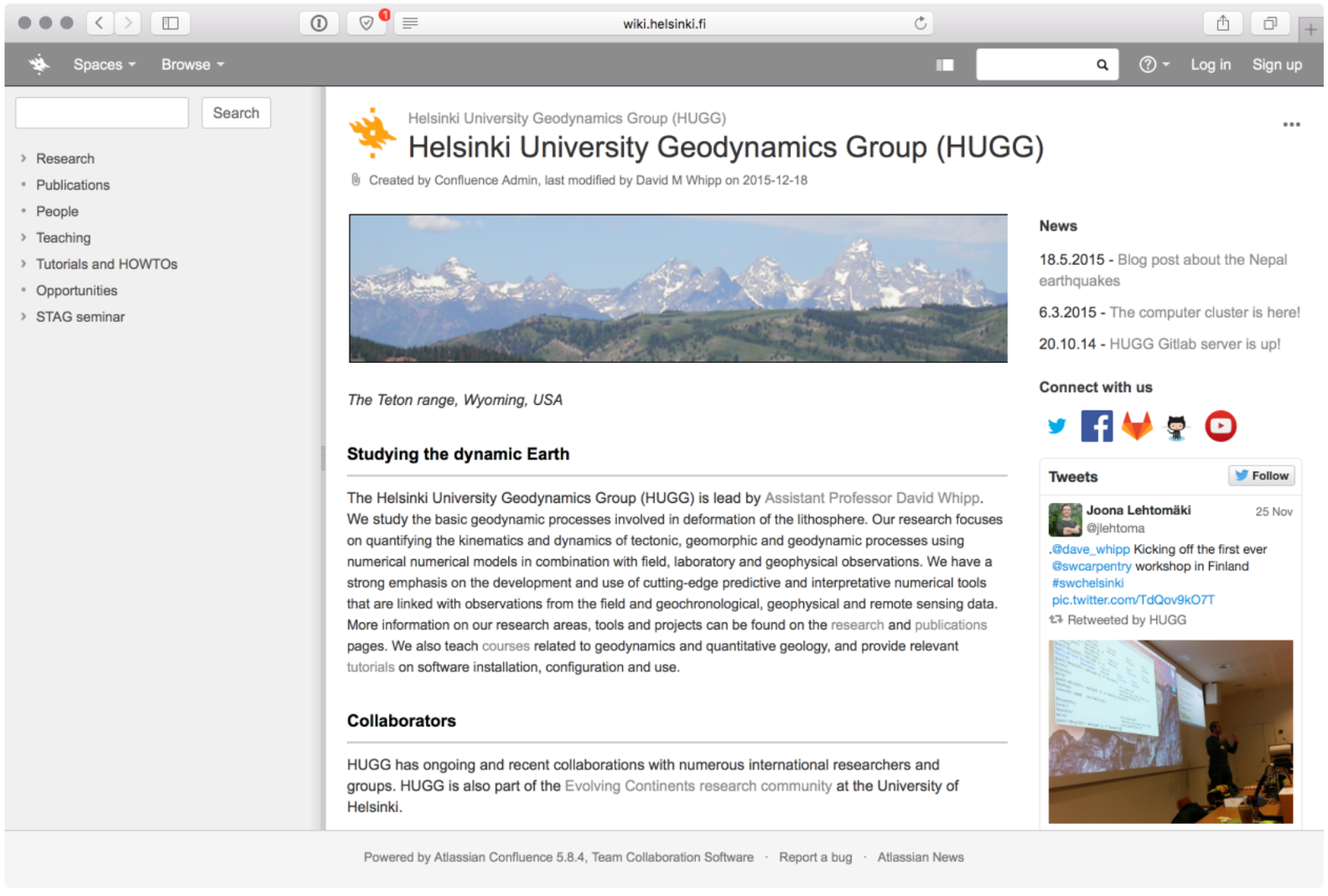
Introduction to lithospheric geodynamic modelling

Course overview

David Whipp and Lars Kaislaniemi
Department of Geosciences and Geography, Univ. Helsinki

Nordic Geological Winter Meeting 2016

Who are we?



The Helsinki University Geodynamics Group (HUGG) wiki

- **David Whipp**
  Assistant Professor
  Head of HUGG
- **Lars Kaislaniemi**
  Postdoctoral researcher
  Member of HUGG

Who are you?

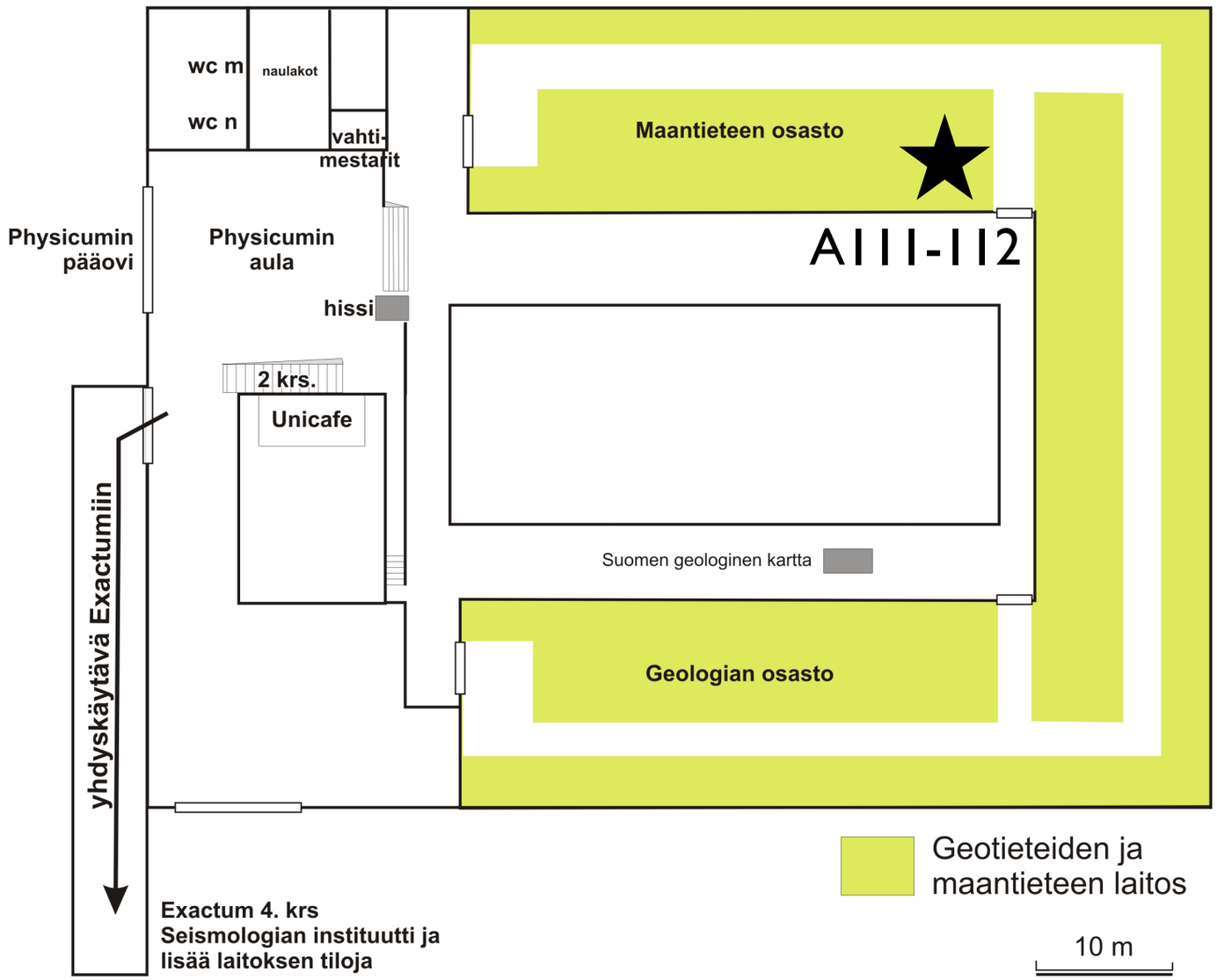
- To help all of us get to know you, we'd like to hear a few things about you
  - Name
  - Home university/organization
  - Geological background/thesis topic
  - Experience with coding/model use

Time to pair up

The dynamic duo

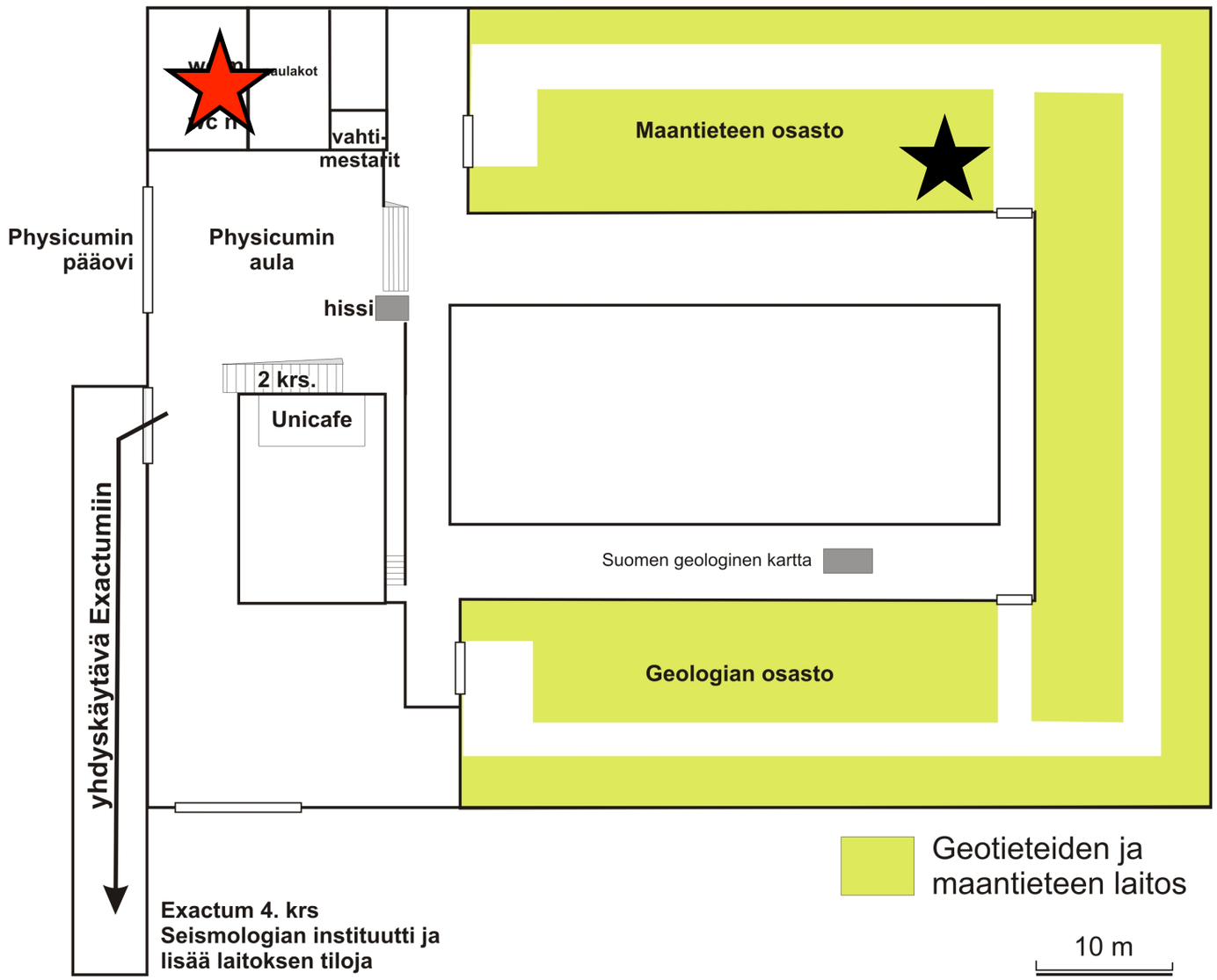
- Before you get too comfortable, and now that we know one another, please find a partner to work with for the rest of the workshop
- An ideal partnership would put a stronger coder/modeller with someone with less coding/ modelling skill
- Groups of 3 are possible, but only if needed

Practical matters: Where are we?



