Instructor's Manual to Accompany Abbott & Samson/Natural Disasters, Fourth Canadian Edition

Chapter 2 Earth's Internal Energy and Plate Tectonics

Overview

Natural disasters necessarily involve the concentration and release of energy. Sources of energy include the Earth's internal heat generated from radioactive decay, solar energy, gravity, and the impact of extraterrestrial bodies.

The most basic divisions of the Earth are, based on density, core, mantle, and crust, or, based on material strength, core, mesosphere, asthenosphere, and lithosphere. The core is the innermost and densest region, composed mainly of iron with a solid inner part and a liquid outer part. Circulation in the outer core creates the Earth's magnetic field. The rocky mantle, extending from roughly half the Earth's radius to close to the Earth's surface, is the second densest region. The shallowest and least dense part of the solid Earth is the rocky crust.

With the exception of the uppermost part, the mantle is hot enough that it flows even though it is mostly solid. This soft plastic layer is called the asthenosphere. The lithosphere floats buoyantly on top of the asthenosphere like icebergs float in seawater. The Earth's lithosphere is cold and solid, and is divided into a number of thin but very wide plates. According to the theory of plate tectonics developed principally by Professor John Tuzo Wilson of the University of Toronto in the 1960s, the relative motions of these plates are responsible for most earthquakes, volcanic eruptions, and mountain-building on Earth. A new plate is formed by upwelling and solidification of magma at divergent zones, and old plates are recycled into the asthenosphere at subduction zones, a type of convergent zone. Evidence of plate tectonics includes magnetization patterns on the seafloor, age of the ocean basins, the distribution of ocean water depth, epicentre and hypocentre locations, and fossil correlations.

Most earthquakes and volcanoes occur at plate boundaries. At spreading centers (divergent zones), the high temperatures near the Earth's surface preclude the occurrence of very powerful or deep earthquakes, though numerous moderate and shallow earthquakes occur. In contrast, the deepest earthquakes and the most powerful earthquakes occur at convergent zones (subduction zones and continent-continent collision zones). Large earthquakes can also occur at transform plate boundaries.

Most volcanic activity on Earth takes place at spreading centres where large amounts of lava are extruded peacefully underwater. Dangerous, explosive volcanic eruptions mostly occur at subduction zones.

Learning Objectives

1. List the sources of energy fueling natural hazards.

2. Describe the Earth's internal structure.

3. Explain the behavious of materials under stress.

4. Explain how plate tectonics operates.

5. Evaluate the evidence for plate tectonics.

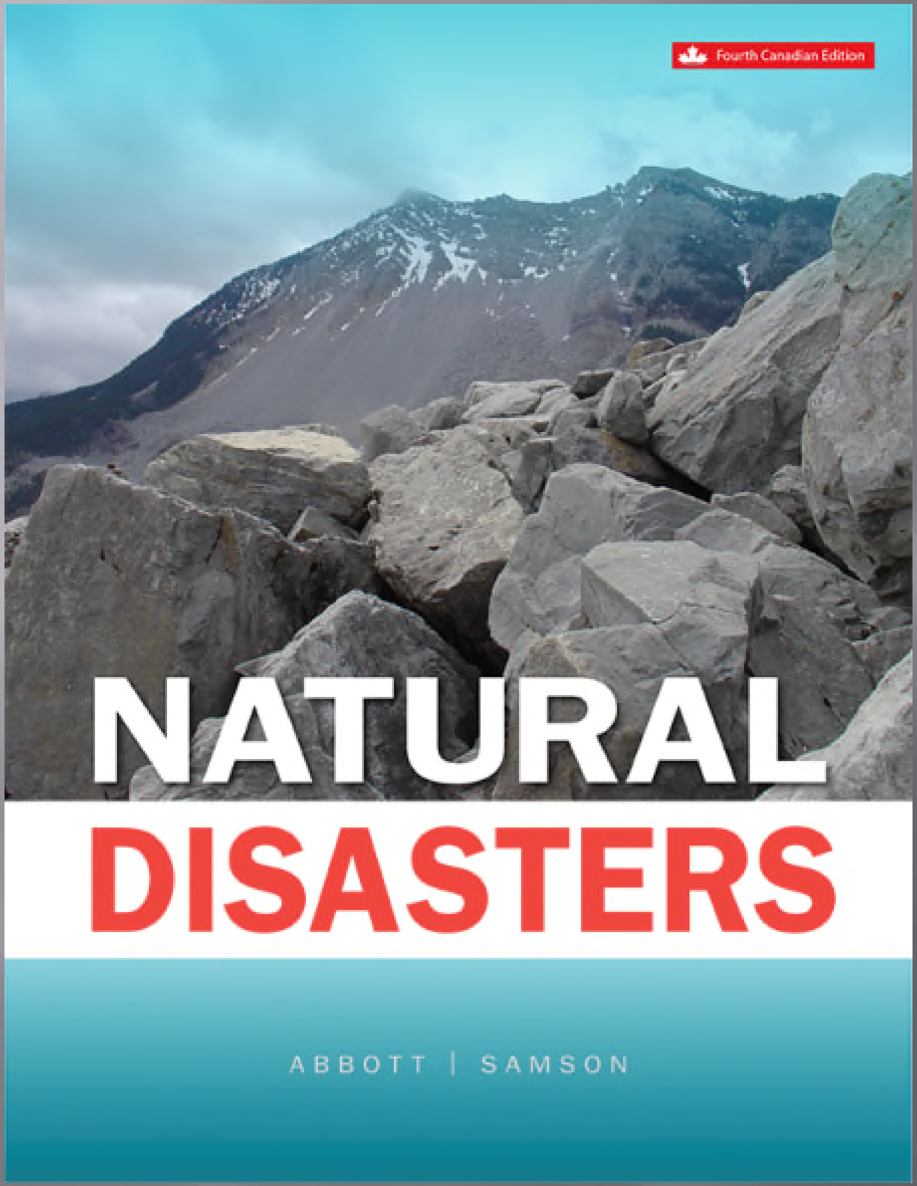
6. Explain the relationship between plate tectonics and the location of earthquakes and volcanoes.

Critical Thinking Questions

1. There are three different styles of rock deformation: elastic, ductile, brittle, and plastic. Can you identify various common objects that show these styles of deformation?

2. The lithospheric plates move around the surface of the Earth, but the surface area of the Earth has not changed over geological time. If a new spreading center (divergent zone) were to develop, what other plate changes might also occur at the same time?

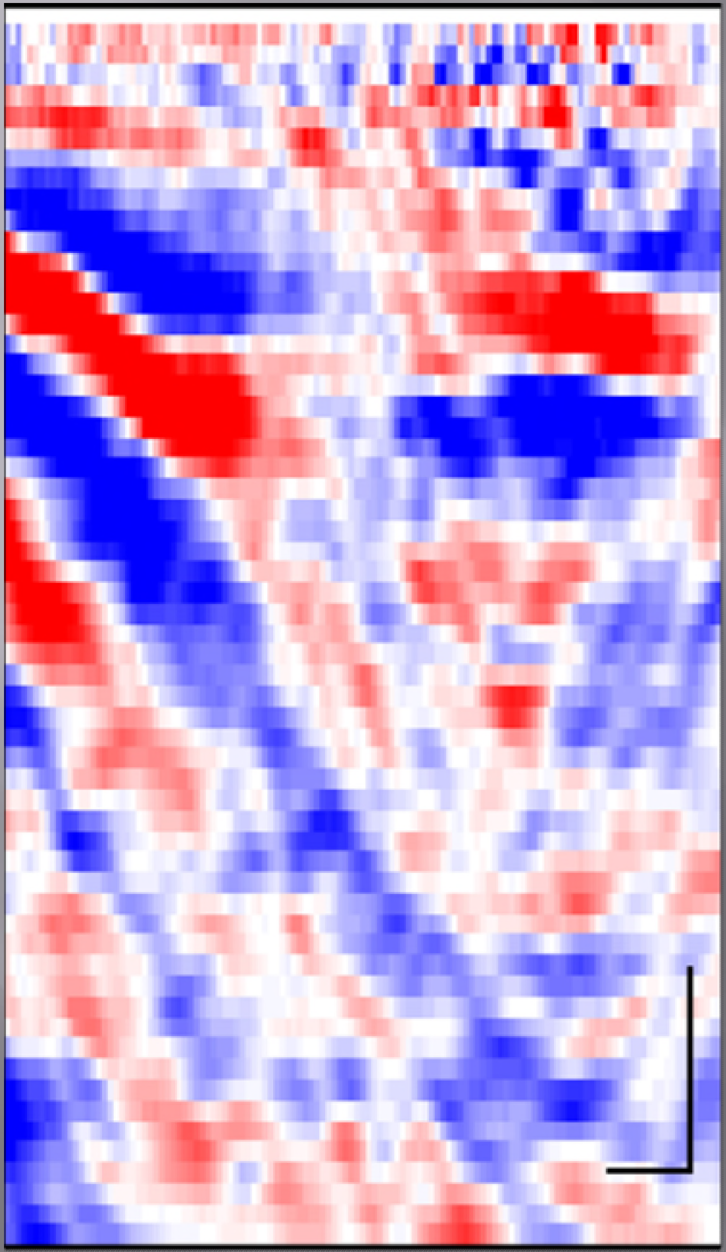
3. Figure 2.41 shows the evolution of the continents with time. Using these to extrapolate, what do you think the continental configuration will look like 50 million years in the future?



NATURAL DISASTERS

Fourth Canadian Edition

Patrick Abbott
Claire Samson



Chapter 2

Earth's Internal Energy and Plate Tectonics

Prepared by Bill Buhay
University of Winnipeg

Learning Outcomes

LO1 - List the sources of energy fueling natural hazards

LO2 - Describe the Earth's internal structure

LO3 - Explain the behaviour of materials under stress

LO4 - Explain how plate tectonics operates

LO5 - Evaluate the evidence for plate tectonics

LO6 - Explain the relationship between plate tectonics and the location of earthquakes and volcanoes

Outline

Energy Sources of Natural Hazards

Origin of the Sun and Planets

The Earth’s Early History

The Layered Earth

Plate Tectonics: Recycling the Earth’s Outer Layers

Evidence of Plate Tectonics

Plate-Tectonic Setting of Earthquakes and Volcanoes

Summary

Energy Sources of Natural Hazards

Primary energy sources:

Earth's internal energy

- Primarily from the radioactive decay of elements
- Smaller contributions from impacts/gravitational compaction (Earth's early history)

Gravity

- Mass movements
- Snow avalanche

Energy Sources of Natural Hazards

Primary energy sources:

