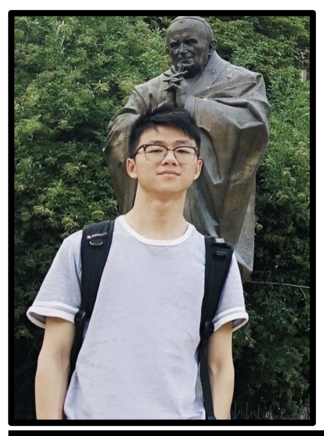

The Pulverization Mechanism of Host Rocks Induced in Faulting: Insights from Grain-scale Fracturing

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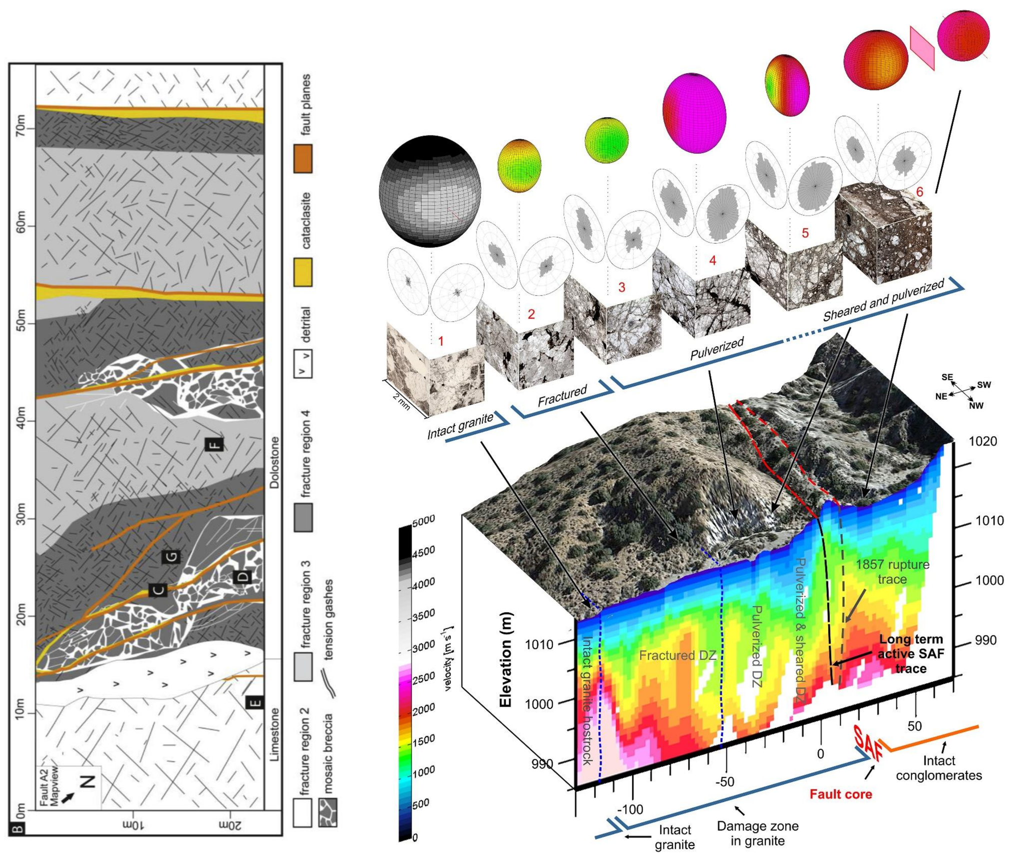
BACKGROUND

Seismogenic faults, capable of causing large magnitude earthquakes (Mw>7.0), continue to cause threats to communities and the built environment. Some faults slip slowly, while others generate catastrophic supershear ruptures, associated to asymmetric faulting, and grain-scale pulverization. To understand the occurrence and mechanism of supershear earthquakes, it is needed to understand the role that different scales of fault zone structures play on various aspects of earthquake and faulting mechanisms, ranging from long-term evolution to brittle rock rheology and dynamic fracturing during the activation, propagation, and occurrence of earthquakes



Evidence showing the role of heterogeneity on grain pulverization in supershear earthquakes [Rempe et al. 2013, Schröckenfuchs et al, 2015].

