The Theory of Plate Tectonics, Pt. II

BI 201 Natural History of Guam

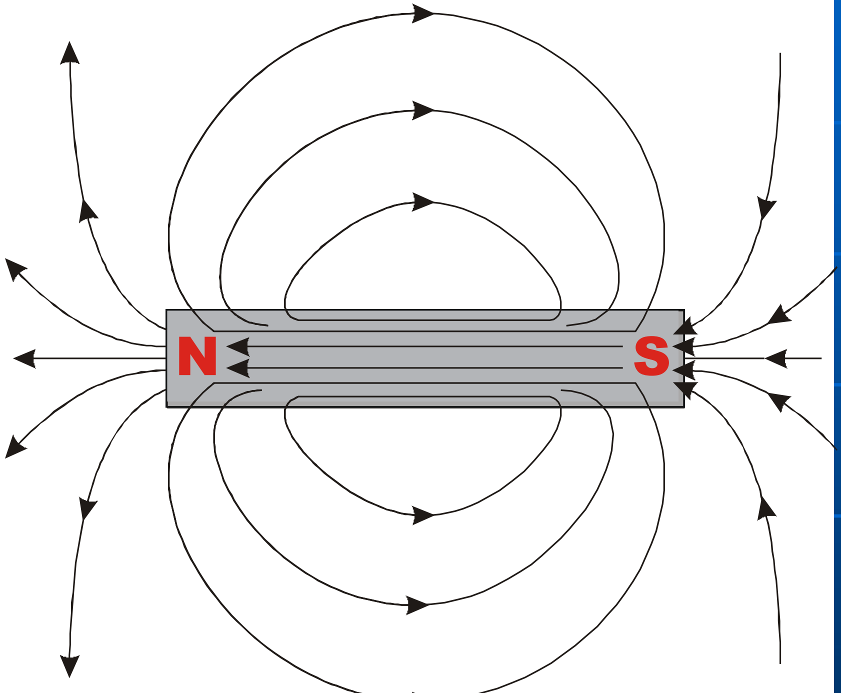
Class Presentation 06

II. The Seafloor Spreading Hypothesis

- Research in two areas of science in the 1940s and 1950s provided additional evidence in support of continental movement, and eventually were integrated into a new model

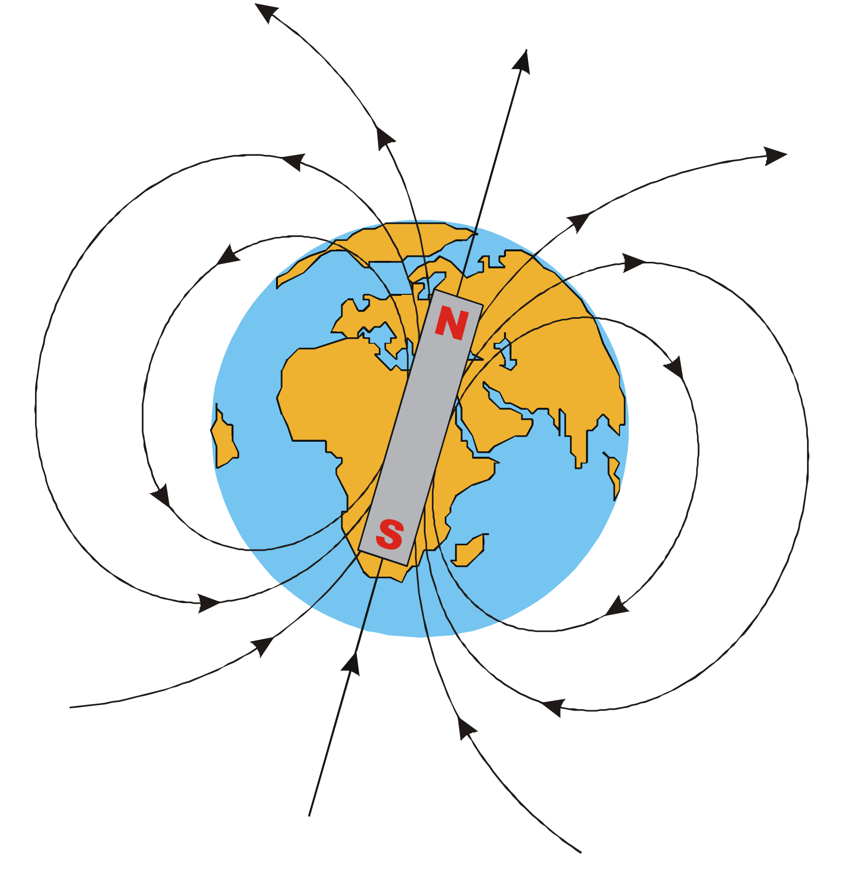
1) **Paleomagnetism**

- This is the study of ancient magnetic fields
- Earth is like a giant bar magnet, surrounded by a magnetic force field



