Micro-slips in an experimental granular shear band replicate the spatiotemporal characteristics of natural earthquakes

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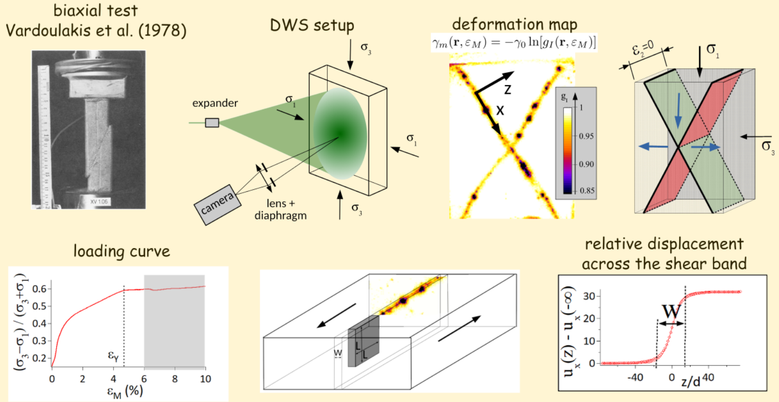
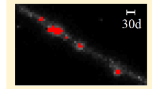
Abstract

We study experimentally the fluctuations of deformation naturally emerging along a shear fault within compressed frictional granular medium. Using laser interferometry, we show that the deformation inside this granular gouge occurs as a succession of localized micro-slips distributed along the fault. The associated distributions of released seismic moments, the memory effects in strain fluctuations, as well as the time correlations between successive events, follow exactly the empirical laws of natural earthquakes. Using a methodology initially developed in seismology, we reveal for the first time at the laboratory scale, the underlying causal structure and identify the triggering kernel. This formal analogy between natural faults and our experimentally controllable shear band opens the way towards a better understanding of earthquake physics. In particular, experiments performed under different deformation rates show that strain, not time, is the right parameter controlling the memory effects in the dynamics of our fault analog.

Experimental setup



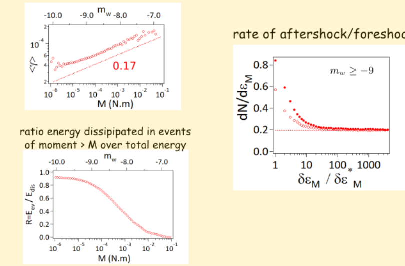
Events statistic

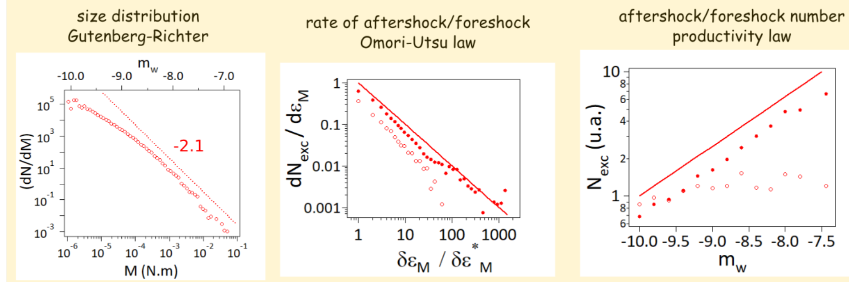


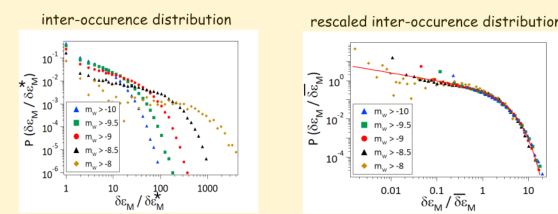
catalog of events
surface Σ_i
microscopic shear γ_i
shear modulus $\mu = 200\ MPa$

'seismic moment' $M_i = \mu \gamma_i \Sigma_i^2 / w$

moment magnitude $m_{w;i} = \frac{2}{3}\log_{10}(M_i) - 6.07$

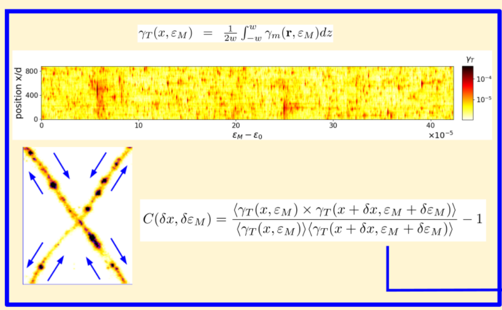






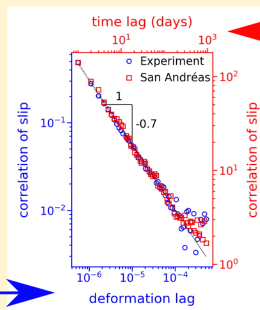
$P(x) \propto x^{q-1}\exp(-x/B)$
with $q = 0.6$ and $B = 1.9$

