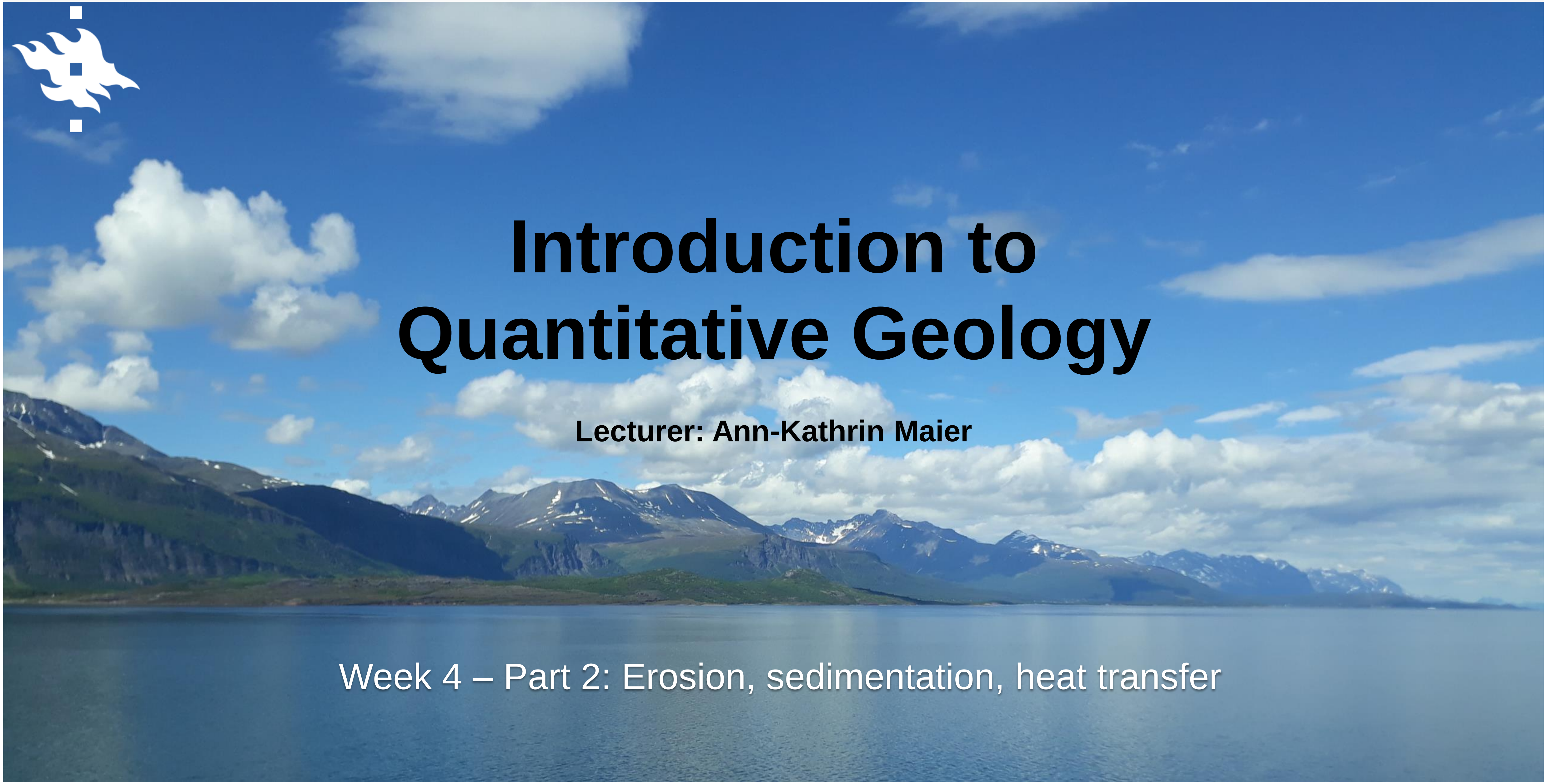


Introduction to Quantitative Geology

Lecturer: Ann-Kathrin Maier

Week 4 – Part 2: Erosion, sedimentation, heat transfer

This week

- **Part 1: Advection**
  - The advection equation
  - Advection in geological processes
- **Part 2: Erosion, sedimentation, heat transfer**
  - Some definitions
  - What happens with the geothermal gradient?

