



University Zagazig



Faculty of Science
Geology Department

Course specification

Program (s) on which the course is given: **First year**

Major or Selective element of Programme: **Major**

Department offering the Programme: **Geology**

Department offering the course: **Geology**

Academic year/ level : **First year science branch** *Credit hour* **First semester**

Date of specification approval: **26-8-2018**

A- Basic Information

Title: **Principles of Geology (1)** Code: **G 101**

Lecture: **2h/ w** Practical: **1h/ w** Total: **3h/ w**

B- Professional Information

1- Overall Aims of Course

- 1- Knowing the basic concepts and importance of different branches of geological sciences
- 2- Understanding the exogenous processes and the Endogenous processes
- 3- Recognizing the Earth resources and Ecosystems .
- 4- Defining weathering, erosion, plate tectonics, sand dunes, soil and soil profile.
- 5- Understanding the concept of structure.
- 6- Comprehension of the geologic time scale, geologic eras and age determination of rocks.
- 7- Identification of volcanism.
- 8- Identification of geological Eras, geologic time scale.

2- Intended Learning Outcomes of Course (ILOs)

a- Knowledge and Understanding:

- a. 1- Define the general geology and the Earth's origin , relief ,dimensions, and its position .
- a.2- Realize the relation between geology and other related sciences .
- a.3- Recognize the internal and external composition of the earth.
- a.4- Know the process of mechanical , physical , chemical and biological weathering
- a.5- Know the processes of erosion by various agents (e.g. wind, water, glaciers) .
- a.6- Comprehend the movements of the Earth's crust, earthquakes , epeirogenesis and orogenesis , igneous and volcanic activities by which given land scape features .
- a.7- Recognize the different types of folds and their different forms .
- a.8- Define the concept of volcanism and plate tectonic .
- a.9- Describe the geological Eras, geologic time scale, its rocks, climate , life and age determination.

b- Intellectual Skills

- b.1- Determine the main features of the earth.
- b.2- Develop the ability of understanding internal and external processes of the earth.
- b.3- Evaluate effective using of coral reefs, oil, natural gas and coal.
- b.4- Determine the general geological structure and texture of the earth crust rocks .
- b.5- Differentiate between the factors affecting the erosion rates and patterns .



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- b.6- Formulate the relation between the depositional pattern and the properties of the transporting particles.
- b.7- Differentiate between forms types of folds.
- b.8- Classify the different type of the earth Ecosystems.

c- Professional and Practical Skills

- c.1- Demonstrate the differences between chemical and mechanical weathering.
- c.2- Scan water distribution all over the world.
- c.3- Explain sea floor spreading, asthenosphere, mantle
- c.4- Demonstrate the variety of earth resources.
- c.5- Diagnose the different type of the earth Ecosystems .
- c.6- Draw the surface contouring maps .

d- General and Transferable Skills

- d.1- Communicate people and improve the ability of time management skills.
- d.2- Continue self-education and development.

3- Contents

Topic	No. of hours	Lecture	Practical
1-DEFINITION AND SCOPE OF GEOLOGY, RELATION WITH OTHER SCIENCES	6	4	2
2-MAJOR FEATURES OF THE EARTH AND WEATHERING AND SOIL	3	2	1
3-WIND ACTION, DUNES, LOESS	3	2	1
4-HYDROLOGIC CYCLE, STREAM FLOW, STAGES OF VALLEY DEVELOPMENT	6	4	2
5-GROUNDWATER	3	2	1
6-GEOLOGICAL STRUCTURES	3	2	1
7-PLUTONS AND VOLCANOES	3	2	1
8-PETROLEUM	3	2	1
9-PLATE TECTONIC AND EARTH HISTORY	6	4	2
10-THE ORIGIN OF THE EARTH, GEOLOGIC TIME SCALE	6	4	2

4-Teaching and Learning Methods

Teaching and Learning Methods	ILOs
4.1- Normal teaching methods using white- and black-board in the classroom.	a.1,a.3,a.5,a.8,c.3,c.5
4.2- Preparing some subjects and essay (included in the course).	a.7,a.9,b.4,b.8
4.3- Self learning by visiting library	c.6,d.1,d.2



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5- Student Assessment Methods

Student Assessment Methods	ILOs
5.1- Written examinations (essay or MCQ) to assess knowledge and understanding skills.	a.1,a.3,a.5,a.7,a.8
5.2- Practical examination to assess knowledge, understanding and intellectual skills.	c.1,c.3,c.5,c.6
5.3- Oral examination to assess understanding and intellectual skills.	a.3,a.4,b.2,b.4,b.5,b.6

Assessment Schedule

Assessment 1: Through the lecture, at the end of each topics (written exercises).

Assessment 2: Mid-term examination (written examination) week 7.

Assessment 3: Final first semester examination (written, oral and practical) week 14.

Weighting of Assessments

Mid-term examination	10 %
Oral examination.	10 %
Practical examination	20 %
<u>Final-term examination</u>	<u>60 %</u>
Total	100 %

6- List of References

- 6.1- Course Notes : An Introduction to crystallography
- 6.2- Essential Text Books: An Introduction to Physical Geology, William J. Miller.
Crystallography, Prof. Zaki Zaghloul and Amina Abd El Rehiem. (1970)
- 6.3- Recommended Books Dynamic earth.
- 6.4- Periodicals, Web Sites: [Wikipodia .com](http://Wikipodia.com) and www.planetdiary.com

7- Facilities Required for Teaching and Learning

Field trips, data show and internet

Course Coordinator: Prof. Dr. Ibrahim Ied, Dr. Ahmed Nosair, Dr. Mostafa Atta and Dr. Hesham Elalfy

Head of Department: Prof. Dr. Mohammed Shehata.

Date: 26-8-2018

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CHAPTER I

ORIGIN OF THE EARTH AND SOLAR SYATEM

1.1. THE SCIENCE OF GEOLOGY

Geology is the study of the Earth, including the materials that it is made of, the physical and chemical changes that occur on its surface and in its interior, and the history of the planet and its life forms.

Why study geology?

- Geology studies both modern and ancient environments, deciphering the processes at work on our planet
- Geology is a means and a method for understanding and discovering the natural resources upon which the modern world is based
- Geology is a study of history, a long view of history that extends back billions of years
- Geology helps us identify and mitigate natural hazards such as earthquakes, coastal erosion, flooding, and landslides.
- Geology is an excellent reason for travel as the Earth itself provides geologists with their primary data.

The Branches of Geology

- Geological sciences are divided into many different fields such as:
- **Stratigraphy**: the study of layered rocks and their interrelationships.
- **Paleontology**: the systematic study of past life forms.
- **Mineralogy**: the study of the physical property, chemical composition and structure of minerals.
- **Crystallography**: the study of crystal forms and systems.
- **Petrology**: the study of the origin and classification of rocks.
- **Geomorphology**: origin of landforms and their modification by dynamic processes.
- **Physical geology**: the nature of the Earth development of its surficial features and the results of the interaction of chemical, physical and, the study of the composition and biological factors on the planet .
- **Sedimentology**: the science of the erosion and sedimentation of the rock particles by wind, water, or ice.

- **Geochemistry:** the study of the chemical composition of earth materials and the chemical changes that occur within the earth and on its surface.
- **Engineering geology:** the study of the interactions of the earth's crust with human-made structures such as tunnels, mines, dams, bridges, and building foundations.
- **Geophysics:** the study of the behavior of rock materials in response to stresses and according to the principles of physics.
- **Historical geology:** deals with the historical development of the earth from the study of its rocks, fossils, orogenies.

1.2. THE EARTH AND ITS MATERIALS

The Earth's radius is about 6370 kilometers, nearly one and a half times the distance from New York to Los Angeles (Fig. 1–1). If you could drive a magical vehicle from the center of the Earth to the surface at 100 kilometers per hour, the journey would take more than two and a half days. Most of the Earth is composed of rocks. Rock outcrops form some of our planet's most spectacular scenery: white chalk cliffs, pink sandstone arches, and the grey granite of Yosemite Valley. Rocks, in turn, are composed of minerals. Although more than 3500 different minerals exist, fewer than a dozen are common.

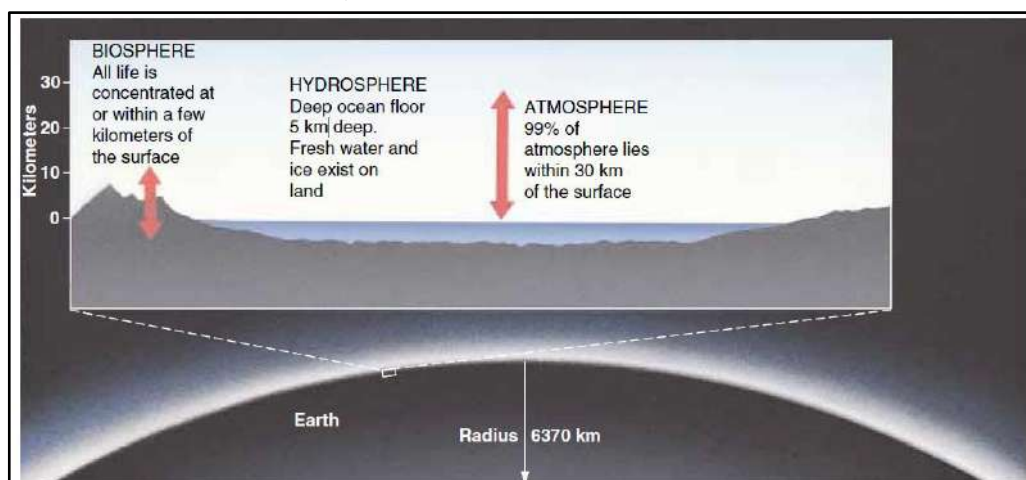


Figure 1–1 Most of the Earth is solid rock, surrounded by the hydrosphere, the biosphere, and the atmosphere.

Geologists study the origins, properties, and compositions of both rocks and minerals. Geologists also explore the Earth for the resources needed in our technological world: fossil fuels such as coal, petroleum, and natural gas; mineral resources such as metals; sand and gravel; and fertilizers. Some search for water in reservoirs beneath Earth's surface.

a) THE ATMOSPHERE

The **atmosphere** is a mixture of gases, mostly nitrogen and oxygen. It is held to the Earth by gravity and thins rapidly with altitude. Ninety-nine percent is concentrated within 30 kilometers of the Earth's surface, but a few traces remain even 10,000 kilometers above the surface. A brief look at our neighbors in space reminds us that the interactions among air, rock, and life affect atmospheric composition, temperature, and movement. The solid Earth, Venus, and Mars are approximately identical in composition. Yet the three planets have radically different atmospheres and climates. Today, the Venusian atmosphere is hot, acidic, and rich in carbon dioxide. The surface temperature is 450°C, as hot as the interior of a self-cleaning oven, and the atmospheric pressure is 90 times greater than that of the Earth. In contrast, Mars is frigid, with an atmospheric pressure only 0.006 that at the surface of the Earth. Venusian water has boiled off into space; almost all Martian water lies frozen in vast underground reservoirs.

b) THE BIOSPHERE

The **biosphere** is the thin zone near the Earth's surface that is inhabited by life. It includes the uppermost solid Earth, the hydrosphere, and the lower parts of the atmosphere. Land plants grow on the Earth's surface, with roots penetrating at most a few meters into soil. Animals live on the surface, fly a kilometer or two above it, or burrow a few meters underground. Sea life also concentrates near the ocean surface, where sunlight is available. Some aquatic communities live on the deep sea floor, bacteria live in rock to depths of a few kilometers, and a few windblown microorganisms are found at heights of 10 kilometers or more. But even at these extremes, the biosphere is a very thin layer at the Earth's surface. Paleontologists are geologists who study the evolution and history of life by examining fossils and other evidence preserved in rock and sediment. The study of past life shows us that the solid Earth, the atmosphere, the hydrosphere, and the biosphere are all interconnected. Internal processes such as volcanic eruptions and migrating continents have altered the Earth's climate and atmospheric composition. Life has altered the atmosphere. The atmosphere reacts with rocks.

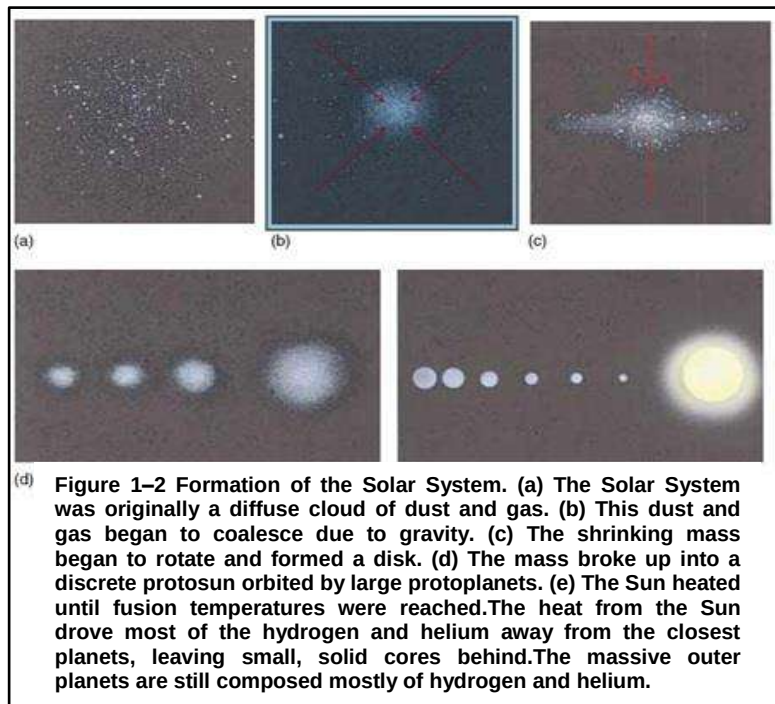
1.3. THE EARTH'S ORIGIN

a) THE EARLY SOLAR SYSTEM

No one can go back in time to view the formation of the Solar System and the Earth. Therefore, scientists will never be able to describe the sequence of events with certainty. The hypothesis given here is based on calculations about the

behavior of dust and gas in space and on observations of stars and dust clouds in our galaxy. The hypothesis states that about 5 billion years ago the matter that became our Solar System was an immense, diffuse, frozen cloud of dust and gas rotating slowly in space. This cloud formed from matter ejected from an exploding star. More than 99 percent of the cloud consisted of hydrogen and helium, the most abundant elements in the Universe. The temperature of this cloud was about -270°C . Small gravitational attractions among the dust and gas particles caused the cloud to condense into a sphere (Figs. 1–2a and 1–2b). As condensation continued, the cloud rotated more rapidly, and the sphere spread into a disk, as shown in Figure 1–2c. Some scientists have suggested that a nearby star exploded and the shock wave triggered the condensation. More than 90 percent of the matter in the cloud collapsed toward the center of the disk under the influence of gravity, forming the **protosun**. Collisions among highspeed particles released heat within this early version of the Sun, but it was

not a true star because it did not yet generate energy by nuclear fusion. Heat from the protosun warmed the inner region of the disk. Then, after the gravitational collapse was nearly complete, the disk cooled. Gases in the outer part of the disk condensed to form small aggregates, much as snowflakes form when moist air cools in the Earth's atmosphere. Over time, the aggregates stuck



together as snowflakes sometimes do. As they increased in size and developed stronger gravitational forces, they attracted additional particles. This growth continued until a number of small rocky spheres, called **planetesimals**, formed, ranging from a few kilometers to about 100 km in diameter. The entire process, from the disk to the planetesimals, occurred quickly in geologic terms, over a period of 10,000 to 100,000 years. The planetesimals then coalesced to form a few large planets, including Earth. At the same time that planets were forming, gravitational attraction pulled the gases in the protosun inward, creating

extremely high pressure and temperature. The core became so hot that hydrogen nuclei combined to form the nucleus of the next heavier element, helium, in a process called **nuclear fusion**. Nuclear fusion releases vast amounts of energy. The onset of nuclear fusion marked the birth of the modern Sun, which still generates its energy by hydrogen fusion.

b) THE MODERN SOLAR SYSTEM

Heat from the Sun boiled most of the hydrogen, helium, and other light elements away from the inner Solar System. As a result, the four planets closest to the Sun—Mercury, Venus, Earth, and Mars—are now mainly rocky with metallic centers. These four are called the **terrestrial planets** because they are “Earthlike.” In contrast, the four outer planets—Jupiter, Saturn, Uranus, and Neptune—are called the **Jovian planets** and are composed primarily of liquids and gases with small rocky and metallic cores. Pluto, the outermost known planet, is anomalous. It is the smallest planet in the Solar System and is composed of rock mixed with frozen water and methane. Figure 1–3 is a schematic representation of the modern Solar System.

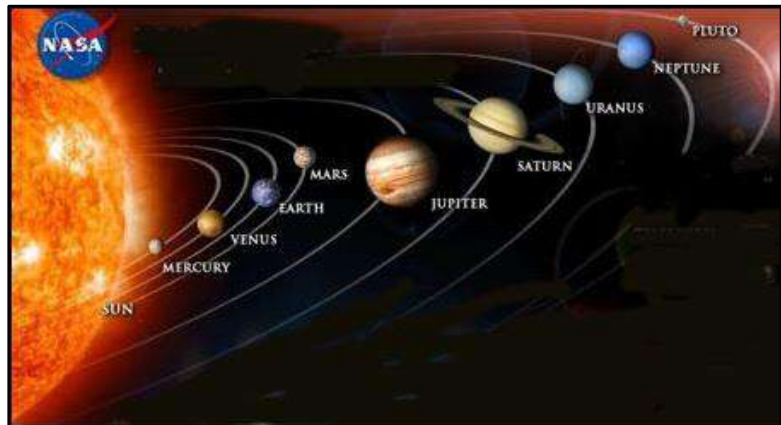


Figure 1–3 A schematic view of the Solar System.

1.4. THE EVOLUTION OF THE MODERN EARTH

Scientists generally agree that the Earth formed by accretion of small particles, as discussed above. They also agree that the modern Earth is layered. The center is a dense, hot **core** composed mainly of iron and nickel. A thick **mantle**, composed mainly of solid rock, surrounds the core and contains 80 percent of the Earth’s volume. The **crust** is a thin surface veneer, also composed of

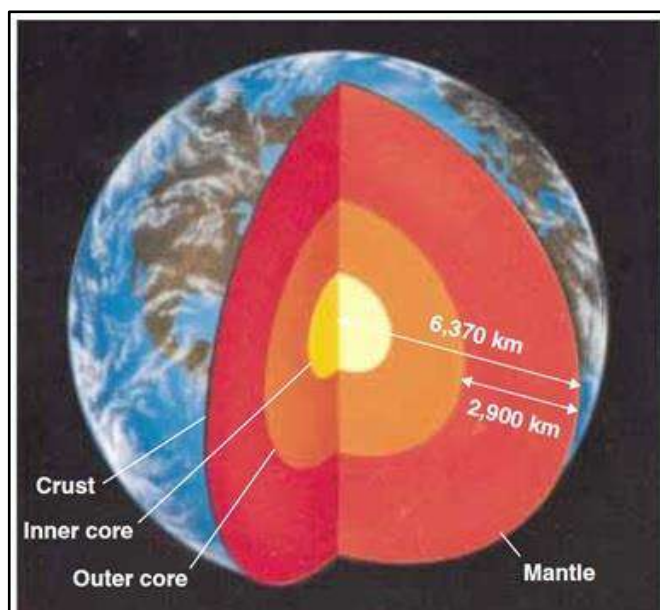


Figure 1–4 A schematic view of the interior of the Earth.

rock (Fig. 1–4). Earth temperature and pressure increase gradually with depth. Ten meters below the surface, soil and rock are cool to the touch, but at a depth between about 100 kilometers and 350 kilometers, the mantle rock is so hot that one or two percent of it is melted, so that the entire mantle flows very slowly, like cold honey. This movement allows continents to move across the globe, ocean basins to open and close, mountain ranges to rise, volcanoes to erupt, and earthquakes to shake the planet. Rock is even hotter deeper in the mantle, but the intense pressure prevents it from melting. The outer core is composed of molten metal, but the inner core, which is as hot as the surface of the Sun, is under such intense pressure that it is solid.

Although scientists agree that our planet is layered, they disagree on how the layering developed. Astronomers have detected both metallic and rocky meteorites in space, and many think that both metallic and rocky particles coalesced to form the planets. According to one hypothesis, as the Earth began to form, metallic particles initially accumulated to create the metallic core, and then rocky particles collected around the core to form the rocky mantle. Thus, the Earth has always been layered.

An alternative hypothesis states that the rock and metal accumulated simultaneously during the initial coalescence, forming a homogeneous (non-layered) planet. The young Earth became hot as gravity pulled the small particles together and later as asteroids, comets, and planetesimals crashed into the surface. At the same time, radioactive decay heated the Earth's interior. Thus, our planet became so hot that all or most of it melted soon after it formed. Heavy molten iron and nickel gravitated toward the center and collected to form the core, while lighter materials floated toward the surface to form the mantle. In both hypotheses, the crust formed later.

How can we determine which of the two hypotheses is correct? By studying modern meteorites and lunar rocks, two geologists recently estimated that the core formed at least 62 million years after the Earth coalesced. This interpretation supports the hypothesis that our planet was initially homogeneous and then separated into the core and mantle at a later date. However, future research may change our views about a sequence of events that occurred so long ago.

1.5. THE EARTH'S LAYERS

The energy released by an earthquake travels through the Earth as waves. Geologists have found that earthquake waves abruptly change both speed and

direction at certain depths as they pass through the Earth's interior. Figures 1-5 and 1-6 and Table 2-2 describe the layers.

a) THE CRUST

The crust is the outermost and thinnest layer. Because the crust is relatively cool, it consists of hard, strong rock. Crust beneath the oceans differs from that of continents. Oceanic crust is 5 to 10 kilometers thick and is composed mostly of a dark, dense rock called basalt. In contrast, the average thickness of continental crust is about 20 to 40 kilometers, although under mountain ranges it can be as much as 70 kilometers thick. Continents are composed primarily of a light-colored, less dense rock called **granite**.

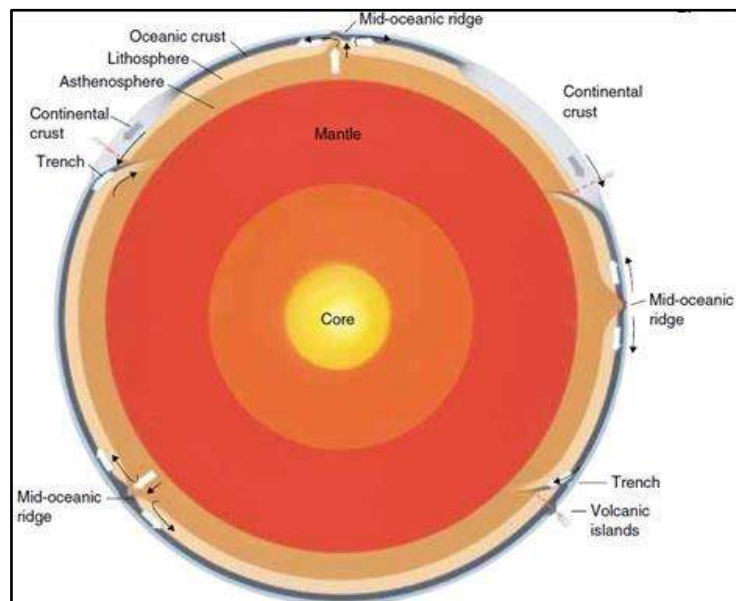


Figure 1-5 Plates of lithosphere glide over the asthenosphere, carrying continents and oceans with them. As a plate moves, old lithosphere sinks into the Earth's interior at its leading edge, and new lithosphere forms at the trailing edge.

Table 2-2 • THE LAYERS OF THE EARTH

	LAYER	COMPOSITION	DEPTH	PROPERTIES
Crust	Oceanic crust	Basalt	5–10 km	Cool, hard, and strong
	Continental crust	Granite	20–70 km	Cool, hard, and strong
Lithosphere	Lithosphere includes the crust and the uppermost portion of the mantle	Varies; the crust and the mantle have different compositions	75–125 km	Cool, hard, and strong
Mantle	Uppermost portion of the mantle included as part of the lithosphere	Entire mantle is ultramafic rock. Its mineralogy varies with depth	Extends to 350 km	Hot, weak, and plastic, 1% or 2% melted Hot, under great pressure, and mechanically strong High pressure forms minerals different from those of the upper mantle
	Asthenosphere		Extends from 350 to 660 km	
	Remainder of upper mantle		Extends from 660 to 2900 km	
Core	Lower mantle			
	Outer core	Iron and nickel	Extends from 2900 to 5150 km	Liquid
	Inner core	Iron and nickel	Extends from 5150 km to the center of the Earth	Solid

b) THE MANTLE

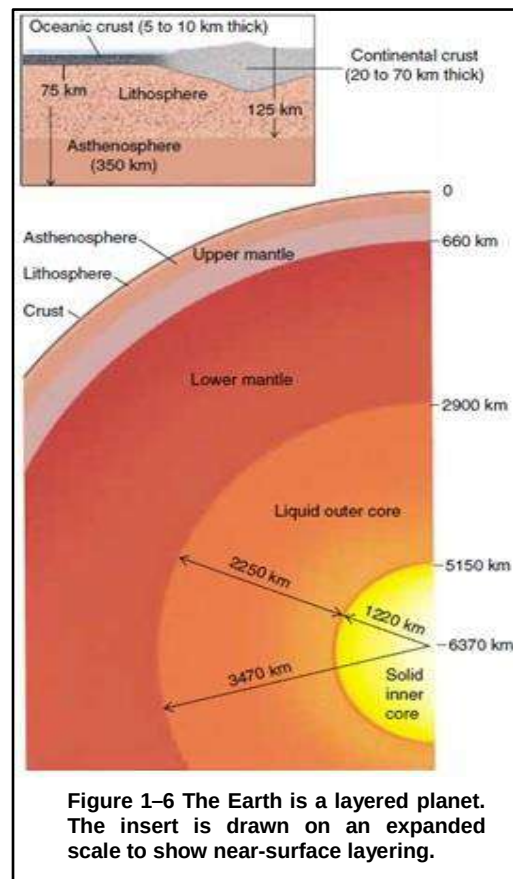
The mantle lies directly below the crust. It is almost 2900 kilometers thick and makes up 80 percent of the Earth's volume. Although the chemical composition may be similar throughout the mantle, Earth temperature and pressure increase with depth. These changes cause the strength of mantle rock to vary with depth, and thus they create layering within the mantle. The upper part of the mantle consists of two layers.

The Lithosphere

The uppermost mantle is relatively cool and consequently is hard, strong rock. In fact, its mechanical behavior is similar to that of the crust. The outer part of the Earth, including both the uppermost mantle and the crust, make up the lithosphere (Greek for "rock layer"). The lithosphere can be as thin as 10 kilometers where tectonic plates separate. However, in most regions, the lithosphere varies from about 75 kilometers thick beneath ocean basins to about 125 kilometers under the continents. A tectonic (or lithospheric) plate is a segment of the lithosphere.

The Asthenosphere

At a depth varying from about 75 to 125 kilometers, the strong, hard rock of the lithosphere gives way to the weak, plastic asthenosphere. This change in rock properties occurs over a vertical distance of only a few kilometers, and results from increasing temperature with depth. Although the temperature increases gradually, it crosses a threshold at which the rock is close to its melting point. As a result, 1 to 2 percent of the asthenosphere is liquid, and the asthenosphere is mechanically weak and plastic. Because it is plastic, the asthenosphere flows slowly, perhaps at a rate of a few centimeters per year. Two familiar examples of solid materials that flow are Silly Putty_ and hot road tar. However, both of these solids flow much more rapidly than the asthenosphere rock. The asthenosphere extends from the base of the lithosphere to a depth of about 350 kilometers. At



the base of the asthenosphere, increasing pressure causes the mantle to become mechanically stronger, and it remains so all the way down to the core.

c) THE CORE

The core is the innermost of the Earth's layers. It is a sphere with a radius of about 3470 kilometers and is composed largely of iron and nickel. The outer core is molten because of the high temperature in that region. Near its center, the core's temperature is about 6000°C, as hot as the Sun's surface. The pressure is greater than 1 million times that of the Earth's atmosphere at sea level. The extreme pressure overwhelms the temperature effect and compresses the inner core to a solid. To visualize the relative thickness of the Earth's layers, let us return to an analogy used in Chapter 1. Imagine that you could drive a magical vehicle at 100 kilometers per hour through the Earth, from its center to its surface. You would pass through the core in about 35 hours and the mantle in 29 hours. You would drive through oceanic crust in only 6 minutes, and most continental crust in about half an hour. When you arrived at the surface, you would have spent the last 3 hours traversing the entire asthenosphere and lithosphere.

REVIEW QUESTIONS

1. Give a concise definition of geology.
2. How thick is the Earth's atmosphere?
3. How old is the Earth?
4. Very briefly outline the formation of the Universe and the Solar System.
5. How did the Sun form? How is its composition different from that of the Earth? Explain the reasons for this difference.
6. Compare and contrast the properties of the terrestrial planets with those of the Jovian planets.
7. List the three major layers of the Earth. Which is the most dense, and which is the least dense?
8. Draw a cross-sectional view of the Earth. List all the major layers and the thickness of each.
9. Describe the physical properties of each of the Earth's layers.
10. Describe and explain the important differences between the lithosphere and the asthenosphere.
11. Describe some important differences between the crust and the lithosphere.
12. Describe some important differences between oceanic crust and continental crust.

CHAPTER II

WEATHERING AND SOIL

2.1. WEATHERING

Weathering is the decomposition and disintegration of rocks and minerals at the Earth's surface. Weathering itself involves little or no movement of the decomposed rocks and minerals. This material accumulates where it forms and overlies unweathered bedrock (Fig. 2-1).



Figure 2-1 This boulder weathered in place.

Erosion is the removal of weathered rocks and minerals by moving water, wind, glaciers, and gravity. After a rock fragment has been eroded from its place of origin, it may be transported large distances by those same agents: flowing water, wind, ice, and gravity. When the wind or water slows down and loses energy or, in the case of glaciers, when the ice melts, transport stops and sediment is deposited. These four processes—weathering, erosion, transportation, and deposition—work together to modify the Earth's surface (Fig. 2-2).

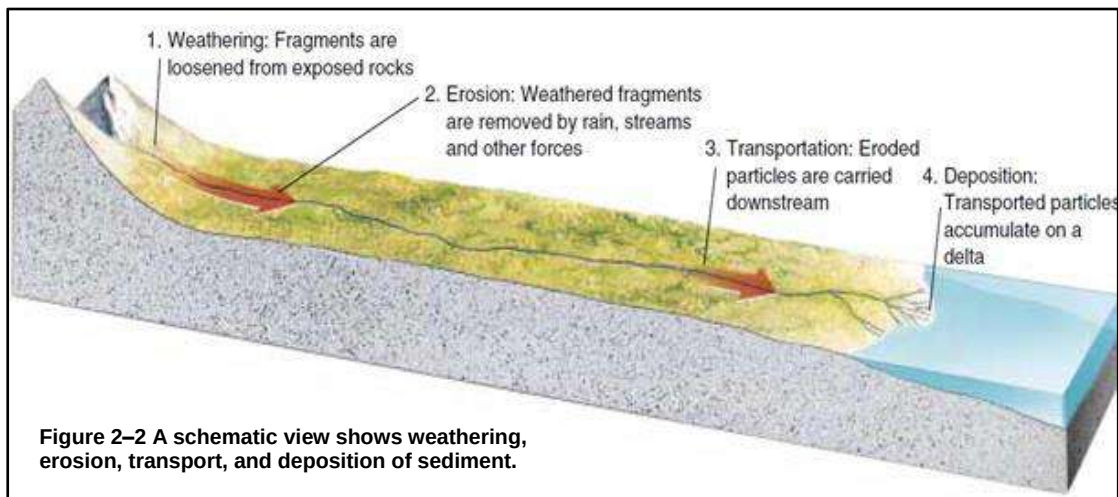


Figure 2-2 A schematic view shows weathering, erosion, transport, and deposition of sediment.

2.1.1. MECHANICAL AND CHEMICAL WEATHERING

The environment at the Earth's surface is corrosive to most materials. An iron tool left outside will rust. Even stone is vulnerable to corrosion. As a result, ancient stone cities have fallen to ruin. Over longer periods of time, rock outcrops and entire mountain ranges wear away. Weathering occurs by both

mechanical and chemical processes. **Mechanical weathering** reduces solid rock to rubble but does not alter the chemical composition of rocks and minerals. In contrast, **chemical weathering** occurs when air and water chemically react with rock to alter its composition and mineral content. These chemical changes are analogous to rusting in that the final products differ both physically and chemically from the starting material.

A. MECHANICAL WEATHERING

Mechanical weathering breaks large rocks into smaller ones but does not alter the rock's chemical nature or its minerals. Think of grinding a rock in a crusher; the fragments are no different from the parent rock, except that they are smaller. Five major processes cause mechanical weathering: pressure-release fracturing, frost wedging, abrasion, organic activity, and thermal expansion and contraction. Two additional processes—salt cracking and hydrolysis expansion—result from combinations of mechanical and chemical processes.

