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The effect of normal stress oscillations on the slip behavior of a critically stable fault

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1. Introduction

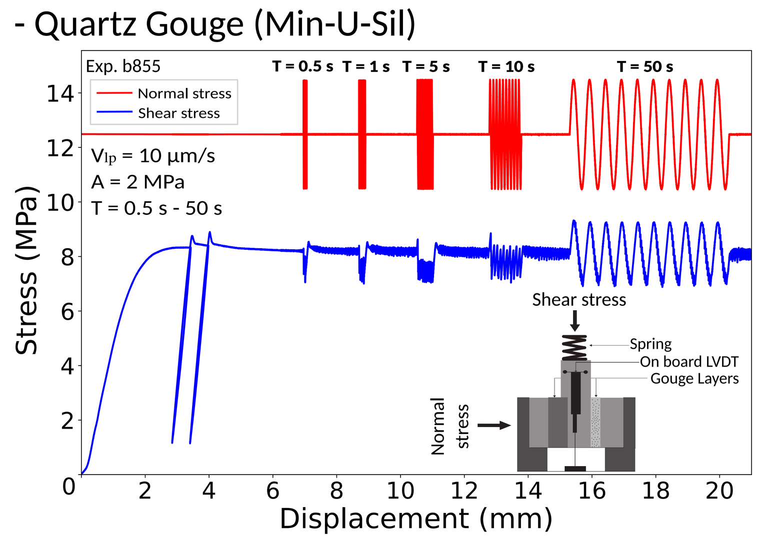
The recurrence time of earthquakes can be influenced by small stress variations arising from external perturbations, varying in space and time favoring the achievement of critical stress conditions for earthquake triggering. We aim at expanding previous work by testing the conditions for dynamic triggering under unexplored boundary conditions at the bifurcation between stable and unstable behavior. Here, we aim at answering 3 questions:

1. How do σ_n oscillations change the slip behavior of critically stable fault?
2. Can σ_n oscillations cause a fault weakening and therefore act as a trigger?
3. Can the extended rate-and-state friction predict laboratory result?

To answer this questions, we performed laboratory experiments on simulated quartz gouge, and focus on the effect of normal stress oscillations on the slip behavior of critically stable system. Particularly, we focus on the link between dynamic weakening and the normal stress perturbation signal (i.e., amplitude and frequency). Additionally, the laboratory results are compared with forward modeling using rate-and-state friction laws.