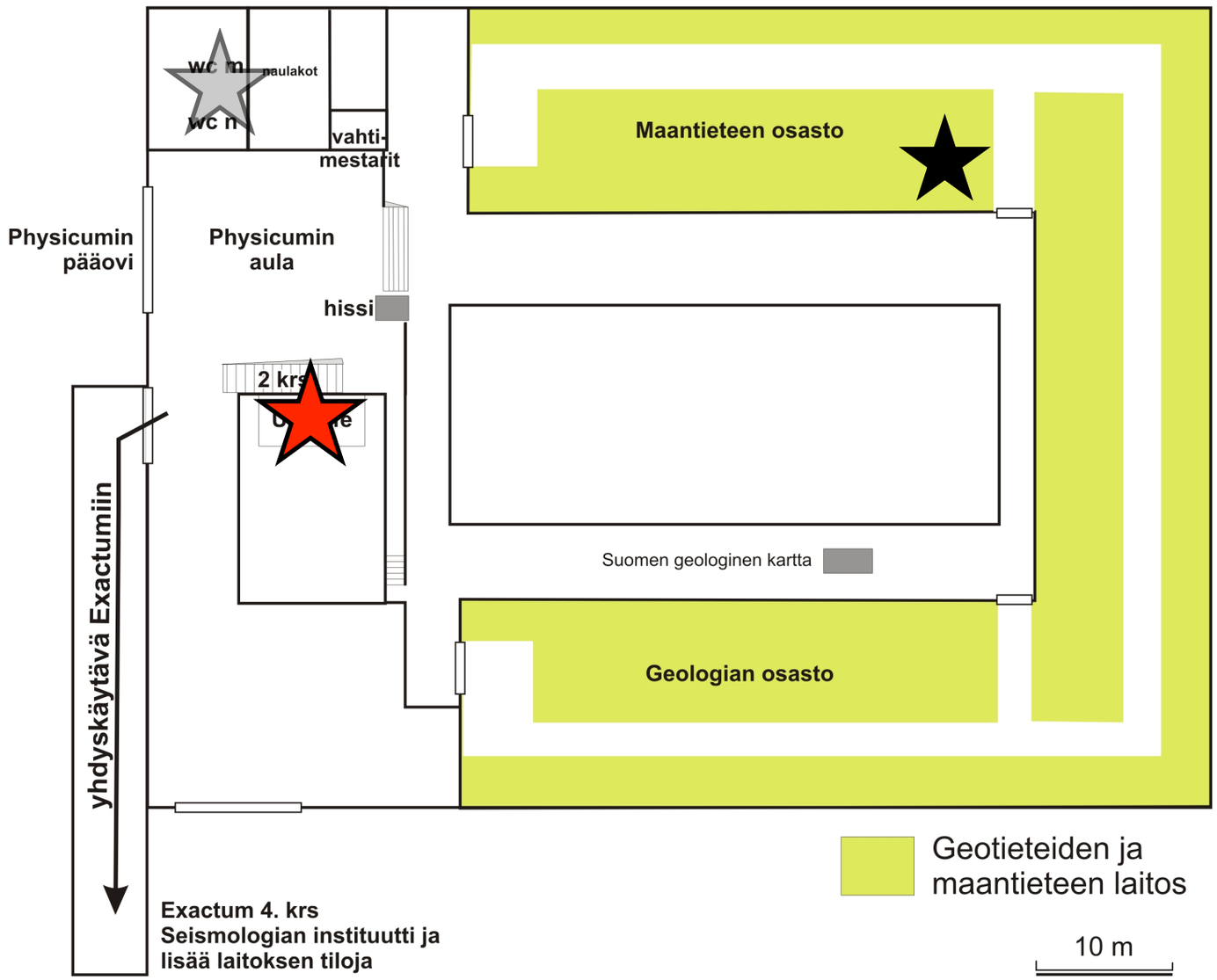
http://www.helsinki.fi/geo/

Practical matters: Toilets



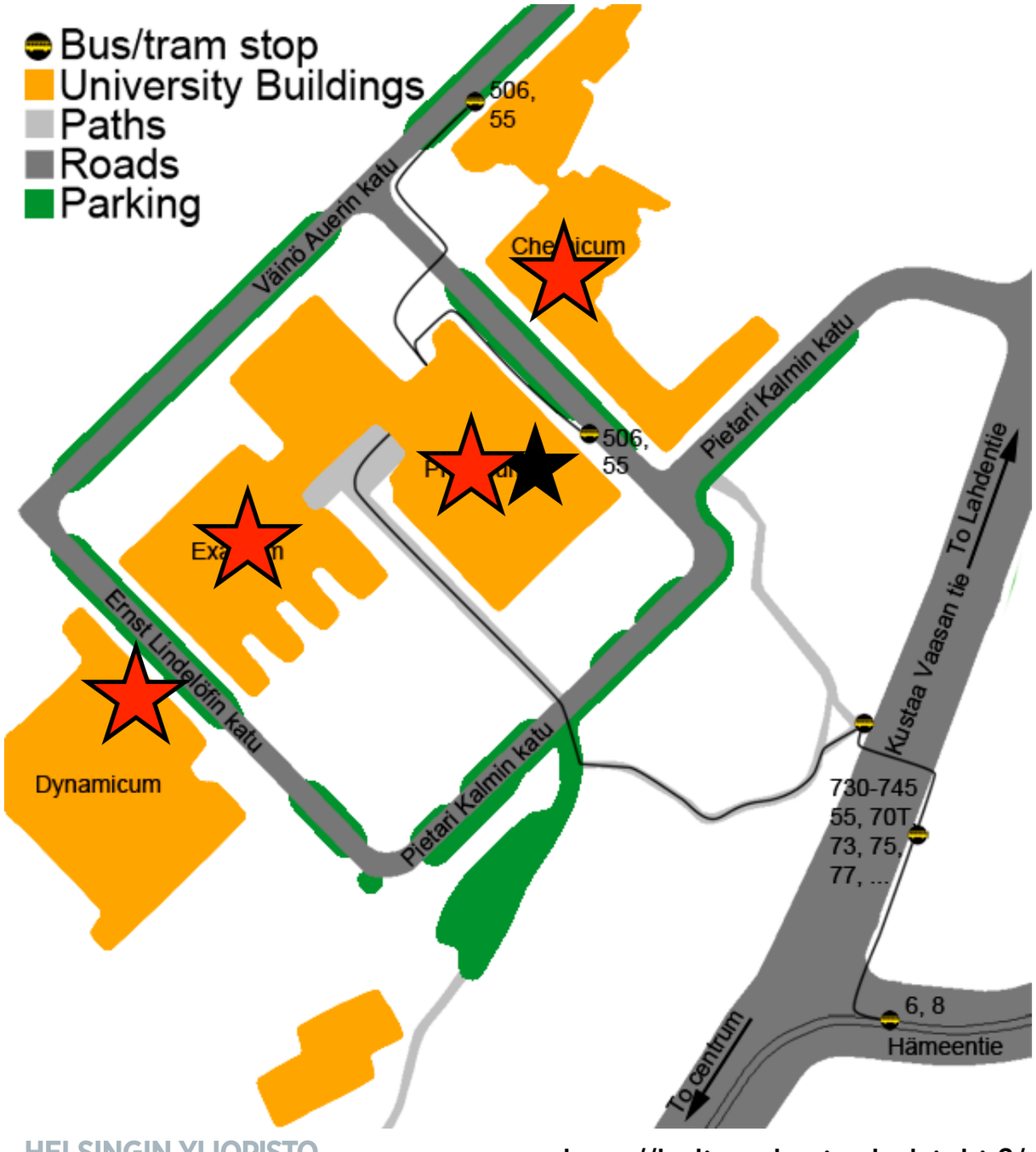
http://www.helsinki.fi/geo/

Practical matters: Coffee/tea



http://www.helsinki.fi/geo/

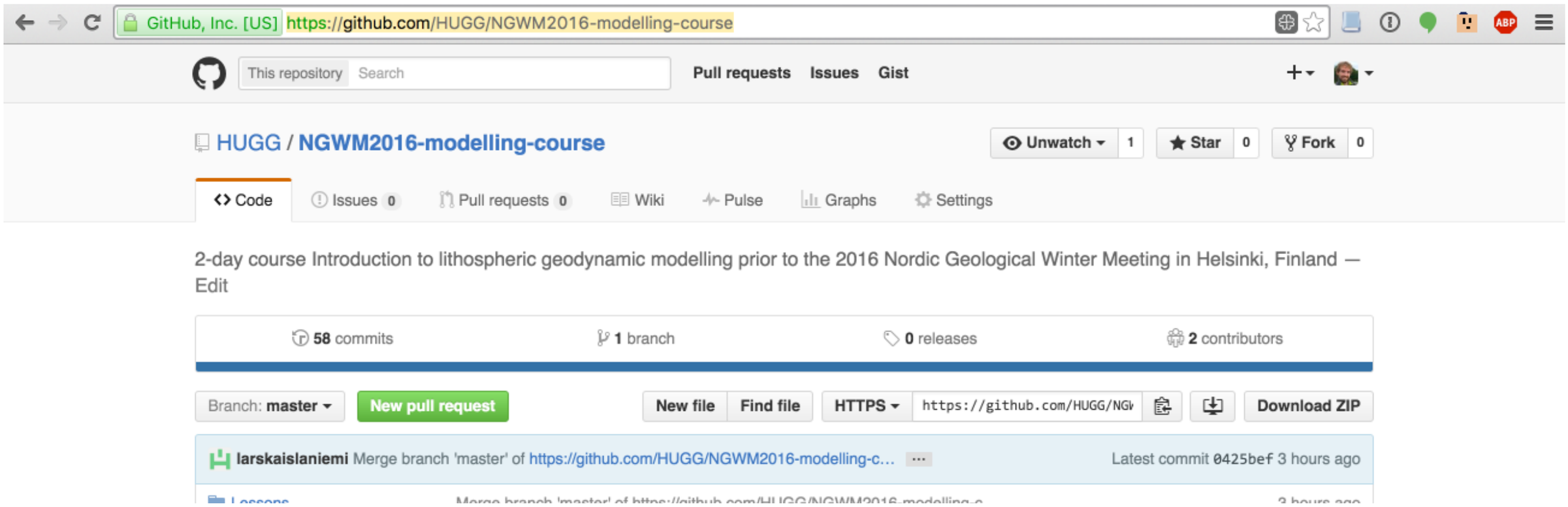
Practical matters: Lunch



- There are numerous lunch options on the Kumpula science campus
- You can get a **full hot lunch** across the street in the Chemicum, in the basement of the Exactum next door, or slightly further away in the Dynamicum (food is pricier, but better).
- The Unicafe (coffee/tea spot) also has **sandwiches/paninis**

http://helixs.physics.helsinki.fi/

Course Github repository



- The contents of this course are available on Github at https://github.com/HUGG/NGWM2016-modelling-course
- This is a useful place to find all course materials and the schedule

Course Github repository

- On the Github pages you can also find a wiki at https://github.com/HUGG/NGWM2016-modelling-course/wiki

- There, you'll find links to download and install all software used in this course on your own computer
  - The course is taught entirely with free software!
- We also have a list of useful links related to geodynamic modelling and this course

Course topics - Day 1

Day 1 - Monday, January 11

09:00-09:45 - General course introduction and practical matters
09:45-10:30 - Physics of heat transfer

10:30-10:45 - COFFEE/TEA BREAK

10:45-12:15 - Analytical solution of the heat transfer equation + python basics and plotting

12:15-13:15 - LUNCH BREAK

13:15-14:45 - Basic fluid mechanics + analytical solutions for simple cases and their limitations

14:45-15:00 - COFFEE/TEA BREAK

15:00-16:30 - Finite difference method + applications to heat eq. and/or flow mechanics
16:30-17:00 - Free time for tinkering

Course topics - Day 2

Day 2 - Tuesday, January 12

09:00-10:30 - Rheology of the lithosphere + plotting lithospheric strength profiles

