Modelling lithosphere dynamics with robust rheological implementations: Towards 3D

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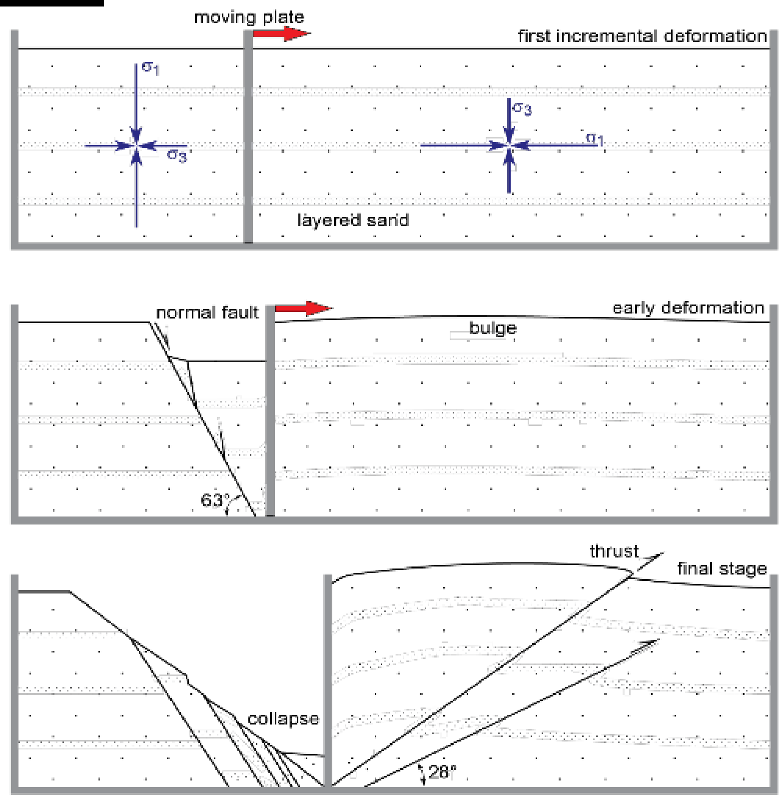
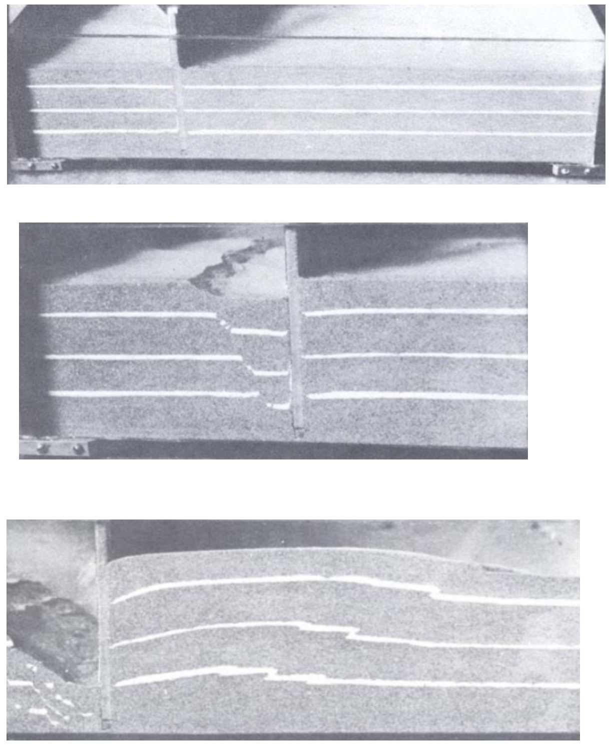
Problem statement



Experimental faulting in sand
Experiment of Hubbert 1951 *Geol. Soc. Am. Bull.* **62(4),** 355-372

J.-P. Burg online lecture notes



Hubbert, 1951

Modelling faulting in a continuum:

Faults have characteristic angles (~30^o from S1)

