3-D computational modelling of the transpressional system of the South Island of New Zealand

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Introduction

The fundamental nature of the lithospheric deformation, especially the deformation of the mantle lithosphere (sub-crustal lithosphere), at the South Island is unresolved. Two end- member behaviours have been proposed: mantle lithosphere may be accommodated by subduction-like underthrusting of one plate along a narrow shear zone (Beaumont et al., 1996); or it may be shortened by distributed thickening of a viscous mantle lithosphere root (Molnar et al., 1999; Stern et al., 2000). It may also be that lithosphere is deforming by a combination of these two, with a temporal transition from one to another (Pysklywec et al., 2002).

An important feature of the South Island tectonics is the highly oblique nature of the plate collision that makes it a transpressional system: strike-slip motion (~4 cm/yr) along the boundary exist at the same time with convergent motion (~1 cm/yr) (fig. 1). However, previous studies on modelling the dynamics of the South Island collision have not included these important factors in the direction parallel to the plate boundary; instead considering this as a two-dimensional problem.

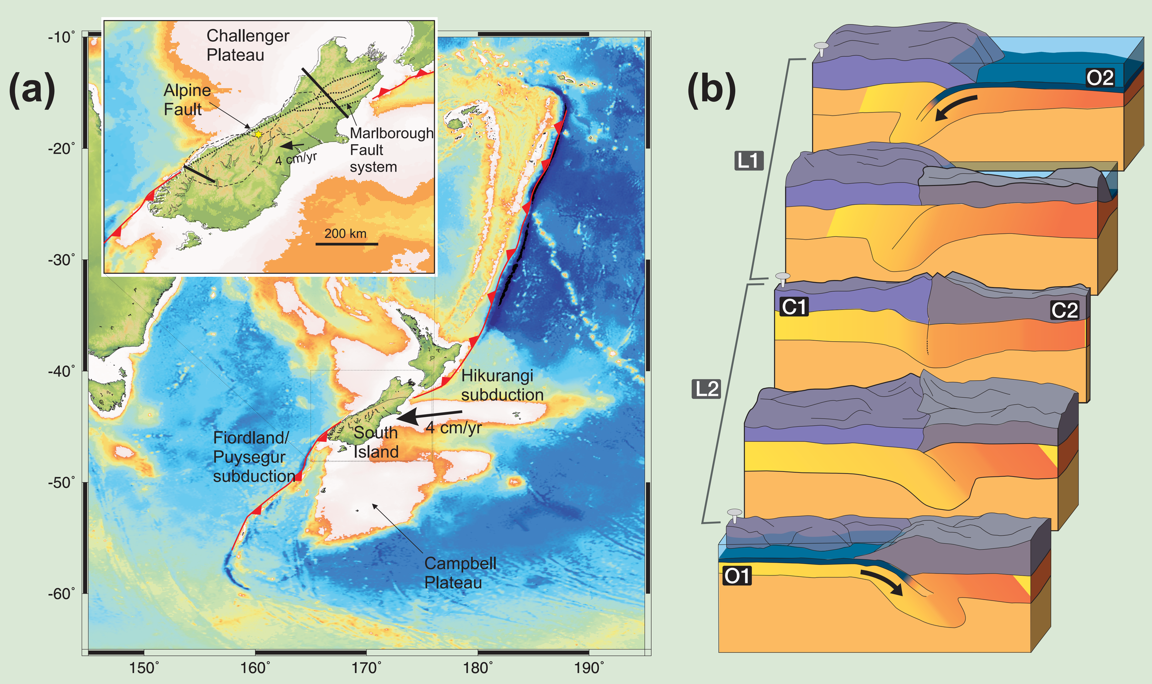


Fig. 1. (a) New Zealand and the modern day plate boundary showing subduction zones and average rate of plate motion (b) Cross-sections showing the switching of subduction direction, from (Pysklywec et al., 2010)

Model setup

The tectonic modelling is conducted using ELEFANT - a code designed for geodynamical simulations at crustal and lithospheric scales (Thieulot, 2014). It solves the Stokes and heat transport equations using the Finite Element method, relying on opensource solvers – MUMPS and SPARSKIT. The code is very versatile and offers such features as:

- The so-called Arbitrary Lagrangian-Eulerian method (Donea et al., 2004) meaning that the grid deforms vertically allowing a free surface, but stays intact along the horizontal axes
- Lagrangian markers used to track the material displacements
- Velocity- and pressure-based boundary conditions allowing more realistic and flexible constraints for the models
- Diverse available rheologies – brittle, viscous and visco-plastic

As a first stage to modelling the South Island oblique collision, we consider various configurations of shortening for a crustal depth model. The oblique collision was modelled by prescribing velocity to two parallel walls of the model. Through varying the values of the imposed velocities, the desired degree of obliqueness was achieved. Having set the total velocity, convergent and along-strike components are being computed as total velocity multiplied by cosine and sine of obliquity angle respectively.