10:30-10:45 - COFFEE/TEA BREAK

10:45-11:30 - Introduction to Gale, model design and running Gale

11:30-12:15 - Running a continental collision experiment

12:15-13:15 - LUNCH BREAK

13:15-14:00 - Data visualization with ParaView

14:00-14:45 - Interpreting your results, comparison with the "correct" answer

14:45-15:00 - COFFEE/TEA BREAK

15:00-16:30 - Running a rifting experiment

16:30-17:00 - Final comparisons, closing remarks and the next steps

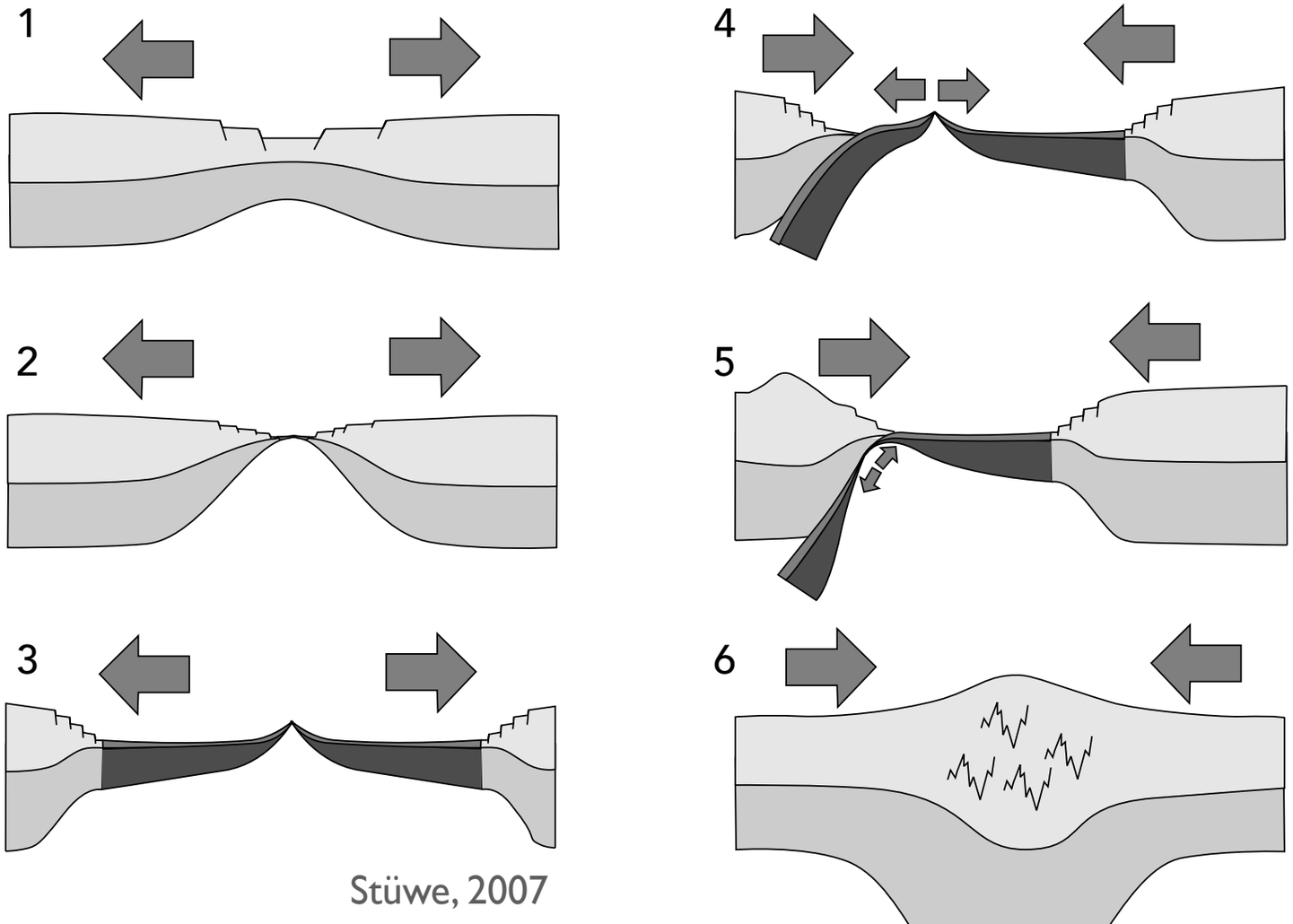
Any questions?

A brief introduction to geodynamic modelling

- The rest of this lecture is an overview of **lithospheric geodynamic modelling**
- Lithospheric geodynamic processes, some examples
- What is a model, and what is a geodynamic model?

Lithospheric geodynamic processes

The Wilson cycle

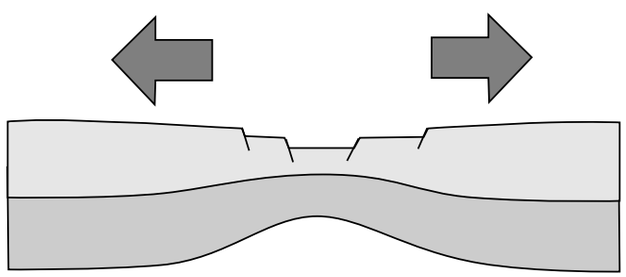


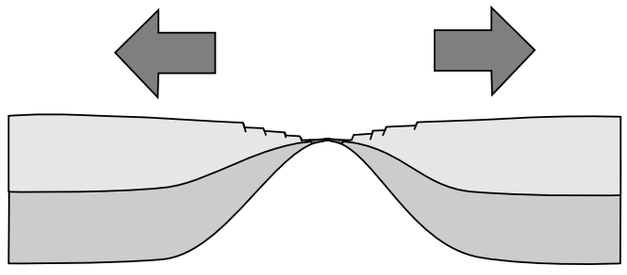
Stüwe, 2007

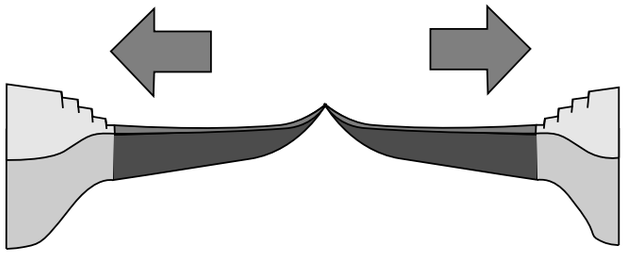
- The focus for this lecture will be on the lithosphere and the dynamic processes involved in its deformation and evolution

- Many of these processes can be directly linked to Plate Tectonics and the Wilson cycle

