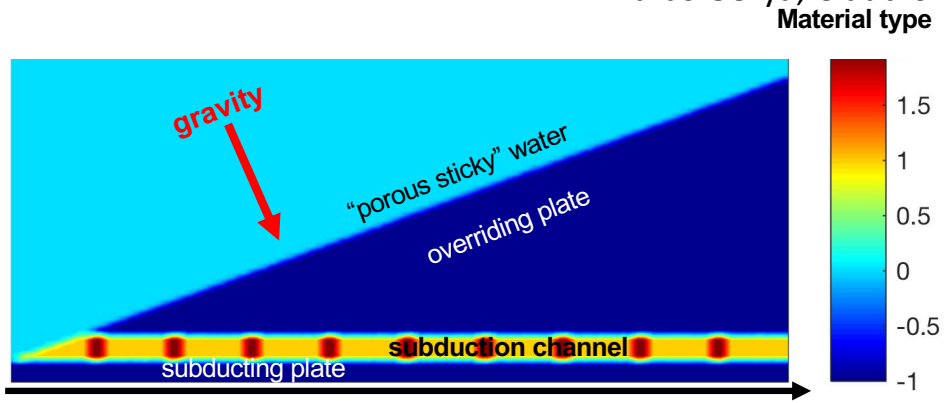
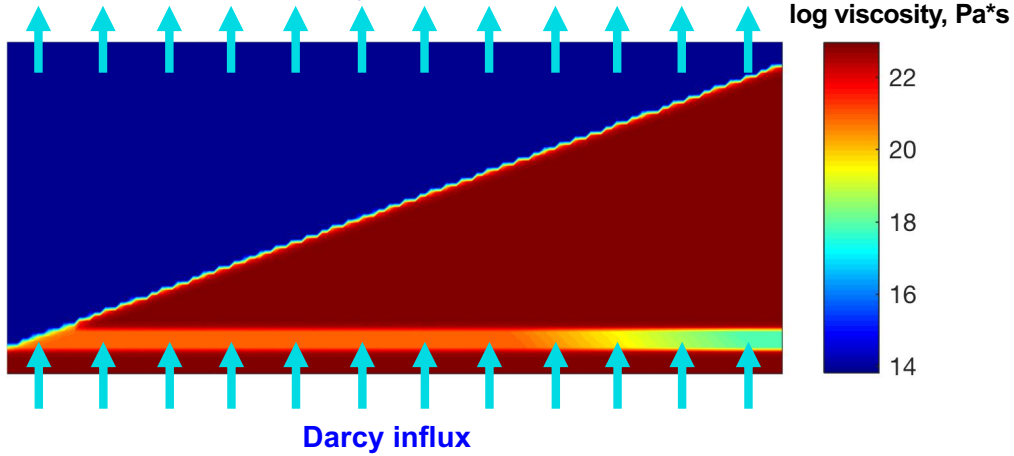
Roles of poro-elastic compressibility, rate-dependent strength and strain-stress dependent dilation for spontaneous generation of seismicity along fluid-bearing fault structures

