ESS 461 – Geological Time

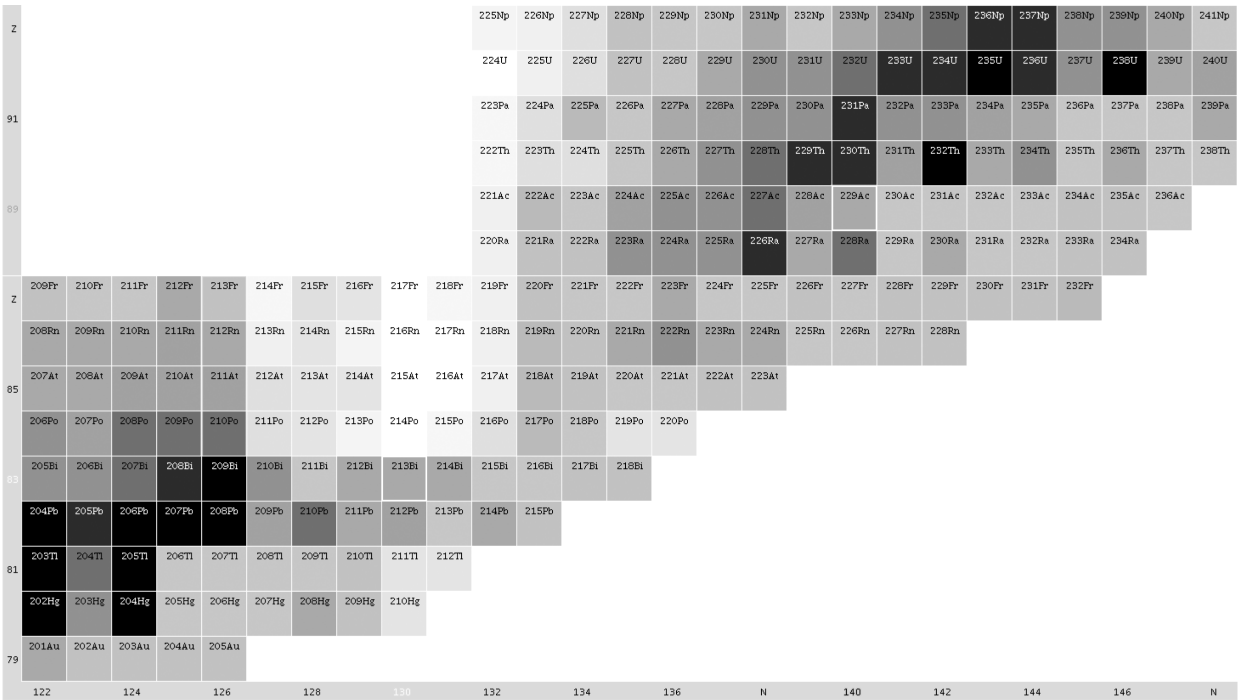
Lab 2 (and homework)

Review of radioactivity

(i) Complete the following table of radioisotopes and their daughter products. This listing includes many, but by no means all, of the nuclides used in geochronology. You will need to consult an authoritative reference such as the Chart of the Nuclides.

Nuclide	Decay mode(s)	Daughter nuclide	Half-life	Uses / notes
^{7}Be	Electron capture (e.c.)	^{7}Li	53.3 days	Cosmic-ray-produced. Tracing sediment sources and mixing.
^{10}Be				Cosmic-ray-produced. Exposure dating. Erosion rates.
^{40}K	(i) (ii)			Dating K-rich minerals (mica, feldspar) and volcanic rocks.
^{87}Rb				Dating K(Rb)-rich minerals and rocks.
^{138}La	(i) (ii)			Dating light-REE enriched rocks. Crust-mantle differentiation.
^{146}Sm				Dating meteorites and early planetary differentiation.
^{147}Sm				Dating a wide range of rock types. Crust-mantle differentiation.
^{176}Lu				Crust-mantle differentiation. Sediment recycling.
^{187}Re				Dating core formation, some ore minerals.
^{232}Th				Dating a wide range of rock types.
^{234}U				Dating corals and stalagmites.
^{235}U				Dating U-rich rocks and minerals, especially zircon
^{238}U				Dating U-rich rocks and minerals, especially zircon

(ii) Use the Chart of the Nuclides (or other authoritative source) to find out the decay modes of the nuclides between ^{238}U and ^{206}Pb. Trace out the ^{238}U decay-series pathway (the succession of daughter products) leading from ^{238}U parent to stable ^{206}Pb. (Beware! The path contains many branches towards the end).



(iii) In the decay series above, how long does an average atom spend as:

Nuclide	Mean life
^{230}Th	
^{226}Ra	
^{222}Rn	
^{210}Pb	

Almost all geochronological work requires chemical and isotopic measurements and calculations. To refresh your skills, calculate the following.

(iv) A sample of Pb from a 28.4 Myr old zircon has the following isotopic ratios (measured by mass spectrometry). What is the atomic weight of this Pb? (Hint: start by calculating the atom fractions of the isotopes, then multiply by the atomic weight of each isotope. Use the correct isotopic masses from the Nuclide Chart).

