

#### Mw 6.3 Earthquake in Italy

#### Monday, April 6, 2009 at 01:32 UTC:

According to the Italian officials, more than 50 people died, and 50,000 were left homeless. The epicenter was in L'Aquila (Abruzzo Region), a medieval fortress hill town, where a number of people were trapped under rubble. Source : ANSA : <u>http://www.ansa.it</u>

Damages in L'Aquila (Italy) 7 Km from the epicenter.





#### **Next up**



#### The earthquake cycle

- Steady accumulation of tectonic strain
  Sudden release of strain in earthquakes
- Earthquakes
  - Appearance of fault trace
  - Mechanics
- Seismic waves and earthquake location
- Then more on tectonics of West Coast

#### The earthquake cycle







Fold





#### From large-scale motion to earthquakes

- Ductile Smooth motion in space and time
  - Large-scale plate motions are smooth
  - Due to flow in ductile mantle underneath
- Brittle Abrupt and localized rupture when stressed
  - During earthquakes
  - Due to brittle nature of crust

#### Many solid materials are elastic

- Elasticity property of materials
  - I that deform when a force is applied
  - and return to original shape if the force is removed
  - such as a spring or a rubber band or a rock at low temperatures
  - Not ductile, does not flow
- Elasticity allows sudden earthquating and seismic waves.



#### **Liquids versus Solids**

- Liquids flow : viscosity η resists.
- Solids deform: rigidity G resists.
- Maxwell characteristic time  $\tau = \eta/G$ 
  - I η is viscosity and G is elastic springiness
  - $\tau$  = 10<sup>-12</sup> seconds for water
  - $\tau = 10^6$  years for earth crust
- Time scale of deformation < τ : solid</p>
- Time scale of deformation >  $\tau$  : liquid
- Examples: silly-putty, salt-water taffy



#### **Elastic Rebound**

- A fault remains locked (by friction) while stress slowly accumulates, gradually twisting the rock
- Then it suddenly ruptures in an earthquake, releasing the stored-up stress.
- Energy is released in the form of heat and seismic waves.

#### **Consequences of Elastic Rebound**



#### **Elastic Rebound**

After 100 years of accumulating strain:



#### **Elastic Rebound**



#### **Elastic Rebound**

Deformation during the earthquake cycle



#### **Another view**



#### **Strain accumulation**



- Steady strain rate over many years
- Distributed across zone about 100 km wide
- Only top 20 km build strain in California
  Deeper rocks seem to flow due to higher temp.
- We see strain accumulate with GPSGlobal Positioning System
- If build-up of strain is steady and featureless, there may be no clues of coming quakes







# **Strike and dip**



of a fault plane, a rock layer, or a subducting slab

**Strike-slip fault - transform** 



#### Strike-slip fault trace

- Deflected stream channels
- Juxtaposed unrelated rock types
- Sag ponds
  - Enclosed depressions
- Shutter ridges
  - Ridges that are truncated



#### Strike-slip trace diagram



A stream channel offset by the San Andreas fault, Carrizo Plain, central California





Another nearby place





#### **Guatemala again**



NOAA web site

Guatemala

1 m offset here

1976

#### **Thrust fault - convergence**



#### **Thrust fault trace**



- Topographically irregular scarp
  In contrast, strike-slip has straight trace
- Fault plane dips at low angle
- Deeply incised canyons
  - From rapid uplift
- Perched terraces
  - Formed when upper block was lower
- Drag fold on hanging wall of fault
  - Permanent, ductile part of deformation



#### **Thrust fault trace diagram**



Thrust fault in Alps



Uplifted terraces at Wairarapa coast from quakes in 1855, 1460, ...



#### Meckering earthquake

1968 thrusting event, 30 km long rupture. Shadow shows scarp. Middle of Australia *Photo by Bruce Bolt* 



Thrust fault scarp, 1980, El Asnam, Algeria



NOAA web site

#### More on Italian earthquake

- 200 fatalities
- M5.6 Aftershock yesterday
- Claim of prediction based on excess radon
  - 6-24 hour window weeks ago
  - Centered on location of an EQ swarm
  - 30 miles away
- Tectonics
  - Normal faulting
  - Complex set of faults

#### **Old houses**







#### A closer look



#### **Normal fault - divergence**



#### Normal fault trace diagram

#### Normal fault trace diagram

- Typically fault plane dips steeply
- Perched terraces
  - Like near thrust fault traces
- Alluvial fans
  - Can be very large, as in Death Valley
- Subsidiary fault traces
  - Offsetting the soft fans and terraces









#### Sierra Nevada cartoon east side of range is very steep





#### Normal fault, Hebgen Lake, 1959



#### Slickensides - grooves made as two sides of fault slide past each other during fault motion



Corona Heights, SF, CA

Slickenside showing polish structures and striations. Related to glacial striations





Slickenlines (large-scale) or grooves in normal fault, Coyote Mountains, Salton Basin, California. Photo by Ed Beutner

### Combination: oblique faulting

Borah Peak 1983 Normal and strike-slip NOAA web site







- Rupture begins
  - I place on fault where stress has exceeded strength
- Crack spreads outward over planar fault surface from focus
  - At about 3 km/sec (near shear-wave velocity).
- Larger area implies larger magnitude and longer duration of rupture

## **Rest of the story**

- Energy from cracking and sliding rocks travels outward.
- These vibrations are felt and cause damage.
- Only a small amount of damage is caused by offset on the fault, vibrations do most of the destruction.

#### Vocabulary

- Focus point where the rupture started
- Hypocenter location and time of quake beginning (same as focus)
- Epicenter surface projection of hypocenter
- No dominant pattern as to where hypocenter is on the fault plane
- Rupture the sliding of one side of the fault against the other side



#### **Epicenter and hypocenter**

# Footwall, hanging wall, focal depth, fault trace



#### **More details**

- Rupture spreads at 2 to 3 km/sec
- A larger quake will generally take longer to rupture, and have greater slip
- Generally, only part of a fault ruptures in each quake
- Usually, big faults have been recognized beforehand

#### **View of rupture**



# Magnitudes and ballpark fault rupture sizes

- Magnitude 8 = 500 km
- Magnitude 7 = 70 km
- Magnitude 6 = 10 km
- Magnitude 5 = 1.5 km
- Magnitude 4 = 200 m
- Magnitude 3 = 30 m
- Magnitude 2 = 5 m

#### **More factoids**

- Largest amount of slip is generally near the middle of the fault rupture plane
- Near the edges, there is less slip
- Slip is generally in the same direction across the entire fault rupture plane
- Fault planes do not open or close, the two sides just slip sideways
- A point on the fault plane slips at a rate around ~1 meter per second

#### **Idealized slip distribution**



Next, seismic waves.





