Isotopes

Same Z, different A (variable # of neutrons)

General notation for a nuclide: $^{14}_{6}\mathrm{C}$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.0079																	2 He 4.0026
2	3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.941	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.8
5	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (97.91)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.6	53 I 126.9	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261.1)	105 Db (262.1)	106 Sg (263.1)	107 Bh (262.1)	108 Hs (265.1)	109 Mt (266.1)	110 Uun (269)	111 Uuu (272)	112 Uub (277)						

Isotopes

Same Z, different A (variable # of neutrons)

General notation for a nuclide: $^{14}_{6}C$

As n varies $\rightarrow$ different isotopes of an element

^{12}C ^{13}C ^{14}C

Radioactive (Radiogenic) Isotopes

- Unstable isotopes decay to other nuclides
- The rate of decay is constant, and not affected by P, T, X…
- *Parent* nuclide = radioactive nuclide that decays
- *Daughter* nuclide(s) are the radiogenic *atomic* products

Isotopic variations between rocks, etc. due to:

1. ***Mass*** fractionation (as for stable isotopes)

   Only effective for light isotopes: H   He   C   O   S

Isotopic variations between rocks, etc. due to:

1. Mass fractionation (as for stable isotopes)
2. Daughters produced in varying proportions resulting from previous event of ***chemical*** fractionation

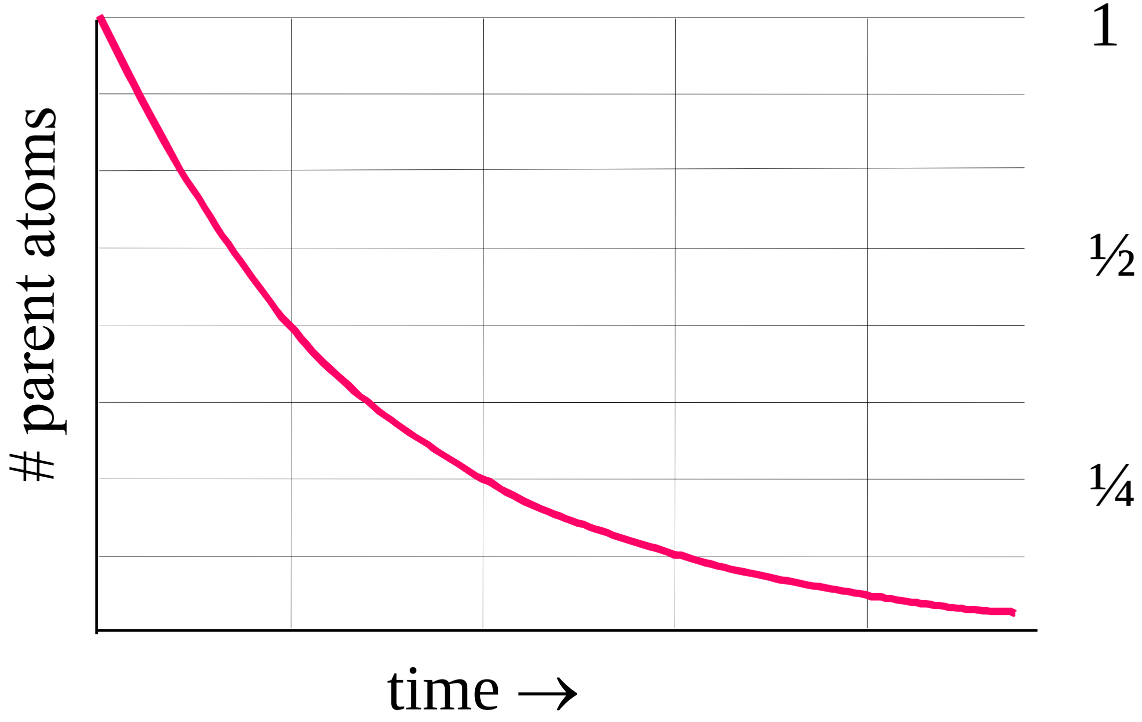
Isotopic variations between rocks, etc. due to:

1. Mass fractionation (as for stable isotopes)
2. Daughters produced in varying proportions resulting from previous event of chemical fractionation
3. Time

Radioactive Decay

The Law of Radioactive Decay

eq. 9.11 $$-\frac{dN}{dt} \propto N \quad \text{or} \quad -\frac{dN}{dt} = \lambda N$$



$$D = Ne^{\lambda t} - N = N(e^{\lambda t} - 1) \quad \text{eq } 9.15$$

→ age of a sample (t) if we know:

- D the amount of the daughter nuclide produced
- N the amount of the original parent nuclide remaining
- λ the decay constant for the system in question

Rb-Sr Systematics

Isotopic composition of Sr has changed continuously since nucleosynthesis because of radioactive ß$^-$ decay of ^{87}Rb to ^{87}Sr.

$$^{87}_{37}\mathrm{Rb} \rightarrow \, ^{87}_{38}\mathrm{Sr} + \beta^- + \bar{\nu} + E$$

Decay of ^{87}Rb: $\lambda = 1.42 \times 10^{-11}\ y^{-1}$

$T_{1/2} = 48.8 \times 10^9\ y$

Growth of radiogenic ^{87}Sr:

$$^{87}\mathrm{Sr} = \, ^{87}\mathrm{Sr}_i + \, ^{87}\mathrm{Rb}(e^{\lambda t}-1)$$

^{87}Sr = total No. of atoms at present time.

