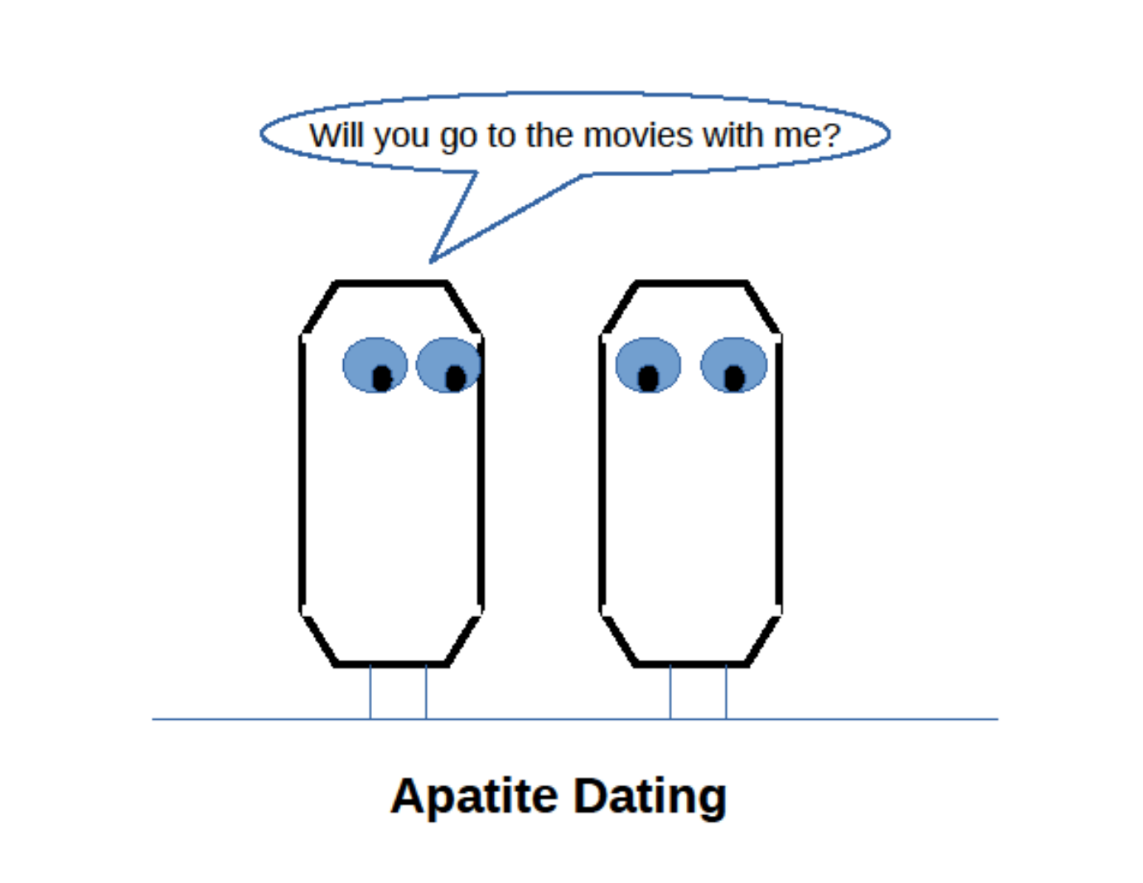
Introduction to Quantitative Geology

Lecturer: Ann-Kathrin Maier

Week 7 – Intro to the final report

Last week

- **Low-temperature thermochronology**
  - Helium dating
  - Fission track dating
  - Argon dating
- **From rock to date**