Solar energy

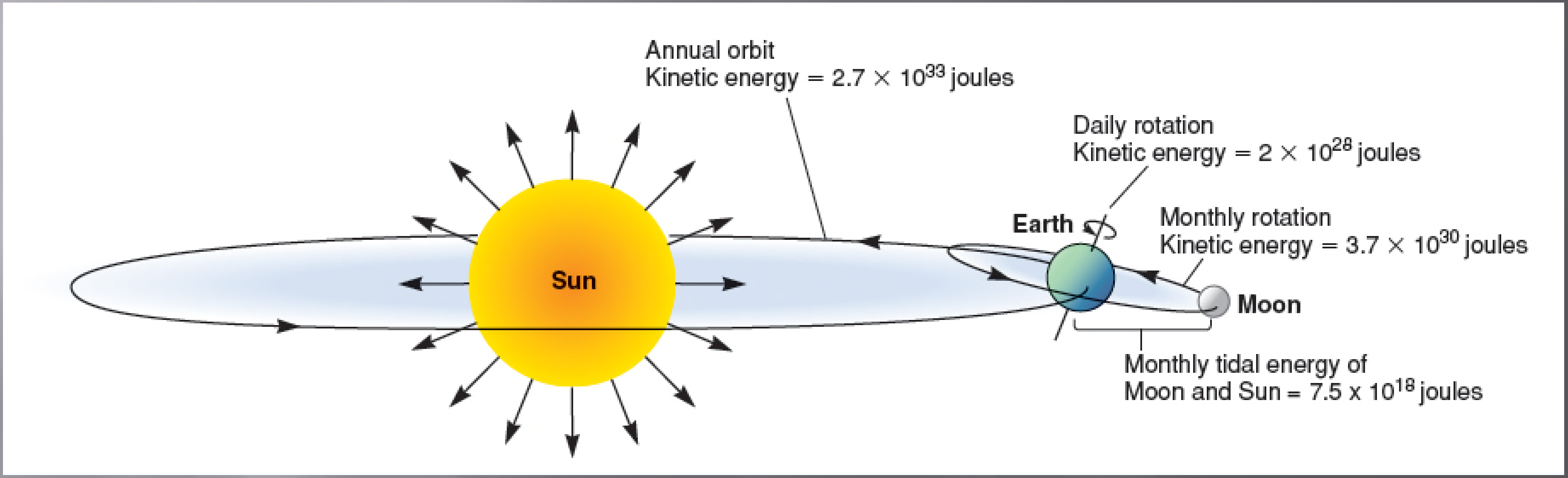
- Hydrologic cycle
- With gravity powers the agents of erosion
- Stored in plants

The impact of extraterrestrial bodies

- Asteroids and comets

Energy Sources of Natural Hazards

Figure 2.2



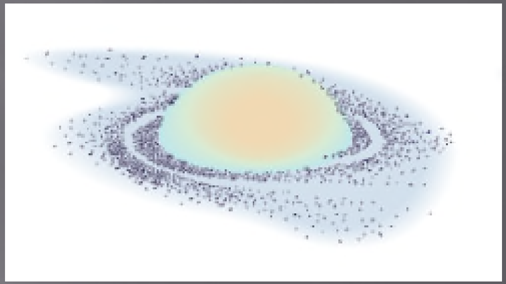
The rotations and orbits of the Earth-Moon-Sun system result in tremendous amounts of energy.

Origin of the Sun and Planets

Figure 2.3

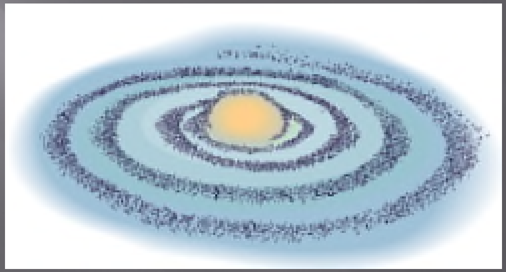
Initial stage

Rotating spherical cloud (ice, gas, debris)



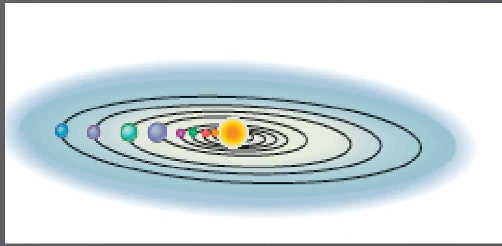
Spinning mass

Contracts into flattened disk (planets grow as particles collide and stick together)



Ignited Sun

Surrounded by planets – Earth is the third planet from the Sun



LO1

Origin of the Sun and Planets

AGE OF THE EARTH

The oldest Solar System materials are about 4.57 billion years old

The oldest Earth rocks are 4.03 billion years old (Acasta gneiss, Northwest Territories, Canada)

The oldest ages obtained from Earth materials (zircons) are 4.37 billion years old (extracted from a 3.1 billion year old sandstone – western Australia)

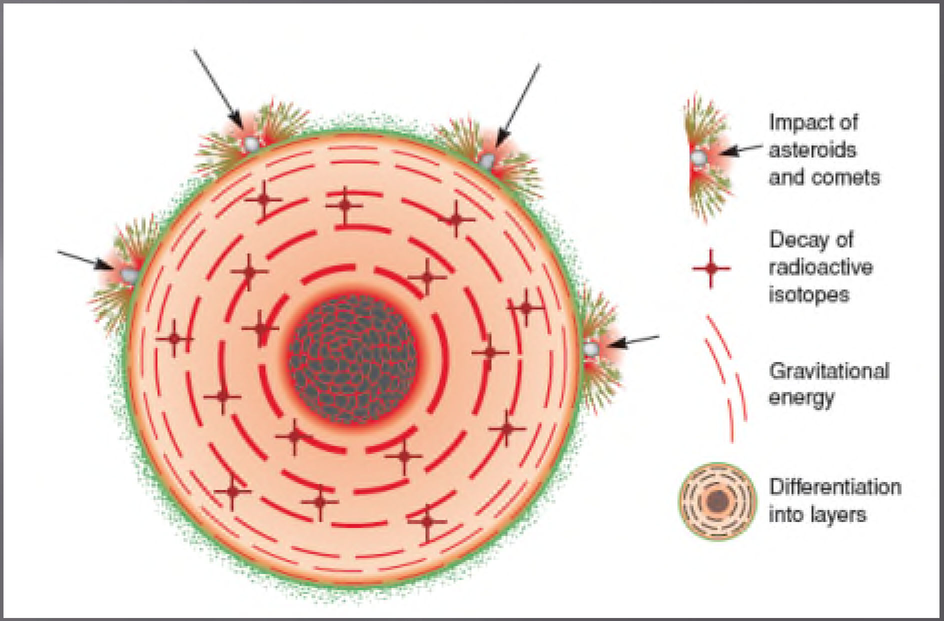
Our planet has existed for about 4.5 billion years

The Earth's Early History

Heat-Transforming the Early Earth

- Impact energy
- Decay of radioactive isotopes
- Gravitational energy

Figure 2.5



Massive amount of heat produced widespread melting that caused the formation of:

- Primitive crust (low –density rock)
- Large oceans
- Dense atmosphere

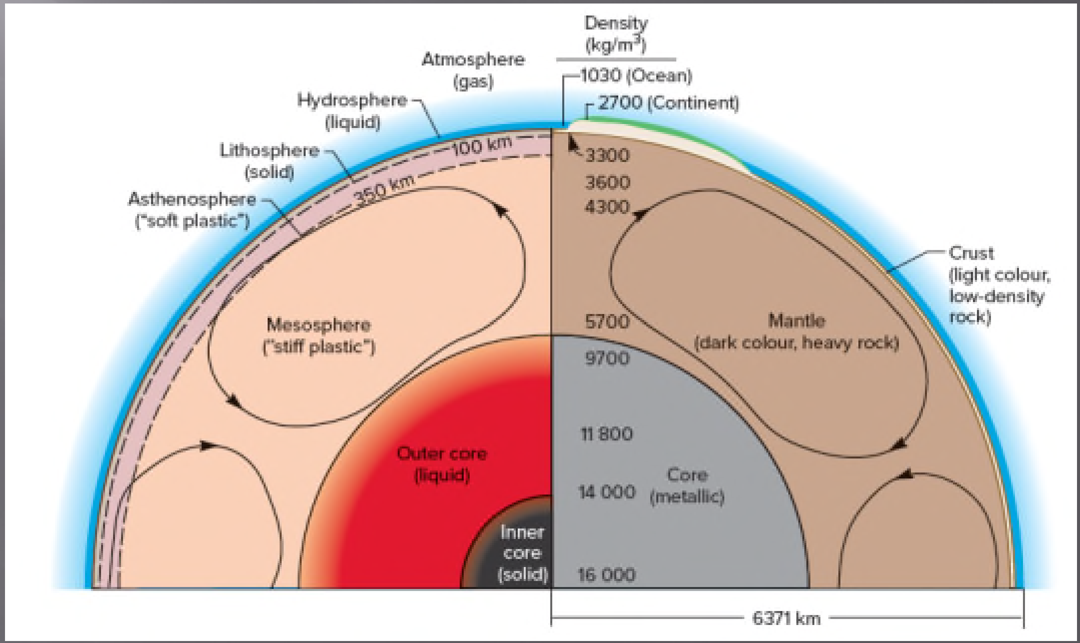
The Layered Earth

Layers based on:

- Density due to different chemical and mineral compositions
  - Core
    - Inner core
    - Outer core
  - Mantle
  - Crust
- Different strengths
  - Mesosphere
  - Asthenosphere
  - Lithosphere

DENSITY LAYERS

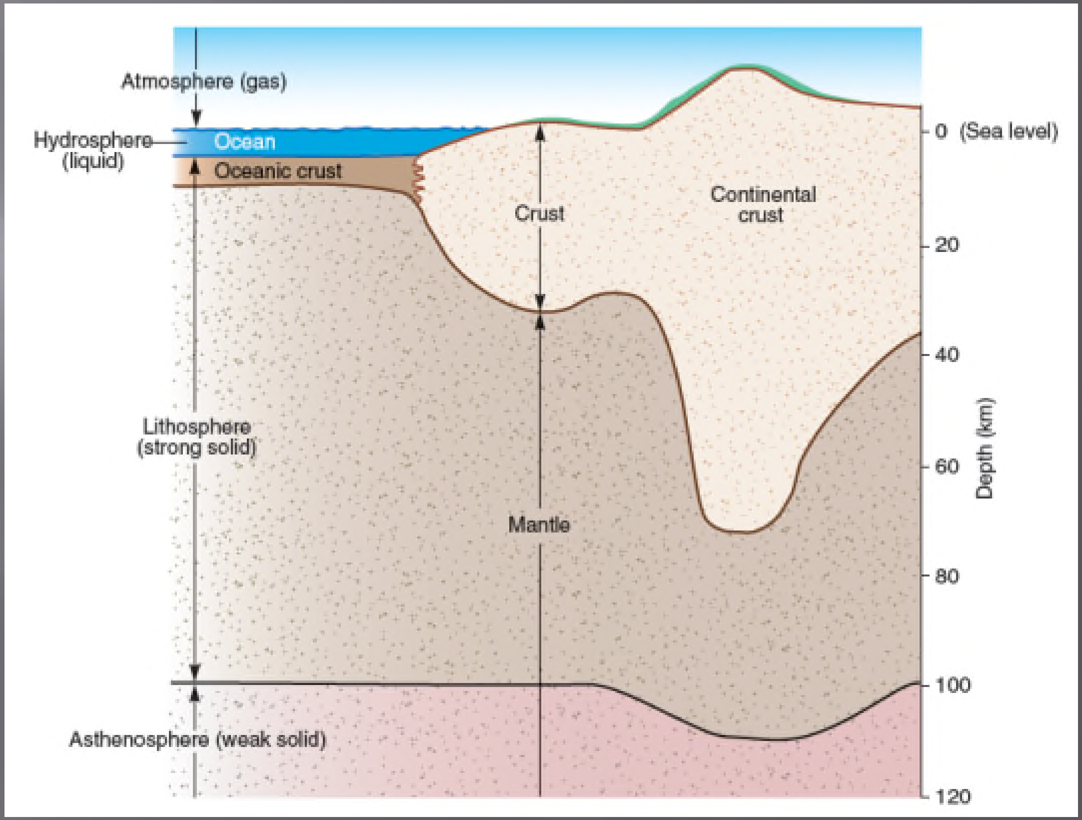
Figure 2.10



The Layered Earth

STRENGTH LAYERS

Figure 2.11



Mesosphere – stiff plastic solid - extends from the core-mantle boundary to ~ 360 km below the Earth's surface

Asthenosphere – soft plastic – surrounds the mesosphere

Lithosphere – rigid outer layer – varies in thickness between a few km under oceans to 100 km under continents.