Magnetic force field around a bar magnet

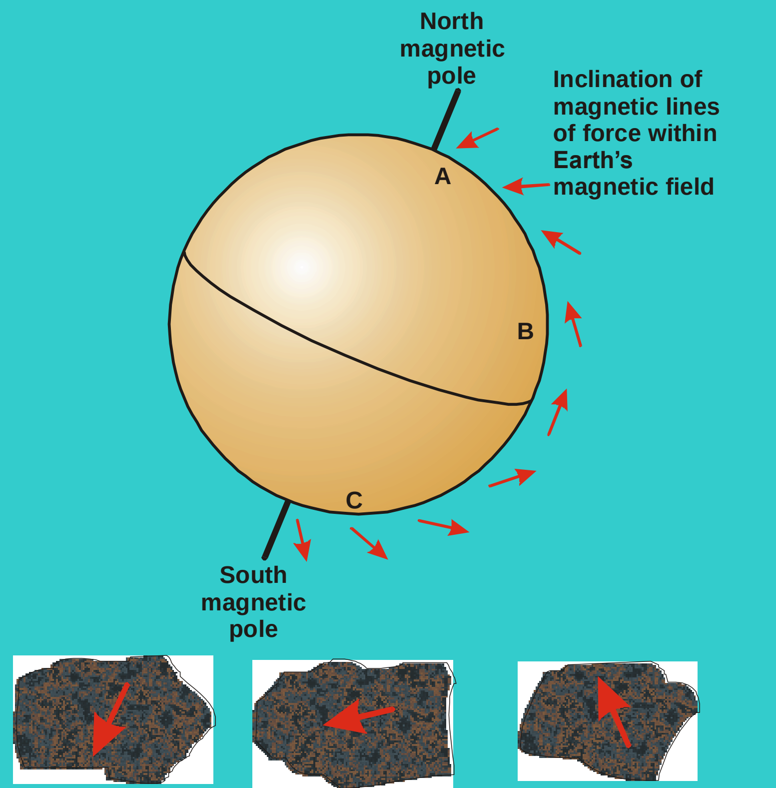
- The magnetic pole is where the strength of the magnetic field is greatest and where magnetic lines of force appear to enter or leave the Earth



Earth’s magnetic field

- Lava flowing to the surface contains tiny crystals of **magnetite**, an iron compound (Fe_3O_4), that are tiny, natural magnets
- These magnetite crystals act like tiny compasses in molten lava and orient with the Earth's magnetic field
- When the lava cools and solidifies, the crystals form a permanent record of Earth's magnetic field

- Because magnetic lines of force dip more steeply as the North magnetic pole is approached, the inclination (i.e., ***dip***) of the magnetite crystals in the lava flows can be used to determine the distance from a flow to the pole
- Therefore, old pole positions can be determined precisely, because the magnetite crystals in igneous rock point toward the pole and indicate its distance by the amount of magnetic dip



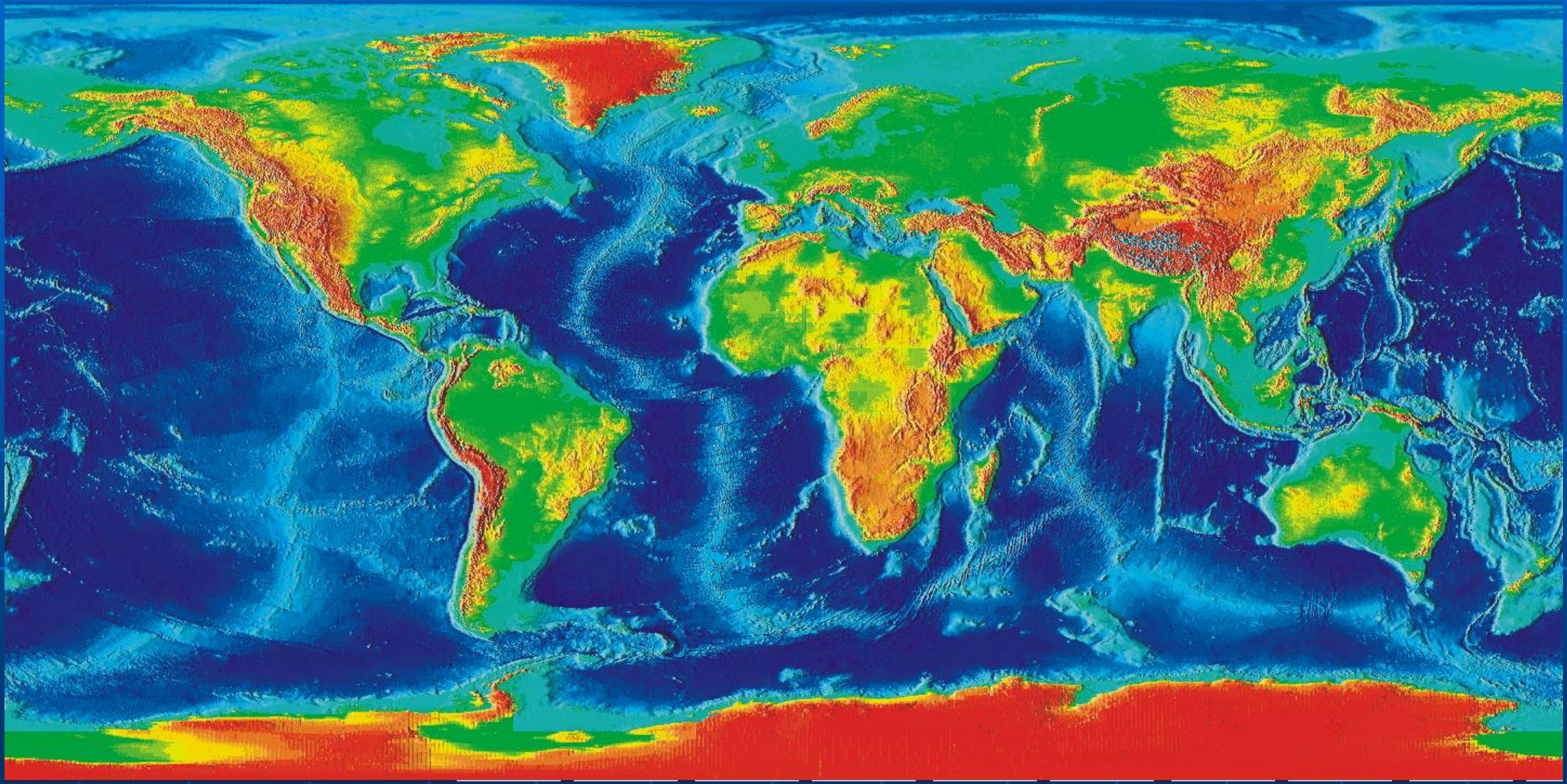
Magnetic dip (= inclination) increases toward the north magnetic pole. Rock samples at the bottom of the figure are taken from points A, B, and C on the globe. The magnetic dip can, therefore, be used to determine the distance from a rock to the north magnetic pole.
[Modified from Plummer and McGeary, 1991.]