1. PRESSURE-RELEASE FRACTURING

Many igneous and metamorphic rocks form deep below the Earth's surface. Imagine, for example, that a granitic pluton solidifies from magma at a depth of 15 kilometers. At that depth, the pressure from the weight of overlying rock is about 5000 times that at the Earth's surface. Over millennia, tectonic forces may raise the pluton to form a mountain range. The overlying rock erodes away as the pluton rises and the pressure on the buried rock



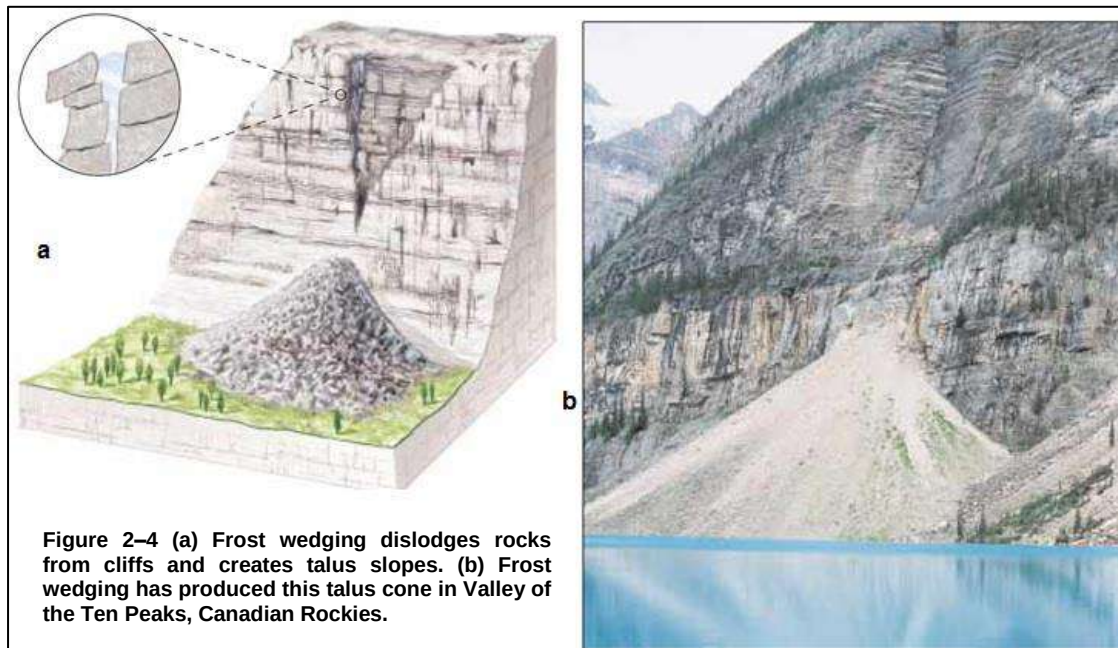
Figure 2–3 Pressure-release fracturing contributed to the formation of these cracks in a granite cliff in Tuolumne Meadows, California.

decreases. As the pressure diminishes, the rock expands, but because the rock is now cool and brittle, it fractures as it expands. This process is called **pressure-release fracturing**. Many igneous and metamorphic rocks that formed at depth, but now lie at the Earth's surface, have been fractured in this manner (Fig. 2–3).

2. FROST WEDGING

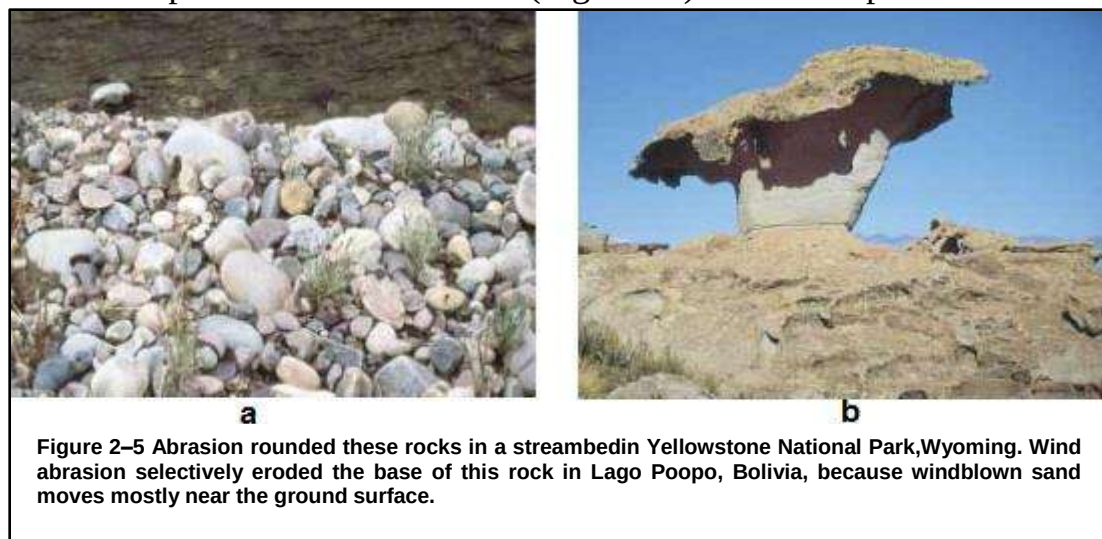
Water expands when it freezes. If water accumulates in a crack and then freezes, its expansion pushes the rock apart in a process called **frost wedging**. In a temperate climate, water may freeze at night and thaw during the day. Ice

cements the rock together temporarily, but when it melts, the rock fragments may tumble from a steep cliff. If you hike or climb in mountains when the daily freeze–thaw cycle occurs, be careful; rockfall due to frost wedging is common. Experienced climbers travel in the early morning when the water is still frozen and ice holds the rock together. Large piles of loose angular rocks, called **talus slopes**, lie beneath many cliffs (Fig. 2–4). These rocks fell from the cliffs mainly as a result of frost wedging.



3. ABRASION

Many rocks along a stream or beach are rounded and smooth. They have been shaped by collisions with other rocks as they tumbled downstream and with silt and sand carried by moving water. As particles collide, their sharp edges and corners wear away. The mechanical wearing and grinding of rock surfaces by friction and impact is called **abrasion** (Fig. 2–5a). Note that pure water itself is



not abrasive; the collisions among rock, sand, and silt cause the weathering. Wind also hurls sand and other small particles against rocks, often sandblasting unusual and beautiful landforms (Fig. 2–5b). Glaciers also cause much abrasion as they drag particles ranging in size from clay to boulders across bedrock. In this case, both the rock fragments embedded in the ice and the bedrock beneath are abraded.

4. ORGANIC ACTIVITY

If soil collects in a crack in solid rock, a seed may fall there and sprout. The roots work their way down into the crack, expand, and may eventually push the rock apart (Fig. 2–6). City dwellers often see the results of organic activity in sidewalks, where tree roots push from underneath, raising the concrete and frequently cracking it.



Figure 2–6 As this tree grew from a crack in bedrock, its roots forced the crack to widen.

5. THERMAL EXPANSION AND CONTRACTION

Rocks at the Earth's surface are exposed to daily and yearly cycles of heating and cooling. They expand when they are heated and contract when they cool. When temperature changes rapidly, the surface of a rock heats or cools faster than its interior and, as a result, the surface expands or contracts faster than the interior. The resulting forces may fracture the rock. In mountains or deserts at mid-latitudes, temperature may fluctuate from -5°C to $+25^{\circ}\text{C}$ during a spring day. Is this 30° difference sufficient to fracture rocks?

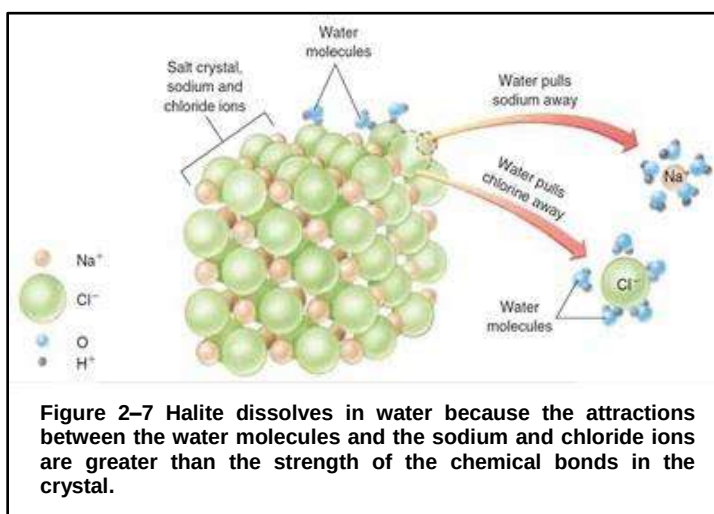
The answer is uncertain. In one laboratory experiment, scientists heated and cooled granite repeatedly by more than 100°C and they did not observe any fracturing. These results imply that normal temperature changes might not be an important cause of mechanical weathering. However, the rocks used in the experiment were small and the experiment was carried out over a brief period of time. Perhaps thermal expansion and contraction are more significant in large outcrops. Or perhaps daily heating–cooling cycles repeated over hundreds of thousands of years may promote fracturing. In contrast to a small atmospheric temperature fluctuation, fire heats rock by hundreds of degrees. If you line a campfire with granite stones, the rocks commonly break as you cook your dinner. In a similar manner, forest fires or brush fires occur commonly in many ecosystems and are an important agent of mechanical weathering.

B. CHEMICAL WEATHERING

Rock is durable over a single human lifetime. Return to your childhood haunts and you will see that the rock outcrops in woodlands or parks have not changed. Over longer expanses of geologic time, however, rocks decompose chemically at the Earth's surface. The most important processes of chemical weathering are dissolution, hydrolysis, and oxidation. Water, carbon dioxide, acids and bases, and oxygen are common substances that cause these processes to decompose rocks.

1. DISSOLUTION

If you put a crystal of halite (rock salt) in water, it dissolves and the ions disperse to form a solution. Halite dissolves so rapidly and completely that this mineral is rare in moist environments. A small proportion of water molecules spontaneously dissociate (break apart) to form an equal number of hydrogen ions (H^+) and hydroxyl ions (OH^-). Many common chemicals dissociate in water to increase either the hydrogen or the hydroxyl ion concentration. For example, HCl (hydrochloric acid) dissociates to release H^+ and Cl^- ions. The H^+ ions increase the hydrogen ion concentration and the solution becomes acid. In a similar manner, NaOH dissociates to increase the hydroxyl ion concentration and the solution becomes a base. Hydrogen and hydroxyl ions are chemically reactive and therefore acids and bases are much more corrosive than pure water. To understand how acids and bases dissolve minerals, think of an atom on the surface of a crystal. It is held in place because it is attracted to the other atoms in the crystal by electrical forces. At the same time, electrical attractions to the outside environment pull the atom away from the crystal. The result is like a tug-of-war. If the bonds between the atom and the crystal are stronger than the attraction of the atom to its outside environment, then the crystal remains intact. If outside attractions are stronger, they pull the atom away from the crystal and the mineral dissolves (Fig. 2-7). Acids and bases are generally more effective at dissolving minerals than pure water because they provide more electrically charged hydrogen and hydroxyl ions to pull atoms out of crystals.



For example, limestone is made of the mineral calcite (CaCO_3). Calcite barely dissolves in pure water but is quite soluble in acid. If you place a drop of strong acid on limestone, bubbles of carbon dioxide gas rise from the surface as the calcite dissolves. Water found in nature is never pure. Atmospheric carbon dioxide dissolves in raindrops and reacts to form a weak acid called carbonic acid. As a result, even the purest rainwater, which falls in the Arctic or on remote mountains, is slightly acidic. As shown in the “Focus On” box “Representative Reactions in Chemical Weathering,” this acidic rainwater dissolves limestone. Industrial pollution can make rain even more acidic. Limestone outcrops commonly show signs of intense chemical weathering as a result of natural and polluted rain. In addition, when water flows through the ground, it dissolves ions from soil and bedrock. In some instances, these ions render the water acidic; in other cases the water becomes basic. Flowing water carries the dissolved ions away from the site of weathering. Weathering by solution produces spectacular caverns in limestone (Fig. 2–8). Most solution reactions are reversible. A reversible reaction can proceed in either direction if conditions change. For example, calcite dissolves readily in acid to form a solution. If a base is added to the solution, solid calcite will precipitate again.

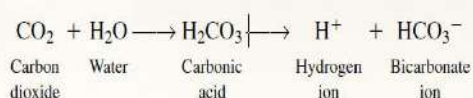


Figure 2–8 Stalactites and stalagmites in a limestone cavern.

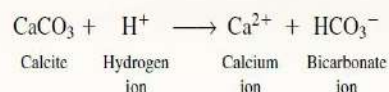
Focus On Representative Reactions In Chemical Weathering

Dissolution of Calcite

Calcite, the mineral that comprises limestone and marble, weathers in natural environments in a three-step process. In the first two steps, water reacts with carbon dioxide in the air to produce carbonic acid, which dissociates to release hydrogen ions:

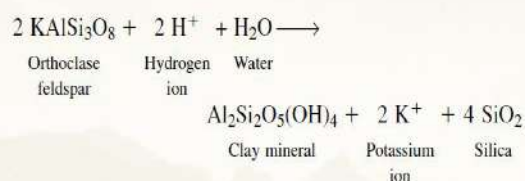


In the third step, calcite dissolves in the carbonic acid solution.



Hydrolysis

An example of a reaction in which feldspar hydrolyzes to clay is as follows:



2. HYDROLYSIS

During dissolution, a mineral dissolves but does not otherwise react chemically with the solution. However, during **hydrolysis**, water reacts with a mineral to form a new mineral with the water incorporated into its crystal structure. Many common minerals weather by hydrolysis. For example, feldspar, the most abundant mineral in the Earth's crust, weathers by hydrolysis to form clay. As feldspar converts to clay, flowing water carries off soluble cations such as potassium. The water combines with the less soluble ions to form clay minerals (see the “Focus On” box “Representative Reactions”). Quartz is the only rock-forming silicate mineral that does not weather to form clay. Quartz resists weathering because it is pure silica, SiO_2 , and does not contain any of the more soluble cations. When granite weathers, the feldspar and other minerals react to form clay but the unaltered quartz grains fall free from the rock. Some granites have been so deeply weathered by hydrolysis that mineral grains can be pried out with a fingernail to depths of several meters (Fig. 2–9). The rock looks like granite but has the consistency of sand. Because quartz is so tough and resistant to weathering, it is the primary component of sand. Much of it is transported to the sea coast, where it concentrates on beaches and eventually forms sandstone.



Figure 2–9 Coarse grains of quartz and feldspar accumulate directly over weathered granite. The lens cap in the middle illustrates scale.

3. OXIDATION

Many elements react with atmospheric oxygen, O_2 . Iron rusts when it reacts with water and oxygen. Rusting is one example of a more general process called **oxidation**. Oxidation reactions are so common in nature that pure metals are rare in the Earth's crust, and most metallic elements exist in nature as compounds. Only a few metals, such as gold, silver, copper, and platinum commonly occur in their pure states. Recall from Chapter 3 that iron is abundant in many minerals, including olivine, pyroxene, and amphibole. If the iron in such a mineral oxidizes, the mineral decomposes. Many metallic elements, such as iron, copper, lead, and zinc, occur as sulfide minerals in ore deposits. When metallic sulfides oxidize, the sulfur reacts to form sulfuric acid, a strong acid. For example, pyrite (FeS_2) oxidizes to form sulfuric acid and iron oxide. The sulfuric acid washes into streams and ground water, where it may harm aquatic organisms. Thus, many natural ore deposits generate sulfuric acid when they

weather. The same reaction may be accelerated when ore is dug up and exposed at a mine site.

2.1.2. CHEMICAL AND MECHANICAL WEATHERING OPERATING TOGETHER

Chemical and mechanical weathering work together, often on the same rock at the same time. Chemical processes generally act only on the surface of a solid object, so the reaction speeds up if the surface area increases. Think of a burning log; the fire starts on the outside and works its way toward the interior. A split log burns faster because the surface area is greater. Mechanical processes crack rocks, thereby exposing more surface area for chemical agents to work on (Fig. 2–10). After mechanical processes fracture a rock, water and air seep into the fractures and initiate chemical weathering. Figure 2–11a shows that chemical weathering attacks a rock face from only one direction but attacks an edge from two sides and a corner from three sides. As a result of the multidirectional attack, the corners and edges weather most rapidly; the faces, attacked from only one direction, weather more slowly. Over time, the corners and edges become rounded in a process called **spheroidal weathering** (Fig. 2–11b). It is common to see rounded boulders still lying where they formed by this process.

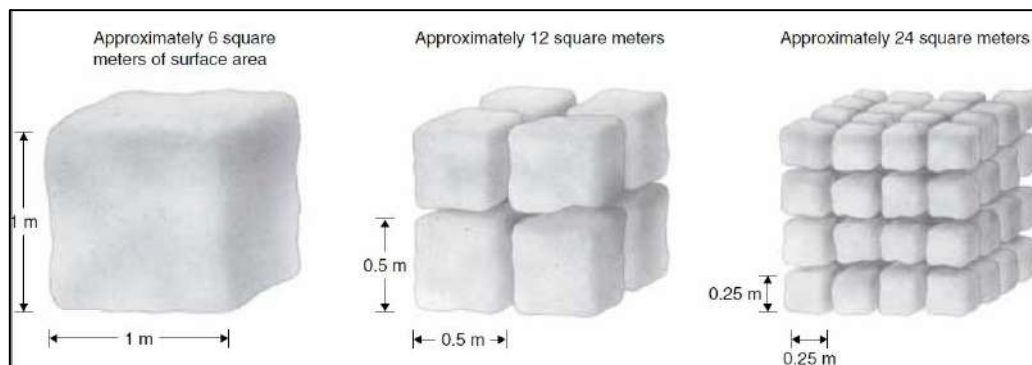


Figure 2–10 When rocks are broken apart by mechanical weathering, more surface is available for chemical weathering.

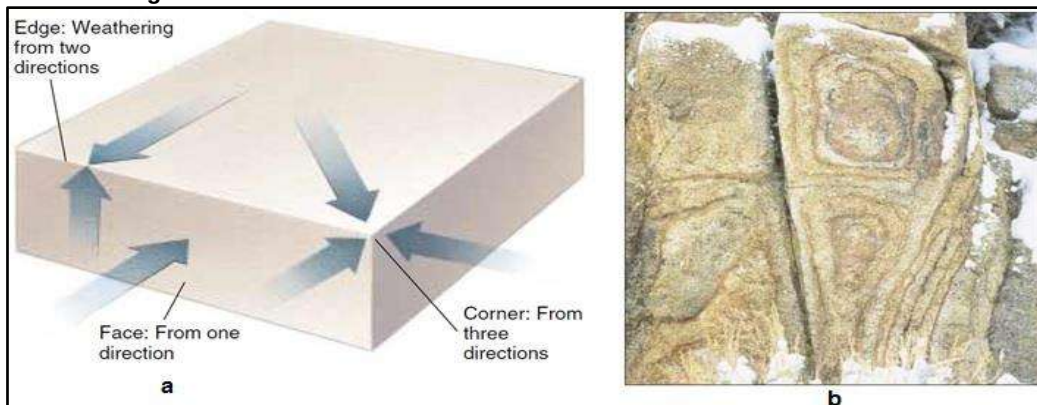


Figure 2–11 (a) More surface area is available for chemical attack on the corners and edges of a cube than on a face. Therefore, corners and edges are rounded during weathering. (b) Both mechanical and chemical processes have weathered this boulder, along old fractures.

1. SALT CRACKING

In environments where ground water is salty, salt water seeps into cracks in bedrock. When the water evaporates, the dissolved salts crystallize. The growing crystals exert tremendous forces, enough to widen a crack and fracture a rock, a process called **salt cracking**. Thus, a mechanical process such as thermal expansion or pressure release may initially fracture bedrock. Then salt water migrates into the crack, and salt precipitates (a chemical process). Finally, the expanding salt crystals mechanically push the rock apart. Many sea cliffs show pits and depressions caused by salt cracking because spray from the breaking waves brings the salt to the rock. Salt cracking is also common in deserts, where surface and underground water often contain dissolved salts (Fig. 2–12).

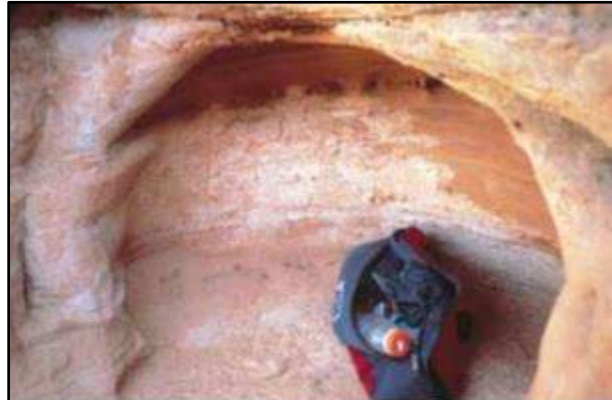


Figure 2–12 Salt cracking formed this depression in sandstone in Cedar Mesa, Utah. The white patches are salt crystals.

2. EXFOLIATION

Granite commonly fractures by **exfoliation**, a process in which large plates or shells split away like the layers of an onion (Fig. 2–13). The plates may be only 10 or 20 centimeters thick near the surface, but they thicken with depth. Because exfoliation fractures are usually absent below a depth of 50 to 100 meters, they seem to be a result

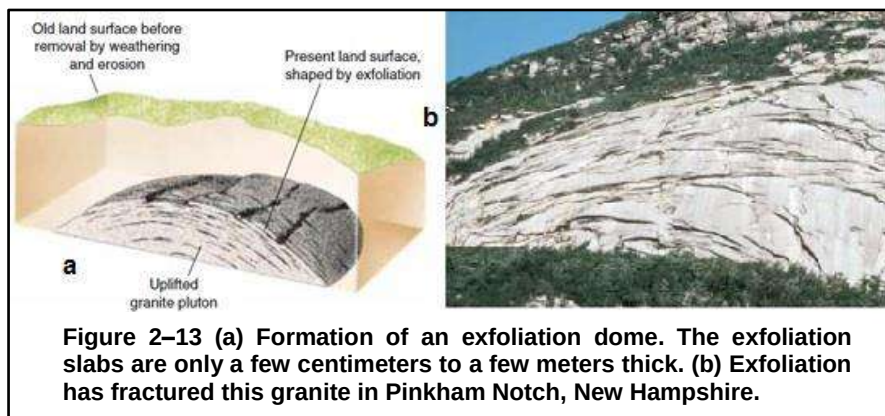


Figure 2–13 (a) Formation of an exfoliation dome. The exfoliation slabs are only a few centimeters to a few meters thick. (b) Exfoliation has fractured this granite in Pinkham Notch, New Hampshire.

of exposure of the granite at the Earth's surface. Exfoliation is frequently explained as a form of pressure-release fracturing. However, many geologists suggest that hydrolysis may contribute to exfoliation. During hydrolysis, feldspars and other silicate minerals react to form clay. As a result of the addition of water, clays have a greater volume than that of the original minerals.

Thus, a chemical reaction (hydrolysis) forms clay, and the mechanical expansion of the clay contributes to the exfoliation fractures.

2.2. SOIL

Mechanical weathering produces both large rock fragments and small particles such as sand and silt. Chemical weathering forms clay and dissolved ions. Some of these weathering products accumulate on the Earth over bedrock. This material is called **regolith**. Soil scientists define **soil** as upper layers of regolith that support plant growth. Soil commonly consists of sand, silt, clay, and organic material. Clay particles are so small and pack so tightly that water does not flow through them readily. In fact, even gases have trouble passing through clay-rich soils, so plants growing in clay soils suffer from lack of oxygen. In contrast, water and oxygen travel easily through loosely packed sandy soils. The most fertile soils contain a mixture of sand, clay, and silt as well as generous amounts of organic matter. Such a mixture is called **loam**. If you walk through a forest or prairie, you can find bits of leaves, stems, and flowers on the soil surface. This material is called **litter** (Fig. 2–14). When litter decomposes sufficiently that you can no longer determine the origin of individual pieces, it becomes **humus**.

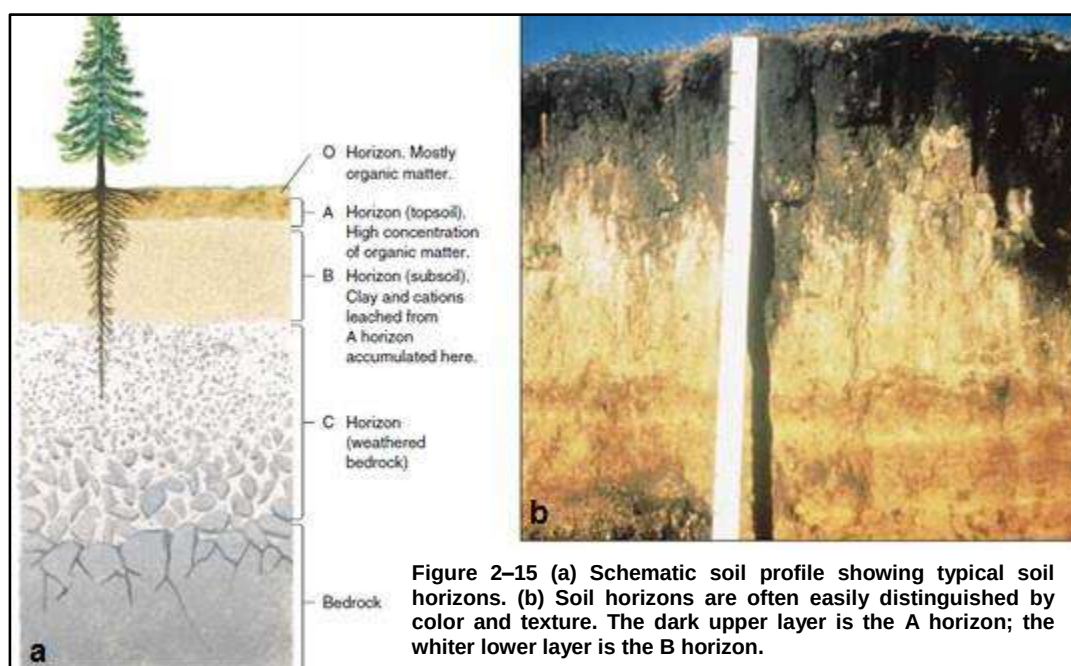


Figure 2–14 Litter is organic matter that has fallen to the ground and started to decompose but still retains its original form and shape.

Humus is an essential component of most fertile soils. If you pour a small amount of water into soil rich in humus, the soil absorbs most of the water. Humus retains so much moisture that humus-rich soil swells after a rain and shrinks during dry spells. This alternate shrinking and swelling loosens the soil, allowing roots to grow into it easily. A rich layer of humus also insulates the soil from excessive heat and cold and reduces water loss by evaporation. Humus also retains nutrients in soil and makes them available to plants. In intensive agriculture, farmers commonly plow the soil and leave it exposed for weeks or months. Humus oxidizes in air and degrades. Running water frequently dissolves soil nutrients and carries them away. Farmers replace the lost nutrients with chemical fertilizers but frequently do not replenish humus. As a result, much of the natural ability of soil to conserve and regulate water and nutrients is lost. When rainwater flows over the surface, it carries soil particles, excess fertilizer, and pesticide residues, polluting streams and ground water.

2.2.1. SOIL PROFILES

A typical mature soil consists of several layers called **soil horizons**. The uppermost layer is called the **O horizon**, named for its **Organic** component. This layer consists mostly of litter and humus with a small proportion of minerals (Fig. 2–15). The next layer down, called the **A horizon**, is a mixture of humus, sand, silt, and clay. The combined O and A horizons are called **topsoil**. A kilogram of average fertile topsoil contains about 30 percent by weight



organic matter, including approximately 2 trillion bacteria, 400 million fungi, 50 million algae, 30 million protozoa, and thousands of larger organisms such as insects, worms, nematodes, and mites.

The third layer, the **B horizon** or subsoil, is a transitional zone between topsoil and weathered parent rock below. Roots and other organic material occur in the B horizon, but the total amount of organic matter is low. The lowest layer, called the **C horizon**, consists of partially weathered rock that grades into unweathered parent rock. This zone contains little organic matter. When rainwater falls on soil, it sinks into the O and A horizons, weathering minerals and carrying dissolved ions to lower levels. This downward movement of dissolved ions is called **leaching**. The A horizon is sandy because water also carries clay downward but leaves the sand behind. Because materials are removed from the A horizon, it is called the **zone of leaching**. Dissolved ions and clay carried downward from the A horizon accumulate in the B horizon, which is called the **zone of accumulation**. This layer retains moisture because of its high clay content. Although moisture retention may be beneficial, if too much clay accumulates, the B horizon creates a dense, waterlogged soil.

2.2.2. SOIL-FORMING FACTORS

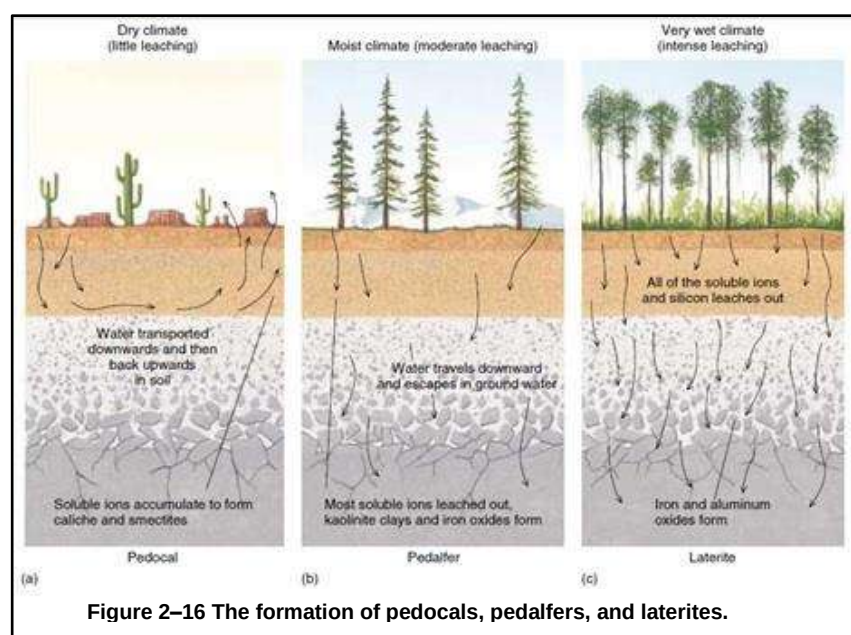
Why are some soils rich and others poor, some sandy and others loamy? Six factors control soil characteristics: parent rock, climate, rates of plant growth and decay, slope angle and aspect, time, and transport.

a) PARENT ROCK

The texture and composition of a soil depends partly on its parent rock. For example, when granite decomposes, the feldspar converts to clay and the rock releases quartz as sand grains. If the clay leaches into the B horizon, a sandy soil forms. In contrast, because basalt contains no quartz, soil formed from basalt is likely to be rich in clay and contain only small amounts of sand. Nutrient abundance also depends in part on the parent rock. For example, a pure quartz sandstone contains no nutrients, and soil formed on it must get its nutrients from outside sources.

b) CLIMATE

Temperature and rainfall affect soil formation. Rain seeps downward through soil, but several other factors pull the water back upward. Roots suck soil water toward the surface, and water near the surface evaporates. In addition, water is electrically attracted to soil particles. If the pore size between particles is small enough, **capillary action** draws water upward. During a rainstorm, water seeps through the A horizon, dissolving soluble ions such as calcium, magnesium, potassium, and sodium. In arid and semiarid regions, when the water reaches the B horizon, capillary action and plant roots then draw it back up toward the surface, where it evaporates or is incorporated into plant tissue. After the water escapes, many of its dissolved ions precipitate in the B horizon, encrusting the soil with salts. A soil of this type is a **pedocal** (Fig. 2–16a). This process often deposits enough calcium carbonate to form a hard cement called **caliche** in the soil. In the Imperial Valley in California, for example,



dissolved ions precipitate in the B horizon, encrusting the soil with salts. A soil of this type is a **pedocal** (Fig. 2–16a). This process often deposits enough calcium carbonate to form a hard cement called **caliche** in the soil. In the Imperial Valley in California, for example,

irrigation water contains high concentrations of calcium carbonate. A thick continuous layer of caliche forms in the soil as the water evaporates. To continue growing crops, farmers must then rip this layer apart with heavy machinery. Because nutrients concentrate when water evaporates, many pedocals are fertile if irrigation water is available. However, salts often concentrate so much that they become toxic to plants (Fig. 2–17). As mentioned previously, all streams contain small concentrations of dissolved salts. If arid or semiarid soils are intensively irrigated, salts can accumulate until plants cannot grow. This process is called **salinization**. Some historians argue that salinization destroyed croplands and thereby contributed to the decline of many ancient civilizations, such as the Babylonian Empire. In a wet climate, water seeping down through the soil leaches soluble ions from both the A and B horizons. The less soluble elements, such as aluminum, iron, and some silicon, remain behind, accumulating in the B horizon to form a soil type called a **pedalfer** (Fig. 2–16b). The subsoil in a pedalfer is commonly rich in clay, which is mostly aluminum and silicon, and has the reddish color of iron oxide.

In regions of very high rainfall, such as a tropical rainforest, so much water seeps through the soil that it leaches away nearly

all the soluble cations. Only very insoluble aluminum and iron minerals remain (Fig. 2–16c). Soil of this type is called a **laterite**. Laterites are often colored rust-red by iron oxide (Fig. 2–18). A highly aluminous laterite, called **bauxite**, is the world's main type of aluminum ore. The second important component of climate, average annual temperature, affects soil formation in two ways. First, chemical reactions proceed more rapidly in warm temperatures than in cooler conditions, so chemical weathering is faster in warmer climates than in cold ones. Second, plant growth and decay are temperature dependent as discussed below.



Figure 6–17 Saline seep on a ranch in Wyoming. Saline water seeps into this depression and then evaporates to deposit white salt crystals on the ground and on the fence posts.



Figure 2–18 Iron oxide colors this Georgia laterite.

c) RATES OF GROWTH AND DECAY OF ORGANIC MATERIAL

In the tropics, plants grow and decay rapidly all year long. When leaves and stems decay, the nutrients are quickly absorbed by the growing plants. As a result, little humus accumulates and few nutrients are stored in the soil (Fig. 2–19a). The Arctic, on the other hand, is so cold that plant growth and decay are slow.



Figure 2–19 (a) Tropical soil of Costa Rica supports lush growth, but organic material decays so rapidly that little humus accumulates. (b) Arctic soil of Baffin Island, Canada, supports sparse vegetation and contains little organic matter.

Therefore, litter and humus form slowly and Arctic soils contain little organic matter (Fig. 2–19b). The most fertile soils are those of prairies and forests in temperate latitudes. There, large amounts of plant litter drop to the ground in the autumn, but decay is slow during the cold winter months. During the spring and summer, litter decomposes and releases nutrients into the soil. However, in a temperate region, plant growth is not fast enough to remove all the nutrients during the growing season. As a result, thick layers of humus accumulate and soil contains abundant nutrients.

d) SLOPE ASPECT AND STEEPNESS

Aspect is the orientation of a slope with respect to the Sun. In the semiarid American West, thick soils and dense forests cover the cool, shady north slopes of hills, but thin soils and grass dominate hot, dry southern exposures. The reason for this difference is that in the Northern Hemisphere more water evaporates from the hot, sunny southern slopes. Therefore, fewer plants grow, weathering occurs slowly, and soil development is retarded. The moister northern slopes weather more deeply to form thicker soils. In general, hillsides have thin soils and valleys are covered by thicker soil, because soil erodes from hills and accumulates in valleys. When hilly regions were first settled and farmed, people naturally planted their crops in the valley bottoms, where the soil was rich and water was abundant. Recently, as population has expanded, farmers have moved to the thinner, less stable hillside soils.

e) TIME

Most chemical weathering occurs at the relatively low temperatures of the Earth's surface. Consequently, chemical weathering goes on slowly in most places, and time becomes an important factor in determining the extent of

weathering. Recall that feldspars weather to form clay, whereas quartz does not decompose easily. In geologically young soils, the decomposition of feldspars may be incomplete and the soils are likely to be sandy. As soils mature, more feldspars decompose, and the clay content increases.

f) SOIL TRANSPORT

By studying recent lava flows, scientists have determined how quickly plants return to an area after it has been covered by hard, solid rock. In many cases, plants appear when a lava flow is only a few years old, even before weathering has formed soil. Closer scrutiny shows that the plants have rooted in tiny amounts of soil that were transported from nearby areas by wind or water. In many of the world's richest agricultural areas, most of the soil was transported from elsewhere. Streams may deposit sediment, wind deposits dust, and soil slides downslope from mountainsides into valleys. These foreign materials mix with residual soil, changing its composition and texture. River deltas and the rich windblown loess soils of China and the North American Great Plains are examples of transported soils.