The Layered Earth

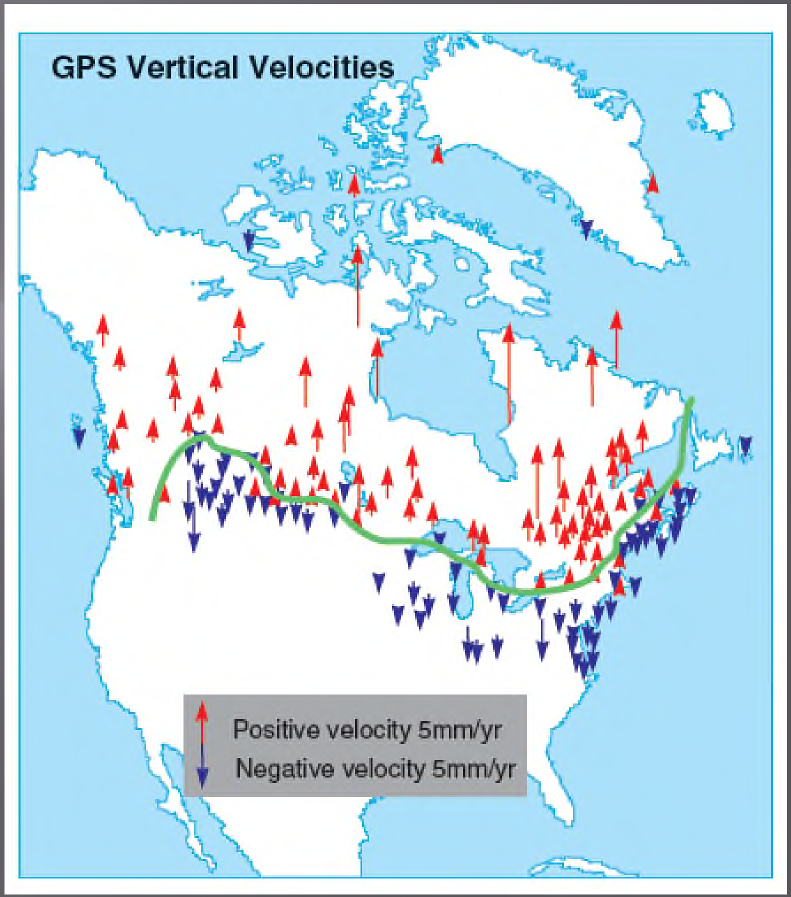
ISOSTASY

Buoyancy principle

low density continents and mountain ranges “float” on the denser mantle below

post-glacial rebound effect in Canada

Figure 2.13



In Greater Depth

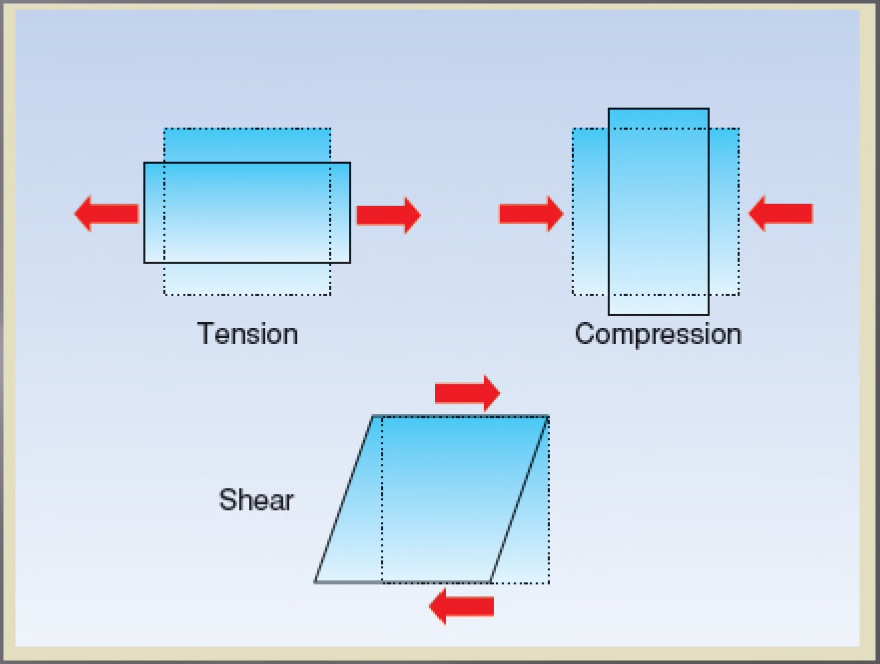
MATERIAL DEFORMATION

materials subjected to **stress**, they deform or undergo **strain**.

Stress can be applied perpendicular to the surface of a body, causing it to stretch under **tension** or to contract under **compression**.

On the other hand, **shear stress**, which is applied parallel to the surface, tends to deform a body along internal planes slipping past one another.

Figure 2.7



In Greater Depth

MATERIAL DEFORMATION

Behaviour of materials

a) **Elastic**: bend thin board; let it go and board recovers its original shape.

b) **Ductile**: squeeze a wad of bubblegum or Silly Putty®; let it go but it stays in the deformed shape.

c) **Brittle**: bend thin board sharply and it breaks.

Figure 2.8

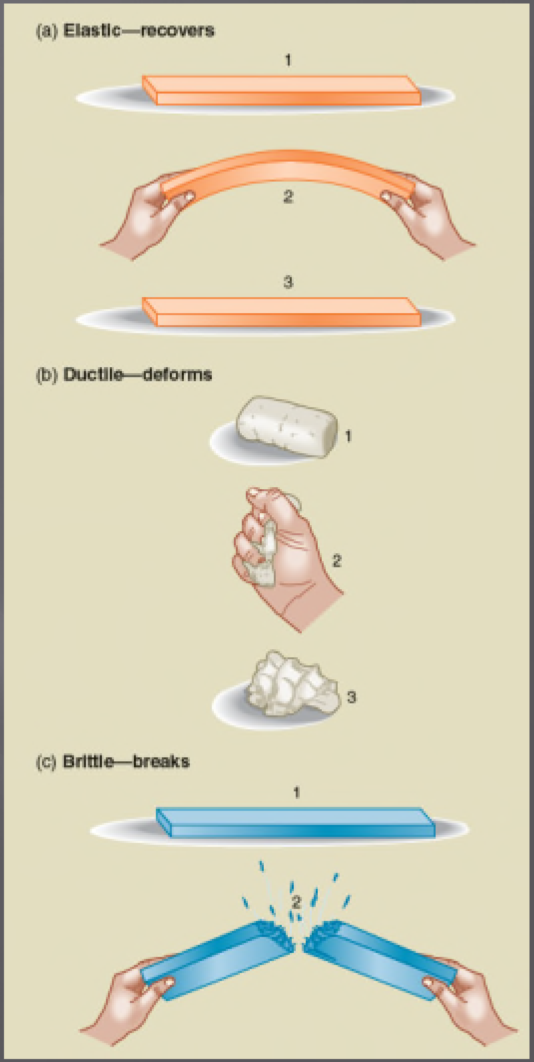


Plate Tectonics: Recycling the Earth's Outer Layers

The lithosphere is broken into pieces called plates.

Plate tectonics

- Greek word "tekton" = to build tectonics.

Dozen larger plates (Pacific plate) and several small plates (Juan de Fuca).

Figure 2.16

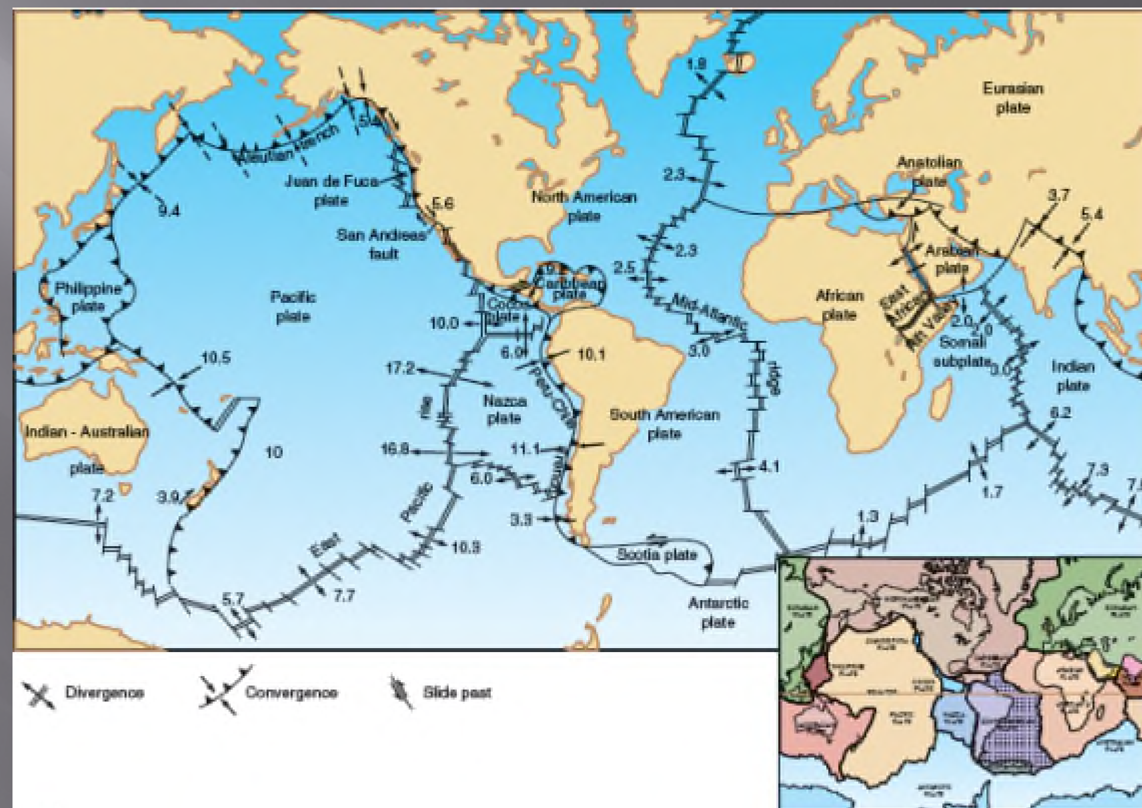


Plate Tectonics: Recycling the Earth's Outer Layers

Tectonic forces form:

- Mountains/plateaus
- Mid-ocean ridges
- Deep ocean trenches
- Chains of volcanic islands

Figure 2.18

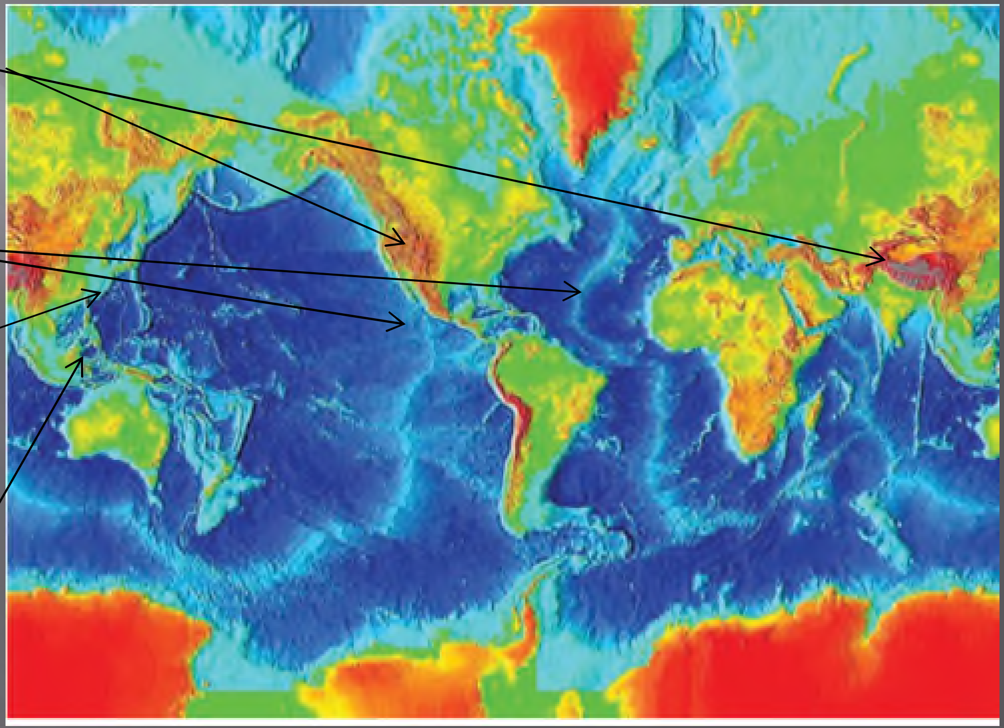


Plate Tectonics: Recycling the Earth's Outer Layers

~ 250 million years to complete the tectonic cycle (seafloor spreading – subduction).

Ocean basins

< 200 million years old.

Figure 2.19

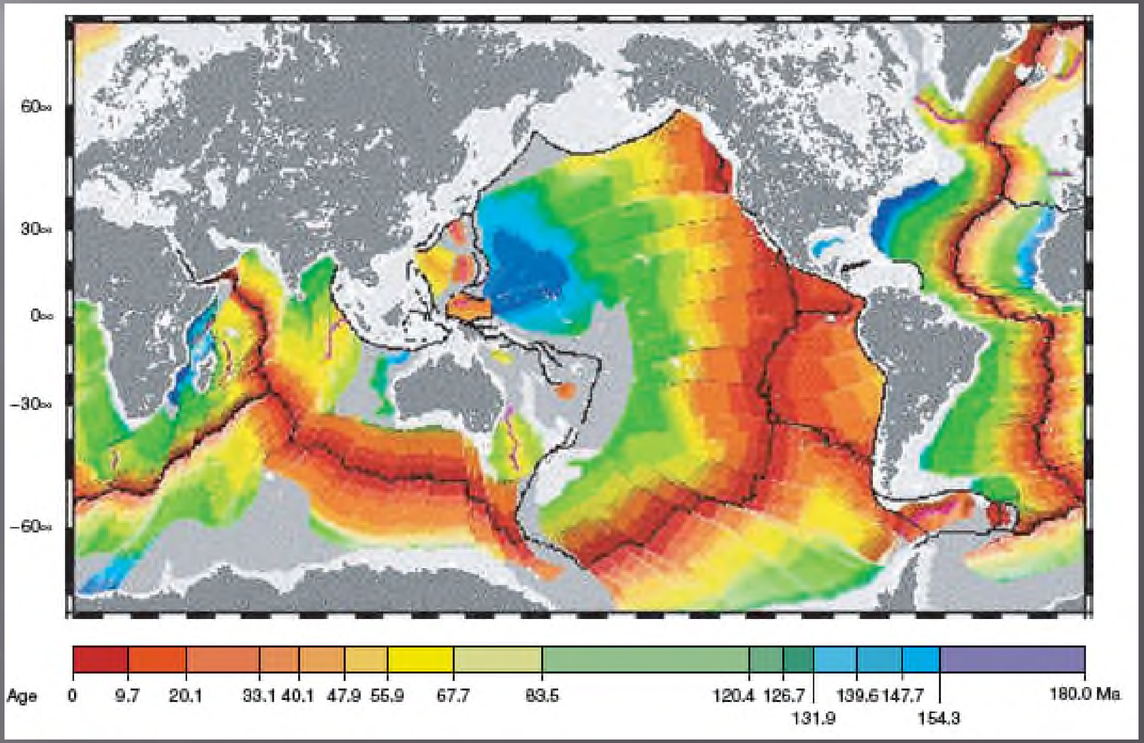


Plate Tectonics: Recycling the Earth's Outer Layers

Figure 2.20

- Magma rises from the asthenosphere – surfaces at oceanic volcanic ridges.
- As the magma cools, the plates move laterally away (continue to cool).
- Plates grow thicker, become denser, collide with less dense plates – then subduct and assimilate in the asthenosphere.

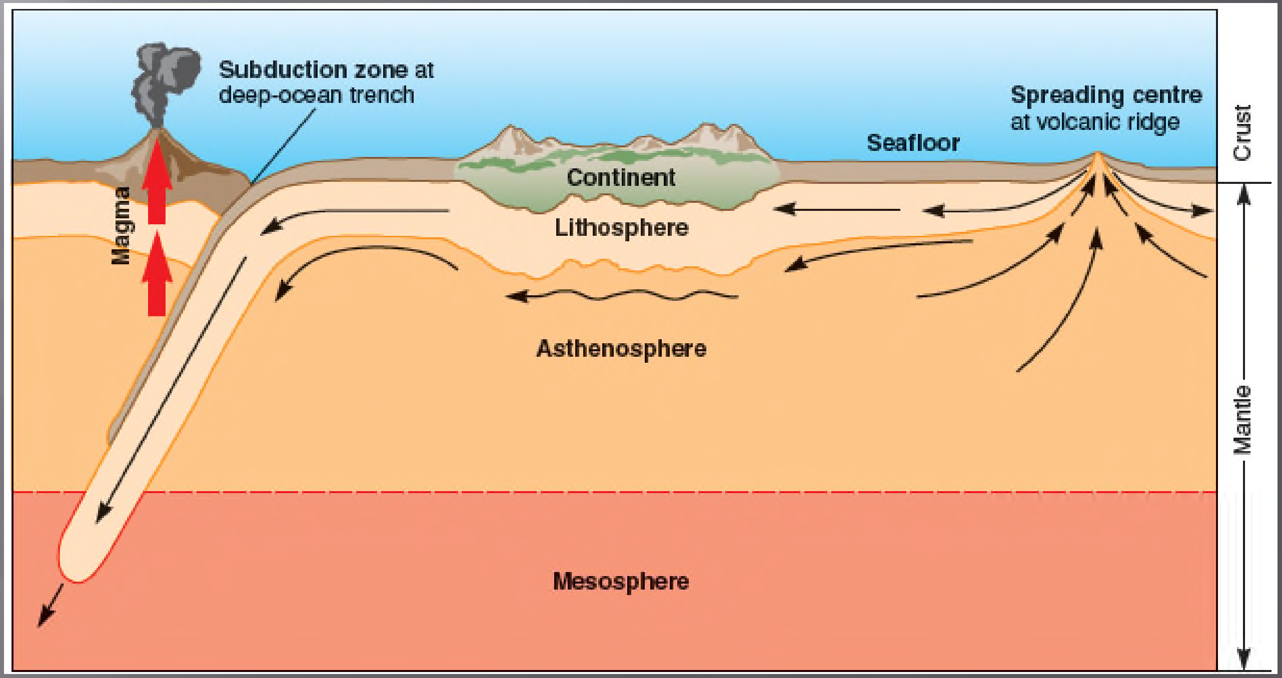


Plate Tectonics: Recycling the Earth's Outer Layers

Figure 2.21

Convection cells in the mantle drive the movement of the overlying tectonic plates.

