The Rb-Sr method

Based on the decay reaction:

$$^{87}_{37}Rb \rightarrow ^{87}_{38}Sr + \beta^-$$

with a half-life

$$T_{1/2} = 48.8 \text{ Ga}$$

geochronometry equation written in terms of the ratio $^{87}Sr/^{86}Sr$ because ratios are more accurately determined by mass spectrometry

$$\frac{^{87}Sr}{^{86}Sr} = \left(\frac{^{87}Sr}{^{86}Sr}\right)_0 + \frac{^{87}Rb}{^{86}Sr}(e^{\lambda t} - 1)$$

measured *always some initial Sr present in a rock* *measured*

The Rb-Sr method

The Rb-Sr method is commonly used to date Rb-rich minerals such as muscovite, biotite and K-feldspar; these minerals usually do not incorporate much Sr at the time of their formation (Goldschmidt’s rules).

During the last decades also cogenetic whole rock samples were analysed by this method.

The Rb-Sr method

^{87}Rb=27.83%
^{85}Rb=72.17%

^{88}Sr=82.53%
^{87}Sr=7.04%
^{86}Sr=9.87%
^{84}Sr=0.56%

} ALL STABLE

Rb/Sr ratios for various rocks:	
Ultrabasic	0.2
Basaltic	0.06
Granites	0.25-10
Shale	0.46
Sandstone	3

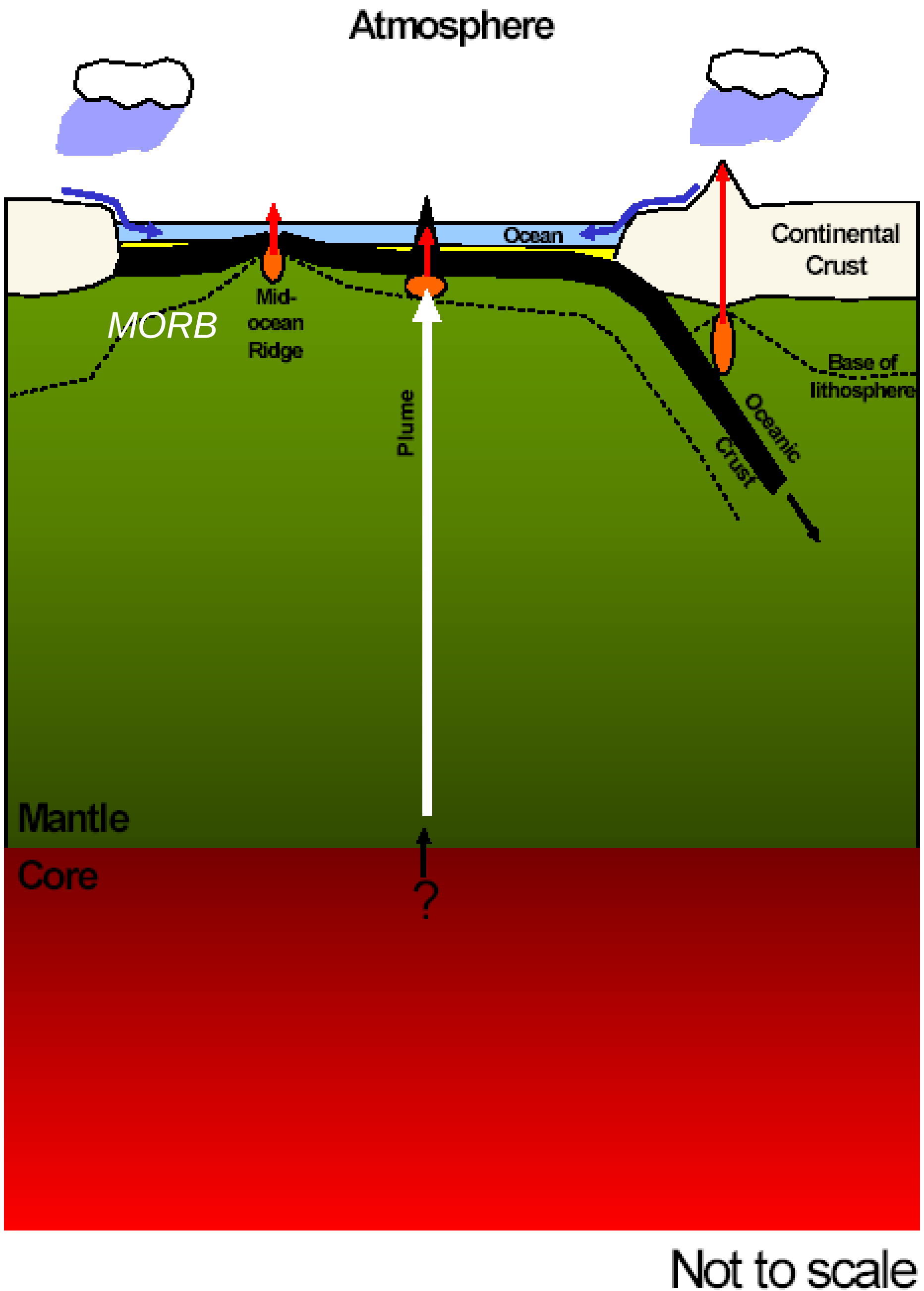
What accounts for huge range in Rb/Sr ratios of rocks?

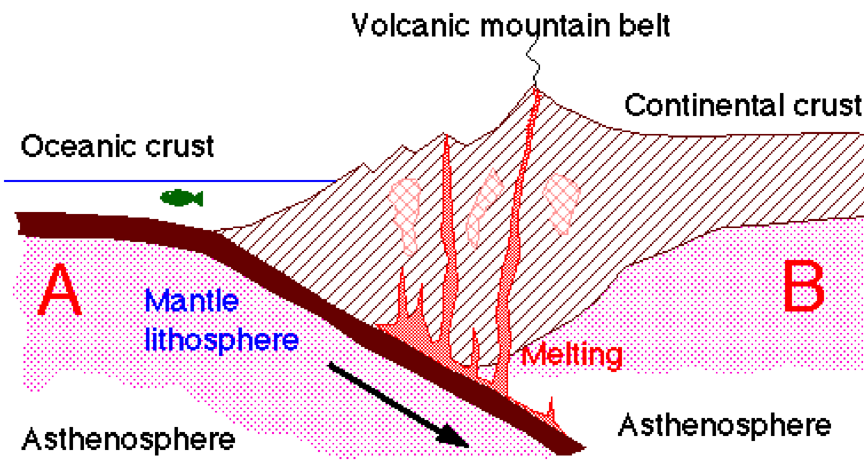
1. Rb subsitutes for K in K-bearing minerals while
   Sr substitutes for Ca in Ca-bearing minerals

2. Rb and Sr are fractionated by igneous processes:
   Rb tends to prefer melt (more incompatible than Sr)

High Rb/Sr rocks contain more ^{87}Sr
Low Rb/Sr rocks contain less ^{87}Sr

Igneous Processes and $^{87}Sr/^{86}Sr$ ratios



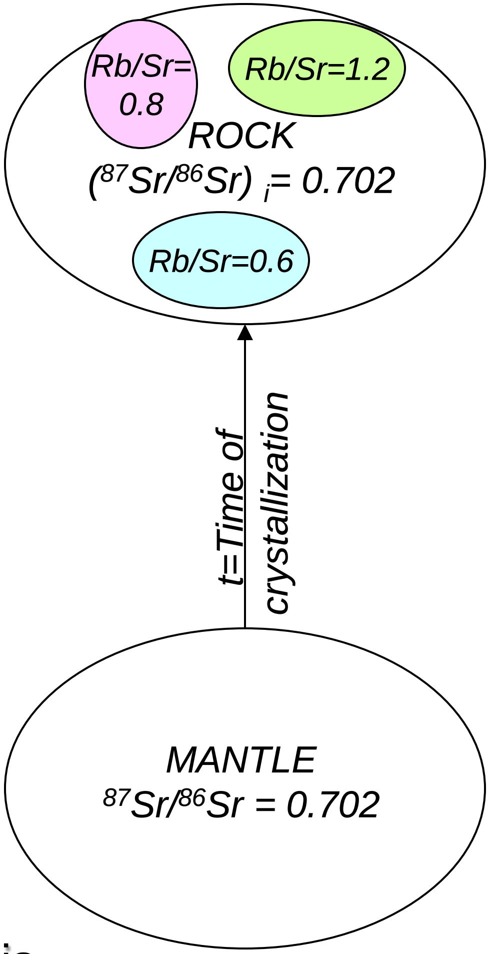


^{87}Rb goes into the melt

$^{87}Sr/^{86}Sr$ ratios of igneous rocks:	
MORB	0.7025
Ocean Islands	>0.704
Continents	0.7119

The Rb-Sr method

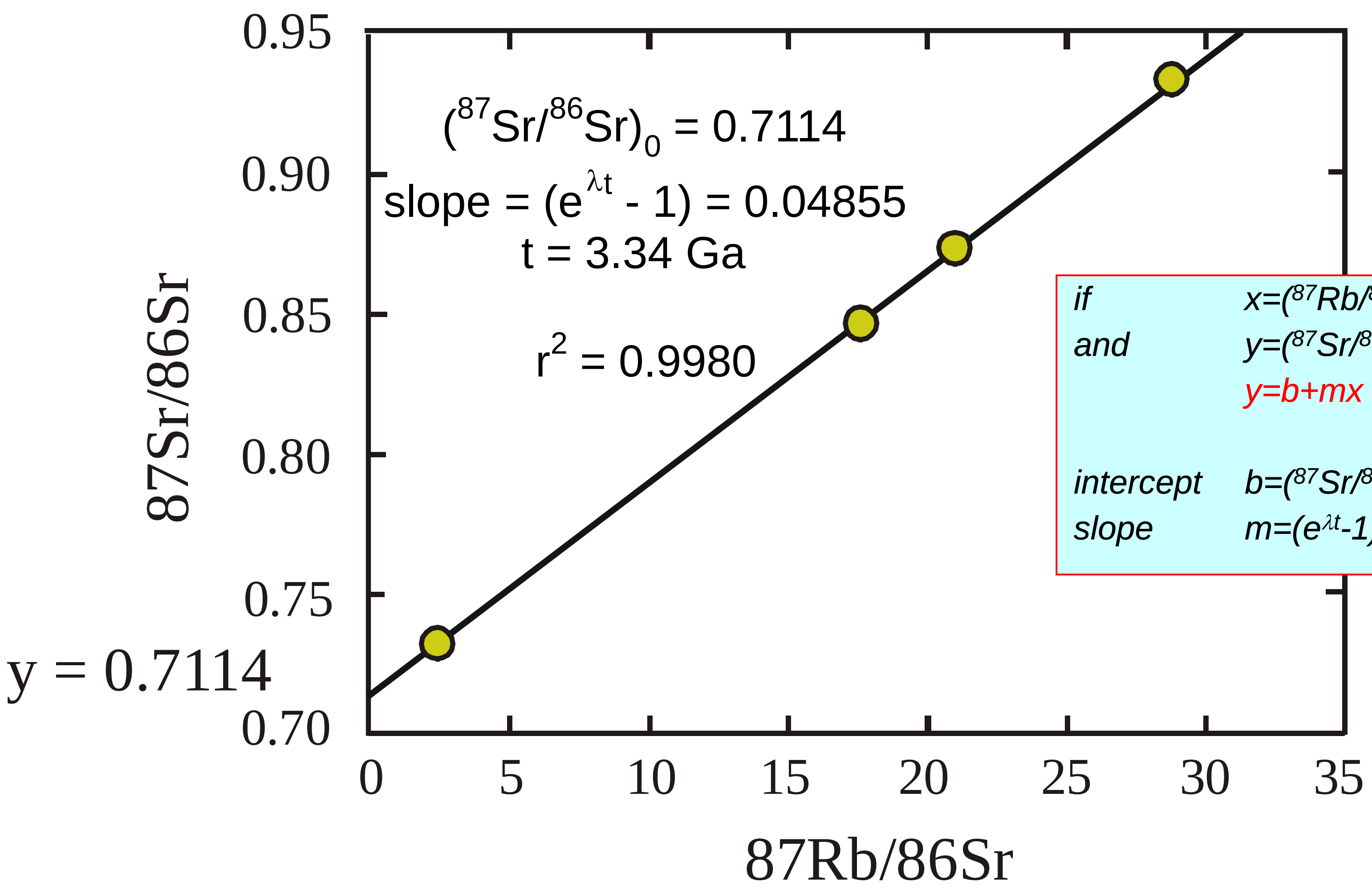
igneous rocks are heterogeneous, different mineral phases will have different Rb/Sr ratios, even though they have the same crystallization age and the same $^{87}Sr/^{86}Sr$ initial



how to get the initial $^{87}Sr/^{86}Sr$ ratio?

usually the isochron method is employed to determine the age and initial $^{87}Sr/^{86}Sr$ ratio of a suite of rock samples

Rb-Sr isochron diagram for a series of cogenetic rock samples formed at the same time



if	$x=(^{87}Rb/^{86}Sr)_m$
and	$y=(^{87}Sr/^{86}Sr)_m$
	$y=b+mx$
intercept	$b=(^{87}Sr/^{86}Sr)_i$
slope	$m=(e^{\lambda t}-1)$

