



# **Introduction to Quantitative Geology**

## **Overview of Exercises 13 and 14**

### **Quantitative thermochronology**

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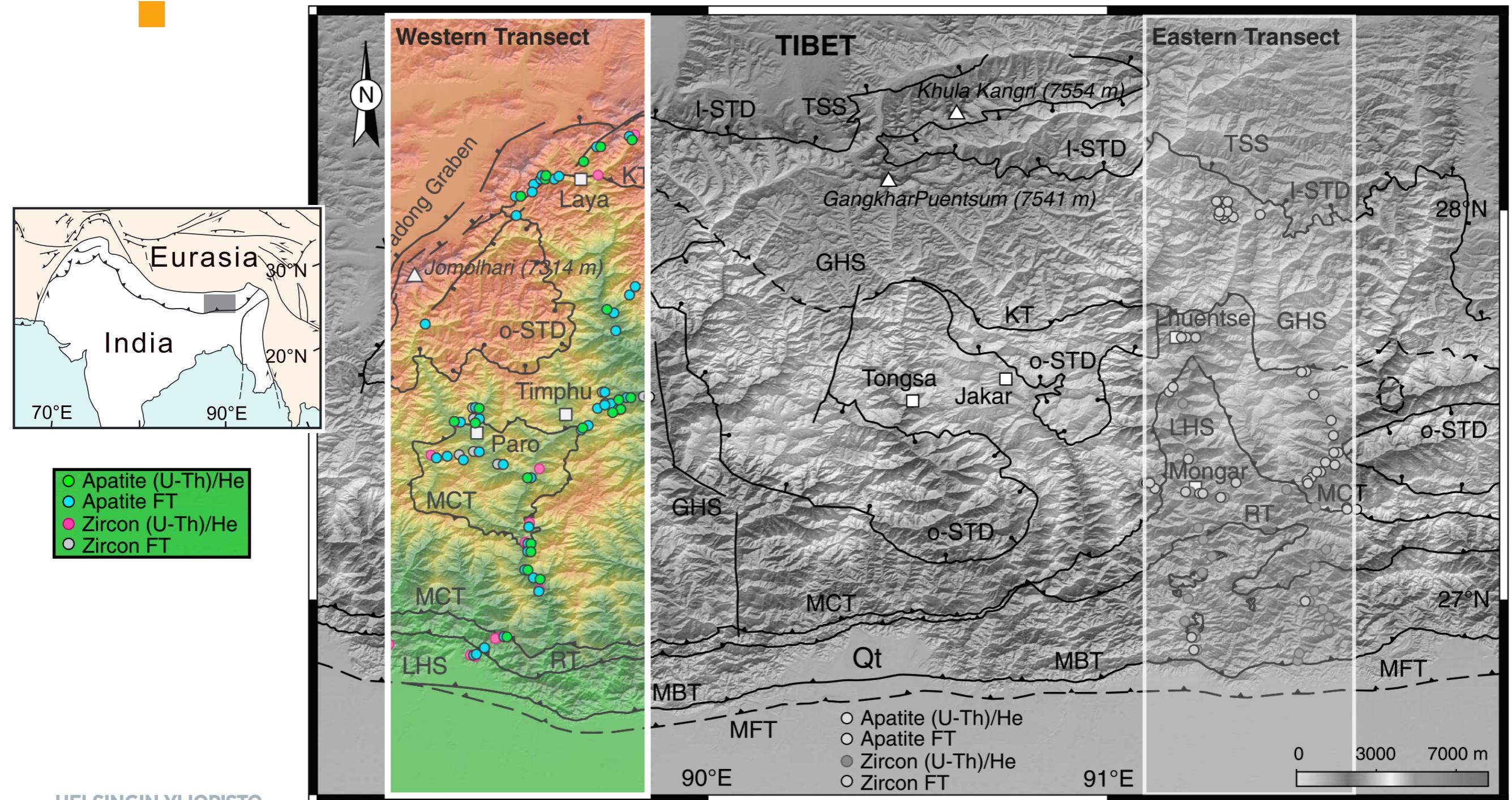


