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Temporal effects in dry friction

JAGLA Eduardo Alberto
Centro Atomico Bariloche
Comision Nacional de Energia Atomica
Ezequiel Bustillo Km 9.5
Bariloche
8400 Rio Negro

Temporal effects in dry fiction

Eduardo Jagla

Bariloche,
Argentina

CONICET
CONSEJO NACIONAL
DE INVESTIGACIONES
CIENTÍFICAS Y TÉCNICAS

Instituto
Balseiro
Bariloche

CNEA
Comisión Nacional
de Energía Atómica

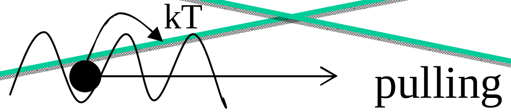
Outline:

- -Description of “temporal effects”
- -Presentation of a spring-block model incorporating “structural relaxation”
- -Obtention of realistic friction properties
- -Application to earthquake dynamics
- -Description of time increase of contact area

Temporal effects originated in…

“horizontal” relaxation

logarithmic decrease of friction force when velocity is reduced

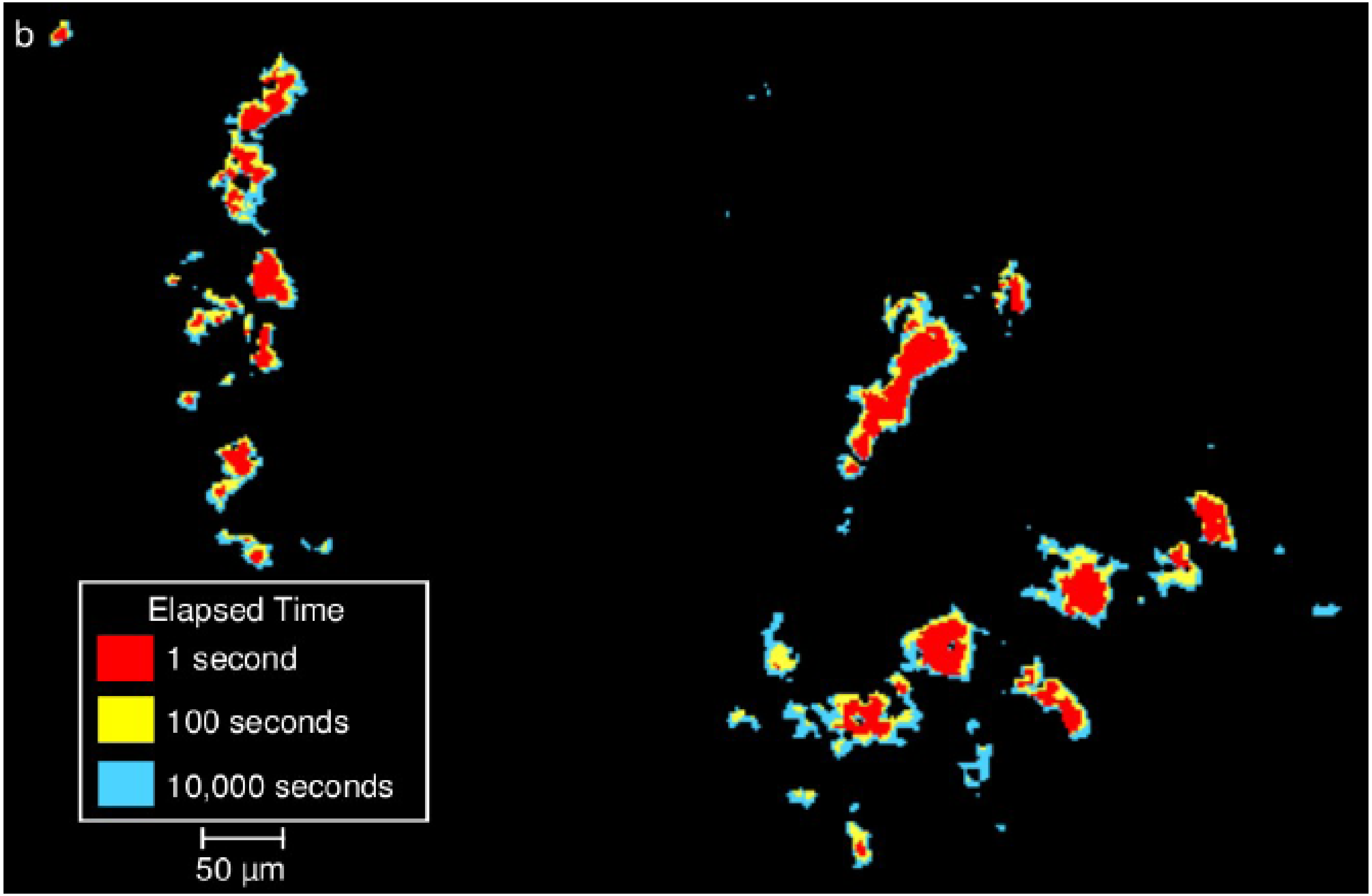


Not to be considered

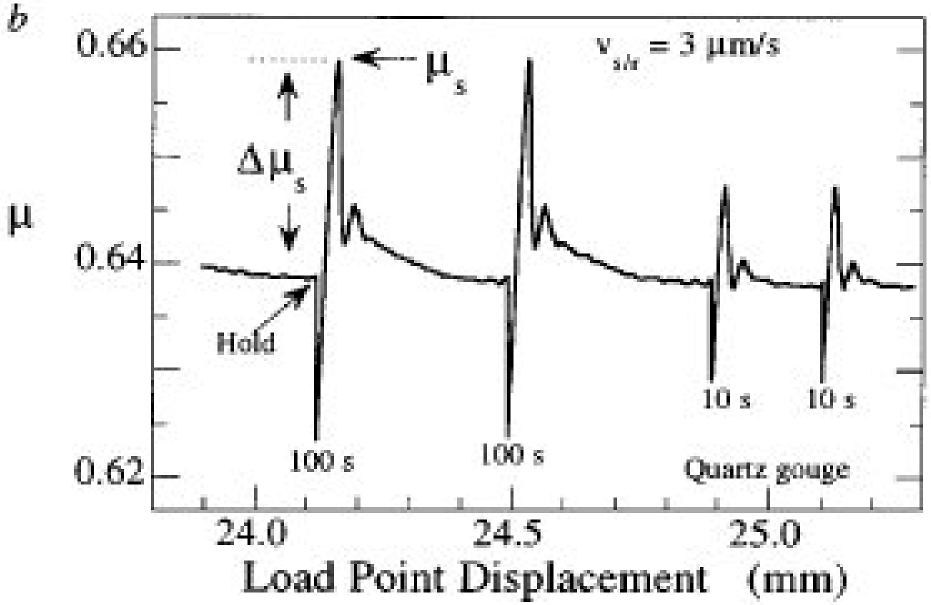
“vertical” relaxation

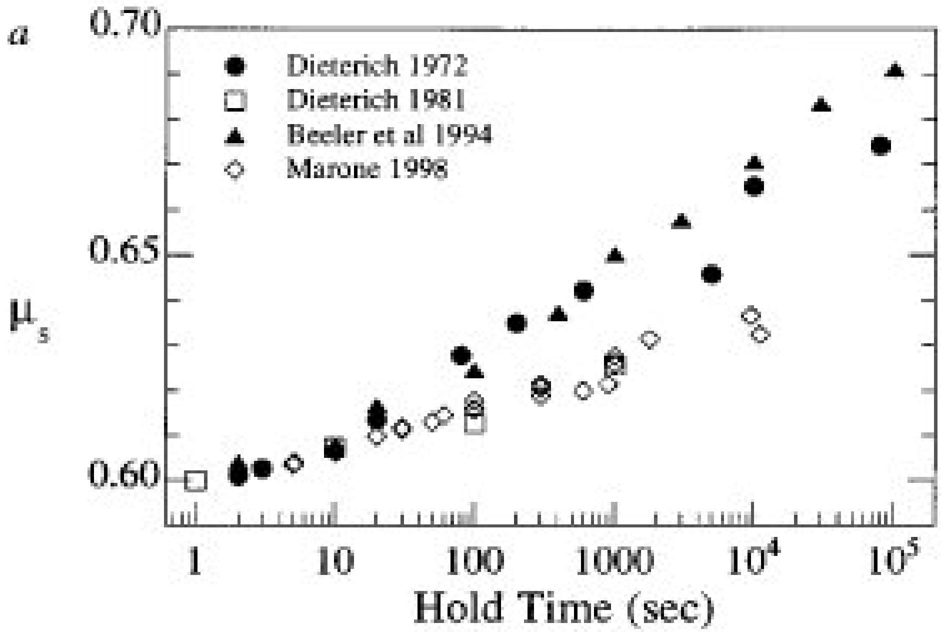
increase of contact area with contact time

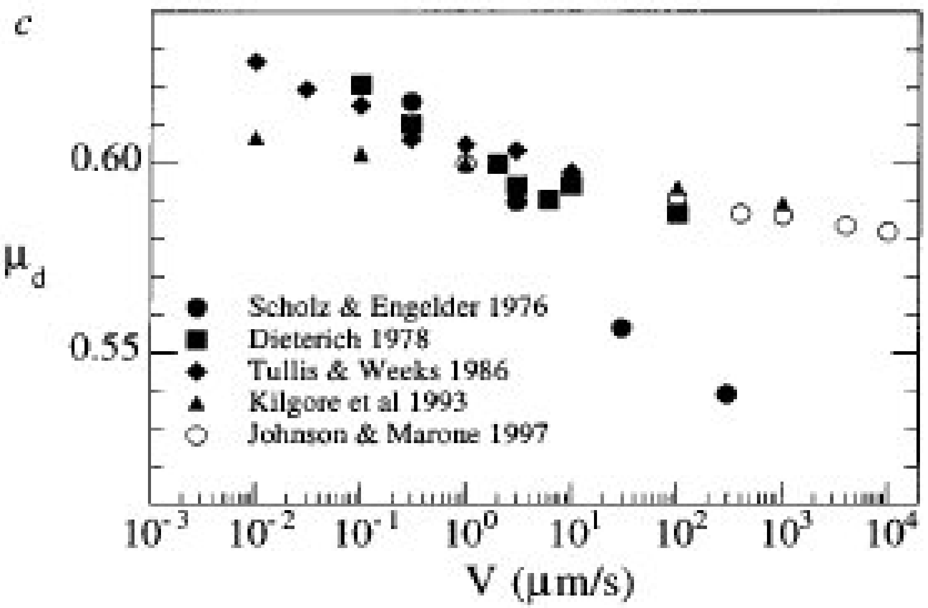
“Aging” effects in dry contact



Dieterich and Kilgore, 1994





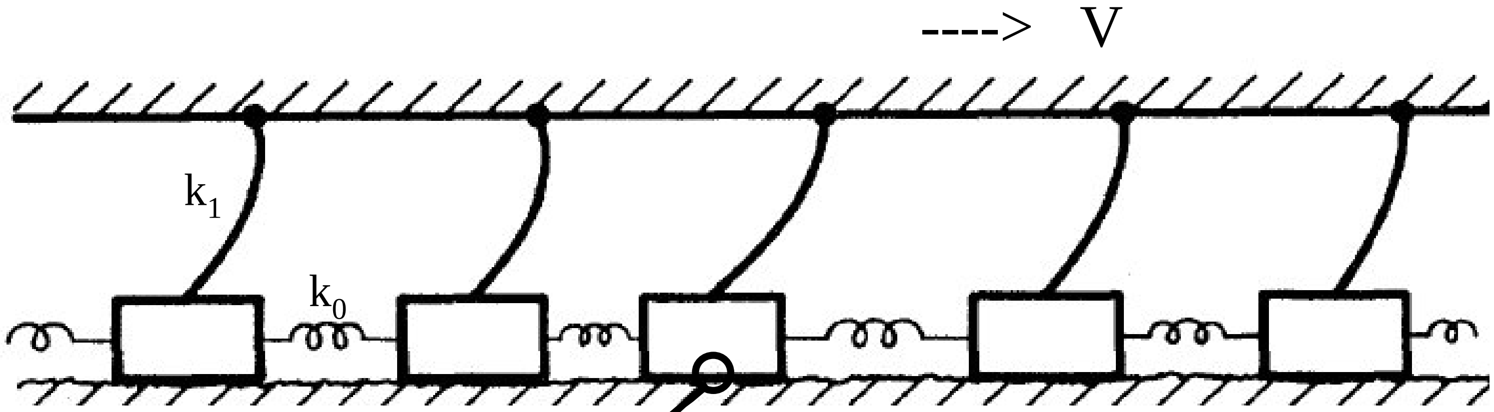


Phenomenological modeling:
rate-and-state equations
(Dieterich, Rice, Ruina, ´80)

$$\mu = \mu_0 + A\ln(V/V_0) + B\ln(V_0\theta/D_c)$$

$$\frac{d\theta}{dt} = 1 - \frac{\theta V}{D_c} \qquad \theta: \text{ state variable}$$

