Thermo-mechanical subduction modeling with ASPECT

Menno Fraters (1), Anne Glerum (1), Cedric Thieulot (1,2), Wim Spakman (1,2)
(1) Utrecht University, Geosciences, Earth Sciences, Utrecht, Netherlands (menno.fraters@outlook.com)
(2) Centre of Earth Evolution and Dynamics, Oslo, Norway
Utrecht University

Introduction

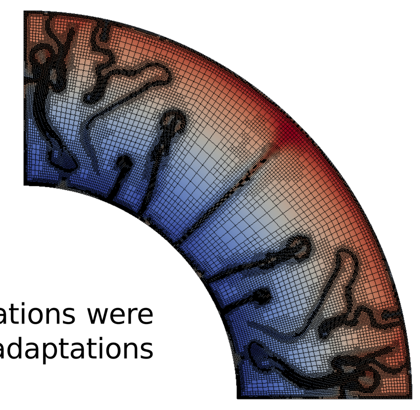
We have investigated the coupling between the earth's mantle and lithosphere in a subduction and rollback setting in the Western Mediterranean. The research presented here is the work of a master project of a year.

The project consists of two parts:
1) Development of a general subduction model for ASPECT;
2) Application of this model to the Western Mediterranean subduction and rollback setting.

ASPECT

ASPECT (Advanced Solver for Problems in Earth's ConvecTion, Kronbichler et al., 2012) is a new and modern numerical code mainly designed for convection problems. It has, among others, the following advantages and properties:

1) Modern numerical methods: linear and nonlinear solvers, stabilization of transport-dominated processes
2) Adaptive mesh refinement
3) Built from the ground up for parallelism
4) Trivial to go from 2D to 3D
5) Built upon well maintained and supported liberies: deal.II, Trilinos and p4est



Because ASPECT has been built as mantle convection software, several large adaptations were required to enable the study of the coupling of the mantle and lithosphere. These adaptations have been partly done by Anne Glerum and partly by the developers of the code.

Towards the Western Mediterranean setting

At 50 Ma in the Western Mediterranean Sardinia and Corcica were connected to Eurasia (France and Spain). On the east margin of the landmass there was a subduction zone (Figure 1).

85 Ma: Start of (slow) convergence between Africa and Iberia
45 Ma: Start of significant convergence between Africa and Iberia
38-34 Ma: Slab reached 100-150 km below Sardinia
30 Ma: Initiation of rollback below Sardinia

Sardinia and Corsica were pulled of Eurasia (Figure 1). The goal of the tectonic reconstruction is to acquire a block like behavour as can be seen in Figure 2.

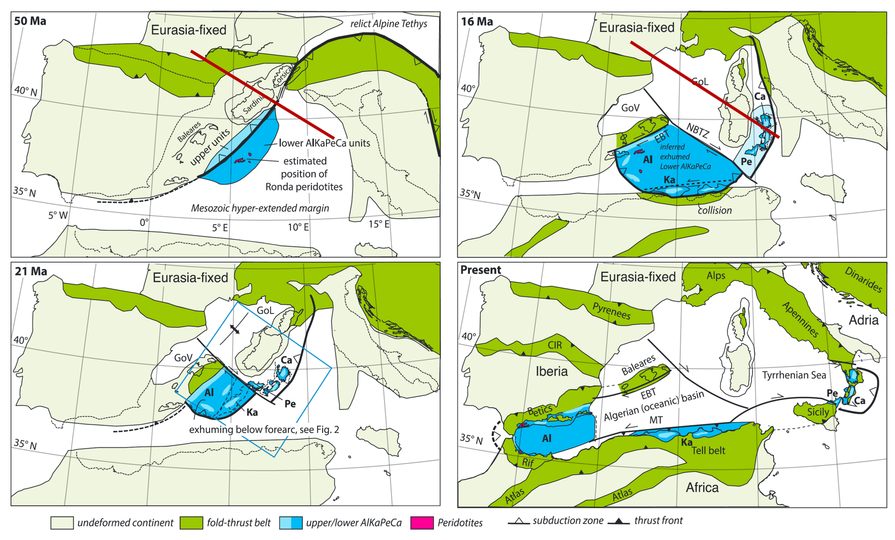


Figure 1: Western Mediterranean evolution, 50 Ma - present (van Hinsbergen et al., 2014). The red line indicates the approximate position of the 2D transect.

