Common dependency on stress of the two fundamental laws of observational seismology

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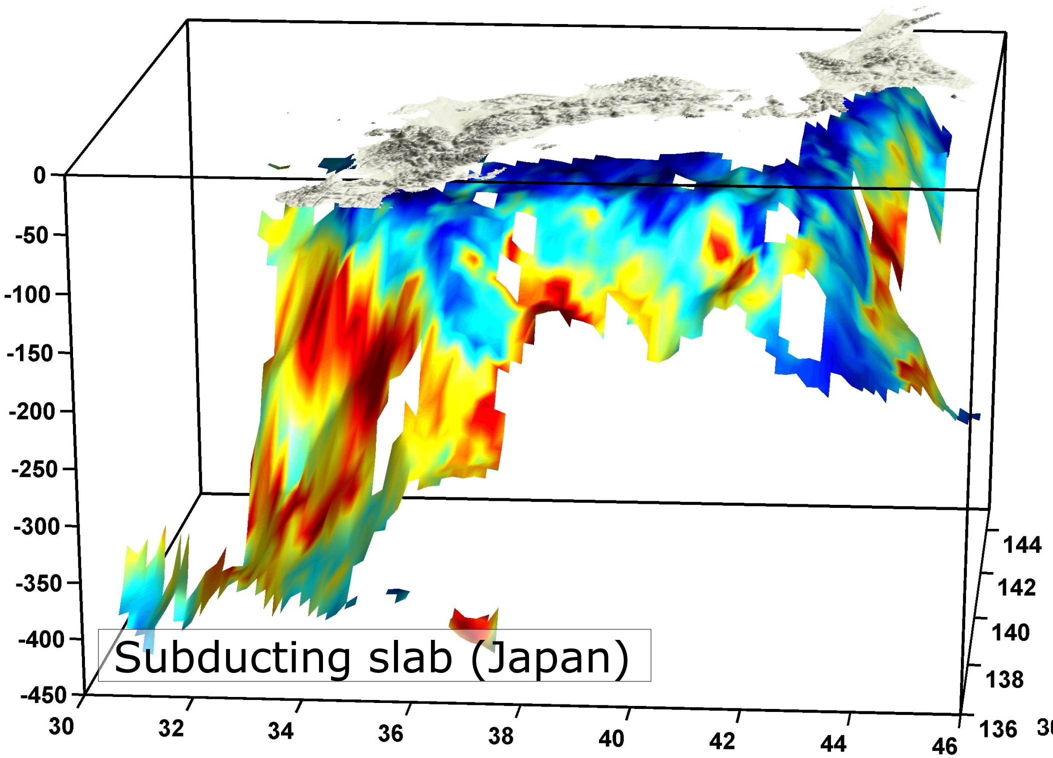
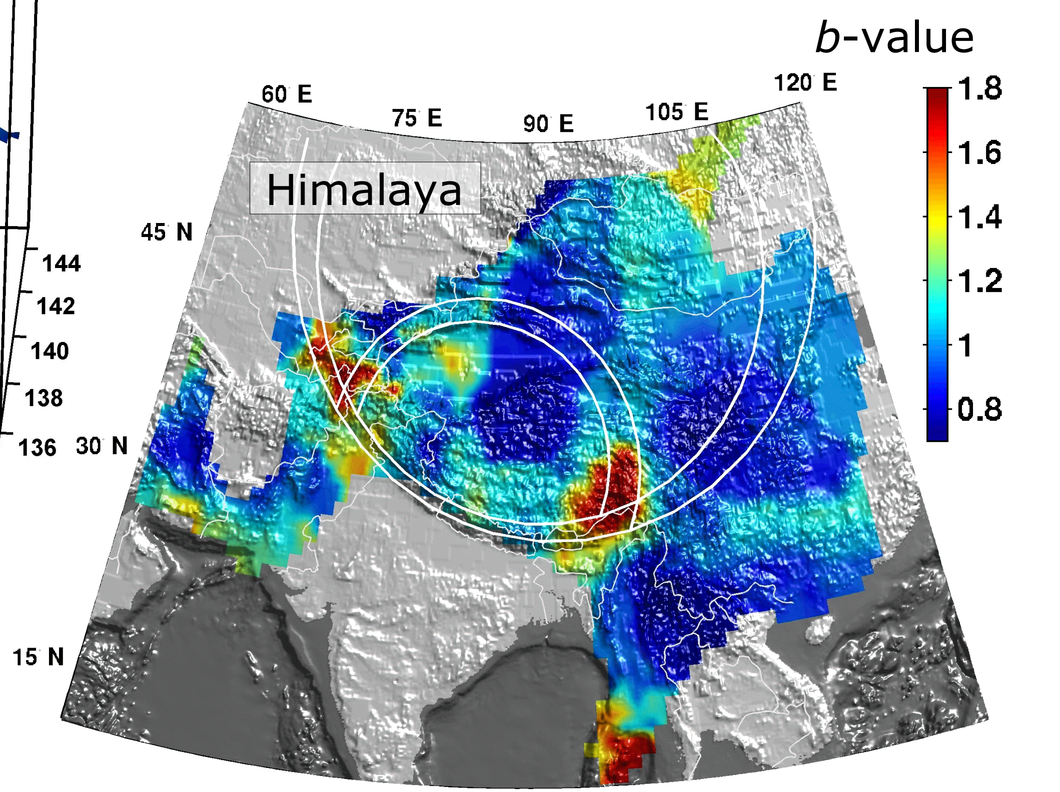
Two Fundamental Laws