Rifting of the lithosphere

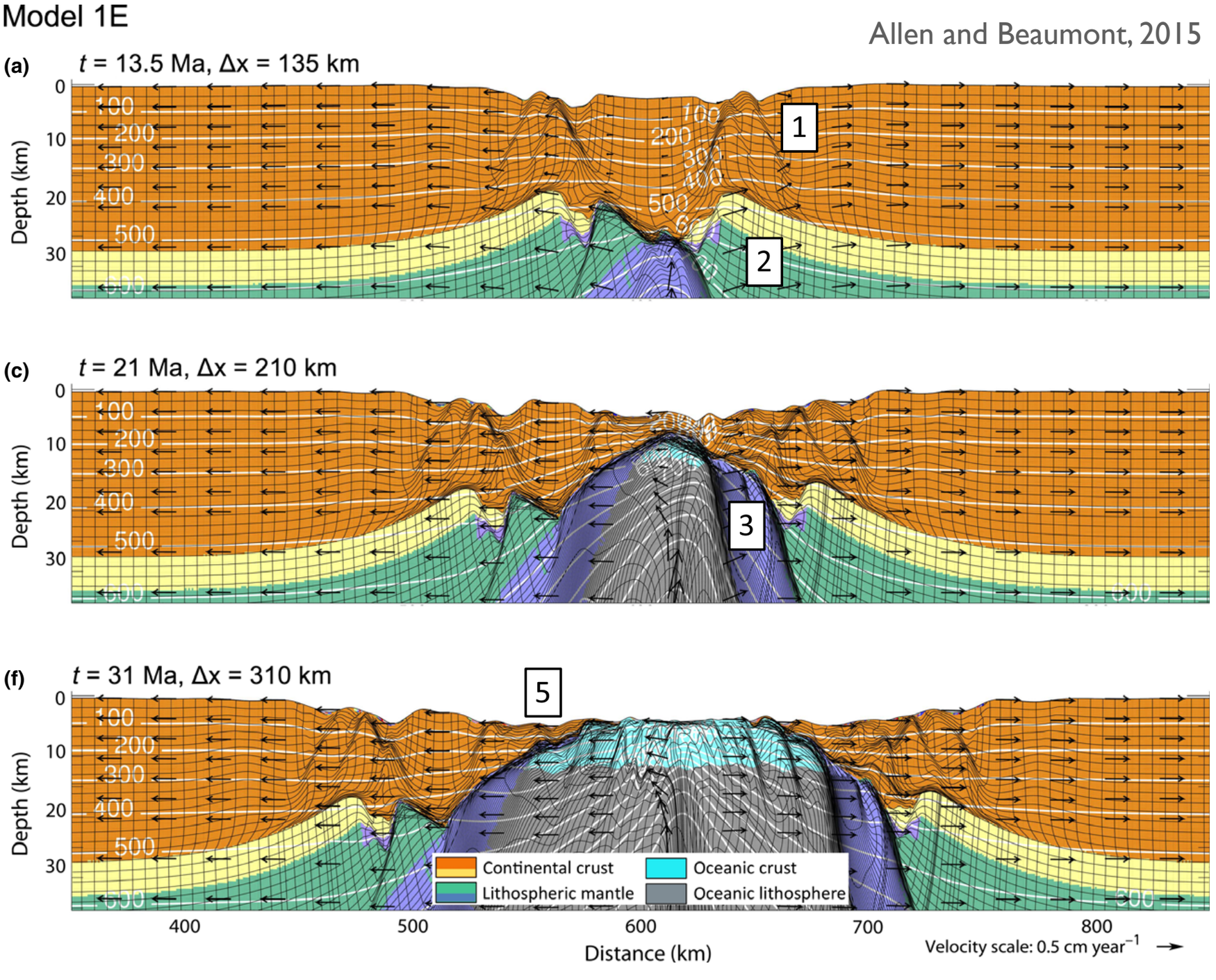




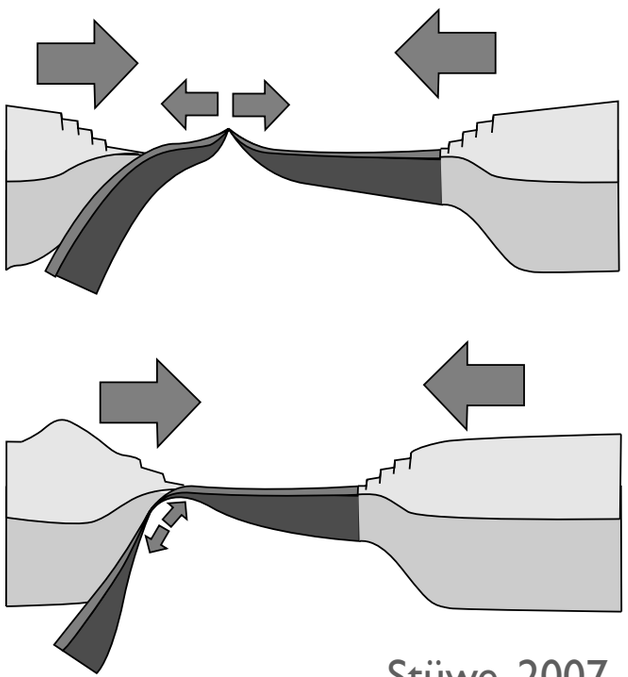


Stüwe, 2007

Allen and Beaumont, 2015

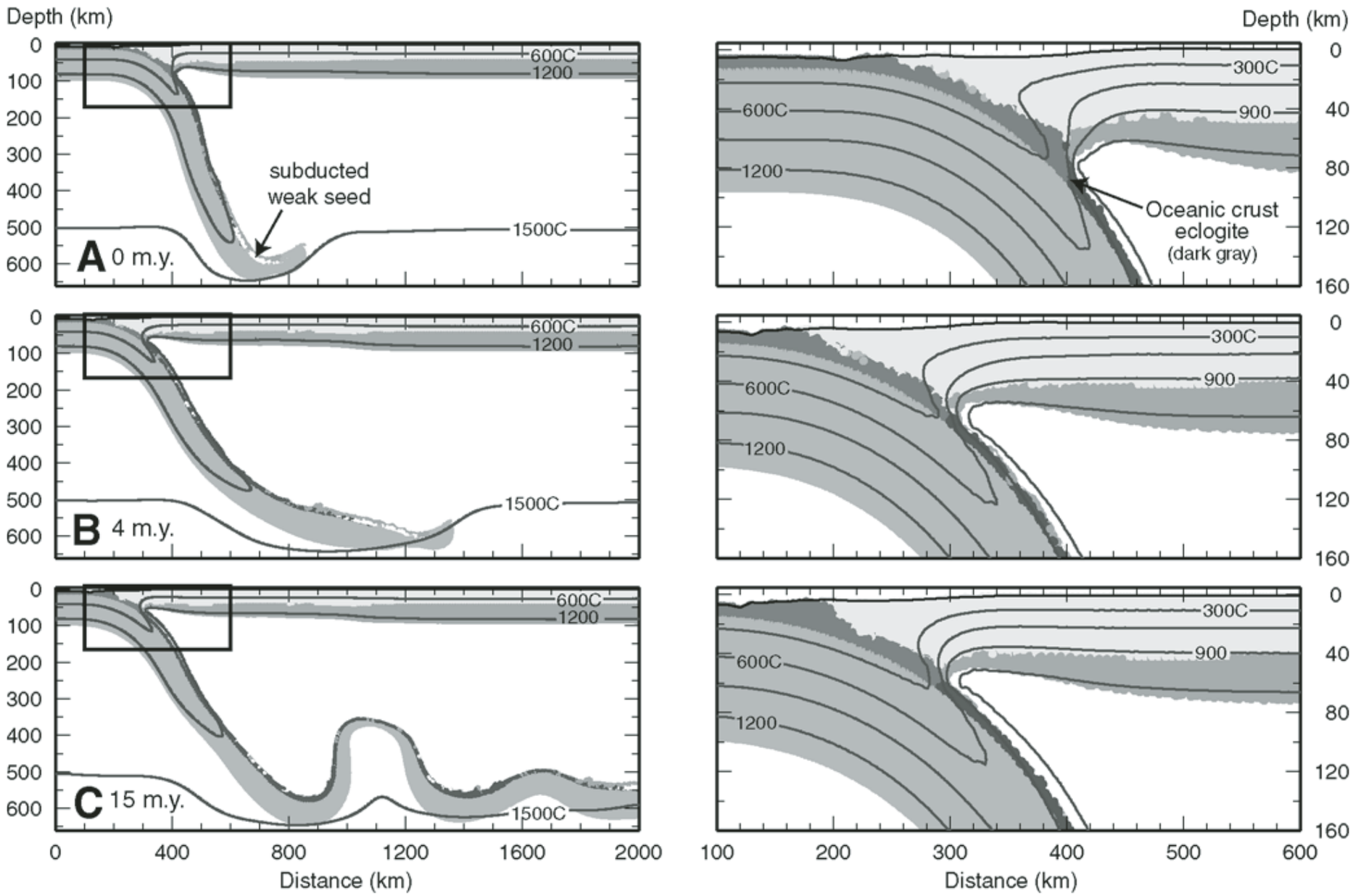


Oceanic subduction

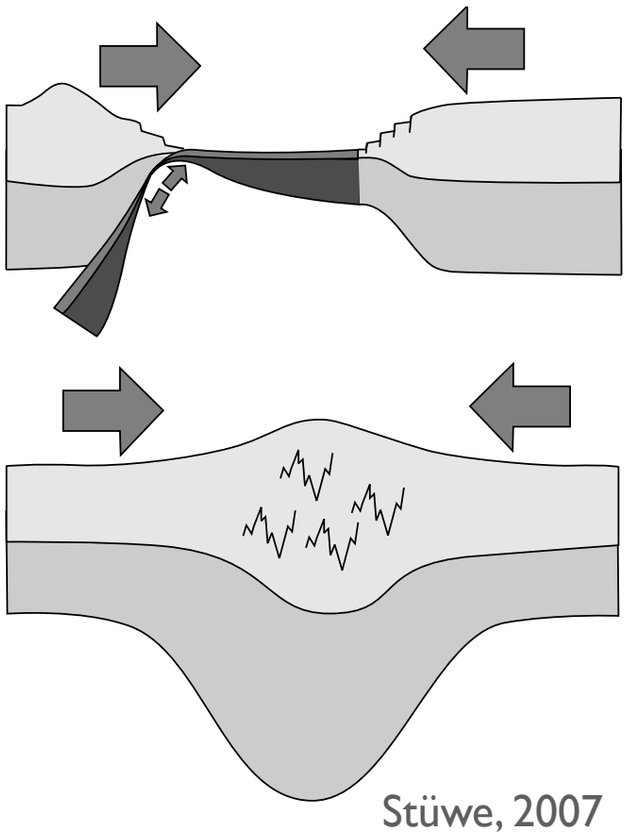


Stüwe, 2007

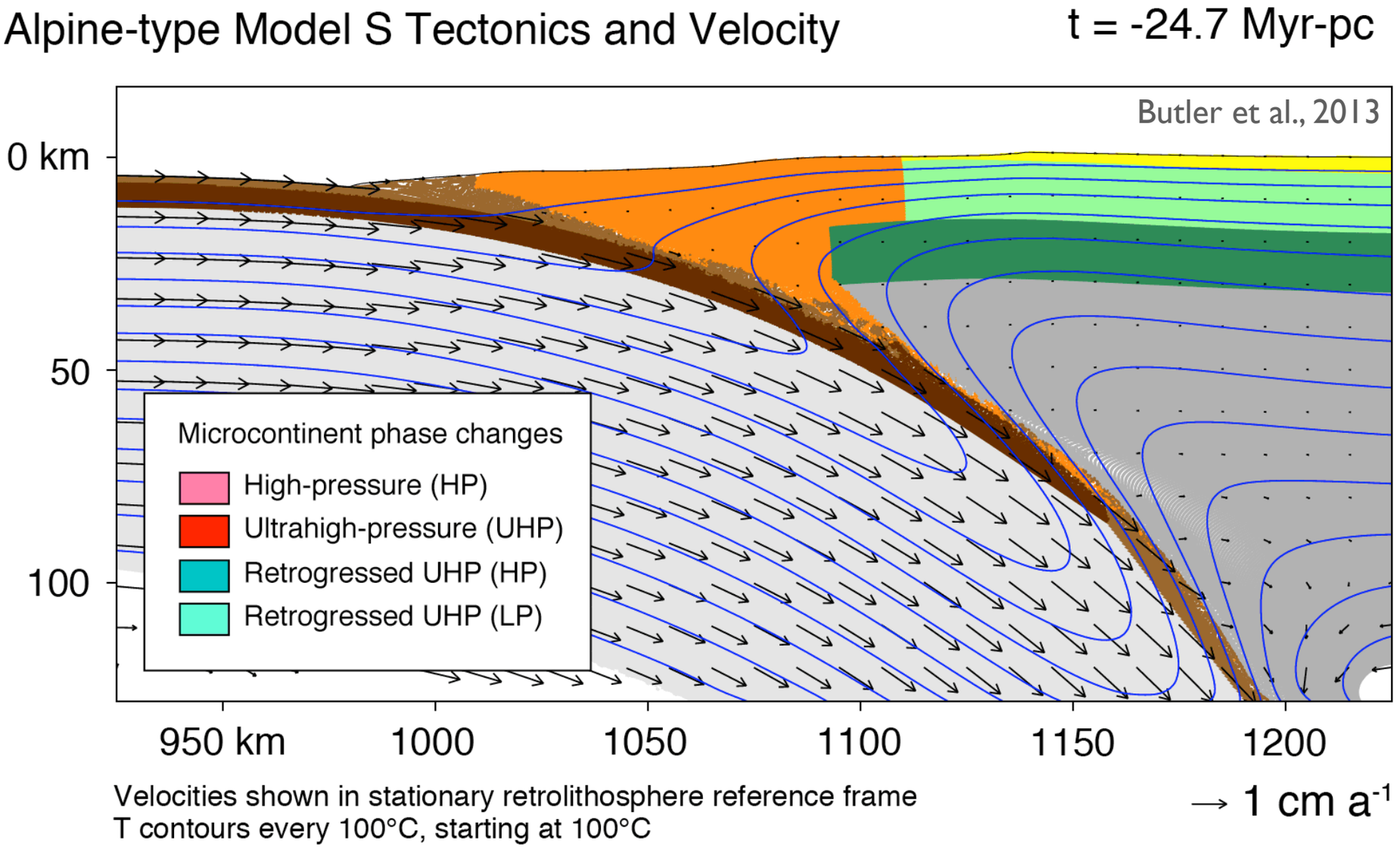
Currie et al., 2015



Continental collision



Stüwe, 2007



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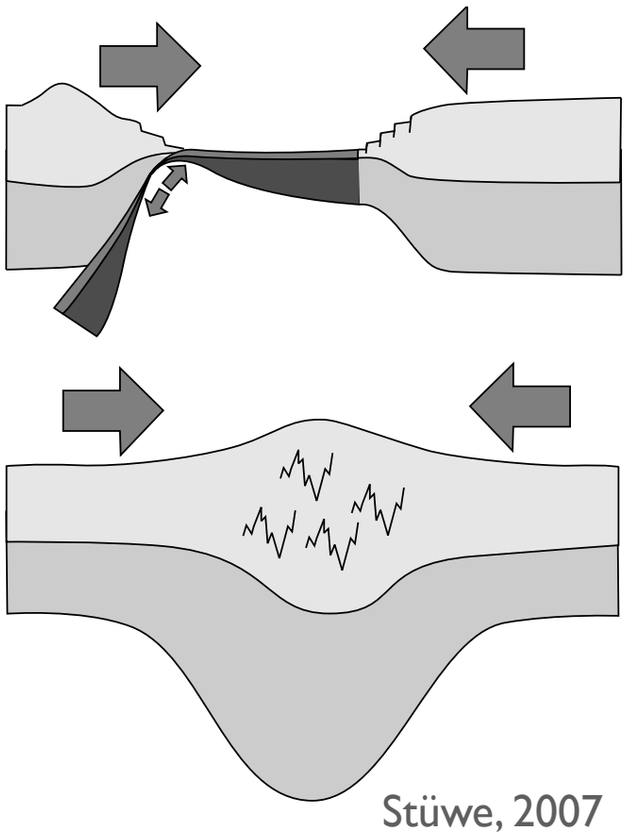
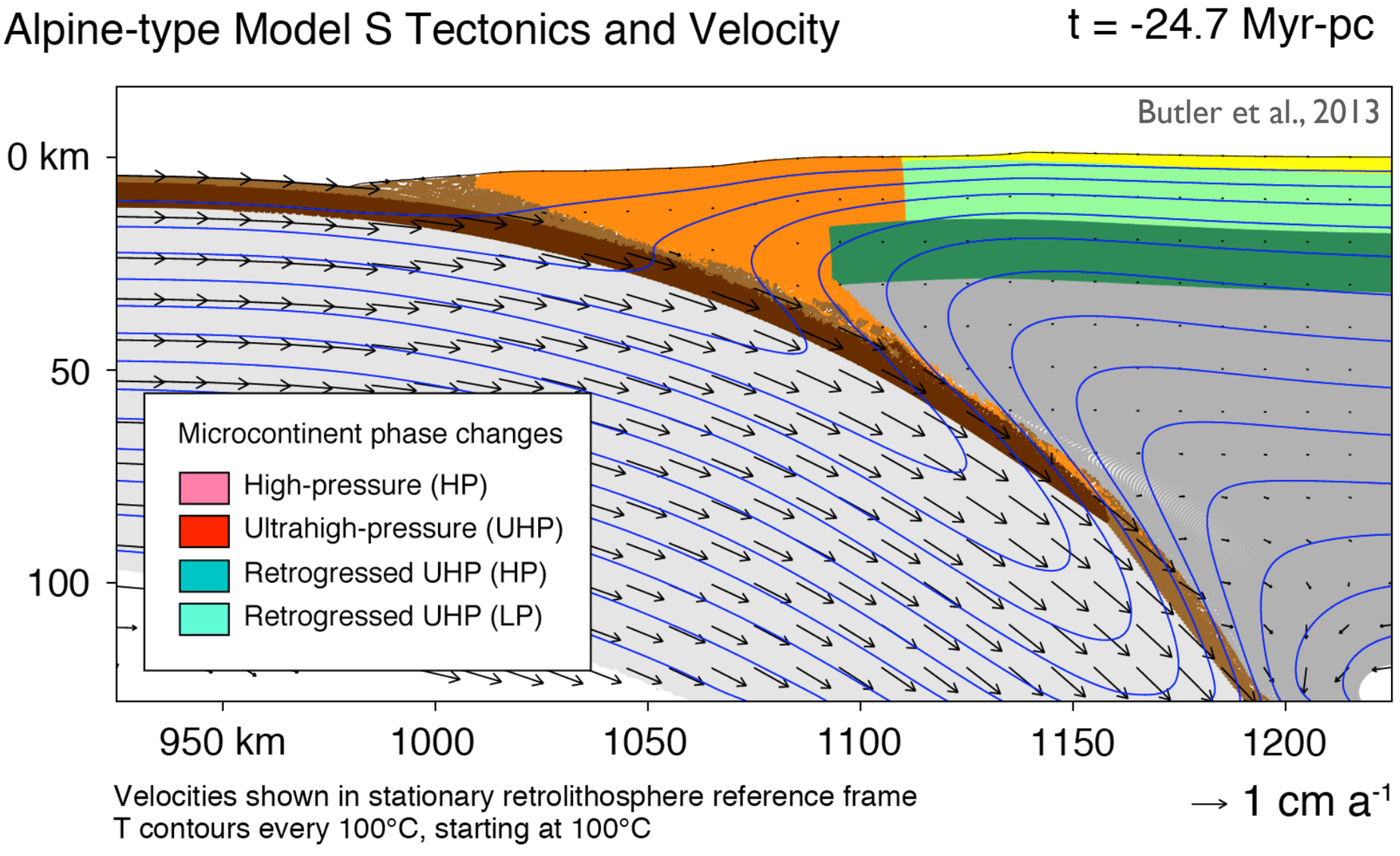
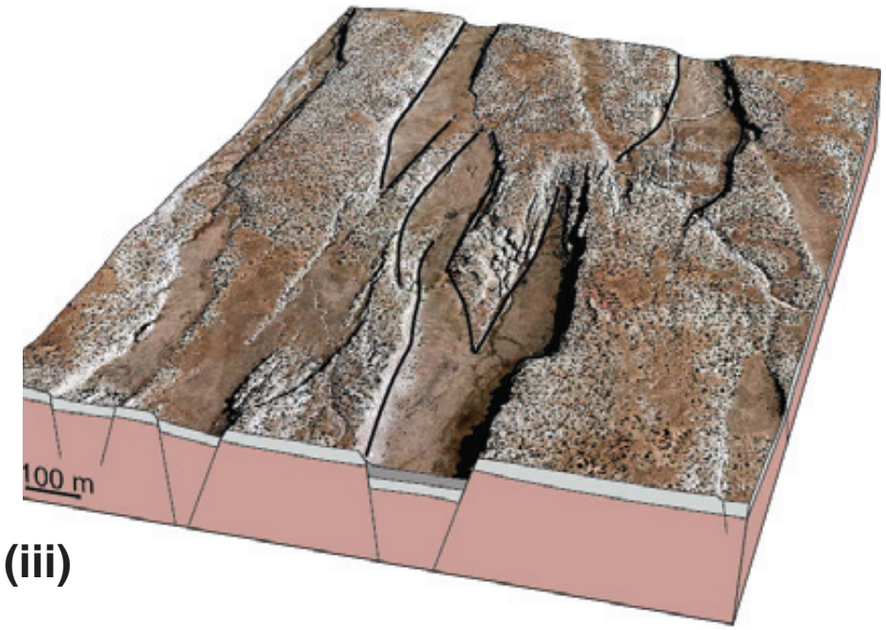


