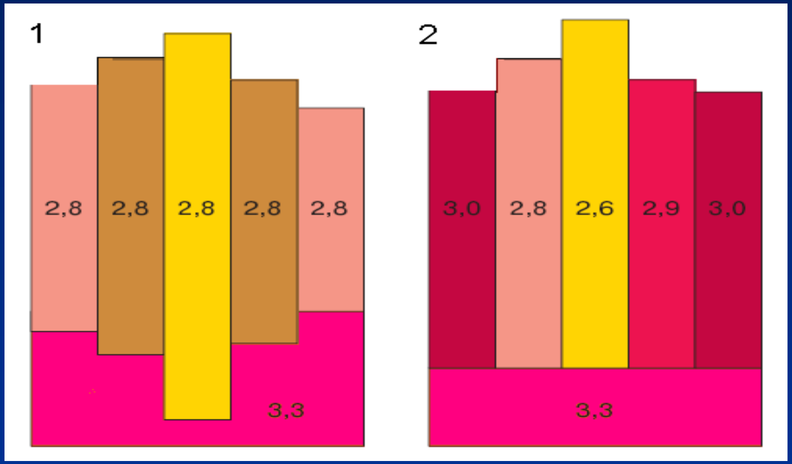
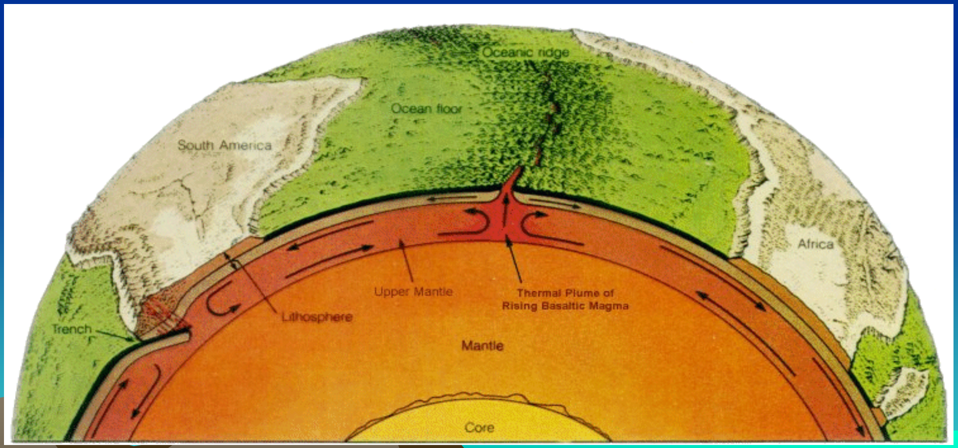
Isostasy and Tectonics Lab

Understanding the Nature of Mobile Floating Lithospheric Plates



Crust –Mantle Dynamics



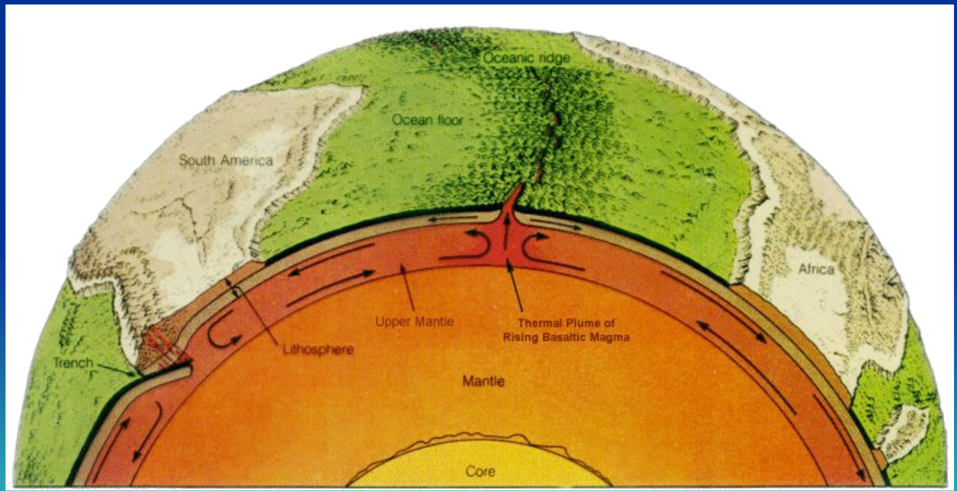
Intro to Earth Systems
ENVI 110 Lab

Ray Rector - Instructor

Isostacy 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

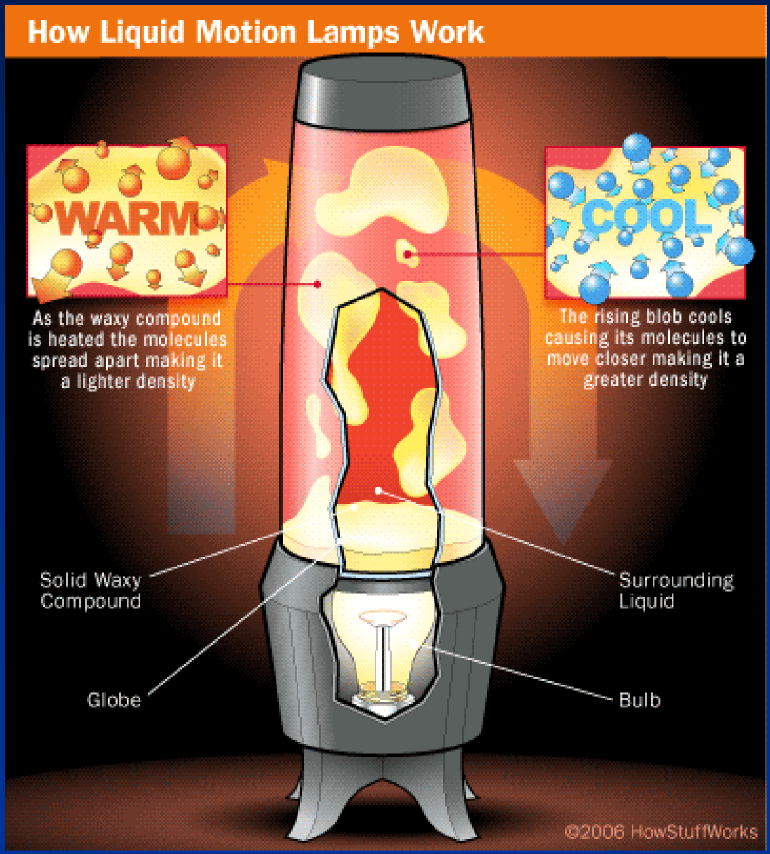
Density, Gravity and the Convection Process

✓ *Differential Heating of a Fluid Under the Influence of Gravity*: Fluid material at bottom of lamp is overheated; material at the top of lamp is under-heated (cooler).

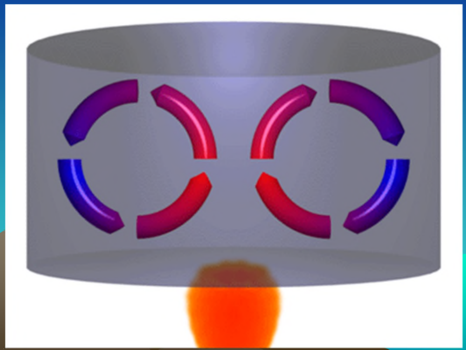
✓Hotter material is less dense than cooler material

✓ Less dense fluid rises while more dense fluid sinks

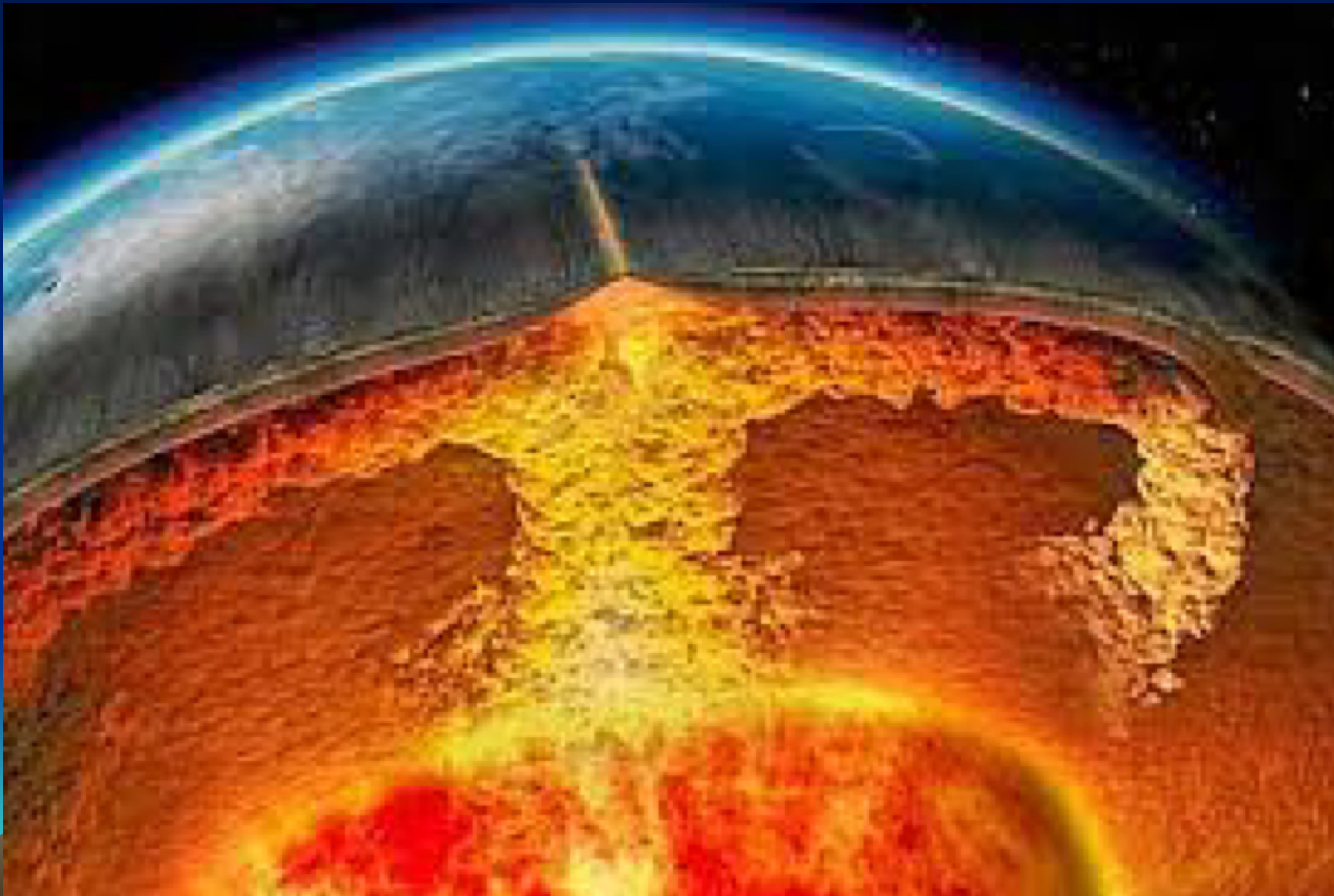
✓ Heat and gravity drive the movement in the system



Convection Process



Convection Inside Our Planet



Concept of Density

1) Density is an important intensive property

2) Density is a function of a substance's mass and volume

3) The density of a substance is a measure of how much mass is present in a given unit of volume.

- The more mass a substance has per unit volume, the greater the substance's density.
- The less mass a substance has per unit volume, the lesser the substance's density.

$$\text{Denisty} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{v}$$

4) Gravity controls the weight of a given volume of a substance, based on the substance's density

- The more dense the material, the heavier it weighs.
- The less dense the material, the less it weighs.

Elements – Crustal Mass and Density

Periodic Table of Elements

Atomic #
Symbol
Name
Atomic Mass

- C Solid
- Hg Liquid
- H Gas
- Rf Unknown

Metals: Alkali metals, Alkaline earth metals, Lanthanoids, Actinoids, Transition metals, Poor metals

Nonmetals: Other nonmetals, Noble gases

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.00794																	2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050											13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.96	43 Tc Technetium (97.9072)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
6	55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57–71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (208.9824)	85 At Astatine (209.9871)	86 Rn Radon (222.0176)
7	87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
89 Ac Actinium (227)	90 Th Thorium 232.03806	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Ptable.com

Determining Material Densities

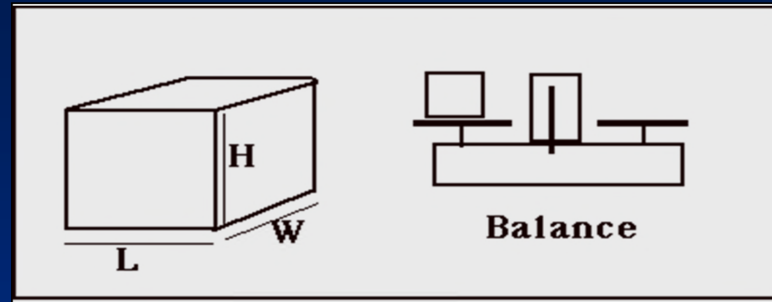
Metal and Wood Block Densities:

1) Determine Mass (grams) with flattop scale.

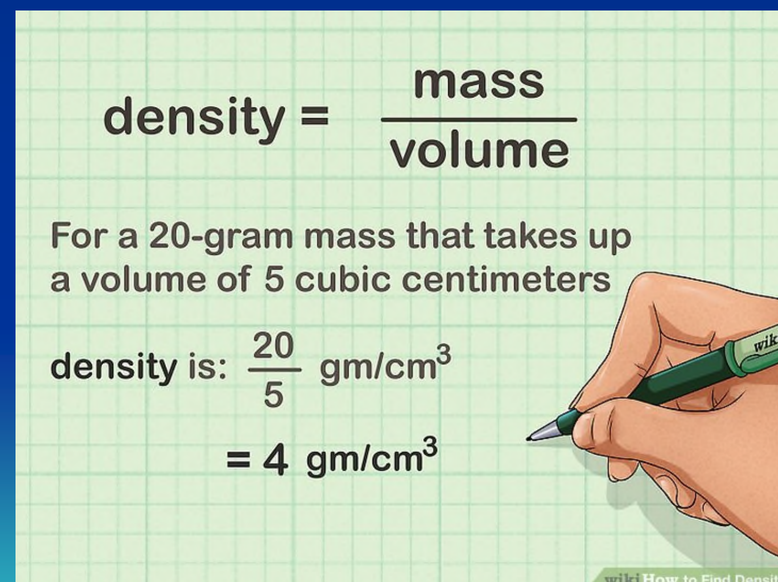
2) Determine Volume (cubic cm) with ruler

   - ✓ Length x height x width

3) Only measure the thick redwood block and oak blocks



$$\text{Denisty} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{v}$$



Earth's Layered Structure

1) The Earth is Vertically Arranged into Ten Density Layers

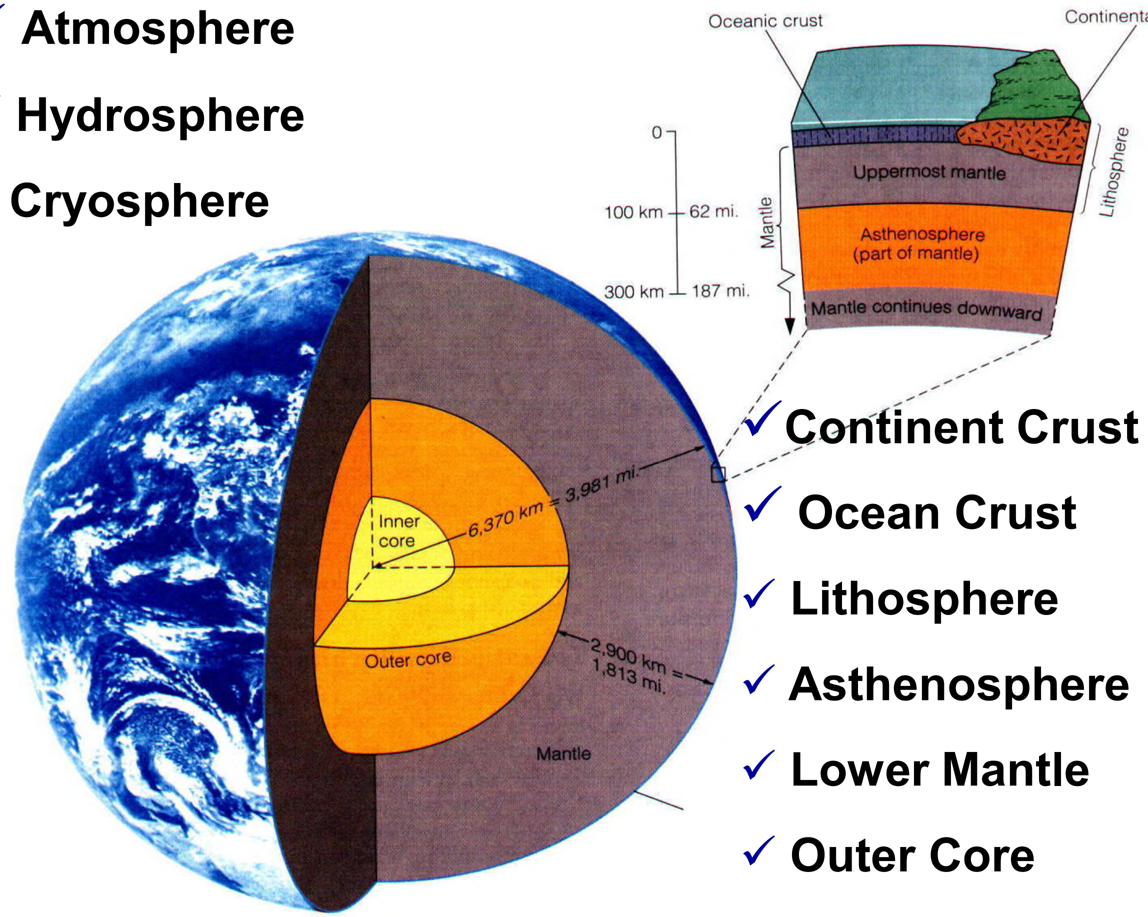
2) Each Layer has Unique Physical and Chemical Properties

3) Layers are Arranged According to Density Value, as Controlled by Gravity

4) Densest Solid = Core

Least Dense Solid = Crust

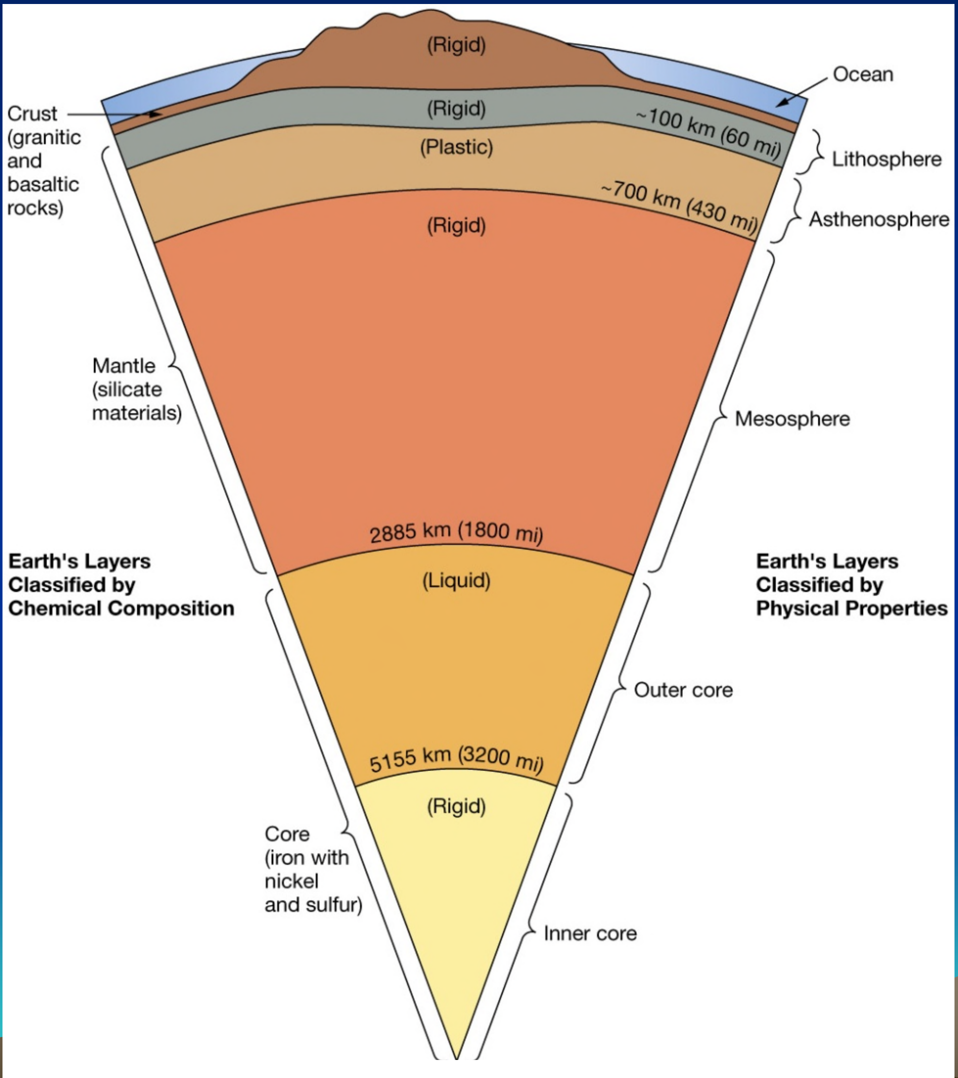
- ✓ Atmosphere
- ✓ Hydrosphere
- ✓ Cryosphere

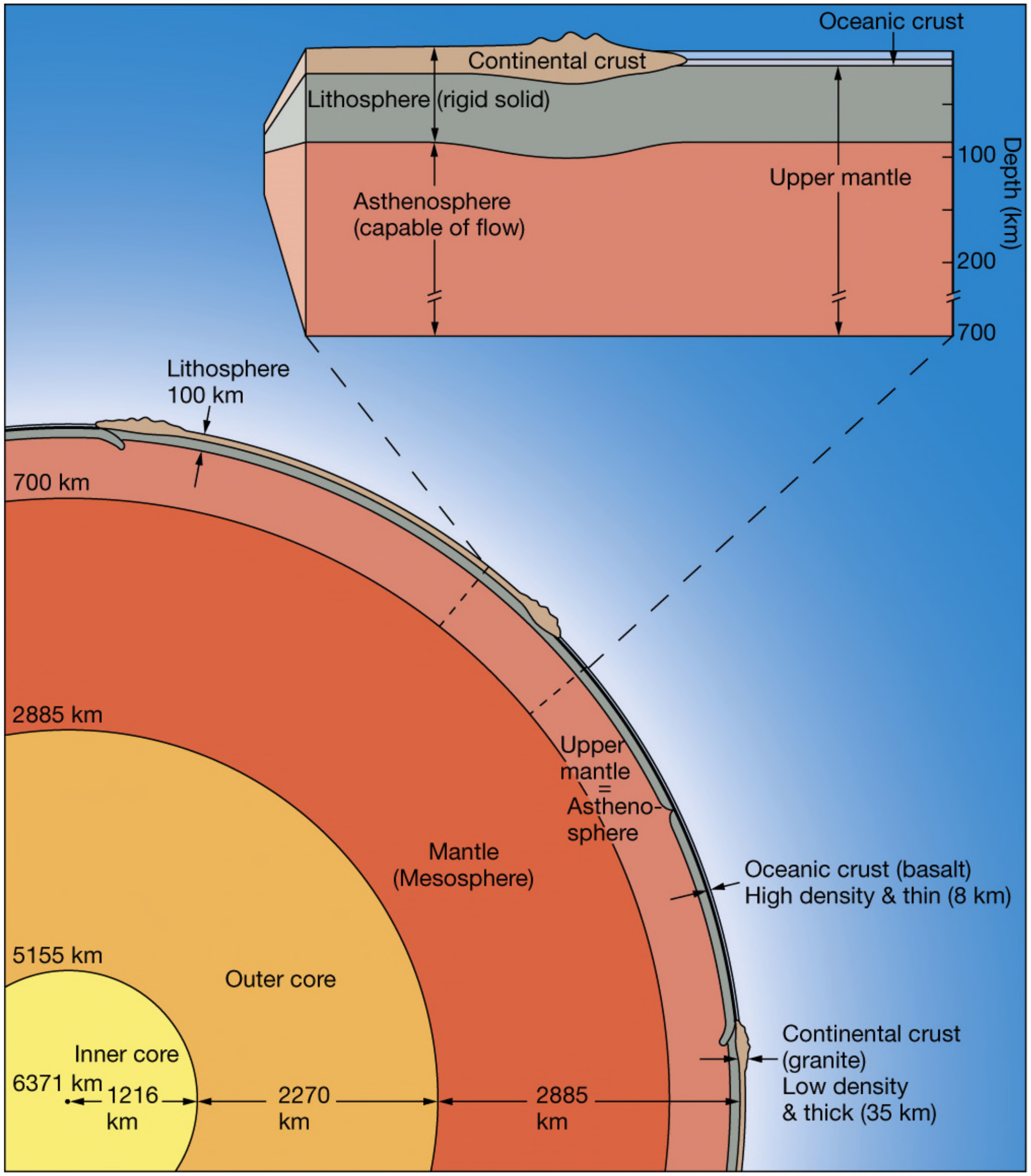


- ✓ Continent Crust
- ✓ Ocean Crust
- ✓ Lithosphere
- ✓ Asthenosphere
- ✓ Lower Mantle
- ✓ Outer Core
- ✓ Inner Core

Earth's Interior

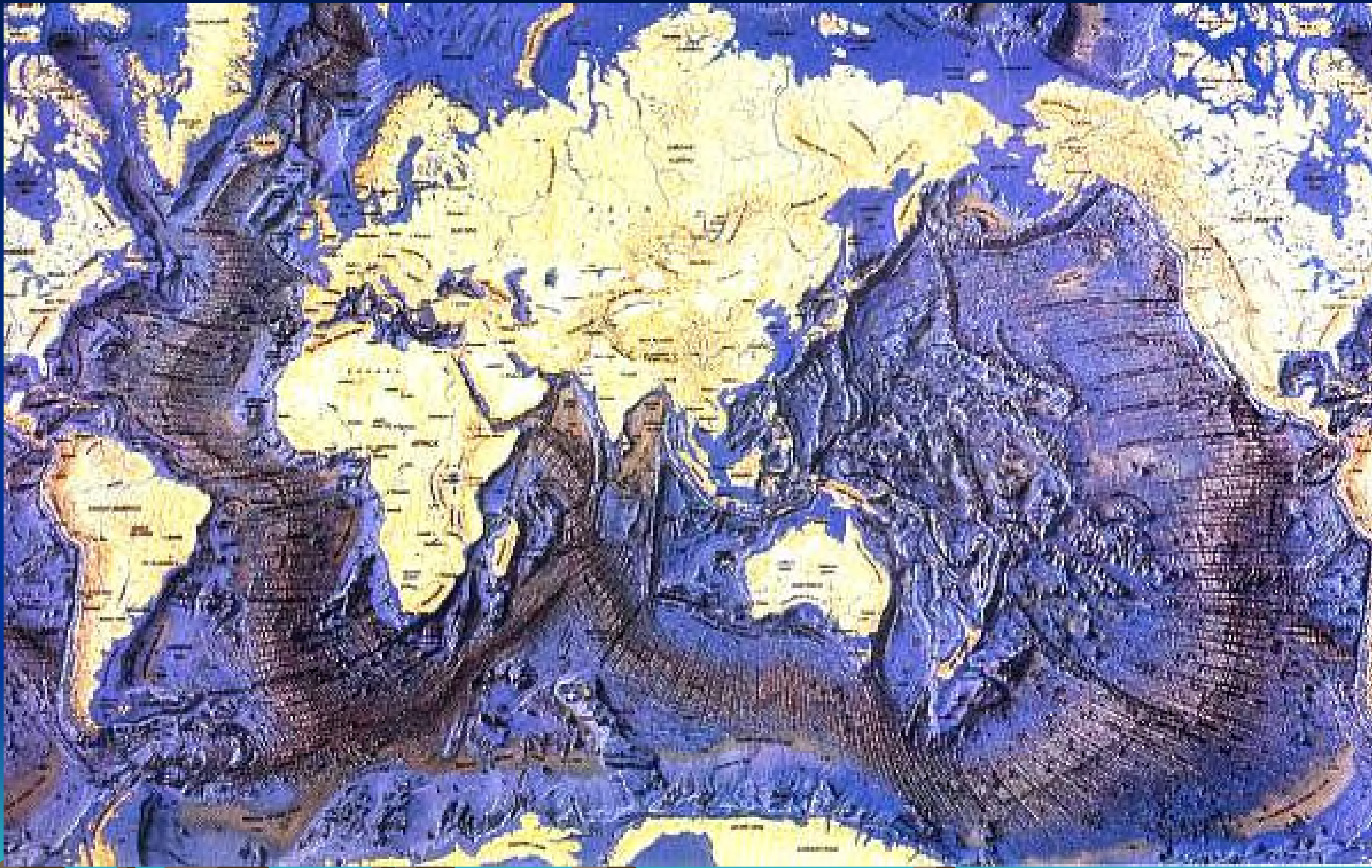
Chemical and Physical Nature of Earth's Interior



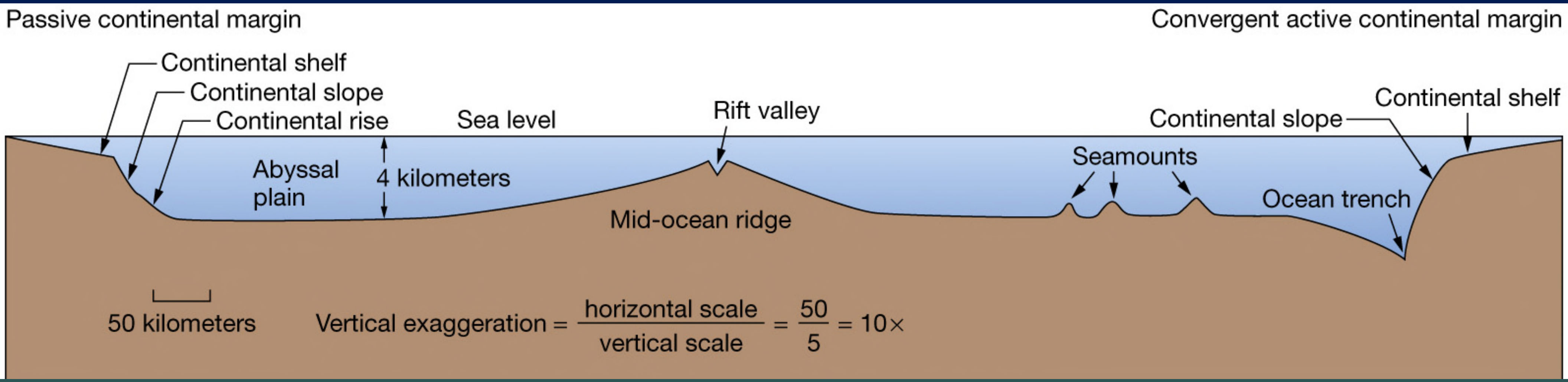


Density Layering of Earth's Interior

Topography of Earth's Ocean Floors



Cross-Section Profile of an Ocean Basin



Large-Scale Ocean Bottom Features

- ✓ Continental shelf, slope, and rise
- ✓ Abyssal plains and hills
- ✓ Mid-ocean ridge and rift valley
- ✓ Oceanic islands, seamounts, and guyots
- ✓ Ocean trench

Earth's Continents and Ocean Basins

1) Two Different Types of Crust

- ✓ Continental - Granitic
- ✓ Oceanic - Gabbroic

2) Continental Crust

- ✓ Lighter (2.7 g/ml)
- ✓ Thicker (30 km)
- ✓ High Standing (1 km elev.)

3) Oceanic Crust

- ✓ Denser (2.9 g/ml)
- ✓ Thinner (7 km)
- ✓ Low Standing (- 4 km elev.)