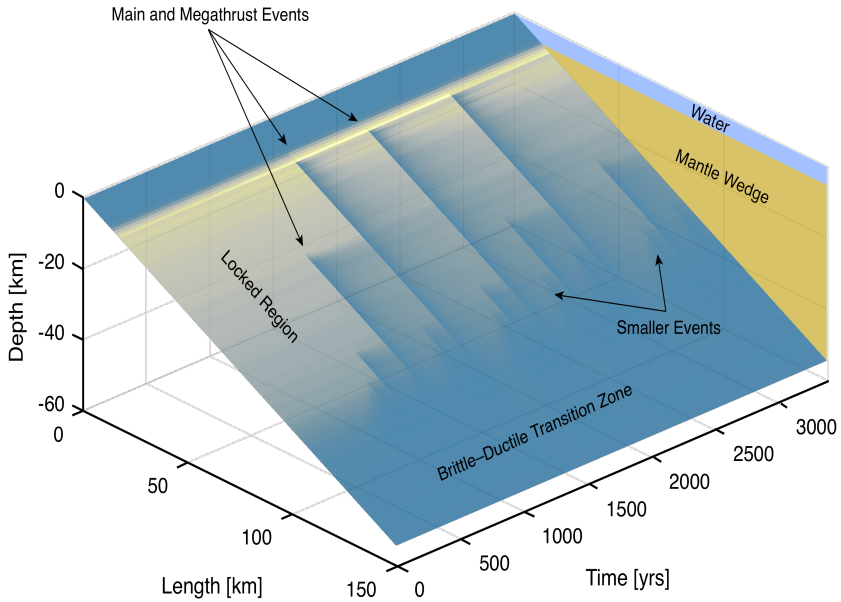
Taras Gerya, Claudio Petrini, Luca Dal Zilio



Numerical setup (150x65 km)



Previous work: fluid-pressure-induced seismic cycle with incompressible solid/fluid model



Petrini et al., 2020, Tectonophysics

Fully compressible model

mass conservation for solid (porous matrix divergence)

mass conservation for fluid (Darcy flux divergence)

elastic — visco-plastic — dilation

$$\operatorname{div}(\vec{v}^{s}) + \beta_d\left(\frac{D^s P^t}{Dt} - K_{BW}\frac{D^f P^f}{Dt}\right) + \frac{P^t - P^f}{(1-\phi)\eta^{\phi}} = 2\dot{\varepsilon}_{II(plastic)}\sin(\psi)$$

$$\operatorname{div}(\vec{q}^{D}) - K_{BW}\beta_d\left(\frac{D^s P^t}{Dt} - \frac{1}{K_{Sk}}\frac{D^f P^f}{Dt}\right) - \frac{P^t - P^f}{(1-\phi)\eta^{\phi}} = -2\dot{\varepsilon}_{II(plastic)}\sin(\psi)$$

Initial state of the pore

Coseismic pore deformation, fluid pressure increases

Postseismic fluid pressure release and elastic pore volume decrease due to the fluid escape

Poro-visco-elasto-plastic seismic cycle

Volume creation by elastic deformation of the matrix due to fluid pressure increase consequently the inablity of fluid to escape because of low permeability

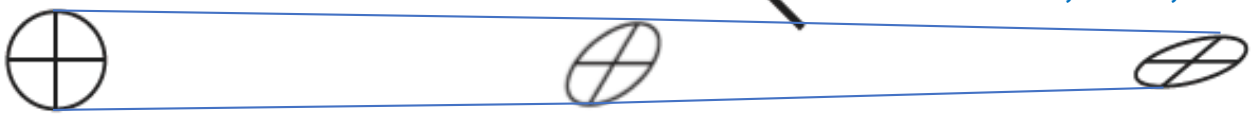
$$\frac{Dp_f}{Dt} > \frac{Dp_t}{Dt}$$

Visco-plastic compaction

Volume reduction by visco-plastic deformation of the matrix producing fluid pressure rise

