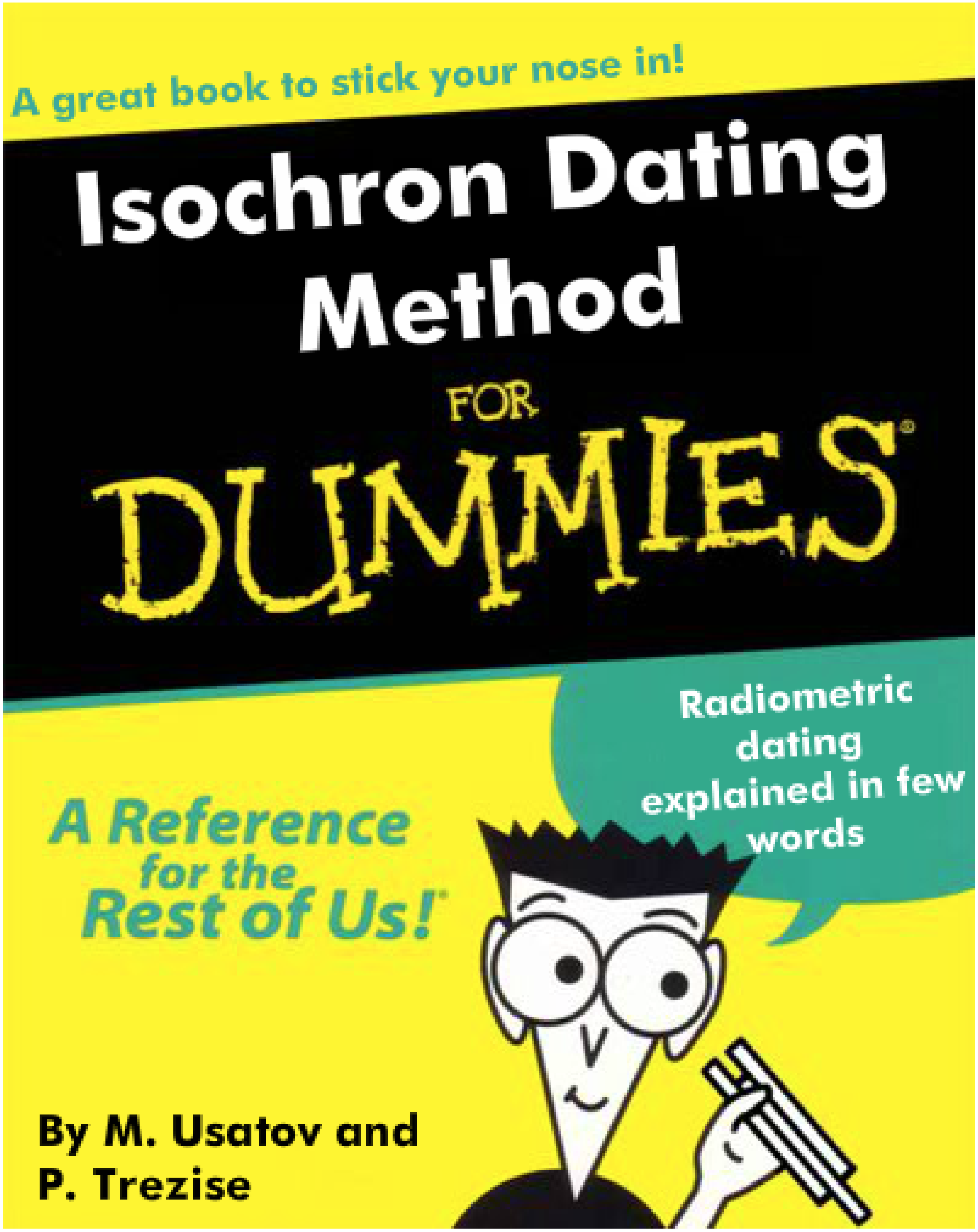
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Isochron Dating Method
FOR
DUMMIES
Radiometric dating explained in few words
A Reference for the Rest of Us!
By M. Usatov and P. Trezise

This text follows the structure of article by Young (2007). Radioactive decay is an exponential process. That is, the rate of decay of isotope N is proportional to its quantity:

$$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N, \tag{1}$$

where λ is the decay constant, related to the half-life of radioactive isotope as $\tau_{1/2} = \ln 2/\lambda$. Isotope half-lives are usually determined experimentally and λ values for different atoms and isotopes are available from various sources. Aleksandrov et al. (1963) teach how differential equation 1 can be solved in order to derive an equation that allows to determine the exact quantity of radioactive isotope at any point of time t:

$$N = N_0 e^{-\lambda t}, \tag{2}$$

where N_0 is the initial quantity of isotope contained in the rock at the time of its formation (crystallization).