Two Primary Types of Earth Crust

1) Two Different Types of Crust

- ✓ Continental = Granitic
- ✓ Oceanic = Gabbroic

2) Continental Crust

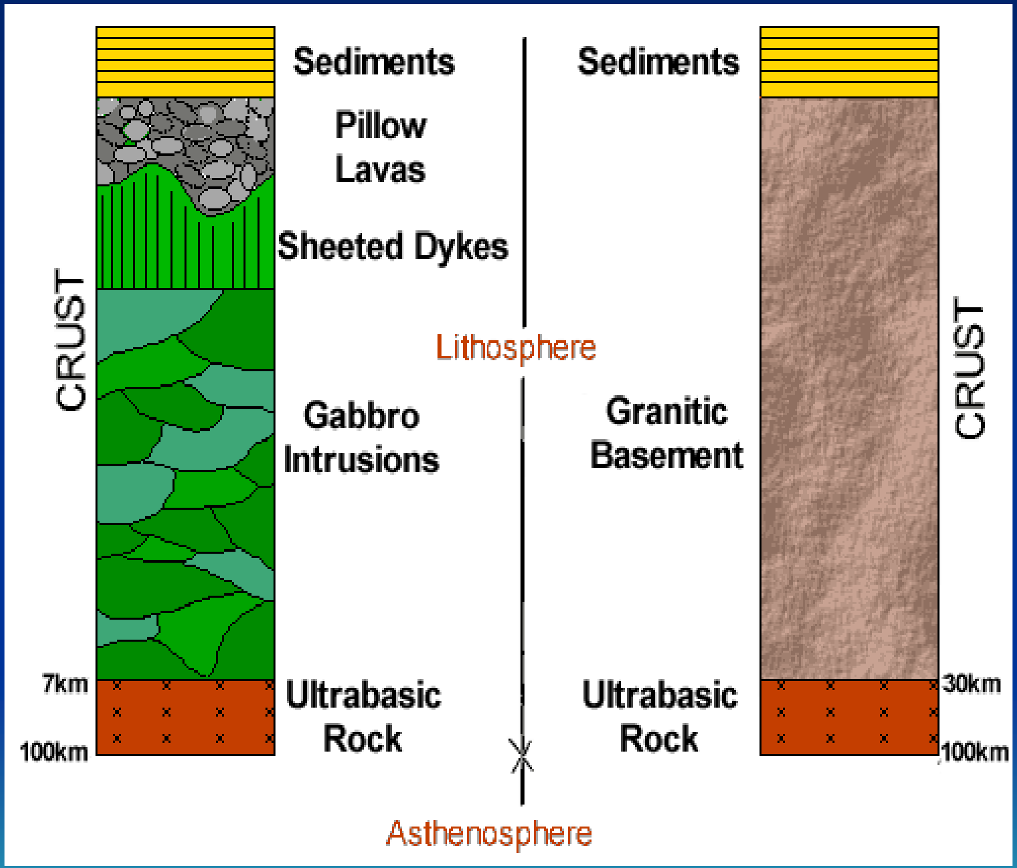
- ✓ Less dense (2.7 g/ml)
- ✓ Thicker (30 km)
- ✓ High Standing (1 km elev.)

3) Oceanic Crust

- ✓ Denser (2.9 g/ml)
- ✓ Thinner (7 km)
- ✓ Low Standing (- 4 km elev.)

Oceanic Crust | **Continental Crust**

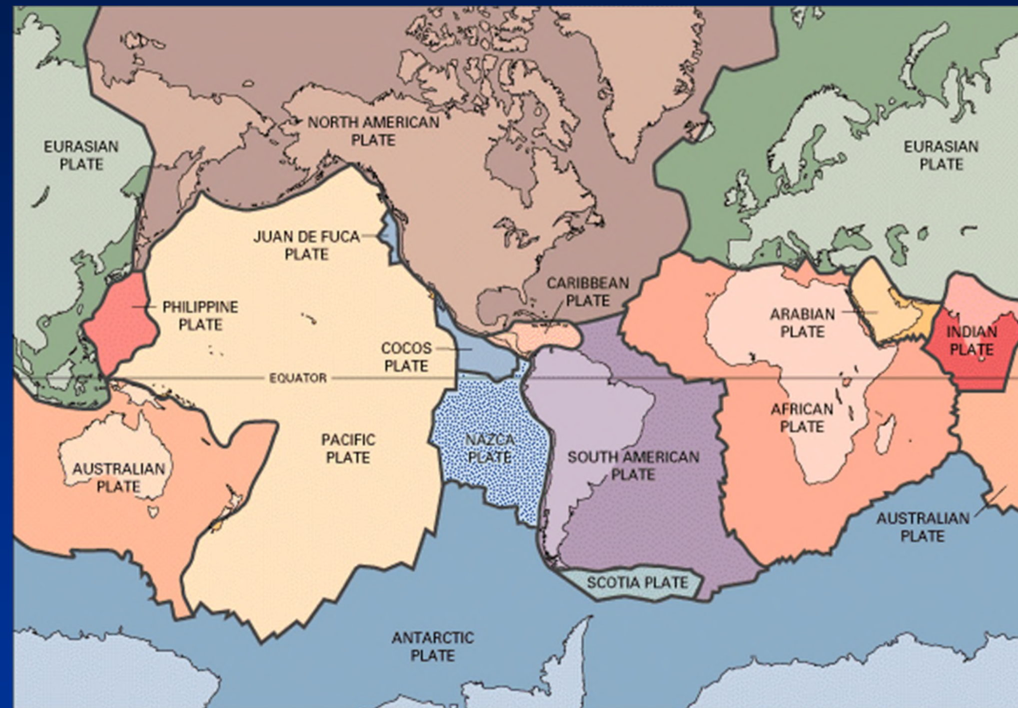
Gabbroic Rock | **Granitic Rock**



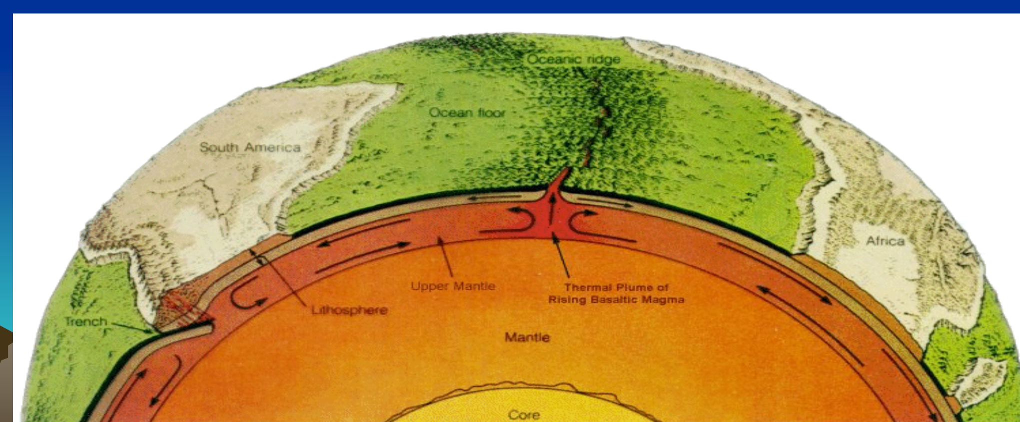
THE TECTONIC PLATES

Key Features:

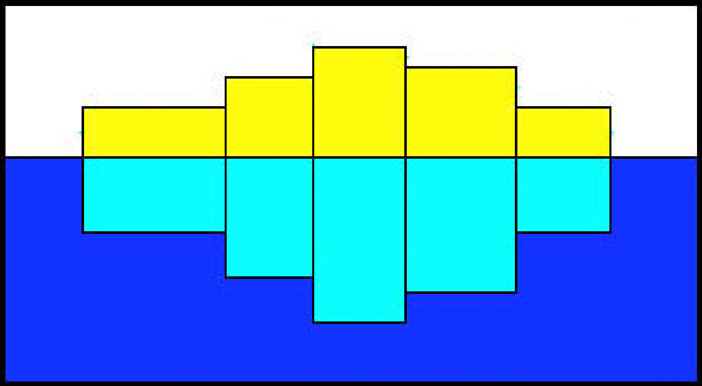
- ✓ Crust and uppermost mantle make up lithosphere
- ✓ Seven major and 10 minor lithospheric plates
- ✓ Plates are 100 km thick
- ✓ Plates are strong and rigid
- ✓ Plates isostatically “float” on fluid-like asthenosphere
- ✓ Plates are mobile, moving rates of centimeters per year



Earth’s Lithospheric Plates

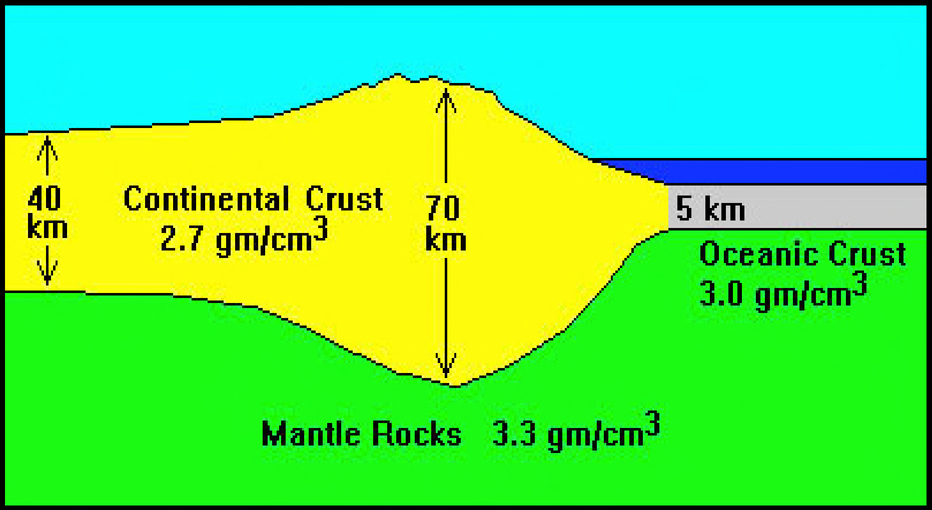


Isostasy



Wooden blocks of different sizes float to different heights (and depths) in equilibrium with the water it floats in.

Likewise, continental and oceanic crust are in equilibrium, floating on the asthenosphere in the upper mantle.



The density of rocks in continental crust are less dense than rocks in oceanic crust.

Concept of Buoyancy

1) Buoyancy is an important force on objects immersed in a fluid.

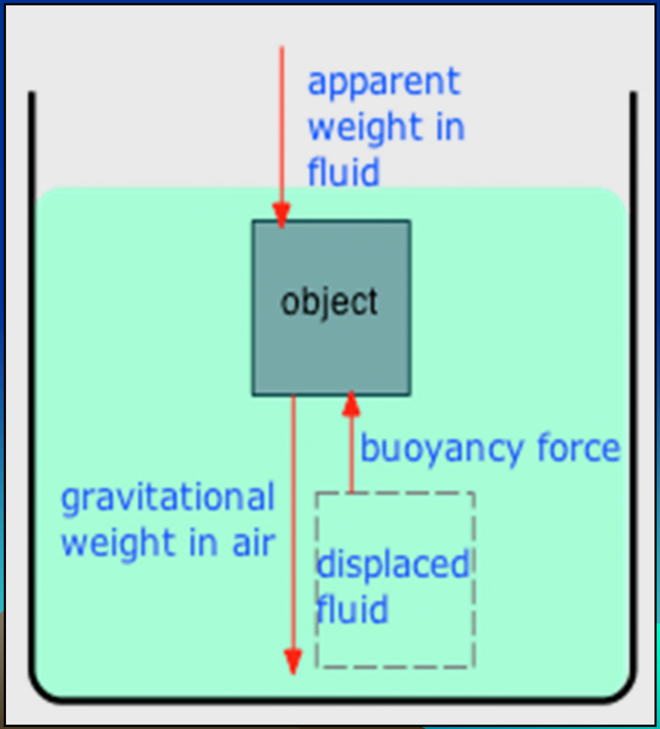
2) Buoyancy is the fluid pressure exerted on an immersed object equal to the weight of fluid being displaced by the object.

3) The concept is also known as Archimedes's principle

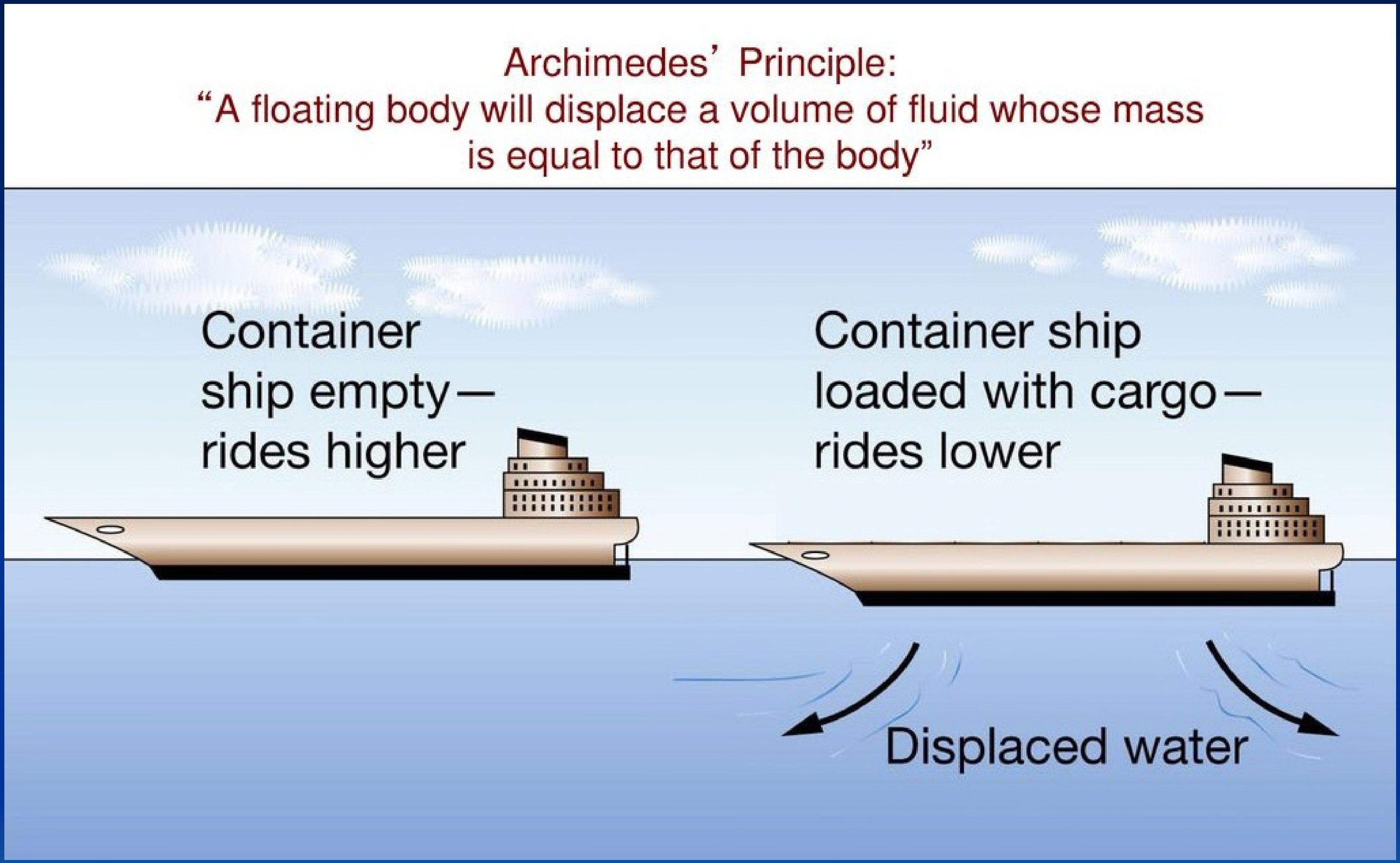
- Principle applies to objects in the air and on, or in, the water.
- Principle also applies to the crust "floating" on the mantle, which is specially termed "isostacy".

4) Density is a controlling factor in the effects of buoyancy between an object and its surrounding immersing fluid

- The greater the difference in density between the object and the fluid, the greater the buoyancy force = sits high
- The lesser the difference in density between the object and the fluid, the lesser the buoyancy force = sits low

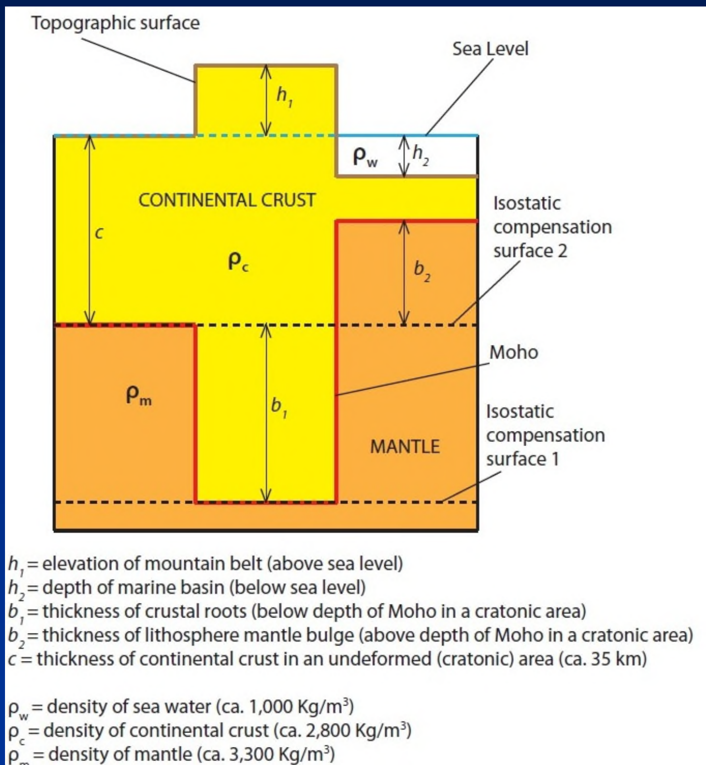


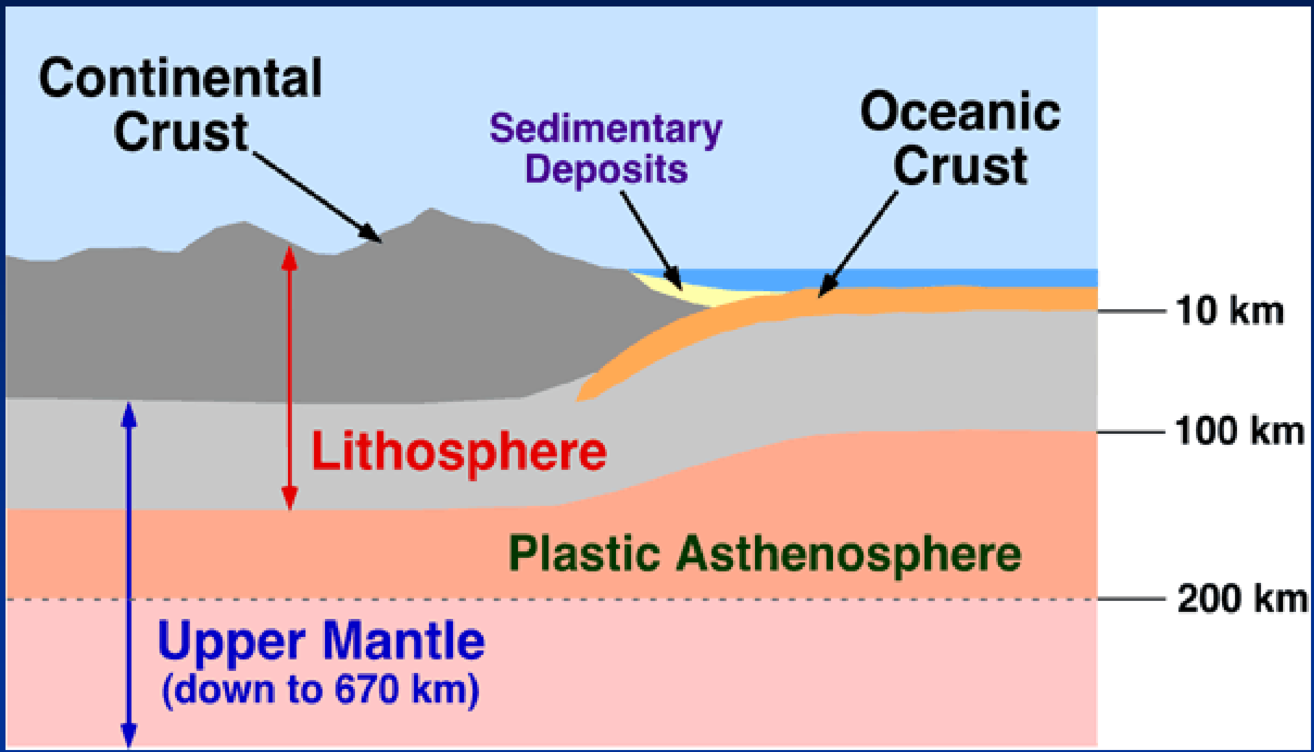
Example of Buoyancy: Boat on a Lake



Question: Can you estimate the ship's mass (weight), based on the ship's displacement and using Archimedes' Principle?

Isostasy: Crust *Floating* in Mantle





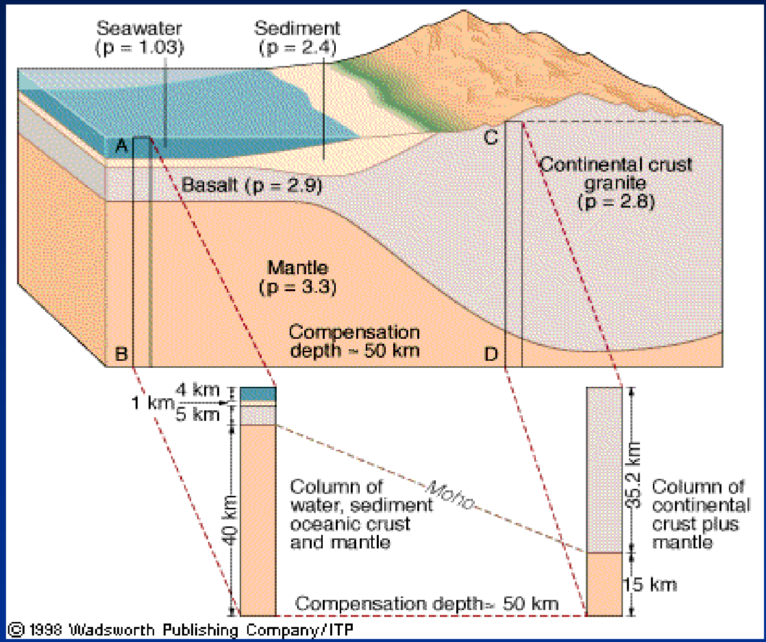
1) Isostatic Equilibrium Between Lithosphere and Asthenosphere

2) Isostatic Adjustments Made Over Geologic Time When A Layer's Density and/ or Thickness Changes

4) Isostatic Adjustments Produce Vertical Movement of Crust – Uplift or Subsidence

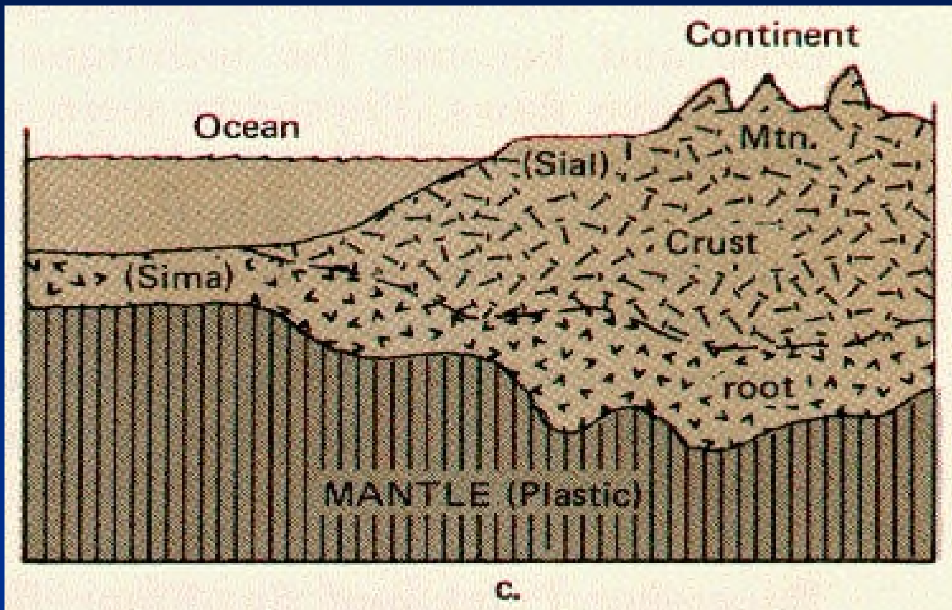
The Concept of Isostasy

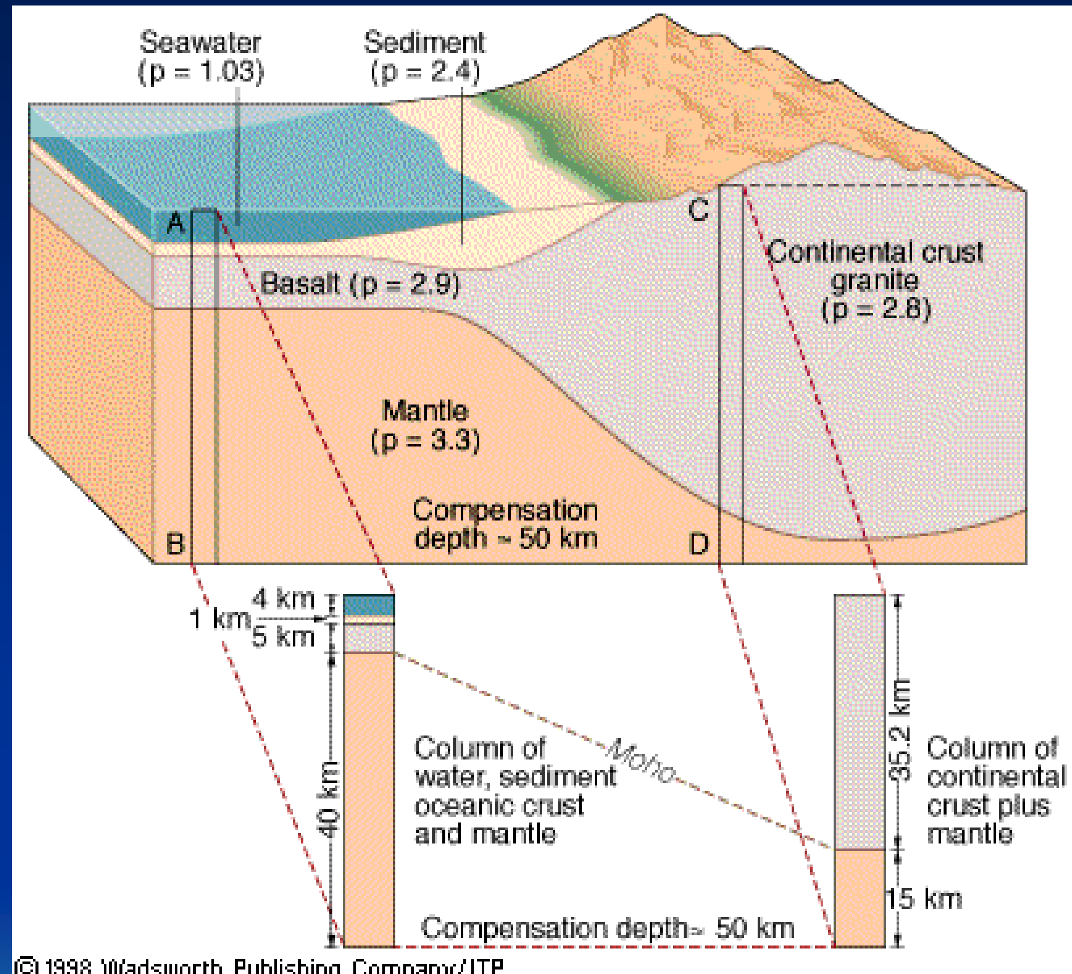
Defined: state of gravitational equilibrium between the earth's *rigid* lithosphere and *fluid* asthenosphere, such that the tectonic plates "float" in and on the underlying mantle at height and depth positions controlled by plate thickness and density.



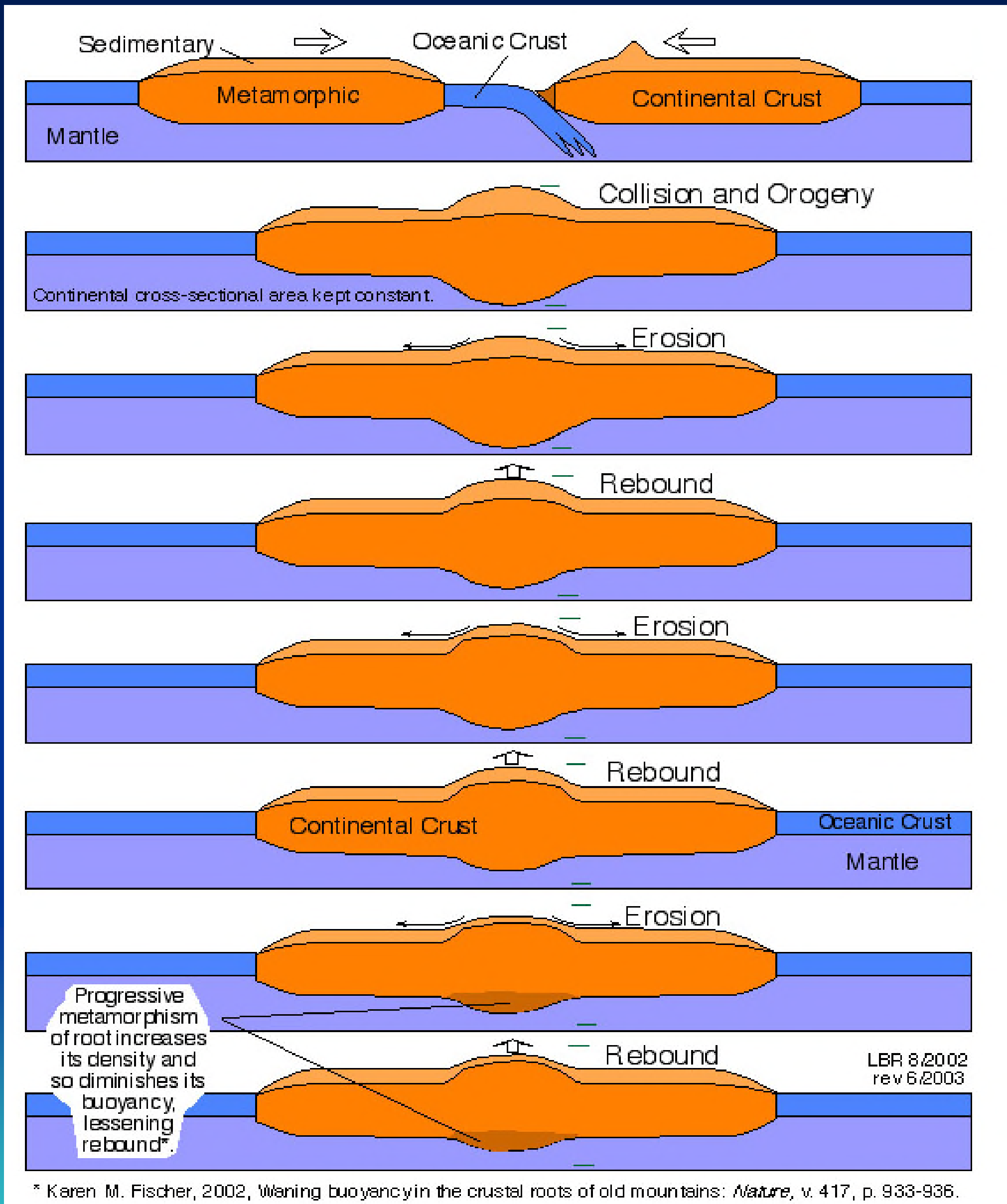
- ➢ The term “isostasy” is from Greek “iso” = equal; “stasis” = equal standing.
- ➢ Earth’s strong rigid plates exert a downward-directed load on the mobile, underlying weaker, plastic-like asthenosphere – pushing down into the mantle.
- ➢ The asthenosphere exerts an upward pressure on the overlying plate equal to the weight of the displaced mantle – *isostatic equilibrium* is established.
- ➢ Mantle will flow laterally to accommodate changing crustal loads over time – this is called *isostatic adjustment*
- ➢ Plate tectonics, erosion and changing ice cap cause isostatic disequilibrium

