



Introduction to Quantitative Geology

Overview of Exercises 6 and 7

Quantitative thermochronology

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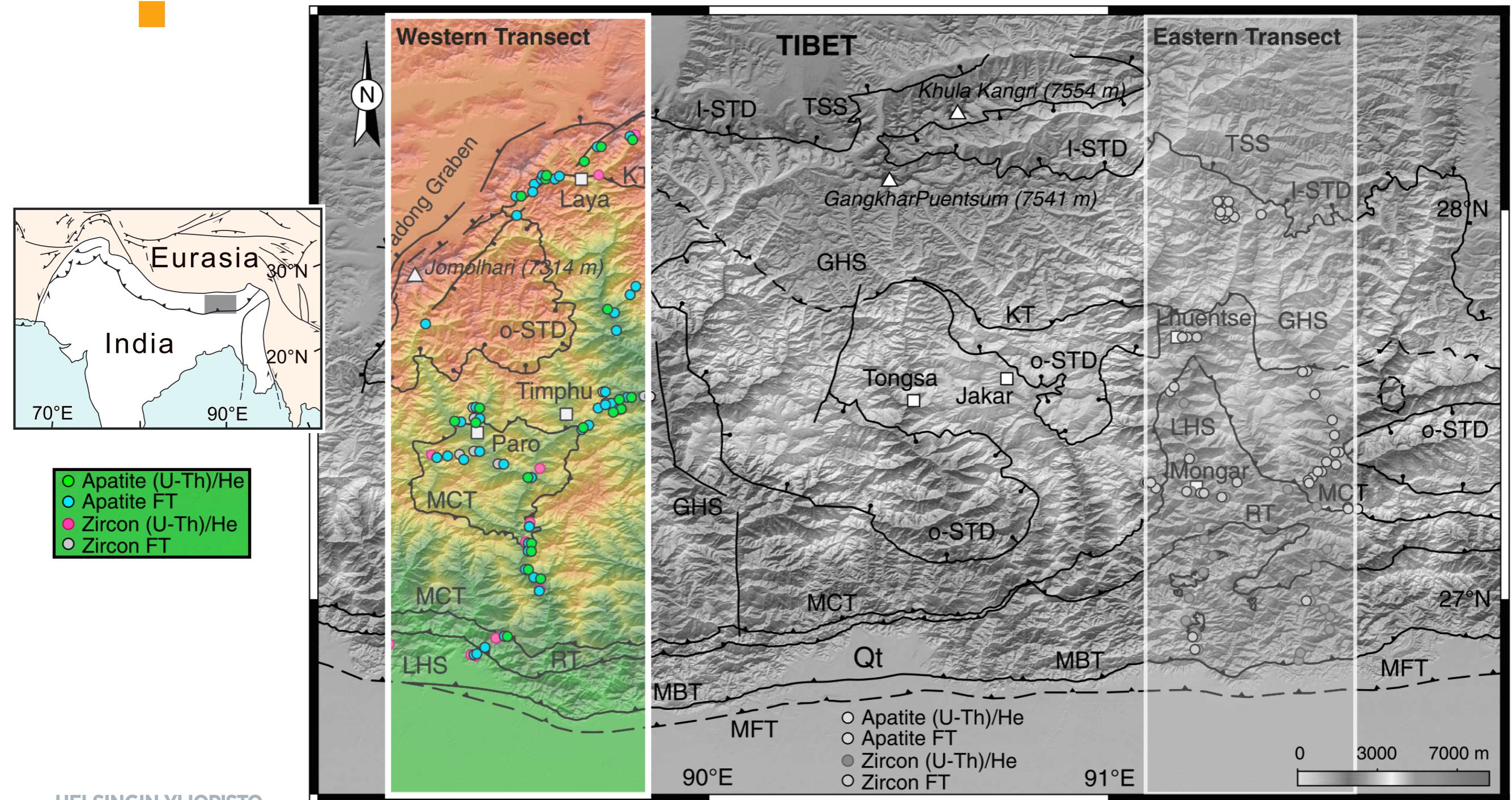


