



Introduction to Quantitative Geology

Laboratory exercises 6-7

Quantitative thermochronology

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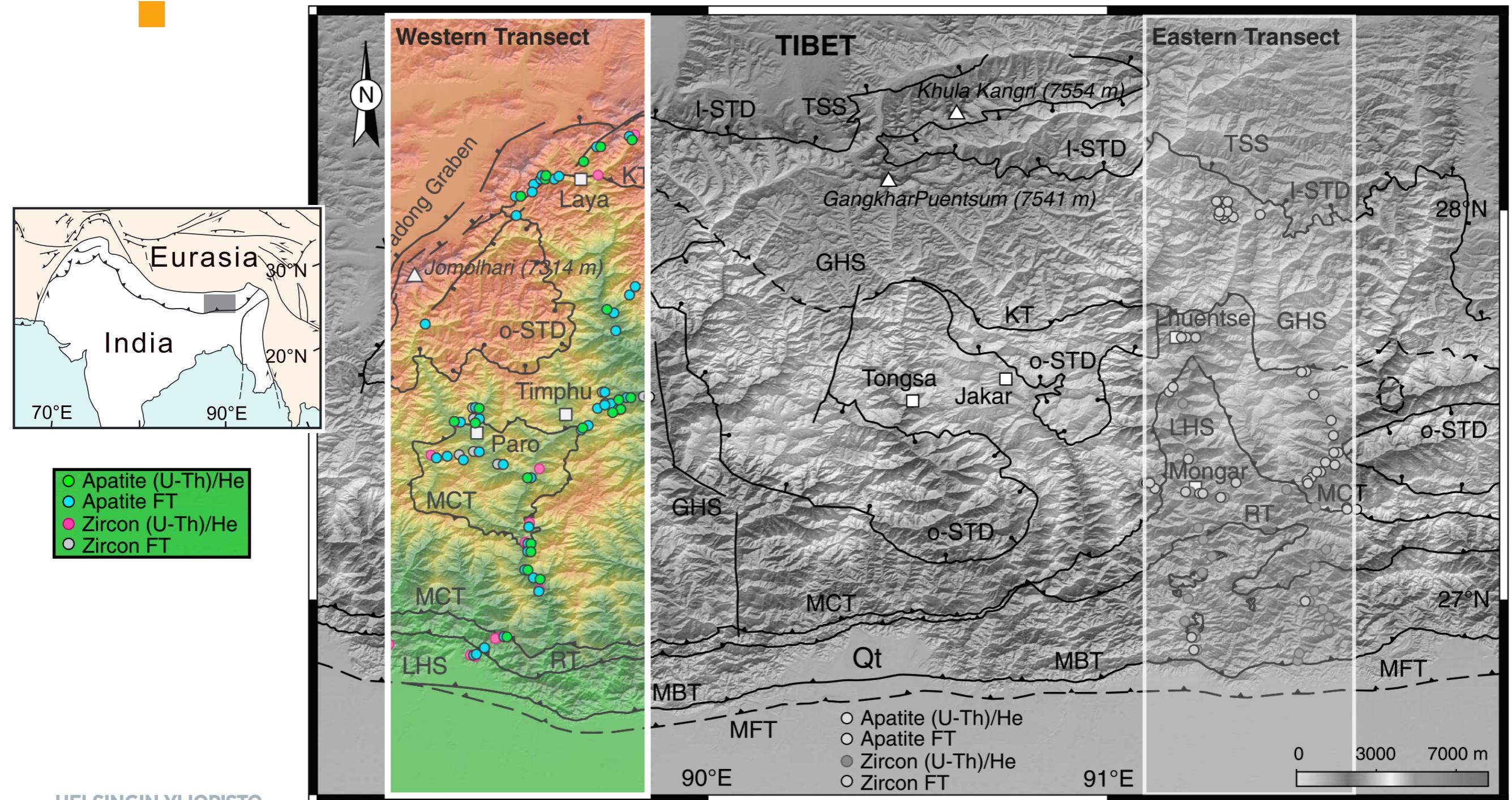