Final report project:
Investigating exhumation rates in the Bhutan Himalayas

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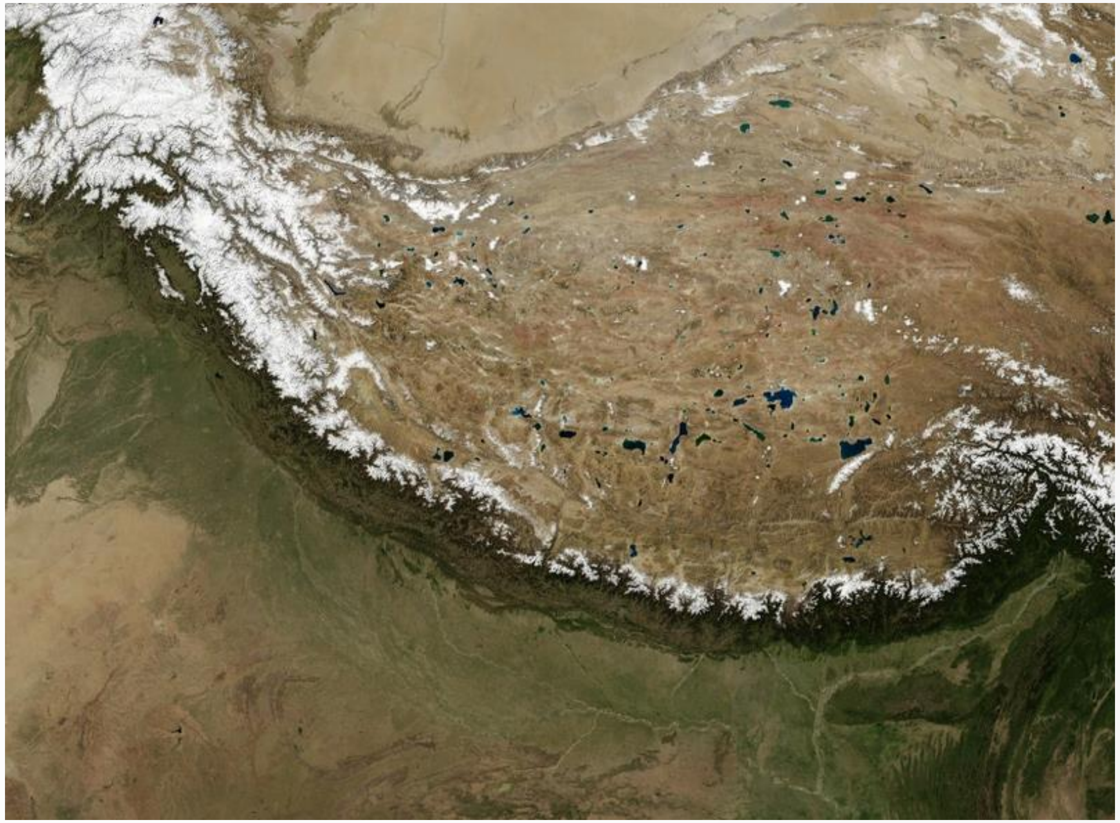
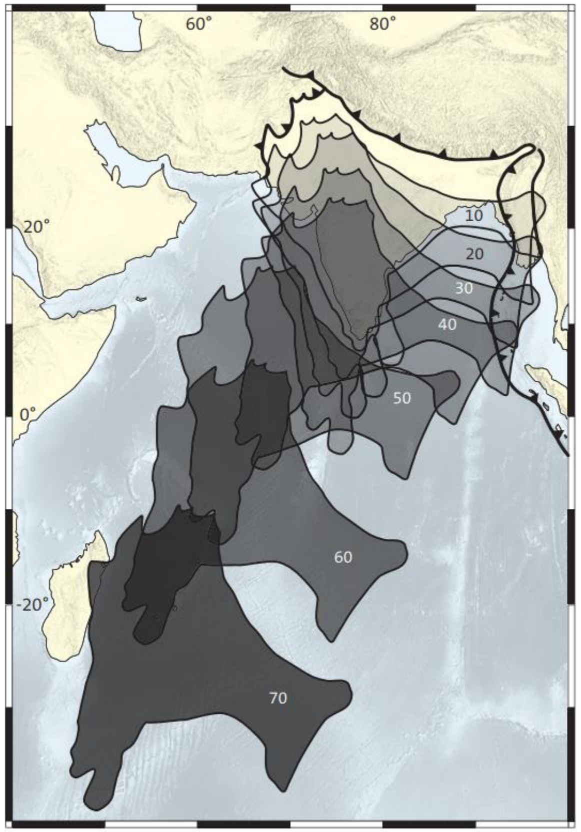
The Himalayas

- 2300 km long mountain range (fold & thrust belt)
- 10 out of the 14 >8,000 m mountains on Earth are in the Himalayas (other 4 are in the Karakoram)
- Greatest relief on the continents (~7000m over 20-30 km horizontal distance)
- Areas of rapid uplift



Himalayas from space NASA, Landsat 7

The Himalayas



Frisch & Meschede (2011)

- Collision zone between Indian and Eurasian plate (+ microcontinents)
- Northward subduction of India

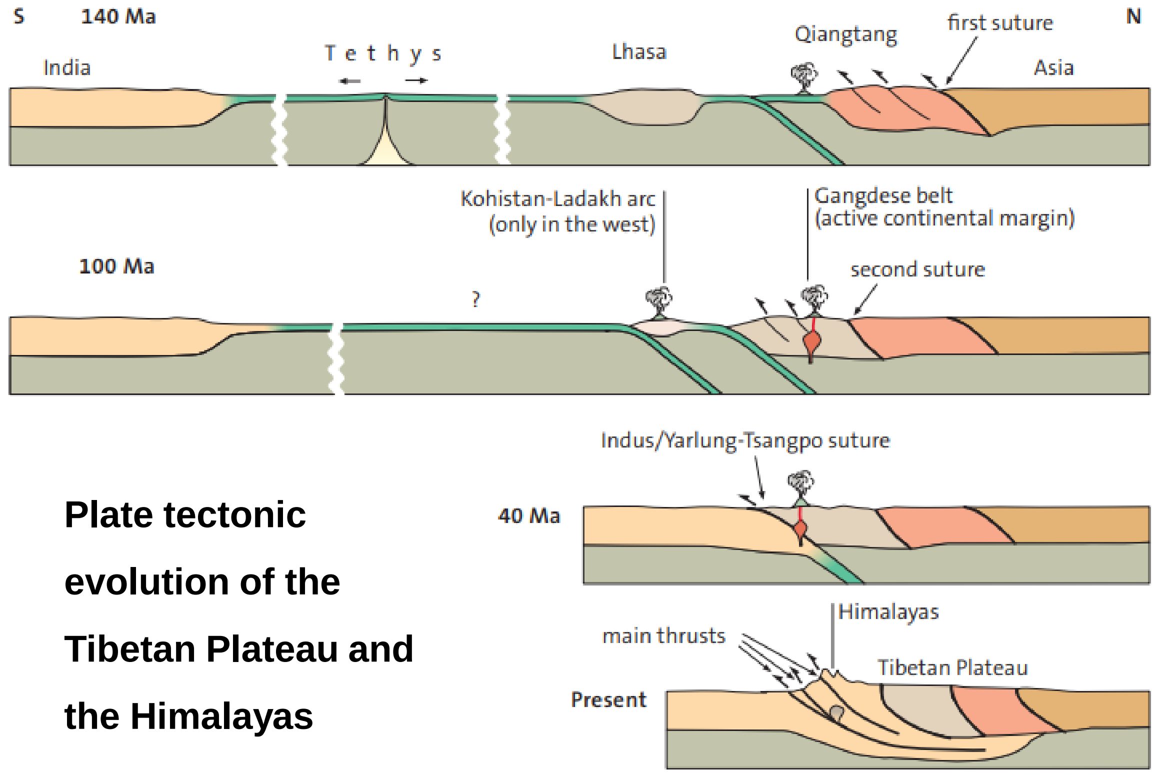
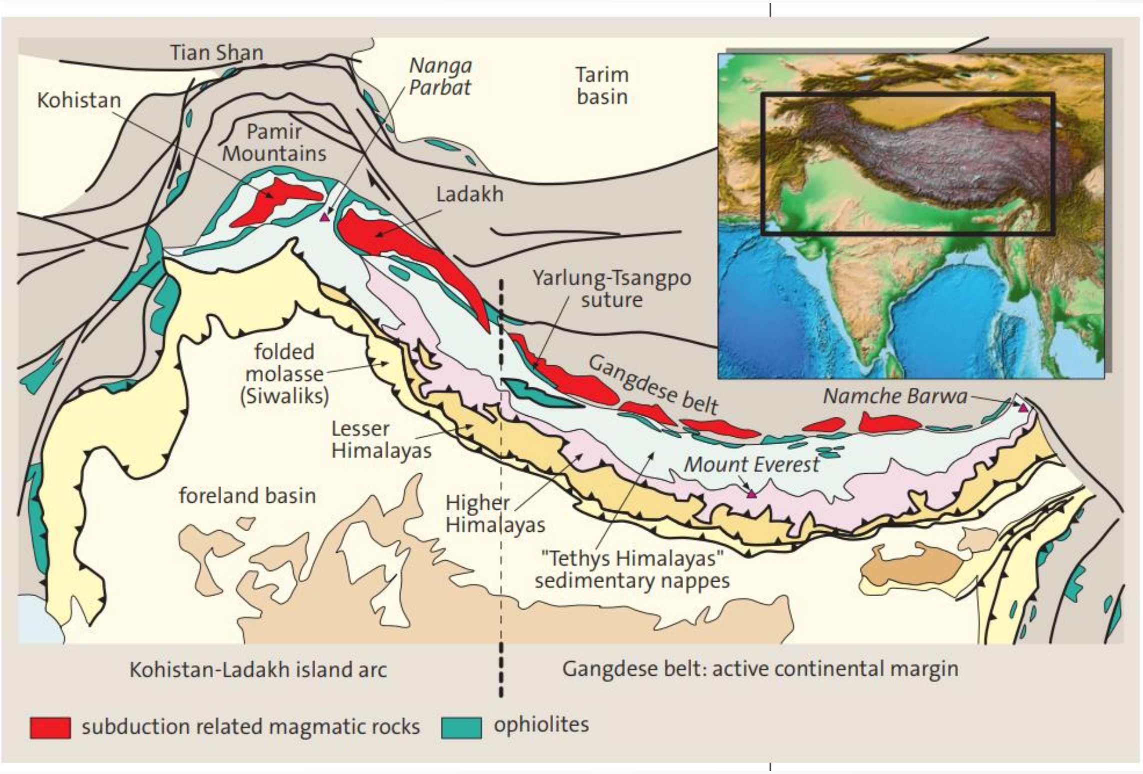