The Himalaya of Bhutan



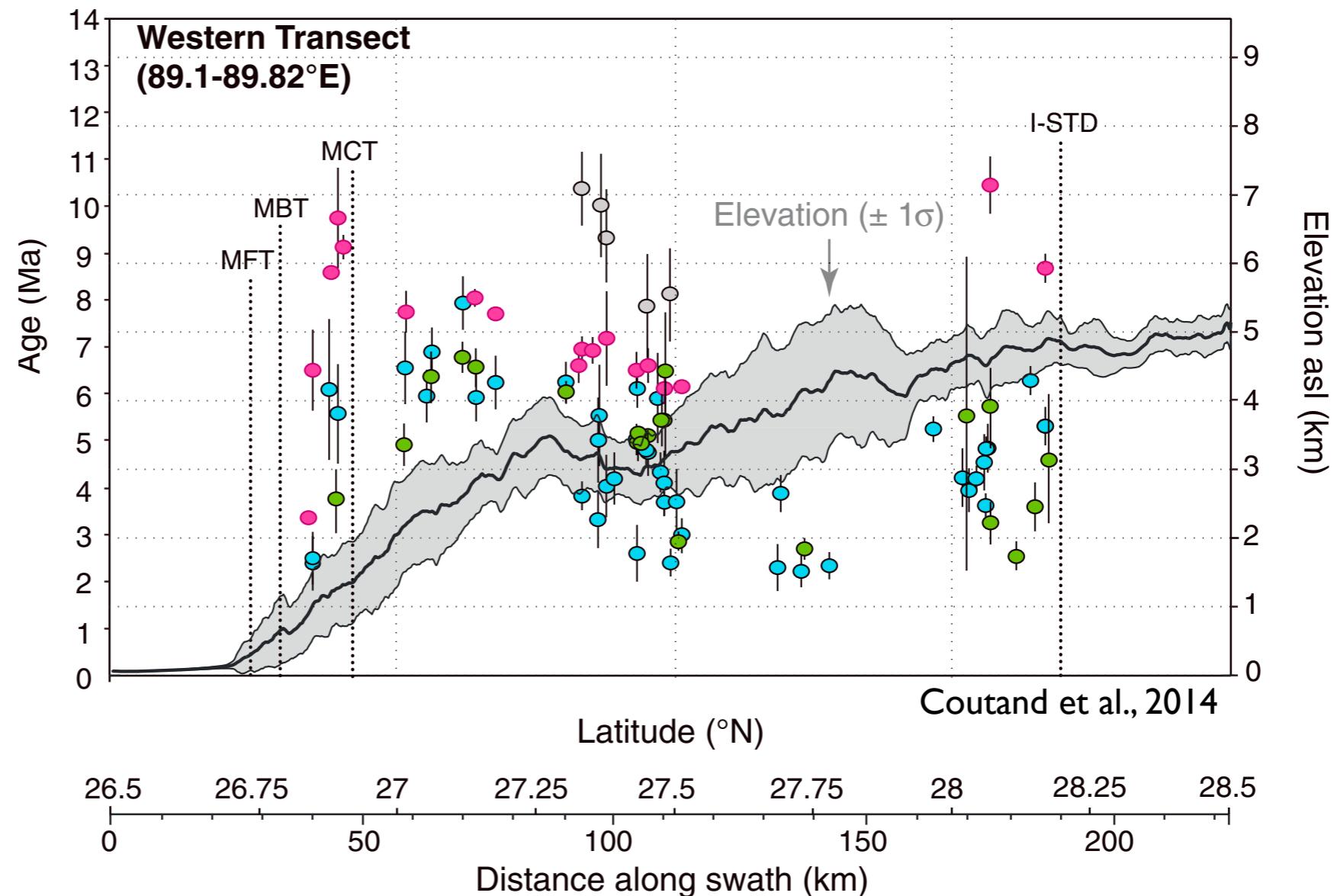


Thermochronometer ages in western Bhutan

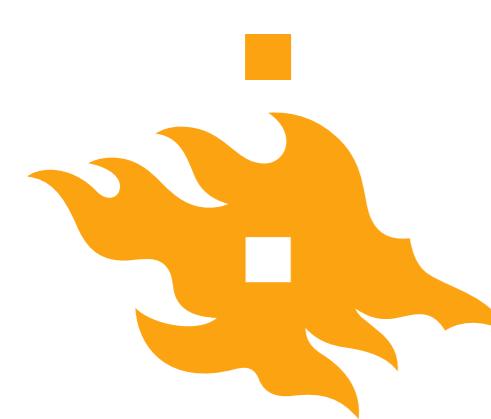




Linking ages to geological processes



- 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 ± 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
- $\dot{e} = 3.75 \text{ km} / 12.3 \text{ Ma} = \mathbf{\sim 0.3 \text{ km/Ma} = \sim 0.3 \text{ mm/a}}$

