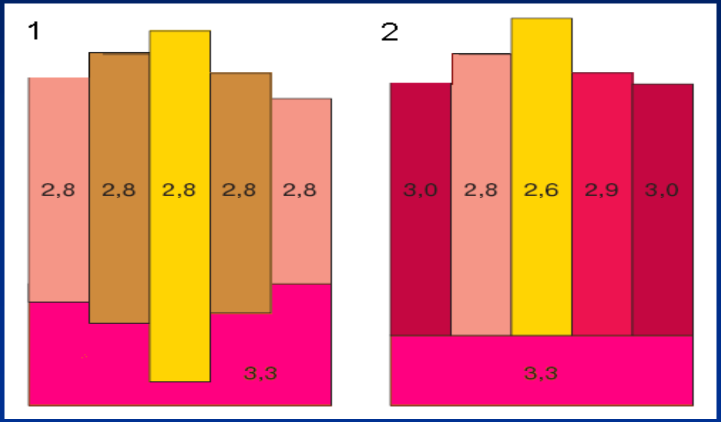
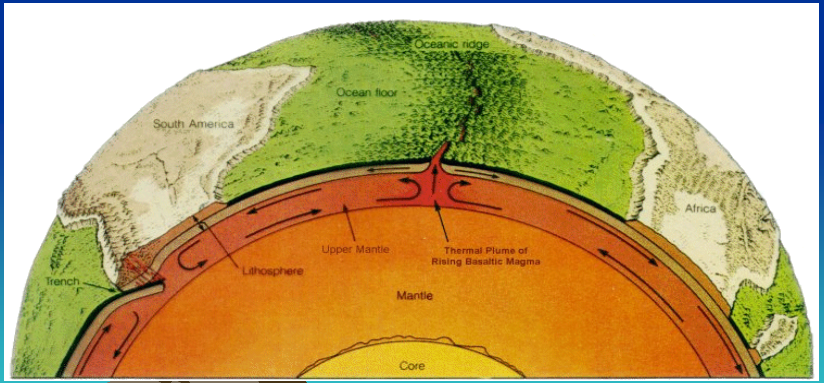
Plate Tectonics Lab

Understanding the Nature of Mobile Floating Lithospheric Plates



Crust –Mantle Dynamics



EOSC105

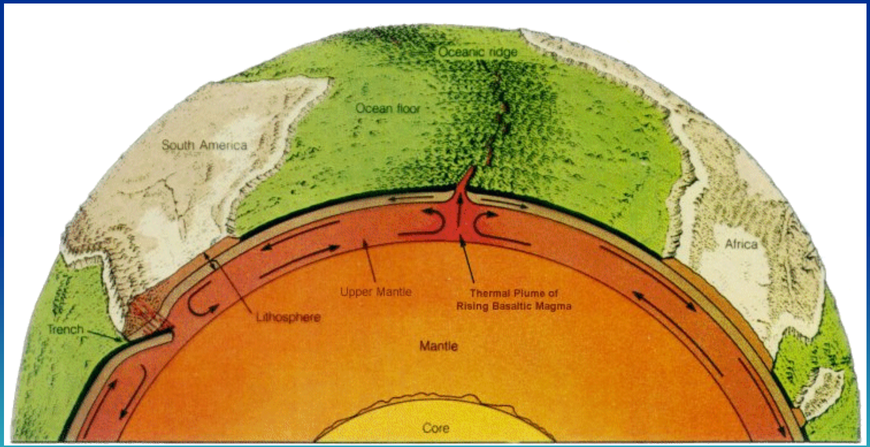
Natural Distaters Lab

Ray Rector - Instructor

Isostasy and Tectonics Laboratory

Topics of Inquiry

1) Concepts of Density and Buoyancy
2) Layered Physiology of the Earth
3) Isostatic Dynamics – Equilibrium vs. Adjustment
4) Modeling Isostasy in Lab
5) Plate Tectonic Theory
6) PT Processes:
   - ✓ Seafloor Spreading
   - ✓ Subduction
   - ✓ Hot Spots
7) Inter-Plate Dynamics
8) Measuring Plate Motion



Inquiry of Lava Lamp Motion

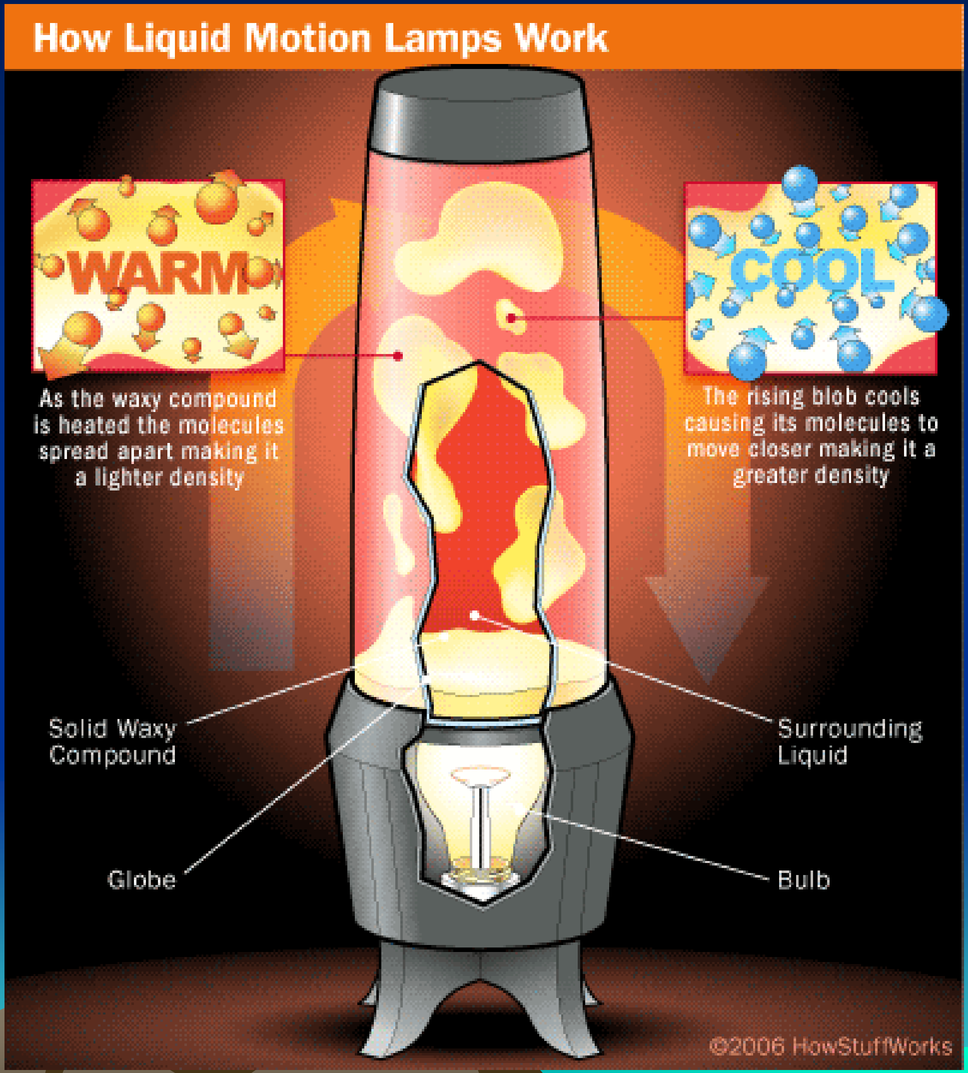
Density and the Convection Process

✓ Fluid material at top of lamp is cooler than material at the bottom.

✓ Hotter material is less dense than cooler material

✓ Less dense fluid rises while more dense fluid sinks

✓ Heat and gravity drive the system



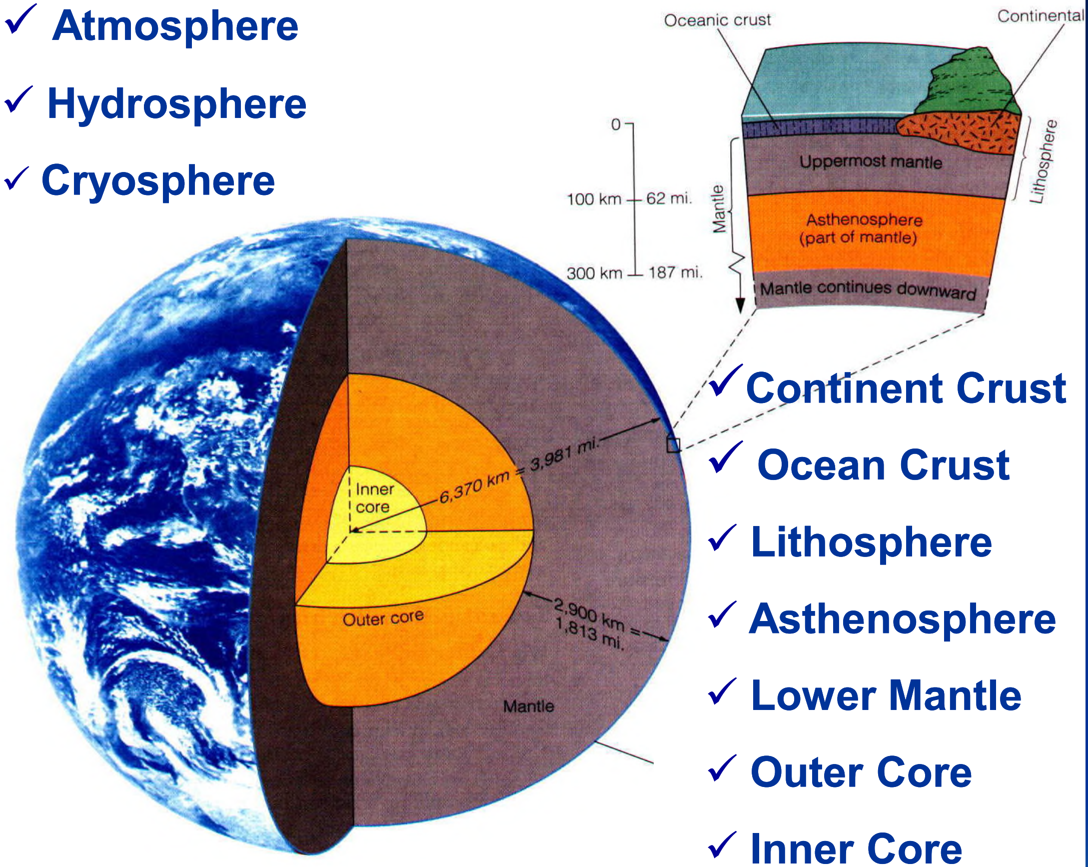
Earth's Layered Structure

1) Ten Different Density Layers

2) Each Layer Has Unique Physical and Chemical Properties

3) All Layers Arranged According to Density

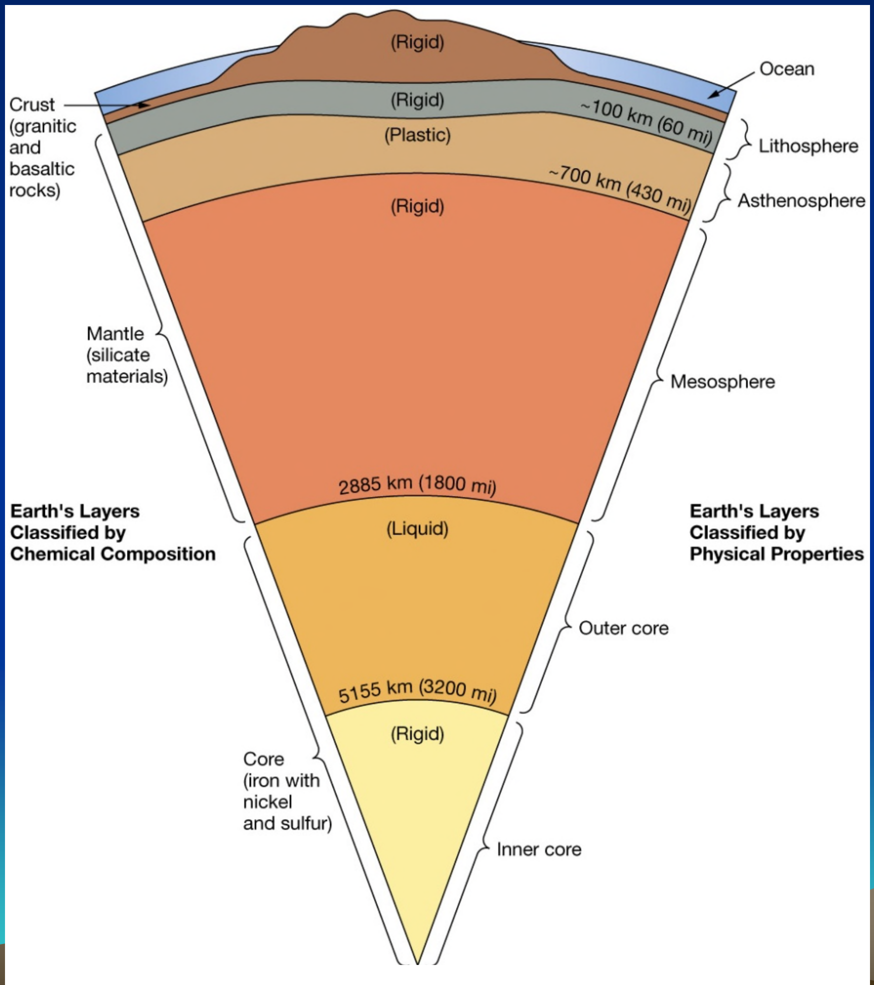
- ✓ Atmosphere
- ✓ Hydrosphere
- ✓ Cryosphere

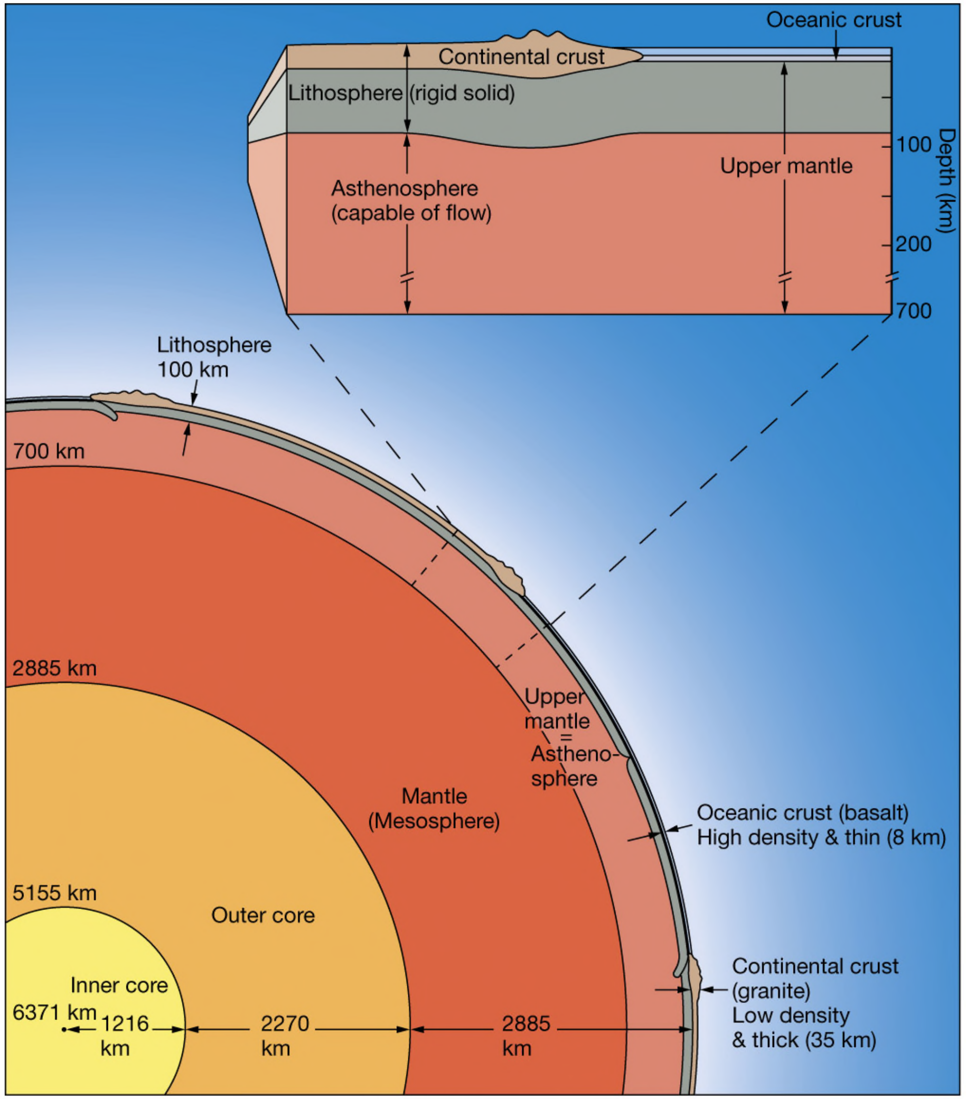


- ✓ Continent Crust
- ✓ Ocean Crust
- ✓ Lithosphere
- ✓ Asthenosphere
- ✓ Lower Mantle
- ✓ Outer Core
- ✓ Inner Core

Earth's Interior

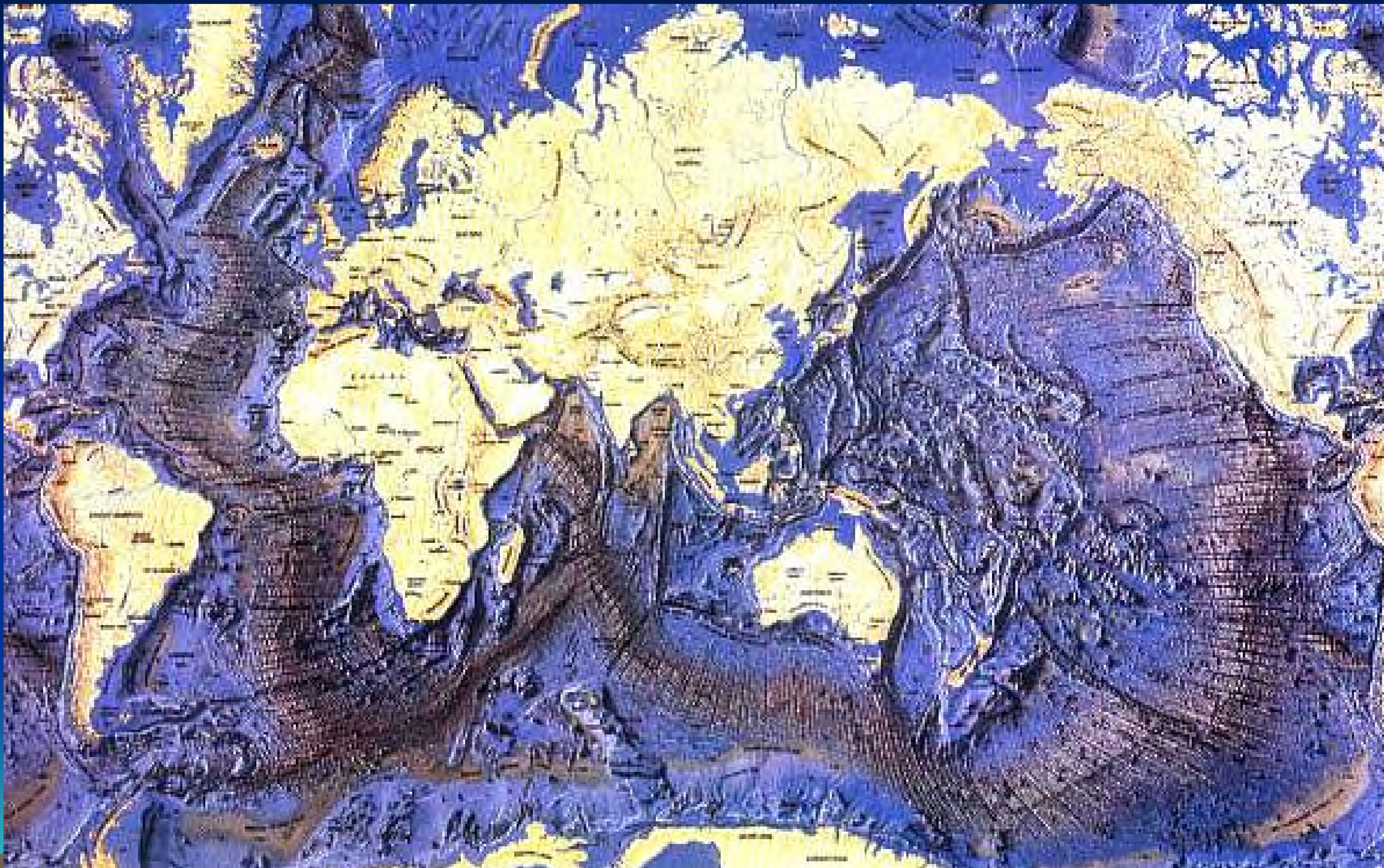
Chemical and Physical Nature of Earth's Interior





Density Layering of Earth's Interior

Earth’s Surface Physiology

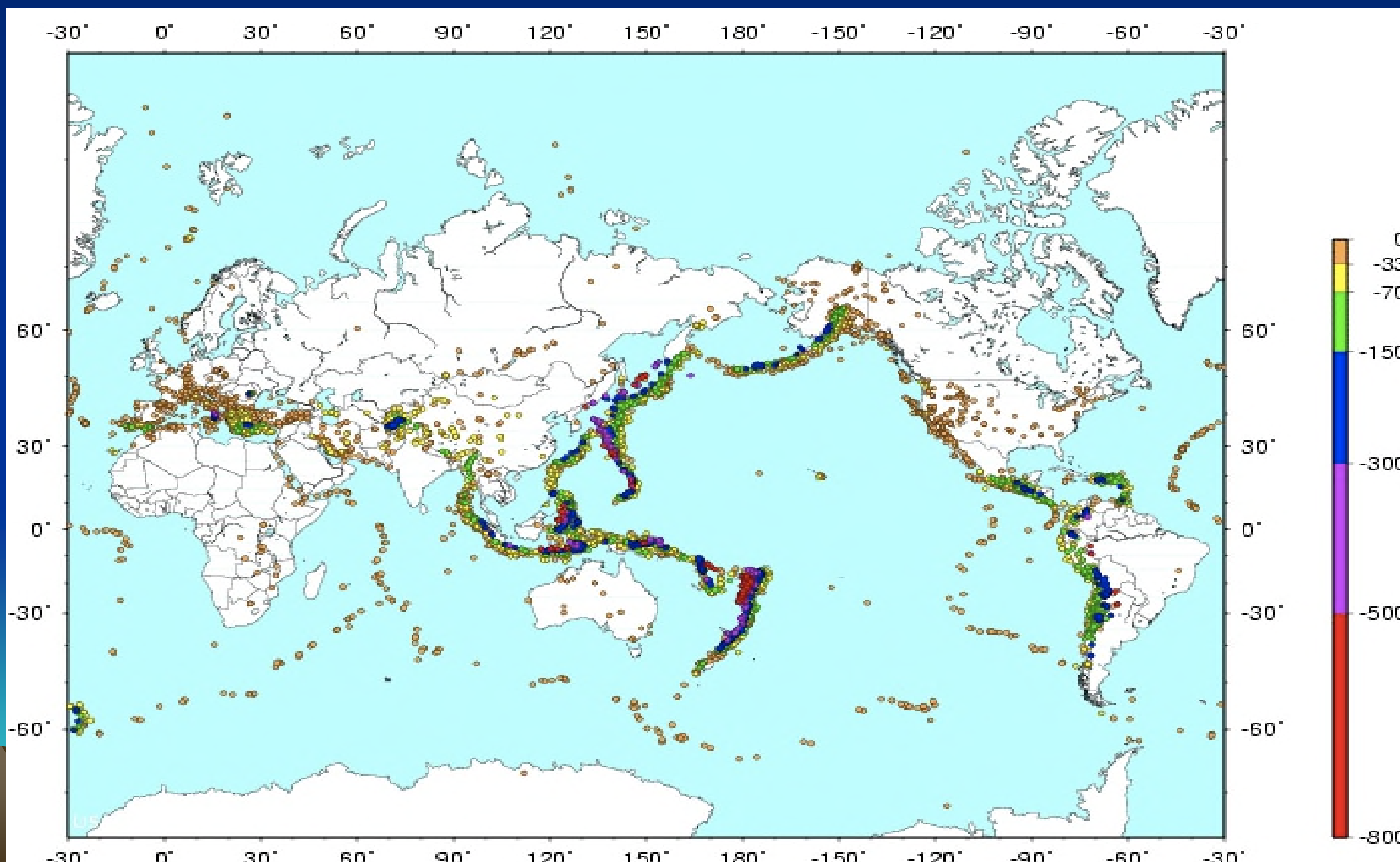


Global-Scale Earthquake Patterns

<u>Observations</u>

1) Earthquakes trace the mid-ocean ridge, trench, and fracture systems
2) Shallow earthquakes trace all the plate boundaries
3) Deep earthquakes trace the trench-volcanic arc systems

