The Evolution of Regional Seismicity Between Large Earthquakes

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From Sykes and Jaumé [1990]
All California Earthquakes $M \geq 6.5$
1950-1995

From Bowman et al., J GR, 1998
Stress Change From Loading a Locked Patch on a Simple Fault

Calculate from motion on all adjacent faults plus creep at depth
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Calculate from motion on all adjacent faults plus creep at depth
Where are pre-earthquake stresses?

Future Earthquake

Creep at Depth

Negative Slip
Accelerating Seismicity in Stress Accumulation Regions
From Bowman and King, GRL, 2001
A Simple Numerical Model

• Based on loading of fault in interseismic period
• Using realistic stress transfer
• Taking into account tectonic history
• Want to produce accelerating moment release over a broad region
Seismogenic zone

Failure stress

Failure stress

Failure stress

Failure stress

Stress relative to failure stress (bars)

Stress drop

Beginning of the earthquake cycle (immediately after large event)

33% of the earthquake cycle

66% of the earthquake cycle

Immediately before the next earthquake

Immediately after the earthquake
An earthquake occurs when stress rises above the failure level.
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An earthquake occurs when stress rises above the failure level.
Seismicity in the Earthquake Cycle

- Start of the Earthquake Cycle
- Approaching the Earthquake
- Immediately before the Earthquake
- Immediately after the Earthquake
- 75% of the Earthquake
- The end of the Earthquake cycle

Aftershocks
Stress shadows
Implications of Regional Stress Accumulation Model
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• Off-fault aftershocks occur in regions of elevated static stress change due to the earthquake
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• Evolution of the frequency-magnitude statistics (Gutenberg-Richter relation)
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  - Stationary (time-independent) $b$-value
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- Evolution of the frequency-magnitude statistics (Gutenberg-Richter relation)
  - Stationary (time-independent) $b$-value
  - $a$-value increase before a large event and decreases after the event
Build-up to the Earthquake

Main Fault is Quiet

Late in the Earthquake cycle

Immediately before the earthquake

Immediately after the earthquake
California Seismicity 1912-2001 M>3.5
Build-up to the Earthquake

Accelerating Moment Release

Late in the Earthquake cycle

Immediately before the earthquake

Immediately after the earthquake
Which cumulative moment release curve is for a REAL seismicity sequence?
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Model

San Fernando Earthquake
Accelerating Seismicity

**Observed**

- **Superstition Hills**
  - Cumulative Bifurcation Strain x 10^7 vs. Year (1982-1988)

- **San Fernando**
  - Cumulative Bifurcation Strain x 10^7 vs. Year (1967-1971)

- **Landers**
  - Cumulative Bifurcation Strain x 10^7 vs. Year (1970-1995)

**Model**

- Cumulative Bifurcation Strain x 10^7 vs. Time (1982-2022)
  - Time: 10, 12, 14, 16, 20, 22

- Cumulative Bifurcation Strain x 10^7 vs. Time (5-25)
  - Time: 5, 10, 15, 20, 25

Graphs show the comparison between observed and modeled cumulative bifurcation strain over time.
Build-up to the Earthquake
Evolution of Gutenberg-Richter Statistics

Late in the Earthquake cycle
Immediately before the earthquake
Immediately after the earthquake
Seismicity in the Pacific Northwest

Two large nearby events show accelerating moment release.

The regions overlap, approximating the evolution of the seismicity over 2.5 cycles.
Pacific Northwest Seismicity

Number of events greater than Magnitude 2.5

Maximum Magnitude

b-value

Earthquakes

Seismicity in the model & Pacific Northwest

Number of events greater than Magnitude 2.5

Maximum Magnitude

b-value

Earthquakes

Cumulative Benioff Strain

Pacific Northwest

Model

Cumulative Benioff Strain $\times 10^7$

Date


Cumulative Benioff Strain $\times 10^7$

Time

0  1  2  3

Earthquake
Evolution of the frequency-magnitude statistics
Evolution of the frequency-magnitude statistics

2 earthquakes → Pacific Northwest region

2 earthquakes → The model
Looking Forward:

• Better calculation of the “noise” functions
  - incorporate stress transfer for background EQs?

• More complex fault geometries
  - simulate real fault networks

• Additional Testing on real data
  - Test on earthquakes from other regions
    (Greece, Turkey, China, etc)
  - False alarm rate?

• Relationship to Time-Dependent Hazard Analysis

Pre/re-prints available at:
http://geology.fullerton.edu/faculty/dbowman
Future California Earthquakes?
Future California Earthquakes?
Future California Earthquakes?

No?
Future California Earthquakes?

No?
Future California Earthquakes?

No?

Yes?
The Seismic Cycle

From Ellsworth [1981]
Creating a Synthetic Catalog

Magnitude of the event depends on the size of the stress concentration.

This allows the calculation of the Frequency-Magnitude relation.
Stress and Seismicity Through the Seismic Cycle

Immediately after the earthquake

25% of the cycle

50% of the cycle

75% of the cycle

Immediately before the earthquake
Evolution of Gutenberg-Richter Scaling Before the 1987 Superstition Hills Earthquake
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![Graph showing earthquake rate vs magnitude before the 1987 Superstition Hills Earthquake. The graph illustrates the scaling relationship between earthquake magnitude and the logarithm of the number of earthquakes per year.]
Evolution of Gutenberg-Richter Scaling Before the 1987 Superstition Hills Earthquake
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![Graph showing earthquake rate vs magnitude before the 1987 Superstition Hills Earthquake.](image)
Evolution of Gutenberg-Richter Scaling Before the 1987 Superstition Hills Earthquake
Static stress (Coulomb) changes during the earthquake cycle.
Current Stress Field = Stress Field From Previous History of EQs + Stress Field From Loading
Characteristics of the Background Stress Field
(for a simple model)
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• Stress must be low along the strike of the fault (or rupture would continue)
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- Stress distant from the fault must approach, but not exceed, the failure stress
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- Coulomb field + background field cannot exceed the failure stress (except locally)
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- Positive Coulomb stresses must have a corresponding negative value in the background field
Stress Change vs. Stress Through the Earthquake Cycle

Stress Change

Tectonic Memory Stress

Stress Level Relative to the Failure Stress