ESS 312 Geochemistry

Practice problems on geochronology and isochron diagrams

(1) Complete the following table:

You may wish to consult the Table of nuclides, here: http://atom.kaeri.re.kr/index.html?
or here: http://www.nndc.bnl.gov/chart/

Parent nuclide	Decay mode(s)	Daughter nuclide	Half-life	Decay const (λ)	Minerals rich in parent element (for geochronology)
^{87}Rb	β^-	^{87}Sr	4.88×10^{10} yr	1.42×10^{-11} yr^{-1}	K-feldspar, muscovite, biotite
^{187}Re	β^-	^{187}Os	4.12×10^{10} yr	1.68×10^{-11} yr^{-1}	Molybdenite (and not much else!)
^{234}U	α	^{230}Th	2.455×10^{5} yr	2.823×10^{-6} yr^{-1}	Calcite, aragonite (e.g. in corals), zircon, other U silicates and oxides
^{40}K	β^-	^{40}Ca	1.248×10^{9} yr	5.554×10^{-10} yr^{-1}	K-feldspar, muscovite, biotite

(2) Carbon-14 ($t_{1/2}$ = 5730 years) is produced by cosmic ray reactions in the upper atmosphere, and quickly reacts to form $^{14}CO_2$, which mixes with isotopically normal CO_2 throughout the atmosphere, biosphere and upper oceans. All living organisms (including you) ultimately derive carbon from atmospheric CO_2, and while alive, maintain an isotopic ratio close to:

$$(^{14}C/^{12}C)_{initial} = 1.2 \times 10^{-12} .$$

After death, ^{14}C is no longer exchanged and the $^{14}C/^{12}C$ ratio begins to decrease by radioactive decay. C-14 dating is based on measuring the present-day ($^{14}C/^{12}C$) ratio in fossil carbon, and comparing it to the initial ratio to determine the time elapsed since death of the organism.

(i) Write an expression for the ^{14}C age, in terms of the present and initial $^{14}C/^{12}C$ ratios, and the ^{14}C decay constant λ.

$$\left({^{14}C}/{^{12}C} \right)_{present} = \left({^{14}C}/{^{12}C} \right)_{initial} e^{-\lambda t}$$

(ii) While digging potatoes in your back yard, you unearth a mammoth tusk. A sample of protein extracted from the tusk has a $^{14}C/^{12}C$ ratio of 4.21×10^{-14}. How long ago did this mammoth live? Note: $\lambda = 1.21 \times 10^{-4}\ yr^{-1}$.

Re-arranging the equation above and substituting the values given, we get:

$$t = -\frac{1}{\lambda} \ln\left(\frac{\left(\frac{^{14}C}{^{12}C}\right)_{present}}{\left(\frac{^{14}C}{^{12}C}\right)_{initial}}\right)$$

$$= -8265 \ln\left(\frac{4.21 \times 10^{-14}}{1.2 \times 10^{-12}}\right)$$

$$= 27{,}700\ yrs$$

(iii) What assumptions do you have to make when calculating this ^{14}C age? What precautions would you need to take when preparing and handling the sample in the lab?

• We assume that the atmosphere 27,000 years ago had the same $^{14}C/^{12}C$ ratio as the atmosphere today (this turns out to be a bad assumption, requiring that radiocarbon dates be calibrated).

• We must also assume that the mammoth had the same C isotopic ratio as atmospheric CO_2 at the time of its death. (Not too bad an assumption, especially for herbivores, but very bad for organisms such as marine clams, corals, oysters, etc that drew their carbon from dissolved bicarbonate ions in seawater. Seawater contains significant and variable amounts of "old" carbon (dissolved long ago), which affect the $^{14}C/^{12}C$ ratio of dissolved inorganic carbon).

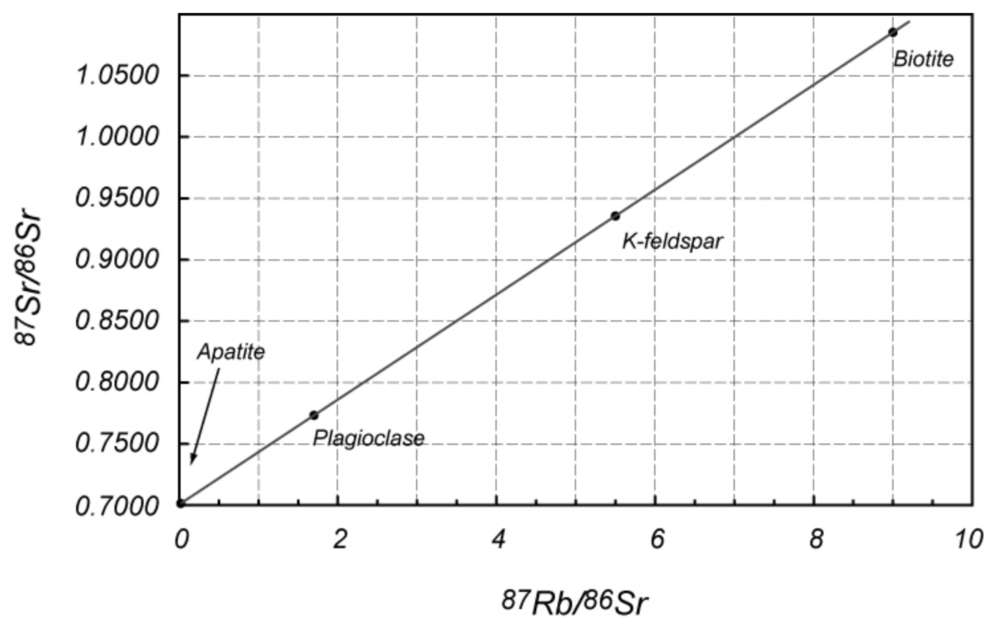
• We assume that the sample has been a closed system – i.e. that the $^{14}C/^{12}C$ ratio has changed only by radioactive decay and not by chemical exchange of carbon with surrounding material in the soil.