1. Ocean Basin Physiology and Tectonism

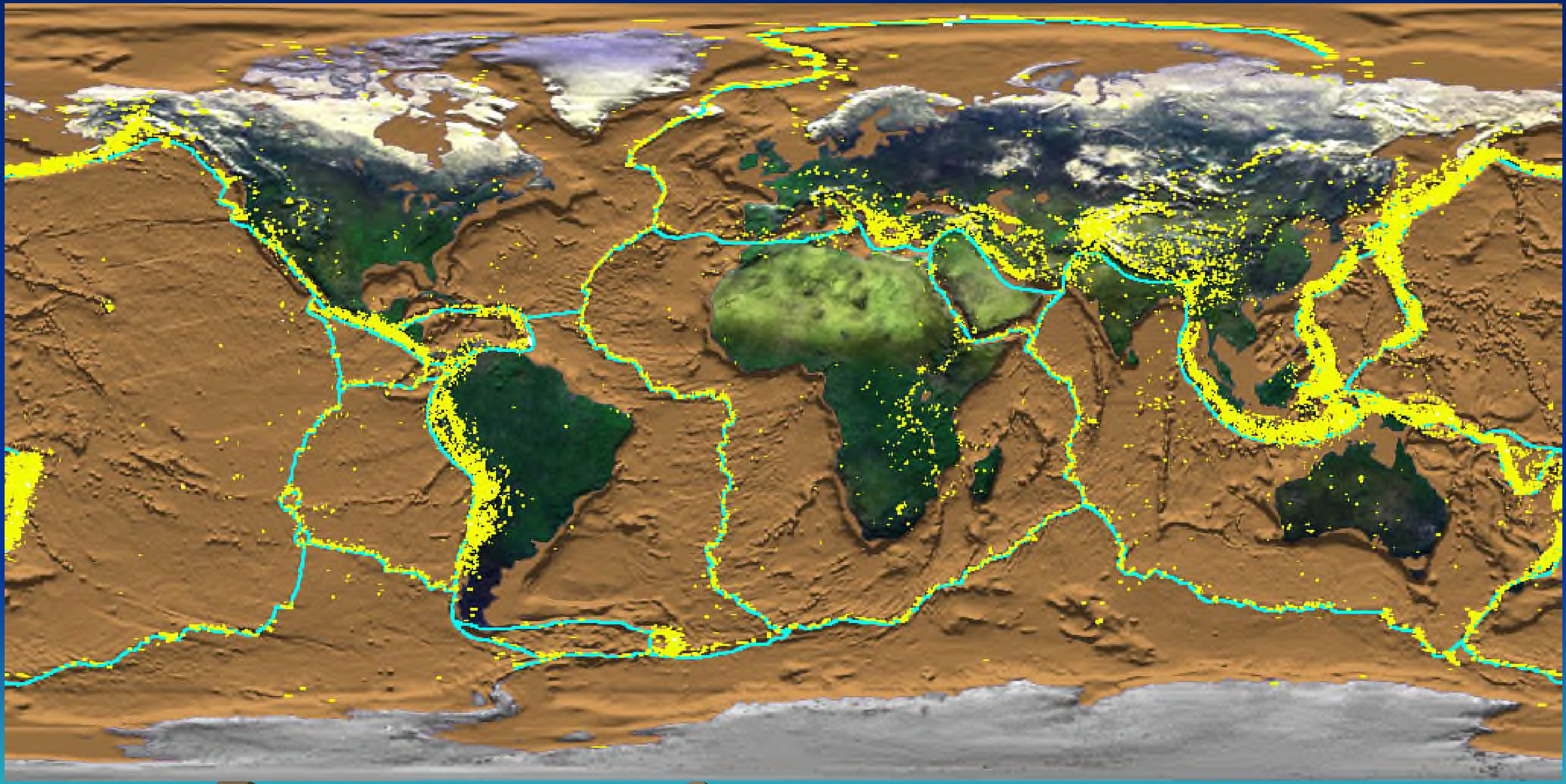


Global-Scale Earthquake Patterns

Observations

1) Narrow earthquake traces at mid-ocean ridges and transform systems
2) Broad earthquakes traces for trenches and collision boundaries

1. Ocean Basin Physiology and Tectonism



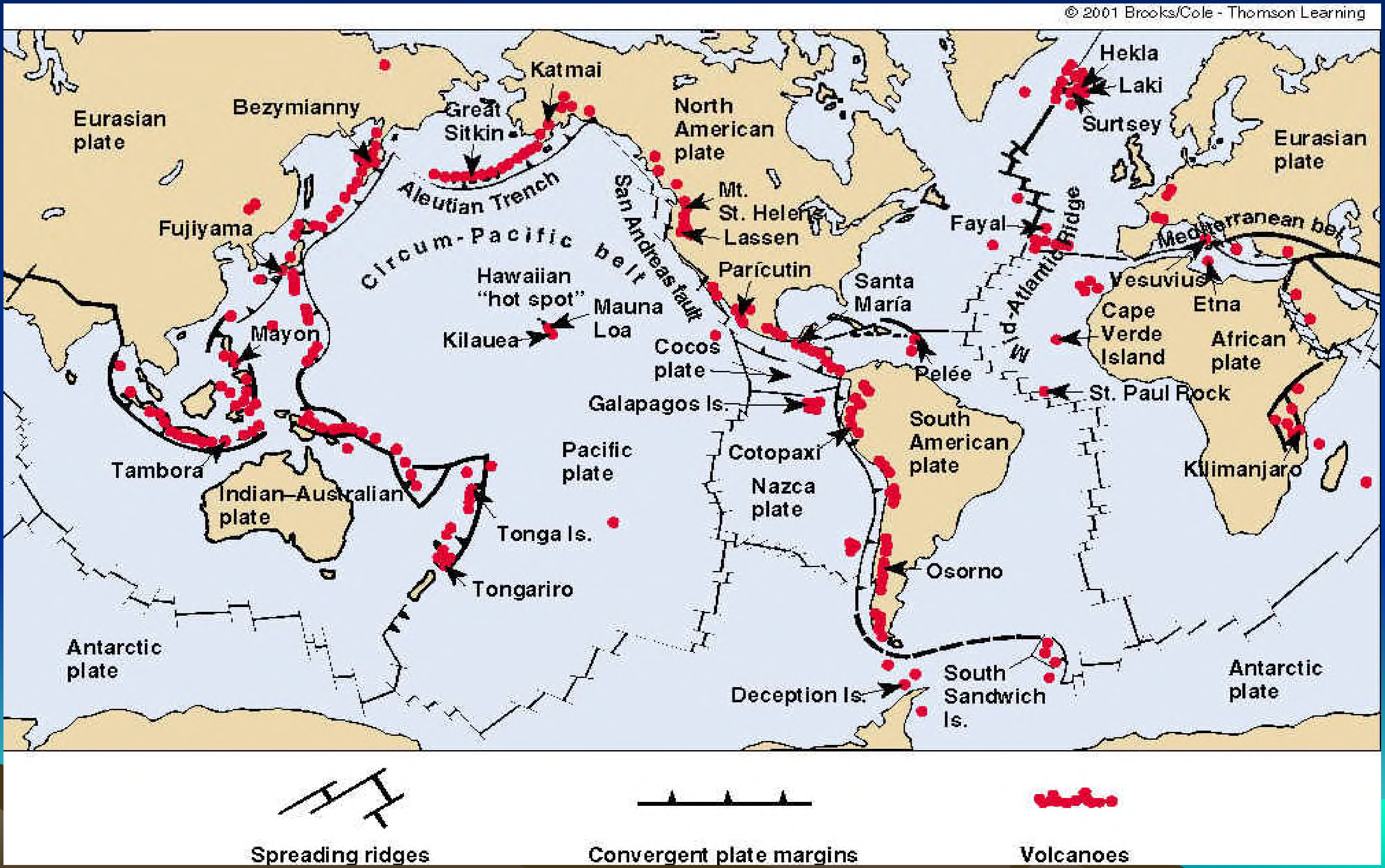
Global-Scale Volcanic Patterns

Observations

1) Active volcanoes trace mid-ocean ridges and volcanic arcs systems

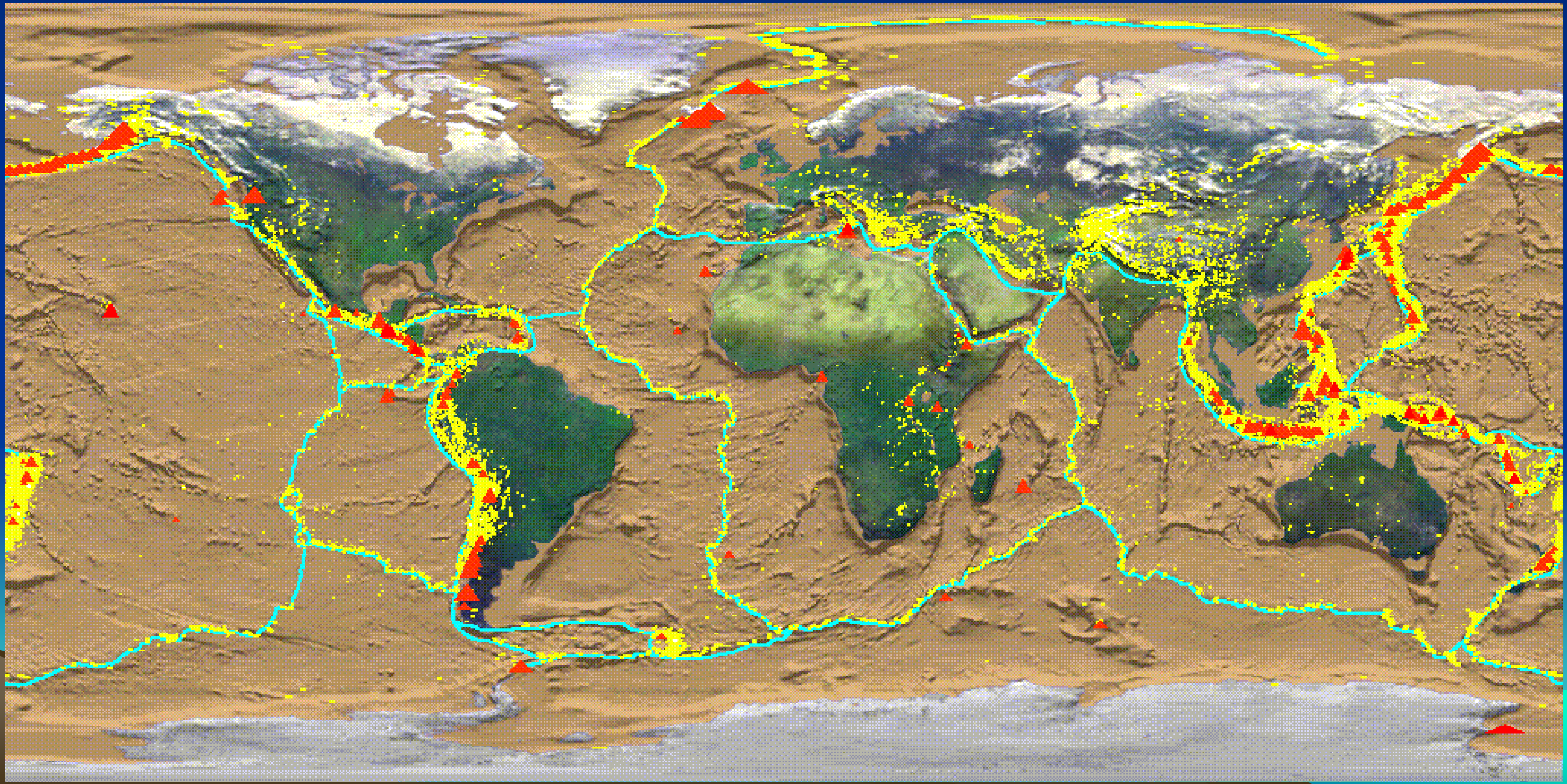
2) Most active volcanoes trace the subduction-related plate boundaries

1. Ocean Basin Physiology and Tectonism



What's the Relationship Between Active Volcanoes, Earthquakes, Seafloor Features, and Plate Boundaries?

1) Active volcanoes trace mid-ocean ridges and deep-sea trench systems
2) Major earthquakes also trace those features, plus major strike slip faults
3) Traces of major earthquakes overlap nicely with active volcanoes



Plotting Earthquake and Volcano Data from Data Maps on to your Transparency Map

1) Plot shallow earthquakes to compare with plate boundaries
2) Plot deep earthquakes to compare with trenches and subduction zones
3) Plot arc volcanoes to compare with trenches and subduction zones.

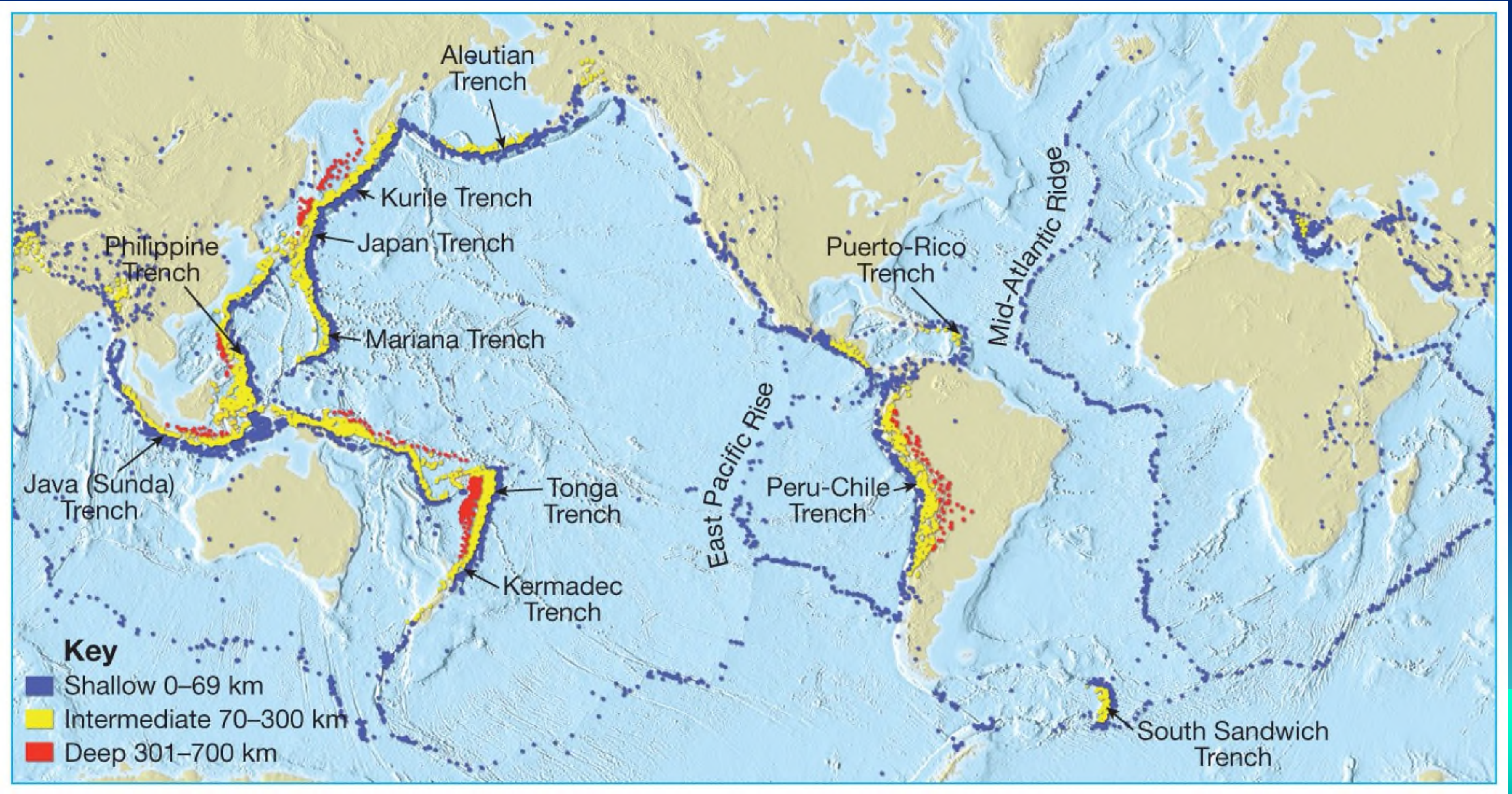
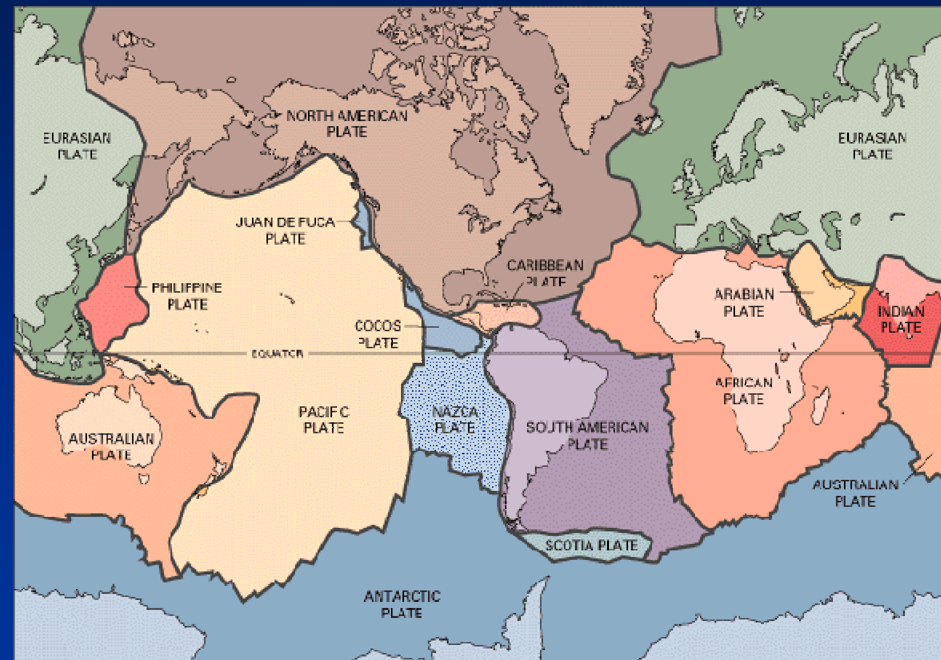


PLATE TECTONICS THEORY

Key Features:

- ✓ 6 Major Plates
- ✓ 8 Minor Plates
- ✓ 100 km thick
- ✓ Strong and rigid
- ✓ Plates float on top of soft asthenosphere
- ✓ Plates are mobile
- ✓ Plates move at a rate of centimeters per year

Earth's Lithospheric Plates



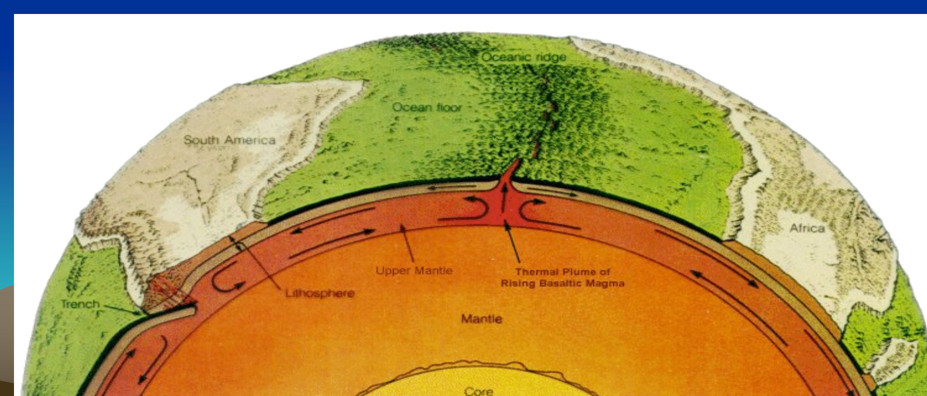
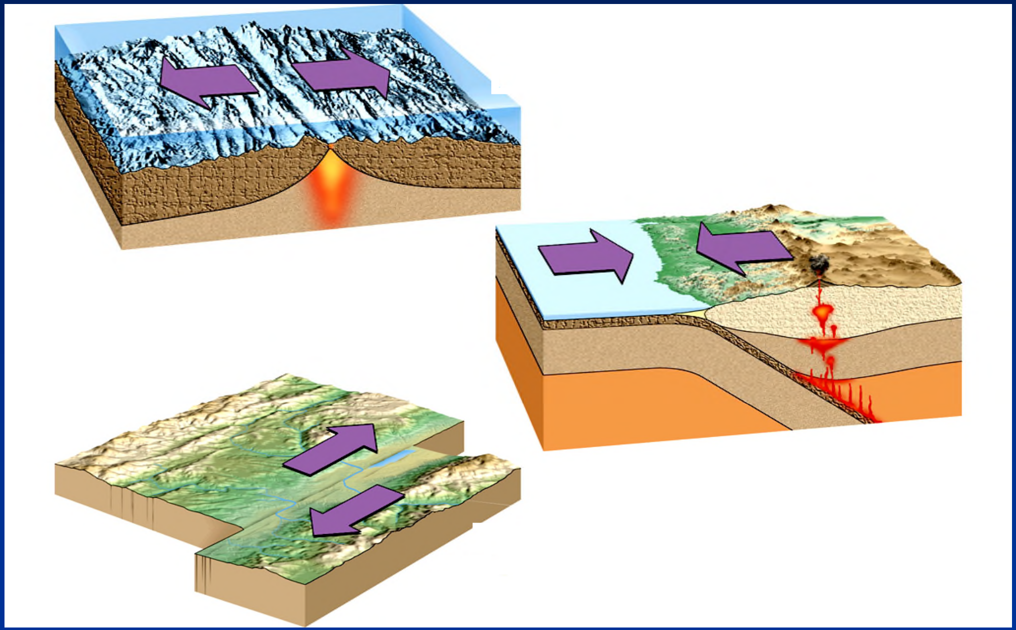
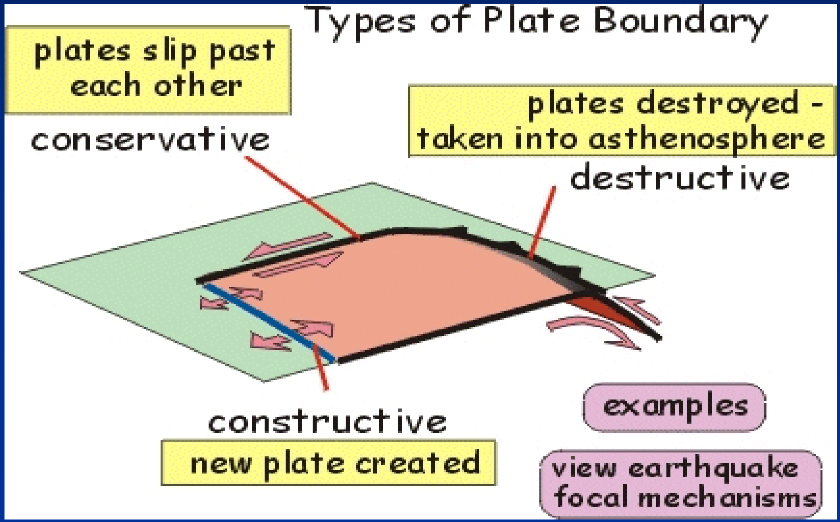


PLATE TECTONICS

Three Principle Types of Plate Boundaries





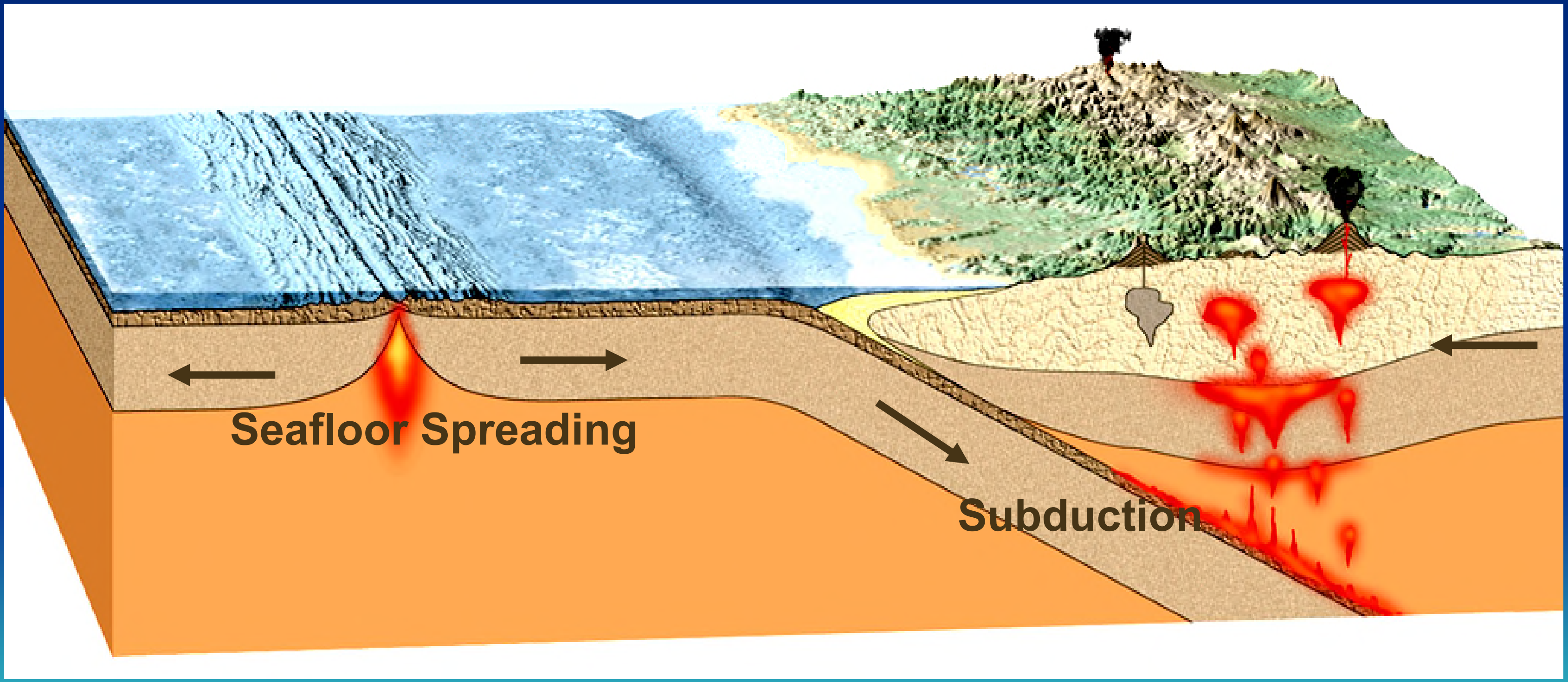
1) **Divergent = Tensional Stress = Constructive Tectonics**
2) **Convergent = Compressional Stress = Destructive Tectonics**
3) **Transform = Lateral Shear Stress = Conservative Tectonics**

