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SIXTH EDITION

Invitation to Oceanography

Chapter 3

The Origin of Ocean Basins

Continental Drift

- **Alfred Wegner** proposed his hypothesis of continental drift based upon
  - the fit of continental outlines
  - fossil evidence
  - geologic evidence

- The continents are sections of a past super continent called Pangea, surrounded by a single ocean he called Panthalassa.

- Pangea broke apart and the continents drifted to their present locations.

Fitting the Continents Together

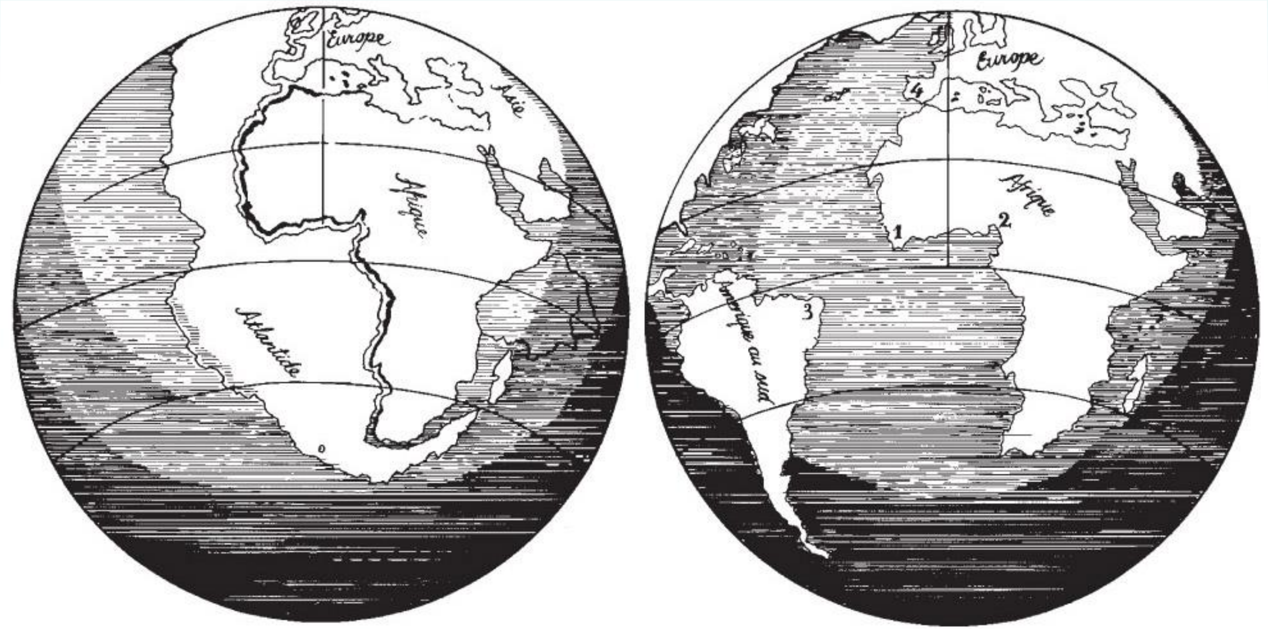


Figure 03.01a: This map, published by Antonio Snider in 1858, shows the arrangement of the continents into a large landmass.

Pangaea, 200 to 300 MYBP

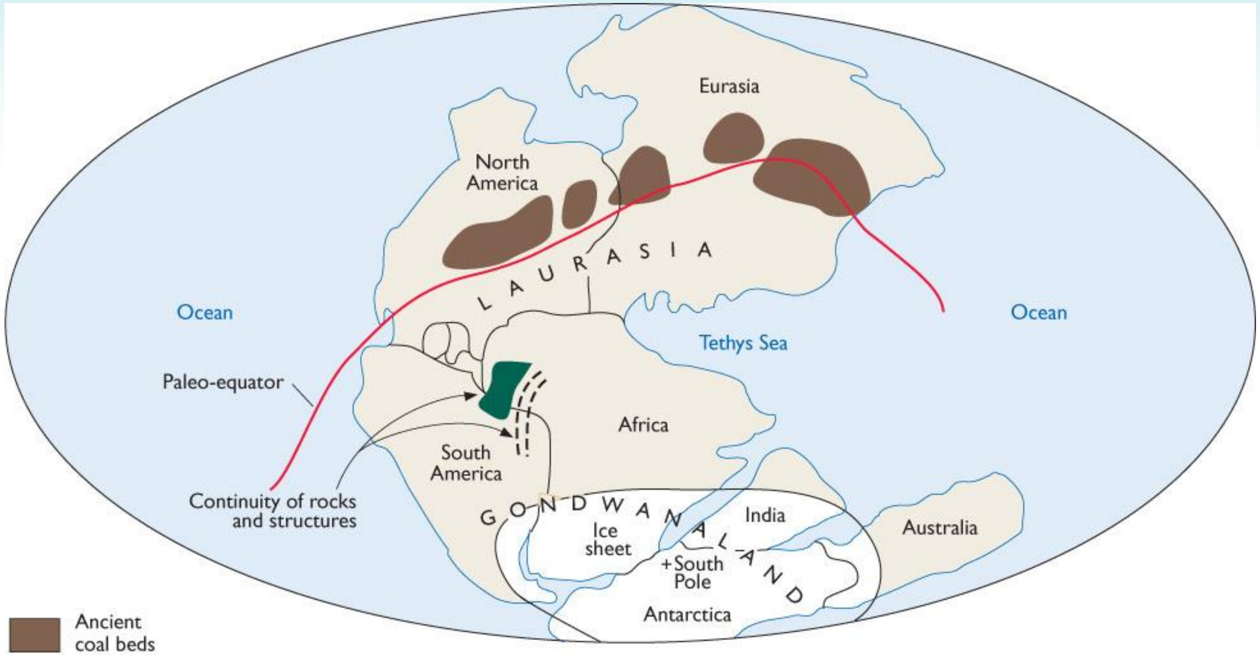


Figure 03.01b: If the continents are arranged into Pangea, coal beds and glacial deposits that are 200 to 300 million years old fall into latitudinal belts.

