CHAPTER 9

BASICS OF GEOLOGY: EARTHQUAKES & VOLCANOES

CHAPTER's Objectives

- To introduce the theory of one supercontinent
- To discuss the clues and proofs that support the theory of one supercontinent
- To discuss the earth's interior layer structures
- To introduce plate tectonics theory and its role to that change earth's surface
- To discuss the connection between earthquakes and volcanoes to plate tectonics
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- To introduce and discuss seismic waves and its role to determine earth's interior structure

The earth is ever changing, from super fluid of minerals and gases to 9 continents as seen today. From simple to more complicated forms, this structural change, though it is very slow, seems to be a process that never ends.

You may possibly have relatives scattered all around the globe; in North and South America, Africa, India, Europe, Australia, and may be a scientist who does research in Antarctica.
It will never cross your friends minds how would your relatives got there in the first place because the answer is easy; they ride over airplanes. But the question that puzzled scientists for long time, from the beginning of last century to before 1960s was how the remains of prehistoric animals (reptiles) and plants (like ferns) were found scattered around the globe? Common sense would exclude the possibility that those animals swam through the big oceans and settled on areas of their choice.

This chapter will answer this question and others like what causes earthquakes and volcanoes, how the mountains took shape as we see them today, is the ocean bed flat or continental as on land? The cause of all these phenomena is attributed to the fact that the earth is a dynamical system; a system that is ever changing.

This chapter is about the violent earth, a behavior that scientists try to understand and control it, but how far did they go?

9.1 Earth's interior

By studying seismic waves that move inside and on the surface of earth, scientists were able to draw a map of earth interior. It is found that the earth consists of three layers as illustrated in Figure (9.1). The ***crust*** is the thin outer layer made of rock, which covers the whole earth and includes the oceanic crust (ocean floor) and the continental crust (land) including mountains. The ***mantle*** is the middle part made of rocks thicker than the crust extends to about 2900 km deep inside earth. The ***core*** is the central part. It consists of an outer part made of molten and flowing iron and nickel and an inner part made of solid iron and nickel because of an enormous of pressure.

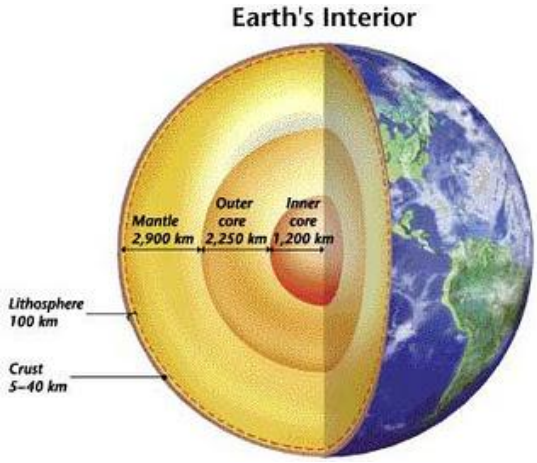
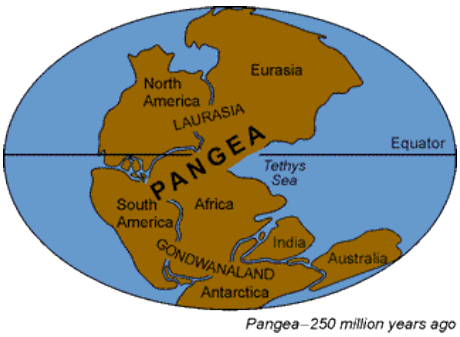


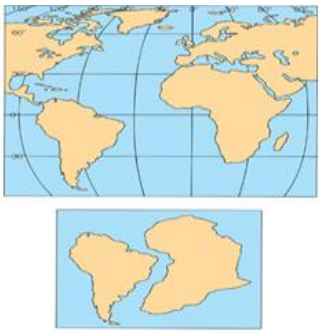
Figure (9.1): The layered structure of earth, the crust, mantle, and the core.

9.2 The continental drift: The Pangaea concept

In 1912 the German meteorologist Alfred Wegener theorized that about 250 million years ago the earth once was a single supercontinent mass of land he called a ***Pangaea***, a Greek word meaning "all land" as illustrated in Figure (9.2a). The hypothetical Pangaea broke up and split into smaller continents that move into their present positions. Wegner's idea was based on his finding that if we get all the nowadays continents back together they will fit like pieces of a jigsaw puzzle Figure (9.2b) shows; the match of the eastern and western line shores of South America and Africa is perfect. The match includes all the pieces (continents).



(a)



(b)

Figure (9.2): (a) The whole world was once one supercontinent called Pangaea. (b) Together, the continents fit like a jigsaw puzzle.

