Introduction to Quantitative Geology
Lecture 1
What is quantitative geology?

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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

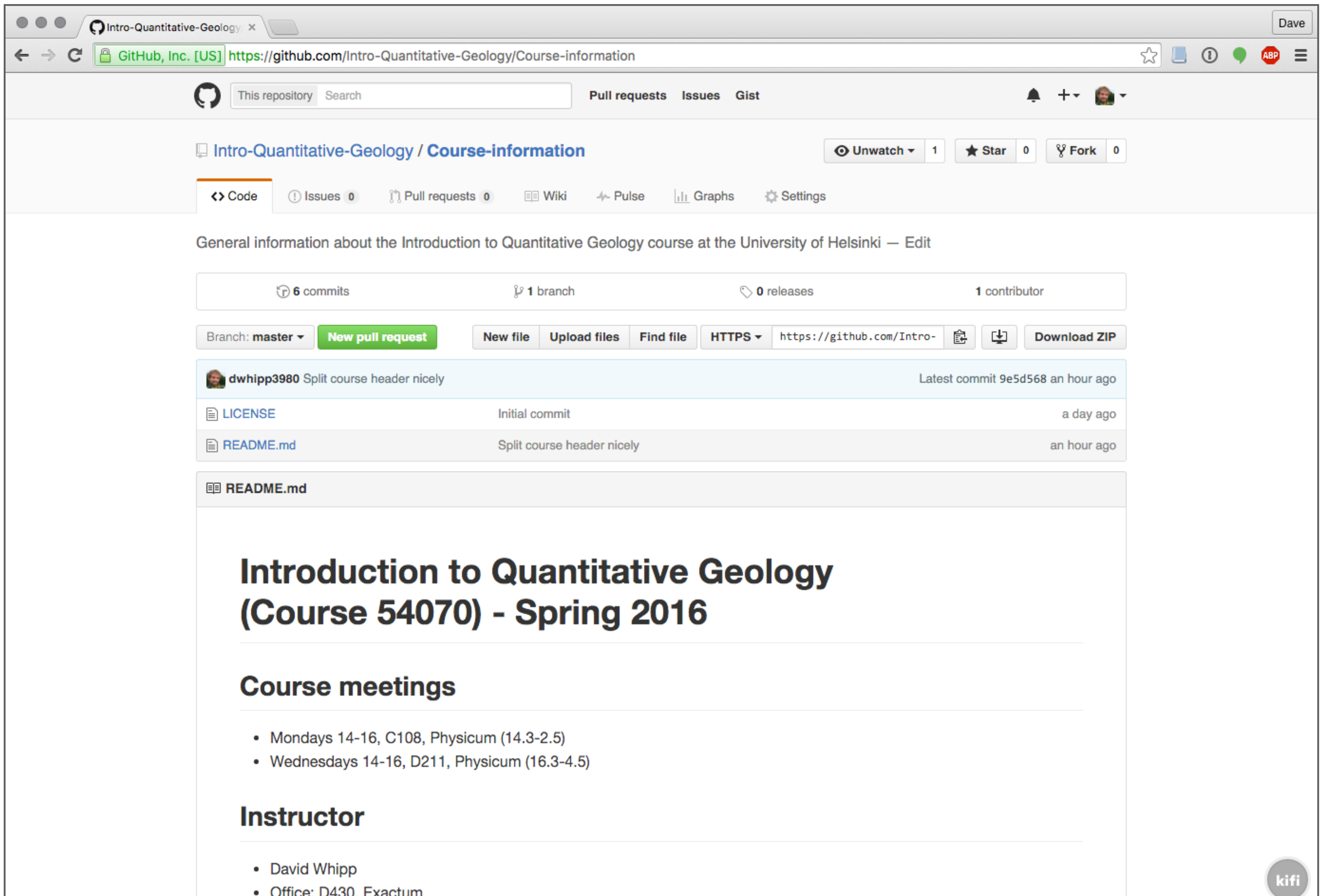
- If you're interested in learning how to program in Python would **recommend** purchasing a copy of the text below:

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

  ~30€ on amazon.de; 50-70€ locally

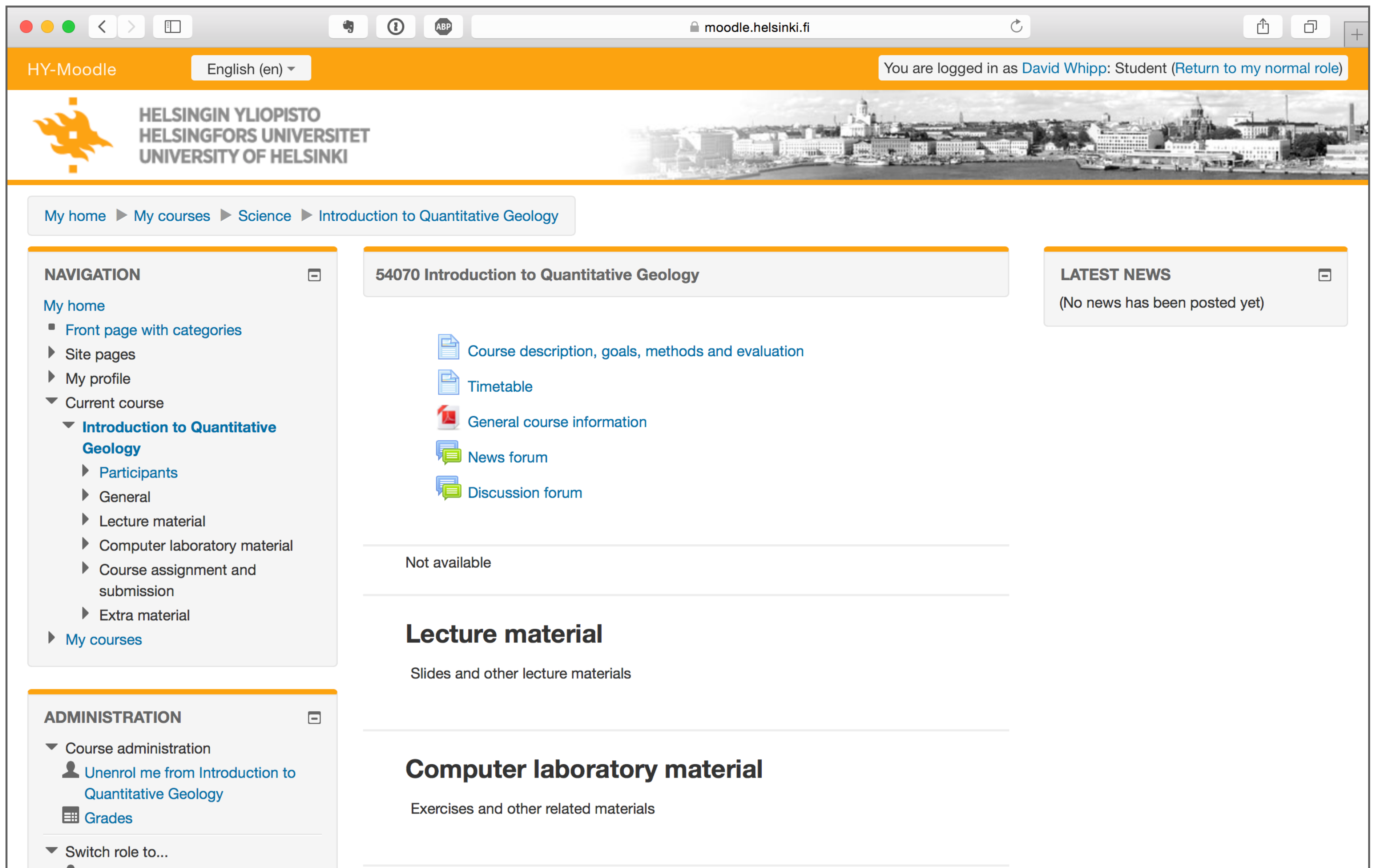
Practical matters - Course GitHub site

- 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



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

A simple example…intuition isn't always right

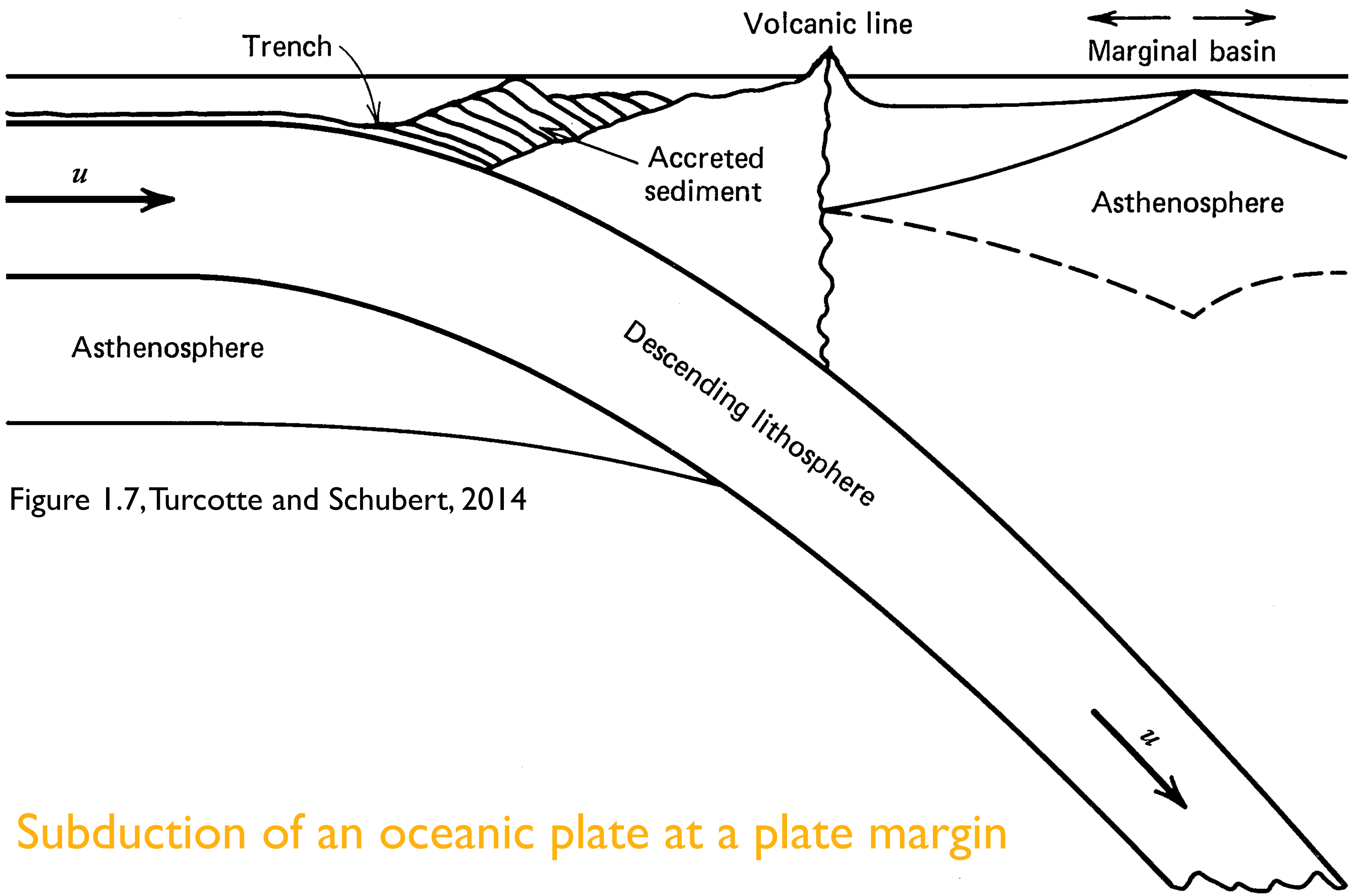
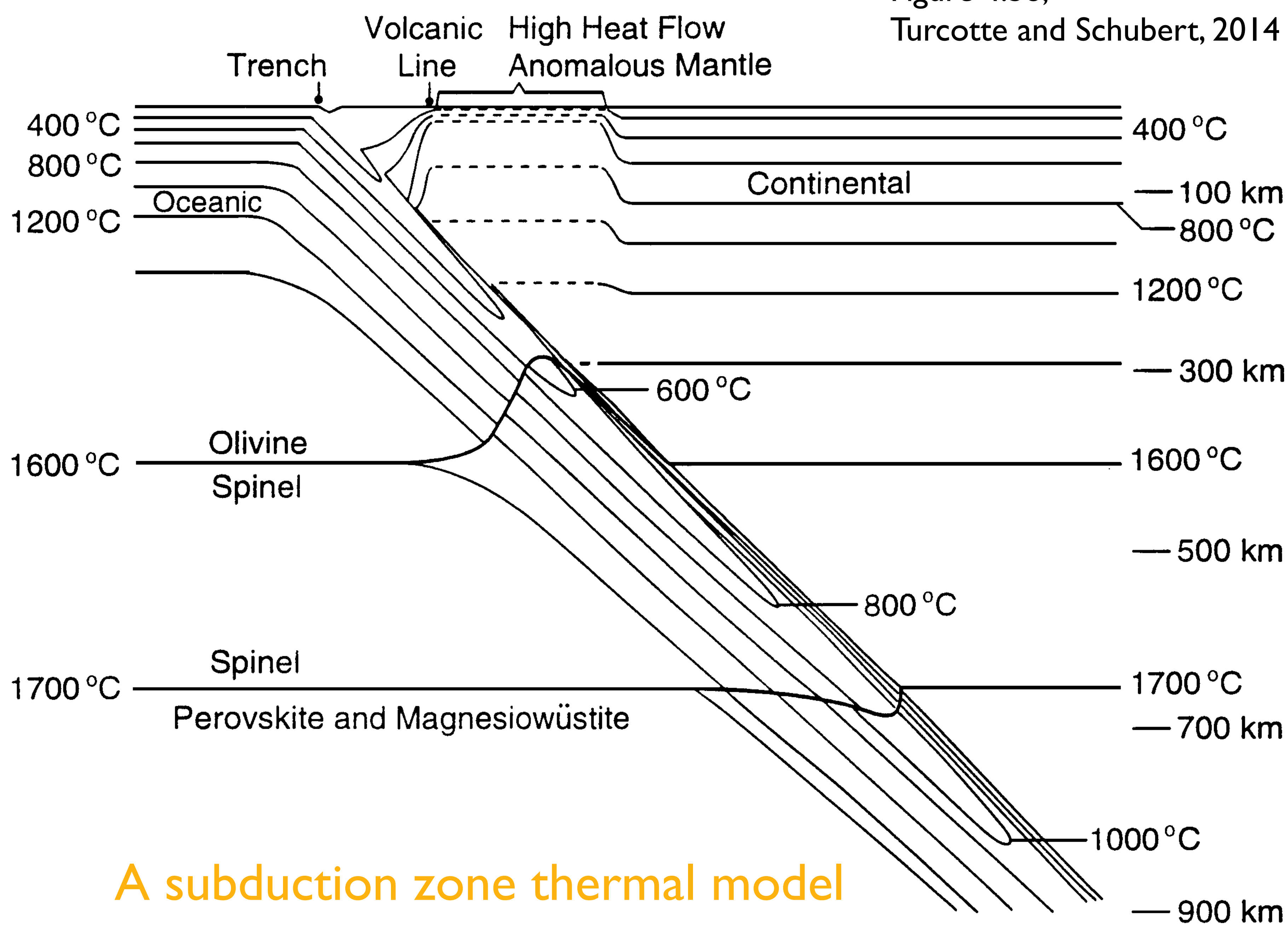


