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Seismogenic Index, Bounds of Magnitude Probability and Triggered versus Induced Earthquakes

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Cumulative event number

The Gutenberg-Richter law:

$$\log N_M = a - bM$$

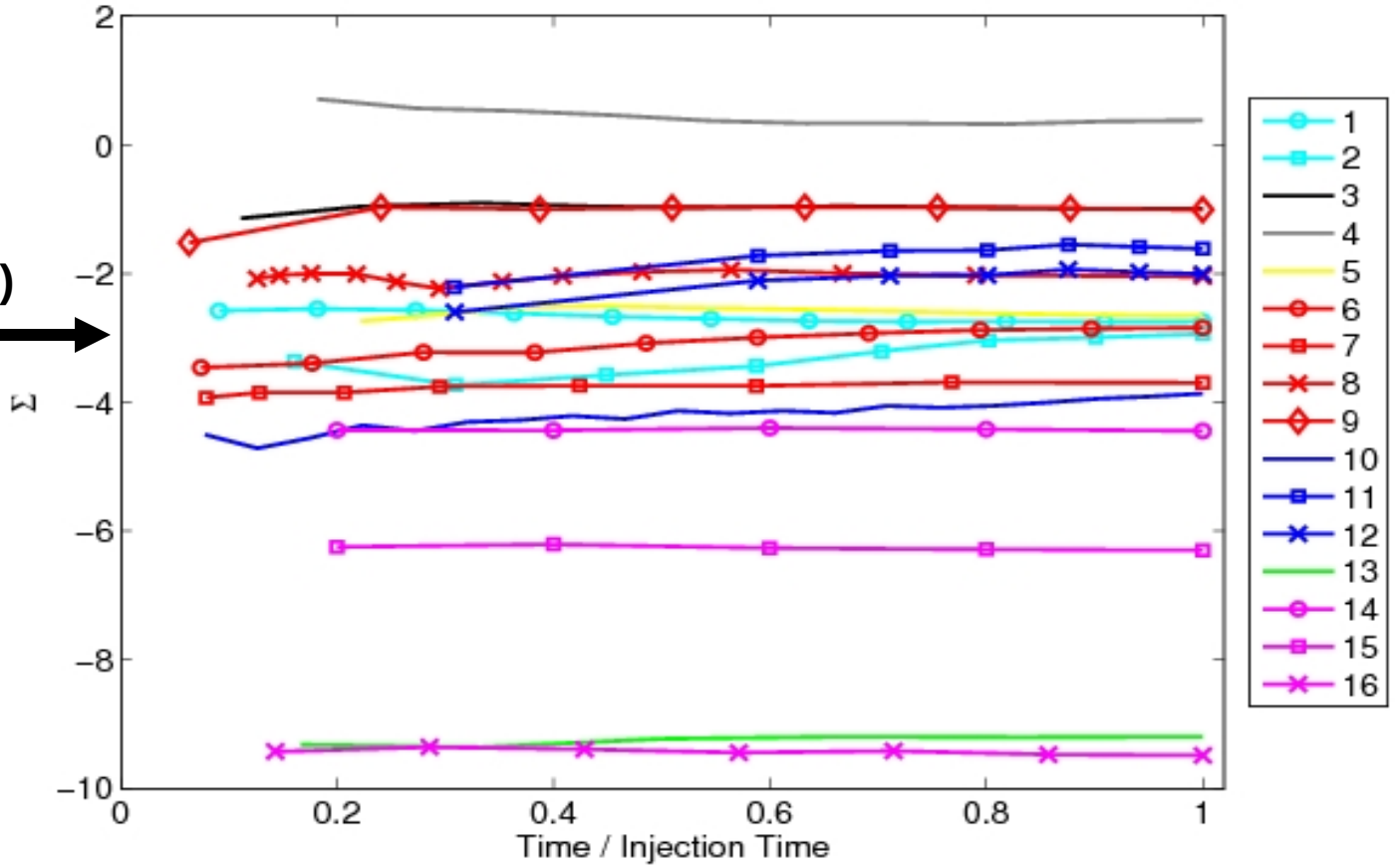
The Gutenberg-Richter law for fluid injections:

$$\log N_M(t) = \Sigma + \log Q_c(t) - bM$$

Seismogenic index, Σ

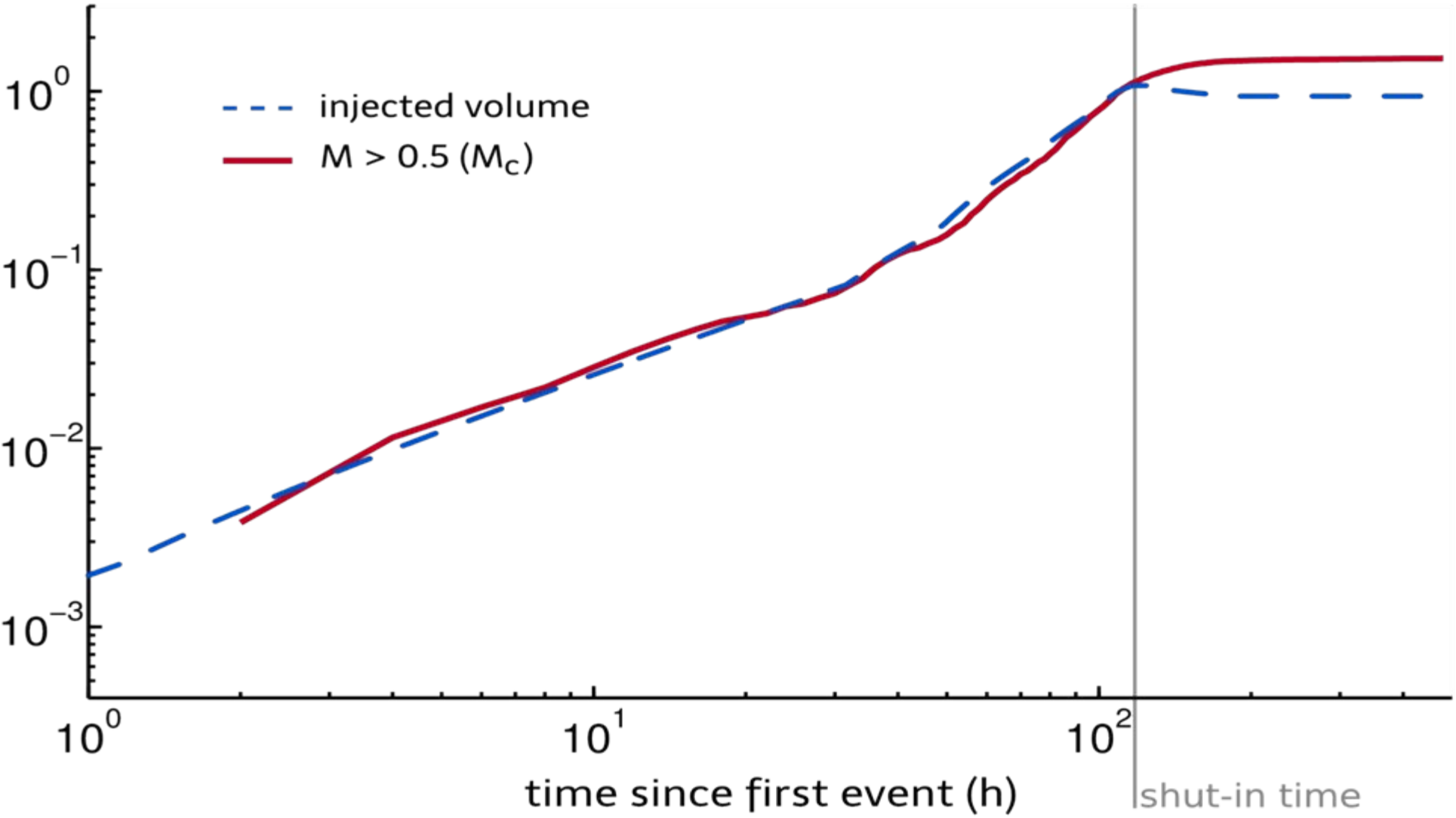
For Basel from tectonic data

(F. Wenzel 2011)

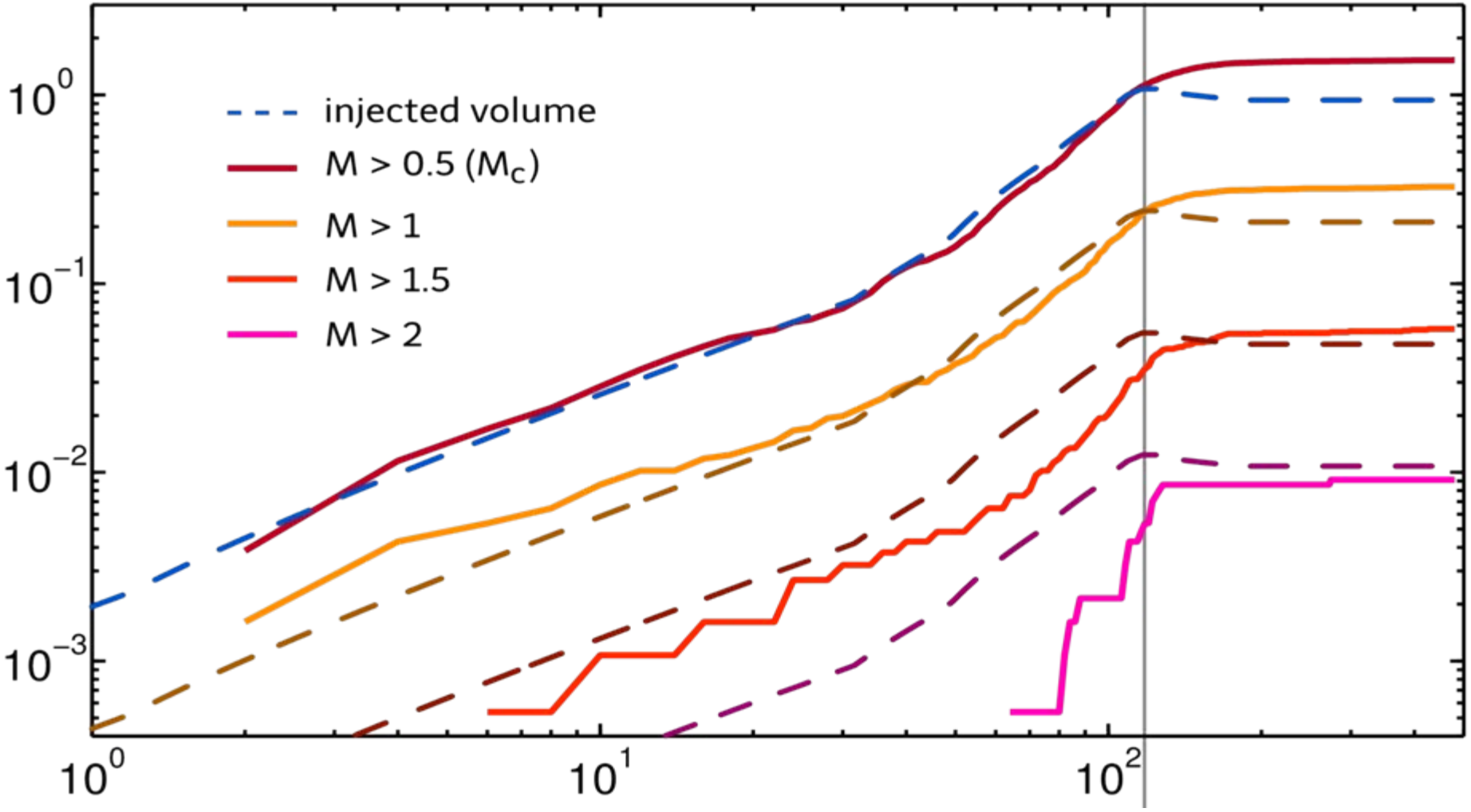


1-2: Ogachi 1991/93, **3**: Cooper Basin 2003, **4**: Basel 2006, **5**: Paradox Valley, **6-9**: Soultz 1996/95/93/00. **10-12**: KTB 2005/94.**13**: Barnett Shale, **14-16**: Cotton Valley stages A, B,C.

Basel: normalized cumulative seismicity and injected volume

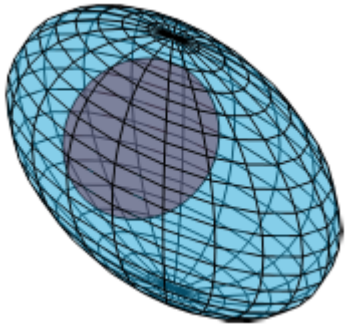


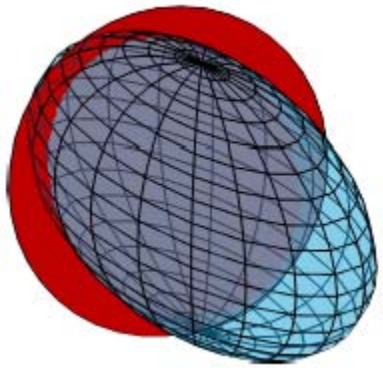
Basel: normalized cumulative seismicity and injected volume

