Introduction to Quantitative Geology
Lecture 4.2
Erosion, sedimentation, and heat transfer

Lecturer: David Whipp
david.whipp@helsinki.fi

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Goals of this lecture

- Clarify some terminology about rock exhumation and erosion
- Review the basic concepts of heat transfer as a result of erosion and sedimentation

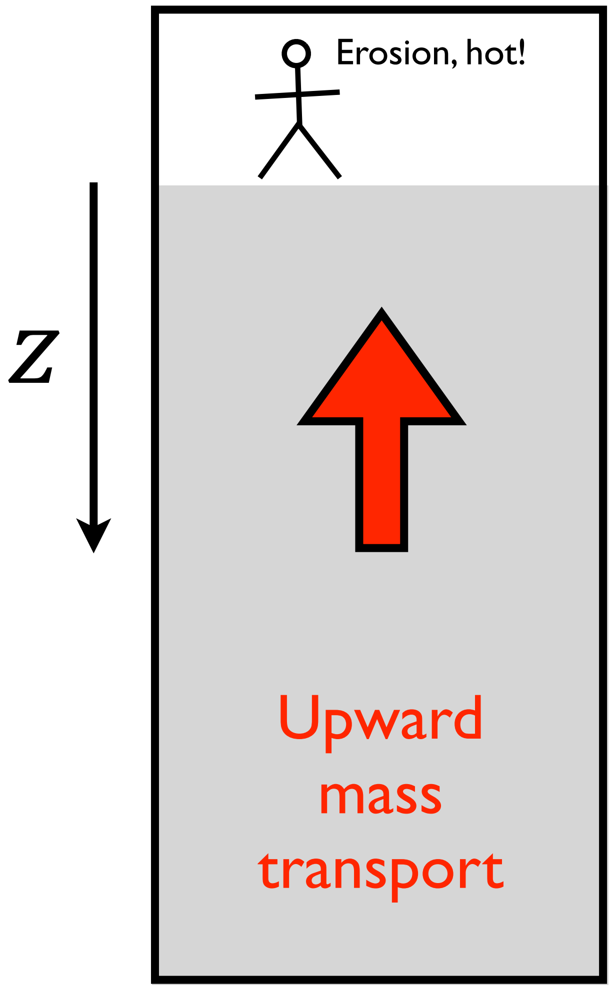
What do thermochronometers record?

- **Cooling**
  - Time since rocks were at a thermochronometer-specific effective closure temperature T_c
- **Exhumation**
  - Advection of rocks toward the surface of the Earth (exhumation)

Erosion versus exhumation

- Erosion and exhumation are terms that are often misused and confused, so we need to start with some definitions (see Ring et al., 1999 for a detailed discussion)
  - **Exhumation**: The unroofing history of a rock; the vertical distance a rock moves relative to the Earth's surface. Can result from tectonic or surface processes.
  - **Denudation**: The removal of rock by tectonic and/or surface processes at a specific point at or beneath the Earth's surface
  - **Erosion**: The removal of mass at a specific point on the Earth's surface by both mechanical and chemical processes

Exhumation



- **Exhumation** results in upward advection of rock as surface rock is eroded and transported away
- Upward motion brings relatively hot rock up from depth toward the surface, increasing the geothermal gradient
- Exhumation typically becomes important at advection velocities of >0.1 mm/a

