

# The Mechanics of Earthquakes and Volcanoes

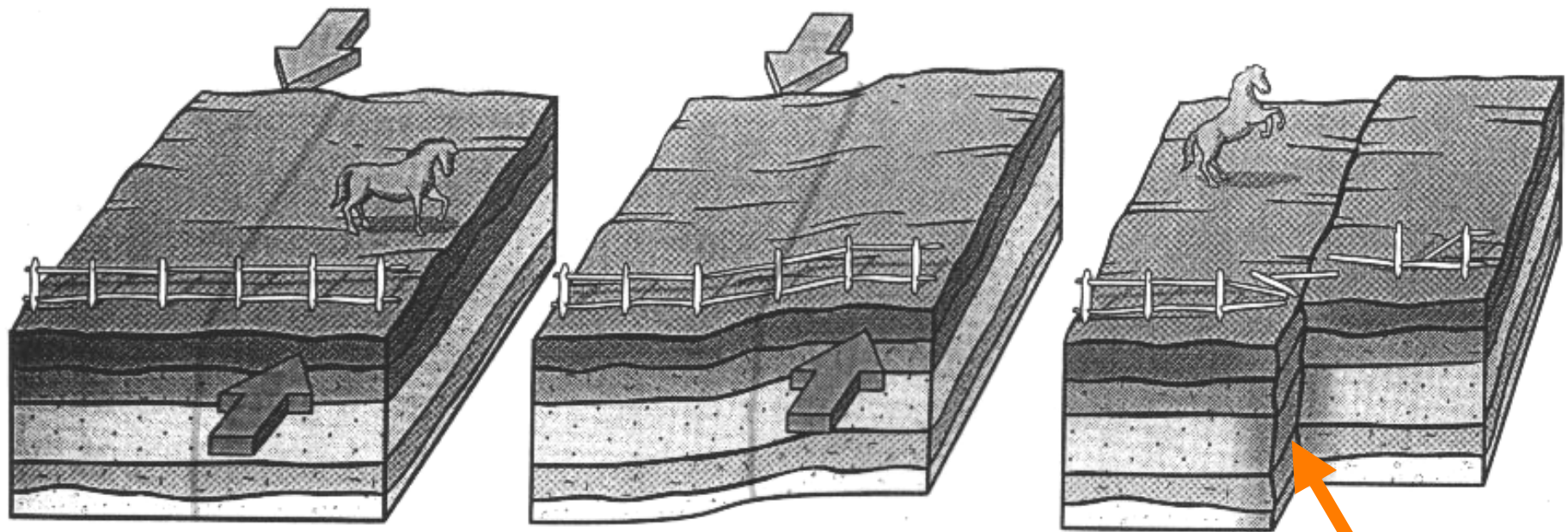
How do they start, keep going and  
stop?

Emily E. Brodsky  
University of California,  
Santa Cruz



# How do earthquakes start?

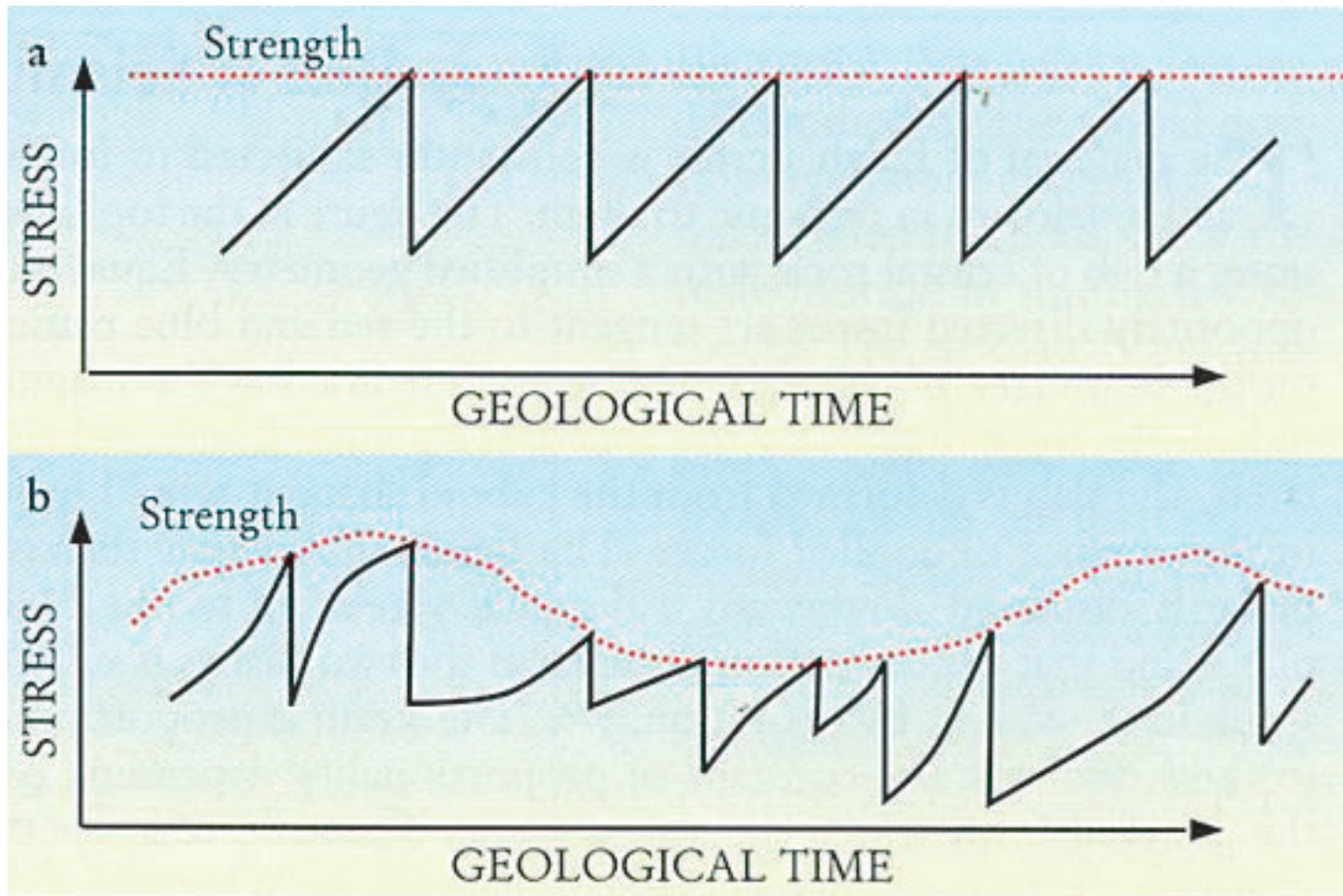
- Before                      Loading                      After quake