The Himalaya of Bhutan



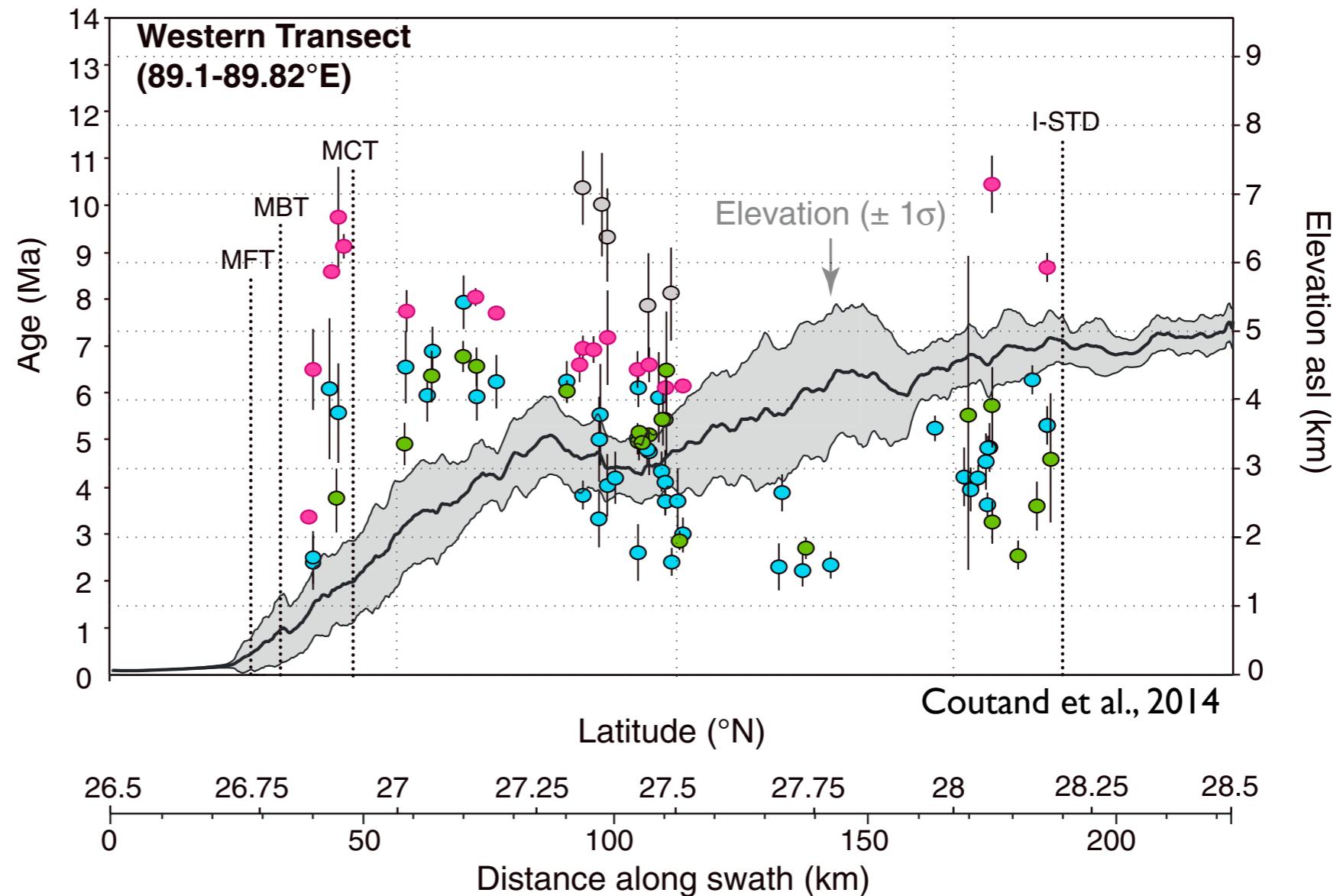


Thermochronometer ages in western Bhutan

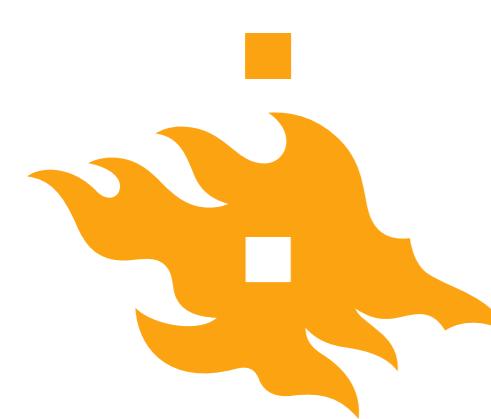




Linking ages to geological processes



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



Estimating rock exhumation rates

Grand Teton National Park, Wyoming, USA

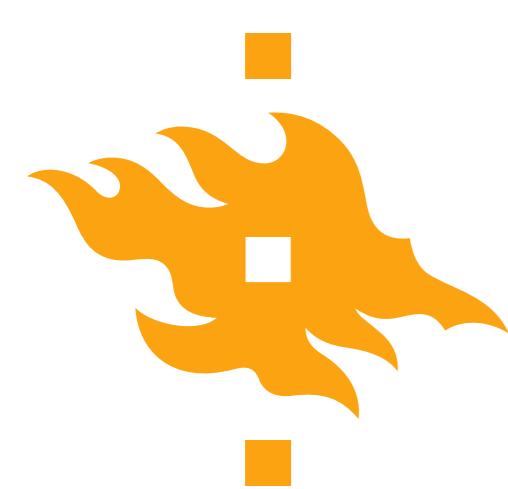


- In mountainous settings, rock exhumation is the result of a erosional (surface) and/or tectonic processes
- **Exhumation:** The unroofing history of a rock, as caused by tectonic and/or surficial processes (Ring et al., 1999)