Figure 1.7, Turcotte and Schubert, 2014

Subduction of an oceanic plate at a plate margin

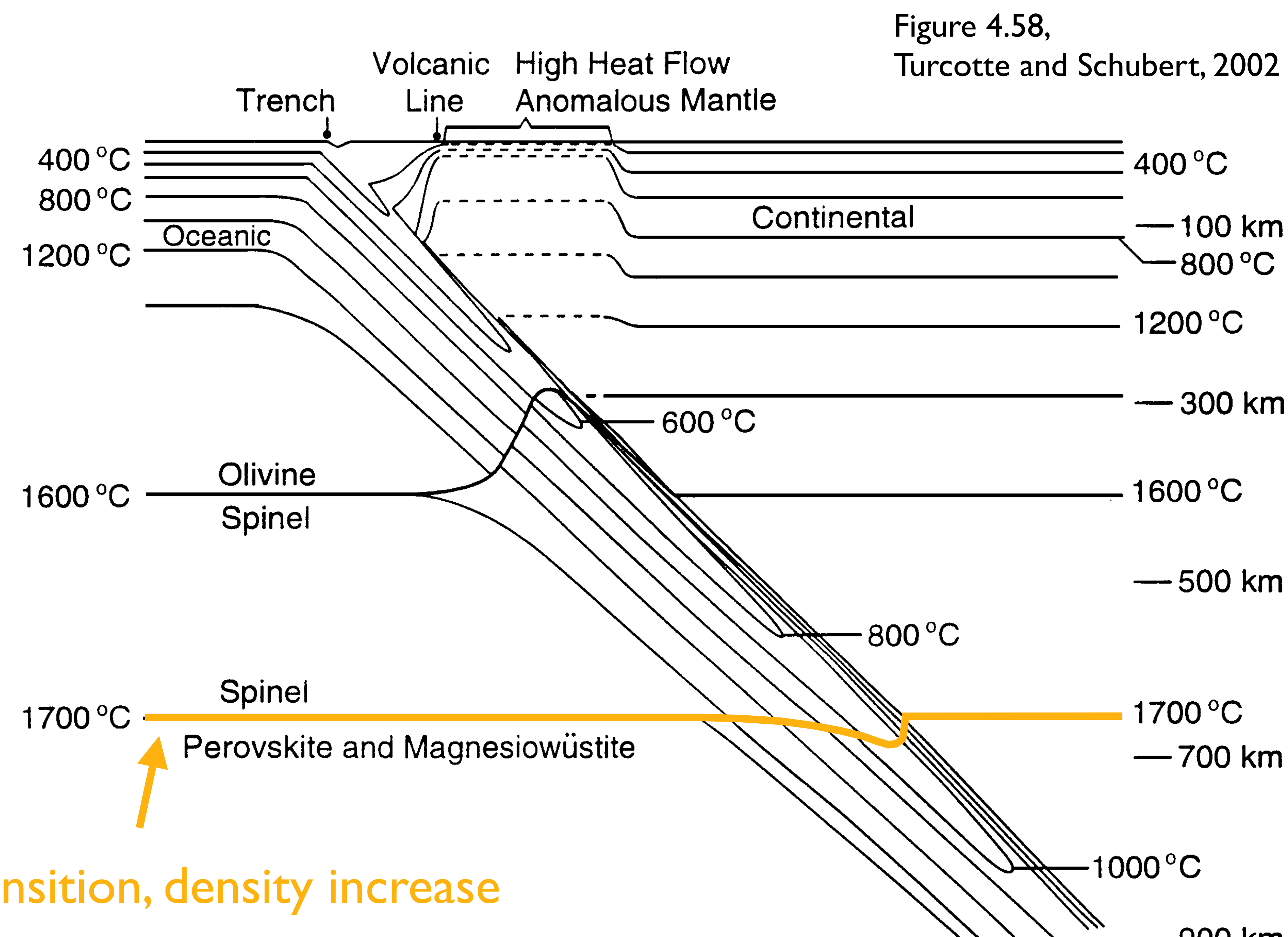
A simple example?

Figure 4.58,
Turcotte and Schubert, 2014



A subduction zone thermal model

A simple example?



Phase transition, density increase

Our general concept

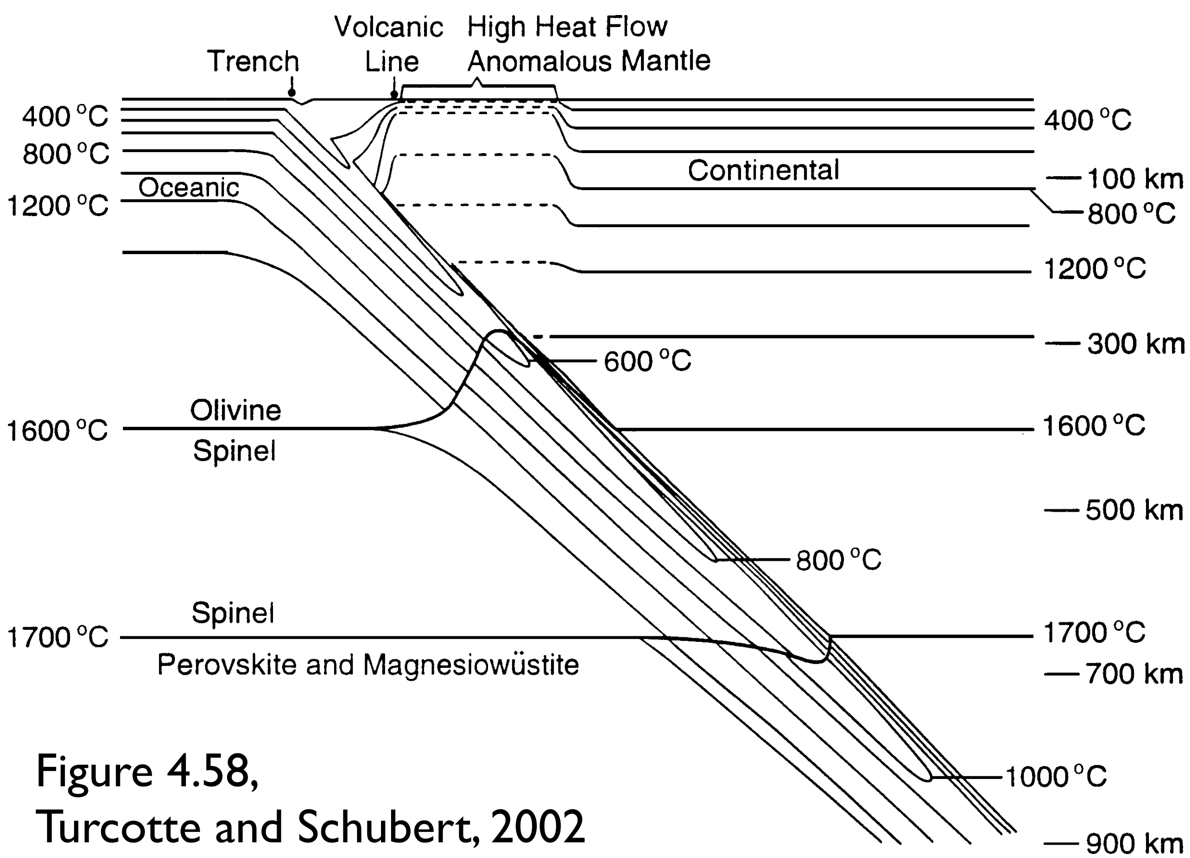


Figure 4.58,
Turcotte and Schubert, 2002

- The phase transition at ~660 km depth significantly increases the density and/or viscosity of the mantle
- This increase would reduce the density contrast between a sinking slab and the surrounding mantle
  - This should make it **difficult for slabs to penetrate the mantle below**

