Introduction to Quantitative Geology

Overview of Exercises 6 and 7
Quantitative thermochronology

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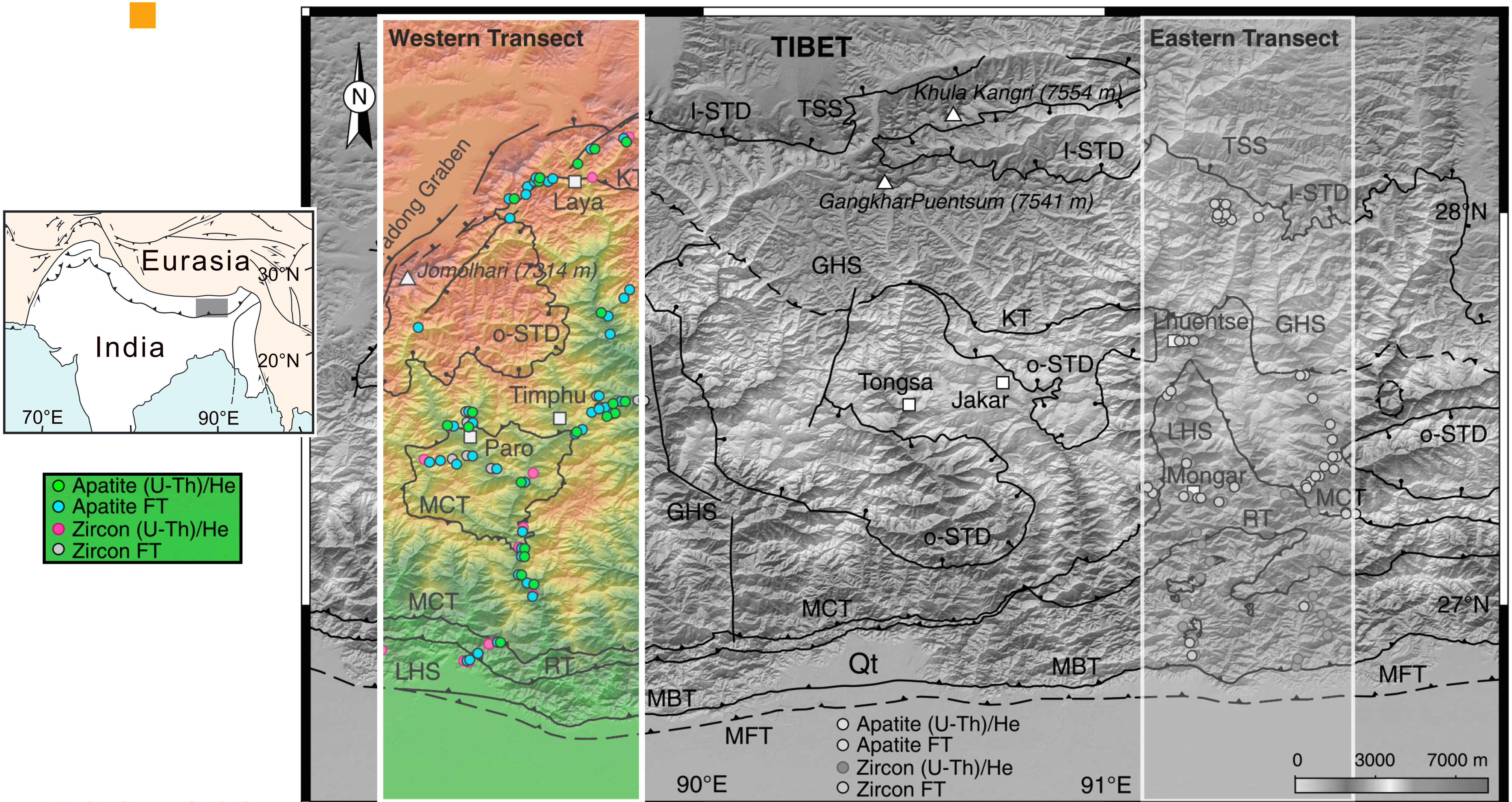
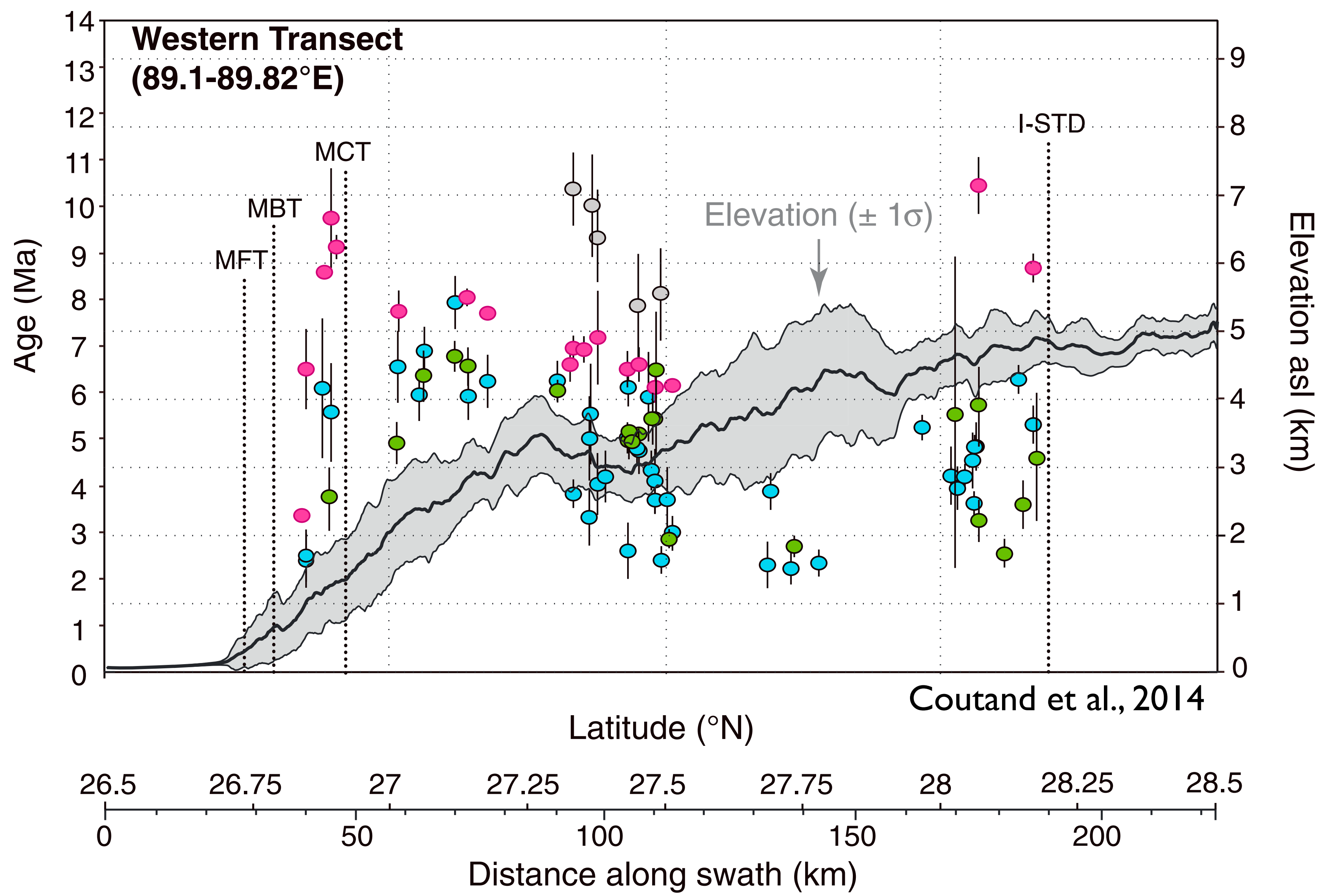
The Himalaya of Bhutan

