Granular origins of rate and state friction behavior of fault gouge

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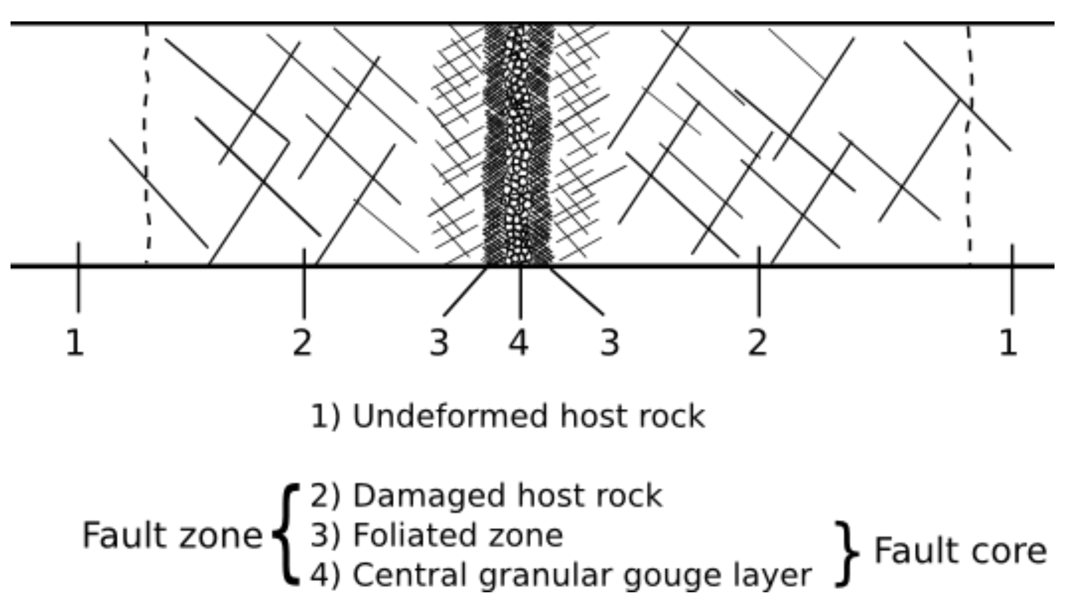
Introduction: Granular fault gouge

Most mature faults contain a **granular layer** at their core, termed "**fault gouge**". Gouge is accumulated through wear and fragmentation of the fault interface and most often is the weakest zone of the fault. The dynamical behavior of gouge thus plays a fundamental role in the stability of the fault system.

A fault gouge within the fault zone. Johnston Ridge Observatory Mt. St. Helens. Image courtesy of Kristie Bradford, http://geology1403.blogspot.com



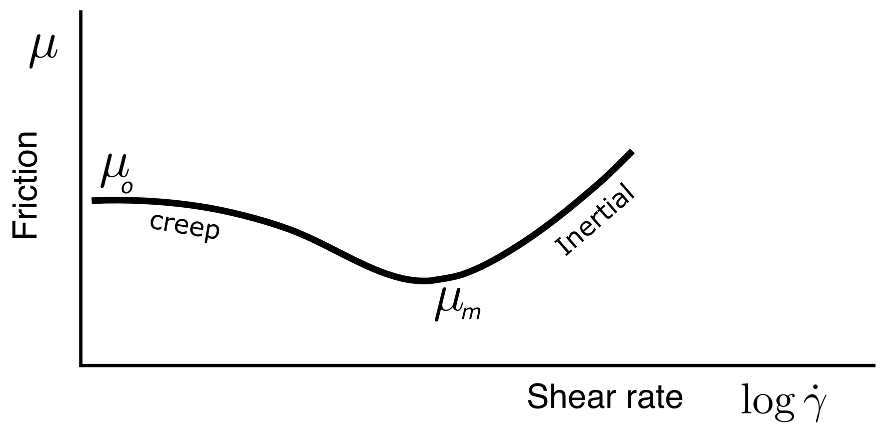
Chester et al. (1993), JGR, 98, 771-786.