- During the Permian, lava flows in North America indicate that the North magnetic pole was in Asia; but in Europe, Permian lava flows indicate a different location, nearer Japan
- Question: Were there <u>two</u> North magnetic poles during the Permian, or have the positions of the continents changed?

Polar wandering of the north magnetic pole as determined from measurements of rocks from North America and Europe. [Modified from Cox and Doell, 1960.]

2) Study of the sea floor

- Oceanographic studies expanded rapidly following the invention of sonar [**SO**und **NA**vigation **R**anging]
  - Sonar enabled production of detailed maps of the sea floor
- Sonar revealed many features on the sea floor, including the mid-oceanic ridge and trenches, as well as other features



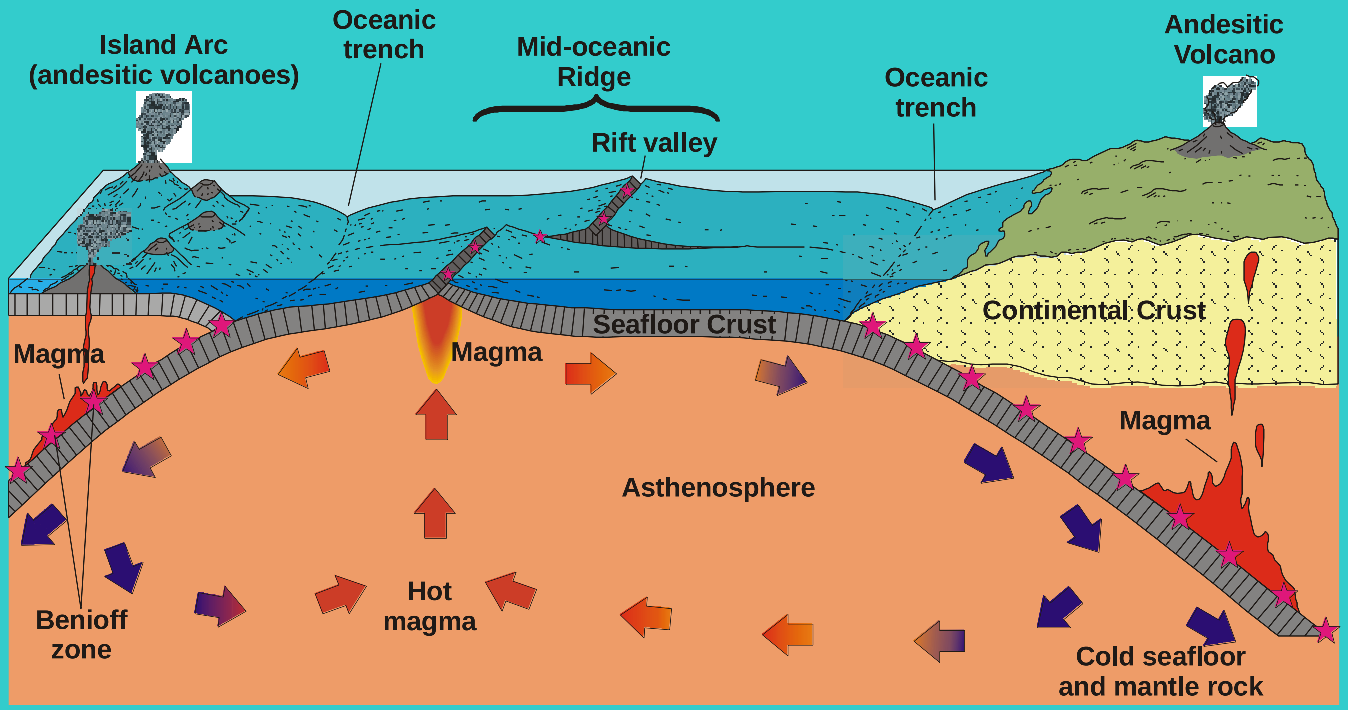
Topographic map of Earth’s crust

- **Harry Hess**, a geologist at Princeton, developed a hypothesis proposing that the sea floor moves