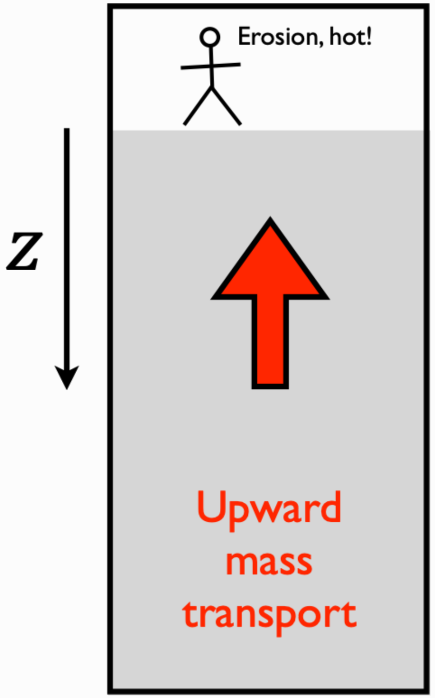
Some terminology

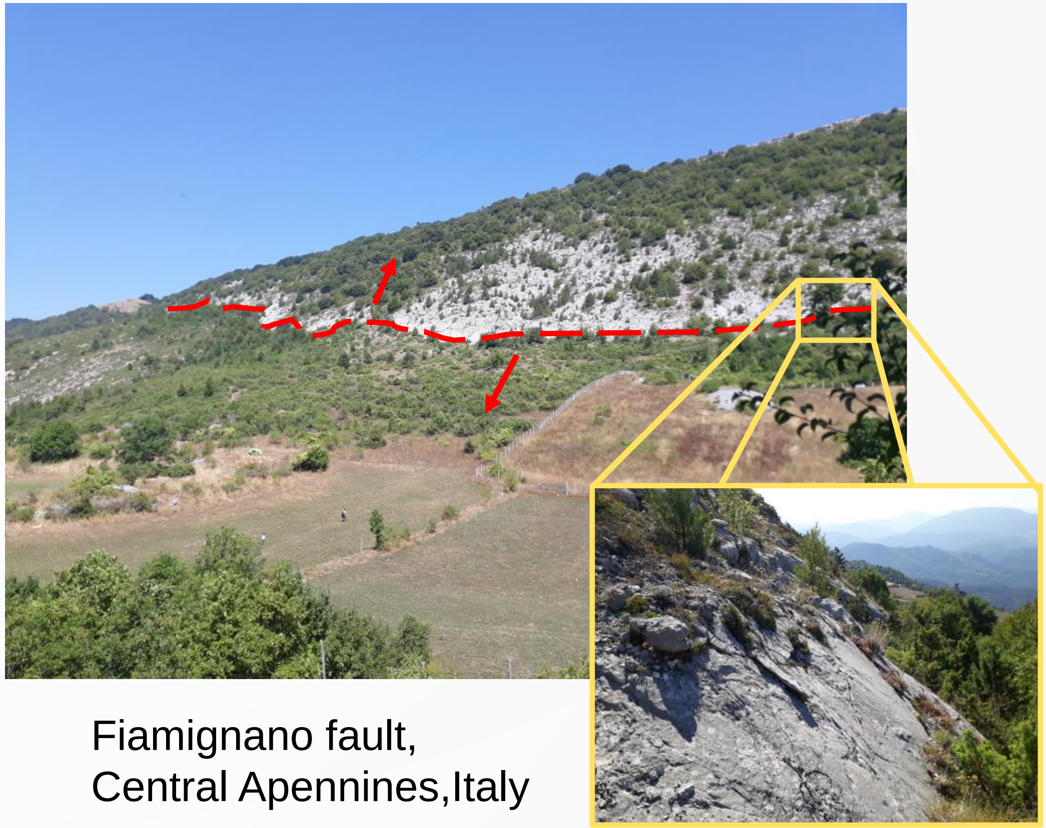
- **Exhumation:** The unroofing history of a rock (vertical movement of the rock relative to the Earth's surface) caused by tectonic or surface processes.
- **Erosion:** The removal of mass at a point on the Earth's surface by chemical and mechanical processes.
- **Denudation:** The removal of rock at a point at or beneath the Earth's surface by tectonic or surface processes.