^{87}Sr$_i$ = initial No. of atoms.

^{87}Rb = No. of atoms at present time.

Rb-Sr Systematics

Chemical Properties

Rb Alkali metal

Ionic radius = 1.48 Å
Similar to K (1.33 Å) = substitution.

Sr Alkaline earths

Ionic radius = 1.13 Å
Similar to Ca (0.99 Å) = substitution.

But restricted, Sr^{2+} favors 8 fold coordinated sites, whereas Ca^{2+} can be in 6 & 8 fold sites.

Rb-Sr System

- Rb behaves like K $\rightarrow$ micas and alkali feldspar
- Sr behaves like Ca $\rightarrow$ plagioclase and apatite (but not clinopyroxene)
- $^{88}Sr : {}^{87}Sr : {}^{86}Sr : {}^{84}Sr$ ave. sample = 10 : 0.7 : 1 : 0.07
- ^{86}Sr is a stable isotope, and not created by breakdown of any other parent

Table 5.1. Average Concentrations (ppm) of Rb, K, Sr, and Ca in Igneous and Sedimentary Rocks

	Concentration			
Rock Type	Rb	K	Sr	Ca
Ultramafic	0.2	40	1	25,000
Basaltic	30	8,300	465	76,000
High-Ca granitic	110	25,200	440	25,300
Low-Ca granitic	170	42,000	100	5,100
Syenite	110	48,000	200	18,000
Shale	140	26,600	300	22,100
Sandstone	60	10,700	20	39,100
Carbonate	3	2,700	610	302,300
Deep-sea carbonate	10	2,900	2000	312,400
Deep-sea clay	110	25,000	180	29,000

Source: Turekian and Wedepohl, 1961.

Rb-Sr Systematics

Easier to measure ratios, divide by ^{86}Sr which is stable:

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

Isotopic Abundances:

$$^{88}_{38}Sr = 82.53\%$$

$$^{87}_{38}Sr = 7.04\%$$

$$^{86}_{38}Sr = 9.87\%$$

$$^{84}_{38}Sr = 0.56\%$$

$$^{85}_{37}Rb = 72.1654\%$$

$$^{87}_{37}Rb = 27.8346\%$$

Isochron Technique

Requires 3 or more cogenetic samples with a range of Rb/Sr

Could be:

- 3 cogenetic rocks derived from a single source by partial melting, FX, etc.