$p_t > p_f$

Schematic pore deformation



Petrini et al., 2020, Tectonophysics

Stress-strain-dependent dilation angle

$$\psi = ab[\exp(-b\gamma_p) - \exp(-c\gamma_p)]/(c-b)$$

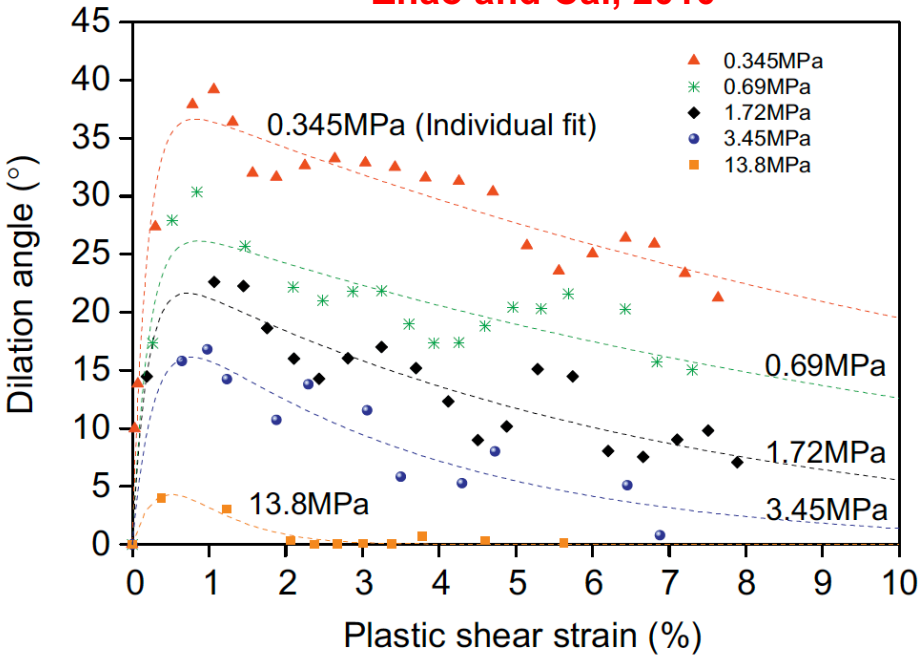
$$a = a_1 + a_2\exp(-\sigma_3/a_3)$$

$$b = b_1 + b_2\exp(-\sigma_3/b_3)$$

$$c = c_1 + c_2(\sigma_3)^{c_3}$$

$\sigma_3 = P_{total} - P_{fluid}$

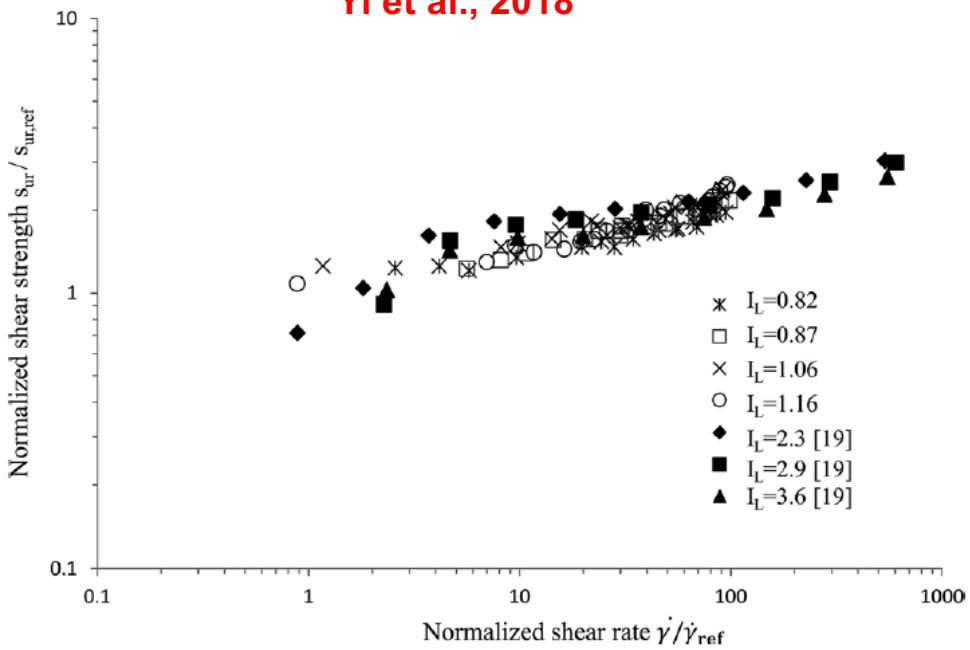
Zhao and Cai, 2010



rate-dependent strength (power-law)

$$\sigma_{II} = (\sigma_c + \mu*(P_{total} - P_{fluid}))*(1+\alpha*(\dot{\varepsilon}_{slip}/\dot{\varepsilon}_0)^{\beta})$$