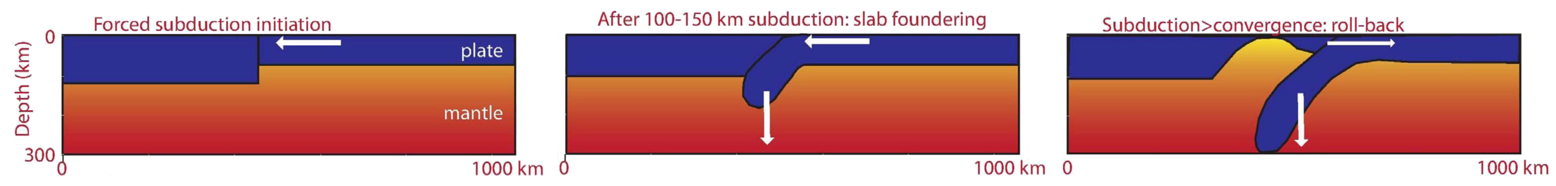


Figure 2: Schematic model of processes of Western Mediterranean (Van Hinsbergen et al., 2014).

Part 1: General subduction modeling with ASPECT

Model setup

For this problem a 2D model is used. ASPECT works with compositional fields. These are fields with the same rheological properties and have a value of 1 inside the field, and 0 outside the field. Table 1 shows the material properties of the different rheological fields, and Figure 3 shows the model domain with the starting distribution of the compositional fields.

The temperature field is defined by an adiabatic mantle temperature, a constant temperature (273 K) for the air, a linear lithosphere temperature (from 273 K to the adiabatic mantle temperature) and a McKenzie (1970) temperature for the slab.

The viscosity is defined by a visco-plastic rheology (dislocation creep, diffusion creep and plasticity).Boundary conditions: the bottom is free-slip, the sides get a velocity and the top is open.

Composition	Material
C1: Mantle	Dry olivine
C2: Subducting plate crust	Heavy wet quartzite
C3: Overriding plate crust	Wet quartzite
C4: Sticky air	High viscosity air

Table 1: Materials in the model.

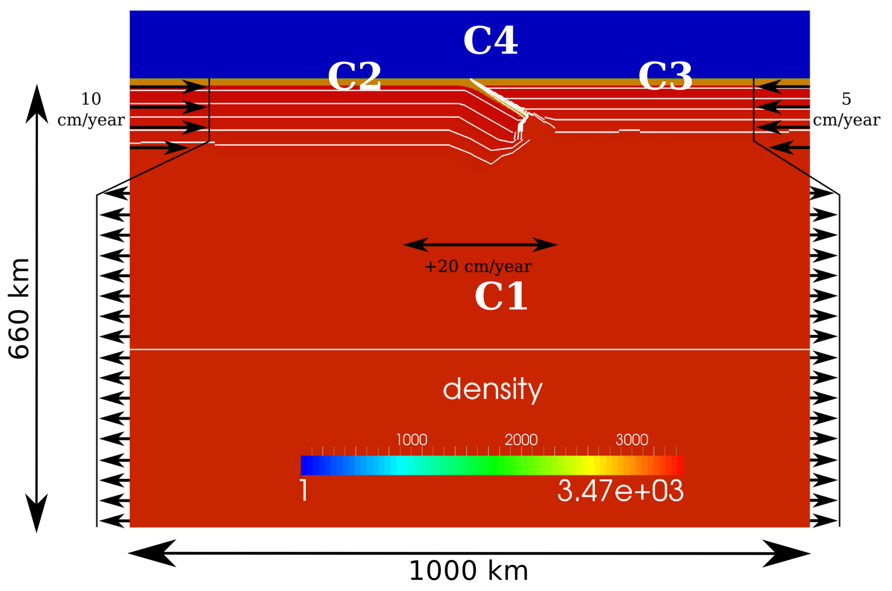


Figure 3: The model setup with 4 components at time 0, showing the density field, temperature isocontours from 500K with steps of 250K, and the prescribed velocity with arrows.

