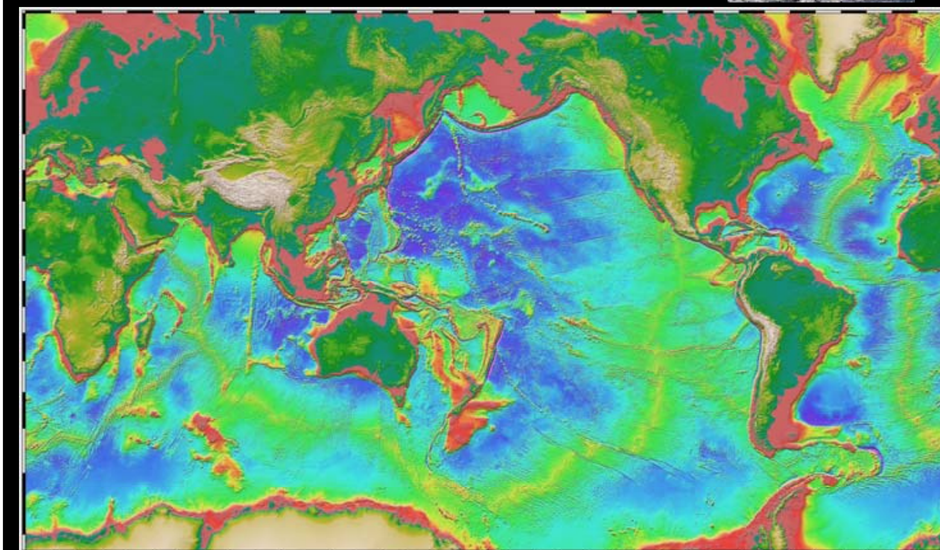
How did we get here?



Learning Objectives

Understand the processes that are continuously changing Earth's surface as lithospheric plates move relative to one another.

Identify the role of oceanic ridges, transform faults and deep-sea trenches in defining the edges of lithospheric plates.

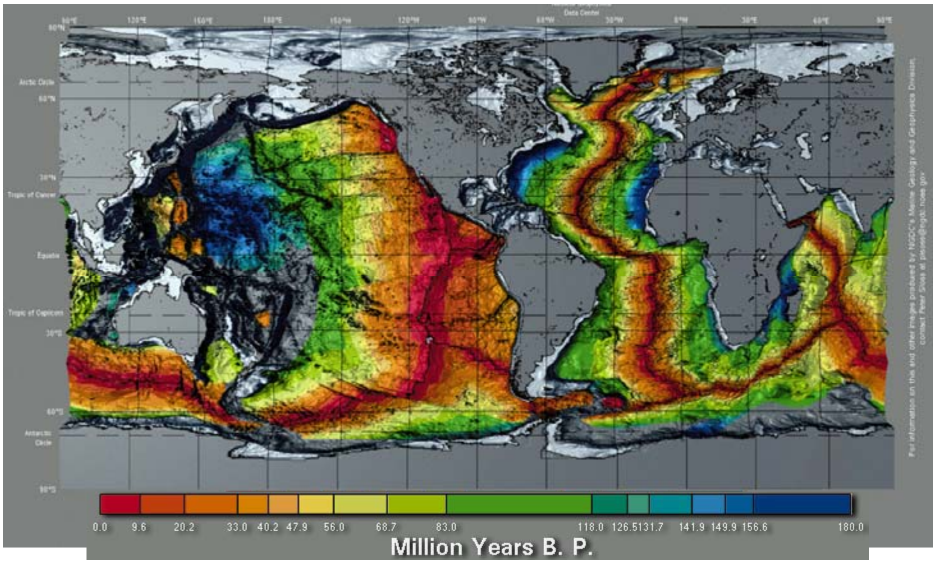
Understand the importance of asthenospheric thermal convection in plate tectonics and the resulting compression or tensional forces at the plate boundaries.

Explain the distribution of magnetic anomaly stripes, seismicity, and volcanism in terms of the concept of global plate tectonics.

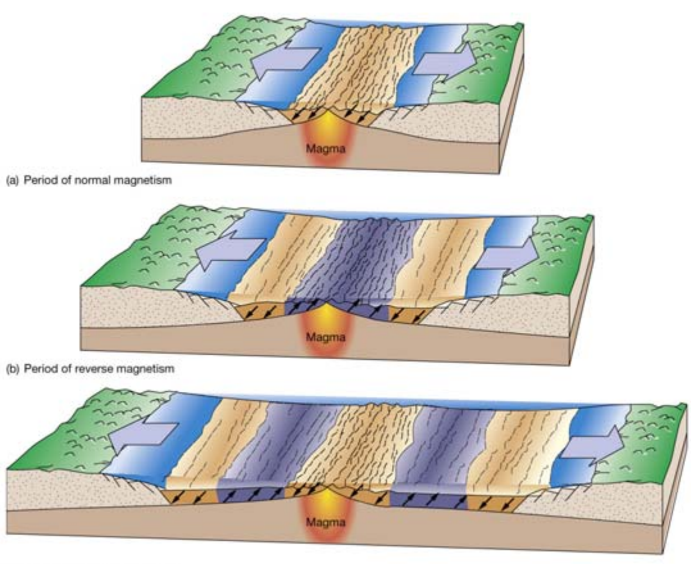
Consider some of the effects of plate tectonics on ocean and climate.

Age of Ocean Crust

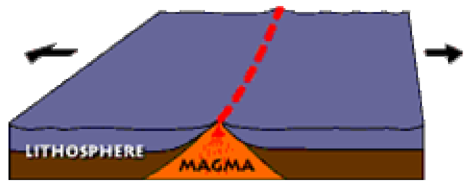
http://www.ngdc.noaa.gov/mgg/geology/geology.html

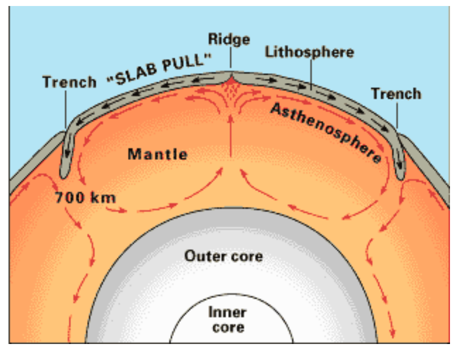


More evidence of plate moving.. Magnetic Evidence



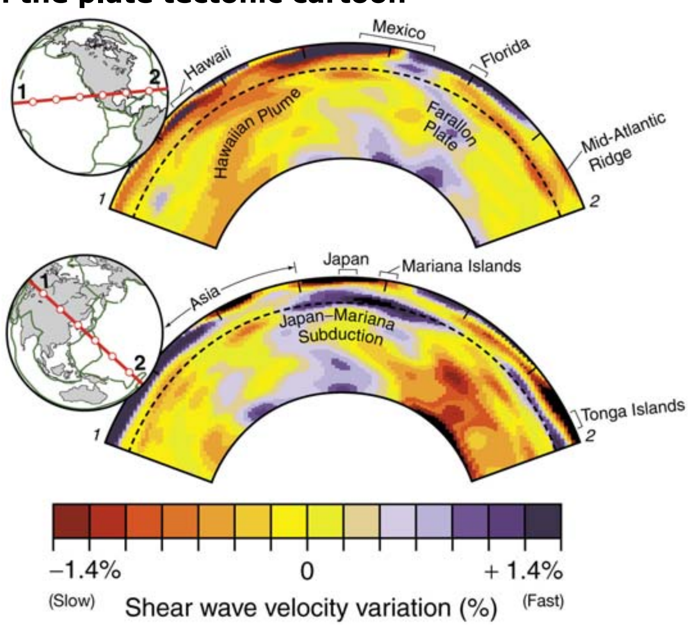
Creating new ocean crust





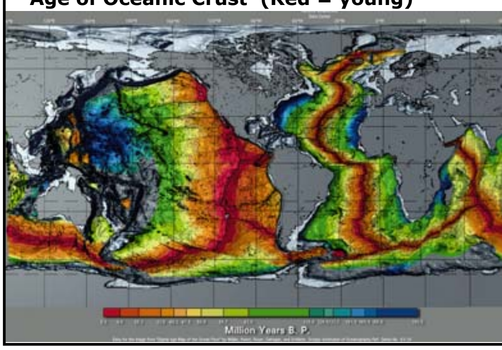
Theory of Plate Tectonics begins to be accepted in the 1960s

