The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

ICTP Diploma Programme - Academic year 2008-2009

Earth Science Physics Diploma

Seismology

Seismic sources - 0
Introduction

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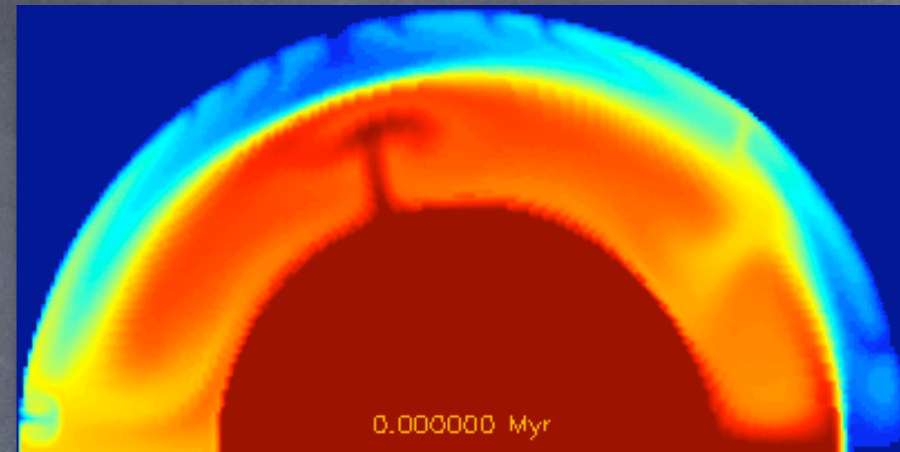
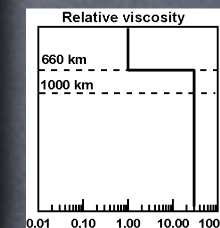
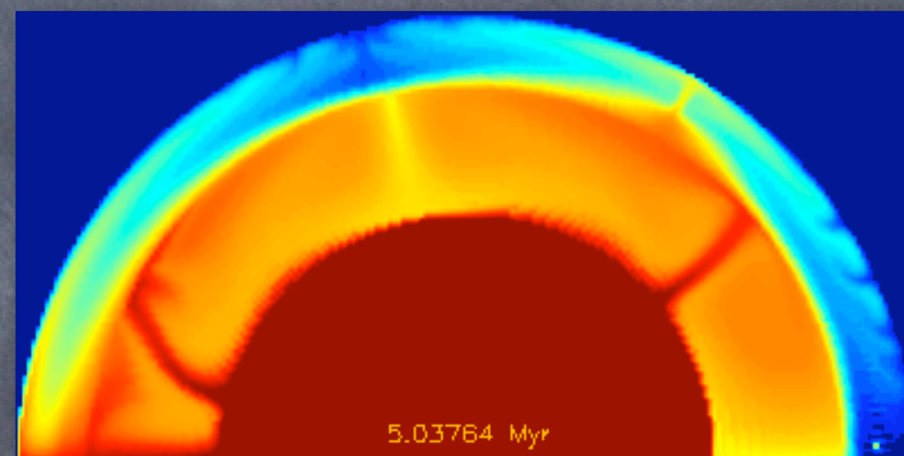
&

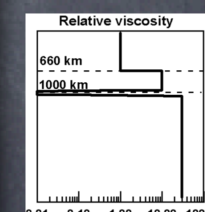
ESP Group of ICTP

Why do earthquakes happen?









Thermo chemical convection
http://geo.mff.cuni.cz/~cizkova/Anim/animace.htm

From Namazu.... to complex fluid dynamics

Tectonic Forces & Convection

- The interior of the Earth is dynamic – it cools down and thus provides energy for convective currents in the outer core and in the asthenosphere.
- Additional energy comes from radioactive decay and Earth tides... enabling tectonic processes

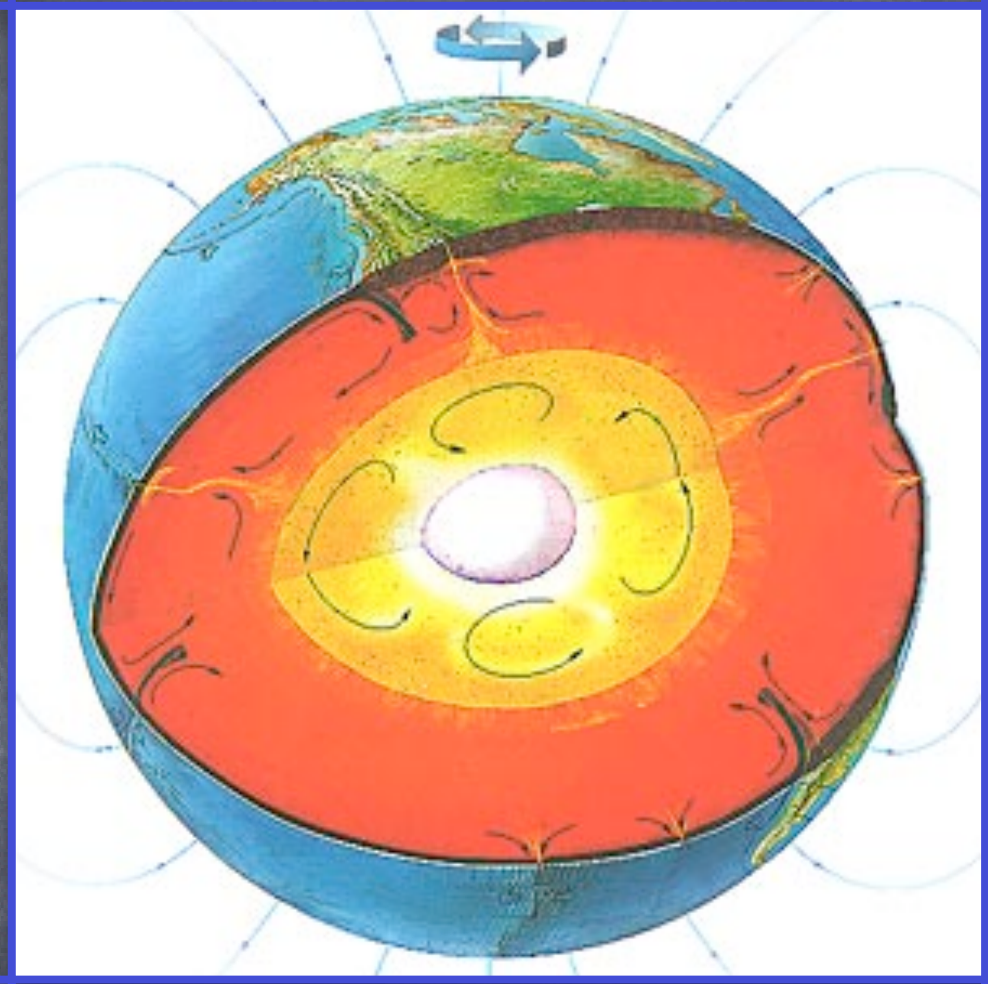
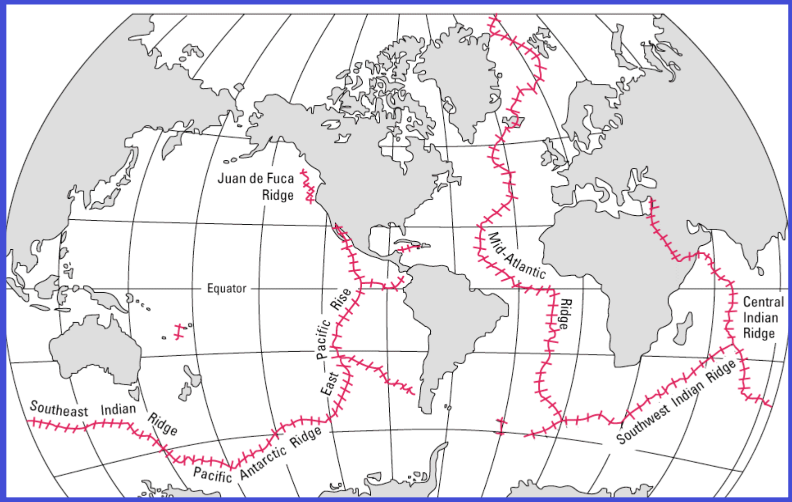


