Plate Tectonics:

- First ideas go back to early map makers

- Later suggested by various geological evidence (e.g., Frank Taylor (1908) showed geological evidence that the Atlantic Ocean had once been closed.

- Born as “Continental Drift” by Alfred Wegener (1912), who put the pieces together.
Plate Tectonics was both proved by and explains the evidence of:

1. Fit of Continents from a previous supercontinent.
2. Mountain ranges at the edges of continents.
4. Continuity of rock types across separate continents.
5. Continuity of fossils across separate continents.
6. Paleomagnetic “stripes” on the ocean sea floor.
7. The fact that the Earth’s mantle should be convecting (e.g., the Rayleigh number is high). First proposed by Arthur Holmes (1929).
8. Unusual features of the ocean sea floor bathymetry (ridges, parabolic increase in depth away from the ridge, guyots, transform faults, fracture zones)
9. Ocean heat flow, which is greatest near the ridges.
10. Distribution of earthquakes and volcanoes.
11. Gravity Anomalies (something is “pulling down” subduction zone regions).
12. GPS measurements, showing horizontal motions.
Figure 2.1
The frontispiece from the first edition of Thomas Burnet's *Telluris theoria sacra*, or Sacred Theory of the Earth.

Figure 2.5
The chaos of the primeval earth as related in Genesis 1. (From first edition.)

Figure 2.6
The perfect earth of the original paradise of Eden, arranged as concentric layers according to density after the descent of particles from primeval chaos. (From first edition.)
In 1858, Antonio Snider-Pelligrini (“Creation and its Mysteries Revealed”) explains the fit of the outlines of the continents as the result of Noah’s Flood waters breaking apart the continents. (Had been previously been hinted at by Francis Bacon and others.)
490 Ma
Tremadocian (Early Ordovician)

PLATES/UTIG
August 2002
400 Ma
Late Praghian/Early Emsian (Early Devonian)

PLATES/UTIG
August 2002
370 Ma
Late Givetian/Early Frasnian (Late Devonian)

PLATES A TIG
August 2002
300 Ma
Kasimovian (Pennsylvanian)

PLATES/UTIG
August 2002
290 Ma
Late Gzelian/Early Asselian (Pennsylvanian/Permian)

PLATES/UTIG
August 2002
250 Ma
Tatarian (Late Permian)

PLATESUTIG
August 2002
210 Ma
Late Norian (Late Triassic)

PLATESAUTIG
August 2002
200 Ma
Sinemurian (Early Jurassic)
170 Ma
Bajocian (Middle Jurassic)

PLATESÆTIG
August 2002
Pangea: Proposed by A. Wegener as part of hypothesis of Continental Drift.

Problem – Wegener couldn’t explain why plates moved, and geologists refused to listen to a weatherman. (though never rejected in Southern Hemisphere)
Formation of Himalayas

Deccan Basalts formed when India sat atop the Reunion hot spot.

Zagros Mountains

India

Arabia

Iran

Pakistan

Tibetan Plateau

Himalayas

Indian lithosphere (Indian-Australian plate)

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Formation of Himalayas I

Diagram showing the geological processes involved in the formation of the Himalayas. The diagram illustrates the interaction of the Indian Plate with the Eurasian Plate, resulting in the formation of oceanic crust, accretionary wedges, and forearc basins over time periods of 60 Ma and 40-50 Ma.
Growth of the Appalachians

1. 800–700 million years ago
   - North American plate
   - Continental fragment
   - Ancestral Atlantic Ocean
   - Island arc
   - Marginal sea

2. 700–600 million years ago
   - Subduction begins
   - Volcanic arc
   - Ancestral Atlantic Ocean begins to close

3. 600–500 million years ago
   - African plate converges westward
   - Continental fragment collides with North American plate

4. 500–400 million years ago (Taconic orogeny)
   - Island arc collides with North American plate

