Earth's Changing Landscape Systems

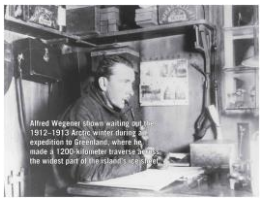
The Tectonic Cycle

Early Theories of Continental Drift

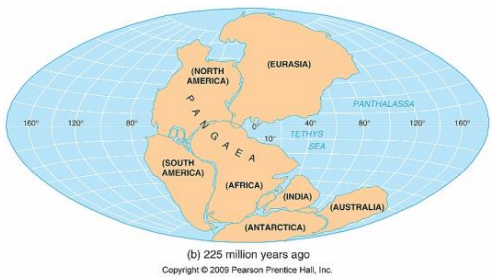
- **Abraham Ortelius (1596) and Sir Francis Bacon (1620):**
  - **Noted how coastlines of some continents appeared to fit together like jigsaw puzzle**
- **Eduard Suess (late nineteenth century):**
  - **Postulated that southern continents were once part of a giant continent called *Gondwanaland***
- **Alfred Wegener (early twentieth century):**
  - **Fitted together separate continents, including Gondwanaland, to form giant supercontinent of *Pangaea***

Continental Drift: An Idea Before Its Time

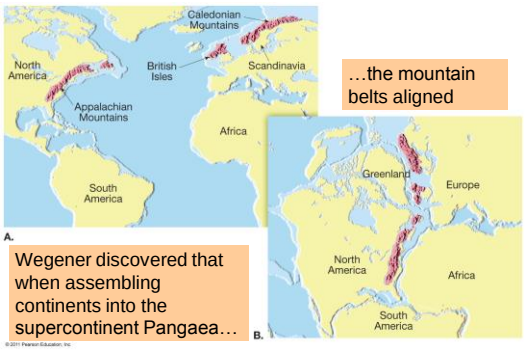
- Alfred Wegener:
  - First proposed his continental drift hypothesis in 1915
  - Published *The Origin of Continents and Oceans*
- Continental drift hypothesis:
  - Supercontinent called Pangaea broke apart and the "pieces" drifted to their present positions to become modern continents



Wegener's Pangaea



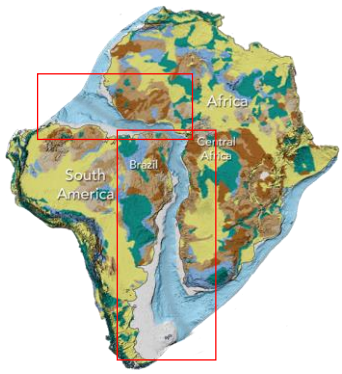
(b) 225 million years ago



…the mountain belts aligned

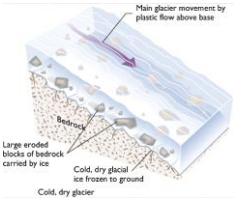
Wegener discovered that when assembling continents into the supercontinent Pangaea…

Geologic Matches Of Rocks And Rock Structures On Opposite Sides Of The Ocean



Paleoclimatic Evidence

- **Glacial deposits found today in South America, Africa, India and Australia:**
  - **Some in places where the climate is now tropical**
- **Grooves in bedrock at these locations may have been carved by ancient glaciers**
- **How do we explain such drastically different climates in the past for these areas?**

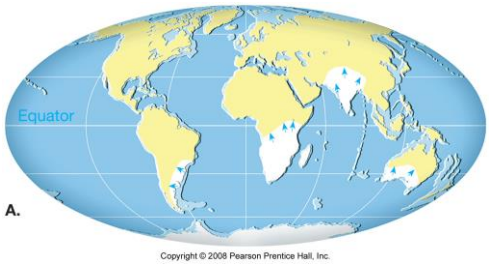


Evidence of Past Glaciation

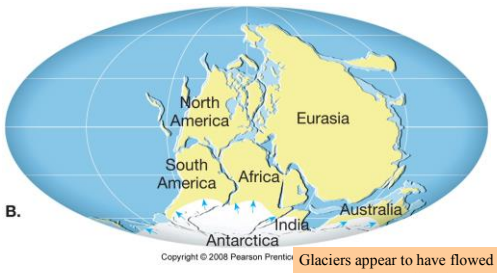
Glacial debris

Grooves in bedrock

Grooves in Bedrock Indicate Weird Ice Flow Directions



But Ice Flows Make Sense If Continents Were Assembled As They Appeared 300 Million Years Ago



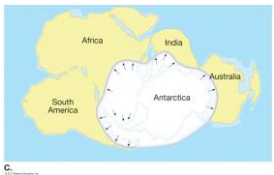
Glaciers appear to have flowed away in different directions from the South Pole