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

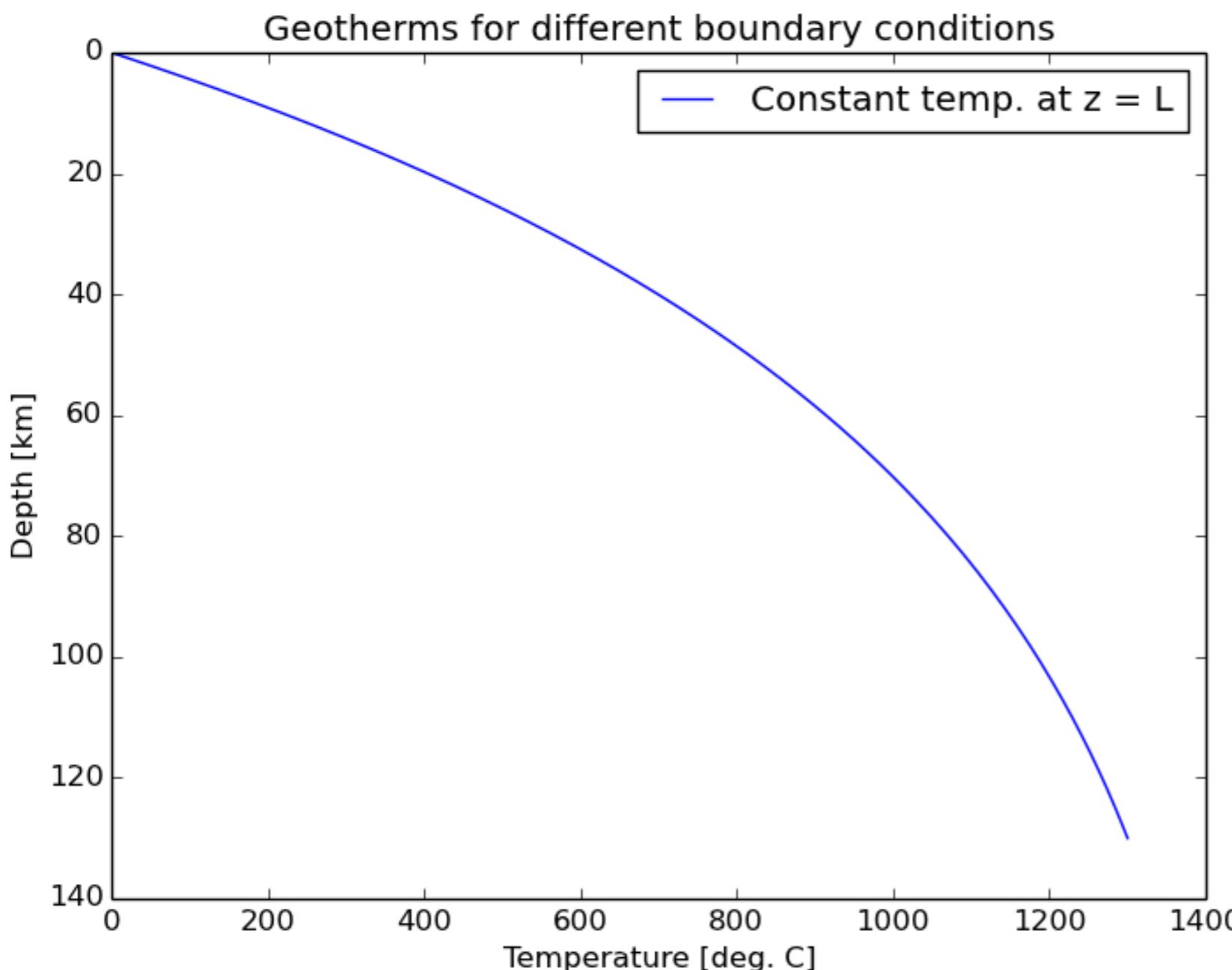


A constant thermal gradient is a bad idea

- This approach works, but it neglects many known thermal factors including ‘bending’ of the geotherm as a result of thermal advection and radiogenic heat production
- A more reasonable approach would be to use a 1-D thermal model to simulate heat transfer processes during rock cooling
- This will be our approach in the final two lab exercises