**By overcoming static friction**

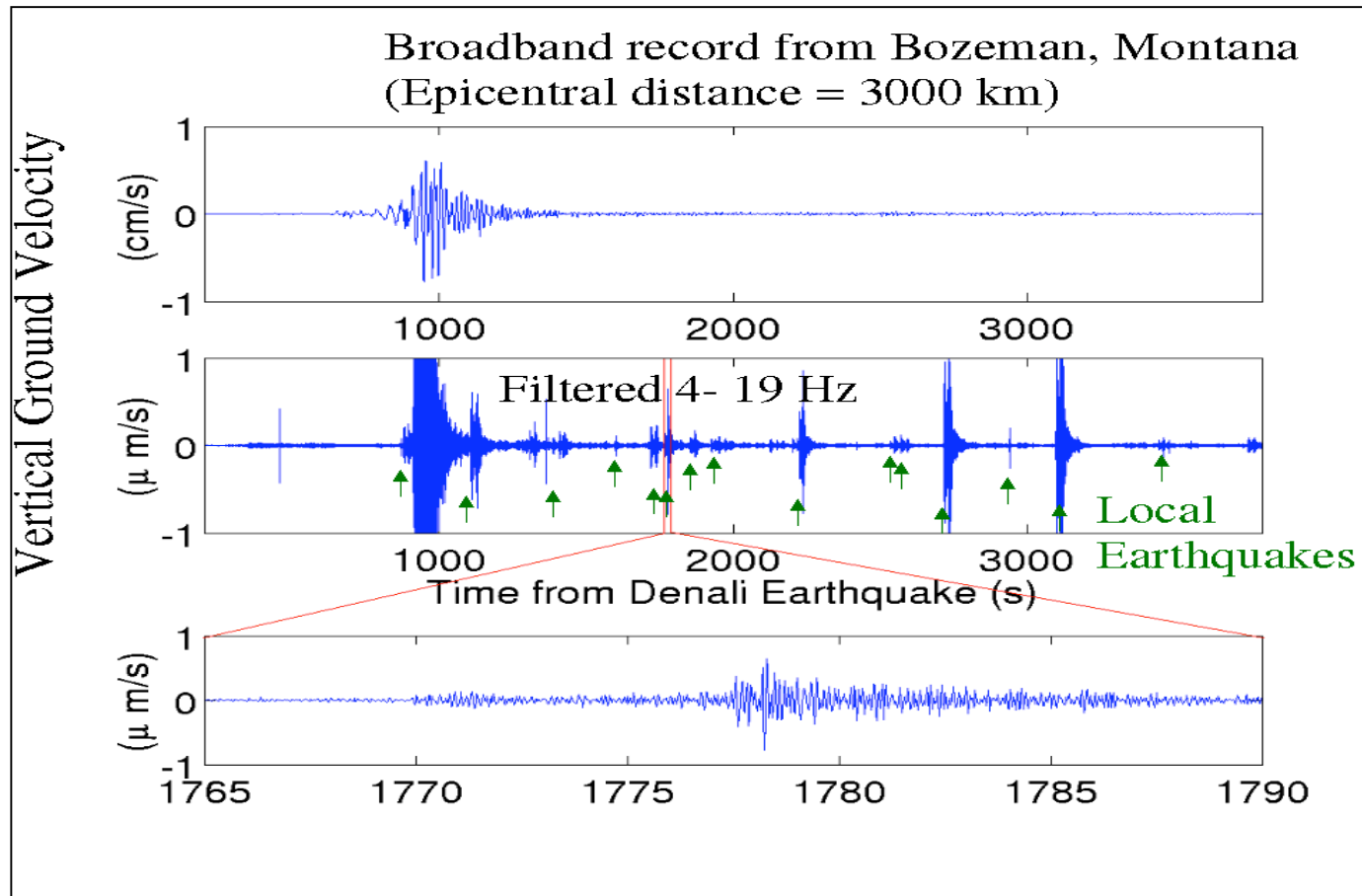
Fault

# What is strength and stress at failure?



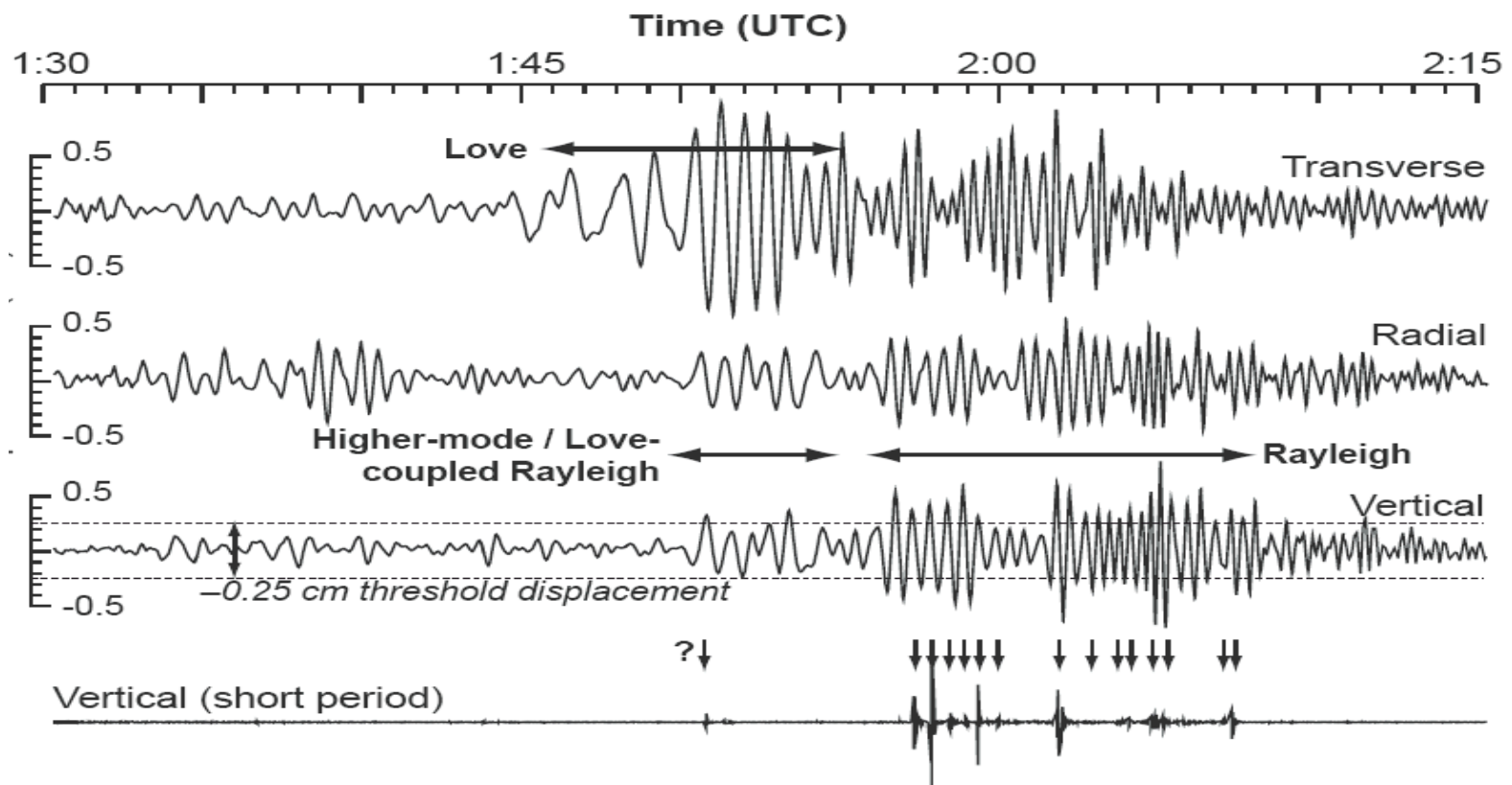
# A window into failure: triggering

## 2002 Mw 7.9 Denali Earthquake





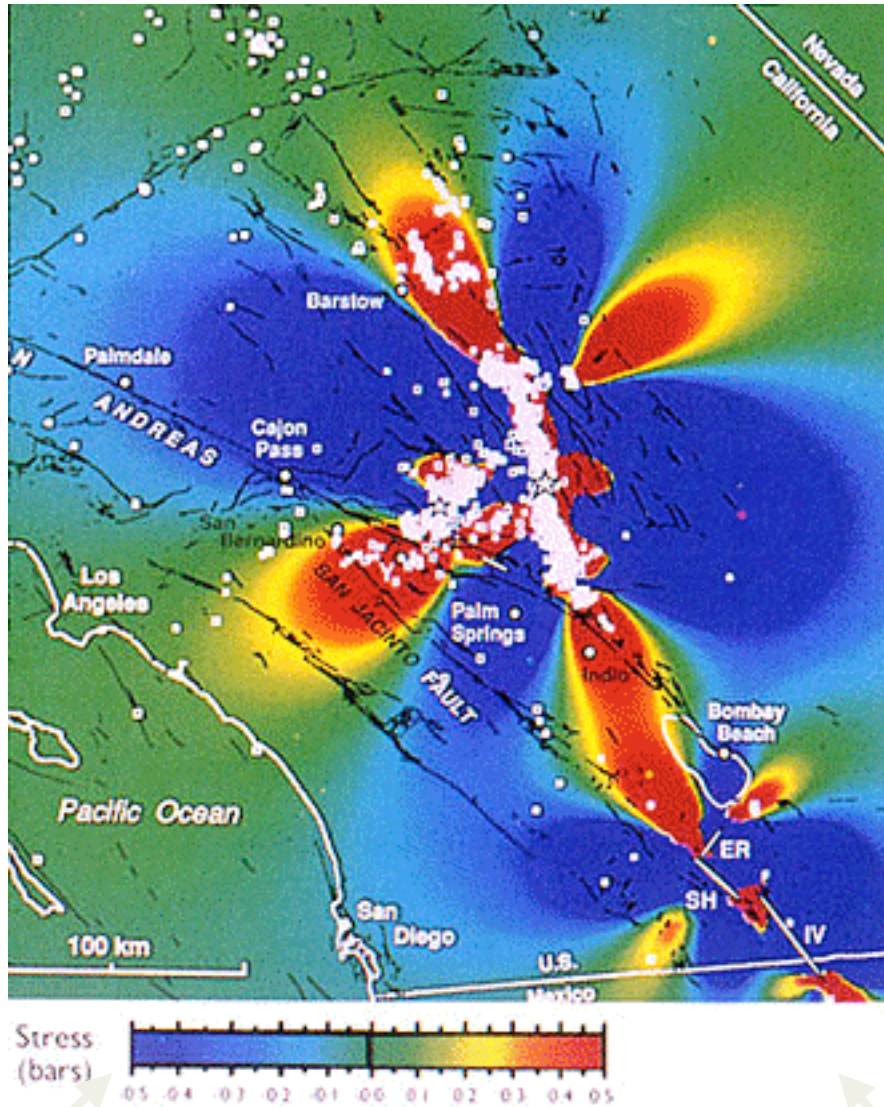
# Synchronized triggered earthquakes



West et al., *Science*, 2005

Stein et al., *Science*, 1992

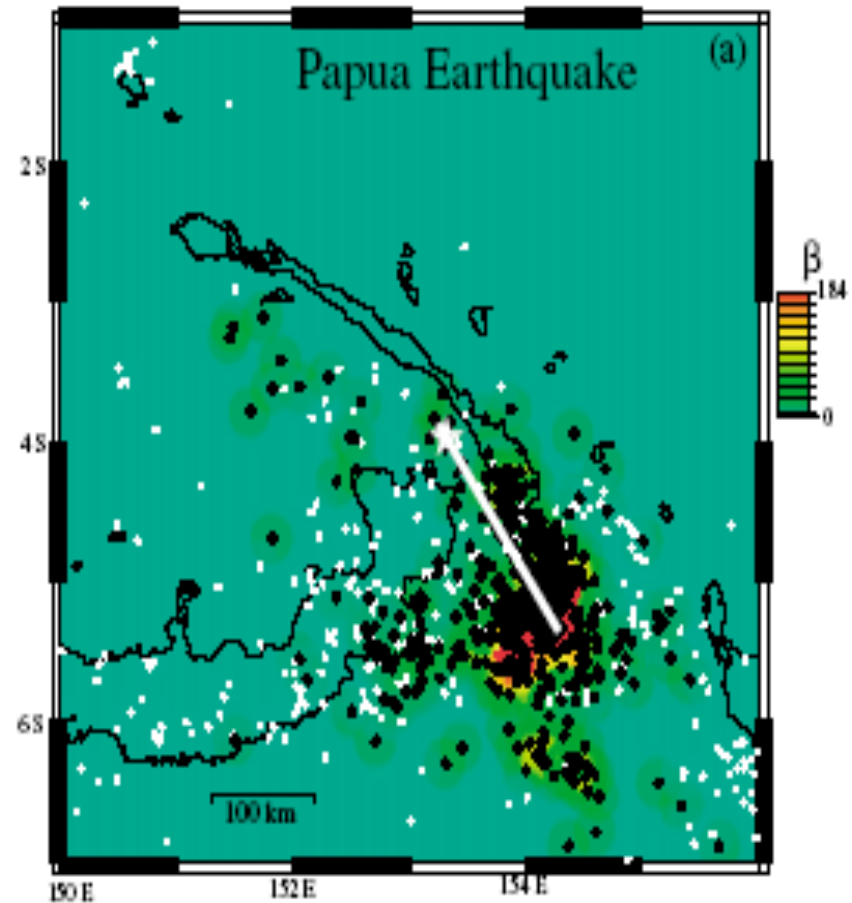
Post-Landers Earthquake



stress  
lowered

stress  
raised

## Nearfield Triggering: Static and/or Dynamic



Gomberg et al., 2003

# How do earthquake continue (become big)?

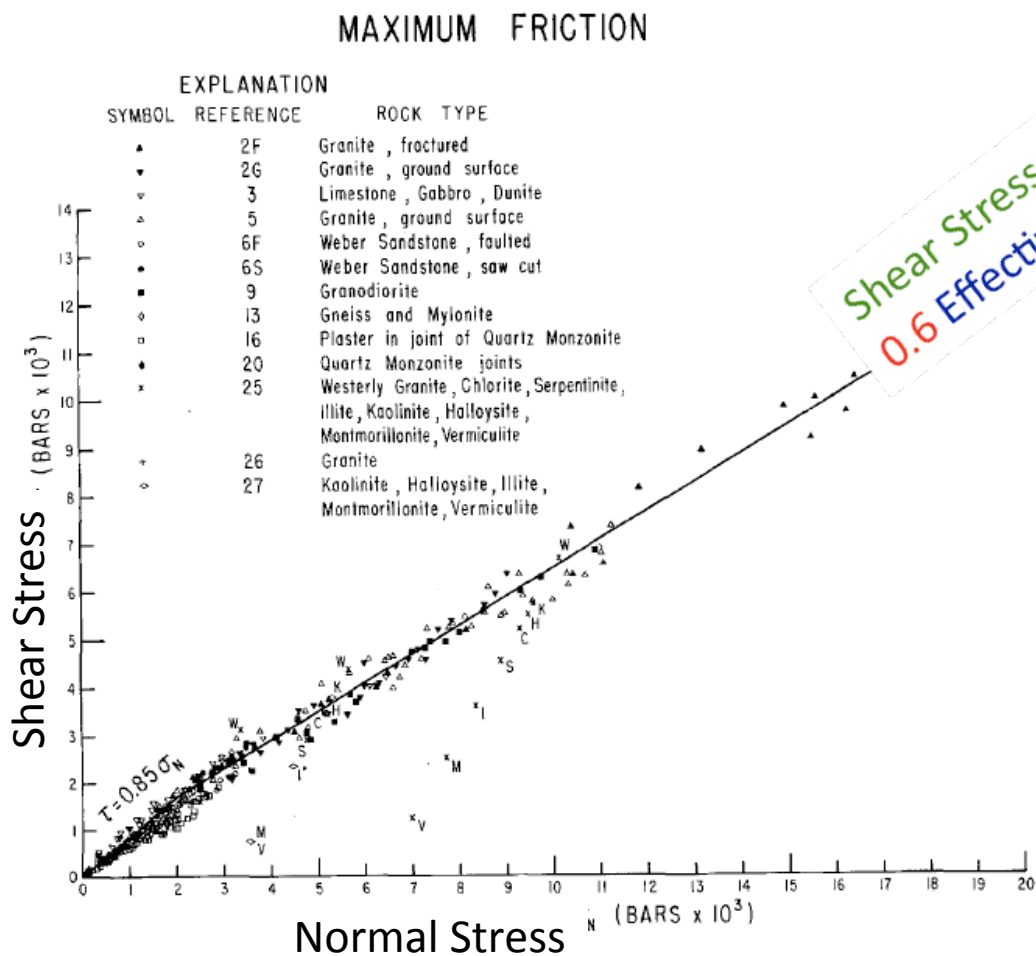