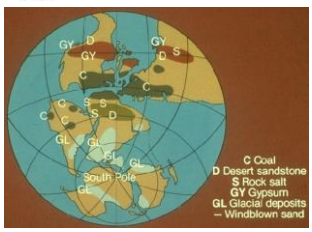
More Paleoclimate Evidence For Continental Drift

Ancient rocks and fossils do not match the climate at their present locations:

- Coal in Antarctica
- Reef-building corals in frozen Greenland
- Glacial deposits in Sahara Desert

Can be explained if continents were at one time at different latitudes and "drifted" to present positons



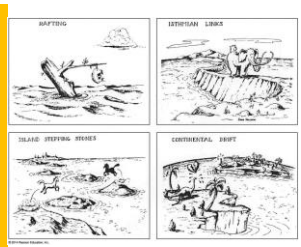


Evidence from Fossils

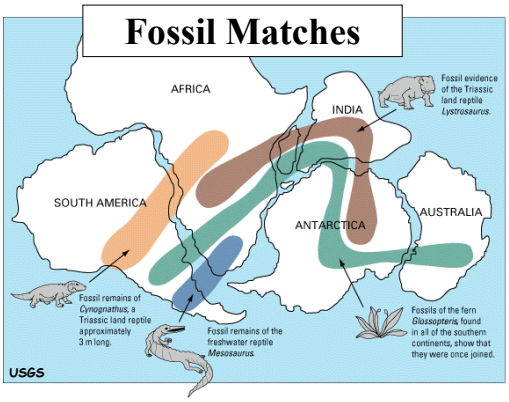
- **Similar fossils of ancient land animals are found today in Africa, South America and other southern continents now separated by oceans**
- **Fossil plants and seeds are also found on these continents:**
  - **Did the animals and plants cross entire oceans?**

Fossil Evidence For Continental Drift

- A. L. Du Toit (early twentieth century) identified ancient fossils on widely separated continents:
  - Some fossils from different continents were remarkably similar to one another
  - Wondered how similar animals could have crossed entire oceans
  - Concluded that the now separated continents have at one time been joined



Various explanations for the occurrence of similar species on different continents (Sketches by John Holden)



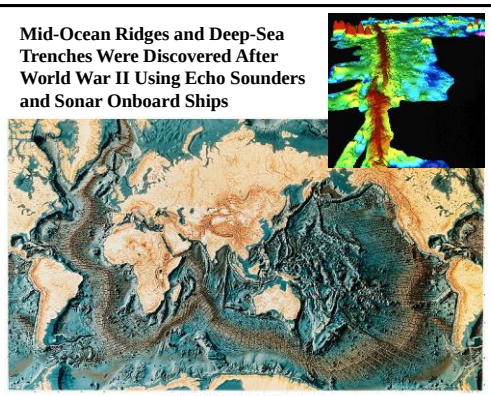
Continental Drift Hypothesis

- **Observations of Wegener and others led to the hypothesis of continental drift.**
- **The flaw was that no one could come up with a viable mechanism to move continents.**
- **In the 1960s, the technologies of WWII finally provided the evidence for a viable mechanism:**
  - **Mantle convection and seafloor spreading.**

Modern Evidence

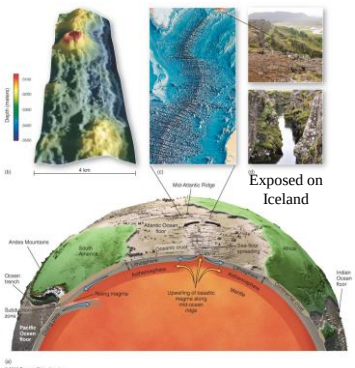
- **Bathymetry of the ocean floor**
- **High heat flow along mid-ocean ridges**
- **Polar wander curves**
- **Magnetic stripes on the seafloor**
- **Distribution of earthquakes and volcanoes in well-defined trends**

Mid-Ocean Ridges and Deep-Sea Trenches Were Discovered After World War II Using Echo Sounders and Sonar Onboard Ships