- Gutenberg-Richter relation
- Omori-Utsu law

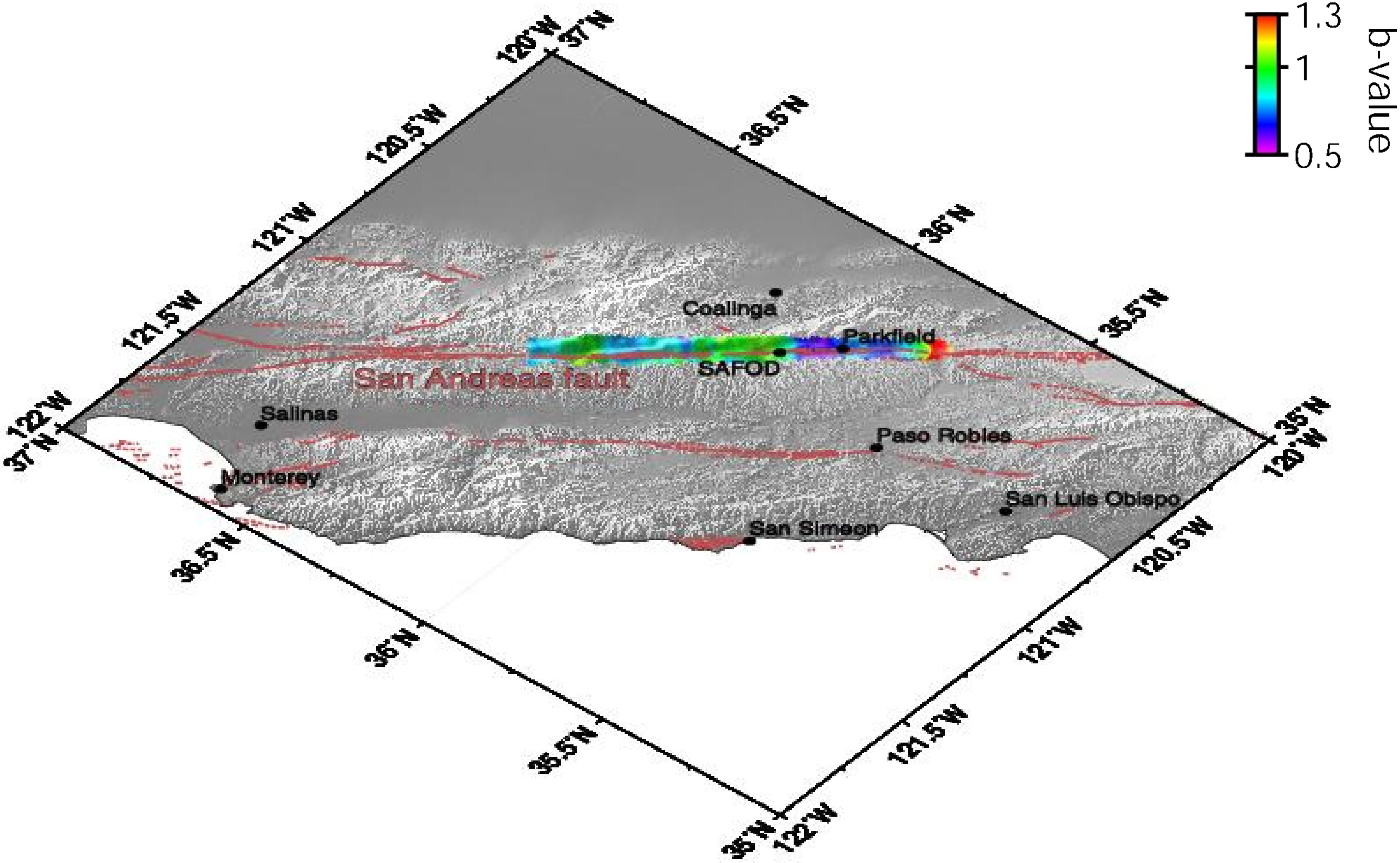
Observations

Spatial variations of b-values exist on different scales

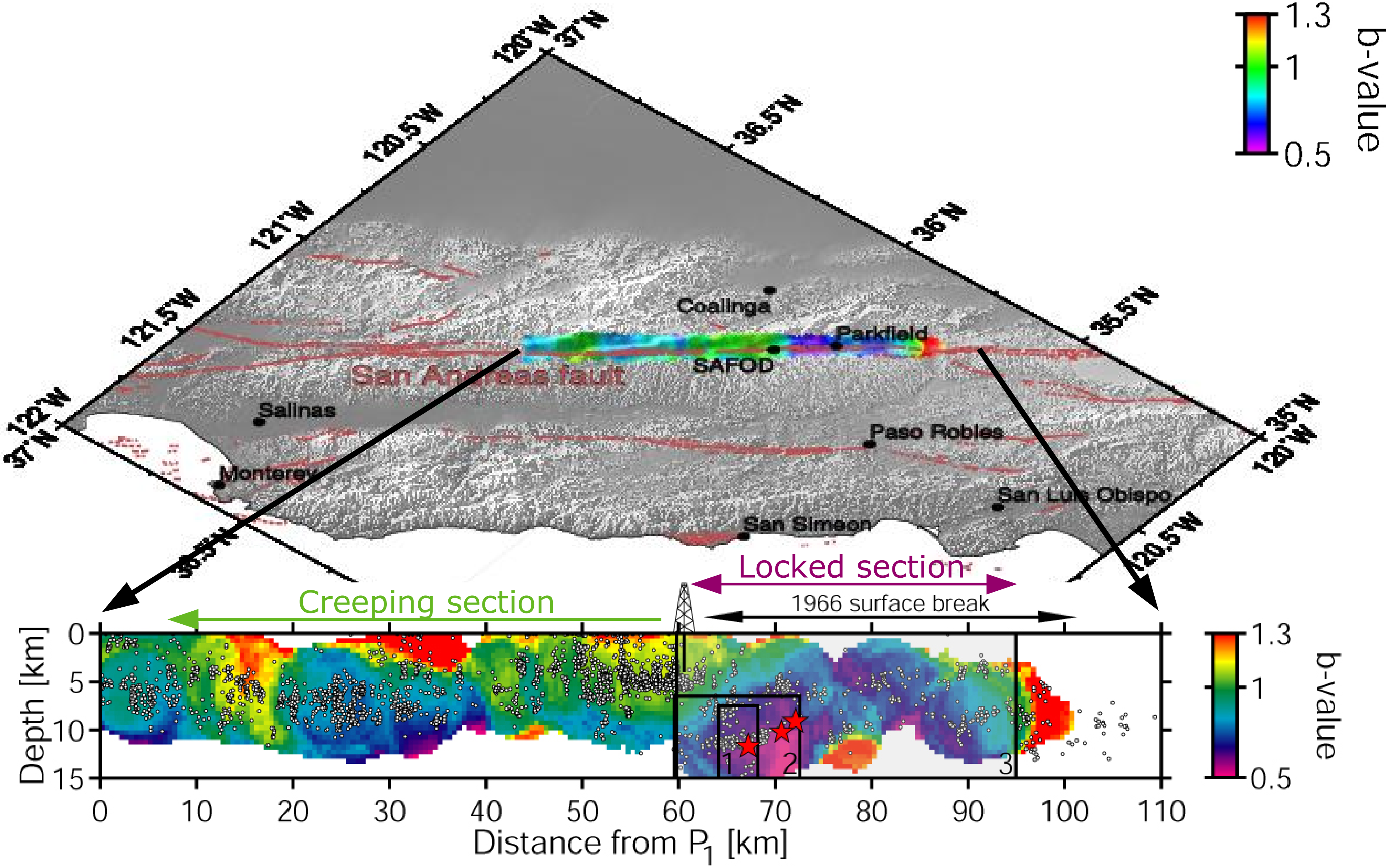




Observations



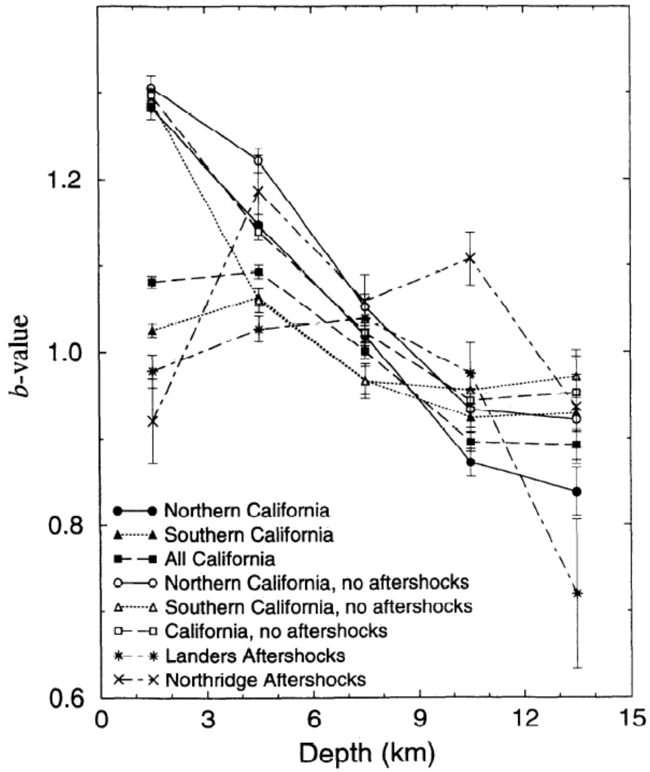
Observations

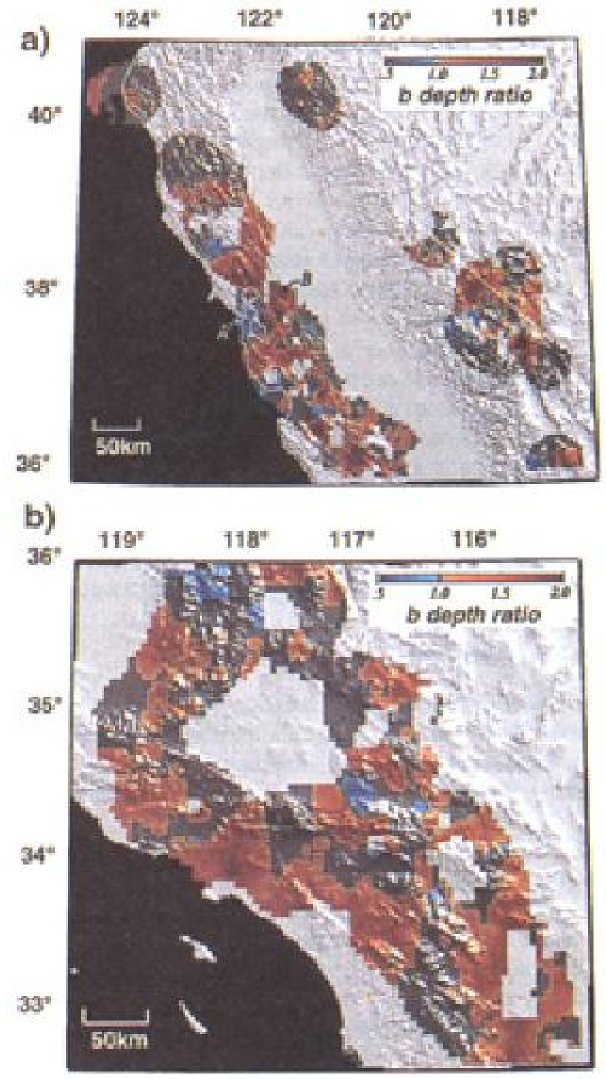


Key Question

What is fundamentally controlling the b-value?

– Depth [*Mori & Abercrombie*, 1997; *Gerstenberger et al.*, 2001]?





– Material heterogeneity [*Mogi*, 1962]?

Key Question

What is fundamentally controlling the b-value?

– Stress (Laboratory measurements) [*Scholz*, 1968]?

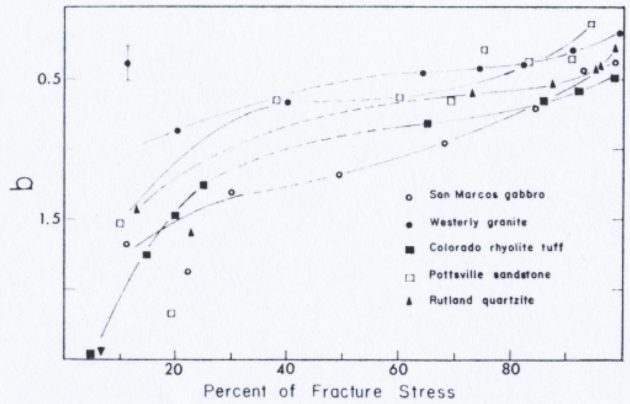


FIG. 3. *b* as a function of normalized stress for five rocks in uniaxial compression. The dashed part of the curves are in the region where few events were detected.