refer to Ring et al. (1999) for details

Exhumation

- Brings relatively hot rock up toward the surface, increasing the geothermal gradient
- **Mechanisms:**
  - Normal faulting, erosion, ductile thinning





Fiamignano fault,
Central Apennines,Italy

Erosion

- An exhumation mechanism
- **Important erosion agents:**
  - Water (e.g. rainfall, rivers/streams, sea/waves)
  - Glaciers (plucking, abrasion)
  - Wind
  - Mass movement

Rain splash

Baltoro glacier, Karakoram


Rice field on landslide, Japan

Wavecut platform, South Wales

Quiz: What is the dominant erosion agent?

Árbol de Piedra, Bolivia

Jebel Kharaz, Jordan

Negev desert, Israel

Quiz: What is the dominant erosion agent?

Sylt, Germany

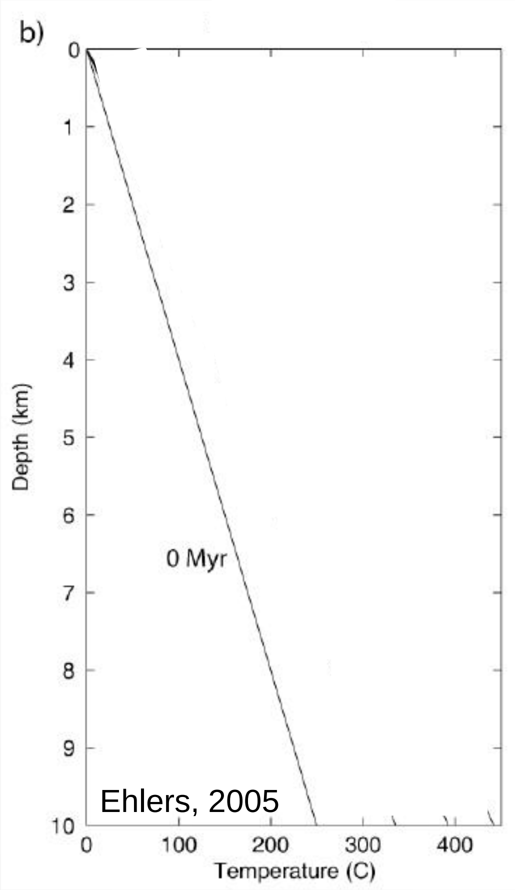
Gran Sasso, Italy

Noto peninsula, Japan

Back to thermochronometers (briefly)

- What do they record?
  - **Cooling:** Time since rocks were at a thermochronometer-specific effective closure temperature Tc
  - **Exhumation:** Advection of rocks toward the surface of the Earth

Thermal gradient changes



Ehlers, 2005

- The **geothermal gradient** is simply the difference in temperature at two different depths in the Earth, with typical values of 15-30°C/km
  - Used to study thermal processes in the (shallow) crust
  - Multiplying the geothermal gradient by the rock thermal conductivity yields the heat flow