The Breakup of Pangaea

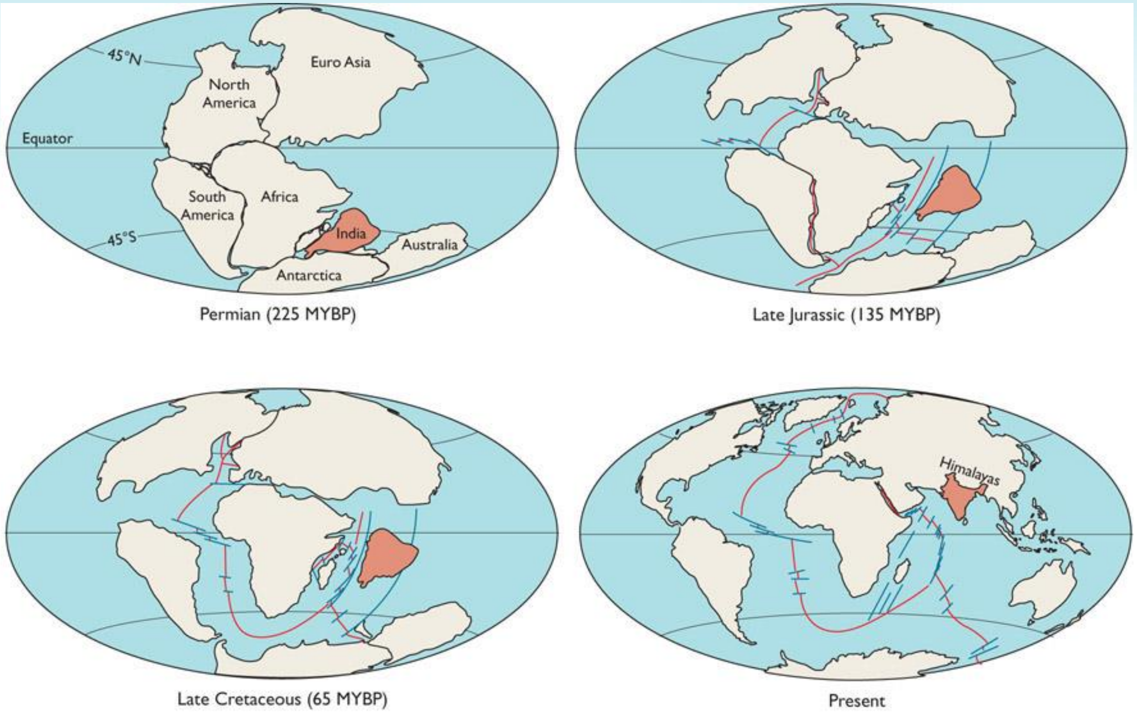


Figure 03.12a: This sequence of maps displays the changing world geography since the time of Pangaea, the megacontinent of the Permian Period.

Sea Floor Spreading

- Sea floor spreading was proposed and confirmed in the 1960s, long after Wegener's hypothesis became very unpopular…
- It demonstrates that:
  - the sea floor moves apart at the oceanic ridges
  - new oceanic crust is added (mainly through volcanic activity) in the rift valleys at the crests of those ridges

- Rift valleys along oceanic ridge crests:
  - indicate tension
  - are bounded by normal faults
  - are floored by recently-erupted basaltic lava flows

Ridges & Faults

Axis of the oceanic ridge (divergent, spreading displacement) is offset by transform (strike-slip) faults which produce lateral displacement.

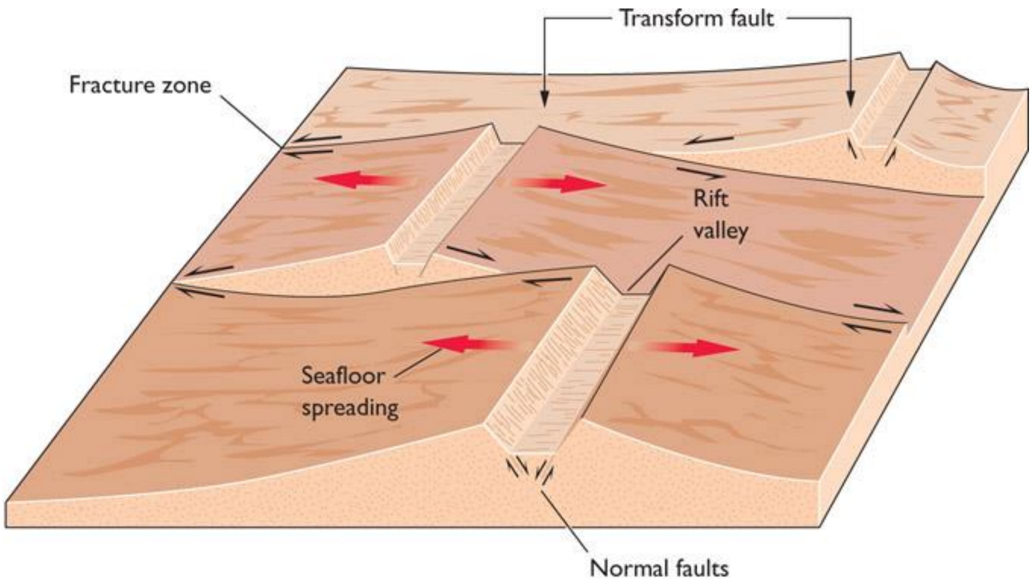


Figure 03.02a: The rift valley at the crest of midocean ridges is formed by tension.