PLATE TECTONICS

Two Principle Tectonic Processes

1) Seafloor Spreading = Constructive

2) Subduction = Destructive



Seafloor Spreading and Subduction Animation

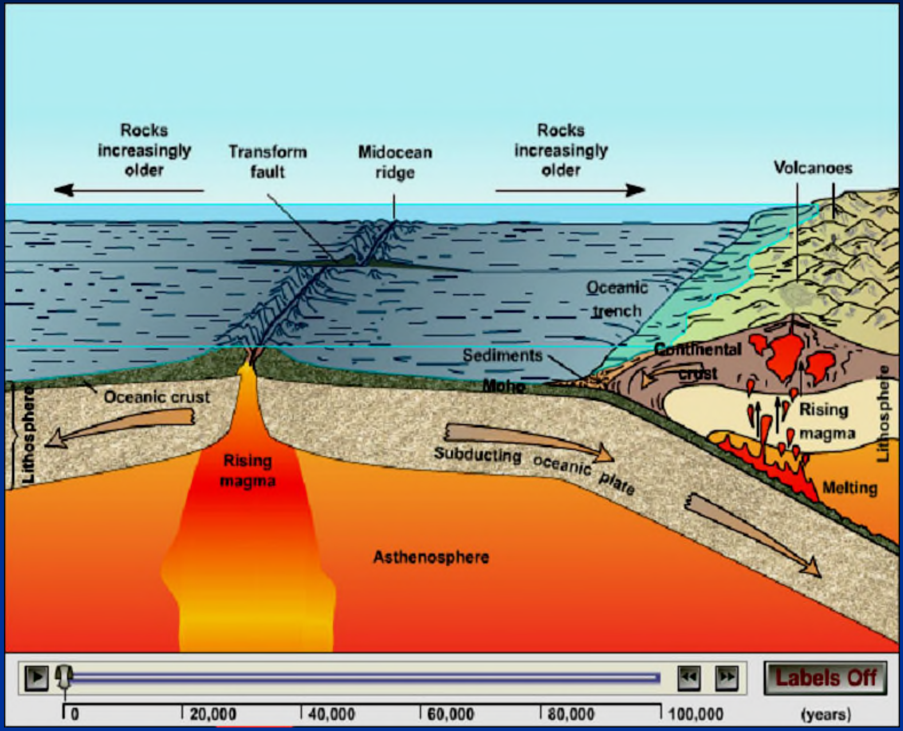
Key Features:

1) **The illustration shows both progressive growth and destruction of oceanic lithosphere by seafloor spreading and subduction, respectively.**

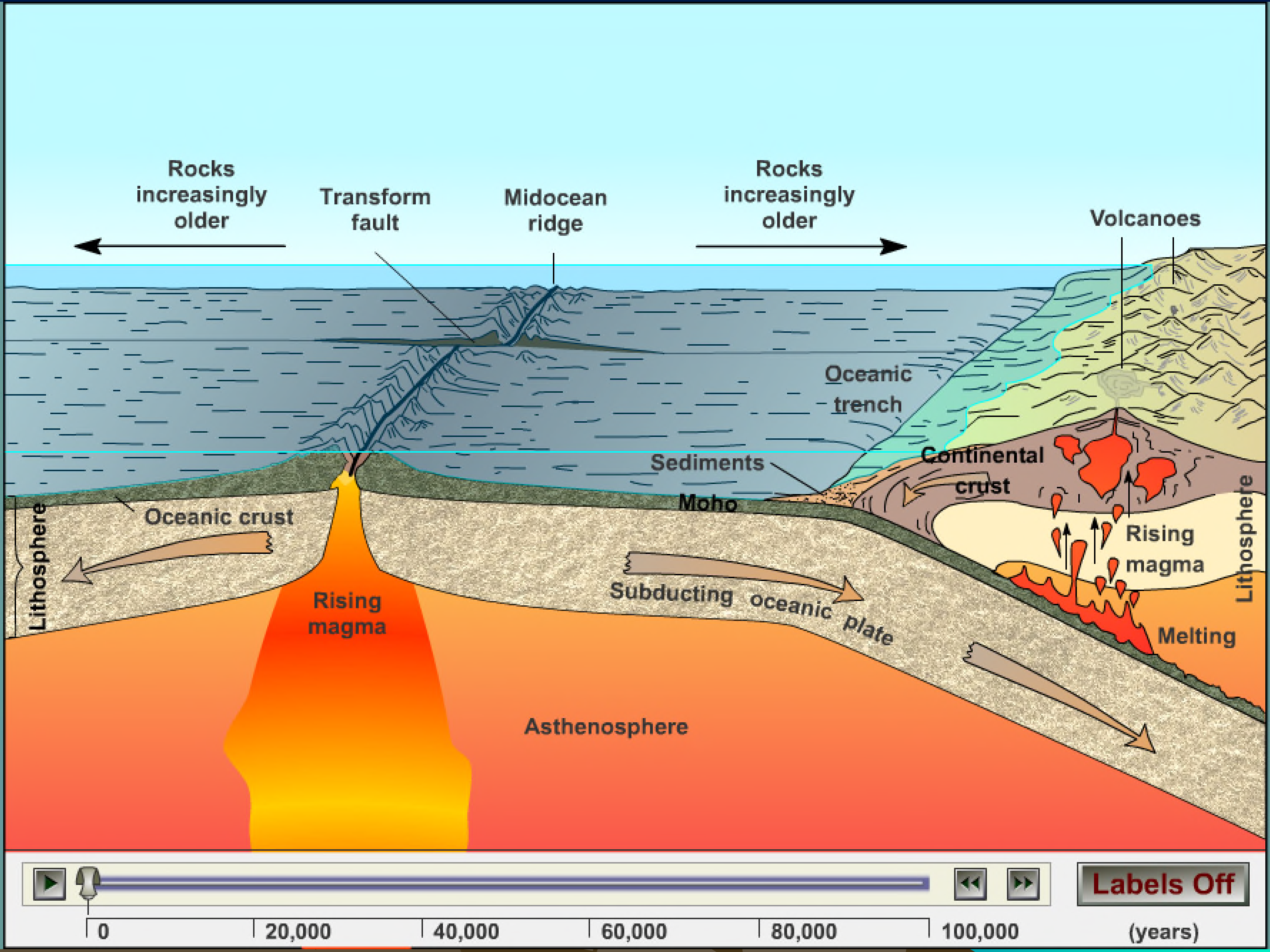
2) **Basaltic magmas are generated at both centers of seafloor spreading and subduction.**

3) **Magmas at seafloor spreading centers are hot, fluid and dry, and produce relatively non-violent eruptions**

4) **Magmas at subduction centers are rich in silica and water and produce infrequent, massive, and violent volcanic eruptions**



Go to the Next Slide To Start Animation



Rocks increasingly older
Transform fault
Midocean ridge
Rocks increasingly older
Volcanoes
Oceanic trench
Sediments
Continental crust
Moho
Oceanic crust
Lithosphere
Rising magma
Subducting oceanic plate
Rising magma
Lithosphere
Melting
Asthenosphere
Labels Off
0
20,000
40,000
60,000
80,000
100,000
(years)

PLATE TECTONICS

Three Types of Convergent Plate Boundaries

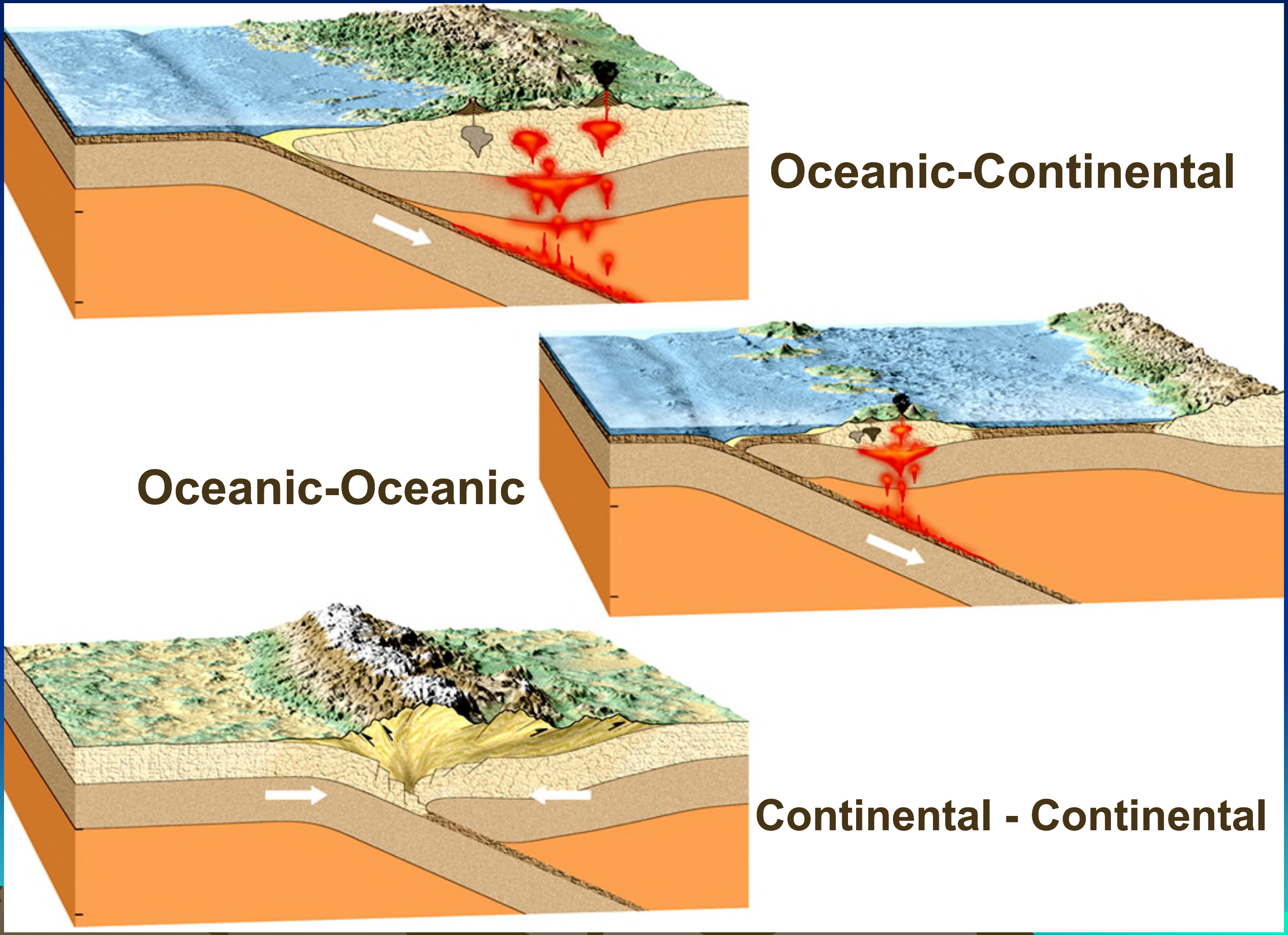
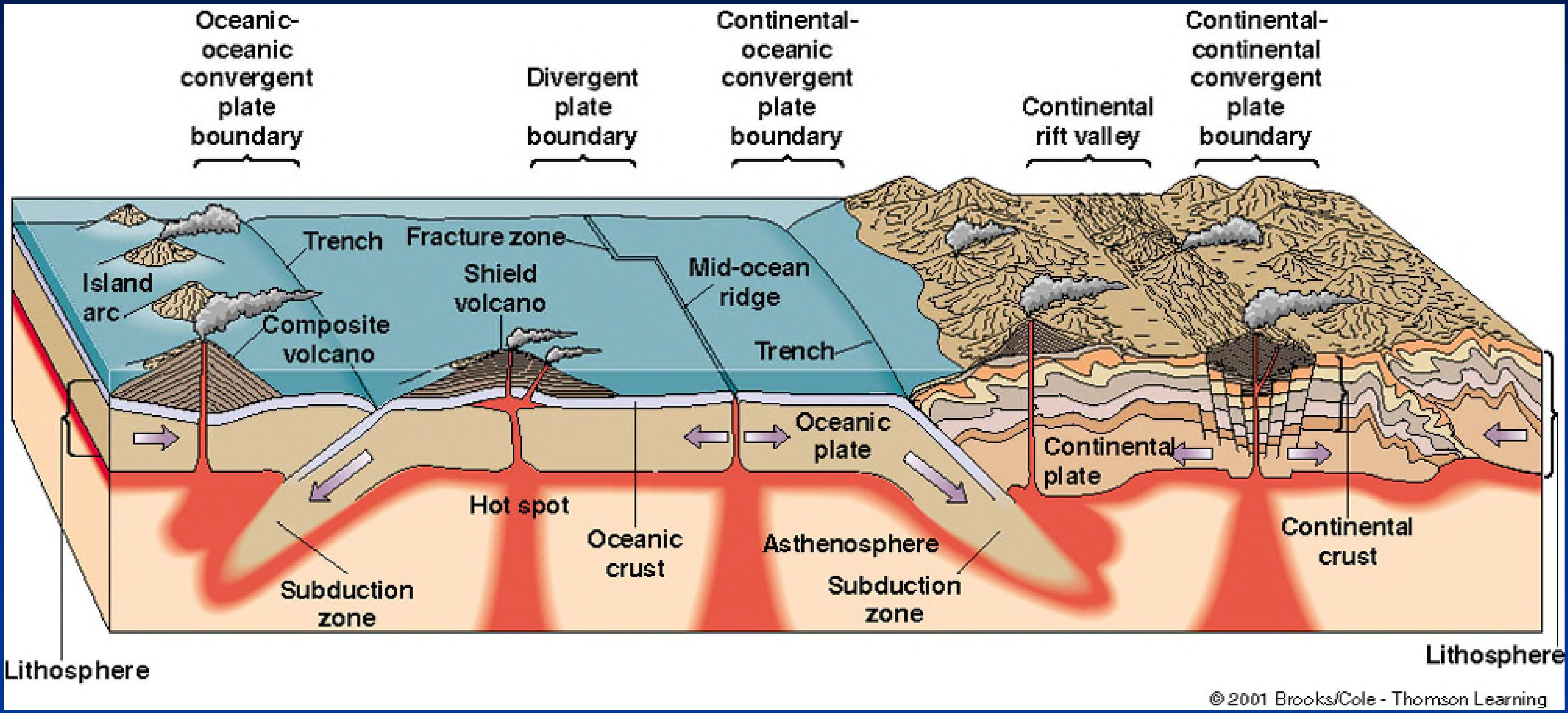
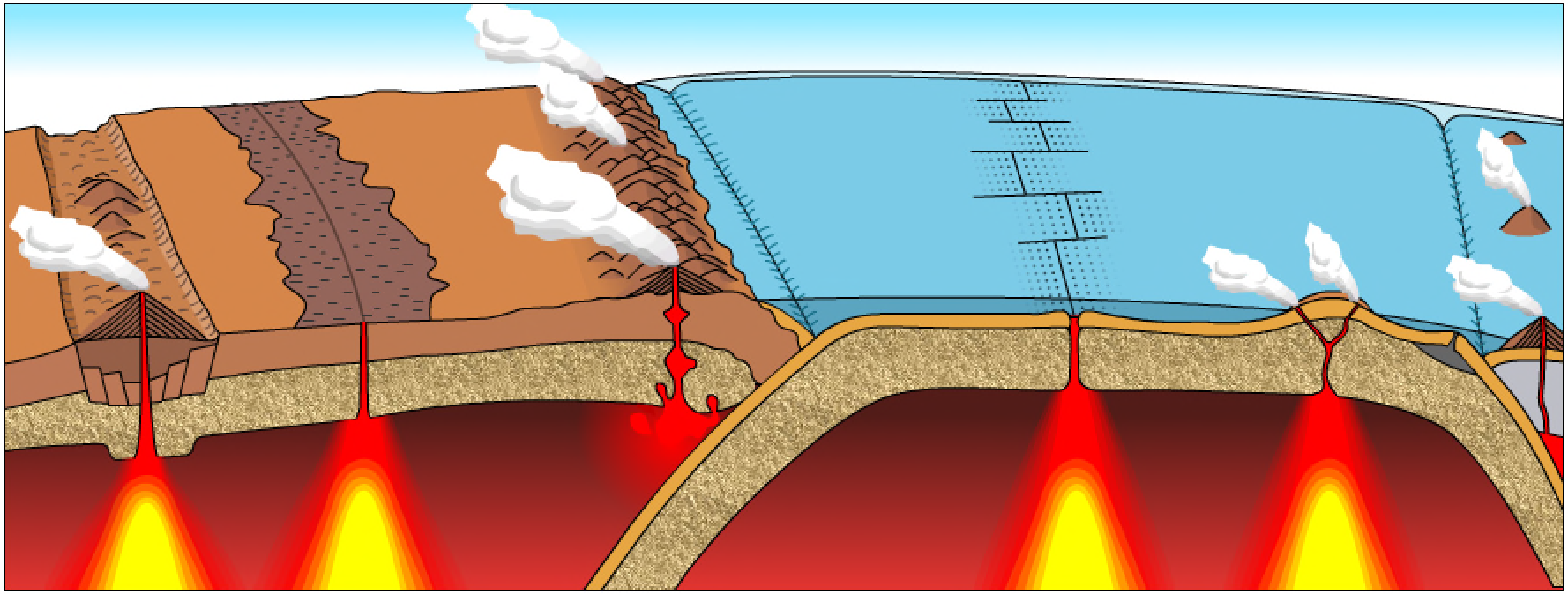


Plate Boundary Configurations



Tectonic Settings of Volcanic Activity

Continental rift volcanism | Continental volcanic arc | Hot-spot volcanoes | Volcanic-island-arc



Three Ways to Determine Plate Motion Direction & Speed

1) Paleomagnetic Anomalies in Seafloor Crust

2) Hot Spot Volcanism

3) Strike Slip Faulting Offsets

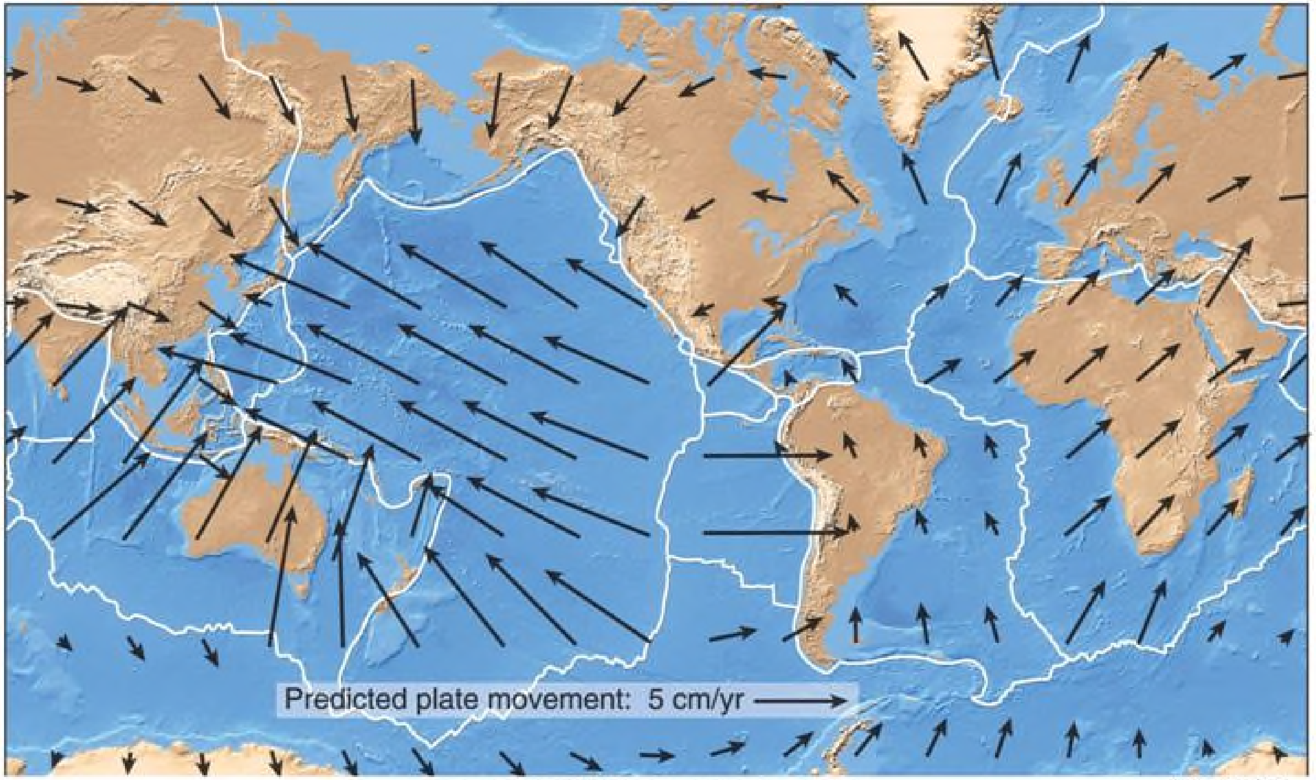


Fig 12.37

Determining Plate Direction and Speed for Transform Faults

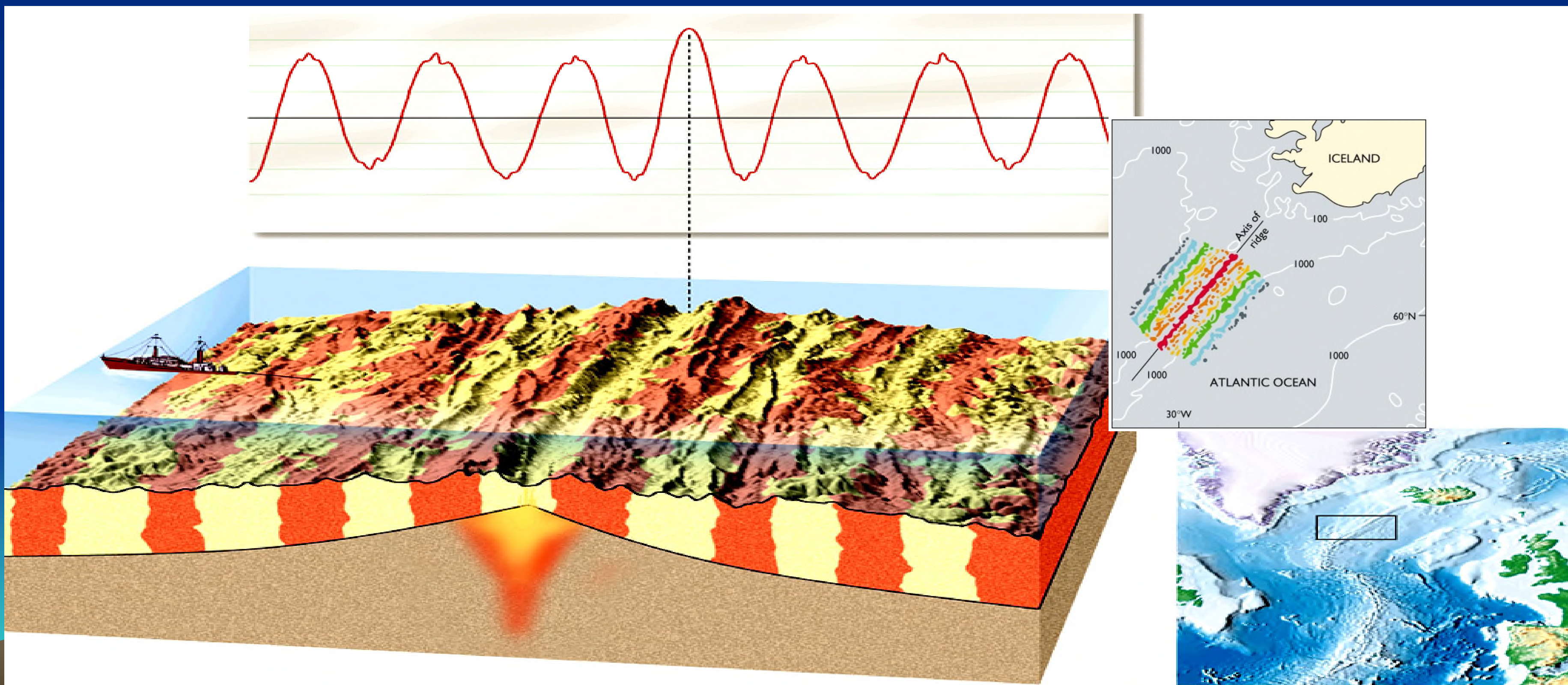
Speed Calculation

- **Rate = Offset Distance / Age of Offset Feature**
- Plate speed measuring cm's/yr
- Km → cm   Conversion: 10^5 cm = 1 km
- 1×10^6 yr = 1 million yr
- Distance: Split Offset Marker distance (use scale on map with ruler)
- Time: Age difference of Offset Marker
- Make sure units cancel when doing conversions