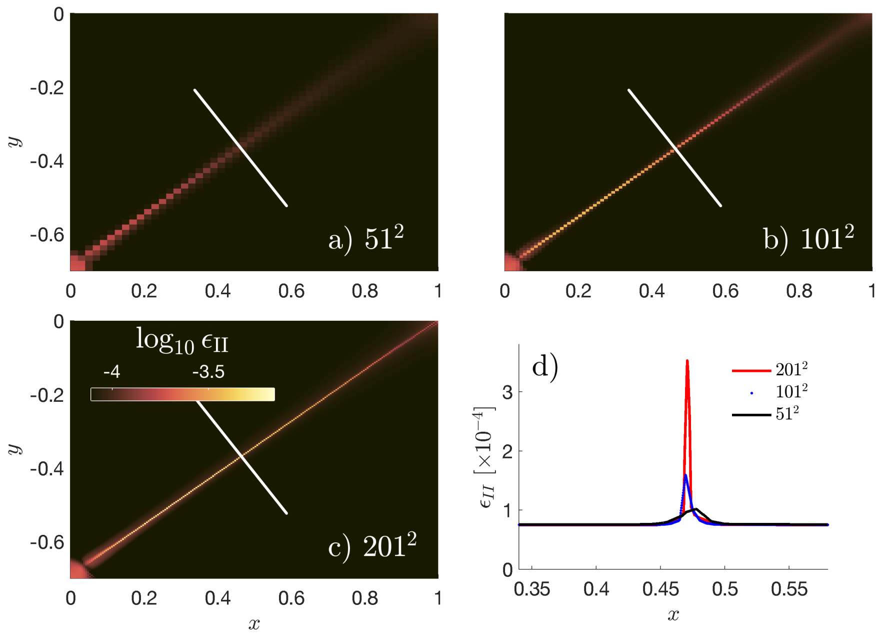
Plasticity is pressure dependent

Deformation in rocks is quasi-incompressible

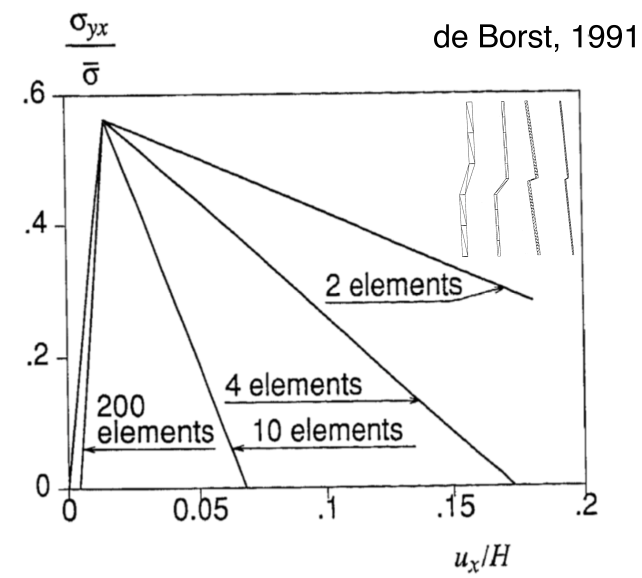
Plastic flow is hence non associated

Difference between friction/dilation angles is large

Strain-dependent material softening may occur



Duretz et al., 2019



Problems with numerical models:

Drucker Prager laws lead to models that:

Have no inherent length scale of localisation

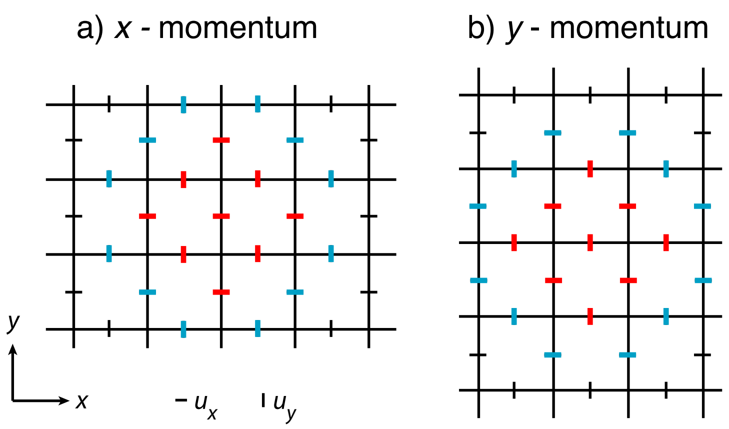
Often fail converging global non-linear equilibrium

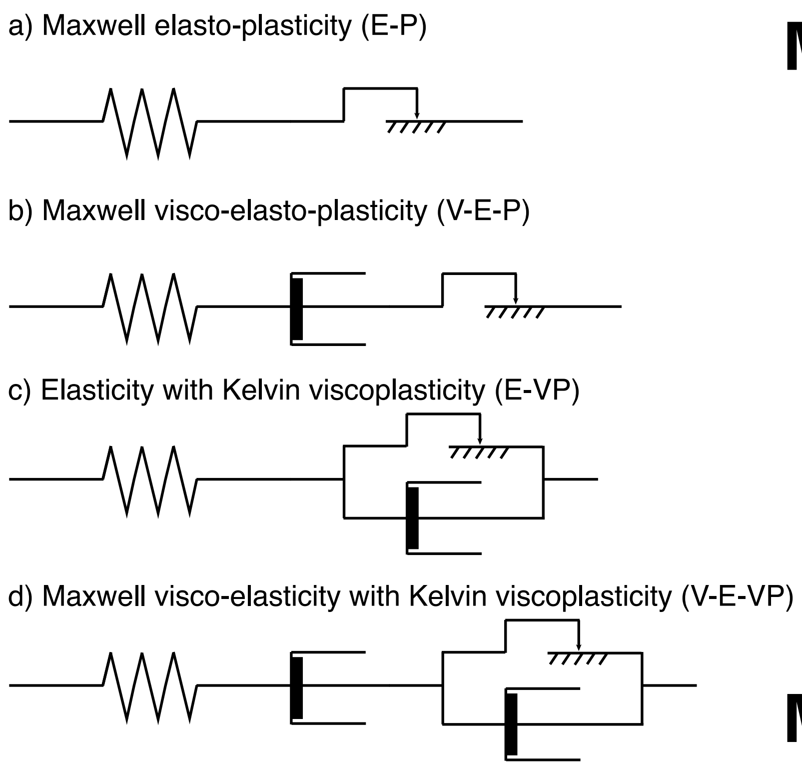
Do not converge upon mesh refinement

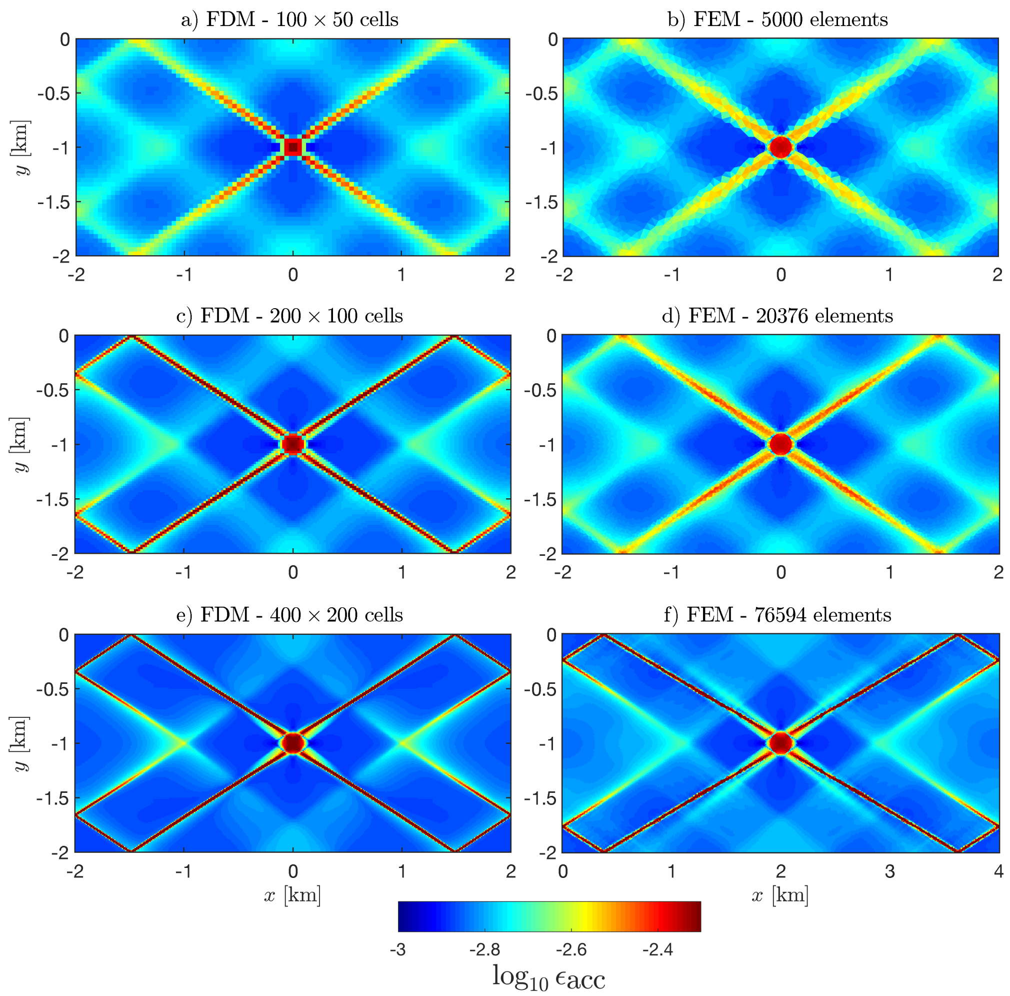
Often fail converging linearized momentum equations

