# The Theory of Plate Tectonics

Continental Drift
Seafloor Spreading
Hydrothermal Vents

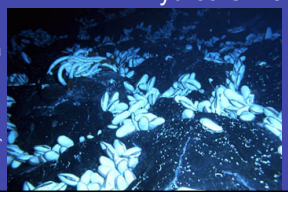


Photo by Richard A. Lutz

tdc02_vid_deepseaventsts_300.mov

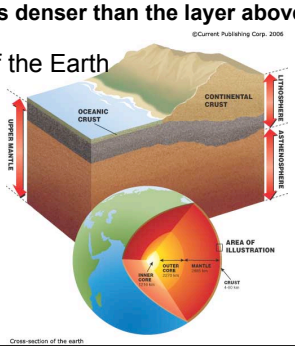
## Chapter 3 Study Plan

- Pieces of Earth's Surface Look Like They Once Fit Together
- Earth's Interior Is Layered
- The Study of Earthquakes Provides Evidence for Layering
- Earth's Inner Structure Was Gradually Revealed
- The New Understanding of Earth Evolved Slowly
- Wegener's Idea Is Transformed
- The Breakthrough: From Seafloor Spreading to Plate Tectonics
- Plates Interact at Plate Boundaries
- A Summary of Plate Interactions
- The Confirmation of Plate Tectonics
- Scientists Still Have Much to Learn about the Tectonic Process

➢**Earth's interior is layered, and the layers are arranged by density.**
**Each deeper layer is denser than the layer above.**

Four major layers of the Earth

- From the center of the Earth:
- Inner core
- Outer core
- Mantle
- Crust



## Density and layering

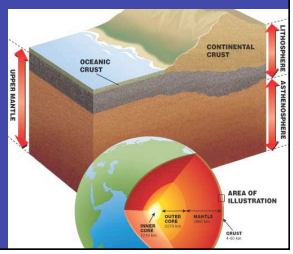
- Density is a key concept for understanding the structure of Earth [and oceans]
- Density measures the mass per unit volume of a substance.

$$\textbf{Density} = \frac{\text{Mass g}}{\text{Volume cm}^3}$$

- Density is expressed as grams per cubic centimeter.
- [Pure] Water has a density of 1 g/cm$^3$

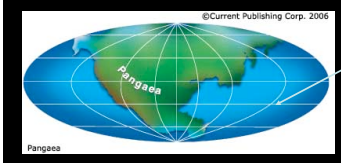
## Two layers of the upper mantle:

- ***Lithosphere*** = uppermost rigid part of the upper mantle and the crust.
- ***Asthenosphere*** = top part of the upper mantle that flows very slowly over time (like old glass or tar)



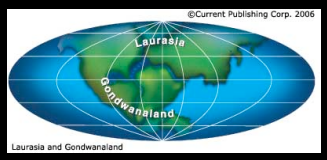

## Theory of continental drift

- Alfred Wegner and Pangaea (single giant continent - *all the Earth)*




Panthalassa: the ocean surrounding Pangaea

- The theory that all the continents were once a single landmass that drifted apart (and are still doing so) is the *theory of continental drift.*



Laurasia and Gondwanaland

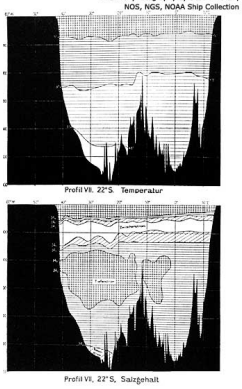
## The Fit Between Continental Edges Suggested That They Might Have Drifted

- Alfred Wegener's theory of continental drift was out of favor with the scientific community until new technology provided evidence to support his ideas.
- Seismographs revealed a pattern of volcanoes and earthquakes.
- Radiometric dating of rocks revealed a surprisingly young oceanic crust.
- Echo sounders revealed the shape of the Mid-Atlantic Ridge

## The theory of seafloor spreading

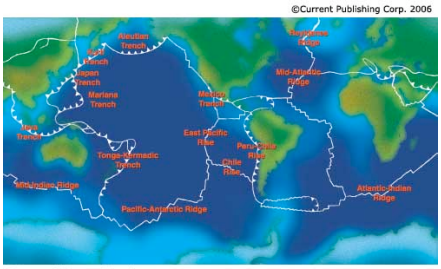
- The invention of SONAR (SOund NAvigation and Ranging) allowed ships to map the topography of the seafloor.