The Geomagnetic Field (Continued)

- These measurements (called **magnetic anomalies**) alternate **strong (positive)** and **weak (negative)** in response to the influence of the sea floor rocks.

- Magnetic anomalies form parallel bands arranged symmetrically about the axis of the oceanic ridge.

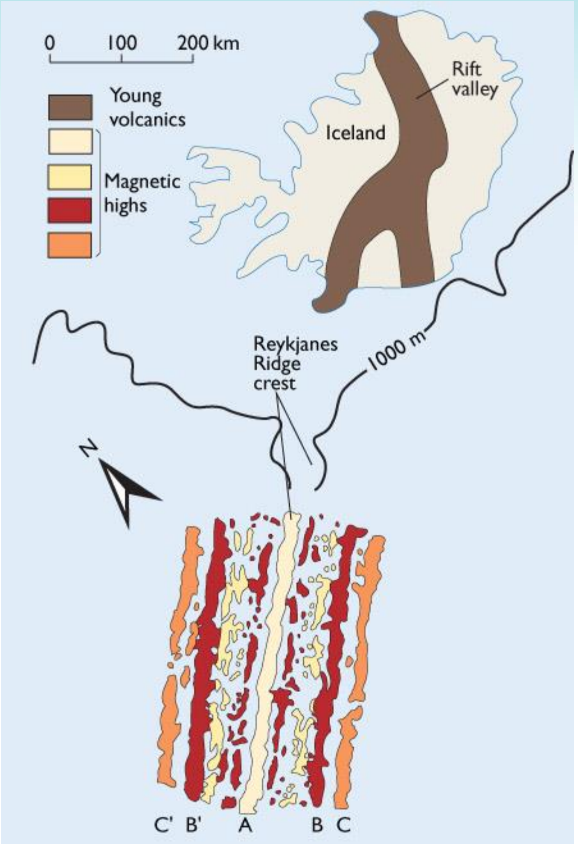


Figure 03.03: Magnetic anomaly stripes run parallel and are symmetrically arranged on both sides of the midocean ridge axis.

The Geomagnetic Field (Continued)

- Ocean floor rocks are mostly basaltic, and they contain minerals rich in iron. These minerals aligned themselves with Earth's magnetic field <u>**as it existed at the time when the lava erupted and froze**</u> to form volcanic basalt.

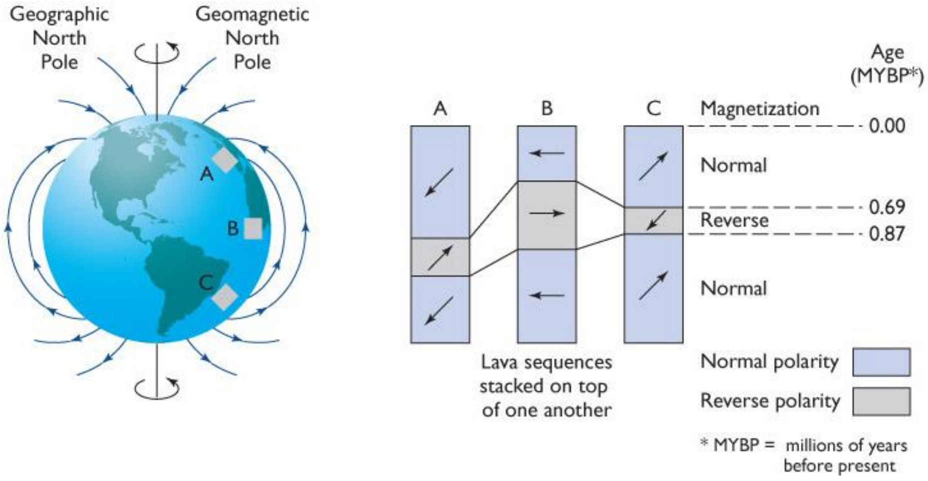


Figure 03.04a: The lava sequences in areas A, B, and C have alternating directions of rock magnetization.

The Geomagnetic Field (Continued)

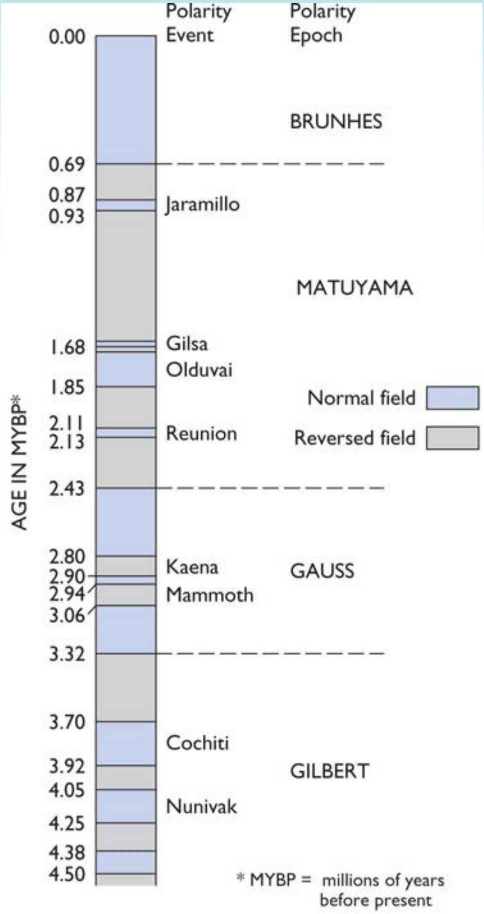


Figure 03.04c: Based on numerous analyses of lava flows on land, the pattern of polarity reversals of the Earth's magnetic field has been accurately established.