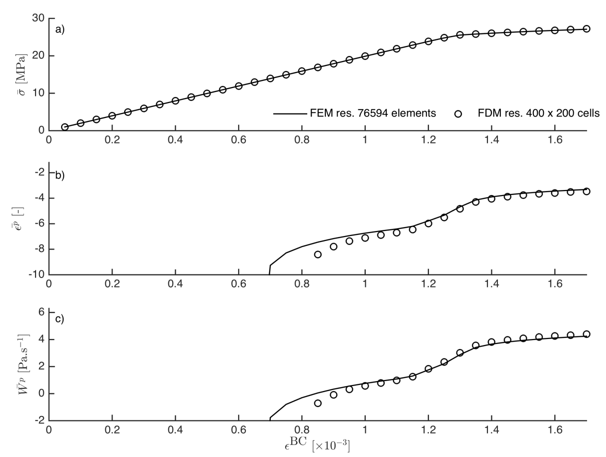
Things get worst with material softening:
load bearing capacities become mesh-dependent

Methodology - viscoplasticity









Duretz et al., 2018

Modelling approach 1: «engineering»

Displacement-based FD mechanical solver

Elastic & plastic compressibility

Non-associated Drucker-Prager

Consistent tangent linearization (CTL)

Modelling approach 2: «geodynamics»

Velocity-based FD mechanical solver

Incompressibity

Non-associated Drucker-Prager

Consistent tangent linearization (CTL)

Effective viscosity approach with Newton linearization (ETA)

Out of the many existing regularization methods, let's test the simplest one!