Plate tectonic evolution of the Tibetan Plateau and the Himalayas

Frisch & Meschede (2011)

Main geological features

- **Indus/Yarlung-Tsangpo Suture Zone (ISZ):** Delineates approximate boundary between Indian and Eurasian plates
- **Himalayan fold & thrust belt:** South of the ISZ, south-vergent thrust sheets and related folds
- **Main Central Thrust:** Thrust fault with inverted metamorphic gradient
- **Himalayan foreland basin system:** South of the Himalayan mountain range

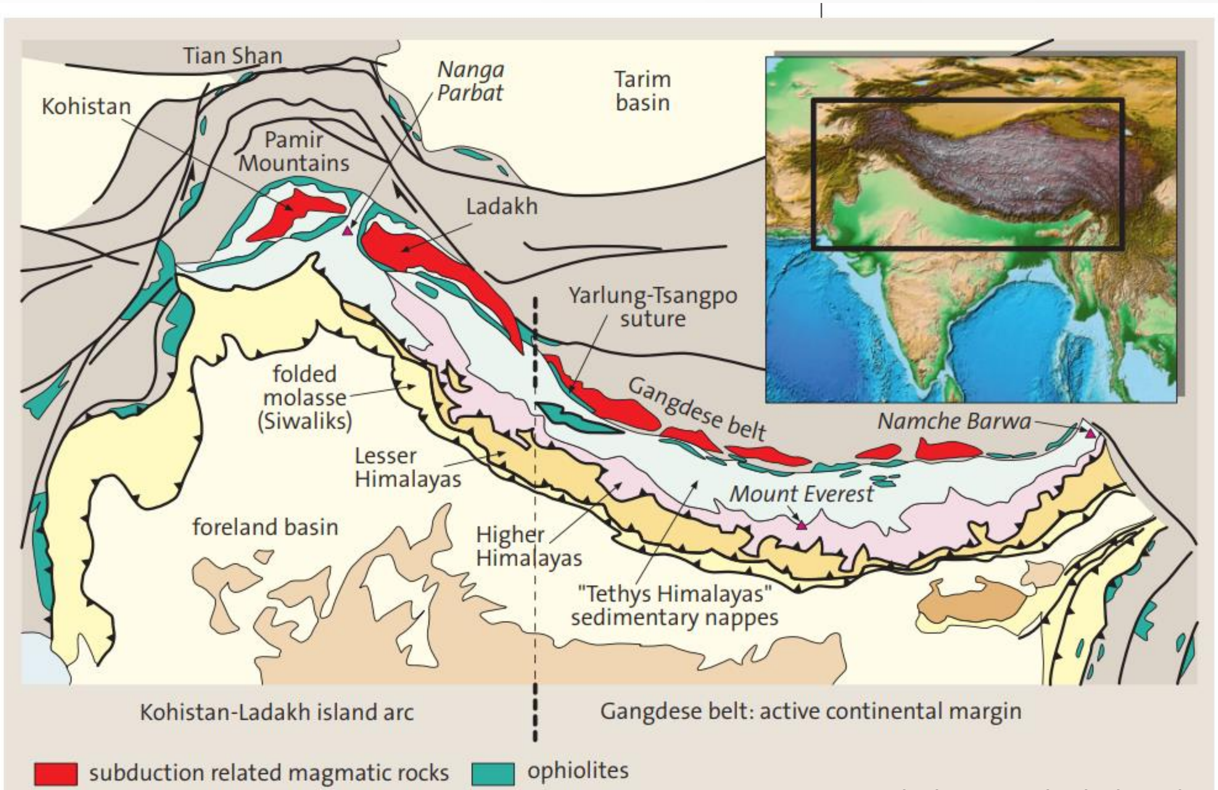


Frisch & Meschede (2011)