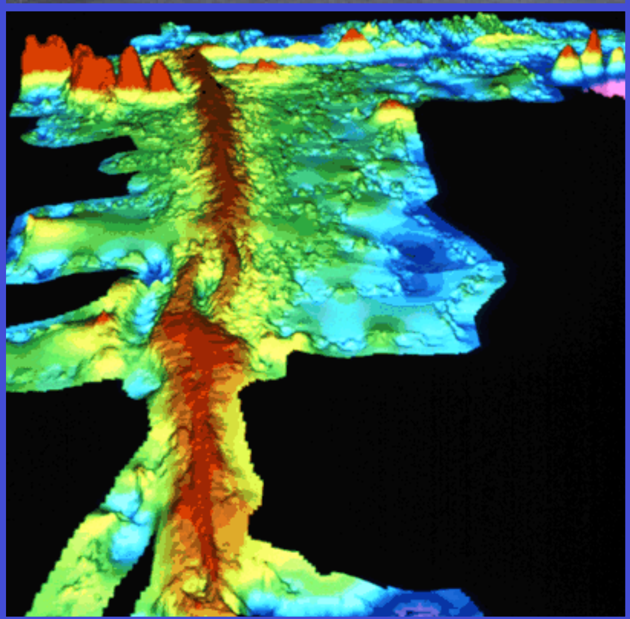
Plate Tectonics – Discovery

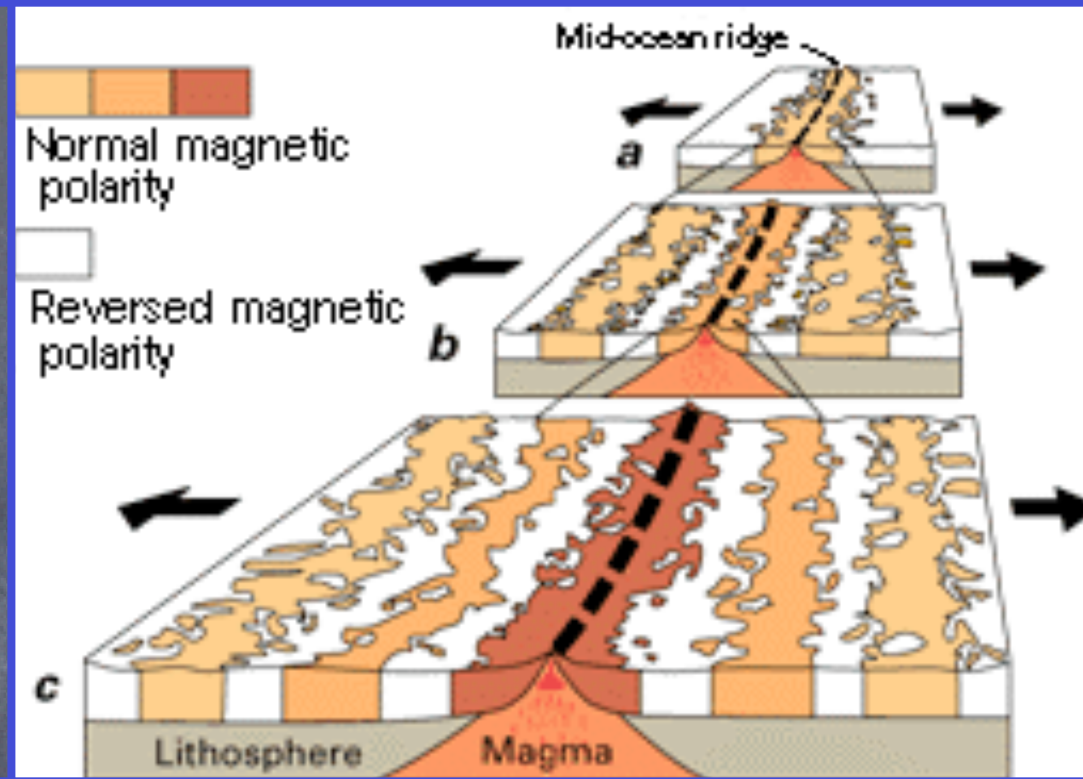
Plate Tectonics – Mid-oceanic ridges

Global ridge system



Topography mid-atlantic ridge

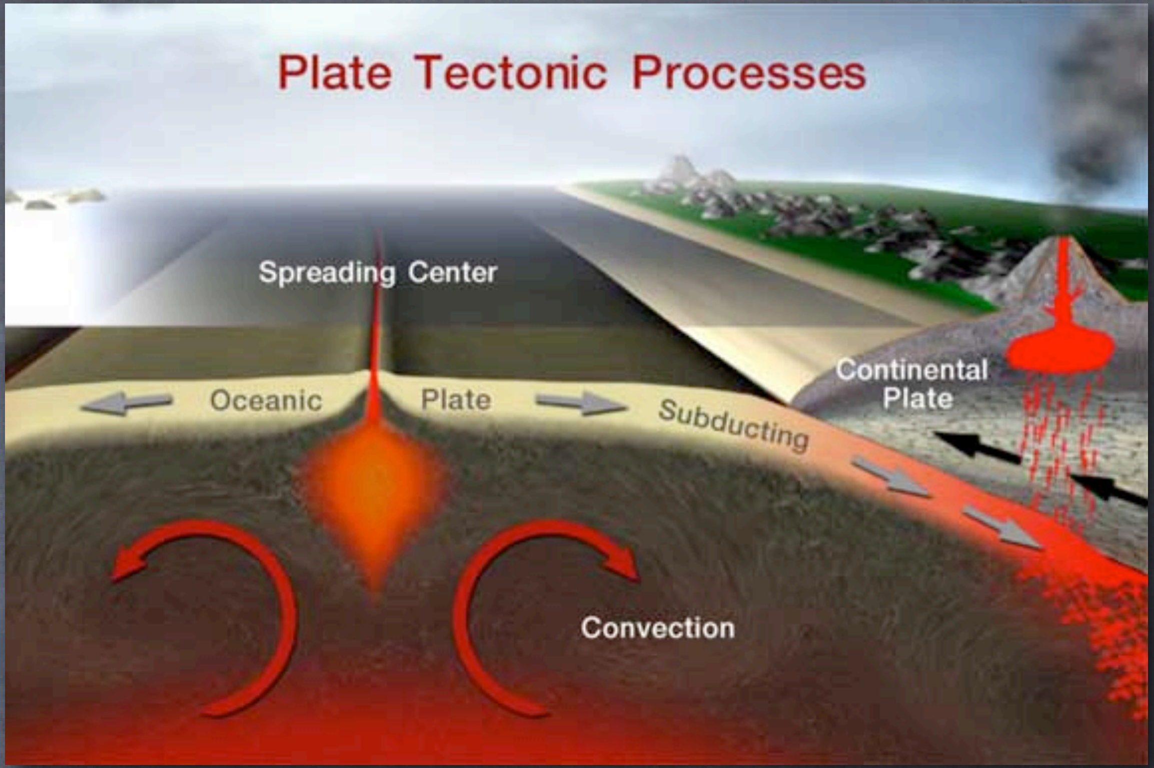




The proof of plate tectonics came from the magnetization of the seafloor as a function of distance from the ridge axes.

Tectonic plates

- Tectonic plates are large parts of lithosphere 'floating' on the asthenosphere

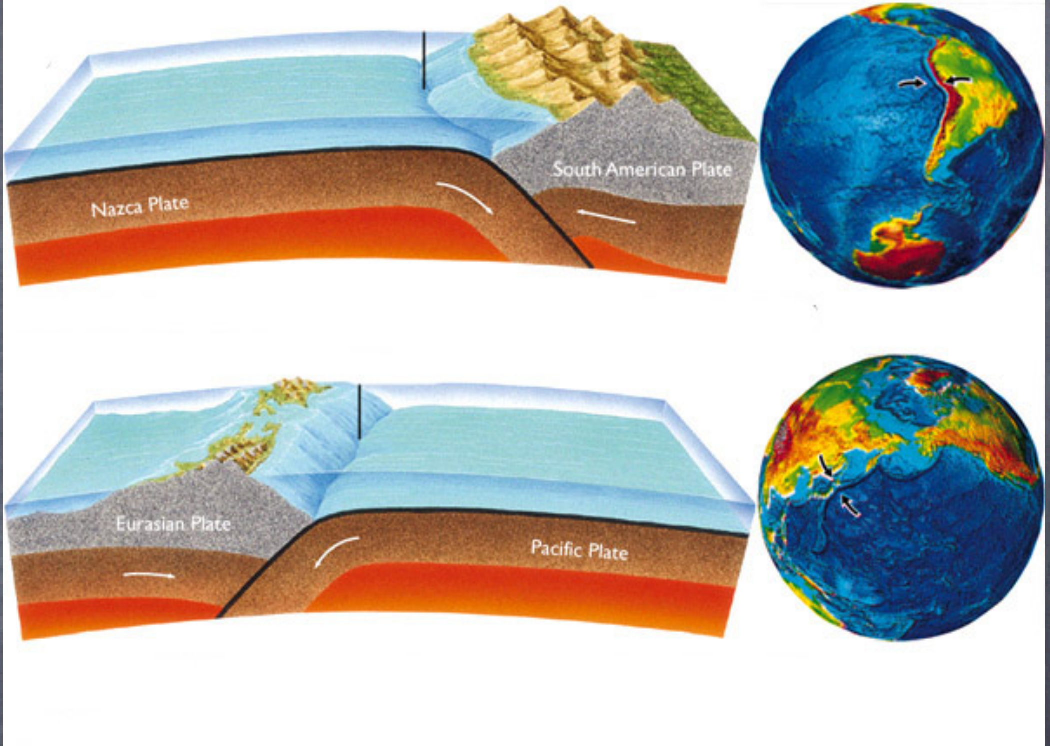


Convective currents, and other forces like Earth tides, move them around with velocities of several cm/year.
The plates interact with one another in three basic ways:

colliding (subduction zones)
moving away from each other (spreading centers)
sliding one past another