**By dynamics  
overcoming friction**

Movie of Sumatra earthquake from  
Ishii et al., 2005

# What do we know about friction?

- Coulomb friction of solid rocks



Shear Stress =

0.6 Effective Normal Stress + 0.5 kBar

Coefficient of friction

$$\tau = \mu \sigma_n + C$$

Frictional shear stress

Effective normal stress = normal stress – pore pressure

Cohesion

Byerlee, *Pure and Applied Geoph*, 1978

# Reasons to think that Byerlee's Law is Problematic for an Earthquake

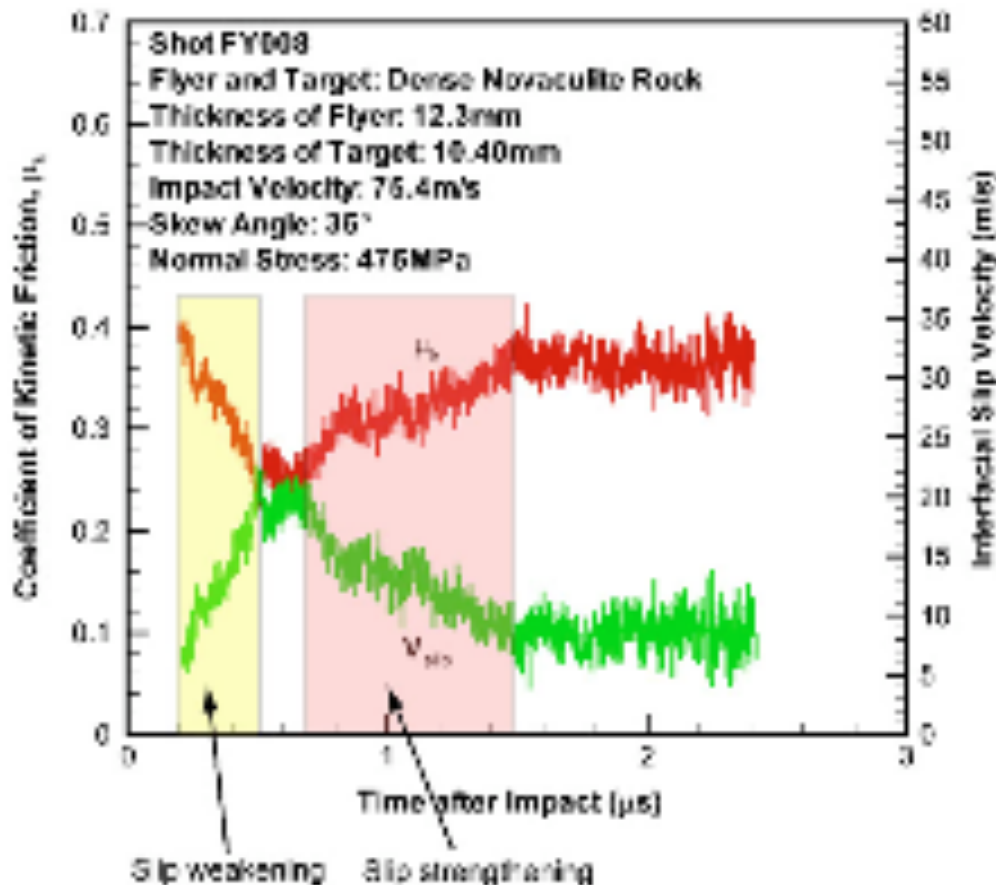
## 1. Geological Evidence: Faults are Complex