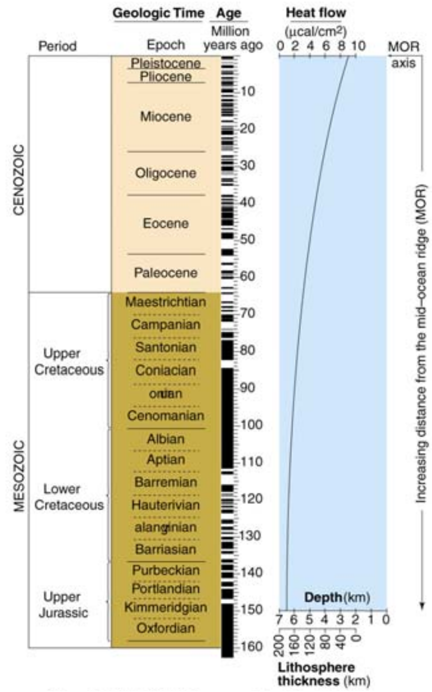
The convection mechanisms in the astenospere are not as clear as in the plate tectonic cartoon



Oceanic crust moves away from Mid Oceanic Ridge (MOR) and cools and subsides

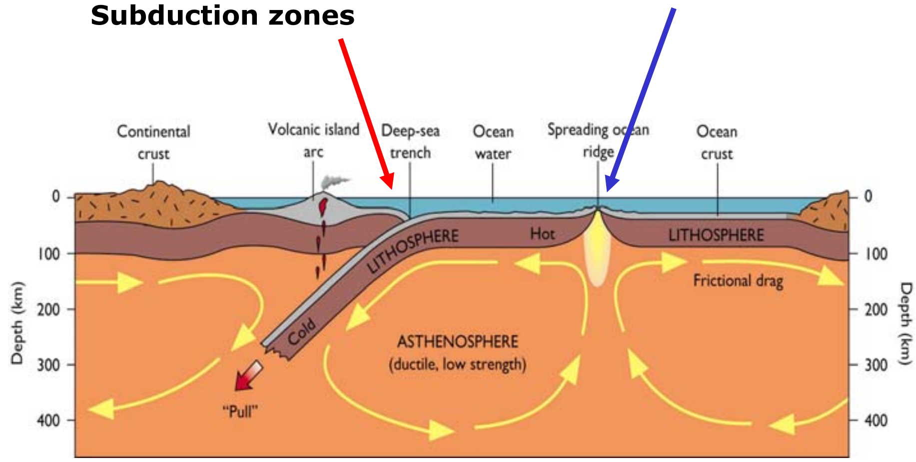
Age of Oceanic Crust (Red = young)



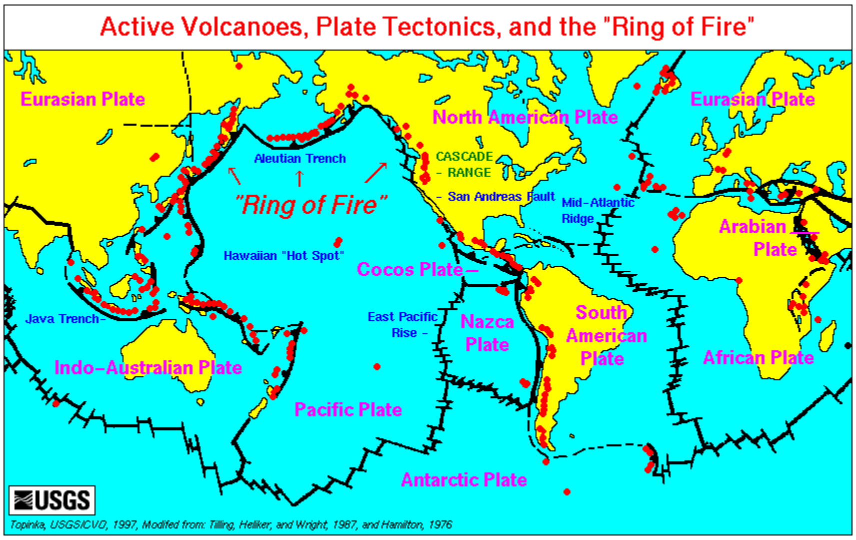


Destructive margins
Subduction zones

Constructive margins
Midocean ridges



Driving Mechanisms for Plate Motions



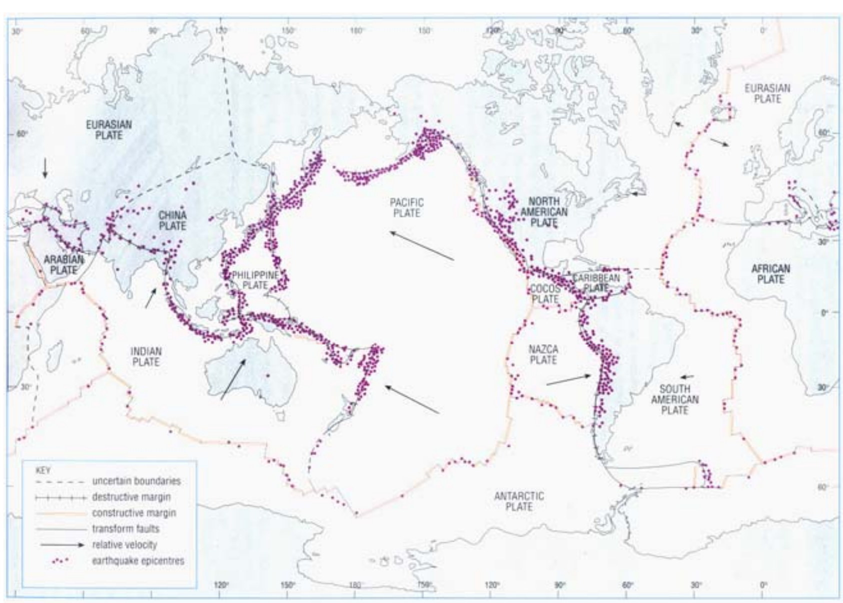
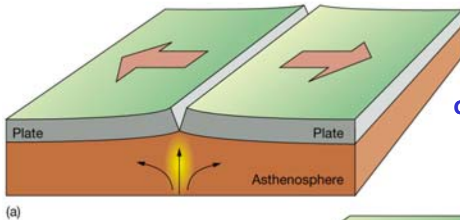


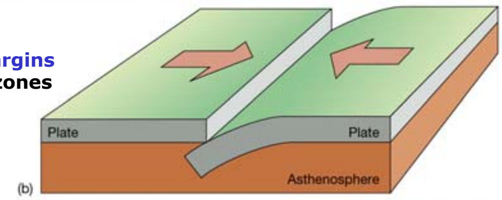
Figure 2.2 The world pattern of plates, ocean ridges, trenches and transform faults in relation to earthquake epicentres indicated by purple dots. Tentative positions of plate margins are indicated by dashed lines. There are seven major plates and six minor ones, plus several smaller ones not named here. The length and direction of the arrows indicate the relative velocities of the plates, averaged over the past few millions of years (Ma). The African Plate is assumed to be stationary. The arrow length in the key corresponds to a relative velocity of 5 cm yr^{-1}.