Wegner's theory became known as ***continental drift***, a term scientists used meaning that the continents could shift positions overtime. Scientists of Wegener period did not find the idea of moving continents plausible and, therefore they dismissed it.

9.2 Evidence of continental break

Later, the evidence to support the continental drift idea came from observational information; two of them are presented here: The fossil and the sea floor spreading information.

9.2.1 Fossil information

Fossils are the remains of dead animals and plants. Fossils of plants and prehistoric reptiles and animals once lived during the dinosaur's period some 250 million years ago were found in different parts of the world, especially in Africa, Australia, India, South America, and Antarctica. This is illustrated in Figure (9.3)

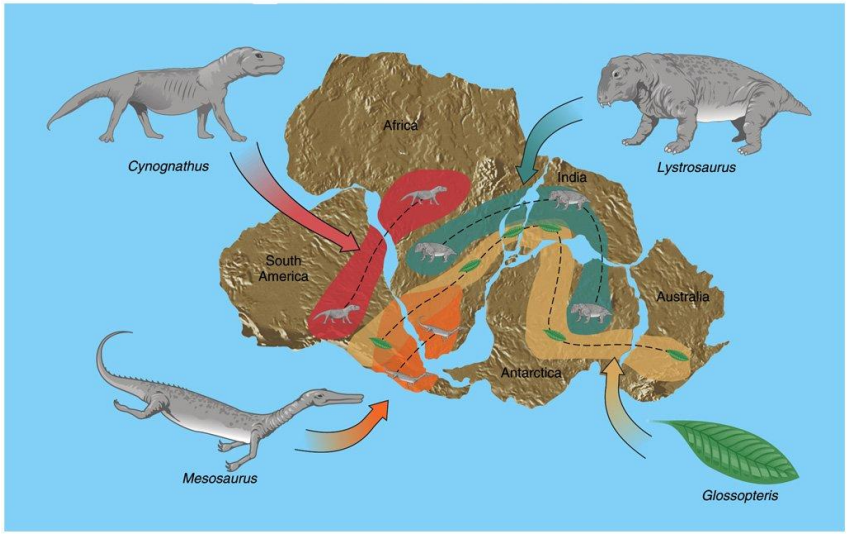


Figure (9.3) A sketch showing same animals and plants living in different parts of the world.

9.2.2 Sea floor spreading

By the late of 1950s, Sonar and advanced technologies were used by scientists to study the nature of ocean floor. Their studies found that the ocean floor is not smooth and flat as was thought, but contains chains of mountains thousands of kilometers long and valleys just like those on the continents. They called these chains of mountains ***oceanic ridges***, one example of these is the Mid-Atlantic Ridge that lies in the center of the Atlantic Ocean and divide it into two nearly equal parts as shown in Figure (9.4). Further studies on Mid-Atlantic Ridge have shown the existence of a long and continuous crack-like line extended along the crest called ***rift***. A sketch of a rift of one of Mid-Oceanic Ridges is shown in Figure (9.5).

Inside the rift, activities like earthquake and escaping heat and fume of gases were observed. Further studies have shown that magma from the upper mantle is forced upward through the rift and to the mid-ocean ridges, cools and forming new seafloor. Scientists call this phenomenon the ***ocean floor spreading***, the formation of new rocks on both sides of rift, which result in spreading the seafloor.

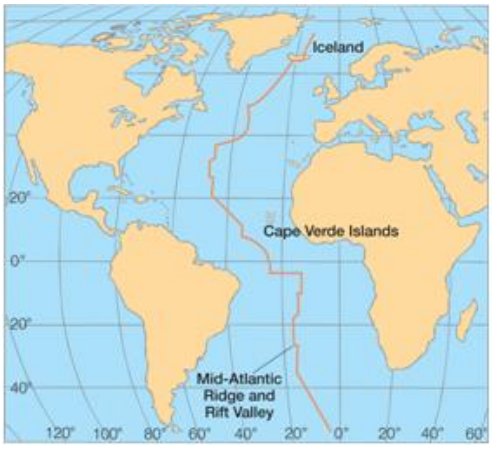


Figure (9.4): The mid-Atlantic Ridge divides the Atlantic Ocean into two nearly equal parts. Where the ridge reaches the sea level, it makes oceanic islands, such as Iceland. Credit:

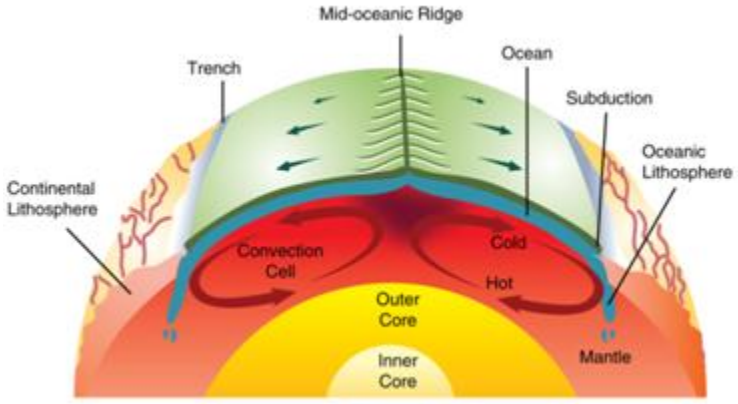


Figure (9.5): A long and continuous crack-like line called rift lies on the crest of a Mid-Oceanic Ridge. Molten magma find access through the rift and settle on top of the rift.

By drilling through the seafloor and pull out samples, scientists found that rocks at the ridges were much younger than those rocks at the continents. Their findings revealed that the rocks become increasingly older the farther away they are from ridges. This pattern of aging is illustrated in Figure (9.6).

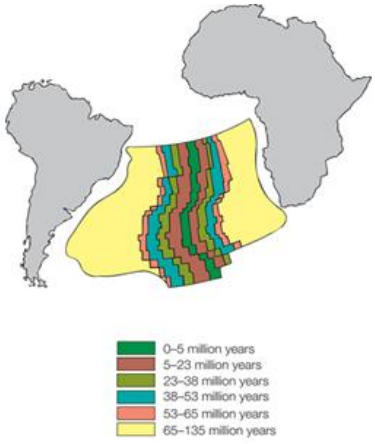


Figure (9.6): Sea floor spreading at work. Younger rocks are found close to the ridge. Credit: *B.Tillery, E. Enger, and F. Ross, "Integrated science," 3rd Ed. McGraw Hill, 2007.*

9.3 Plate tectonics theory

Plate tectonics is a theory that explains the movements of continents (continental drift). The theory suggests that the earth's crust and the upper mantle, normally made up of solid rock called ***lithosphere*** are broken into a number of rigid plates that move on the lower part of the mantle called ***asthenosphere***. Figure (9.6) shows 12 world major plates.

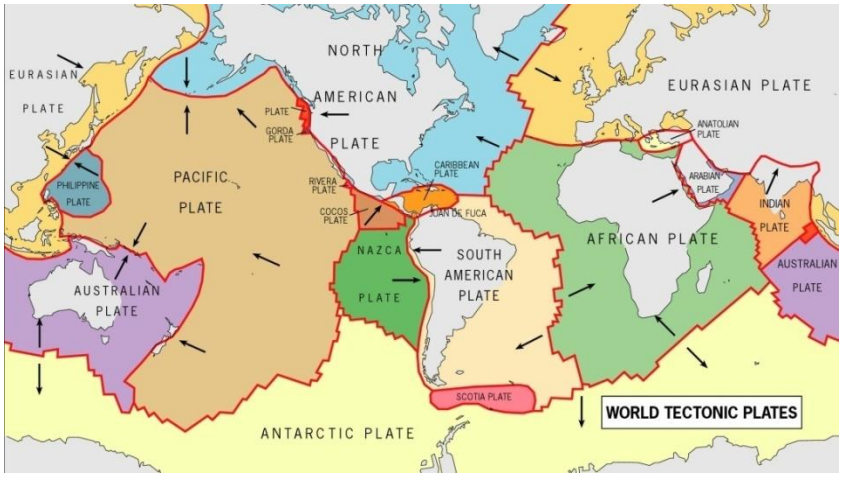


Figure (9.6): The world major plates of lithosphere that move on the asthenosphere.

As Figure (9.6) shows, some plates include continents and part of an ocean, while others include oceans only. The material of asthenosphere is not perfect solid. It behaves like a thick liquid that flows due to heat. The flowing asthenosphere creates convection cells shown as circles in Figure (9.7). The convection currents make the various plates to move around. Usually, the plates move in the direction of arrows of these convection cells as depicted in Figure (9.7).

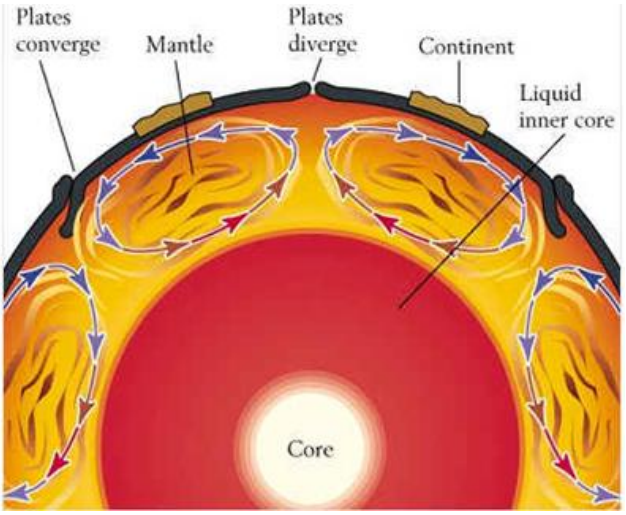


Figure (9.7): Convection currents caused by heat from below force the lithosphere plates to move in the direction of convection currents shown in arrows.