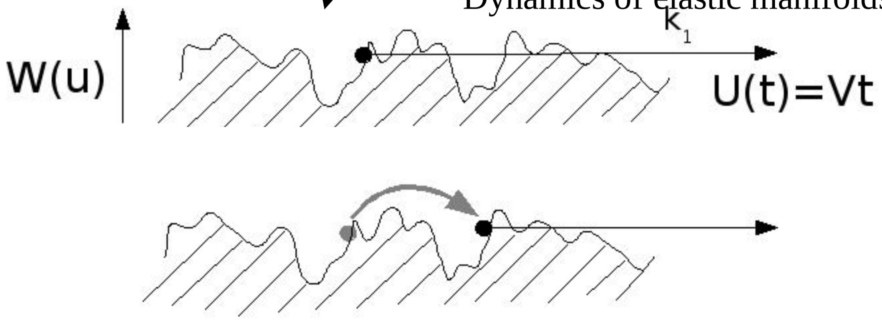
The starting point:



Friction by the Tomlinson mechanism

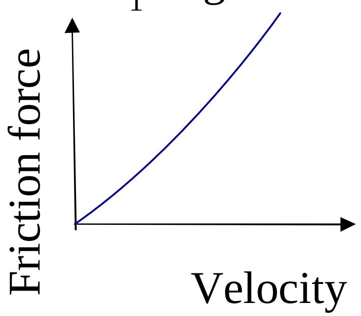
Stochastic Prandtl-Tomlinson model

Dynamics of elastic manifolds driven on disordered potentials

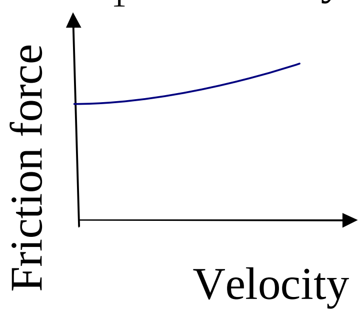


Note corrugation is not at the atomic scale!

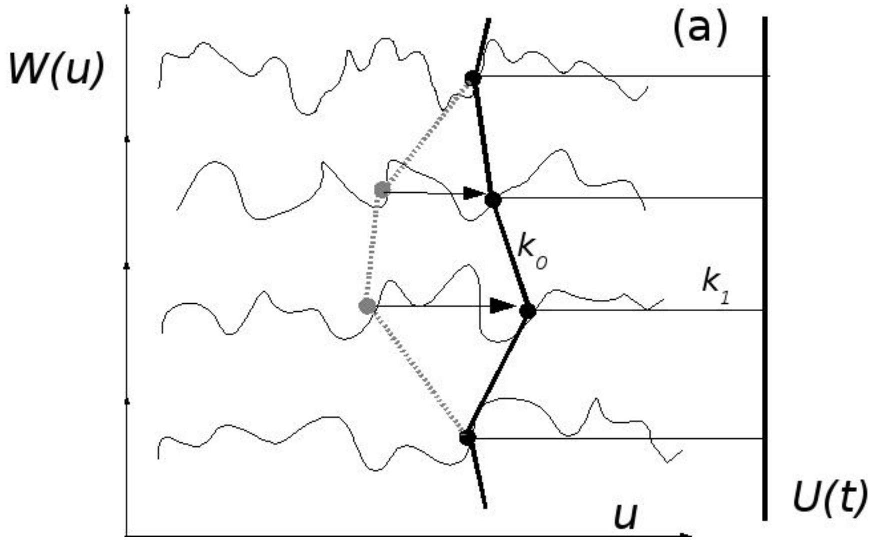
k_1 large



k_1 sufficiently small



The starting point:



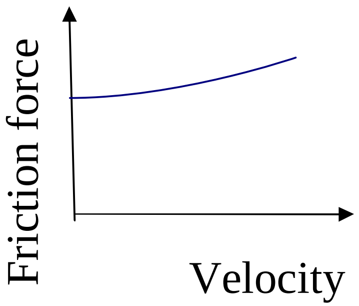
(1D picture, but simulations are made in the 2D case)

$$E = \sum_{i,j;i',j'} \frac{k_0}{2} (u_{i,j} - u_{i',j'})^2 + \sum_{i,j} \frac{k_1}{2} (U(t) - u_{i,j})^2 + $$