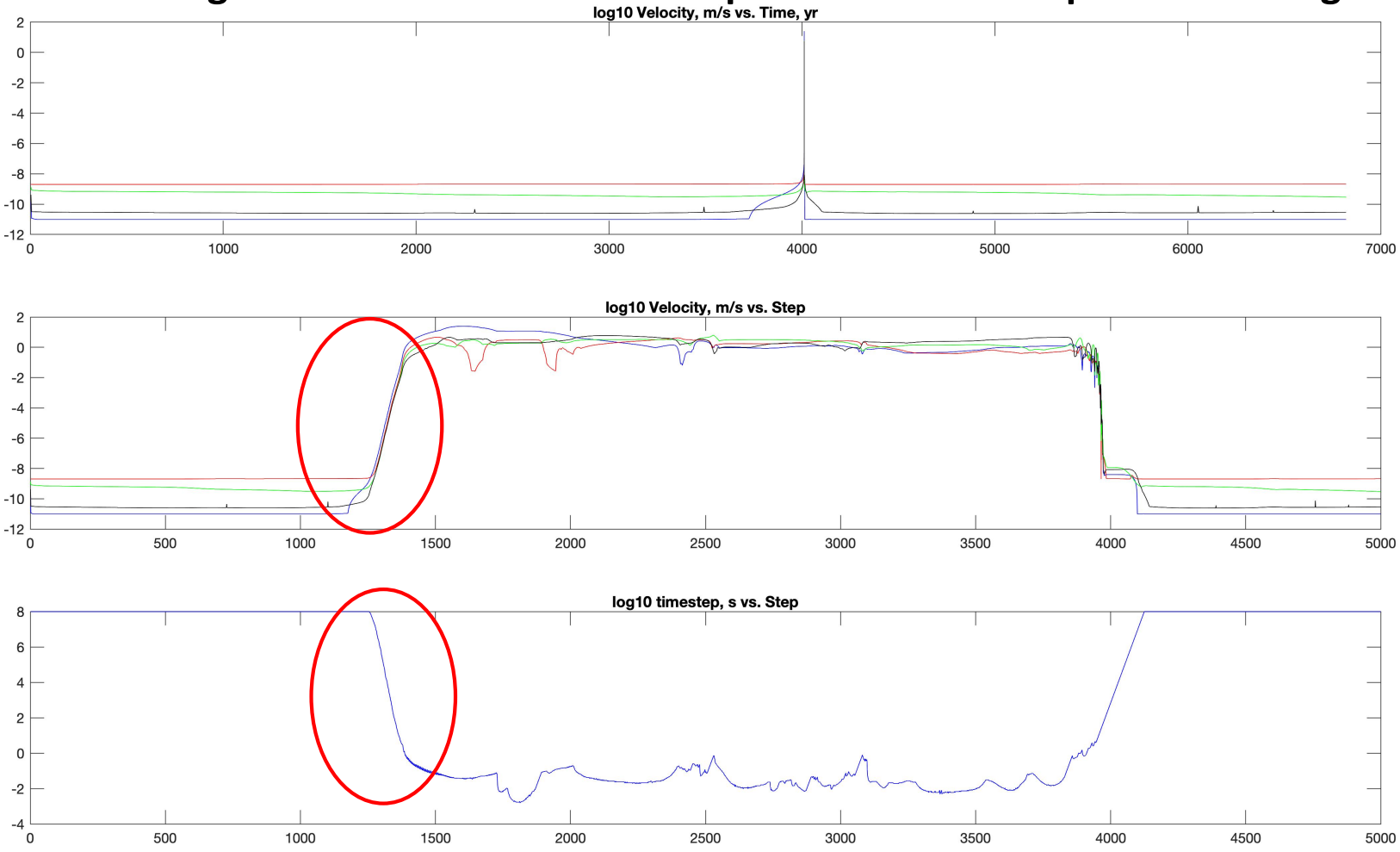
Yi et al., 2018