PURPOSE

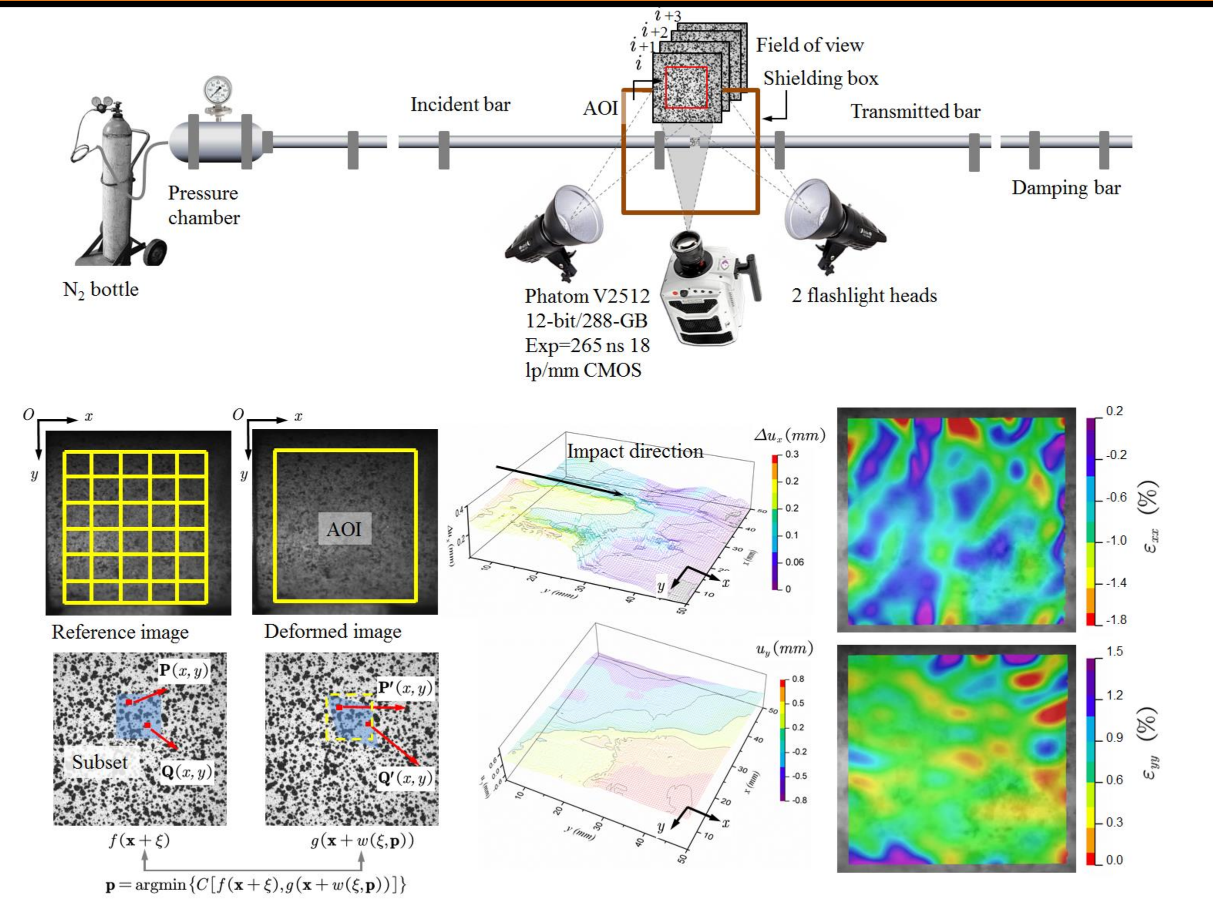
The explicit consideration of the actual microheterogeneity in rocks both in-situ and in laboratory testing is important. Many problems remain to be solved to bridge the variability of rock microstructures with the macro dynamic properties of the fault which shows significant rate dependency, including:

- How to characterize the actual heterogeneity at the grain scale in microscopy?
- What are the causes for the conversion from intergranular fracturing to transgranular fracturing in solids?
- What is the relationship between the microstructures and crack velocities?

