Chapter 2

Internal Structure of Earth and Plate Tectonics

Introduction to Environmental Geology, 5e

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Chapter Two Overview

- Basic internal structure and processes of Earth
- Basic ideas and evidence of plate tectonics
- Mechanism of plate tectonics
- Relate plate tectonics to environmental geology

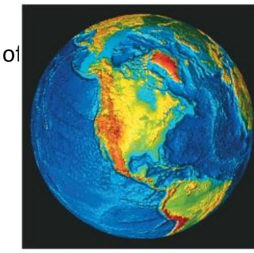
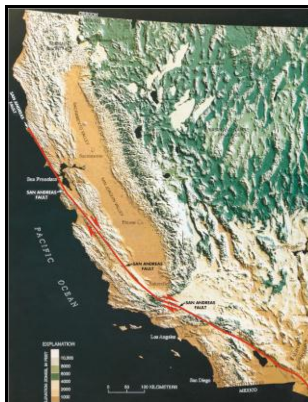


Figure 2.2a

Case History: Two Major CA Cities

- San Andreas fault: a transform plate boundary between the North American and the Pacific plates
- Two major cities on the opposite sides of the fault: Los Angeles and San Francisco
- Many major earthquakes related to fault system
- Loss of many lives and billions of property damages due to earthquakes
- New construction and retrofitting of infrastructures has become more expensive
- When will be the next “big one” and what to do? How to deal with the potential consequence?



San Andreas Fault System

Figure 2.1

Internal Structure of Earth

- The Earth is layered and dynamic: Interior differentiation and concentric layers.
- <u>Chemical</u> model by composition and density (heavy or light): Crust, mantle, and core. Moho discontinuity between the crust and mantle.
- <u>Physical</u> property model (solid or liquid, weak or strong): Lithosphere (crust and upper rigid mantle), asthenosphere, mesosphere, liquid outer core, inner solid core.

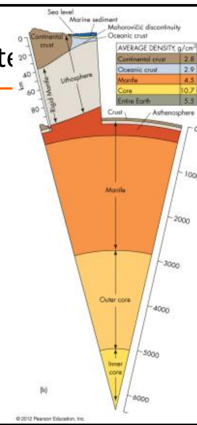
Internal Structure of Earth

- Chemically different layers:
  - Crust – outermost layer, solid, embedded in top of lithosphere, consists of either ocean crust or continental crust, and made up of 8 major elements plus many minor.
  - Mantle – mostly composed of iron and other magnesium bearing silicate minerals
  - Core – interior of the Earth, metallic, mostly composed of iron

Internal Structure of Earth

- Physically different layers;
  - Lithosphere – outer layer, cold, rigid rock, makes up oceanic and continental plates
  - Asthenosphere – upper zone of mantle, hot, slow-flowing, weak rock
  - Mesosphere – middle zone, hot, fast-flowing fluid/rock
  - Outer core – fluid, very hot, convective flow
  - Inner core – behaves like a solid, as hot as the Sun's surface, about the size of the moon

Model of Earth's Inte



Magma likely generated in the asthenosphere.

Slabs of lithosphere have apparently sunk deep into the mantle.

Variability of lithosphere thickness reflects changes in age and history of the plate.

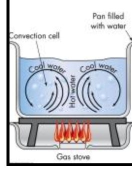


Figure 2.2b & 2.3

Study of Earth's Interior Structure

- Knowledge primarily through the study of seismology
  - Seismology: Study of earthquakes and seismic waves
- Examining the paths and speeds of seismic waves through reflection and refraction
  - Two basic types of seismic waves:
    - Body waves: primary (P) and secondary (S) waves
    - Surface waves

Seismic P Wave

- Primary or push-pull wave, travels like sound wave
- Direction of rock particle vibration parallel to that of wave propagation
- Fastest rates of propagation, first arrival to the seismograph
- Body wave travels through Earth interior and all media— solid and liquid

