Introduction to Quantitative Geology

Overview of Exercises 6 and 7
Quantitative thermochronology

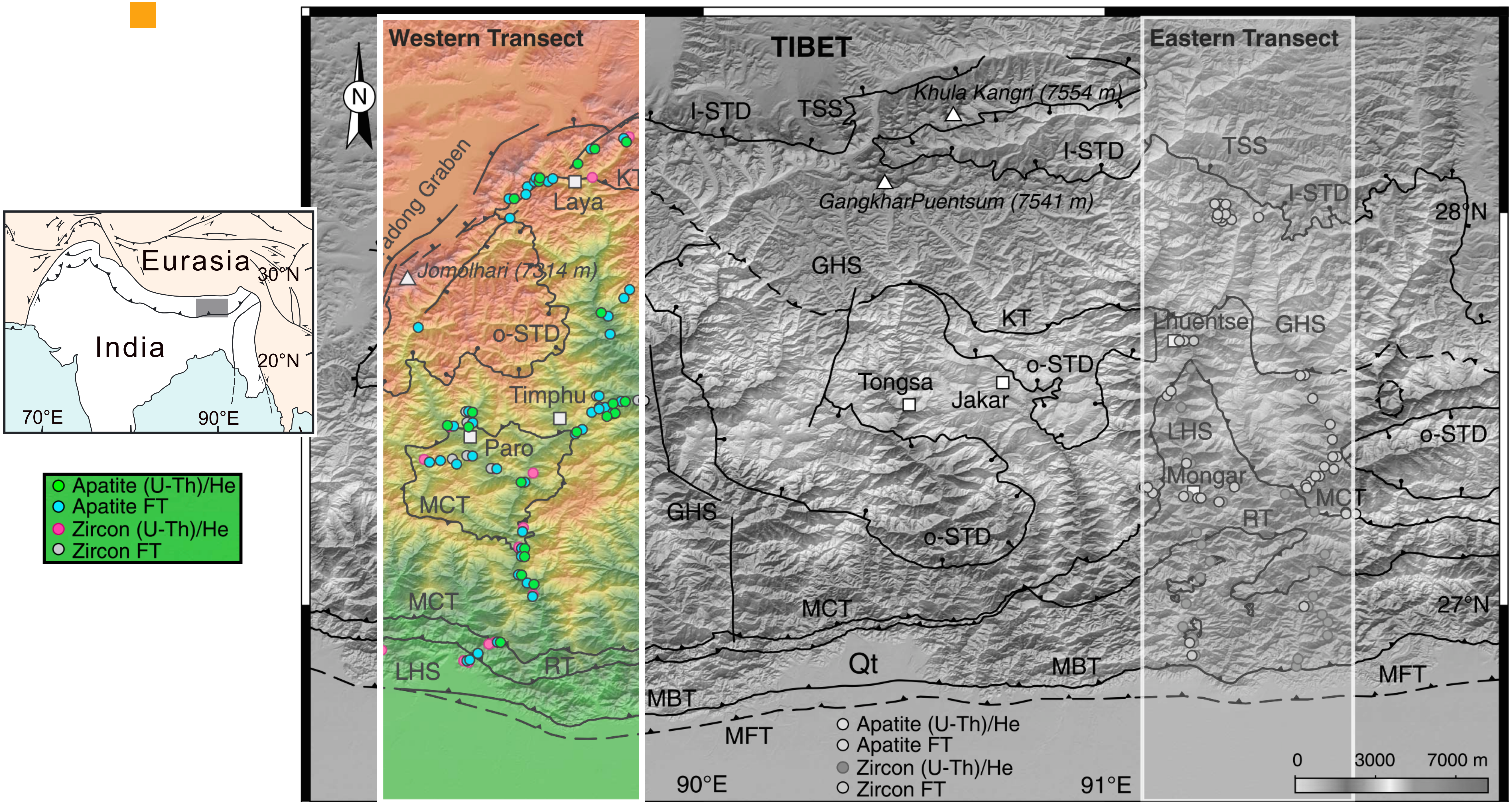
Instructor: David Whipp
david.whipp@helsinki.fi

