Universality of the Gutenberg-Richter Relationship
(with b=1)

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Definition of Universal Gutenberg-Richter

An earthquake nucleating anywhere, at any time, will randomly grow to a magnitude ≥ M according to the distribution

$$\log(N) = a - bM,$$

⇒The probability that any nucleating earthquake will grow to magnitude ≥ M is

$$\Rightarrow P(M) = 10^{\,b(Mmin - M)}$$

N = # eqs ≥ M, $a \propto$ earthquake rate, b = constant (1.0), $Mmin$ = minimum earthquake magnitude

Definition of Universal Gutenberg-Richter

On a major fault ~

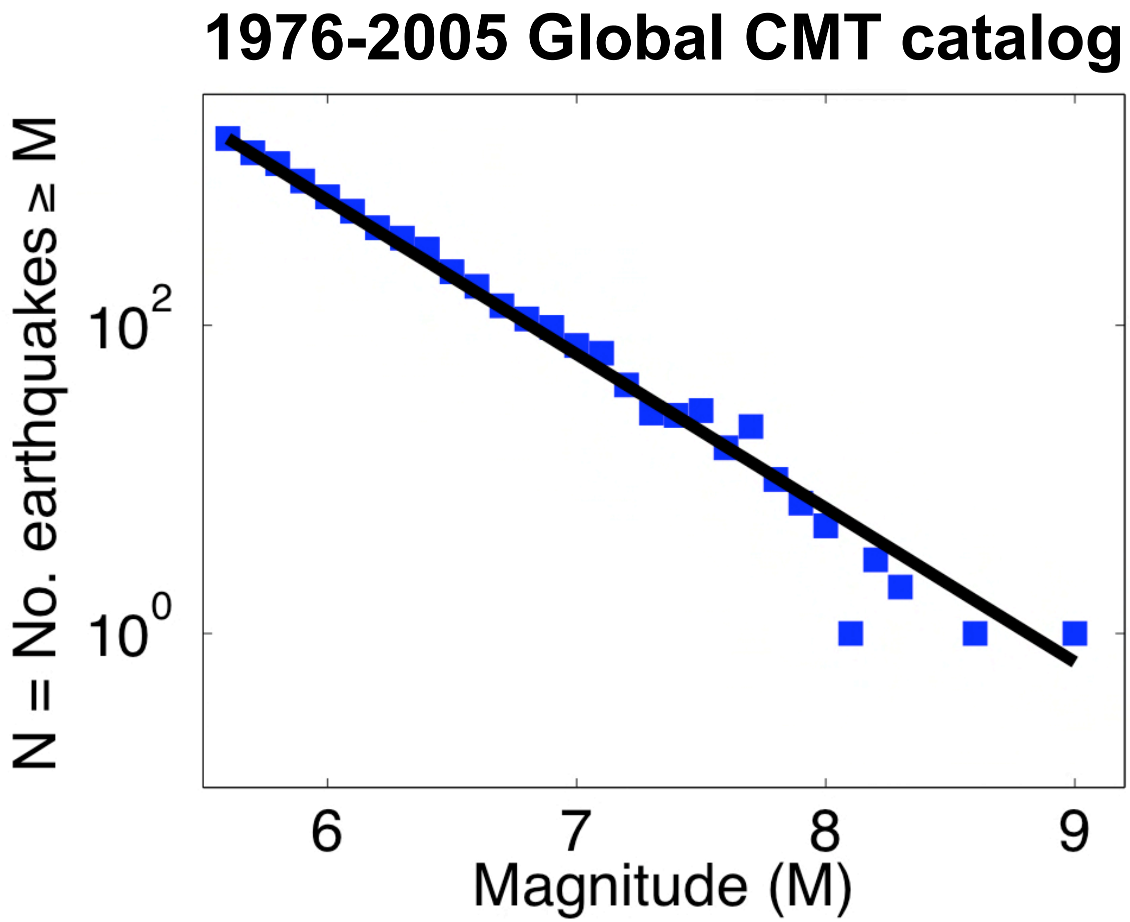
$P(M) = 10^{b(Mmin - M)}$

In the boonies ~

$P(M) = 10^{b(Mmin - M)}$

(relationship applicable until region-specific *Mmax*)

If the magnitudes associated with hypocenters occurring in any random box are sampled for long enough, the distribution will look like:



Why do we care if the GR relationship is universal?