2. Methods

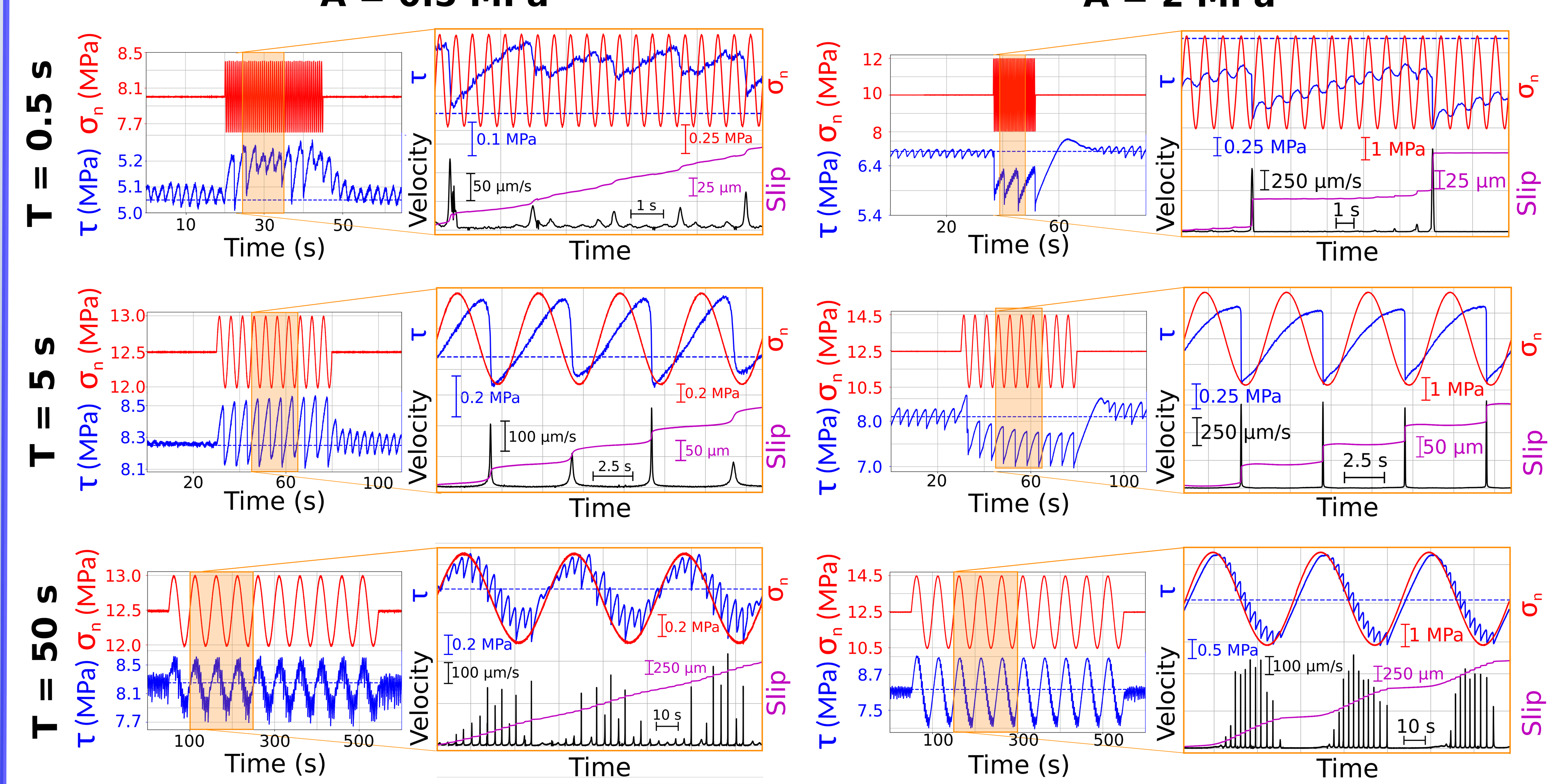
- Biaxial apparatus
- Double Direct Shear configuration
- Quartz Gouge (Min-U-Sil)



- Under controlled 100% humidity condition
- Critical stiffness condition K'/Kc' ~ 1.3
- Mean normal stress: σ_n = 8, 10, 12.5 and 13.5 MPa
- Loading rate: V_{lp} = 10 µm/s
- Oscillation periods: T = 0.5 s to 50 s
- Oscillation amplitudes: A = 0.5 MPa, 1 MPa and 2MPa

3. Effect of normal stress oscillations on fault frictional response

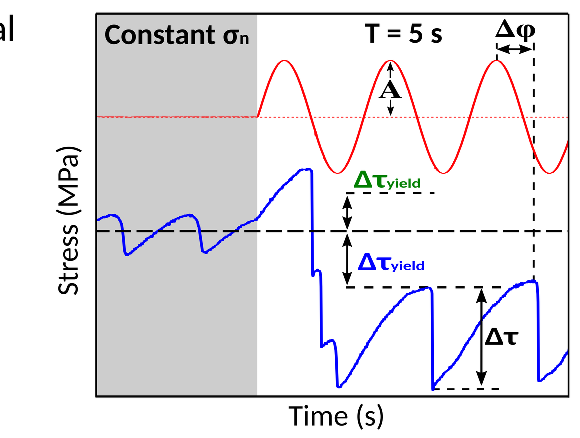
As normal stress oscillations are imposed, the shear stress shows different responses that depend on the amplitude and the period of the oscillation.