1D transient advection-diffusion equation

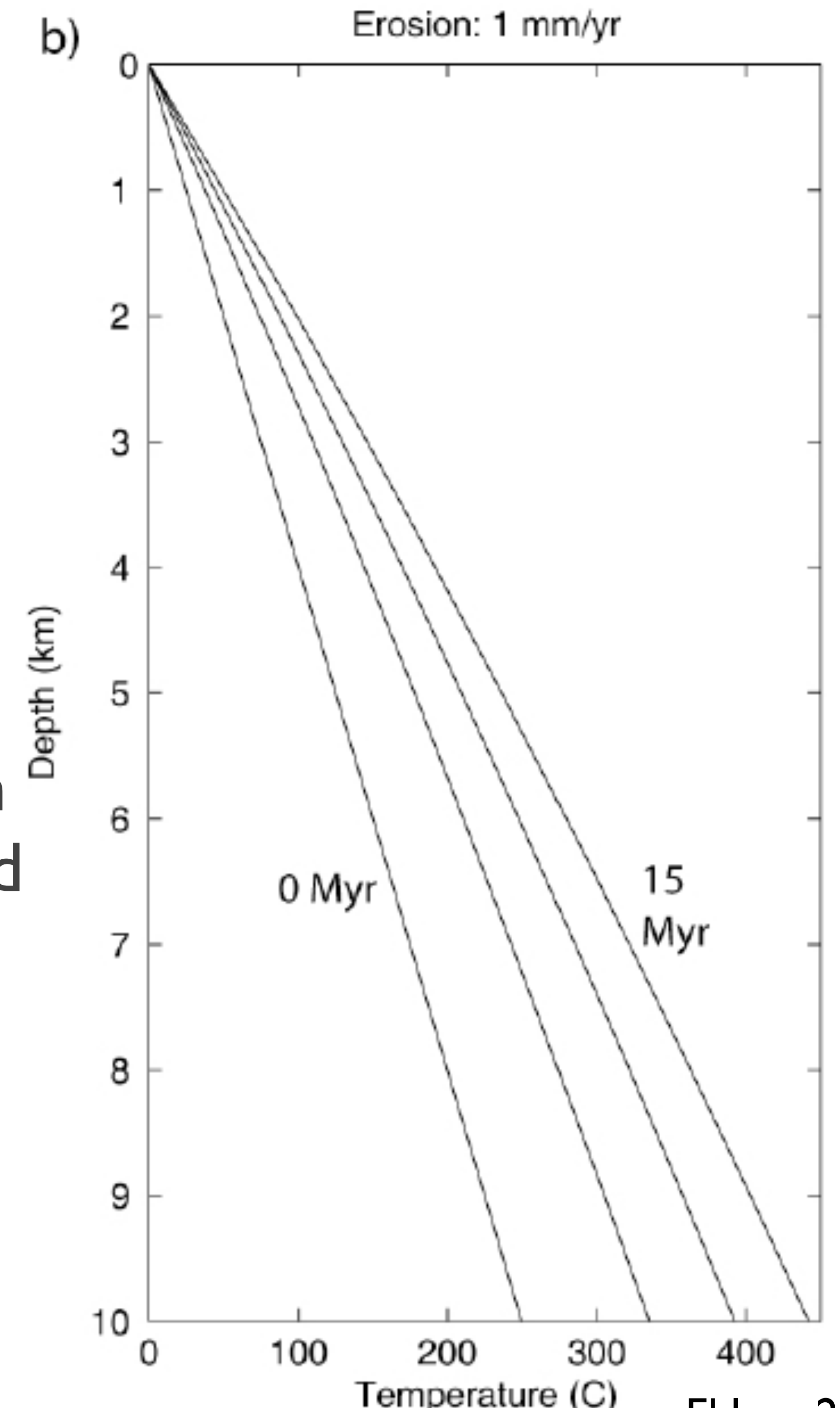
$$T(z,t) = G(z + v_z t) + \frac{G}{2}\left[(z - v_z t)\mathrm{e}^{-v_z z/\kappa}\mathrm{erfc}\left(\frac{z - v_z t}{2\sqrt{\kappa t}}\right) - (z + v_z t)\mathrm{erfc}\left(\frac{z + v_z t}{2\sqrt{\kappa t}}\right)\right]$$

- As you will see in the exercise this week, the thermal field in the crust of the Earth will be affected by the rate of vertical advection of rock and the time that the rate of advection is applied (as well as other factors)
  - The equation above is from this week's exercise and the exercise notebook defines all the variables

Effects of erosion and sedimentation

Erosion increases temperatures in the crust by the largest amount initially, but temperatures will continue to increase with time