Because the plates cover the whole earth, they meet at certain areas called the ***plate boundaries***. At these boundaries natural phenomena occur such as mountain formation, earthquakes, and volcanoes. Each one

of these is determined by the kind of motion of plate movement. Indeed, there are three kinds of movements, which we will discuss separately.

9.3.1 Divergent boundaries

Divergent boundary is the boundary between two plates that are moving away from each other. As the plates separate, a rift valley is formed, filled by magma and creating new crust zone. The new crust moves horizontally on both sides of the divergent boundary producing seafloor spreading as shown in Figure (9.8). Seas and oceans were created this way .The new crust zones may also occur on the continental crust, but mostly occur on the oceanic crust.

The measured rate of spreading is very slow; it is about 1-6 cm per year. This process has been going on for long period of times creating great water gaps like the Atlantic Ocean. The red Sea is another example of divergent boundary movement result when Saudi Arabia (Arabian plate) was separated from the African continent (African plate).

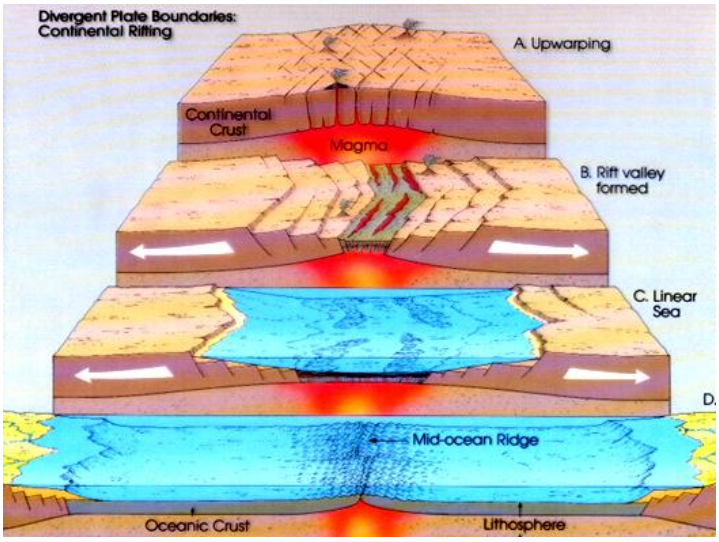


Figure (9.8): Plates move away from each other creating new crust zone as magma rises, cools, and add new crust to the edges of the moving plates.

9.3.2 Convergent boundaries (plate collision)

When new crust is added in some areas due to divergence of plates, old crust must be destroyed at other areas, so that earth shape stays stable. This destruction of old crust occurs when two plates converge or collide, meaning the two plates move toward each other. There are three kinds of plates collisions that we will discuss separately.

9.3.2.1 Oceanic-continental plates convergence

When an oceanic plate collide with a continental plate, the more dense crust of the oceanic crust sinks under the less dense crust of continental plate; this is called ***subduction***. A trench, volcanoes mountains, and shallow and deep earthquakes are formed as illustrated in Figure (9.9).

9.3.2.2 Oceanic-oceanic plates convergence

This type of collision leads to the formation of oceanic trench, shallow earthquakes near the trench, and deep earthquakes near the continent as Figure (9.10) illustrates. Figure (9.10) also shows a group of islands like Japan and Indonesia that are formed due to the rise up of the melted material of leading edge of one plate crust that sinks below the edge of the other plate. These islands are located near the zone of deep earthquakes as Figure (9.10) shows.