- This imparts a permanent magnetic field, called **paleomagnetism**, to the rock.
- This is measured by looking at magnetic rocks of <u>known age</u> that are collected from <u>one place</u> to construct a **paleo-magnetic time scale.**

The Geomagnetic Field (Continued)

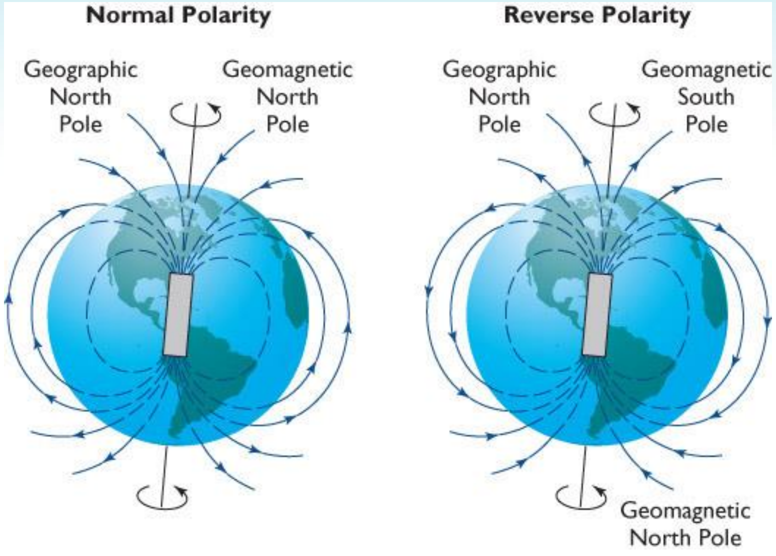


Figure 03.04b: During normal polarity, the geomagnetic north pole lies near the geographic north pole. During a reversal, it flips with the geomagnetic south pole.

The geomagnetic polarity time scale, a.k.a. the paleomagnetic time scale shows that over geologic time, the Earth's magnetic field polarity (direction) periodically reverses poles

The Sea Floor and the Geomagnetic Field

- Because of their paleomagnetism, rocks of the sea floor influence the magnetic field recorded by magnetometers.
- Rocks on the sea floor with **normal** polarity (e.g. the same as today) paleomagnetism **locally reinforce** Earth's magnetic field making it **stronger** and producing a **positive anomaly**.

- Rocks on the sea floor with **reverse** polarity (e.g. the opposite from today) paleomagnetism **locally weaken** Earth's magnetic field, producing a **negative anomaly.**

Magnetic Reversals

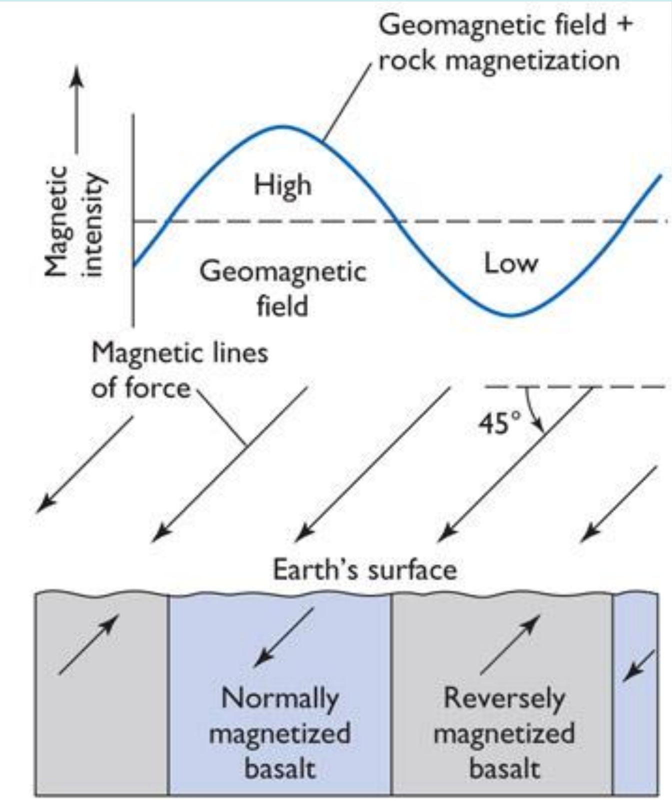


Figure 03.04d: A magnetometer measures simultaneously both the Earth's magnetic field and the fossil magnetization in the rocks.

Magnetic reversals give rise to a magnetic anomaly signature that is the sum total of both the modern field and the influence of the ocean floor rocks.

Dating and the Magnetic Field

- Rocks forming at the ridge crest record the magnetic field existing at the time (and place) when they solidify.
- Sea floor increases in age and is more deeply buried by sediment away from the ridge because sediments have had a longer time to collect.
- It also gets deeper as it cools, because colder rocks are denser and "float" lower (isostasy!)