Interacting plates

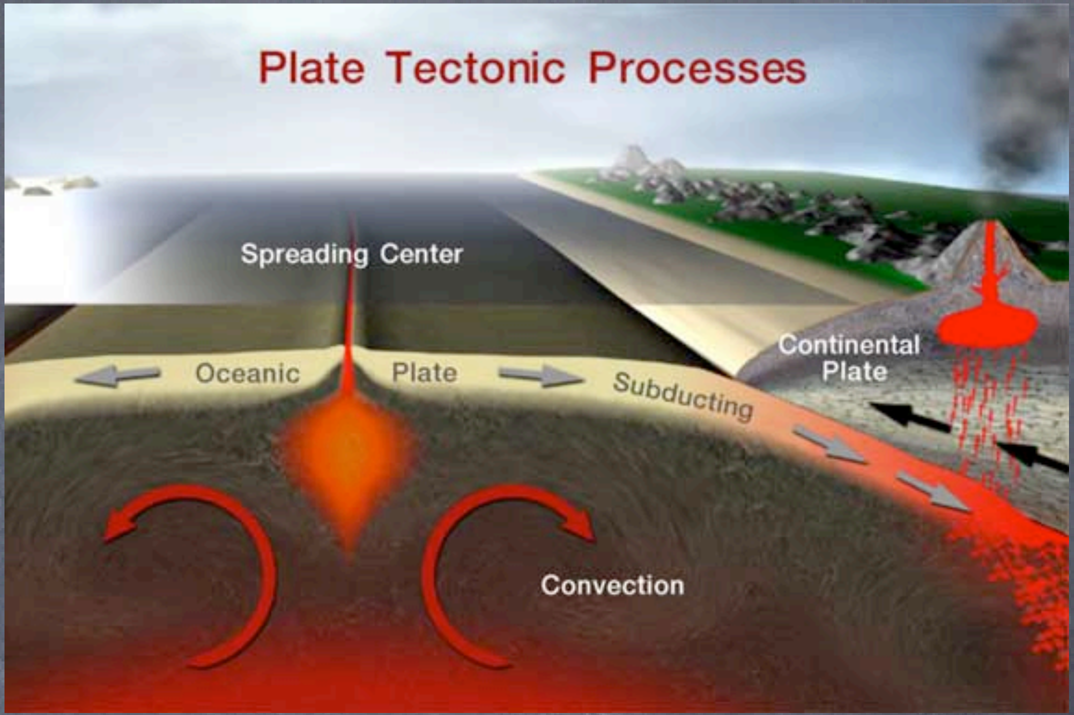
- Collision leads to SUBDUCTION of one plate under another. Mountain ranges may also be formed (Himalayas, Alps...).
- It produces strong and sometimes very deep earthquakes (up to 700 km).
- Volcanoes also occur there.



EXAMPLES: Nazca – South America - Eurasia – Pacific

Interacting plates

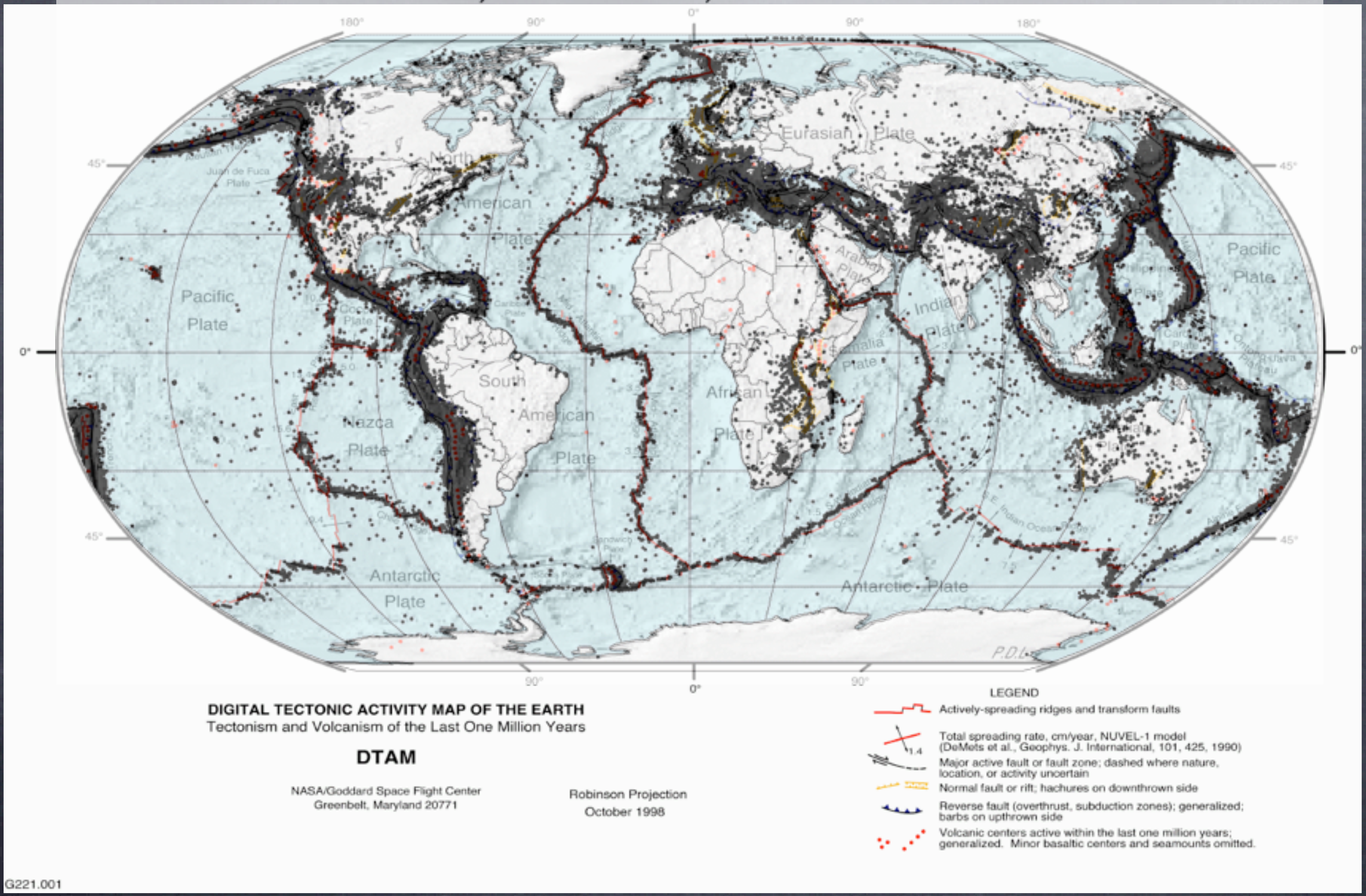
- Plates moving away from each other produce **RIDGES** between them (spreading centres).
- The earthquakes are generally weaker than in the case of subduction.