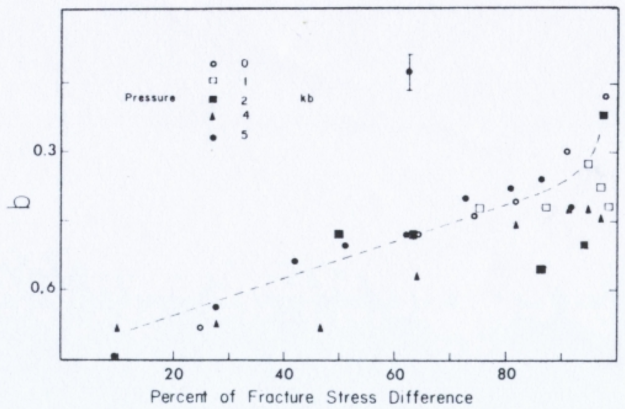
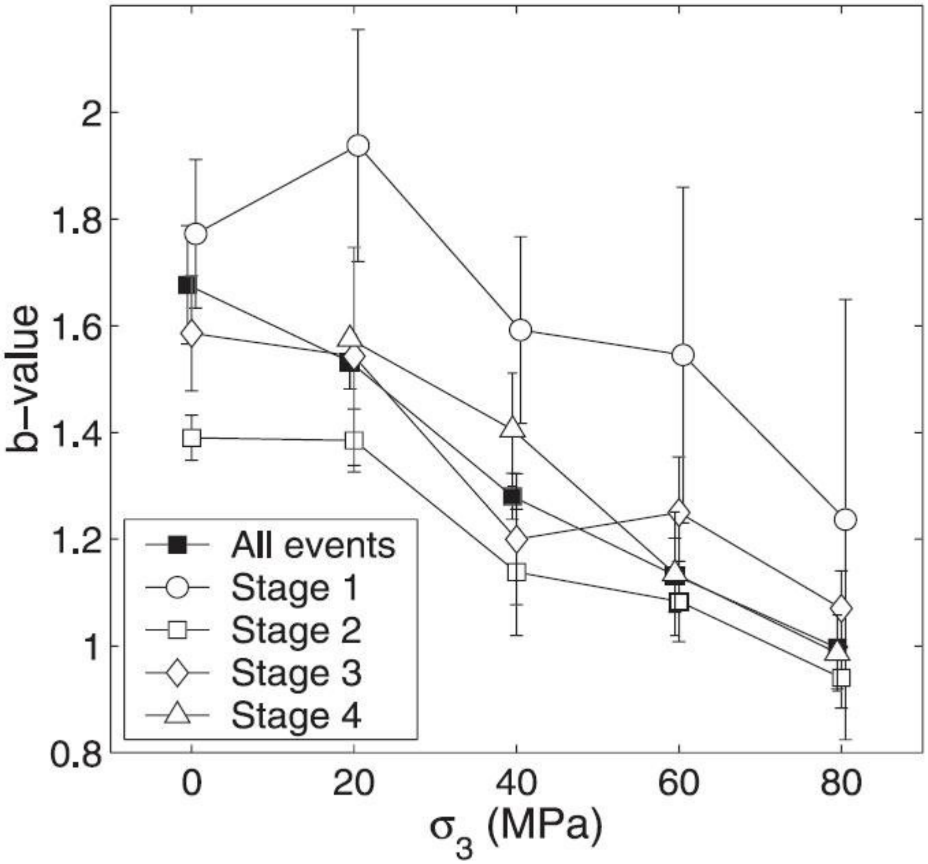


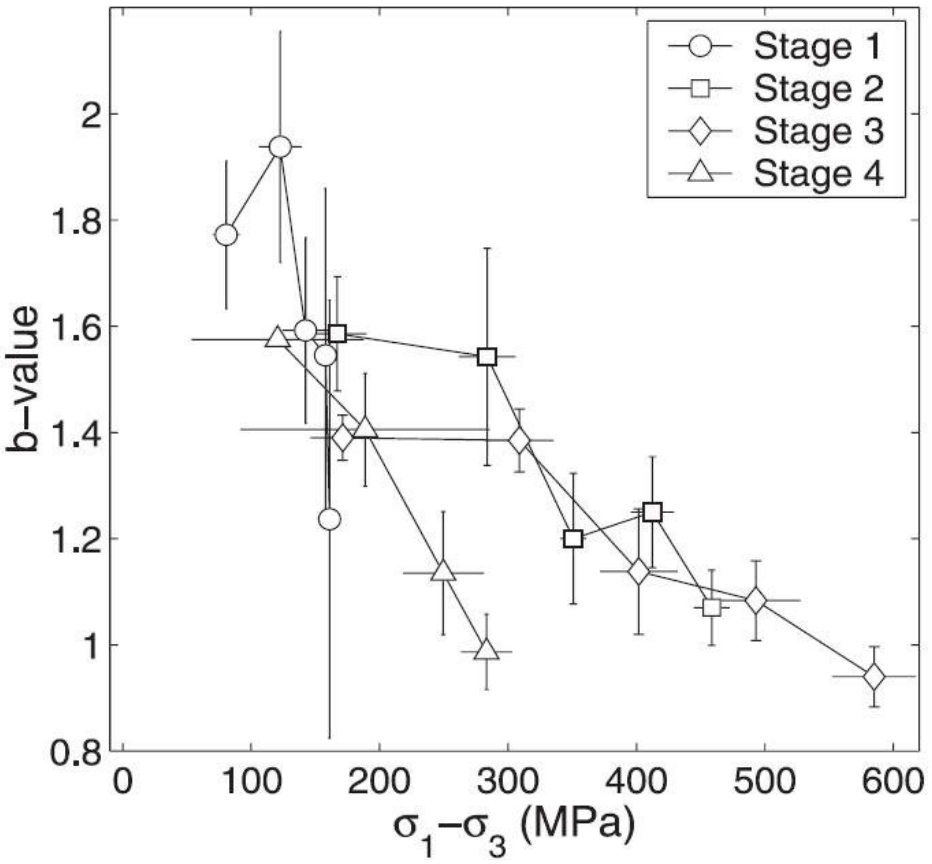
FIG. 4. *b* versus normalized stress difference for Westerly granite at five different confining pressures.

Key Question

What is fundamentally controlling the b-value?

– Stress (Laboratory measurements) [Amitrano, 2003]?





Key Question

What is fundamentally controlling the b-value?

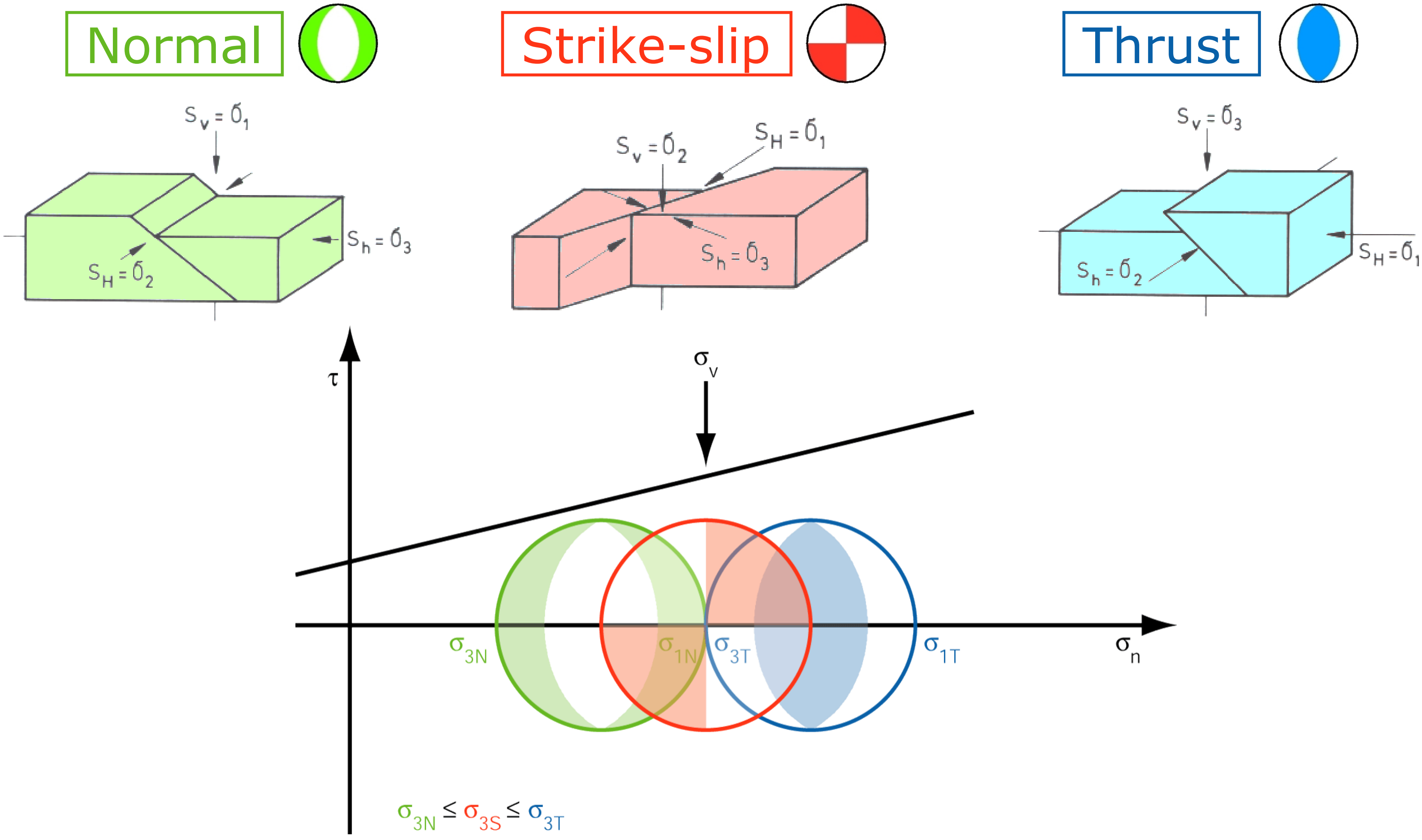
- Depth [*Mori & Abercrombie*, 1997; *Gerstenberger et al.*, 2001]?
- Material heterogeneity [*Mogi*, 1962]?
- Stress (Laboratory measurements) [*Scholz*, 1968; *Amitrano*, 2003]?