Seismic S-Wave

- Secondary or shear waves
- The direction of particle vibration perpendicular to that of propagation
- Propagates slower than P waves
- Body wave, propagating through Earth's interior, but not its liquid layers

Seismic Waves and Internal Structures

- Earth's interior boundaries: Sudden changes in the speed and direction of seismic waves
  - Different characteristics: Different rates and paths of wave propagation
  - P waves travel slower in liquids.
  - P waves refract in materials with different densities
- *Asthenosphere*: Low velocity zone, major source of Earth magma
- Outer Core: Liquid, no S wave transmits through it

Internal Dynamics of Earth

- Evidence
  - Earth's landscape
  - Dynamic phenomena: earthquakes, volcanoes
- Plate Tectonics: Hypothesis and Theory
  - Continental drift
  - Seafloor spreading
  - Plate tectonics – a unifying theory

Dynamic Earth—Evidence

- Mountain belts…continental mountain ranges and oceanic ridges
- Many earthquakes occur in specific, concentrated zones and times
- Most volcanism occurs specific, concentrated zones and times
- Visibly detect plate boundaries by observing volcanism and earthquake occurrence
- Continental drift and seafloor spreading

Earthquakes and Volcanoes

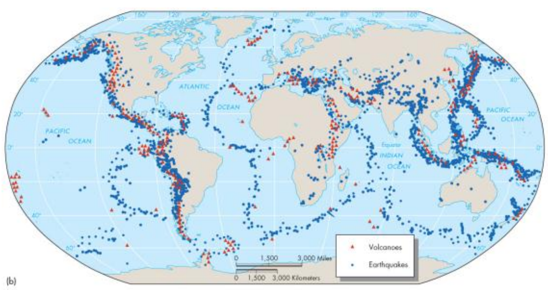


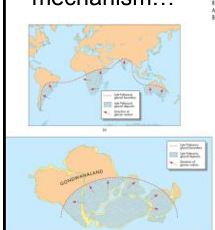
Figure 2.4

Continental Drift

- 1910s Alfred Wegener proposed idea
  - Rock types match, fossils match, paleoclimate evidence match, continental 'fit'
- Pangaea (Pan-jee-ah): All land, unified super-continent, fully formed about 250 mya
- Two parts of Pangaea: Laurasia (N) and Gondwana (S)
- Pangaea drifting apart: ~ 200 mya

Continental Drift

Hess couldn't indicate a mechanism…



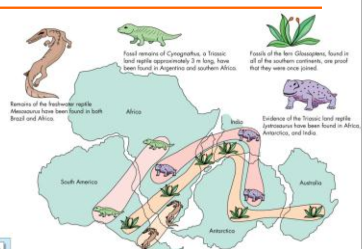


Figure 2.18

Continental Drift

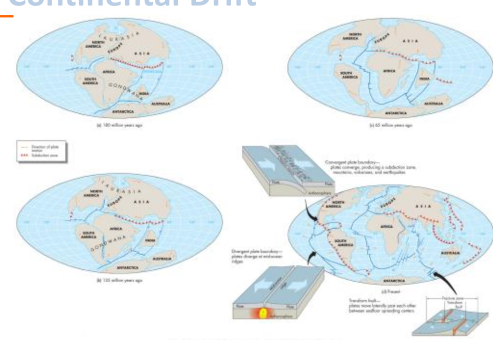


Plate Tectonics

- A unified theory: Study the dynamic creation, movement, and destruction processes of plates
- Plate are fragments of lithosphere
- Plates move in relation to others at varied rates
- No major tectonic movements within plates
- Actions concentrated along plate boundaries
- Plate boundaries: plates come together. Defined by areas of concentrated seismic and volcanic activity, rifts, faults, and mountain ridges