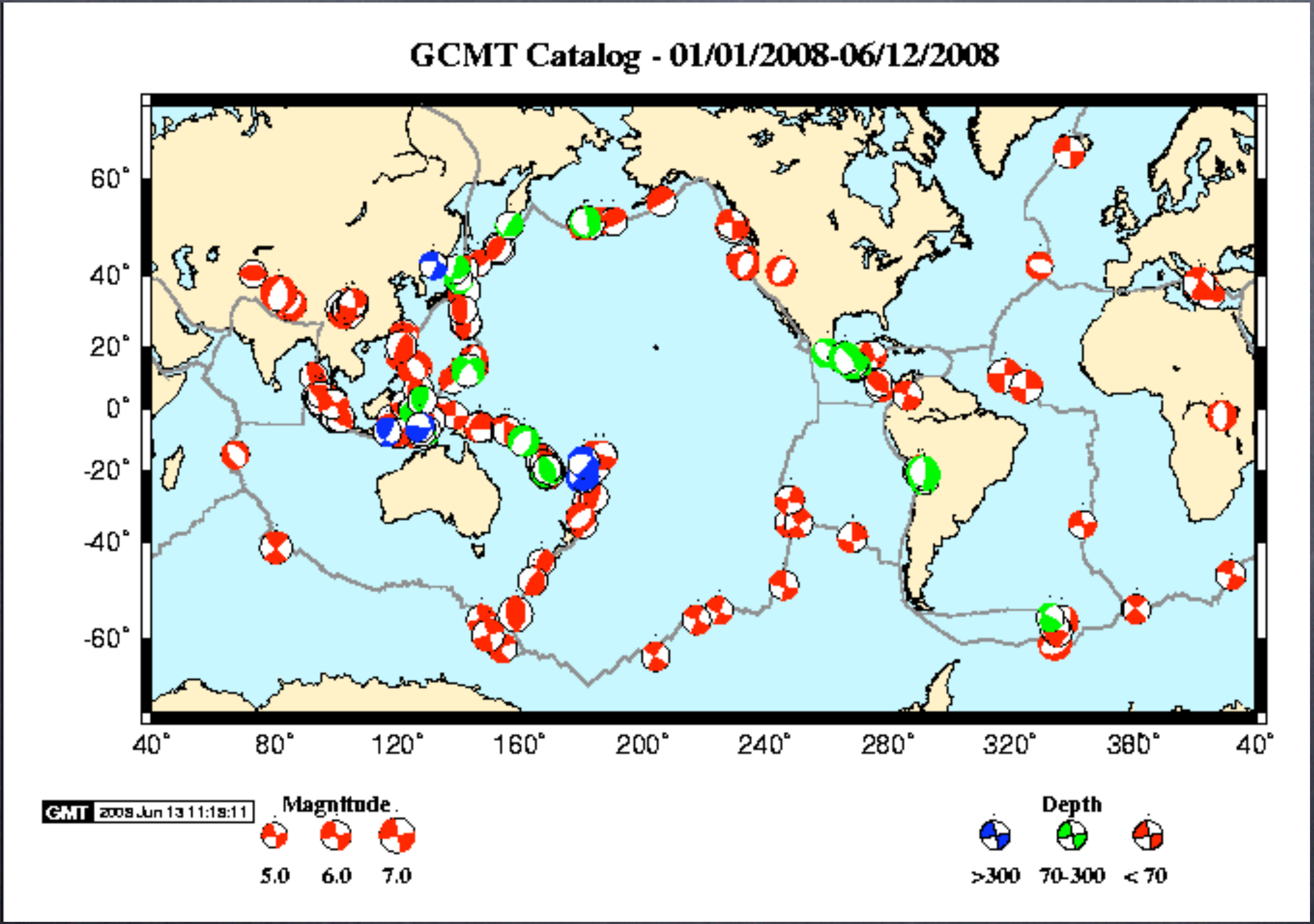
EXAMPLES: Mid-Atlantic ridge (African – South American plates, Euroasian –North American plates)

Major tectonic plates

358,214 Events, 1963 - 1998



Recent seismicity



http://seismo.berkeley.edu/weekly/global_prev.html

Plate tectonics

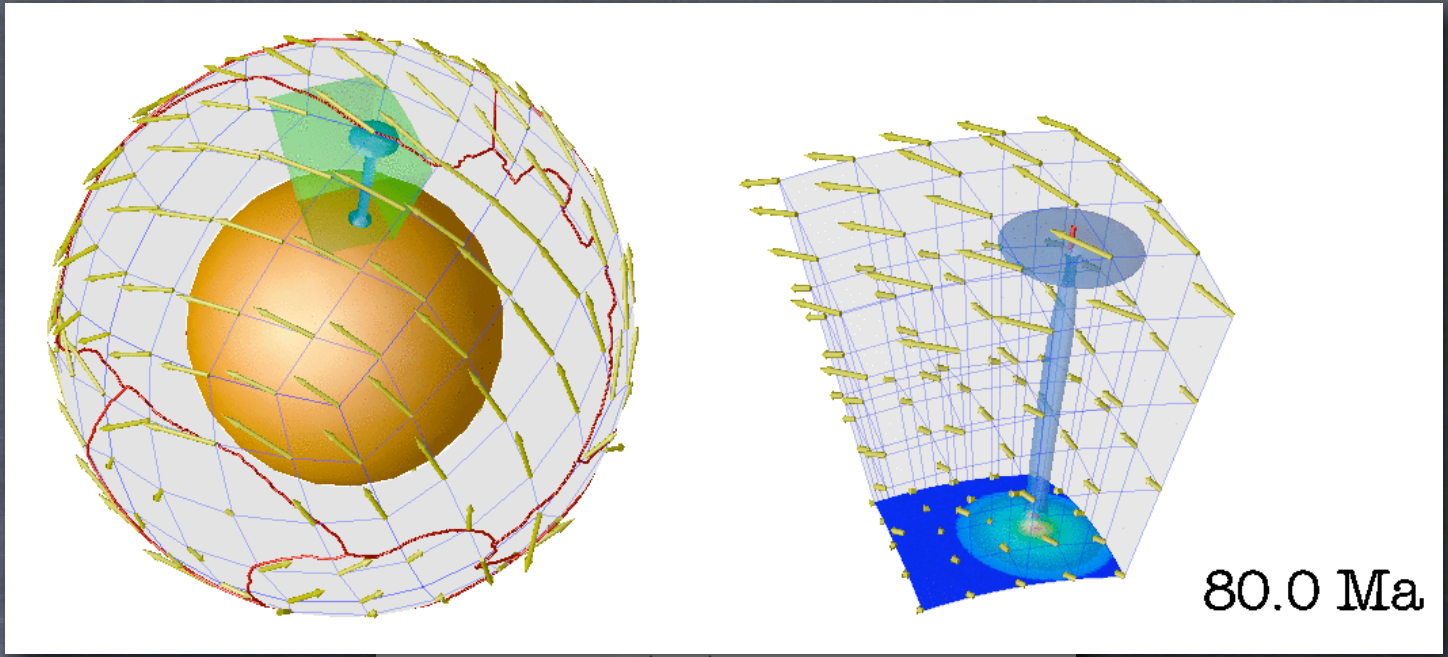
theory that is very young (1960-ies)

and provides answers to the most fundamental questions in seismology:

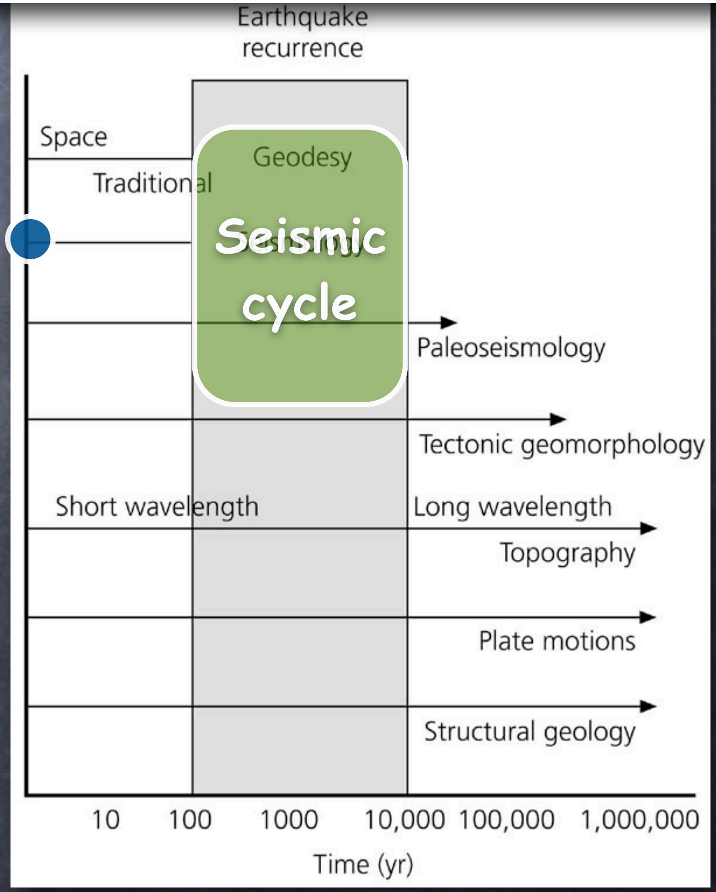
- Why earthquakes occur?
- Why are earthquake epicenters not uniformly distributed around the globe?
- At what depths are their foci?