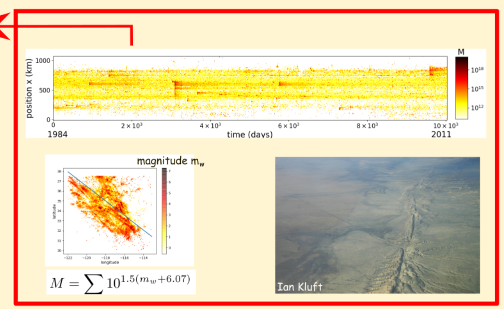
Memory effects: comparison of strain fluctuations in the lab and Californian catalog



$\gamma_T(x,\varepsilon_M) = \frac{1}{2w}\int_{-w}^{w}\gamma_m(\mathbf{r},\varepsilon_M)dz$

$C(\delta x, \delta\varepsilon_M) = \frac{\langle \gamma_T(x,\varepsilon_M) \times \gamma_T(x+\delta x, \varepsilon_M + \delta\varepsilon_M)\rangle}{\langle \gamma_T(x,\varepsilon_M)\rangle \langle \gamma_T(x+\delta x, \varepsilon_M+\delta\varepsilon_M)\rangle} - 1$

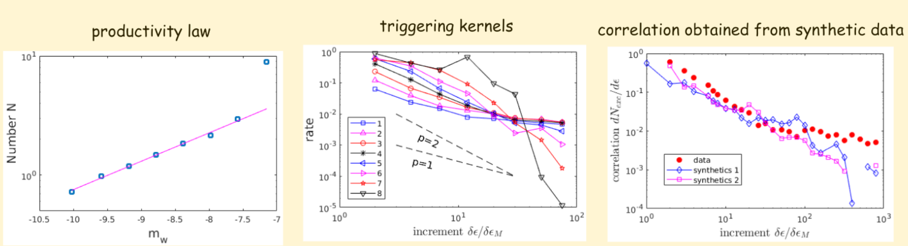




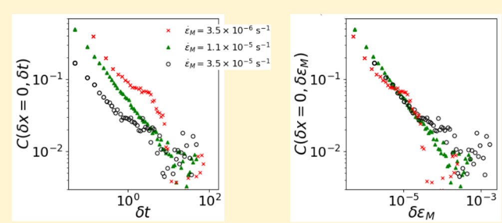
$M = \sum 10^{1.5(m_w + 6.07)}$

Triggering of deformation events

declustering of the causal structure using a maximum likehood algorithm



Structural vs. temporal memory effects



Synthetic comparison between natural gouges and granular shear band

Property	earthquakes	our experiment
Temporal correlation function: $C(\delta x = 0, \delta t) \sim \delta t^{-\theta}$	$\theta \simeq 0.70$	$(^*)$ $\theta \simeq 0.74$
Moment or energy distribution: $dN/dM \sim M^{-\beta}$	$\beta \simeq 1.7$	$\beta \simeq 2.1$
Aftershocks rate: $dN_{as}/dt \sim t^{-p}$	$p \simeq 1.0$	$(^*)$ $p \simeq 1.0$ $(^a)$; 1.7 $(^b)$
Productivity law: $N_{as} \sim 10^{\alpha m_w}$	$\alpha \simeq 0.8$	$(^*)$ $\alpha \simeq 0.4$ $(^a)$; 0.24 $(^b)$
Recurrence time distribution: $P(x) \sim x^{q-1}\exp(-x/B)$	$q \simeq 0.7$	$q \simeq 0.6$
Stress drop / shear modulus: $\Delta\tau/\mu$	$\simeq 3.10^{-5}$	$\simeq 10^{-4}$
Branching ratio	$0.8 - 1.$ [51]	$\lesssim 1.$

"Micro-slips in an experimental granular shear band replicate the spatiotemporal characteristics of natural earthquakes", D. Houdoux, A. Amon, D. Marsan, J. Weiss, J. Crassous, in press in Communications Earth & Environment