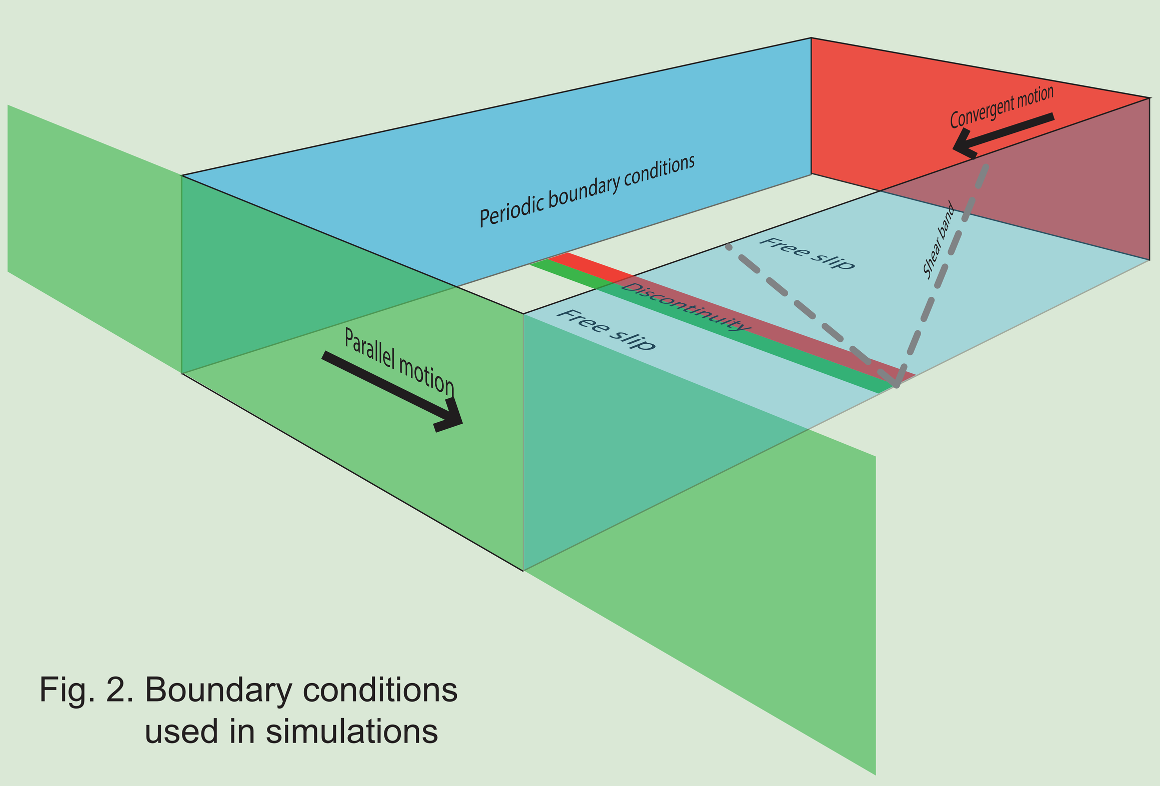


Fig. 2. Boundary conditions used in simulations

Simplified setup used for preliminary studies:

- 1 timestep
- Domain limited to crust
- Brittle rheology
- Temperature effects not taken into account

