The science of landscapes: Earth and planetary surface processes
Winter 2020
Problem set 6

Due Wednesday 11 March, 10:30am.

Q1. Plot the expected steady-state pattern (as a function of distance from the crest) of discharge of regolith on a convex hillslope in a climate in which the production rate of regolith is 20 mm/yr. Report your answer in m^2/year. If the regolith was 0.8 m thick, what would be the spatial pattern of the mean downslope velocity of the regolith? How would these numbers change if 25% of the mass loss occurred in solution (dissolved in rainwater)? (From Anderson & Anderson)

Q2. (*From Hartley et al., Nature Geoscience, 2011*)
Seismic reflection profiling between Iceland and the UK shows a drowned landscape that was above sea level 55 Ma. The landscape was cut into mudstones and is now buried beneath >1 km of sediment, plus 700m of water. The landscape (black square in the below figure) was uplifted and then reburied due to the arrival of the head of mantle plume whose "stalk" now fuels volcanism at Iceland:

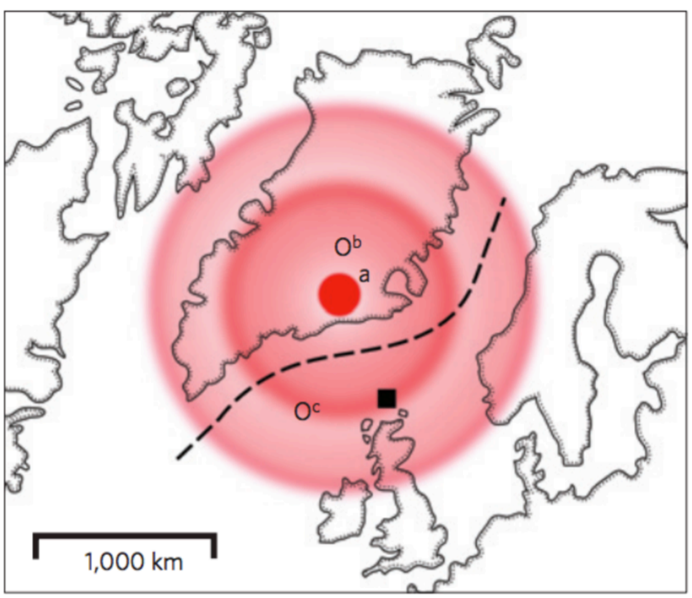


Figure 1 | Icelandic plume. Reconstructed palaeogeography of the North Atlantic Ocean during Late Palaeocene times[23]. a, b and c are proposed plume centres of ref. 6, ref. 24 and ref. 1, respectively. Dashed black line, location of continental break-up; black square, region of study shown in Fig. 2; red shading, idealized extent of Icelandic plume, where ripples represent radial spreading of hotter annuli of plume material.