large, nearly rigid plates of the Earth slide past each other and

earthquakes accommodate the motion



Wave propagation

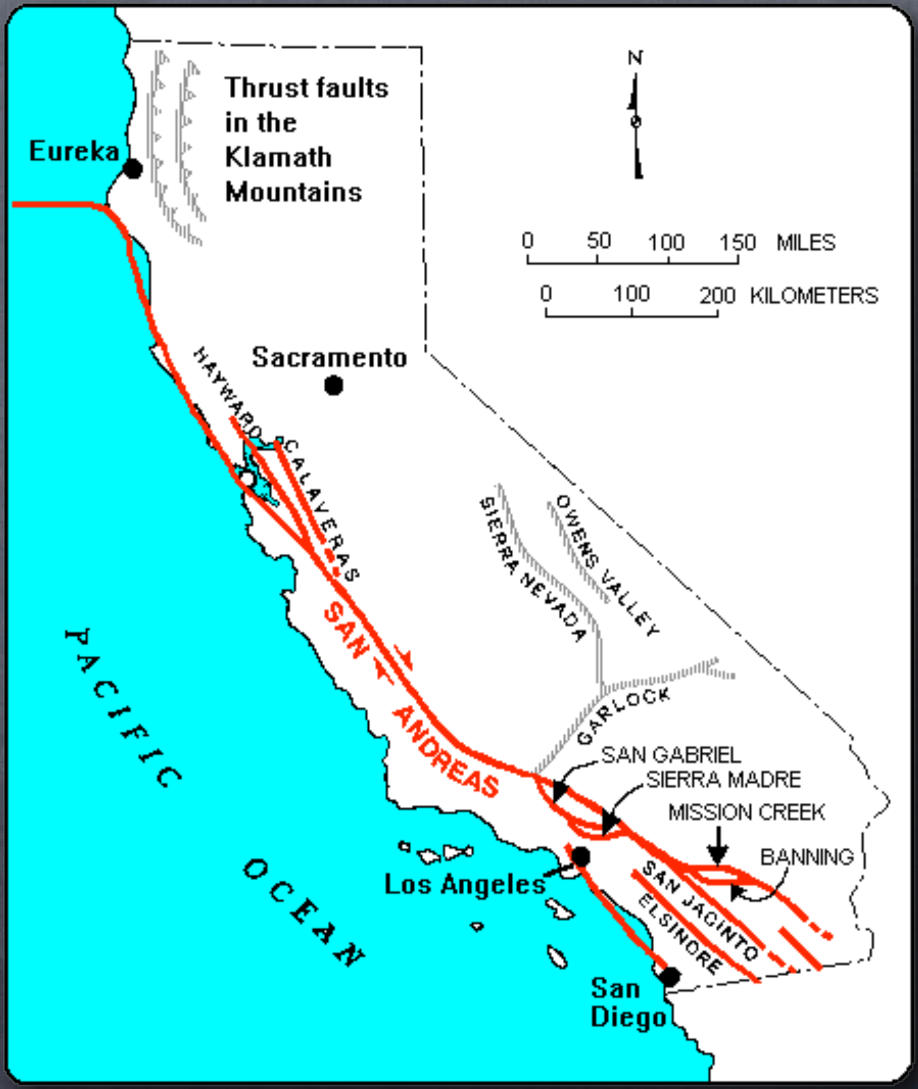


Different time scales...