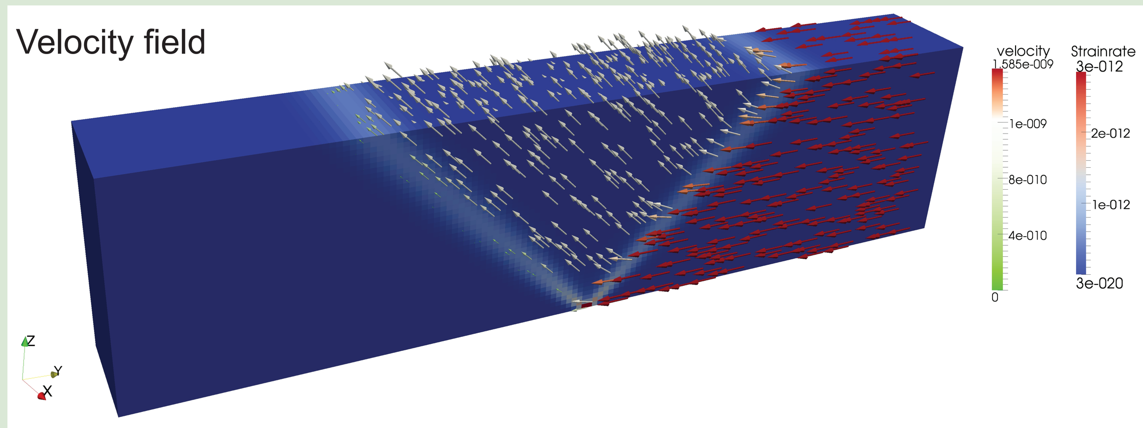
Physical properties used for the models:

Domain size: 5x10x40 km
Resolution: 8*45*150
Imposed velocity: 2, 5, 10 cm/yr total
Obliqueness: 0, 20, 40, 60, 80 deg.
Density: 2700kg/m3
Angle of internal friction: 0, 10, 20, 30 deg.
Cohesion: 40, 400, 4000 MPa