# The Himalaya of Bhutan



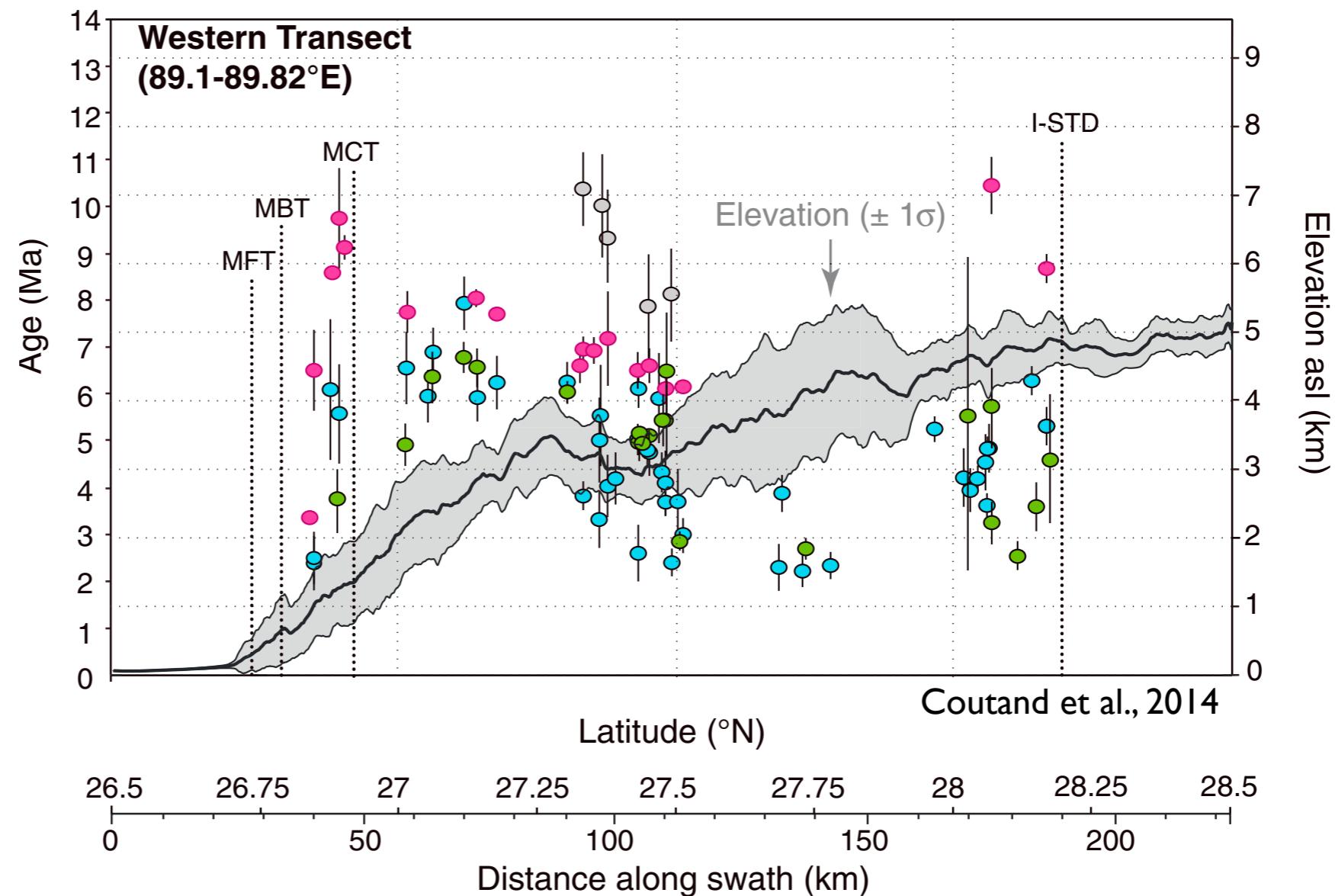


# Thermochronometer ages in western Bhutan

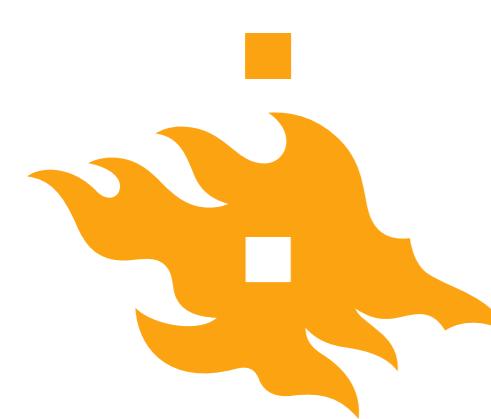




# Linking ages to geological processes



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



# Estimating rock exhumation rates

Grand Teton National Park, Wyoming, USA

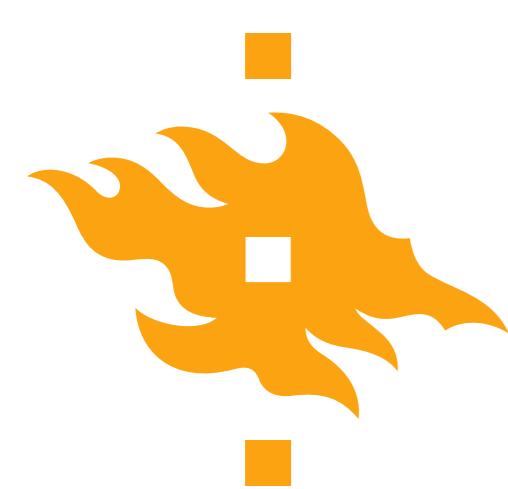


- In mountainous settings, rock exhumation is the result of a erosional (surface) and/or tectonic processes
- **Exhumation:** The unroofing history of a rock, as caused by tectonic and/or surficial processes (Ring et al., 1999)



# 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  $12.3 \pm 0.9$  Ma in a sample
- Assume a nominal closure temperature  $T_c$  of  $75 \pm 5^\circ\text{C}$  and a “typical” geothermal gradient of  $20^\circ\text{C}/\text{km}$
- **How would you find the exhumation rate?**



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- **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
- $z_c = 75^\circ\text{C} / (20^\circ\text{C/km}) = \mathbf{3.75 \text{ km}}$
- An **exhumation rate**  $\dot{e}$  can be estimated by dividing that depth by the measured age
- $\dot{e} = 3.75 \text{ km} / 12.3 \text{ Ma} = \mathbf{\sim 0.3 \text{ km/Ma} = \sim 0.3 \text{ mm/a}}$