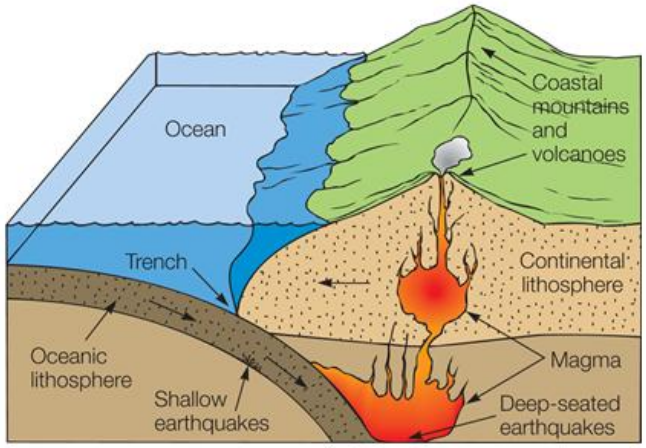


Figure (9.9): The convergence of the oceanic-continental plates. Mountains, volcanoes, and shallow and deep earthquakes are formed plates boundary. Credit: *B.Tillery, E. Enger, and F. Ross, "Integrated science," 3rd Ed. McGraw Hill, 2007.*

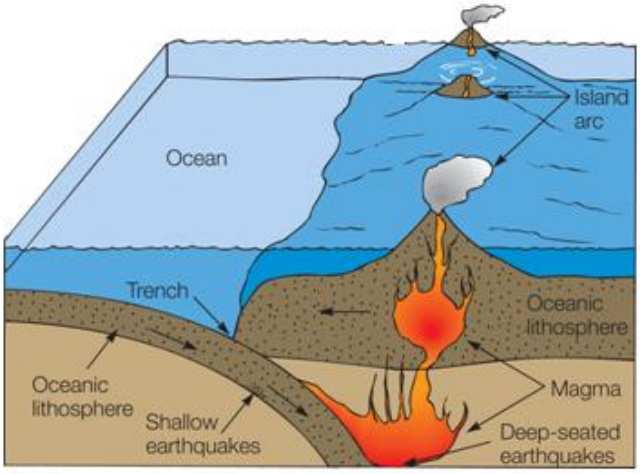


Figure (9.10): The convergence of oceanic-oceanic plates. The convergence causes volcanoes, earthquakes, and the formation of volcanic islands. Credit: *B.Tillery, E. Enger, and F. Ross, "Integrated science," 3rd Ed. McGraw Hill, 2007.*

9.3.2.3 Continent-continent plate convergence

The leading crust edges, of same density, of both colliding plates as Figure (9.11) shows rise up and form mountains. The Himalayan Mountains formed this way when the Indian plate collided with the Eurasian plate.

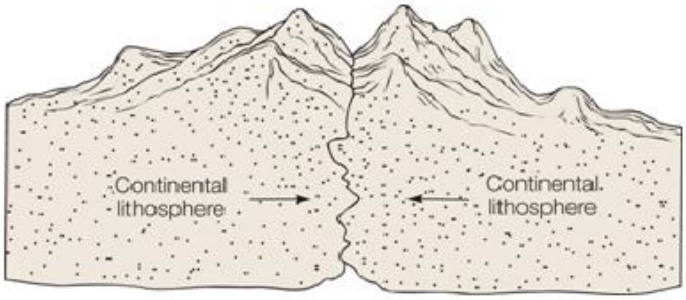


Figure (9.11): The continent-continent plates collide forming mountains. Credit: *B.Tillery, E. Enger, and F. Ross, "Integrated science," 3rd Ed. McGraw Hill, 2007.*

9.4 Earthquakes

Earthquake is the shaking and vibrating of the ground. It is caused by the break of a huge rock under the ground that is under severe stress. Stress causes the rock to bend and fracture into blocks that move into different position as illustrated in Figure (9.12). The break of the rock releases energy carried by waves called ***seismic waves***. Usually, the earthquake occurs at the convergent boundary, when one crust sinks (or subduct) under the less dense plate.

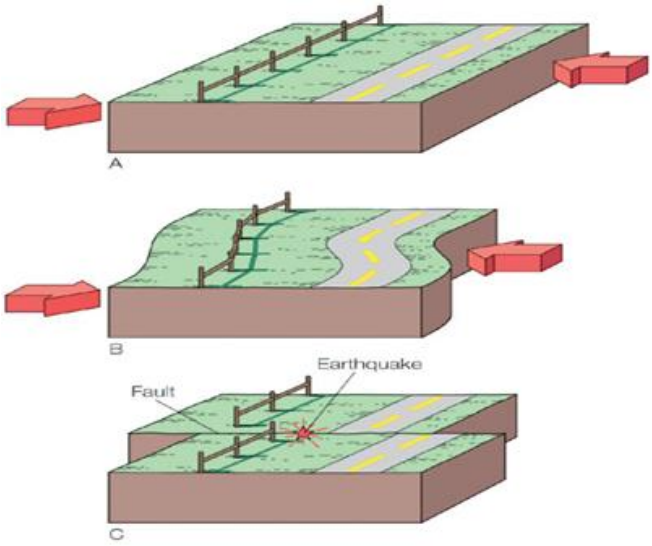


Figure (9.12): An earthquake occurs at three stages. In (A) the rock is under stress, (B) rock deformed, and (C) the rock breaks and release energy with blocks shift to new positions. Credit: *B.Tillery, E. Enger, and F. Ross, "Integrated science," 3rd Ed. McGraw Hill, 2007.*