Plate Tectonics - Fault Zones

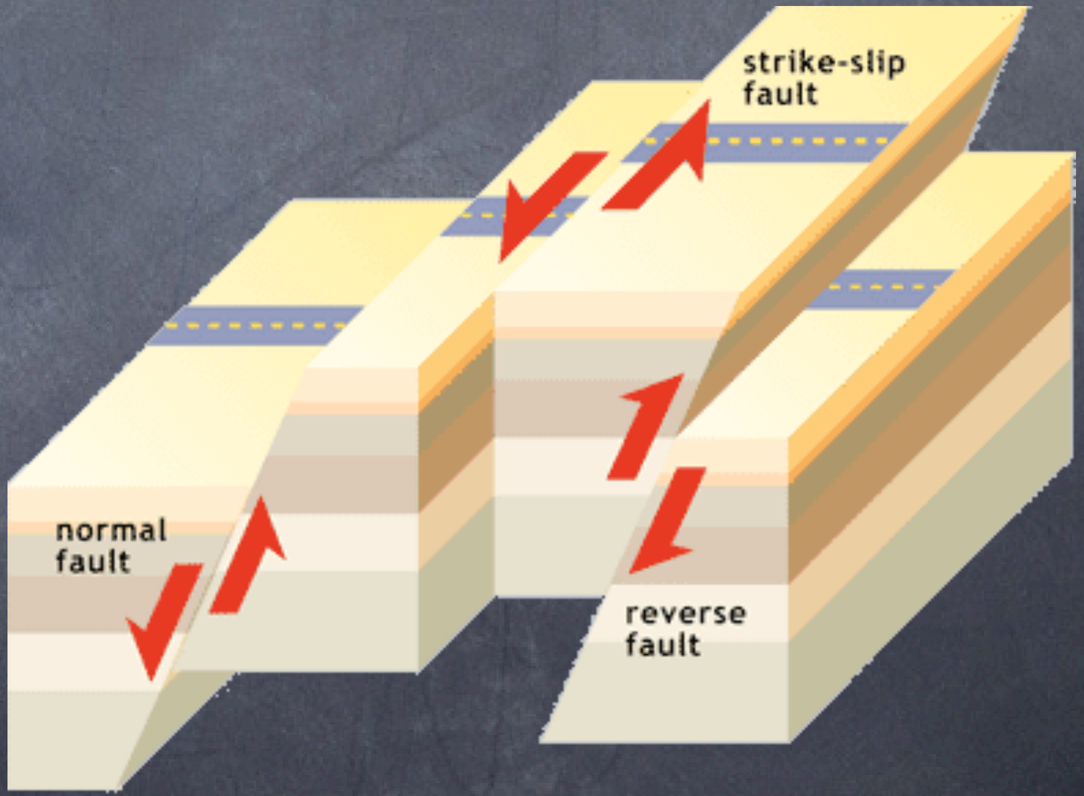
San Andreas Fault

Fault zones in California

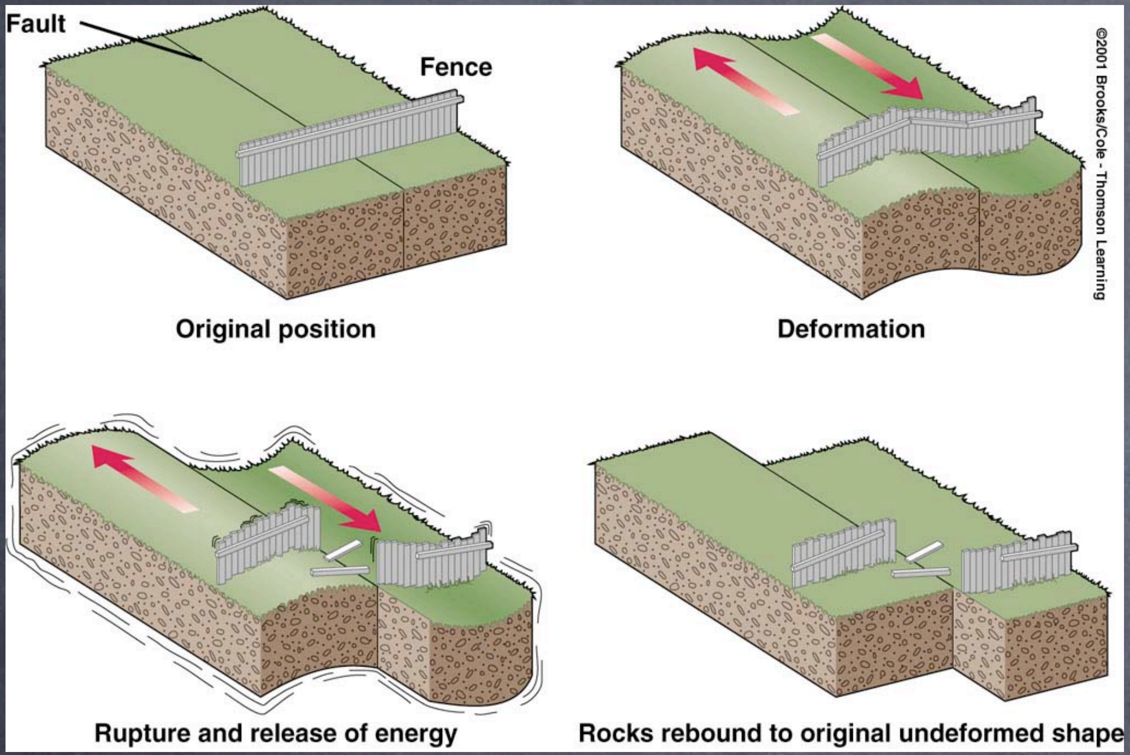


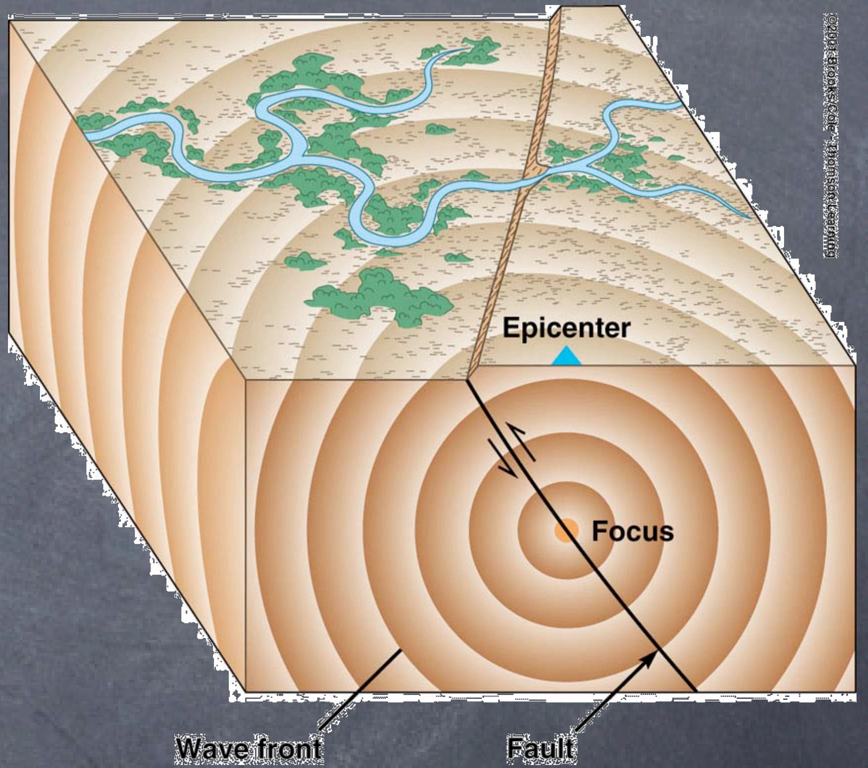
How earthquakes occur?

- Earthquakes occur at **FAULTS**.
- Fault is a weak zone separating two geological blocks.
- Tectonic forces cause the blocks to move relative one to another.



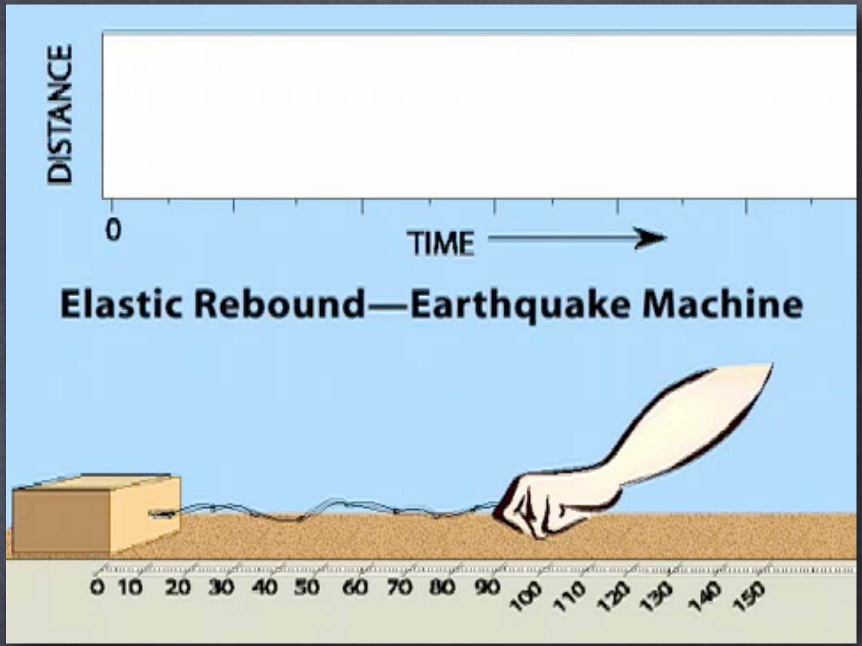
What is an earthquake?
Elastic rebound theory

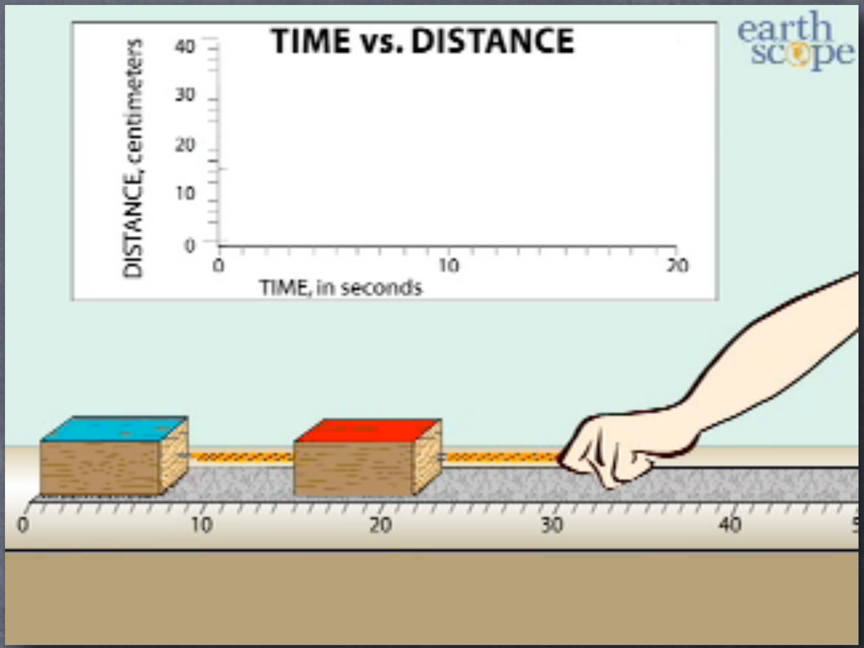


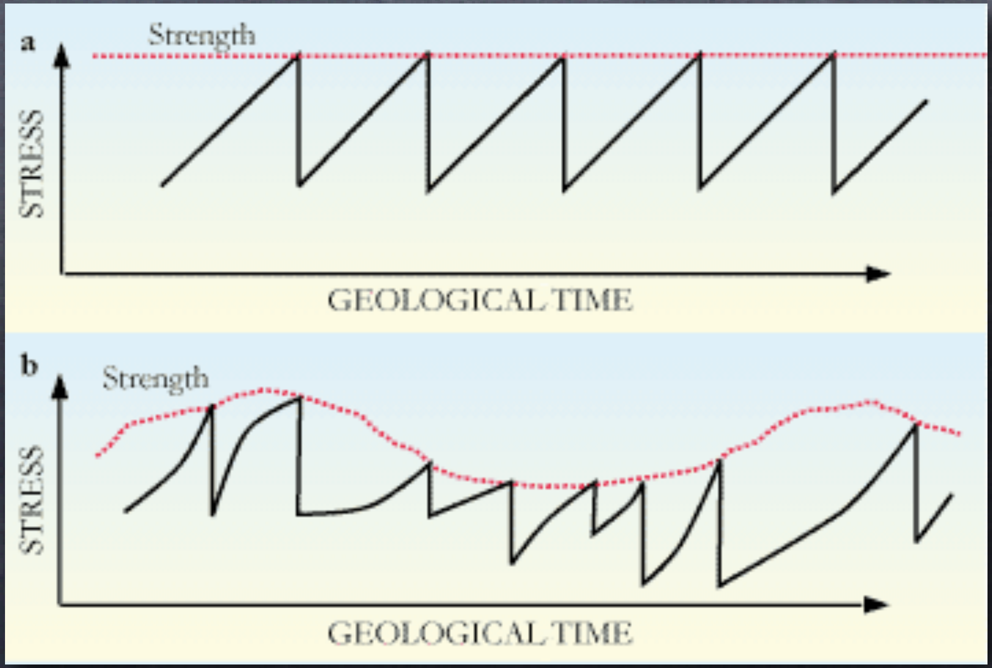


- Because of friction, the blocks do not slide, but are deformed.
- When the stresses within rocks exceed friction, rupture occurs.
- Elastic energy, stored in the system, is released after rupture in waves that radiate outward from the fault.