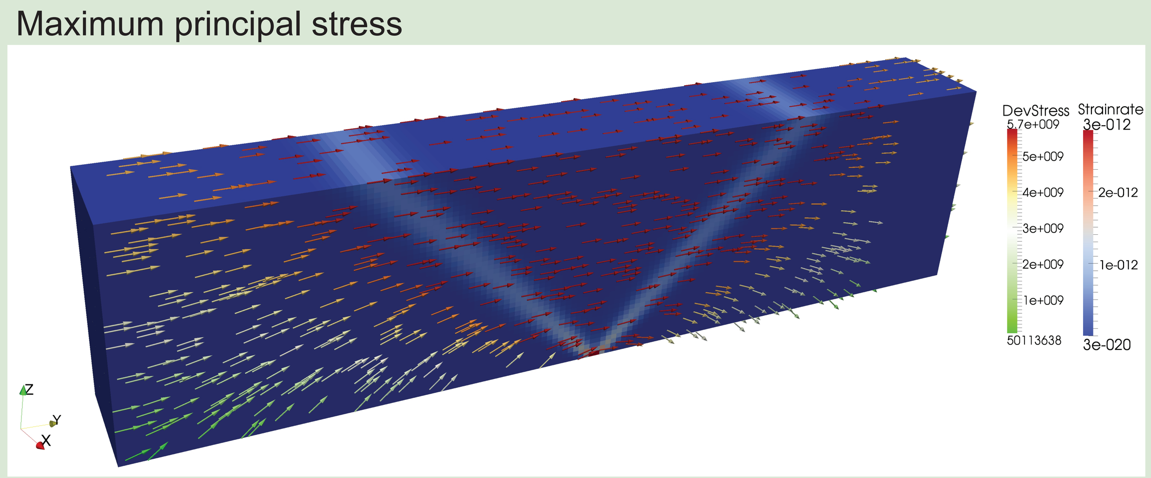
Results

Obliquity 0°

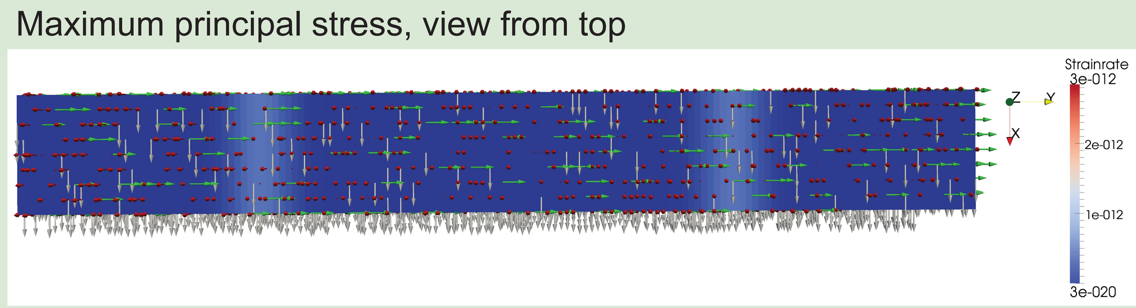
Velocity field



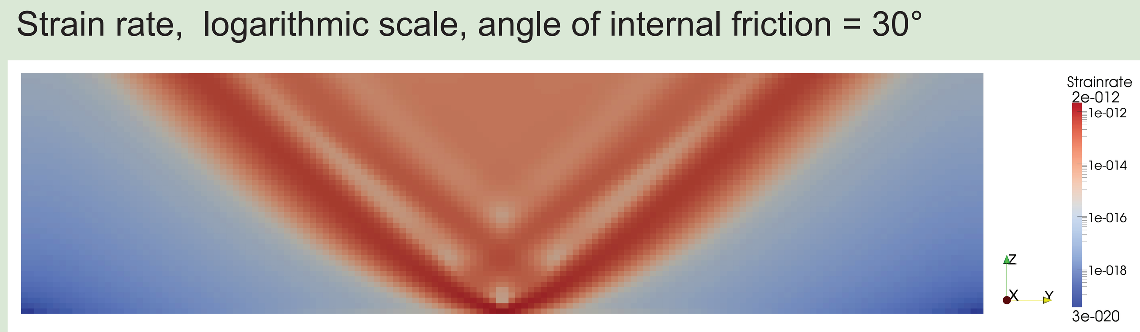
Maximum principal stress



Maximum principal stress, view from top

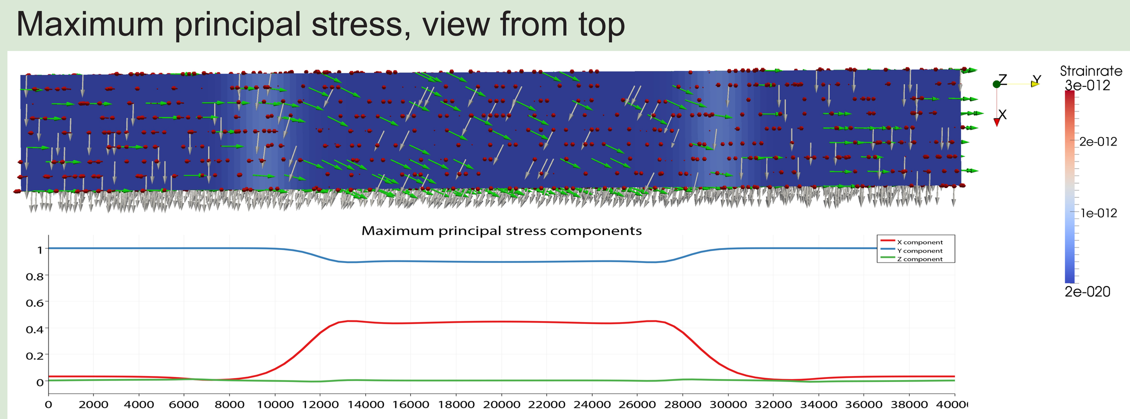


Strain rate, logarithmic scale, angle of internal friction = 30°

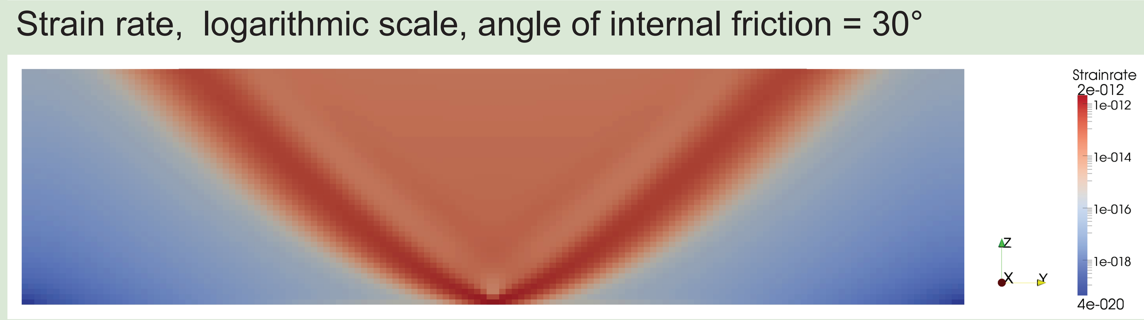


Obliquity 20°

Maximum principal stress, view from top

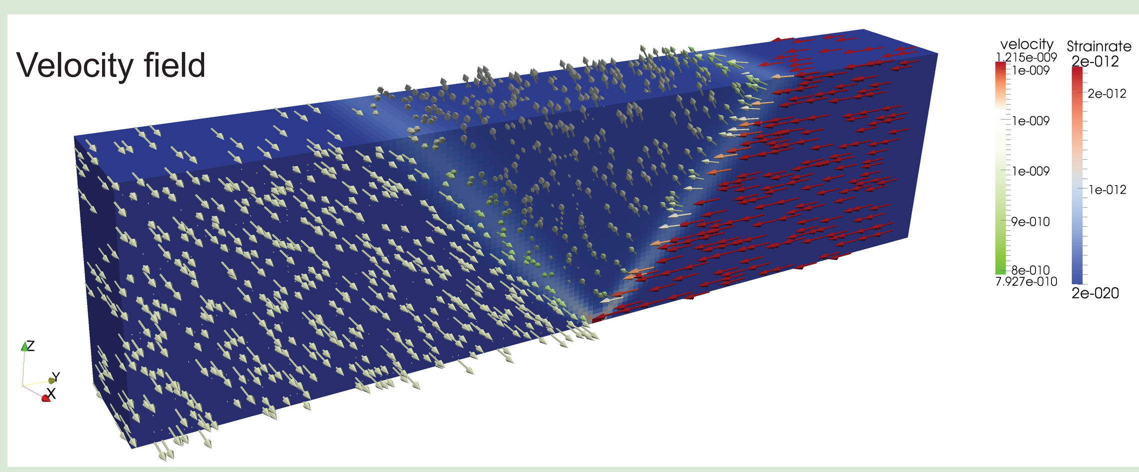


Strain rate, logarithmic scale, angle of internal friction = 30°

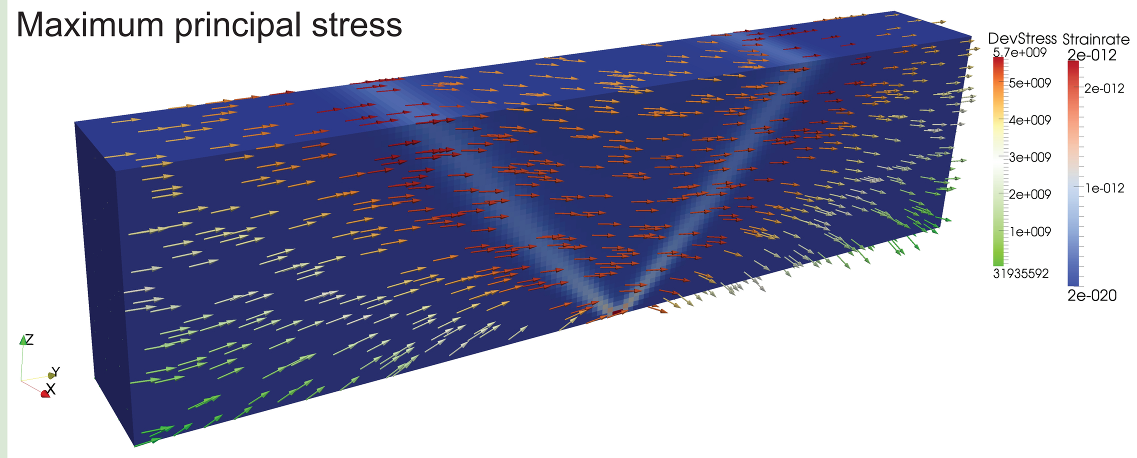