5. 400–350 million years ago (Acadian orogeny)
   - Subduction beneath North American plate
   - Fold-thrust belt

6. 350–270 million years ago (Allegheny orogeny)
   - African plate collides with North American plate
   - Fragment of African plate left attached to North American plate
   - Appalachian Plateau
   - Blue Ridge
   - Piedmont
   - Coastal plain
   - Modern Atlantic Ocean
   - Mauritanides
   - West Africa

7. About 200 million years ago (beginning of breakup of Pangaea)
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Locations of deserts and tropical climates are largely a function of latitude.
Places that are now warm show previous evidence of glaciation.
Fossil remains of *Cynognathus*, a Triassic land reptile approximately 3 m long, have been found in Argentina and southern Africa.

Fossils of the fern *Glossopteris*, found in all of the southern continents are proof that they were once joined.

Remains of the freshwater reptile *Mesosaurus* have been found in both South America and Africa.

Evidence of the Triassic land reptile *Lystrosaurus* has been found in Africa, Antarctica, and India.
The apparent magnetic pole moves if a continent moves. Different continents have moved differently, so their apparent magnetic poles seem to be different. If you account for the previous plate motions, the poles line up.
Determining Plate Velocity

- Satellite positioning
  - Global positioning system
- Hot-spot tracking
- Seafloor magnetic stripes

Measures absolute plate velocity
GPS sensors help give us the exact velocities (direction and speed) of plates. Today's velocities (from GPS) are the same as those averaged over the past 5 million years (from paleomagnetism and earthquake faulting).
Determining Plate Velocity

- Satellite positioning
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Measures absolute plate velocity
Determining Plate Velocity

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Measures relative plate velocity
Normal magnetic field (as today)

Reversed magnetic field

* Reversal of the field must occur at some time between the flows above and below the horizon
Map of Ocean Seafloor from Laser Altimetry
1. Most earthquakes are at plate boundaries.

2. All deep earthquakes are at subduction zones
The plates are NOT entirely rigid – about 15% of the Earth’s surface is deforming. You can think of these as diffuse plate boundaries.
Crustal deformations associated with the India-Eurasia palte
GPS motions for a portion of the Africa-Arabia-Eurasia plate
Q. Why are the plates moving?
Q. Why are the plates moving?

A. Mantle Convection. Plate tectonics can be viewed as the surface expression of mantle convection.
Q. What are the forces that directly move the plates?
Q. What are the forces that directly move the plates?

A. Primarily “slab pull,” but there are other forces involved.
The important forces moving plates are:

- Slab Pull – most important
- Ridge Push – like surfing
- Viscous Drag
- Slab Resistance

Subducting plates accelerate until viscous resistance equals slab pull ("terminal velocity").
Remember: Even the “magma chamber” is mostly solid. The Earth’s mantle is solid rock, even though it moves a lot.
A Portion of the Mid-Atlantic Ridge System
Mountains!!

→ Erosion (Carbonic Acid)
→ Deposition of Carbonates in the Oceans
→ Reduced CO₂ in Atmosphere
→ Global Cooling
What drives the intermediate-term temperature changes? (20,000 – 400,000 years)
Fluctuations in Earth’s Orbit (Milankovich Cycles)
What about some of the narrow, sharp spikes?
Toba Volcano – 72,000 years ago
→ 280,000 km³ ejected!
→ 1 gigaton tnt explosion!
Based on genetic diversity, it is estimated that all modern humans evolved from only 1000-10,000 individuals following the Toba eruption.
About 5 million years ago our ancestors became increasingly bipedal.

Why?
A major cooling trend changed forests to savannas??
By 100,000 years ago, Homo Sapiens was emerging as dominant hominid. Why?
Selection for large brains during strong Ice Ages that occurred 120,000-90,000 years ago.
50,000-40,000 years ago there was a cultural explosion in Europe. Why? Warming trend in Europe. Life was easier?
North American Mammoths evolved in Asia. How did they get here 20,000 years ago?
→ 20,000 years ago was time of Ice Ages. Sea levels were low. Mammoths walked here!