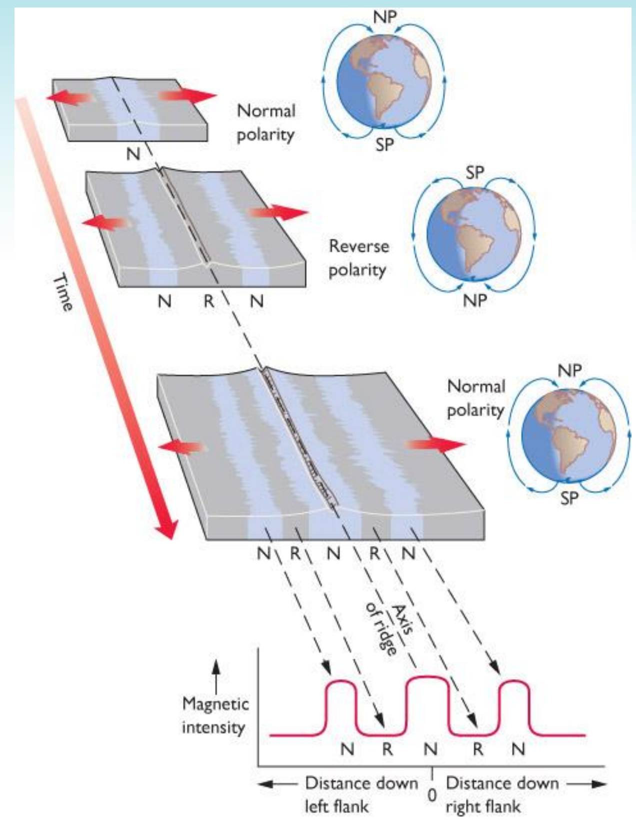


Figure 03.05a: Sea-floor speading combined with geomagnetic polarity reversals creates magnetic anomaly stripes

Determining Rates of Change

- Rates of sea-floor spreading vary from 1 to 10 cm per year for each side of the ridge.
- Rates can be determined by dating magnetic anomaly stripes of the sea floor and measuring their distance from the ridge crest.
- Continents are moved by the expanding sea floor - they ride on larger blocks we call "Lithospheric Plates".

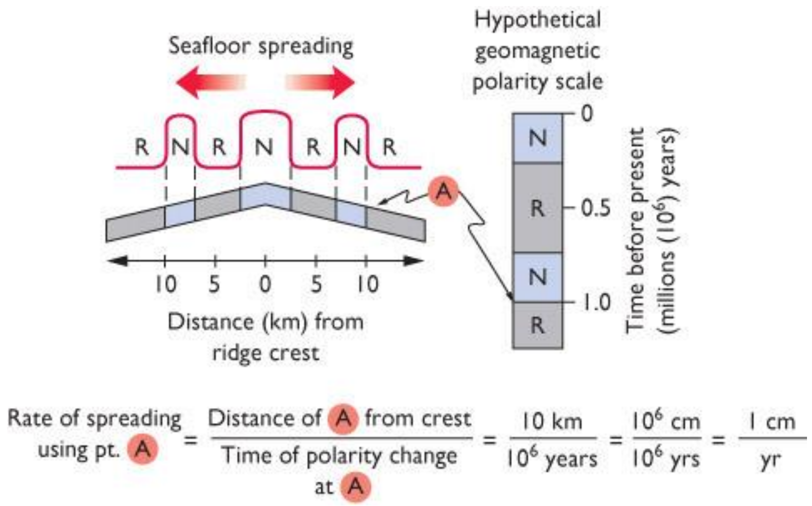


Figure 03.05b: The rate of seafloor spreading is easily calculated using the age and distance from the ridge crest of any magnetic anomaly stripe.

The Changing Ocean Floor

- Because Earth's size has not changed, expansion of the crust in one area requires destruction (throuh convergence) of the crust elsewhere.
- Currently, the Pacific Ocean basin is shrinking (because the oceanic lithospheric plate is being forced back into the mantle) as other ocean basins expand. This process is violent, and produces many earthquakes.
- Seismicity is the frequency, magnitude and distribution of earthquakes.
- Tectonism refers to the deformation of Earth's crust.

3. Global Plate Tectonics

- Because Earth's size is constant, expansion of the crust in one area requires destruction of the crust elsewhere.
- Earthquakes are concentrated along oceanic ridges, transform faults, trenches, and island arcs.
- Subduction is the process at a trench whereby one part of the sea floor plunges below another and down into the asthenosphere

Earthquakes

Earthquakes are concentrated along oceanic ridges, transform faults, trenches and island arcs; larger and deeper earthquakes at trenches, smaller and shallower earthquakes at ridges.