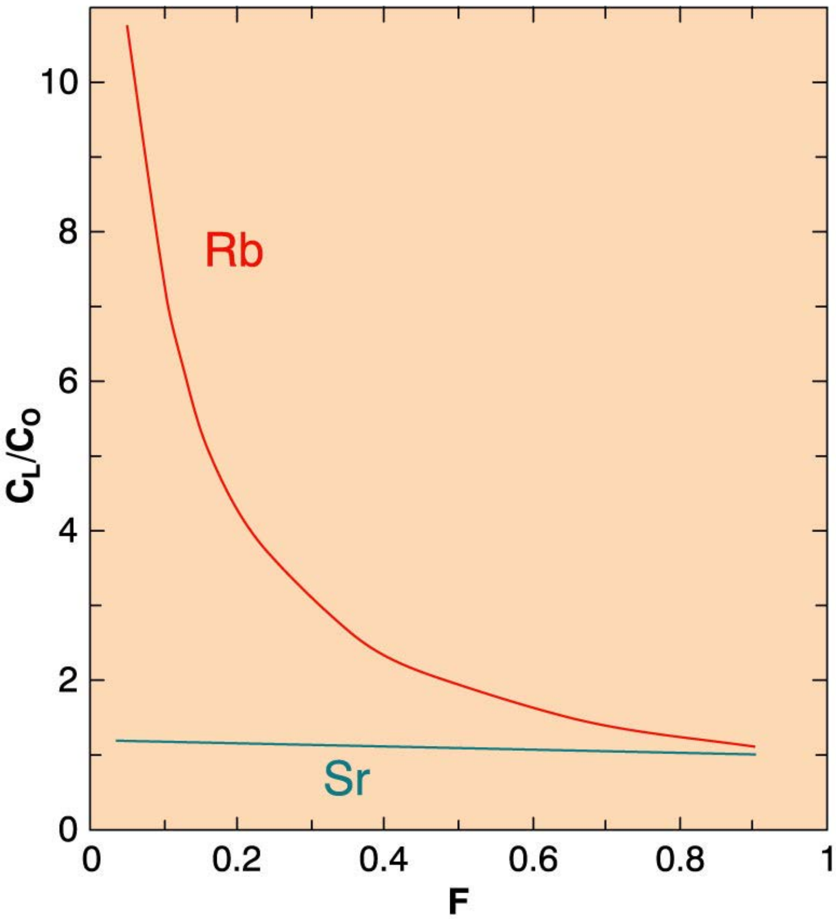


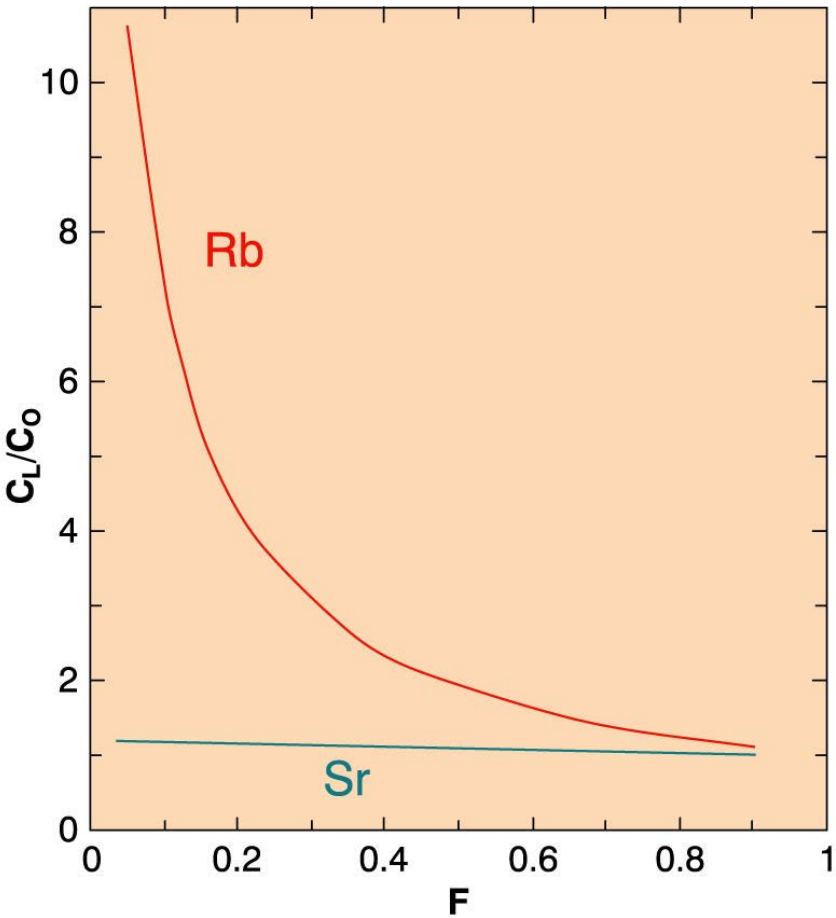
Figure 9.3. Change in the concentration of Rb and Sr in the melt derived by progressive batch melting of a basaltic rock consisting of plagioclase, augite, and olivine. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Isochron Technique

Requires 3 or more cogenetic samples with a range of Rb/Sr

Could be:

- 3 cogenetic rocks derived from a single source by partial melting, FX, etc.
- 3 coexisting minerals with different K/Ca ratios in a single rock



Recast age equation by dividing through by stable ^{86}Sr

$$^{87}Sr/^{86}Sr = (^{87}Sr/^{86}Sr)_o + (^{87}Rb/^{86}Sr)(e^{\lambda t} - 1) \qquad \text{eq 9.17}$$

$$\lambda = 1.4 \times 10^{-11}\ a^{-1}$$

For values of λt less than 0.1: $e^{\lambda t} - 1 \simeq \lambda t$

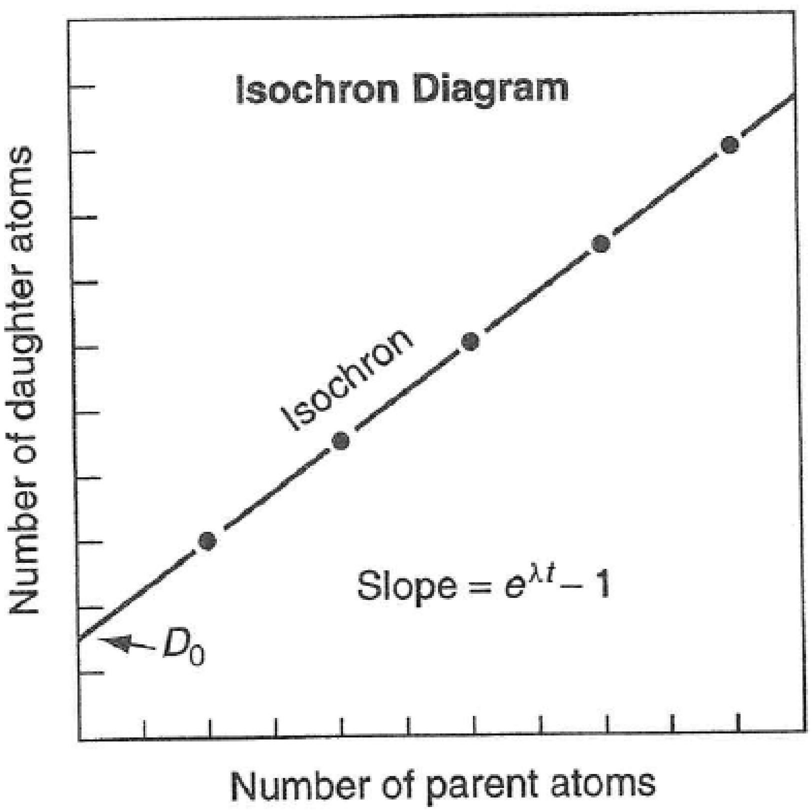
Thus eq. 9.15 for $t < 70$ Ga (!!) reduces to:

$$\text{eq 9.18} \qquad ^{87}Sr/^{86}Sr = (^{87}Sr/^{86}Sr)_o + (^{87}Rb/^{86}Sr)\lambda t$$

$$y \quad = \quad b \quad + \quad x \quad m$$

= equation for a line in $^{87}Sr/^{86}Sr$ vs. $^{87}Rb/^{86}Sr$ plot

Rb-Sr Isochrons



Age determination for suite of cogenetic samples.

Plot of N versus D yields straight line = ***isochron*.**

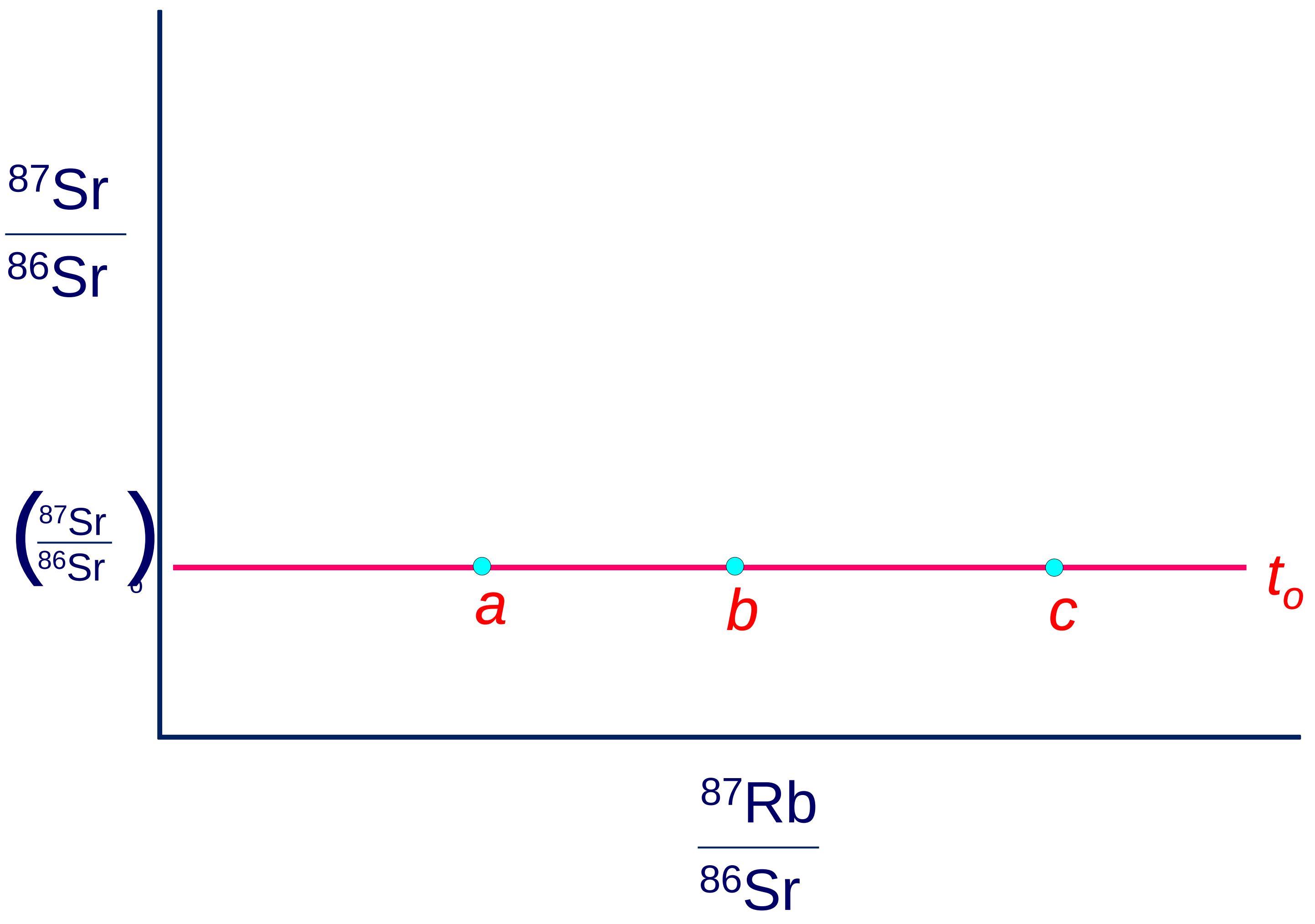
$$y = mx + b$$

Age is calculated from slope:

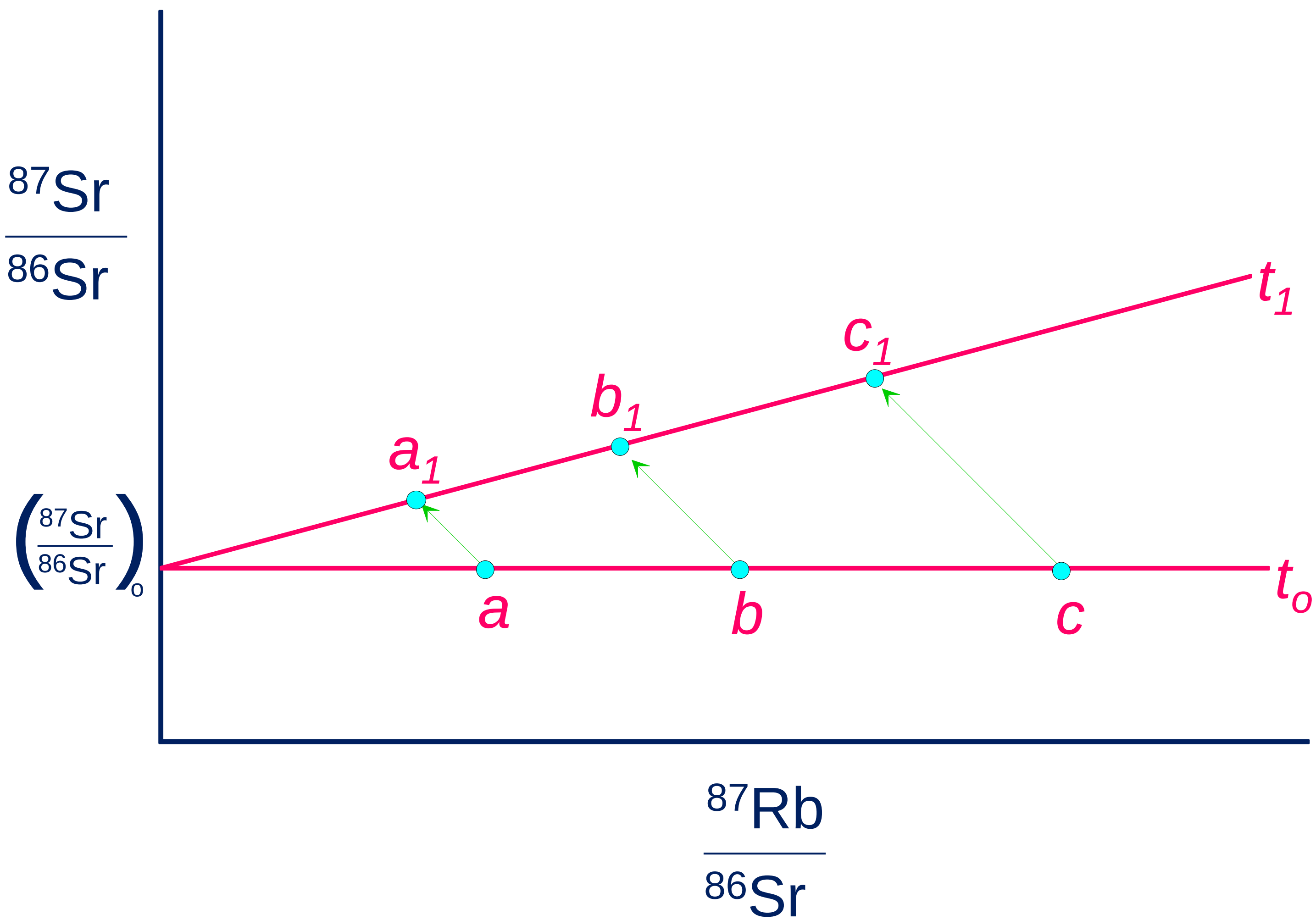
$$m = \left(e^{\lambda t} - 1\right)$$

$$\boxed{t = \frac{1}{\lambda} \ln\left(m + 1\right)}$$

Begin with 3 rocks plotting at a b c at time t_o

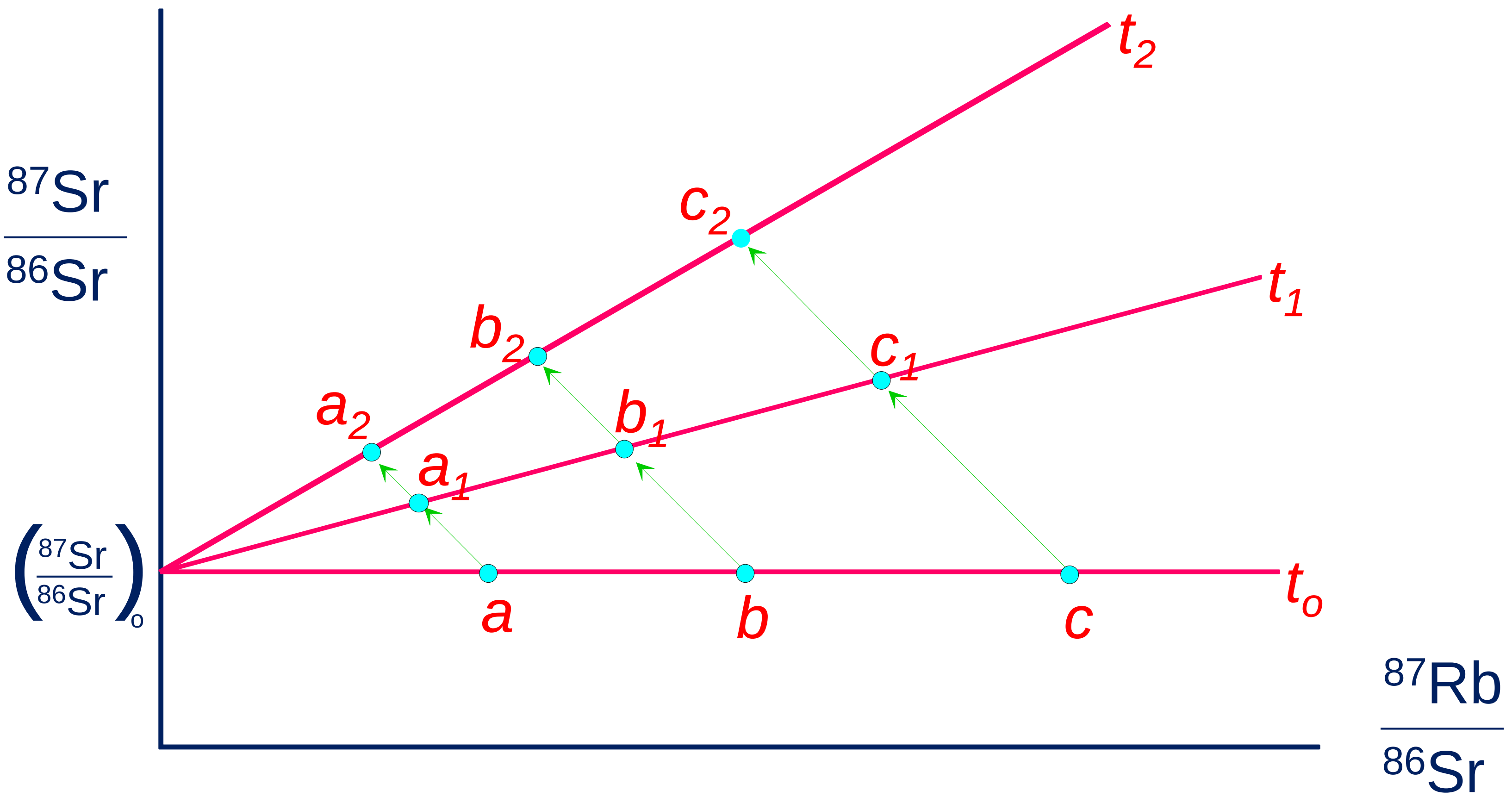


After some time increment ($t_0 \rightarrow t_1$) each sample loses some ^{87}Rb and gains an equivalent amount of ^{87}Sr