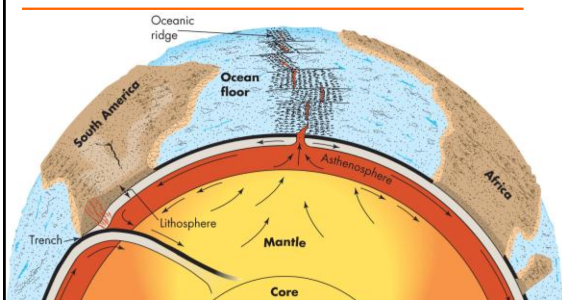
Plate Tectonics

Three major types of plate boundaries

- Divergent: plates moving apart and new lithosphere produced in mid-oceanic ridge
- Convergent: plates collide, subduction and mountain building (3 sub-types)
- Transform: two plates slide past one another

Earth interior convection is the mechanism for plate tectonics.

Plate Movement - Tectonics



Figure

Plate Tectonics - Mechanism

Driving force behind plate tectonics…

- Earth's internal heat and convection
- Ridge-push and slab-pull motion
- Motion made 'easier' by changes in density and temperature of crust

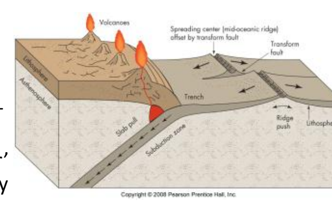


Figure 2.20

Plate Tectonics

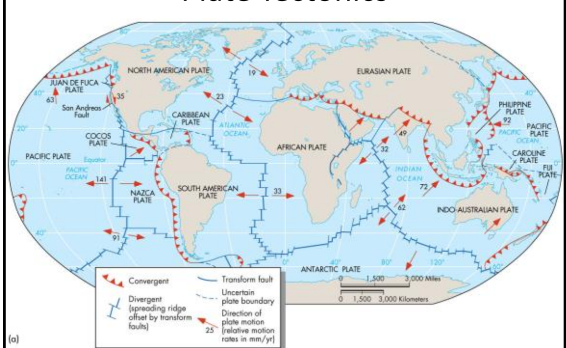


TABLE 2.1 Types of Plate Boundaries: Dynamics, Results, and Examples

Plate Boundary	Plates Involved	Dynamics	Results	Example
Divergent	Usually oceanic	Spreading. The two plates move away from one another, and molten rock rises up to fill the gap.	Mid-ocean ridge forms, and new material is added to each plate.	African and North American plate boundary (Figure 2.4a) Mid-Atlantic Ridge
Convergent	Ocean–continent	Oceanic plate sinks beneath continental plate.	Mountain ranges and a subduction zone are formed with a deep trench. Earthquakes and volcanic activity are found here.	Nazca and South American plate boundary (Figure 2.4a) Andes Mountains Peru-Chile Trench
Convergent	Ocean–ocean	Older, denser, oceanic plate sinks beneath the younger, less dense oceanic plate.	A subduction zone is formed with a deep trench. Earthquakes and volcanic activity are found here.	Fiji plate (Figure 2.4a) Fiji Islands
Convergent	Continent–continent	Neither plate is dense enough to sink into the asthenosphere; compression results.	A large, high mountain chain is formed, and earthquakes are common.	Indo-Australian and Eurasian plate boundary (on land) (Figure 2.4a) Himalaya Mountains
Transform	Ocean–ocean or continent–continent	The plates slide past one another.	Earthquakes are common. May result in some topography such as linear troughs and uplifts (often appearing as lines [faults] at nearly right angle to the ridge).	North American and Pacific plate boundary (Figures 2.10 and 2.21) San Andreas fault

Plate Tectonics - Divergent

Divergent Plate Boundary:

- Plates move away from each other
- Mid-ocean ridges
- Continental rift valleys
- Creative force – generates new material
- Exhibits extensional, normal stress
- Produces shallow earthquakes
- Basaltic volcanism

Plate Tectonics - Convergent

Convergent Plate Boundary

- Plates collide with each other
- Destructive force, recycles old material
- Exhibits compressional, reverse stress
- Produces shallow, intermediate, and deep earthquakes
- Various types of volcanism…depending on plate material