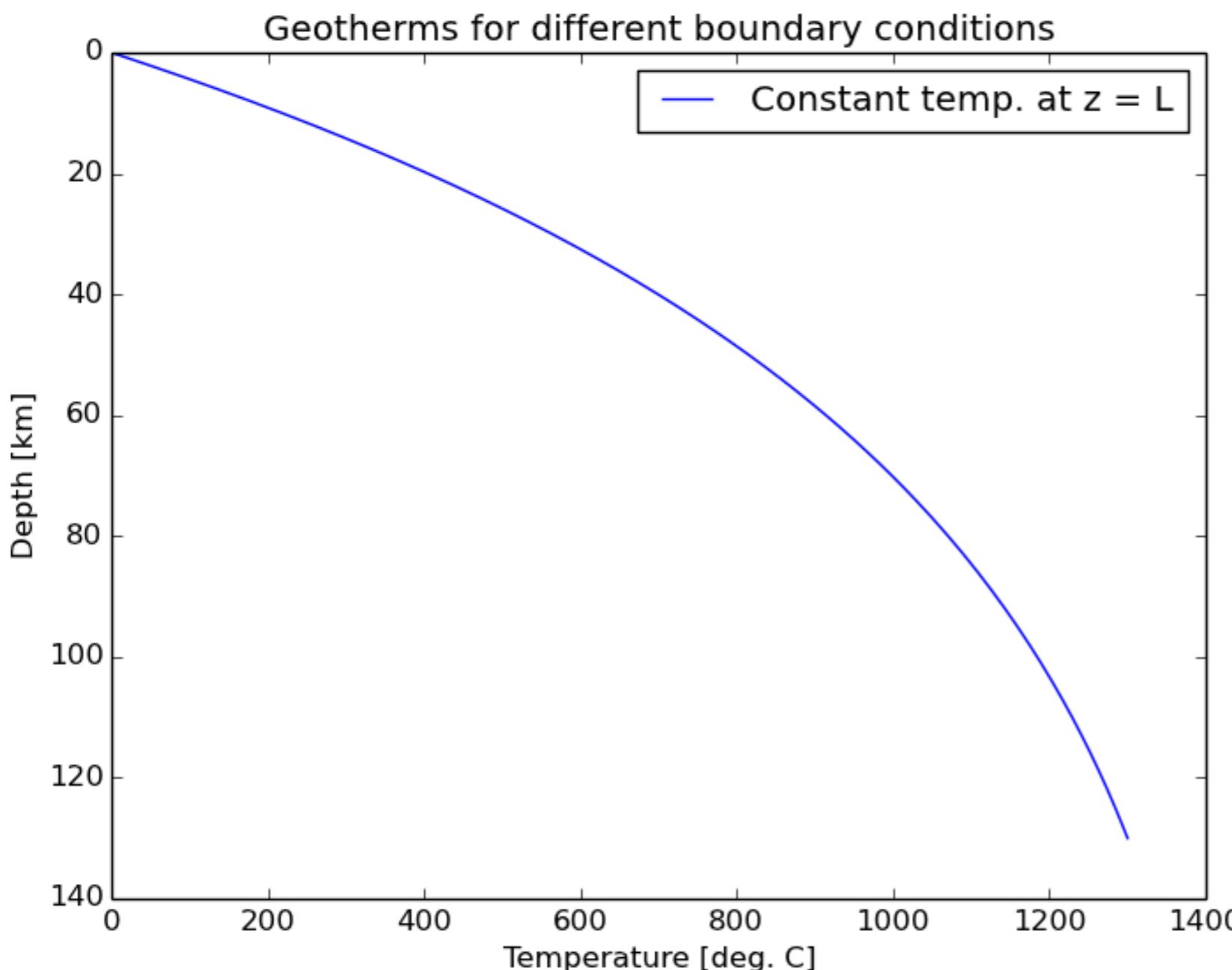


# A constant thermal gradient is a bad idea

- 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

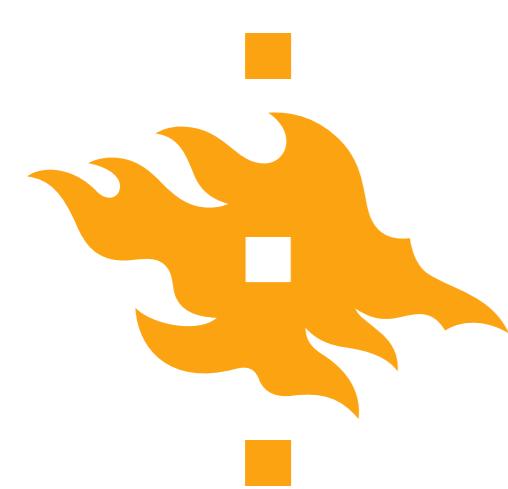


# 1-D steady-state geotherms



- **Advection** is often the main thermal influence on thermochronometer ages in mountainous regions
- Thus, advection must be considered by using an appropriate equation

