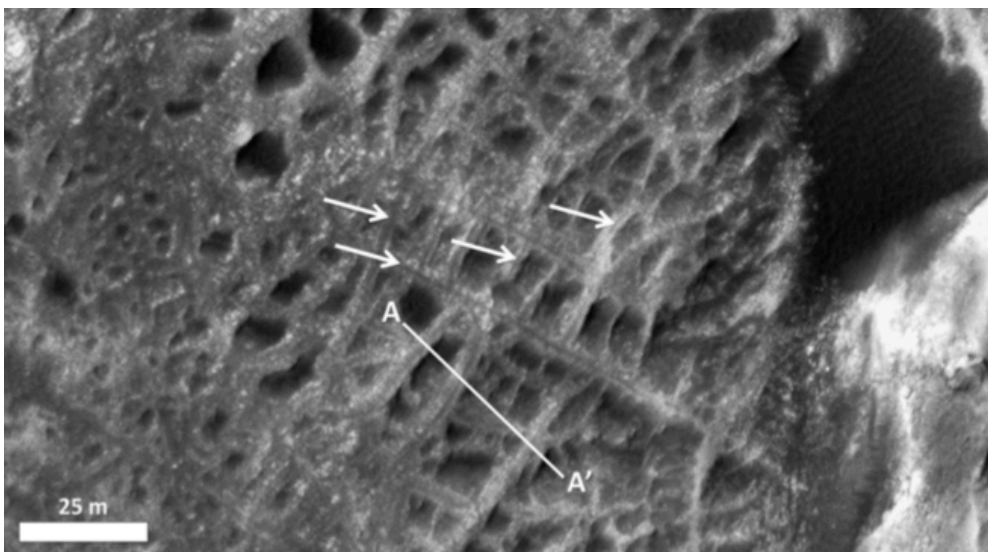
GEOS 32060 / GEOS 22060 / ASTR 45900
Homework 3

Due in class on Monday 1 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.

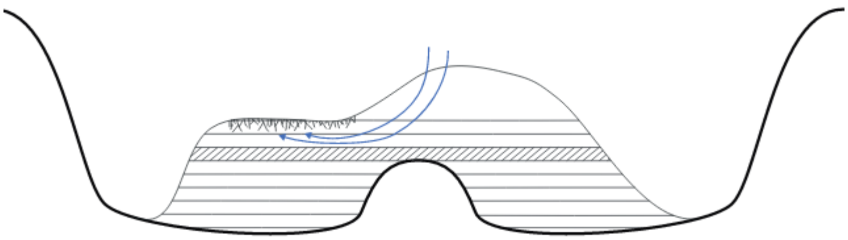
Q1. Mars boxwork and groundwater circulation.
Mars Reconnaissance Orbiter has found "boxwork" structures along the future path of the *Curiosity* rover. These light-toned ridges are interpreted as preferentially-cemented halos around dark central fractures formed during a past episode of groundwater flow (the rocks have since been wind-eroded, and the cement resists erosion). The scale bar on this image is needed to answer this question.



a) Assume the haloes form by chemical diffusion at a diffusivity of 10^{-17} m^2 s^{-1}. What is the formation time of the haloes?
b) Now assume that the haloes formed by infiltration of cementing fluids through a network of pores (pores not resolved from orbit). Model the network of pores as a cubical matrix of tubes – equation given in lecture 4, slide 34. Assume lattice spacing 0.1 mm and pore diameter 0.005 mm. What is the permeability? How long did the haloes take to form? (There is no need to do a complicated calculation for formation time; dimensional reasoning is acceptable.) You may ignore the feedback of cementation on permeability, and you may assume (for this part of the question) that the dark central fractures have very high permeability.

c) Discuss (quantitatively, with at least two examples) the dependence of formation time on pore spacing and on pore diameter. Which factor is more important?

d) Assume the boxwork once contained 30% pore space that is now completely occluded by cementing minerals. Assume water migrated vertically as it passed through the boxwork layer, had salinity 1 wt%, and that all salts were precipitated out to form the boxwork. Boxwork thickness is estimated at 40 m. Assume the pressure driving fluid flow corresponds to a water-table difference of 1 km over a baseline of 20 km, and an effective fracture (dark central features) permeability of 10^{-7} m^2 s^{-1}. What is the duration of subsurface fluid flow needed for boxwork formation?



