Al-Karkh University for Sciences
College of Remote Sensing and Geophysics
Geophysics Department

The Dynamic and Evolving Earth

Prepared by
Dr. Rami M. Idan
Petroleum Geologist

by

Dr. Rami M. Idan

Introduction

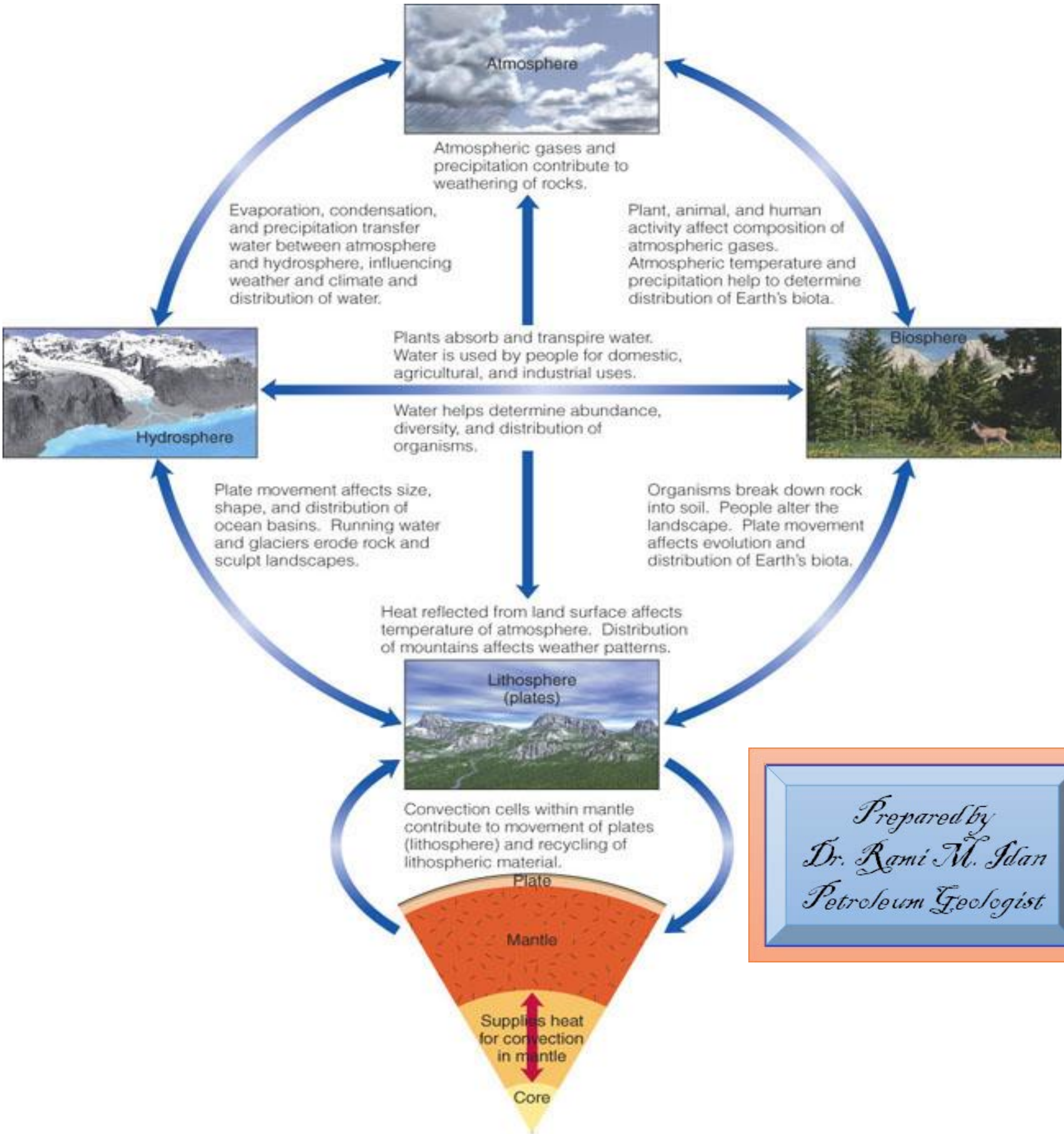
What kind of movie would we have if it were possible to travel back in time and fi lm Earth's history from its beginning 4.6 billion years ago? It would certainly be a story of epic proportions, with incredible special effects, a cast of trillions, a plot with twists and turns—and an ending that is still a mystery!

Every good movie has a theme, and the major theme of *The History of Earth* is that Earth is a complex, dynamic planet that has changed continuously since its origin some 4.6 billion years ago. Because of its epic nature, three interrelated sub-themes run throughout *The History of Earth*. The first is that Earth's outermost part is composed of a series of moving plates *(plate tectonics)* whose interactions have affected the planet's physical and biological history. The second is that Earth's biota has evolved or changed throughout its history *(organic evolution)*. The third is that the physical and biological changes that occurred did so over long periods of time *(geologic* or *deep time)*. These three interrelated sub-themes are central to our understanding and appreciation of our planet's history.

As you study and read the various topics covered in this book, keep in mind that the themes and topics discussed in this chapter and throughout the book are like the interconnected components of a system, and not just isolated and unrelated pieces of information. By relating each chapter's topic to its place in the entire Earth system, you will gain a greater appreciation of Earth's evolution and the role of its various interacting internal and external systems, subsystems, and cycles.

By viewing Earth as a whole—that is, thinking of it as a system—we not only see how its various components are interconnected, but we can also better appreciate its complex and dynamic nature. The system concept makes it easier for us to study a complex subject, such as Earth, because it divides the whole into smaller components that we can easily understand, without losing sight of how the separate components fit together as a whole.

A **system** is a combination of related parts that interact in an organized manner. We can thus consider Earth as a system of interconnected components that interact and affect each other in many different ways. The principal subsystems of Earth are the *atmosphere, biosphere, hydrosphere, geosphere, mantle,* and *core* (Figure). The complex interactions among these subsystems result in a dynamically changing planet in which matter and energy.



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Petroleum Geologist

We must understand the science of how Earth works and how to effectively integrate scientific findings with the needs of society. Scientists collect data on natural phenomena such as tsunami, but it is often politicians (and, indirectly, the people who elect them) who determine what actions should be taken to protect the public. In *The Good Earth* we introduce you to the study of earth science. **Earth science can be broadly defined as the investigation of interactions among the four components of the earth system—the atmosphere (air, weather), hydrosphere (water, ice), biosphere (plants, animals), and geosphere (land, rocks)**. Together, these components form an elegant support

system for life. **In addition, the sun and assorted features from space, collectively termed the exosphere,** interact with the earth system and are sometimes considered a fifth earth system component. The historic 2004 tsunami involved three of the components— the hydrosphere, geosphere, and biosphere (Figure 1.4). Throughout this book, we will examine the characteristics of each of the components through the lens of human experience. After all, Earth is the only home we have, and we want to take care of it. We will also be interested in how these components interact and how changes in one component influence processes in the others. The second word in the term *earth science* is just as important to us as the first. Much of what you learn in college about science will happen in this and perhaps one other course. Therefore, we want you to have a firm understanding of what science are—and what it is not. **Science is not a list of facts to be memorized that have no relevance to your life.** So in this chapter, and throughout the book, we will give you lots of examples to show that science is a *process,* a way of thinking about the natural world.

Now we can define **Geology**: is a complex, integrated system of related parts, components, or subsystems. These systems and subsystems interact in an organized fashion, affecting one another in various ways.

Earth is being as dynamic system like engine. Its input is the materials, while their outputs are the external and internal processes on earth that make the target of geology.

Physical Geology

Physical Geologists are concerned with exploring the earth and its dynamicity. They seek to determine the earth materials, especially minerals and rocks and the interrelation between them in dynamic context. Equally the important is the relation of these materials and processes created to the humans as well as the development of natural resources and the environment impacts.

Historical geology is concerned with the origin and evolution of Earth's continents, oceans, atmosphere, and life.

Geologists are employed in diverse occupations, which include:

- Mineral and energy resource exploration
- Solving environmental problems
- Predicting natural disasters

Themes of Physical Geology:

1. Dynamic Earth: to put all the internal and external processes on earth in a unifying theory to explain its continuous changes since 4.6 billion years till now and in the future. Such phenomenon could be explained by the Plate Tectonic Theory and the Rock Cycle.
2. Earth Materials: These are mainly the molten magma, minerals, and rocks (igneous, sedimentary, and metamorphic) that could be placed in the context of rock cycle.
3. Earth Processes: these are earth internal and external processes that are essential for changing the state of a material, environmental impact, and natural resources development.

Uses and Applications of Geological Sciences

1. Exploration for minerals, oil, and gas.
2. Environmental problems: Hazards of flooding, Glaciations, Rocks stability, and Volcanicity.
3. Ground and underground water for irrigation and drinking water.
4. Pollution in soil, water, and gas. There are organic and chemical pollution.
5. Geologic engineers: location of dams and power plant.
6. Monitoring earth quakes and volcanicity.
7. Mining: extraction of sulfur, phosphates, iron, etc…..

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Earth's Interior Layers

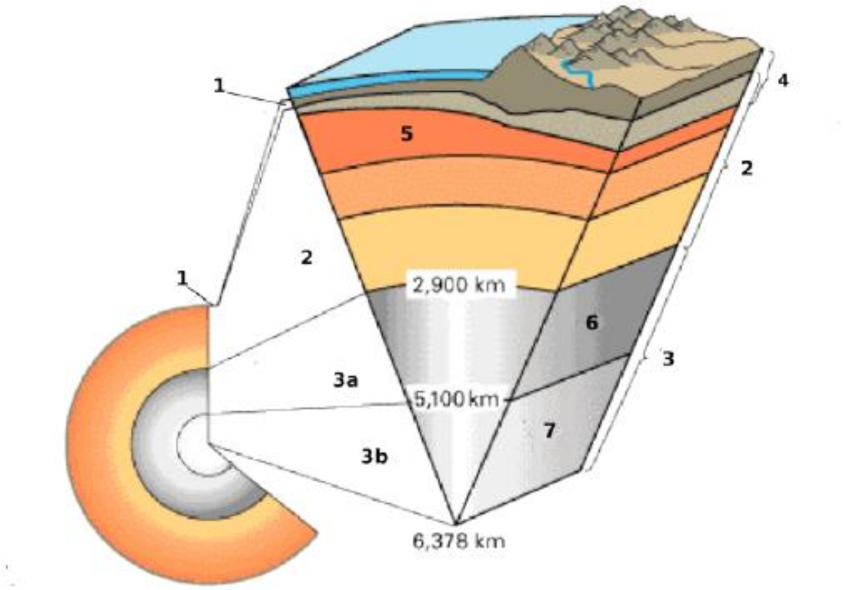
Core, mantle, and crust are divisions based on composition:

- The crust is less than 1% of Earth by mass. The oceanic crust is mafic (minerals with high levels of ferromagnesian), while continental crust is often more felsic (minerals that are primarily made of feldspars and quartz) rock.
- The mantle is hot, ultramafic rock. It represents about 68% of Earth's mass.
- The core is mostly iron metal. The core makes up about 31% of the Earth.

Lithosphere and asthenosphere are divisions based on mechanical properties:

- The lithosphere is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid.
- The asthenosphere is partially molten upper mantle material that behaves plastically and can flow.
- The mesosphere refers to the mantle in the region under the lithosphere, and the asthenosphere, but above the outer core. The difference between mesosphere and asthenosphere is likely due to density and rigidity differences, that is, physical factors, and not to any difference in chemical composition.

This animation shows the layers by composition and by mechanical properties: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html



A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

Note: Earth's lithosphere is made of several plates that move because of convection currents in the asthenosphere.

References:

McConnell, D., 2007. The Good Earth, Introduction to Earth Science-McGraw-Hill.

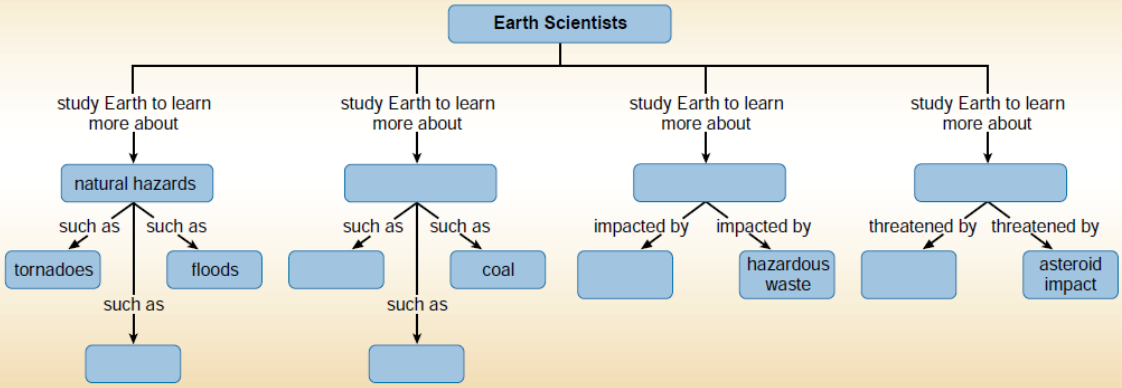
Utah State Office of Education, 2013. Earth Science.

Wicander, R., and Monroe, J. S. 2010. Historical geology-Books-Cole.

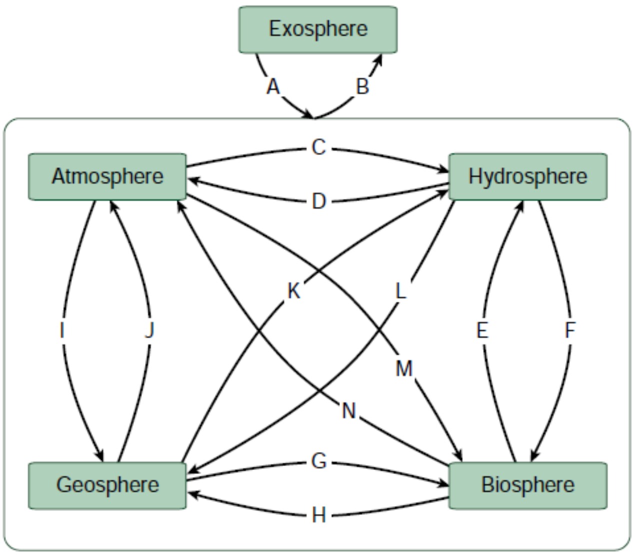
Home works

Checkpoint 1.15

Complete the following concept map to summarize the characteristics of the four principal roles that earth scientists play in society.



Interaction	Letter
Plants absorb carbon dioxide.	
Earthquake destruction causes deaths.	
Wind blows sand.	
Spacecraft explore deep space.	
Continents deflect ocean currents.	
Plants release oxygen.	
Fish live in oceans.	
Asteroid impacts Earth.	
Volcano emits toxic gases.	
Animals drink water.	
Water evaporates from the oceans.	
Humans mine coal.	
Winds generate waves.	
A stream carves a canyon.	