- Big issue in earthquake hazard mapping
- Important implications for physics of earthquake growth, faults, and predictability

Outline

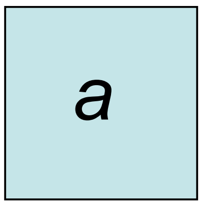
1. A physical hypothesis for where the GR relationship comes from and why it should be universal
2. Traditional arguments for non-universal GR and where they go wrong

Physical hypothesis for the GR relationship

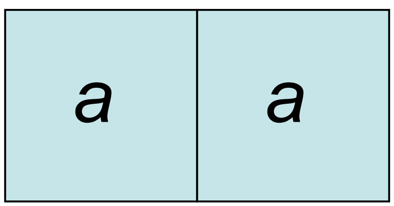
The process of earthquake growth after nucleation may be modeled as a struggle between **pushing forces** (rupture-induced stresses) and **stopping forces** (resistance from the unruptured fault)

We will show: The GR relationship results if the pushing force exerted is linearly proportional to the current rupture area, while the stopping forces remain a constant

Illustration of pushing force ∝ to current faulting area



A rupture that has an area of *a* has a 50% probability of growing to area 2*a*

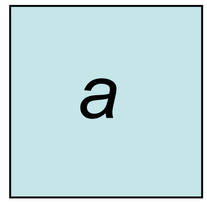


A rupture that has grown to 2*a* has twice as much pushing power, so it has a 50% chance of growing to area 4*a*.

And so on

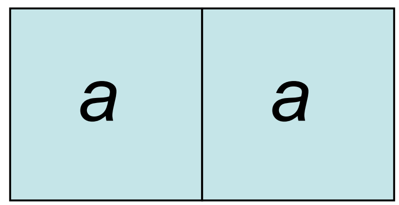
Resulting area-frequency statistics

For every *n* ruptures of area *a*



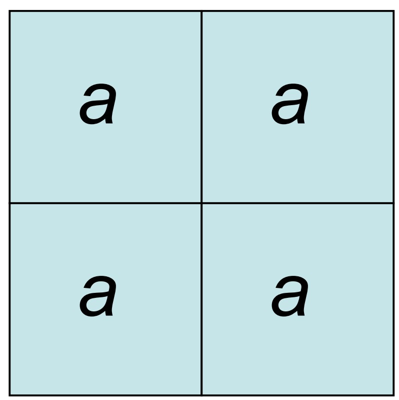
50% of these grow to area 2*a*

=> *n*/2 ruptures of area 2*a*



50% of these grow to area 4*a*

=> *n*/4 ruptures of area 4*a*



In general:

$N \propto 1/A$

A = total area

From N $\propto$ 1/A we follow *Kanamori and Hanks* (1975) to get back to the GR relationship:

(1) $N \propto \frac{1}{A}$

(2) $A \propto 10^{M}$

(3) $N \propto 10^{-M}$

Where (3) is the Gutenberg-Richter relationship with b=1

Analogy: Push from current faulting area <=> Pull from a team of horses

2 horses have a probability P of making it X km

Resistance on carriage from road = constant

At X km, 2 more horses are added. They can now travel 2X km with probability P

How the strength of the horses and the smoothness of the cobblestones affect the results