# Reasons to think that Byerlee's Law is Problematic for an Earthquake

## 2. Laboratory Experiments: High-Speed Friction is Low



Gas gun experiments indicate  $\mu = 0.2$ - $0.4$  for coseismic friction

# Reasons to think that Byerlee's Law is Problematic for an Earthquake

## 3. Theoretical: High-Speed Frictional Mechanisms

- Melting (Fialko, 2005)
- Silica Gel (Di Toro et al., 2004)
- Flash heating (Rice, 2006)
- Thermal Pressurization (Andrews, 2002)
- Elastohydrodynamic lubrication (Brodsky and Kanamori, 2001)
- Acoustic fluidization (Melosh, 1979)

# How to measure friction



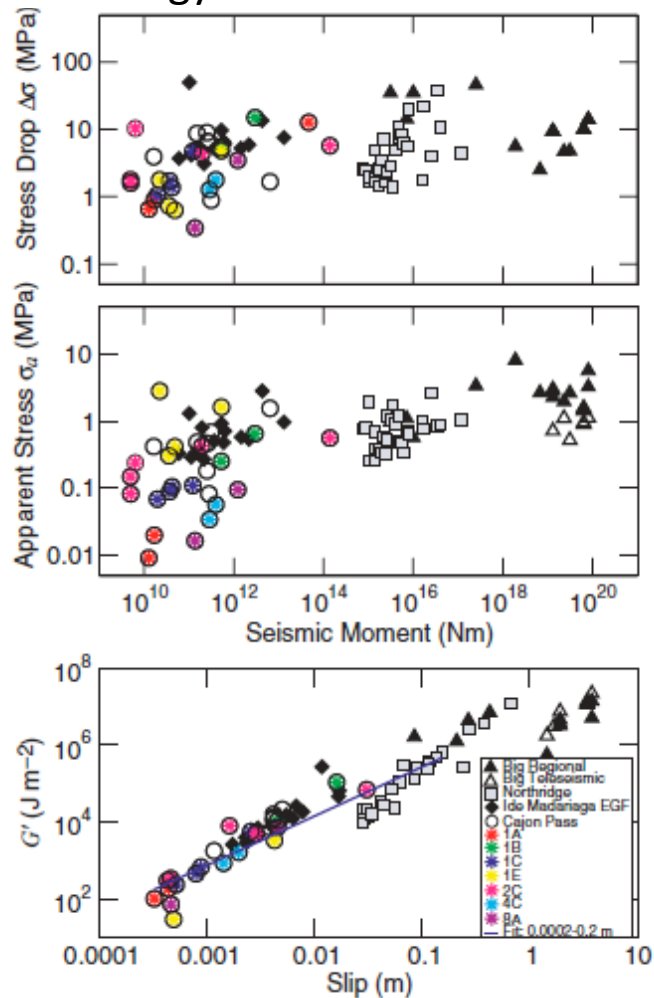
NOT directly by seismology alone....

– Seismologists can measure:

- Seismic moment = Shear modulus x Area x Slip
- Radiated energy
- Stress CHANGE
  
- NOT FRICTION DIRECTLY

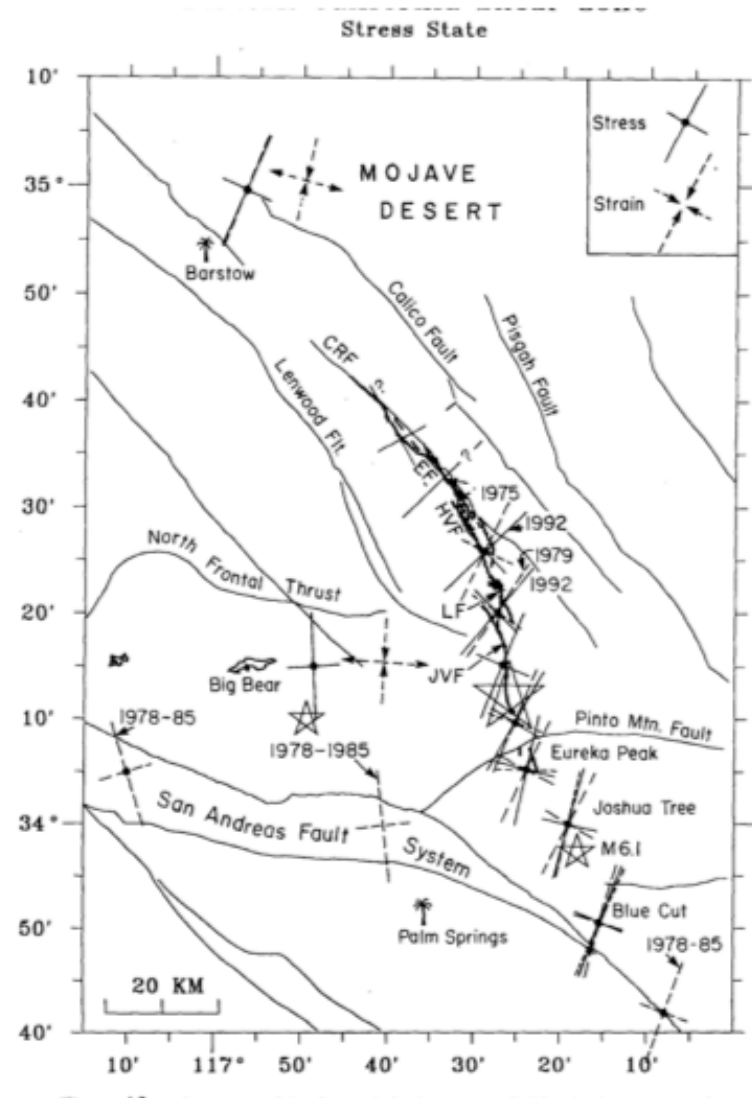
# Seismologists' Attempt to Measure Resisting Stress