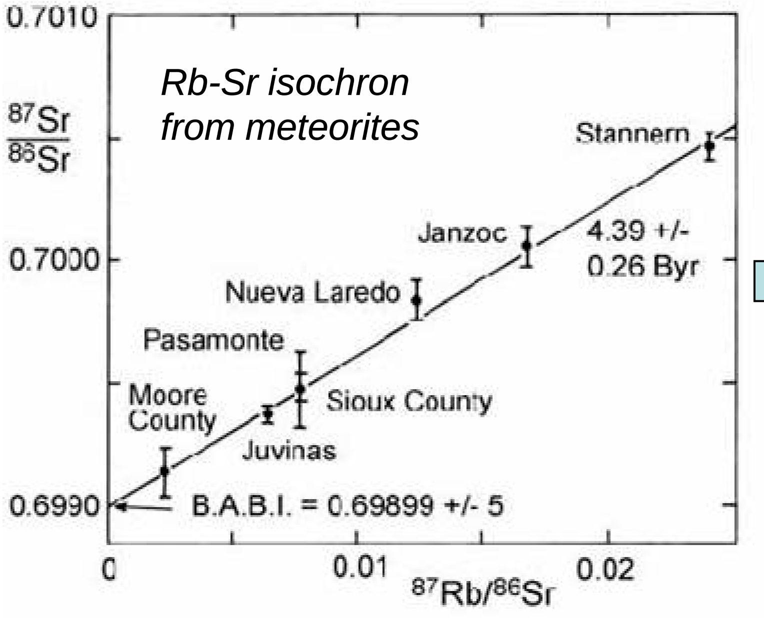
Exercise 11

Isochron (part II): regression treatment with pocket calculator

sample	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
L14	446.6	2.76164
L12	600.4	3.4311
L16	820.6	4.4054
L15	999.1	5.1927

The Rb-Sr method

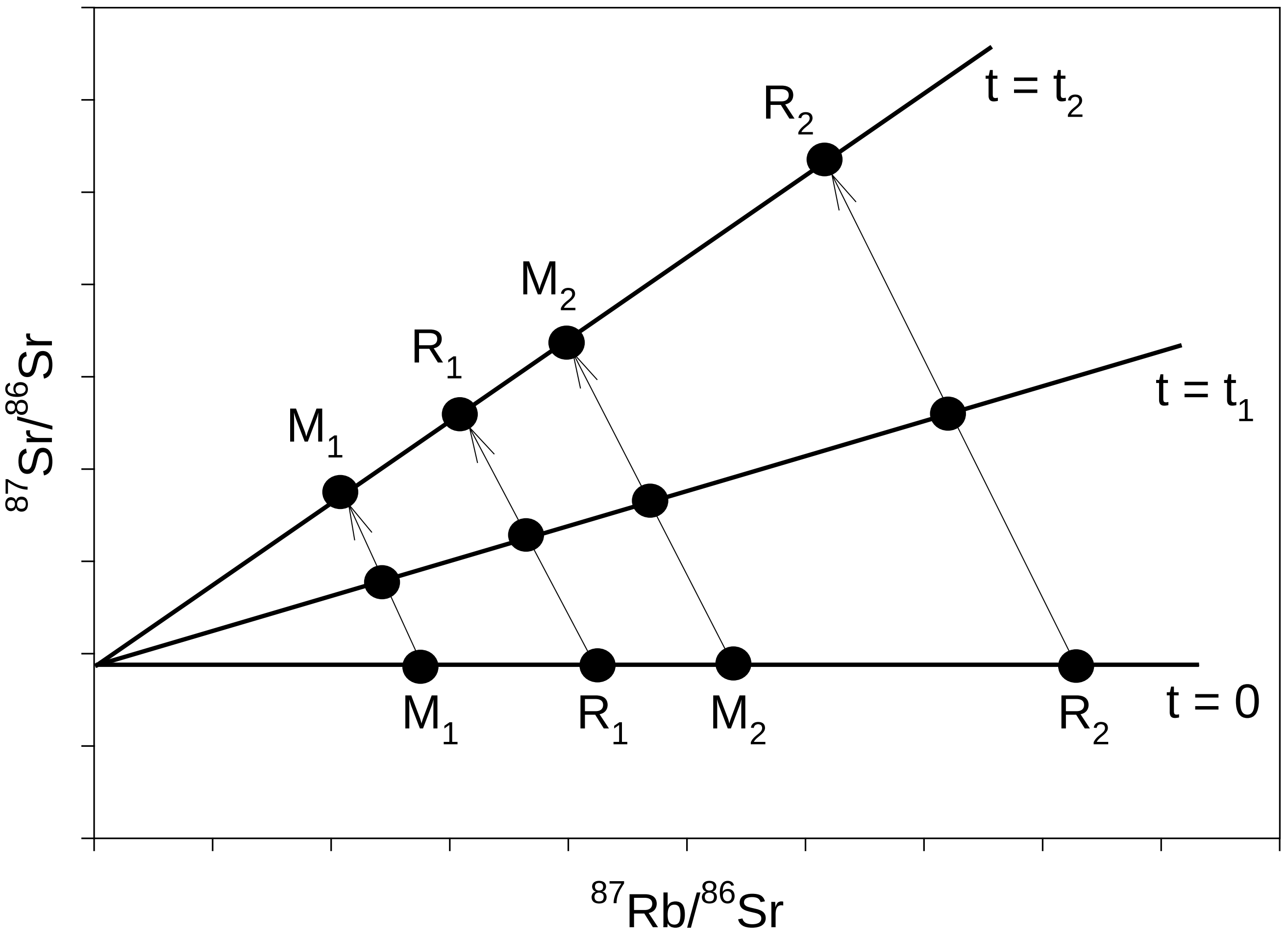
BABI - Basaltic Achondrite Best Initial = Bulk Earth, undifferentiated



T=4.5Ga

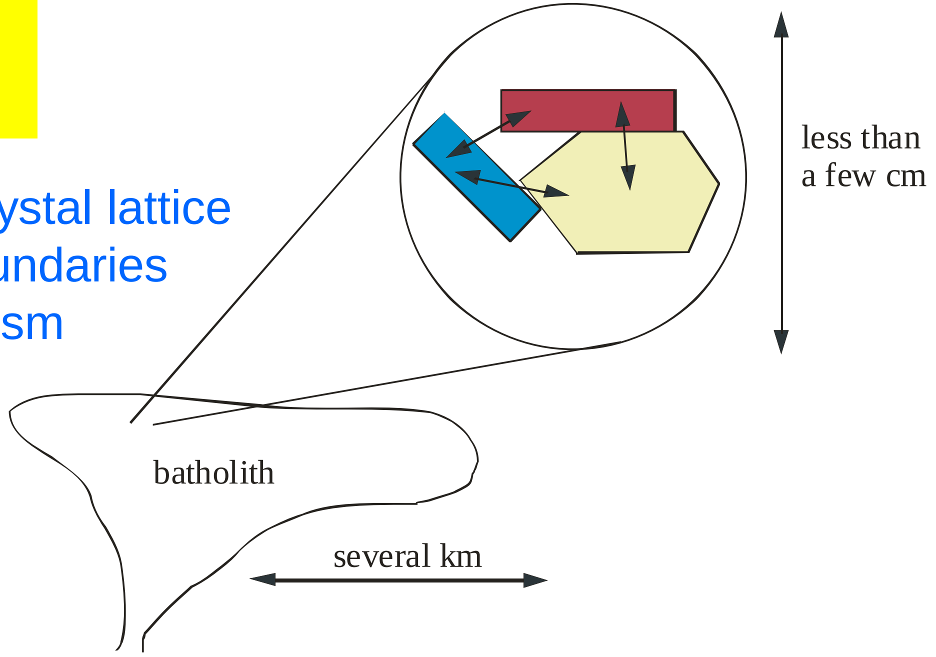
$^{87}Sr/^{86}Sr$ ratios of igneous rocks:	
MORB	0.7025
Continents	0.7119
Ocean Islands	>0.704
vs.	
Meteorites	0.699

Rb-Sr isochron diagram illustrating how the isochron evolves as a function of time. M_1 and M_2 are cogenetic minerals and R_1 and R_2 are cogenetic rocks, all with different initial Rb/Sr ratios

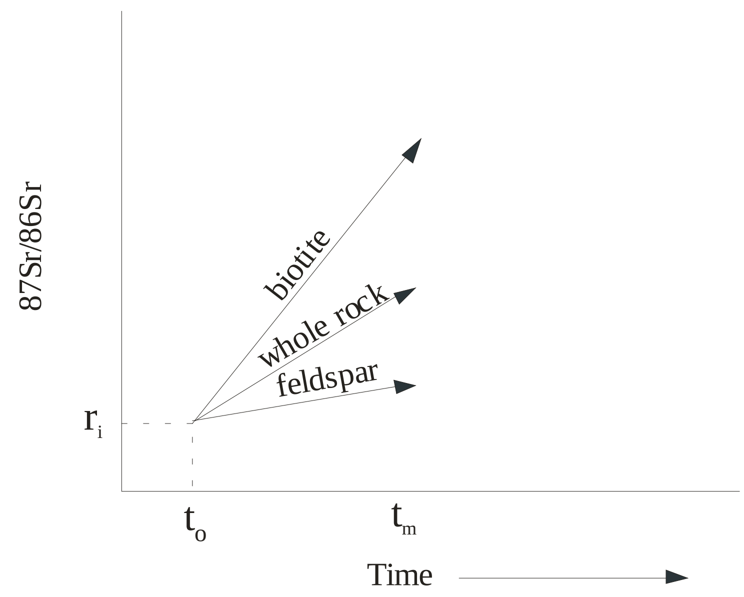


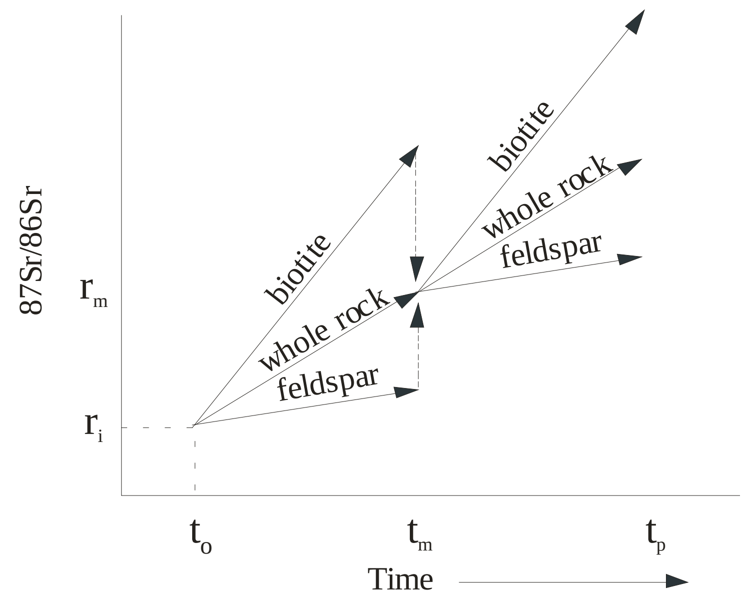
Response of Rb/Sr-system during metamorphism

