Class overview today - March 14, 2016

- **Part I - What is quantitative geology?**
  - Introductions and practical course information
  - What is quantitative geology?
  - Skills of a quantitative geologist
  - What is a model?
- **Part II - Essentials of computing**
  - What is a computer?
  - What is a program?
  - Elements of a computer program

Introduction to Quantitative Geology
Lecture 1
What is quantitative geology?

Lecturer: David Whipp
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14.3.2016

Practical matters - Class location

- When/where is class?
  - **Lecture**:
    - Monday 14-16, C108, Physicum (14.3 - 2.5)
    - No class 28.3
  - **Computer lab**:
    - Wednesday 14-16, D211, Physicum (16.3 - 4.5)
    - No class 30.3

Course content by week

Week	Lecture	Lab	Homework
11	1 - What is Quantitative Geology? 2 - Essentials of computing	1 - Intro to Python/Numpy I	Get GitHub account
12	3 - Statistical methods in geoscience 4 - What to ages mean?	2 - Intro to Python/Numpy II	Lab 1 due
13	**NO CLASS - Easter**		
14	5 - Natural diffusion processes 6 - Solving the diffusion equation	*3 - Diffusion of Earth's surface*	Lab 2 due
15	7 - Advection of Earth's surface 8 - Solving the advection eqn	*4 - River profile calculations*	Lab 3 due
16	9 - Rocks, ice as viscous materials 10 - Equations of viscous flow	*5 - Glacier mechanics*	Lab 4 due
17	11 - Intro. to Thermochronology 12 - Low-T Thermochronology	*6 - Quantitative thermochronology I*	Lab 5 due
18	13 - Erosion and Thermochronology 14 - Thermochronology and landscapes	*7 - Quantitative thermochronology II*	Lab 6 due
19			**Final project due**

Practical matters - Grades

- Course grades will be based on a combination of laboratory exercise write-ups and a final project report
  - **50% Exercise write-ups** (6 in total)
  - **50% Final project report** (includes Exercise 7)

- The final project will involve writing a short Python script that will be applied to a real geologic dataset in order to interpret the data. The geologic problem, your code, and main results will be described in a short paper that is due at the end of the course. Details will be provided later in the course.
- There is **no final exam**

Practical matters - Book

- There is **no required textbook** for this course
- A list of recommended and optional texts is provided on the syllabus

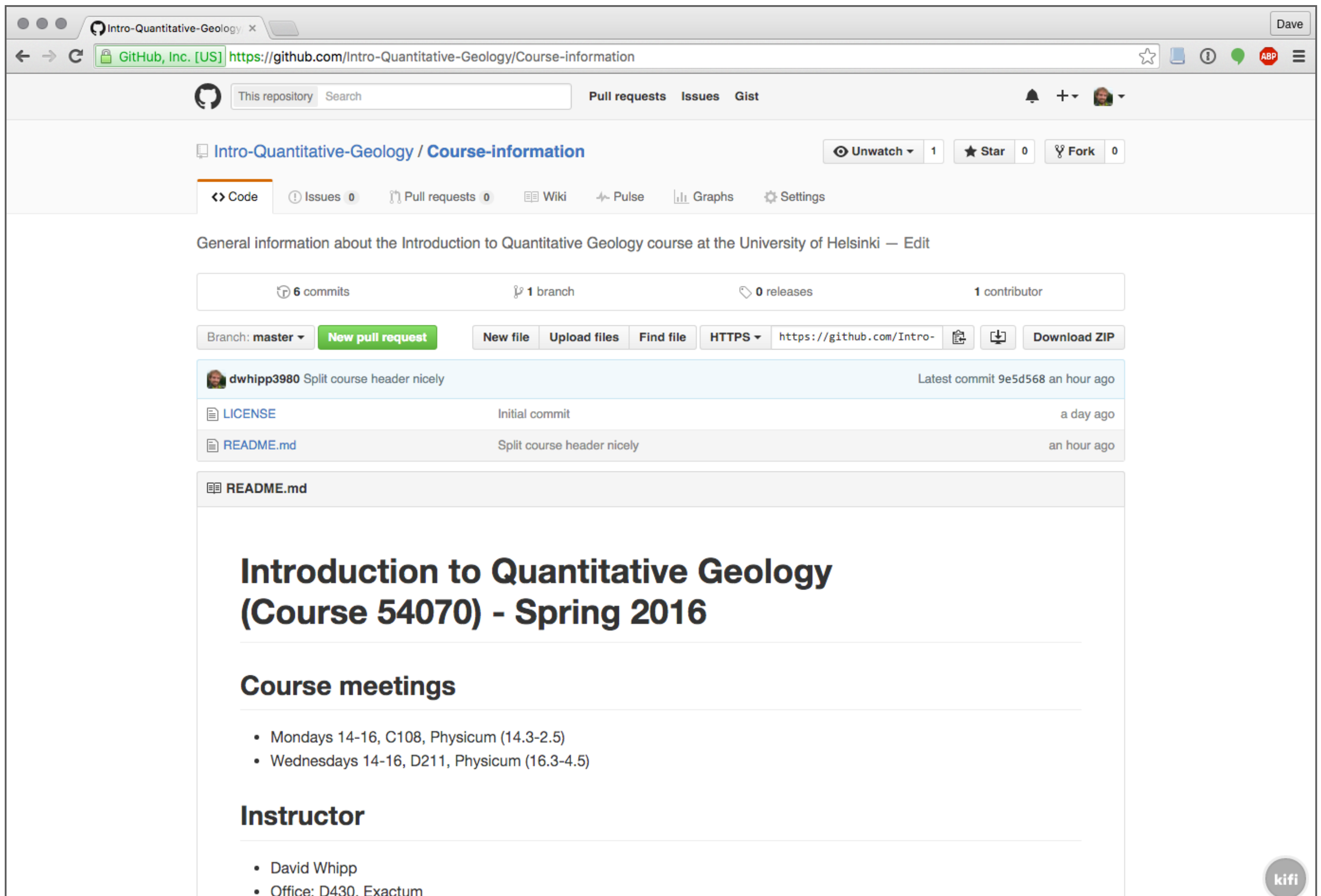
- If you're interested in learning how to program in Python would **recommend** purchasing a copy of the text below:

  Zelle, J. (2010) *Python Programming: An Introduction to Computer Science*, Second edition. Franklin, Beadle & Associates.

  ~30€ on amazon.de; 50-70€ locally

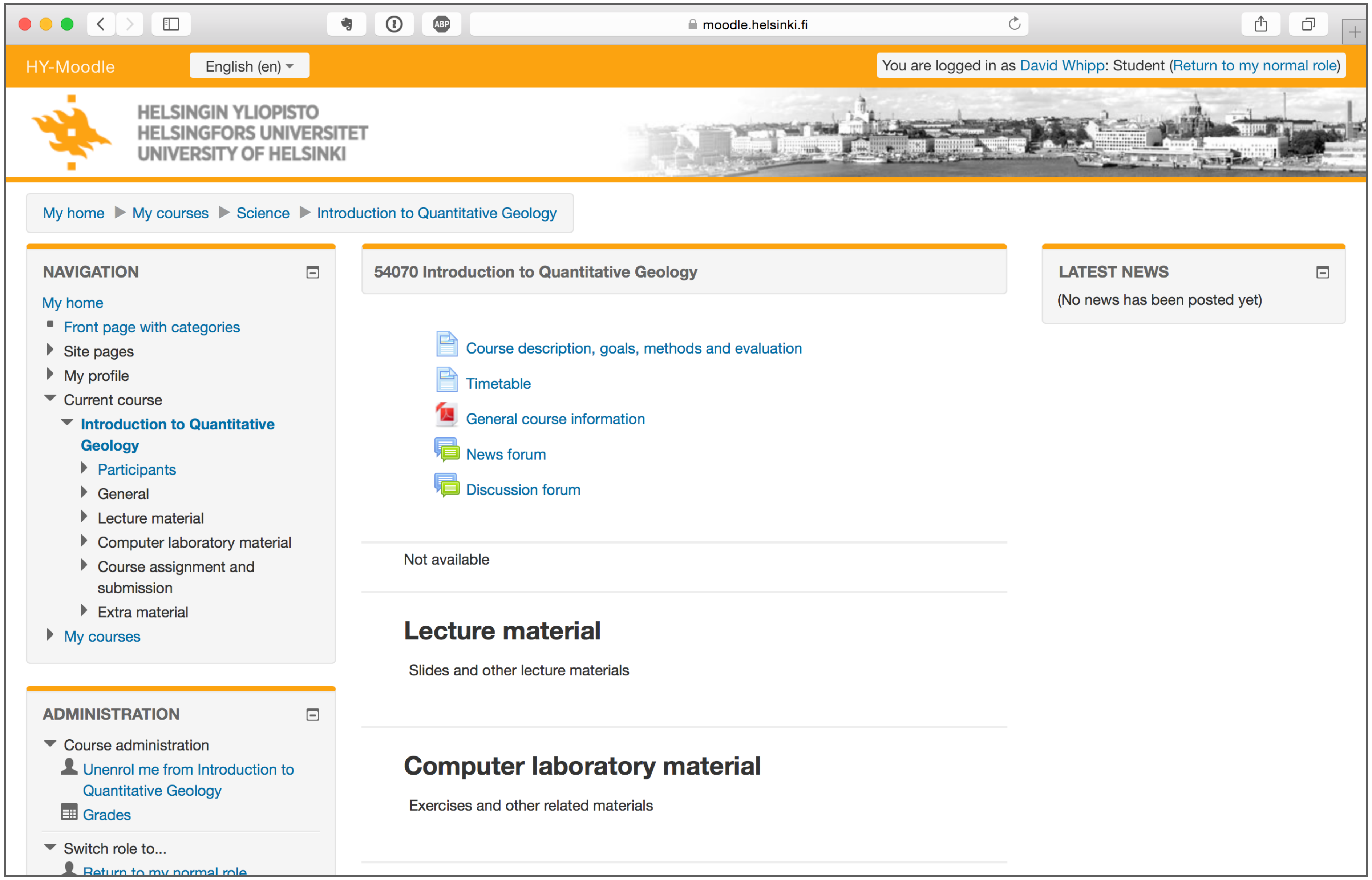
Practical matters - GitHub site

- We will be using GitHub in this course for distributing course materials, code and for learning how to be responsible coders



Practical matters - Moodle

- The Moodle page for the course is at https://moodle.helsinki.fi/course/view.php?id=12453



A simple example…intuition isn't always right

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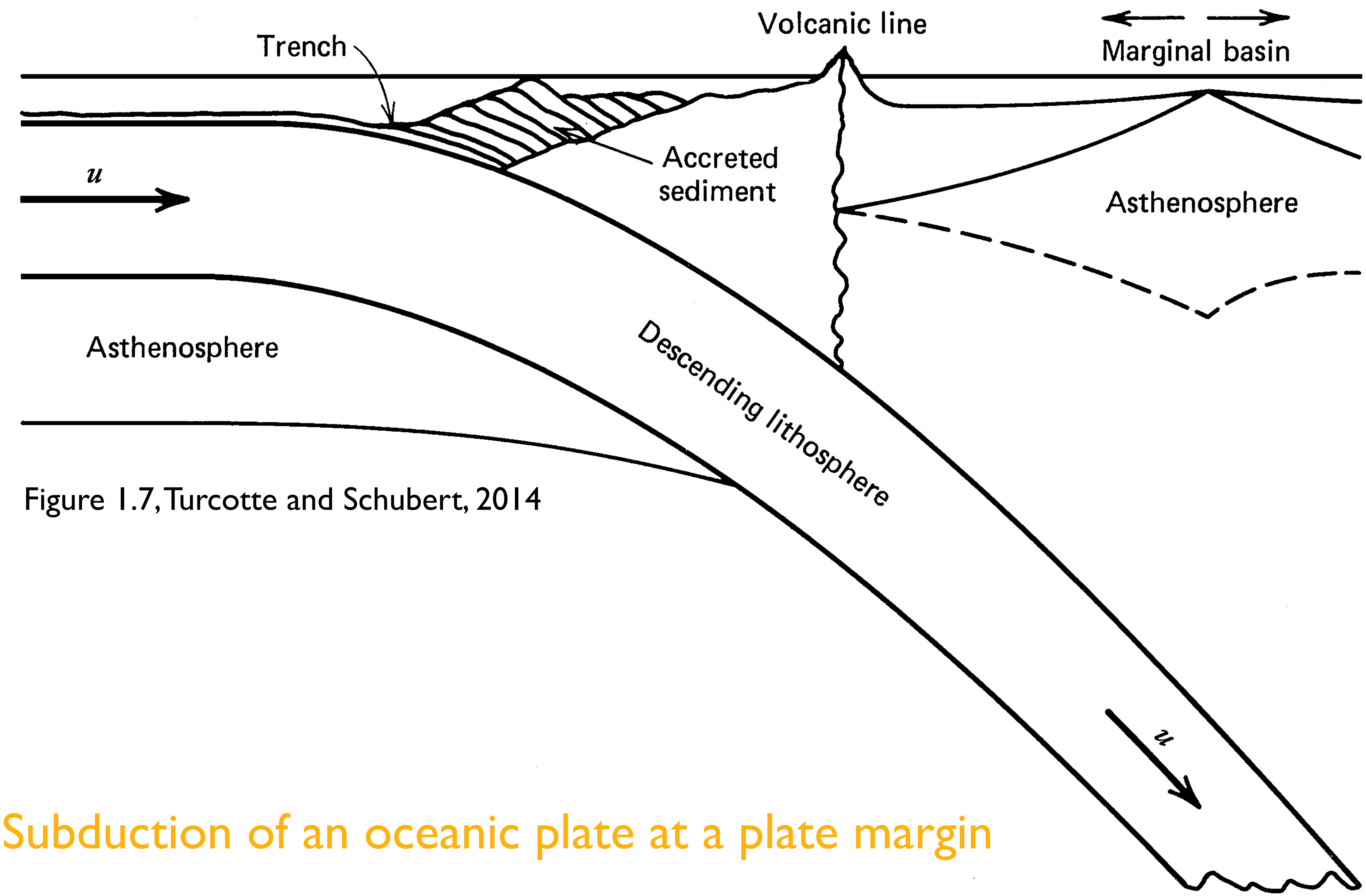