Type of boundary between plates:

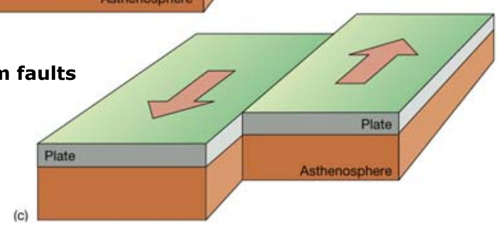


Constructive margins → **Midocean ridges**

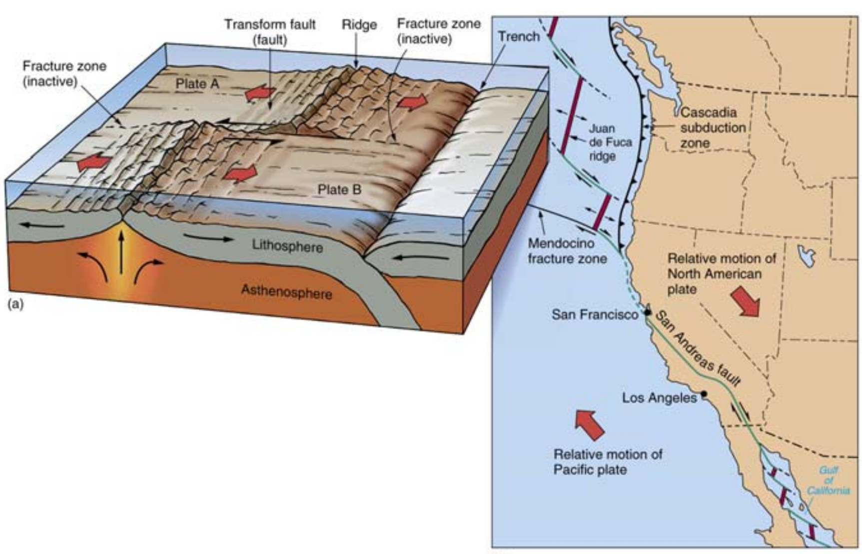
Destructive margins
→ **Subduction zones**



Conservative margins → **Transform faults**



Conservative margins
Transform faults

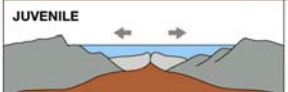
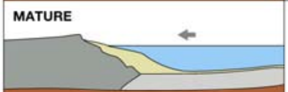
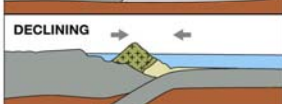
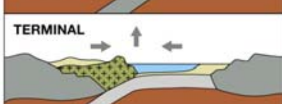
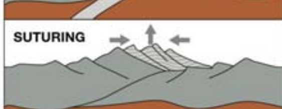


Conservative margins
Transform faults

(a) PLATE BOUNDARY

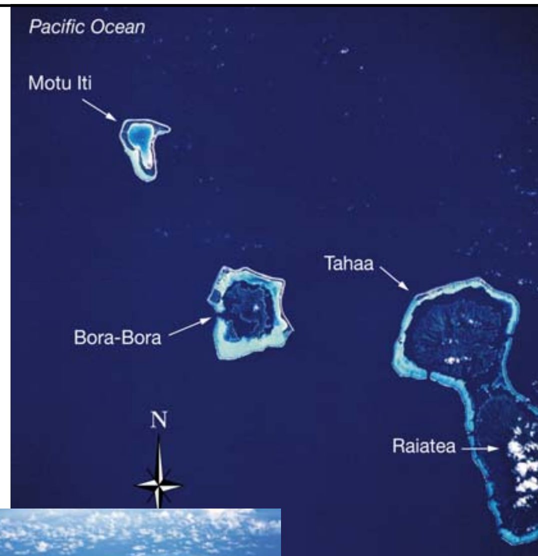
The San Andreas fault in southern California

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 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	Himalaya Mountains

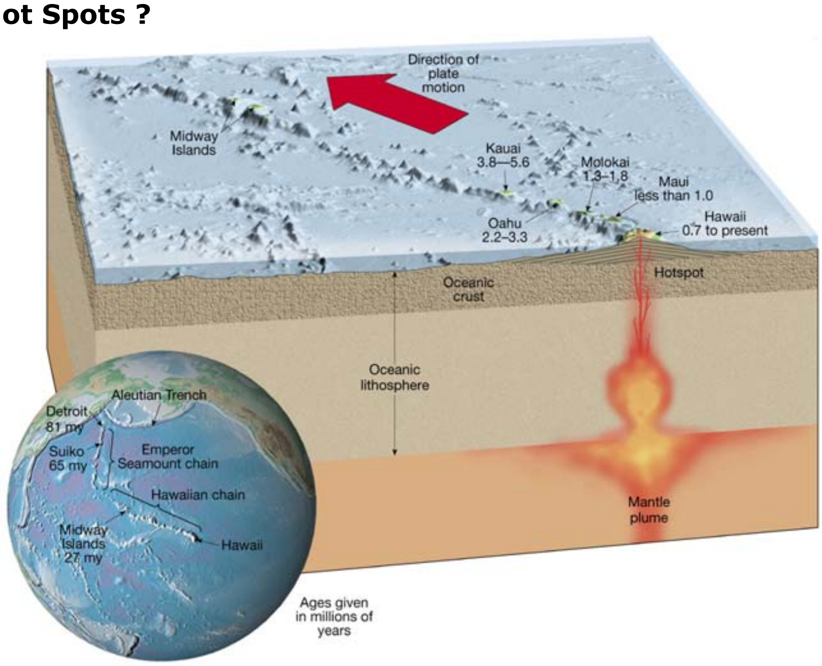
Atolls →

Palmyra Island

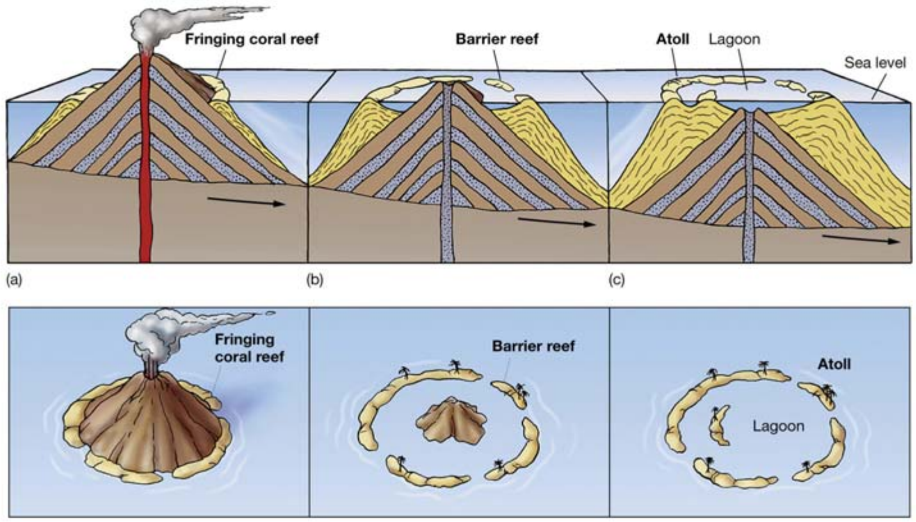


Fanning Island

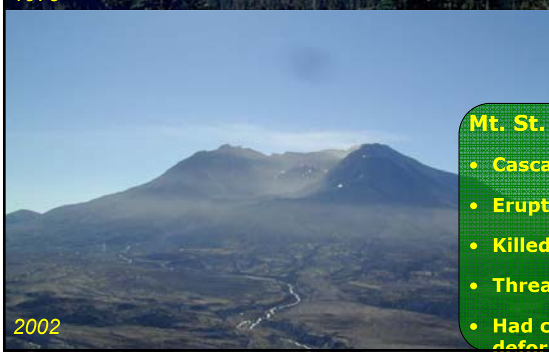
Hot Spots ?



Coreal Reefs



Other ways Plate Tectonics affect ocean circulation and climate?



Mt. St. Helens

- Cascade's most historically active volcano
- Erupted May 18,1980 (~0.1- 0.3 km³)
- Killed 57 people
- Threatens nearby Portland
- Had considerable, but mostly unobserved deformation prior to eruption

Nevado del Ruiz, Columbia

- Erupted November 13, 1985
- Only minor eruption (<0.01 km³)
- Melted glacier and created massive lahars (volcanically induced mudflows) that killed ~23,000 people in Armero
- Similar eruption and lahar killed ~2000 in Armero in 1800's

Effects of Volcanic eruptions on the solar incoming radiation

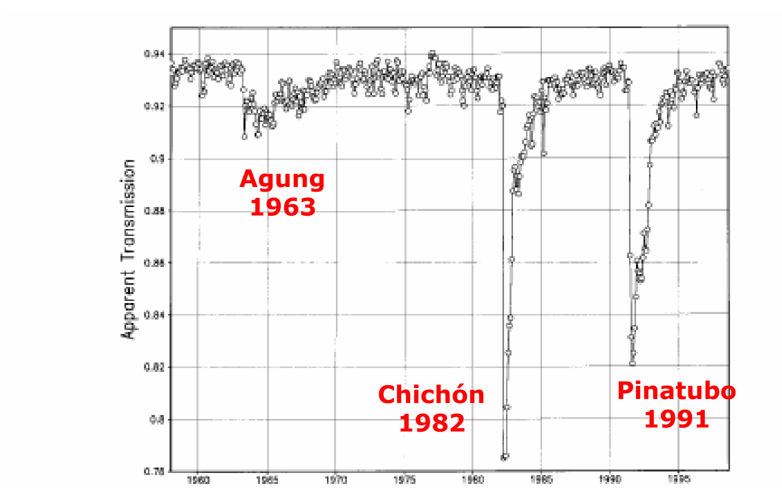


Figure 1. Broadband spectrally integrated atmospheric transmission factor, measured with the *pyrheliometer* shown in Plate 2. *Dutton et al.* [1985] and *Dutton* [1992] describe the details of the calculations, which eliminate instrument calibration and solar constant variation dependence, and show mainly the effects of aerosols. Effects of the 1963 Agung, 1982 El Chichón, and 1991 Pinatubo eruptions can clearly be seen. Years on abscissa indicate January of that year. Data courtesy of E. Dutton.