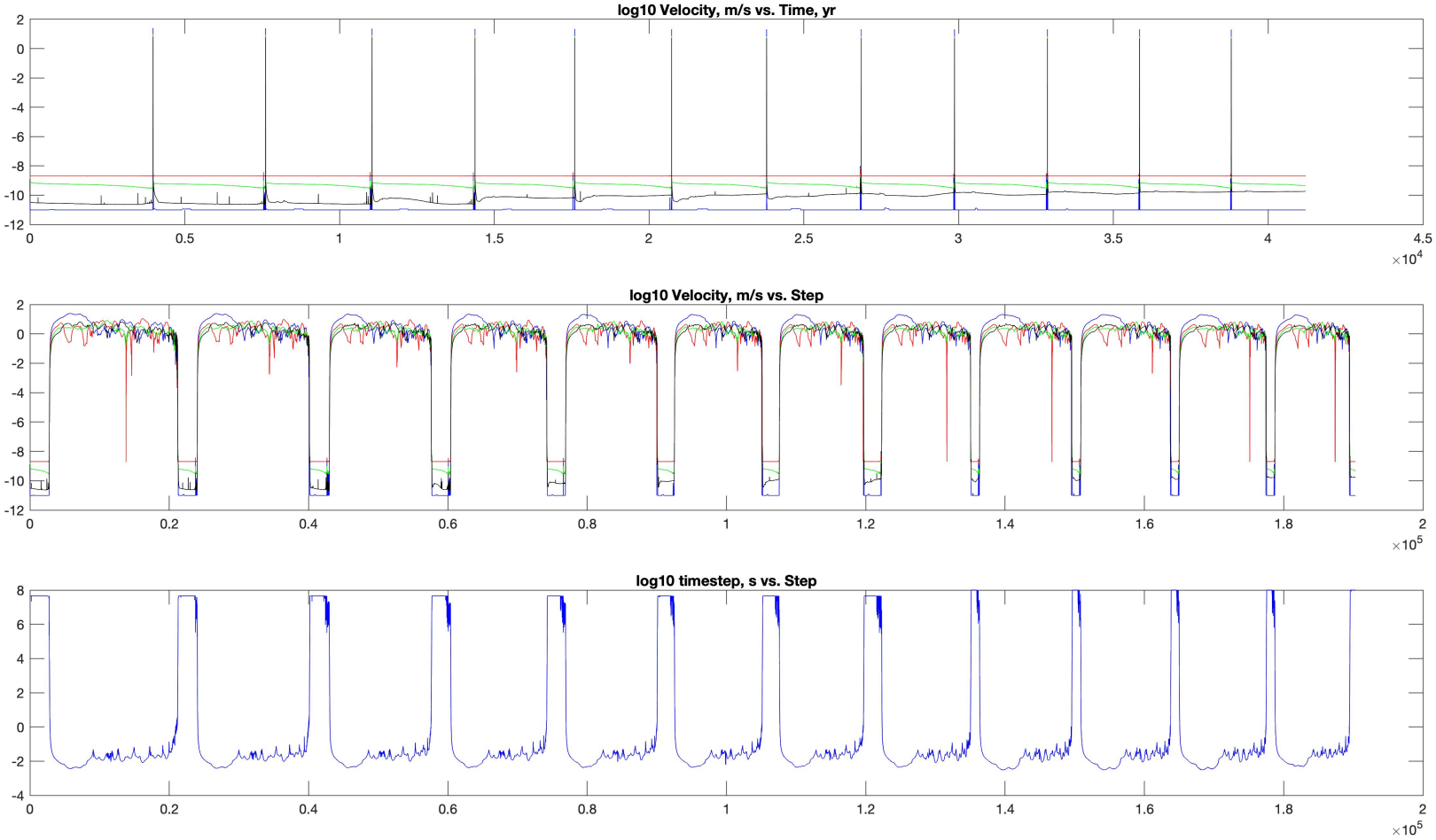
rate-dependent strength (logarithmical)