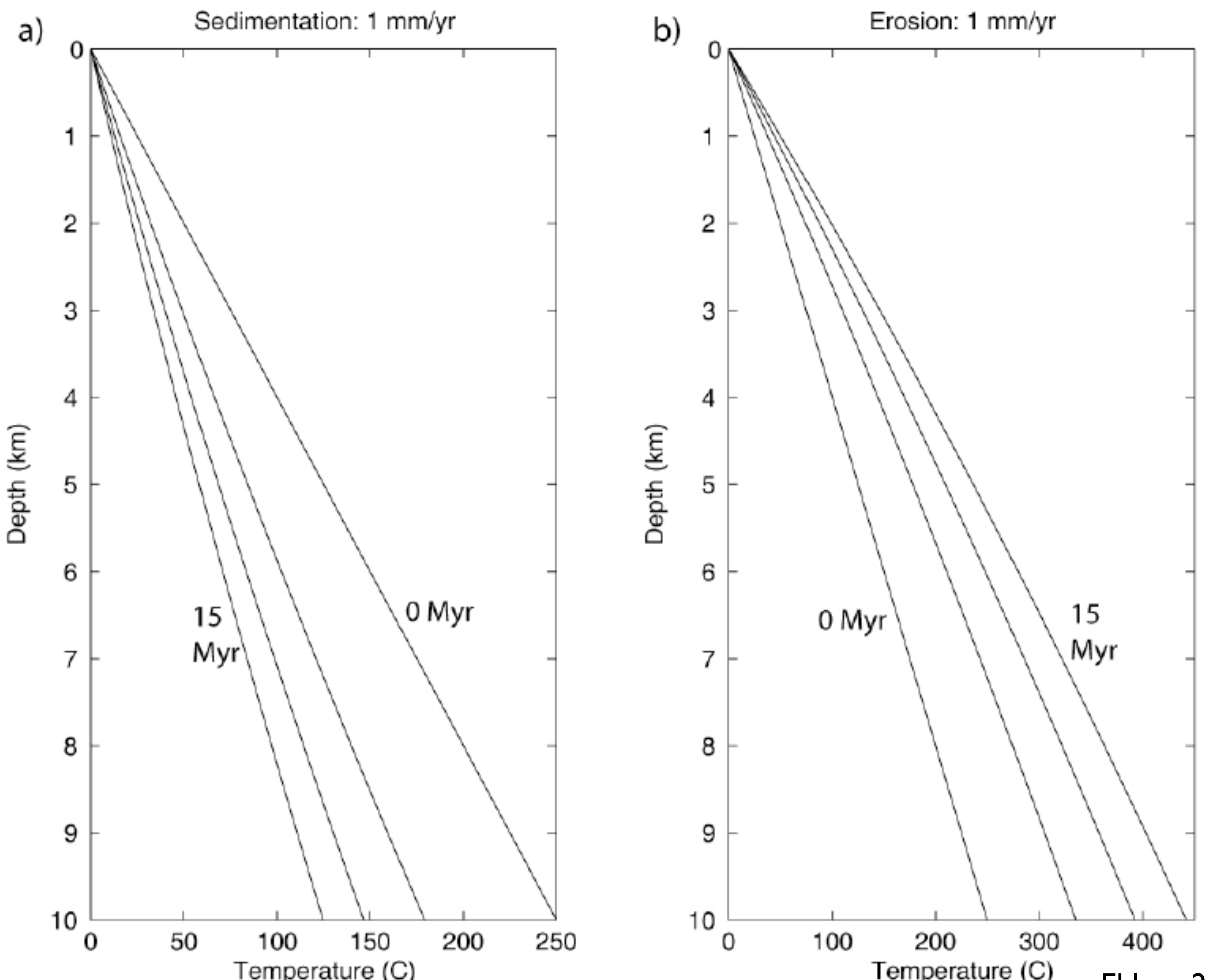
For this particular equation, no boundary condition limits the temperature at the base of the model and steady state will not be reached