A rock sample is considered a closed system if neither parent nor daughter isotopes have been introduced after its formation by an external process. This is a requirement for accurate dating. A closed system can, thus, be characterized as having its:

$$N + D = N_0 + D_0, \tag{3}$$

where D and D_0 are correspondingly the present-time and initial amounts of the daughter isotope. Combining equations 2 and 3, we obtain equation for radiometric dating:

$$D = D_0 + N(e^{\lambda t} - 1). \tag{4}$$

It is difficult to measure absolute amounts of isotopes in a sample, but mass spectrometers can measure isotope ratios. Thus, we can introduce stable non-radiogenic isotope d into equation 4:

$$D/d = D_0/d_0 + (N/d)(e^{\lambda t} - 1). \tag{5}$$

With rubidium-strontium dating, whereby ^{87}Rb decays into ^{87}Sr, this becomes:

$$^{87}\mathrm{Sr}/^{86}\mathrm{Sr} = (^{87}\mathrm{Sr}/^{86}\mathrm{Sr})_0 + (^{87}\mathrm{Rb}/^{86}\mathrm{Sr})(e^{\lambda t} - 1), \tag{6}$$

where stable isotope is ^{86}Sr. This equation can be rearranged into

$$^{87}\mathrm{Sr}/^{86}\mathrm{Sr} = (e^{\lambda t} - 1)(^{87}\mathrm{Rb}/^{86}\mathrm{Sr}) + (^{87}\mathrm{Sr}/^{86}\mathrm{Sr})_0, \tag{7}$$

which has a form of linear equation with two variables, $y = mx + b$, with slope m represented by $(e^{\lambda t} - 1)$. The slope of the line, thus, is related to time t passed since crystallization. If ^{87}Sr/^{86}Sr values are used as ordinate (y-axis) and ^{87}Rb/^{86}Sr for abscissa (x-axis), then the constant $(^{87}\mathrm{Sr}/^{86}\mathrm{Sr})_0$ would correspond to b, which is the y-intercept, given that initial and present-time ratios of stable isotope ^{86}Sr remain constant.

By analyzing multiple samples of isotope ratios (^{87}Sr/^{86}Sr and ^{87}Rb/^{86}Sr) within the same rock, it is possible to plot multiple points on the isochron diagram and determine the slope of the line, $(e^{\lambda t} - 1)$—see figure 1. From the slope, knowing the half-time of the isotope (or decay constant λ), it is possible to find t of rock crystallization. Initial ratios of isotopes in the rock can also be derived from the y-intercept.

Bouvier et al. (2015) report that the age of the Moama meteorite is 4519 ± 34 Myr by constructing an isochron diagram for the ^{147}Sm–^{143}Nd. Below we perform our own analysis using the equation presented above. The radioactive decay that is used in this case is the alpha decay of ^{147}Sm to form the daughter ^{143}Nd with a half life 106 Byr. Table 1 shows the data from Bouvier et al. (2015) for the