$$\sigma_{II} = (\sigma_c + \mu*(P_{total} - P_{fluid}))*(1+a/\mu*\ln(\dot{\varepsilon}_{slip}/\dot{\varepsilon}_0))$$

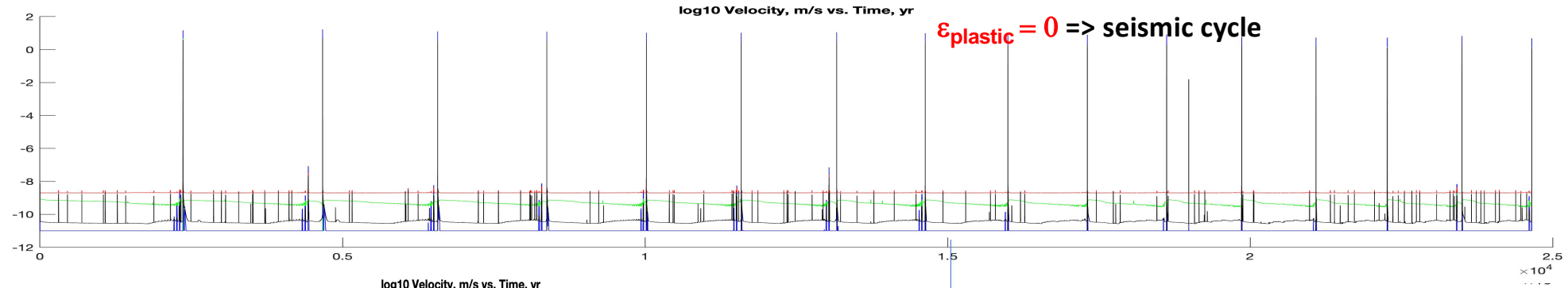
Resolving transition to the coseismic phase with rate-dependent strength



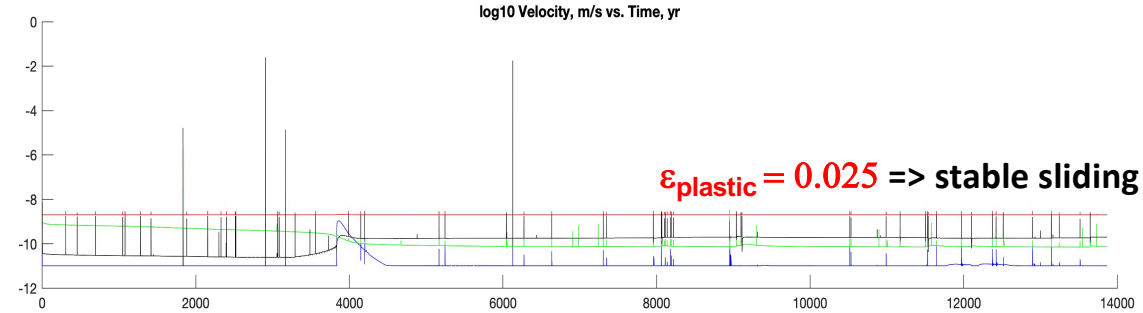
Obtaining multiple megathrust events with fully compressible model