Paleomagnetism and Seafloor Spreading

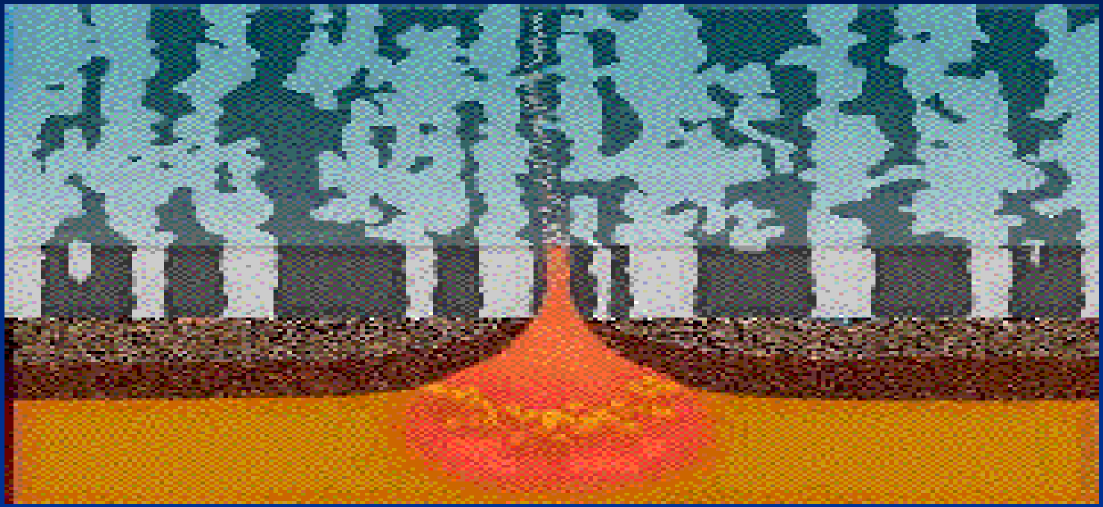
Magnetic Polarity-Reversal Anomalie in Seafloor Crust

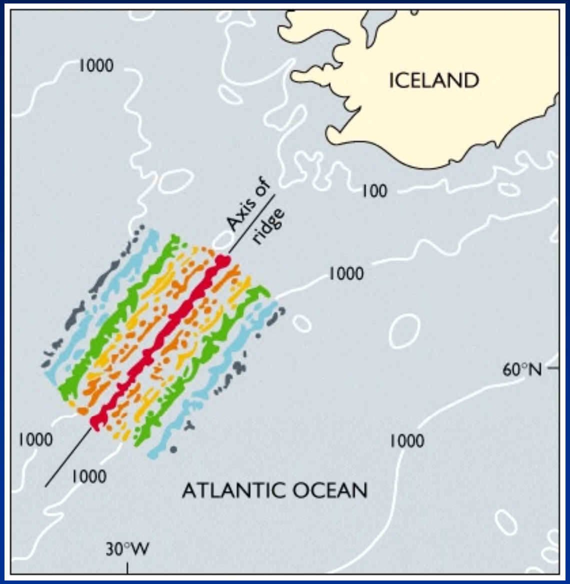
- Spatial layout of seafloor rock magnetization
- Age relationships of recorded polarity reversals
- Mid-ocean ridge systems mirrors polarity patterns



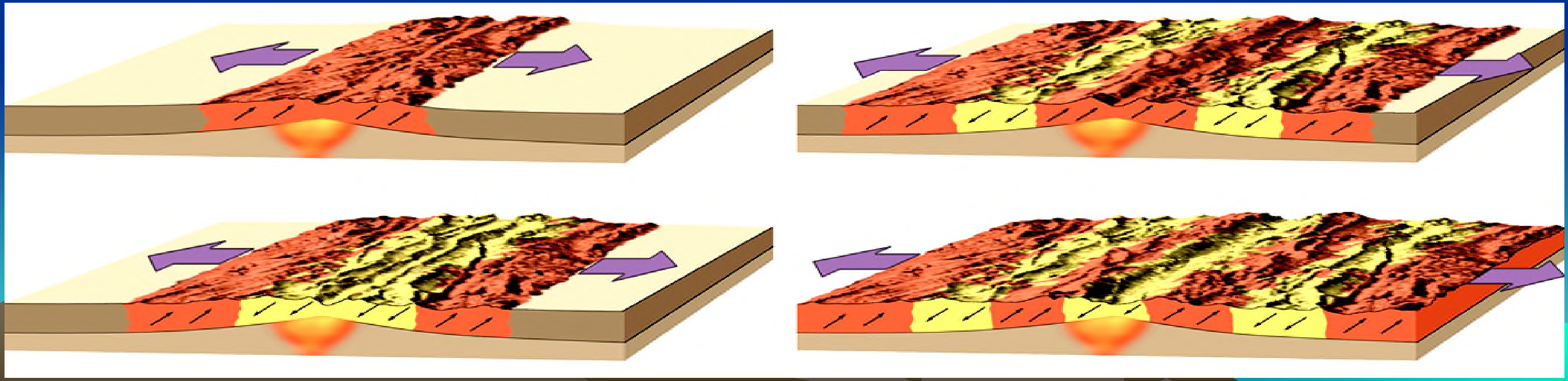
Evidence for Seafloor Spreading and Oceanic Plate Motion

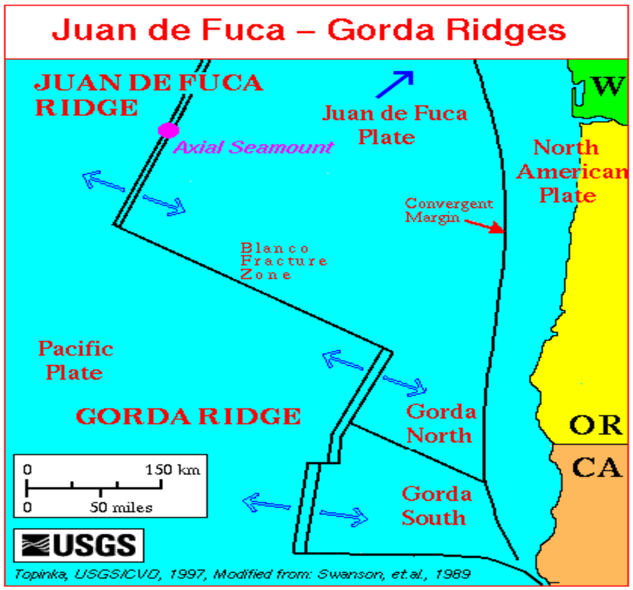
Magnetic Polarity-Reversal Anomalies of Seafloor Rocks

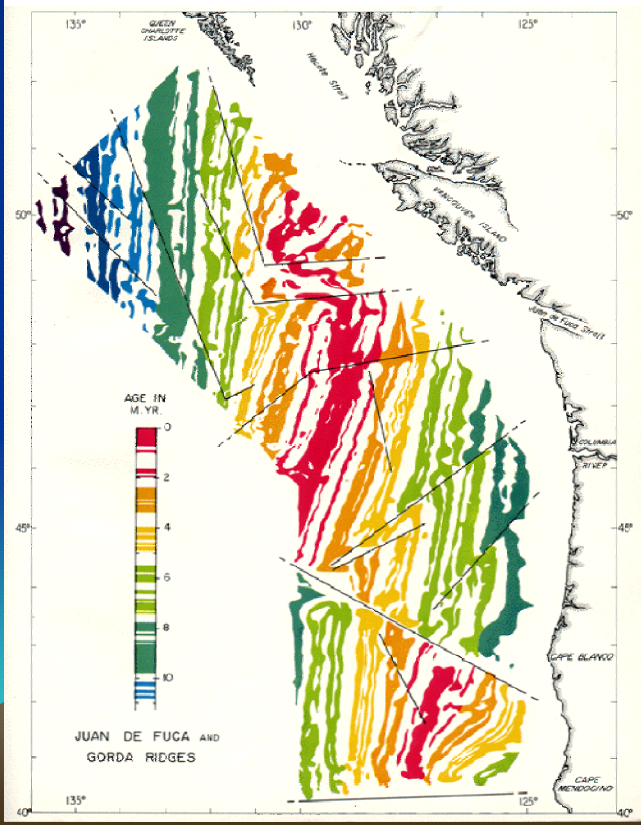


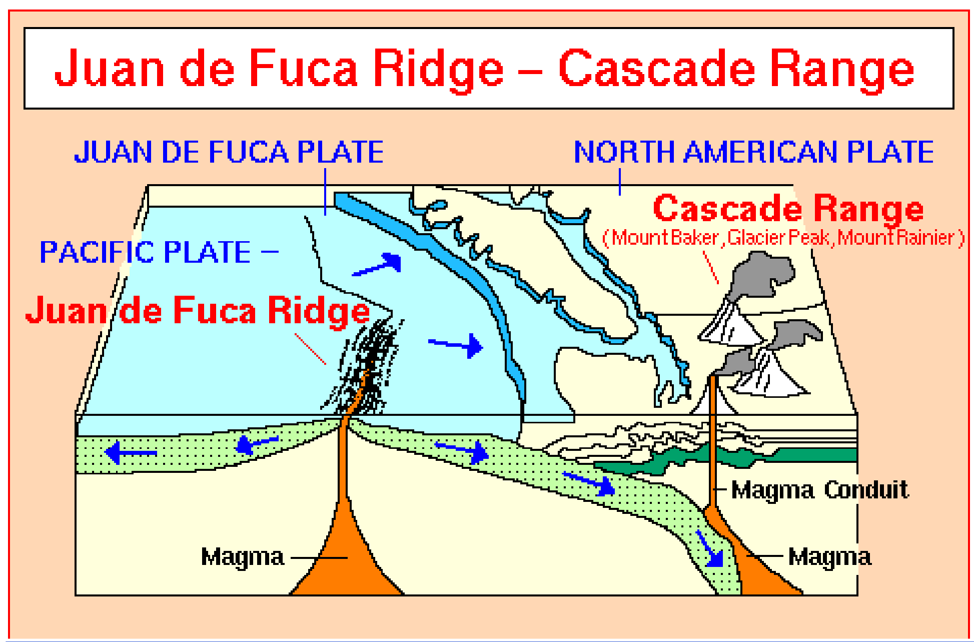


Example: North Atlantic









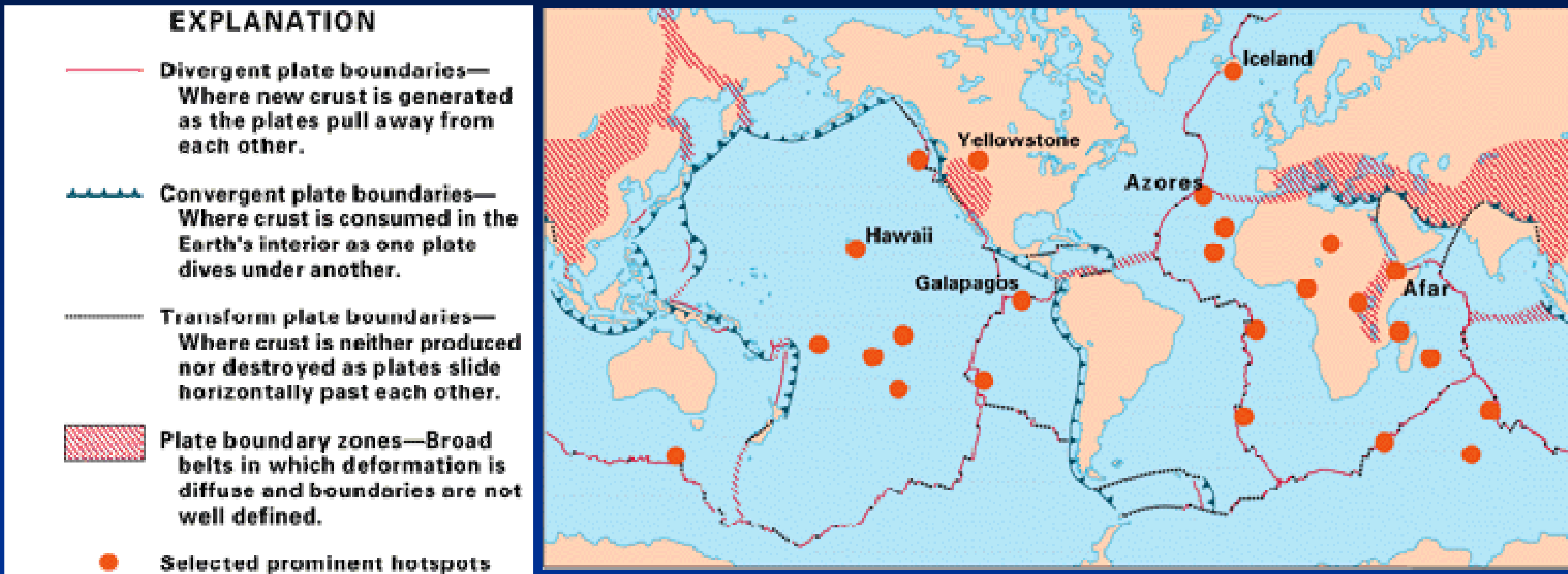
Juan de Fuca Spreading Center and Cascade Subduction System

Determining Plate Directions and Speed for Seafloor Spreading Centers

peed Calculation

- **Rate = Distance / Time**
- Plate speed measuring cm's/yr
- Km → cm   Conversion: 10^5 cm = 1 km
- 1×10^6 yr = 1 million yr
- Distance: Between Age-paired Magnetic Stipes across MOR (use scale on map with ruler)
- Time: Age difference of Magnetic Stripes
- Make sure units cancel when doing conversions

Earth's Hot Spots

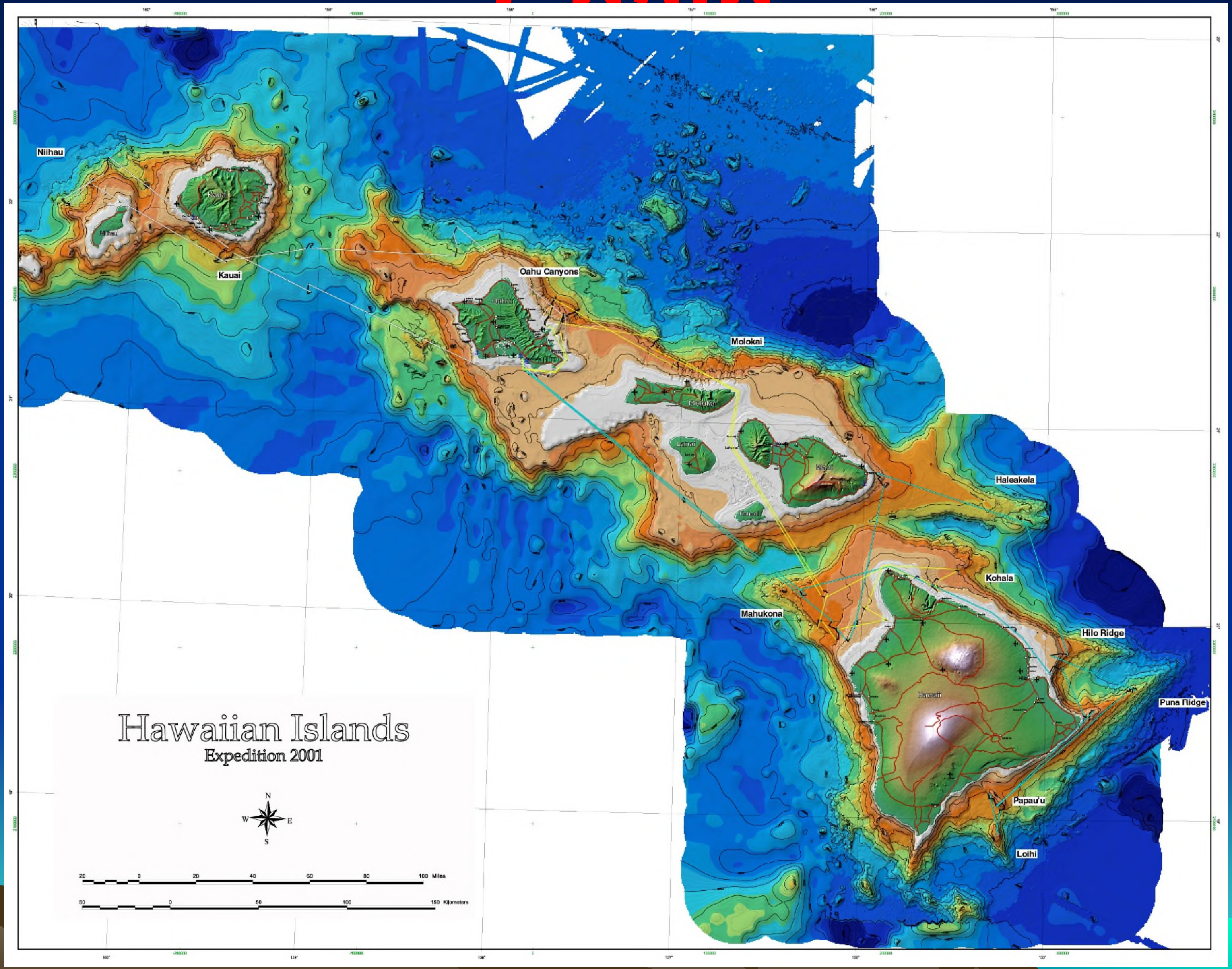



Hawaii

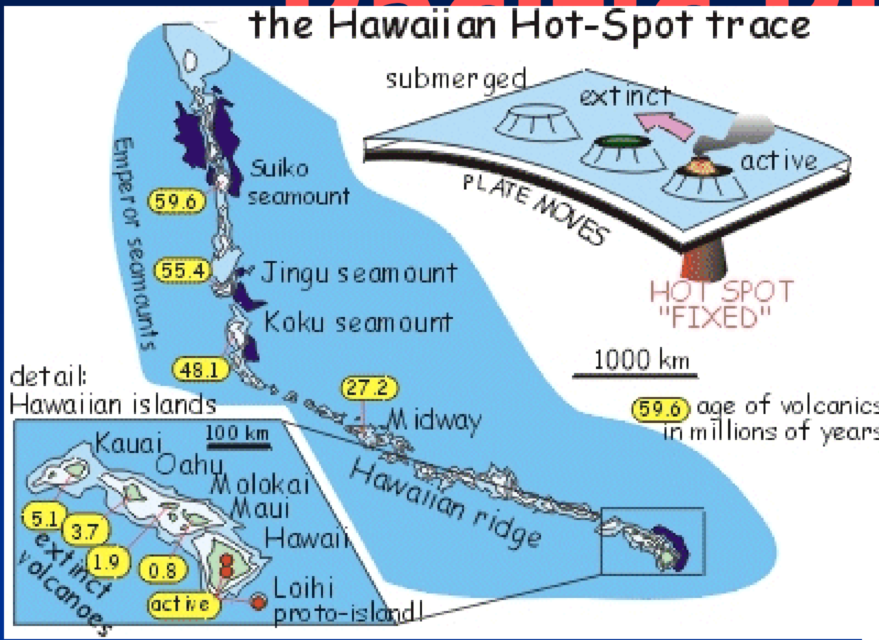

Yellowstone

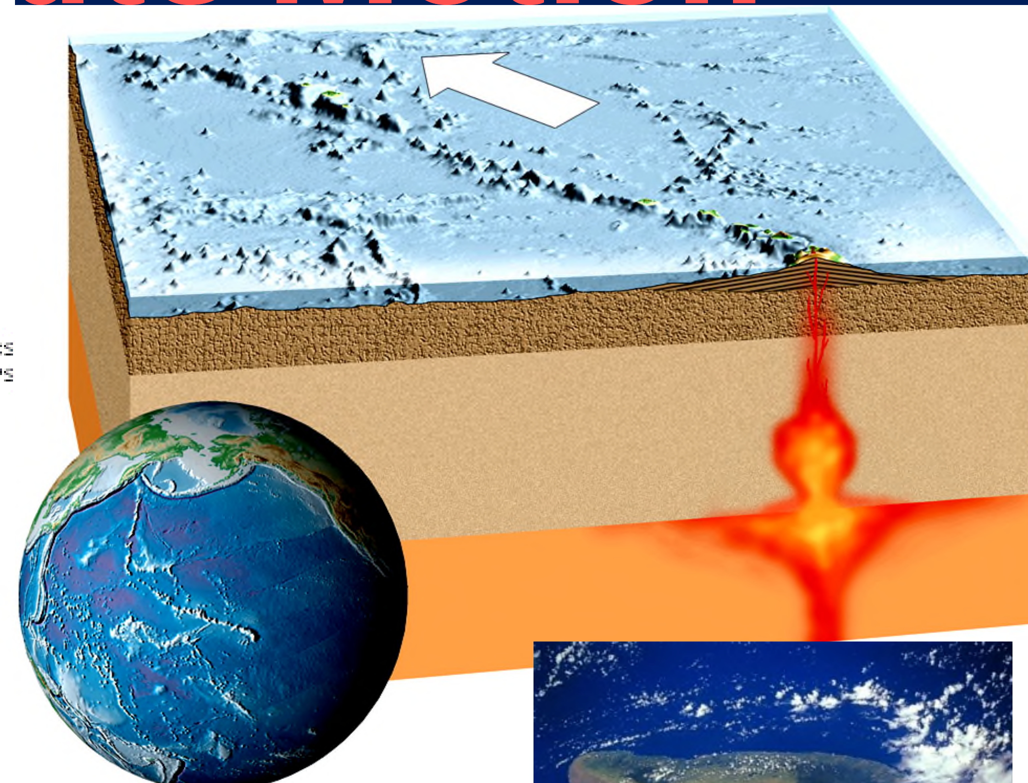

Iceland

Hawaiian Island Volcanic Chain



Hawaiian Hot Spot and Pacific Plate Motion



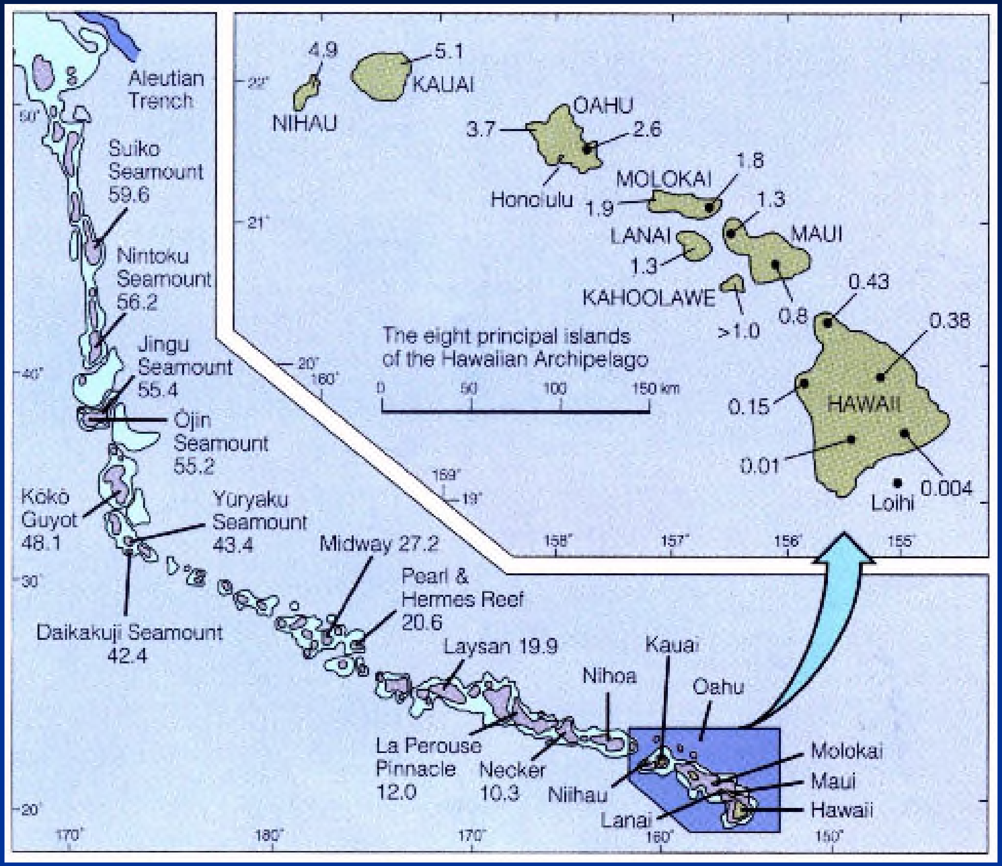


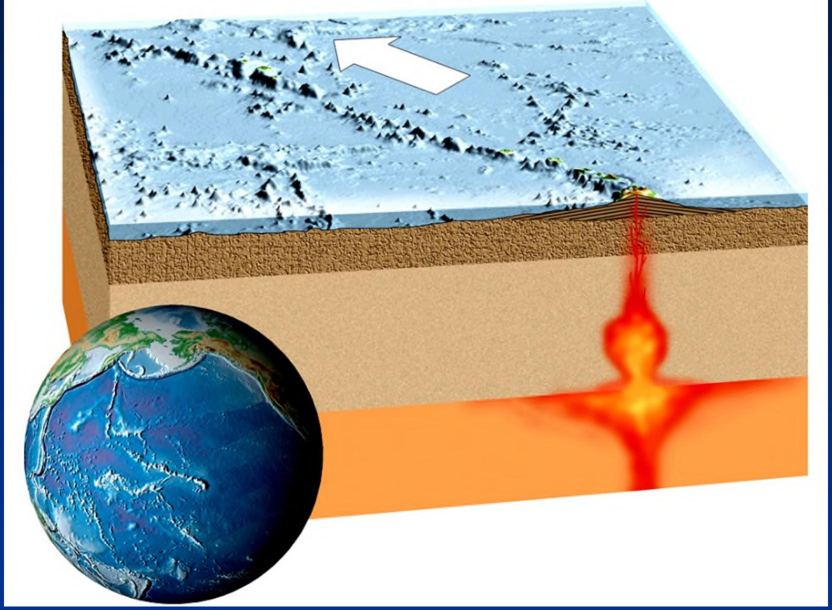
Key Points:

✓ Hot spot plume anchored in mantle = assumed to be ***stationary***

✓ ***Distance and age*** between linear sequence of hot spot- generated volcanic centers indicates the ***direction and rate*** of motion of lithospheric plate

