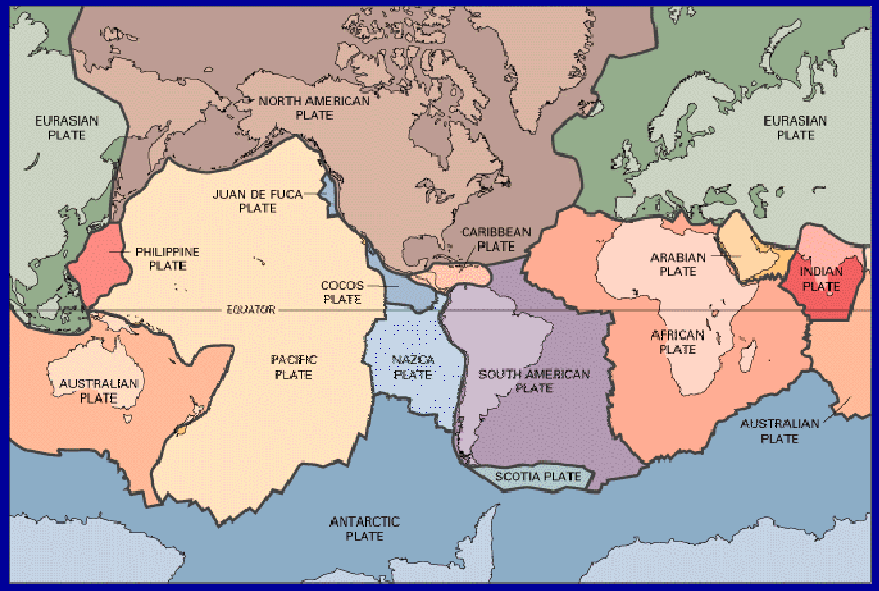
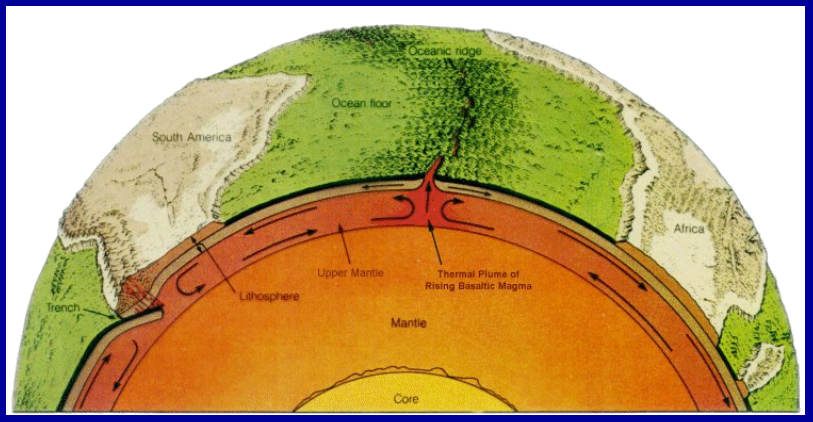
# PLATE TECTONICS - Part II

## Geology's Modern Paradigm

### Theory and Evidence



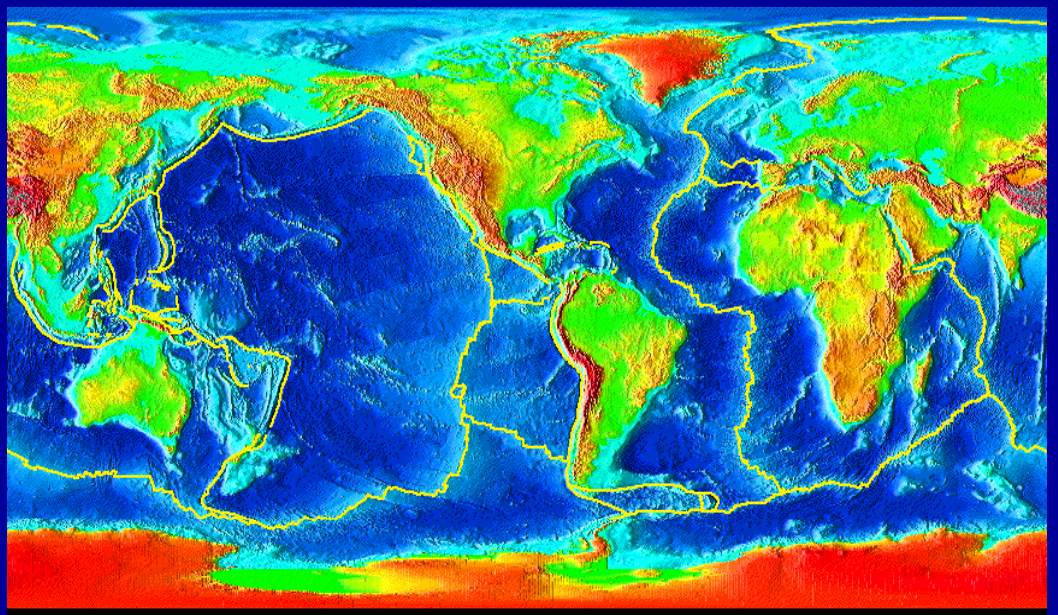

## Physical Geology – GEOL100

Ray Rector - Instructor

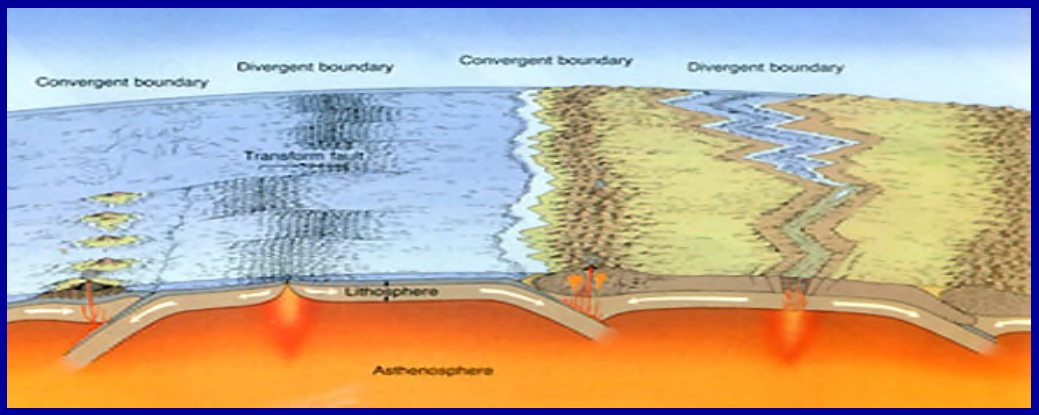
# Topics in Plate Tectonics

## Today's Topics

- ✓ Review of PT Theory
- ✓ Seafloor Spreading
- ✓ Subduction
- ✓ Evidence for the Theory
- ✓ Plate Dynamics
- ✓ Hot Spots
- ✓ Supercontinent Cycles
- ✓ Driving Mechanisms

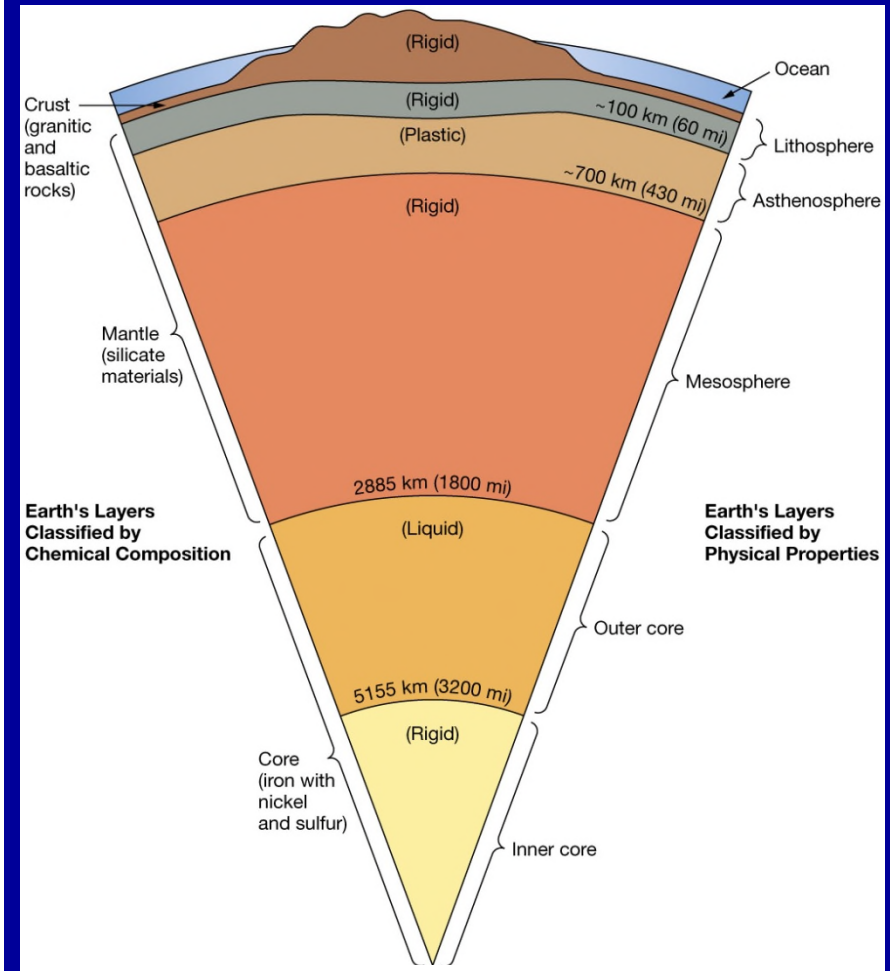


Crustal Plate Boundaries

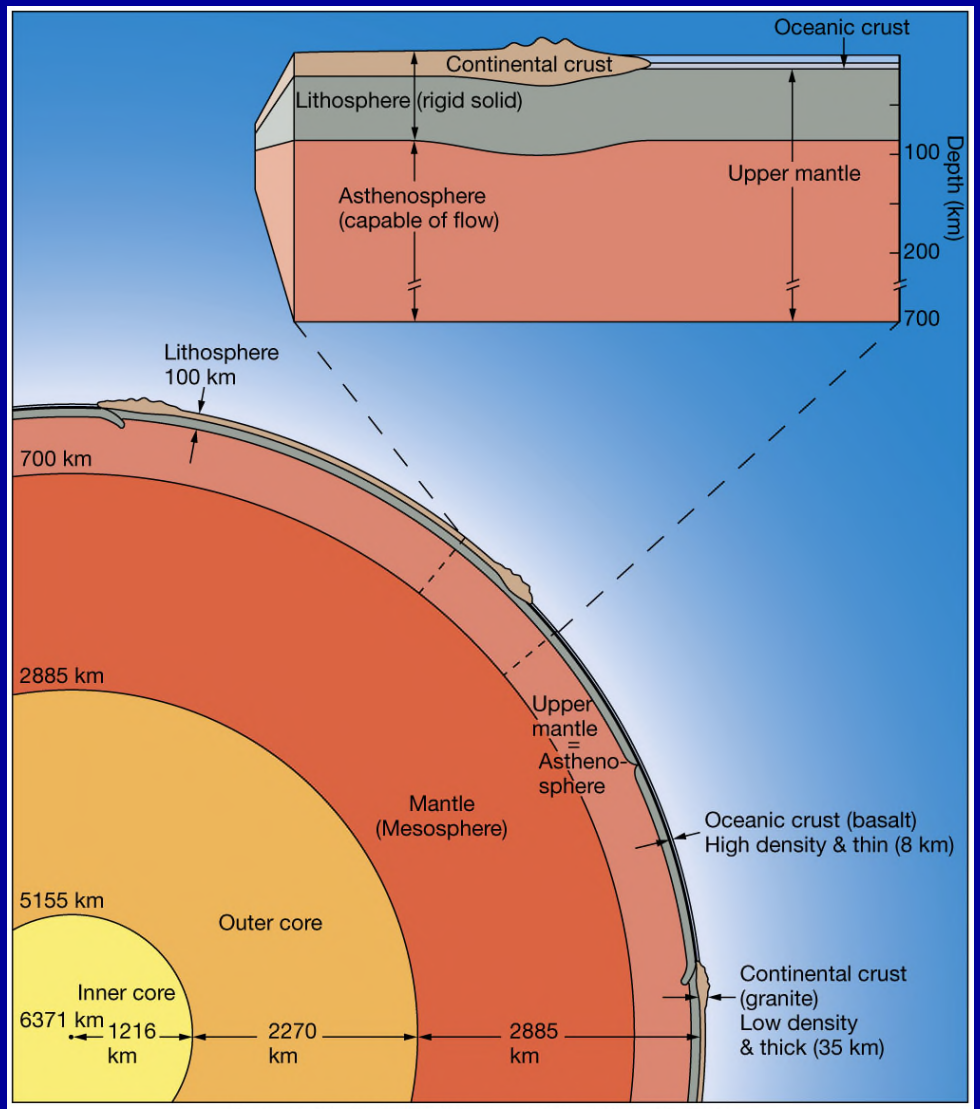


# Earth's Anatomy Today

## Chemical and Physical Nature of Earth's Interior

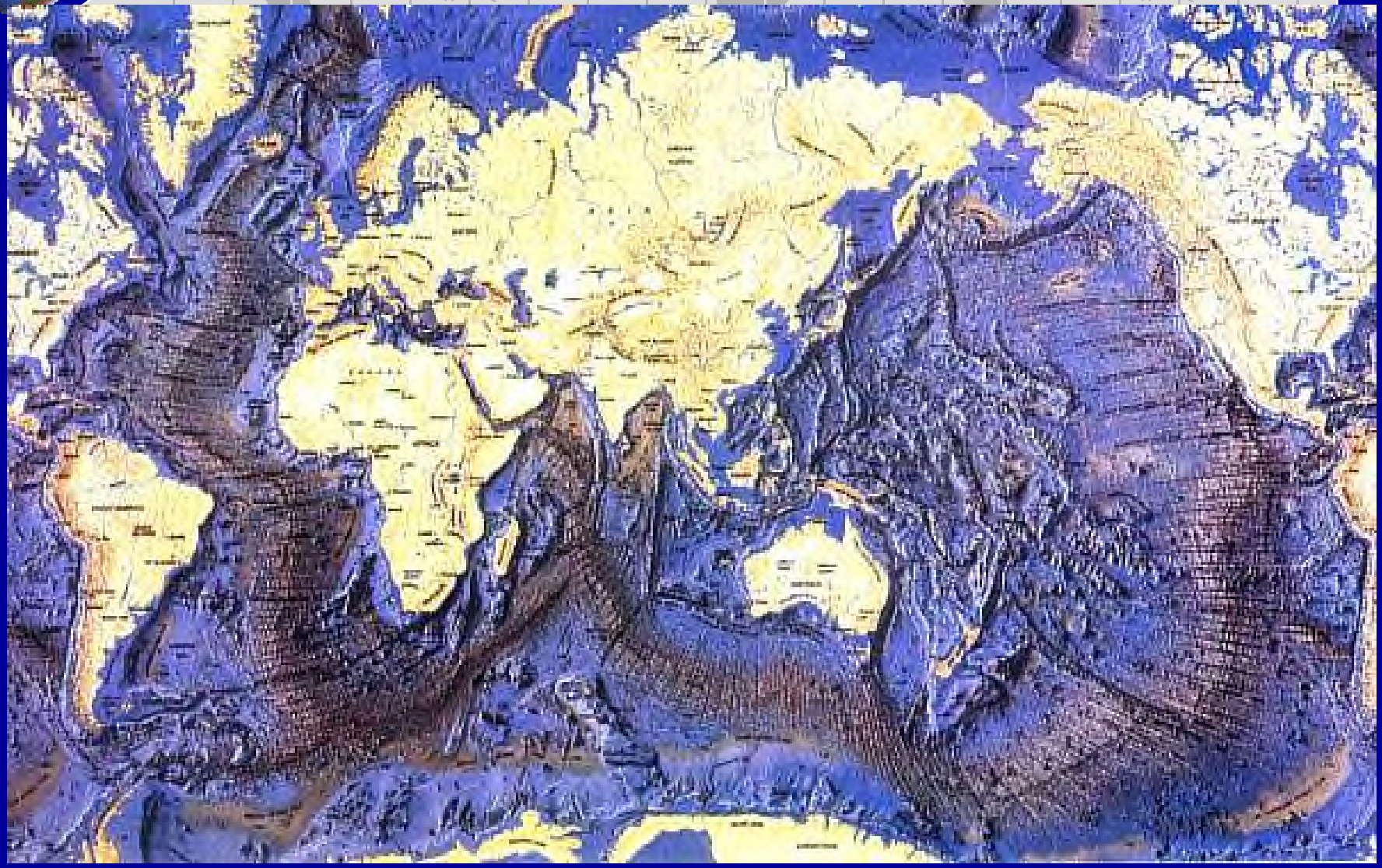




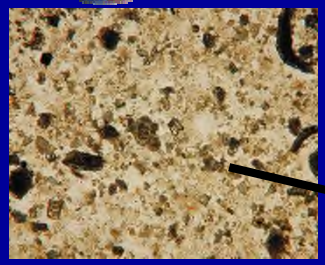

Density Layering of Earth's Interior

# Earth's Continent's & Ocean Basins



An Earth with No Ocean!

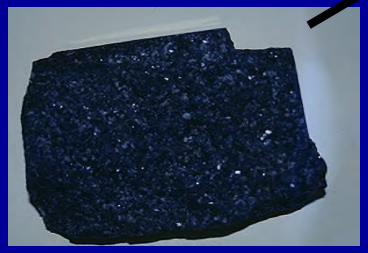
# Two Primary Types of Earth Crust



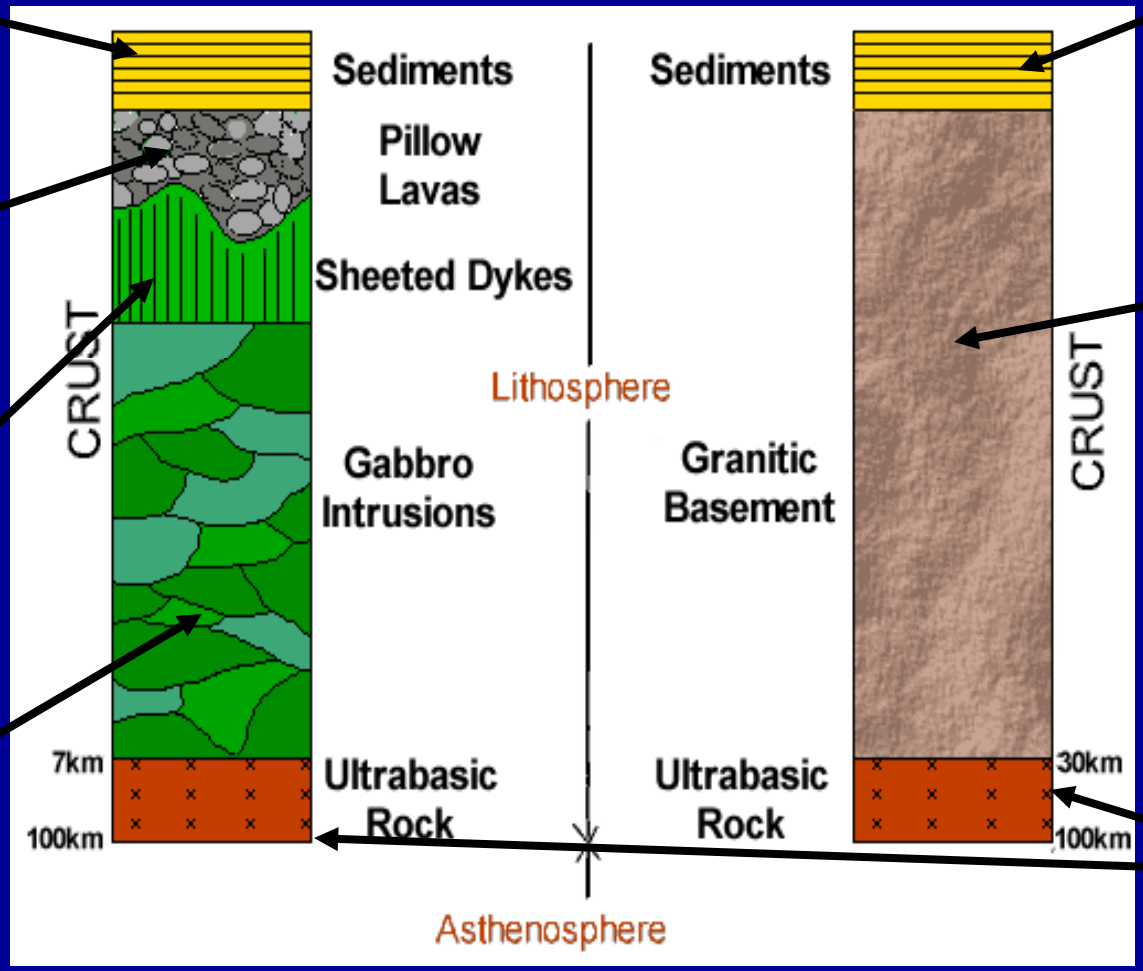
Deep Sea Ooze

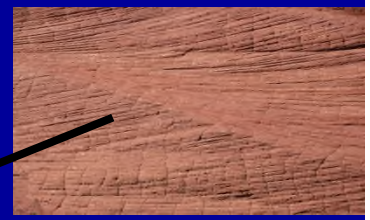
Pillow Basalt

Sheeted Dykes

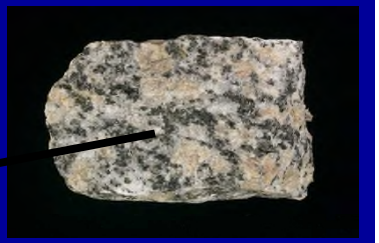


Gabbro



Sedimentary



Granite and Gniesses

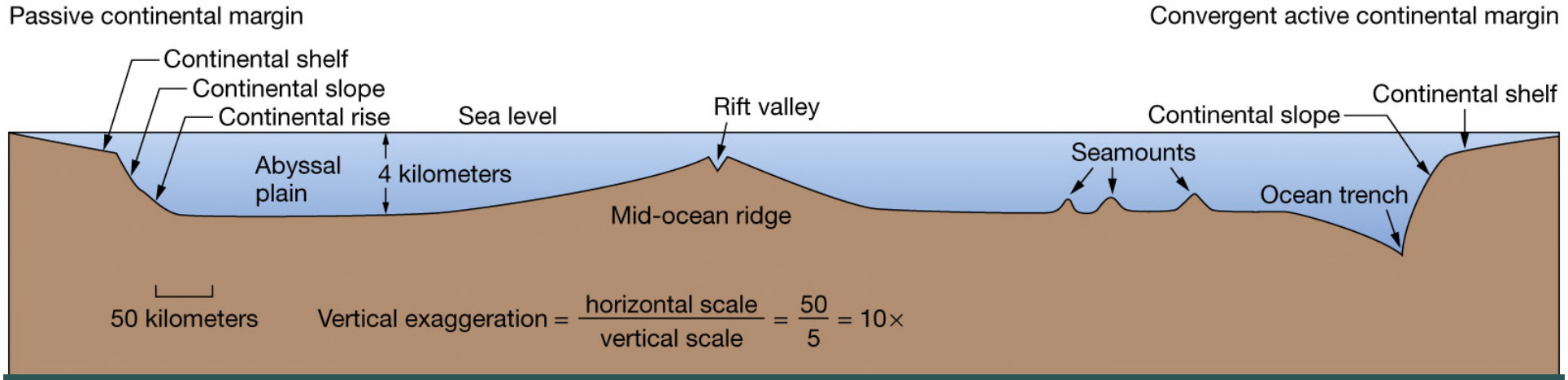
Ultrabasic mantle rock

# OCEANOGRAPHY COMES OF AGE

- Technologic Innovations Light Up the Ocean Bottoms
  - ✓ Sonar and Radar Mapping
  - ✓ Piston coring and Drilling
  - ✓ Magnetometer surveys
  - ✓ Radiometric and fossil dating
  - ✓ Submersible investigations
  - ✓ Subsurface seismic surveys
  - ✓ Computer-assisted research
- Detailed Seafloor Image Emerges
  - ✓ Ridges, fracture zones, trenches
- Radical New Ideas Take Hold
  - ✓ Seafloor Spreading and Subduction
  - ✓ The Plate Tectonic Theory

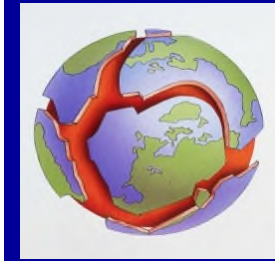
The Seafloor Illuminated!