Plate Tectonics - Convergent

Convergent plate boundary – 3 sub-types:

- C-C boundary: Major young mountain belts and shallow earthquakes
- C-O boundary: Major volcanic mountain belts, subduction zone and oceanic trench, earthquakes
- O-O boundary: Subduction zone, deep oceanic trench, volcanic island arc, wide earthquake zones

Plate Tectonics - Convergent

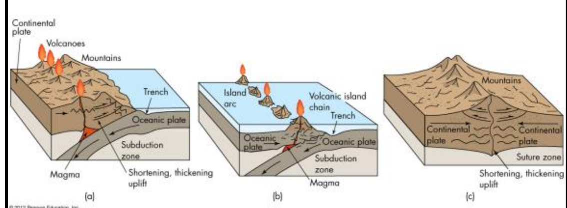


Figure 2.8

Plate Tectonics - Transform

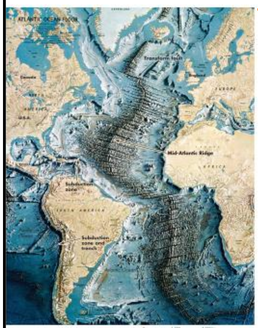
Transform plate boundary

- Locations where the edges of two plates slide past one another
- Spreading zone is not a single, continuous rift offset by transform faults
- Most transform plate boundaries are within oceanic crust, some occur within continents
- Famous transform plate boundary on land is the San Andreas fault

Plate Tectonics

Figure 2.10 & 2.11

Plate Boundary



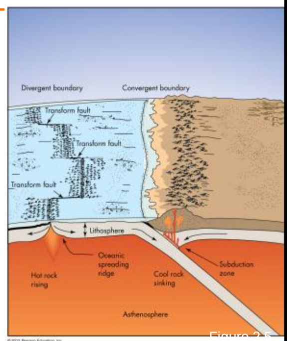


Plate Motion

- Plates move a few centimeters per year: about the growth rate of human fingernails
- The rates of movement changes over time
- North American plate along the San Andreas fault about 3.5 cm (1.4 in.) per year
- When rough edges along the plate move quickly, an earthquake may be produced
- Often slow creeping movement
- The direction of movement changes too (see Figure 2.4a)
- Wilson Cycle: The cyclic nature of plate tectonics

Seafloor Spreading

- 1950s and early 1960s, ocean expedition increased knowledge of oceanography
- In 1960s, Harry Hess proposed seafloor spreading
  - Seafloor not a single static piece
  - Mid-oceanic ridges, or spreading centers where new crust is formed and seafloor spreads
- Age of seafloor rocks: Progressively younger toward the mid-oceanic ridge
- Thickness of seafloor sediments: Progressively thinner toward the ridge

Seafloor Spreading

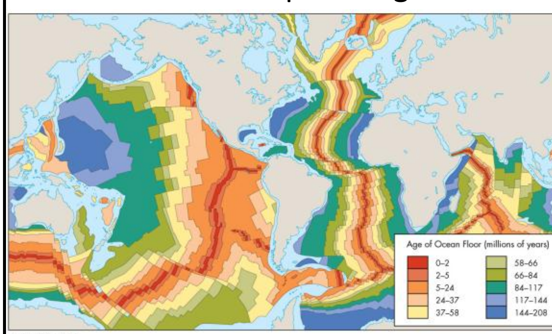
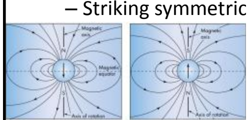


Figure 2.15

Seafloor Spreading

- Paleomagnetic data:
  - Dipolar magnetic field (~ last 3 million years)
  - Magnetic field direction is recorded by iron-bearing igneous rocks
  - Striking symmetric