7.12.21

The Himalaya of Bhutan

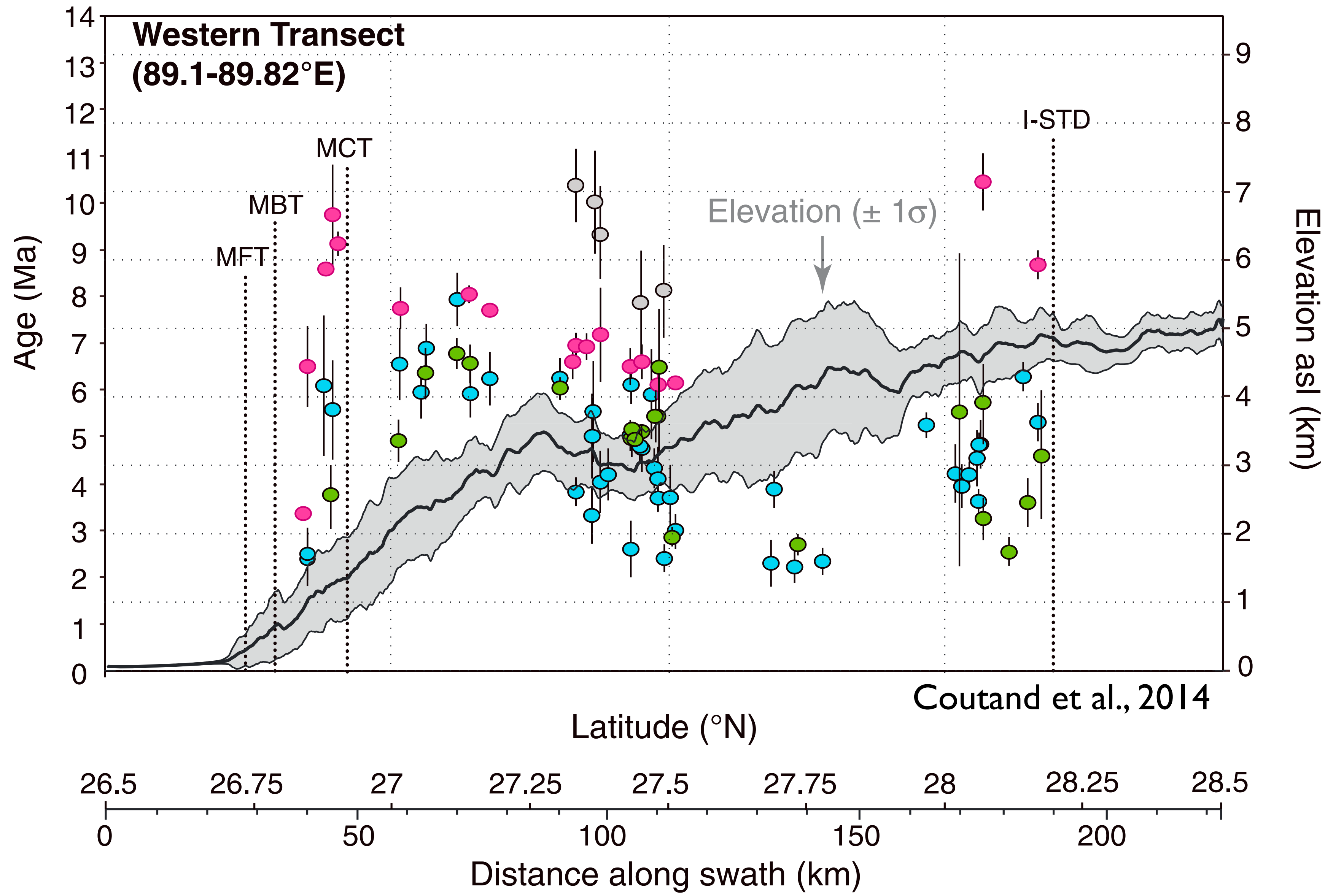
http://commons.wikimedia.org

Thermochronometer ages in western Bhutan



Coutand et al., 2014

Linking ages to geological processes



- Thermochronometer ages contain valuable information about past geological processes, but age interpretation is difficult

Estimating rock exhumation rates

- In mountainous settings, rock exhumation is the result of a erosional (surface) and/or tectonic processes
  - **Exhumation**: The unroofing history of a rock, as caused by tectonic and/or surficial processes (Ring et al., 1999)

