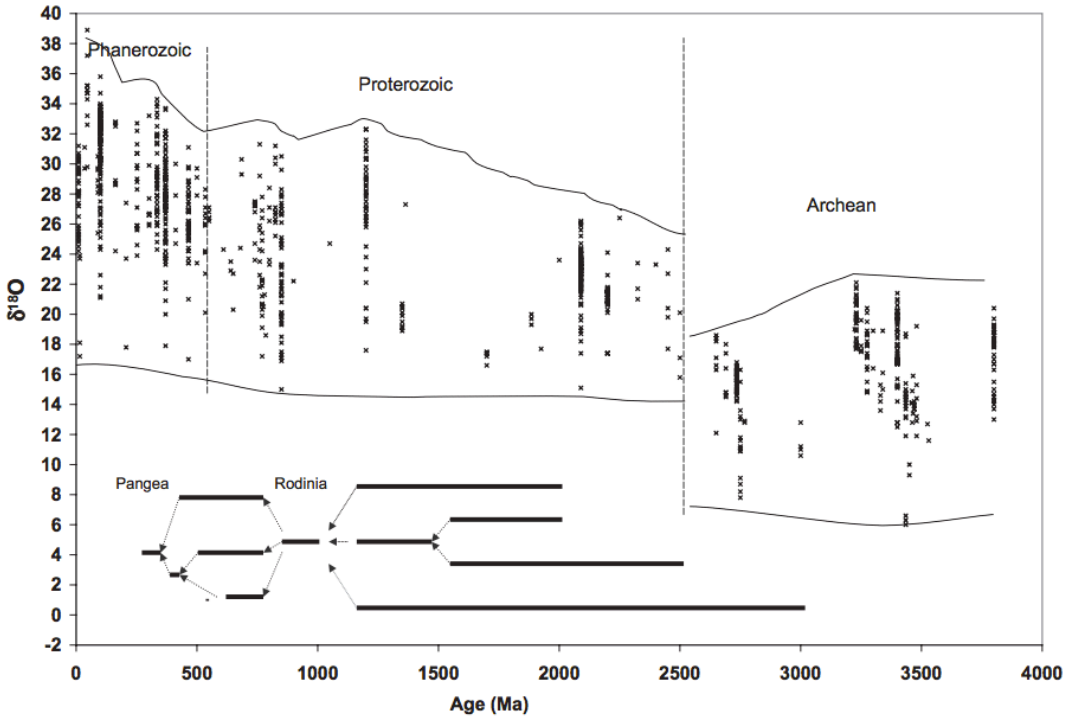
GEOS 32060 / GEOS 22060 / ASTR 45900
Homework 6

Due in class on Monday 22 Feb 4pm.
No credit will be given for answers without working. It is OK to use e.g. Mathematica, but if you do, please print out the work.

Q1. The integrity of the ancient O-isotope record.
The following figure is from Knauth (2005, Palaeogeography Palaeoclimatology Palaeoecology); see also Knauth & Lowe (GSA Bulletin, 2003). The horizontal bars at the bottom show supercontinent breakup and dispersal (not needed to answer the question). "Delta notation" refers to parts-per-thousand enrichment relative to a standard.



(a) Assume that silica (e.g. chert) is enriched in ^{18}O by 6 parts per thousand relative to calcite (i.e. chert is 6 delta units heavier than calcite), but that the temperature dependence of fractionation is similar[1]. Assume that formation temperature (in C) for calcite is given by

$$t = 16.5 - 4.3\delta + 0.14\delta^2$$

What is the sign and magnitude of Earth cooling since 3.5 Ga recorded by chert?

(b) Assume that burial and exhumation is a random walk with step size 250m and step length 50 Myr. What is the typical *peak* burial depth of sediments initially at the seafloor, and now exposed at the surface, that are 500 Myr in age? What

[1] These are adequate approximations for Archean-to-recent comparisons.

about 3 Gyr in age? (Remember that sediments cannot have a negative burial depth).

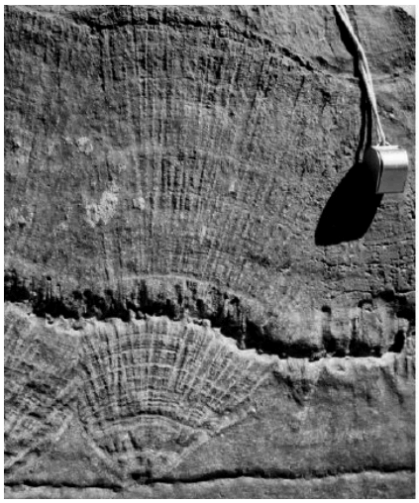
(c) If geothermal heat flow is 0.1 W/m^2, thermal conductivity is 2 W/m/K , and sediment oxygen-isotope composition is reset to the temperatures at peak burial depth, what would be the percentage correction to your answer to part (a)?

(d) Does the model assumed in part (b) provide a good explanation for the scatter in the figure (i.e. the vertical width of the "envelope" of data points)? Why or why not?

Q2. The fossil record of declining [Dissolved Inorganic Carbon].

Consistent with a decline in Dissolved Inorganic Carbon concentrations, there is evidence that calcite saturation state has decreased through the Precambrian.

Calcite saturation state is given by $\Omega = [Ca^{2+}] \times [CO_3^{2-}]/K_{sp}$, where K_{sp} is solubility constant. Primary seafloor $CaCO_3$ fans, indicating extremely rapid growth of $CaCO_3$, are ubiquitous on 2.7 Ga - 2.5 Ga carbonate platforms (example below, hand lens is ~1 cm wide):



(a) Today's ocean has [CO_3^{2-}] approximately 70 micromol/kg (decreasing with depth), K_{sp} = 5x10^{-9}, and has 10 mmol/liter [Ca^{2+}]. Calculate calcite saturation state.

(b) It is noted that calcite precipitation is kinetically inhibited, so that precipitation requires a saturation state >1. Below pCO_2 = 0.36% of 1 bar, calcifying organisms use enzymatic means to promote calcite precipitation. In the absence of calcifying organisms (e.g., pre-2.5 Ga), would calcite saturation state increase or decrease? Why?

(c) While very rare after the Archean, aragonite fans occur in the earliest Triassic (right after the largest mass extinction in Earth history). State and explain two possible causes.

(d) What might your answer to (a) imply for the dissolution of the shells of marine organisms if anthropogenic ocean acidification decreases saturation state by a factor of 2?