Main geological units

Higher Himalayas (or Greater Himalayan Sequence or Higher Himalayan Crystalline)

- Nappe system comprising medium to high-grade metasedimentary rocks
- Bounded by the South Tibetan Detachment System and the Main Central Thrust
- Hanging wall of the Main Central Thrust

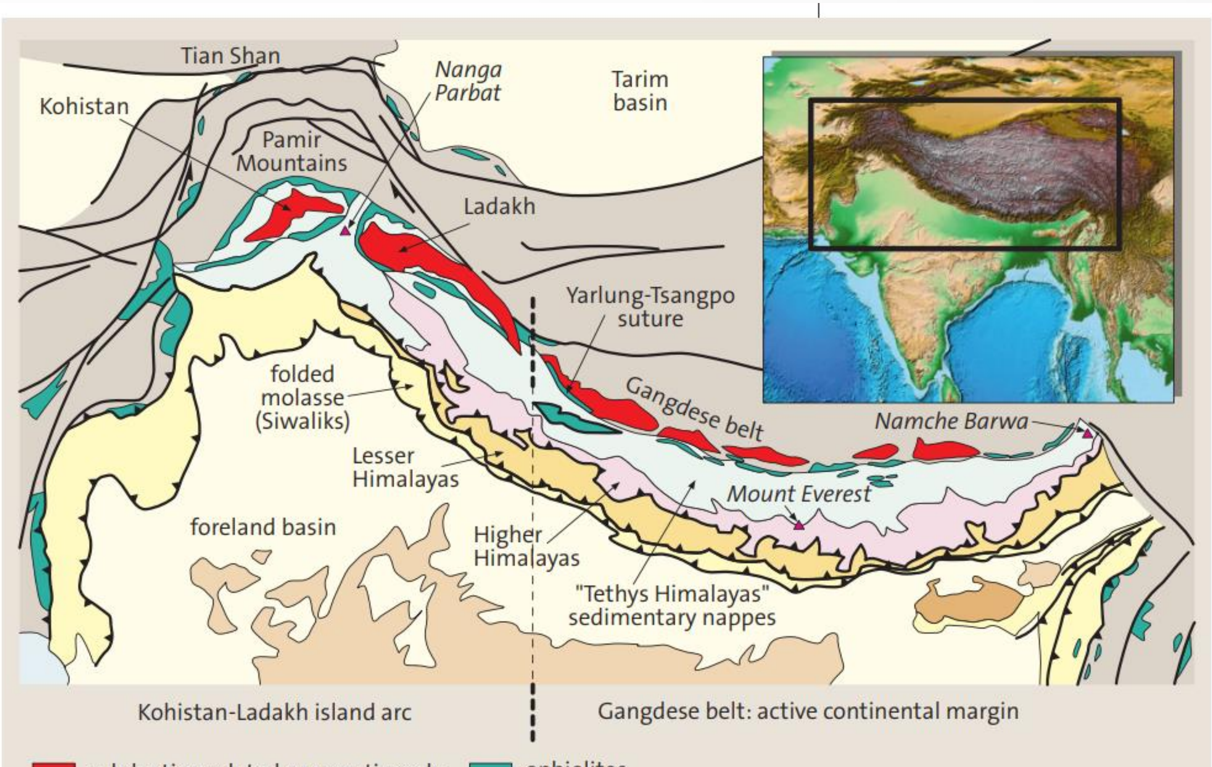


Frisch & Meschede (2011)

Main geological units

Lesser Himalayas

- Nappe system containing metamorphosed sedimentary rocks
- Sediments formerly deposited in the Tethys Sea
- Footwall of the Main Central Thrust