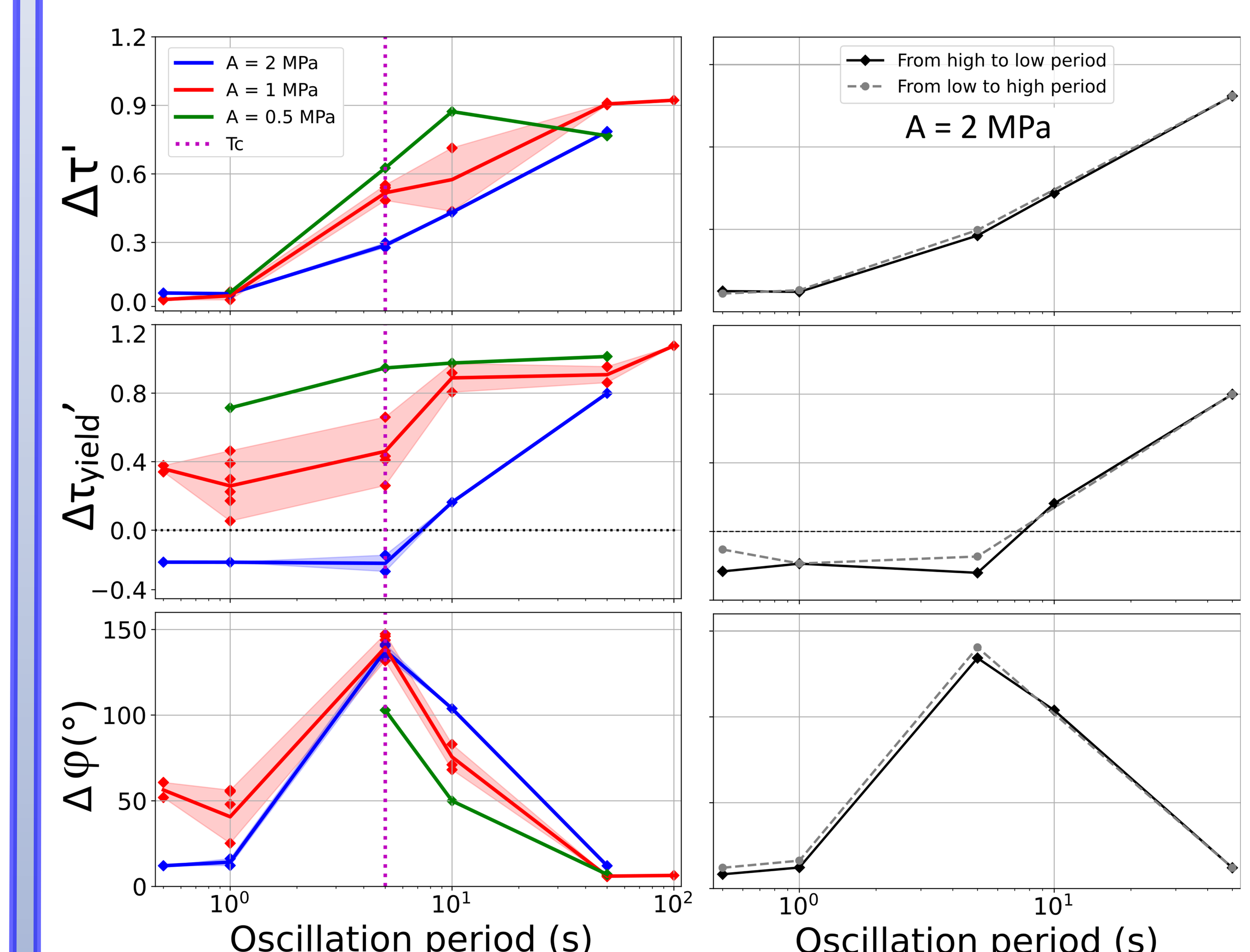


4.Parametrization of the shear stress response

Three parameters to quantify the frictional response:

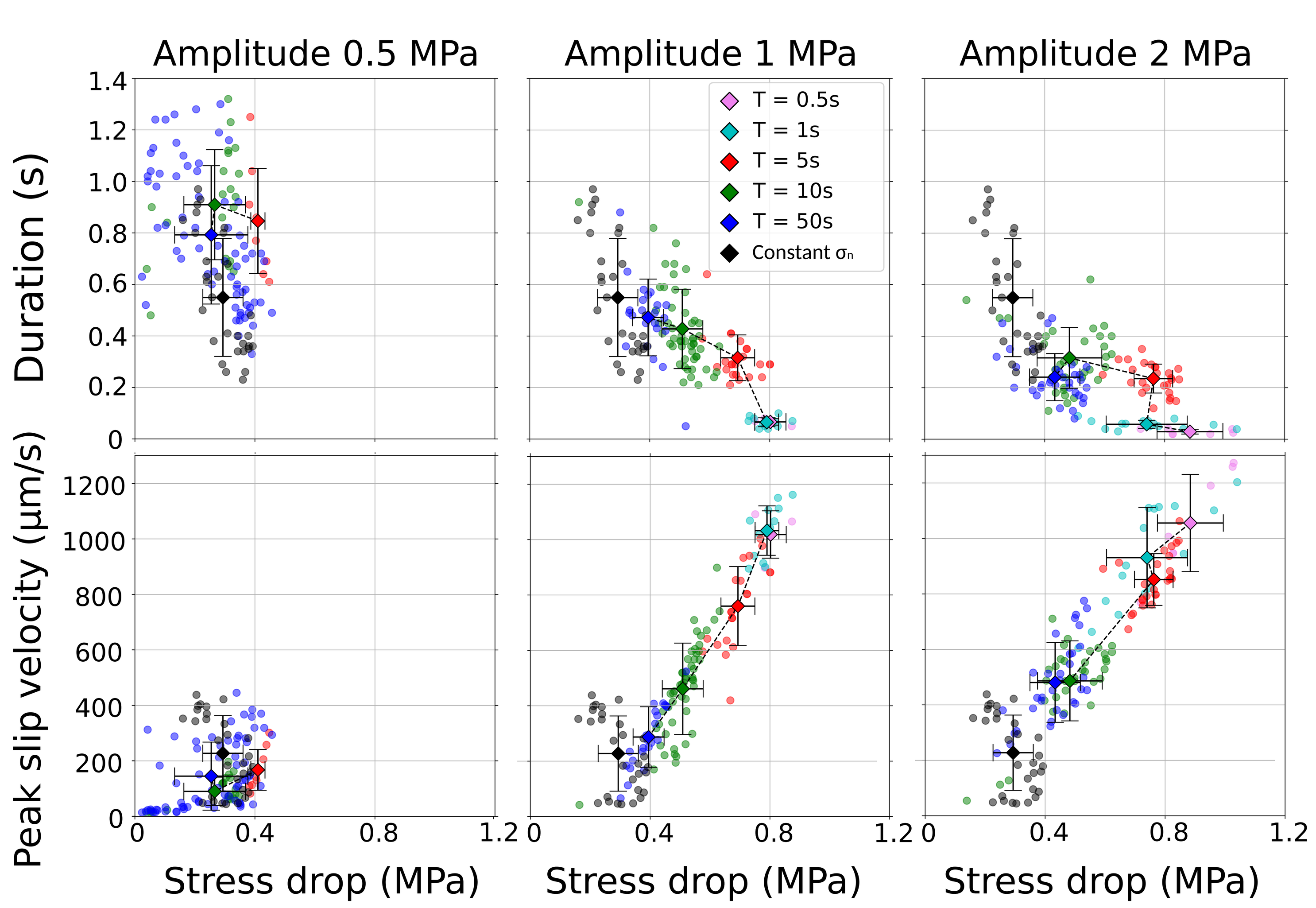
- Δτ, frictional strength variation;
- $\Delta\tau_{yield}$, variation in peak yield strength;
- Δφ, phase lag.