Earthquake Scaling  
and Energy Balance



Stress rotation  
- Temporally  
- Spatially

Abercrombie and Rice, *GJI*, 2005

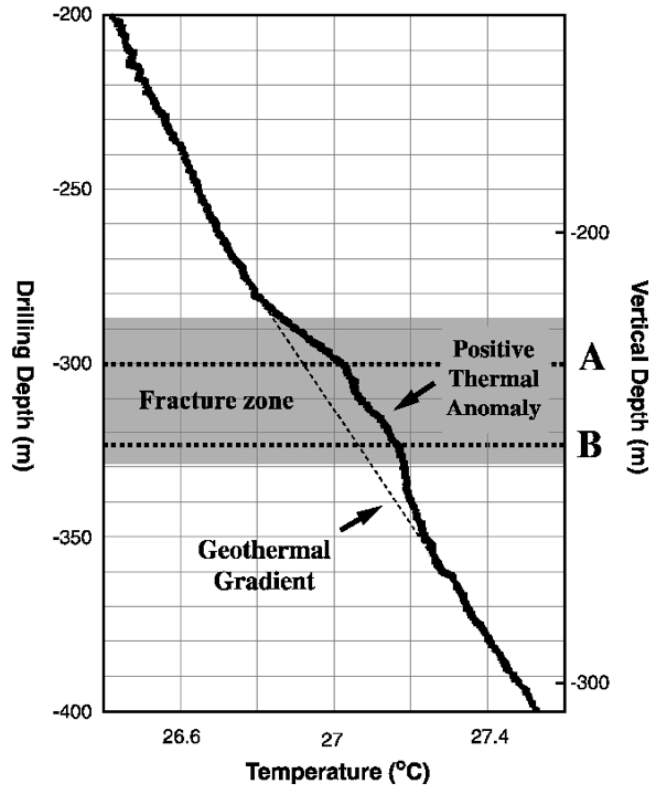


Hauksson, *BSSA*, 1994

# Other methods to measure friction

Temperature just after an earthquake

15 months at 300 m



Tanaka et al., *Geophys. Res. Let.*, 2006

Geological indicators

Pseudotachylytes

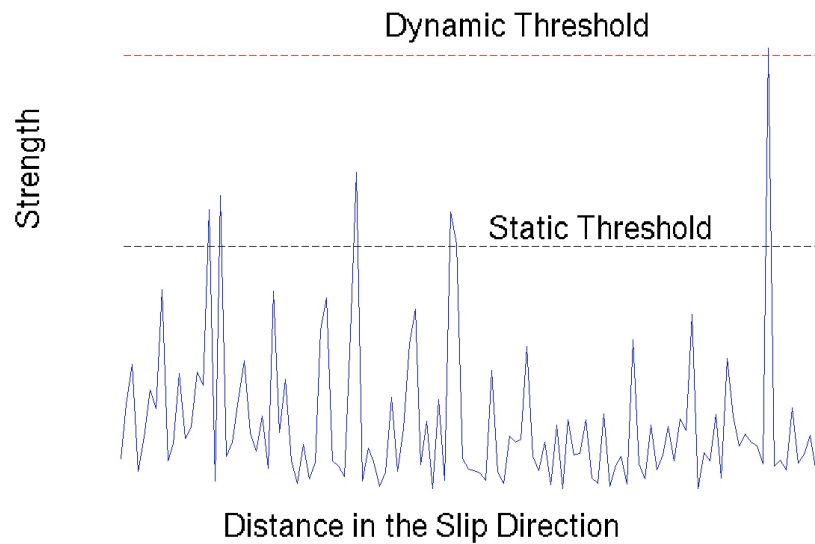


Rowe et al., *Geology*, 2005



**How do earthquakes stop?**

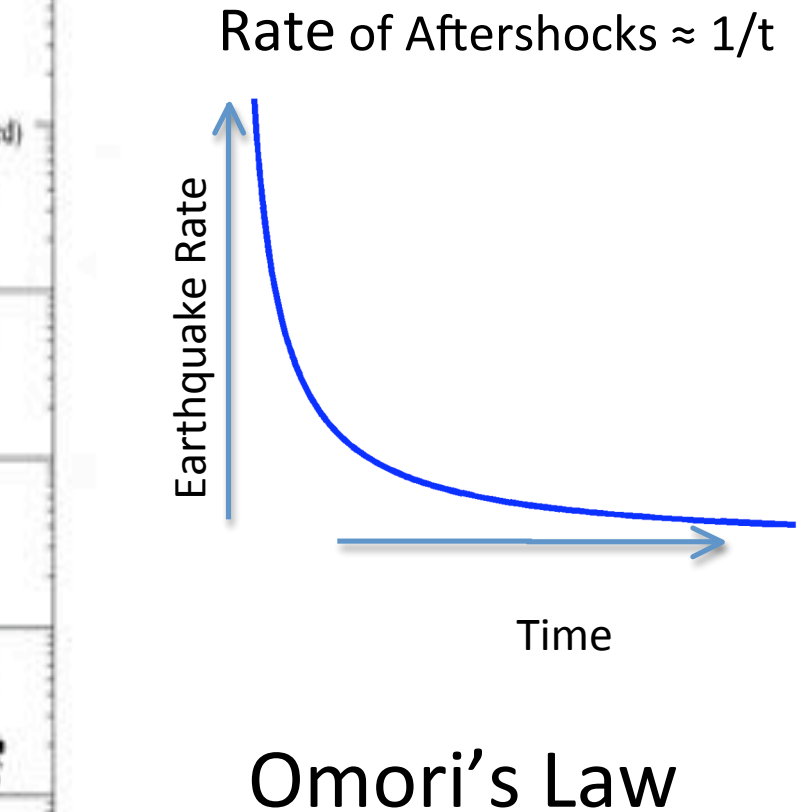
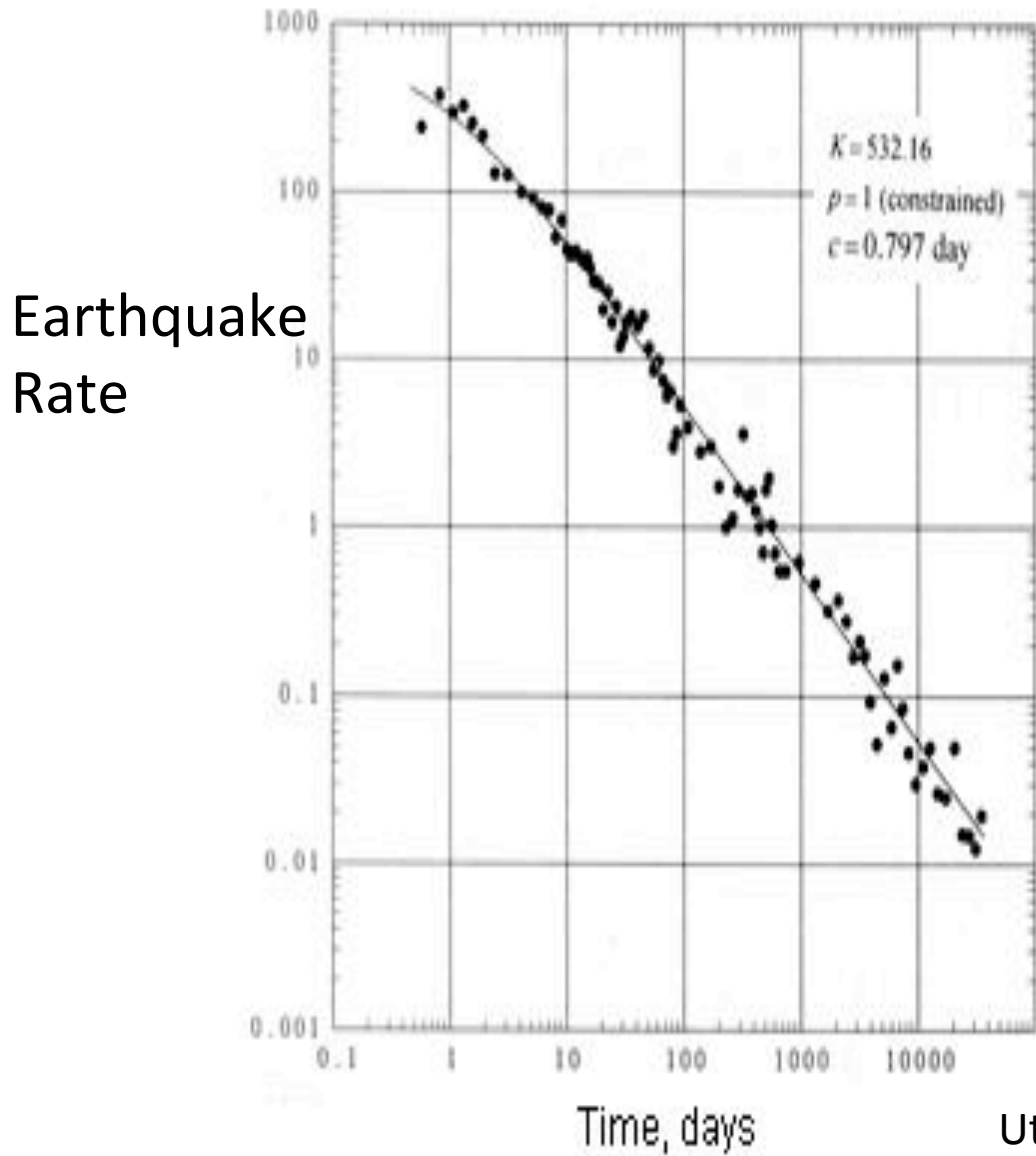
# Individual earthquakes: Bumps



Western Fucino Basin,  
Italy

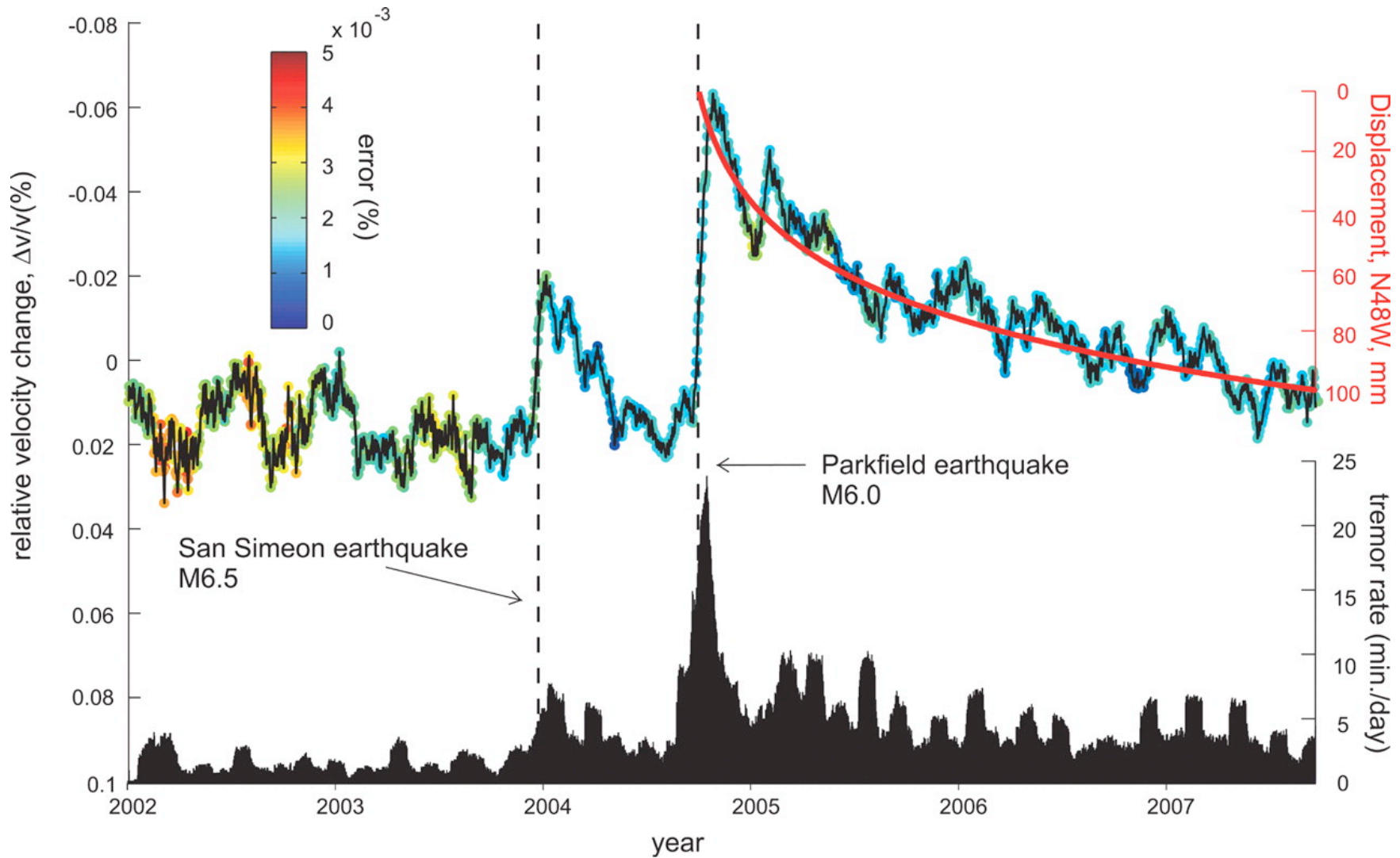


# Populations of earthquakes stopping



Utsu (2002)

# Healing?





# Volcanoes

## To Begin:

What are the physical differences between intrusions and eruptions?