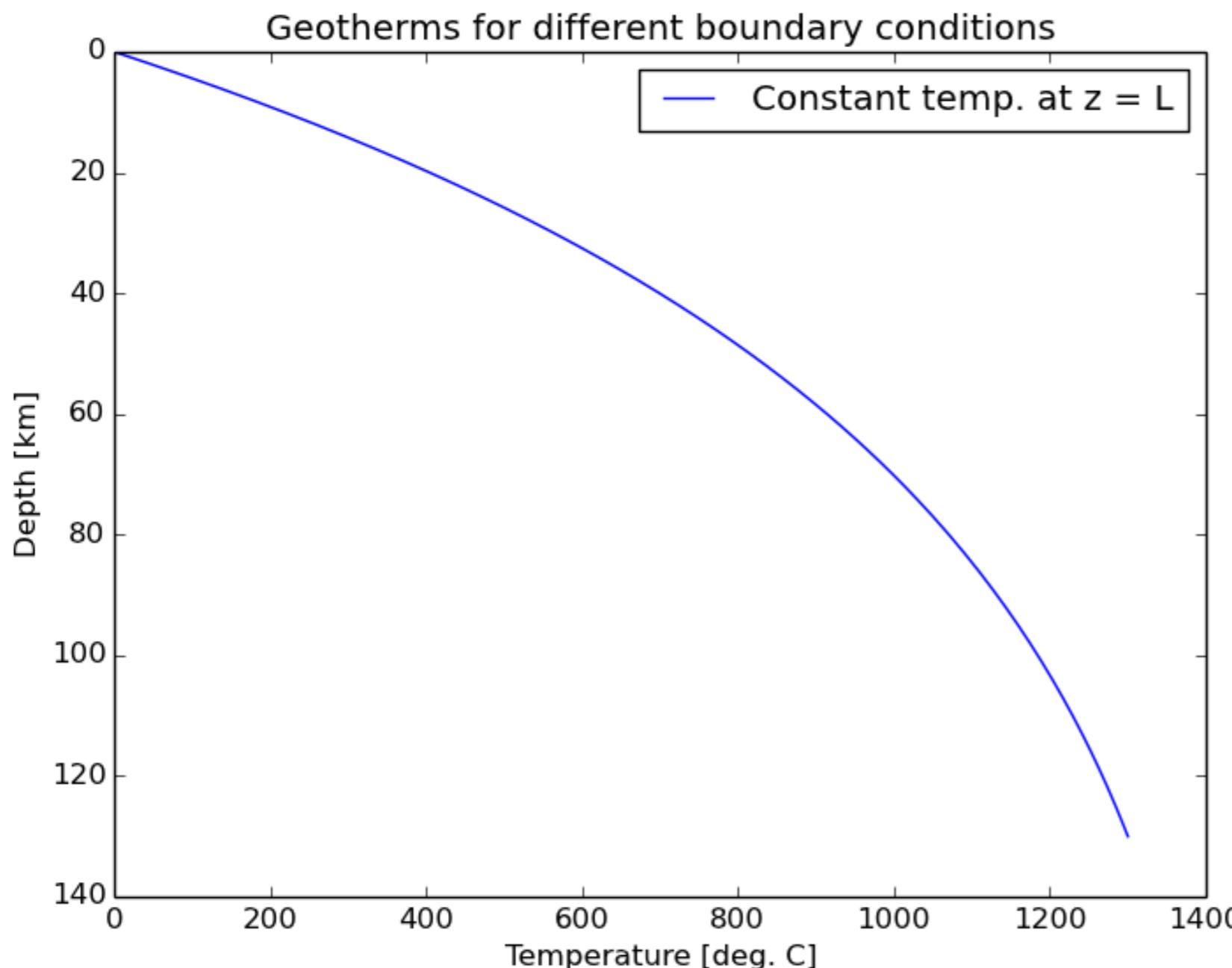


A constant thermal gradient is a bad idea

- 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?**

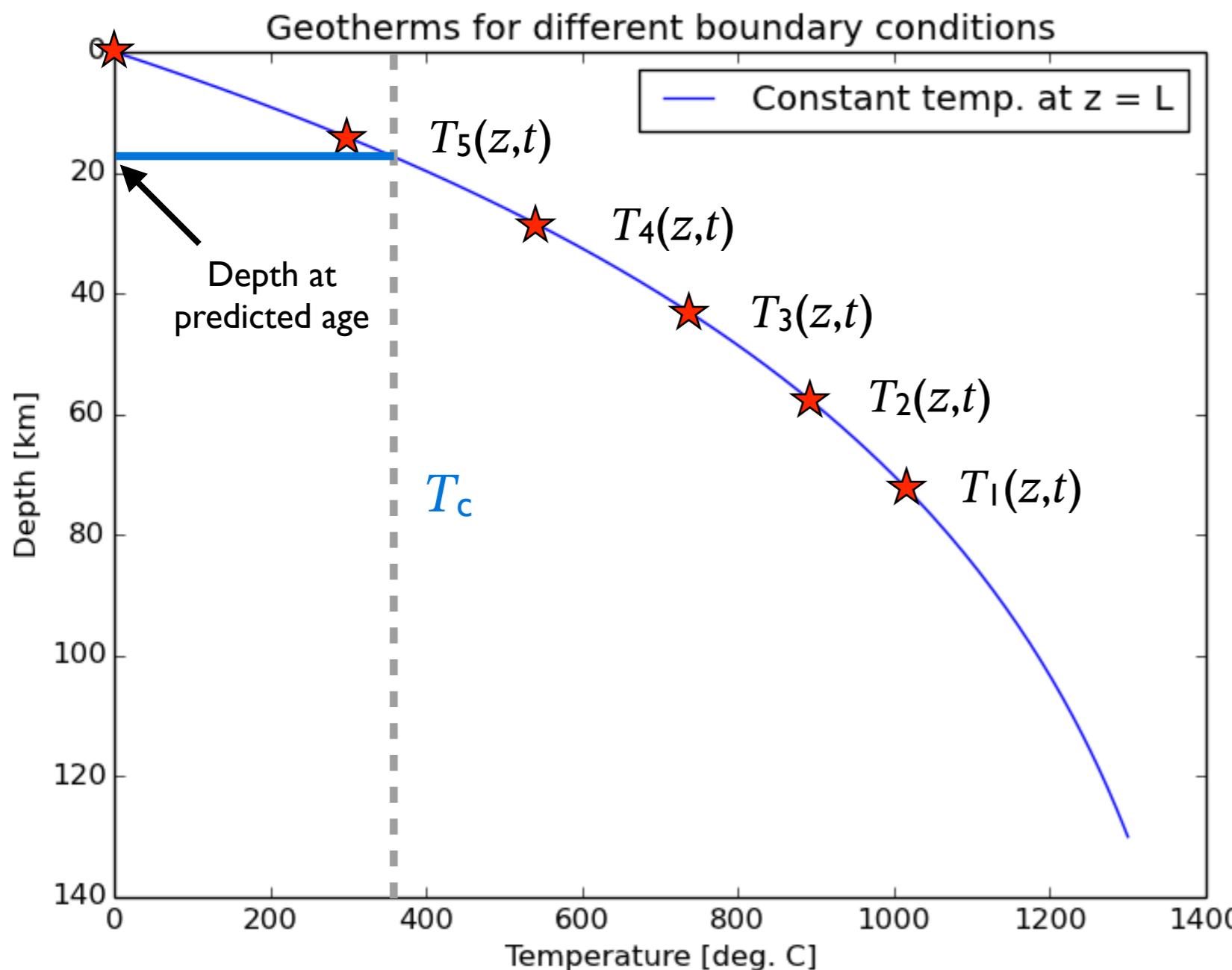


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- We know the sample is **at the surface ($z = 0$) today**, and we can use the **advection velocity v_z** to determine the cooling history