Archival photography by Sean Linehan, NOS, NGS, NOAA Ship Collection



Early map of the seafloor

## Map of ridges and trenches



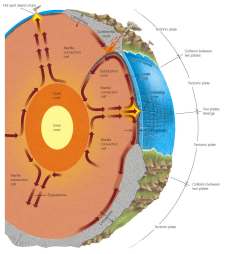

Patterns of ridges and trenches

## The Theory of Plate Tectonics

- The ideas of continental drift and seafloor spreading were tied together in the theory of plate tectonics. Main points of the theory include:
  - Earth's outer layer is divided into lithospheric plates
  - Earth's plates float on the asthenosphere
  - Plate movement is powered by convection currents in the asthenosphere seafloor spreading, and the downward pull of a descending plate's leading edge.

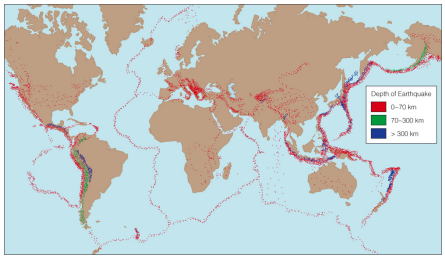
## The Theory of Plate Tectonics

**Where does the heat within Earth's layers come from?**
Heat from within Earth keeps the asthenosphere flowing. This allows the lithosphere to keep moving. Most of the heat that drives the plates is generated by **radioactive decay**, given off when nuclei of unstable elements break apart.



(Left) The tectonic system is powered by heat. Some parts of the mantle are warmer than others, and convection currents form when warm mantle material rises and cool material falls. Above the mantle floats the cool, rigid, lithosphere, which is fragmented into plates. Plate movement is powered by gravity: The plates slide down the ridges at the places of their formation; their dense, cool leading edges are pulled back into the mantle.

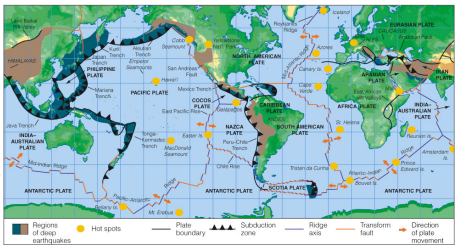
## Most Tectonic Activity Occurs at Plate Boundaries




Seismic events worldwide, January 1977 through December 1986. The locations of about 10,000 earthquakes are colored red, green, and blue to represent event depths of 0-70 kilometers, 70-300 kilometers, and below 300 kilometers.

## Most Tectonic Activity Occurs at Plate Boundaries

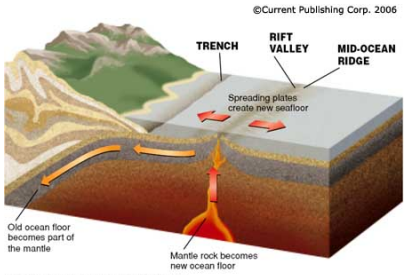
The major lithospheric plates, showing their directions of relative movement and the location of the principal hot spots. Most of the million or so earthquakes and volcanic events each year occur along plate boundaries.




## Ridges and Trenches (continued)

- Rift Valley: a valley running through the center of a **mid-ocean ridge** where the seafloor spreads and new seafloor originates.
- Trench: a deep ravine in the ocean floor where two tectonic plates meet and one is pushed under the other (subduction zone).