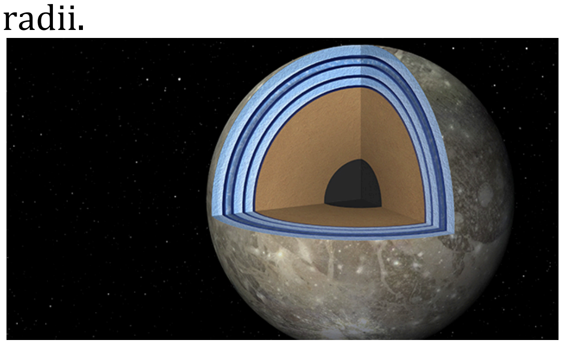
From Siebach & Grotzinger 2014.

e) Would you direct a paleolife-seeking rover to sample the boxwork?[1] To which of the above assumptions and parameters is your decision most sensitive?

Q2. Gravity anomalies on Ganymede.

Water-rock reactions are associated with gravity lows, because pore space is less dense than rock (even if liquid-filled); and hydrated minerals produced by water-rock reactions are usually less dense than anhydrous minerals.

Ganymede is a 0.4 Earth-radius moon of Jupiter with a probable "club sandwich" outer layer of multiple salty oceans and high-pressure-ice shells, a rocky mantle, and a liquid metal core with a strong dynamo. Moon density and J2 constrain the rock-metal boundary to be at ~0.25 Ganymede radii and the rock-water boundary to be at 0.65 Ganymede radii.



[1] \$10 mn (amortized) for in-situ sampling; >\$100 mn for return to Earth.

Ganymede is notable for its large gravity anomalies (detected during close flybys by the Galileo Jupiter orbiter). The anomalies are not correlated with surface geology. At closest approach (200 km), the anomalies produced a change in acceleration of ~1×10^{-5} m s^{-2}.

a) What is the approximate spatial resolution (the observational "footprint") of a flyby gravity measurement at the surface? At the rock-ice boundary? At the rock-metal boundary? You may neglect planet curvature.
b) Density of metal = 7 g/cc; of rock = 3 g/cc; of high-pressure water substance, 1.5 g/cc. Assuming a "mountain" of metal (a perturbation of the rock-metal boundary) is responsible for the gravity anomalies, and the mountain radius is the footprint size from part (a), what is the height of the mountain? Repeat the calculation for a mountain of rock at the rock-ice boundary. You may neglect planet curvature.
c) Assume the viscosity of ice is 10^{13} Pa s, the viscosity of rock is 10^{18} Pa s, and the viscosity of liquid metal is 10^{1} Pa s. Modeling the mountains as spheres, what is the time for the mountains to sink? (There are many ways of doing this but the simplest is to balance Stokes drag and the negative buoyancy of the mountain. Consider the reduction in gravity inside the moon). Are the "mountains" a reasonable explanation for the data? ***Warning/hint:*** Consider what has to happen on both sides of the interfaces in order for the boundaries to re-equilibrate!
d) An alternative explanation for the data is a porosity anomaly just below the rock-ice boundary. Assuming a 10% difference in porosity, and a porosity-anomaly radius (i.e. lateral extent on the rock-ice boundary) equal to the relevant "footprint" from part (a), what is the depth of the porosity anomaly?
e) Assume the temperature at the Ganymede rock-ice boundary is 350K, and that for T>1000K, pores flow shut within 4 Gya. Assume heat flow is in balance with radioactive decay (H = 10^{-11} W/kg) and that radioactive decay occurs only in the rock. Assume a thermal conductivity of 2 W/m/K. What is the depth of a porous layer on Ganymede if all porosity was produced 4 Gya?