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Lecture TWO

Plate Tectonics

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Dr. Rami M. Idan
Petroleum Geologist

by

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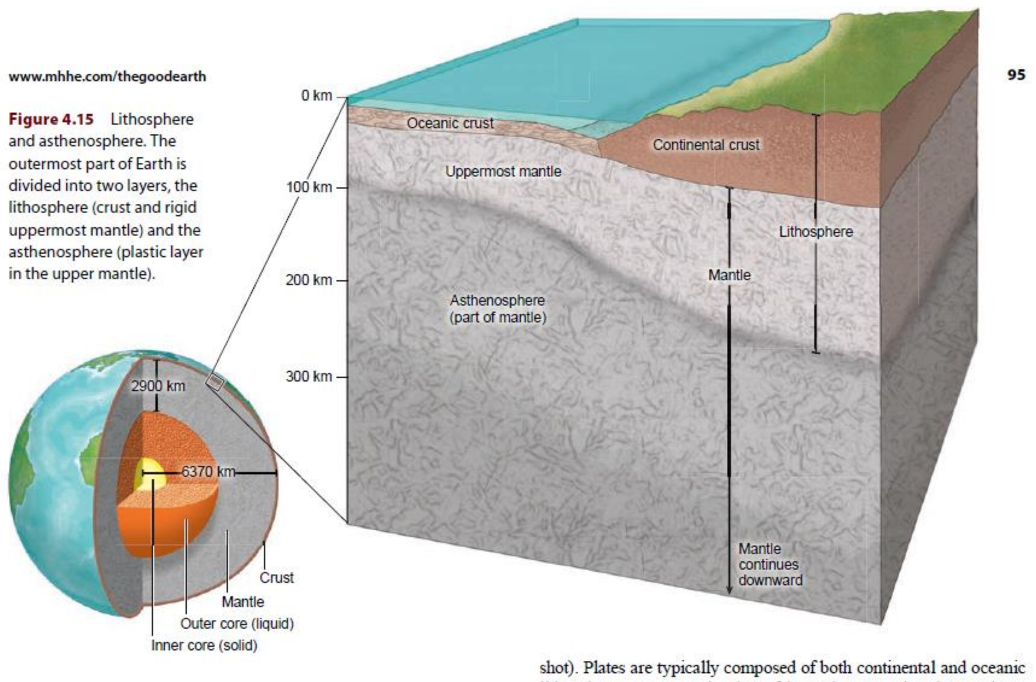
What are Plate Tectonics?

It is a modern theory (found by Alfred Wegener in 1911) used to explain how Earth's physical features (geology and geography) have formed. This theory explains the formation, movement, and subduction of Earth's tectonic plates.

Wegener's Idea

Alfred Wegener, born in 1880, was a meteorologist and explorer. In 1911, Wegener found a scientific paper that listed identical plant and animal fossils on opposite sides of the Atlantic Ocean. Intrigued, he then searched for and found other cases of identical fossils on opposite sides of oceans. The explanation put out by the scientists of the day was that land bridges had once stretched between these continents. Instead, Wegener pondered the way Africa and South America appeared to fit together like puzzle pieces. Other scientists had suggested that Africa and South America had once been joined, but Wegener was the idea's greatest supporter. Wegener obtained a tremendous amount of evidence to support his hypothesis that the continents had once been joined. Imagine that you're Wegener's colleague. What sort of evidence would you look for to see if the continents had actually been joined and had moved apart?

Remember the Layers of the Earth in Lecture One



Wegener's Evidences

Here is the main evidence that Wegener and his supporters collected for the continental drift hypothesis:

1. Continental shelf fit: Continents appear to fit together in their edges.

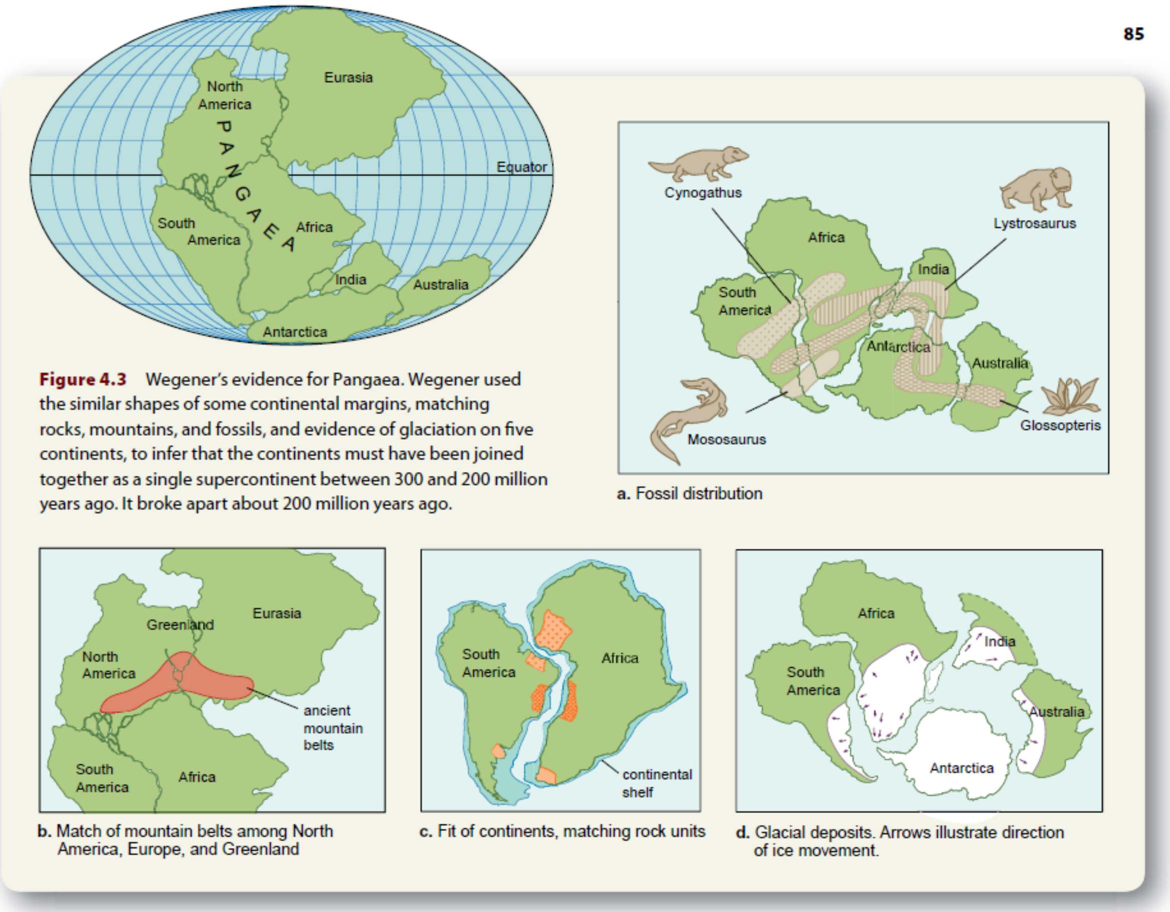


Figure 4.3 Wegener's evidence for Pangaea. Wegener used the similar shapes of some continental margins, matching rocks, mountains, and fossils, and evidence of glaciation on five continents, to infer that the continents must have been joined together as a single supercontinent between 300 and 200 million years ago. It broke apart about 200 million years ago.

2. Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated (See Figure below). Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. His critics suggested that the organisms moved over long-gone land bridges, but Wegener thought that the organisms could not have been able to travel across the oceans.

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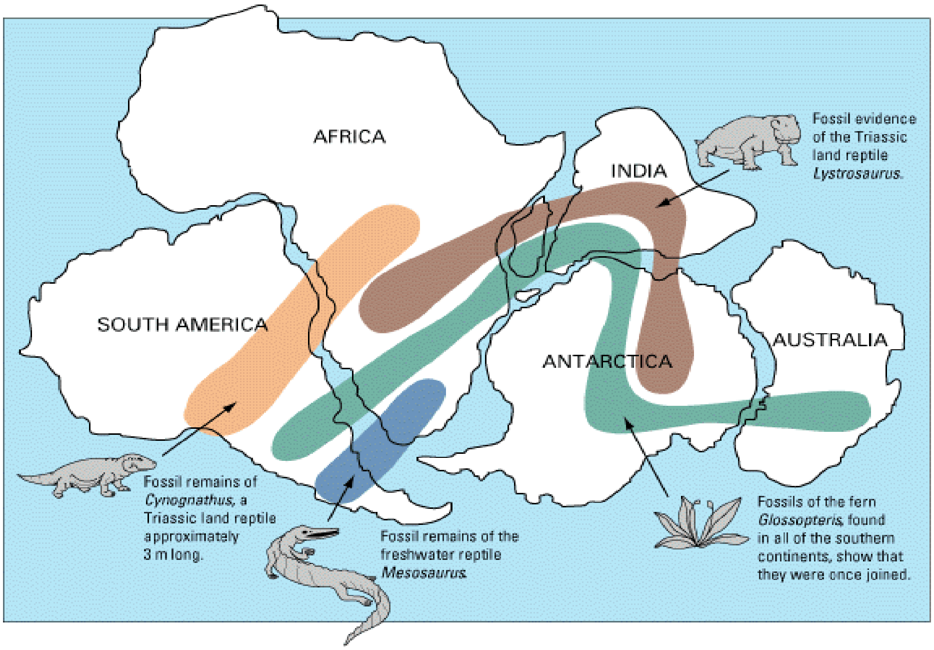
Dr. Rami M. Idan
Petroleum Geologist



- Fossils of the seed fern Glossopteris were too heavy to be carried so far by wind.
- Mesosaurus was a swimming reptile, but could only swim in fresh water.
- Cynognathus and Lystrosaurus were land reptiles and were unable to swim.

3. Identical rocks, of the same type and age, are found on both sides of the Atlantic Ocean. Wegener said the rocks had formed side by side and that the land had since moved apart.
4. Mountain ranges with the same rock types, structures, and ages are now on opposite sides of the Atlantic Ocean. The Appalachians of the eastern United States and Canada, for example, are just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway (See Figure 2.2a Image 3). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.
5. Paleoclimate: Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the equator. This would indicate that the glaciers either formed in the middle of the ocean and/or covered most of the Earth. Today, glaciers only form on land and nearer the poles. Wegener thought that the glaciers were centered over the southern land mass close to the South Pole and the continents moved to their present positions later on.
   Coral reefs and coal-forming swamps are found in tropical and subtropical environments, but ancient coal seams and coral reefs are found in locations where it is much too cold today. Wegener suggested that these creatures were alive in warm climate zones and that the fossils and coal later drifted to new locations on the continents.

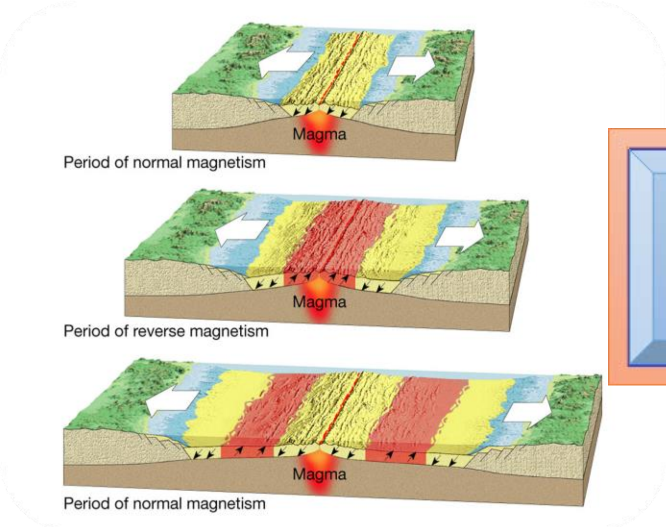
6. Seafloor Spreading Hypothesis

Because the observations just described contradicted predictions of the contracting Earth model, a new explanation for the origin of the ocean floor was needed. Scientists combined evidence of heat flow, volcanism, earthquakes, and changes in the topography and age of the seafloor (Figure 4.10a) to develop a new hypothesis. According to this new **seafloor spreading hypothesis, new oceanic floor is being *continuously* formed along the ridge system by magma rising from below, and as this occurs, the existing rocks move away from the ridge** (Figure 4.10b in Good Earth). The seafloor spreading hypothesis led scientists to conclude that the migration of hot magma from below the ridge heats the overlying seafloor, causing it to expand to produce the higher topography of the oceanic ridge. The ocean floor was interpreted to act as a conveyor belt, gradually moving away from the ridge and creating a gap that was continuously filled with new magma from below.

Because new material is constantly being generated at ridges, old material must be destroyed somewhere else, or Earth would expand. Since Earth is not expanding, there had to be places on Earth's surface where older ocean floor was destroyed. The fact that the deepest earthquakes and older ocean floor are adjacent to trenches led scientists to hypothesize that the **ocean floor is consumed as it *descends* into Earth's interior adjacent to ocean trenches.**

http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sonar.html.

7. Paleomagnetism-Magnetic patterns in rocks indicate continental shift.



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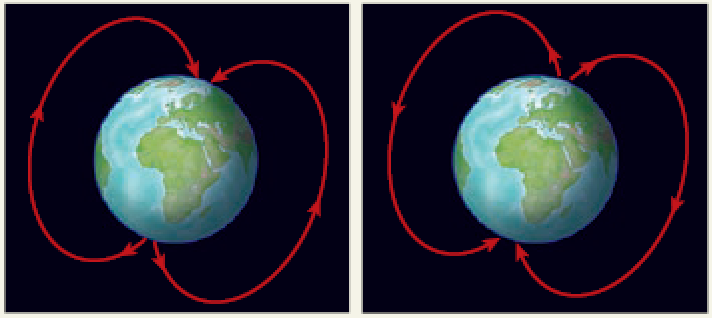
Petroleum Geologist

Magnetic patterns and Sea floor Spreading in the rock records.



a. Normal polarity b. Reversed polarity

Figure 4.12 Polarity of Earth's magnetic field. (a) The inclination of the magnetic field varies with latitude. The field is horizontal at the magnetic equator, steeper at high latitudes, and vertical at the magnetic poles. The magnetic field is inclined downward in the Northern Hemisphere and upward (away from Earth's surface) in the Southern Hemisphere. (b) The magnetic field has reverse polarity, meaning that the positive and negative polarities have switched positions.

https://media.wr.usgs.gov/science/2004/jul04.mp4

https://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A49.gif

8. Earthquakes

The transfer of earthquake energy happens in the form of waves. These waves can happen in a couple of different ways.

The energy from an earthquake arrives in three distinct waves. The fastest and therefore the first to arrive was named the Primary wave or p-wave. The second to arrive was named the secondary wave or s-wave. The slowest and last to arrive was named the surface wave.

P-wave: P-waves are a form of longitudinal waves. These waves vibrate in a direction parallel to the direction in which the energy is transferred. For example, in an east moving p-wave objects vibrate in an east-west direction. This is the type of wave demonstrated in the first two videos above.

S-wave: S-waves are a form of transverse waves. These waves vibrate in a direction perpendicular to the direction in which the energy is transferred. For example, in an east moving s-wave, objects vibrate in a north-south direction. This is more destructive than the vibrations in a p-wave. This is the type of wave demonstrated in the third video above.

Surface Wave: Also known as a Love wave, the surface wave is much slower than the p-wave or s-wave. A surface wave is a combination of a transverse and a longitudinal wave in which the particles vibrate both

perpendicularly and parallel to the direction of energy transfer. An object struck by a surface wave would vibrate both north-south and east west. The result is that the objects move in a circle. This is the most destructive of the three types of wave. A surface wave is similar to the ripples you see when an object is dropped into a body of water. Observe a QuickTime video of this type of wave. Notice the motion of the ball floating in the water. If you watch closely, you can see the circular motion.
http://utahscience.oremjr.alpine.k12.ut.us/sciber08/8th/geology/html/wavenrgy.htm)

9. Volcanoes:

During a volcano, the heat energy is transferred through lava to the Earth's surface. The magma may come up to the surface as maglavama bringing heat energy with it. The volcanoes which erupt on the island of Hawaii are an example of this transfer of heat energy. Notice, the lava is very hot as it comes up to the surface. The lava immediately begins to cool. As the heat escapes, the lava hardens to dark black rock. Magma which becomes trapped below the surface can build up pressure that must be released as mechanical energy. An example of this release of mechanical energy was the eruption of Mt. Saint Helens in Washington State. As the heat energy in the magma built up below the surface of the mountain, the pressure increased. This pressure was released in a gigantic explosion which blew off the top of the mountain.
(For more information and details see the references).