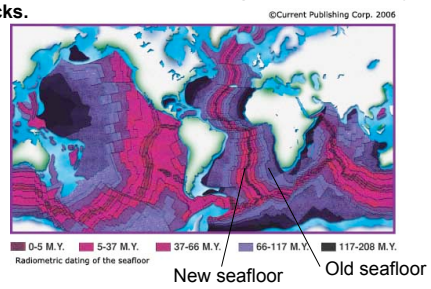
## The creation and destruction of seafloor




Creation and destruction of the seafloor

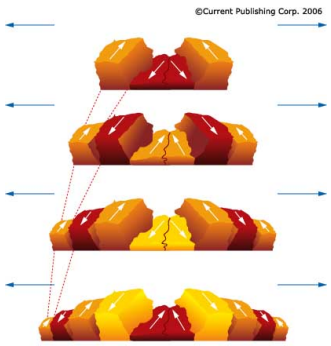
## Age of the seafloor

**Seafloor is younger near ridges where spreading occurs. Seafloor is older farther from ridges, shown here by age of rocks.**



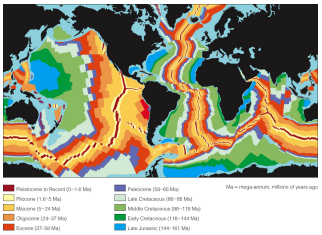

**Evidence of seafloor age: reversal of Earth's magnetic fields**

Location of Earth's magnetic poles changes periodically (over millions of years) as shown by orientation of magnetic particles.



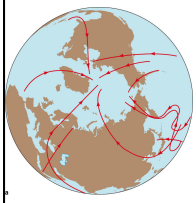

The Vine and Mathews model

## A History of Plate Movement Has Been Captured in Residual Magnetic Fields




The age of the ocean floors. The colors seen here represent an expression of seafloor spreading over the last 200 million years as revealed by paleomagnetic patterns. Note, especially the relative symmetry of the Atlantic basin in contrast with the asymmetrical Pacific, where the spreading center is located close to the eastern margin and intersects the coast of California.

## A History of Plate Movement Has Been Captured in Residual Magnetic Fields




**Apparent Polar wandering:** plate movement causes the apparent position of the magnetic poles to have shifted.

(a) The magnetic properties of rocks in North America, South America, Europe, and Africa suggest that the north magnetic pole apparently migrated to its present position from much farther south, possibly from a point in the Pacific Ocean.

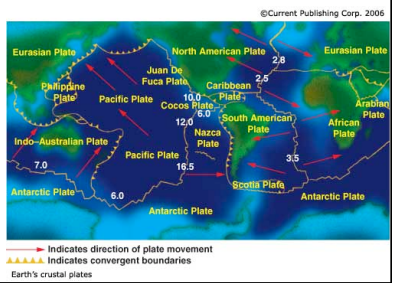
(b) The problem can be solved if the pole remained fixed but the continents have moved. For example, if Europe and North America were previously joined, the paleomagnetic fields in the rocks would indicate a single pole until the continents drift apart.

## What is the theory of plate tectonics?

- **The Earth's lithosphere consists of more than a dozen separate plates. The plates are rigid and float on the asthenosphere.**

•The plates include oceanic and continental crust.

•Continents and oceans are formed and destroyed where plates collide, flex, and sink.

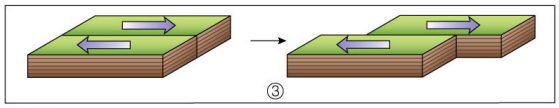


## Boundaries and faults

- **What are the 3 types of boundaries?**
- **Divergent:** is a boundary between 2 plates moving away from each other (rift valleys).
- **Convergent:** is a boundary between 2 colliding plates (mountains; trenches).
- **Transform:** is a boundary between 2 plates sliding against each other - often where earthquakes occur.

