B03: Earthquake Rupture Modelling of a Rough Fault in Laboratory Experiments

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Preamble

In this study, we analyse results from a concerted laboratory study [aa1, aa2]. During a suite of direct shear friction experiments we found that:

A. (Seismicity) Small impulsive events were located and found to release energy along the weaker frictional fault plane [aa1].

B. (Precursory slow slip) These events appeared in an accelerated preslip phase moments before full fault failure.

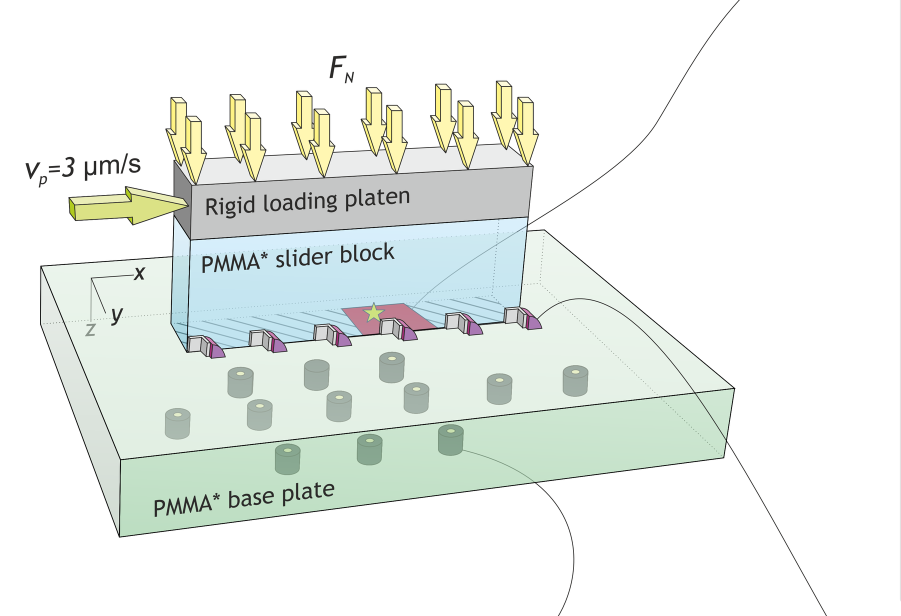
C. (Seismogenic region) These events were located and found to exist in a specific region of the fault that had large strain gradients.

D. (Interfacial wear) The fault displayed large amounts of wear within the seismogenic region [aa2].

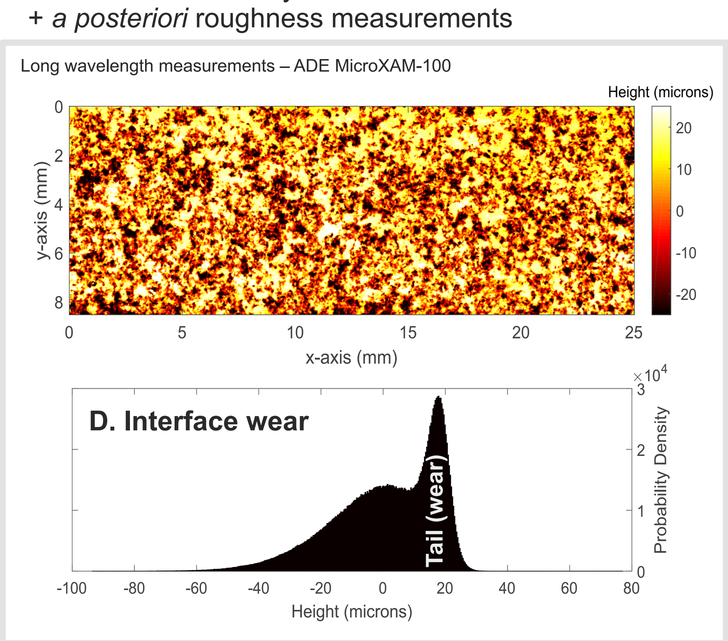
Motivation:

We investigate possible mechanisms leading to concurrent slow and fast slip, along a worn section of our fault analog prior to global stick-slip failure. Our modelling attempts to reconcile inferred seismic source parameters using a dynamic 1D RS friction model with rheologically heterogeneous properties.