--> testing V-E-VP instead of V-E-P model

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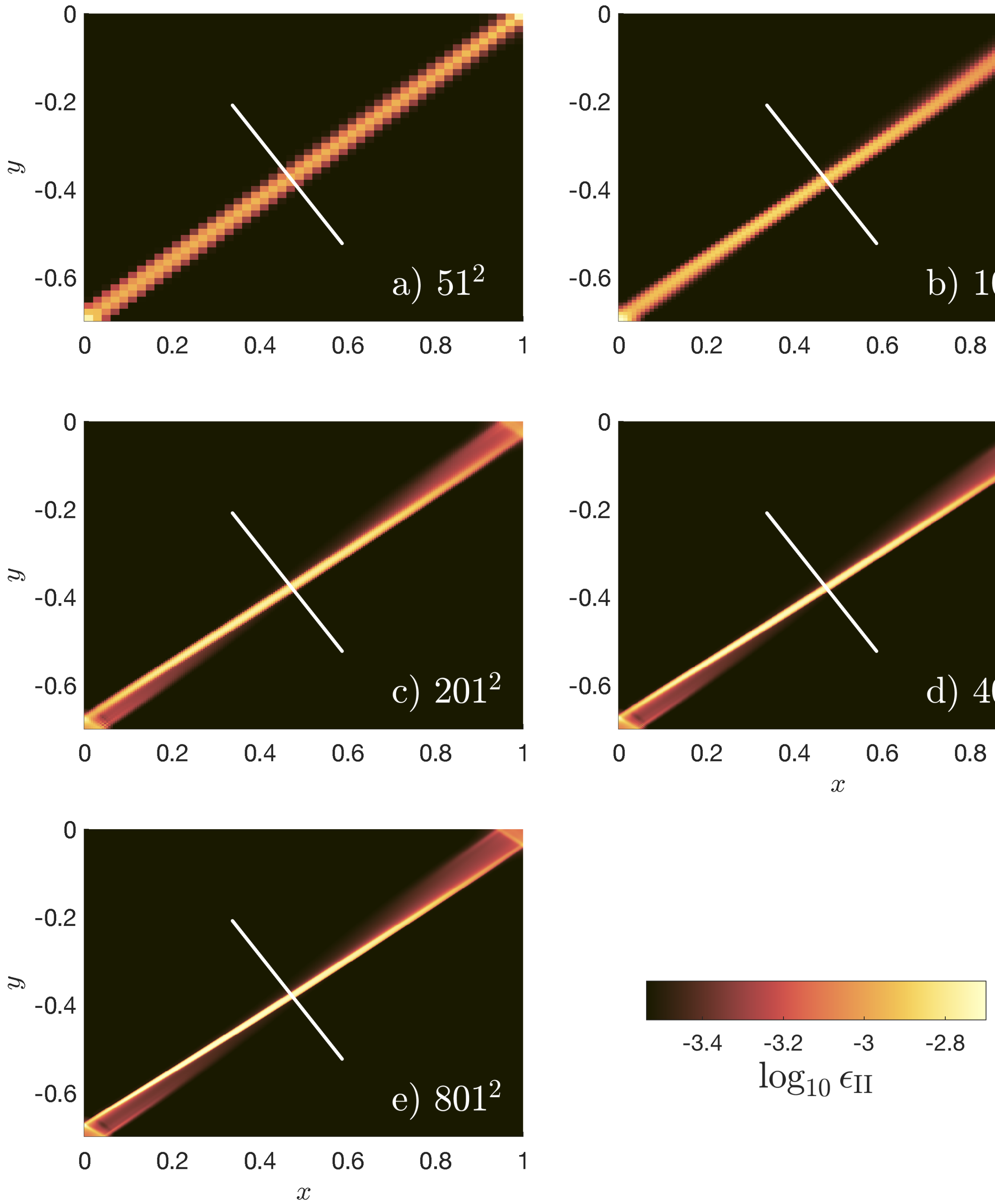
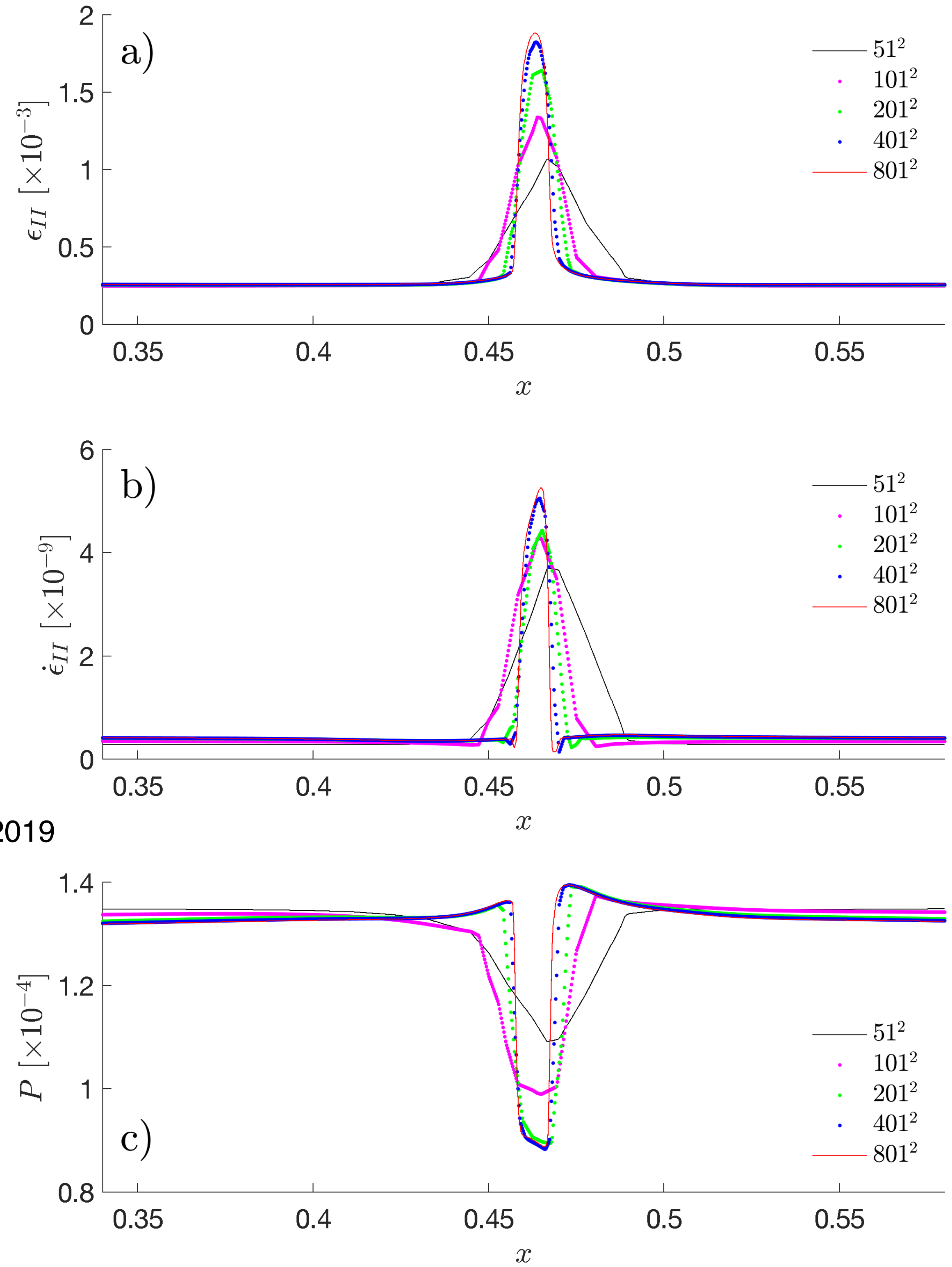
Shear band analysis