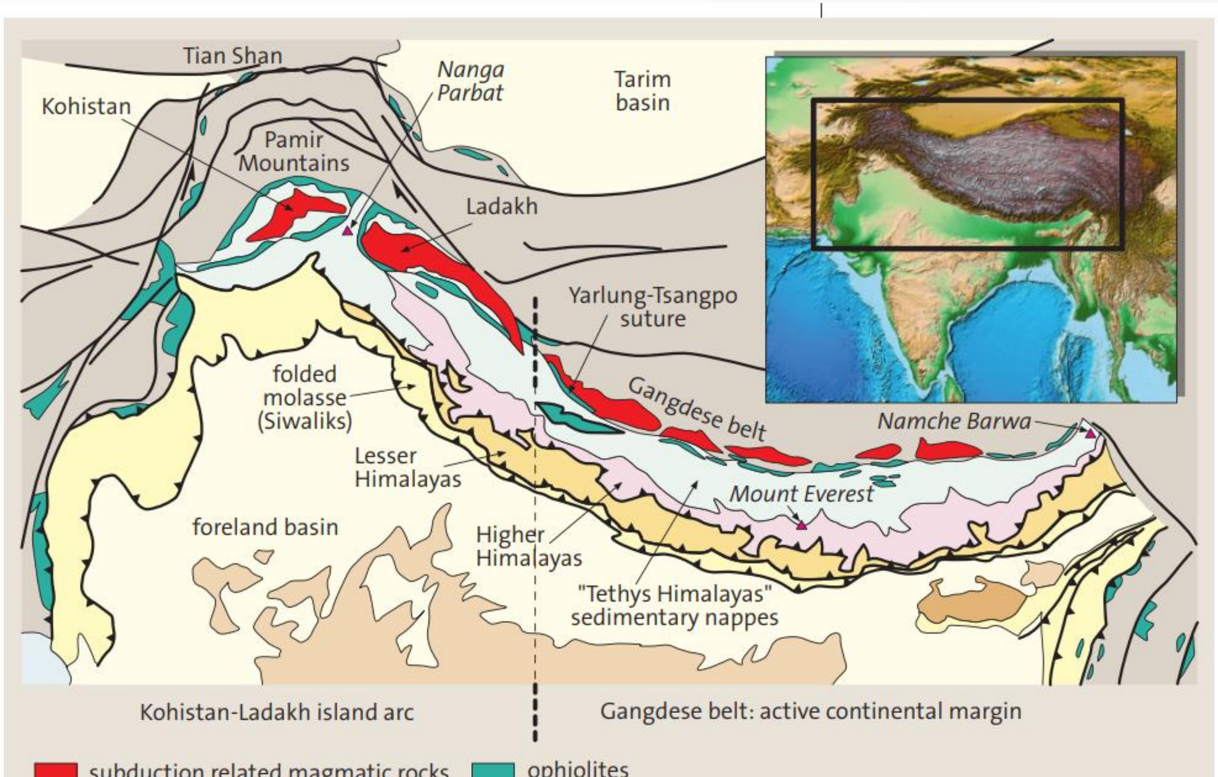


Frisch & Meschede (2011)

Main geological units

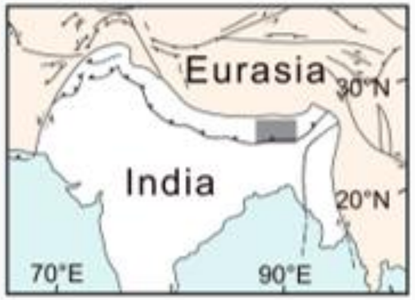
Siwaliks

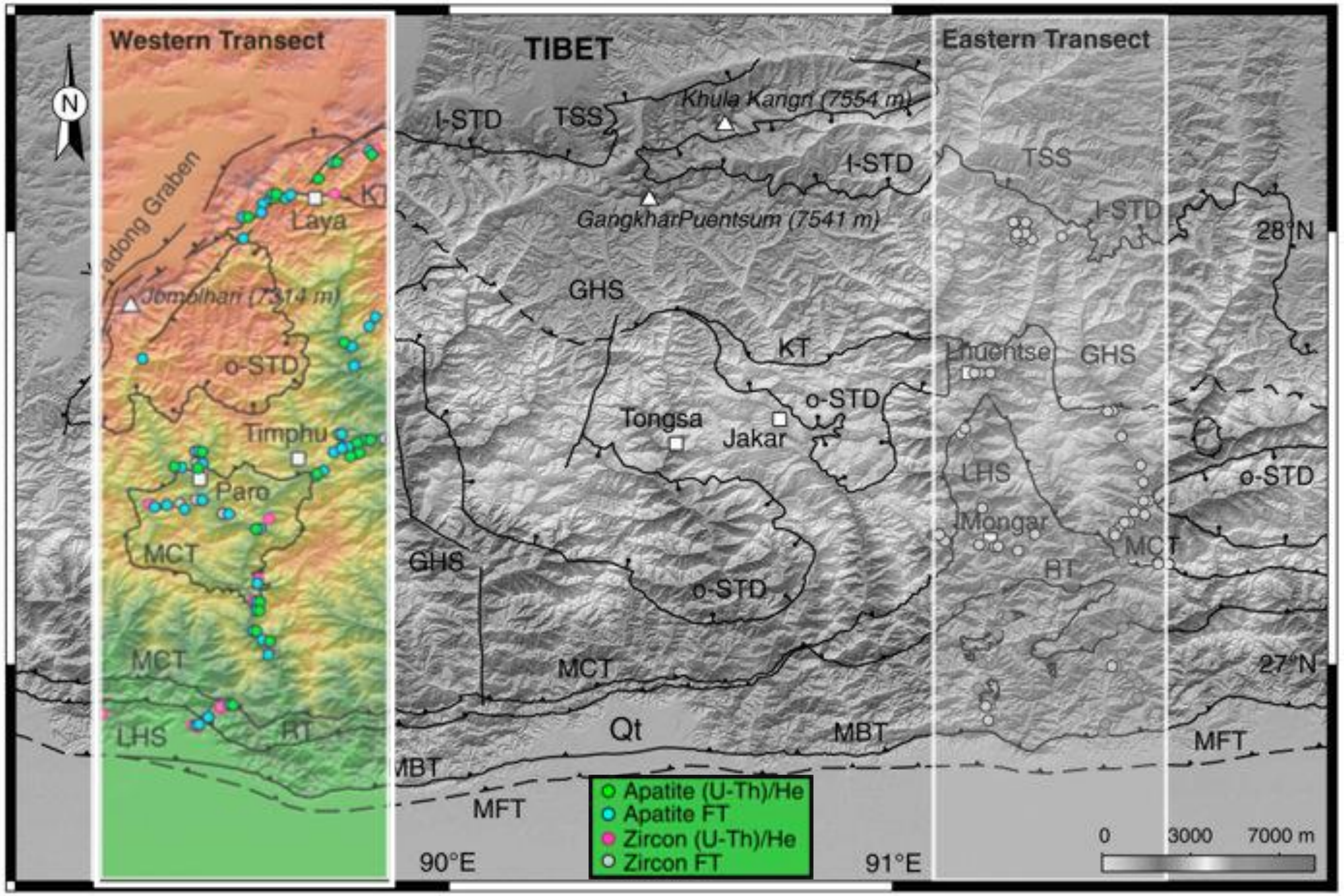
- Neogene molasse that infilled the foredeep/ foreland basin on the Indian continent.
- Have been overridden (& metamorphosed) by the Higher and Lesser Himalayas
- Are thrust over more interior parts of the Indian continent