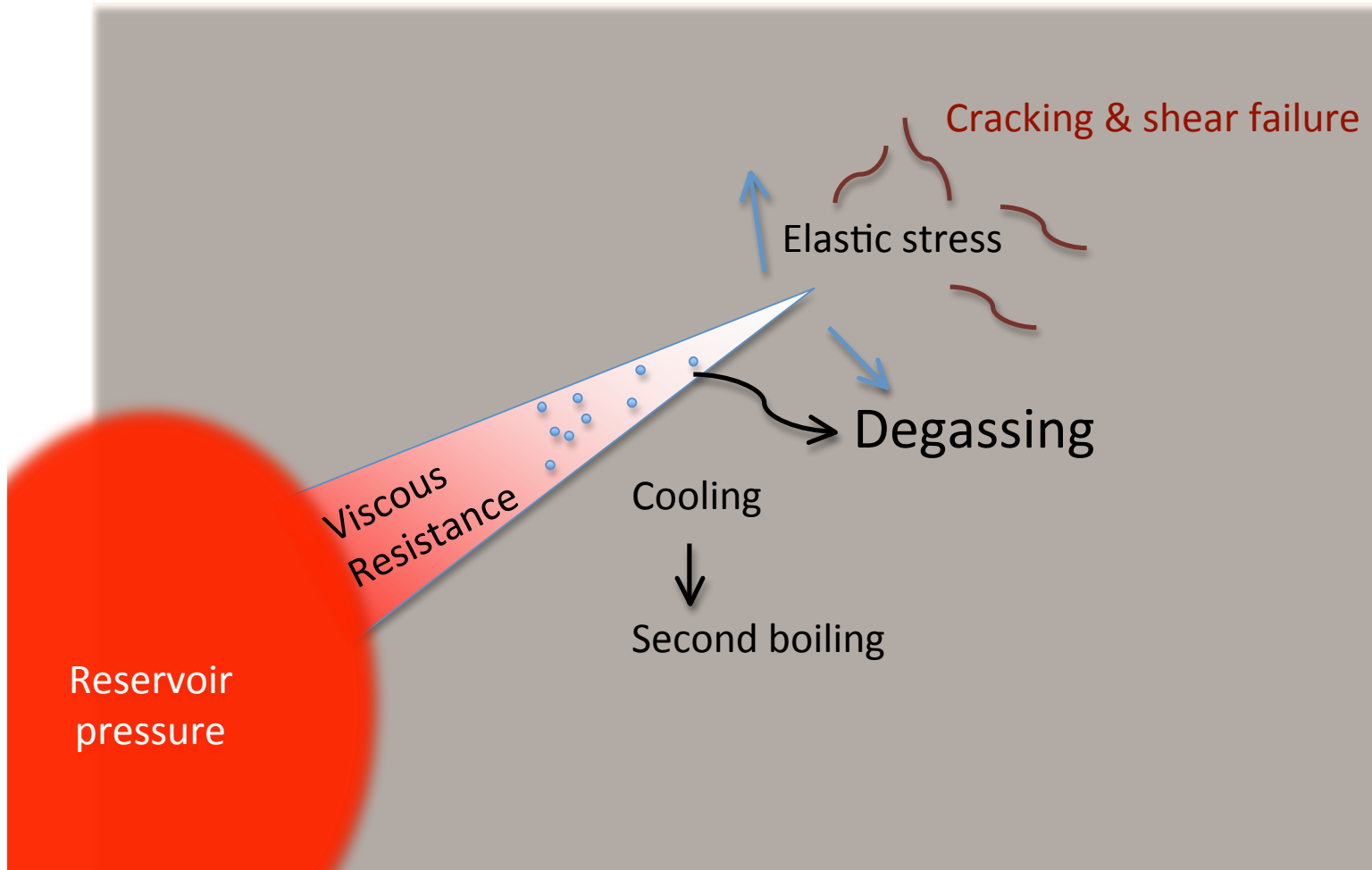
- Corollary: What are the observable differences?





# Diking

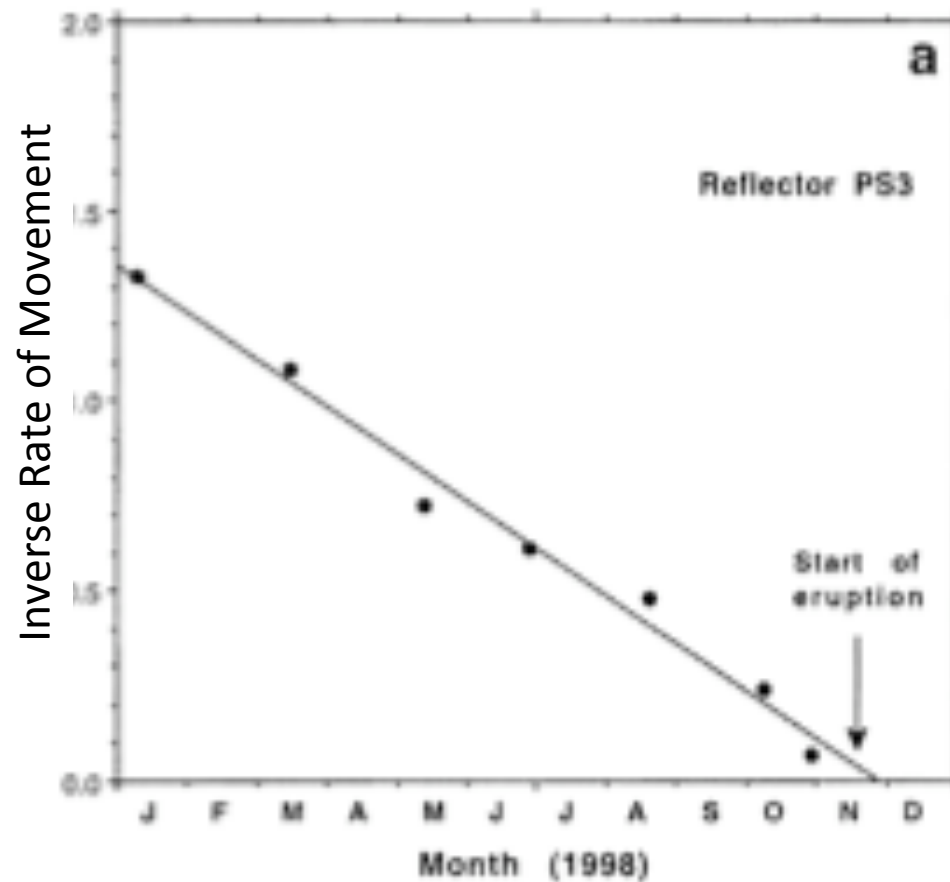
Magma Pressure at Tip  $\geq$   
Rock Strength



Very similar  
to hydrothermal  
activity except  
....  
Seismic velocity  
Temperature  
Density