Figure 1.7, Turcotte and Schubert, 2014

Subduction of an oceanic plate at a plate margin

A simple example…intuition isn't always right

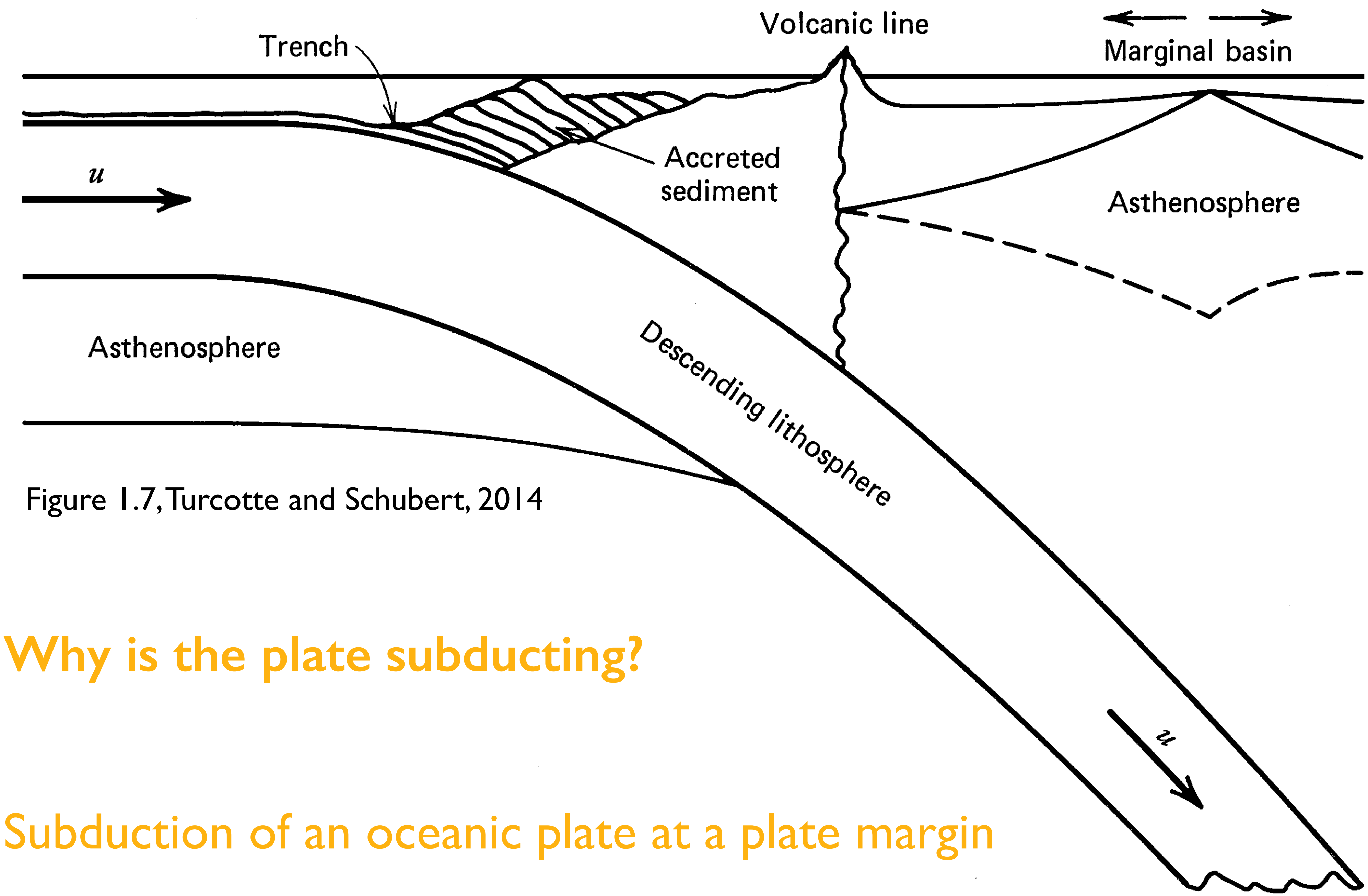


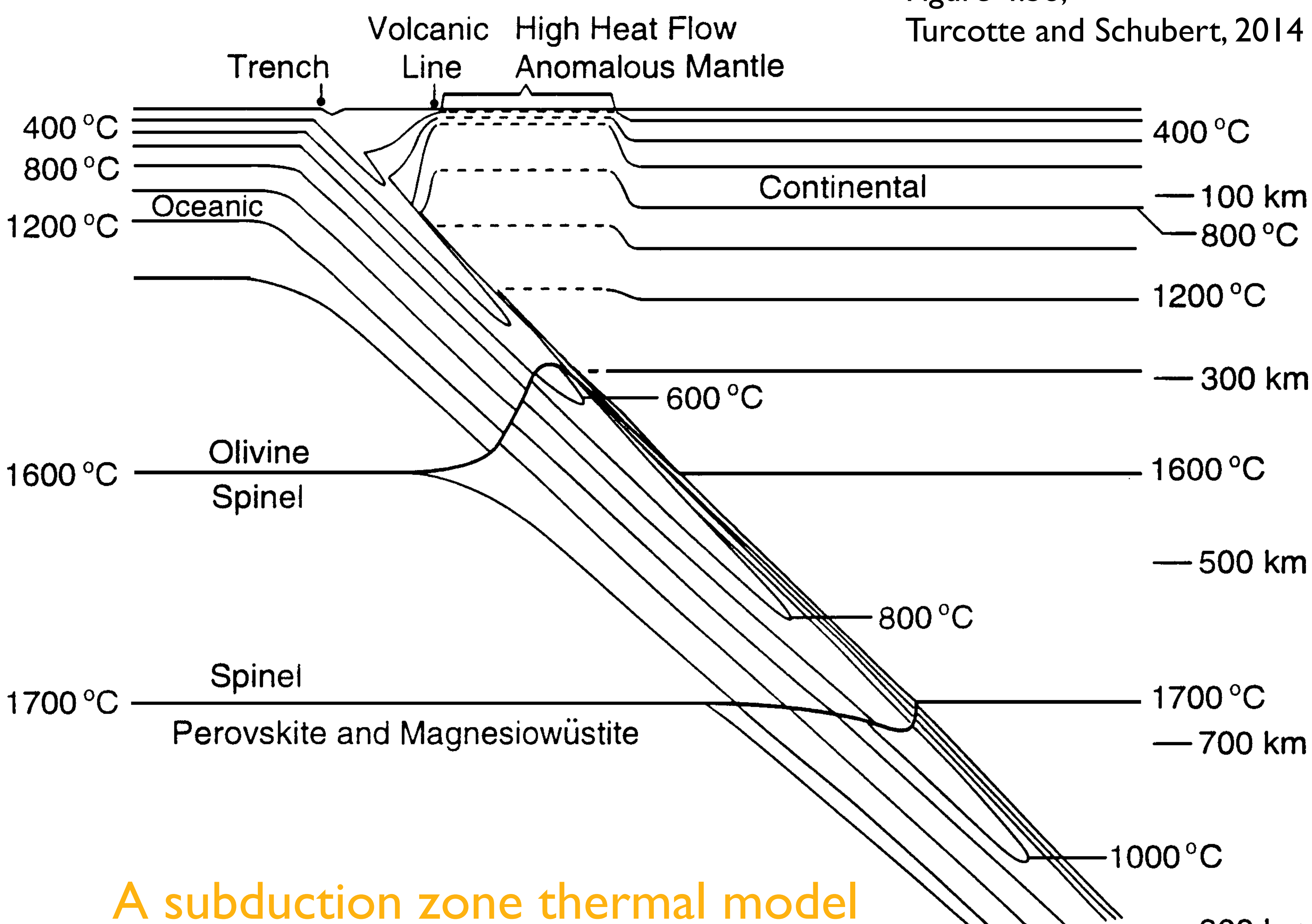
Figure 1.7, Turcotte and Schubert, 2014

Why is the plate subducting?

Subduction of an oceanic plate at a plate margin

A simple example?

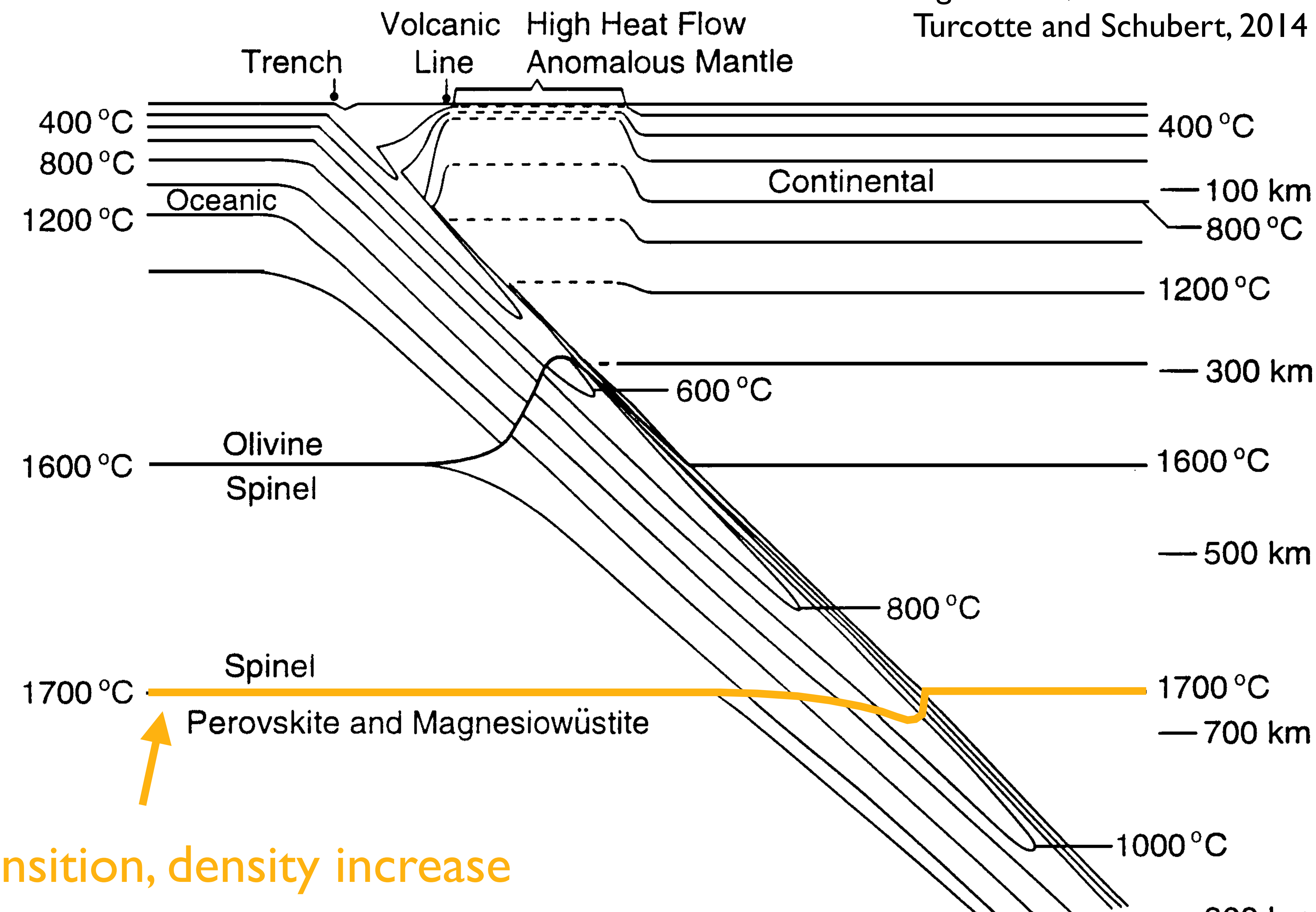
Figure 4.58,
Turcotte and Schubert, 2014



A subduction zone thermal model

A simple example?