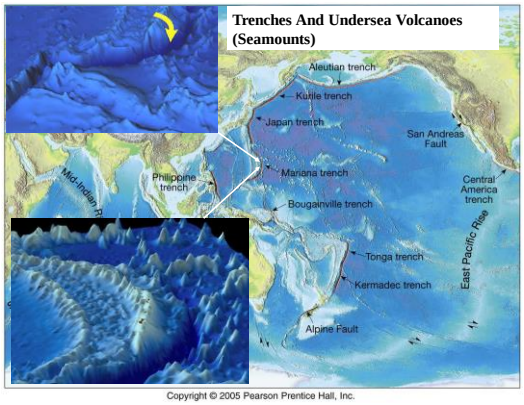


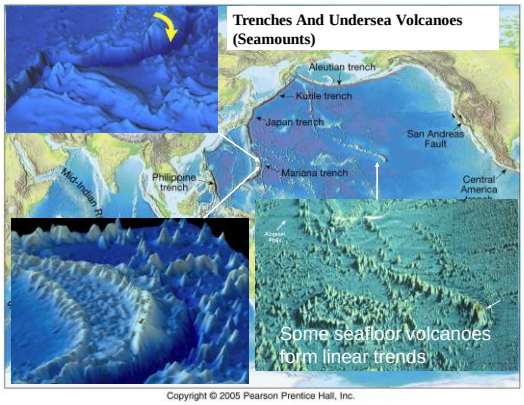
Mid-ocean Ridges Are Sites Of Undersea Volcanoes And High Heat Flow

Hydrothermal discharge on seafloor



Exposed on Iceland

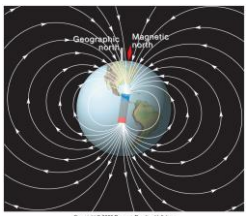


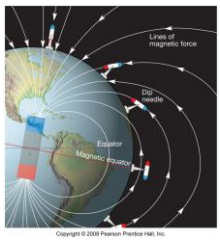


Earth's Magnetic Field

- **Discovered by Chinese (13th century) floating a lodestone on a piece of wood – it pointed north.**
- **Compass directions define two components of magnetism:**
  - **Inclination – Tilt of magnetization.**
  - **Declination – Horizontal swing.**

Declination
Compass direction presently points to the magnetic north pole

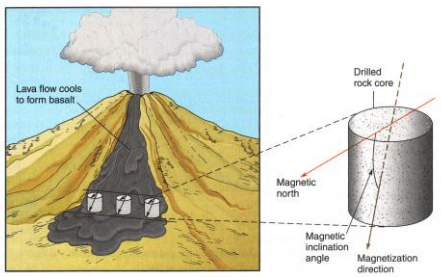




Inclination
Magnetic inclination is the angle a compass needle makes with Earth's surface and is a function of latitude

Inclination and Declination

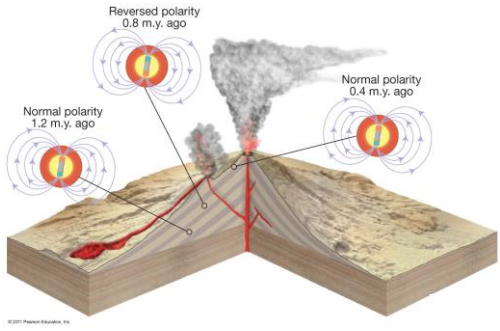
Measuring Paleomagnetism in Rocks



Paleo-Magnetic Reversals

- By examining volcanic rock layers spanning millions of years, geophysicists found that some older layers exhibited polarity opposite from Earth's present magnetic field:
  - Earth's magnetic field reversed in the past
- Evidence suggests that Earth's magnetic field flipped from normal to reverse polarity, then back again, many times in the past

Older Lava Flows Record Reversals in the Earth's Magnetic Field at Various Times in the Past

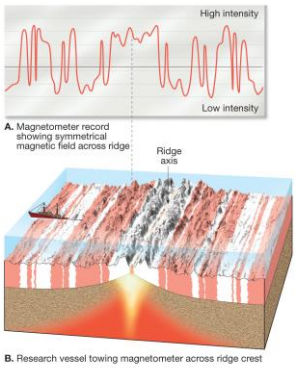


Earth's Magnetic Field

Marine Magnetic Anomalies

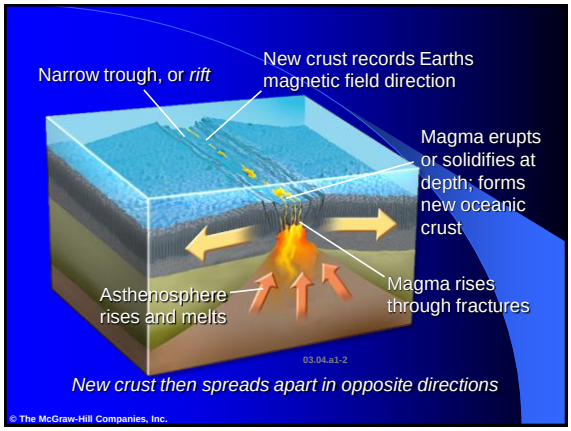
- During WWII, technology was developed to detect submarines by magnetism (they're made of iron) and to chart the magnetism on the ocean floor to aid submarine navigation
- Incredible matching magnetic stripes were found extending away from both sides of oceanic mountain chains known as mid-ocean ridges