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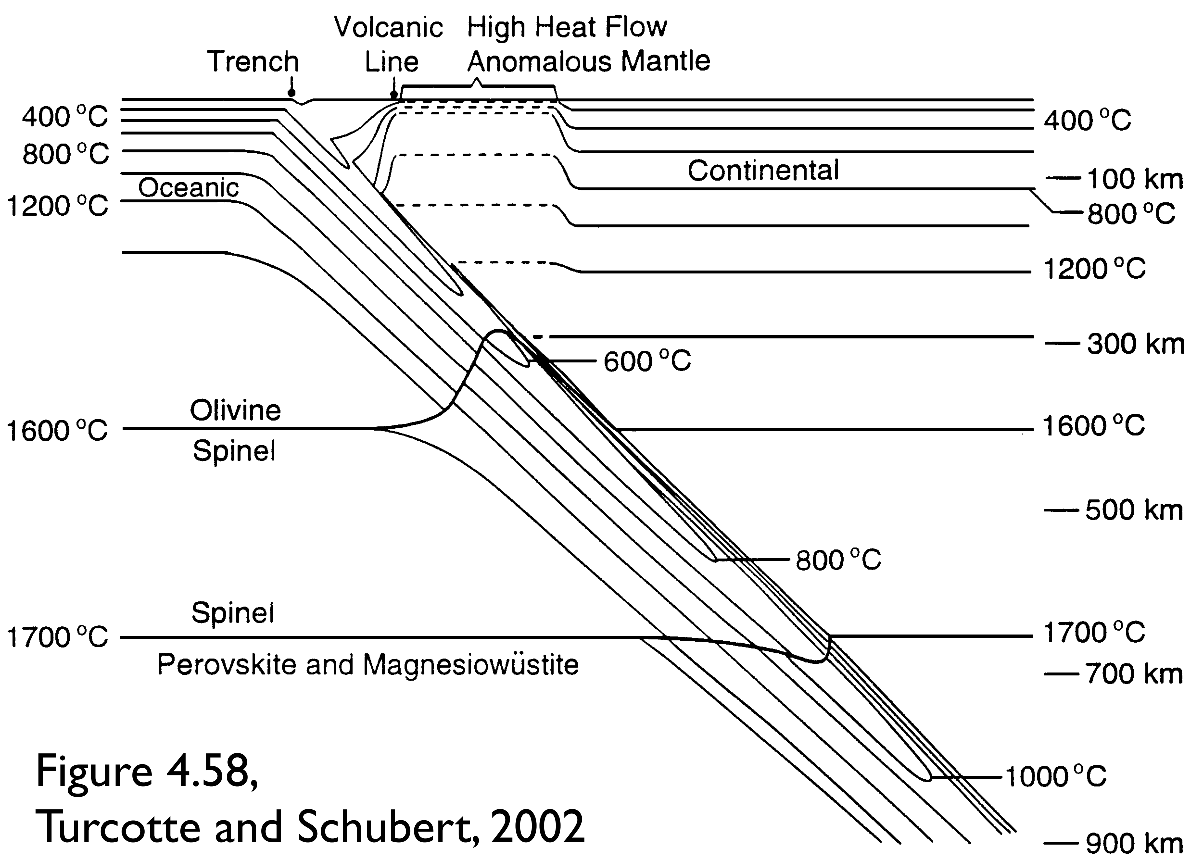

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Does the age of the subducting lithosphere matter? Why?

Our conceptual model hypothesis

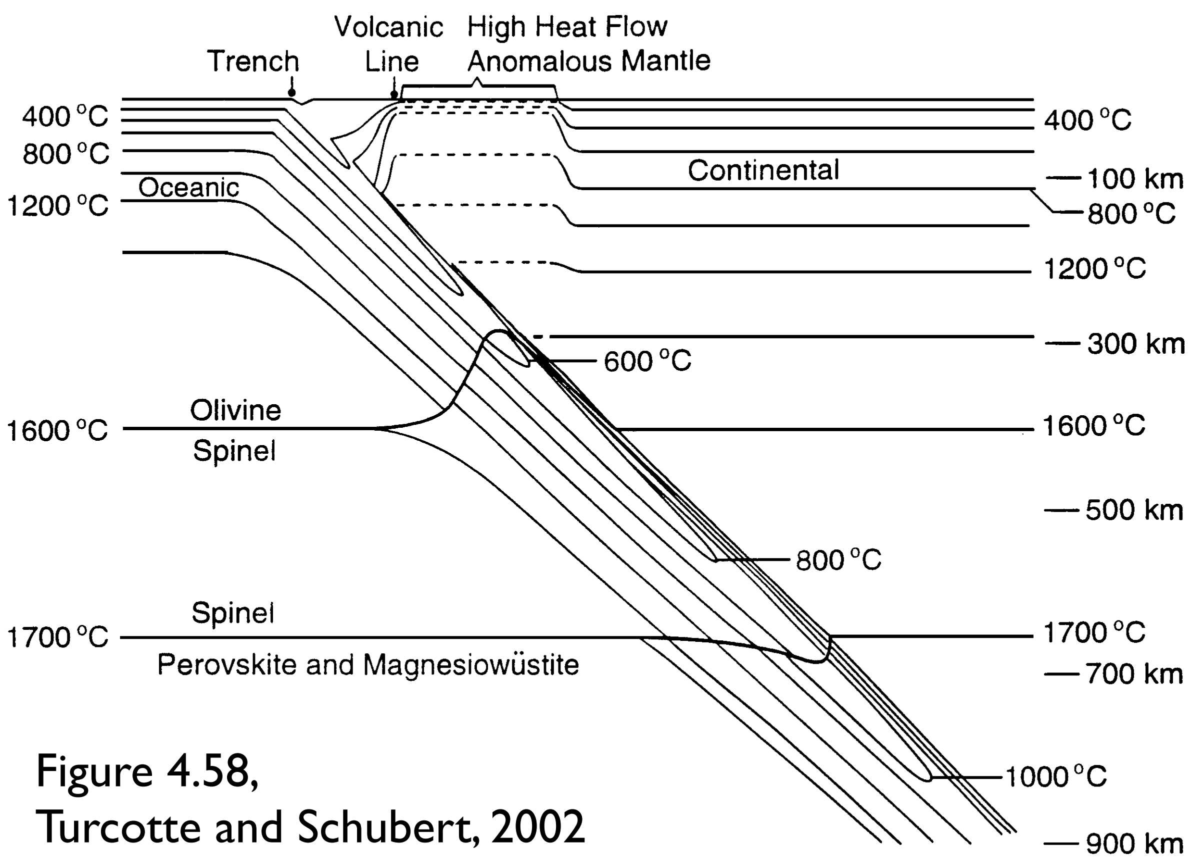

Figure 4.58,
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- Older slabs are <u>colder and more dense</u>, so they should **penetrate the lower mantle more easily**
    - Conversely, younger slabs should be <u>warmer and less dense</u>, and experience more resistance to subduction into the lower mantle

Testing our hypothesis

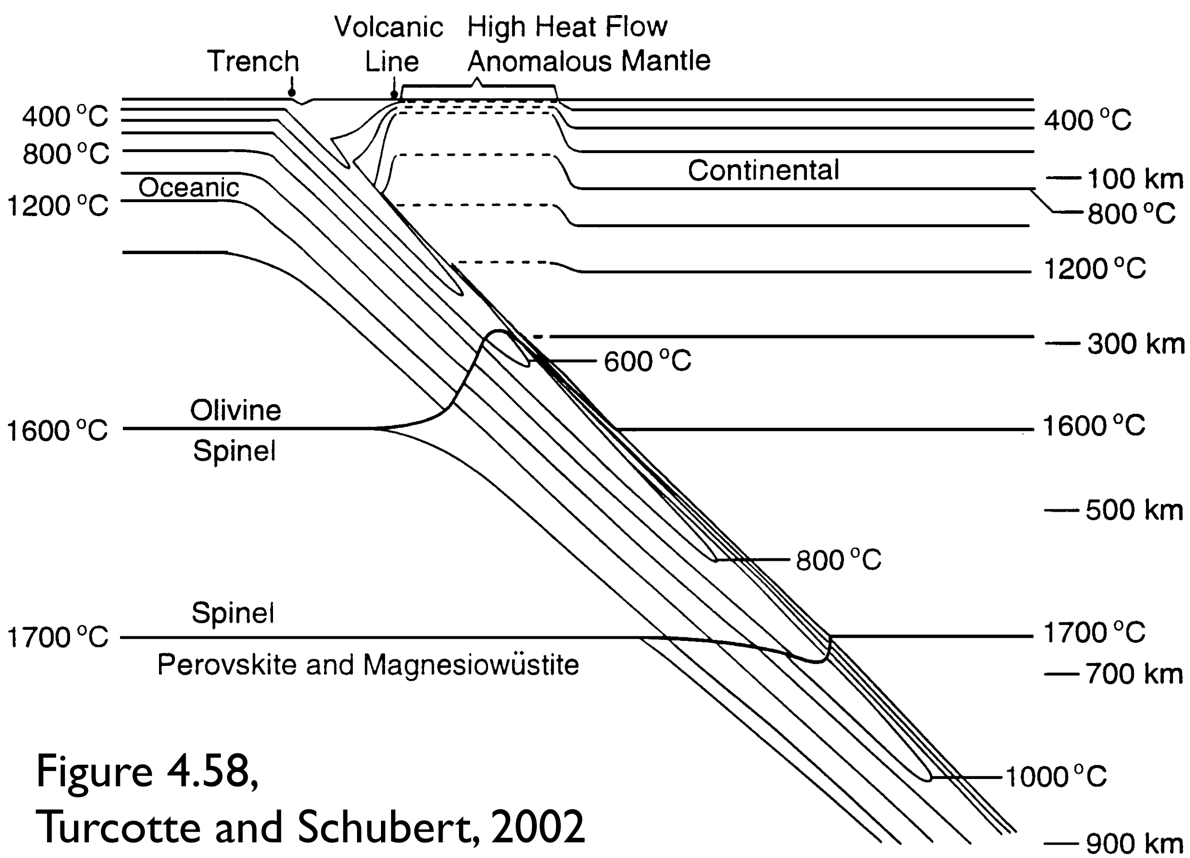
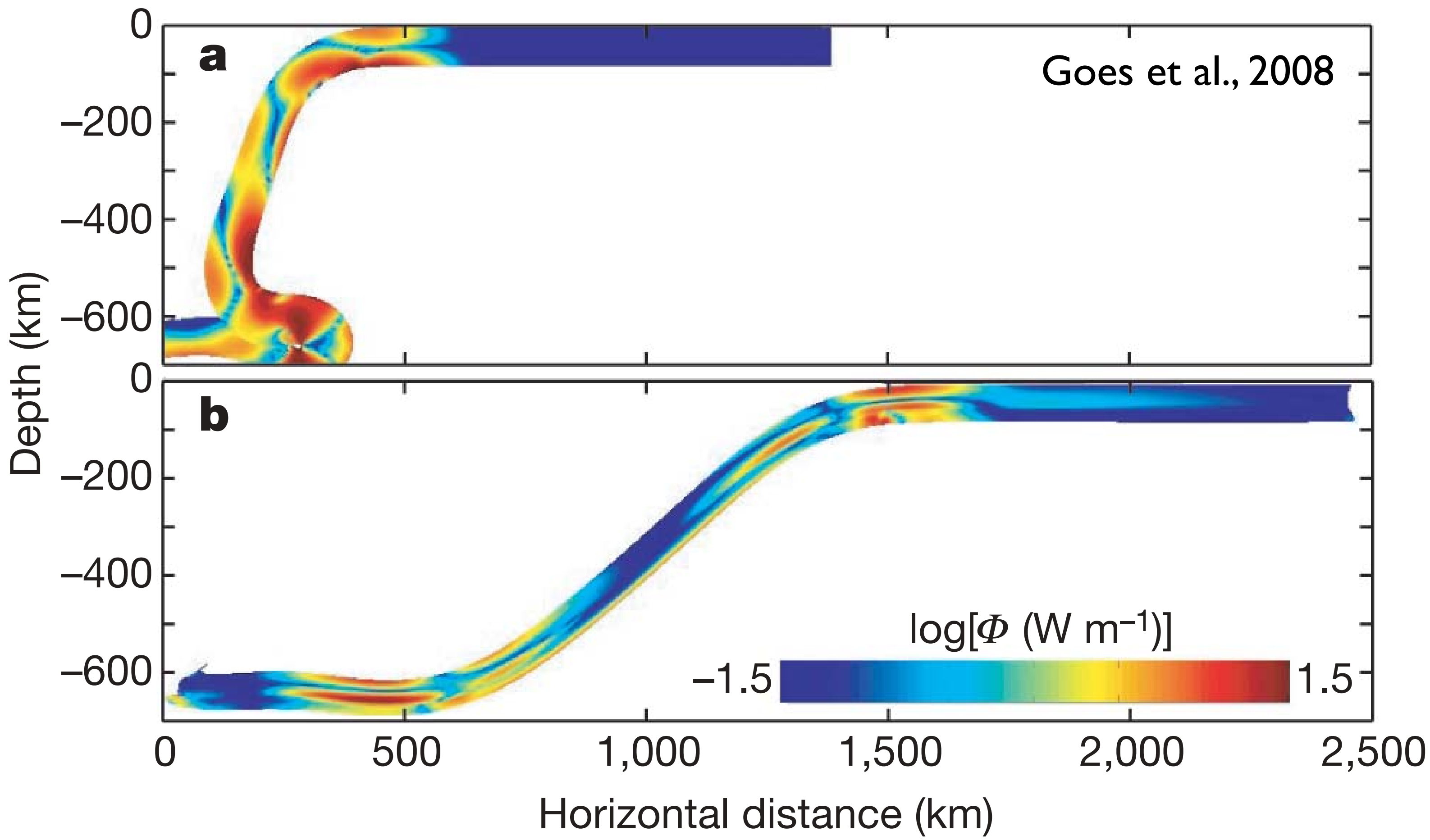