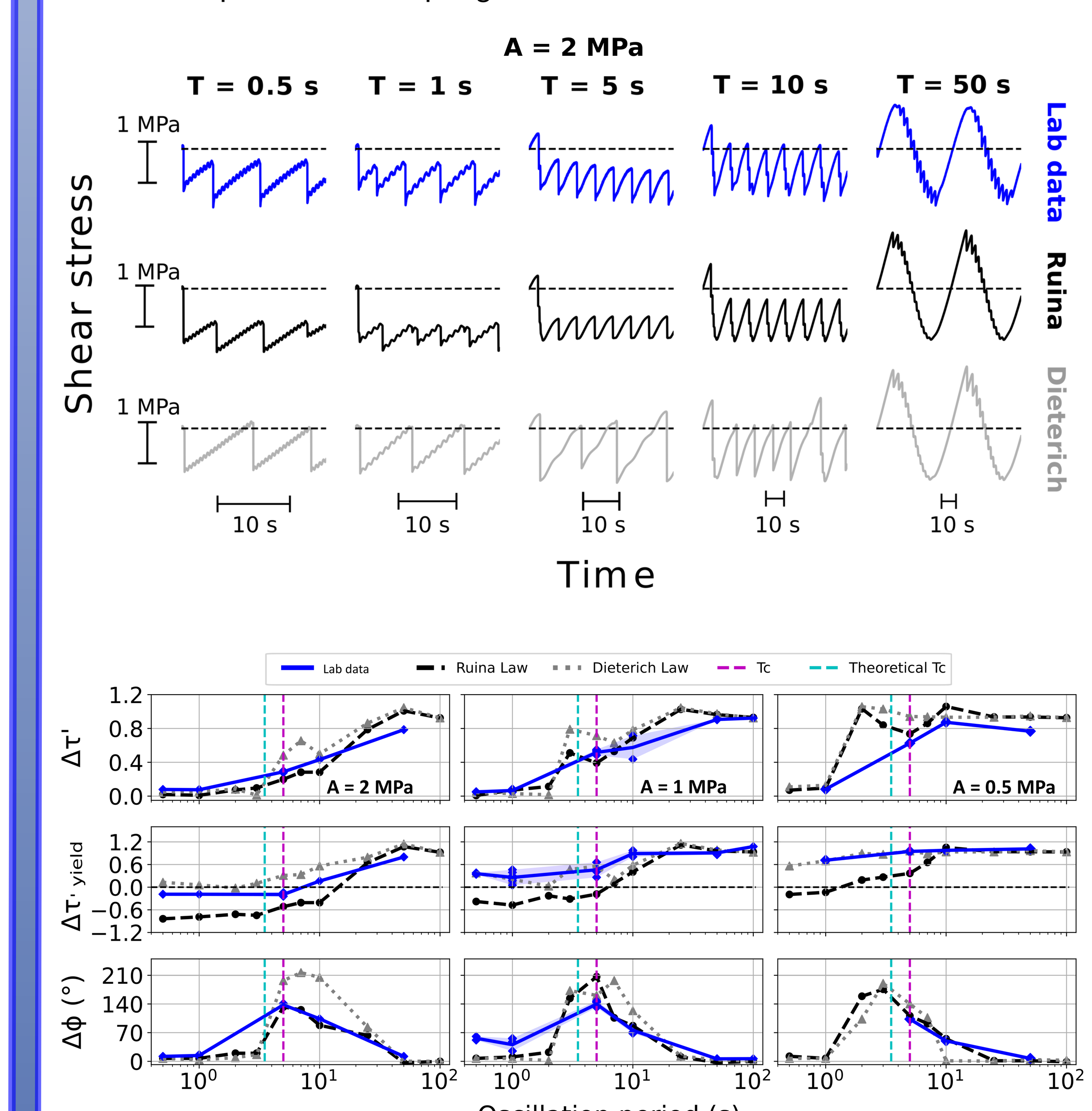
5. Instabilities triggered by normal stress oscillation

Depending on normal stress oscillation amplitude and period we document a spectrum of slip behaviors from slow to fast events.