Model results

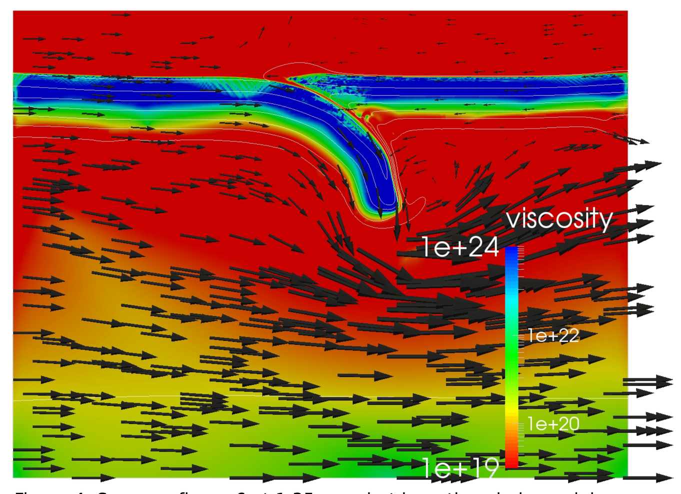


Figure 4: Same as figure 6 at 1.35 myr, but here the whole model is shown with flow arrows.

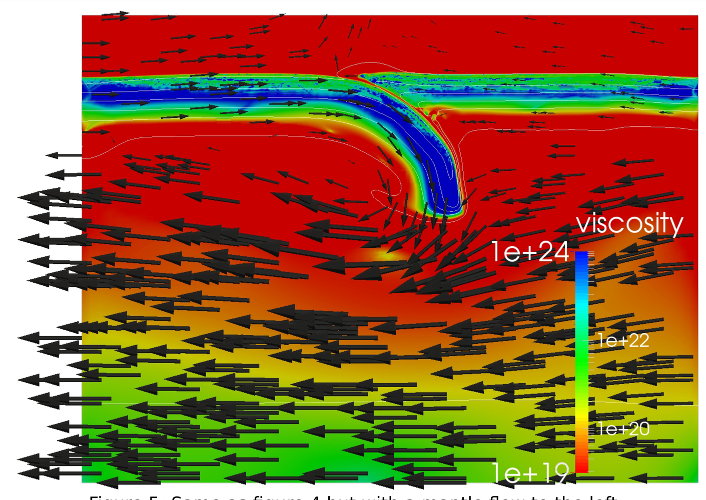


Figure 5: Same as figure 4 but with a mantle flow to the left.

- Clear shear bands visible in the upper lithosphere

- Shear bands are located at expected places: bending of subducting and overriding plate,

- Topography building (min/max 6 km),

- Detachment of crust material in subduction zone,

- Viscosity of upper mantle directly under the lithosphere very dependent of stress produced by the subduction process.

Part 2: Slab detachment and the influence of weak zones

Model setup

We now make a model to represent the western Mediterranean initial setting.

- The height has remained the same, but the model is now 1000 km long.

- The thicknesses of the crust of the subducting plate (oceanic) and overriding plate (continental) have been changed to 7 km and 38 km respectively.

- The density of the crust of the oceanic plate has been slightly increased to 3000 kg/m^3 (+100 kg/m^3).

- A lithospheric weakzone is placed in the overriding plate in setup B.

The Adaptive Mesh Refinement (AMR) in these models is dependent on the temperature, composition, strainrate and user defined areas.