- ***How Paleomagnetism Supports the Seafloor Spreading Hypothesis?***

Plate Boundary Interactions

Plate Boundary: is a Border between two tectonic plates, which is usually an area of earthquake and volcano activity.

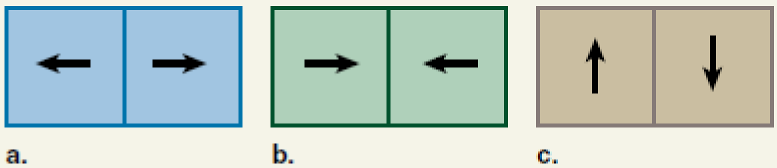


Figure 4.21 Three types of plate boundaries. (a) At a divergent boundary, plates move apart. (b) At a convergent boundary, plates move toward each other. (c) At a transform boundary, plates move parallel to one another in opposite directions.

Oceanic ridges and trenches, volcanoes, and earthquakes are just some of the phenomena present at the boundaries that separate the tectonic plates. The type and distribution of features are characteristic of the relative motions of the plates on either side of the boundary. We classify plate boundaries into three categories based on their relative plate motions:

• **<u>Divergent plate boundaries</u> occur where plate motions cause plates to move apart** (Figures 4.19, 4.21a). For example, South America and Africa are on either side of the Mid-Atlantic Ridge, a divergent plate boundary (see Chapter Snapshot).

The evolution of a divergent plate boundary has three recognizable stages that we can loosely characterize as birth, youth, and maturity. The birth of a divergent boundary occurs when an existing piece of continental lithosphere begins to break apart. Such a location is characterized by thinning of the lithosphere, often accompanied by volcanic activity (Figure 4.22). This process is happening today on the continent of Africa, in an area known as the East African Rift zone (Figure 4.23, Chapter Snapshot). As the continental lithosphere breaks apart, it **forms a wide, steep walled depression known as a rift valley (Figure 4.22a).** The underlying asthenosphere is close to the surface below the rift valley, and decompression melting generates magma that forms volcanoes. Eventually, the continental crust in the rift valley separates to form a gap where rising magma creates new oceanic floor. Inflow of seawater forms a narrow ocean (the youth stage), much like the Red Sea to the north of the East African Rift zone that separates the Arabian peninsula from Africa (Figures 4.23; 4.28). It takes millions of years for narrow oceans to expand to form a mature ocean like the present-day Atlantic or Pacifi c Ocean because the rates of plate motions are so slow (Figure 4.22c).

• **<u>Convergent plate boundaries</u> occur where plate motions cause plates to collide with each other** (Figures 4.19, 4.21b). This most commonly occurs where plates move toward each other—for example, along the Peru- Chile trench where the Nazca plate meets the western edge of the South American plate (see Chapter Snapshot).

Oceanic lithosphere is consumed at subduction zones where it descends into the mantle beneath trenches. The less dense crust of the continental lithosphere does not descend into subduction zones but is piled up to form high mountain belts at convergent boundaries. Convergent boundaries come in three varieties, depending on the types of lithosphere involved in the collision (Figure 4.25).

- ***Oceanic Plate versus Oceanic Plate Convergence.***
- ***Oceanic Plate versus Continental Plate Convergence.***
- ***Continental Plate versus Continental Plate Convergence.***

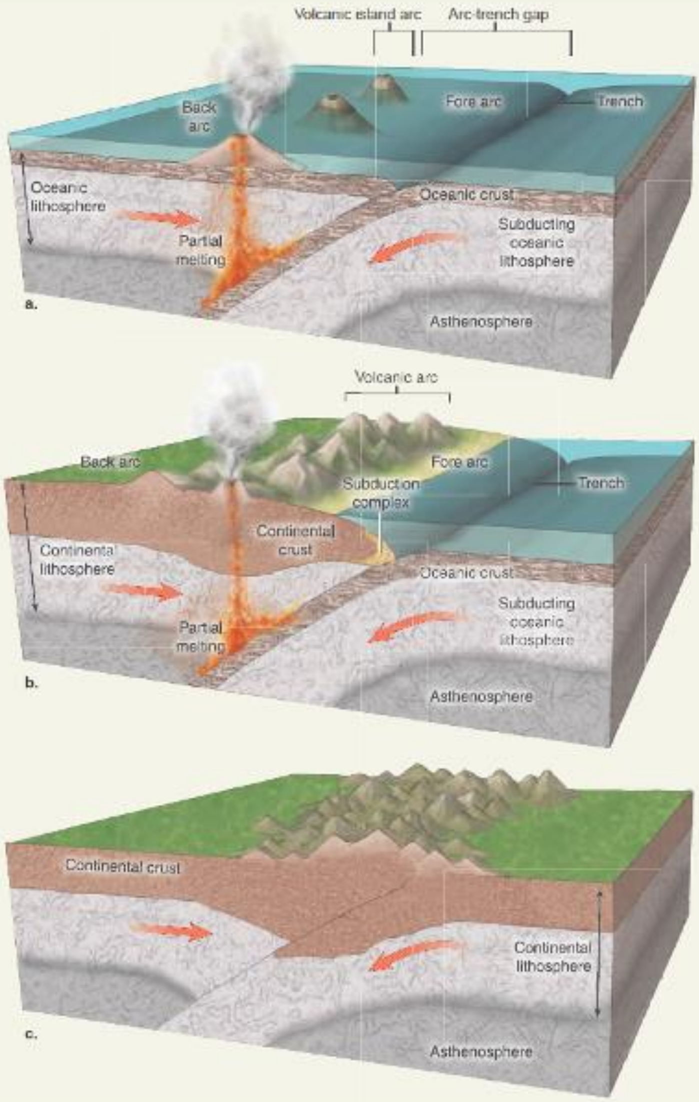


Figure 4.25 Cross sections of convergent plate boundaries. (a) When two oceanic plates collide, the plate with the older (cooler, denser) lithosphere descends into the subduction zone. A chain of volcanic islands (island arc) forms on the overriding plate. (b) In an oceanic-continental collision, the oceanic plate descends, and a chain of volcanoes forms on the continental plate. (c) A continental-continental collision is marked by a high mountain range but little volcanic activity. Crustal thickness is increased, but scientists still debate the fate of the mantle lithosphere in this type of collision.

Prepared by
Dr. Rami M. Idan
Petroleum Geologist

• **<u>Transform plate boundaries</u> occur where plates slide past each other** (Figures 4.19, 4.21c) without opening a gap or undergoing a direct collision, like two cars driving in opposite directions on different sides of the same street. For example, a thin strip of southwest California is separated from the rest of North America by a transform boundary along the San Andreas Fault system (see Chapter Snapshot).

<u>The Mechanism for Continental Drift</u>

Seafloor spreading is the mechanism for Wegener's drifting continents. Convection currents within the mantle take the continents on a conveyor-belt ride of oceanic crust that, over millions of years, takes them around the planet's surface. The spreading plate takes along any continent that rides on it. Seafloor spreading is the topic of this Discovery Education video:

- http://video.yahoo.com/watch/1595570/5390151.

The history of the seafloor spreading hypothesis and the evidence that was collected to develop it are the subject of this video:

- http://www.youtube.com/watch?v=6CsTTmvX6mc&feature=rec-LGOUT-exp_fresh+div-1r-2 (8:05).

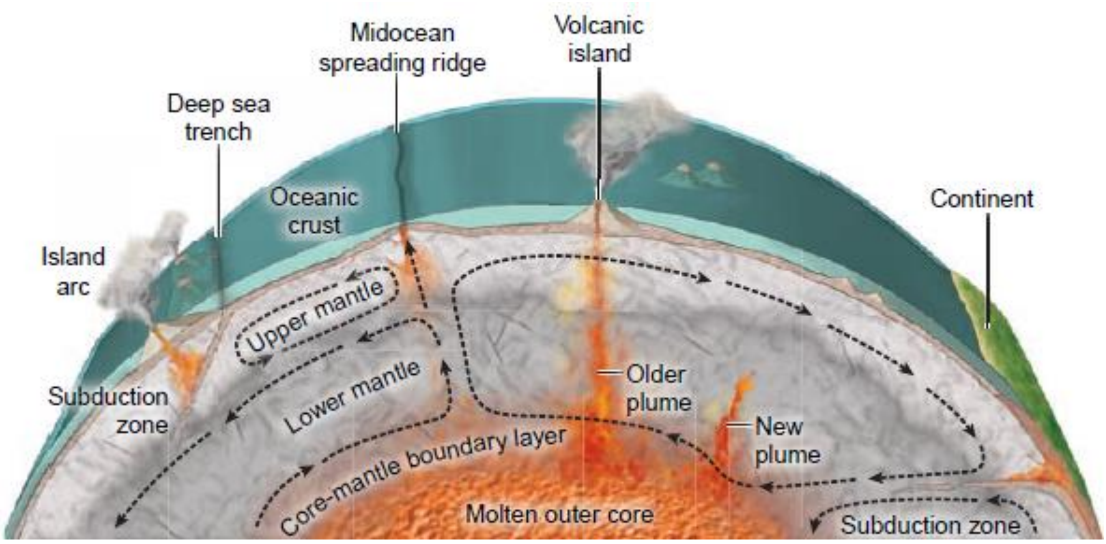
The Theory of Plate Tectonics—what is a Plate?

During the 1950s and early 1960s, scientists set up seismograph networks to see if enemy nations were testing atomic bombs. These seismographs also recorded all of the earthquakes around the planet. The seismic records were used to locate an earthquake's epicenter, the point on Earth's surface directly above the place where the earthquake occurs.

Why is this relevant? It turns out that earthquake epicenters outline the plates. This is because earthquakes occur everywhere plates come into contact with each other. In addition to this, a vast number of volcanoes from around the world are also located where plates meet. With this evidence and the combined evidences about Sea Floor Spreading, magnetic striping of the ocean floor, and more, the answer to what could cause the Continents to Drift apart became real. The Plate Tectonics theory provides the answers to the two questions that Alfred Wegener could not explain. 1) What causes plates to move, and what force could cause this to happen? Today, our general understanding about the Plate Tectonic Theory is that the Earth is divided into several crustal plates composed of oceanic lithosphere and thicker continental lithosphere, each topped by its own kind of crust. Tectonic plates are able to move because the Earth's lithosphere has a higher strength and lower density than the underlying asthenosphere. Along convergent boundaries, subduction carries plates into the mantle; the material lost is roughly balanced by the formation of new (oceanic) crust along mid-ocean ridges by seafloor spreading. In this way, the total surface of the globe remains the same. Tectonic plates are able to move because the Earth's lithosphere has a higher strength and lower density than the underlying asthenosphere. Plate movement is thought to be driven by a combination of the motion of the seafloor away from the mid-ocean ridges (due to variations in topography and density of the crust, which result in differences in gravitational forces) and drag, downward suction, at the subduction zones.

[Synopsis: Hot magma in the earth moves toward the surface, cools, and then sinks again and creates convection currents beneath the plates that cause the plates to move] as shown in video below.

https://www.youtube.com/watch?v=ryrXAGY1dmE



The concept of the convection currents and its implication in plate movement.

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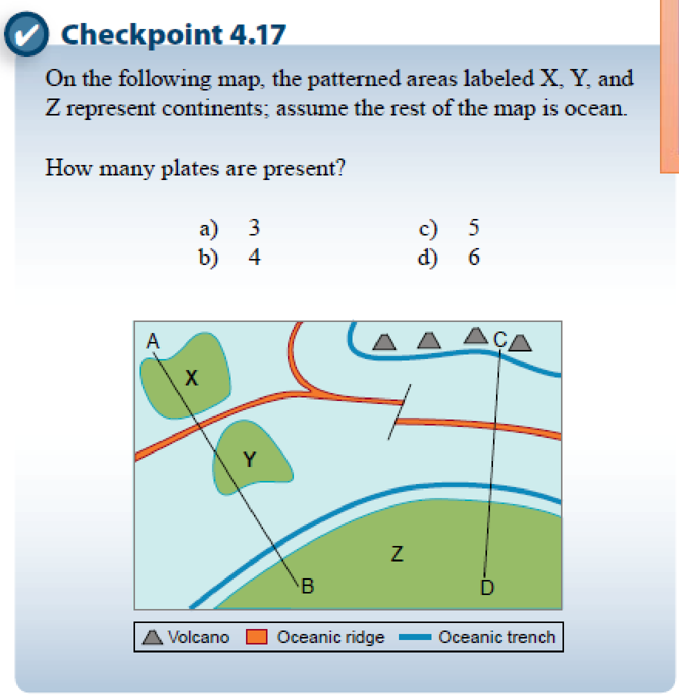
Utah State Office of Education, 2013. Earth Science.

Wicander, R., and Monroe, J. S. 2010. Historical geology-Books-Cole.

Homework:

Prepared by
Dr. Rami M. Idan
Petroleum Geologist


Checkpoint 4.17

On the following map, the patterned areas labeled X, Y, and Z represent continents; assume the rest of the map is ocean.

How many plates are present?

a) 3
b) 4
c) 5
d) 6

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Lecture THREE

Prepared by
Dr. Rami M. Idan
Petroleum Geologist

Rocks and Minerals

by

Dr. Rami M. Idan

What is the mineral?

Minerals: Naturally occurring, inorganic solids of one or more elements that have a definite chemical composition with an orderly internal arrangement of atoms.

1. A mineral occurs naturally forms by natural processes not in the laboratory.

2. A mineral is solid which cannot be a gas or a liquid.

3. A mineral has a definite chemical composition, which is expressed by a specific chemical formula.

- Calcite ($CaCO_3$)
- Quartz (SiO_2)
- Pyrite (FeS_2)

or made of only one type of atom (element) are called native elements.

- Gold (Au)
- Copper (Cu)
- Silver (Ag)

4. A mineral's atoms are arranged in an orderly pattern. Highly ordered atomic arrangement of atoms are in regular geometric patterns. So, minerals are crystals with a repeated inner structure.

5. A mineral is inorganic (was never alive) that mean minerals are not made from living things.

From the almost 4000 known minerals, only about 30 are common. The most common are quartz, feldspar, mica, and calcite. These minerals make up most of the rocks found in the Earth's crust. In fact, over 60% of the Earth's crust is made up of the family of minerals known as feldspar.

To be able to identify these and other minerals, we need to look at the properties used to separate and distinguish these minerals.

Types of minerals:

Minerals are most commonly classified by chemical composition. The 2 main groups are silicates and non-silicates.

1. Silicates:

Silicates are minerals containing a combination of silicon (Si) and oxygen (O). Silicate minerals comprise about 90% of the Earth's crust. Silicates minerals often contain other elements such as Al, Fe, Mg, and K.

a) Feldspar:

Feldspar minerals make up half of the Earth's crust and are the main component of most of the rocks found on the Earth's surface. Feldspar contains Si, O, Al, K, Na, and Ca. The feldspar minerals are Albite, Anorthite, orthoclase, and Plagioclase.

b) Mica:

They are soft and shiny minerals that which can be separated easily into sheets. Biotite and Muscovite are the main minerals of mica group.

c) Quartz:

Quartz is the Silicon dioxide (SiO_2) which it the basic building blocks of many rocks.