Figure 4.58,
Turcotte and Schubert, 2002

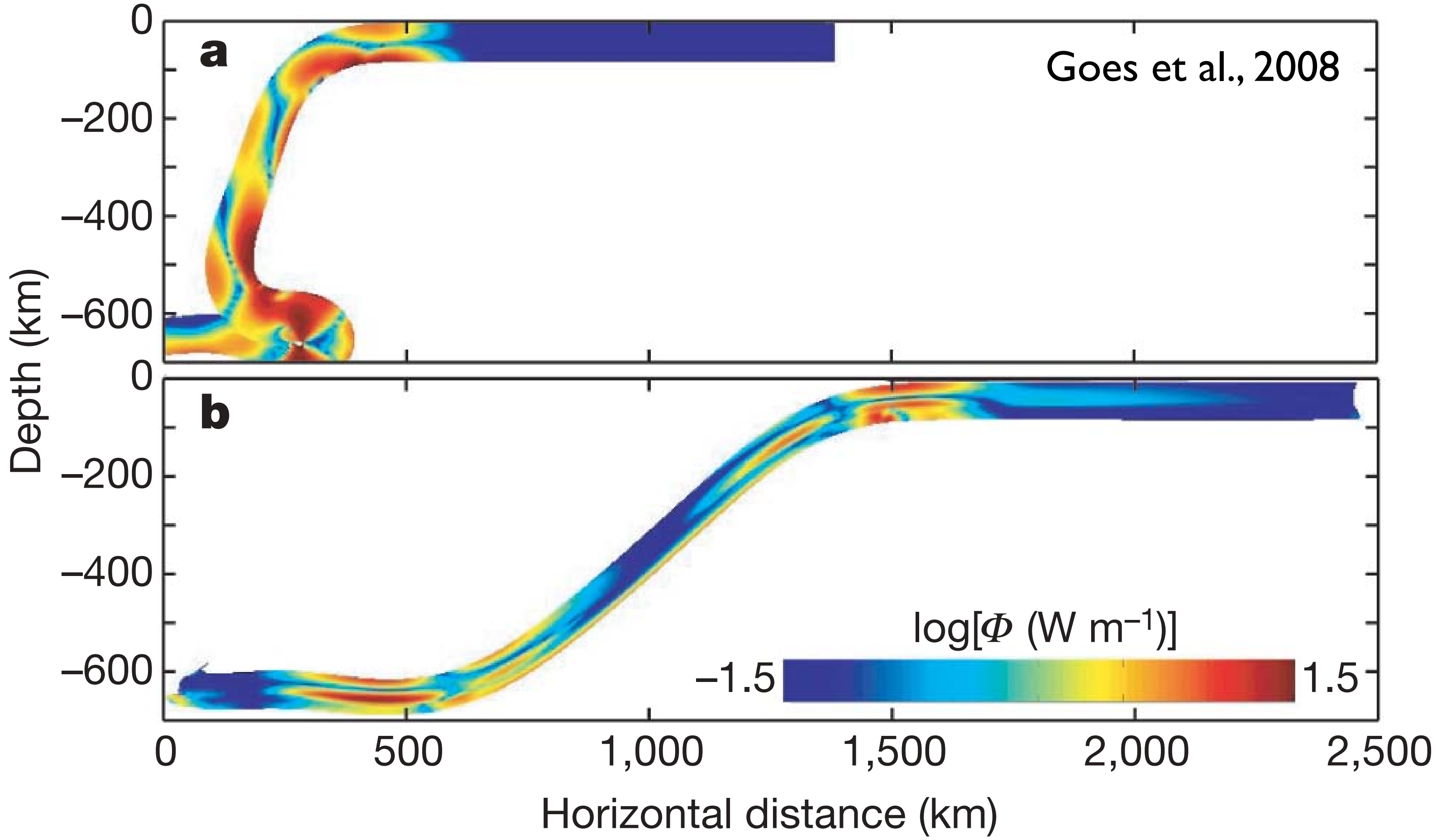
- Go collect data needed to test this idea
  - <u>Expensive and not easy to do</u>
- **Test the idea quantitatively using a numerical model**

Results



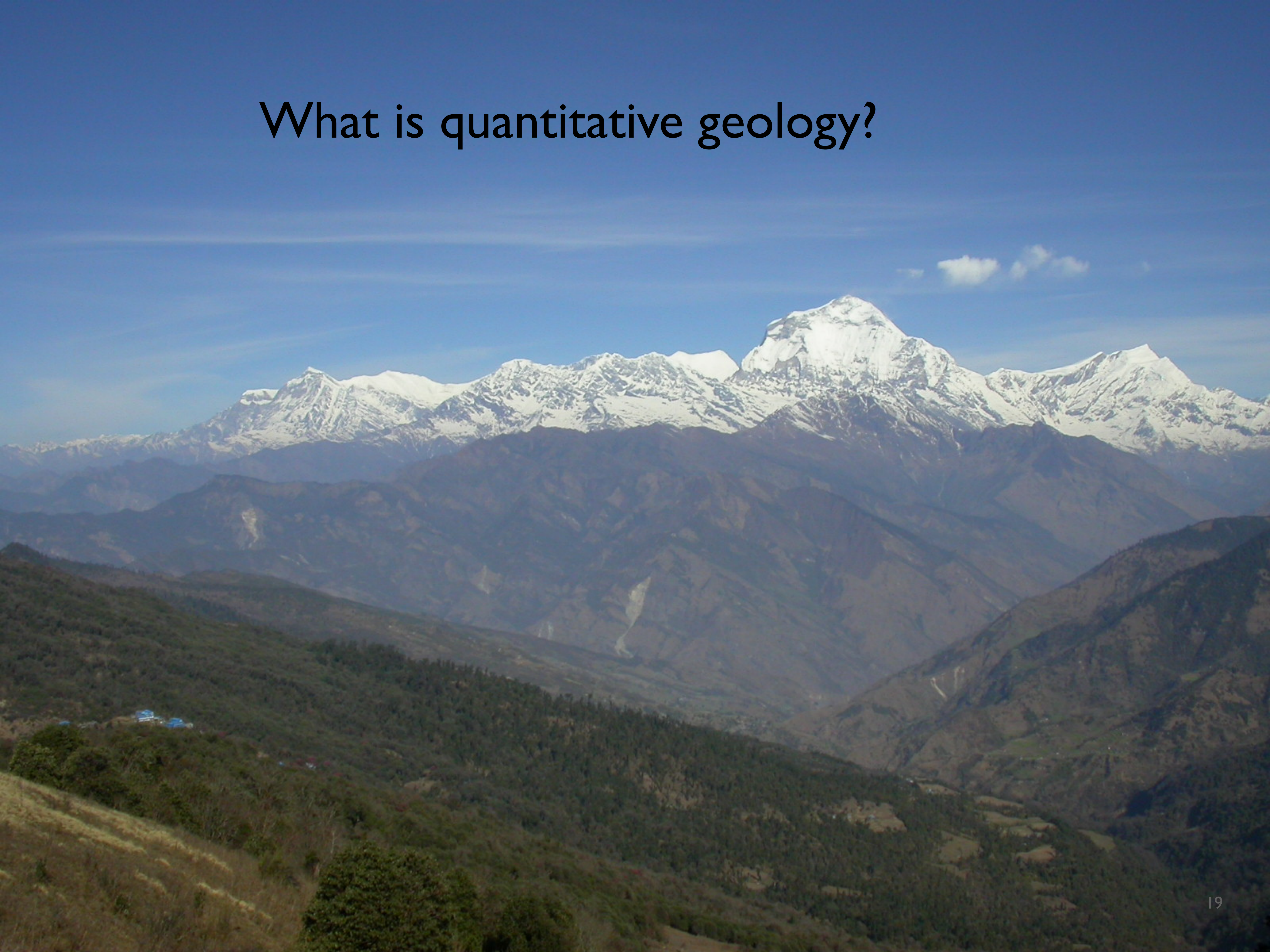
- Numerical model predictions suggest the <u>opposite</u> of our hypothesis: **Younger slabs may subduct more easily**
- Why?
  - Younger slabs deform more easily and thicken, which <u>enhances negative buoyancy in the slab</u>, making subduction easier
  - Older slabs, in contrast, tend to <u>experience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

What did we learn?