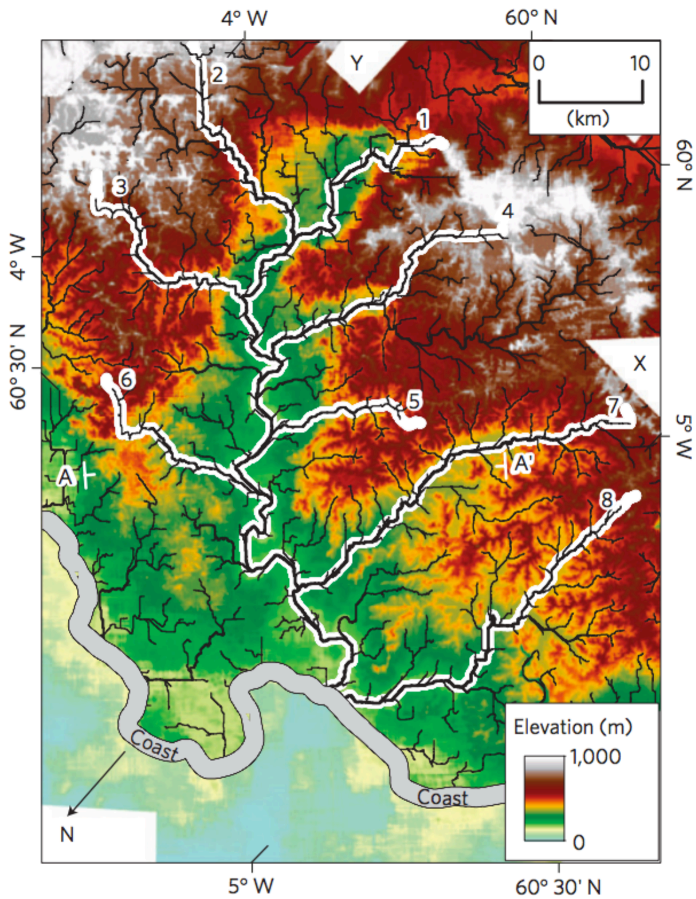
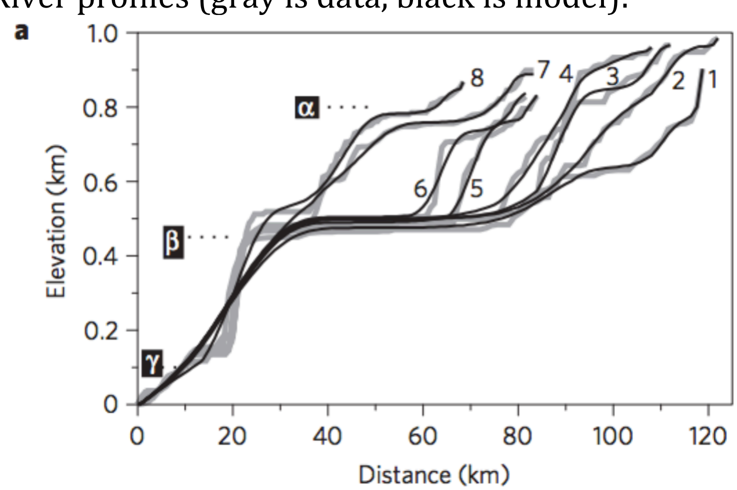


Figure 3 | Topographic map of buried landscape. Numbered black-on-white lines, eight river tributaries traced out by a flow-routing algorithm that reconstructs drainage networks from digital elevation models[11]; grey band, inferred coastline[2]. A–A′, position of vertical slice shown in Fig. 2a; X and Y, orientation aids (Fig. 2c). The line spacing of seismic data is typically 30 m.

River profiles (gray is data, black is model):



What is the slope of the knickpoint marked β?

What is the (range of) approximate drainage areas at β?

A feature of the streampower law with n = 1 is that knickpoints (steep parts of the channel profile) appear to be advected upstream over time, preserving their shape. Assuming n=1 in the streampower law (so that knickpoint shape is preserved on retreat), what is the knickpoint retreat rate vA^m? You can assume v = 2.75 Myr^{-1} and m = 0.5 for this question.

$$\frac{\partial z}{\partial t} = U(t) - vA^m \frac{\partial z}{\partial x}$$

Approximately how many years prior to the landscape becoming "drowned" (frozen in shape) was the knickpoint initiated?

Refer to Figure 1. Assume the initiation of knickpoint β corresponds to the arrival of the "mushroom head" of the mantle plume, and the drowning of the landscape corresponds to the switch to the modern, narrow "plume tail" configuration.

What is the area over which uplift occurred?

Assuming the red-circled area was horizontal and below sea level before the plume arrived, what is the volume of uplifted rocks?

Assuming the drowned landscape under investigation is representative of the fractional erosion of the uplifted landscape across the whole red-circled area, what is the volume of rocks fluvially eroded in the plume area during the plume event?

What is the erosion flux in km^3 yr^{-1}?

How does this compare to the Holocene pre-dam global sediment flux of 8 km^3 yr^{-1}?

Q3. In lecture we discussed accumulation of a stable cosmogenic isotope in a rock undergoing exhumation, and we also discussed accumulation of a radioactive cosmogenic isotope in a rock that has no erosion. In this question we will combine exhumation and decay.

Assume a production rate of ^{10}Be of 5 atoms/(gram quartz)/yr at the surface, with an e-folding depth of 1 m (so the production rate is 1.84 atoms/(gram quartz)/yr at 1m depth). ^{10}Be decays exponentially with a half-life of 1.4 Myr. Plot the expected concentration of ^{10}Be at the surface, as a function of erosion/exhumation rate, for a quartzite rock. Make sure to consider the endmembers of very slow erosion/exhumation (for which the ^{10}Be concentration will reach equilibrium between production and decay), and the endmember of very fast erosion/exhumation (for which decay is unimportant in setting the ^{10}Be concentration).