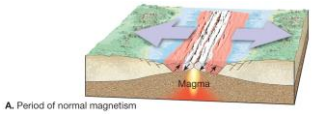
Magnetic stripes of normal and reverse polarity parallel Juan de Fuca mid-ocean ridge



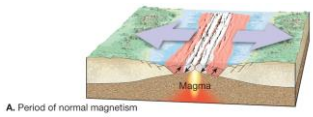
A Pattern Explained

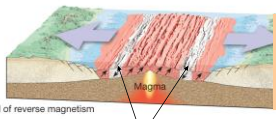
- Mid-ocean ridges are sites where new oceanic crust forms
- Spreading along the ridge pushes older rocks aside as new crust forms:
  - This would occur in conjunction with occasional flips in Earth's magnetic field
- This would explain the mirror image of magnetic stripes on opposite sides of mid-ocean ridges





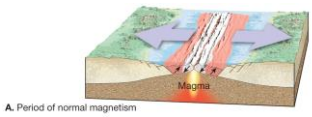
Oceanic crust formed during this time acquires normal polarity



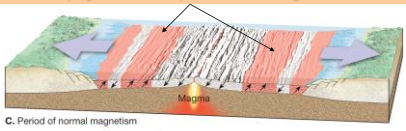


Oceanic crust formed during this time acquires reversed polarity

Previously-formed crust of normal polarity had split apart and move in opposite directions, forming stripes on either side of the mid-ocean ridge



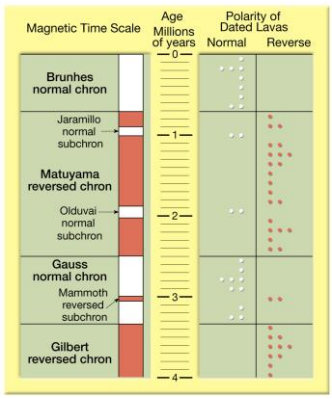
Previously-formed crust of reversed polarity now separated and moving apart, forming additional stripes



Seafloor Spreading and Rock Magnetism

Magnetic Reversal Time Scale

- Magnetic reversals in volcanic rocks on land and in oceans were isotopically dated
- The Geomagnetic Time Scale was thus established
- Scale based on dating rocks of different ages and magnetic polarities from the oceans and continents



Change in measured locations of north magnetic pole over time

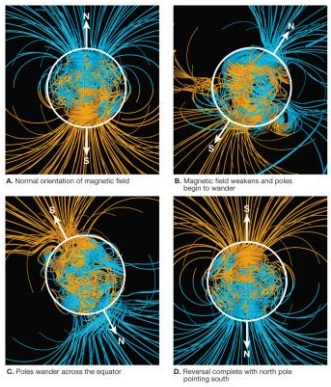
Magnetic field has also weakened by ~10% over the last century

Is Earth's magnetic field in the process of reversing?

Computer simulation showing how Earth's magnetic field could reverse direction

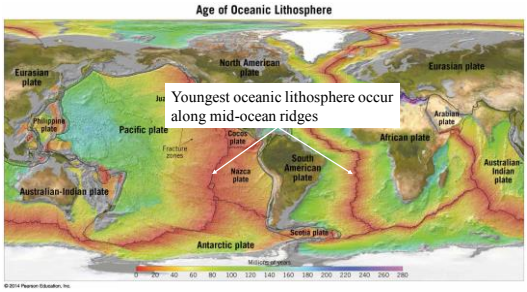
The whole process takes only a few thousand years

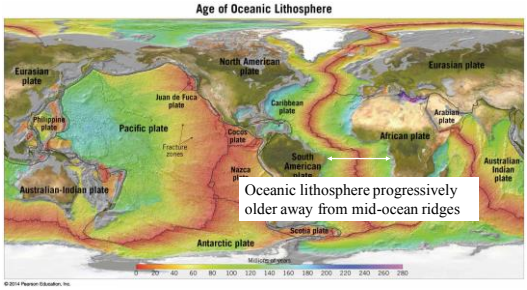
What would be the effects on life?