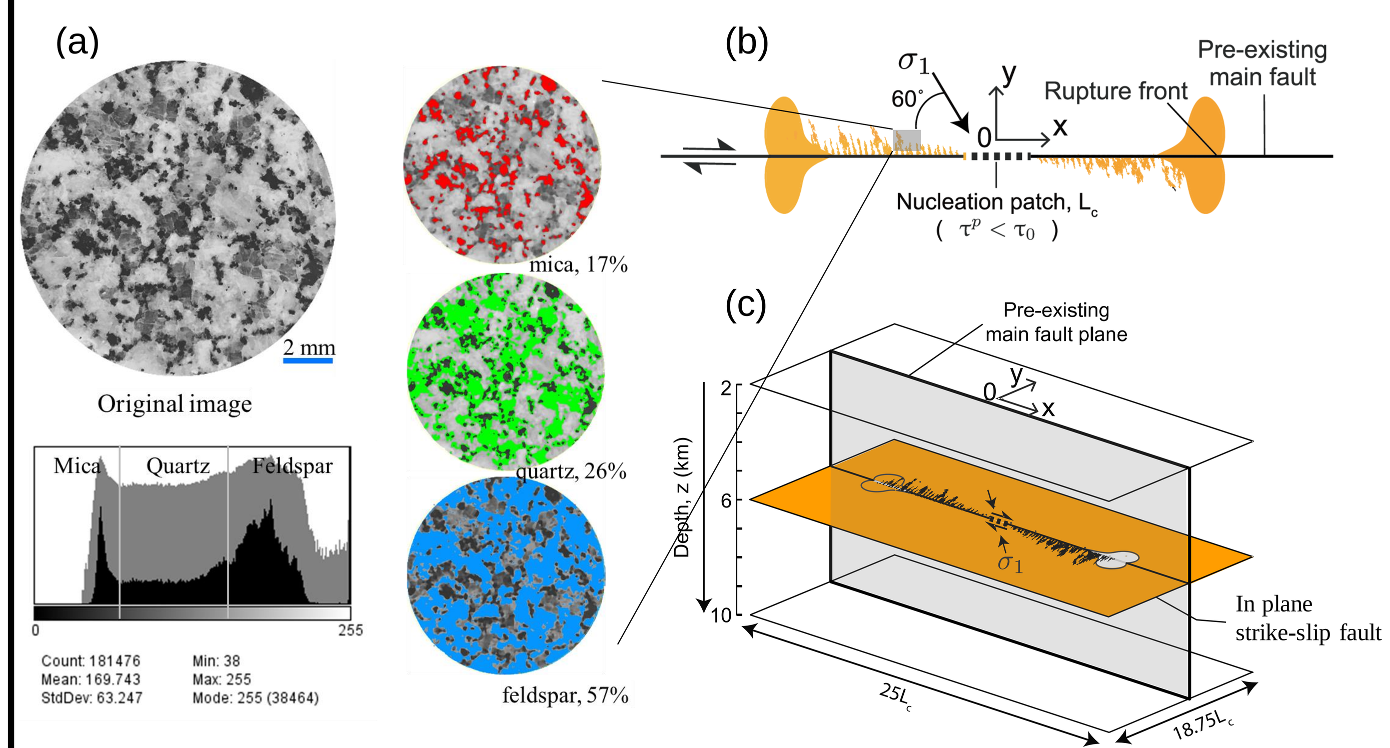
Due to difficulty in reproducing natural earthquakes in the laboratory, available computational methods can be used to model site-scale faulting. In this work, laboratory observations and the finite-discrete element method (FDEM) are combined to further understand how the microheterogeneity in crystalline rocks reduce the critical threshold that causes rock pulverization. Solutions can explain the reason why pulverized rocks are commonly found several hundred meters away from the fault core for large earthquakes.

METHODOLOGY

Rock pulverization is reproduced experimentally using a split Hopkinson pressure bar setup. The loading rate is changed to mimic the dynamic rupturing encountered in natural sub-Rayleigh and supershear earthquakes for 24 granite samples. Initiation and propagation of cracks are captured using an ultra-highspeed camera having a maximum framerate of 1 million frames per second. The highspeed digital image correlation (DIC) measurement together with a finite element method formulation, are used to overcome the huge strain gradient discontinuity due to large deformation after impact. Fragment size analysis is carried out using a combination of manual sieving and watershed image segmentation technique for the fragmented rocks.



Split Hopkinson pressure bar system and highspeed DIC.