Harry Hess, 1906-1969

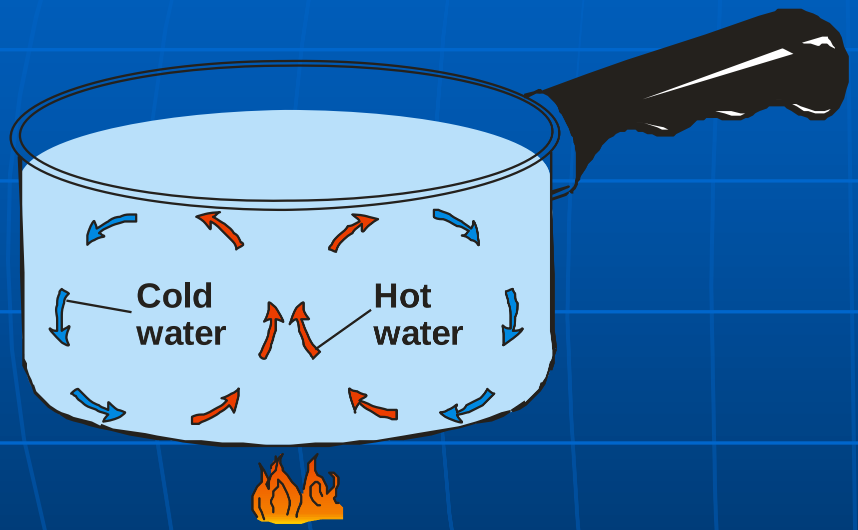
- Hess proposed that new sea floor is created at the mid-oceanic ridge by magma seeping into rifts and cooling
- At first glance, this would cause the Earth to increase in diameter
- To address this problem, Hess proposed that old seafloor sinks back into the mantle at trenches, maintaining Earth’s diameter

- Therefore, the sea floor is moving like giant conveyor belt away from crest of mid-oceanic ridge, down the flanks of the ridge, and across the deep ocean basin, to disappear finally by plunging into a trench beneath a continent or island arc
- Hess' hypothesis was called sea floor spreading, because he reasoned that the ridge crest is the spreading center

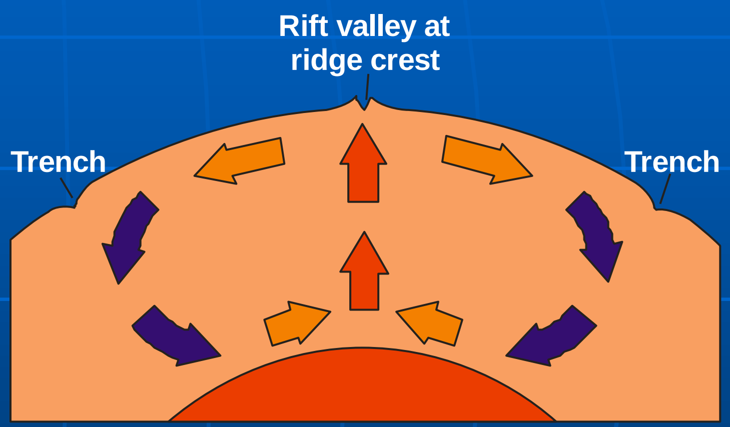


Hot magma rising beneath the mid-oceanic ridge causes basaltic volcanism and high heat flow. Divergence of the sea floor splits open the rift valley and causes shallow-focus earthquakes (smaller stars on ridge). Sinking of cold, dense rock causes subduction of old seafloor at trenches, producing Benioff zones of deep-focus earthquakes (larger stars on subducting seafloor) and andesitic volcanism.

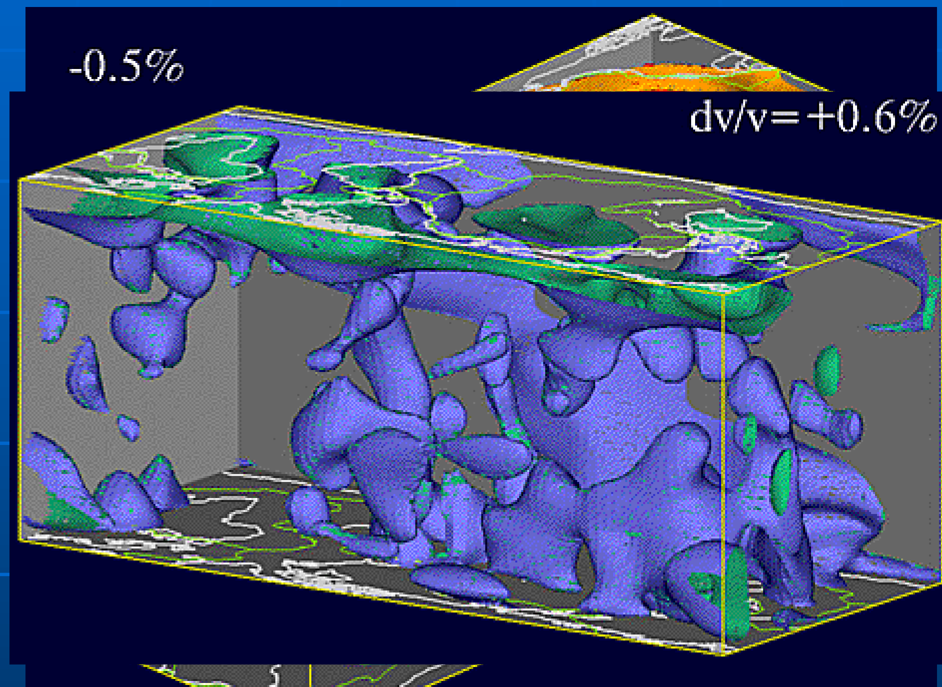
- What was the driving force for seafloor spreading?
  - Hess proposed that **convection currents** of magma in the **asthenosphere**
    - A convection current is a very slow circulation of a fluid substance driven by differences in temperature and density within that substance
    - The asthenosphere is a weak zone within the upper mantle, underlying the lithosphere and consisting of hot, plastic magma that acts as a lubricating layer for tectonic plate movement



Convection currents in a pot of water.