Laboratory experiments suggest that b-values are inversely proportional to differential stresses and confining pressure

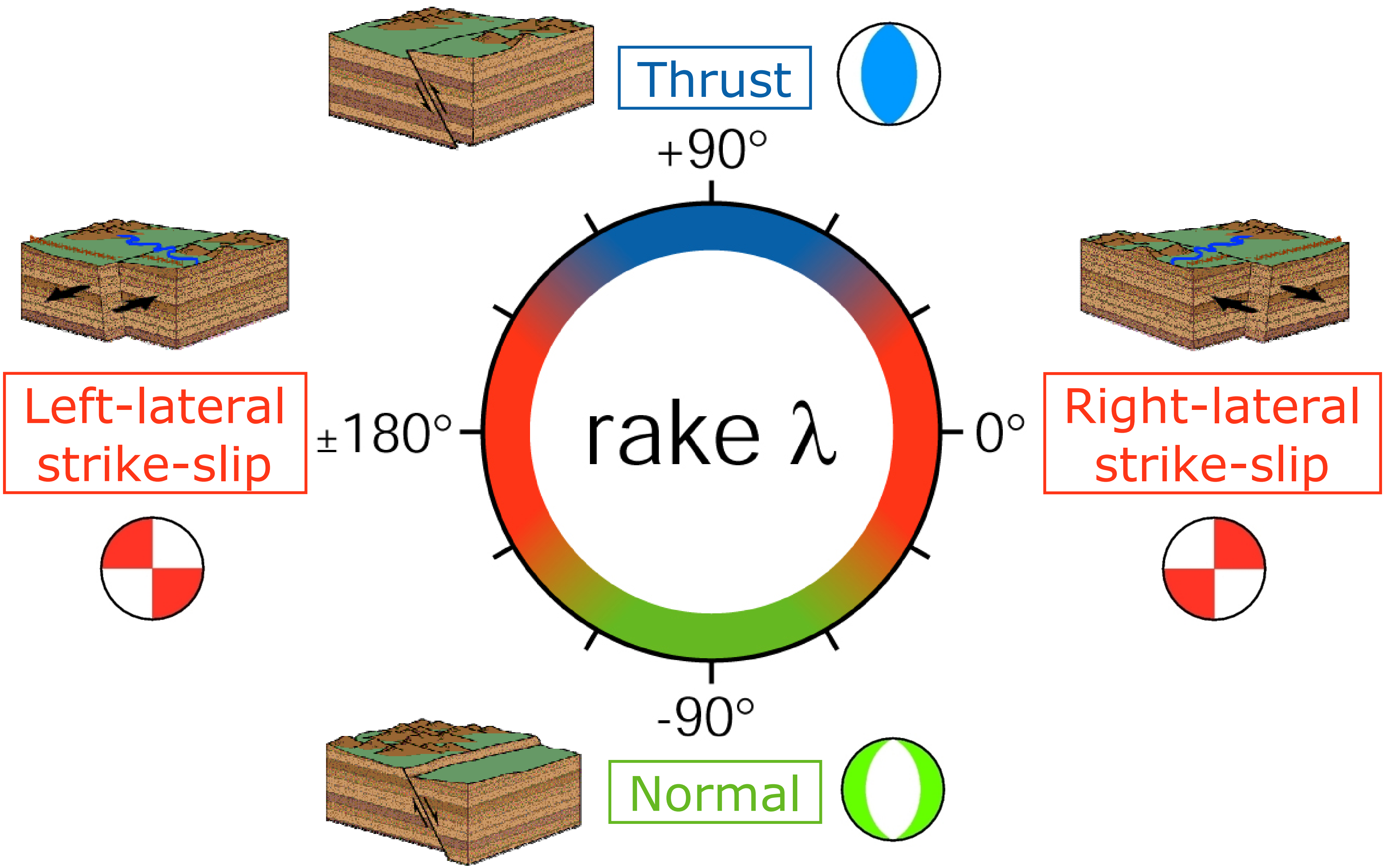
Can these findings be extrapolated to the magnitude range of earthquakes?

Types of Faulting

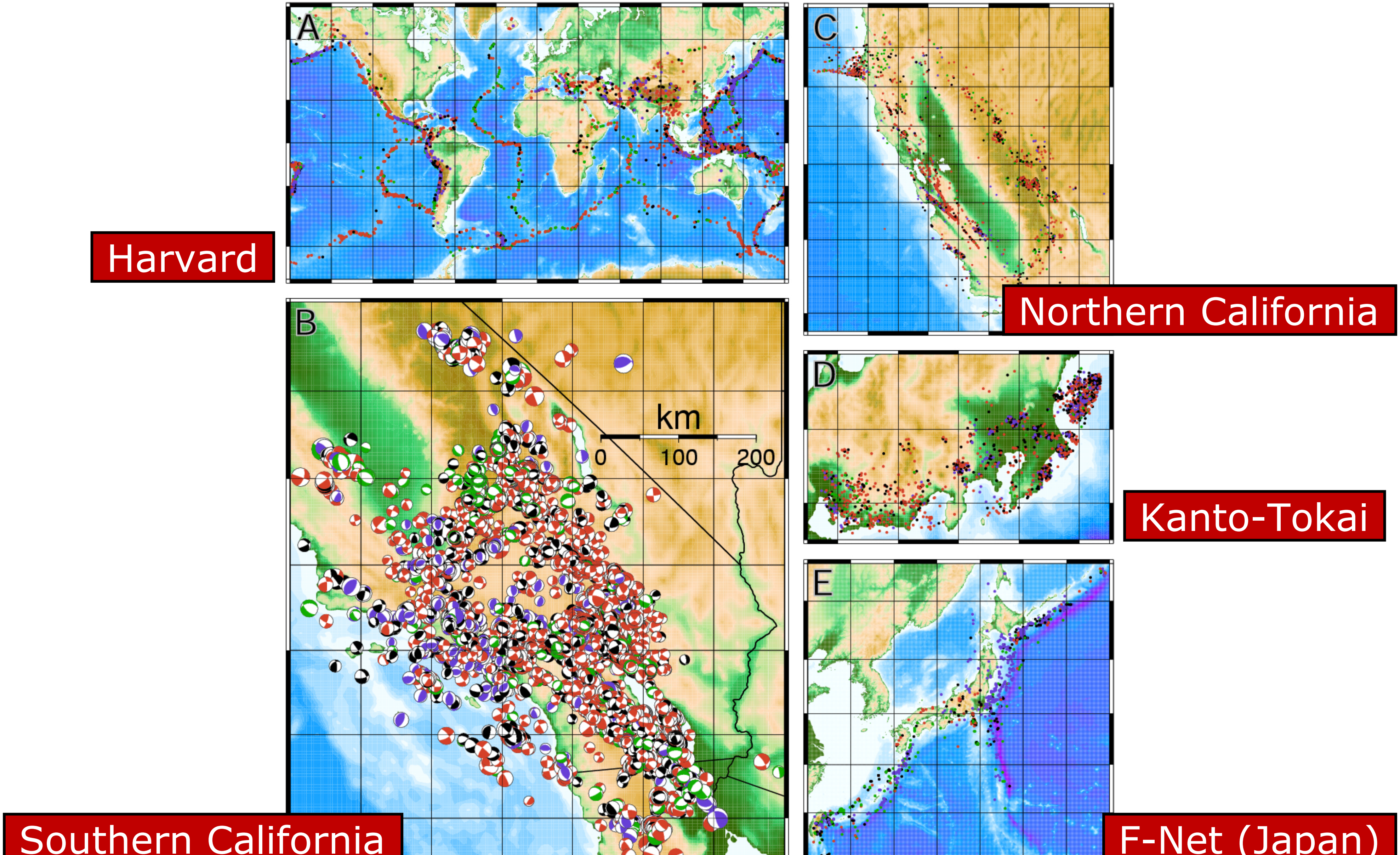
For a given σ_v (depth level): $b_T < b_S < b_N \leftrightarrow \sigma_T > \sigma_S > \sigma_N$