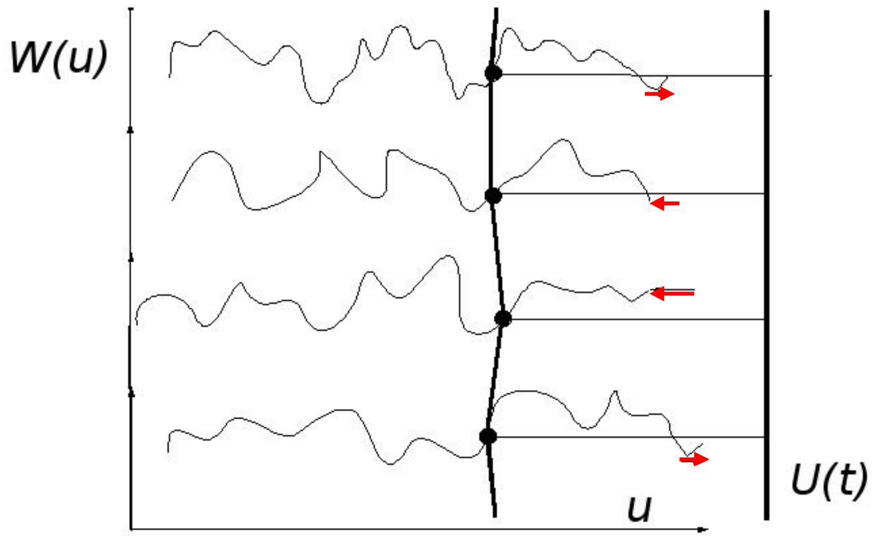
$$+ \sum_{i,j} W_{i,j}(u_{i,j})$$

$$\frac{du_{i,j}}{dt} = -\lambda \frac{\delta E}{\delta u_{i,j}}$$

$\lambda \to \infty$



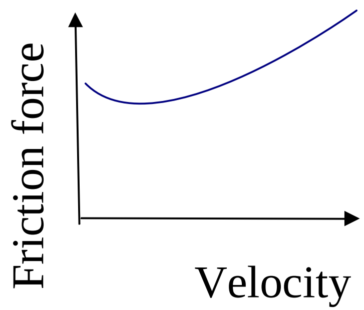
We need an internal ‘aging’ mechanism

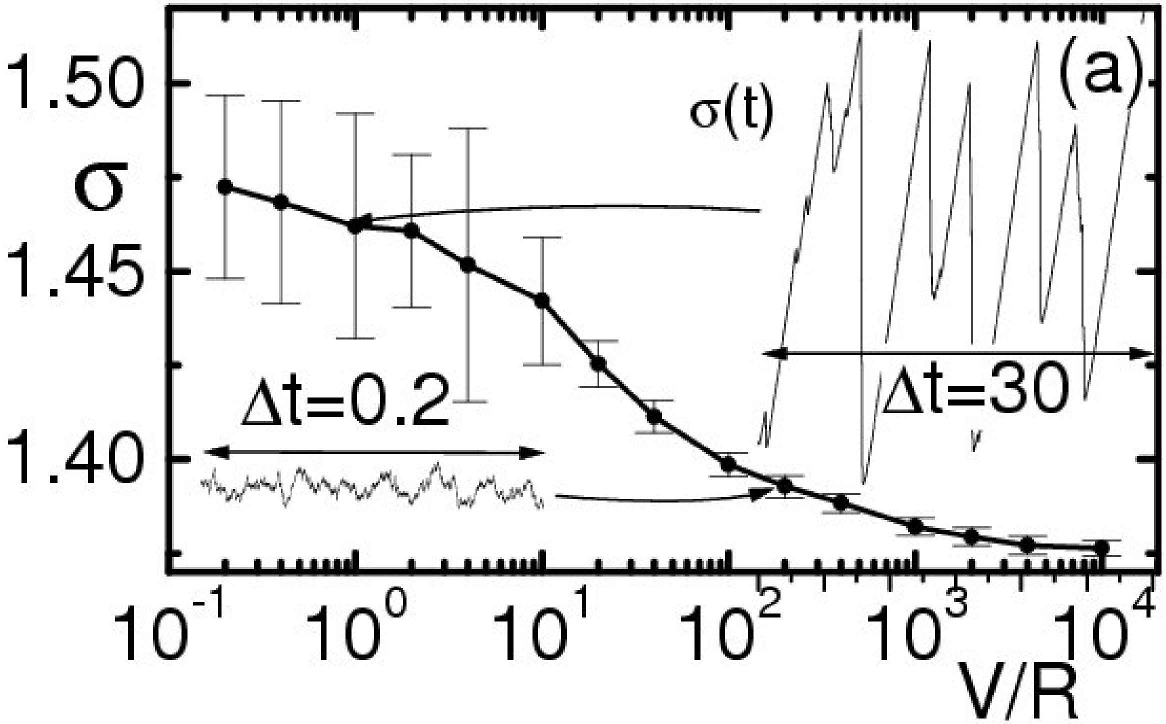


$$\sum_{i,j} W_{i,j}(u_{i,j}) \to \sum_{i,j} W_{i,j}(u_{i,j} - u^0_{i,j})$$

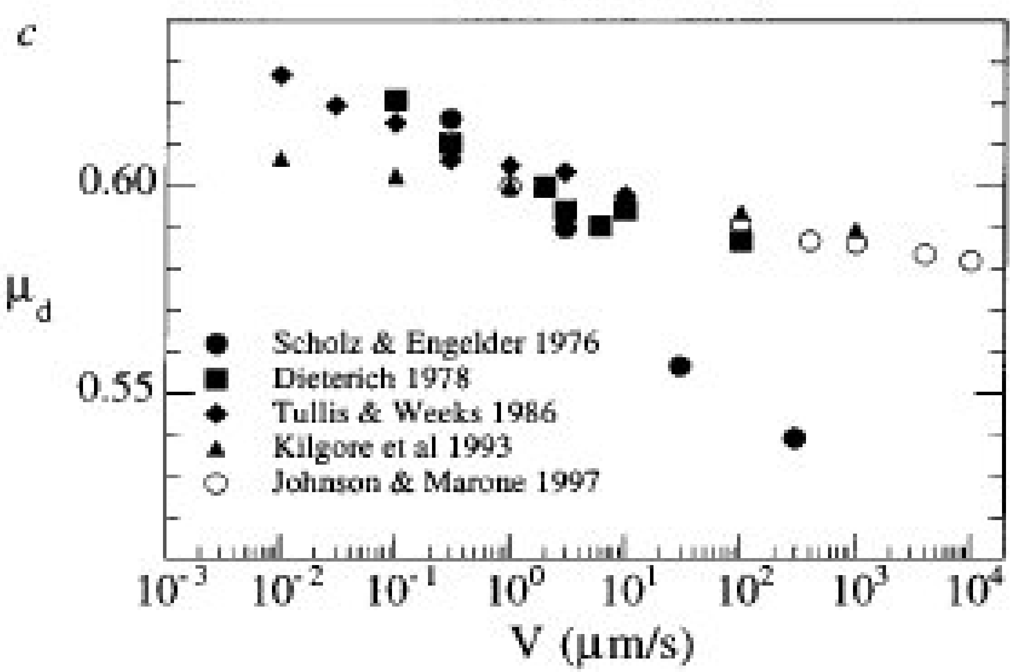
$$\frac{du^0_{i,j}}{dt} = R\nabla^2 \frac{\delta E}{\delta u^0_{i,j}}$$

“velocity weakening”