Hawaiian Hot Spot and Pacific Plate Motion



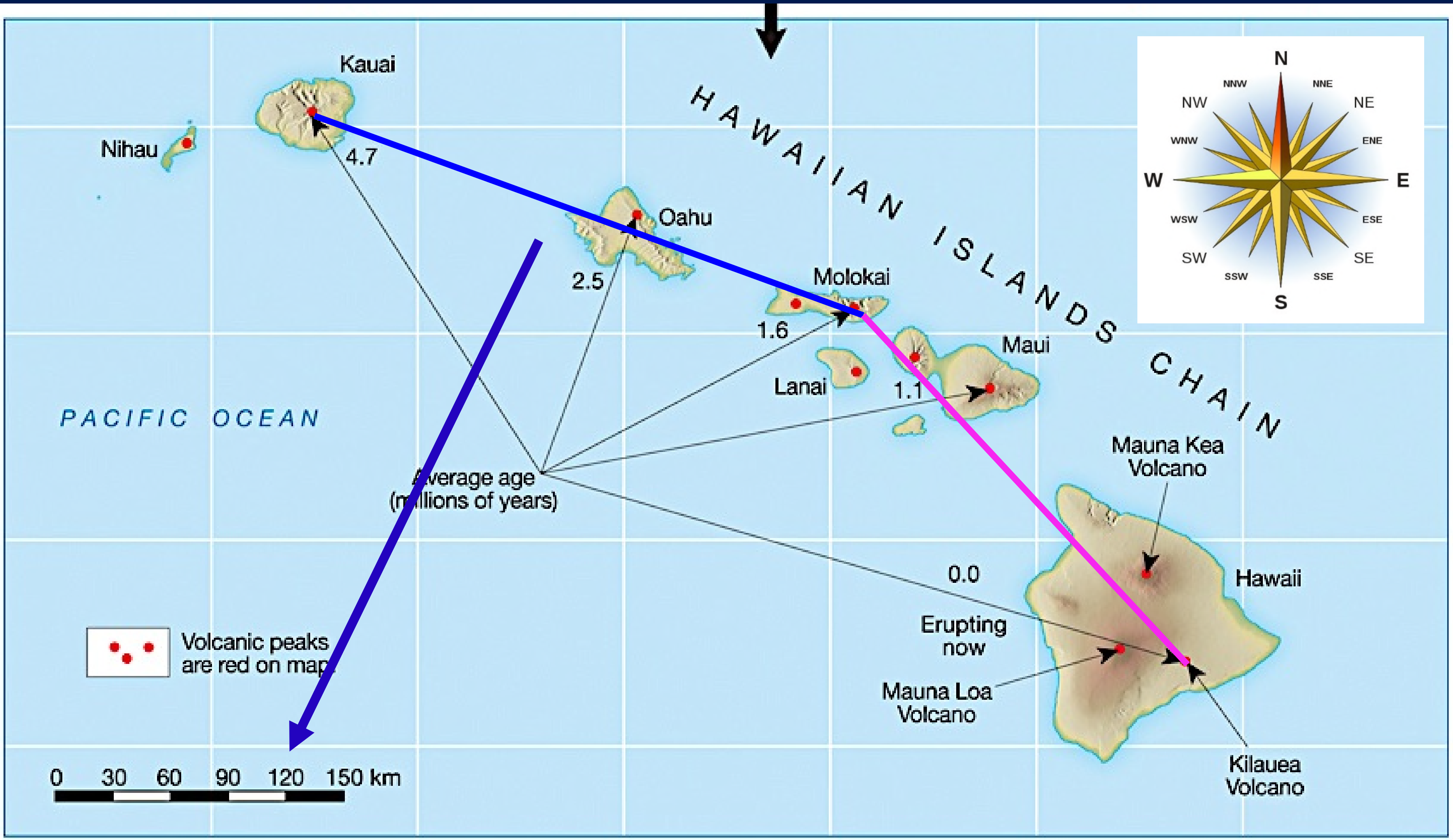


Key Points:

✓ Hot spot plume anchored in mantle = assumed to be ***stationary***

✓ ***Distance and age*** between linear sequence of hot spot- generated volcanic centers indicates the ***direction and rate*** of motion of lithospheric plate

Determining Plate Direction and Speed

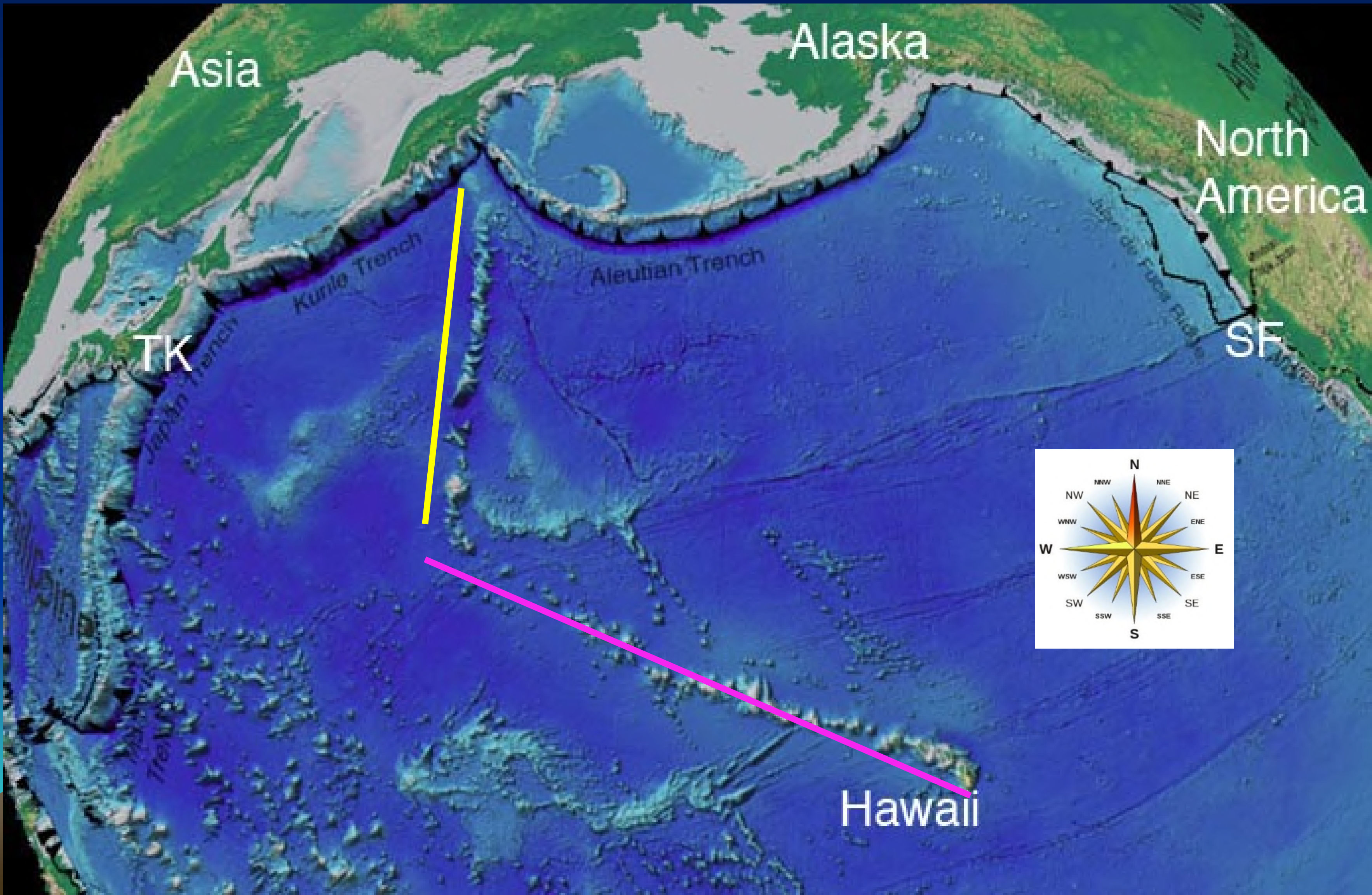


Determining Plate Direction and Speed for Hot Spot Traces

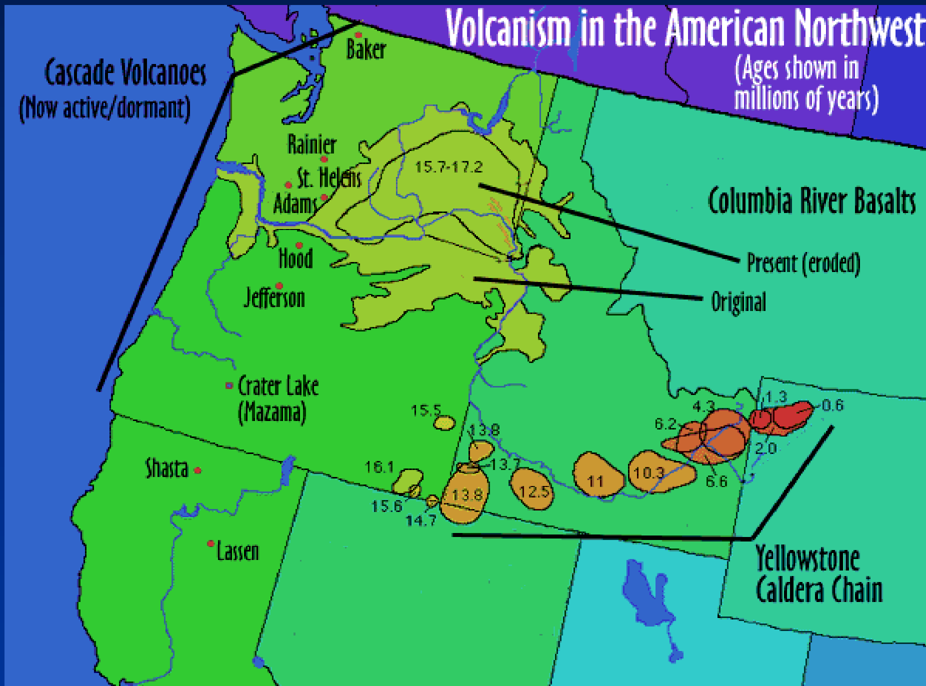
peed Calculation

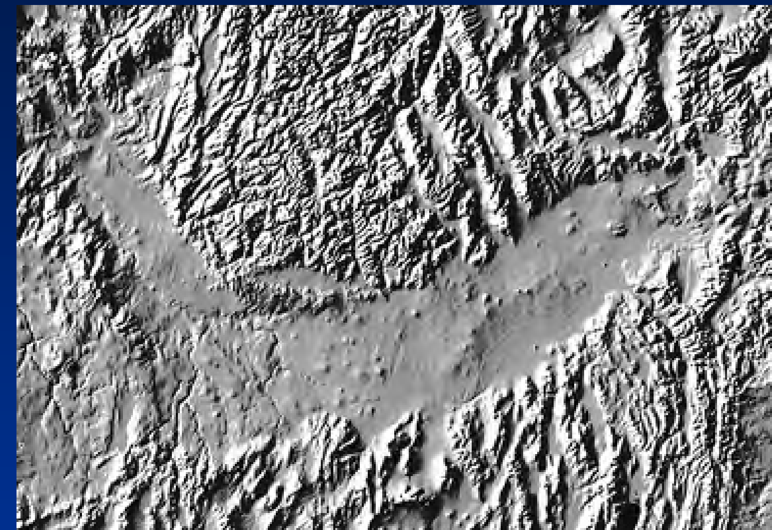
- **Rate = Distance / Time**
- Plate speed measuring cm's/yr
- Km → cm   Conversion: 10^5 cm = 1 km
- 1×10^6 yr = 1 million yr
- Distance: Between Volcanic Centers (use scale on map with ruler)
- Time: Age difference two Islands or Seamounts
- Make sure units cancel when doing conversions

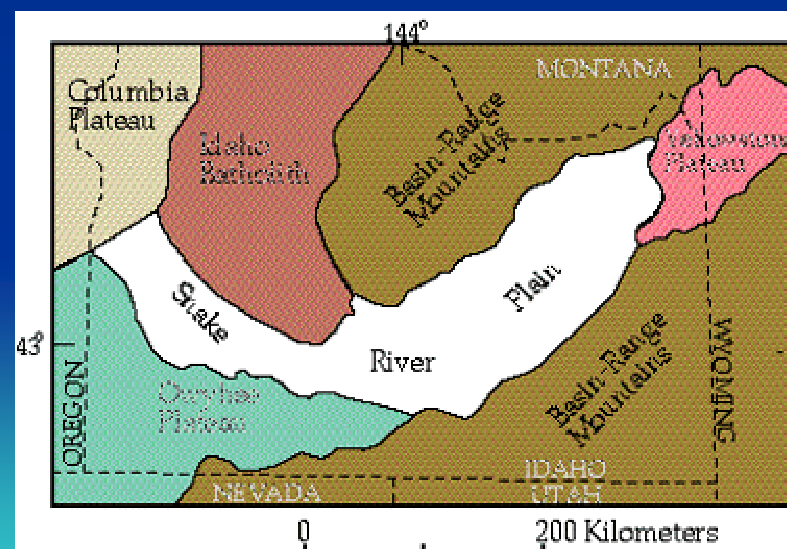
Emperor – Hawaiian Volcanic Island/Seamount Chains



Yellowstone Hot Spot





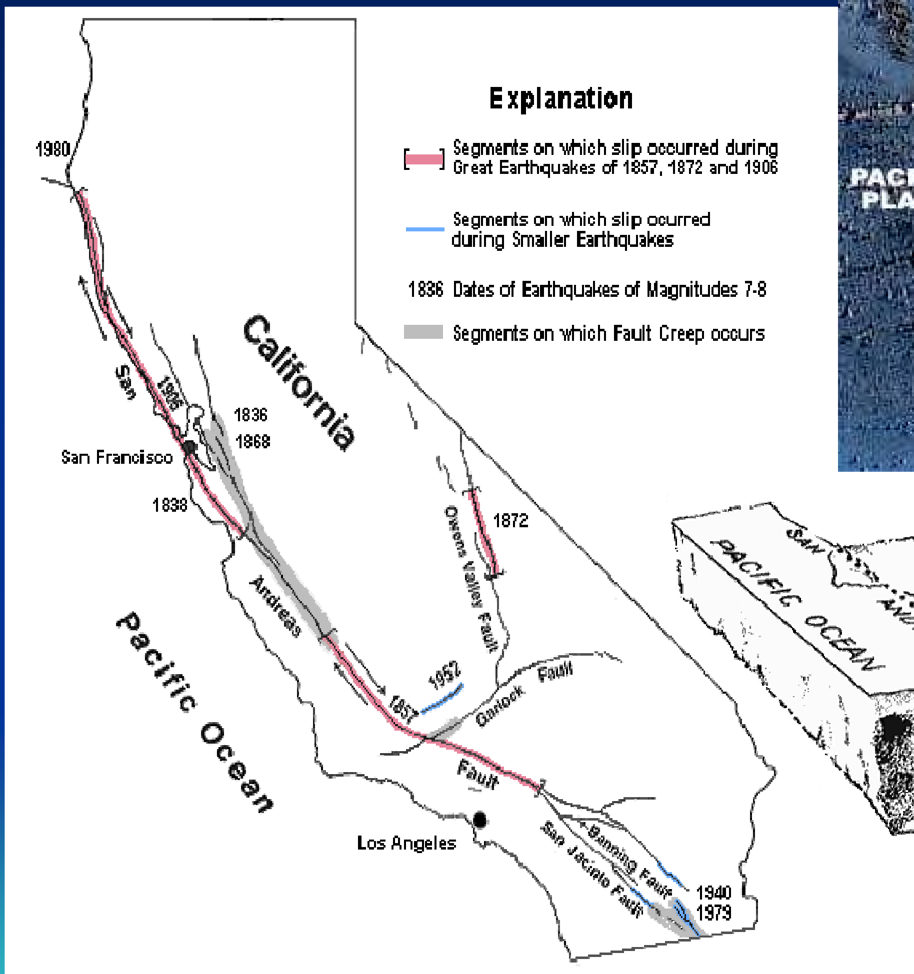


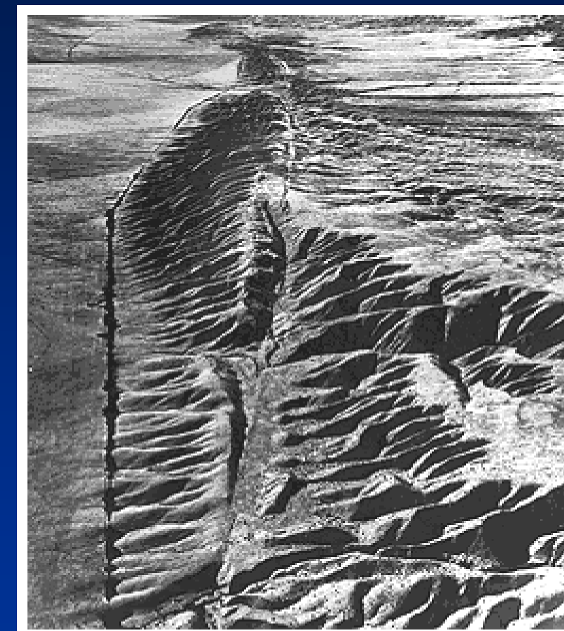
Key Points:

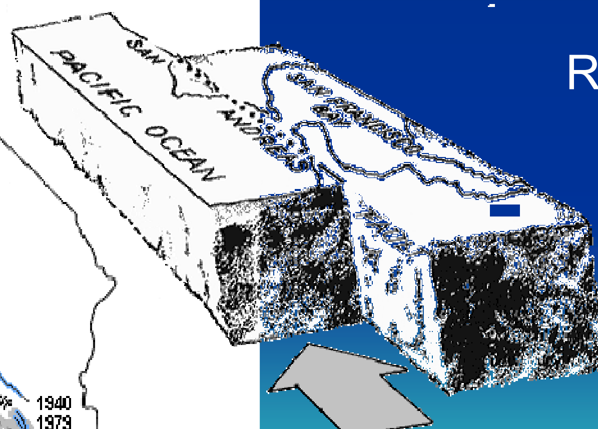
✓Hot spot plume anchored in mantle = assumed to be ***stationary***

✓ ***Distance and age*** between linear sequence of hot spot- generated volcanic centers indicates the ***direction and rate*** of motion of lithospheric plate

San Andreas Transform Fault

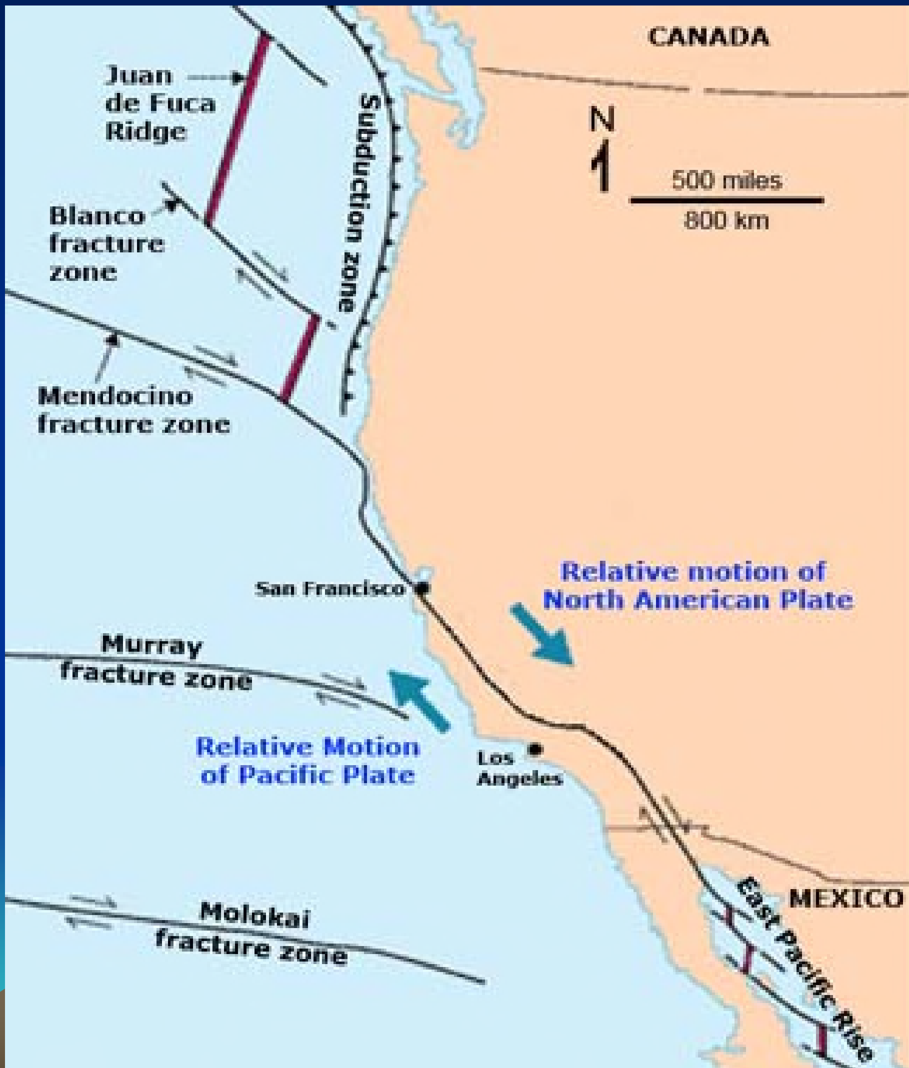


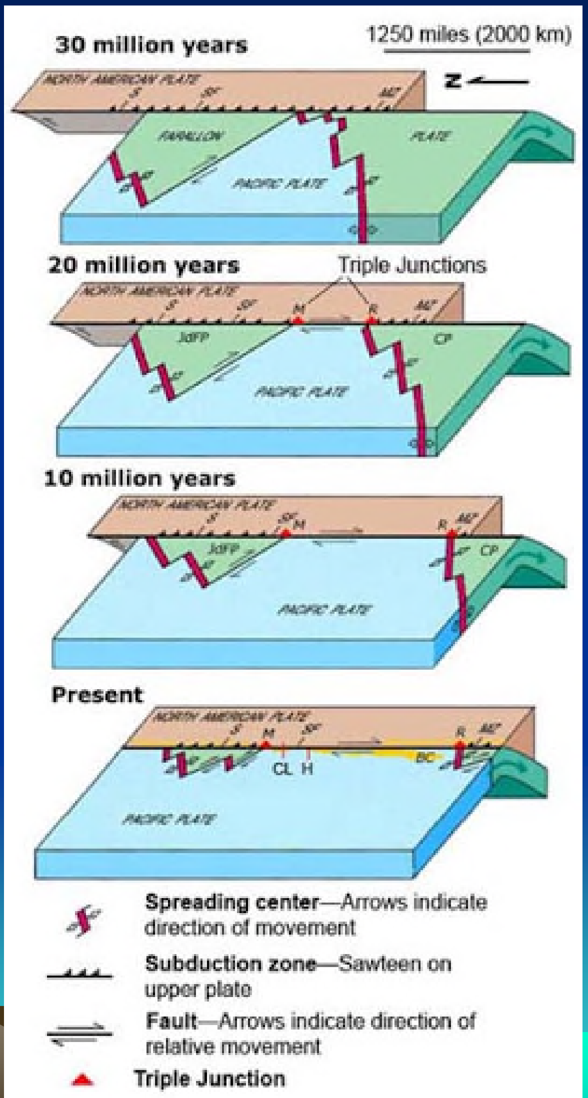


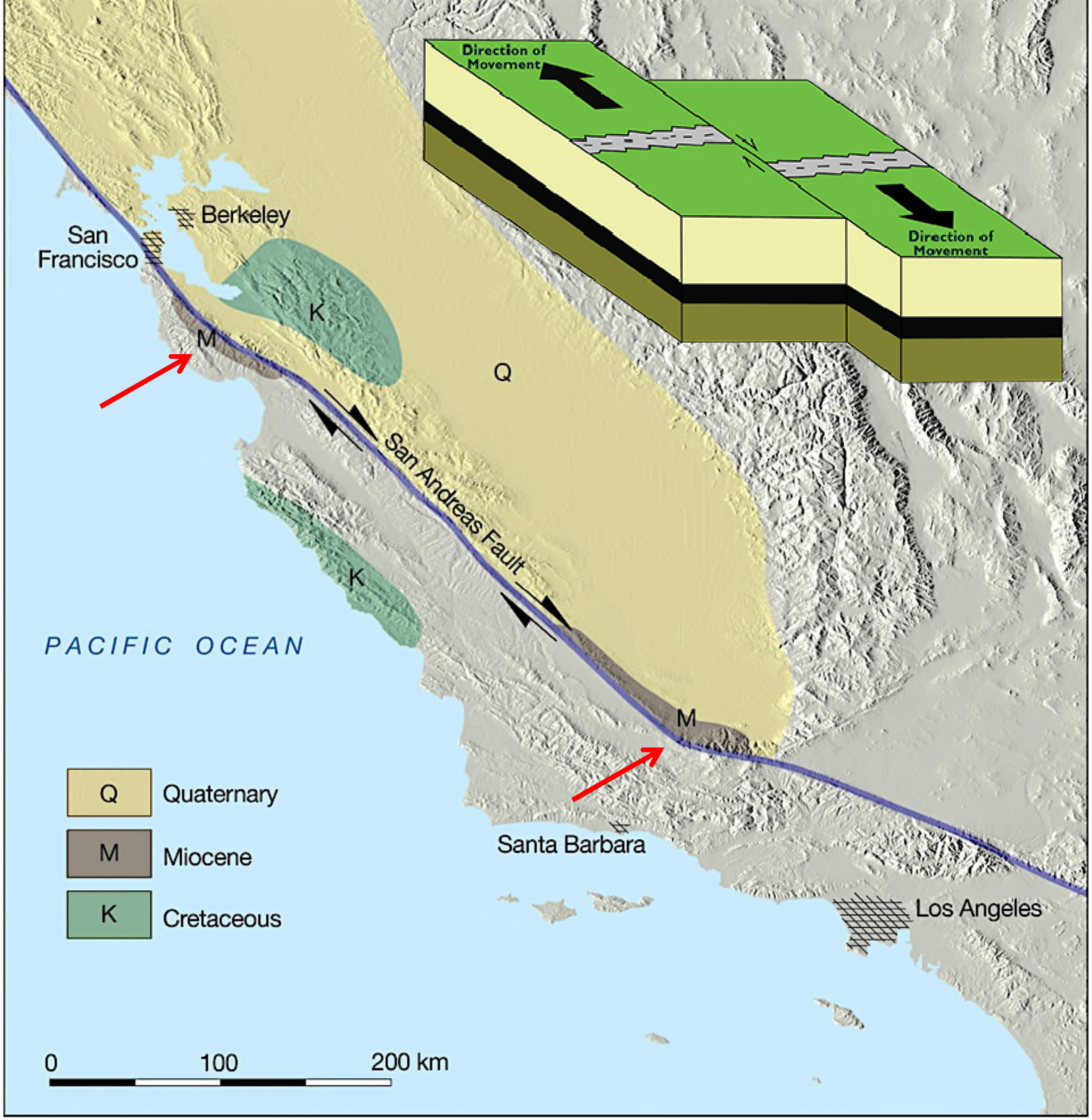


Right Lateral Strike-slip Offset

San Andreas Fault and West Coast Transform Tectonics





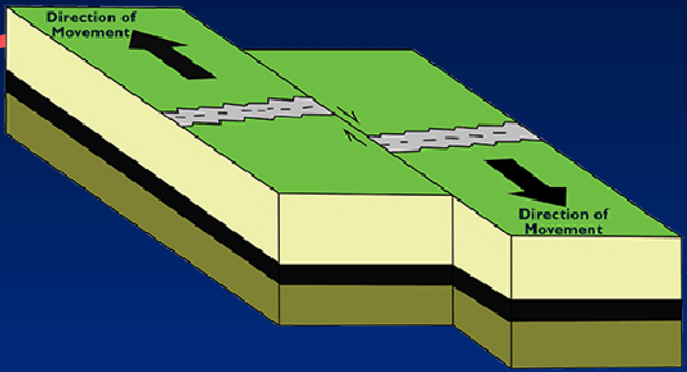


Measure offset in cm: will vary depend on how measure. Try M to M

Use bar scale at bottom to turn your cm into km: # cm on map represents # km in real world!