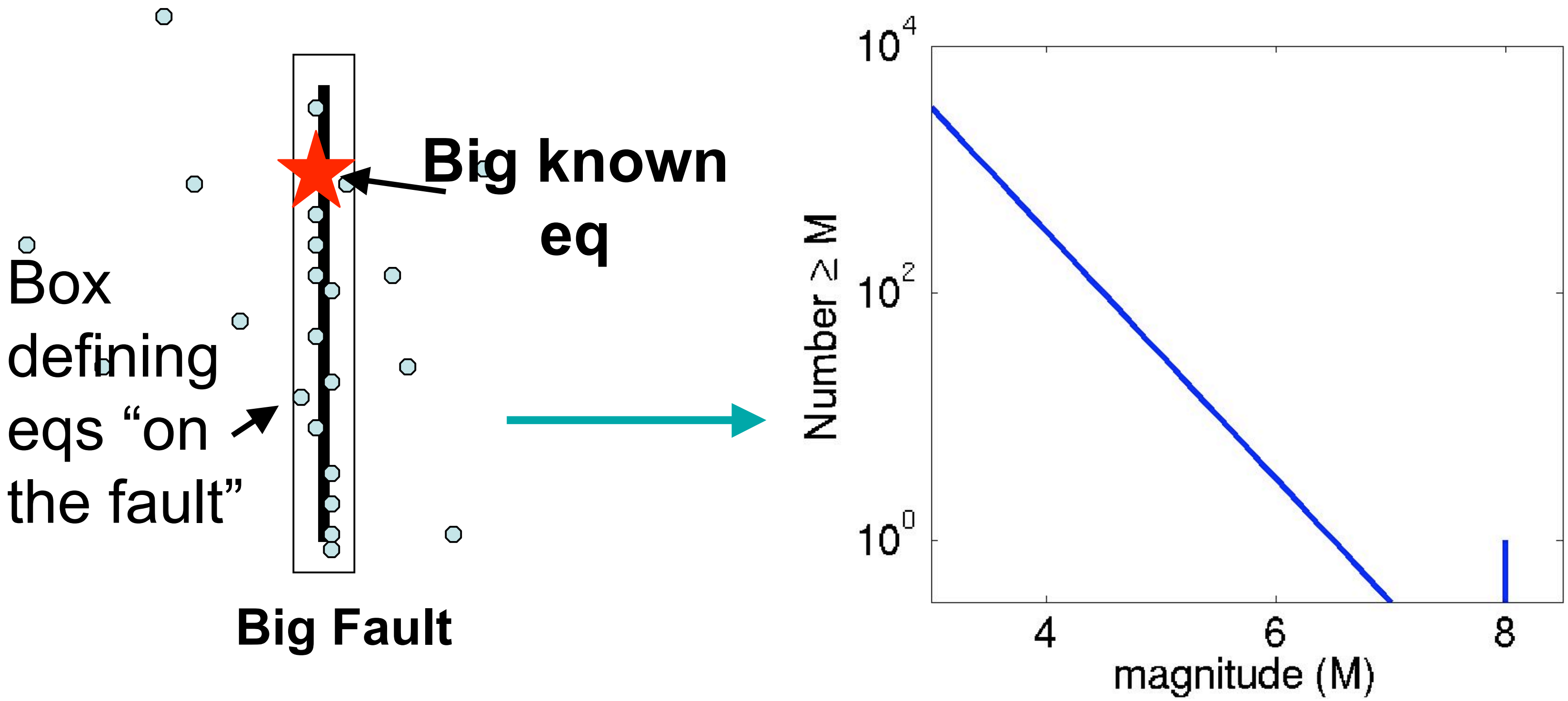
- Smoother cobblestones (**smoother/more developed fault**) does not change the relative distance that 2 vs. 4 horses can cover
- The strength of the horses (**stress on the fault**) does not change the relative distance that the horse teams can cover

=> The GR magnitude distribution is universal -- not affected by variations in physical conditions

Arguments for non-universal GR and their problems

1) The Characteristic Earthquake Model

(*Wesnousky et al.* 1983)

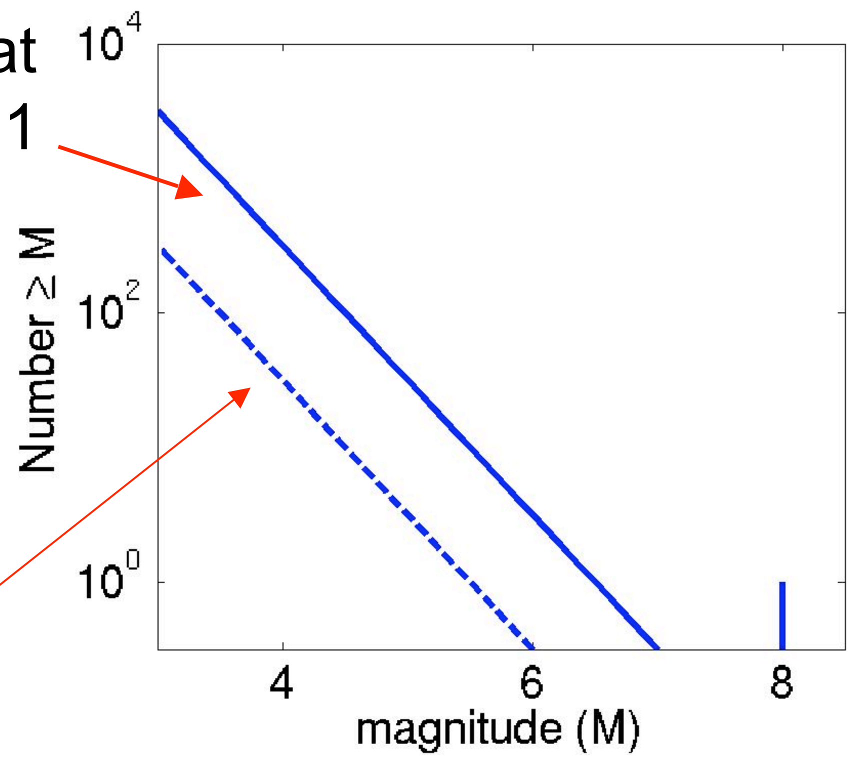


Observation claimed to show that large earthquakes on the fault are more probable than indicated by the GR relationship