Frisch & Meschede (2011)

Thermochronometer ages in western Bhutan

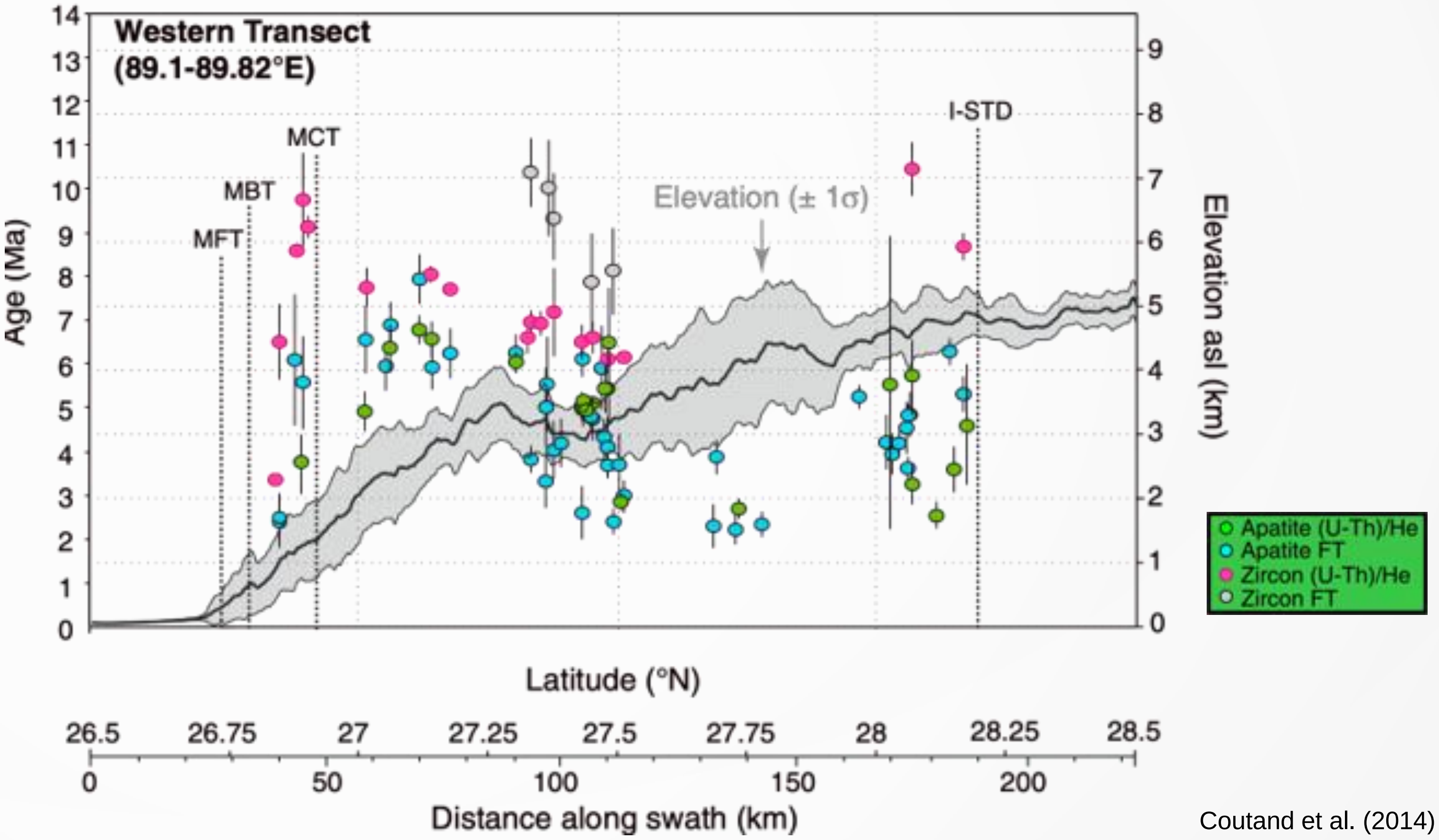




Coutand et al. (2014)

Linking ages to geological processes

- **Something strange about the ages?**
  - •Thermochronometer ages contain valuable information about past geological processes, but *age interpretation is difficult*.



Coutand et al. (2014)

Estimating rock exhumation rates

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

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
- **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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  - **How would you find the exhumation rate?**

→**The simple approach is to find the depth of Tc and divide that depth by the age**

Estimating exhumation rates from ages

- If we assume the surface temperature is 0°C, the depth zc of Tc is simply Tc divided by the geothermal gradient:

$$z_c = 75°C / (20°C/km) = 3.75\ km$$

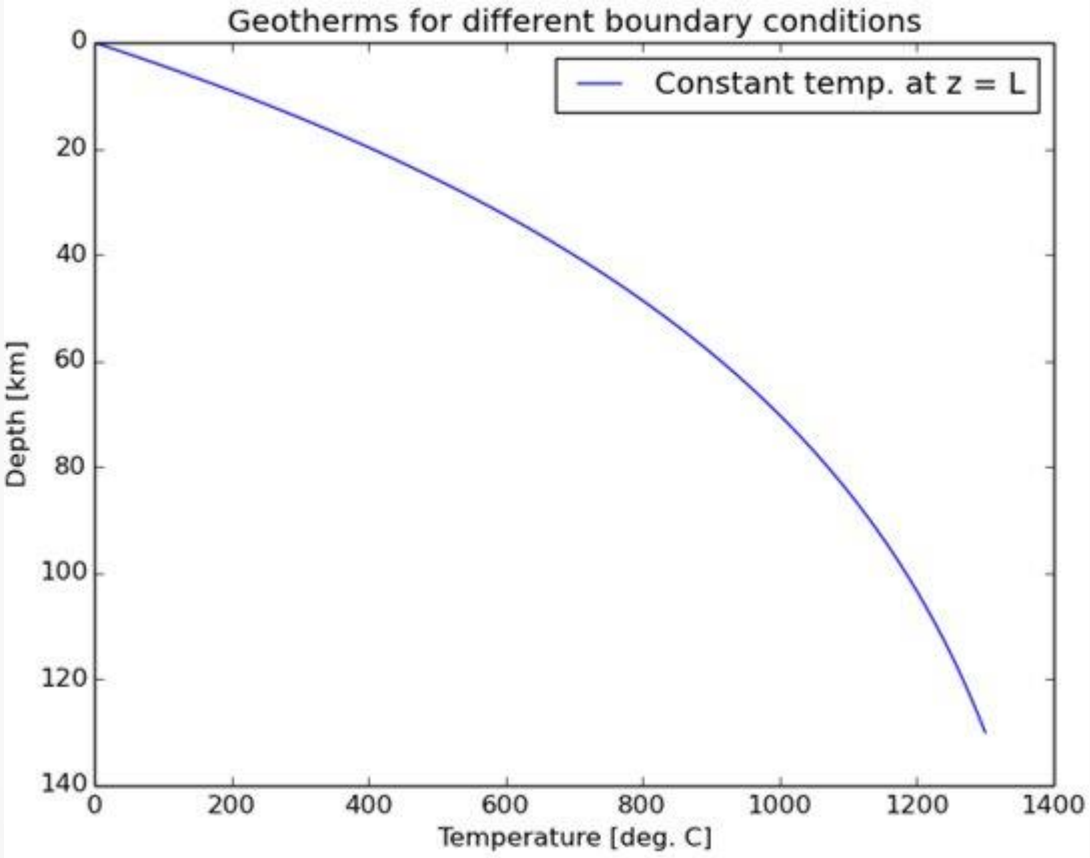
- An **exhumation rate ė** can be estimated by dividing that depth by the measured age

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

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 your approach in the final exercise & report

1-D steady-state geotherms



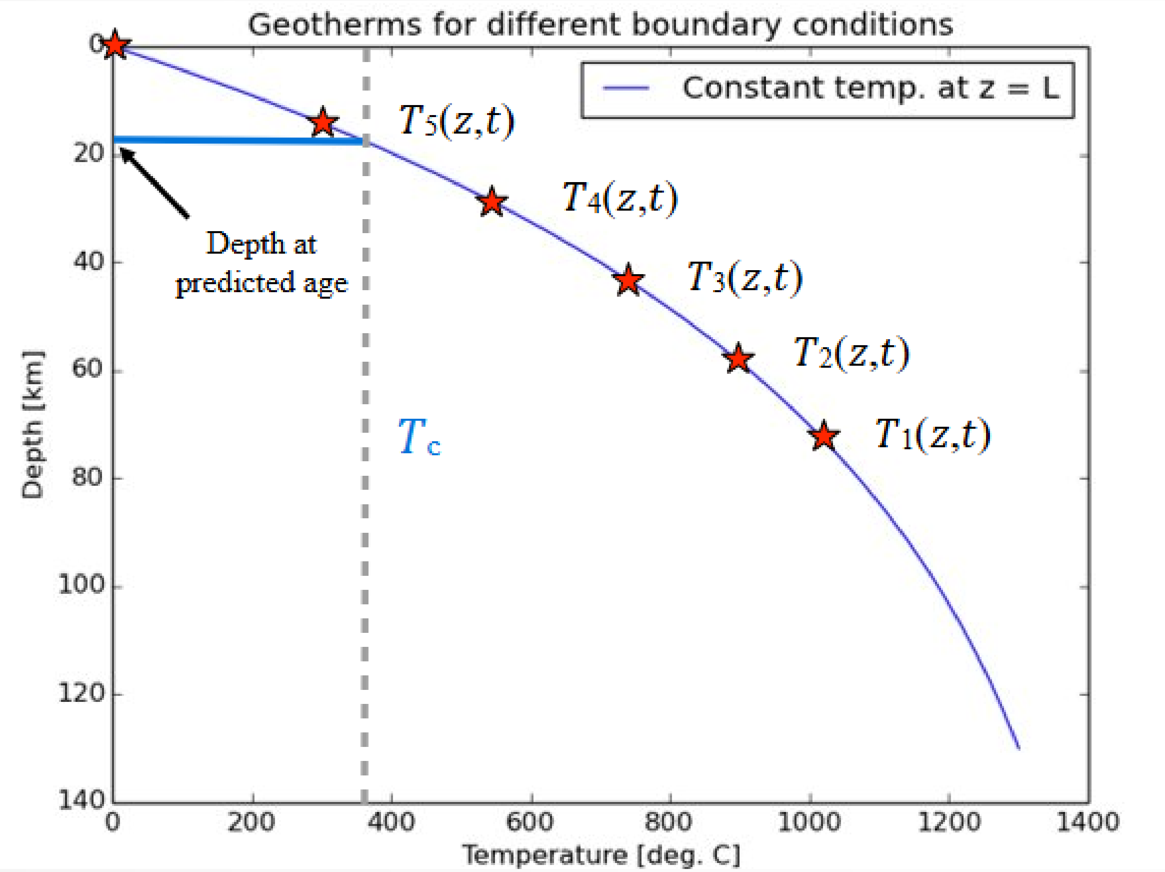
- **Advection** is often the main thermal influence on thermochronometer ages in mountainous regions
- Thus, advection must be considered by using an appropriate equation

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

Now what?