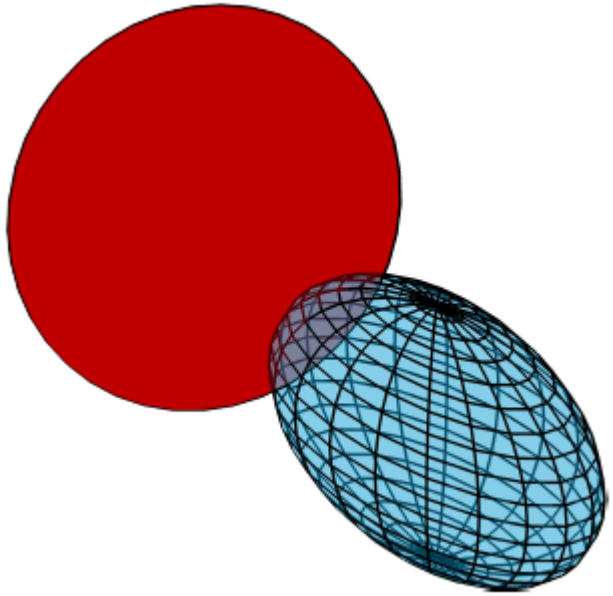


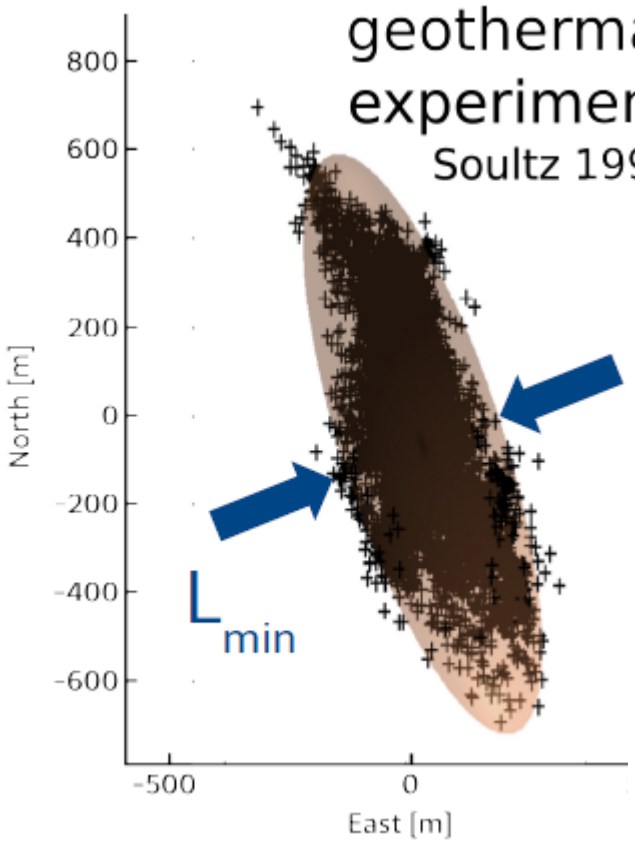
Finite stimulated volume

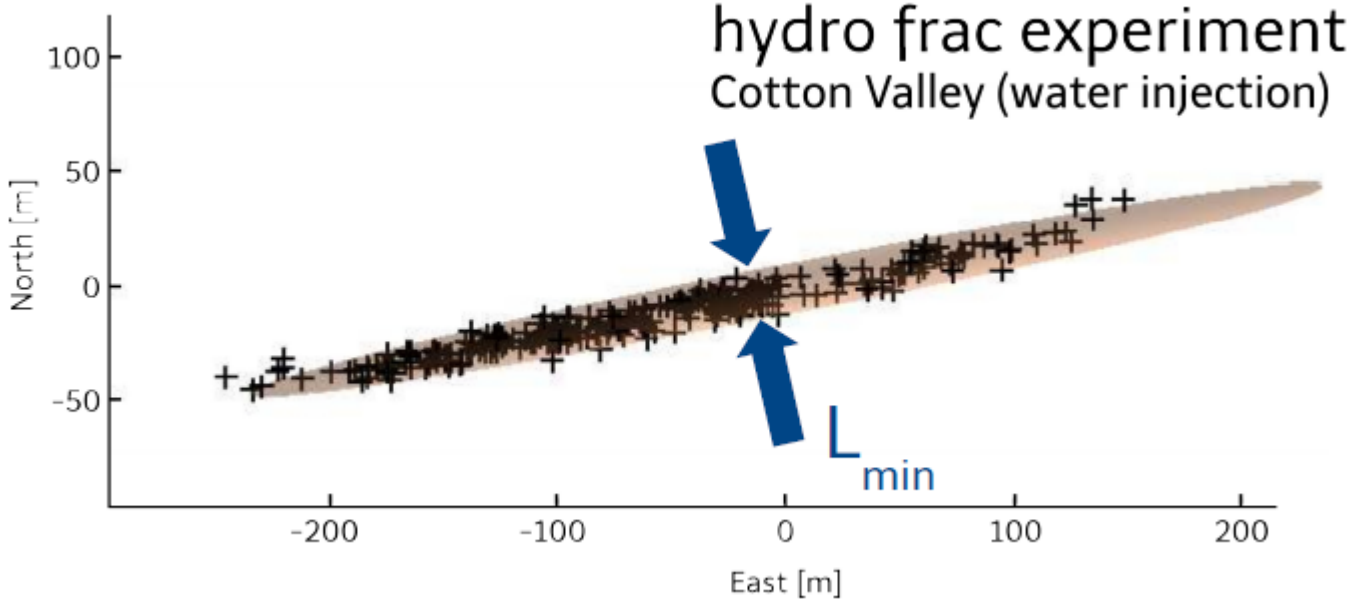
Shapiro et al, 2011,
Geophysics, v. 76, #6.











Effect of the geometry

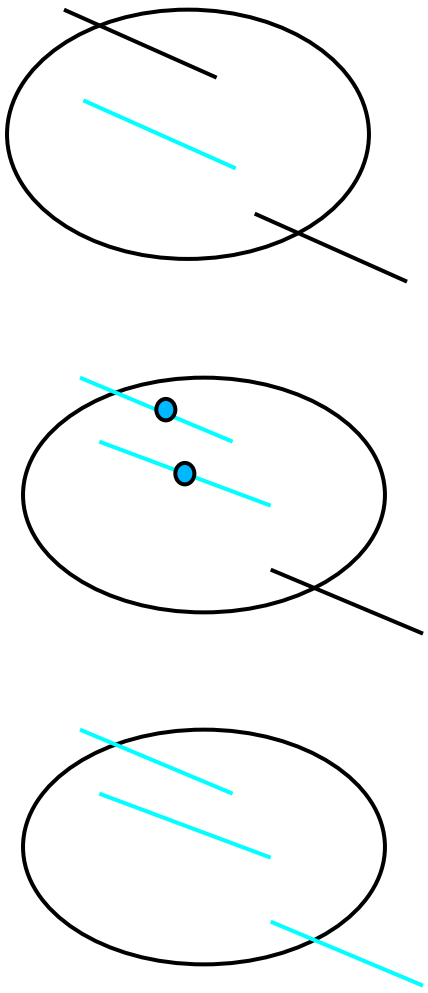
A power-law type of the probability of a rupture of the size L produces the Gutenberg-Richter magnitude distribution:

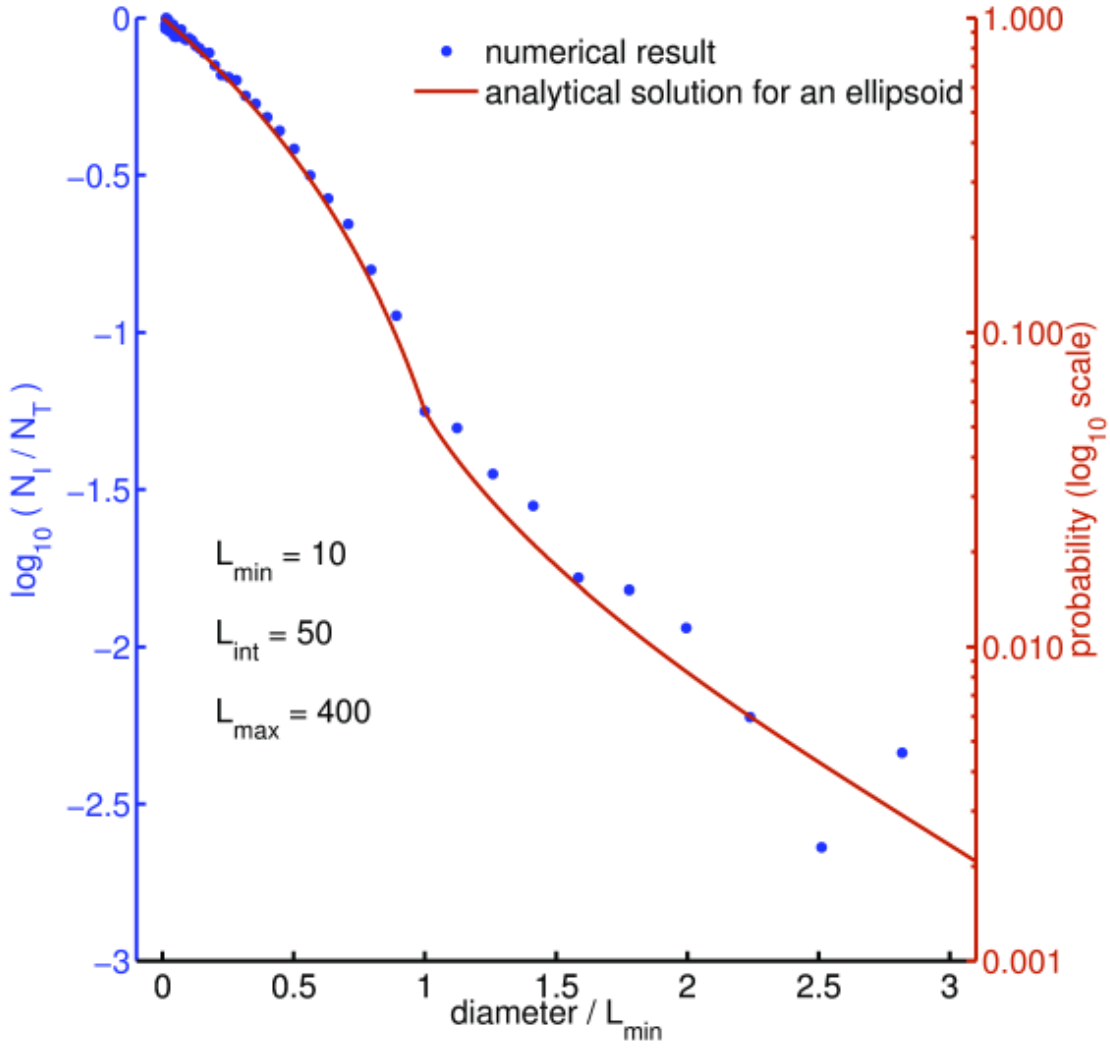
$$W_F \propto L^{-2b-1}\delta L$$

The following product takes effects of the geometry into account:

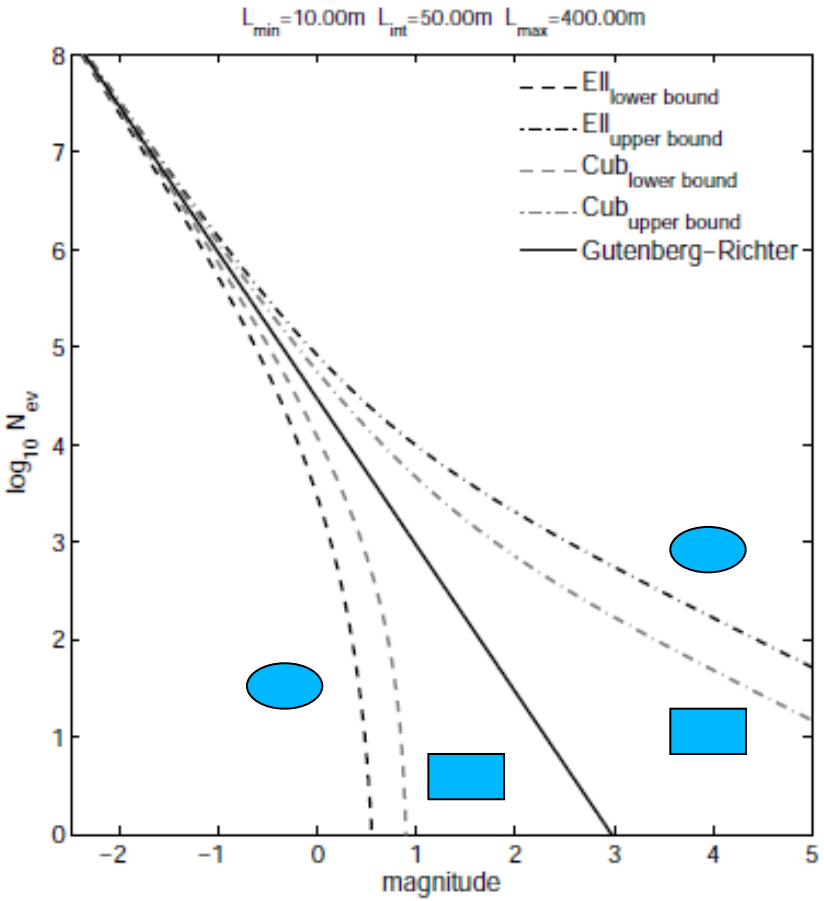
$$W_F(L)W_{geometry}(L)$$

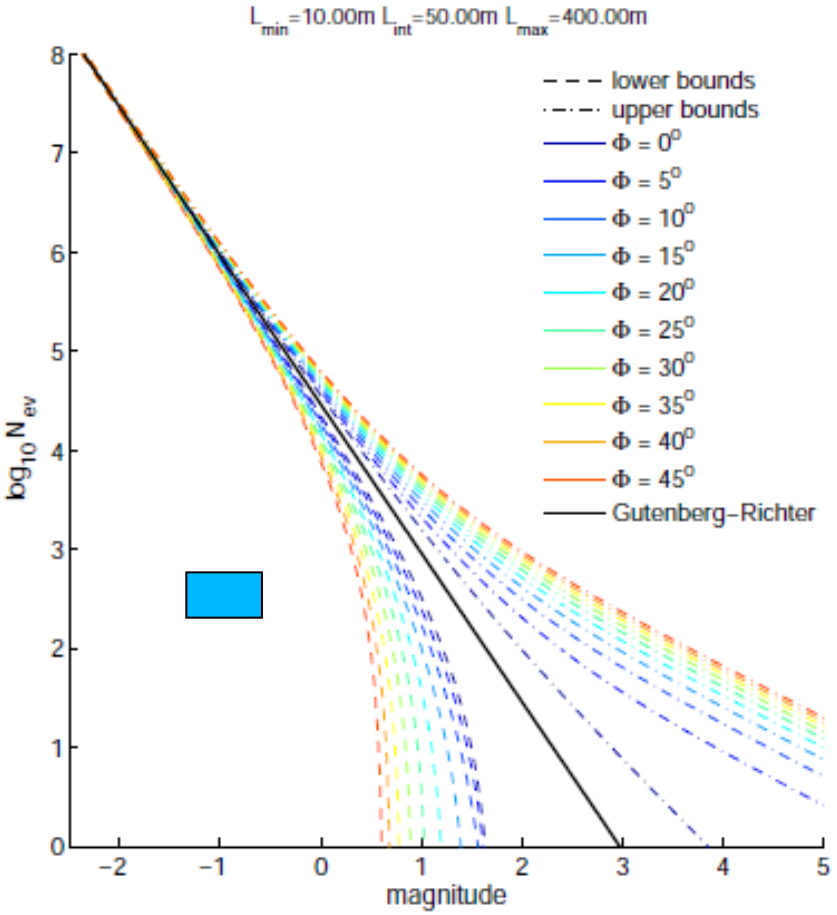
The geometry of two bounds



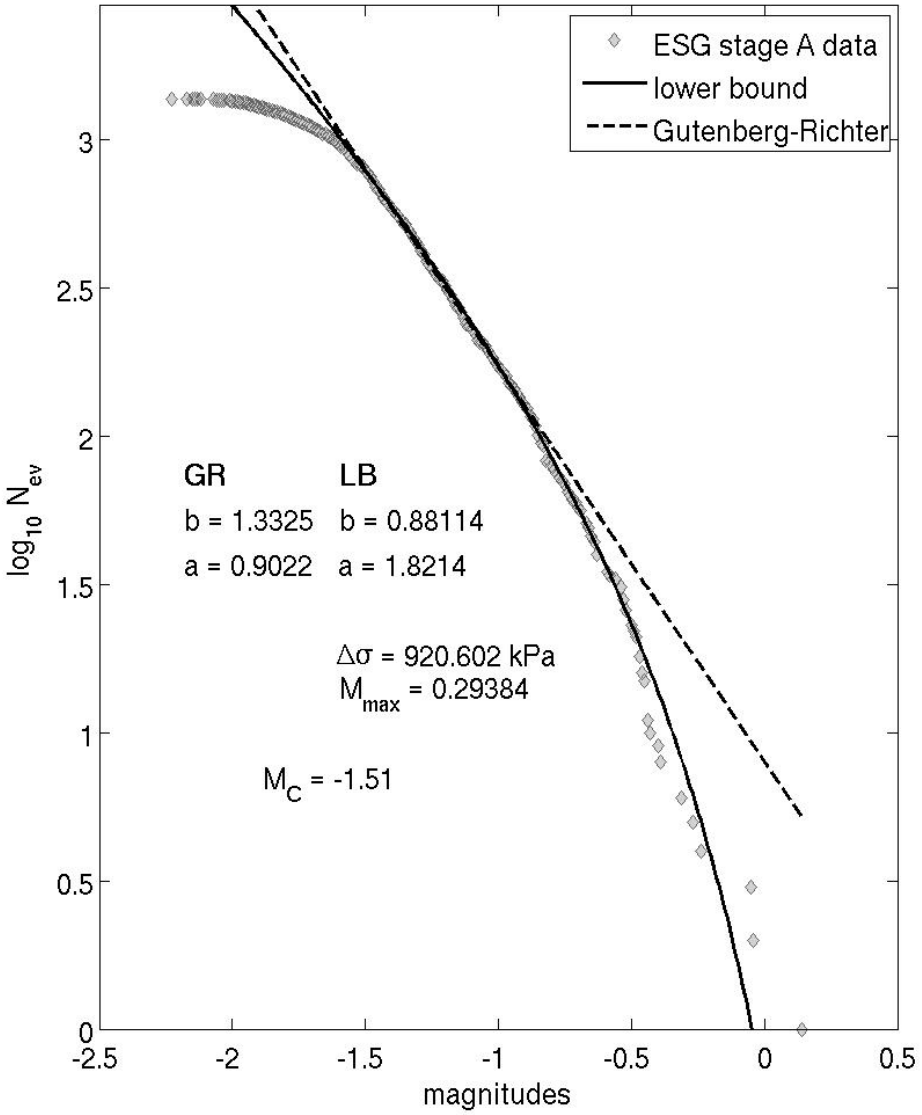