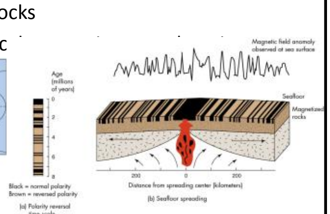
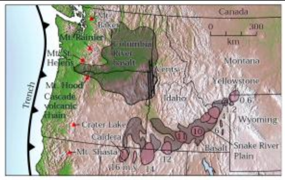


Figure 2.12 & 2.14

Hot Spots

- Places on Earth: Volcanic centers with magma source from deep mantle, perhaps near the core-mantle boundary
- Hot spots can be on continents and oceans, **Yellowstone** and **Hawaii**
- Forming a chain of volcanoes over a stationary hot spot: Example, the Hawaiian–Emperor Chain in the Pacific Ocean
  - The bend of a seamount chain over a hot spot representing the change of plate motion

Hot



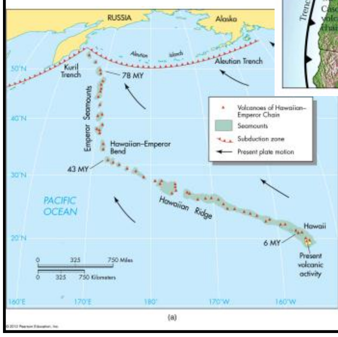


Figure 2.16a

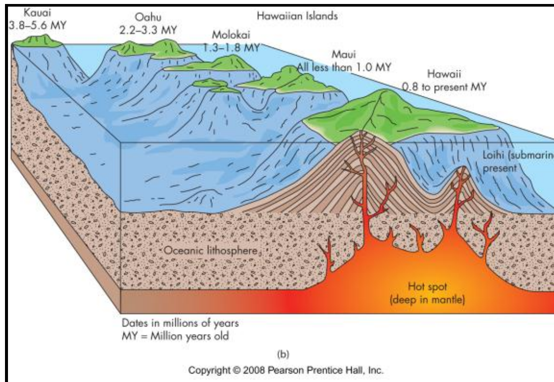


Figure 2.16

Wilson Cycle

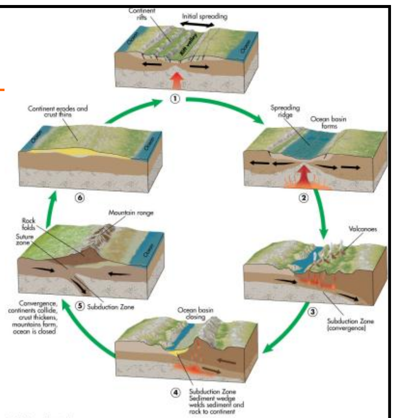


Figure 2.23

Tectonics and Environmental Geology

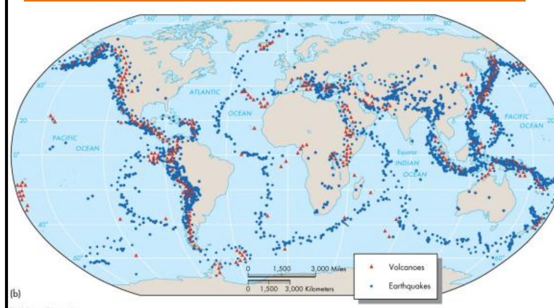


Figure 2.4b

Plate Tectonics and Environmental Geology

- Significance of tectonic plate motion
  - Global zones of resources
    - Oil, gas, hydrothermal energy, mineral resources
  - Global belts of catastrophic hazards from volcanoes and earthquakes
  - Impacts on the landscape and global climates
  - Geologic knowledge of plate tectonics as a foundation for:
    - Urban development, hazard mitigation, resource management

Critical-Thinking Topics

- Assume the Pangaea never broke up, how might today's environments be different?
- What are the major differences in plate tectonic settings between the U.S. eastern and western coasts?
- Will the tectonic cycle ever stop? Why or why not?
- Why is most seismic and volcanic energy released along the Pacific rim?
- Does plate tectonics play a role in shaping your local environment?