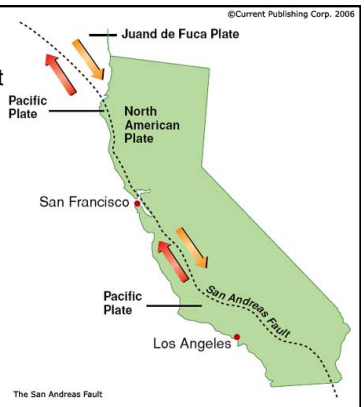
## Most Tectonic Activity Occurs at Plate Boundaries

**Transform plate boundaries** - locations where crustal plates move past one another, for example, the San Andreas fault.




(above) Translation at transform boundaries causes shear.

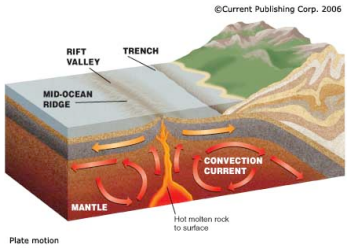
Earthquake zone: San Andreas Fault is an example of a transform boundary where the North American Plate and Pacific Plate meet.



## Why do plates move?

**Convection** is a primary force causing seafloor spreading and continental drift.

Plates are carried along as though on a conveyor belt.




## Ocean Basins Are Formed at Divergent Plate Boundaries

**Divergent plate boundaries** – Boundaries between plates moving apart, further classified as:

- ✓ **Divergent oceanic crust** – for example, the Mid-Atlantic Ridge
- ✓ **Divergent continental crust –** for example, the Rift Valley of East Africa.

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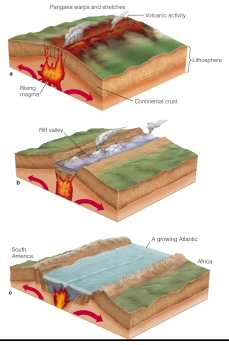
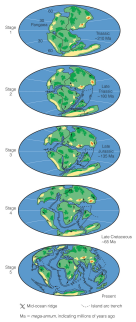


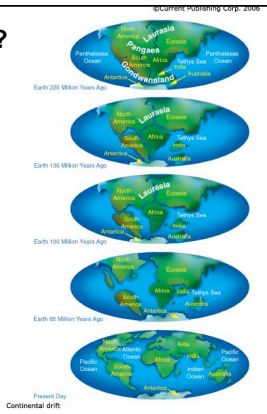

## Ocean Basins Are Formed at Divergent Plate Boundaries



The breakup of Pangaea shown in five stages beginning about 225 million years ago. (Note: *Ma = mega-annum*, indicating millions of years ago). Inferred motion of lithospheric plates is indicated by arrows. Spreading centers (mid-ocean ridges) are shown in red.

## What happens next?

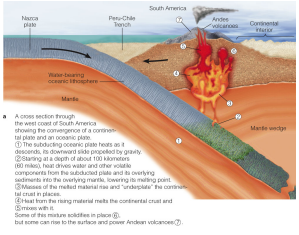
Theory is that over the next several million years:
Atlantic and Indian Oceans will expand;
Pacific Ocean will shrink;
Mediterranean Sea will close as Africa moves northward.




# Convergent Plate Boundaries

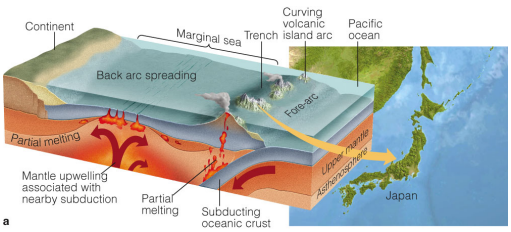
**Convergent Plate Boundaries -** Regions where plates are pushing together can be further classified as:

- **Oceanic crust toward continental crust** - for example, the west coast of South America.
- **Oceanic crust toward oceanic crust** - occurring in the northern Pacific.
- **Continental crust toward continental crust** – one example is the Himalayas.