S U M M A R Y

Weathering is the decomposition and disintegration of rocks and minerals at the Earth's surface. **Erosion** is the removal of weathered rock or soil by moving water, wind, glaciers, or gravity. After rock or soil has been eroded from the immediate environment, it may be transported large distances and eventually deposited. Mechanical weathering can occur by **frost wedging**, **abrasion**, **organic activity**, **thermal expansion and contraction**, and **pressure-release fracturing**. **Chemical weathering** occurs when chemical reactions decompose minerals. A few minerals dissolve readily in water. Acids and bases often markedly enhance the solubility of minerals. Rainwater is slightly acidic due to reactions between water and atmospheric carbon dioxide. A serious environmental problem is caused by **acid rain**. The **hydrolysis** of feldspar and other common minerals, except quartz, is a form of chemical weathering. **Oxidation** is the reaction with oxygen to decompose minerals. Chemical and mechanical weathering often operate together. For example, solution seeping into cracks may cause rocks to expand by growth of salts or hydrolysis. Hydrolysis combines with pressure-release fracturing to form **exfoliated** granite.

Soil is the layer of weathered material overlying bedrock. **Sand**, **silt**, **clay**, and **humus** are commonly found in soil. Water **leaches** soluble ions downward through the soil. Clays are also transported downward by water. The uppermost

layer of soil, called the **O horizon**, consists mainly of litter and humus. The amount of organic matter decreases downward. The **A horizon** is the **zone of leaching**, and the **B horizon** is the **zone of accumulation**. Six factors control soil characteristics: parent rock, climate, rates of growth and decay, slope aspect and steepness, time, and transport. In dry climates, **pedocals** form. In pedocals, leached ions precipitate in the B horizon, where they accumulate and may form **caliche**. In moist climates, **pedalfer** soils develop. In these regions, soluble ions are removed from the soil, leaving high concentrations of less soluble aluminum and iron. **Laterite** soils form in very moist climates, where all of the more soluble ions are removed.

REVIEW QUESTIONS

1. Explain the differences among the terms weathering, erosion, transport, and deposition.
2. Explain the differences between mechanical weathering and chemical weathering.
3. List five processes that cause mechanical weathering.
4. Explain how thermal expansion can establish forces that could fracture a rock.
5. What is a talus slope? What conditions favor the formation of talus slopes?
6. What is oxidation? Give an example.
7. Explain why limestone dissolves very slowly in pure water. Why does it dissolve more rapidly in strong acids? Why does it dissolve in rainwater?
8. What is hydrolysis? What happens when granitic rocks undergo hydrolysis? What minerals react? What are the reaction products?
9. What is pressure-release fracturing? Why is pressure release fracturing an example of chemical and mechanical processes operating together?
10. List the products of weathering in order of decreasing size.
11. What are the components of healthy soil? What is the function of each component?
12. Characterize the four major horizons of a mature soil.
13. List the six soil-forming factors and briefly discuss each one.
14. Imagine that soil forms on granite in two regions, one wet and the other dry. Will the soil in the two regions be the same or different? Explain.
15. Explain how soils formed from granite will change with time.
16. What are laterite soils? How are they formed? Why are they unsuitable for agriculture?

DISCUSSION QUESTIONS

1. What process is responsible for each of the following observations or phenomena? Is the process a mechanical or chemical change?
 - a. A board is sawn in half.
 - b. A board is burned.
 - c. A cave is formed when water seeps through a limestone formation.
 - d. Calcite is formed when mineral-rich water is released from a hot underground spring.
 - e. Meter thick sheets of granite peel off a newly exposed pluton.
 - f. Rock fall is more common in mountains of the temperate region in the spring than in mid-summer.
2. Most substances contract when they freeze, but water expands. How would weathering be affected if water contracted instead of expanded when it froze?
3. Discuss the similarities and differences between salt cracking and frost wedging.
4. What types of weathering would predominate on the following fictitious planets? Defend your conclusions.
 - a. Planet X has a dense atmosphere composed of nitrogen, oxygen, and water vapor with no carbon dioxide. Temperatures range from a low of 10°C in the winter to 75°C in the summer. Windstorms are common. No living organisms have evolved.
 - b. The atmosphere of Planet Y consists mainly of nitrogen and oxygen with smaller concentrations of carbon dioxide and water vapor. Temperatures range from a low of -60°C in the polar regions in the winter to -35°C in the tropics. Windstorms are common. A lush blanket of vegetation covers most of the land surfaces.
5. The Arctic regions are cold most of the year, and summers are short there. Thus decomposition of organic matter is slow. In contrast, decay is much more rapid in the temperate regions. How does this difference affect the fertility of the soils?

CHAPTER III

WIND ACTION

When wind blows through a forest or across a prairie, the trees or grasses protect the soil from wind erosion. In addition, rain accompanies most windstorms in wet climates; the water dampens the soil and binds particles together. Therefore, little wind erosion occurs. In contrast, a desert commonly has little or no vegetation and rainfall, so wind erodes bare, unprotected soil. One can hardly think about deserts without imagining a hidebehind- your-camel-type sandstorm.

3.1. WIND EROSION

Wind erosion, called **deflation**, is a selective process. Because air is much less dense than water, wind moves only small particles, mainly silt and sand. (Clay particles usually stick together, and consequently wind does not erode clay effectively.) Imagine bare soil containing silt, sand, pebbles, and cobbles (Fig. 3–1a). When wind blows, it removes only the silt and sand, leaving the pebbles and

cobbles as a continuous cover of stones called **desert pavement** (Fig. 3–1b). Desert



Figure 3–1 (a) Wind erodes silt and sand but leaves larger rocks behind to form desert pavement. (b) Desert pavement is a continuous cover of stones left behind when wind blows silt and sand away.

pavement prevents the wind from eroding additional sand and silt, even though they may be abundant beneath the layer of stones. Thus, most deserts are rocky and covered with gravel, and sandy deserts are relatively rare.

3.2. TRANSPORT AND ABRASION

Because sand grains are relatively heavy, wind blows sand near the surface (usually less than 1 meter above the surface) and carries it only a short distance. In a windstorm, the sand grains bounce over the ground by saltation. Sand also moves by saltation in a stream bed.) In contrast, wind carries fine silt in suspension. Skiers in the Alps commonly encounter a silty surface on the snow,

blown from the Sahara Desert and carried across the Mediterranean Sea. Windblown sand is abrasive and erodes bedrock. Because wind carries sand close to the surface, wind erosion occurs near ground level. If you see a tall desert pinnacle topped by a delicately perched cap, you know that the top was not carved by wind erosion because it is too high above the ground. However, if the base of a pinnacle is sculpted, wind may be the responsible agent (Fig. 3–2). (Salt cracking at ground level also contributes to the weathering of desert rocks.) Cobbles and boulders lying on the desert surface often have faces worn flat by windblown sand. Such rocks, called **ventifacts**, often have two or three flat faces because of changing wind directions (Fig. 3–3).



Figure 3–2 Wind abrasion selectively eroded the base of this rock because windblown sand moves mostly near the surface.

3.3. DUNES

A **dune** is a mound or ridge of wind-deposited sand (Fig. 3–4). As explained earlier, wind removes sand from the surface in many deserts, leaving behind a rocky desert pavement. The wind then deposits the sand in a topographic depression or other place where the wind slows down. Approximately 80 percent of the world’s desert area is rocky and only 20 percent is covered by dunes. Although some desert dune fields cover only a few square kilometers, the largest is the Rub Al Khali (Empty Quarter) in Arabia, which covers 560,000 square kilometers, larger than the state of California. Dunes also form where glaciers have recently melted and along sandy coastlines. A glacier deposits large quantities of bare, unvegetated sediment. A sandy beach is commonly unvegetated



Figure 3–3 A ventifact shows flat faces scoured by windblown sand.

because sea salt prevents plant growth. Thus, both of these environments contain the essentials for dune formation: an abundant supply of sand and a windy environment with sparse vegetation. Dunes form when wind erodes sand



Figure 3–4 Sand Dunes.

because sea salt prevents plant growth. Thus, both of these environments contain the essentials for dune formation: an abundant supply of sand and a windy environment with sparse vegetation. Dunes form when wind erodes sand

from one location and deposits it nearby. A saucer or trough-shaped hollow formed by wind erosion in sand is called a **blowout**. In the 1930s, intense, dry winds eroded large areas of the Great Plains and created the Dust Bowl. Deflation formed tens of thousands of blowouts, many of which remain today. Some are small, measuring only 1 meter deep and 2 or 3 meters across, but others are much larger (Fig. 3–5). One of the deepest blowouts in the world is the Qattara



Figure 3–5 Many blowouts are only a meter or two deep, but some can be much larger. The grassy surface on top of the hummock is the level of the prairie before wind erosion occurred.

Depression in western Egypt. It is more than 100 meters deep and 10 kilometers in diameter. Ultimately, the lower limit for a blowout is the water table. If the bottom of the depression reaches moist soil near the water table, where water binds the sand grains, wind erosion is no longer effective. If wind-transported sand moves over a rock, a natural depression, or a small clump of vegetation, the wind slows down in the downwind, or **lee**, side of the obstacle. Sand settles out in this protected zone. The growing mound of sand creates a larger windbreak, and more sand accumulates, forming a dune. Dunes commonly grow to heights of 30 to 100 meters, and some giants exceed 500 meters. In places, they are tens or even hundreds of kilometers long. Most dunes are asymmetrical. Wind erodes sand from the windward side of a dune, and then the sand slides down the sheltered leeward side. In this way, dunes migrate in the downwind direction (Fig. 3–6). The leeward face of a dune is called the **slip face**. Typically, the slip face is about twice as steep as the windward face.

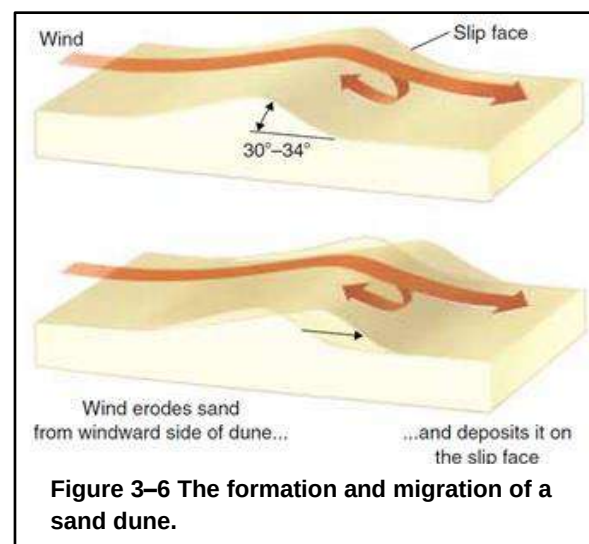


Figure 3–6 The formation and migration of a sand dune.

Migrating dunes overrun buildings and highways. For example, near the town of Winnemucca, Nevada, dunes advance across U.S. Highway 95 several times a year. Highway crews must remove as much as 4000 cubic meters of sand to

reopen the road. Engineers often attempt to stabilize dunes in inhabited areas. One method is to plant vegetation to reduce deflation and stop dune migration. The main problem with this approach is that desert dunes commonly form in regions that are too dry to support vegetation. Another solution is to build artificial windbreaks to create dunes in places where they do the least harm. For example, a fence traps blowing sand and forms a dune, thereby protecting areas downwind. Fencing is a temporary solution, however, because eventually the dune covers the fence and resumes its migration. In Saudi Arabia, dunes are sometimes stabilized by covering them with tarry wastes from petroleum refining.

3.3.1. Fossil Dunes

When dunes are buried by younger sediment and lithified, the resulting sandstone retains the original sedimentary structures of the dunes. Figure 3–7 shows a rock face in Zion National Park in Utah. The sloping sedimentary layering is not evidence of tectonic tilting but is the original steeply dipping layers of the dune slip face. The beds dip in the direction in which the wind was blowing when it deposited the sand. Notice that the planes dip in different directions, indicating changes in wind direction. The layering is an example of **cross-bedding**.

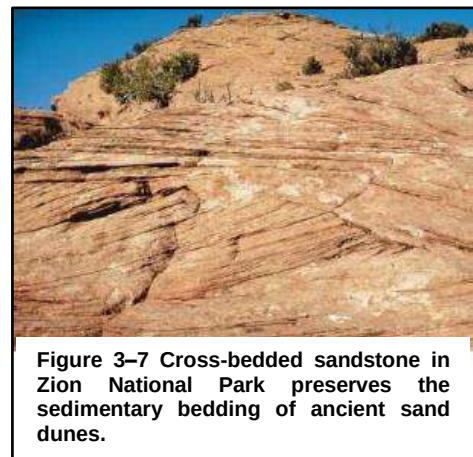


Figure 3–7 Cross-bedded sandstone in Zion National Park preserves the sedimentary bedding of ancient sand dunes.

3.3.2. Types of Sand Dunes

Wind speed and sand supply control the shapes and orientation of dunes (Fig. 3–8). **Barchan dunes** form in rocky deserts with little sand. The center of the dune grows higher than the edges (Fig. 3–9a). When the dune migrates, the edges move faster because there is less sand to transport. The resulting barchan dune is crescent shaped with its tips pointing downwind

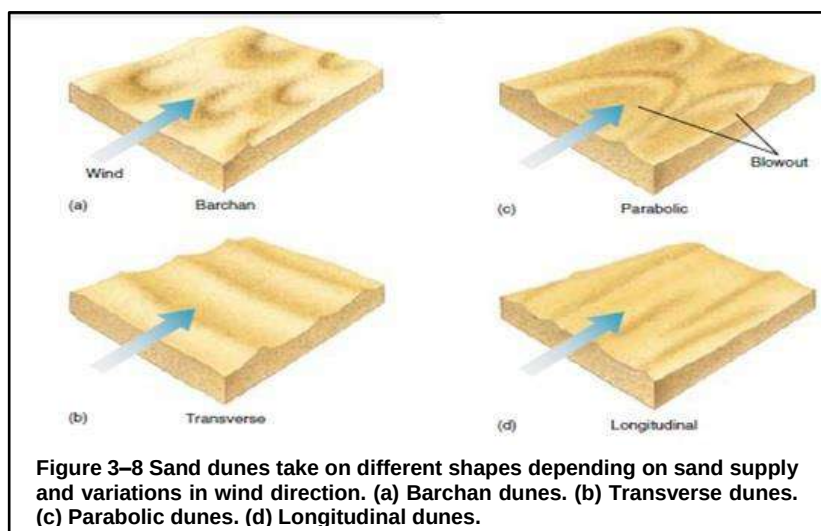
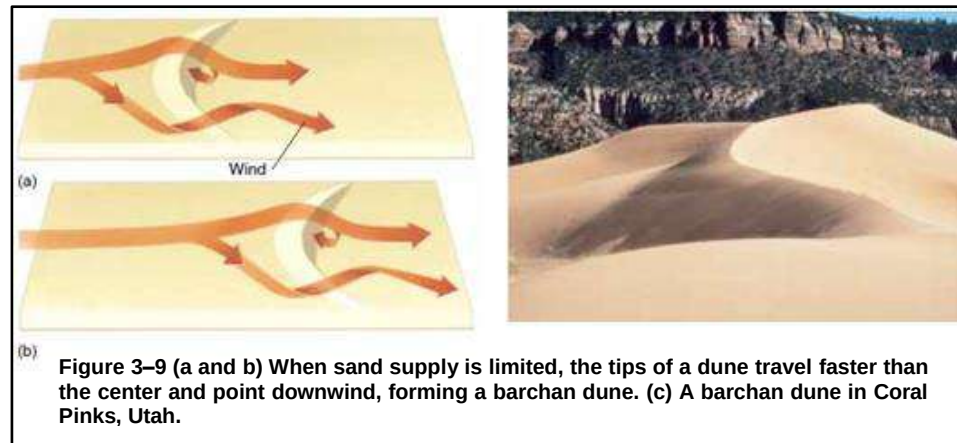


Figure 3–8 Sand dunes take on different shapes depending on sand supply and variations in wind direction. (a) Barchan dunes. (b) Transverse dunes. (c) Parabolic dunes. (d) Longitudinal dunes.

(Fig. 3–9b). Barchan dunes are not connected to one another, but instead migrate independently. In a rocky desert, barchan dunes cover only a small portion of the land; the remainder is bedrock or desert pavement. If sand is plentiful and evenly dispersed, it accumulates in long ridges called **transverse dunes** that align perpendicular to the prevailing wind (Figs. 3–8b and 3–10). They are shaped like sand ripples, although they are much larger. If desert vegetation is plentiful, the wind may form a blowout in a bare area among the desert plants. As sand is carried out of the blowout, it accumulates in a

parabolic dune, the tips of which are anchored by plants on each side of the blowout (Figs. 3–8c and 3–11). A



parabolic dune is similar in shape to a barchan dune, except that the tips of the parabolic dune point into the wind. Parabolic dunes are common in moist semidesert regions and along seacoasts. If the wind direction is erratic but prevails from the same general quadrant of the compass and the supply of sand is limited, then long, straight **longitudinal dunes** form parallel to the prevailing wind direction (Figs. 3–8d and 3–12). In portions of the Sahara Desert, longitudinal dunes reach 100 to 200 meters in height and are as much as 100 kilometers long.



Figure 3–10 Transverse dunes form perpendicularly to the prevailing wind direction in regions with abundant sand, such as this part of the Oregon coast.



Figure 3–11 A parabolic dune in Death Valley, California, has formed where wind blows sand from a blowout, and grass or shrubs anchor the dune tips.



Figure 3–12 Longitudinal dunes on the Oregon coast form where the wind is erratic and the sand supply is limited.

3.4. LOESS

Wind can carry silt for hundreds or even thousands of kilometers and then deposit it as **loess** (pronounced luss). Loess is porous, uniform, and typically lacks layering. Often the angular silt particles interlock. As a result, even though the loess is not cemented, it typically forms vertical cliffs and bluffs (Fig. 3–13). The largest loess deposits in the world, found in central China, cover 800,000 square



Figure 3–13 Villagers in Askole, Pakistan, have dug caves in these vertical loess cliffs.

kilometers and are more than 300 meters thick. The silt was blown from the Gobi and the Takla Makan deserts of central Asia. The particles interlock so effectively that people have dug caves into the loess cliffs to make their homes. However, in 1920 a great earthquake caused the cave system to collapse, burying and killing an estimated 100,000 people. Large loess deposits accumulated in North America during the Pleistocene Ice Age, when continental ice sheets ground bedrock into silt. Streams carried this fine sediment from the melting glaciers and deposited it in vast plains. These zones were cold, windy, and devoid of vegetation, and wind easily picked up and transported the silt, depositing thick layers of loess as far south as Vicksburg, Mississippi. Soils formed on loess are generally fertile and make good farmland. Much of the rich soil of the central plains of the United States and eastern Washington State formed on loess.

SUMMARY

Deflation is erosion by wind. Silt and sand are removed selectively, leaving larger stones on the surface and creating **desert pavement**. Sand grains are carried short distances and a meter or less above the ground by **saltation**, but silt can be transported great distances at higher elevations. Wind erosion forms **blowouts**. Windblown particles are abrasive, but because the heaviest grains travel close to the surface, abrasion occurs mainly near ground level. A **dune** is a mound or ridge of wind-deposited sand. Most dunes are asymmetrical, with gently sloping windward sides and steeper **slip faces** on the lee sides. Dunes migrate. The various types of dunes include **barchans dunes**, **transverse dunes**, **longitudinal dunes**, and **parabolic dunes**. Wind-deposited silt is called **loess**.

REVIEW QUESTIONS

1. Why are many deserts concentrated along zones at 30° latitude in both the Northern and Southern Hemispheres?
2. List three conditions that produce deserts.
3. Explain why angular topography is common in desert regions.
4. Why do flash floods and debris flows occur in deserts?
5. Why are alluvial fans more prominent in deserts than in humid environments?
6. Compare and contrast floods in deserts with those in more humid environments.
7. Compare and contrast pediments and bajadas.
8. Why is wind erosion more prominent in desert environments than it is in humid regions?
9. Describe the formation of desert pavement.
10. Describe the evolution and shape of a dune.
11. Describe the differences among barchan dunes, transverse dunes, parabolic dunes, and longitudinal dunes. Under what conditions does each type of dune form?
12. Compare and contrast desert plateaus, mesas, and buttes. Describe the formation of each.
13. Compare the effects of stream erosion and deposition in the Colorado Plateau and Death Valley.

DISCUSSION QUESTIONS

1. Coastal regions boast some of the wettest and some of the driest environments on Earth. Briefly outline the climatological conditions that produce coastal rainforests versus coastal deserts.
2. Explain why soil moisture content might be more useful than total rainfall in defining a desert. How could one region have a higher soil moisture content and lower rainfall than another region?
3. Discuss two types of tectonic change that could produce deserts in previously humid environments.
4. Imagine that you lived on a planet in a distant solar system. You had no prior information on the topography or climate of the Earth and were designing an unmanned spacecraft to land on Earth. The spacecraft had arms that could reach out a few meters from the landing site to collect material for chemical analysis. It also had instruments to measure the immediate meteorological conditions and cameras that could focus on anything within a range of 100 meters. The

batteries on your radio transmitter had a life expectancy of two weeks. The spacecraft landed and you began to receive data. What information would convince you that the spacecraft had landed in a desert?

5. Deserts are defined as areas with low rainfall, yet water is an active agent of erosion in desert landscapes. Explain this apparent contradiction.

6. Compare and contrast erosion, transport, and deposition by wind with erosion and deposition by streams.

7. Imagine that someone told you that an alluvial fan had formed by wind deposition. What evidence would you look for to test this statement?

8. What type of dunes form under the following conditions? (a) Relatively high vegetation cover, sand supply, and wind strength. (b) Low vegetation and sand supply.

9. What type of environment would produce fossilized seashells embedded in lithified sand dunes?

CHAPTER IV

RUNNING WATER

4.1. Hydrologic Cycle:

Physical processes controlling distribution and movement of water on, above and below the earth surface (**Fig. 4.1**). The hydrologic cycle is an open system powered by solar radiation. Water from the oceans evaporates into the atmosphere, is carried to land as precipitation, and eventually returns back to the oceans.

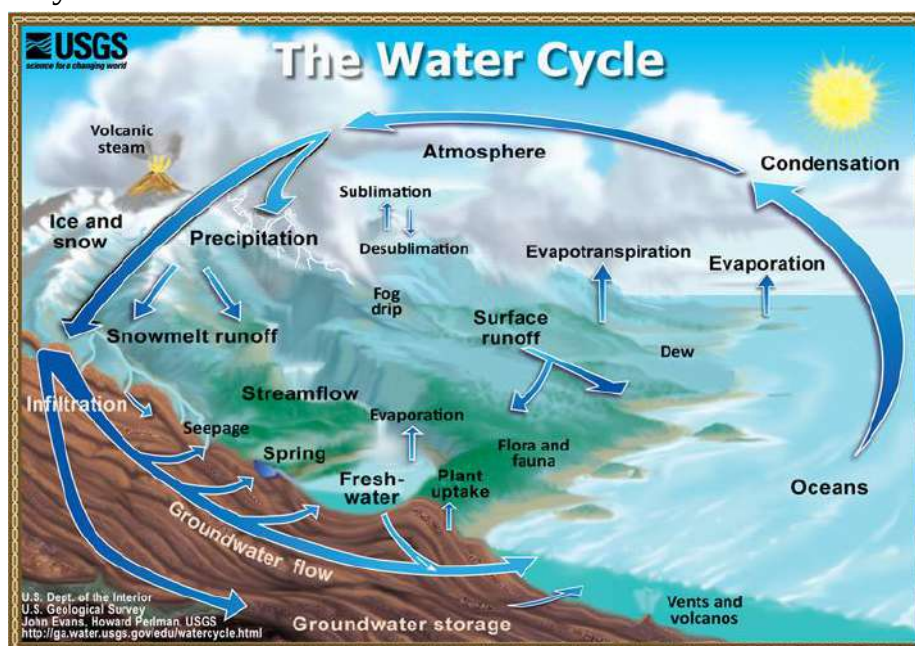


Fig. 4.1: The earth's water cycle

4.1.1. Precipitation

Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth. Most precipitation falls as rain.

4.1.2. Infiltration

A portion of the water that falls as rain and snow infiltrates into the subsurface soil and rock. Some water that infiltrates will remain in the shallow soil layer, where it will gradually move vertically and horizontally through the soil and subsurface material. Some of the water may infiltrate deeper, recharging groundwater aquifers.

Factors affecting infiltration

- 1- Soil characteristics: Some soils, such as clays, absorb less water at a slower rate than sandy soils. Soils absorbing less water result in more runoff overland into streams.
- 2- Soil saturation: Like a wet sponge, soil already saturated from previous rainfall can't absorb much more ... thus more rainfall will become surface runoff.
- 3- Land cover: Vegetation can slow the movement of runoff, allowing more time for it to seep into the ground. Impervious surfaces, such as parking lots, roads, and developments, act as a "fast lane" for rainfall - right into storm drains that drain directly into streams.
- 4- Slope of the land: Water falling on steeply-sloped land runs off more quickly and infiltrates less than water falling on flat land.

4.1.3. Evaporation

Evaporation is the process by which water changes from a liquid to a gas or vapor. Evaporation is the primary pathway that water moves from the liquid state back into the water cycle as atmospheric water vapor.

4.1.4. Transpiration

The release of water from plant leaves. Studies have revealed that transpiration accounts for about 10 percent of the moisture in the atmosphere.

4.1.5. Evapotranspiration

In general, evapotranspiration is the sum of evaporation and transpiration. It is the water lost to the atmosphere from the ground surface, evaporation from the capillary fringe of the groundwater table, and the transpiration of groundwater by plants whose roots tap the capillary fringe of the groundwater table.

4.1.6. Runoff:

Runoff can be described as the part of the water cycle that flows over land as surface water instead of being absorbed into groundwater or evaporating.

What affects runoff?

- 1-The amount of rainfall directly affects the amount of runoff.
- 2-The ability of the ground surface to absorb water will affect how much surface runoff occurs.
- 3-There is less runoff in highly vegetated areas because the water is used by the plants instead of flowing off the surface of the ground.
- 4-The slope of a surface: The steeper a surface is, the faster it will flow down the slope. A flat surface will allow the water time to absorb into the surface.

4.2. Stream Flow

Stream is used to denote channelized flow of any size, from the smallest trickle to the mightiest river. Water may flow in one of two ways, either as laminar flow or turbulent flow (**Fig. 4.2**).

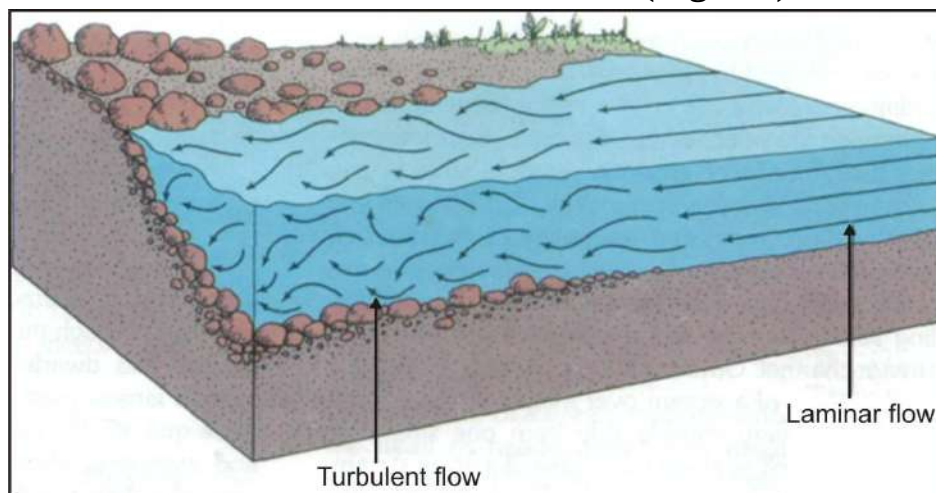


Fig. 4.2: Laminar and turbulent flow

Laminar flow: when the movement is laminar, the water particles flow in straight line paths that are parallel to the channel. The water particles move steadily downstream without mixing.

Turbulent flow: when the flow is turbulent, the water moves in a confused and erratic fashion that is often characterized by swirling, whirlpool-like eddies.

▪ The stream's velocity is the primary factor that determines whether the flow is laminar or turbulent. Laminar flow is only possible when water is moving very slowly through a smooth channel. If the velocity increases or the channel becomes rough, laminar flow changes to turbulent flow. Several factors determine the velocity of a stream and therefore control the amount of erosional work a stream may accomplish. These factors include: **(1)** the gradient, **(2)** the shape, size, and roughness of the channel, and **(3)** the discharge.

1- Gradient (slope): is typically expressed as the vertical drop of a stream over a fixed distance.

2- Shape, size, and roughness of the channel: The cross-sectional shape of a channel determines the amount of water in contact with the channel and hence affects the frictional drag. The most effective channel is one with the least perimeter for its cross sectional area. **Figure 4.3** compares three types of channels. Although the cross-sectional area of all three is identical, the semicircular shape has less water in contact with the channel than the others and therefore less frictional drag. As a result, if all other factors are equal, the water will flow more rapidly in the semicircular channel.

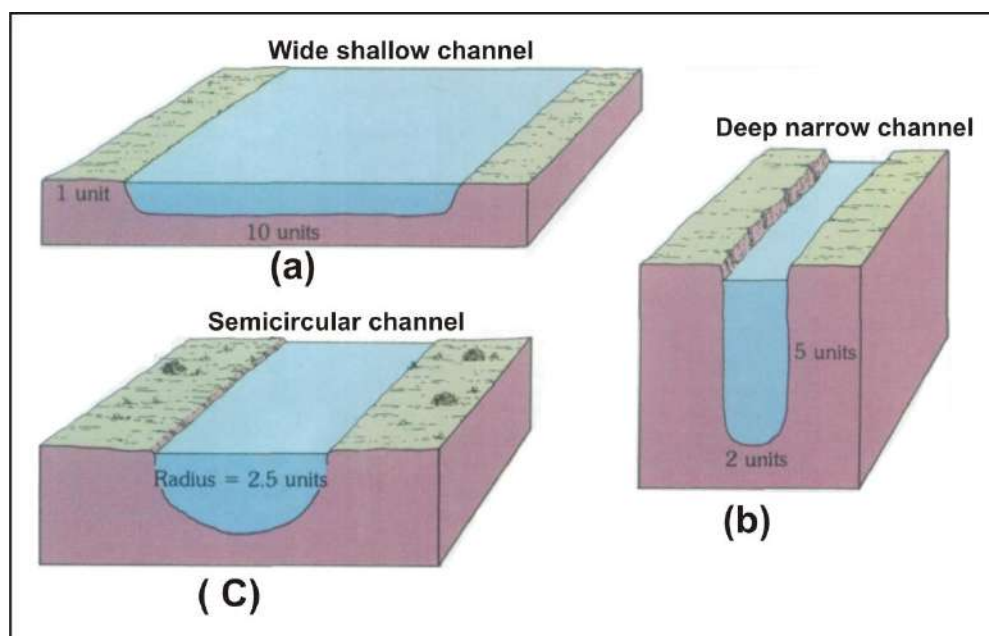


Fig. 4.3: Influence of channel shape on velocity

An increase in the size of channel reduces the ratio of perimeter to cross sectional area and therefore increases the efficiency of flow. A smooth channel promotes a more uniform flow, while irregular channel

filled with boulders creates enough turbulence to significantly retard the stream's forward motion.

3- Discharge: The discharge of a stream is the amount of water flowing past a certain point in a given unit of time. This is usually measured in cubic meters per second or cubic feet per second.

$$\text{Discharge (m}^3\text{/second)} = \text{channel width (meters)} \times \text{channel depth (meters)} \times \text{velocity (meters/second)}$$

Figure 4.4 shows a longitudinal profile along the length of a stream, it is observed that there is a concave upward curve of the profile, with a steeper gradient upstream and a gentler gradient downstream. There is an inverse relationship between gradient and discharge. Where the gradient is high, the discharge is small, and where the discharge is great, the gradient is small.

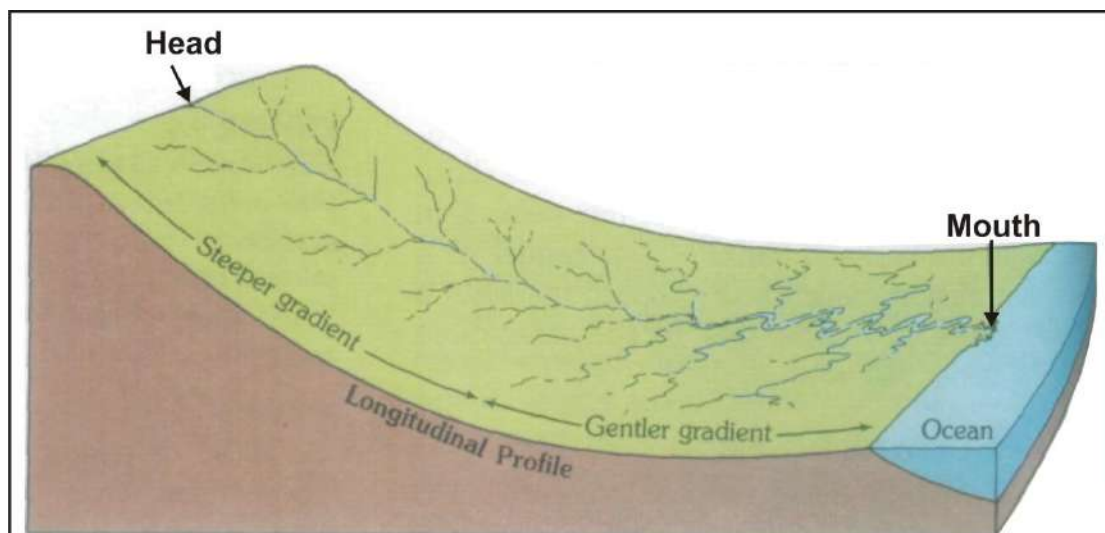


Fig. 4.4: A longitudinal profile is a cross section along the length of a stream

4.3. Stream erosion

Streams may erode their channels in several different ways: **by lifting loosely consolidated particles, by abrasion, and by solution activity.** When the flow of water is turbulent, the water whirls and eddies. When an eddy is sufficiently strong, it can dislodge particles from the channel and lift them into the moving water. In this manner, the force of running water swiftly erodes poorly consolidated materials on the bed and bank of the stream. The stronger the current, the more effectively the stream will lift particles.