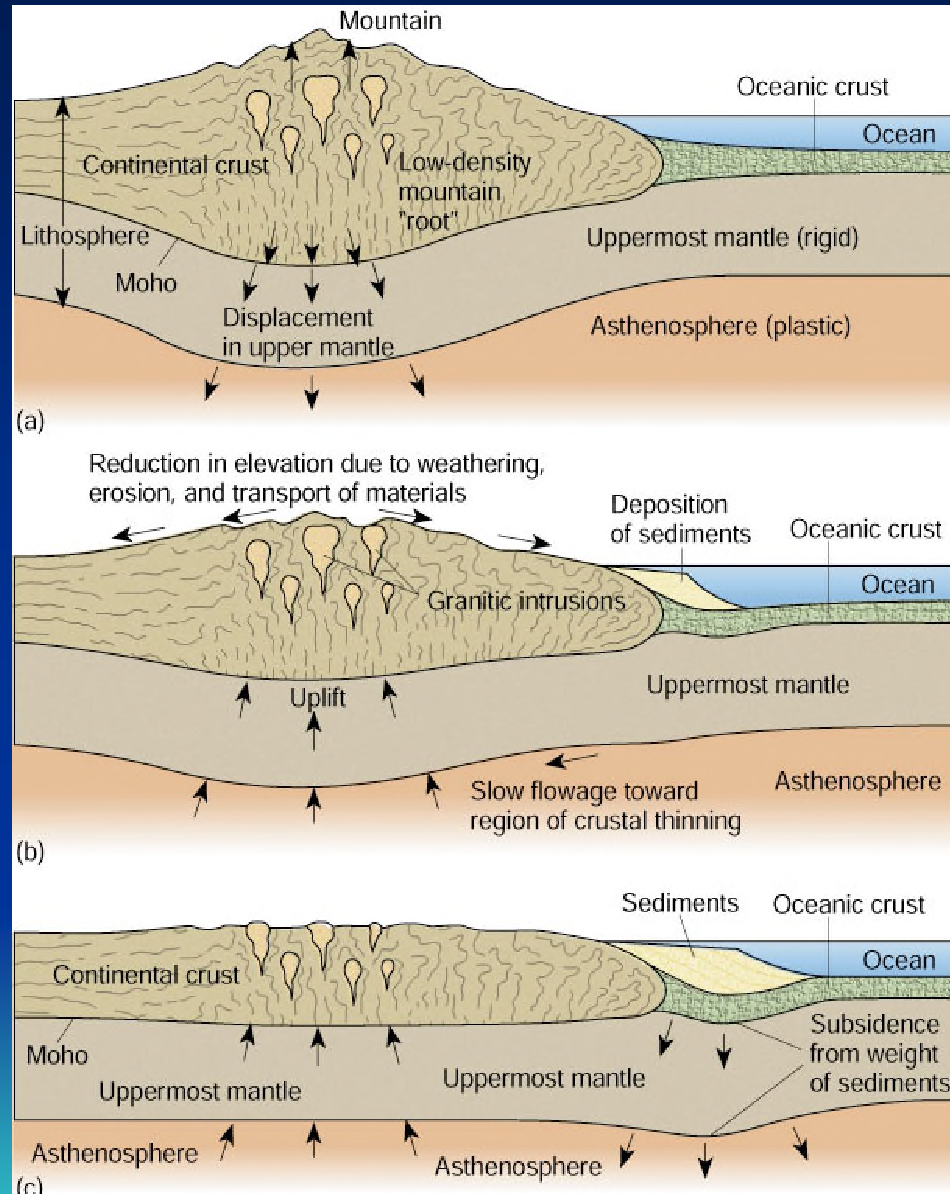
The Isostatic Equilibrium





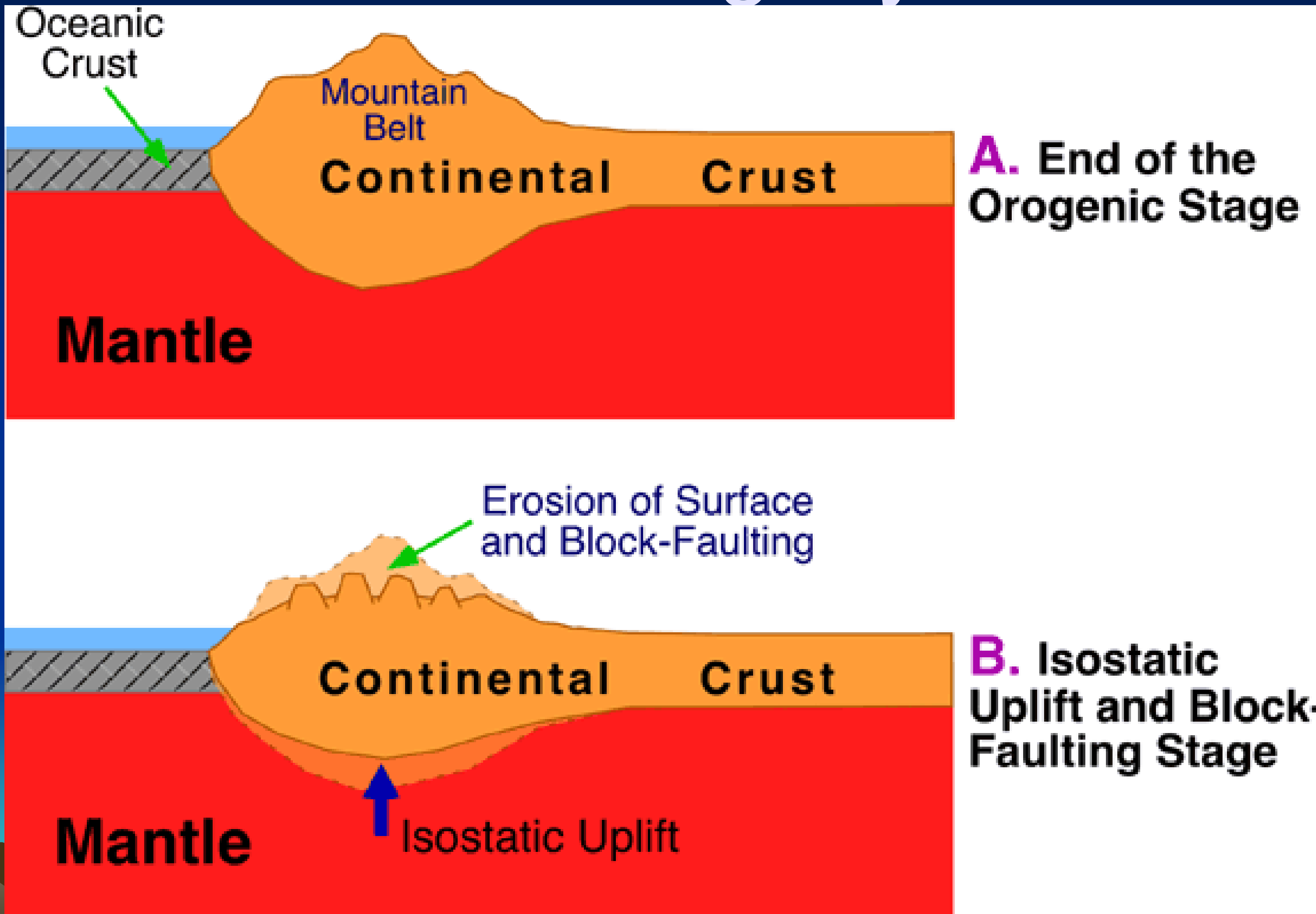
Isostatic Adjustment - Orogeny



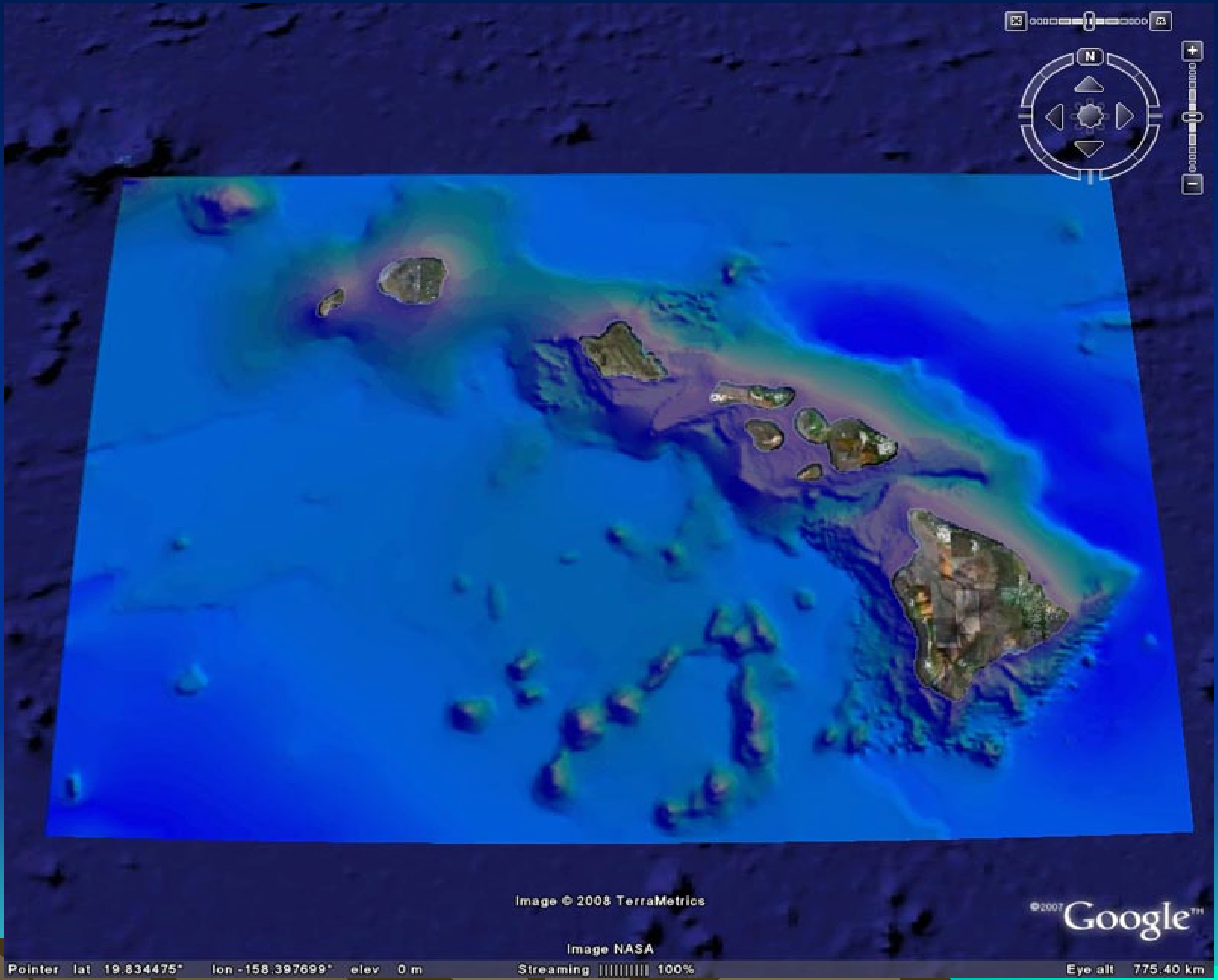


Isostatic Loading and Rebound – *Orogeny and Erosion*

Isostatic Adjustment - Orogeny

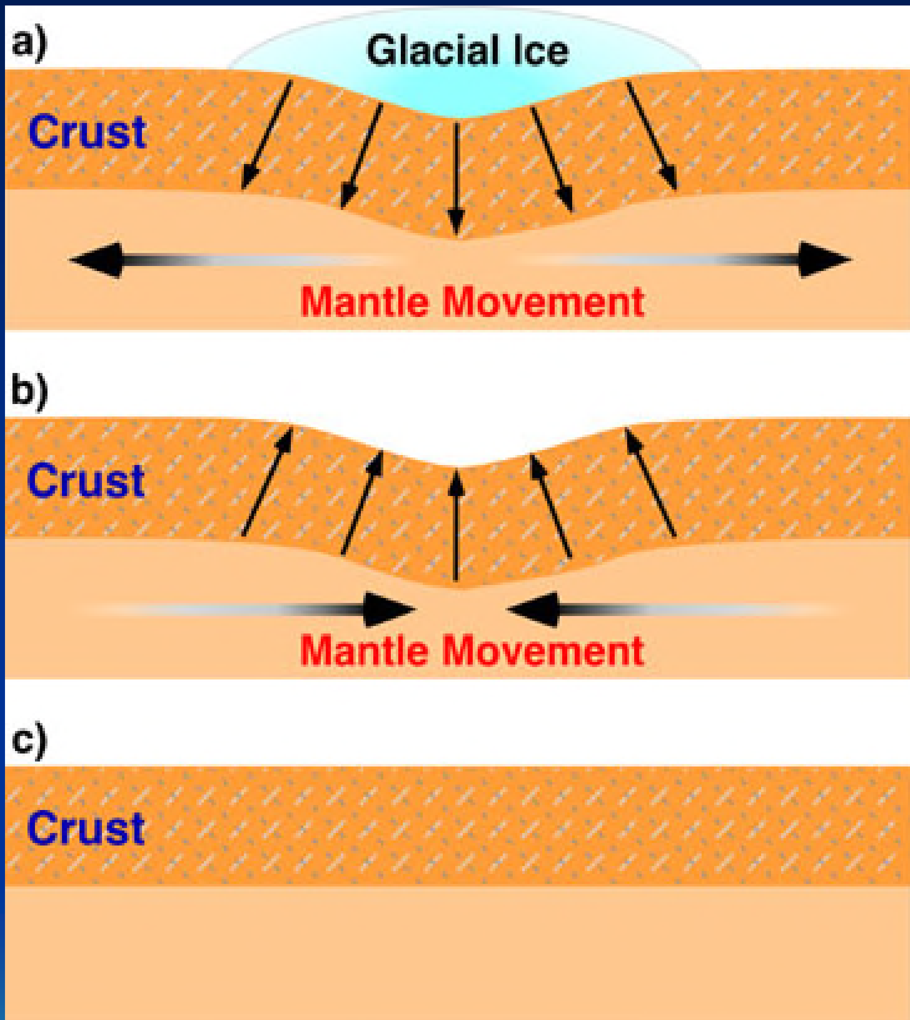


Isostatic Adjustment – Volcanism

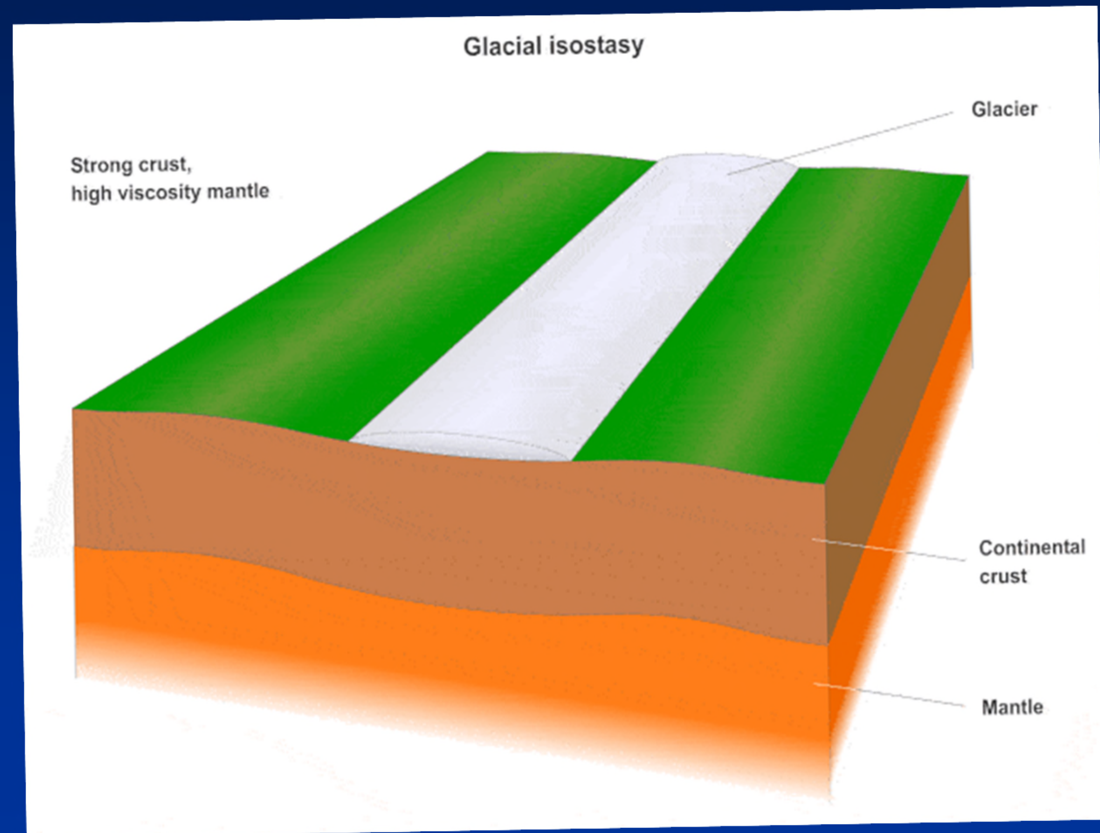


Growth of the Hawaiian Islands – Crustal Depression

Isostatic Adjustment – Ice Caps



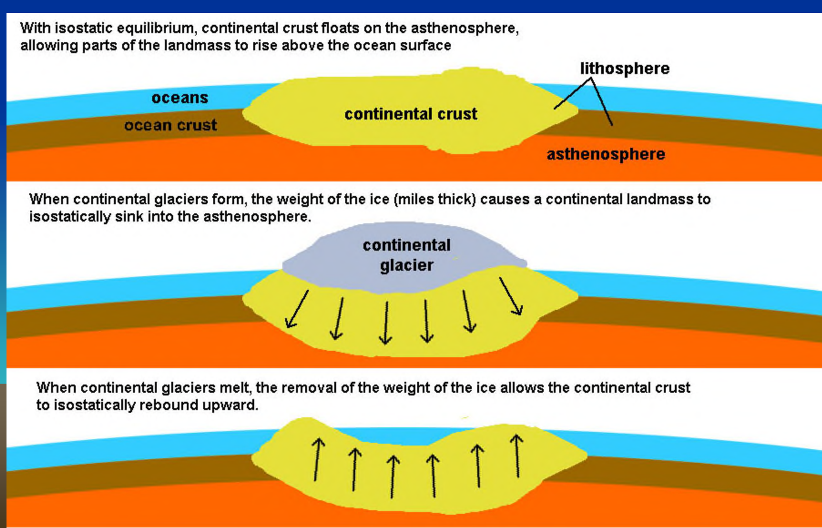
Glacial Adjustment



Isostatic Response to Changing Ice Thickness

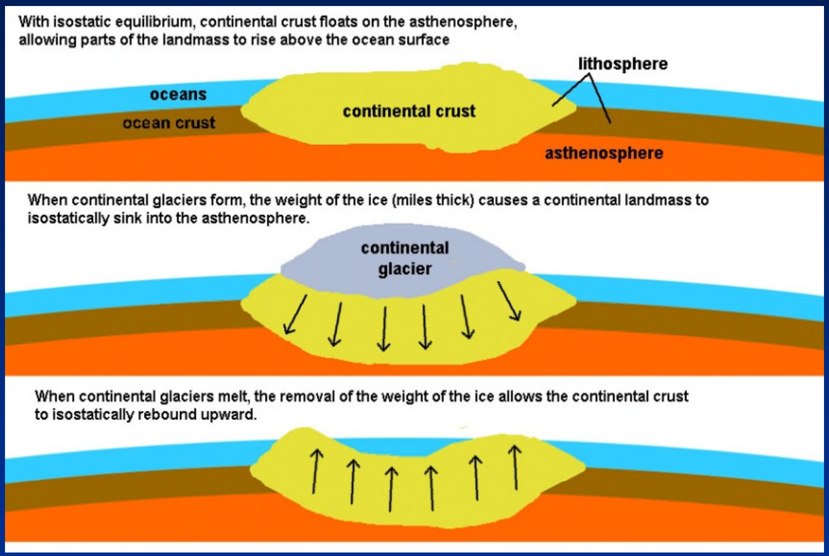
North American Pleistocene Ice Cap

- ✓ Ice Cap Maximum: 20,000 ya
- ✓ Ice Cap Retreat: By 6,000 ya
- ✓ Last 6,000 years:
  - ➢ Sea level rising = 13 meters
  - ➢ Land uplifting = Variable
- ✓ To establish an accurate rate of uplift, you need to take into account eustatic sea level rise with uplifting crust.



20,000 years ago

North American Pleistocene Ice Cap



Isostatic Adjustment

Ice Cap Maximum: 20,000 ya

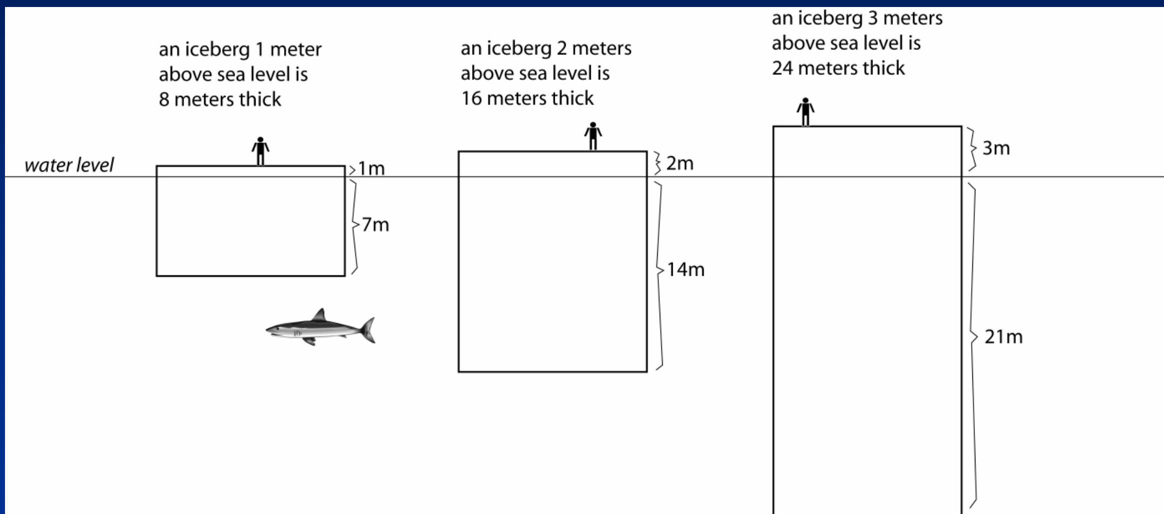
Ice Cap Retreat: Today

✓ Land around Hudson Bay 150 meters higher (above sea level), compared to 6000 years ago. Global sea level also rose 13 meters.

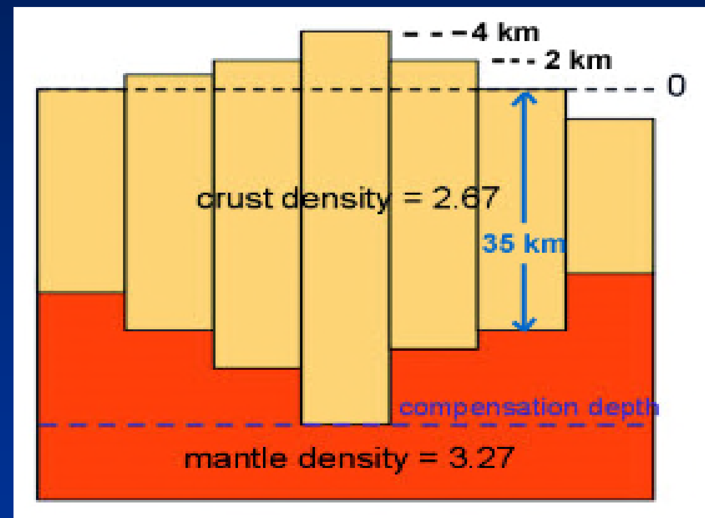
✓ To establish an accurate rate of uplift, you need to add rise in sea level to uplift amount to get true amount of uplift.

Isostatic Equilibrium and Thickness

- The One to Eight Rule -



Icebergs of different thicknesses



Crust of different thicknesses

1) For icebergs and continental crust, apply the **1-to-8 rule**, assuming ice or continental crust is in isostatic equilibrium.

2) Continental crust at **sea level** averages about 35 kilometers thick. (1 km = 0.6 miles.)

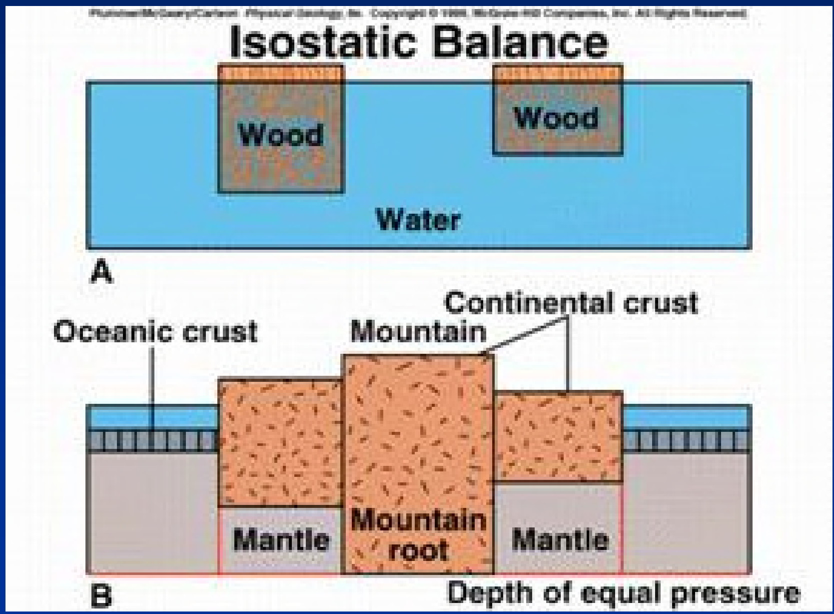
3) How thick must the crust be to support a:

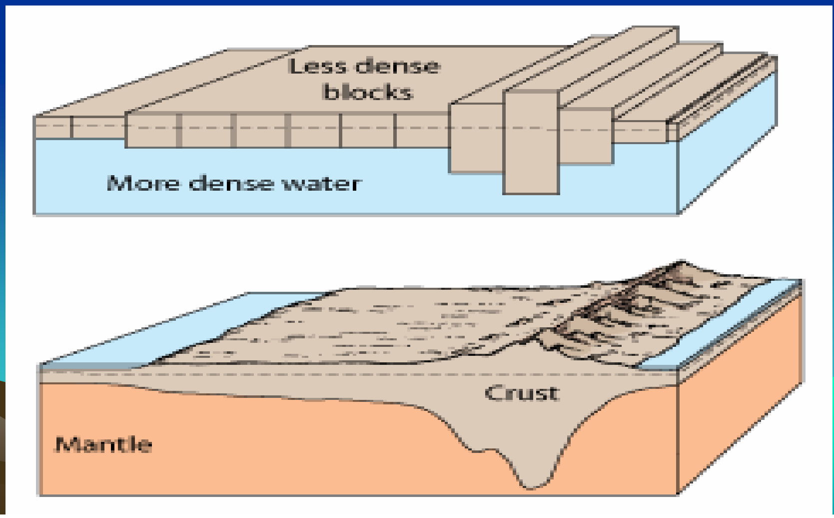
1-kilometer high mountain belt? 2-kilometer high mountain belt? km 5-kilometer high mountain belt?

Modeling Earth's Isostasy

Using Wood Blocks and Water to Understand the Key Concepts of Isostatic Equilibrium and Adjustment

- Density of Floating Blocks
- Thickness of Floating Block
- Density of Liquid Water





The Lab Model:

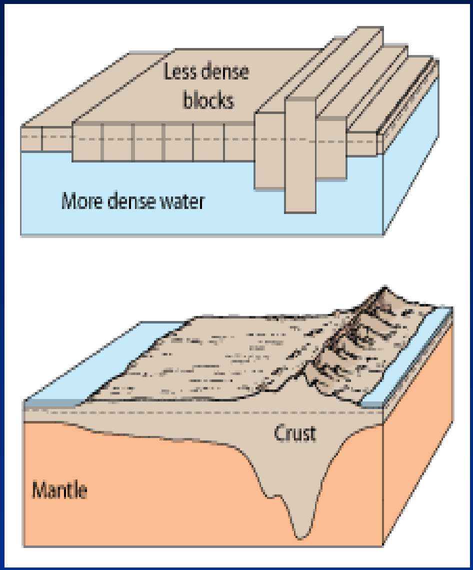
1) Oak as Ocean Crust

2) Redwood as Continental Crust
   - ✓ Thick = Mountains
   - ✓ Thin = Low-lying Regions

3) Water as the Underlying Mantle

Density/Thickness – Buoyancy Relationship

Modelling Wood Block Behavior in Water:



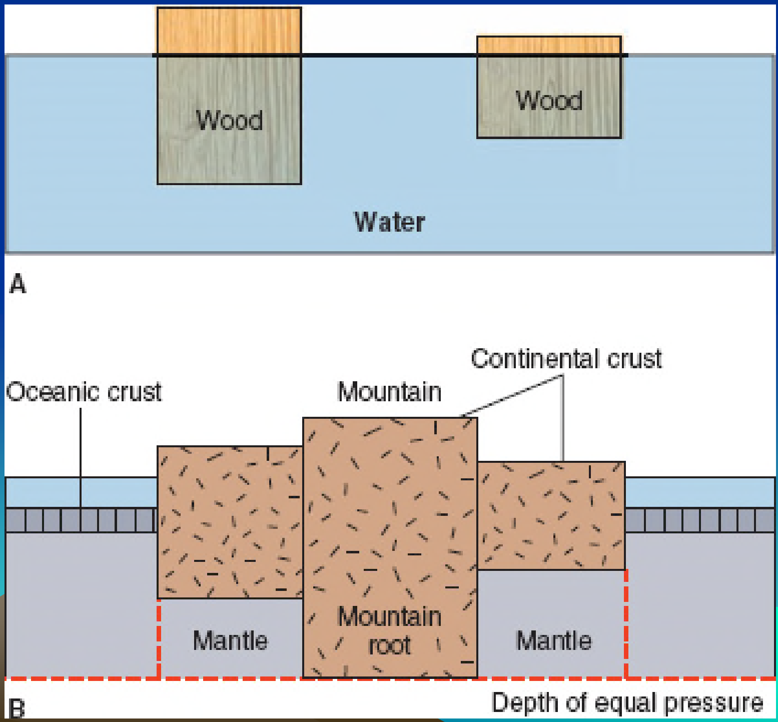
1) Density of wood in relation to water density determines level of buoyancy: (percentages in/out of water)

2) Thickness of block determines absolute height of block in and out of water

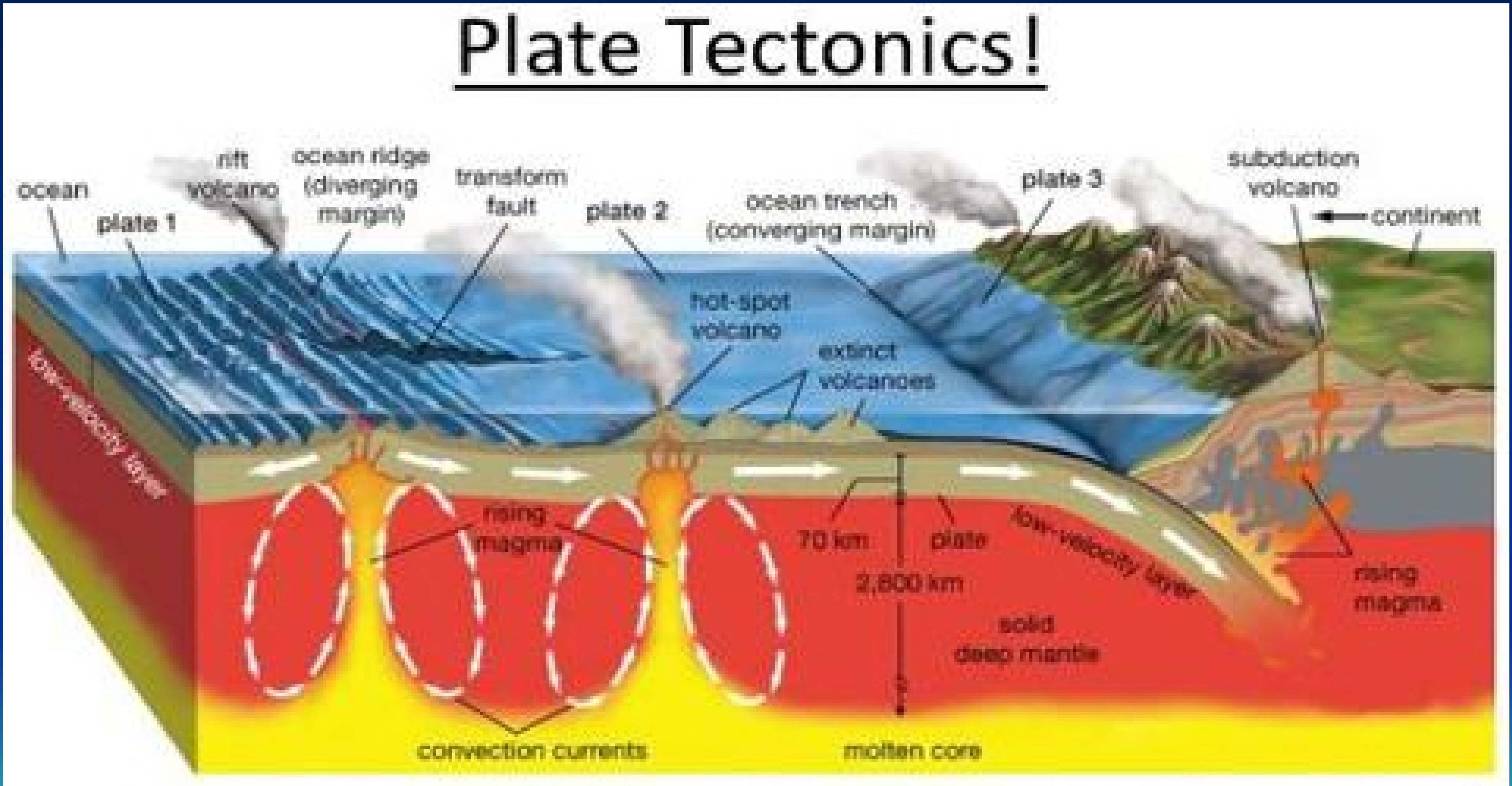
3) Compare redwood and oak wood blocks floating in water to that of continental and oceanic crust floating the mantle

4) Keep in mind the differences in BOTH ***density*** and ***thickness*** of the two different blocks and the two different types of crust

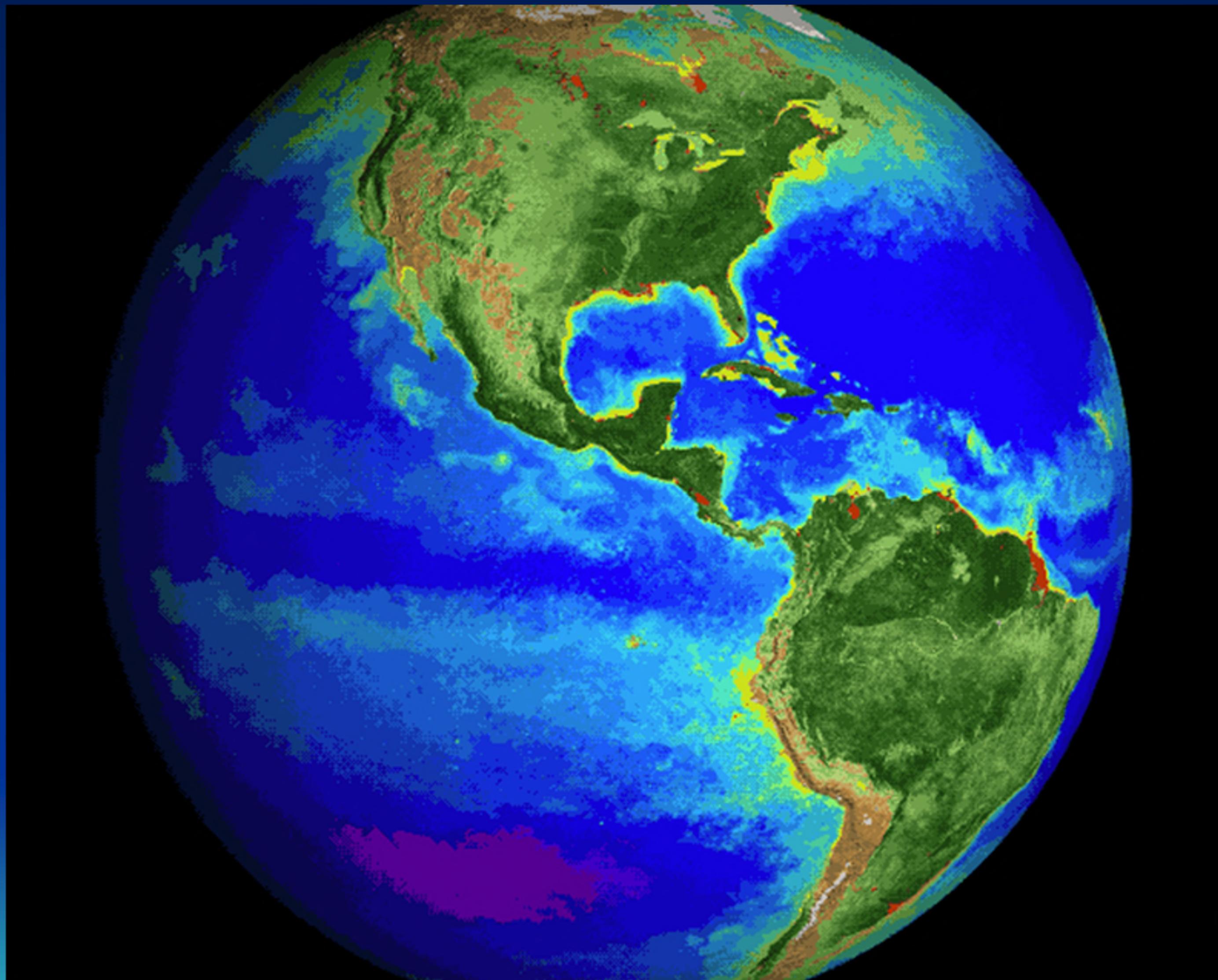
5) Note that high-standing floating objects require a much deeper bottom portion to maintain (hold up) the high-standing portion.



