What controls b-value variations: insights from a physics based numerical model

Pierre Dublanchet [1]

[1]Centre de Géosciences MINES ParisTech, PSL Research University

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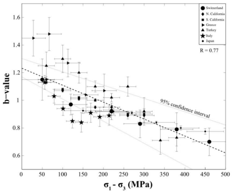
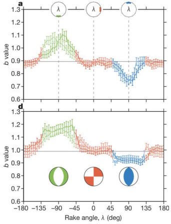
Observations: stress dependence of b value

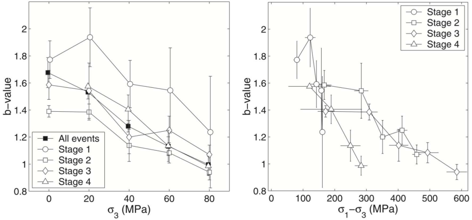
In the field [Scholz, 2015 & Spada et al., 2013]



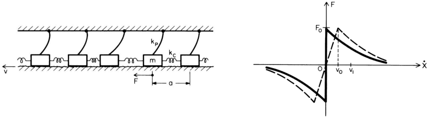
In the field [Schorlemmer et al., 2005]



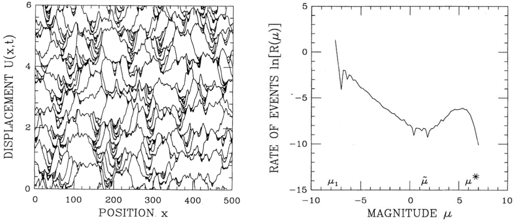
In the lab [Amitrano, JGR 2003]



Burridge-Knopoff models [Burridge 1967]

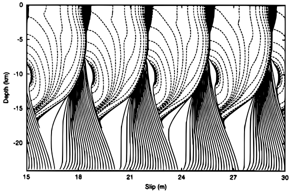


[Carlson, Langer & Shaw 1994]

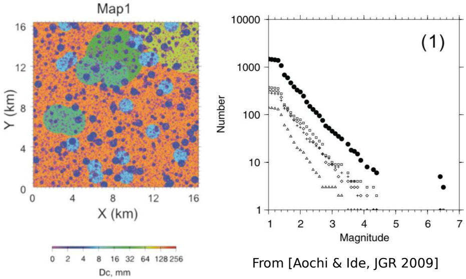


Continuous models: characteristic earthquakes and fault heterogeneity

Homogeneous fault: characteristic earthquake [Lapusta & al., JGR 2000]



Fracture energy heterogeneity: GR distribution [Aochi & Ide, JGR 2009]



From [Aochi & Ide, JGR 2009]

What controls b-value variations

What we know:

- Normal/Differential stress dependence of b-value in the field and in the laboratory
- Mechanical models coupling elasticity and friction reproduce GR decay under particular conditions
- Need to introduce discrete model, heterogeneity, or consider a very small nucleation length

Main questions:

- What physical mechanism causes b-value dependence with stress?
- Do mechanical models produce b-value dependence with stress?

Governing Equations

- Slip δ, slip rate $v = \dot{\delta}$, normal stress σ
- Rate-and-State Friction: *Dieterich 1979, Ruina 1983*

$$\tau_f = f\sigma = \left[f_0 + a \ln \frac{v}{v*} + b \ln \frac{\theta v*}{d_c} \right] \sigma$$

$$\dot{\theta} = 1 - \frac{v\theta}{d_c}$$

- Quasi-Dynamic Stress Balance: *Rice 1993*

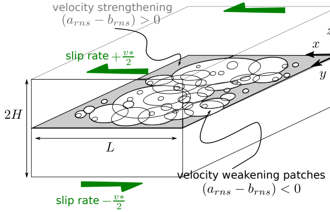
$$\tau_f = \tau_b + \kappa * \delta - \frac{\mu}{2c_s} v$$