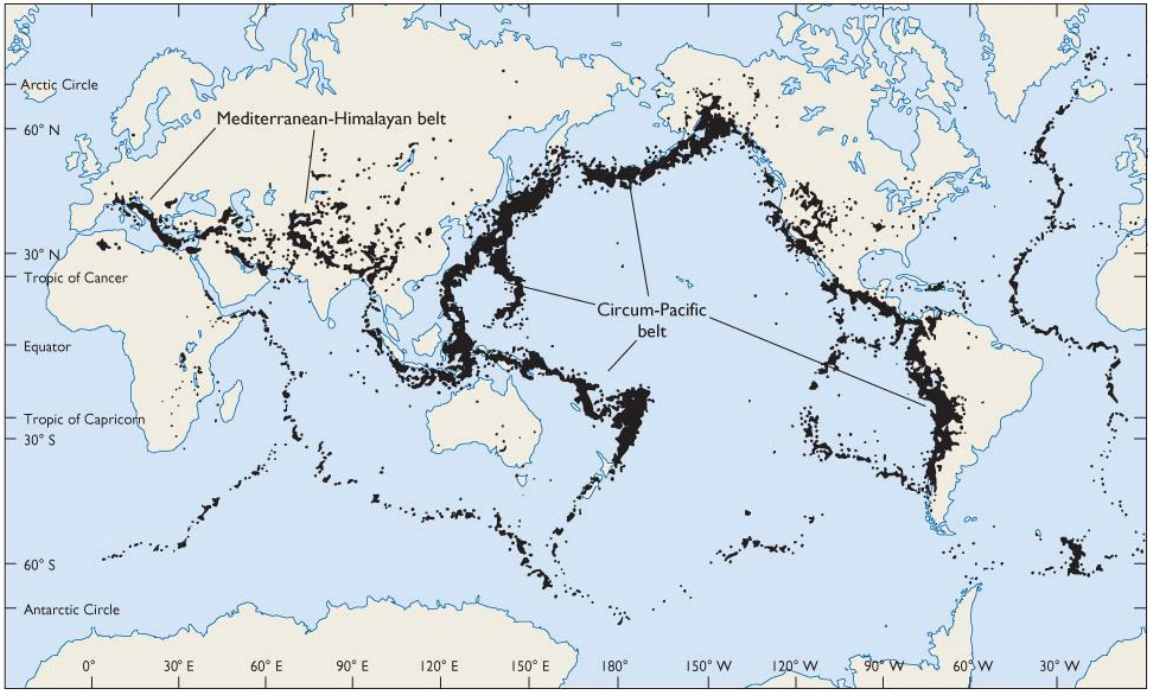


Figure 03.06a: Most earthquakes (represented by black dots) clearly coincide with midocean ridges, transform faults, and deep-sea trenches.

Subduction Zones

- Destruction of sea floor occurs in **subduction** zones.
- Subduction is the process at a trench whereby one part of the sea floor plunges below another and down into the asthenosphere.
- The final stage of subduction is the collision between continents that ride on the lithospheric plates… these continents are too low-density to allow subduction to continue (isostasy again!), and mountain belts form

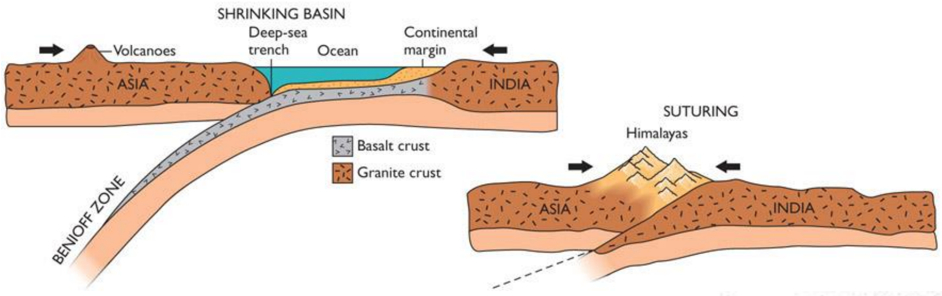


Figure 03.12b: These diagrams depict the collision and suturing of the India and Asia plates.

Subduction Zones

- The Wadati/Benioff Zone is an area of increasingly deeper seismic activity that runs parallel to a subduction trench and slopes down into the mantle parallel to the down-going plate.

- It is inclined from the trench downward in the direction of the island arc.

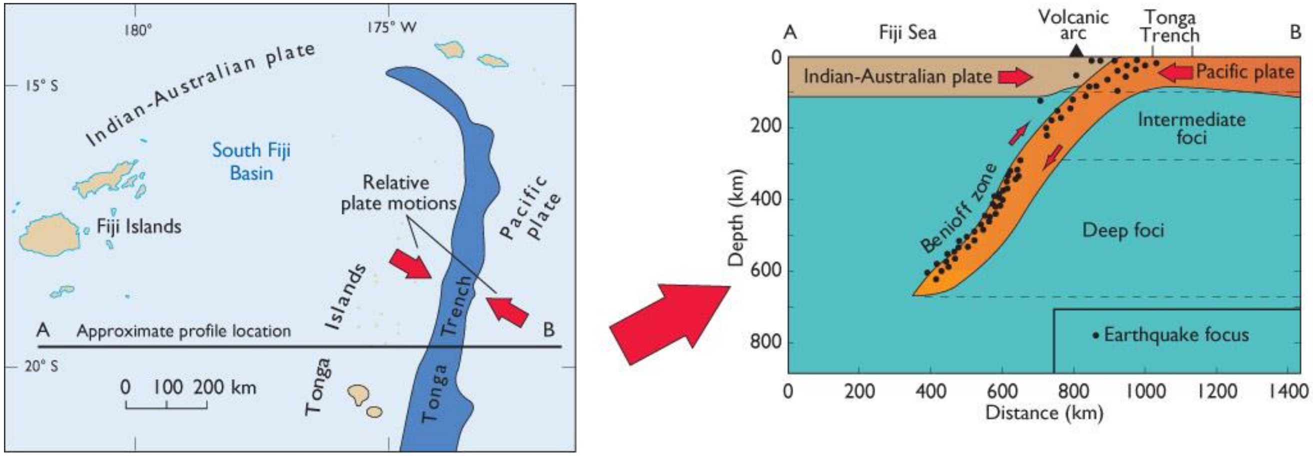


Figure 03.06b: Sketch map of the south Fiji Basin and cross section showing a plot of earthquakes that clearly defines a Benioff zone.