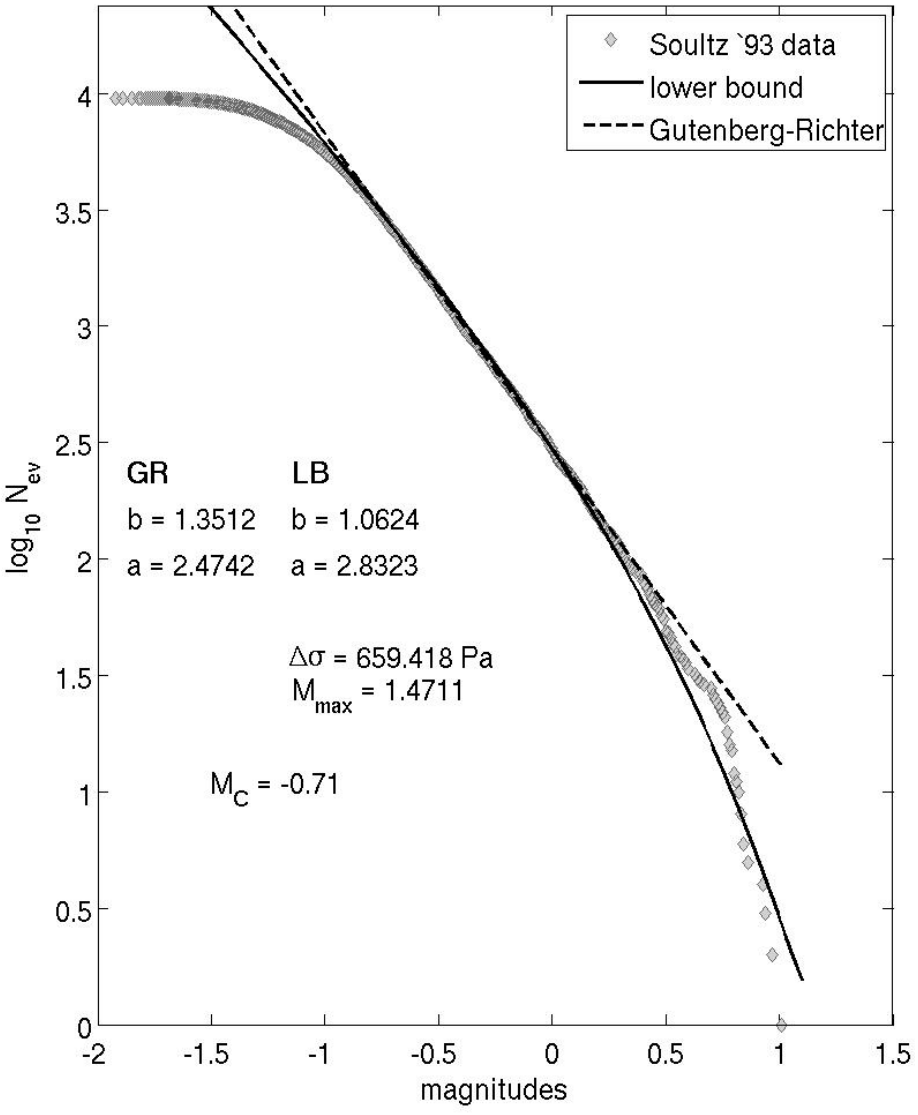
The bounds for magnitude distributions



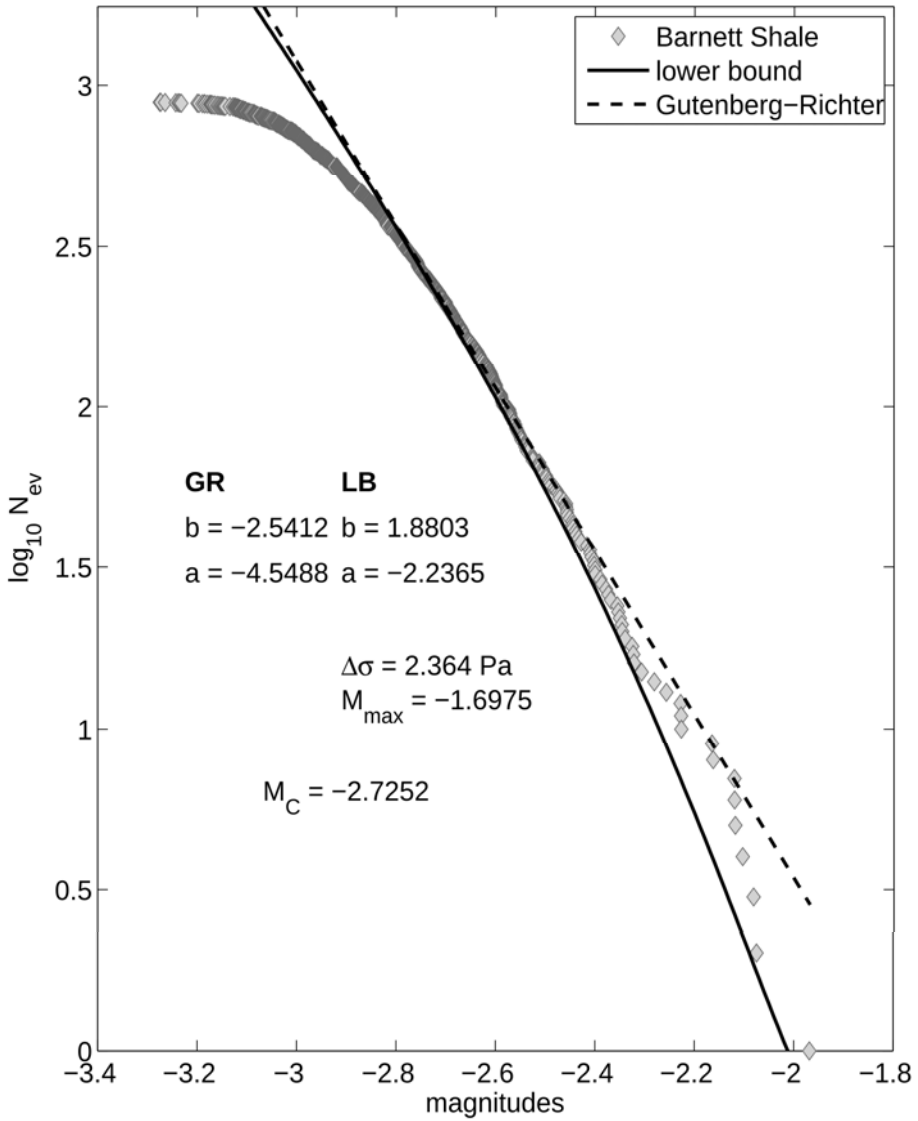


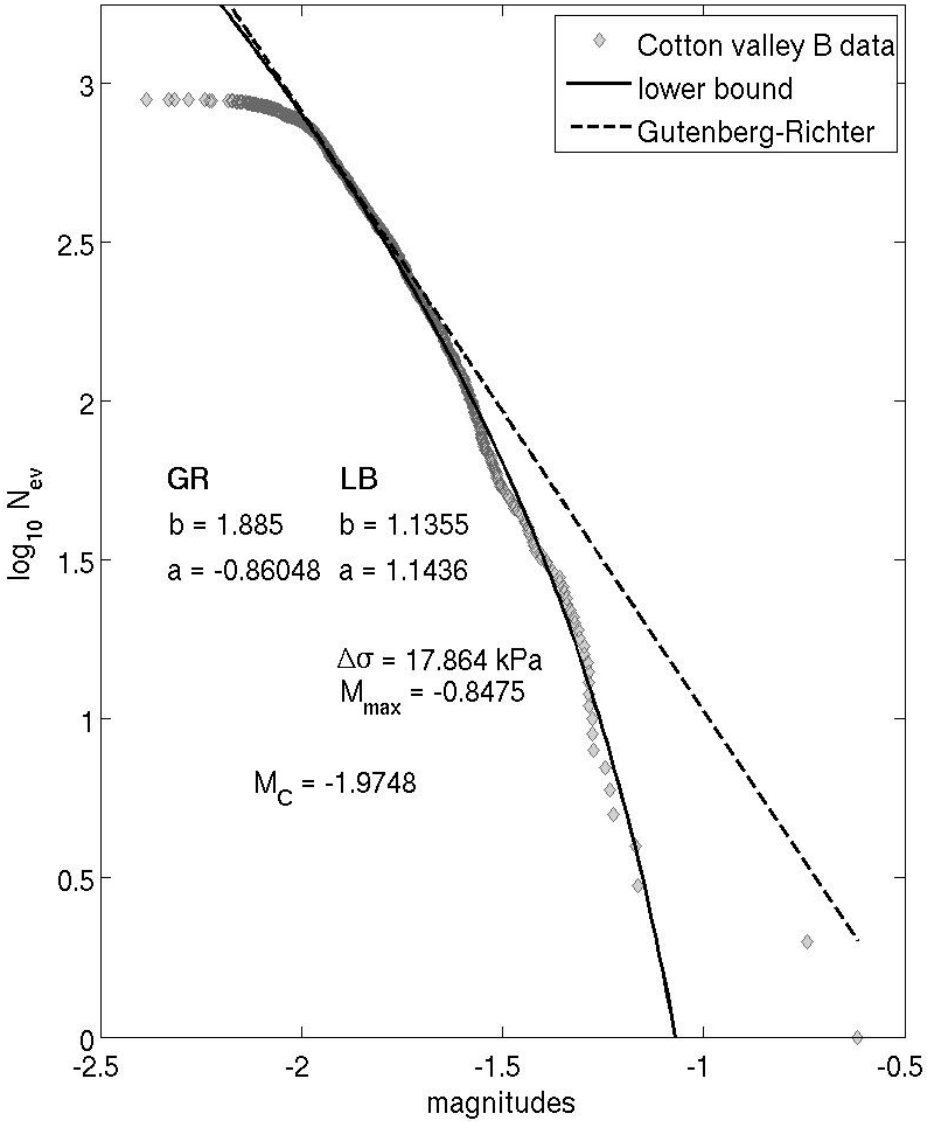
The lower bound seems to be preferred!