Figure 4.58,
Turcotte and Schubert, 2014



Phase transition, density increase

Our general concept

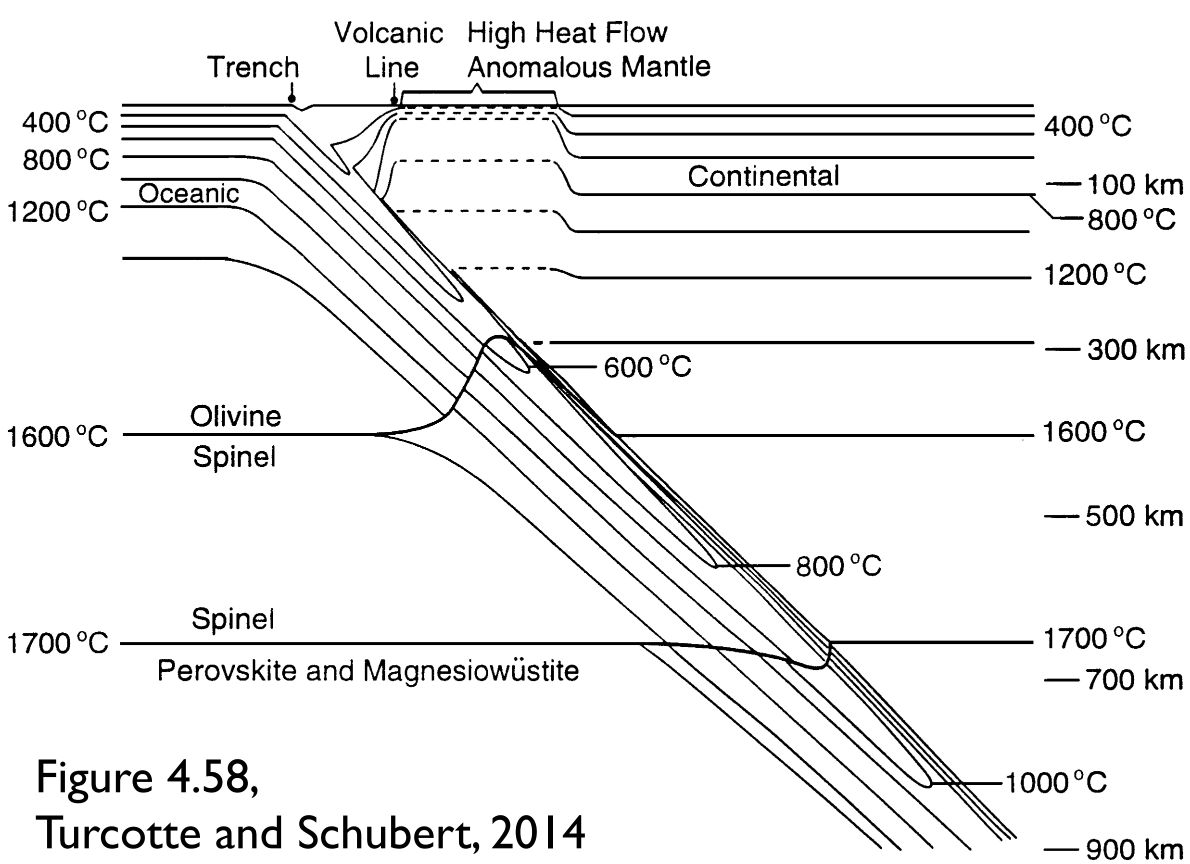
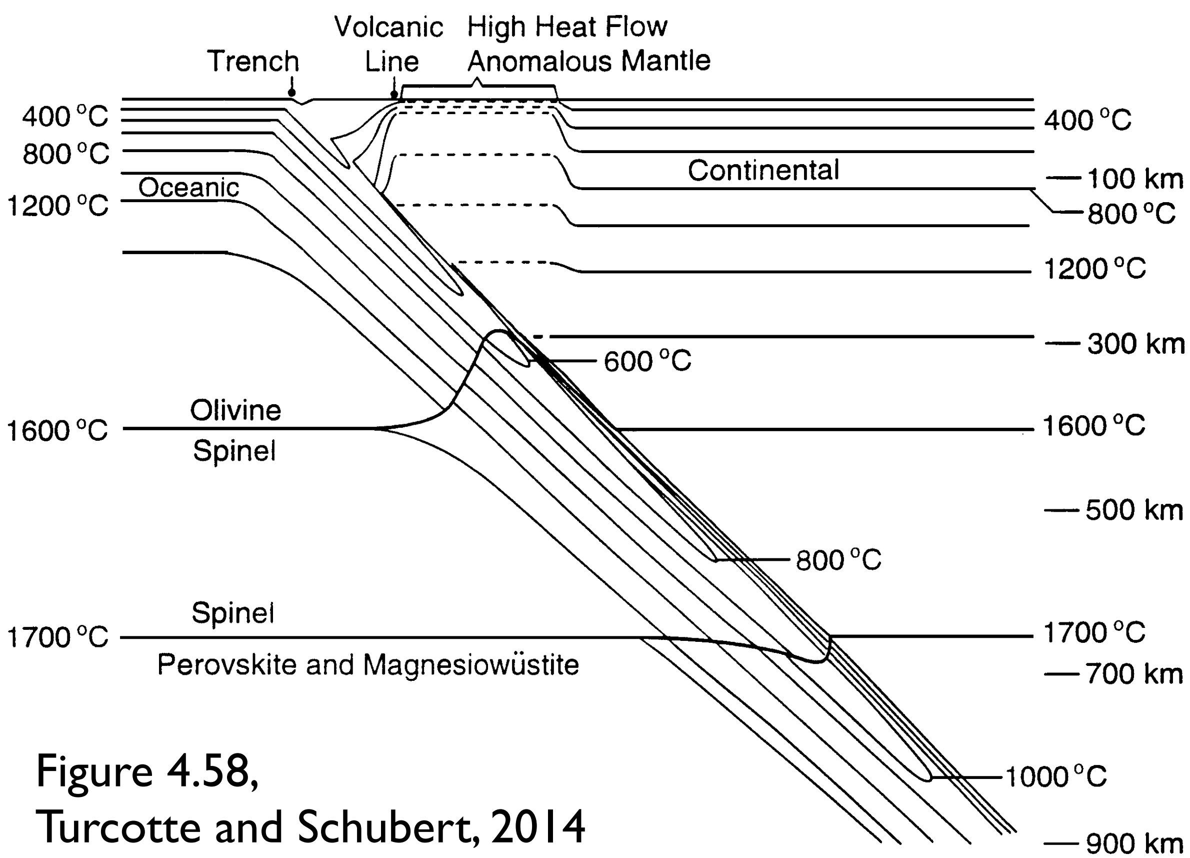


Figure 4.58,
Turcotte and Schubert, 2014

- Density and/or viscosity of the mantle increase significantly at ~660 km depth due to a phase transition
- This reduces the density contrast (buoyancy force) between the subducting plate and the mantle
  - This should make it **difficult for slabs to penetrate the mantle below**

Our general concept



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What about the age of the subducting lithosphere?
Could this matter?

Our conceptual model hypothesis

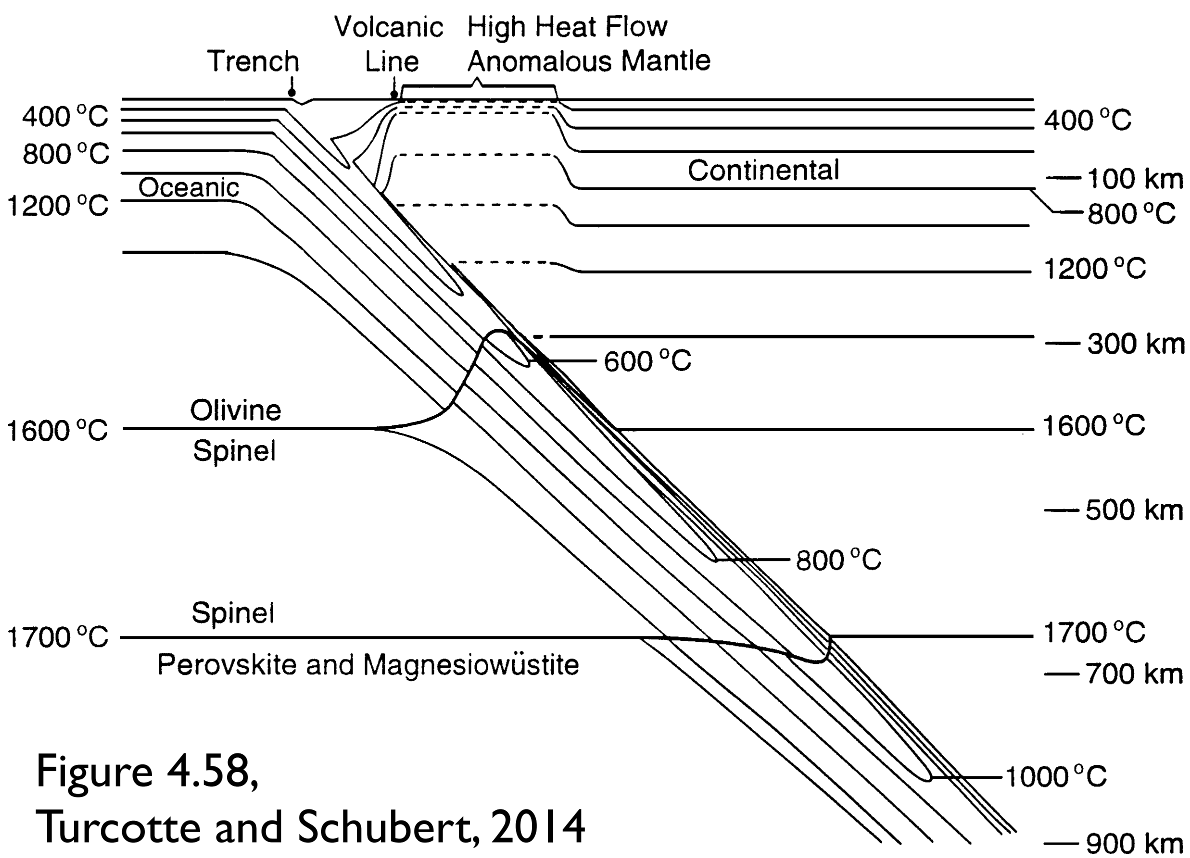


Figure 4.58,
Turcotte and Schubert, 2014

- Let's make a prediction (hypothesis)
- Older oceanic plates are colder and more dense, so they should **sink into the lower mantle more easily**
  - Conversely, younger plates are warmer and less dense, and should experience more resistance to subduction into the lower mantle

Testing our hypothesis

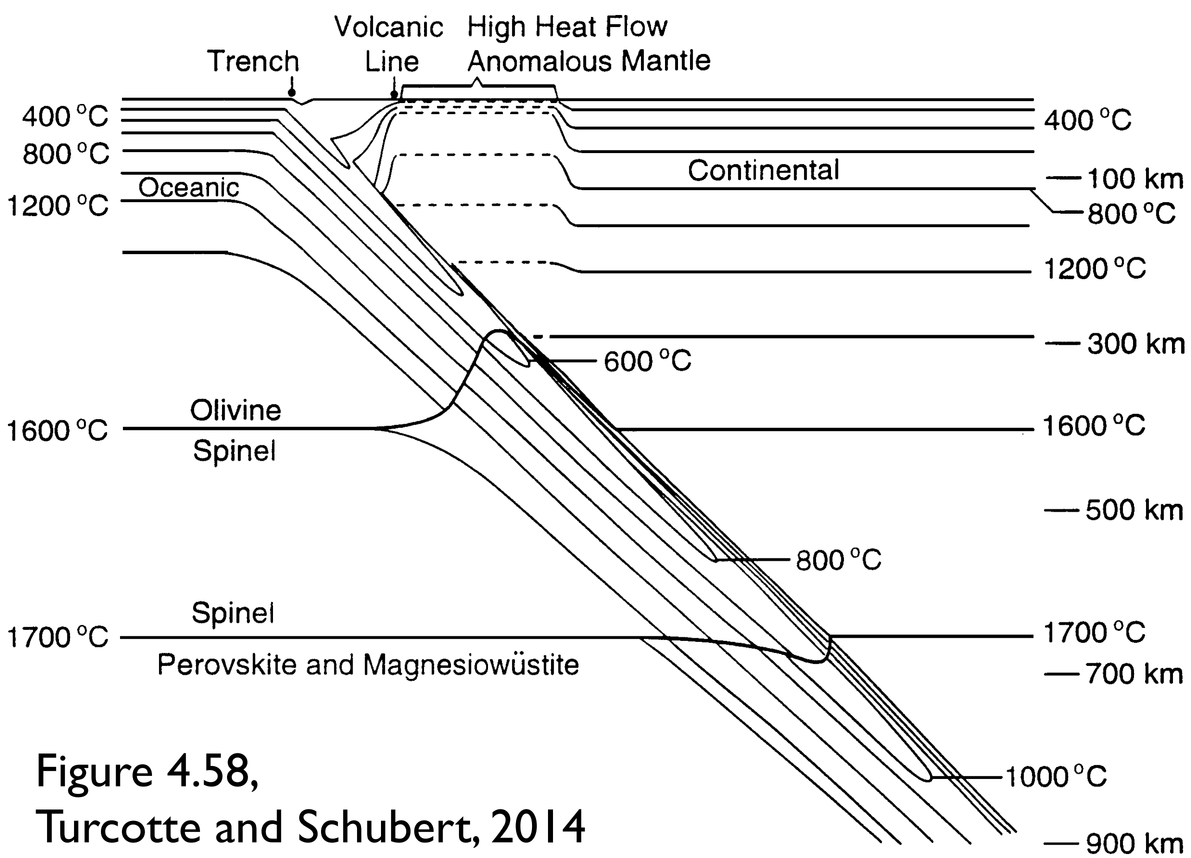


Figure 4.58,
Turcotte and Schubert, 2014

- How can we test our hypothesis?