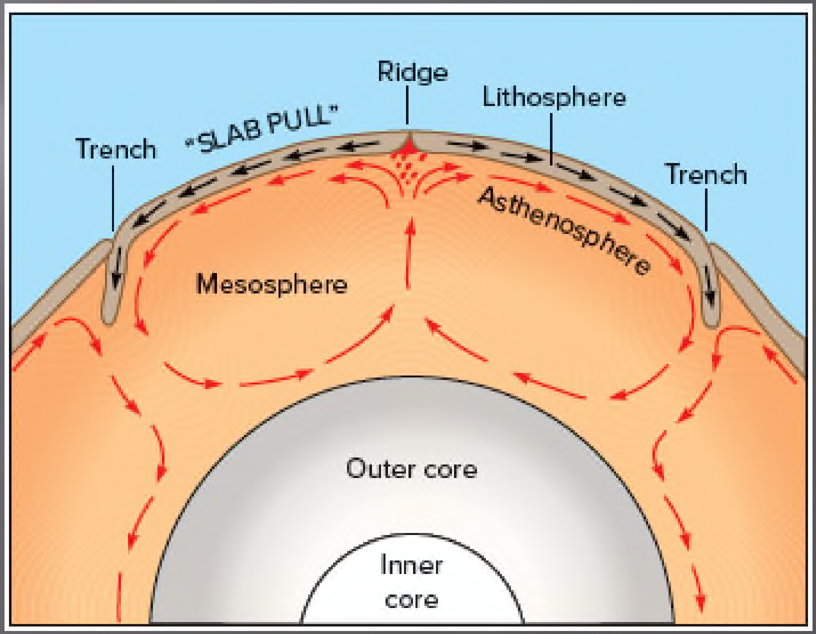


Plate Tectonics: Recycling the Earth's Outer Layers

Figure 2.22

Divergent zones

Convergent zones

Transform plate boundaries

Hot spots

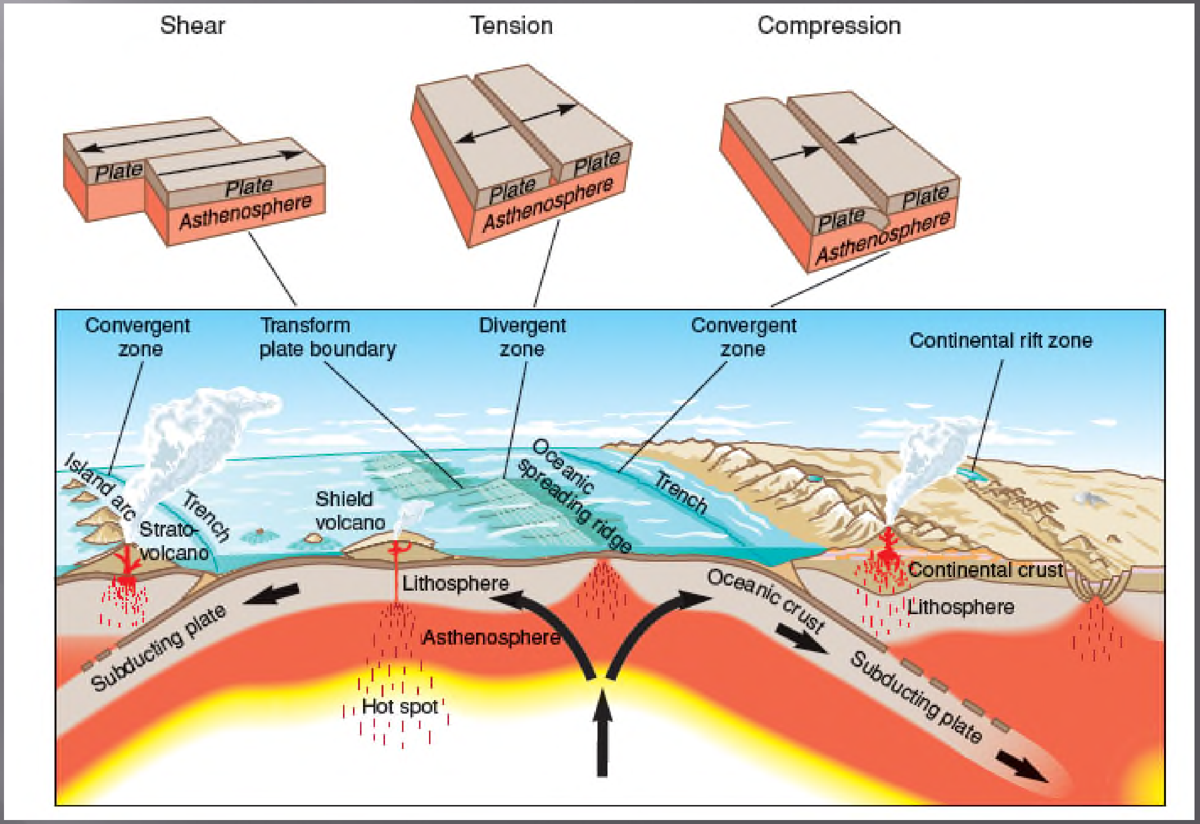
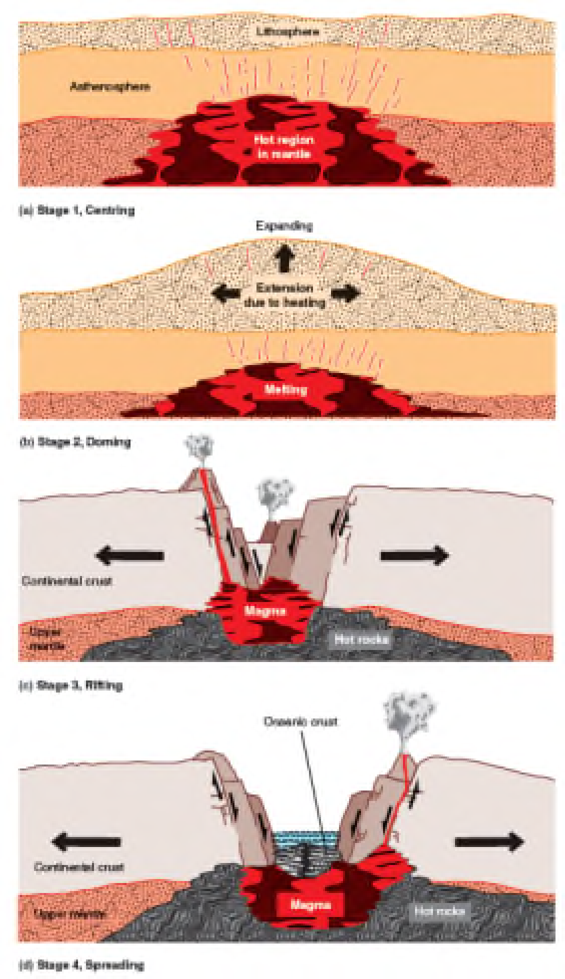


Plate Tectonics: Recycling the Earth's Outer Layers

DIVERGENT ZONES

Figure 2.23



Centering: lithosphere moves over centres of anomalously hot mantle regions

Doming: mantle heat causes surface doming through uplifting, stretching and fracturing

Rifting: dome's central area sages – forms valley

Spreading: Advanced pulling apart – forming new seafloor

Plate Tectonics: Recycling the Earth's Outer Layers

DIVERGENT ZONES

Figure 2.24

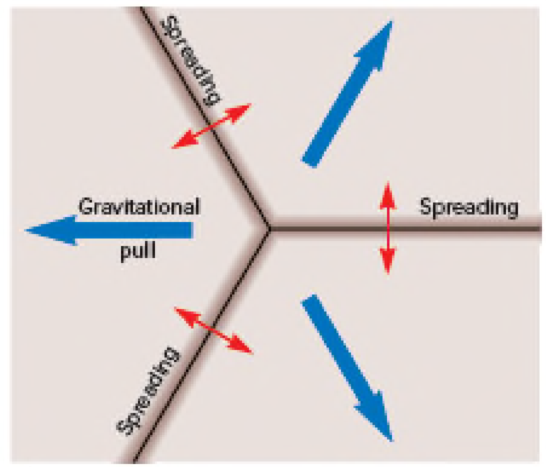
Triple Junction
(Afar Triangle)

Northeast Africa being torn apart by three spreading centres:

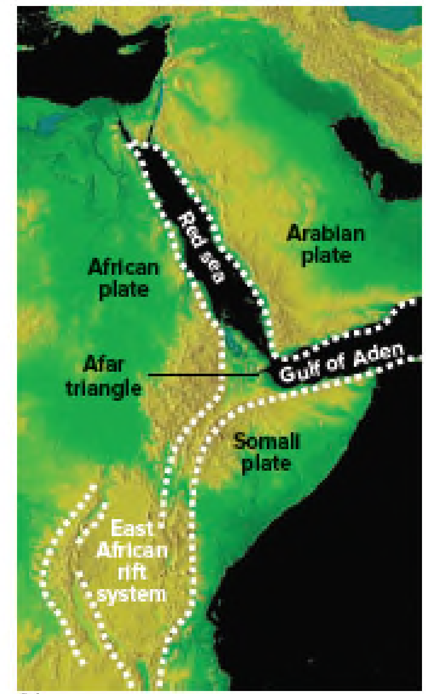
Red Sea

Gulf of Aden

East African rift system



(a)



(b)

Figure 2.24
Triple junction. (a) Schematic example. (b) Northeast Africa is being torn apart by three spreading centres: the Red Sea, the Gulf of Aden, and the East African rift system. The spreading centres meet at a triple junction in the Afar Triangle.

Plate Tectonics: Recycling the Earth's Outer Layers

CONVERGENT ZONES

Plates deform under compression at convergent zones.

Three classes of collisions:

- Oceanic plate-Oceanic plate
- Oceanic plate-Continent plate
- Continent plate-Continent plate

Plate Tectonics: Recycling the Earth's Outer Layers

CONVERGENT ZONES

a) **Oceanic-oceanic convergence** – formation of a deep offshore trench and seafloor volcanoes that can eventually form an island arc

b) **Oceanic-continental convergence** - formation of a coastal trench and adjacent chain of volcanoes

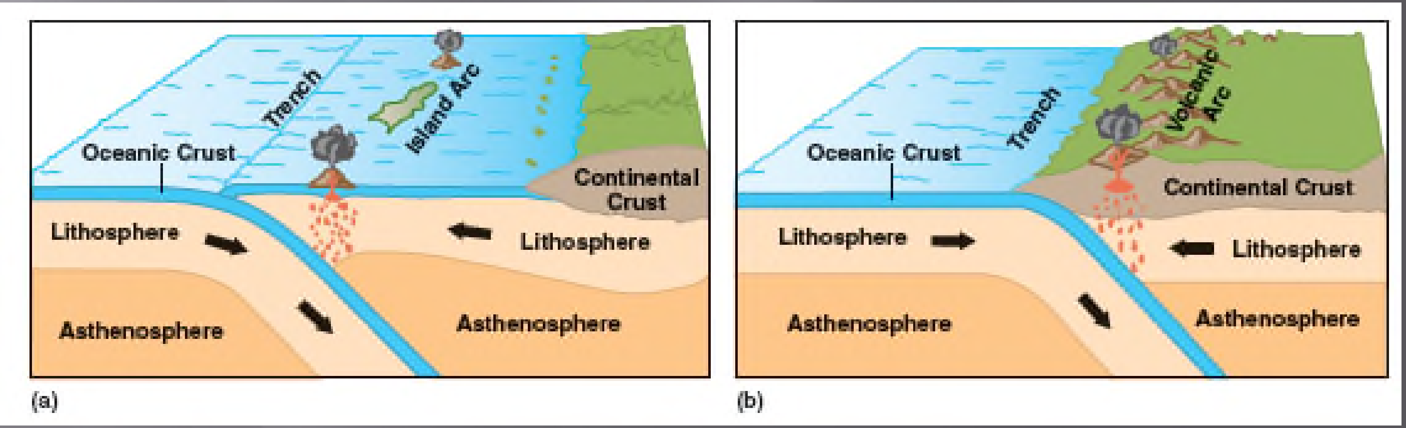


Figure 2.25

Plate Tectonics: Recycling the Earth's Outer Layers

CONVERGENT ZONES

Figure 2.26

Bonne Bay, Gros Morne National Park, Newfoundland.

500 million years ago – piece of oceanic plate was scraped off the subducting plate.

Provides geologists with exposed oceanic plate.

Plate Tectonics: Recycling the Earth's Outer Layers

CONVERGENT ZONES

When Godwanaland began separating – India moved northward towards Asia.

Once the seafloor between then had been subducted (under Asia) – India collided with Asia (~2000 km of crustal shortening/mountain building so far).