Thermochronometer ages in western Bhutan



Coutand et al., 2014

Linking ages to geological processes



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

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?**

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  - 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

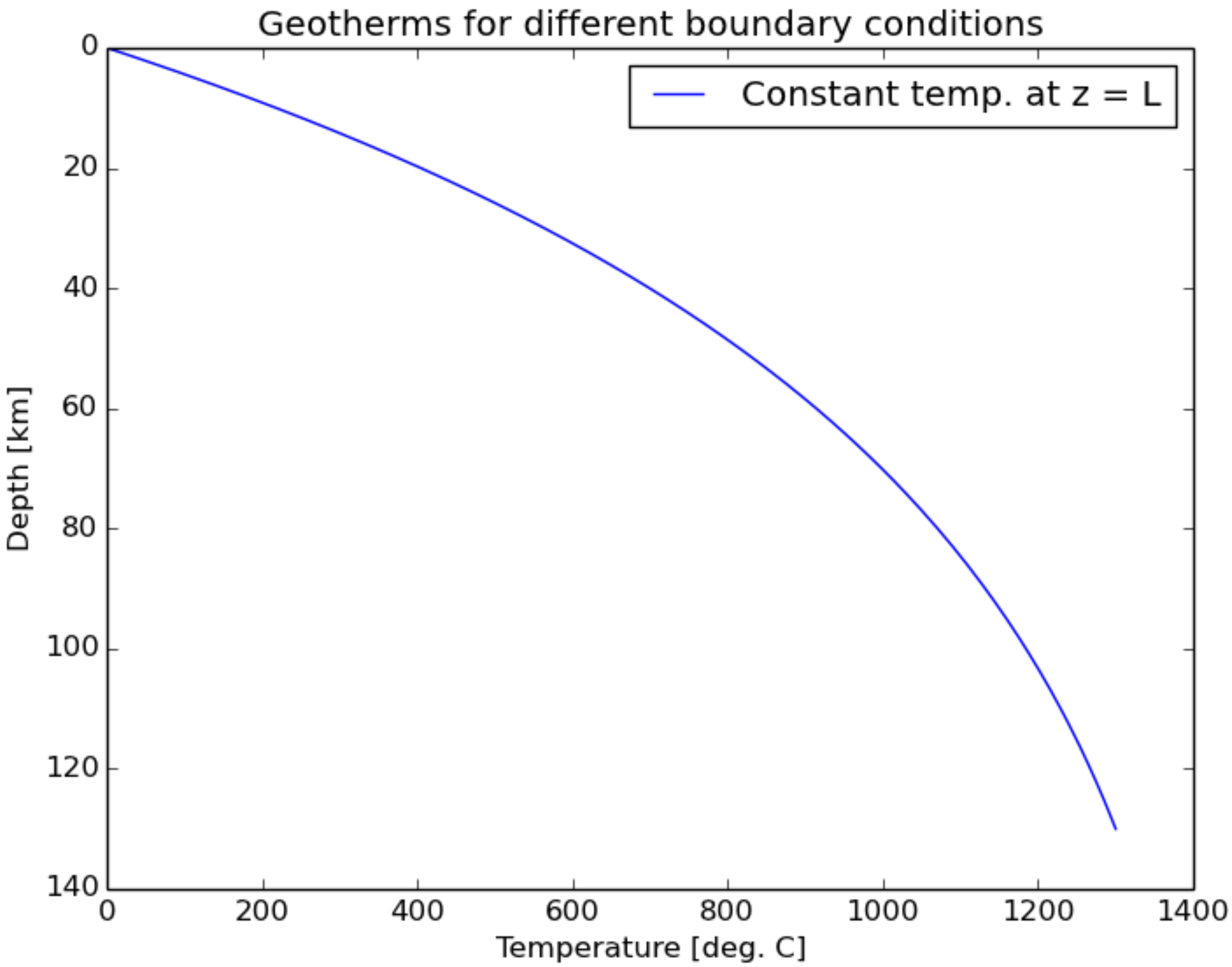
- If we assume the surface temperature is 0°C, the depth z_c of T_c is simply T_c divided by the geothermal gradient
  - z_c = 75°C / (20°C/km) = **3.75 km**
- An **exhumation rate $\dot{e}$** can be estimated by dividing that depth by the measured age
  - $\dot{e}$ = 3.75 km / 12.3 Ma = **~0.3 km/Ma = ~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?**