Transport of sediment by streams

Sediment transport is the movement of organic and inorganic particles by water. Streams transport their load of sediment in three ways: (1) in solution (dissolved load), (2) in suspension (suspended load), and (3) along the bottom of the channel (bed load).

Dissolved load: the greatest portion of the dissolved load transported by most streams is supplied by groundwater. As water percolates through the ground, it first acquires soluble soil compounds. As the water seeps deeper through cracks and pores in the bedrock below, additional mineral matter may be dissolved. Eventually much of this mineral-rich water finds its way into streams.

Suspended load: suspended sediment are any particles found in the water column, whether the water is flowing or not. The suspended load, on the other hand, is the amount of sediment carried downstream within the water column by the water flow. Suspended loads require moving water, as the water flow creates small upward currents (turbulence) that keep the particles above the bed (**Fig. 4.5**). The size of the particles that can be carried as suspended load is dependent on the flow rate. Larger particles are more likely to fall through the upward currents to the bottom. Only fine sand, silt and clay-sized particles can be carried by this way, but during flood stage larger particles are carried as well. Factors affecting on the type and amount of material carried in suspension:

- 1- Velocity of the water
- 2- settling velocity of each sediment grain

Settling velocity is defined as the speed at which a particle falls through a still fluid. The larger the particles, the more rapidly it settles toward the stream bed.

Bed load is the portion of sediment transport that rolls, slides or bounces along the bottom of a waterway. This sediment is not truly suspended, it consists of sediments is too large to be carried in suspension. Sediment moving by saltation appears to jump or skip along the stream bed (**Fig. 4.5**).

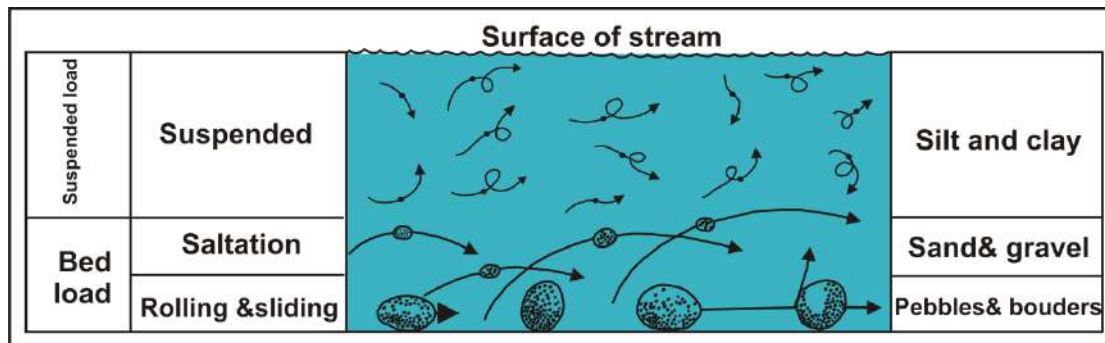


Fig. 4.5: Transportation of a stream's load

Sorting is the mechanism by which solid particles of various sizes are deposited. It explains why particles of similar size are deposited together.

Alluvium is the well sorted material typically deposited by a stream, it is applicable term to any stream-deposited sediments.

Channel deposits

As a river transports sediment toward the sea, some material may be deposited within the channel. Channel deposits are most often composed of sand and gravel, the coarser components of a stream's load, and are commonly referred to as **bars**.

Floodplain deposits

It is the part of valley that is inundated during a flood. Most streams are bordered by floodplains. Although some are impressive features that are many kilometers across, others are very modest, having widths of just a few meters. Some of the alluvium covering a floodplain consists of coarse sand and gravel that was originally deposited as point bars by meanders shifting laterally across the valley floor. Other sediments would be composing of fine sands, silts and clays that were spread across the floodplain whenever water left the channel during floodstage

4.4. Stream valleys

Stream valleys can be divided into two general types. Narrow, V-shaped valleys and wide valleys with flat floors exist as the ideal forms, with many gradations between. The sides of most valleys are shaped primarily as the result of weathering, sheet flow, and mass wasting. A narrow, V-shaped valley indicates that the primary work of the stream has been down cutting toward base level.

Erosional flood plain

Once a stream has cut its channel closer to base level, it approaches a graded condition, and down ward erosion becomes less dominant. At this point more of the stream's energy is directed from side to side. The reason for this change is not fully understood, but the reduced gradient probably is an important factor. Nevertheless it does occur, and the result is a widening of the valley as the river cuts away first at one bank and then the other (**Fig. 4.6**). In this manner the flat valley floor, or floodplain, is produced. This is an appropriate name because the river is confined to its channel except during floodstage when it overflows its banks and inundates the flood plain.

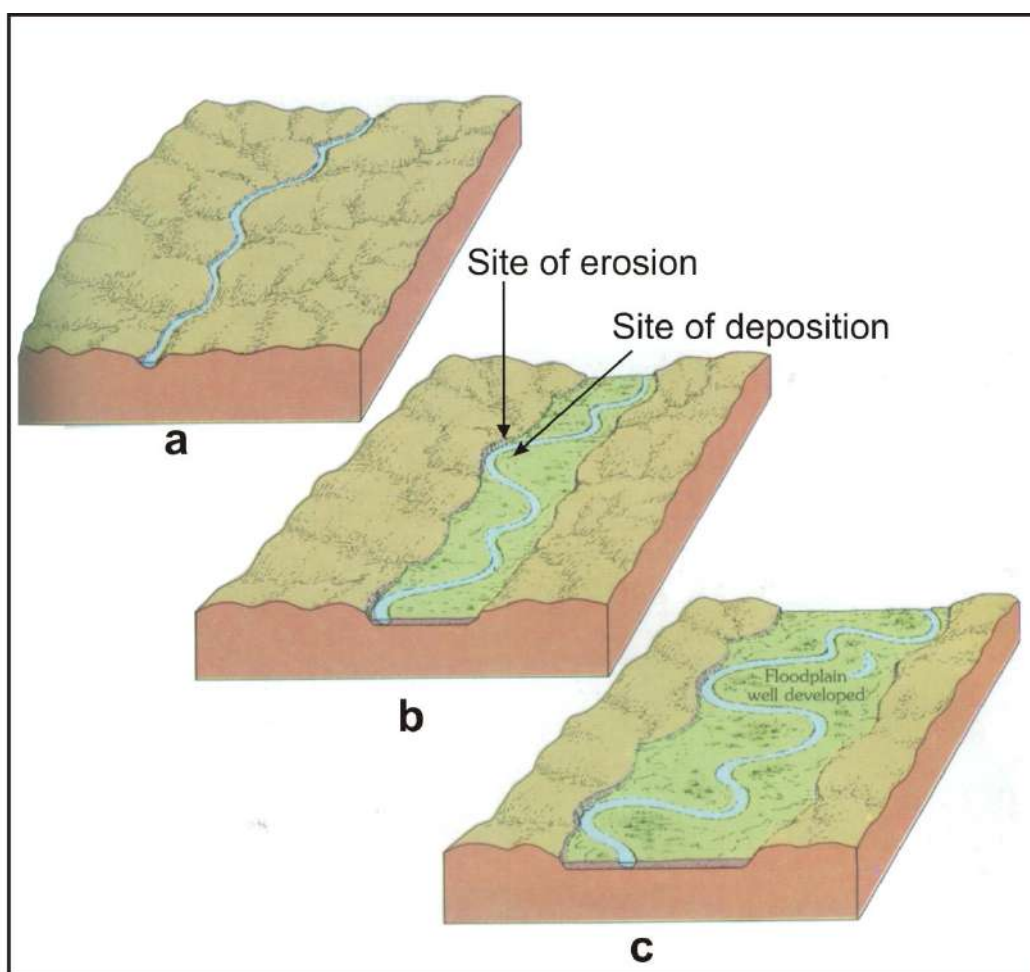


Fig. 4.6: Stream eroding its flood plain

Meanders are the streams that flow upon floodplains, whether erosional or depositional, move in sweeping bends. Once a bend in the channel begins to form, it grows larger. Erosion occurs on the outside of the meander where velocity and turbulence are greatest. As the bank becomes oversteepened, it fails by slumping into the channel. Because the outside

of a meander is zone of active erosion, it is often referred to as the cut bank.

Thus, meanders migrate laterally, while keeping the same cross-sectional area, by eroding on the outside of the bends and depositing on the inside (Fig. 4.7).

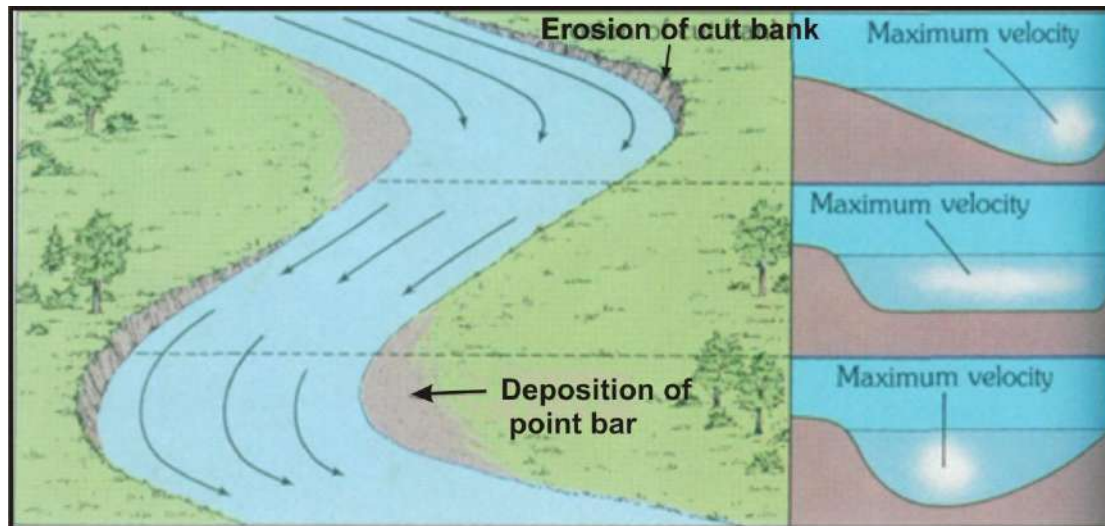


Fig. 4.7: Lateral movement of the meander

Due to the slope of the channel, erosion is more effective on the downstream side of a meander. Therefore, in addition to growing laterally, the bends also gradually migrate down the valley. Sometimes the downstream migration of a meander is slowed when it reaches a more resistant portion of the flood-plain. This allows the next meander upstream to "catch up." Gradually the neck of land between the meanders is narrowed. When they get close enough, the river may erode through the narrow neck of land to the next loop (Fig. 4.8). The new, shorter channel segment is called a cutoff and, because of its shape, the abandoned bend is called an oxbow lake.

Drainage networks

The drainage basin of one stream is separated from another by an imaginary line called a **divide** (Fig. 4.9). Divides range in size from a ridge separating two small gullies to continental divides, which split continents into enormous drainage basins.

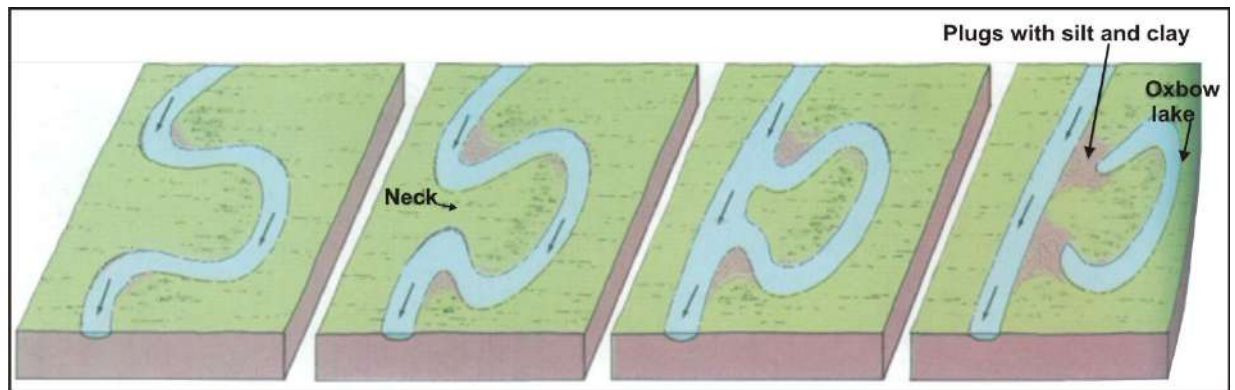


Fig. 4.8: Formation of a cutoff and oxbow lake

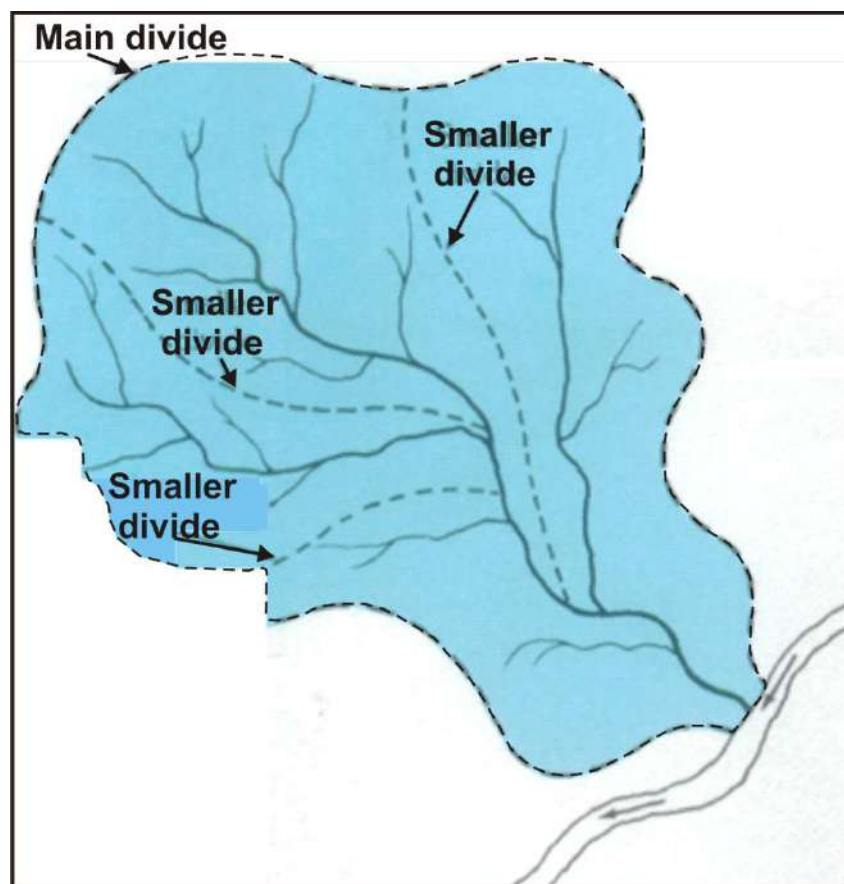


Fig. 4.9: Drainage basins and divides

Drainage patterns

There are many types of drainage patterns. All drainage systems are made up of an interconnected network of streams which together form particular patterns.

Dendritic pattern is characterized by irregular branching of tributary streams that resembles the branching pattern of a deciduous tree (**Fig.**

4.10 a). The dendritic pattern forms where underlying bedrock is relatively uniform, such as flat-lying strata or massive igneous rocks.

Rectangular pattern develops when the bedrock is crisscrossed series of joints and faults, since these structures eroded more easily than unbroken rock, their geometric pattern guides the directions of valleys (**Fig. 4.10 b**).

Radial pattern occurs when streams diverge from a central area spokes from the hub of a wheel. This pattern typically, develops on isolated volcanic cones and domal up lifts (**Fig. 4.10 c**).

Trellis pattern a rectangular pattern in which tributary streams is nearly parallel to one another and have the appearance of a garden trellis. This pattern forms in areas underlain by alternating bands of resistant rock (**Fig. 4.10 d**).

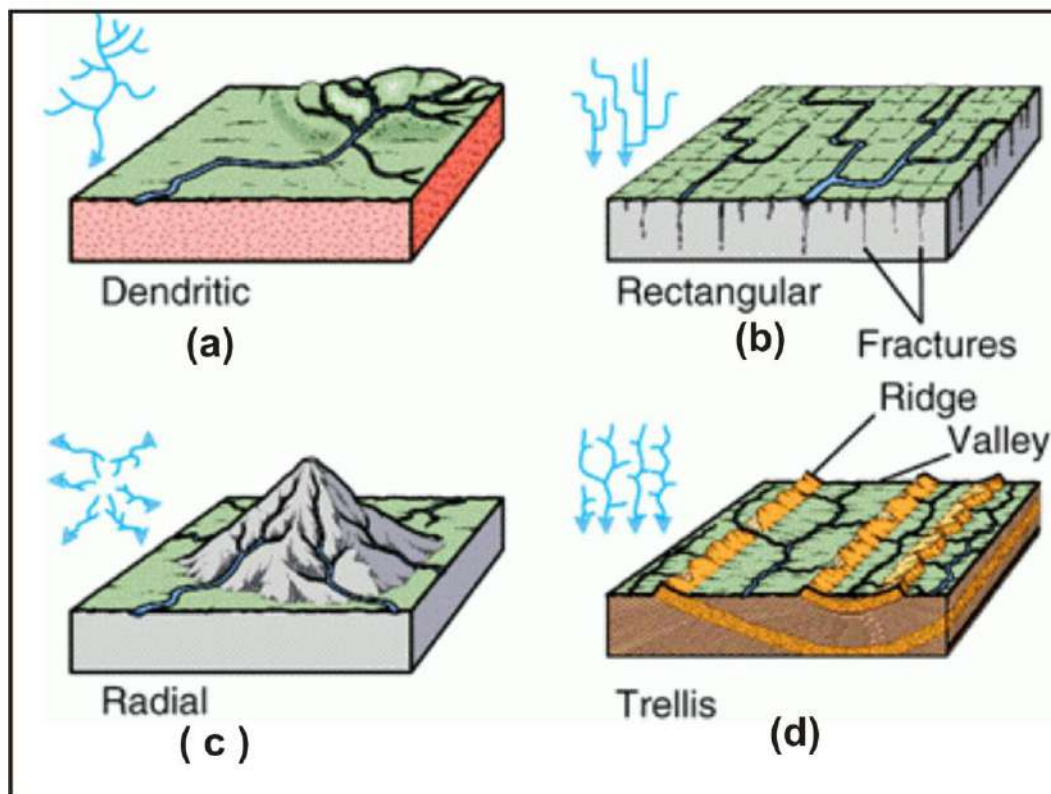


Fig. 4.10: Drainage pattern: (a) dendritic, (b) rectangular, (c) Radial, (d) trellis

4.5. Stages of valley development

Valley develops through different stages as shown in (**Fig. 4.11**):

(a) Youth stage which is characterized by down cutting and V-shaped valley. **(b)** When a stream reaches maturity, downward erosion diminishes and lateral erosion dominates. Thus the mature stream begins actively cutting its flood plain and meandering upon it. **(c)** During the

mature stage cutoffs occur, producing oxbow and a few streams may even produce natural levees. **(d) Old age**; After the valley has been cut several times wider than the width of the meander belt, it has entered old age.

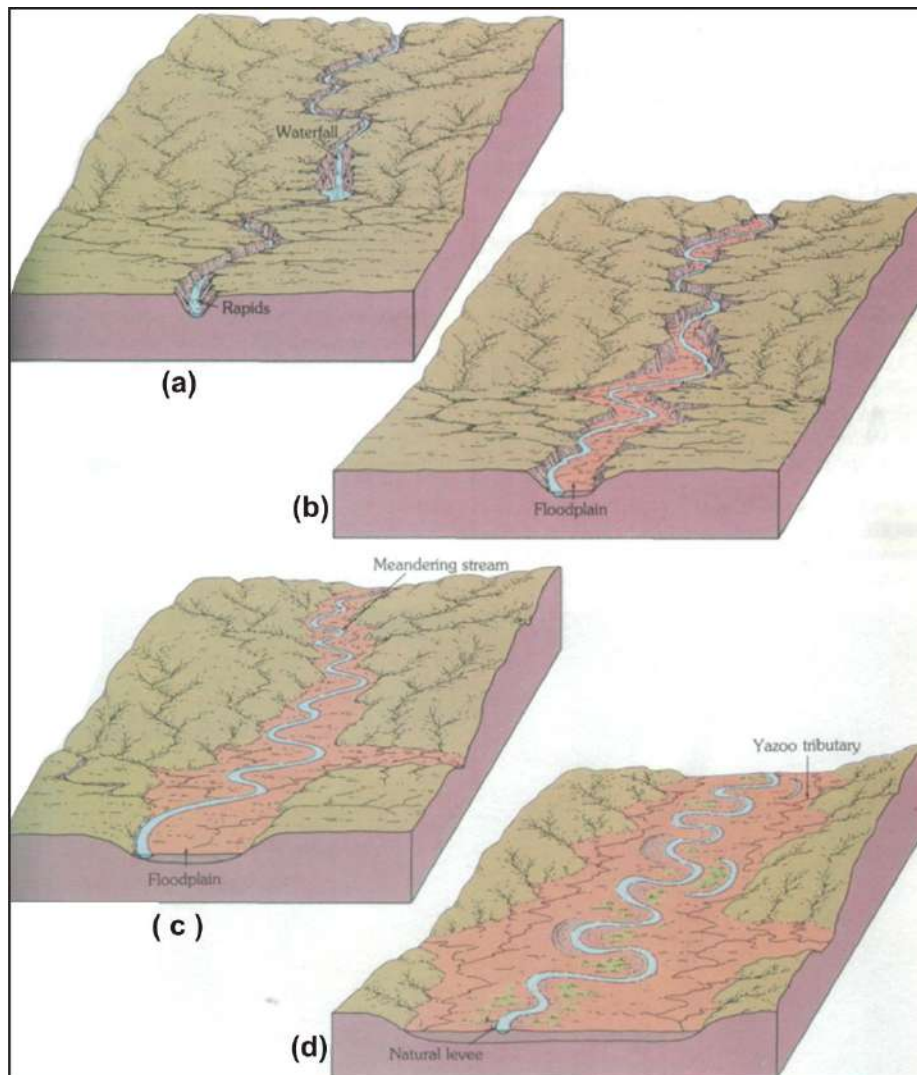


Fig. 4.11: Stages of valley development

REVIEW QUESTIONS

1. Describe the movement of water through the hydrologic cycle.
2. Describe the factors that determine the velocity of stream Flow.
3. Distinguish among the three types of stream erosion: hydraulic action, solution, and abrasion.
4. List and explain three ways in which sediment can be transported by a stream. Which type of transport is independent of stream velocity? Explain.
5. In what transport mode is most sediment carried by a stream?
6. Explain how a stream forms and shapes a valley.

7. In what type of terrain would you be likely to find a V shaped valley? Where would you be likely to find a meandering stream?
8. What is a meander and how may it become an oxbow lake?
9. Examine Figure 4–12. If you were building a house near this river, would you choose site A or B? Defend your choice.

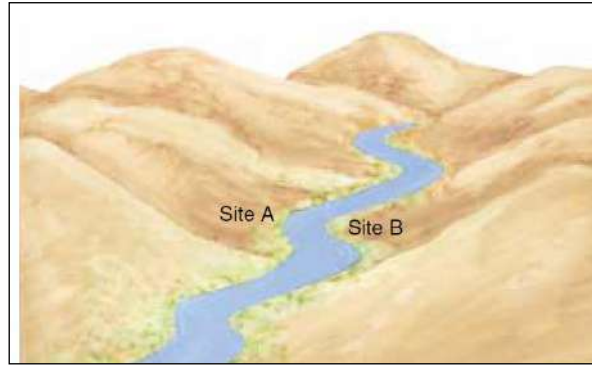


Figure 4–12 Two possible house sites along a river.

CHAPTER V

GROUNDWATER

5.1. Groundwater

Groundwater comes from precipitation. Precipitated water must filter down through the vadose zone to reach the zone of saturation, where groundwater flow occurs (Fig. 5.1). The rate of infiltration is a function of soil type, rock type, antecedent water, and time.

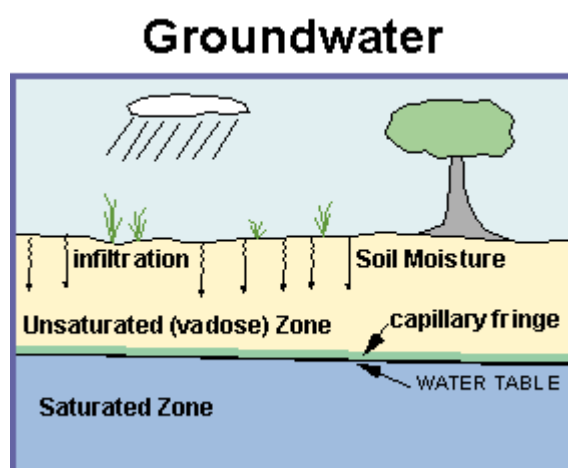


Fig. 5.1: Infiltration of water

The vadose zone includes all the material between the Earth's surface and the zone of saturation. Near the upper boundary of the zone of saturation where water pressure equals atmospheric pressure, is the water table. The capillary fringe is a layer of variable thickness that directly overlies the water table. Water is drawn up into this layer by capillary action.

The vadose zone has an important environmental role in groundwater systems. As with water, surface pollutants must filter through the vadose zone before entering the zone of saturation.

5.1.1. Groundwater aquifers

Large amounts of water are stored beneath the earth's surface in aquifers. To be an aquifer, the stored water must be accessible at a usable rate. Aquifers consist of porous material such as sand, gravel, and fractured rock.

Aquifers can be confined or unconfined. Confined aquifers have non-porous layers above and below the aquifer zone. The non-porous layers hold water and restrict water movement. Such layers are referred to as aquitards or aquicludes. Clay soils, shales, and non-fractured, weakly porous igneous and metamorphic rocks are examples of aquitards. Sometimes a lens of non-porous material will be found in material that is more permeable. Water percolating through the unsaturated zone will be intercepted by this layer and will accumulate on top of the lens. This water is a perched aquifer. An unconfined aquifer does not have confining layers that retard water movement.

Some aquifers are confined under pressure. These aquifers are called artesian systems. Sufficient pressure results in free-flowing water, either from a spring or from a well.

Water is continually recycled through aquifer systems. Groundwater recharge is any water added to the aquifer zone. Processes that contribute to groundwater recharge include precipitation, streamflow, leakage (reservoirs, lakes, aqueducts), and artificial means (injection wells). Groundwater discharge is any process that removes water from an aquifer system. Natural springs and artificial wells are examples of discharge processes.

Pumping water from a well causes a cone of depression to form in the water table at the well site. Overpumping can have two effects. It can cause a change in the groundwater flow direction. It also lowers the water table, making it necessary to dig a deeper well.

5.1.2. Groundwater Movement

Movement of groundwater depends on rock and sediment properties and the groundwater's flow potential. Porosity, permeability, specific yield and specific retention are important properties of groundwater flow. Porosity is the volume of pore space relative to the total volume (rock and/or sediment + pore space).

Primary porosity (% pore space) is the initial void space present (intergranular) when the rock formed. Secondary porosity (% added openings) develops later. It is the result of fracturing, faulting, or dissolution. Grain shape and cementation also affect porosity (Fig. 5.2).

Permeability is the capability of a rock to allow the passage of fluids. Permeability is dependent on the size of pore spaces and to what degree the pore spaces are connected. Grain shape, grain packing, and cementation affect permeability. (Fig. 5.2)

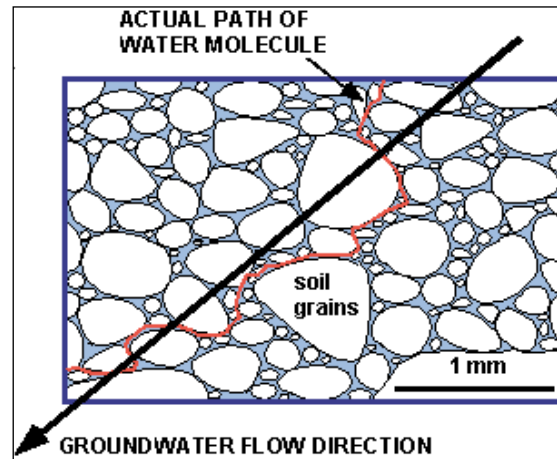


Fig. 5.2: Groundwater movement

Specific yield (S_y) is the ratio of the volume of water that drained from a rock (due to gravity) to the total rock volume. Grain size has a definite effect on specific yield. Smaller grains have larger surface areas. Larger surface areas mean more surface tension. Fine-grained sediment will have a lower specific yield than more coarsely-grained sediment. Sorting of material affects groundwater movement. Poorly sorted material is less porous than well-sorted material.

Specific retention (S_r) is the ratio of the volume of water a rock can retain (in spite of gravity) to the total volume of rock.

Specific yield plus specific retention equals porosity (often designated with the Greek letter phi).

Porosity, permeability, specific yield, and specific retention are all components of hydraulic conductivity. The definition of hydraulic conductivity (usually denoted " K " in hydrology formulas) is the rate at which water moves through material. Internal friction and the various paths water takes are factors affecting hydraulic conductivity. Hydraulic conductivity is generally expressed in meters per day.

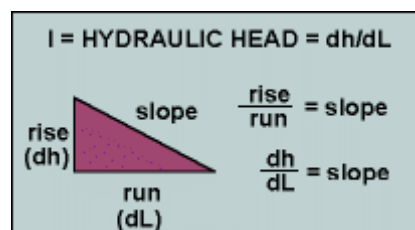
Hydraulic head (denoted " h " in hydrology formulas) is the name given to the driving force that moves groundwater. The hydraulic head combines fluid pressure and gradient, and can be thought of as the

standing elevation that water will rise to in a well allowed to come to equilibrium with the subsurface. Groundwater always moves from an area of higher hydraulic head to an area of lower hydraulic head. Therefore, groundwater not only flows downward, it can also flow laterally or upward. Direction of flow is dependent on local conditions.

The hydraulic gradient (I) is approximately the slope of the water table—in a simple unconfined water system (remember however, that confined aquifer systems can be more complex, in such systems, fluid pressure must also be considered).

5.1.3. The Water Table

Water table contour lines are similar to topographic lines on a map. They essentially represent "elevations" in the subsurface. These elevations are called the hydraulic head mentioned above.



Water table contour lines can be used to tell which way groundwater will flow in a given region. Lots of wells are drilled and hydraulic head is measured in each one. Water table contours are drawn that join areas of equal head (like "connect-the-dots"!). These water table contours lines are also called equipotential lines.

Darcy's law: $Q = KIA$

Where, Q is rate of flow (m^3/time), K is hydraulic conductivity (m/time), I is hydraulic gradient (dimensionless) and A is cross-sectional area of the aquifer (aquifer width x thickness).

In 1856, Henry Darcy studied the movement of water through porous material. He determined an equation that described groundwater flow. The following description tells how Darcy determined his equation:

A horizontal pipe filled with sand is used to demonstrate Darcy's experiment. Water is applied under pressure through end A, flows

through the pipe, and discharges at end B. Water pressure is measured using piezometer tubes (thin vertical pipes installed at each end of the horizontal pipe). The difference in hydraulic head (between points A and B) is dh (change in height). Divide this by the flow length (i.e. the distance between the two tubes), dl , and you get the hydraulic gradient (I)

The velocity of groundwater is based on hydraulic conductivity (K), as well as the hydraulic head (I). Therefore, the equation determined by Darcy to describe the basic relationship between subsurface materials and the movement of water through them is $Q = KIA$ where Q is the volumetric flow rate (or discharge) and A is the area that the groundwater is flowing through. This relationship is known as Darcy's law.

Now, rearrange the equation to $Q/A = KI$, which is known as the flux (v), which is an apparent velocity. Actual groundwater velocity is lower than that determined by Darcy, and is called Darcy Flux (v_x).

*units - distance/time EX. (m/sec)

$$*v = Q/A = KI$$

*this is a velocity measure and gives the IDEAL velocity of groundwater (assumes that water molecules can flow in a straight line through the subsurface .

*this is ideal because it doesn't account for tortuosity of flow paths (this means that the water molecules actually follow a very windy path in and out of the pore spaces and so travel quite a bit slower in reality than the flux would indicate.

-Darcy Flux

*symbol - v_x

*units - distance/time EX. (m/sec)

$$*v_x = Q/A_n = KI/n$$

*This is the ACTUAL velocity of groundwater and DOES account for tortuosity of flow paths by including porosity in its calculation.

Darcy's law is used extensively in groundwater studies. It can help answer important questions such as what direction an aquifer pollution plume is moving in, and how fast it is travelling. [Click here for an explanatory figure.](#)

5.1.4. Hot springs:

A spring may be the result of karst topography where surface water has infiltrated the Earth's surface (recharge area), becoming part of the area groundwater. The groundwater then travels through a network of cracks and fissure-openings ranging from intergranular spaces to large caves. The water eventually emerges from below the surface, in the form of a karst spring.

The forcing of the spring to the surface can be the result of a confined aquifer in which the recharge area of the spring water table rests at a higher elevation than that of the outlet. Spring water forced to the surface by elevated sources are artesian wells. This is possible even if the outlet is in the form of a 300-foot-deep (91 m) cave. In this case the cave is used like a hose by the higher elevated recharge area of groundwater to exit through the lower elevation opening.

Non-artesian springs may simply flow from a higher elevation through the earth to a lower elevation and exit in the form of a spring, using the ground like a drainage pipe.