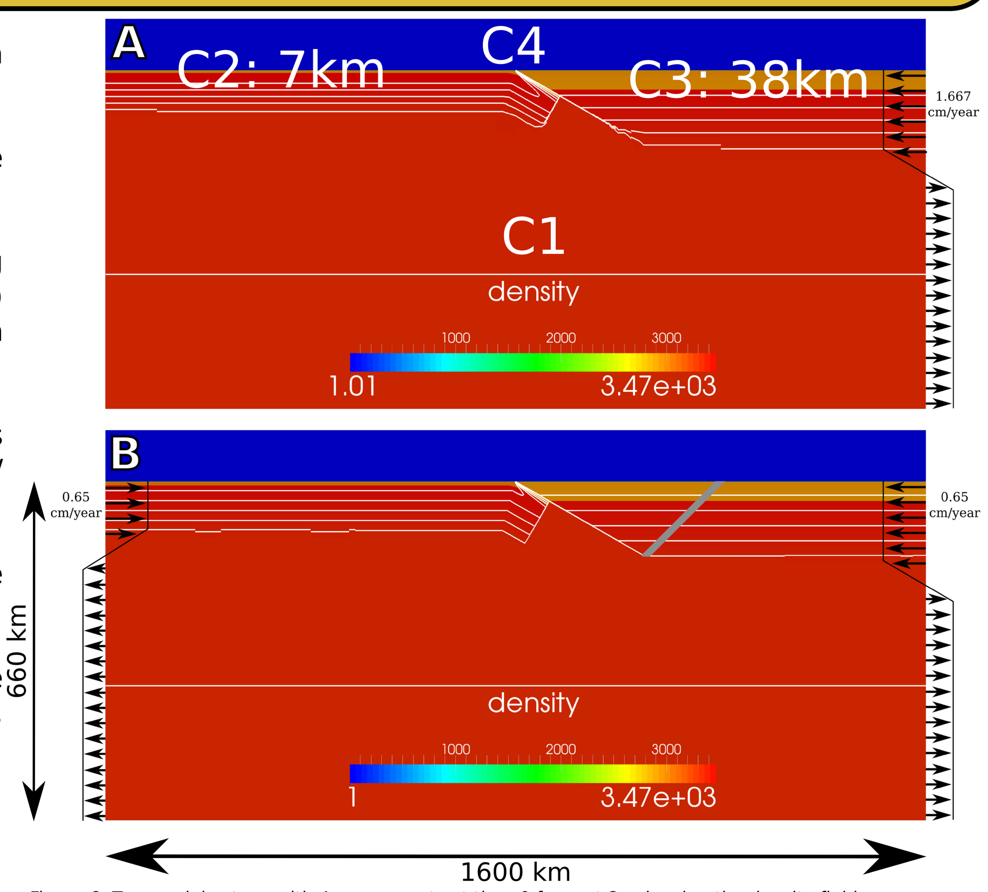


Figure 6: Two model setups with 4 components at time 0 for part 2., showing the density field, temperature isocontours from 500K with steps of 250K, and the prescribed velocity with arrows. The grey area in setup B indicates the position of the weak zone.

Model results (work in progress)

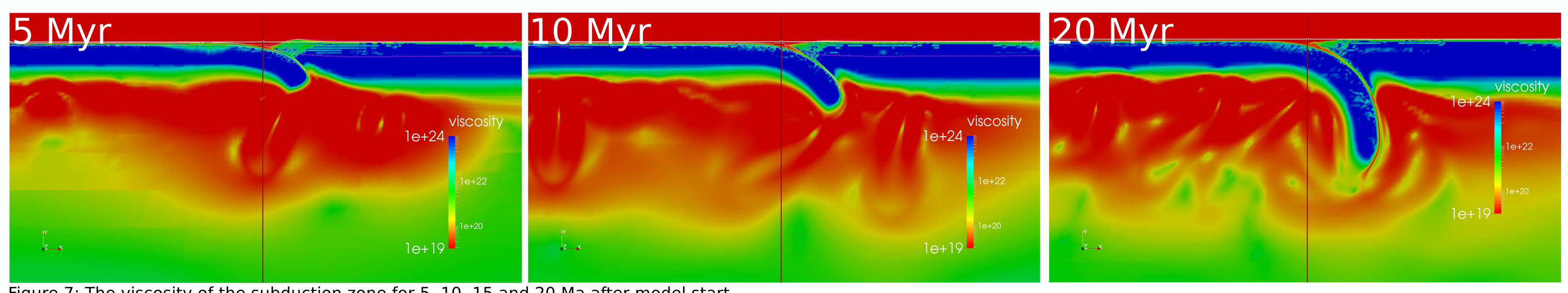


Figure 7: The viscosity of the subduction zone for 5, 10, 15 and 20 Ma after model start.