# Cross-Section Profile of an Ocean Basin




## Large-Scale Ocean Bottom Features

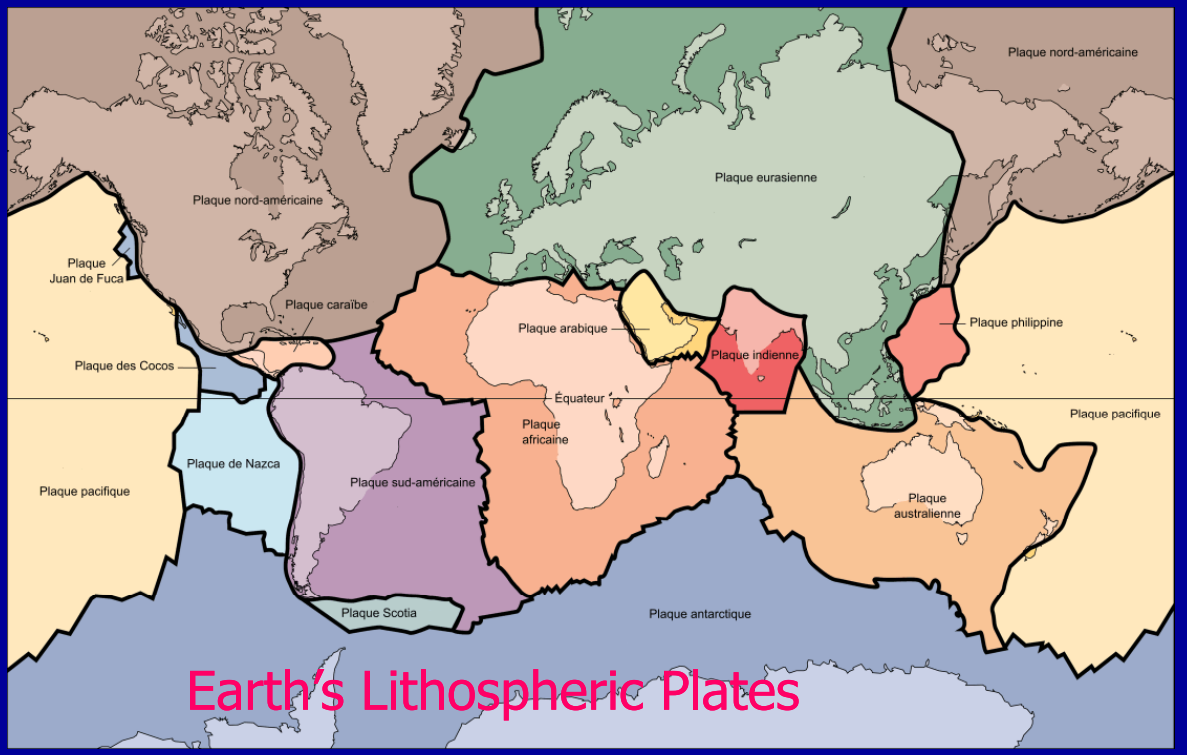
- ✓ Continental shelf, slope, and rise
- ✓ Abyssal plains and hills
- ✓ Mid-ocean ridge and rift valley
- ✓ Oceanic islands, seamounts, and guyots
- ✓ Ocean trench



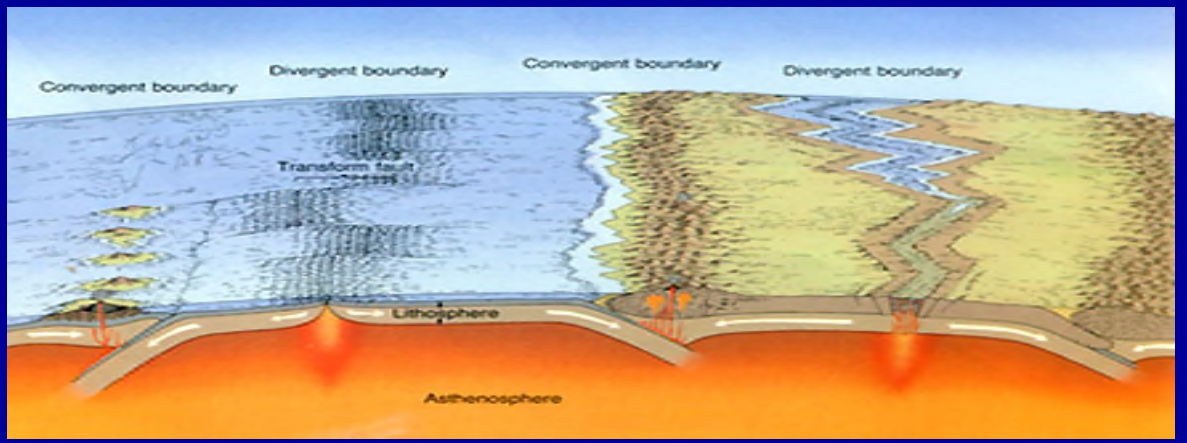
# PLATE TECTONICS OVERVIEW

## Key Features:

- ✓ 14 Lithosphere Plates
- ✓ 6 Major, 8 Minor
- ✓ 100-300 km thick
- ✓ Strong and rigid
- ✓ Plates float on partially molten asthenosphere
- ✓ Plates are mobile
- ✓ Cm's/yr motion rates
- ✓ Seafloor Spreading creates new oceanic plates
- ✓ Subduction destroys older oceanic plates



Earth's Lithospheric Plates

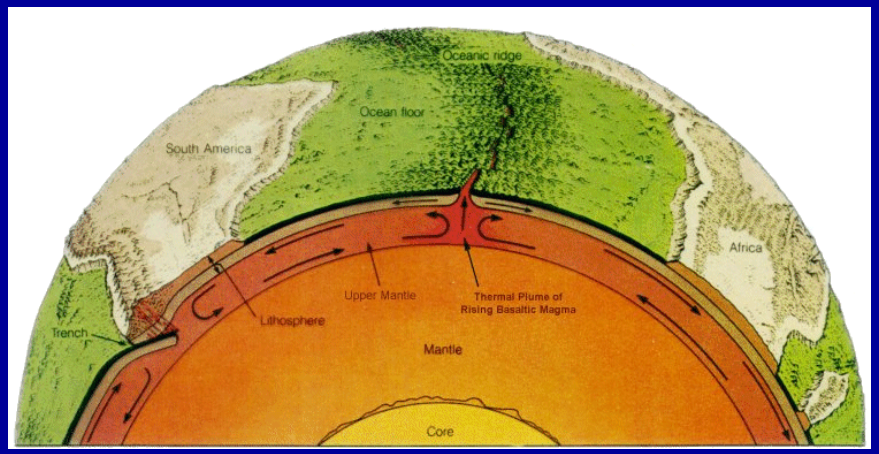


# PLATE TECTONIC THEORY

## Key concepts:

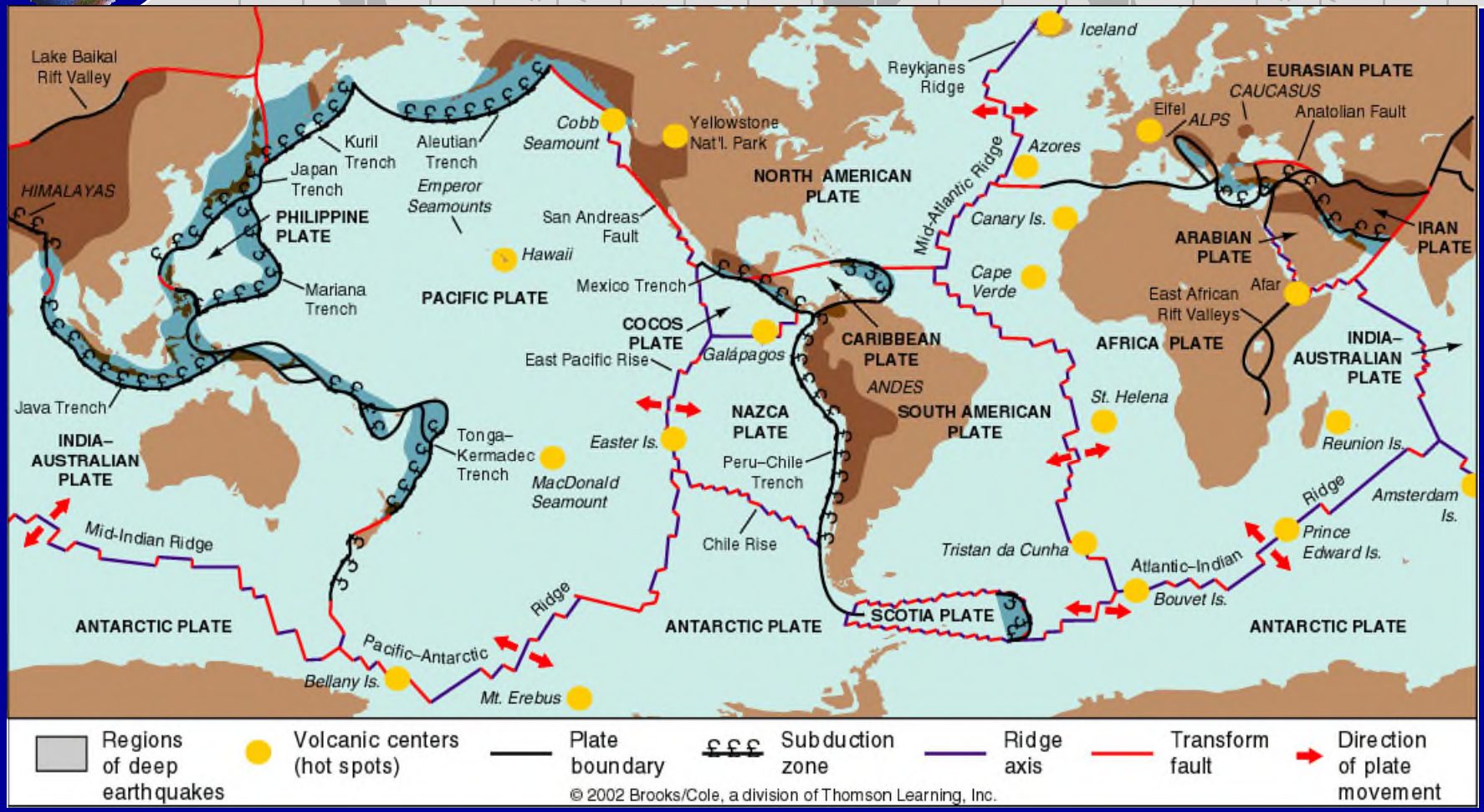
1) Lithospheric plates ride independently atop the underlying partially-molten mantle called the asthenosphere
2) Three types of dynamic lithospheric plate boundaries:
3) Earth's crust and uppermost mantle broken up into 18 mobile, rigid slabs called lithospheric plates

   Divergent, Convergent, and Transform
4) Divergent boundaries
   - Continental rifting
   - Seafloor-spreading
5) Convergent boundaries
   - Subduction
   - Terrane accretion
   - Continental collision
6) Transform boundaries
   - Strike-slip faulting




7) Plate tectonics is driven primarily by mantle convection
8) Plate tectonic theory explains most geologic phenomena

# Lithospheric Plate Boundaries and Hotspots

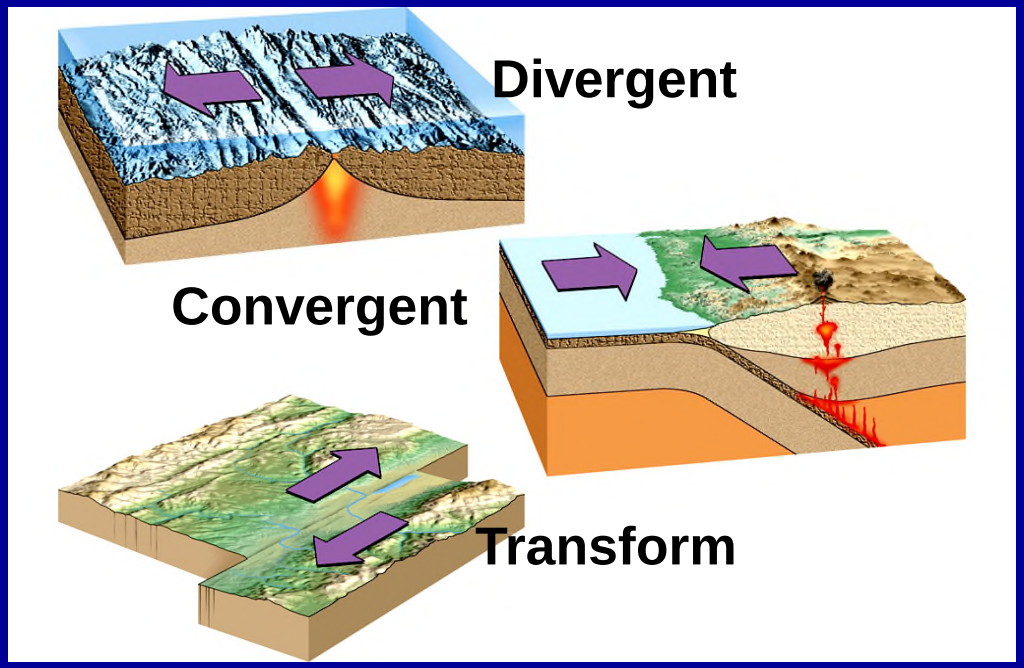


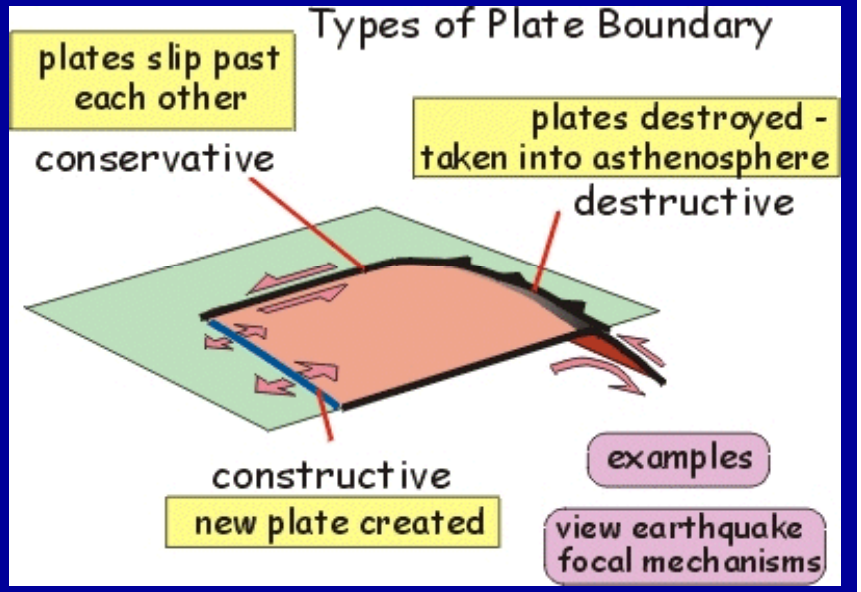

1) Most of Earth's active Faults and Volcanoes are located along narrow belt-like regions that coincide with the lithospheric plate boundaries

2) The major plate boundaries are shown in red and green on the map

# Tectonic Plate Boundaries

## Three Principle Types of Plate Boundaries



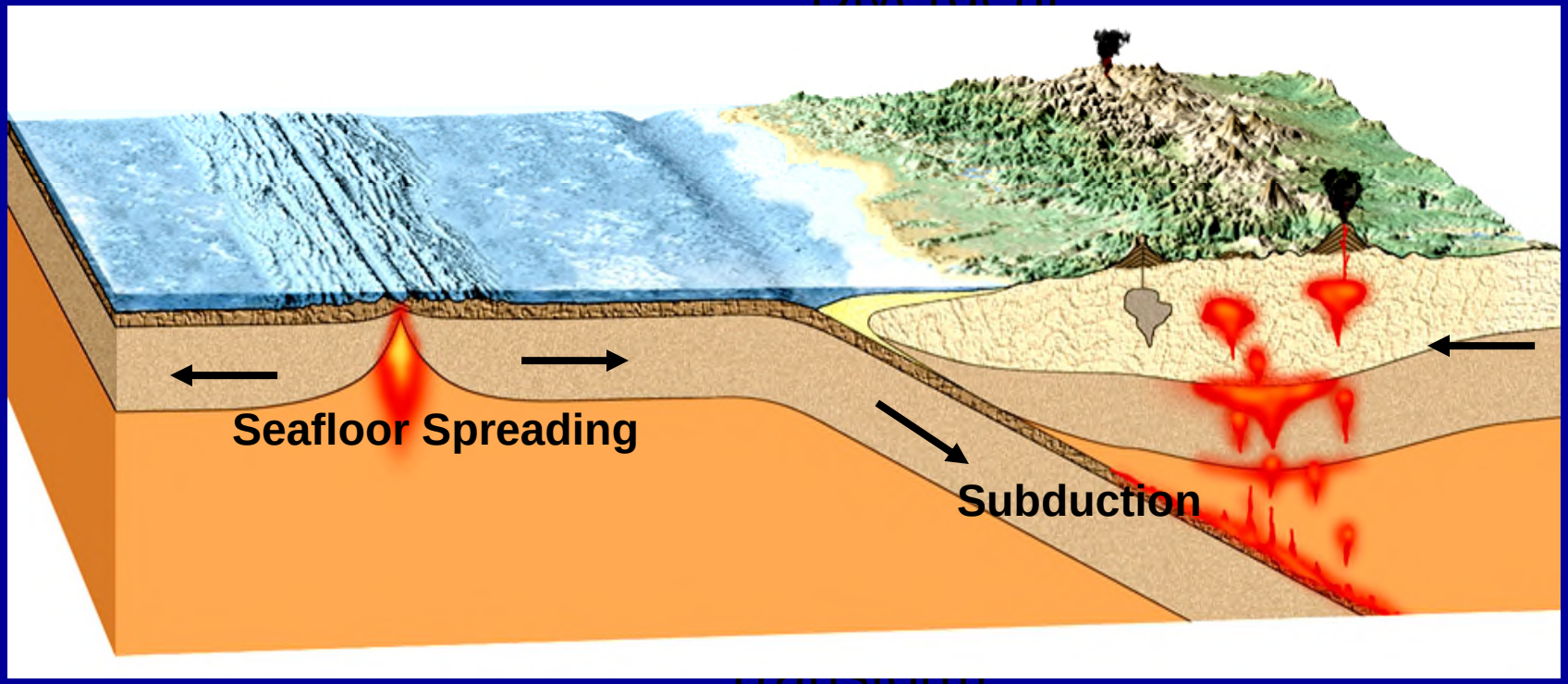

1) Divergent = Constructive
2) Convergent = Destructive
3) Transform = Conservative

# TECTONICS PROCESSES

## *Two Principle Tectonic Processes*

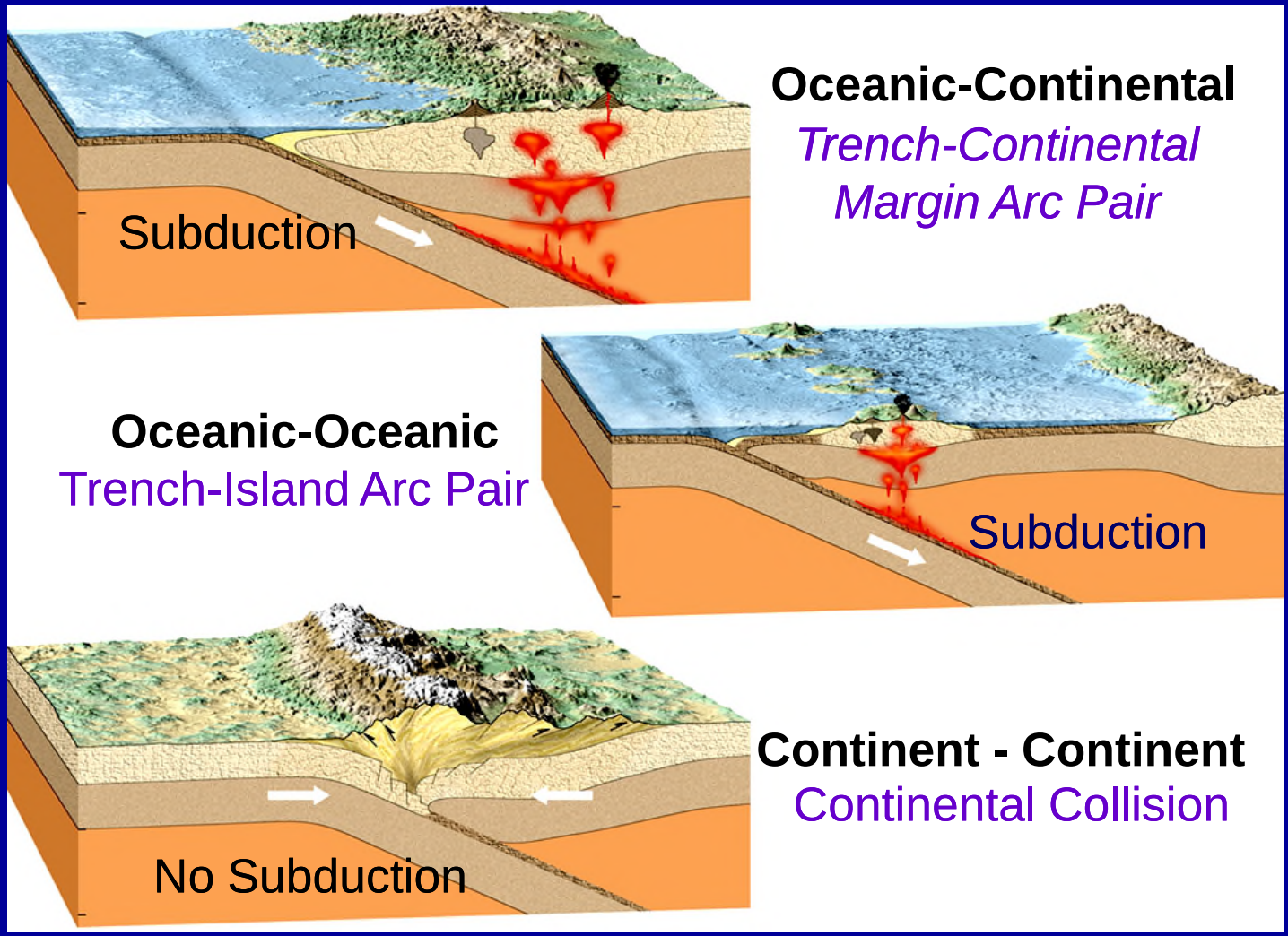
1) Seafloor Spreading = Constructive = Divergent

2) Subduction = Destructive = Convergent

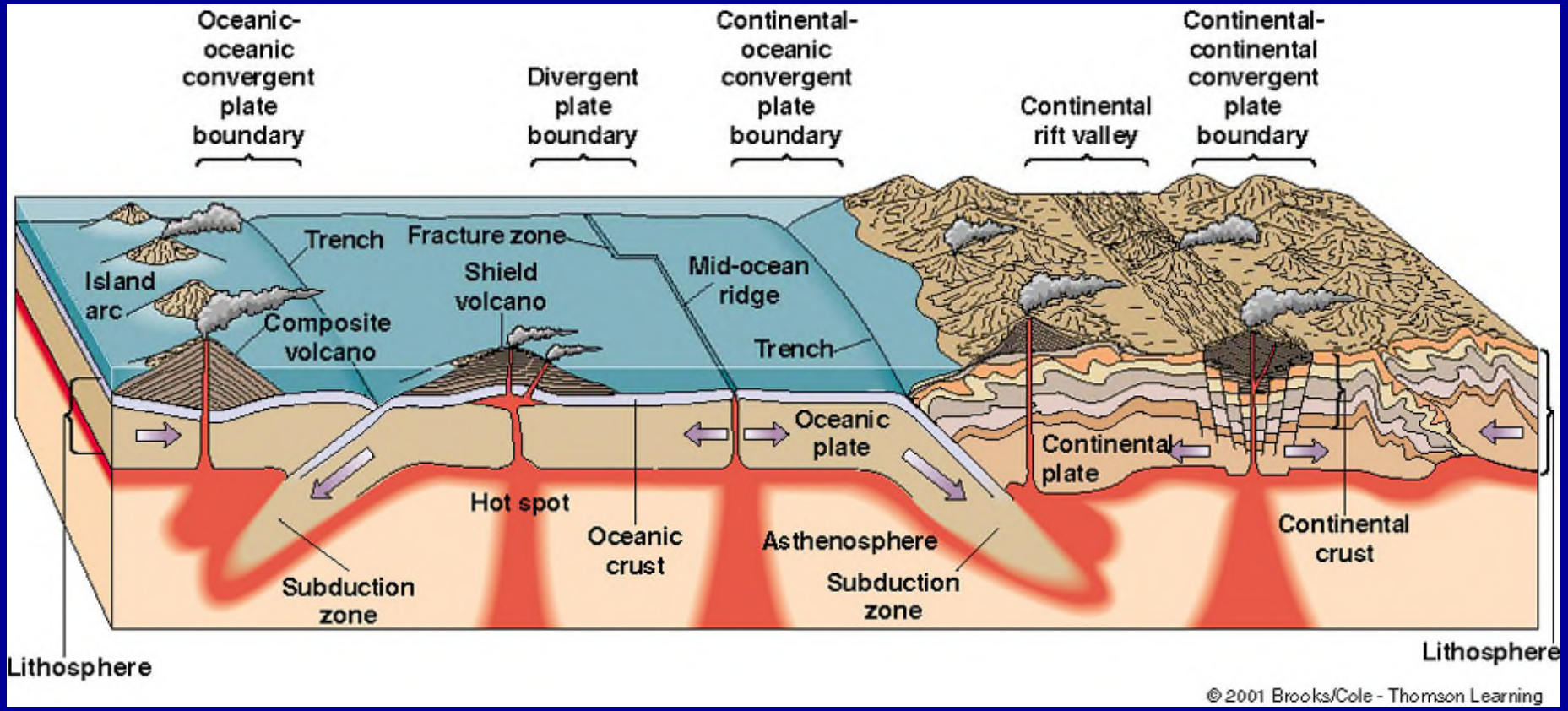


# Convergent Plate Boundaries

## Three Types of Convergent Plate Boundaries

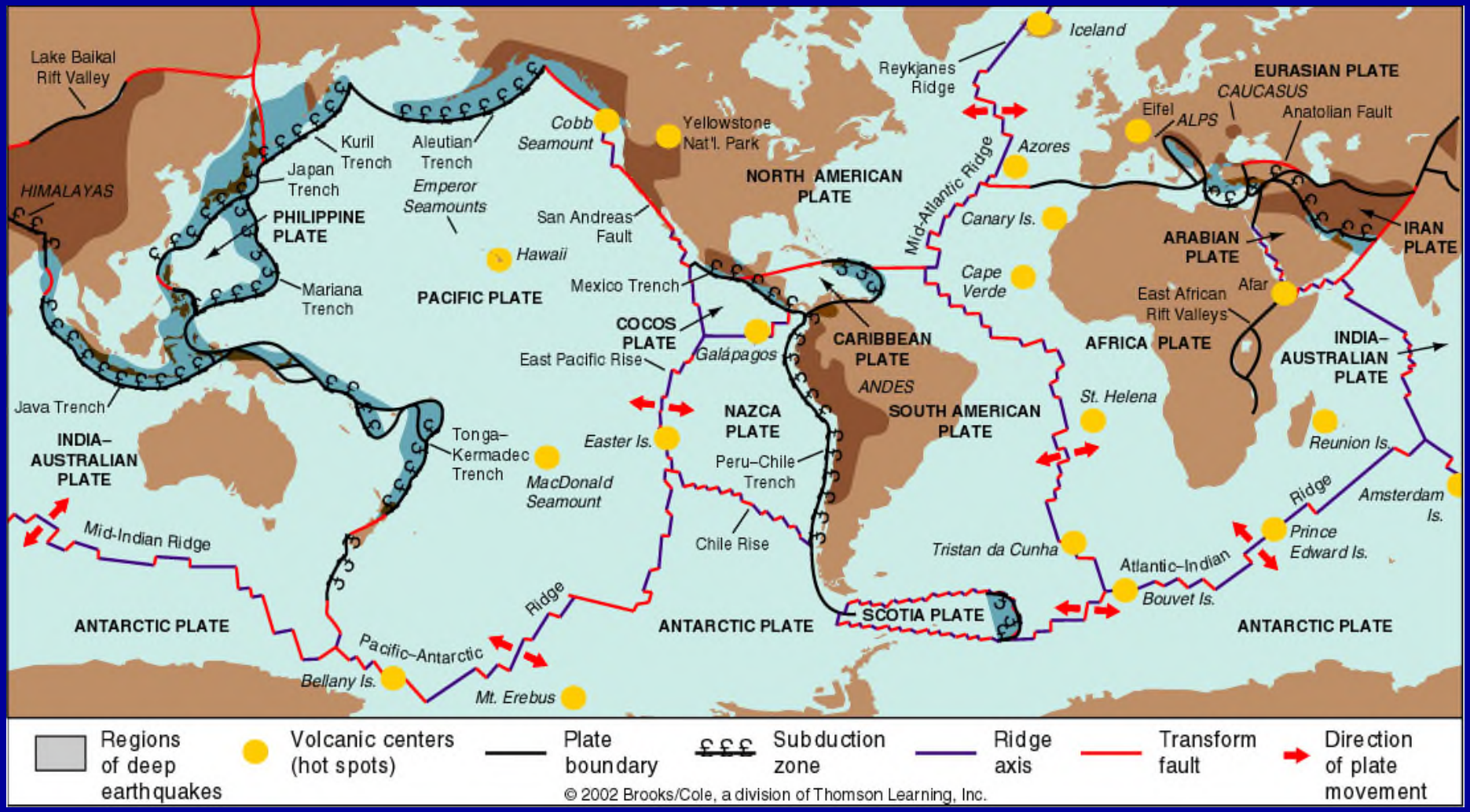


# Plate Tectonic Boundaries




1) Two types of divergent boundaries – Oceanic and Continental
2) Three types of convergent boundaries – O-O; O-C; & C-C
3) Two types of Transform boundaries– Oceanic and Continental

# The Mobile Lithospheric Plates

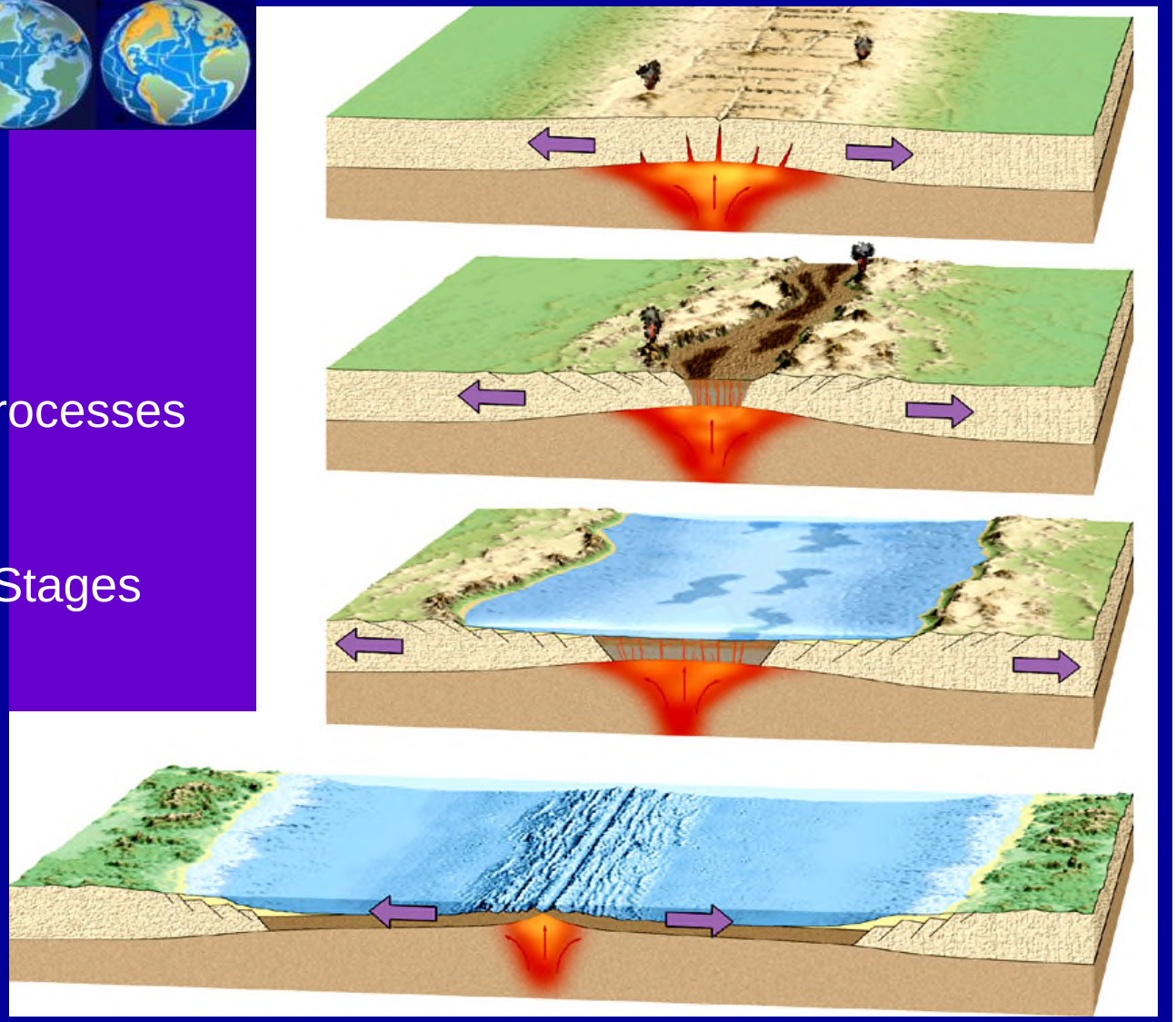



**Click Here for Animation Showing Plate Boundaries, Earthquakes, and Volcanism**

# Seafloor Spreading

## Topics:

- Main Concepts
- Seafloor Spreading Processes
- Lines of Evidence
- Ocean Basin Growth Stages