diffusion through crystal lattice
and along grain boundaries
during metamorphism

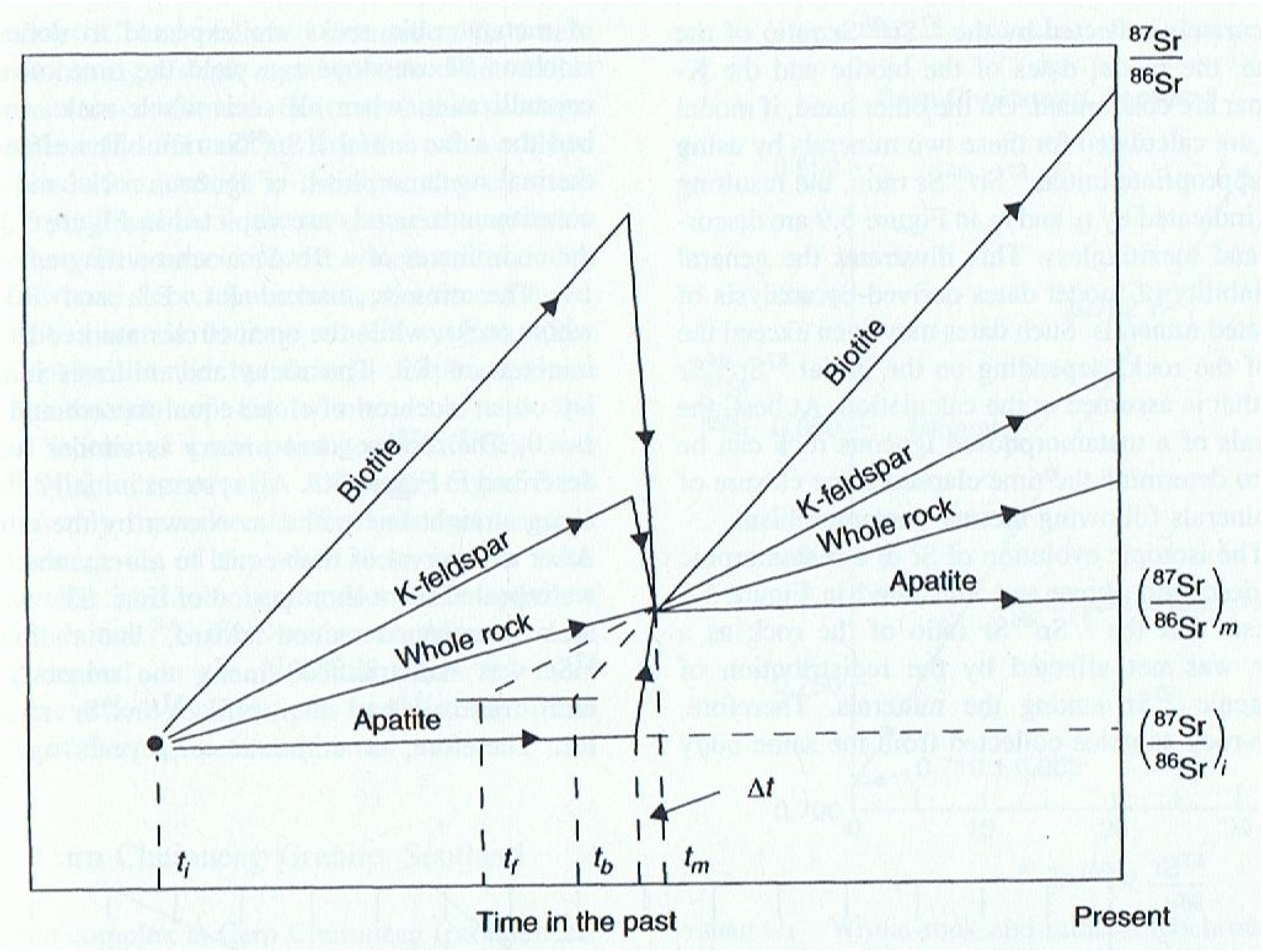


Response of Rb/Sr-system
during metamorphism

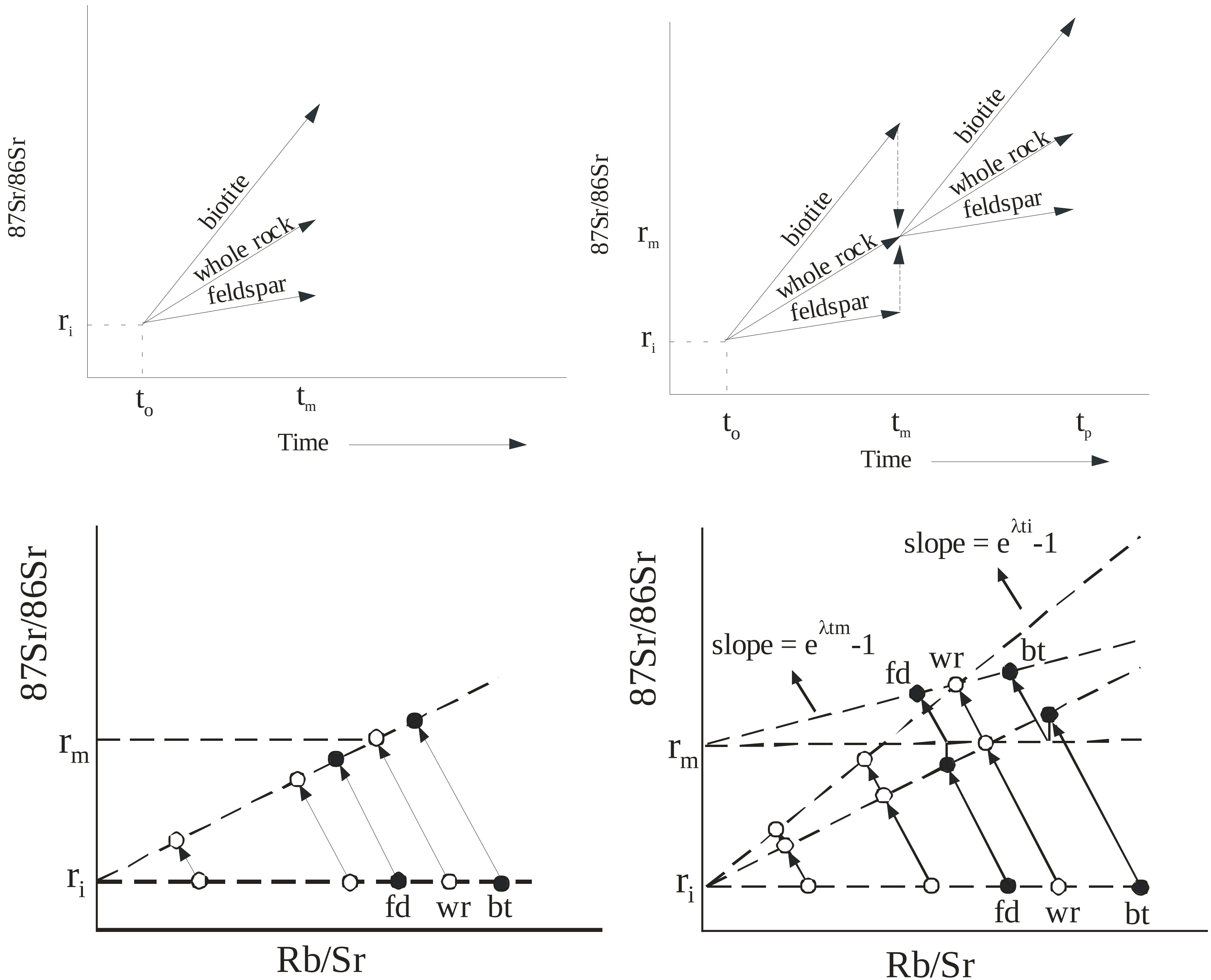




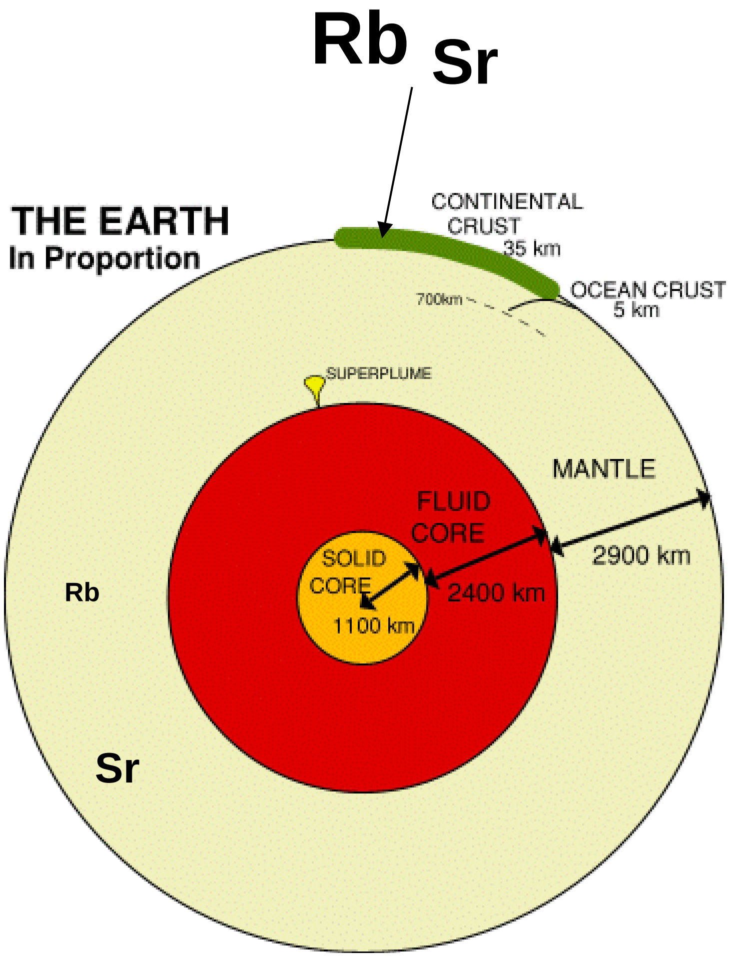
Response of Rb/Sr-system during metamorphism



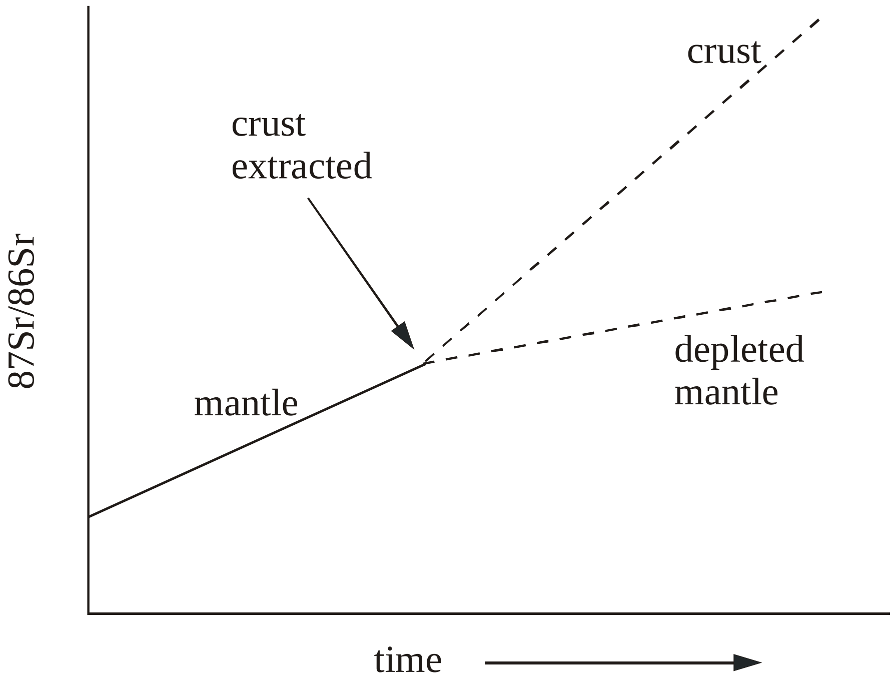
Response of Rb/Sr-system during metamorphism



Sr isotopic evolution of the Earth

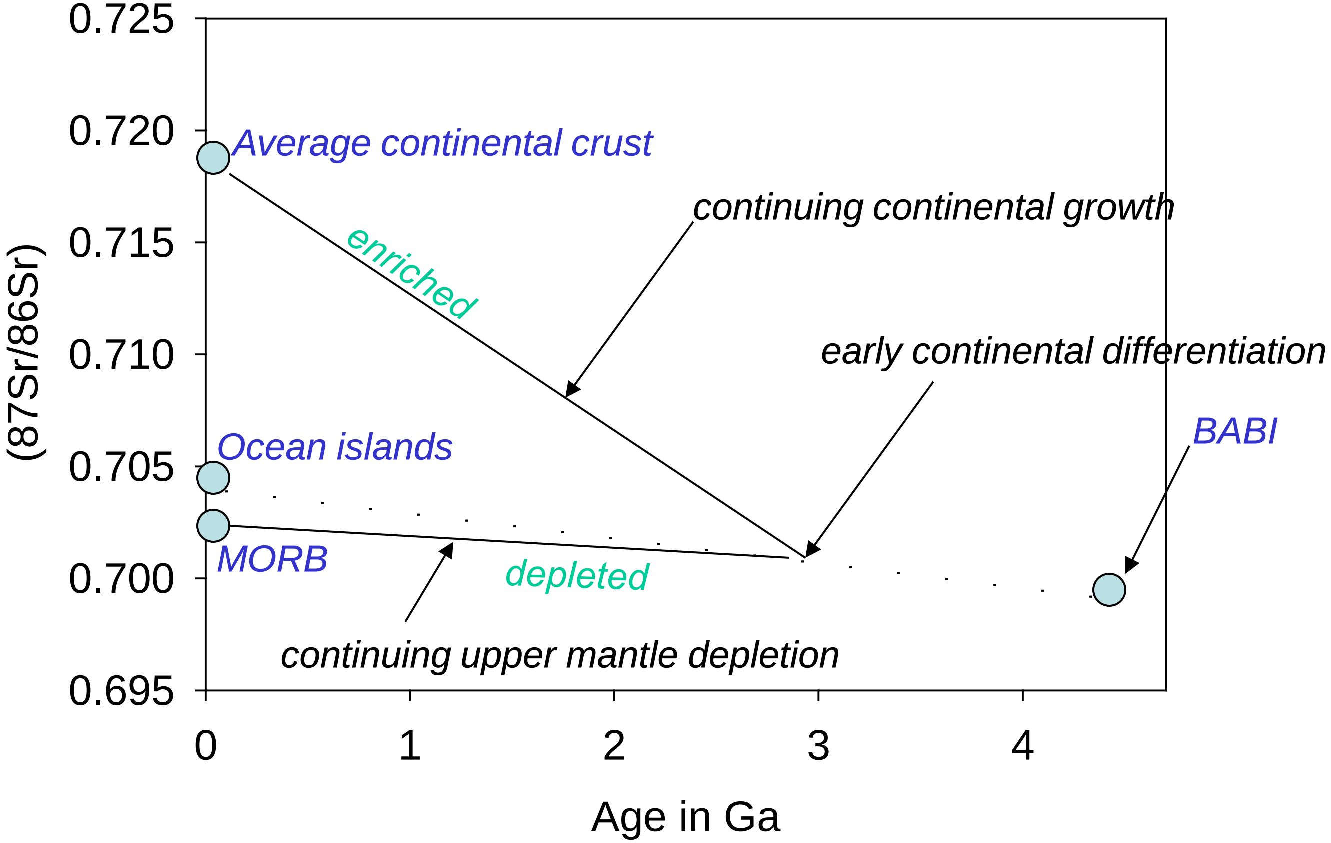


$^{87}Sr/^{86}Sr$ ratio of the crust is higher than that of the mantle due to the preferential partitioning of Rb into the crust relative to Sr.