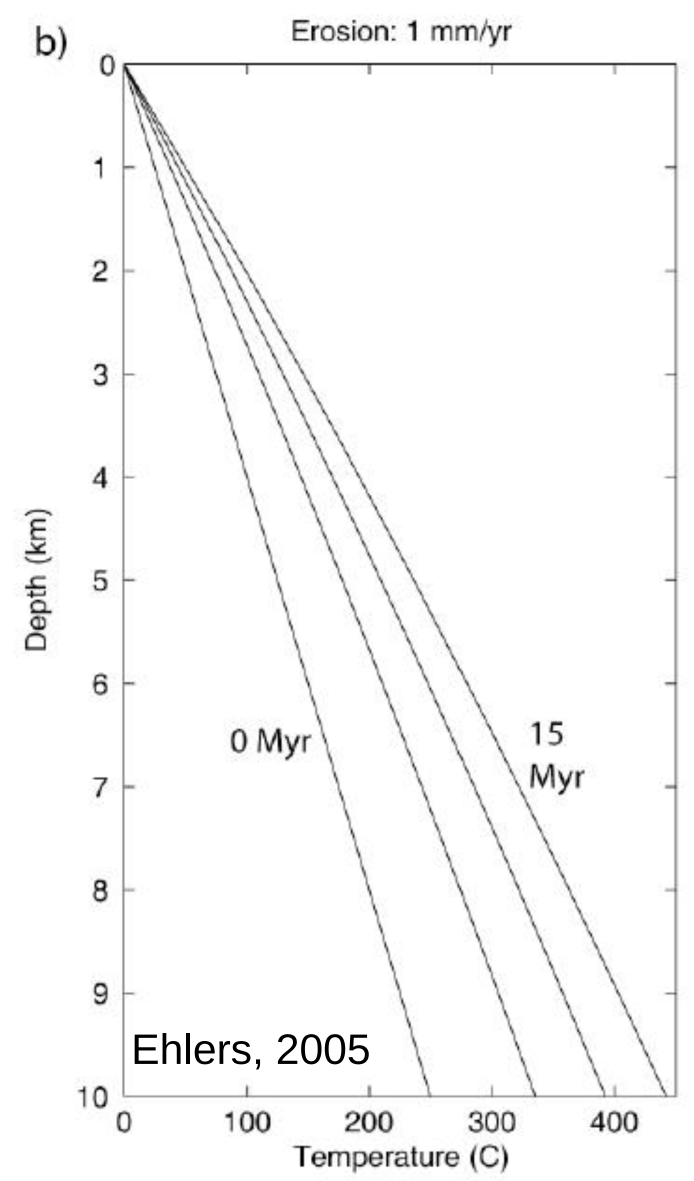
1D transient advection-diffusion equation

$$T(z,t) = G(z + v_z t) + \frac{G}{2}\left[(z - v_z t)\mathrm{e}^{-v_z z/\kappa}\mathrm{erfc}\left(\frac{z - v_z t}{2\sqrt{\kappa t}}\right) - (z + v_z t)\mathrm{erfc}\left(\frac{z + v_z t}{2\sqrt{\kappa t}}\right)\right]$$

- This week's exercise ☺
- The thermal field in the Earth's crust is affected by the rate of vertical advection of rock and the time that the rate of advection is applied (and other factors)
- The exercise notebook for this week defines all the variables!

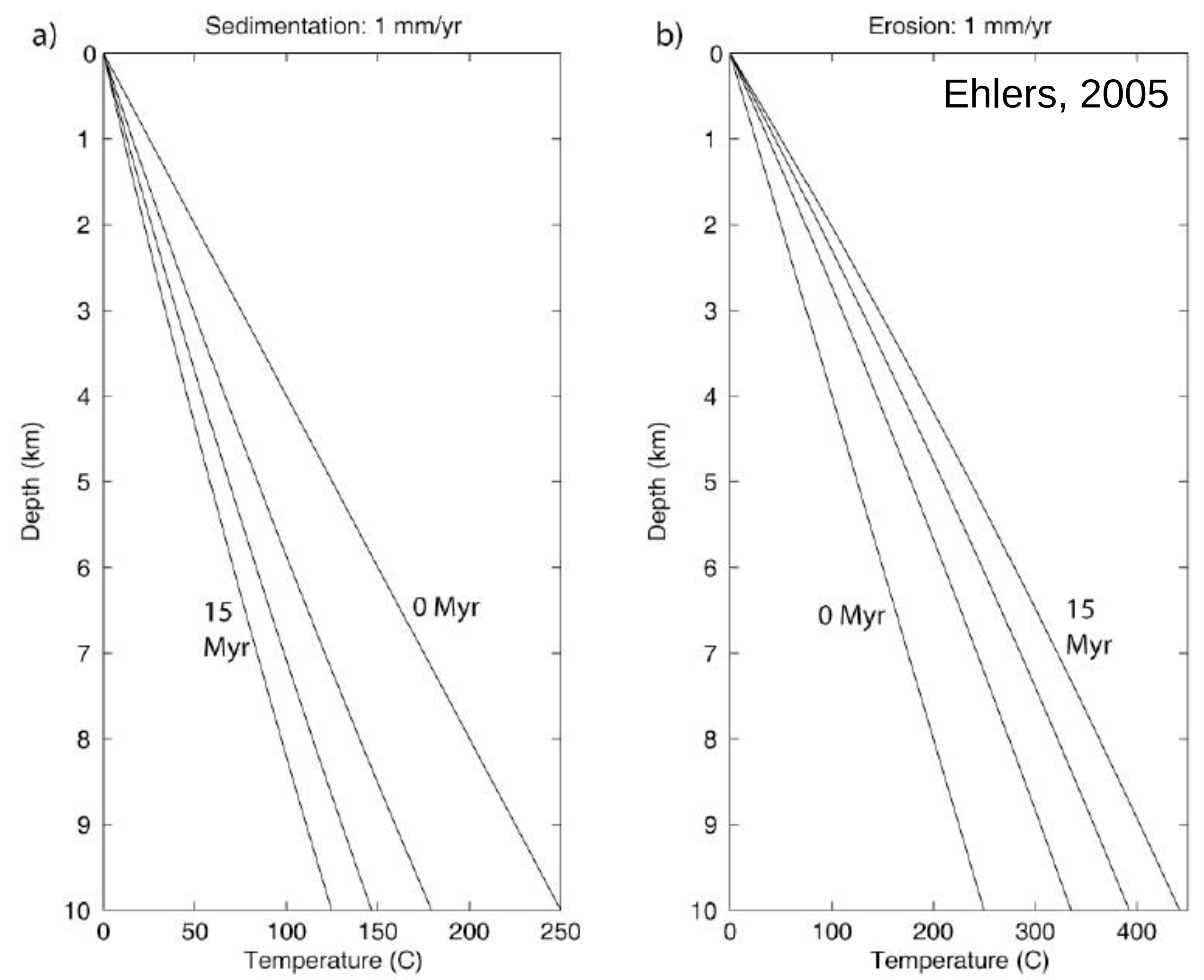
Effects of erosion on the geothermal gradient