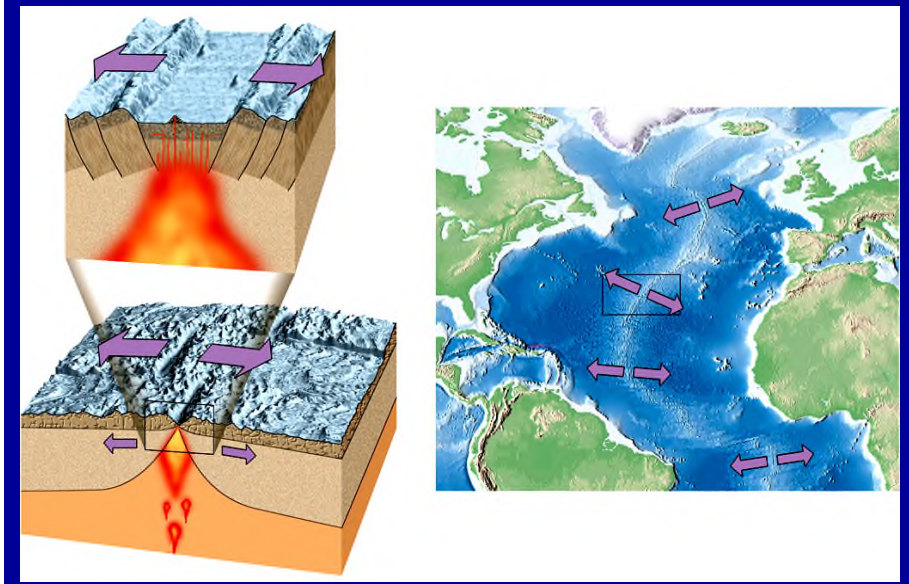
# Seafloor Spreading

## Main Ideas:

**1.** Seafloor spreading is a double conveyor belt-like process that produces "mirrored" growth of new seafloor

**2.** Initiated by continental rifting event

**3.** Mid-ocean ridge system is the site of active spreading

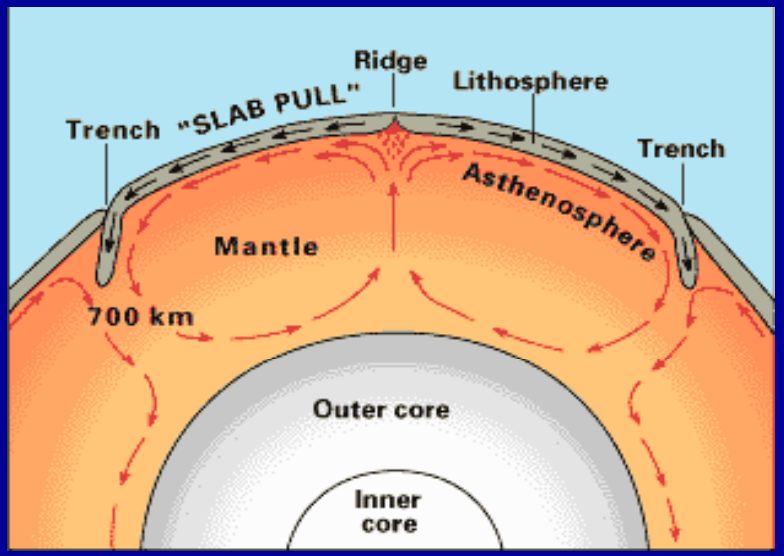


**4.** Plates "spread" apart to accommodate new additions at the ridge center (rift valley)

**5.** Basaltic magmas generated by the decompression melting of upwelling asthenosphere rock beneath the spreading centers

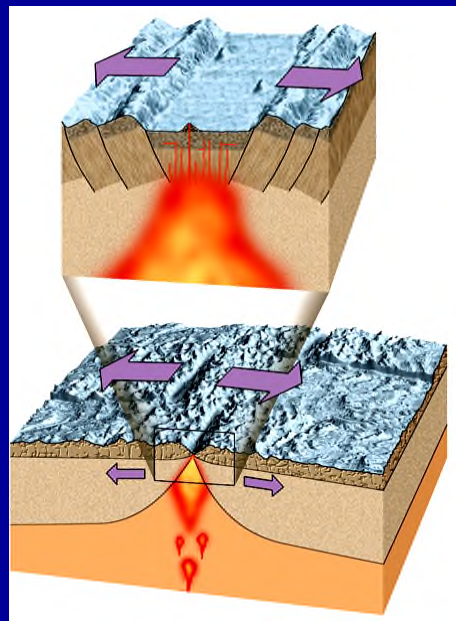
# Seafloor Spreading

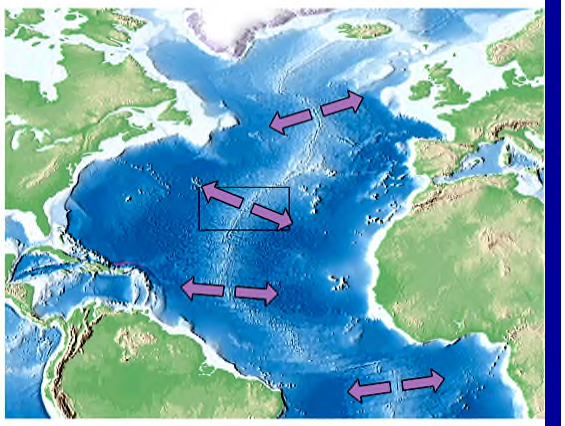
## Seafloor Spreading Processes




- Ascending Mantle Convection
- Decompression Melting of Underlying Asthenosphere

- Basaltic Seafloor Magmatism
- Extensional Crustal Tectonics
- Divergent Growth of Ocean Basin
- Deep-sea Hydrothermal Activity





# Seafloor Spreading Animation

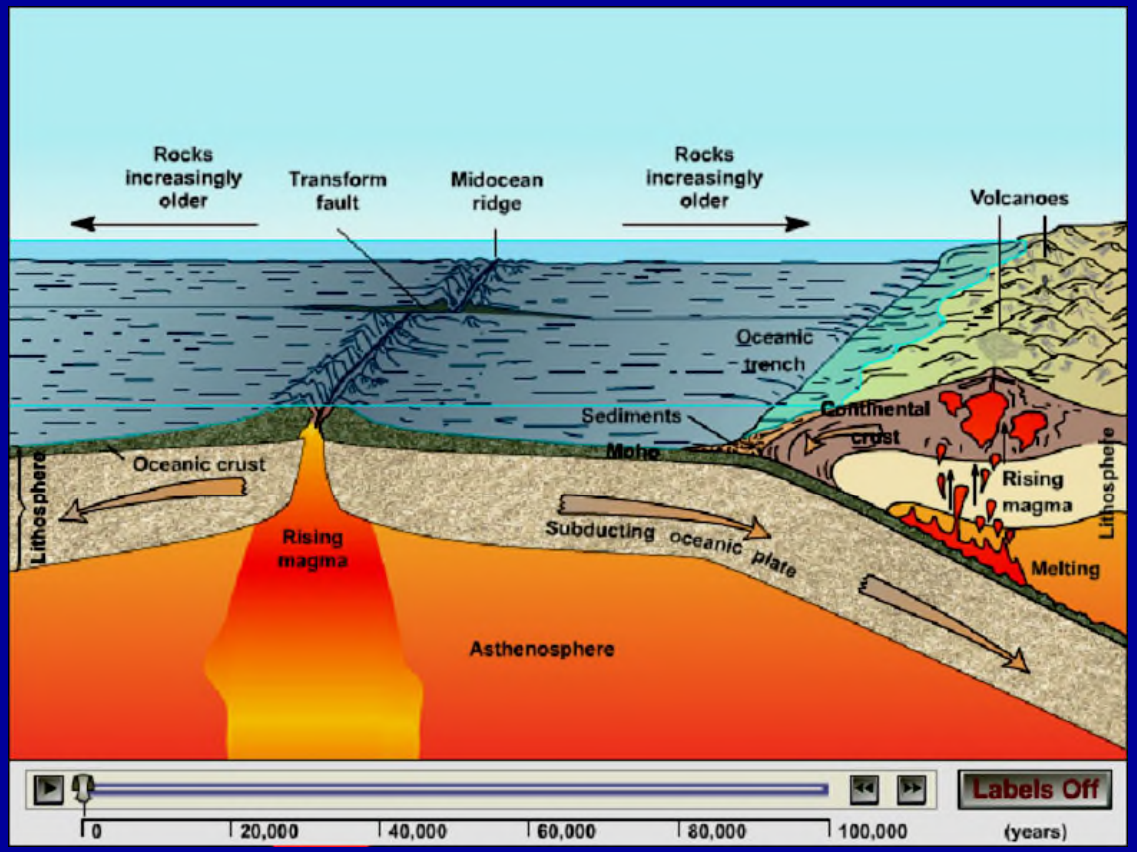
## Key Features:

The illustration to the right shows the progressive growth of oceanic seafloor at a mid-ocean ridge due to seafloor spreading

Basaltic magmas arise from decompression melting of hot ascending asthenosphere beneath the mid ocean ridge

As new oceanic lithosphere is constructed at the mid ocean ridge, older plate material passively moves off and away from both sides of ridge

Most oceanic lithosphere will eventually get subducted back into the asthenosphere

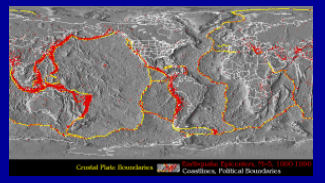



Click Here for Seafloor Spreading Animation

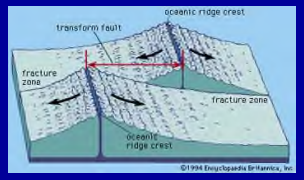
# Evidence for Seafloor Spreading

## Lines Of Evidence

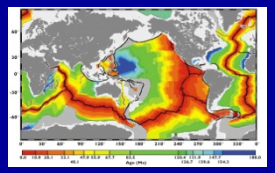
1. Ocean basin physiology and tectonism



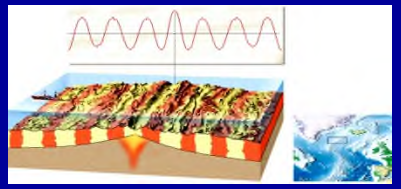
2. Ridge-ridge transform fault motions



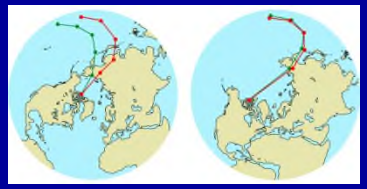

3. Ocean floor age profiles



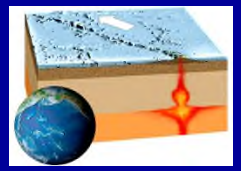
4. Magnetic polarity-reversal anomalies



5. Apparent polar wander paths



6. Hot spot traces



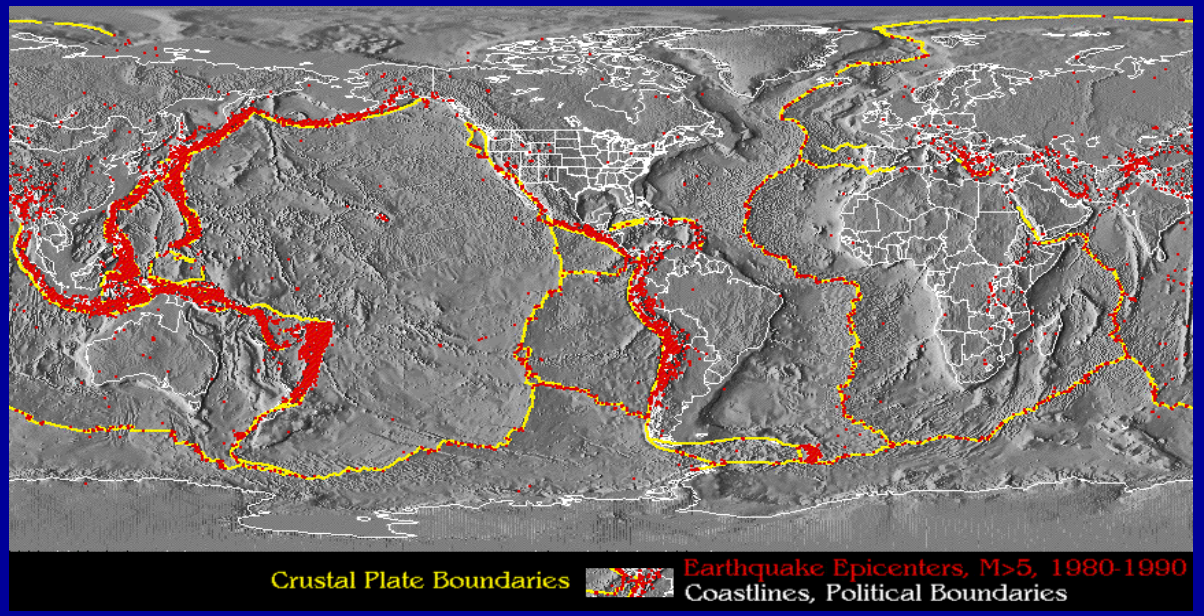
7. Geodesy plate velocity measurements

# Evidence for Seafloor Spreading

## First Line Of Evidence

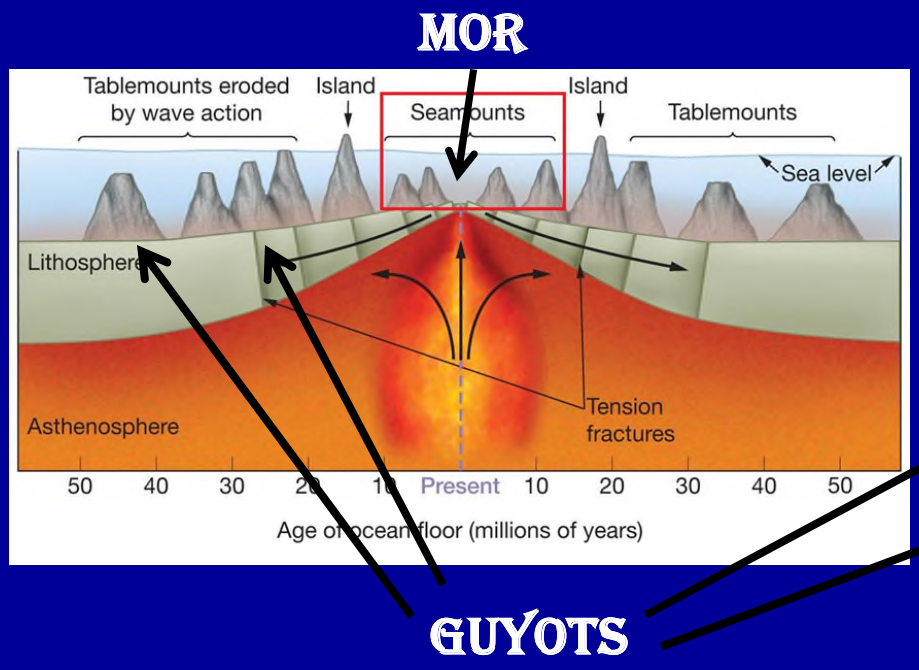
### 1. Ocean Basin Physiology and Tectonism

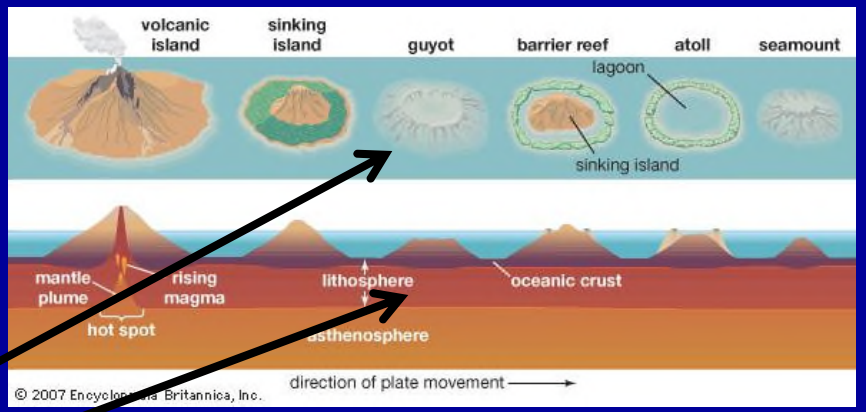
- Tectonically-active mid-ocean ridge, trench, and fracture systems
- Oceanic Island / Seamount chains / Guyots
- Site of present-day volcanism, earthquakes and faulting




***Click Here for Animation Showing Relationship Between Seafloor Spreading, Earthquakes, and Volcanism***

# Guyot Distribution on Seafloor



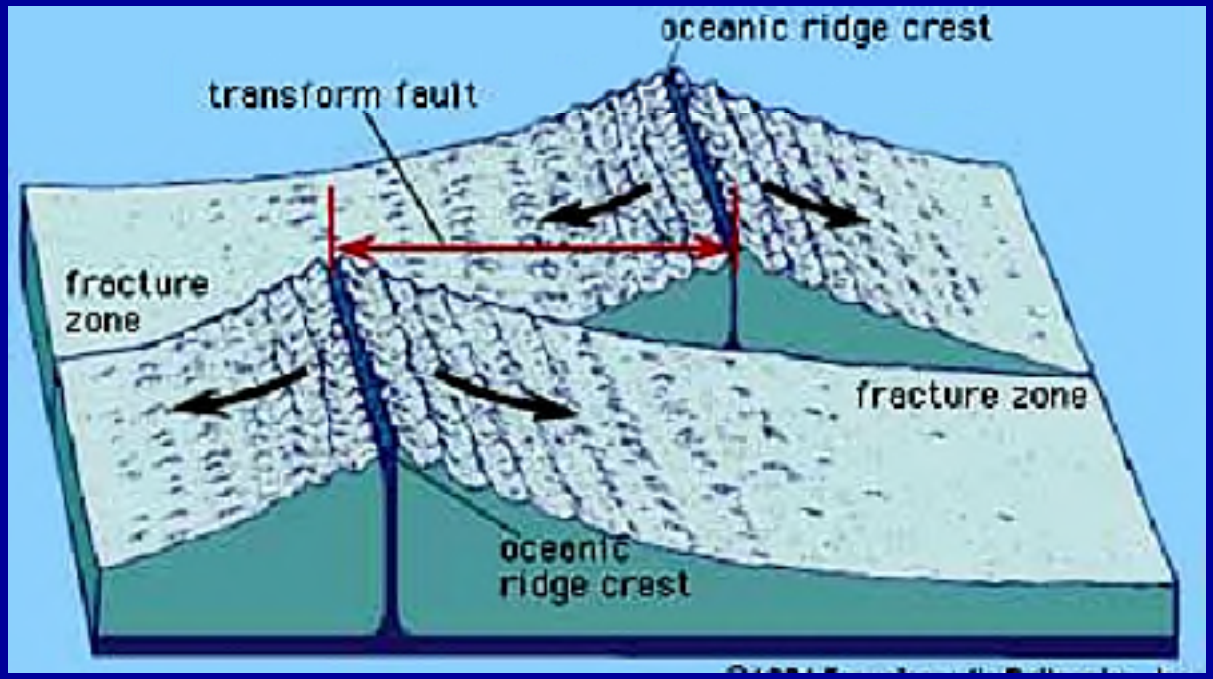

- Guyots are flat-topped seamounts that have eroded top surfaces, which were originally at sea level
- Youngest guyots in ocean basins are shallowest and closest to a mid-ocean ridge (spreading center)
- Oldest guyots are deepest and furthest from mid-ocean ridge (spreading center)

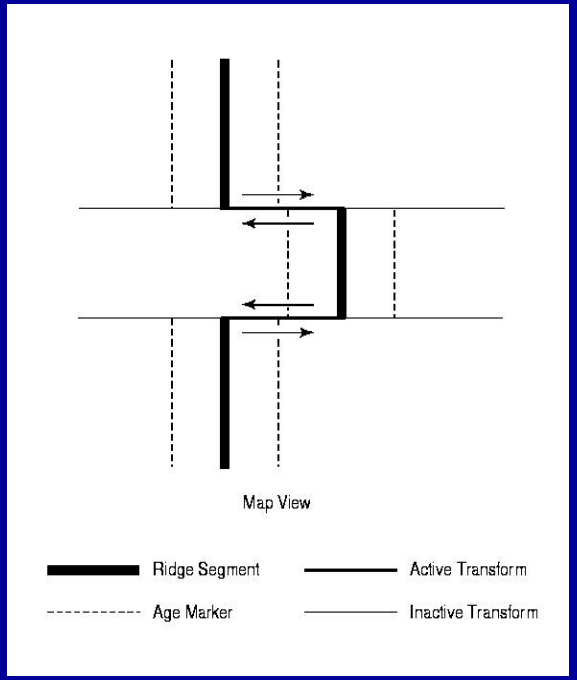
# Evidence for Seafloor Spreading

## Second Line Of Evidence

### 2. Ridge-Ridge Transform Fault Motions

- Fault motion between ridge segments is opposite to offset position
- No apparent motion between fault blocks outside of ridge-ridge region



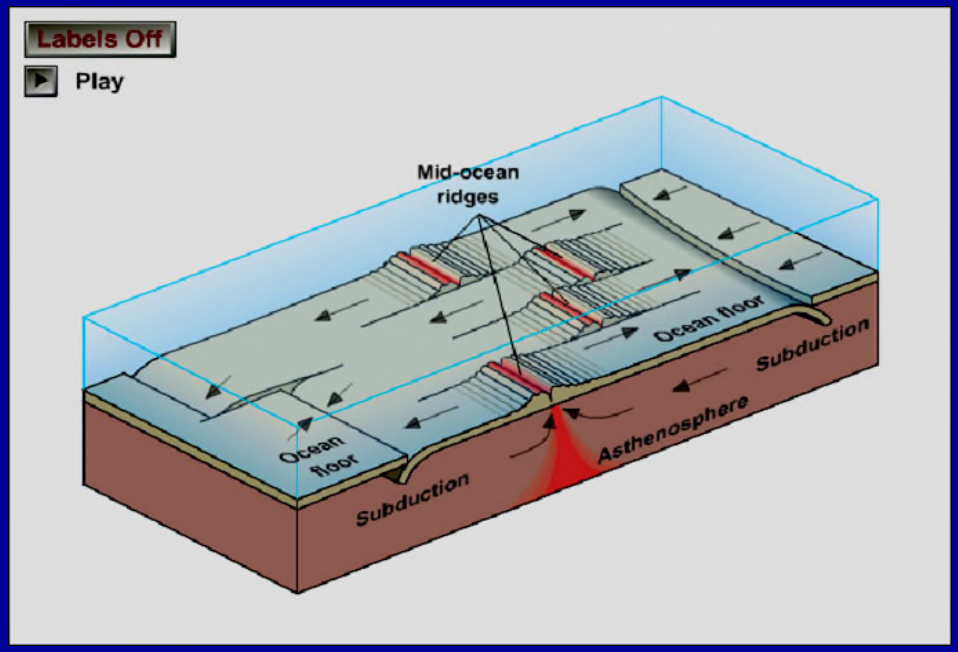



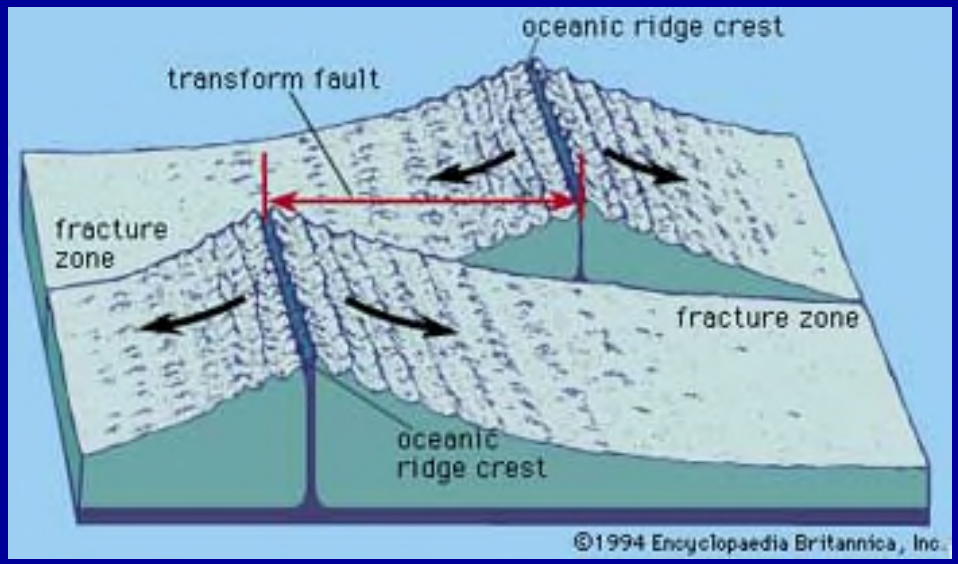
# Mid-Ocean Ridge Transform Faults

The animation shows the progressive transform faulting motion of oceanic seafloor perpendicular to the mid-ocean ridge due to seafloor spreading

Seafloor spreading at offset segments of the mid ocean ridge is accommodated by the strike-slip fault motion along the transform fracture zones