Definition of Focal Mechanisms

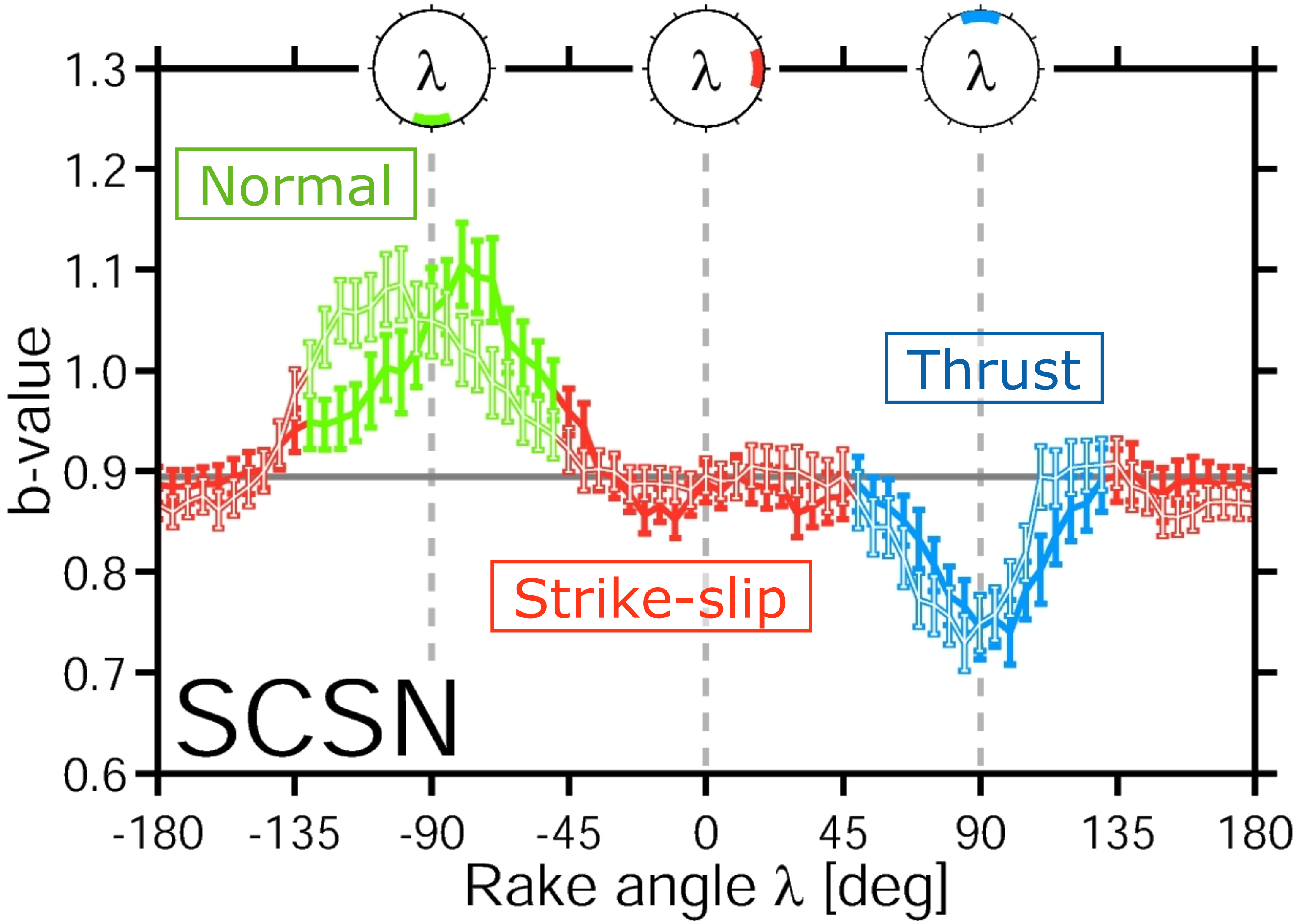


Catalogs with Focal Mechanisms

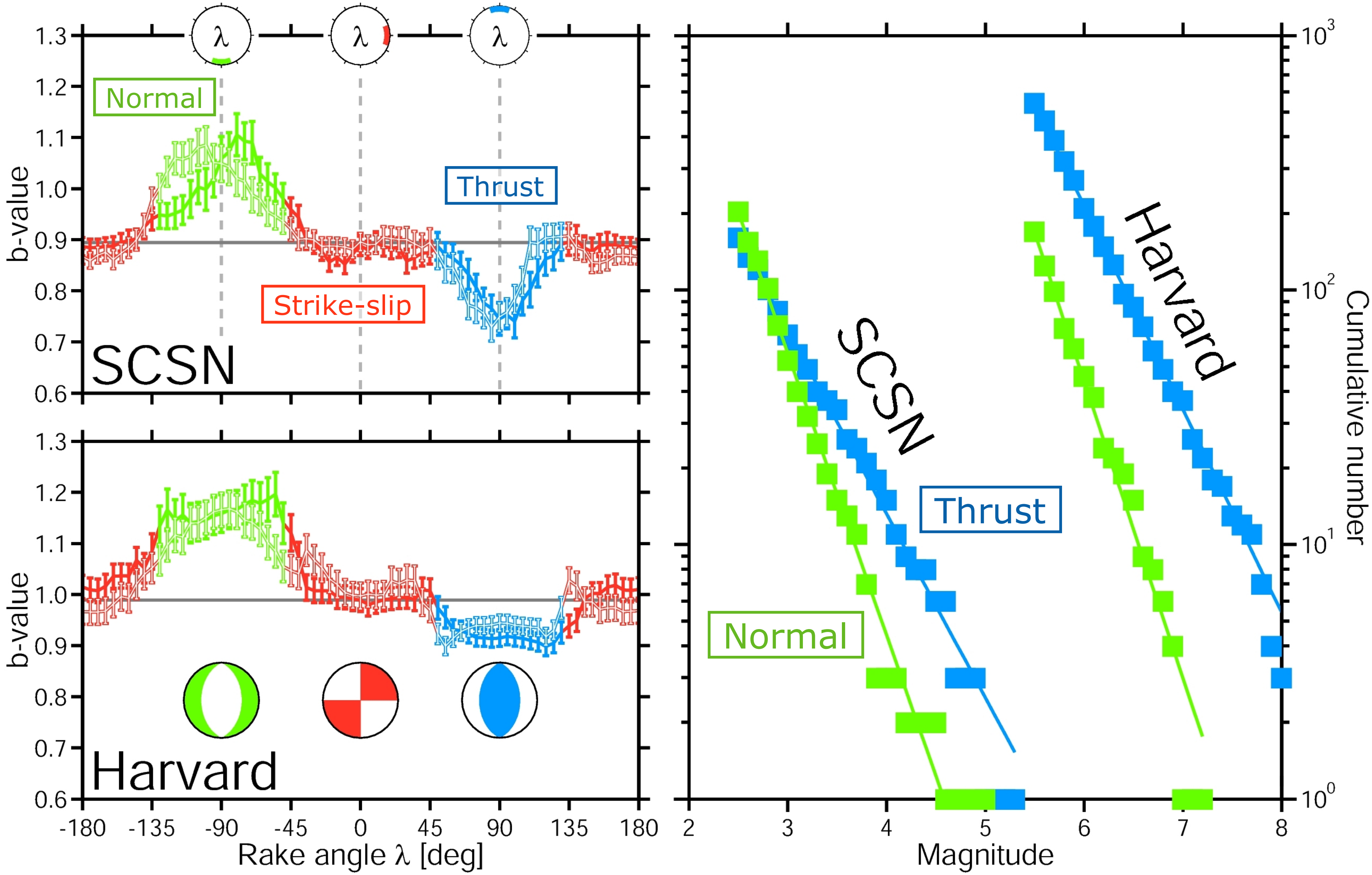


Results

b-value as function of the rake angle λ

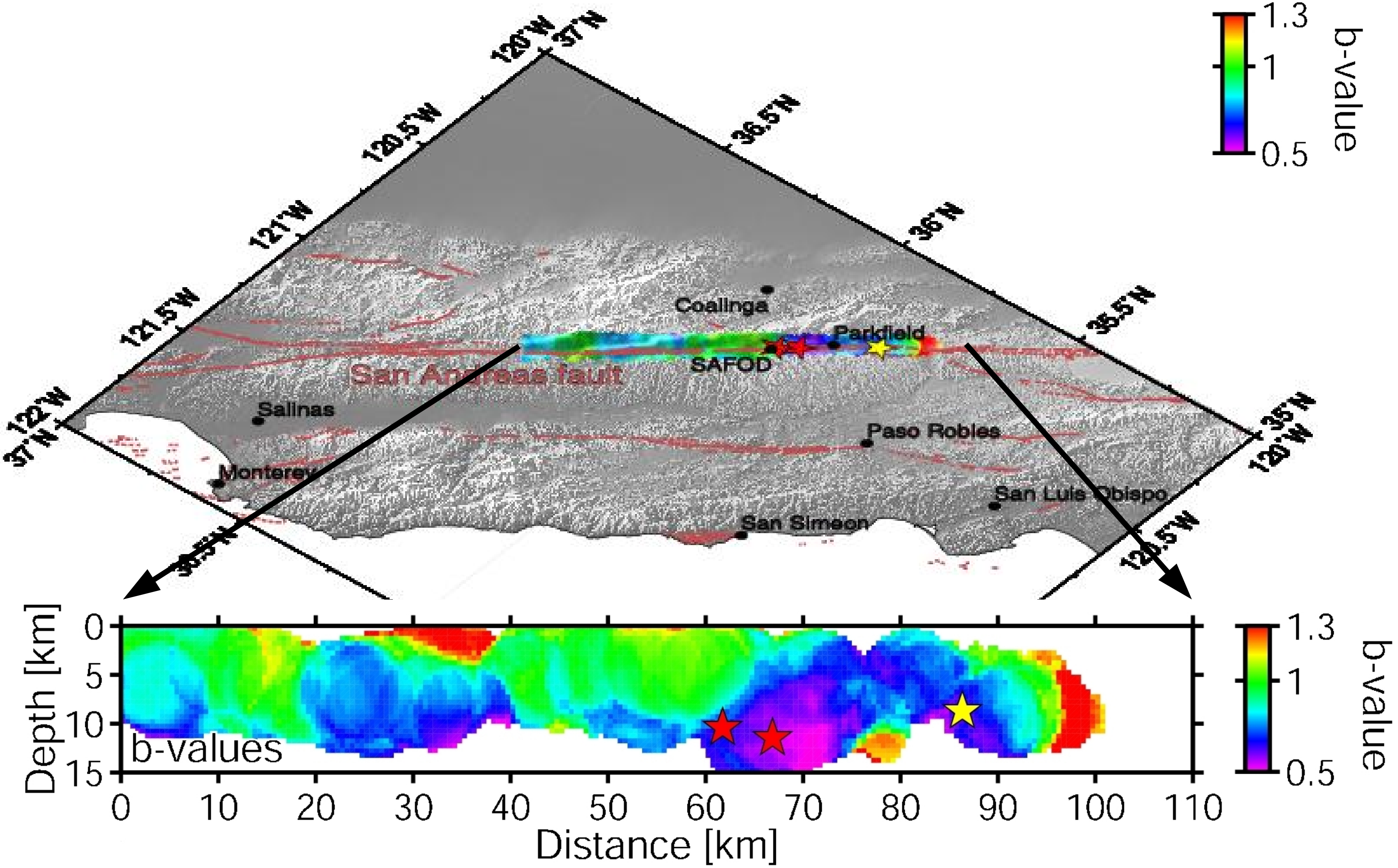


Results



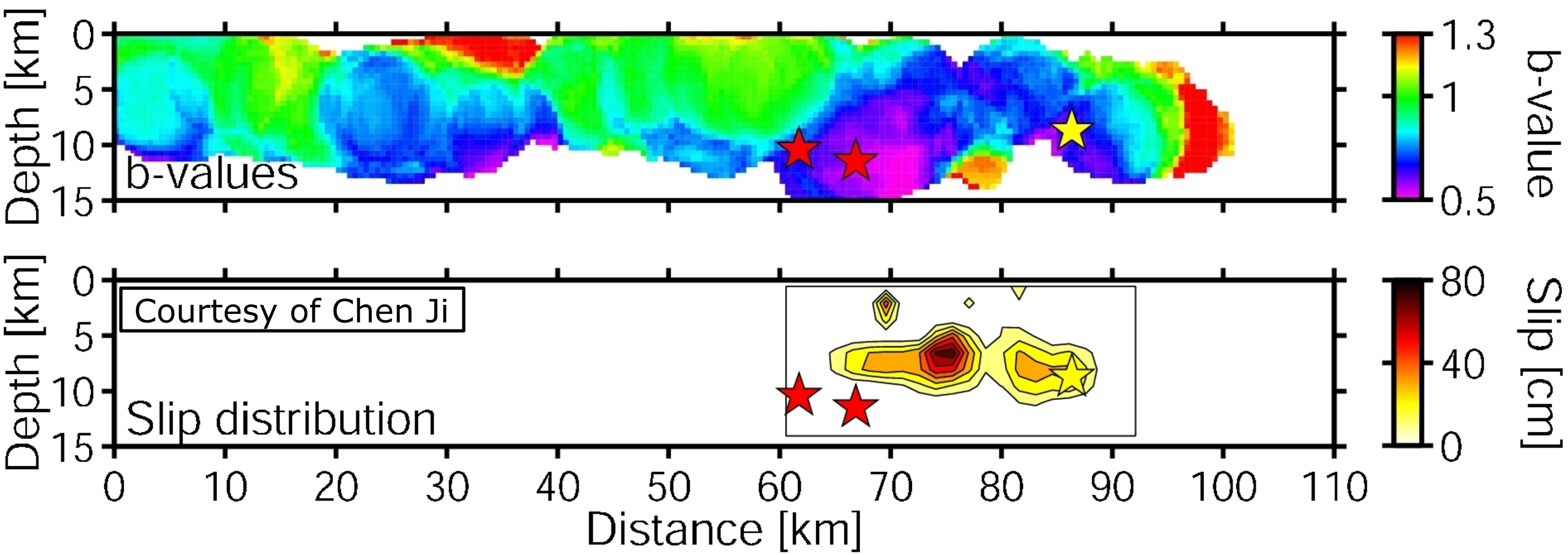