Physics of sheared granular layers

Granular layers exhibit a variety of dynamical behavior from **steady-sliding** to **stick-slip** and **creep** when subjected to shearing at increasing confining pressures and decreasing shearing velocities in laboratory experiments and simulations.

Sick-slip instabilities have been associated with a non-monotonic shear stress vs. shear rate response in disordered granular layers with frictional dissipation [1,2].

The non-monotonic response [1-4] is suggestive of inherent instabilities and has been argued to be a source of rate and state dependent frictional behavior [3].



Objectives and approach

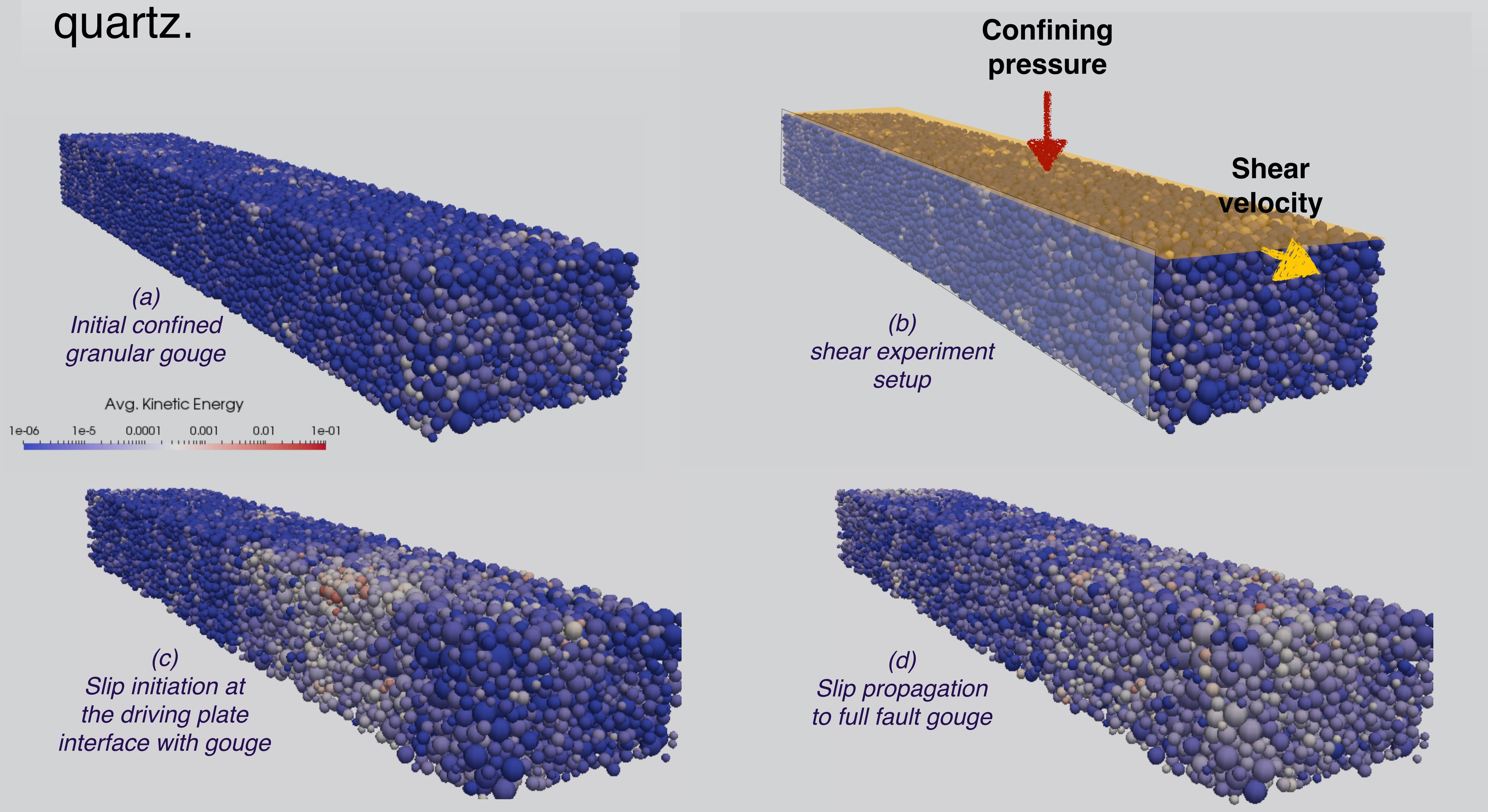
We seek to understand the physics of rate and state friction behavior of simulated fault gouge using theory and methods from the field of granular physics.