Figure 2.27

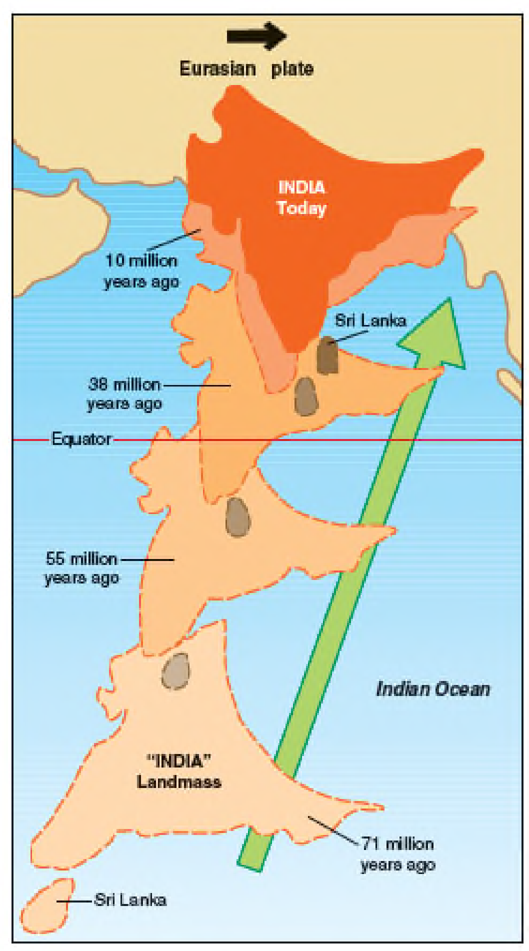


Plate Tectonics: Recycling the Earth's Outer Layers

Figure 2.29

CONVERGENT ZONES

Himalaya Mountains/Tibetan Plateau.

Tectonic Map – India pushing north and colliding with Asia.

Collision resulting in crustal shortening and the uplift of the Himalayan mountains and the Tibetan Plateau.

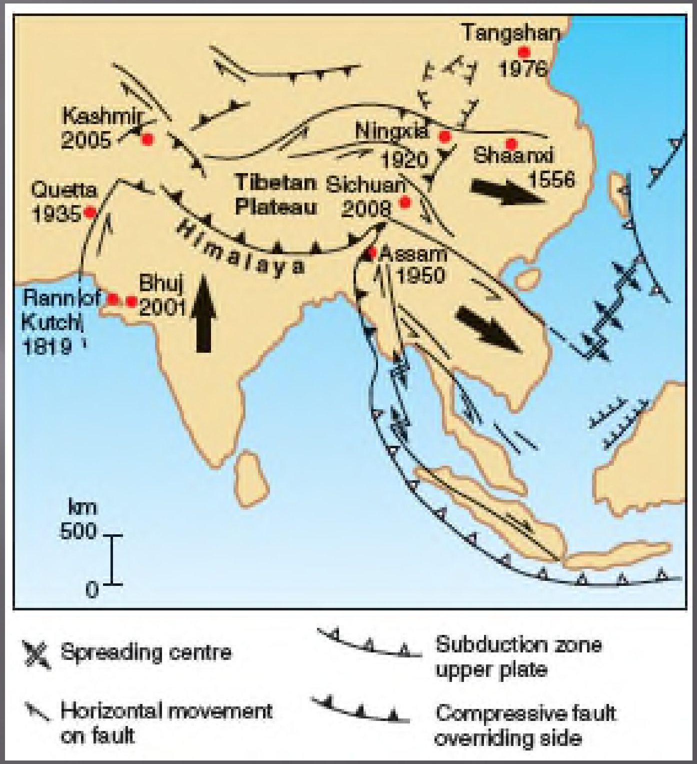
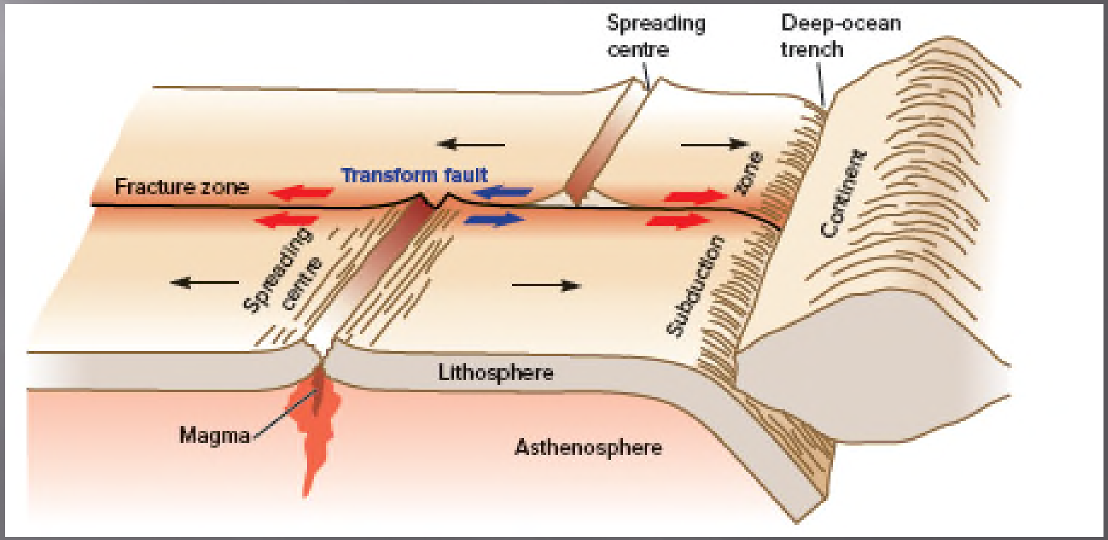


Plate Tectonics: Recycling the Earth's Outer Layers

Transform plate boundaries

Figure 2.31



Shear stress at transform plate boundaries.

To accommodate the Earth's curvature the plates must fracture – ***transform faults.***

Human Focus: John Tuzo Wilson (1908-1993)

Figure 2.33

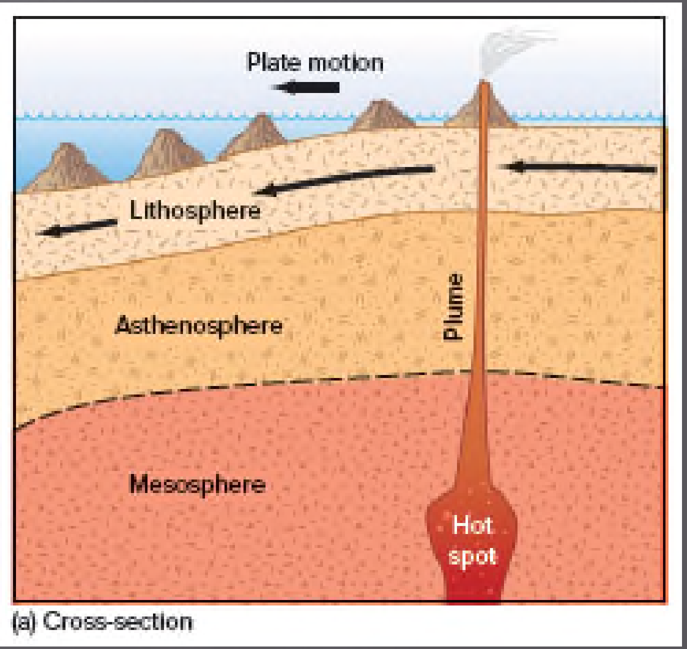
1963 -1966: Tuzo Wilson (U of Toronto)

Father of Plate Tectonics

Plate Tectonics: Recycling the Earth's Outer Layers

Hot Spots

Figure 2.32a



(a) Cross-section

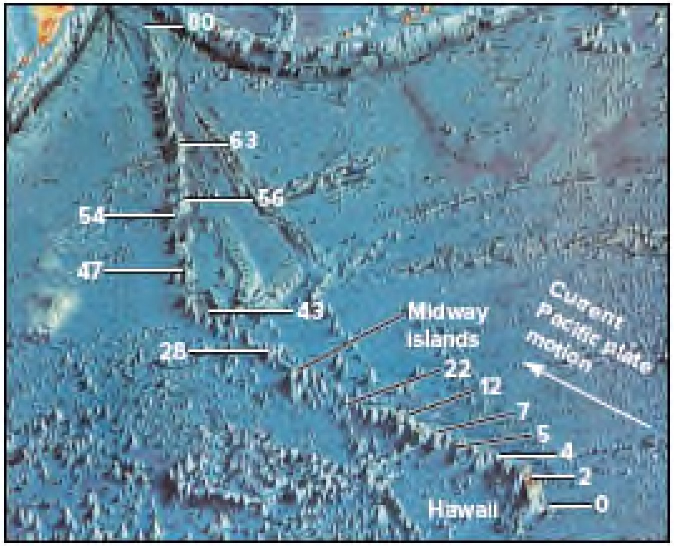
hot mantle rock (from the mesosphere) rises up through the asthenosphere and lithosphere as a plume of magma supplying a volcano.

lithospheric plate keeps moving - new volcanoes are formed.

Plate Tectonics: Recycling the Earth's Outer Layers

Figure 2.32b

A chain of hot spot fed volcanoes formed as the Pacific plate moved (changed direction between 47 and 63 million years ago).



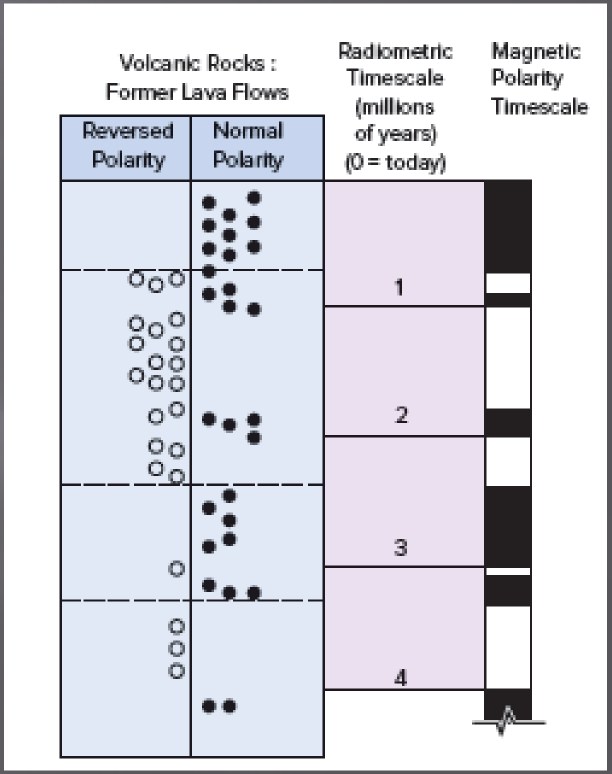
(b) Map

Evidence of Plate Tectonics

MAGNETIZATION PATTERNS ON THE SEAFLOORS

Figure 2.34

Magnetic polarity measurements in volcanic rocks combined with radiometric ages determined from the same rocks allow the building of a timescale based on magnetic polarity reversals.



Evidence of Plate Tectonics

MAGNETIZATION PATTERNS ON THE SEAFLOORS

magnetically striped Pacific Ocean floor.

Figure 2.35

black areas are magnetized pointing to a north pole, yellow areas to a south pole.

mirror-image patterns on each side of the Juan de Fuca ridge.