Ehlers, 2005

Effects of erosion and sedimentation

Erosion and sedimentation work similarly, but in the opposite sense



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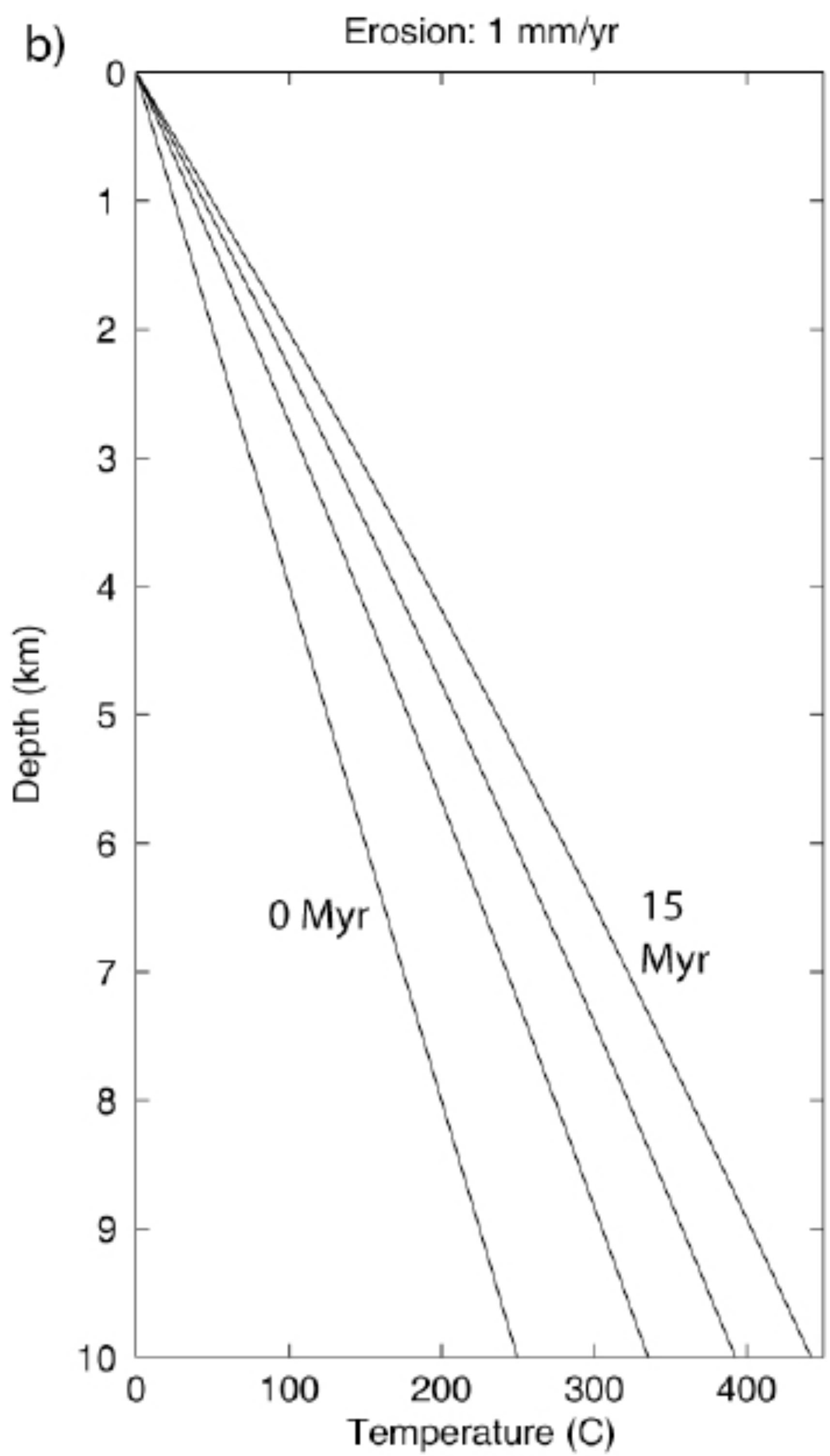
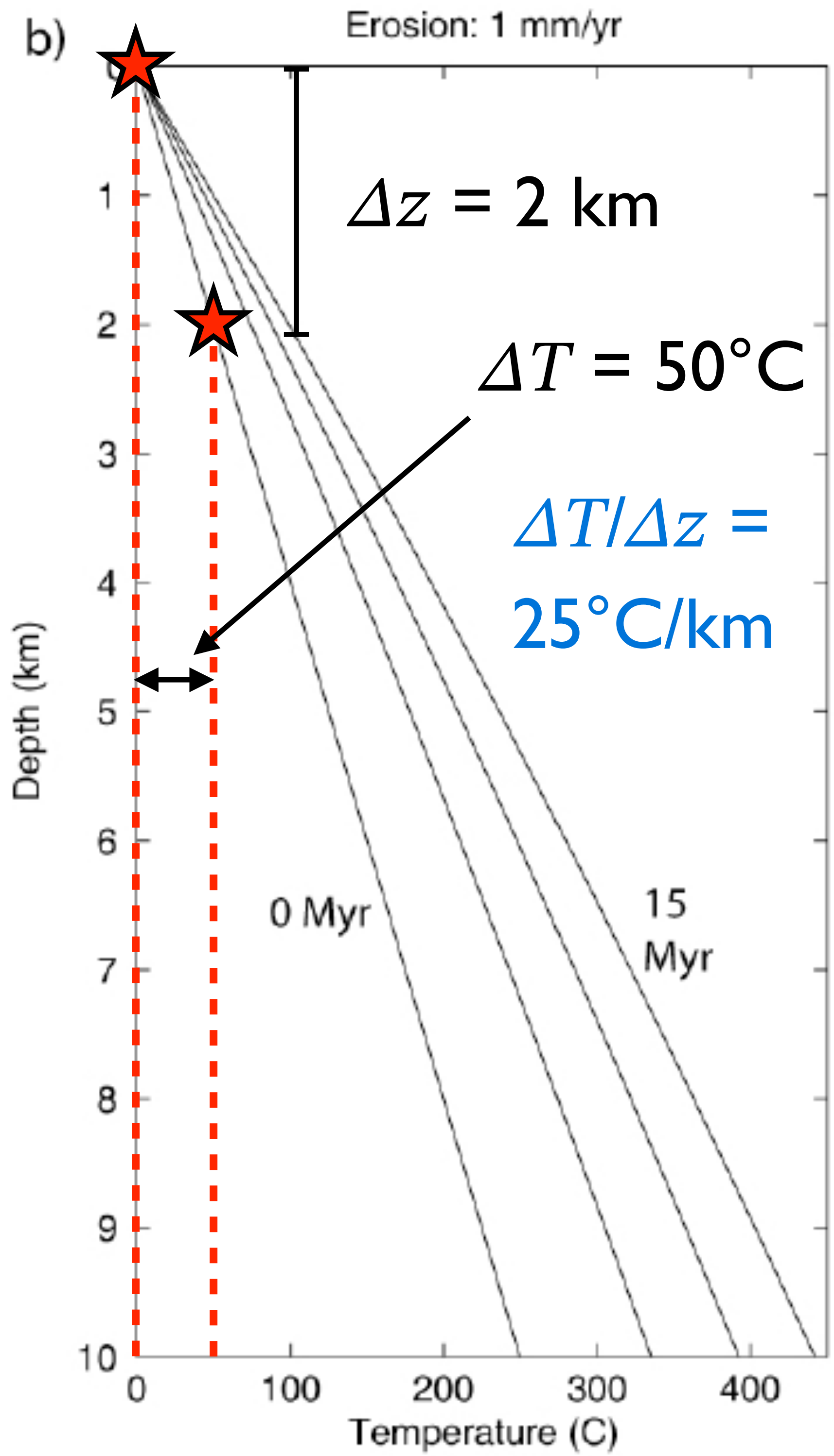
Thermal gradient changes