Continental crust: 32-78 ppm Rb, 260-333 ppm Sr
Depleted Mantle: 0.6 ppm Rb, 19.9 ppm Sr

Tracking $(^{87}Sr/^{86}Sr)_i$ through time



$(^{87}Sr/^{86}Sr)_i$ ratios indicate how enriched or depleted its mantle source was
i.e. $(^{87}Sr/^{86}Sr)_i$ = 0.7020 at 1 Ga means a depleted source

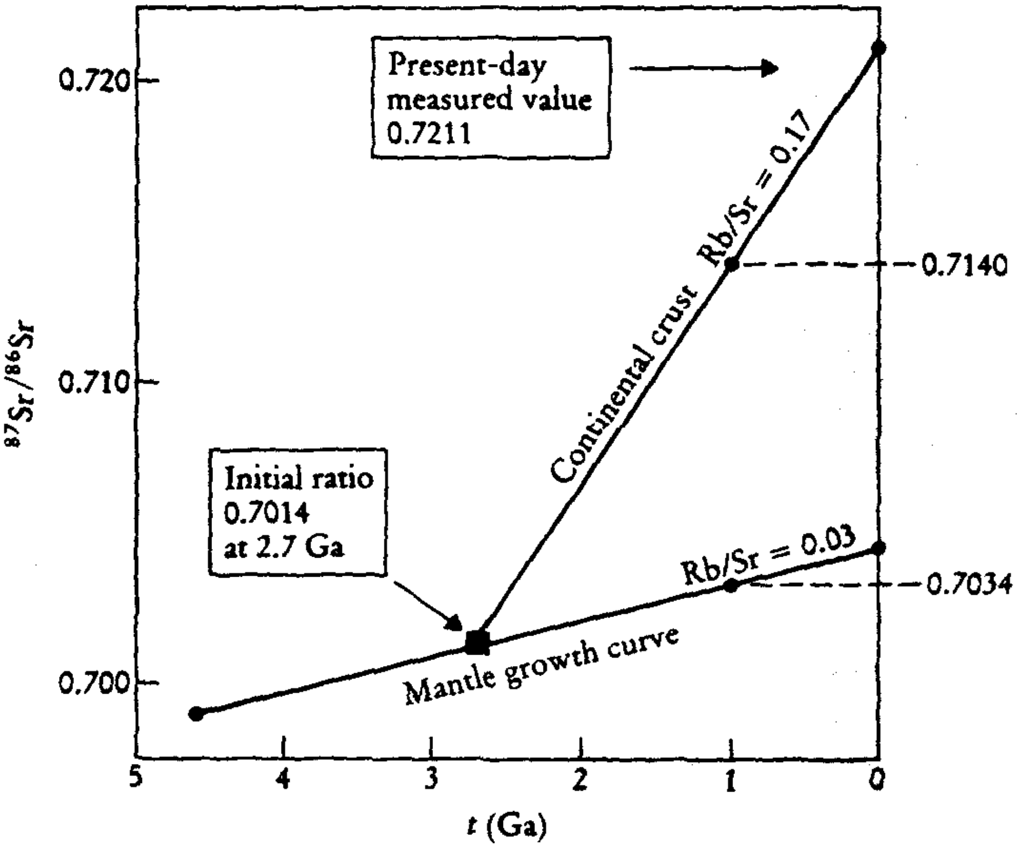
$(^{87}Sr/^{86}Sr)_i$ value of 0.728 at 1 Ga?

The evolution of $^{87}Sr/^{86}Sr$ with time in the continental crust and mantle

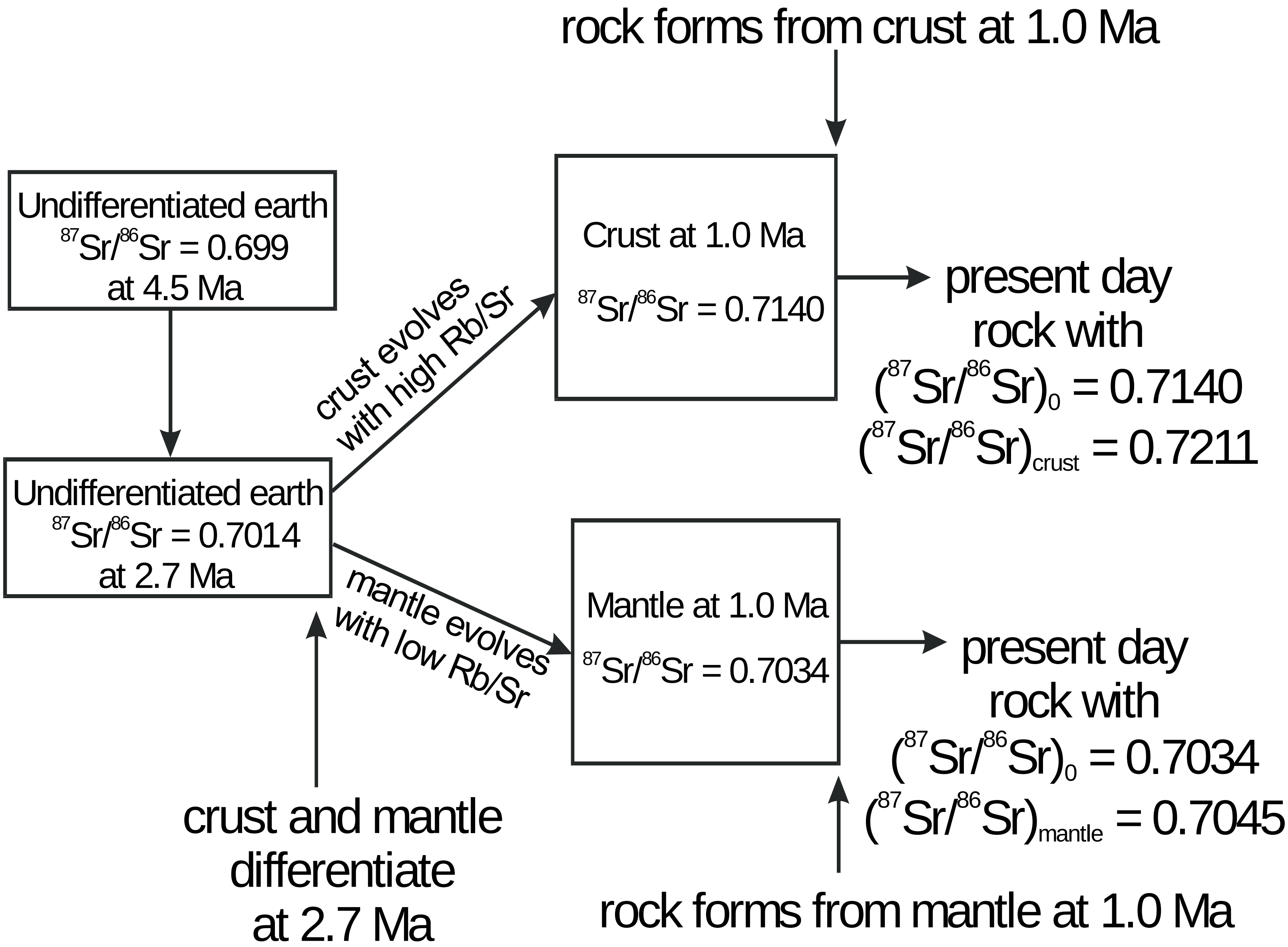
$(^{87}Sr/^{86}Sr)_0$ ratios can be used as a tracer to determine if a magma evolved from the mantle or if crust was involved

For mantle-derived rocks:
$(^{87}Sr/^{86}Sr)_0 \approx 0.700\text{-}0.706$

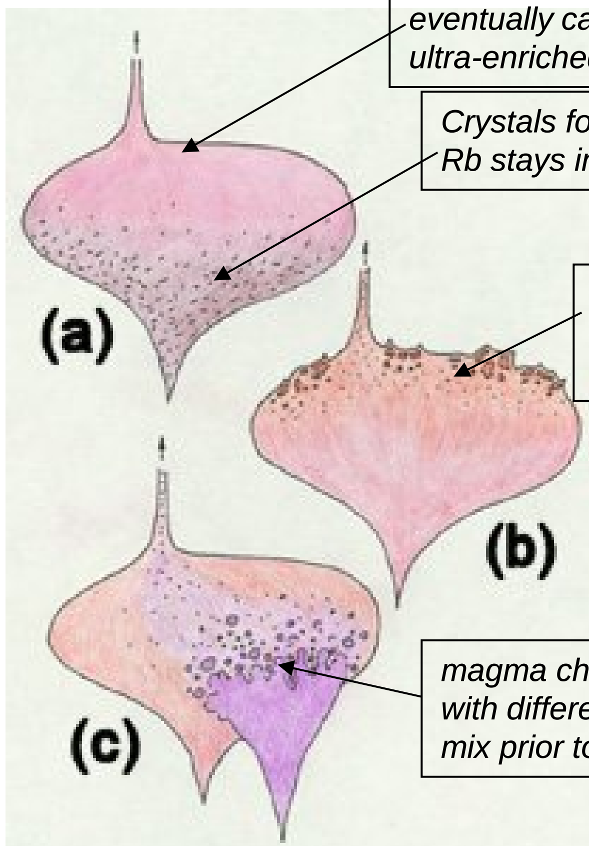
For crustal involvement:
$(^{87}Sr/^{86}Sr)_0 \approx 0.705\text{-}0.740$



Sr isotopes as tracer of rock origin



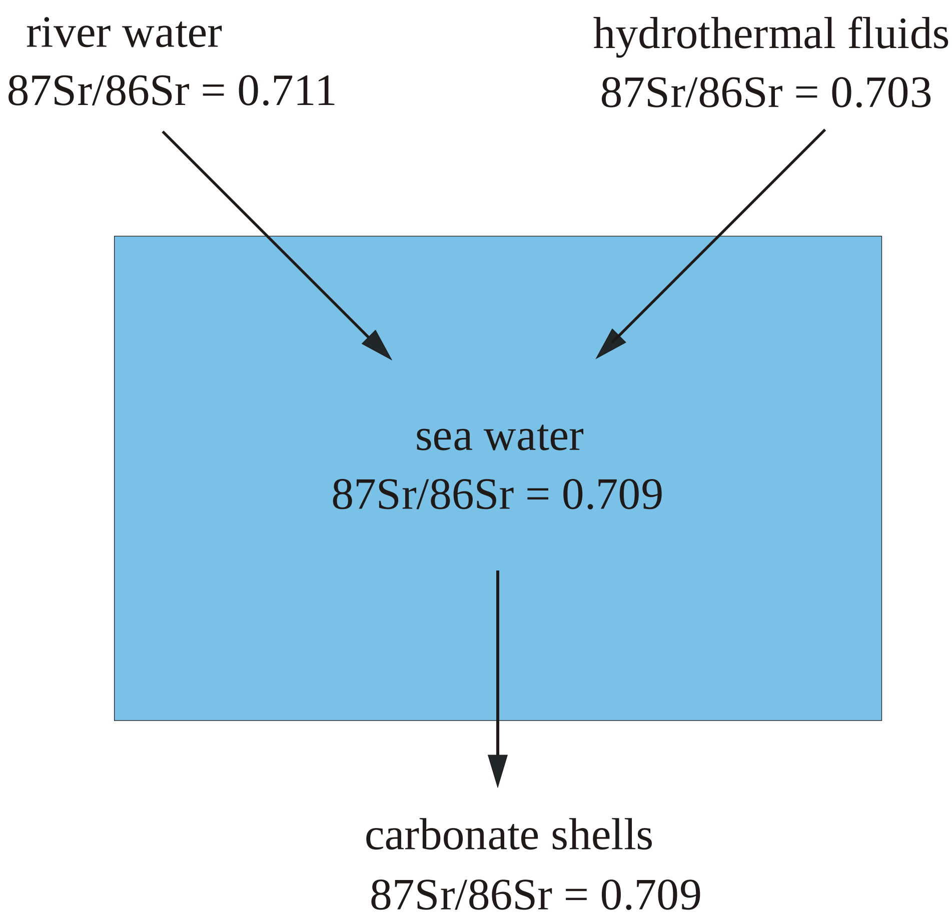
Sr isotopes as tracer of rock origin

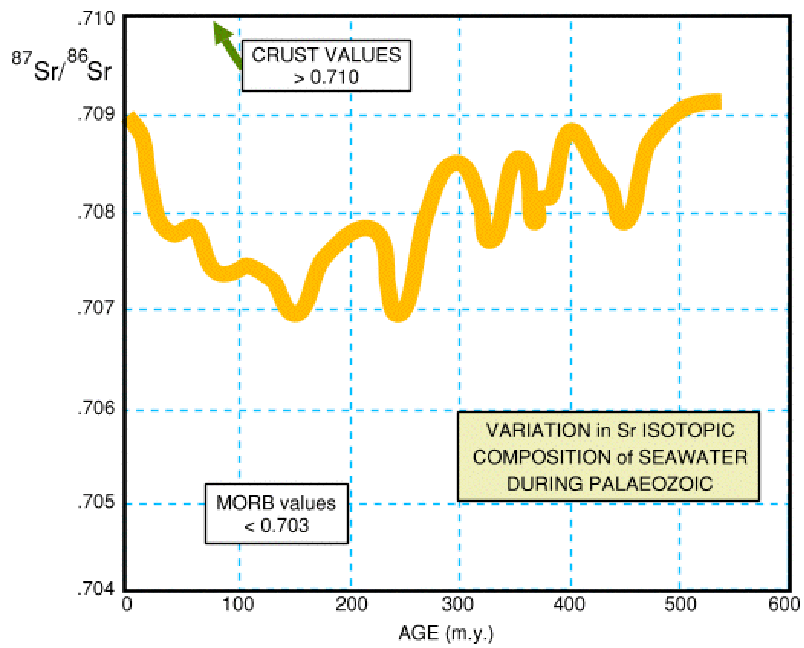


Sr in the oceans through time

Sr isotope composition of the oceans is determined by the relative contributions of Sr from river waters and hydrothermal sources

Why is the river Sr isotope value the highest?
Why is the hydrothermal Sr isotope value the lowest?
Why is carbonate recrystallization Sr isotope value equal to that of seawater?