Prepared by
Dr. Rami M. Idan
Petroleum Geologist

2. Non-silicates:

They are minerals that do not contain the combination of Si oxides. Non-silicates are divided into:

a) Native Elements:

Native elements are composed of only one element. About 20 exist including Au, Pt, C, Cu, S, and Ag.

b) Carbonates:

Contain the combinations of Carbon and Oxygen in their chemical structure. Calcite ($CaCO_{3)}$ is an example.

c) Halides:

Form when atoms containing fluorine, chlorine, iodine, or bromine (halogens) combine with potassium or calcium.

- Halite (NaCL) is better known as rock salt.
- Fluorite (CaF_2) can have many different colors.

d) Oxides:

These compounds formed when elements like aluminum or iron bond with oxygen. Corundum (Al_2O_3) and Magnetite (Fe_3O_4) are important oxides.

e) Sulfates:

These minerals are containing sulfur and oxygen (SO_4).

- Gypsum ($CaSO_{4.}2H_2O$) is a common example.

f) Sulfides:

Minerals containing one or more elements such as lead, iron, or nickel combines with sulfur. Galena (PbS) is a sulfide.

Where do Minerals come from?

In general, minerals form in four ways:

1. Magma:

Magma is molten material from the mantle that hardens or crystallizes to form rock. Lava is magma that reaches the surface. Minerals form as hot magma cools inside the crust, or as lava hardens on the surface. When these liquids cool to the solid state, they form crystals of the minerals.

Size of Crystals (minerals):

The size of any mineral crystals depends of several factors:

a) The rate at which the magma cools.

b) The amount of gas that magma contains.

c) The chemical composition of the magma.

When magma remains deep below the surface, therefore, minerals that form in plutonic rocks have plenty of time to grow into large crystals as the magma cools slowly. Slow cooling leads to the formation of large crystals. Magma closer to the surface cools much faster, producing smaller crystals.

2. Minerals from Hot Water Solutions:

Sometimes, the elements that form a mineral dissolve in hot water and form a solution. A solution is a mixture in which one substance dissolves in another. When a hot water solution begins to cool, the elements and compounds leave the solution and crystallize as minerals. This can happen on the ocean floor when ocean water seeps down through cracks in the crust.

3. Minerals formed by Evaporation:

Minerals can also form when solutions evaporated. The water in restricted lakes dissolves the elements in the substrate. Evaporated water cannot carry these elements due to heaviness of their atomic weight in respect to water. As a result, the residual element bonded together to

make new minerals. Several useful minerals from by the evaporation are rock salt, Gypsum, and Calcite.

4. Minerals formed by Metamorphism:

When rocks are put under extreme heat and pressure, the chemical composition of the rock can change or re-arrange forming new minerals like Garnet.

Economic Importance of Minerals:

Minerals are in many things we see and use everyday such as; bricks, glass, cement, plaster, iron, gold.

e.g.

- Halides are often used in making fertilizers.
- Sulfates are commonly used in cosmetics, toothpaste and paints.
- Sulfides are used to make batteries, medicines and electronic parts.
- Carbonates are used in cement, building stones and fireworks.

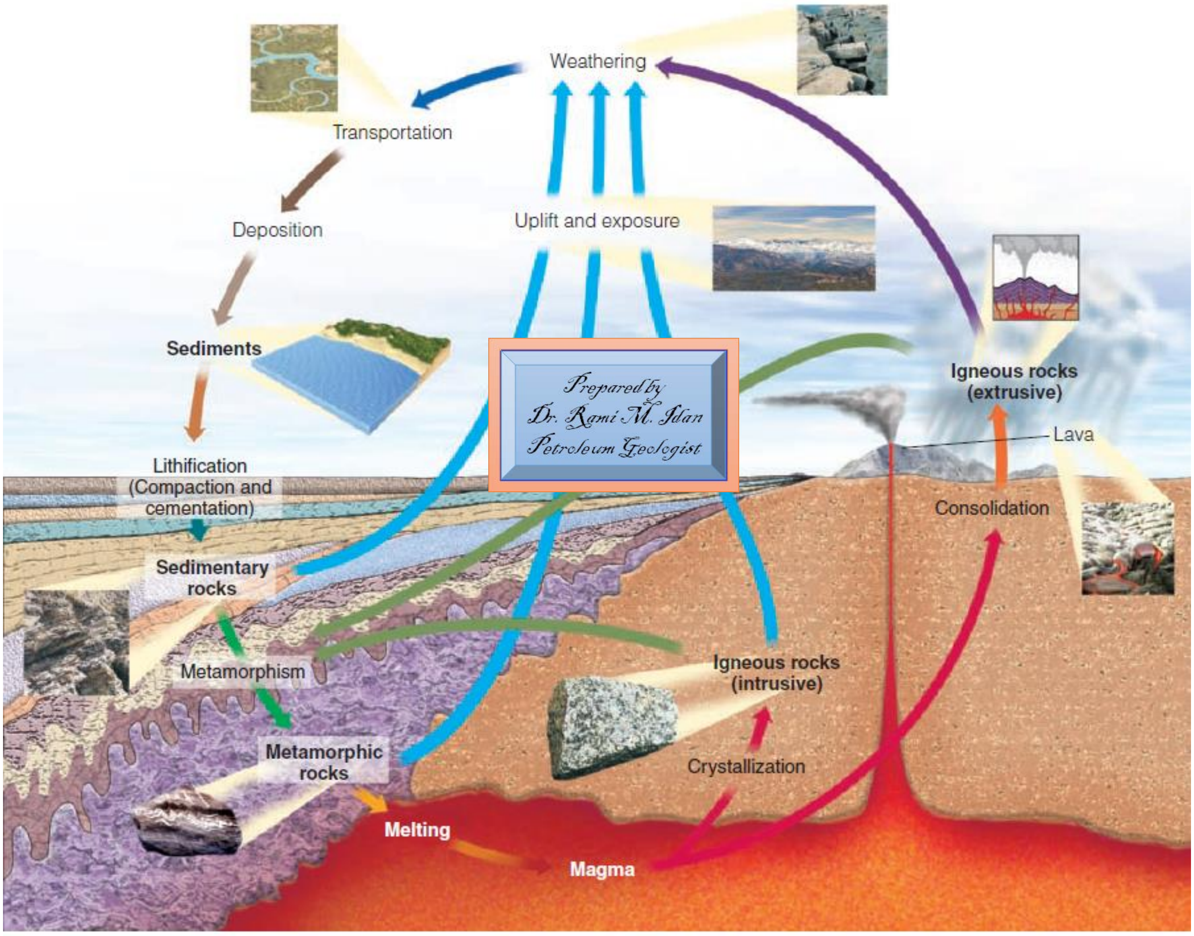
What is the rock?

Rock is composed of an aggregate of one or more minerals.

The Rock Cycle:

Minerals form rocks, as well as, all rocks can be transformed into other rock types. Rocks are divided into 3 categories.

- Igneous Rocks- crystalline from Magma when liquid cools.
- Metamorphic Rocks- crystalline from heated and/or pressed rocks.
- Sedimentary Rocks - non-crystalline- smaller pieces or chemicals from other rocks.



• Figure 2.7 The Rock Cycle This cycle shows the interrelationships among Earth's internal and surface processes and how the three major rock groups are related. An ideal cycle includes the events on the outer margin of the cycle, but interruptions indicated by internal arrows are common.

The Rock Cycle (in Wicander and Monroe, 2010)

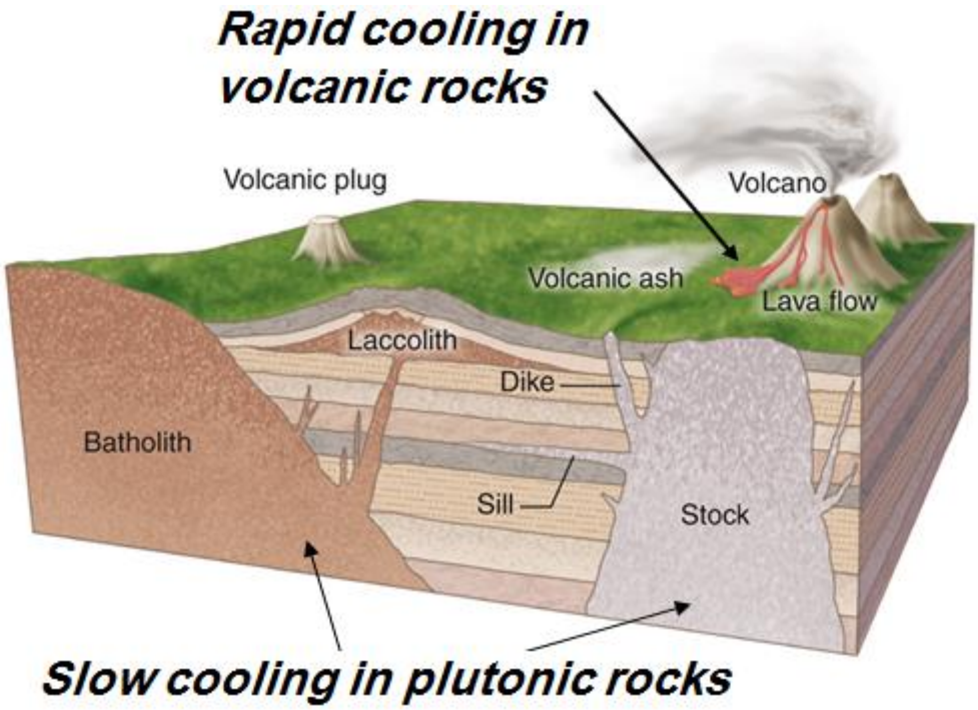
Igneous Rocks:

Igneous Rocks: are formed from crystallization of magma which the Magma is a molten rock while Lava is a magma that is on the Earth's surface.

Two Main Types of Igneous Rocks: Two types of igneous rocks are classified based on texture and composition (*The same magma can form both rock types*).

- **Volcanic rocks:** form when magma rises to Earth's surface produces volcanoes, lava flows, tephra. The molten rock cools rapidly due to low temperatures and pressure, resulting "Fine Texture".

- **Plutonic rocks:** form when magma solidifies below Earth's surface produces **plutons** that remain hidden until exposed by erosion. Molten rock cools slowly, resulting "Coarse Texture". Batholith, stock, sill, dike, laccolith are the best example of plutons.
- There are another type of Igneous Rocks known as **Intermediate Rocks**, which located somewhere near to the surface.

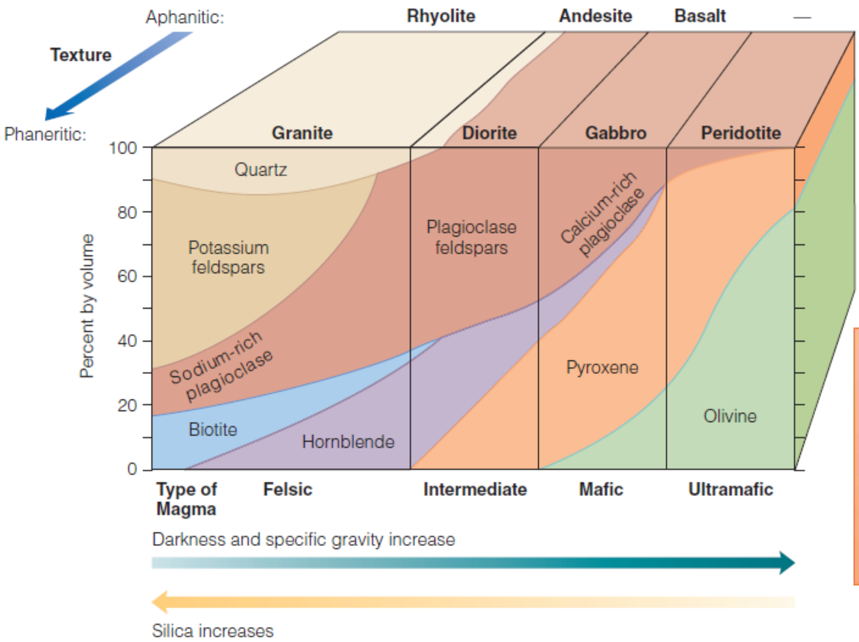


<u>Texture:</u> is the size of crystals of minerals in igneous rocks depends on rate of cooling of magma.

- Fine-grained (***aphanitic***) rapid cooling produces microscopic crystals.
- Coarse-grained (***phaneritic***) slow cooling produces large, visible crystals.
- Some igneous rocks, though, have a combination of markedly different-sized minerals—a so-called ***porphyritic texture***; the large minerals are ***phenocrysts***, whereas the smaller ones constitute the rock's ***groundmass.***
- A ***glassy texture*** results from cooling so rapidly that the atoms in lava have too little time to form the three-dimensional framework of minerals. As a result, the natural glass ***obsidian*** forms.

Color of Igneous Rocks:

With few exceptions, the primary constituent of magma is silica, but the silica content varies enough for us to recognize magmas characterized as ***felsic*** (>65% silica), *intermediate* (53–65% silica), ***mafic*** (45–52% silica), and ***ultramatic*** (<45% silica).Felsic magma also contains considerable sodium, potassium, and aluminum, but little calcium, iron, and magnesium. In contrast, mafic magma has proportionately more calcium, iron, and magnesium. Intermediate magma, of course, has a composition between those of felsic and mafic magmas.



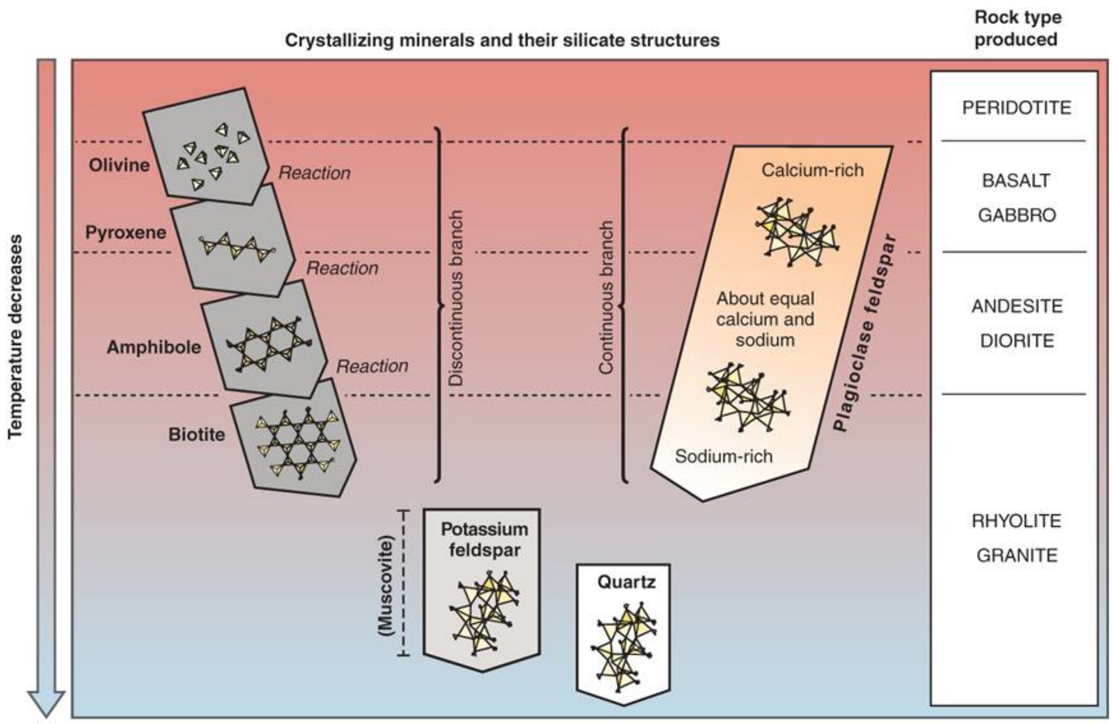
• Figure 2.10 **Classification of Igneous Rocks** This diagram shows the proportions of the main minerals and the textures of common igneous rocks. For example, an aphanitic (fine-grained) rock of mostly calcium-rich plagioclase and pyroxene is basalt.