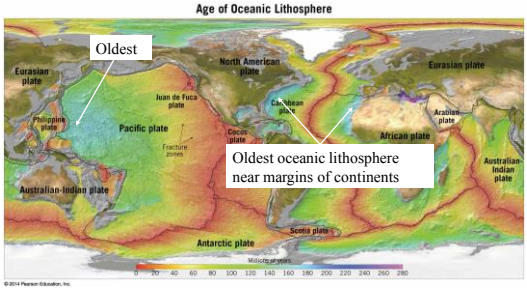


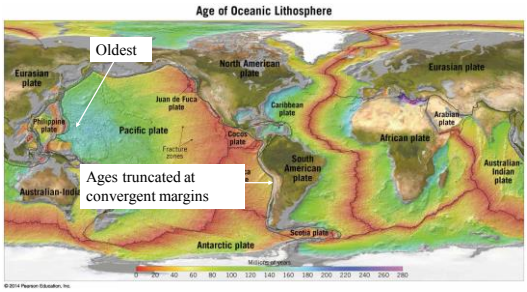
Determining Ages Of Oceanic Crust

- **Seafloor is dated using fossils from overlying sediments and correlating magnetic stripes with the Geomagnetic Time Scale:**
  - **Seafloor spreading occurs at rates ranging from 1-18 centimeters per year**
  - **Youngest oceanic crust occurs along mid-ocean ridges**
  - **Oceanic crust becomes progressively older away from ridges**
  - **Oldest oceanic crust only Late Jurassic (~180 m.y. old) in age**









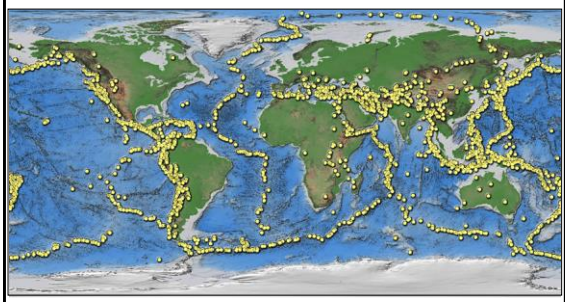
Earthquakes

- Shallow earthquakes recorded over time match the trends of mid-ocean ridges
- Shallow and deep earthquakes match the trends of ocean trenches

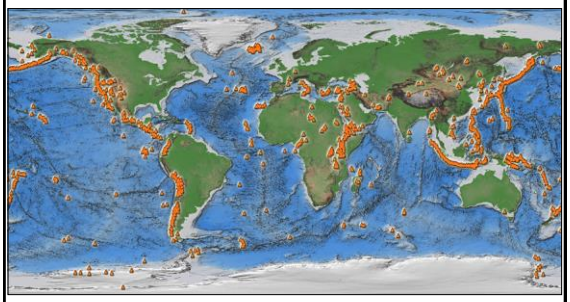
Volcanoes

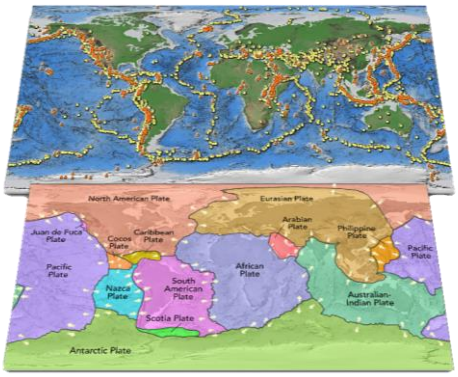
- The distribution of volcanoes also show definite trends:
  - Active undersea volcanism occurs along mid-ocean ridges
  - Lines of volcanoes on continents and oceans parallel ocean trenches
  - Volcanic islands and seamounts in the oceans also follow linear trends

Recent Earthquakes



Active Volcanoes





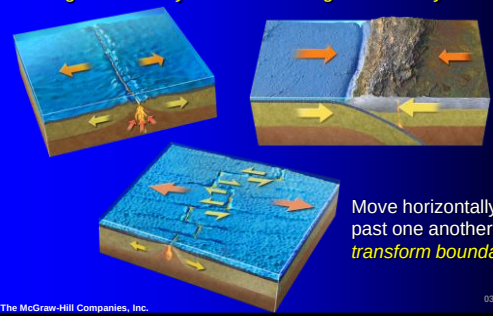
Plates

- The lithosphere is divided into plates of different sizes
- The plates are separated by three types of boundaries:
  - Divergent (mid-ocean ridges) where plates pull apart
  - Convergent (subduction zones) where plates come together
  - Transform boundaries where plates slide laterally past one another

Three Types of Relative Plate Motions

Move apart:
divergent boundary

Move toward each other:
convergent boundary



Move horizontally past one another:
transform boundary

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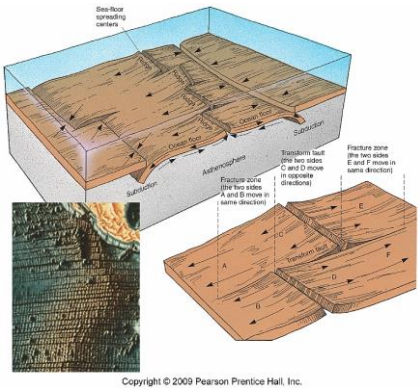
Transform Fault Boundaries