***Click This Link To Start Animation of Fracture Zone Transform faulting***

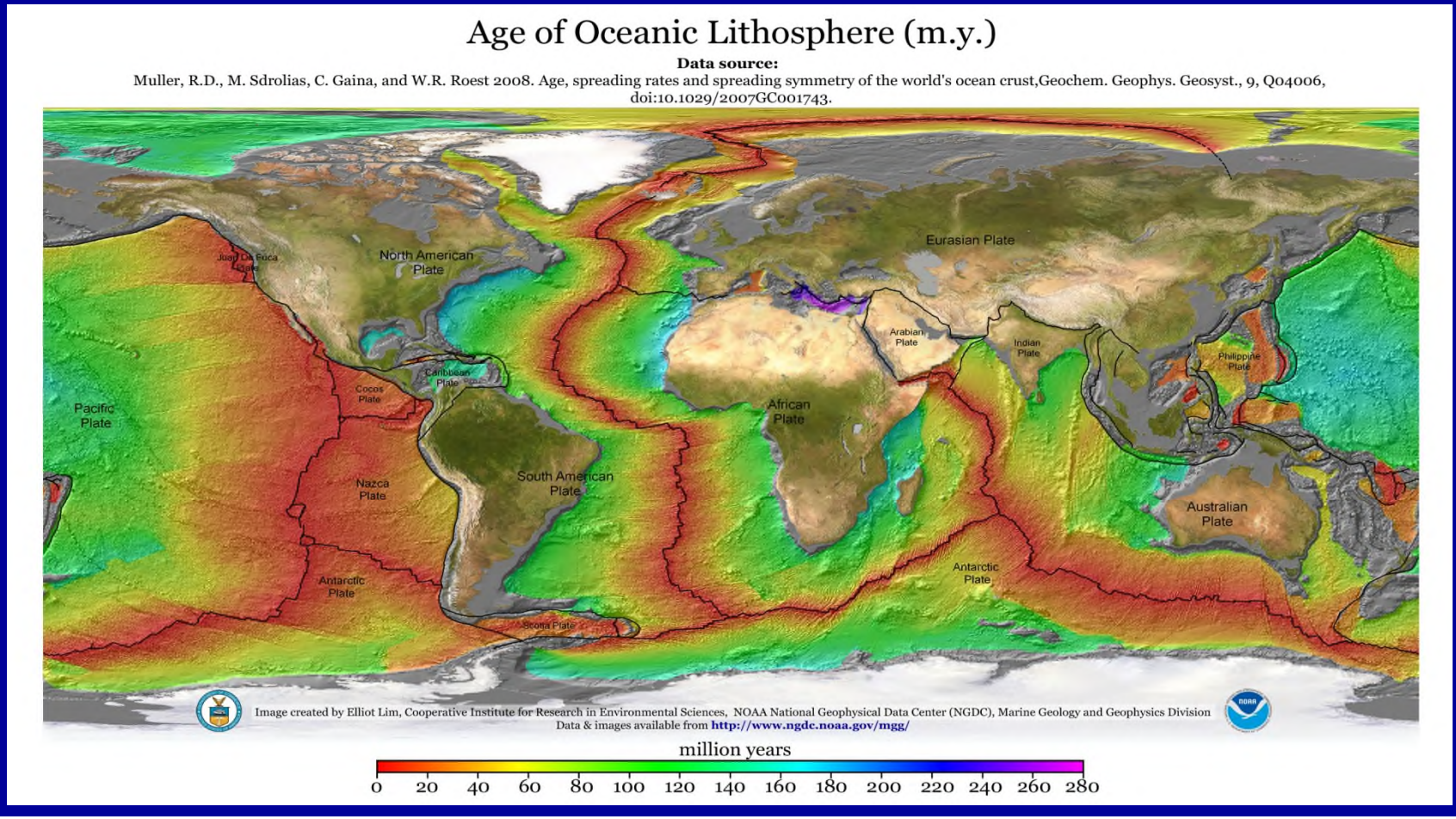


# Evidence for Seafloor Spreading

## Third Line Of Evidence 3. Ocean Floor Age Profiles

- Geologically youthful oceanic crust
- Mid-ocean ridge systems mirrors age patterns

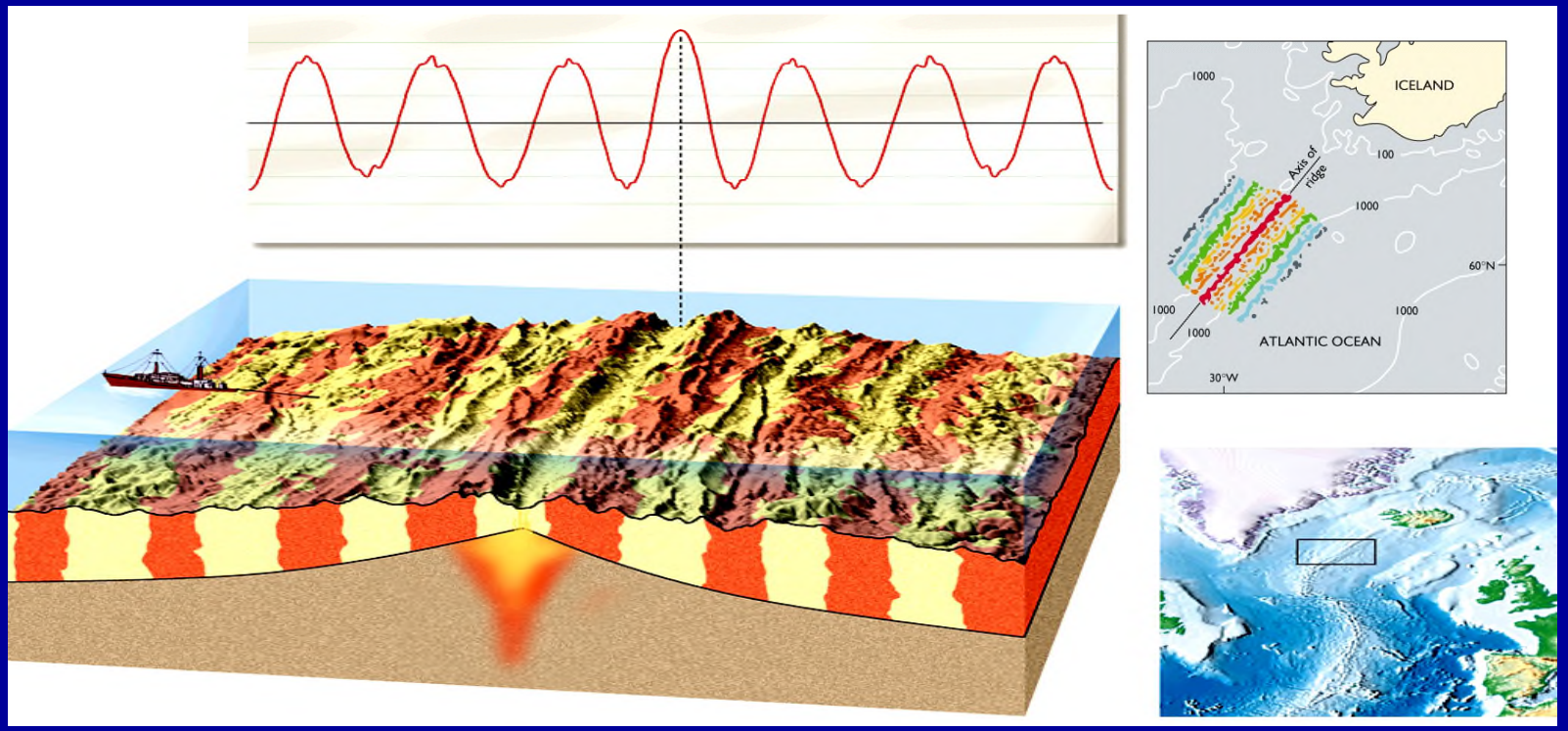


# Evidence for Seafloor Spreading

## Fourth Line Of Evidence

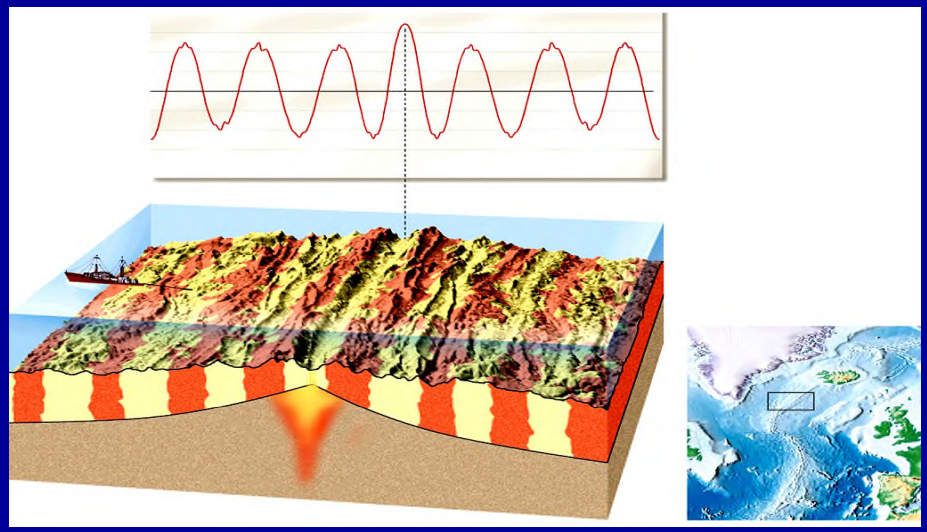
### 4. Magnetic Polarity-Reversal Anomalies

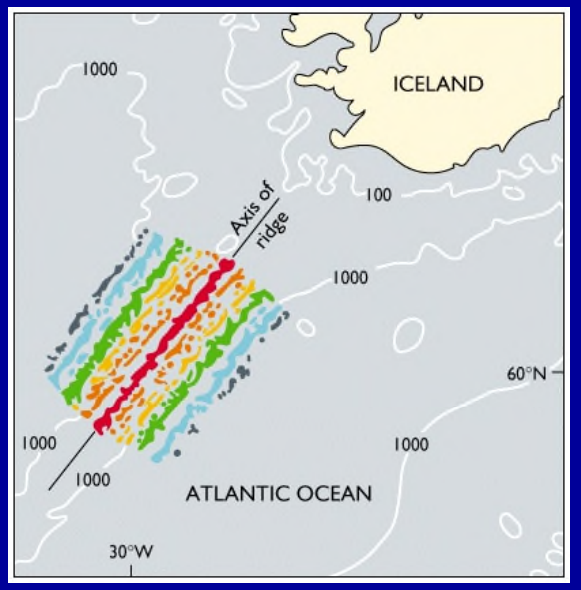
- Spatial layout of seafloor rock magnetization
- Age relationships of recorded polarity reversals
- Mid-ocean ridge systems mirrors polarity patterns



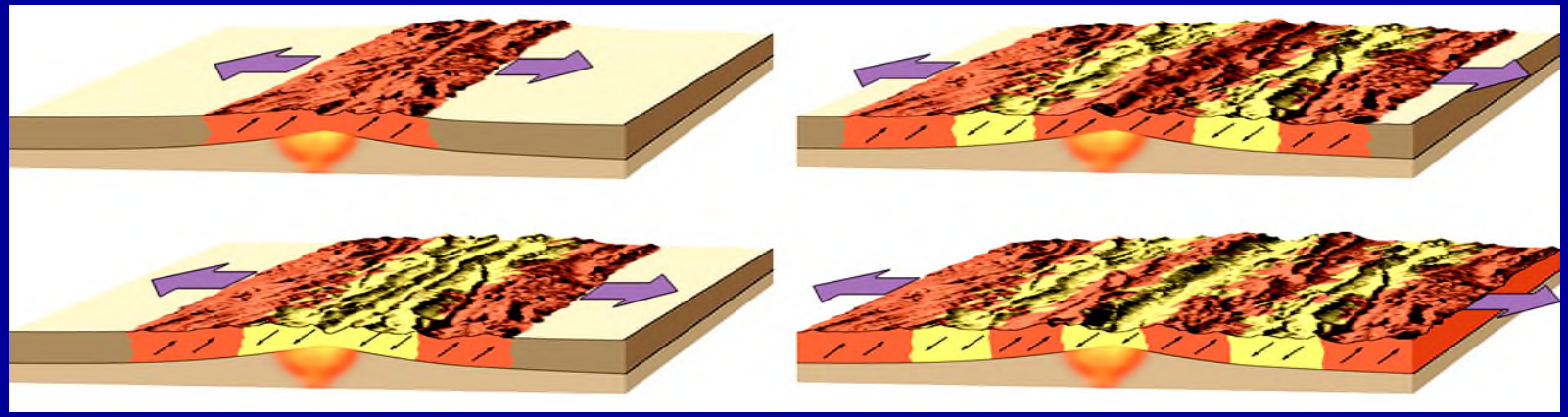
# Evidence for Seafloor Spreading

## Magnetic Polarity-Reversal Anomalies of Seafloor Rocks



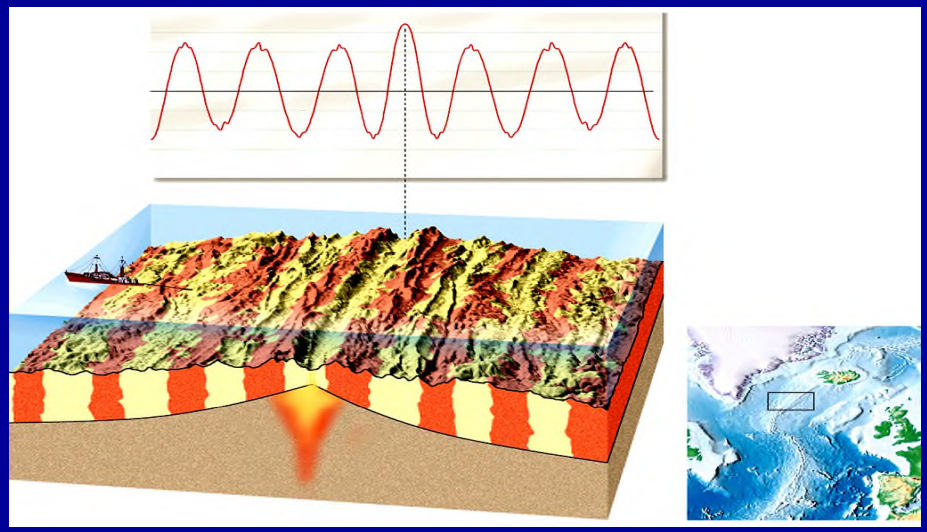


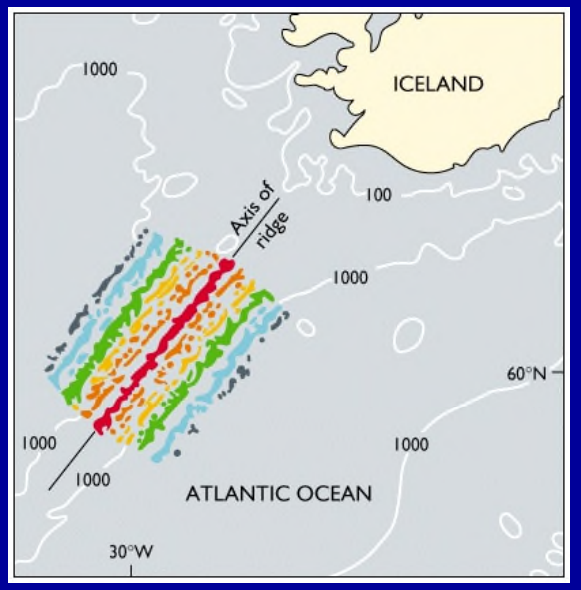

Example: North Atlantic



# Evidence for Seafloor Spreading

## Magnetic Polarity-Reversal Anomalies of Seafloor Rocks





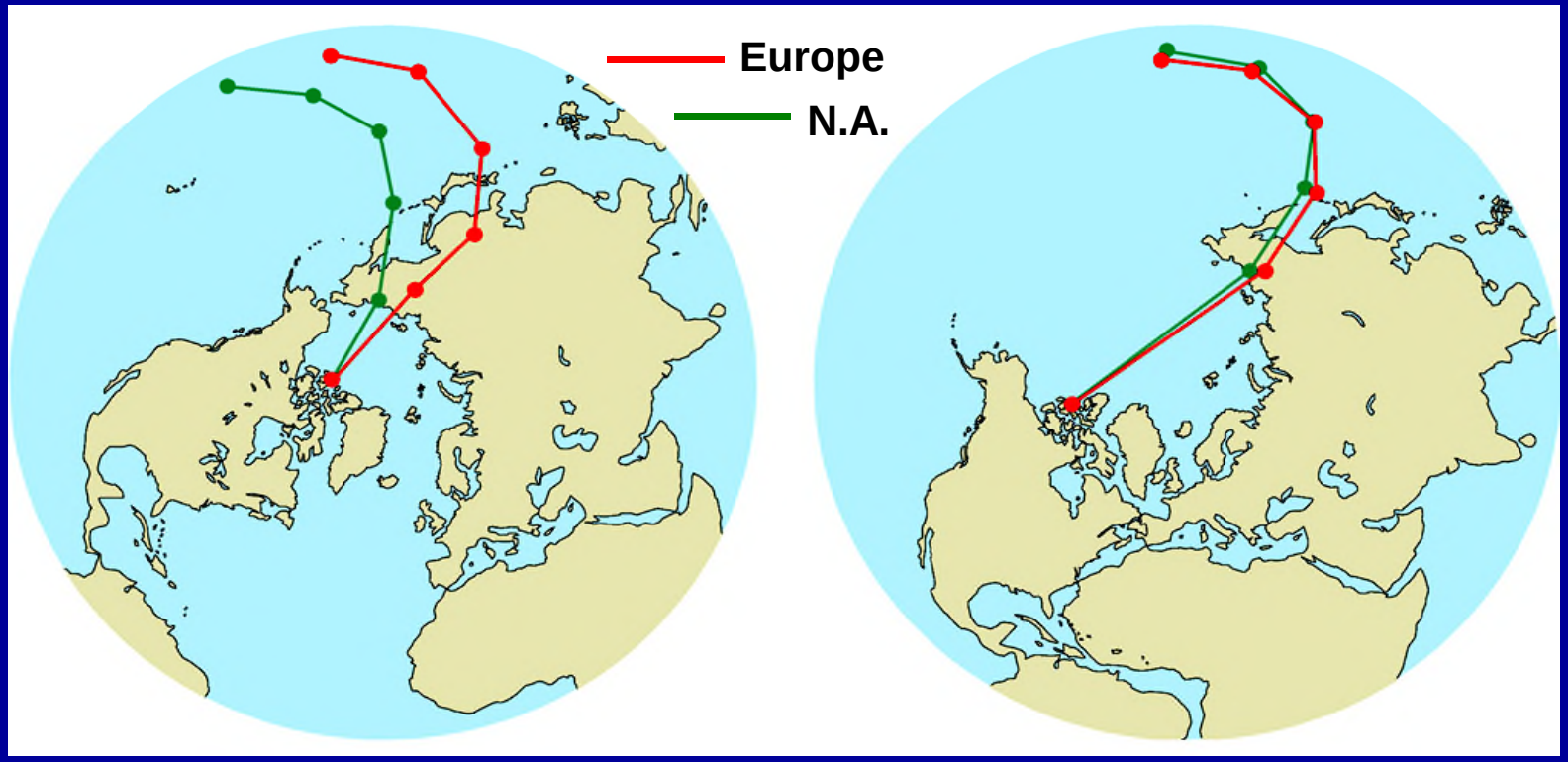

***Click this link for animation of magnetic polarity reversal process on seafloor***

# Evidence for Seafloor Spreading

## Fifth Line Of Evidence

### 5. Apparent Polar Wander Paths

- Each continent has a different polar wander path
- Best explained by progressive separation of continents

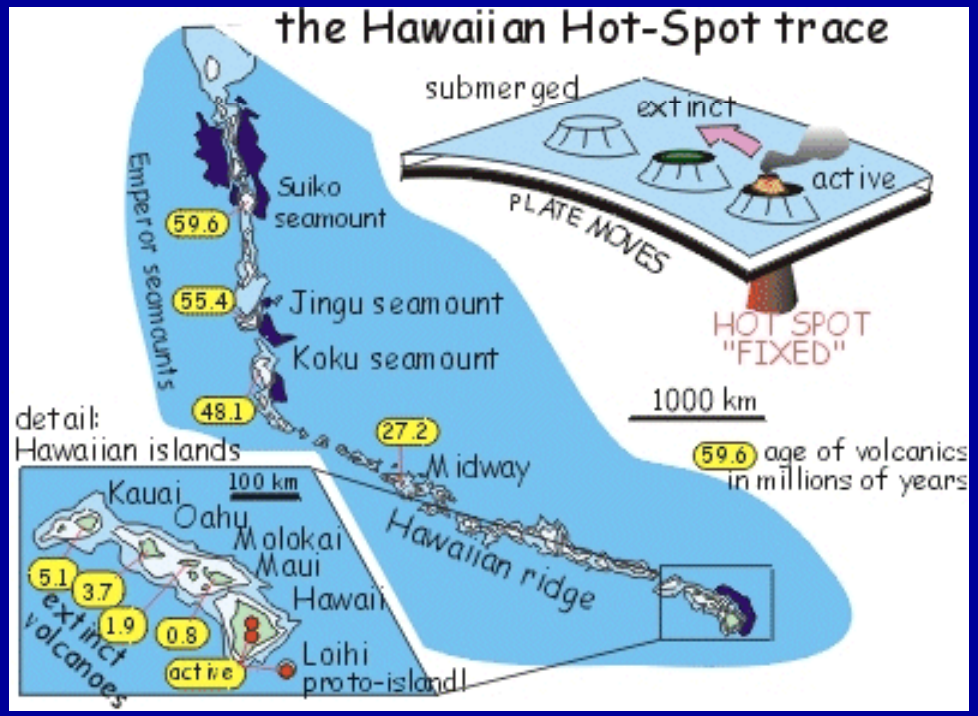


# Evidence for Seafloor Spreading

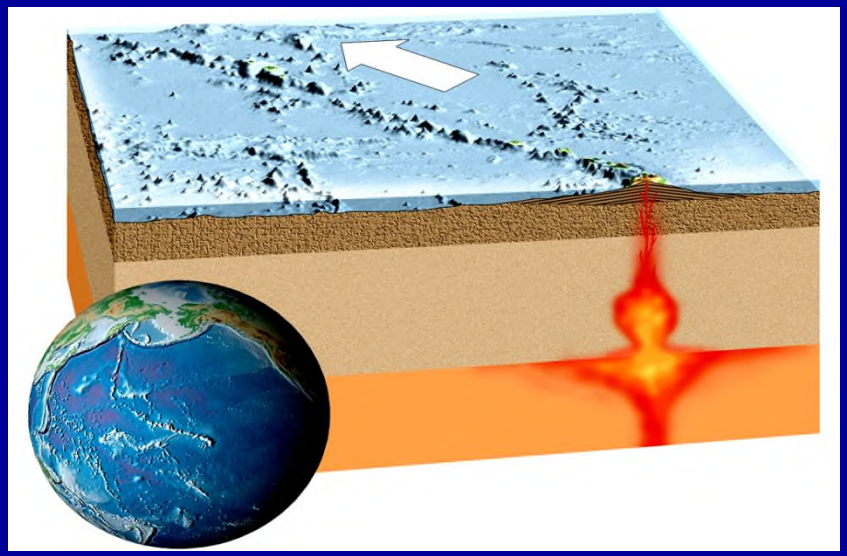
## Sixth Line Of Evidence

### 6. Hot Spot Traces

- Magma source is anchored in the relatively stationary mantle
- Motion of lithospheric plate over hot spot is away form ocean ridge




Hawaiian Hot Spot

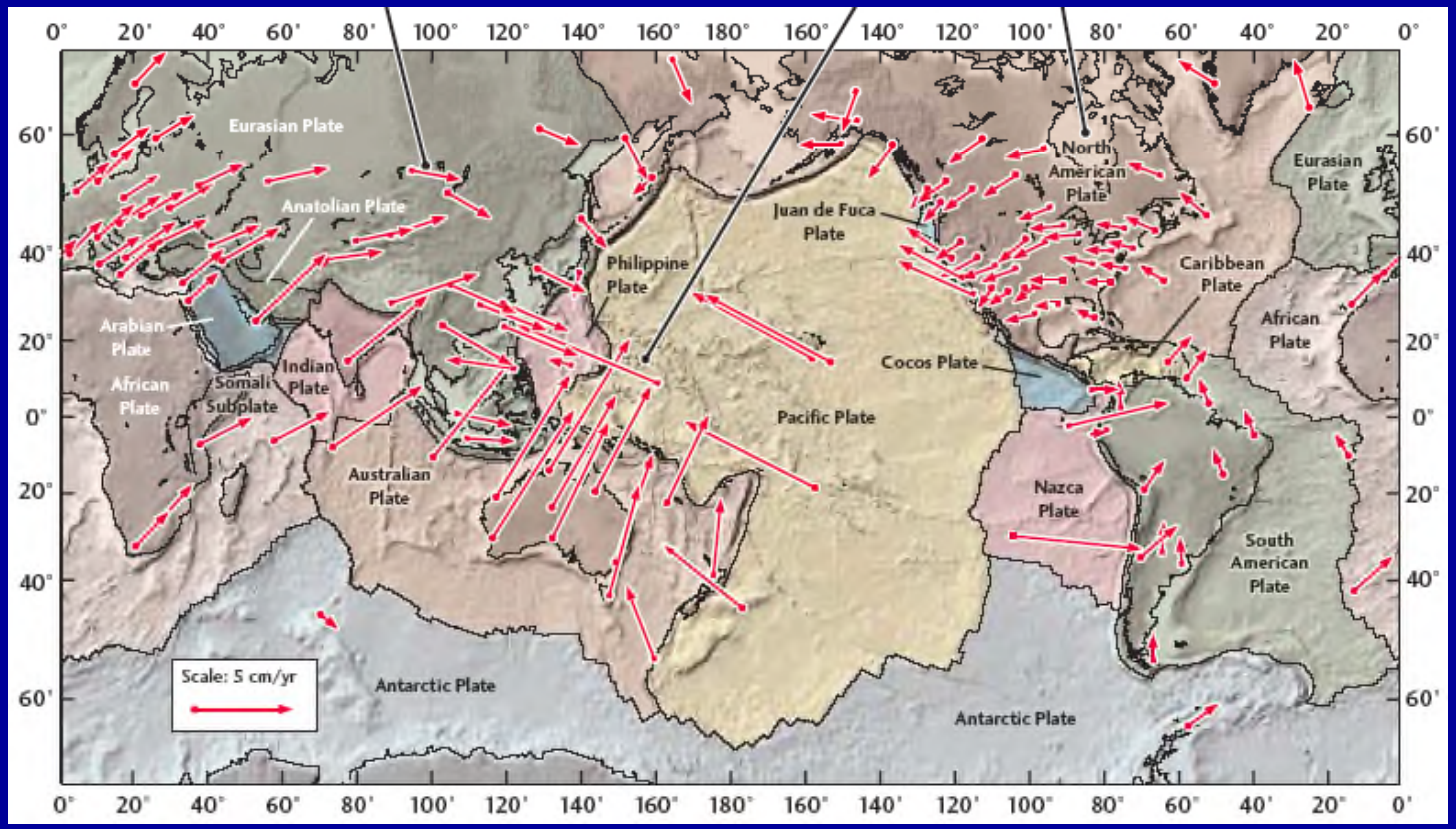


# Evidence for Seafloor Spreading

## Seventh Line Of Evidence

### 7. Geodesy Plate Velocity Measurements

- Measured divergent plate motion across mid-ocean ridges
- Motions are consistent and unique for each lithospheric plate