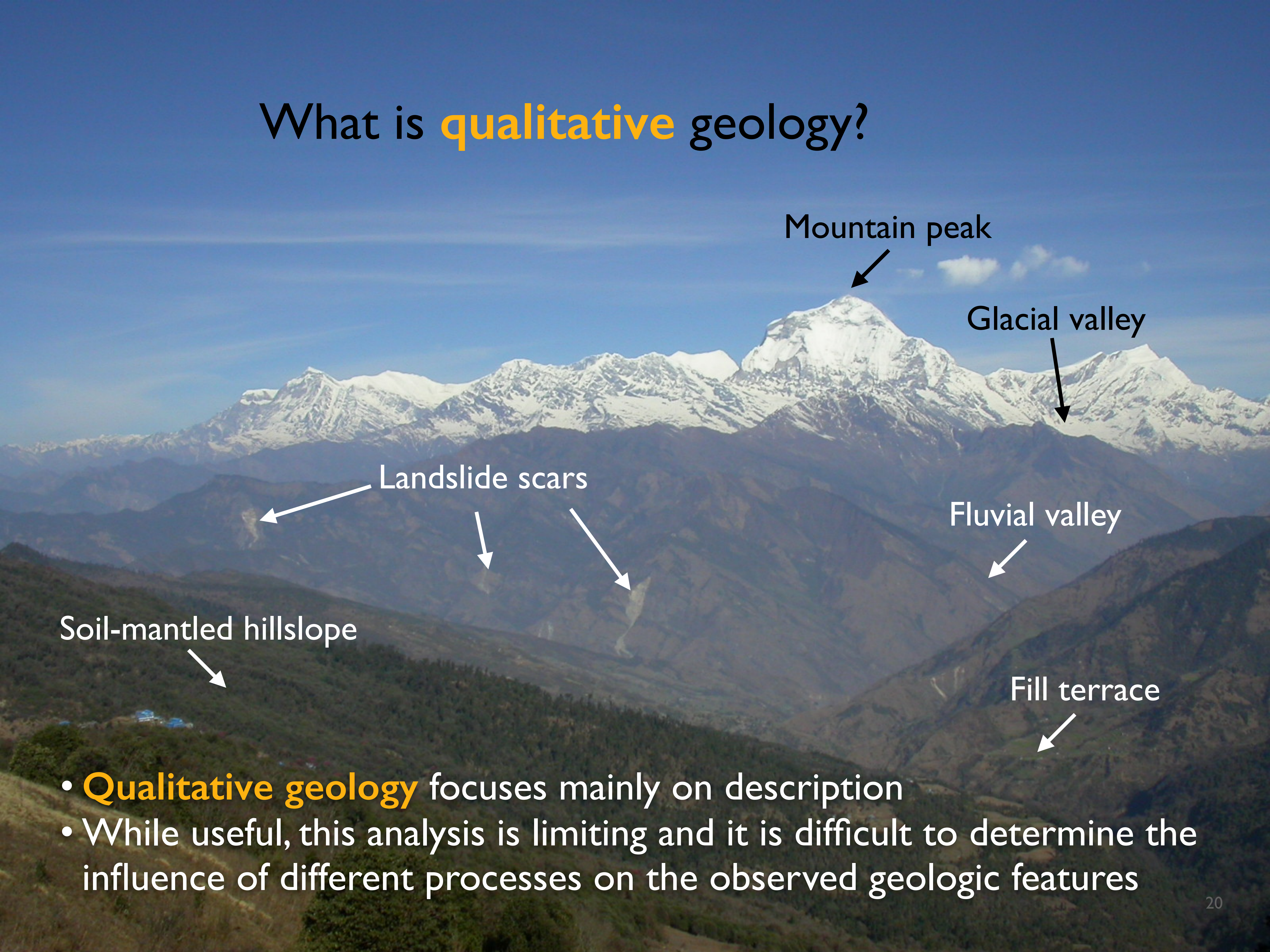


- Geology (or nature for that matter) isn't always intuitive
- Good conceptual ideas need testing in a rigorous, quantitative way
- It is critical to compare model results to observables (data) in order for the models to have any value

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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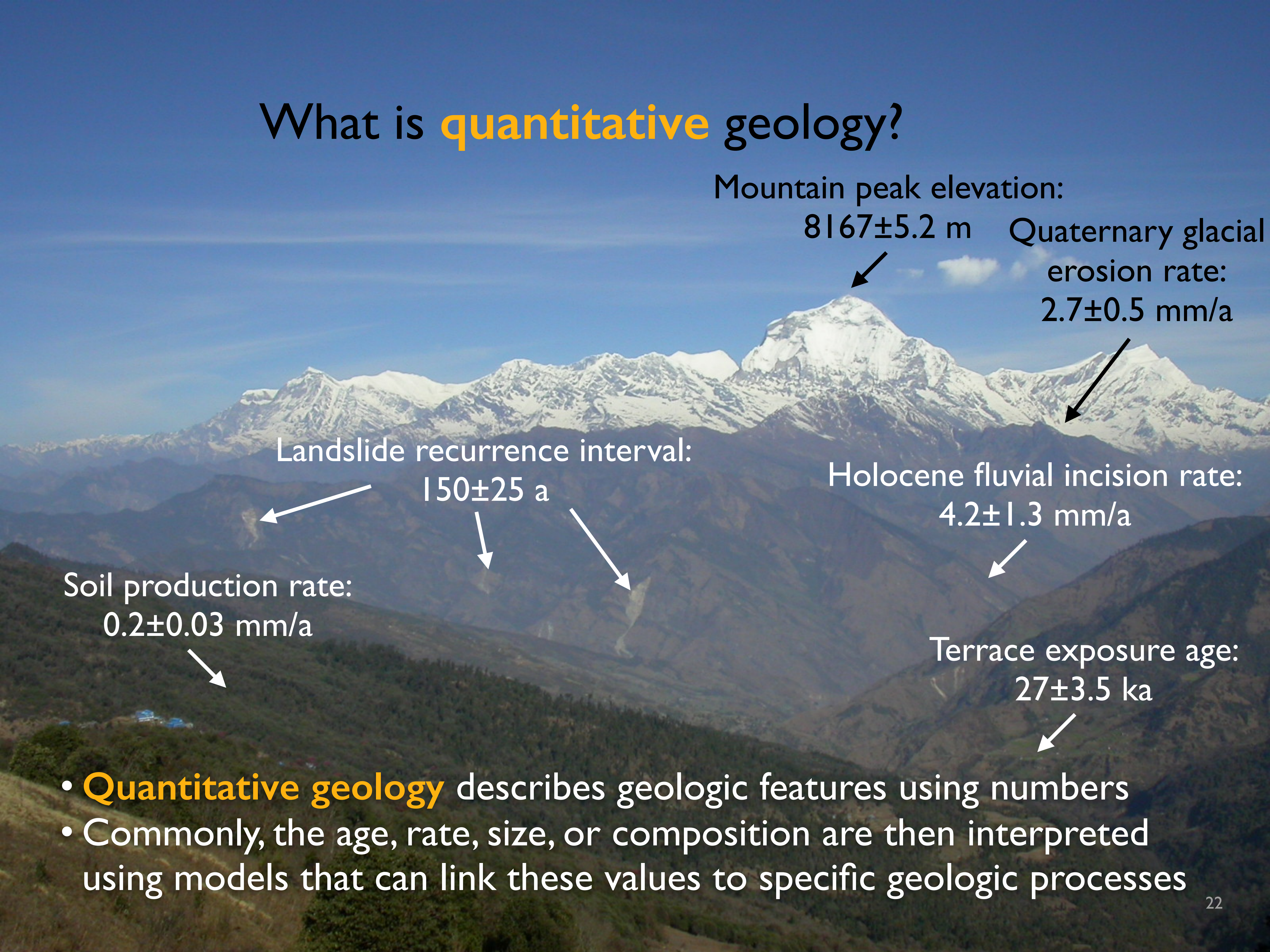

- **Quantitative geology** describes geologic features using numbers
- Commonly, the age, rate, size, or composition are then interpreted using models that can link these values to specific geologic processes

What 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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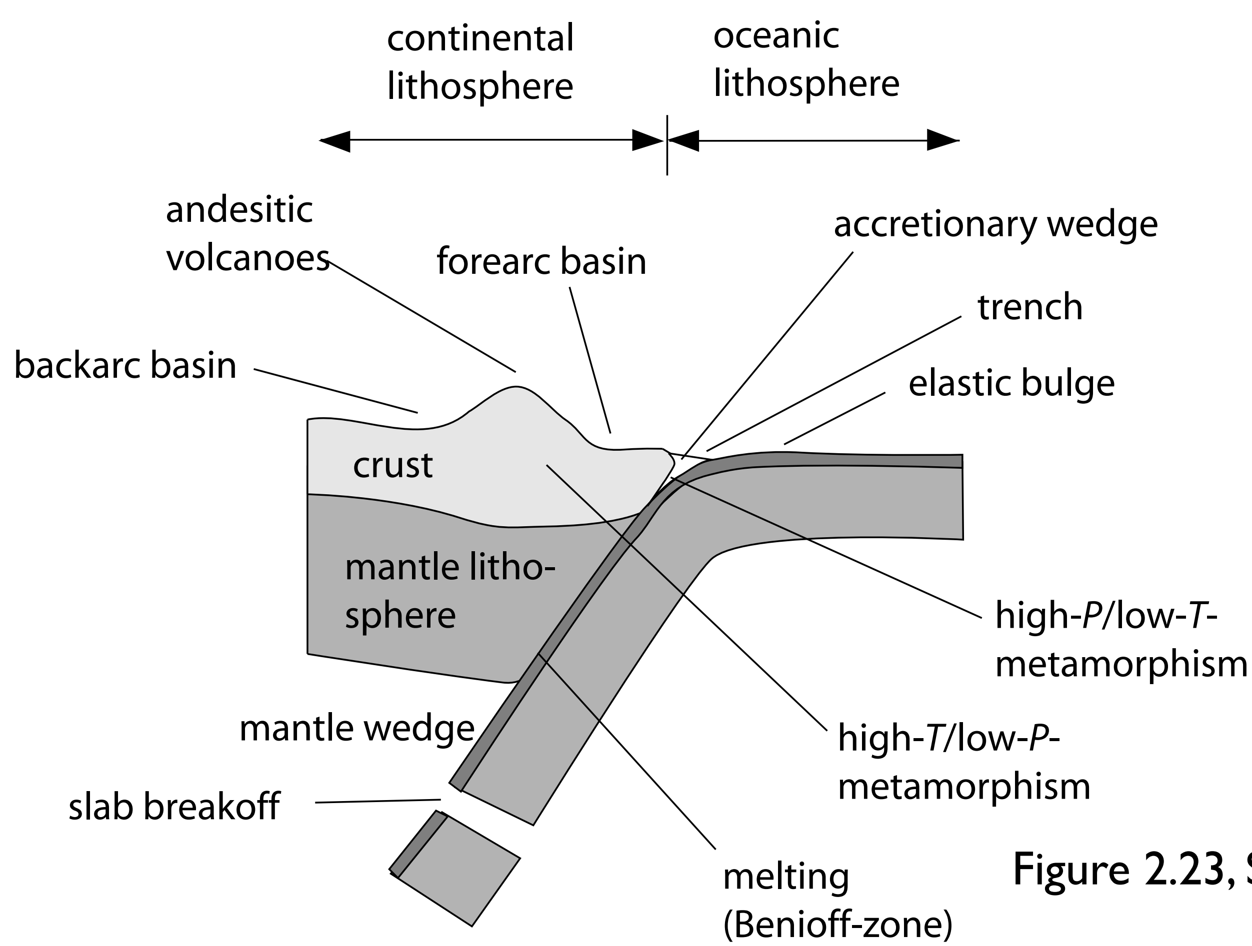

Figure 2.23, Stüwe, 2007

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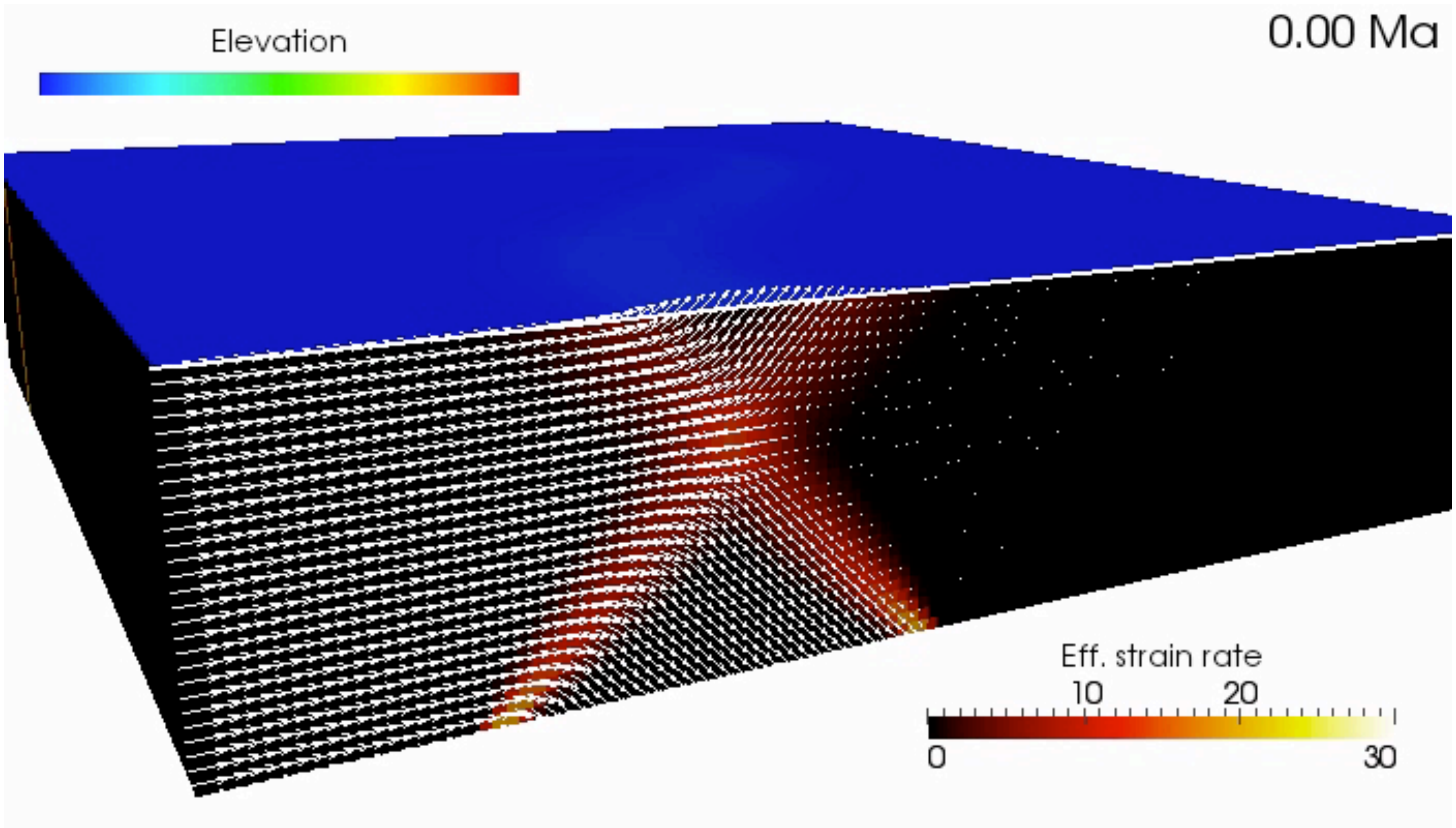