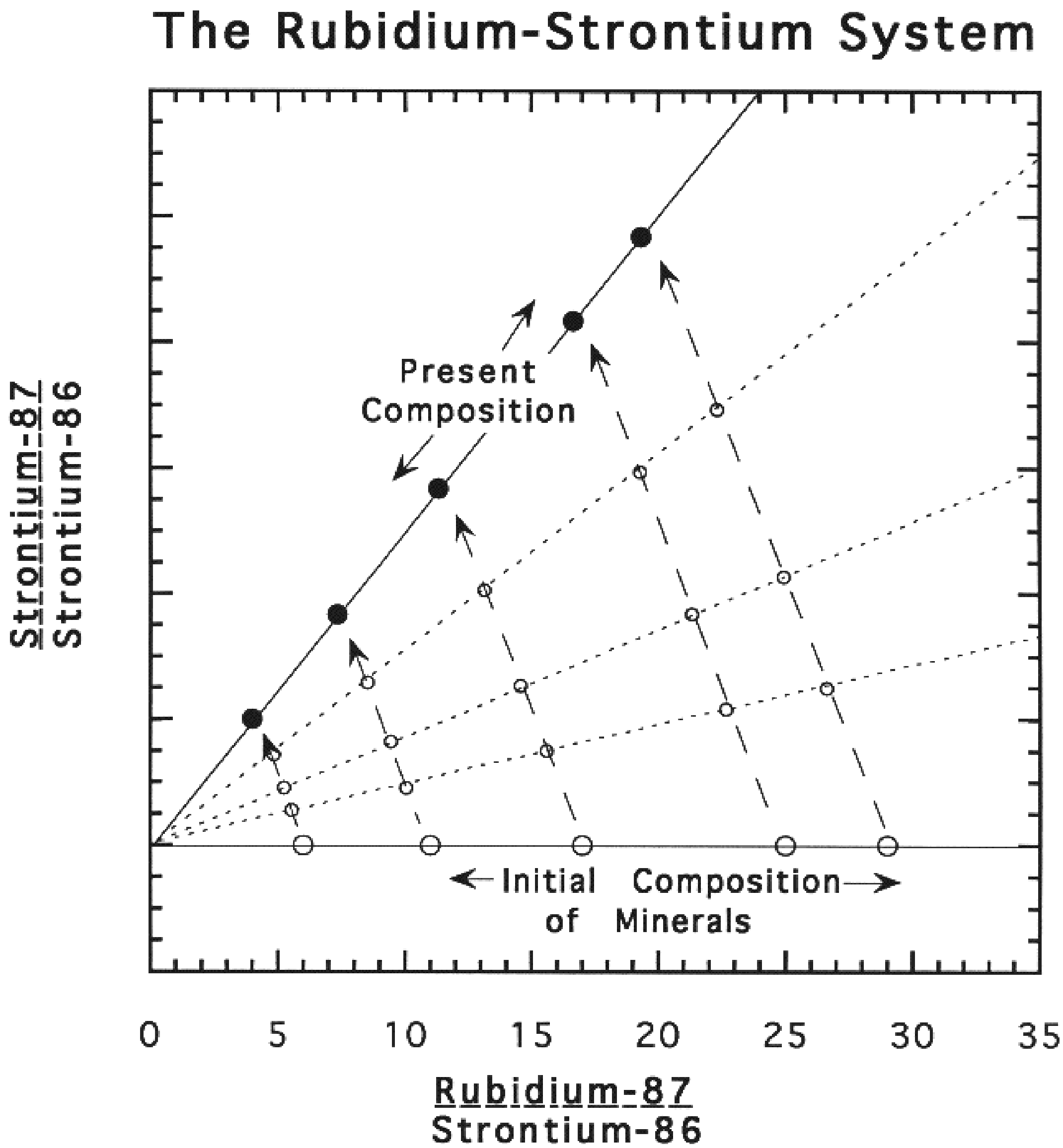

FIG. 1.— Rubidium-strontium isochron diagram. ^{87}Rb decays into ^{87}Sr, while stable isotope ^{86}Sr remains constant. The slope of the isochron is $(e^{\lambda t} - 1)$. As the rock becomes older, the isochron pivots around the y-intercept that corresponds to the initial amounts of isotopes $(^{87}Sr/^{86}Sr)_0$. The older the rock, the steeper is the isochron. Figure by R. Wiens.

pyroxene, plagioclase and whole rock abundances of the ^{147}Sm / ^{144}Nd and ^{143}Nd / ^{144}Nd ratios. Plotting these ratios gives the chart shown on figure 2. Using the least squares linear regression functions in Excel we determined that this line is $y = mx + b$, where $m = 0.029943 \pm 0.00014$ and $b = 0.506747 \pm 0.000036$. From equations above, the slope of the line is given by the expression

$$m = e^{\lambda t} - 1, \tag{8}$$

so

$$t = \frac{\ln(m+1)}{\ln 2} \times \tau_{1/2} = \frac{\ln(0.0299943 + 1)}{\ln 2} \times 106 \text{ Byr} = 4.512 \text{ Byr}. \tag{9}$$

TABLE 1
Moama meteorite, data from Bouvier et al. (2015).

Group	^{147}Sm / ^{144}Nd	^{143}Nd / ^{144}Nd
Whole rock	0.2317	0.513705
Pyroxene	0.3523	0.517287
Plagioclase	0.1151	0.510184

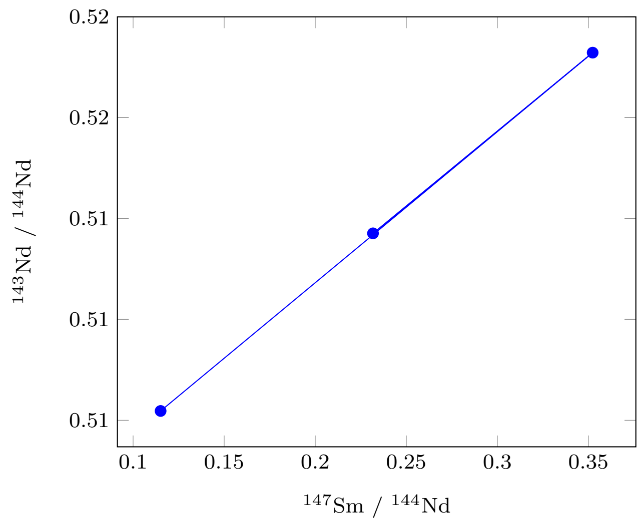

Fig. 2.— Isochron diagram for pyroxene, plagioclase and whole rock ratios of ^{147}Sm–^{143}Nd radioactive decay in the Moama meteorite.

This is quite close to the value reported in the paper of 4519 Myr.

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