# Seafloor Spreading - Ocean Basin Growth

## Four Stages of Ocean Basin Growth

- Conception
- Embryonic
- Juvenile
- Mature

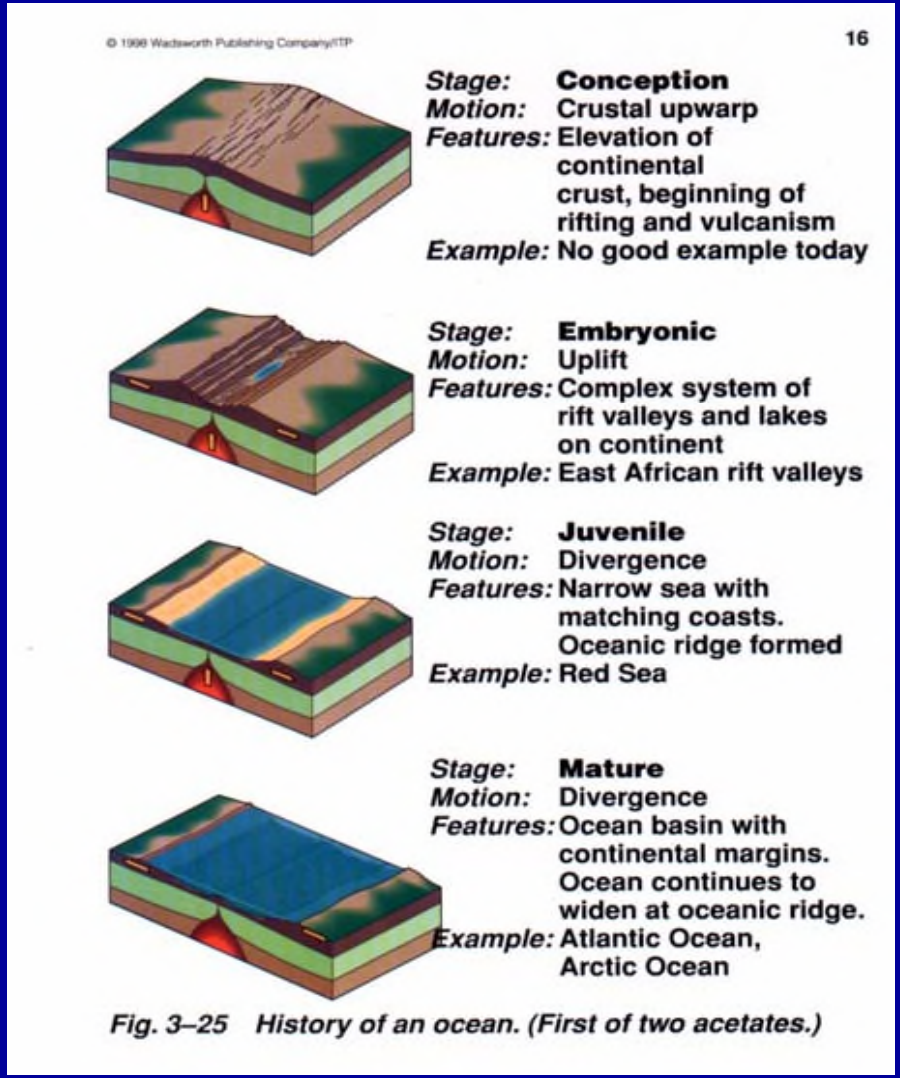
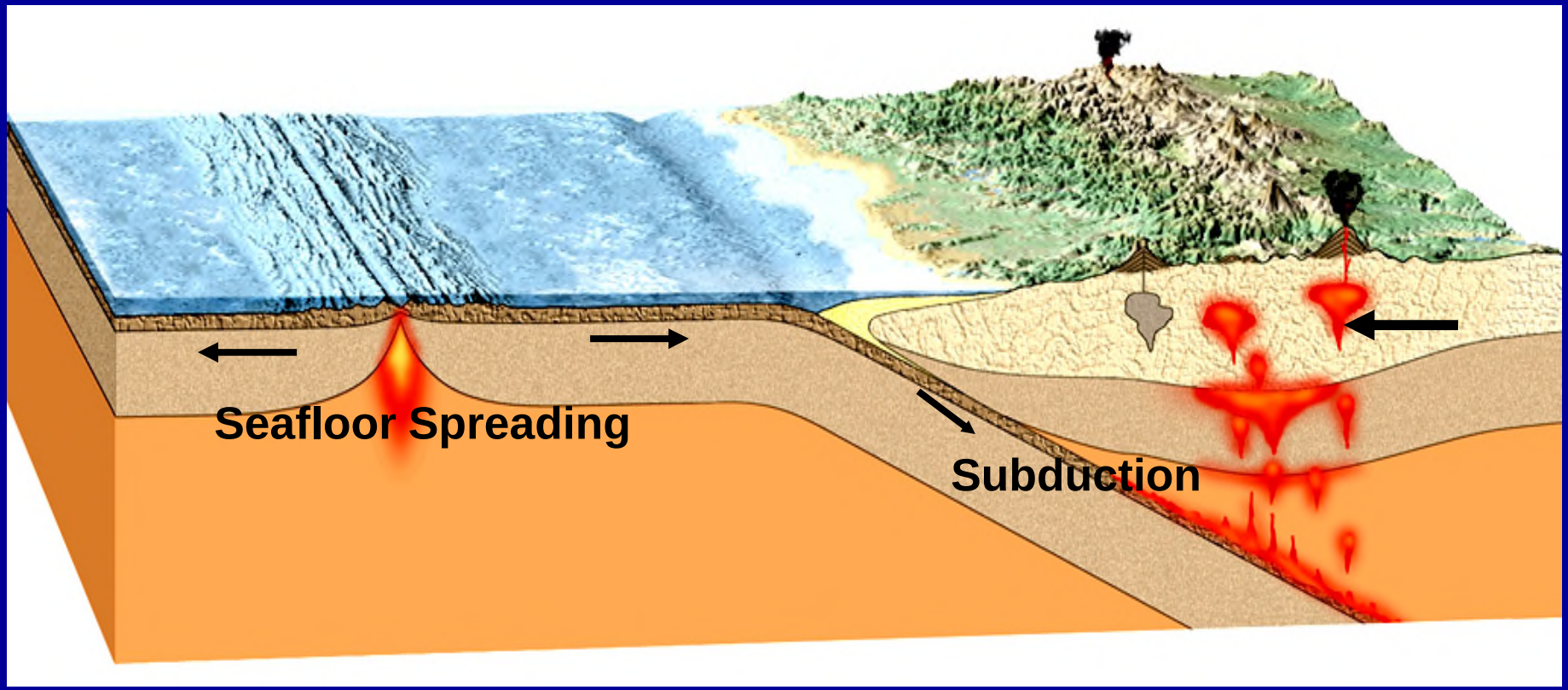


*Fig. 3–25 History of an ocean. (First of two acetates.)*

# Subduction vs. Seafloor Spreading

## Plate Tectonic Process that Mass Counter-Balances Seafloor Spreading



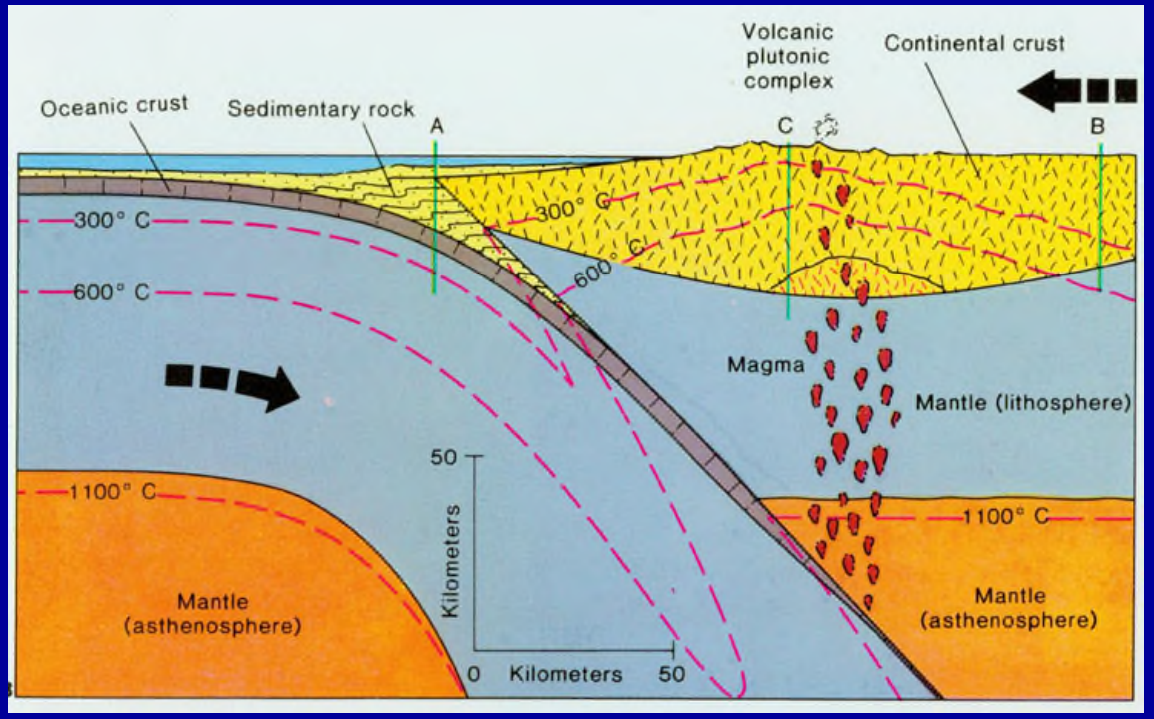

**“What Spreads Out Must Eventually Subduct Down”**

# Subduction

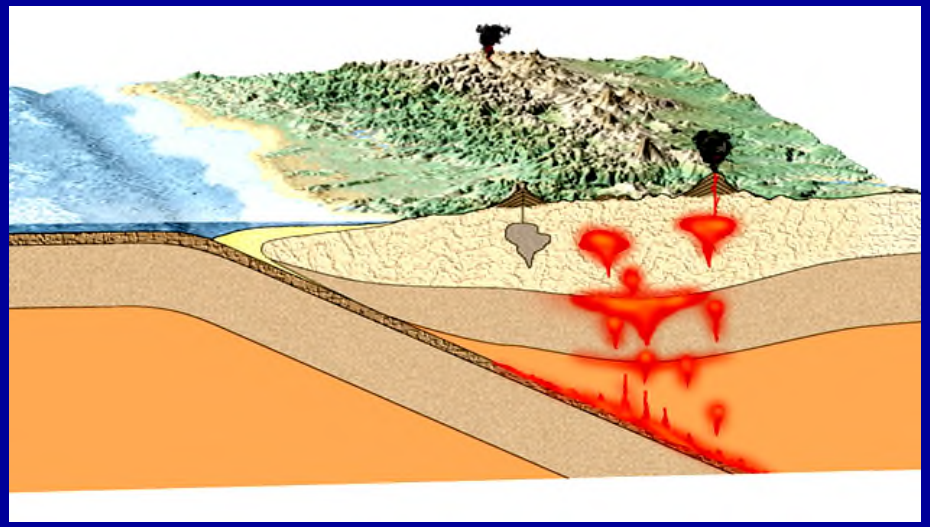
- Destroyer of Oceanic Lithosphere
- Builder of Continents

**Topics:**

- Main Concepts of Theory
- Convergent Boundaries
- Subduction Processes
- Lines of Evidence
- Ocean Basin Collapse
- Terrane Accretion



# Subduction Theory



## Main Ideas:

**1)** Process of destroying old oceanic lithosphere by sinking down into the mantle at convergent plate boundaries

**2)** Subduction zones are marked by a paired trench-volcanic arc system

**3)** Andesite-dominated volcanic arc magmas are generated by dehydration melting of subducted slab and mantle wedge beneath the volcanic arc

**4)** Highly explosive volcanic arc eruptions due to high silica and $H_2O$ content

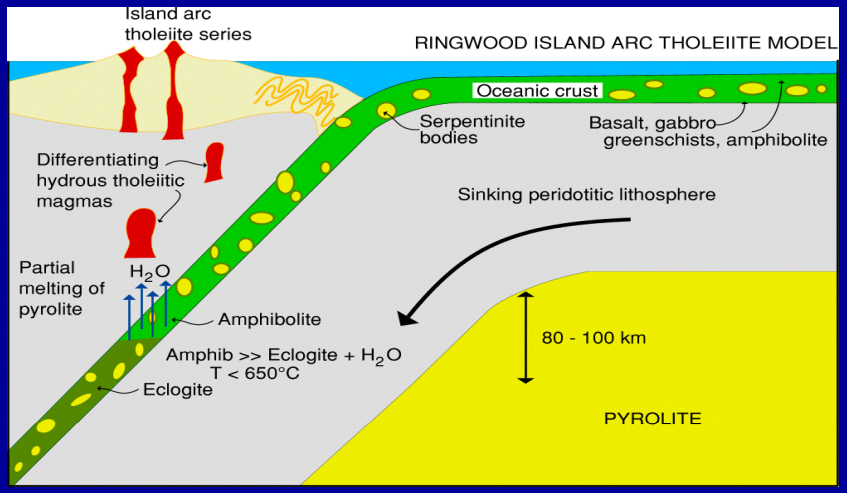
**5)** Subduction causes ocean basins to collapse

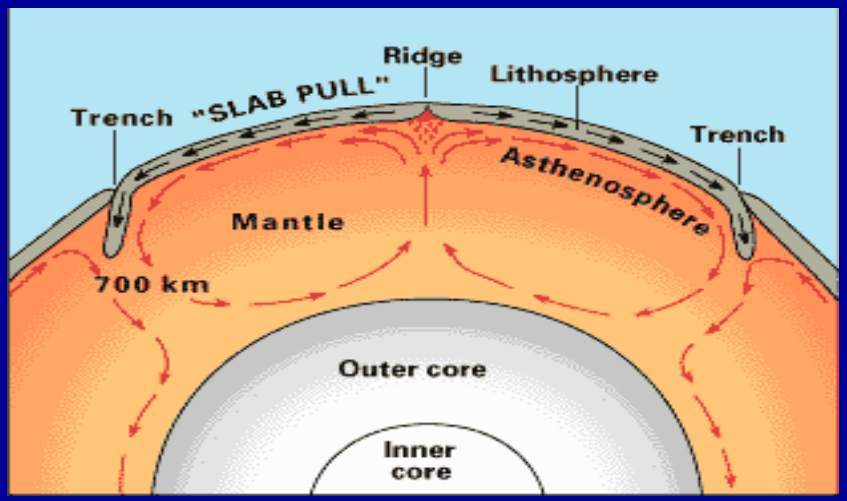
**6)** Subduction initiates the accretion of exotic terranes

**7)** Subduction is the site of building new continental crust

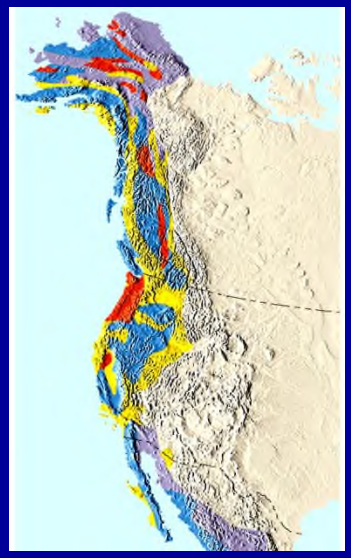
# Subduction Theory

## Subduction Processes



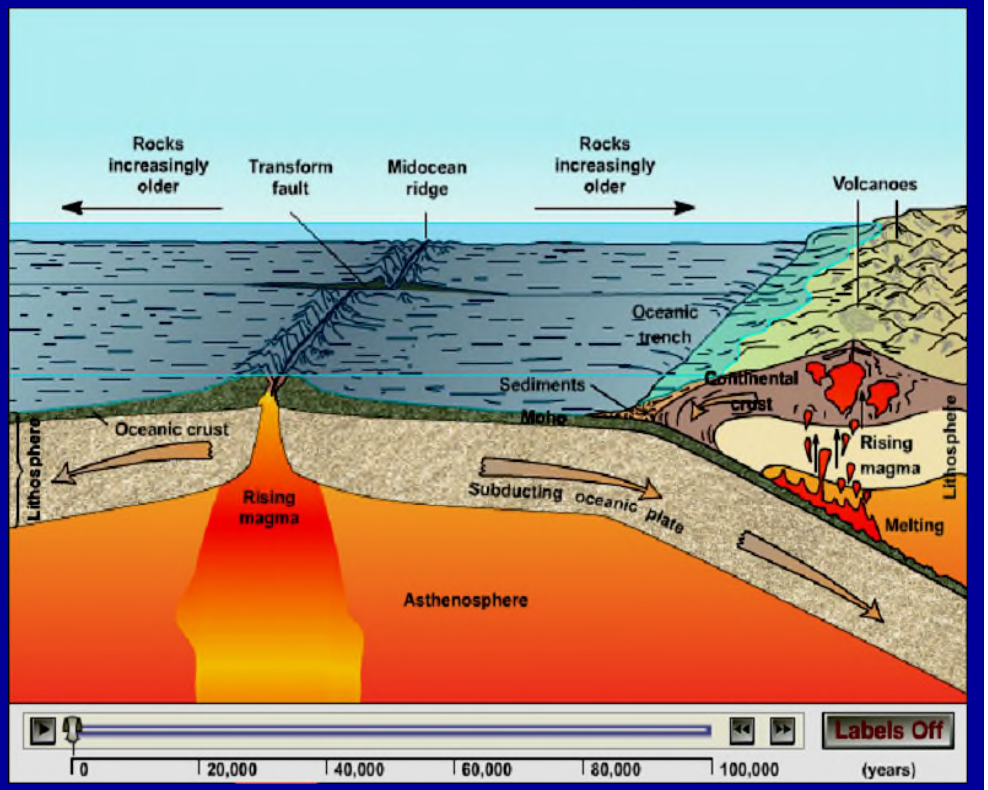

- Descending Mantle Convection
- De-watering Induced Melting
- Compressional Crustal Tectonics
- Andesitic Arc Magmatism
- Exotic terrane accretion



# Subduction Animation

## Key Features:

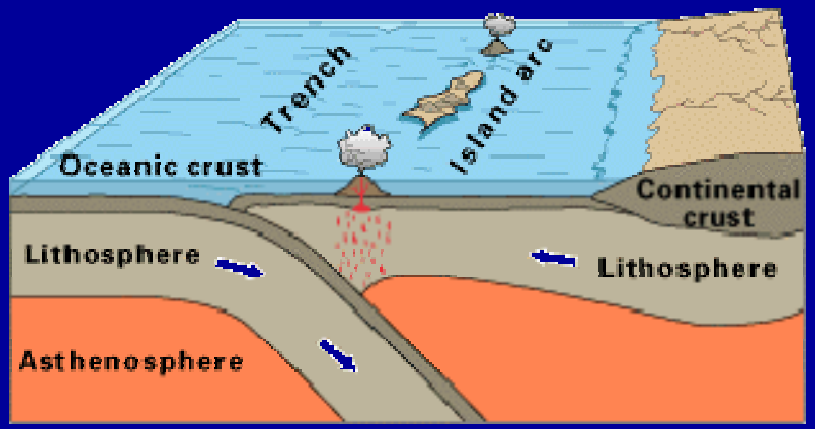
1) The illustration shows progressive destruction of oceanic lithosphere at trench by subduction process.
2) Andesite-dominated magmas originate by water-fluxed melting of both dehydrating slab and mantle wedge in subduction zone.
3) Magmas are rich in silica and water and produce infrequent, massive, and violent volcanic eruptions
4) Buoyant crustal terranes attached to downgoing oceanic slabs will become accreted onto the leading edge of the overriding plate.



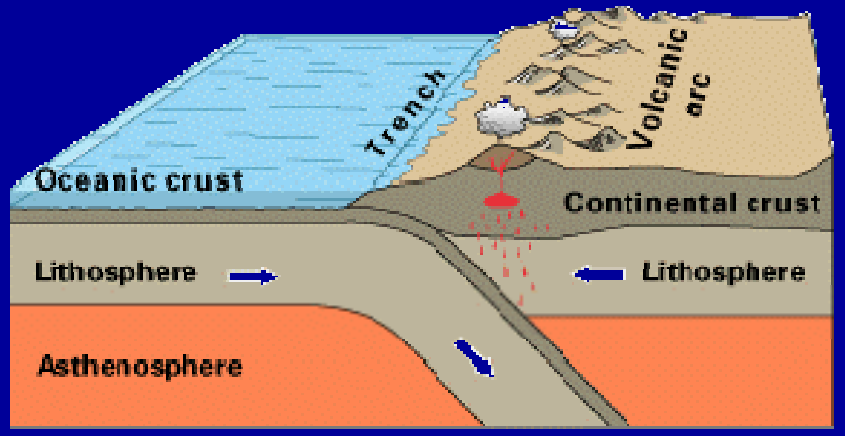

***Animation Link***

# Types of Subduction Systems

- Two General Types of Subduction Systems
  - Oceanic-Oceanic
  - Oceanic-Continental



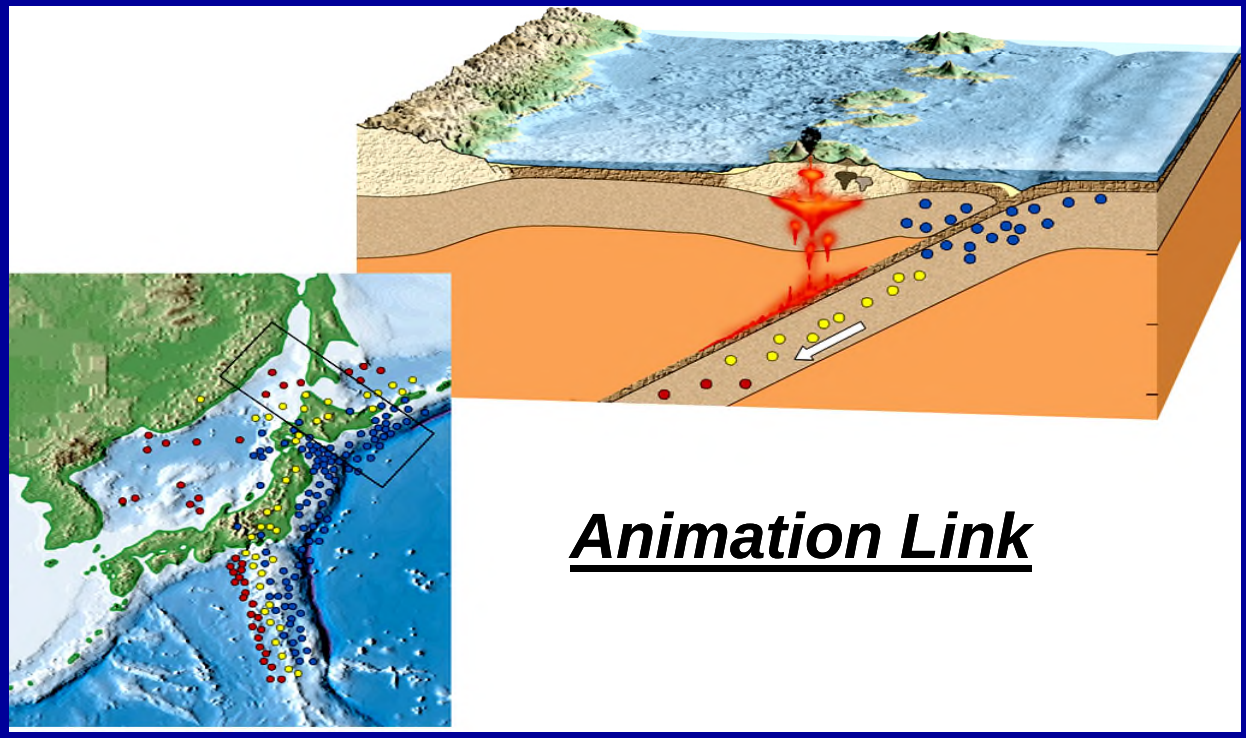

Oceanic-oceanic convergence




Oceanic-continental convergence

# Ocean-Ocean Subduction Systems

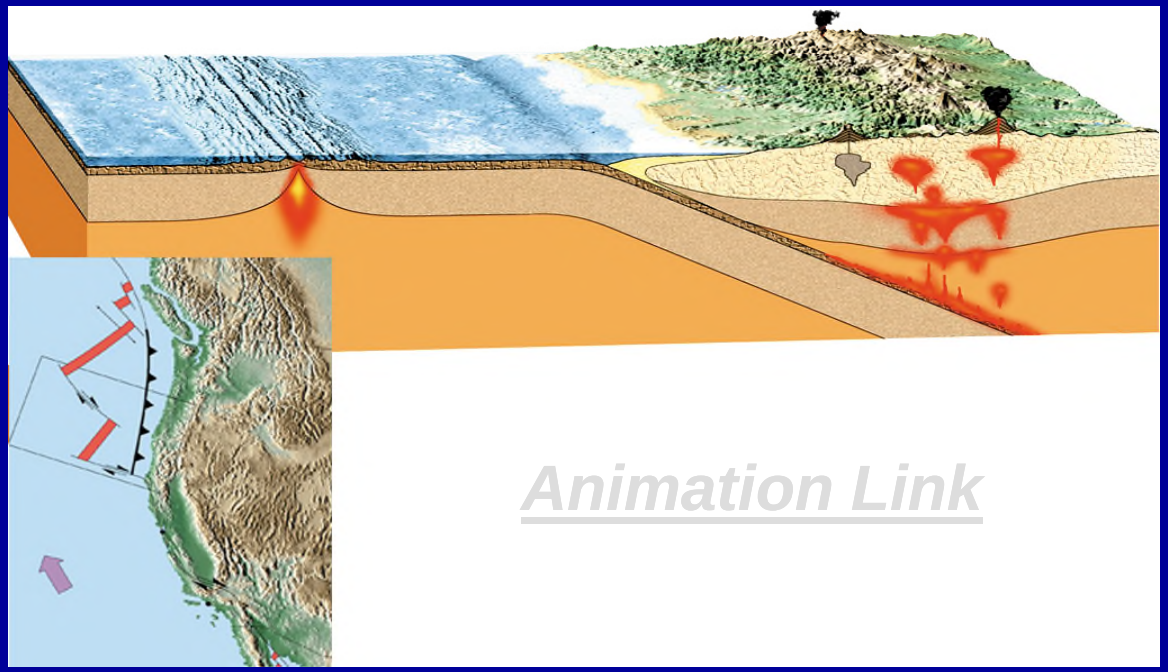
- Example of Oceanic-Oceanic Subduction – Island of Japan
  - **Pacific plate subducts beneath Eurasian plate near Japan**
  - **Subduction marked by oceanic trench and volcanic island arc**
  - **Depth profile of earthquakes marks plane of subduction**
  - **Growth of Japanese Islands is due to subduction-related magmatism**



***Animation Link***

# Ocean-Continental Subduction Systems

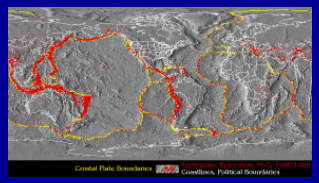
- Example of Oceanic-Continental Subduction - Cascades
  - Juan de Fuca plate subducts beneath North American continent
  - Subduction marked by oceanic trench and continental margin arc
  - Depth profile of earthquakes marks plane of subduction
  - Growth of Cascade Range is due to subduction-related magmatism



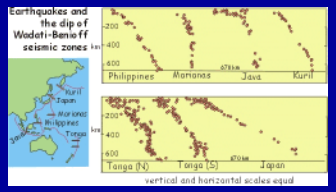
# Evidence for Subduction

## Lines Of Evidence

1. Ocean basin physiology and tectonism

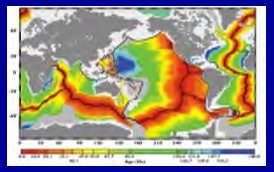


2. Wadati-Benioff Zones




3. Magnetic polarity-reversal anomalies

4. Ocean floor age profiles



5. Geodesy plate velocity measurements

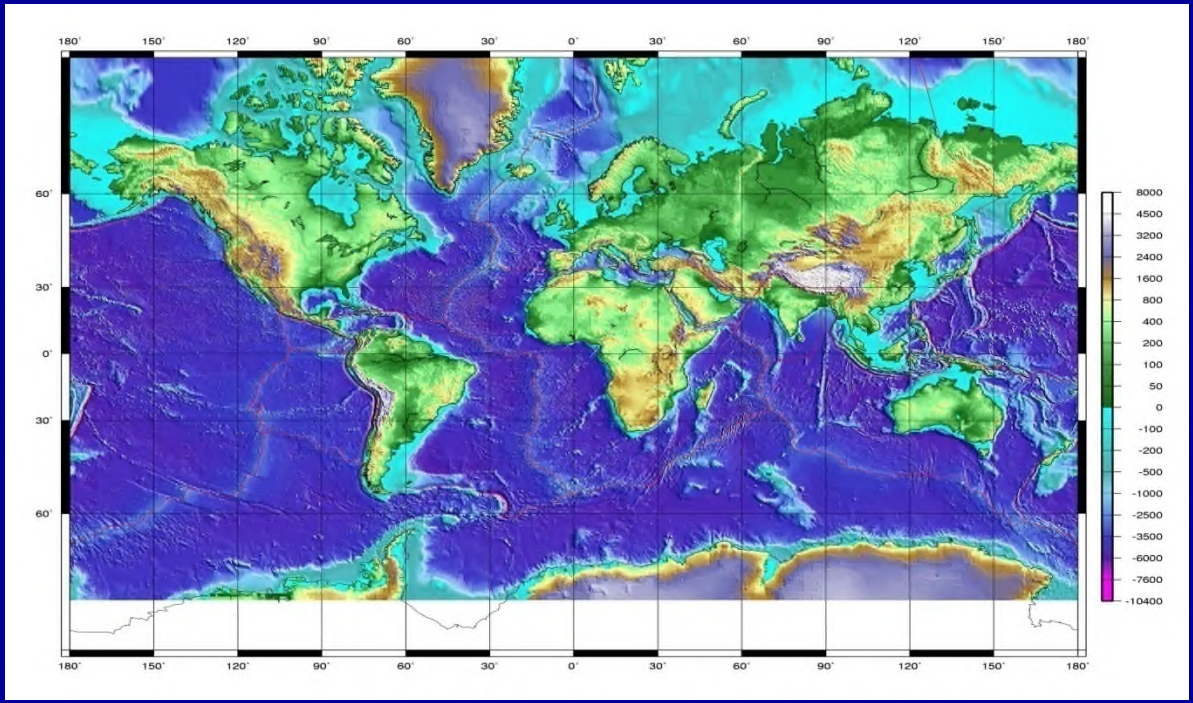
6. “Ring of Fire” arc volcanism

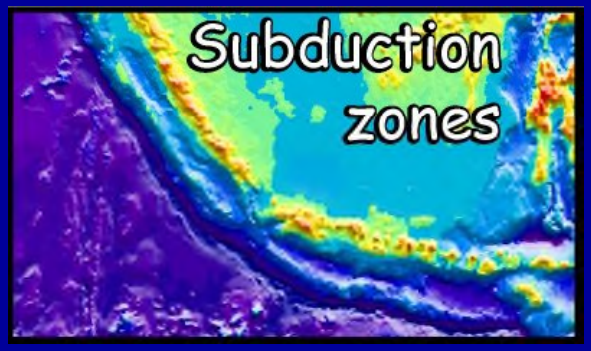
# Evidence for Subduction

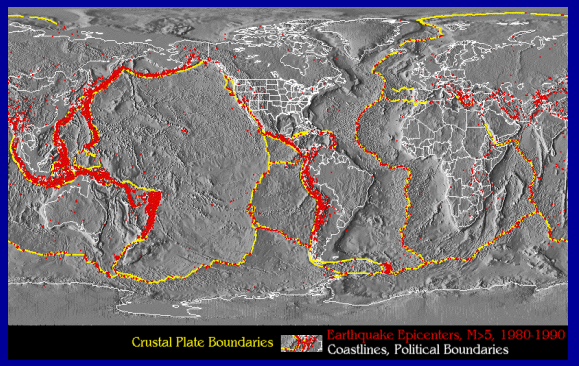
## First Line Of Evidence

### 1. Geographic Features and Tectonic Activity

- Paired active trench-volcanic arc systems
- Associated earthquakes and active volcanisms