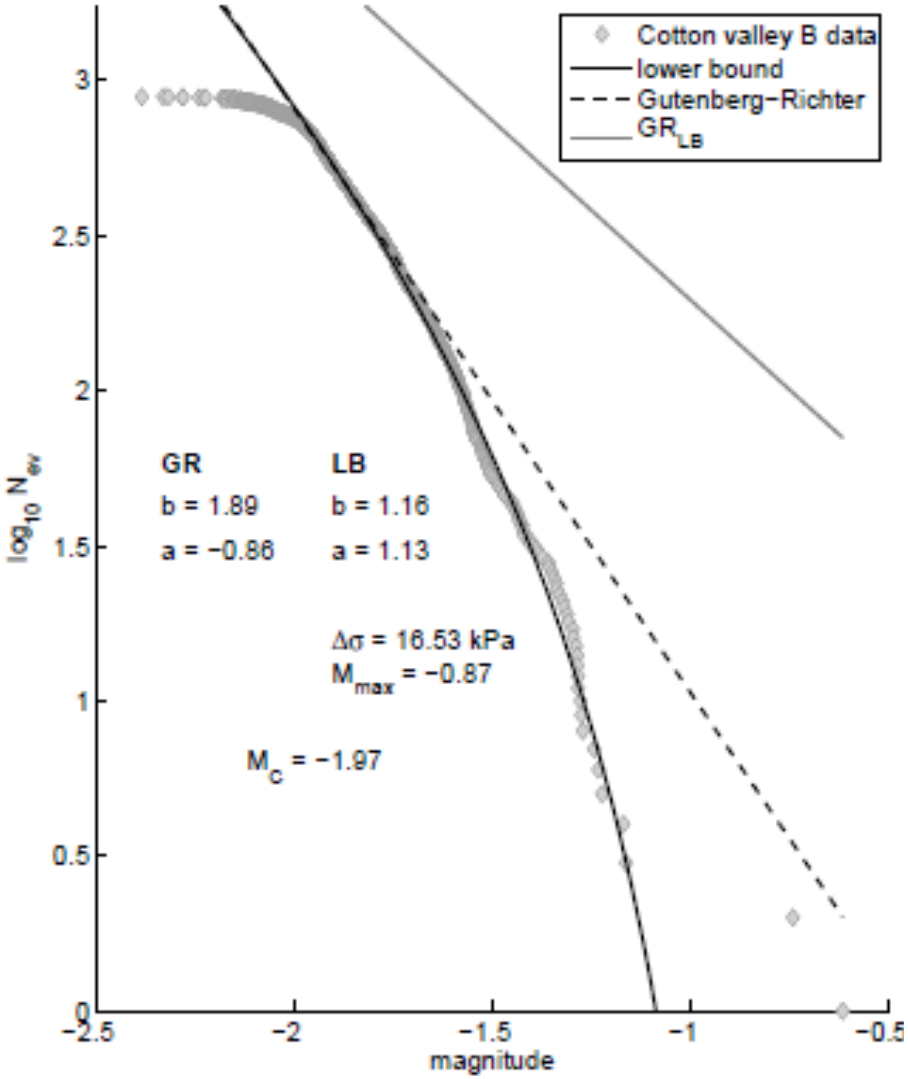


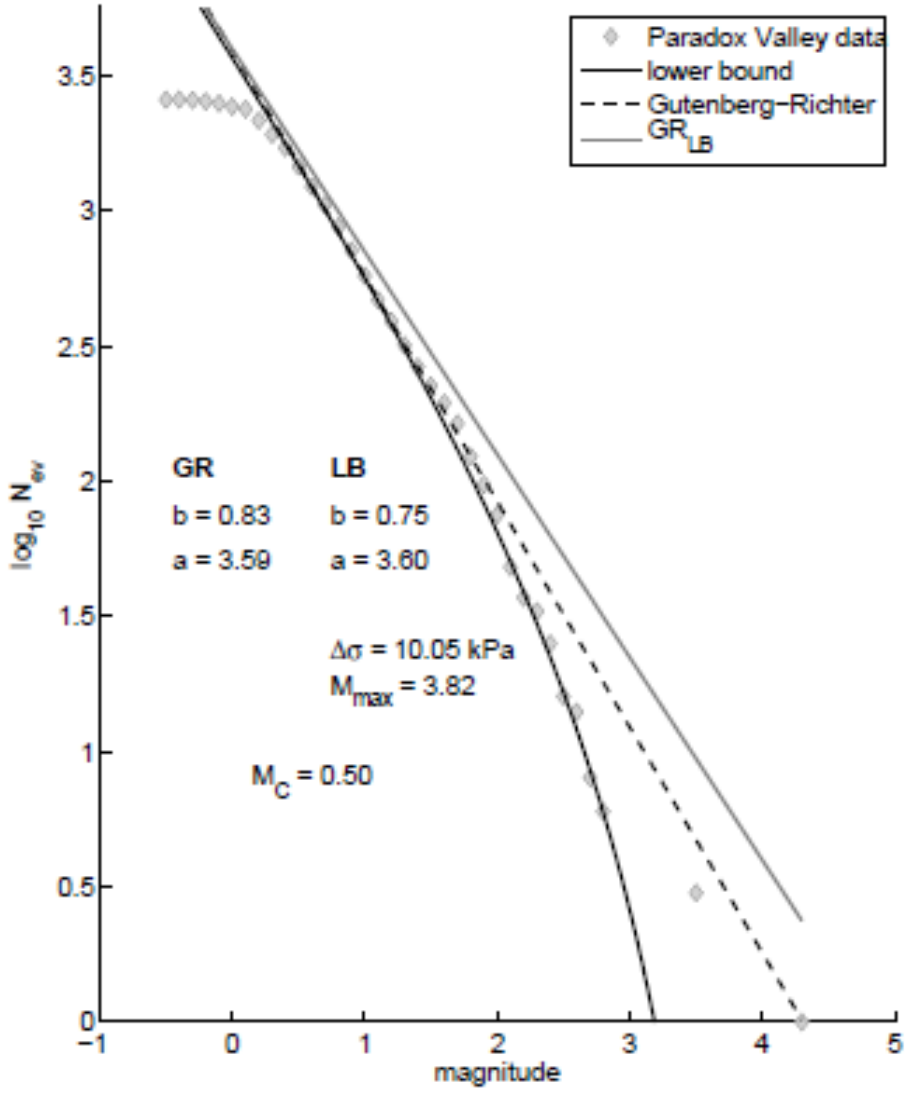
Induced and some triggered events!