Estimating exhumation rates from ages

- The simplest way to estimate a long-term average exhumation rate from a thermochronometer age is to assume a constant geothermal gradient and determine the depth from which the sample was exhumed
  - For example, assume we measure an apatite (U-Th)/He age of 12.3±0.9 Ma in a sample
  - Assume a nominal closure temperature T_c of 75±5°C and a "typical" geothermal gradient of 20°C/km
  - **How would you find the exhumation rate?**

Estimating exhumation rates from ages

- The simplest way to estimate a long-term average exhumation rate from a thermochronometer age is to assume a constant geothermal gradient and determine the depth from which the sample was exhumed
    - For example, assume we measure an apatite (U-Th)/He age of 12.3±0.9 Ma in a sample
    - Assume a nominal closure temperature T_c of 75±5°C and a "typical" geothermal gradient of 20°C/km
    - **How would you find the exhumation rate?**
        - The simple approach is to find the depth of T_c and divide that depth by the age

Exhumation rate example

- If we assume the surface temperature is 0°C, the depth z_c of T_c is simply T_c divided by the geothermal gradient
  - z_c = 75°C / (20°C/km) = **3.75 km**

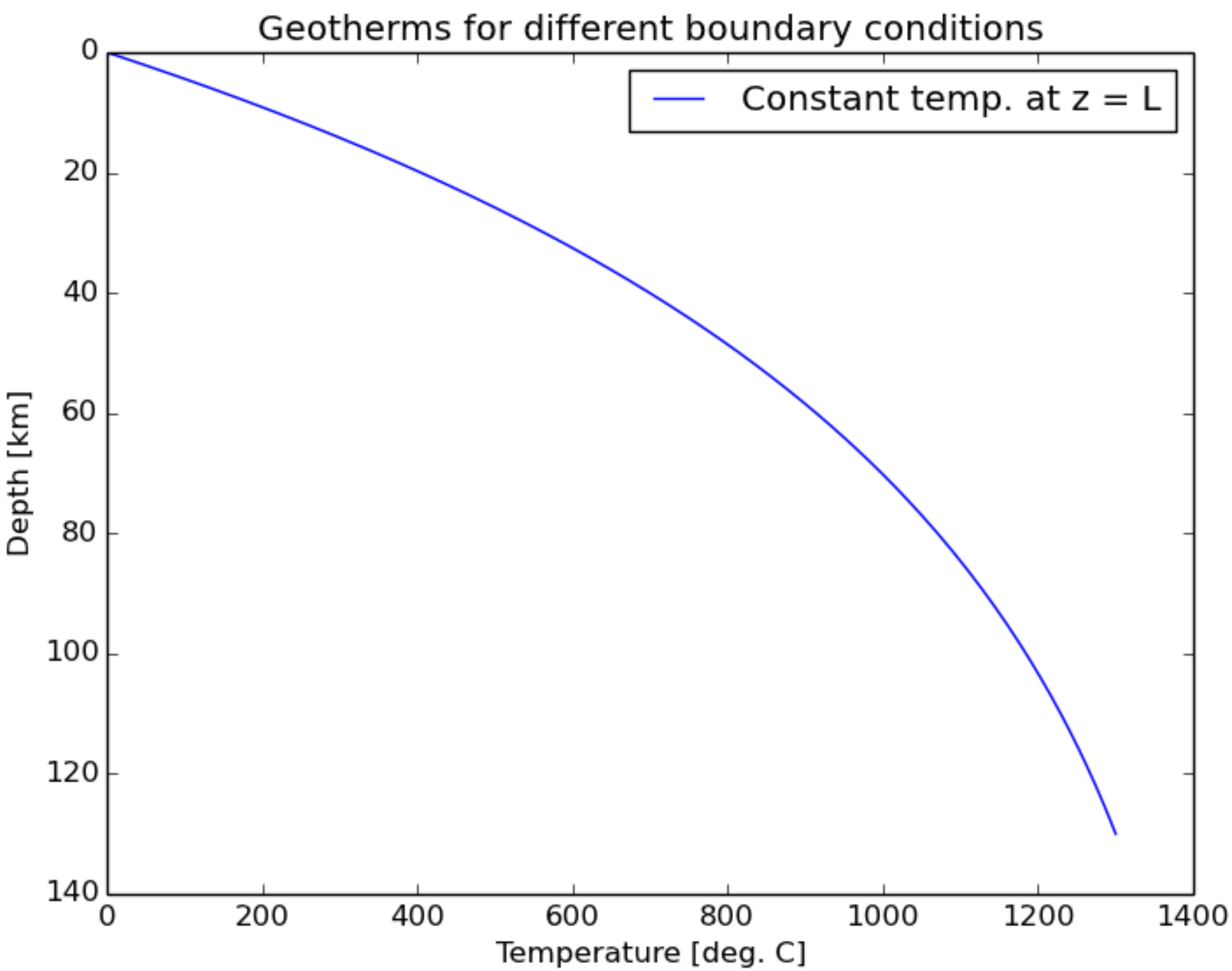
- An **exhumation rate ė** can be estimated by dividing that depth by the measured age
  - ė = 3.75 km / 12.3 Ma = **~0.3 km/Ma = ~0.3 mm/a**