Earthquake (complex) cycle







Rate (v) and State (θ) Friction Constitutive Laws

$$\mu(\theta, V) = \mu_o + a\, ln\left(\frac{V}{V_o}\right) + b\, ln\left(\frac{V_o\theta}{D_c}\right)$$

state variable, characterizes physical state of surface or shearing region

critical slip distance

reference velocity

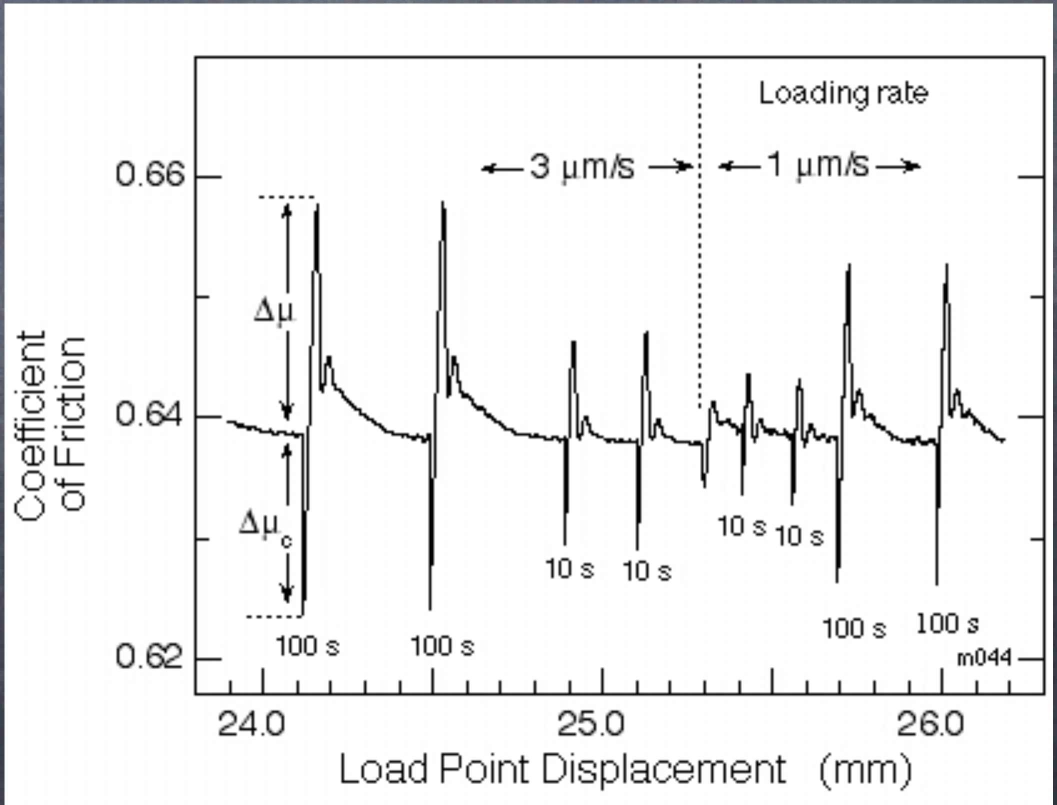
reference value of base friction

$$\frac{d\theta}{dt} = 1 - \frac{V\theta}{D_c}$$

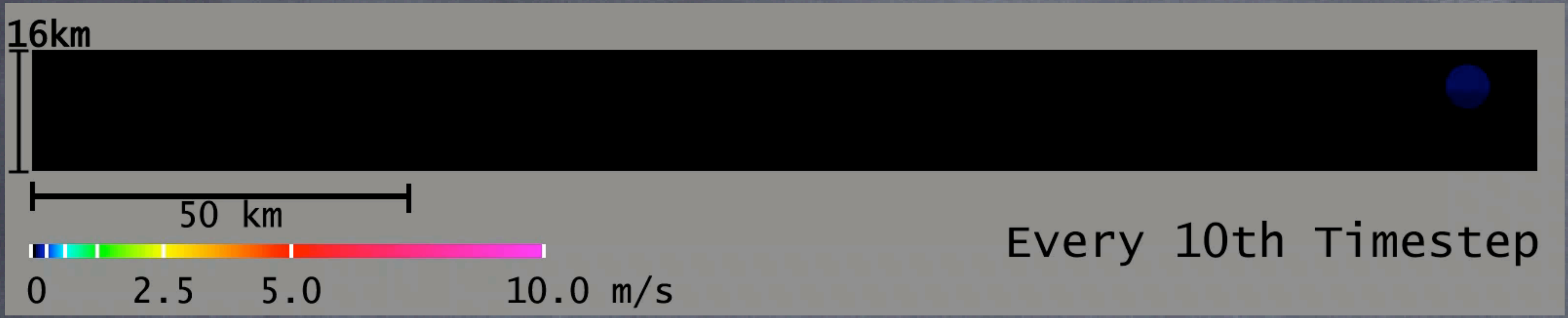
Dieterich, aging law

$$\frac{d\theta}{dt} = -\frac{V\theta}{D_c} ln(\frac{V\theta}{D_c})$$

Ruina, slip law

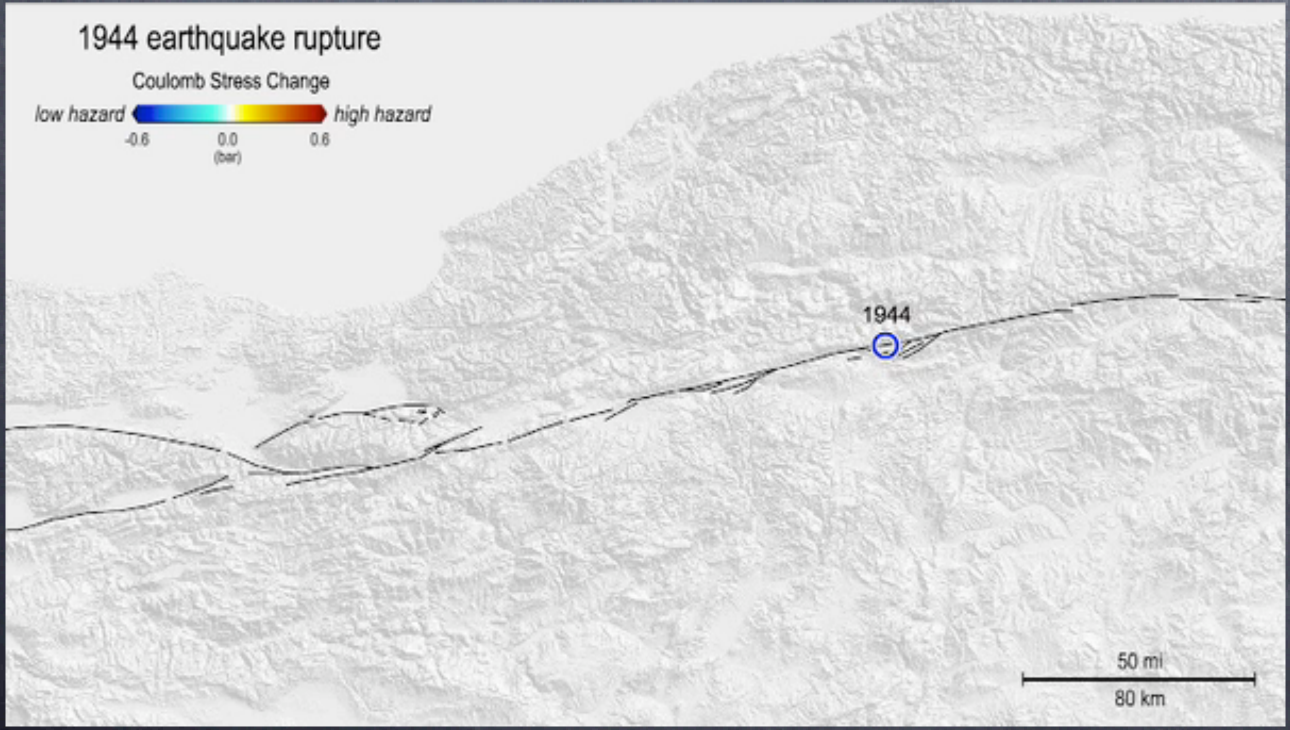


Dynamic rupture and stress transfer



rupture velocities of a dynamic rupture model of a magnitude 7.7 on the southernmost San Andreas fault
www.scec.org