Cartoon of Volcanic Impacts on the Earth Heat Budget

Robock, Reviews of Geophysics, 38, 2 / May 2000

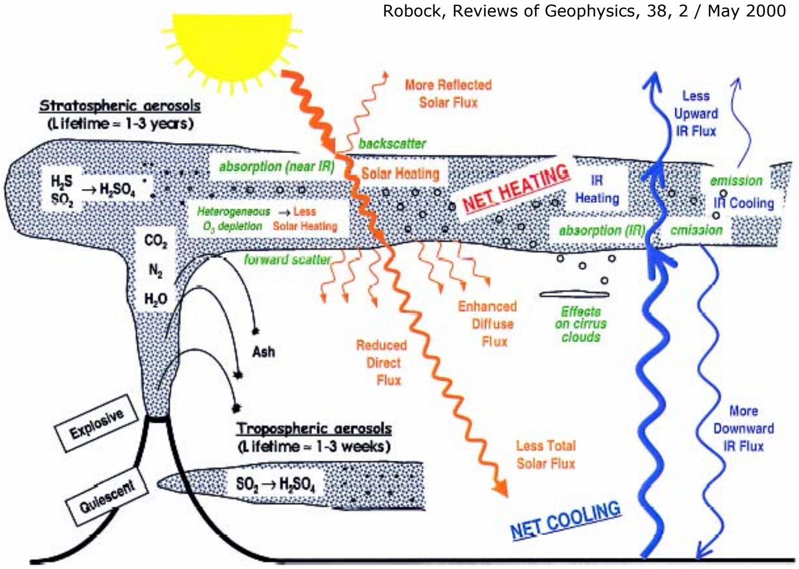


Plate 1. Schematic diagram of volcanic inputs to the atmosphere and their effects. This is an extended version of Figures 1 and 2 of *Simarski* [1992], drawn by L. Walter and R. Turco.

Volcanic Impacts on Ocean and Climate

1. Warmer Stratosphere and Cooler earth surface if eruption reaches stratosphere

2. Stronger JET stream in the Northern Hemisphere and warmer winter on continents (non-linear effects)

3. Diurnal Cycle may be reduced in amplitude

4. Hypothesis that Volcanic eruptions may trigger **El Nino**? Theoretical basis:

   * perturbation in the heat budget may lead to a reduction in the trade winds.

   * uniform cooling in the tropics results in an east-west asymmetric response in the Sea Surface Temperature leading to a reduction in the trades.

ENSO/Climate → change Atmospheric Circulation or Ice Loading → change Litoshperic Stresses →Eruptions!

Sources of heat to our planet:

- solar radiation → 100 W m^{-2}
- **geothermal inputs** → 0.05-0.2 W m^{-2}
- Tides (small)

The Ocean Circulation is generally considered to be forced by wind stress, heat and freshwater fluxes at the sea surface.

However

Impact of Geothermal Heating on the Global Ocean Circulation

Alistair Adcroft and Jeffery R. Scott

Massachusetts Institute of Technology, Cambridge, Massachusetts

Jochem Marotzke

Southampton Oceanography Centre

Abstract. The response of a global circulation model to a uniform geothermal heat flux of 50 mW m^{-2} through the sea floor is examined. If the geothermal heat input were transported upward purely by diffusion, the deep ocean would warm by 1.2°C. However, geothermal heating induces a substantial change in the deep circulation which is larger than previously assumed and subsequently the warming of the deep ocean is only a quarter of that suggested by the diffusive limit. The numerical ocean model responds most strongly in the Indo-Pacific with an increase in meridional overturning of 1.8 Sv, enhancing the existing overturning by approximately 25%.

Estimates of the Effects of Geothermal Heating on the mean temperature profiles in the World Ocean

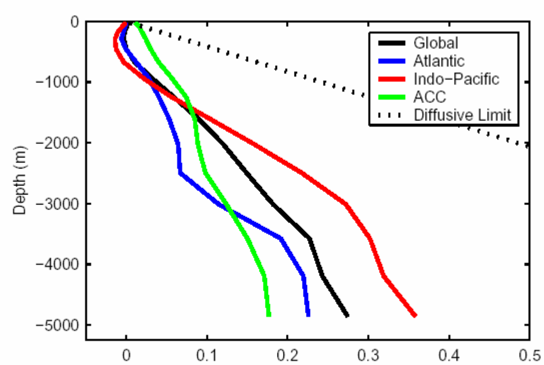
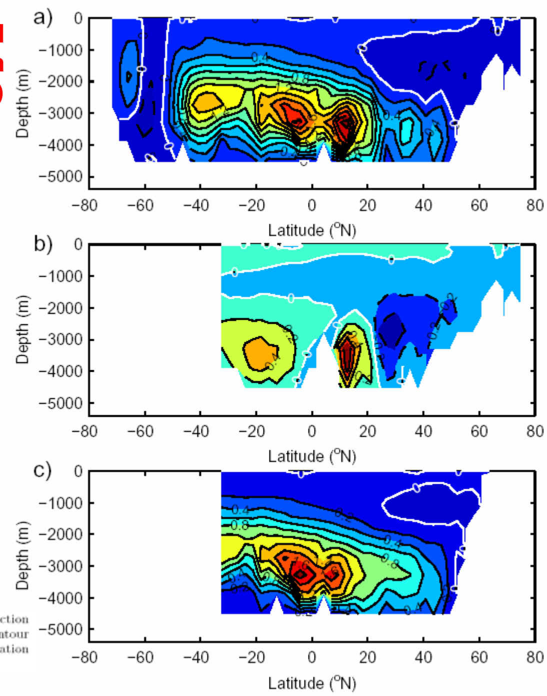


Figure 1. Horizontal mean temperature difference between geothermal and control runs. Shown are profiles for the global average, Atlantic basin and Indo-Pacific basins and the Southern Ocean (ACC). Also plotted, for comparison, is the theoretical profile in a purely diffusive limit.

Changes in the Vertical Circulation of the Ocean (Thermohaline Circulation)



Atlantic Ocean

Indian Ocean

Figure 4. Difference in meridional overturning stream function for a) the globe, b) the Atlantic and c) the Indo-Pacific. Contour interval is 0.2 Sv. Positive numbers indicate clockwise circulation anomaly.

Today's Objectives

Processes that are continuously changing Earth's surface as lithospheric plates move relative to one another.

The role of oceanic ridges, transform faults and deep-sea trenches in defining the edges of lithospheric plates.

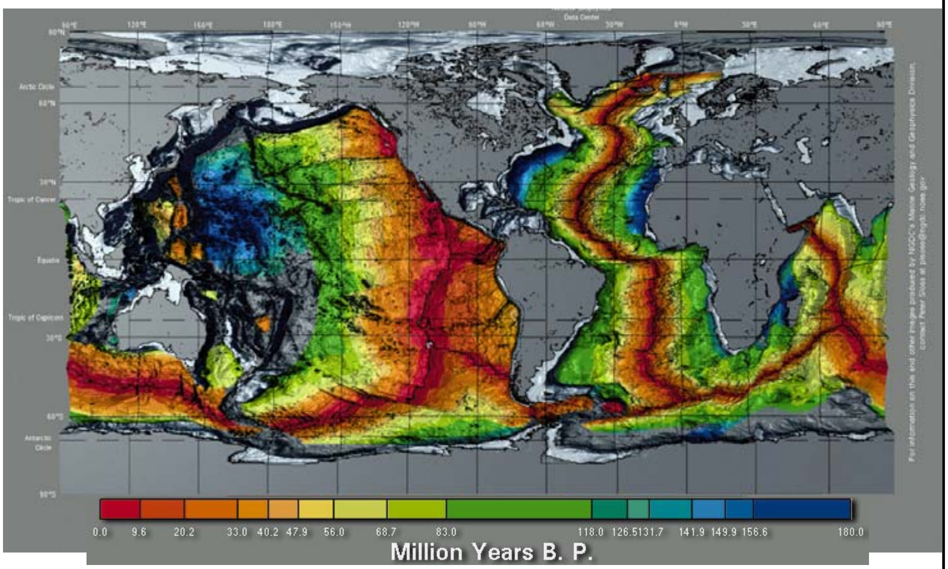
The role of asthenospheric thermal convection in plate tectonics

World seismicity, and volcanism in terms of the concept of global plate tectonics.