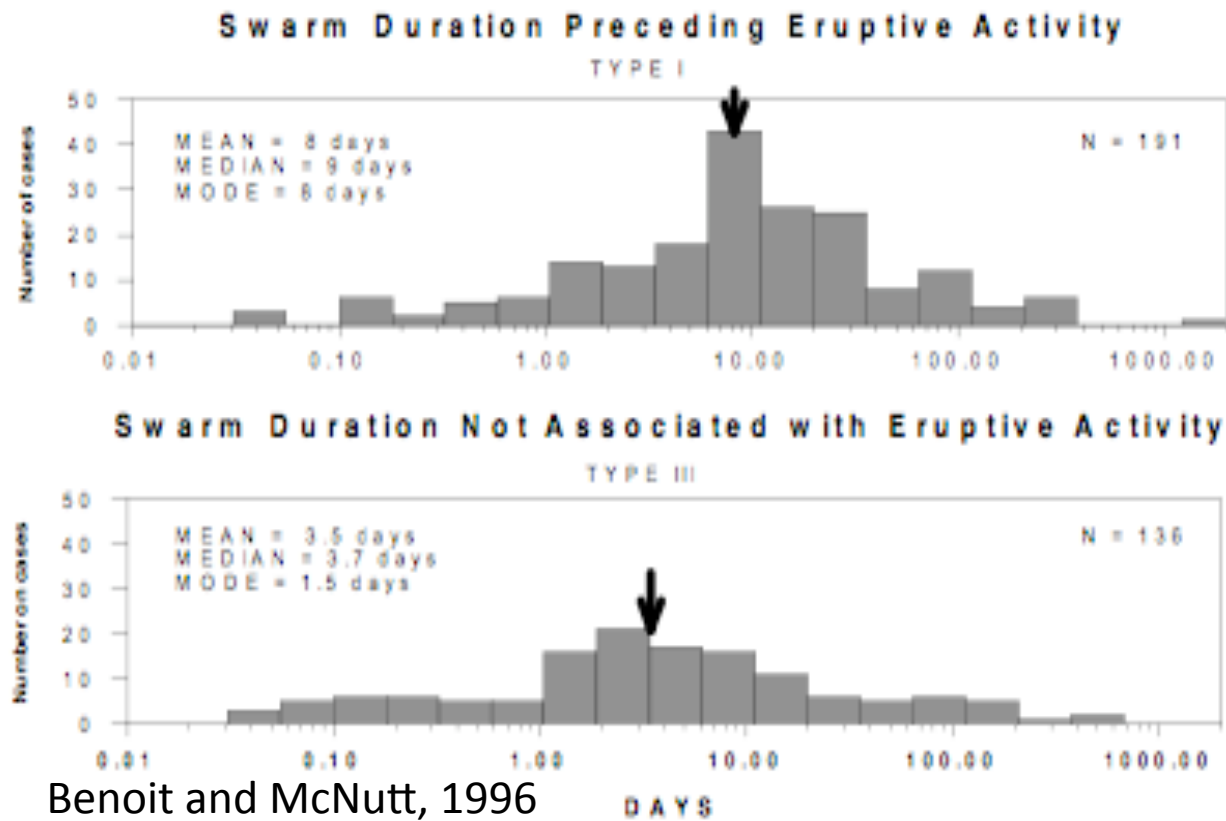
# Acceleration to failure

- Colima 1998 - Geodesy



Murray and Ramirez-Ruiz, *JVGR*, 2002

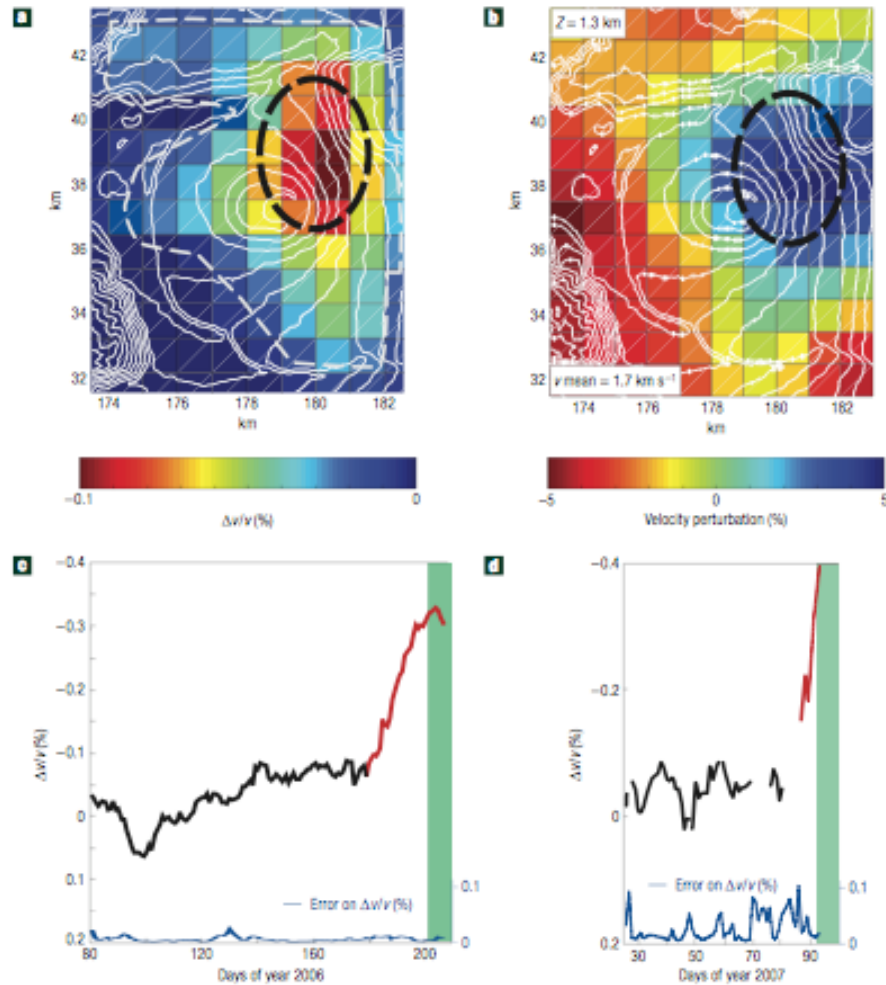
# Earthquake swarm characteristics



Benoit and McNutt, 1996

# Time Dependent Seismology

5 days prior to an eruption

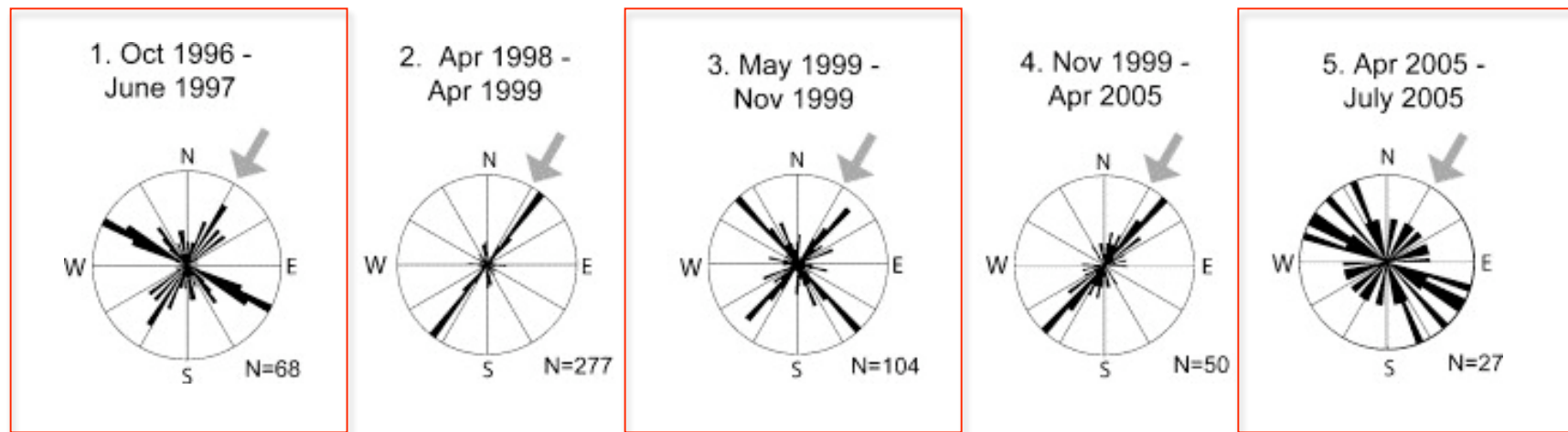


Piton de la Fournaise

Brenguier et al., *Nature Geoscience*, 2008

# Intrusions and eruptions

## Stress Field



Soufriere Hills, Montserrat

Roman et al., 2006



## **To Continue:**

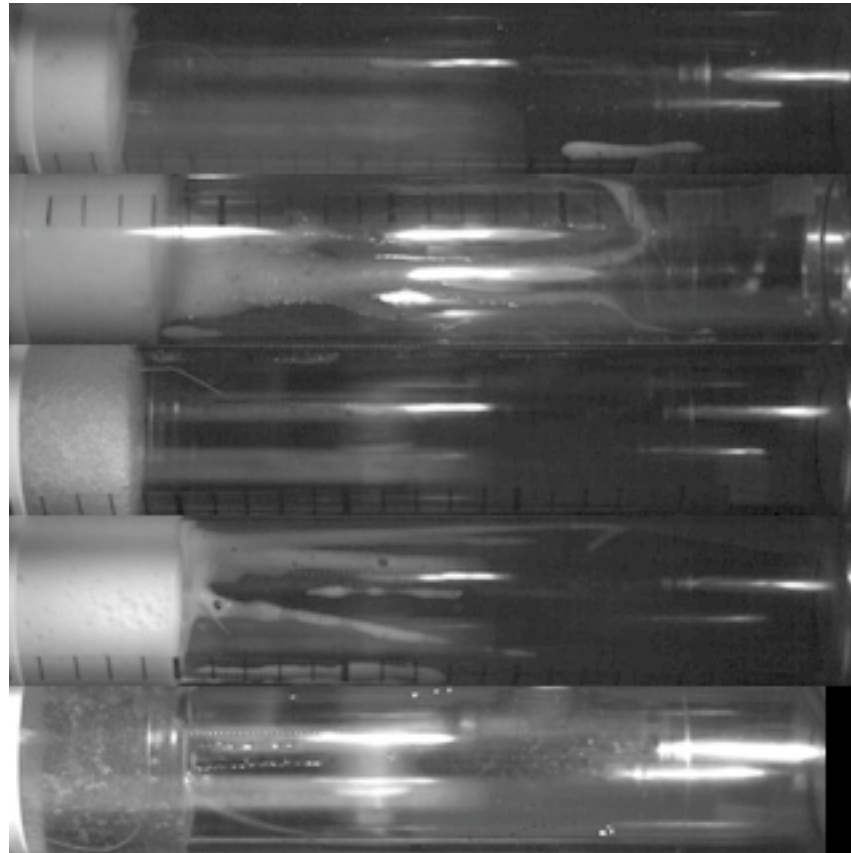
What are the physical/observable differences between explosive/effusive eruptions?