Answer in cm/yr = convert km to cm and million years to years

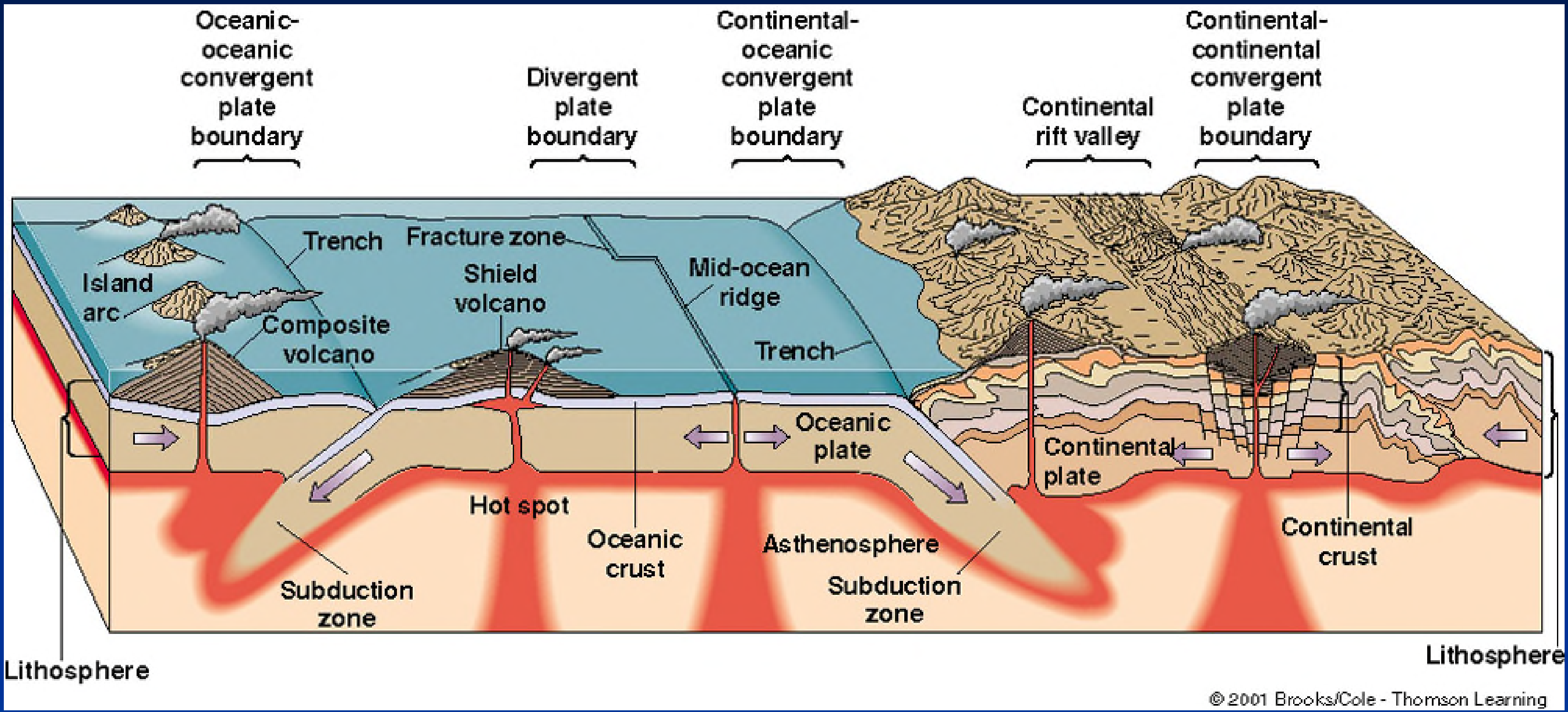
Determining Plate Direction and Speed for Transform Faults



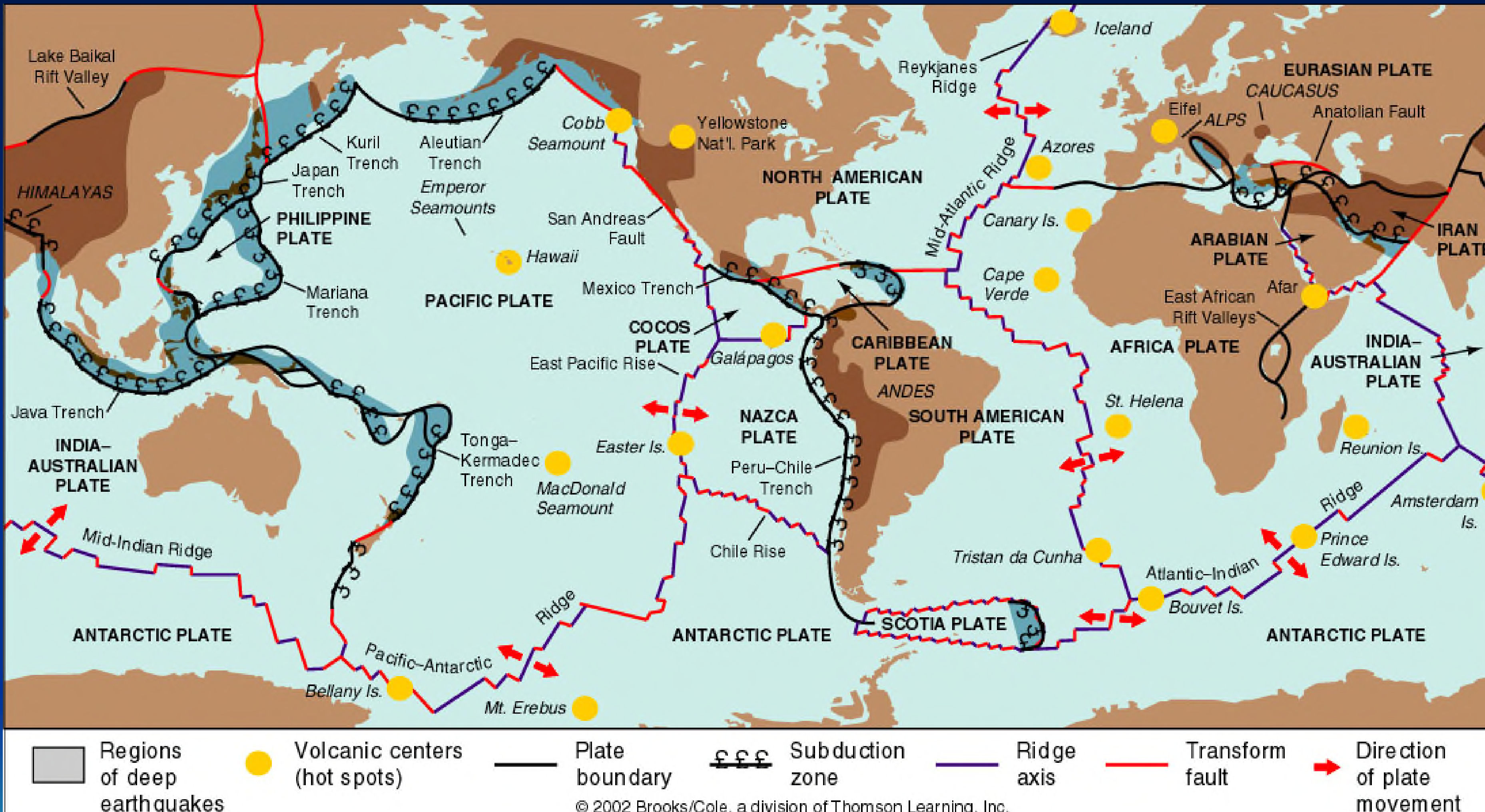
peed Calculation

- **Rate = Offset Distance / Age of Offset Feature**
- Plate speed measuring cm's/yr
- Km → cm   Conversion: 10^5 cm = 1 km
- 1×10^6 yr = 1 million yr
- Distance: Split Offset Marker distance (use scale on map with ruler)
- Time: Age difference of Offset Marker
- Make sure units cancel when doing conversions

Plate Boundary Configurations

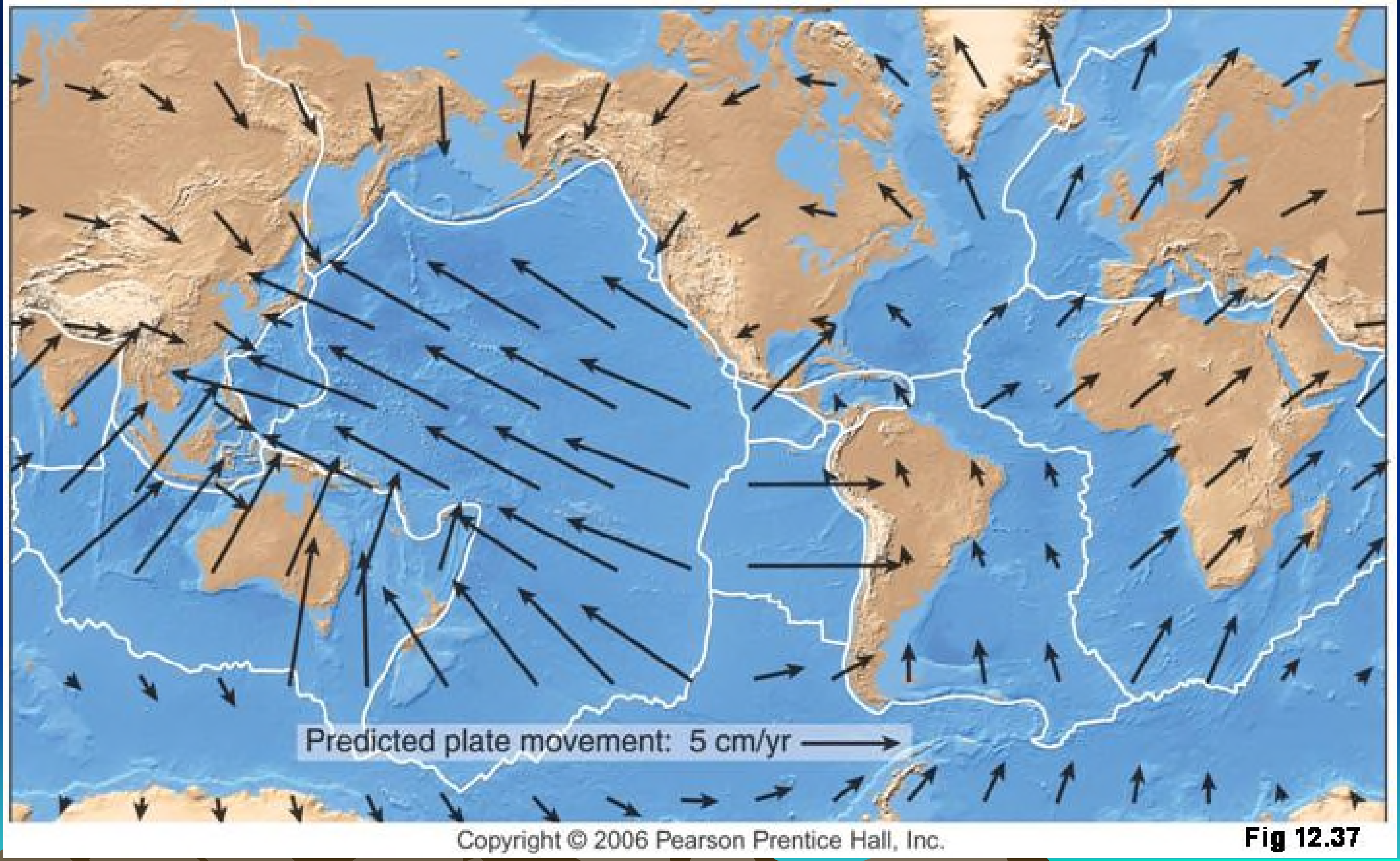


The Mobile Lithospheric Plates

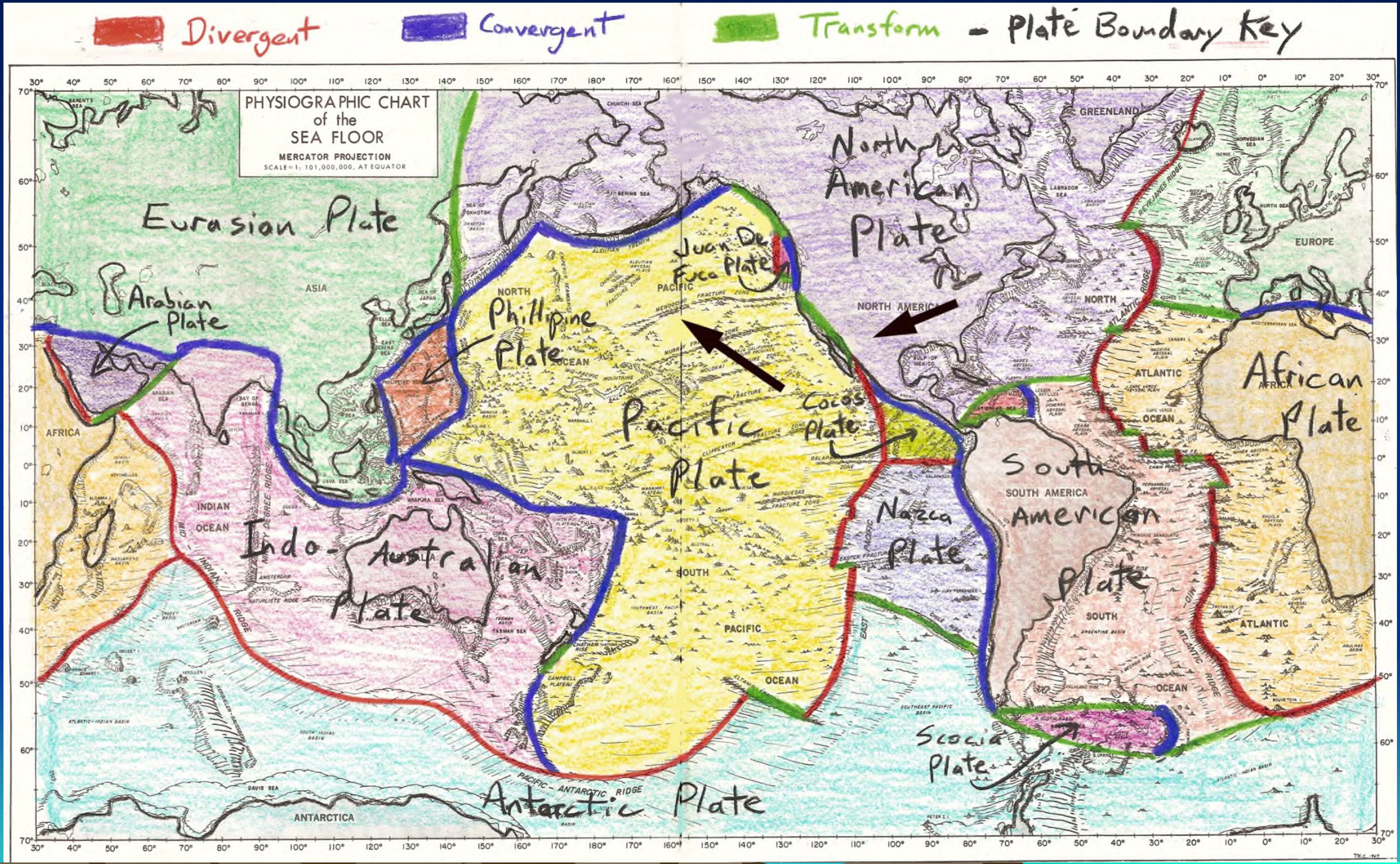


Convergent = Black line/Blue shading **Divergent** = Purple line **Transform** = Red line

Plate Motion - Direction & Speed

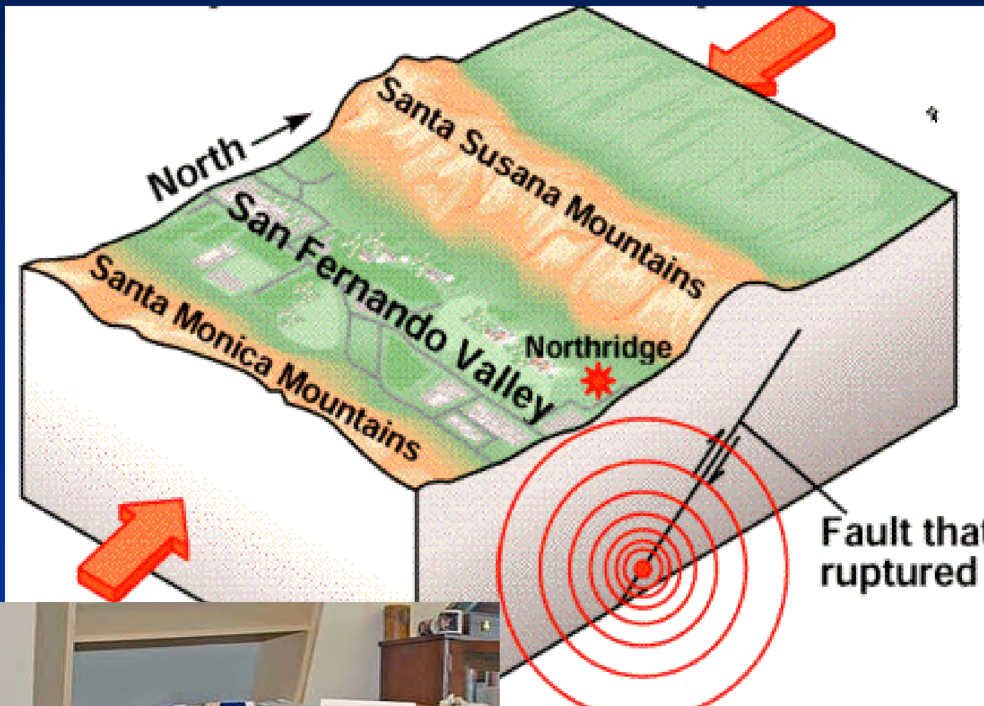


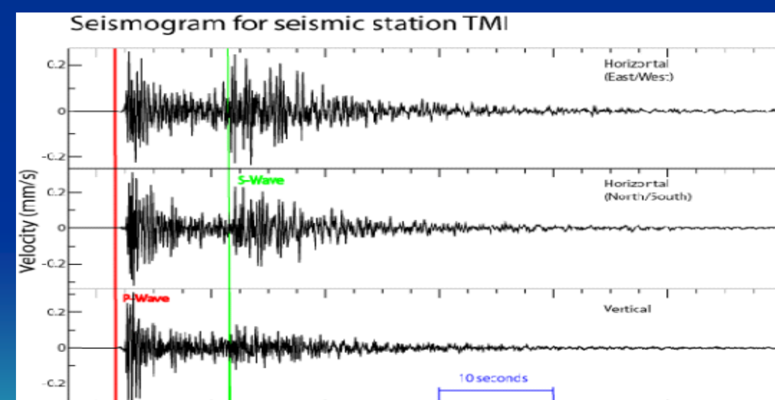
Global Plate Tectonic Map



Earthquake!

Principles and Applications



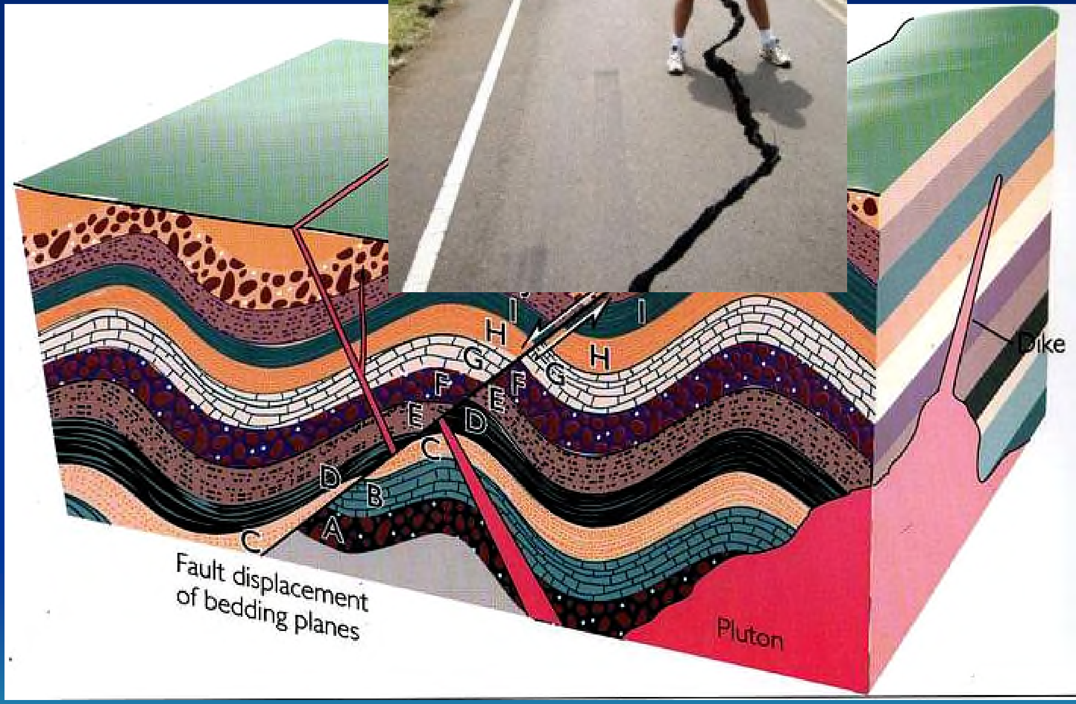


Earthquakes Occur Along Active Fault Zones

1) Faults are planar surfaces (zones of weakness) in the upper crust where brittle fracture takes place between two offsetting crustal blocks

2) Most active faults occur along tectonic plate boundaries

3) Earthquakes are the instant release of built-up elastic strain energy as result of fault rupture



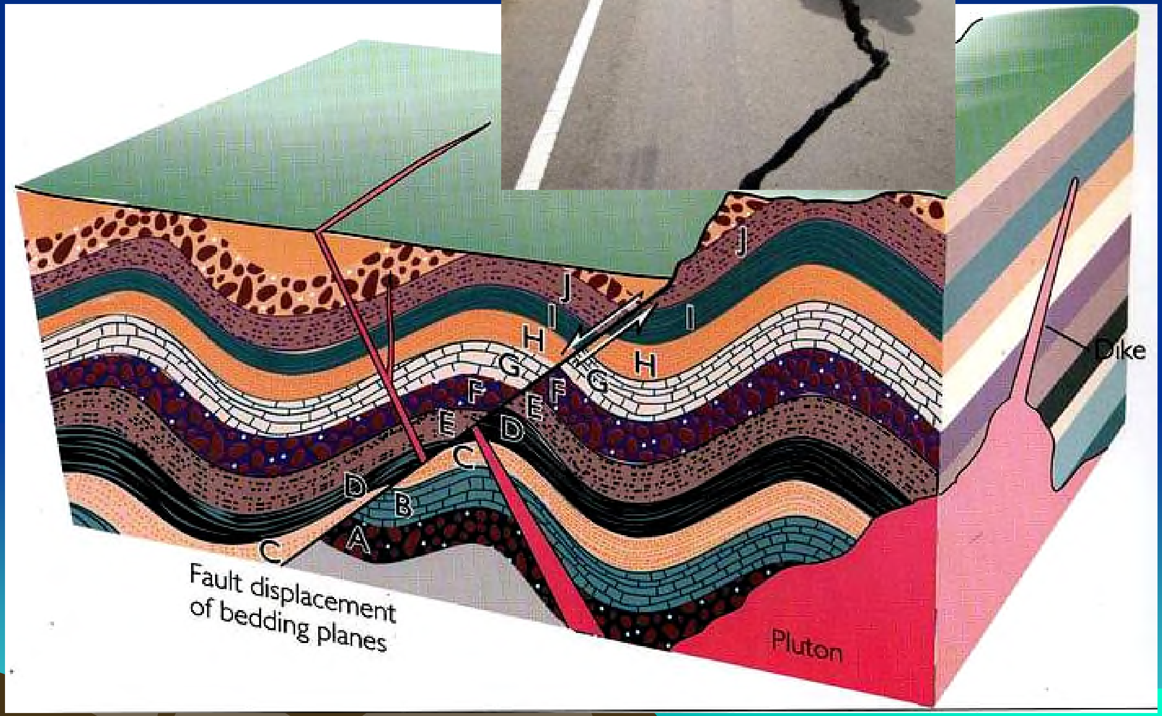
Earthquakes Occur Along Active Fault Zones