Summarized direct shear results:

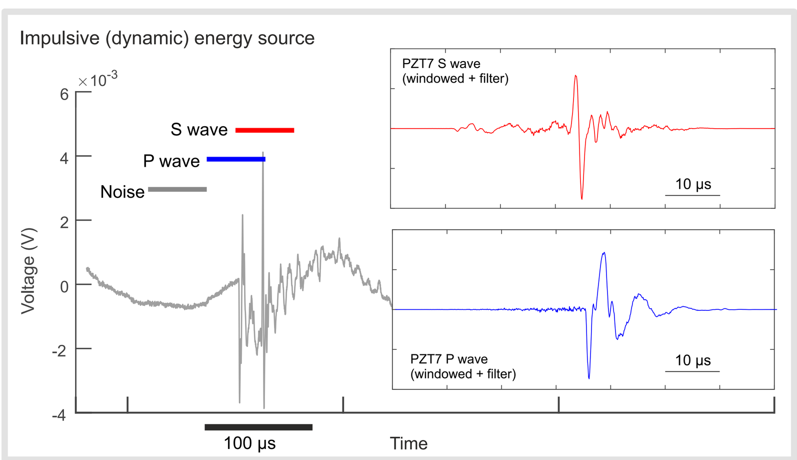


C. Seismogenic region
+ Produced seismicity
+ *a posteriori* roughness measurements



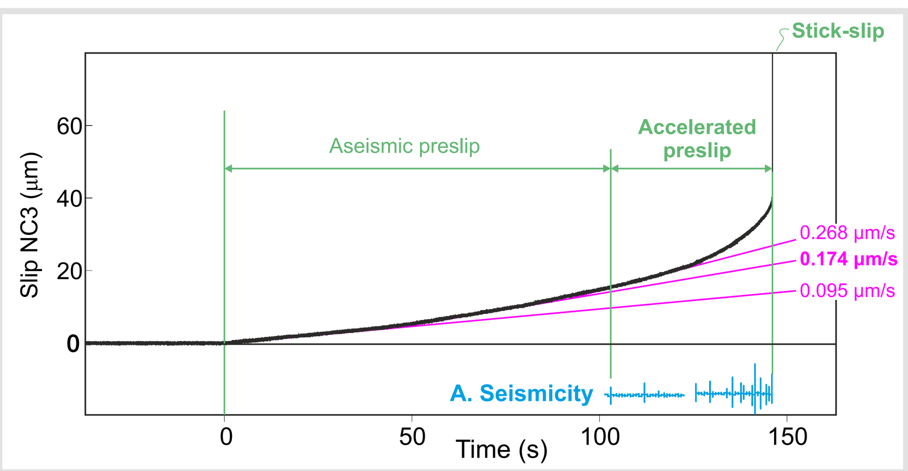
*PMMA = Poly(methyl) metharcylate

A. Seismicity (local fast slip)
+ Calibrated piezoelectric (PZT) sensor array
+ Kinematic models estimted the source parameters (methods not presented here) [zz1]



Estimated: Seismic moment M_o, radius a and stress drop $\Delta\sigma$

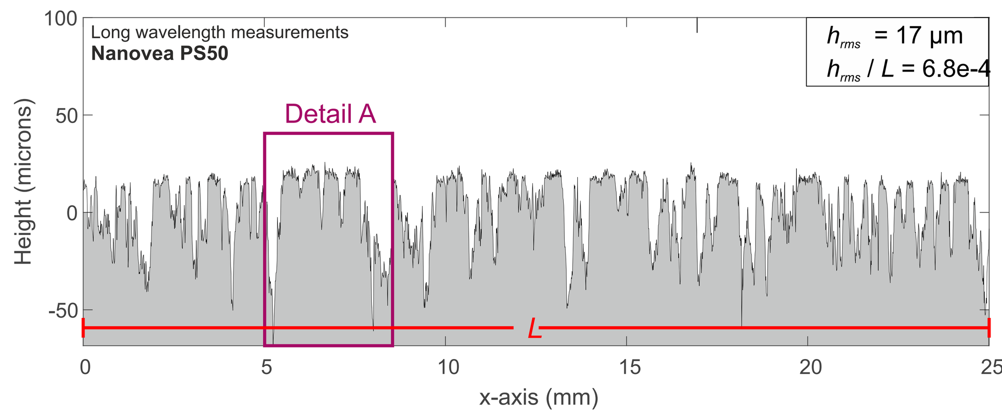
B. Slow slip (macroscopic)
+ Eddy current slip transducers