Still other springs are the result of pressure from an underground source in the earth, in the form of volcanic activity. The result can be water at elevated temperature such as a hot spring.

Sunrise at Middle Spring, Fish Springs National Wildlife Refuge, Utah

The action of the groundwater continually dissolves permeable bedrock such as limestone and dolomite, creating vast cave systems.

Types of springs

Seepage or filtration spring; the term seep refers to springs with small flow rates in which the source water has filtered through permeable earth.

Fracture springs, discharge from faults, joints, or fissures in the earth, in which springs have followed a natural course of voids or weaknesses in the bedrock. Tubular springs; the water flows from underground caverns.

Spring Flow:

Spring discharge, or resurgence, is determined by the spring's recharge basin. Factors that affect the recharge include the size of the area in which groundwater is captured, the amount of precipitation, the size of capture points, and the size of the spring outlet. Water may leak into the underground system from many sources including permeable earth, sinkholes, and losing streams. In some cases entire creeks seemingly disappear as the water sinks into the ground via the stream bed. Human activity may also affect a spring's discharge--withdrawal of groundwater reduces the water pressure in an aquifer, decreasing the volume of flow.

Classification of spring

Springs are often classified by the volume of the water they discharge. The largest springs are called "first-magnitude," defined as springs that discharge water at a rate of at least 2800 liters or 100 cubic feet (2.8 m³) of water per second. The scale for spring flow is as follows:

Magnitude	Flow (ft ³ /s, gal/min, pint/min)	Flow (L/s)
1 st magnitude	> 100 ft ³ /s	2800 L/s
2 nd magnitude	10 to 100 ft ³ /s	280 to 2800 L/s
3 rd magnitude	1 to 10 ft ³ /s	28 to 280 L/s
4 th magnitude	100 US gal/min to 1 ft ³ /s (448 US gal/min)	6.3 to 28 L/s
5 th magnitude	10 to 100 gal/min	0.63 to 6.3 L/s
6 th magnitude	1 to 10 gal/min	63 to 630 mL/s
7 th magnitude	2 pint to 1 gal/min	8 to 63 mL/s
8 th magnitude	Less than 1 pint/min	8 mL/s

Water content

Minerals become dissolved in the water as it moves through the underground rocks. This may give the water flavor and even carbon dioxide bubbles, depending on the nature of the geology through which it passes. This is why spring water is often bottled and sold as mineral water, although the term is often the subject of deceptive advertising. Springs that contain significant amounts of minerals are sometimes called 'mineral springs'. Springs that contain large amounts of dissolved sodium salts, mostly sodium carbonate, are called 'soda springs'. Many resorts have developed around mineral springs and are known as spa towns.

Water from springs is usually clear. However some springs may be colored by the minerals that are dissolved in the water. Iron and tannins often give spring water an orange color.

A stream carrying the outflow of a spring to a nearby primary stream is called a spring branch or run. Groundwater tends to maintain a relatively long-term average temperature of its aquifer; so flow from a spring may be cooler than a summer day, but remain unfrozen in the winter. The cool water of a spring and its branch may harbor species such as certain trout that are otherwise ill-suited to a warmer local climate.

Uses

Springs have been used for a variety of human needs including drinking water, domestic water supply, irrigation, mills, navigation, and electricity generation. Other modern uses include recreational activities such as fishing, swimming, and floating; therapy; water for livestock; fish hatcheries; and supply for bottled mineral water.

Sacred springs

A sacred spring, or holy well, is a small body of water emerging from underground and revered either in a pagan or a Christian context, often both. The lore and mythology of ancient Greece was replete with sacred and storied springs—notably, the Corycian, Pierian and Castalian. In medieval Europe, holy wells were frequently pagan sacred sites that later became Christianized. The term "holy well" is commonly employed to refer to any water source of limited size (i.e. not a lake or river, but including pools and natural springs and seeps), which has some significance in the folklore of the local area. This can take the form of a

particular name, an associated legend, the attribution of healing qualities to the water through the numinous presence of its guardian spirit or Christian saint, or a ceremony or ritual centred on the well site. In Christian legend, the spring water is often said to have been made to flow by the action of a saint, a familiar theme especially in the hagiography of Celtic saints.

5.1.5. Groundwater Well

Basically, a well is a hole drilled into the ground to access water contained in an aquifer. A pipe and a pump are used to pull water out of the ground, and a screen filters out unwanted particles that could clog the pipe. Wells come in different shapes and sizes, depending on the type of material the well is drilled into and how much water is being pumped out.

Three Basic Types of Wells

Bored or shallow wells are usually bored into an unconfined water source, generally found at depths of 100 feet or less.

Consolidated or rock wells are drilled into a formation consisting entirely of a natural rock formation that contains no soil and does not collapse. Their average depth is about 250 feet.

Unconsolidated or sand wells are drilled into a formation consisting of soil, sand, gravel or clay material that collapses upon it.

Well Construction

All private well construction is based on establishing the right location for the well, sizing the system correctly and choosing the proper construction techniques. Only professional water well contractors should install wells. They are familiar with the hydrology in an area and all local codes and regulations. Proper well construction is key to operating and maintaining a well.

A well is composed of many components. The most important materials used include:

Casing is used to maintain an open access in the earth while not allowing any entrance or leakage into the well from the surrounding formations.

The most popular materials used for casing are black steel, galvanized steel, PVC pipe and concrete pipe.

Grout is a sealant that is used to fill in the spaces around the outside of the well. It protects the well against the intrusion of contaminants. A grout mixture can be made of cement, bentonite, or concrete (each used separately).

Screen keeps sand and gravel out of the well while allowing groundwater and water from formations to enter into the well. Screen is available in many materials, the most popular being stainless steel and slotted PVC pipe. Screen is used when wells are drilled into unconsolidated materials.

Gravel pack is placed around the outside of the screen to prevent sand from entering the well or clogging the screen and to stabilize the well assembly.

Well Contamination

A well can easily be contaminated if it is not properly constructed or if toxic materials are released into the well. Toxic material spilled or dumped near a well can leach into the aquifer and contaminate the groundwater drawn from that well. Contaminated wells used for drinking water are especially dangerous. Wells can be tested to see what chemicals, pathogens and other contaminants may be in the well and if they are present in dangerous quantities.

5.1.6. Problems associated with groundwater withdrawal

a. Overuse and Depletion

Groundwater is the largest source of usable, fresh water in the world. In many parts of the world, especially where surface water supplies are not available, domestic, agricultural, and industrial water needs can only be met by using the water beneath the ground.

Groundwater depletion is primarily caused by sustained groundwater pumping. Some of the negative effects of groundwater depletion:

b. Lowering of the Water Table

Excessive pumping can lower the groundwater table, and cause wells to no longer be able to reach groundwater.

c. Increased Costs

As the water table lowers, the water must be pumped farther to reach the surface, using more energy. In extreme cases, using such a well can be cost prohibitive.

d. Reduced Surface Water Supplies

Groundwater and surface water are connected. When groundwater is overused, the lakes, streams, and rivers connected to groundwater can also have their supply diminished.

e. Land Subsidence

Land subsidence occurs when there is a loss of support below ground. This is most often caused by human activities, mainly from the overuse of groundwater, when the soil collapses, compacts, and drops.

5.1.7. Groundwater pollution

Over 50% of the United States population depends on groundwater for drinking water. Groundwater is also one of our most important sources of water for irrigation. Unfortunately, groundwater is susceptible to pollutants.

Groundwater contamination occurs when man-made products such as gasoline, oil, road salts and chemicals get into the groundwater and cause it to become unsafe and unfit for human use.

Materials from the land's surface can move through the soil and end up in the groundwater. For example, pesticides and fertilizers can find their way into groundwater supplies over time. Road salt, toxic substances from mining sites, and used motor oil also may seep into groundwater. In addition, it is possible for untreated waste from septic tanks and toxic chemicals from underground storage tanks and leaky landfills to contaminate groundwater.

- **Dangers of Contaminated Groundwater**

Drinking contaminated groundwater can have serious health effects. Diseases such as hepatitis and dysentery may be caused by contamination from septic tank waste. Poisoning may be caused by toxins that have leached into well water supplies. Wildlife can also be harmed by contaminated groundwater. Other long term effects such as certain types of cancer may also result from exposure to polluted water.

- **Potential Sources of Groundwater Contamination**

a. Storage Tanks

May contain gasoline, oil, chemicals, or other types of liquids and they can either be above or below ground. There are estimated to be over 10 million storage tanks buried in the United States and over time the tanks can corrode, crack and develop leaks. If the contaminants leak out and get into the groundwater, serious contamination can occur.

b. Septic Systems

Onsite wastewater disposal systems are used by homes, offices or other buildings that are not connected to a city sewer system. Septic systems are designed to slowly drain away human waste underground at a slow, harmless rate. An improperly designed, located, constructed, or maintained septic system can leak bacteria, viruses, household chemicals, and other contaminants into the groundwater causing serious problems.

c. Uncontrolled Hazardous Waste

Hazardous waste sites can lead to groundwater contamination if there are barrels or other containers laying around that are full of hazardous materials. If there is a leak, these contaminants can eventually make their way down through the soil and into the groundwater.

d. Landfills

Landfills are the places that our garbage is taken to be buried. Landfills are supposed to have a protective bottom layer to prevent contaminants from getting into the water. However, if there is no layer or it is cracked, contaminants from the landfill (car battery acid, paint, household cleaners, etc.) can make their way down into the groundwater.

e. Chemicals and Road Salts

The widespread use of chemicals and road salts is another source of potential groundwater contamination. Chemicals include products used on lawns and farm fields to kill weeds and insects and to fertilize plants, and other products used in homes and businesses. When it rains, these chemicals can seep into the ground and eventually into the water. Road salts are used in the wintertime to put melt ice on roads to keep cars from sliding around. When the ice melts, the salt gets washed off the roads and eventually ends up in the water.

f. Chemical waste

Detergents are relatively mild substances. At the opposite end of the spectrum are highly toxic chemicals such as polychlorinated biphenyls (PCBs). They were once widely used to manufacture electronic circuit boards, but their harmful effects have now been recognized and their use is highly restricted in many countries. Nevertheless, an estimated half million tons of PCBs were discharged into the environment during the 20th century. In a classic example of trans-boundary pollution, traces of PCBs have even been found in birds and fish in the Arctic. They were carried there through the oceans, thousands of miles from where they originally entered the environment. Although PCBs are widely banned, their effects will be felt for many decades because they last a long time in the environment without breaking down.

Another kind of toxic pollution comes from heavy metals, such as lead, cadmium, and mercury. Lead was once commonly used in gasoline (petrol), though its use is now restricted in some countries. Mercury and cadmium are still used in batteries (though some brands now use other metals instead). Until recently, a highly toxic chemical called tributyltin (TBT) was used in paints to protect boats from the ravaging effects of the oceans. Ironically, however, TBT was gradually recognized as a pollutant: boats painted with it were doing as much damage to the oceans as the oceans were doing to the boats.

g. Radioactive waste

People view radioactive waste with great alarm—and for good reason. At high enough concentrations it can kill; in lower concentrations it can cause cancers and other illnesses.

h. Oil pollution

When we think of ocean pollution, huge black oil slicks often spring to mind, yet these spectacular accidents represent only a tiny fraction of all the pollution entering our oceans. Even considering oil by itself, tanker spills are not as significant as they might seem: only 12 percent of the oil that enters the oceans comes from tanker accidents; over 70 percent of oil pollution at sea comes from routine shipping and from the oil people pour down drains on land. However, what makes tanker spills so destructive is the sheer quantity of oil they release at once — in other words, the concentration of oil they produce in one very localized part of the marine environment. The biggest oil spill in recent years (and the biggest ever spill in US waters) occurred when the tanker Exxon Valdez broke up in Prince William Sound in Alaska in 1989. Around 12 million gallons (44 million liters) of oil were released into the pristine wilderness—enough to fill your living room 800 times over! Estimates of the marine animals killed in the spill vary from approximately 1000 sea otters and 34,000 birds to as many as 2800 sea otters and 250,000 sea birds. Several billion salmon and herring eggs are also believed to have been destroyed.

i. Plastics

If you've ever taken part in a community beach clean, you'll know that plastic is far and away the most common substance that washes up with the waves. There are three reasons for this: plastic is one of the most common materials, used for making virtually every kind of manufactured object from clothing to automobile parts; plastic is light and floats easily so it can travel enormous distances across the oceans; most plastics are not biodegradable (they do not break down naturally in the environment), which means that things like plastic bottle tops can survive in the marine environment for a long time. (A plastic bottle can survive an estimated 450 years in the ocean and plastic fishing line can last up to 600 years.)

While plastics are not toxic in quite the same way as poisonous chemicals, they nevertheless present a major hazard to seabirds, fish, and other marine creatures. For example, plastic fishing lines and other debris can strangle or choke fish. (This is sometimes called ghost fishing.) About half of all the world's seabird species are known to have eaten plastic residues. In one study of 450 shearwaters in the North Pacific,

over 80 percent of the birds were found to contain plastic residues in their stomachs. In the early 1990s, marine scientist Tim Benton collected debris from a 2km (1.5 mile) length of beach in the remote Pitcairn islands in the South Pacific. His study recorded approximately a thousand pieces of garbage including 268 pieces of plastic, 71 plastic bottles, and two dolls heads.

j. Atmospheric Contaminants

Since groundwater is part of the hydrologic cycle, contaminants in other parts of the cycle, such as the atmosphere or bodies of surface water, can eventually be transferred into our groundwater supplies.

k. Nutrients

Suitably treated and used in moderate quantities, sewage can be a fertilizer: it returns important nutrients to the environment, such as nitrogen and phosphorus, which plants and animals need for growth. The trouble is, sewage is often released in much greater quantities than the natural environment can cope with. Chemical fertilizers used by farmers also add nutrients to the soil, which drain into rivers and seas and add to the fertilizing effect of the sewage. Together, sewage and fertilizers can cause a massive increase in the growth of algae or plankton that overwhelms huge areas of oceans, lakes, or rivers. This is known as a harmful algal bloom (also known as an HAB or red tide, because it can turn the water red). It is harmful because it removes oxygen from the water that kills other forms of life, leading to what is known as a dead zone. The Gulf of Mexico has one of the world's most spectacular dead zones. Each summer, according to studies by the NOAA, it grows to an area of around 5500 square miles (14,000 square kilometers), which is about the same size as the state of Connecticut.

l. Saline intrusion

The saline water body interface the fresh groundwater and so the salinity rapidly increase specially the area near to the sea and suffering from extra sever pumping.

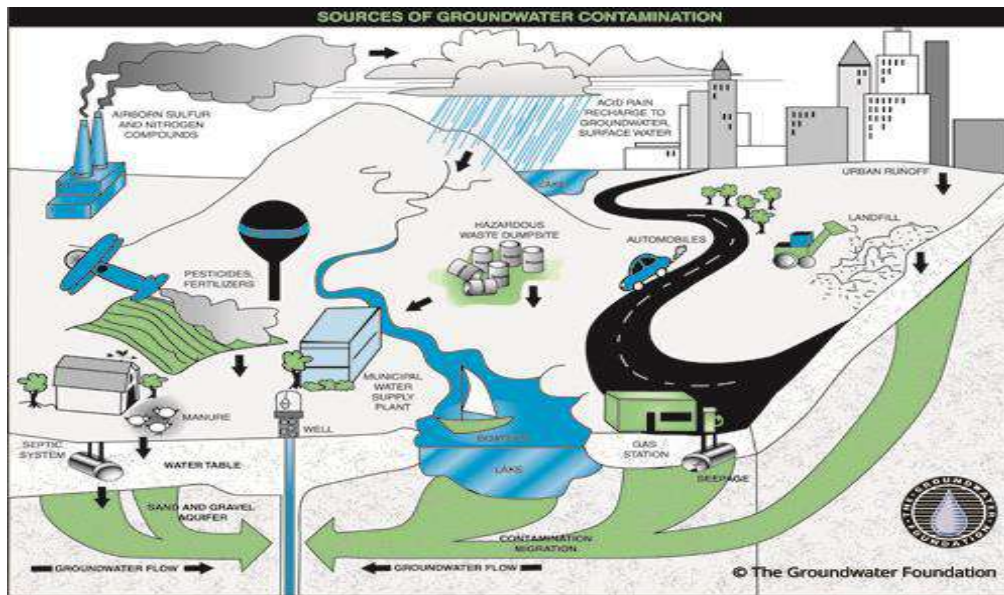


Fig. 2.4: Sources of groundwater contamination

CHAPTER 6

GEOLOGICAL STRUCTURES

6.1. PRIMARY STRUCTURES

Primary Sedimentary structures are those structures formed during sediment deposition. The process of deposition usually imparts variations in layering, bed-forms, or other structures that give clues to environment in which deposition occurs.

6.1.1. Stratification and Bedding

a. Layering (Bedding)

One of the most obvious features of sedimentary rocks and sediment is the layered structure which they exhibit. The layers are evident because of differences in mineralogy, clast size, degree of sorting, or color of the different layers. In rocks, these differences may be made more prominent by the differences in resistance to weathering or color changes brought out by weathering (Figure 6.1).

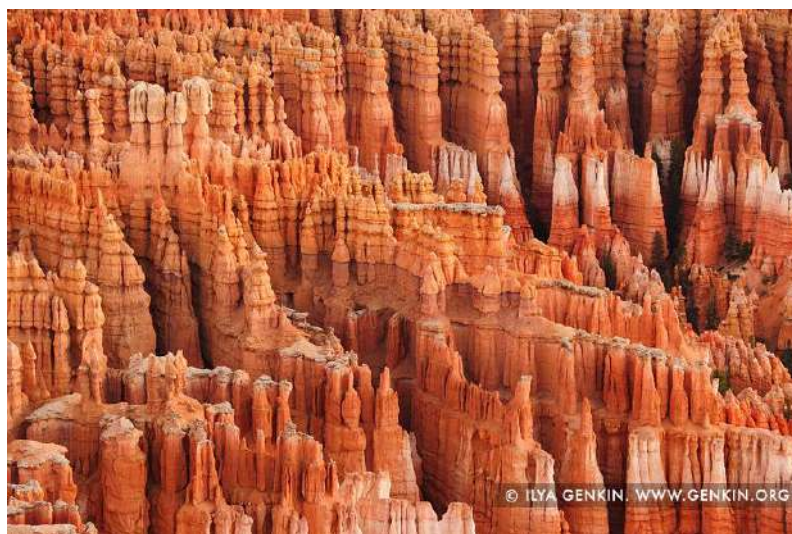


Figure 6.1. Differential erosion of bedding surfaces

b. Graded Bedding

Graded beds display progressive fining of clast/grain size from the base to the top (Figure 6.2), and are a consequence of deposition from turbidity flows. A **turbidity flow** is a cloud of sediment that moves down a slope under water because the density of the sediment-water mixture is greater than that of clean water, and denser liquids sink through less dense liquids. Turbidity flows are triggered by major storms or earthquakes (because of their association with seismicity, the occurrence of turbidities may indicate that the sediment source region was tectonically active). This gives us a method for determining tops and bottoms of beds, since reverse grading will not be expected unless deposition occurs under unusual circumstances.

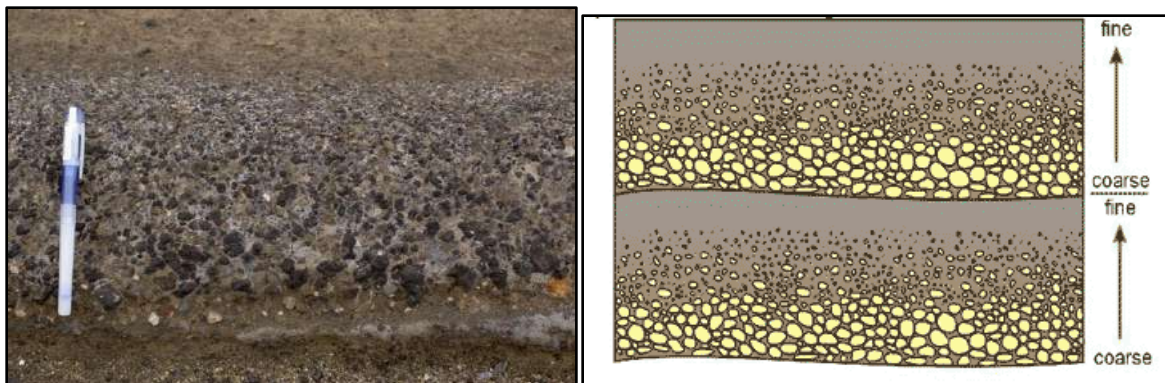


Figure 6.2 Graded bedding in a turbidity sequence (<https://iapedancaptain.wordpress.com>).

c. Cross Bedding

Cross Bedding is sets of beds that are inclined relative to one another (Figure 6.3). The beds are inclined in the direction that the water was moving at the time of deposition. Boundaries between sets of cross beds usually represent an



Figure 6.3. Cross bedding in sandstone.

erosional surface. Cross bedding is very common in beach deposits, sand dunes, and river deposited sediment. Individual beds within cross-bedded strata are useful indicators of current direction and tops and bottoms.

6.1.2. Surface Features

a. Ripple Marks

Ripple marks are characteristic of shallow water deposition. They are caused by waves or winds piling up the sediment into long ridges. Asymmetrical ripple marks can give an indication of current direction when formed in water, and when formed by wind, give wind direction. Symmetrical ripples form when the water moves back and forth. Symmetrical ripple marks occur in environments where there is a steady back and forth movement of the water, such as tidal action (Figure 6.4).

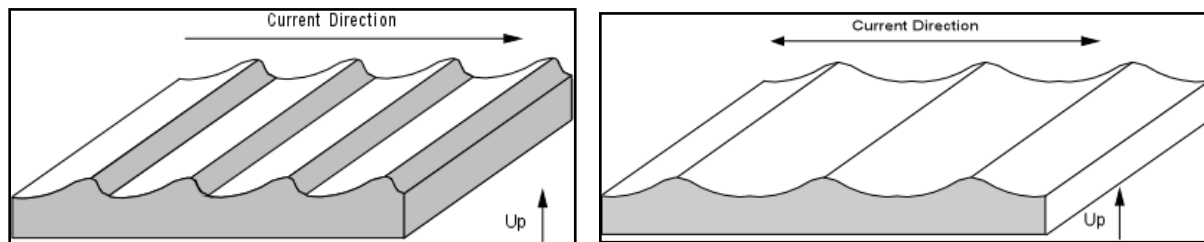


Figure 6.4. Symmetrical and asymmetrical ripple marks

b. MudCracks

These structures result from the drying out of wet sediment at the surface of the Earth. The cracks form due to shrinkage of the sediment as it dries. In cross section the mudcracks tend to curl up, thus becoming a good top/bottom indicator. The presence of mudcracks indicates that the



Figure 6.5. Mudcracks.

sediment was exposed at the surface shortly after deposition, since drying of the sediment would not occur beneath a body of water (Figure 6.5).

6.1.3. Casts and Molds

Any depression formed on the bottom of a body of water may become a mold for any sediment that later gets deposited into the depression. The body of sediment that takes on the shape of the mold is referred to as a cast.

- **Load Casts** - These are bulbous protrusions that are formed when compaction causes sediment to be pushed downward into softer sediment (Figure 6.6a).
- **Flute Casts** (Sole Marks) - Flutes are elongated depressions that form on the bottom of a body water as the current erodes. The flutes may form a mold into which new sediment is deposited. Preservation of the overlying sediment as a cast result in flute casts, which are sometimes referred to as sole marks. Flute casts are excellent indicators of current direction and tops/bottoms of beds (Figure 6.6b).

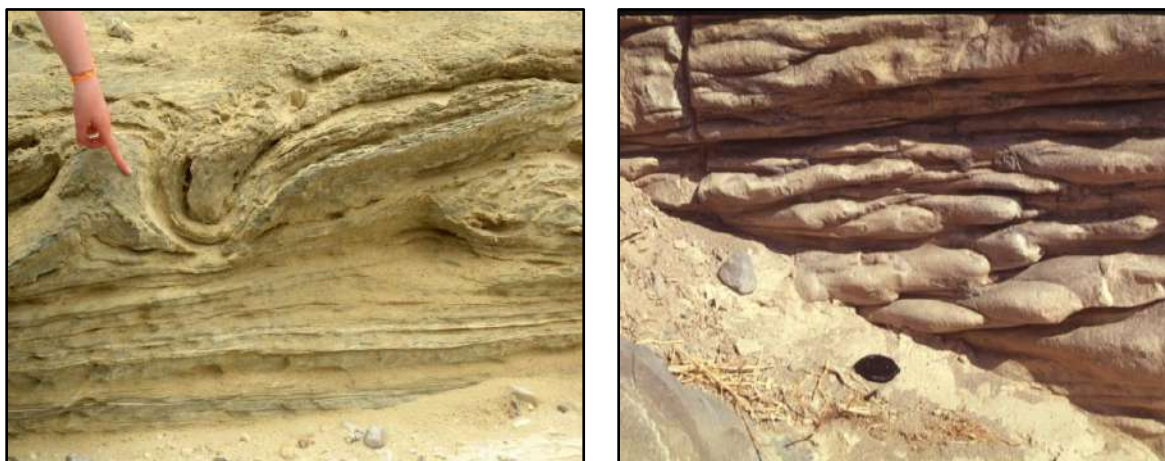


Figure 6.6 a) Load casts.

6.2. ROCK DEFORMATION

Deformation is a word that is used in several ways. It refers to the structural changes that take place in the original location, orientation, shape, and volume of a body of rock. It refers to the physical and

chemical processes that produce the structural changes. And it refers to the geologic structures that form to accommodate the changes. Any body of rock, no matter how hard, will deform if the conditions are right.

A solid body subjected to external forces tends to change its position or its displacement or its shape. During rigid body deformation (**Figure 6.7**), rocks are translated and/or rotated while their original size and shapes are preserved.

If a body absorbs some or all the forces acting on it instead of being moved, the body becomes stressed. The forces then cause particle displacements so that the body changes its shape: it becomes deformed. Strain is the change in shape, or **non-rigid body deformation (Figure 6.8)**, of a rock caused by stresses.

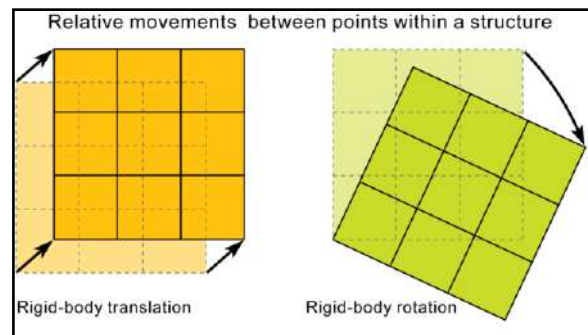


Figure 6.7. Rigid body deformation.

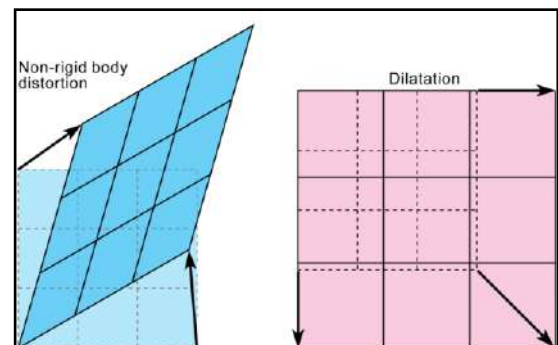


Figure 6.8. Non-rigid body deformation.

There are different kinds of stress that rocks experience, and these determine how the rocks deform (**Figure 6.9**). **Tensional** stress is when rock is stretched apart. This is similar to pulling on a string from both ends after the string has already been fully extended. **Compressional** stress is when rock is pressed together. Here, rocks are squeezed together, like a car caught in the middle of a long pile-up on the highway. **Shear stress** is when rock slips in a horizontal direction. With shear stress, the rock is being pulled in opposite directions but on different ends.

A deformational feature observed on one scale typically reflects processes occurring on other scales. For example, we can't understand continental deformation without understanding mountains, we can't understand mountains without understanding folding and faulting, and we can't understand folding and faulting without understanding ductile and brittle deformation mechanisms at the atomic scale.

As rocks are stressed, they go through stages of deformation. Rocks may become so deformed that the change is not reversible, which is called **ductile**

deformation. Ductile means that something can be changed into a new shape, but once this happens, it stays that way. This is like the copper wiring in your house.

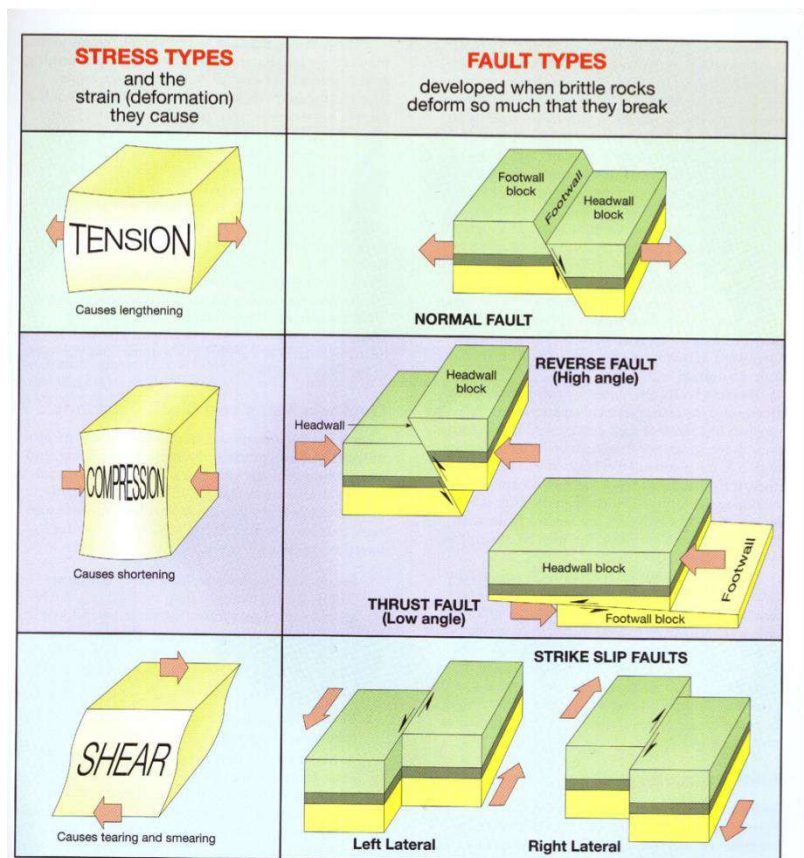


Figure 6.9. The three principal types of stress; A. Compression; B. Tension; C. Shear.

Copper is ductile, meaning you can stretch it into long, thin wires. However, once you've made this change, you can't 'unstretch' it, and the same is true for rocks in this stage of deformation.

If rocks are stressed enough, they fracture, which is when the change is irreversible and the rock breaks, which is called **brittle deformation**. If you fall down hard enough, you may fracture a bone in your body, and rocks experience the same thing when the stress is great enough.

Structural deformation results from stresses (for now, think of "pressures") that exceed rock strength. When strength is exceeded, the rock will fail by brittle (by **fracturing** or **faulting**) or ductile (by **folding**) deformation, depending on how the physical environment has affected the ability of the rock to resist the stresses.

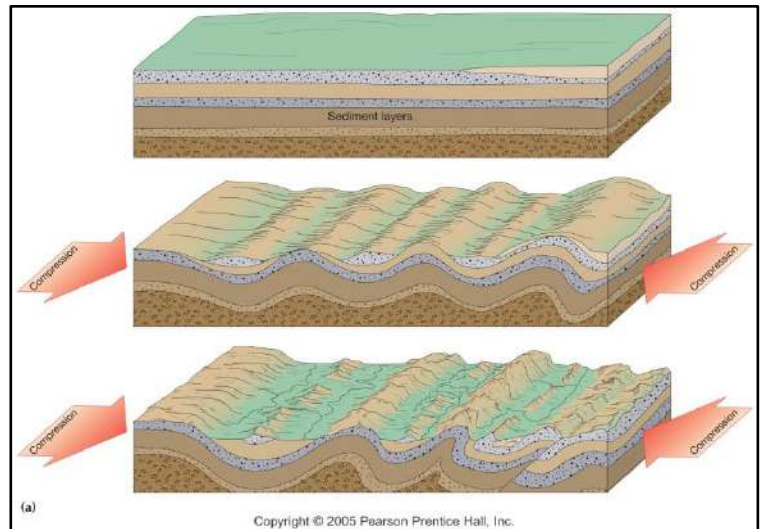
Fractures are planes of separation on which no shear displacement has taken place. They are reasonably continuous and through-going planar fractures, commonly on the scale of centimeters to tens or hundreds of meters in length, along which there has been imperceptible "pull-apart" movement more or less perpendicular to the fracture surface.

A **fault** is a discrete fracture between blocks of rock that have been displaced relative to each other, in a direction parallel to the fracture plane. Faults occur on all scales in the lithosphere, and geologists study them for several reasons.

We describe the shear sense on a dip-slip fault with reference to a horizontal line on the fault, by saying that the movement is **hanging-wall up** or **hanging-wall down** relative to the footwall. Hanging-wall down faults is called **normal faults**, and hanging-wall up faults is called **reverse faults (Figure 6.9)**. To define sense of slip on a strike-slip fault, imagine that you are standing on one side of the fault and

are looking across the fault to the other side. If the opposite wall of the fault moves to your right, the fault is **right-lateral** (or **dextral**), and if the opposite wall of the fault moves to your left, the fault is **left-lateral** (or **sinistral**; **Figure 6.9**).

Folds are wave like structures that produced by deformation of bedding, foliation or other planar surfaces in the rocks. Folds in rocks vary in size from microscopic crinkles to mountain-size folds. They occur singly as isolated folds and in extensive fold trains at all scales. A set of folds distributed on a regional scale constitutes a fold



belt. Fold belts are typically associated with convergent plate boundaries and directed compressive stress (**Figure 6.10**).

A convex-upward fold is an **antiform**; a convex-downward fold is a **synform**. They often come in pairs. The region towards the inner, concave side of a folded layer is the **core** of the fold. **Anticline** and **syncline** are terms with stratigraphic significance. Anticlines are antiforms in which the oldest strata are in the core of the fold. Synclines are synforms in which the youngest strata are in the core (**Figure 6.11**).

An oval-shaped antiform with no distinct trend of the hinge line, in which layering dips outward from a central point, is termed a **dome**, a synform with no distinct trend of hinge line, i.e. in which layering dips inward toward a central point, is a **basin** (**Figure 6.11**).