1) Most fault activity occurs at or near plate boundaries and regions of volcanism

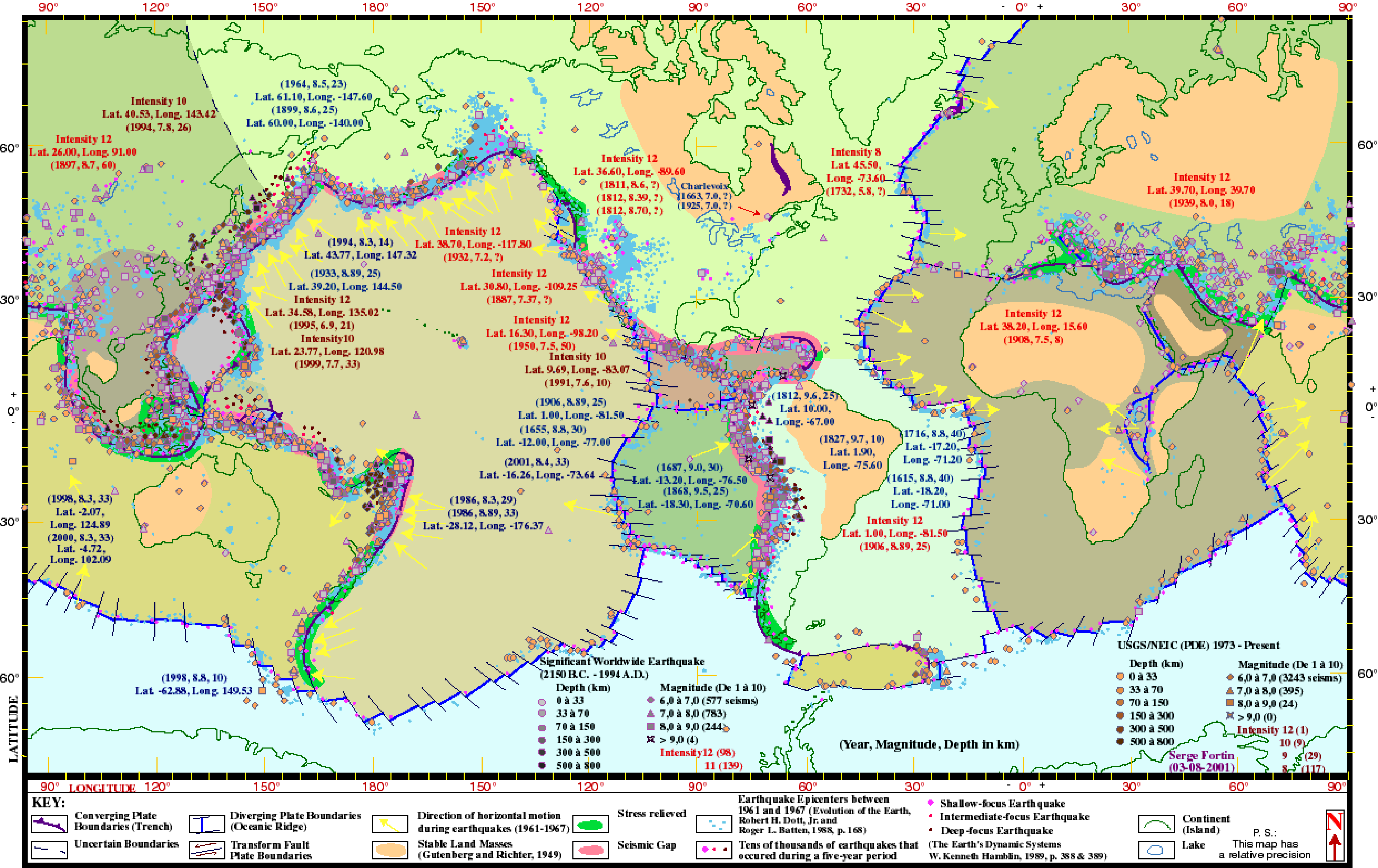
2) Fault activity is associated with tectonic stresses and/or movement of magma

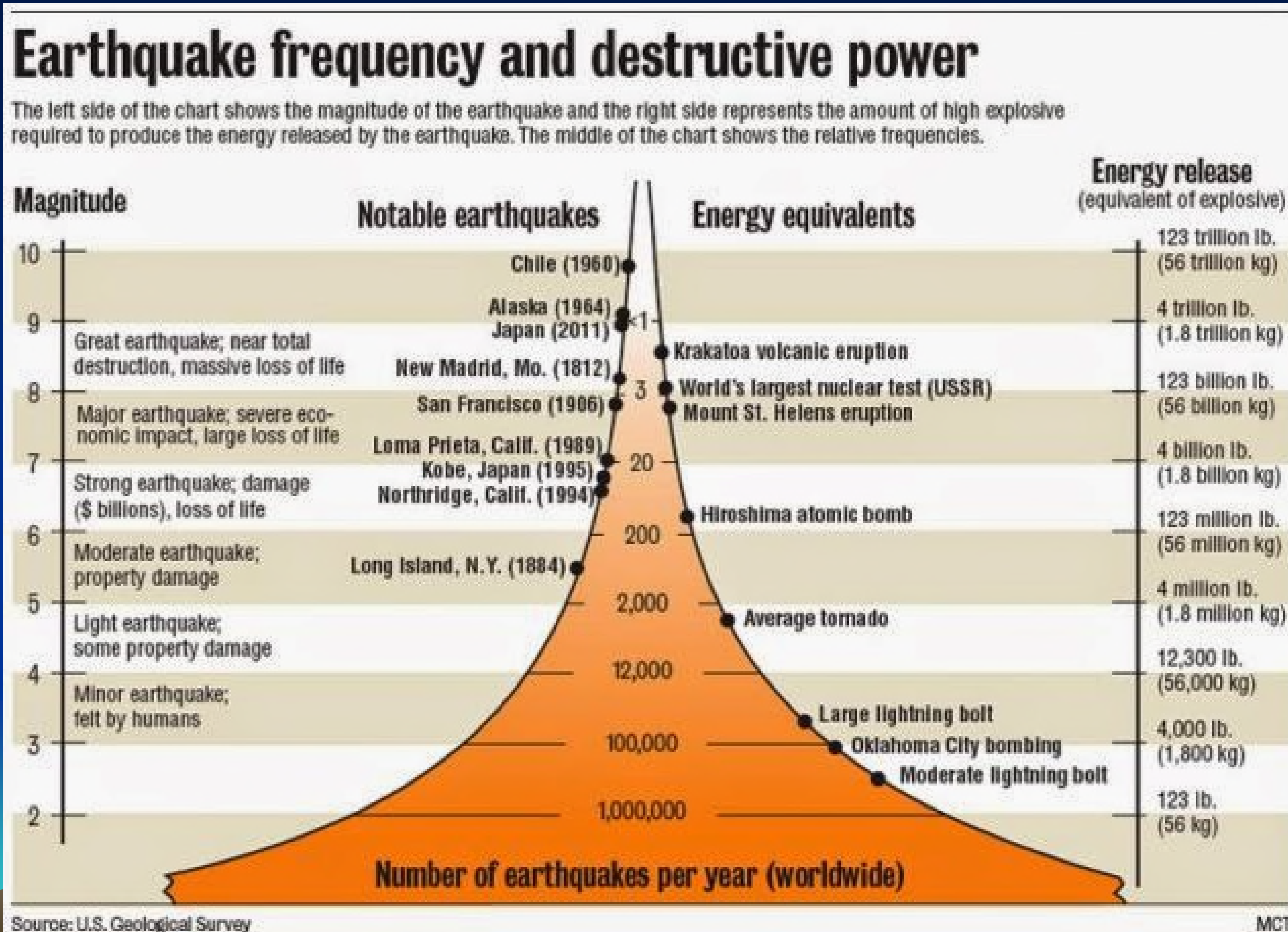
3) Earthquakes are the result of released stress between adjacent blocks of brittle/elastic-behaving crustal rocks

4) Earthquakes can be measured for size, intensity, and location using seismometers.

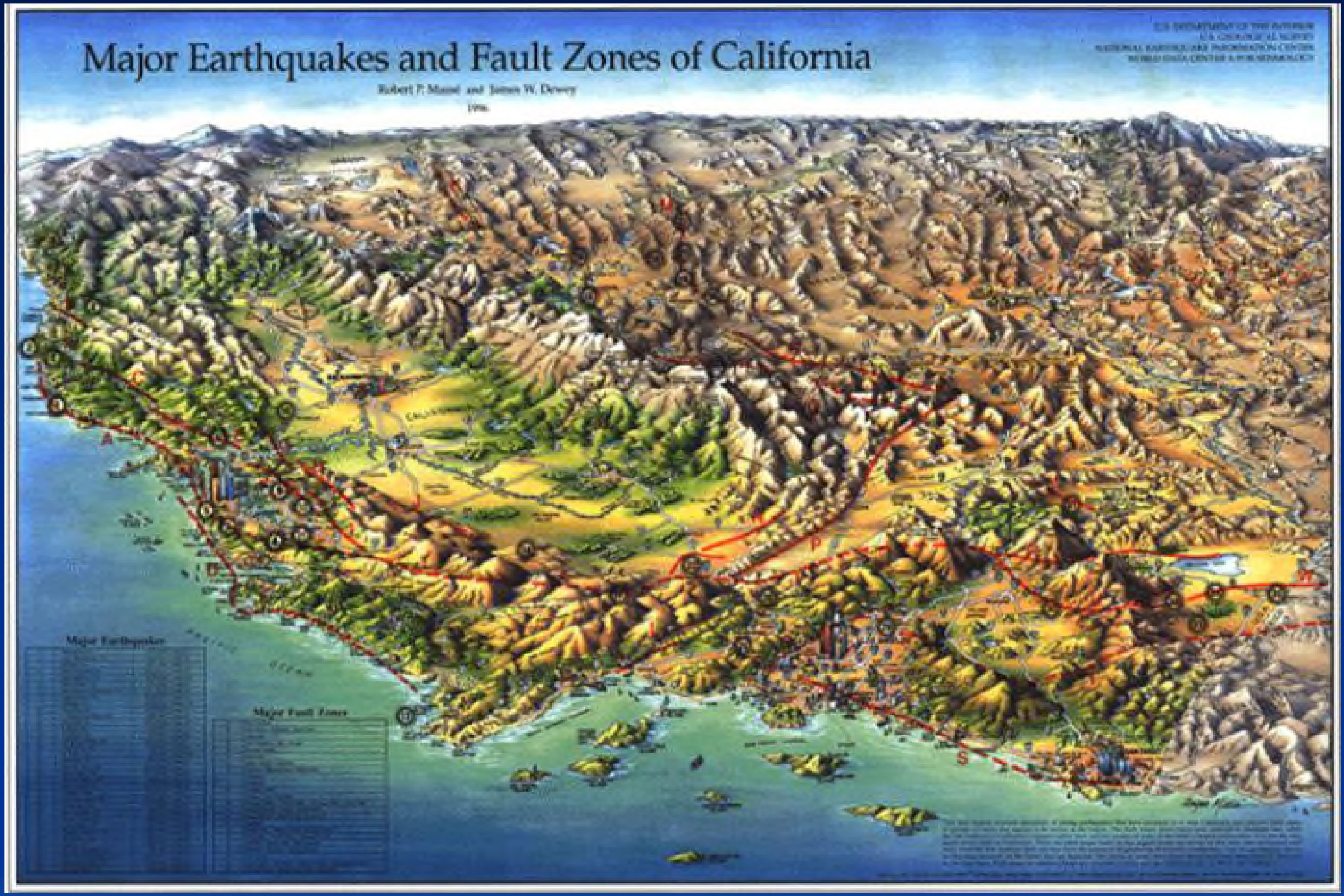


Major Earthquakes and Fault Zones of the World



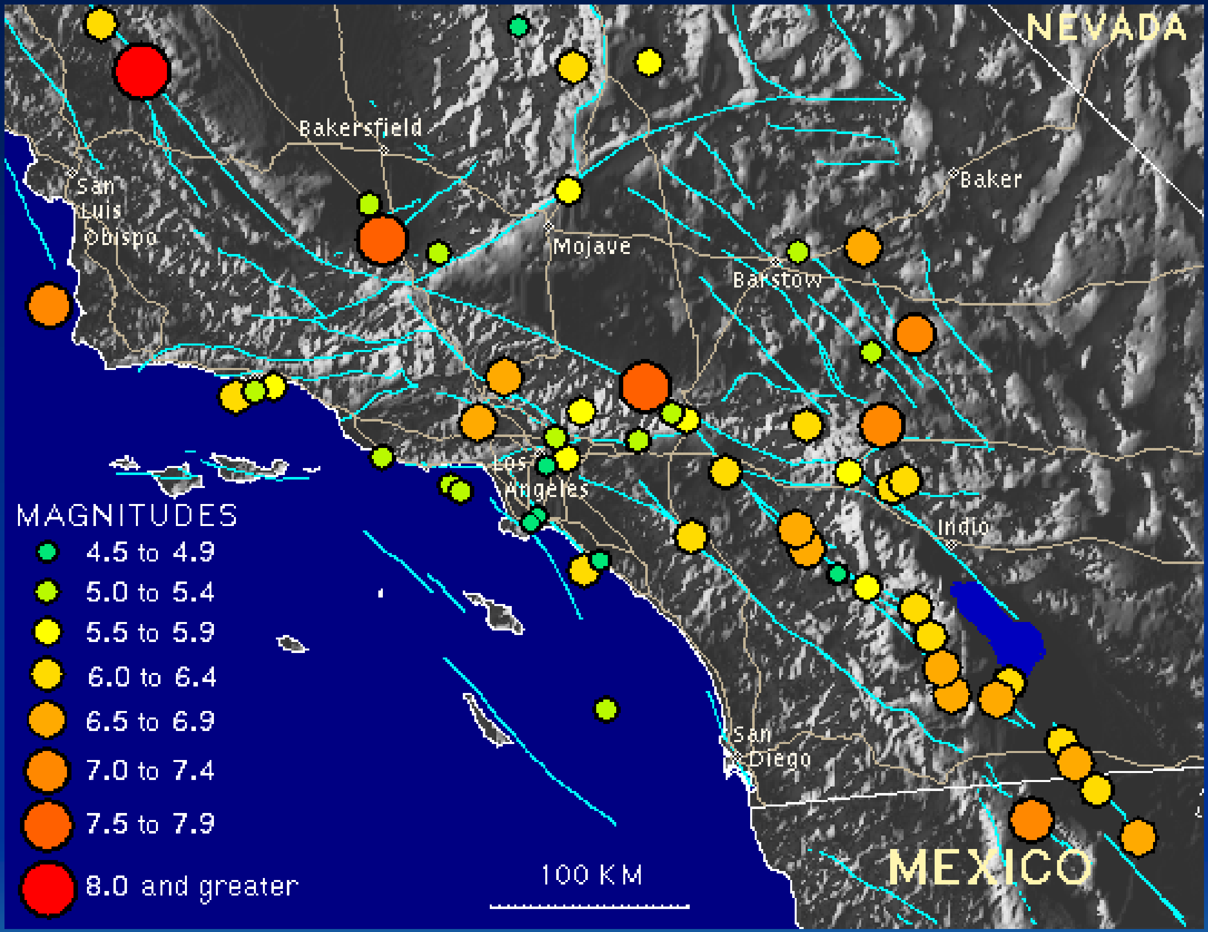

Earthquake frequency and destructive power
The left side of the chart shows the magnitude of the earthquake and the right side represents the amount of high explosive required to produce the energy released by the earthquake. The middle of the chart shows the relative frequencies.
Magnitude
Notable earthquakes
Energy equivalents
Energy release
(equivalent of explosive)
10
9
8
7
6
5
4
3
2
Great earthquake; near total destruction, massive loss of life
Major earthquake; severe economic impact, large loss of life
Strong earthquake; damage ($ billions), loss of life
Moderate earthquake; property damage
Light earthquake; some property damage
Minor earthquake; felt by humans
Chile (1960)
Alaska (1964)
Japan (2011)
New Madrid, Mo. (1812)
San Francisco (1906)
Loma Prieta, Calif. (1989)
Kobe, Japan (1995)
Northridge, Calif. (1994)
Long Island, N.Y. (1884)
<1
3
20
200
2,000
12,000
100,000
1,000,000
Krakatoa volcanic eruption
World's largest nuclear test (USSR)
Mount St. Helens eruption
Hiroshima atomic bomb
Average tornado
Large lightning bolt
Oklahoma City bombing
Moderate lightning bolt
123 trillion lb. (56 trillion kg)
4 trillion lb. (1.8 trillion kg)
123 billion lb. (56 billion kg)
4 billion lb. (1.8 billion kg)
123 million lb. (56 million kg)
4 million lb. (1.8 million kg)
12,300 lb. (56,000 kg)
4,000 lb. (1,800 kg)
123 lb. (56 kg)
Number of earthquakes per year (worldwide)
Source: U.S. Geological Survey
MCT

Major Fault Zones of California



The majority of California's abundance of faults are part of the San Andreas Fault Zone – a transform boundary fault system

Largest Earthquakes of Southern California



The San Andreas Fault is capable of up to 8.0 M earthquakes.
The most active fault in So Cal is the San Jacinto Fault

Most Recent Earthquakes in California

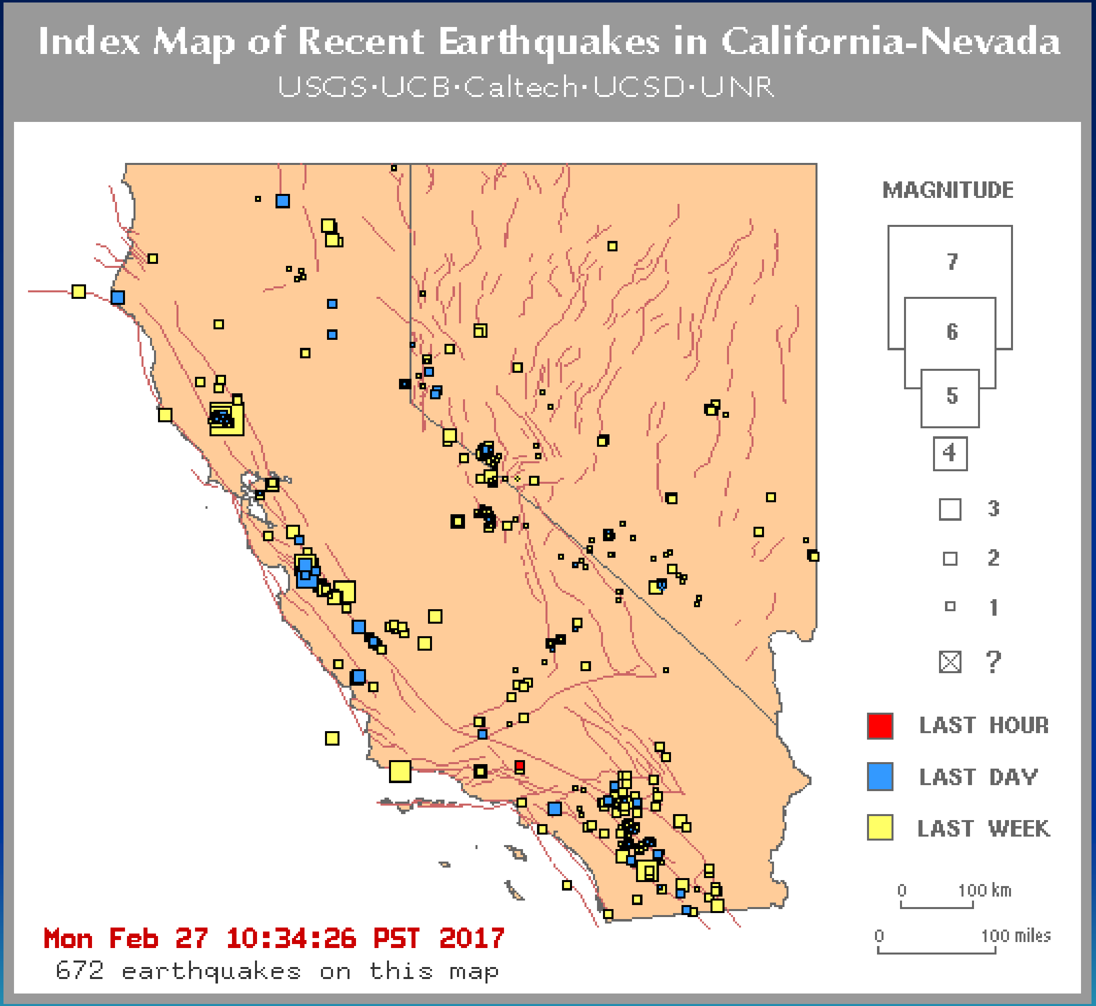
1) Most fault activity is associated with the San Andreas Fault Zone

2) The other zone is the Eastern Sierra region

3) The most active in Southern California are the San Jacinto and Elsinore faults

4) Short range quake prediction does not exist at this time

5) Where will the next “Big One” (> 7.5M) hit?