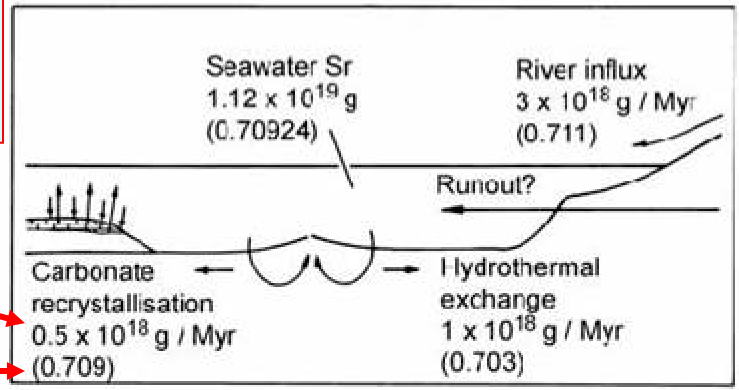


Sr in the oceans through time

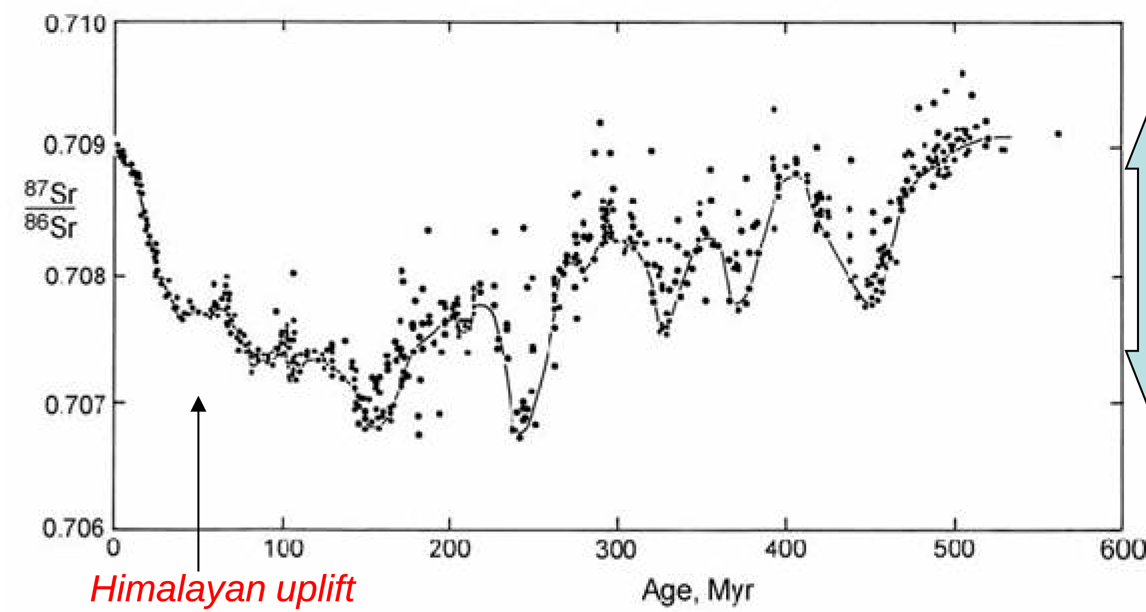
Controls on seawater Sr isotopic composition

Sr flux rate

Sr isotope ratio



Seawater Sr Isotopic Curve (as measured on old and young carbonates)

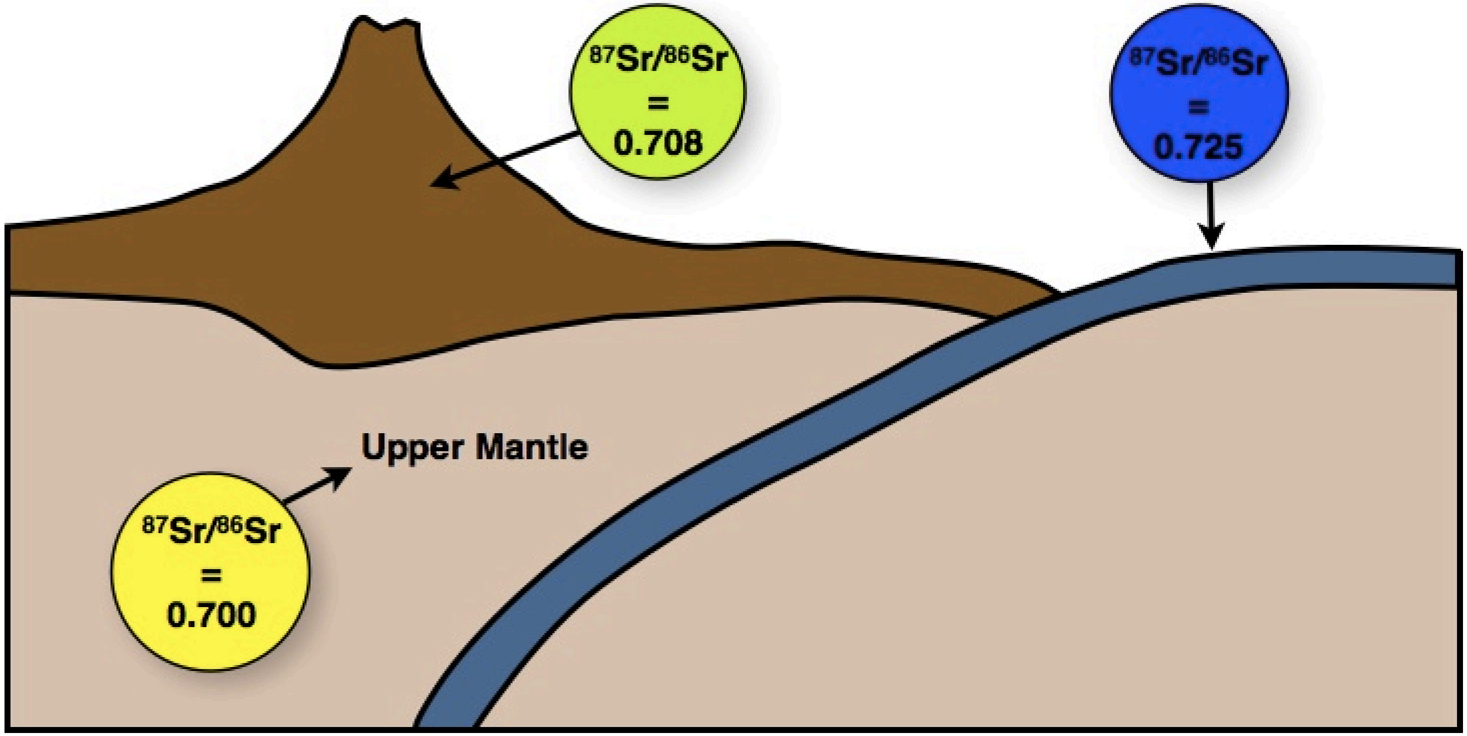


Himalayan uplift

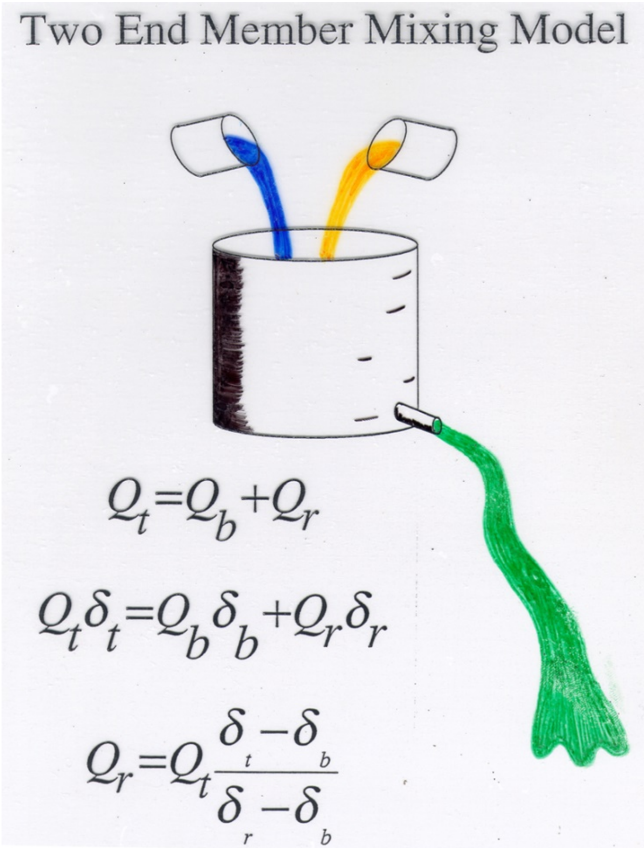
mountain-building

hydrothermal activity

Elemental- and isotopic mixtures



Binary mixtures



$$f_A = A / (A + B)$$

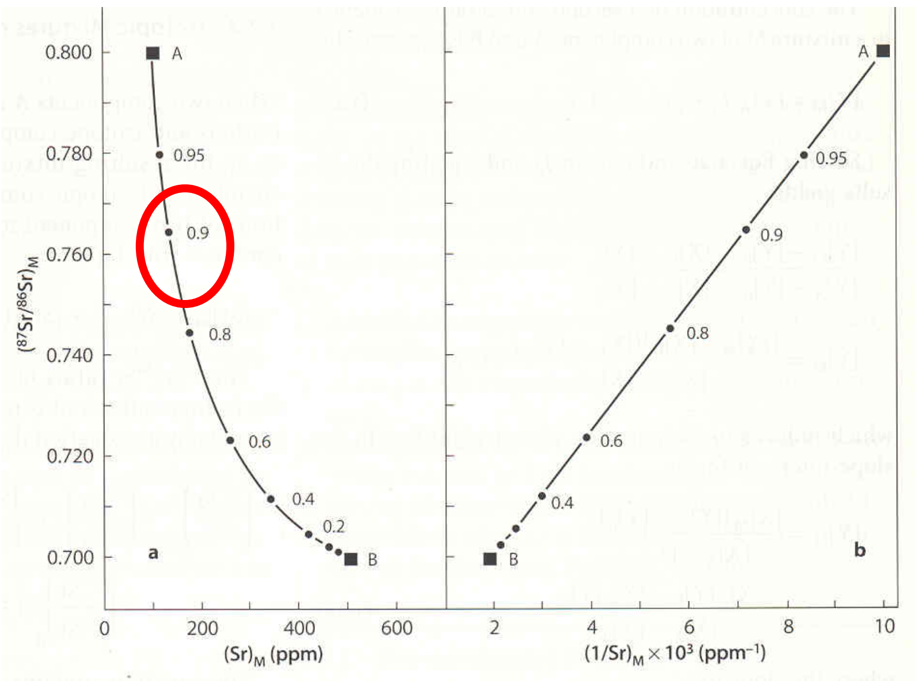
$$f_B = 1 - f_A$$

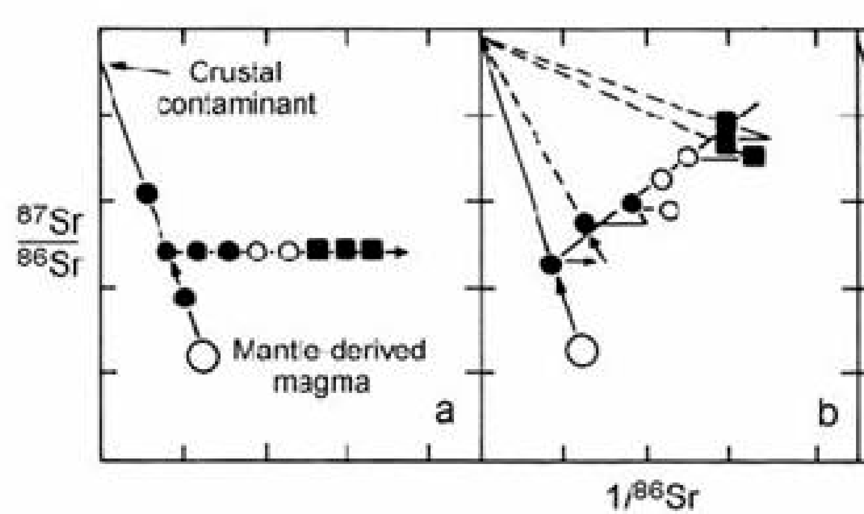
$$(X)_M = (X)_A f_A + (X)_B (1 - f_A)$$

$$\left(\frac{^{87}Sr}{^{86}Sr}\right)_M = \left(\frac{^{87}Sr}{^{86}Sr}\right)_A \times f_A \left(\frac{Sr_A}{Sr_M}\right) + \left(\frac{^{87}Sr}{^{86}Sr}\right)_B \times (1 - f_A) \left(\frac{Sr_B}{Sr_M}\right)$$