Hess proposed that convection extended throughout the mantle. (Scale of ridge and trenches is exaggerated.)



Seismic tomography of sinking magma in Earth’s mantle

Seismic tomography of rising magma in Earth’s mantle

- This hypothesis helped explain data about many features of sea floor
  - Mid-oceanic ridge
    - The ridge crest is 1000s km higher than the surrounding abyssal plain
    - High heat flow is measured along the mid-oceanic ridge
    - Fresh basalt is found at the ridge crest
    - Frequent, shallow earthquakes are recorded along the mid-oceanic ridge

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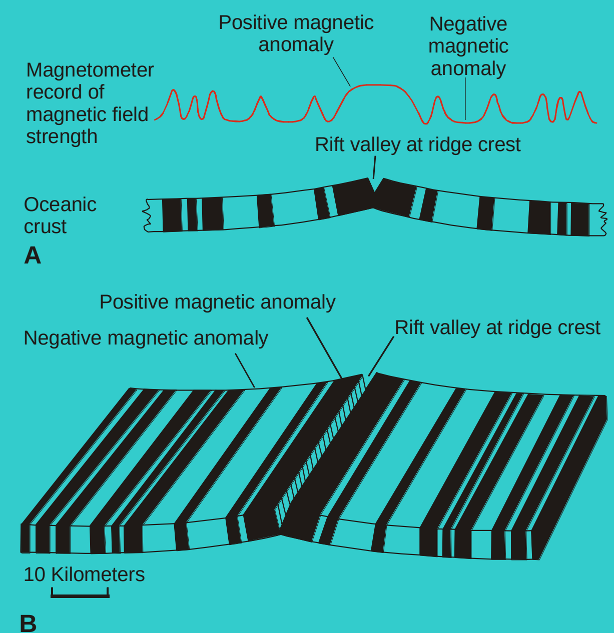
- Hess suggested that if convection drives sea-floor spreading, then hot mantle rock must be rising under the mid-oceanic ridge
- As hot rock continues to rise, the circulation pattern splits and diverges away from ridge near the lithosphere
- Friction of the hot, molten rock moving horizontally away from the ridge on each side creates tension at the ridge crest
- The tension is released by cracking open of the oceanic crust to form the rift valley and causing its associated shallow-focus earthquakes

- Oceanic trenches
  - Hot mantle rock moving horizontally drags the overlying sea floor along with it
  - As the seafloor rock moves away from the mid-oceanic ridge, it cools and becomes denser
  - Eventually, the sea floor becomes cold and dense enough to sink back into the mantle, where it is re-melted

- The downward plunge of the seafloor rock produces **oceanic trenches**
- The interaction between plunging crust and floating crust produces [Benioff] zones of earthquakes associated with trenches
- This interaction also produces andesitic volcanism, which forms volcanoes either in island arcs or on the edge of a continent