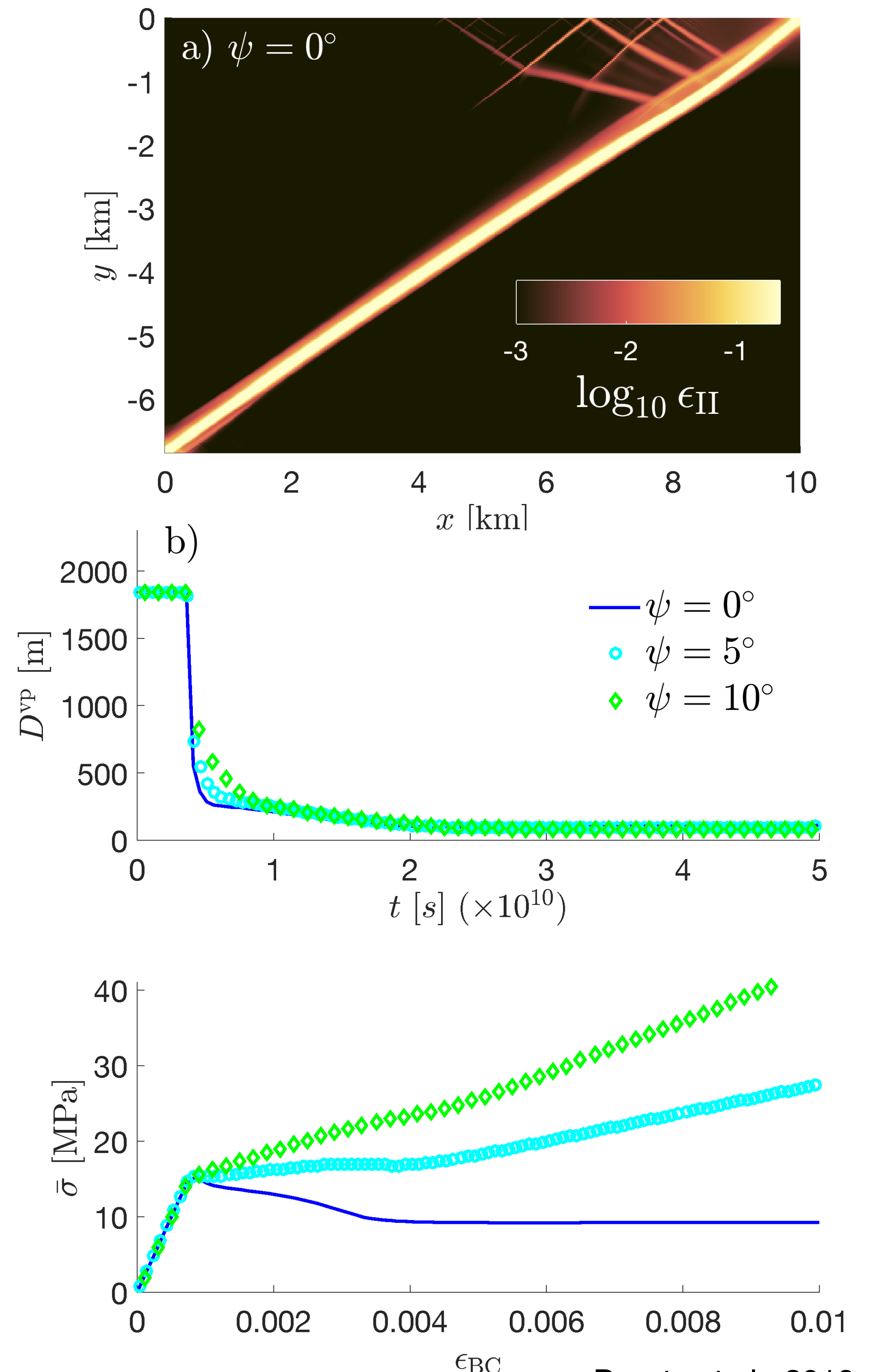
Duretz et al., 2019



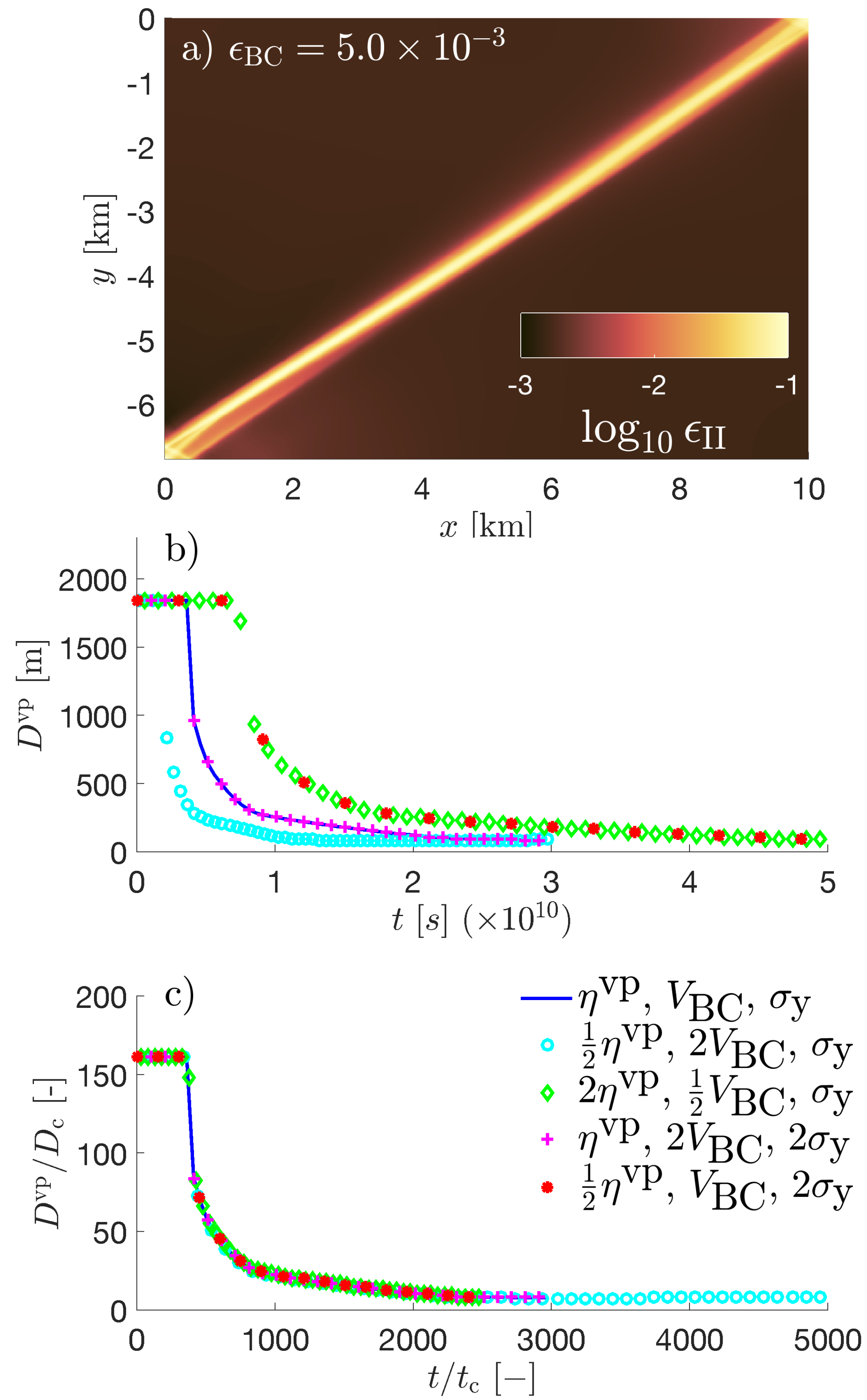
Shear bands <u>angle is not affected</u> by viscoplastic regularization

Shear band thickness, strain, strain rate, pressure <u>converge upon mesh refinement</u>.