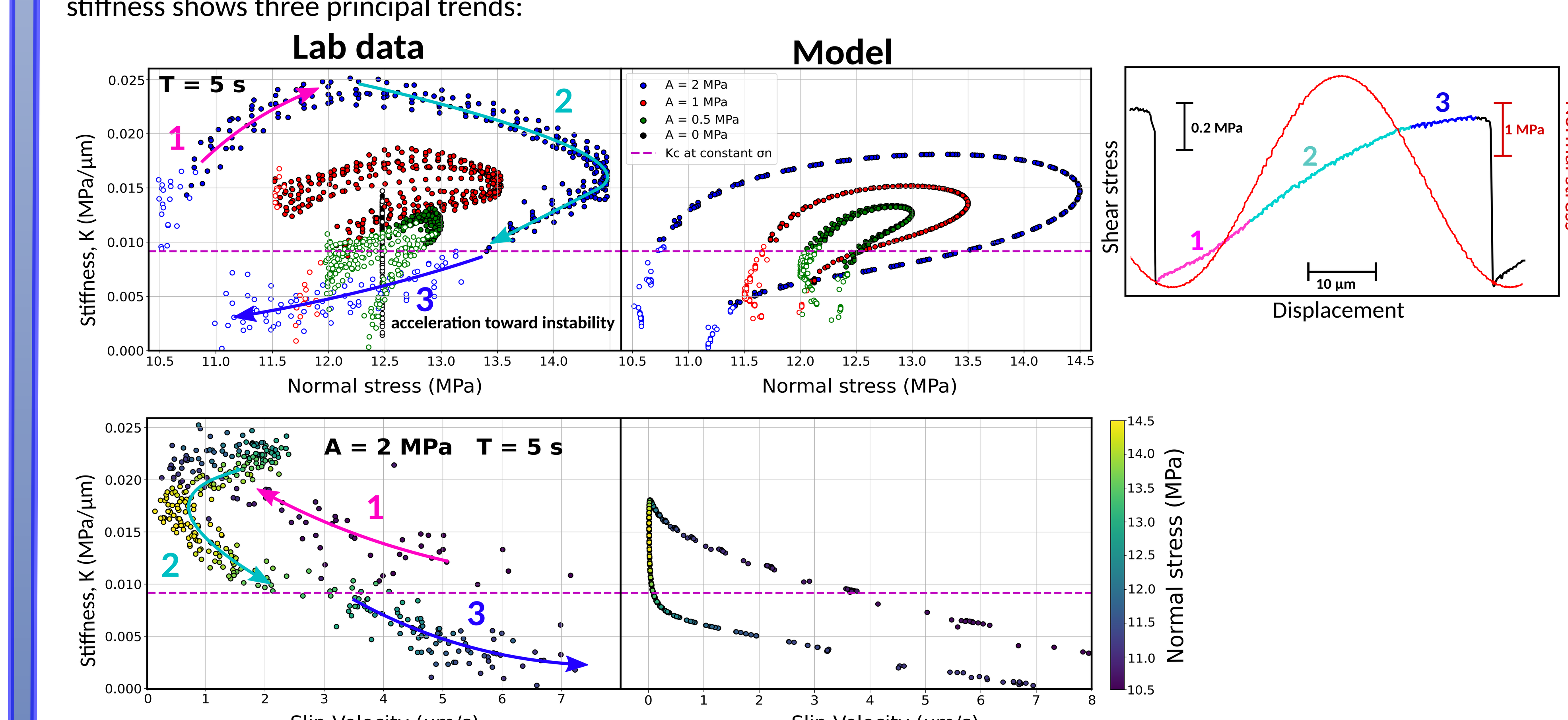
6. Rate-and-State modeling

Our experimental results are compared to a model using rate-and-state friction coupled with a 1D spring-slider.



7. Stiffness analysis

At the critical period of 5 s a regular fast stick slip behavior is triggered, to understand this behavior we measure the stiffness evolution during the normal stress oscillation. During the perturbation at high amplitude (A = 2 MPa and A = 1 MPa) the stiffness shows three principal trends:



8. Summary

Our laboratory experiments show that the fault slip behavior is controlled by oscillation amplitude and periods. Low oscillation amplitude tend to stabilize the fault and the high amplitude at short periods (T < 5 s) tend to destabilize the fault by generating a regular fast stick slip behavior. Depending on normal stress oscillation amplitude and period we can clearly see the transition from slow to fast events. At 5 s oscillation periods (critical period) regular stick slip are triggered and the evolution of the stiffness during the oscillation show fault acceleration toward the rupture when K becomes smaller than K_c. Finally, rate-and-state modeling, using both Ruina and Dieterich evolution law, is consistent with laboratory data reproducing well the behaviour observed experimentally.