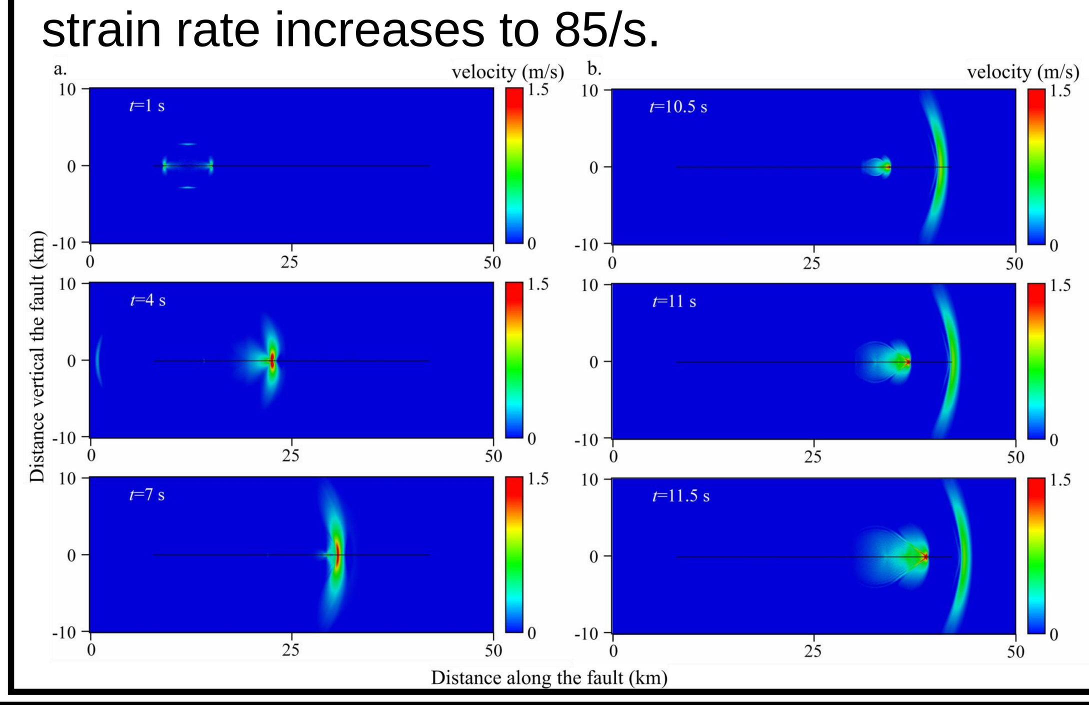
The multiscale 2D strike-slip model generated in OpenFDEM. (a) Zoom-in of the realistic grain-based model near the fault core, (b) schematic of the in-plane fault, and (c) schematic of the model with depth (modified after Okubo et al. 2019).

To study the role of grain-scale fracturing and microheterogeneity on rate-dependency and rock pulverization, a model is built using the open-source package, OpenFDEM, a multiscale continuum-discontinuum model. The heterogeneity in mineral components is reproduced using Voronoi tessellation constrained by realistic grain images. Each Voronoi element is finely meshed, thus the model can account for both transgranular and intragranular fracturing. The rate-and-state friction law is implemented in the package to reveal the effect of friction on dynamic faulting..