- **Erosion increases temperatures in the crust**
  - For this particular equation, no boundary condition limits the temperature at the base of the model and steady state will not be reached



Effects of sedimentationon the geothermal gradient

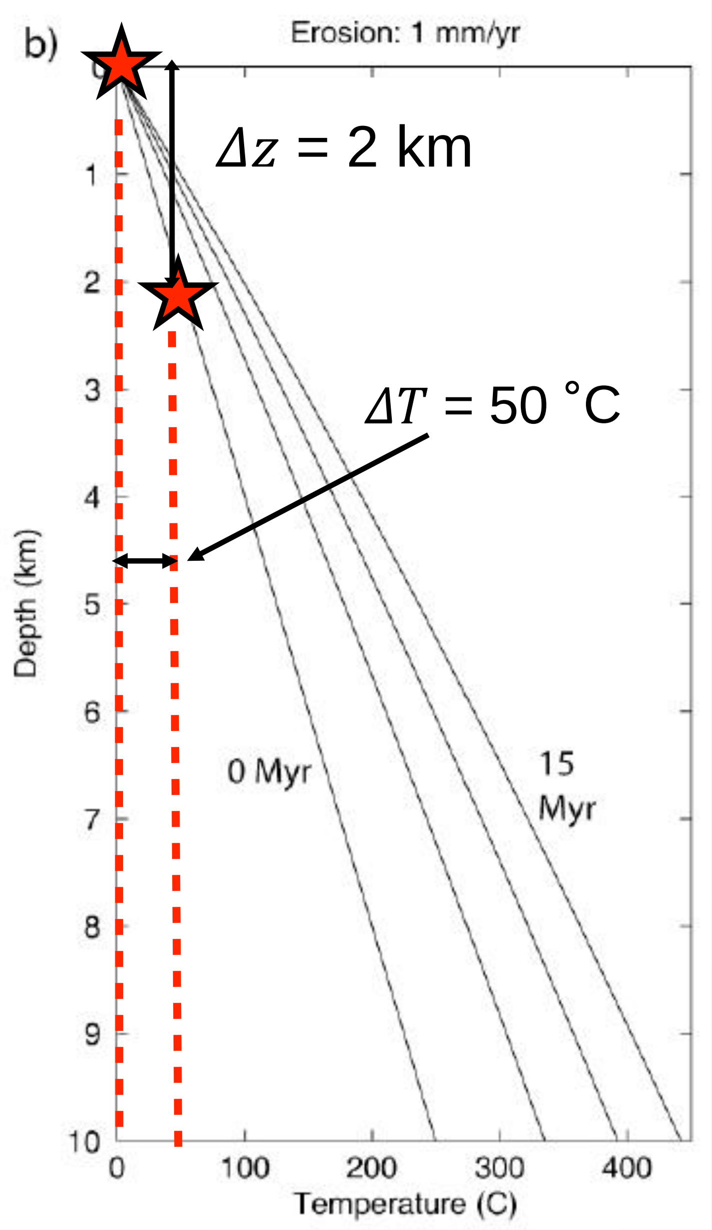
Erosion and sedimentation work similarly, but in the **opposite** sense!