4 *Incompressible limit and strain softening*

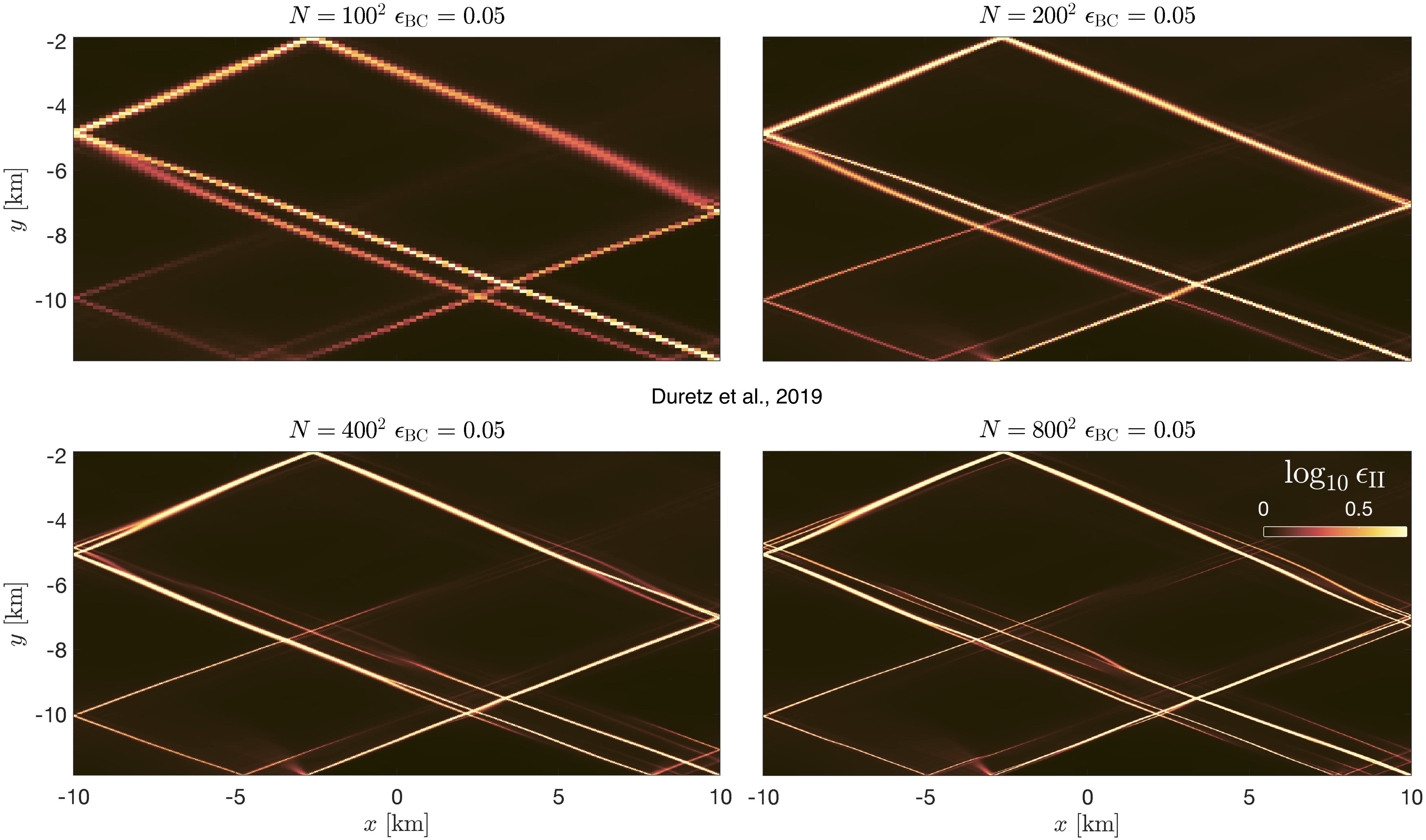


Duretz et al., 2019



Regularization also works together in the plastic <u>incompressible limit</u>
and together with cohesion <u>strain-softening</u>.