The Plate Tectonic Revolution



We Live on a Very Active Planet



The Earth has been *Rocking It* every single day of its 4.6 billion year life….and its only at its mid-point in lifespan

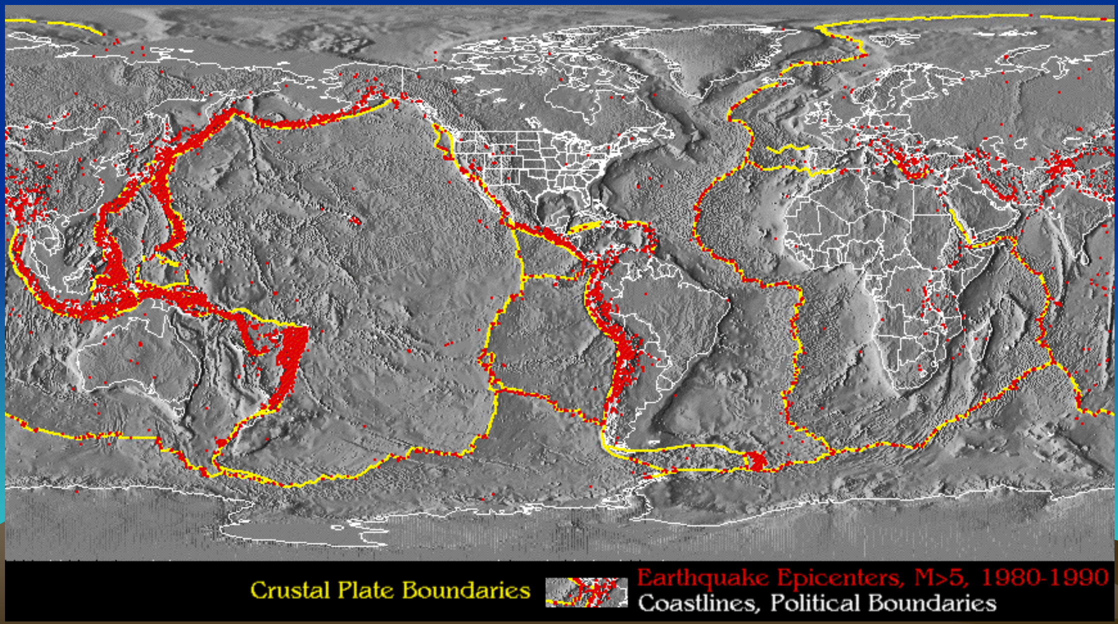
Dynamics of a Restless Planet

Earth's Crust Exhibits Extensive Fault Activity

✓ Evidence of faulting stretching over billions of years of time

✓ Worldwide occurrence of local and regional-scale faulting occur along belt-like regions

✓ Faulting and associated quakes found in both continental and oceanic settings

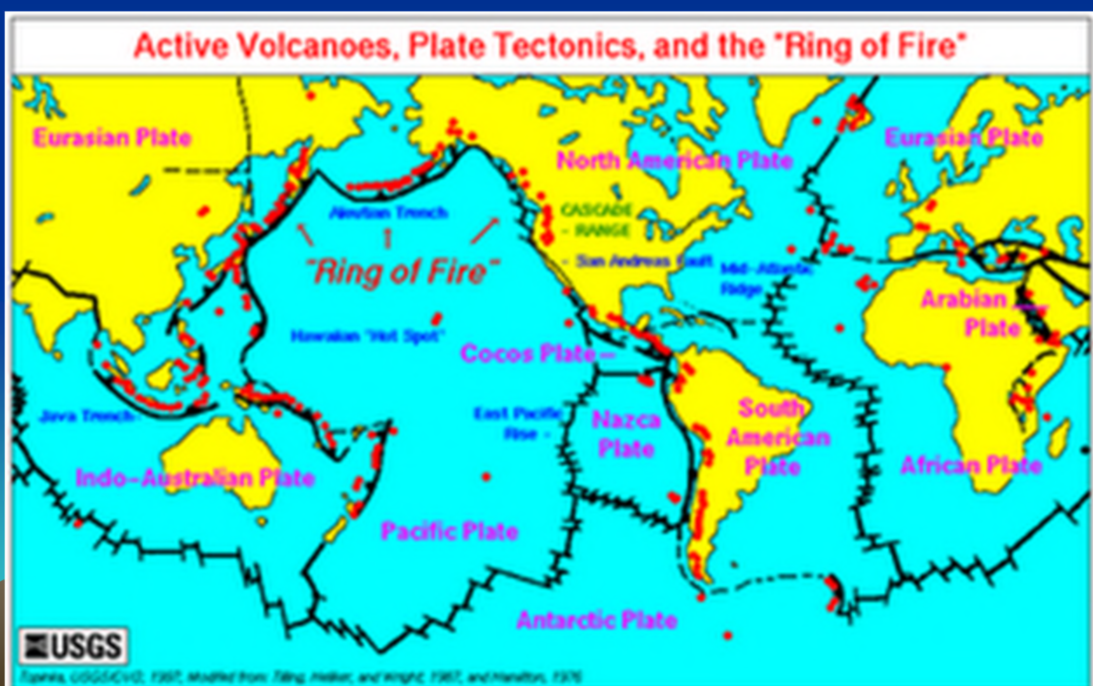


Great San Fran EQ of 1906

Dynamics of a Restless Planet

Earth's Surface Exhibits a Long History of Volcanic Activity

- ✓ Billions of years of volcanic activity
- ✓ Widespread evidence of regional-scale volcanism occur in belt-like exposures
- ✓ Volcanism found in both continental and oceanic settings



Mt St Helens Eruptions

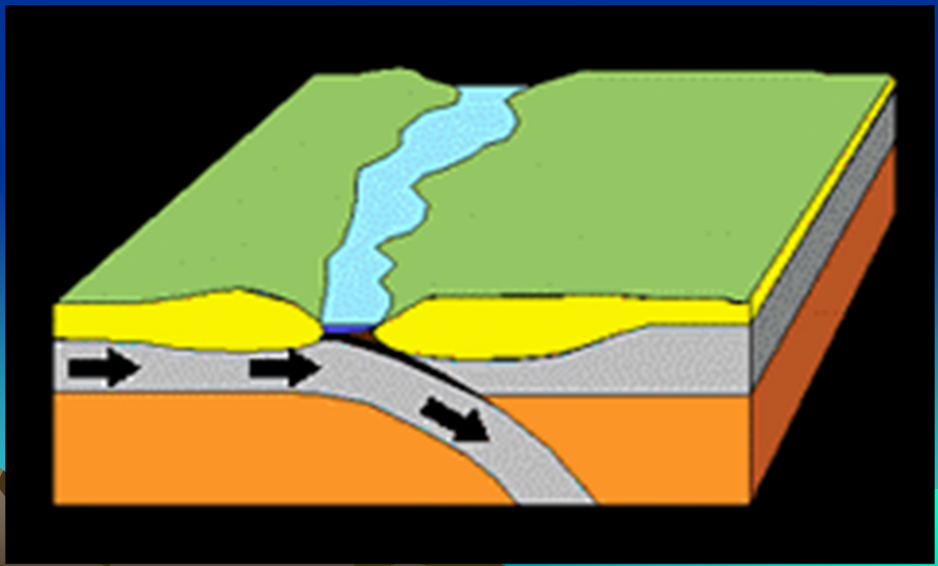
Dynamics of a Restless Planet

Earth Exhibits a Long History of Mountain Building Events

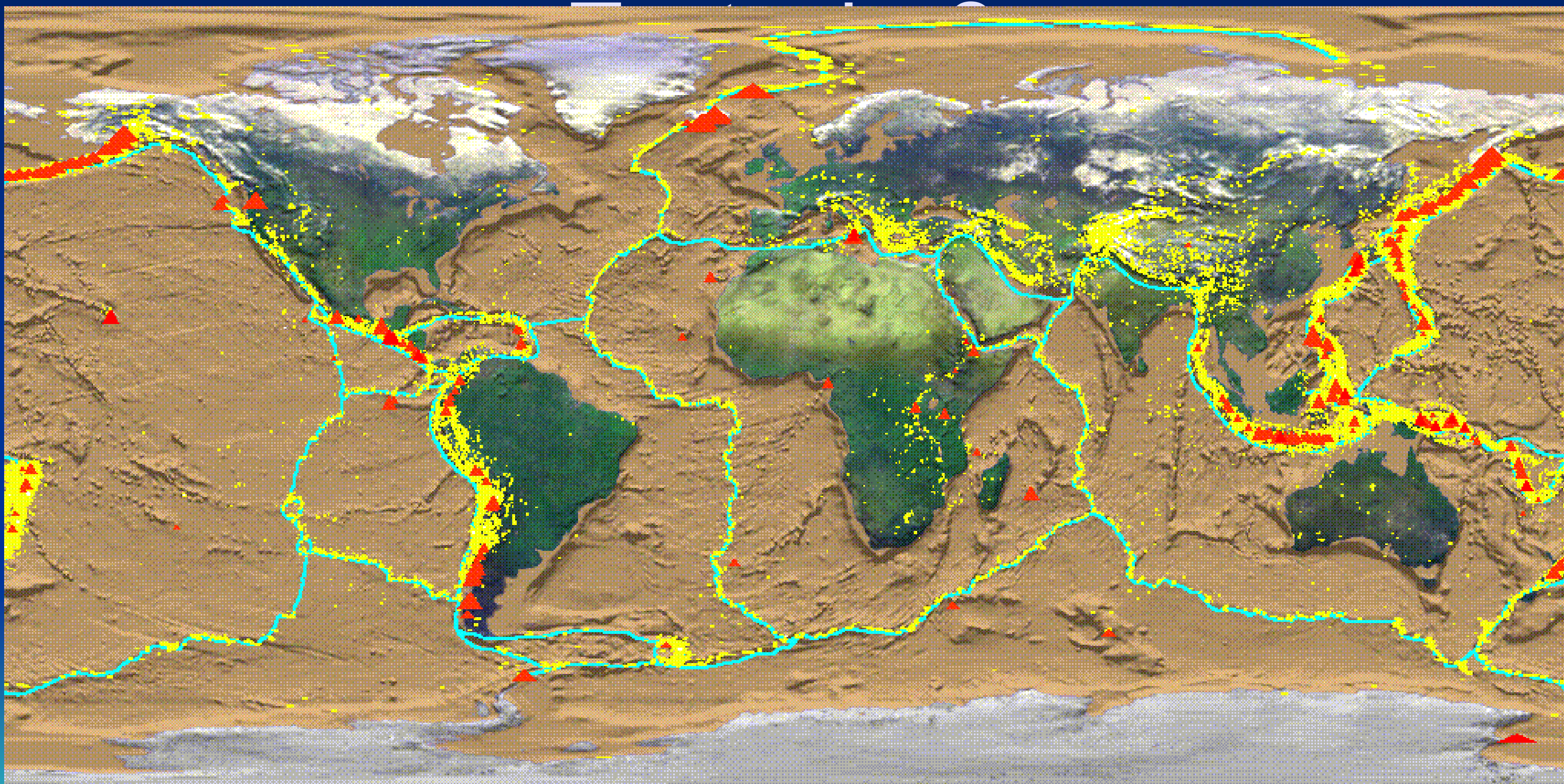
✓ Activity stretching over billions of years of time

✓Numerous belt-like regions of exposed crustal rocks show intense deformation

Present-day Mountain Belt of Folded and Faulted Crust



What is the Relationship Between Earthquakes, Active Volcanoes, Global-scale Seafloor Features, and Plate Tectonics?



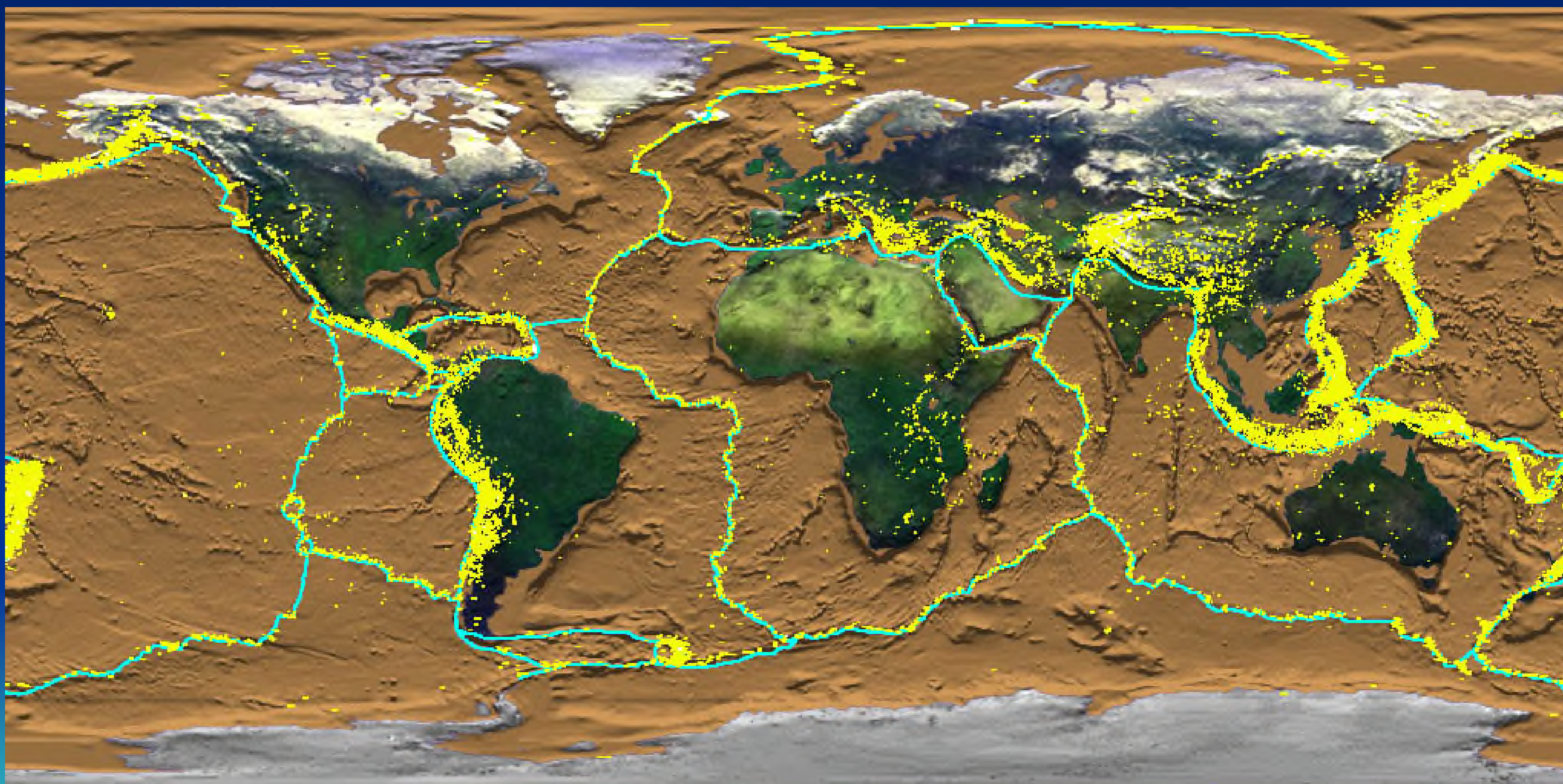
Global-Scale Earthquake Patterns

<u>Observations</u>

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



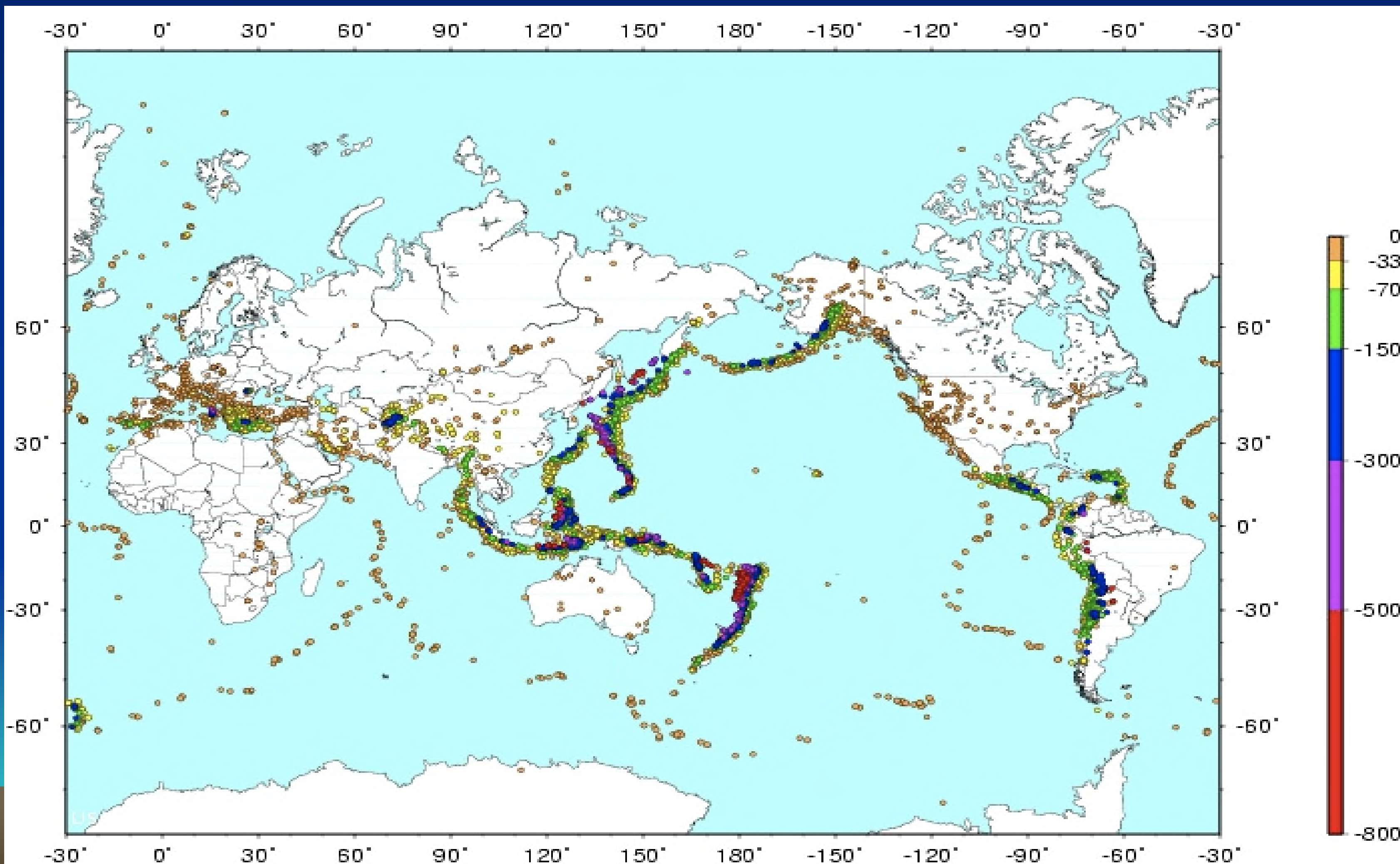
Worldwide Earthquakes – Shallow versus Deep

Observations

1) Shallow earthquakes trace all the plate boundaries

2) Deep earthquakes trace the trench-volcanic arc (subduction) systems

1. Ocean Basin Physiology and Tectonism

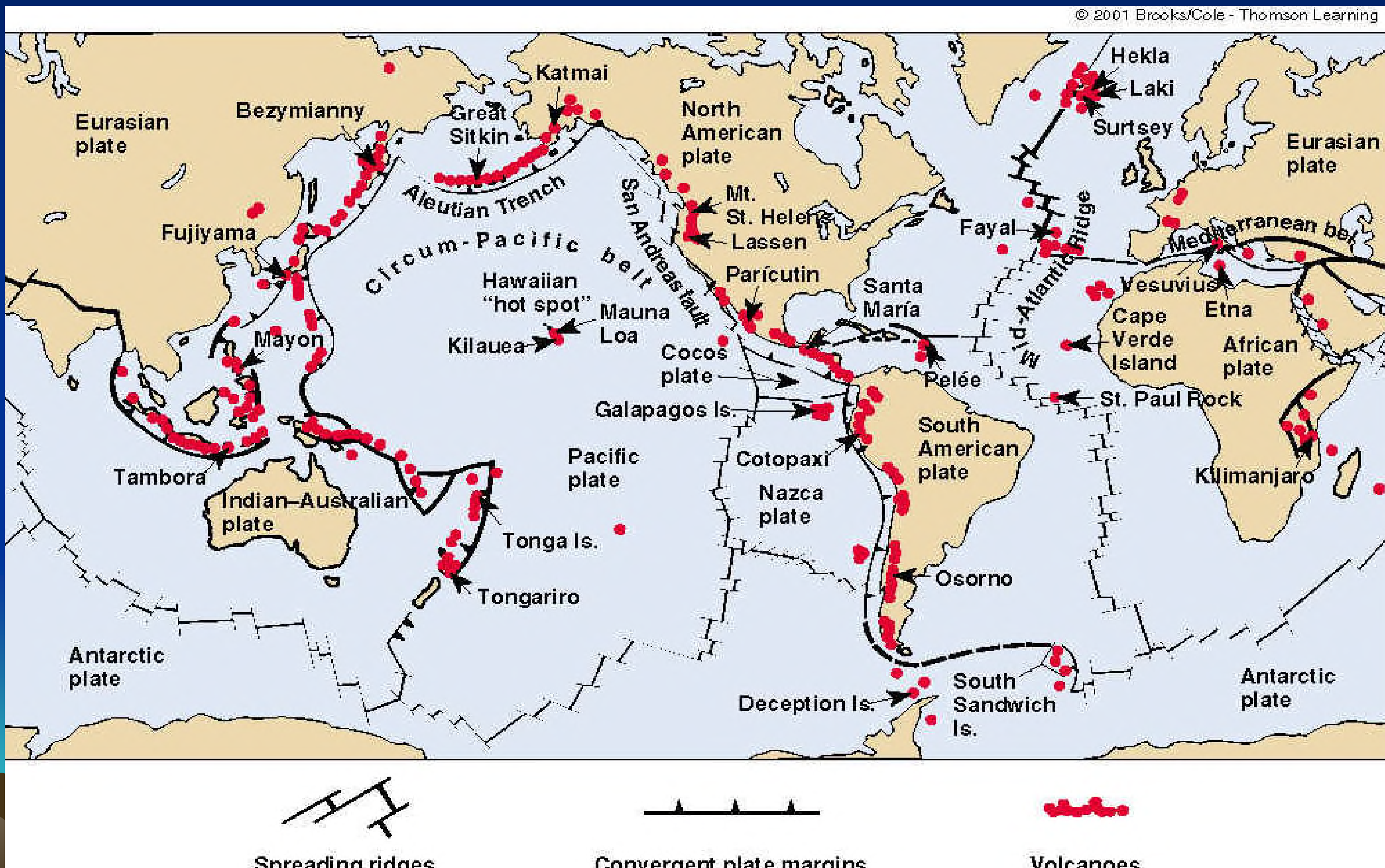


Global-Scale Volcanic Patterns

Observations

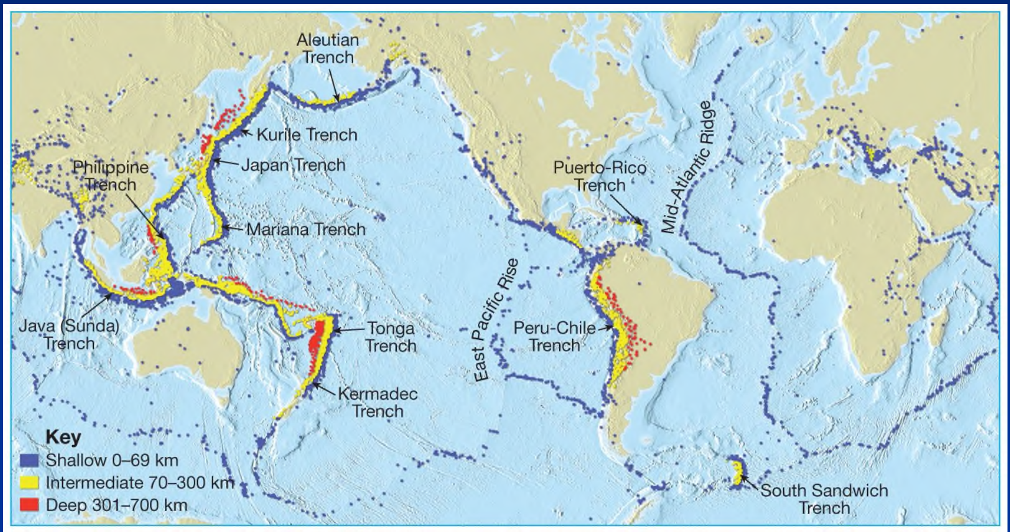
1) Active volcanoes trace mid-ocean ridges and volcanic arcs systems
2) Active “arc” volcanoes trace the subduction-related plate boundaries

1. Ocean Basin Physiology and Tectonism

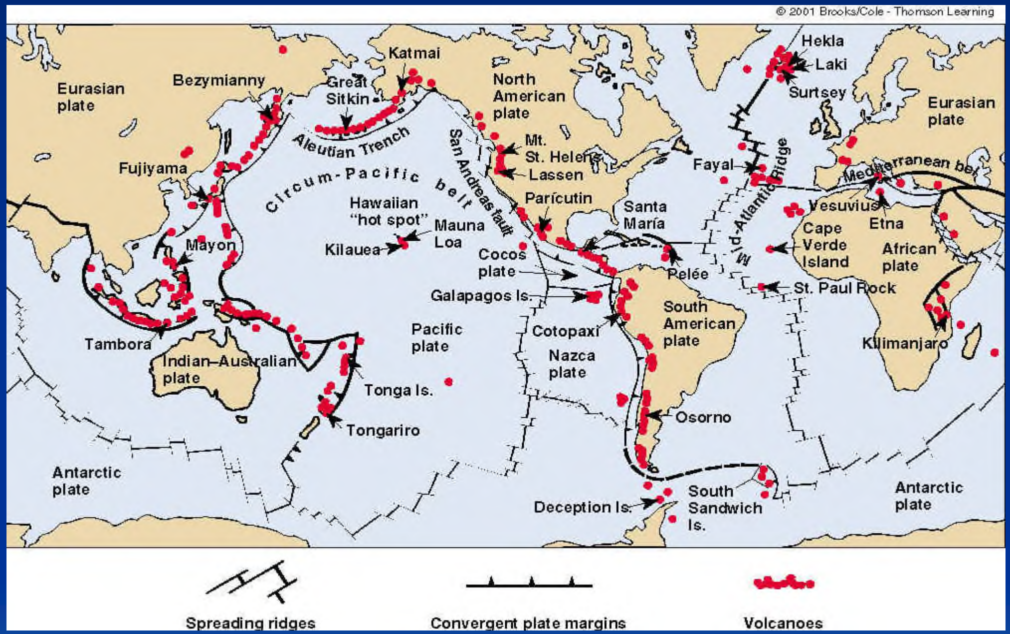


Comparing Earthquake and Volcano Data to Plate Boundaries

1) Compare shallow earthquakes locations with plate boundaries
2) Compare deep earthquakes with trenches and subduction zones
3) Compare arc volcanoes with trenches and subduction zones.