Ehlers, 2005

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

Thermal gradient changes



Ehlers, 2005

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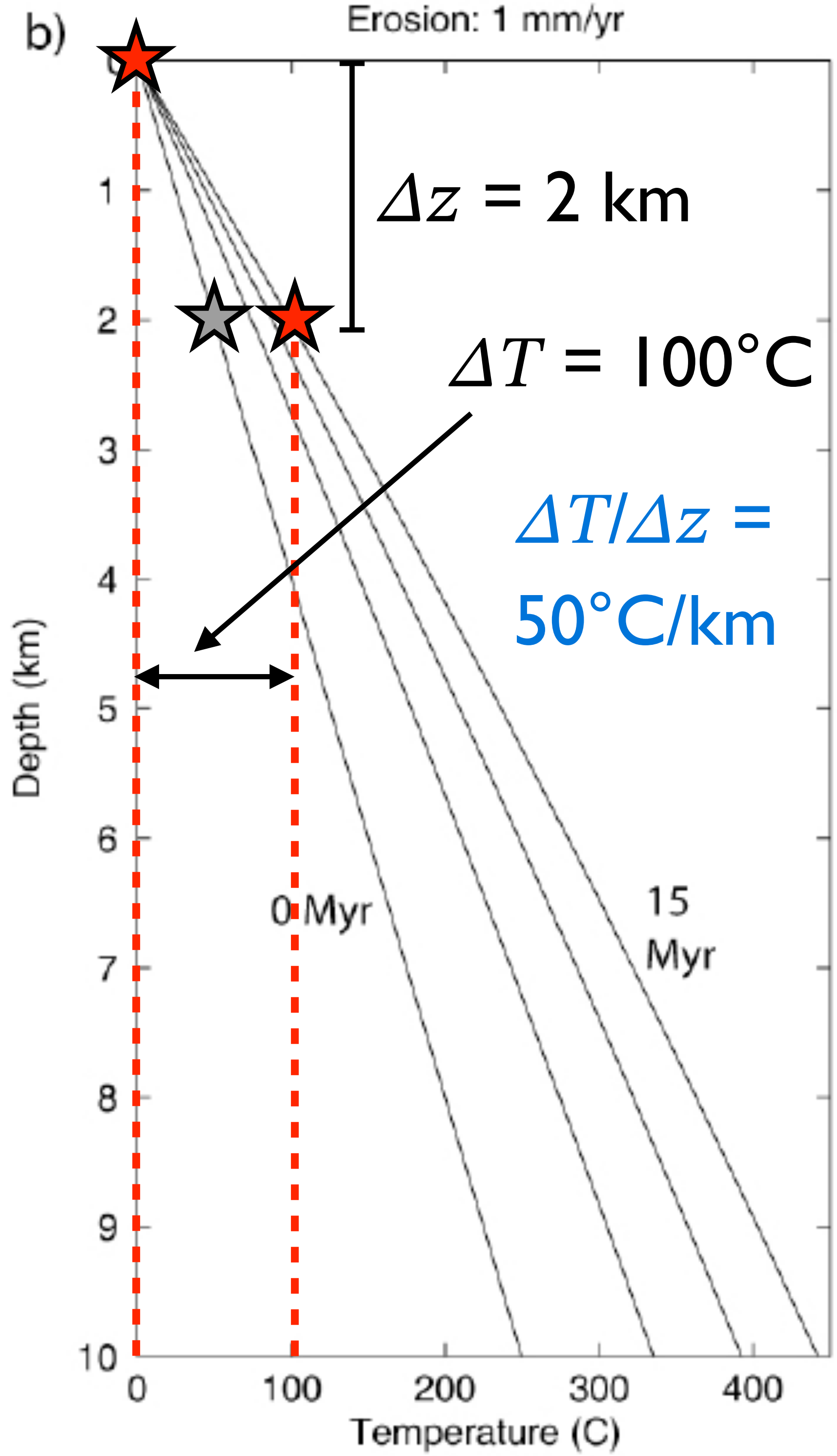
Thermal gradient changes



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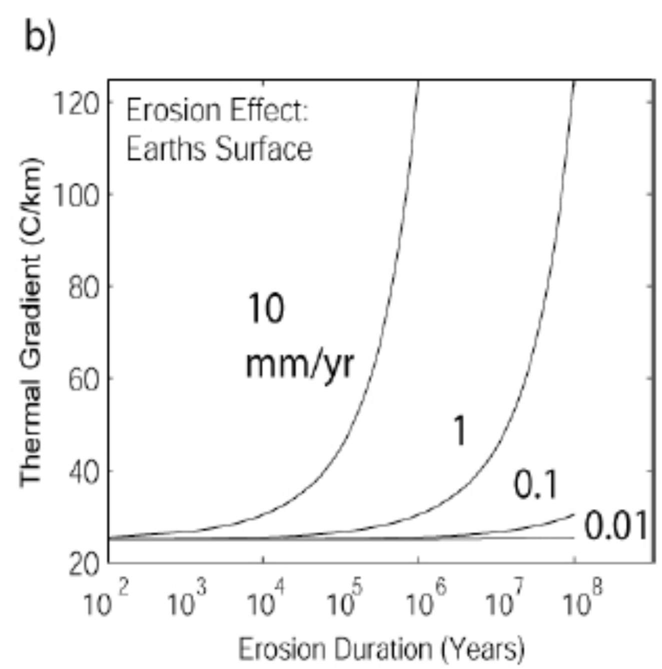
- In this example, the geothermal gradient doubles over the first 15 Myr of the calculation