Possible Effects of Volcanoes and Geothermal Heating on ocean circulation and climate.

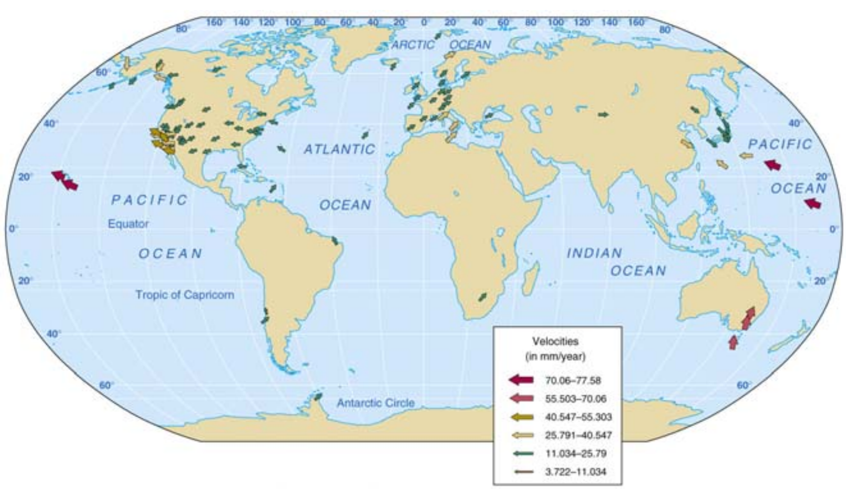
How did we get here? The geological history

Age of Ocean Crust/ Spreading rates

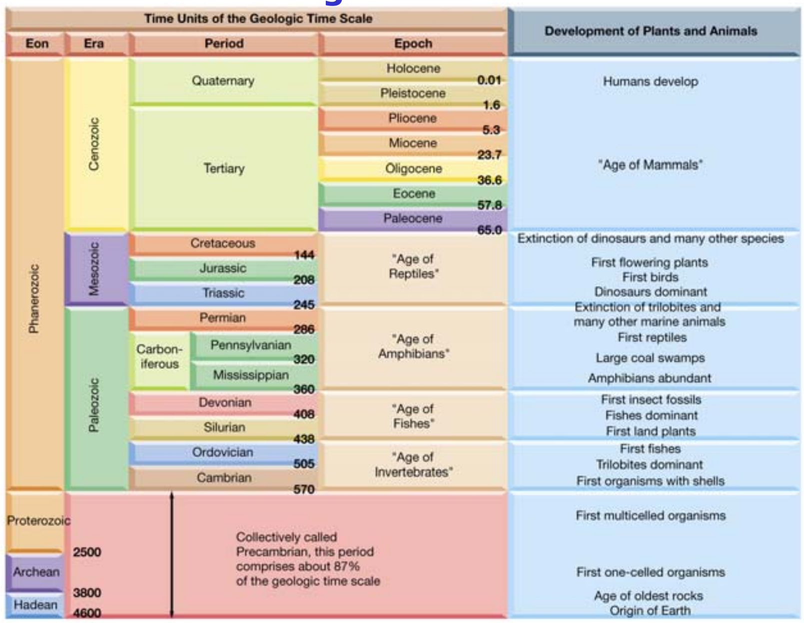


http://www.ngdc.noaa.gov/mgg/geology/geology.html

Spreading rates



Geological Periods

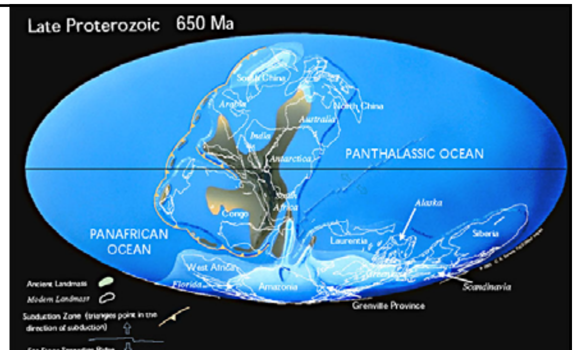


Geological Periods

Precambrian	**4.6 B - 570** Ma	solidification
Cambrian	**514 Ma**	Gondwana, hard shell anim.
Ordovician	**458 Ma**	separation, coldest
Silurian	**425 Ma**	Laurentia collides with Baltica
Devonian	**390 Ma**	pre-Pangea, equatorial forests
Early Carboniferous	**356 Ma**	
Late Carboniferous	**306 Ma**	western Pangea is complete
Permian	**255 Ma**	deserts, reptiles, major ext.
Triassic	**237 Ma**	Life begins to rediversify, Pangea
Jurassic	**195 Ma**	Dinosaurs, Pangea starts to break
Late Jurassic	**152 Ma**	Pangea rifts apart, Atlantic
Cretaceous	**94 Ma**	New oceans, India
K/T extinction	**66 Ma**	end of dinosaurs
Eocene	**50.2 Ma**	India collides with Asia
Miocene	**14 Ma**	Modern look
Modern		
Future World	**+50 Ma**	N. Atlantic widens, Med. vanish
Future	**+100** Ma	new subduction
Future	**+250** Ma	new Pangea

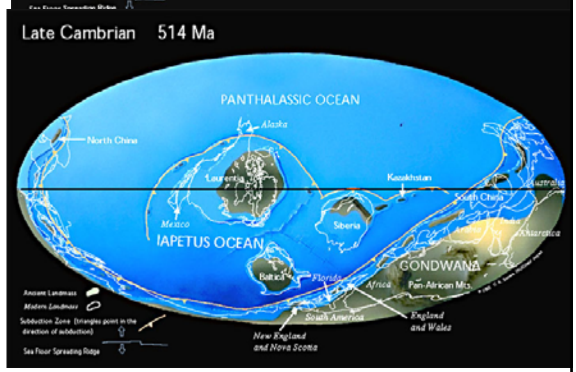
Precambrian

break-up of the supercontinent, Rodinia, which formed 1100 million years ago. The Late Precambrian was an "Ice House" World, much like the present-day.



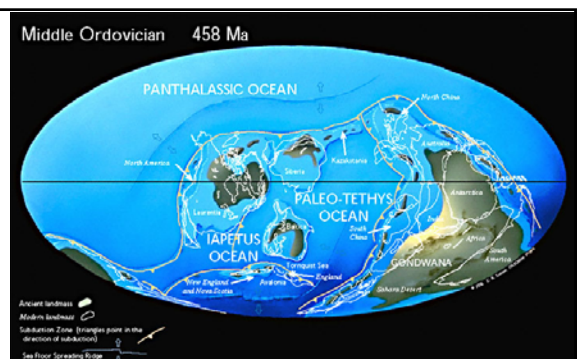
Cambrian

Animals with hard-shells appeared in great numbers for the first time during the Cambrian. The continents were flooded by shallow seas. The supercontinent of Gondwana had just formed and was located near the South Pole.



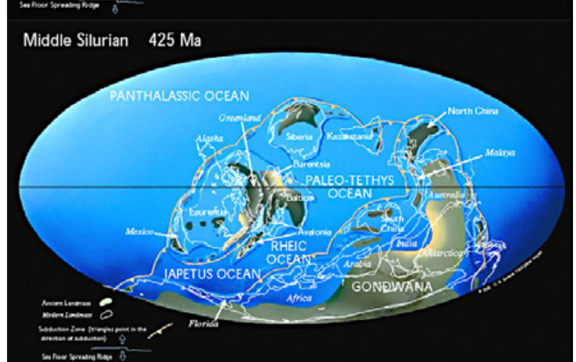
Ordovician

During the Ordovician ancient oceans separated the barren continents of Laurentia, Baltica, Siberia and Gondwana. The end of the Ordovician was one of the coldest times in Earth history. Ice covered much of the southern region of Gondwana.