A constant thermal gradient is a bad idea

- This approach works, but it neglects many known thermal factors including ‘bending’ of the geotherm as a result of thermal advection

- A more reasonable approach would be to utilize a 1-D thermal model to simulate heat transfer processes during rock cooling, which will be our approach in the final two lab exercises

1-D steady-state geotherms



- **Advection** is often the <u>main thermal influence</u> on thermochronometer ages in mountainous regions

- Thus, advection must be considered by using an appropriate equation

$$T(z) = T_L \left(\frac{1 - \mathrm{e}^{-(v_z z/\kappa)}}{1 - \mathrm{e}^{-(v_z L/\kappa)}} \right)$$

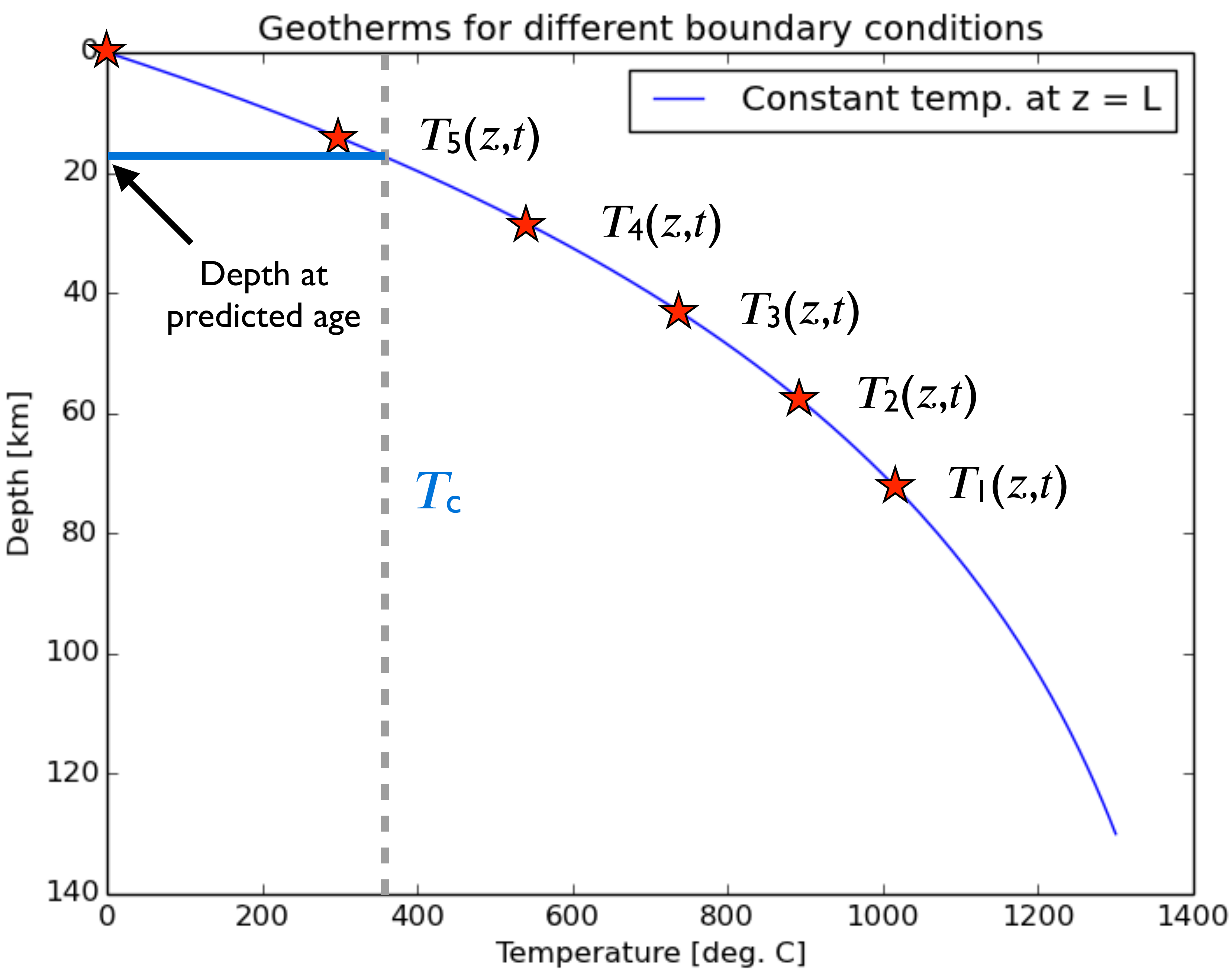
Now what?