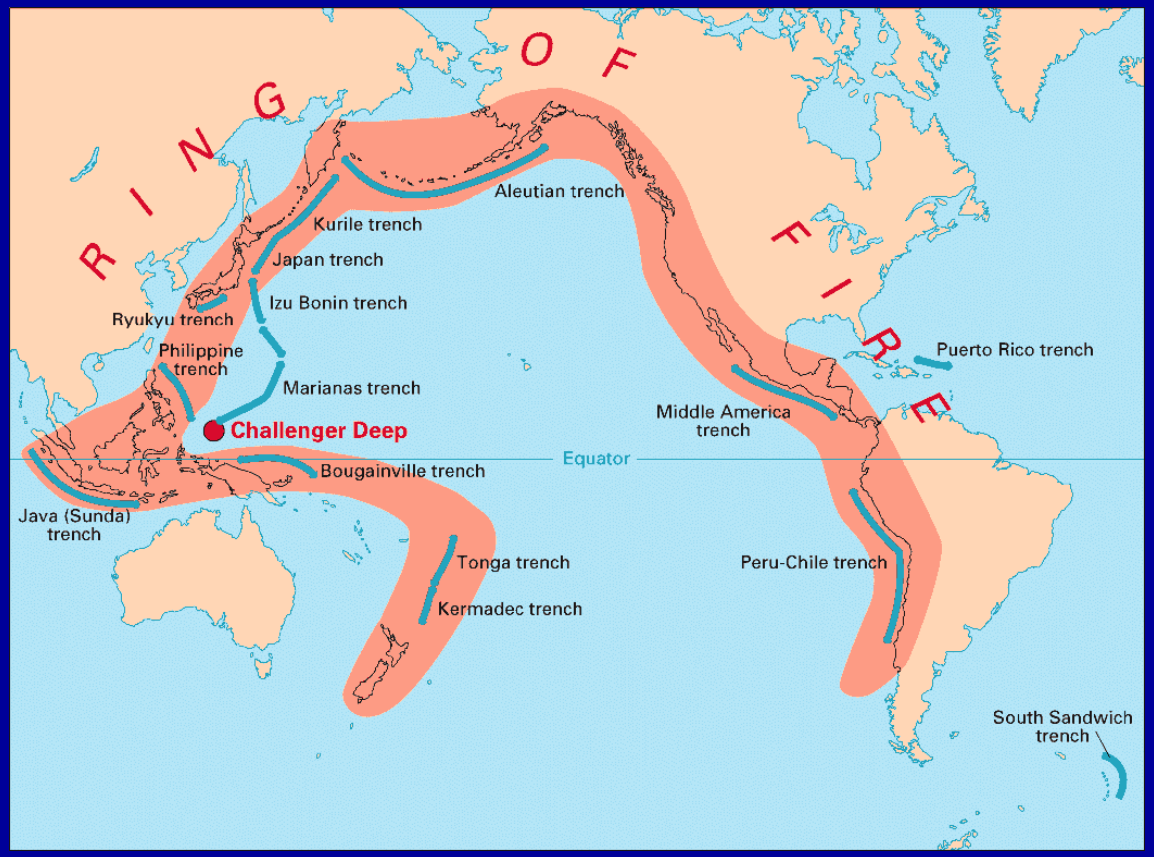



# Evidence for Subduction

## *The Pacific Ring of Fire –*

### *Paired Trench-Volcanic Arc Systems*

- Paired Trench-Active Volcanic Arc Systems mark the location of convergent plate boundaries and subduction zones
- Trenches occur where oceanic lithosphere plunges into the mantle
- The Subduction process destroys oceanic lithosphere, generates new continental crust, and initiates terrane accretion

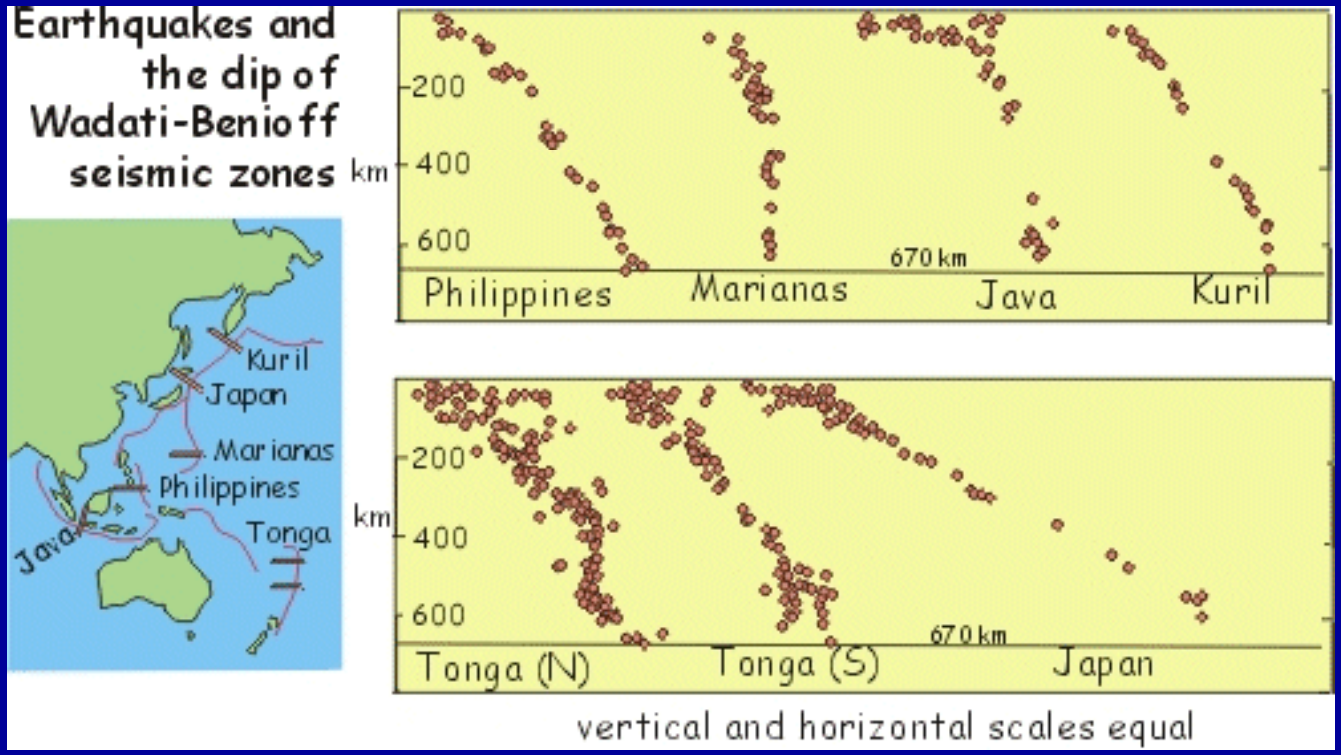


# Evidence for Subduction

## Second Line Of Evidence

### 2. Wadati-Benioff Seismic Zones

- Planar dipping zones of earthquake foci beneath active volcanic arcs
- Fault motions indicate bottom plate thrusts beneath top plate

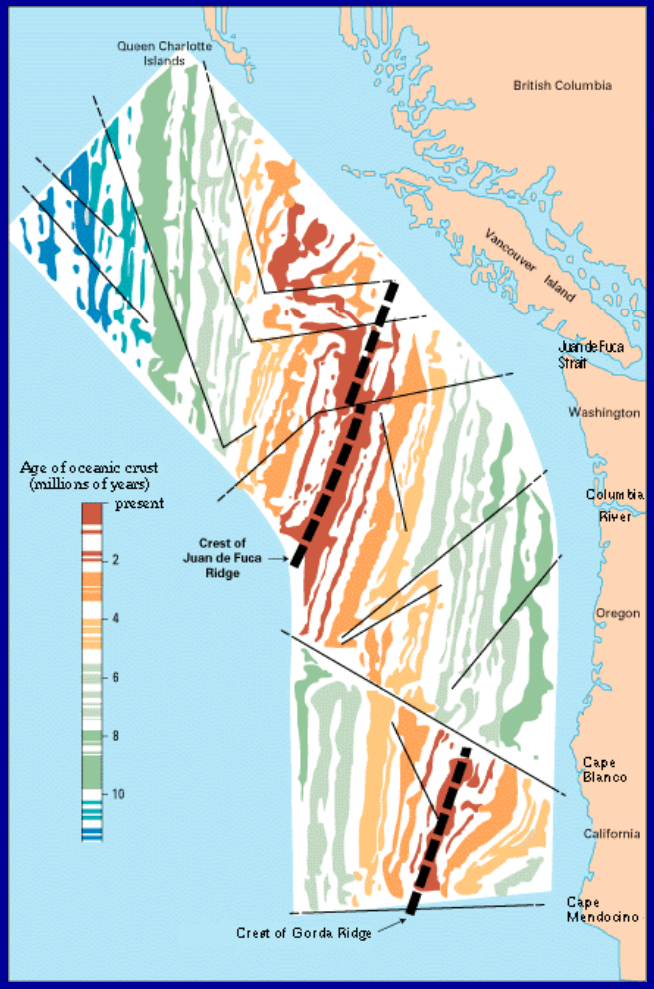


# Evidence for Subduction

## Third Line Of Evidence

### 3. Seafloor Magnetic Anomaly Patterns

- Magnetic stripe pattern truncated at trenches
- Unaccounted for missing seafloor near edges of continents and island arcs
- Northeastern Pacific seafloor good example
- Asymmetrical pattern at Juan de Fuca Ridge

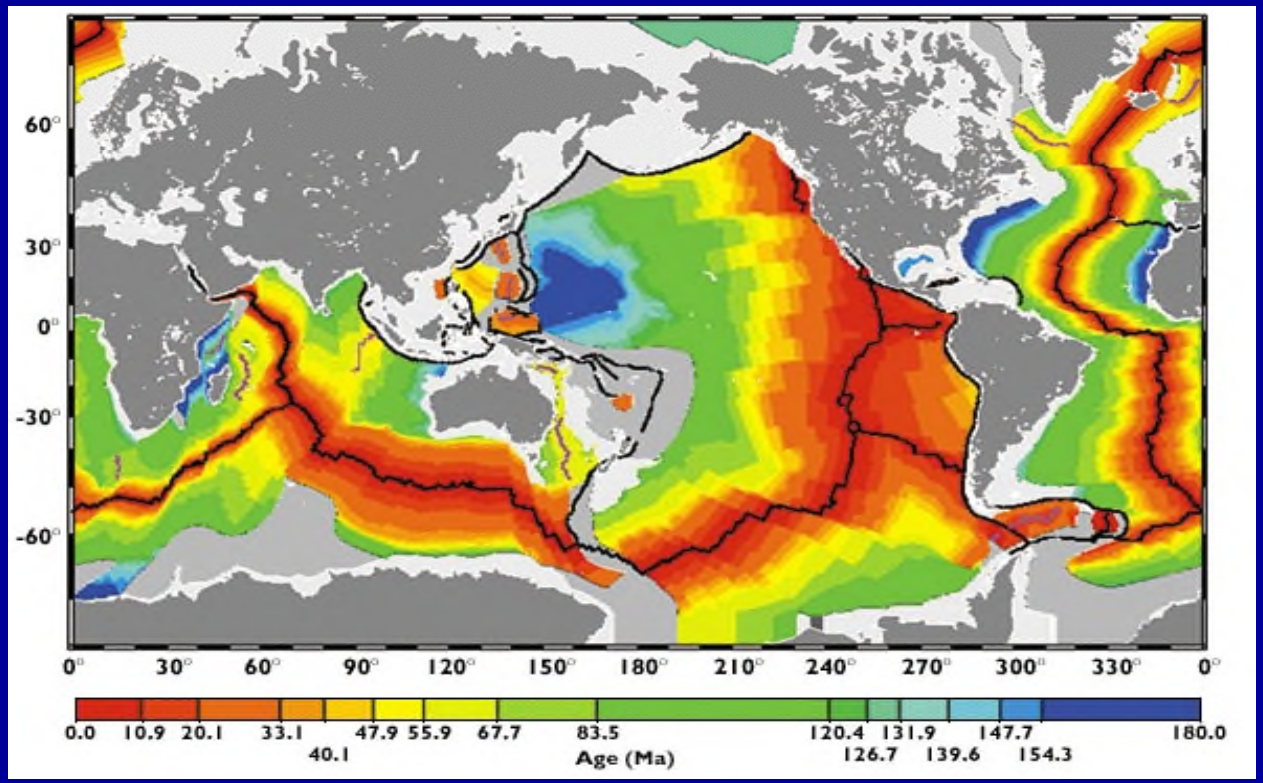


# Evidence for Subduction

## Fourth Line Of Evidence

### 4. Seafloor Age Profiles

- Truncation of age profile next to trenches
- Similar truncation not seen along passive margins

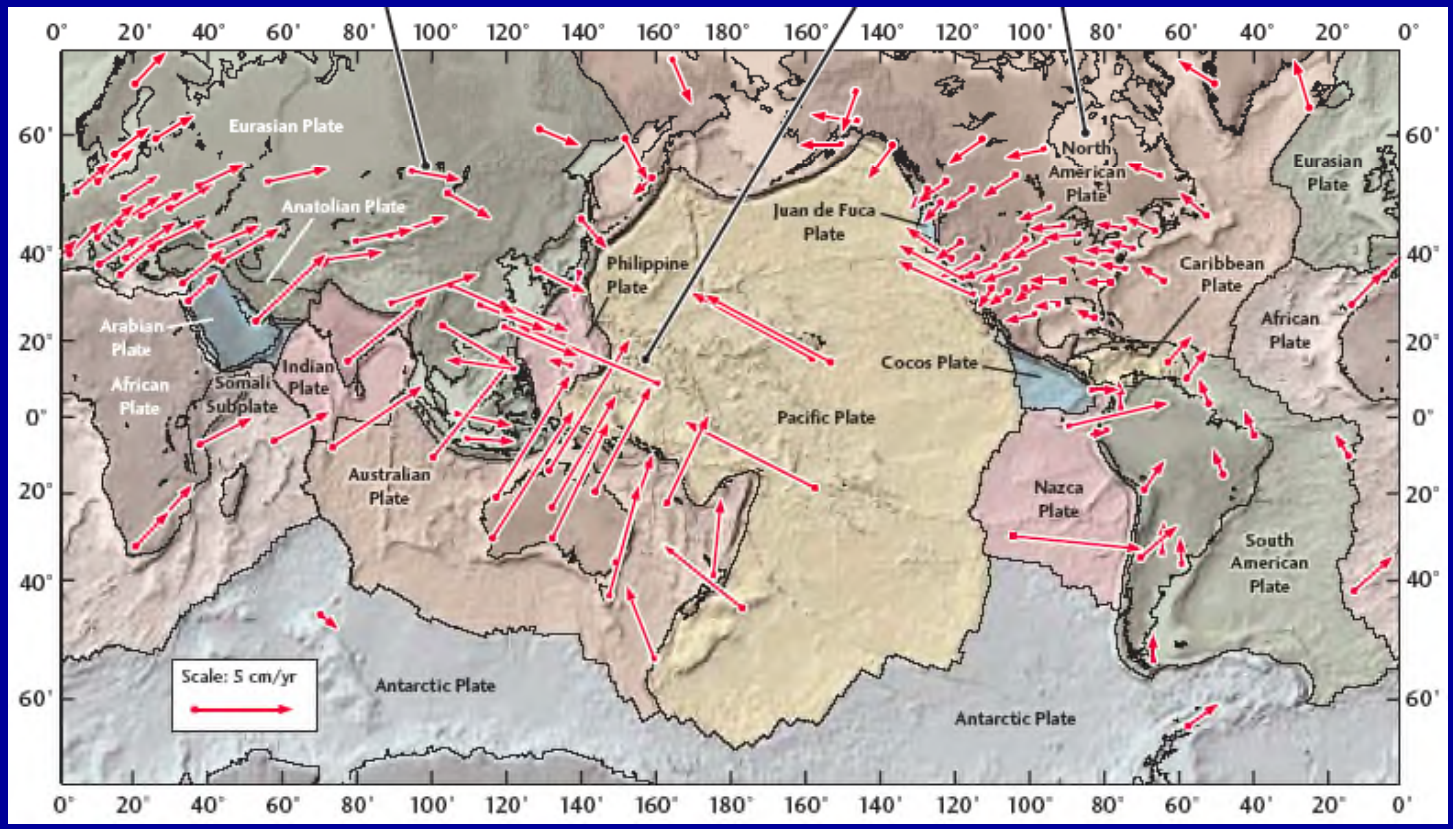


# Evidence for Subduction

## Fifth Line Of Evidence

### 5. Geodesy Plate Velocity Measurements

- Measured convergent plate motion across trench-arc systems
- Motions are consistent and unique for each convergent boundary

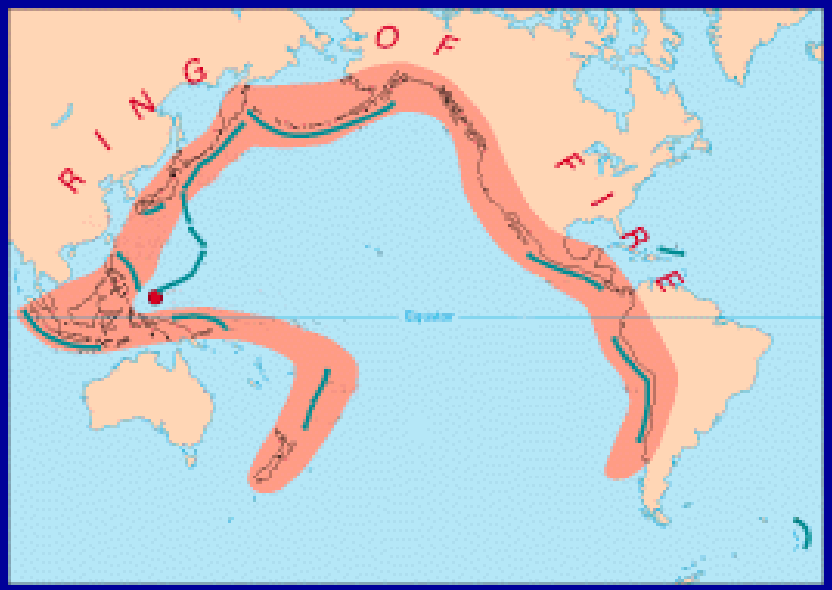


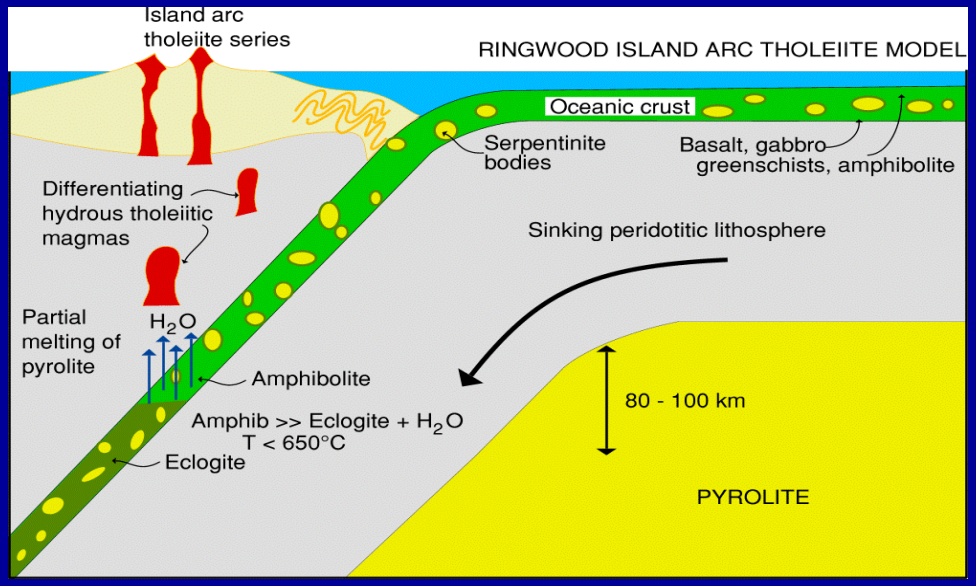
# Evidence for Subduction

## Sixth Line Of Evidence

### 6. Ring of Fire Volcanism

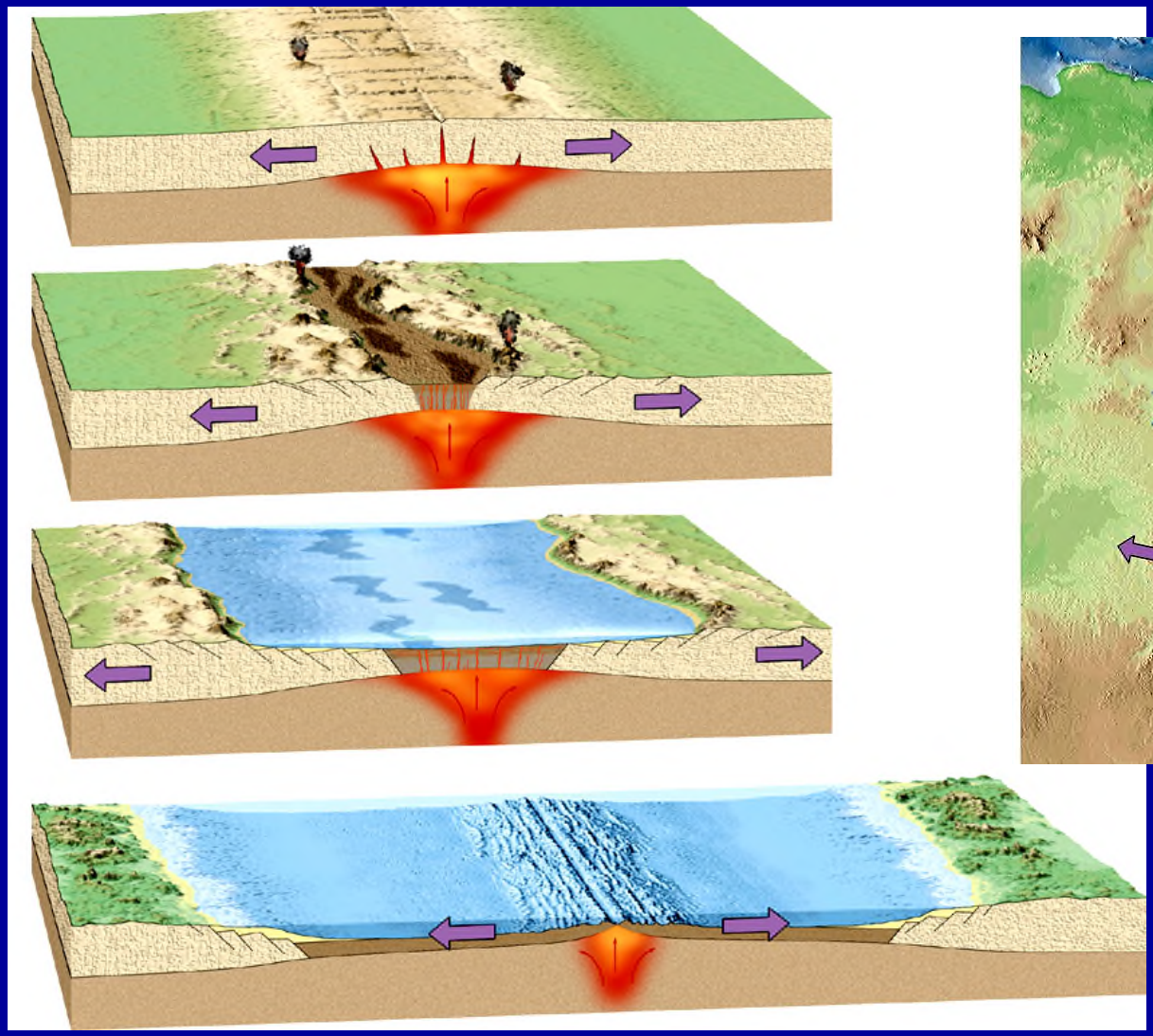
- Island and continental margin arc magmatism
- Wet, silica-rich magmas
- Isotope data indicates a seawater component

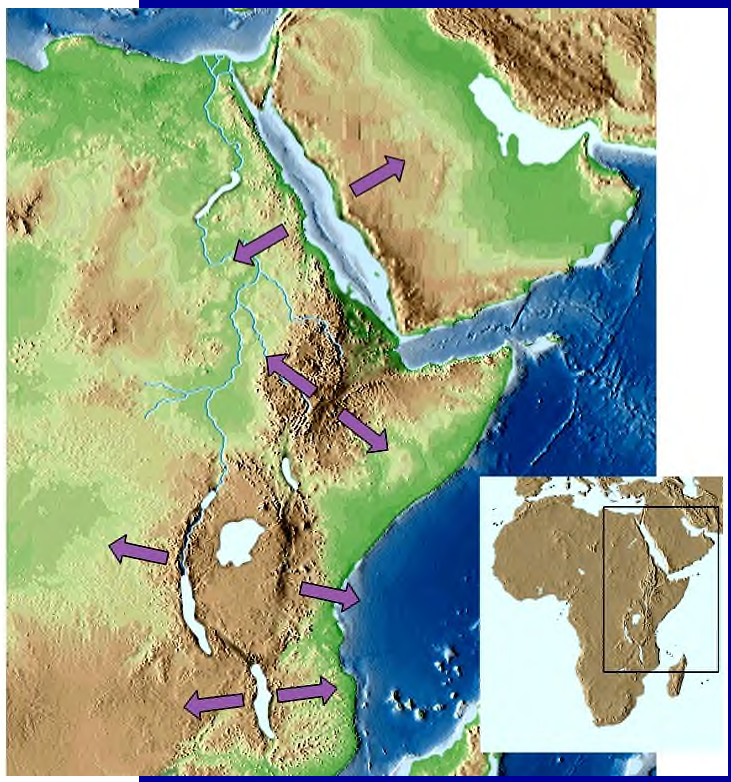


# Continental Rifting & Ocean Basin Development

## Progression from Continental Rifting to Seafloor Spreading

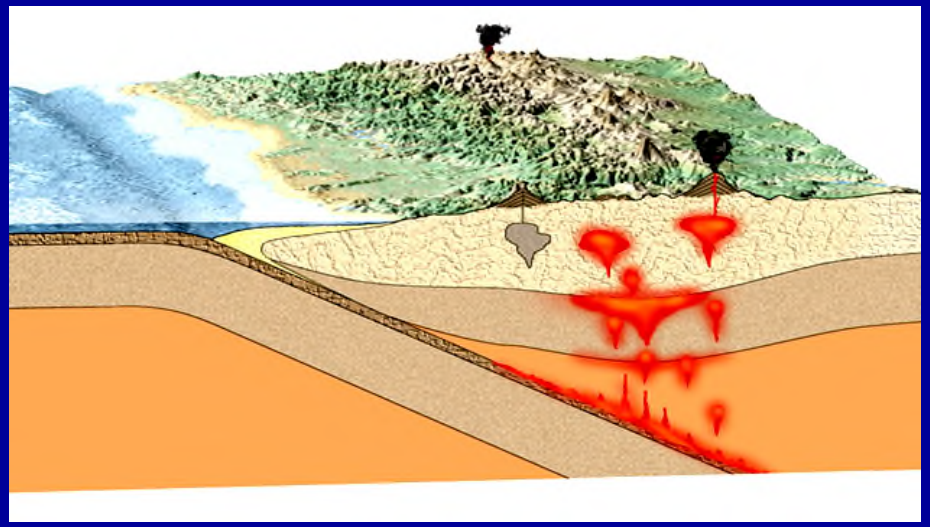




East Africa and Arabia

# Subduction Process

## Main Ideas:



**1)** Process of destroying old oceanic lithosphere by sinking down into the mantle at convergent plate boundaries

**2)** Subduction zones are marked by a paired trench-volcanic arc system

**3)** Andesite-dominated volcanic arc magmas are generated by dehydration melting of subducted slab and mantle wedge beneath the volcanic arc

**4)** Highly explosive volcanic arc eruptions due to high silica and $H_2O$ content

**5)** Subduction causes ocean basins to collapse

**6)** Subduction initiates the accretion of exotic terranes

**7)** Subduction is the site of building new continental crust

# Subduction and Ocean Basin Collapse

## Three Stages of Ocean Basin Collapse

1) **Declining = Basin shrinkage**

2) **Terminal = MOR subducted**

3) **Suturing = Continental collision and extinguished subduction**

The ***climax*** of an ocean basin collapse is the formation of a tall, extensive "fold and thrust" mountain chain, much like the Himalayas of today, along with the extinction of the subduction system (loss of active volcanism).