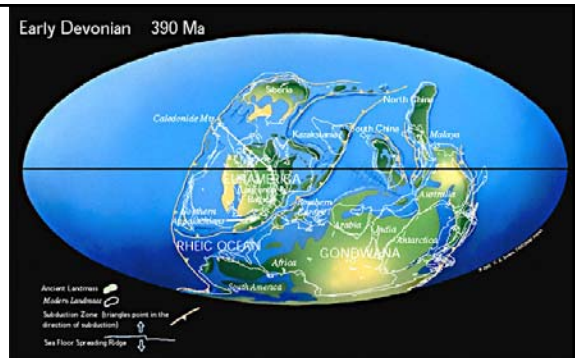
Silurian

Laurentia collides with Baltica closing the northen branch of the Iapetus Ocean and forming the "Old Red Sandstone" continent. Coral reefs expand and land plants begin to colonize the barren continents.



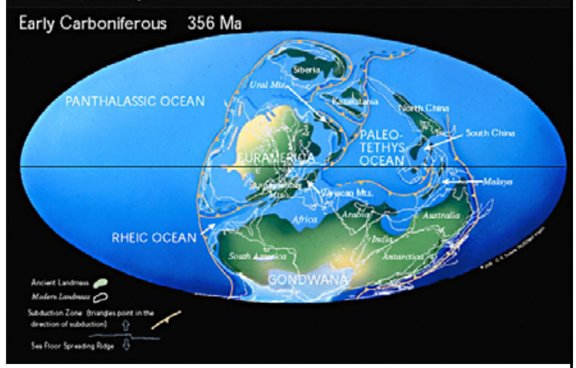
Devonian

By the Devonian the early Paleozoic oceans were closing, forming a "pre-Pangea". Freshwater fish were able to migrate from the southern hemisphere continents to North America and Europe. Forests grew for the first time in the equatorial regions of Artic Canada.



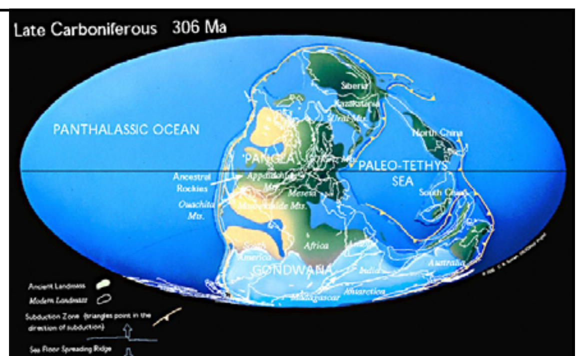
Early Carboniferous

During the Early Carboniferous the Paleozoic oceans between Euramerica and Gondwana began to close, forming the Appalachian and Variscan mountains. An ice cap grew at the South Pole as four-legged vertebrates evolved in the coal swamps near the Equator.



Late Carboniferous

By the Late Carboniferous the continents that make up modern North America and Europe had collided with the southern continents of Gondwana to form the western half of Pangea. Ice covered much of the southern hemisphere and vast coal swamps formed along the equator.

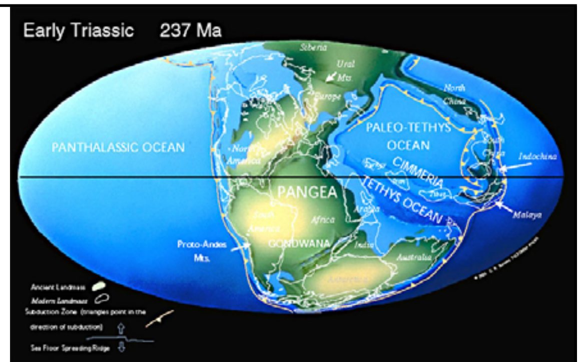


Permian

Vast deserts covered western Pangea during the Permian as reptiles spread across the face of the supercontinent. 99% of all life perished during the extinction event that marked the end of the Paleozoic Era.

Triassic

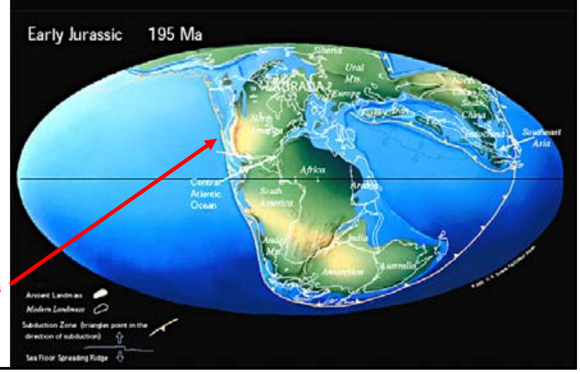
The supercontinent of Pangea, mostly assembled by the Triassic, allowed land animals to migrate from the South Pole to the North Pole. Life began to rediversify after the great Permo-Triassic extinction and warm-water faunas spread across Tethys.



Jurassic

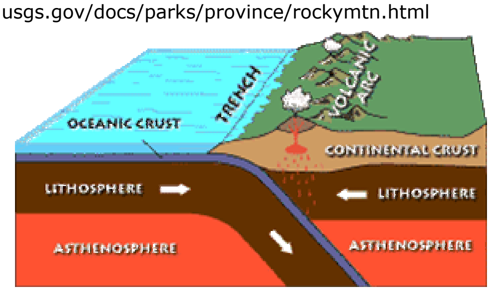
By the Early Jurassic, south-central Asia had assembled. A wide Tethys ocean separated the northern continents from Gondwana. Though Pangea was intact, the first rumblings of continental break up could be heard.

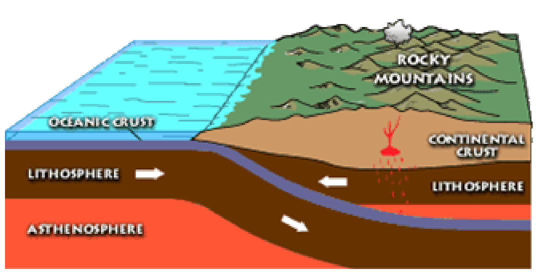
Subduction zone→ Rocky Mountains



Formation of the Rocky Mountains

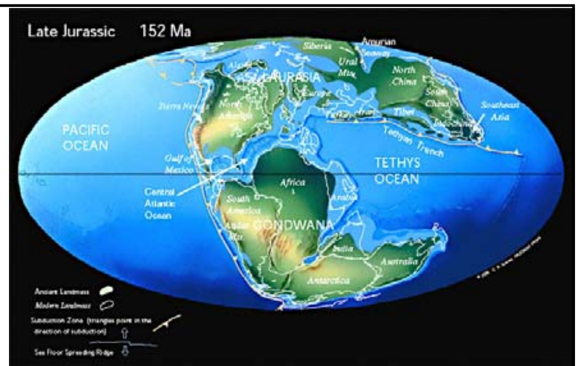
http://wrgis.wr.usgs.gov/docs/parks/province/rockymtn.html





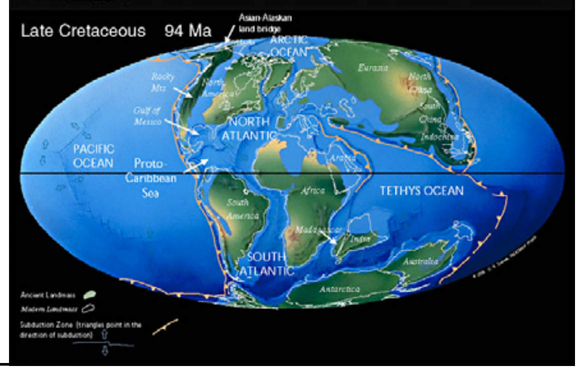
Late Jurassic

The supercontinent of Pangea began to break apart in the Middle Jurassic. In the Late Jurassic the Central Atlantic Ocean was a narrow ocean separating Africa from eastern North America. Eastern Gondwana had begun to separate form Western Gondwana



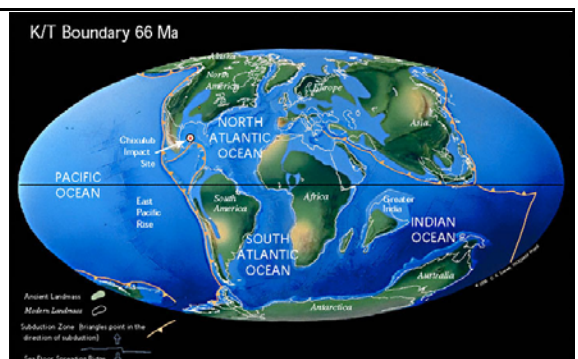
Cretaceous

During the Cretaceous the South Atlantic Ocean opened. India separated from Madagascar and raced northward on a collision course with Eurasia. Notice that North America was connected to Europe, and that Australia was still joined to Antarctica.