Composition of the magma:

It is a slushy mix of molten rock, gases, and mineral crystals which the common elements are; oxygen (O), silicon (Si), aluminum (Al), iron (Fe), magnesium (Mg), calcium (Ca), potassium (K) sodium (Na). While the most abundant compounds in magma is silica (Sio_2), which make the greatest effect on magma characteristics and affects the melting temperature and viscosity of magma.

Bowen's Reaction Series:

N.L. Bowen a Canadian scientist in 1900's stated that "as magma cools, minerals form in predictable patterns" now-a-days known as Bowen's Reaction Series.



Discontinuous Chain: Magnesium (Mg) cools around 1800^0C, when olivine crystallizes, this continuous up to 1557°C. Now Pyroxene begins to form. All olivine that was formed is now turned to pyroxene. Quartz is the last to form, because silica and oxygen are the last to crystallize.

Continuous Chain: First Feldspars are rich in Calcium (Ca). Sodium (Na) increases as cooling continues. Last Feldspars to form are Sodium rich Feldspar.

Sedimentary Rocks: form as horizontal layers (beds), identified based on composition, thickness, as well as, oldest beds at bottom and the youngest at top. Sedimentary rocks are subdivided into three types, which they Clastic, Chemical, and Biochemical, and Identified by materials that make up the rock and/or the process by which they formed.

Clastic Sedimentary Rocks (also called "**Detrital**")

The most common type of sedimentary rock composed of mineral and rock fragments from older rocks. Three stages of formation

Generation: Physical and chemical breakdown of any rock at Earth's surface (weathering) to form sediment (rock and mineral fragments). Sediment classified by grain size into

Sediment		Rock
Clay	↓ *Increasing grain size*	Shale
Silt		Siltstone
Sand		Sandstone
Gravel		Conglomerate or Breccia

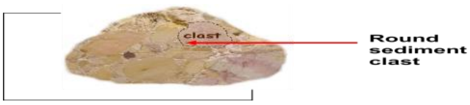
Transportation, (Erosion) happened when sediment moved from place of origin by streams, wind, glaciers. Size of transported grains depends on velocity of transport agent.

Lithification: when sediment deposited due to decreases of velocity of the transport agent, the larger grain sizes deposited first, finest grains remain in suspension and are deposited last. Over time, sediment is slowly compacted and grains are cemented together to form a new rock.

Some of Sedimentary clastic rocks

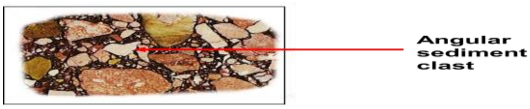
1) Conglomerate

Consist of poorly sorted *rounded* gravel size particles. Form in shoreline and river environments where mixtures of sediments are deposited. The *rounded* rock fragments suggest that the sediment was transported great distances. This allowed angular edges to be eroded to produce rounded fragments.



2) Breccia

Consist of poorly sorted, *angular* gravel size particles. Form in shoreline and river environments where mixtures of sediments are deposited. The *angular* rock particles suggest that the sediment was not transported far from the place where it originated, thus angular fragments.

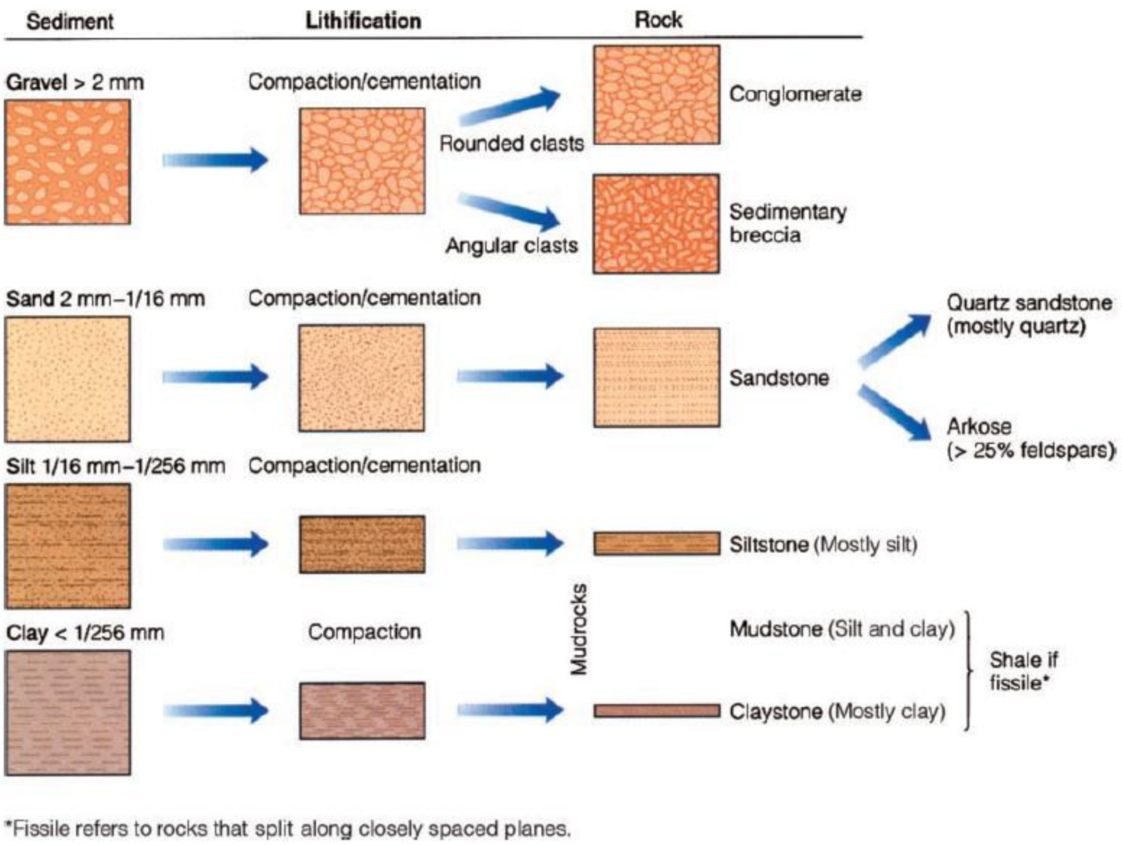


3) Sandstone

Consist of well sorted sand size particles. Sand size sediment is a result of erosion due to wind, water, and ice acting on rock fragments over a long period of time.

4) Shale

Consist of fine clay sized particles compacted to form thin layers. Form in deeper water environments where clay is transported and deposited.



• Figure 2.13 **Lithification and Classification of Detrital Sedimentary Rocks** Notice that little compaction takes place in gravel and sand, that two types of sandstone are shown, and that mudrock is a collective term for detrital sedimentary rocks made up of silt and clay.

Chemical Sedimentary Rocks:

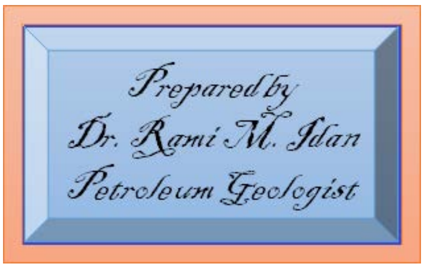
Form when minerals precipitate (crystallize) from a solution (fresh water in lakes, groundwater or seawater) as a result of changing in physical conditions which is commonly temperatures (evaporation). Some of chemical rocks are

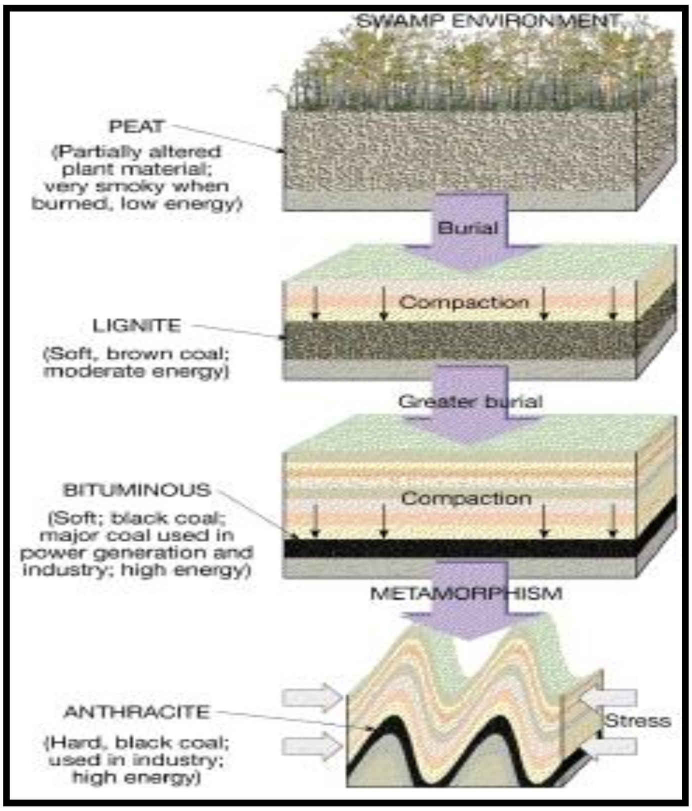
1) **Gypsum:** This is hydrated calcium sulphate; the sulphates are the second major group to form as sea water evaporates.

2) **Anhydrite:** This is calcium sulphate without the bound molecular water that defines gypsum.

Biochemical Sedimentary Rocks:

Form due to actions of living organisms that cause minerals to be extracted from solution (The mineral calcite is present in the rock limestone formed by coral organisms that build tropical reefs) or from the remains of dead organisms like <u>Coquina</u> which is limestone formed from broken shell fragments. These rocks link the biosphere and lithosphere in subsystem interaction.





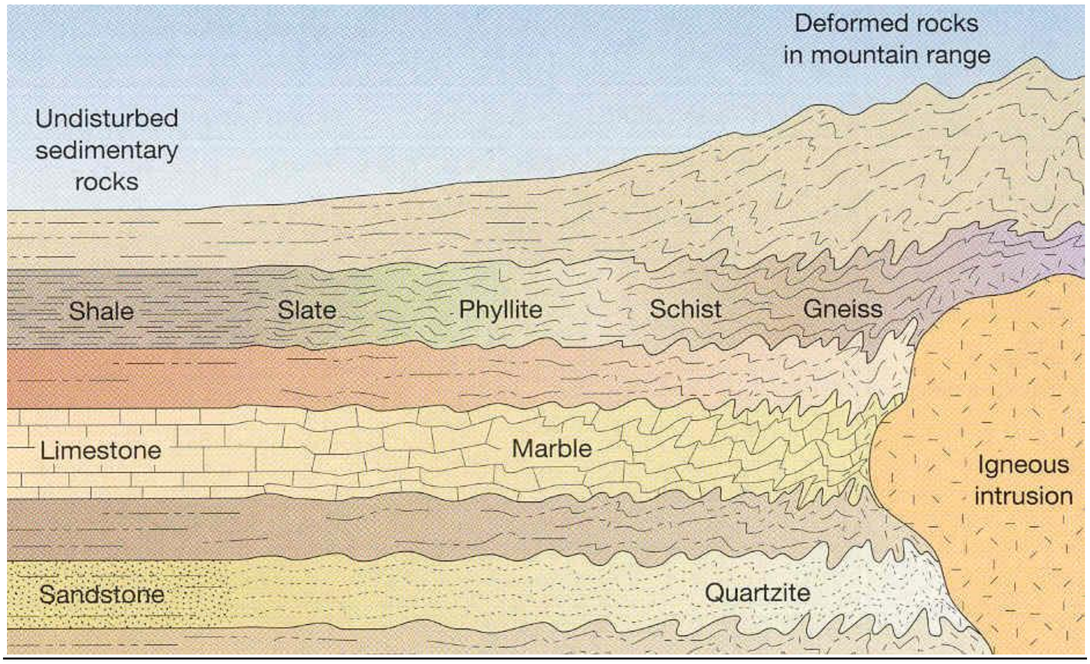
Coal is the important biochemical rock.

Metamorphic Rocks:

Metamorphism: Are changes in mineral composition and texture that can occur in any solid rock. These changes are due to increasing **temperature** and/or **pressure** and/or the **presence of fluids.** In this case, Temperatures are high enough to promote chemical reactions but not high enough to cause melting. The temperature reaches approximately 200 ^{o}C -1100 ^{o}C, depending on rock type and conditions. Similar temperatures found deep in crust or near magma chambers

There are two types of **metamorphism**

1. Contact metamorphism: Changes due to increases in temperature where rocks come in contact with heat source (e.g. magma chamber). Example: limestone around a magma chamber is baked by heat to form marble.



Contact metamorphism, note that each rock metamorphose to its equivalent.

2. Regional metamorphism: Increased heat and pressure associated with plate tectonic processes that form mountains. Increased pressures and temperatures cause tabular minerals to take on a preferred orientation, known as **foliation**, perpendicular to direction of pressure.

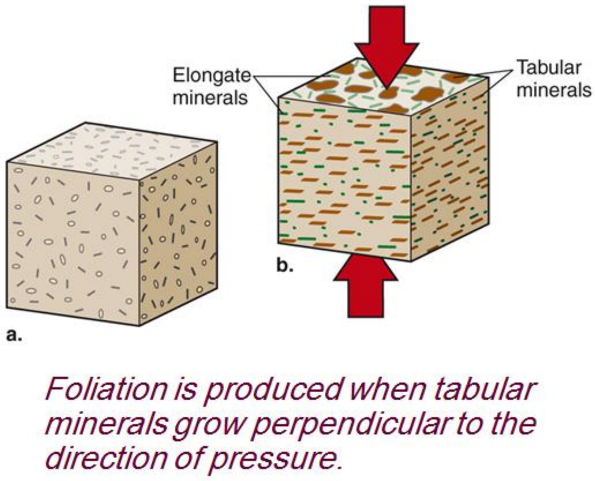


Table 7.6 Metamorphic Rocks Based on Foliation and Texture (Grain Size)

	Grain size		
Foliation	**Fine (< 0.1 mm)**	**Medium (~0.1–4 mm)***	**Coarse (> 2 mm)***
No	Hornfels	Marble, quartzite	Marble, quartzite
Yes	Slate, phyllite	Schist	Gneiss

<u>Common metamorphic rocks</u> (depend on rock texture)

<u>Non-foliated rocks</u>

<u>Quartzite</u>: Formed from a parent rock of quartz-rich sandstone. Quartz grains are fused together. It forms in intermediate T, P conditions.

Photomicrograph (26.6x)
Sample width is 1.23 mm

Sample of quartzite

<u>Marble</u>: Coarse and crystalline and it parent rock are usually limestone which is composed of calcite crystals and the fabric can be random or oriented.