5 Localization with random seeds and resolution



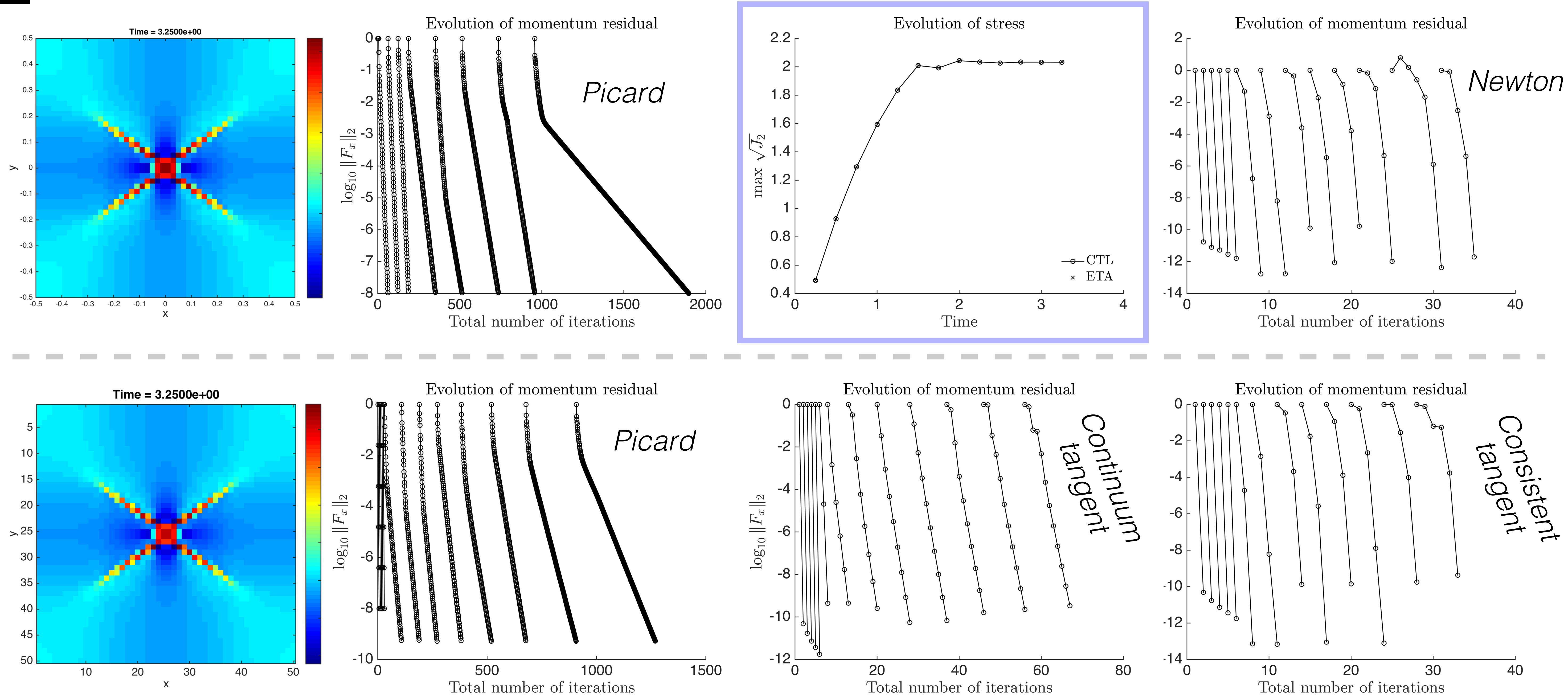
Fairly good convergence upon mesh refinement even with random seeds and softening.

Most importantly, momentum balance converges quadractically at every timestep, whatever the resolution.

6 Applicable to geodynamic models?

ETA

CTL



Duretz et al., in prep.

CTL was developped for velocity-based geodynamic codes including compressible and incompressible cases.

Both succeed at modelling strain localization in visco-elasto-(visco)plastic continuum.

Both the CTL and ETA approach deliver comparable results with V-E-P models.

Both can lead to quadratically converging momentum equilibrium.