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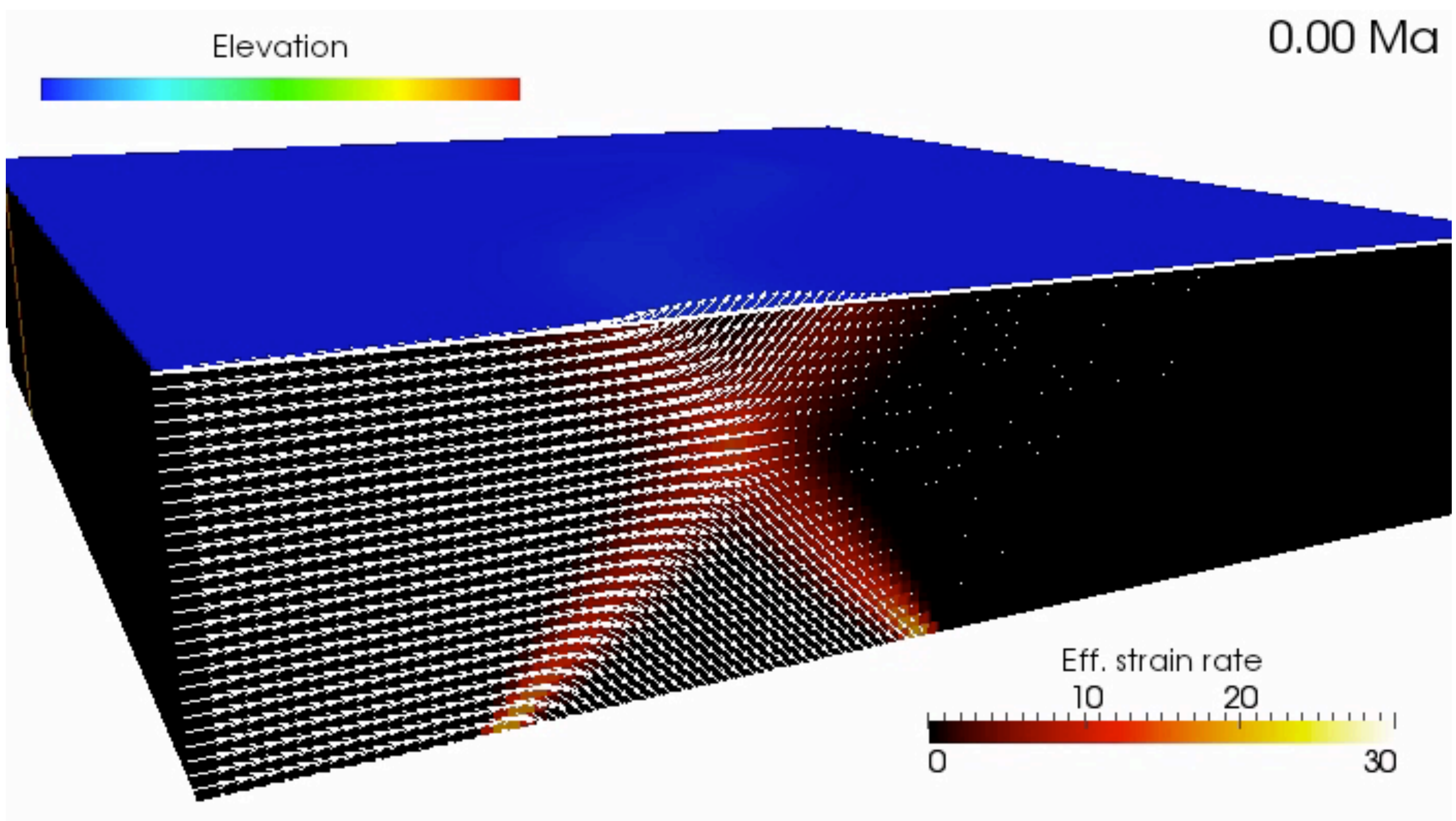
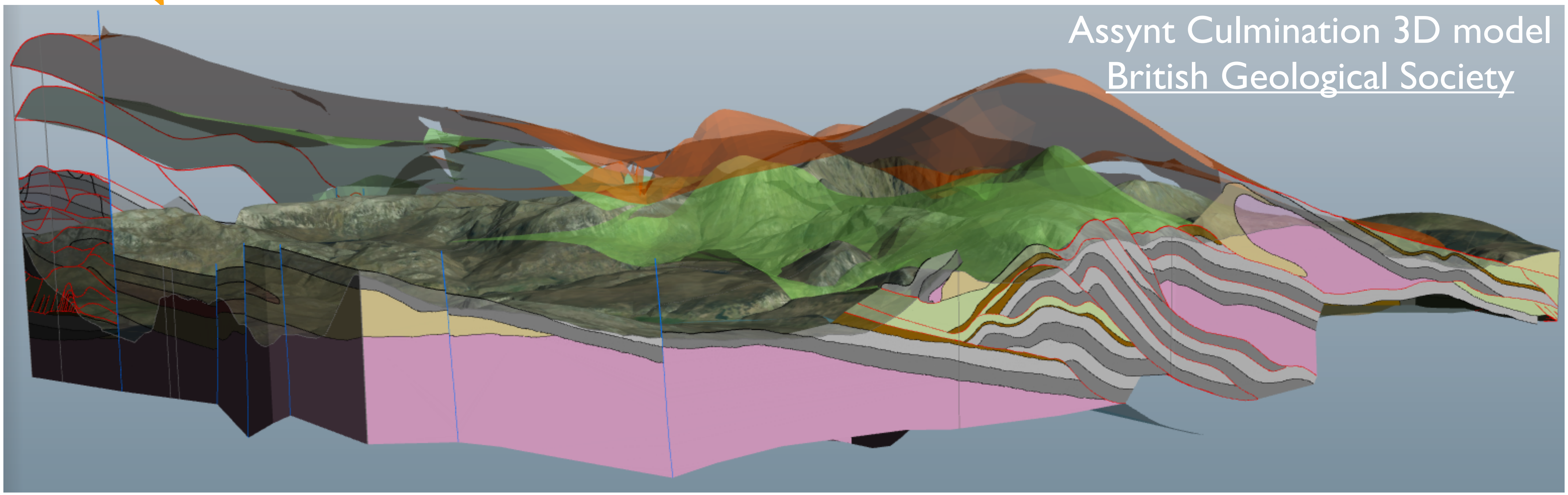


What is a good model?

What is a good model?

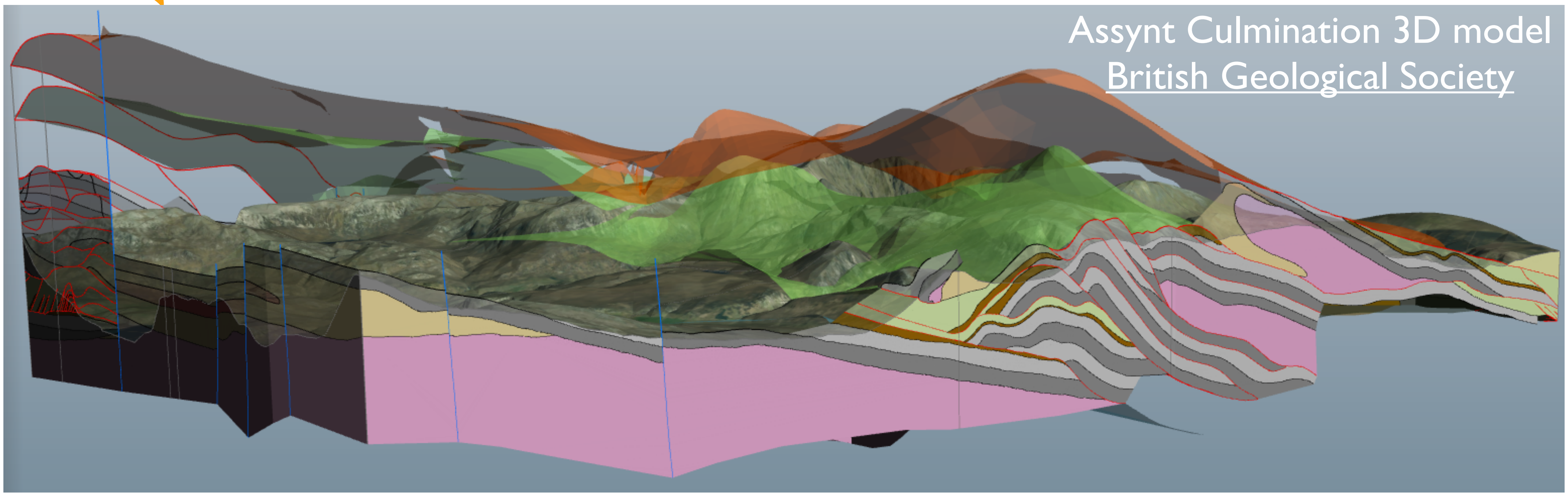
- According to Stüwe, 2007, a <u>good model</u> is a description of nature that should…
  - Describe a <u>large set of observations with a relatively small set of input parameters</u>
  - Be usable as <u>a tool to predict facts</u> that have not yet been observed
  - <u>Testable</u> using future experiments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