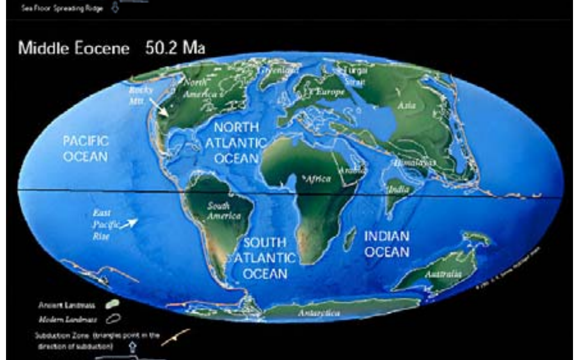
K/T extinction

The bull's eye marks the location of the Chicxulub impact site. The impact of a 10 mile wide comet caused global climate changes that killed the dinosaurs and many other forms of life. By the Late Cretaceous the oceans had widened, and India approached the southern margin of Asia.

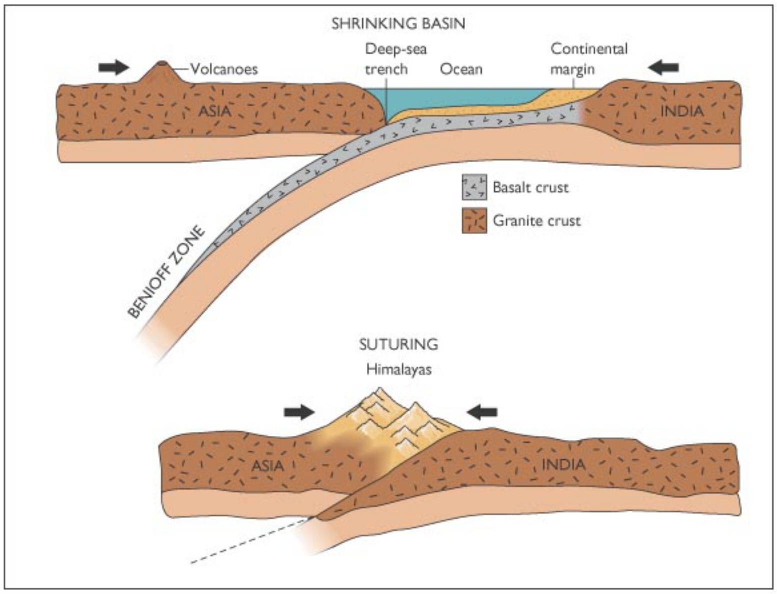


Eocene

50 - 55 million years ago India began to collide with Asia forming the Tibetan plateau and Himalayas. Australia, which was attached to Antarctica, began to move rapidly northward.

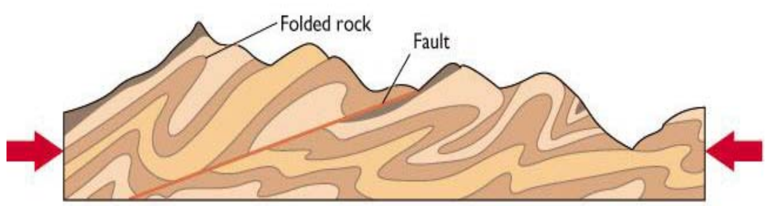


Collision of continental crust



Sea-Floor Spreading

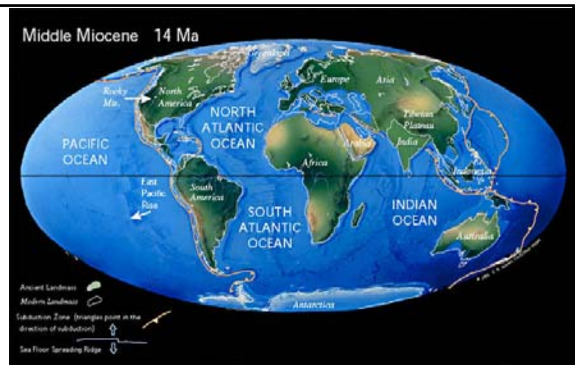
- **Whereas oceanic ridges indicate tension, continental mountains indicate compressional forces are squeezing the land together.**



Sedimentary Rocks Squeezed by Compression

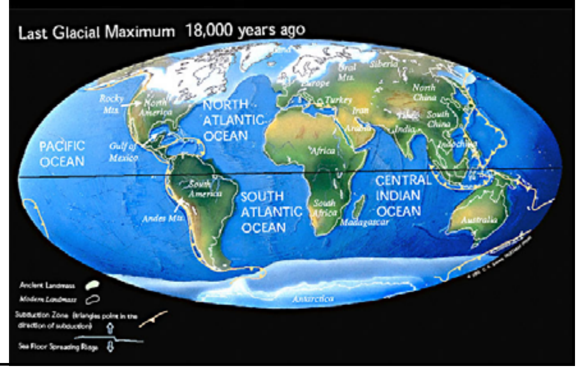
Miocene

20 million years ago, Antarctica was coverd by ice and the northern continents were cooling rapidly. The world has taken on a "modern" look, but notice that Florida and parts of Asia were flooded by the sea.



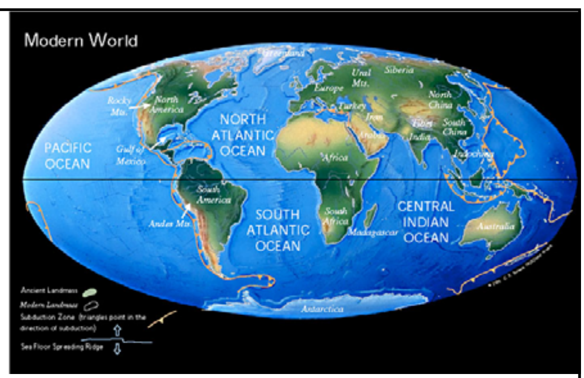
Last Ice Age

When the Earth is in its "Ice House" climate mode, there is ice at the poles. The polar ice sheet expands and contacts because of variations in the Earth's orbit (Milankovitch cycles). The last expansion of the polar ice sheets took place about 18,000 years ago.



Modern World

We are entering a new phase of continental collision that will ultimately result in the formation of a new Pangea supercontinent in the future. Global climate is warming because we are leaving an Ice Age and because we are adding greenhouse gases to the atmosphere.