Problem: Unknown total length of seismic cycle & long term seismicity rate. If underestimated, the small earthquake count cannot be expected to match

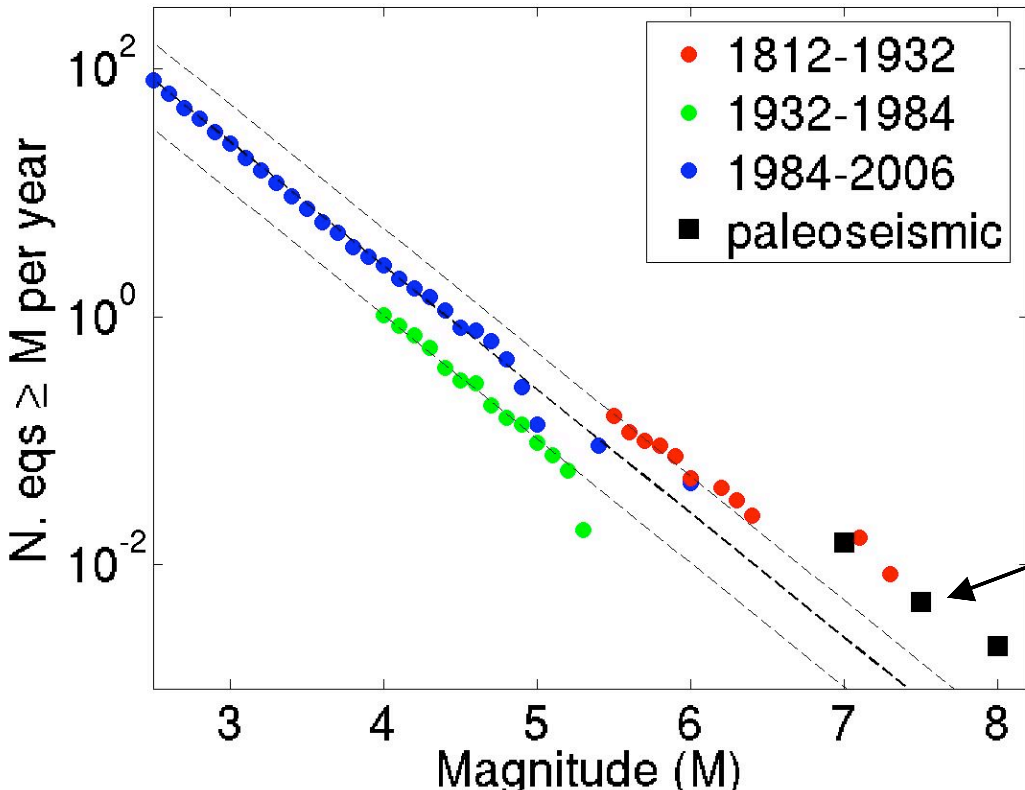
Expected line at time periods < 1 seismic cyle

If current seismictiy rateas are part. low we expect this line



Wesnousky (1994) notes the California record not long enough to prove the Characteristic model

Ray Weldon & I have been trying to compile the longest record possible for the Southern SAF



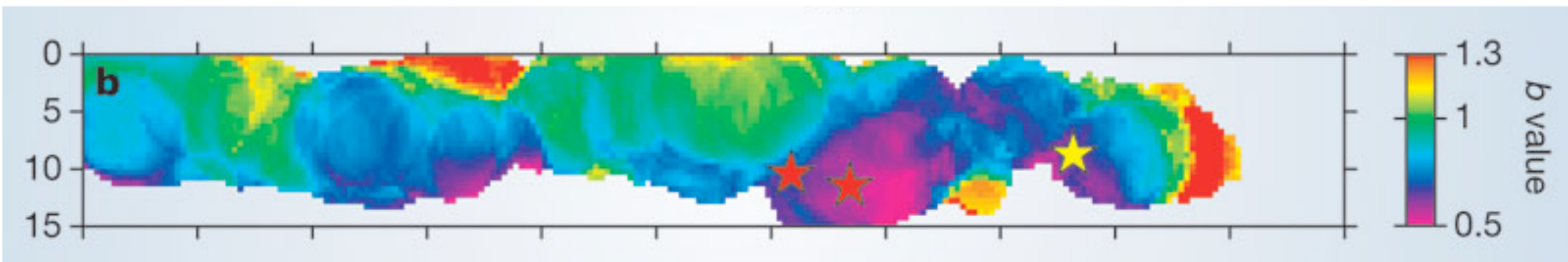
Earthquakes taken from within10 km of the fault

Ray's & Glenn's data points

Different eras show different seismicity rates, but each era internally shows GR stats and agrees with the others within a factor of 2.