Binary mixtures

	Component A	Component B
Sr	100 ppm	500 ppm
$^{87}Sr/^{86}Sr$	0.800	0.700





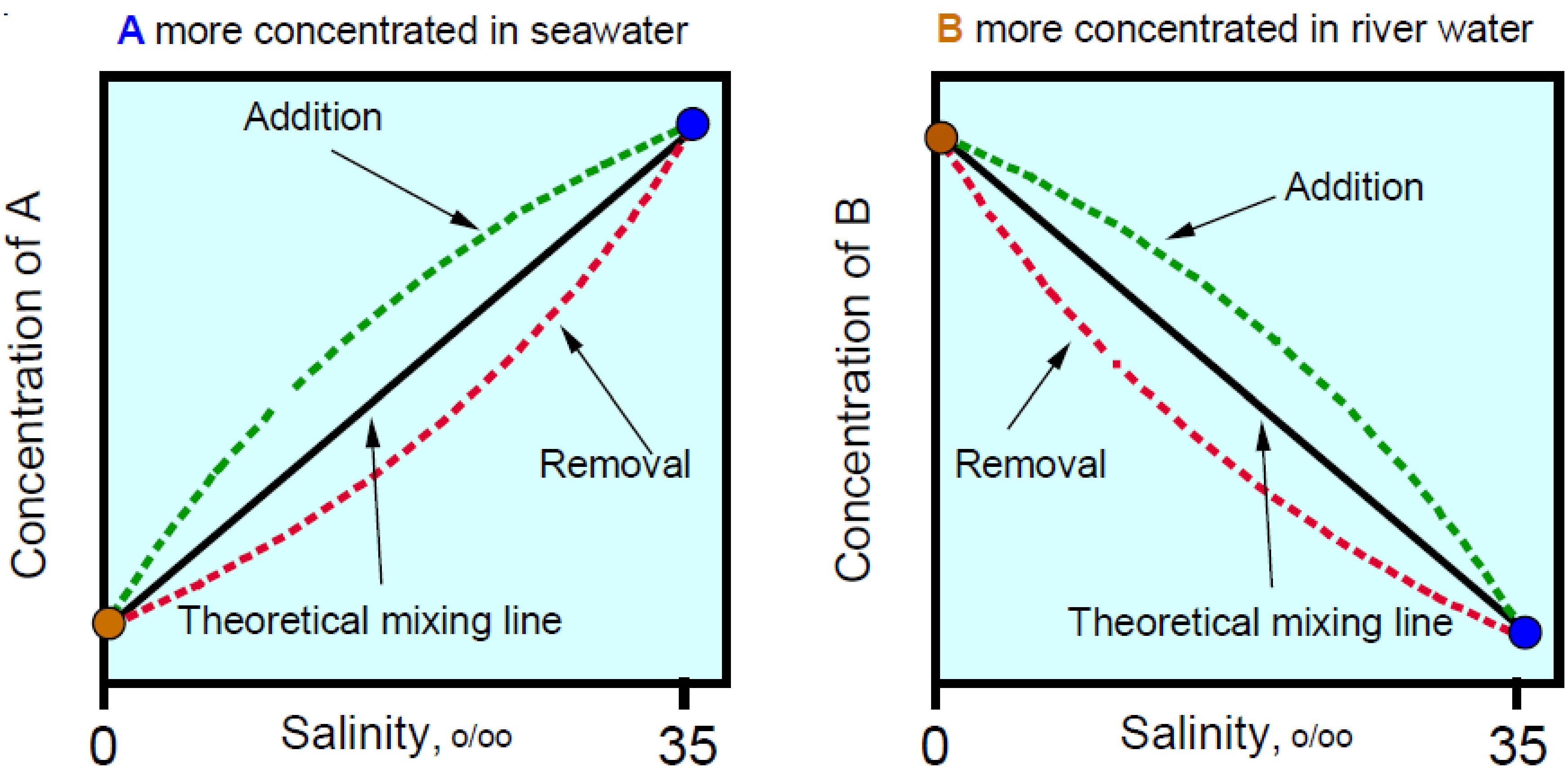
Briquet & Lancelot 1979

$$(X)_M = (X)_A f_A + (X)_B(1-f_A)$$

$$\left(\frac{^{87}Sr}{^{86}Sr}\right)_M = \left(\frac{^{87}Sr}{^{86}Sr}\right)_A \times f_A\left(\frac{Sr_A}{Sr_M}\right) + \left(\frac{^{87}Sr}{^{86}Sr}\right)_B \times (1-f_A)\left(\frac{Sr_B}{Sr_M}\right)$$

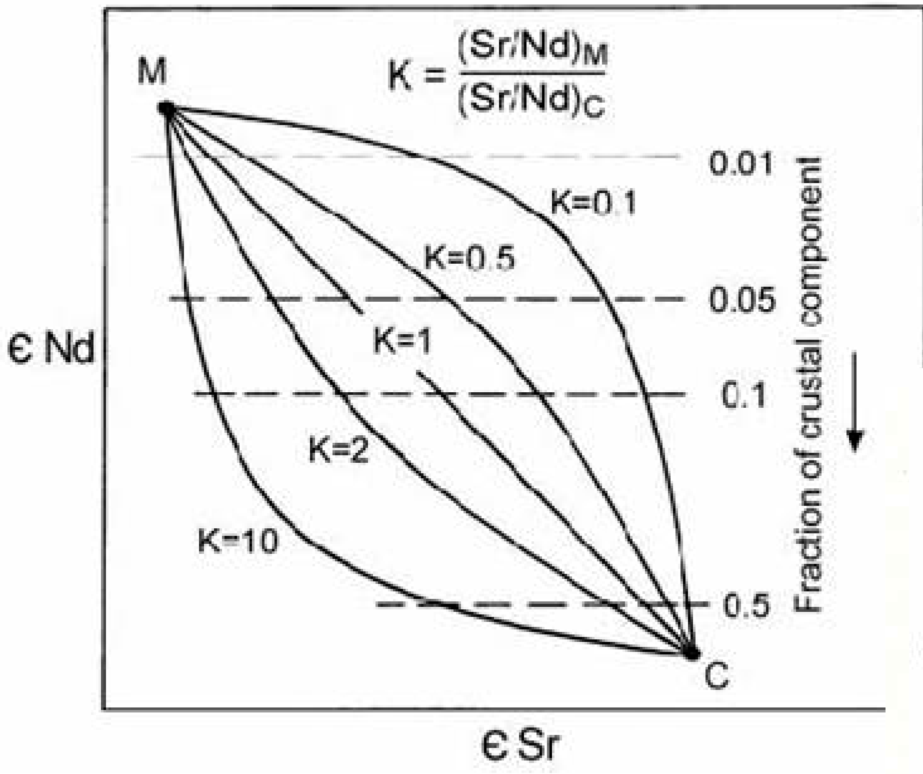
G. Faure, 1977, 2005

Water mixing in estuaries

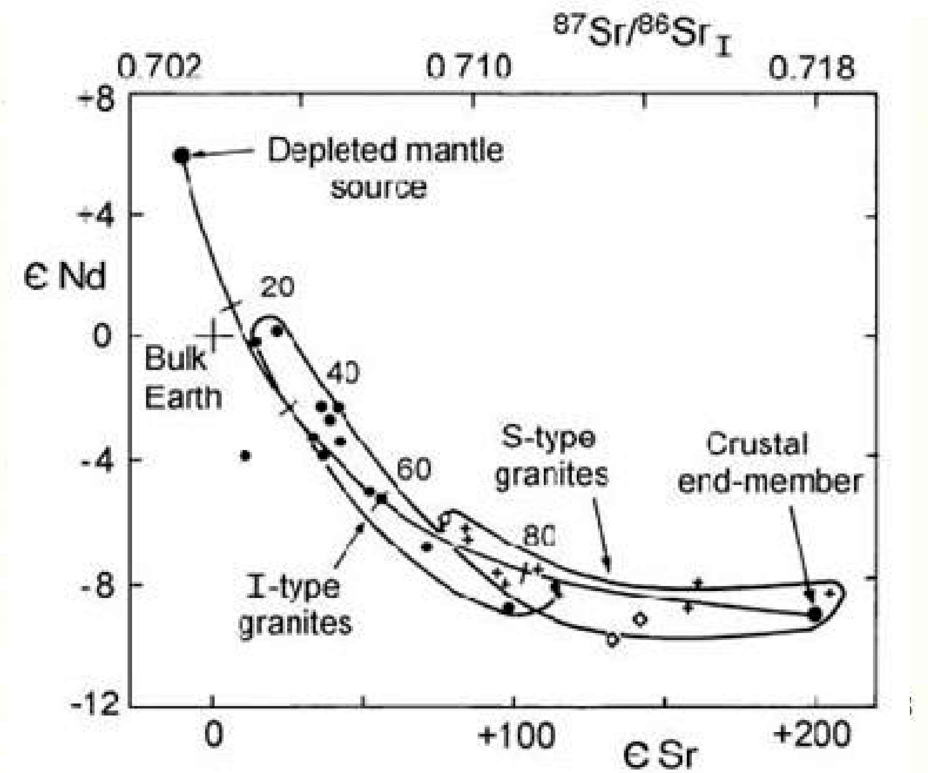


Chester *Marine Geochemistry*

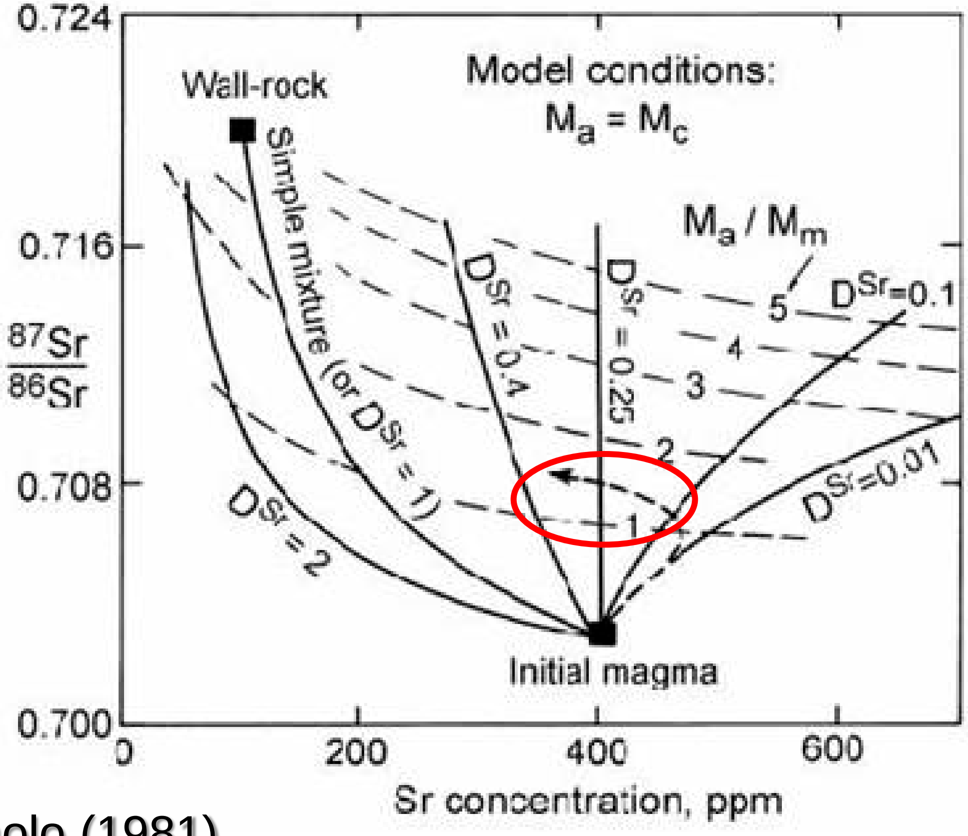
Models for crustal contamination



DePaolo & Wasserburg (1979)