Thermal gradient changes

$\Delta T / \Delta z = 25$ ℃/km

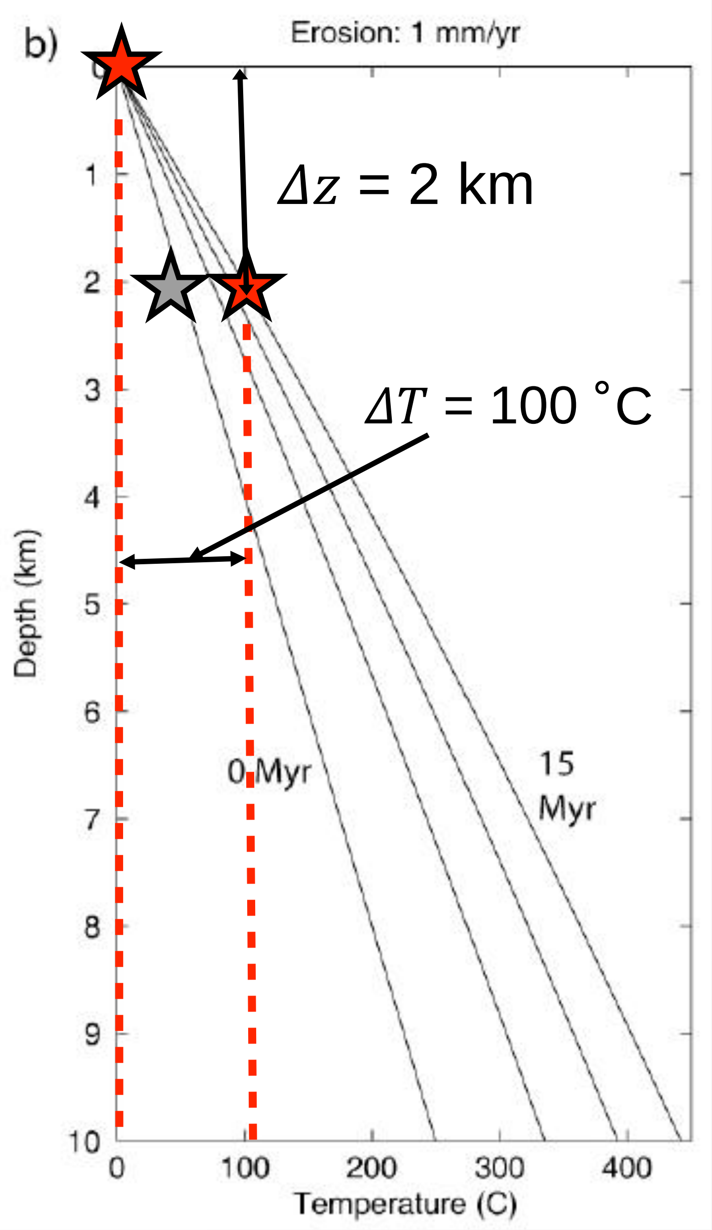
In this example, the geothermal gradient for t=0 Myr is 25 °C/km.