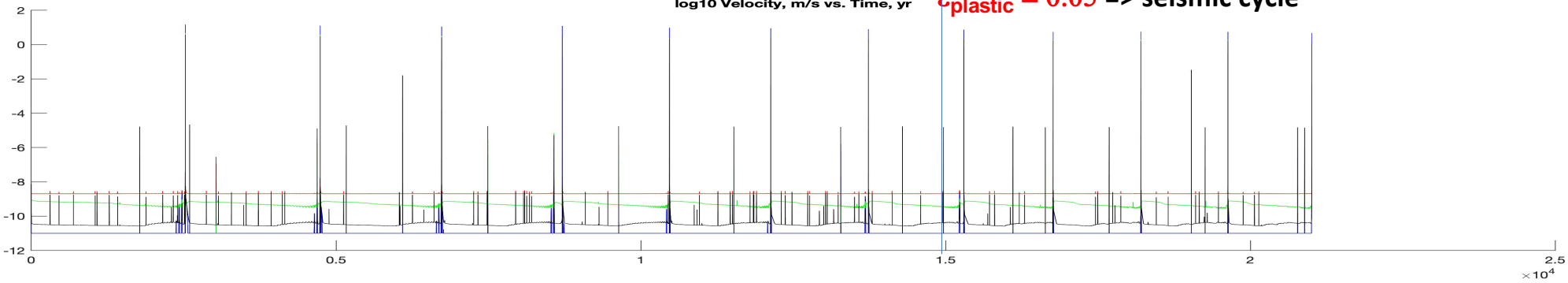
Influence of assumed constant steady state plastic strain $\varepsilon_{plastic}$ for dilatation