Earthquake Distribution



Volcano Distribution

Global Earthquake Distribution Coincides with Active Volcanoes

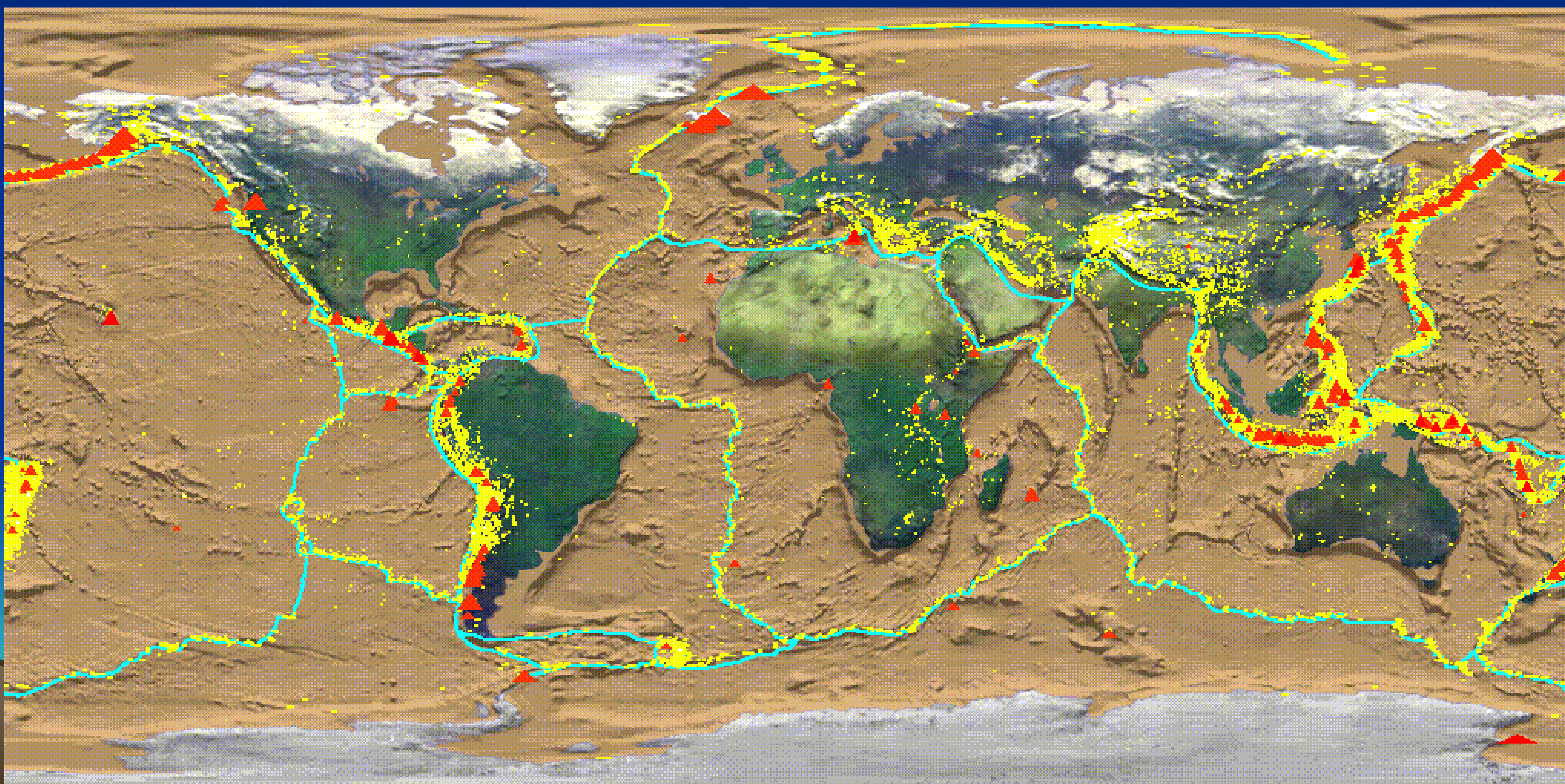
✓ Most active faults are located along curvi-linear belts where both, active volcanism and mountain building are occurring

✓ Earthquakes and active volcanoes trace out the edges of tectonic plates

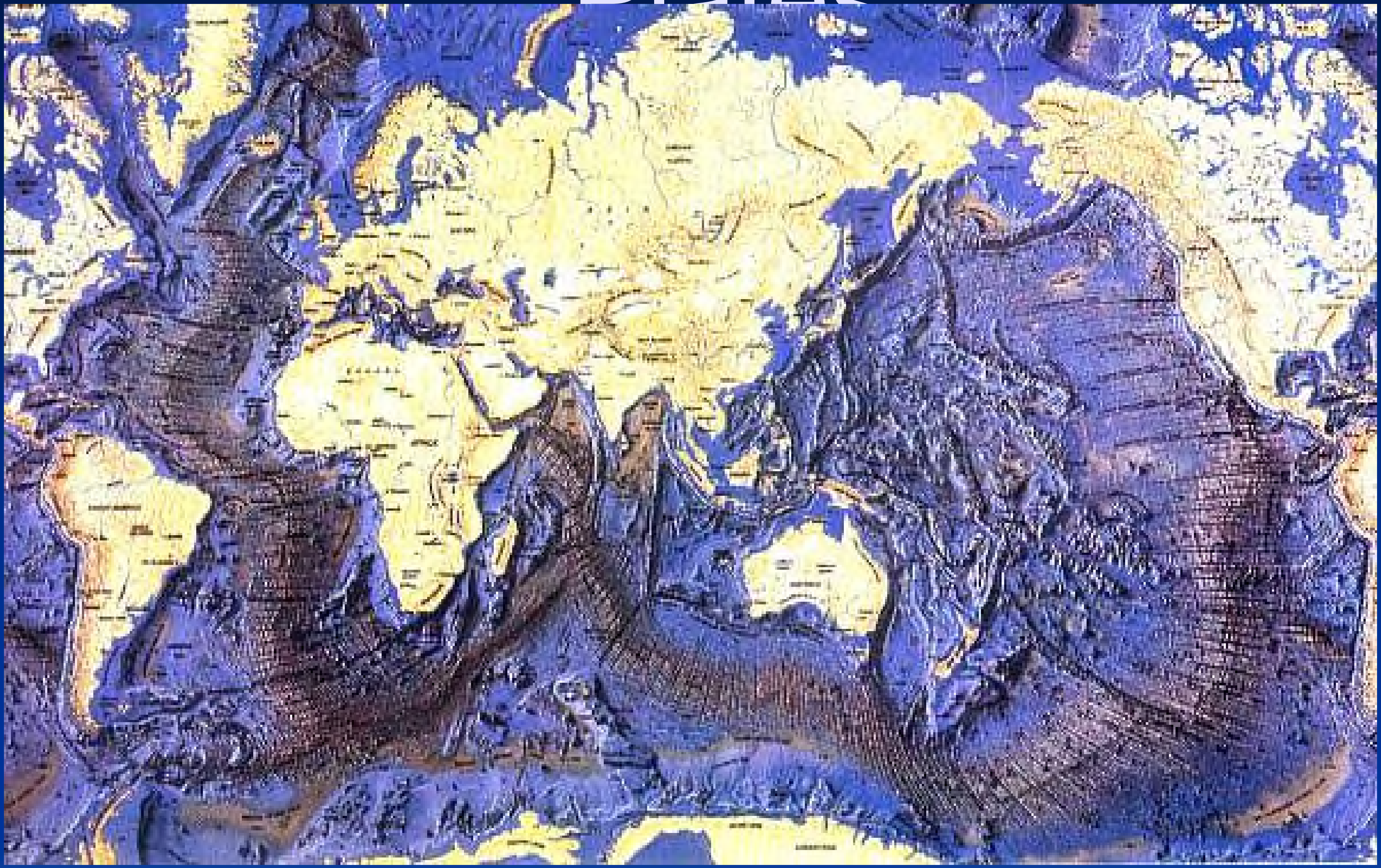
http://d3tt741pwxqwm0.cloudfront.net/WGBH/conv16/conv16-int-tectonic/index.html

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

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



Earth's Geography and Tectonic Plates



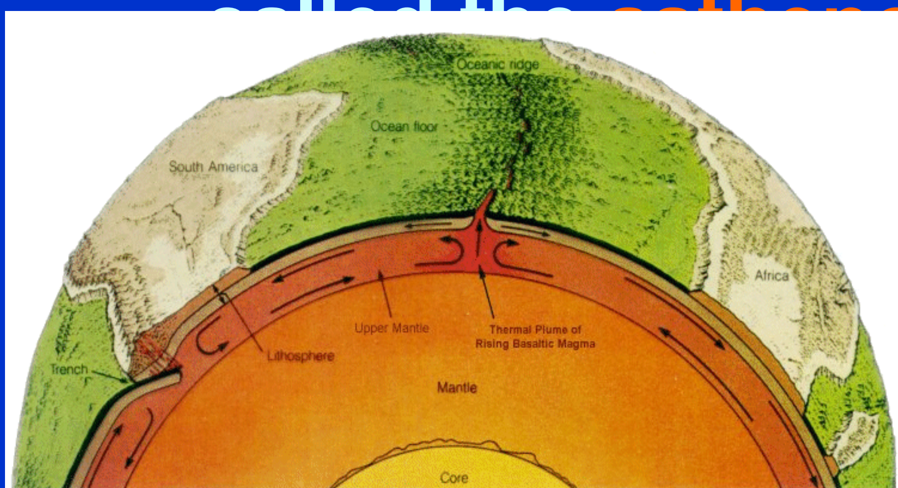
1) Earth's major surface features are primarily the result of plate tectonic motion and processes
2) Most of Earth's earthquakes and volcanism are the result of plate tectonic motion and processes

PLATE TECTONICS - The Plates

Key Concepts

1) **Earth's crust and uppermost mantle broken up into 16 mobile, rigid slabs called lithospheric plates**

2) **Lithospheric plates ride independently atop the underlying, p**



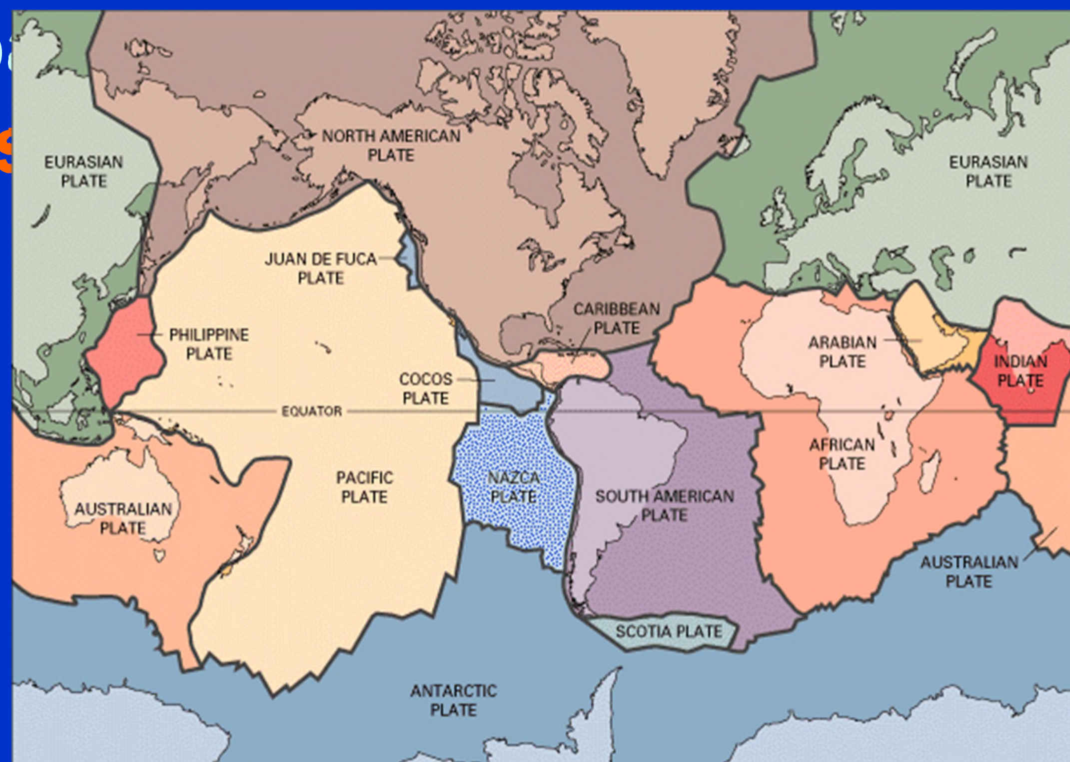


PLATE TECTONICS - The Plates

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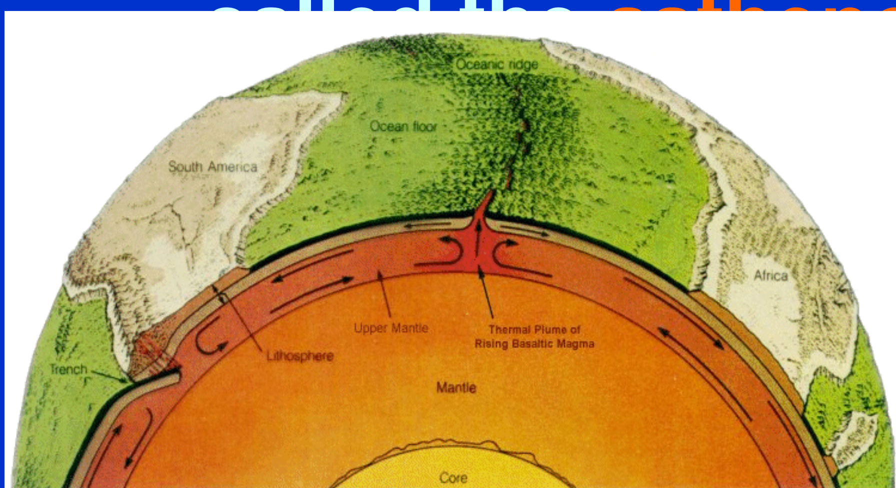


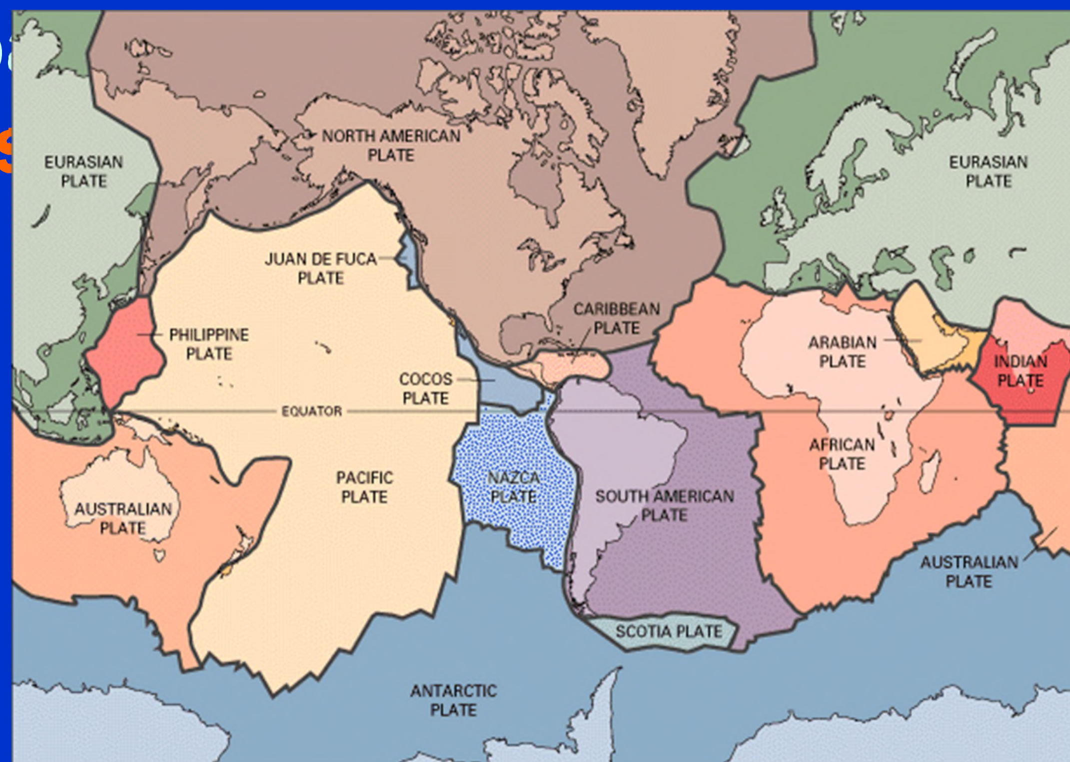
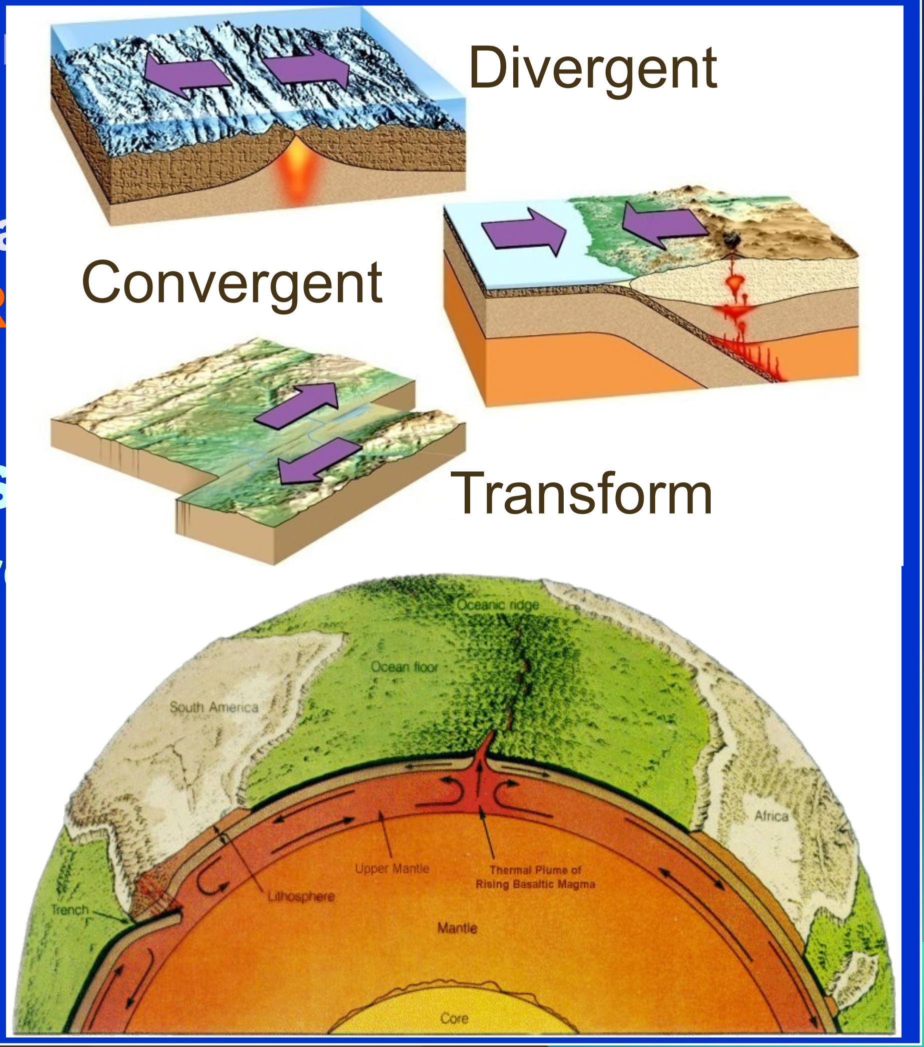
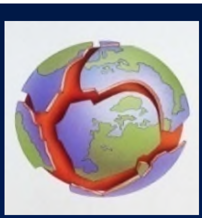


PLATE TECTONICS - Plate Boundaries

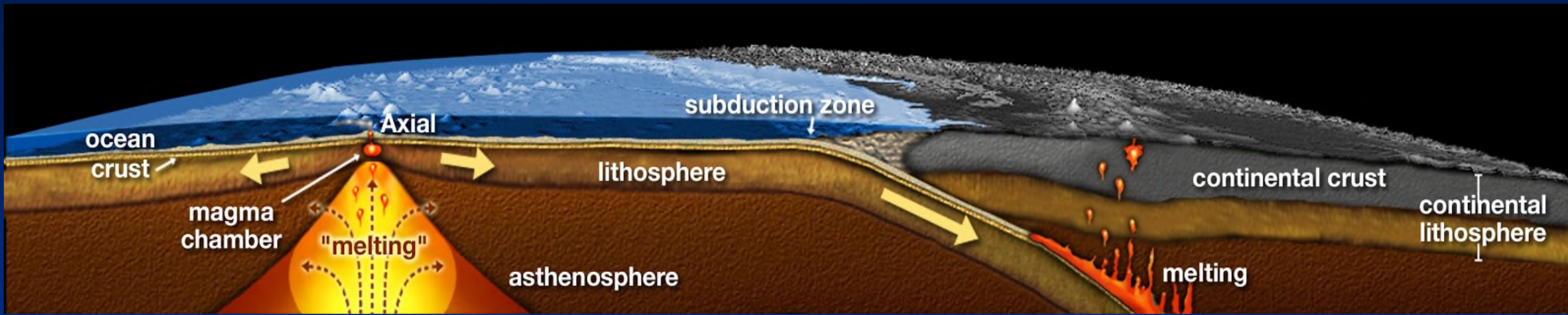
Key Concepts

1) **Three types of dynamic lithospheric plate boundaries:**
   - **Divergent, Convergent, and Tr**
2) **Divergent boundaries**
   - **Continental rifting – Rift Va**
   - **Seafloor-spreading = MOR**
   - **Basalt Volcanism**
3) **Convergent boundaries**
   - **Subduction = Trenches/Ar**
   - **Terrane accretion**
   - **Continental collision**
4) **Transform boundaries**
   - **Strike-slip faulting**
   - **No Volcanism**





Two Principle Tectonic Processes



Seafloor Spreading

Subduction

1) Seafloor Spreading = Creation of New Oceanic Plate

- Coincides with mid-ocean ridges
- Divergent plate boundary
- Tholiietic basaltic volcanism

2) Subduction = Destruction of Old Oceanic Plates

- Coincides with deep sea trenches and volcanic arcs
- Convergent plate boundary
- Explosive Andesitic volcanism

Animation of Overview of Plate Tectonics – on YouTube

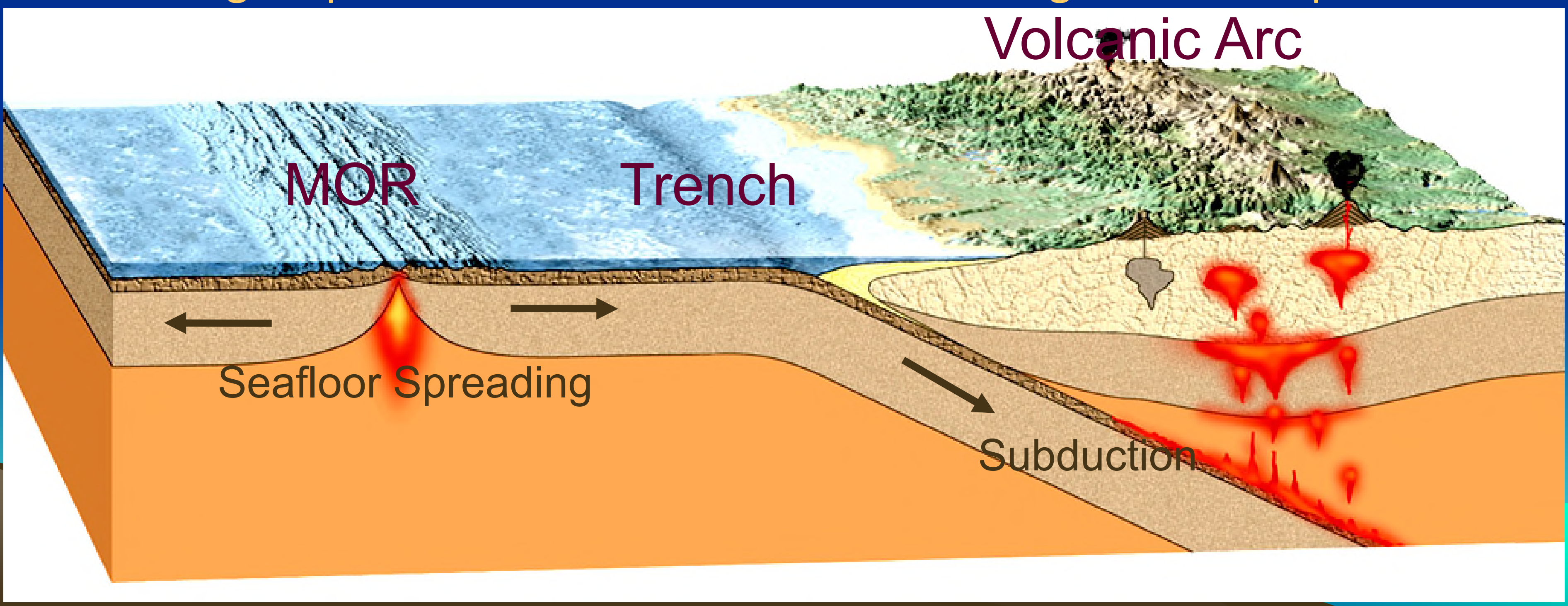
Seafloor Spreading and Subduction

Seafloor Spreading

- ✓ Constructive
- ✓ Tensional normal faulting
- ✓ Shallow earthquakes
- ✓ Decompress mantle melting
- ✓ Basaltic volcanism
- ✓ Mid Ocean Ridge and Facture
- ✓ Divergent plate boundaries

Subduction

- ✓ Destructive
- ✓ Compression thrust faulting
- ✓ Shallow to deep earthquakes
- ✓ Dewatering mantle melting
- ✓ Explosive andesitic volcanism
- ✓ Trench – Volcanic Arc Pair
- ✓ Convergent oceanic plate boundarie



Types of Plate Tectonic Boundaries

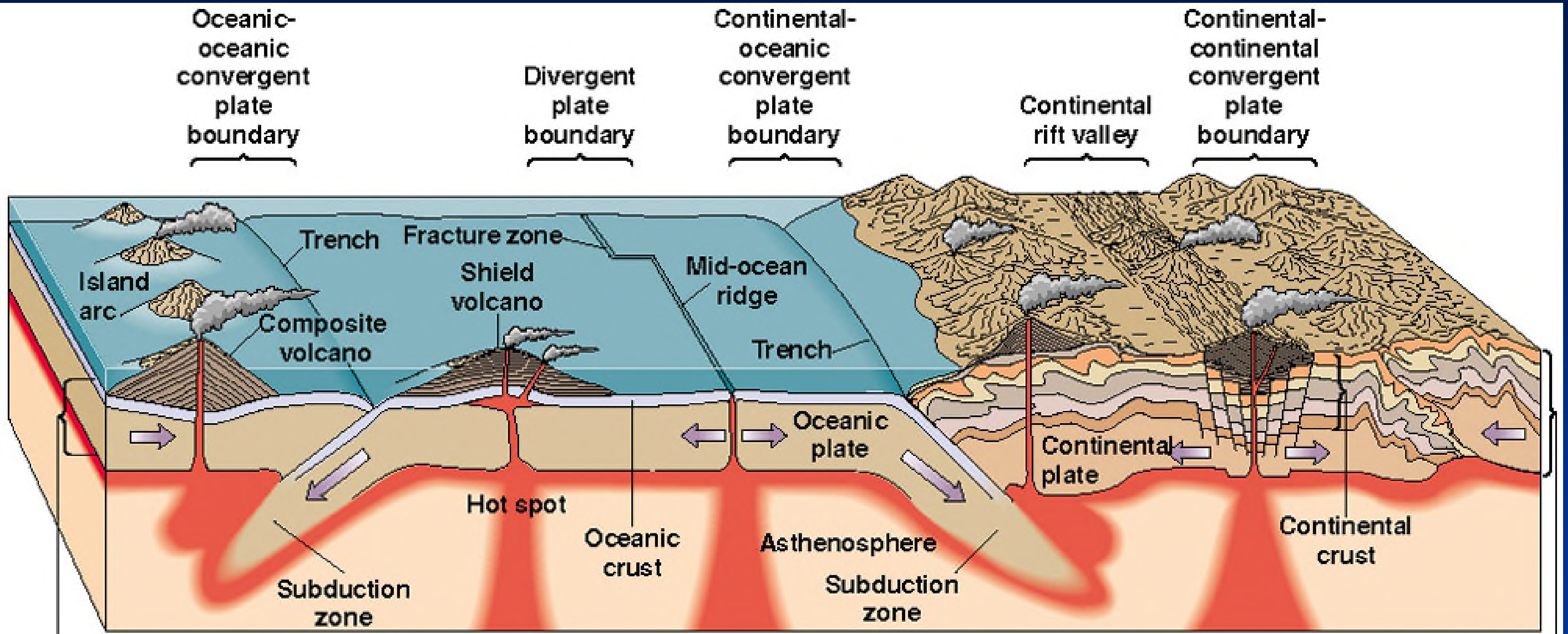


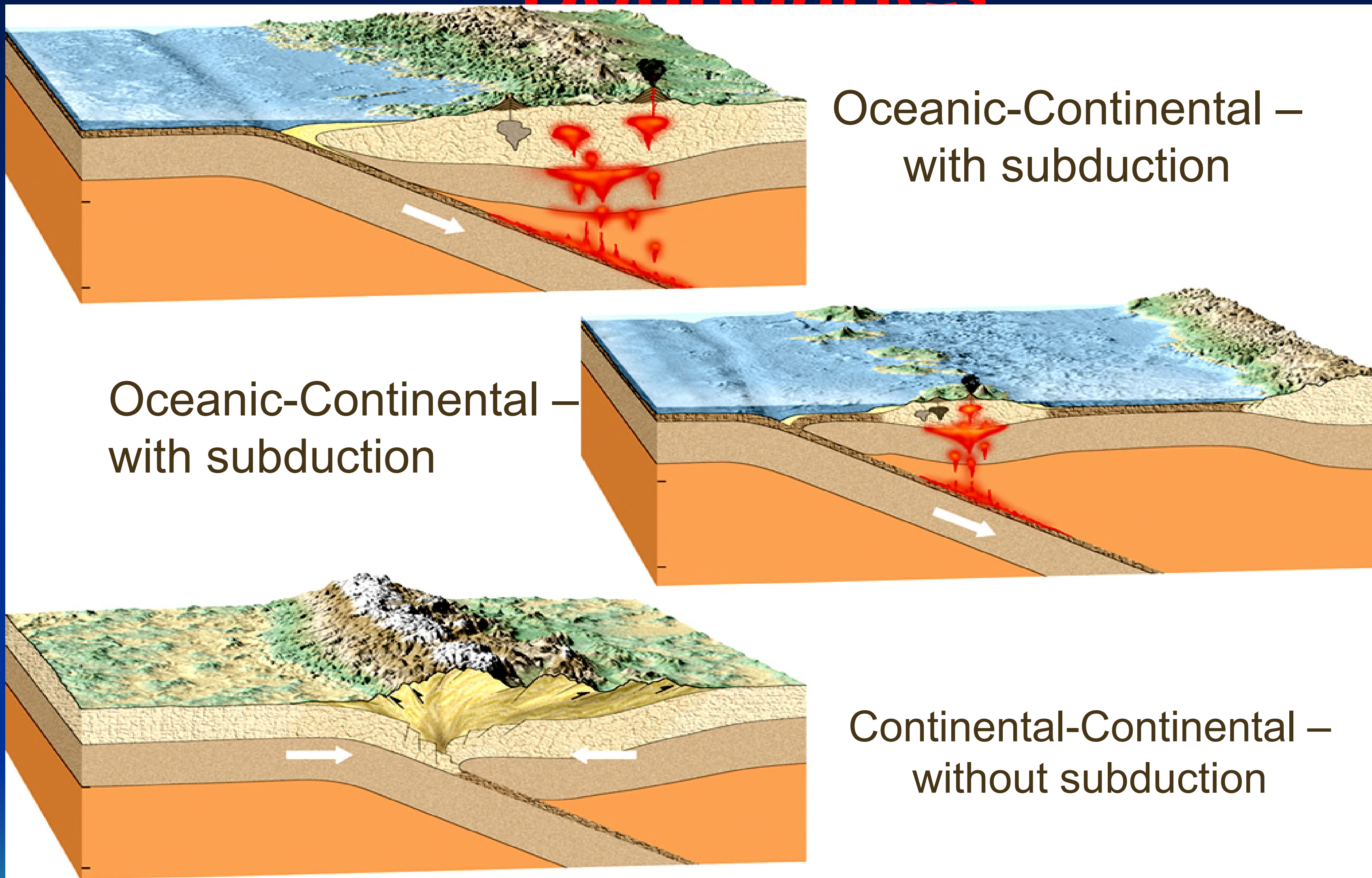
Illustration showing the various common types of plate boundaries

Divergent: Ocean-ocean = mid-ocean ridge; Continental-continental = cont. rift valley

Convergent: Divergent: Ocean-ocean = mid-ocean ridge; Continental-continental = cont. rift valley ; Ocean-continental = trench/continental margin arc; Continental-continental = continental collision zone

Transform: Divergent: Ocean-ocean = ocean fracture zone; Continental-continental = continental fracture zone.