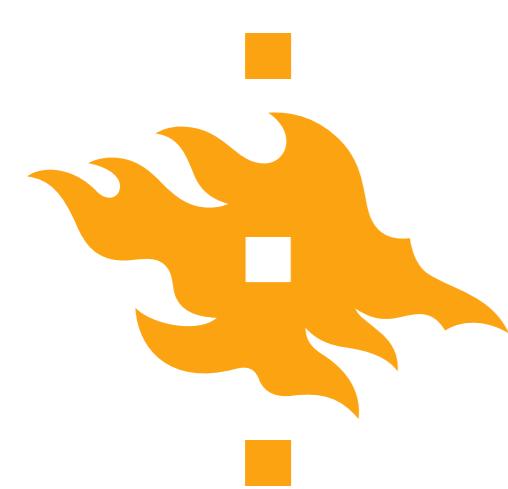


1-D steady-state geotherms



- **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?**

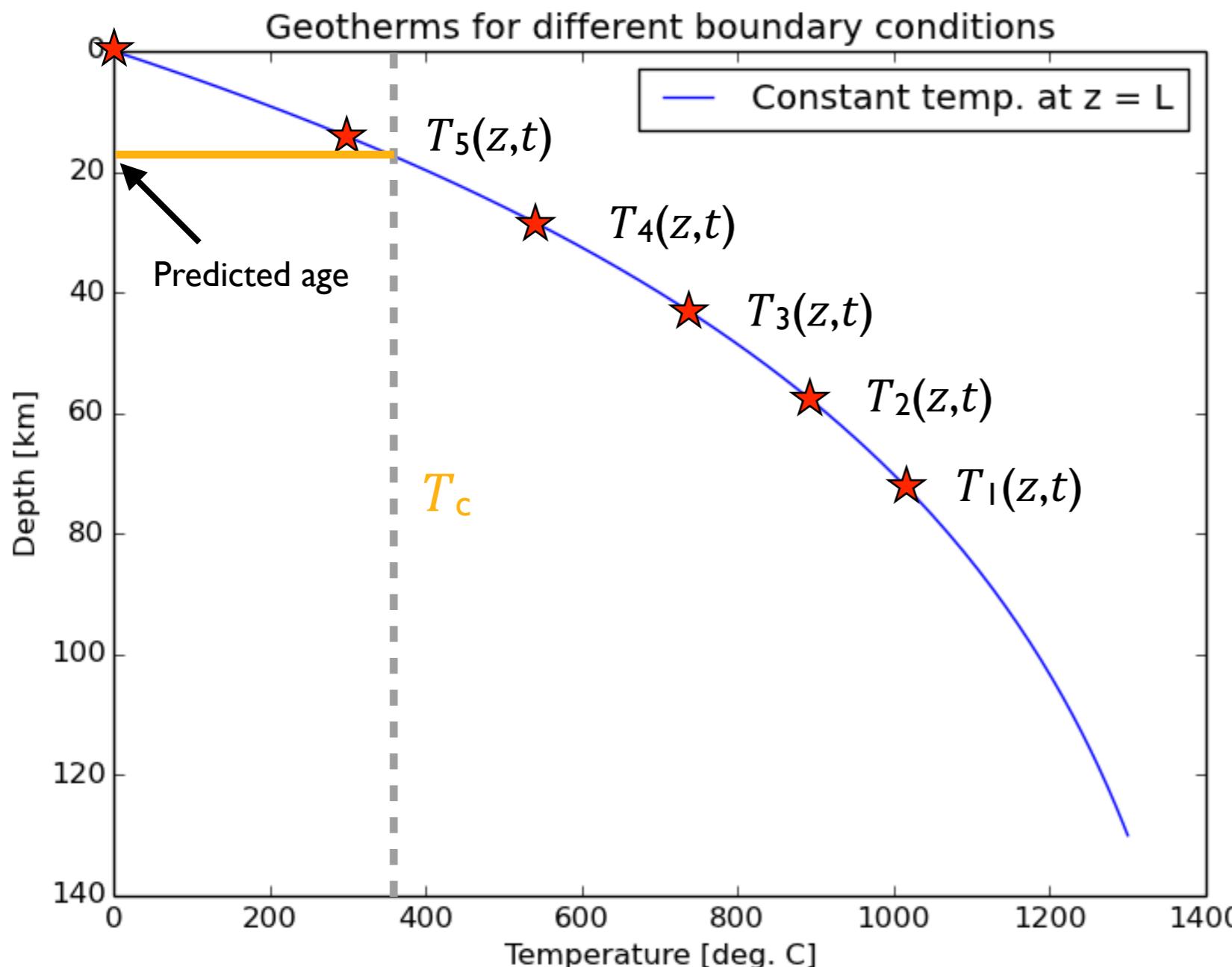


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- We know the sample is **at the surface ($z = 0$) today**, and we can use the **advection velocity v_z** to determine the cooling history