We examine the response of the system to a change in shear rate (in simulated velocity-stepping tests), providing insight into granular processes at the core of observed velocity-weakening and velocity-strengthening behaviors.

Model description

We use particle dynamics simulations to explore the response of fault gouge to a range of loading conditions, at confining pressures of 0.6 to 30 MPa and shear velocities of 5 to 1000 μm/s.
Our granular system is constructed of grains with the mechanical properties of quartz.

Simulation parameters	
Contact stiffness	60 GPa
Interparticle friction	0.5
Restitution coefficient	0.999
Grain density	2500 kg/m3
Initial box size	(0.3 x 0.06 x 0.06) m
Number of particles	23162



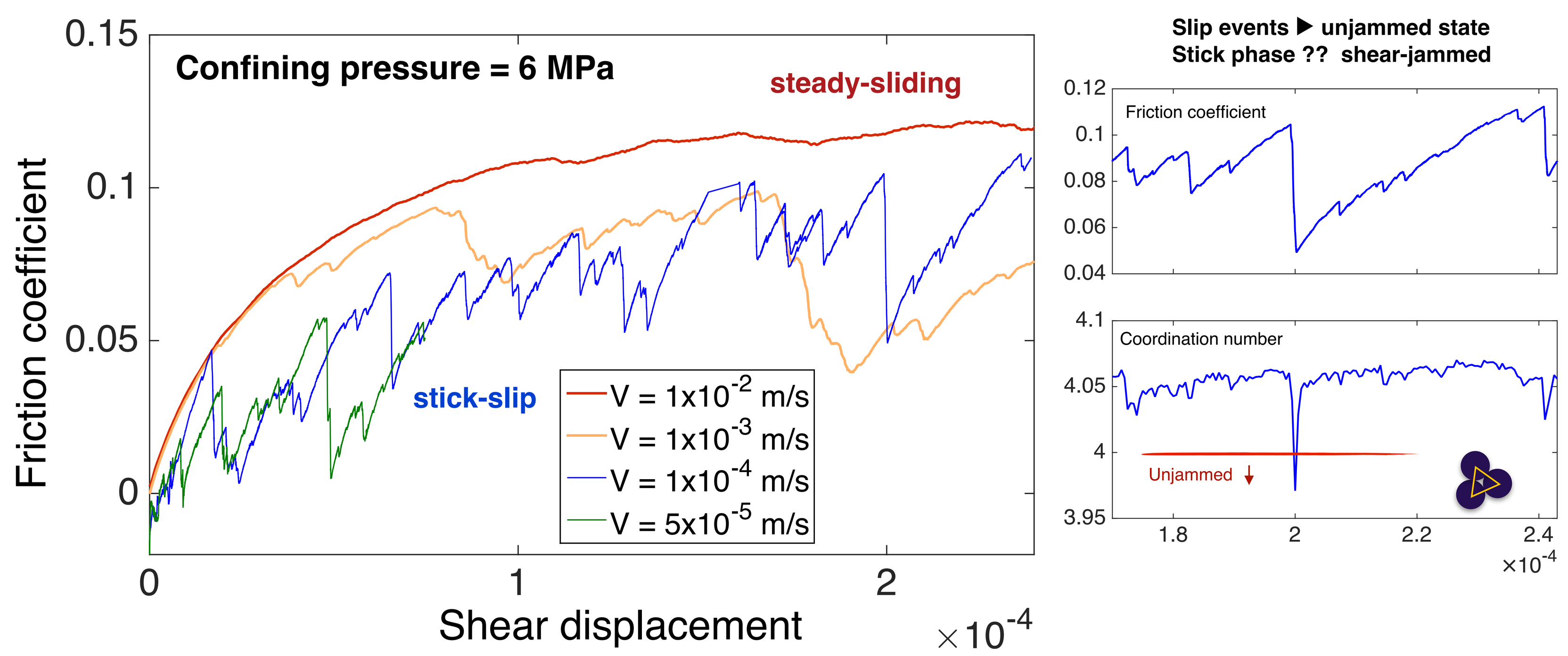
(a) Initial confined granular gouge

(b) shear experiment setup

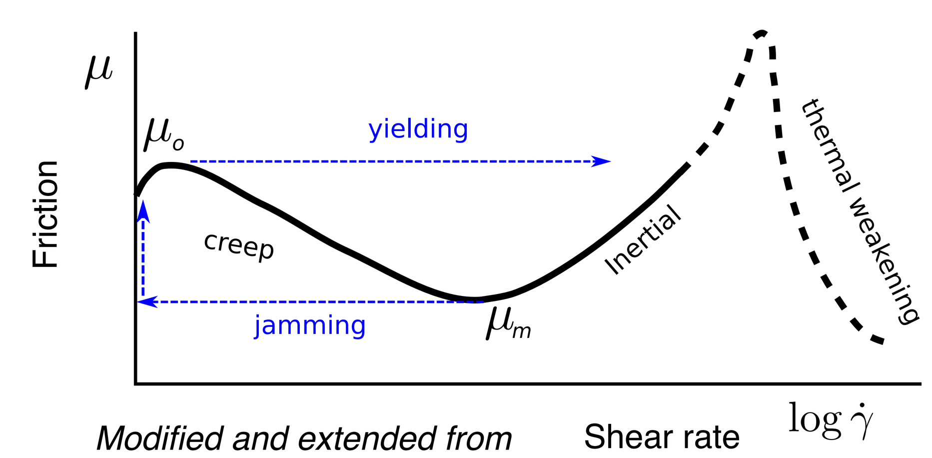
(c) Slip initiation at the driving plate interface with gouge