Normal
Thrust
Strike-slip
SCSN
Harvard
b-value
Rake angle λ [deg]
Normal
Thrust
SCSN
Harvard
Magnitude
Cumulative number

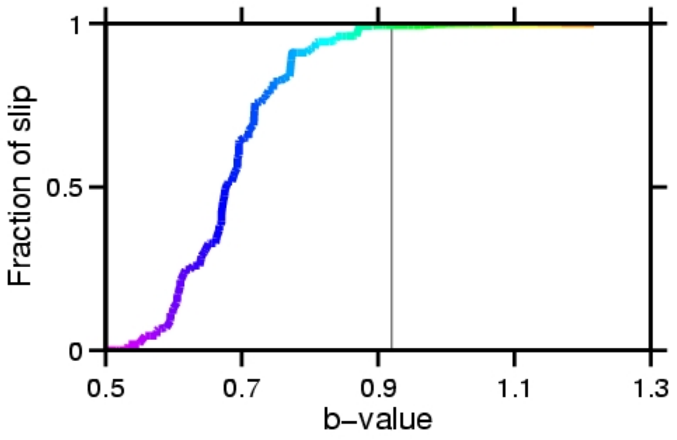
Analysis of Parkfield 2004



Analysis of Parkfield 2004

The slip area correlates with the low *b*-value area.