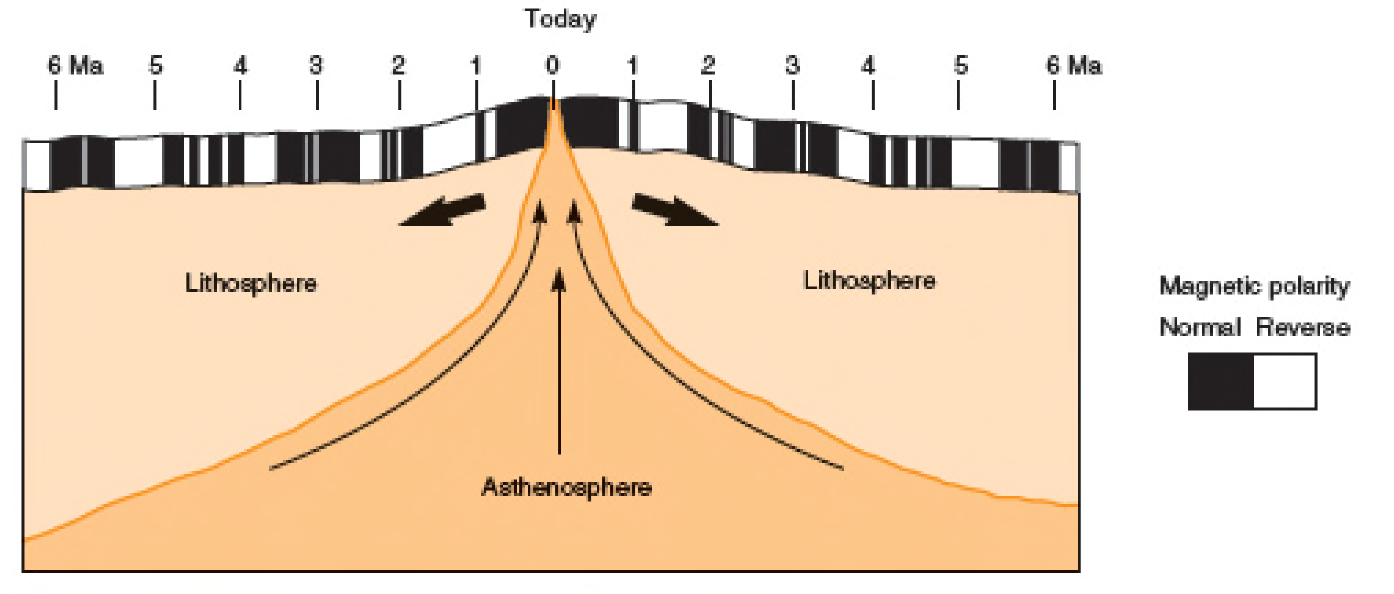
Evidence of Plate Tectonics

MAGNETIZATION PATTERNS ON THE SEAFLOORS

Cross-section of magnetically striped seafloor.

mirror-image pattern documents movements away from oceanic ridges.

Figure 2.36



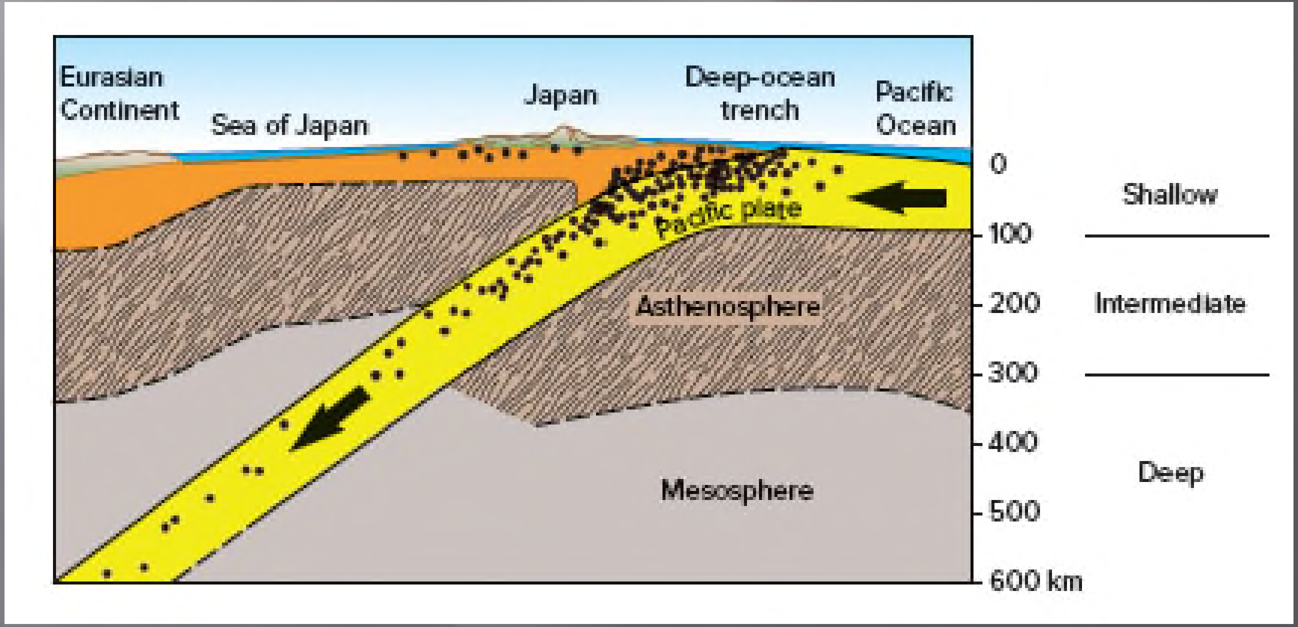
Evidence of Plate Tectonics

EARTHQUAKE EPICENTRES AND HYPOCENTRES

Shallow hypocentres - earthquakes generated in brittle rocks in both subducting (brown) and overriding (orange) plates

Deeper hypocentres - only the interior of the subducting Pacific plate is cold enough to maintain the rigidity necessary to produce earthquakes

Figure 2.37

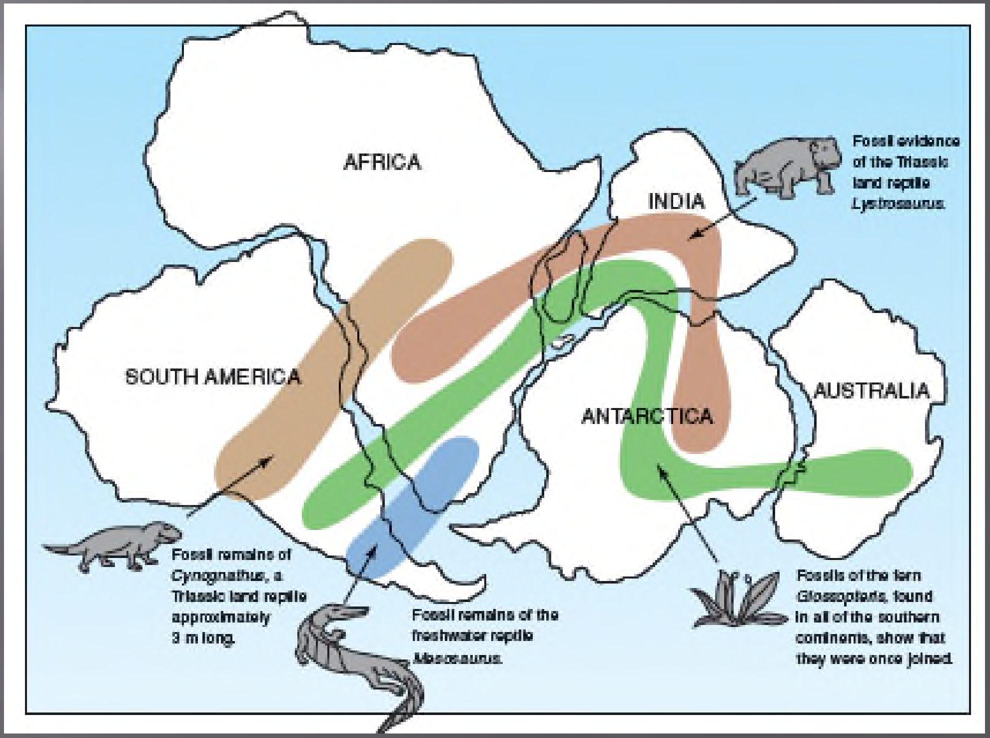


Evidence of Plate Tectonics

CONTINUITY OF GEOLOGICAL FEATURES

Figure 2.38

distribution of several fossils is continuous when the continents are restored to the position they occupied when these life forms existed.



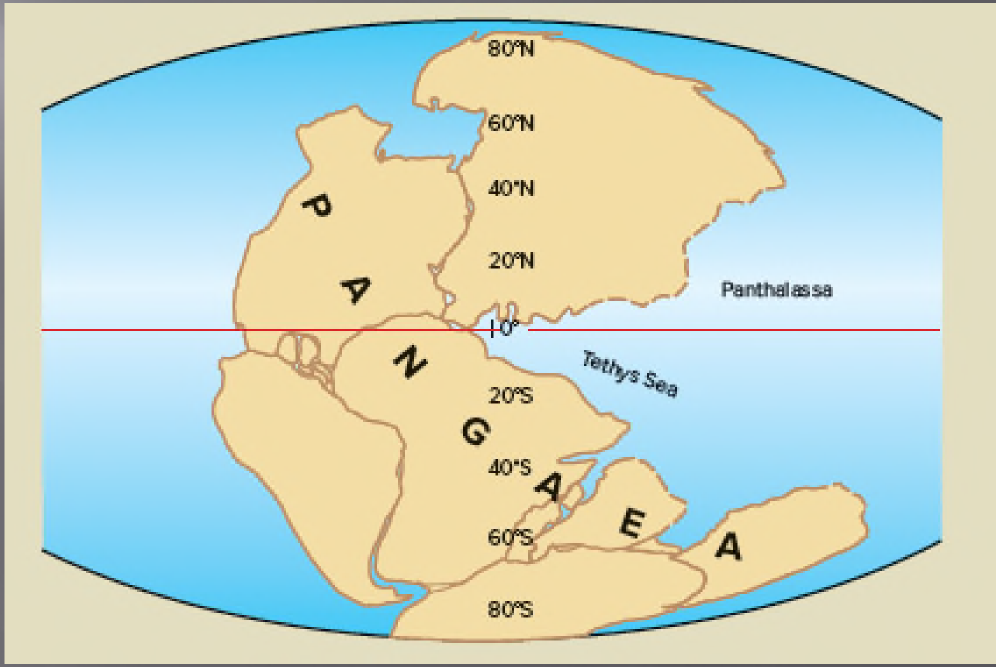
In Greater Depth

THE DANCE OF THE CONTINENTS

continuity of mountain ranges and fossils across oceans.

suggest that all the continents were once united in a supercontinent (Pangaea - 220 million years ago).