Testing our hypothesis

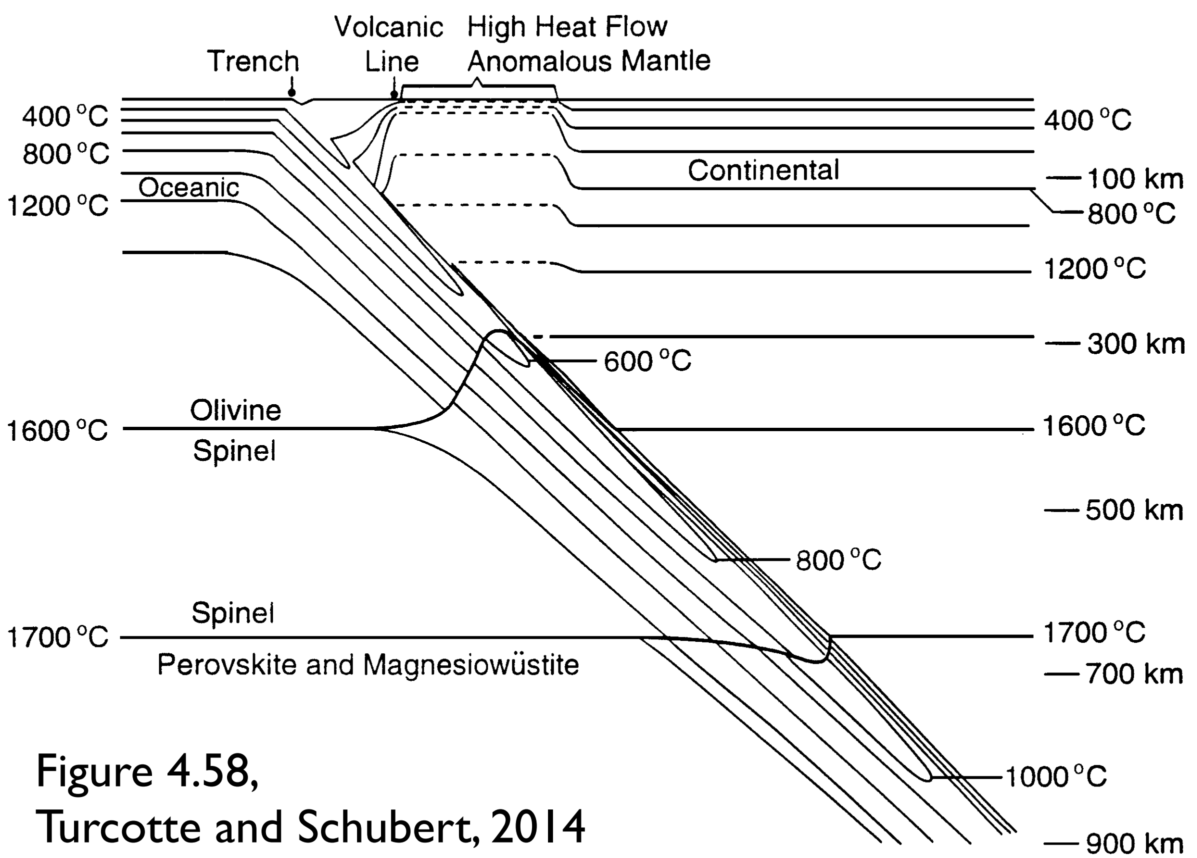
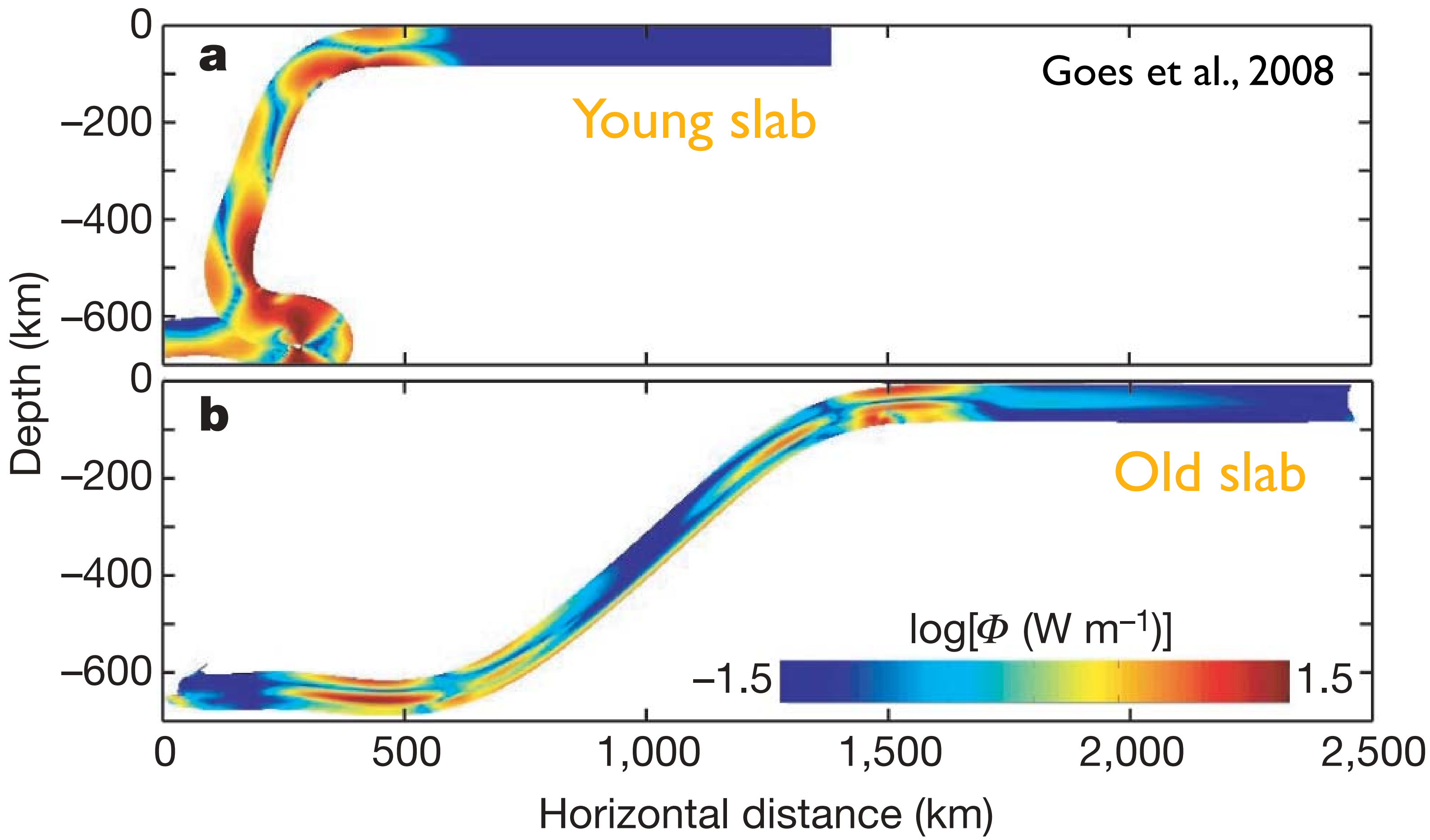


Figure 4.58,
Turcotte and Schubert, 2014

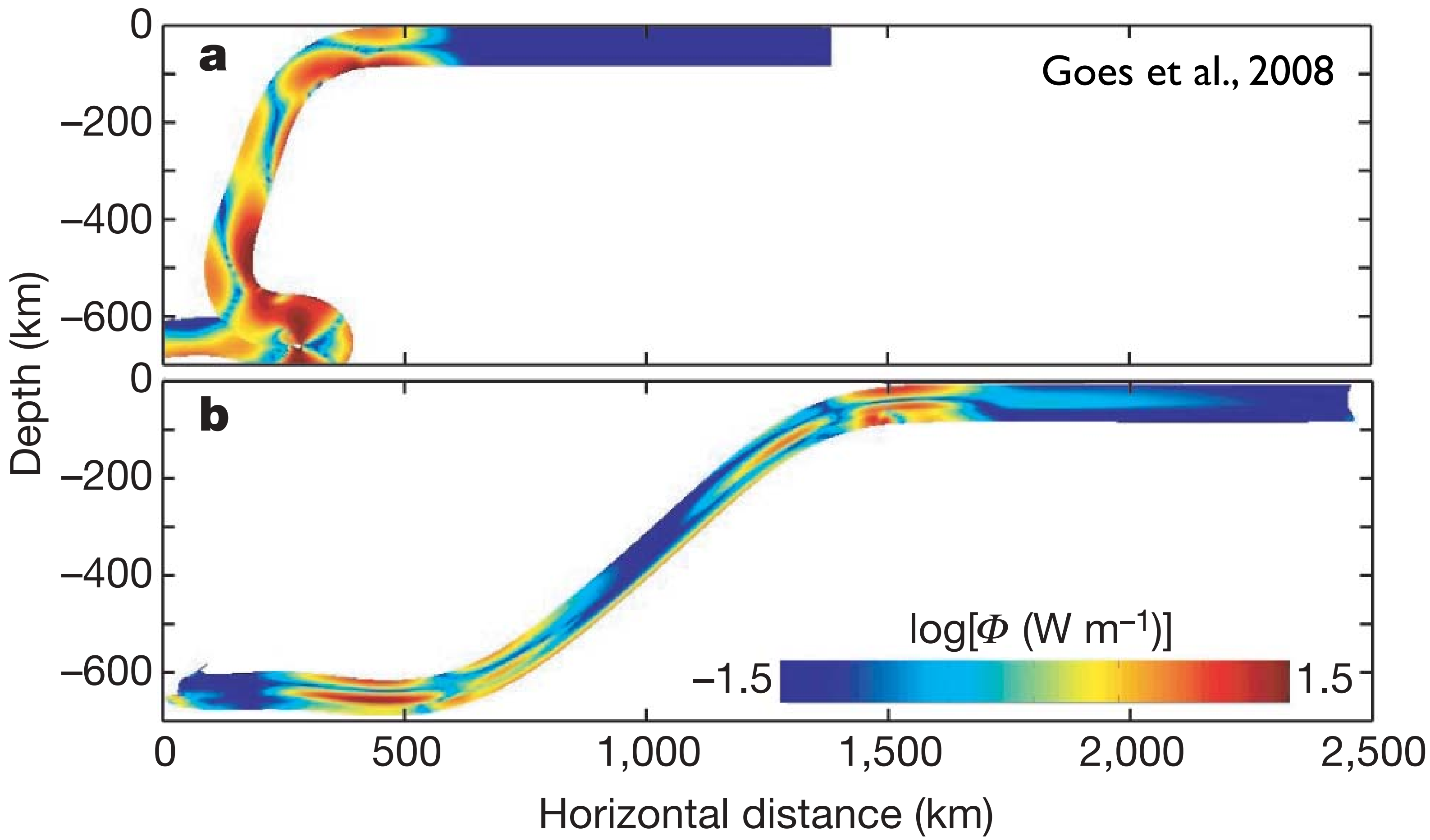
- Go collect necessary data
  - <u>Expensive, time-consuming and possibly difficult to interpret</u>
- **Test the idea quantitatively using a numerical model**

Results



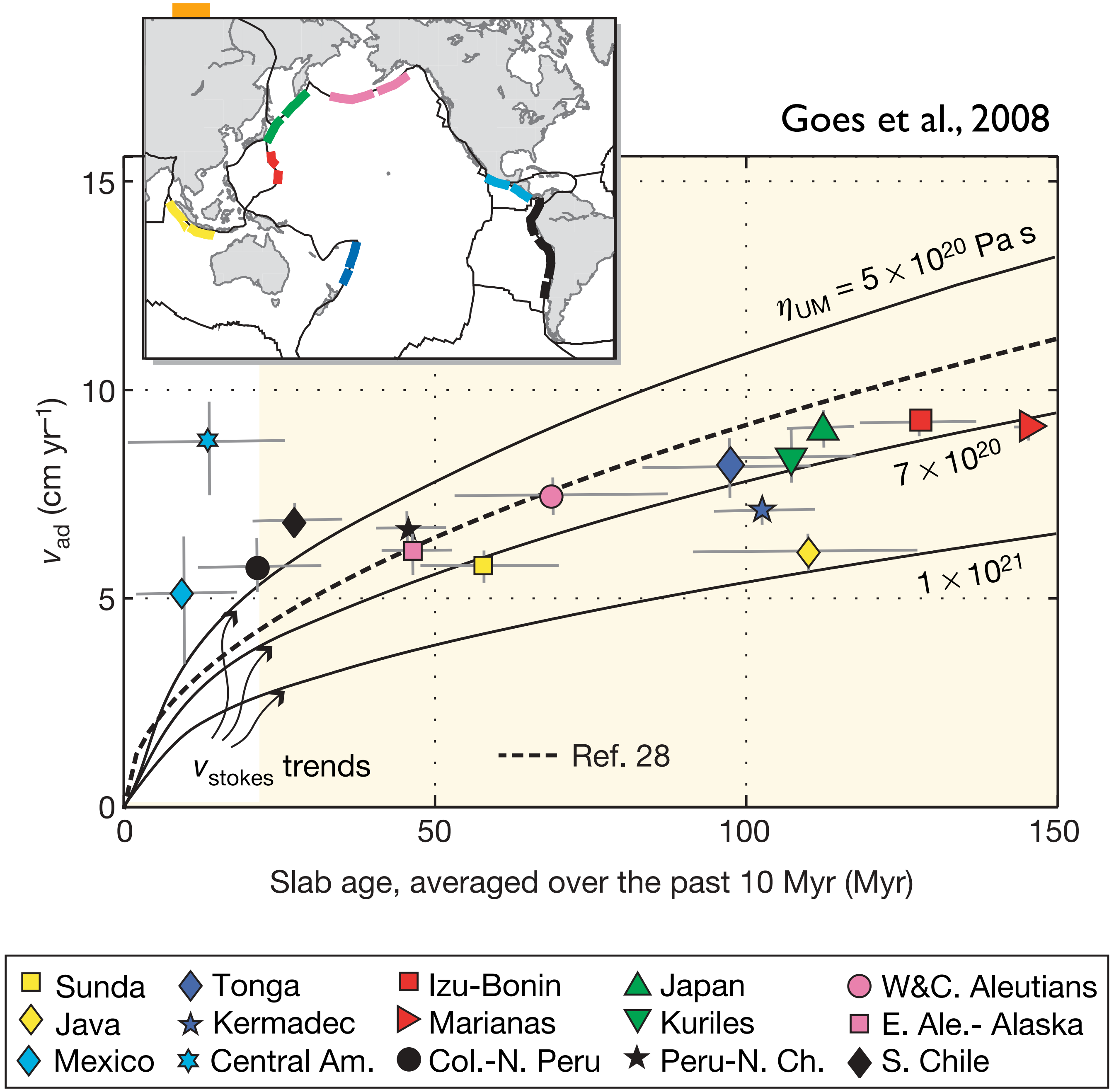
- Numerical model predictions suggest the opposite of our hypothesis: **Younger plates may subduct more easily (!)**
- Why?
  - Younger plates deform more easily and thicken, which enhances negative buoyancy in the slab, making subduction easier
  - Older slabs, in contrast, tend to experience slab rollback and "lie down" on the 660-km discontinuity

What did we learn?