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



# 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?**

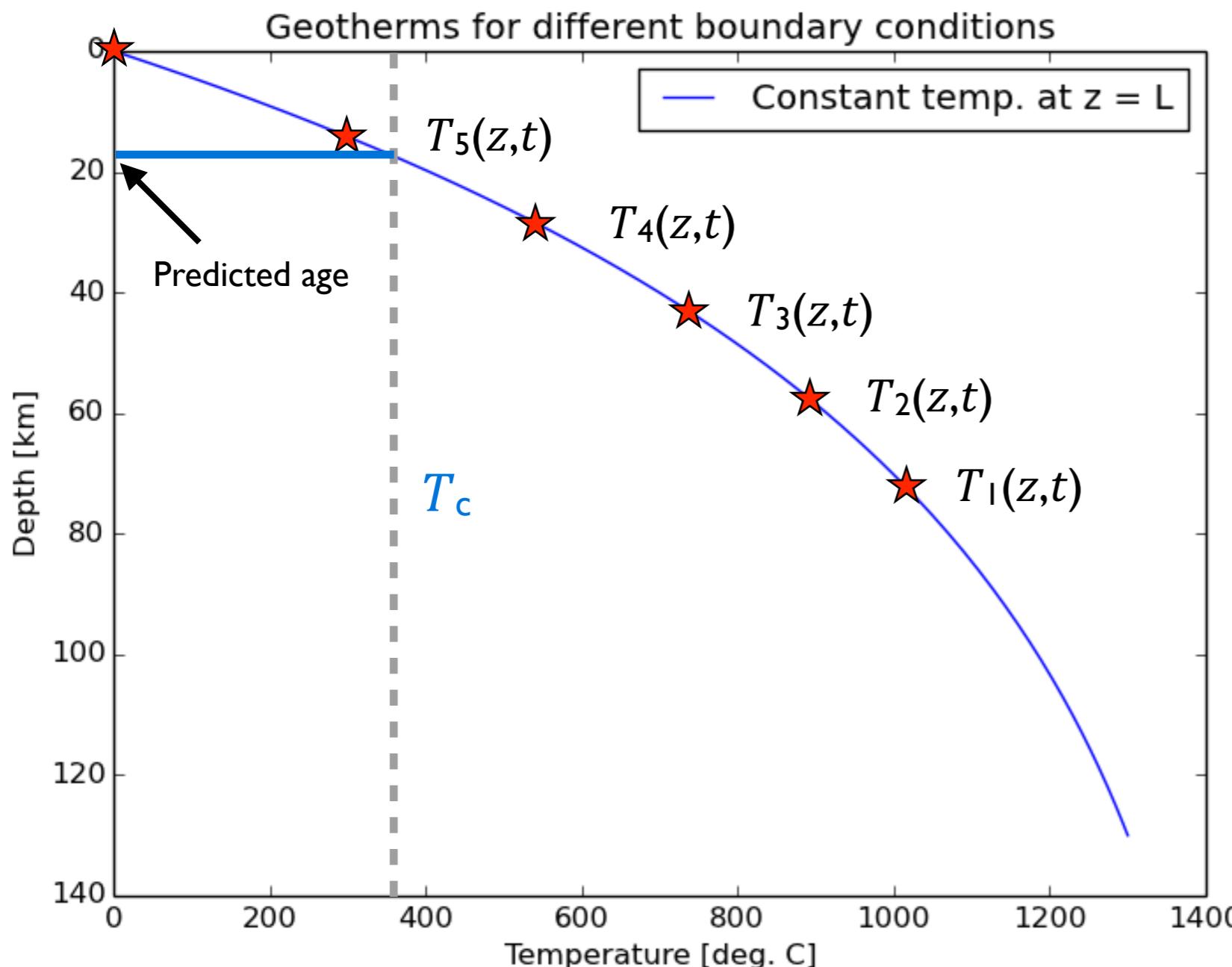


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- We know the sample is **at the surface ( $z = 0$ ) today**, and we can use the **advection velocity  $v_z$**  to determine the cooling history
- **How?**
  - We can calculate the **past depth** of a rock sample by **using time steps** back to some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



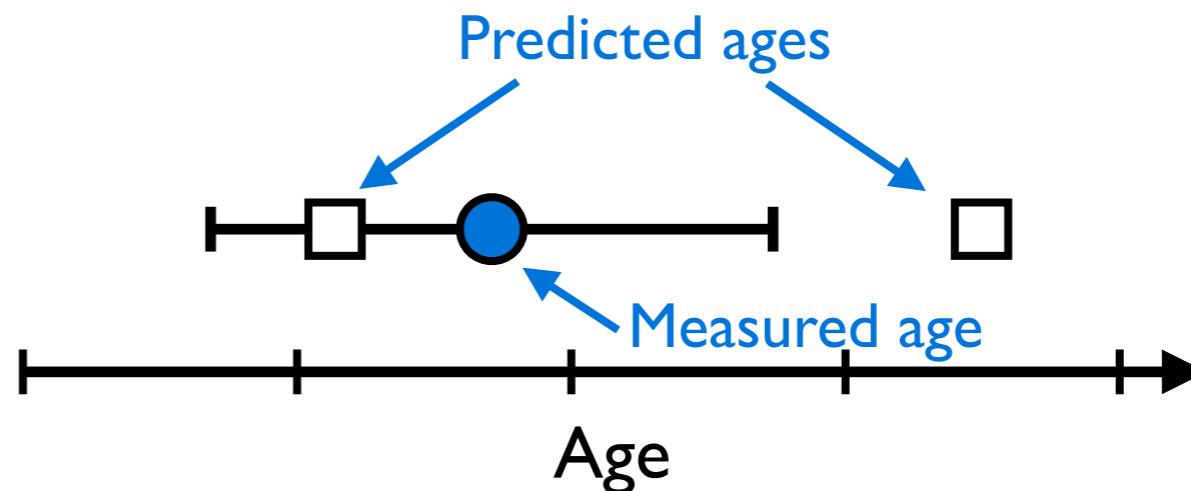
# Generating a thermal history



- 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