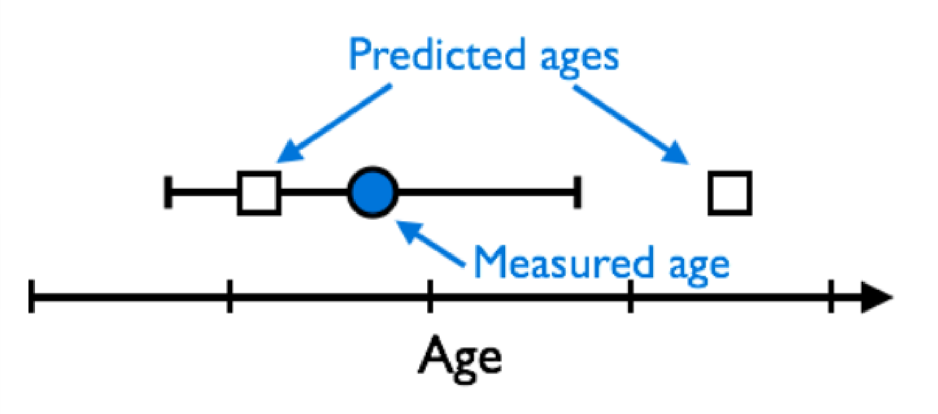
- With a predicted 1-D thermal field, the next step is to determine the cooling history for a rock sample
- We know the sample is at the surface (z = 0) today, and we can use the advection velocity vz to determine the cooling history
- **How?**
  - We can calculate the past depth of a rock sample by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

Generating a thermal history



- At each time, record the depth and temperature, then move the particle upward by $vz \times dt$
- 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



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

FINAL REPORT

- **6-8 pages, not longer**
  - including text & figures
- 12 pt Times New Roman (or a similar font)
- single line spacing
- references and the appendix can be on additional pages

- Title
- Abstract
- Introduction (2-4 paragraphs)
- Geological background (1-3 paragraphs)
- Methods (at least 1 paragraph)
- Results (at least 1 paragraph)
- Discussion (several paragraphs)
- Conclusions/Summary (1-2 paragraphs)
- Acknowledgements (optional)
- References
- Appendices

Abstract

- A summary of the exercise and your results not longer than 250 words
  - *Why did you do what you did?*
  - *What did you do?*
  - *How did you do it? → Be brief, no details!*
  - *What did you find?*
  - *What do you conclude?*

- Needs to be understandable without the text that follows.

Introduction

- **2-4 paragraphs**
- Clearly state the problem you are addressing (or hypothesis being tested) and its significance. → min. 1 paragraph
    - *What is the problem/hypothesis & why should the reader care?*
- Provide background information on the topic → min. 1 paragraph
    - *Show that you understand what has been done before. Focus on what is relevant to your problem.*
- Explain how this exercise contributes to understanding the stated problem. → 1 short paragraph
    - *Introduce what you did and what you hope to learn from it.*

Geological Background

- **1-3 paragraphs**
- Include a general overview of the main features of the study region, such as the major faults, rock units, variations in rainfall, etc.
    - *Providing a map can be helpful.*
    - *General description of the area.*
- Provide enough information to understand the main “drivers” of uplift and erosion of the thermochronometer data you’re studying.
    - *More detailed information specific to your data and the problem you investigate.*

Methods

- **Min. 1 paragraph**
- Describe everything the reader needs to know to understand what you did.
- Clearly state the different methods used for each part of the exercise.
  - *E.g. one paragraph to describe the thermal model & one paragraph to describe how thermochronometer ages are calculated.*
- Describe the equations you are solving:
  - *What does the equation do?*
  - *What are the variables or free parameters?*
  - *How did you calculate the solution?*

Results

- **Min. 1 paragraph**
- **Describe** the results from your experiments:
  - *E.g. the exhumation rates that provide a minimum goodness-of-fit to the data.*
- Include selected figures from Exercises 6 and 7.
  - *Provide figure captions and at least 1 paragraph of text that describes each figure*

Important: *Only* observations, no interpretations!

Discussion

- **Several paragraphs**
- Interpretation and discussion of your results. Can have multiple subsections.
  - *Main message. Answer the question/problem from the introduction and provide supporting evidence. (The findings show that X contributes to Y.)*
  - *Critical assessment: Any shortcoming and limitations (in the study design/methods) should be discussed.*
- Example discussion section topics include:
  - *How do the exhumation rates that provide a minimum misfit to the different thermochronometer age systems vary?*
  - *How well do the model predictions compare to the measured ages?*
  - *What are the limitations of the modeling approach and how do they affect the results?*
  - *What are the implications of your results for the problem/hypothesis you stated in the introduction?*
  - *Have you sufficiently tested your hypothesis or are more experiments needed?*
  - *Any other topics you feel should be discussed about the implications of the model results.*

Conclusions

- **1-2 paragraphs**
- This should summarise the **main findings** of your exercise.
  - *Not a summary of the entire report.*
  - *Main findings that you want the reader to remember.*
  - *Don't repeat the Abstract.*

IMPORTANT DATES

- **Exercise 7** due 17 December at 12:15
- **Final report** due 18 January 2026 at 23:59, submit via e-mail to david.whipp@helsinki.fi or via Github classroom (link on course page)
- Course feedback form open from 13.12.2025 to 27.12.2025

References

- Coutand, I., D. M. Whipp Jr., D. Grujic, M. Bernet, M. G. Fellin, B. Bookhagen, K. R. Landry, S. K. Ghalley, and C. Duncan (2014), Geometry and kinematics of the Main Himalayan Thrust and Neogene crustal exhumation in the Bhutanese Himalaya derived from inversion of multithermochronologic data, *J. Geophys. Res. Solid Earth*, 119, 1446–1481, doi:10.1002/2013JB010891.
- Frisch, W., Meschede, M. and Blakey, R.C. (2011) Plate Tectonics: Continental Drift and Mountain Building. Springer, Berlin, 212 p. https://doi.org/10.1007/978-3-540-76504-2
- Ring, U., M. T. Brandon, S. D. Willett, and G. S. Lister (1999), Exhumation processes, *Geological Society Special Publications*, *154*, 1–27.