- With a predicted 1-D thermal field, the next step is to determine the **cooling history** for a rock sample
- We know the sample is at the surface (z = 0) today, and we can use the advection velocity v_z to determine the cooling history
- **How?**

Now what?

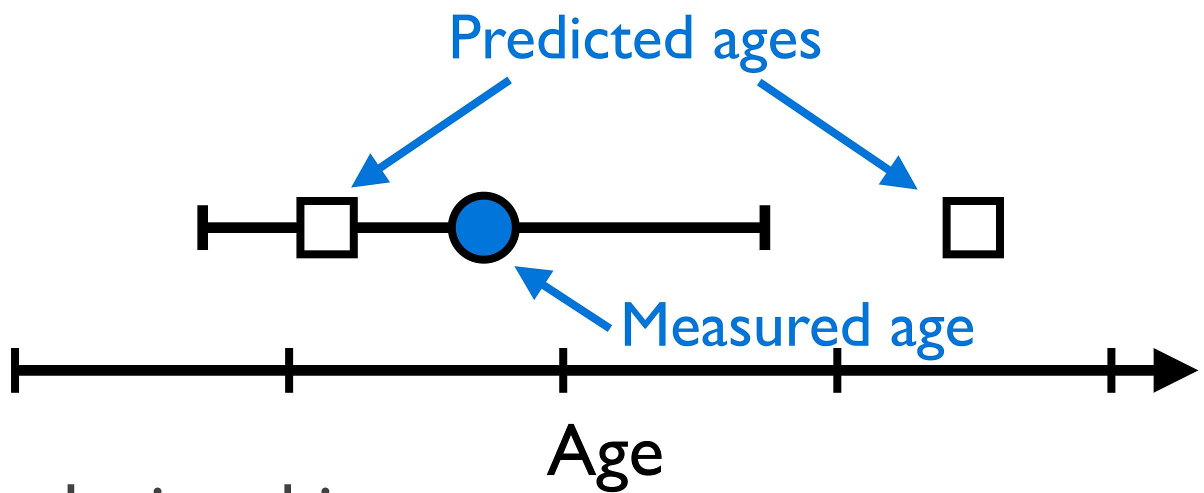
- With a predicted 1-D thermal field, the next step is to determine the **cooling history** for a rock sample
- We know the sample is at the surface (z = 0) today, and we can use the advection velocity v_z to determine the cooling history
- How?
  - We can calculate the past depth of a rock sample by using time steps back to some time in the past
  - Each time step, the rock will be displaced by $v_z \times dt$

Generating a thermal history



- At each time, record the depth and temperature, then move the particle upward by $v_z \times dt$
- The result is a thermal history for a given exhumation (advection) rate that can now be linked to an estimated closure temperature to predict a cooling age and compare to data

General concept for age prediction



1. Create depth-time history
2. Generate thermal history using depth-time history for selected advection velocity v_z
3. Use thermal history to calculate T_c
    - Calculate new T_c using Dodson function if still above T_c
4. Use predicted T_c to find point in thermal history where temperature equals T_c (predicted age)
5. Calculate goodness-of-fit for predicted age to measured ages
6. Repeat steps 1-5 as needed until a good fit is observed