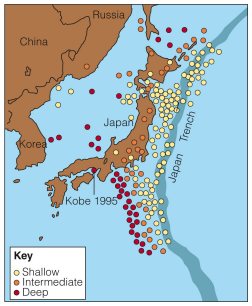

(Above Right) A cross section through the west coast of South America, showing the convergence of a continental plate and an oceanic plate. The subducting oceanic plate becomes more dense as it descends, its downward slide propelled by gravity. At a depth of about 80 kilometers (50 miles), heat drives water and other volatile components from the subducted sediments into the overlying mantle, lowering its melting point. Masses of the melted material, rich in water and carbon dioxide, rise to power Andean volcanoes.

# Convergent Plate Boundaries




(Above) The formation of an island arc along a trench as two oceanic plates converge. The volcanic islands form as masses of magma reach the seafloor. The Japanese islands were formed in this way.

## Convergent Plate Boundaries

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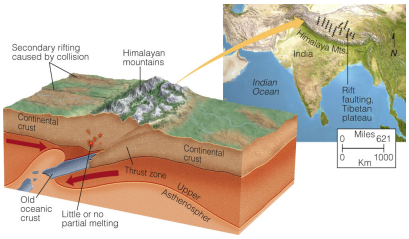
The distribution of shallow, intermediate, and deep earthquakes for part of the Pacific Ring of Fire in the vicinity of the Japan trench.

Note that earthquakes occur only on one side of the trench, the side on which the plate subducts.

The great Indonesian tsunami of 2005 was caused by these forces; the site of the catastrophic 1995 Kobe subduction earthquake is marked.

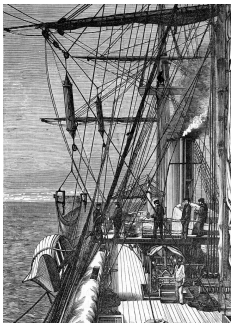
## Convergent Plate Boundaries




(Above) A cross section through southern China, showing the convergence of two continental plates. Neither plate is dense enough to subduct; instead, their compression and folding uplift the plate edges to form the Himalayas. Notice the massive supporting "root" beneath the emergent mountain needed for isostatic equilibrium.

## Continental Margins and Ocean Basins
(Garrison Chapter 4)

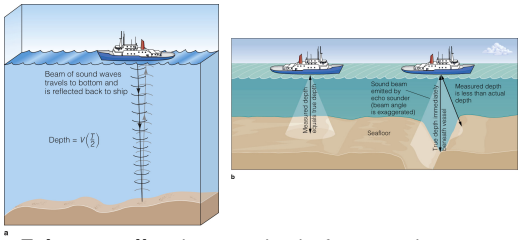
## The Ocean Floor Is Mapped by Bathymetry



The discovery and study of ocean floor contours is called **Bathymetry.**

Early bathymetric studies used a weighted line to measure depth to the ocean floor.

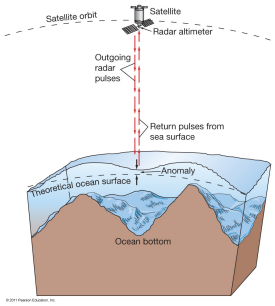
## Echo Sounders Bounce Sound off the Seabed



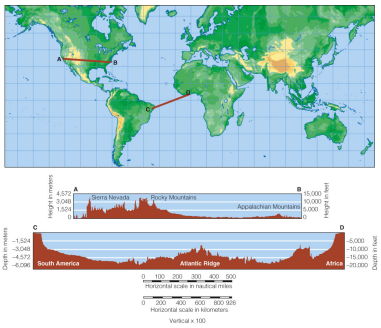

**Echo sounding** is a method of measuring seafloor depth using powerful sound pulses

## Sea Floor Mapping from Space

- Satellites image sea floor features based on gravitational bulges in sea surface
- Indirectly reveals bathymetry