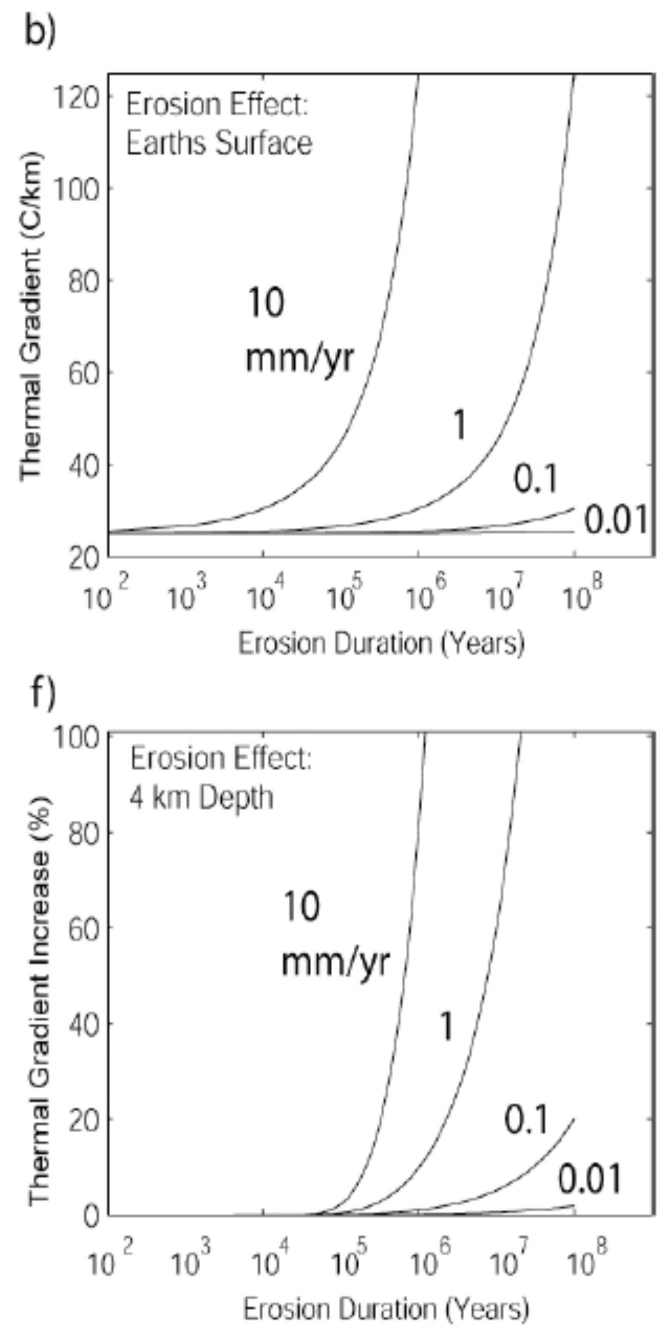
Thermal gradient changes



- 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
- Here we can easily see that erosion rates of ≥0.1 mm/yr are needed to change temperatures over time scales of millions of years

