The Mechanics of Earthquakes and Volcanoes

How do they start, keep going and stop?

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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

Broadband record from Bozeman, Montana
(Epicentral distance = 3000 km)

Vertical Ground Velocity

Filtering 4-19 Hz
Synchronized triggered earthquakes

West et al., Science, 2005
Nearfield Triggering: Static and/or Dynamic

Stein et al., *Science*, 1992
Post-Landers Earthquake

Gomberg et al., 2003

stress lowered
stress raised
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

\[ \tau = \mu \sigma_n + C \]

\[ \text{Effective normal stress} = \text{normal stress} - \text{pore pressure} \]

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

Geological indicators
Pseudotachylytes


Rowe et al., *Geology*, 2005
How do earthquakes stop?
Individual earthquakes: Bumps

Western Fucino Basin, Italy
Populations of earthquakes stopping

Earthquake Rate

Rate of Aftershocks $\approx 1/t$

Omorí’s Law

Utsu (2002)
Healing?

Brenguier et al., Science, 2008
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

Viscous Resistance

Reservoir pressure

Elastic stress

Cooling

Second boiling

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

Cracking & shear failure
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 Fornaise

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

Namiki and Manga, *JGR*, 2006
To End:
How does a volcano evolve during an eruption and ultimately turn itself off?

http://www.flowwatch.net/
Lithic-rich layers in ignimbrites

http://www.ac.wwu.edu/~debari/309/lec13.html
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