Photomicrograph (6.5x)

Marble (non-foliated)

<u>Foliated rocks</u>

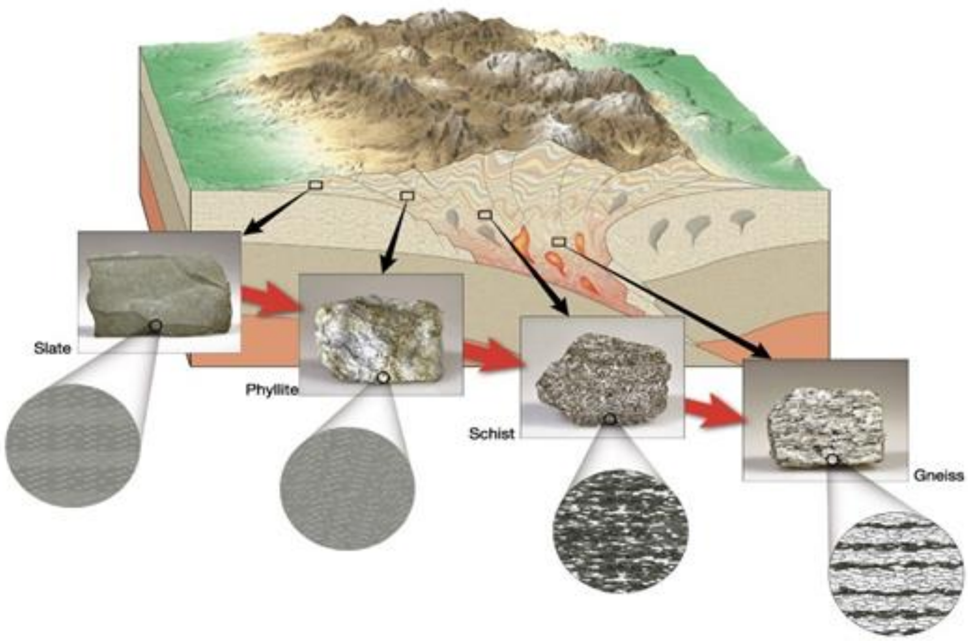
<u>Slate</u>: very fine-grained with excellent rock cleavage, often perpendicular to original made by low-grade metamorphism of shale.

Phyllite: Grade of metamorphism between slate and schist, made of small platy minerals, glossy sheen with rock cleavage, composed mainly of muscovite and/or chlorite.

Schist: Medium- to coarse-grained, comprised of platy minerals (micas), the term *schist* describes the texture. To indicate composition, mineral names are used (such as mica schist).

Gneiss: Medium- to coarse-grained, banded appearance High-grade metamorphism Composed of light-colored feldspar layers with bands of dark mafic minerals.

Change in metamorphic grade with depth



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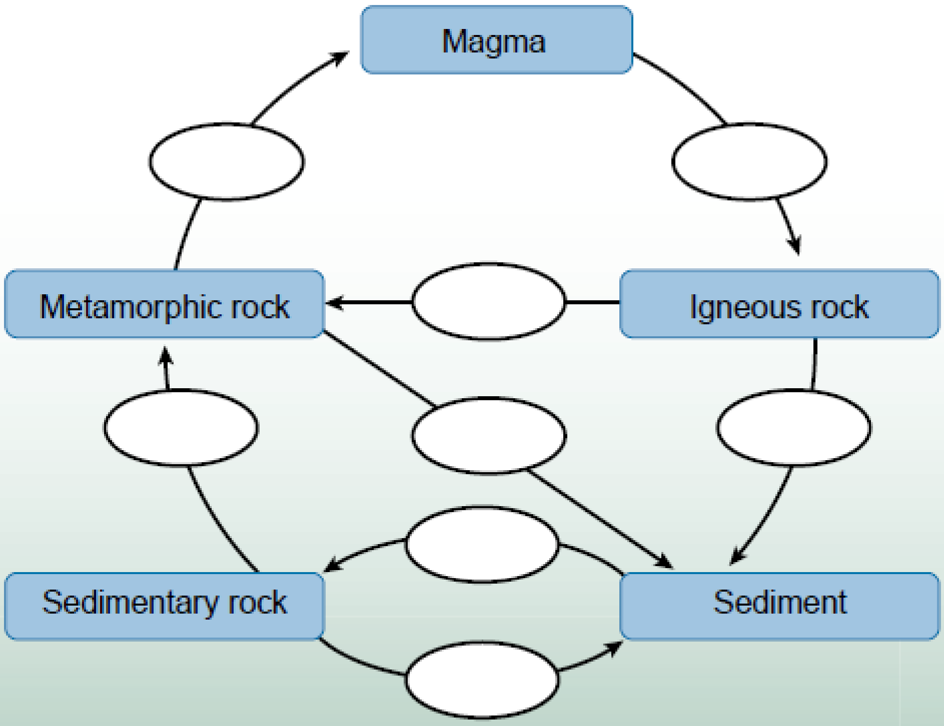
Prepared by
Dr. Rami M. Idan
Petroleum Geologist

Checkpoint 7.22

Rock Cycle Diagram

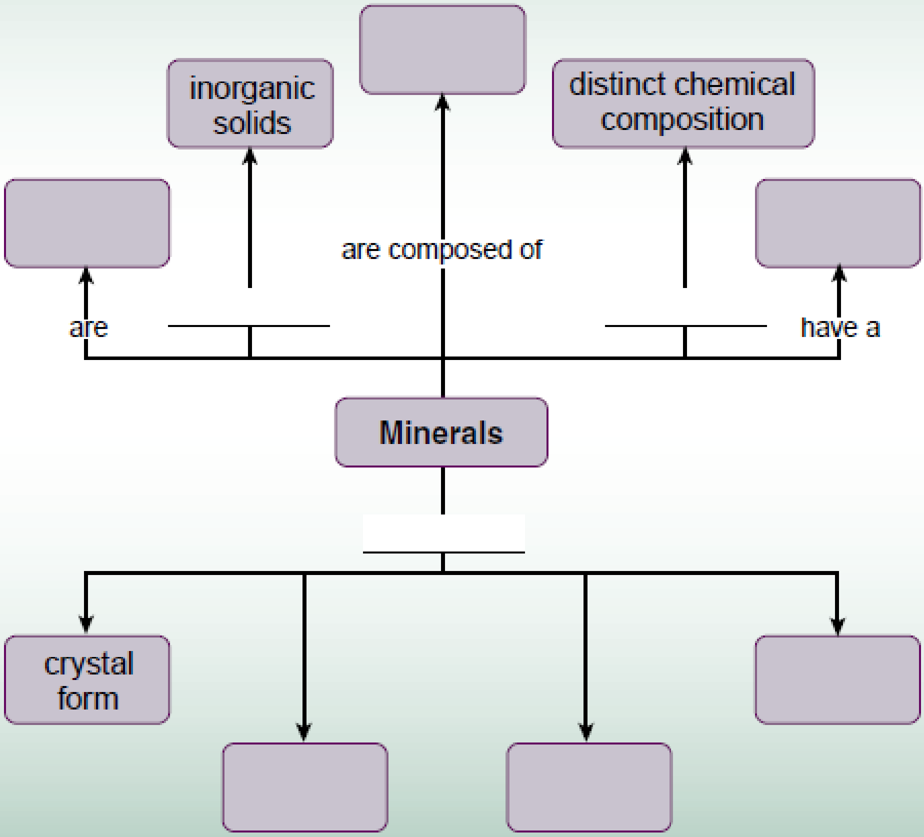
The following diagram illustrates the rock cycle. Match the lettered responses to the blank ovals on the diagram. (Note: some letters are used more than once.) Example: If you believe that metamorphic rock is converted to magma by cementation and compaction, enter "a" in the top left oval.

a) Cementation and compaction (lithification)
b) Heat and pressure
c) Weathering, transportation, deposition
d) Cooling and solidification
e) Melting



Checkpoint 7.6

Finish the partially completed concept map for minerals provided here. How could you add additional levels to the concept map?



Prepared by

Dr. Rami M. Idan

Petroleum Geologist

Al-Karkh University for Sciences
College of Remote Sensing and Geophysics
Geophysics Department

Lecture FOUR

Weathering and Mass Wasting

Prepared by
Dr. Rami M. Idan
Petroleum Geologist

by
Dr. Rami M. Idan

Introduction

Weathering is a process of a slow continuous breakdown of rocks into smaller particles that are in equilibrium with the prevailing environment. This process involves both decomposition (chemical breakdown) and disintegration (physical breakdown) of rocks and minerals. When particles are moved from their place of formation (either by moving water, wind, glaciers, and gravity), the process is called **Erosion**. Hence, products of weathering are a major source of sediments for both erosion and deposition. Additionally, weathering also contributes to the formation of soil by providing mineral particles like sand, silt, and clay. The fact that oceans are saline is also due to the release of ion salts from rocks and minerals caused by weathering.

Weathering and Erosion terms are often used interchangeably. The other name for Erosion is Mass Wasting.

Mass Wasting is simply the down slope movement effected by gravity. The sample of Mass Wasting are: rock falls, slumps, and debris flows.

Weathering is largely of ***two types***: physical (mechanical) and chemical. The third, biological, only forms a small fraction.

Physical weathering causes the parent rock to break into smaller fragments (reduction in size), but without changing the chemical composition of the parent material.

Chemical weathering changes the composition of the parent rock through chemical reactions. In it, the mineral constituents react with chemically active reagents such as H2O, CO2, O2, or organic acids to form new minerals and/or to dissolve elements from minerals. Both physical and chemical weathering operates together and one often assists the other.

Types of Weathering

The Chemical, Physical, and Biological are the three major categories of weathering that work together to breakdown rocks and minerals into smaller fragments and into minerals that are more stable (and in equilibrium) near the earth's surface or with the prevailing environment.

Physical Weathering

The breakdown of minerals or rock materials by entirely mechanical means. In this process, the chemical composition of the weathered rock (mineral) remains unchanged. Some of the breaking forces actually originate within the rock or mineral itself, while others are applied externally. The stresses (both internal and external) lead to increased strain that finally ruptures the rock. This mechanical rupture is largely due to ❶abrasion, ❷crystallization of salt, ❸thermal insolation, ❹unloading (pressure-release), ❺and cycles of wetting and drying. *It must also be noted that a rock broken into smaller fragments exposes more surface area of the original rock, thereby also increasing the available channels and chances of weathering.*

Abrasion

When two rock surfaces come together causing mechanical wearing or grinding of their surfaces, abrasion occurs. This collision normally occurs through the erosional transport of materials by wind, water, and ice. Pure water is not abrasive but the collisions among rock, sand, and silt results in weathering. The wind hurls sand and other small particles against rocks, which results in sandblasting forming unusual and beautiful landforms. Glaciers also cause abrasion as they drag particles ranging in size from clay to boulders across the bedrock. In such a scenario, both the rock fragments (embedded in the ice) and the bedrock beneath are abraded.

Unloading or Pressure-Release

The removal of thick layers of sediments overlying deeply buried rocks by erosion or uplift is called Unloading or Pressure-release. Erosion removes the overlying rocks, and thus decreases pressure on the buried ones. Rocks are slightly elastic, hence, they respond to this pressure reduction by expanding. This results in the formation of fractures (cracks or fissures) parallel to the surface. With continued erosion, these rocks are exposed on the surface as slabs of rock that break off along the pressure-release fractures. These results in bare rock surfaces that are more resistant than the surrounding rocks. These are Exfoliation domes (large, rounded masses of rock) and the slabs of rock that break off are called Exfoliation sheets. Granite commonly fractures by exfoliation, a process in which large plates or shells split away like the layers of an onion. However, Exfoliation fractures are absent below a depth of 100 m, hence, they seem to be a result of exposure of the granite at the earth's surface.

Unloading plutonic Igneous rocks form depth also creates zones of weakness in them. Hence, when these rocks are exposed, they expand, and the zones of weakness open up as joints. Spalling, the vertical development of fractures, occurs because of the bending stresses of unloaded sheets across a three-dimensional plane.

Although, exfoliation is a form of pressure-release fracturing, however, some scientists have also attributed this to Hydrolysis where feldspars and other silicate minerals react to form clay. This water addition (change from Orthoclase Feldspar to Kaolinite) results in clay having a greater volume than that of the original mineral. Thus, a chemical reaction (hydrolysis) forms clay (Kaolinite), and the mechanical expansion of the clay contributes to exfoliation fractures in onion-shells.

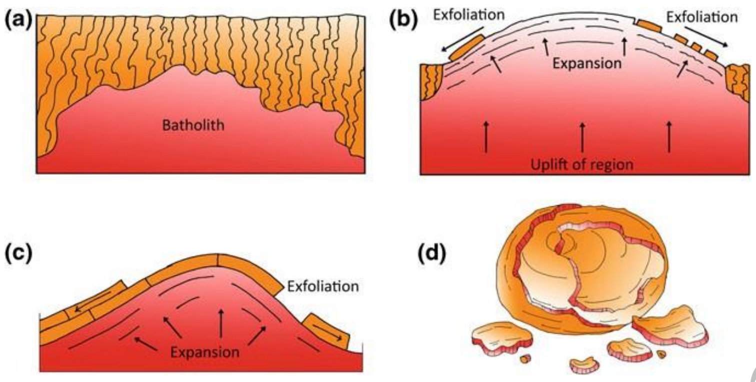


Fig. Unloading and Exfoliation. The great white granite domes and cliffs of the High Sierra (like the Half Dome, Yosemite, California, USA), owe their appearance to exfoliation. a These rocks were emplaced as molten bodies, or plutons, deep underground, raising the Sierra Nevada range. b Erosion unroofed the plutons and took away the pressure of the overlying rock. c As a result, the solid rock acquired fine cracks through pressure-release jointing. Mechanical weathering opened up the joints further and loosened these as slabs. d Granite commonly fractures by exfoliation, a process in which large plates or shells split away like the layers of an onion

Wetting and Drying

Slaking is the alternate wetting and drying of rocks. It is an important contributor to weathering. The rock grains are pulled apart with great tensional stress due to the increasing thickness of water. About 20 cycles of alternating wetting and drying can disintegrate a rock sample.

Variation in Temperature

Insolation weathering is the physical breakdown of rock by expansion and contraction due to diurnal (daily) temperature changes (which at times on a daily basis can be as large as 30 °C or more). Heat causes expansion, and cooling cause contraction. The surface of the rock expands more than its interior, resulting in stress that eventually or finally causes the rock to rupture. This differential expansion and contraction may also be due to the variance in colors of individual grains of mineral within the rock. Dark colored minerals expand more due to their increased absorptive properties.

Freezing and Thawing

Water expands as much as 9 % of its volume as it is converted to ice. Freezing water can exert a pressure of 150 tons per square foot. Freezing and thawing occur on a daily cycle. The expansion force of water as it freezes can split any mineral or rock.