99% of the slip occurred in low *b*-value area

Analysis of Parkfield 2004

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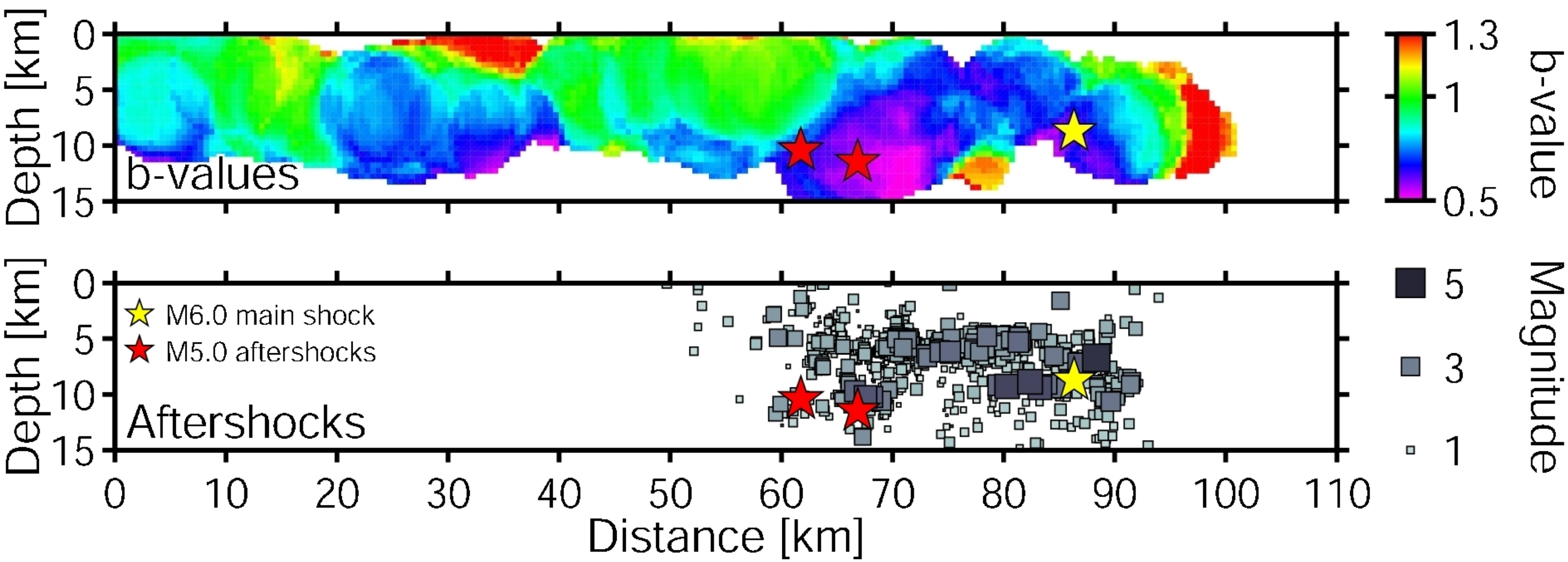
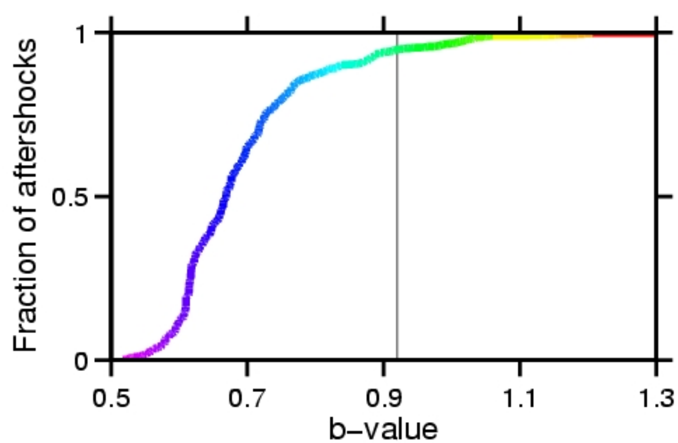




95% of the aftershocks occurred in low *b*-value area

Two Fundamental Laws

– Gutenberg-Richter relation

– Omori-Utsu law

Omori-Utsu Law

We compute *c*-values as a function of mainshock rake angles:

– Select catalogs for mainshocks (with focal mechanisms) and aftershocks (low completeness magnitude)

Omori-Utsu Law

We compute *c*-values as a function of mainshock rake angles:

- Select catalogs for mainshocks (with focal mechanisms) and aftershocks (low completeness magnitude)
- Identify mainshocks
  - No physical definition exists.
  - Distinction between main shocks and aftershocks is given by the declustering algorithms
  - Space-time window:

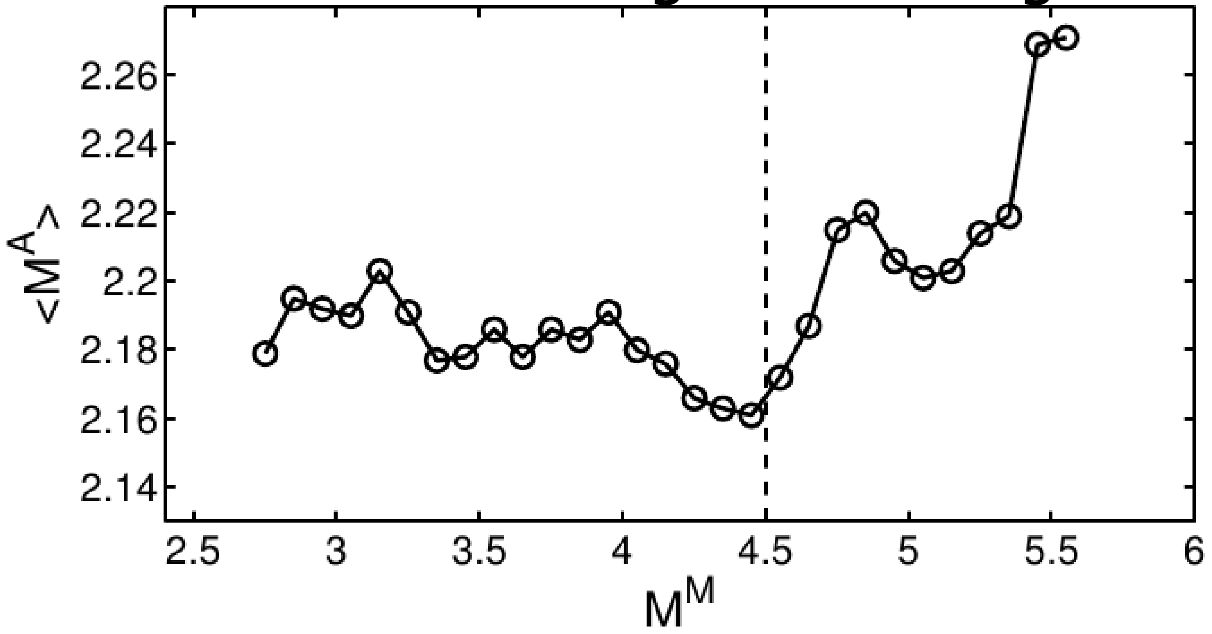
$$R_w(M) = 0.020 \cdot 10^{0.50M}$$

$$T_w(M) = 0.125 \cdot 10^{0.55M}$$

Omori-Utsu Law

We compute *c*-values as a function of mainshock rake angles:

- Select catalogs for mainshocks (with focal mechanisms) and aftershocks (low completeness magnitude)
- Identify mainshocks
- Determine the mainshock magnitude range