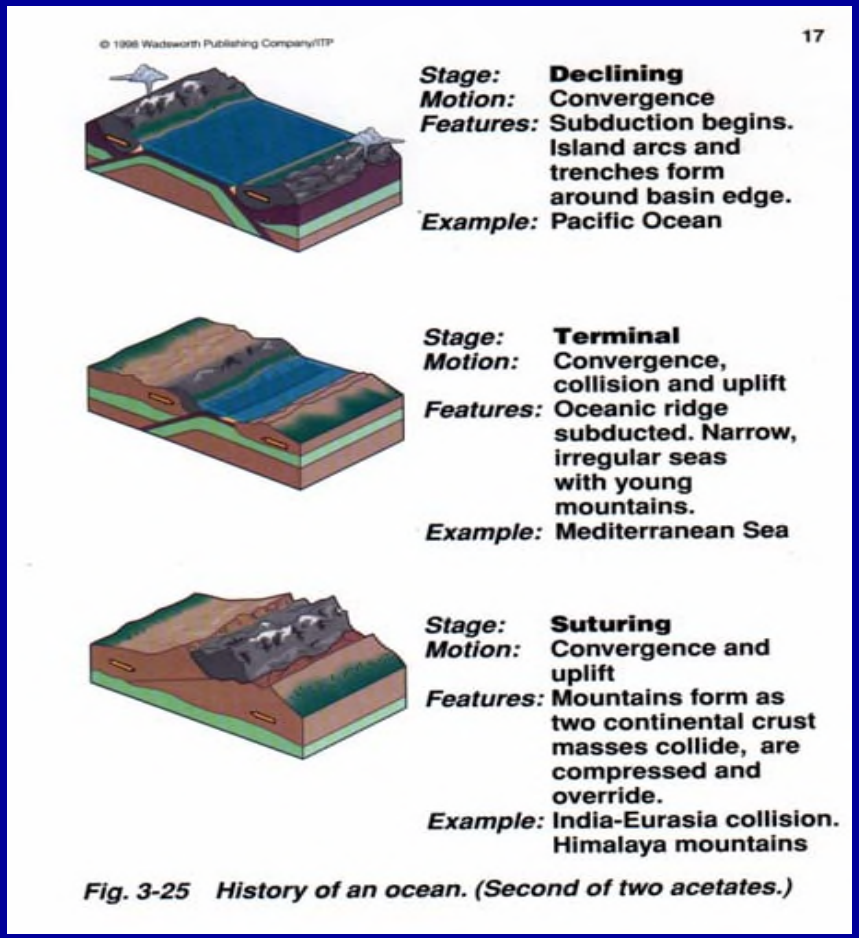


*Fig. 3-25 History of an ocean. (Second of two acetates.)*

# Ocean Basin Collapse

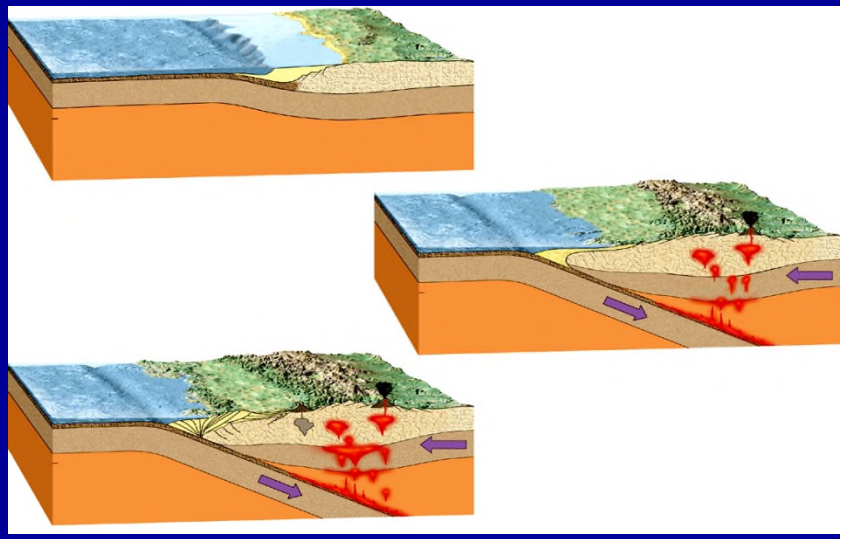
## Progression from Mature Ocean Basin to Continental Collision

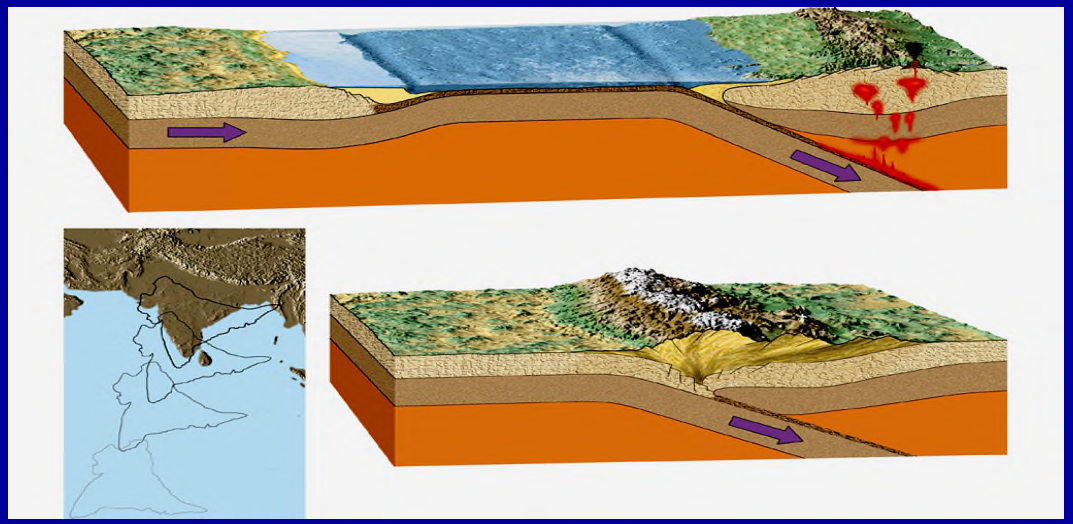
1) Initiation of subduction at passive margin

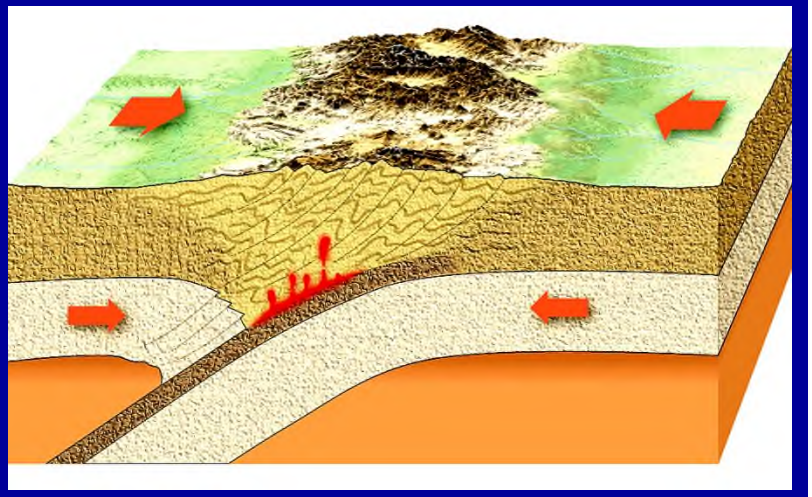
2) Progressive development of volcanic arc and accretionary wedge complex

3) Progressive collapse of ocean basin punctuated by exotic terrane accretion events

5) Total collapse of ocean basin climaxed by continental collision event







# Ocean Collapse and Terrane Accretion

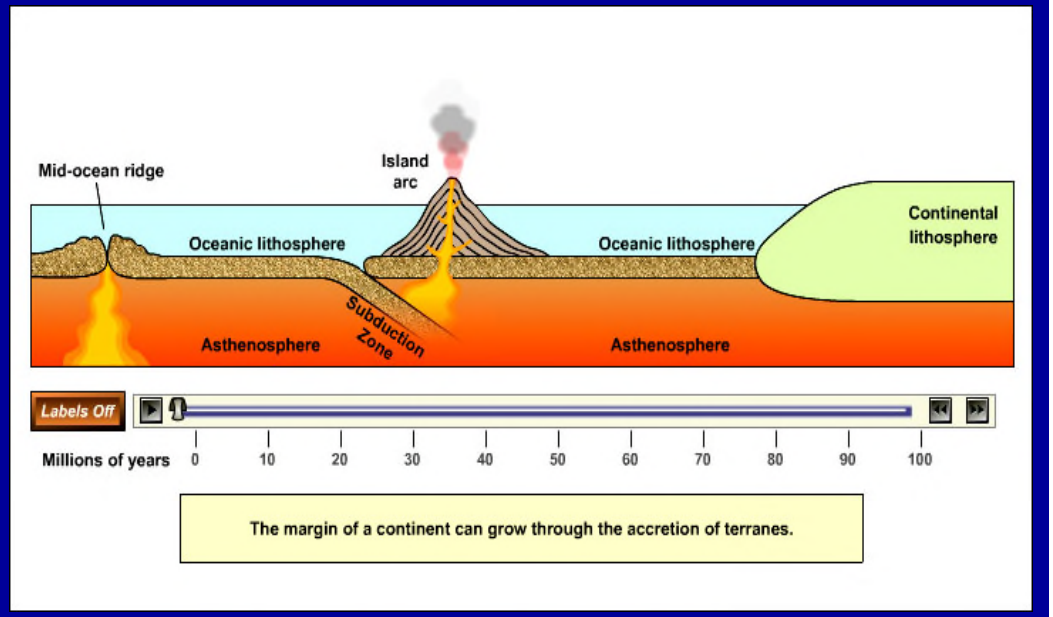
1) The animation shows two things:

   a) Progressive destruction of oceanic seafloor due to subduction, and

   b) Accretion of terranes such as island arcs and seamounts onto the edge of a continent at a convergent boundary

2) Terranes become accreted due to their buoyancy, and resist going down a subduction zone.

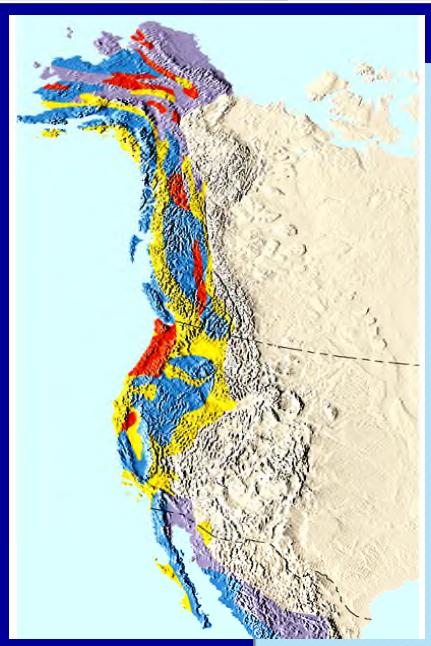
3) In many cases, an accretion event will chock a subduction zone, causing subduction to cease, or to jump to another location in the ocean.




***Click This Link To Start Animation of Terrane Accretion***

# Accreted Terranes of Western North America

- Western North America is a mosaic of numerous accreted terranes
- The accretion of these terranes has occurred over the last 200 million years
- Most of California is made up of exotic accreted terranes



# Continental Collision

**Himalayan Mountains**

1) Continental collision is a process that collides and joins two continental plates into one larger plate at a convergent plate boundary

2) Massive folded and thrust-faulted mountain belts form as the result of continental collision

3) Animation shows the collision of India with the Asian plate with the result of the Himalayan Mountains

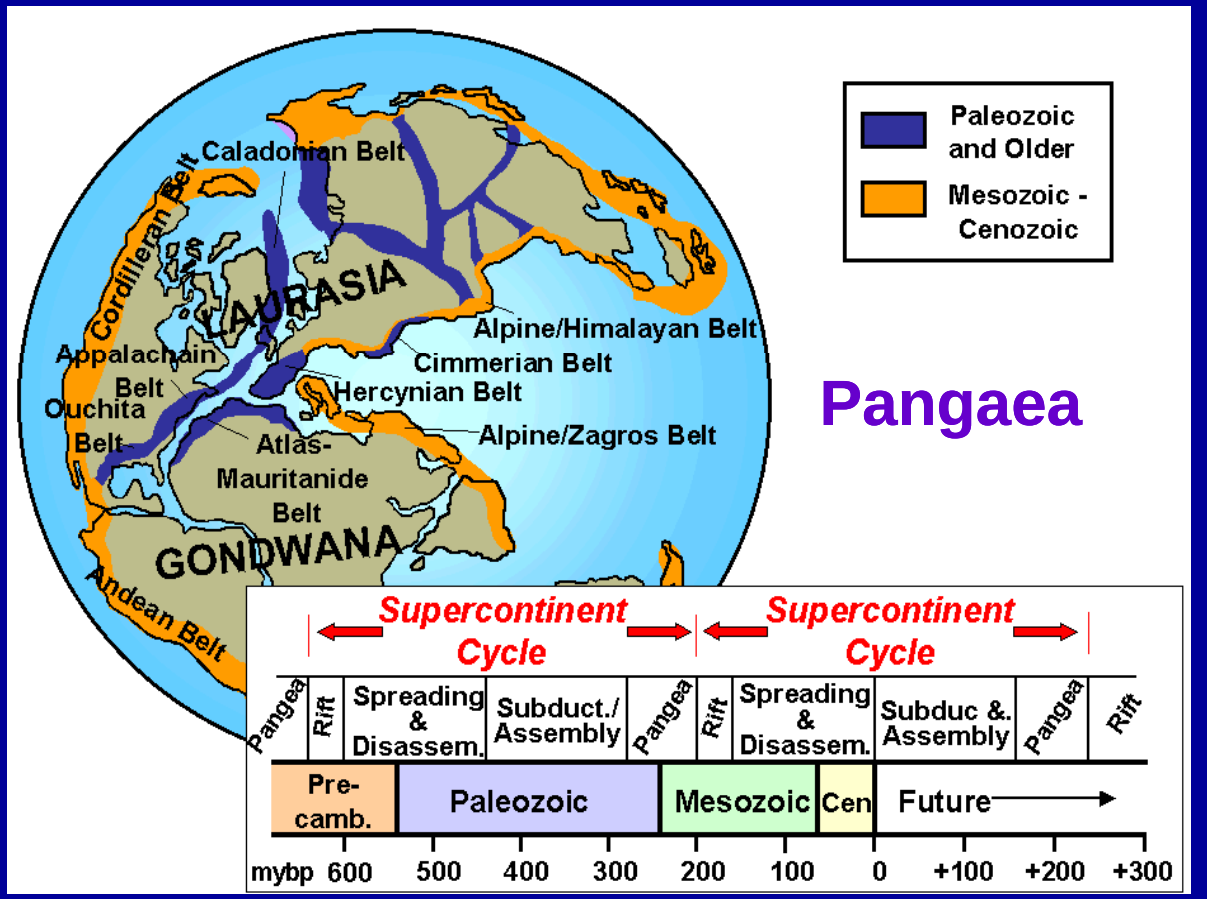
India-Asia collision animation

*Click this link to start animation of continental collision*

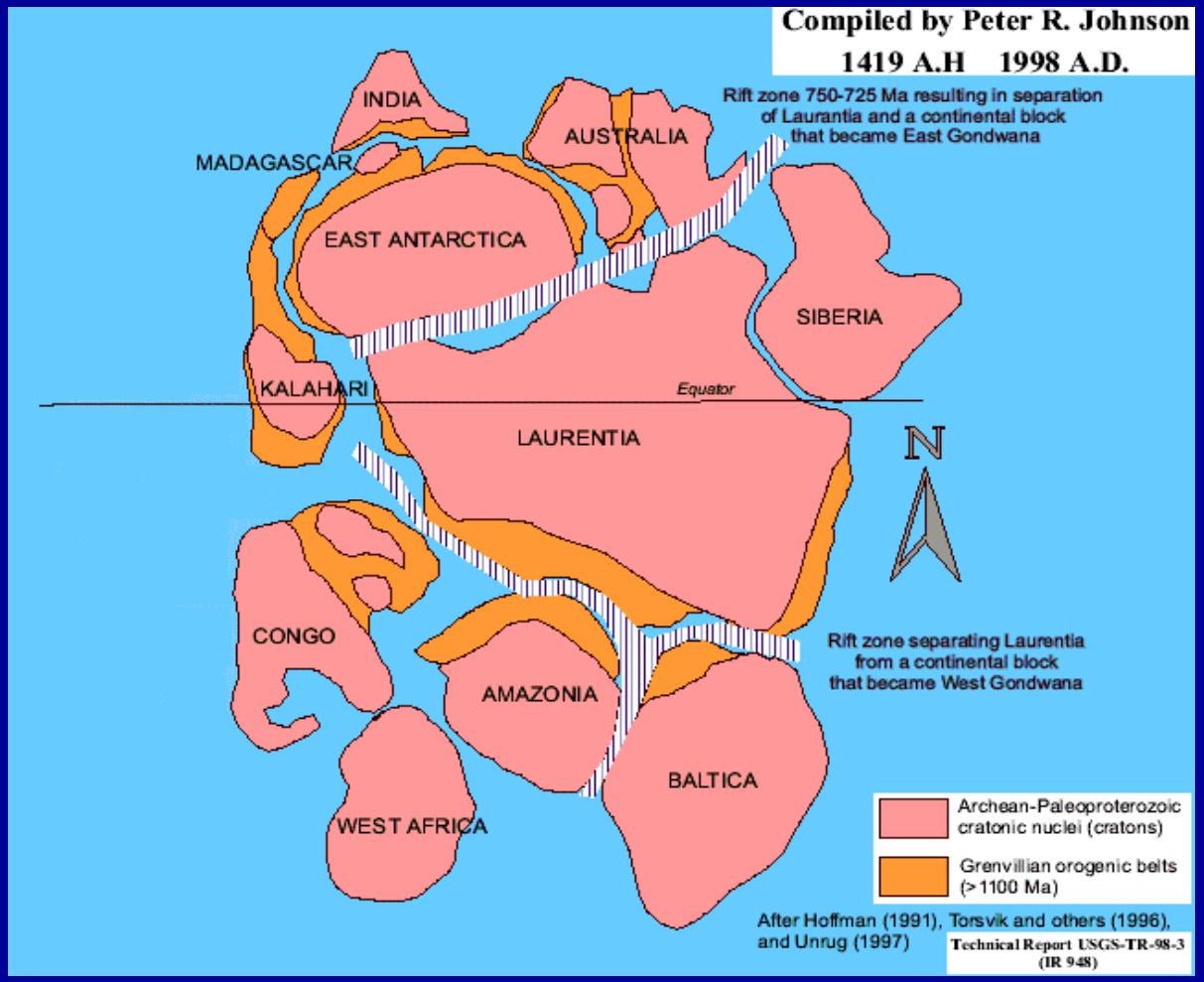
# The Supercontinent Cycle

## The 500 Million-Year Supercontinent Cycle

1) Earth has experienced several supercontinent cycles over the last billion years.
2) Each cycle consists of supercontinent rifting, spreading, drifting of fragments, and eventual reassembly of continents
3) Massive folded and thrust-faulted mountain belts form as the result of continental reassembly



# Proto-Pangaea: Supercontinent Rhodinia




- Formed 1100 Million years ago
- Broke up 750 million ago

# Earth's Hot Spots

**EXPLANATION**

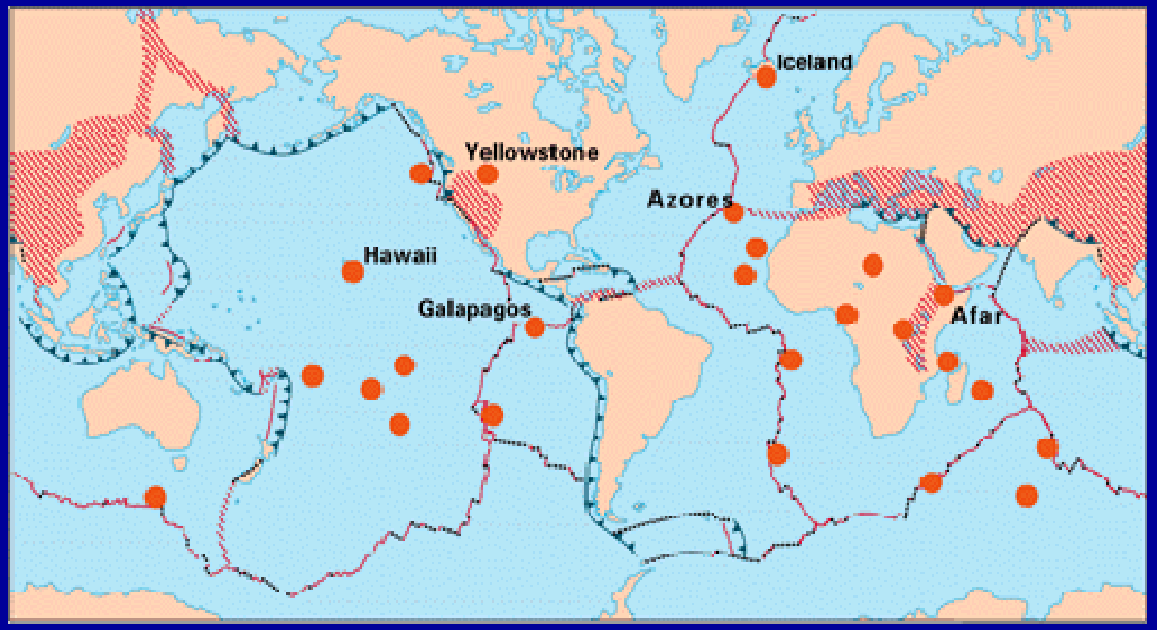
Divergent plate boundaries—Where new crust is generated as the plates pull away from each other.

Convergent plate boundaries—Where crust is consumed in the Earth's interior as one plate dives under another.

Transform plate boundaries—Where crust is neither produced nor destroyed as plates slide horizontally past each other.

Plate boundary zones—Broad belts in which deformation is diffuse and boundaries are not well defined.

Selected prominent hotspots

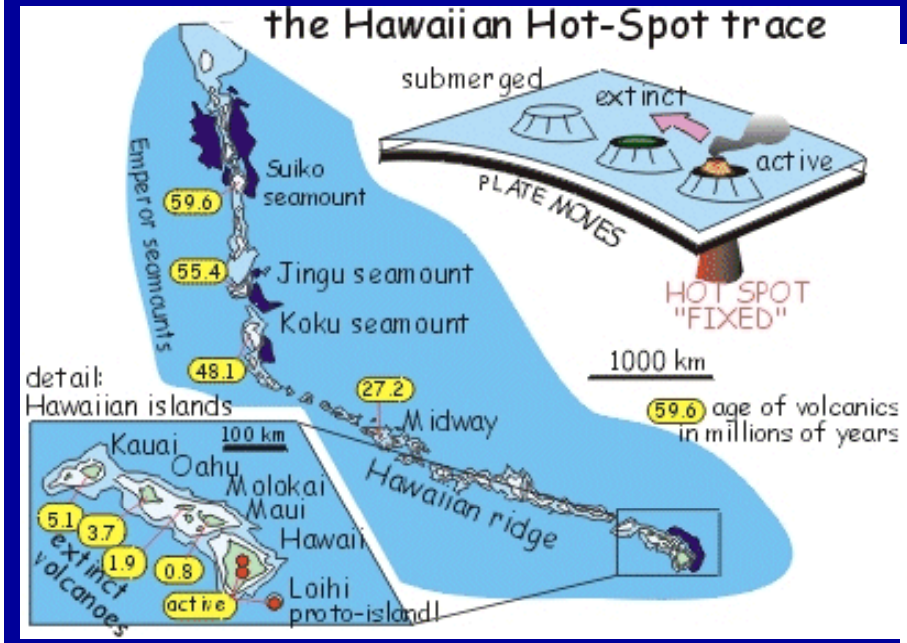


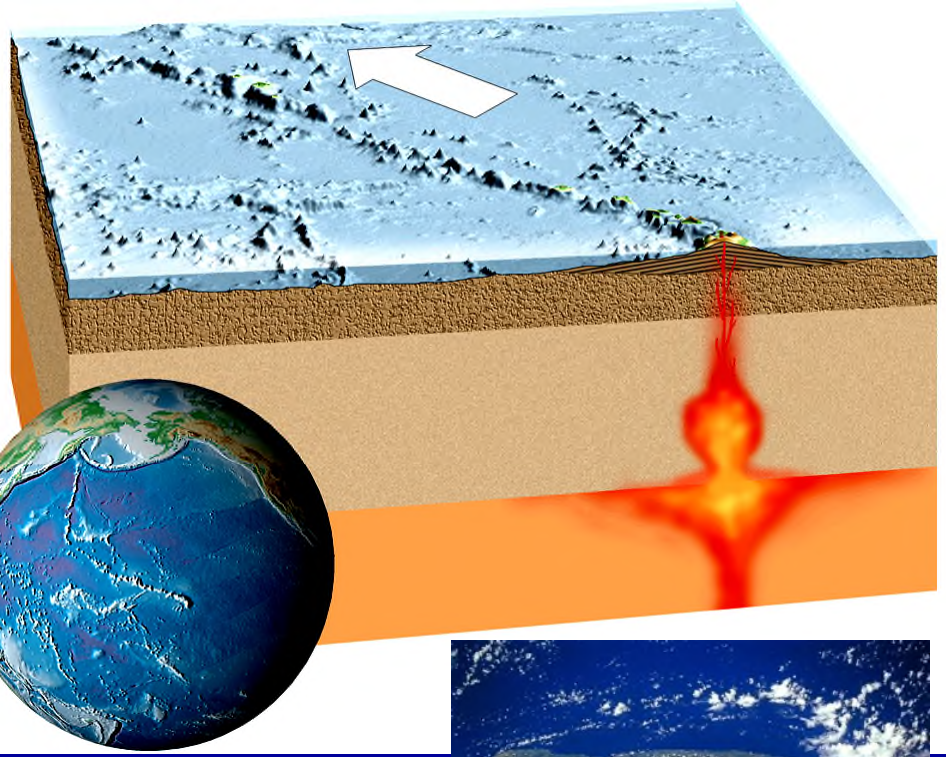

Hawaii

Yellowstone

Iceland

# Hot Spots and Plate Motion



## Hawaiian Hot Spot

### Key Points

- ✓ Hot spot plume anchored in mantle = ***stationary***
- ✓ ***Distance and age*** between linear sequence of hot spot- generated volcanic centers indicates the ***direction and rate*** of motion of lithospheric plate