2) *b* value varies with location

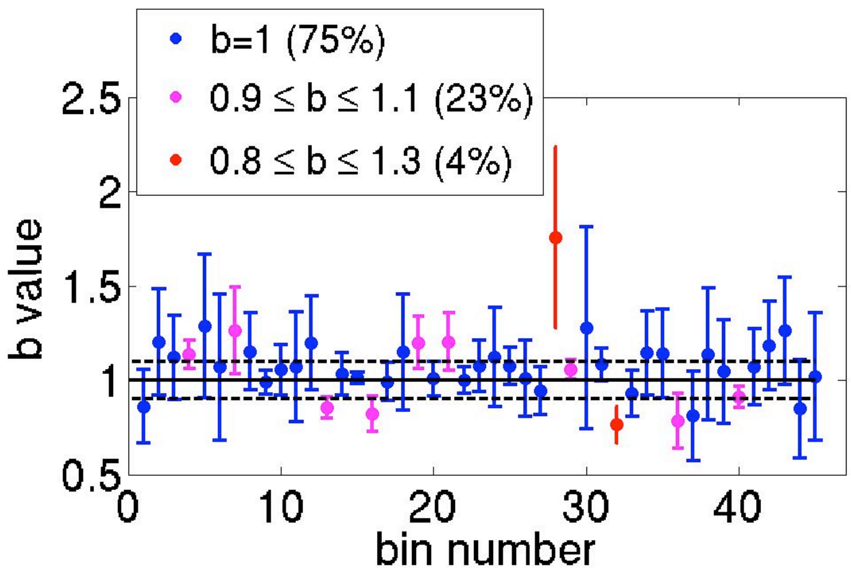
(*Shi and Bolt*, 1982; *Schorlemmer and Wiemer*, 2004…..)



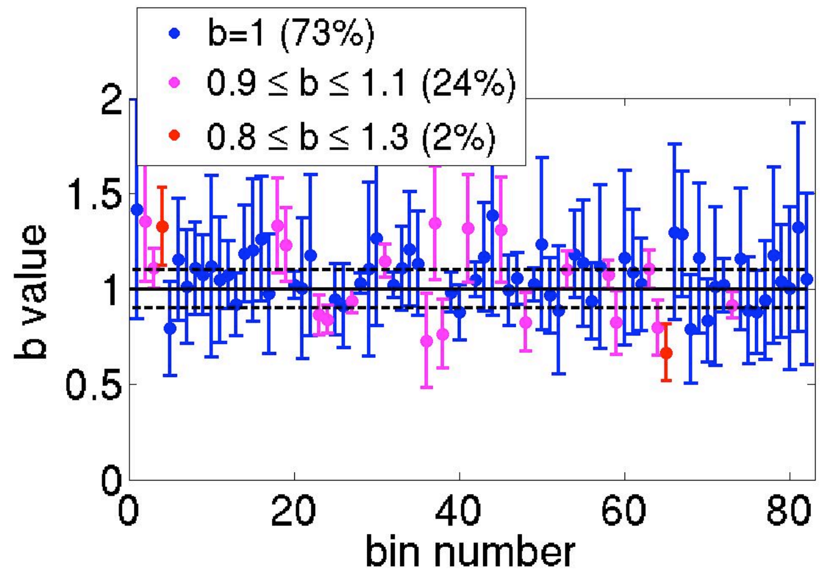
From *Schorlemmer and Wiemer,* (2005)

Problem: *b* value calculations naturally have high errors unless large (>2000 eq) data sets with high magnitude accuracy are used

Dividing California into spatial bins of any size, most *b* values are consistent with *b*=1 (or *b*=0.9 to 1.1) within error



100 by 100 km bins



50 by 50 km bins

Conclusions

- A simple model in which earthquake growth potential ∝ current faulting area while resistance remains constant => universal GR relationship
- All data available for the Southern SAF indicates a GR magnitude distribution
- *b* value variations seen in CA are in a narrow range when error is taken into account, supporting GR and *b* value universality