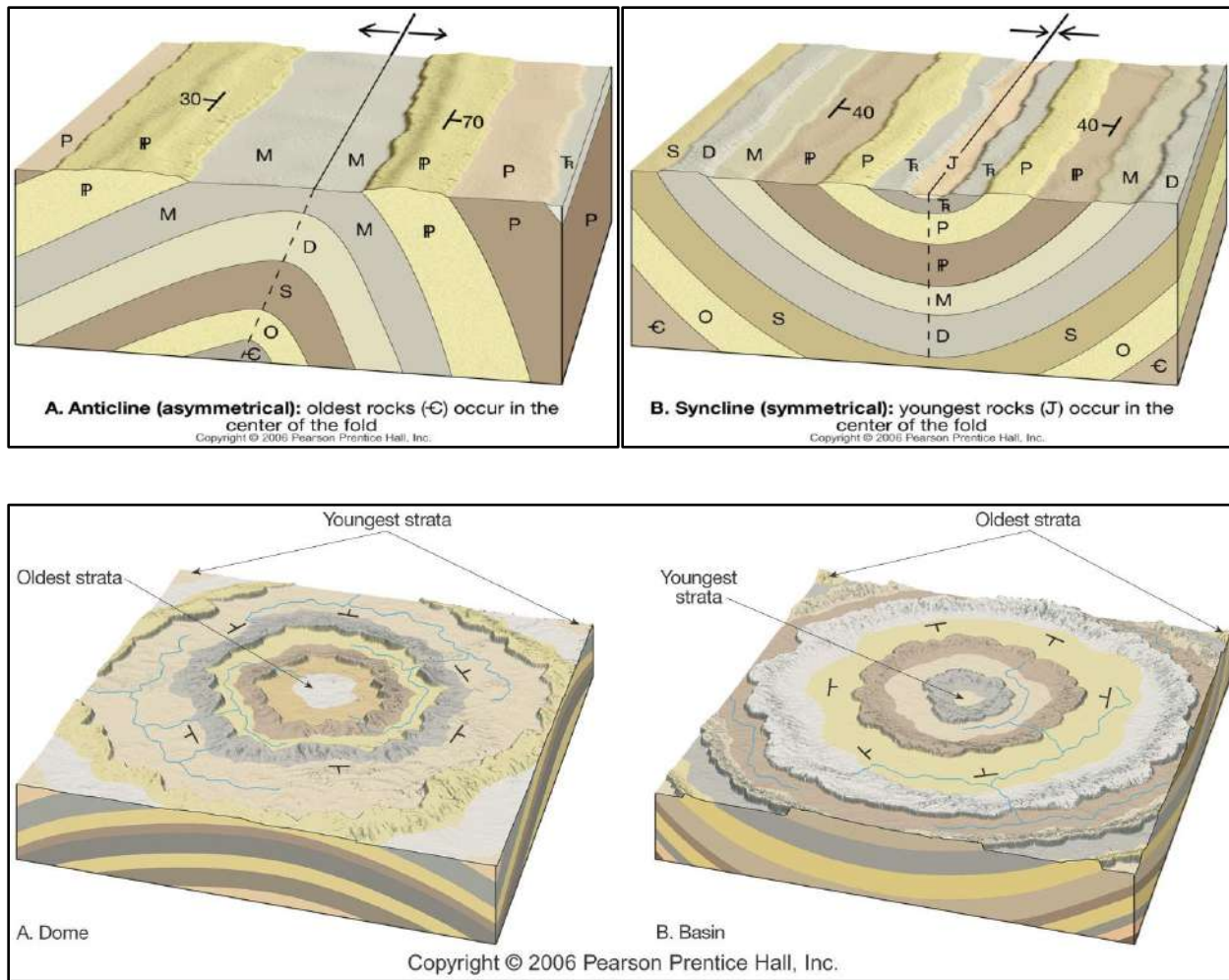


Figure 6.11 Fold Types.

CHAPTER VII

Plutons and Volcanoes

7.1. PLUTONS

In most cases, granitic magma solidifies within the Earth's crust to form a **pluton** (Fig. 7-1). Many granite plutons are large, measuring tens of kilometers in diameter. To form a large pluton, a huge volume of granitic magma must rise through continental

crust. How can such a large mass of magma rise through solid rock? If you place oil and water in a jar, screw the lid on, and shake the jar, oil droplets disperse throughout the water. When you set the jar

down, the droplets coalesce to form larger bubbles, which rise toward the surface, easily displacing the water as they ascend. Granitic magma rises in a similar way. It forms near the base of continental crust, where surrounding rock behaves plastically because it is hot. As the magma rises, it shoulders aside the hot, plastic rock, which then slowly flows back to fill in behind the rising bubble. After a pluton forms, tectonic forces may push it upward, and erosion may expose parts of it at the Earth's surface. A **batholith** is a pluton exposed over more than 100 square kilometers of the Earth's surface (Fig. 7-2). A large

batholith may be as much as 20 kilometers thick, but an average one is about 10 kilometers thick. A **stock** is similar to a batholith but is exposed over less than 100 square kilometers.

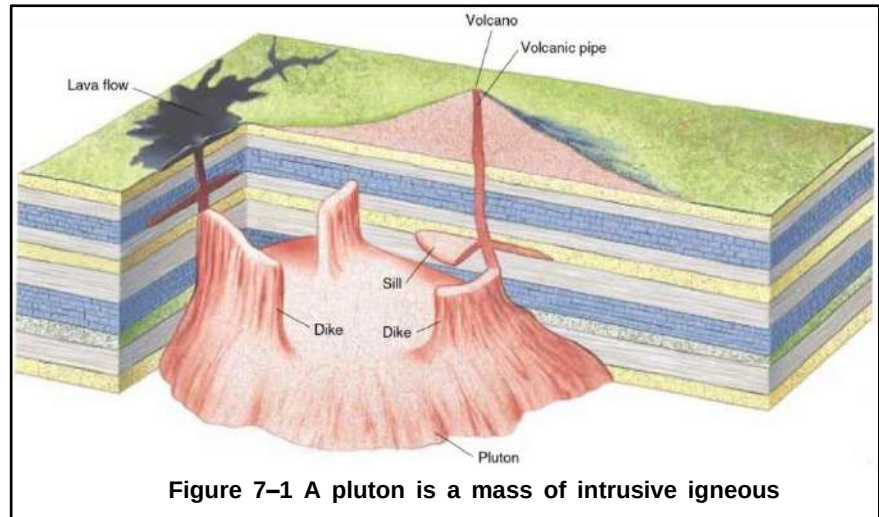


Figure 7-1 A pluton is a mass of intrusive igneous

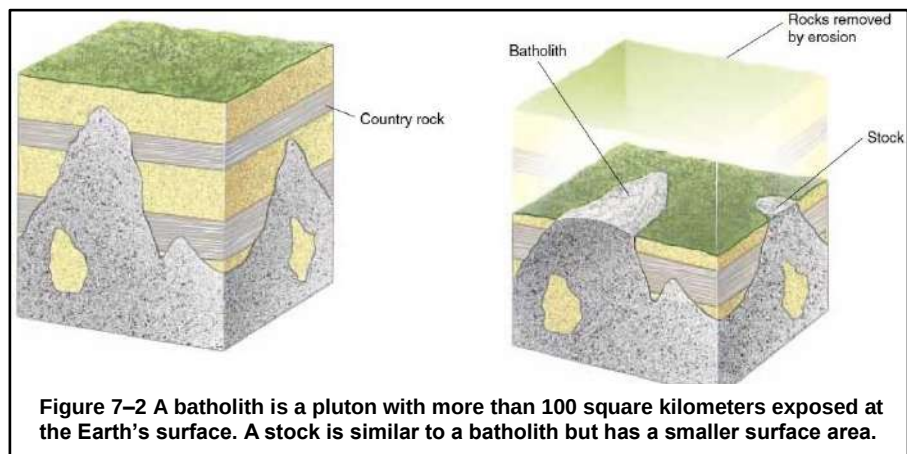
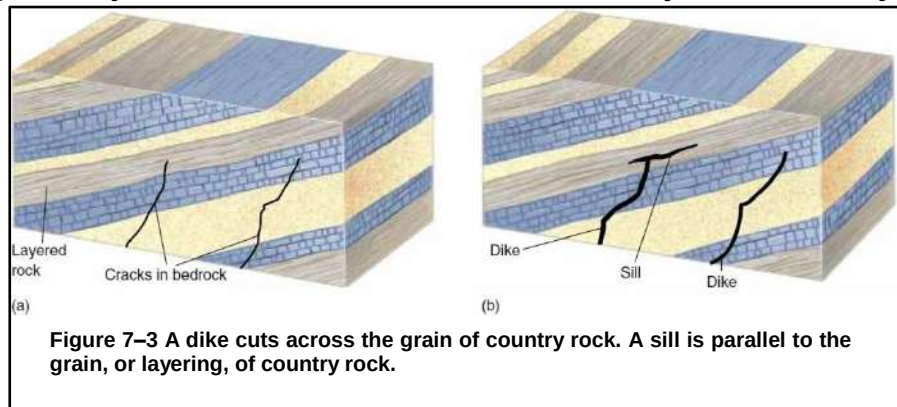
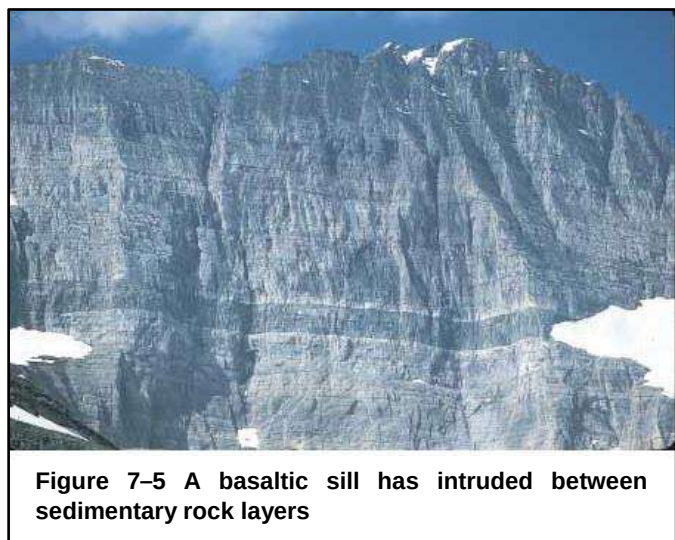


Figure 7-2 A batholith is a pluton with more than 100 square kilometers exposed at the Earth's surface. A stock is similar to a batholith but has a smaller surface area.

A large body of magma pushes country rock aside as it rises. In contrast, a smaller mass of magma may flow into a fracture or between layers in country rock. A **dike** is a tabular, or sheet like, intrusive rock that forms when magma oozes into a fracture (Fig. 7–3). Dikes cut *across* sedimentary layers or other



features in country rock and range from less than a centimeter to more than a kilometer thick (Fig. 7–4a). Dikes commonly occur in parallel or radiating sets called a dike swarm, where magma has intruded a set of fractures. A dike is commonly more resistant to weathering than surrounding rock. As the country rock erodes away, the dike is left standing on the surface (Fig. 7–4b). Magma that oozes between layers of country rock forms a sheetlike rock parallel to the layering, called a **sill** (Fig. 7–5). Like dikes, sills vary in thickness from less than a centimeter to more than a kilometer and may extend for tens of kilometers in length and width.



7.2. VOLCANOES

If lava is too viscous to spread out as a flood, it builds a hill or mountain called a **volcano**. Volcanoes differ widely in shape, structure, and size (Table 5–1). Lava and rock fragments commonly erupt from an opening called a **vent** located in a **crater**, a bowl-like depression at the summit of the volcano (Fig. 7–6). As mentioned previously, lava or



Figure 7–6 Two vents in the crater of Marum volcano, Vanuatu.

pyroclastic material may also erupt from a fissure on the flanks of the volcano. An **active volcano** is one that is erupting or is expected to erupt. A **dormant volcano** is one that is not now erupting but has erupted in the past and will probably do so again. Thus, no clear distinction exists between active and dormant volcanoes. In contrast, an **extinct volcano** is one that is expected never to erupt again.

TYPE OF VOLCANO	FORM OF VOLCANO	SIZE	TYPE OF MAGMA	STYLE OF ACTIVITY	EXAMPLES
Basalt plateau	Flat to gentle slope	100,000 to 1,000,000 km ² in area; 1 to 3 km thick	Basalt	Gentle eruption from long fissures	Columbia River Plateau
Shield volcano	Slightly sloped, 6° to 12°	Up to 9000 m high	Basalt	Gentle, some fire fountains	Hawaii
Cinder cone	Moderate slope	100 to 400 m high	Basalt or andesite	Ejections of pyroclastic material	Parícutín, Mexico
Composite volcano	Alternate layers of flows and pyroclastics	100 to 3500 m high	Variety of types of magmas and ash	Often violent	Vesuvius, Mount St. Helens, Aconcagua
Caldera	Cataclysmic explosion leaving a circular depression called a caldera	Less than 40 km in diameter	Granite	Very violent	Yellowstone, San Juan Mountains

Shield Volcanoes

Fluid basaltic magma often builds a gently sloping mountain called a **shield volcano** (Fig. 7–7). The sides of a shield volcano generally slope away from the vent at angles between 6° and 12° from horizontal. Although their slopes are gentle, shield volcanoes can be enormous. The height of Mauna Kea volcano in

Hawaii, measured from its true base on the sea floor to its top, rivals the height of Mount Everest.

Cinder Cones

A **cinder cone** is a small volcano composed of pyroclastic fragments. A cinder cone forms when large amounts of gas accumulate in rising

magma. When the gas pressure builds up sufficiently, the entire mass erupts explosively, hurling cinders, ash, and molten magma into the air. The particles then fall back around the vent to accumulate as a small mountain of volcanic debris. A cinder cone is usually active for only a short time because once the gas escapes, the driving force behind the eruption is gone. As the name implies, a cinder cone is symmetrical. It also can be steep (about 30°), especially near the vent, where ash and cinders pile up (Fig. 7-8).

Most are less than 300 meters high, although a large one can be up to 700 meters high. A cinder cone erodes easily and quickly because the pyroclastic fragments are not cemented together.



Figure 7-7 Mount Skjoldbreidier in Iceland shows the typical low-angle slopes of a shield volcano.



Figure 7-8 These cinder cones in southern Bolivia are composed of loose pyroclastic fragments.

Composite Cones

Composite cones, sometimes called **stratovolcanoes**, form over a long time by repeated lava flows and pyroclastic eruptions. The hard lava covers the loose pyroclastic material and protects it from erosion (Fig. 7-9). Many of the highest mountains of the Andes and some of the most spectacular mountains of western North America are composite cones. Repeated eruption is a trademark of a composite volcano. Mount St. Helens erupted dozens of times in the 4500 years

preceding its most recent eruption in 1980. Mount Rainier, also in Washington, has been dormant in recent times but could become active again at any moment.

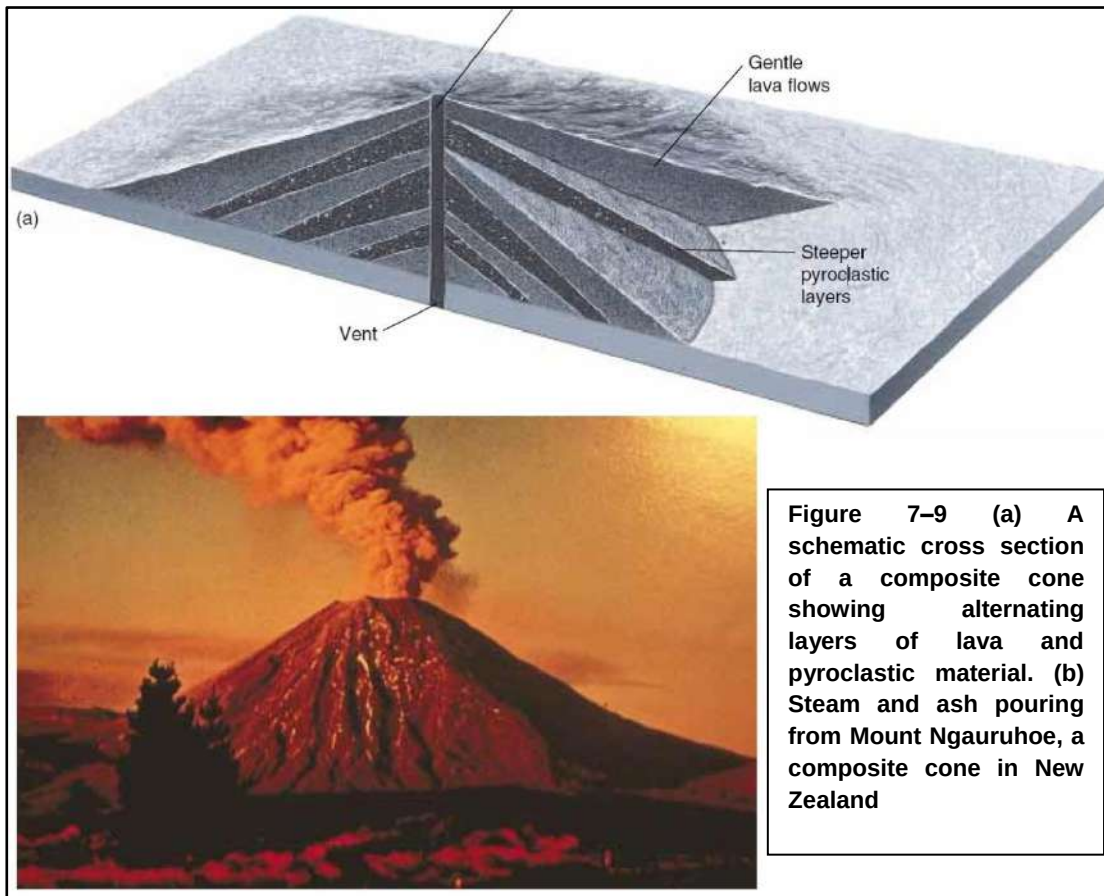


Figure 7-9 (a) A schematic cross section of a composite cone showing alternating layers of lava and pyroclastic material. (b) Steam and ash pouring from Mount Ngauruhoe, a composite cone in New Zealand

Volcanic Necks and Pipes

After a volcano's final eruption, magma remaining in the vent may cool and solidify. This **volcanic neck** is commonly harder than surrounding rock. Given enough time, the slopes of the volcano may erode, leaving only the tower-like neck exposed (Fig. 7-10). In some locations, cylindrical dikes called **pipes** extend from the asthenosphere to the Earth's surface. They are conduits that once carried magma on its way to erupt from a volcano, but they are now filled with solidified magma.

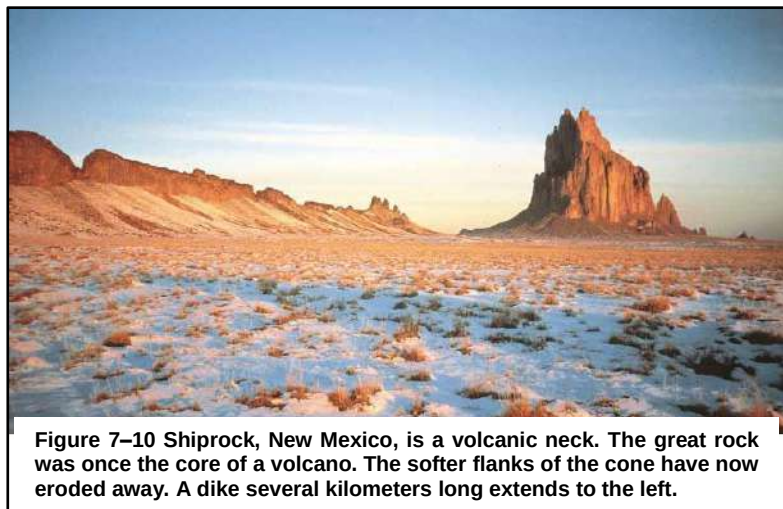


Figure 7-10 Shiprock, New Mexico, is a volcanic neck. The great rock was once the core of a volcano. The softer flanks of the cone have now eroded away. A dike several kilometers long extends to the left.

An unusual type of pipe contains a rock called **kimberlite**, which is the only known source of diamonds. Under asthenosphere pressure, small amounts of carbon found in the mantle crystallize as diamond, but at shallower levels of the Earth carbon forms graphite. If the kimberlite's journey to the surface were slow, the pipes would contain graphite rather than diamonds. Thus, the presence of diamonds suggests that the kimberlite magma shot upward through the lithosphere at very high, perhaps even supersonic, speed. It is thought that high mantle pressure drove the kimberlite magma through the lithosphere at such high speed. Most known pipes formed between 70 and 140 million years ago, and most occur in continental crust older than 2.5 billion years. The most famous diamond-rich kimberlite pipes are located in South Africa, although others are known in Canada's Northwest Territories, Arkansas, and Russia.

7.3. PREDICTING VOLCANIC ERUPTIONS

Approximately 1300 active volcanoes are recognized globally, and 5564 eruptions have occurred in the past 10,000 years. Many volcanoes have erupted recently, and we are certain that others will erupt soon. How can geologists predict an eruption and reduce the risk of a volcanic disaster?

REGIONAL PREDICTION

Volcanoes concentrate near subduction zones, spreading centers, and hot spots and are rare in other places. Thus, the first step in assessing the volcanic hazard of an area is to understand its tectonic environment. Western Washington and Oregon are near a subduction zone and in a region likely to experience future volcanic activity. Kansas and Nebraska are not. Furthermore, the potential violence of a volcanic eruption is related to the environment of the volcano. If an active volcano lies on continental crust, the eruptions may be violent because granitic magma may form. In contrast, if the region lies on oceanic crust, the eruptions may be gentle because basaltic volcanism is more likely. Violent eruptions are likely in Western Washington and Oregon, but less so on Hawaii or Iceland. Risk assessment is based both on frequency of past eruptions and on potential violence. However, regional prediction just outlines probabilities and cannot be used to determine when a particular volcano will erupt or the intensity of a particular eruption.

SHORT-TERM PREDICTION

In contrast to regional predictions, short-term predictions attempt to forecast the specific time and place of an impending eruption. They are based on instruments that monitor an active volcano to detect signals that the volcano is about to

erupt. The signals include changes in the shape of the mountain and surrounding land, earthquake swarms indicating movement of magma beneath the mountain, increased emissions of ash or gas, increasing temperatures of nearby hot springs, and any other signs that magma is approaching the surface. In 1978, two United States Geological Survey (USGS) geologists, Dwight Crandall and Don Mullineaux, noted that Mount St. Helens had erupted more frequently and violently during the past 4500 years than any other volcano in the contiguous 48 states. They predicted that the volcano would erupt again before the end of the century. In March 1980, about two months before the great May eruption, puffs of steam and volcanic ash rose from the crater of Mount St. Helens, and swarms of earthquakes occurred beneath the mountain. This activity convinced USGS geologists that Crandall and Mullineaux's prediction was correct. In response, they installed networks of seismographs, tiltmeters, and surveying instruments on and around the mountain.



Figure 7–11 Eruption of Mount St. Helens, May 18, 1980.

In the spring of 1980, the geologists warned government agencies and the public that Mount St. Helens showed signs of an impending eruption. The U.S. Forest Service and local law enforcement officers quickly evacuated the area surrounding the mountain and averted a much larger tragedy that might have occurred when the mountain exploded (Fig. 7–11). Using similar kinds of information, geologists predicted the 1991 Mount Pinatubo eruption in the Philippines, saving many lives.

REVIEW QUESTIONS

1. Do batholiths and stocks differ chemically or physically, or both chemically and physically?
2. Explain the difference between a dike and a sill.
3. How do a shield volcano, a cinder cone, and a composite cone differ from one another? How are they similar?
4. How does a composite cone form?
5. What is a volcanic neck? How is it formed?

CHAPTER VIII

EARTHQUAKES

8.1. What is an earthquakes?

Earthquakes occur when energy stored in elastically strained rocks is suddenly released. This release of energy causes intense ground shaking in the area near the source of the earthquake and sends waves of elastic energy, called seismic waves, throughout the Earth. Earthquakes can be generated by volcanic eruptions and sudden slippage along faults. Earthquakes are definitely a geologic hazard for those living in earthquake areas, but the seismic waves generated by earthquakes are invaluable for studying the interior of the Earth.

8.2. Seismology, the Study of Earthquakes

When an earthquake occurs, the elastic energy is released and sends out vibrations that travel throughout the Earth. These vibrations are called seismic waves. The study of how seismic waves behave in the Earth is called *seismology*.

8.3. Origin of Earthquakes

Most natural earthquakes are caused by sudden slippage along a fault zone. The ***elastic rebound theory*** suggests that if slippage along a fault is hindered such that elastic strain energy builds up in the deforming rocks on either side of the fault, when the slippage does occur, the energy released causes an earthquake (Fig. 8.1).

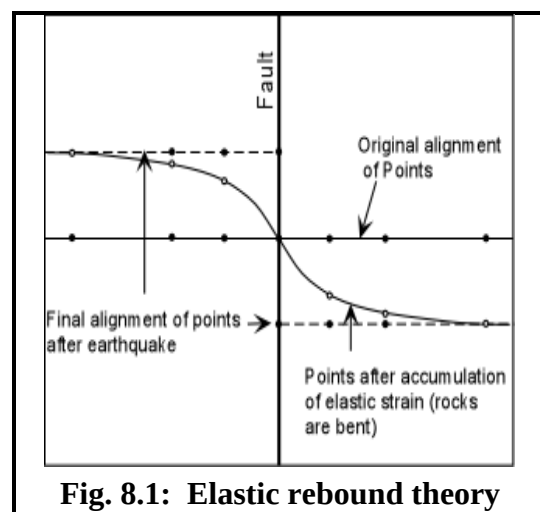


Fig. 8.1: Elastic rebound theory

Prior to an earthquake it is noted that the rocks adjacent to the fault were bending. These bends disappeared after an earthquake suggesting that the energy stored in bending the rocks was suddenly released during the earthquake.

8.4. Seismographs

Seismic waves travel through the Earth as vibrations. A **seismometer** is an instrument used to record these vibrations and the resulting graph that shows the vibrations is called a **seismograph**. The seismometer must be able to move with the vibrations, yet part of it must remain nearly stationary (Fig. 8.2).

This is accomplished by isolating the recording device (like a pen) from the rest of the Earth using the principal of inertia. For example, if the pen is attached to a large mass suspended by a spring, the spring and the large mass move less than the paper which is attached to the Earth, and on which the record of the vibrations is made.

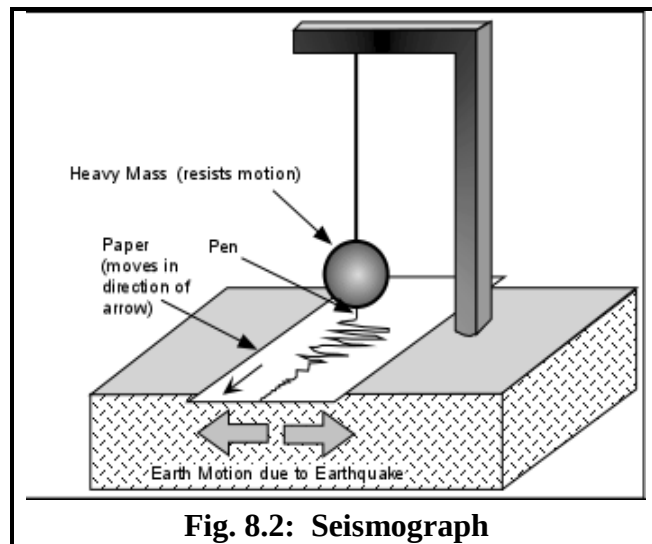


Fig. 8.2: Seismograph

8.5. Earthquake focus

The source of an earthquake is called the **focus**, which is an exact location within the Earth where seismic waves are generated by sudden release of stored elastic energy (Fig. 8.3).

The **epicenter** is the point on the surface of the Earth directly above the focus. Sometimes the media get these two terms confused. Seismic waves emanating from the focus can travel in several ways, and thus there are several different kinds of seismic waves.

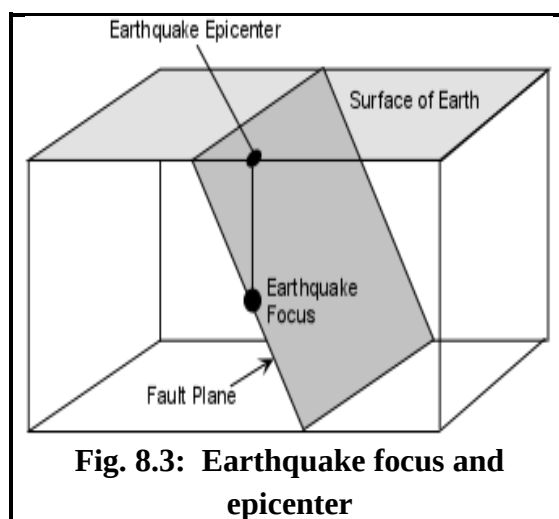


Fig. 8.3: Earthquake focus and epicenter

8.6. Types of seismic waves

• **Body Waves** - emanate from the focus and travel in all directions through the body of the Earth. There are two types of body waves:

- 1- **P - waves** - are Primary waves. They travel with a velocity that depends on the elastic properties of the rock through which they travel. P-waves are the same thing as sound waves. They move through the material by compressing it, but after it has been compressed it expands, so that the wave moves by compressing and expanding the material as it travels. P-waves have the highest velocity of all seismic waves and thus will reach seismographs first (Fig. 8.4).
- 2- **S-Waves** - Secondary waves, also called shear waves. They travel with a velocity that depends only on the rigidity and density of the material through which they travel. S-waves travel through material by shearing it or changing its shape in the direction perpendicular to the direction of travel. The resistance to shearing of a material is the property called the rigidity. It is notable that liquids have no rigidity, so that the velocity of an S-wave is zero in a liquid. Note that S-waves travel slower than P-waves, so they will reach a seismograph after the P-wave (Fig. 8.4).

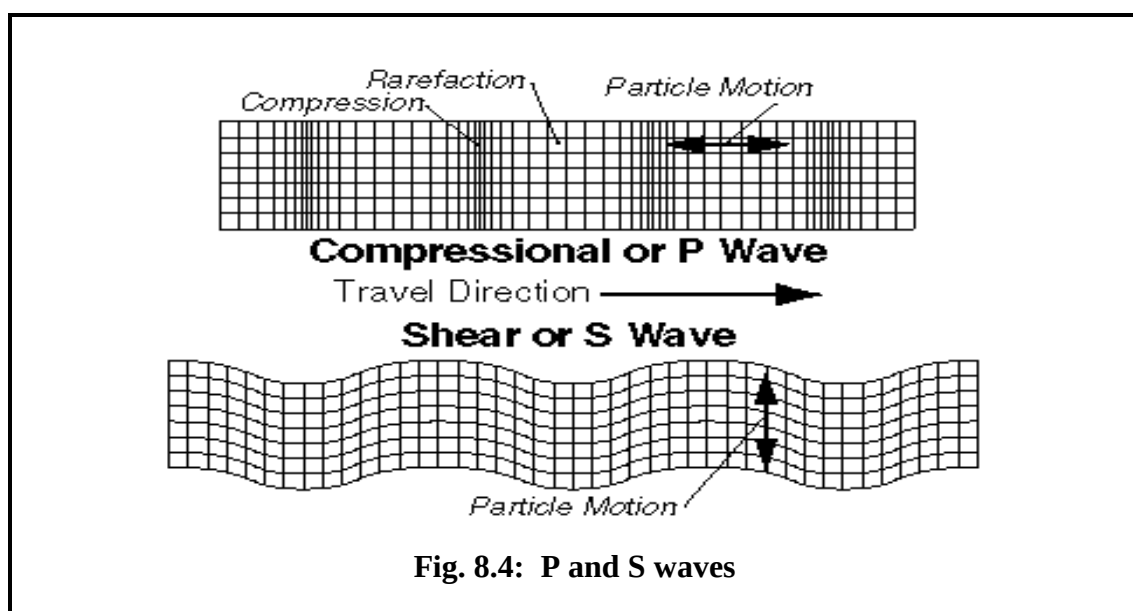


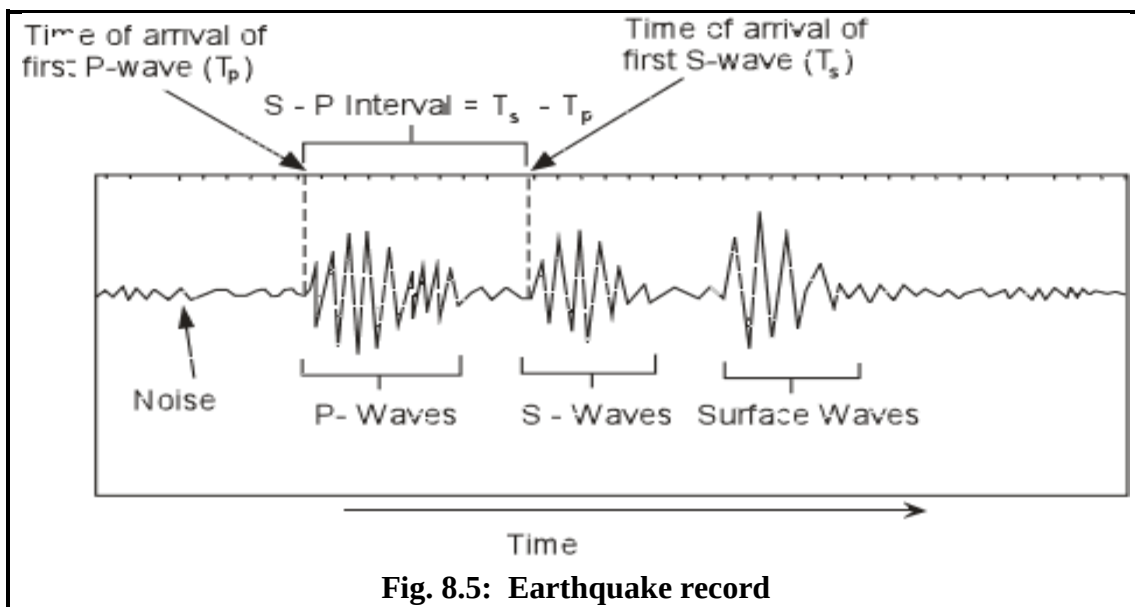
Fig. 8.4: P and S waves

- **Surface Waves** – Surface waves differ from body waves in that they do not travel through the Earth, but instead travel along paths nearly

parallel to the surface of the Earth. Surface waves behave like S-waves in that they cause up and down and side to side movement as they pass, but they travel slower than S-waves and do not travel through the body of the Earth.