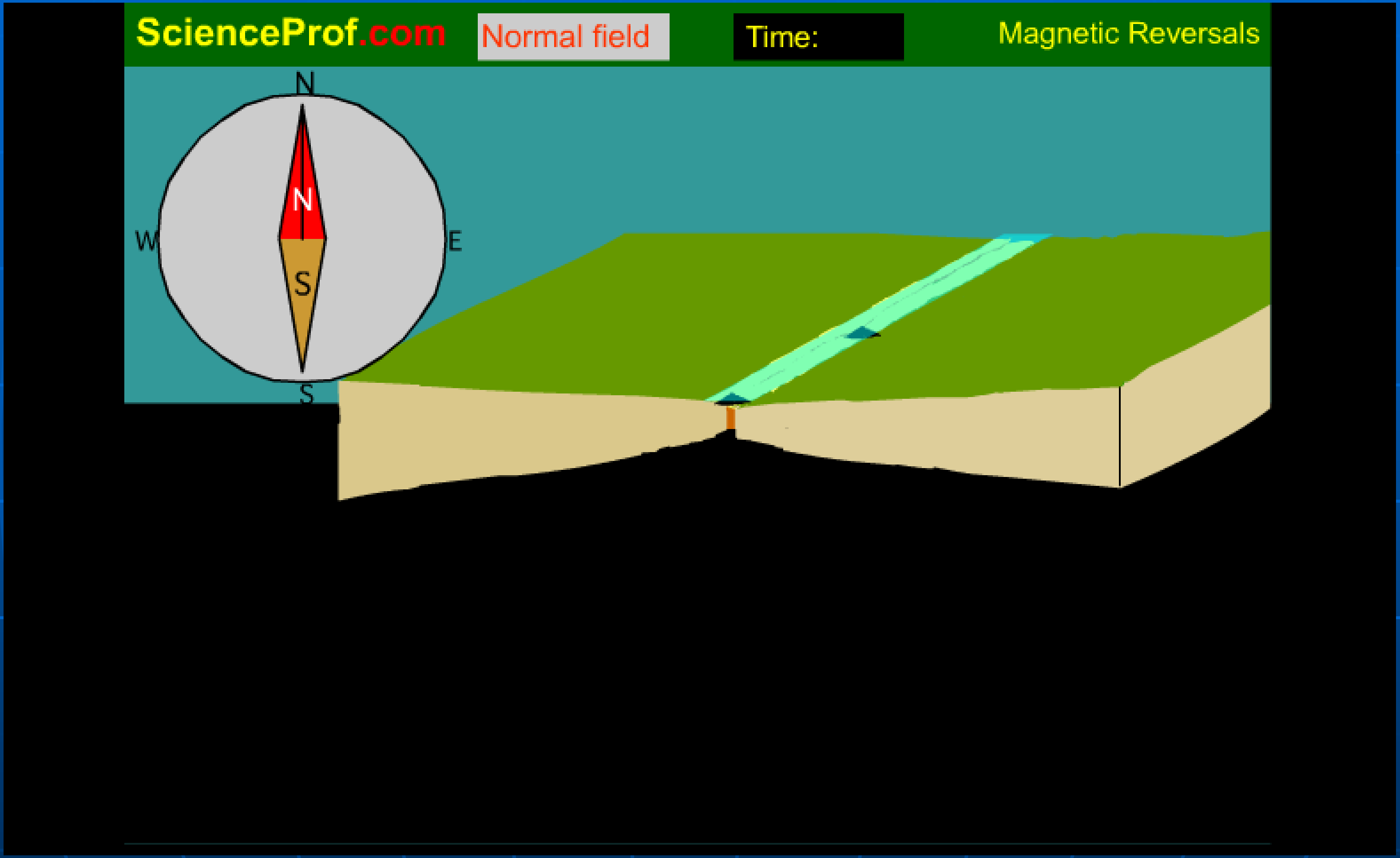
- Seafloor spreading was verified by deep sea research, with an added bonus
  - Deep-sea drilling revealed marine magnetic anomalies in the seafloor
  - The magnetic record on the sea floor contained banding patterns of magnetic polarity reversals

- The bands were parallel to the mid-oceanic ridge crest, and they matched with the record of magnetic reversals recorded in lava flows on continents



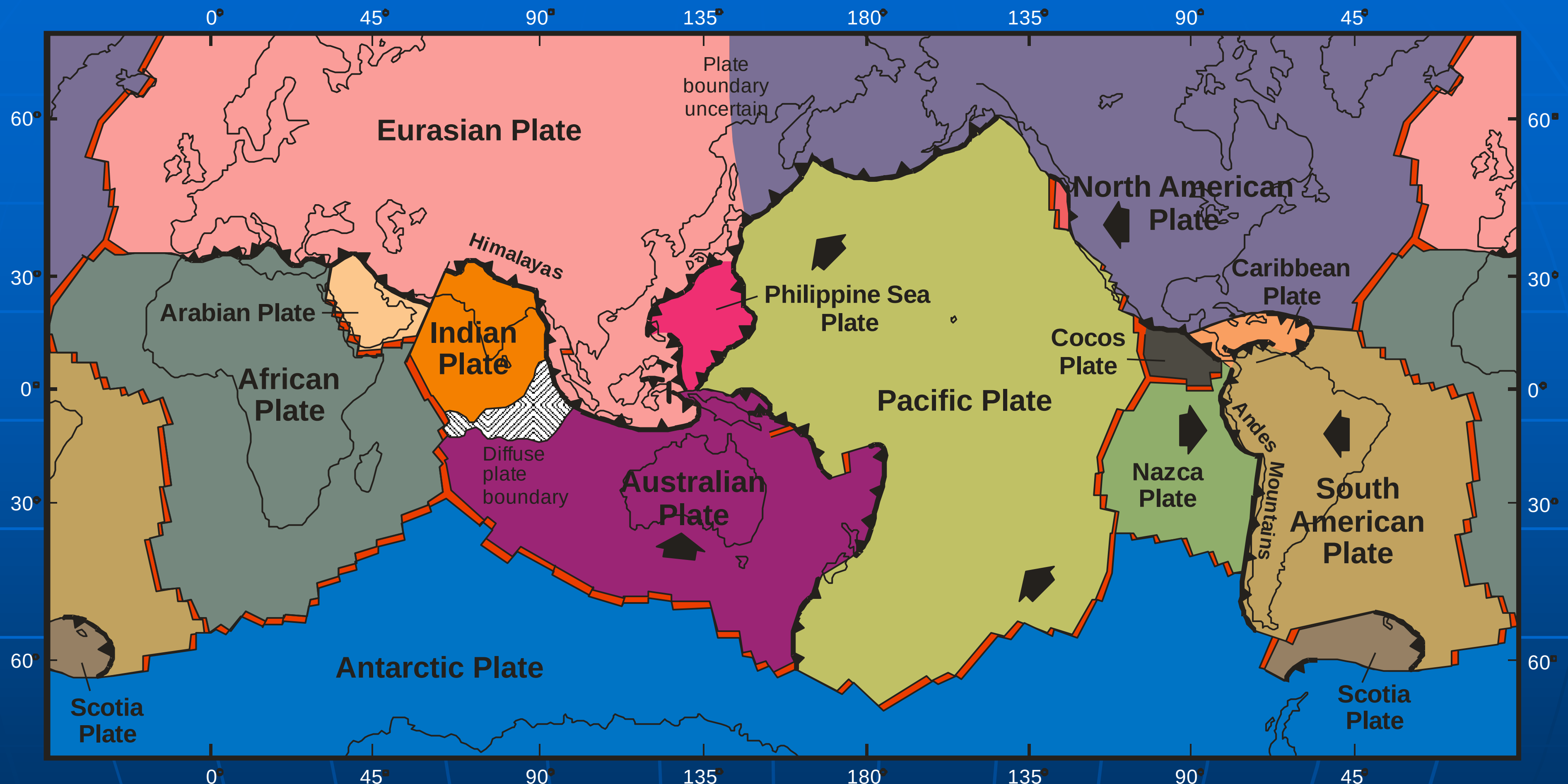
Marine magnetic anomalies. (A) The red line shows positive and negative anomalies as recorded by a magnetometer towed behind a ship. In the cross section of oceanic crust, positive anomalies are drawn as black bars and negative anomalies are drawn as white bars. (B) Perspective view of magnetic anomalies shows that they are parallel to the rift valley and symmetric about the ridge crest.
[Adapted from Plummer and McGeary, 1991.]