Three Types of Convergent Plate Boundaries



Convergence involving an oceanic plate will have subduction occurring

Subduction-related convergence produces a deepsea trench plus active volcanic arc

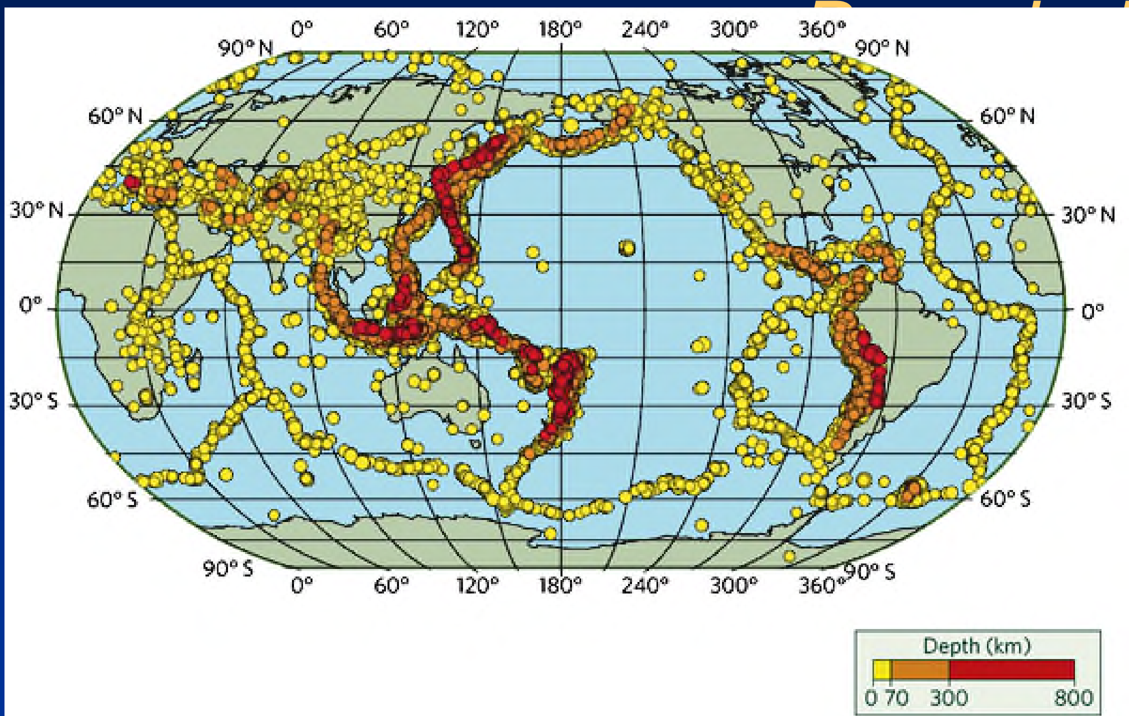
- The Pacific Ring of Fire –

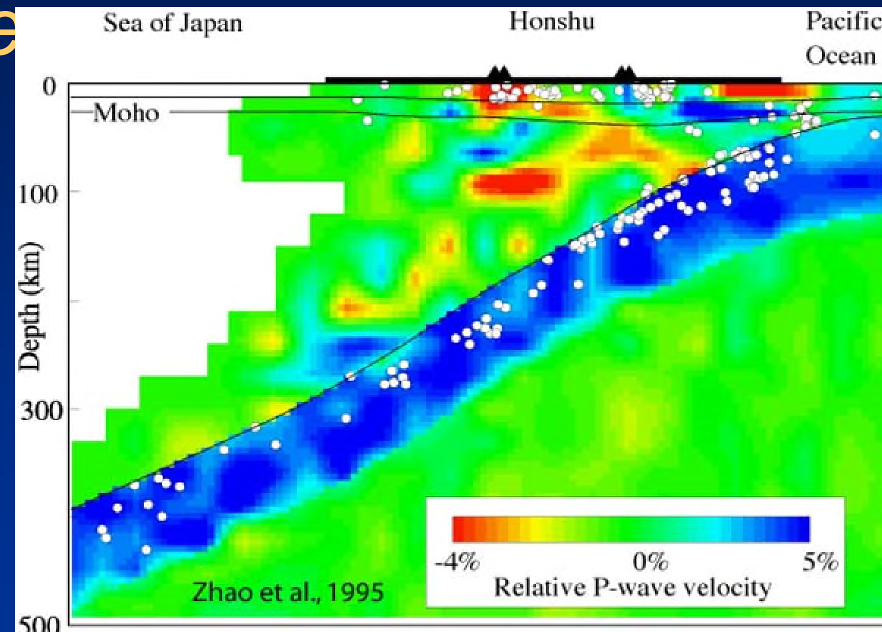
Active Volcanoes Associated with Deep Sea Trenches

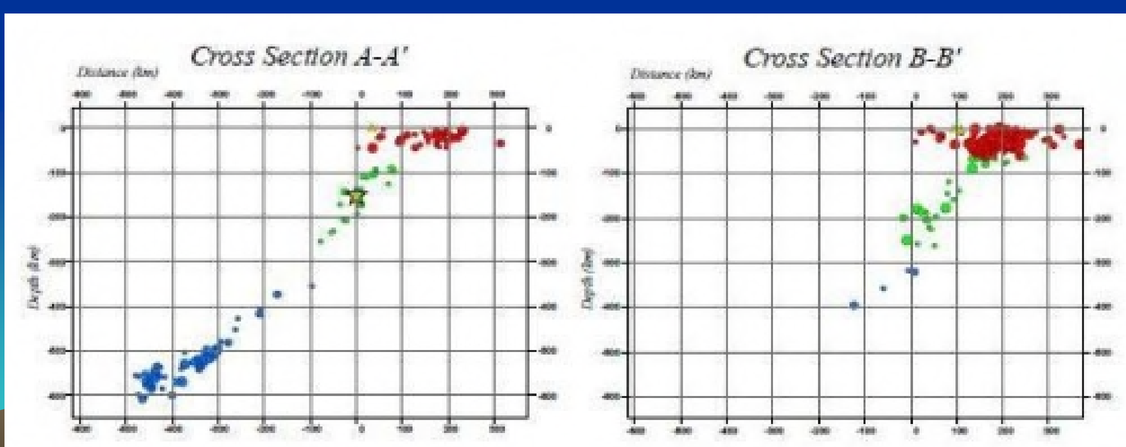
The Ring of Fire is Fueled by Subduction

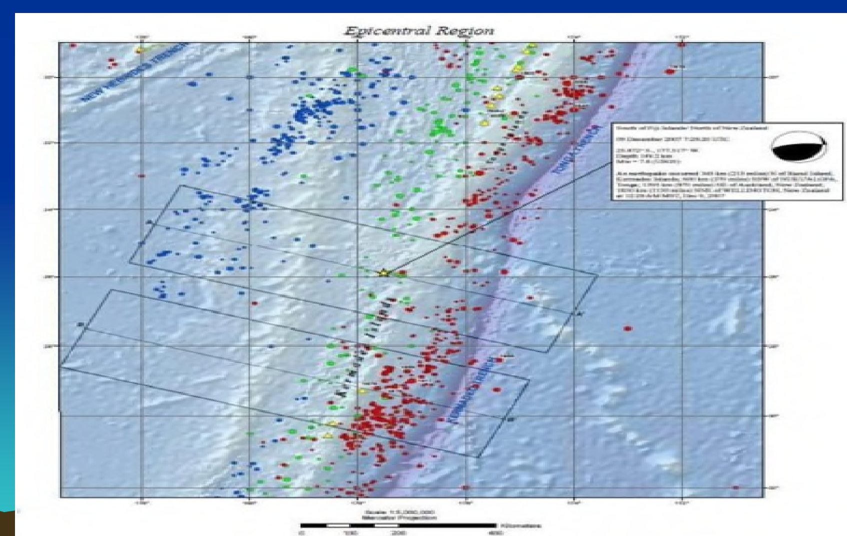
Subduction and Deep Earthquakes

Associated with Oceanic Convergent Plate Boundaries



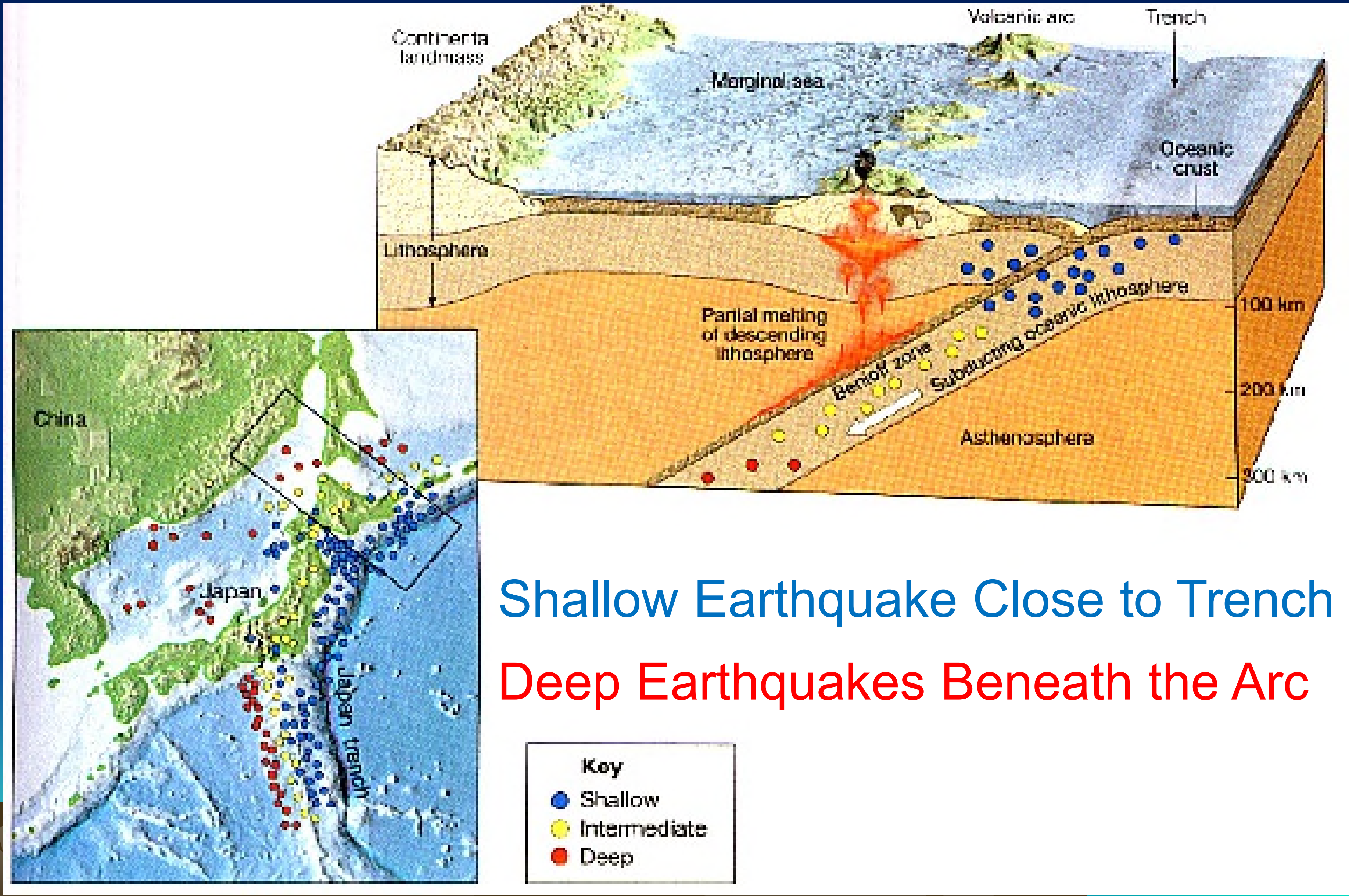






A Well-Studied Subduction System

The Japan Trench-Arc System



Shallow Earthquake Close to Trench

Deep Earthquakes Beneath the Arc

Plate Motion - Direction & Speed

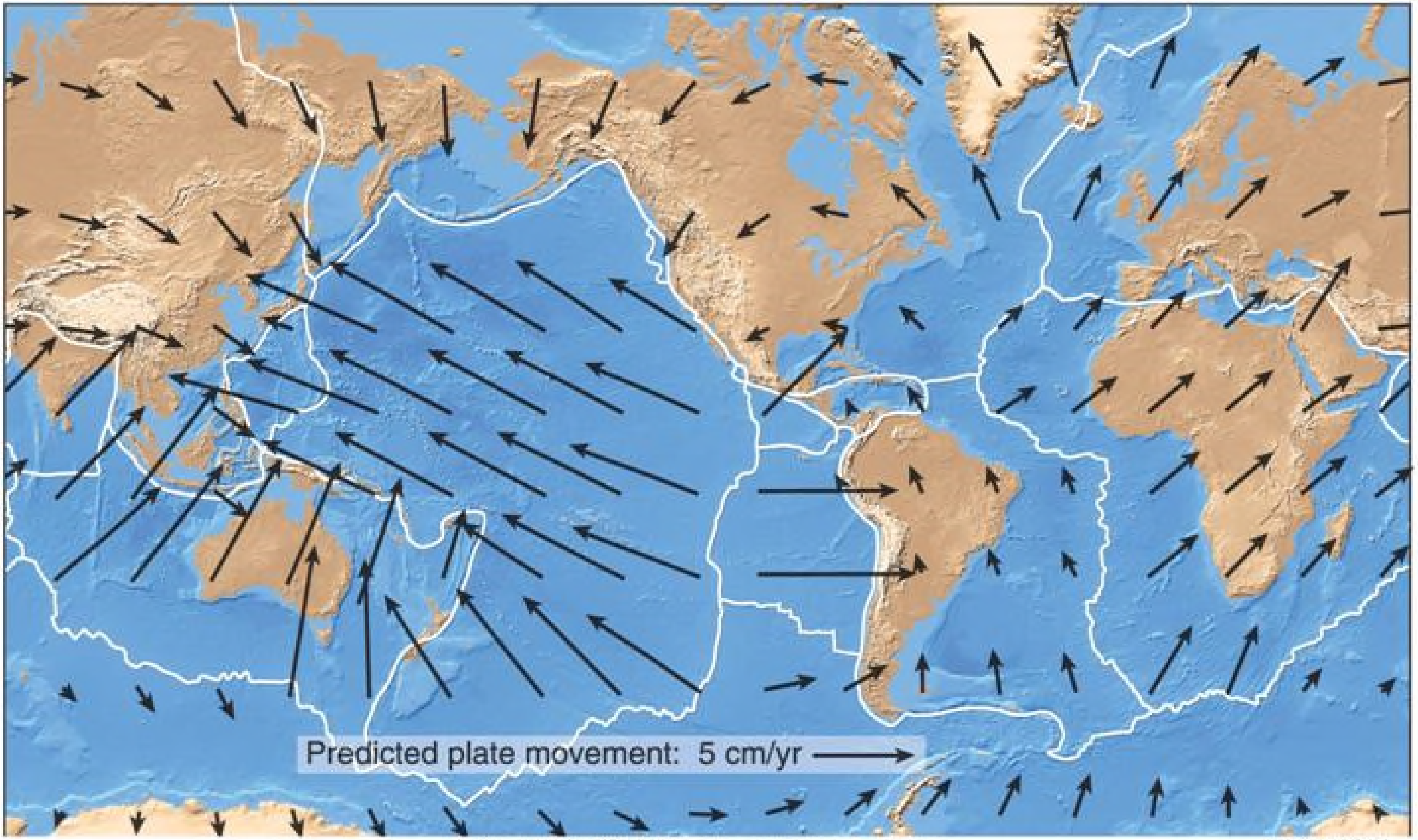
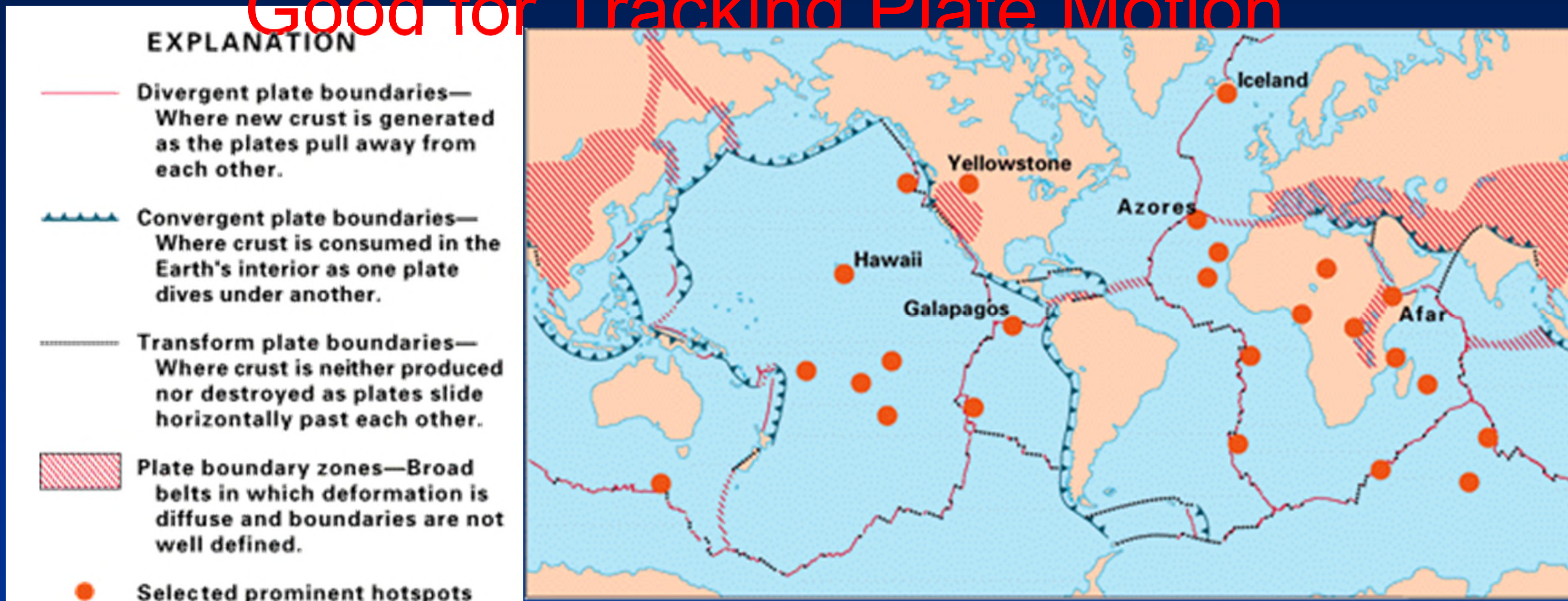


Fig 12.37

Earth's Hot Spots

Good for Tracking Plate Motion

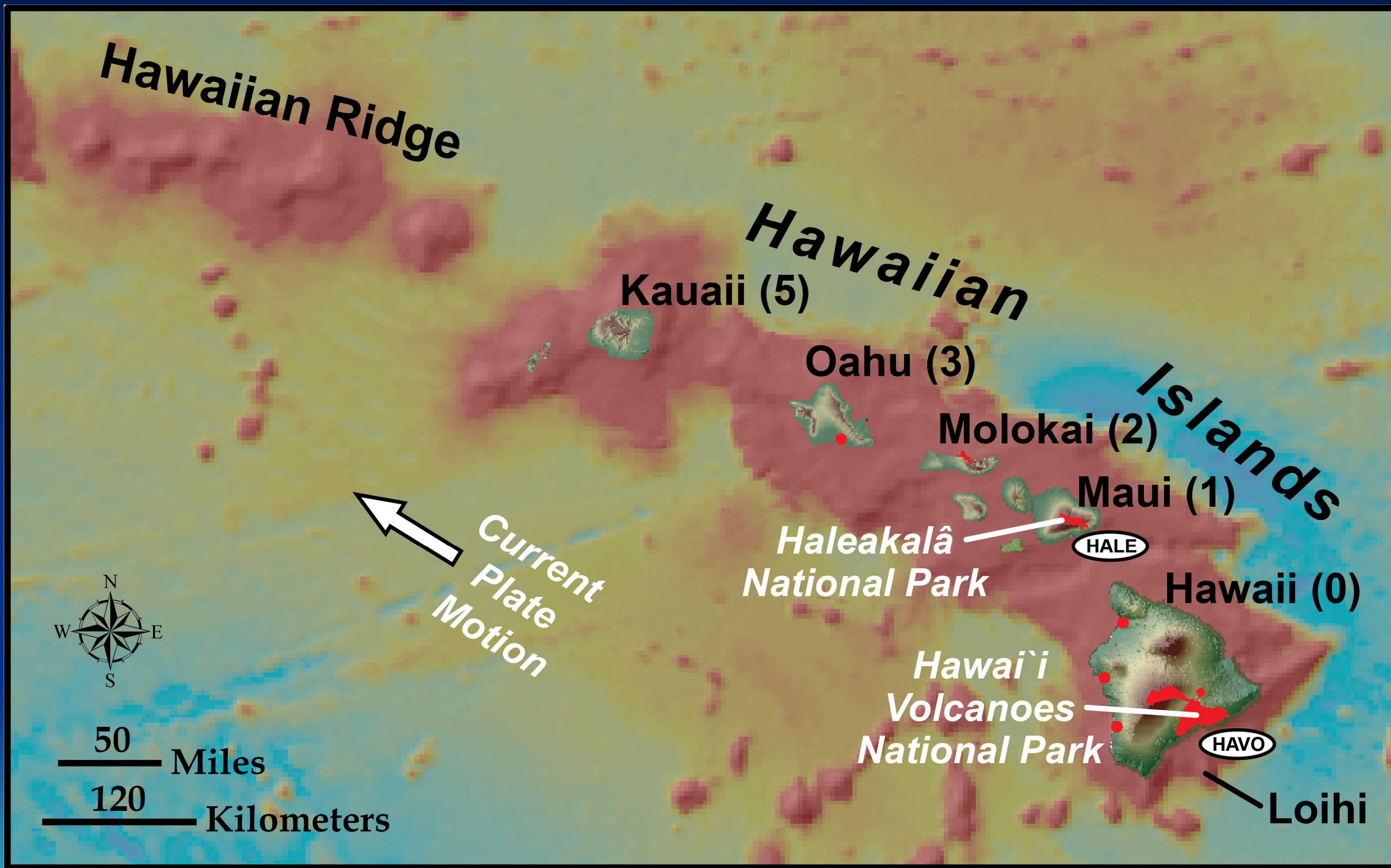


Hawaii

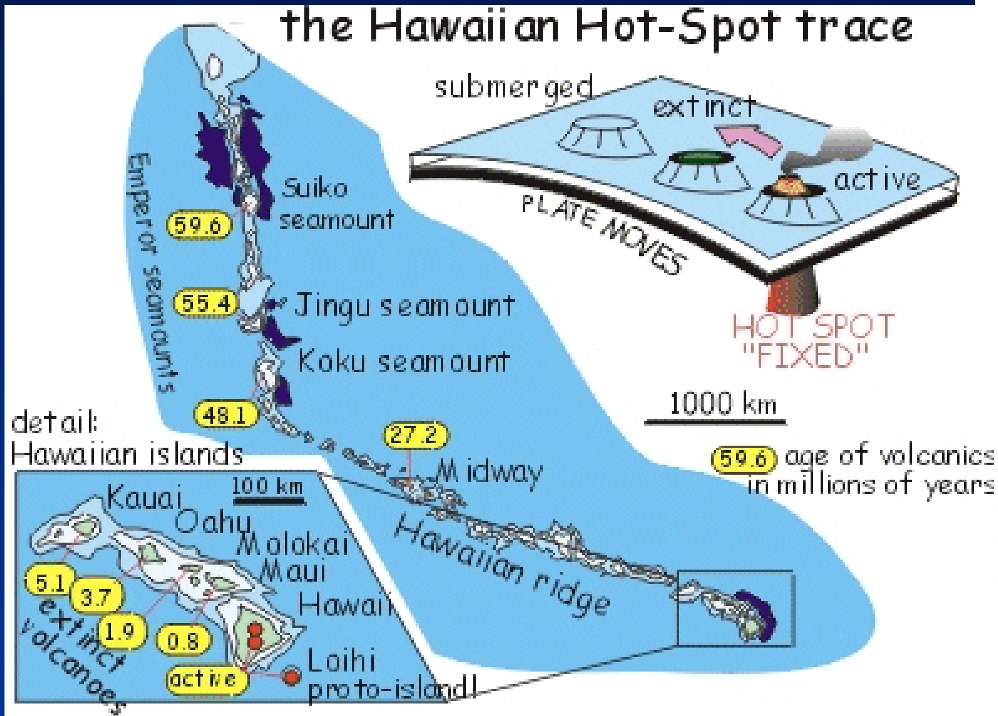
Yellowstone

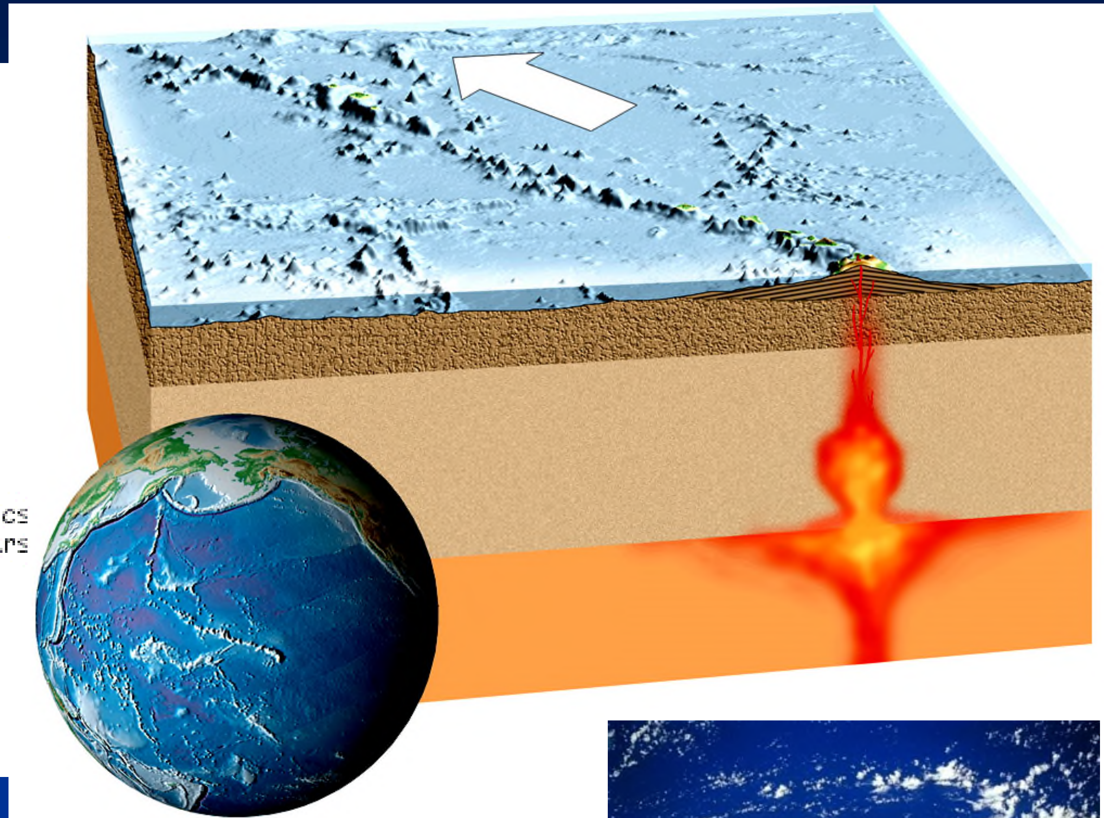
Iceland

Hawaiian Island Volcanic Hot Spot Chain



Hawaiian Hot Spot and Pacific Plate Motion





Big Island of Hawaii

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 is beneath the Big Island today

Determining Plate Direction and Speed for Hot Spot Traces

Speed 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 bar scale on map with ruler)
- Time: Age difference two Islands or Seamounts
- Plate moves towards older volcanic centers
- Make sure units cancel when doing

Example of Island Hot Spot Calculation

$$\frac{200\ \text{km}}{2{,}000{,}000\ \text{years}} \times \frac{100{,}000\ \text{cm}}{1\ \text{km}}$$

$$= 10.0\ \text{cm/year}$$

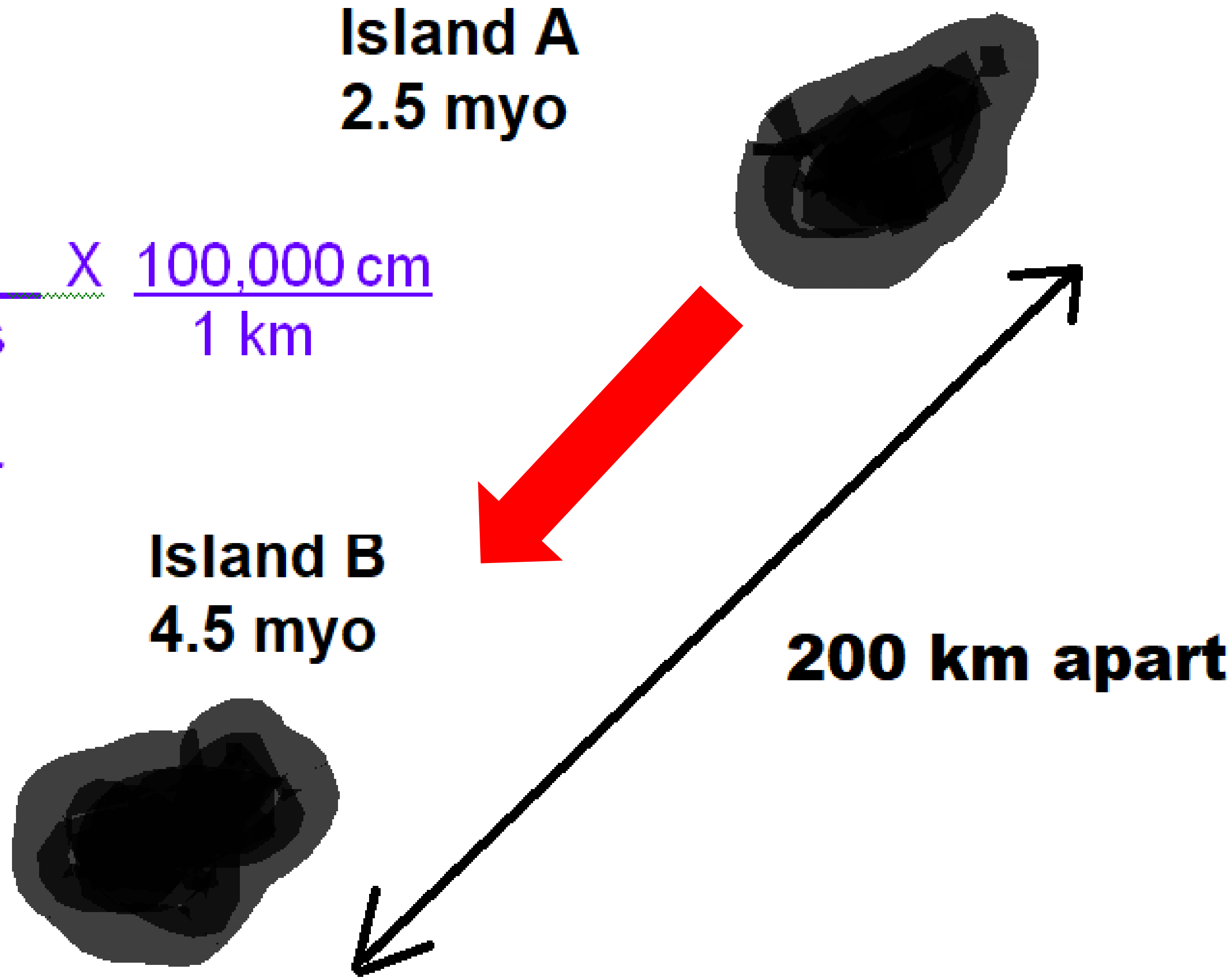
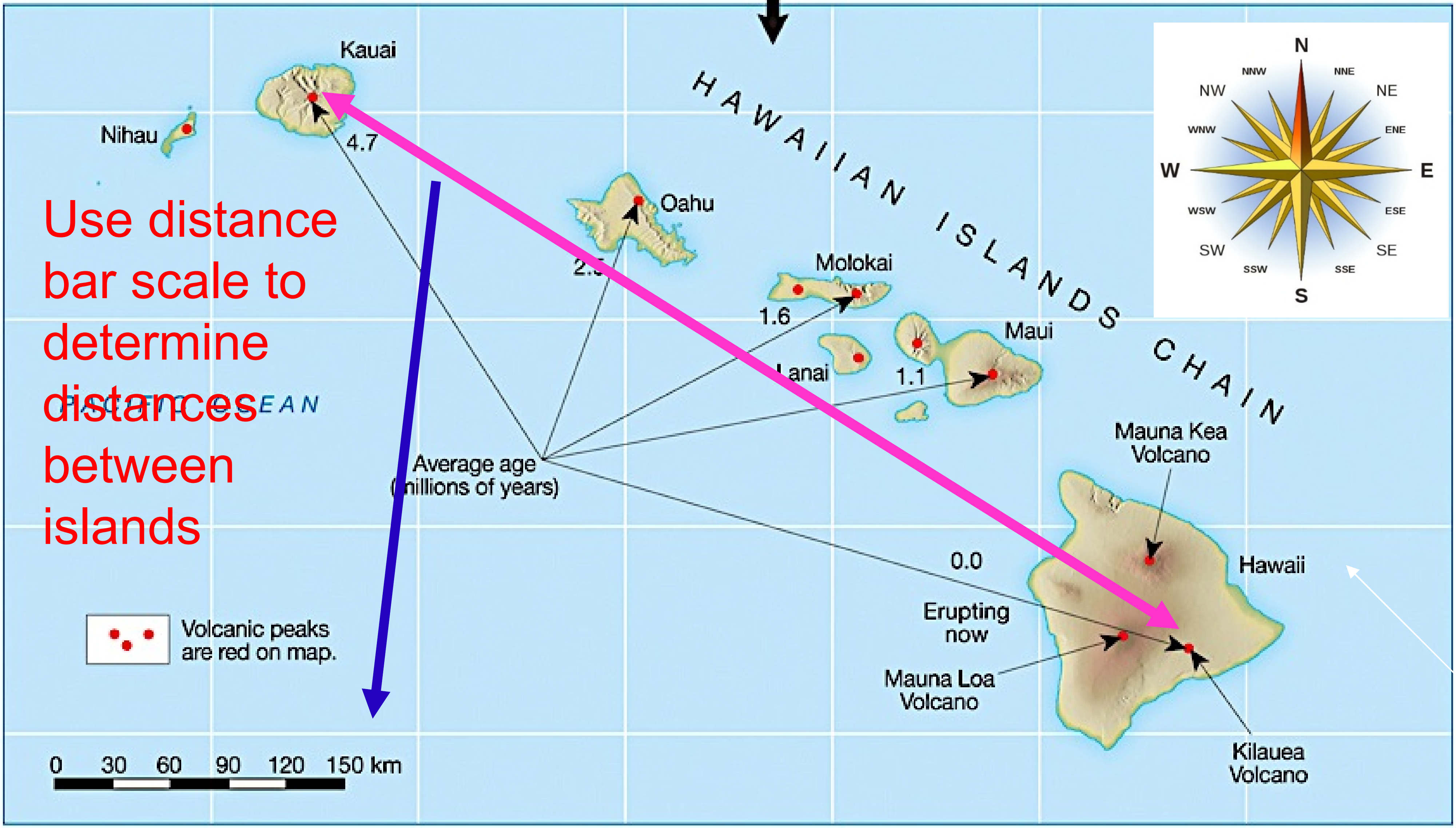