Lithospheric Plates

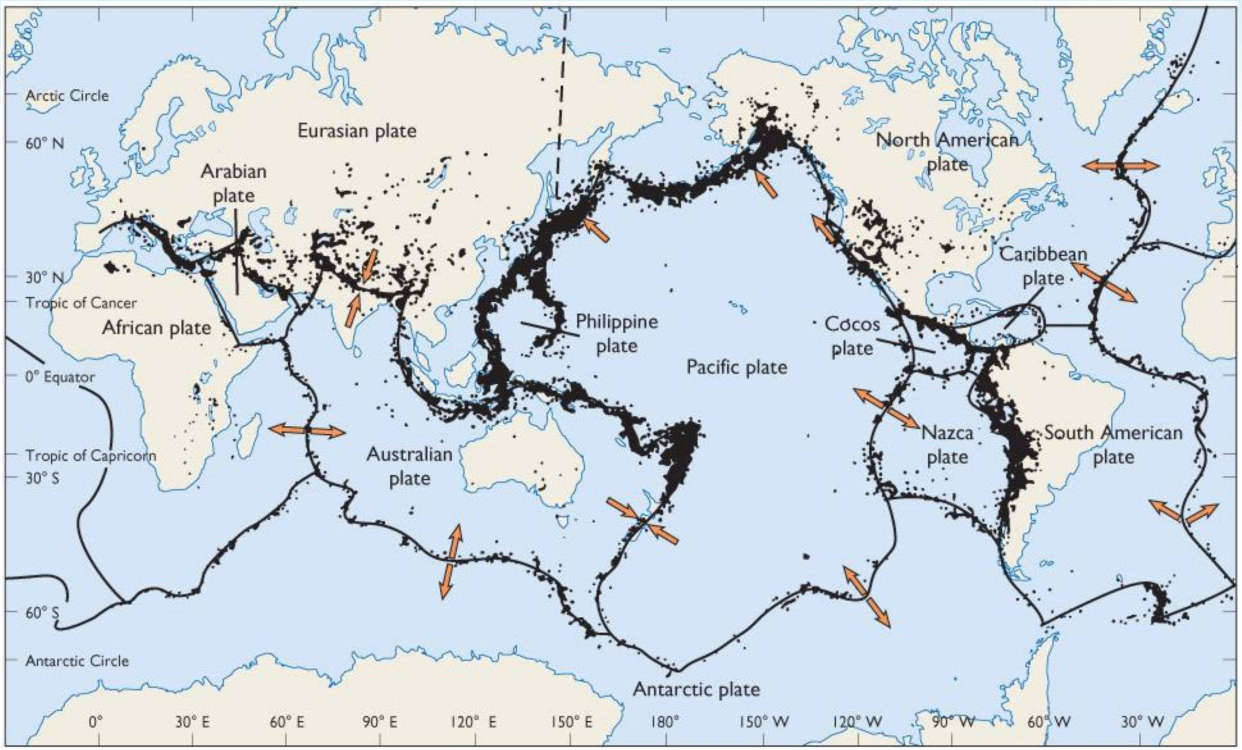


Figure 03.07a: The edges of large lithospheric plates are indicated by bands of seismicity. The arrows indicate relative plate motions.

Plate Movement

Movement of plates is caused by thermal convection of the "plastic" rocks of the asthenosphere which drag along the overlying lithospheric plates.

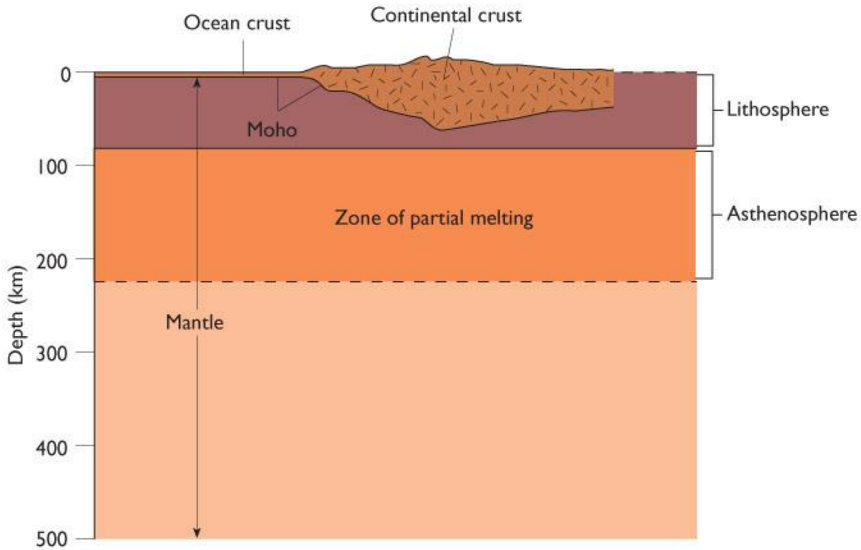


Figure 03.07b: A brittle lithospheric plate, which includes the crust and the upper mantle, overlies and moves relative to the plasticlike asthenosphere.

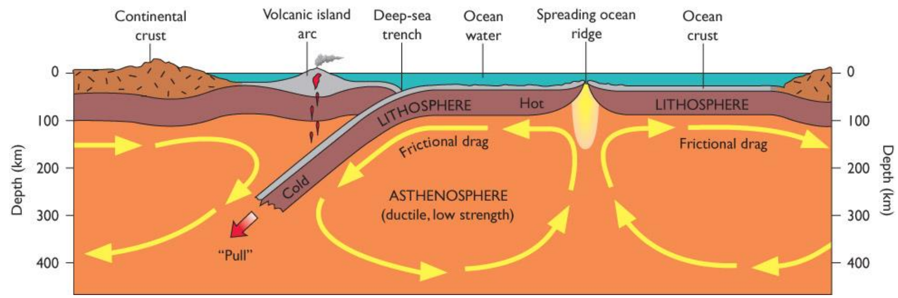


Figure 03.08: Convection in the asthenosphere drags lithospheric plates away from the crests of ocean ridges.