- **How?**
 - We can calculate the **past depth** of a rock sample by **using time steps** back to some time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



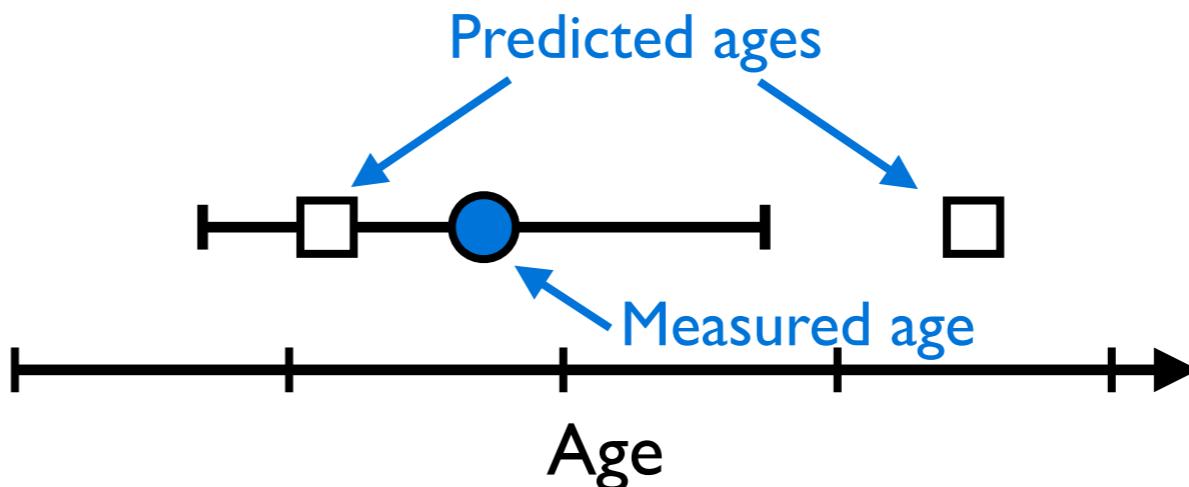
Generating a thermal history



- 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. 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