- This new evidence enabled scientists to:
  1) measure the rate of sea-floor motion
  2) predict and determine the age of the sea floor


ScienceProf.com
Normal field
Time:
Magnetic Reversals
N
W
E
S
N
S

- The hypotheses of Wegener and Hess were unified into the theory of plate tectonics
  - The surface of Earth consists of large, mobile slabs of rock called plates
  - There are 10 major plates, 12 minor plates, and numerous microplates
    - Plates are part of the rigid outer shell of Earth, called the **lithosphere**

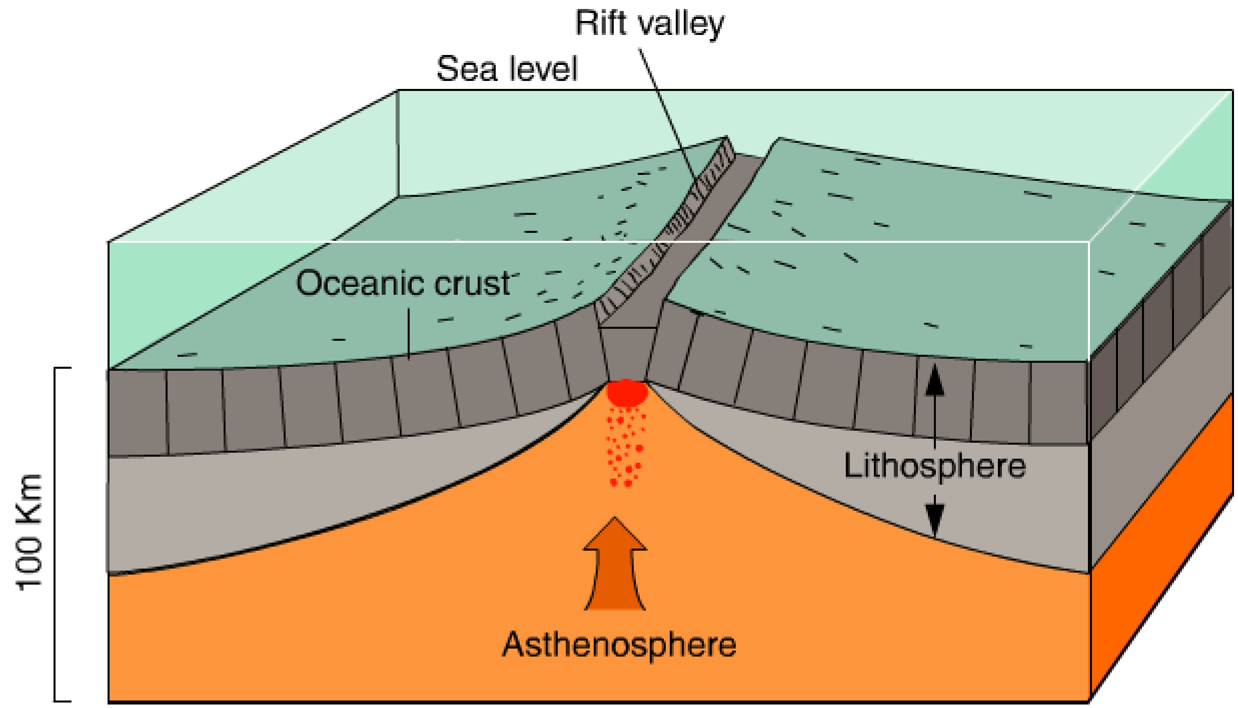
- Below the lithosphere is the **asthenosphere**
  - The asthenosphere is a zone of about 100 km thickness, consisting of hot, plastic **magma** [=semi-molten rock]
  - The asthenosphere acts like a lubricating layer under the lithosphere and allows plate movement



The major tectonic plates of the world. The western edge of the map repeats the eastern edge so that all plates can be shown unbroken. Spreading centers are in red, and converging boundaries are indicate d by heavy lines with triangles. (Modified from W. Hamilton (1977, U.S. Geological Survey) and National Geographic Society (1995).