- Plates slide laterally past one another:
  - Lithosphere is neither created nor destroyed
- Transform faults are important features in ocean basins and on continents:
  - Most join segments of a mid-ocean ridge along breaks in the oceanic crust known as fracture zones
  - A few (the San Andreas fault and the Alpine fault of New Zealand) cut through continental crust



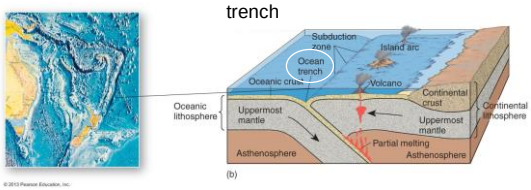
Transform Faults

Convergent Plate Boundaries

- Two plates come together with one plate (usually oceanic) subducting (sinking) beneath another along an oceanic trench
  - Subducting lithosphere destroyed
- Trenches are associated with volcanic arcs

Deep-ocean Trenches Are Parallel To Nearby Volcanic Arcs

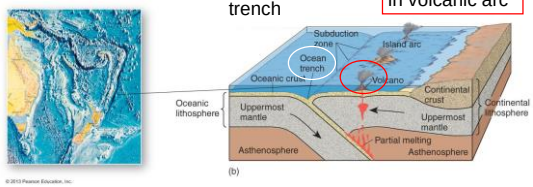
Low heat flow in trench



Deep-ocean Trenches Are Parallel To Nearby Volcanic Arcs

Low heat flow in trench

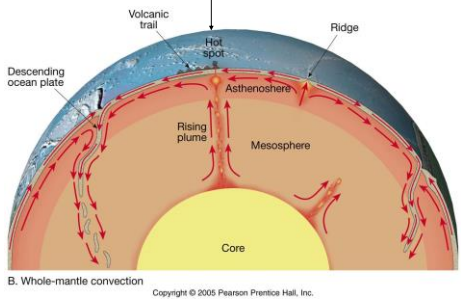
High heat flow in volcanic arc



Intraplate Volcanism

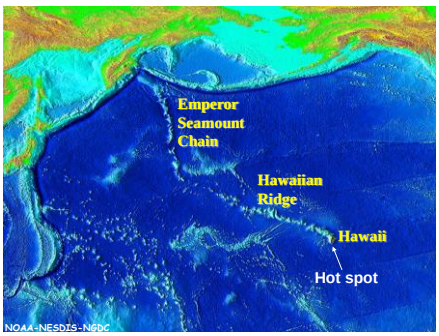
- **Linear chains of volcanoes also occur in ocean basins far removed from plate boundaries**
- **These volcanoes are generated by rising mantle plumes that impinge upon the base of the overlying plate to produce hot spots:**
  - **Hawaiian islands is an example**

Rising Mantle Plume Impinges Upon The Base Of The Lithosphere To Form A Hot Spot

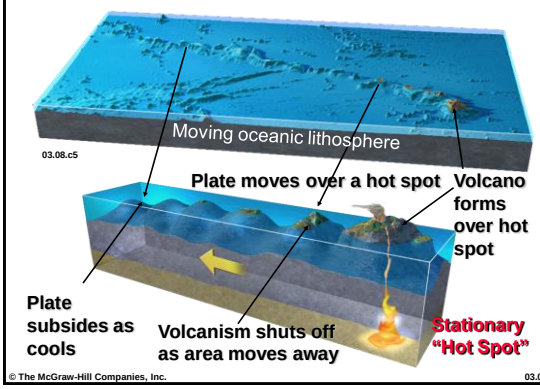


B. Whole-mantle convection

Hot Spot Beneath Hawaii Produced Linear Chain Of Volcanoes Over 70 Million Years



Formation of Linear Island Chains



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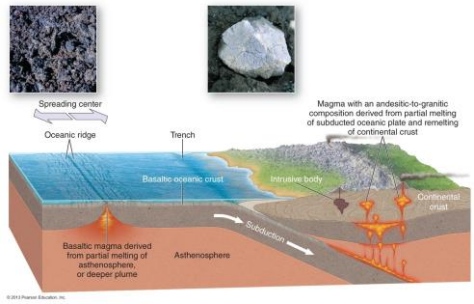
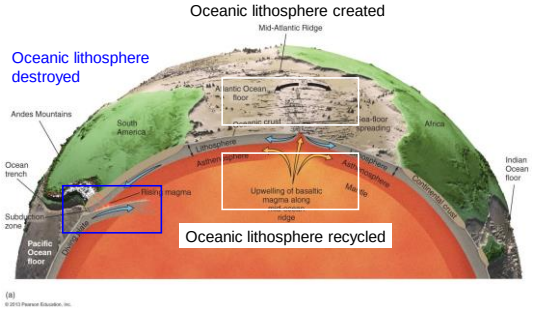
Hot Spot Volcano