Stüwe, 2007



Toward three dimensions

Rifting



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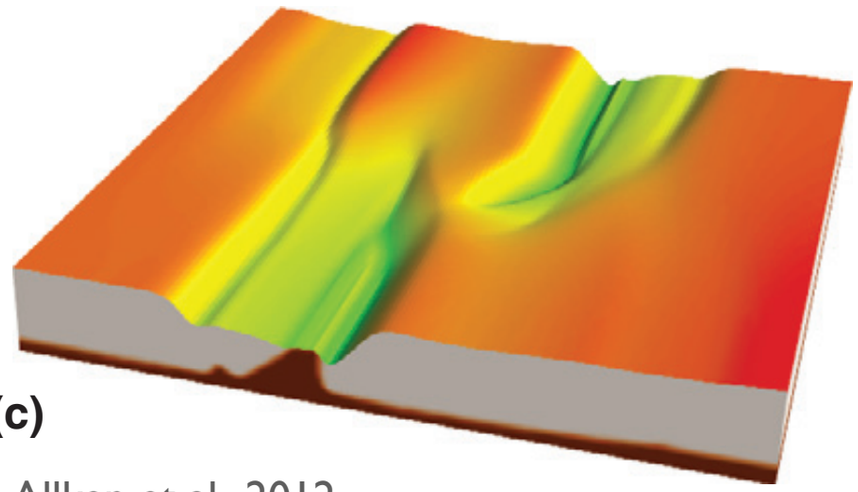

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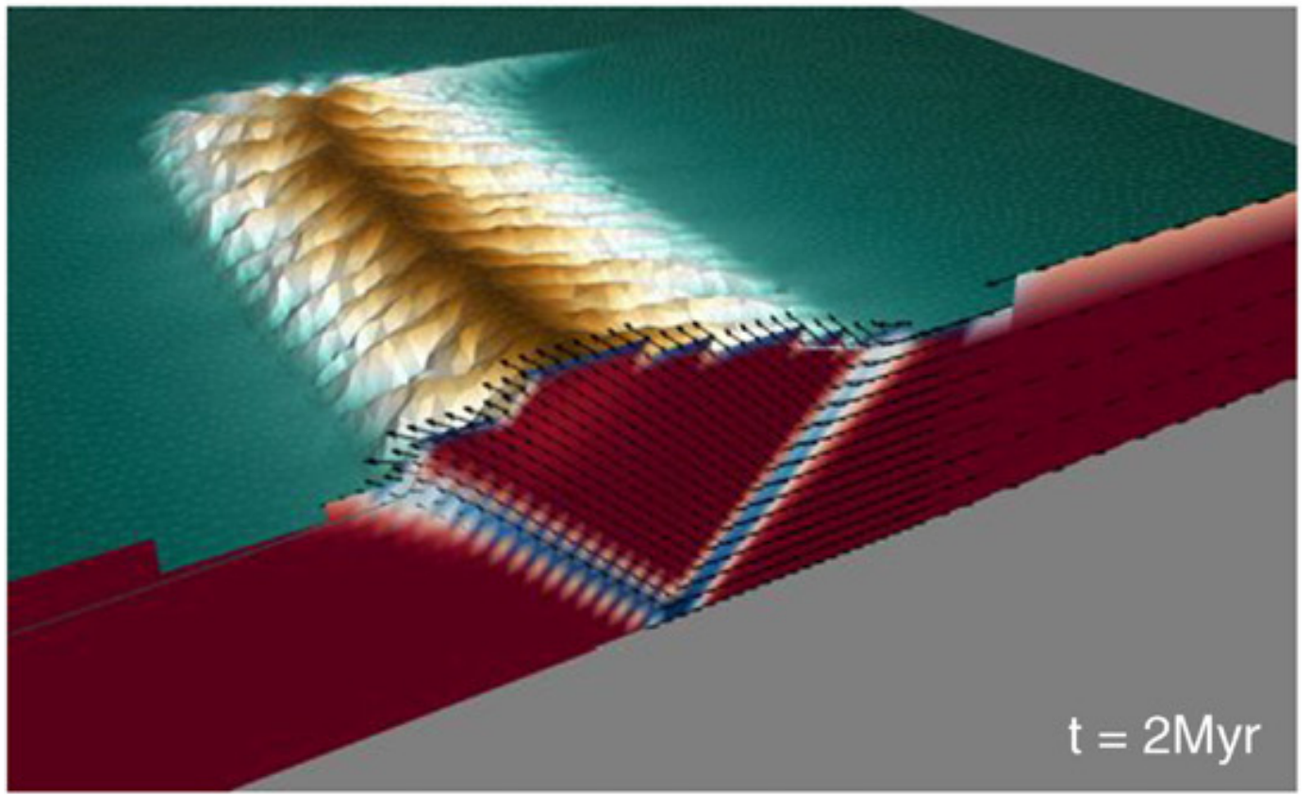
Allken et al., 2012

Continental collision



Braun and Yamato, 2010

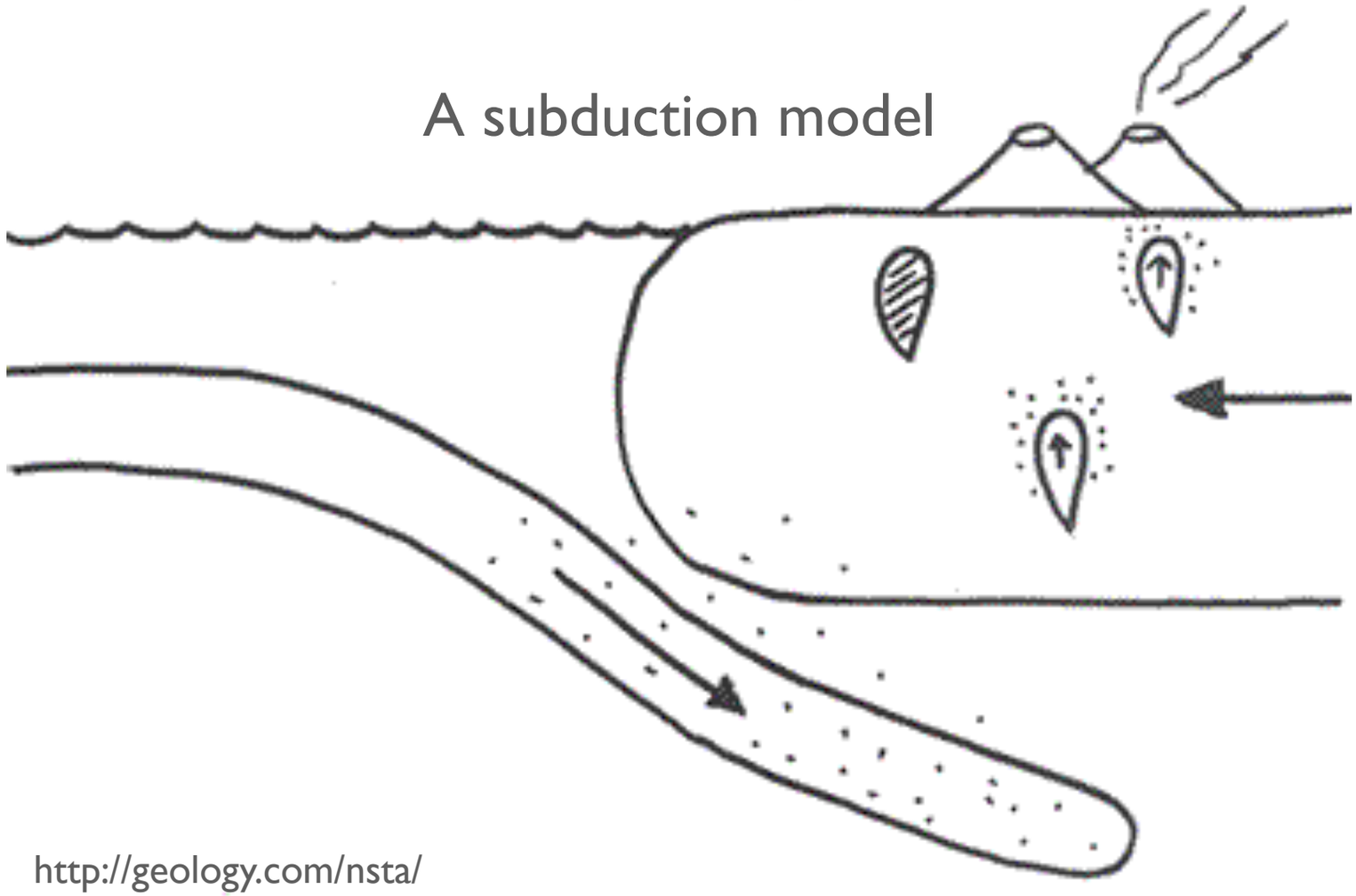
What is a model?

- "A **model** it tool used to describe the world around us in a *simplified way* so that we can *understand it better*"

  Stüwe, 2007

What is a model?