(d) Slip propagation to full fault gouge

Frictional behavior of granular gouge

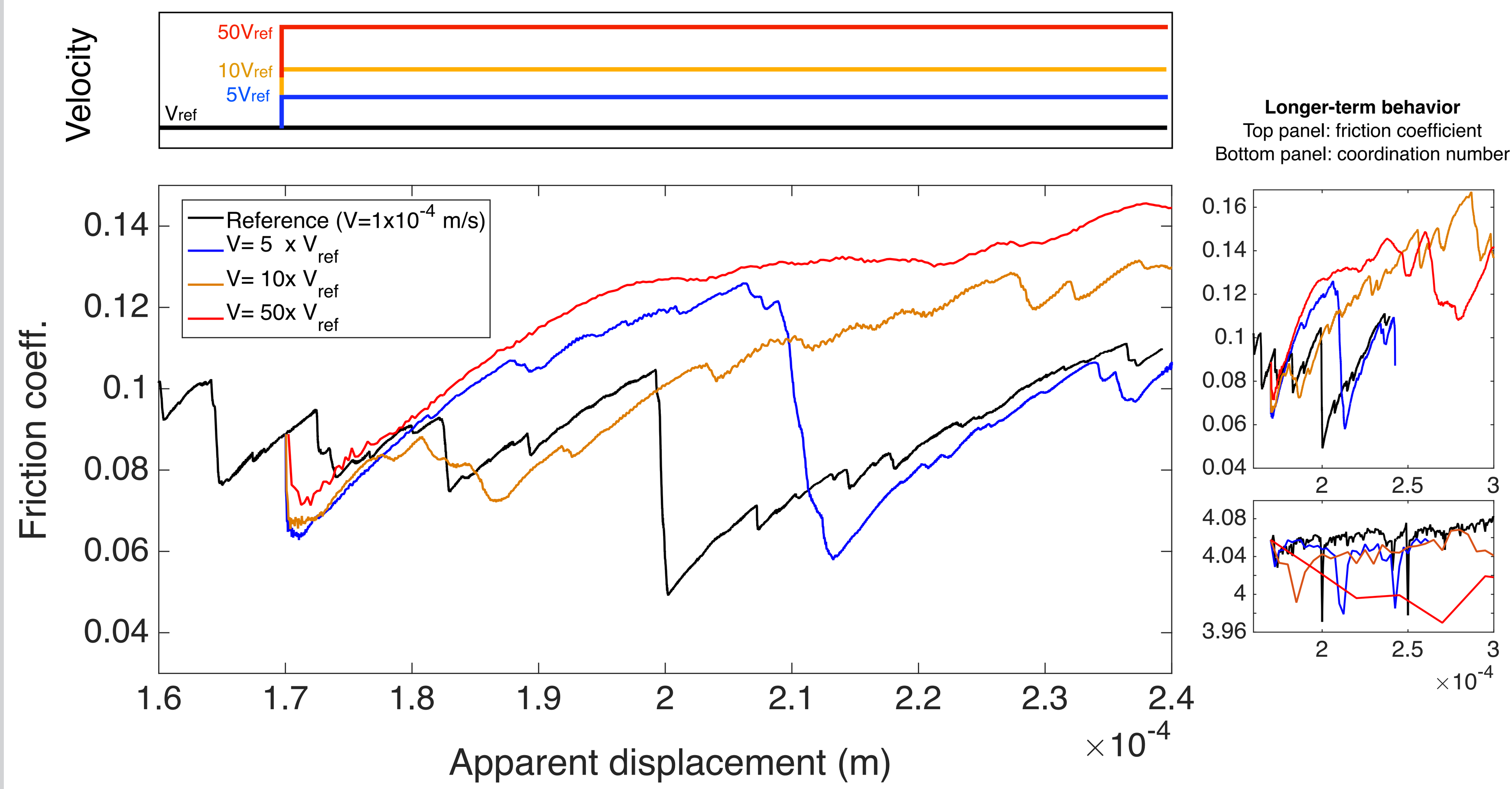


- The granular gouge shows a range of behavior from steady-sliding to stick-slip and creep as the shearing velocity is decreased.
- Our simulations confirm the hypothesis by van Hecke (2015) that slip (local minima) can in fact be an unjammed state. However, whether (and how) it is followed by another approach to jamming is not yet sufficiently explored.



Modified and extended from Ref [2,5]

Velocity step (increase) tests



Increasing drive velocity initially causes an instability (advanced slip) - larger friction drop for larger velocity increase ($\propto$ acceleration) - followed by velocity-strengthening response.

The velocity-strengthening response can be actually interpreted as a continuous evolution of dynamical behavior of the granular gouge also evidenced by the change of the coordination number to different levels.

Conclusions and future works

- A disordered granular gouge layer has an inherent instability that results in a range of dynamical behavior from steady-sliding to stick-slip and creep at varying shear rates.
- Investigating the rheology of confined shear gouge can be a key step toward physically-based friction laws applicable for fault gouge.
- It is important to know if the jamming-unjamming paradigm-as a widely explored source of instability in granular systems- has any implications for fault friction. We know already that slip is an unjammed state, but what is the nature of the transition from stick to slip states?
- After understanding and quantifying the contribution of disordered granular structure to rate and state frictional response, the next steps can be exploring the role of humidity, fluid and plastic deformation at the contact scale.

References

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