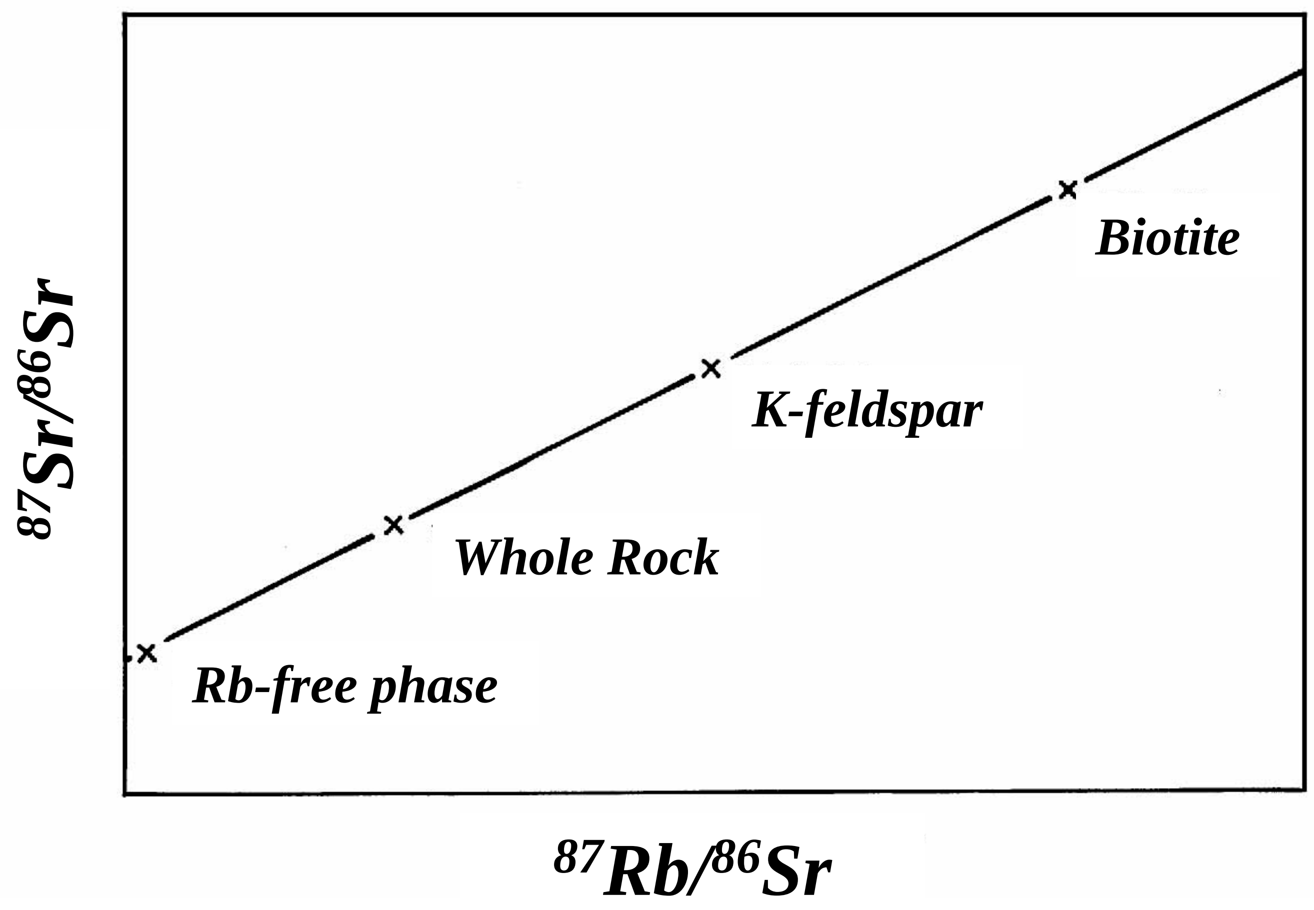


At time t_2 each rock system has evolved → new line

Again still linear and steeper line



Internal Rb-Sr Isochrons



Dickin, Radiogenic Isotope Geology, 2005

Isochron technique produces 2 valuable things:

1. The age of the rocks (from the slope = λt)
2. $(^{87}Sr/^{86}Sr)_o$ = the initial value of $^{87}Sr/^{86}Sr$

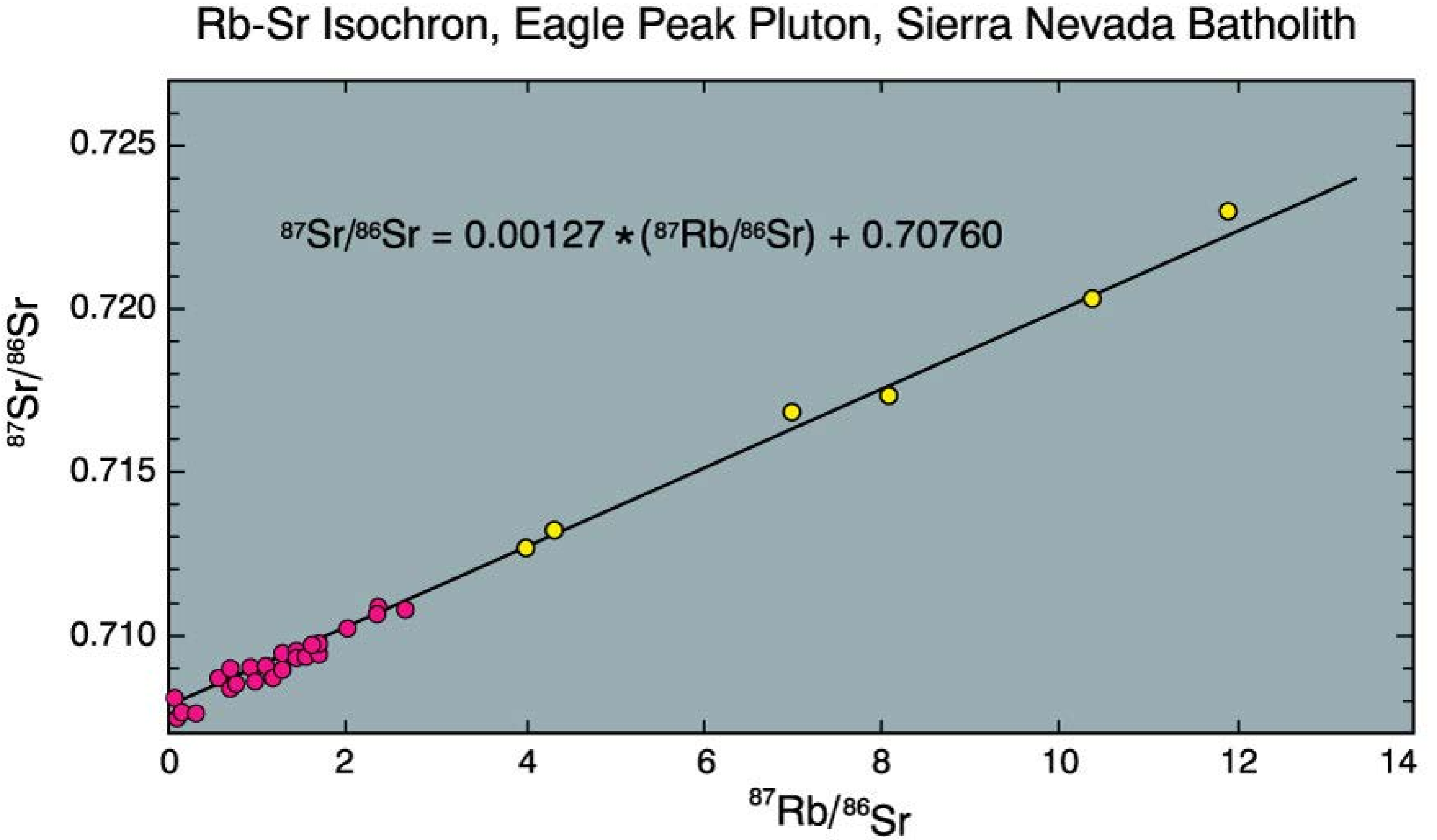


Figure 9.12. Rb-Sr isochron for the Eagle Peak Pluton, central Sierra Nevada Batholith, California, USA. Filled circles are whole-rock analyses, open circles are hornblende separates. The regression equation