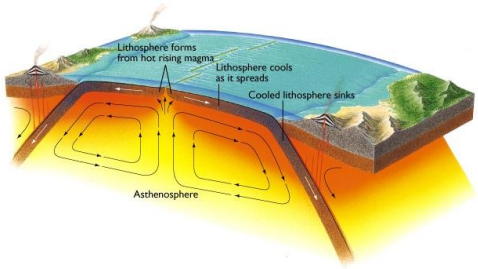
New Oceanic Lithosphere Formed At Mid-ocean Ridge Is Ultimately Destroyed Along Convergent Plate Boundary



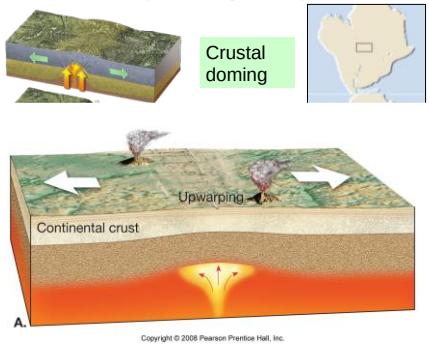
The Plate Tectonic Cycle



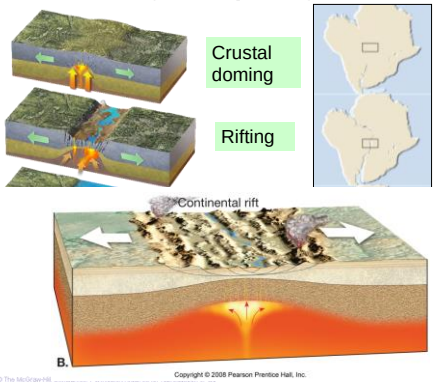
The Plate Tectonics Cycle Is Driven By Mantle Convection And Powered By Earth's Internal Heat



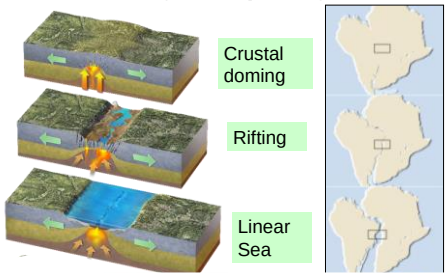
Wilson Cycle: Opening of an Ocean



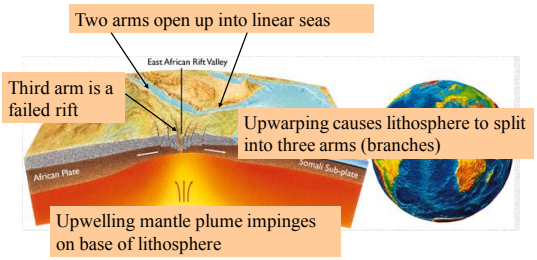
Wilson Cycle: Opening of an Ocean

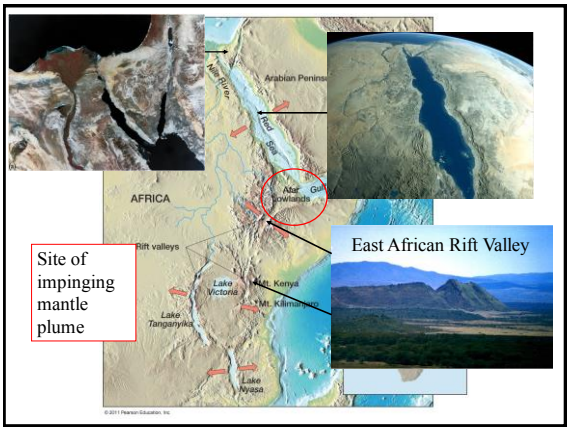


Wilson Cycle: Opening of an Ocean

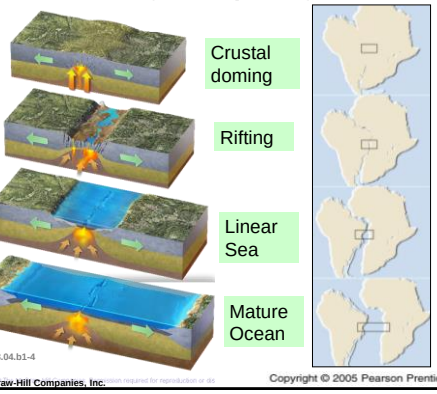


East African (Afar) Triple Junction

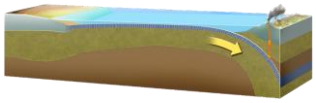




Wilson Cycle: Opening of an Ocean



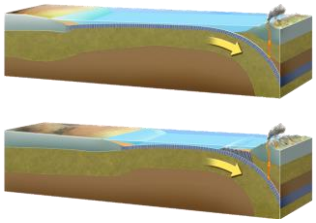
Wilson Cycle: Closing of an Ocean



Declining Stage:
e.g. Pacific Ocean

 03.05.d1

The Wilson Cycle (cont)