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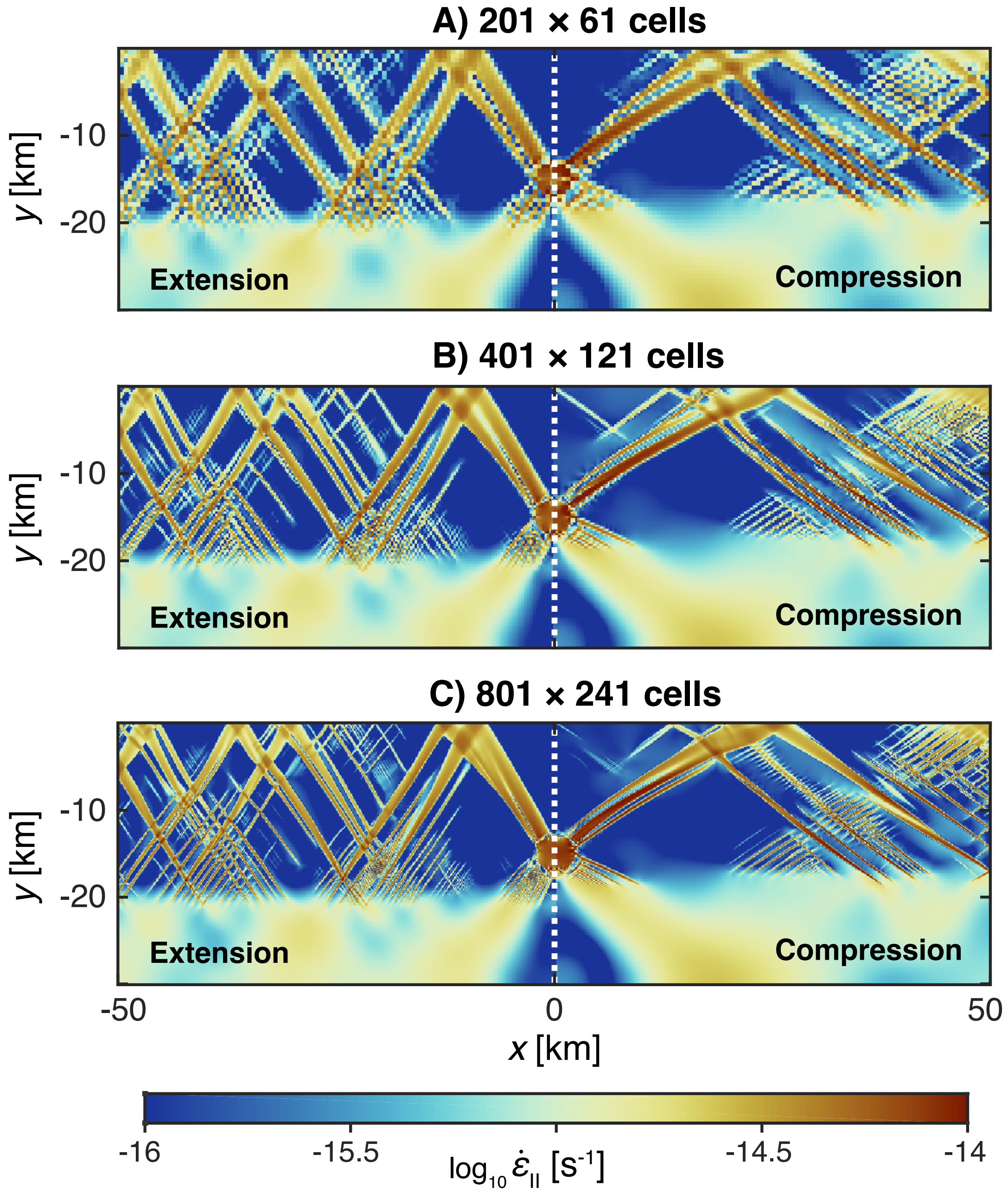
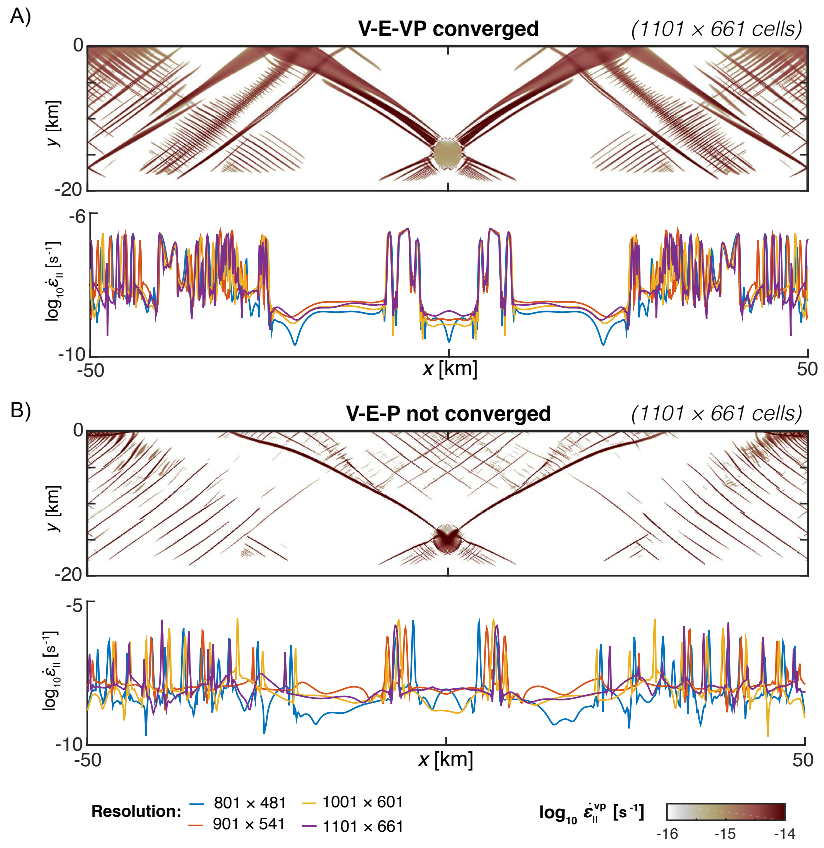
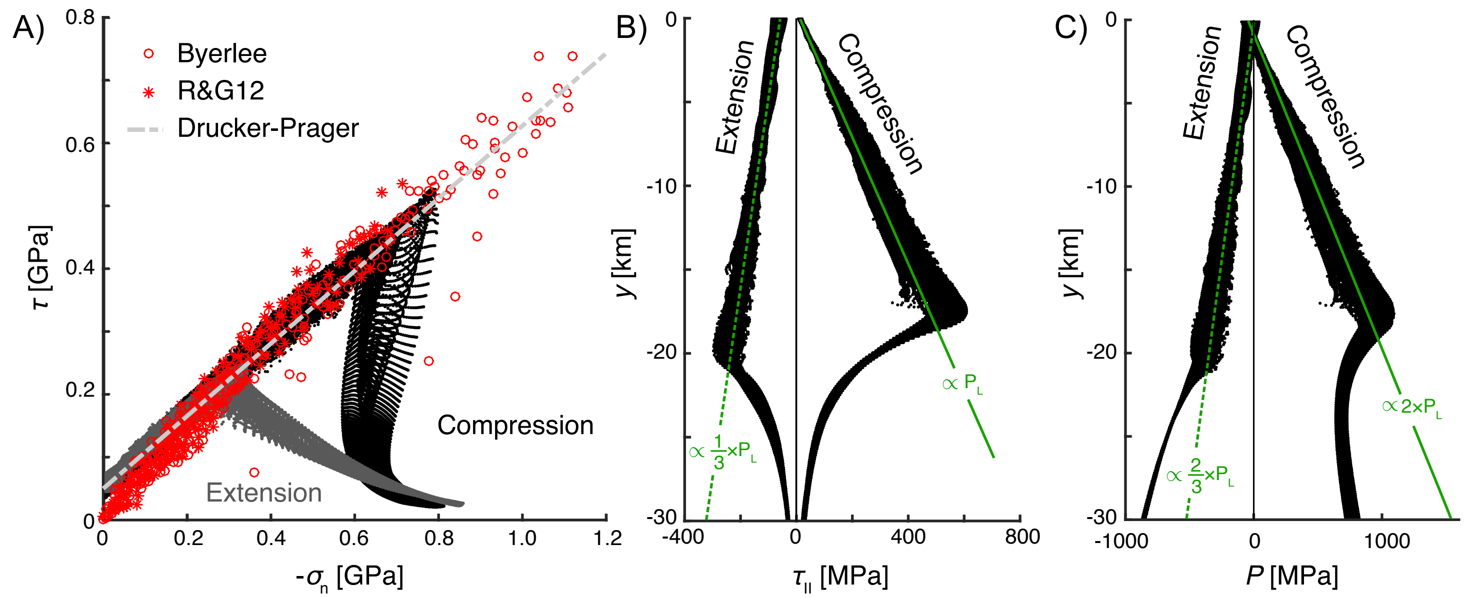
Crustal-scale application



Duretz et al., 2020





Code based on M2Di routines

Incompressible velocity based formulation.

Viscoplastic regularization, gravity, temperature-dependent power-law creep - V-E-VP model

<u>Quadratic convergence of momentum equations + good convergence upon mesh refinement!</u>