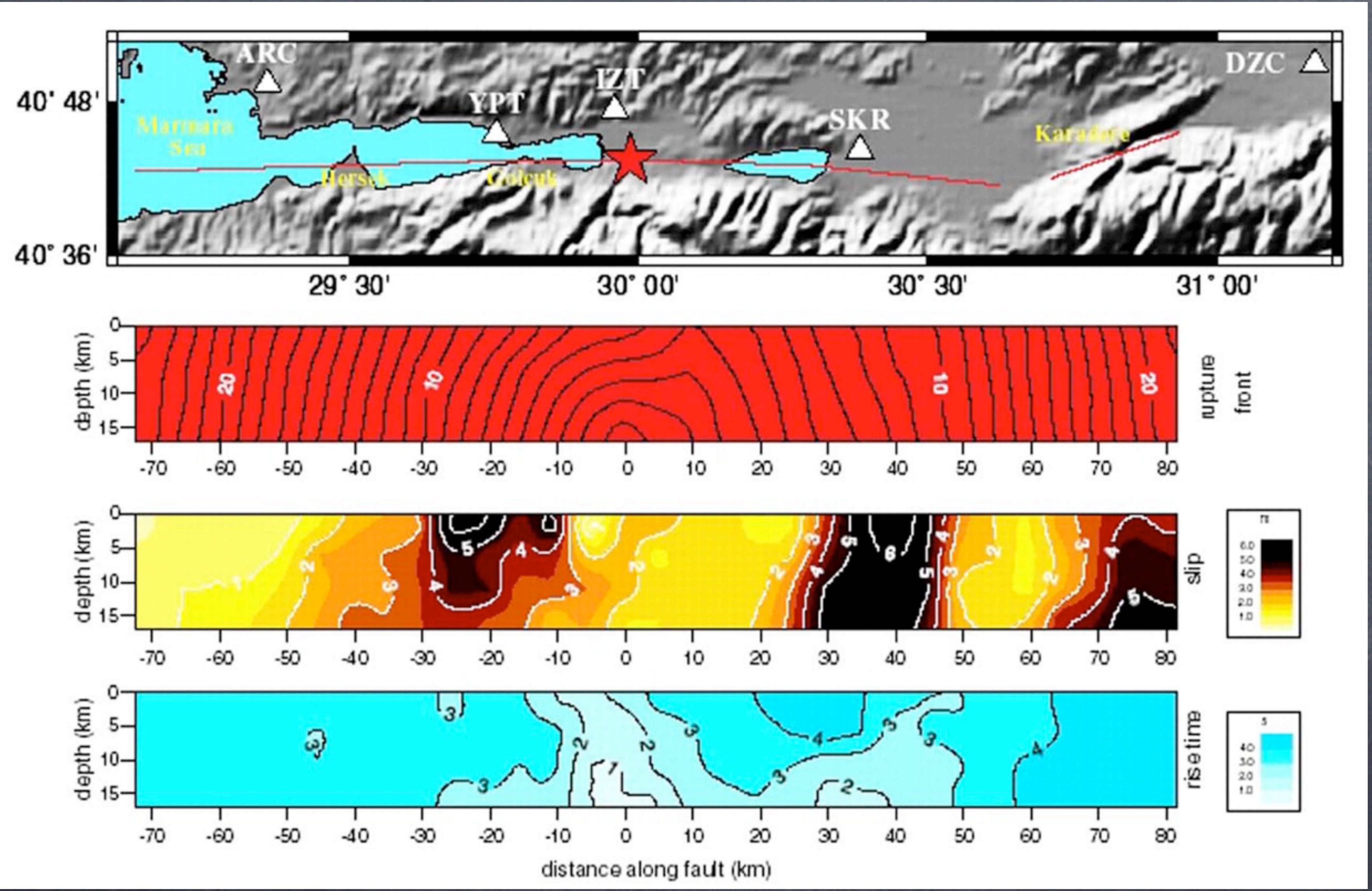
When a fault fails during an earthquake, it modifies the stress field in its surroundings. The modification of the stress pattern can give a rough idea of where the next shocks are more likely occur.



Coulomb stresses transmitted by seismic wave propagation for the M=7.2 1944 earthquake on the North Anatolian fault.

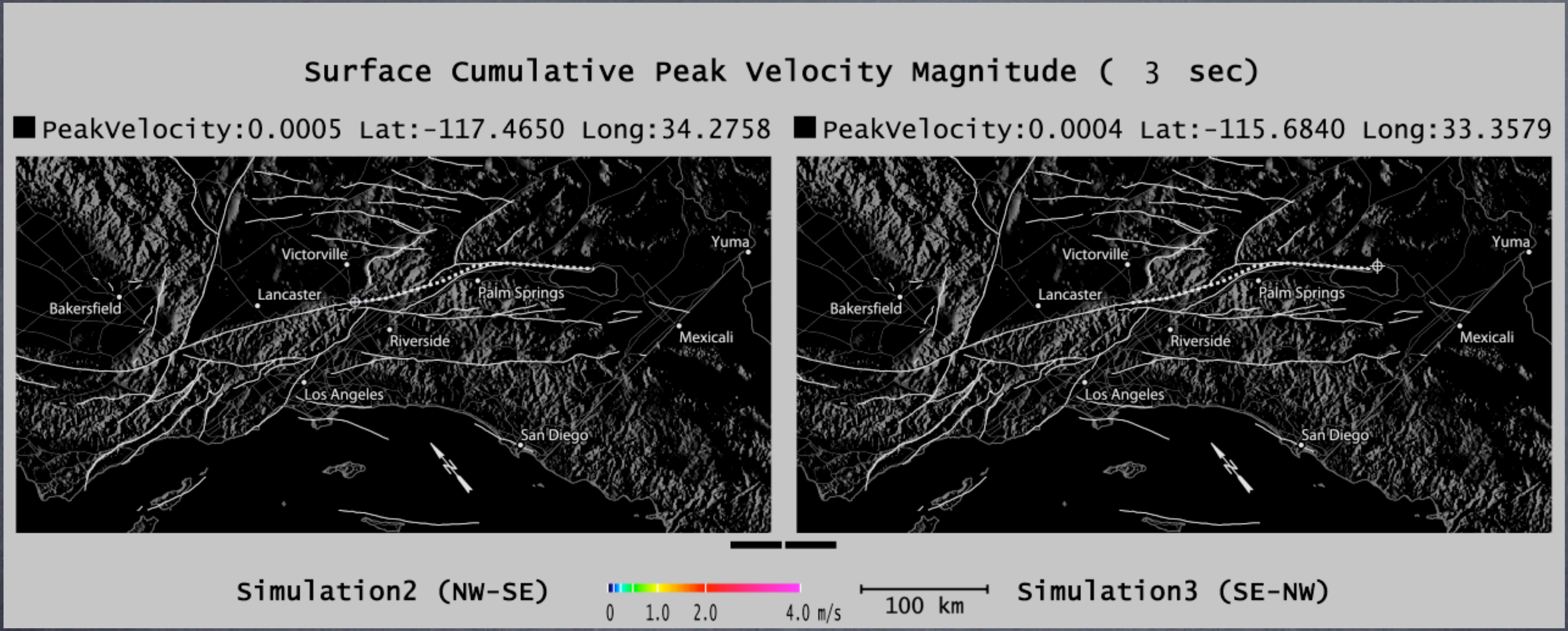
Courtesy of Kim B. Olsen

Kinematic description



Map of the surface rupture of the **Izmit earthquake** (red line). The geometry of the fault model used in the inversion follows the red line but is continuous across the junction with the eastern segment. The symbols indicate the location of the epicenter (red star) and of the recording stations (triangles). Middle and bottom: Images of the rupture front, slip, and rise time on the fault. The position of the rupture front is shown at 1-sec intervals from the beginning of the rupture. From: **Bouchon et al., 2002. BSSA; v. 92; no. 1; p. 256-266**

Ground motion scenarios



The two views in this movie show the cumulative velocities for a San Andreas earthquake TeraShake simulation, rupturing south to north and north to south. The crosshairs pinpoint the peak velocity magnitude as the simulation progresses.

www.scec.org

Any strategy for seismic risk reduction should be outlined trying to answer two basic questions:

- When, where and how big we have to expect a strong earthquake to strike a region?

- What should we expect when it occurs?

The answer to the first question is matter for earthquake prediction,
while the second one is matter for
sound seismic (&tsunami) hazard assessment...

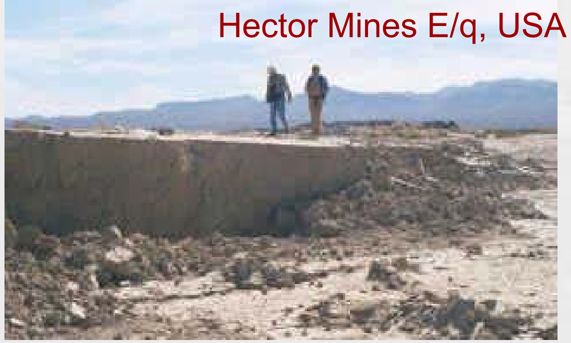
Earthquake effects

ground shaking

liquefaction

surface rupture

Chi Chi E/q, Taiwan



Hector Mines E/q, USA

Hazard, Risk & Vulnerability

Risk = Hazard * Vulnerability

Hazard: Nature decided, and can be assessed

Vulnerability: Man decided, and can be reduced

$$R = \langle H_i, P_i, C_i \rangle$$

- H_i: set of i-events with possible adverse consequences
- P_i: associated probabilities of their occurrence
- C_i: associated intolerable consequences