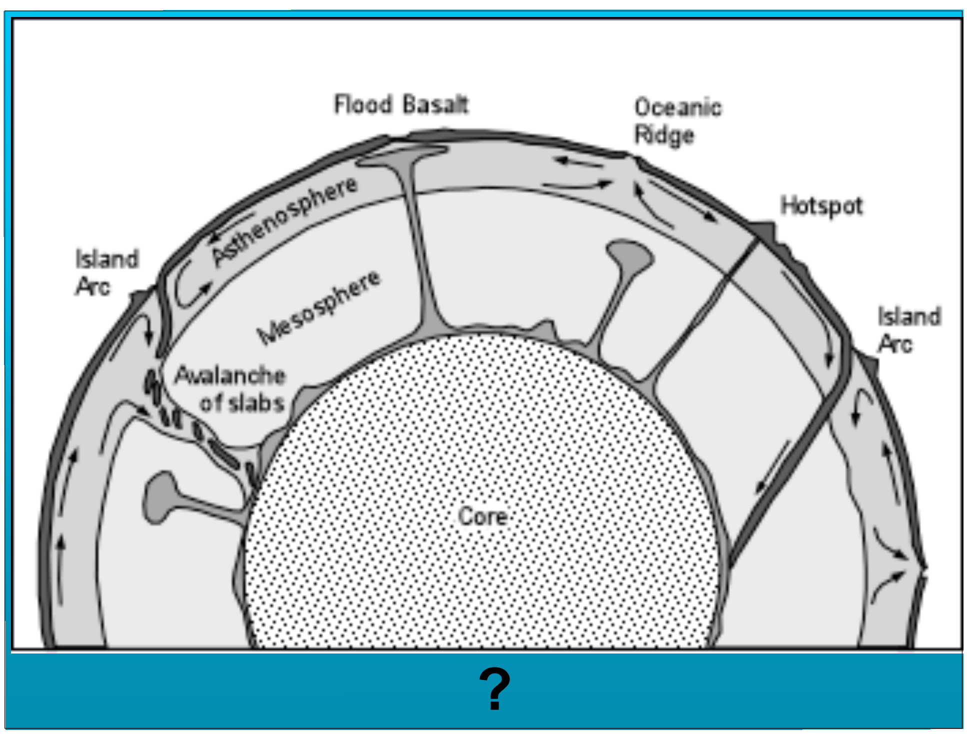


Figure 16.3. Sr and Nd isotope ratios of the suboceanic mantle as sampled by oceanic basalts.




10
5
0
ε_{Nd}
Slope ∝ Sm/Nd
'MORB'
'ARCS'
0
1
2
3
4
20
15
10
5
ε_{Hf}
Slope ∝ Lu/Hf
'MORB'
'ARCS'
0
1
2
3
4
AGE, Ga
Vector of isotopic evolution expected from the Sm/Nd of the Depleted Mantle
Vector of isotopic evolution *observed* for the Depleted Mantle
Vector of isotopic evolution expected from the Sm/Nd of old continental crust
Low slope of isotopic evolution of depleted mantle reflects recycling of continental crust back into the mantle


Flood Basalt
Oceanic Ridge
Hotspot
Island Arc
Island Arc
Asthenosphere
Mesosphere
Avalanche of slabs
Core
?