Obliquity 40°

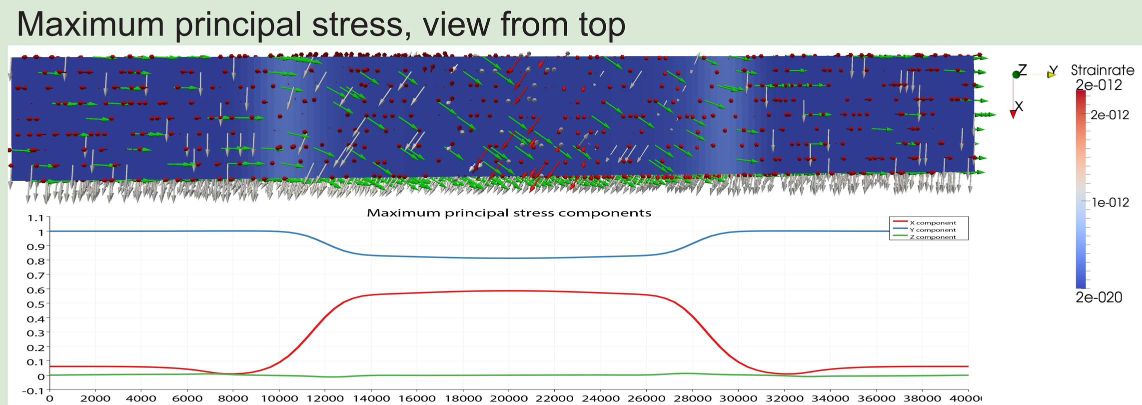
Velocity field



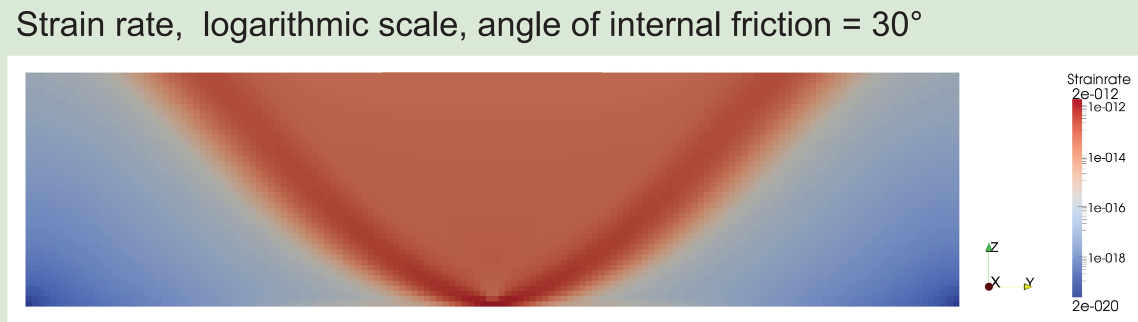
Maximum principal stress



Maximum principal stress, view from top

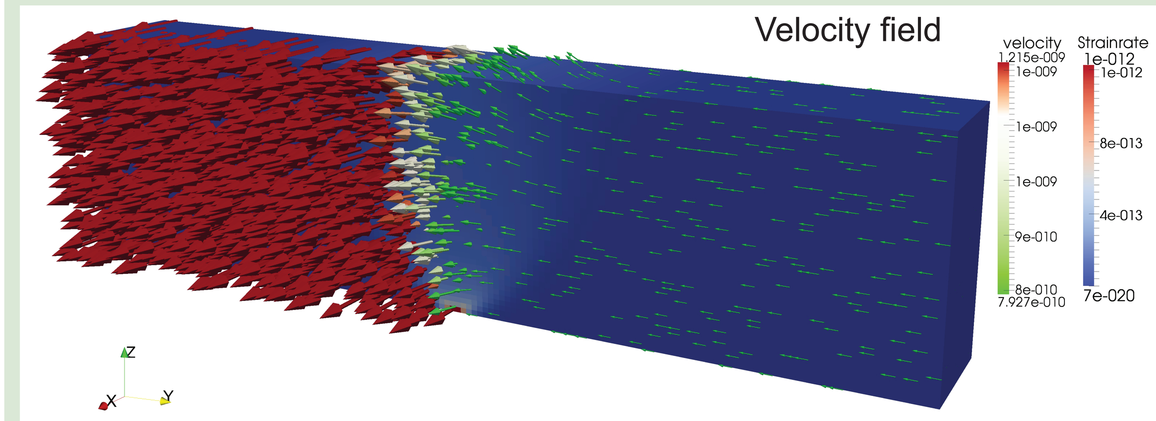


Strain rate, logarithmic scale, angle of internal friction = 30°

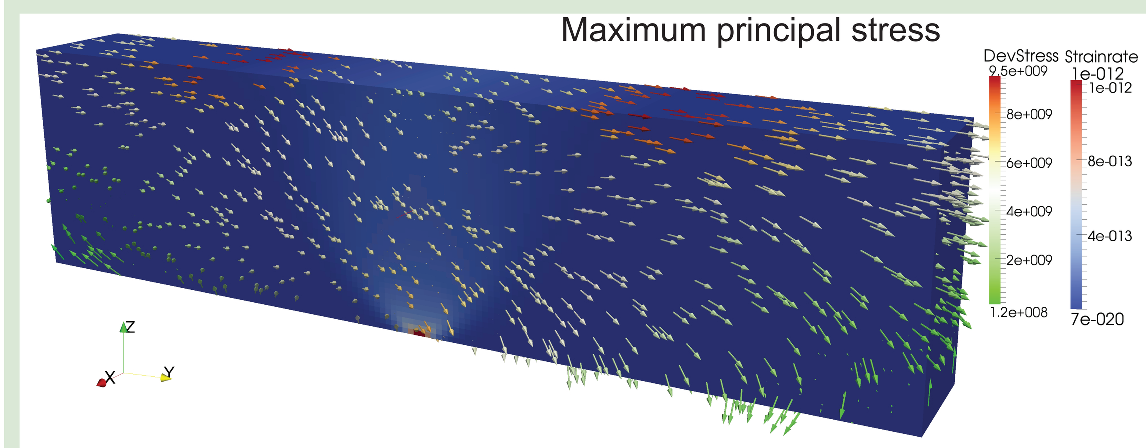


Obliquity 80°

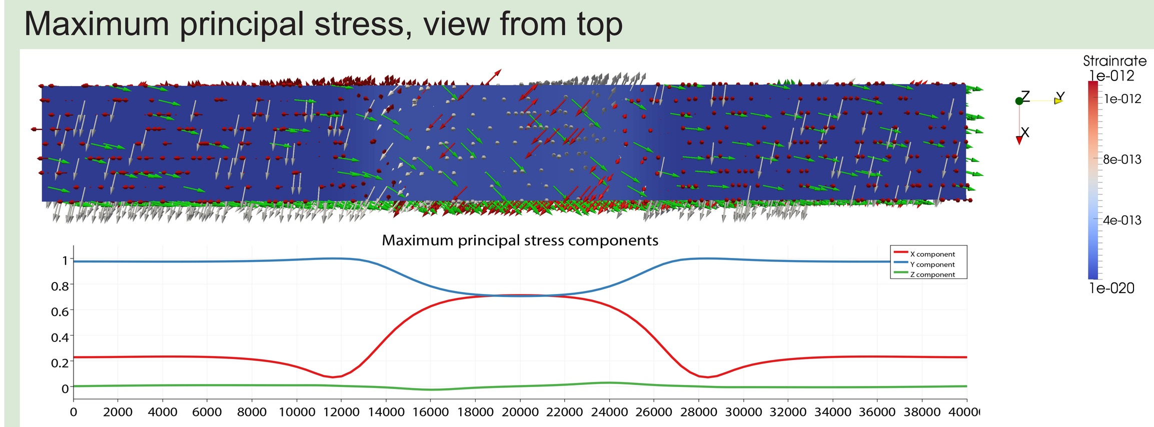
Velocity field



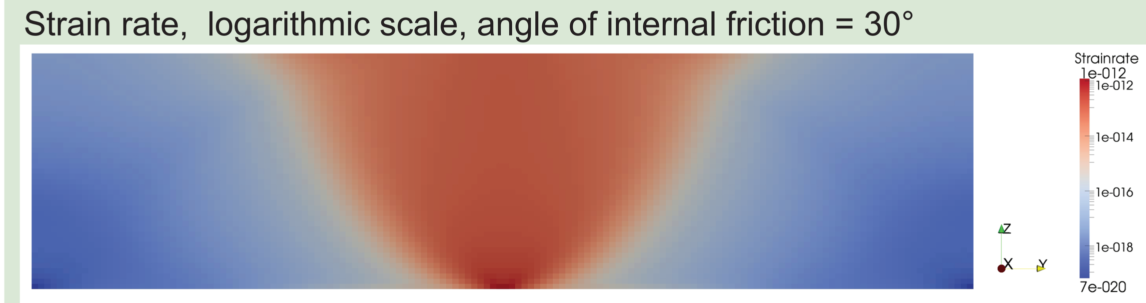
Maximum principal stress



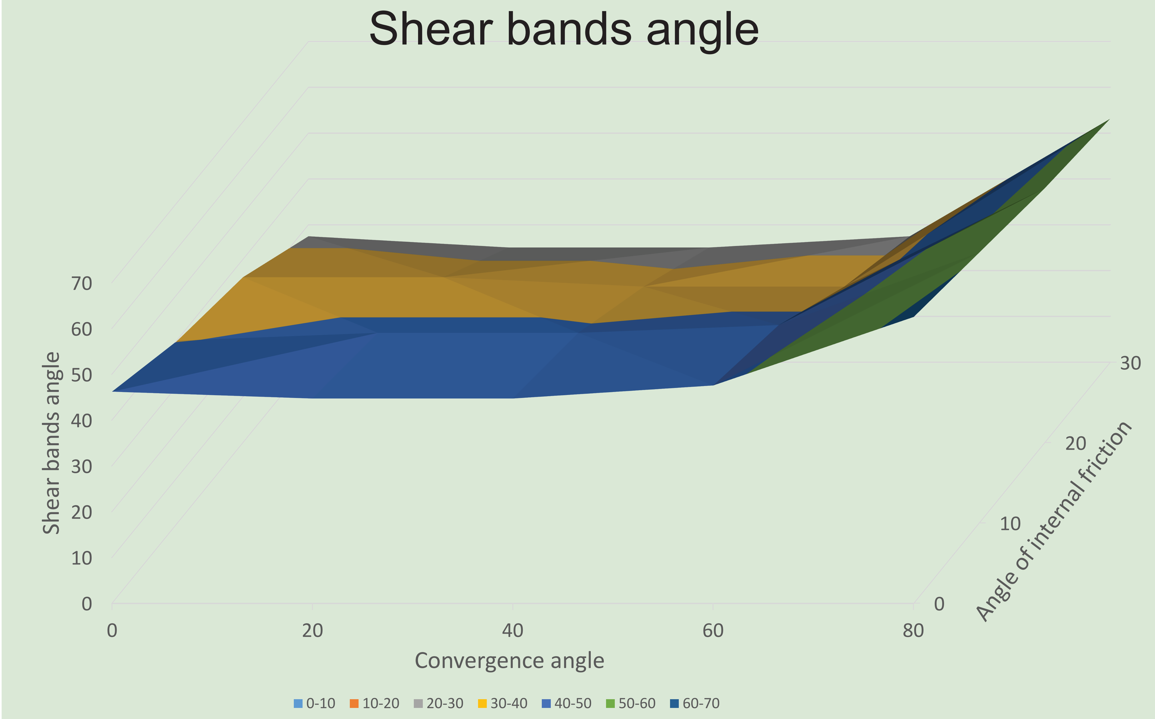
Maximum principal stress, view from top



Strain rate, logarithmic scale, angle of internal friction = 30°