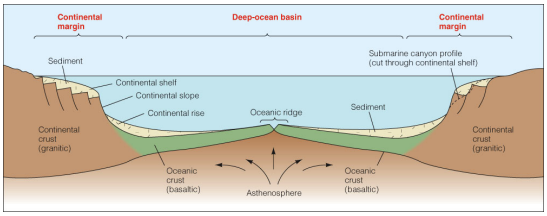


## The Topography of Ocean Floors




Cross section of the Atlantic ocean basin and the continental United States

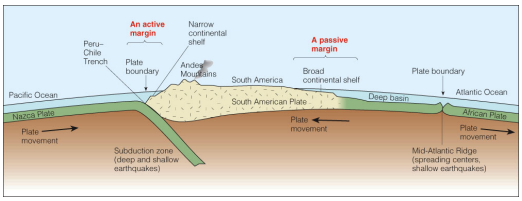
## Ocean-Floor Topography Varies with Location




The submerged outer edge of a continent is called the *continental margin*.

The deep-sea floor beyond the continental margin is properly called the *ocean basin.*

## Continental Margins May Be **Active** or **Passive**




Typical continental margins bordering the tectonically active (Pacific-type) and passive (Atlantic-type) edges of a moving continent.

## Continental Margins

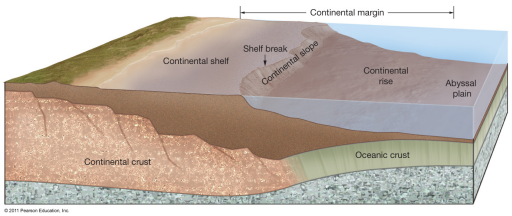
- Passive
  - Not close to any plate boundary
  - No major tectonic activity
- Active
  - Associated with convergent or transform plate boundaries
  - Much tectonic activity

## Active Continental Margins

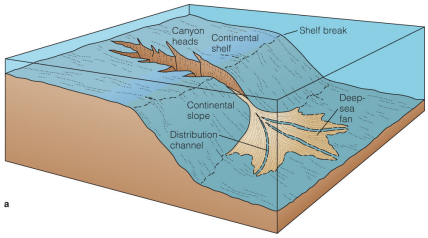
- Convergent Active Margin
  - Narrow shelf
  - Offshore trench
  - Example: Western South America
- Transform Continental Margin
  - Transform plate boundaries
  - Example: Coastal California along San Andreas Fault

## Continental Slope

- Where deep ocean basins begin
- Greater slope than continental shelf
- Marked by submarine canyons



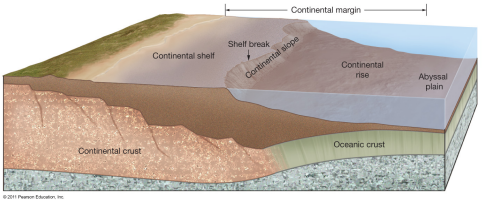
## Submarine Canyons Form at the Junction between Continental Shelf and Continental Slope




**Submarine canyons** cut into the continental shelf and slope, often terminating on the deep-sea floor in a fan-shaped wedge of sediment.

## Continental Rise

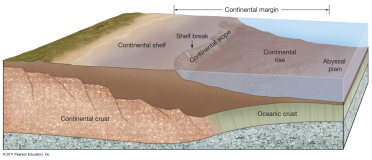
- Transition between continental and oceanic crust
- Deposits generate deep-sea fans, or submarine fans






## Abyssal Plains

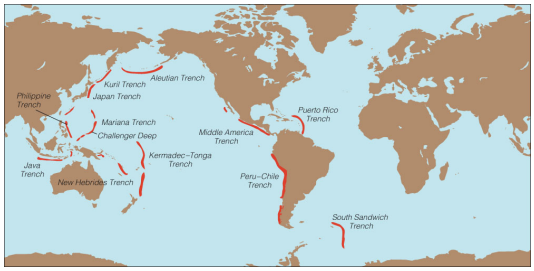
- Deep, flat parts of Earth
- Well-developed in Atlantic and Indian Oceans
- Extend from base of continental rise