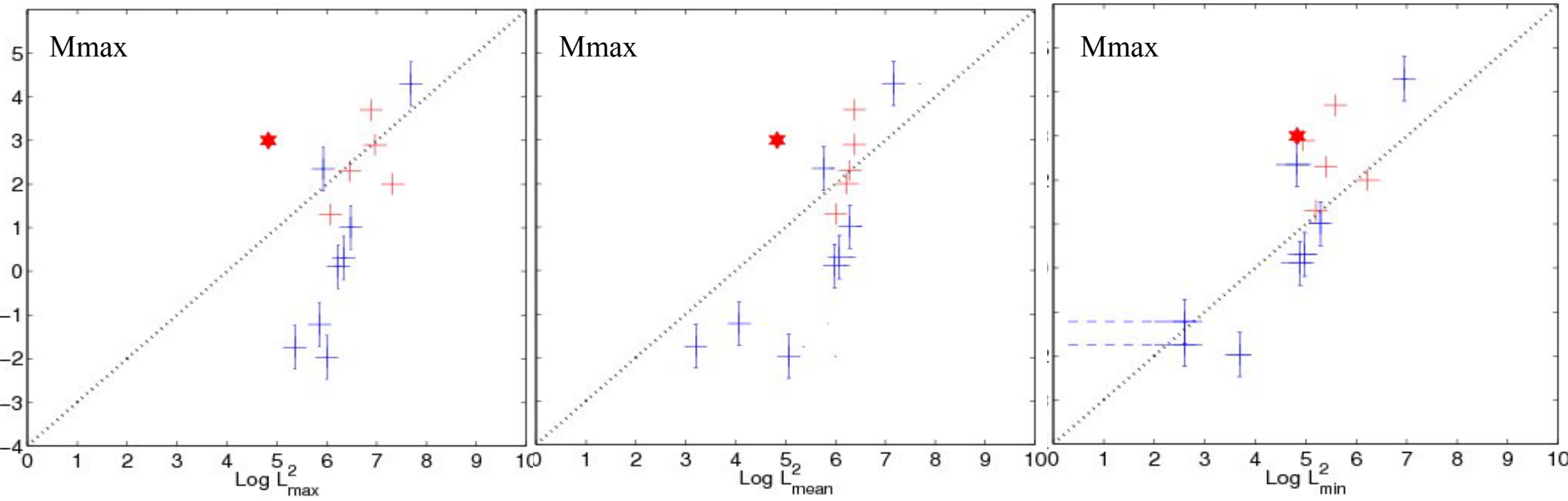


Impact on the Gutenberg-Richter parameters



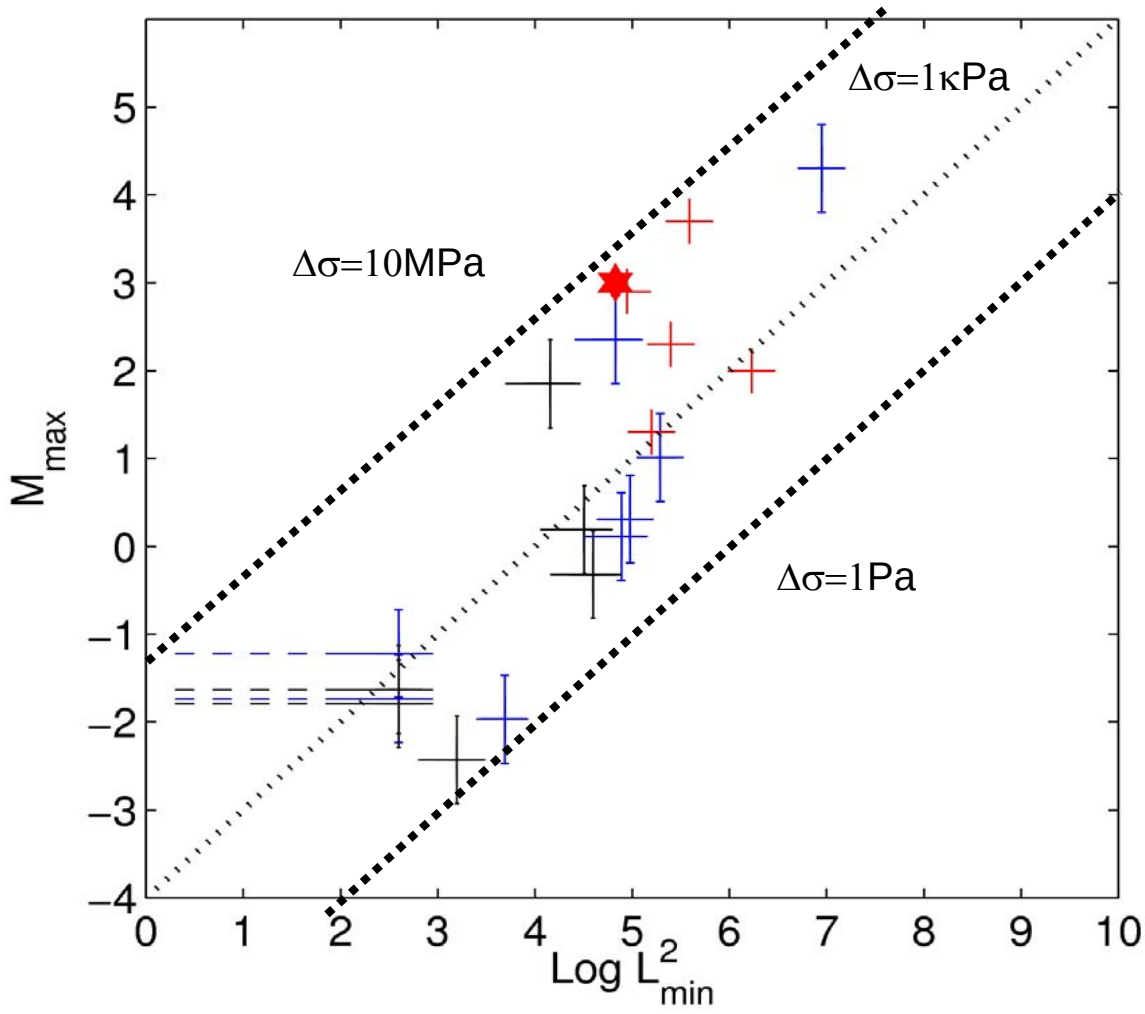


The scale controlling maximum magnitudes



$$M_L = \log L^2 + [\log \Delta\sigma - \log C]/1.5 - 6.07$$

Maximum magnitude vs minimum axis



$$MAX\{M_{max}\} \approx 2 \log L_{min} - 1$$

Conclusions

- Geometry of a stimulated volume impacts statistics of activated rupture surfaces.
- The minimum principal axis of this volume and the stress drop control the maximum induced magnitude.
- Both, a− and b− Gutenberg-Richter values are strongly affected.
- The geometry implies lower and upper bounds of frequency-magnitude distributions.
- Induced seismicity tends to follow the lower bound.
- The bounds help to distinguish between induced and triggered events.
- Stress drops and maximum expected magnitudes can be estimated.