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

Pierre Dublanchet

\(^1\)Centre de Géosciences MINES ParisTech, PSL Research University

May 3, 2020
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: Gutenberg-Richter (GR) distribution

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]
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?
Heterogeneous rate-and-state fault model

**Governing Equations**

- Slip \( \delta \), slip rate \( v = \dot{\delta} \), normal stress \( \sigma \)

- 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*

\[
\tau_f = \tau_b + \kappa \ast \delta - \frac{\mu}{2 c_s} v
\]

- Power law distribution of VW patch size \( R \):

\[
pdf(R) = CR^{-p}
\]

- Scale dependent critical slip:

\[
d_c = \frac{d_c^0 R}{R_0}
\]

From [Dublanchet, subm. GRL]
Synthetic seismicity: example

[Dublanchet, subm. GRL]
Asperity size distribution ($p$) and normal stress ($\sigma$) control

Control on FMD:

- patch size distribution (exponent $p$)
- normal stress $\sigma$ (reference: $\sigma_0$)

[Dublanchet, subm. GRL]
Normal stress $\sigma$ dependence

b-value and maximum magnitude

b-value vs. $\sigma$

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

max magnitude $m_f$ vs. $\sigma$

- log increase of $m_f$ with $\sigma$
- corresponds to a linear increase of stress drop with $\sigma$

[Dublanchet, subm. GRL]
Conclusions

**Stress dependence of b value:**

- the model reproduces realistic FMDs and b values
- the asperity distribution controls the FMD to some extent ($\rho$ 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.