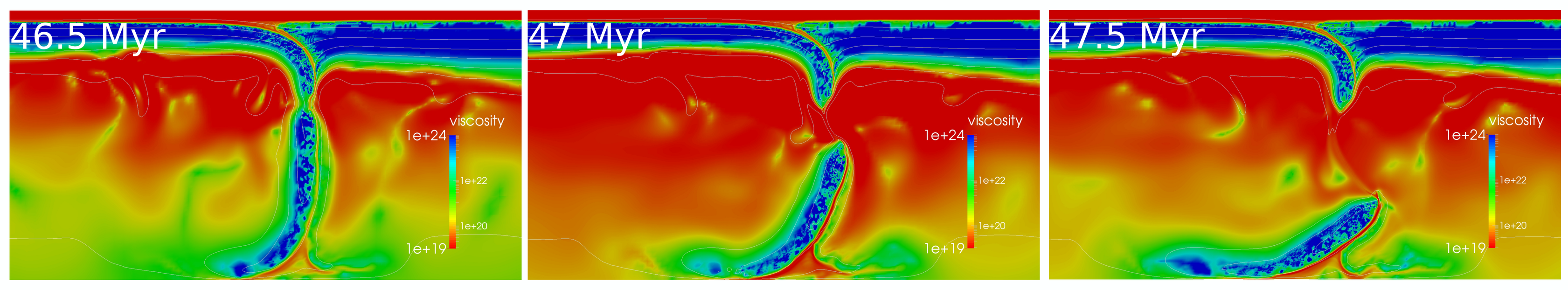


Figure 8: Slab detachment at about 47 Ma after the start of the model.

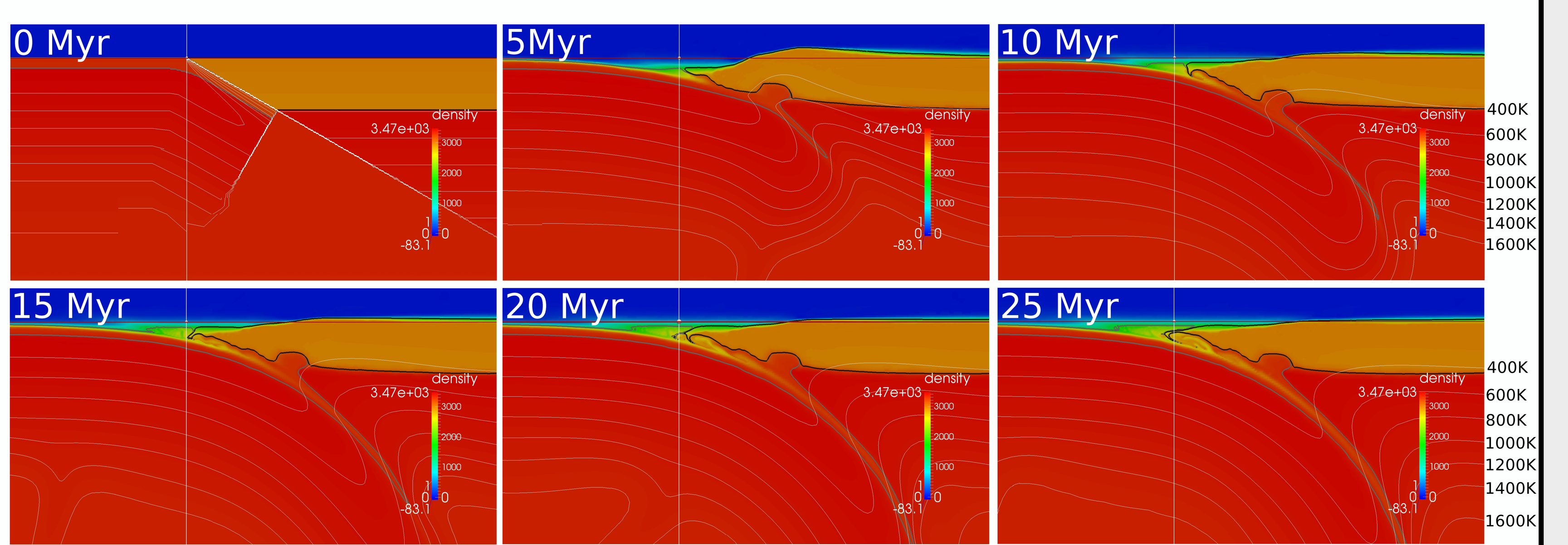


Figure 9: The density of the subduction zone at different times. Although in the first 2.5-5Ma a large topography develops (min/max: 4-6km), this is flattened when the slab reaches 150 km depth. An other interesting feature is the accumulation of oceanic crust under the overriding plate, which in reality might have partly molten (this is not yet implemented in ASPECT) and thereby creating a weakened zone above it. This might initiate the blocklike behavior which is observed with Sardinia and Corsica.