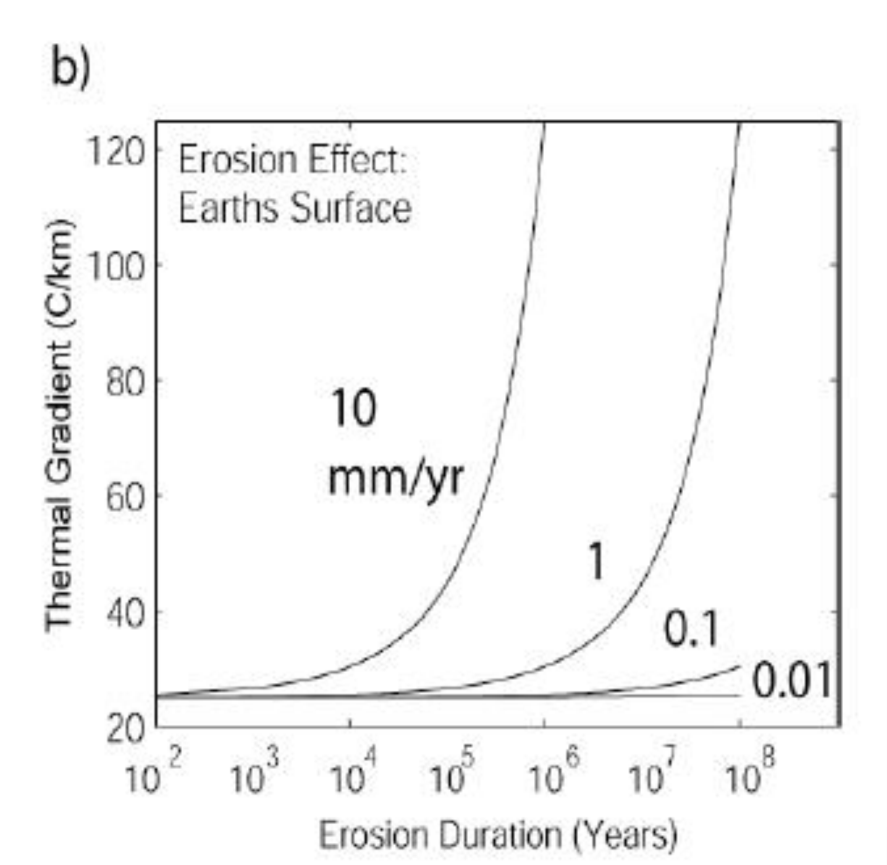
Thermal gradient changes

$\Delta T / \Delta z = 50^{\circ}$ C/km

In this example, the geothermal gradient doubles over the first 15 Myr of the calculation.

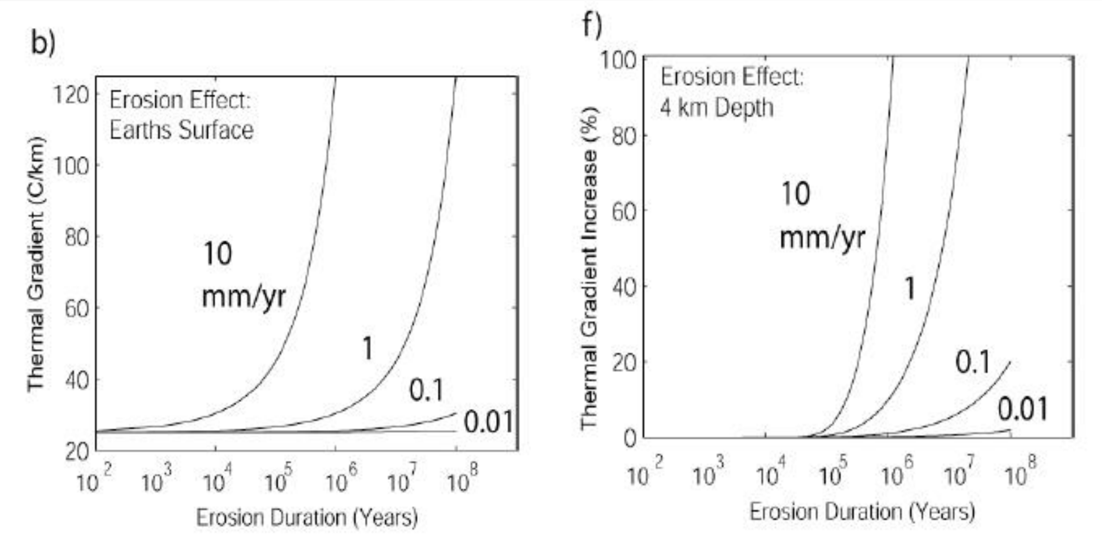


Thermal gradient changes



- Depending on the rate of advection, the timing of changes in the geothermal gradient near the Earth’s surface will vary
  - Faster advection velocities result in more rapid changes in geothermal gradient