## Ocean Trenches

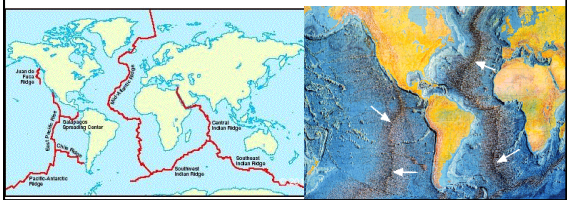
- Convergent (active) margins cause ocean trenches.
  - Deepest part of oceans
  - Most in Pacific Ocean
  - Deepest trench – Mariana Trench at 11,022 meters (36,161 feet)

**Trenches** are depressions in the ocean floor caused by the **subduction** of a **converging** ocean plate. Most trenches are around the edges of the active Pacific.



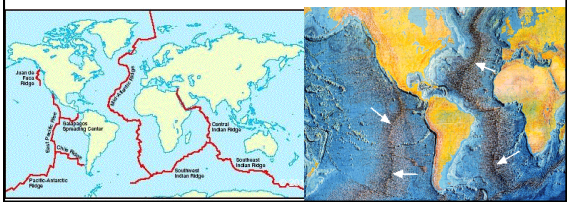

## Mid-Ocean Ridge

- An underwater mountain range, formed by plate tectonics.
- Uplifting of the **ocean** floor occurs when convection currents rise in the mantle beneath the **oceanic** crust and create magma where two tectonic plates meet at a divergent boundary.



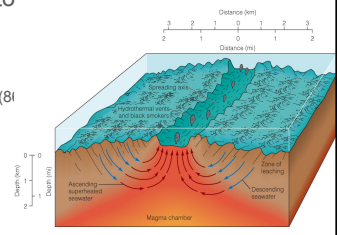
## Mid-Ocean Ridge

- Longest mountain chain
- On average, 2.5 km (1.5 miles) above surrounding sea floor
- Wholly volcanic

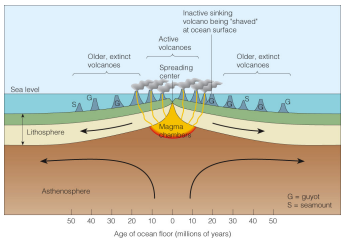


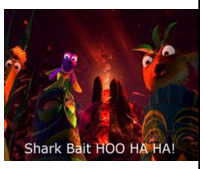

## Hydrothermal Vents Are Hot Springs on Active Oceanic Ridges

- Sea floor hot springs
- Foster unusual deep-ocean ecosystems able to survive without sunlight
- White smokers
  - temps from 30–350˚C (8 662˚F)
- Black smokers
  - temps above 350˚C




## Volcanic Seamounts and Guyots Project above the Seabed

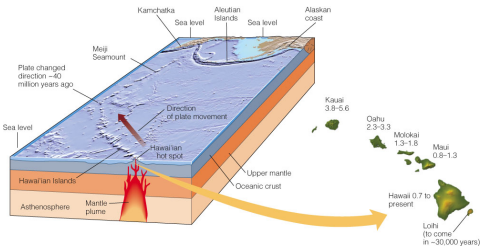



**Seamounts** are volcanic projections from the ocean floor that do not rise above sea level. Flat-topped seamounts eroded by wave action are called **guyots**

**Abyssal hills** are flat areas of sediment-covered ocean floor found between the continental margins and oceanic ridges. **Abyssal hills** are small, extinct volcanoes or rock intrusions near the oceanic ridges.

# Plate Movement above Mantle Plumes and Hot Spots




(above) Formation of a volcanic island chain as an oceanic plate moves over a stationary mantle plume and hot spot. In this example, showing the formation of the Hawai'ian Islands, Loihi is such a newly forming island.