A subduction model



http://geology.com/nsta/

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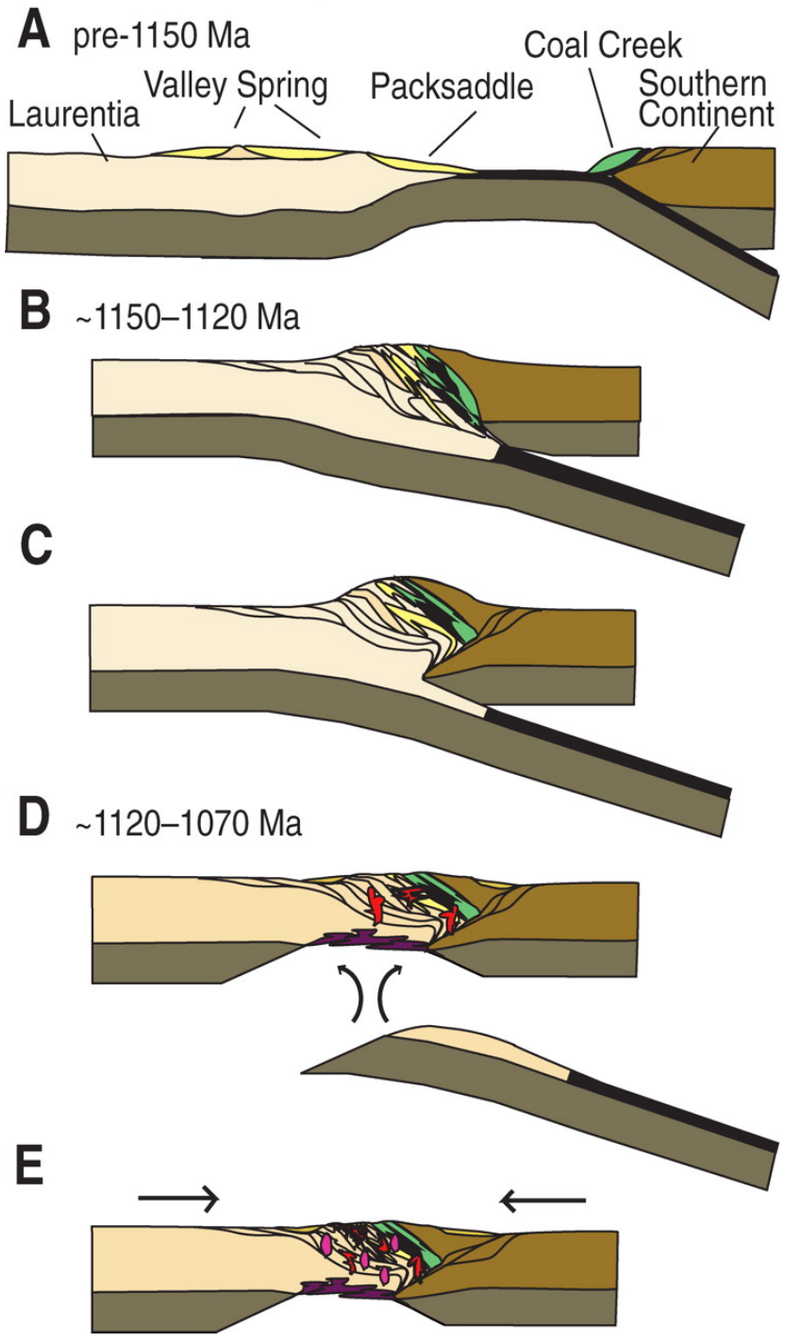
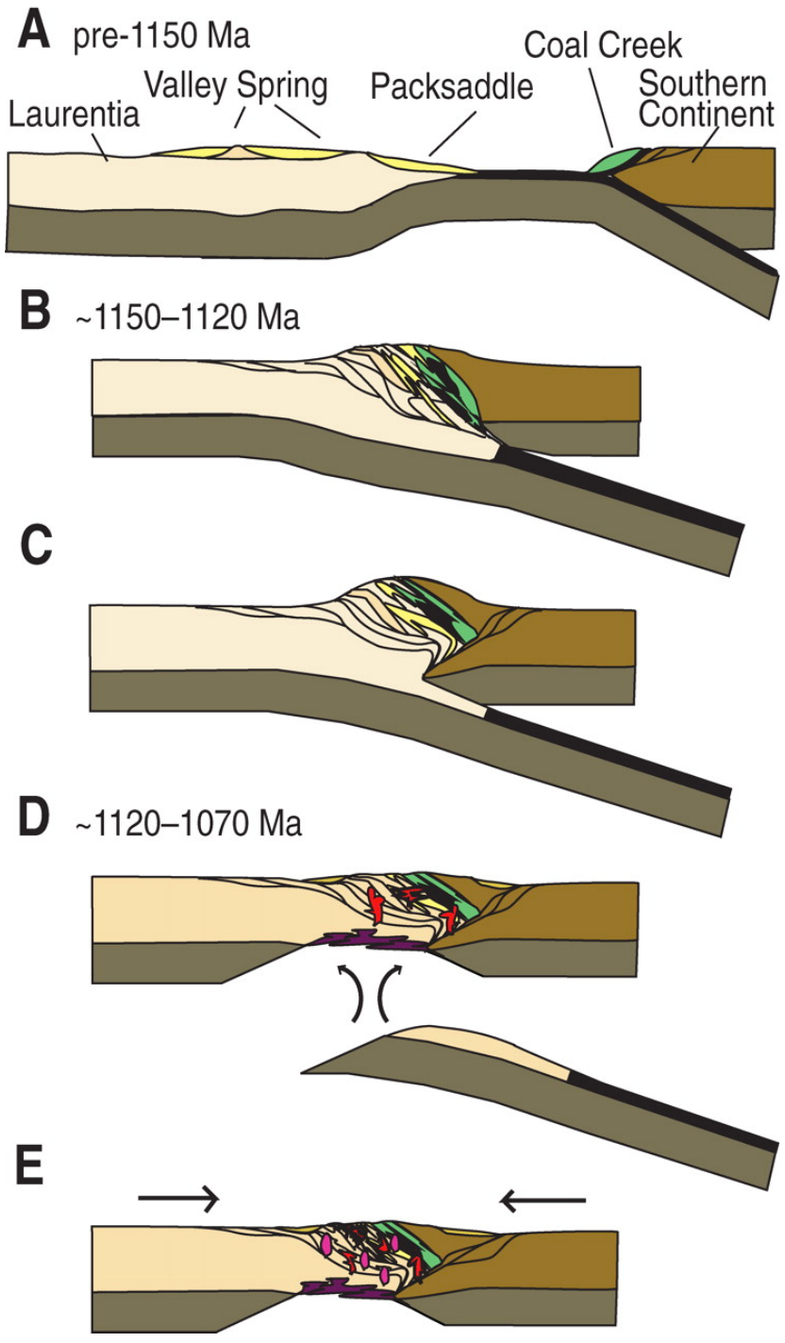
Types of geological models



- **Tectonic diagrams** are a familiar form of model to help clarify the time evolution of a study area
  - Typically this kind of model is used to simplify the complex modern geology and restore it to a pre-deformation state
  - These models, though, have no basis in physics

Mosher et al., 2008

Types of geological models



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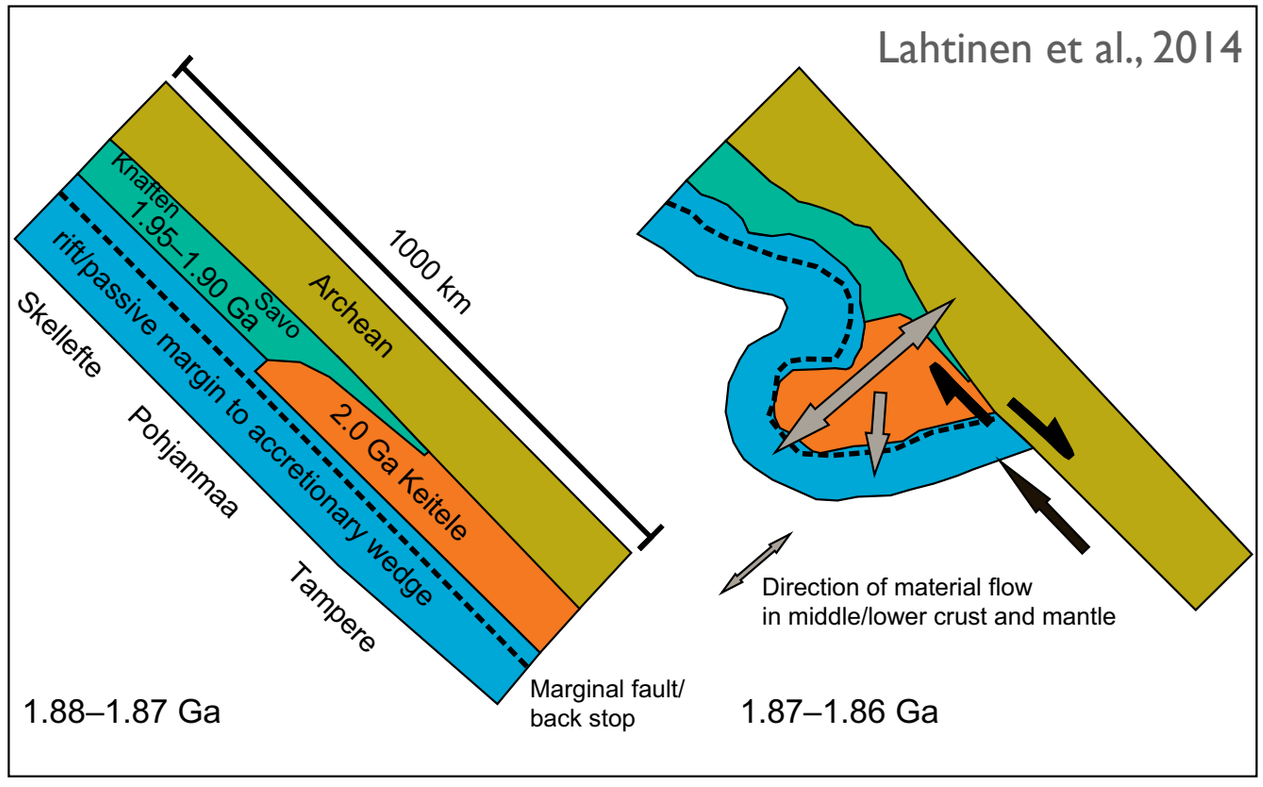