- Earth isn't always intuitive
- Good conceptual ideas need to be tested in a rigorous, quantitative way

What else should we consider?



- It is critical to compare model results to observables (data) in order for the models to have any value

Goals of this course

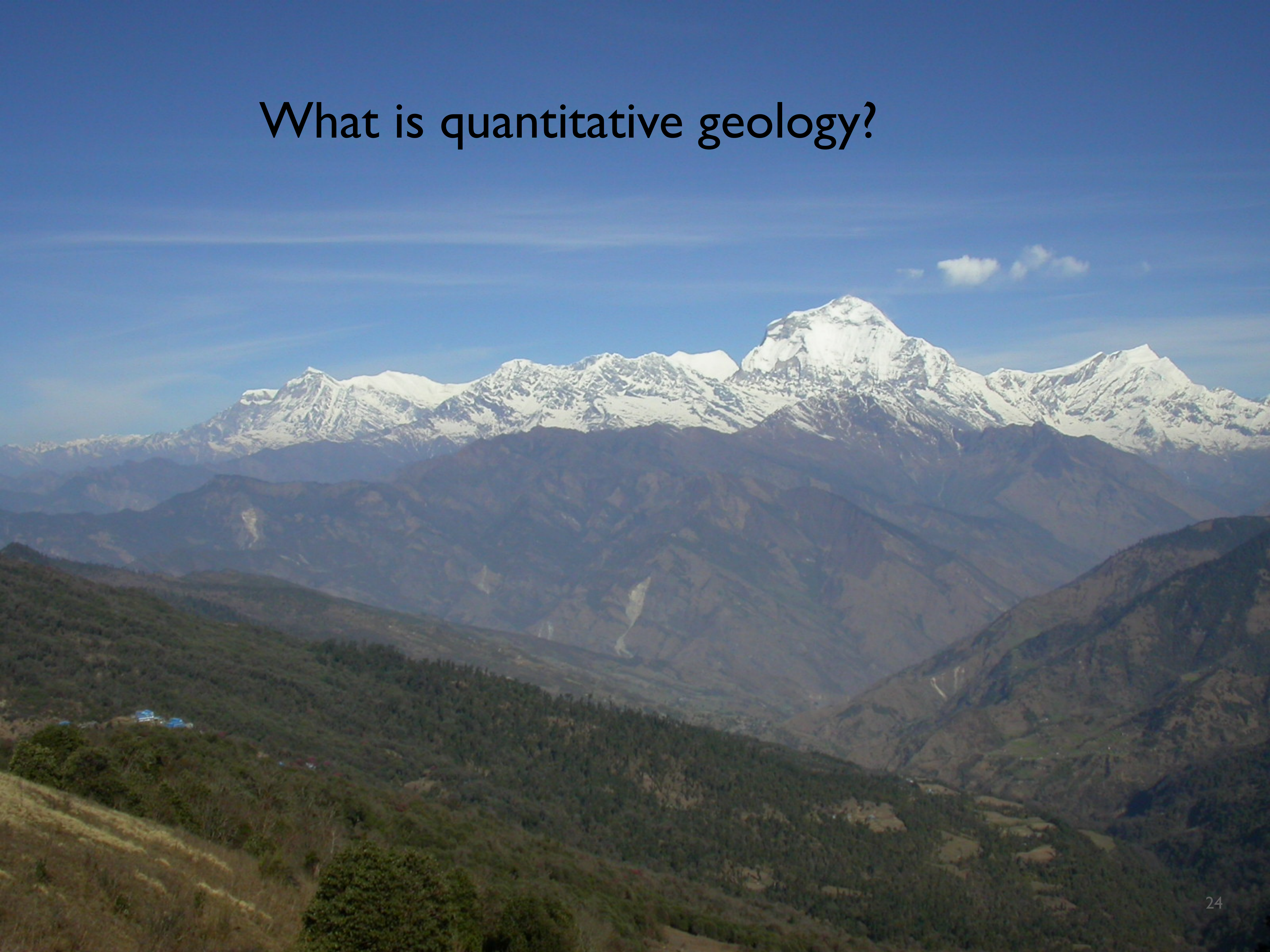
There are basically three goals in this course

1. Learn how to use several **common equations** that apply to a variety of Earth science fields

2. Introduce the Python programming language and the **essential (good) programming practices** needed by young scientists

3. Discuss how to **compare model predictions to data**, and when (and why) results are or are not meaningful

What is quantitative geology?



What is **qualitative** geology?

- **Qualitative geology** focuses mainly on description
- While useful, this analysis is limiting and it is difficult to determine the influence of different processes on the observed geologic features

What is **quantitative** geology?

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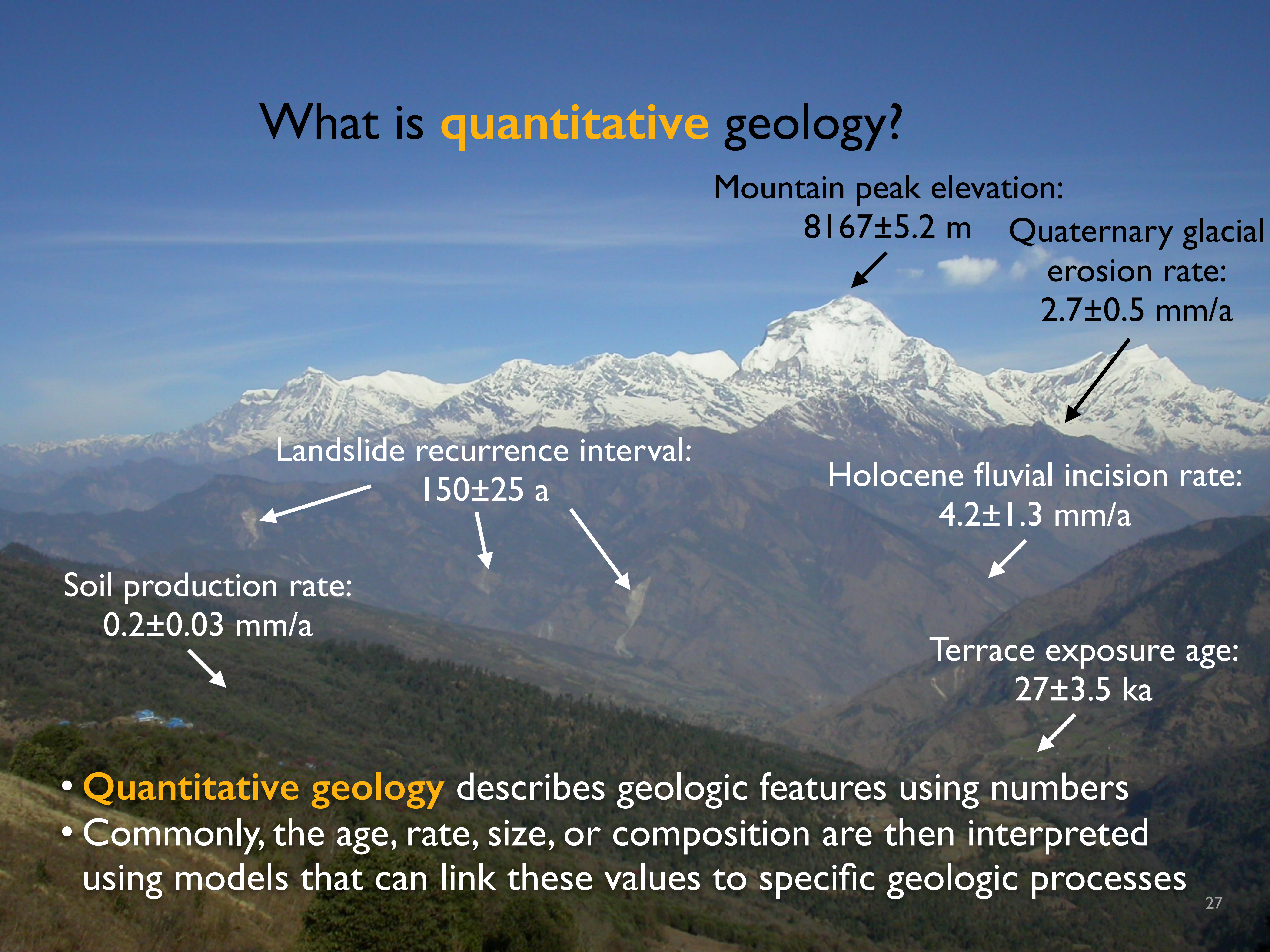


- **Quantitative geology** describes geologic features using numbers
- Commonly, the age, rate, size, or composition are then interpreted using models that can link these values to specific geologic processes

What skills should a quantitative geologist have?

Think back to the course goals. **What skills do you need to reach those goals?**

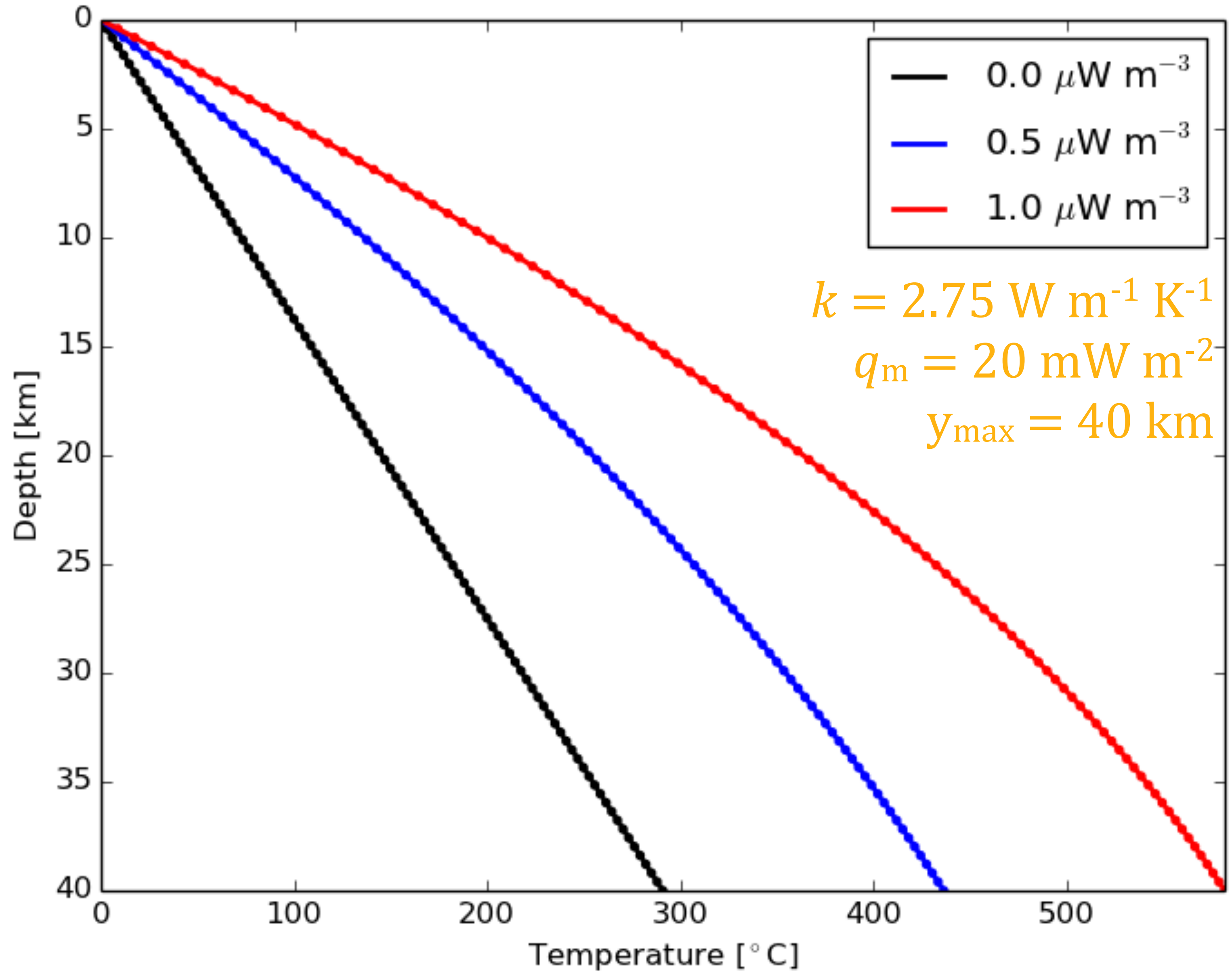
What skills should a quantitative geologist have?

Head conduction in 1D

$$k\frac{d^2T}{dy^2} + \rho H = 0$$

Solution to heat conduction equation

$$T = T_0 + \frac{q_0}{k}y - \frac{\rho H}{2k}y^2$$



1. Basic mathematical skills

- Understanding equations, solving equations, plotting equations

What skills should a quantitative geologist have?

```
# Define plot variables
misfit = NA_data[:,0]
var1 = NA_data[:,1]
var2 = NA_data[:,2]
var3 = NA_data[:,3]
clrmin=roung(min(misfit),3)
clrmax=round(mbn(misfit),2)
trans=0.75
ptsize=40
```

Python source code

2. Basic programming skills

- Knowledge of the Python language (syntax), understanding of the basic concepts of programming, practice writing code

What skills should a quantitative geologist have?

