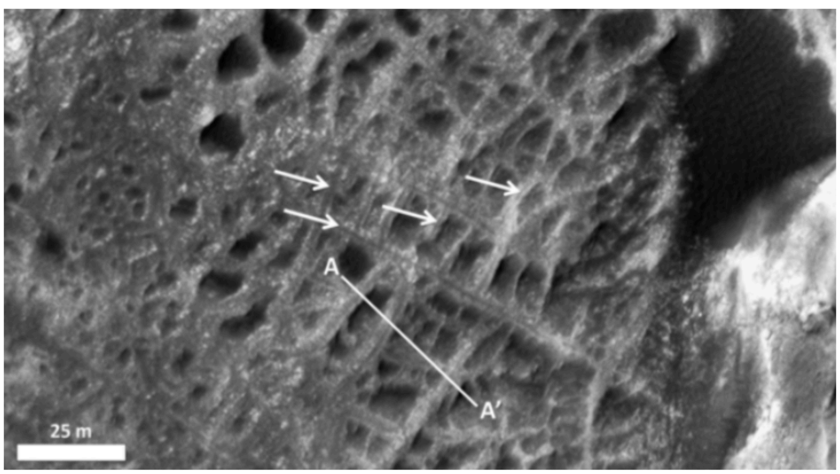
GEOS 22060/32060 – Spring 2019 – Homework 5

Due in Kite mailbox (which is in the mailroom on the 1st floor of the Hinds building) 4pm Friday 24th May. To get to the mailroom on the 1st floor of the Hinds building, turn left on entering Hinds through the main (East) entrance, walk past the sofas, and just after entering a windowless corridor, the mailroom will be the first room on your left. 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.

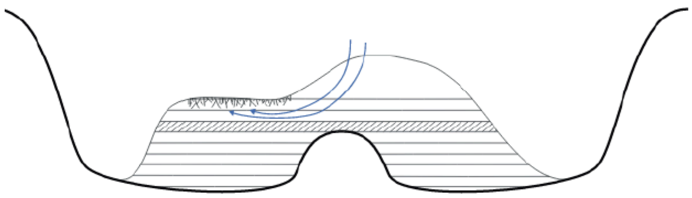


a) Assume the haloes form by chemical diffusion at a diffusivity of 10^{-17} m^2 s^{-1}. What is the formation time of the haloes?

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?

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

Q2. Ejecta weathering. In addition to tectonic uplift, impacts can eject fresh-mineral surface area for weathering. Assume the mass distribution of impactors contains no impactors smaller than a pebble or larger than Ceres, and within that range follows the power law $N(>m) = (m/m_{max})^{-b}$, where m_{max} is the mass of the largest impactor, $N(>m)$ is the cumulative number of impactors greater than mass m, and b = ¾.

a) Is impacting mass concentrated in the largest impactors or the smallest impactors? Show why.

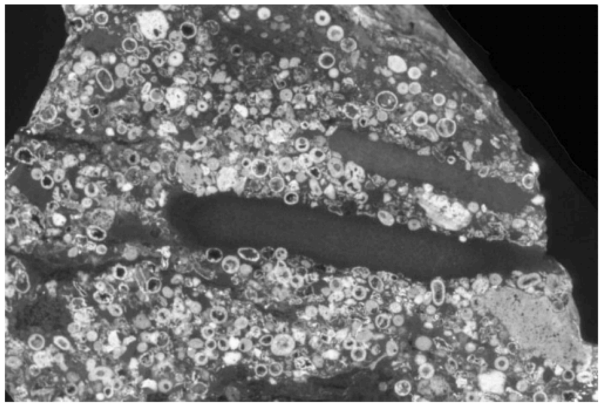


Figure 2 Polished surface of hand sample from lower, spherule-rich part of late Archean Jeerinah layer. Spherules range in shape from spheres to ovoids and typically have an outer rim of fibrous K-feldspar (*light gray*) plus a core of sparry quartz and/or K-feldspar crystals (*dark gray to black*). Long dark slabs are shale intraclasts. Medium gray particle in lower right corner is an irregular, finely vesicular impact melt clast. Long axis of field of view is 33 mm.

Simonson & Glass, Annual Reviews of Earth and Planetary Science, 2004. The scale given in this image will be helpful in answering the question.

b) Ancient impactors on Earth are recorded by spherule beds (the craters have subducted). Spherules condense from rock vapor in impact plumes during the minutes after impact, then fall to Earth as fresh, initially unweathered material. Assume a weathering (dissolution) rate for spherules of 3 mm/(10^6 yr), what is the duration of the weathering pulse associated with the above layer?

c) Assuming a (Ca+Mg) content of 10 wt %, a (spherule layer):impactor mass ratio of 10^2, and an Archean atmosphere+ocean C inventory and recycling time equal to that of the modern Earth (300 Kyr), what is the impactor radius needed in order for the Jeerinah layer to have transiently doubled Earth's weathering rate?

d) Suppose that a planet has ongoing volcanism but no plate tectonics and no mountain uplift (modern Mars is an example). Suppose that the rate of volcanism is sufficient to increase CO_2 pressure by 100 mbar every 10 Myr. Assume the gravity and surface area of Mars. Determine the flux of 10 km-diameter (dinosaur-killing) impactors needed to generate enough weathering to consume as much CO_2 as is released and thus prevent runaway warming.

e) Comment, given your answer to (a), on whether this set-up can lead to a stable climate in practice. For what value of *b* might your answer change?

f) Now consider a Super-Earth (r = 2x Earth, g = 25 m/s^2). How does your answer to part (d) change? Why?