The seismic waves are of two kinds, the body waves include ***S-wave*** (secondary), ***P-wave*** (primary) and surface waves. The P-wave is faster than all seismic waves and registered first by the ***seismograph***, a device that measures the seismic shown in Figure (9.13). The device provides information about the location of an earthquake and information about the earth's interior structure. The seismic waves are released under the ground from a point called the ***focus***. Seismic waves from the focus propagate in all direction inside earth and on the surface of earth as Figure (9.14) illustrates. The point on the surface and directly above the focus is called ***epicenter*** of earthquake.

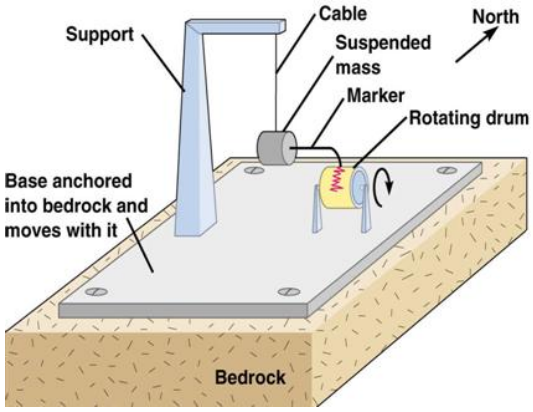


Figure (9.13): Seismograph, an instrument that measures seismic waves and locate earthquakes.

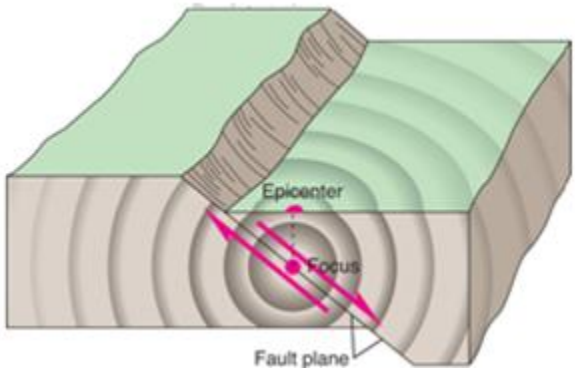


Figure (9.14): The focus is the center of the seismic waves, epicenter is directly above it. Credit: *B.Tillery, E. Enger, and F. Ross, "Integrated science," 3rd Ed. McGraw Hill, 2007.*

A ***Richter scale*** is a scale used by scientists to measure the strength of an earthquake. The scale is marked from 0-9, with the maximum 9 means the magnitude of the earthquake is great with total destruction as Table (9.1) illustrates.

Table (9.1): Richter scale

Richter Magnitudes	Description
0–2	Smallest detectable earthquake
2–3	Detected and measured but not generally felt
3–4	Felt as small earthquake but no damage occurs
4–5	Minor earthquake with local damage
5–6	Moderate earthquake with structural damage
6–7	Strong earthquake with destruction
7–8	Major earthquake with extensive damage and destruction
8–9	Great earthquake with total destruction

Tsunami is very large oceanic waves that travel at speeds about 700km/h caused by an earthquake or volcanic eruption. Figure (9.15) illustrates a tsunami caused by an earthquake.