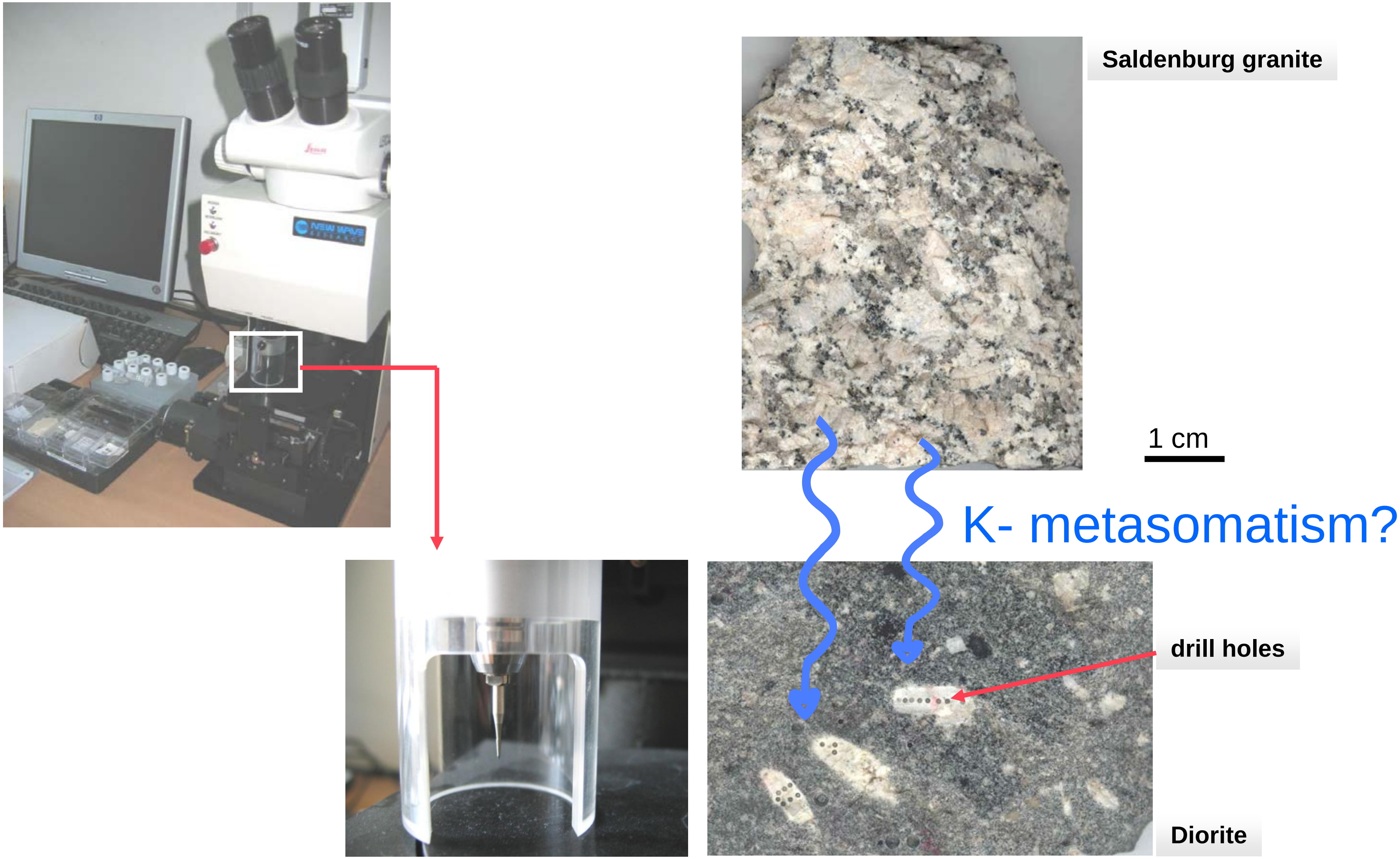


AFC - process

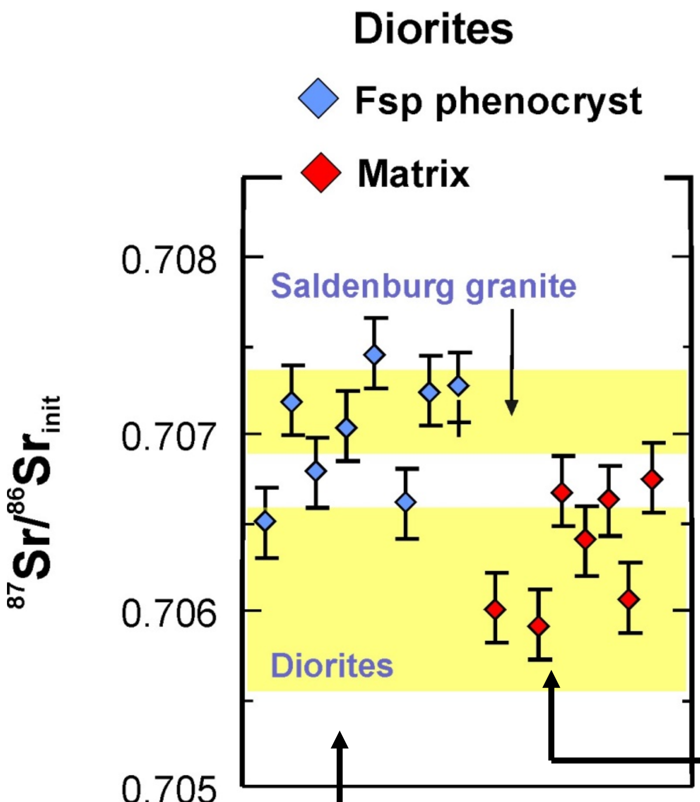


DePaolo (1981)

Sr isotopic fingerprinting

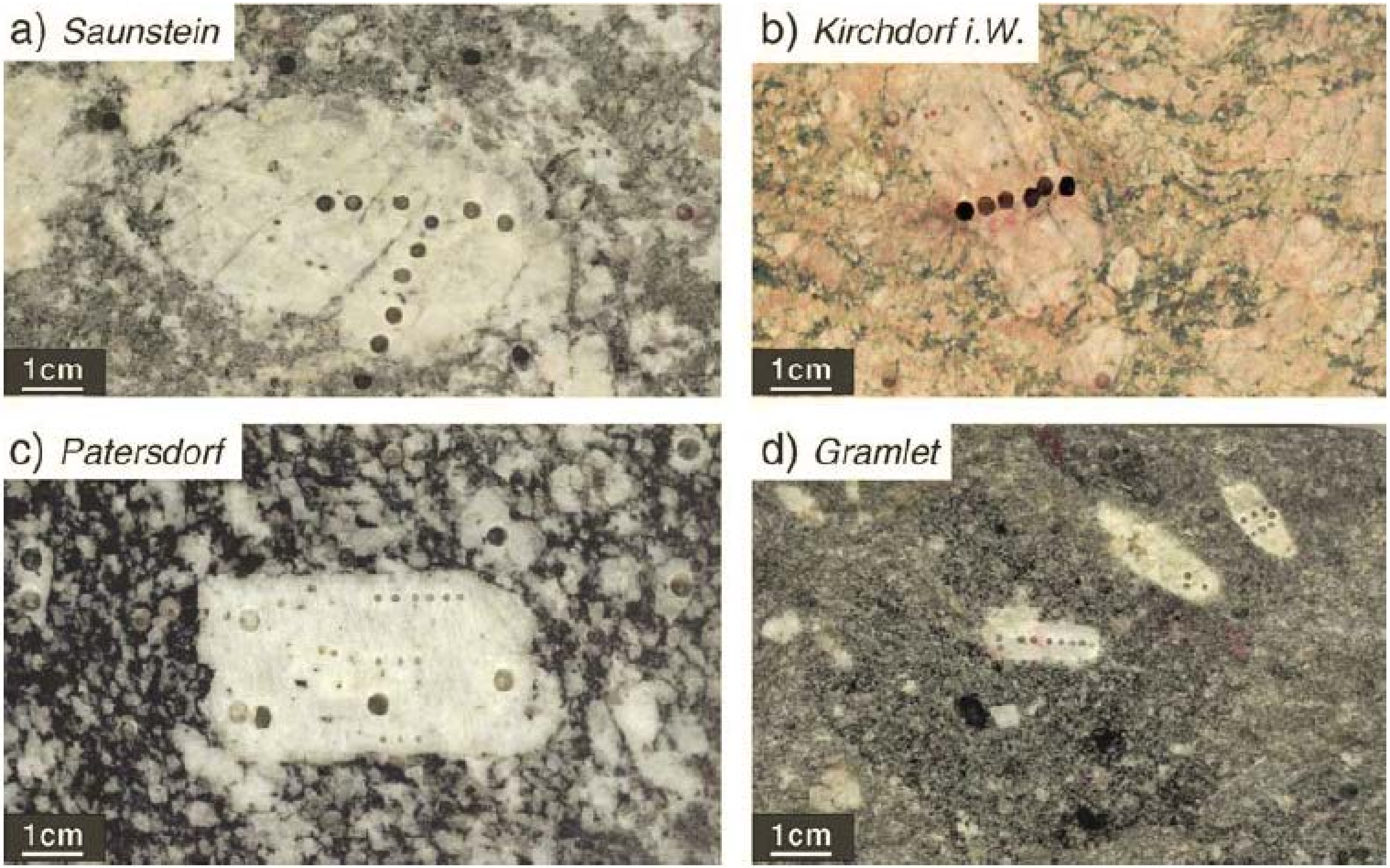


Sr isotope fingerprinting



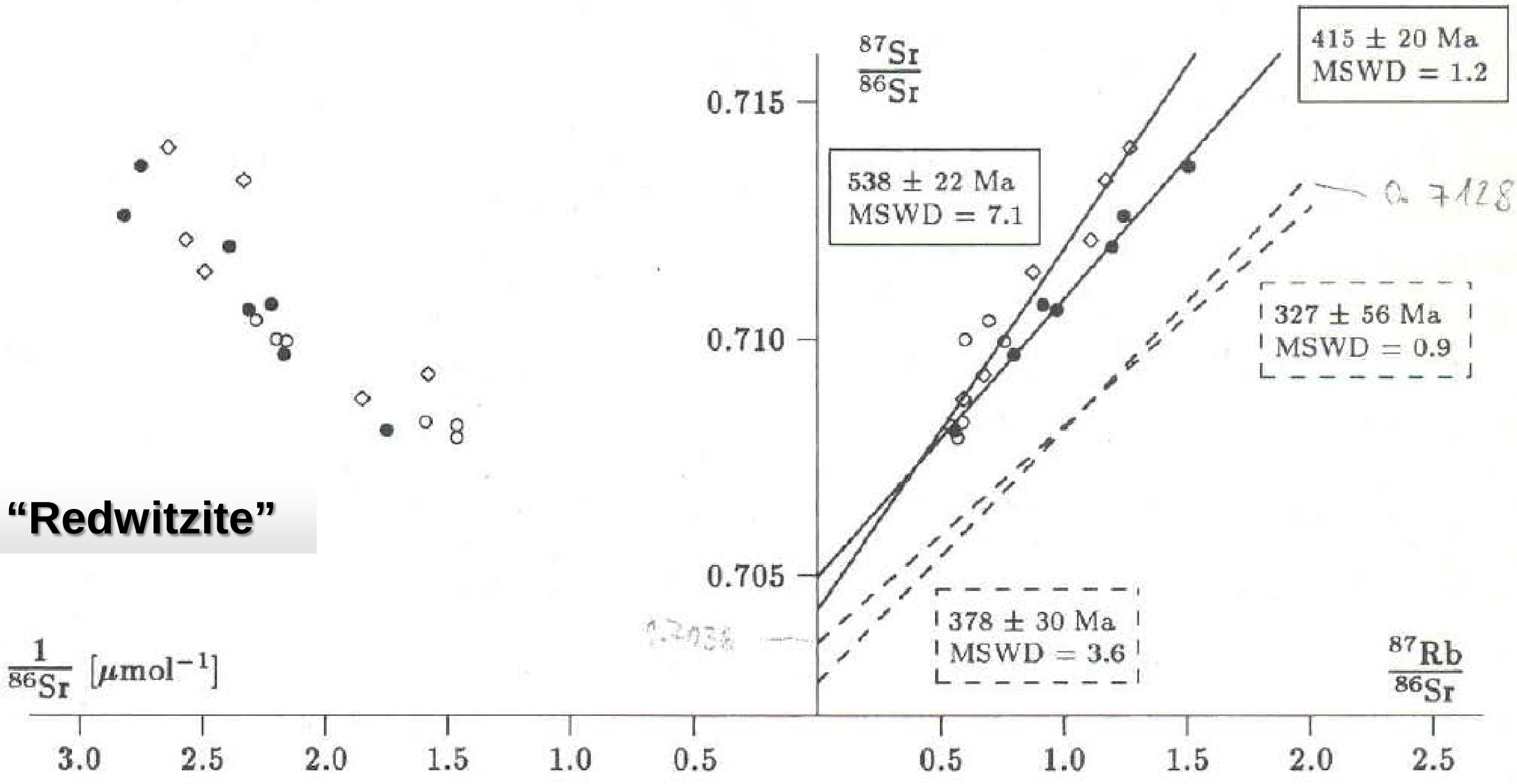
Siebel et al. (2005)
Chem Geol 222

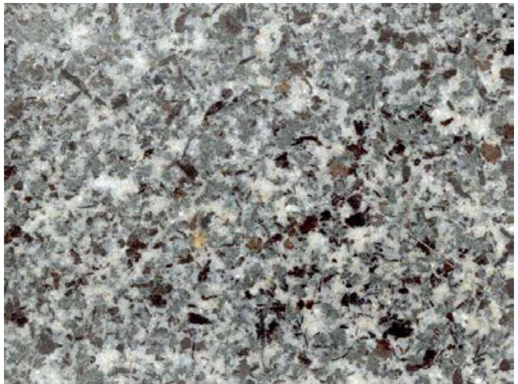
Sr isotope fingerprinting



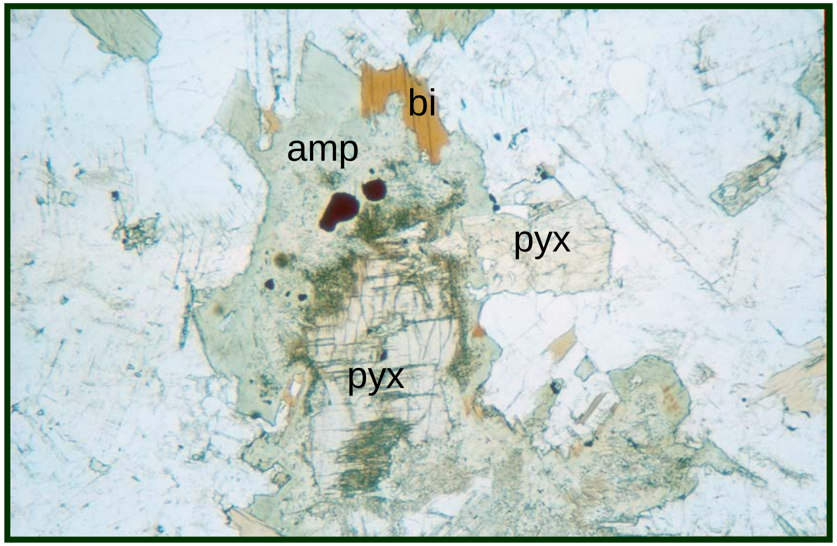
Isochron or mixing line?