Figure 2.40



In Greater Depth

THE DANCE OF THE CONTINENTS

positions of the continents:

(a) 180 million years ago

(b) 135 million years ago

(c) 65 million years ago

(d) Today

Figure 2.41

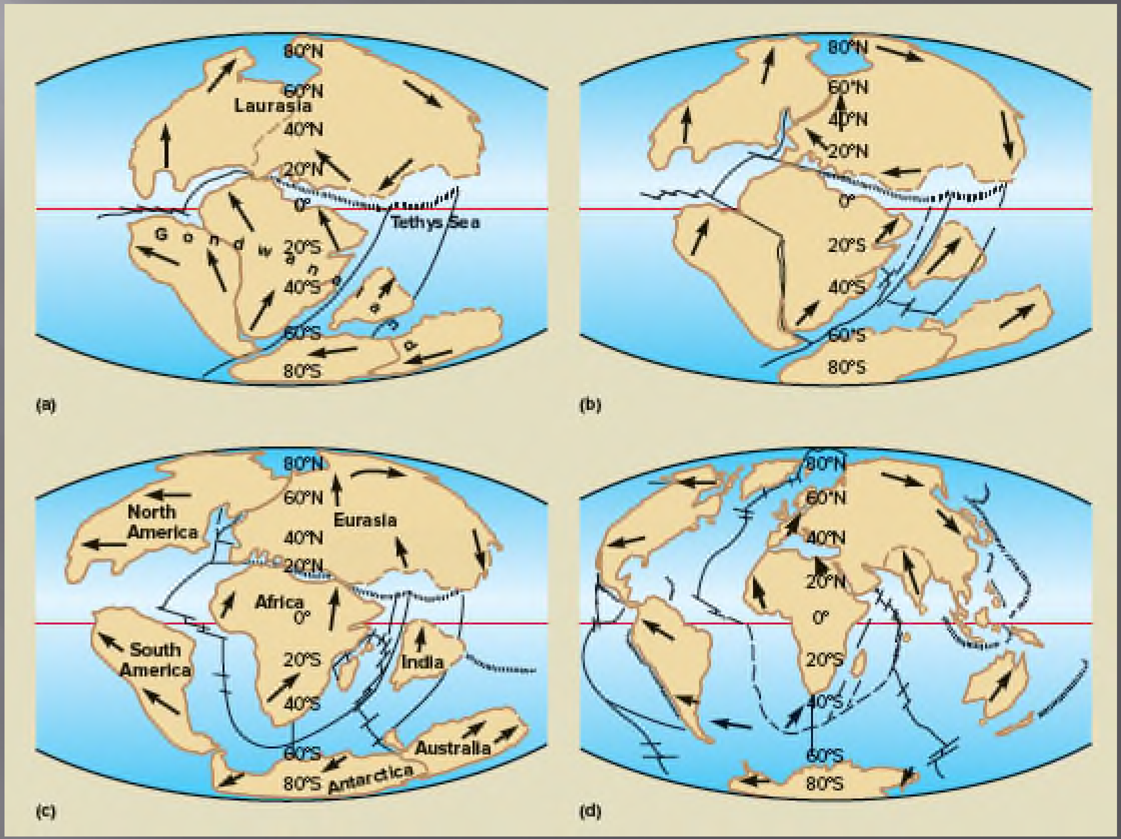


Plate-Tectonic Setting of Earthquakes and Volcanoes

Figure 2.39

idealized tectonic plate and the varying earthquake hazards that are concentrated at plate edges

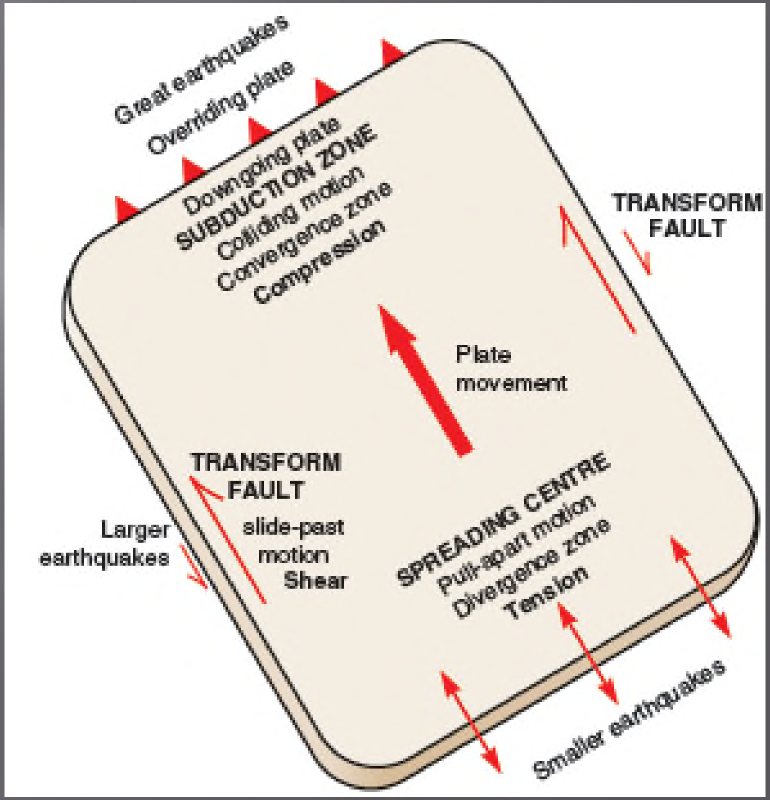


Plate-Tectonic Setting of Earthquakes and Volcanoes

Table 2.3

TABLE 2.3 TECTONIC ENVIRONMENTS AND EARTHQUAKE CHARACTERISTICS

		Earthquake Characteristics		
Tectonic Environment	**Deformation Force**	**Frequency**	**Maximum Size**	**Maximum Hypocentre Depth**
Divergent zone	Tension	Frequent	Strong	Shallow
Convergent zone	Compression	Infrequent	Great	Deep
Transform fault	Shear	Infrequent	Major	Shallow
Hot spot	Tension Compression	Frequent	Strong	Shallow

Plate-Tectonic Setting of Earthquakes and Volcanoes

Table 2.4

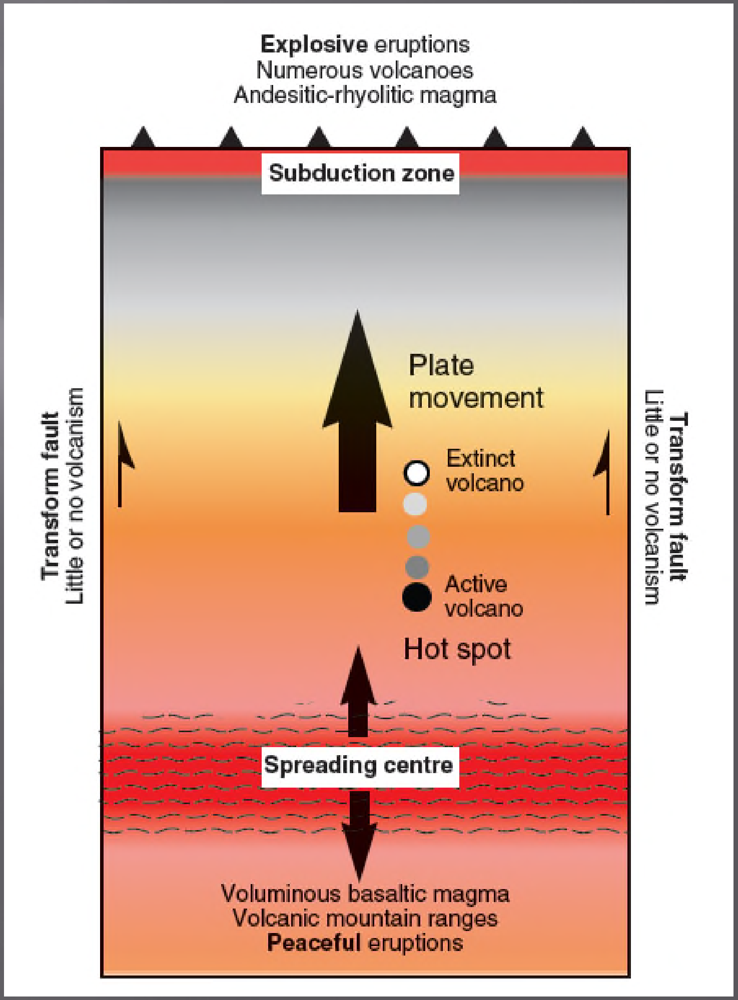
TABLE 2.4 THE EARTH'S GREATEST EARTHQUAKES, 1900–2013

Year	Location	Magnitude	Cause
1960	Chile	9.5	Subduction—Nazca plate under South American plate
1964	Alaska	9.2	Subduction—Pacific plate under North American plate
2004	Indonesia	9.1	Subduction—Indo-Australian plate under Eurasian plate
2011	Japan	9.0	Subduction—Pacific plate under North American plate
1952	Kamchatka	9.0	Subduction—Pacific plate under North American plate
2010	Chile	8.8	Subduction—Nazca plate under South American plate
1906	Ecuador	8.8	Subduction—Nazca plate under South American plate
1965	Alaska	8.7	Subduction—Pacific plate under North American plate
2012	Indonesia	8.6	Subduction—Indo-Australian plate under Eurasian plate
2005	Indonesia	8.6	Subduction—Indo-Australian plate under Eurasian

Plate-Tectonic Setting of Earthquakes and Volcanoes

Figure 2.42

Volcanic hazards associated with an idealized tectonic plate.



Summary

The Solar system formed over a short period – earth ~ 4.57 billion years old.

Gravity pulled the Earth into layers of differing density – stratified – solid inner core surrounded by a liquid outer core.

Convection within the plastic mesosphere and asthenoshpere.

Earth's outer layers – ridged lithosphere.

Earth's internal energy is heat generated by ongoing radioactive decay – contributions from impact energy and gravitational attraction.

Summary (cont.)

Earth's internal energy drives earthquakes and volcanos.

Earth's outer layer is broken into tectonic plates (12 large, several smaller ones).

The boundary between the rigid lithosphere and the underlying plastic asthenosphere provides a sliding surface for plates to move.

Convection in the asthenosphere and gravity are the driving mechanisms of plate movement.

Summary (cont.)

Different processes take place in the four different tectonic environments: (1) divergent zones, (2) convergent zones, (3) transform plate boundaries, and (4) hot spots.

New lithosphere is created by seafloor spreading when plates are pulled apart at divergent zones. Old lithosphere is being reabsorbed into the asthenosphere by subduction where two plates of differing densities collide.

Transform faults accommodate the along-side movements of plates without creation or destruction of lithosphere. Hot spots originate deep in the Earth and are the source of isolated plumes of partially molten rock rising through the asthenosphere and lithosphere.

Summary (cont.)

Hot spots originate deep in the Earth and are the source of isolated plumes of partially molten rock rising through the asthenosphere and lithosphere.

Ocean studies have contributed solid evidence attesting to the movement of tectonic plates. Magnetization patterns on the seafloor delineate the newly formed lithosphere in space and time. Bathymetric surveys have mapped deep subduction trenches and relatively shallow volcanic ridges.

Ocean floors are relatively young features on the surface of the Earth, being constantly recycled by seafloor spreading and subduction. Continents comprise older lower-density rock that rides on top of the denser rock of the moving plates.

Summary (cont.)

Most earthquakes are caused by fault movements and occur preferentially along the edges of tectonic plates. Magma movement in the shallow subsurface at spreading centres and hot spots tends to induce swarms of small earthquakes.

The dominantly horizontal movements at transform faults produce large earthquakes. The compressional movements at subduction zones and continent–continent collisions generate the largest earthquakes.

Most volcanic eruptions occur underwater at spreading centres where an enormous volume of lava solidifies to form new seafloor.

END OF CHAPTER 2