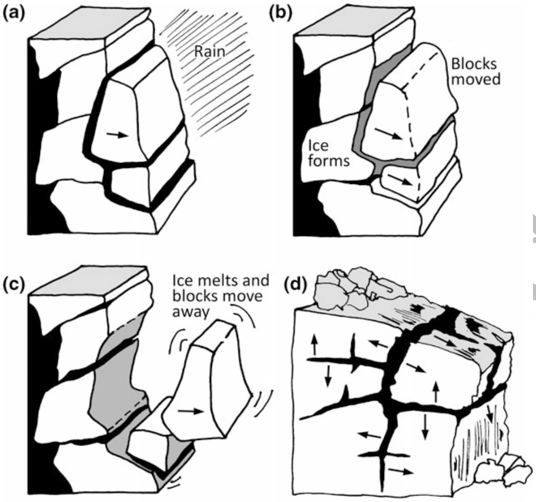


Fig. Frost wedging takes place when water seeps into cracks a, expands as much as 9 % of its volume as it freezes b, and pries loose angular pieces of rock (c–d). d Redrawn from Earth's Dynamic Systems with permission of Eric H. Christiansen

Chemical Weathering

Minerals in rocks are chemically altered by this process which subsequently decompose and decay. Increasing ❶ precipitation (rain) speeds up the chemical weathering process. In fact, water is an essential agent for chemical weathering. ❷Increasing temperature also accelerates chemical reactions causing minerals to degrade. Additionally, climate is another important factor affecting chemical weathering. ❸Climatic conditions control the rate of weathering that takes place by regulating the catalysts of . moisture

Dissolution and Solution

Dissolution occurs when rocks and/or minerals are dissolved by water.

Carbonodioxide (CO_2) dissolves in water (H_2O) to form Carbonic acid (H_2CO_3) which reacts chemically with minerals. This acid dissolves them or alters them into other minerals. The dissolved material is transported away . leaving a space in the rock

Hydration

Some minerals react with water and acid to take up hydrogen and remove other cations. This process is called Hydration. The combination of a mineral or element with water increases the size of the chemical structure, thereby leading to a softer, more stressed, and more easily decomposed mineral. Good examples of Hydration are the conversions (chemical changes) of Hematite to Limonite and of Anhydrite ($CaSO_4$) to Gypsum ($CaSO_4 . 2H_2O$), . when water is added

Oxidation

Oxidation is a chemical combination of oxygen with a compound. Oxygen combines with compound elements in rocks to form oxides. Oxidized minerals increase in volume and often become softer. Oxidation process is most evident in the weathering of iron-bearing minerals. A good example of this is ***Rusting***. Oxygen reacts with iron in minerals to .(form iron oxide, like Hematite (Rust

Hydrolysis

Hydrolysis is also one of the most important weathering process that brings changes in the soil profile. The carbonic .acid ionizes (breaks down) into two ions

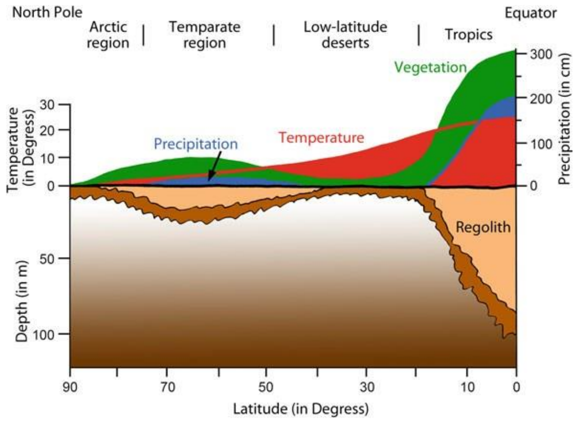


Fig. The type and extent of weathering is a function of the prevailing climate. The diagram shows the combined effects of precipitation, temperature, and vegetation. Weathering is most pronounced in the tropics, where precipitation, temperature, and vegetation reach a maximum. Redrawn from earth's Dynamic Systems with permission of Eric H. Christiansen

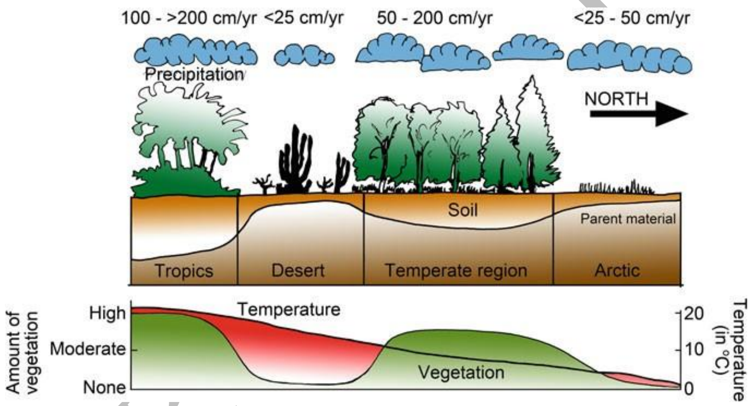


Fig. Tropical weathering rates are three and a half times higher where temperature, moisture, and vegetation are at their maximum, than the rates noted in temperate environments (note the higher amounts of eroded soil.

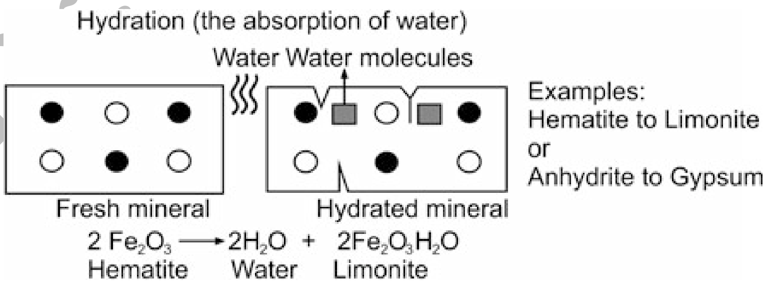


Fig. Hydration occurs when some minerals react with water and acids to take up hydrogen and remove other cations. Good examples are the conversions (chemical changes) of Hematite to Limonite. Others example is of Anhydrite ($CaSO_4$) to Gypsum ($CaSO_4 . 2H_2O$), when water is added

It occurs when water (often in the form of precipitation), disrupts the chemical composition and the size of a mineral, thereby creating a less stable mineral. Thus, less stable rock forms will also weather more readily.

Reduction

Reduction is the addition of one or more electrons. Hence, it is the reverse of Oxidation. Reduction in minerals results in electrically unstable compounds, more soluble ones, or more internally stressed ones.

Carbonation and Acidification

Carbonation is especially active when the reacting environment is abundant with CO_2. Carbonation is the reaction of carbonate and bicarbonate ions with minerals.

Biological Weathering

Living organisms, ranging from bacteria to plants to animals (including Lichens and Algae), breakdown rocks. This process of breakdown and their action is biological weathering.

Tree Roots

Tree roots grow into cracks and widen them, thus, facilitating physical weathering.

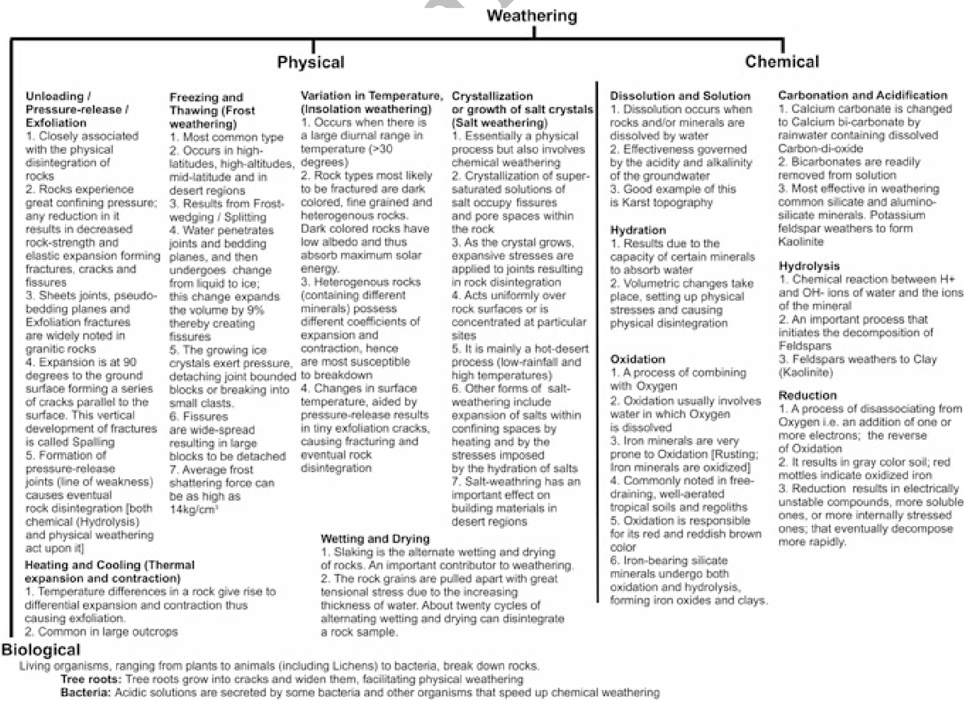
Bacteria

Acidic solutions are secreted by some bacteria and other organisms that speed up chemical weathering. Chitons and Limpets also facilitate biological weathering as they bore into beach rocks.

Prepared by
Dr. Rami M. Idan
Petroleum Geologist

<u>All in all, it must be noted that in a given area, although a single weathering process often dominates, but all three weathering processes (physical, chemical, or biological), often occur simultaneously.</u> *Hence, these processes cannot be separated from one another as all three proceed at the same time (though not necessarily at the same rate). Physical weathering helps chemical weathering by breaking rocks into smaller pieces, thus, allowing more surface area to be exposed. With more surface area, chemical reactions occur faster. Chemical weathering helps physical weathering by weakening the mineral grains that binds the rock together. Biological weathering helps both physical and chemical weathering. Trees fracture rocks with their roots, which make the rocks easier to break up physically, thereby, exposing more surface area for chemical weathering. Bacteria secretes acid solutions which speed up the chemical weathering process. Thus, working in concert, these three weathering processes can reduce a once resistant rock into nothing (as in case of limestones) or to easily erode into weaker materials (such as clays).*

Table: Summary of the three types of weathering, physical, chemical and biological



Weathering Products

Weathering by products include

(a) The complete loss of particular atoms or compounds from the weathered surface.

(b) The addition of specific atoms or compounds to the weathered surface.

(c) A breakdown of one mass into two or more masses, with no chemical change in the mineral or rock.

Thus, the residue of weathering consists of chemically altered and unaltered materials. The most common unaltered residue is ***Quartz*** which is resistant to chemical decay, and therefore, only undergoes size reduction during transportation. Other minerals such as feldspar, olivine, augite, and hornblende react with chemical reagents to produce various products.

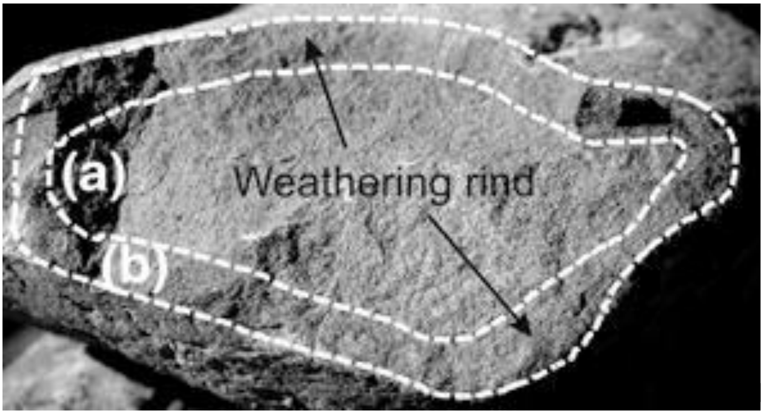
Weathering and Associated Rocks

When rock weathers, they usually do so by working inward from a surface that is exposed to the weathering process. This results in Spheroidal weathering, Exfoliation, and Weathering rinds.

Exfoliation

These are shells of weathering that form on the outside of a rock and become separated from the rock with the release of stress that results from changes in the volume of minerals that occur as a result of the formation of new minerals. This process is also called Onion-skin weathering.

Spheroidal Weathering



Weathering rind. Note the presence of an outer weathered zone (weathering rind) and an inner unweathered zone. As weathering progresses, the thickness of the weathering rind increases. It is, thus, sometimes also used as an indicator of the amount of time the rock has been exposed to the weathering process.

Rates of Weathering

Weathering rates are a function of the rock type, slope (topography), structure, and the prevailing climate. Rocks that are most resistant are composed of minerals that are relatively unaffected by chemical weathering. Quartz is a classic example which is unaffected by dissolution, hydrolysis and oxidation. Therefore, rocks composed almost exclusively of Quartz are more resistant than any other rock types.

Chemical weathering occurs fastest at the sharp edges of rocks as they have a large surface area and less volume. This results in faster chemical reactions, thereby, converting the sharp edges into rounded ones. Some general statements can be made about the factors that influence the rate of weathering. These are:

1- *Time:*

Time is a crucial factor in weathering as it determines the rate of weathering. Rates of weathering vary from rapid to extremely slow.

2- *Slope (Topography):*

On steep slopes, rain may quickly wash the weathering products away. However, on gentle slopes the weathering products accumulate.

3- *Climate*

4- *Type of Rock (Mineral Composition)*

The susceptibility of a rock type to weathering is largely a function of its constituent minerals.

5- *Exposure*

Materials that have a high surface area exposed to air, water, or organisms have higher rates of weathering.

6- *Particle Size*

As particle size decreases, more surface area is exposed, thereby, increasing the chances of weathering.

7- *Rock Structure*

Joints, Fractures, Fissures, and Bedding planes provide potential surfaces for both physical and chemical weathering processes to act.

8- *Gravity*

It is the primary agent for the movement of weathered material from the site of weathering to the site of deposition.

9- *Animals*

Burrowing organisms like rodents, earthworms, and ants, bring material to the surface were it can be exposed to the various agents of weathering.

Mass Wasting

Gravity-initiated down slope movement of **Regolith** (loose particles of soil and rock) without the aid of a transporting medium (such as water, ice, or wind) is called Mass Wasting. The term is often used interchangeably with Mass Movement and comes within the scope of erosional processes, between weathering and stream transport. The loose particles of soil and rock (Regolith) are picked up by the transporting agent and then moved to a site of deposition (such as an ocean basin or a stream bed). For the regolith to move on its own (the basic criterion for a mass wasting process), it must be on a slope allowing gravity to affect and cause motion.

The Mass Wasting Process

Many classifications of types have been proposed. However, it is now universally agreed that for such classification to be successful, it should be based on the following criteria:

(a) The type of material in motion (particle size, degree of coherence).

(b) The nature of motion (falling, toppling, sliding, flowing, etc.).

(c) The speed of motion. But, the mode, speed, and volume of down slope mass movements vary enormously. Some types of commonly recognized landforms based on the nature of motion include creep debris, landslide, avalanche debris, mudflow, flow debris, rock fall, slide, rock slide, earthflow, slump, gelifluction, solifluction, and lahar.