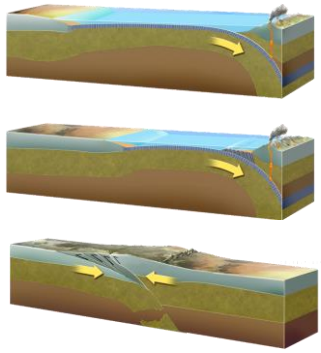
Declining Stage:
e.g. Pacific Ocean

Remnant Stage:
e.g. Mediterranean Sea

 03.05.d1

Mediterranean Sea Is A Remnant Of The Much Larger Tethyan Sea

The Wilson Cycle (cont)

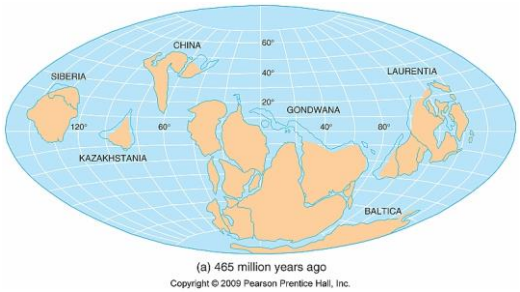


Declining Stage:
e.g. Pacific Ocean

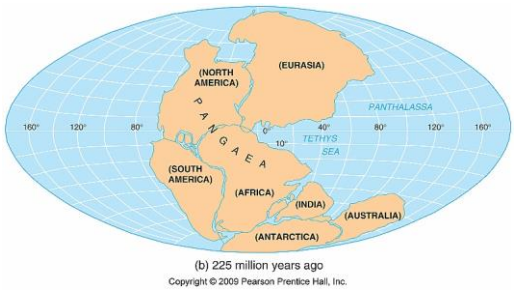
Remnant Stage:
e.g. Mediterranean Sea

Suture Zone:
e.g. Himalayan Mts

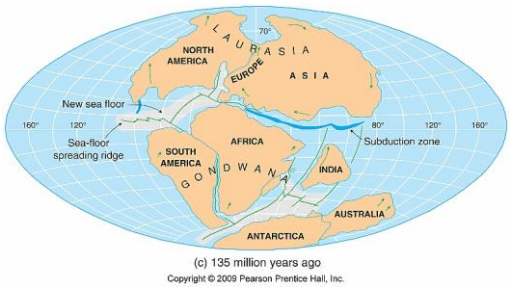
03.05.d1



(a) 465 million years ago

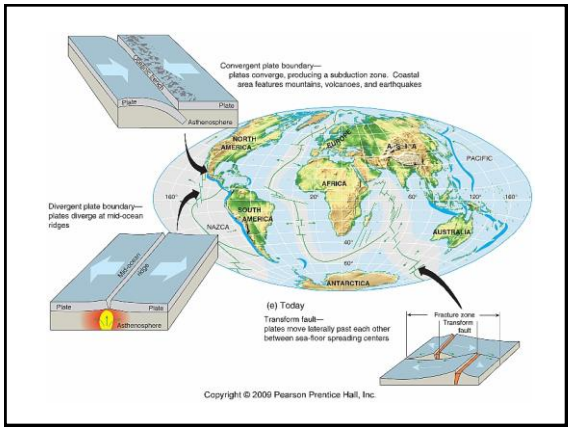


(b) 225 million years ago



(c) 135 million years ago

(d) 65 million years ago


Convergent plate boundary—
plates converge, producing a subduction zone. Coastal
area features mountains, volcanoes, and earthquakes
Plate
Plate
Asthenosphere
NORTH AMERICA
EURO
ASIA
PACIFIC
AFRICA
SOUTH AMERICA
NAZCA
AUSTRALIA
ANTARCTICA
Divergent plate boundary—
plates diverge at mid-ocean
ridges
Mid-ocean ridge
Plate
Plate
Asthenosphere
(e) Today
Transform fault—
plates move laterally past each other
between sea-floor spreading centers
Fracture zone
Transform fault
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