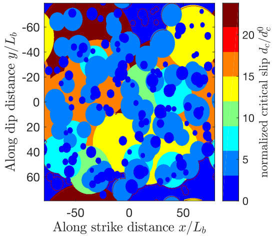
- Power law distribution of VW patch size R:

$$pdf(R) = CR^{-p}$$

- Scale dependent critical slip:

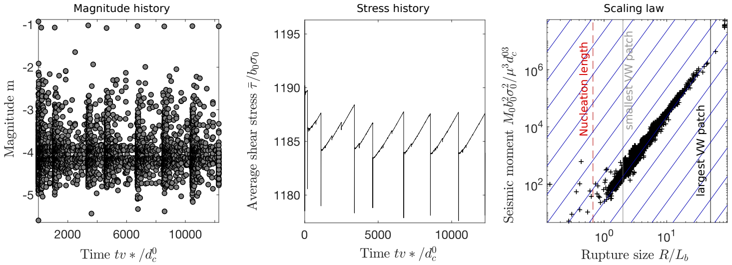
$$d_c = d_c^0 R / R_0$$





From [Dublanchet, subm. GRL]

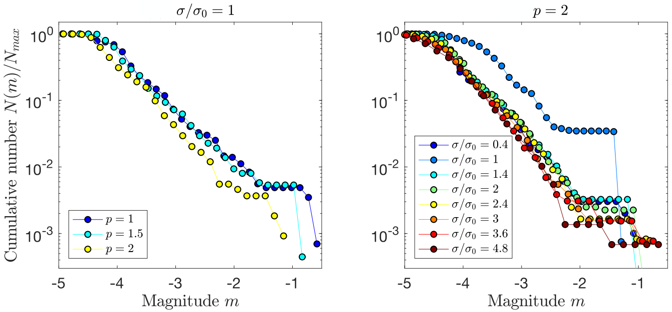
Synthetic seismicity: example



[Dublanchet, subm. GRL]

Magnitude-Frequency Distributions (FMD)

Asperity size distribution (p) and normal stress (σ) control

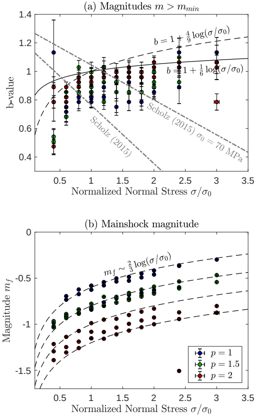


[Dublanchet, subm. GRL]

Control on FMD:

- patch size distribution (exponent p)
- normal stress σ (reference: σ_0)

b-value and maximum magnitude



[Dublanchet, subm. GRL]

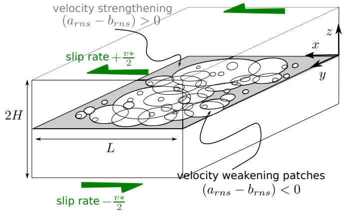
b-value vs. σ

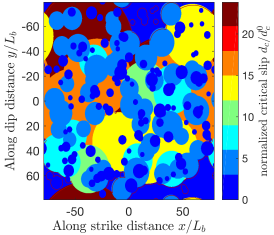
- b-value increases with normal stress σ
- explained by a reduction of critical nucleation length with σ:
  $\rightarrow$ reduction of minimum magnitude
  $\rightarrow$ increase of partial ruptures
- enhanced productivity of smallest magnitudes
- theoretical result: log dependence of b on σ

max magnitude m_f vs. σ

- log increase of m_f with σ
- corresponds to a linear increase of stress drop with σ

Conclusions





Stress dependence of b value:

- the model reproduces realistic FMDs and b values
- the asperity distribution controls the FMD to some extent (p dependence)
- b value and maximum magnitude increase as $\log \sigma$
- reflects the decrease of critical nucleation length and increase of stress drop with normal stress
- the observed decrease of b value with differential stress could be attributed to variations of shear stress during the seismic cycle at constant normal stress.

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