$\varepsilon_{plastic} = 0$ => seismic cycle

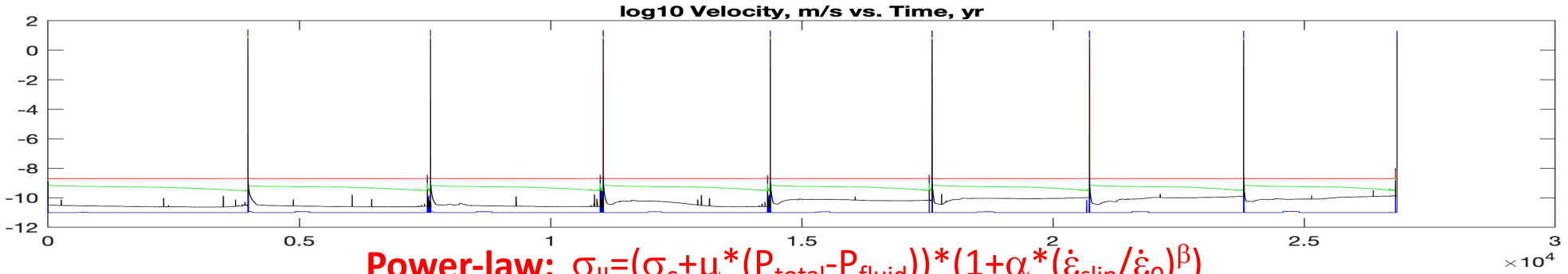


$\varepsilon_{plastic} = 0.025$ => stable sliding

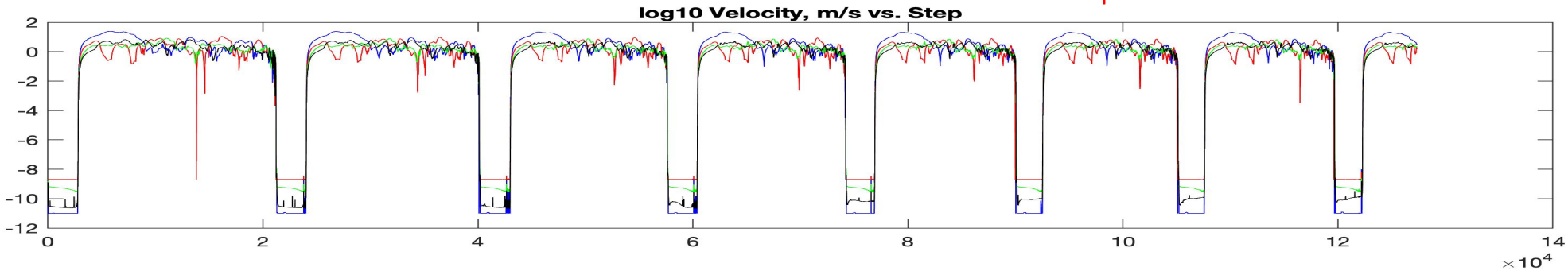


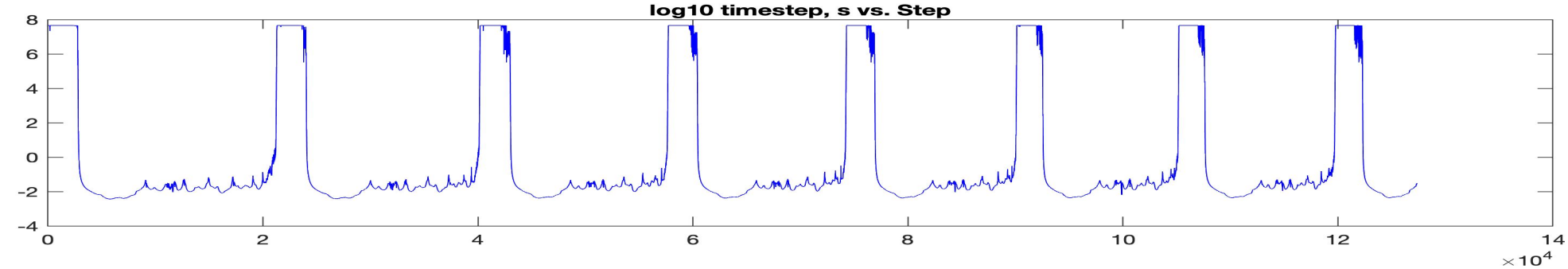
$\varepsilon_{plastic} = 0.05$ => seismic cycle

Influence of assumed rate-strengthening law

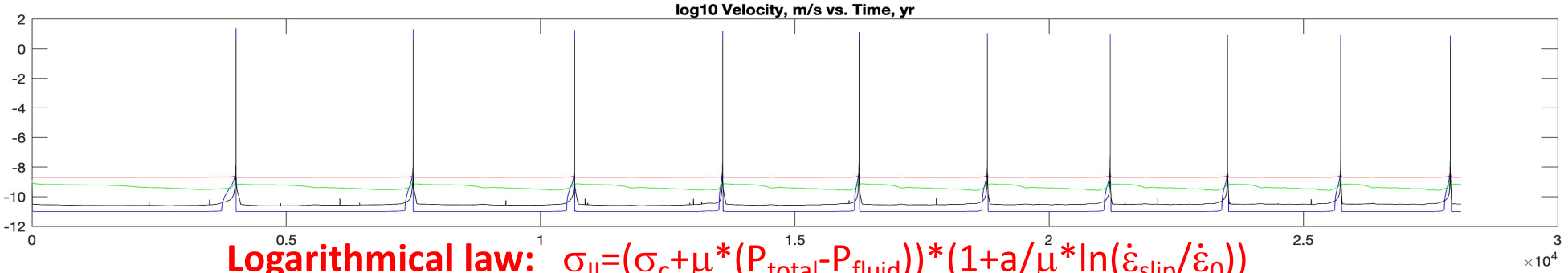


Power-law: $\sigma_{II}=(\sigma_c+\mu*(P_{total}-P_{fluid}))*(1+\alpha*(\dot{\varepsilon}_{slip}/\dot{\varepsilon}_0)^{\beta})$





Influence of assumed rate-strengthening law



Logarithmical law: $\sigma_{II}=(\sigma_c+\mu^*(P_{total}-P_{fluid}))^*(1+a/\mu^*\ln(\dot{\varepsilon}_{slip}/\dot{\varepsilon}_0))$