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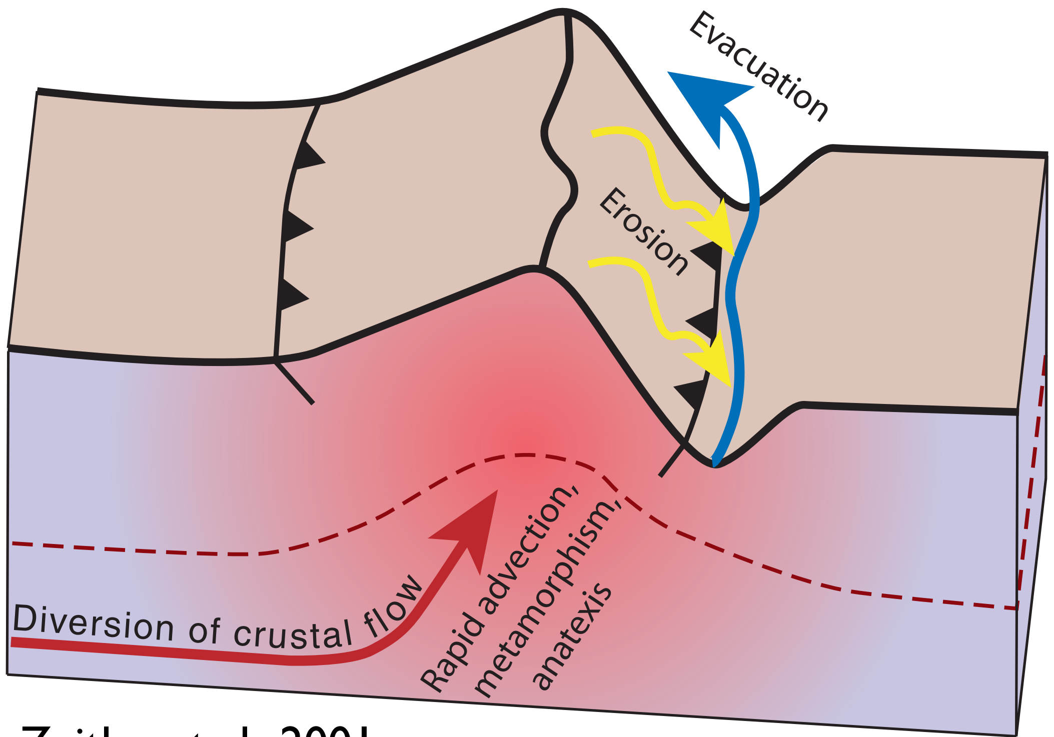
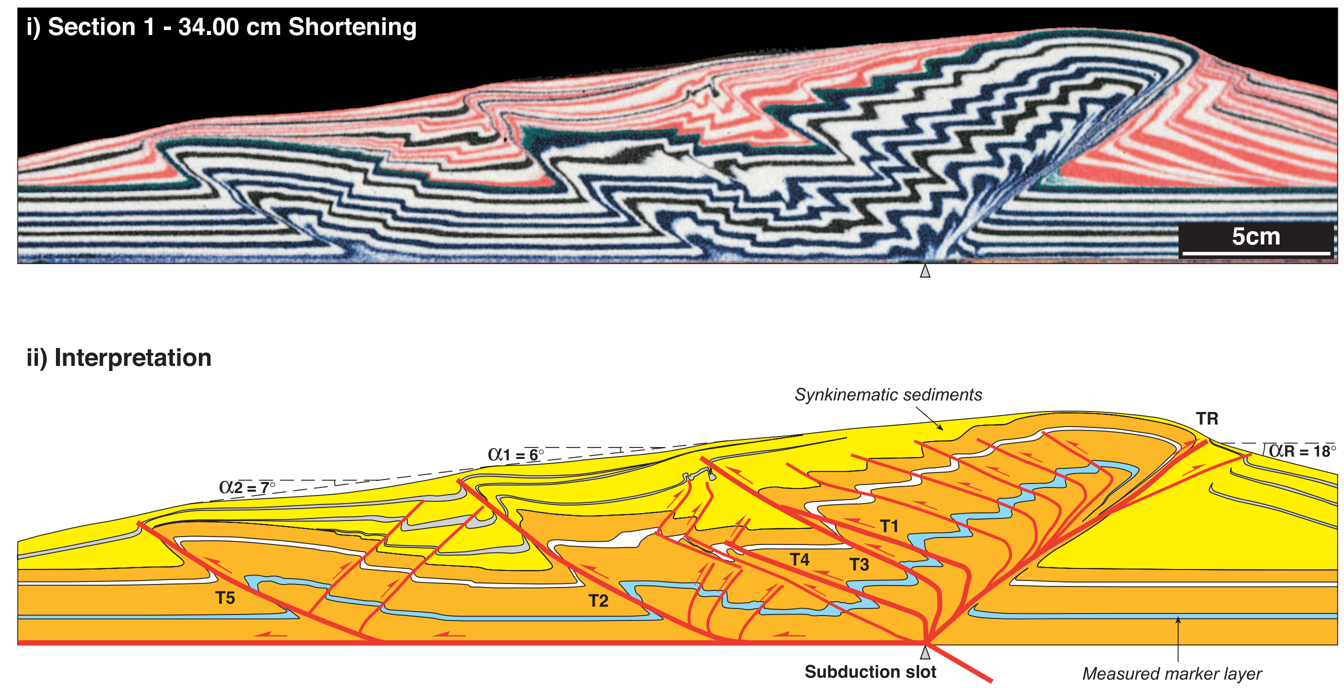


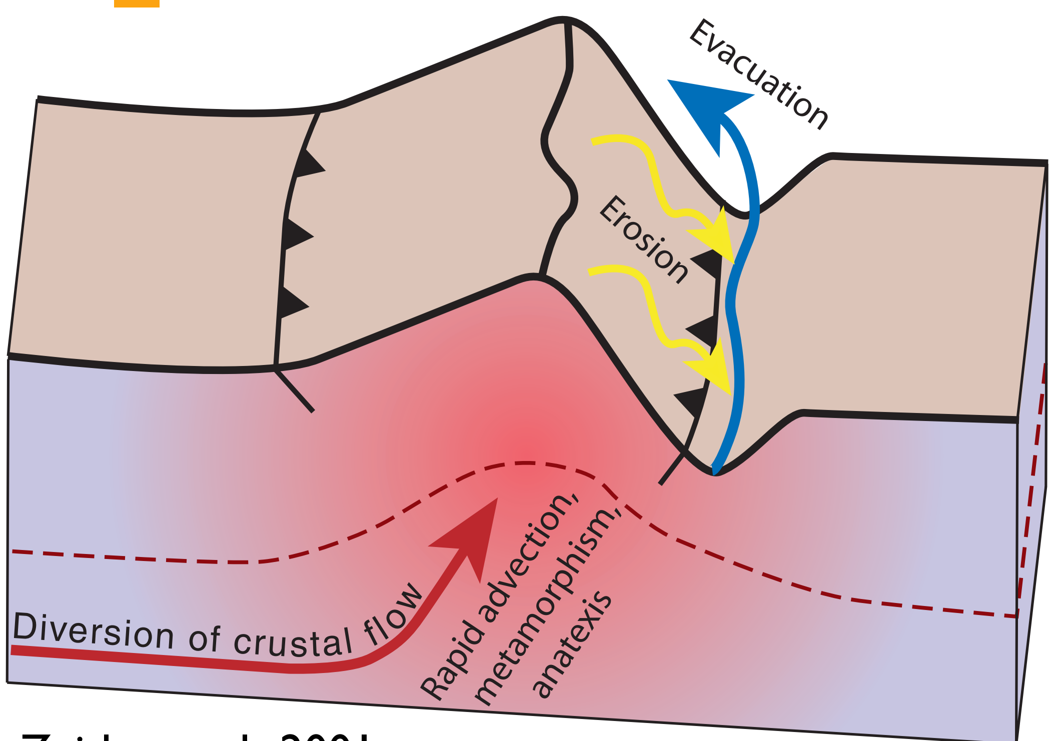
Zeitler et al., 2001



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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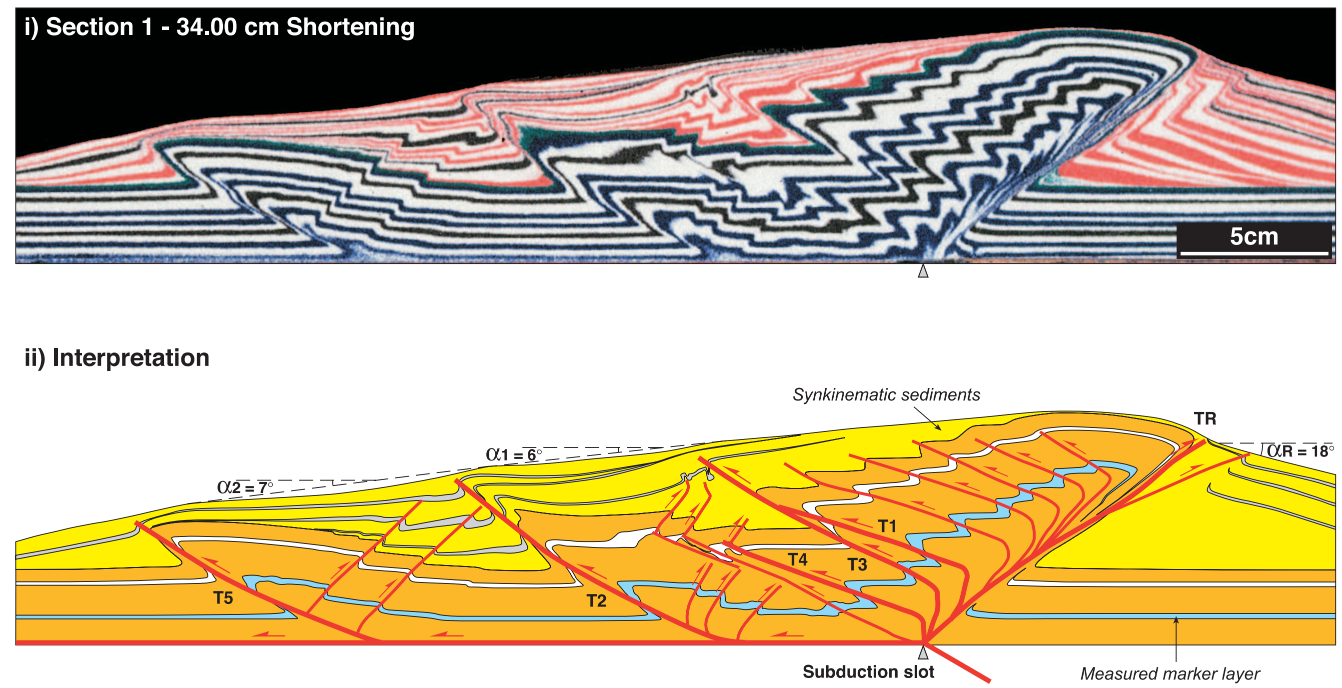
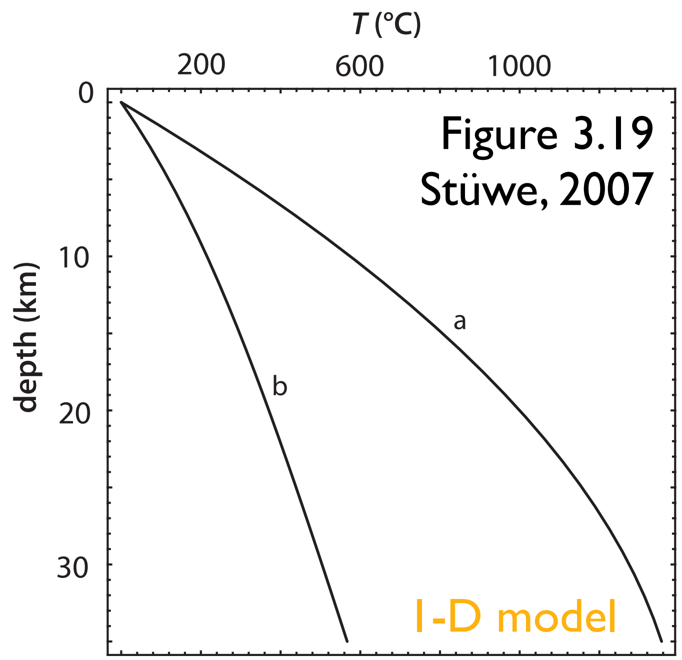
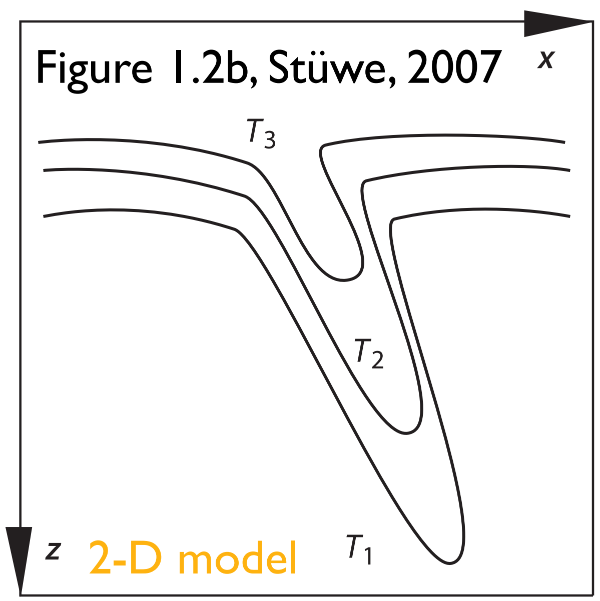