→ Native Americans followed 14,000 years ago!!!!
The start of civilization didn’t occur until 10,000 years ago. Why?
The start of a warm and relatively stable climate period!!!
Many cultures have a myth similar to the story of the expulsion from Eden. Why?
Rising Sea Levels
After the End of the Ice Age forced many people from their homelands!!
The Egyptian and Semitic peoples originated in Eastern Europe. Why did they leave?
The Black Sea flooded dramatically 5,600 BCE!!

Most of these cultures have similar flood myths!!
3000 BCE: Time of alternating droughts and flooding.

→ Complex societies like Akkadian Empire evolve in order to survive.
Story of Joseph warning the Egyptian Pharaoh to prepare for 7 lean years.
2200 BCE: Period of extended drought causes Akkadian Empire to collapse.
1900 BCE: Cold and dry period.
→ Desertification destroys Indus Civilizations.
1200 BCE: Variable atmospheric circulation patterns hurt agriculture.

→ Mycenaean culture collapses.
1200 BCE: Variable atmospheric circulation patterns hurt agriculture.

→ Also causes mass migrations of Phrygian and Hittite peoples.
500-400 BCE: North Atlantic thermohaline circulation shuts down.

→ Colder temperatures in Europe cause more southward migrations. Macedonians overrun Greece.
300 BCE: Warming period in Asia.

→ Opening of the “Silk Route.”
0 – 100 AD: Stable temperatures allow Roman Empire to thrive. Empire = >60 million people. Rome = >1 million.

So...why did Rome collapse?
400-500 AD: Cold spell; prolonged freezing.
→ Southward migration of Northern Europeans
Why is Leif Ericsson able to sail to America?
Why is Leif Ericsson able to sail to America?

950-1300 AD: Warm and dry period
950-1300 AD: Warm and dry period
→ Mayan culture collapses
950-1300 AD: Warm and dry period
→ American Southwest cultures like the one at Chaco Canyon collapse. Anasazi peoples disappear.
Why does the plague strike in the 1300s?
1300 AD: Cold spell due to a minimum in solar activity

→ Great famine of 1315-1317

→ Black Death, 1345
Begins with flooding in China. More than 7 million drown in Yangtze River.
Plague returned in 1563, 1578, 1593, 1603, 1625, 1636, and 1665.

The 1563 outbreak in places like England was worse than for the Great Plague.
Late 1500’s: Mega-droughts in North America

→ May have led to demise of Jamestown Colony, 1587-89.
1550-1850: Little Ice Age

→ Maunder minimum (1645-1715) – period of depressed solar activity

→ Eskimos land in Scotland (1690).

→ Scots emigrate to Ireland.
1840s: Increased warming and rains in Europe
→ Led to potato blight in Ireland. Huge migration to America.
After 1815 there is a huge push of U.S. Westward Expansion. Why?
1816 is known as the “Year without a summer.”
It snows in New England in the summer.
Volcanoes!

1812: Soufriere volcano, St. Vincent Island
1814: Mayon volcano, Philippines
1815: Tambora volcano, Indonesia
Why does the French Revolution occur in 1789?
1783: Hekla volcano, Iceland; Asama volcano, Japan
Last 10,000 years: VERY warm AND stable!!

Variations in Earth's average surface temperature, over the past 20,000 years

- Average temperature over past 10,000 years = 15°C
- IPCC (2001) forecast: +2–3 °C, with band of uncertainty
- 21st century: very rapid rise

Key events:
- End of last ice age
- Younger Dryas
- Holocene Optimum
- Mesopotamia flourishes
- Agriculture emerges
- Vikings in Greenland
- Little ice age in Europe (15th–18th centuries)
- Medieval Warm
- Now
- +100

Number of years before present (quasi-log scale)