The science of landscapes: Earth and planetary surface processes
Winter 2019
Problem set 1

Due in class Wed 23 Jan, 3pm. Office hours 11:30a-12:30p Monday 21 Jan, or email me to set up a time.

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. True Polar Wander. The kinetic energy of rotation of a body with a principal moment of inertia I about some axis is given by $E = 0.51\omega^2$, where ω is the angular rotation rate (radians/s). The angular momentum L of a rotating body is given by $L = I\omega$. For fixed angular momentum, show that the kinetic energy of a rotating body is a minimum if it rotates about the axis with the maximum moment of inertia C of the three principal moments $C \geq B \geq A$. (Melosh "Planetary Surface Processes," question 2.3)

Question 2. Lucy's targets. The "Lucy" spacecraft (named after the hominin fossil), now under construction, is a mission to the Trojan asteroid swarms. The largest target is the binary minor planet Patroclus-Menoetius. The members of the binary are 141 km (Patroclus) and 112 km (Menoetius) in diameter. For uniform density and water-ice composition what is the central pressure inside Patroclus? Menoetius? Do we expect these worlds to be roughly spherical, and if so why? Suppose Lucy finds that these worlds are roughly spherical, what would that tell us about their history?

Question 3. The transition between elastic behavior on short timescales and viscous behavior on long timescales. In class we mentioned that the lithospheric thickness is time-dependent, but we did not quantify this. Here we shall. Assume that the temperature in the upper mantle of the earth is 273K at the surface and rises linearly to 1473K at 100 km depth (roughly the source depth of basaltic rocks that erupt at this temperature). Still deeper the temperature, controlled by convection, is approximately constant. Use the following wet olivine creep law

strain rate (s^{-1}) = $10^{4.0} \sigma^{3.4}$(σ in MPa) exp $(-444$ kJ mol^{-1} / RT)

with R = 8.314 J/K, to estimate the Maxwell time as a function of depth for a typical stress $\sigma \approx 30$ MPa (produced by loads ca. 1 km thick). Upper mantle shear modulus $\mu = 65$ GPa. How thick is the "lithosphere" for loads applied for: 1 Myr, 10 Myr, 100 Myr, and 1 Gyr? How sensitive is this thickness to the assumed stress? Beware of unit conversions! (Melosh "Planetary Surface Processes," question 4.3)