The science of landscapes: Earth and planetary surface processes
Winter 2020
Problem set 2

Due 5pm Thursday 6 Feb (the extra day is because I will have no time to grade on 6 Feb due to a proposal deadline).

Collaboration policy. You may discuss homework questions with each other, but you should not be in the same room as another student when you are writing up the answers. Questions in this problem set are "open book" and may draw on concepts in the required reading.

Question 1. What is the minimum timescale for a travertine ($CaCO_3$) terrace to aggrade by 1 m? Assume travertine density 2 g/cc, initial total C content 8 millimolar, pool depth d = 3 cm, and terrace width 5 m. For flow velocity v, use $v = C\,(d\,s)^{0.5}$, where s is a characteristic slope of the water surface, and C ~ 10 is the Chézy coefficient. Alternatively, use any other flow velocity equation you prefer (show your working). How does this growth timescale compare to the time-lapse movie we saw in lecture? How does this compare to the picture (1st Millennium AD temple entombed by travertine) shown above? Comment on which assumption or assumptions in the set-up of this idealized calculation might be most responsible for the discrepancy with real growth rates.

Background on the process of travertine-terrace build-up can be found in Veysey & Goldenfeld, "Watching rocks grow", Nature Physics, 2008, and the accompanying News & Views article by Hammer. Both are included in: http://geosci.uchicago.edu/~kite/doc/Veysey_and_Goldenfeld_2008.pdf

Question 2. Building Olympus Mons. (This is question 5.6 in the Melosh text, included in the required reading pdf).

Use the theory of lava flow lengths derived in Section 5.3.2 to relate the radius of a volcanic edifice, L, with a height H to the eruption rate Q_E. Assume that central eruptions last long enough that the length of each flow that builds up the edifice is limited by its solidification time. That is, if L is of order $Q_E\, t_e/h$, where t_e is the duration of the flow and h is its thickness, then t_e is of order h^2/κ, where the thermal diffusivity of rock, κ, is about 10^{-6} m²/s. Assume that the thickness of the flow is given by the Bingham yield stress Y_B,

$$h = Y_B/(\rho g \sin \alpha)$$

where α is the mean angle of the volcano's slope, $\tan \alpha = H/L$. Derive an expression relating volcano radius (that is, maximum lava flow length, L) to eruption rate Q_E and height H. Note that you will have to make some approximations to account for the fact that the volcano is circular in plan while the estimates above for L and h are on a per unit width basis.

Use this relation to derive an eruption rate and mean flow thickness for Olympus Mons on Mars, a 400 km diameter central volcano made predominantly of basaltic lava, where $Y_B = 10^3$ Pa. The average surface slope of this 24 km high volcanic edifice is about 7°. Compare the derived eruption rate to the typical eruption rate of terrestrial basaltic volcanoes, ca. 3×10^7 m³/day. What does this mean?

Note: There is no single "right answer" to this problem, which requires you to make a number of "reasonable" approximations. This problem is a thinking exercise in how simple theories are concocted.

Question 3.
You may want to refer to the https://geosci.uchicago.edu/~kite/doc/Melosh_ch_5.pdf for guidance on this question.

(a) Disintegrating magma planets. What is the maximum-sized world that can disintegrate via CO_2-driven explosive volcanism? Assume constant density 5 g/cc. Show your working.

(b) The fire fountains at Tvashtar on Jupiter's moon Io are 1.5 km tall. Assume the fountains are driven by exsolving SO2, what is the minimum SO2 content of the erupting magma? Assume ideal gas behavior. Io's radius is 0.3x Earth and Io's density is 3.5 g/cc.