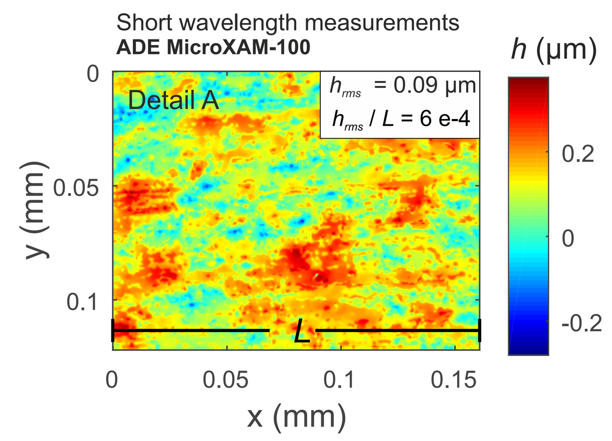


1 Introduction

Previous studies have successfully shown that RS friction can explain nucleation prosesses leading up to stick-slip failure in the lab [mm1, mm2]. We attempt to **prescribe frictional heterogeneity that explains complex frictional behaviour, where both slow and (locally) fast slip were recorded prior to stick-slip.** We compute seismic catalogs using the RS model and compare these results to source-extent properties inferred from the seismicity.

2 Roughness investigated



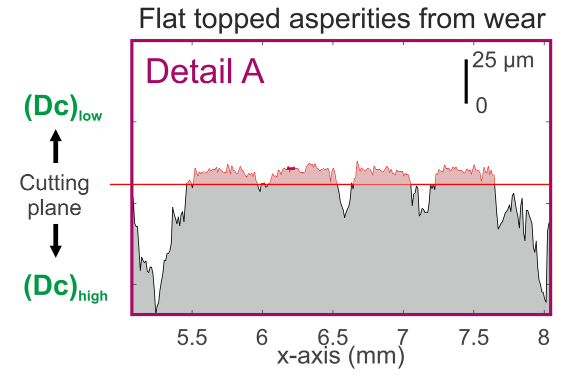


(Above) Height profile along transect in the seismogenic region. Measured at two length-scales using two devices. **(Right)** Locally, wear produced smooth sections of the fault, conversely longer length-scales retained higher levels of h_{rms}. (Q: h_{rms} /L was similar at both length scale?)

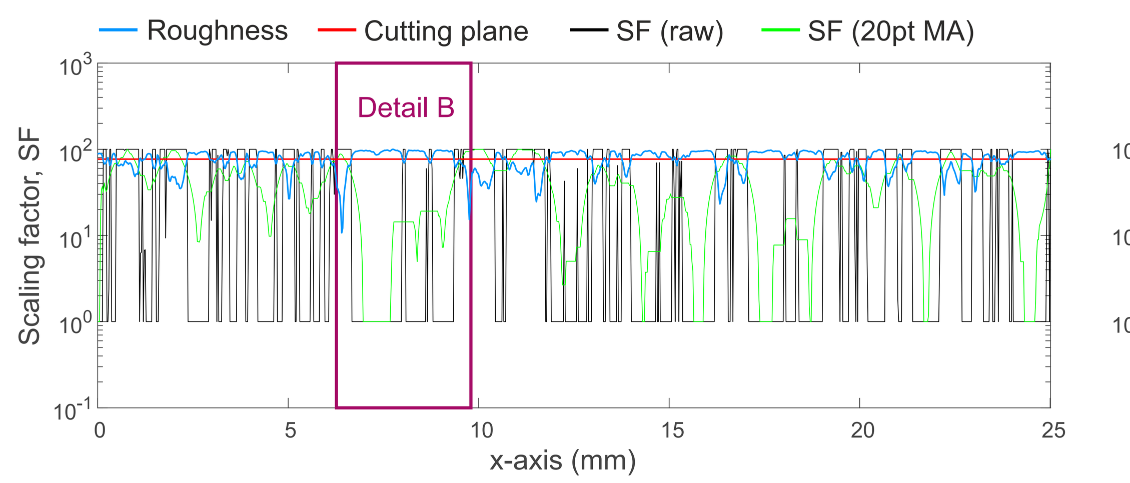
Micromechanical basis:

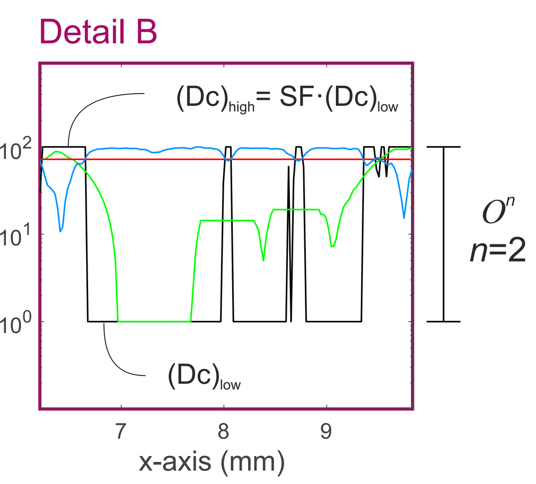
Yoshioka and Iwasa (1996, PAGEOPH) numerically investigated the characteristic displacement (D_c) in a micromechanical point of view for *dry, unlubricated interfaces*. They found that D_c is related to the distance where real contact is fully replaced with new contacts after a velocity step. **They showed that D_c is larger on rougher faults than on smoother ones.**

Flat topped asperities from wear



Model heterogeneity (above right): From this we used a "cutting plane" method that creates binary description of Dc that varies spatially in accordance to the natural wear on the interface.





3 1D QDYN Model

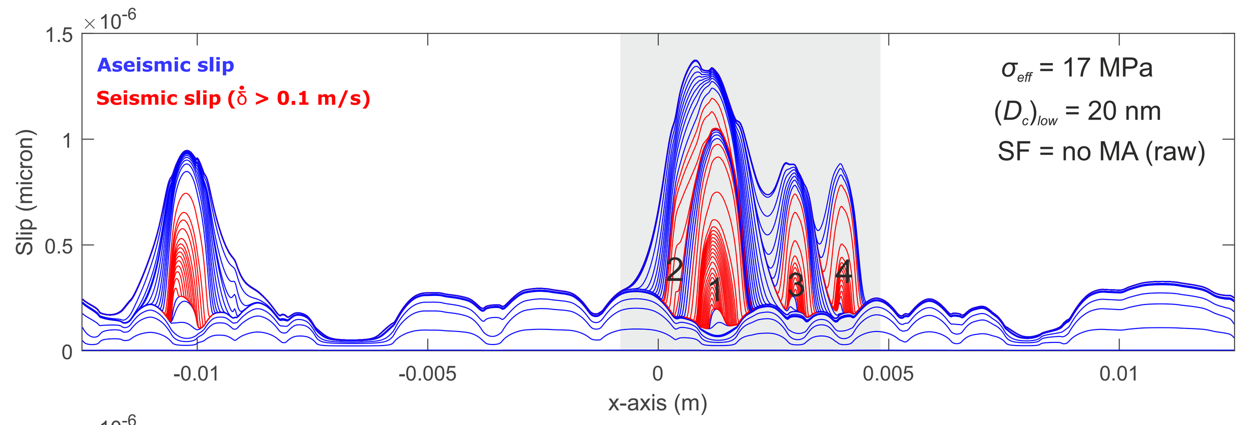
$$\tau = \sigma_{eff}\left[f_0 + a\ln\left(\frac{V}{V_0}\right) + b\ln\left(\frac{V_0\theta}{D_c}\right)\right], \quad \text{[rr1, rr2]}$$

$$\frac{d\theta}{dt} = -\left(\frac{V\theta}{D_c}\right)\ln\left(\frac{V\theta}{D_c}\right) \quad \text{Slip law [rr3, mm2]}$$