Version 1

```
# Define plot variables
misfit = NA_data[:,0]
var1 = NA_data[:,1]
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clrmin=roung(min(misfit),3)
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```

Python source code

Version 2 - "Fixed typos"

```
# Define plot variables
misfit = NA_data[:,0]
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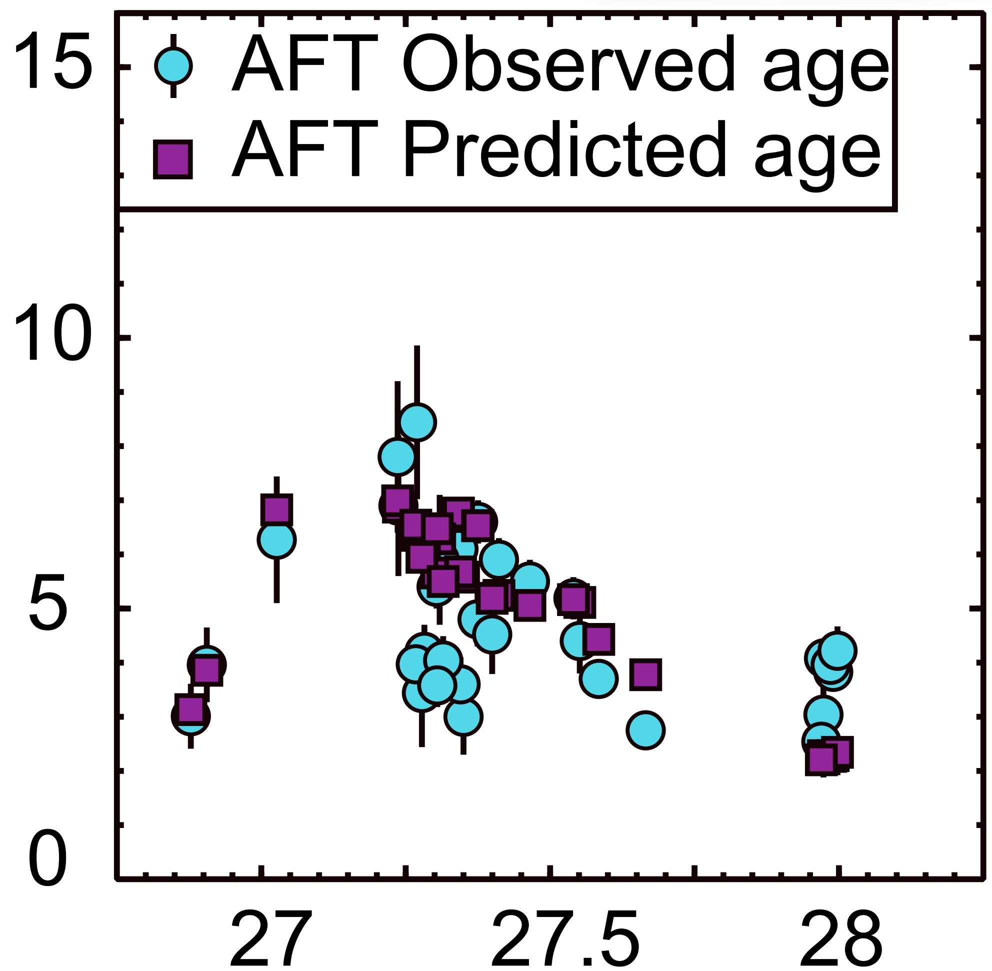
What skills should a quantitative geologist have?

Coutand et al., 2014



Are the predicted ages a "good fit" to the observed?

3. **Data interpretation skills**

- Understanding how to manipulate and plot data, ideas of how to compare models to data, understanding uncertainty

What skills should a quantitative geologist have?

- This course will provide these skills, and also introduce you to important "best practices" for young scientists, including
  - **Processing data** files with Python
  - Making your results **reproducible** using software version control
  - Writing code that is **easy to read/understand**
  - Making computers **repeat tasks**
  - Understanding some of the benefits of "**open science**"

What is a model?

- A tool we use to describe the world around us in a simplified way so that we can understand it better (Stüwe, 2007)
- A working hypothesis or precise simulation, by means of description, statistical data, or analogy, of a phenomenon or process that cannot be observed directly or that is difficult to observe directly (AGI Dictionary of Geological Terms, 1984)

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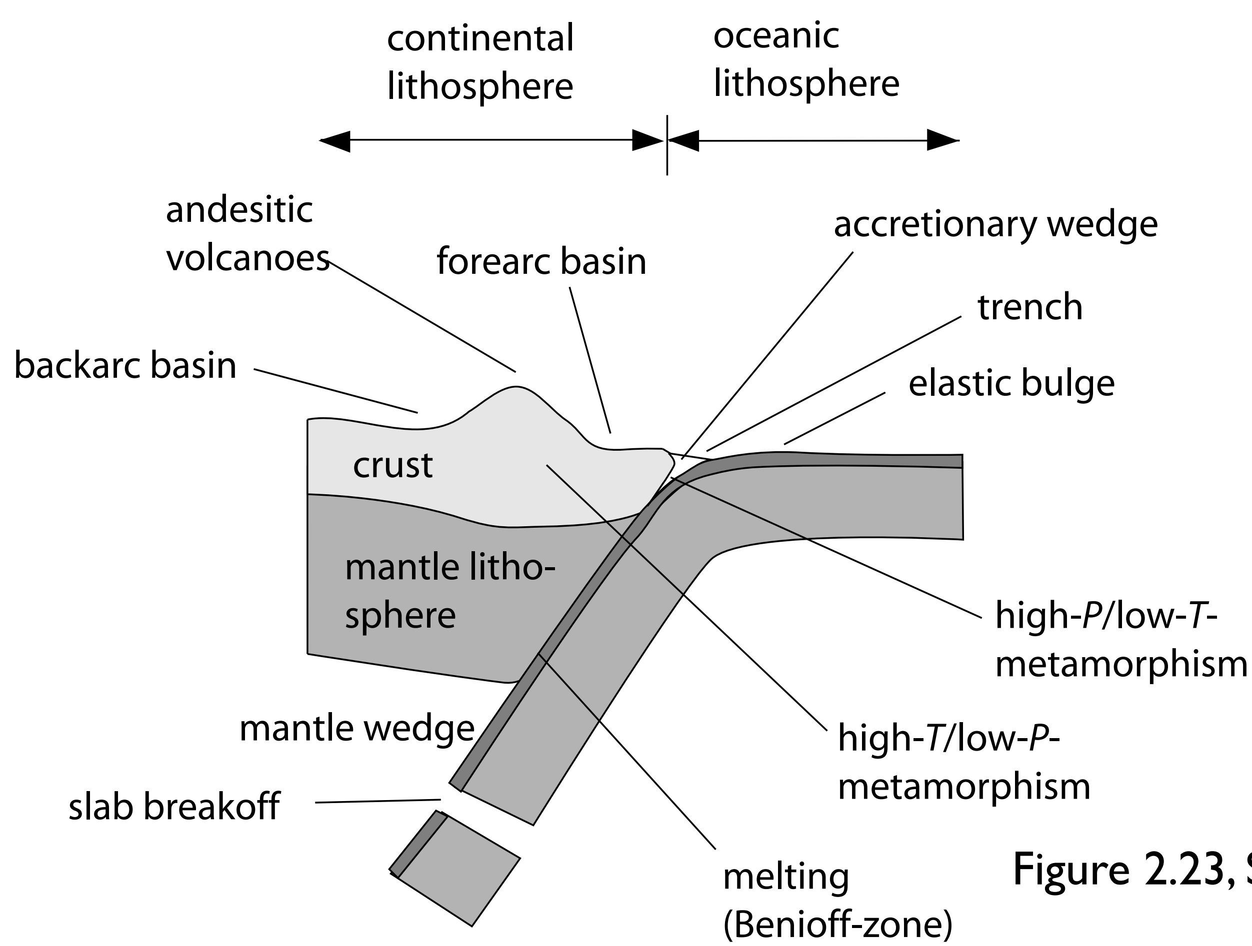

Figure 2.23, Stüwe, 2007

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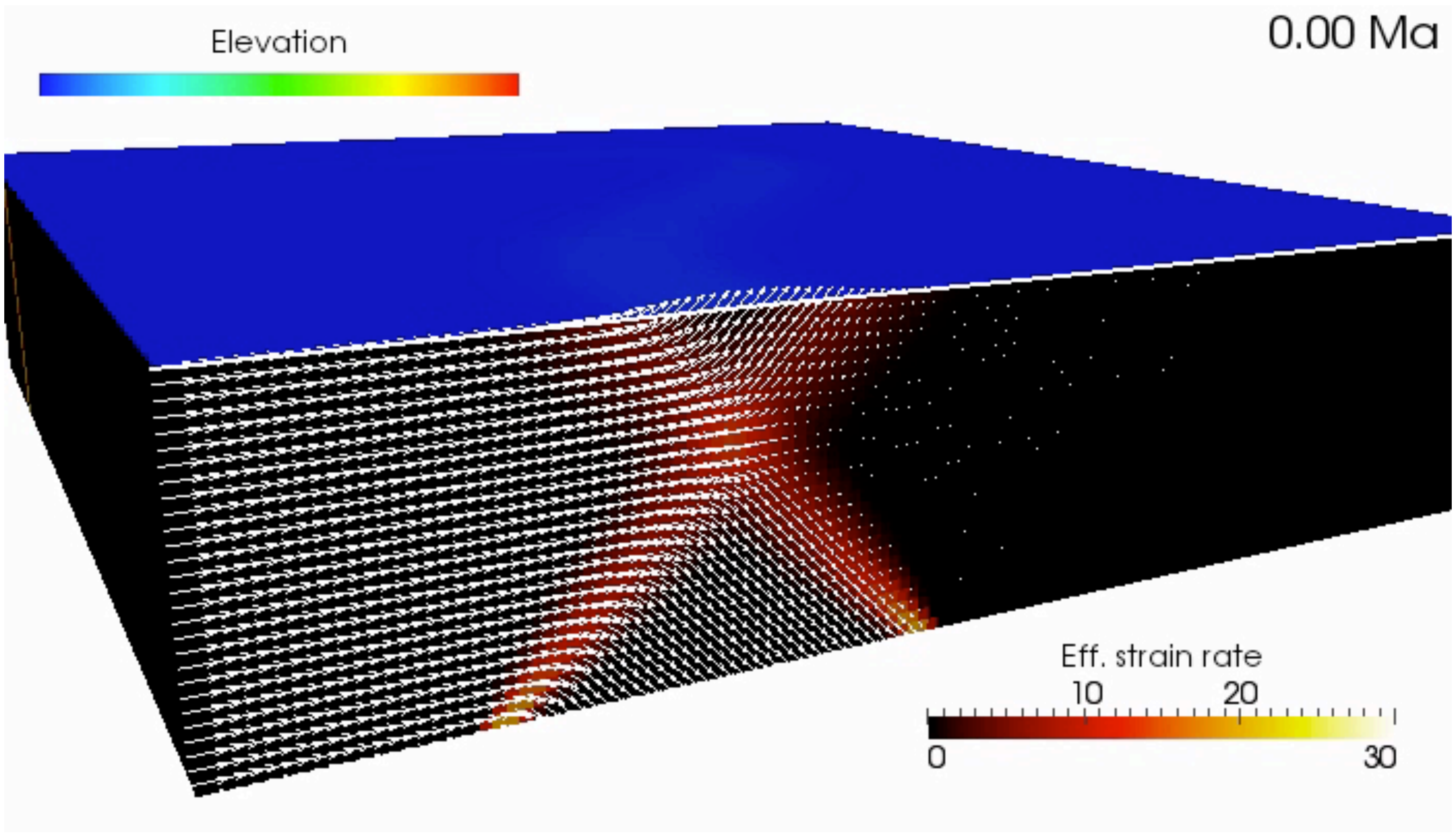