Shear bands angle



Conclusions

- Shear bands angle increases with increasing obliquity and decreases with increasing angle of internal friction
- Shear bands localization deteriorates with increasing obliquity
- At 20 degrees obliquity the maximum principal stress is rotated between the shear bands approximately 25 degrees with two local maximums at the shear bands
- At 80 degrees obliquity the rotation angle reaches 46 degrees with local minimums at shear bands. There is noticable rotation (around 13 degrees) of principal stress axis outside of the maximum strain rate zone
- At 40 degrees obliquity intermediate behaviour is observed: less expressed local minimums with principal stress axis rotation ranging from 4 degrees in the outer part of the model to 35 degrees between the shear bands
- At high obliquity angles in the lower parts of the model there are noticable upward and downward rotations of principal stress, whereas on the surface the Z component of the maximum principal stress vector is negligible
- Neither absolute values of imposed velocity nor cohesion affect the results

Limitations

- Shear bands angle cannot be measured precisely due to resolution
- Resolution cannot yet be increased significantly due to memory limitations
- Constant temperature throughout the domain

Future plans

- Applying pressure boundary conditions to side faces
- Adding layers beneath the crust
- Changing the rheology to be temperature-dependent
- Adding timestepping and tracers to the experiments
- Adding markers and strain weakening
- Changing boundary conditions, adding a zone zone of high accumulated stress mimicking the Alpine fault
- Adding surface processes (erosion)

References

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