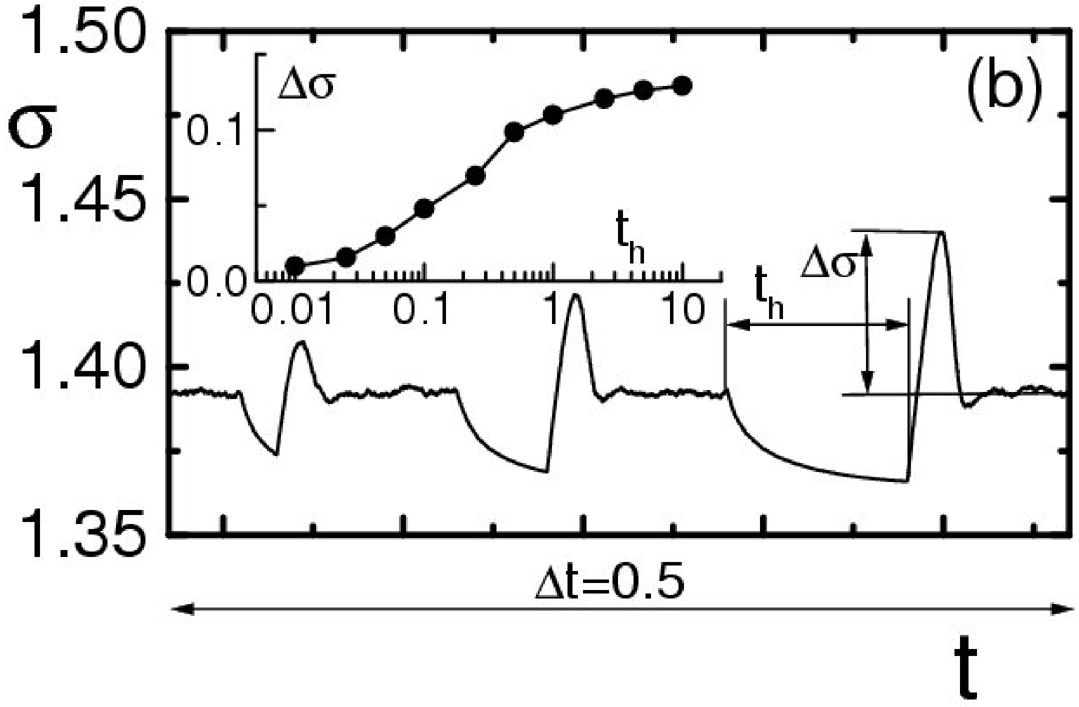


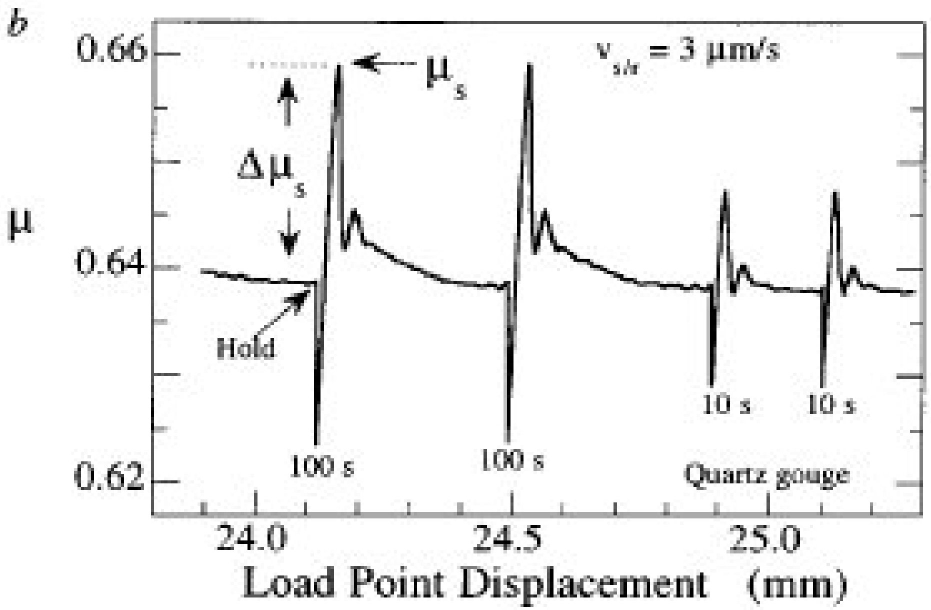


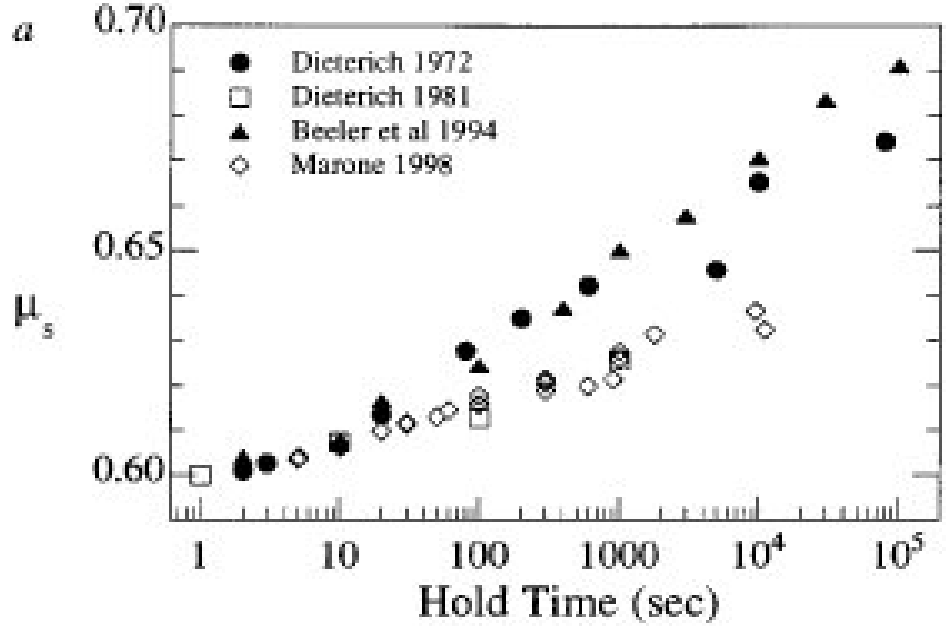
1.50
1.45
1.40
σ
σ(t)
(a)
Δt=0.2
Δt=30
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
V/R

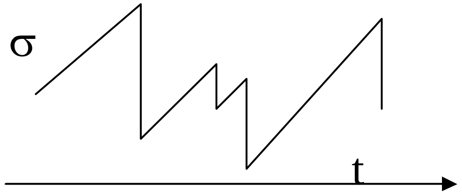


c
0.60
0.55
μ_d
Scholz & Engelder 1976
Dieterich 1978
Tullis & Weeks 1986
Kilgore et al 1993
Johnson & Marone 1997
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
V (μm/s)


(b)
σ
1.50
1.45
1.40
1.35
Δσ
0.1
0.0
0.01
0.1
1
10
t_h
Δσ
Δt=0.5
t

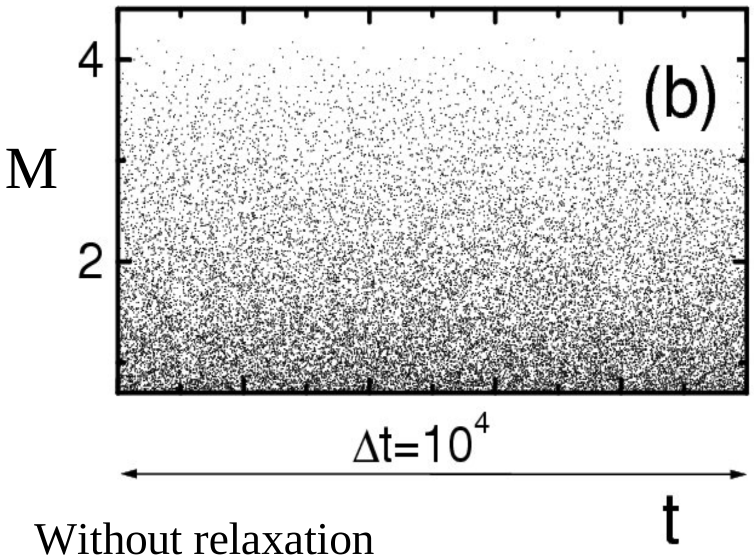

b
0.66
0.64
0.62
μ
$v_{s/r}$ = 3 μm/s
μ_s
$\Delta\mu_s$
Hold
100 s
100 s
10 s
10 s
Quartz gouge
24.0
24.5
25.0
Load Point Displacement (mm)


a
0.70
0.65
0.60
μ_s
Dieterich 1972
Dieterich 1981
Beeler et al 1994
Marone 1998
1
10
100
1000
10^4
10^5
Hold Time (sec)