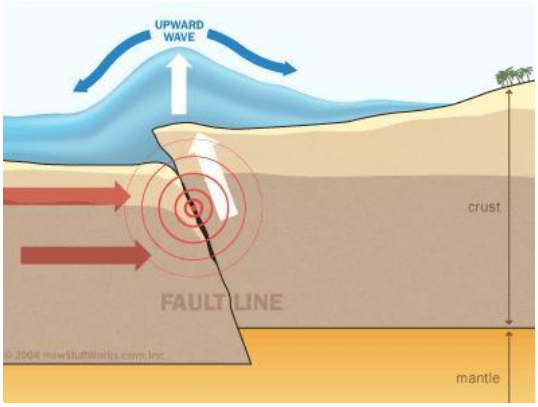
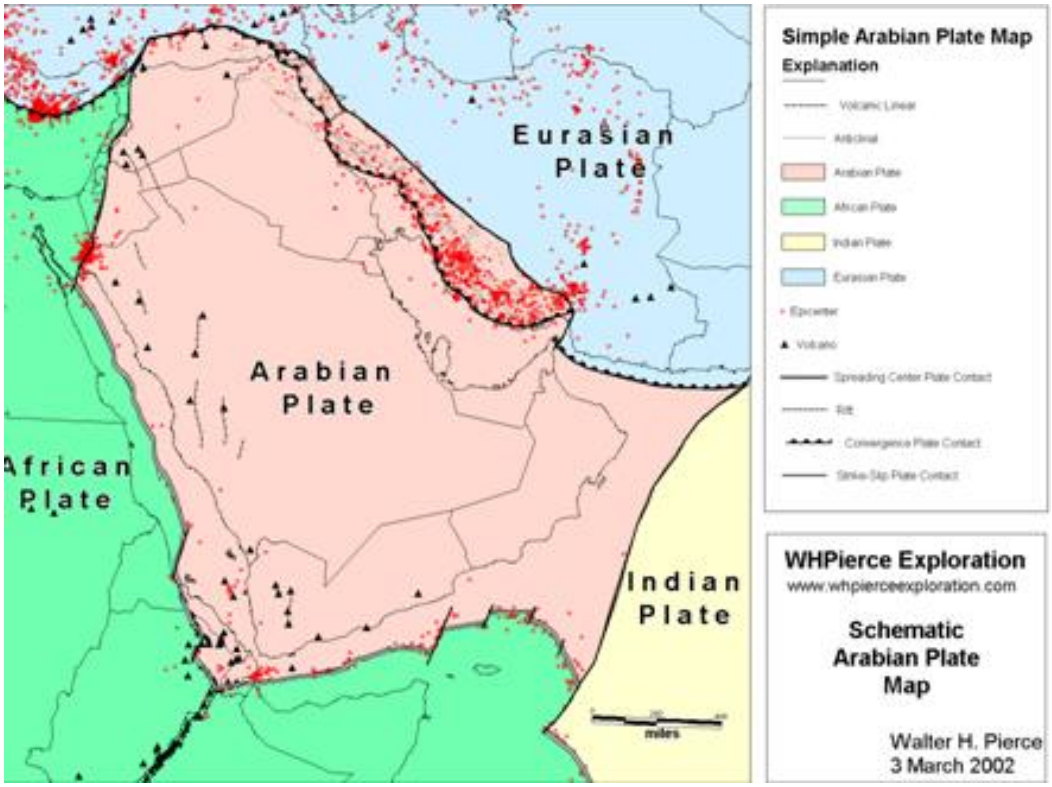


Figure (9.15): Tsunami is a huge wave caused by an earthquake. Credit: *B.Tillery, E. Enger, and F. Ross, "Integrated science," 3rd Ed. McGraw Hill, 2007.*

9.5 Volcanoes

By definition, a ***volcano*** is a rocky structure in the form of a hill or mountain formed by the ejected lava from magma beneath the earth surface and deposit in a conical shape. Volcanoes are found in three places: divergent boundaries, convergent boundaries, and at hot spots. In the ocean, the lava that find its way up through rifts in the ocean floor cool by water, pile up over time and form islands. Iceland was originated this way. Unlike Iceland, Hawaiian Islands, located at the Pacific plate, did not formed at the plate boundaries, but at areas called ***hot spots or hot springs***. These areas were formed when hot magma in the mantle was pushed out and flows as lava. The Hawaiian Islands were formed when the Pacific plate were moved over these hot spots in the Pacific Ocean. Figure (9.16) locates the volcanic areas at the Arabian plate and its surrounding.



Figure(9.16): Location of volcanoes and earthquakes in the Arabian plate.

Summary of chapter 9

The earth interior is so hot because of high temperature. Thermal energy from beneath the surface of earth is transformed into heat and kinetic energy. Heat is used to melt rocks below the surface into *magma*, which is then pushed up to form new crusts. Kinetic energy is to move the earth's continental and oceanic plates around. This lead to creation of new crust zones.The theory that explains plate's movement is called *plate tectonics*. The movement of these plates results in the formation of earthquakes, volcanoes, and mountains. All of these changes on earth's surface occur at the plate boundaries. *Earthquakes* are the vibration and shaken of grounds due to the release of enormous amount of energy resulted from the breaking of huge rocks subjected to huge stress generated by the collision of plates in subduction areas under the ground. The quake vibration energy is carried out to the surface by body and surface *seismic waves*. These waves can be detected by a *seismograph*. Scientists use these waves to map the earth interior. It is found that the earth's interior consists of three layers, the *crus*t, *mantle*, and *core*. Volcanoes are hills or mountains in a conic form resulted from a continuous lava flow over time. Volcanoes are formed at the plate boundaries and at areas called hot spots or hot springs.