# HEAT and GRAVITY: Driving Forces of Plate Motion

## Mechanisms for Plate Motion

### #1) SLAB PULL

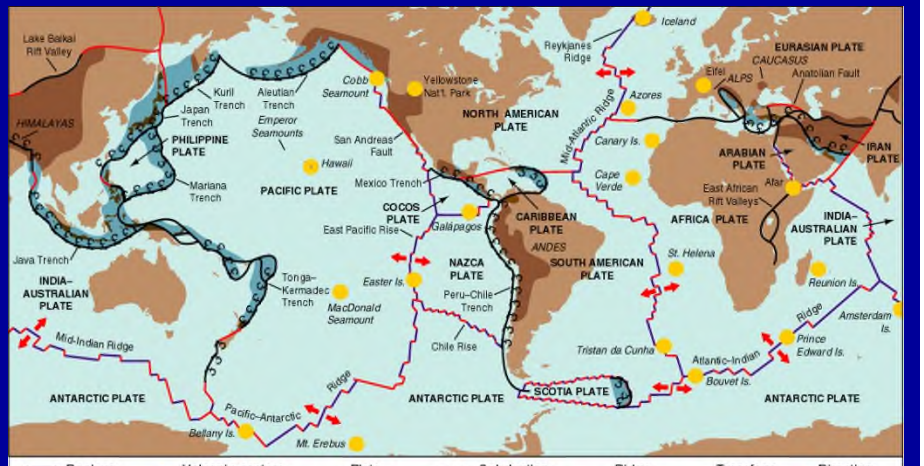
- WEIGHT OF OVER-DENSE SUBDUCTING SLAB PULLS REST OF PLATE

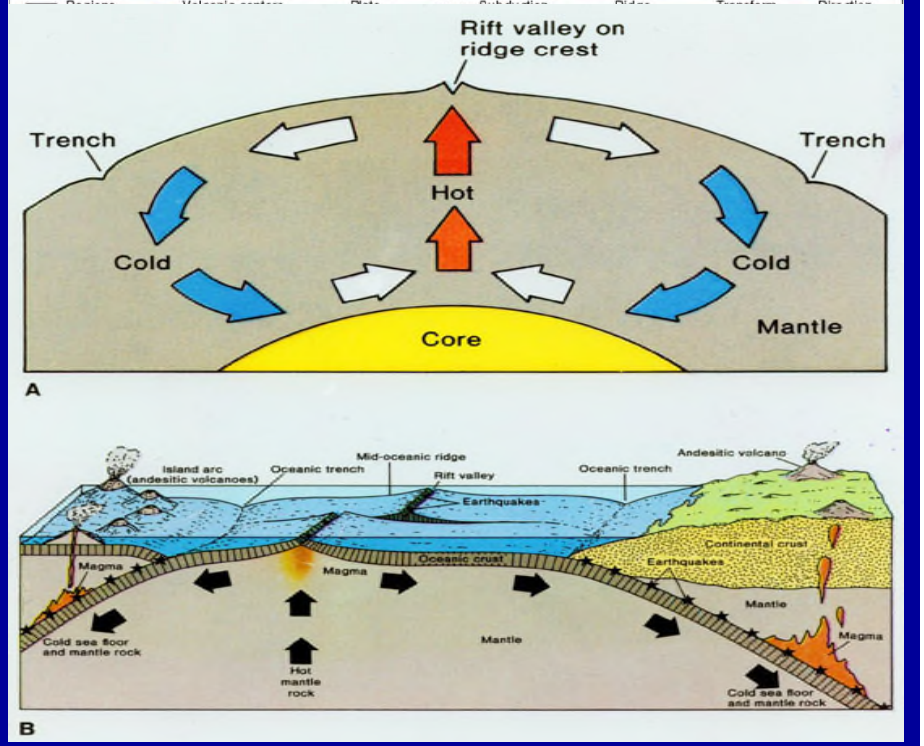
### #2) MANTLE CONVECTION

- HEAT FROM RADIOACTIVE ELEMENTS
- CONVECTIVE OVERTURN MOTION OF MANTLE AFFECTS OVERLYING LITHOSPHERE

### #3) TRENCH SUCTION

- DESCENDING SLAB CREATES DOWNDRAFT IN THE MANTLE WEDGE SURROUNDING SLAB
- ACCENTUATES SLAB PULL



# Plate Motion-Driving Mechanisms

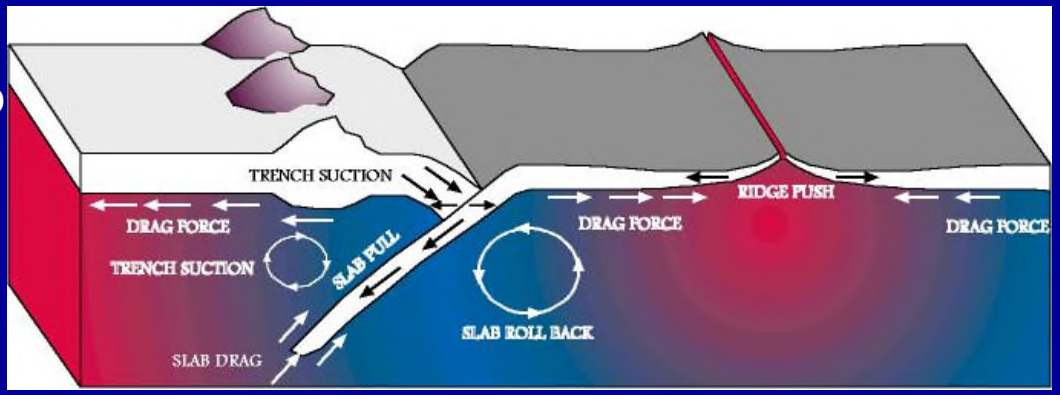
## Four Principle Mechanisms Driving Plates

### 1) Slab Pull

- Pulling whole plate by the sinking of the subducting slab
- Gravity-assist

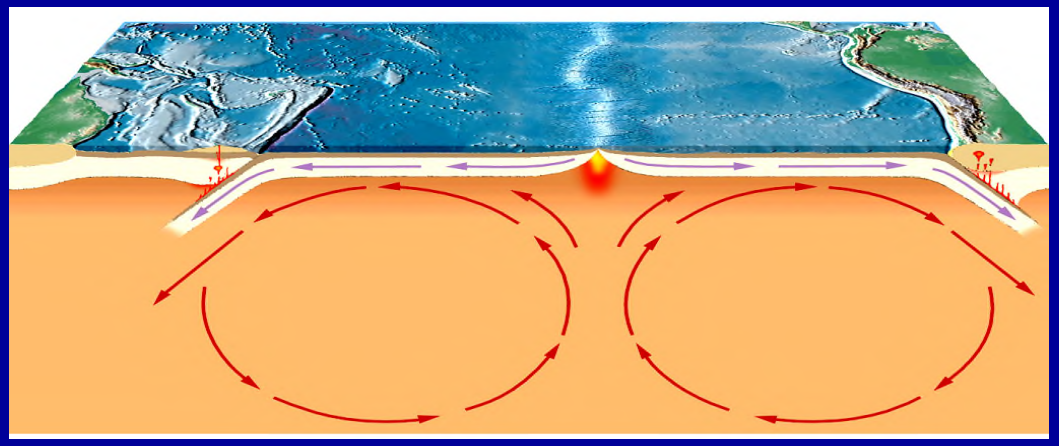
### 2) Trench Suction

- Sucking of slab downward
- Downward flow of asthenosphere around slab




### 3) Ridge Push

- Pushing of "elevated" ocean ridge lithosphere toward trench
- Gravity-assist



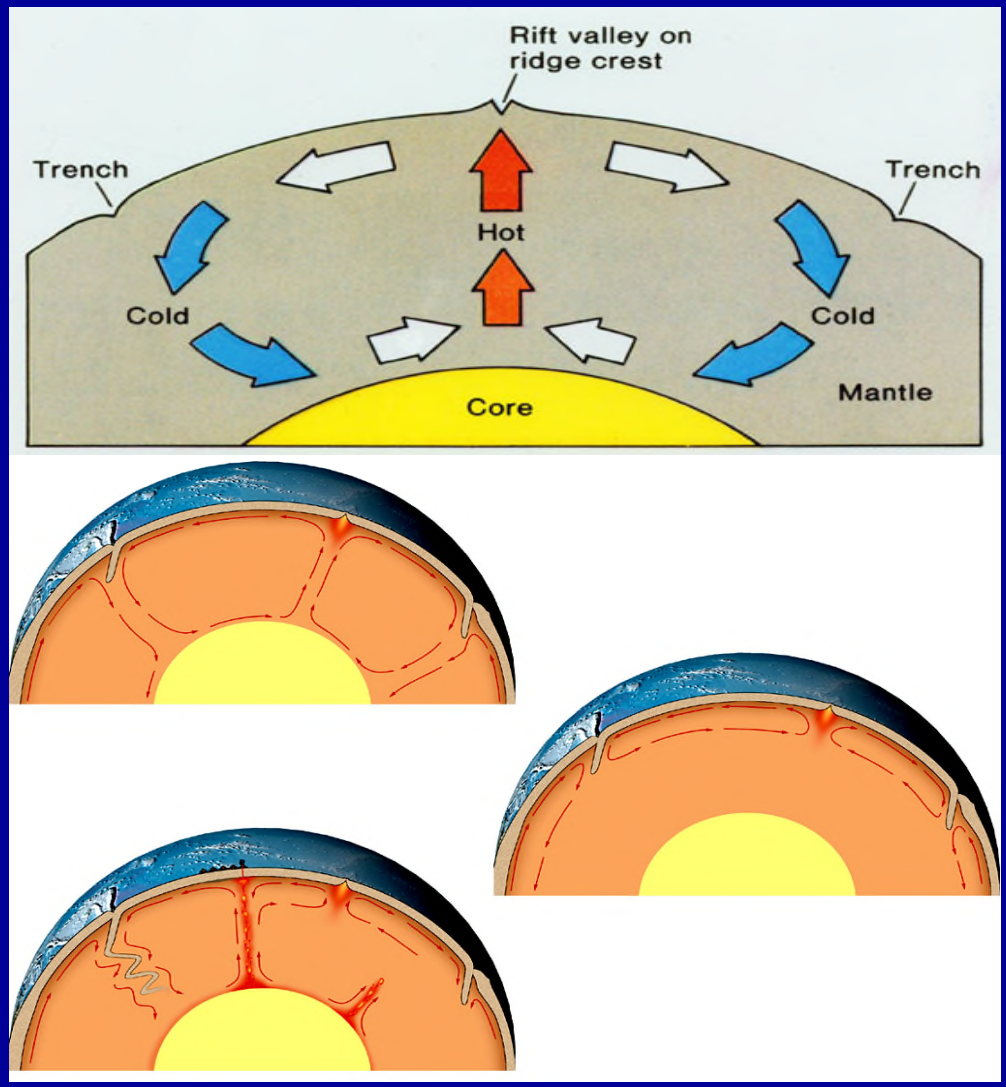
### 4) Drag Force

- Dragging forces on base of lithosphere by asthenosphere
- Earth's mantle convection

# Mantle Convection Models

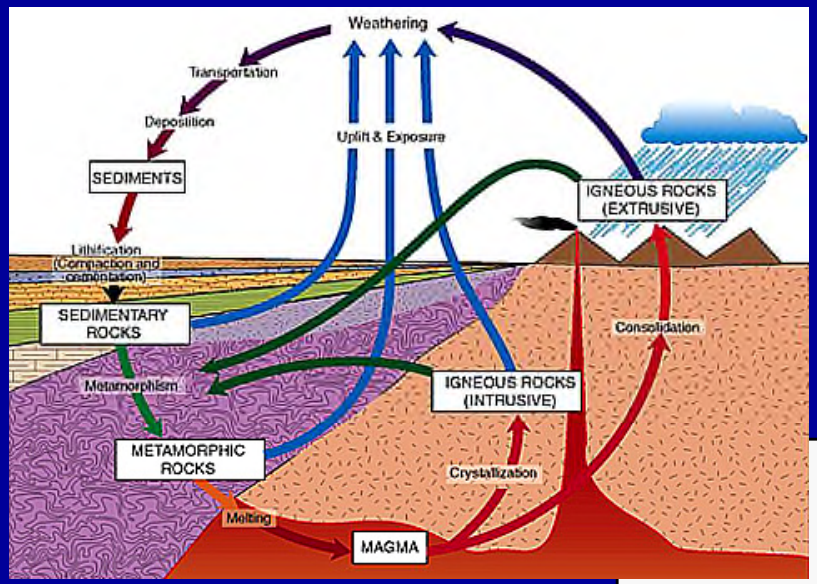
## Three Convection Models

1) Full Mantle Convection
   - Core to Lithosphere
   - Multi-celled
2) Upper Mantle Convection
   - Only Asthenosphere
   - Multi-celled
3) Compound Convection
   - Multi-scale cells
   - Ascending Mantle Plumes
   - Descending Slab Drips
   - Incomplete Cells



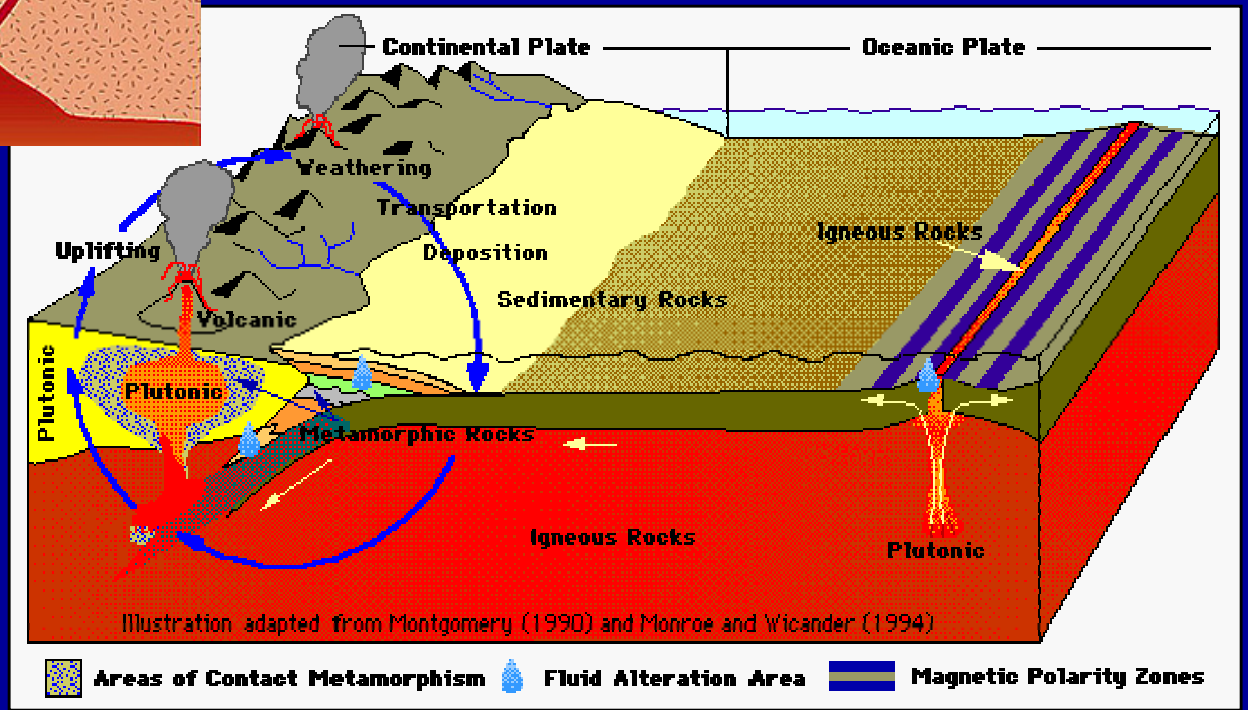
# TECTONICS - ROCK CYCLE CONNECTION

## Discussion Questions:

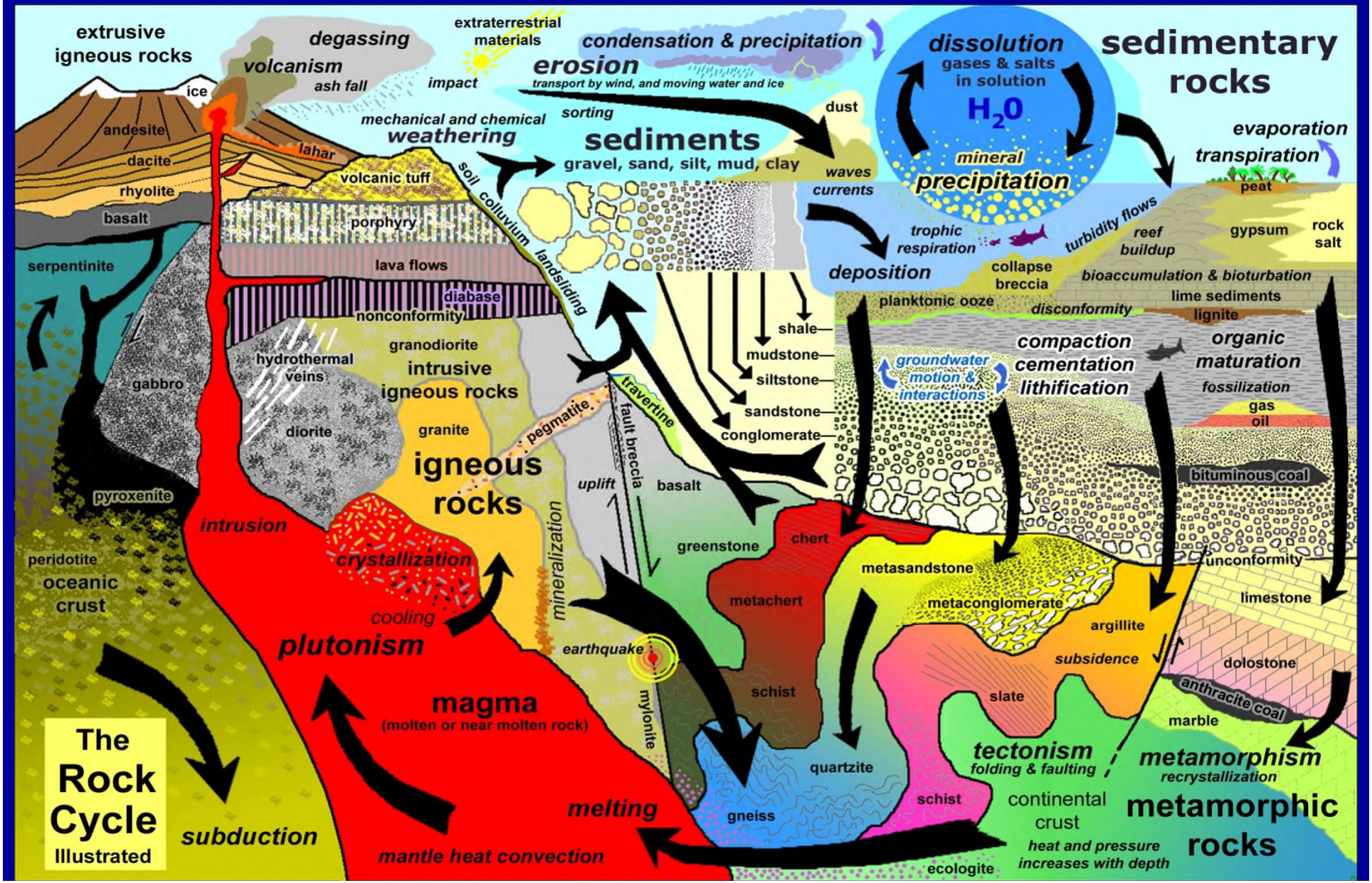



1) How does plate tectonics influence Earth's rock cycle?

2) How does Earth's rock cycle cycle influence plate tectonics?

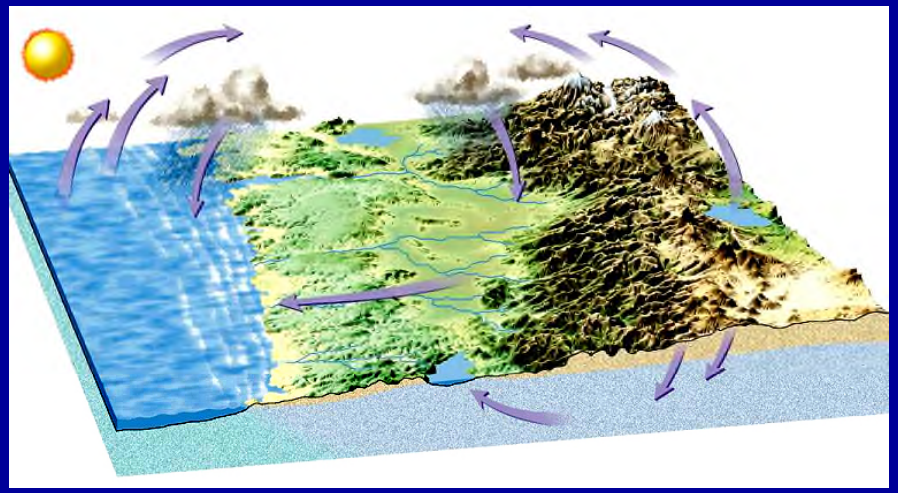


# TECTONICS – OCEAN-ROCK CONNECTION



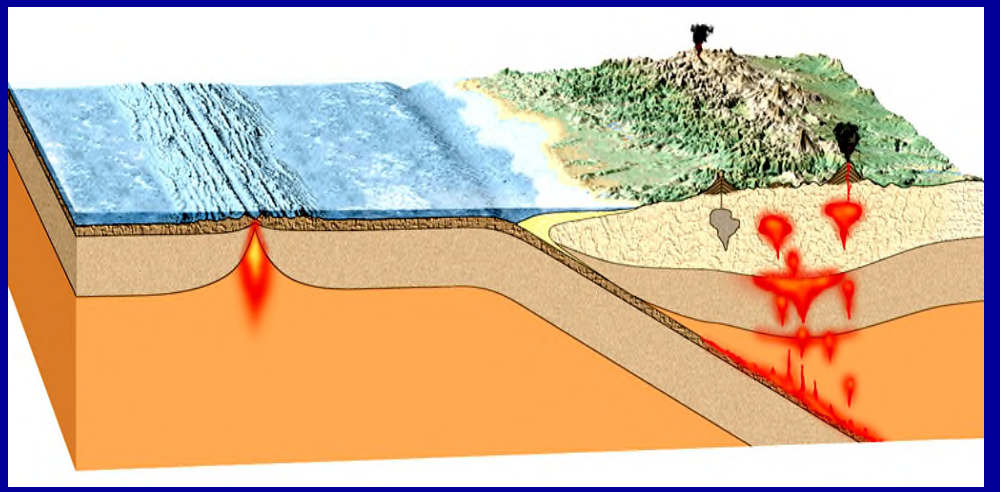
# TECTONICS - WATER CYCLE CONNECTION

## Discussion Questions:



1) How does plate tectonics influence Earth's $H_2O$ cycle?

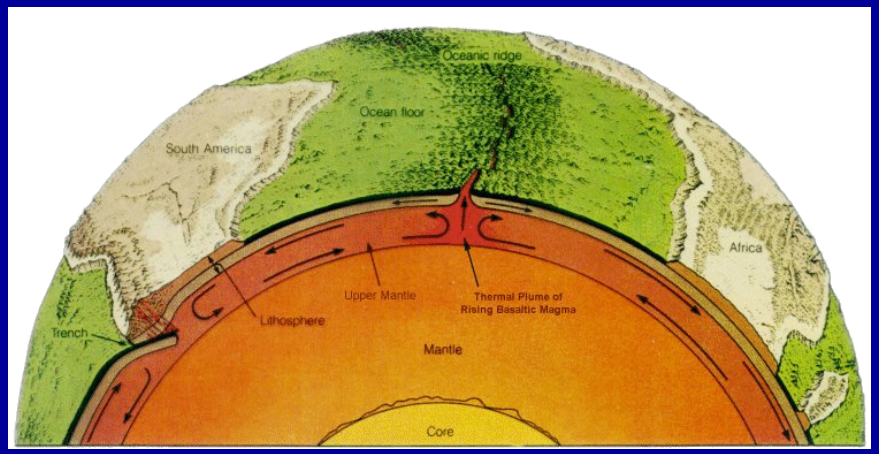
2) How does Earth's H2O cycle influence plate tectonics?



# Review of Plate Tectonic Theory

## Key concepts:

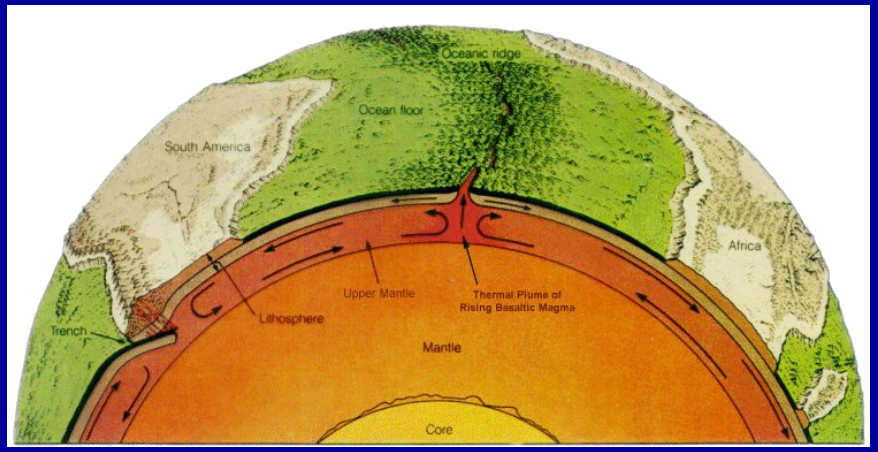
1) Earth's crust and uppermost mantle broken up into 18 mobile, rigid slabs called ***lithospheric plates***
2) Lithospheric plates ride independently atop the underlying partially-molten mantle called the ***asthenosphere***
3) Three types of dynamic lithospheric plate boundaries:
   Divergent, Convergent, and Transform
4) Divergent boundaries
   - Continental rifting
   - Seafloor-spreading
5) Convergent boundaries
   - Subduction
   - Terrane accretion
   - Continental collision
6) Transform boundaries
   - Strike-slip faulting

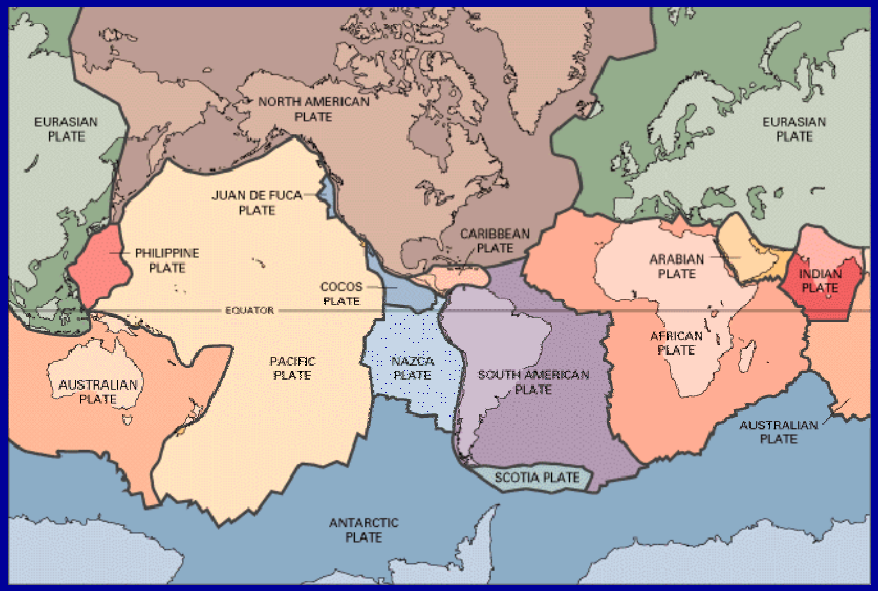



7) Plate tectonics is driven primarily by mantle convection
8) Plate tectonic theory explains most geologic phenomena

# PLATE TECTONICS DISCUSSION

## Convective Thoughts?

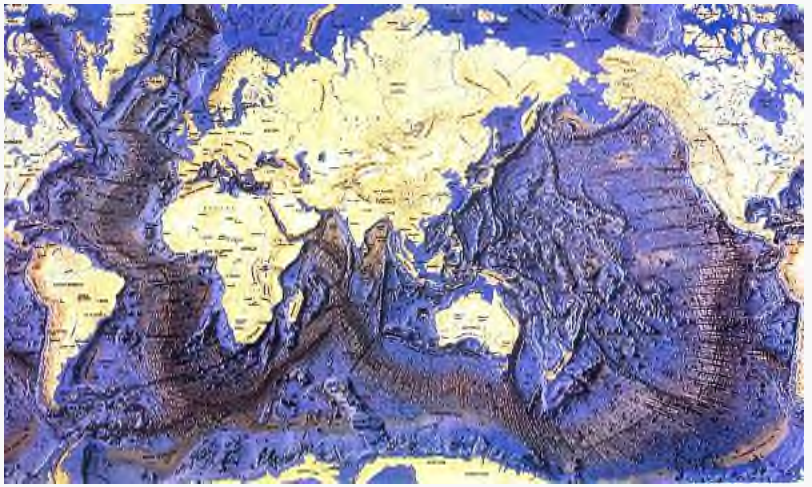


# Preparation for Next Meeting

## Next Meeting Topics

1) Mapping the Seafloor
2) Nature of Seafloor Rocks
3) Regional Seafloor Features
4) Origin of Seafloor Features



## Homework Assignment:

- **Read Chapter 3 in Textbook**
- **Study Instructor's Website**
  - **@ www.oceansci.com**
    - ✓ **Lecture Notes**
    - ✓ **PowerPoint**
    - ✓ **ER Video 4**