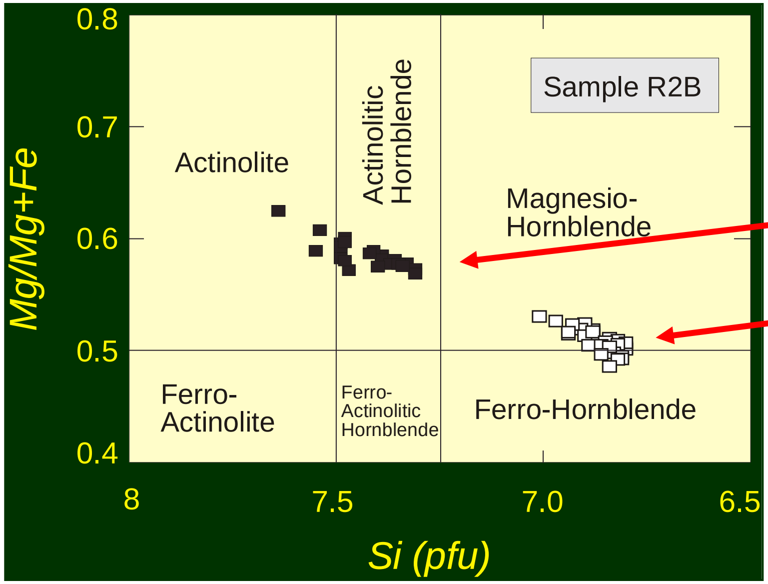
“Redwitzite”

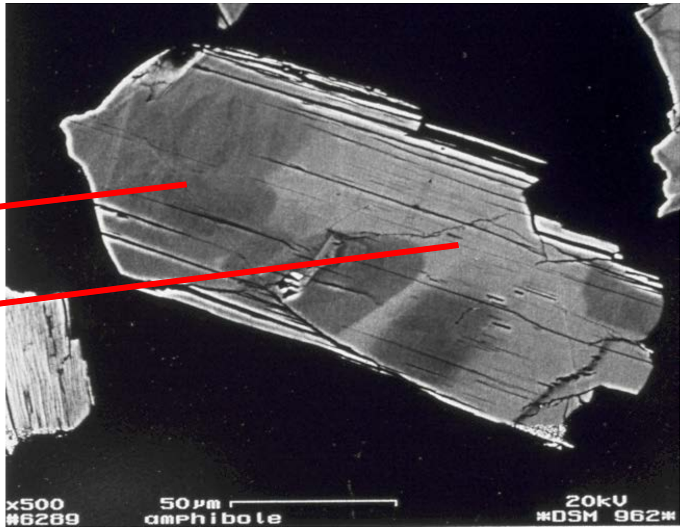




“Redwitzites”: amphibole composition

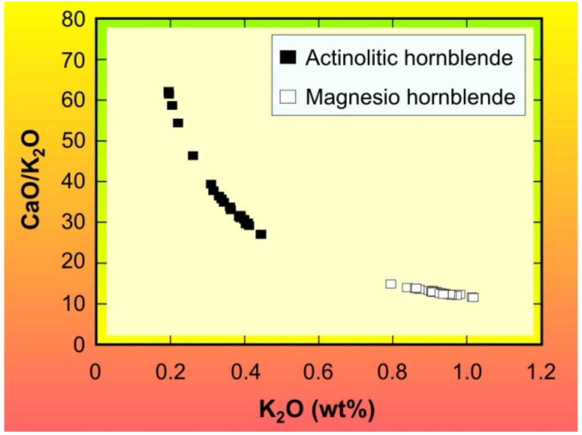






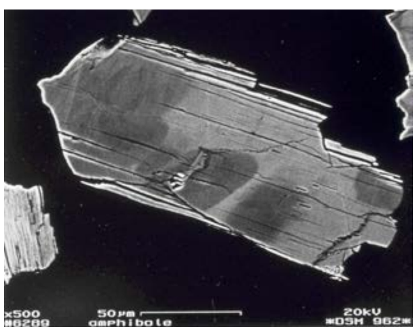
Siebel et al. (1998) Geology 26

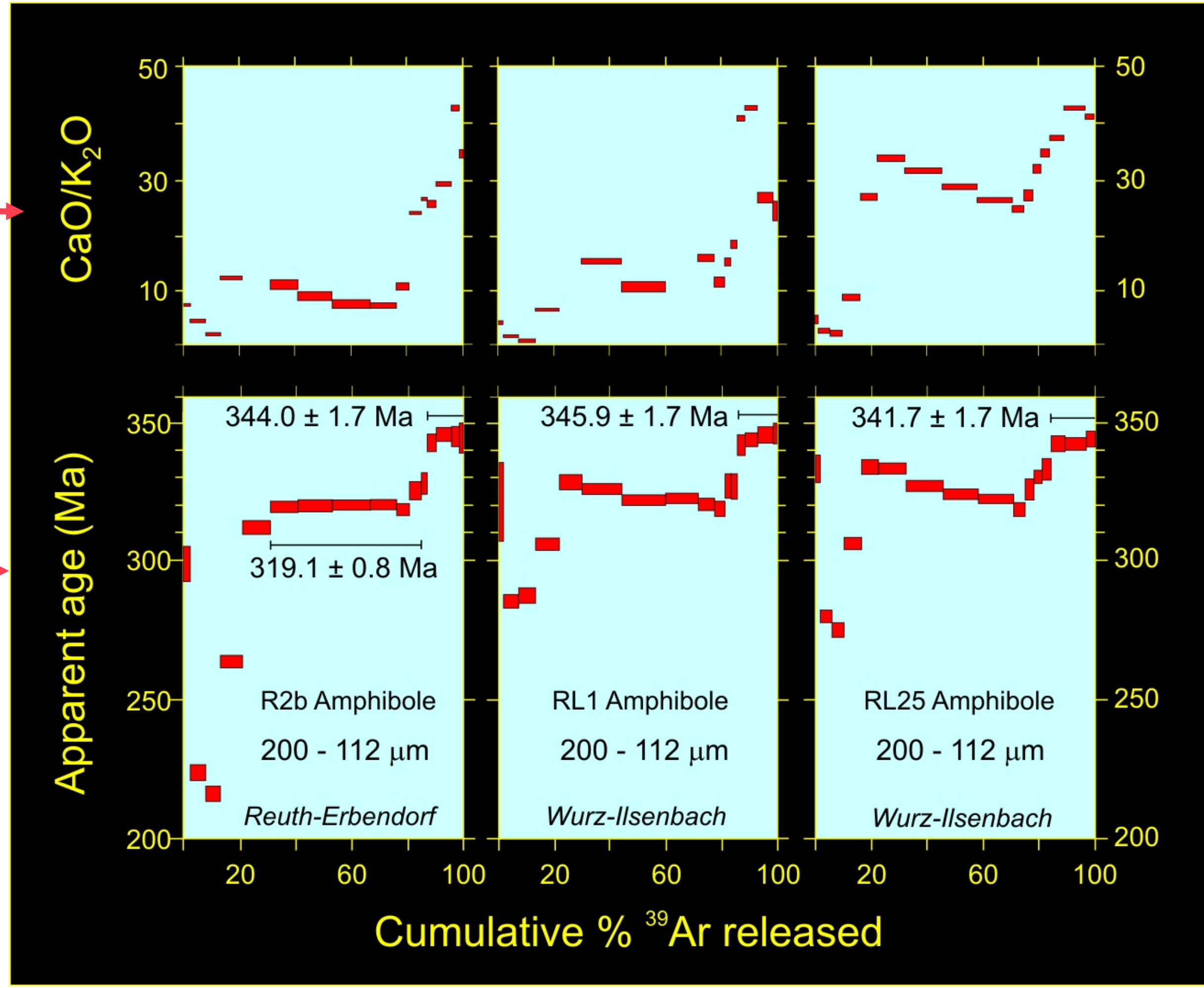
"Redwitzites": ^{40}Ar-^{39}Ar geochronology



$^{37}Ar/^{39}Ar$ ~ Ca/K

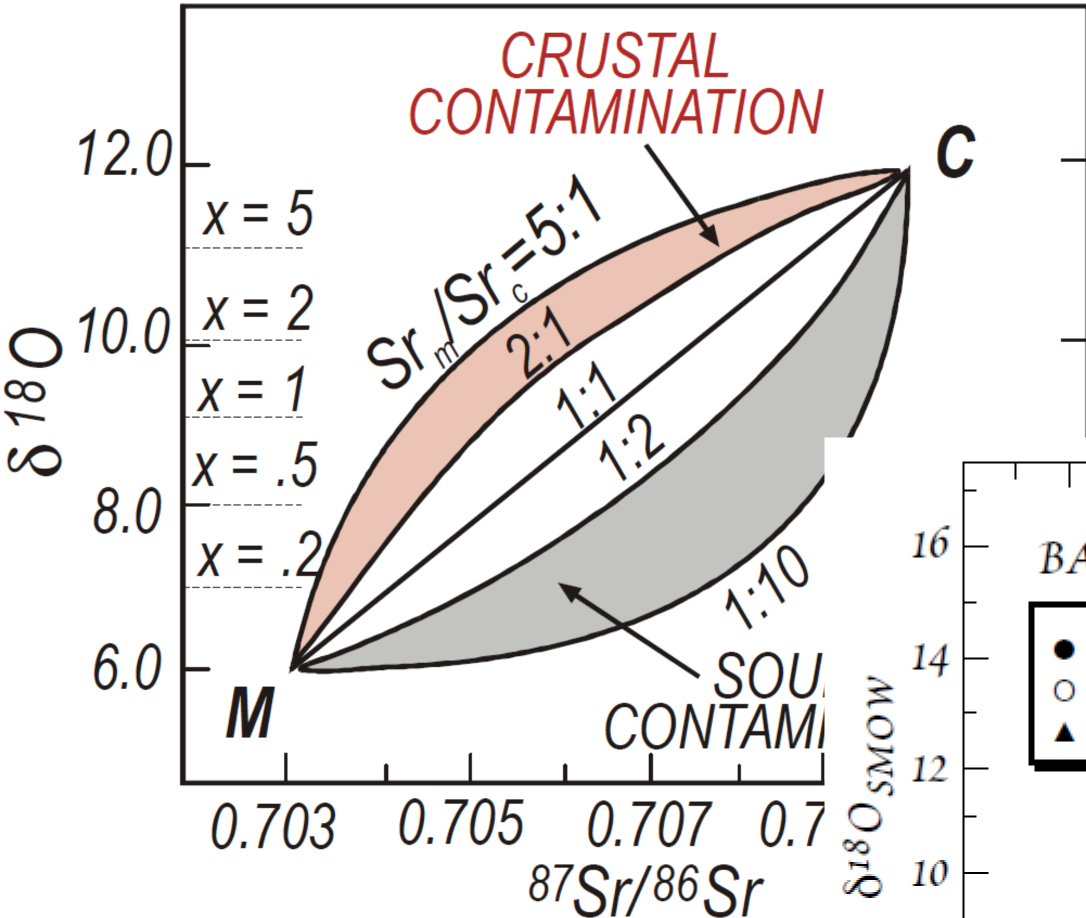
$^{40}Ar/^{39}Ar$ ~ age



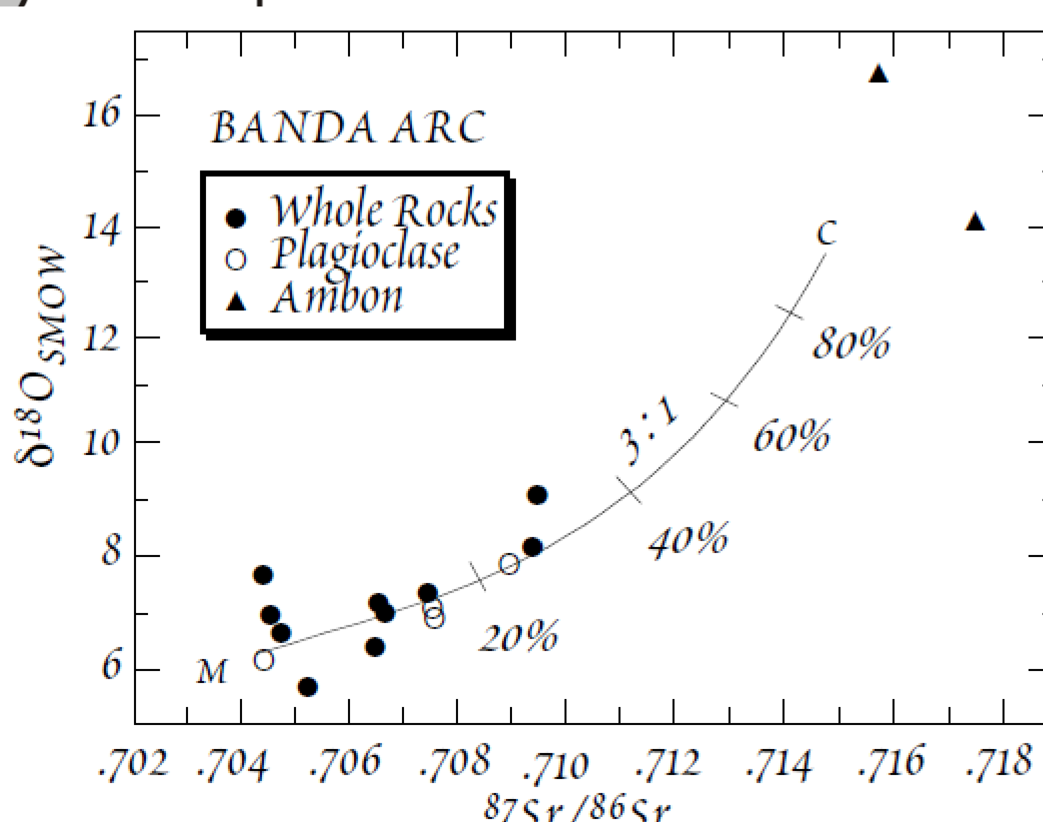


Siebel et al. (1998) Geology 26

Source contamination vs. crustal contamination



White: Geochemistry Lec. 31



Magaritz et al. (1978) EPSL 40: 220-230

James (1981) J. Geol Soc Lond 141:823-830