McClay and Whitehouse, 2004

- **Schematic diagrams (cartoons)**: Visual representations of geologic phenomena; Generally qualitative
- **Analog models (sandbox models)**: Controlled physical simulation of a geological system; Can be qualitative or quantitative
- **Numerical models**: Computer-based simulation of a geological system; Quantitative

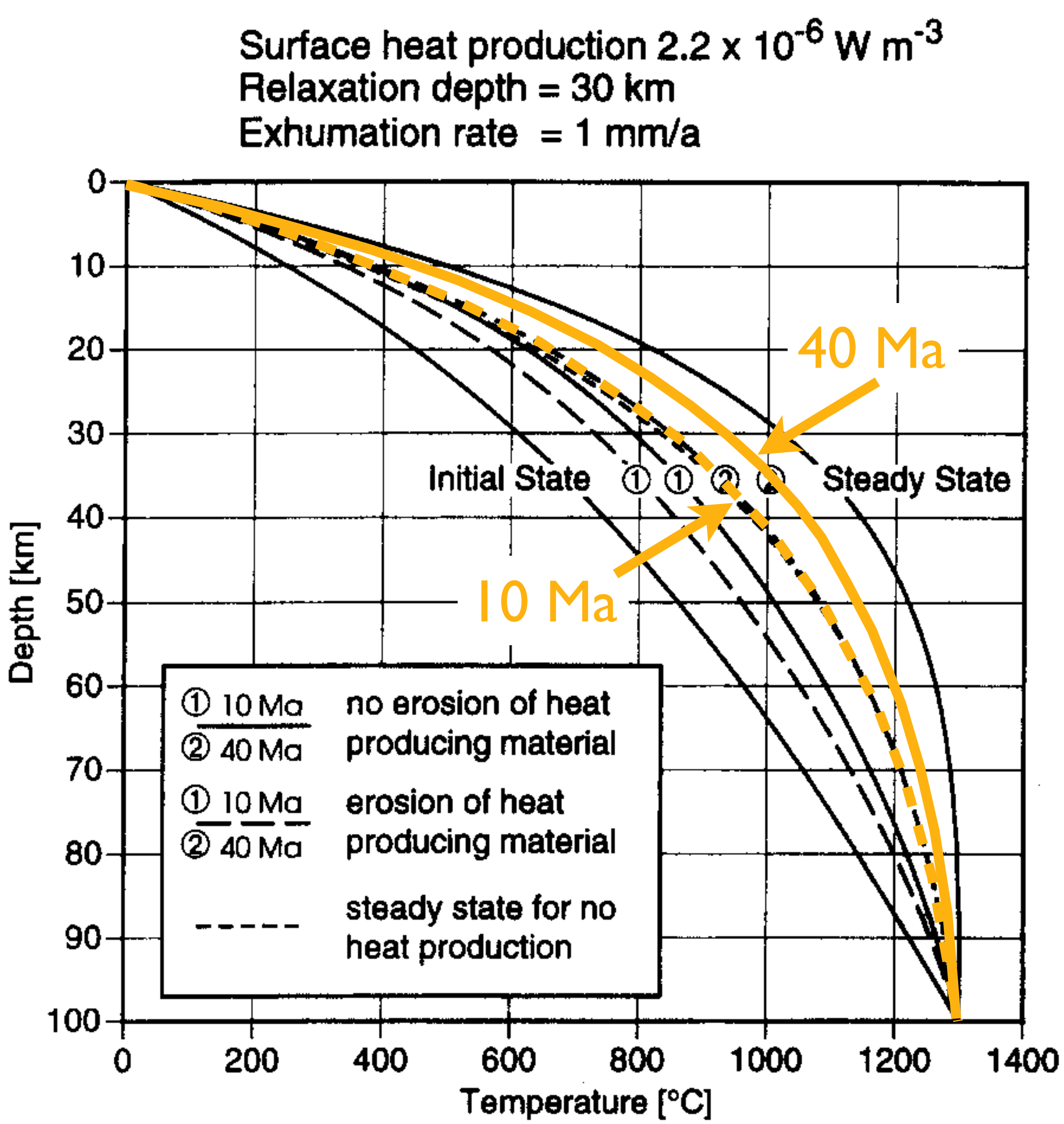
Numerical models





- Numerical models range from incredibly simple to very complex
- The model geometry is defined by its spatial dimension
  - 1-D: Variation of temperature with depth in the Earth
  - 2-D: Temperature variation in a subduction zone
  - 3-D: Stresses acting on an oblique thrust fault
  - Zero-dimensional: Accumulation of a daughter product from radioactive decay

Numerical models



Mancktelow & Grasemann, 1997

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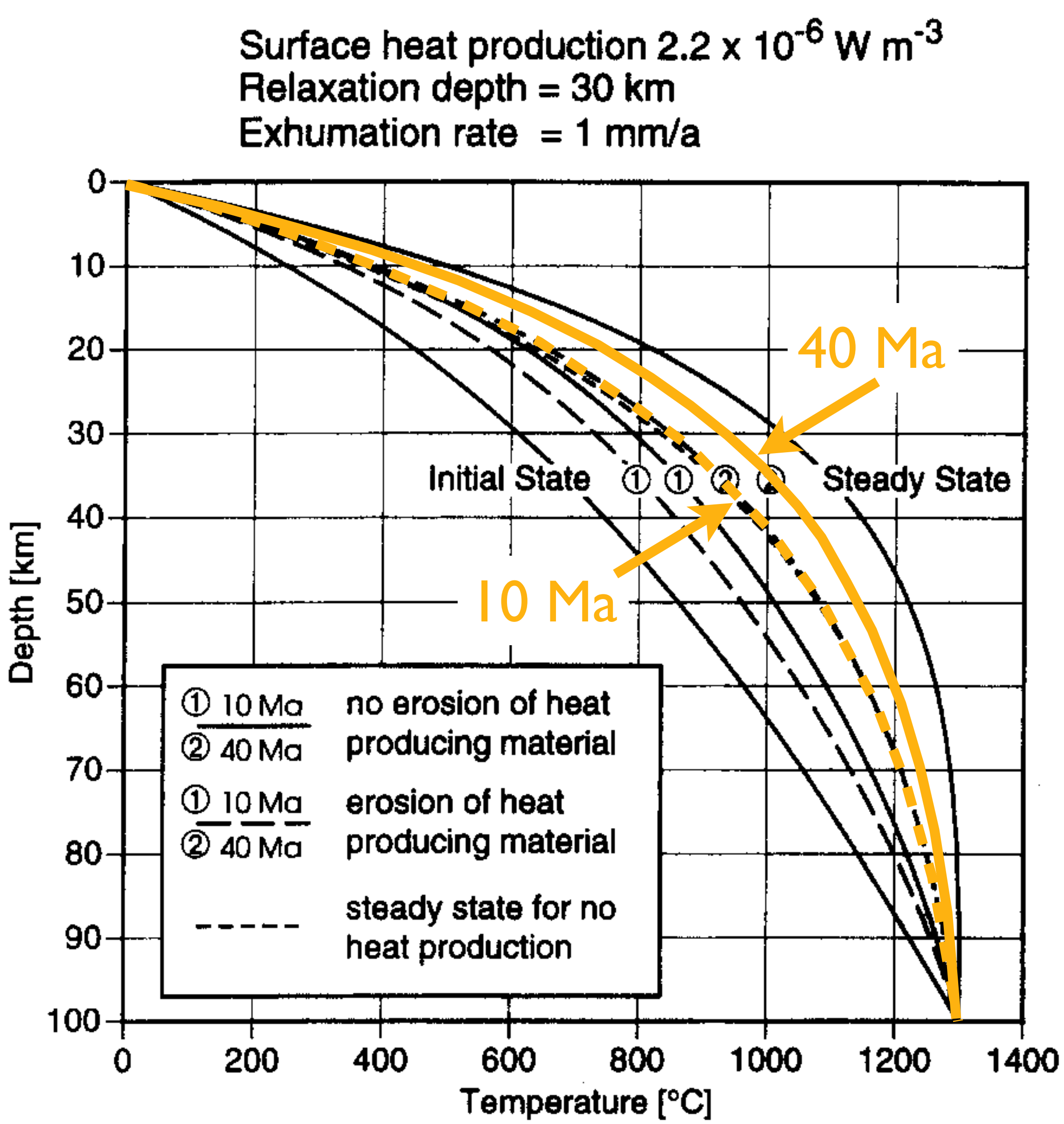
- Time variation
  - **Steady state**: Solution does not depend on time
  - **Transient**: Solution is a function of time

Numerical models



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- Numerical models range from incredibly simple to very complex
- Time variation
  - **Steady state**: Solution does not depend on time
  - **Transient**: Solution is a function of time
- **Our goal: Simulate physical processes numerically and relate them to data**

Advantages of numerical modeling

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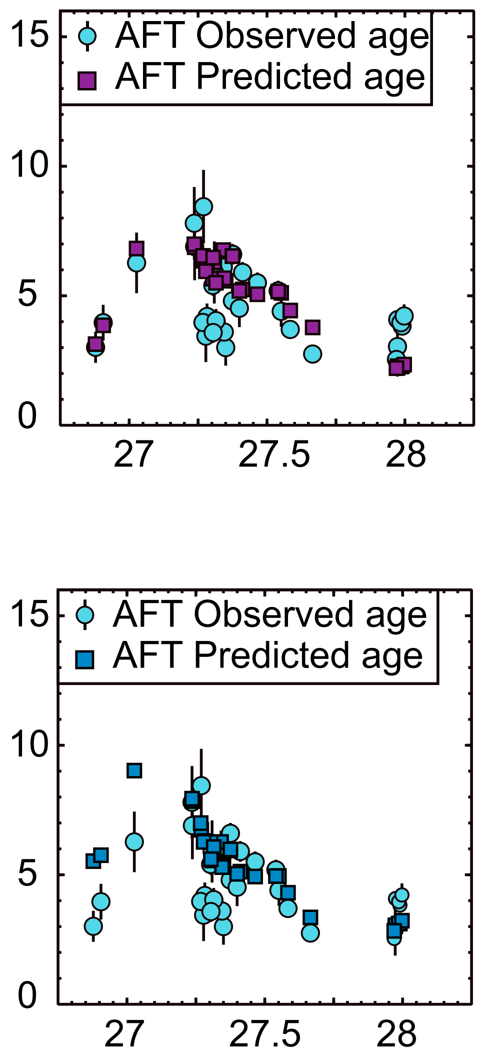

Coutand et al., 2014

- Numerical modeling offers numerous advantages over other modeling approaches
  - Math and basic physics can be used to test proposed conceptual models
  - Numerical experiments can directly simulate geologic time, rates of geological processes and geological material properties without a need for scaling, as is common in analog modeling
  - Model results can be quantitatively related to geologic field observations, laboratory data or geophysical datasets

Disadvantages of numerical modeling?

Some words of caution

- Although they may be incredibly powerful and complex, **numerical models aren't magic**
- **GIGO: Garbage in = garbage out**
    - Poor choice of model inputs or model design will produce poor results
- 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 <u>direct evidence of geologic processes</u>
- The trouble is that <u>field data alone seldom provide direct insight into the processes</u> 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 <u>cannot explain how the ages were generated</u>
    - For that, a model is needed

Recap

- Quantitative geology involves moving beyond description of geologic features by applying basic math, physics and programming to understand geologic processes

- Models allow us to describe the world around us more simply in a way we can understand

- Our goal is to combine programming, common Earth science equations and geological data to understand geological processes within the resolution of our data

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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