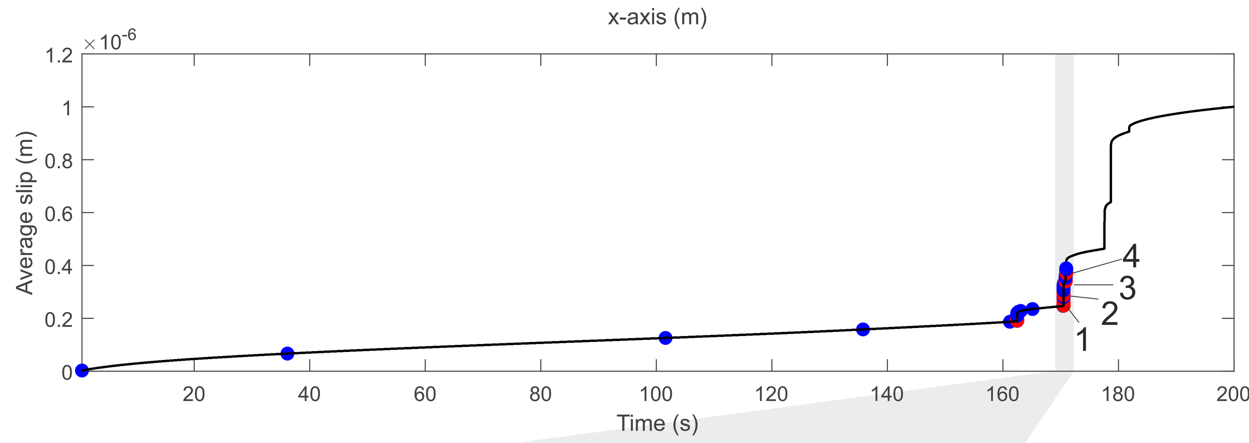
Parameter	Symbol	Value
Shear modulus (Mode II)	$\mu^* = \mu/(1-\nu)$	3.5 GPa
Density	ρ	1810 kg/m3
Poisson's ratio	ν	0.32
Ref. slip rate	V_0	0.15 µm/s
Critical slip distance	D_c	SF*$(D_c)_{low}$
Lower bound D_c	$(D_c)_{low}$	[**20**, 360]* nm
Order of D_c hetero.	n	**2**
Length of (VW) domain	L	0.025 m
RS parameter a in VW	a	0.0098
RS parameter b in VW	b	0.0140
Eff. normal stress	σ_{eff}	[10, **15**, 25]** MPa

*Nucleation theory [aa2] **Pressure sensitive film measurements [aa2]

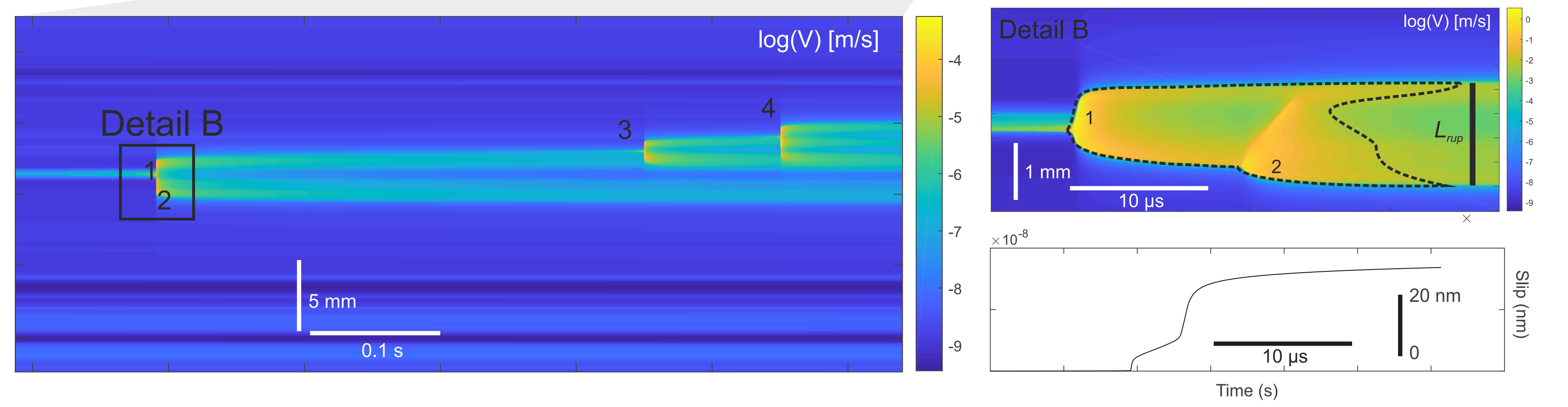
4 Example result: localized seismic sequence



(Left) Along-strike slip with a total of five local events were recorded.