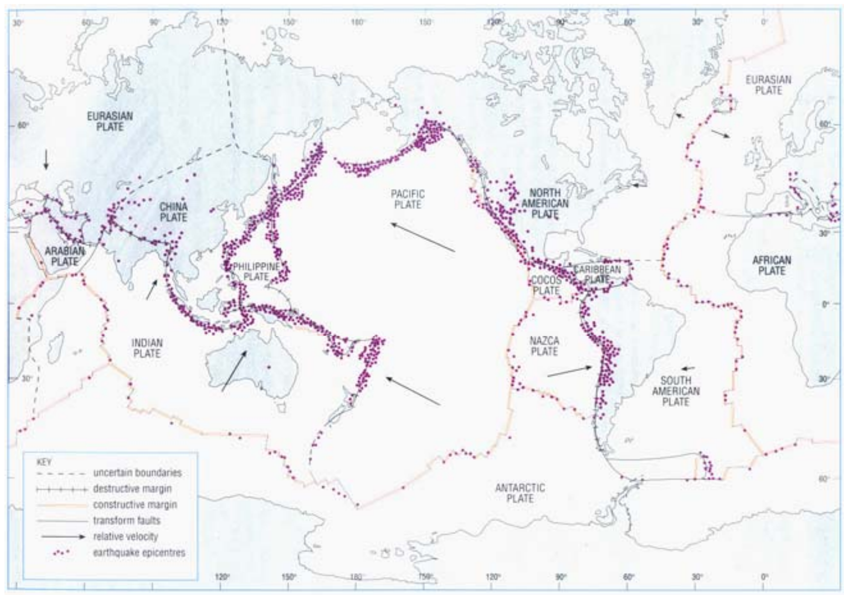
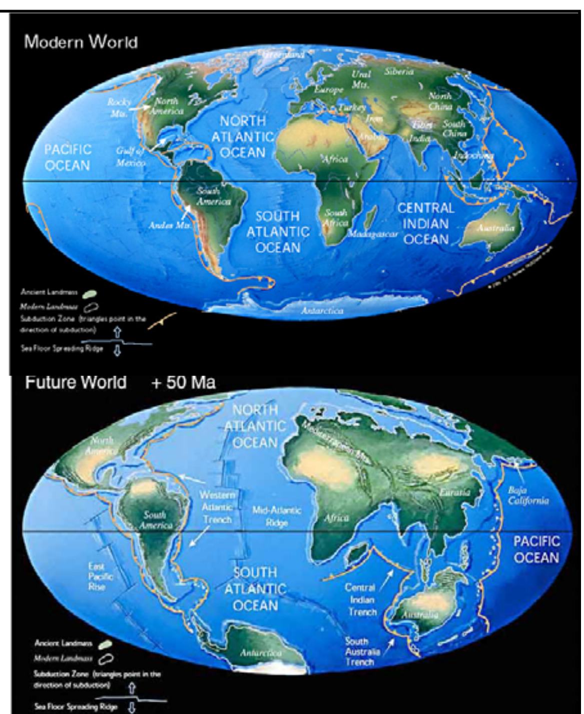


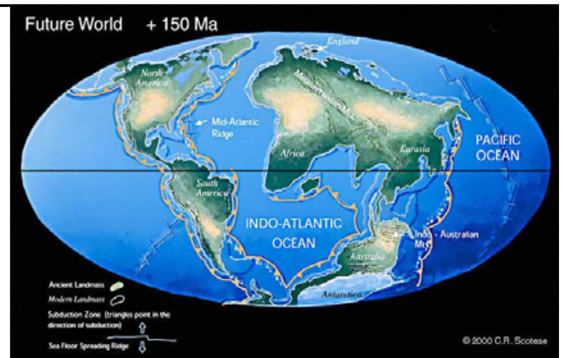
Figure 2.2 The world pattern of plates, ocean ridges, trenches and transform faults in relation to earthquake epicentres indicated by purple dots. Tentative positions of plate margins are indicated by dashed lines. There are seven major plates and six minor ones, plus several smaller ones not named here. The length and direction of the arrows indicate the relative velocities of the plates, averaged over the past few millions of years (Ma). The African Plate is assumed to be stationary. The arrow length in the key corresponds to a relative velocity of 5 cm yr^{-1}.

Modern World

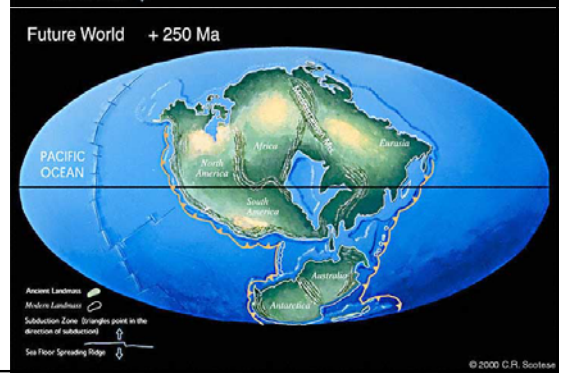


If we continue present-day plate motions the Atlantic will widen, Africa will collide with Europe closingthe Mediterranean, Australia will collide with S.E. Asia, and California will slide northward up the coast to Alaska.

Future +100



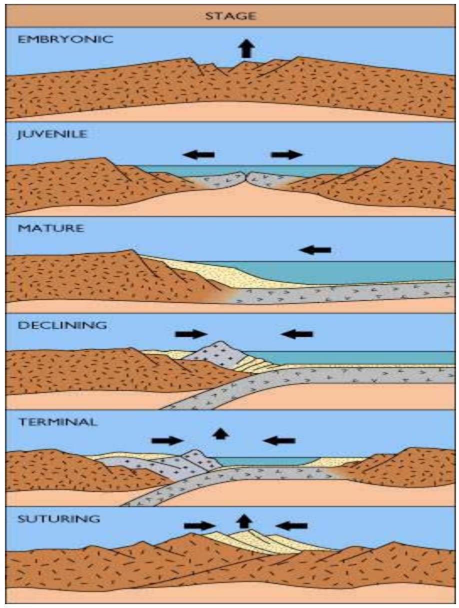
Future +250

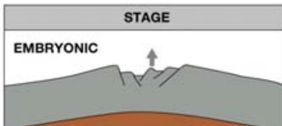
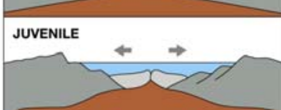
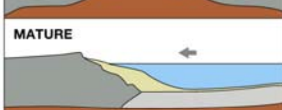
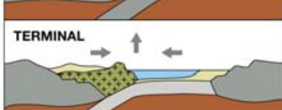


Figures are found at:

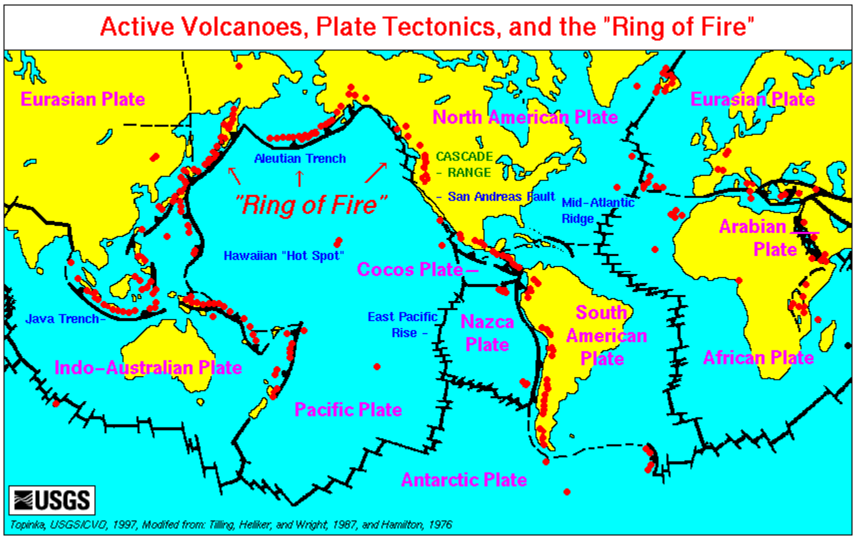
http://www.scotese.com/earth.htm

The Wilson Cycle

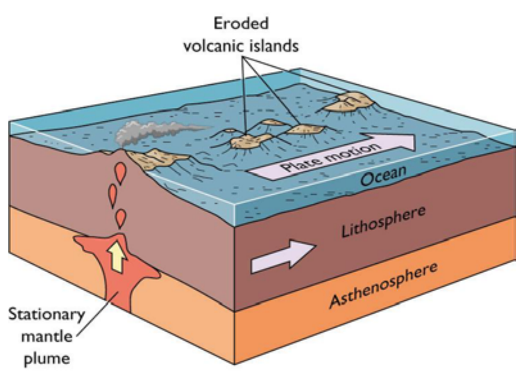


STAGE	MOTION	PHYSIOGRAPHY	EXAMPLE
EMBRYONIC 	Uplift	Complex system of linear rift valleys on continent	East African rift valleys
JUVENILE 	Divergence (spreading)	Narrow seas with matching coasts	Red Sea
MATURE 	Divergence (spreading)	Ocean basin with continental margins	Atlantic and Arctic Oceans
DECLINING 	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	Himalaya Mountains

The Wilson Cycle



- **Mantle plumes originate deep within the asthenosphere as molten rock which rises and melts through the lithospheric plate forming a large volcanic mass at a "hot spot".**



Mantle Plume