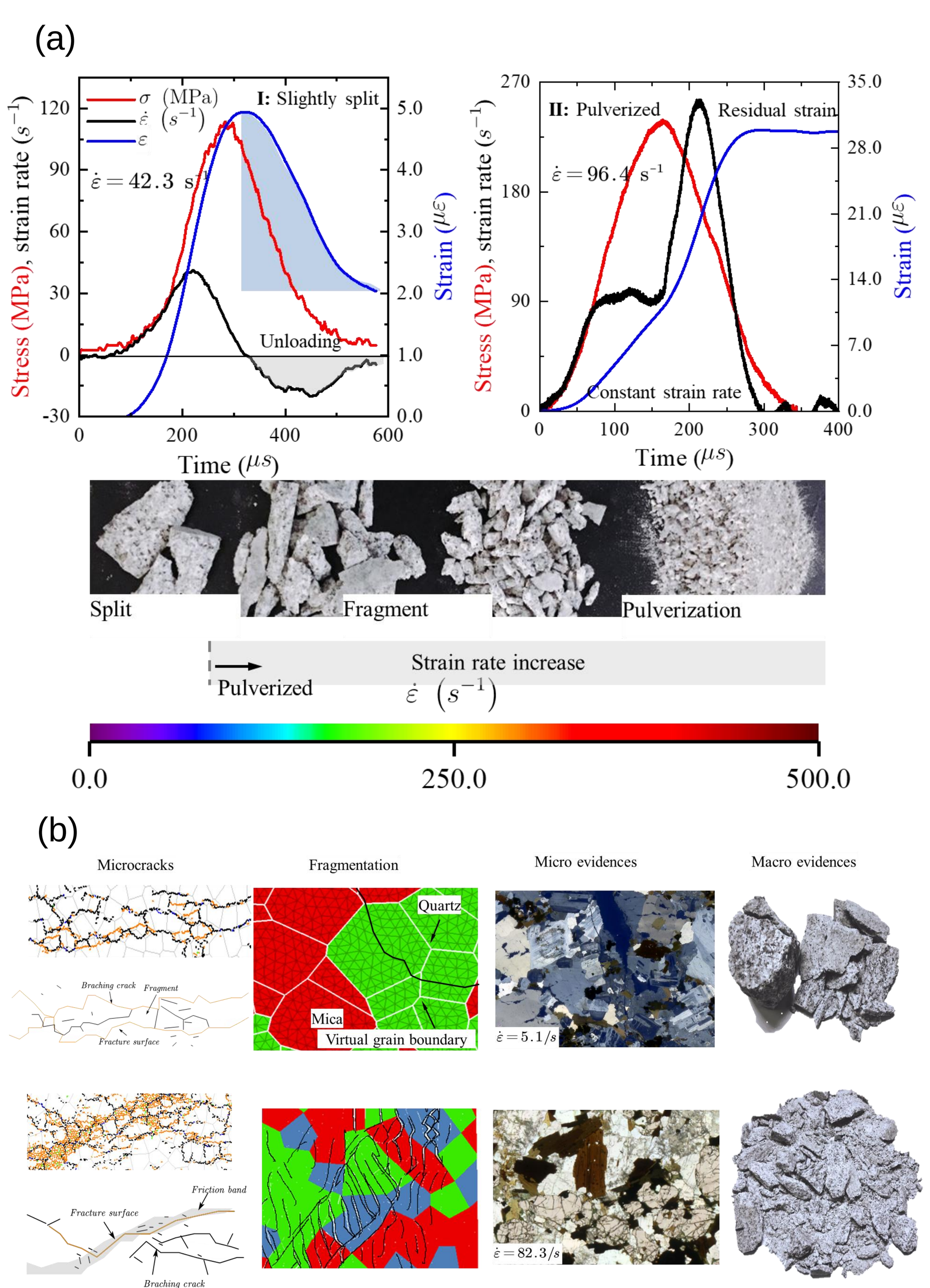
RESULTS

The dynamic stress-strain curves are categorized into class I and class II by the features of residual strain, fracture pattern, and strain rate. The strain rate threshold representing the dynamic pulverization for granites is 80/s, which is similar to the value of 85-100/s for granitic rocks subject to successive impacts [Aben et al, 2016], but much smaller than the value from Yuan et al, 2011. The critical strain rate determining the pulverization is identical with the on-site observations from the Caleta Coloso fault [Okubo et al. 2019], and the numerical results indicated that the grain size plays a significant role in reducing this critical value.

The transition from sub-Rayleigh to supershear propagation occurs when stresses moving at intersonic speeds ahead of expanding sub-Rayleigh ruptures exceed the peak strength of the fault, initiating slip within a daughter crack. The transition from sub-Rayleigh shear to supershear can be realized by increasing the initial shear stress. The maximum strain rate for sub-Rayleigh shear is about 5/s and the seismic strength parameter (S) is 1.79. When the S decreases to 0.9, the Mach cone can be found in the front of the fracture, the rupture velocity increases from 2.23 km/s to 5.47 km/s, and the maximum strain rate increases to 85/s.



Snapshots of different time in the progress of dynamic rupture propagation. (a) sub-Rayleigh shear, and (b) supershear (Mach cone is observed in front of the fault). The fragmentation results are shown in the right image, the sub-Rayleigh shear results in split failure in the damage zone and the supershear results in pulverization in the damage zone.



(a) Stress, strain rate, and strain curves as functions of time for class I and class II failure in granites, the critical strain rate for fragmentation and pulverization is about 80/s [Li et al. 2018], pulverized rocks occur preferably when the strain rate is increased (supershear) or the grain size is increased (microheterogeneity is enhanced), (b) typical split and pulverized failure in granites observed from tests and numerical results.

The rock microheterogeneity is a major factor to determine the critical strain rate required for rock pulverization during supershear earthquakes.

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