- **How?**
 - We can calculate the **past depth** of a rock sample by **using time steps** back to some time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



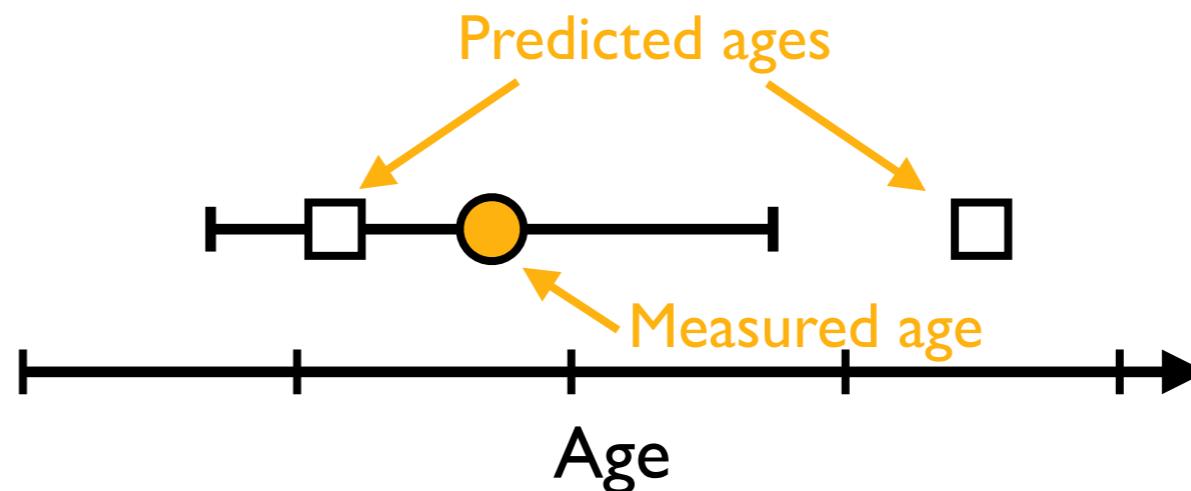
Generating a thermal history



- 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