for the data is also given. After Hill et al. (1988). Amer. J. Sci., 288-A, 213-241.

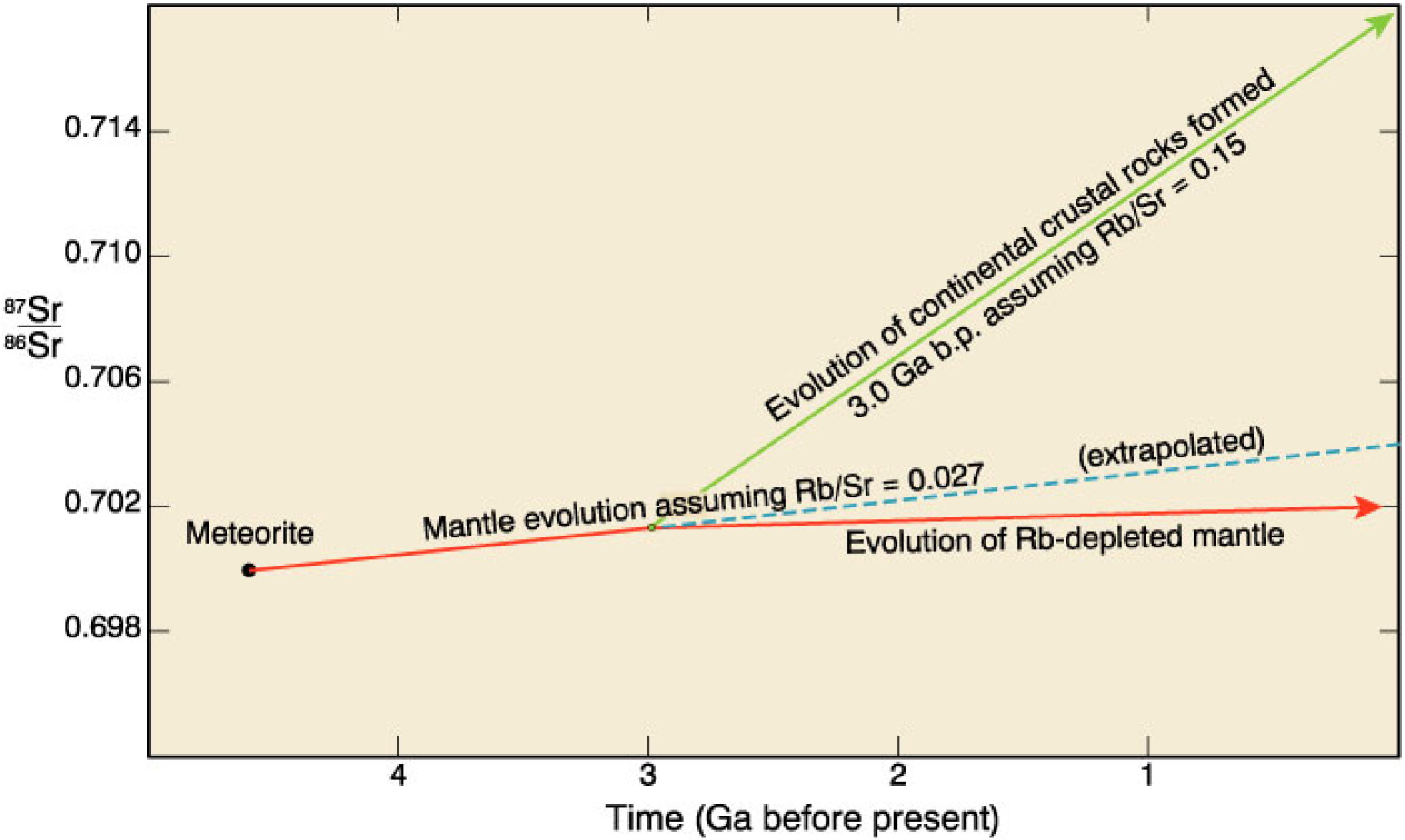


Figure 9.13. Estimated Rb and Sr isotopic evolution of the Earth's upper mantle, assuming a large-scale melting event producing granitic-type continental rocks at 3.0 Ga b.p After Wilson (1989). Igneous Petrogenesis. Unwin Hyman/Kluwer.