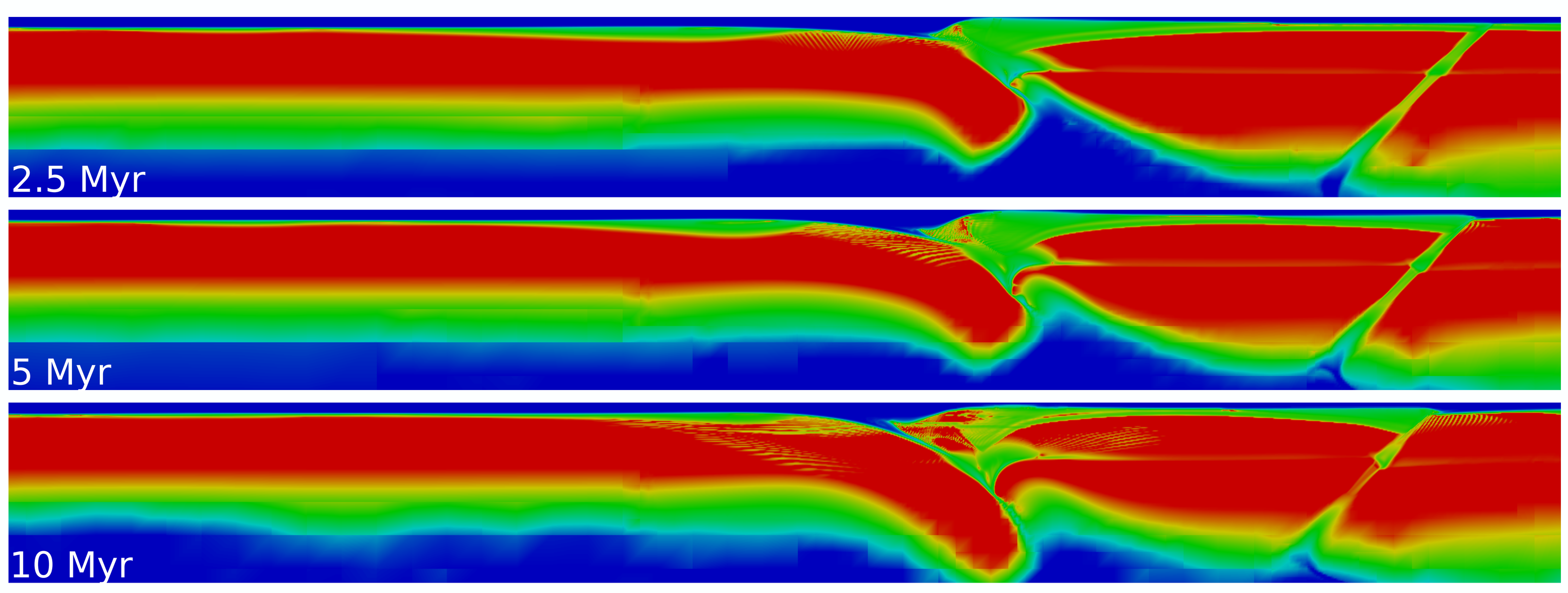


Figure 10: A zoom on the subduction zone showing the viscosity field of the model with a weak zone at 2.5, 5 and 10 Myr.

Conclusions

- Realistic topography can be reached

- To create blocklike behavior like Sardinia and Corsica weakening is required. The question is what kind and what strength of weakening is required to initiate this behavior.

- The dependency of shearbands on resolution might also play an important role, because it can concentrate stress and strain, leaving the rest strong enough for blocklike behavior.

- Another lead to a possible cause for weakening in the overriding plate is back-arc volcanism, which might initiate from the accumulated oceanic crust at the bottom of the overriding plate. This can be modeled by locally raising the temperature.

- The mantle flow might have an important role in strengthening the pull of rollback, but its exact role of the mantle flow needs more investigation.

- Influence of a weak zone in the overriding plate is unkown due to numerical problems.

References

Kronbichler, M., Heister, T., and Bangerth, W. (2012), High accuracy mantle convection simulation through modern numerical methods, Geophysical Journal International,191, 12-29, doi:10.1111/j.1365-246X.2012.05609.

van Hinsbergen, D.J.J., Vissers, R.L.M. and Spakman, W. (2014), Origin and consequences of western Mediterranean subduction, rollback, and slab segmentation, Tectonics, doi: 10.1002/2013TC003349