• Great care must be taken not to contaminate the sample with other carbon-bearing material during collection or in the lab. Contamination with "modern" carbon (e.g. organic contamination from scientists themselves) is especially bad, because it contains such a high ratio of $^{14}C/^{12}C$ compared to the sample. Contamination with ancient ("dead") carbon would lower the sample's $^{14}C/^{12}C$ ratio, causing the date to be erroneously old. Contamination with modern carbon increases the $^{14}C/^{12}C$ ratio, making the sample appear erroneously young.

(2) Use EXCEL (or MATLAB, or Mathematica, or Maple, or even graph paper) to plot the following isochron data, and determine the age of the rocks from which they were taken.

(i) Granodiorite intrusion from the Shaw Granitic Complex, underlying Proterozoic rocks of the Mt Bruce Supergroup. (Note - this includes the Hamersley Ranges Banded Iron Formation sequence, ancient sedimentary rocks which mark the growth of oxygen in Earth's atmosphere).

Mineral	Present-day $^{87}Rb/^{86}Sr$	Present-day $^{87}Sr/^{86}Sr$
apatite	0.02	0.7014
plagioclase	1.70	0.7732
K-feldspar	5.50	0.9356
biotite	9.00	1.0853

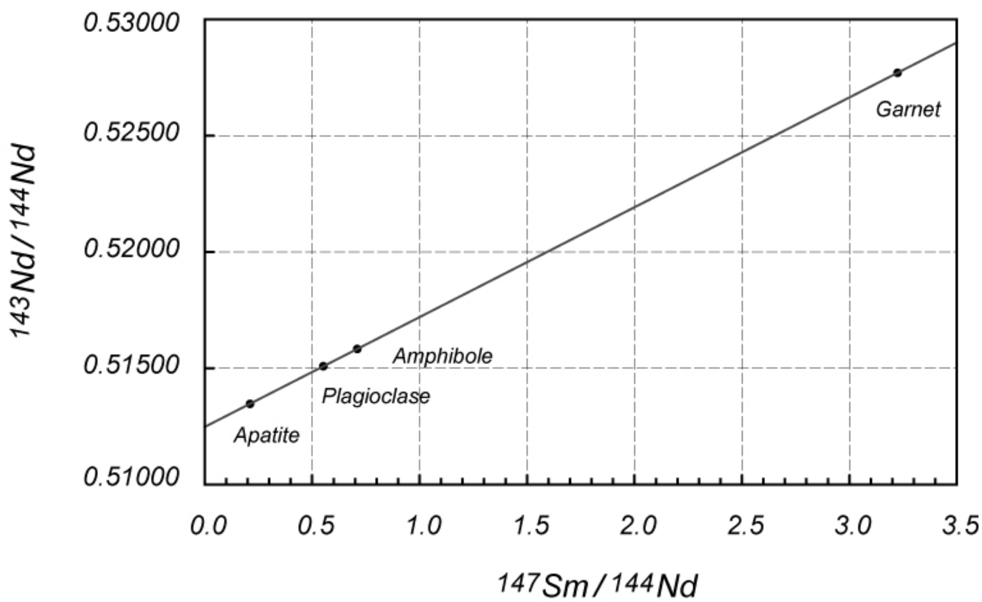


Slope of the isochron = $(e^{\lambda t} - 1)$ = 0.04275

Solve for t = 2.95×10^9 years

(ii) Garnet-bearing granulite gneiss from the Furua Complex in Tanzania. Metamorphism of this rock is associated with the Pan-African Orogeny, a complex sequence of thermal and tectonic events preceding formation of the supercontinent Gondwana.

Mineral	Present-day $^{147}Sm/^{144}Nd$	Present-day $^{143}Nd/^{144}Nd$
apatite	0.211	0.51347
plagioclase	0.552	0.51509
amphibole	0.710	0.51583
garnet	3.224	0.52770



Slope of the isochron = $(e^{\lambda t} - 1)$ = 0.004722

Solve for t = 720 x 10^6 years

(iii) Jingchuan Ni-Cu-Pt deposit, China.

	Present-day $^{187}Re/^{188}Os$	Present-day $^{187}Os/^{188}Os$
Whole-rock	6.11	0.2533
molybdenite	34.4	0.6711

Plot as above ….

Slope of the isochron $= (e^{\lambda t} - 1) = 0.0148$

Solve for t $= 880 \times 10^6$ years

You will need the following decay constants:

$\lambda\ ^{87}Rb = 1.42 \times 10^{-11}\ yr^{-1}$

$\lambda\ ^{147}Sm = 6.54 \times 10^{-12}\ yr^{-1}$

$\lambda\ ^{187}Re = 1.67 \times 10^{-11}\ yr^{-1}$.