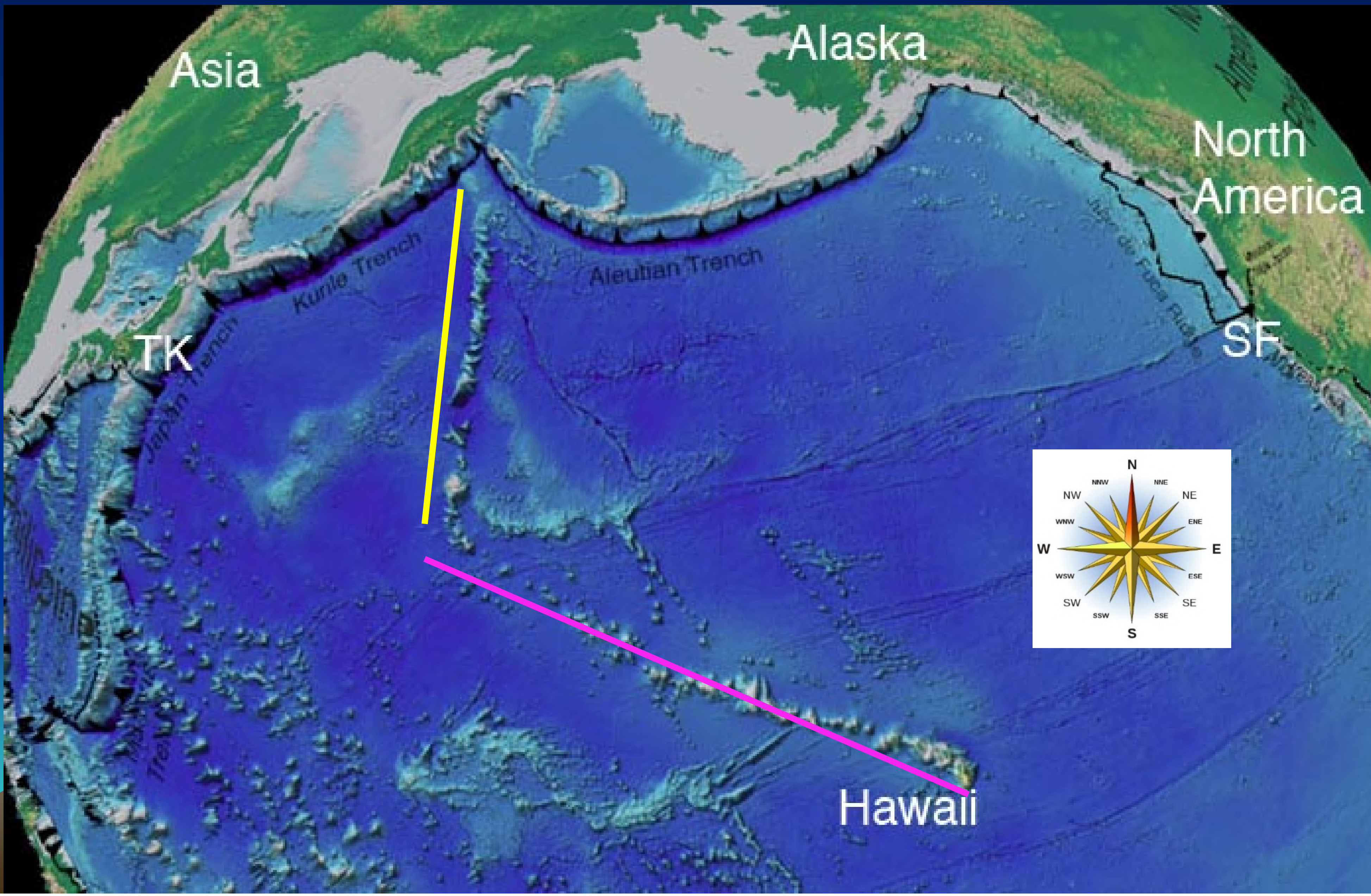
Plate movement direction towards older volcanoes/islands

Determining Plate Direction and Speed

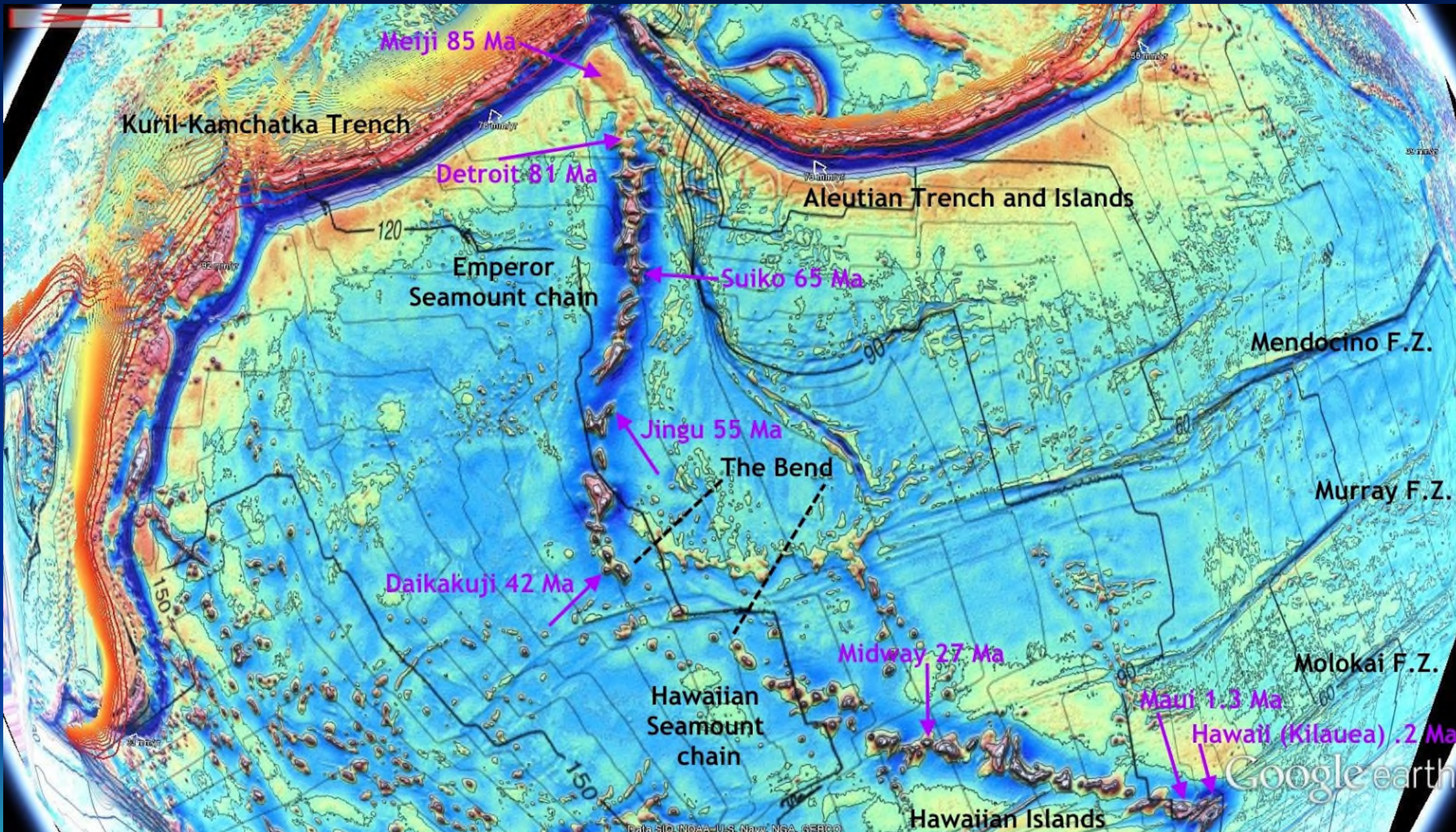


Use distance bar scale to determine distances between islands

Emperor – Hawaiian Volcanic Island/Seamount Chains

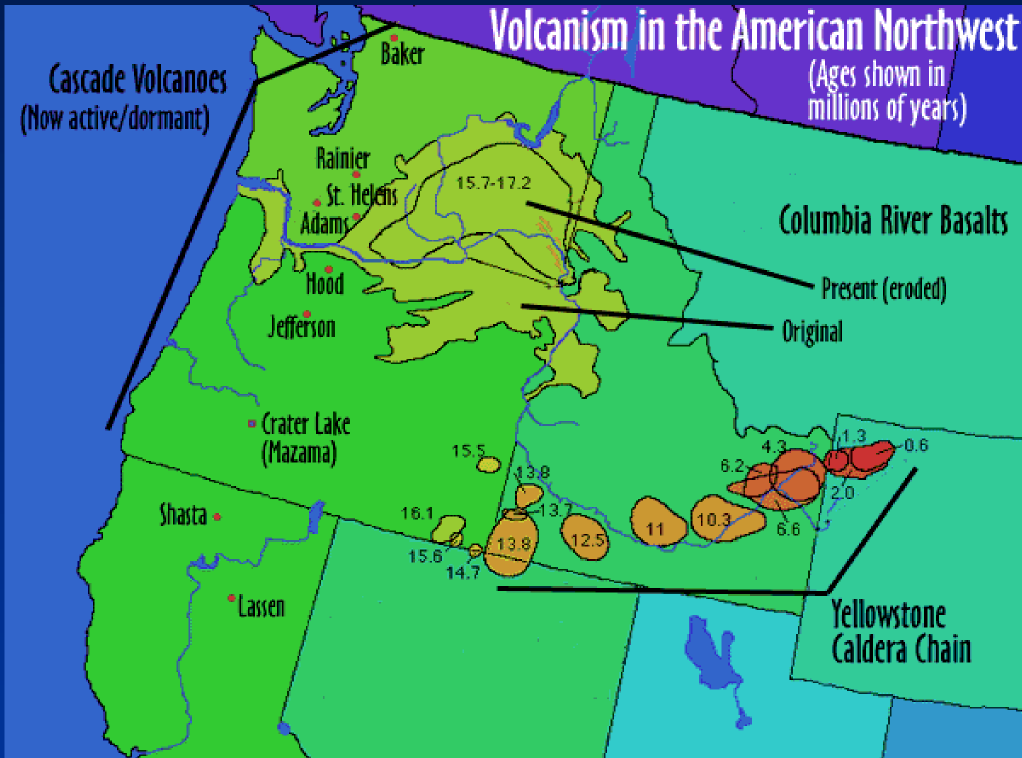


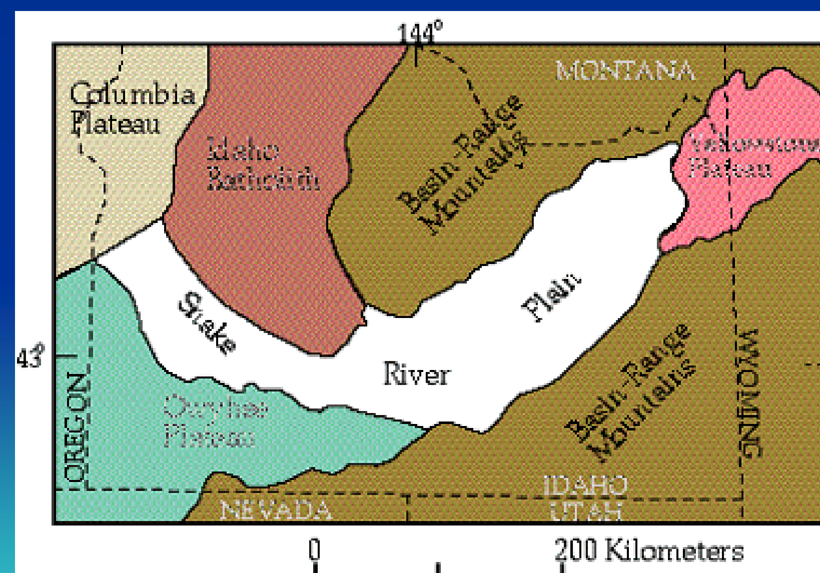
Hawaiian Hot Spot and Pacific Plate Motion



- ✓ Hot Spot trace includes Hawaiian Island Na Emperor Seamount chains
- ✓ Major bend in the hot spot trace between Hawaiian and Emperor segments

The Yellowstone Hot Spot – Exam Problem





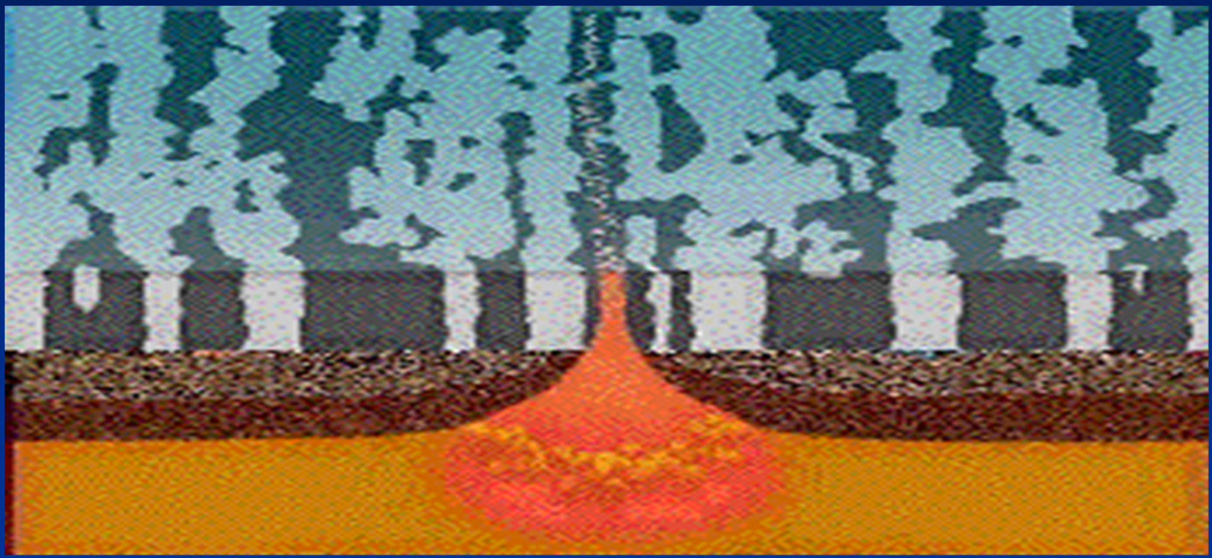
Key Points:

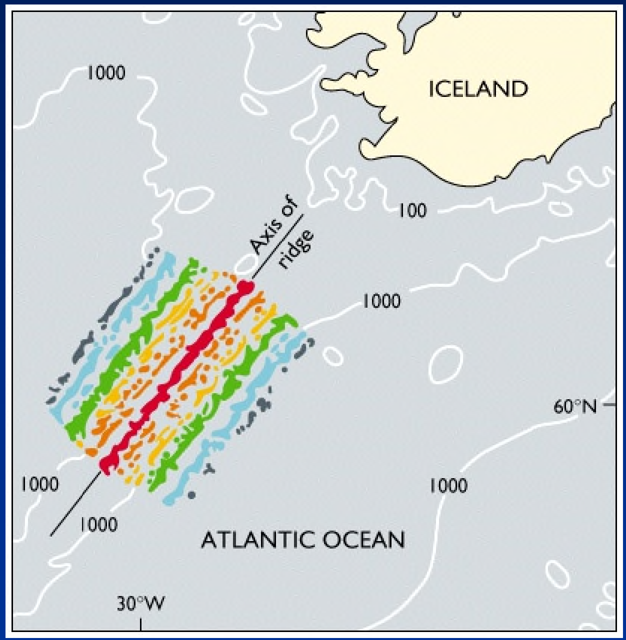
✓ Hot spot plume anchored in mantle = assumed to be *stationary*

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

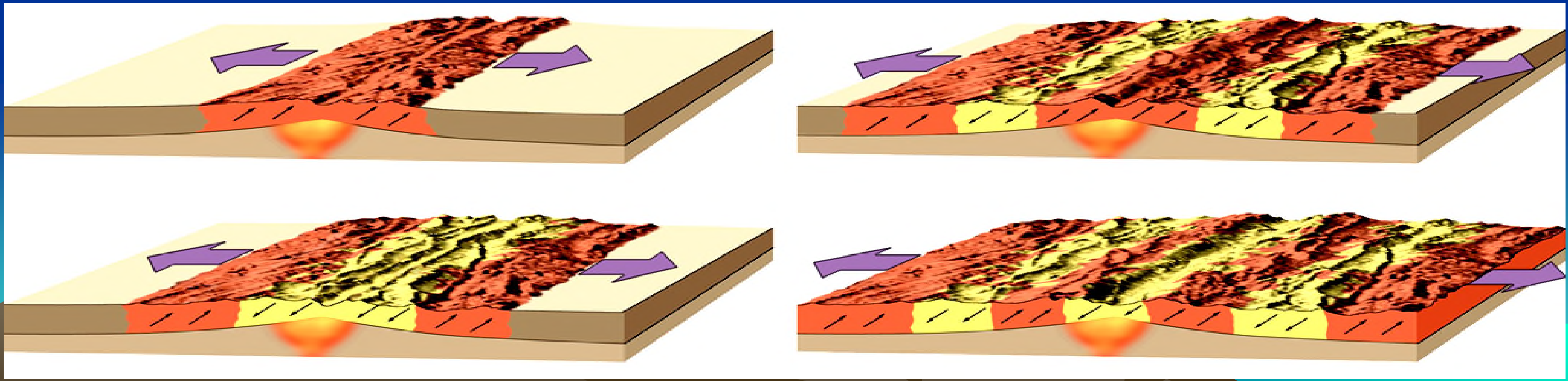
Evidence for Seafloor Spreading and Oceanic Plate Motion

Magnetic Polarity-Reversal Anomalies of Seafloor Rocks

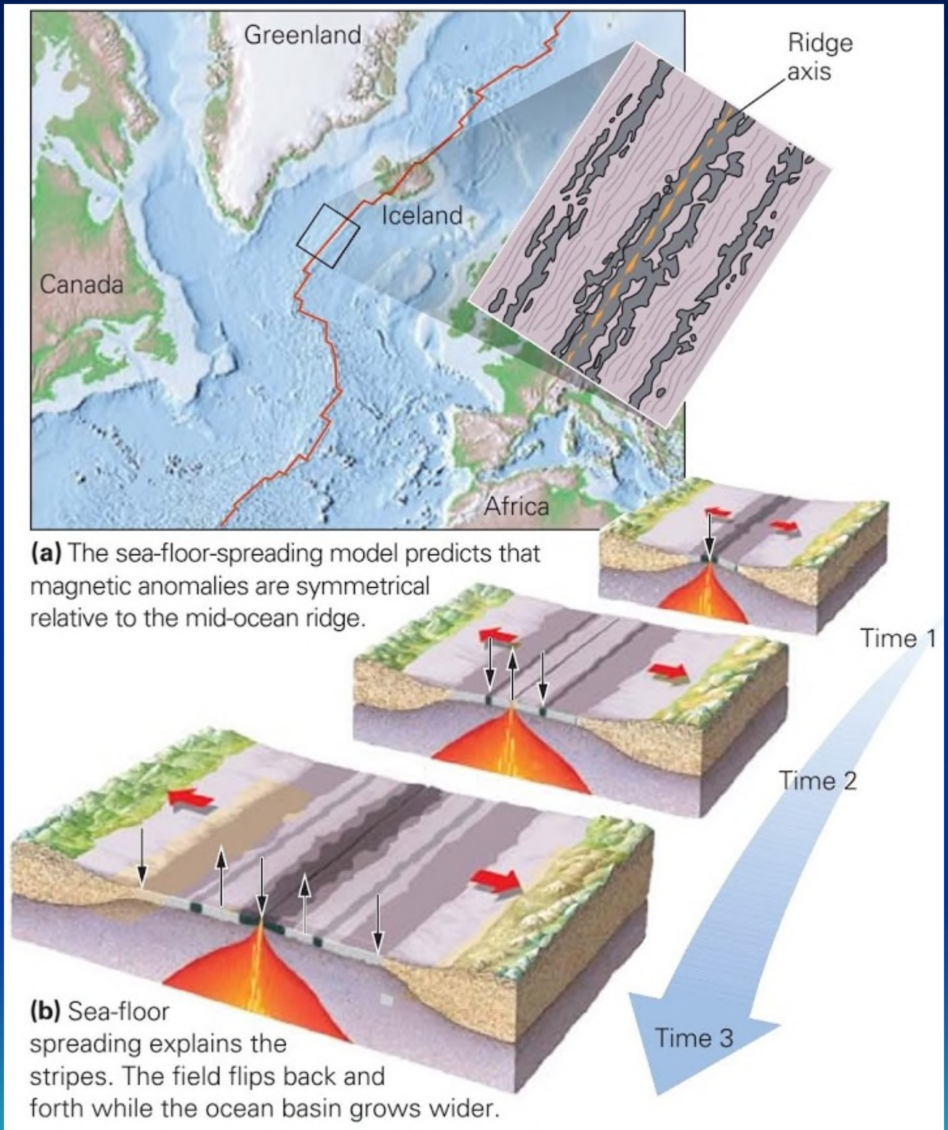




Example: North Atlantic



Magnetic Anomalies of Earth's Seafloors

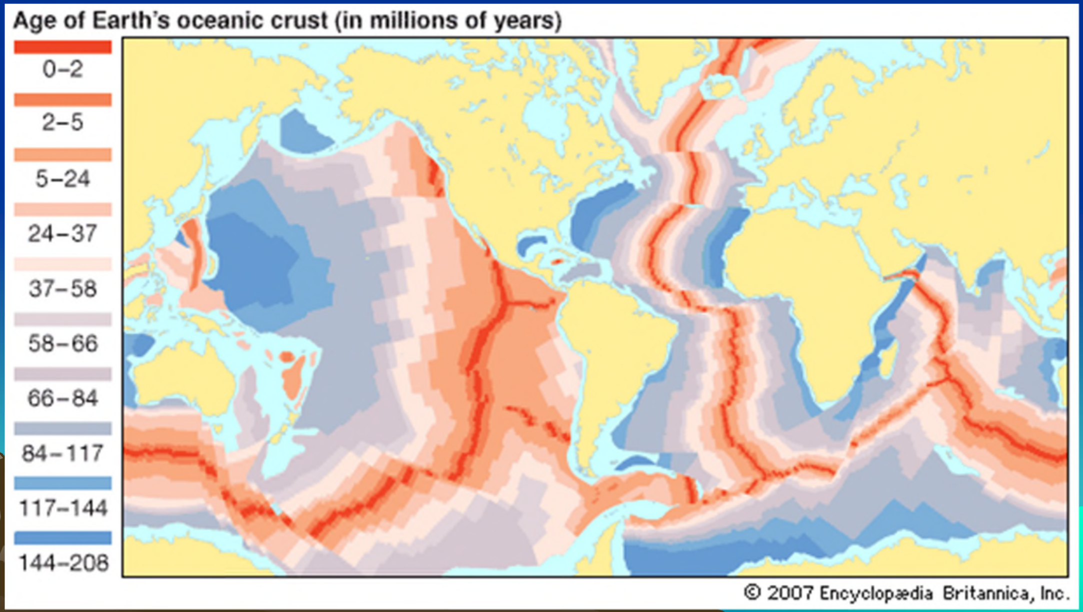


(a) The sea-floor-spreading model predicts that magnetic anomalies are symmetrical relative to the mid-ocean ridge.

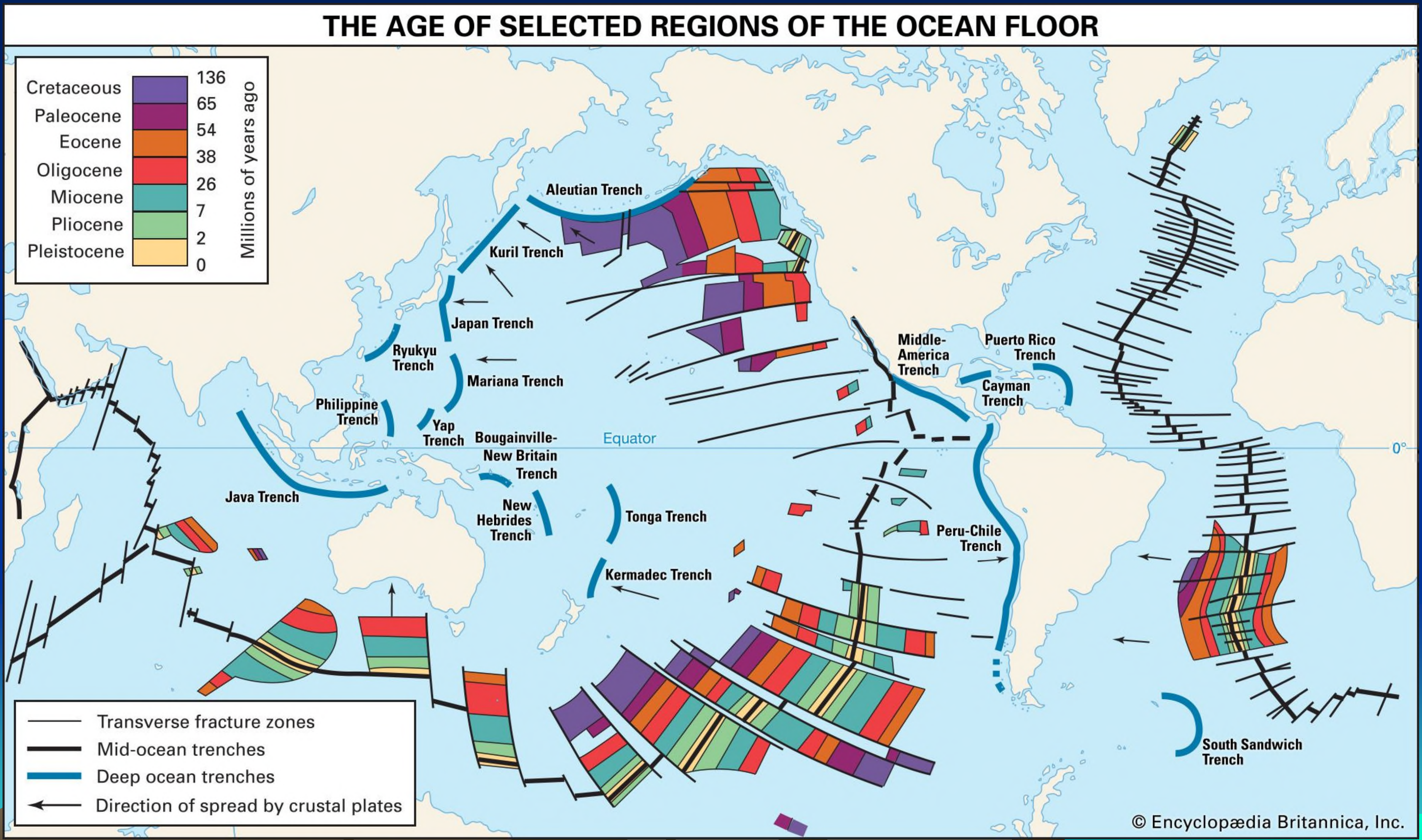
(b) Sea-floor spreading explains the stripes. The field flips back and forth while the ocean basin grows wider.

Earth's seafloors grow at mid-ocean ridges and rises by the seafloor spreading process

Earth's magnetic field reverses polarity many times during the formation of basaltic seafloor basins, producing a distinctive magnetic pattern in the seafloor rocks that can be dated



Paleomagnetic Anomalies and Age of Earth's Seafloors



Determining Plate Directions and Speed for Seafloor Spreading Centers

Speed 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
- Directions plate move are away from mid-ocean ridge (spreading center), perpendicular to ridge axis
- Make sure units cancel when doing conversions

Mid-Ocean Ridge Spreading Rate Example

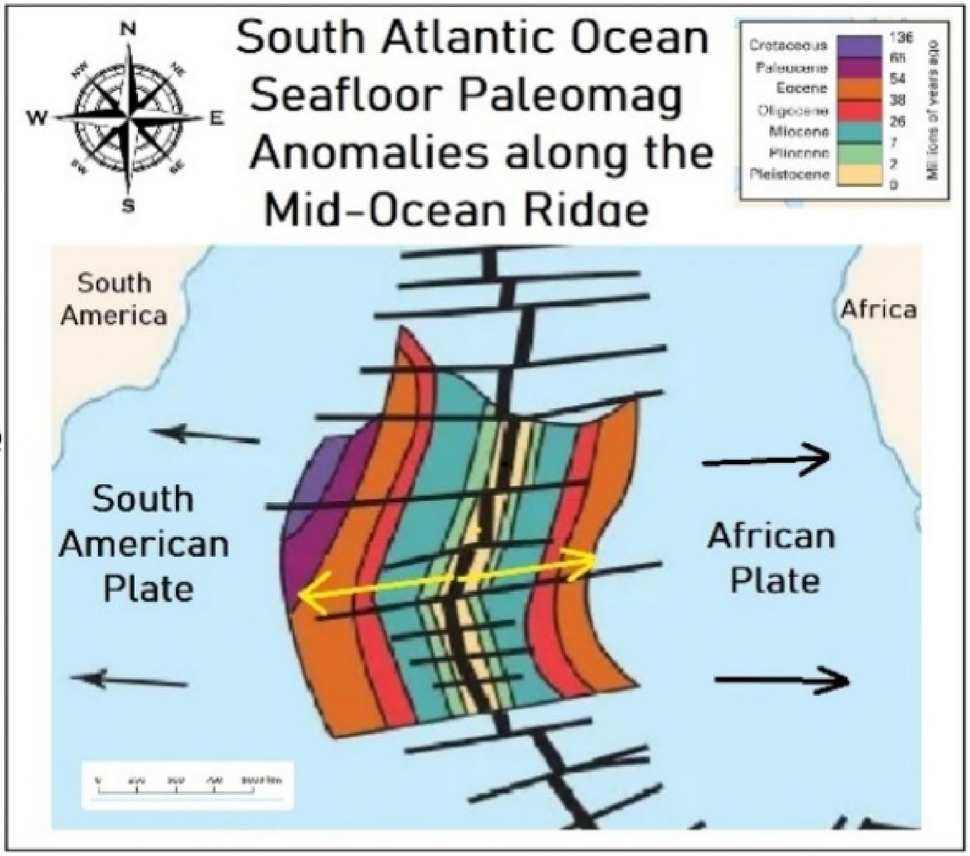
Calculation Set Up:

$$\frac{1{,}000 \text{ km}}{54{,}000{,}000 \text{ years}} \times \frac{100{,}000 \text{ cm}}{1 \text{ km}} =$$

$$= 1.9 \text{ cm/year}$$

Measure distance from mid-ocean ridge out to desired dated magnetic anomaly stripe (see yellow arrows). Mid-ocean ridge stripe is zero age. Get average spreading rate for either plate by dividing distance by the age of the magnetic strip (at arrow head). Convert from kilometers to centimeters to get average spreading rate in centimeters per year.