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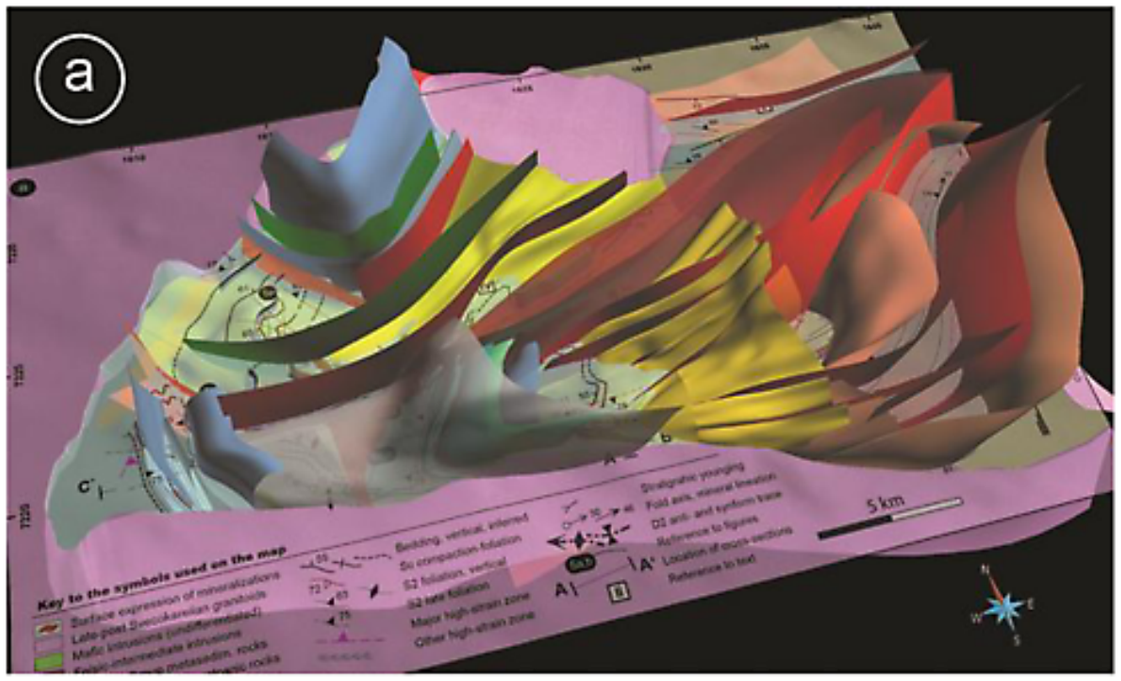
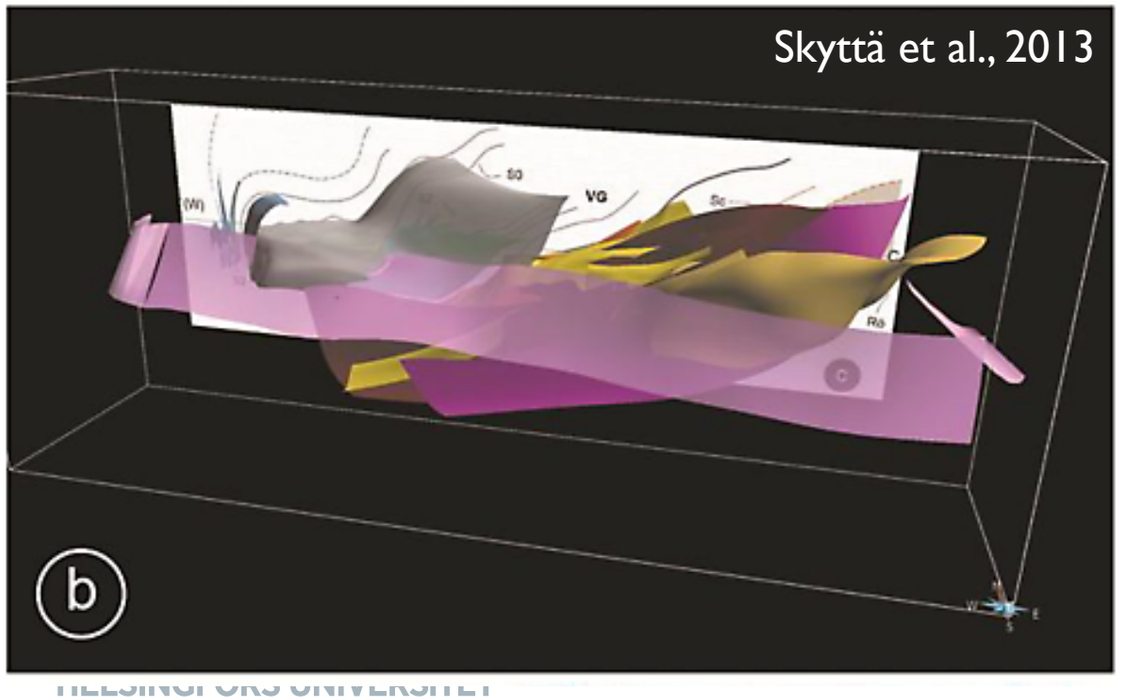
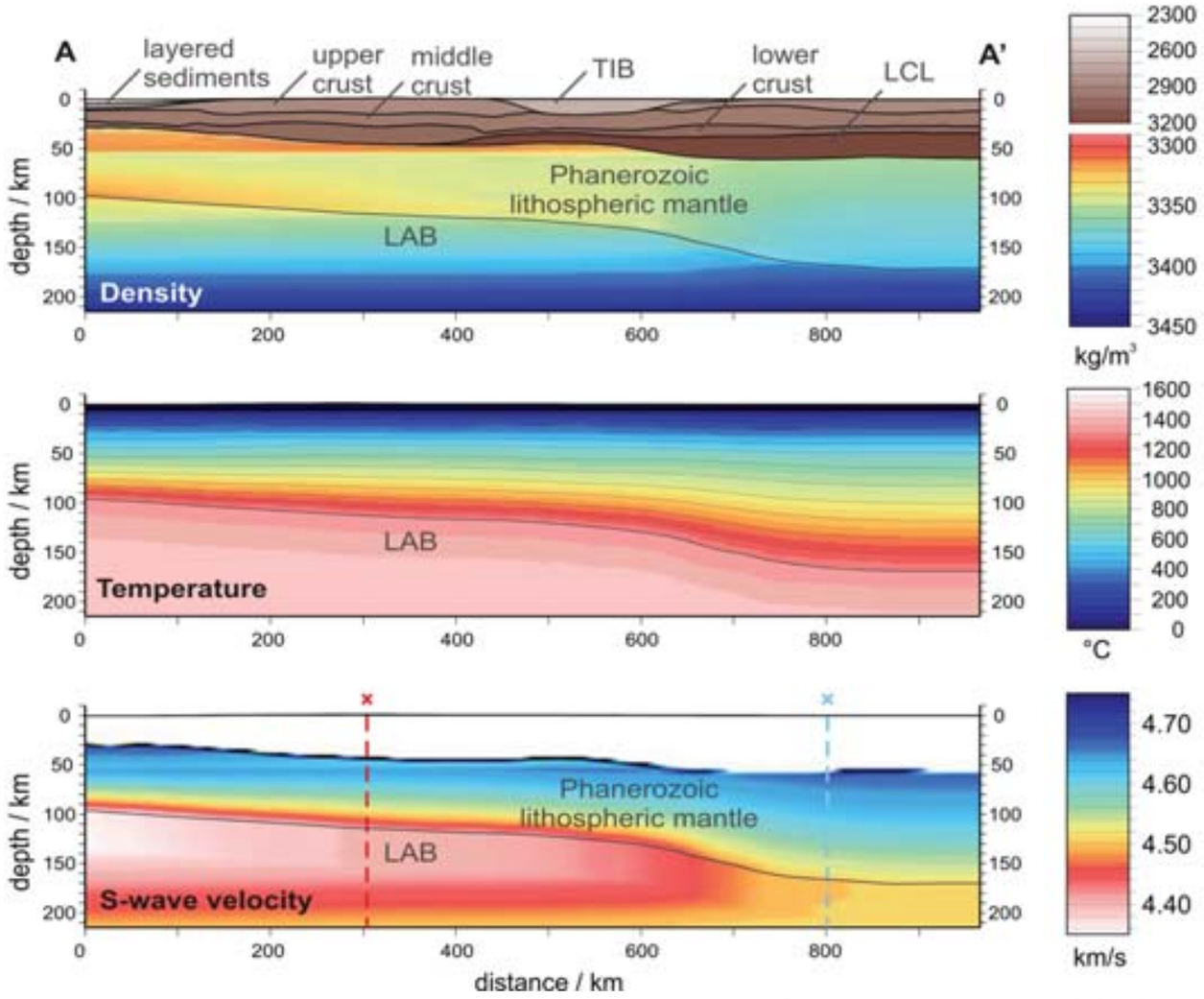




- **3D structural** or **geological models** are closer to reality in that they are based on a combination of surface and subsurface geological and geophysical observations
- The primary goal of these models is data visualisation, again helping us understand complex geometries
- Models of this type typically do not simulate physical processes

Integrated geophysical modelling

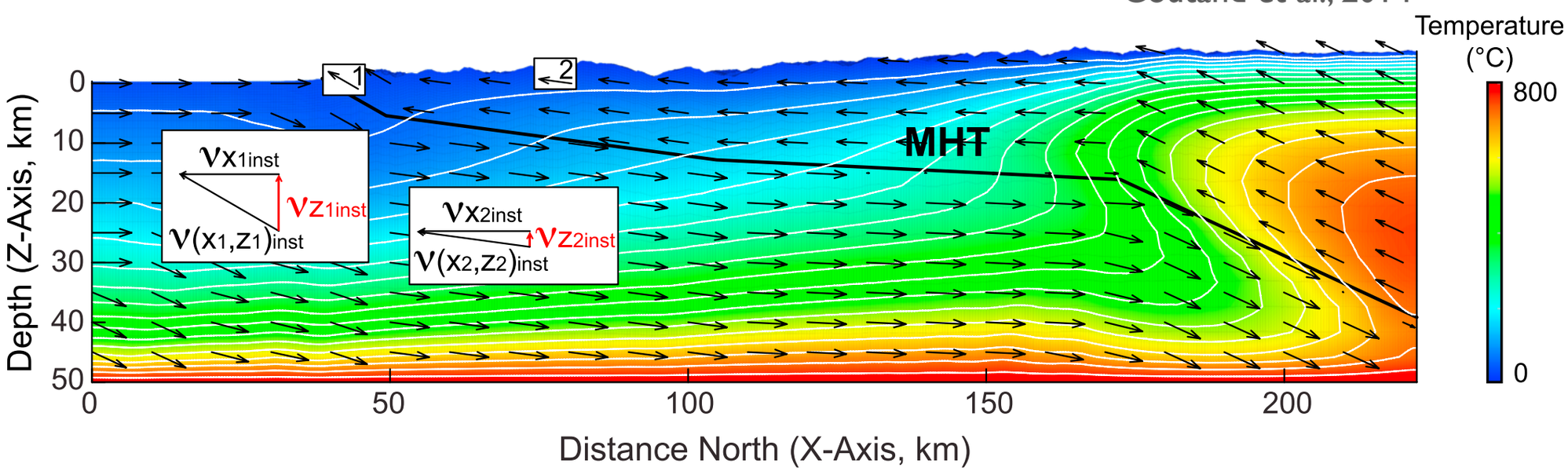


Gradmann et al., 2013

- **Integrated geophyiscal models** use a combination of an input crustal structure and composition, and rock thermal properties to calculate various properties of the lithosphere (gravity anomalies, seismic velocities, surface heat flow, etc.)
- These models involve a 2D or 3D geometrical model and calculation of heat transfer in the lithosphere and upper mantle

Types of geological models

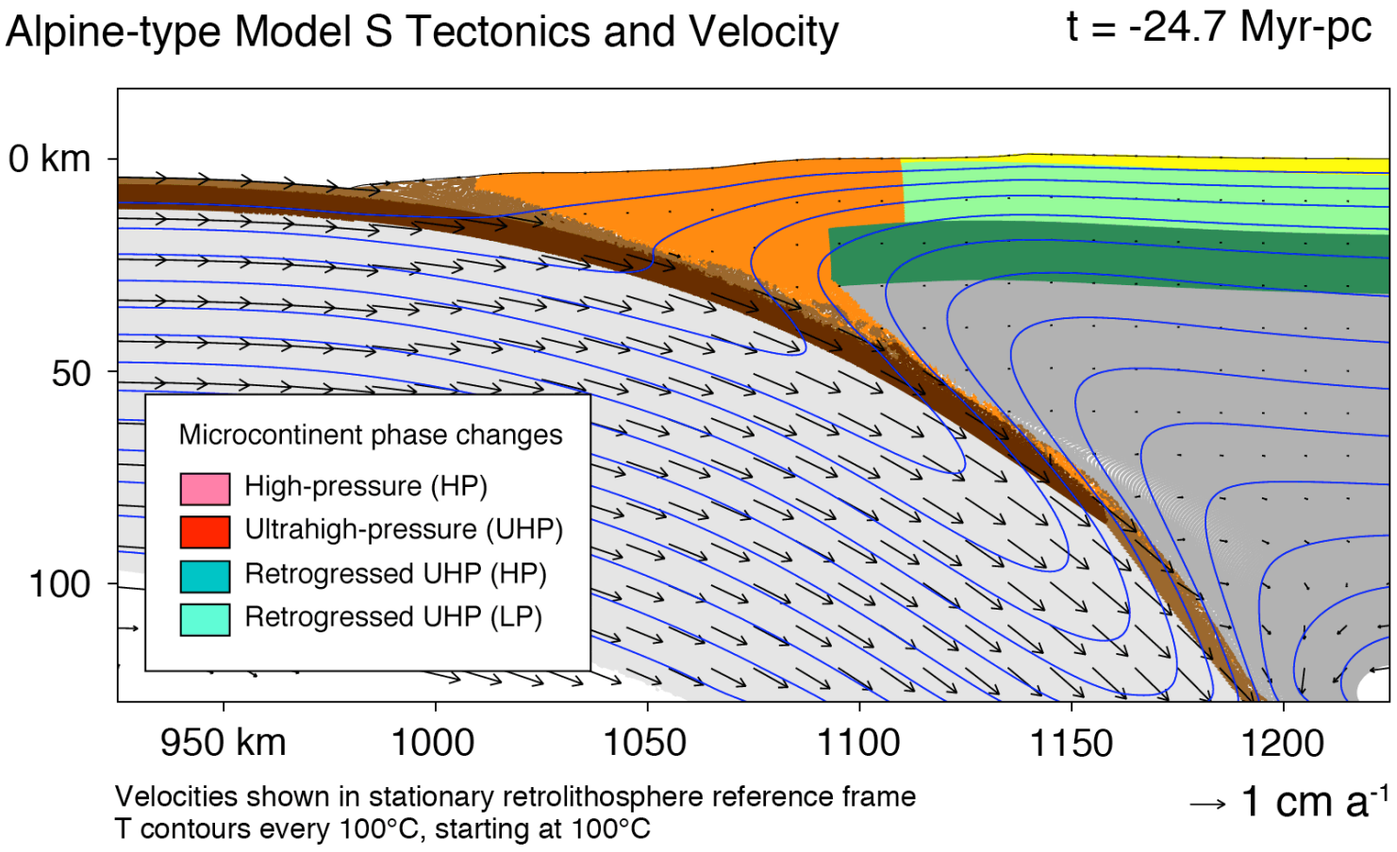
Coutand et al., 2014



- **Thermo-kinematic** (or **thermokinematic**) **models** simulate both mass transport and heat transfer using a pre-defined velocity field and input rock thermal/physical properties

- Models of this type can be compared to a number of observables, including surface heat flow and mineral cooling ages, and typically have a geometry based on surface geological observations and geophysical data such as reflection seismics