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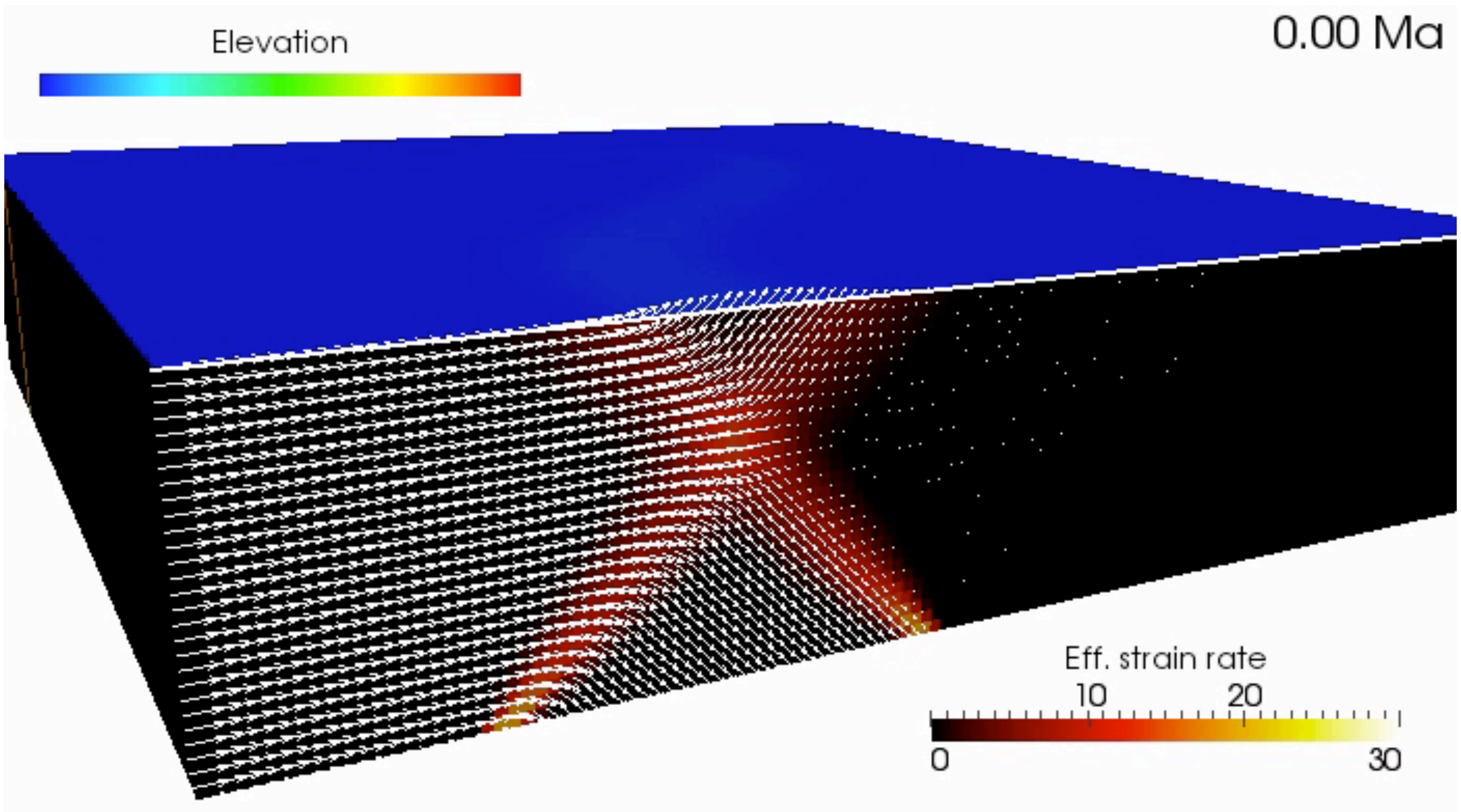
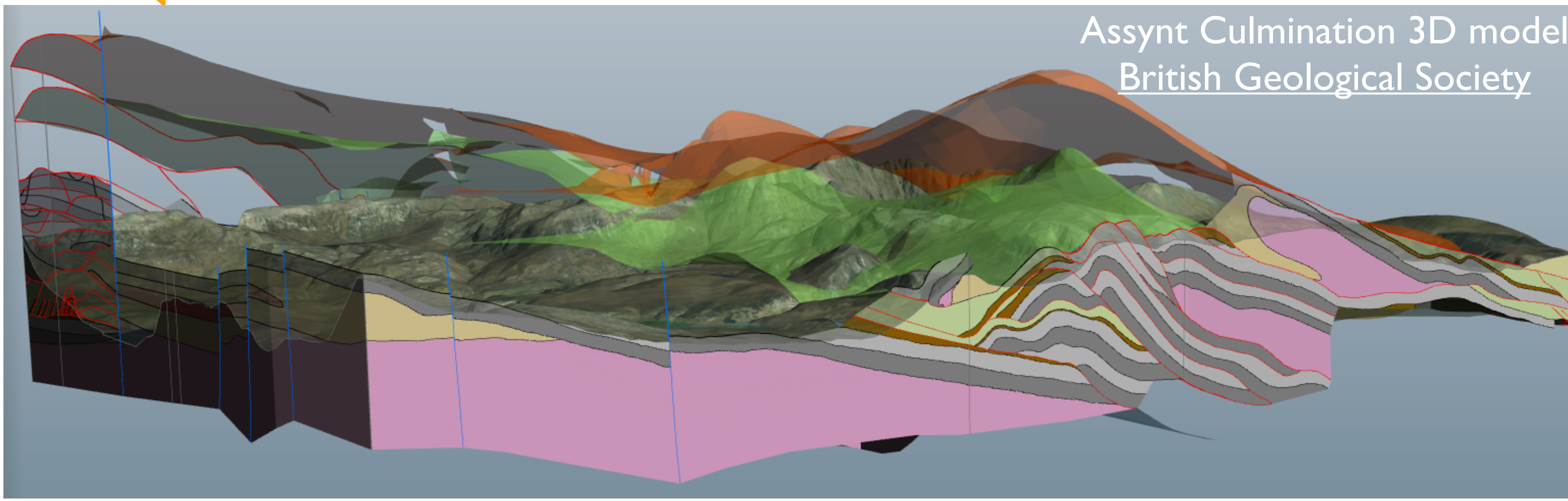


What is a good model?

What is a good model?

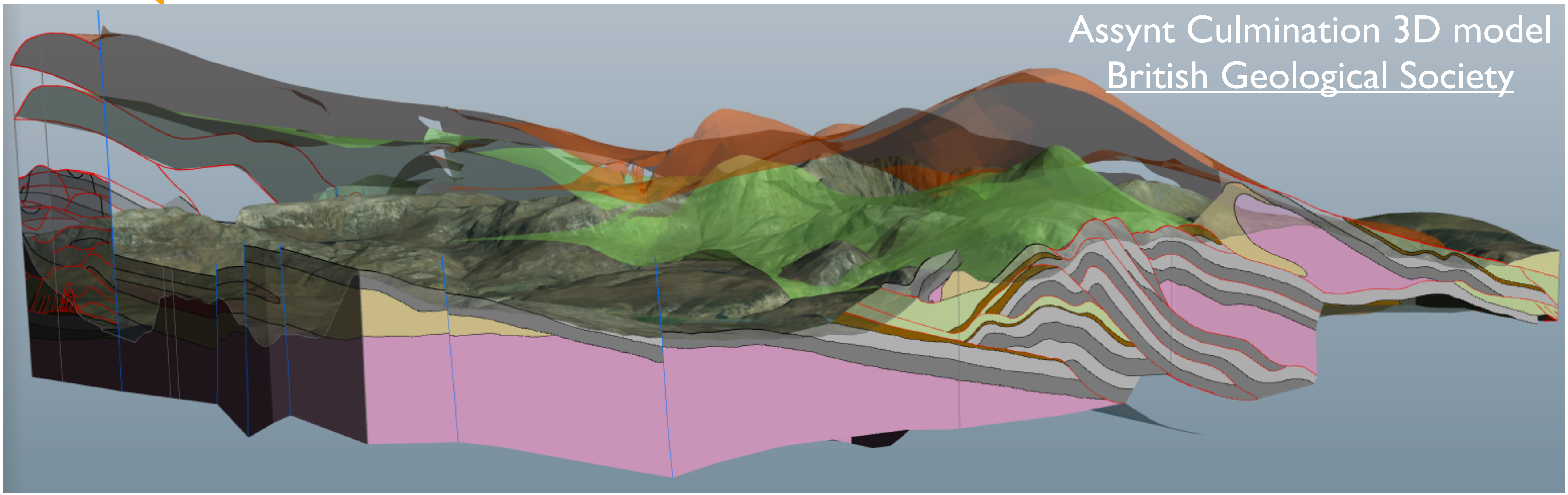
- According to Stüwe, 2007, a good model is a description of nature that should…
  - Describe a large set of observations with a relatively small set of input parameters
  - Be usable as a tool to predict facts that have not yet been observed
  - Testable using future experiments or observations

Types of geological models



- **(2D) Geological maps** are essentially a collection of field observations simplified and interpreted to illustrate field observations (a model!)
  - The geologist must decide: What should be mapped? Which observations should be reported? What is visible at the scale of the map?
- **3D models** incorporate subsurface data to link surface and subsurface features into a common 3D geological framework

Types of geological models



- (2D) Geological maps are essentially a collection of field observations simplified and interpreted to illustrate field observations (a model!); Can be qualitative or quantitative
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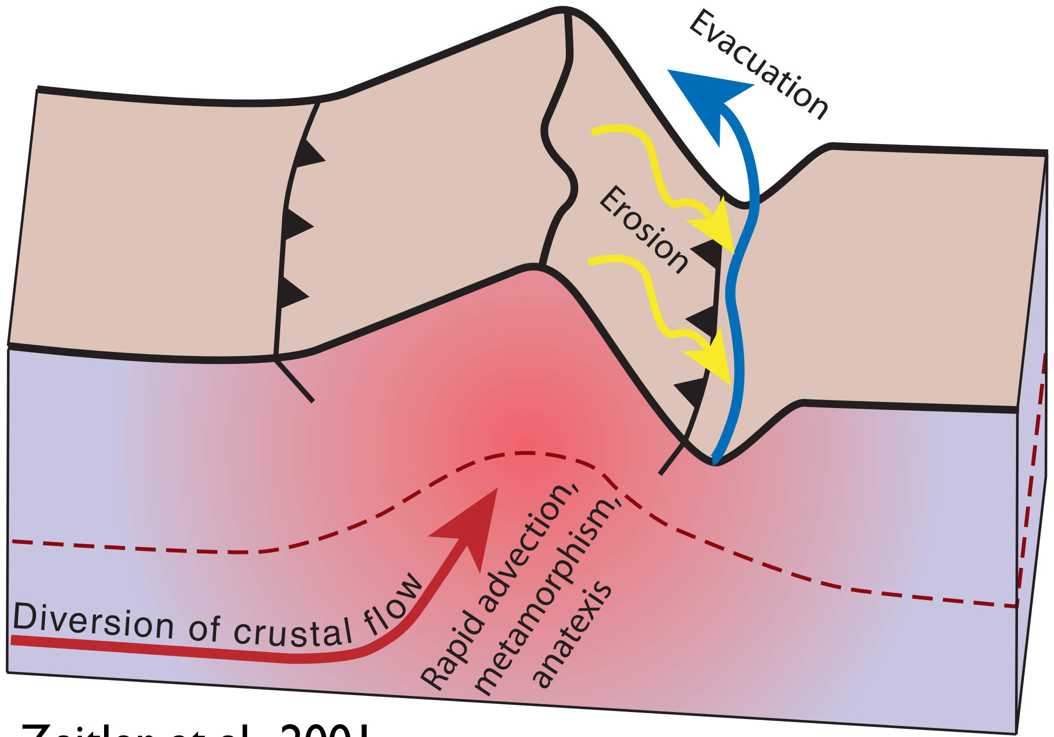
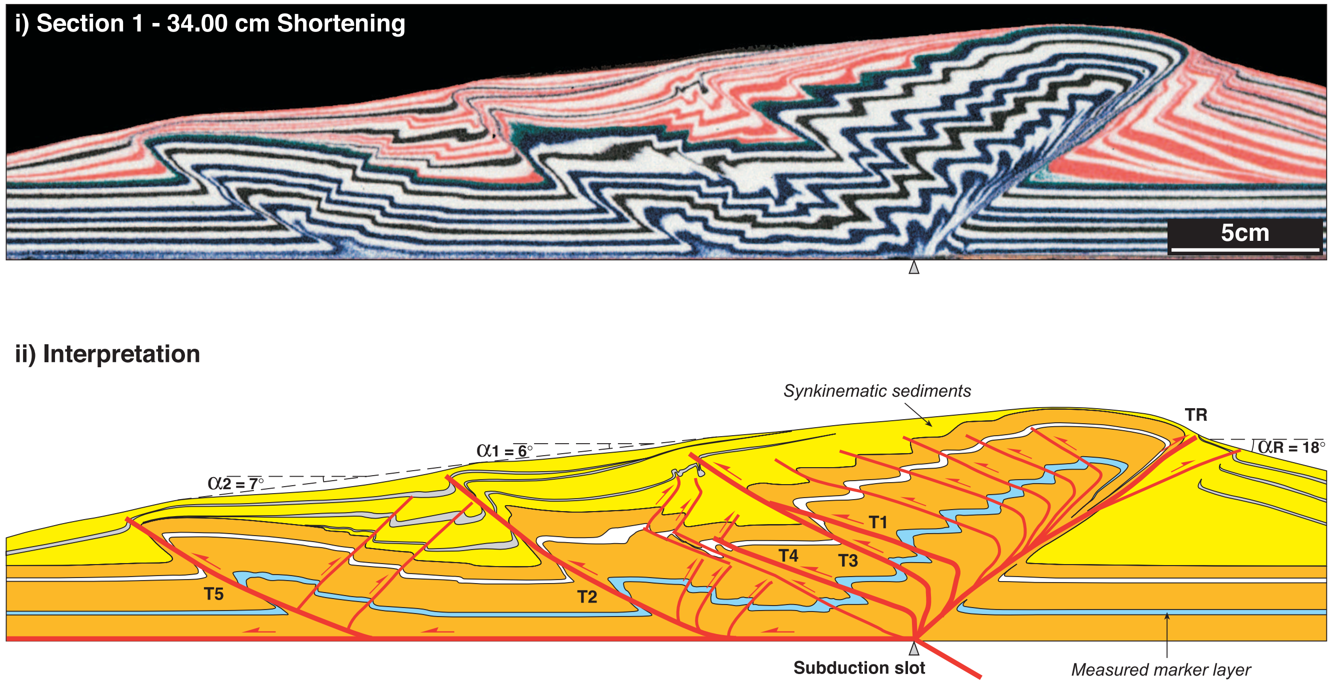