8.7. Earthquake Record

The record of an earthquake, a seismograph, as recorded by a seismometer, will be a plot of vibrations versus time (Fig. 3.5). On the seismograph, time is marked at regular intervals, so that we can determine the time of arrival of the first P-wave and the time of arrival of the first S-wave. (Note again, that because P-waves have a higher velocity than S-waves, the P-waves arrive at the seismographic station before the S-waves).



8.8. Location of Earthquakes

In order to determine the location of an earthquake, we need to have recorded a seismograph of the earthquake from at least three seismographic stations at different distances from the epicenter of the quake. In addition, we need one further piece of information - that is the time it takes for P-waves and S-waves to travel through the Earth and arrive at a seismographic station.

From the seismographs at each station one determines the S-P interval (the difference in the time of arrival of the first S-wave and the time of arrival of the first P-wave). Note that on the travel time curves, the S-P

interval increases with increasing distance from the epicenter. Thus the S-P interval tells us the distance to the epicenter from the seismographic station where the earthquake was recorded (Fig. 8.6-A).

At each station we can draw a circle on a map that has a radius equal to the distance from the epicenter. Three such circles will intersect in a point that locates the epicenter of the earthquake (Fig. 8.6-B).

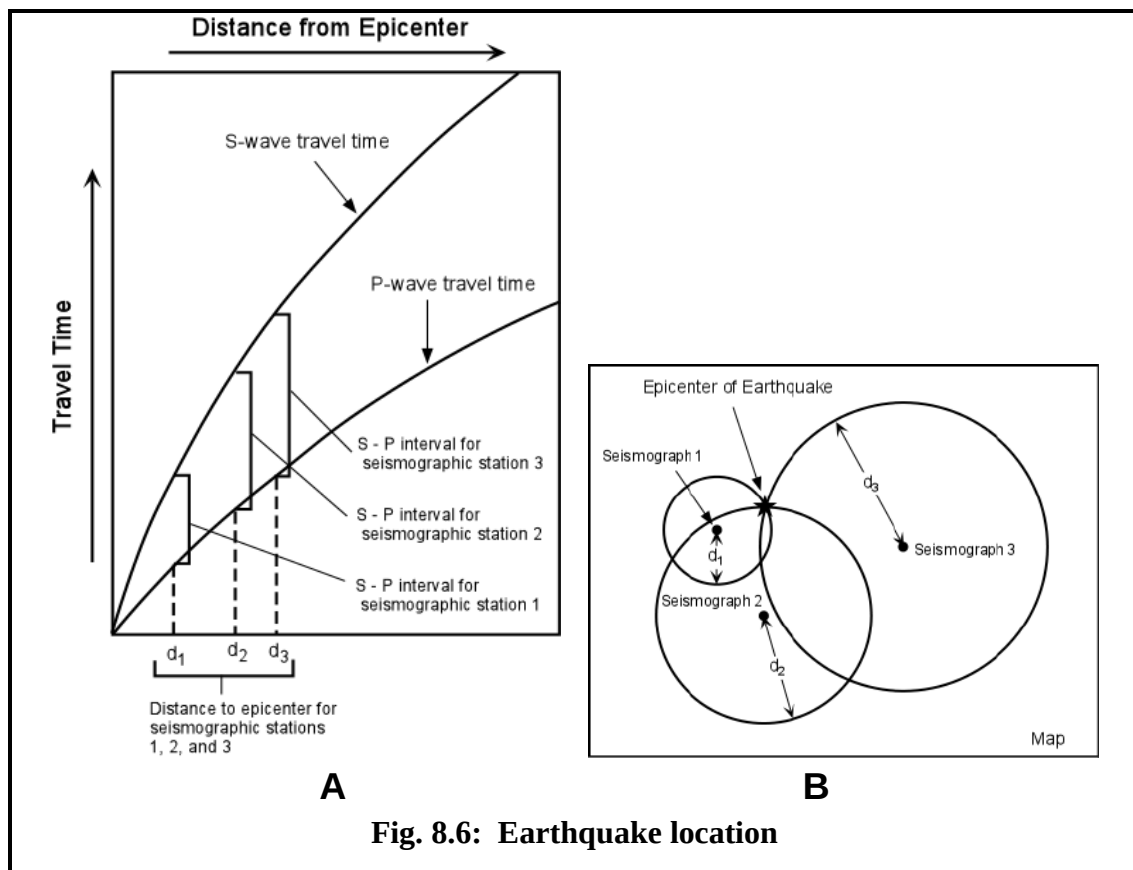


Fig. 8.6: Earthquake location

8.9. Magnitude of Earthquakes

Whenever a large destructive earthquake occurs in the world the press immediately wants to know where the earthquake occurred and how big the earthquake was. The size of an earthquake is usually given in terms of a scale called the **Richter** Magnitude. Richter Magnitude is a scale of earthquake size developed by a seismologist named Charles F. Richter. The Richter Magnitude involves measuring the amplitude (height) of the largest recorded wave at a specific distance from the earthquake.

8.10. Earthquake Damage

Many seismologists have said that "earthquakes don't kill people, buildings do". This is because most deaths from earthquakes are caused

by buildings or other human construction falling down during an earthquake. Earthquakes located in isolated areas far from human population rarely cause any deaths. Thus, in earthquake prone areas there are strict building codes requiring the design and construction of buildings and other structures that will withstand a large earthquake. Damage from earthquakes can be classified as follows:

- **Ground Shaking** - Shaking of the ground caused by the passage of seismic waves near the epicenter of the earthquake is responsible for the collapse of most structures. The intensity of ground shaking depends on distance from the epicenter and on the type of bedrock underlying the area.
 - In general, loose unconsolidated sediment is subject to more intense shaking than solid bedrock.
 - Damage to structures from shaking depends on the type of construction. Concrete and masonry structures, because they are brittle are more susceptible to damage than wood and steel structures, which are more flexible.
- **Ground Rupture** - Ground rupture only occurs along the fault zone that moves during the earthquake. Thus structures that are built across fault zones may collapse, whereas structures built adjacent to, but not crossing the fault may survive.
- **Fire** - Fire is a secondary effect of earthquakes. Because power lines may be knocked down and because natural gas lines may rupture due to an earthquake, fires are often started closely following an earthquake. The problem is compounded if water lines are also broken during the earthquake since there will not be a supply of water to extinguish the fires once they have started. In the 1906 earthquake in San Francisco more than 90% of the damage to buildings was caused by fire.
- **Rapid Mass-Wasting Processes** - In mountainous regions subjected to earthquakes ground shaking may trigger rapid mass-wasting events like rock and debris falls, rock and debris slides, slumps, and debris avalanches.
- **Liquefaction** - is a process that occurs in water-saturated unconsolidated sediment due to shaking. In areas underlain by such

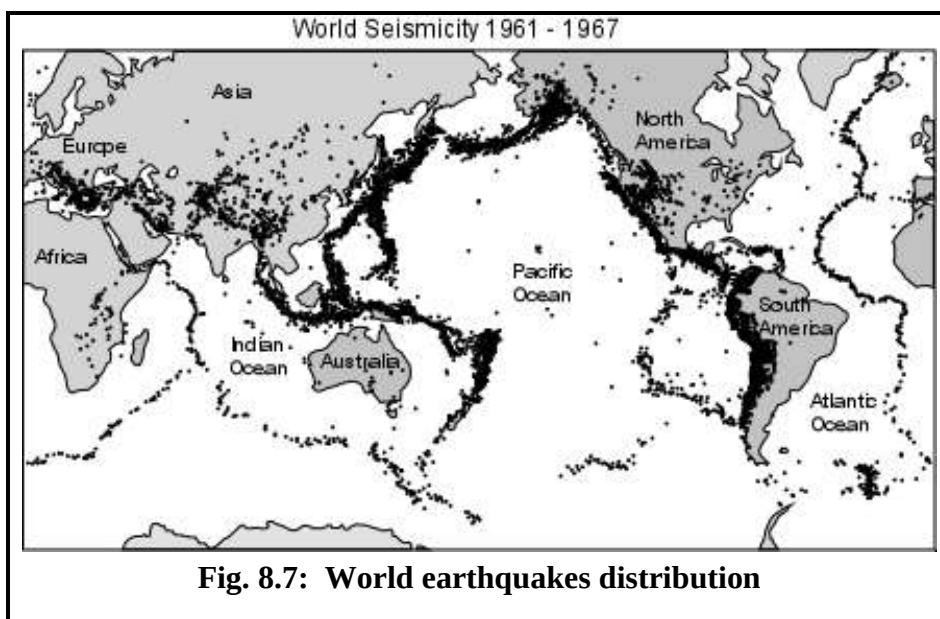
material, the ground shaking causes the grains to lose grain to grain contact, and thus the material tends to flow.

- **Tsunamis** - Tsunamis are giant ocean waves that can rapidly travel across oceans, as we discussed in the Oceans and Their Margins. Earthquakes that occur along coastal areas can generate tsunamis, which can cause damage thousands of kilometers away on the other side of the ocean.

8.11. World Distribution of Earthquakes

The distribution of earthquakes is referred to as **seismicity**. Most earthquakes occur along relatively narrow belts that coincide with plate boundaries (Fig. 8.7).

This makes sense, since plate boundaries are zones along which lithospheric plates move relative to one another. Earthquakes along these zones can be divided into shallow focus earthquakes that have focal depths less than about 70 km and deep focus earthquakes that have focal depths between 75 and 700 km.



- **Earthquakes at Diverging Plate Boundaries.**

Diverging plate boundaries are zones where two plates move away from each other, such as at oceanic ridges. In such areas the lithosphere is in a state of tensional stress and thus normal faults and rift valleys occur. Earthquakes that occur along such boundaries show normal fault

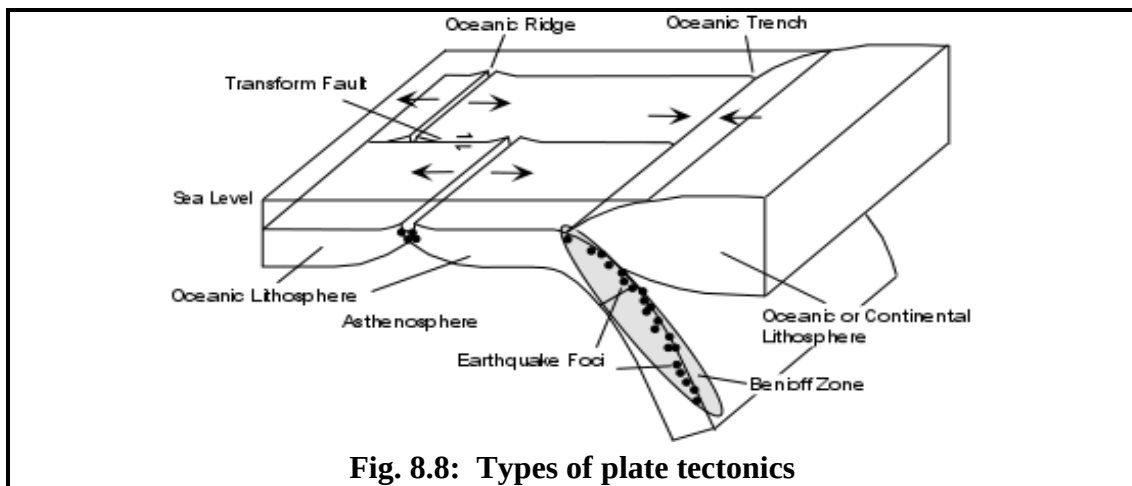
motion and tend to be shallow focus earthquakes, with focal depths less than about 20 km. Such shallow focal depths indicate that the brittle lithosphere must be relatively thin along these diverging plate boundaries (Fig. 8.8).

- **Earthquakes at Transform Fault Boundaries.**

Transform fault boundaries are plate boundaries where lithospheric plates slide past one another in a horizontal fashion. The San Andreas Fault of California is one of the longer transform fault boundaries known. Earthquakes along these boundaries show strike-slip motion on the faults and tend to be shallow focus earthquakes with depths usually less than about 50 km.

- **Earthquakes at Converging Plate Boundaries**

Convergent plate boundaries are boundaries where two plates run into each other. Thus, they tend to be zones where compressional stresses are active and thus reverse faults or thrust faults are common. There are two types of converging plate boundaries. (1) subduction boundaries, where oceanic lithosphere is pushed beneath either oceanic or continental lithosphere; and (2) collision boundaries where two plates with continental lithosphere collide.



- **Subduction boundaries**

At subduction boundaries cold oceanic lithosphere is pushed back down into the mantle where two plates converge at an oceanic trench. Because the sub ducted lithosphere is cold it remains brittle as it descends and thus can fracture under the compressional stress. When it fractures, it generates earthquakes that define a zone of earthquakes

with increasing focal depths beneath the overriding plate. This zone of earthquakes is called the **Benioff Zone**. Focal depths of earthquakes in the Benioff Zone can reach down to 700 km.

8.12. The Earth's Internal Structure

Much of what we know about the interior of the Earth comes from knowledge of seismic wave velocities and their variation with depth in the Earth.

Over the years seismologists have collected data on how seismic wave velocities vary with depth in the Earth. Distinct boundaries, called discontinuities are observed when there is sudden change in physical properties or chemical composition of the Earth. From these discontinuities, we can deduce something about the nature of the various layers in the Earth. As we discussed way back at the beginning of the course, we can look at the Earth in terms of layers of differing chemical composition, and layers of differing physical properties.

- **Layers of Differing Composition**

The Crust - Mohorovicic discovered the boundary between crust and mantle, thus it is named the **Mohorovicic Discontinuity** or **Moho**. The composition of the crust can be determined from seismic waves by comparing seismic wave velocities measured on rocks in the laboratory with seismic wave velocities observed in the crust. Then from travel times of waves on many earthquakes from many seismic stations, the thickness and composition of the crust can be inferred (Fig. 8.9).

- In the ocean basins crust is about 8 to 10 km thick, and has a composition that is basaltic.
- Continental crust varies between 20 and 60 km thick. The thickest continental crust occurs beneath mountain ranges and the thinnest beneath lowlands. The composition of continental crust varies from granitic near the top to gabbroic near the Moho.
- The Mantle - Seismic wave velocities increase abruptly at the Moho. In the mantle wave velocities are consistent with a rock composition of peridotite which consists of olivine, pyroxene, and garnet.
- The Core - At a depth of 2900 Km P-wave velocities suddenly decrease and S-wave velocities go to zero. This is the top of the outer

core. As discussed above, the outer core must be liquid since S-wave velocities are 0. At a depth of about 4800 km the sudden increase in P-wave velocities indicate a solid inner core. The core appears to have a composition consistent with mostly Iron with small amounts of Nickel.

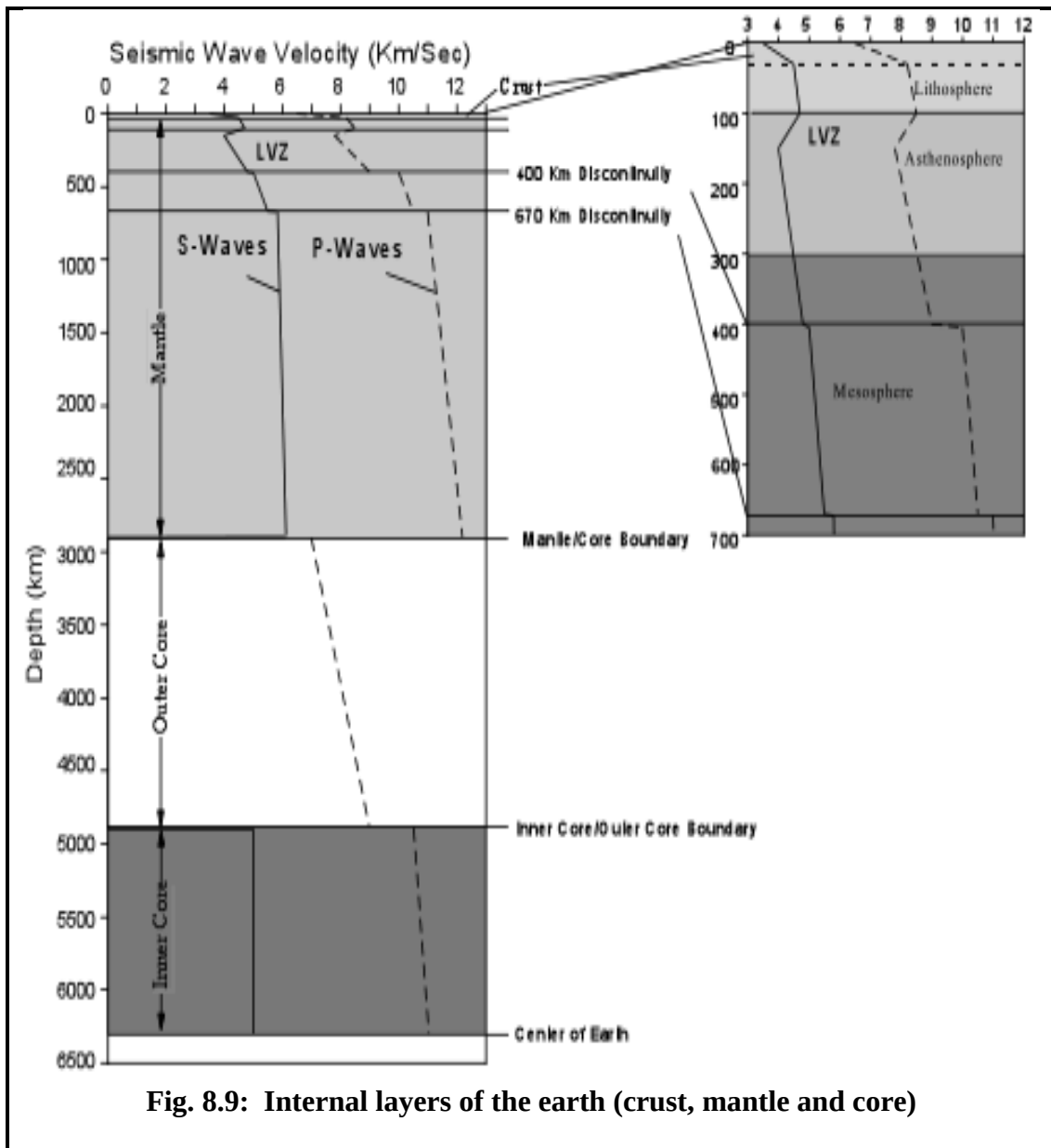


Fig. 8.9: Internal layers of the earth (crust, mantle and core)

- **Layers of Different Physical Properties**

- At a depth of about 100 km there is a sudden decrease in both P and S-wave velocities. This boundary marks the base of the lithosphere and the top of the asthenosphere. The lithosphere is composed of both crust and part of the upper mantle. It is a brittle layer that

makes up the plates in plate tectonics, and appears to float and move around on top of the more ductile asthenosphere.

- At the top of the asthenosphere is a zone where both P- and S-wave velocities are low. This zone is called the **Low-Velocity Zone (LVZ)**. It is thought that the low velocities of seismic waves in this zone are caused by temperatures approaching the partial melting temperature of the mantle, causing the mantle in this zone to behave in a very ductile manner.
- At a depth of 400 km there is an abrupt increase in the velocities of seismic waves, thus this boundary is known as the **400 - Km Discontinuity**.
- Another abrupt increase in seismic wave velocities occurs at a depth of 670 km. It is uncertain whether this discontinuity, known as the **670 Km Discontinuity**, is the result of a polymorphic phase transition involving other mantle minerals or a compositional change in the mantle, or both.

REVIEW QUESTIONS

1. Why do most earthquakes occur at the boundaries between tectonic plates? Are there any exceptions?
2. Define *focus* and *epicenter*.
3. Discuss the differences between P waves, S waves, and surface waves.
4. Discuss earthquake mechanisms at the three different types of tectonic plate boundaries.
5. What is the Moho? How was it discovered?
6. Explain how geologists learned that the core is composed of iron and nickel.

CHAPTER IX

PLATE TECTONIC AND EARTH HISTORY

9.1. Continental drift

The drift of the plates across the surface of the earth has been going on over millions of years, which still changes the outward appearance of the earth. When you look at the map of the world, you see how well the east coast of North and South America fits into the west coast of Europe and Africa. Over millions of years these continents have slowly drifted apart, (Continental drift).

-In the 19th and early 20th centuries, several scientists suggested that the continental masses had the ability to move across the Earth's surface. These early theories of continental drift were based on the following evidence:

-Locations of fossil occurrences suggested that some of the continental masses may have been connected in the geological past.

-Paleoclimatic evidence indicates that now tropical regions on some continents had polar climates in the past. This may indicate that these regions were located at different latitudes.

-Some continents seem to fit together like a jigsaw puzzle.

-Some geologic deposits of rocks on the East coast of North and South America are similar to deposits found on the West coast of Africa and Europe.

By combining the sea floor spreading theory with continental drift and information on global seismicity, the new theory of Plate Tectonics became a coherent theory to explain crustal movements.

Plates are composed of lithosphere, about 100 km thick that "float" on the ductile asthenosphere.

While the continents do indeed appear to drift, they do so only because they are part of larger plates that float and move horizontally on the upper mantle asthenosphere. The plates behave as rigid bodies with some ability to flex, but deformation occurs mainly along the boundaries between plates.

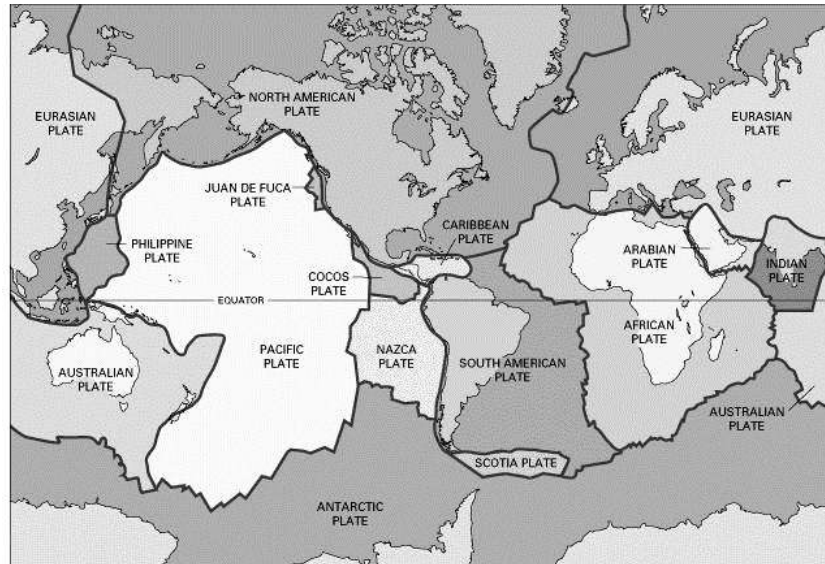


Fig. 9.1: The plate boundaries can be identified because they are zones along which earthquakes occur. Plate interiors have much fewer earthquakes.

The plate boundaries can be identified because they are zones along which earthquakes occur. Plate interiors have much fewer earthquakes.

Plate name	Area 10^6 km^2
<u>African Plate</u> ^[note 10]	78.0
<u>Antarctic Plate</u>	60.9
<u>Indo-Australian Plate</u>	47.2
<u>Eurasian Plate</u>	67.8
<u>North American Plate</u>	75.9
<u>South American Plate</u>	43.6
<u>Pacific Plate</u>	103.3

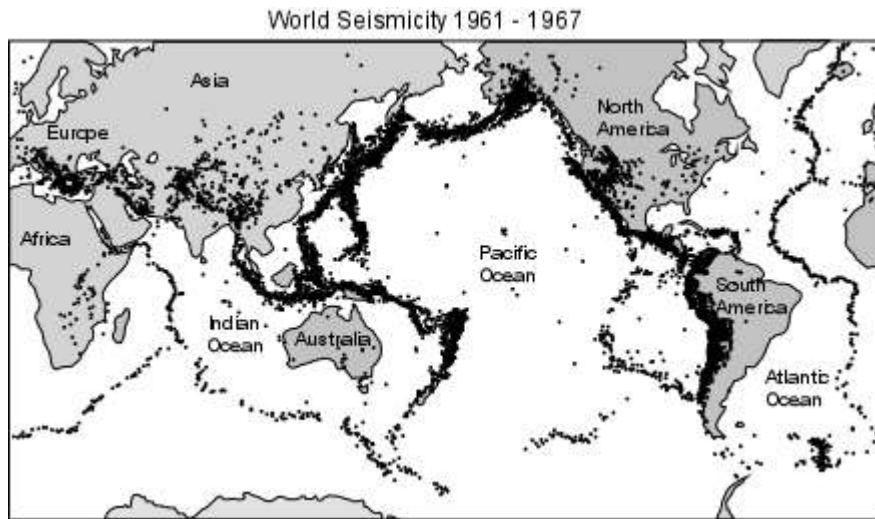


Fig. 9.2: World Seismicity 1961-1967

9.2. Types of Plate Boundaries

There are three types of plate boundaries:

1. Divergent Plate boundaries, where plates move away from each other.
2. Convergent Plate Boundaries, where plates move toward each other.
3. Transform Plate Boundaries, where plates slide past one another.

- **Divergent Plate Boundaries**

These are *oceanic ridges* where new oceanic lithosphere is created by upwelling mantle that melts, resulting in basaltic magmas which intrude and erupt at the oceanic ridge to create new oceanic lithosphere and crust. As new oceanic lithosphere is created, it is pushed aside in opposite directions. Thus, the age of the oceanic crust becomes progressively older in both directions away from the ridge.

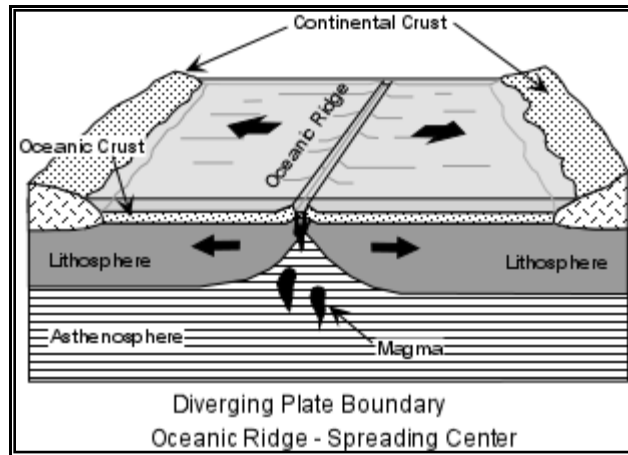


Fig. 9.3: Diverging plate boundary oceanic ridge – spreading center

Because oceanic lithosphere may get subducted, the age of the ocean basins is relatively young. The oldest oceanic crust occurs farthest away from a ridge. In the Atlantic Ocean, the oldest oceanic crust occurs next to the North American and African continents and is about 160 million years old (Jurassic). In the Pacific Ocean, the oldest crust is also Jurassic in age, and occurs off the coast of Japan.

Because the oceanic ridges are areas of young crust, there is very little sediment accumulation on the ridges. Sediment thickness increases in both directions away of the ridge, and is thickest where the oceanic crust is the oldest.

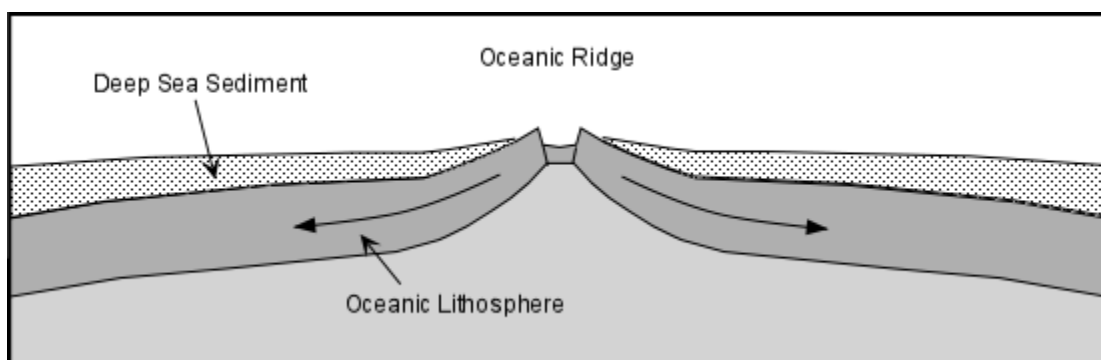


Fig. 9.4: Sea floor spreading topography and the oceanic lithosphere

Knowing the age of the crust and the distance from the ridge, the relative velocity of the plates can be determined. (Absolute velocity requires further information to be discussed later).

Relative plate velocities vary both for individual plates and for different plates.

Sea floor topography is controlled by the age of the oceanic lithosphere and the rate of spreading.

If the spreading rate (relative velocity) is high, magma must be rising rapidly and the lithosphere is relatively hot beneath the ridge. Thus for fast spreading centers the ridge stands at higher elevations than for slow spreading centers. The rift valley at fast spreading centers is narrower than at slow spreading centers. As oceanic lithosphere moves away from the ridge, it cools and sinks deeper into the asthenosphere. Thus, the depth to the sea floor increases with increasing age away from the ridge.

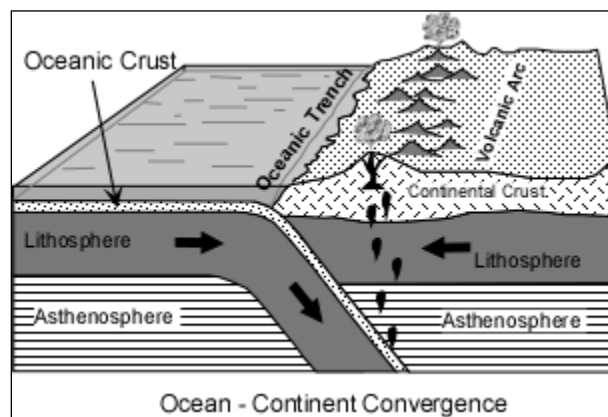


Fig. 9.5: Ocean – Continent Convergence

- **Convergent Plate Boundaries**

When a plate of dense oceanic lithosphere moving in one direction collides with a plate moving in the opposite direction, one of the plates subducts beneath the other. Where this occurs an oceanic trench forms on the sea floor and the sinking plate becomes a subduction zone. The *Wadati-Benioff Zone*, a zone of earthquakes located along the *subduction zone*, identifies a subduction zone. The earthquakes

may extend down to depths of 700 km before the subducting plate heats up and loses its ability to deform in a brittle fashion.

As the oceanic plate subducts, it begins to heat up causing the release water of water into the overlying mantle asthenosphere. The water reduces the melting temperature and results in the production of magmas. These magmas rise to the surface and create a volcanic arc parallel to the trench.

- If the subduction occurs beneath oceanic lithosphere, an *island arc* is produced at the surface (such as the Japanese islands, the Aleutian Islands, the Philippine islands, or the Caribbean islands)

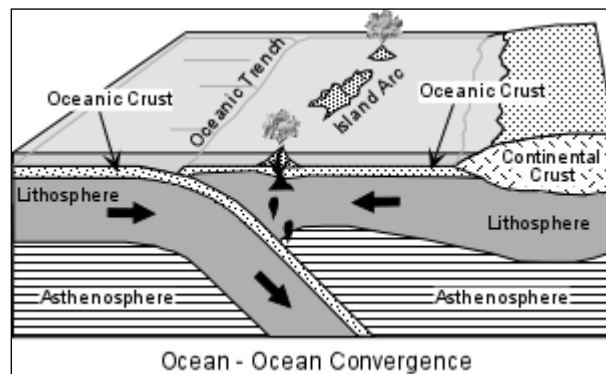


Fig. 9.6: Ocean – Ocean Convergence

- If the subduction occurs beneath continental crust, a *continental volcanic arc* is produced (such as the Cascades of the western U.S., or the Andes mountains of the South America)
- If one of the plates has continental lithosphere on its margin, the oceanic plate will subduct because oceanic lithosphere has a higher density than continental lithosphere.
- Sediment deposited along the convergent margin, and particularly that in the trench will be deformed by thrust faulting. This will break the rocks up into a

chaotic mixture of broken, jumbled, and thrust faulted rock know as an *accretionary prism*.

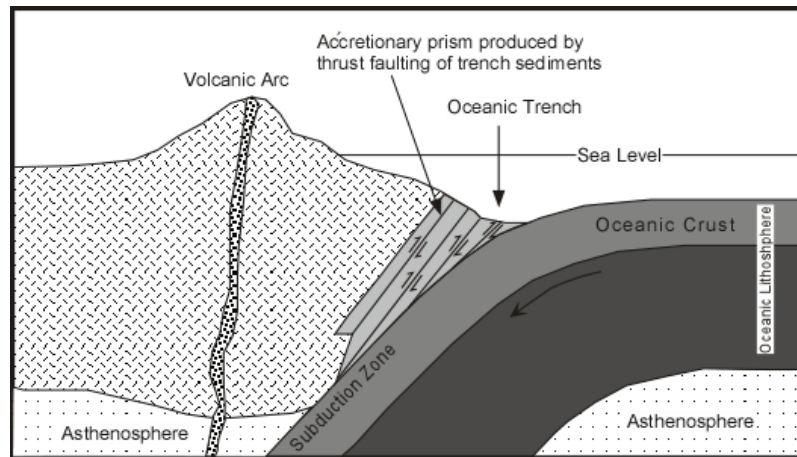


Fig. 9.7: The formation of thrust faulted rock knows as an *accretionary prism*.

- **Transform Plate Boundaries**

Where lithospheric plates slide past one another in a horizontal manner, a *transform fault* is created. Earthquakes along such transform faults are shallow focus earthquakes.