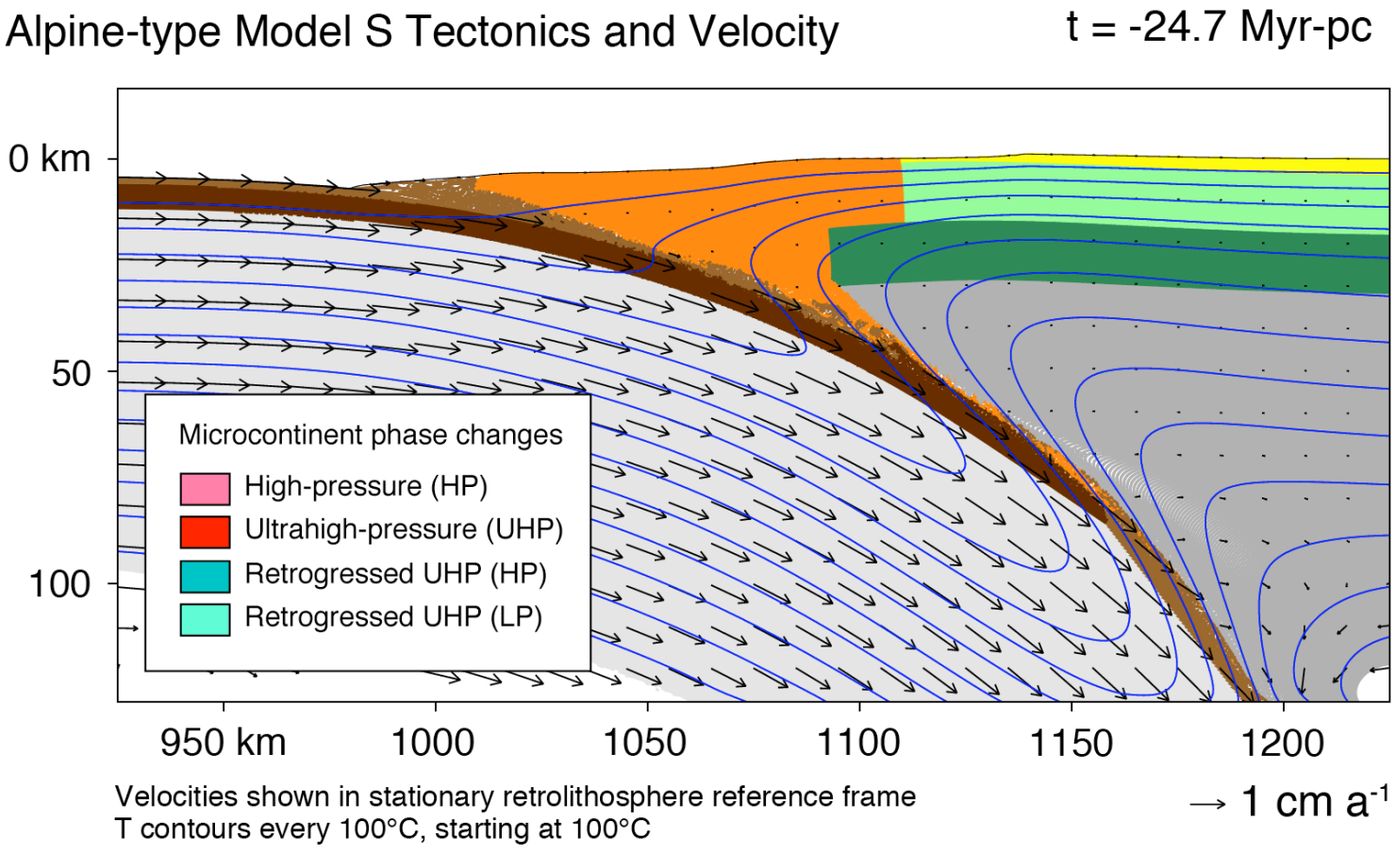
Types of geological models



Butler et al., 2013

- **Thermo-mechanical models** truly simulate lithospheric dynamics
  - Internal deformation in the model is determined based on the material properties of rock in the model and not prescribed
  - Heat transfer will vary as a result of model deformation, but also affect the model material properties

Types of geological models



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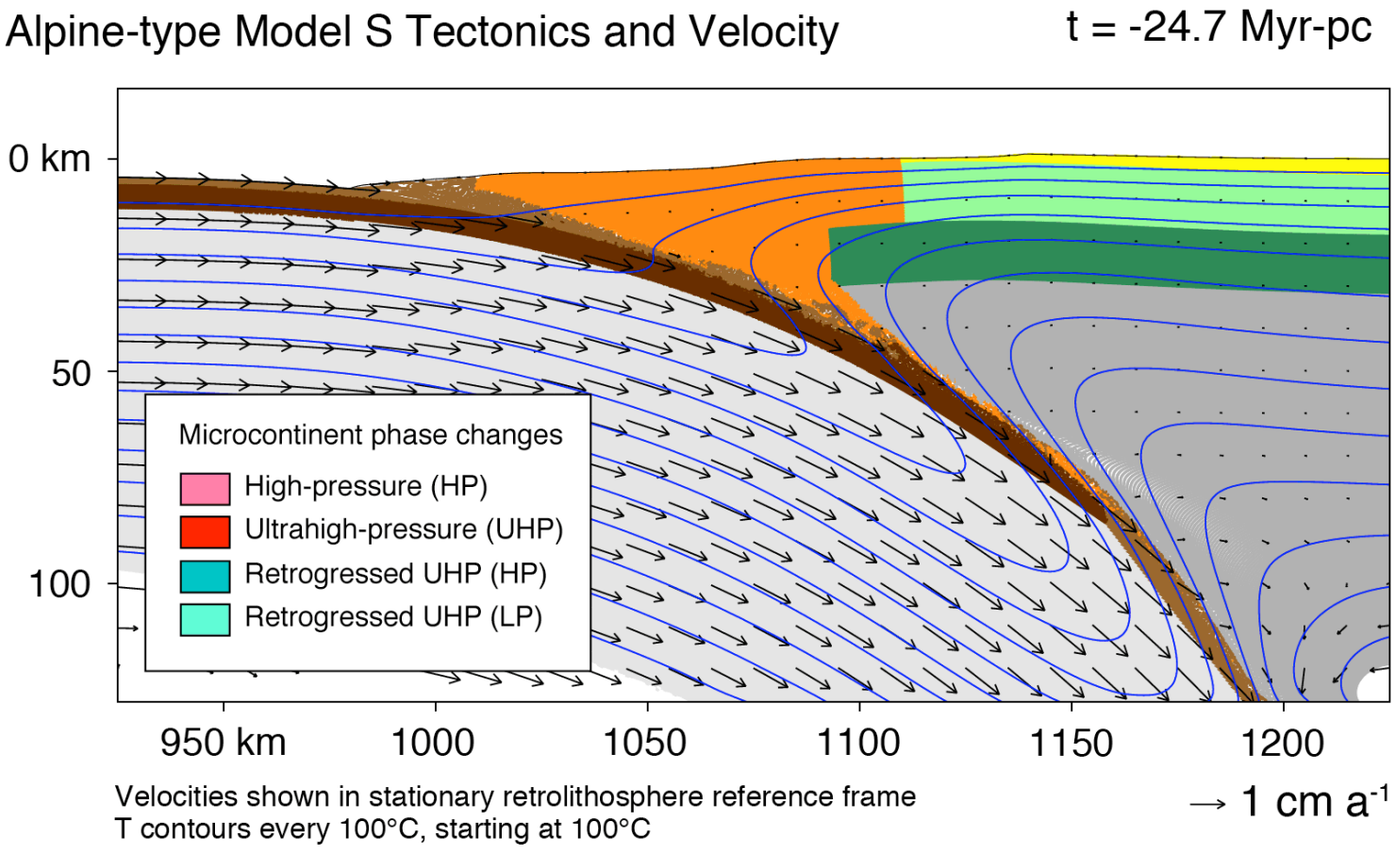

Butler et al., 2013

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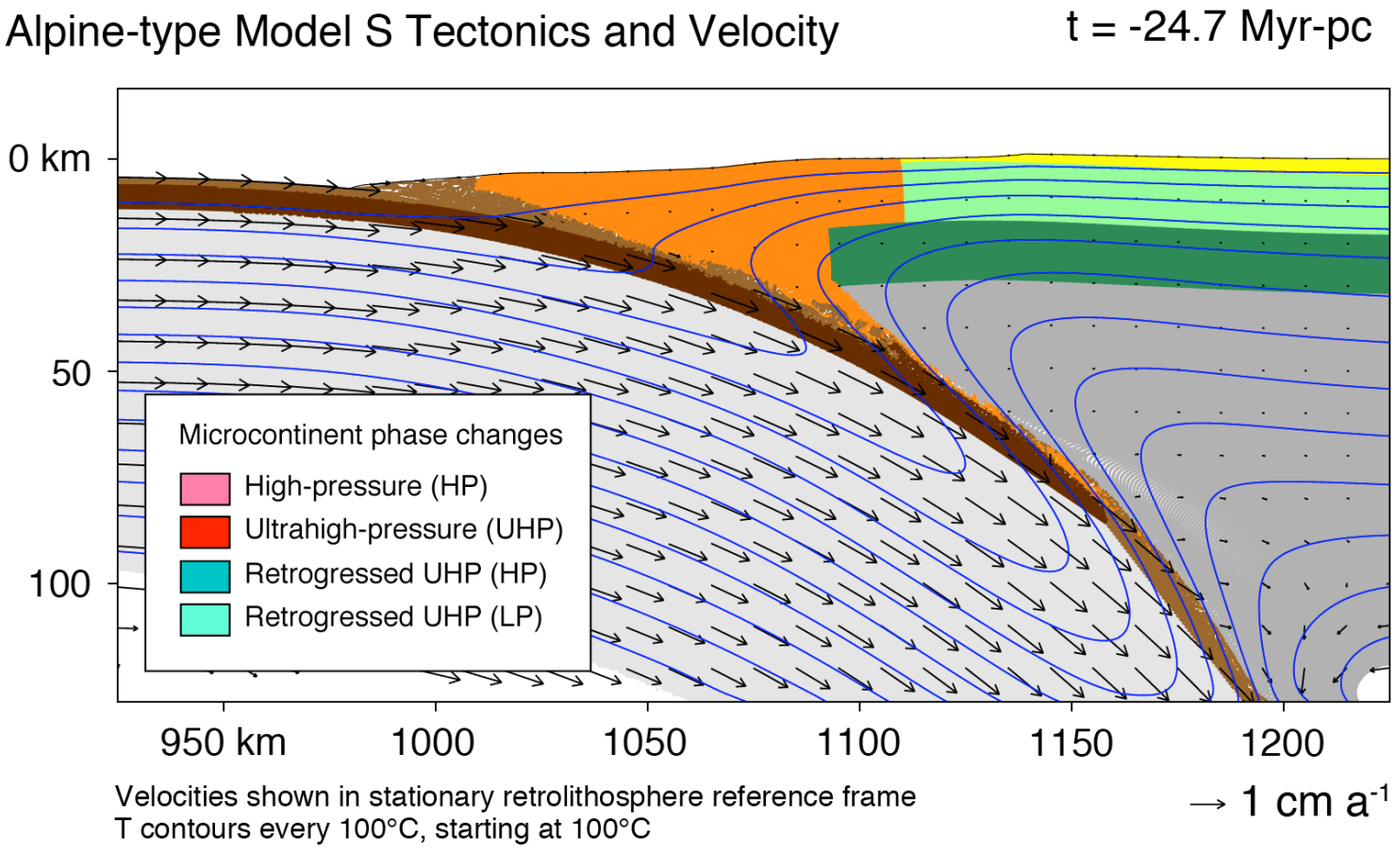
  - This type of model offers the greatest predictive power, but can be difficult to directly link to geological observations because the model evolution is not known *a priori*
- This kind of model is the focus for the remainder of this presentation

Types of geological models



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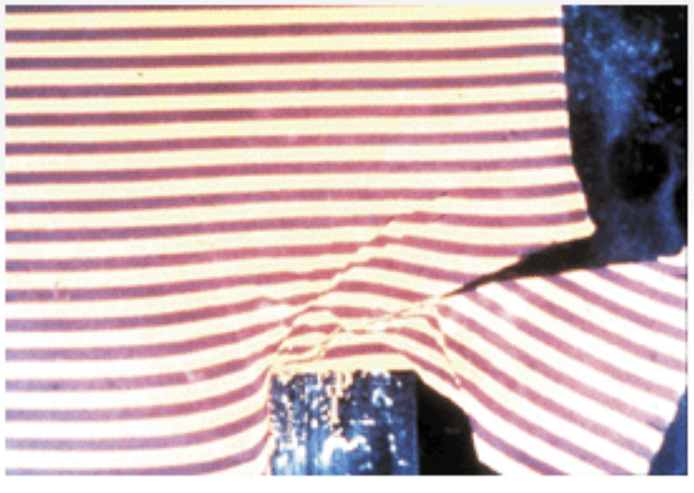
Analogue versus numerical models



Tapponnier et al., 1982

- **Analogue models** are an alternative to thermomechanical models where materials analogous to Earth materials are used to simulate deformation of the Earth in physical models

- These models do not prescribe any material behavior, but rather allow the material to deform subject to imposed deformation at the boundaries

- Though these are a viable alternative to numerical models, it is difficult to simulate temperature-dependent materials and scaling of the model properties can be a problem

Summary

- Geodynamic processes in the lithosphere are generally related to Plate Tectonics and include rifting, subduction and continental collision, among others
- Geodynamic numerical models allow us to study these processes over long natural timescales and for large amounts of deformation to better understand geological and geophysical observations

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