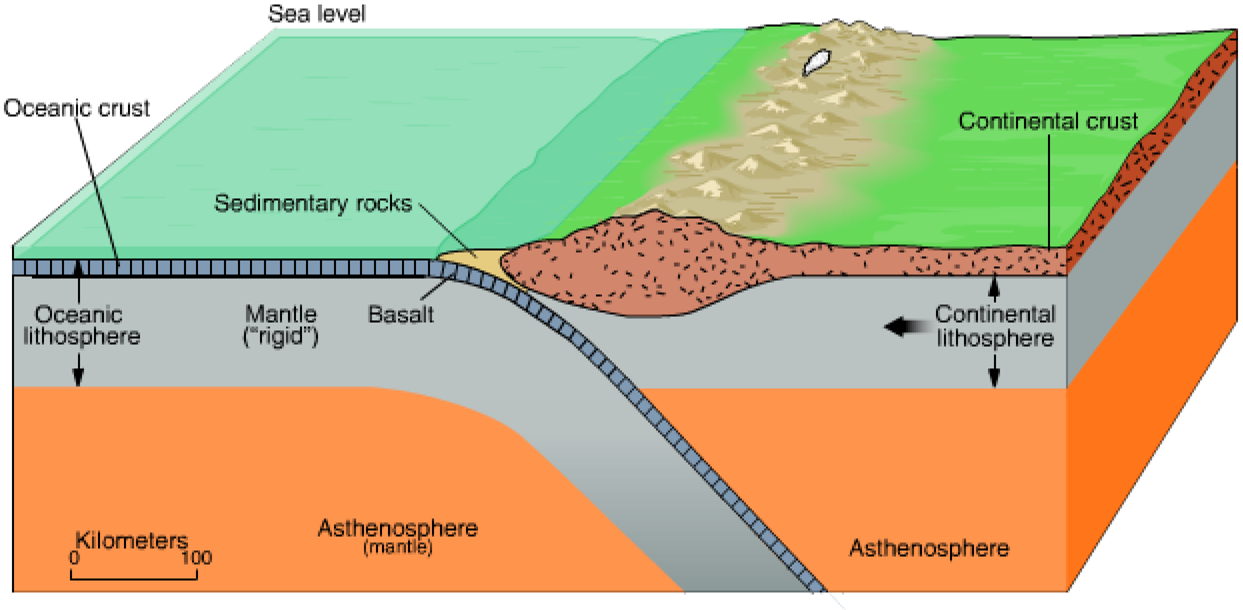
- The theory of plate tectonics suggests that there are three types of plate boundaries

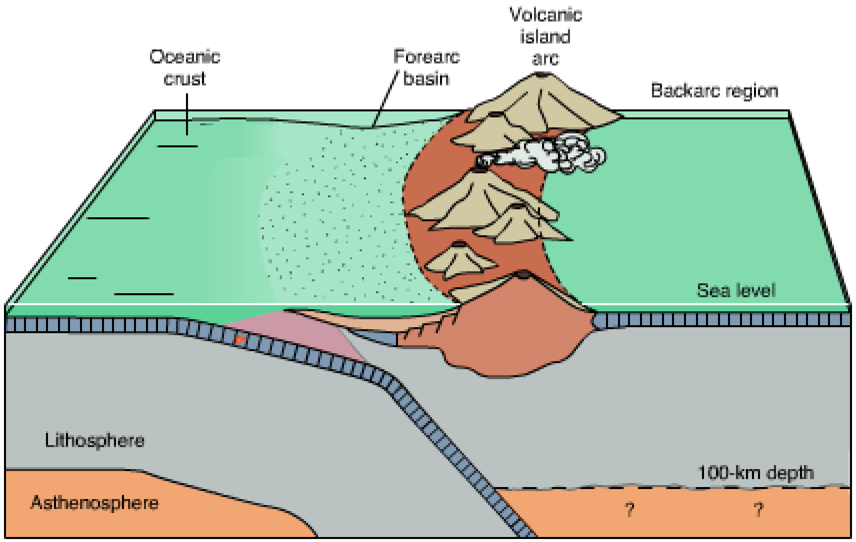
1. Diverging boundaries
   - Diverging boundaries are where plates move apart
   - They form rift zones where new crust is made


Rift valley
Sea level
Oceanic crust
Lithosphere
100 Km
Asthenosphere

2. Converging boundaries

- Converging boundaries are where plates collide
- They form subduction zones, where trenches are produced, or thrust zones, where mountains are formed


Sea level
Oceanic crust
Sedimentary rocks
Continental crust
Oceanic lithosphere
Mantle ("rigid")
Basalt
Continental lithosphere
Kilometers
0
100
Asthenosphere
(mantle)
Asthenosphere



Volcanic
island
arc
Oceanic
crust
Forearc
basin
Backarc region
Sea level
Lithosphere
100-km depth
Asthenosphere
?
?

3. <u>Transform boundaries</u>

- Transform boundaries are where plates slide past each other in opposite directions

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Empirical data supporting plate tectonics theory

	Oceanic Crust	**Continental Crust**
Crust Thickness [Plate Lithosphere Thickness	7 km 70 km	30-50 km 125 km]
Density of Rock	3.0 g/cm^3	2.7 g/cm^3
Probable Composition	Basalt	Granite
Age (i.e., Oldest)	~190 Mybp	3.964 Bybp