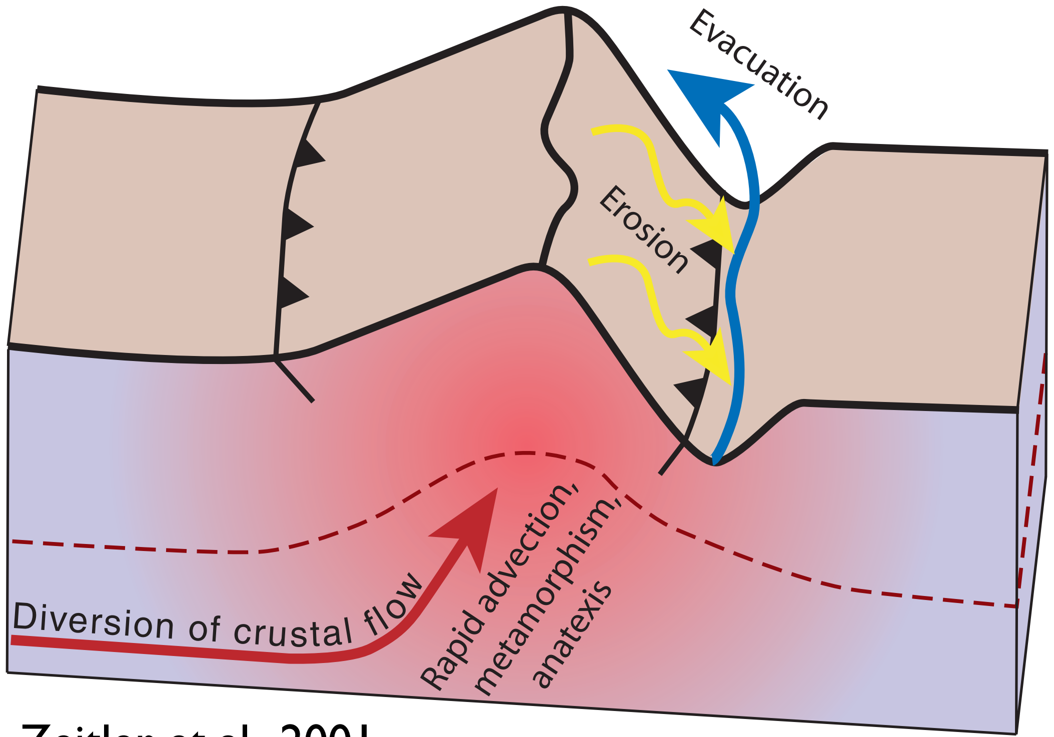
Zeitler et al., 2001



McClay and Whitehouse, 2004

- **Schematic diagrams (cartoons)**:Visual representations of geologic phenomena
- **Analog models (sandbox models)**: Controlled physical simulation of a geological system
- **Numerical models**: Computer-based simulation of a geological system

Types of geological models



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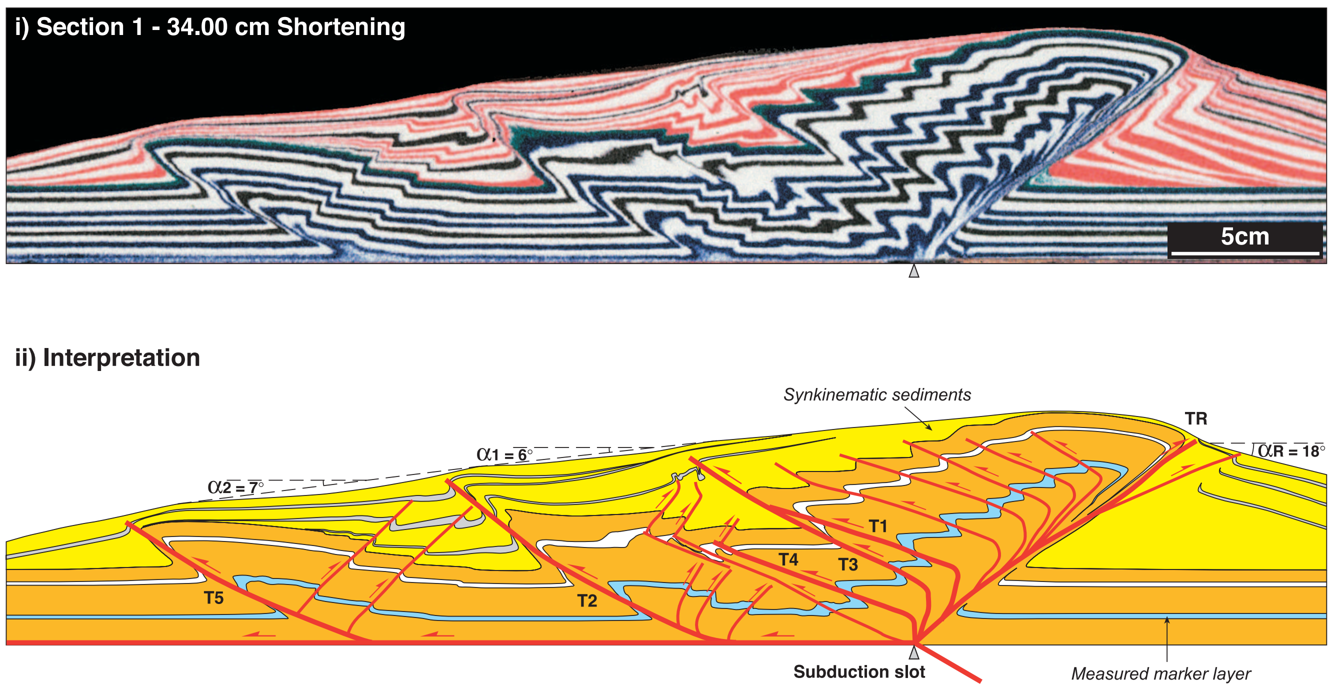

McClay and Whitehouse, 2004

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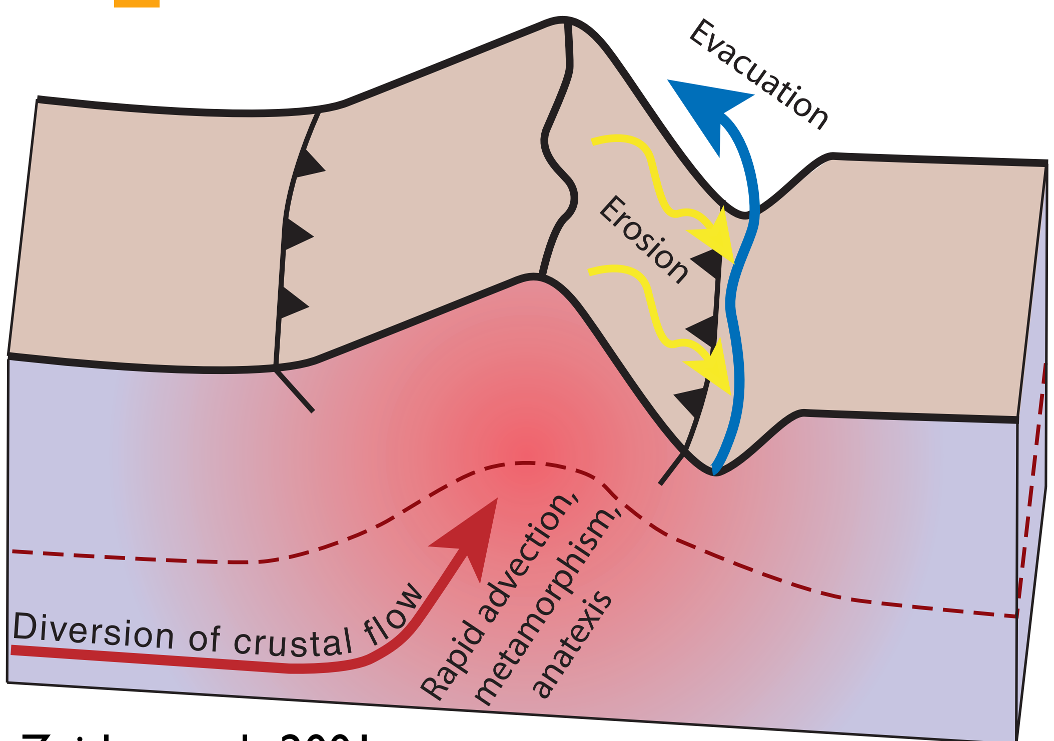
- **Numerical models**: Computer-based simulation of a geological system; Quantitative

Types of geological models



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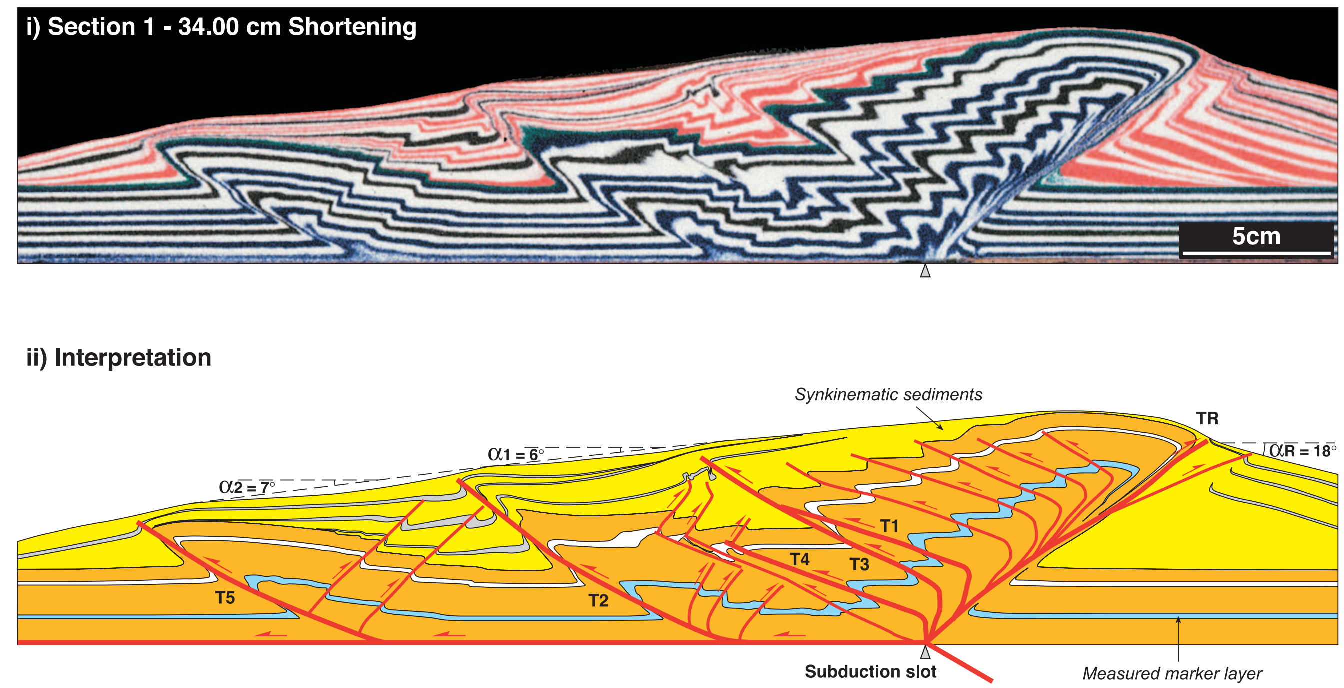

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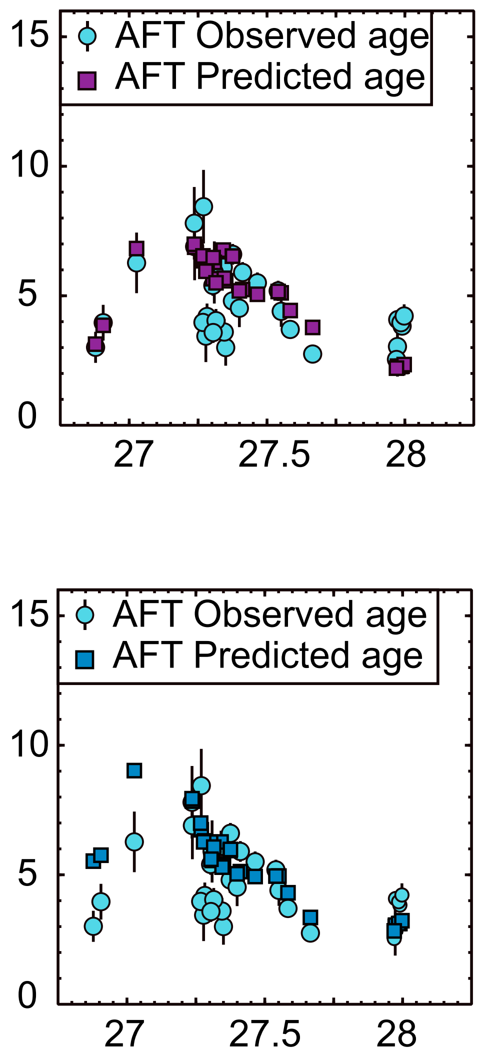
Advantages of numerical modelling



Coutand et al., 2014

- <u>Math and basic physics can be used</u> to test proposed conceptual models
- Numerical experiments can <u>directly simulate geologic time, rates of geological processes and geological material properties</u> without a need for scaling, as is common in analogue modelling
- Model results can be <u>quantitatively related to geologic field observations, laboratory data or geophysical datasets</u>

Disadvantages of numerical modelling?

Some words of caution

- Although they may be powerful and complex, **numerical models aren't magic**
- **GIGO: Garbage in = garbage out**
  - Poor choice of model inputs or model design will produce results that may not be understandable
- Results must be carefully checked to ensure they're geologically reasonable
- Don't forget, our goal is to use a model to make observations easier to understand/interpret
  - We must consider which observations should be reproduced by the model

Is field data good enough?

- No. Not by itself, at least

- Field data is clearly a key component to understanding the Earth, as it is direct evidence of geologic processes
- The trouble is that field data alone seldom provide direct insight into the processes that produced the given mineral assemblage, outcrop or field area
  - Exhaustive dating of bedrock in a field study area could provide exceptional data on age variations within the region, but cannot explain how the ages were generated
  - For that, a model is needed

Recap

- **What is quantitative geology?**
- Skills of a quantitative geologist
- What is a model?

Recap

- What is quantitative geology?
- **Skills of a quantitative geologist**
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Recap

- What is quantitative geology?
- Skills of a quantitative geologist
- **What is a model?**

References

Coutand, I., Whipp, D. M., Grujic, D., Bernet, M., Fellin, M. G., Bookhagen, B., et al. (2014). Geometry and kinematics of the Main Himalayan Thrust and Neogene crustal exhumation in the Bhutanese Himalaya derived from inversion of multithermochronologic data. *Journal of Geophysical Research: Solid Earth*, n/a–n/a. doi:10.1002/2013JB010891

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