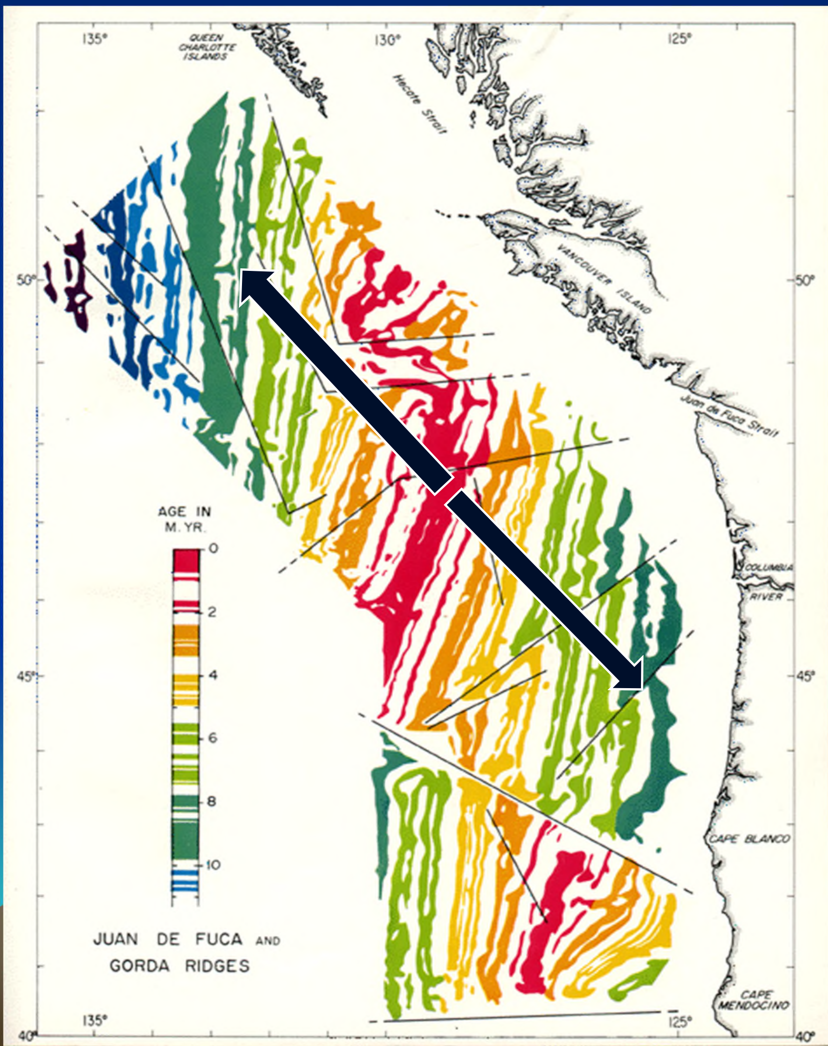
Direction of plate motion is towrds older anomalies and perpendicular to stripes

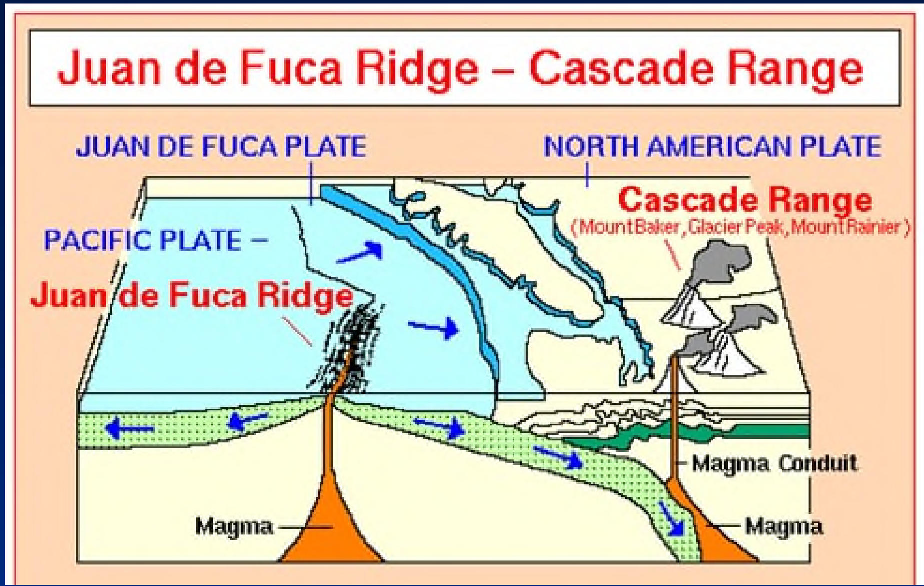


Mid-Ocean Ridge Speading Problem Example

Juan de Fuca Spreading Center Cascade Subduction System

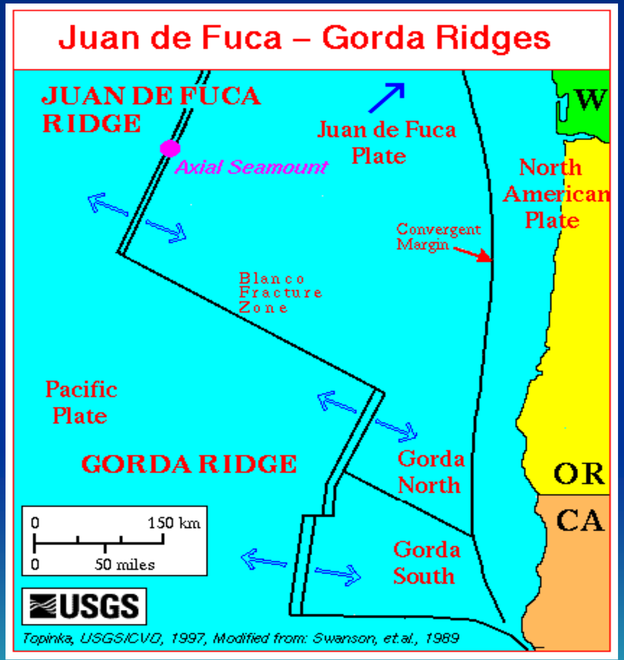
Measure seafloor spreading direction and speed by using age-dated paleomagnetic seafloor anomalies



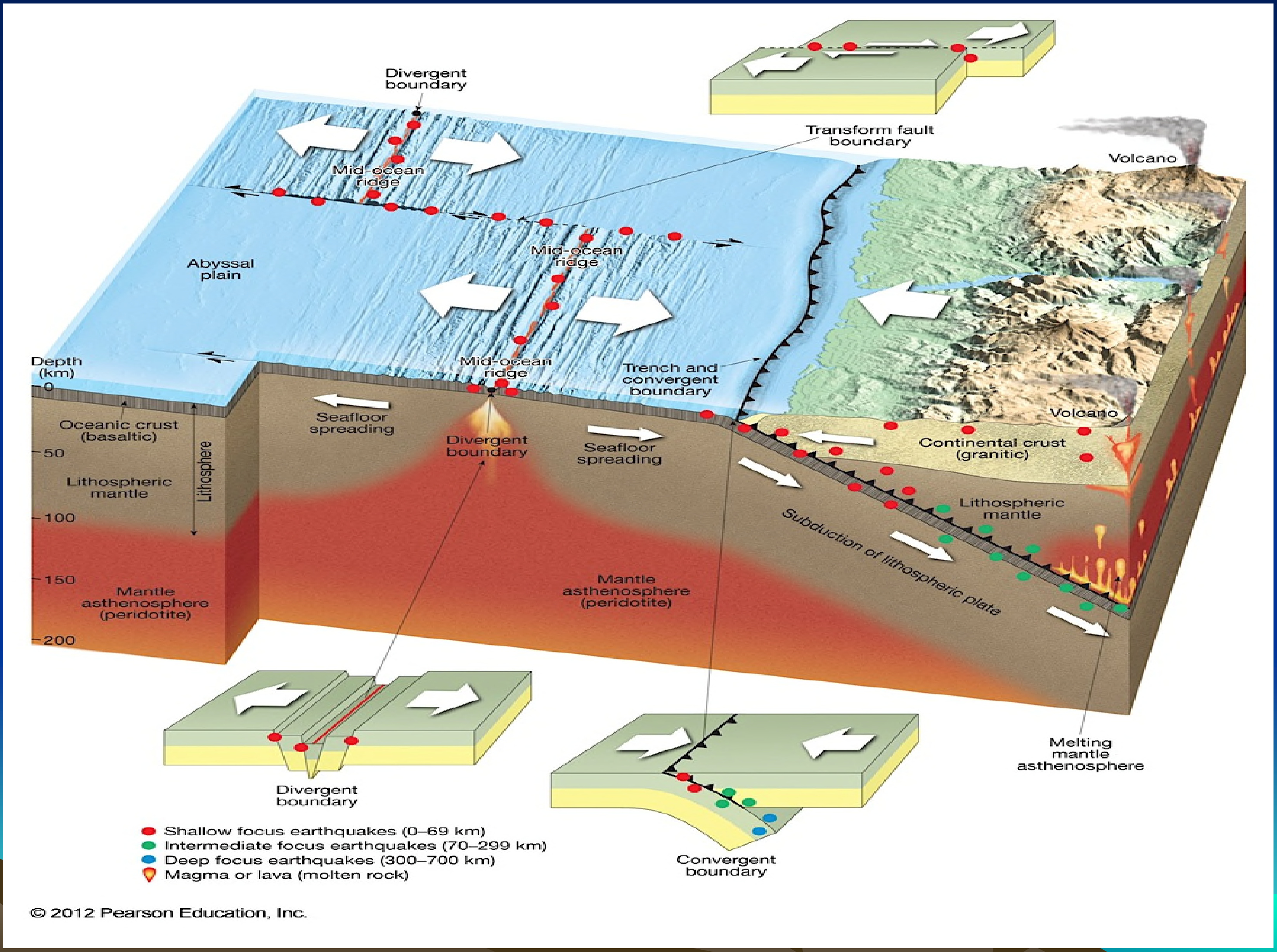


Measure from center of ridge (age zero red stripe) out to the 10-My-age dark green stripe

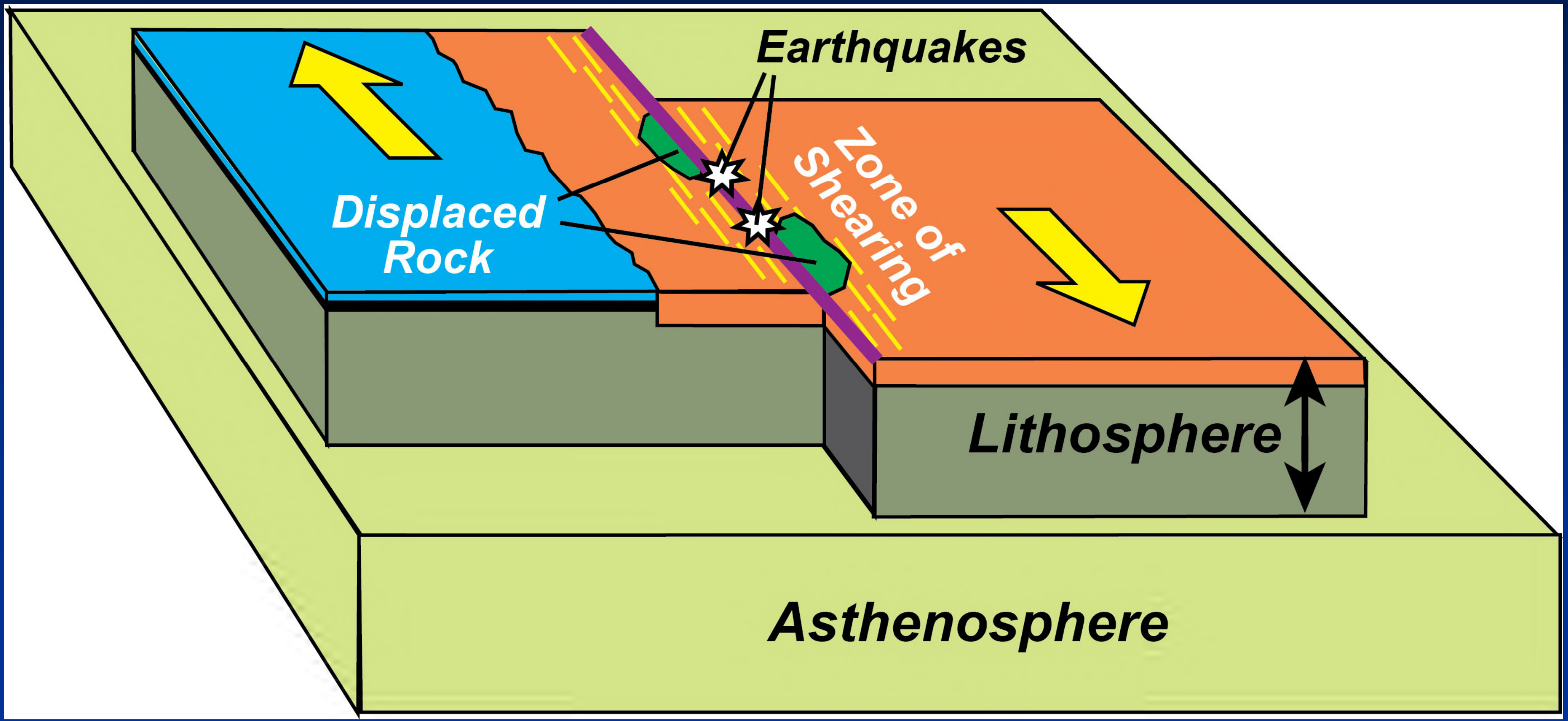
Measure for both the Pacific Plate and the Juan-de-Fuca Plate



Juan de Fuca Spreading Center Cascade Subduction System



Transform Plate Boundary Motion



Transform Plate Boundaries have two plates that laterally move past one another in opposite directions.

The rate of lateral offset and relative lateral movement can be determined by using a dated offset marker

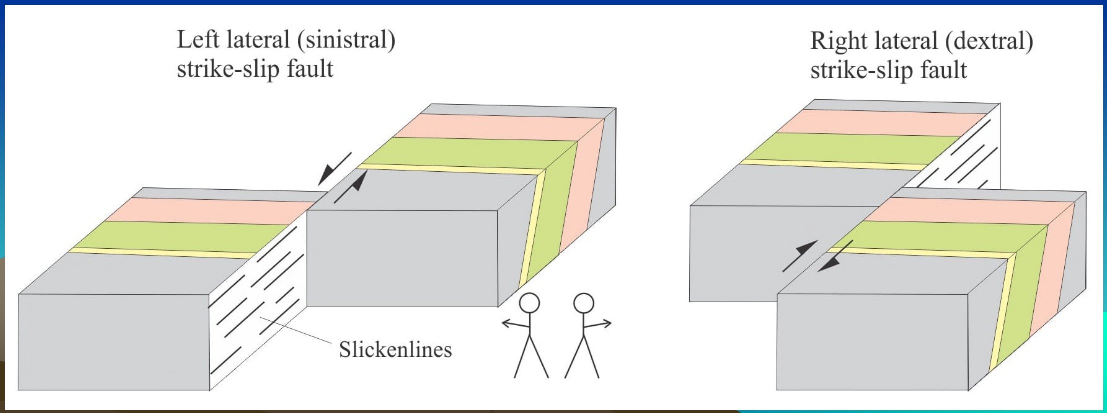
Determining Plate Motion for Transform Faults

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

Relative Offset Direction

Right-Lateral
or
Left- Lateral



Transform Fault Motion Problem Example

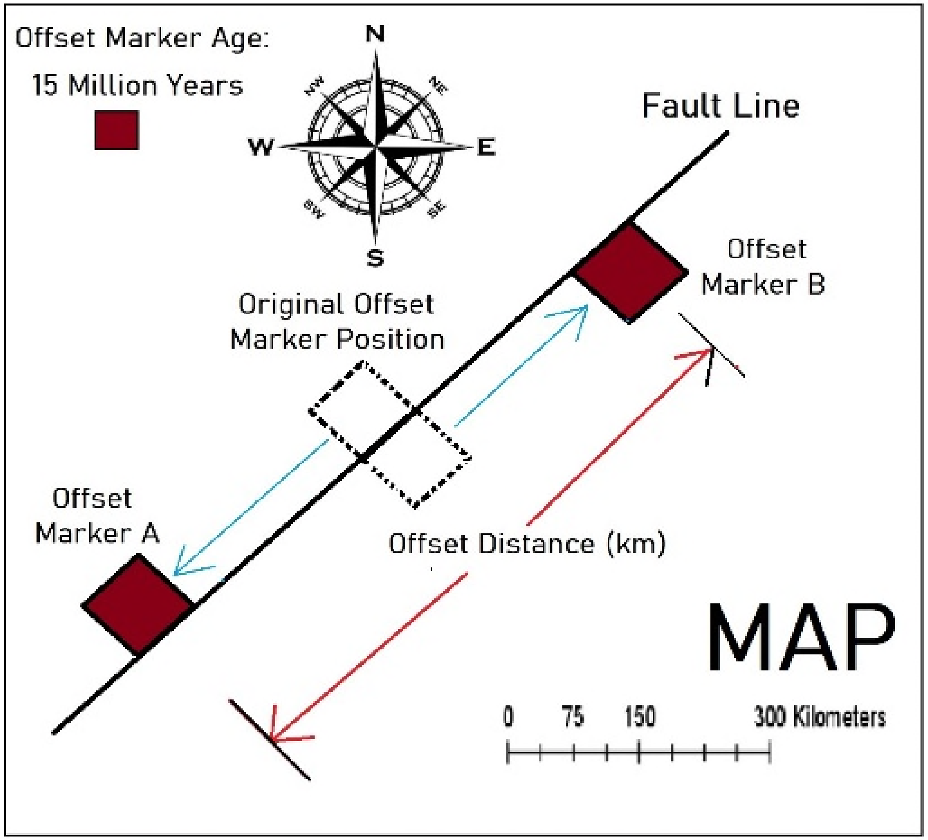
Calculation Set Up:

$$\frac{600 \text{ km}}{15{,}000{,}000 \text{ years}} \times \frac{100{,}000 \text{ cm}}{1 \text{ km}} =$$

$= 4$ cm/year of average transform offset along fault over the the last 15 million years

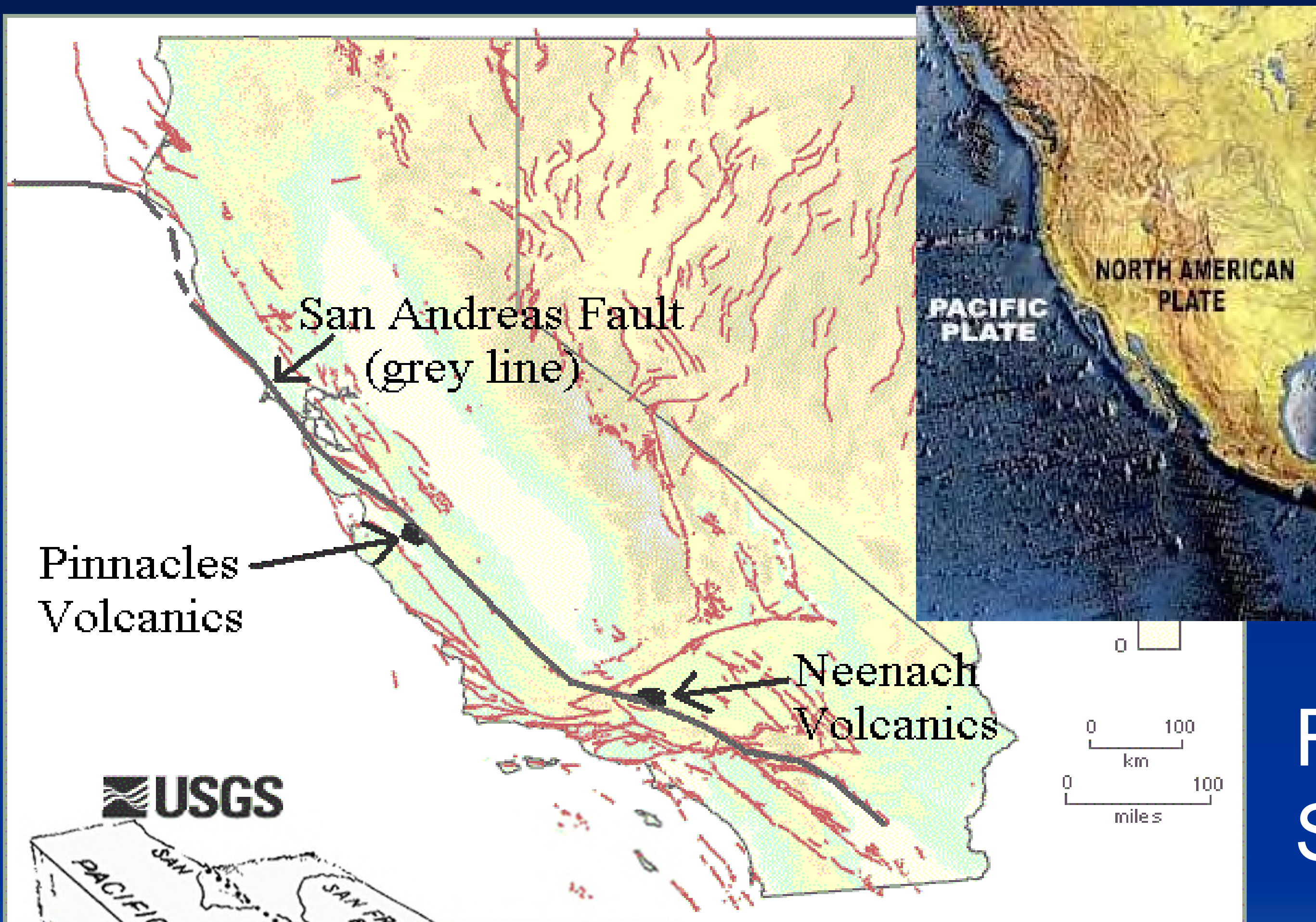
The relative strike-slip motion across this fault is left-lateral

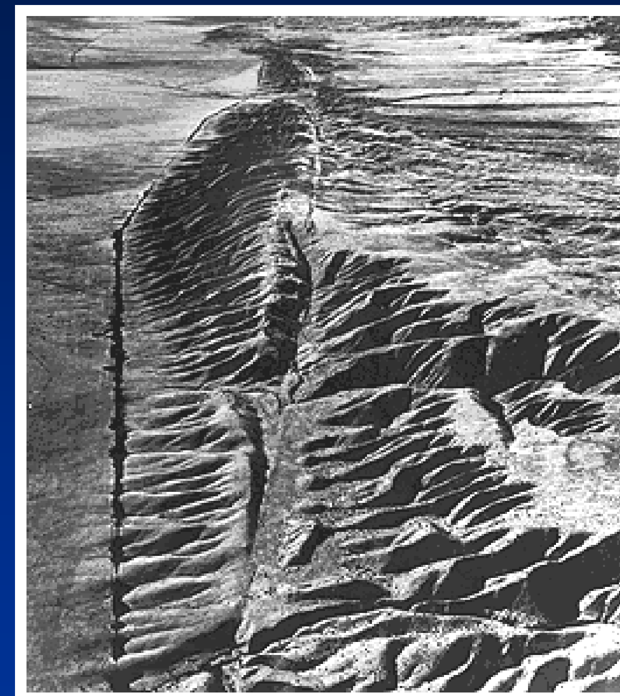
Left lateral because the offset marker on the opposite side of the fault (relative to your viewing position) moved towards the left. This works for both sides of the fault that you view the marker from



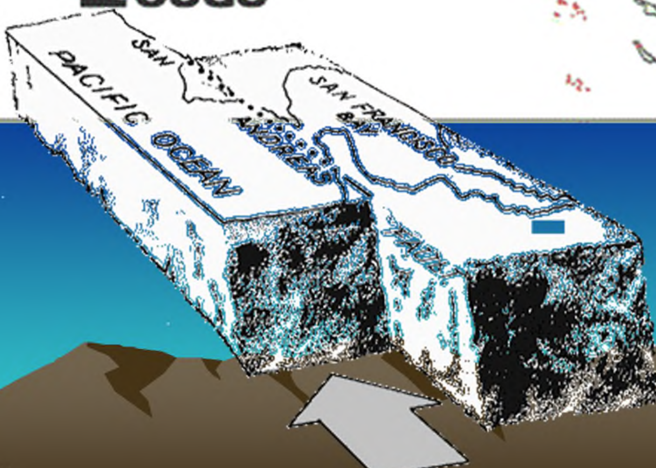
Transform Fault Offset Problem Example

San Andreas Transform Fault Offset





Right Lateral
Strike-slip Offset



- 320 Kilometer Offset
- 25 Million Year Old Oligocene Volcanics

San Andreas Fault Motion Problem

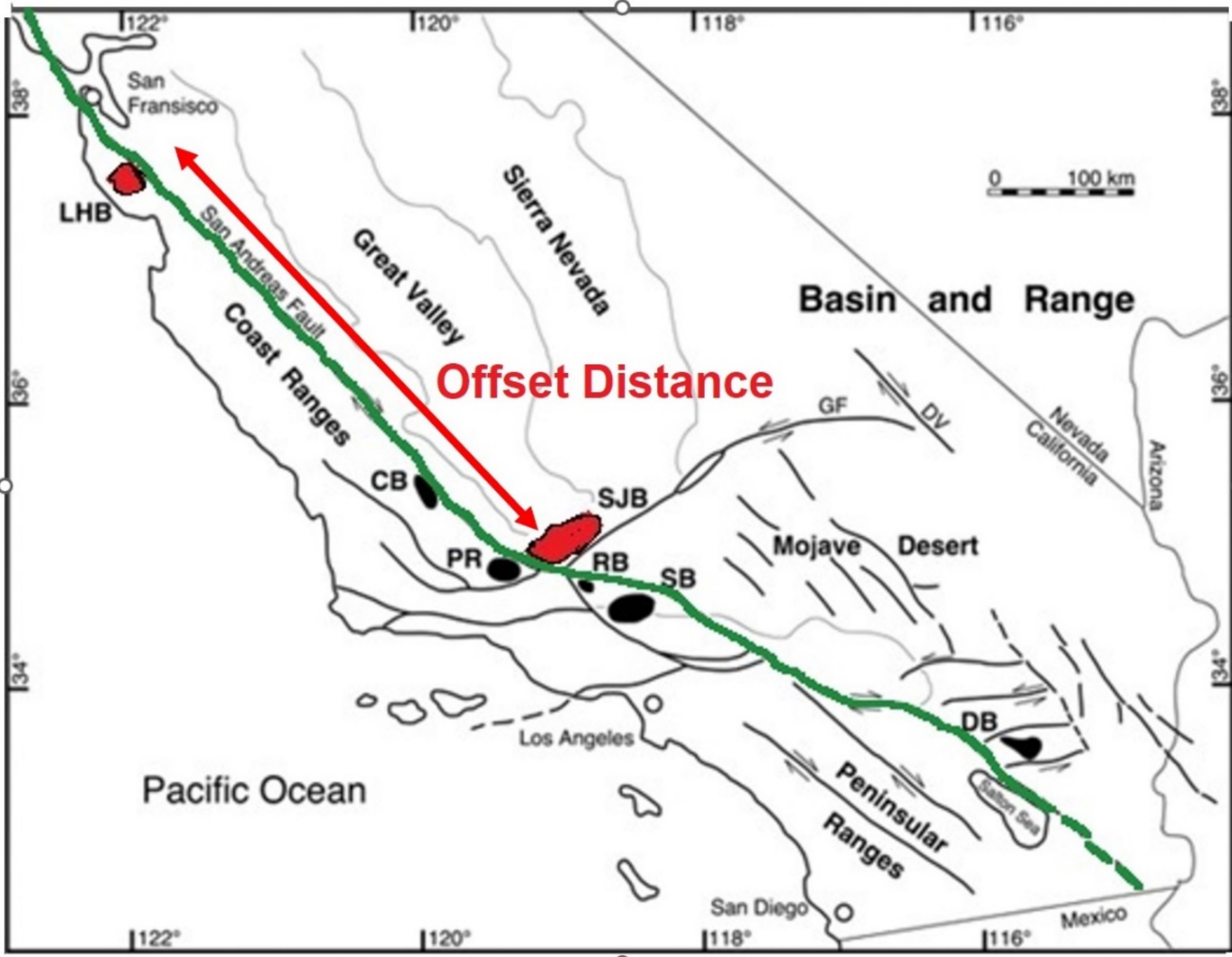


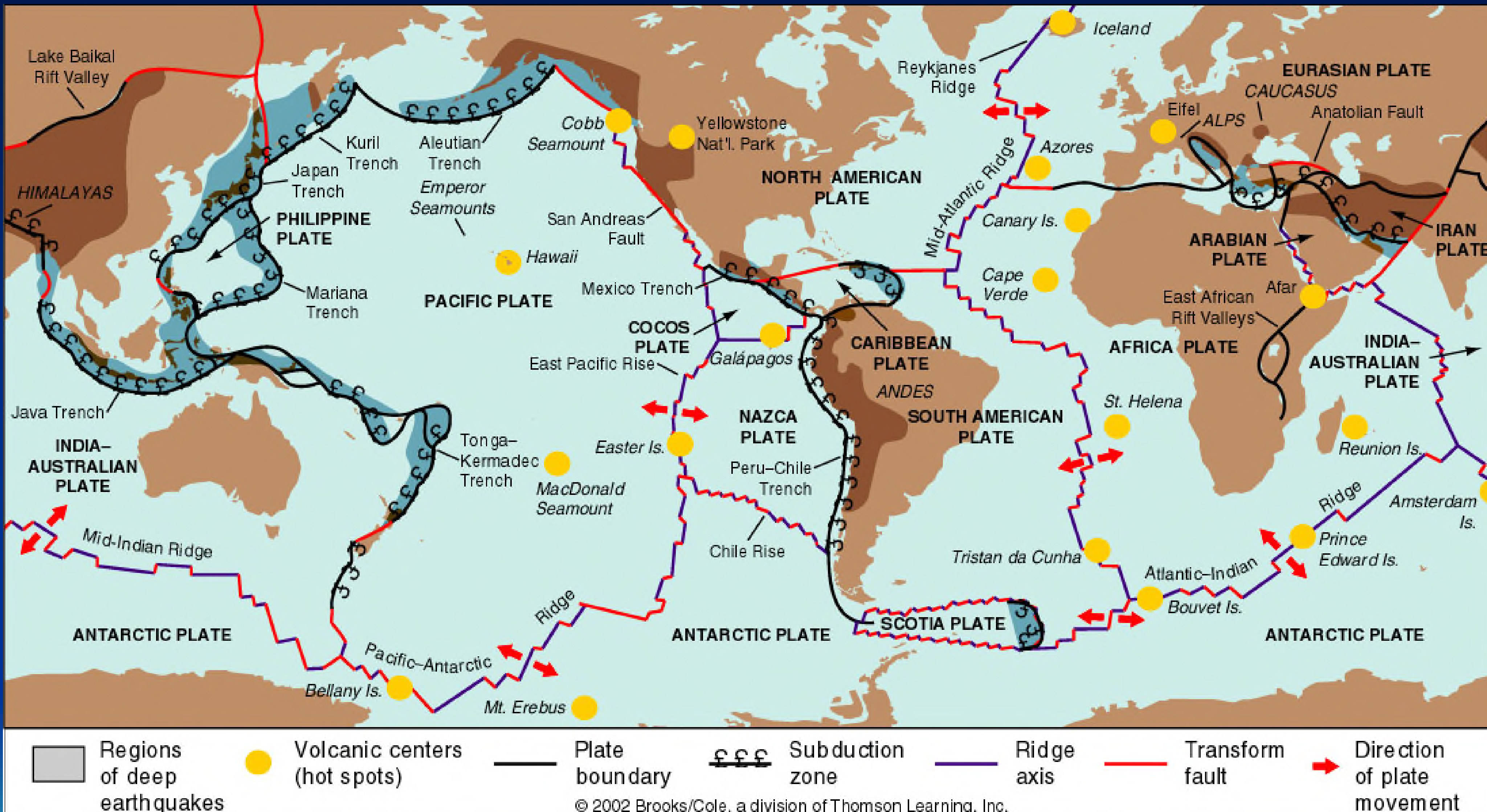
Figure 5. The San Andreas Fault.

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

The Mobile Lithospheric Plates



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