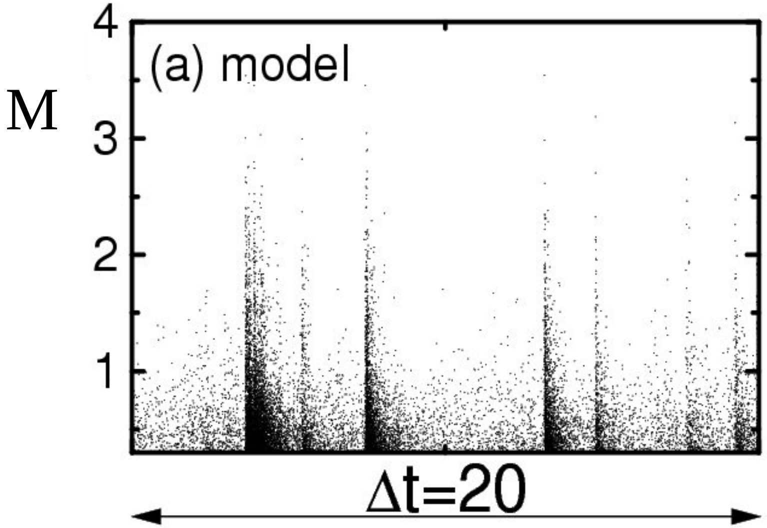


Statistics of stress drops Δσ

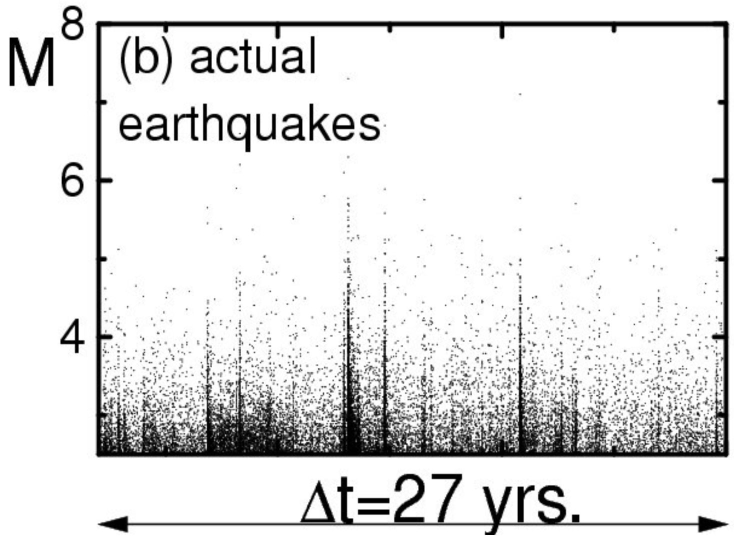
Earthquakes: $M = \frac{2}{3}\log_{10}(\Delta\sigma)$



Without relaxation



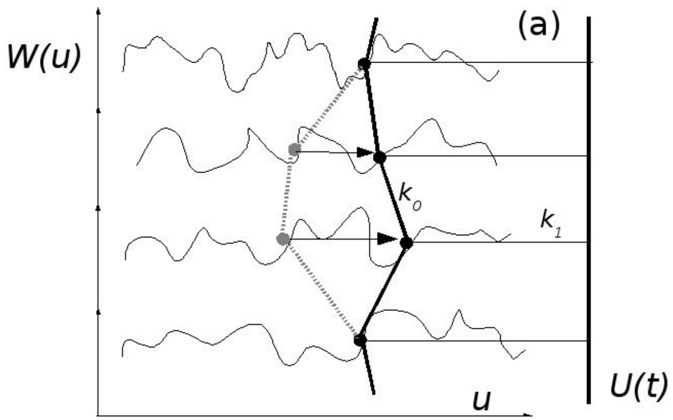
With relaxation

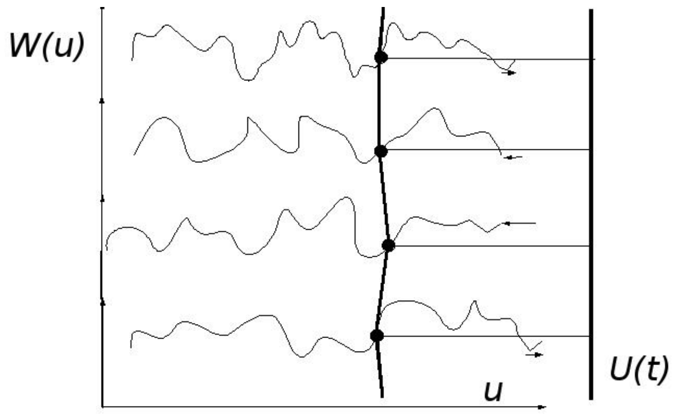


Gutenberg-Richter law:
Number of earthquakes as a function of Magnitude $N(M) \sim 10^{-bM}$

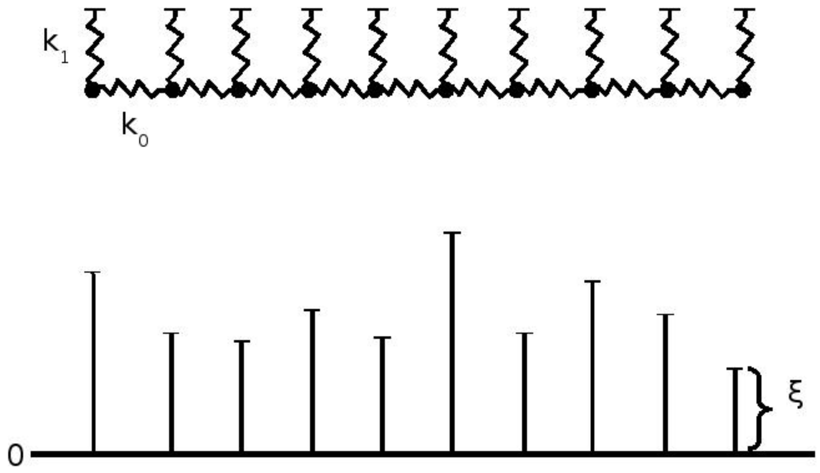
b~0.4 without relaxation
b~1.1 with relaxation
b~0.8-1.2 experimentally

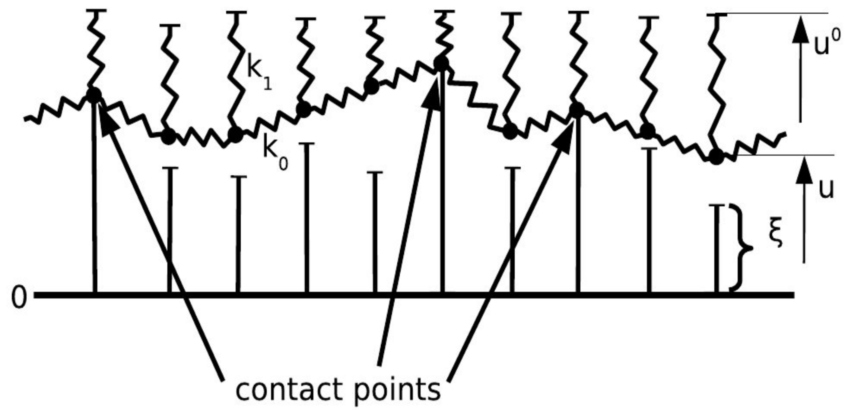
What about time dependence of contact area?