$^{208}Pb/^{204}Pb = 58.26$

$^{207}Pb/^{204}Pb = 13.915$

$^{206}Pb/^{204}Pb = 298.0$

Is this the same atomic weight quoted for Pb in the Periodic Table?

Before the development of mass spectrometry for measuring isotopic abundances, some geochemists attempted to calculate ages from the atomic weight of Pb in U- and Th-bearing minerals. Why did these efforts fail?

(v) Carbon-14 dating originally used beta counting to measure the *specific activity* of samples. Specific activity (A) is defined as the *activity per gram of carbon*, in units of *decays per minute per gram of carbon* (dpm/g C). The activity value A_0 for "modern" (1950) atmospheric CO_2 is 13.6 dpm/g C. In these units, radiocarbon decay is described by:

$$\mathbf{A = A_0 \exp(- \lambda_{C\text{-}14}\, t)}$$

and the radiocarbon age is given by the equation:

$$\mathbf{t = -\ln(A / A_0) \; / \; \lambda_{C\text{-}14}}$$

(a) Assuming a value for the ^{14}C half-life of 5730 yr, how many ^{14}C atoms must be present in a gram of "modern" carbon to produce an activity $A_0 = 13.6$ dpm?

(b) What is the $^{14}C/^{12}C$ ratio of modern carbon?

Geochronological methods based on decay of a radioactive parent

Carbon-14 dating is probably the best known geochronological method, and, at least in its basic concept, it is one of the simplest. Time is measured by comparing the β^{-} activity or isotopic ratio of a carbon sample with the corresponding value in "modern" living material. As we will find out in lectures, several of underlying assumptions are not strictly true, requiring additional corrections and "calibration" to a curve based on ^{14}C in tree-rings of known age. For the lab today, we will confine ourselves to calculating "conventional" radiocarbon ages, given by the equation you encountered above:

$$\mathbf{t = -\ln(A / A_0) \; / \; \lambda_{C\text{-}14,\,Libby} = -8266 \ln(A / A_0)}$$

Nowadays most ^{14}C measurements are made by accelerator mass spectrometry (AMS) which compares the $^{14}C/^{12}C$ ratio, R, to a standard ratio, R_0, representative of carbon in living matter:

$$\mathbf{t = -\ln(R / R_0) \; / \; \lambda_{C\text{-}14,\,Libby} = -8266 \ln(R / R_0)}$$

Note that conventional ^{14}C ages are still calculated assuming the original half-life (5,568 yr) used by Libby [the rationale being that (i) this preserves consistency with early measurements, (ii) all ^{14}C dates will then be calibrated, so that use of an inaccurate half-life doesn't matter].

Try it …

(1) Suppose an antiques dealer in Cairo offers you a good deal on a collection of papyrus manuscripts, claiming they are first edition copies of the Dead Sea scrolls. You check the $^{14}C/C$ ratio of a tiny sample, and find that its 79.3% of the ratio in your lab standard (which is chosen to mimic wood grown in 1950). In the jargon, it contains "79.3 percent modern carbon".
Would you buy these artifacts?

(a) Calculate the ^{14}C age of the papyrus. Note that the age is in years before 1950.

(b) What <u>event</u> have you actually dated with this measurement, and how does it relate to the age of the writing on the scrolls?

(c) List the assumptions that underlie your age estimate. This is to get you thinking. We will cover these in detail in class.

(d) It turns out that your scrolls refer to events during the reign of Emperor Trajan (98 – 117 AD), and must have been inscribed shortly after that time. How can you reconcile this with your ^{14}C date?

Other examples of dating methods based only on the decay of a radioactive parent include a family of interesting methods aimed at dating *groundwater*. Dating groundwater is an important part of establishing flow and recharge rates, which in turn allow us to set sustainable limits on pumping (so as not to exhaust the resource).

The parent nuclides used in these methods are ^{36}Cl ($t_{1/2}$ = 301,000 yr) and ^{81}Kr ($t_{1/2}$ = 229,000 yr), both produced by cosmic ray reactions in the atmosphere. The elements Cl and Kr are soluble, so they pass underground with rainwater at the time of recharge. Radioactive decay reduces their abundance as they move with the water through the aquifer, so it should be possible to infer the age of a groundwater sample by comparing its ^{36}Cl or ^{81}Kr abundance to the corresponding abundance in rainfall.

This assumes that radioactive decay is the only process causing the nuclide concentrations to decrease. Is this a valid assumption?

(i) Carbon-14 dissolves in rainfall (mostly as the bicarbonate ion; HCO_3^-). ould you

Collon, P. et al. (2000) ^{81}Kr in the Great Artesian Basin, Australia : a new method for dating very old groundwater. Earth. Planet. Sci. Lett. 182, 103-113.

Patterson, L.J. et al. (2005) Cosmogenic, radiogenic, and stable isotopic constraints on groundwater residence time in the Nubian Aquifer, Western Desert of Egypt. Geochemistry, Geophysics, Geosystems Vol. 6, Number 1, doi:10.1029/2004GC000779