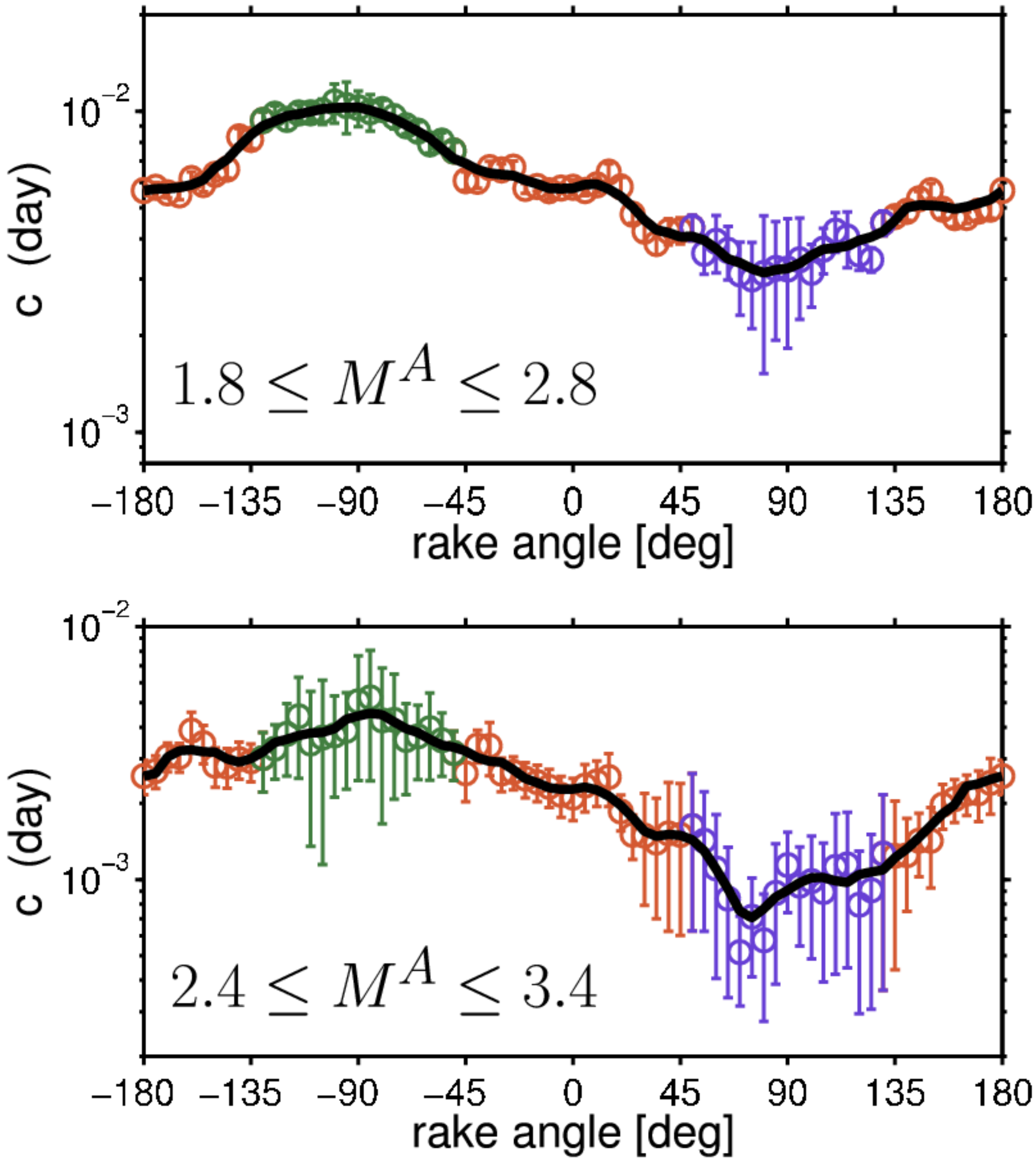


Omori-Utsu Law

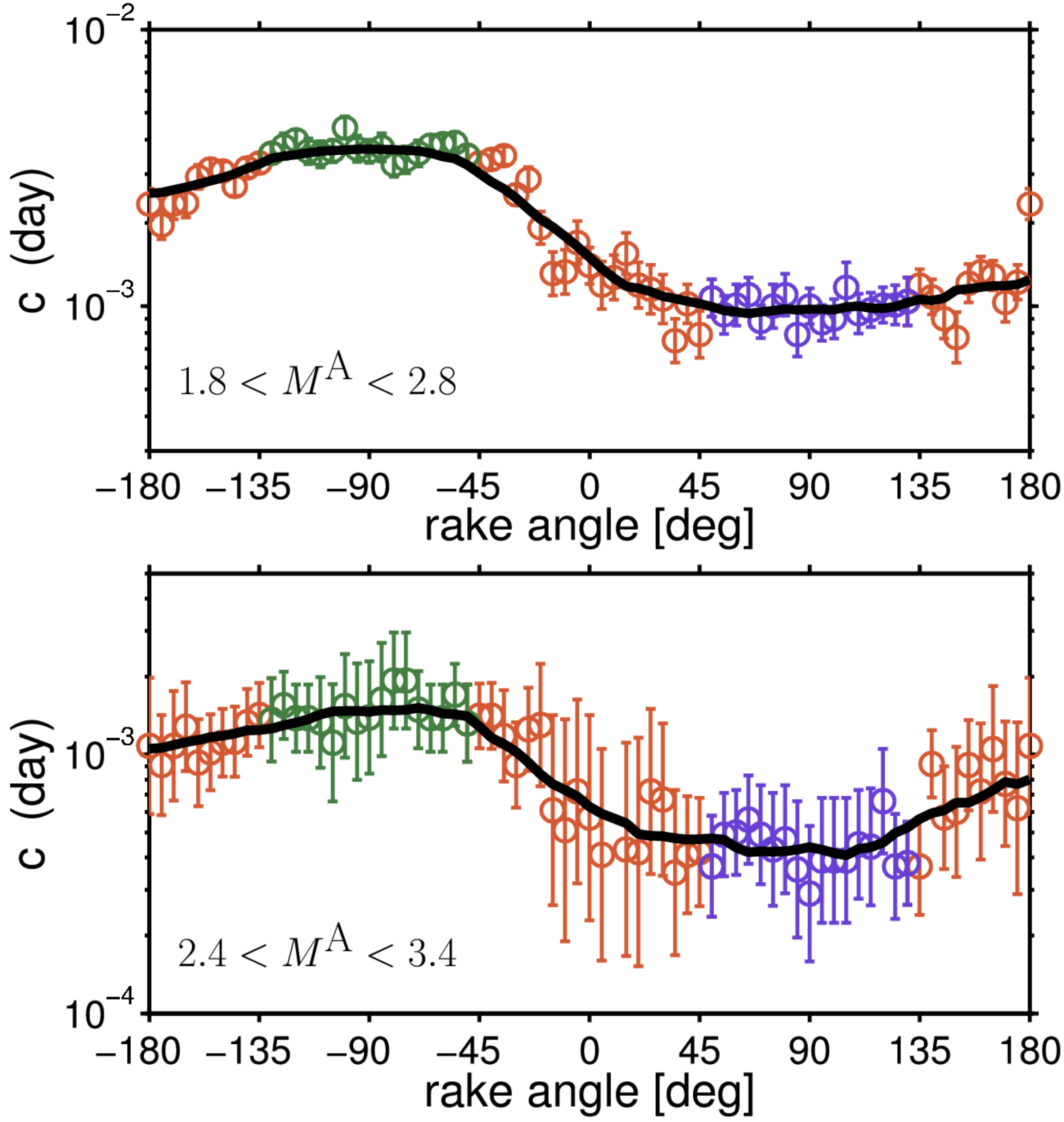
We compute *c*-values as a function of mainshock rake angles:

- Select catalogs for mainshocks (with focal mechanisms) and aftershocks (low completeness magnitude)
- Identify mainshocks
- Determine the mainshock magnitude range
- Define aftershock magnitude range
- Stack aftershocks according to mainshock rake angle and estimate the *c*-value

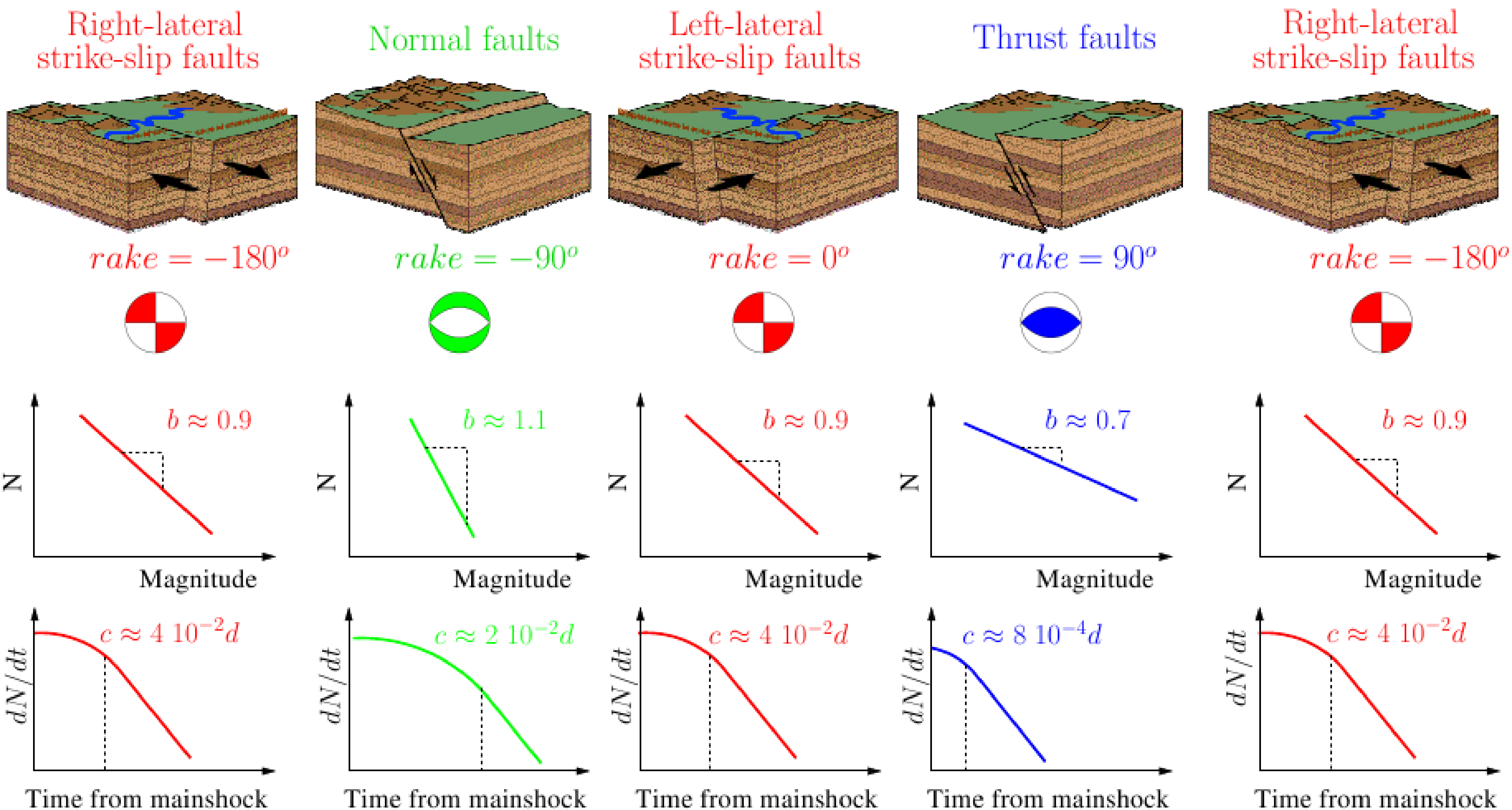
Results (Southern California)



Results (Japan)



Result Summary



$$\sigma_1^n - \sigma_3^n \quad < \quad \sigma_1^{ss} - \sigma_3^{ss} \quad < \quad \sigma_1^{th} - \sigma_3^{th}$$

Summary

– *b*-values are fundamentally controlled by stresses
– The *b*-value describes the ability for an earthquake rupture to propagate (lower *b*-value) or not (higher *b*-value)
– The *b*-value-stress dependency is modified by the roughness of the faulting surface
– The Parkfield experience suggests that we can map future rupture areas with *b*-values

– *c*-values are controlled by stresses
– Aftershocks help forecasting main shocks (EAST model)

– Both fundamental laws of statistical seismology show stress dependency