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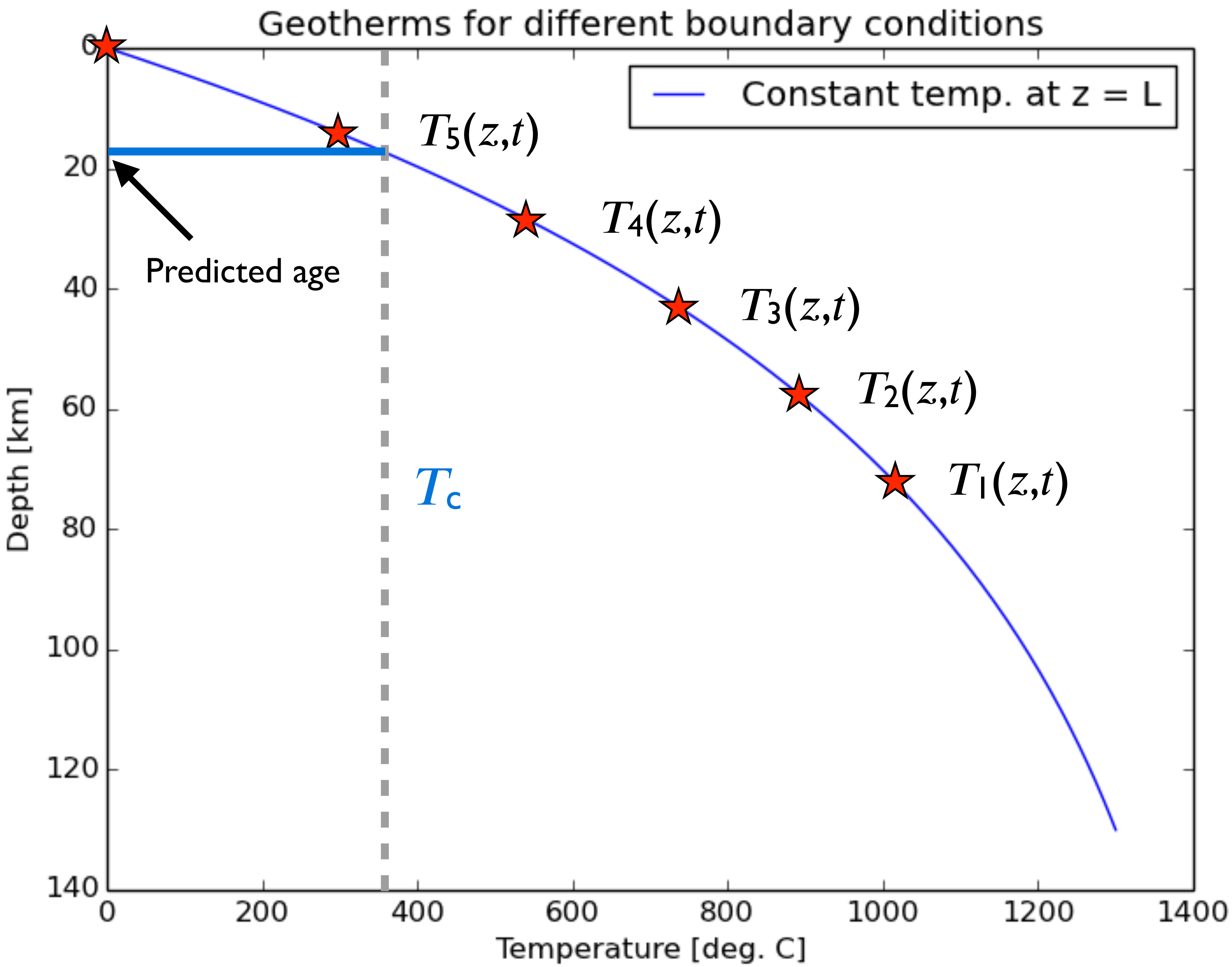
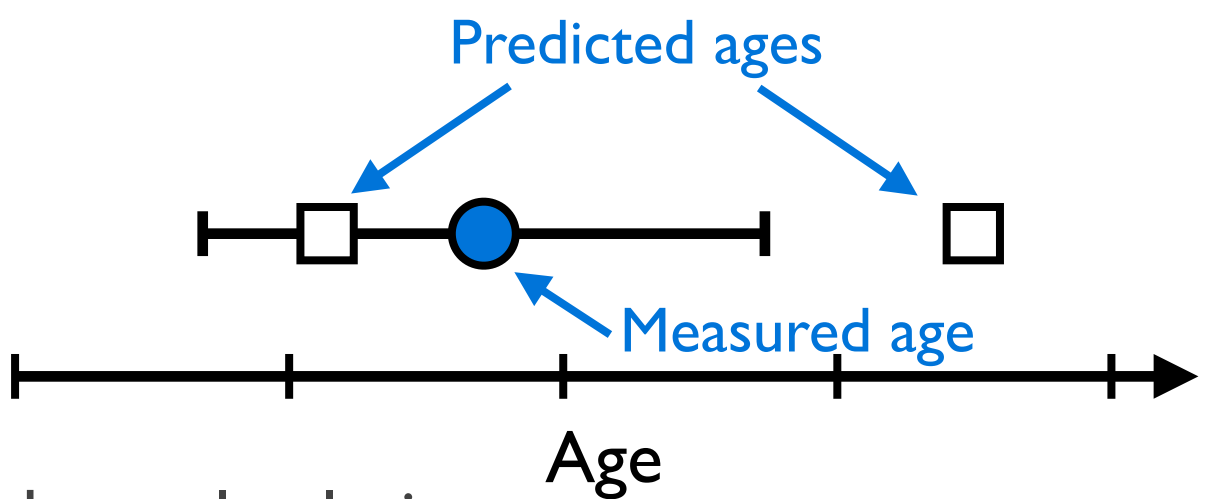
- With a predicted 1-D thermal field, the next step is to determine the **cooling history** for a rock sample
- We know the sample is at the surface (z = 0) today, and we can use the advection velocity v_z to determine the cooling history
- **How?**
  - We can calculate the past depth of a rock sample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

2. Generate thermal history based on thermal solution and advection velocity

3. Use thermal history to calculate T_c

4. Record time at which sample cools below T_c (predicted age)

5. Compare predicted age to measured age

6. Repeat steps 1-5 as needed until a good fit is observed