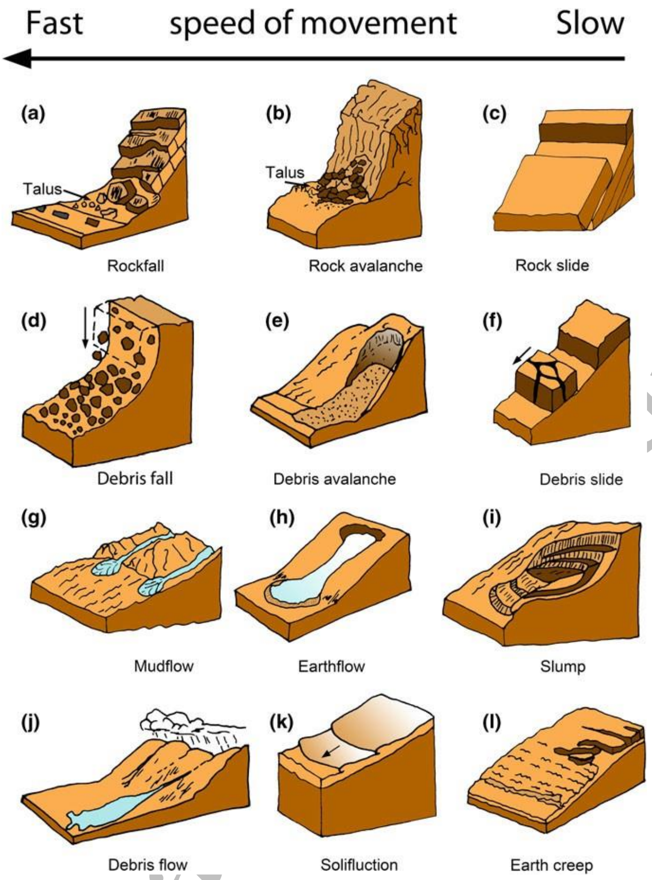


Fig. Diagrammatic representation of Mass wasting classification discussed above. Modified from (USGS, 2004).

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Prepared by
Dr. Rami M. Idan
Petroleum Geologist

Al-Karkh University for Sciences
College of Remote Sensing and Geophysics
Geophysics Department

Lecture FIVE

STRUCTURAL GEOLOGY

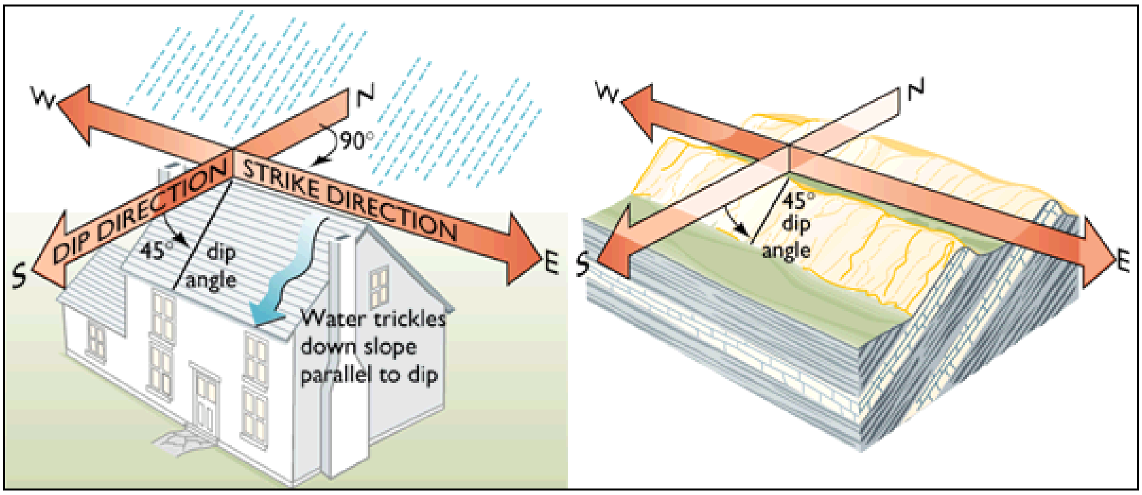
Prepared by
Dr. Rami M. Idan
Petroleum Geologist

by
Dr. Rami M. Idan

Structural geology is the study of rocks deformed by stress and strain. This involves trying to understand stress and strain forces to interpret its pre-deformed state.

When working in the field, Strike and Dip measurements are used to determine the orientation of rock units and other features

Strike: is the geographic direction of a horizontal line occurring on the planar structure. Or it is the compass direction of a line at the intersection of a geologic plane and a horizontal plane (water line).
Dip: is the direction that refers to the geographic direction of a horizontal line at a right angle to the strike and towards the downward inclination of the planar structure.i.e. is the angle between the inclined plane and horizontal, perpendicular to strike.
Apparent dip
The surface of a planar structure may not be exposed in all outcrops. The *apparent dip* is the inclination of the trace of the planar structure on a vertical section that makes an angle with the dip direction.
The main Structural features are: Folds, faults, and unconformities are the three main features that structural geologists examine.



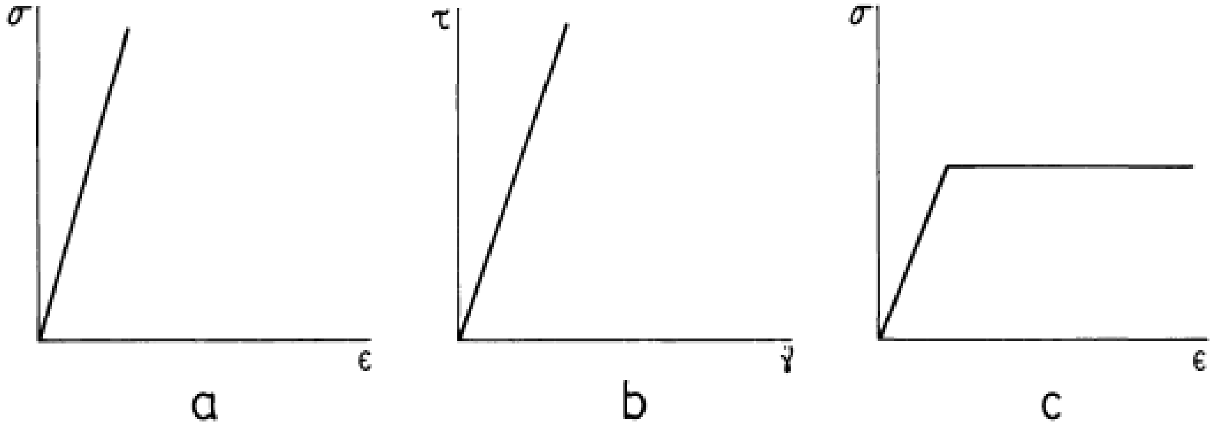
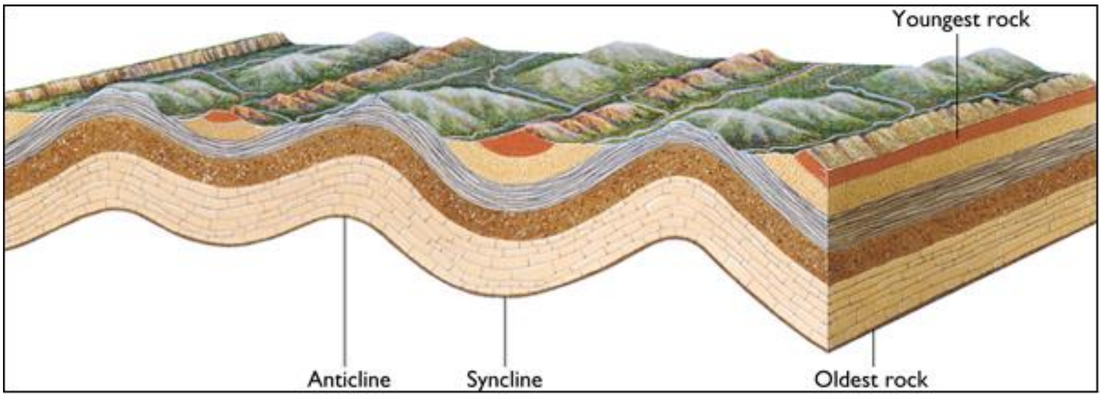
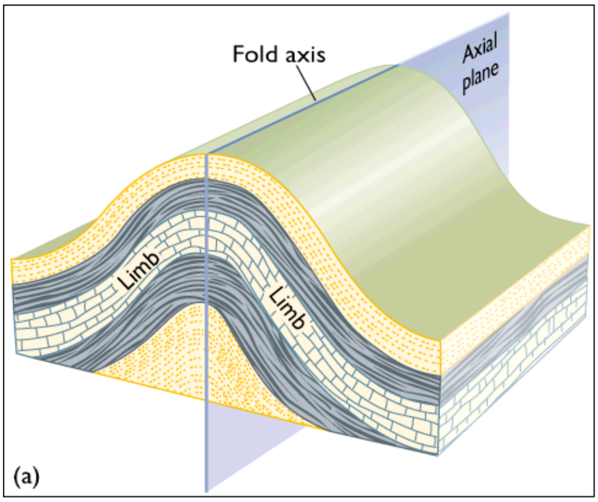


FIG. 7.1. (a) Stress–strain curve for perfectly elastic solid. (b) Relation between shear stress and rate of shear strain in a perfectly viscous liquid. (c) Stress–strain curve for a plastic substance.

Folds: occur when originally horizontal rock units deform under compressive forces. Common types of folds are <u>anticlines</u> and <u>synclines</u>. For every fold there is a <u>fold axis</u>, which it in the <u>axial plane</u>





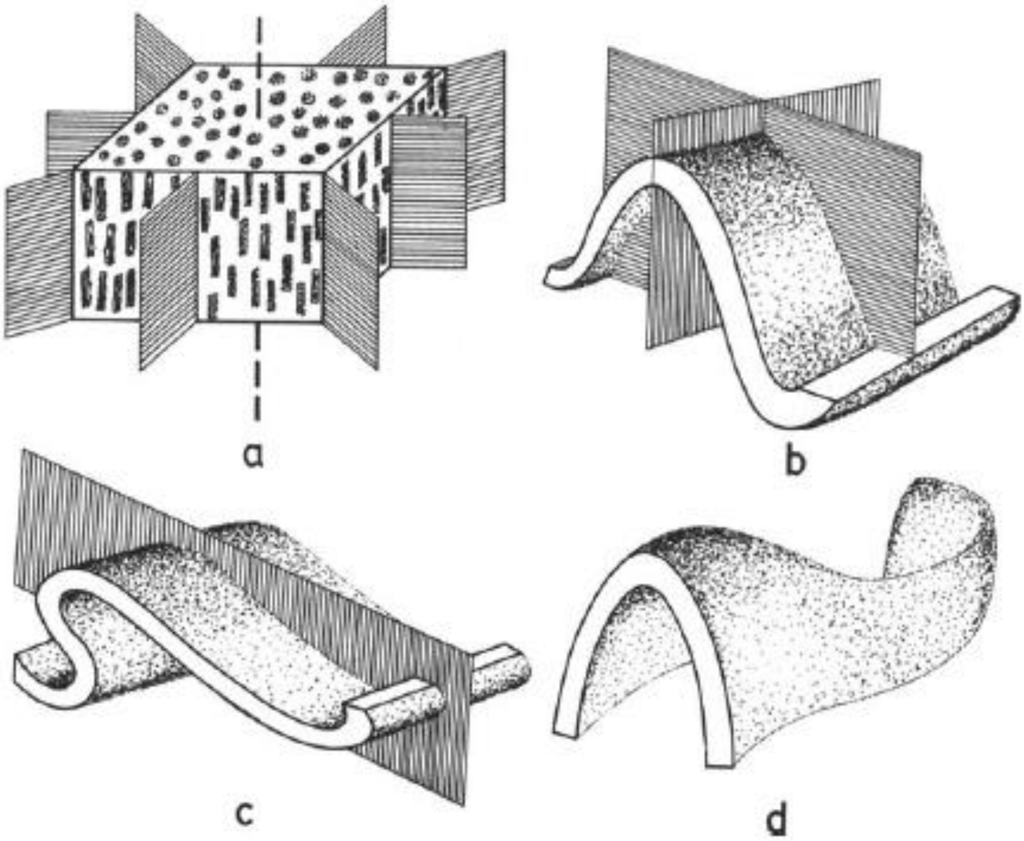
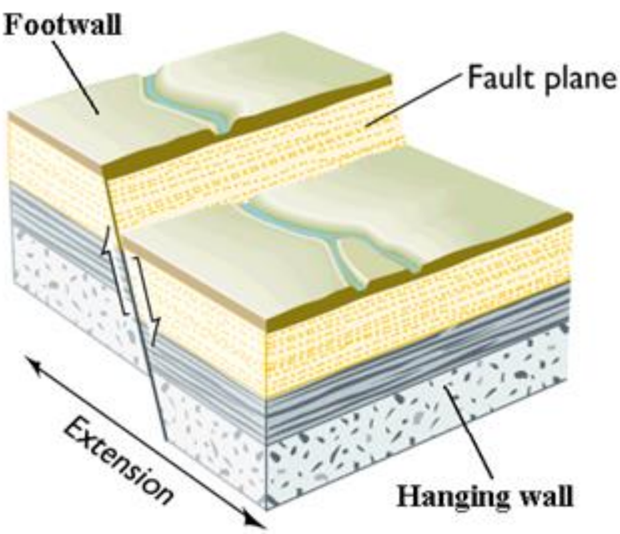


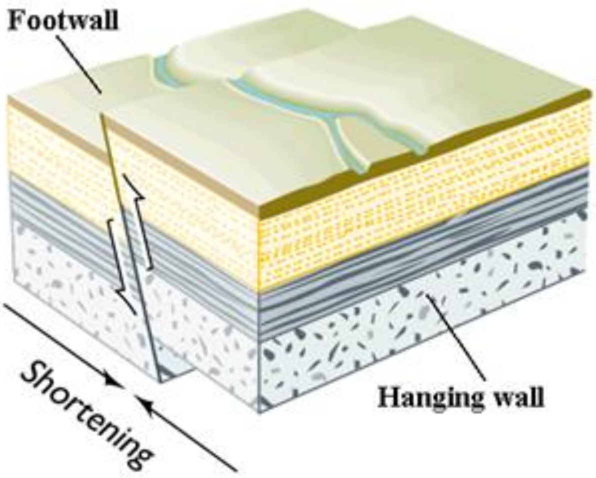
FIG. 1.4. (a) A rock showing a mineral lineation marked by needle-shaped minerals has an axial symmetry; any plane parallel to the lineation is a plane of symmetry. (b) A symmetrical cylindrical fold shows an orthorhombic symmetry with two mutually perpendicular planes of symmetry. (c) An asymmetrical fold shows a monoclinic symmetry with a single plane of symmetry perpendicular to the fold axis. (d) A fold with triclinic symmetry.

Faults are breaks in rock units were movement has occurred. There are three major types of faults.

Normal Fault – Hanging wall (top surface) moves down relative to the footwall (bottom surface), caused by tension (extension).



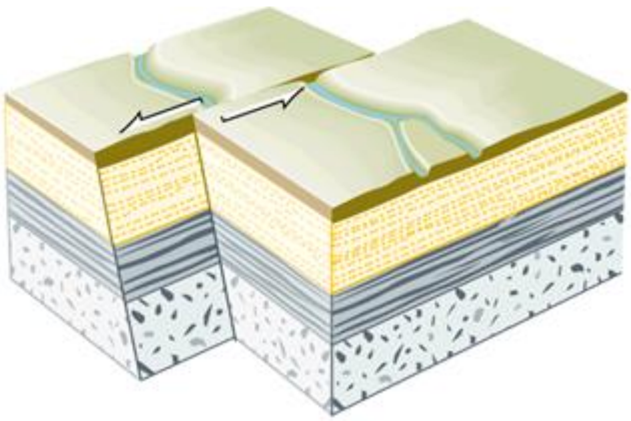
Normal Fault



Reverse Fault

Reverse Fault – Hanging wall moves up relative to the footwall, caused by compression (shortening).

Strike-Slip Fault – Movement along the fault is horizontal, parallel to the strike of the fault plane. If, standing on one side of the fault, the block on the other side is displaced to the right, the fault is termed right-lateral. If the block on the other side is displaced to the left, the fault is termed left lateral.



Strike – Slip Fault