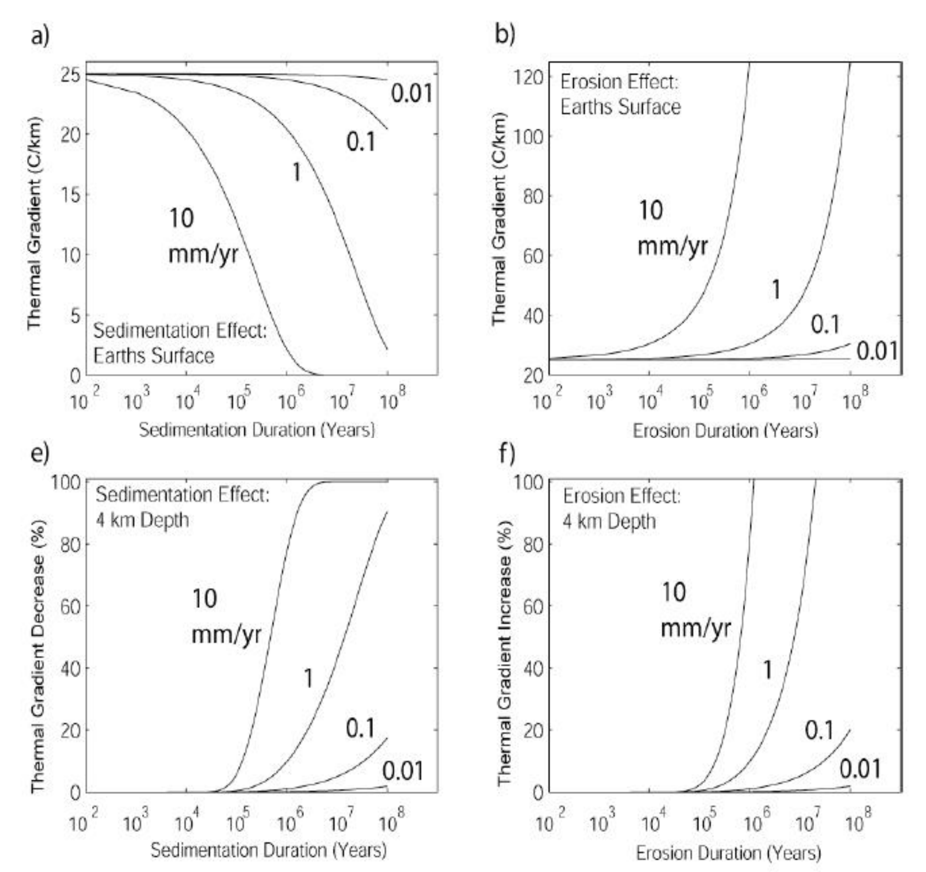
Thermal gradient changes



Ehlers, 2005

- Deeper in the Earth:
  - The timing of changes in the geothermal gradient will **lag behind** the changes in near the surface

Thermal gradient changes



Ehlers, 2005

- The same thing can be said for sedimentation, but in the opposite sense.

Recap

- Erosion and sedimentation will affect crustal temperatures due to the advection of heat
- The rate and duration of advection will determine how much temperatures are affected
- **General expectation: Exhumation heats the crust; sedimentation cools the crust.**

Exercise 4: Advection and diffusion of heat

- You will explore

$$T(z,t) = G(z + v_z t) + \frac{G}{2}\left[(z - v_z t)\mathrm{e}^{-v_z z/\kappa}\mathrm{erfc}\left(\frac{z - v_z t}{2\sqrt{\kappa t}}\right) - (z + v_z t)\mathrm{erfc}\left(\frac{z + v_z t}{2\sqrt{\kappa t}}\right)\right]$$

- **Due: 26 Nov. at 12:15**

Wishlist for the following weeks

- Ok as is?
- More equations/ math?
- More case studies or fewer case studies?
- More in-class coding?

References

Ehlers, T. A. (2005), Crustal Thermal Processes and the Interpretation of Thermochronometer Data, in *Low-Temperature Thermochronology: Techniques, Interpretations and Applications*, vol. 58, edited by P. W. Reiners and T. A. Ehlers, pp. 315–350, Mineralogical Society of America.

Ring, U., M. T. Brandon, S. D. Willett, and G. S. Lister (1999), Exhumation processes, *Geological Society Special Publications*, *154*, 1–27.