# Decompression rate and fragmentation in a viscoelastic fluid

Decompression Rate

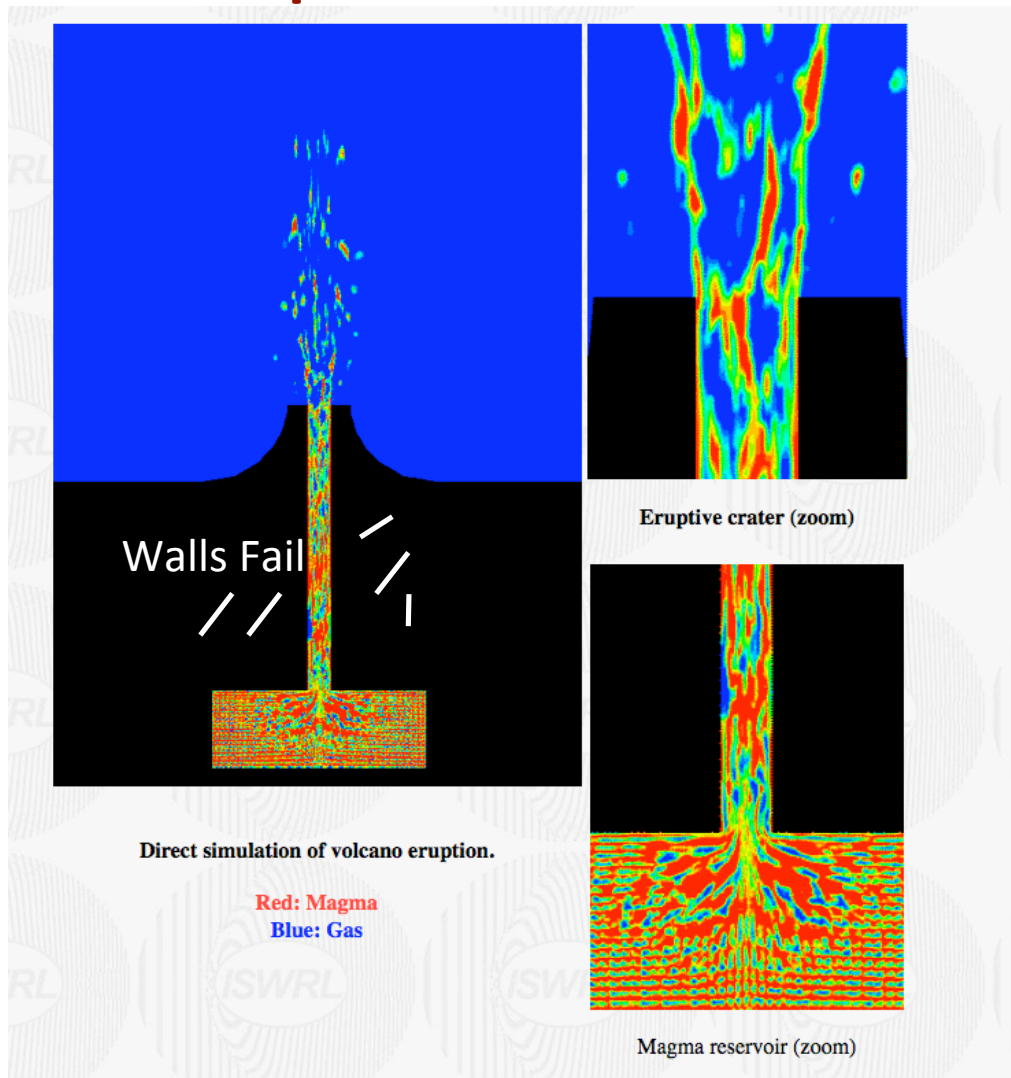
Fast

Slow



## To End:

How does a volcano evolve during an eruption and ultimately turn itself off?



<http://www.flowwatch.net/>

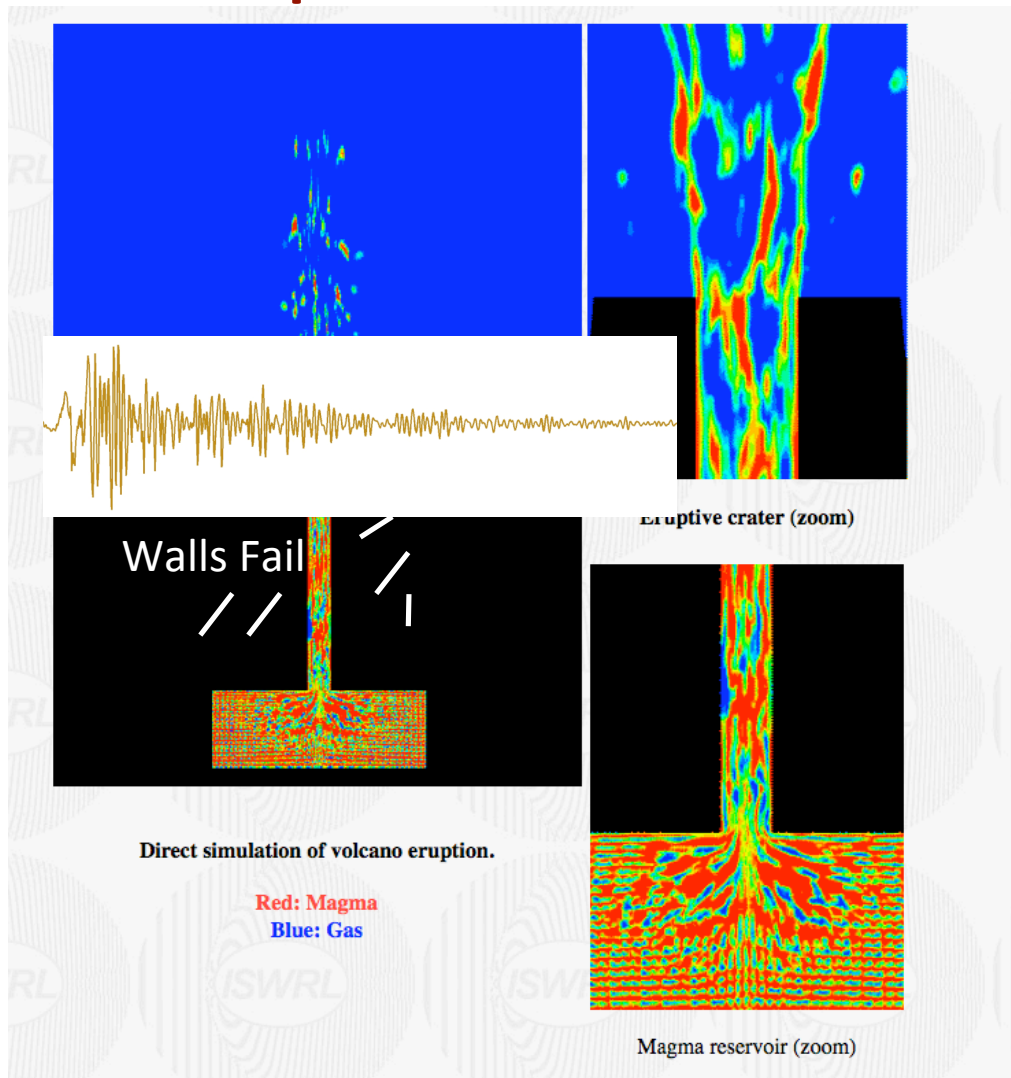




Lithic-rich layers in  
ignimbrites

# To End:

## How does a volcano evolve during an eruption and ultimately turn itself off?



<http://www.flowwatch.net/>

# Challenges

- Earthquakes
  - To determine the thresholds for earthquake initiation.
    - Strategy: Earthquake triggering
  - To determine the resistance to continued slip.
    - Strategy: Lab, Geology + Seismology
  - To determine the recovery processes on faults.
    - Strategy: Time-dependent seismic imaging
- Volcanoes
  - To determine the physical distinctions between eruptions and intrusions (and their observable consequences).
    - Strategy: Seismicity, stress and time-dependent geophysics
  - To determine the combination of fluid and solid mechanics that results in conduit collapse and thus governs the end of the eruption.
    - Strategy: Co-eruptive seismology