Ehlers, 2005

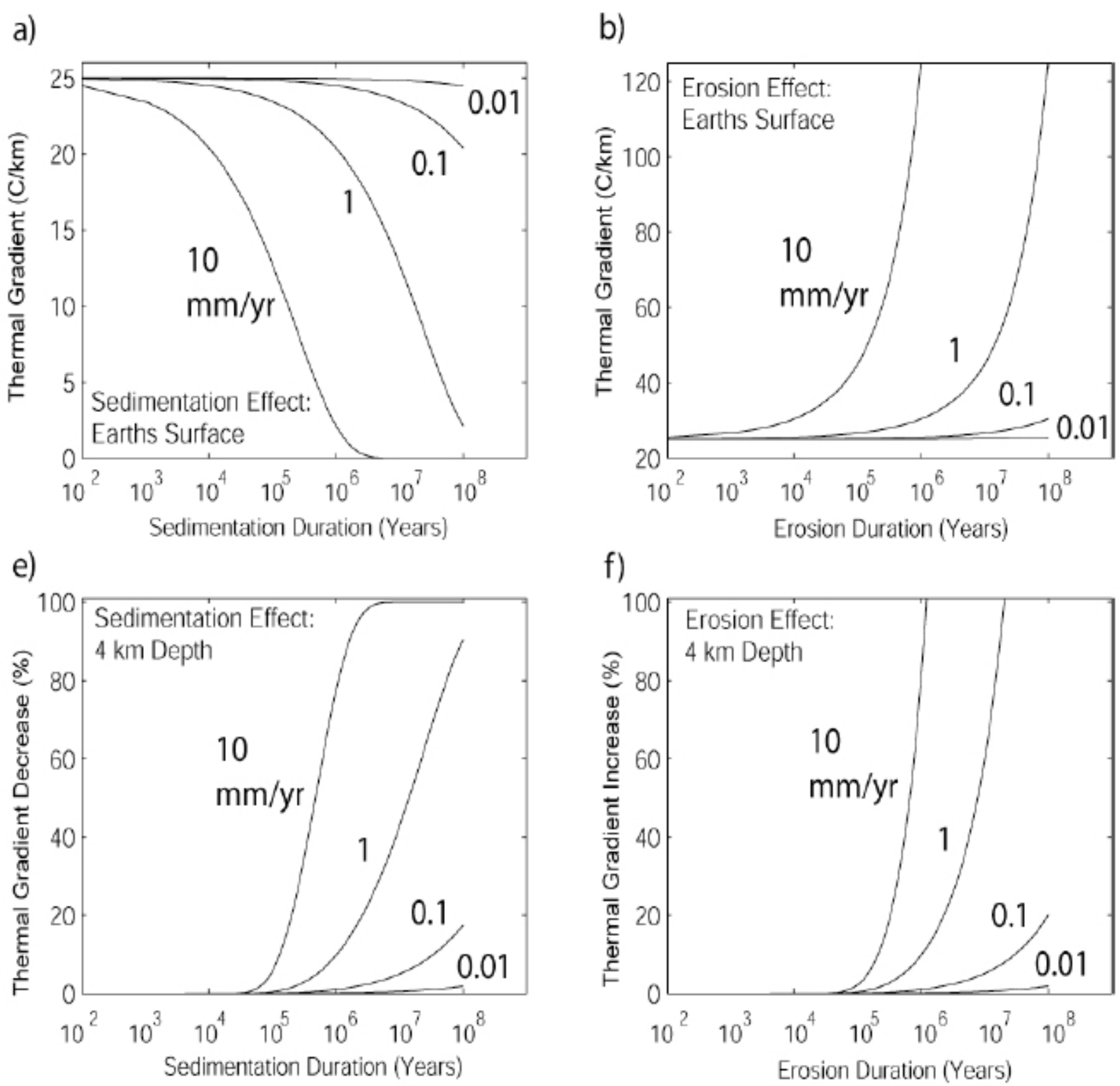
Thermal gradient changes



- Thermochronometers are sensitive to temperatures deeper in the earth, and the timing of changes in the geothermal gradient will thus lag behind the changes in near the surface

Ehlers, 2005

Thermal gradient changes



Ehlers, 2005

- As before, the same thing can be said for sedimentation, but in the opposite sense

Recap

- Erosion and sedimentation both will affect crustal temperatures due to the advection of heat

- The rate and duration of advection will determine how much temperatures are affected

- If you remember nothing else, the general expectation is:
  - Exhumation heats the crust
  - Sedimentation cools the crust

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.