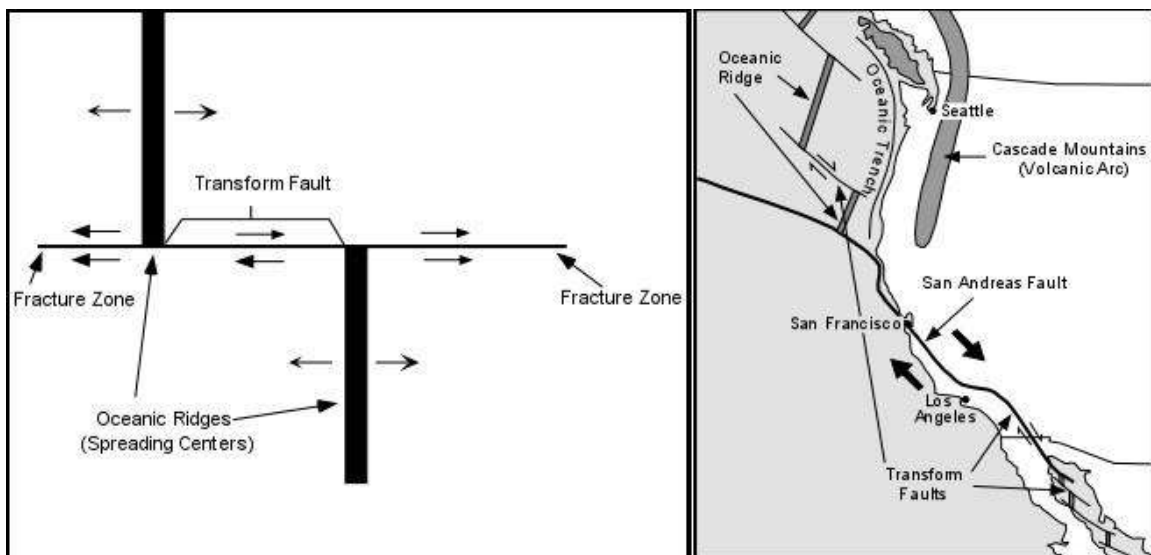


Fig. 9.8: Formation of the transform fault, San Francisco transform fault

Most transform faults occur where oceanic ridges are offset on the sea floor. Such offset occurs because spreading takes place on the spherical surface of the Earth, and some parts of a plate must be moving at a higher relative velocity than other parts. One of the largest such transform boundaries occurs along the boundary of the North American and Pacific plates and is known as the San Andreas Fault. Here the transform fault cuts through continental lithosphere. *Triple Junctions* occur at points where three plates meet.

9.3. What Causes Plate Tectonics?

From seismic wave velocities we know that the asthenosphere behaves in ductile manner, that is even though it is solid it can flow under stress and behave like a liquid. If this is the case, then it can also convect. Convection is a mode of heat transfer wherein the heat moves with the material. Convection is caused when material that occurs at a deeper level is heated to the point where it expands and becomes less dense than the material above it. When this occurs, the hot less dense material rises. In a confined space, rising hot material will eventually cool and become denser than its surroundings. This cool dense material must then sink. This gives rise to convection cells, with hot rising currents and cool descending currents.

If the asthenosphere is in fact moving as a result of convection, then convection could be the mechanism responsible for plate tectonics. Hot rising currents would occur beneath oceanic ridges.

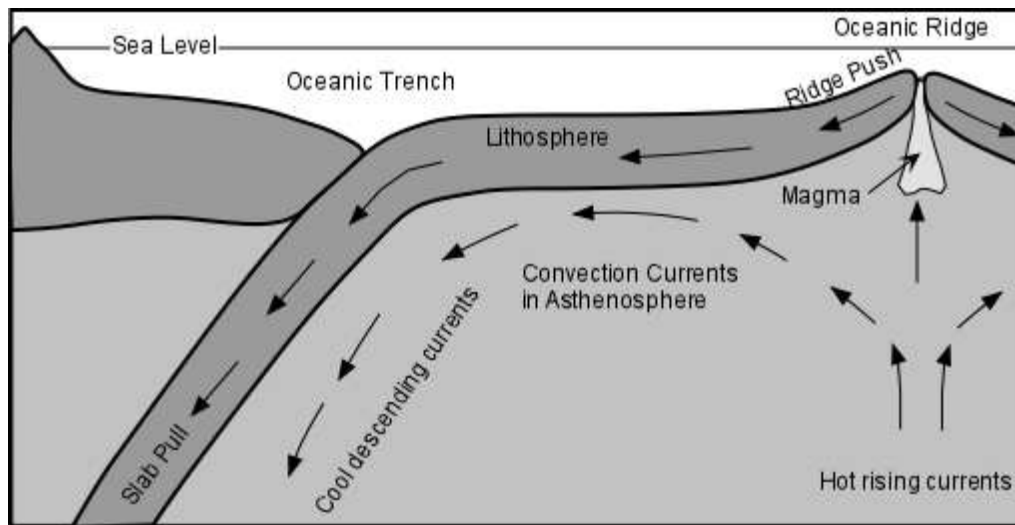


Fig 9.9: The mechanism responsible for plate tectonics

Magma intruding into the ridge would push lithosphere apart at the ridge. As the new lithosphere cools, it will slide off the topographic high that results from the upwelling of the mantle and will eventually become cold and dense. This dense lithosphere will tend to pull the rest of the lithosphere downward. A combination of dragging the lithosphere along the top of the convection cell, ridge push, sliding, and slab pull all appear to be contributing factors to the cause of plate tectonics.

There is still some debate as to whether asthenospheric convection drives the plates or the plates themselves drives plate tectonics. Until we have a better idea of what is happening in the mantle this debate will not likely be resolved. At least for now it appears that both convection and slab pull are the major factors (note that your textbook comes to a bit different conclusion).

CHAPTER X

GEOLOGIC TIME

Geological events can be given a precise date at a point in time, or they can be related to other events that came before and after them. Geologists use a variety of methods to give both relative and absolute dates to geological events. They then use these dates to find the rates at which processes occur. Uses of age determination of rocks can be summarized as follows:

- 1- Reading the Geologic history of the Earth: Continents, Oceans and Mountains.
- 2- Reading the geologic history of orogenic movements.
- 3- Determined the exact boundaries between Eons, Eras and Periods
- 4- In research in petroleum and other economic minerals in subsurface prospecting.
- 5- Corellation and calibration between different areas and aging on the Earth.

10.1. ABSOLUTE DATING

Geologists can also give precise absolute dates to geologic events. These dates are useful on their own, and can also be used in conjunction with relative dating methods or to calibrate relative dating methods.

A large advance in geology in the advent of the 20th century was the ability to give precise absolute dates to geologic events through radioactive isotopes and other methods. The advent of radiometric dating changed the understanding of geologic time. Before, geologists could only use fossils to date sections of rock relative to one another. With isotopic dates, absolute dating became possible, and these absolute dates could be applied fossil sequences in which there was datable material, converting the old relative ages into new absolute ages.

For many geologic applications, isotope ratios are measured in minerals that give the amount of time that has passed since a rock passed through its particular closure temperature, the point at which different radiometric isotopes stop diffusing into and out of the crystal lattice. These are used in geochronologic and thermochronologic studies. Common methods include uranium-lead dating, potassium-argon dating and argon-argon dating, and uranium-thorium dating. These methods are used for a variety of applications. Dating of lavas and ash

layers can help to date stratigraphy and calibrate relative dating techniques. These methods can also be used to determine ages of pluton emplacement. Thermochemical techniques can be used to determine temperature profiles within the crust, the uplift of mountain ranges, and paleotopography.

Fractionation of the lanthanide series elements is used to compute ages since rocks were removed from the mantle.

Other methods are used for more recent events. Optically stimulated luminescence and cosmogenic radionuclide dating are used to date surfaces and/or erosion rates. Dendrochronology can also be used for the dating of landscapes. Radiocarbon dating is used for young organic material.

10.1.1. Importance of absolute age dating

- 1- Knowing the geologic events of the Earth, establish Geologic Time Scale .
- 2- Used in conjunction with relative dating methods or to calibrate relative dating methods .
- 3- Radioactive isotopes and other methods of radiometric dating changed the understanding of geologic time .
- 4- Dating of lavas and ash layers can help to date stratigraphy and calibrate relative dating techniques

In radiometric dating, we need two measurements, the parent to daughter ratio measured with a mass spectrometer and the decay constant measured by scintillometer.

10.1.2. Radioactivity and Radioactive decay

Radioactive decay is the process by which an atomic nucleus of an unstable atom loses energy by emitting ionizing particles. Usually protons and neutrons are emitted by the nucleus; Sometimes an electron is emitted by the nucleus, which changes a neutron to a proton. The emission is spontaneous, in that the atom decays without any physical interaction with another particle from outside the atom. Usually, radioactive decay happens due to a process confined to the nucleus of the unstable atom. The chance that a given atom will decay is constant over time.

Common Radioactive Elements

Parents	and	Daughters
• Uranium-235 (U235)		Lead-207(Pb207)
• Uranium-238 (U238)		Lead-206 (Pb206)
• Carbon-14 (C14)		Nitrogen-14 (N14)
• Potassium-40 (K40)		Argon-40 (Ar40)
• Rubidium-87 (Rb87)		Strontium-87(Sr 87)

10.1.3. Half-life

Half-life (abbreviated $t_{1/2}$): is the period of time it takes for the amount of a substance undergoing decay to decrease by half. The name was originally used to describe a characteristic of unstable atoms radioactive decay (but it may apply to any quantity which follows a set-rate decay). The original term, dating to 1907, was "half-life period", which was later shortened to "half-life" in the early 1950s.

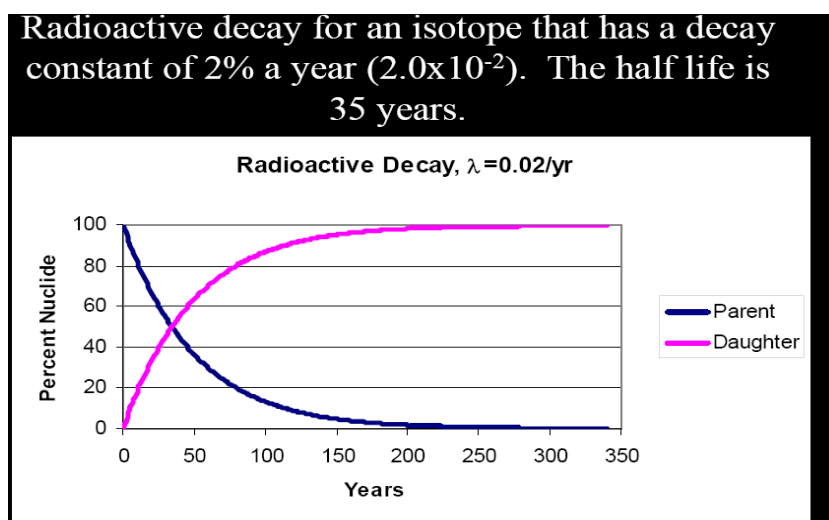


Fig. 10.1: Radioactive decay curve

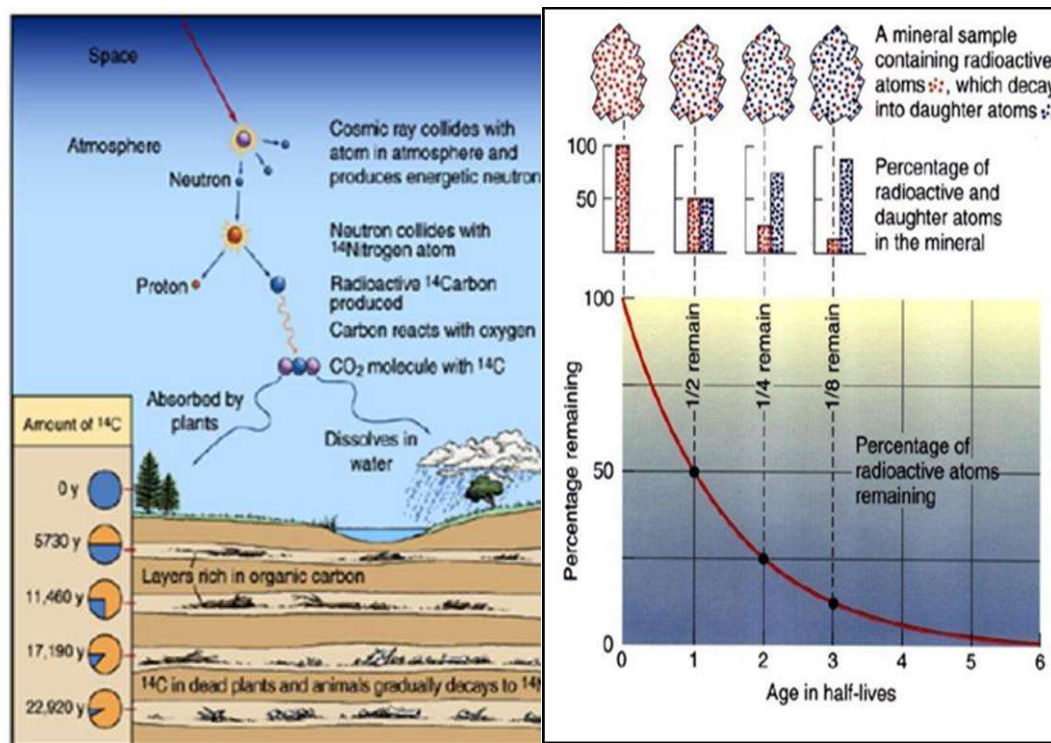


Fig. 10.2: Steps of formation of carbon isotopes

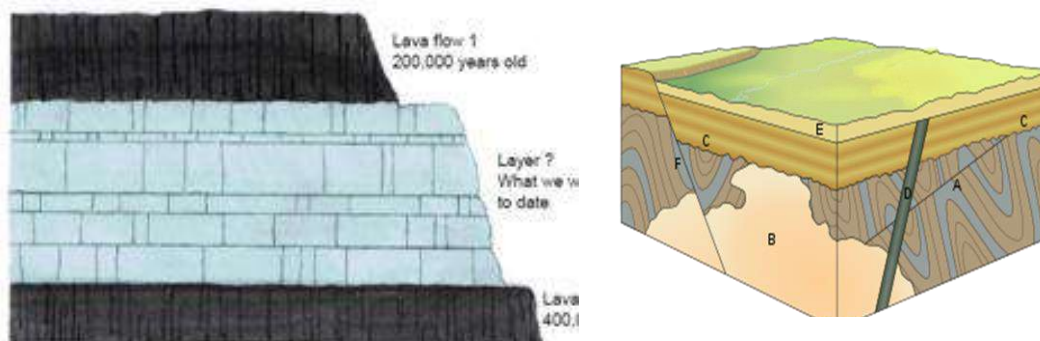


Fig. 10.3: Geologic section for relative dating

10.2. RELATIVE DATING

This exercise introduces the concept of relative dating of geologic sequences. Basically, relative dating means determining which rock units are older and which are younger in some particular geologic setting. **Stratification** or **bedding** is the most obvious large scale feature of sedimentary rocks. Bedding is readily seen in a view of the Grand Canyon, or almost any other sequence of sedimentary rocks. Each of the beds or **strata** (*singular* = **stratum**) is the result of a natural event in geologic history, such as a flood or storm. As time passes

many such events occur and the sediment piles up, layer upon layer. In this way, thick sedimentary sequences are formed.

10.3. THE PRINCIPLE OF STRATIGRAPHY

a-The principle of uniformitarianism states that the geologic processes observed in operation that modify the Earth's crust at present have worked in much the same way over geologic time. A fundamental principle of geology advanced by the 18th century Scottish physician and geologist James Hutton, is that "the present is the key to the past." In Hutton's words: "the past history of our globe must be explained by what can be seen to be happening now.

b- The principle of superposition states that a sedimentary rock layer in a tectonically undisturbed sequence is younger than the one beneath it and older than the one above it. Logically a younger layer cannot slip beneath a layer previously deposited. This principle allows sedimentary layers to be viewed as a form of vertical time line, a partial or complete record of the time elapsed from deposition of the lowest layer to deposition of the highest bed.

STENO'S LAWS: It was recognized in the 1600's that in a sedimentary sequence, *the older beds are on the bottom, and the younger beds are on the top.*

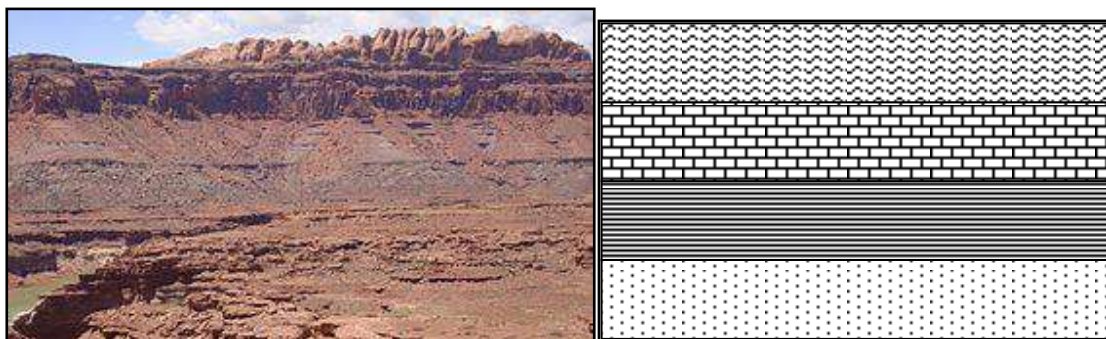


Fig. 10.4: Vertical geologic section (ordered of beds).

c- Steno's second law is the Principle of Original Horizontality, which states that *sediments are deposited in flat, horizontal layers*. We can recognize this easily if we consider a sedimentary environment such as the sea floor or the bottom of a lake. Any storm or flood bringing sediment to these environments will deposit it in a flat layer on the bottom because of the sedimentary particles settling under the influence of gravity. As a result, a flat, horizontal layer of sediment will be deposited.

d- Steno's third law is the Principle of Original Lateral Continuity. If we consider again the sediment being deposited on the seafloor, *the sediment will*

not only be deposited in a flat layer, it will **be a layer that extends for a considerable distance in all directions**. In other words, the layer is laterally continuous.

10.4. DETERMINING "UP DIRECTION"

When you approach a sequence of beds which has been tectonically deformed, before you can determine which beds are younger and which are older, it is first necessary to determine the "*up direction*". This is done by examining the sedimentary structures for clues. Sedimentary structures such as graded beds, cross beds, mudcracks, flute marks, symmetrical (but not asymmetrical) ripples, stromatolites, burrows, tracks, and others can be used to establish the original orientation of the beds. (Fossils can also be used to establish up direction, if they are present in the rock in life position.) You should examine carefully the sedimentary structures in any dipping sedimentary sequence, because the rocks can be *overturned* by tectonic forces, and what initially appears to be younger because it is on top, may in fact turn out to be at the bottom of the section!

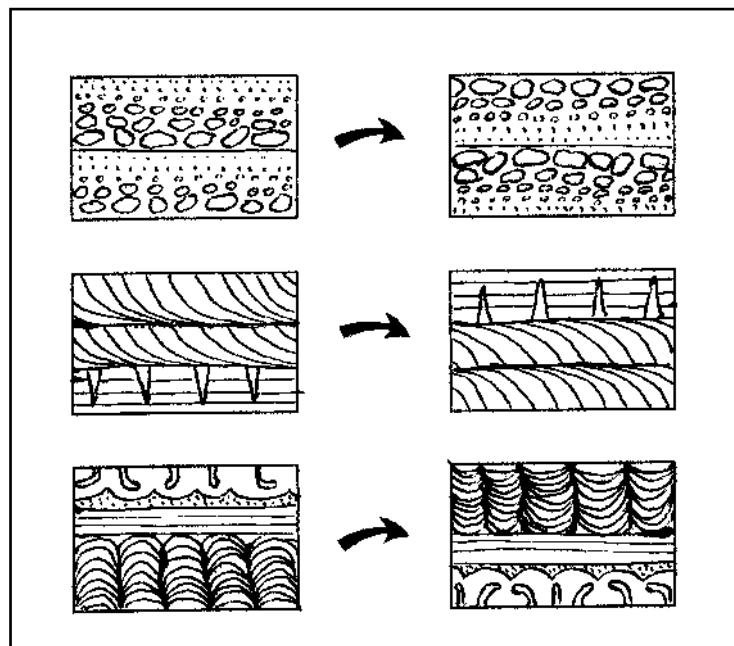
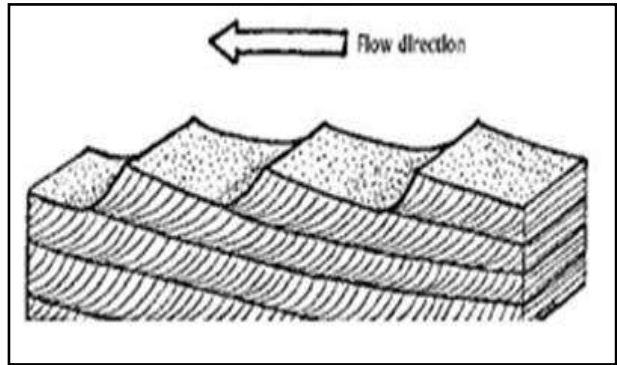


Fig. 10.5: Illustration of overturned beds.

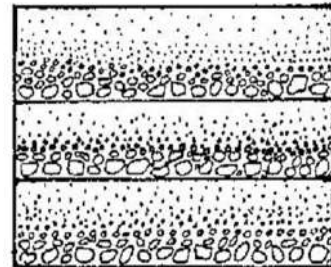
- a- **Varves** are a special type of lamination which forms in glacial lakes. Varves represent deposition over one year, and their formation is related to seasonal influences. Varves are generally graded, with the coarser material at the bottom (silt or sand) representing the spring and summer meltwater runoff, and the finer material at the top representing slow settling of clays and organic matter from suspension during the winter months when the lake is covered with ice. Counting of varves in the

geologic record has been used to measure the ages of some sedimentary deposits.

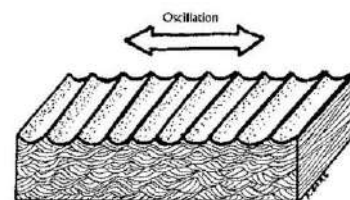
- b- Cross-stratification** is a general term for the internal bedding structure produced in sand by moving wind or water. If the individual inclined layers are thicker than 1 cm, the cross-stratification may be referred to as **cross-bedding**. Thinner inclined layering is called **cross-lamination**. Cross-stratification forms beneath ripples and dunes. The layering is inclined at an angle to the horizontal, dipping downward in the downcurrent direction. Hence, cross-beds may be used as paleocurrent indicators, or indicators of ancient current flow directions. Cross-beds usually curve at the bottom edge, becoming tangent to the lower bed surface. The upper edge of individual inclined cross-beds is usually at a steep angle to the overlying bedding plane.



- c- Graded bedding** results when a sediment-laden current (such as turbidity current) begins to slow down. The grain size within a graded bed ranges from coarser at the bottom to finer at the top.

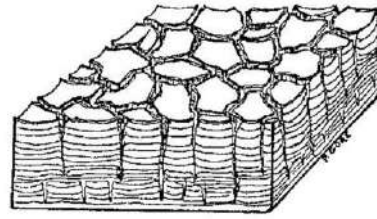


- d- Ripples** are undulations of the sediment surface produced as wind or water moves across sand. Ripples which form in *unidirectional currents* (such as in streams or rivers) tend to be **asymmetrical**. Crests of asymmetrical ripples may be straight, sinuous, or lobe-like, depending on water velocity. Asymmetrical ripples have a steep slope on the downstream side, and a gentle slope on the upstream side. Because of this unique geometry, asymmetrical ripples in the rock record may be used to determine ancient current directions or paleocurrent directions. In *waves or oscillating water*, **symmetrical ripples** are produced. Crests of

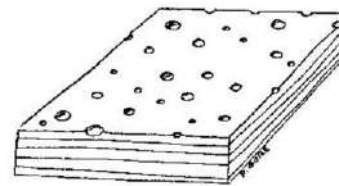


symmetrical ripples tend to be relatively straight, but may bifurcate (or fork).

- e- **Mud cracks** are a polygonal pattern of cracks produced on the surface of mud as it dries. The mud polygons between the cracks may be broken up later by water movement, and redeposited as intraclasts (particularly in lime muds).



- f- **Raindrop prints** are circular pits on the sediment surface produced by the impact of raindrops on soft mud.



10.5. OTHER BASIC PRINCIPLES OF GEOLOGY

In addition to Steno's Laws, there are a number of other basic geologic principles which can be used for relative dating.

a. The Principle of Intrusive Relationships

The principle of intrusive relationships concerns crosscutting intrusions. In geology, when an igneous intrusion cuts across a formation of sedimentary rock, it can be determined that the igneous intrusion is younger than the sedimentary rock. There are a number of different types of intrusions, including stocks, laccoliths, batholiths, sills and dikes.

b. The Principle of Cross-Cutting Relationships

The principle of cross-cutting relationships pertains to the formation of faults and the age of the sequences through which they cut. Faults are younger than the rocks they cut; accordingly, if a fault is found that penetrates some formations but not those on top of it, then the formations that were cut are older than the fault, and the ones that are not cut must be younger than the fault. Finding the key bed in these situations may help determine whether the fault is a normal fault or a thrust fault.

c. Principle of Components or Inclusions

The principle of inclusions and components states that, with sedimentary rocks, if inclusions (or clasts) are found in a formation, then the inclusions

must be older than the formation that contains them. For example, in sedimentary rocks, it is common for gravel from an older formation to be ripped up and included in a newer layer. A similar situation with igneous rocks occurs when xenoliths are found. These foreign bodies are picked up as magma or lava flows, and are incorporated, later to cool in the matrix. As a result, xenoliths are older than the rock which contains them.

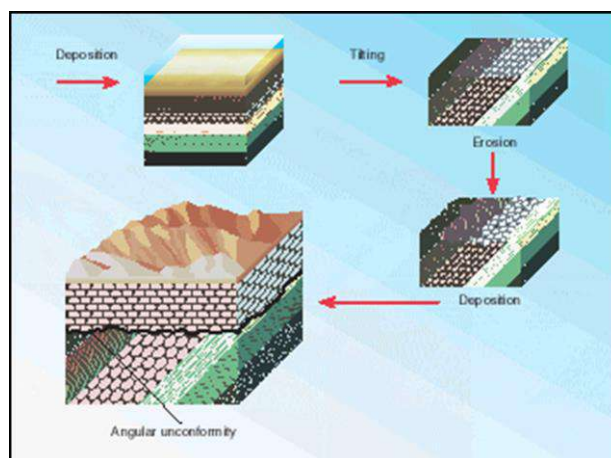
d. Principle of Fossil Succession

The **principle of faunal succession** is based on the appearance of fossils in sedimentary rocks. As organisms exist at the same time period throughout the world, their presence or (sometimes) absence may be used to provide a relative age of the formations in which they are found. Based on principles laid out by William Smith almost a hundred years before the publication of Charles Darwin's theory of evolution, the principles of succession were developed independently of evolutionary thought.

10.6. UNCONFORMITY SURFACE

An **unconformity** is a buried erosion surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous.

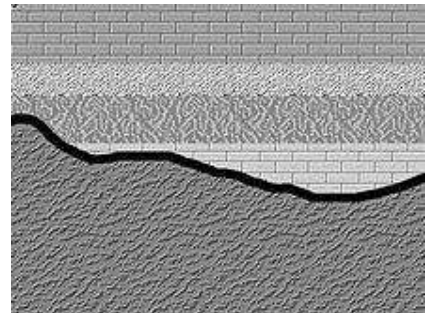
The rocks above an unconformity are younger than the rocks beneath (unless the sequence has been overturned). An unconformity represents time during which no sediments were preserved in a region. The local record for that time interval is missing and geologists must use other clues to discover that part of the geologic history of that area. The interval of geologic time not represented is called a *hiatus*.



10.6.1. Types of unconformities

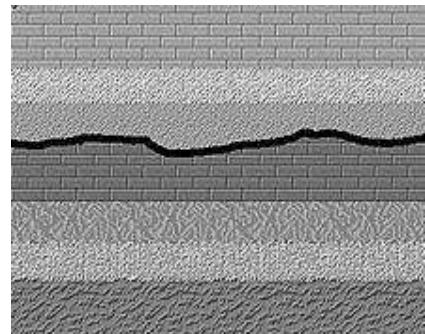
a- Nonconformity

Nonconformity exists between sedimentary rocks and metamorphic or igneous rocks when the sedimentary rock lies above and was deposited on the pre-existing and eroded metamorphic or igneous rock. Namely, if the rock below the break is igneous or has lost its bedding by metamorphism, the plane of juncture is nonconformity.



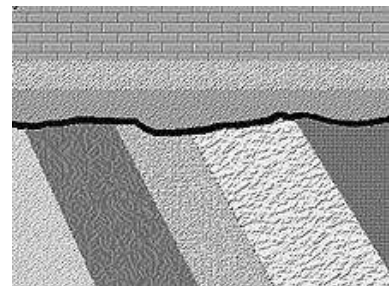
b- Disconformity

A disconformity is an unconformity between parallel layers of sedimentary rocks which represents a period of erosion or non-deposition. Disconformities are marked by features of subaerial erosion. This type of erosion can leave channels and paleosols in the rock record. A paraconformity is a type of disconformity in which the separation is a simple bedding plane with no obvious buried erosional surface.



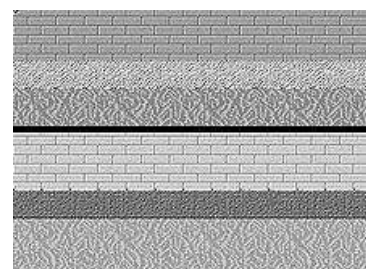
c- Angular unconformity

An angular unconformity is an unconformity where horizontally parallel strata of sedimentary rock are deposited on tilted and eroded layers, producing an angular discordance with the overlying horizontal layers. The whole sequence may later be deformed and tilted by further orogenic activity.



d-Paraconformity

A paraconformity is a type of unconformity in which strata are parallel; there is little apparent erosion and the unconformity surface resembles a



simple bedding plane. It is also known as non-depositional unconformity.

10.7. GEOLOGIC TIME SCALE

The **geologic time scale** provides a system of chronologic measurement relating stratigraphy to time that is used by geologists, paleontologists and other earth scientists to describe the timing and relationships between events that have occurred during the history of the Earth. The table of geologic time spans presented here agrees with the dates and nomenclature proposed by the International Commission on Stratigraphy, and uses the standard color codes of the United States Geological Survey.

Evidence from radiometric dating indicates that the Earth is about 4.570 billion years old. The geological or deep time of Earth's past has been organized into various units according to events which took place in each period. Different spans of time on the time scale are usually delimited by major geological or paleontological events, such as mass extinctions. For example, the boundary between the Cretaceous period and the Paleogene period is defined by the Cretaceous–Tertiary extinction event, which marked the demise of the dinosaurs and of many marine species. Older periods which predate the reliable fossil record are defined by absolute age.

The largest defined unit of time is the **supereon**, composed of **eons**. Eons are divided into **eras**, which are in turn divided into **periods**, **epochs** and **ages**. The terms eonothem, erathem, system, series, and stage are used to refer to the layers of rock that correspond to these periods of geologic time.

Units in geochronology and stratigraphy		
Segments of rock (strata) in <u>chronostratigraphy</u>	Periods of time in <u>geochronology</u>	Notes
<u>Eonothem</u>	<u>Eon</u>	4 total, half a billion years or more
<u>Erathem</u>	<u>Era</u>	12 total, several hundred million years
<u>System</u>	<u>Period</u>	
<u>Series</u>	<u>Epoch</u>	tens of millions of years
<u>Stage</u>	<u>Age</u>	millions of years
<u>Chronozone</u>	<u>Chron</u>	smaller than an age/stage,

Table I-1 • THE GEOLOGIC TIME SCALE									
TIME UNITS OF THE GEOLOGIC TIME SCALE									
Eon	Era	Period		Epoch	DISTINCTIVE PLANTS AND ANIMALS				
Phanerozoic Eon (<i>Phaneros</i> = “evident”; <i>Zoon</i> = “life”)	Cenozoic Era	Quaternary		Recent or Holocene	“Age of Mammals”	Humans			
				Pleistocene		Mammals develop and become dominant Extinction of dinosaurs and many other species			
		Tertiary	Neogene				Pliocene		
							Miocene		
			Paleogene				Oligocene		
							Eocene		
							Paleocene		
			Mesozoic Era	Cretaceous			“Age of Reptiles”	First flowering plants, greatest development of dinosaurs	
				Jurassic				First birds and mammals, abundant dinosaurs	
	Triassic			First dinosaurs					
	Paleozoic Era	Permian		“Age of Amphibians”	Extinction of trilobites and many other marine animals				
		Carboniferous	Pennsylvanian		Great coal forests; abundant insects, first reptiles				
			Mississippian		Large primitive trees				
			Devonian		“Age of Fishes”	First amphibians			
		Silurian		First land plant fossils					
		Ordovician		“Age of Marine Invertebrates”	First fish				
		Cambrian			First organisms with shells, trilobites dominant				
		Proterozoic	Sometimes collectively called Precambrian			First multicelled organisms			
		Archean				First one-celled organisms			
	Hadean	Approximate age of oldest rocks							
	4600±	Origin of the Earth							

Fig. 10.6. Geologic time scale

REVIEW QUESTIONS

1. What is radioactivity?
2. What is a stable isotope? An unstable isotope?
3. What is the relationship between parent and daughter isotopes?
4. What is meant by the half-life of a radioactive isotope?
5. How is the half-life used in radiometric age dating?
6. Some radioactive isotopes are useful for measuring relatively young ages, whereas others are useful for measuring older ages. Why is this true?
7. Describe the two ways of measuring geologic time. How do they differ?
8. Give an example of how the principle of original horizontality might be used to determine the order of events affecting a sequence of folded sedimentary rocks.
9. How does the principle of superposition allow us to determine the relative ages of a sequence of unfolded sedimentary rocks?
10. Explain the principle of crosscutting relationships and how it can be used to determine age relationships among sedimentary rocks.
11. Explain a conformable relationship in sedimentary rocks.
12. Explain the differences among unconformities, disconformities, angular unconformities, and nonconformities



رؤية قسم الجيولوجيا

التميز في مجال علوم الأرض للمساهمة في بناء مجتمع المعرفة

رسالة قسم الجيولوجيا

تقديم برامج دراسية متطورة في مجالات علوم الأرض وتطبيقاتها لإعداد خريجين وباحثين لهم القدرة على الإبداع والبحث والتطبيق والمشاركة الفاعلة في التنمية المجتمعية محليا وإقليمياً ودولياً.

الأهداف الإستراتيجية

- 1- تطوير البرامج والمقررات الدراسية في ضوء المعايير القومية والدولية
- 2- إستخدام أساليب التكنولوجيا الحديثة في مجال التعليم والتعلم.
- 3- تأهيل الخريجين لتلبية إحتياجات سوق العمل.
- 4- القيام بالبحوث الأكاديمية والتطبيقية والإستشارات والتأليف في جميع مجالات علوم الأرض لمواكبة التقدم العلمى فى أنحاء العالم.
- 5- تقديم الإستشارات العلمية والدورات التدريبية للمشاركة فى حل المشكلات المجتمعية.
- 6- الإستمرار فى زيادة التعاون الدولى (الشراكات الدولية).