The Wilson Cycle

- The Wilson Cycle refers to the sequence of events leading to the formation, expansion, contracting and eventual elimination of ocean basins. This cycle is thought to repeat over 200-500 million year time scales.
- Stages in basin history are:
  - **Embryonic -** rift valley forms as continent begins to split.
  - **Juvenile -** sea floor basalts begin forming as continental fragments diverge.
  - **Mature -** broad ocean basin widens, trenches eventually develop and subduction begins.
  - **Declining -** subduction eliminates much of sea floor and oceanic ridge.
  - **Terminal -** last of the sea floor is eliminated and continents collide forming a continental mountain chain.

The Wilson Cycle

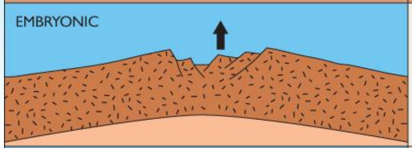
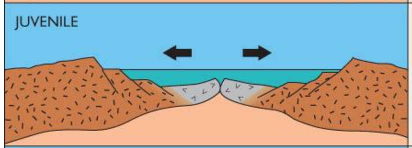
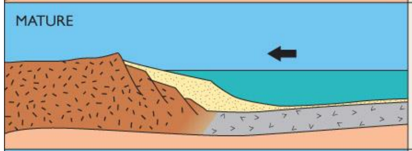
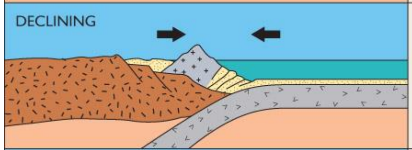
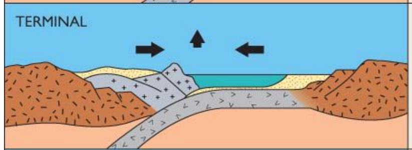
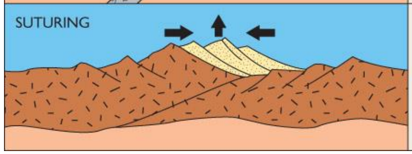
STAGE	MOTION	PHYSIOGRAPHY	EXAMPLE
EMBRYONIC 	Uplift	Complex system of linear rift valleys on continent	East African rift valleys
JUVENILE 	Divergence (spreading)	Narrow seas with matching coasts	Red Sea
MATURE 	Divergence (spreading)	Ocean basin with continental margins	Atlantic, Indian, and Arctic oceans
DECLINING 	Convergence (subduction)	Island arcs and trenches around basin edge	Pacific Ocean
TERMINAL 	Convergence (collision) and uplift	Narrow, irregular seas with young mountains	Mediterranean Sea
SUTURING 	Convergence and uplift	Young to mature mountain belts	Himalayas

Figure 03.11: The Wilson cycle depicts ocean-basin development as proceeding through a sequence of distinct stages.

The Red Sea

- The Red Sea is a juvenile ocean basin that is forming as the African plate diverges from the Arabian plate.
- New basaltic ocean crust is just beginning to form in the center of the Red Sea.

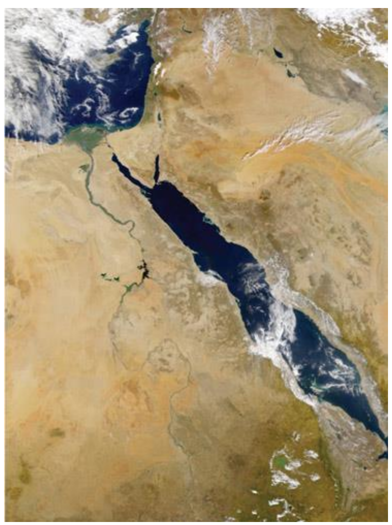


Figure B03.04a: This satellite image shows the terrain of the Red Sea region.

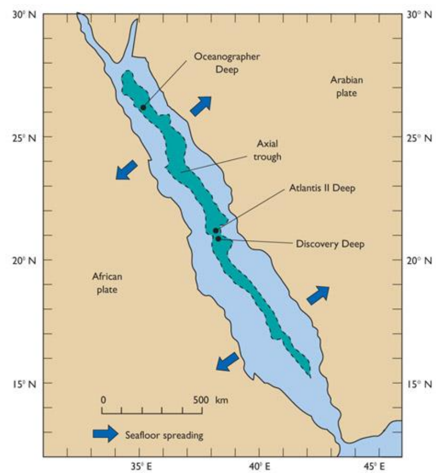


Figure B03.04b: The Red Sea is a juvenile ocean basin that has just recently opened up as the Arabian plate separates from the African plate.

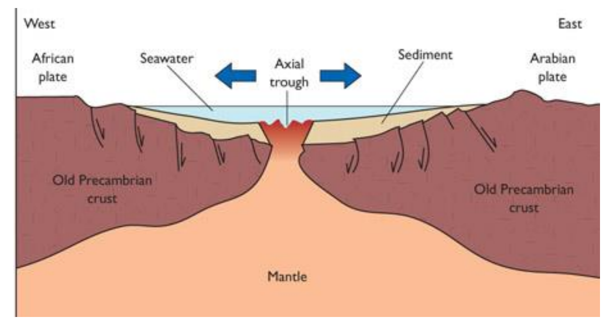


Figure B03.04c: New oceanic crust is forming in the axial trough of the Red Sea by the process of seafloor spreading.