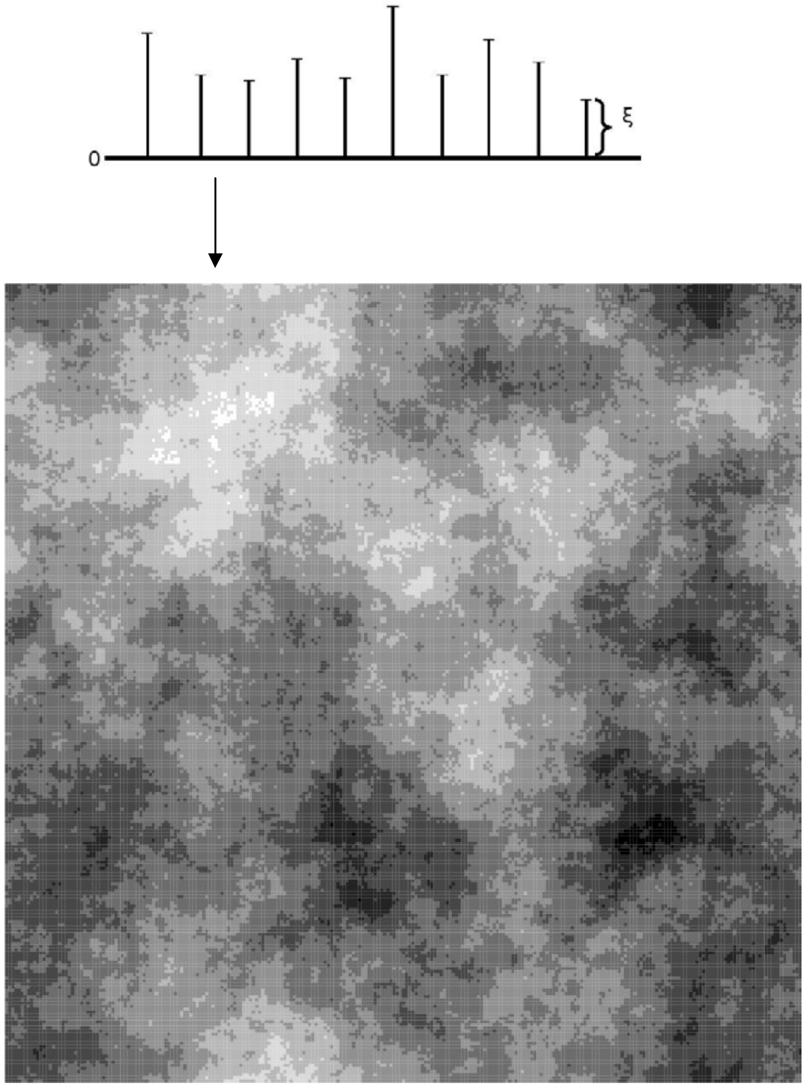


Poor-man description of an elastic body surface

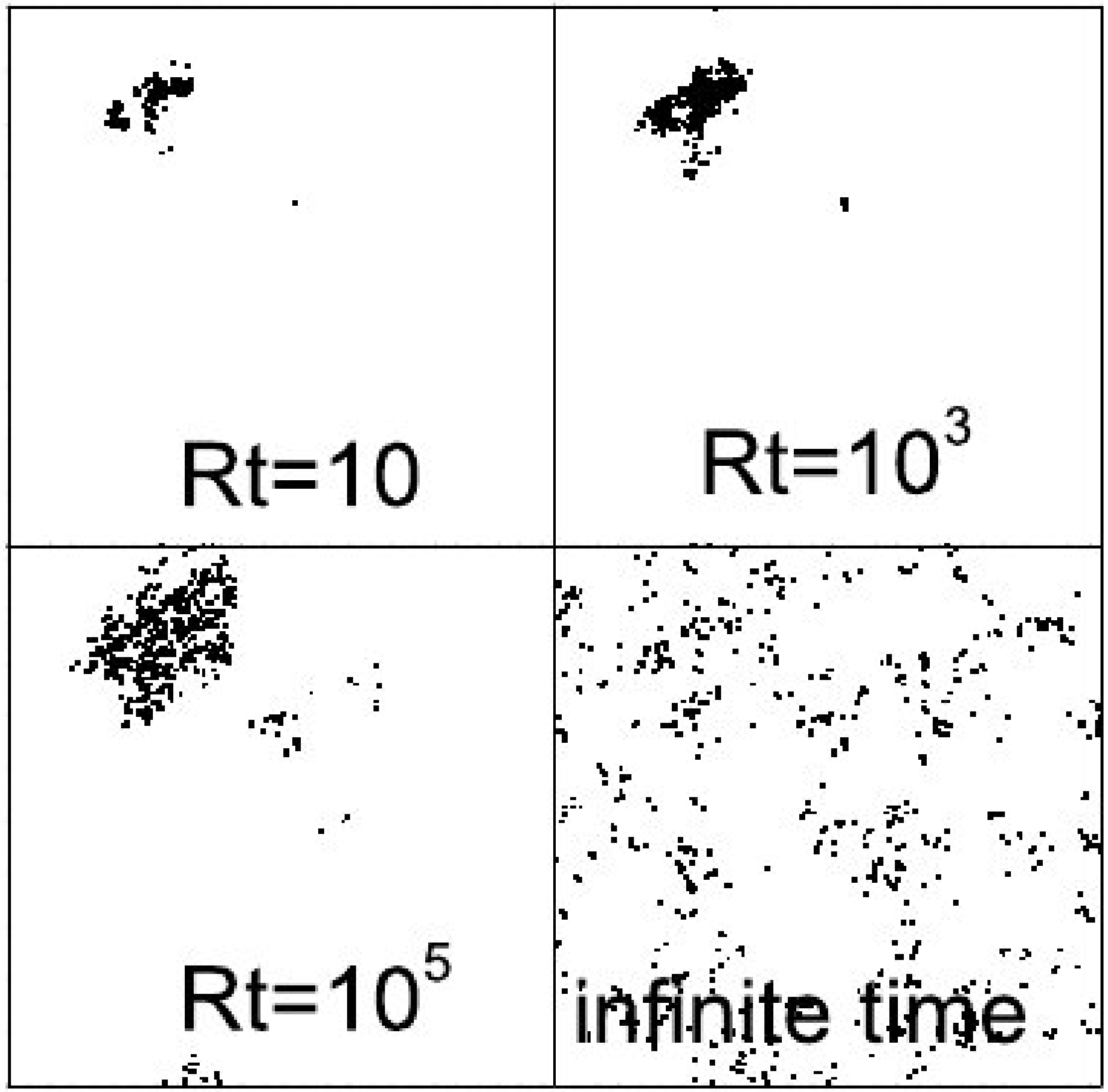




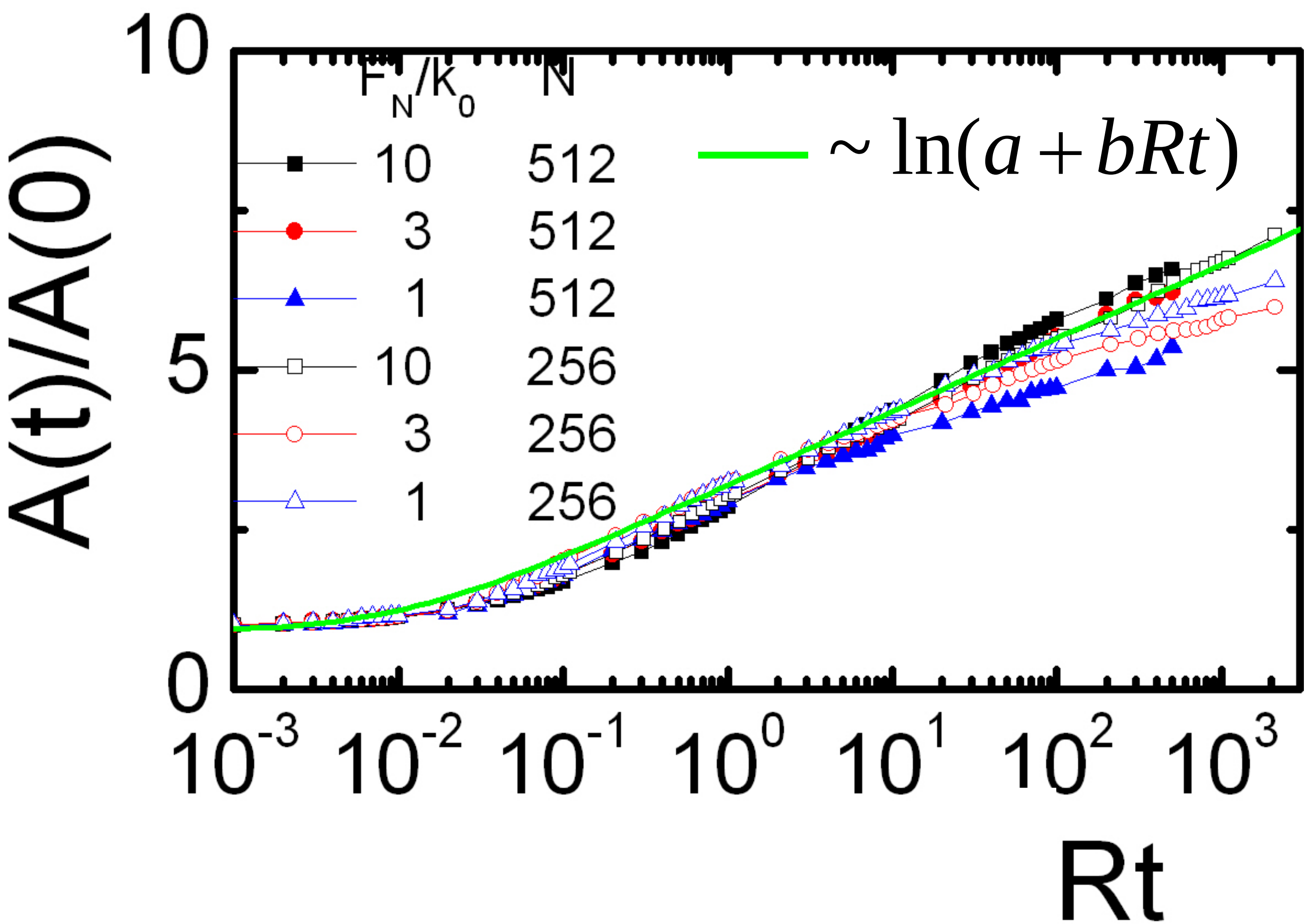
$$\frac{du^0_{i,j}}{dt} = R\nabla^2 \frac{\delta E}{\delta u^0_{i,j}}$$



Self affine surface



$$\frac{du_{i,j}^{0}}{dt} = R\nabla^{2}\frac{\delta E}{\delta u_{i,j}^{0}}$$



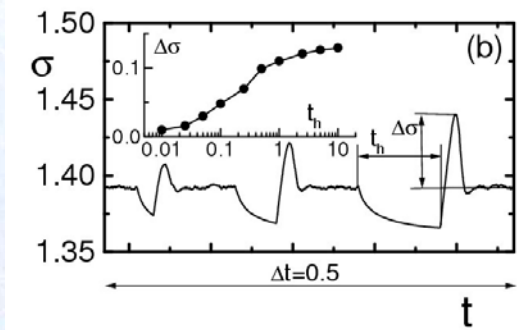
In the limit of very few independent contacts, the logarithmic behavior can be worked out analytically

$$\frac{du^0_{i,j}}{dt} = R\nabla^2 \frac{\delta E}{\delta u^0_{i,j}}$$

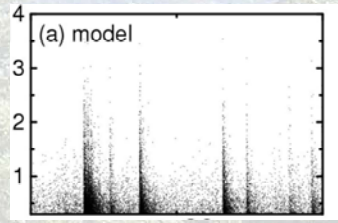
Conclusions:

With a simple mechanism of structural relaxation
on a spring-block system we have been able to…

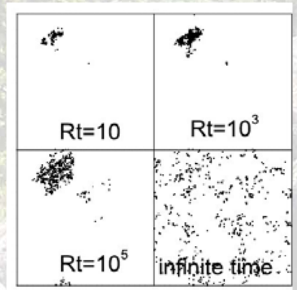
-reproduce the phenomenology of dry friction:



-obtain realistic temporal sequences
of stress drops (earthquakes, not shown in detail)



-show that the modeling is compatible with the
logarithmic time increase of contact area

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