(Left) Average slip on the fault during 200 seconds of simulation. Enumerated events correspond to the events above.



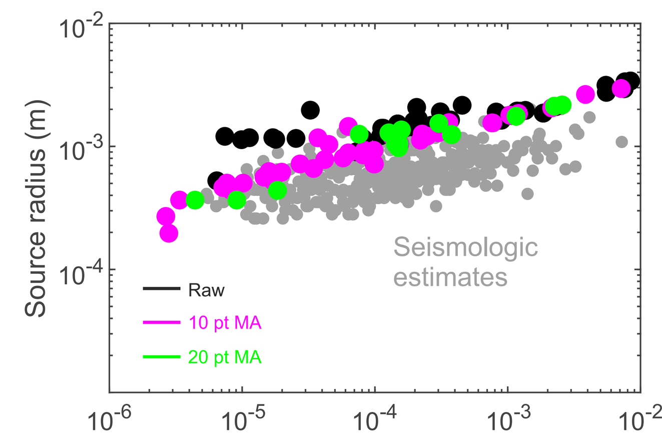
(Above) Spatio-temporal evolution of slip rate of the sequence. An image detection algorithm was used to calculate the length of the rupture L_{rup} . **(Bottom right)** Total slip during the event allowed us to calculate the seismic moment M_o (= $\mu A\delta$). This event in Detail B has a moment magnitude of M_w ~ -8.4.

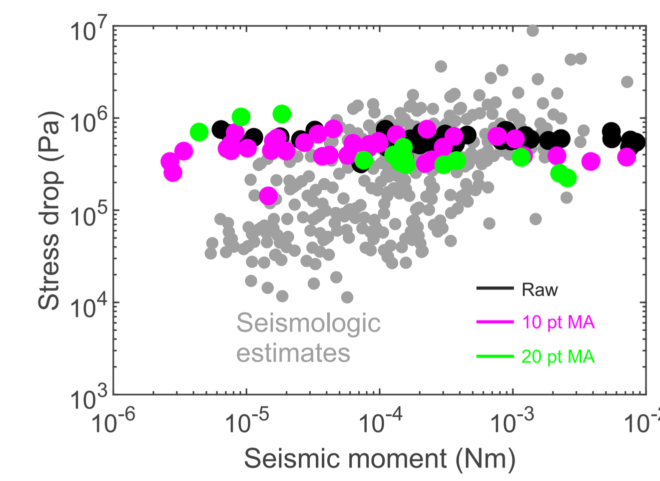
5 Catalogue development

Catalogues were generated using the analysis described above for three types of Dc heterogeneity (coloured points) mentioned in Part 2.

(right top) Source radii versus seismic moment appeared to follow estimates made using kinematic models from analyzing the seismic waves (gray).

(right bottom) Average static stress drop was in the typical range for natural seismicity (0.1 to 1 MPa) but remained (relatively) constant in comparision to inferred estimates of stress drop made kinematically.





6 Summary

Spatial heterogeneity in D_c. was justified since length-scale dependent wear has made locally polished asperities. While the micromechanical mechanism offered here might only be valid for dry interfaces, it appears to explain how localized event might have persited in the presence of a macroscopic slow slip front. Future simulations will estimate the effect of increased reference loading rate (V_0) believed to be analogous to the accelerated preslip phase.

[aa1] Selvadurai and Glaser, *J Geophys Res*, 2015.
[aa2] Selvadurai and Glaser, *Geophys J Int*, 2017.
[mm1] Kaneko and Ampeuro, *Geophys Res Lett* , 2010.
[mm2] Kaneko et al., *J Geophys Res*, 2016.
[mm3] Luo et al., *QDY*, 2017.
[zz1] Selvadurai, in review