Basic principles and facts

1. Seafloor is spreading (expanding).
2. Seas and oceans are huge water gaps created due to seafloor spreading.
3. Crust destroys in some areas and created at others.
4. Age of oceanic crust changes as the distance from the center increases.
5. Upper part of mantle is rigid (solid) and the lower part is thick fluid-like that flows around.
6. Plates move on the asthenosphere
7. Subduction zones created when there difference in density of colliding crusts.
8. Rocks break at subduction areas.
9. Most earthquakes occur near the plates boundaries

Chapter 9 worksheet

Part1: Multiple choices

1. The earth's interior consists of three layers, which include
A. Core, mantle, and lithosphere
B. Core, mantle, and asethnosphere
C. Crust, magma, and core
D. Crust, mantle, and core

2. The evidence for the Earth's inner structure comes from
A. Seismic waves
B. Samples taken from earth's surface
C. Samples taken from oceans
D. Fossil samples

3. Pangaea is the name of
A. One of tectonic plates
B. Volcano in South America
C. An assumed supercontinent.
D. Scientist

4. Which of the following technologies was used to map the ocean floor and provide evidence for plate tectonic theory?
A. Seismographs
B. X-rays
C. Sonar
D. Doppler radar

5. The age of oceanic crust
A. Increases with distance from the center of an ocean floor
B. Decreases with distance from the center of an ocean floor
C. Remains constant for each ocean floor
D. Alternately increases and decreases from the center of an ocean floor

6. The word "plate" in plate tectonics refers to rigid, moving part of Earth's
A. Asthenosphere
B. Oceanic crust
C. Continental crust
D. Lithosphere

7. Tectonic plates move in the
A. Mantle
B. Asthenosphere
C. lithosphere
D. Ocean crust

8. Seafloor spreading occurs where
A. Oceanic plates diverge
B. Oceanic plates converge

C. Oceanic plates collide to form mountains
D. Oceanic plates oscillate

9. Which of the following is associated with mountain formation
A. oceanic-continental convergent plate boundaries
B. continental-continental convergent plate boundaries
C. oceanic-oceanic convergent plate boundaries
D. volcanoes

10. Leading edge crust sinks (subducted)into the mantle and Islands chain form as melted subducted material rises on
A. Oceanic-oceanic convergent plate boundaries
B. Oceanic-continental convergent plate boundaries
C. Divergent plate boundaries
D. Volcanoes

11. When rock breaks, the sudden movement produces vibrations that are called

A. Seismic waves
B. Surface aves
C. S- Waves
D. P -waves

12. Most earthquakes occur

A. Near the center of mass of a plate
B. Near the boundary of a plate
C. Equally anywhere on a plate
D. Deep below a plate

Part2: True/False

13. The crust beneath the oceans is much younger than continental crust.
A. True
B. False

14. Marine studies indicated that there is long, high and continuous mountain ranges run through the middle of the oceans
A. True
B. false

15. Hot magma is forced up from earth's interior spreads the ocean floor and causing the continents to drift apart.
A. True
B. False

16. According to plate tectonics, new crustal material is created at convergence boundaries.
A. True
B. False

17. The Himalayan Mountains were formed as a result of continent-continent plate convergence.
A. True
B. False

18. Seismic sea waves are called tsunami.

A. True
B. False

Part3: Exercises

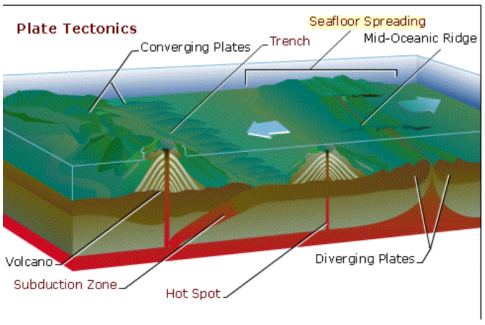
19. What lies directly beneath the earth's crust?
20. The inner core is composed of _____ and _____
21. In which plate you are located by now?
22. What is a volcano?
23. What finally convinced scientists that the continents did move?
24. What causes the earth's tectonic plates to move?
25. What causes an earthquake?
26. What is the theory of plate tectonics?
27. How many lithosphere plates are there?
28. What is subduction zone?
29. On the average how far do the plates move per year?
30. What drives the plates movement?
31. What is continental drift?

Part4: Learning from observation

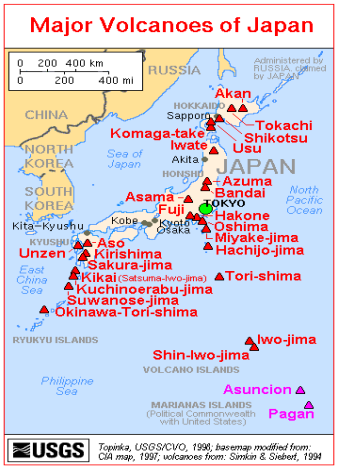
In few lines describe your understanding from observing these images

A.

B.



C.



D.