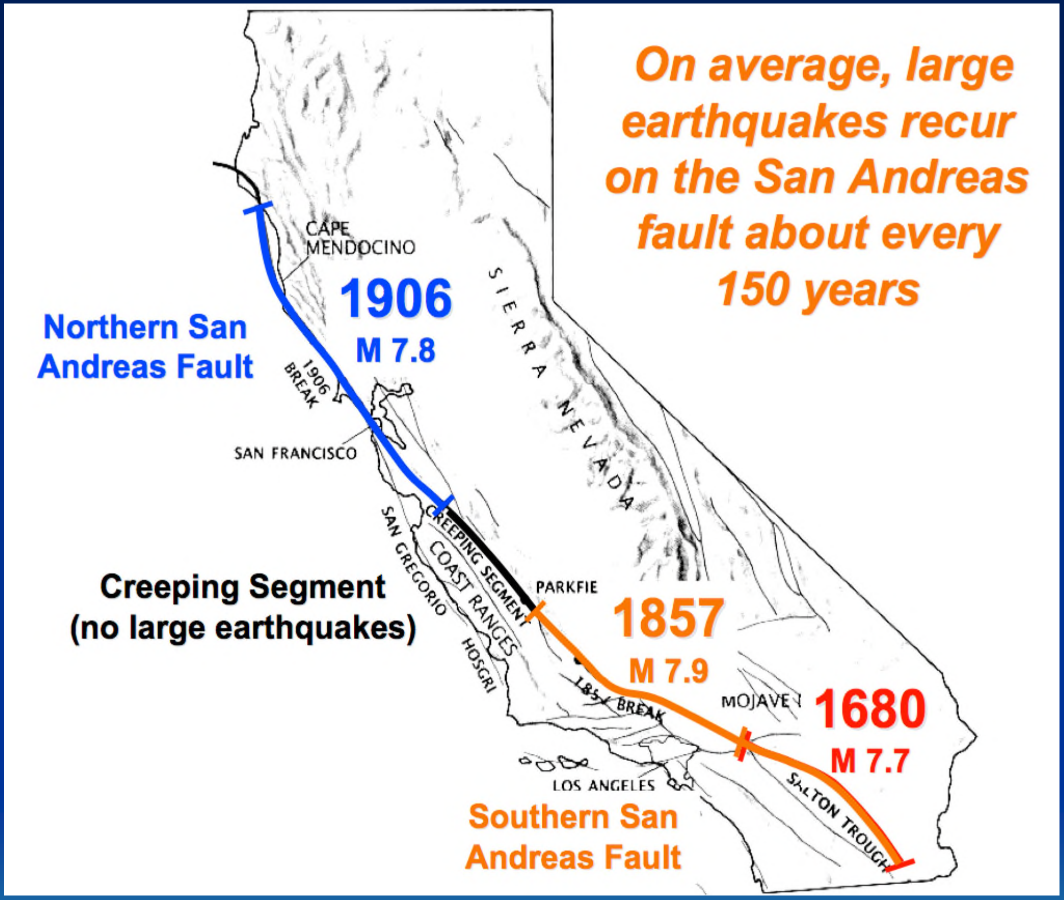
"Big Ones" on the San Andreas

1) Three Big Ones in the last 500 years on the SAF

2) Last Big One was on the Northern California segment in 1906

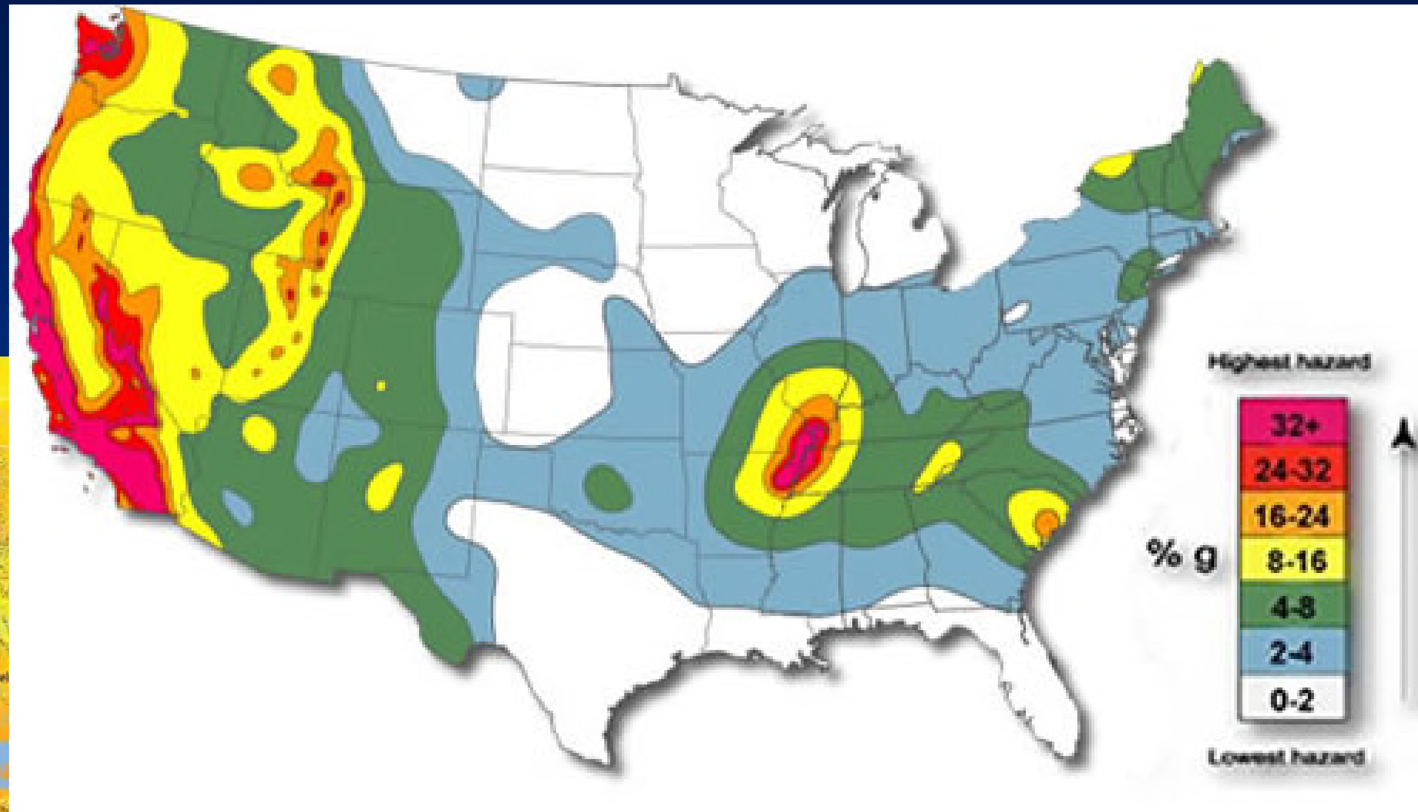
3) Last Big One on the Southern California segment was in 1680

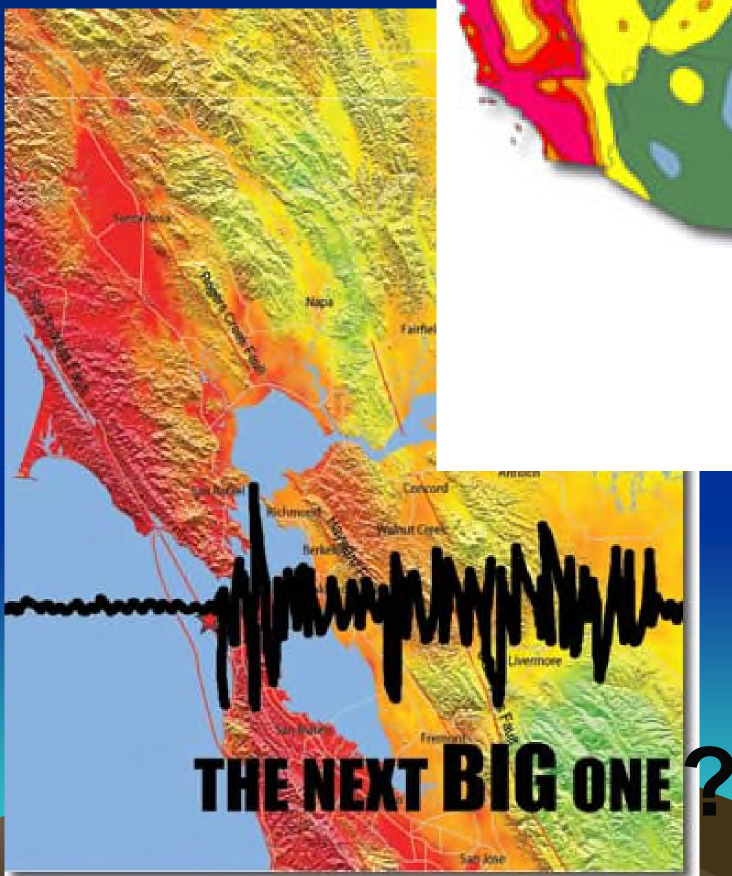
4) A "Big One" occurs about every 400 years on each of the SAF segments



5) Based on this map, where will the next "Big One" on the SAF most likely strike?

Earthquake Hazard Levels in USA





1) Geologists cannot predict an earthquake at the present time

2) Geologists can make statistically-based probability estimates for a given faults's chances of rupture

Earthquake Preparation and Mitagation

Fundamentals of an Earthquake

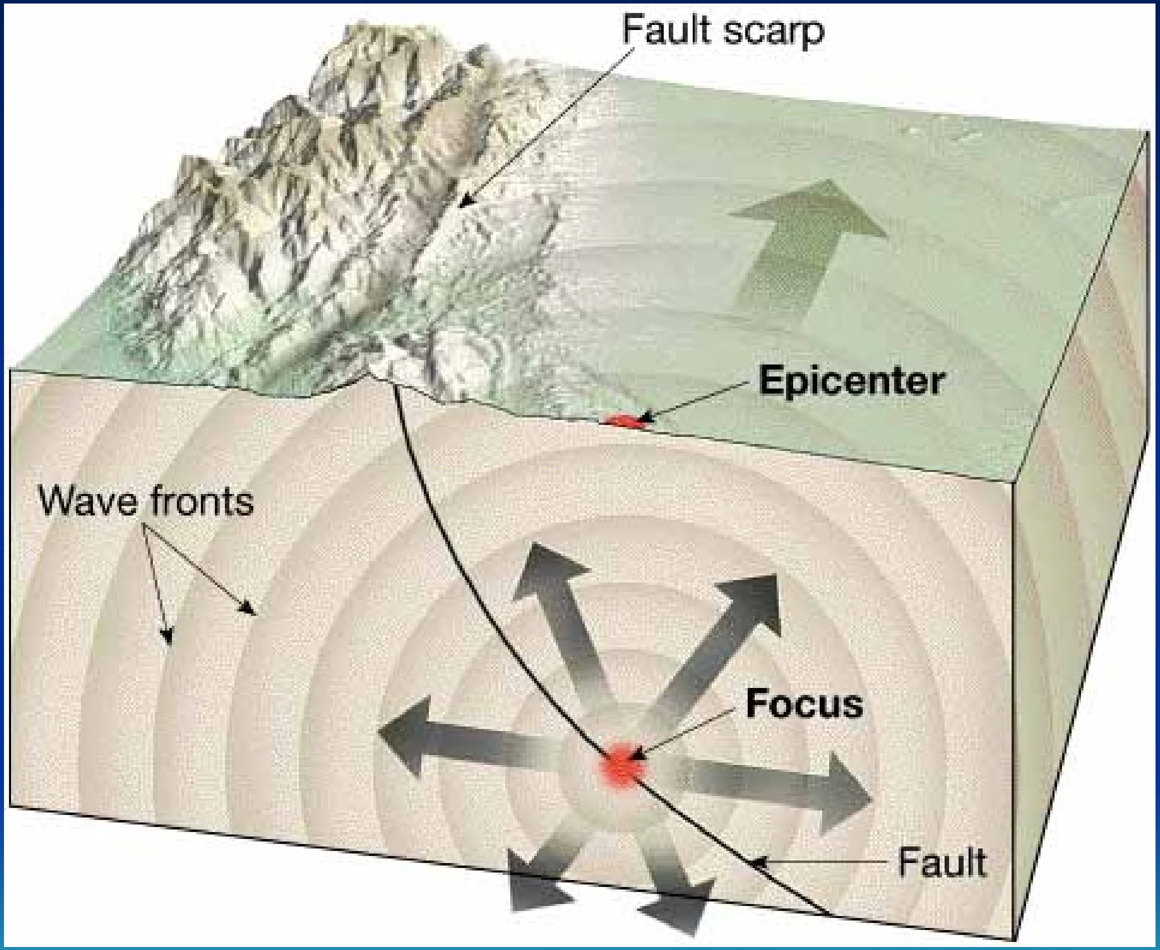
1) Fault rupture

2) Fault scarp

3) Focus

4) Epicenter

5) Seismic Waves



What Causes an Earthquake?

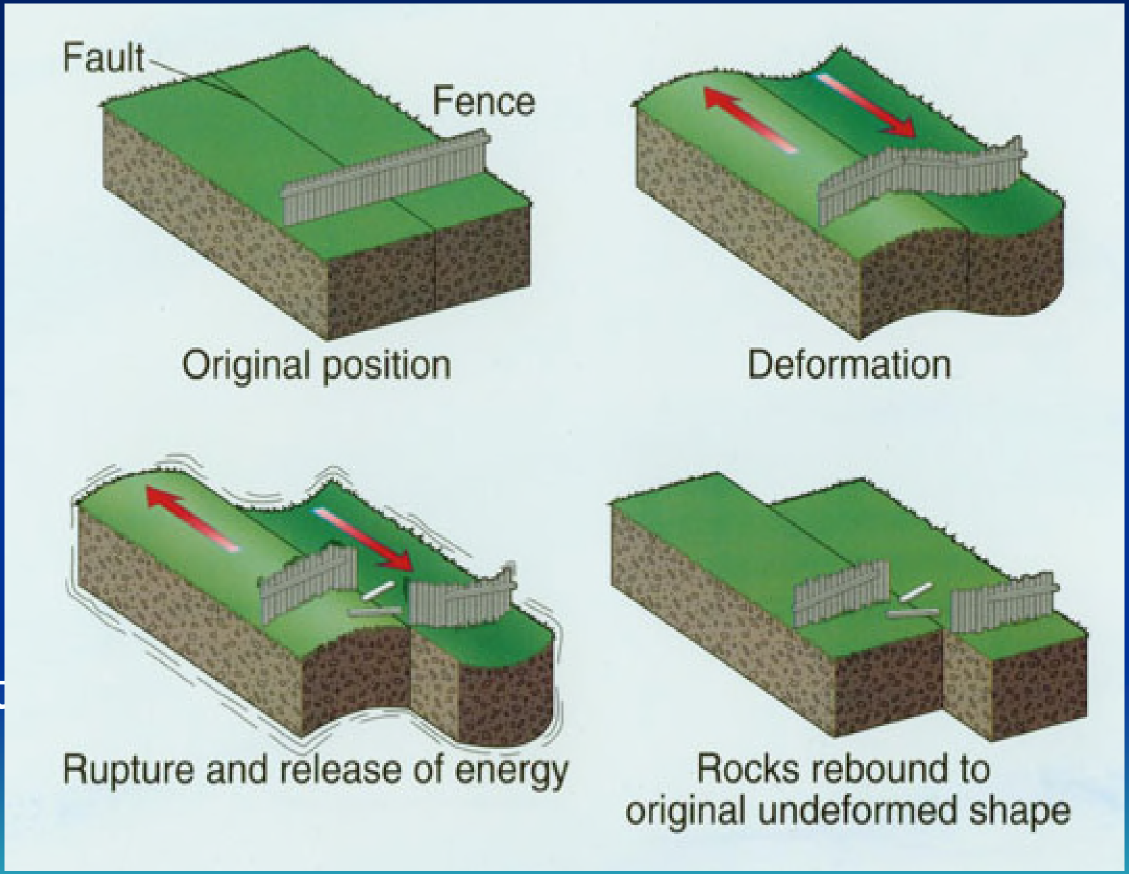
Reid's Elastic Rebound Theory

1) Pre-load Period
- No Stress
- No Deformation

2) Bending Period
- Slow Stress Loading
- Elastic Deformation

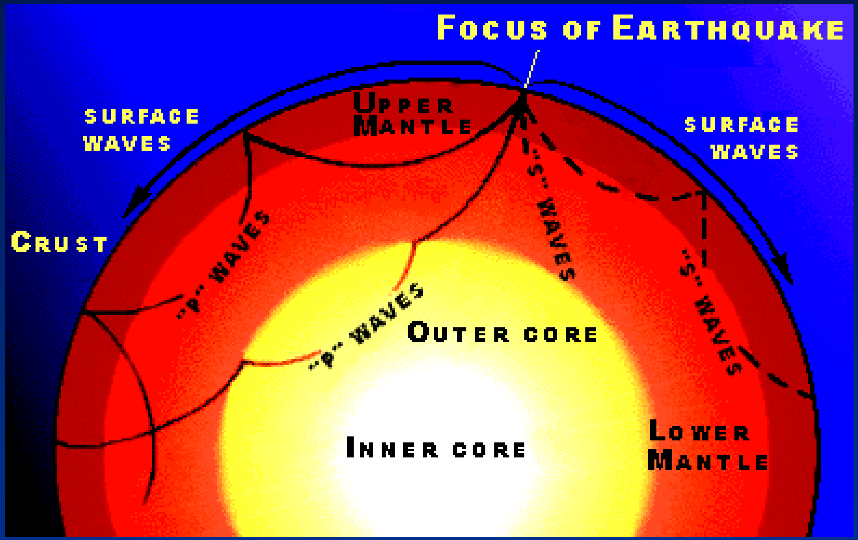
3) Rupture Period
- Instant Stress Release
- Brittle Deformation/Offset

4) Rebound Period
- Removal of Bending
- Stress Relieved



Four Stages

Types of Seismic Waves



Body Waves

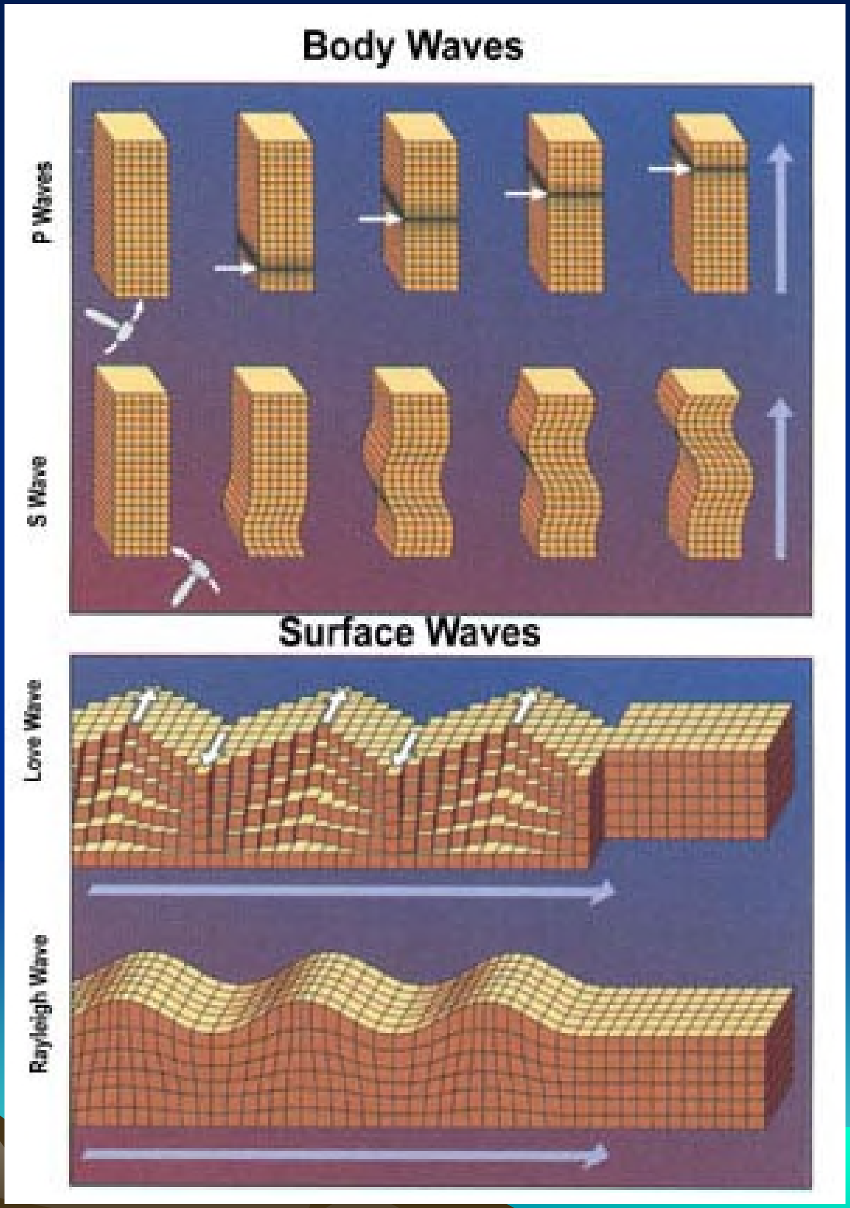
1) P-waves

2) S-waves

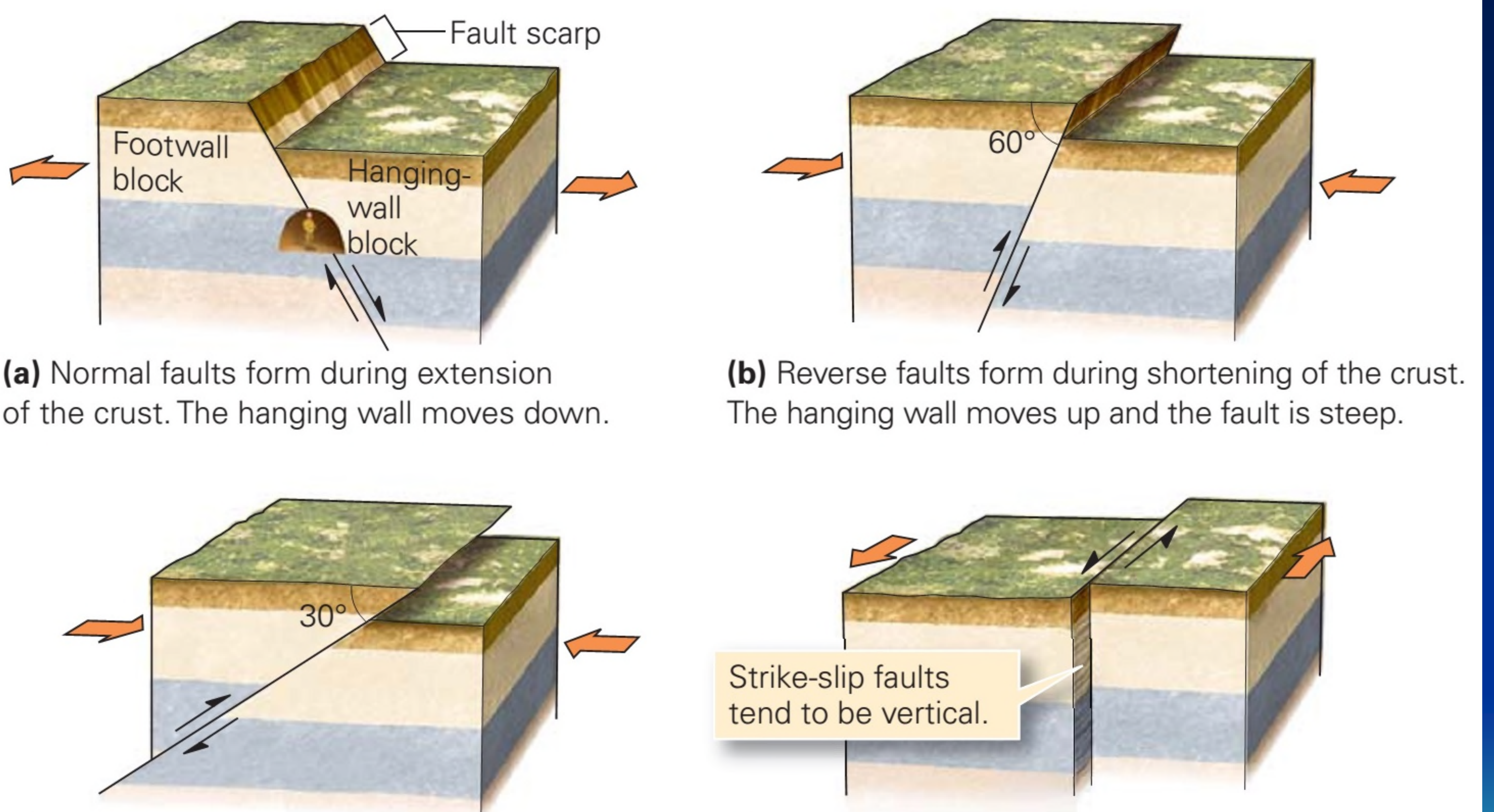
Surface Waves

1) Love-waves

2) Raleigh-waves



Types of Faults and Associated Stresses



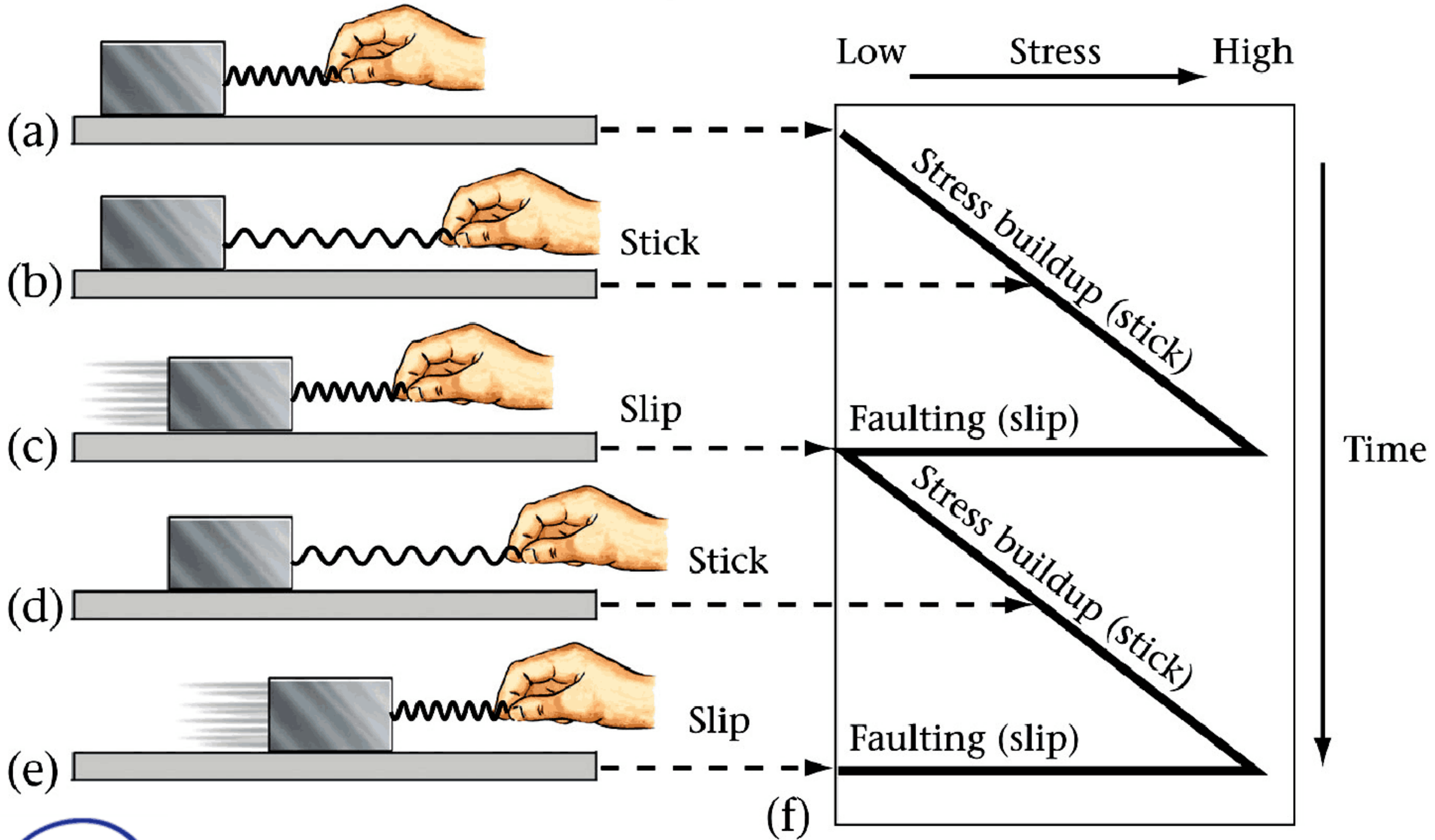
(a) Normal faults form during extension of the crust. The hanging wall moves down.

(b) Reverse faults form during shortening of the crust. The hanging wall moves up and the fault is steep.

(c) Thrust faults also form during shortening. The fault's slope is gentle (less than 30°).

(d) On a strike-slip fault, one block slides laterally past another, so no vertical displacement takes place.

Stick Slip Behavior



out stick slip behavior, large earthquakes would not happen!

aults would constantly move (i.e. ***creep***) and not build up significant stress